MICROWAVE PROPAGATION STUDIES,
MEASUREMENTS AND EDUCATION IN
SURABAYA, INDONESIA

Edited by

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Microwave

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by the

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Department of Electrical Engineering,
Eindhoven University of Technology,
Eindhoven, The Netherlands,

and

Fakultas Teknik Elektro,
Institut Teknologi "10 Nopember" Surabaya,
Surabaya, Indonesia,

with support of the

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Bandung, Indonesia,

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SUMMARY

A development cooperation project in the field of telecommunication in Indonesia is described. The cooperating institutions were the Eindhoven University of Technology (Netherlands) and the Surabaya Institute of Technology (Indonesia). The period was from 1976 to 1980.

A microwave line-of-sight link Gunung Sandangan - Surabaya and a troposcatter link Situbondo - Surabaya were realized. Measurements at 4 and 7 GHz line-of-sight and 4 GHz troposcatter (main and cross-polar components) were made and reception of meteorological satellite signals was carried out. Seasonal atmospheric influences were investigated.

Curricular and other educational activities, such as lectures, courses, consulting, workshops, were performed by the members of the Dutch team in Surabaya.

A microwave laboratory, mechanical and electronics workshops, a meteorological station and an electrical engineering and electronics basic library were set up in Surabaya.

Contacts with other Indonesian Universities and Institutions were established.

FOREWORD

In this report results are presented of the Project THE-2 on microwave propagation in Surabaya (Indonesia) carried out in the period from 1976 to 1980 as a continuation of a previous project THD/E/T-2 (initiated in 1969).

The cooperating institutions were the Eindhoven University of Technology (Netherlands) and the Institut Teknologi Surabaya. The project was sponsored on the Dutch side by the Netherlands University Foundation for International Cooperation (NUFFIC) and on the Indonesian side by the PERUMTELE (Indonesian PTT). The work was performed by the Telecommunication Group of the Department of Electrical Engineering of the Eindhoven University of Technology on the Dutch side and the Fakultas Teknik Elektro of the Institut Teknologi Surabaya on the Indonesian side.

This report was written by several members of the team. Use was made of the results achieved by the students and the staff members of both institutions in Indonesia as well as in the Netherlands. Data from different practical work and final study reports of Dutch as well as Indonesian students were used.

We are indebted to all those, who did their best to make our work in Indonesia succesfull. We thank Mr. P. Hermans for useful advice to the organization of this report, Mrs. V. Smith Hardy (Waalre, Netherlands), who corrected the language, and Mr. L.J.C.M. Koolen who processed the measured data.

Our special thanks are due to our colleague Ir. S. Tirtoprodjo who always was ready to give a valuable advice in all matters concerning the project due to his profound knowledge of both the Indonesian and the Dutch cultures.

Vignettes on the title pages of various chapters originate from the ancient Hindu epic "Mahabharata" as depicted in Javanese Wayang shadow play. Subscripts were furnished by our Surabaya partners.

We hope that the results of our research and educational activities will add to the future development of Indonesian telecommunications.

The editors.

Eindhoven, March 1983
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## List of symbols and abbreviations

In the following list the English alphabet precedes the Greek alphabet, and lower-case letters precede upper-case letters. Sometimes a symbol may be used in quite different contexts, in which case it is listed for each separate context. Subscripts are used to modify the meaning of symbols. The order is:

1. Symbol without a subscript
2. Symbol with a subscript (letter subscripts in alphabetical order followed by number subscripts in numerical order)
3. Symbol as a special function
4. Abbreviations

Following each definition a page number is given to show the term in its proper context.

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<td>$\alpha$</td>
<td>constant according to a Rayleigh-like distribution function</td>
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<td>APT</td>
<td>Automatic Picture Transmission</td>
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<td>$b$</td>
<td>constant according to a Rayleigh-like distribution function</td>
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<td>$B$</td>
<td>constant in the CCIR formula for Rayleigh fading occurrence</td>
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<td>$B$</td>
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<td>CCIR</td>
<td>International Radio Consultative Committee</td>
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<td>CDF</td>
<td>Cumulative Distribution Function</td>
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\[\begin{align*}
\varepsilon & \quad \text{dielectric constant [farad/m]} \quad 5.2 \\
\varepsilon_0 & \quad \text{dielectric constant in vacuum} = \; 8.85 \times 10^{-12} \; \text{farad/m} \quad 5.4 \\
\varepsilon_r & \quad \text{relative dielectric constant} \quad 5.5 \\
\eta & \quad \text{constant in formula for rain attenuation} \quad 5.57 \\
\theta & \quad \text{subtending angle between two points on the earth surface [rad]} \quad 4.6 \\
\theta_s & \quad \text{scatter angle [rad]} \quad 6.6 \\
\lambda & \quad \text{wave length [m]} \quad 5.20 \\
\mu & \quad \text{magnetic permeability [henry/m]} \quad 5.2 \\
\mu_0 & \quad \text{magnetic permeability in vacuum} = \; 4\pi \times 10^{-7} \; \text{henry/m} \quad 5.4 \\
\mu_r & \quad \text{relative magnetic permeability} \quad 5.5 \\
\rho_c & \quad \text{space charge density [coulomb/m}^3\text{]} \quad 5.2 \\
\rho_s, \rho_r(r) & \quad \text{correlation factor} \quad 5.43/6.4 \\
\rho & \quad \text{normalised raindrop diameter} = \; 2\pi \; a/\lambda \quad 5.54 \\
\rho_r & \quad \text{radius of the ray path [m]} \quad 4.4 \\
\sigma & \quad \text{electrical conductivity [mho/m]} \quad 5.2 \\
\sigma_s & \quad \text{scatter cross-section [1/m]} \quad 6.6 \\
\sigma_R & \quad \text{standard deviation for lognormal distribution} \quad 10.13 \\
\sigma_{R_s} & \quad \text{standard deviation of surface roughness} \quad 5.30 \\
\tau & \quad \text{electrical phase difference [rad]} \quad 11.2 \\
\tau_f & \quad \text{filter time constant} \quad 10.8 \\
\phi & \quad \text{angle of ray relative to local vertical [rad]} \quad 4.3 \\
\phi_0 & \quad \text{angle relative to local vertical of incident wave [rad]} \quad 5.29 \\
\phi_1 & \quad \text{angle relative to local vertical of reflected wave [rad]} \quad 5.29 \\
\phi_2 & \quad \text{angle relative to local vertical of refracted wave [rad]} \quad 5.29 \\
\phi_B & \quad \text{Brewster angle [rad]} \quad 5.29 \\
\psi & \quad \text{grazing angle of the incident wave [rad]} \quad 5.30 \\
\omega & \quad \text{angular wave frequency [rad/sec]} \quad 5.3
\end{align*}\]
\[ \Omega_0 \] solid angle with respect to receiving antenna in vacuum [rad] 5.15
\[ \Omega_t \] solid angle with respect to receiving antenna in troposphere [rad] 5.15

Notation:

- \( n \) real number
- \( n \) complex number
- \( \bar{n} \) mean value
- \( \hat{E} \) vector
- \( \bar{E} \) complex vector
- \( \langle E \rangle \) time average
- \( \hat{E} \) maximum value

Statistical notation:

- \( X_{50} \) median value
- \( x \) statistical variable
- \( \xi(x) \) ensemble average

\[ P(x \leq x < x + dx) = f(x).dx \]

\[ F(x) = \int_{-\infty}^{x} f(x').dx' \approx P(x \leq x) \]
MICROWAVE PROPAGATION STUDIES, MEASUREMENTS AND EDUCATION IN SURABAYA, INDONESIA

Part 1: Research Activities

Bima
Second brother of Pandawa: An extraordinary figure, radiating strength and readiness to defend just causes.
Chapter 1

THE COOPERATION SCHEME BETWEEN THE SURABAYA INSTITUTE OF TECHNOLOGY AND THE EINDHOVEN UNIVERSITY OF TECHNOLOGY

Arjuna
Third brother of Pandawa, always the winner and the champion, eminently capable of obtaining glorious achievements in many fields.
1. The cooperation scheme between the Surabaya Institute of Technology and the Eindhoven University of Technology

1.1. History

The origin of the project NUFFIC - THE/2 lies back in 1968, when the "Proposal for cooperation between technological universities in the Netherlands and in Indonesia" was presented to the Indonesian Institutes of Technology in Bandung (ITB) and in Surabaya (ITS) by a delegation from the Dutch Universities of Technology in Delft (THD) and in Eindhoven (THE). The initiative for this proposal originated from the professors Bordewijk and Niesten, both of whom took part in the delegation to Indonesia.

The result of this proposal was a cooperation scheme between the Technological University of Delft and the Institute of Technology in Bandung and another cooperation scheme between the Eindhoven University of Technology and the Institute of Technology in Surabaya. This latter cooperation scheme resulted in a research project [1, 39, 40], known as project THD/E/T-2. In a follow-up project, project THE-2, attention was paid to research and educational activities directed to solving more of the ITS problems compared to the former project, project THD/E/T-2.

The first part of the project concentrated on the time distribution of the received power level of a so-called line-of-sight (LOS) microwave link from Gunung Sandangan, Madura, to Surabaya on East Java, using a frequency of 4 GHz [1]. This project was succeeded by a similar project, in which the study of line-of-sight links was extended to rain-induced effects. For this purpose a frequency of 7 GHz in combination with the 4 GHz was chosen. In addition, another type of microwave link was chosen as subject for propagation study: a troposcatter link, between Situbondo and Surabaya.

<table>
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<tr>
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<tr>
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<td>-advices</td>
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<td>-reporting</td>
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1.2. Organization

The project THE is part of the NUFFIC PUO-program*, which is the program for Development Cooperation between universities. The NUFFIC itself is financed by the Dutch Ministry for Development Cooperation.

Eindhoven University of Technology was executing the project. The office of Development Cooperation of the university (B.O.S.) provided the major part of the administration of the project while all technological support was provided by the Telecommunications Group of the Department of Electrical Engineering of the Eindhoven University.

The working group "Indonesia" of this department assisted and guided the execution of the project and was headed by Prof.dr.ir. J.G. Niester.

The functional organisation of the project THE/2 shows a symmetry between the Indonesian and Dutch sides. At THE Prof. Niester was the leader of the project and at ITS' Faculty of Electrical Engineering (FTE)* this function was held by its dean: Ir. S. Sukardjono M.Sc., Ph.D.

The Indonesian executive body of the project was the Microwave Team headed by Indonesian and Dutch project leaders. The team members were ITS-staff members, Dutch field-engineers, ITS and THE-students.

The Indonesian financial contribution was made by the Indonesian Telecommunication Administration PERUMTEL*.

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* NUFFIC - Netherlands University Foundation for International Cooperation.
PUO - Programma Universitaire Ontwikkelingssamenwerking.
PERUMTEL - Perusahaan Umum Telekommunikasi.
FTE - Fakultas Teknik Elektro.
Fig. 1.1. Organisation structure of project THE/2.
Chapter 2

OUTLINE OF THE MICROWAVE PROJECT THE-2

Abimanyu
Son of Arjuna and Sumbadra, who, for his gifts of character and martial skill, was the Pandava's chosen candidate for the throne of Astina.
2. Outline of the microwave project THE/2

2.1. Objectives of the cooperation

The general aim of the project is to assist the Institut Teknologi Surabaya to gain more experience and knowledge in the Telecommunication field [3]. This is in accordance with the particular interest of the Indonesian Government in the design and construction of reliable telecommunication links, especially because of the problems caused by geographical features of Indonesia.

The microwave project was divided in three main sections:

a. Research activities.
   These included the continuation of a LOS test link between Gunung Sandangan at Madura and Surabaya and the construction of a troposcatter link between Situbondo and Surabaya, measurements and the interpretation of the measurements results.

b. Educational activities.
   These included lectures, set-up of practical work, workshop and coaching of students.

c. Supporting activities.
   These included all activities, which were provided in order to extend the facilities of FTE in the field of telecommunications.

2.2. Research activities

The subject of research was the study and measurement of the performance of microwave test links:
- the link Gunung Sandangan - Surabaya, a 50 km LOS-link on 4 and 7 GHz.
- the troposcatter link Situbondo - Surabaya over a distance of 150 km on 4 GHz.

To support the evaluation of the obtained results, data collection of weather stations were included and a receiving station for a geostationary weather satellite was developed.

The results of these activities will be described extensively in this report.
2.3. **Educational activities**

The educational activities of the project have been planned in order to improve the educational facilities of FTE, to upgrade the know-how of the staff and to educate students in the technical field. An elaborate description of these activities is given in Part 2 of this report.

2.4. **Supporting activities**

In order to extend the facilities of FTE the project has been contributing to:

- **the library.**
  
The selection and delivery of books and periodicals on electrical communication techniques in particular and on other electrical subjects in general.

- **the mechanical workshop.**
  
  Support in spare parts has been given in order to overhaul the existing mechanical equipment in the workshop.

- **the electronic-workshop.**
  
  Instruments for a complete electronic workshop were delivered. With these instruments repairs on equipment in the audio until the microwave field can be carried out.

- **microwave laboratory.**
  
  In this laboratory, equipment has been installed in order to do experiments in the microwave field. Some attention was paid to equipment for satellite communication reception.

2.5. **Organization**

At the Institut Teknologi Surabaya a microwave project team was formed. The task of this team was to arrange the facilities for the execution of the project according to the plan of operations. The team consisted of the Dutch project leader(s), an Indonesian project leader, three lecturers and an average number of 10 students. Regular meetings were held in which current problems and ideas were discussed. The team was formerly headed by Ir. B. Purwanto and later was led by Ir. A. Purnomo. Two Dutch student-assistants were assisting the work in Indonesia. On the Dutch side, the Telecommunications group of the Department of Electrical Engineering developed special equipment,
and did the selection of materials. Technicians of this group regularly visited Surabaya to assist in the activities.

Photo 2.1. The new campus Sukolilo of ITS, Surabaya, under construction.
Chapter 3

OBJECTIVES OF THE RESEARCH

Dewa Bayu
God of the wind; the task of castigating all evil characters reflected in his brave and strong countenance.
3. Objectives of the research

3.1. The Indonesian microwave network

Indonesia is a very large country, covering about 5000 km from the west to the east and 2000 km from north to south. It consists of thousands of islands. The largest are Java, Sumatra, Kalimantan, Sulawesi and Irian Jaya.

In order to provide communications in the country the Indonesian Telecommunication Administration, Perumtel, planned a microwave network all over the archipelago, where microwave links between the islands are provided [4].

Several types of microwave links are used in the network, due to the geographical conditions of the Indonesian country. Across the land and the straight line-of-sight microwave links are planned and already installed. Between the islands long distance line-of-sight and troposcatter links are used.

After consulting with Perumtel, the microwave link Gunung Sandangan - Surabaya was chosen for investigation of its characteristics. The results of these investigations are given in [1].

But for the planning of microwave LOS-links more facts about its characteristics had to be known.

This project aimed at collecting additional statistical propagation data of the same link at the existing frequency of 4 GHz and at another frequency of 7 GHz. The latter was added in order to get more insight into the fading behaviour of such a link during heavy tropical rains. Another objective was a further investigation of the deviation improvement due to space and frequency deviation.

In the Indonesian microwave network also long distance line-of-sight and troposcatter links are used for connection between the main islands, therefore Perumtel asked for a study of the propagation behaviour of a troposcatter link of which the propagation path is located mainly over the sea.

This subject was also recommended by CCIR, the International Radio [53] Consultative Committee, since insufficient research has been done so far on this subject in tropical areas. In order to investigate the relationship between microwave propagation and meteorological phenomena in tropical areas, measurements of the most important meteorological parameters like temperature, atmospheric pressure and humidity were planned too.
Fig. 3.1. The Indonesian microwave network
In September 1969, the first Indonesian satellite earth station at Jatiluhur went into service. The antenna of this station faced out towards the Intelsat satellite located over the Indian Ocean. But the Perumtel was unable to meet the existing demand satisfactorily.

In 1976 a domestic satellite was launched. This satellite operates at 6/4 GHz, has 12 transponders and is called Palapa 1 (see Fig. 3.2.).

Fig. 3.2. The Palapa 1, Indonesian domestic satellite launched in 1976, providing communication service for television, telephone, telex, etc. [4], p. 690.

(Gadjah Mada, 14th century prime minister of the kingdom of Majopahit, who wished to unify all people living in Nusantara (Indonesia) vowed not to eat "palapa", a great delicacy at that time, until the country was united. To commemorate this sacrifice, the Indonesian domestic satellite was named Palapa).

Due to this satellite it is also possible to provide a good communication service (television, telephone, telex, data) to remote places and the interior regions not reached by the conventional microwave network. The project THE/2 planned to do investigations on satellite communication with its own satellite receiving station.

To obtain the necessary experience on satellite communication and reception, it was decided to build a receiving station for the geostationary meteorological satellite (GMS) which operates at 1.7 GHz. The data obtained from this satellite would be of great value for the investigations on meteorological conditions in the Surabaya area and meteorological conditions is of great importance to gather relevant data to describe propagation conditions of radio waves.
Fig. 3.3. The GMS (Geostationary Meteorological Satellite) transmitting weather information of the Indonesian archipelago. [69, fig. 1-2]

3.2. **Required research on propagation problems in the Surabaya region**

Much research has already been done on the behaviour of microwaves in moderate climates. The CCIR developed methods to predict the behaviour of radio waves in LOS and tropospheric scatter links using data mostly obtained from links in moderate climates. Data is still needed from experiments in tropical areas, so the project would fit very well in the recommended research program of CCIR. [53].

3.2.1. **Line-of-sight links**

Due to the high reflection coefficient of the rice fields (sawah) and the water of the straits between the islands, deep fading will occur in the received microwave signal. Because in the microwave network of Perumtel 4 GHz links are usually used, much research on the behaviour of microwaves on this frequency was done [1]. More knowledge was needed about the influence of tropical rain on higher frequencies and the possibility for improvement of reception by frequency and space diversity.

3.2.2. **Long distance line-of-sight and troposcatter links**

Although much is known about long distance line-of-sight and tropo-scatter propagation in moderate climates, little is known about the
behaviour in tropical areas, especially over-sea links. The statistical behaviour of a microwave signal in relation to the meteorological parameters should be investigated, especially the occurrence of duct propagation which could occur frequently. Some attention could be given to the cross-polar propagation on a troposcatter link.

3.2.3. Satellite communication

As mentioned before, there are some satellites which can be used in the Indonesian area for reception purposes. With the experience in the microwave telecommunications field we gained, some research on the reception of the GMS and Palapa satellites was possible. First a start was made by constructing receiver equipment and antennas and thus experience can be gained in the field of satellite communication. An international interest in the behaviour of satellite signals in tropical areas stimulated the start of research in this field, which is, in fact, similar to the research on the LOS and troposcatter links.
Chapter 4

SHORT INTRODUCTION TO THE PROPAGATION OF MICROWAVES

Duryudono causing the outbreak of the Baratayuda war, as a consequence of his determination to remain illegal occupant of Astina's throne.
4. Short introduction to the propagation of microwaves

4.1. Refractive index of troposphere and the relation to the meteorological parameters

The propagation of microwaves, or electromagnetic radiowaves in general, is mainly influenced by the refractive index \( n \) of the medium in which the waves travel.

The refractive index is defined as the ratio of the speed of light in vacuum to the actual velocity of electromagnetic waves. For terrestrial microwave links the medium in which they travel is the troposphere, the lower part of the atmosphere extending from the surface of the earth to approx. 10 km above.

The refractive index is a function of the meteorological parameters, describing the state of the troposphere, i.e. the temperature, humidity and pressure.

Because the refractive index differs only slightly from unity, a more convenient quantity is introduced with the relationship, denoted as \( N \):

\[
N = (n-1) \times 10^6
\]

(4.1)

The formula for \( N \) is defined as:

\[
N = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2}
\]

(4.2)

where \( N \) = refractivity (dimensionless)

\( P \) = air pressure (mbars)

\( T \) = temperature (Kelvin)

\( e \) = water vapour pressure (mbars)

This formula has been adopted and recommended by CCIR [9], to describe the properties of the troposphere. As the meteorological parameters at one place change with time, the refractive index, and thus the refractivity, changes also.

However, the problem of predicting the behaviour of the refractive index in a complete microwave link is far more complicated than the formula for \( N \) suggests.

The meteorological parameters change not only with time but also in space and so they may give rise to a very complex refractive index distribution.

Fortunately, the variation of \( n \) in a horizontal direction is negligible
with respect to the variation in a vertical direction. Therefore, one is normally only interested in the variation of the refractive index in the vertical direction.

It has been proved that the average variation of the refractive index per meter of altitude \( z \) (vertical gradient of the index) near the ground for a standard atmosphere is:

\[
\frac{dn}{dz} = -0.039 \times 10^{-6} \text{ per meter} \tag{4.3}
\]

or \(-39\) N-units per km.

The value of the refractivity at an altitude of \( z \) km is given by:

\[
N(z) = (n-1) \times 10^6 = 289 \times e^{-0.136 z} \text{ N-units} \tag{4.4}
\]

Small as it may be, this variation in the refractive index strongly affects wave propagation.

We shall define a standard atmosphere as a horizontally homogeneous atmosphere in which the refractive index varies with altitude according to equation (4.4).

The term 'standard' should not be misinterpreted. The standard atmosphere is an ideal atmosphere that only represents the mean condition in the actual atmosphere all over the world. In tropical regions, other values for the constants of (4.3) and (4.4) are valid.

4.2. \textit{k-factor model}

The result of this variation of the refractive index is primarily the bending of radio waves. This can be seen from Snellius' Law, which says:

\[
n \sin \phi = \text{constant}
\]

where \( n \) = refractive index

\( \phi \) = angle of ray, relative to local vertical.

If \( n \) changes, \( \phi \) will change also and therefore the path of the ray. See Fig. 4.1.
Fig. 4.1. Curvature of radiowave according to variations of the refractive index

From Snellius' Law it can be derived that the ray path will have a curvature of:

$$\frac{1}{\rho_r} = - \frac{dn}{dz}$$  \hspace{1cm} (4.5)

where \( \rho_r \) = radius of the path
\( \frac{dn}{dz} \) = gradient of refractive index.

The result will be a curved ray path above a curved earth surface. Therefore the concept of effective earth radius is introduced. The actual earth radius is multiplied by a factor \( k \), which depends on the refractive index gradient:

$$k = \frac{1}{1 + R \frac{dn}{dz}}$$  \hspace{1cm} (4.6a)

where \( R \) = actual earth radius.

For linear variation of \( n \) with height, \( k \) is a constant and the ray paths become straight lines above an earth with radius \( kR \).

In general, the meteorological parameters \( p \), \( T \) and \( e \) and therefore the refractive index gradient vary rather randomly with height. Knowing the vertical variation of the refractive index along the entire path, it should be possible to trace the ray path, which obviously would no longer be a straight line.

An effective \( k \)-factor is defined, representing the propagation properties which are related to the total curvature of the ray and to the mean distance between the ray and the earth's surface - from which results its general use in diffraction problems. On the other hand, it does not take into account the actual shape of the ray.
Due to the continuous variation of meteorological conditions, the effective k-factor is a random function of time, consequently it can be characterised by its mean value and statistical distribution. Generally it is accepted that the effective $\bar{k}$-factor can be calculated by the formula:

$$\bar{k} = \frac{1}{1 + 64 \times 10^{-3} \Delta N}$$

(4.60)

where $\Delta N$ is the difference between refractivities at an altitude of 1 km and at ground level.

An average value of $\Delta N$ is -39 N-units, used in the standard atmosphere, will result in an effective $\bar{k}$-factor of 4/3. However, for tropical climates with their high mean humidity, the value of $\bar{k}$ is higher.

For the Surabaya region a median value of 1.52 was calculated from measured meteorological data. See [1] and [15], at 7 h. in the morning. The apparent decrease or increase of earth's curvature may effect microwave communications strongly, as it determines the earth bulge. With a decreasing k-factor the earth bulge may penetrate the microwave beam thus blocking the propagation path. The resulting type of fading in the received signal is known as diffraction fading. The opposite is also possible: in a troposcatter link the receiving antenna normally can not 'see' the transmitting antenna directly, because the two antennae are too far apart (because of the earth bulge). For large values of the k-factor (or even negative values resulting in inversion of the earth's curvature) the earth bulge will decrease, enabling both antennas to see each other. This type of propagation is called ducting, because of the accompanying high signal levels.

Fig. 4.3 illustrates these different types of earth bulges due to different k-factors.

![Earth bulges due to different k-factors](image)

Fig. 4.3. Earth bulges due to different k-factors and its effect on microwave propagation
4.3. Duct propagation

In a standard troposphere a linear refractive index profile is assumed. In practice a non-linear profile will often occur causing the rays to be refracted in different directions.

At each point P of the troposphere Snellius Law is valid:

\[ n(r) \cdot r \cdot \sin(\phi(r, \theta)) = \text{constant} \quad (4.8) \]

where: \( n(r) = \) refractive index as function of radius \( r \).

For a small displacement along the wave path we find:

\[ r \sin\phi \, dn + n \sin\phi \, dr + n \, r \cos\phi \, d\phi = 0 \quad (4.9) \]

After elimination of \( \theta \), the following equation

\[ \cot\phi = \frac{1}{r} \, \frac{dr}{d\theta} \quad (4.10) \]

and differentiation to \( \theta \) it will result in the following equation*:

\[ \frac{d^2r}{d\theta^2} = \frac{1}{r} \left( \frac{dr}{d\theta} \right)^2 + r^2 \left( 1 + \frac{dr}{d\theta} \right)^2 \left( \frac{1}{n} \frac{dn}{dr} + \frac{1}{r} \right) \quad (4.11) \]

In L.O.S. and troposcatter links generally \( \frac{dr}{d\theta} \) is very small, which results in a simplification of (4.11):

\[ \frac{d^2r}{d\theta^2} = r^2 \left( \frac{1}{n} \frac{dn}{dr} + \frac{1}{r} \right) \quad (4.12) \]

A coordinate transformation (see Fig. 4.3) applying:

\[ z = r - R = \text{height above earth surface} \]

*) For full details see Section 5.2.
will result in the following differential equation:

\[
\frac{d^2 z}{dx^2} = \frac{1}{n} \frac{dn}{dz} + \frac{1}{R} \quad (4.13)
\]

In case of a linear function for the refractive index \( n(z) \), resulting in a constant \( \frac{dn}{dz} \), a \( k \)-factor is defined, resulting in:

\[
\frac{d^2 z}{dx^2} = \frac{1}{kR} \quad (4.14)
\]

The factor \( k \) represents the meteorological influence of the troposphere on the radio propagation.

The height of the radiowave \( z(x) \) as function of the distance \( x \) can be determined when the height of the transmitting and receiving antenna and the distance \( d \) between receiver and transmitter are also known:

\[
z(x) = \frac{x^2}{2kR} + \left( \frac{h_r - h_t}{d} \right) - \frac{d}{2kR} x + h_t \quad (4.15)
\]

where:
- \( h_t \) = height transmitter antenna
- \( h_r \) = height receiver antenna
- \( d \) = distance receiver - transmitter.

This is the ray equation of a LOS link above a spherical earth.

A simpler representation of a ray path can be obtained by representing the earth as a flat plane. This results in a modified refractive index \( m(z) \).

---

**Fig. 4.4.** Propagation of waves above a plane earth model
Snellius Law is still valid and is represented by:

\[ m(z) \sin\phi(z,x) = \text{constant} \quad (4.16) \]

For a small displacement (see Fig. 4.4) we will have:

\[ \sin\phi \, dm + m \cos\phi \, d\phi = 0 \quad (4.17) \]

and

\[ \frac{dz}{dx} = \frac{1}{m \tan\phi} \quad (4.18) \]

After differentiation of (4.18) and substitution in (4.17) we find:

\[ \frac{d^2 z}{dx^2} = \frac{1}{m} \left(1 + \left(\frac{dz}{dx}\right)^2\right) \frac{dm}{dz} \quad (4.19) \]

For troposcatter and LOS, links \( \frac{dz}{dx} \ll 1 \), resulting in a simplification of equation (4.19):

\[ \frac{d^2 z}{dx^2} = \frac{1}{m} \frac{dm}{dz} \quad (4.20) \]

A comparison with equation (4.13) results in:

\[ m(z) = n(z) + \frac{z}{R} \quad (4.21) \]

Because \( m \) and \( n \) almost equal unity:

\[ \begin{align*} 
N &= (n-1) \times 10^6 \\
M &= (m-1) \times 10^6 = N + \frac{z}{R} \times 10^6 
\end{align*} \quad (4.22) \]

From equation (4.15) it is possible to derive a ray equation above a plane earth, in case of a linear M-profile:

\[ z(x) = \frac{x^2}{2} \frac{dM}{dz} \times 10^{-6} + \left(\frac{h_r - h_t}{d} - \frac{d}{2} \frac{dM}{dz}\right) 10^{-6}x + h_t \quad (4.23) \]

From equation (4.23) it can be seen that \( \frac{dM}{dz} \) determines the ray path.

As has been explained before, the refractivity \( N \) depends on the meteorological conditions of the troposphere.

The numeric value for \( M \) is:

\[ \frac{dM}{dz} = \frac{dN}{dz} + \frac{10^6}{R} = 0.27 \frac{dp}{dz} + 4.4 \frac{de}{dz} - 1.28 \frac{dT}{dz} + 157 \quad (4.24) \]
Temperature and water pressure will influence the ray-path most. Normally a negative gradient for temperatures and a positive gradient for water pressure will exist resulting in $\frac{dM}{dz} > 0$.

The radiowaves will be bent away from the earth's surface (see Fig. 4.5).

![Fig. 4.5 Ray-paths at $\frac{dM}{dz} > 0$ for several elevation angles $\alpha$](image)

But $\frac{dM}{dz}$ can also become negative, for example when the water vapour pressure decreases as function of height: $\frac{de}{dz} < 0$.

Especially above sea surface a situation as described above can easily occur. The water vapour pressure near the sea surface is high. Within a layer above the sea surface the water vapour pressure decreases relatively fast in order to reach its normal value at high altitude.

Also the temperature can have a positive gradient ($\frac{dT}{dz} > 0$) due to the low temperature of the sea water and the high temperature of the air above (Fig. 4.6).

![Fig. 4.6 Relation between e, T, N and M for a ground based duct, mostly occurring above sea level](image)
At ground level \((z = 0)\) radiowaves transmitted at an elevation angle smaller than \(\alpha_d\) (see Fig. 4.7) will be refracted back to ground level. The angle \(\alpha_d\) depends on the elevation of the duct and transmitter.

It will be understood that radiowaves, refracted in a duct, can be reflected at ground (sea) level and propagated in a way as indicated in Fig. 4.7. It can occur that propagation of radiowaves over a distance of more than 1000 km is possible by means of a duct.

Fig. 4.7 Propagation of a radiowave in a ground based duct.

- \(h_t\) = height of transmitter,
- \(h_d\) = height of duct,
- \(\alpha_d\) = max. elevation angle [7] for duct propagation.

When the height of the transmitting antenna is above \(h_d\) (see Fig. 4.8) propagation via the duct will not occur.

Fig. 4.8. Ray-paths when transmitting antenna is above the top of the ground based duct
A practical representation of a ground based duct is by a linear and a parabolic $M$-profile.

A parabolic approximation is valid for $z < h_m$:

$$M(z) = M_d + \beta (z - h_d)^2$$  \hfill (4.25)

and for $z > h_m$ a linear approximation can be used

$$M(z) = M_m + \beta' (z - h_m)$$  \hfill (4.26)

where: $h_d =$ height of the duct 
$h_m =$ height where $\frac{dN}{dz} = 0$ with $\beta$ and $\beta'$ constants

In the case of an "elevated" duct, the negative part of the $M$-gradient is at a higher altitude. Propagation over long distance is possible again, provided the transmitter antenna is between the levels $h_1$ and $h_2$ and elevation angles within limits (see Fig. 4.9).

![Fig. 4.9 Ray paths in the case of an elevated duct](image)

In Fig. 4.10 the influence of ducts on a radio signal is shown. Also in a troposcatter link duct occurrence will give rise to very high signal levels compared with the normally weak troposcatter signal.

In a troposcatter system ducting is considered an undesirable effect because of saturation of receiver input amplifiers. Recently shielding (artificial obstacles in the radio path) and optimal transmitter elevation angles are used in order to minimize the possibility of the radiowave being coupled into a duct.
Fig. 4.10 Signal types during different M-profiles occurrences
a. Substandard, b. Standard, c. Ground duct
d. Ground duct and elevated duct.  [16]
Chapter 5

THE PROPAGATION CHARACTERISTIC MEASUREMENT OF LINE-OF-SIGHT LINK GUNUNG SANDANGAN - SURABAYA

Kresna
King of Dwarawati, supervisor of Pandawa, fondly revered for his wise advice to Arjuna on the eve of the Baratayuda war.
5.1. Additional theory on the propagation of microwaves concerning the line-of-sight.

As is known, electromagnetic waves are not propagated along straight lines but are bent a little by the atmosphere. How much they will be bent depends on the meteorological conditions of the atmosphere. The Maxwell equations for electromagnetic waves propagated through a medium are [30]:

\[
\begin{align*}
\nabla \times \vec{E} + \mu \frac{\partial \vec{H}}{\partial t} &= \vec{0} \quad (5.1.a) \\
\nabla \times \vec{H} - \varepsilon \frac{\partial \vec{E}}{\partial t} &= \sigma \vec{E} \quad (5.1.b) \\
\n\nabla \cdot \vec{E} &= \frac{\rho}{\varepsilon} \quad (5.1.c) \\
\n\nabla \cdot \vec{H} &= 0 \quad (5.1.d)
\end{align*}
\]

where: 
- \( \vec{E} \) is the electric field strength (V/m) (complex vector notation)
- \( \vec{H} \) is the magnetic field strength (A/m) (complex vector notation)
- \( \varepsilon \) is the dielectric constant (F/m)
- \( \mu \) is the magnetic permeability (H/m)
- \( \sigma \) is the electrical conductivity (mho/m)
- \( \rho_c \) is the space charge density (coulomb/m\(^3\))
In order to describe the propagation of waves, the following assumptions are made:

1. the medium is linear, isotropic and homogeneous. Linear means that \( \varepsilon \) and \( \mu \) do not depend on the amplitudes of \( \mathbf{E} \) and \( \mathbf{H} \); isotropic means that \( \varepsilon \) and \( \mu \) at an arbitrary point are not dependent on the direction and homogeneous means that \( \varepsilon \) and \( \mu \) are not dependent on the place.

2. the field strengths are harmonic functions of the time.

\[
\mathbf{E} \stackrel{\text{Def}}{=} \text{Re}\{ \mathbf{E} e^{j\omega t} \}, \quad (5.2.a)
\]
\[
\mathbf{H} \stackrel{\text{Def}}{=} \text{Re}\{ \mathbf{H} e^{j\omega t} \}, \quad (5.2.b)
\]

Using these assumptions the Maxwell equations (5.1.a, 5.1.b) can be written as:

\[
\nabla^2 \mathbf{E} - \varepsilon \mu \frac{\partial^2 \mathbf{E}}{\partial t^2} = j\omega \varepsilon \mathbf{E} \quad (5.3.a)
\]
\[
\nabla^2 \mathbf{E} + (\omega^2 \varepsilon \mu - j\omega \sigma) \mathbf{E} = 0 \quad (5.3.b)
\]

Assuming moreover:

\[
\mathbf{E} = \mathbf{E}(x),
\]

the field strength is only a function of \( x \) and \( t \) and the waves propagate to the \( x \)-direction (plane wave).

\[
\nabla^2 \mathbf{E}_x = \frac{\partial^2 \mathbf{E}_x}{\partial x^2} + \frac{\partial^2 \mathbf{E}_x}{\partial y^2} + \frac{\partial^2 \mathbf{E}_x}{\partial z^2} \quad (5.4)
\]

Thus for this case:

\[
\nabla^2 \mathbf{E}_x = \frac{\partial^2 \mathbf{E}_x}{\partial x^2} \quad (5.5)
\]

Combining (5.3.b) and (5.5):

\[
\frac{\partial^2 \mathbf{E}_x}{\partial x^2} + (\omega^2 \varepsilon \mu - j\omega \sigma) \mathbf{E}_x = 0 \quad (5.6)
\]

Suppose \( \mathbf{E}_x = A e^{\gamma x} \).

Thus:
\[ \frac{\delta E_x}{\delta x} = A \gamma e^{\gamma x} \]

and

\[ \frac{\delta E_x}{\delta x^2} = A \gamma^2 e^{\gamma x} \] (5.7)

Combining (5.6) and (5.7):

\[ A \gamma^2 e^{\gamma x} + (\omega^2 \mu e - j \omega \sigma) A e^{\gamma x} = 0 \]

\[ \gamma^2 + (\omega^2 \mu e - j \omega \sigma) = 0 \]

\[ \gamma = \pm j \sqrt{\omega^2 \mu e - \omega \sigma} \] (5.8)

Thus:

\[ E_x = A e^{-j \sqrt{\omega^2 \mu e - \omega \sigma} x} + B e^{j \sqrt{\omega^2 \mu e - \omega \sigma} x} \]

where \( A \) and \( B \) are integration constants.

\( \Rightarrow \)

\[ \tilde{E}_x = \text{Re}[(A e^{-j \sqrt{\omega^2 \mu e - \omega \sigma} x} + B e^{j \sqrt{\omega^2 \mu e - \omega \sigma} x}) e^{j \omega t}] e_x \]

\[ \tilde{E}_x = \frac{\gamma}{\sqrt{\mu c}} \tilde{E}_x \] (5.10.a)

with:

\[ \gamma = j \sqrt{\omega^2 \mu e - \omega \sigma} \] (5.10.b)

\[ \gamma = j \frac{\omega}{c} \sqrt{\frac{\mu}{\varepsilon}} \sqrt{1 - \frac{j \sigma}{\omega c}} \] (5.10.c)

\[ c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 3.10^8 \text{ m/sec}, \]

the electric wave velocity in vacuum.

\( \gamma \) represents the propagation constant.

\( A \) and \( B \) are complex constant vectors which can be calculated if the boundary conditions are known.
\[ \gamma = j \frac{\omega}{c} \sqrt{\mu_r \varepsilon_r} \sqrt{1 - j \frac{\sigma}{\omega \varepsilon}} = \alpha + j\beta \]  
(5.11.a)

\[ \alpha = \frac{\omega}{c} \sqrt{\mu_r \varepsilon_r} \sqrt{-1 + \sqrt{1 + \frac{\sigma^2}{\omega^2 \varepsilon^2}}} \]  
(5.11.b)

\[ \beta = \frac{\omega}{c} \sqrt{\mu_r \varepsilon_r} \sqrt{1 + \sqrt{1 + \frac{\sigma^2}{\omega^2 \varepsilon^2}}} \]  
(5.11.c)

The phase velocity will be:

\[ v_{ph} = \frac{c}{\sqrt{\varepsilon_r \mu_r} \sqrt{1 + \sqrt{1 + \frac{\sigma^2}{\omega^2 \varepsilon^2}}}} \]  
(5.12)

The refractive index is defined as the ratio of the phase velocity in vacuum and in the medium concerned. So we can write:

\[ n = \frac{c}{v_{ph}} = \frac{1}{\sqrt{\varepsilon_r \mu_r} \sqrt{1 + \sqrt{1 + \frac{\sigma^2}{\omega^2 \varepsilon^2}}}} \]  
(5.13)

This formula shows that the refractive index depends on the electrical behaviour of the medium and the frequency used. It gives also the relation of the refractive index to the electrical parameters \( \varepsilon, \mu, \sigma \) derived from the Maxwell equations. For the troposphere is valid:

\[ \mu_r = 1 \text{ and } \sigma = 0 \]

Derived from 5.13:

\[ n = \sqrt{\varepsilon_r} \]  
(5.14)

and

\[ N = (n-1) \times 10^6 \]  
(5.15)

In the following formulas we see that the refractive index \( n \) depends on the atmospheric conditions but in fact it will vary with elevation, because
the composition and pressure of the atmospheric gases vary with elevation too.

From experiments it is found that $N$ can be described with meteorological parameters, namely the pressure ($P$), temperature ($T$) and the partial water vapour pressure ($e$).

The empirical equation for $N$ is:

$$N = K_1 \frac{P_d}{T} + K_2 \frac{e}{T} + K_3 \frac{e}{T^2} + K_4 \frac{P_c}{T}$$

where:
- $P_d$ = partial dry air pressure (mbar)
- $e$ = partial water vapour pressure (mbar)
- $P_c$ = partial CO$_2$ pressure (mbar)
- $T$ = absolute temperature (K).

According to Smith and Weintraub [31] who have already done many experiments in this field, the best set $K_1$, $K_2$ and $K_3$ values are:

$$K_1 = 77,607 \pm 0,13 \text{ K/mbar}$$

$$K_2 = 71,6 \pm 8,5 \text{ K/mbar}$$

$$K_3 = (3,747 \pm 0,031) \times 10^5 \text{ K}^2/\text{mbar}.$$

The influence of CO$_2$ is already included in $K_1$.

If we use these values for formula 5.11, we get:

$$N = 77,6 \frac{P_d}{T} + 72 \frac{e}{T} + 3,75 \times 10^5 \frac{e}{T^2}$$

(5.17a)

$$N = 77,6 \frac{P}{T} - 5,6 \frac{e}{T} + 3,75 \times 10^5 \frac{e}{T^2}$$

(5.17b)

where: $P = P_d + e$, the total air pressure.

We can simplify formula (5.12b) to

$$N = 77,6 \frac{P}{T} + 3,73 \times 10^5 \frac{e}{T^2}$$

(5.17c)

with:
- $P$ = total air pressure in mbar
- $e$ = water vapour pressure in mbar
- $T$ = temperature in Kelvin.
This formula is recommended by the CCIR [32], for frequencies up to 30 GHz as giving 0.5% accuracy. This accuracy is sufficient, as the pressure P, the water vapour pressure e and the temperature T measurements already give a bigger error indications, due to the transducer accuracy. Thus, to define the value of N it is very important to control the accuracy of the transducers which are used for measuring the pressure P, the humidity e and the temperature T values, especially the value of humidity e.

The variations of N with time in relation with the variations of the P, e and T at a certain average value of refractivity \( N = N_0 \) will be:

\[
\Delta N = \left( \frac{\delta N}{\delta T} \right)_o \Delta T + \left( \frac{\delta N}{\delta P} \right)_o \Delta P + \left( \frac{\delta N}{\delta e} \right)_o \Delta \begin{array}{c} e \\ 0 \end{array}
\]

The preceding equation shows the influence of small variations of the meteorological parameters on the refractivity. According to equation 5.17c the following expressions are valid:

\[
\left( \frac{\delta N}{\delta T} \right)_o = 77.6 \frac{P_o}{T_o^2} - 7.46 \times 10^5 \frac{e_o}{T_o^3}
\]

\[
\left( \frac{\delta N}{\delta P} \right)_o = \frac{77.6}{T_o}
\]

\[
\left( \frac{\delta N}{\delta e} \right)_o = \frac{3.73 \times 10^5}{T_o^2}
\]

For Indonesia the mean values of the meteorological parameters are:

\[
\begin{array}{c}
T_o = 299.5 \text{ K} \\
P_o = 1011.0 \text{ mbar} \\
e_o = 27.7 \text{ mbar} \\
N_o = 377.4
\end{array}
\]

so:

\[
\Delta N = -1.64 \Delta T + 0.26 \Delta P + 4.16 \Delta e
\]

From this expression we can see that the influence of humidity variation is the most important, therefore the humidity measurement should be as accurate as possible.

The influence of the pressure variation is small in comparison with the other two parameter variations.
5.2. Propagation of microwaves in a layered medium

In the preceding paragraph the propagation of electromagnetic waves in a homogeneous medium has been described. In fact, the electromagnetic wave medium, the troposphere is not a homogeneous medium but a layered medium, which means that the meteorological parameters are not constant, but change with distance and height. Thus, the refractivity $N$ is a function of the height above the ground surface.

The propagation of microwaves can be described by the Maxwell equations but can often be described by radio optics theory (rays), namely if the following conditions are met:

1. the variation of the refractive index at a distance of one wave length is less than $2\pi$ [22].
2. the variations of the distance of the rays between transmitter and receiver, within a path length of one wave length, is less than $2\pi$ [22].

These statements have been investigated and proved by Früchtenicht [22]. The first condition is always met, for the variations of the refractive index is about $10^{-4}/\text{km}$.

The second condition means that if the waves are diverging strongly, the radio optics model is very limited.

The two conditions are met in a normal troposphere condition, so the radio optics model can be used for propagation of waves in the troposphere.

5.2.1. Raytraces in the troposphere

In the layered troposphere the Snellius law is also valid for the ray traces. The Snellius law can be written as follows: for a flat surface:

$$\frac{n_1}{n_2} = \frac{\sin \phi_1}{\sin \phi_2}$$

Fig. 5.4. Ray traces above a flat surface
\[ n_1 \sin\phi_1 = n_2 \sin\phi_2 \]  
(5.20)

or

\[ n \sin\phi = \text{constant} \]

For a spherical surface:

\[ \frac{d^2 r}{d\theta^2} = \frac{dr}{d\theta} \cot(\phi) - \frac{r}{\sin^2 \phi} \frac{d\phi}{d\theta} \]  
(5.22b)

From equation (5.21):

\[ \frac{d\phi}{d\theta} = -\tan\phi \left\{ \frac{1}{n \frac{dn}{dr}} + \frac{1}{r} \right\} \frac{dr}{d\theta} \]

Thus we get:

\[ \frac{d^2 r}{d\theta^2} = \cot(\phi) \frac{dr}{d\theta} + \frac{r}{\sin^2 \phi} \tan\phi \left\{ \frac{1}{n \frac{dn}{dr}} + \frac{1}{r} \right\} \frac{dr}{d\theta} \]

\[ = \left\{ \cot(\phi) + \frac{r}{\sin \phi \cos \phi} \left( \frac{1}{n \frac{dn}{dr}} + \frac{1}{r} \right) \right\} \frac{dr}{d\theta} \]

\[ = \frac{1}{r} \frac{dr}{d\theta} + \frac{r}{Dr \cdot d\theta} \frac{1}{dr^2 + (r d\theta)^2} \left( \frac{1}{n \frac{dn}{dr}} + \frac{1}{r} \right) \frac{dr}{d\theta} \]
\[
\frac{d^2 r}{d \theta^2} = \frac{1}{r} \left( \frac{dr}{d \theta} \right)^2 + r^2 \left( 1 + \frac{1}{r} \left( \frac{dr}{d \theta} \right)^2 \right) \frac{1}{n} \frac{dn}{dr} + \frac{1}{r}
\]

The solution of this differential equation gives the equation of the wave's ray trace.

In the line of sight (L.O.S.) links the value of \( \frac{1}{r} \frac{dr}{d \theta} \ll 1 \), and so equation (5.23) can be simplified to:

\[
\frac{d^2 r}{d \theta^2} = r^2 \left( \frac{1}{n} \frac{dn}{dr} + \frac{1}{r} \right)
\]

In order to get a more practical formula, the following coordinate transformation can be used:

\[ z = r - R; \text{ the height above the earth surface} \]
\[ x = R \theta; \text{ the distance along the earth surface,} \]

and so:

\[
\frac{d^2 z}{dx^2} = \frac{1}{n} \frac{dn}{dz} + \frac{1}{R}
\]

\[ R = \text{the earth radius.} \]

The solution of this equation gives the height of the ray trace above the earth surface as a function of the distance at the earth surface from a certain point at the earth surface.

The initial values for this equation are:

\[ z(0) = h_t, \text{ the height of the transmitter} \]
\[ z(d) = h_r, \text{ the height of the receiver.} \]

In this case the coordinate \( x \) gives the distance from the transmitter. The receiver is placed at a distance \( d \) from the transmitter.
Equation (5.25) can be used to calculate the ray traces by propagation in a medium with a defined refraction index profile. To simplify calculations, two models will be introduced.

Model 1: Ray traces above the flat earth

In this model we assume that the earth is flat and for the ray traces calculations we use the modified refraction index model \( m(z) \).

\[
\begin{align*}
\text{For Fig. 5.6 the Snellius law can be written as follows:} \\
m(z) \sin \phi(x, z) &= \text{constant} \quad (5.26) \\
\text{From Fig. 5.6: } \frac{dz}{dx} &= \frac{1}{\tan \phi(x, z)} , \text{ and so:} \\
\frac{d^2 z}{dx^2} &= \frac{1}{m(z)} \frac{dm(z)}{dz} \text{ if } \frac{dz}{dx} \ll 1 \quad (5.27)
\end{align*}
\]

The solution of this equation gives the height of the ray trace above the earth surface as a function of distance from the transmitter; if the initial conditions are the same as in equation (5.25).

By comparing equation (5.25) and (5.27) we can see the relationship between \( m(z) \) and \( n(z) \). Because the coordinates \( z \) and \( x \) describe the same quantities, the right hand side of the equations should also be the same.

Thus:

\[
\frac{1}{m(z)} \frac{dm(z)}{dz} = \frac{1}{n(z)} \frac{dn(z)}{dz} + \frac{1}{R}
\]

Since \( m(z) \) and \( n(z) \) are nearly one, we get:
\[
\frac{dm}{dz} = \frac{dn}{dz} + \frac{1}{r} \quad \text{or} \quad m(z) = n(z) + \frac{z}{R}
\]  \hspace{1cm} (5.28)

\(m(z)\) is called the modified refractive index.

Thus if we assume that the earth surface is flat, we should use the modified refractive index to do the ray trace calculations.

The modified refractive index modulus is defined as:

\[
M(z) = [m(z) - 1] \times 10^6
\]  \hspace{1cm} (5.29)

**Model 2: the k-factor model**

Now if we assume that the ray propagates in a straight line above the earth, the \(n(z)\) changes linearly with the height above the earth surface \(z\) (Appendix I).

**Fig. 5.7. The artificial earth with radius \(R_a\)**

**Fig. 5.7** shows an artificial earth for which the ray traces will be straight lines.

A good approximation is given by:

\[
z(x) = \frac{x^2}{2R_a} + \tan\alpha_t x + h_t
\]  \hspace{1cm} (5.30a)

or:

\[
\frac{d^2z(x)}{dx^2} = \frac{1}{R_a}
\]  \hspace{1cm} (5.30b)

According to equation (5.25) we can conclude that:
\[
\frac{1}{R_a} = \frac{1}{n} \frac{dn}{dz} + \frac{1}{R}
\]

(5.31)

If

\[
R_a = kR; \quad \frac{1}{kR} = \frac{1}{n} \frac{dn}{dz} + \frac{1}{R}
\]

(5.32)

\[
kR = \frac{1}{\frac{1}{n} \frac{dn}{dz} + \frac{1}{R}}
\]

(5.33)

\[
k = \frac{1}{\frac{R}{n} \frac{dn}{dz} + 1}
\]

or

\[
k(z) = \frac{1}{1 + \frac{R}{n} \frac{dn}{dz}}
\]

(5.34)

Thus, to obtain the k-factor model, the straight line ray traces model, we should multiply the earth radius \( R \) with the k-factor, \( k(z) \).

So the conclusion is that the influence of the troposphere on the propagation of waves can be brought into account when the physical earth radius \( R \) is multiplied by a term \( k \), which is a function of the refractive index gradient.

The model using the artificial earth radius \( R_a = kR \), is called the k-factor model.

The reason for the introduction of the k-factor model is clear, for the ray traces in this model are straight lines, so easy geometric formulas can be used in order to describe the path calculations.

The use of the k-factor model is limited to refractive index profiles which are linear with the height above the earth surface and depend only on the height above the earth surface.

If \( n(z) \) is linear, \( \frac{dn}{dz} \) will be constant and

\[
k = \frac{1}{1 + \Delta N \frac{R}{10^6}}
\]

(5.35)

and for \( R = 6370 \) km we can draw the k-factor as a function of the \( \Delta N \) and can be found at Fig. 5.8.

\( \Delta N = N \) at 1000 m height - \( N \) at earth surface.
Fig. 5.8. The k-factor as function of the refractivity gradient $\Delta N$ according to equation $k = \frac{1}{1 + \Delta N \cdot R \cdot 10^{-6}}$ and $R = 6370$ km.

5.3. **Focusing in the troposphere**

In the previous paragraph it has already been explained that the ray traces will be straight lines if $k = 1$ and the power density in the front of the receiving antenna will be $S_o = \frac{P_T \cdot G_t}{4\pi x^2}$, as described in the radio equation.

The most important difference between propagation of microwaves in free space (homogeneous medium) and in the troposphere is:

In free space it propagates as a straight line and in the troposphere the ray traces are not straight lines.

In general this means that in the troposphere, the power density in front of the receiving antenna will differ from $S_o$.

Thus, when propagation in free space occurs, the power transmitted within the solid angle $\Omega_o$, will reach the receiving antenna. In the layered troposphere this solid angle will be $\Omega_t$, which depends on the way that the waves are refracted between the transmitting and the receiving antenna.
So in a layered medium the power density at the front of the receiving antenna will be:

$$S_t = \frac{\Omega_t}{\Omega_o} S_o \quad (\text{W/m}^2)$$  \hspace{1cm} (5.36)

where: $\Omega_o$ is the solid angle of the beam of energy transmitted which reaches the receiving antenna if propagation occurs in a homogeneous medium.

$\Omega_t$ is the solid angle of the beam of energy transmitted which reaches the receiving antenna if propagation occurs in a layered troposphere.

The ratio $\sqrt{\frac{\Omega_t}{\Omega_o}}$ is called the focusing factor and it is valid for a ray which transmits from point A to point B.

$$S_t = \left| \frac{\Omega_t}{\Omega_o} \right| S_o \quad (\text{W/m}^2)$$  \hspace{1cm} (5.37)

$$\frac{|E_t|}{|E_o|} = \sqrt{\frac{\Omega_t}{\Omega_o}} = C_d$$

The focusing factor $C_d$ can be calculated and the result is: [34]
\[
C_d = \frac{E_t}{E_o} = \sqrt{d \left| \frac{d\alpha_t}{dh} \right|} \quad h = h_r \quad \frac{1}{\cos\alpha_r \cos\alpha_t}
\] (5.38)

where:

- \(C_d\) = focusing factor
- \(E_t\) = electric field strength at the receiving antenna if propagation is in a layered medium
- \(E_o\) = electric field strength at the receiving antenna if propagation takes place in free space
- \(d\) = distance between antennas
- \(\alpha_t\) = elevation angle of the ray at the transmitter
- \(\alpha_r\) = elevation angle of the ray at the receiver.

Fig. 5.10. Schematic diagram concerning formula 5.38

\[
C_d^2 = \frac{d \left| \frac{d\alpha_t}{dh} \right|}{\cos\alpha_r \cos\alpha_t}
\]

It can be derived that 

\[
d \left| \frac{d\alpha_t}{dh} \right| = \cos^2 \alpha_t \quad h = h_r
\]

Thus:

\[
C_d^2 = \frac{\cos^2 \alpha_t}{\cos\alpha_r \cos\alpha_t} = \frac{\cos\alpha_t}{\cos\alpha_r}
\]

\[
C_d = \sqrt{\frac{\cos\alpha_t}{\cos\alpha_r}}
\]
Fig. 5.11. Schematic diagram for calculating the focusing factor $C_d$.

Fig. 5.12. Ray traces above artificial earth

As previously described

$$k = \frac{1}{1 + \frac{R}{n} \frac{dn}{dz}}$$

and the differential equation of the rays is:

$$\frac{d^2z}{dx^2} = \frac{1}{kR}$$

where: $z =$ the height of the ray above the earth surface

$x =$ the distance from the transmitter to the receiver.

At $x = 0$, at the transmitter, $z(0) = h_t$; the height of the transmitting antenna.

At $x = d$, at the receiver, $z(d) = h_r$; the height of the receiving antenna.

Using this initial condition we obtain:

$$z(x) = \frac{x^2}{2kR} + \left(\frac{h_r - h_t}{d} - \frac{d}{2kR}\right)x + h_t$$

(5.39)
With this formula we can draw the ray trace above the earth surface if \( h_t, h_r, d, \) and \( k \) are known.

5.5. *Path clearance*

The path clearance of line of sight links is very important for defining the quality of the link. Depending on the terrain and the quality requirement the path clearance can be determined.

A table from [33] is given as an example of how to define a path clearance according to the requirements.

<table>
<thead>
<tr>
<th>propagation condition</th>
<th>perfect</th>
<th>ideal</th>
<th>average</th>
<th>difficult</th>
<th>very difficult</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>weather</strong></td>
<td>standard atmosphere</td>
<td>no surface layer or fog</td>
<td>some sub-standard and little fog</td>
<td>surface layers ground fog</td>
<td>surface layers fog over water</td>
</tr>
<tr>
<td><strong>location in U.S.A.</strong></td>
<td>Rocky Mountains</td>
<td>great plains and east</td>
<td>coastal</td>
<td>coastal water</td>
<td></td>
</tr>
<tr>
<td><strong>propagation reliability</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60 - 85 %</td>
<td></td>
<td>( 0.6 F_1 ) ( k = 4/3 )</td>
<td>( 1.0 F_1 ) ( k = 4/3 )</td>
<td>( 0.6 F_1 ) ( k = 1 )</td>
<td></td>
</tr>
<tr>
<td>85 - 98 %</td>
<td>( 0.6 F_1 ) ( k = 4/3 )</td>
<td>( 1.0 F_1 ) ( k = 4/3 )</td>
<td>( 0.6 F_1 ) ( k = 1 )</td>
<td>( 0.3 F_1 ) ( k = 2/3 )</td>
<td></td>
</tr>
<tr>
<td>98 - 99.9 %</td>
<td>( 0.6 F_1 ) ( k = 4/3 )</td>
<td>( 1.0 F_1 ) ( k = 4/3 )</td>
<td>( 0.6 F_1 ) ( k = 1 )</td>
<td>( 0.3 F_1 ) ( k = 2/3 )</td>
<td>grazing ( k = \frac{1}{3} )</td>
</tr>
<tr>
<td>99.9 - 99.99 %</td>
<td>( 1.0 F_1 ) ( k = 4/3 )</td>
<td>( 0.6 F_1 ) ( k = 1 )</td>
<td>( 0.3 F_1 ) ( k = 2/3 )</td>
<td>grazing ( k = \frac{1}{3} )</td>
<td>grazing ( k = 5/12 )</td>
</tr>
</tbody>
</table>

Table showing the path clearance needed [33] to guarantee a certain propagation probability.

\( F_1 \) = First Fresnel zone, see page 5.20.
Fig. 5.13. Typical M-profiles (M(z)), see formula 5.29 [33]
Definition:
The \( n \)th Fresnel zone is a set of points where the path length difference between the reflected waves at those points and the direct wave is \( n\frac{\lambda}{2} \).
The contour of Fresnel zones are ellipsoids with the transmitter and receiver as the focuses. The path clearance for the line of sight link in Surabaya will be sufficient when the first Fresnel zone is free of obstructions.
The height difference between the direct wave and the ellipsoid which includes the \( n \)th Fresnel zone can be formulated as:

\[
F_n = \sqrt{\frac{\lambda}{2} n x \left(1 - \frac{x}{d}\right)}
\]  
(5.40)

with: \( \lambda \) = the wave length
\( x \) = distance of the point from the transmitter in the direction of the receiver
\( d \) = distance between the transmitter and the receiver.

The first Fresnel zone:

\[
F_1 = \sqrt{\frac{\lambda}{2} x \left(1 - \frac{x}{d}\right)}
\]  
(5.41)

Thus if the obstacle is \( h_{obs} \) above the sea level, then the path clearance should be:

\[
z(x) - h_{obs} > F_1
\]

\( z(x) \) also depends on \( k \) and increases if \( k \) increases.
So we have a \( k \)-minimum, where \( z(x) - h_{obs} = F_1 \).

\[
k_{\text{min}} = \frac{x}{2R} \sqrt{\frac{h_{t} - h_{r}}{d} x + h_{obs} - h_{t} + \sqrt{\lambda x \left(1 - \frac{x}{d}\right)}}
\]  
(5.42)

When the value of \( k_{\text{min}} \) has been calculated, the path clearance criterium will be met for \( k \)-values more than \( k_{\text{min}} \).
The statistics of the \( k \)-factor will show the percentage of the time when the path clearance is sufficient.

5.6. Focusing of the direct wave

As previously described, the transmitted waves will be focused by
the layered troposphere and the focusing factor is:

\[ C_d = \sqrt{\frac{\cos \alpha_t}{\cos \alpha_r}} \]

For the k-factor model further calculations can be done as follows:

![Diagram of wave propagation](image)

**Fig. 5.13. The direct and reflected wave**

\[ z(x) = \frac{x^2}{2kR} + \left( \frac{h_r - h_t}{d} - \frac{d}{2kR} \right)x + h_t \]  (5.39)

For A to B directly:

\[ z(x) = \frac{x^2}{2kR} + \left( \frac{h_r - h_t}{d} - \frac{d}{2kR} \right)x + h_t \]

\[ \frac{dz}{dx} = \frac{x}{kR} + \frac{h_r - h_t}{d} - \frac{d}{2kR} \]

tangent of the elevation angle of the ray at the transmitter

\[ \tan \alpha_t = \frac{dz}{dx} / x = 0 = \frac{h_r - h_t}{d} - \frac{d}{2kR} \]

tangent of the elevation angle of the ray at the receiver

\[ \tan \alpha_r = \frac{dz}{dx} / x = d = \frac{h_r - h_t}{d} + \frac{d}{2kR} \]

So, if it is further calculated:

\[ \cos \alpha_t = \frac{1}{\sqrt{1 + \tan^2 \alpha_t}} = \frac{1}{\sqrt{1 + \left( \frac{h_r - h_t}{d} - \frac{d}{2kR} \right)^2}} \]

\[ \cos \alpha_r = \frac{1}{\sqrt{1 + \tan^2 \alpha_r}} = \frac{1}{\sqrt{1 + \left( \frac{h_r - h_t}{d} + \frac{d}{2kR} \right)^2}} \]
For A to C:

\[
z(x) = \frac{x^2}{2kR} + \left(\frac{r_{t} - h_{t}}{d} - \frac{d_{t}}{2kR}\right)x + h_{t}
\]  

(5.39)

In this case: \(h_{r} = 0\)

\[d = d_{t}\]

So,

\[
z(x) = \frac{x^2}{2kR} + \left(\frac{r_{t} - h_{t}}{d_{t}} - \frac{d_{t}}{2kR}\right)x + h_{t}
\]

\[
\frac{dz}{dx} = \frac{x}{kR} + \left(\frac{r_{t}}{d_{t}} - \frac{d_{t}}{2kR}\right)
\]

\[
\tan \alpha_{t} = \frac{dz}{dx}/x=0 = \frac{-h_{t}}{d_{t}} - \frac{d_{t}}{2kR}
\]

\[
\tan \alpha_{r} = \frac{dz}{dx}/x = d_{t} = \frac{-h_{t}}{d_{t}} + \frac{d_{t}}{2kR}
\]

\[
\cos \alpha_{t} = \sqrt{\frac{1}{1 + \tan^2 \alpha_{t}}} = \sqrt{\frac{1}{1 + \left(\frac{-h_{t}}{d_{t}} + \frac{d_{t}}{2kR}\right)^2}}
\]

\[
\cos \alpha_{r} = \sqrt{\frac{1}{1 + \tan^2 \alpha_{r}}} = \sqrt{\frac{1}{1 + \left(\frac{-h_{t}}{d_{t}} - \frac{d_{t}}{2kR}\right)^2}}
\]

\[
C_{d_{t}} = \sqrt{\frac{\cos \alpha_{t}}{\cos \alpha_{r}}} = \left(\frac{1 + \left(\frac{-h_{t}}{d_{t}} + \frac{d_{t}}{2kR}\right)^2}{1 + \left(\frac{-h_{t}}{d_{t}} - \frac{d_{t}}{2kR}\right)^2}\right)
\]
\[ C_{d_t} = 4 \sqrt{\frac{1 + \left( \frac{h_t}{d_t} \right)^2 \left( \frac{d_t}{2kR} \right)^2}{1 + \left( \frac{h_t}{d_t} - \frac{d_t}{2kR} \right)^2}} \] (5.44)

For B to C: in this case: \( h_t = 0 \)
\[ d = d_r. \]

\[ z(x) = \frac{x^2}{2kR} + \frac{h_r}{d_r} \left( \frac{d_r}{2kR} \right)x \]

\[ \frac{dz}{dx} = \frac{x}{kR} + \left( \frac{h_r}{d_r} - \frac{d_r}{2kR} \right) \]

\[ \tan \alpha_t = \frac{dz}{dx} / x = 0 = \frac{h_r}{d_r} - \frac{d_r}{2kR} \]

\[ \tan \alpha_r = \frac{dz}{dx} / x = d_r = \frac{h_r}{d_r} + \frac{d_r}{2kR} \]

\[ \cos \alpha_t = \sqrt{\frac{1}{1 + \tan^2 \alpha_t}} = \sqrt{\frac{1}{1 + \left( \frac{h_r}{d_r} - \frac{d_r}{2kR} \right)^2}} \]

\[ \cos \alpha_r = \sqrt{\frac{1}{1 + \tan^2 \alpha_r}} = \sqrt{\frac{1}{1 + \left( \frac{h_r}{d_r} + \frac{d_r}{2kR} \right)^2}} \]

\[ C_{d_t} = \frac{\cos \alpha_t}{\cos \alpha_r} = \sqrt{\frac{1 + \left( \frac{h_r}{d_r} - \frac{d_r}{2kR} \right)^2}{1 + \left( \frac{h_r}{d_r} + \frac{d_r}{2kR} \right)^2}} \]

\[ C_{d_r} = \sqrt{\frac{1 + \left( \frac{h_r}{d_r} + \frac{d_r}{2kR} \right)^2}{1 + \left( \frac{h_r}{d_r} - \frac{d_r}{2kR} \right)^2}} \] (5.45)

In practice \( C_d, C_{d_t}, \) and \( C_{d_r} \) will be very close to one and can be assumed to be one in further calculations.

For example:
Gunung Sandangan (258 m) - Surabaya (28 m)
For $k = 0.2, 1.5, 100$, we get as results of the focusing factor calculations:

\[
C_d = 1.000000 \\
C_{d_t} = 1.000000 \\
C_d = 1.000000
\]

So it is clear that it is not important to bring the focusing factor into the calculations of normal line of sight links. The focusing factor can be assumed to be one.

5.7. **Divergence factor** $(D)$, **divergence effect caused by spherical surfaces at a reflected wave**

If waves are reflected by a flat surface, no defocusing effect will be observed after reflection, but if they are reflected by a spherical surface than they will be defocused (divergence effect).

The divergence factor can be defined as shown below.

If $D$ is the absolute value of the ratio of the electric field strength of waves reflected by a spherical surface and the electric field strength of waves reflected by the flat surface with these boundary conditions:

1. the reflecting surfaces are of the same material
2. the transmitted power within a solid angle $d\Omega$ are the same
3. the total distances are the same for both situations,

it can be calculated that [34]:

\[
D = \sqrt{\frac{1}{1 + \frac{2d_r}{d_t} \frac{d_r}{d_t k F d \tan\psi}}}
\] (5.46)

\[d = d_t + d_r\]

**Fig. 5.14. Reflection by a spherical surface**
An example is taken from the link Gunung Sandangan - Surabaya and the graph appears as follows:

\[
\text{divergence factor } D
\]

\[
\begin{align*}
& h_t = 258 \text{ m} \\
& h_r = 28 \text{ m} \\
& d = 50.6 \text{ km} \\
& \lambda = 7.5 \text{ cm}
\end{align*}
\]

Fig. 5.15. The divergence factor D as a function of the k-factor for the link Gunung Sandangan - Surabaya

Thus D will vary from 0.4 to 0.9 as the k-factor varies from 0.5 to 3.0 in this example. This is logical because if the k-factor increases, the reflecting surface will be flatter and defocusing effect will be less and D will of course increase.

5.8. The reflection point

For calculating the divergence factor D and other parameters it is necessary to calculate the reflection point of course if there are reflected waves coming to the receiving antenna. The reflection point is very important in determining the reflection coefficient and the whole link calculation.

The ray trace of the reflected wave can be calculated by using the formula (5.39) and the fact that at the reflection point the grazing angles of incident and exident waves are equal.

The result is:

\[
2d_t^3 - 3d d_t^2 + \left( d^2 - 2kR(h_t + h_r) \right) d_t + 2kR h_t d = 0 \quad (5.47)
\]
Fig. 5.16. The calculation of the reflection point

The solution of this equation is:

\[ d_t = \frac{d}{2} + q \cos \left( \frac{\psi + \pi}{3} \right) \]  

(5.48a)

with:

\[ q = \frac{2}{\sqrt{3}} \sqrt{k R (h_t + h_r) + \left( \frac{d}{2} \right)^2} \]  

(5.48b)

Fig. 5.17. The reflection point as a function of the k-factor for Gunung Sandangan - Surabaya path. \( h_t = 258 \) m; \( h_r = 28 \) m; \( d = 50.6 \) km
\[ \psi = \arccos \left( \frac{2kR(h_r - h_t)}{q^3} \right) \]  

(5.48c)

see appendix II.

An example can be found at Fig. 5.17.

If the k-factor increases, the surface becomes flatter, the reflection point will move out from the transmitter (the highest antenna). The nearest reflection point to the transmitter will be achieved if the k-factor reaches the smallest value and the most distant reflection point will be met at the greatest k-factor value.

![Diagram of reflection points](image)

Fig. 5.18. The reflection point at \( k = \infty \) and \( k \neq \infty \). It moves in the direction of the arrow.

5.9. The Reflection Coefficient, Fresnel Equations

The reflection formulas for vertical and horizontal polarisation (Fresnel equations) are deduced as follows:

Horizontal polarisation:

\[ \hat{E}_o \perp \hat{n} \text{ or } \hat{E}_o \parallel \text{ boundary plane}. \]
Fig. 5.19. Horizontal polarisation, where:
- \( \mathbf{n} \) = unit vector \( \perp \) boundary plane
- \( \mathbf{n}_o \) = unit vector \( \perp \) wavefront of incident wave
- \( \mathbf{n}_1 \) = unit vector \( \perp \) reflected wave
- \( \mathbf{n}_2 \) = unit vector \( \perp \) refracted wave.

From literature [23] the results are as follows:

\[
E_2 = \frac{Z_2}{Z_2 \cos \phi_1 + Z_1 \cos \phi_2} \cdot E_o
\]  
(5.49)

and

\[
E_1 = \frac{Z_2 \cos \phi_o - Z_1 \cos \phi_2}{Z_2 \cos \phi_1 + Z_1 \cos \phi_2} \cdot E_o
\]  
(5.50)

\[
Z_i = \frac{E_i}{H_i} \quad i = 1, 2.
\]

Vertical polarisation:
- \( \mathbf{H}_o \perp \mathbf{n} \) or \( \mathbf{H}_o \parallel \) boundary plane.
From literature [35] the results can be found:

\[ H = \frac{Z_1 (\cos \phi_1 + \cos \phi_0)}{Z_1 \cos \phi_1 + Z_2 \cos \phi_2} \cdot H_0 \]  

(5.51)

and

\[ H_1 = \frac{Z_1 \cos \phi_0 - Z_2 \cos \phi_2}{Z_1 \cos \phi_1 + Z_2 \cos \phi_2} \cdot H_0 \]  

(5.52)

Thus the reflection coefficients are:

\[ \frac{R_{\text{horizontal}}}{{(R \parallel)}} = \frac{Z_2 \cos \phi_0 - Z_1 \cos \phi_2}{Z_2 \cos \phi_1 + Z_1 \cos \phi_2} \]  

(5.53)

and

\[ \frac{R_{\text{vertical}}}{{(R \perp)}} = \frac{Z_1 \cos \phi_0 - Z_2 \cos \phi_2}{Z_1 \cos \phi_1 + Z_2 \cos \phi_2} \]  

(5.54)

For clarity we can add the definition:

The reflection coefficient is the ratio of the field strengths of the reflected and incident waves.

It can be derived that for real \( \phi_B \), the \( \frac{R_{\text{horizontal}}}{(R \parallel)} \) will never reach zero but \( \frac{R_{\text{vertical}}}{(R \perp)} \) will become zero if \( \phi_B = \tan^{-1} n \). This angle \( \phi_B = \tan^{-1} n \), is called the Brewster angle. If the media are lossy then the \( \frac{R_{\text{vertical}}}{(R \perp)} \) will not be zero at the Brewster angle \( \phi_B \) but it will be minimum.

So, based on this theory, it can be written that:

The reflection coefficient \( \frac{R_{\text{refl}}}{R_{\text{in}}} \) is the ratio of the field strengths (complex) of the reflected and incident waves at the reflection point

\[ \frac{R}{R_{\text{in}}} = \frac{E_{\text{refl}}}{E_{\text{in}}} = |R| e^{i\delta} \]  

(5.55)

The modulus \(|R|\) and the argument \(\delta\) depend on:

- the polarization of waves
- the electrical properties of the reflecting surface (\( \varepsilon, \mu \) and \( \sigma \))
- the wavelength \( \lambda \)
- the grazing angle of the incident wave
- the smoothness of the surface.
For line of sight links it can be calculated that the grazing angle is only a fraction of one degree, so it is very small.

From the next graph (Fig. 5.20) it can be seen that the magnitude of the reflection coefficient is one for horizontal and vertical polarisation and the phase shift is $180^\circ$ if the incident angle is very small and the waves are reflected by smooth seawater.

Fig. 5.20. The magnitude and the phase of the reflection coefficient as function of the angle of incidence and polarisation; frequency as parameter if the wave is reflected by smooth seawater [35]

So we can conclude: $R_\parallel = R_\perp = -1$ if the reflection occurs at a smooth sea surface.

The influence of the smoothness of the sea can be expressed by [15]

$$\frac{R_e}{R_o} = e^{-8\left(\frac{\sigma_R \sin \psi}{\lambda}\right)^2}$$

(5.56)

for exponent $\ll 1$:

$$\frac{R_e}{R_o} \approx 1 - 80\left(\frac{\sigma_R \sin \psi}{\lambda}\right)^2$$

(5.57)

where: $R_e$ is the effective reflection coefficient of the rough surface $|R_o| = 1$ is the reflection coefficient of the smooth sea surface $\sigma_R$ is the standard deviation of the surface roughness $\psi$ is the grazing angle of the incident wave $\lambda$ is the wavelength.
For Gunung Sandangan - Surabaya:

\[ \sigma_R \approx 0.5 \text{ m} \]
\[ \psi \approx 0.3 \text{ degree} \]
\[ \lambda \approx 0.075 \text{ m} \]

Thus:

\[ |R_e| = e^{-8 \left( \frac{\pi \sigma_R \sin \psi}{\lambda} \right)^2} \]
\[ = e^{-8 \left( \frac{0.5 \sin 0.3}{0.075} \right)^2} \]
\[ = 0.908. \]

Thus if there is no wind, the sea (Madura Street) will not be rough and at the receiver we can expect deep fadings as result of the reflection by the sea. If the sea is very rough the reflection coefficient magnitude will decrease and deep fadings will not be present.

For instance, if \( \sigma_R = 1.5 \text{ m} \), then:

\[ |R_e| = e^{-8 \left( \frac{\pi \sigma_R \sin \psi}{\lambda} \right)^2} = 0.42 \]

5.10. The path length difference

The direct wave and the reflected wave will have a different path length. In general the reflected wave will have a longer path length than the direct one.

The path length difference is not important for the magnitude but it is very important that it be included in the calculation for the phase difference between both electric fields at the receiving antenna.

In the k-factor model, the path length difference can be calculated with geometric formulas as the ray traces are straight lines. The calculation can be found in Appendix III and the result is:

\[ \Delta S = S_r - S_d \]
\[ = 2 \frac{h_r h_t}{d} \cdot (1 - \frac{d_r^2}{2kR_h}) (1 - \frac{d_t^2}{2kR_h}) \]  
\[ (5.58) \]
Fig. 5.21. The calculation of path length difference $\Delta S$

where: $S_r =$ path length of the reflected wave  
$S_d =$ path length of the direct wave  
$d_r =$ distance from the receiver to the reflection point  
$d_t =$ distance from the transmitter to the reflection point  
h_r =$ height of the receiving antenna above sea level  
h_t =$ height of the transmitting antenna above sea level

For high values of k-factor the path length difference will reach:

$$\Delta S = \frac{2h_t h_r}{d}$$

Fig. 5.22: The path length difference $\Delta S$ as function of the k-factor for the path Gunung Sandangan - Surabaya, $h_t = 258$ m; $h_r = 28$ m; $d = 50.6$ km.
As the k-factor increases the path length difference $\Delta S$ will also increase. Every time it changes with $\frac{1}{\lambda}$ the received signal will also change, for example: from a minimum to a maximum.

5.11. The interference pattern

Thus at the receiving antenna we get two waves, one is the direct wave and the other is the reflected wave (two-wave model).

The field strength of the direct wave at the receiving antenna will be $\vec{E}_d$ and can be calculated as follows:

If $S_o$ is the flux density at the receiving antenna and $S_o = \frac{|E_o|^2}{120\pi}$ so the complex field strength of the direct wave will be:

$$\vec{E}_d = C_d \vec{E}_o e^{j\omega t} e^{-j\frac{2\pi}{\lambda} S_d}$$

$C_d =$ focusing factor
$S_d =$ path length of the direct wave

In the same way it is found that the complex field strength of the reflected wave at the receiving antenna is:

$$\vec{E}_r = C_{d_t} C_{d_r} D \vec{E}_o e^{j\omega t} e^{-j\frac{2\pi}{\lambda} S_r}$$

$C_{d_t} =$ defocusing factor of the reflected wave before reflection
$C_{d_r} =$ defocusing factor of the reflected wave after reflection
$D =$ divergence factor due to spherical surface
$S_r =$ path length of the reflected wave.

$R =$ reflection coefficient

From the calculations it appears that $C_d, C_{d_t}$ and $C_{d_r}$ are very close to one and it will be assumed that they are one for a normal line of sight link.

The total field strength at the front of the receiving antenna is the vectorial sum of $\vec{E}_d$ and $\vec{E}_r$:

$$\vec{E}_t = \vec{E}_d + \vec{E}_r$$
\[ \vec{E}_t = \vec{E}_0 e^{j\omega t} e^{-j \frac{2\pi}{\lambda} S_d} [1 + D \frac{R}{|R|} e^{-j \frac{2\pi}{\lambda} \Delta S + j\delta}] \]  \hspace{1cm} (5.60)

with \( \Delta S = S_r - S_d \) = path length difference.

The power density at the front of the receiving antenna will be:

\[ S_t = \frac{|E_t|^2}{120\pi} \]

and so:

\[ S_t = S_o [1 + D^2 |R|^2 + 2D R \cos (2\pi \frac{\Delta S}{\lambda} + \delta)] \]  \hspace{1cm} (5.61)

The available power at the output of the receiving antenna will be:

\[ \frac{P_r}{P_o} = \frac{S_t}{S_o} \frac{P_o}{P_o} \]

where: \( A_{er} = \) effective aperture receiving antenna

\[ \frac{P_r}{P_o} = 1 + D^2 |R|^2 + 2D R \cos (2\pi \frac{\Delta S}{\lambda} + \delta) \]  \hspace{1cm} (5.62)

where: \( P_r = \) the received power

\( P_o = \) the received power if there is only direct wave

\( D = \) the defocusing factor of the spherical reflecting surface

\( R = \) the reflection coefficient

\( \Delta S = \) the path length difference

\( \lambda = \) the wave length

\( \delta = \) the phase shift at the reflection point.

From the above formula we can see that \( \frac{P_r}{P_o} \) is a function of the k-factor, frequency, heights of the transmitting and receiving antennas.

The pattern will show minimums and maximums if one of the parameters changes. More detailed analysis will be given in the next paragraph and illustrations can be found in Fig. 5.23 and Fig. 5.23a.

Examining the above formula we see the variation of the received signal due to multipath fading.
Fig. 5.23. The received power below the free space level as a function of the k-factor, reflection by smooth sea, G. Sandangan-Surabaya.

 logarithm of the relative loss coefficient in dB

Fig. 5.23a: The received power below the free space level as a function of the k-factor, reflection by smooth sea. G. Sandangan-Surabaya.

h_t = 258 m
h_r = 28 m
d = 50.6 km
\lambda = 7.5 \text{ cm}

(logarithmic k-scale)
5.12. **Statistical distribution of the received signal**

As previously pointed out, the amplitude of the received signal in a microwave link will vary with time. This variation can be expressed with the amplitude distribution function which is an analytical expression that gives the value of the probability that the received signal is below a certain level. Knowledge of this function is important for the proper engineering of a microwave link.

To determine this function experimentally is time consuming and expensive. Therefore a theoretical prediction of this function has to be found. As a matter of fact, many theories have already been developed; some fully theoretical, others empirical. A combined theoretical and empirical theory will now be presented to predict the behaviour of a microwave link.

The field at the receiving antenna can, in general, be considered as an interference field with a strong, almost constant component, equal to the free space moment, and many weak components with random amplitudes and phases. The theory of statistics shows that the amplitude of the resultant component has a probability density function known as the $I_0$-distribution,

$$ f(E) = \frac{2E}{\langle E^2 \rangle} I_0 \left( \frac{2E}{\langle E^2 \rangle} \right) \exp \left( -\frac{E^2 + \langle E^2 \rangle}{\langle E^2 \rangle} \right) \quad (E \geq 0) \quad (5.63) $$

with:

- $f(E)$ : probability
- $E$: amplitude of the constant component
- $\langle E^2 \rangle$: RMS value of the signal
- $I_0(x)$: modified Bessel function of the zero order, first kind

As the amplitude of the constant component tends to zero, the probability density function will tend to the so-called Rayleigh function:

$$ f_R(E) = \frac{2E}{\langle E^2 \rangle} \exp \left( -\frac{E^2}{\langle E^2 \rangle} \right) \quad E \geq 0 \quad (5.64) $$

For the probability of $E$ being smaller than a certain level $E$, which is the cumulative distribution function $F_R(E)$, follows:

$$ P(E \leq E) = \int_0^E f(E') \, dE' = 1 - \exp \left( -\frac{E^2}{\langle E^2 \rangle} \right) \quad (5.65) $$
The region of interest is for small values of $E$, $E^2 < 0.01 \langle E^2 \rangle$ where this formula simplifies to: [1], p. 7.13, [54], p. 327.

$$\Pr(E) = \Pr(E < E) = \frac{E^2}{\langle E^2 \rangle} = \mathcal{L}^2 \quad \text{with} \quad \mathcal{L} = \frac{E}{\sqrt{\langle E^2 \rangle}} \quad (5.66)$$

This function is given in Fig. 5.44.

The assumptions of this situation, indicated as Rayleigh fading, [54], p. 332, relate to an unfavourable situation, so in general reality will be better. The main assumption is that there exists no dominant component, which, normally does certainly exist.

The periods during which Rayleigh fading occurs are the worst periods. A first approximation of the probability of occurrence of Rayleigh fading then already gives an impression of the quality of a link.

An empirical formula for the Rayleigh fading occurrence probability $\Pr$ in the worst season propagation conditions has been derived from year-long observation of various microwave links in Japan [37] and Europe [36]. The fading probability $\Pr$ is given by the following formula:

$$\Pr = \left(\frac{f}{4}\right)^B Q' d^{3.5} \quad (\Pr < 0.3) \quad (5.67)$$

with: $\Pr$ : the Rayleigh fading occurrence probability

$f$ : frequency in GHz

$Q'$ : $2.0 \times 10^{-9}$ (for mountains)

$5.1 \times 10^{-9}$ (over plains)

$3.7 \times 10^{-7} \times \bar{h}^{-\frac{1}{2}}$ (over the sea or coast)

$\bar{h} = (h_t + h_r)/2$ is average path height in meters

$B$ : $= 1.2$ for Japan

$= 1$ for Europe

$d$ : path distance in km.

This method only relates to clear line-of-sight paths with negligible earth reflections. If the earth reflection is not negligible, this theory has to be modified. A method of estimating an equivalent Rayleigh fading occurrence rate in this case follows.
5.12.1. **Prediction of cumulative distribution for a line-of-sight reflected wave path**

Morita [38] developed a theory for the prediction of the cumulative distribution function of a microwave link in which earth reflections are not negligible. His theory is based on the assumption that during times when Rayleigh fading occurs, the probability of occurrence is given by the empirical formula (5.67). The median received power is not equal at all times but varies, with the result that the received power distribution variance becomes larger than that of the Rayleigh distribution variance. This is particularly the case when there are two, or more, almost equal components present at the receiver side. Therefore the Rayleigh fading occurrence probability as follows from the above formula will be modified.

![Graph](image)

Fig. 5.24. Determining the equivalent Rayleigh fading occurrence probability. [38]
According to Morita, the Rayleigh fading occurrence probability can be obtained from Fig. 5.24 with the Rayleigh fading occurrence probability in the absence of reflection, $P_R$, plotted along the abcissa and the effective reflection coefficient $|R_e|$ as parameter.

The value, obtained from the ordinate is called the equivalent Rayleigh fading occurrence probability and is denoted as $P_e$.

The cumulative distribution function then becomes:

$$P_e(\xi \leq \xi) = P_e \xi^2 \quad (5.68)$$

In the link for Sandangan - Surabaya (see Fig. 5.1) where there are no obstacles to shield the reflected wave, the influence of the reflected wave may not be ignored, and, hence, the equivalent Rayleigh fading occurrence probability has to be taken into account.

5.13. **Diversity Techniques**

In designing a line of sight system one must always take care that the received signal is higher than a certain minimum value for a suitable percentage of the time.

This minimum value is given by the noise of the receiver or other noise sources like the antenna noise and the intermodulation noise.

If the signal becomes lower than this minimum value because of the fading, communication will break down.

The percentage of time that the fading is more than a certain level can be calculated from the cumulative distribution of the amplitude of the received signal.

This percentage is a measure of the system's reliability/quality.

Depending on the system, communication should usually work well for 99.9% to 99.99% of the time, thus the signal level at the receiver should not be below a certain level more than 0.01% to 0.1% of the time.

Diversity techniques are used to obtain a greater reliability of the system by avoiding deep fadings and communications break downs. That is why more than one signal with the same information should be available at the receiving site simultaneously.

These signals will be further processed and combined to get an improved output.
In order to achieve more than one signal with the same information at the receiving site simultaneously, the following methods can be used:

1. **polarisation diversity**

   This method is applied if we have two separate links with different polarisation. It can only be used for H.F. frequency bands (wave length $10 - 100$ m.)

2. **angle diversity**

   This method is very good for troposcatter links with pencil beam antennas. Thus there are more possibilities to receive signals from the common volume.

3. **frequency diversity**

   Several frequencies are used simultaneously to transmit the same information. Usually, two different frequencies do not suffer fading at the same time if they are sufficiently far apart and attenuation fading is neglected.

4. **space diversity**

   At the receiving site, more than one antenna is placed, one above the other or one beside the other at suitable spacing.

5. **route diversity**

   There are some other routes to be used for connecting the transmitter and the receiver sites, especially used if there is power (attenuation) fading.

Space diversity and frequency diversity are often used in line-of-sight links. These techniques will be described in more detail later on. The miscellaneous diversities can be combined, for instance space diversity each with two frequencies. Thus there is dual diversity, triple diversity or even quadruple diversity. With only-diversity, one means the dual diversity, thus two channel diversity.
In fact, diversity may also protect the link from equipment break down. The link will always be reliable because there is always a spare channel available.

Assuming that by the use of diversity techniques some signals with different amplitude and phase are received before or after demodulation these signals could be fed to a combining system, called pre or post detection system, respectively.

Fig. 5.25. Examples of the diversity combination possibilities
a. dual space diversity
b. triple frequency diversity
c. combination of dual space-frequency diversity.
Fig. 5.26. Combining system.

a. post detection combining system
b. pre detection combining system

The principle of the combining system can be explained as follows:

1. **Selective switching between the signals**

The signal with the highest amplitude will appear continuously at the output of the system. An example is shown in Fig. 5.26.a.

Fig. 5.26.a. The output signal of a combining system with selective switching principle.
2. **Equal gain diversity**

This is the simplest system; all signals are equally amplified and all of them are added taking no account of their levels.

3. **Maximum signal to noise ratio diversity**

The amplitude and the phase of each signal is processed, so that at the output the signal with maximum signal to noise ratio will always be presented.

The most important factor for success in applying diversity techniques is that the instantaneous fading of the signals should be uncorrelated.

The cross correlation of two signals \( E_1(t) \) and \( E_2(t) \) is defined by:

\[
\rho = \frac{<E_1(t) E_2(t)>}{\sqrt{<E_1^2(t)> <E_2^2(t)>>}
\]

where: \( \rho \) = correlation coefficient

\( E_1(t) \) and \( E_2(t) \) are both signals which form the diversity signal

\(<E_1(t) E_2(t)> = \) the average value of the product of \( E_1(t) \) and \( E_2(t) \) at an instantaneous time \( t \) over a certain period.

This period should be determined in such a way that there are enough samples of the signals \( E_1(t) \) and \( E_2(t) \). In Fig. 5.27 some registration can be seen of \( E_1 \) and \( E_2 \) pairs for three values of the correlation coefficient \( \rho \).

![Fig. 5.27. The relation of \( E_1 \) and \( E_2 \) for three correlation coefficient \( \rho \) values.](image)

It is clear that a negative correlation coefficient will be ideal for diversity purposes, so if one signal is minimum then the probability that
the other signal is maximum will be high.

It seems that the correlation coefficient $\rho$ is a function of the parameters of the transmission path like distance between the transmitter and the receiver, reflection coefficient, frequency, etc.

An example of measurement results is given in Fig. 5.28, $\rho$ as function of the antenna height difference ($\Delta h$) for space diversity and also $\rho$ as a function of $\Delta f$, the frequency separation for frequency diversity.

![Graph of the measured correlation coefficient $\rho$ for space diversity $\rho_s$ and frequency diversity $\rho_f$ [41].](image)

**Fig. 5.28.** Graph of the measured correlation coefficient $\rho$ for space diversity $\rho_s$ and frequency diversity $\rho_f$ [41].

5.13.1. The influence/improvement of the diversity

It will now be described what the influence of the diversity is on signals with Rayleigh distribution behaviour.

It is assumed that the signals are not correlated, so the cross correlation factor $\rho = 0$, which means that the probability that both signals $E_1$ and $E_2$ are both below or equal to the value $E_0$ can be written as:

$$P(E_1 < E_0; E_2 < E_0) = P(E_1 < E_0) P(E_2 < E_0)$$  \hspace{1cm} (5.70)

If the signals are negatively correlated, then it can be said that:

$$P(E_1 < E_0; E_2 < E_0) < P(E_1 < E_0) P(E_2 < E_0)$$  \hspace{1cm} (5.71)

Definition:

Diversity gain factor is the ratio of the levels $E_{d,n}$ and $E_{d,1}$, where $E_{d,n}$ is the level to which the signal received by the diversity technique is equal or less for $P$ percent of the time and $E_{d,1}$ the comparable level without diversity technique.
The probability that the amplitude of the field strength $E_1$ of the signal is below a certain level $E_{d,1}$ can be calculated as follows:

$$F_1(E_{d,1}) = P(E_1 < E_{d,1}) = 1 - \exp\left(-\frac{E_1^2}{2k^2}\right)$$  \hspace{1cm} (5.73)

with: $<E_1^2> = 2k^2$.

where $F(I)$ is the cumulative distribution function for single channel.

Link with diversity:

Diversity with two signals $E_1$ and $E_2$. The simultaneous cumulative distribution when level $E_{d,2}$ is the level where the signal is below or equal to it at a certain percentage of the time can be written as follows:

$$F_2(E_{d,2}) = P(E_1 < E_{d,2}) P(E_2 < E_{d,2})$$

$$= [1 - \exp\left(-\frac{E_{1,2}^2}{2k^2}\right)]^2$$  \hspace{1cm} (5.74)

with: $<E_1^2> = <E_2^2> = 2k^2$.

where $F(2)$ is cumulative distribution function for dual diversity.

Analog for n-diversity:

$$F_n(E_{d,n}) = P(E_1 < E_{d,n}) P(E_2 < E_{d,n}) \ldots P(E_n < E_{d,n})$$

$$= [1 - \exp\left(-\frac{E_{1,n}^2}{2k^2}\right)]^n$$  \hspace{1cm} (5.75)

with: $<E_1^2> = <E_2^2> = \ldots = <E_n^2> = 2k^2$.

$F(n)$ is cumulative distribution function for n channel diversity.

According to the definition can be written:

$$[1 - \exp\left(-\frac{E_{1,n}^2}{2k^2}\right)] = [1 - \exp\left(-\frac{E_{1,n}^2}{2k^2}\right)]^n = q$$  \hspace{1cm} (5.76)

so:

$$\frac{E_{d,n}^2}{E_{d,1}} = \frac{10}{10 \log(1 - q^{1/n})}$$  \hspace{1cm} (5.77)

Thus the diversity gain factor is:
\[ G(q,n) = 20 \log_{10} \left( \frac{E_{d,n}}{E_{d,1}} \right) = 10 \log_{10} \left( \frac{1 - q^{1/n}}{1 - q} \right) \]  \hspace{1cm} (5.78) \]

Diversity is especially important at small values of \( E_{d,2} \ll k \). So formula (5.78) can be simplified to:

\[ G(q,n) = 10 \log_{10} \left( \frac{q^{1/n}}{q} \right) = \frac{n-1}{n} \log_{10} \frac{1}{q} \] \hspace{1cm} (5.79) \]

\[ \text{dB} \]

**Fig. 5.29.** The diversity gain \( G(q,n) \) [dB] as function of the probability \( q \) in % according to formula (5.79) [44], p. 204

The diversity gain will increase with an increase of used channels, but the relative increase of the diversity gain is less.

The cost of diversity channels is almost linear with the number of channels so a compromise between the cost and the diversity gain should be taken into account in planning a microwave link.

In formula (5.79) and Fig. 5.29 it can be seen that diversity will be most effective just at low signal level and so also at low probability which is precisely what is needed.

**Fig. 5.30** gives the cumulative distribution of a Rayleigh distribution without diversity and the cumulative distribution of dual diversity with the three combining systems mentioned before.
Diversity not only gives an increase in the percentage of time that the signal is equal or less than a certain level but also a flattening effect on the Rayleigh distribution, thus lessening the variation of the signal.

This theory is valid for any diversity type but, the diversity type determines the correlation coefficient and thus of course also the possible diversity gain.
Fig. 5.31. The cumulative distribution of a dual diversity signal with correlation coefficient as parameter [42]

Fig. 5.32. Curve A: limiting curve without diversity
Curve B: limiting curve with dual switched diversity
——— frequency diversity with \( \Delta f/f = 1\%, 2\% \) and 4%
———- space diversity [36]
So, the conclusions are:
- Diversity increases the quality of the link by reducing number of total break downs because the deep fading frequency becomes less.
- The diversity effect depends on the correlation coefficient of the signals contributing to the diversity reception.

5.13.2. Optimal spacing of space diversity technique

As established, the received signal will be: (5.62)

\[
\frac{P_r}{P_o} = 1 + D^2 \langle R \rangle^2 + 2 D \langle R \rangle \cos \left(2\pi \frac{\Delta S}{\lambda} + \delta\right)
\]

(5.62)

Reflection by smooth sea, vertical or horizontal polarisation, and small grazing angle \(\left(\mathbf{R} = \mathbf{R}_o = -1\right)\):

\[
\frac{P_r}{P_o} = 1 + D^2 + 2 D \cos \left(2\pi \frac{\Delta S}{\lambda} + \pi\right)
\]

or:

\[
\frac{P_r}{P_o} = 1 + D^2 - 2 D \cos \left(2\pi \frac{\Delta S}{\lambda}\right)
\]

(5.81)

\[
\Delta S = \frac{2 h_r h_t}{d} \left(1 - \frac{d r^2}{2 k R h_t} \right) \left(1 - \frac{d t^2}{2 k R h_t} \right)
\]

(5.58)

\[
d_t = \frac{d}{2} + q \cos \left(\frac{\psi + \pi}{3}\right)
\]

(5.48a)

\[
d_r = d - d_t
\]

\[
q = \frac{2}{\sqrt{3}} \sqrt{\frac{k R (h_r + h_t)}{d_r^2} + \left(\frac{d}{2}\right)^2}
\]

(5.48b)

\[
\psi = \arccos \left(\frac{2 k R (h_r - h_t)}{q^3} \right)
\]

(5.48c)

So, if \(h_r\) is varied, the received signal will also vary if the other parameters are kept constant. So the received signal is a function of \(h_r\).

If \(h_r^1\) the signal is maximum and at \(h_r^2\) minimum, than \(\Delta S_1 - \Delta S_2 = (n-1)\lambda; n\) is an integer.

If \(h_r^1\) is known, \(h_r^2\) can be calculated. Because of practical and economic considerations, the antenna spacing should be as small as possible, thus \(n\) should be minimum too.
For Gunung Sandangan - Surabaya link:

\[ d = 50.6 \text{ km} \]
\[ h_r = 28 \text{ m} \]
\[ h_t = 258 \text{ m} \]
\[ f = 4 \text{ GHz} \]

\[
\Delta S = \frac{2h_r h_t}{d} \left( 1 - \frac{d_r^2}{2kR_h r} \right) \left( 1 - \frac{d_t^2}{2kR_h t} \right)
\]

(5.58)

\[
\frac{\Delta(\Delta S)}{\Delta h_r} = \frac{2h_t}{d} \left( 1 - \frac{d_t^2}{2kR_h t} \right)
\]

for \( n = 1 \), \( \Delta(\Delta S) = (1 - \frac{1}{2}) 7/2 \text{ cm} = 3.75 \text{ cm} \)

\[
\log_{10} \frac{3.75}{50.600} = \frac{2.258}{43085} \left( 1 - \frac{43085}{2(1.5)6370000.258} \right)
\]

\[ \Delta h_r = 5.9 \text{ m} \]

Thus the second antenna should be placed about 6 meter under the first antenna to obtain optimal diversity reception.

Fig. 5.33. The received power as function of the k-factor
Gunung Sandangan - Surabaya, relative to the free space power level.
5.13.3. **Optimal frequency separation at frequency diversity reception**

As established, the received signal is:

\[
\frac{P_r}{P_o} = 1 + D^2 - 2D \cos \left( \frac{2\pi}{\lambda} \Delta S \right)
\]  

(5.81)

\(\Delta S\) is not frequency dependent, so if two frequencies are used the path length difference for both signals is the same. The phase difference between the direct and the reflected wave of the first signal is:

\[
\frac{2\pi}{\lambda_1} \Delta S.
\]

and for the second signal:

\[
\frac{2\pi}{\lambda_2} \Delta S.
\]

If \(f_1 > f_2\) , one can write:

\[
\frac{2\pi}{\lambda_1} \Delta S - \frac{2\pi}{\lambda_2} \Delta S = (2n-1) \pi
\]

(5.82)

If one requires the two signals to antiphase to achieve negative correlation and as:

\(c = f_1 \lambda_1 = f_2 \lambda_2 = 300,000 \text{ km/sec}\)

the velocity of light in a vacuum, then:

\[
f_1 - f_2 = \Delta f = \frac{(2n-1)c}{2 \Delta S}
\]

(5.83)

where: \(\Delta f = f_1 - f_2\) = frequency difference of both channels

\(n = \text{integer number } n = 1, 2, \ldots\)

\(\Delta S = \text{the path length difference, can be calculated if } h_r, h_t\)

distance and the median value of the k-factor are known.

Thus the minimum and optimal frequency separation is:

\[
\Delta f = \frac{c}{2 \Delta S}
\]

(5.84)
For Gunung Sandangan - Surabaya:

\[ h_r = 28 \text{ m} \]
\[ h_t = 258 \text{ m} \]
\[ d = 50.6 \text{ km} \]
\[ f = 4 \text{ GHz} \]

From Fig. 5.22 it can be read off that at \( k = 1.5 \), the path length difference \( \Delta S = 15 \text{ cm} \), so the minimum and optimal frequency separation is:

\[ \Delta f = \frac{3 \times 10^{10}}{2.15} = 10^9 \text{ Hz} = 1 \text{ GHz} \]

Thus the second frequency used should be 5 GHz or 3 GHz to achieve good diversity reception.

Fig. 5.34. The receiver power \( 10 \log \frac{P_r}{P_o} \) as function of the k-factor Gunung Sandangan - Surabaya, relative to the free space power level.
In the Plan of Operations [27] of this project experiments at 8 GHz had been planned. The aim of these experiments is to investigate the behaviour of a microwave link at this frequency in comparison with 4 GHz. Perumtel is presently planning the extension of their microwave network to frequencies in the 6 and 7 GHz band in connection with the inauguration of the Indonesian satellite communication system in 1977. With increasing frequency, other parameters will start to act upon the propagation of radiowaves.

For instance, theoretical considerations indicate that the influence of rain in moderate climates will become important at frequencies above approx. 8 GHz. But in a tropical climate with its relatively high precipitation rate due to the occurrence of torrential rain showers, the influence of rain may become an important factor for even lower frequencies.

Here follows a summary of a study carried out in the framework of this project by the Indonesian and Dutch team, to investigate the influence of rain in line-of-sight microwave links.

5.14.1. Influence of rain on radiowave propagation

In terrestrial communication networks where the troposphere is the transmission medium, attenuation will occur through absorption and reflection by molecules, for instance oxygen and water vapour, and by the hydrometeors like rain, hail and snow. For frequencies below 10 GHz the influence of oxygen and water vapour is negligible. Studies have also shown that of the various kinds of precipitation the influence of rain is the greatest. Computation of the attenuation caused by rain can be done by calculating the extinction cross-section of one rain drop. On assuming spherical rain drops it is possible to evaluate the sum of scattered and absorbed energy by using the theory developed by Mie and Stratton. This model is of course a first approximation because a falling raindrop is not spherical but is flattened at the bottom. The error made however, is small compared with the uncertainty caused by the variation of the drop size distribution.

By adding the attenuation for every drop by means of the known raindrop distribution, it is possible to evaluate the attenuation per kilometer in a rain environment.

By using the large numbers of experiments performed all over the world it is possible to develop a statistical model. With the expected rain statistics it is then possible to give an estimation of the influence of
Electromagnetic waves crossing through a medium with rain will be attenuated through scattering and absorption of energy by rain drops. Calculation of the attenuation can be done by applying Stratton's theory [23] on scattering by a sphere, to the spherical raindrop. By using the power balance of the incident wave and the scattered and absorbed power it is possible to introduce an electromagnetic cross-section of the sphere. This is defined as the ratio of the total scattered plus absorbed energy $P_s$ respectively $P_a$ and the power density of the incident wave $S_o$

$$Q(a,\lambda) = \frac{P_a + P_s}{S_o}$$

(cm$^2$) (5.85)

Using the boundary conditions at the surface of a sphere with a radius "a" it is possible to derive for the cross-section $Q(a,\lambda)$

$$Q(a,\lambda) = \frac{\lambda^2}{2\pi} R \sum_{n=1}^{\infty} (2n+1)(a+b_n)$$

(5.86)

with:

$$a_n = \frac{J_n(\rho)[n_c \rho J_n(n_c \rho)] - J_n(n_c \rho)[\rho J_n(\rho)]}{H_n(\rho)[n_c \rho J_n(n_c \rho)] - J_n(n_c \rho)[\rho H_n(\rho)]}$$

(5.86a)

$$b_n = \frac{n_c^2 J_n(n_c \rho)[\rho J_n(\rho)] - J_n(\rho)[n_c \rho J_n(n_c \rho)]}{n_c^2 J_n(n_c \rho)[\rho H_n(\rho)] - H_n(\rho)[n_c \rho J_n(n_c \rho)]}$$

(5.86b)

with: $J_n$ = (complex) Bessel function
$H_n$ = (complex) Hankel function
$n_c$ = refractive index of a spherical raindrop
$\rho = \frac{2\pi}{\lambda} a$
$a$ = radius of the sphere
$\lambda$ = wavelength

When an electromagnetic wave propagates through a medium uniformly filled with rain drops, the decrease of power of the incident wave is given by:
\[-dS = \int_{0}^{\infty} S \, dl \, N(a) \, Q(a, \lambda) \, da\]  \hspace{1cm} (5.87)

with: \(N(a) = \) number of drops with radius \(a\) per unit volume

\(dl = \) length of the path

![Diagram showing the attenuation of a wave through rain](image)

Fig. 5.35. Attenuation of a wave through rain

Investigation of the formula (5.86a) will give the relation of the power of the electromagnetic wave along the path:

\[S = S_0 \, \exp(-\alpha \, l)\]  \hspace{1cm} (5.88)

\[\alpha = \int_{0}^{1} N(a) \, Q(a, \lambda) \, da \quad \text{Neper/km}\]  \hspace{1cm} (5.89)

By introducing \(\gamma = 4.34 \, \alpha \) \, dB/km

(5.90)

it is possible to give the attenuation of the rain filled medium in dB/km.

To be able to calculate \(\alpha\) in formula (5.89) it is necessary to know the distribution of the amount of drops in a unit volume.

In order to find the attenuation as a function of precipitation rate "\(I\)" in mm/hour, instead of the number of drops "\(N\)", it is necessary to develop a relation between "\(N\)" and "\(I\)". If the drop size is uniformly distributed it is simply found that this expression is given by:

\[I = \frac{4}{3} \pi \frac{1}{8} a^3 v(a) N \, 3600 \, 10^3 \]

\[= 6\pi \, 10^5 v(a) N \, a^3\]  \hspace{1cm} (5.91)

with: \(I = \) precipitation rate in mm/hour

\(v(a) = \) velocity in m/sec of the raindrop

\(a = \) diameter of the raindrop in m.

\(N = \) number of drops per unit volume \((m^{-3})\).
However, the drop shape and diameter are not uniformly distributed. Representative distributions were obtained by Law and Parson. To evaluate the effect of the drop size distribution suppose that, for a particular rain intensity I, \( f(a) \) is the probability density function of raindrops with a diameter "a" cm. Then from eq. (5.91) follows:

\[
N(a) = \frac{I \cdot f(a)}{6 \times 10^{-5} \cdot \nu(a) \cdot a^3}
\]  

(5.92)

Together with the formulas (5.86), (5.89), (5.90) and (5.92) and the distribution given by Law and Parson it is now possible to calculate the attenuation by a uniform rain environment [47].

Fig. 5.36. Theoretical rainfall attenuation versus rain intensity for various frequencies [51]
5.14.3. Equivalent precipitation rate

Usually it is possible to describe the attenuation caused by rain with a relation of the form: [49], p.71]

\[ \gamma(I) = K I(x)^\eta \]

with: \( \gamma(I) \) = attenuation in dB/km
\( I(x) \) = precipitation rate in mm/hour
K and \( \eta \) = constants depending on frequency but \( \eta \) is very near to unity.

If rain was uniformly distributed along the propagation path Fig. 5.36 would give the attenuation per kilometer. However, for a given path, the precipitation rate is not the same everywhere. The horizontal size of a rain shower with a high precipitation rate will be less extensive than a shower with a low rate, therefore one has to define an equivalent precipitation rate, which is the rate that would give the same attenuation to the radio path with length "1" if the rain was uniformly distributed. If the total attenuation is given by \( \gamma_t \), one gets:

\[ \gamma_t = K \int_{0}^{1} [I(x)]^\eta dx = K[I_{eq}]^\eta . L \quad \text{[dB]} \]  

(5.93)

which means that:

\[ I_{eq} = \left\{ \frac{1}{1} \int_{0}^{1} I(x) \eta dx \right\}^{1/\eta} \]  

(5.94)

Because "\( \eta \)" is so close to unity a minor error is made if "\( \eta \)" is replaced by one. The equivalent rain intensity is then given by:

\[ I_{eq} = \frac{1}{1} \int_{0}^{1} I(x) \ dx \]  

(5.95)

This means that the equivalent precipitation rate is nothing else than the mean value of the rain intensity along the whole radio path.
5.14.4. Rain statistics

With the cumulative rain distribution it is possible to describe the probability of the precipitation rate being higher than a certain amount at an arbitrary point. As far as possible, the cumulative distribution must be found in experiments executed on the spot. However, there are many places on earth without adequate experimental data. Efforts have been made to give this distribution for an arbitrary point on earth. Using the total annual rainfall volume as a parameter already gives a rough estimate. A recommendation on this point has been given by the CCIR. [48]

In this report the earth surface is divided into five zones, and for each zone the cumulative distribution is given. The cumulative rain distribution can be found in Fig. 5.37 and the boundaries of the zones in Fig. 5.38.

---

Fig. 5.37. Percentage of the time that the precipitation rate exceeds a certain rainfall rate for the five zones given in Fig. 5.38. [48], p111
Updated method (1982) for the prediction of rain attenuation statistics [84]

5.14.4. Rain statistics

According to the CCIR [84] Indonesia belongs to rain climatic zone P. The following table applies for zone P.

<table>
<thead>
<tr>
<th>Percentage of time (%)</th>
<th>1.0</th>
<th>0.3</th>
<th>0.1</th>
<th>0.03</th>
<th>0.01</th>
<th>0.003</th>
<th>0.001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain intensity exceeded (mm/h)</td>
<td>12</td>
<td>34</td>
<td>65</td>
<td>105</td>
<td>145</td>
<td>200</td>
<td>250</td>
</tr>
</tbody>
</table>

5.14.5. Influence of the length of the radiopath [87]

The effective pathlength $l_{eff}$ of the link is obtained by multiplying the actual pathlength $l$ (km) by a reduction factor $r$, [87]

$$ r = \frac{90}{90 + 41} $$

N.B. This formula can only be used in relation with a point rain intensity exceeding for 0.001% of time.

5.14.6. The cumulative attenuation distribution [87]

For practical applications the relationship between specific attenuation $\gamma(I)$ (dB/km) and rain rate $I$ (mm/h) can be approximated by the power law $\gamma(I) = K I^\eta$ (5.93). The following table gives the regression coefficients for $K$ and $\eta$ for the frequencies 7.10 and 12 GHz.

<table>
<thead>
<tr>
<th>Freq. (GHz)</th>
<th>$K_{\text{hor}}$</th>
<th>$K_{\text{vert}}$</th>
<th>$\eta_{\text{hor}}$</th>
<th>$\eta_{\text{vert}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.00301</td>
<td>0.00265</td>
<td>1.332</td>
<td>1.312</td>
</tr>
<tr>
<td>10</td>
<td>0.0101</td>
<td>0.00887</td>
<td>1.276</td>
<td>1.264</td>
</tr>
<tr>
<td>12</td>
<td>0.0188</td>
<td>0.0168</td>
<td>1.217</td>
<td>1.200</td>
</tr>
</tbody>
</table>
The prediction method for calculation of the long-term statistics of the rain attenuation [87] consists of the following steps.

- Obtain the rain intensity exceeded for 0.01% of time in Indonesia.
  Answer \( I = 145 \text{ mm/h} \).

- Calculate the specific attenuation \( \gamma(I) \) dB/km according
  \[
  \gamma(I) = k \cdot I^n \text{ (dB/km)}.
  \]

- Calculate the pathlength reduction factor \( r \).
  (For \( I = 50 \text{ km} \); \( r = 0.31 \)).

- Calculate the attenuation exceeded for 0.01% of time
  \[
  \gamma_t = \gamma(I) \cdot r \cdot l \text{ (dB)}.
  \]

- Calculate the attenuation exceeded for 0.1 and 0.001% of time
  according
  
  \[
  \gamma_t(0.1\%) = \gamma_t(0.01\%) \times 0.468 \quad \text{and} \quad \gamma_t(0.001\%) = \gamma_t(0.01\%) \times 2.57.
  \]

The following values are calculated for Indonesia (rain climate zone P) and frequencies 7.10 and 12 GHz and horizontal polarisation.

<table>
<thead>
<tr>
<th>( I \text{ mm/h} )</th>
<th>% of time</th>
<th>( \gamma_t \text{ (dB)} )</th>
<th>( \gamma_t \text{ (dB)} )</th>
<th>( \gamma_t \text{ (dB)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>0.1</td>
<td>14.5</td>
<td>41.9</td>
<td>58.3</td>
</tr>
<tr>
<td>145</td>
<td>0.01</td>
<td>31.1</td>
<td>89.8</td>
<td>124.6</td>
</tr>
<tr>
<td>250</td>
<td>0.001</td>
<td>79.9</td>
<td>230.7</td>
<td>320.3</td>
</tr>
</tbody>
</table>

This table shows very great differences with the attenuation values calculated in Fig. 5.41. Future measurements must justify the presented method in this paragraph.
5.14.5. **Influence of the length of the radio path**

Because the rain intensity along the path to be explored is unknown, formula (5.95) is inconvenient to use. To be able to evaluate the influence of length of the path the CCIR has a recommendation [49] concerning the extensiveness of rain showers. This is done by means of a factor which makes it possible to convert the precipitation rate at an arbitrary point into the equivalent precipitation rate of the complete radio path. This means that formula (5.95) can be written as:

\[ I_{eq} = U I(x) \]  
(5.96)

with: \( U \) = factor which depends on the rain intensity and the path length

\( I(x) \) = rain intensity at an arbitrary point \( x \).

On account of the rain intensity having a probability distribution, the factor \( U \) will depend, not only on the length of the radiopath, but also on the probability of the precipitation rate. The relationship between the factor \( U \) in formula (5.96) and the length of the path is shown in Fig. 5.39, with the probability as parameter.
5.14.6. The cumulative attenuation distribution

To get an estimate of the cumulative rain attenuation for any given path, it is first necessary to evaluate the equivalent rain intensity distribution \( P(I_{\text{eq}} > I) \). This can be done by means of the equation

\[
P(I_{\text{eq}} > I) = U \times P(I > I)
\]

with: \( P(I > I) = \) probability rain distribution at an arbitrary point

\( U = \) reduction factor which is a function of the rain rate distribution.

The distribution \( P(I > I) \) can be found by using Figs. 5.37 and 5.38 and the reduction factor \( U \) can be obtained by using Fig. 5.39. The distribution function for rain attenuation \( P(Y_t > Y_c) \) can then be found through:

\[
P(Y_t > Y_c) = \mathcal{L} \times P(I_{\text{eq}} > I)
\]

with: \( \mathcal{L} = \) length of the radio path
\[ \gamma(l) = \text{rain attenuation coefficient} \ [\text{dB/km}] \]

As an example one can calculate the expected attenuation distribution for the link Gunung Sandangan - Surabaya which has a path length of 50 km and which is situated in a tropical area. This means that to find the expected rain rate distribution, one has to use the graph number 1 in Fig. 5.37. Together with the reduction factor shown in Fig. 5.39 it is possible to deduce the equivalent rain rate distribution. The distribution is drawn in Fig. 5.40.

![Graph showing equivalent rain intensity distribution](image)

**Fig. 5.40.** The equivalent rain intensity distribution for a link, 50 km long, situated in a tropical area

Multiplying this distribution by the length of the path and by the attenuation coefficient associated with the frequency used in the link, the cumulative attenuation distribution is found.
Fig. 5.41. Cumulative attenuation distribution for a link, 50 km long, situated in a tropical area for three transmitting frequencies.

5.15. Realization of the experiments in the link Gunung Sandangan – Surabaya

As stated in the Plan of Operations the following research has been carried out: [3] [27]

1. investigation of the propagation characteristics of the link Gunung-Sandangan – Surabaya at a frequency of 4 GHz,
2. the improvement of the link by diversity techniques, in particular space and frequency diversity at 4 GHz,
3. investigation of the propagation characteristics of the link at 7 GHz and comparison with those at 4 GHz.

Description of the link Gunung Sandangan – Surabaya

The actual subject of research was the line-of-sight microwave link between a hill on the island of Madura, Gunung Sandangan, and the city of Surabaya. This link is the first hop in the commercial microwave net-
work of Perumtel between Surabaya and the city Banjarmasin on Kalimantan. The next figure gives the path profile of this link, drawn on a map with special grid which takes into account the earth's curvature as well as normal atmospheric refraction, i.e. the ray paths for effective $k$-factor $4/3$ are straight lines. Some ray paths have been drawn for other values of $k$.

![Diagram]

**Fig. 5.42. Path profile of the link Gunung Sandangan - Surabaya**

**Site information**

1. **Surabaya**

   - location: latitude $S$ 7°15'48"
   - longitude $E$ 112°44'12"
   - station elevation: 3 m
   - antenna height: 28 m
   - direction to Gunung Sandangan: 71°30'00".

2. **Gunung Sandangan**

   - location: latitude $S$ 7°05'37"
   - longitude $E$ 113°19'52"
   - station elevation: 255 m
   - antenna height: 258 m
   - direction to Surabaya: 251°30'00".

3. **Path length**: 50.6 km.
The path profile shows that the link is fully line-of-sight for values of \( k \) as low as 0.5.

From formula (5.67) follows that the Rayleigh fading occurrence probability in the link Gunung Sandangan - Surabaya: [38]

\[
P_R = 0.028
\]

For the factor \( B \) the value 1.2 is assumed:

\[
Q = 3.7 \times 10^{-7} / \sqrt{h} \\
\frac{h_t + h_r}{h} = 2
\]

With these values then it follows from Fig. 5.24 that the equivalent Rayleigh fading occurrence probability: \( p_e = 0.4 \); (reflection by swampy area)

\[
P_e = 0.22.
\]

In conclusion, Morita's theory predicts for this particular link a cumulative probability distribution function for the worst month:

\[
F(L) = P(L \leq L) = 0.22 L^2
\]  \hspace{1cm} (5.97)

5.15.1. **Performance of the propagation experiments at 4 GHz**

Measurements have been continuously made during the period October 7, 1976, to April 23, 1977.

5.15.1.1. **Description of the microwave and data recording system**

The 4 GHz system operated at a frequency of 4012 MHz, being the first auxiliary frequency in the 4 GHz band.

**Transmitter**

The transmitter was a solid state microwave source with an output power of about 1 Watt. The transmitter was located in the top of the mast, at
the rear of the antenna, in a watertight box and was connected with the antenna feed by means of a semi-rigid cable of appr. 50 cm length. Thus the cable losses were minimised to appr. 0.5 dB, including waveguide to cable coupling losses. The transmitted signal contained no information as it was an unmodulated continuous wave. Tests had proved that the frequency stability was about $10^{-9}$ for the long term while the output power was stable to within 0.2 dB. Therefore the output power and the frequency of the transmitter were not monitored or recorded. The antenna consists of a 3 meter paraboloid reflector, fed by a waveguide horn. The gain of the antenna was 39 dB. The antenna was mounted between two 6 meter masts at the summit of the hill Gunung Sandangan, bringing the antenna height to 258 meters. The power for the transmitter side was obtained from the generator of the Perumtel relay station, located on the same summit.

Receiver
The receiving station was located in a room on the top floor of the main building of the Surabaya Institute of Technology. An antenna identical to the transmitting one, was used as receiving aerial. The antenna was mounted in the top of two masts of 15 meter on the roof of the building, bringing the total height of the receiving antenna to 28 meters above sea level. The connection with the equipment in the receiver room was made by means of a coaxial cable, Flexwell HF 7/8" Cu2Y, of appr. 15 meter length which gave a loss of appr. 1.5 dB at 4 GHz. The receiver was a superheterodyne type, with the local oscillator tuned at 4042 MHz, resulting in an intermediate frequency of 30 MHz at the output of the mixer, followed by a 30 MHz logarithmic amplifier, with the result that the output voltage of this amplifier was proportional to the input power in decibels. The characteristic of this receiver was linear within 0.1 dB in the range from -30 to -100 dBm. The DC output signal of the receiver was recorded on paper, with a normal y-t recorder with a paper speed of 6 cm per hour. Furthermore, this signal was fed into a data processing system which analysed the statistical properties of the received signal. Basically this data processing system consisted of counters which registered the time during which the signal was below 15 different consecutive reference levels. The arrangement of the reference levels was such that from the theoretical free space level of
-35 dBm the first three reference levels were separated 5 dB, so in sequence -35, -40, -45 and -50 dBm and the next levels were separated 3 dB so -53, -56 down to -80 dBm. With this configuration the cumulative distribution of the signal was recorded. A picture was taken automatically of the counters every hour.

The whole system ran unattended except for regular maintenance and calibration procedures.

The next figure gives a schematic drawing of the whole 4 GHz system.

---

**Processing of the data**

Due to the regular maintenance and calibration procedures and equipment or power failures the measurements sometimes had to be interrupted. One particular equipment problem was a malfunctioning photo camera which caused the loss of much valuable information. However, since the registration of the data always took place simultaneously on both the paper recorder and the data registration unit, the data were not completely lost. For the times the photo data were missing, the gaps were filled with data taken from the paper recordings. This was done manually by simply measuring the time, with a special ruler, during which the signal was below the defined reference levels. Although this method was less accurate than the automatic one, the data obtained with it were useful. Comparison tests of times from which both sorts of data were available revealed that this manual method introduced errors in the order of 10 percent; in every respect acceptable. In this way some 3000
5.67

hours of useful data were available.

Visual inspection of the paper recordings revealed some interesting features. Contrary to expectation, it appeared from the recordings that the received signal contained very few periods with strong fading during the actual rainy season, which lasted approximately from January to March. The rainy season started two months later than usual. During the transition period from dry to wet season or vice-versa relatively more strong fading occurred. The numerical calculations confirmed this for the month December, which turned out to be the worst month, but not, however, for April. After developing the films, the data from the photographs were read out by means of a viewer and noted on paper. This data was arranged into the months during which they were collected.

Then the cumulative distribution function of the received signal of each month was derived by determining the ratio:

\[ F(L) = P(L \leq L) = \frac{\Sigma t_L}{T_L} \quad (5.98) \]

with: \( \Sigma t_L \): sum of all times during which the signal was below the level \( T_L \): total available registration time for each individual month.

The next figure gives the results of these calculations.

From Fig. 5.44 it appears that December 1976 was the worst month and March 1977 the best one. The month February 1977 is missing in the figure because too little reliable data were available for this month. It is also clear from the figure that all distribution functions follow straight lines, in this special diagram, for levels below -45 dBm and that the slope of the line will tend to the Rayleigh distribution for the worst month.

As the distribution functions are straight lines, it is obvious to express them analytically in the following way, analogue to the Rayleigh distribution:

\[ F(L) = P(L \leq L) = a.L^b \quad (5.98) \]

with: \( L \): signal level, relative to reference level ( -35dBm) \( a \) and \( b \): constants.
Fig. 5.44. The measured cumulative distribution functions for different months.
The reference level is taken as -35 dBm, the theoretical free-space-level, which actually was the signal level during non-fading conditions, mostly in the morning between 8 and 11 hours.

In Fig. 5.44 both the absolute received power in decibels relative to 1 mWatt as well as the signal level relative to the free-space-level is indicated. Table 1 lists the constants a and b for the different months.

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>October 1976</td>
<td>0.15</td>
<td>2.53</td>
</tr>
<tr>
<td>November</td>
<td>0.22</td>
<td>2.42</td>
</tr>
<tr>
<td>December</td>
<td>0.23</td>
<td>2.02</td>
</tr>
<tr>
<td>January 1977</td>
<td>0.16</td>
<td>2.67</td>
</tr>
<tr>
<td>March</td>
<td>0.93</td>
<td>4.07</td>
</tr>
<tr>
<td>April</td>
<td>0.27</td>
<td>2.92</td>
</tr>
</tbody>
</table>

Table 1. The constants a and b for the different months in $F(\ell) = a \ell^b$

It is remarkable to see the very good agreement between the prediction with Morita's theory and the actual experimental results. It may, therefore, be concluded that this link gives the same results, as obtained from the theoretical and empirical model of Morita and it seems reasonable to assume that this theory is also valid in a tropical climate, although it is basically derived for a temperate climate. As a matter of fact, CCIR has already mentioned this theory as prediction formula for Rayleigh fading on line-of-sight microwave links. [36]

These experiments confirmed that this supposition was justified for this particular link.

5.15.1.2. The height gain pattern measurement

The relative received power can be written according to formula (5.62) as follows:

$$\frac{P_r}{P_o} = 1 + D^2 - 2D \cos \left( \frac{2\pi}{\lambda} \Delta S \right); \quad (R_o = -1)$$

(5.81)

where:
\[
D^2 = \left| \frac{1}{2d_t d_r} \right| \left( 1 + \frac{2d_t d_r}{1 - 2kR dt \tan \psi} \right)^{-1} \tag{5.46}
\]

\[
\Delta S = \frac{2h_t h_r d}{d^2} \left( 1 - \frac{d_t^2}{2kR h_t} \right) \left( 1 - \frac{d_r^2}{2kR h_r} \right) \tag{5.58}
\]

\[d_t = \frac{d}{2} + p \cos \left( \frac{\psi + \pi}{3} \right) \tag{5.48a}\]

\[q = \frac{2}{\sqrt{3}} \sqrt{kR (h_t + h_r) + \left( \frac{d}{2} \right)^2} \tag{5.48b}\]

\[\psi = \arccos \left( \frac{2kR (h_r - h_t)}{d} \right) \tag{5.48c}\]

\[d_r = d - d_t\]

So it can be seen that the received power is a function of \(h_r\), the receiving antenna height.

With height gain pattern measurement

1. the optimum spacing of the antennas if used for diversity purpose, can be measured.
2. the \(k\)-factor at that moment, can be calculated.
3. the optimum frequency separation if frequency diversity is used to protect the link against deep fadings, can be determined.

**Performance of the measurements**

The movable antenna used for the height gain pattern measurement was a wave guide horn with a gain of 15.5 dB, mounted on a carriage which was movable between two rails.

These rails were fixed at the main mast where the receiving antenna was mounted. The carriage was driven by a motor winch, located at the base of the antenna mast.

A flexible coaxial cable of approx. 6 meters connected the horn antenna with the receiver and was placed in a watertight box in the middle of the main mast. Height indication was obtained by means of small magnets fixed to a guiding rail at one meter intervals. These magnets activated a magnetic reed relay, mounted on the antenna carriage to run on the rails. The whole system was remote controllable from the receiving room.
Fig. 5.45. A theoretical height gain pattern G. Sandangan – Surabaya
\[ d = 50.6 \text{ km}; \ \h_t = 258 \text{ m}; \ k = 1.5; \]
reflection at the smooth sea surface \( R_o = -1 \)

Figure 5.46 gives a schematic drawing of the measuring system.
The coaxial cable gave an extra loss of appr. 8.5 dB, thus yielding a free space level at the input of the receiver of -67 dBm. Minimum detectable level was -95 dBm, thus the total dynamic range was about 30 dB. The signal from the horn antenna was recorded on a dual line y-t-recorder simultaneously with the signal from the main antenna. The recorder always had an event marker which could be activated by the reed relay on the carriage, thus giving the height of the horn antenna relative to the main antenna. The height range of the installation was 10 meters from 2 meters to 12 meters below the centre of the main antenna. It was not possible to measure right up to the height of the main antenna because the main antenna would then shield the horn antenna. But this range is of less interest anyway. The horn antenna moved with a speed of 0.5 m/sec., thus the total time for one scan was 20 seconds. This speed was chosen as a compromise between operation possibilities and the speed of variations of the main signal.
It indeed appeared that the signal of the main antenna remained constant within ± 0,5 dB during a scan.

During the first week of May 1978 some 375 height patterns were recorded. It was during the change of the monsoon from wet season to dry season.
The receiving station was permanently manned from 07.00 – 24.00 hours.
The scans were made every 15 minutes. The idea was to make height gain patterns during all typical periods of the daily fading pattern.

**Processing of the measuring data**

A visual observation of the recording paper gave the impression that there were no clear height patterns, the difference between minimum and maximum level is about 5 to 6 dB. Only some times there were up to 9 dB differences and this was related to a high received signal level. Anyway it was still possible to recognise the maximum and minimum. The average distance is 6,1 meters.

With the aid of the computer the correlation coefficient $\rho$ between the signal at the top antenna and the signals at various heights was calculated.

![Fig. 5.47. The correlation coefficient $\rho$ as a function of $\Delta h$.](image)

Height gain pattern measurement Gunung Sandangan - Surabaya.
Conclusions

From the graph of the correlation coefficient $\rho$ as a function of the height difference between the antennas, it can be seen that the minimum will be reached if the height difference is $6.1$ m and the correlation coefficient $\rho = -0.3$, the signals are negative correlated. So this $6.1$ m is a good spacing for the second antenna away from the main antenna to achieve an optimum diversity gain if the space diversity technique is used to increase the quality of the link.

5.15.1.3. Frequency diversity measurements

Another technique to eliminate or minimise deep fading in microwave links is to transmit the information on two carrier frequencies simultaneously, which are slightly shifted in frequency. The principle of this technique is that the fading caused by multipath propagation is frequency dependent.

This is easy to see because the same physical ray paths will contain different wave lengths for different carrier frequencies. So with proper choice of the two carrier frequencies it is possible to arrange that when one of the two signals exhibits a minimum the other shows a maximum. When looking at the formula (5.81) for the received power $P_r$ in a link with two ray propagation and smooth sea ($R_o = -1$):

$$\frac{P_r}{P_o} = 1 + D^2 - 2D \cos \left( \frac{2\pi}{\lambda} \Delta S \right) \tag{5.81}$$

it is simple to see the dependence of the received power on the frequency. The next figure is a plot of $P_r/P_o$ as a function of the frequency for the link Gunung Sandangan - Surabaya on a logarithmic scale.
Fig. 5.48. Calculated relative power as function of the frequency for the link Gunung Sandangan-Surabaya on dB-scale (relative to isotropic free space transmission).

Description of the performed measurements

During the period 13th November 1976 to 15th January 1977 frequency measurements were taken in the link Gunung Sandangan-Surabaya. The next figure gives a schematic drawing of the system.

Fig. 5.49. Frequency diversity experiment arrangement
The existing microwave experiment was extended with a diplex system at both the transmitter and receiver side to transmit simultaneously two frequencies with the same antennas.

The second channel was tuned at a frequency of 3800 MHz. This frequency had to be chosen to prevent interference with the commercial microwave link of Perumtel. A repeater station was located on the same hill on Madura while the stations in Surabaya were only located three kilometers apart. So in fact, the two links ran parallel to each other. As the commercial link operated at carrier frequencies of 4182.5, 4124.5, 4066.5, 3969.5, 3911.5 and 3853.5 MHz, the choice was rather limited and made at 3800 MHz.

The transmitting diplex system was mounted directly behind the antenna feed and shielded with a water tight box. Semirigid cables connected it with the transmitters.

With this set-up only 1.5 dB cable and microwave losses were introduced. The effective transmitted power of the diversity signal was appr. +29 dBm which resulted in a free space level at the receiver of appr. -34 dBm.

The receiver side consisted of a similar diplex system to split the frequencies of the incoming antenna signal. The diplex system was located in the receiver room and was connected with the receiving antenna by means of a coaxial cable of appr. 15 meters length. Again, the outputs of the diplex system were connected with the receiver inputs by semirigid cables.

The data registration was done by recording the DC output voltages of the receivers, which were a direct measure of the received power, on a two line y-t recorder and simultaneously on the data registration unit. This unit was equipped with a triple system, as described in a former chapter, to collect the statistical properties of two individual signals plus a third signal which was the maximum of the two input signals and which was automatically selected by the data unit.

The processing of the data was similar to that described previously with the 4 GHz propagation measurements.

The results of the measurements are shown in the next figure.
Fig. 5.50. Cumulative distribution function of the single and diversity received signals

The cumulative distribution function of the single received signal for the period of investigation, which happened to coincide with the worst month, can be expressed as: $F(L) = 0.23 L^{2.02}$ (page 5.69) and can be approximated as:

$$0.2 L^2$$

and for the diversity signal is found:

$$0.28 L^4$$

The diversity gain factor is: (see formula 5.72)  
- non diversity signal $P(E < E_o) = 0.2 \left(\frac{E}{E_o}\right)^2$  
- frequency diversity signal $P(E_{div} < E_o) = 0.28 \left(\frac{E_{div}}{E_o}\right)^4$.

At $q = 0.1\%$ we obtain:

$$- 0.001 = 0.2 \left(\frac{E}{E_o}\right)^2$$
\[
\left(\frac{E}{E_0}\right)^2 = 0.005 \\
(E)^2 = 0.005\ (E_0)^2.
\]

For the diversity signal we obtain for \( q = 0.1\%: \)
\[
0.001 = 0.28 \left(\frac{E_{\text{div}}}{E_0}\right)^4 \\
\left(\frac{E_{\text{div}}}{E_0}\right)^2 = 0.06 \\
(E_{\text{div}})^2 = 0.06\ (E_0)^2.
\]

\[
G(0.1, 2) = 20 \log \frac{E_{\text{div}}}{E}
\]

\( = 10.8 \text{ dB}. \)

where: \( E = \) the signal field strength
\( E_{\text{div}} = \) the diversity signal field strength
\( E_0 = \) the free space signal field strength
\( G(q, n) = \) the diversity gain factor.

This result is very good, bearing in mind that the frequency separation is only 200 MHz; if the frequency separation is 1 GHz, a diversity gain factor of 15 dB can be expected (fig. 5.29).

5.15.2. Propagation experiments at 7 GHz

Allocation of frequency

In consultation with Perumtel the frequency of 7,120 MHz has been allocated for this experiment. This frequency is chosen for various reasons. The lower 7 GHz band is in actual use by Perumtel for connection between the local television broadcasting station and the telephone exchange office in Surabaya with the nearby satellite ground station. So the frequency has to be either above or below this band in order to avoid possible mutual interferences.

However, a frequency in the upper 7 or 8 GHz band was beyond the limit of the available microwave equipment. The frequency had to be chosen below the lower 7 GHz band and was fixed at 7,120 MHz.
Development of new feed system

The experiment had to be carried out on the same link Gunung Sandangan - Surabaya as the 4 GHz measurements. In order to use the same antennas, a new feed system had to be designed because the two frequencies were located in different frequency bands which ruled out the use of a simple diplex system as in the frequency diversity experiments.

A device which is suitable for this purpose is an orthomode coupler. This is basically a circular waveguide which is fed with two frequencies, one of them through a transversal slot in the side wall and the other one, axial through a circular waveguide taper. To obtain optimal decoupling between the two signals, the polarisation directions have to be perpendicular to each other. Such a device has been developed for higher frequency bands. A prototype for the specific case of this project has been designed and built by the group Communications Systems and also a special feed, which fitted with this device. After testing and some modifications a final design was developed. Fig. 5.51 shows the orthomode coupler with special feed.

Fig. 5.51. Orthomode coupler with scalar feed
Performance of the propagation measurements

During the months February until April 1977 propagation measurements were performed. A reflex klystron was used as a transmitter for the 7 GHz channel. This was placed in a water tight box together with the power supply behind the antenna alongside the 4 GHz transmitter box. Locating the power supply close to the klystron had the advantage of a stable temperature inside the box due to the heat generated by the power supply. But, nevertheless, the frequency appeared to deviate considerably; appr. 3 MHz due to the daily temperature changes.

A week-long test revealed that the output power of the klystron was, according to the specifications, 24 dBm or 250 mWatt and constant within ± 0.5 dB.

The output level, therefore, has not been monitored. The receiver was a factory build one; Rhode and Schwarz type USU 3, and was connected directly with the receiving antenna by means of a coaxial cable, Flexwell HF 3/8" CU2Y, of appr. 15 meters. The DC output of the receiver, which was linearly proportional to the input power, was recorded on paper and registered with the data collecting unit. The receiver itself was equipped with an automatic phase control unit and was able to lock an input signal if the frequency deviation was - or + 1 MHz from the hand-tuned frequency.

However, the actual frequency deviations were 3 MHz so a special device had to be designed to keep the receiver in lock. The device automatically tracked the frequency deviations by means of a motor drive. In this way it was possible to follow the frequency deviations within 3 MHz. The next figure gives a block diagram of the 7 GHz system.
Fig. 5.52. 4 and 7 GHz measuring system

Table 2 summarizes some parameters of the 4 and 7 GHz link.

<table>
<thead>
<tr>
<th></th>
<th>4,012 MHz</th>
<th>7,120 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>*transmitted power</td>
<td>30 dBm</td>
<td>24 dBm</td>
</tr>
<tr>
<td>*antenna gain</td>
<td>39 dBm ((\eta=50%))</td>
<td>43 dB ((\eta=40%))</td>
</tr>
<tr>
<td>*free space loss</td>
<td>139 dB</td>
<td>144 dB</td>
</tr>
<tr>
<td><strong>losses at transmitter side</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- orthomode coupler</td>
<td>1 dB</td>
<td>1.5 dB</td>
</tr>
<tr>
<td>- coax to waveguide transition</td>
<td>0.5 dB</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>- cable</td>
<td>0.5 dB</td>
<td>2 dB</td>
</tr>
<tr>
<td><strong>losses at receiver side</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- orthomode coupler</td>
<td>1 dB</td>
<td>1.5 dB</td>
</tr>
<tr>
<td>- coax to waveguide transition</td>
<td>0.5 dB</td>
<td>0.5 dB</td>
</tr>
<tr>
<td>- cable</td>
<td>1 dB</td>
<td>9 dB</td>
</tr>
<tr>
<td>*free space level</td>
<td>-35 dBm</td>
<td>-49 dBm</td>
</tr>
</tbody>
</table>

Table 2

After inauguration of the link it appeared that the theoretical free-space level for 7 GHz was never reached.
The maximum received power in non-fading conditions was appr. -60 dBm, so 10 dB too low. A probable cause is the surface irregularities of the paraboloid reflectors. Due to this low level the dynamic range of the receiver was limited to appr. 15 dB. Nevertheless, some measurements were done, however, too little to collect reliable data. No numerical results are available. But comparison between the 4 and 7 GHz recordings did not reveal striking differences; in particular, no indications could be found that during periods of rain the 7 GHz link exhibited larger attenuation than the 4 GHz link.

5.15.3. Conclusions and suggestions

It has been ascertained that the theory of Morita on the prediction of behaviour of a microwave line-of-sight wave-reflected path applies to this particular link. Furthermore, the measurements did not give cause to conclude that the 7 GHz link behaves differently to expectation, although no strong attenuation could be measured due to limitations in the measuring system.

Then, applying Morita's theory to the 7 GHz link yields Rayleigh fading occurrence probability $p_r$ from formula (5.67):

$$p_r = 0.056$$

The effective reflection coefficient reduces for the 7 GHz link, due to the shorter wavelength, to

$$|R_e| = 0.35$$

It follows from Fig. 5.24 that the equivalent Rayleigh fading occurrence probability:

$$P_e = 0.3$$

The cumulative distribution function for the worst month is found to be:

$$P(L \leq L) = 0.3 L^2$$
If the predictions for the cumulative distribution function for the worst month for both mechanisms, multipath propagation and rain attenuation, are plotted in one figure it is easy to see the influence of the mechanisms individually.

This is done in Fig. 5.53.

From this figure follows that only for frequencies above appr. 10 GHz does the influence of rain become comparable to the multipath propagation. For these frequencies, attenuations exceeding 20 dB will be caused mainly by rain. Therefore, to investigate the influence of rain, a frequency in the band between 10 and 12 GHz has to be chosen.

**Fig. 5.53. Cumulative distribution function for:**
- measured multipath fading for 4 GHz and the extrapolated fading for 7 GHz and 12 GHz
- expected rain attenuation for 7 GHz, 10 GHz and 12 GHz.
5.16. **Suggestions**

- Satellite experiments are very useful in gaining data in the tropical region.
- The experiments should be followed up by other L.O.S. experiments with trajectories which can easily be reached from Surabaya e.g. Surabaya - Mojokerto or Surabaya - Tretes, both sites are 50 km from Surabaya and the paths will pass through wet rice fields.
- Experiments in the 12 GHz band will be interesting, especially for measuring the rain attenuation and other types of power fading.
- Cross polar measurements would be important in order to apply frequency re-use.
- A long distance line-of-sight measurement should be taken into consideration (> 120 km L.O.S.). It is especially important for the Indonesian archipelago.

5.17. **Conclusions**

1. Focusing by the troposphere does not influence the amplitude of the signal. The reflected waves are also not affected. $C_d \approx 1$. (see Chapter 5.6).
2. The divergence factor is between 0.4 and 0.9 if the k-factor varies from 0.5 to 3.0 (see Fig. 5.15).
3. The prediction with Morita's theory agreed with the actual experimental results (see 5.15.1.1.).
4. During the measurement period (October 7, 1976 to April 23, 1977) it appeared that December 1976 was the worst month and March 1977 the best one. (see 5.15.1.1.). (page 5.68).
5. The amplitude cumulative distribution graph of the received signal in the worst month (December 1976) for levels below -45 dBm has a slope which tends to the Rayleigh distribution.

6. The best vertical spacing of the antennas for the link Gunung Sandangan - Surabaya is 6.1 m. and the correlation coefficient of the signal at the main antenna and the second antenna is -0.3 (see 5.15.1.2.).
7. For the 4 GHz link Gunung Sandangan - Surabaya, frequency diversity technique with 200 MHz frequency separation will already give a diversity gain factor of 10.8 dB, compared with the maximum of 15 dB which
could be achieved if the frequency separation is 1 GHz (see 15.5.1.3.).

At 7 GHz the rain attenuation is not important compared with the multi-path fading, it only becomes interesting if the frequency used is higher than 10 GHz. (see Fig. 5.53).

Photo 5.1. Height gain pattern measurement installation.
Intersection: the movable horn antenna.
Appendix I (Straight lines for ray traces in relation to the k-factor model)

See Fig. 5.7 and formula (5.25)

\[
\frac{d^2z}{dx^2} = \frac{1}{n} \frac{dn}{dz} + \frac{1}{R} \quad (5.25)
\]

\(z(x)\) gives the ray traces height above the earth with a constant radius \(R\), at a certain distance \(x\) from a reference point.

It is known that in a homogeneous medium \((\frac{dn}{dz} = 0)\), the ray traces will be straight lines and formula (5.25) will become:

\[
\frac{d^2z}{dx^2} = \frac{1}{R} \quad (1)
\]

So, if an artificial earth with a constant radius \(R_a\) is introduced, where \(\frac{1}{R_a} = \frac{1}{n} \frac{dn}{dz} + \frac{1}{R}\), formula (5.25) will modify to:

\[
\frac{d^2z}{dx^2} = \frac{1}{R_a} \quad (2)
\]

Formulas (1) and (2) have an identical form, so it can be concluded that curve \(z(x)\) calculated from \(\frac{d^2z}{dx^2} = \frac{1}{R_a}\) will also be a straight line.

So, if an effective earth with constant radius

\[
R_a = \frac{1}{\frac{1}{n} \frac{dn}{dz} + \frac{1}{R}}
\]

is imagined and replaces the real earth with radius \(R\), the ray traces will become straight lines.

The relative curvature of the ray traces and the earth is the same as the relative curvature of the straight lines and the artificial earth.

This model is used because of its simple geometrical calculations, and it is simple if the radius is constant.

Thus to achieve the goal of this model, \(R_a\) should be constant and this means that \(\frac{dn}{dh}\) should be constant too, or, with other words, \(n(h)\) should be linear.
Appendix II

The derivation of the reflection point formula (5.47)

\[ 2d_t^3 - 3d_t d_t^2 + [d_t^2 - 2kR(h_t + h_r)]d_t + 2kR h_t d_t = 0 \]  

(5.17)

Suppose: \( a = 2 \)  
\( b = -3d \)  
\( c = d_t^2 - 2kR (h_t + h_r) \)  
\( d' = 2kR h_t d_t \)

(1.a)  
(1.b)  
(1.c)  
(1.d)

A new variable: \( y = d_t + \frac{b}{3a} = d_t - \frac{d}{2} \)

Thus:

\[ ad_t^3 + bd_t^2 + cd_t + d' = 0 \]  

(2)

\[ d_t = y + \frac{d}{2} \]  

(3)

\[ a(y^3 + 3y^2 \frac{d}{2} + 3\frac{d^2}{4}y + (\frac{d}{2})^3) + b(y^2 + dy + \frac{d^2}{4}) + \]

\[ c(y + \frac{d}{2}) + d' = 0 \]  

(4)

Further calculations:

\[ ay^3 + (\frac{3ad}{2} + b)y^2 + (\frac{3ad^2}{4} + bd + c)y + \frac{ad^3}{8} + \frac{bd^2}{4} + \frac{cd}{2} + d' = 0 \]  

(5)

Dividing with \( a \):

\[ y^3 + (\frac{3d}{2} + \frac{b}{a})y^2 + (\frac{3d^2}{4} + \frac{bd}{a} + \frac{c}{a})y + \frac{d^3}{8a} + \frac{bd^2}{4a} + \frac{cd}{2a} + \frac{d'}{a} = 0 \]  

(6)

Combining (1.a - 1.d) with (6):

\[ y^3 + (\frac{-d^2}{4} - kR(h_t + h_r))y - \frac{d^3}{4} + \frac{d^3 - 2kR(h_t + h_r)d}{4} + \frac{2kR h_t d}{2} = 0 \]  

(7)

\[ y^3 + (\frac{-d^2}{4} - kR(h_t + h_r))y + \frac{kR(h_t - h_r)d}{t} = 0 \]

\[ y^3 - \frac{3}{4} p^2 y + 2q = 0 \]  

(8)

With:
\[ \frac{3}{4} p^2 = \frac{d^2}{4} + kR(h_t+h_r) \quad (9) \]
\[ 2q = \frac{kR(h_t-h_r)d}{2} \quad (10) \]

Suppose: \( y = A \cos B \) \quad (11)

Combining (8) and (11):

\[ A^3 \cos^3 B - \frac{3}{4} p^2 A \cos B + 2q = 0 \quad (12) \]
\[ A^3 \left( \frac{\cos 3B + 3 \cos B}{4} \right) - \frac{3}{4} p^2 A \cos B + 2q = 0 \]
\[ \frac{3A^3}{4} \cos 3B + \left( \frac{3A^3}{4} - \frac{3}{4} p^2 A \right) \cos B + 2q = 0 \]
\[ \frac{3A^3}{4} - \frac{3p^2 A}{4} = 0; A \neq 0; A = \pm p; \text{ we take the} \]
\[ A = p \quad (13) \]
\[ \frac{A^3}{4} \cos 3B + 2q = 0; \frac{p^3}{4} \cos 3B + 2q = 0 \]
\[ \cos 3B = \frac{-2q}{p \cdot 3/4} = -\frac{8q}{3} \frac{3}{p} \]
\[ 3B = \arccos \left( -\frac{8q}{3p} \right) + 180^\circ \]
\[ 180^\circ + \arccos \left( \frac{8q}{3} \right) \]
\[ B = \frac{\arccos \left( \frac{8q}{3} \right)}{3} \quad (14) \]

Thus the solution is:
\[ y = p \cos \left( \frac{180^\circ + \arccos \left( \frac{8q}{3} \right)}{3} \right) \quad (15) \]
\[ dt = \frac{d}{2} + p \cos \left( \frac{\phi + 180^\circ}{3} \right) \quad (16) \]

where:
\[ p = \frac{2}{\sqrt{3}} \sqrt{\frac{d^2}{4} + kR(h_t+h_r)} \quad (17) \]
\[ q = \frac{kRd}{4} (h_t-h_r) \quad (18) \]
\[ Q = \arccos \left( \frac{8q}{3p} \right) \rightarrow dt = \frac{d}{2} + p \cos \left( \frac{\phi + 180^\circ}{3} \right) \quad (19) \]
Appendix III (the derivation of the path length difference between reflected and direct wave)

Fig. 1. The schematic diagram of the direct and reflected wave (geometrical)

Calculating \( h_{t1} \) and \( h_{r1} \).

For line-of-sight links it can be said that: \( dt' \approx dt \). (See Fig. 2).

So,

\[
(kR)^2 + d_t^2 = (kR + h_{t2})^2
\]

\[
(kR)^2 + d_t^2 = (kR)^2 + (h_{t2})^2 + 2(kR)h_{t2}
\]

\[
d_t^2 = (h_{t2})^2 + 2kR h_{t2}
\]

\[
h_{t2}^2 < 2kR h_{t2}
\]

So,

\[
2kR h_{t2} = dt^2
\]

\[
h_{t2} = \frac{dt^2}{2kR}
\]

Analog:

\[
d_r^2 = \frac{dt^2}{2kR}
\]

Fig. 2. Calculating \( h_{t2} \)
From Fig. 1:

\[
\begin{align*}
    h_{t_1} &= h_t - \frac{d_t^2}{2kR} \\
    h_{r_1} &= h_r - \frac{d_r^2}{2kR} \\
    S_d^2 &= (h'_r - h'_t)^2 + d^2 \\
    S_r^2 &= (h'_t + h'_r)^2 + d^2 \\
    S_r^2 - S_d^2 &= (d^2 + h'_r^2 + h'_t^2 + 2h'_r h'_t) - (d^2 + h'_r^2 + h'_t^2 - 2h'_r h'_t) \\
    &= 4 h'_r h'_t
\end{align*}
\]

(3)

(4)

(5)

In this case: \( h'_t \approx h_t \) and \( h'_r \approx h_r \). So:

\[
\Delta S = S_r - S_d = \frac{S_r^2 - S_d^2}{S_r + S_d} = \frac{4h'_t h'_r}{2d}
\]

\[
\Delta S \approx \frac{2h'_t h'_r}{d}
\]

(6)

If \( h'_t \) is substituted by \( h_{t_1} \) and \( h'_r \) by \( h_{r_1} \):

\[
\Delta S = \frac{2(h_{t_1} - \frac{d_t^2}{2kR})(h_{r_1} - \frac{d_r^2}{2kR})}{d}
\]

\[
\Delta S = \frac{2h_{t_1} h_{r_1}}{d} \left(1 - \frac{d_t^2}{2kR h_t}ight) \left(1 - \frac{d_r^2}{2kR h_r}ight)
\]

(7)

\[
h_t = h_{t_1} + h_{t_2}
\]

\[
h_r = h_{r_1} + h_{r_2}
\]
Chapter 6

TROPOSPHERIC SCATTER PROPAGATION, THEORY

Sangkuni
Uncle of Duryudono, prime minister, who suggested to take over Astina, a person of illwill, full of crookedness.
6. Tropospheric scatter propagation, theory

6.1. Introduction to the scatter mechanism [6]

In the foregoing chapters we considered the earth's troposphere in order to find the trajectory of an electromagnetic beam, propagated through this troposphere. In the formulas that were derived a gradual decrease of refractivity as function of height was considered. For linear refractivity profiles we found the k-factor as key parameter for tropospheric propagation of radiowaves.

According to the k-factor model and the diffraction theory over a flat earth, a rapid exponential decrease of the received signal over the radio horizon was expected.

Fig. 6.1. No signal was expected for over-the-horizon propagation

But the facts showed that also behind the horizon was a small signal, though strongly subject to deep fading, which could be received, despite the fact that the receiving antenna could not 'see' the transmitting antenna.

At first this phenomenon was thought to originate from accidental meteorological circumstances in the troposphere or special conditions of the ionosphere. But it occurred more frequently and more constantly than the meteorological special circumstances allowed.

In some way fractions of the radiowaves had to be reflected or refracted in the troposphere into all possible directions. A small part of it could be received by the receiving antenna. This type of radiowave propagation is called scattering and the resulting over-the-horizon field is called scattered field.

Around 1950 and later several fundamental theories attempting to explain this phenomenon were published.

The over-the-horizon propagation of radiowaves is explained as originating from an irregular refractivity profile of the troposphere. Due to meteo-
logical phenomena such as a non homogeneous distribution of the sun's radiation, the presence of winds, clouds, turbulences and the like, the actual refractivity profile shows small deviations which change in time and place. The imperfect mixing in the troposphere causes local inhomogeneities which cause fractions of radiowaves to be reflected and/or refracted into all possible directions and thus causing the over-the-horizon field.

One theory about tropospheric scatter presumes a troposphere consisting of extensive layers (feuillets) of different thickness and different refractivity. The borders of these layers can be seen as reflection surfaces because of the difference in refractivity. See Fig. 6.2a and 6.3a.

Another theory claims that the troposphere, due to the meteorological variations, consists of spheres (blobs, eddies) each with a different refractivity. These blobs will refract the incident wave in all directions. See Fig. 6.2b and 6.3b.

Since only a small fraction of the wave's energy is scattered, the scattered wave is much weaker than the direct wave. This so-called scattering loss comes on top of the 'normal' propagation loss (= free space loss). In troposcatter propagation the path attenuation will be very high, which means, that compared to the line-of-sight links, high
power transmitters and low noise receivers have to be used. In addition large high gain antennas are used.

6.2. Physical explanations of the scatter mechanism

One of the main quantities in the troposphere is the dielectric constant $\varepsilon$. This is also a quantity that can be easily measured with, for instance, an aeroplane.

6.2.1. Variations of the dielectric constant $\varepsilon$

Due to the constant atmospheric turbulences, the refractivity in the troposphere will have discontinuities and random fluctuations, by which the electromagnetic field will be scattered.

Imagine the troposphere being composed of many homogeneous rotating eddies of different sizes. The dielectric constant varies from eddy to eddy and deviates little from a mean value $\bar{\varepsilon}$.

$$\varepsilon_r(P) = \bar{\varepsilon} + \Delta \varepsilon_r(P) \quad (6.1)$$

where $P$ = position in troposphere.

The mean square value of the inhomogeneities in a volume $V$ is:

$$\overline{(\Delta \varepsilon_r)^2} = \frac{1}{V} \int_V (\Delta \varepsilon_r)^2 \, dV \quad (6.2)$$

Eddies close to each other will have a high correlation between their dielectric constants, while those at greater distance a small correlation. A correlation function for $\Delta \varepsilon_r$ is defined as:

$$\rho(r) = \frac{1}{V \overline{(\Delta \varepsilon_r)^2}} \int_V \Delta \varepsilon_r(P) \Delta \varepsilon_r(P') \, dV \quad (6.3)$$

where $r = |P-P'|$ is the distance between positions $P$ and $P'$.

The dielectric constant can be expressed in several meteorological quantities by a semi-empirical formula:

$$\varepsilon_r = 1 + P \left( \frac{C_1}{T} + \frac{C_2 \varepsilon}{T^2} \right) \quad (6.4)$$
where \( p = \) atmospheric pressure (m bar)

\( T = \) absolute temperature (Kelvin)

\( e = \) water vapour pressure (m bar)

\( C_1, C_2 = \) constants. \( \frac{K}{m^2 N}, \) resp. \( \frac{K^2 m^2}{N} \).

The deviations around the mean value are mainly caused by fluctuations of temperature and atmospheric pressure:

\[
\Delta \varepsilon_r = \frac{\partial \varepsilon_r}{\partial T} \Delta T + \frac{\partial \varepsilon_r}{\partial p} \Delta p
\]

(6.5)

where \( \bar{p} = \) mean pressure at height \( h \)

\( \bar{T} = \) mean absolute temperature at height \( h \).

From thermodynamics we have:

\[
\bar{p} = \frac{\bar{p}_0}{\bar{T}_0} \bar{T} \exp\left(\frac{-Mgh}{RT}\right)
\]

(6.6)

with \( \bar{p}_0 = \) mean pressure at sea level [mB]

\( \bar{T}_0 = \) mean temperature at sea level [°K]

\( h = \) height above sea level [m]

\( M = \) molecular weight of air = 28.9 [gr]

\( R = \) universal gas constant = 8.3 [J/K]

\( g = \) gravity constant = 9.8 [m/s²]

The temperature does not vary rapidly over long periods, so \( |\Delta T| \ll \bar{T} \).

Then we can find that:

\[
\Delta p = 3.5 \frac{\bar{p}}{3.5 \bar{T}} \Delta T
\]

(6.7)

Using the equations (6.4), (6.5), (6.6) and (6.7) we find for the deviation of the dielectric constant:

\[
\Delta \varepsilon_r = \left[3.5 \frac{\bar{p}}{\bar{T}} \left( C_1 + \frac{C_2 e}{\bar{T}} \right) - \left( C_1 + \frac{2C_2 e}{\bar{T}} \right) \right] \frac{\bar{p}_0}{\bar{T}_0} \frac{1}{\bar{T}} \exp\left(\frac{-Mgh}{RT}\right) \Delta T
\]

(6.8)

Equation (6.8) shows that the deviations of the dielectric constant decrease with increasing altitude, i.e. the intensity of scattering will decrease as a function of height.
6.2.2. Scatter angle and scatter volume

There are two parameters important in troposcatter engineering: the scatter angle $\theta$ and the common volume $V$. The scatter angle is the smallest angle between the main axes of the two antennas, the common volume is the intersection volume between the two antenna beams.

![Diagram of scatter angle and common volume](Image)

**Fig. 6.4. Scatter angle $\theta$ and common volume $V$**

The scatter angle $\theta$ is the angle over which the propagating beam must be bent. The scattering-loss depends heavily on the magnitude of this angle $\theta$.

The common volume is the volume filled by both receiving and transmitting antenna beams. This volume contains the scattering 'objects' in the troposphere.

6.2.3. Scatter cross section $\sigma$, scattered power

The ability to scatter in the common volume is expressed by the 'scatter cross section' $\sigma$ per unit meter. It is defined as the proportion between the scattered power $P_s(\theta,\phi)$ (per unit volume and angle into the direction ($\theta,\phi$)) and the power density $S_o(\theta',\phi')$ in the scatter volume:

$$\sigma(\theta',\phi',\theta,\phi) = \frac{1}{S_o(\theta',\phi')} \lim_{\Delta V \rightarrow 0} \frac{\Delta P_s(\theta,\phi)}{\Delta V \Delta \Omega} \quad [m^{-1}]$$

(6.9)

Using the above definition it is possible to formulate a general expression for the received scattered power. The received power by the receiving antenna is:

$$dP_r(\theta,\phi) = A_e \frac{dP_s}{R^2} = \frac{\lambda^2}{4\pi R^2} G_r \frac{dP_s}{d\Omega}$$

(6.10)
where: $A_e =$ effective antenna aperture of receiving antenna
$P_s =$ scattered power in the direction of receiving antenna
$\lambda =$ wavelength
$R_r =$ distance from common volume to receiving antenna
$G_r =$ gain of the receiving antenna
$R_r \approx R_t >>$ dimensions of common volume

The power density in the common volume is:

$$S_0(\theta', \phi') = P_t \frac{\lambda}{4\pi R_t^2}$$  \hspace{1cm} (6.11)

where: $P_t =$ transmitted power
$R_t =$ distance between transmitter and common volume.

The scattered power in the common volume, using the scatter cross section $\sigma$, will be:

$$dP_s = F_0(\theta', \phi') \sigma dV$$  \hspace{1cm} (6.12)

where: $S_0(\theta', \phi') =$ power density in the common volume
$\sigma =$ scatter cross section.

So the relationship of the transmitted and the received scattered power is, after integration over the total common volume:

$$P_r = P \frac{\lambda^2}{(4\pi)^2} \int \frac{G_t G_r}{V R_t^2 R_r^2} \sigma dV$$  \hspace{1cm} (6.13)

Fig. 6.5. Propagation path and its characteristic units

Usually the received power is compared with the power received in free space over a distance $R_r + R_t \approx d$.

The power received in free space would be:
where 10 log 1/Q is the extra attenuation in dB on top of the free space attenuation in a troposcatter link.

6.2.4. Scale of turbulence

In a first attempt to explain the proportions of the scatter cross section $\sigma$, Booker and Gordon [5] developed a theory in which they considered the scatter contributions of all volume parts $dV$ separate from the total receiving field. In this theory it is assumed that all parts $dV$ are polarized by the incident wave and will transmit - like a dipole antenna - energy in the direction of the receiving antenna.

First the radiation density is determined by integration over the total common volume of the complex vector $\vec{S} = \vec{E} \times \vec{H}$.

In these calculations we also find a volume integral over the multiplication of $\Delta \varepsilon \Delta \varepsilon'$. $\Delta \varepsilon$ and $\Delta \varepsilon'$ are the deviations (from a mean value $\bar{\varepsilon}$) of two volume elements at distance $r$ from each other.

The integral

$$\rho(r) = \frac{1}{V} \sqrt{\frac{\Delta \varepsilon_r^2}{\Delta \varepsilon_r^2}} \int \frac{(\Delta \varepsilon_r)(\Delta \varepsilon'_r)}{V} dV$$

(6.16)

represents a function determining the structure of the total common volume. It is the so-called 'auto-correlation function' of the scattering medium, where:

$$\frac{\Delta \varepsilon_r^2}{\Delta \varepsilon_r^2} = \frac{1}{V} \int \frac{(\Delta \varepsilon_r)^2}{V} dV$$

(6.17)

where: $\frac{\Delta \varepsilon_r^2}{\Delta \varepsilon_r^2} = $ mean square value of the deviations.

So $\rho(r)$ represents the relation of the value of $\varepsilon_r$ in each small volume element at distance $r$ from each other.
Fig. 6.6. Auto correlation function of relationship of ε in different parts of the common volume [6]

For an isotropic inhomogeneous medium ρ is only a function of the distance $r = |\mathbf{r}|$ between two volume elements $dV$ and $dV'$.

$\rho(r)$ is a normalized auto correlation function and equals 1 for $r = 0$ and tends to 0 for increasing distance.

Now we can define a distance $r = l₀$ for which, for instance, $\rho(r) = 1/e$ and interpret this distance as a mean size of the radius of the scattering volumes. This distance is said to be the scale of turbulence. Also sometimes for $l$ is chosen:

$$Z₀ = \int_{0}^{\infty} \rho(r) dr$$  \hspace{1cm} (6.18)

Thus the common volume is considered to consist of small volumes of a radius $l$ and a homogeneous value of $\varepsilon$ in each volume.

6.2.5. Scatter vector, scatter spectrum

In description of the scatter cross section $\sigma$, next to the auto correlation function, is another characteristic structure function $S(\mathbf{k})$, called the scatter spectrum function. This function is related to $C(r)$ by means of a Fourier transformation.

First we define a scatter vector, which determines the relationship of the direction of the incident and scattered wave. See Fig. 6.7.

Fig. 6.7. Scatter vector
The scatter vector is defined as:

\[
\vec{K} = \vec{K}_2 - \vec{K}_1
\]  

(6.19)

The absolute values of the vectors are equal:

\[
|\vec{K}_1| = |\vec{K}_2| = k = \frac{\omega}{C} = \frac{2\pi}{\lambda}
\]  

(6.20)

So we can derive from Fig. 6.7:

\[
|\vec{K}| = 2k \sin \frac{\theta}{2}
\]  

(6.21)

where \(\theta\) = scattering angle.

The relation between \(\rho(\tau)\) and \(S(\vec{K})\) is:

\[
S(\vec{K}) = (\Delta \varepsilon_r)^2 \int \rho(\tau) e^{j\vec{K} \cdot \vec{r}} dV
\]  

(6.22)

Both functions \(\rho(\tau)\) and \(S(\vec{K})\) form the statistical structure functions of the scattering medium. From their formulation it can be seen that the scatter cross section \(\sigma\) depends on the frequency and distance. The analytical formulation of \(\rho(\tau)\) and \(S(\vec{K})\) is used in several troposcatter theories.

6.3. Scattering by turbulence

A medium composed of eddies as described before, is an inhomogeneous medium. The influence of an electromagnetic field on such a medium is researched by Booker and Gordon [5].

In their considerations they assumed no multiple scattering - a twice scattered signal is too weak to be considered.

The general Maxwell equation gives:

\[
\nabla \times \vec{H} = \varepsilon \vec{E} + \sigma \vec{E}
\]  

(6.24)

We assume an isotropic troposphere, conductivity of the medium is zero \((\sigma = 0)\); magnetic permeability \(\mu = \mu_0\); dielectric constant \(\varepsilon_r = \varepsilon_o + \Delta \varepsilon_r\) and the electric field is time dependent as: \(\vec{E} = R_e(\vec{E}_0 e^{j\omega t})\). Then:

\[
\nabla \times \vec{H} = \varepsilon_0 \varepsilon_r \varepsilon_o \vec{E}_0 = \omega \varepsilon_0 \varepsilon_r \varepsilon_o \vec{E}_0 + j \omega \varepsilon_0 \Delta \varepsilon_r \varepsilon_o \vec{E}_0
\]  

(6.25)

From the above equation together with the Maxwell equation for an electro-
magnetic wave as below:

$$\nabla \times \vec{H} = j\omega \varepsilon_0 \vec{E} + \sigma' \vec{E}$$  \hspace{1cm} (6.26)$$

where: $\sigma' = \text{conductivity of the medium.}$

We can see that the inhomogeneities of the dielectric constant in the medium have the same effect as harmonic currents in a medium with a density of

$$i' = \Re\{\vec{I} e^{j\omega t}\}:

$$i' = \sigma' \frac{\vec{E}}{E_0} = j\omega \varepsilon_0 \Delta \varepsilon_r \frac{\vec{E}}{E_0} \hspace{1cm} (6.27)$$

These currents will cause a momentum. Consider for this a volume $dV$ with a length $dl$ and section $dA$ (Fig. 6.8).

![Figure 6.8](image)

Fig. 6.8. Momentum caused by incident electric field (a) and angle between incident electric field and receiver (b) [5]

For the electric moment caused by the incident electric field we find:

$$d\vec{M} = Idl = i \vec{E} \cdot dl = i \int dV = j\omega \varepsilon_0 \Delta \varepsilon_r \frac{\vec{E}}{E_0} dV \hspace{1cm} (6.28)$$

The angle between incident electric field and receiver is $\chi = 90^\circ + \theta$.

According to the theory of the electric dipole we obtain for the electric field at the receiver:

$$d\vec{E} = -j \frac{k Z_0}{4\pi R_r} \sin \chi e^{-jkR_r} \hspace{1cm} (6.29)$$

where: $R_r = \text{distance to receiver}$

$k = \text{wave number}\ \frac{2\pi}{\lambda} = \frac{\omega}{c}$

$Z_0 = \text{wave impedance in vacuum.}$
Substitution of (6.28) in (6.29) will result in:

\[ \frac{\mathbf{dE}}{\mathbf{dE}} = \frac{k}{4\pi} \mathbf{E}_0 \Delta \mathbf{e} \frac{e^{jk\mathbf{R}_r}}{R_r} \sin\chi \, dV \]  
(6.30)

When also the phase of the incident wave is included in the calculation when \( E_0 = E_0' e^{jk\mathbf{R}_t} \):

\[ \frac{\mathbf{dE}}{\mathbf{dE}} = \frac{k}{4\pi} \mathbf{E}_0' \Delta \mathbf{e} \frac{e^{jk(R_t + R_r)}}{R_r} \sin\chi \, dV \]  
(6.31)

The power density at the receiver can be calculated from:

\[ ds_r = \frac{1}{2} | \mathbf{dE} \times \mathbf{dE}^* | = \frac{1}{2Z_o} (\mathbf{dE} \cdot \mathbf{dE}^*) \]  
(6.32)

By integrating over all scattering parts in the scattering volume we get:

\[ S_r = \frac{1}{2Z_o} \int_V \mathbf{dE}(p) \int_V \mathbf{dE}^*(p') \]  
(6.33)

![Fig. 6.9. Phase difference between two scattering parts at position P and P' [8]](image)

The phase difference between two scattering parts at position P and P' in the common volume is:

\[ \Delta \phi = k(R_t - R_t' + R_r - R_r') = 2kr \sin \frac{\theta}{2} = \mathbf{k} \cdot \mathbf{r} \]  
(6.34)

When substituting equation (6.31) in (6.33) we find for the power density
at the receiver: \( (R_r \approx R'_r) \)

\[
S_r = \frac{|E|^2}{2Z_0} \left( \frac{k^2 \sin \chi}{4\pi R_r} \right)^2 \int \int \Delta \varepsilon_r(p) \Delta \varepsilon_r(p') e^{-jk\{R_t + R_r - (R_t'R_r')\}} dV' dV
\]

(6.35)

The ratio between the power density \( S_r \) at the receiver and the incident power density \( S_o \) is:

\[
\frac{S_r}{S_o} = \left( \frac{k^2 \sin \chi}{4\pi R_r} \right)^2 \int \int \Delta \varepsilon_r(p) \Delta \varepsilon_r(p') e^{-jk\mathbf{r} \cdot (\mathbf{r} - \mathbf{r}')} dV' dV
\]

(6.36)

\( \sin \chi = 1 \) because \( \theta \) will usually be very small.

From equation (6.3) we can derive:

\[
\int \int \Delta \varepsilon_r(p) \Delta \varepsilon_r(p') dV' = V \left( \Delta \varepsilon_r \right)^2 \rho(r)
\]

(6.37)

For the double integral of equation (6.36) we find now, together with equation 6.22:

\[
V \left( \Delta \varepsilon_r \right)^2 \int \rho(r) e^{-jk\mathbf{r} \cdot \mathbf{r}'} dV = V S(\mathbf{k})
\]

(6.38)

The equation (6.36) can now be simplified:

\[
\frac{S_r}{S_o} = \left( \frac{k^2 \sin \chi}{4\pi R_r} \right)^2 V S(\mathbf{k})
\]

(6.39)

The ratio between the scattered power \( \frac{dP_s}{S_o} \) per unit volume and angle in the direction of the receiver and the incident power density \( S_o \) will now be:

\[
\frac{dP_s}{S_o} = \left( \frac{k^2}{4\pi} \right)^2 S(\mathbf{k}) dV
\]

(6.40)

because: \( dP_s = \int \mathbf{r} \cdot \mathbf{r}' \cdot S(\mathbf{k}) dV \).

For the scatter cross section \( \sigma \) per unit angle and volume we now get using definition (6.9):

\[
\sigma = \left( \frac{k^2}{4\pi} \right)^2 S(\mathbf{k})
\]

(6.41)

Booker and Gordon in their theory assumed that the correlation between the fluctuations of the dielectric constant decreases exponentially as function of the distance, relative to the scale of turbulence \( l_o \):
\[ \rho(r) = e^{-r/1_o} \]  

(6.42)

For the scatter cross section Booker and Gordon [5] derived:

\[ \sigma = \frac{\Delta\varepsilon}{\varepsilon} \frac{2\pi l_0^3}{\lambda} \frac{2.2\pi l_0}{\lambda} \sin \frac{\theta}{2} \]  

\[ \lambda \left( 1 + \left( \frac{\lambda}{\lambda} \sin \frac{\theta}{2} \right)^2 \right) \]  

(6.43)

where: 
- \( l_o \) = scale of turbulence
- \( \theta \) = scattering angle
- \( \lambda \) = wavelength and \( \varepsilon = \varepsilon_0 \varepsilon_r \Delta\varepsilon_r = \frac{\Delta\varepsilon}{\varepsilon_r} \)

From equation (6.43) it is seen that the scatter cross section depends strongly on the ratio of the scale of turbulence \( l_o \) and the wavelength \( \lambda \) of the radio signal, and can be expressed by [6]:

\[ \sigma : = \frac{(\Delta\varepsilon)^2}{\varepsilon} \frac{x^3}{(1 + Ax^2)^2} \]  

(6.44)

where \( x = \frac{l_0}{\lambda} \)

\( A = 16\pi^2 \sin^2 \left( \frac{\theta}{2} \right) \)

The scattering cross section shows a maximum:

\[ \sigma_m = B \frac{(\Delta\varepsilon)^2}{\varepsilon} \frac{\sin \frac{3\theta}{2}}{\sin \frac{\theta}{2}} \]  

(6.45)

for

\[ \hat{\lambda} = \frac{\sqrt{3}}{4\pi \sin \frac{\theta}{2}} \]

when \( B \) is a constant.

The propagation medium is composed of many spheres (eddies) of different size.

The energy contained in the eddies can be dissipated in two ways:
1. by moving to other parts of the medium, thus creating new eddies,
2. heat due to friction.

Big eddies have a high kinetic energy and because their surfaces are small compared to their mass losses due to friction with other eddies can be neglected. For this 'large scale of turbulence' we have \( x \gg \hat{\lambda} \), so:
For a small scattering angle $\theta \ll 1$ counts:

$$\sigma = \frac{\langle \Delta \varepsilon \rangle^2}{\langle \varepsilon \rangle} \frac{1}{1_0 \sin (\frac{\theta}{2})} \quad (6.47)$$

From equation (6.44) it is seen that the scatter-cross-section and thus also the received power decrease with the fourth power of the scatter angle. Because of this, the scatter angle must be kept very low i.e. the common volume very small.

Small eddies on the other hand have a small kinetic energy and, their surfaces larger compared to their mass, will dissipate energy by producing heat.

For $x \ll \lambda$, the scattering occurs in conditions of 'small scale of turbulence'. Within this limit, the scatter cross-section takes the form:

$$\sigma = \frac{\langle \Delta \varepsilon \rangle^2}{\langle \varepsilon \rangle} \left( \frac{1}{\lambda} \right)^3 \quad (6.48)$$

![Fig. 6.10 Scattering cross-section as function of $x = \frac{1_0}{\lambda}$](image)

For microwave frequencies the large scale turbulence is of most importance. In this case the frequency dependence of the scatter spectrum can usually be described by:

$$S(k) \propto k^{-\alpha} \quad (6.49)$$
For the scatter cross section is approximately calculated:

\[ \sigma :: k^{(4-\alpha)} :: f^{(4-\alpha)} \]  \hspace{1cm} (6.50)

In the theory of Booker and Gordon \( \alpha = 4 \) is used, and \( \sigma \) is not dependent on the frequency.
In practice a value of \( \alpha = 5 \) is accurate. This also results from a theory about mixing of gases. A correlation function in this case was adopted:

\[ \rho(r) = \frac{r}{l_0} K_1 \left( \frac{r}{l_0} \right) \]  \hspace{1cm} (6.51)

where: \( K_1 \) is the modified Bessel function of the second order and first kind.
For the scatter spectrum is calculated in this case:

\[ S(\vec{r}) = \frac{6\pi^2 (\Delta \varepsilon)^2}{1 + (\varepsilon_0^2)^2} \left( \frac{l_0}{r} \right)^3 \]  \hspace{1cm} (6.52)

But in this theory the dependence of the \( S(\vec{r}) \) on the distance between transmitter and receiver is not included. With increasing distance \( \theta \) will also increase. The common volume will be at a higher altitude. At higher altitude \( \varepsilon \) decreases resulting in a deviation from the theoretical approximation.
For distances between transmitter and receiver of 150 km up to 300 km, the distance dependence is \( d^{-5.5} \) and the height of the scatter volume dependence is \( h^{-2} \).

6.4. **Fading of a troposcatter signal**

In practice a troposcatter signal will vary around a medium value as has been explained in the previous chapters. This variation is called
'fading'. Fading is characterised by the following features:
- fading depth: amount of dB variation in the signal.
- fading speed: amount of dB variation per second of the signal.
- fading frequency: the number of times per second the signal is lower than a reference level.
- fading time: the number of seconds per fade. Time interval in which the signal is below the reference value.

A fading signal is a stochastic magnitude presenting a statistical distribution.

The statistical behaviour of a fading signal is usually described by a specific function $F(x)$, of which $x$ is a parameter of the received signal. In line-of-sight links, for the parameter $x$, the received power in dB is chosen, related to the power without fading. $F(x)$ is then defined as the probability that the received signal level is the same or higher than a certain value $x$. To determine the shape of the function $F(x)$ one has to investigate the variations of $x$ as a function of time.

The signal was evaluated during a time period $T_t$ (sample period), where $T_t$ is long enough to obtain 'statistically relevant information' concerning the signal.

The evaluation was carried out by choosing a set $x_n$, in which each $x_n$ is a fixed amount of dB.

![Diagram of statistical evaluation of a fading signal](image)

Fig. 6.11. Statistical evaluation of a fading signal.

$T_t$ = observation time

$T(x_n) = t_1 + t_2 + t_3$

The total time $T(x_n)$ within the period $T_t$ the signal is below or equal to a level $x_n$ is determined for every level $n$. 
The function $T_n(x_n)/T_n$ for every level $x_n$ is the required function $F(x)$. Thus the percentage of time which the signal is below or equal to a given value is determined from the observations and the relevant curve is plotted. It is also possible to calculate the level where the signal is below or equal to it during a given percentage of time, using the distribution function.

In order to provide information for good quality information, the received power levels exceeding for 90% or 99% of the time were investigated. For interference purposes the 10% or 1% levels were investigated. A signal level which is attained or exceeded during 50% of the time is called the median signal level.

By dividing the received signal level in discrete intervals $\Delta x$ it was possible to determine the total amount of time the signal level $x$ was between $x$ and $x + \Delta x$ during a period $T_t$.

The probability of the signal level is given in the interval by:

$$P(x < x \leq x + \Delta x) = \lim_{T_t \to \infty} \frac{\sum_{i=1}^{N} t \Delta x_i n}{T_t}$$

(6.53)

where: $T_t = \text{total measuring time}$

$N = \text{amount of times } x < x \leq x + \Delta x$

The cumulative distribution function $F(x)$ is the probability the signal $x$ is smaller than or equal to a certain reference level $x$, and is determined for each level by:

$$F(x) = P(x \leq x) = \lim_{T_t \to \infty} \frac{\sum_{i=1}^{N} x_i n}{T_t}$$

(6.54)

By choosing a sufficiently small interval $\Delta x$ a continuous probability distribution function $f(x)$ can be introduced:

$$x \leq x < x + \Delta x = f(x) \, dx$$

(6.55)

and

$$F(x) = P(x \leq x) = \int_{-\infty}^{x} f(x') \, dx'$$

(6.56)

In Fig. 6.12 an example is given of the functions $f(x)$ and $F(x)$ determined from registration of the received signal $x$. 
A troposcatter signal will be subject to fast and slow fading. The slow fading originates from influences of the season, day and night variations and other slowly varying influences. The fast fading is characteristic for a troposcatter signal and originates mainly from fluctuations of the refractivity in the common volume and from travelling of radio waves over different trajectories and thus mutual interference. It is not possible to give a general indication of the sampling time $T_{T}$ in order to analyze a troposcatter signal correctly. To distinguish between the fast and the slow fading one has to determine the sampling time experimentally. It is understood that the slow variations are represented by a lognormal distribution and the fast variations by a Rayleigh-distribution.

6.4.1. The lognormal distribution [26]

A stochastic variable is said to be lognormally distributed when the logarithmic of this variable has a normal distribution. When $y$ is the lognormal distributed variable ($y > 0$) then $x = \ln y$ is normally distributed.

The probability density function of $x$ is [26]:

$$f(x) = \frac{1}{\sigma_x \sqrt{2\pi}} \exp\left[-\frac{(x-\mu)^2}{2\sigma_x^2}\right] \quad (6.57)$$
where $\mu_x = \text{expected mean value of } x$

$$\mu_x = \xi_x = \int_{-\infty}^{\infty} x f(x) dx$$ \hspace{1cm} (6.58)$$

$\sigma_x = \text{standard deviation}$

$$= \sqrt{\xi_x^2 - (\xi_x)^2} = \sqrt{\int_{-\infty}^{\infty} x^2 f(x) dx - \mu_x^2} \hspace{1cm} (6.59)$$

The cumulative distribution function is given by:

$$F(x) = P(x \leq x) = \int_{-\infty}^{x} f(x') dx' = \frac{1}{2} [1 + \text{Erf}(\frac{x-\mu_x}{\sigma_x\sqrt{2}})] \hspace{1cm} (6.60)$$

where:

$$\text{Erf}(v) = \frac{2}{\sqrt{\pi}} \int_{0}^{v} e^{-t^2} \, dt \hspace{1cm} (6.61)$$

Special values of $F(x)$ are:

$$F(\mu_x) = F(x_{50}) = 0.5$$

and

$$F(\mu_x - \sigma_x) = 0.16$$

A 'telecommunication' signal is often expressed by the power in dBW as:

$$P(\text{dBW}) = 10 \cdot 10^{-\log_{10} \frac{P(\text{Watts})}{1 \text{ W}} = 4.343 \ln \frac{P(\text{W})}{1\text{W}} \hspace{1cm} (6.62)}$$

When a radiosignal is distributed according to a lognormal distribution, the received power expressed in dB will have a normal distribution.

The long term distribution of a troposcatter signal will have a lognormal distribution; the median value of the signal during one hour is supposed to be at 0 dB; $P_{50} = \mu_p \geq 0$ dB.

Other signal levels are related in dB to the median value.

In Fig. 6.13 a lognormal distribution is given with standard deviation of 8 dB.

Fig. 6.14 shows the cumulative distribution function of the signal.
Fig. 6.13 Lognormal distribution, probability density function [26], p. 355

![Lognormal PDF Graph]

Fig. 6.14 Lognormal cumulative distribution function when $\sigma = 8$ dB [26], p. 356

![Lognormal CDF Graph]
6.4.2. The Rayleigh distribution

The envelop of a signal which is composed of a great number of independently interfering components of different amplitude and phase will have a Rayleigh distribution.

The short term fading of a troposcatter signal is represented by a statistical Rayleigh distribution: [26] (see Fig. 6.15):

\[ f(x) = \frac{x}{k^2} \exp\left(-\frac{x^2}{2k^2}\right) ; \quad x \geq 0 \] (6.63)

\( k \) = maximum value of \( f(x) \).

![Rayleigh probability density function](image)

**Fig. 6.15 Rayleigh probability density function [26], p.30**

The cumulative distribution function is given by:

\[ F(x) = P(x \leq x) = \int_0^x f(x')dx' = 1 - \exp\left(-\frac{x^2}{2k^2}\right) \] (6.64)

When function \( F(x) \) as well as the power level \( x^2 \) related to the median power level \( X_{50} \), are presented on a logarithmic scale, the Rayleigh distribution will tend to a straight line for small values of \( x \) (see Fig. 6.16).

6.4.3. The Rice distribution

The short term fading of a troposcatter signal is described by a Rayleigh distribution. But when this signal is affected by a strong harmonic signal, as in the case of a duct, the resulting signal will often be distributed like a Nakagami-Rice distribution.

The probability density function is given by:
\[ f(x) = \frac{2x}{x_R} \exp\left(-\frac{x^2 + x_C^2}{2}\right) I_o\left(2\frac{x x_C}{x_R}\right) \]  
(6.65)

where: \( I_o \) = modified Bessel function, first kind zero order
\( x_R \) = root-mean-square of Rayleigh component
\( x_C \) = root-mean-square of 'sine' component

In the case of a small influence of the harmonic component on the received signal \( (x/x_C >> 1) \) the distribution will be represented by a Rayleigh distribution:

\[ f_R(x) = \frac{2x}{x_R} \exp\left(-\frac{x^2}{x_R^2}\right) \]  
(6.66)

For \( x_I/x_C << 1 \) a normal distribution is valid:

\[ f_N(x) = \frac{1}{x_R \sqrt{\pi}} \exp\left[-\frac{(x - x_C)^2}{x_R^2}\right] \]  
(6.67)

The cumulative distribution is given in Fig. 6.16, in which the percentage of time a signal level is attained related to the median signal level, as a function of \( x_R/x_C \).

It is seen that a Rayleigh distribution is valid for \( x_R/x_C > 6 \text{ dB} \) and a normal distribution for \( x_R/x_C < -20 \text{ dB} \).

Fig. 6.16 Cumulative Rice distribution [25]
Chapter 7

CALCULATIONS, PROPERTIES AND PREDICTION METHODS
OF THE TOTAL TROPOSCATTER MICROWAVE SYSTEM

Gareng
Servant of Pandawa;
a loyal and honest person,
open-hearted and law-abiding.
7. Calculations, properties and prediction methods of the total troposcatter microwave system

7.1. Introduction

In this chapter we will describe the calculation of the main characteristics of a troposcatter link, in particular the link Situbondo – Surabaya in East Java.

Some of the quantities can be calculated directly, because they originate from directly measurable variables (i.e. distance, height, antenna gain etc.), others originate from statistical knowledge of the weather circumstances and of the general behaviour of a troposcatter signal. Some prediction methods for practical use are discussed. The total calculation of the Situbondo – Surabaya link is based on the recommended method by the CCIR [9], which results in an estimated tropospheric scatter loss for 50% of the time (median value).

7.2. Geographical situation

The troposcatter link is between the towns of Situbondo and Surabaya in the east of the island of Java.

Situbondo, a small provincial town, (Photo 7.1) is situated at a distance of 7.5 km from the Strait of Madura. The transmitter site was chosen on a hill (Gunung Patok, 82 m.) just outside the town.

Fig. 7.1. Geographical situation of the troposcatter link Situbondo – Surabaya. Transmitter in Situbondo, receiver in Surabaya.
Photo 7.1. View over the town of Situbondo in East Java. The transmitting antenna is placed on the hill Gunung Patok, 82 m.

Photo 7.2. Transmitter site. The 4 GHz transmitter of 3 Watt was placed in the boxes behind the antenna. Electricity was obtained from the local public network. Voltage varying around 110 V AC.
The propagation path of ± 150 km is mainly over sea and has no obstructions (Fig. 7.1).
The receiving antenna was initially placed on the top of the university building in the middle of the town of Surabaya at a distance of 7.5 km from the sea (altitude 28 m.). In the last year of the measurements the antenna was erected on a building on the new university campus, only 1 km distance from sea (see photo 7.3).

The coordinates of the transmitter and receiver sites are:

- Situbondo: 7°40'54" Lat. S. and 114°1'20" Long. E.
- Surabaya: 7°15'0" Lat. S. and 112°44'0" Long. E.

7.3. Meteorological circumstances

The Surabaya region is characterised by tropical weather conditions. The year is divided into a dry and a wet season. During the wet season monsoon rains will occur during 50% of the time. This period lasts from November until April/May. The dry season is characterised by stable weather conditions.

The climatological parameters have been investigated during a period of five years, resulting in yearly mean values of the parameters at sea level. In the Surabaya region they are:

- mean air pressure: \( P_s = 1011.1 \text{ mb.} \)
- mean temperature: \( T_s = 26.4^\circ \text{ C.} \)
- mean water vapour pressure: \( e_s = 27.7 \text{ mb.} \)
- mean N-value: \( N_s = 377.4 \)
- median k-value: \( k = 1.52 \)

7.4. Calculations of the parameters of the troposcatter link Situbondo-Surabaya

To calculate the total attenuation of the radiowave during the propagation in the troposphere many empirical and approximation formulas are used. Several parameters used in these formulas will be discussed below.

7.4.1. Distance transmitter - receiver

In case the coordinates of the receiver and transmitter sites are known it is possible to calculate the distance between receiver and transmitter
Photo 7.3. The receiver site. The antenna on top of the building of Electrical Engineering is pointed towards Situbondo. In front the 5 m. diameter parabolic antenna used for satellite communication experiments.

Photo 7.4. Another view of the new Campus Sukolilo which is still situated between the rice fields (sawah)
by means of spherical goniometry.
In a sphere the following rule can be applied (see Fig. 7.2):

\[
\cos a = \cos b \cos c + \sin b \sin c \cos \gamma
\]  

(7.1)

\[a = \text{distance between A and B in degrees}\]
\[b = \text{the latitude difference between the north pole and point A}\]
\[c = \text{the latitude difference between north pole and point B}\]
\[\gamma = \text{difference between longitude A and B}\]

Fig. 7.2. Configuration for calculation of distance between two points on the surface of a sphere.
M is centre of sphere.

For two sites situated on the northern hemisphere one can sketch the situation as given in Fig. 7.3.

\[A = \text{site of smallest latitude}\]
\[B = \text{site of longest latitude}\]
\[LB = \text{longitude site B}\]
\[LA = \text{longitude site A}\]
\[AB = \text{distance between A and B in degrees}\]
\[\gamma = \text{difference between longitude A and B}\]

Fig. 7.3. Configuration for calculating the distance between two sites A and B on the northern hemisphere

From equation (7.1) follows (see Fig. 7.3):

\[
\cos AB = \cos(90^\circ - LA) \cos(90^\circ - LB) + \sin(90^\circ - LA) \sin(90^\circ - LB) \cos \gamma
\]
\[= \sin LA \sin LB + \cos LA \cos LB \cos \gamma
\]

(7.2)
The distance $AB$ in degrees is:

$$AB = \arccos\{\sin LA \sin LB + \cos LA \cos LB \cos \gamma\} \quad (7.3)$$

The radius of the earth is in Indonesia approximately $6370$ km. Then:

$$d = 6370 \frac{\pi}{180} \ AB \ km \quad (7.4)$$

where: $d = \text{distance in km between site A and B}$.

Substitution of the coordinates of Situbondo and Surabaya results in a distance:

$$d = 149,967 \ km \approx 150 \ km.$$  

7.4.2. Scatter angle $\theta$

One of the most important parameters in the calculations for tropospheric losses is the scatter angle $\theta$. It is the smallest angle between the main axes of the transmitter and the receiver antenna.

In troposcatter links it is necessary to make the angle $\theta$ as small as possible because the transmission losses increase in the order of about $\theta^4$ (see 6.44). To reduce the losses the antennas have to be placed as high as possible or the distance of one hop as small as possible.

![Fig. 7.4. Schematic of the scatter angle $\theta$ and the elevation angles $\theta_t$ and $\theta_r$ in a general troposcatter link.](image-url)

To calculate the scatter angle $\theta$ one needs to know the height above sea level of the transmitting and receiving antennas. In case of obstacles in the propagation path (like mountains, high buildings), their height
above sea level have also to be known (Fig. 7.4). Generally the elevation angle is very small ($\theta_{r,t} << 1$) so for the elevation angles we get:

$$\theta_{r,t} \simeq \frac{h_{obs} - h_{r,t} - d_{obs}}{h_0}$$

(7.5)

where: $h_{obs}$ = height above sea level of obstacle determining the optical horizon

$h_{r,t}$ = height of antenna above sea level

d_{obs} = distance antenna - obstacle

$R_a = kR$ = earth radius corrected with the k-factor.

For the scatter angle we get:

$$\theta = \frac{d}{R_a} - \theta_r - \theta_t$$ [rad.]

(7.6)

where: d = distance transmitter - receiver.

For the Surabaya - Situbondo link we have:

- height transmitter = 88 m
- height receiver = 28 m
- distance = 150 km

There are no obstacles on the propagation path because the path is almost completely over sea. This will result in negative elevation angles. In case of a free horizon we use the following formula:

$$\theta_{r,t} = \frac{\sqrt{2h}}{R_a}$$

(7.7)

which results in the following values for the link Situbondo - Surabaya ($k=1.52$):

- $\theta_{receiver} = -2.4$ mrad $\equiv -0.14^\circ$
- $\theta_{transmitter} = -4.3$ mrad $\equiv -0.24^\circ$

The distance to the optical horizon is calculated by:

$$d_{r,t} = \sqrt{\frac{2}{R_a} h_{r,t}}$$

(7.8)
Then: for \( k = \frac{4}{3} \)
\[
\begin{align*}
\text{d}_{\text{receiver}} &= 21.8 \text{ km} \\
\text{d}_{\text{transmitter}} &= 38.7 \text{ km}
\end{align*}
\]

for \( k = 1.52 \)
\[
\begin{align*}
\text{d}_{\text{receiver}} &= 23.3 \text{ km} \\
\text{d}_{\text{transmitter}} &= 41.2 \text{ km}
\end{align*}
\]

Because the distance of the transmitter, as well as the receiver, to the sea is 7.5 km, the reflection point (optical horizon) will be on sea.

The scatter angle can be calculated from (7.6):
\[
\begin{align*}
\theta &= 10.5 \text{ mrad} \equiv 0.6^\circ \quad \text{for } k = \frac{4}{3} \text{ (standard)} \\
\theta &= 8.8 \text{ mrad} \equiv 0.5^\circ \quad \text{for } k = 1.52 \text{ (average)}
\end{align*}
\]

7.4.3. **Free space attenuation** *(isotropic).*

The free space attenuation is calculated by:
\[
L_{fs} = \left(\frac{4\pi d}{\lambda}\right)^2
\]

(7.9)

On logarithmic scale:
\[
L_{fsi} = 20 \log \frac{4\pi d}{\lambda} \quad \text{dB}
\]

(7.10)

where \( d = \) distance transmitter - receiver
\( \lambda = \) wavelength

In literature often the following notation is used: [10], p.2.7

\[
L_{fsi} = 32.45 + 20 \log f + 20 \log d \quad \text{dB}
\]

(7.11)

where: \( d = \) distance in km.
\( f = \) frequency in MHz.

The frequency used in the link Situbondo - Surabaya is 4012 MHz, ± 2 MHz, distance \( d = 150 \text{ km} \), which results in a free space loss of:

\[
L_{fs} = 149.1 \text{ dB}
\]
7.4.4. **Antenna 'gain' and antenna 'gain loss'**

In microwave systems parabolic antennas are usually used. The effective aperture of these antennas is calculated by:

\[ A_e = \eta \frac{\pi D^2}{4} \]

where: \( D \) = diameter of dish  
\( \eta \) = efficiency coefficient = 0.5.

The gain of the antenna is then:

\[ g = \frac{A_e}{A_{e,\text{isotrope}}} = \frac{0.5 \frac{\pi D^2}{4}}{\frac{\lambda^2}{4\pi}} = \frac{1}{2} \left( \frac{\pi D}{\lambda} \right)^2 \]  \( (7.12) \)

or:

\[ G = 10 \log g \quad \text{dB.} \]

In the link Situbondo - Surabaya parabolic dishes of 3 m. diameter are used. The wavelength is 7.5 cm. Then:

\[ G = 39 \text{ dB.} \]

Measurements on tropospheric propagation paths showed that the power received by a parabolic antenna does not increase linearly with increasing antenna aperture. This effect is called the 'aperture to medium coupling loss' of the antenna gain.

Which ever explanation is given to this phenomenon, its effect needs to be included in the calculations. A generally accepted explanation of the antenna gain loss claims that the wave front arriving at the receiving antenna originates from many different incoherent sources in the troposphere. Because all these contributions to this wave front are out of phase, the components will interfere and thus cause a reduction in the total gain of the antenna.

Another explanation is as follows:

By increasing the transmitted power by a factor \( n \) dB, the scattered power will also increase by each irregularity in the troposphere by \( n \) dB. Therefore the received power will also increase by \( n \) dB.
On the other hand, when the antenna gain is increased by n dB, while keeping the transmitted power constant, the new common volume will become smaller because of the decrease of the beamwidth of the antennas (see Fig. 7.5). Because of this, the new common volume will have a smaller amount of irregularities compared to the old common volume.

![Fig. 7.5. Dependency of antenna gain of the irregularities in the troposphere](image)

Also in this case the scattered power will increase by n dB by each inhomogeneity, only, the amount of inhomogeneities taking part in the scattering decrease. Thus the received signal will increase less than n dB.

CCIR suggests an empirical graph and an approximation formula to determine the antenna to medium coupling loss (antenna gain loss). [50]

\[ L_c = 0.07 \exp 0.055 \left( G_t + G_r \right) \text{ dB} \]  

(7.13)

where: \( G_t \) = gain transmitter antenna in dB  
\( G_r \) = gain receiver antenna in dB.

The antenna-to-medium-coupling-loss for the antennas in the link Situbondo - Surabaya is, when \( G_t = G_r = 39 \text{ dB} \):

\[ L_c = 5.1 \text{ dB} \]
the sum of the free space antenna gains \((G_t + G_r)\)

Fig. 7.6. Graphical representation of (7.13). [50; p.229]

Antenna gain for antennas applied in troposcatter links

7.4.5. **Beam angle of an antenna**

The beam angle of an antenna is defined as the angle within which the gain is 3 dB lower than the maximum gain.

![Diagram of beam angle](image)

Fig. 7.7. Schematic representation of beam angle

An approximation formula to calculate the beam angle of parabolic antennas is:

\[ \alpha_{3dB} \approx \frac{70 \lambda}{D} \text{ degrees} \]  

(7.14)

where: \(\lambda = \) wavelength in m.

\(D = \) diameter of antenna [m]

The beam angle of the antennas used in the link Situbondo - Surabaya is when \(D = 3\) m, \(\lambda = 7.5\) cm:

\[ \alpha_{3dB} \approx 1.75^\circ \approx 30\text{ mrad}. \]
7.5. Scatter losses according to CCIR prediction methods

Several semi empirical prediction methods have been developed using the data available from hundreds of troposcatter links. In general the prediction method of the CCIR is accepted as reliable to estimate the tropospheric scatter losses.

According to this method the troposcatter losses exceeding a certain value for 50% of the time (median losses) can be calculated:

\[ L_{50}^{i} = 30 \log f - 20 \log d + F(\theta d) + L_c - V(d_e) \]  \hspace{1cm} (7.15)

where:  
\( f \) = frequency in MHz  
\( d \) = distance in km  
\( \theta \) = scattering angle (annual median value)  
\( d_e \) = effective distance (see 7.6.1)

and:  
\( F(\theta d) \) = scatter loss function  
\( L_c \) = total antenna gain loss  
\( V(d_e) \) = climatological correction factor.

7.6. Complete calculations of the troposcatter losses according to the CCIR method

In order to calculate the median transmission losses according the CCIR prediction method it is necessary to do some preliminary calculations, using the measurable quantities of the troposcatter link.

7.6.1. Effective distance \( d_e \)

Meteorological data from all over the world are used to define several climatological areas of the world. In order to describe the influences of the meteorological areas on the troposcatter signal, an 'effective distance' is defined as a function of the propagation path with length \( d \), the effective antenna heights \( h_{te} \) and \( h_{re} \) (m) above the foreground terrain and the radio frequency \( f \) in MHz in the following way:
Define $\theta_s$ as the angular distance where diffraction and forward scatter transmission loss are approximately equal over a smooth earth of effective radius $R_a = 9000$ km and define $d_{s1}$ as $9000 \theta_s$. Then:

$$
d_{s1} = 65 \left(\frac{100}{f}\right)^{1/3} \text{ km} \tag{7.16}
$$

The path length $d$ is compared with the sum of $d_{s1}$ and the smooth earth distances to the radio horizons:

$$
d_L = 3\sqrt{2h_{te}} + 3\sqrt{2h_{re}} \text{ km} \tag{7.17}
$$

where: $h_{te}$ and $h_{re}$ in meters.

It has been observed that the long term variability of hourly median transmission loss is greatest on average for values of $d$ only slightly greater than the sum of $d_{s1}$ and $d_L$; the effective distance $d_e$ is arbitrarily defined as:

$$
\begin{align*}
\text{for } d &< d_{s1} + d_L & d_e &= 130 \frac{d}{(d_{s1} + d_L)} \text{ km} \\
\text{for } d &> d_{s1} + d_L & d_e &= 130 + d - \left(\frac{d_{s1} + d_L}{30}\right) \text{ km} \tag{7.18}
\end{align*}
$$

Applied to the link Situbondo - Surabaya, where $f = 4012$ MHz, $h_{re} = 28$ m, $h_{te} = 82$ m and $d = 150$ km:

$$
\begin{align*}
d_{s1} &\approx 19 \text{ km} \\
d_L &\approx 62 \text{ km} \\
d_e &\approx 200 \text{ km}
\end{align*}
$$

7.6.2. Determination of the climatological factor $V(d_e)$

The CCIR defines nine climatological types over the world. For each type the climatological parameters are averaged over a long period and are used for the calculation of propagation data. The corrections are deduced from measured data. [48]

The division of the CCIR is rather crude and local geographical conditions may require substantial modifications. Values of $V(d_e)$ are shown in Fig. 7.8, as a function of effective distance and climate.
Fig. 7.8. The function $V(d_e)$ for the types of climates indicated on the curves. [50], p.217

According to the description of the climate types, type nr. 3 of the CCIR would best fit the Surabaya region.

For $d_e = 200$ km we get: $V(d_e) = 7$ dB.

Type 3 stands for: subtropical maritime.

7.6.3. Scatter loss function $F(\theta d)$

The scatter loss function depends on the variables $d$ (real distance between transmitter and receiver), the scattering angle $\theta$ and the surface refractivity $N_S$. In most cases it is possible to determine the loss function from a graph (Fig. 7.9).

An analytical approximation of the function $F(\theta d)$ for $N_S = 301$ is given by:

$$F(\theta d) = 135.82 + 0.33 \cdot \theta d + 30 \log (\theta d) \text{ dB} \quad (7.19)$$

For other median values of the surface refractivity $N_S$ it is possible to correct equation (7.19) with: [10]

$$F(\theta d, N_S) = F(\theta d, N_S = 301) - 0.1 \cdot (N_S - 301) \exp(-\theta d/40) \text{ dB} \quad (7.20)$$
Fig. 7.9. The scatter loss function $F(\vartheta d)$. Parameters $\vartheta$, $d$ and $N_s$.

$\vartheta$ in radians, $d$ in km. [50], p. 217

Applied to the link Situbondo - Surabaya, where

$$k = 1.52$$
$$\vartheta = 8.8 \text{ mrad}$$
$$N_s = 377.4$$
$$d = 150 \text{ km}$$

it will result in: $\vartheta d = 1.325$ and $F(\vartheta d) = 132.5 \text{ dB}$.

7.6.4. Median transmission losses between isotropic antennas.

Annual median transmission losses for the link Situbondo - Surabaya (150 km path) will be for the 150 km path (equation 7.15):
\[ L = 30 \log f - 20 \log d + F(\theta d) + L_c - V(d_e) \] dB

\[ = 30 \log 4012 - 20 \log 150 + 132.5 + 5.1 - 7 \] dB

\[ = 195.2 \text{ dB}. \]

7.6.5. Variation of the median losses

As a reference level for transmission losses the previously calculated median transmission loss \( L_{50} \) is chosen. To estimate the losses \( L_i \), there are the losses \( L \) exceeding for \((100 - q)\%\) of the time, a factor \( Y_q \) is introduced. This factor \( Y_q \) is based on empirical data obtained of troposcatter links.

The variations of the total losses are expressed by:

\[ L_i^q = L_{50}^i - Y_q \]

For an effective distance of \( d_e = 200 \text{ km} \) the estimated variations are:
-20 up to +30 dB for \( q \) respectively 99% and 1% of the time.
Fig. 7.10. Variation of the total transmission losses as function of
the effective distance $d_e$ in a maritime subtropical climate.
This type of climate fits also to the description of the
climate in the Surabaya region. [50], p.221

7.6.6. Outline of the calculations

The result of the calculations by the approximation formulas for Situbondo-
Surabaya links is:

<table>
<thead>
<tr>
<th></th>
<th>distance transmitter - receiver $d$</th>
<th>150 km</th>
<th>140 km *p.7.19</th>
</tr>
</thead>
<tbody>
<tr>
<td>effective distance</td>
<td>$d_e$</td>
<td>200 km</td>
<td>185 km</td>
</tr>
<tr>
<td>free space attenuation</td>
<td>$L_{fsi}$</td>
<td>149.1 dB</td>
<td>148.5 dB</td>
</tr>
<tr>
<td>antenna gain</td>
<td>$G_t + G_r$</td>
<td>78 dB</td>
<td>78 dB</td>
</tr>
<tr>
<td>antenna gain loss</td>
<td>$L_{fsi}$</td>
<td>5.1 dB</td>
<td>5.1 dB</td>
</tr>
<tr>
<td>total antenna gain</td>
<td>$L_{fsi}$</td>
<td>72.9 dB</td>
<td>72.9 dB</td>
</tr>
<tr>
<td>beamwidth antenna</td>
<td>$L_{fsi}$</td>
<td>30 mrad</td>
<td>1,75°</td>
</tr>
<tr>
<td>climatological correction</td>
<td>$L_{fsi}$</td>
<td>7 dB</td>
<td>6 dB</td>
</tr>
<tr>
<td>loss function</td>
<td>$F(\theta)$</td>
<td>132.5 dB</td>
<td>129.9 dB</td>
</tr>
<tr>
<td>median scatter loss (isotrr)</td>
<td>$L_{fsi}$</td>
<td>195.2 dB</td>
<td>194.2 dB</td>
</tr>
</tbody>
</table>

According to the CCIR method the median value of the transmission loss [9]
in the link Situbondo - Surabaya will be (150 km path):
\[ L_{50}^i = 195.2 \text{ dB} \]

subject to variations of -20 up to +30 dB for \( q \) is 99% resp. 1%.

Fig. 7.11 shows all data referring to the link Situbondo - Surabaya.

* For the 140 km path, after relocation of the receiver site towards the sea, one calculates \( L_{50}^i = 194.2 \text{ dB} \) a difference of only 1 dB with respect to the 150 km path.

---

**Receiver Surabaya**

- \( P_{r,50} = -90 \text{ dBm} \)
- \( h_r = 28 \text{ m} \)
- \( G_r = 39 \text{ dB} \)
- \( L_e = 6 \text{ dB} \)
- \( \theta_{e,r} = -0.14^\circ \)

**Transmitter Situbondo**

- \( P_t = 3 \text{ Watt} \)
- \( h_t = 88 \text{ m} \)
- \( G_t = 39 \text{ dB} \)
- \( L_e = 2 \text{ dB} \)
- \( \theta_{e,t} = -0.24^\circ \)
- \( f = 4012 \text{ MHz} \)

**Distance transmitter - receiver:** 149.9 km
**Distance over sea:** 135 km
**Distance transmitter - sea:** 7.5 km
**Distance receiver - sea:** 7.5 km

Fig. 7.11. Data of the characteristics in the troposcatter link

Situbondo - Surabaya for the 150 km path, \( k=1.52 \) (annual median value)

For the 140 km path one calculates \( \theta = 0.45^\circ \).
Chapter 8

TROPOSPHERIC SCATTER PROPAGATION, PRACTICE

Karna
King of Awangga; a brave and dedicated figure, loyal to the illegal king of Astina, opposes the Pandawa in spite of their close kinship.
8. Tropospheric scatter propagation, practice

8.1. Introduction to the microwave system

In this chapter the microwave system and the data processing unit will be described, as they have been designed and used for the measurements of the received troposcatter signal. The working frequency of 4012 MHz was chosen because of the availability of equipment used during former experiments and also because of the availability of an auxiliary channel in the 4 GHz band, used by the Indonesian Telecommunication Administration. A transmitter output of 3 Watt (see Fig. 8.1) results in a very low signal at the receiver site (appr. -110 dBm). The detection of this signal was achieved by means of phase-locked-loop techniques. The antennas used at transmitter and receiver sites are of the same type: 3 m. diameter focal fed parabolic reflector. The output signals of the receiver are supplied to a processing system, based on a M6800 microprocessor. This system analyzed the statistical properties of the received troposcatter signal.

8.2. Microwave system at the transmitter site

The microwave system at the transmitting site has been drawn in a schematic way in Fig. 8.1.

Fig. 8.1. Block diagram of the 3 Watt, 4012 MHz transmitter at Gunung Patok, Situbondo.

This transmitter, which was developed in the Department of Telecommunication Engineering of THE uses a crystal stabilized frequency source which is temperature stabilized in order to increase the frequency stability.
Fig. 8.2. A block diagram of the phase-locked-loop troposcatter receiver

Fig. 8.3. Block diagram of local oscillator
Photo 8.1.
Receiving station.
The 4.012 GHz signal is mixed with a local oscillator signal of 4.042 GHz. A phase locked loop receiver on 30 MHz detects the result.
The output signal is recorded and also fed to a microprocessor unit. This unit evaluates the signal statistically, thus the behaviour of the received signal was known.

Photo 8.2.
Receiving station, data processing.
The microprocessor unit, teleprinter and recorder. Also seen is the no-break power supply which was needed because of the unstable public electricity network.
Some specifications of the receiving system are listed below:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver type</td>
<td>triple superheterodyne, frequencytracking phase locked loop</td>
</tr>
<tr>
<td>IF-frequencies</td>
<td>30 MHz; 9.0 MHz and 125 kHz</td>
</tr>
<tr>
<td>Input noise figures</td>
<td>6.8 dB</td>
</tr>
<tr>
<td>Input frequency</td>
<td>4012 MHz ± 50 kHz</td>
</tr>
<tr>
<td>Input impedance</td>
<td>50 Ω coaxial</td>
</tr>
<tr>
<td>Tracking bandwidth</td>
<td>selectable from 10 Hz to 1000 Hz, in steps of about a factor three</td>
</tr>
<tr>
<td>Signal outputs</td>
<td>logarithmic and linear</td>
</tr>
<tr>
<td>Receiving antenna</td>
<td>focal fed parabola, 3 m. diameter</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>39.0 dB</td>
</tr>
<tr>
<td>Feeder losses</td>
<td>2.0 dB</td>
</tr>
<tr>
<td>Cable losses</td>
<td>4.0 dB</td>
</tr>
</tbody>
</table>

The minimum detectable signal by the receiver was -128 dBm.
The measurement range, using a tracking bandwidth of 100 Hz was:

- Maximum gain: -128 dBm to -65 dBm
- Minimum gain: -98 dBm to -30 dBm.

A schematic representation of the total receiving station is given in Fig. 8.4.
In the first period of the research activities the receiving station was situated on the top floor of a university building in the middle of the town of Surabaya.
The station was moved to another site, close to the sea at the new university campus, resulting in a shorter propagation path.
8.4. Weather station

The meteo station was designed in Eindhoven, in analogy to a meteo station used for satellite communication experiments. The following meteorological parameters are measured:
- atmospheric pressure (P)
- temperature (T)
- water vapour pressure (e)
- rain intensity (I)

The output signals of the above transducers are fed into the signal conditioners adapting the output signal to the input voltage range of the A/D-converter of the data processing unit (see Fig. 8.4.). Specifications of the meteotransducers may be found in [17].
8.5. The data processing system

The data processing system was developed to realize the same data processing as the former system described in Lit. 1. Improvements were built in where easily possible.

The data processing system is built around the Motorola microprocessor MC6800. This 8 bit microprocessor uses a so-called bus system as communication channel between its several plug-in units. This common bus has the advantage that additional plug-in units for memory expansion or more peripherals are easily incorporated into the system.

The microprocessor is provided with a complete set of spare parts which are built together as a second computer system which may be used for educational purposes and software development. This microprocessor has a memory capacity of only 2 k words of 8 bits, whereas the dataprocessor has 8 k words of 8 bits. A block diagram of the dataprocessor is given in Fig. 8.5.

![Block diagram of the dataprocessor](image)

The clock module contains a crystal-stabilized oscillator plus divider chain, providing date and time of day in a LED-display. The clock also supplies the necessary timing information to the data processing program: every 100 ms an interrupt pulse to start the sampling routine and every hour to start the output routine.
The data processor software supports seven analogue inputs:
- four meteorological parameters: atmospheric pressure, water vapour pressure, temperature and rain intensity;
- the amplitude of the received troposcatter signal;
- the gain of the tropo-receiver (high or low)
- 'lock' or 'unlock' signal from the tropo-receiver.
The meteo inputs $P$, $T$ and $e$ are averaged over one hour and with an output every hour. The rain-intensity meter output is averaged over one minute, memorised and output is every hour as sixty consecutive values.
The output voltage of the tropo-receiver which is proportional to the logarithm of the received signal amplitude, is sampled at a rate of 10 Hz. A sample, taken during 'unlock' condition or immediately after a change-over of the gain switch or if the value of the sample is lying outside the normal output voltage range, is rejected and designated as 'invalid'.
Subsequently, according to the value of the sample, one out of a group of 32 counters, each representing a step in level of 3 dBm is incremented. In this way a histogram is created.
Finally, if the value of the sample is lower than the previous one, the levels in between have obviously been crossed since the previous sample. These downward crossings are kept in a separate record, which enables the calculation of average fade durations. The above records: number of invalid samples, histogram and number of downward crossings per level, are output every hour on a teletype. In addition, a graph is produced on the teletype of the cumulative distribution. Each hourly output is provided with appropriate time and date.

Listing of the registration form:
- real time
- list of the measured values in 'number' and 'through'
- weather station: hygrometer, barometer, temperature meter, 60 values of one minute rain registrations
- median value of every antenna signal
- cumulative diagram of every antenna signal
- total number of invalid samples.

8.5.1. **Software program of the data processing unit**

The software program of the data processing unit was developed at the THE. The complete information is given in Lit. [24].
A simplified block diagram is given below:

```plaintext
interrupt every 0.1 sec

real time clock

new hour?
  yes
  change memory locations for sampled data
  start procedure 'print out' number, through, P, T, e and rain
  calculate mean value and cumulative distribution. print out

compare real time

new minute?
  yes
  sample channel P, T and e
  average with former data
  store data
  determine level signal n 1 ≤ n ≤ 32
  increment determined signal level number
  level at t < level at t - 0.1
    yes
    increment levels between value t and t - 0.1 through
  no
    all channels sampled?
      no
      end interrupt
    yes
    next channel

sample signal at time t

clock interrupt every 0.1 sec.
```

Fig. 8.6. Simplified representation of software flow diagram of the data processing unit
8.5.2. Presentation of data by means of a microprocessor and teleprinter

Figure 8.7 presents an example of the hourly output.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MONTH</th>
<th>DAY</th>
<th>HOUR</th>
<th>MIN</th>
<th>DATE/TIME: 79 05 27 06 00</th>
</tr>
</thead>
</table>

1. date and time of measured hour
2. signal level
3. number of time signal in (aant) and through (door) level
4. weather data
5. calculated level median value
6. number of invalid samples
7. presentation of data in cumulative distribution.
Also a paper tape output was produced for each hour. This tape was used to evaluate the data obtained by means of a more sophisticated computer at Eindhoven University.

Two strip chart recorders are provided:
- one provides a continuous recording of the tropo-signal after filtering by a low-pass filter with a time constant of 3 minutes and with a paper speed of 6 cm/hour.
- the other records the unfiltered troposignal with a much higher speed but only at interesting moments.

8.6. Power supplies at transmitter and receiver site

8.6.1. Transmitter power supply

Fortunately the hill Gunung Patok was not far from the town of Situbondo, so an extra electricity line could be installed leading to the top of the hill and guaranteed a constant power supply as long as no power failures in the local electricity net occurred.

The schematic representation of the power supply in Situbondo is given below.

![Fig. 8.9. Block diagram power supply transmitter site](image)

8.6.2. Power supply at receiving site

Although the receiver could be directly connected to the local electricity network in Surabaya, the power supply for the data processing unit was more complicated.

A short break of electricity supply of only a few milliseconds would destroy the complete program stored in the data processing unit. To avoid a regular destruction of the program and with that a loss of data, a 'no-break power supply' was installed.

In Fig. 8.10 the schematic representation of the system is given, which guaranteed an extra five to ten hours of electricity supply when disconnected from the mains.
The voice communication system was based on a bought set of SSB-transceivers, working in the 144 MHz band. The working range of these transceivers was extended by adding power amplifiers of 100 W PEP and low noise input amplifiers with a noise figure of 3 dB. In addition, 10 element Yagi antennas were used having a directivity gain of 15 dB each. Good voice communication was possible over the distance of 150 km. (during 99.9% of the time a signal to noise ratio exceeding 40 dB).
Chapter 9

TROPOSPHERIC REFRACTIVE INDEX IN THE REGION OF SURABAYA

Kresna
King of Dwarawati; supervisor of Pandawa, fondly revered for his wise advice to Arjuna on the eve of the Baratayuda war.
9. Tropospheric refractive index in the region of Surabaya.

9.1. Introduction.
As was shown in chapter 4 design and planning of VHF, UHF and microwave telecommunication networks in any country require an extensive knowledge of the characteristics of the local atmosphere. These characteristics depend on climate.

One of the most important parameters in microwave-link design is the k-factor defined in chapter 4 as:

\[ R_a = kR \]  \hspace{1cm} (9.1)

where \( R_a \) - artificial earth radius [m]

\( R \) - actual earth radius [m]

The importance of it will become obvious in the total received power formula (chapter 10). The statistics of the received signal depends very strongly upon the statistics of the k-factor.

The k-factor is calculated from the refractivity of air, which is constructed according to the formula of Smith and Weintraub [31] adopted by CCIR [32]:

\[ N = 10^6 (n - 1) = \frac{77.6}{T} \left( P + 4810 \frac{e}{T} \right) \]  \hspace{1cm} (9.2)

where \( n = 1 + N 10^6 \) is the radio refractive index,

\( P \) - atmospheric pressure [mb]

\( e \) - water vapour pressure [mb]

\( T = 273 + t^\circ C \) - absolute temperature [K]

Meteorological stations in different parts of the world take regular pressure, temperature and humidity readings once or twice per day, using a radiosonde attached to a balloon which ascends into the atmosphere. This makes it possible to deduce the law of the variation \( N(z) \) of the refractive index according to altitude \( z \).

The meteorological services generally give humidity in the form of relative humidity which is the ratio between the existing water
vapour pressure and the saturating water vapour pressure at the same
temperature and is expressed in percent:
\[ \text{RH} = 100 \frac{e_s}{s_o} \quad [\%] \quad (9.3) \]
where existing water vapour pressure \( e_s \) and the saturating water pressure
\( s_o \) can be calculated by the following approximate equations:
\[ s = 622 \frac{e_s}{P} \quad (9.4) \]
s being expressed in grammes of water per kilogramme of air, and
\[ s_o = 1.69 \cdot 10^{12} \exp \left( - \frac{5434}{T} \right) \quad (9.5) \]
Boitthias [75]
The k-factor is calculated from the formula derived in section 4.2
\[ k = \frac{157}{157 + \Delta N} \quad (9.6) \]
where \( \Delta N \) is the gradient of \( N \) within the first 1000 m. As we have no
data of \( N \) at 1000 m height, we have to calculate \( \Delta N \) from the three
isobaric layers: the earth surface, 1000 mbar layer and 850 mbar layer.
These values of \( \Delta N \) can be calculated from the formulas:
gradient of \( N \) for the region between the 1000 mbar (= 100 m) layer
and the surface:
\[ \Delta N_{s-1000} = \frac{N_s - N_{1000}}{h_s - h_{1000}} \quad 1000 \quad [\text{N-units/km}] \quad (9.7) \]
gradient of \( N \) for the region between the 850 mbar (= 1500 m) layer and
the surface:
\[ \Delta N_{s-850} = \frac{N_s - N_{850}}{h_s - h_{850}} \quad 1000 \quad [\text{N-units/km}] \quad (9.8) \]
gradient of \( N \) for the region between the 1000 mbar (= 100 m) layer
and the 850 mbar (= 1500 m) layer:
\[ \Delta N_{1000-850} = \frac{N_{1000} - N_{850}}{h_{1000} - h_{850}} \quad 1000 \quad [\text{N-units/km}] \quad (9.9) \]
where \( N_s \) - refractivity at the earth surface \quad [\text{N-units}]
\( N_{850} \) - refractivity at the 850 mbar layer \quad [\text{N-units}]
\( N_{1000} \) - refractivity at the 1000 mbar layer \quad [\text{N-units}]
\( h_s \) - height above the sea level at surface \quad [m]
\( h_{850} \) - height above the sea level at 850 mbar layer \quad [m]
\( h_{1000} \) - height above the sea level at 1000 mbar layer \quad [m]
9.2. Meteorological parameters for the region of Surabaya.

Widjaja and Neessen [72] found in the previous project period following approximate equations based on the observations from the period 1961-1971 (table 9.5) for P, e, T and N as function of height z [km] .

Temperature:  \[ T(z) = 26.4 - 6.7 z \ [°C] \]  (9.10)

Pressure: \[ P(z) = 1011 \exp(-0.1118 z) \ [\text{mbar}] \]  (9.11)

Water vapour pressure: \[ e(z) = 27.7 \exp(-0.3925 z) \ [\text{mbar}] \]  (9.12)

Air refractivity: \[ N(z) = 377.4 \exp(-0.1645 z) \ [\text{N-units}] \]  (9.13)


During the period 1973-1977 data from 715 radiosonde measurements were collected for the region of Surabaya. The measurements were performed by the meteorological station at the airport Surabaya of the Lembaga Meteorologi dan Geofisika (Departemen Perhubungan) at 7.00 WIB (West Indonesian Time) at the latitude 7°12' South, longitude 112°43' East and elevation 3 metres. Data for 38 months (see table 9.1) were available for surface, 1000 mbar (= 100 m) and 850 mbar (=1500 m) layers for pressure, temperature and humidity.

Making use of the equations (9.2) through (9.9) we calculated the k-factor defined in the equation (9.1) for the three layers according to the equations (9.7) through (9.9) [21].

Histograms and cumulative distribution functions on normal probability scale are reproduced for following situations:

\[ k_{s-1000} \] - k-factor between surface and 1000 mbar (= 100 m) layer (fig. 9.1);

\[ k_{s-850} \] - k-factor between surface and 850 mbar (= 1500 m) layer (fig. 9.2);

\[ k_{1000-850} \] - k-factor between 1000 mbar (= 100 m) layer and 850 mbar (= 1500 m) layer (fig. 9.3).

Because of great dispersion of the measured values we are interested in the median values, i.e. values for level not exceeding 50% of the time as also used in [87].

(+ Station No. 96933. 7.00 WIB = 0.00 GMT
For the period 1973-1977 we found following median values for the k-factor in three different atmospheric layers:

\[
\begin{align*}
  k_{S-1000} &= 1.562 \\
  k_{S-850} &= 1.54 \\
  k_{1000-850} &= 1.527
\end{align*}
\]

For the period of 55 months in the years 1961-1971 [73], measurements having been performed under the same conditions (latitude 7°12' South, longitude 112°43' East, elevation 3 metres, 7.00 WIB) at Surabaya, following median values were obtained:

\[
\begin{align*}
  k_{S-1000} &= 1.736 \\
  k_{S-850} &= 1.576 \\
  k_{1000-850} &= 1.569
\end{align*}
\]

It is interesting to compare these data from Surabaya with those obtained by Ben Sutanto [43] for Jakarta over the period January 1960 until December 1964, for daily observations held at 7.00 WIB on the co-ordinates of Jakarta: latitude 6°11' South, longitude 106°50' East and altitude 6 metres above sea level. He found following median values for slightly different layers:

\[
\begin{align*}
  k_{S-1000} &= 1.62 \\
  k_{S-900} &= 1.52
\end{align*}
\]

Cumulative distributions of his measurements can be seen in fig. 9.4.

9.4. Correlation of $\Delta N$ with the surface refractivity $N_s$ [90, p. 137].

The determination of the value of $\Delta N$ by radiosonde measurements takes much time and work and requires much money, though it is the only correct method to measure the value of $\Delta N$ and the k-factor. To make it easier, it is important to study the correlation between $\Delta N$ and the surface refractivity $N_s$. If we know the correlation between them, it is possible to determine the approximate value of $\Delta N$ and also k from the eq. (9.6) by calculating it from the value of the surface refractivity $N_s$. $N_s$ can be calculated from the surface meteorological measurements. In the table 9.2 we composed different regression equations for Surabaya, Jakarta, India and Japan. For the calculation of Surabaya regressions the Hewlett Packard Statpac HP 9820 was used.
9.5. Surface refractivity $N_s$ in the region of Surabaya.

In tab. 9.1 mean values $N_s$ for Surabaya for 93 months over the period 1961-1977 are given. Mean month and year values are calculated. The total mean value for the whole period results in $N_s = 378.40$.

In fig. 9.5 a graphical presentation of month mean values and their range is given.

Tab. 9.3. Number of months observed.

<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>7</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>93</td>
</tr>
</tbody>
</table>

Making use of the $N_s$ values from tab. 9.1 and of the regression equations from tab. 9.2 and equations (9.6) through (9.9) k-factor for various atmospheric layers can be approximated.

Remarks to tab. 9.1 and fig. 9.5:
- There is a seasonal correlation between the maximal, mean and minimal values of $N_s$ as can be seen from fig. 9.5.
- Number of observations available for various months varies too much. For April we have 5 mean values, for July, August and October there are 10. For more reliable results there should be equal number of monthly measurements during the whole observed period.
- There are only three years where mean values for all months are available: 1962, 1971, 1973. Therefore, year mean values are not comparable. Whilst $N_s$ for "complete" years is about the same:

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>381.68</td>
</tr>
<tr>
<td>1971</td>
<td>380.53</td>
</tr>
<tr>
<td>1973</td>
<td>380.84</td>
</tr>
</tbody>
</table>

the mean values for "incomplete" years vary strongly, as for example for 1969 is $N_s = 370.91$ obtained from 7 months measurements and for 1974 results $N_s = 377.93$ from 3 months measurements only.
- Only one daily measurement at 7.00 A.M. was made. Therefore, no diurnal variations can be evaluated.
9.6. **Degree of accuracy of radiometeorological measurements.**

Radiometeorology means observing of the climatic conditions on behalf of radio propagation. It is relatively a new field of scientific research which came to development especially during the World War II.

I. Katz [95; p. 272] says:

"The study of microwave propagation places new emphasis on meteorological instrumentation. For the usual meteorological purposes temperature and humidity are measured with instruments unsuited to the fine detail necessary for low-level soundings."

This was said in 1951. The problem remains till the present day. The most important radiometeorological parameter, the refractivity of air $N$, from which the gradients $\Delta N$ for different atmospheric layers are calculated, is estimated from the radiosonde measurements of humidity, pressure and temperature taken over from normal meteorological services. As Katz points out accuracy requirements of normal meteorology cannot meet the accuracy standards of radiometeorology. Unfortunately, in the most cases of radiometeorological investigations the data of normal meteorological services are the only available. This was also our situation in Surabaya. We were happy with the data offered to us by the Surabaya meteorological station. Though we do not know the exact conditions under which the radiosonde measurements were made in Surabaya, we will try to indicate the error boundaries of our calculations of the $k$-factor.

Following sources of errors occur in the radiosonde measurements:
- error due to the time lag (time constant) of the meteorological instruments (pressure, humidity, temperature);
- error due to instruments inaccuracy;
- error due to the receiver;
- error due to the use of different constants recommended by different authors;
- atmospheric radiation;
- errors due to human factor (experience of the personnel).

In the following we will limit ourselves to errors caused by time lag and inaccuracy of the instruments. We do not possess data about other sources of errors.

For the error calculations we assume the standard radiosonde of the Finnish company Vaisälä (Helsinki) and the balloon BERITEK of the British Guide Bridge Rubber Company (Vulcan Mill, Bury, Lancashire).

Table 9.4. Instruments accuracy.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Range</th>
<th>Time lag</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermometer (bimetal)</td>
<td>+40...-85°C</td>
<td>5 sec at 1000 mbar</td>
<td>±0.2°C</td>
</tr>
<tr>
<td>Barometer (aneroid capsule)</td>
<td>1050-0 mbar</td>
<td>-</td>
<td>±2 mbar</td>
</tr>
<tr>
<td>Hygrometer (rolled hair Frankenberger)</td>
<td>0-100 % RH</td>
<td>10 sec</td>
<td>±1% RH</td>
</tr>
</tbody>
</table>

BERITEK seamless sounding balloons rate of ascent: \( v = 6 \text{ m/sec} \)

The general formula for the time lag correction is [70; p. 41]:

\[
\theta_{e, n+1} = \theta_{i, n+1} + \frac{\theta_{i, n+1} - \theta_{i, n}}{h_{n+1} - h_n} \tau v
\]

(9.14)

where \( \theta_i \) - indicated value

\( \theta_e \) - environmental value

\( v \) - rate of ascent \([\text{m/sec}]\)

\( \tau \) - time constant of the instrument \([\text{sec}]\)

\( n, n+1 \) - indication of the boundaries considered

By the means of eq. (9.14) we calculate the corrected values for the following atmospheric layers:

- \( s = 1000 \text{ mbar} \) (\( \approx 0 - 100 \text{ m} \))
- \( s = 850 \text{ mbar} \) (\( \approx 0 - 1500 \text{ m} \))
- \( 1000 - 850 \text{ mbar} \) (\( \approx 100 - 1500 \text{ m} \))

As the accuracy of the humidity reading is expressed in the terms
of RH % we must deduce from the eq. (9.3) through (9.5) the expression for water vapour pressure:

\[ e = 2.72 \cdot 10^7 \text{RH exp}(-5434/T) \text{ [mbar]} \] (9.15)

Change \( \Delta \text{RH} \) gives the change

\[ \Delta e = 2.72 \cdot 10^7 \Delta \text{RH exp}(-5434/T) \text{ [mbar]} \] (9.16)

where \( T \) - temperature \ [K]

Where necessary we refer to the standard atmosphere of Surabaya:

Tab. 9.5. Calculated mean values of the meteorological parameters for the region of Surabaya for the period 1961-1971 (55 months). [73; p. 79]

<table>
<thead>
<tr>
<th>( P ) [mb]</th>
<th>( h ) [m]</th>
<th>( T ) [°C]</th>
<th>( e ) [mb]</th>
<th>( N_{\text{dry}} )</th>
<th>( N_{\text{wet}} )</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1010.98</td>
<td>3</td>
<td>26.40</td>
<td>27.72</td>
<td>262.09</td>
<td>115.36</td>
<td>377.41</td>
</tr>
<tr>
<td>1000</td>
<td>100.40</td>
<td>25.64</td>
<td>26.54</td>
<td>259.85</td>
<td>110.98</td>
<td>370.84</td>
</tr>
<tr>
<td>850</td>
<td>1508.89</td>
<td>16.30</td>
<td>14.17</td>
<td>227.99</td>
<td>63.19</td>
<td>291.19</td>
</tr>
<tr>
<td>700</td>
<td>3136.78</td>
<td>7.81</td>
<td>6.07</td>
<td>193.44</td>
<td>28.84</td>
<td>222.29</td>
</tr>
<tr>
<td>500</td>
<td>5833.44</td>
<td>-6.84</td>
<td>1.74</td>
<td>145.79</td>
<td>9.15</td>
<td>154.92</td>
</tr>
<tr>
<td>400</td>
<td>7545.22</td>
<td>-16.47</td>
<td>0.71</td>
<td>121.01</td>
<td>4.04</td>
<td>125.04</td>
</tr>
<tr>
<td>300</td>
<td>9645.64</td>
<td>-30.62</td>
<td>0.16</td>
<td>96.05</td>
<td>1.02</td>
<td>97.07</td>
</tr>
<tr>
<td>200</td>
<td>12387.59</td>
<td>-51.43</td>
<td>-</td>
<td>70.12</td>
<td>-</td>
<td>70.12</td>
</tr>
<tr>
<td>150</td>
<td>14174.64</td>
<td>-64.98</td>
<td>-</td>
<td>55.98</td>
<td>-</td>
<td>55.98</td>
</tr>
<tr>
<td>100</td>
<td>16576.54</td>
<td>-73.29</td>
<td>-</td>
<td>38.87</td>
<td>-</td>
<td>38.87</td>
</tr>
</tbody>
</table>

For a change \( \Delta N^* \) in \( N \) caused by a change of parameters \( P, T, e \) we use the formula derived by Arini Retnoningsih [74; p. 10] for the region of Surabaya:

\[ \Delta N^* = 0.256 \Delta P + 4.063 \Delta e - 1.441 \Delta T \] (9.17)

For the calculation of the lag correction of our measurements we use eq. (9.14), (9.16), (9.17) and data from the tables 9.4 and 9.5.
Table 9.6. Lag correction for the rate of ascent \( v = 6 \) m/sec.

<table>
<thead>
<tr>
<th>Pressure [mb]</th>
<th>( h ) [m]</th>
<th>( T_1[^\circ C] )</th>
<th>( e_1 ) [mb]</th>
<th>( \tau = 5 ) sec</th>
<th>( \Delta T ) [(^\circ C)]</th>
<th>( \Delta e ) [mb]</th>
<th>( \Delta N' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1010.98</td>
<td>3</td>
<td>26.40</td>
<td>27.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>100.40</td>
<td>25.64</td>
<td>26.54</td>
<td>-0.23</td>
<td>-0.73</td>
<td>-2.63</td>
<td></td>
</tr>
<tr>
<td>850</td>
<td>1508.89</td>
<td>16.30</td>
<td>14.17</td>
<td>-0.20</td>
<td>-0.53</td>
<td>-1.87</td>
<td></td>
</tr>
</tbody>
</table>

In the table 9.6 we calculated the correction \( \Delta N' \) for the layer boundaries 1000 and 850 mbar. These values must be added to the values of \( N \) calculated from the uncorrected measurements. The corrections \( \Delta N' \) inserted in the eq. (9.7) through (9.9) give following changes in the gradient \( \Delta N \):

\[
\Delta N_{n-(n+1)} \text{ corrected} = \Delta N_{n-(n+1)} + \frac{\Delta N_1 - \Delta N_{n+1}}{h_n - h_{n+1}} \quad 1000
\]

where \( n \) and \( n+1 \) are boundaries of the layers considered.

Table 9.7. Corrections in the gradient \( \Delta N \) and the k-factor due to time lag. Region of Surabaya for the period 1973-1977.

<table>
<thead>
<tr>
<th>Layer [mb]</th>
<th>( \Delta N' )</th>
<th>( \Delta h ) [m]</th>
<th>( \Delta N_{\text{corr.}} )</th>
<th>( k_{50} )</th>
<th>( \Delta N )</th>
<th>( \Delta N_{\text{eff}} )</th>
<th>( k_{\text{eff}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-1000</td>
<td>-2.63</td>
<td>100</td>
<td>-26.30</td>
<td>1.562</td>
<td>-56.49</td>
<td>-82.79</td>
<td>2.12</td>
</tr>
<tr>
<td>s-850</td>
<td>-1.87</td>
<td>1500</td>
<td>-1.25</td>
<td>1.540</td>
<td>-55.05</td>
<td>-56.30</td>
<td>1.56</td>
</tr>
<tr>
<td>1000-850</td>
<td>-2.63+       +1.87=</td>
<td>-0.54</td>
<td>1.527</td>
<td>-54.18</td>
<td>-54.72</td>
<td>1.54</td>
<td></td>
</tr>
</tbody>
</table>

In the table the corrections of the layer boundary refractivities \( \Delta N' \) are taken from the table 9.6. The gradient corrections for different layers are calculated from the second term of the eq. (9.18):

\[
\Delta N_{\text{corr}} = \frac{\Delta N_{n} - \Delta N_{n+1}}{h_n - h_{n+1}} \quad 1000
\]

where \( h_n - h_{n+1} = \Delta h \)

\( k_{50} \) are the median values of the measured values from the tables 9.1 through 9.3. \( \Delta N \) are the gradient values belonging to the \( k_{50} \)
values and calculated from
\[ \Delta N = \frac{157}{k} - 157 \]  \hspace{1cm} (9.19)

\[ \Delta N_{\text{eff}} = \Delta N + \Delta N_{\text{corr}} \] is the new gradient value for the new k-factor
where the time lag is respected:
\[ k_{\text{eff}} = \frac{157}{157 + \Delta N_{\text{eff}}} \]  \hspace{1cm} (9.20)

In figure 9.6 a number of correction curves was drawn for the change of the k-factor depending from the changes of the gradient \( \Delta N \).

According to a personal communication of the radiosonde section of the Royal Dutch Meteorological Institute (KNMI, De Bilt) in the radiosonde measurements, which are performed twice a day no lag corrections are made. We must assume that this was the case in Surabaya too.

In the following we will try to estimate the errors due to instruments inaccuracy. The Root Mean Square error in N-readings depending from small changes in the P, e and T readings is derived from the eq. (9.17) [74; p. 10]:
\[ \sqrt{\Delta N'^2} = \sqrt{(0.256 \Delta P)^2 + (4.063 \Delta e)^2 + (1.441 \Delta T)^2} \]  \hspace{1cm} (9.21)

In order to calculate the errors caused by the instruments inaccuracy at different layer boundaries we take the data for standard instruments from table 9.4 and the data for Surabaya standard atmosphere from table 9.5. For deducing the water vapour pressure \( \Delta e [\text{mb}] \) from the RH [%] we use eq. (9.16). Then we calculate from eq. (9.21) the RMS errors \( \Delta N' \). The results are tabulated in table 9.8 for three layer boundaries. The error caused by the RMS error \( \Delta N' \) resulting from the inaccuracy of the instruments in the k-factor is calculated in table 9.9.

(+ ) March 1983
Table 9.8. RMS error due to instruments inaccuracy.

<table>
<thead>
<tr>
<th>Layer boundaries</th>
<th>ΔRH [%]</th>
<th>T [°C]</th>
<th>Δe [mb]</th>
<th>ΔT [°C]</th>
<th>ΔP [mb]</th>
<th>AN'</th>
</tr>
</thead>
<tbody>
<tr>
<td>s [mb]</td>
<td>±1</td>
<td>26.40</td>
<td>±0.36</td>
<td>±0.2</td>
<td>±2</td>
<td>±1.58</td>
</tr>
<tr>
<td>1000</td>
<td>±1</td>
<td>25.64</td>
<td>±0.34</td>
<td>±0.2</td>
<td>±2</td>
<td>±1.50</td>
</tr>
<tr>
<td>850</td>
<td>±1</td>
<td>16.30</td>
<td>±0.19</td>
<td>±0.2</td>
<td>±2</td>
<td>±0.97</td>
</tr>
</tbody>
</table>

Table 9.9. Errors in the gradients AN and the k-factor due to instruments inaccuracy. Region of Surabaya for the period 1973-1977. (According to time lag corrected values).

<table>
<thead>
<tr>
<th>Layer [mb]</th>
<th>Δh [m]</th>
<th>ΔNerror</th>
<th>k50eff</th>
<th>ANeff</th>
<th>k50max</th>
<th>k50min</th>
<th>k50</th>
</tr>
</thead>
<tbody>
<tr>
<td>s-1000</td>
<td>100</td>
<td>±30.80</td>
<td>2.12</td>
<td>-82.79 ± 30.80</td>
<td>3.62</td>
<td>1.50</td>
<td>1.562</td>
</tr>
<tr>
<td>s-850</td>
<td>1500</td>
<td>±1.70</td>
<td>1.56</td>
<td>-56.3 ± 1.70</td>
<td>1.59</td>
<td>1.53</td>
<td>1.540</td>
</tr>
<tr>
<td>1000-850</td>
<td>1400</td>
<td>±1.76</td>
<td>1.54</td>
<td>-54.72 ± 1.76</td>
<td>1.56</td>
<td>1.51</td>
<td>1.527</td>
</tr>
</tbody>
</table>

ΔNerror in table 9.9 is the greatest sum of the ΔN' from table 9.8 for layers concerned. The value of the k-factor corrected due to time lag was taken from table 9.7. In the column ΔNeff are the values of the gradient values from table 9.7 with the error boundaries. k-factors belonging to these error boundaries are calculated in the columns k50max and k50min. In the last column is again the measured uncorrected value of the median k50 given.

Table 9.9 gives the final result of our error discussion.
9.7. Conclusions.

Radiometeorological measurements in Surabaya in the years 1973-1977 result in following median values for the k-factor for level not exceeding 50% of the time with indicated error boundaries due to inaccuracy of instruments:

Table 9.10. Median values of the k-factor with instruments inaccuracy boundaries (without time lag corrections).

<table>
<thead>
<tr>
<th>Layer</th>
<th>( \Delta N \pm \text{RMS-error} )</th>
<th>( k_{50} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>calculated</td>
</tr>
<tr>
<td>s-1000 mb (( \approx 0-100 \text{ m} ))</td>
<td>-56 ( \pm ) 31</td>
<td>1.562</td>
</tr>
<tr>
<td>s-850 mb (( \approx 0-1500 \text{ m} ))</td>
<td>-55 ( \pm ) 2</td>
<td>1.540</td>
</tr>
<tr>
<td>1000-850 mb (( \approx 100-1500 \text{ m} ))</td>
<td>-54 ( \pm ) 2</td>
<td>1.527</td>
</tr>
</tbody>
</table>

\( k_{50} \)-values were calculated from the meteorological measurements (fig. 9.1, 9.2 and 9.3). The \( \Delta N \)-values belonging to them were calculated from the equation (9.19). The RMS-errors of \( \Delta N \) were taken from table 9.9 (column 5). The error boundaries for the k-factor were estimated from the equation (9.20). For less exact readings fig. 9.6 could be also used.

In table 9.10 no respect was paid to time lag corrections. In the available literature on practical surveys of the radio refractive index, as for example [78], [79], [91], [92], radiosonde measurements of official meteorological services were used and no time lag correction was made. Therefore, also in Surabaya we followed the same way.

During the project the value \( k_{50} = 1.52 \) was used. The reason was that this value is close to that found by Ben Sutanto [43] for Jakarta and this value has a general acceptance for Indonesia.

From the calculations in section 9.5 is obvious that the value of the k-factor would take a much greater value, if the time lag correction would be made.
Concerning other sources of errors as those due to the receiving apparatus, radiation and human factor we do not possess enough information in order to be able to estimate additional inaccuracy factors.

Influence of the use of different constants in the equations was studied by Bean and Dutton [70; p. 8] and not found of overwhelming importance.

Following remark must be made on the RMS-errors in the N-value measurements. As the N-values are a fluctuating quantity we are not allowed to assume that the RMS-error will become inversely proportional to the root of the number of measurements √n (as assumed by Bean and Dutton [70; p. 107]). This is a common experience from the 1/f-noise measurements too (personal communication by Dr.ir. L.K.J. Vandamme, Electrical Materials Group, Dept. of Electrical Engineering, Eindhoven University of Technology). In opposite it is valid for a fluctuating quantity X with a spectral density $S_X \propto 1/f$ that

$$\sigma^2 = \langle (X_i - \langle X \rangle)^2 \rangle \propto \log n$$

where f is the frequency.

Values for the 0-100 m layer show a great dispersion when possible errors are taken into account. Because of narrow boundaries of this layer the k-factor is very sensitive to any variation of P, T and e, as obvious from the equations (9.7) and (9.17).

It was found - confirmation of Katz [95; p. 272] - that standard meteorological methods do not suite to the requirements of radiometeorology, which needs more exact data.

Measurements from radiosonde observations once a day only were available, which were taken at 7.00 A.M. local time. Therefore, no graphs of diurnal variations could be made.
In order to refine the quality of meteorological radiosonde measurements on behalf of radiometeorologists following improvements should be made:
- there should be reported which corrections were made (radiation, time lag);
- instruments accuracy should be indicated;
- as the measured meteorological parameters are fluctuating the radiosonde measurements should not be made at exactly the same time of the day in all countries of the world (0.00 and 12.00 GMT) but on shifted time intervals, so that diurnal variations could be examined;
- besides the atmosphere models in the form of
  \[ N = f(z), \quad T = f(z), \quad e = f(z) \] (section 9.2) and \( \Delta N = f(N_s) \) (tab. 9.2)
  also models in the form of
  \[ N = f(N_s, P), \quad T = f(T_s, P) \] and \( e = f(e_s, P) \) ev. \( RH = f(RH_s, P) \)
  should be tried.

There remains still a task for meteorologists and radiometeorologists throughout the world to refine the measurements of the radiorefractive index and to Indonesian radio propagation experts to use them in different regions of their big country.
Tab. 9.1. Surface refractivity $N_s$ for the region of Surabaya.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td>-</td>
<td>386.5</td>
<td>383.8</td>
<td>-</td>
<td>-</td>
<td>385.8</td>
<td>377.68</td>
<td>377.35</td>
<td>-</td>
<td>372.52</td>
<td>379.65</td>
</tr>
<tr>
<td>Feb</td>
<td>-</td>
<td>384.3</td>
<td>385.0</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>385.75</td>
</tr>
<tr>
<td>Mar</td>
<td>-</td>
<td>388.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>376.42</td>
<td>-</td>
<td>379.68</td>
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<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>388.24</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>390.6</td>
<td>388.7</td>
<td>384.79</td>
<td>-</td>
<td>-</td>
<td>376.27</td>
<td>385.67</td>
</tr>
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<td>Jun</td>
<td>374.1</td>
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<td>375.1</td>
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<td>-</td>
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<td>-</td>
<td>385.51</td>
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<td>Jul</td>
<td>365.7</td>
<td>376.0</td>
<td>364.8</td>
<td>365.0</td>
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<td>378.20</td>
<td>-</td>
<td>371.66</td>
<td>366.27</td>
<td>367.95</td>
</tr>
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<td>-</td>
<td>368.5</td>
<td>376.37</td>
<td>-</td>
<td>-</td>
<td>364.13</td>
<td>367.74</td>
</tr>
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<td>Oct</td>
<td>378.6</td>
<td>381.6</td>
<td>369.6</td>
<td>365.2</td>
<td>372.1</td>
<td>379.1</td>
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<td>-</td>
<td>379.96</td>
<td>372.12</td>
<td>369.99</td>
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<td>Nov</td>
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<td>373.4</td>
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<td>381.9</td>
<td>375.85</td>
<td>-</td>
<td>-</td>
<td>376.38</td>
<td>379.42</td>
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<td>Dec</td>
<td>-</td>
<td>387.5</td>
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<td>383.1</td>
<td>379.57</td>
<td>-</td>
<td>376.37</td>
<td>377.37</td>
<td>-</td>
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<td>$\overline{N_s}$</td>
<td>375.57</td>
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<td>375.22</td>
<td>370.91</td>
<td>376.53</td>
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<td>380.84</td>
<td>377.93</td>
<td>375.07</td>
<td>373.03</td>
<td>377.08</td>
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Tab. 9.2. Correlation between $\Delta N$ and $N_s$.

<table>
<thead>
<tr>
<th>Region</th>
<th>Period</th>
<th>Layer</th>
<th>Lit.</th>
<th>linear regression</th>
<th>exponential regression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\Delta N = a N_s + b$</td>
<td>$\Delta N = c \exp (d N_s)$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$a$</td>
<td>$b$</td>
</tr>
<tr>
<td>Surabaya</td>
<td>1961-71</td>
<td>s-1000 mbar</td>
<td>[73]</td>
<td>-0.49</td>
<td>118.6</td>
</tr>
<tr>
<td>Surabaya</td>
<td>1961-71</td>
<td>s-850 mbar</td>
<td>[73]</td>
<td>-0.23</td>
<td>28.5</td>
</tr>
<tr>
<td>Surabaya</td>
<td>1973-77</td>
<td>s-1000 mbar</td>
<td>[21]</td>
<td>-0.18</td>
<td>7.50</td>
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<tr>
<td>Surabaya</td>
<td>1973-77</td>
<td>s-850 mbar</td>
<td>[21]</td>
<td>-0.10</td>
<td>-18.08</td>
</tr>
<tr>
<td>Surabaya</td>
<td>1973-77</td>
<td>1000-850 mbar</td>
<td>[21]</td>
<td>-0.09</td>
<td>-21.94</td>
</tr>
<tr>
<td>Jakarta</td>
<td>1960-64</td>
<td>s-900 mbar</td>
<td>[43]</td>
<td>-0.36</td>
<td>82</td>
</tr>
<tr>
<td>Japan</td>
<td>1959-64</td>
<td>1000-900 mbar</td>
<td>[90]</td>
<td>-0.357</td>
<td>75.39</td>
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<tr>
<td>India</td>
<td>1959-63</td>
<td>s-900 mbar</td>
<td>[92]</td>
<td></td>
<td></td>
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</tbody>
</table>
Fig. 9.1. $k$-factor distribution in the region of Surabaya for the period 1973-1977.

$s = 1000$ mbar layer ($z = 0 - 100$ m)
Interval = 0.10  715 measurements = 100%

Percentage of time (%) that $k$-factor is equal or less than indicated value
Fig. 9.2. k-factor distribution in the region of Surabaya for the period 1973-1977.

s - 850 mbar layer (z0 - 1500 m)

Interval = 0.11

715 measurements = 100%

Percentage of time(%) that k-factor is equal or less than indicated value
Fig. 9.3. k-factor distribution in the region of Surabaya for the period 1973-1977.
1000 - 850 mbar layer (z 100 - 1500 m)
Interval = 0.12    715 measurements = 100%

%  

<table>
<thead>
<tr>
<th>Interval</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
<th>1.7</th>
<th>1.8</th>
<th>1.9</th>
<th>2.0</th>
<th>2.1</th>
<th>2.2</th>
<th>2.3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>5</td>
<td>27</td>
<td>264</td>
<td>78</td>
<td>22</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Percentage of time (%) that k-factor is equal or less than indicated value
Fig. 9.4. k-factor distribution in the region of Jakarta for the period 1960-1964 [43].

$s = 1000 \text{ mbar layer (} z = 0 - 100 \text{ m)}$

and

$s = 900 \text{ mbar layer (} z = 0 - 1000 \text{ m)}$

percentage of time (%) that k-factor is equal or less than indicated value
Fig. 9.5. Surface refractivity $N_s$ in the region of Surabaya for the period 1961-1977. Seasonal variations of 93 month mean values (maximum, mean, minimum). (Table 9.1)
Fig. 9.6. Correction curves for the $k$-factor according to error $\Delta N'$ in the refractivity gradient.

Example: Calculated from uncorrected measurements: $k = 1.52$. Correction due to time lag is $\Delta N' = -30$ N-units/km. We read from the curve $\Delta N' = -30$: $k_{\text{eff}} = 2.12$. For a RMS error $\Delta N' = +30$ lies the expected value of the $k$-factor between 1.52 and 3.54 (curves for $\Delta N' = 0$ and $\Delta N' = -60$).

\[
k_{\text{effective}} = \frac{157}{157 + \Delta N + \Delta N'}
\]
Chapter 10

THE RESULTS OF THE TROPOSCATTER MEASUREMENTS

Petruk
Servant of Pandawa; a loyal and honest person, open-hearted and law-abiding.
10. The results of the troposcatter measurements

10.1. Introduction

In order to investigate the troposcatter properties of the link Situbondo - Surabaya, a continuous unmodulated carrier on 4012 MHz was transmitted during 24 hours from Situbondo to Surabaya over a distance of 150 km. The total period of the experiment lasted about two years (July 1978 - May 1980) of which the first part, until February 1980, is contained in the following evaluations.

No registrations were made during the periods November - December 1978, the second week of February 1979, June - July 1979, medio September 1979 and the last week of October 1979.

During June and July 1979 the receiver station was moved to another site, resulting in a 10 km shorter total distance transmitter - receiver.

Registration by means of the microprocessor was obtained during 70% of the time before and for 80% of the time after its move to the new site. The analogue registrations on the strip-chart x/t recorder were almost continuous in the first period (95%) and for 75% in the second period.

The detected troposcatter signal by the PLL-receiver was fed into the microprocessor data processing unit. The signal was sampled with a rate of 10 Hz and the signal level was classified in one of the 31 power level intervals of 3 dB as follows:

\[ P_n = [-127 + 3n] \text{ dB} \]

\[ [-127 + 3n] < N_n (\text{dBm}) < [-127 + 3(n+1)] \]  

where \( n = 0, 1, 2, \ldots, 31 \)

\( P_n \) = lowest power level of the \( n \)th interval [dB]

\( N_n \) = power level interval with index \( n \)

The total attenuation at a given time percentage \( q \) [%] of a given received signal at level \( n \) can be calculated as follows (see also fig. 10.1a):

\[ L_{is} = L_{tot} + C_t + G_r = P_t - P_{r,q} - L_a - L_{att} + G_t + G_r = [230 - 3n] \text{ dB} \]  

where:

\( P_t \) = transmitter power at 4012 MHz = 34.7 dBm = 3 watt

\( C_t = G_r \) = antenna gain = 39 dB

\( L_{att} \) = attenuation loss [dB]

\( L_a \) = absorption losses (feeders, cables) [dB]

\( P_{r,q} \) = received power level at a percentage of time \( q \) [%] =

\[ P_n = [-127 + 3n] \text{ [dBm]} \]
For different transmitter - receiver distances following values are valid:

<table>
<thead>
<tr>
<th>d</th>
<th>$L_a$</th>
<th>$L_{att}$</th>
<th>$L_a + L_{att}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>140 km</td>
<td>6.5 dB</td>
<td>3.2 dB</td>
<td>9.7 dB</td>
</tr>
<tr>
<td>150 km</td>
<td>8 dB</td>
<td>1.7 dB</td>
<td>9.7 dB</td>
</tr>
</tbody>
</table>

The registrations, classified in intervals, were stored by the microprocessor unit in tables "Aant" (number: $N_n$). Also the downwards passing of the intervals between the two samples was registrated and stored in the table "door" (through: $H_n$).

Each hour results of 36,000 samples were given (see Fig. 8.7). The system of data processing is given in Fig. 10.1b.

The table "Aant" is used to determine the attenuation characteristics of the troposcatter link, the table "door" is used to evaluate fading characteristics. The output presentation for each hour is given in Fig. 8.7.

The evaluated data originate from measurements during the wet and the dry season. This enables comparison between the behaviour of the troposcatter signal in both seasons.

It appeared that "ducting" occurred frequently during the period of measurements. This phenomena is also amply discussed.

Part of the available data was already evaluated in Surabaya [18] and [19]. The complete representation was produced in Eindhoven by means of a Burroughs computer [20].
Fig. 10.1b. (a) The received radio signal and sample moments $t_1$, $t_2$, $t_3$, $t_4$ at intervals of 0.1 sec.
(b) Registration by the microprocessor in the tables $N_n$ (number) and $H_n$ (through).
10.2. Influence of the seasons

The propagation in radiowaves is mainly determined by the meteorological condition of the troposphere. Thus also the seasons, having different climatological conditions, will influence the transmission losses in a radio link.

In Indonesia, two seasons can be distinguished: the dry and the wet monsoon, mainly differing in precipitation and humidity.

In order to investigate the influence of both seasons on the propagation conditions, the transmission losses have been determined during the total period. Calculations have been made for the median value of the transmission losses and the value of the losses where 0.01% of the time is exceeded. Both values are calculated from the available data per hour and averaged over a week (Fig. 10.2).

The total period of the measurements is divided into two parts: the link Situbondo - Surabaya of 150 km and (after relocation) of the receiver site in June 1979) the link of 140 km. Both parts are divided in a wet and a dry monsoon.

From Fig. 10.2 the following median and 0.01% values are derived:

<table>
<thead>
<tr>
<th></th>
<th>50%</th>
<th>0.01%</th>
</tr>
</thead>
<tbody>
<tr>
<td>wet</td>
<td>dry</td>
<td>wet</td>
</tr>
<tr>
<td>195.2</td>
<td>193.2</td>
<td>228.7</td>
</tr>
<tr>
<td>192.8</td>
<td>188.4</td>
<td>227.1</td>
</tr>
</tbody>
</table>

Transmission losses in dB; median values and 0.01% values for wet and dry monsoon in the 150 and 140 km link Situbondo - Surabaya. (Decimals are due to calculations. For RMS and maximal errors see section 10.9).

Three conclusions can be derived from Table 10.1.
1. The median value of the attenuation during the wet monsoon is higher than during the dry monsoon.
2. The difference between dry and wet monsoon is higher in the 140 km link than in the 150 km link.
3. The decrease in attenuation as result of the shortening of the link distance from 150 to 140 km is more (3 to 5 dB) than predicted according the CCIR method (1 dB).
Fig. 10.2 Transmission losses averaged per week. 

- $L_{50}^{is}$ = attenuation exceeded for 50% of the time
- $L_{0.01}^{is}$ = attenuation exceeded for 0.01% of the time

---

The CCIR method estimates correctly the median transmission losses for the period in the wet monsoon and for the 150 km link. In the dry monsoon the median losses were 2 dB lower. This is ascribed to meteorological circumstances giving rise to a more frequent duct formation than during the wet monsoon. The duct causes a stronger median signal level at the receiver.

This phenomena becomes more and more important when the distance between transmitter and receiver becomes shorter and the path is closer to the sea. During the transition periods between the dry and wet monsoons no exceptional phenomena occured allowing the division of the year in two seasons each of 6 months.

10.3. Ducting

When the attenuation over the troposcatter propagation path approximates the free space attenuation a 'total duct' over the complete distance will exist. Mostly only one or more 'local ducts' will exist on the propagation path. Earlier investigations \[\text{[1],[21]}\] revealed a very small probability of a local duct over land in the Surabaya region (less than 0.1\%) while an over water local duct could exist for about 10\% of the time.

Especially in the first 20 m altitude above sea water the profile of the modified refractivity $M$ approximates a logarithmic curve \[\text{[44]}\]. For higher altitudes the profile will tend, via a parabolic curve, to a normal linear curve. In the layer between sea level and 30 m altitude duct conditions will often occur \[\text{[22]}\]. The link Situbondo - Surabaya is mainly an over sea radio path, resulting in a 10\% probability of the existence of a local duct at each location in the propagation path. The probability of the occurrence of any duct on the propagation path is higher than 10\% but the propability for a complete duct over the total propagation distance is very small.

The influence on the propagation of a local duct may be two fold:
- the scatter angle $\theta$ decreases, resulting in a considerably less scatter transmission losses which are proportional to $\theta^4$. See Eq. (6.44).
- the common volume shifts to a lower altitude where more dielectric variations occur (proportional to $h^{-2}$) resulting in less scatter losses.

The influence of ducting is indicated in Fig. 10.3. A distinction is made between a local duct within the over-horizon distance, between the optical horizon and microwave antenna and a complete duct.
Fig. 10.3. Influence of ducting on troposcatter propagation.

a) duct within the over-horizon distance
b) duct close to transmitter and receiver
c) complete duct

By means of the analog registrations of the strip chart x/t recorder provided with a filter (τ = 3 min.), the time percentage of the duct occurrence was determined. Fig. 10.4 shows an example of a registration during a duct. It can be seen that within half an hour a signal increase and decrease of 15 to 20 dB can occur.

Relative criterion for ducting determination:

In order to distinguish between scatter and duct propagation we distinguish between pure scatter hours and hours in which (local) ducts occurred, signals, rising during one hour more than 6 dB above the median troposcatter signal, were considered to be a duct. (For absolute criterion see page 10.10).

The total amount of ducting is expressed in the mean percentage per week. The total period under consideration is from July 1978 until November 1979.
Fig. 10.4a Example of the growth and decay of a duct.
Fig. 10.4b Ducting. Increase and decrease of the received signal. Occurrence of local ducts.

Recording by means of analog real-time recorder ($\tau = 3$ min. filter applied).
Three parts are distinguished:
1. wet monsoon for the 150 km link
2. dry monsoon for the 150 km link
3. dry monsoon for the 140 km link.

The duct occurrence rate is given in fig. 10.5 a, b.

The duct spectrum is given in Fig. 10.5c. From this figure can also be derived that during the dry monsoon period more ducts will occur than during the wet monsoon. Also in the 140 km link more ducts occurred than in the 150 km link.

The differences between the two monsoons can be explained by means of differences in humidity (M-profile) and differences in rain intensity as could be seen from registrations of the weather station.

The difference in duct occurrence between the 150 km link and 140 km link can be explained by the fact that the receiving station in the second link is only at 1.5 km distance from sea, increasing the probability that the receiving antenna is situated in a duct originating from sea. In the 150 km link the receiver site was at 7.5 km from sea, in the middle of the town. This resulted in a more difficult coupling into a duct because almost no ducts occur above town.

Also a shorter beyond-the-horizon distance between transmitter and receiver gives an increase in the influence by means of ducting.

To establish a LOS-link between Situbondo and Surabaya a minimum k-factor of 7.1 is needed (from the 140 km link). From [21] it can be seen that 7.1 < k < 0 hardly occurs in Indonesia.

**Absolute criterion for ducting determination:**

To evaluate the received signals by means of the computer an attenuation lower than 185 dB was considered as a duct; a higher attenuation level was considered as a pure troposcatter signal (150 km path). For the 140 km path the criterion is 182 dB. (For relative criterion see page 10.7).

10.4. **Instantaneous transmission losses**

The output of the microprocessor unit is used to determine the distribution of the instantaneous transmission losses.

The evaluation is presented by a histogram of the probability density function (percentage of time that a given attenuation interval of 3 dB occurs) and the cumulative distribution function (the probability a given level is not exceeded) of the received troposcatter signal.

A distinction has been made between both seasons (wet and dry monsoon) and the two links (150 km and 140 km).
This could be an indication that in the dry season the duct occurrence rate is much higher than in the rainy season. But much more evidence will be needed to show that it is not just a coincidence.
Fig. 10.5c Duct percentage per week during the total period of the measurements.

Data derived from real-time strip chart registrations.

Each line representing the average value of a week.
By means of the probability density function the mean value and standard deviation were calculated. According to the theoretical considerations [9, 26 and 44] the long term fading of the median value of the signal will be distributed lognormally and the short term fading according to a Rayleigh distribution. The instantaneous signal will be a convolution of both types of distribution functions.

In order to compare the convoluted characteristic with the log normal one, the cumulative distribution was plotted along a Gaussian distributed axis. Also the log normal distribution, the mean value and the standard deviation (calculated from the probability density function) were plotted in the same graph.

The cumulative distribution finally leads to the mean values.

Table 10.2 gives a summary of the measured distributions and their characteristic parameters, including the graphs depicting the distributions.

<table>
<thead>
<tr>
<th>link (km)</th>
<th>monsoon</th>
<th>mean value (dB)</th>
<th>standard deviation (dB)</th>
<th>median value (dB)</th>
<th>( f(L_{is}) )</th>
<th>( F(L_{is}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>wet</td>
<td>194.6</td>
<td>5.3</td>
<td>195.6</td>
<td>10.6</td>
<td>10.7</td>
</tr>
<tr>
<td>150</td>
<td>dry</td>
<td>193.0</td>
<td>6.2</td>
<td>194.0</td>
<td>10.8</td>
<td>10.9</td>
</tr>
<tr>
<td>140</td>
<td>wet</td>
<td>192.2</td>
<td>10.4</td>
<td>194.1</td>
<td>10.10</td>
<td>10.11</td>
</tr>
<tr>
<td>140</td>
<td>dry</td>
<td>187.7</td>
<td>11.5</td>
<td>188.9</td>
<td>10.12</td>
<td>10.13</td>
</tr>
</tbody>
</table>

Table 10.2. Instantaneous transmission losses and the number of the successive graphs

From the graphs 10.6 until 10.13, among others, it can be concluded that:

- During the wet monsoon in the 150 km link, the instantaneous level of the signal was for 0.08% of the time lower than the sensitivity of the receiver. During the other three periods this situation almost did occur.

- During the wet monsoon in the 150 km link complete ducting didn't occur. During the other periods complete ducting occurred, even up to 0.4% of the time during the dry season of the 140 km link (see 'free space attenuation' indication in the graphs).

- The median value of the attenuation during the wet monsoon approximates the calculated value according the CCIR: 195.2 dB (150 km) and 194.2 dB (140 km). During the dry monsoon these values are higher compared with the CCIR values [9]. This is due to the more frequent duct occurrence
than expected.
- The median attenuation levels are nowhere equal to the mean values, but always higher. This is due to the duct levels where less deep fadings occur.
- During the wet monsoon the distribution function in the 150 km link is close to the calculated lognormal distribution except for large attenuation levels; while during the three other periods the lower attenuation levels diverge from lognormal distribution. This can also be explained as originating from ducts.

Really the cumulative distribution should not be compared with lognormal distribution but with a convolution of a lognormal and a Rayleigh distribution. This leads to intricate mathematical calculations and has not been done in this case. [45]

In this case the instantaneous signal is split into two parts: the median value per hour in order to determine the long term fading characteristics and the instantaneous distribution related to this median value in order to calculate the short term fading characteristics.

Fig. 10.6. Transmission losses: percentage of the total period of measurements. 150 km link, wet monsoon, mean value: 194.6 dB
Fig. 10.7. Cumulative distribution of 150 km link during wet monsoon.

$F(L_{is})$ is the probability the attenuation is below level $L_{is}$.

$L_{is}^s = 149.1$ dB = free space attenuation; $L_{is}^s = 231.7$ dB = receiver sensitivity

--- = lognormal distribution ($\mu = 194.6$ dB, $\sigma = 5.3$ dB)
Fig. 10.8. Transmission losses: percentage of total period of measurements. 150 km link; dry monsoon.
Mean value = 193.0 dB.
Fig. 10.9. Cumulative distribution of transmission loss of 150 km link during dry monsoon.

- $F(L)$: the probability the attenuation is less than $L_{fs}$-value.

- $L_{fs} = 149.1$ dB = free space loss; $L^b = 231.7$ dB = receiver sensitivity.

- $L_{fs} = 149.1$ dB; $L^b = 231.7$ dB = lognormal distribution ($\mu = 193$ dB, $\sigma = 6.2$ dB)
Fig. 10.10. Transmission losses: percentage of the total period of measurements.

140 km link, wet monsoon; mean value = 192.2 dB.
Fig. 10.11 Cumulative distribution of 140 km link during wet monsoon. $L = \text{transmission loss (dB)}$

$F(L) =$ the probability the attenuation is less than the value $L$.

$L = 148.5 \text{ dB} =$ free space attenuation; $L = 231.7 \text{ dB} =$ receiver sensitivity.

--- = lognormal distribution ($\mu = 192.2 \text{ dB}, \sigma = 10.4 \text{ dB}$)
Fig. 10.12. Transmission losses: percentage of the total period of measurements.

140 km link: dry monsoon

mean value: 187.7 dB
Fig. 10.13. Cumulative distribution of transmission loss of the 140 km link during dry monsoon.

\[ F(L) = \text{the probability the attenuation is less than level } L. \]

\[ L = 148.5 \text{ dB } \triangleleft \text{ free space attenuation}; \quad L = 231.7 \text{ dB } \triangleleft \text{ receiver sensitivity.} \]

\[ \quad \quad \quad \quad \quad \quad = \text{lognormal distribution (} \mu = 187.7 \text{ dB, } \sigma = 11.5 \text{ dB)} \]
10.5. Median transmission losses

The median values of every hour were taken and averaged over longer periods in order to gain insight into the long term transmission losses and the influence of the seasons. Again the probability density functions and cumulative distributions have been calculated.

This time no distinction has been made between wet and dry monsoon; the influence of ducting has been expressed by calculating first the distribution of all hours together and then the distribution of only hours during which pure troposcatter occurred.

Table 3 gives the results of the calculations and the number of the graphs.

<table>
<thead>
<tr>
<th>link</th>
<th>incl. / excl. duct hours</th>
<th>mean value (dB)</th>
<th>standard deviation (dB)</th>
<th>median value (dB)</th>
<th>number of graph</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 km</td>
<td>incl.</td>
<td>193.2</td>
<td>7.1</td>
<td>195.8</td>
<td>10.14</td>
</tr>
<tr>
<td>150 km</td>
<td>excl.</td>
<td>195.2</td>
<td>4.1</td>
<td>196.9</td>
<td>- -</td>
</tr>
<tr>
<td>140 km</td>
<td>incl.</td>
<td>188.4</td>
<td>9.9</td>
<td>192.8</td>
<td>10.17</td>
</tr>
<tr>
<td>140 km</td>
<td>excl.</td>
<td>192.8</td>
<td>5.1</td>
<td>194.8</td>
<td>- -</td>
</tr>
</tbody>
</table>

Table 3. Median transmission losses and relevant graph numbers.

From the graphs can be concluded,

- In the 150 km link a mean duct occurrence of 11% of the time was recorded, in the 140 km link for 23% of the time.
- Both in the 150 km link and in the 140 km link, the troposcatter characteristics is a lognormal distribution. When the duct hours are included a divergence occurs for the higher signal levels.
- Ducting gives rise to a high standard deviation in the distribution of the mean values.
- Note the 3 dB difference in the criterium for the determination of duct level between the "150" and the "140" km path length. This is chosen in accordance with the difference in the mean signal value along the both paths.
Fig. 10.14. Transmission losses - median value per hour, 150 km link percentage of total period of measurements. (shaded part ≈ duct levels ≈ 11%) mean value including ducts = 193.2 dB mean value excluding ducts = 195.2 dB.
Fig. 10.15. Cumulative distribution of median transmission loss per hour for the 150 km link including duct hours. $F(L)$ = the probability the attenuation is higher than level $L$. 
--- --- --- = lognormal distribution ($\mu = 193.2$ dB, $\sigma = 7.1$ dB)
Fig. 10.16. Cumulative distribution of median transmission loss per hour for the 150 km link excluding duct hours. $F(L)$ = the probability the attenuation is higher than level $L$.

---

$L$ = median transmission loss (dB)
Fig. 10.17. Transmission loss median value per hour during percentage of time of total period of measurements (shaded part = duct levels ≥ 23%).

140 km link: mean value included ducts = 188.4 dB, mean value excluding ducts = 192.8 dB.
Fig. 10.18. Cumulative distribution of median transmission loss per hour for the 140 km link including duct hours. $F(L)$ is the probability the medium attenuation is higher than level $L$.

$-- -- -- = \text{lognormal distribution (}\mu = 188.4 \text{ dB, } \sigma = 9.9 \text{ dB})$
Fig. 10.19. Cumulative distribution of median transmission loss per hour of the 140 km link excluding duct hours. $F(L) =$ the probability the median attenuation is higher than level $L$.

$\mu = 192.8$ dB, $\sigma = 5.1$ dB.
10.6. Diurnal variations

Another long term variation of the received troposcatter signal can be expressed in the variation during the period of one day, averaged over a long period. The variation originates from day and night influence of meteorological conditions.

The variation can be caused by the high temperature variations between day and night (10°C) during the dry monsoon and an extra high humidity during afternoon and evening hours.

These phenomena also influence the probability of ducting. Because of this a distinction has been made between the dry and the wet monsoon. Also the levels which have been exceeded for 0.01% of the time have been determined as an indication of the quality of the link (see Fig. 10.19 and 10.20). From the graph can be deducted:
- During both monsoons, ducts occur in the period 13.00 - 23.00 hrs.
  Most ducts occur at 15.00 hr.
- During the duct hours the level of L_{is}^{0.01} is closer to the median level from which one can conclude that the short term fading of an instantaneous signal is less deep during ducting.
- During the period 9.00 - 11.00 hrs the value of L_{is}^{0.01} is below the sensitivity of the receiver.
- During the worst hour the signal was ducting 0.12% of the time below the receiver sensitivity.
- During the best hour a 'complete' duct occurred during 0.1% of the time.
For the worst hour (11.00 h) and the best hour (15.00 h) the probability density function and the cumulative distribution of the instantaneous attenuation have been calculated (see Fig. 10.21 and 10.22). The mean values are 196.4 dB for the worst hour of the day and 187.6 dB for the best hour of the day.

10.7. Short term fading

After elimination of the seasonal variations (diurnal, year) of the received troposcatter signal, the short term or fast fading will remain.

The short term fading is the variation of the signal related to the median value for a short period of time.
Fig. 10.19. Transmission losses: median attenuation per hour of the day averaged over dry and wet monsoon. $L_{50}^{is}$

- = wet monsoon
- - - = dry monsoon
worst hour = 11.00 h.
best hour = 15.00 h.
Fig. 10.20. Transmission loss: \( L_{0.01} \)

Losses exceeded for 0.01% of the time per hour of the day.

- ------ = wet monsoon
- --------- = dry monsoon

best hour = 15.00 h.
worst hour = 11.00 h.
Fig. 10.21. Transmission losses - percentage of the total time of the measurements for:

- the worst hour (11.00 h) - mean value = 196.4 dB
- the best hour (15.00 h.) - mean value = 187.6 dB.
Fig. 10.22. Cumulative distribution of transmission loss for the worst hour (11.00h) and the best hour (15.00 h). $L_{\text{free space}} = 149.1\, \text{dB}$ $\equiv$ free space attenuation; $L = 231.7\, \text{dB}$ $\equiv$ lowest detected signal level

$L = \text{transmission loss (dB)}$
Fig. 10.23 illustrates an instantaneous real time signal in two cases: with and without the presence of a duct and typical data processing outputs. One can see that during duct occurrence the fading is less deep and less rapid than during pure troposcatter. The short time fading characteristics are obtained by evaluation of the microprocessor outputs (number; aant) and relating all power levels to the median value. The results are often presented by a cumulative distribution indicating the probability of signal level being less or equal to a given value (relative to the median value):

\[ P\left(\frac{X}{X_{50}}\right) \leq \frac{X}{X_{50}} \text{ or } P(X \leq X) \text{ with } X = 20 \log \frac{X}{X_{50}} \]  

(10.3)

In Fig. 10.24 the characteristic graphs can be seen:
- duct situations
- pure troposcatter

The mean troposcatter characteristic for the two monsoon periods is according the predicted Rayleigh distribution. That is to say an exponential decrease of the probability at a decrease of signal strength, resulting in a straight line in the case of a logarithmic scale for the probability (10 dB/decade) for the low level signal. Fig. 10.24 gives the results after averaging many short periods of measurements.

During duct occurrence a Rice-like distribution has been measured although there is no question of a real harmonic component next to the Rayleigh component (→ only local ducts and no LOS-mode). Here it was also shown that the main influence was the low signal levels. The fading is considerably less deep than in the case of pure troposcatter. Combined calculations of the data number ('aant') and through ('door') leads to more fading parameters: first the fading frequency, the times per second the instantaneous signal is below a given level relative to the median signal level.

The fading frequency is calculated over one hour (= 3600 sec.). For a given level \( P_n \) it is:

\[ f_f(n) = \frac{\text{Door (} H_n \text{)}}{3600} \text{ (Hz) where } H_n \text{ is the number of downwards crossings of a given level } n \text{ in the intervals between two samples.} \]  

(10.4)
Fig. 10.23a. Typical troposcatter signal: Mostly occurring during the day-time. Registration speed: 50 mm/min.
Fig. 10.23b. Typical duct signal:
Sometimes occurring in the afternoon, many times during the first half of the night.
Registration speed: 50 mm/min.
Fig. 10.23c. Typical data processing output for troposcatter occurrence.
Hourly cumulative distribution of troposcatter signal, in the presence of a duct.

Fig. 10.23d. Typical data processing output for duct occurrence.
Fig. 10.24.
Short term fading. (mean values)
Probability $P$ that the signal (relative to the median value) is less or equal to a given value $X = \frac{x}{x_{50}}$.
In Fig. 10.25 the fading frequency has been plotted for cases of ducting and pure troposscatter.

It can be concluded that during ducting the frequencies are much lower than during pure scatter (a factor 3 at the $-10$ dB level and a factor 8 at a $-30$ dB level). It can also be seen that the fading frequency is about exponentially proportional to the signal level (a straight line in a case of a logarithmic scale): in case of ducting: $11$ dB/decade. in case of troposscatter: $16$ dB/decade.

Data points from [57] and [60] should be corrected for distance $d$.

$$f_f(x) = \frac{f(\text{GHz})}{4} \frac{d(\text{km})}{150} x$$

Fig. 10.23

Fig. 10.25. Fading frequency (Hz).

Number of times per second the signal is below a given level for ducting and troposscatter.
Another parameter which can be calculated is the fading time, which is the average time period of one fade, or the total time a signal is continuously below a given level.

Since the sampling time of the troposcatter was 0.1 sec. one can calculate the fading time by:

\[
\frac{0.1 \cdot \sum_{i=0}^{n} \text{aant}(i)}{H_n} \text{ (sec)} = \frac{0.1 \cdot N_n}{H_n} \text{ (sec)}
\]  
(10.5)

The fading time has been plotted in Fig. 10.26 for cases of pure troposcatter and ducting.

During duct occurrence the mean fading time appears to be longer than during troposcatter. The decrease is again exponential (25 dB/decade). During pure troposcatter the decrease in the higher signal levels is also exponential (20 dB/decade) but in case of lower signal levels the curve tends to 0.1 sec., which is the sampling time and thus the minimal discrimination power of the data processing unit. But literature shows that the total curve is exponential [1].

The time interval between the start of two fades can be determined by taking the inverse of the fading frequency. By combining this function with the time of one fade, one can determine the mean time between the end of a fade and the start of the next fade at the same depth, as a function of the signal strength (Fig. 10.27 and Fig. 10.25a).

\[
\frac{t_{ff}(X)}{t_{f}(X)} = \frac{1}{f_{f}(X)} - t_{f}(X) \text{ (sec)}
\]  
(10.6)

(Artificial average fading signal)
\[ t_f(X) = \frac{x^2}{f_f(X)} \geq X \frac{4}{f(\text{GHz})} \frac{150}{d(\text{km})} \]

**Fig. 10.26.** Fading time (sec) - time period of one fade below a given level for duct and troposcatter.
Fig. 10.27 Fading characteristic

Time period between end of a fade and start of the next fade (of same depth) in sec. = $t_{ff}(x)$
Averaged over a period of one year (150 km link)
10.8. **Correlation of the troposcatter signal with the meteorological quantities**

The amplitude of a troposcatter signal is proportional to the square of the variations of the dielectric constant within the common volume:

\[ P_r = \frac{(\Delta \varepsilon)^2}{\varepsilon} \quad \text{(see Eq. 6.48)} \]  

(10.6)

The exact value of \( \varepsilon \) is not very important for the scattering of radio waves, but more important for the propagation of radio waves within the medium between transmitter and receiver antenna. The altitude of the common volume, scatter angle and probability of ducting are mainly determined by the gradient of the refractivity.

The relative dielectric constant \( \varepsilon_r \) and thus the refractive index \( n \) depends on the meteorological quantities as follows (see Eq. 6.4):

\[ \varepsilon_r = n^2 = 1 + P \left( \frac{C_1}{T} + \frac{C_2 \varepsilon}{T^2} \right) \]  

(10.7)

Registration data from the project's weather station and the 'Stasiun Meteorologi Perak Surabaya' [1 and 15] have been averaged in order to obtain yearly and daily variations of these meteorological quantities. The yearly variation is presented in Fig. 10.28. It can be seen that [21] the pressure (P) is higher during the dry monsoon, temperature (T) is maximum during the periods between the monsoons (May, November), vapour pressure (\( \varepsilon \)) is, naturally, higher during the wet monsoon and the refractivity at the earth surface (\( N_s \)) has high correlation with the humidity. The gradient of the refractivity within the first 1500 m of the troposphere (\( \approx \) surface - 850 mbar) does not exceed (fig. 9.2) for 90\% of time the level \( \Delta N = -65 \) (\( k = 1.71 \)), for 5\% of time the level \( \Delta N = -45 \) (\( k = 1.4 \)), for 50\% of time the level \( \Delta N = -55 \) (\( k = 1.54 \)), thus for 85\% of time \( \Delta N = -55 + 10 \) (k-factor between 1.4 and 1.71), when no ducting occurs.

The probability for a duct (\( \Delta N < -157 \)) varies between 1\% (wet monsoon) and 10\% (dry monsoon). The higher probability for ducting during the dry monsoon can also be derived from the registrations of the transmission losses.

Fig. 10.29 shows the diurnal variations of the signal during two situations.

One day without rain and one day with a shower between 14.00 h and 18.00 h.
Fig. 10.28. Seasonal variations of meteorological parameters in the course of one year for the region of Surabaya, averaged over the years 1961 until 1971.
Pressure P (mbar), temperature T (°C), water vapour pressure e (mbar), surface refractivity $N_s$. 
[73]
Fig. 10.29. Diurnal variation of meteorological parameters. Temperature (°C), water vapour pressure (mbar), surface refractivity $N_s$.

--- = day with rain
--- --- = day without rain

It appears that in the case of no rain the temperature $T$ during the day is much higher than during the night, whereas the water vapour pressure $e$ and the surface refractivity $N_s$ have a minimum around noon (12.00 h.).

If it is raining, the temperature drops and $e$ and $N_s$ rise.

The diurnal variations of air pressure and the influence of a shower on the air pressure are negligible. No data was available in order to calculate the diurnal variations of the refractivity index gradient $\Delta N$.

The high probability for ducting during the afternoon can be explained by continuous heating of the sea surface by the sun, resulting in a high evaporation and thus a negative humidity gradient within the first 30 m. altitude. This gradient is not disturbed by the light wind of about 1 m/sec.

During a rain shower higher wind speeds (> 5 m/sec) will often occur resulting in a good mixing of the different air-layers and thus decreasing the probability of ducting.

A correlation between the data registrations of the troposcatter signal and the weather quantities can be calculated. For this the linear regression method was used, in which the relation between a meteorological quantity $X$ and the median transmission loss $\bar{L}_{50}$ in dB/hour is:

$$X = a\bar{L}_{50} + b$$  \hspace{1cm} (10.8)

where:

$$a = \frac{\sum_{i=1}^{N} (L_i - \bar{L})(X_i - \bar{X})}{\sum_{i=1}^{N} (L_i - \bar{L})}$$  \hspace{1cm} (10.9)

$$b = \bar{X} - a\bar{L}$$

$N = \text{total number of registrations.}$

The correlation coefficient can be calculated by:

$$\rho = \frac{\sum_{i=1}^{N} (L_i - \bar{L})(X_i - \bar{X})}{\sqrt{\sum_{i=1}^{N} (L_i - \bar{L})^2 \sum_{i=1}^{N} (X_i - \bar{X})^2}}$$  \hspace{1cm} (10.10)
Results of the calculations are given below [20]:

\[
\begin{align*}
\text{air pressure} & : \quad P = 0.19L + 978.5 \ \text{(mbar)}; \quad \rho = 0.27 \\
\text{temperature} & : \quad T = -7.10^{-3}L + 29.1 \ \text{({°C})}; \quad \rho = -0.22 \\
\text{relative humidity} & : \quad RH = 0.22L + 27.7 \ \text{(%)}; \quad \rho = 0.24 \\
\text{refr. index modulus} & : \quad N = 0.37L + 298.1; \quad \rho = 0.02
\end{align*}
\]

(10.11)

The water vapour pressure \( e \) can be calculated by multiplying the relative humidity \( RH \) with saturation water vapour pressure \( e_s \); this is a function of temperature \( T \) (°C):

\[
e = \frac{RH}{100} \cdot e_s = \frac{RH}{100} \cdot 13.144 \cdot \exp\left[0.06(T-10)\right] \ \text{(mbar)}
\]

(10.12)

where: 
- \( e \) is water vapour pressure (mbar)
- \( RH \) is relative humidity (%)
- \( T \) is temperature (°C)

It can be seen that the influence of the air pressure and temperature is not large, whereas the refractivity has a large influence but with a low correlation.

The highest influence on the troposcatter signal is from the water vapour pressure (also high correlation).

Numerical values in case of pure troposcatter during an 'average' situation might be:

\[
\begin{align*}
\overline{L} &= 195 \ \text{dB}, \quad \overline{P} = 1015.5 \ \text{mbar}, \quad \overline{T} = 27.7 \ \text{°C} \\
\overline{RH} &= 70.6 \ %, \quad \overline{e} = 25.8 \ \text{mbar}, \quad \overline{N} = 370.3
\end{align*}
\]

In case of a total duct over the propagation path:

\[
\begin{align*}
\overline{L} &= 149.1 \ \text{dB}, \quad \overline{P} = 1006.8 \ \text{mbar}, \quad \overline{T} = 28.1 \ \text{°C} \\
\overline{RH} &= 60.0 \ %, \quad \overline{e} = 23.2 \ \text{mbar}, \quad \overline{N} = 318.5.
\end{align*}
\]

Result (10.11) suggests that there is a relation between the troposcatter transmission loss and the meteorological parameters.
10.9. **Accuracy of the measurements**

Several inaccuracies in the results of the measurements can occur, which originate from:
- deviations in equipment from nominal values
- inaccuracies of measurement
- inaccuracy of calculation.

The inaccuracies of transmitter and receiver are listed in the following table:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Transmitter</th>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute</td>
<td>Relative</td>
</tr>
<tr>
<td>Power</td>
<td>+ 0.2 dB</td>
<td>+ 0.023</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>+ 0.2 dB</td>
<td>+ 0.023</td>
</tr>
<tr>
<td>Cable loss</td>
<td>+ 0.2 dB</td>
<td>+ 0.023</td>
</tr>
<tr>
<td>Feeder loss</td>
<td>+ 0.2 dB</td>
<td>+ 0.023</td>
</tr>
<tr>
<td>Instability</td>
<td>+ 0.5 dB</td>
<td>+ 0.056</td>
</tr>
<tr>
<td><strong>Total error</strong></td>
<td>+ 1.3 dB</td>
<td></td>
</tr>
<tr>
<td><strong>RMS error (maximal)</strong></td>
<td>+ 0.65 dB</td>
<td></td>
</tr>
</tbody>
</table>

The receiver instability is temperature dependent and is greater for the lower signal levels but never exceeding + 0.2 dB. The sampled troposscatter signal is divided into intervals, each of 3 dB, implicating an inaccuracy of + 1.5 dB.

The mean inaccuracy is

\[
\Delta_{x} = \frac{\Delta_{x}}{\sqrt{N}}
\]  

(10.13)

where: \(\Delta_{x} = \) inaccuracy per sampled point = + 1.5 dB \(N = \) number of data points

For the absolute error from above table is valid:

absolute error [dB] = 20 \log \frac{V_{1}}{V_{2}} \quad \text{then} \quad V_{2} = 10^{-\frac{\text{abs. error}}{20}}

and

relative error = \frac{V_{1} - V_{2}}{V_{1}}

where \(V_{1} = \) reference voltage = 1 volt

\(V_{2} = \) voltage error
For the following calculations we will obtain:

- per season: \( N_n \approx 1600, \Delta X = 0.04 \text{ dB} \)
- per week: \( N_n \approx 125, \Delta X = 0.13 \text{ dB} \)
- per hour of the day: \( N_n \approx 80, \Delta X = 0.17 \text{ dB} \)

short term characteristics: \( N_n \approx 500, \Delta X = 0.07 \text{ dB} \)

It can be concluded that \( \Delta X \leq \pm 0.2 \text{ dB} \)

A combination of the RMS inaccuracies for transmitter, receiver and data processing leads to an approximation of the total inaccuracy, RMS (total) \( \leq \pm 1 \text{ dB} \), absolute maximal error being \( \pm 2.5 \text{ dB} \).

10.10 Conclusions

1. In general the measured transmission losses in the Situbondo-Surabaya link agreed well with the predicted values by the CCIR method.

2. The difference between the calculated CCIR value of 195.2 dB and the average measured median value per hour is less than the \( \pm 2.5 \text{ dB} \) max. inaccuracy of the used microwave system.

3. The long term median fading shows a lognormal characteristic with an average spread of 6 dB.

4. The short term fading follows the Rayleigh distribution.

5. This link with the length of its common volume almost as long as its overhorizons distance, which is above water and rather short, is not a pure troposcatter link, but has a lot of ducting influences ('long-distance-line-of-sight').

6. In the wet monsoon the ducting occurrence was not so high (\( \approx 10\% \) of the time), but in the dry monsoon it became much more important (\( \approx 25\% \) of the time).

7. After the relocation of the receiver site towards the coast, the ducting influences increased significantly.

8. The maximal measurable transmission loss of 230 dB was exceeded during the worst season (wet monsoon) for average 0.08% of the time, and during the worst hour of the day (11.00 h.) for 0.15%.
9. Ducting normally occurs in the late afternoon and early evening namely about 15.00 hours. That hour is the best hour of the day and in the opposite way 11.00 hours is the worst. From economical point of view: it is not pleasant, as the Indonesian peak business hours with the highest demand for telecommunication channels lay between 10.00 hours and 14.00 hours.

10. The measured deep and rapid short term fading supports the assumed theoretical model of scattering by many turbulent tropospherical volumina. This gives the mean fading frequency \( \bar{f}(x) \approx \frac{f[\text{GHz}]}{4} \times \frac{d[\text{km}]}{150} \times X \)

10.11 Suggestions

1. For further experiments, crosspolar measurements with transmitting both polarization directions simultaneously, so that cross talk and fading correlation can be investigated, would be interesting.

2. Investigation into the influence of the elevation angle of the antenna to the ducting phenomena.

3. Experiments with a modulated radiosignal to investigate the frequency selective fading and the pulse dispersion in the case of digital modulation.
Chapter 11

EXPERIMENT ON CROSSPOLARISATION IN THE TROPOSCATTER LINK
SITUBONDO – SURABAYA

Abimanyu
Son of Arjuna and Sumbadra, who, for his gifts of character and martial skill, was the Pandava’s chosen candidate for the throne of Astina.
11. Experiment on crosspolarisation in the troposcatter link Situbondo - Surabaya

11.1. Introduction

A general electromagnetic plane wave can be considered as a sum of two linear polarized electric fields, perpendicular to each other and perpendicular to the direction of propagation. It can also be considered as a sum of two circular polarized waves, rotating in opposite directions.

Depolarization can occur when a signal is propagated through the troposphere, which can be understood as an energy transfer from one polarization to another. A possible origin of this depolarization is through scattering, where waves change direction, frequency and polarisation when propagated through a medium. The propagation constant \( \gamma = \alpha + j \beta \) will differ for two (polarized waves) perpendicular to each other in the case of forward scattering (like troposcatter). This will result in a different attenuation and phase for both polarisations at the receiver site.

In the transmission of a wave, linearly polarized in one direction, electric component perpendicular to this wave can be detected at the receiver site. This is called the cross-polar component, which is of importance for the design of radio communication systems using both polarization directions for data transmission.

Consider two electromagnetic waves and their electric field components perpendicular to each other (horizontal and vertical):

\[
\vec{E}_x = E_x \hat{e}_x = E_1 \sin(\omega t) \hat{e}_x \\
\vec{E}_y = E_y \hat{e}_y = E_2 \sin(\omega t + \tau) \hat{e}_y
\]

where: \( E_1 \) and \( E_2 \) = magnitudes of \( E_x \) and \( E_y \)
\( \tau = \) phase difference between \( E_x \) and \( E_y \).

For the components of the electric fields in the resulting wave, we find, after elimination of the time dependent component:

\[
\frac{E_x}{E_1} + \frac{E_y}{E_2} = 2 \frac{E_x E_y}{E_1 E_2} \cos \tau = \sin^2 \tau
\]

Equation (11.2) is the equation of an ellipse, representing the end-point of a vector \( \vec{E} = \vec{E}_x + \vec{E}_y \).
Fig. 11.1. Composition of two polarizations of electric fields of two waves. \( \mathbf{E} = \mathbf{E}_x + \mathbf{E}_y \) (ellipse).

Several situations can occur:
- \( E_1 \) or \( E_2 = 0 \): the ellipse will degenerate to a straight line, representing linear polarization.
- \( \phi = \pm n \pi \) (\( n \) is integer): linear polarization again.
- \( E_1 = E_2 \) and \( \tau = \pm \frac{2m + 1}{2} \pi \) (\( m \) is integer): the total E-field is now presented as a circle, (circular polarization) where two situations can be distinguished:
  - \( m = \) even: right oriented circular
  - \( m = \) uneven: left oriented circular.

In case of circular polarization the electric components of the waves can be described as:

right: \( \mathbf{E}_x = \frac{1}{2}(E_1 + E_2) \cos \omega t \mathbf{e}_x + \frac{1}{2}(E_1 + E_2) \sin \omega t \mathbf{e}_y \)  
left: \( \mathbf{E}_1 = \frac{1}{2}(E_1 - E_2) \cos \omega t \mathbf{e}_x - \frac{1}{2}(E_1 - E_2) \sin \omega t \mathbf{e}_y \)  

In Fig. 11.2 the waves polarized in two directions (x and y) can be seen. The transmission direction is into the z-direction.

The definitions of the components are:

\( E_{xx} = \) signal transmitted and received in x-direction
\( E_{yy} = \) signal transmitted and received in y-direction.
\( E_{yx} = \) signal transmitted in x-direction and received in y-direction.
\( E_{xy} = \) signal transmitted in y-direction and received in x-direction.
Fig. 11.2. Definition of cross-polarization

Definitions:
- Cross-polar discrimination (XPD) = fraction of energy transferred to the component of the other polarization direction.

\[ XPD_x = -20 \log \left( \frac{|E_{yx}|}{E_{xx}} \right) \ (\text{dB}) \]
\[ XPD_y = -20 \log \left( \frac{|E_{yx}|}{E_{yy}} \right) \ (\text{dB}) \]  

(11.4)

- Cross-talk discrimination (XTD) = fraction of energy received from the component of the other polarization direction.

\[ XTD_x = -20 \log \left( \frac{|E_{xy}|}{E_{xx}} \right) \ (\text{dB}) \]
\[ XTD_y = -20 \log \left( \frac{|E_{xy}|}{E_{yy}} \right) \ (\text{dB}) \]

(11.5)

11.2. Project description

This report on Co and X-polar measurements is part of the troposcatter measurement on the troposcatter link Surabaya - Situbondo (East Java). In general, X-polar measurements fulfill two aims. Firstly, measurements are useful for scientific purposes related to the physical description of the medium which is responsible for the cross-polarization phenomena. Secondly, the measurements are useful for practical purposes for any one wanting to use the communication link for re-use of frequency purposes or for a diversity link using two orthogonal polarizations.
The measurement system described in this paper, although now working on a tropolink, can be used for co-polar and X-polar measurements on line of sight links and satellite communication links as well.

11.3. Description of the equipment

11.3.1. Description of the general block diagram of the measuring equipment (Fig. 11.3)

To measure the main (Co) and cross (X) polar signals, a 3 m. diameter parabolic antenna was placed on a 12 m. high mast on the roof of the Fakultas Teknik Elektro building in Surabaya. The Co- and X-polar signals were separated by the orthomode transducer (OMT) which is at the focal point of the antenna, and lead to the receiver room via two low loss coaxial cables. The main polar and cross polar receiving station consists of two nearly identical front-end down converters and Phase Lock Loop (PLL) receivers (see Fig. 11.3). In the main polar chain the 4012 MHz RF-signal passed the OMT and is converted down to 30 MHz. After filtering and amplification a second down converting is necessary, since the PLL receiver input frequency is 10 MHz. This increases the selectivity and it is a contribution in suppressing unwanted spurious outputs. Because of the large signal amplitude variations there was an extra 30 dB 30 MHz IF-amplifier installed to be switched on or off manually or automatically. The switch was operated by a switch driver and its high gain/low gain position depends on the log D.C. output level. After leaving the OMT the cross polar signal entered the other 4012 MHz mixer and identically treated in a second 30 MHz and 10 MHz IF-strip. Even without a crosspolar signal the crosspolar receiver was tuned to the right frequency, because both receivers are driven by the same Voltage Controlled Oscillator (VCO). Furthermore this "slaved" crosspolar receiver contained a 0 - 360° phase detector. To avoid unwanted phase shifts in the receiving station, the local oscillator outputs were split and had the same phase relationship. Cables, directional couplers, amplifiers, attenuators etc., had to be kept in their original position for the same reason. The lin, log and phase detector outputs were recorded on a chart recorder for "visible" result and also treated by a data processor.
Fig. 11.3: General block diagram of measuring equipment for cross-polar measurement.
11.3.2. **Description of the block diagram of the 10 MHz main polar phase locked loop and "slaved" 10 MHz cross-polar receivers (Fig. 11.4)**

The 10 MHz mainpolar receiver contains a double balanced mixer and together with the 10.125 MHz Voltage Controlled Oscillator (VCO) output frequency, the 10 MHz RF-signal is mixed down to 125 kHz I.F. (See Fig. 11.4 and 11.5). The digital control unit is equipped with a sweep generator, comparator and decision filter. The incoming IF-signal is compared with the 125 kHz 0° reference signal. When the resulting output frequency of the phase comparator is within the chosen bandwidth, the decision filter will stop the sweep generator and the loop is closed. The DC voltage output of the loop filter becomes 0 Volts as the loop phase detector is fed by an 125 kHz signal with 90° phase difference. When no 10 MHz input signal is available the decision filter starts the sweep generator and the output voltage of the loop filter varies following a triangle waveform, adjustable from ± 200 mV for ± 1 kHz to ± 10 Volts for ± 50 kHz frequency variation. So, the output frequency changes from 10.075 MHz to 10.175 MHz to cover deviations and instabilities of frequency sources. The 125 kHz IF frequency is fed to the synchronous amplitude detector unit/audio amplifier and is compared with the 125 kHz 0° reference frequency. The resulting DC voltage drives the linear and log. amplifier. Several output connectors are available for a chart recorder, microprocessor, etc.

**The 10 MHz cross-polar receiver:**

There are some design differences in the cross-polar receiver compared with the main receiver as the narrow bandwidth of 1-2-5 Hz, it needs a second IF of 5 kHz. The 120 kHz Voltage Controlled Crystal Oscillator (VCXO) can be swept over a small range (+ 1 kHz) too, for covering drifts when there is no cross-polar signal available at the input. As mentioned earlier, the cross-polar receiver is tuned by the main polar receiver's V.C.O. So, if the main polar input frequency deviates, its crosspolar component will have the same deviation.

The phase detector is fed by the 120 kHz reference signal and the 120 kHz VCXO output frequency. The output depends on the phase shift between these two inputs. Passing the 0.3 - 3 - 30 Hz adjustable low pass filter compared with a fixed D.C. voltage of the operational amplifier 0 - 360° variations will give a 0 - 10 Volts DC output signal.

It was recommended to drive the reference generator with a highly stable extern 1 MHz frequency source. However, for "in the field" operations this reference generator was equipped with a 1 MHz 10⁻⁶ crystal oscillator.
Fig. 11.4: 10 MHz phase locked loop main polar receiver and slaved cross polar receiver.
Fig. 11.5: Block diagram Co-polar and X-polar receivers.
11.3.3. **Calibration of the measuring system**

**Fig. 11.6:** Arrangement for receiver calibration.

Fig. 11.6 is a block diagram of the system including the calibrating signal source. A power meter is omitted in the diagram.

In this arrangement the successive losses and gains are determined following the insertion loss (gain) measuring method.

In Table 1 the main characteristics of the receiver will be listed. Firstly, the co-polar receiver is calibrated and then the X-polar receiver. Note that the co-polar receiver remains locked during calibration of the X-polar receiver. The receiver sensitivity is in accordance with the theoretical expectations. The receiver "white" noise level can be calculated as follows: (including the antenna noise $T_A = 290 \, \text{K}$.)

$$ n = k T_0 B F $$

(11.6)

\[ k = \text{Boltzmann constant} \]
\[ T_0 = 290 \, \text{K} \]
\[ B = \text{system bandwidth} = 10 \, \text{Hz} \]
\[ F = \text{system noise figure} = 10 \, \text{dB} \]

One can also write:
\[ N = 10 \log n = 10 \log F + 10 \log \frac{B}{1 \text{ Hz}} + 10 \log \frac{kT_0}{1 \text{ Hz} 1 \text{K}} \]  
(11.7)

or

\[ N = 10 \log n = F_{\text{dB}} + 10 \log \frac{B}{1 \text{ Hz}} - 174 \text{ dBm} \equiv -154 \text{ dBm}. \]  
(11.8)

With this simple formula and taking into account a 10 dB loop signal to noise ratio the receiver bottom sensitivity is -144 dBm. This figure can be found in practice. The dynamic range is 60 dB for both receivers. This is not enough for the registration of the daily signal variations so a "signal switched amplifier" is built in the receiver.

<table>
<thead>
<tr>
<th></th>
<th>main polar</th>
<th>crosspolar</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF input frequency</td>
<td>10 MHz</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Min. (in lock) input level</td>
<td>-80 dBm</td>
<td>-86 dBm</td>
</tr>
<tr>
<td>Max. input level</td>
<td>0 dBm</td>
<td>-26 dBm</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>60 dB</td>
<td>60 dB</td>
</tr>
<tr>
<td>Linearity of dynamic range</td>
<td>± 0.3 dB</td>
<td>± 0.3 dB</td>
</tr>
<tr>
<td>Min. sweep range</td>
<td>± 1 kHz</td>
<td>± 1 kHz</td>
</tr>
<tr>
<td>Max. sweep range</td>
<td>± 50 kHz</td>
<td>± 1 kHz</td>
</tr>
<tr>
<td>IF frequency</td>
<td>125 kHz</td>
<td>125 kHz</td>
</tr>
<tr>
<td>IF bandwidth</td>
<td>10 kHz</td>
<td>3 kHz</td>
</tr>
<tr>
<td>Loop band width (manual/automatic)</td>
<td>100-200-500</td>
<td>1-2-5-Hz</td>
</tr>
<tr>
<td></td>
<td>1000 Hz</td>
<td></td>
</tr>
<tr>
<td>Phase detector bandwidth</td>
<td>--</td>
<td>0.3-3-30 Hz</td>
</tr>
<tr>
<td>Phase stability (15 - 40°C)</td>
<td>--</td>
<td>± 1°</td>
</tr>
<tr>
<td>Synchronous detector stability (15-40°C)</td>
<td>± 0.5 dB</td>
<td>± 0.5 dB</td>
</tr>
<tr>
<td>VCO frequency</td>
<td>10.125 MHz</td>
<td>--</td>
</tr>
<tr>
<td>VCO freq. stability (open loop, 15-40°C)</td>
<td>± 1 kHz</td>
<td>--</td>
</tr>
<tr>
<td>VCXO frequency</td>
<td>--</td>
<td>120 kHz</td>
</tr>
<tr>
<td>VCXO freq. stability (open loop, 15-40°C)</td>
<td>--</td>
<td>± 200 Hz</td>
</tr>
</tbody>
</table>

Table 1: Characteristics of the PLL main and crosspolar receivers.
11.4. Results of the experiment

11.4.1. Conclusions

In Situbondo only vertically polarized signals were transmitted. In Surabaya both directions were detected (vertical and horizontal polarization).

It was only possible to do the measurements during a short period, so that no definite conclusion can be made from the registrations. But some indication about the behaviour in this link can be given.

From the registrations (see Fig. 11.3 and Fig. 11.4) the following approximation could be calculated:

\[ XPD_y = 20 \log \left| \frac{E_{xy}}{E_{yy}} \right| = -30 \text{ to } -40 \text{ dB} \]  

(11.6)

where index \(x\) = horizontal \\
\(y\) = vertical.

From this it can be concluded that within a tropospheric scatter link of 140 km a good isolation between both polarizations can be obtained, resulting in a good communication link for two channels.

From the registrations a high correlation between the main and cross polar signals could (also) be concluded. From this it is not possible to conclude that a high correlation between horizontal and vertical polarizations exists, other experiments, in which simultaneous transmission on both polarizations would be needed. From literature it is known that a high correlation exists between vertical and horizontal polarization which means that the polarization diversity is not effective in a troposcatter link. During ducting, both main and cross-polar signals increase, but the cross polar signal not as much.

This means a higher isolation between main and cross-polar signal in the case of ducting.

11.4.2. Preliminary measurement results

Fig. 11.7. shows a recording of the long term main and cross-polar signals together with the phase variation between them.
Fig. 11.8. A graph showing the correlation between main polar, cross-polar and phase during an "event" in March, 1980.

Fig. 11.9. An impression of the short term recording of the X-polar (dotted line) and phase (solid line) correlation.

Fig. 11.10 Short term recording of the main polar (dotted line), and phase (solid line) signal correlation.

Fig. 11.11 The main and cross-polar signals long term recording. Note the scale displacement is 20 dB. The average isolation is 30 to 40 dB. Below is a recording of short term main and cross-polar signals.

11.4.3. Problems that occurred with the measurement equipment

The following problems occurred with the measurement equipment:

- Although the transmitting antenna was linear (vertical) polarized, one still has a cross-polar component due to the feeder and the paraboloid. This component is at least -35 dB relative to the co-polar component. Not only the on-axis decoupling of the transmitting antenna is of importance as with LOS systems, but also the off-axis X-polar diagram because of the scattering volume which was illuminated by the crosspolar antenna radiation pattern.

- Further the receiving and transmitting co-polar planes have to be in parallel position.

- The receiving antenna on-axis cross polarization decoupling is also better than 35 dB.

- The receiver decoupling between co and X-polar is better than 65 dB and it seems sufficient relative to the antenna decoupling.

- The lock in time of the slaved X-polar receiver during very deep fades was lower than -150 dBm receiver input signal.

- At present, it is not possible to measure troposcatter decoupling phenomena greater than 35 dB due to antenna and orthomode imperfections.
Fig. 11.7. Recording of the main and cross-polar signal, and also the phase variation between both signals. March 1980, stable scatter-duct signal.
Fig. 11.8. Recording of the main and crosspolar signal, and the phase variation between both signals.
March 1980, unstable scatter signal.
Fig. 11.9: Short term X-polar and phase correlation. X-polar (dotted line) and Phase (solid line). (Note: recorder pen distance is 3.5 mm).

Date: 9 October 1980.
Fig. 11.10: Short term recording correlation. Mainpolar (dotted line).
Phase (solid line). (Note: pen distance is 3.5 mm);
Date: 9 Oct. 1980.
Fig. 11.11: Long term recording main and cross-polar with $\tau = 30$ sec. filter. Pen displacement = 5 mm. 2 October 1980

Scale displacement 20 dB due to IF gain difference in co and X-receivers

Fig. 11.12: Short term recording main (solid line) and cross-polar (dotted line). Filter bandwidth = 30 Hz. (Note: distance between pens is 5 mm). (4 Oct. 1980)
Chapter 12

EXPERIMENTS ON SATELLITE RECEPTION

Semar
Servant of Pandawa, father of Gareng and Petruk; in reality he is a god in the guise of a lowly person.
12. Experiments on satellite reception

12.1. Satellite reception in Surabaya

In order to facilitate post project activities by our Indonesian colleagues possibilities in satellite reception have been created to be fitted within the framework of this project. In general, there are a number of possibilities e.g. experiments in the 137 MHz weather satellite band, the 145 MHz amateur band, where currently two satellites are available, the 1.7 GHz weather satellite band and finally the 4 and 6 GHz telecommunication satellite band.

Taking into account the limited amount of finances as well as available time, a choice has been made for the reception of the geostationary meteorological satellite (GMS) in the 1.7 GHz band primarily, with the possibility of extension for receiving 137 MHz satellites, although this band is not further explored and will probably not be used for this purpose in the near future. By means of using equipment which has to be constructed by ITS itself, it should be possible to do reception experiments in the 4 and 6 GHz bands, using part of the equipment installed in the framework of the project THE/2.

The main reason for choosing the reception of the GMS satellite is the fact that this satellite may provide extra weather information on the propagation path Surabaya - Situbondo, which is of importance for the evaluation of the propagation data. Furthermore, the satellite is of the geostationary type, and so a simple antenna pointing system can be used. The geostationary satellites will probably dominate in the future, so the choice is a logical one too. The technology of the lower microwave region (1.7 GHz) is not too difficult to be mastered and in the meantime being a welcome diversification from the technology introduced so far. Finally, the whole receiving installation for the GMS satellite lends itself well for 'do-it-yourself' activities, as has been proved by some amateur enthusiasts in Europe. Bearing in mind not only the possibilities but also the limitations of our Indonesian colleagues, this approach offered the most realistic chance of success.
12.2. Geostationary Meteorological Satellite (GMS), General description

The GMS weather satellite is one of the five satellites, being used for a world wide system of weather information satellites. Its position is approximately 140 degrees East of Greenwich and as the satellite is a geostationary one, its position is directly above the equator. It can be proved that a geostationary satellite orbits the earth at an altitude of 36000 kilometers and that the time, needed for one complete orbit is exactly 24 hours. In other words, if the satellite orbits in the correct direction, it virtually does not change its position, seen from the earth. Therefore, an antenna system with fixed elevation and azimuth can be used for the reception of this satellite. [28]

The GMS satellite provides several kinds of information. This information is obtained, using a 'scanning radiometer'. In this way, 'pictures' of the earth are taken in the visible light region, the infra-red region and the hydrogen absorption region. These pictures are transmitted to the ground station, using digitally coded PSK-modulation*. After demodulation and processing, the processed pictures are sent back to the satellite, which in turn retransmits these pictures to earth, however this time the APT-transmission** system is used. The differences between the two systems can be understood from the following. The original picture is obtained by rotating the satellite around its own axis and simultaneously elevating the parabolic receiving system, which forms the radiometer system. Three different sensors provide the different types of radiation patterns. After conversion to digital information, the pictures are stored and processed as the earth covers only 5\% of the total scan of the radiometer. In this way a more conventional picture of the earth is transmitted to the ground station, using PSK-modulation. Visible information is coded in 64 intensity levels, each picture consisting of 5000 lines, each line consisting of 5000 'points'. Infra-red pictures contain 2500 lines, 2500 points and use 256 intensity levels, whereas the hydrogen information is only coded into 2500 lines, 2500 points with 64 levels. Bearing in mind that for the processing of such a picture fairly complicated computer systems must be used, it is obvious that for the reception under less sophisticated circumstances a much simpler system has to be used. This system is the APT-system,**

* PSK = Phase Shift Keying
** APT = Automatic Picture Transmission
which in fact has already been used for a very long time. This system is commonly used for the reception of non-geostationary satellites in the 137 MHz band. The RF carrier is frequency modulated with a subcarrier, which in turn is amplitude modulated with the information. One picture is composed according to Fig. 12.1. Summarising, the APT picture consists of 800 lines, each containing 840 picture points. No discrete levels can be distinguished in this picture. Relatively simple methods of modulation are used, hence the detection will not be too complicated.

![Diagram](image.png)

Fig. 12.1. Composition of picture transmitted by the GMS satellite.

[56, fig. 7a]

Registration of these pictures can be done by means of electromechanical registration using electro-sensitive paper or by means of photographic methods using light sensitive paper.

12.3. **GMS satellite and the RF signal**

The information from the satellite is transmitted to the earth using 1694.5 or 1691.0 MHz. The satellite's effective radiated power amounts to +48 dBm. These figures are for the APT-modulated transmissions. The polarisation used is linear. The carrier frequency is frequency modulated with a 2400 Hz subcarrier which in turn is amplitude modulated with the video information. Maximal frequency deviation is 9 kHz resulting in a maximal transmission bandwidth of 26 kHz. Maximal video bandwidth is 1.6 kHz.

12.4. **Reception of the GMS signals, equipment**

Assuming that for pictures of satisfactory quality an IF signal to
noise ratio of 20 dB is needed, and assuming that the receiver noise figure amounts 6 dB, the necessary antenna gain can be calculated. Let the receiver's bandwidth be 25 kHz, then follows that the signal level will be \( F_k T_0 B \frac{S}{N} \):

\[
P_s = 1.38 \times 10^{-23} \times 25 \times 10^3 \times 3 \times 10^2 \times 4 \times 10^2 \text{ W}
\]

(12.1)

The level will be -106 dBm.
The transmission attenuation follows from \( 22 + 20 \log D/\lambda \) and amounts to 188 dB.
Together with the transmitted ERP of +48 dBm, there follows that the required antenna gain will be \( 188 - 48 - 106 = 34 \text{ dB} \).

Note: A signal to noise ratio of 20 dB in the i.f. system will in fact lead to a video signal to noise ratio of over 40 dB.
Assuming an antenna efficiency of 60%, a parabolic reflector antenna with a diameter of 4 meters will be needed.
For pictures of slightly less quality or when using a receiver with a better noise figure, a diameter of 2 to 2.5 meters will suffice. In practice, using simple equipment and a 1.2 meter diameter antenna, reasonable pictures have been received in Europe, using the European version of GMS, METEOSAT.
For certainty reasons however, a diameter of e.g. 5 metres is advisable. An antenna of this kind can be obtained at reasonable cost in Indonesia. Simultaneously, however, an antenna with a diameter of 2.5 meters can be constructed, using relatively simple means and at little cost.

12.5. A receiver for GMS, general

A receiving system for GMS signals must be able to receive frequency modulated signals at 1691.0 and 1694.5 MHz. Although many alternatives are possible, the system now selected offers some distinct advantages.
A crystal controlled receiver is used for one frequency, in this case 137 MHz. This receiver is used with a crystal controlled converter ahead of it.
In this way it is also possible to receive signals from earlier satellites, operating in the 137 MHz band. If this would be applicable, the receiver could be equipped with a variable oscillator in order to be able to tune continuously from 130 to 138 MHz. At present this is not
the case, only reference to the possibility is made.
The block diagram of the receiving installation can be seen in Fig. 12.2.

![Block diagram of the GMS receiver](image)

Following the receiver, use is made of a video processor and detector to drive the display unit. A modified oscilloscope is used as an electronic display, together with a polaroid camera which takes the pictures. Signals from the satellite can be stored, using a tape recorder. Input to the display can be selected both from the receiver and the tape-recorder. See also block diagram in Fig. 12.3.

![Block diagram of processor for weather pictures from the GMS satellite](image)
12.6. The GMS receiver in more detail

Fig. 12.4. Detailed block diagram of the GMS receiver

The front-end amplifier/mixer/L.O.-tripler.
To be mounted in the parabolic antenna, a container is constructed which houses those parts of the receiving installation which must be very close to the antenna radiator. The first amplifier is equipped with a very low noise transistor amplifier, using a teflon printed circuit board. This amplifier yields a gain of 8 dB at a noise figure of 2.8 dB. It is a self contained unit [29].

Following this unit is a unit, housing a three stage amplifier followed by the mixer transistor.

Inside the container is also the local oscillator signal tripler/amplifier. This unit is fed from a source, to be placed at the base of the antenna. In this way, a signal in the 518 MHz range is supplied to the tripler unit, which generates a frequency of approximately 1554 MHz.

This frequency is filtered and amplified to the level, needed for driving the BFR 91 mixer transistor. This transistor will produce the difference frequency of 137 MHz, derived from the satellite signal and the local oscillator. The amplifier unit is equipped with 3 times NE57835. As the container is to be used in the open air, it is vital to give it a thorough treatment against moisture, both from water vapour as well as from rain!
For the circuit diagram and the components lay-out of the tripler/amplifier unit see [29].

The signals, originating from the mixer circuit, are fed via a coaxial cable to an amplifier unit, placed at the base of the antenna in a second container. This container also houses the crystal oscillators and multiplier circuits for the driving of the tripler unit.

The amplifier is intended to compensate the loss of the coaxial cable between antenna and 137 MHz receiver, to be placed in the university buildings. The amplifier consists of a 2N5245 fet in grounded source configuration. The amplifier is neutralised for optimal stability.

In the same container, the crystal oscillator and subsequent multiplier x5 and x2 are arranged.

The oscillator is temperature controlled in order to obtain necessary stability. Selection between two crystals can be made by means of a hand-operated switch. The crystals are in the 51 MHz range. In the subsequent stage the 51 MHz signals are multiplied 5 times, so a 259 MHz signal is the result. This signal is filtered and amplified in the following two stages then passes an active frequency doubler, followed by a filter and a final amplifier. The resulting 518 MHz signal is fed to the tripler section in the parabolic antenna.

The 137 MHz FM-receiver is arranged on a single printed circuit. The front-end amplifier is equipped with a BF 905 dual gate mosfet. This front-end amplifier together with the double balanced diode mixer and the subsequent buffering amplifier of the front-end yield a noise figure of 1.5 dB.

Following the buffer amplifier, there is a crystal filter. The buffer is matched to the impedance of the filter. The filter pass-band is flat within 0.25 dB over 20 kHz and within 2 dB over 30 kHz. Following the filter is an impedance matching network which feeds a buffering amplifier. The signal (10.7 MHz) from this amplifier is fed into a CA3028A mixer IC. This IC is also fed by a crystal oscillator on 10.125 MHz. The resulting 575 kHz is filtered and passed along to a second CA3028A IC, now as an amplifier. From this CA3028A, the signals are passed along to an NE562B integrated PLL FM-detector. Via a buffering amplifier the resulting audio is fed to an integrated audio power amplifier and loudspeaker as well as to the video detector/processor. The VHF-receiver is completed by the crystal oscillator and subsequent tripler/amplifier which delivers a 126 MHz signal of 5 milliwatt to the MD 108.
double-balanced diodemixer.
The video detector/processor is an idea of M.L. Christieson and was published in Wireless World [46]. No attempt has been made to modify his circuits, except a necessary change of circuit, probably an editors error. By means of a number of potentiometers, it is possible to create different types of transfer characteristics. This is done in order to suppress informationless parts of the image, at the same time giving an extra accent to more important parts of such an image. For the circuit diagram and the components lay-out, see [29].

Output from the video processor as well as the sawtooth generator is fed to three front panel mounted BNC receptacles and are marked X, Y and Z modulation. Four coloured led indicators give information on the status of the unit. (Start, end, clear and ready).

12.7. The antenna for the reception of GMS signals

As was pointed out earlier, an antenna with a diameter of 2,5 to 5 meters should suffice for the reception of GMS signals. Project finances allowed the purchase of a domestically produced solid parabolic reflector with a diameter of 5 meters. At the same time however, a reflector antenna was constructed, using aluminium tubing for the frame work and wire mesh as reflector surface. For both reflectors, a primary feeder antenna had to be constructed. For this antenna a cylindrical horn was suggested and constructed.

Although this type of feeder has the disadvantage of a non-uniform radiation in the E and H plane, it was felt that this disadvantage was overcome by the simplicity of the construction of such a feed. The more elaborate type of feeds would take much more time to be manufactured, when using Eindhoven University's facilities. For the cylindrical horn feeder, see fig. 12.5

![Diagram of antenna](image-url)
At the time of writing, no data were available on the performance of the antennas. Considering the ample safety margin in design, no difficulties are to be expected.

With the exception of the construction of the feeder, it should be concluded that this part of the installation offered a splendid opportunity for activities in Surabaya which, as far as can be judged, have been accepted very well.

12.8. Future

As was stated earlier, the 5 meter antenna, together with modified equipment, should be made suitable for the reception of signals from telecommunication satellites in the 4 and 6 GHz range. First of all, the reflector has sufficient surface tolerance for this frequency. Design and construction of primary feeders for these frequencies are not too difficult, moreover, after the experiments on 4 GHz tropo-scatter propagation in Surabaya are finished, it will be possible to use existing feeders for the antenna.

Most parts of the transmitting and receiving equipment for 4 GHz can be used for reception experiments with the domestic Indonesian satellite system 'Palapa'.

![Photo 12.1. 3 m open mesh parabolic antenna for GMS reception, built by students of ITS/FTE](image-url)
Photo 12.2. The 5 meter parabolic antenna for experiments in the field of satellite communication.

Photo 12.3. Example of data output from meteorological satellite signal reception. (courtesy of LAPAN)
In this report reference is made to the CCIR reports and recommendations issued before 1982. The following "CCIR References Updating Table" gives a relation between previous CCIR references [9]→[53] and the latest (1982) references [83]→[94].

<table>
<thead>
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<th>Reference number [ ] of CCIR documents</th>
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<td>53</td>
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Eindhoven University of Technology
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Eindhoven \hspace{2cm} The Netherlands

MICROWAVE PROPAGATION STUDIES,
MEASUREMENTS AND EDUCATION IN
SURABAYA, INDONESIA

Part 2: Educational Activities

Eindhoven
1983
Chapter 1.

EDUCATIONAL ACTIVITIES, WORKSHOPS AND TECHNICAL ASSISTANCE.

1.1. Introduction.

A decision was made to combine research and educational activities in order to meet the aims of project THE-2. In this way the research activities, in which many students and staff-members were involved, proved to be a source for educational subjects. We may mention here microwave techniques, basic electronics, satellite communication, troposcatter, line-of-sight links, computer techniques as well as mechanical problems and the design, assembly and care for the equipment.

Apart from lecturing, the staff members also participated in several other subjects of the electrical engineers training program at FTE, such as the organisation of practical work for the students and coaching the students in the final studies.

Special activities, e.g. microprocessor workshops, stimulated short lectures and contributed to the total programme of project THE-2.

1.2. Description of the Institute of Technology in Surabaya.

The Institute of Technology in Surabaya was founded in 1957. It developed in 1962 a plan to purchase a site for a new campus east of Surabaya. The plan was financed by a loan from the Asian Development Bank (Appendix E), which stimulated the development of the campus considerably.

When project THE-2 made a start in Surabaya in 1976, the development of the new campus was in full operation. This fact effected the THE-2 project in several ways.

- Project THE-2 was offered a specific place within the educational activities of the Faculty of Electrical Engineering of ITS, which was not forseen in the original plans.
- The knowledge transfer for the project from the Dutch team to their Indonesian colleagues took more time than expected, as several Indonesian lecturers were abroad at that time following courses and attending seminars.
- The Faculty of Electrical Engineering which was the first to be moved from the old building to the new campus, had to face many organizational problems, therefore, project THE-2 had all freedom for its
- The students were very interested in this active research project being the only project of a new campus under construction.

The Dutch staff for project THE-2 participated in part-time lecturing, especially in those subjects directly related to the microwave project. They also took part in coaching students in the last stage towards graduation. More details are available in Sect. 1.5.

1.3. Lectures.

This section summarises some details of the courses given by the Dutch members of the team available in Surabaya.

The courses were divided into compulsory and voluntary parts.

The study programme for the students was built up in such a way that up and including the fourth year of study all courses were compulsory. Courses given in the 5th year of study were voluntary. The enrolment for the voluntary course (3 to 15 students) appeared to be lower than for the compulsory courses (~ 30 students).

Table 1 gives a survey of the courses lectured during project THE-2.

<table>
<thead>
<tr>
<th>Name of the course</th>
<th>semesters lectured</th>
<th>students enrolled</th>
<th>students examined</th>
<th>Lec. notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Electronics</td>
<td>2</td>
<td>58</td>
<td>30</td>
<td>yes</td>
</tr>
<tr>
<td>Microwave Laboratory Instruments</td>
<td>1</td>
<td>15</td>
<td>9</td>
<td>yes</td>
</tr>
<tr>
<td>Design of Microwave links</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>yes</td>
</tr>
<tr>
<td>Antennas</td>
<td>3</td>
<td>30</td>
<td>25</td>
<td>yes</td>
</tr>
<tr>
<td>Transmission Lines</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>yes</td>
</tr>
<tr>
<td>Satellite Communication</td>
<td>1</td>
<td>10</td>
<td>6</td>
<td>yes</td>
</tr>
<tr>
<td>Microproc. Workshop</td>
<td>2</td>
<td>50</td>
<td>-</td>
<td>yes</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11</strong></td>
<td><strong>174</strong></td>
<td><strong>76</strong></td>
<td></td>
</tr>
</tbody>
</table>

During each course, two tests were given. A final examination took place at the end of the course, followed, if required, by a re-examination a few weeks later.

All examinations were of the open book type, which means that any reference or text book could be used by the candidates. Therefore, no facts were questioned but only applications or conclusions from the lectured theory.
1.3.1. Description of the lectures.

All lectures were presented in the English language and lecture notes distributed during the course. Most lectures were given in cooperation with an Indonesian co-lecturer, thus reducing the language barrier and facilitating the continuation of the course by this Indonesian colleague.

1. Digital Electronics.

For this course a reference book was used titled: "Digital Electronics for Scientists" by Malmstadt and Enke. This book [9] explains mainly digital components. Additional lecture notes were issued, explaining more basic background of a few topics.

(The lecture notes were compiled and edited [1].

2. Microwave Laboratory Instruments.

This course dealt with a great number of microwave equipment used for the experiments during the project. Lecture notes, prepared during the previous project THD/E/T-2.1, and a reference book were used. A laboratory exercise was introduced during the course and carried out by all students.

3. Design of Microwave Links.

Main Textbook "Planning and engineering of radio relay links" [10] by Brodhage and Hormuth. More literature was added in order to stress topics like tropospheric wave propagation and noise performance of microwave links. This additional literature was:

Panter, Ph.F. Modulation, Noise and Spectral Analysis [12]
Panter, Ph.F. Communications System Design [13]
Niesten, J.G.et al. Microwave Propagation study and Measurements in the Surabaya Region [2, part 1].

Lecture notes were made available, compiled and edited [3].


This course dealt with the theoretical part of antenna techniques based on the lecture notes of a similar course, given at THE. Practical instruction was given using the antennas available from the project THE-2. (No lecture notes available).

5. Transmission lines.

This course dealt with special aspects of transmission lines and is a follow-up of another course dealing with the basics of trans-
mission lines.
The lectures were based on a similar course given at THE.


This subject was lectured at FTE for the first time.
As references were used:

J.J. Spilker Jr. Digital Communications by Satellite [14]
Palapa System Summary: Vol. I - Space Segment
Vol. II - Ground Segment. [15]

Dutch PTT Instruction material on Satellite Communication
Subjects as referred to in [16]

The course was directed at a basic understanding of the main factors
governing the quality of satellite communications: contribution to
noise, limitations on satellite power as well as multiple access
techniques.
The complete lecture notes were compiled and edited for future
reference [4].

1.3.2. Experiences and results

The main problem met during the lectures was the language gap. The Dutch
lecturer, not capable lecturing in the Indonesian language, used English,
which was not always completely understood by the Indonesian students,
who had only a basic knowledge of the English language. These problems
were partly removed by the presence of a co-lecturer, explaining in cases
of complete confusion. The lecture notes helped very much to bring better
understanding of the lectured objects.

Another problem was to meet the need for practical examples concerning
the subjects lectured. Most often equipment available in the project
was used, or an excursion was held to, for example, a neighbouring
Palapa satellite ground station, offering a wide range of practical
examples about telecommunications.

The Dutch lecturers found their Indonesian counterparts always ready and
helpful in promoting the project activities in the Faculty of Electrical
Engineering. Many students who took part in the practical work of the
project were recruited during the lectures, given by the Dutch team
members.

To investigate the students' opinions about the course 'Antennas' a
questionnaire was given after the semester.
1.4. Workshops

1.4.1. Microprocessor workshops

A new topic was introduced by applying a microprocessor for the data processing in the microwave troposcatter system of the project THE-2. Spare parts of the processing unit were built into a small independent working microprocessor system, normally used to prepare short software alterations in the main program, without disturbing the processing of the troposcatter signal.

At the beginning of the project, students started to exercise individually at the spare microprocessor. Because of the need of a more structured instruction program a workshop was given.

The high interest-rate of lecturers and students on this modern topic led to two more workshops being given during the project.

The workshop consisted of a theoretical and a practical part:

Theoretical: - instruction to microprocessors in general
- system design and internal organisation of Motorola 6800 microprocessor
- programming in M6800 machine language
- software programs examples.

Practical: - exercises using the two available microprocessor systems
- structural instruction program dealing with possibilities of the M6800 microprocessor
- solving a practical control problem by means of the M6800 microprocessor.

An average of 30 persons attended each workshop during the theoretical lectures and an average of 20 attended the adjoining practical program.

The complete program of the workshop is given in [5].

1.4.2. Rhetoric workshop

Students, doing their final examination, had to present their thesis in a short speech to a board of examiners and other audience.

A discussion in the microwave team (see 1.5) showed a lack of knowledge about rhetoric techniques, such as:
- schematic representation of a speech
- timing
- visual techniques: black board
  overhead projector
  slide projector
- manner of presentation.

About ten students took part in this experimental workshop while many other students were very interested in a follow-up. A follow-up was not possible because the project was coming to an end.

1.5. Coaching of the students during practical work and final study

In the FTE curriculum several practical aspects of Electrical Engineering are treated. Apart from practicals and the like, there were 'practical jobs' 'special subjects' and 'final subjects'.

Two practical jobs, completed successfully, were compulsory for graduation. These jobs were normally performed at some electrotechnical or communications industry, but laboratory work was preferred.

A special subject was not obligatory but could be taken by a student who had already enough elective lectures but who was still in need of 'credit points'. A special subject was a thorough, three months' study of a subject and normally this subject was a theoretical one.

The final subject or final study was an independent, thorough study of a subject, taking about one year. Ideally, this subject should be both theoretical and practical but extremes occurred as well. This final study was necessary for graduation.

1.5.1. Organization of the Microwave Team

The team engaged in the activities of the microwave research project, consisted of:
- four Indonesian lecturers
- the Dutch lecturers present (1 or 2) in Surabaya
- five students as student-member of the microwave team
- several other students (up to 10) doing their practical work or final study within the team.
In order to improve team work, a weekly meeting was held between all members of the team, during which all current problems were discussed. The experimental troposcatter link involved many activities, most of which could be modelled as a practical work or a final study. The student members, mostly in the final stage of their study, also assisted in practical jobs in support of the research program. Another weekly meeting which was held in the evening, provided the opportunity to coordinate and to check the progress of the practical work, special subjects and final study work of the students. In these meetings the progress and the activities of the project were discussed with the students and then the topic of the week was discussed.

1.5.2. Practical work and final study

According to the curriculum of the "Fakultas Teknik Elektro - Institut Teknologi Surabaya" (FTE-ITS), the student who wants to graduate, has to complete his study with two kinds of practical work and a task which is called final study. A practical work is an electrotechnical work and it takes about one month. The work should be completed with a technical report. It could be carried out in the laboratories of FTE-ITS, in the factories (industry) or in other laboratories outside ITS. A final study is research work which should be carried out by the students who wish to complete their study. The work should last about 9 to 12 months, depending on the working conditions and situation. Usually it is the design and construction of an instrument or piece of equipment, which can later on be utilized by the faculty, other institutes or factories. Within the project activities, a weekly meeting was held to organize and to arrange the practical work and final studies. In these meetings the progress of the students could be checked, guidance to the students was given and also discussions about the studies could take place. The kinds of studies and the number of students involved can be listed as follows:
<table>
<thead>
<tr>
<th>Type of job</th>
<th>No.</th>
<th>Subject</th>
<th>No. of students involved</th>
<th>Status per Dec. 1979</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practical job</td>
<td>1.</td>
<td>Preparation of demonstration model of microwave link</td>
<td>3</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>2.</td>
<td>Repair of Digital AVO-meter and of a transistorised AVO-meter</td>
<td>2</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>3.</td>
<td>Calibration of a precision wave-guide attenuator</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>4.</td>
<td>Design and construction of a general binary BCD I/O interface for the microcomputer</td>
<td>2</td>
<td>finished/not yet finished</td>
</tr>
<tr>
<td>Special Subject</td>
<td>5.</td>
<td>Feasibility study of the use of Perumtel's 6 m. antenna in the experimental troposcatter link Situbondo - Surabaya</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>6.</td>
<td>The A/D converter of the tropo data processor system</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>7.</td>
<td>Software linearization of receiver output characteristic</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>8.</td>
<td>Shortening of output tapes from the tropo data processor</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>Final Study</td>
<td>9.</td>
<td>General overhaul of microwave practical work (equipment and instruction)</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>10.</td>
<td>Design and construction of a logarithmic IF amplifier</td>
<td>1</td>
<td>not yet finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>11.</td>
<td>Preparatory study on the microprocessor M6800</td>
<td>1</td>
<td>finished</td>
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<td>&quot;</td>
<td>12.</td>
<td>Feasibility study on the use of the 145 MHz FM transceivers on the link Situbondo - Surabaya</td>
<td>1</td>
<td>finished</td>
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<tr>
<td>&quot;</td>
<td>13.</td>
<td>Preparatory study on the troposcatter link Situbondo - Surabaya</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>14.</td>
<td>Investigation into the statistical properties of the K-factor</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>15.</td>
<td>Correlation between tropospheric scatter propagation and meteorological parameters</td>
<td>1</td>
<td>not yet finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>16.</td>
<td>Phase-locked-loop techniques</td>
<td>1</td>
<td>finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>17.</td>
<td>Evaluation of tropospheric propagation data from the link Situbondo - Surabaya</td>
<td>1</td>
<td>not yet finished</td>
</tr>
<tr>
<td>&quot;</td>
<td>18.</td>
<td>Design and construction of a high-speed papertape reader</td>
<td>1</td>
<td>not yet finished</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>22</td>
<td></td>
</tr>
</tbody>
</table>
1.5.3. Extra curricular activities

The extra curricular activities can be described as follows:
- In order to give more information about the project to the students, an extra half hour was spent after each microwave team meeting, to explain the principles of the troposcatter mechanism and data processing.
- A short course about basic electronics was given in order to fill gaps in practical information. The subject was 'transistor circuits', and was attended by the microwave team members.
- Two exhibitions.
  The first in 1978, organized by ITS to promote itself to students of secondary schools, was considered as an opportunity for the project THE-2 to make acquaintance with the public.
  The microwave team presented:
  - a demonstration model of a microwave link.
  - a microprocessor, programmed with instructional games.
  The second one was held in 1979, and it was a technical exhibition, organized by a local technical organization. The exhibition took place on the ITS campus. The microwave team presented the home made 3 m paraboloid antenna and also photographs with project activities as centre of interest.
  Both exhibitions were attended by hundreds of students and the project demonstration was said one of the most interesting subjects.

1.5.4. Financial support for the students

Students in need of components or special tools to carry out their practical work or final study work, generally had to pay all expenses themselves. This is one of the reasons that they tend to choose theoretically oriented final studies.
To encourage the students in the microwave team to tackle more practically based topics of study, a working fund was available to reimburse students declared expenses.

1.5.5. Results and conclusions

During the execution of the project there were a lot of students involved in the project activities, not only the research activities but also the educational activities. The number of students and other people involved
in the project can be seen in the list of people contributing to the project, (See page III) and in the list of people contributing to the practical work, special subjects and final year studies (see page 8). So we can conclude that the project has achieved the aims concerning the know-how transfer to our Indonesian colleagues.

1.6. Fellowships

During the period of the project THE-2, two ITS staff members were in the Netherlands for a fellowship program; each of them stayed one year at the Eindhoven University of Technology.

The first fellow, ir. Prawiro Sugondo, stayed in Eindhoven from August 28, 1976 until November 30, 1977, and concentrated on the development of a small, portable meteorological station, especially in the design and development of the electronic circuit, involved in handling and processing meteorological signals.

The second fellow, ir. Faisal Gunawan, who stayed in Eindhoven from January 1978 until January 1979, concentrated on microprocessor programming and rain intensity meters, especially the measurement of its calibration characteristic.

Both fellows attended some courses and took examinations in those subjects. The courses were on the telecommunication engineering field. The fellowships are reported separately in [6] and [7]. Besides these two fellowships, the Indonesian project leader, ir. Budhi Purwanto, was also in Eindhoven for one month. During his visit, he discussed project matters with the Dutch project leader and also he made acquaintance with application of microprocessors in Eindhoven, which is of the same type as used in Surabaya.

Further information about his activities can be read in his sojourn report [8].

1.7. Technical lectures given by guest lecturers in Indonesia

During the execution of the project THE-2, there were some short term visits to Surabaya by the technicians, members of the Telecommunication Division TH Eindhoven, who gave their technical assistance to the project. During these visits, the project THE-2 utilized the opportunity by asking the visiting technicians to give extra lectures concerning their work.
The items lectured were:
- microprocessors, introduction and practice.
- data processing and control by microprocessors.
- receiving station for geostationary meteorological satellite and processing of weather picture signals from this satellite.
- crosspolar measurements in a troposcatter link.
- satellite communication techniques.
- microwave transmitters and receivers.

The lectures were not only given in Surabaya but they were also given in Yogyakarta and Jakarta, due to the good relationship between the project THE-2, ITS and other universities, namely the Gajah Mada University, Yogyakarta and Trisakti University, Jakarta. The contents of the lectures can be found in the sojourn reports of Messrs. A.C.A. van der Vorst, K.G. Holleboom, P.F. Maartense and L. Wijdemans.[77] - [83].

1.8. Publications

During the visit of Messrs. J. Dijk, L. Wijdemans and P. Sugondo to Surabaya, Sept. 1980, project THE-2 was invited to present its results and activities to a workshop in Jakarta, held on October 27, 28 and 29, 1980, jointly organized by LAPAN* and DFVLR**.

Three papers were presented in Jakarta by the microwave team members of project THE-2. The three papers were:
1. The propagation characteristic measurement of the line-of-sight link Gunung Sandangan - Surabaya and some analysis results of long distance line-of-sight links. [17]
2. Measured and calculated properties of the experimental troposcatter link Situbondo - Surabaya. [18]
3. Experiment on crosspolarization in the troposcatter link Situbondo - Surabaya. [19]

The contents of the papers can be seen in the library of the Department of Electrical Engineering, TH Eindhoven.

A certificate from LAPAN and DFVLR was also handed out to the presentator of the papers.

The workshop/conference was attended by more than one hundred participants, they were from universities, government bodies, private companies, expatriate experts working in Indonesia and of course also the DFVLR team and LAPAN staff-members.

* LAPAN = Indonesian National Institute of Aeronautics and Space, Jakarta
** DFVLR = German Aeronautics and Space Research Institute, Köln
Chapter 2

SUPPORTING ACTIVITIES

2.1. Introduction

The plan of operation of the project THE-2 mentioned that some of the aims for the Faculty of Electrical Engineering (FTE) were:
- to obtain more possibilities for the maintenance of equipment and instruments
- to obtain more facilities for expanding ITS research activities
- to extend the amount of literature of the basic library.

To achieve these aims an electronic workshop for the maintenance of the apparatus of the project would be equipped and the construction of other electronic equipment would be stimulated. By supplying additional literature relevant to the project and other activities at FTE, the use of the library would be stimulated.

During the course of the NUFFIC-project THD/E/T-2.I attention was paid to the installation of a mechanical workshop. As support from the mechanical workshop for the execution of the research program was expected, it was included in the planning to assist the overhaul of the mechanical workshop equipment by sending spare parts of the machines.

The supporting activities of the project THE-2 can be divided into three main groups:
1. activities concerning the mechanical workshop
2. activities concerning the electronic workshop
3. activities concerning the library.

In the next chapters each activity will be described separately.

2.2. Situation at the Eindhoven University of Technology (Eindhoven TH: THE) and Institute of Technology Surabaya (ITS)

The project THE-2 was an extension of the former NUFFIC-project THD/E/T-2.I, a cooperation development project between these same institutes during the current operation of project THD/E/T-2.I.

The project THE-2 was a research and educational project in the field of microwave propagation and the supporting activities concerning the project had already been started in the former project, resulting in experience in organization and planning of the supporting facilities.

The Telecommunications Division TH Eindhoven has been carrying out an extensive research program on microwave propagation and satellite com-
Based on experience gained in this program, it was possible to arrange the necessary equipment, to be used in the research program in Surabaya. Special attention was paid to widely applicable (universal) apparatus and protection against the tropical weather conditions. Contacts with THE and other institutes abroad were utilized for obtaining advice about efficient and effective organization of the library, mechanical and electronic workshops of FTE-ITS. Effective support was given by Eindhoven University of Technology by sending the basic equipment and instruments, spare parts and components, and also servicing the defect equipment and instruments.

The faculty of Electrical Engineering of the Institute of Technology Surabaya (FTE-ITS) needed not only a fully equipped microwave laboratory but also a workshop in order to repair and maintain the equipment and instruments of the faculty.

At the beginning of the project the set-up of an electronic workshop met some delay for several reasons: firstly the lack of suitable trained personnel, the move of the faculty to the new campus, the short term availability of laboratory rooms, lastly the temporary housing of the faculty in the first completed building of the campus and the lack of electricity at the definitive location.

During the last year of the project THE-2, plans to organize and to install an electronic workshop were implemented. A fully equipped microwave laboratory was steadily installed in the microwave team's laboratory room. Practical experience about the possible systems that can be set up by using the available equipment and instruments was gained during the execution of the project THE-2.

A problem of the faculty of Electrical Engineering was the availability of up-to-date literature in the field of microwave and computer techniques.

During the full period of the current operation of the project literature was supplied, especially in the field of satellite communications, microwave propagations, computer science and on general electronic subjects.

2.3 Microwave propagation and satellite communication research equipment

The project THE-2 research activities dealt with microwave propagation measurements.
The first measurements were between Gunung Sandangan - Surabaya, the distance being 50 km and frequency used 4 GHz. The set-up consisted of a transmitter with a fixed frequency of 4012 MHz and a tunable one with 3.8 GHz to 4.2 GHz frequency range, diplex system for applying one antenna system to two frequencies, transmitting and receiving antenna systems, two receivers, one for the 4012 MHz and the other for the tuned frequency, paper recorders and Automatic Counting Level Device; later on a microprocessor system for the data processing. So amplitude variations for the received signal could be investigated, also frequency deviations and height gain pattern measurements could be executed because a height gain pattern installation was also available. So it was necessary that ITS becomes self reliant in:

- tuning of microwave circuits
- frequency measurements
- signal power level measurements
- construction of microwave circuits
- performing basic calculations
- continuing the existing research program independently of Eindhoven T.H. and starting a new research program by themselves.

Later on, the project was continued with troposcatter measurements on the link, Situbondo - Surabaya, the distance being 150 km and the frequency used is 4 GHz. Most of the equipment used was that from the previous work on the link Gunung Sandangan - Surabaya. The equipment was extended with crosspolar measurements, using PLL receivers (see Part I). Also a system for receiving and processing GMS signal was supplied during the execution of this project (see Part I). So, after the duration of the project, ITS will have many facilities to do its own experiments, especially because the GMS set-up was considered to be an initial investment to prepare for satellite communication experiments.
2.4. Mechanical workshop

The mechanical workshop was set-up at the beginning of the first project period*, which ran from 1970 up to and including 1974. This took place during the years 1971 and 1972 in cooperation with our counterpart, namely ITS.

The workshop was housed in a separate room specially reserved for this purpose in the new ITS building on Jl. Cokroaminoto, Surabaya.

At the beginning of 1972 the workshop was almost complete and was also suitable for, among other things, the mechanical technology laboratory exercise. The total number of students doing their laboratory exercise was about one hundred.

At that time the financial position of ITS was inadequate to pay the workshop employees, so the workshop manager tried various possibilities to solve this problem.

Finally the solution of accepting paid orders from people outside the project and outside ITS was found.

So the mechanical workshop acted also as a small factory, producing office furniture, poles for electric power networks, etc.

During the THE-2 project this workshop was, and still is giving support to the project by manufacturing anchors, spare parts and other mechanical products.

At the end of the first project period the mechanical workshop also provided the facilities for a local technical secondary school, the mechanical group, for their practical exercises program. The reason was that this workshop was the only one where they could use a large range of machines and instruments. In this way good instruction and laboratory exercise could be provided.

After several years, it appeared that this workshop had rapidly become a very busy workshop and it is now impossible to separate it from FTE-ITS activities.

During the second project period (project THE-2) 1975-1980 this workshop still supported the project and FTE-ITS excellently, and it is now on the Sukolilo campus.

Because of some changes in the organization, it seems that there are sufficient employees working for the workshop and therefore the project

* THD/E/T-2.I project.
orders can be carried out smoothly and without problems. 
So, the moving of the transmitting antenna from Madura to Situbondo and the moving of the receiving antenna from Cokroaminoto to Sukolilo could also be carried out by the workshop crew, under the supervision of the team members. 
The workshop people being familiar with handling antenna materials, the work was done with minimum delay.

At the end of 1979 the mechanical workshop was completely moved to a temporary site on the new Sukolilo campus. After negotiations between the project leaders and the head of the workshop, a lot of spare parts (fl. 7.500,--) for the mechanical workshop were sent to Surabaya at the end of the current operation of the project.

Mechanical workshop.
In the production of a special feed for reception of the weather satellite GMS, the mechanical workshop assisted the project with construction work.
Before moving the machines to their final place, they will first be overhauled. After the project has expired, FTE-ITS will have a workshop with machines in good working condition. A 3 m paraboloid antenna designed by an FTE student was also built using the workshop facilities. This antenna was a final study task for the above mentioned student. It is installed in front of the FTE building.

A 3 m open mesh parabolic antenna for GMS reception, was built by a student of FTE-ITS, using the mechanical workshop facilities.

2.5. **Electronic workshop**

The general aims of the electronic workshop were:
- maintenance and repair of the available equipment in the faculty of electrical engineering.
- enabling students to calibrate self-developed equipment.
- performing of measurements in the frequency range from 0 up to 300 MHz, with an emphasis on the audio frequency band.

At the end of the first project (project THD/E/T-2.I, 1974), one began to feel that an electronic workshop would be very useful and helpful in furthering the project. It is a very important factor in the framework of the whole project, especially for maintenance and repair of the used project equipment and instruments. It saves great difficulties not to have the defective equipment repaired by third parties. After very extensive negotiations between the Indonesian counterpart and the Dutch project leaders, an electronic workshop was started with the available instruments, which were directly used every day in the project activities as a beginning to building up a representative electronic workshop. After running for some time it appeared that it was not only being used for maintenance and repairing equipment and instruments, but also being used by the students for their practical work and final study task too. Because of the presence of a large variety of basic instruments this electronic workshop is essential for the electrotechnical education at FTE-ITS. This function has been stimulated and expanded during the carrying out of the second project (project THE-2). In discussion with Indonesian colleagues, in the beginning of 1977, a list of the basic instruments was compiled. During the second project period the electronic workshop was completed based on this list. In the beginning the workshop was situated in the same place as the microwave laboratory and also it was only a part of the microwave laboratory room. A microwave laboratory set-up which supported the project educational activities fitted in with the faculty curriculum. After moving to the new campus Sukolilo it got a separate room. The new campus is being built phase by phase and the final site of the electronic workshop is not yet ready and after some discussions with the electronic people of ITS, it was housed temporarily. Instruments and equipment which were not directly needed for repair and maintenance, were used for the students' practical work, but remain the property of the electronic workshop.
In the near future, a maintenance department will be set up on the new campus. To realize this, it will first be essential to have a maintenance technician to start up and run the department. With the instruments and equipment purchased during the project periods FTE-ITS will have a well equipped electronic workshop.

2.6. Electronic components

The local market in Surabaya has a good supply of components as far as the audio range was concerned. It was very difficult to purchase high frequency components locally. It was also discovered that the available components at the local market were of inferior quality, causing much trouble, especially for test and precision applications. Therefore the precision components were ordered via the Eindhoven University of Technology, so many valuable working hours were not lost working with inferior components for more precise work.

2.7. The FTE-ITS library

At the beginning of 1969 the Committee for International Cooperation of the Eindhoven University of Technology decided to cooperate with two Indonesian institutes of technology: the "Institut Teknologi Bandung" (I.T.B.) and the "Institut Teknologi Surabaya" (I.T.S.). In order to realize this cooperation a Working Group Indonesia of the Department of Electrical Engineering was formed under the chairmanship of Professor Dr.Ir. J.G. Niesten.

Part of the program concerned was the establishment of a basic library on electrical engineering and electronics for the Department of Electrical Engineering (Fakultas Teknik Elektro) of the Institut Teknologi Surabaya (FTE-ITS). The first step was to select a list of suitable books. For the draft of this list the following considerations were taken into account:
- The number of books should be about 1000 with total value of about US$ 13,000.
- The language of the books; English was considered, since English is the most widely understood foreign language in Indonesia.
- The level; preference should be given to introductory texts suitable for reference for undergraduate students, but a number of titles
should also be included suitable for technical and scientific staff.

- The **subjects covered** should be nearly the same as at the Eindhoven University of Technology. All modern disciplines such as semiconductor physics, computers, systems theory, etc. should be represented, although perhaps at that time there would be not much practical use for them because of shortage of suitable apparatus. A number of titles on applied mathematics and physics was also included.

- Only books in print (i.e. available at the publishers) should be considered, so that no difficulties would arise in providing them.

Catalogues mainly of McGraw-Hill, Wiley, Iliffe and several other publishing houses with original descriptions of the books were used for the compilation of the list of suggested titles. The first selection was made by the librarian of the Department of Electrical Engineering of the Eindhoven University of Technology and discussed with the scientific staff of the Department with the result that some titles were dropped and some others added.

The first draft of the "Electrical Engineering and Electronics Basic Library" of November 1969, comprising some 800 titles was sent to the FTE-ITS. The scientific staff of the FTE-ITS studied this issue and asked us to add some 100 titles more. After examining them we found that some of them were out of print at that time. Therefore, we included other subsidiary titles. Further we added some more titles on subjects such as electromagnetic theory, television, electrical supply and distribution, microwave engineering, etc., where they were most required. In accordance with the desire of the FTE-ITS, some German and Dutch books were also introduced, although for the original draft only English books were selected. As a result of these considerations an additional list was compiled.

The procedure of obtaining the consent of all responsible authorities in Indonesia and the Netherlands for definitive ordering of the books took almost two years. By that time we found that some 100 titles of the original 1969 list were out of print, of some others new editions were available, almost all prices were augmented, therefore, we checked all titles on availability, updated the price indications and included ISBN - International Standard Book Numbers - where possible. We tried to complement the textbooks by including the Solution Manuals.
We also updated the list by including some 190 new titles published during 1970 and the first months of 1971. We used the latest bibliographical material we could find (Bowker, Whitaker, book publishers' trade lists) in order to achieve the highest possible grade of exactness. The revised ordering list included 1,128 items (incl. Solution Manuals) to the then value of US$ 12,900. These books reflected the state of the technique in the years 1969-1971. They were dispached to Surabaya by the Ministry of Development Cooperation in Spring 1972.

Here it must be emphasized that this work would never has been done without the enthousiasm, initiative and drive of Professor Niesten, Chairman of our Working Group Indonesia.

In the course of the projects being carried out at the FTE/ITS, namely:
- electrical energy distribution in the region of Surabaya;
- transportation study in Surabaya;
- propagation project THE-2 (94 titles, see Appendix 1),

further specialized titles were added to the basic library as the need arose.

In order to facilitate the retrieval of the books a new catalogue was made. The draft of 1969 and the two additional lists were unified in a single catalogue titled

ELECTRICAL ENGINEERING AND ELECTRONICS BASIC LIBRARY.


An "Index of authors and editors" (see for a sample Appendix 2) was compiled. The sections of the "Index in order of classification" (Appendix 3) were provided by a letter code, according to which the corresponding pages of the catalogue were also numbered (see a specimen of a catalogue page in Appendix 4).

A loose-leaf edition of the catalogue was made for the FTE/ITS-library, where pages with new titles can be inserted. The numbers of pages are used for labelling the books. The books are placed on the shelves in order of the pages of the catalogue. So for example all books registered on page HC 1 of the catalogue (page 1 of the section "Computers. Digital") can be found on the shelf under the label HC 1. Labels were typed in Eindhoven and sent to Surabaya. Glue and brushes for fixing the labels were also provided.

Some words must be said about the ordering and dispatching procedure.
The greatest portion of the books was ordered and dispatched to Surabaya by the Ministry of Development Cooperation (Library Program) in The Hague after the approval of our lists by the Indonesian Government. We never saw these books in Eindhoven. The Basic Library catalogue is, therefore, based for the greatest part on the publishers' trade lists only. A smaller portion could be ordered by the Eindhoven University of Technology Library administration. In these cases we could catalogue the books correctly and we sent them to Surabaya afterwards. This second way is much more adequate to the real needs. There is no delay of two or three years caused by the approval procedure in Indonesia and the cataloguing can be made according to the rules of good librarianship. There is no experienced library staff at the FTE/ITS, which could catalogue the books well.

Upgrading of the FTE/ITS librarian personnel is one of the tasks, which should be considered in the future. Upgrading facilities for library personnel were offered by Miss Luwarsih Pringgoadisurjo, Directress of the "Pusat Dokumentasi Ilmiah Nasional" (National Scientific Documentation Center) in Jakarta, but not yet used by the FTE/ITS. In addition to the furnishing of books all IEEE Transactions and Journals were subscribed to in the first years on behalf of the FTE/ITS-Library. Also about 15,000 kg of older journals were offered by the N.V. Philips Gloeilampenfabrieken in Eindhoven to FTE/ITS. However, our experience was that binding, shelving and the administration of journals is too difficult a task for the FTE/ITS library at its present stage. A selected supply of photocopies from Eindhoven was more effective than FTE/ITS having its own journal collection. Since 1976, we sent about 5,300 pages of photocopies of scientific articles to scientists in Indonesia.

A powerful tool for retrieval of scientific literature is the series of Science Abstracts published by INSPEC (subsidiary of the Institution of Electrical Engineers, London) and consisting of Electrical and Electronics Abstracts, Computer and Control Abstracts and Physics Abstracts. However, for proper use instruction is needed, which could not be given to users in Surabaya until recently.

According to the reports received, the FTE/ITS library is used very frequently by the scientific staff and the students. Simplifying of the ordering procedure of new books, upgrading of the library staff and the library user instruction would contribute to its further development.
Appendix I

In the period of December 1976 to April 1980, the following books were sent from Eindhoven to FTE-ITS-library:

<table>
<thead>
<tr>
<th>Section of the catalogue</th>
<th>Number of volumes</th>
</tr>
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<tbody>
<tr>
<td>AA Applied Mathematics. General.</td>
<td>1</td>
</tr>
<tr>
<td>AC Applied Statistics</td>
<td>1</td>
</tr>
<tr>
<td>C Electrical Engineering. General</td>
<td>1</td>
</tr>
<tr>
<td>DB Electromagnetic Theory</td>
<td>2</td>
</tr>
<tr>
<td>DC Electrical Circuits</td>
<td>1</td>
</tr>
<tr>
<td>GA Electronics. General</td>
<td>2</td>
</tr>
<tr>
<td>GC Semiconductors</td>
<td>1</td>
</tr>
<tr>
<td>GD Electronic Circuits</td>
<td>5</td>
</tr>
<tr>
<td>GE Electronic Noise</td>
<td>2</td>
</tr>
<tr>
<td>HA Computers. General</td>
<td>2</td>
</tr>
<tr>
<td>HB Logical Circuits</td>
<td>2</td>
</tr>
<tr>
<td>HC Digital Computers</td>
<td>19</td>
</tr>
<tr>
<td>JA Telecommunication. General. Information Theory</td>
<td>8</td>
</tr>
<tr>
<td>JB Propagation and Antennas</td>
<td>35</td>
</tr>
<tr>
<td>JC Radio</td>
<td>2</td>
</tr>
<tr>
<td>KH Power Electronics</td>
<td>3</td>
</tr>
<tr>
<td>M High Voltage (Lightning)</td>
<td>2</td>
</tr>
<tr>
<td>P Microwave Engineering</td>
<td>4</td>
</tr>
<tr>
<td>U Miscellaneous (Climatology)</td>
<td>1</td>
</tr>
</tbody>
</table>

Total: 94

The following volumes were ordered, but not yet received in September 1980:

<table>
<thead>
<tr>
<th>Section of the catalogue</th>
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<tbody>
<tr>
<td>JB Propagation and Antennas</td>
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### Index of authors and editors

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<th>Initials</th>
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<tr>
<td>Dawes, C.L.</td>
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<td>Day, W.D.</td>
<td>AB 1, AD</td>
<td>1</td>
</tr>
<tr>
<td>D'azzo, J.J.</td>
<td>FB 3</td>
<td></td>
</tr>
<tr>
<td>Deboo, G.J.</td>
<td>GD 4</td>
<td></td>
</tr>
<tr>
<td>Decaulne, P.</td>
<td>FA 3</td>
<td></td>
</tr>
<tr>
<td>Dekker, A.J.</td>
<td>N 1</td>
<td></td>
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<tr>
<td>Delhom, L.A.</td>
<td>HB 1</td>
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<tr>
<td>Del Mar, W.</td>
<td>C 2</td>
<td></td>
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<tr>
<td>Del Toro, V.</td>
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<td>DeRusso, P.</td>
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<td>Lorian, A.F.</td>
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<tr>
<td>Dorn, W.S.</td>
<td>HC 9</td>
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<td>GD 4, GD</td>
<td>5, JB 2</td>
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<td>C 1</td>
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<tr>
<td>Duncan, W.J.</td>
<td>AD 2</td>
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<tr>
<td>Dunn, D.A.</td>
<td>JB 2</td>
<td></td>
</tr>
<tr>
<td>Durney, C.H.</td>
<td>DB 2</td>
<td></td>
</tr>
<tr>
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### Appendix 2

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### A APPLIED MATHEMATICS
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### B APPLIED PHYSICS
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### J TELECOMMUNICATION
- JA General. Information Theory
- JB Propagation in Antennas
- JC Radio
- JD Television

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From: ELECTRICAL ENGINEERING AND ELECTRONICS BASIC LIBRARY.
Compiled by I.V. Bruza. 3rd ed.
Department of Electrical Engineering, Eindhoven University of Technology, December 1971.
BARTEE—Digital Computer Fundamentals, 2nd Ed.  
By THOMAS C. BARTEE, Harvard Univ.  
430 pp., 6 x 9, 143 illus. (1966)  
McGraw-Hill  
ISBN 0-07-003875-9  
$ 0.35

BECKETT AND HURT—Numerical Calculations and Algorithms  
By ROYCE BECKETT and JAMES HURT, both of Univ. of Iowa. Series in Intro. Proc. & Cmpt.  
298 pp., 6 x 9, 73 illus. (1967)  
A textbook for teaching the use of digital computer in the solving of engineering problems. A variety of numerical procedures is presented with solution outlines in the form of flow charts. Acceptable computer programs in any of the basic algebraic languages can be written from these flow charts. The text is adaptable to self-study.  
McGraw-Hill  
ISBN 0-07-004250-0  
$ 10.50

CHAPIN—360 Programming in Assembly Language  
512 pp., 6 x 9, 366 illus. (1968)  
$ 12.50  
This book covers programming in assembly language for all small and medium, and some large size models of the IBM System/360, RCA Spectra-70, and Univac-9000 series computers for nearly all operations. Representative IBM System/360 models covered include: 20, 25, 30, 40, 50, 65, and 85. The author's approach is carefully structured and organized, presenting the most basic and important operations early in the book and the more complex and less frequently used operations later. The clear, lucid exposition presents the material in a practical, down-to-earth manner with more than 360 illustrations. The book has been classroom tested, and the reader is assumed to possess only a minimal background in data processing.  
McGraw-Hill  
Workbook: ISBN 0-07-010551-0  
$ 3.95

DAVIS—An Introduction to Electronic Computers  
By GORDON B. DAVIS, Univ. of Minn. Accts. Ser.  
541 pp., 6 x 9, 180 illus. (1966)  
General introduction to the concepts and basic features of all electronic computers for business, engineering, or liberal arts students with no previous knowledge of this field. Uses the latest American Standard Association flow charting standards and FORTRAN IV standards. Separate chapters on how computers are being used today, on current and prospective developments in the field, on detecting and controlling errors. Selected references included at the end of chapters. Separate workbook manuals available for IBM 1620, IBM 7090/94, IBM System/360, and IBM 1401.  
McGraw-Hill  
ISBN 0-07-015815-0  
$ 11.50

GALLER—The Language of Computers  
By BERNARD A. GALLER, The Univ. of Mich.  
254 pp., 6 x 9, 47 illus. (1962)  
The basic approach is the gradual development of a computer language accomplished by examining several typical problems. Each problem is examined in detail, showing the need for adding new features to the language. All problems illustrate techniques actually needed in solving real problems in computers. Ideas and techniques involved in communicating to a computer the solution of a problem are introduced.  
McGraw-Hill  
$ 9.95

ANTON AND BOUTELL—Fortran and Business Data Processing  
By HECTOR R. ANTON and WAYNE S. BOUTELL, both of the Sch. of Bus. Admin. Univ. of Calif., Berkeley, Acad. Ser.  
240 pp., 8½ x 11, 61 illus. (1968)  
Represents FORTRAN within a business and administration framework. It stresses the more elementary aspects of FORTRAN programming, but an introduction is provided for more advanced work. Accounting examples form the bulk of the illustrative material. The book may be used as a supplementary text for an elementary accounting sequence of courses. Examples are also drawn from other business areas and from economics. McGraw-Hill  
ISBN 0-07-002123-6; $ 5.95  
$ 2.95

BECKETT AND HURT—Digital Computer Organization  
360 Programming, Numerical Control.  
By JAMES BECKETT and WESLEY HURT.  
1125 pp., 6 x 9, 820 illus. (1961)  
ISBN 0-07-001055-1  
$ 11.50
The library FTE/ITS. The library of the faculty of Electrical Engineering received support in literature in the field of telecommunications specifically and electronics in general.

Supporting library.
A shipment of many periodicals were sorted out and put in their proper places.
Chapter 3.

INSTALLATION OF A MICROWAVE LABORATORY

3.1. Introduction

Since 1973, during the execution of project THD/E/T/-2.I, a room, on the 4th floor of the ITS building, 12a Cokroaminoto Street, Surabaya, was used as the place for the receiving station for the system used for the research activities Gunung Sandangan - Surabaya. All equipment and instruments which came from Eindhoven were installed in this room. The antenna system was installed on the roof of the building, directly above the microwave room.

For the installation of the equipment and antenna system, the project got a lot of support from the mechanical workshop. The mechanical workshop constructed the working platform, a simple height gain pattern construction, the foundation for the antennas and other mechanical jobs.

3.2. Aims of the laboratory

The aims of the laboratory can be listed as follows:

1. to enable the students following the microwave course to use the facilities.
2. to provide opportunities for staff members and students to work with microwave equipment and instruments.
3. to provide facilities for the maintenance of all ITS microwave equipment.
4. to supply ITS the opportunity to run a microwave telecommunication research project.
3.3. General set-up and organization of the microwave laboratory

The microwave laboratory at this moment actually consists of three rooms.
1. the room used for keeping the documentation of the equipment, data collected, literature in the microwave field. This room is also used to do calculation using the Hewlett Packard computers.
2. the working room of the head of the laboratory and his assistants. This room is also used for practical work, maintenance of the equipment and other activities.
3. the room used for receiving signals from Situbondo, which is a small and airconditioned room, and which also houses the microprocessors.

The laboratory is coordinated by a staff member of ITS who is called: the head of the microwave laboratory.
A technician is employed for the daily maintenance and testing. Every ITS student or staff member can get permission to use the microwave laboratory facilities.

During the execution of the project THE-2, a lot of students have carried out their practical work and final study work in the microwave laboratory. (see page 8).

Also students coached by a non-microwave team staff member sent to the microwave team for subcoaching used the laboratory facilities and also came often for theory instruction.

3.4. Equipment and tools

At the end of the project the laboratory has many facilities. It has its own tools for simple mechanical work. Many instruments and equipment were available e.g. transmitters, phase locked loop receivers, antenna systems, a power meter, a frequency meter, oscilloscopes, computers, literature and other things, which can be examined in the list of instruments, equipment and materials sent to Indonesia in the frame work of project THE-2.

Due to cumulative effect, the laboratory became a good and a complete one, offering many facilities for microwave and electronic research.

3.5. Personnel

Besides the FTE/ITS staff members and the head of the laboratory, the microwave team worked in the microwave laboratory during the execution of the project.

Thus, the microwave laboratory was one of the most active ones, and after moving to the new campus, it was fully integrated with the Faculty of Electrical Engineering and many students and staff members used the microwave laboratory facilities.

Two students in the final study phase worked for the project, they were student-assistants paid by the project, guiding other students working in the laboratory, giving instruction in using the HP-computer etc.

Besides the two project field engineers and the Dutch student finishing his study in Surabaya, within the framework of the project, five staff members of ITS were engaged excluding the above mentioned student
assistants.

3.6. Conclusions

During the project execution, the microwave laboratory has served the Department of Electrical Engineering for training and research goals. The equipment and instruments, sent during the project execution, formed quite a complete laboratory, with the capability to support independent research and service the equipment in the laboratory itself. By utilizing the project equipment and instruments, students have facilities for carrying out their laboratory exercises, their practical work and final study work. So, the results of the installation of the microwave laboratory fulfil the aims of the project.

Project announcement board on the Situbondo 4 GHz transmitter site.
Chapter 4.

CONTACTS BETWEEN ITS AND OTHER UNIVERSITIES AND INSTITUTES IN INDONESIA

4.1. Relation between ITS and Perumtel (Indonesian Telecommunication Administration)

The good relationship between ITS and Perumtel was much increased since the start of project THD/E/T-2.1 and especially during the execution of the project THE-2 the contact became closer; particularly with the research department of Perumtel which is headed by Ir. B. Sutanto. Perumtel staff members visited the project in Surabaya and the microwave team visited Perumtel in Bandung to discuss the progress of the project. A report concerning the results of project THE-2, in accordance with the contract between ITS and Perumtel, was submitted to Perumtel. It is hoped that in the future ITS will have a new cooperation project with Perumtel, as ITS has facilities to do research and Perumtel has technical problems to be solved. Also contacts with Perumtel Surabaya and Denpasar became closer due to project activities.

The microwave team visited Perumtel Surabaya, to discuss problems on the microwave propagation field and many students carried out their practical work at Perumtel relay and ground stations. Some visits were paid to Denpasar to discuss the behaviour of the long distance line-of-sight links which operate in the eastern microwave network of Perumtel, connecting relay stations in the eastern part of the Indonesian Archipelago.

4.2. Contact between ITS and other Universities in Indonesia

4.2.1. Airlangga University (Surabaya)

Due to project THD/E/T-2.1 and project THE-2 activities, there were project leaders from Eindhoven visiting Surabaya. Besides inspecting both projects mentioned above, they also wanted to start another project which could be useful to Indonesia and Eindhoven. After negotiations, it was decided to start a new project in the biomedical engineering field. The cooperators would be ITS, Airlangga University and Eindhoven University of Technology. It is a pity that the project could not be brought to fruition but the contact between Airlangga University and ITS since the above effort, remains warm and now ITS and Airlangga University cooperate in the
biomedical engineering field. ITS gives post graduate courses to staff members of the Airlangga University and also gives assistance in the maintenance of the biomedical equipment and instruments.

4.2.2. Gajah Mada University (Yogyakarta)

Some visits were paid to the Gajah Mada University by the project team members to discuss cooperation projects. As we know Gajah Mada University has a cooperation with the "Vrije Universiteit Amsterdam" within a NUFFIC long term cooperation scheme. So the project organization and the project results could be compared and both sides could benefit from the discussions held during the visits. A team from Gajah Mada University visited the project in Surabaya, which not only helped keeping the contact warm between ITS/project THE-2 and Gajah Mada University, but also provided the opportunity to see project THE-2 activities live and not only read about it in reports. The microwave team members gave a microprocessor lecture with practical training at the Gajah Mada University, Yogyakarta.

4.2.3. Institut Teknologi Bandung (ITB)

The project team members together with the ITS staff members visited ITB paying particular attention to the radio and microwave laboratory. Discussions about microwave propagation, transmitters and receivers took place. Also discussed were microwave antenna systems, which would be used for the reception of satellite signals related to the project plan in enlarging the development value of the project. The project wanted to provide ITS with the opportunity to receive satellite signals for its research project activities after the end of project THE-2. As a result of the discussions a 5 m. paraboloid antenna was purchased by project THE-2 together with ITS and was used to receive the GMS signals and later on it can also be used to receive other satellite signals. The antenna was purchased from the firm "Radio Frequency Communication" (RFC), an Indonesian firm which is closely related to ITB radio laboratory.

4.2.4. Trisakti University (Jakarta)

During the execution of project THE-2, there were also contacts with Trisakti University. Some advice was given to Trisakti and due to those contacts, a cooperation contract between ITS and Trisakti was born and
as the first result, in this case for Trisakti, a 12 GHz set was borrowed from ITS to be used by Trisakti to start microwave experiments. Also some literature on the microwave and microprocessor field was sent to Trisakti.

4.2.5. **Universitas Indonesia (Jakarta)**

Some discussions with staff members of Universitas Indonesia took place during the project period. The activities of both sides and possibilities to start a cooperation project in the digital communications field were discussed. There was no follow-up to the discussions and there is still no official agreement between Universitas Indonesia with either TH Eindhoven or ITS. It is hoped that the contact between ITS and Universitas Indonesia will become closer in future, thus they can learn from each other.

4.3. **Contacts between ITS and other institutes in Indonesia**

4.3.1. **LEN (Lembaga Elektronika Nasional; Bandung)**

The microwave team visited LEN in Bandung; discussions took place about manufacturing paraboloid antennas and also about the possibilities of purchasing an antenna to receive satellite signals. LEN produced paraboloid antennas used for small ground stations ordered by the Indonesian Government. After this visit the relationship between ITS/project THE-2 and LEN became better. They know each other and more engineers who graduated at ITS work for LEN.

4.3.2. **Contact with LAPAN (Lembaga Penerbangan dan Antariksa Nasional; Indonesian National Institute of Aeronautics and Space) (Jakarta)**

As we know in the years 1974/1975, there was an effort to start a cooperation project in the meteorological satellite field between NUFFIC/TH Eindhoven on one side and LAPAN/ITS on the other. A contract between ITS and LAPAN was signed, but NUFFIC gave no priority to this project. This project would continue the former project THD/E/T-2.1 as well as project THE-2. During the execution of project THE-2, the contact between LAPAN and ITS/project THE-2 became better. Regular discussions and information
exchanges took place. ITS/project THE-2 members visited LAPAN several times, also LAPAN's staff members went to Surabaya to see project activities and to gain experience in the field of microwave and microprocessor by using project facilities.

During the last visit of the Dutch project leader to Surabaya in September/October 1980, a proposed cooperation project between LAPAN and THE was discussed, resulting in a "Draft Proposal for Cooperation on the Subject of Satellite Communications Research in the Tropical Areas with the Indonesian National Institute of Aeronautics and Space" (LAPAN), a five year cooperation plan.

Also during this last project visit, project THE-2 was invited by LAPAN to present its results and still running activities at a joint workshop on satellite communications, organized by LAPAN and DFVLR* (German Space Organization), on October 27, 28 and 29, 1980.

The invitation was accepted and three papers were presented which were:

1. The propagation characteristics measurement of the line-of-sight link Gunung Sandangan - Surabaya and some analysis results of long-distance line-of-sight links.
2. Measured and calculated properties of the experimental troposcatter link Situbondo - Surabaya.
3. Experiments on cross-polarization in the troposcatter link Situbondo - Surabaya.

4.4. Influence of project THE-2 on the contacts between ITS and other Universities and Institutes

Other Universities and Institutes are stimulated to keep a warm contact with ITS, partly due to the project THE-2 activities and up to date equipment and experiments.

Discussions with Perumtel about microwave propagation, data processing by microprocessors and other topics on the field of telecommunications had taken place largely due to project activities, e.g. reporting directly to Perumtel.

Exchange of information and experience happened. After the expiration of the project, ITS will have established good contact with the PERUMTEL one of the most important bodies to be attracted as a partner in research projects on the telecommunication field.

Contacts are growing between ITS and other Universities and Institutes in Indonesia and overseas.

* Deutsche Forschung und Versuchs-Anstalt für Luft und Raumfahrt
Chapter 5

RESULTS OF THE PROJECT THE-2

5.1. Results at ITS

5.1.1. Technical results

The technical results can be classified as follows:

1. ITS has a microwave laboratory with the basic instruments and the essential (practical laboratory work) facilities. It is possible for ITS to maintain all microwave equipment itself and it also has the capacity to do microwave experiments independently.

2. ITS has microwave equipment, which can be installed as a complete system for experiments, e.g. line-of-sight experiments, long-distance line-of-sight experiments, troposcatter experiments, rain measurements, cross-polar measurements, satellite experiments, etc.

With the intention to enlarge the development value of project THE-2, two sets of microwave equipment working in the 12 GHz band were sent to ITS. Each set consists of a transmitter with the possibility of modulation, a receiver, a power supply, spare parts and the antenna system needed.

Utilizing this equipment, some experiments could be carried out, modulated or unmodulated.

For the same purpose, a 5 m paraboloïd antenna was purchased and it was used for receiving the GMS signals (Geostationary Meteorological Satellite). This 5 m paraboloïd antenna together with some other receiving and photographic equipment form a ground station which is able to receive GMS signals.

This new satellite ground station for the reception of GMS can be extended for other satellite experiment purposes.

3. ITS has skilled people in the field of microwave engineering, students have the facilities to carry out their work in the microwave laboratory.

4. ITS has two installations for data processing. The first one is a data processing unit, called Automatic Counting Level Device, working with relays and comparators and can be used for demonstration, to introduce the primary principles of data processing.

The second one, based on the microprocessor M6800 and teletypewriter ARC 390, called "Data Registratie Indonesia Projekt" (DRIP), can be used for the data processing of future experiments. Finally a Hewlett
Packard computer is very useful for calculations and drawings which will be needed for future experiments and laboratory work.

5. For the smooth running of a project, a mechanical workshop is essential.

Within the frame work of the former project THD/E/T-2.I, a mechanical workshop was installed in 1972. This mechanical workshop was also supporting project THE-2 and it was supplied with spare parts, therefore at the end of project THE-2, the workshop was functioning well. (See Chapter 2.4).

6. During the operation of the former project THD/E/T-2.I, it was experienced that an electronic workshop is essential to guarantee the smooth running of a project.

During the operation of project THE-2, an electronic workshop was built up step by step, phase by phase. The instruments sent for carrying out the project were used to equip the workshop and to form it to be a good one. The instruments of the workshop were also used for laboratory exercises (see Chapter 2.5).

7. As a part of the supporting activities during the operation of the former project THD/E/T-2.I, a library was set up at FTE-ITS. It was essential for and gave back-up to the project.

During the operation of project THE-2, this library was completed by supplying it with new literature, technical journals and photo copies of articles requested (see Chapter 2.7).

8. FTE-ITS, in accordance with the contract, has submitted a report concerning the technical results of project THE-2 to Perumtel* (see Chapter 4.1).

9. FTE-ITS/project THE-2 was invited to present the measurement results at a joint workshop on satellite communications, organized by LAPAN** and DFVLR***. This opportunity was utilized and three papers were presented (see Chapter 4.3).

* Perumtel: Indonesian Telecommunication Administration, Bandung.

** LAPAN : Indonesian National Institute of Aeronautics and Space, Jakarta.

*** DFVLR : German Aerospace Research Establishment, Köln.
5.1.2. Educational results

The educational results are:

1. ITS is building-up a new campus.

Many staff members were sent abroad for post graduate studies or other kinds of studies. The courses given by those staff members should be taken over by another staff member and not all of the courses could be taken over. So there was a continuous problem. During the time of this gap, caused by sending staff members abroad, parts of the missing courses were given by team members of project THE-2.

Parts of the courses given by project THE-2 team members were also attended by an ITS staff member, so that FTE could take over the running of these courses after one semester.

The courses given during the operation of project THE-2 are mentioned in the chapter "Educational Activities" of this report.

2. Three sets of course notes were compiled, much literature was sent to the library of FTE-ITS and there was also support on technical periodicals, especially on the telecommunication field.

3. Students were guided in their study by project THE-2 team members. The guidance was on practical work, special subject and final study task.

4. The microwave laboratory exercise bench was revised and a new laboratory exercise instruction manual in the Indonesian language was written by a student carrying out his final study task within the framework of project THE-2.

5. Advice and guidance were given to students who were not related to the project THE-2 but coming to project team members with questions and problems.

6. Workshops on microprocessors were held, which were attended by students and ITS staff-members.

7. Some lectures of practical kind were given by technicians visiting ITS, on GMS reception, microprocessor, crosspolarization, etc. Also lectures and demonstrations were held for other Universities in Indonesia, e.g. microprocessor workshop held at the Gajah Mada University, microprocessor workshop held in Surabaya for LAPAN staff members, GMS reception lectures at Trisakti University, etc.

8. Two fellows studied at the Eindhoven University of Technology, each
for one year. They have followed research and educational activities at the Eindhoven University. During their stay in Eindhoven, the fellows assisted in the construction, calculations and calibration of the equipment needed to carry out the project.

5.1.3. Organizational results

1. In Indonesia there are some differences in the status of Universities. The general distinction is: the state Universities and the private (non-state) Universities. There are some groups of the private Universities e.g. the acknowledged Universities, the Universities considered to be on equal level with the state Universities, etc. There are two status among the state-Universities, the "Universitas Pembina" status and the "non-Universitas Pembina" status. A state University appointed as "Universitas Pembina" gets the task to lead the "non-Universitas Pembina" in the educational and research activities. Only the Universitas Pembina has the right to provide post-graduate studies, and of course, gets more money than the "non-Universitas Pembina". The "Universitas Pembina" must fulfill certain criteria laid down by the Indonesian Ministry of Higher Education. The considerations to appoint an University to be an "Universitas Pembina" are: the academic level and number of the teaching staff, the condition of the campus and University facilities, the present University activities, etc. From 1972 to 1980 ITS carried out research projects in cooperation with TH Eindhoven (NUFFIC-projects) and such cooperation with foreign Universities is honored with high credits. Therefore, it could be that partly due to these NUFFIC cooperation projects, ITS had the honor and trust from the Indonesian Government to receive the Asian Development Bank (ADB) loan, a US $ 24 million loan, for building up a totally new campus. This was also the impression got by the Dutch project responsible during his discussions with the ITS officials. A new campus is under construction at Sukolilo, Surabaya, and a lot
of staff members were sent abroad for post graduate studies or other kind of studies.

There is a great chance that ITS will be appointed as "Universitas Pembina", after having these new facilities. Until this moment ITS is a "non-Pembina Universitas".

When this happens, Eindhoven University of Technology, namely E-working group Indonesia, will be very happy.

Further report on the ADB loan can be found in Appendix A.

2. FTE-ITS has at this moment good contacts with other Universities and Institutes partly due to project activities.

Cooperation contracts between ITS and Trisakti and between ITS and LAPAN were signed.

ITS has contact with the Eindhoven University of Technology, information exchange between the two Universities can be continued after the project THE-2 has expired.

In the framework of project THE-2, the Indonesian project leader visited the Eindhoven University of Technology for one month. This provided the opportunity for him to compare the organizational and educational affairs and the organization and management structure of FTE-ITS with the Eindhoven University of Technology.

ITS has a good contact with Perumtel after carrying out cooperation projects for about 8 years namely projects THD/E/T-2.1 and THE-2.

5.2 Results at other Universities and Institutes in Indonesia

In the first place, the project technical results were presented by ITS to Perumtel. Perumtel could use the results and can have a partner (ITS) for solving problems of common interest in the future.

Discussions between project THE-2 team members and staff members of Gajah Mada University, Yogyakarta, led to information exchange. A microprocessor workshop was held in Yogyakarta for the staff members of Gajah Mada University.

Information exchange also took place with LAPAN and Trisakti University in Jakarta.

LAPAN had sent staff members to Surabaya to study microprocessor and microwave techniques.

LAPAN has a cooperation contract with ITS, and has contact with the staff members of the Eindhoven University of Technology and it is possible for LAPAN and Eindhoven University of Technology to exchange
information directly. Trisakti has a cooperation with ITS via the project THE-2 activities. A 12 GHz microwave telecommunication set, sent to Surabaya in the frame work of project THE-2 has been borrowed by Trisakti from ITS for their microwave experiments. Because of shortage of microwave literature, copies of a set of microwave and microprocessor literature were sent by project THE-2 team members to Trisakti University staff members. Trisakti has contacts with staff members of the Eindhoven University of Technology, so information exchange between both Universities is possible. A lecture about GMS reception was given at Trisakti University by a project technician who was visiting Surabaya. The suggestion arose to expand the university research activities in the microwave telecommunication field.

5.3. Profit to local population at the transmitter site

The transmitter was located at Gunung Patok Situbondo, at a height of 80 m situated near Situbondo. During the construction of the site, the local people were employed on the project, also during the measurement period. A local site security man was employed. Before the execution of the project, there was no electricity at the site and surrounding villages. As the transmitter site needed electricity, an 800 m long PLN (Indonesian Electricity Administration) power transmission line was drawn from the nearest PLN transformer to the site. This electricity facility, financed by the project, is utilized by the village people too.

5.4. Self reliance of Indonesian telecommunication engineer and the Indonesian Telecommunication Association, APNATEL

ITS staff members worked in the microwave laboratory, students did their practical works, final study work and special subjects in the microwave laboratory, guidance was given by the microwave staff members. All these facts mean that more graduating engineers have microwave telecommunications as their specialization. These graduates will transfer their knowledge if they go into industry, work in the factories or if they work for other Universities or Institutes.
Thus the self-reliance of Indonesia in educating microwave telecommunication engineers is speeded up and microwave telecommunication engineering could be developed more effectively. Also ITS has the capacity and experience to carry out microwave telecommunication experiments. So it is possible for ITS to have cooperation or own research projects in microwave telecommunications, e.g. in cooperation with Perumtel, LAPAN or other Universities.

This expertise of ITS in the microwave telecommunication field is important for being more independent from foreign countries, e.g., in purchasing telecommunication equipment. Indonesia can participate more actively in the design and calculation of the links, so the business is not relied too much on the advice and calculations of foreign companies.

Also in the maintenance of the equipment, Indonesia can rely more on the work of its own telecommunication engineers.

During the operation of the project THE-2, within the project activities discussions took place about telecommunication engineering, where telecommunication engineers met each other. Project THE-2 engineers visited other universities' and institutes' engineers and the visits were reciprocated. These discussions and meetings led to information exchange, especially in the telecommunication field.

These contacts, made possible through the project activities, should be maintained regularly and it would be very effective if the existing Indonesian telecommunication association could be more activated. More information exchange should be guaranteed and technical workshops, where useful activities and scientific information exchange can take place, should be organized regularly.

So the contacts which were not intensive before the operation of the project THE-2, stimulated and encouraged during the operation of the project because of its activities should be kept going strong by the mentioned Indonesian Telecommunication Association. This will stimulate the goal to achieve an optimal cooperation and information exchange between the Indonesian telecommunication engineers or in short to achieve self-reliance in telecommunication engineering faster.

5.5. Results at the Eindhoven University of Technology

During the execution of the cooperation projects, the results gained by
Eindhoven University of Technology can be mentioned as follows:

1. **Technically**
   a. more experience in the microwave and microprocessor fields.
   b. more tropical microwave propagation data were collected.
   c. more experience in maintaining and choosing suitable equipment/instruments/components used in tropical regions.

2. **Educationally**
   a. many students worked on topics taken from the project research subject.
   b. some students carried out their final study task in Surabaya.
   c. the data obtained were used as (attractive) examples in the telecommunication lectures given in Eindhoven.
   d. a staff member having the experience in carrying out NUFFIC-projects in Indonesia, was sent through the NUFFIC-project UNZA/THT/ELENG to lecture at the University of Zambia, Lusaka. His period of stay was three months.

3. **Organizationally**
   a. Eindhoven University of Technology has contacts with the Indonesian Universities and Institutes which could be useful for future international cooperation.
   b. people have the opportunity to compare the way of working in the Netherlands and Indonesia.
   c. the field engineers, students and staff visiting Indonesia, have the experience of working in a country with totally different culture than in the Netherlands.
   d. Eindhoven University of Technology has more experience in preparing and carrying out international cooperation projects.
Appendix A.

Names and addresses of Institutes, Universities and persons closely involved with the project activities.

In the Netherlands:

Eindhoven University of Technology,
P.O. Box 513,
5600 MB EINDHOVEN
Tel. (040) 479111
Telex 51163

On the same address:

- Bureau Ontwikkelingssamenwerking,
  Tel. (040) 472246

- Telecommunication Group,
  Department of Electrical Engineering,
  Tel. (040) 473451

Netherlands University Foundation for International Cooperation (NUFFIC),
Badhuisweg 251,
P.O. Box 90734,
2509 LS 's-GRAVENHAGE
Tel. (070) 574201

In Indonesia:

Institut Teknologi Surabaya (ITS),
Fakultas Teknik Elektro,
Kampus Komplek ITS,
Keputih Sukolilo,
SURABAYA
Tel. 69621

Perusahaan Umum Telekomunikasi - Perumtel
(Indonesian Telecommunication Administration),
Jl. Cisanggarung 2,
BANDUNG
Tel. (082) 59400 and (082) 55330
Telex BD 08-821.
Contact with Ir. Boedi Santoso.

Ir. Ben Sutanto,
Perumtel,
Jl. Hegerkalong,
BANDUNG
Tel. 863420

Indonesian National Institute of Aeronautics and Space (LAPAN)*,
Jl. Pemuda Persil 1,
P.O. Box 3048,
JAKARTA
Tel. 482802/482653 Telex 45675 I.A.
Persons contacted: Ir. E. Jamin, Drs. Jon Rijono,
Ir. Slamet Hadisaputro and Drs. Alit Bondan.

* LEMBAGA PENERBANGAN DAN ANTARIKSA NASIONAL
Universitas Trisakti,
Fakultas Teknik,
Jl. Kiai Tapa, Grogol,
JAKARTA
Tel. 596355
Persons contacted: Ir. H. Arif Oewen,
    Ir. Joke Setianti Muljadi,
    Ir. Samuel Tirtamihardja,
    Ir. Tjandra Susila
Appendix B.

Publications and reports resulting from the project activities.

A number of publications resulted from the propagation project activities in Indonesia during the years:
- proposals to the sponsors [64], [65], [69].
- plan of operations [22].
- progress reports [63], [73], [86].
- conference papers [17], [18], [19], [50], [51].
- technical reports written by the staff members of the Eindhoven University of Technology [52], [53], [55] - [61].
- technical reports written by the project staff members in Surabaya [54], [62], [85], [86].
- lecture notes written by the project staff members in Surabaya on behalf of the ITS-students [1], [3], [4], [67], [68].
- practical work reports written by the students of the Eindhoven University of Technology ("stageverslag") [23] - [40].
- final study reports written by the students of the Eindhoven University of Technology ("afstudeerverslag") [41] - [49].
- practical work reports written by the students of the Institut Teknologi Surabaya ("Tugas Khusus") [87] - [93].
- final study reports written by the students of the Institut Teknologi Surabaya ("Tugas Sarjana") [94] - [104].
- work visit reports written by the staff members of the Eindhoven University of Technology, who visited Indonesia [74] - [84].
- fellowship reports written by the staff members of the Institut Teknologi Surabaya, who spent some time in the Netherlands [6] - [8], [70] - [72].

Some of these reports originate from the previous project period. However, they were used during the THE-2 project.
Appendix C.

Staffing of the project THE-2 concerning the exchange program.

During the operation of the project THE-2, from 1976 to 1980, three project engineers were engaged in the project and stationed in Surabaya.

The first one, ir. H.J.J. Cuppen (February 1976 - August 1977) was a technical field engineer, whose main task was to carry out line-of-sight measurements on the link Gunung Sandangan - Surabaya, at 4 and 7 GHz. He was assisted by a student, F. Vincent (August 1976 - April 1977) [48]. During this period a progress visit was paid by Prof.dr.ir. J.G. Niesten (July 1977).

The second engineer was ir. A.A.J. Otten (July 1977 - June 1979), who was the general Dutch field project leader and also the Dutch educational project engineer. His task was especially in the educational field [73].

The third one was ir. Th.P. Vlaar (July 1977 - March 1980). He was the technical project engineer; his main task was to carry out the troposcatter measurements Situbondo - Surabaya, distance 150 km, frequency 4 GHz.

Mr. Otten and Mr. Vlaar were assisted by a student, R.J. Deenen [47].

During this period ing. K.G. Holleboom paid two visits to Surabaya. The first one was in January 1978 [79]. His main task was to install his own designed data processing unit using the microprocessor M6800 [55], [56]. The second visit was in October/November 1979 [80]. His main task was to overhaul the microprocessor. He also gave some lectures about microprocessors for ITS staff memebers and others.

Mr. P.F. Maartense visited Surabaya twice. The first time was in May/June 1978 [77]; he assisted with the removal of the transmitter from Gunung Sandangan to Situbondo. The second time was in May/June 1979 [78]; he helped with the removal of the receiving station from Cokroaminoto to the new ITS Kampus Sukolilo. He also had to install his newly constructed receiving equipment [59].

Ing. A.C.A. van der Vorst paid one visit to Surabaya in February 1980 [81]. He assisted with the installation of the GMS receiving station and he assisted the team members in receiving the GMS signals. Also he gave instruction about the 12 GHz, sent to ITS for the continuation of its research program.

Ir. P. Sugondo was from Eindhoven in Indonesia in September - October 1980 [84].
Mr. L. Wijdemans visited Surabaya twice. The first time was in March 1980 [82] and the main task was to carry out the installation of the cross polar measurement equipment. The second time was in September/October 1980 [83]; the main task was to assist in developing the systems used to receive the GMS signal and cross polar measurement. Progress visits to Surabaya were paid by ir. J. Dijk three times. The first one was in January 1979 [74], the second one in August 1979 [75] and the third one in September/October 1980 [76]. His task and results are reported in his progress visit reports.

Two Indonesian fellows studied in Eindhoven. The first one, ir. P. Sugondo, stayed in Eindhoven from August 1976 until November 1977 [6], [70], [71], [72]. The second one, ir. F. Gunawan, stayed in Eindhoven for the year 1978 [7]. The Indonesian project leader, ir. Budhi Purwanto, visited Eindhoven in October 1976. His activities can be followed in his sojourn report [8].

A schematic time-table of the visits can be seen on the next page.
<table>
<thead>
<tr>
<th>Staffing of project THE-2, concerning the exchange program.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Project engineers:</th>
<th>Dutch students in Sby:</th>
<th>Visits technicians:</th>
<th>progress visits:</th>
<th>Fellows in Eindhoven:</th>
<th>Short visit to Eindhoven:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td></td>
<td>R.J. Deenen</td>
<td>P.F. Maartense</td>
<td>ir. J. Dijk</td>
<td>ir. P. Sugondo</td>
<td></td>
</tr>
<tr>
<td>1979</td>
<td></td>
<td></td>
<td>L. Wijdemans</td>
<td>ir. J. Dijk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td></td>
<td></td>
<td></td>
<td>ir. P. Sugondo</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D.

Time schedule of activities within the framework of THE-2.

As written previously, the activities within the framework of project THE-2 can be divided along three main lines:

1. Research activities,
2. Educational activities,
3. Supporting activities.

To give more overview of the research and educational activities, a schematic time schedule was constructed, which can be seen on the next page.
### Research activities:
- line-of-sight measurements
- freq. diversity measurements LOS
- height gain pattern measurements LOS
- removal transm. from Sandangan to Situbondo
- troposcatter measurements
- removal receiving station to new campus
- cross polar measurements
- installation GMS receiving antenna
- installation GMS station
- preparation 12 GHz link Simpang-Sukolilo
- preparation Palapa satellite receivers

### Educational activities:
#### Lectures:
- Digital electronics
  - Microwave lab. installation
  - Design of microwave links
  - Antennas
  - Transmission lines
  - Satellite communication

#### Workshop:
- Microprocessors
  - Retorica

#### Extra lectures by guests

#### Coaching students

**Time schedule of activities within the framework of project THE-2**
Appendix E.

ITS and its planned development in the framework of the ADB-loan*

1. History

In commemoration of the heroes who fell on November 10, 1945 in Indonesia's struggle for independence, a group of spirited citizens set up an "Institute of Higher Learning" on November 10, 1957. As the local branch of the Indonesian Engineers' Union played a major role in its initial development, the institute was established for the training of engineers. The institute initially offered courses in civil and mechanical engineering only and functioned with only part-time teaching staff in those two faculties. The faculty buildings comprised two converted houses and one shed.

In 1960 the institute was nationalized and became the "10 Nopember Surabaya Technical Institute (ITS)". It was expanded to five faculties by the addition of five years degree courses in Electrical, Chemical and Shipbuilding engineering. It continued to function with only part-time staff.

At that time the student enrollment reached 350, but accommodation and facilities were extremely limited. Laboratory facilities were non-existent at the institute and all prescribed practical work was performed by the students externally by utilizing day-school facilities during the evenings. Due to lack of laboratory facilities, teaching at ITS was devoted mainly to theory.

During the period from 1964 to 1968 the premises belonging to a former Chinese school together with other buildings were acquired to provide laboratories for Basic Chemistry, Analytical Chemistry and Basic Physics. A limited amount of electronic equipment and library books was also acquired during that period. Funds for such development were derived from Government allocations as well as from public donations.

Additional funds were provided by the Government for the development of ITS during Repelita I. This resulted in the construction of the Cokroaminoto Campus to provide accommodation for the added faculties of Archi-

* This appendix is mainly based on the Asian Development Bank-report no. INO:AP-31, where possible supplemented with more recent data.
tecture and Science (Mathematics and Physics), as well as offices for central administration. Additional laboratory equipment and teaching materials were also acquired. The cost of such development was about Rp. 425 million, of which Rp. 211 million came from the Government's development budget; the balance was made up from public donations.

2. Present physical facilities

In 1980, ITS offers undergraduate programs in seven faculties, viz.: Civil, Mechanical, Electrical and Chemical Engineering, Shipbuilding, Architecture and Science. The existing physical facilities of ITS are located in five widely separated campuses in Surabaya. These are listed in Table E-1 and a map showing the locations of the campuses is given in Fig. E.1 on page 54.

<table>
<thead>
<tr>
<th>Location</th>
<th>Gross Buildings Area m^2</th>
<th>Age years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Jl. Simpang Dukuh</td>
<td>772 (1246)</td>
<td>over 50</td>
</tr>
<tr>
<td>2. Jl. Baliwerti</td>
<td>4392 (4592)</td>
<td>mostly over 50</td>
</tr>
<tr>
<td>3. Jl. Cokroaminoto</td>
<td>4540 (6345)</td>
<td>under 5</td>
</tr>
<tr>
<td>4. Jl. Kaliasin</td>
<td>433 (433)</td>
<td>30 to 50</td>
</tr>
<tr>
<td>5. Jl. Manyar</td>
<td>3518 (4386)</td>
<td>under 5</td>
</tr>
<tr>
<td>6. Sukolilo</td>
<td>- (6640)</td>
<td>(under 5)</td>
</tr>
</tbody>
</table>

The Simpang Dukuh campus, which was used by the faculty of Electrical Engineering until 1977 is an old hospital building. In the beginning of 1977 the Faculty of Electrical Engineering moved to a new building in the Sukolilo area.

The Baliwerti campus is located on a very busy and noisy street and comprises eight old buildings which are used by the faculties of Mechanical Engineering, Chemical Engineering and Architecture. The Cokroaminoto campus comprises three buildings of recent construction; the faculties of Architecture and Science as well as the central administration and library are located on this campus. The Kaliasin campus consists of an old building used by the faculty of Shipbuilding and is extremely overcrowded. The Manyar campus comprises 13 single-storey buildings constructed recently to house the faculty of Civil Engineering.
LEGEND:
1. Baliwerti Campus
2. Kaliasin Campus
3. Cokroaminoto Campus
4. Manyar Campus
5. Simpang Dukuh Campus
6. New ITS Campus
7. Proposed new roads

Fig. E.1: Surabaya map showing the campuses.
The present space provisions at ITS are grossly inadequate compared to normally acceptable standards. A survey of some reputable public colleges and universities indicates average provisions of the order of 16.0 m² of teaching, administration and support space and 8.5 m² of laboratory space per engineering student, compared to 2.8 m² of teaching and administrative space and 1.6 m² of laboratory space per student at ITS. The urgent need for additional laboratory space and facilities at ITS is underlined by the fact that 60 per cent of the students entering their fourth academic year at ITS were unable to complete their third year laboratory work due to shortage of space and facilities. The total building space, available at ITS in 1975 amounts to 13,655 m² which by reasonable standards for an engineering campus would be adequate for a student enrolment of about 850, compared to an actual enrolment of about 3,000.

The location of the facilities of ITS at five widely separated sites makes it difficult for students and faculty members to use common facilities, such as library and laboratory facilities. There are also inherent difficulties in administration and communication due to physical separation of the campuses. ITS has long felt the need for an integrated campus.

3. **Existing equipment**

Laboratory equipment in all the faculties is extremely limited and many items of equipment are also obsolete. The following sample is indicative of the general need for more laboratory equipment at ITS of the existing laboratory equipment in the faculty of Electrical Engineering, laboratory equipment for electrical power distribution is almost totally lacking and the available electronic test equipment is inadequate; lack of humidity control in the laboratory has also rendered some existing equipment inoperable, proper equipment maintenance is virtually non-existent.

The 1980 cost of the existing laboratory and teaching equipment at ITS is about US $ 100,– per student place, which is a very poor provision.

4. **Existing library**

The existing main library has a collection of some 15,000 books, comprising about 3200 different titles and duplicate copies. Most of the books are out-of-date. Due to the limited numbers of reference books and textbooks,
the books are allowed to be borrowed by students for up to 3 days.

The situation in the library of the faculty of Electrical Engineering is slightly better. In the current cooperation between ITS and the Eindhoven University of Technology in this project THE-2, a basic library of about 1000 recent titles in the field of electrical engineering was received in 1974. Moreover thousands of engineering journals were made available to the Electrical Engineering Library.

5. **Staffing and students**

The basic salary scales for the teaching staff are not competitive with those offered by industry for staff with similar qualifications. Hence, it has been difficult for ITS to attract and retain highly qualified full-time teaching staff. Therefore, ITS has to depend extensively on part-time teaching staff to supplement its full-time teaching staff. The 1975 staffing position of ITS is shown in Table E-2.

<table>
<thead>
<tr>
<th>Faculty</th>
<th>Students</th>
<th>Teaching Staff (full-time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil Engineering</td>
<td>719</td>
<td>23</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>620</td>
<td>9</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>510</td>
<td>19</td>
</tr>
<tr>
<td>Chemical Engineering</td>
<td>472</td>
<td>18</td>
</tr>
<tr>
<td>Architecture</td>
<td>390</td>
<td>17</td>
</tr>
<tr>
<td>Shipbuilding Engineering</td>
<td>304</td>
<td>7</td>
</tr>
<tr>
<td>Science (Physics &amp; Mathematics)</td>
<td>235</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>3250</td>
<td>113</td>
</tr>
</tbody>
</table>

In addition to the 113 full-time teaching staff shown in Table E-2, ITS employs at present 112 part-time teachers. The ratio of students/full-time teaching staff at ITS is high at an average of 28:1 with a maximum for Mechanical Engineering of 69:1. A more reasonable student/teaching staff ratio for a technological university such as ITS would be 12:1.

Because of difficulties in attracting senior academic personnel with good working experience, more than 50% of the regular teaching staff at ITS are recent graduates with a limited experience in technical institute work.
6. **Curricular aspects**

At present ITS offers five year degree courses in Civil Engineering, Mechanical Engineering, Electrical Engineering, Chemical Engineering, Shipbuilding Engineering, Architecture and Science. The degrees of ITS are of a reasonable standard and are generally considered to be equivalent to four-year Bachelor's degrees of many other countries.

Although the department of Electrical Engineering at ITS has a well developed curriculum, many problems in this implementation do exist:

1. The heavy reliance on part-time teaching staff has resulted in most courses being taught on the basis of a single lecture of several-hours per week, rather than on several shorter lectures per week, since part-time staff members find difficulties in breaking away from their regular industrial jobs. This practice obviously does not improve learning efficiency.

   Also due to the shortage of regular teaching staff, many of the courses are taught every other semester instead of every semester. This practice does not permit students, who have failed in a course in one semester, to repeat during the next semester and this results in undue loss of time.

   Another consequence resulting from the lack of full-time teaching staff is the limited opportunity for student-staff contacts.

2. At present ITS operates with inadequate laboratory and workshop equipment, because of inadequate funds for purchase, maintenance and replace of equipment. The result is that undue emphasis is put on theoretical studies. Due to this inadequacy in practical training and due to insufficient attention to management aspects of engineering in the curricula, the graduates of ITS do not receive optimal preparation for their future career as professional engineers.

3. Many textbooks, periodicals and reference materials relating to engineering science and practice are published in the English language. Thus a good understanding of English will be a necessity for Indonesian engineering students since there are virtually no textbooks on engineering subjects in the Indonesian language.
Students' hostels and dormitories are extremely limited in Surabaya. The majority of students usually has very poor home study facilities rather than the solitude and quietness needed for learning. Coupled with the above mentioned low efficiency of teaching at ITS the drop-out rate of the students is high. The average student takes about nine to ten years to complete his graduate studies at ITS and the ratio of graduates to new students' enrolment each year has been as low as 8% in 1972. This ratio has been rising in the last couple of years to 22.4% in 1978. In 1980 ITS produced a total of 413 graduates comprising 126 civil engineers, 63 mechanical engineers, 66 electrical engineers, 64 chemical engineers, 16 shipbuilding engineers, 38 architects and 40 science engineers from a total student enrolment of 3598.

7. **ITS Development Plan**

In 1962 ITS purchased a site of 187.5 hectares at Sukolilo on the perimeter of the city (see map on page 54).

ITS has long recognized many of its deficiencies and, in 1973, produced a Development Program covering the period 1974 - 1993. This program included the following objectives:

a. Sending existing and new staff members overseas for upgrading and advanced training;

b. Purchase of up-to-date laboratory equipment;

c. The development of a single integrated campus;

d. The provision of staff housing to assist in the recruitment and retention of high-level staff.

This plan drew the attention of the Asian Development Bank and after examination by a Bank Fact Finding mission it was found well enough conceived to warrant more detailed study. Consultation with Government resulted in a request for Technical Assistance to examine the feasibility of the plan and to suggest modifications where necessary. The Technical Assistance was provided and the ITS Development Plan modified on the basis of the following main considerations:

a. The original ITS Plan was developed on the basis that only limited funds would be made available each year and thus the plan was extended over a 20 year period. However, the need for improvement of ITS and the provision of better engineering graduates is now and in the immediate future.
b. Again, because the ITS plan was based on the annual release of funds from the Government budget and not on the provision of funds when most required, the resulting development would be more costly and wasteful. Temporary solutions might have had to be implemented.

These foregoing considerations plus additional inputs of university development expertise provided during the Technical Assistance resulted in the formulation of a Project for Implementation within 5 years. In addition to shorten the development period of ITS, changes from the additional Plan include: more substantial input for staff development, provision of a higher level of equipment per student, refinement of proposed curricula and additional input of foreign expertise.

No recommendations have been included in respect of shipbuilding engineering as at that time the possibility of upgrading the provision for training shipbuilding engineers was being studied by ITS in collaboration with representatives of the Federal Republic of Germany. Shipbuilding engineering is closely related to mechanical and civil engineering and it is realistic to assume that, should any development in this area take place, the utilization of shared resources, i.e. materials testing, hydraulics, structural mechanics, should be considered. The master plan for ITS allows for this integrated development.

The actual cooperation between the Department of Shipbuilding Engineering of the University of Aachen, Germany, and the Faculty of Shipbuilding Engineering of ITS started in the middle of 1978.

8. The project

The project consists of the development of the Surabaya Institute of Technology (ITS) by means of the implementation over a 5-year program aimed mainly at the improvement of the four faculties of Civil Engineering, Mechanical Engineering, Electrical Engineering and Chemical Engineering. The objective of the project is to improve the quality of presentation of the lectures so as to minimize repetition and drop-out rate and thus increase the output of graduates from ITS while maintaining student enrolment constant at current levels.

This is to be achieved by:

a. construction of an integrated campus;

b. provision of adequate laboratory facilities and equipment;
c. provision of adequate library facilities and textbooks;
d. implementation of a staff development program and
e. establishment of an academic link with a reputable overseas university
   for development of curricula and academic standards.

The project includes the following major components:
1. site development for the new campus;
2. construction of buildings for the new campus including:
   a. academic buildings;
   b. administrative offices;
   c. communal and maintenance facilities;
   d. student dormitories;
   e. staff houses;
3. provision of equipment and furniture for laboratories, classrooms
   and administrative, communal and maintenance facilities;
4. provision of technical books, periodicals, journals and other library
   facilities;
5. provision of printing and reproduction facilities;
6. provision of a computer centre;
7. provision of fellowships for staff development;
8. provision for visiting advisors and services from an overseas university
   for development of curricular standards and to advice on space and
   equipment requirements;
9. provision for consultant services for site investigations, master
   planning, architectural designs and supervision of construction.

The project is designed to cater for a total student enrolment of 3000
and an eventual full-time staff of 250, so as to achieve a reasonable
student teaching staff ratio of 12 : 1 compared to a curricular student/
teaching staff ratio of about 28 : 1. Measures will be taken to reduce
the student drop-out rate at ITS. Towards this end and apart from im-
proving the quality of instruction, assurances have been received from
the Government that it will devise appropriate entrance tests. This is
to ensure that only students with interest and aptitude in technical
education would be admitted. The planned annual student intake, total
student enrolment and full-time teaching staff to be developed at ITS
is given in Table 3, on the next page.
<table>
<thead>
<tr>
<th>Faculty</th>
<th>Annual student intake</th>
<th>Total enrolment</th>
<th>No. of full-time teaching staff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Civil engineering</td>
<td>100</td>
<td>550</td>
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<tr>
<td>Science</td>
<td>60</td>
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<td>Total:</td>
<td>500</td>
<td>3000</td>
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The total cost involved in the project is estimated at US $25 million.
Appendix F.

Some examination results.
The course "Antennas" was concluded by the last examination on June 9, 1978. The subject was lectured by ir. Th.P. Vlaar in cooperation with Prawiro Sugondo.
The latter was always present during the lectures to elucidate in cases of serious misunderstanding of the English language. In addition, Prawiro organized a few afternoons during which questions from students were answered.
For this obligatory course, 22 students enrolled, 20 of them attended the course.
In total 26 x 2 hours of lecturing were given, at a rate of two lectures of two hours each per week.
As main reference of the course, the notes on the lecture "Antennas" by prof.ir. B. van Dijl, were used, which are available in the Indonesian language. Further the book "The Antenna" by L. Thourel was used, as was "Microwave Antenna Theory and Design" by Silver [20] and [21].
The first "quiz" (half term examination) showed a very bad result (two satisfactory grades out of 20 candidates) which was probably caused by over estimation of the students' capacity and too short an examination time. In fact, the questions were too difficult. On request, a re-examination was given. The results of this examination are presented below in code: A = very good = 81 - 100
B = good = 66 - 80
C = satisfactory = 56 - 65
D = unsatisfactory = 41 - 55
F = failure = 0 - 41
BL = incomplete.

<table>
<thead>
<tr>
<th>A</th>
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<th>C</th>
<th>D</th>
<th>F</th>
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<td>re-examination</td>
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<td>5</td>
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<tr>
<td>3rd examination</td>
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<td>average</td>
<td>3</td>
<td>6</td>
<td>3</td>
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