MASTER

The conversion of the analog S-TV-chain into a digital chain

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The conversion of the analog S-TV-chain into a digital chain

by

A.C.M.M. van den Abeele

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Report of a graduation project done at Philips Medical Systems Nederland B.V. from November 1987 until November 1988 supervised by Ir. R. Kemner (PMSN) and Dr. Ir. A.F.P. van Putten (EUT).

The Faculty of Electrical Engineering of the Eindhoven University of Technology does not accept any responsibility regarding the contents of student project- or graduation reports.
Abstract

The use of application specific integrated circuits makes it possible to replace a complete, often digital, printed circuit board by one integrated circuit. This means already by small lots a considerable reduction in both cost price and volume. One of the television chains Philips Medical Systems produces is meant to cover the low-end market: cheap, but still high quality performance. It is wishful that this analog chain is converted into a digital chain as much as possible.
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## Abbreviations

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<td>AD</td>
<td>Analog-to-Digital</td>
</tr>
<tr>
<td>ADC</td>
<td>Automatic Dose Control</td>
</tr>
<tr>
<td>AGC</td>
<td>Automatic Gain Control</td>
</tr>
<tr>
<td>ASIC</td>
<td>Application Specific Integrated Circuit</td>
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<tr>
<td>CC</td>
<td>Contour Correction</td>
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<tr>
<td>CCD</td>
<td>Charge-Coupled Device</td>
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<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
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<tr>
<td>C-MOS</td>
<td>Complementary Metal-Oxide Semiconductor</td>
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<tr>
<td>DA</td>
<td>Digital-to-Analog</td>
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<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DHC</td>
<td>Dynamic Highlight Compression</td>
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<tr>
<td>DSB</td>
<td>Diagnostic Systems Best</td>
</tr>
<tr>
<td>D-MOS</td>
<td>Depletion Metal-Oxide Semiconductor</td>
</tr>
<tr>
<td>e.g.</td>
<td>exempli gratia (= for example)</td>
</tr>
<tr>
<td>EUT</td>
<td>Eindhoven University of Technology</td>
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<tr>
<td>FT</td>
<td>Frame Transfer</td>
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<tr>
<td>GC</td>
<td>Gamma Correction</td>
</tr>
<tr>
<td>i.e.</td>
<td>id est (= that is)</td>
</tr>
<tr>
<td>i.a.</td>
<td>inter alia (= among others)</td>
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<tr>
<td>IC</td>
<td>Integrated Circuit</td>
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<tr>
<td>IDC</td>
<td>Integrated Dynamic Control</td>
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<tr>
<td>IDSC</td>
<td>Image Detection Segment Controller</td>
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<tr>
<td>ID&amp;D</td>
<td>Image Detection &amp; Display</td>
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<tr>
<td>IEEE</td>
<td>the Institute of Electrical &amp; Electronics Engineers</td>
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<tr>
<td>IH</td>
<td>Image Handling</td>
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<tr>
<td>IPSC</td>
<td>International Production &amp; Supply Centre</td>
</tr>
<tr>
<td>JND</td>
<td>Just Noticeable Difference</td>
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<tr>
<td>LED</td>
<td>Light Emitting Diode</td>
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<tr>
<td>LUT</td>
<td>Look-Up Table</td>
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<td>NTSC</td>
<td>National Television System Committee</td>
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<tr>
<td>PACS</td>
<td>Picture Archiving &amp; Communication System</td>
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<tr>
<td>PC</td>
<td>Personal Computer</td>
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<tr>
<td>PCB</td>
<td>Printed Circuit Board</td>
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<td>PCR</td>
<td>Philips Computed Radiography</td>
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PDR  Perceived Dynamic Range
PMS  Philips Medical Systems
PMSN Philips Medical Systems Nederland B.V.
PPI  Programmable Parallel Interface
RAM  Random Access Memory
R&D  Research & Development
SMPTE the Society of Motion Picture and Television Engineers
SSIS Solid State Image Sensor
TCOP Test software Control Package
TI   Texas Instruments
TTL  Transistor-Transistor Logic
TUE  Technische Universiteit Eindhoven
TV   Television
UDI  Universal Development Interface
USA  the United States of America
viz. videlicet (= namely)
VCA  Voltage Controlled Amplifier
VIKS Video, Blanking & Synchronization Pulses
VICA Video from Camera
VIKV Video for kV-control (power control)
VIME Video for Measuring
XTV  X-ray Television
Preface

This document presents the Master of Science Thesis as a final result of the graduation project to gain the grade of "Electrotechnisch Ingenieur" at the Eindhoven University of Technology (EUT), the Netherlands. The project was done within the Image Detection & Display (ID&D) Predevelopment Group at Philips Medical Systems Nederland B.V. (PMSN) in Best.

The project was supervised by Dr. Ir. A.F.P. van Putten, member of the Digital Systems Group of the EUT Faculty of Electrical Engineering and, Ir. R. Kemner, Head of the ID&D Predevelopment Group.

PMSN markets a complete program of medical equipment i.a. X-ray diagnostic systems. Part of a typical X-ray diagnostic system is a television system (XTV-chain). The aim of the graduation project was to investigate which parts of the conventional analog XTV-chain can be implemented using digital techniques. One of the advantages of digital circuitry is the possible implementation in Application Specific Integrated Circuits (ASIC’s). With ASIC’s i.a. a considerable reduction in cost price and volume can be established. Especially a low-end, cheap XTV-chain benefits by ASIC’s.

After an introduction to PMSN in Chapter 1, X-rays and radiation physics will be explained in a nut-shell in Chapter 2. In Chapter 3 a typical X-ray diagnostic system will be described. Parts of an X-ray television system will be introduced in Chapter 4.

Chapter 5 explains the aims of the graduation project and introduces the reader to an existing XTV-chain. In Chapter 6 the results of the project are summarized. Starting with a first block diagram, the evaluations and considerations will be given, that resulted in a final block diagram of a prototype XTVD(igital)-chain. Chapter 7 gives more details of the built prototype. The written software is described in Chapter 8. Finally Chapter 9 contains conclusions and recommendations.

Best, October 1988.
Chapter 1

Philips Medical Systems

1.1 Introduction

At the turn of the century Philips Medical Systems (PMS) was already one of the leaders in the field of X-ray tubes for radiography and fluoroscopy. That position is maintained in today's range of advanced products and systems. It reflects Philips Medical Systems' innovative strength, and its policy of constant improvement and refinement. Philips Medical Systems' manufacturing resources are located at eight centres around the world:

- Best, the Netherlands
- Heerlen, the Netherlands
- Carrières, France
- Crawley, United Kingdom
- Santa Ana, California, USA
- Shelton, Connecticut, USA
- Hamburg, West Germany
- Monza, Italy

The function of these centres is to act as an international supply centre for specific product groups. They are called International Production & Supply Centres (IPSC). Plant Best is Philips Medical Systems' World headquarters. It is the centre for administration and personnel training. At the Philips Medical Systems International Service Training Centre in Best service technicians can pass through specialised courses on each new system. The plants in Best and Heerlen are part of the organisation called Philips Medical Systems Nederland B.V. (PMSN).
1.2 Research fields and product ranges

Every centre has its own research fields and product range. Shelton is the United States' development and production centre for PCR (Philips Computed Radiography) and PACS (Picture Archiving and Communication Systems); Santa Ana is dedicated to a range of diagnostic systems for Ultrasound, cardiac and B-scan applications. In Best development and production of magnetic resonance imaging systems, computed tomography and special procedure X-ray diagnostics are the main activities, besides administration and personnel training. Heerlen is the centre where image intensifier tubes and wiring looms are developed and produced. Hamburg is dedicated to the development and manufacture of X-ray tubes, plus universal X-ray diagnostic systems. In Monza development and production of dental radiographic equipment is done; in Carrières de remote controlled universal X-ray stands; and in Crawley of linear accelerators for radiation therapy.

1.3 Organization PMSN

The organizational structure is hierarchical. PMSN is divided in three Business Groups. One of them, X-ray is divided in three Product Groups. Next to Image Handling (IH) and Diagnostic Systems Best (DSB), the third Product Group is Image Detection and Display (ID&D), where I have done my graduation project in the Predevelopment Group under supervision of Ir. R. Kemner.
Chapter 2

X-rays and radiation physics

2.1 The discovery and nature of X-rays

X-rays were discovered by Wilhelm Konrad Röntgen in 1895. They are often called röntgen rays. They are emitted from the positive electrode (anode or target) in an electrical discharge tube through which a current is passing (Figure 2.1). One of their first applications was in the medical field: Röntgen made a radiograph of his wife's hand showing the soft tissue and bone structure and the great radiopacity of the wedding ring.

The main properties of X-rays which make them suitable for the purposes of medical diagnosis and therapy are:

- Their capability to penetrate matter coupled with differential absorption observed in various materials.
- Their ability to produce luminescence and their effect on photographic emulsions.
- Their ability to ionise gasses i.e. remove electrons from atoms to form ions.
- Their ability to produce biological effects in living tissues.

It was shown that X-rays were a form of electromagnetic radiation and also shares its duality: they behave as a wave motion in space and are emitted and absorbed in the form of discrete particles of energy, known as quanta or photons.

Figure 2.1: The production of X-rays.
The wavelengths of the X-rays used in medical diagnostic radiology range from about 100-5 pm, corresponding to a range of quantum energies from about 10–200 keV. Because such quantum energies are relatively so large (visible light has a quantum energy of about 3 eV), and the devices used to detect X-rays are so sensitive, that the particulate nature of X-rays is clearly evident in clinical practice. Therefore it is more useful to refer to the quantum energy of the radiation rather than to its wavelength.

When an X-ray beam is attenuated there must have been an interaction with matter. This can take place in three basic ways:

- Absorption (photo-electric attenuation)
- Scatter (Compton attenuation)
- Pair production

Absorption
X-ray photons can be completely absorbed by an atom. Some of the energy of the X-ray photon is used to release an electron from its atomic orbit and the remainder is used to give the electron some kinetic energy. The ejected electron travels through the surrounding matter where it is slowed down by collisions which liberate secondary electrons and lower energy radiation, including X-rays. The vacancy in the electron path is filled by an electron from a higher energy level with the emission of its excess energy in the form of characteristic radiation.

Compton effect
When an X-ray photon interacts with an electron, some of its energy is transferred to the electron. This effect is called Compton Scatter. The electron receives kinetic energy at the expense of the scattered X-ray photon which has a longer wavelength, lower energy and other direction. In this interaction energy and momentum are conserved.

Pair production
If the X-ray photon possesses a very high energy (> 1 MeV), it can be converted into an electron-positron pair i.e. it is changed into two particles. The positron is similar to an electron in mass but has a positive charge.

In diagnostic energy levels, the tube voltage rarely exceeds 200 kV, therefore we will not meet the last effect. In medical diagnostic radiology the X-ray beam is attenuated either by absorption or by scattering.

Assume that a monoenergetic beam of X-rays falls upon matter. If the intensity of the incident radiation is \( I_0 \), that of the transmitted intensity \( I \), and the thickness of the matter is \( \alpha \) cm, then:

\[
I = I_0 e^{-\mu \alpha}
\]
\( \mu \) is called the total linear attenuation coefficient of that particular kind of matter for that particular monoenergetic radiation. It is the fractional decrease per centimetre for that radiation in that substance. This law may be recognized as the exponential law; equal incremental thicknesses of matter produce equal fractional decrements in intensity. Note that this law is not followed exactly in the case of heterogeneous radiation; i.e. for the radiation from the X-ray tube. Nevertheless it is a useful approximation, particular in the case of heavily filtered beams. As mentioned before, the exponential attenuation of the radiation intensity is caused by absorption and scattering.

X-rays of high quantum energy (hard X-rays) are more penetrating than those of low quantum energy (soft X-rays). Hence if a filter of aluminium or copper is placed in the beam, the soft X-rays are attenuated to a greater extent than are the hard X-rays; the whole beam becomes more penetrating and is said to be harder. This technique is of importance in clinical radiology because the softer components in a spectrum are preferentially absorbed in the superficial layers of a patient's tissue nearest to the X-ray tube, with unwanted biological effects.

### 2.2 X-ray image formation and detection

When a beam of X-rays from an X-ray tube falls on a patient, part of the energy is removed from the beam. The energy remaining in the beam that emerges from the patient carries information about the internal structures of the body in the form of a distribution of intensity perpendicular to the beam axis. This distribution may be called the X-ray image.

Most X-ray imaging processes produce a two-dimensional representation of a three-dimensional object. The relative intensities (contrasts) in this representation convey information about the radiological thicknesses (attenuations) of various structures in the body parallel to the beam axis, whereas the spatial distribution of the intensities conveys information about the shapes and fine structures of the organs of the body perpendicular to the beam axis. The X-ray image is a shadowgraph.

X-ray energy is not directly visible; therefore the X-ray image is allowed to fall on an X-ray image transducer (Figure 2.2). This converts the X-ray image into visible form in which it is detected and perceived by the visual system of the radiologist.

For a simple treatment of the whole process from the X-ray tube to the radiologist's brain, the process is divided into three, as shown in Figure 2.2. The divisions occur naturally at the X-ray image and at the visible light image as shown.
Most X-ray transducers in routine clinical use commence with a simple fluorescent screen which converts the absorbed X-ray energy into light. All materials which change radiation into light are known as phosphors. The substance most widely used in the manufacture of fluoroscopic screens is a mixture of zinc sulphide and cadmium sulphide. This has the advantage, when subjected to X-ray bombardment, of emitting a green/yellow light to which the human eye is most sensitive. In all uses of the fluorescent screen it is necessary to match the colour output to the colour sensitivity curve of the light detector. The light image produced by the fluorescent screen is detected in two ways in current clinical practice. This is either by a photographic emulsion in radiography or by the human eye (directly or indirectly) in fluoroscopy. In the next chapter the latter will be described in an X-ray diagnostic system.
Chapter 3

X-ray diagnostic systems

3.1 Fluoroscopy

Fluoroscopy is the dynamic radiological study of the human anatomy. As these examinations can last several minutes every effort must be made to limit the radiation dose to a low level. Therefore the fluorescent screen should convert as much radiation energy into light as possible. As the brightness of a typical phosphor is very low, the best way to view is in darkness. The observer requires time, at least 15 minutes, to adapt his vision to see in a darkened room. Even when so dark-adapted, the information on the screen is far less than that available from a radiograph. To improve the quality of the image in fluoroscopy a device was required that would increase the luminance of the fluorescent screen without increasing the X-ray exposure rate, which was already at a tolerable maximum. The answer was found in the X-ray image intensifier.

3.2 Image intensifier

Figure 3.1 shows a cross-section of an X-ray image intensifier tube. The X-ray image falls on a fluorescent screen that is in intimate contact with a photocathode. The X-rays produce visible light, which in turn produces photoelectrons from the photocathode. These photoelectrons are accelerated and focused through an electron lens system on an output fluorescent screen. The latter is backed by a thin layer of aluminium, which serves to transmit the electrons and prevents

![Figure 3.1: An X-ray image intensifier tube.](image)
Figure 3.2: An X-ray image intensifier television system.

Feedback of light from output to input; it also acts as an electrode. The electrons are accelerated by a constant potential difference of about 25 kV between the photocathode and the aluminium layer; focusing is achieved by intermediate potentials being applied to intermediate electrodes. The input screen is typically 225 mm in diameter, and the output screen is about 20–25 mm in diameter, hence a gain in luminance of about 100 is obtained by the consequent reduction in area (the so-called minification). A further factor of about 50 is attained by the acceleration of the electrons. The result is a total luminance gain of the order of 5000. The gain of a modern intensifier, is normally not expressed as a dimensionless factor, but in terms of the output screen luminance to input dose rate ratio.

The output of an image intensifier, an image of about 25 mm in diameter, was originally viewed through a simple magnifier. Such a viewing device is in practice highly inconvenient. For a short time, binocular microscopes and similar optical systems were in use. When the small industrial type of close-circuit television system had been developed, this was soon adapted to the output of the image intensifier. It was claimed for the television system that not only would viewing be possible on the television monitor in full room lighting, but also that many other television techniques such as image enhancement, video-tape recording, etc., would be applicable to the X-ray image. Moreover, by imaging the output of the intensifier on a small-format still or cine-film, a permanent record of the X-ray image, either static or dynamic could be made. The static film, the so-called spot-film, would have the advantage that a much smaller dose to the patient would be required than in the case of full size radiography, though of course the image quality would be inferior. Figure 3.2 shows a functional diagram of a typical clinical X-ray image intensifier television system.
3.3 Tandem optics

In practice only a single lens (Figure 3.3) is sufficient for the optical coupling between the intensifier and, say, the television camera. Disadvantage of a single lens system is that unless the lens is rigidly mounted, variations in the picture will occur. This is due to slight changes in the position of either intensifier output phosphor, lens or camera tube. In addition to this the lens efficiency is low. Often the output of the intensifier is required to supply a number of different optical devices: cine camera, spot-film camera, or television camera. Therefore some other method must be used and the tandem lens system (Figure 3.4) is the one generally adapted. Here two lenses are used. The object lens is rigidly mounted on the intensifier and is adjusted to bring the image of the output phosphor to focus at infinity. The light output from this lens is therefore a parallel beam of light. The camera lens is adjusted to bring to focus an object at infinity (that is, it will focus a parallel beam of light). The camera lens is rigidly mounted on the camera and the focus set to infinity. Where the two lens systems are mounted as shown in Figure 3.4 the focus is independent of distance between the lenses, although too great a distance will produce vignetting (the image will be brighter at the centre than at the edge). The lens efficiency is also higher than in the single lens case.

Since there is now considerable flexibility in the relative positions of the two lenses, it is a simple matter to exchange cameras. The operation of the equipment can be further simplified by inserting an image distributor containing a surface silvered mirror into the light beam (Figure 3.5). So that by rotating the mirror the light beam may be directed into the appropriate lens. A specially
made mirror having a very thin coating may be used so that only 90% of the light is reflected. The other 10% of light passes through the mirror so that two devices may be used simultaneously.

To the image distributor several optical imaging devices are coupled. A television camera tube followed by a closed-circuit television system is one of them and will be discussed in the next chapter. Other devices are the earlier mentioned spot-film camera and cine-camera. With a spot-film camera pictures (100 mm) are taken with 1–6 frames per second. A cine-camera is used for taking pictures (35 mm) at 12–150 frames per second.
4.1 Introduction

In closed-circuit television the connection between pick-up device and display device is typically a cable. The difference with normal broadcasted television is that the scene information is not spread through free-air. Closed-circuit television has been used in X-ray systems for more than 25 years. As seen before, in X-ray systems, closed-circuit television is always used in conjunction with an image intensifier tube. A basic system is shown in Figure 4.1. It starts with a pick-up device, a video camera, where the optical image of the image intensifier output phosphor is converted into a series of electrical pulses called the video signal. This video signal is transmitted through the camera cable to the control unit, where it is processed and then transmitted to the television monitor for displaying the original scene. In the monitor a conversion takes place of the video signal into an optical image.

4.2 Camera tubes

The most frequently used pick-up device in closed-circuit television is the camera tube. In a television camera tube, photo-conductive effects are used to convert an optical image into an electrical signal. In 1950, the Vidicon was announced. This is a pick-up device using beam scanning and direct read-out from a photo-conductive target. The usual form of a Vidicon tube is a glass cylinder

![Figure 4.1: A basic X-ray TV system.](image-url)
approximately 15 cm long with an 8 pin valve base at the rear. The front is closed by a glass face plate. It is beyond the scope of this report to discuss in full detail how a camera tube works. Anyone interested, however, is suggested to read [1,2]. In 1962 a new type of tube was announced with a different target material. The Philips trademark for this camera tube is Plumbicon. Both tubes are nowadays used in X-ray system closed-circuit television.

4.3 CCD image sensors

One of the developments in semi-conductor technology is the Solid State Image Sensor (SSIS). Like all other electronic image sensors, the SSIS converts an optical image into a video signal. The SSIS uses Charge Coupled Devices (CCD's) to convert light quanta into charges that can be stored in localized regions and then read out in sequence. The SSIS does not use the type of read-out system used at present in the camera tubes, i.e. no scanning beam. The SSIS is in many aspects superior to the camera tube [1].

Nowadays, a type of SSIS known as the Frame Transfer sensor (CCD-FT) seems an attractive alternative to the camera tube. In this image sensor, charge is introduced into the device when light from a scene is focussed on the photosensitive surface. As in all semi-conductors, the absorption of light quanta generates void/electron pairs, which under the influence of a potential beneath each storage electrode, are collected as charge packets. Thus the quantity of charge stored at any storage site (pixel) is proportional to the amount of photons which enter that site (i.e. the intensity of light on that pixel). A spatial charge representation of the image to be televised is stored in this sensor over the duration of a field and transferred to a storage region during the vertical blanking period. This storage region is covered with aluminium against light. During the next field, a new representation of the image is stored in the imaging region. Meanwhile, the pixels of the storage region are divided over three register lines and read out sequentially. In the output stage the pixel charge is converted into a video signal via a source follower. This was in a nutshell the processes which take place in a CCD-FT sensor. A detailed description can be found in [3].

4.4 Control unit

The control unit for a closed-circuit television system associated with an X-ray system controls several functions. Necessary functions like camera adjustment, synchronization and power supplying are obvious. Other functions which are of importance in the scope of this text are:

- Gamma (\(\gamma\)) correction

- Contour correction

- Automatic gain control (AGC)
• Automatic dose rate control (ADC)

• Dynamic highlight compression (DHC)

In several publications a detailed description of the first four functions can be found [1], however, a brief explanation follows.

**Gamma correction**

If in a closed-circuit television system the luminances of the image on the monitor are proportional to the corresponding luminances of the televised scene, the system is said to be free of luminance distortion. Due to the type of pick-up device and display device used, this proportional relationship cannot be achieved without a compensation circuit. The basis of luminance distortion compensation (usually called $\gamma$-correction) is the specific non-linearity of the picture tube. The light output of typical picture tube versus control electrode voltage above cut-off is approximately a power function, the light output varying between the second and third power of the voltage. Typical $\gamma$-correction systems are based on a exponent in the 2.2-2.8 range. To compensate for the picture-tube characteristic, the amplitude of the luminance signal is arranged to vary as the 2.2-2.8 root of the input luminance to the camera.

**Contour correction**

The lens, optical beam-splitting system, and pick-up tube, in total contribute here to a loss in resolution at higher spatial frequencies, both horizontally and vertically. These elements exhibit a $\frac{\sin \alpha}{\alpha}$ (phaseless) type of loss which can produce an overall response curve that does not follow a simple law. Contour or aperture correction therefore is used in all high-quality camera systems to improve the subjective picture quality. With this correction the depth of modulation at 400 or 500 lines is restored to that obtained at approximately 50 lines. Transversal delay lines and second-derivative type of correction are frequently used since they exhibit high frequency boost without phase-shift, thus complementing the $\frac{\sin \alpha}{\alpha}$ roll-off, i.e. boosting the high frequencies without introducing ringing.

**Integrated dynamic control**

Within PMSN, nowadays ADC and AGC are known as Integrated Dynamic Control or IDC. The basic diagrams of the two control loops are given in Figure 4.2. The function of the AGC-loop is to keep the video level at the monitor input constant. The ADC-loop’s function is to keep the X-ray dose rate constant, i.e. indirectly keeping the image intensifier output constant. The camera produces a video signal VICA, which has an certain amplitude during the scan-time and equals $0 \text{ V}$ during the retrace-time. The VICA-signal splits up in two ways, one to $A1$, to be used for the AGC-loop voltage generation, and the second, to the amplifier $A3$ for the ADC-loop.

Amplifier $A1$ is a so called voltage controlled amplifier. It's gain is controlled by the AGC-voltage from $A2$. This control voltage is generated by means of
Figure 4.2: The IDC loops.

A sample-and-hold circuit and an integrator. The video signal is sampled in a capacitor $C_1$ during one field scan-time. During the following retrace-time the charge on $C_1$ is transferred to a second capacitor $C_2$ before starting the new sampling (scan-time). The voltage on $C_2$ is integrated for stability reasons and a DC-voltage called AGC-voltage appears. This control voltage controls the gain of $A_1$ and so the video signal VIBS can be held constant.

The ADC-loop voltage generation takes place in a similar way as in the AGC-loop. After sampling-and-holding the DC-voltage is inverted in $A_4$ and not inverted in $A_5$ and used to control the power delivered to the X-ray tube. A differential signal is used to eliminate interference received on the transmission line (which may be quite long) from control unit to the X-ray power generator. In this generator the differential signals plus interference $\Delta U$ are subtracted to give:

$$ (U + \Delta U) - (-U + \Delta U) = 2 \cdot U $$

A differential amplifier is used to subtract the signals, so the interference $\Delta U$ is eliminated. The amplifier is adjusted according to a dose rate adjustment procedure. The main purpose is to align a certain dose rate value on the input of the image intensifier tube, which results in a stabilizing control voltage on $A_4$ and $A_5$ (0 V). So if the object is repositioning, the ADC-loop voltage changes and the power to the X-ray tube is adapted. The ADC-loop stabilizes, when the dose rate on the image intensifier input reaches the aligned value.

Dynamic highlight compression
The DHC compresses the dynamic range of the video signal to make it displayable on a TV-monitor without losing too much contrast in the image black parts. It is a dynamic regulation, i.e. it depends on the contents of the video signal (Figure 4.3). The elevation of the thick drawn line is a function of the
4.5 The monitor

The last part of a closed-circuit television system is the display device, the monitor. The early mentioned VIBS-signal (Figure 4.4) contains all relevant information for the monitor, to display the original image. Inside the monitor the video information is amplified and connected to the cathode grid of the display system deflection unit. The synchronization pulses are used to synchronize camera and monitor deflection circuits. Those circuits generate sawtooth currents in the deflection units of camera and monitor. The sawtooth current generates a linear varying induction field $B$, which magnetic force is able to deflect an electron beam in the display system. The electron beam is deflected across a luminescent screen and will hit every point of the screen according to the used scan pattern. When the electrons strike a screen coated with a luminescent substance the screen will glow. The greater the number of electrons, the greater will be the brightness produced on the screen. So an amplitude modulated beam current causes a varying brightness, which can be seen through the glass display screen. In Figure 4.5 a typical monitor picture tube plus deflection unit are shown. For the interested reader [1,4] are recommended for more details.

4.6 Clamping and blanking

As can be seen in Figure 4.4 one portion of the video signal amplitude range is selected to transmit the video brightness information. The maximum radiated signal is selected as the brightest to be transmitted. A lower level is chosen as the value of black. A small amplitude range between the black level and a lower level, the blanking level, is used as a guard interval. This is the setup. It facilitates the separation of video modulation from synchronizing and also avoids...
VIBS: video-blanking-synchronization pulse
T-sync synchronization pulse
T-tl blanking pulse during retrace time
T-scan scanning time
T-rep repetition time line video pulse.

Figure 4.4: The VIBS-signal.

Figure 4.5: A typical picture tube configuration.
distortion in the blacks from the circuits -limiters or clamps- which maintain the blanking level. The other portion of the video amplitude range is selected for synchronizing pulses.

The video signal is blanked to a certain level to avoid the visibility of the electron beam moving across the monitor screen during the retrace or fly-back time. Clamping is a video processing operation that provides a line-by-line correction of the video blanking or sync tip level to a fixed DC reference voltage. Because of their different DC settings, the stages in a typical video amplifier configuration are often coupled by a capacitor. Some processing circuitry, however, needs the original DC component of the video signal. Therefore clamping is used for restoring the DC component of the video signal prior to further processing.

All clamp circuits inherently introduce a certain amount of distortion in the video signal at the point of clamping. But, because the video signal is clamped during the retrace time and if the distortion does not cause the video signal to exceed the black level, this causes no problems for the video information.
Chapter 5
The project goals

5.1 Introduction

The official title of this project is "Converting the analog S-TV chain into a digital TV chain" or in Dutch "Het omzetten van de analoge S-TV keten naar een digitale keten". Philips Medical Systems produces several television systems for X-ray diagnostic systems. They are usually called XTV chains. One of these chains is meant to cover the low-end market: a cheap system with minimal features, but still a high quality performance. It is now in the development end stage and will soon be introduced on the market under the name XTV8. This chain had to be converted more or less into a digital chain.

5.2 Why digital?

• A new technology is becoming popular more and more and has a growing field of application in both analog and digital circuits. It is the use of Application Specific Integrated Circuits (ASIC's). With ASIC's several printed circuit boards (PCB's) can be replaced by a single integrated circuit. The applied method makes its use already paying by low number production series. This was the main reason for ID&D predevelopment to start a study about the possibilities of using ASIC's in the low-end chain. ASIC's seems a good technology to get a considerable reduction in both cost price and PCB volume [5]. Two projects were started. Ing. Leo Diepstraten is working on the first ASIC within ID&D. It implements an already digital part of the low-end chain. The second project is this report's subject: a feasibility study of the possible conversion of more analog parts of the low-end chain into digital circuits, with the implementation in ASIC's in mind.

• Next to ASIC's, the introduction of digital circuitry in the XTV-chain has several other advantages. When, for example, a microcomputer becomes part of the system, one may think of a built-in self-test [6]. At power-up or by a remote command the system tests itself and reports the user about its "health" and may also indicate which parts of his body fails. Or it
may perform a software self-diagnosis and tell the operator "how good" the system functions at the moment.

- A philosophy within Philips Medical Systems is to supply the service technician in future with an intelligent tool, a portable personal computer, the so-called service engineer PC. The three main technical areas of this PC are:
  - Host for testing, calibration and customizing of the equipment
  - Tester for Data Communication interfaces
  - Communication tool for Remote Service & Support

Main administrative areas are: call/dispatch and accounting, spare parts logistics, product quality reporting, configuration registration and general mailbox. In this philosophy the introduction of a digital TV chain controlled by a microcomputer with its advantages are quite obvious. Now the service engineer can easily calibrate and adjust parameters of e.g. the XTV chain. Without screwdriver and multimeter or oscilloscoop as it is done now. The parameters become a variable or constant in a computer program and in this way not sensitive to external influences or disturbances. Remote Service & Support is also an interesting application. If the service engineer ran out of his tests or the problem is to complicated, he is able to connect his PC to a centrally located bigger computer with a large data bank support. This computer then takes over and performs more complicated tests. It may use the data bank for historical information about the system and instructs the service engineer what to do.

- Automatic quality control in the factory seems then possible.
- Software adjustment instead of hardware adjustment.
- Software adjustable interfaces to select a certain configuration.
- Reliability.
- New design horizons; like complex adjustable measuring fields; integration of fluoroscopy and exposure modes; intelligent expert input feasible.

In short, there are very good reasons for researching the possibilities of a digital XTV chain.

5.3 XTV8

The XTV8 is the first chain with a CCD sensor as a pick-up device. Next to functions like automatic gain control, automatic dose rate control, dynamic highlight compression and contour correction (See chapter 4), it also performs image reversal, image compression and circle blanking. In the XTV8, the last functions are already implemented digitally as can be seen in Figure 5.1. A brief
The project goals

1. BLACK BALANCE
   WHITE BALANCE
   MULTIPLEXING
   FILTERING
   CLAMPING
   BLANKING

2. AUTOMATIC GAIN CONTROL
   AUTOMATIC DOSE RATE CONTROL
   DYNAMIC HIGHLIGHT COMPRESSION
   CONTOUR CORRECTION
   CLAMPING

3. IMAGE COMPRESSION
   IMAGE REVERSAL
   CIRCLE BLANKING

4. SYNC ADDING

A/D : ANALOG-TO-DIGITAL CONVERSION
D/A : DIGITAL-TO-ANALOG CONVERSION

Figure 5.1: XTV8 block diagram.
In the XTV8 a frame transfer charge coupled image sensor is used, designed for single chip colour television applications. Therefore the effective image area has the typical broadcast television 4 to 3 ratio. For example, the television monitors also have this screen ratio. As one may know, almost every part in an X-ray diagnostic system configuration is designed for a round image (image intensifier, optics, camera tube).

Image compression & reversal
When using a CCD sensor as a pick-up device the question arises how to detect the image in the most effective way, i.e. how to use the CCD image area as efficient as possible without losing image information. In Figures 5.2 and 5.3 two extreme situations are shown. In Figure 5.2, the sensor imaging area is used rather inefficiently without any loss of information. In Figure 5.3, The area is used more economically but some information is lost. The solution to this problem lies somewhere between, literally between image intensifier and CCD-sensor: in the optics. With an optical trick using two prisms, the image is distorted in that way, that the image of Figure 5.3 is compressed vertically giving the result in Figure 5.4: an efficient use without information losses. The task of the control unit is to get the original image back again. This is done "digitally". After digital-to-analog conversion, a video line is stored in a first-in first-out memory. It is written in the memory by the normal pixel clock speed. However, the memory is read by a higher speed, viz. a factor 4 to 3 higher speed. In this way a horizontal, line compression is realized, resulting in an image which is round like the original one (Figure 5.2). By using a last-in first-out memory, a horizontally image reversal is realized without much effort.

Circle blanking
As said before, the typical diagnostic X-ray image is round. Therefore a so called circle blanking is introduced which diameter is relatively slightly smaller than the corresponding diameters in other parts of the X-ray system. In the XTV8, the circle blanking is realized digitally. Result of the circle blanking is a stable grey area around the image circle, without diversive side-effects like noise.

The results of the project are given in the next chapter. After a chronological summary of the actions involved with this project, a brief 'block diagram' de-
Figure 5.3: A large CCD sensor coverage.

Figure 5.4: An optimal CCD sensor coverage.

scription of the built prototype will be given. Chapters 7 and 8 contains a more detailed description of hardware respectively software.
Chapter 6

The results

6.1 Introduction

In the next section the author's way of work is discussed more or less chronologically. This is followed by a section about the results of the feasibility study. Finally in the last section, a 'block diagram' description of the built prototype will conclude this chapter.

6.2 Way of work

The project was started at November 2, 1987 and should originally terminate on August 31, 1988. This period is later expanded to 12 months, so ending October 30, 1988. At the beginning of the period, after two weeks, a planning was made. The first two months were scheduled for gathering information, a service training course and consulting several persons. Then, in January 1988, a concept block diagram should be ready. After two months of evaluating and filling in the details of the diagram, the realization of the prototype on printed circuit boards was planned, starting in March. From the end of June, about two months were scheduled for writing this report.

What came out of this planning? In January a concept block diagram was ready. After several evaluations and some practical excursions in the field of analog video circuitry design, the final block diagram including details was presented at the end of April. The assembling of the analog part of the circuitry was started in May. This lasted, including some testing and redesign until June. Then a start was made with the building of the digital circuitry, i.a. using the Wire-Wrap technique, and the writing of software for the Intel microcomputer system using the C programming language [7,8,9]. Just before the factory summer closing period, the printed circuit boards were completed. Because there was no CCD sensor plus peripheral boards available at that time, about two weeks were spent with some parts of this report and also with some checks of the circuitry. At the beginning of August a new sensor was available and the testing could go on. At the end of the same month, the practical part was ended
and the writing of this report could begin.

6.2.1 Information

The first weeks of the project were spend in several libraries. Next to the PMSN library in building QP, the libraries of the Eindhoven University of Technology and the Institute for Perception Research were helpfull information sources. Digital video/television were used as catchwords. A lot of information about these subjects can be found in the journals of the Society of Motion Picture and Television Engineers (SMPTE) and the IEEE Consumer Electronics Conferences (IEEE = the Institute of Electrical and Electronics Engineering). Also several books were consulted to get sufficiently informed about the project. A complete list is given in the Bibliography, starting on page 79.

Medical image formation

Already many years medical images are made of the human body. In [10] medical image formation using several kinds of electromagnetic radiation is discussed. It gives an overview of several methods and also, although indirectly, of Philips Medical Systems' product range.

Digital video/television


Television principles

For an overview of television principles and the typical video signal characteristics, several publications exist. Oldies like [18,19,4], but also a more recent one, [1], gives a clear insight into television basics. In [2] a description of a television system acuminated for X-ray systems is described.

X-ray diagnosis principles

To be able to write the previous chapters 2 and 3, [20,21] were consulted. Of a scope of different X-ray diagnostic system configurations, a basic one is selected and described in chapter 3.

CCD sensors

To get familiar with this solid state image sensor, several books and publications were read. Next to [3,22] development notes of the Philips FT4 sensor
has been studied. The Philips FT4 is a frame transfer CCD sensor with a 600 x 600 pixel screen resolution and is used in many video applications at the moment.

More interesting information
Interesting information can be found in a special issue of *Proceedings of the IEEE*, the April 1985 (Vol.73 No.4) issue is concerned with visual communication systems. It brings together the technology as well as specific applications and experiences of users. The issue covers basics of digital representation and coding of pictures, digital codecs (coders-decoders) as well as receivers for television, high-definition television, various forms of picture conferencing systems, Facsimile and Teletext, transmission and distribution of video signals. Three articles are useful in the scope of this project. A review of the 1985 technology for television cameras can be found in [23]. In [24] the impact of digital technology in television receivers is reviewed with some predictions of the future. Application of digital technology for coding, transmission and storage of the broadcast television signals is reviewed in [25].

6.2.2 XTV5/6 service training course

From November 30, 1987 up to December 4, 1987 inclusive the XTV5/6 service training course was attended. This course is meant for service technicians of PMS equipment from several countries. Its main objectives are twofold. At the end of the course, the student has to understand the principles of the television systems XTV5/6; and he has to be able to repair the television systems on PCB-level. The author got a clear insight into these two systems from the course, although, to his opinion the course time schedule was rather tight.

6.2.3 Conversations

The author had some interesting conversations with several persons. Particular useful were the following ones. Ing. W.E. Spaak, Development ID&D, explained diagnostic methods using PMS equipment; discussed the place of the XTV-chain in the Image Detection Segment Controller (IDSC); mentioned the existence of a service terminal and a Test-software Control Package (TCOP). Ir. D.J. de Graaff, Service R&D, told me some PMS philosophies about service using TCOP and a portable IBM-compatible personal computer as a service terminal.

6.3 What are the results?

At the beginning of 1988 a first block diagram was presented. This diagram is divided into two parts. A fast, video part with a speed dependent on the used sensor clock frequency and a slower microcomputer part (Figure 6.1). From this first block diagram to the final one, several design steps were made, concerning the realization of the various functions. In the next part of this chapter, a concise
System clock & timing
In the prototype a CCD-FT sensor is used. It is a solid-state high resolution image sensor for NTSC black-and-white television systems. The sensor, a Texas Instruments (TI) VID 282, has a 774 x 484 pixel resolution and needs a 14.3 MHz pixel clock. To provide this sensor with the right signals TI also supplies four peripheral integrated circuits for the VID 282. There is a timing generator for a correct timing of the actions inside the CCD. This generator also supplies signals for configuring a typical CCD television system. Two driver IC's interfaces the timing generator and the sensor. The last peripheral IC contains differential sample-and-hold amplifiers to convert the signals from the three CCD output terminals to appropriate video levels. The decision has been made to base the prototype timing on the used sensor sensor plus timing generator. This means a deviation from the proposed digital video standard [13].

Multiplexing the 3 output signals
The CCD sensor output stage consists of three serial registers. It is apparent that there might be differences in gain and DC-level between the three output registers. The compensation of these differences are colloquially called white-balance (gain) and black-balance (DC-level). During the horizontal blanking interval the pixel charge is transferred line-by-line from each group of columns into the corresponding serial registers and prepared for read-out (Three adjacent pixels on one line are transferred into three different registers). The three
output signals have to be multiplexed to retain the original video signal. Two philosophies existed. The first implied an analog-to-digital conversion of the three output signals before multiplexing. An advantage is that slower, cheaper converters can be used (4.77 MHz). The black-balance and the white-balance of the three signals can now be done digitally more or less. After balancing, the signals are digital multiplexed to get one signal. The second philosophy implied a conversion after multiplexing as in the XTV8; thus analog black-balance and white-balance. For several reasons a decision has been made in favor of the last mentioned philosophy. A market gap exists concerning analog-to-digital converters, especially converters to be used in a low-end, cheap XTV-chain. On one end there are very fast converters (8 bit wide, sampling speed > 20 MHz) and on the other end wide converters, but not fast enough (up to 12 bit, several 100 kHz). In the frequency range between, useful converters are sparse. So extra expensive converters have to be used for a function which can be realized very simple. In the XTV8, the balancing and multiplexing is done using only a few components with a very reasonable image result. Choosing this philosophy means that as prototype input a signal from the XTV8 preprocessing PCB is used, which is already multiplexed. The video signal right after the filter section is taken. It has a maximum amplitude of 1750 mV.

How many bits?
The analog video signal has to be converted into a digital video signal. Earlier was decided to use the timing signals from the sensor's timing generator, i.e. a 14.3 MHz pixel clock. So the video signal has to be converted with the same speed to prevent side-effects. But how many bits are sufficient? The X-ray image is a shadow image. The important information source is the contrast between parts of the image. The video signal in an XTV chain contains no color information, but is typical a black-and-white signal. The question arises how many bits (i.e. how many levels on the grey scale) have to be used in the conversion? In [26] it has been concluded that the perceived dynamic range (PDR), the number of different levels which can be distinguished by the visual system (just noticeable differences or JND's) from a monitor equals approximately 90. This implies that if more than 90 different values are present in the digital image they cannot be simultaneously perceived from a monitor. In [27] it has been concluded that the number of levels for a linearized scale should be between 1.5 and 2 times the PDR of the scale. If the scale is not linear, the discretization must be finer to make the adjacent levels indistinguishable in the part of the scale for which the JND is the lowest. If the images to be displayed are themselves noisy, these requirements can be relaxed somewhat. This means that for a grey scale with PDR = 90 JND about 135 to 180 levels are sufficient. This implies an 8 bit conversion. This is confirmed by [28], where at least 7 bit are suggested.

Measurement of the video signal
As explained in Chapter 4 the video signal has to be measured for the IDC-loops. This is realized by means of a sample-and-hold circuit and a integrator and so an average of the video signal is estimated. Digitally the average of the video signal
in a certain measuring field can easily be calculated. If one knows the sum of all the byte values in this measuring field and also the number of bytes, this means a simple division. But a problem arises. The used pixel clock is $14.3 \text{ MHz}$. It is not possible now for an existing microcomputer to copy a pixel value to his memory by this speed. Therefore the digital part is split in two. A fast part where the two values, sum and number, are estimated and a slower part, the microcomputer system, where the calculations are done.

**Location of the functions**

In Figure 6.1 the functions Image Reversal, Image Compression, Circle Blanking, Gamma Correction and Contour Correction can be seen. Where are the other functions? Although not very clear, the Automatic Dose Control function is present. The two symmetric signals for the X-ray tube power generator are part of the data out signals. To realize the Automatic Gain Control and Dynamic Highlight Compression functions a look-up table (LUT) can be used. This LUT can be e.g. a dual-port RAM (Random Access Memory) configured as an input-output function. The input byte is the RAM address. The addressed data is the new byte value. The RAM data is refreshed by the microcomputer system. Their values depend on e.g. a measured average and parameters. In this way the AGC and DHC can be realized. The next paragraph more considerations about the AGC are given.

**Automatic Gain Control**

At first the idea existed to implement the AGC function completely digitally. For quality reasons, however, this is not advisable. In the low-input signal case the analog-to-digital converter is not used very economically. This low signal will be discretized to a certain number of levels. Amplifying this signal will not increase nor decrease this number. Thus the number of grey levels will be a function of the input signal. This is not so if the video signal is stabilized before analog-to-digital conversion. Then the number of grey levels only depends on the video level to which is stabilized. Therefore an analog amplifier is used which is voltage controlled by the microcomputer.

**XTVD block diagram**

The above considerations led to the XTVD block diagram (Figure 6.2). This diagram is realized in a prototype in which only the ADC and AGC functions are realized. As indicated in the diagram, the prototype input signal is a signal from the XTV8 preprocessing board. The interface to the microcomputer system is via a programmable parallel interface (PPI). The prototype circuitry will be explained in detail in Chapter 7.
Figure 6.2: XTVD block diagram.
Chapter 7

The built prototype: XTVD

7.1 Introduction

The prototype is built on three different printed circuit boards (PCB's). The smallest PCB (XTVD-S) is mounted near the XTV8 CCD sensor. The other two have an E6 double Eurocard size. XTVD-I contains most of the digital circuitry. XTVD-V contains the analog video circuitry, the analog-to-digital and digital-to-analog converters and some digital circuitry (Figure 7.1). In the next sections, the PCB's will be described in detail. In section 7.2 the smallest PCB and in sections 7.2 & 7.3 the other two. In section 7.4 the used microcomputer system (AMS-M6-A8) will be described briefly.

7.2 XTVD-S

This PCB contains several drivers to interface the XTV8 timing signals needed on the other prototype PCB's. In Appendix C, page 59, the rather straightforward driver circuitry is shown.

Figure 7.1: PCB interconnections.
7.3 XTVD-V

The XTVD-V PCB contains the analog video circuitry, the analog-to-digital and digital-to-analog converters plus some digital integrated circuits. The diagrams are shown in Appendix A, pages 50-52. In the following subsections a detailed description of XTVD-V will be given. In 7.1.1 up to 7.1.7 inclusive the analog circuitry; in 7.1.8 the interface circuitry and finally in 7.1.9 the converters' part.

7.3.1 Input stage

The video signal from the XTV8 preprocessing board is connected to the prototype XTVD-V board via a 75 Ω line connection. As shown in Figure 7.2 a 301 Ω fixed resistor parallel with a variable resistor of 100 Ω forms a correct 75 Ω line termination. In this way the input sensitivity can also be adjusted. An emitter-follower serves as a buffer after which the video signal is clamped and blanked. This is realized rather simply with two electrolytic capacitors and three N-channel D-MOS type field effect transistors. The transistor used, a BST 70 A, can be interfaced directly with C-MOS and TTL signals; i.e. in this configuration the gate input signals may have typical C-MOS or TTL switching levels.

7.3.2 VCA

A wideband monolithic four-quadrant multiplier is used to build a voltage controlled amplifier (VCA). In Figure 7.3 the schematic circuit of the multiplier, an MC 1495 is given. The MC 1495 operates on the principle of variable conductance. The differential output is given by:

\[ I_2 - I_{14} = \Delta I = \frac{2 \cdot V_X \cdot V_Y}{R_X \cdot R_Y \cdot I_3} \]

where \( I_2 \) and \( I_{14} \) are the currents coming out from pins 2 and 14; \( R_X \) and \( R_Y \) are the resistors connected between pins 10 and 11 respectively pins 5 and 6;
$V_X$ and $V_Y$ are the X and Y input voltages at the multiplier input terminals. By proper selection of external components, the multiplier can be tailored to a specific application.

In Figure 7.4 a basic multiplier circuit is given. It can be seen that the output voltage is given by:

$$V_0 = \frac{2 \cdot R_L}{R_X \cdot R_Y \cdot I_3} \cdot V_X \cdot V_Y = K \cdot V_X \cdot V_Y$$

The maximum output voltage of the signal from the XTV-8 preprocessing board is 1750 mV. Because of the 75 Ω line connection, the maximum video level is about 875 mV. $V_Y$ is taken as a control voltage (with a maximum value of 7000 mV) to set a certain gain. So $V_{X(max)} = 875 \text{ mV}$ and $V_{Y(max)} = 7000 \text{ mV}$. A symmetric power supply with $V^+ = 15 \text{ V}$ and $V^- = -15 \text{ V}$ is chosen. The circuit output has to be connected to an analog-to-digital converter with an input range of 2100 mV typical. With the multiplier an automatic gain control is wanted with a maximum gain of say 5, when the maximum control voltage is applied. So a 1400 mV control voltage means a gain of 1. With this control voltage applied, an input voltage $V_X = 875 \text{ mV}$ should give $V_0 = 2100 \text{ mV}$. From this information the transfer factor is calculated to be: $K = 583 \text{ V}^{-1}$.

We will now proceed with the dimensioning of the circuit. First we select $I_3$ and $I_{13}$, the currents into pins 3 and 13 respectively. Only the power dissipation of the device forms a restriction on the selection of these currents. To set currents $I_3$ and $I_{13}$ to the desired values, it is only necessary to connect a resistor between pin 3 and ground and between pin 13 and ground. From Figure 7.3 it can be seen that the resistor values necessary are given by:

$$R_3 + 500 \Omega = \frac{|V^-| - 0.7 \text{ V}}{I_3} \quad R_{13} + 500 \Omega = \frac{|V^-| - 0.7 \text{ V}}{I_{13}}$$
Figure 7.4: Basic multiplier circuit.

With $I_3 = 0.5 \, mA$ and $I_{13} = 2.75 \, mA$ the resistor values are calculated to be $R_3 = 4.7 \, k\Omega$ and $R_{13} = 28.1 \, k\Omega$. With chosen resistor values of $R_3 = 4.75 \, k\Omega$ and $R_{13} = 27.5 \, k\Omega$ the currents become $I_3 = 0.51 \, mA$ and $I_{13} = 2.72 \, mA$.

To insure that the input transistors will always be active, the following conditions should be met:

\[
\frac{V_X}{R_X} < I_3 \quad \frac{V_Y}{R_Y} < I_3
\]

A good rule of thumb is to make $I_3 \cdot R_Y \geq 1.5 \cdot V_{Y(\text{max})}$ and $I_{13} \cdot R_X \geq 1.5 \cdot V_{X(\text{max})}$. With $R_X = 511 \, \Omega$, $R_Y = 14.7 \, k\Omega$, $V_{X(\text{max})} = 875 \, mV$ and $V_{Y(\text{max})} = 7000 \, mV$, the above conditions are sufficiently met.

In order to maintain transistors $Q_1$, $Q_2$, $Q_3$ and $Q_4$ (Figure 7.3) in an active region when the maximum input voltages are applied, their respective collector voltages should be at least a few tenths of a Volt higher than the maximum input voltage. Therefore to handle $7 \, V$ at the inputs ($V_{Y(\text{max})}$), the voltage at pin 1 must be at least $9 \, V$. Let $V_1 = 11 \, V$. Since the current flowing into pin 1 is always equal to $2 \cdot I_3$, the voltage at pin 1 can be set by placing a resistor, $R_1$ from pin 1 to the positive supply. With $R_1 = 3.65 \, k\Omega$, $V_1$ becomes:

\[
V_1 = V^+ - 2 \cdot R_1 \cdot I_3 = 11.2 \, V
\]

Note that the voltage at the base of transistor $Q_5$, $Q_6$, $Q_7$ and $Q_8$ is one diode-drop below the voltage at pin 1. Thus in order that these transistors stay active, the voltage at pin 2 and pin 14 should be approximately halfway between the voltage at pin 1 and $V^+$, say $13.1 \, V$.

It is usually desirable to convert the differential output to a single-ended output voltage referenced to ground. The circuit shown in Figure 7.5 performs this so called level-shifting function. It can be seen that the output voltage of this
circuit is given by the same formula as found earlier:

\[ V_0 = \frac{2 \cdot R_L}{R_X \cdot R_Y \cdot I_3} \cdot V_X \cdot V_Y = K \cdot V_X \cdot V_Y \]

With \( R_L = 3.92 \, k\Omega \) and the values estimated before this becomes:

\[ V_0 = 2.05 \, V^{-1} \cdot V_X \cdot V_Y \]

So an input voltage \( V_X = 875 \, mV \) needs a control voltage \( V_Y = 1173 \, mV \) (gain 1) to give \( V_0 = 2100 \, mV \). This also means that the maximum gain of the circuit is approximately 6.

When \( V_X = V_Y = 0 \), the currents \( I_2 \) and \( I_{14} \) will be equal to \( I_{13} \). Earlier \( R_L \) was chosen as \( 3.92 \, k\Omega \) and both \( V_2 \) and \( V_{14} \) were found to be 13.1 \( V \). From this information \( R_0 \) can be calculated easily from the following equation (neglecting the operational amplifiers bias currents):

\[ \frac{V_2}{R_L} + I_{13} = \frac{V^+ - V_2}{R_0} \]

\[ \frac{13.1 \, V}{3.92 \, k\Omega} + 2.75 \, mA = \frac{15 \, V - 13.1 \, V}{R_0} \Rightarrow R_0 = 313 \, \Omega \]

With \( R_0 = 301 \, \Omega \), the voltages at pins 2 and 14 are calculated to be \( V_2 = V_{14} = 13.2 \, V \).

In Figure 7.6 the multiplier plus phe ripherical components used in the prototype are shown. It must be remarked that the connections between the multiplier and operational amplifier are reversed. So the input signal is not only amplified or attenuated but also inverted. This is done, because the used analog-to-digital converter needs this kind of signal. The following voltages have been measured on the built prototype board: \( V_1 = 11.14 \, V; V_2 = 12.91 \, V; V_3 = -14.12 \, V \Rightarrow I_3 = 0.51 \, mA; V_{13} = -12.89 \, V \Rightarrow I_{13} = 2.71 \, mA; \) and \( V_{14} = 12.90 \, V \). The measured AGC-range was 26 \( dB \) (1 - 11 \( MHz \)). This corresponds with a gain factor of 20.
7.3.3 DA-2

Figure 7.7 shows the DA-2 stage. It merely consists of an operational amplifier that buffers the signal from the second digital-to-analog converter, before it is used as a control voltage in the voltage controlled amplifier stage. The output voltage range of this digital-to-analog converter is set to $0 - 7 \, V$.

7.3.4 AD-1

In the AD-1 stage (Figure 7.8) the inverted signal from the multiplier stage is clamped and buffered. The buffering is realized with two transistors in a Darlington configuration. It has two purposes. First, the clamping needs a high impedant termination and secondly, the used analog-to-digital converter needs a low-impedant input source. These requirements are fulfilled with the Darlington buffer.

One may remark that the clamping is realized in a different way than what was shown in the input stage. The used transistors in the input stage have a restriction on the applied drain-to-source voltage $V_d$. This voltage always be positive for proper functioning. As mentioned before, the signal was inverted in the multiplier stage. So the drain-to-source voltage can be negative, when clamping
to voltage zero. An different kind of transistor is used that does not have this restriction. However this type of transistor can not directly be interfaced with TTL signals. Therefore two transistors are used to convert the TTL levels to the right gate voltages to switch the transistor which performs the actual clamping.

The video signal is not clamped to zero, but to a positive voltage to compensate the two diode-drops in the buffer transistors. A variable reference source is realized with a zener-diode, some resistors, a capacitor and a transistor.

### 7.3.5 DA-1

To the video signal from the digital-to-analog converter (ADC1) a synchronization pulse should be added. Then the resulting signal can be send to a monitor. In this way the pick-up device, the CCD-sensor, and the read-out device, the monitor, are synchronized. This sync-adding is realized with an operational amplifier (Figure 7.9). The used digital-to-analog converter has an output voltage range of maximum 2100 mV depending on the applied reference voltages. The synchronizing signal CSYNC has a normal 5 V TTL high level. The transfer function of the circuit can be calculated using:

\[
\begin{align*}
V_O &= \frac{3}{100E} V_I + \frac{3}{2} V_K \\
V_I &= \frac{1}{R_1} V_S + \frac{1}{R_2} \left( \frac{1}{R_3} V_S + \frac{3}{2} V_K \right)
\end{align*}
\]
Figure 7.9: The DA-1 stage.

\[
V_+ = V_I \quad V_- = V_K \\
\frac{V_K - V_O}{R_3} + \frac{V_K}{R_2} + \frac{V_K - V_S}{R_1} = 0
\]

With these equations the transfer function becomes:

\[
V_O = \left(1 + \frac{R_3}{R_1} + \frac{R_3}{R_2}\right) \cdot V_I - \frac{R_3}{R_1} \cdot V_S \\
V_O = K_1 \cdot V_I + K_2 \cdot V_S
\]

The monitor signal is specified as follows:

- maximum video level 1400 mV
- sync level -600 mV

So \(K_2\) should have a value of -0.12. To fine-adjust the sync level, a 500 \(\Omega\) variable resistor in series with a 332 \(\Omega\) fixed resistor is used. With \(R_3 = 68.1 \Omega\), \(K_2\) can be varied between 0.08 and 0.2 approximately. To get \(K_2 = -0.12\) the variable resistor should be set to about 230 \(\Omega\). With these values and \(R_2 = 100 \Omega\), factor \(K_1\) becomes 1.14. A reference voltage of approximately 1226 mV for the digital-to-analog converter will be sufficient to give the maximum video level. The additional filtering of the video signal may influence the shape of the sync pulse. It is therefore suggested to filter the video-without-sync before the sync pulse is added. In this way the rise and fall times of the sync pulse remain short.

### 7.3.6 AD-2

In Figure 7.10 the AD-2 stage is shown. This stage processes the clamped and blanked signal to a level for a second analog-to-digital converter. The circuit consists of a buffer followed by an operational amplifier in an inverter configuration.
7.3.7 DA-3

The DA-3 stage (Figure 7.11) serves to provide the proper signals for the X-ray tube power generator. Two symmetric signals are needed with a $-6\,V$ to $+6\,V$ range. The signal from the third digital-to-analog converter, DAC-3 ranges from $-5\,V$ to $+5\,V$, so this signal should be amplified and inverted. This is realized with two basic operational amplifier circuits. The diodes protect the circuit from unwanted high voltages from the power generator.

7.3.8 Connectors

The connectors part (Appendix A, page 52) consists of a receiver part, where the timing signals from the XTV8 preprocessing board enter the XTVD-V board. A 100 $\Omega$ line termination followed by a 244 driver to obtain right TTL levels again is the main part. The rest of the circuitry is clear and needs no further explanation.

7.3.9 Converters

In the converters part the two analog-to-digital convertors and the three digital-to-analog converters can easily be recognized (Appendix A, page 51). The convertors above are the two video convertors, the convertors in the input-to-output
signal line. The two NE 5018 converters are digital-to-analog ones and used to provide the VCA control voltage and the symmetric signal pair for the X-ray tube power generator. The lower one is configured in a bipolar mode and provides a $-5 \, V$ to $5 \, V$ output range. The upper one is set up in a $0 - 10 \, V$ range unipolar mode.

Obvious are the several reference voltage parts. Three '244 tri-state bus drivers are used to select the point where the video signal is shunted. For testing purposes also a dipswitch is selectable.

### 7.4 XTVD-I

The circuitry present on the XTVD-I PCB is divided over 4 diagrams. They are given in Appendix B on pages 54-57. This board serves as an interface between the XTVD-V board and a microcomputer system. In the next section more details are given about this system. The XTVD-I diagrams are discussed page by page.

On the first diagram, page 54, two connectors are shown each consisting of two parts. The X92 connector leads to the microcomputer system; X91 to the XTVD-V board. Obvious are the three busses POA, POB and POC. They are connected to the three ports of an 8255A-5 programmable parallel interface used in the microcomputer system. Seen from this system, port A (POA0-POA7) is used as an input port; port B (POB0-POB7) as an output port; and port C as dataflow control. In the upper left corner there are two '138 decoders. With rC2 a device can be selected to put its contents on the POA bus. IC1 is used to select a device to which the contents of the POB bus can be copied; an example is IC7. Next to IC7 two resistor arrays can be seen. They prevent reflections to occur on the fast signal lines, to which they are connected. The fast signal lines are now terminated with the characteristic impedance of the flat cable used in the line connection.

The remaining part, IC3-IC6 is a detection circuit (Figure 7.12). It detects the ending of the measuring field in a video field. After the beginning of a certain video field, indicated by HGATE, the occurrence of a high MFLD signal activates the detection circuit. This circuit then detects the first video line in which MFLD did not become high and makes REG...FULL high at the end of this video line. The function of REG...FULL will be explained later; it can be reset by LE2. The MBO-MB7 signal bus originates from the XTVD-V board and contains video information. Signal /14MC is the inverted 14 MHz system clock signal.

The circuitry on page 55 can be divided in two parts. To the right four registers can be seen. The other part summates all video information bytes present in the measuring field within a video field. Signal REG...FULL latches the resulting big sum into the four '374 registers. The sum can be reset by LE2. The latches can be put on the POA-bus one at the time by four enable signals EN4-EN7 and
7 The built prototype: XTVD

A similar circuit is shown on page 56. This circuit, except IC25, counts the number of video information bytes present in the measuring field in a certain video field. The resulting number is latched in three '374 registers by REG_FULL. The counters are reset by LE2. Register IC25 is used by the microcomputer system to poll timing signals or to look at the status of switches. These so called DIP-switches are shown on page 57. On top of this diagram a circuit can be seen to display, using light emitting diodes (LED's), the status of the three busses to the microcomputer system.

7.5 Microcomputer system

The used system is a Siemens AMS-M6-A8. It consists of an Intel 8 MHz 8086 central processing unit (CPU); an 8255A-5 programmable multifunction interface; an 8251A serial interface; an 8253-5 programmable timer/counter; an 8259 programmable interrupt controller and provisions for connecting an 8089 I/O processor and an 8087 co-processor. On board 128 kByte random access memory (RAM) is available. A block diagram is shown in Figure 7.13. The connection to the XTVD-I board is via the three 8255A-5 ports. The microcomputer system was part of a software test environment for in-target hardware tests [29]. It is intended for targets containing an 80x86 or 80x80 processor. Via a serial (RS232) link an IBM-like personal computer is connected to this target system. With a certain command (TGCOM) the communication link is established between the PC and the target system. The monitor program within the target will respond with a message and the standard monitor commands can be used. The iSDM86 monitor was available on the target.

Within this test environment a program can be downloaded to the target and then that program can perform terminal and input/output actions on the PC. So it is possible to read a file from the PC's hard-disk, if present, or to print a status-report on a connected printer.

The test environment supplies the user with a subset of the Intel Universal
Development Interface (UDI) standard. The subset is chosen with the run-time libraries for the Intel C Compiler (iC-86 V3.0) in mind. It is also possible to write test programs in other languages, as long as the supported subset is used. The Intel C Compiler [8] compiles programs written in the C programming language, as described by Kernighan and Ritchie [9].
8.1 Introduction

The software is written in the C programming language. As stated in the preceding chapter, the iC-86 Intel C compiler is used. It compiles programs written in the C programming language, as described by Kernighan and Ritchie ([9]).

Several advanced features are supported, in addition to the full range of features described in [9]. The data type void is a special type that may not be used in expressions. It is typically used in the definition of a function that returns no value; it prevents the use of a null value in a value context. The derived type enum specifies an enumerated data type.

The compiler translates programs into relocatable object files or assembly language-like source files. Once generated, relocatable object code may be linked with the standard C run-time support libraries and, if necessary converted into an absolute module.

The microcomputer system is connected to the XTVD-I PCB via the three ports of an 8255A-5 programmable parallel interface. The three ports are called PORTA, PORTB and PORTC. Their addresses can be found in the listing of the xtvd.h file. Seen from the target system PORTA is a data input port; PORTB serves as a data output port and, PORTC is used as a control bus. Bits 6 & 7 of PORTC are comparable with typical read and write signals; the remaining bits are used as an address to select a certain device.

8.2 Software description

Next to file xtvd.c the software includes files stdio.h, string.h, ctype.h and xtvd.h. The main program is xtvd.c and it uses the other four files as can be seen in the first lines of the program (Appendix D, page 61). File xtvd.h contains definitions of constants, strings and variables. File stdio.h contains some standard input/output routines; string.h and ctype.h contains additional routines. Listings of the last three mentioned files are not given. In the following a
brief description will be given of the functions/routines in the xtvd.c file. It will be done in the same order as the listing, i.e. it ends with the main program body.

**int ch_input ()**
This function waits until a button a button is pressed on the keyboard. When a button is pressed, upper-case characters are made lower-case. Then it waits for a new-line (ENTER) and returns with the character integer value.

**unsigned long int udiv (uli1, uli2)**
This function performs a correct division of unsigned long integers. The standard function / also divides, but truncates down, i.e. no correct rounding-off. This function does. Also a check is made on an eventually zero value of the two integers uli1 and uli2.

**unsigned long int chg_par (message, old)**
In the program parameters can be changed using this routine. It first prints a message on the PC monitor screen with the old value and asks for the new value. When only ENTER is pressed, the old value is retained.

**void lo_to_hi (mask), void hi_to_lo (mask)**
These functions poll a certain register bit-value transition. By mask the bit-value is indicated. The register is addressed by XTVD_STAT and is named IC6 in the XTVD-I diagram (Appendix B, page 54).

**int value (mask)**
This function returns the value of a register bit. This bit is indicated by mask. The register is addressed by XTVD_STAT.

**void out_data (port, data)**
With this routine data can be send to a certain port.

**reset_data ()**
This routine merely generates a reset signal. In the drawings this signal is named LE2. It is a low-active signal.

**unsigned long int in_data (port)**
This function returns the integer value present at the register as indicated by port.

**void get_data ()**
This function uses the preceeding function to get data from seven registers. Four registers are used to form sum, the sum of all bytes in the measuring field. Three registers are used to form m1d, the size of the measuring field in pixels.

**void calculate ()**
To generate the control values for the AGC-loop and the ADC-loop, this func-
tion performs the calculations. First a zero measuring field is checked. Then the average is calculated. This value is compared with some reference values and the result is used to generate two values: adcout and agcout.

The program is menu-driven, i.e. when the program is run, a menu is shown on the monitor screen. One of several options can be chosen. After completing the chosen option, the menu returns on the monitor an a new option can be chosen. In the present version, the menu contains seven valid options. They are described in the following.

void get_new_values ()
It may be obvious that with this option some parameter values can be changed.

void scan_xtv_chain ()
This routine performs the actual work. It waits for the occurrence of the vertical drive pulse VD. Then outputs two values, one for the ADC-loop and one for the AGC-loop. It resets the counters and gets the new values, if present. After calculations the new values are copied and again it waits for the VD signal. This loop is left when a certain button is pressed. Then the last five values of mfld and sum are shown on the monitor screen together with their quotient, i.e. the average. Again pressing the button will retain the menu on the screen.

void transfer_test ()
With this option the transfer characteristic of the prototype circuit can be tested. The voltage controlled amplifier can be set to a certain gain, by typing a certain value on the keyboard. The program loops as long as the red button is not pressed. When pressed, the last ten values of mfld and sum are shown on the monitor screen, together with their quotient (average). By giving a new value the loop is either restarted or the program is left.

void make_tables ()
This option can be used to generate several tables. It also generates data files which can be used by Philpac, to generate drawings.

void test_5018 (sw)
With this routine a byte value can be send to one of the two used 5018 digital-to-analog converters. The converter is chosen with sw. There are two possibilities. A fixed value can be send, or a time-increasing value can be send, i.e. a staircase-like signal. This routine may be usefull for adjusting the converters to the correct input-output behaviour.

The main program merely consists of four functions.

void welcome ()
It initializes the 8255A-5 PPI and some parameters.
void show_menu()
This routine generates a menu on the monitor screen.

int choice_made()
The function asks for a valid menu option and if so calls the chosen corresponding routine. When the exit option is chosen, it returns with a special value indicating the program main body to stop and then return to the iSDM86 monitor.

void say_goodbye()
It merely re-initializes PORTB and PORTC and wipes the screen.

main()
The main program is very short and needs no further explanation.
Chapter 9
Conclusions and recommendations

9.1 Conclusions

- It is evident that there always will be some analog circuitry in an XTV-chain. The digital body will be surrounded by analog preprocessing and postprocessing.

- Especially the circuitry that estimates the sum of the bytes in a measuring field and the corresponding number of bytes, lends itself to implementation in ASIC's.

- Introducing a microcomputer system makes the XTV-chain very flexible. It now becomes very easy to adjust parameters and to change methods of control.

- This graduation project was orientated very broad. The author came in contact with various techniques: analog video circuitry, fast digital circuits, voltage references, converters (AD and DA), microcomputer architecture and software (C programming language).

9.2 Recommendations

- In the prototype a second analog-to-digital converter is used to measure the video signal. In this way the AGC loop is open, i.e. no feedback. The loop can be closed by using the video AD converter (Figure 9.1). This saves one converter plus additional circuitry. The AGC loop can now be more stable. A disadvantage may be that for the ADC loop the transfer characteristic from analog video input to digital video should be known very accurate in all cases, i.e. for all possible gain factors.

- A rather big microcomputer system is used for the testing of this prototype with many unused features. It may be worth designing a smaller microcomputer system with only necessary functions.
• Only the ADC and AGC loops are implemented in this project. Enough topics are left for possible future (graduation) projects: implementation of DHC, CC & GC; a built-in self-test; Fourier analysis implementation to estimate the XTV-chain quality.

• It may be worth considering the use of a digital signal processor (DSP) in the XTV-chain for the implementation of some functions.
Figure 9.1: XTVD block diagram 2nd version.
Appendix A contains the drawings of the XTVD-V printed circuit board.
Appendix B

Appendix B contains the drawings of the XTVD-I printed circuit board.
summation of all bytes present in measuring field
counting number of bytes present in measuring field
display of the three busses
Appendix C

Appendix C contains the drawings of the XTVD-S printed circuit board.
line drivers
Appendix D

This Appendix contains the software listing of xtvd.c. It is written in the C programming language.
```c
#include "stdio.h"
#include "string.h"
#include "ctype.h"
#include "xtvd.h"

/**********************************************************/

int ch_input ()
{
    int ch1, ch2, ch3;

    while (((ch1 = getchar ()) == ','))
    {
        if (isascii (ch1) && isalpha (ch1))
            tolower (ch1);
        ch2 = ch1;
        if (ch1 != ENTER)
            while (((ch3 = getchar ()) != ENTER))
                ;
        return (ch2);
    }

unsigned long int udiv (ulil, uli2)
{
    unsigned long int uli1, uli2;

    unsigned long int temp1, temp2;

    if ((uli1 == 0) || (uli2 == 0))
        temp1 = 0;
    else {
        temp1 = (uli1 / uli2);
        temp2 = ((uli1 % uli2) << 1);
        if (temp2 >= uli2)
            temp1++;
    }
    return (temp1);
}

unsigned long int chg_par (message, old)
{
    char message [50];
    unsigned long int old;

    char buf [10];
    unsigned long int new;

    printf (message, old);
```

```c
fflush (stdout);
fgets (buf, sizeof (buf), stdin);
if (sscanf (buf, "%ld", &new) != 1)
    new = old;
printf (CR);
return (new);
}

void lo_to_hi (mask)
{
    int mask;
    output (PORTC, XTVD_STAT);
    output (PORTM, SET_RD);
    while ((input (PORTA) & mask) != LOW)
    {
        while ((input (PORTA) & mask) == LOW)
        {
            output (PORTM, RESET_RD);
        }
    }
}

void hi_to_lo (mask)
{
    int mask;
    output (PORTC, XTVD_STAT);
    output (PORTM, SET_RD);
    while ((input (PORTA) & mask) == LOW)
    {
        while ((input (PORTA) & mask) != LOW)
        {
            output (PORTM, RESET_RD);
        }
    }
}

int value (mask)
{
    int mask;
    int val;
    output (PORTC, XTVD_STAT);
    output (PORTM, SET_RD);
    val = (input (PORTA) & mask);
    output (PORTM, RESET_RD);
    return (val);
}
```
void out_data(port, data)
    int port;
    unsigned long int data;
{
    output (PORTC, port);
    output (PORTB, data);
    output (PORTB, data);
    output (PORTM, SET_WR);
    output (PORTM, RESET_WR);
}

void reset_data()
{
    output (PORTC, RESET);
    output (PORTM, SET_WR);
    output (PORTM, RESET_WR);
}

unsigned long int in_data(port)
    int port;
{
    unsigned long int data;

    output (PORTC, port);
    output (PORTM, SET_RD);
    data = input (PORTA);
    output (PORTM, RESET_RD);

    return (data);
}

void get_data()
{
    unsigned long int s3, s2, s1, s0;
    unsigned long int m2, m1, m0;

    s3 = in_data (SUM_3);
    s2 = in_data (SUM_2);
    s1 = in_data (SUM_1);
    s0 = in_data (SUM_0);
    m2 = in_data (MFLD_2);
    m1 = in_data (MFLD_1);
    m0 = in_data (MFLD_0);

    sum = (((((s3 & 0x7F) << 8) | s2) << 8) | s1) << 8) | s0;
    mfld = (((((m2 & 0x7F) << 8) | m1) << 8) | m0);
}
void calculate ()
{
    unsigned long int avg;
    unsigned long int temp1, temp2, temp3, temp4;

    if (mfl0 == 0) {
        adeout = adcbakj
        age out = agebak;
        temp1 = temp2 = temp3 = temp4 = avg = 0;
    }
    else {
        avg = udiv (sum, mfl0);

        temp1 = (avg * adcrng);
        temp2 = (adclvl << 1);
        adcout = udiv (temp1, temp2);
        if (adcout > 255)
            adcout = OxFF;
        adcbak = adcout;

        temp3 = (agclvl * 11108L); /* 11108 = 255 * 255 / 5.85 */
        temp4 = (avg * agcrng);
        if (temp4 == 0)
            agcout = 0xFF;
        else
            agcout = udiv (temp3, temp4);
        if (agcout > 255)
            agcout = 0xFF;
        agcbak = agcout;
    }
}

/************************************************************/
void get_new_values()
{
    printf (CLS);
    printf ("*************************");
    printf (" XTVD Test Utility - Change Parameters ");
    printf ("*************************");
    printf (CR2);
    adcmin = chg_par (MES00, adcmin);
    adcmx = chg_par (MES01, adcmx);
    adclvl = chg_par (MES02, adclvl);
    agcmin = chg_par (MES03, agcmin);
    agcmx = chg_par (MES04, agcmx);
    agclvl = chg_par (MES05, agclvl);
    adcrng = abs (adcmx - adcmin);
    agcrng = abs (agcmx - agcmin);
}

void scan_xtv_chain()
{
    int reg_full;
    unsigned long int s0, s1, s2, s3, s4;
    unsigned long int m0, m1, m2, m3, m4;
    unsigned long int a0, a1, a2, a3, a4;

    printf (CLS);
    printf ("**********");
    printf (" XTVD Test Utility - Scan XTVD Chain");
    printf ("**********");
    printf (CR2);
    printf (MES11);
    printf (CR);
    reset_data();
    s0 = s1 = s2 = s3 = s4 = 0;
    m0 = m1 = m2 = m3 = m4 = 0;
    while (value (RED_BUTTON) == LOW) {
        lo_to_hi (VD);
        out_data (KV, adcout);
        out_data (VCA, agcout);
        reg_full = value (REG_FULL);
        reset_data();
        if (reg_full != LOW) {
            get_data();
            calculate();
        }
    }
    s0 = s1;
s1 = s2;
s2 = s3;
s3 = s4;
s4 = sum;
m0 = m1;
m1 = m2;
m2 = m3;
m3 = m4;
m4 = mfld;
}
a0 = udiv (s0, m0);
a1 = udiv (s1, m1);
a2 = udiv (s2, m2);
a3 = udiv (s3, m3);
a4 = udiv (s4, m4);
printf ("%10.00 %10.00 %3.00\n", s0, m0, a0);
printf ("%10.00 %10.00 %3.00\n", s1, m1, a1);
printf ("%10.00 %10.00 %3.00\n", s2, m2, a2);
printf ("%10.00 %10.00 %3.00\n", s3, m3, a3);
printf ("%10.00 %10.00 %3.00\n", s4, m4, a4);
while (value (RED_BUTTON) == LOW) {
    reset_data ();
    output (PORTC, 0);
    output (PORTB, 0);
}
void transfer_test () {
    char buf [10];
    unsigned long int in, out, reg_full;
    unsigned long int s0, s1, s2, s3, s4, s5, s6, s7, s8, s9;
    unsigned long int m0, m1, m2, m3, m4, m5, m6, m7, m8, m9;
    unsigned long int a0, a1, a2, a3, a4, a5, a6, a7, a8, a9;

    printf (CLS);
    printf ("***********");
    printf (" XTVO Test Utility - A/D Transfer Test ");
    printf ("***********");
    printf (CR2);
    printf (MES10);
    fflush (stdout);
    in = 0;
s0 = s1 = s2 = s3 = s4 = s5 = s6 = s7 = s8 = s9 = 0;
m0 = m1 = m2 = m3 = m4 = m5 = m6 = m7 = m8 = m9 = 0;

    for (out = 0; in != 999; out++) {

if (out == 256)
  out = 0;
if (in <= 255)
  out = in;
out_data (VCA, out);
while (value (RED_BUTTON) == LOW) {
  lo_to_hi (VD);
  reg_full = value (REG_FULL);
  reset_data ();
  if (reg_full != LOW)
    get_data ();
s0 = s1;
s1 = s2;
s2 = s3;
s3 = s4;
s4 = s5;
s5 = s6;
s6 = s7;
s7 = s8;
s8 = s9;
s9 = sum;
m0 = m1;
m1 = m2;
m2 = m3;
m3 = m4;
m4 = m5;
m5 = m6;
m6 = m7;
m7 = m8;
m8 = m9;
m9 = mild;
}
a0 = udiv (s0, m0);
a1 = udiv (s1, m1);
a2 = udiv (s2, m2);
a3 = udiv (s3, m3);
a4 = udiv (s4, m4);
a5 = udiv (s5, m5);
a6 = udiv (s6, m6);
a7 = udiv (s7, m7);
a8 = udiv (s8, m8);
a9 = udiv (s9, m9);
printf (CLS);
printf ("***********");
printf (" XTVD Test Utility - A/D Transfer Test ");
printf ("***********");
printf (CR2);
printf ("VCA: %3.0D\n", out);
printf (CR);
printf ("%10.0D %10.0D %3.0D\n", s0, m0, a0);
printf ("%10.0D %10.0D %3.0D\n", s2, m2, a2);
printf ("%10.0D %10.0D %3.0D\n", s4, m4, a4);
printf ("%10.0D %10.0D %3.0D\n", s6, m6, a6);
printf ("%10.0D %10.0D %3.0D\n", s8, m8, a8);
printf (CR);
printf ("%10.0D %10.0D %3.0D\n", s1, m1, a1);
printf ("%10.0D %10.0D %3.0D\n", s3, m3, a3);
printf ("%10.0D %10.0D %3.0D\n", s5, m5, a5);
printf ("%10.0D %10.0D %3.0D\n", s7, m7, a7);
printf ("%10.0D %10.0D %3.0D\n", s9, m9, a9);
printf (CR);
printf ("\n> Give VCA value, give 999 to quit\n"); 
fflush (stdout);
fgets (buf, sizeof (buf), stdin);
if (sscanf (buf, "%0", &in) != 1)
in = 256;
printf (CR);
printf (MES10);
fflush (stdout);
}

void make_tables ()
{
    FILE *fopen ();
    FILE *ftbl, *fadc, *fagc;
    char ntbl [15], nadc [15], nagc [15];
    int ch;
    unsigned long int havg, hadc, hagc;
    unsigned long int adcdavg, agcdavg, dagc;
    long int dadc;
    unsigned long int adcr, agcr, adcl, agcl;
    unsigned long int temp1, temp2, temp3, temp4, temp5, temp6;

    adcr = udiv (adcrng, 100L);
    agcr = udiv (agcrng, 100L);
    adcl = udiv (adclvl, 10L);
    agcl = udiv (agclvl, 10L);
    sprintf (ntbl, STR90, adcr, adcl, agcr, agcl);
    sprintf (nadc, STR91, adcr, adcl);
    sprintf (nagc, STR92, agcr, agcl);
    printf (CLS);
    printf ("************");
printf("XTVD Test Utility - Make ADC/AGC Tables");
printf("************");
printf(CR2);
printf(STRO0, adclvl);
printf(STRO1, adcrng);
printf(STRO2, agclvl);
printf(STRO3, agcrng);
printf(MES12);
fflush(stdout);

if (ch_input() != 'n') {
    printf(CR);
    printf(MES13);
    fflush(stdout);
    ch = ch_input();
    printf(CR);
    printf(STRO4, ntbl, nadc, nagc);
    ftbl = fopen(ntbl, "w");
    fadc = fopen(nadc, "w");
    fagc = fopen(nagc, "w");

    fprintf(ftbl, CR2);
    fprintf(ftbl, "************");
    fprintf(ftbl, " XTVD Test Utility - Make ADC/AGC Tables ");
    fprintf(ftbl, "************");
    fprintf(ftbl, CR2);
    fprintf(ftbl, STR00, adclvl);
    fprintf(ftbl, STR01, adcrng);
    fprintf(ftbl, STR02, agclvl);
    fprintf(ftbl, STR03, agcrng);
    fprintf(ftbl, STR05, ntbl);
    fprintf(ftbl, " mV mV mV mV |");
    fprintf(ftbl, " mV mV mV mV |");
    fprintf(ftbl, CR);
    fprintf(ftbl, "-------------------------");
    fprintf(ftbl, "-------------------------+");
    fprintf(ftbl, CR);
    fprintf(fadc, STR10, adclvl, adcrng);
    fprintf(fadc, STR12);
    fprintf(fadc, STR13);
    fprintf(fadc, STR14);

    fprintf(fagc, STR11, agclvl, agcrng);
    fprintf(fagc, STR12);
    fprintf(fagc, STR13);
    fprintf(fagc, STR14);
fprintf (fabc, STR14);

for (havg = 0; havg < 256; havg++) {
    temp1 = (havg * adcrng);
    adcdavg = udiv (temp1, 255L);
    temp2 = (havg * agrcrng);
    agcdavg = udiv (temp2, 255L);

    temp3 = (adclvl << 1);
    hadc = udiv (temp1, temp3);
    if (hadc > 255)
        hadc = OxFF;
    temp4 = (12000L * hadc);
    dadc = (-6000L + (udiv (temp4, 255L)));

    temp5 = (agclvl * 11108L);
    hage = udiv (temp5, temp2);
    if (((havg == 0) || (hage > 255))
        hage = OxFF;
    temp6 = (7000L * hage);
    dage = udiv (temp6, 255L);

    if (ch != 'y') {
        printf (".");
        printf ("%s", (havg % 64 == 63) ? CR : "");
        fflush (stdout);
    } else {
        printf ("AVG: %03.0X", havg);
        printf (CR);
        printf ("ADC: %03.0X %5.0D mV %5.0U mV",
                hadc, dadc, adcdavg);
        printf ("%10.0U %10.0U %10.0U", temp1, temp4, temp3);
        printf (CR);
        printf ("AGC: %03.0X %5.0U mV %5.0U mV",
                hage, dagc, agcdavg);
        printf ("%10.0U %10.0U %10.0U", temp2, temp6, temp5);
        printf (CR);
        printf ("\33[3A");
    }
    fprintf (ftbl, "%02.0X : ", havg);
    fprintf (ftbl, "%4.0U %02.0X %5.0D : ",
            adcdavg, hadc, dadc);
    fprintf (ftbl, "%4.0U %02.0X %5.0U |",
            agcdavg, hage, dagc);
    fprintf (ftbl, "%s", (havg % 2 == 1) ? CR : "");
if ((havg == 0x59) || (havg == 0xC9)) {
    fprintf (ftbl, CR8);
    fprintf (ftbl, "       mV   mV   mV   mV |");
    fprintf (ftbl, "       mV   mV   mV   mV |");
    fprintf (ftbl, CR);
    fprintf (ftbl, "------------------------------------+");
    fprintf (ftbl, "------------------------------------+");
}

if ((havg == 0xC9) && (havg == 255)) {
    fprintf (fadc, "%U,%D", adcavg, dadc);
    fprintf (fadc, "%s", (havg == 255) ? CR : SCR);
    fprintf (fagc, "%U,%U", agcdavg, dagc);
    fprintf (fagc, "%s", (havg == 255) ? CR : SCR);
}

fclose (ftbl);
fprintf (fadc, STR15);
fprintf (fadc, STR16);
fclose (fadc);
fprintf (fagc, STR15);
fprintf (fagc, STR16);
fclose (fagc);
}

void test_5018 (sw)
{
    int sw;
{
    int sw1, out, sw2;
    long int in;
    char str [5];
    char buf [10];

switch (sw) {
    case ADC:
        strcpy (str, "ADC\0");
        sw1 = KV;
        break;
    case AGC:
        strcpy (str, "AGC\0");
        sw1 = VCA;
        break;
    default:
        strcpy (str, "XXX\0");
        sw1 = KV;
    }

    printf (CLS);
printf ("**************");
printf ("XTVD Test Utility - %s Output Test ", str);
printf ("**************");
printf (CR2);
printf (MES14);
fflush (stdout);
fgets (buf, sizeof (buf), stdin);
if ((sscanf (buf, "%ld", &in) != 1) || (in > 256))
  in = 256;
printf (CR);
printf (MES10);
fflush (stdout);
while (value (RED_BUTTON) == LOW)
  ;
while (value (RED_BUTTON) != LOW)
  ;
printf (CR);
printf (MES11);
sw2 = ADC;
while (value (RED_BUTTON) == LOW) {
  hi_to_lo (VD);
  output (PORTC, sw1);
  if (in > 255)
    for (out = 0; out < 256; out++) {
      output (PORTB, out);
      output (PORTM, SET_WR);
      output (PORTM, RESET_WR);
    }
  else {
    output (PORTB, in);
    output (PORTM, SET_WR);
    output (PORTM, RESET_WR);
    if (sw2 == ADC)
      sw2 = AGC;
    else
      sw2 = ADC;
  }
  output (PORTB, 0);
}
output (PORTB, 0);
output (PORTC, 0);
}
void welcome ()
{
    output (PORTM, PORT_MODE);
    output (PORTB, 0);
    output (PORTC, 0);
    adcmin = agcmin = 0;
    adcmx = 750;
    adcrng = 750;
    agcmx = 840;
    agcrng = 840;
    adclvl = agclvl = 400;
    agcbak = agcout = Ox2C;
    adcbak = adcout = Ox7F;
}
void show_menu ()
{
    printf (CLS); /* clear screen */
    printf ("*************************");
    printf (" XTVD Test Utility ");
    printf ("*************************");
    printf (CR2);
    printf ("Valid Menu Options:");
    printf (CR2);
    printf ("c - Change Parameters:");
    printf (CR);
    printf ("");
    printf ("minimum ADC level: %4.0ld mV", adcmin);
    printf (CR);
    printf ("");
    printf ("maximum ADC level: %4.0ld mV", adcmx);
    printf (CR);
    printf ("");
    printf ("ADC stabilization level: %4.0ld mV", adclvl);
    printf (CR);
    printf ("");
    printf ("minimum AGC level: %4.0ld mV", agcmin);
    printf (CR);
    printf ("");
    printf ("maximum AGC level: %4.0ld mV", agcmx);
    printf (CR);
    printf ("");
    printf ("AGC stabilization level: %4.0ld mV", agclvl);
    printf (CR);
    printf ("s - Scan XTVD Chain.");
    printf (CR2);
printf ("k - Make ADC/AGC Tables.");
printf (CR);
printf ("l - ADC Output Test.");
printf (CR);
printf ("m - AGC Output Test.");
printf (CR);
printf ("n - A/D Transfer Test.");
printf (CR2);
printf ("x - Exit XTVD Test Utility and ");
printf ("Return to iSDM 86 Monitor.");
printf (CR2);
}

int choice_made ()
{
    int ch, cr;
    int choice, go_on;
    choice = YES;
    do {
        go_on = NO;
        printf ("Your choice > ");
        fflush (stdout);
        while ((ch = getchar ()) == , )
        {
            if (isascii (ch) && isalpha (ch)) {
                tolower (ch);
                while ((cr = getchar ()) != ENTER)
                {
                    switch (ch) {
                    case 'c':
                        get_new_values ();
                        break;
                    case 's':
                        scan_xtv_chain ();
                        break;
                    case 'k':
                        make_tables ();
                        break;
                    case 'l':
                        test_5018 (ADC);
                        break;
                    case 'm':
                        test_5018 (AGC);
                        break;
                    case 'n':
                        transfer_test ();
                    }
break;
case 'x':
  choice = STOP;
  break;
default:
  go_on = YES;
  printf ("Invalid option: %c", ch);
  printf (CR);
  }
}
else if (ch != ENTER) {
  go_on = YES;
  printf ("Invalid character 0%0xH", ch);
  printf (CR);
  while ((cr = getchar ()) != ENTER) ;
}
} while (go_on);
return (choice);

void say_goodbye ()
{
  output (PORTB, 0xFF);
  output (PORTC, 0xFF);
  printf (CLS);
}

/******************************************************************************/
main ()
{
  welcome ();
  do {
    show_menu ();
  } while (choice_made () != STOP);
  say_goodbye ();
  return (0);
}

/******************************************************************************/
Appendix E

This Appendix contains the software listing of xtvd.h. This file contains definitions of constants and variables. It is used by xtvd.c.
```c
#define PORTA 0xD8
#define PORTB 0xDA
#define PORTC 0xDC
#define PORTM 0xDE
#define PORT_MODE 0x90
#define RESET_WR (2 * 7 + 0)
#define SET_WR (2 * 7 + 1)
#define RESET_RD (2 * 6 + 0)
#define SET_RD (2 * 6 + 1)
#define ADC 0
#define AGC 1
#define RESET 2
#define KV 4
#define VCA 5
#define MFLD_0 0
#define MFLD_1 1
#define MFLD_2 2
#define XTVD_STAT 3
#define SUM_O 4
#define SUM_1 5
#define SUM_2 6
#define SUM_3 7
#define REG_FULL 1 /* 00000001 */
#define FI 2 /* 00000010 */
#define VD /* 00000100 */
#define RED_BUTTON 8 /* 00001000 */
#define NO 0
#define YES 1
#define LOW 0
#define STOP 0
#define ERROR 2
#define CLS "\33[2J"
#define ENTER '\n'
#define CR "\n"
#define CR2 "\n\n"
#define CR8 "\n\n\n\n\n\n\n\n"
#define SCR ";\n"
```
```c
#define MESO0 "Give minimum ADC level in mV [%4.0U]"
#define MESO1 "Give maximum ADC level in mV [%4.0U]"
#define MESO2 "Give ADC stabilization level in mV [%4.0U]"
#define MESO3 "Give minimum AGC level in mV [%4.0U]"
#define MESO4 "Give maximum AGC level in mV [%4.0U]"
#define MESO5 "Give AGC stabilization level in mV [%4.0U]"
#define MES10 "Press red button to start !\n"
#define MES11 "Press red button to stop !\n"
#define MES12 "Parameters OK? [Y]"
#define MES13 "Show intermediate results? [N]"
#define MES14 "Give test value [sawtooth]"

#define STRO0 "ADC stabilization level: %4.0U mV\n"
#define STRO1 "ADC video range: %4.0U mV\n"
#define STRO2 "AGC stabilization level: %4.0U mV\n"
#define STRO3 "AGC video range: %4.0U mV\n"
#define STR04 "Output files: %s, %s, %s\n"
#define STR05 "Output file: %s\n"
#define STR90 "%02.0U%02.0U%02.0U%02.0U.TBL"
#define STR91 "ADC%02.0U%02.0U.PHP"
#define STR92 "AGC%02.0U%02.0U.PHP"
#define STR10 " title: ADC %4.0U mV %4.0U mV $\n"
#define STR11 " title: AGC %4.0U mV %4.0U mV $\n"
#define STR12 " cptime: 20$\n"
#define STR13 " circuit $ r999(999,0) 1$ e999(999,0) 1$\n"
#define STR14 "table:'xtvd'\n"
#define STR15 "$\n y='xtvd'(x)$\n end$\n dc$\n x=as(1,255,1)$\n"
#define STR16 " print: y$\n file: y$\n end$\n run$\n"

extern unsigned int input ();
extern unsigned int inword ();
extern void output ();
extern void outword ();

unsigned long int adcmnin, adcmmax, adclvl;
unsigned long int adcmrcng, adcmrback, adcmrout;
unsigned long int agcmnin, agcmmax, agclvl;
unsigned long int agcmrcng, agcmrback, agcmrout;
unsigned long int sum, mflld;
```
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