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Characteristics of Upstream Channel Noise in CATV-networks.

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Abstract—Currently there is a growing demand towards interactive multi-media services using high capacity hybrid fibre-coax (HFC) CATV-networks. With regards to the realisation of upstream traffic, many problems occur with the accumulation of noise due to the tree and branch architecture of the coaxial access network [1,4]. In this paper, the properties of the spectral noise signature resulting from the accumulation of noise have been studied by performing measurements in two major CATV-networks in Europe. Serious noise accumulation was found with levels up to resp. -70dBm and -50dBm in the two networks. Interference from short-wave broadcasting caused interference levels up to resp. -60dBm and -40dBm. We show that upstream noise is time dependent, and is not only caused by CATV-network subscribers.

I. Introduction

The increasing demand to interactive television and data services on the one hand and the liberalisation of many telecommunications markets on the other, are both resulting in a growing demand to bandwidth on publicly available networks. Much attention is being paid to hybrid fibre-coax (HFC) CATV-networks because of their high penetration level, high available capacity, and good linearity in the downstream channels. However, upstream channels available in a common European CATV-network are far from ideal. Only limited bandwidth (25MHz to 55MHz) is provided, and undesired accumulation of ingress noise and interference appears due to the partial tree and branch architecture. The resulting noise characteristics will determine the choice of modulation and multi-access techniques. Recently, the noise characteristics have been studied briefly in a CATV-network [1]. In this paper we also present the time dependency of the accumulated upstream noise in CATV-networks. Based on long term measurements, we discuss the consequences on the useability of the upstream channel. Useability is expressed in terms of time the noise level exceeds a certain limit (channel availability).

II. Lay-out of CATV-networks

Modern HFC CATV-networks in Europe are characterised by an optical ring-shaped backbone and a coaxial "sharedmedium" access network with a tree and branch architecture [1,4]. This structure results in physically separated 'cells' of ± 150 connections. For our measurements, two CATV-networks in two different, major European cities have been chosen. One network is a HFC-type network with 100.000 connections (hereinafter called network A). The other network is a full tree and branch network with 70.000 connections (hereinafter called network B).

Worth mentioning is that network B was constructed in the late '60s with most cables and amplifiers on the facades of houses. Network A was constructed in the early '80s, with all cables underground, and all amplifiers in street cabinets.

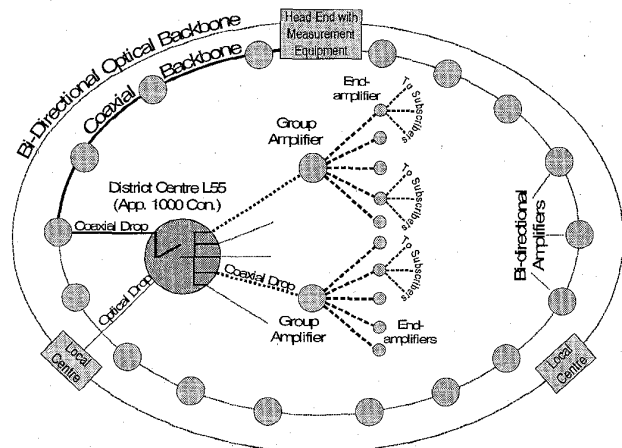


Figure 1: Network lay-out of CATV-network A. The coaxial backbone (out of use for distribution) carries the accumulated noise signal from the disconnectable district centre to the head-end (thick line).

III. Measurement Set-up

Measurement equipment situated at the head-end, consisted of a Tektronix 2712b spectrum analyser, a Philips PM5193 programmable synthesised function generator, and a PC with harddisk. The accumulated noise signals were transported to the head-ends using the coaxial backbone of the networks (Figure 1). In network A, two district centres were chosen. One situated in the city-centre (district A1) and one situated in a residential quarter (district A2). The districts could be disconnected from the trunk by remote controlled switches. This allowed us to measure the accumulated noise signal of each district centre separately. To measure the effect of noise accumulation in the coaxial trunk, we also performed measurements with no district centre connected. Each half hour, the three measurements (district A1, A2, trunk) were performed subsequently. In each district, two group amplifiers were chosen. We measured the accumulated noise from all subscribers connected to the chosen group amplifiers. In network B, the accumulated noise from one district with 1000 connections was measured. Additional network details and spectrum analyser settings are summarised below.

* Start frequency	: 3MHz
* Stop frequency	: 28MHz
* Resolution bandwidth	: 300kHz
* Video filter bandwidth	: 3kHz
* Acquisition Mode	: Peak
* RF-attenuation	: 0dB
* Input Impedance	: 75Ω
* Reference Level:	
Network A	: -62,9dBm
Network B	: -41,9dBm
* Number of connections:	
Network A, district A1	: 360
Network A, district A2	: 242
Network B	: 1000

IV. Sources of Ingress Noise

In general, three categories of noise sources can be distinguished; inside sources, narrowband outside sources, and broadband outside sources. Inside sources can be distinguished from outside sources because inside sources are somehow connected to the network and thus form a physical part of the network. Narrowband outside sources can be distinguished from broadband outside sources because narrowband sources are often recognisable at their spectral noise signature.

- **Inside noise sources** are a part of the network, such as CATV-network equipment and terminals at the subscribers premises. Many sources can be indicated, such as noisy switched power supplies, amplifiers, TV-sets, etc. But also bad connectors leading to common mode distortions in the network can be a source of noise.
- **Outside sources** can be present anywhere, but are not a part of the network. Several sources can be addressed here, ranging from microwave ovens, hair dryers, electric raisers, welding machines, computers and various other equipment to lightning, car ignitions, and short-wave radio transmitters. In fact, all equipment that arcs, welds, or produces an electromagnetic field must be regarded as a noise source. An example of a narrowband noise source is a short-wave radio transmitter.

The behaviour of the noise sources considered is not equal. Inside noise sources are always present, but the noise level depends on external influences. Examples are the temperature of the CATV-network equipment, and the number of active user terminals. Because inside noise sources can be identified, their behaviour can to a certain extent be predicted. For instance, the number of TV-sets switched on is the highest in the evening. Additional noise can therefore be expected in the evening hours.

The behaviour of outside sources is far more unpredictable because the greater part of the sources is unknown, and liable to a great variation in intensity. In addition, a source's contribution is not only determined by its power, but also by the propagation paths from the

source to the points of penetration. For the frequencies considered, signal propagation is better during the evening, night, and morning. Furthermore, we assume that during working hours (9.00AM - 17.00PM), many office machines and various other equipment is in use, leading to a change in the noise signature.

Important is the way all noise accumulates from the source to the head-end. It may be assumed that noise adds non-coherently. However, it is sometimes said that interference from short-wave broadcast stations adds coherently [1]. This is true, but radio signals are penetrating at several geographically separated locations in the network. Thus the path lengths from these locations of penetration to the head-end are all different. Consequently, it is unlikely that signals from one short-wave source will accumulate exactly in phase, although they are correlated. In addition, radio broadcast signals are subject to fading, resulting in multiple signals with different phases arriving at the locations of penetration.

V. Measurement Results

More than 80MB of data have been processed in order to show the relationship between noise power on the one hand, and frequency, time, and type of district and network on the other. The time-exposure in Figure 2 represents an averaged measurement result of the spectral signature. In this time exposure narrowband noise can be clearly distinguished from broadband noise. We found that the narrowband noise was mainly caused by short-wave radio broadcast stations.

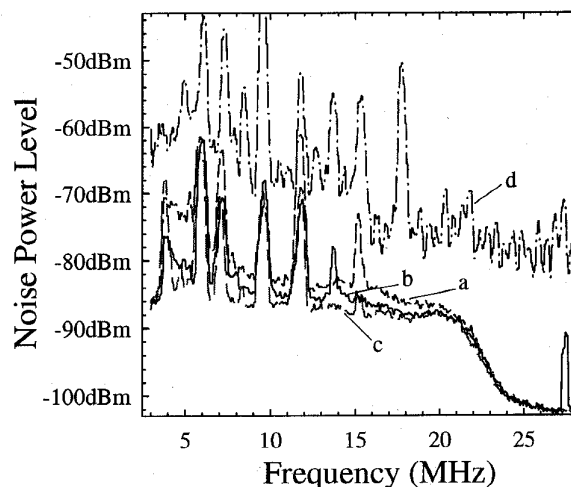


Figure 2: Spectral signature of accumulated noise in: a) district A1; b) district A2; c) trunk of network A; d) network B [4].

We note the difference in noise power level (20dB) between network A and network B, and the difference in the number of radio signals. Based on the number of connections, only a difference in noise power level of 4.7dB is expected between network A and B, and thus there have to be other reasons for this difference. A possible cause can be that in network B all cables have been mounted on facades of houses. This implies that the

cables in network B are more exposed to electromagnetic radiation than are the cables in network A.

Also a difference in noise power level of 2dB between districts A1 and A2 can be seen. This difference can be fully explained from the difference in the number of connections measured: 242 (rural) to 360 (city centre), yielding an expected difference of 1.7dB. The spectral signature measured in the trunk of network A is of the same form as the ones measured in districts A1 and A2, only the level is about 2dB lower. This implies that the shielding of the trunk is not optimal and a significant contribution to the noise level may be expected.

Although Figure 2 is a representation of the spectral noise signature, it is only an averaged profile. By performing long term measurements (4 weeks), we found that the accumulated upstream noise is time dependent. Different time dependencies have been found for the narrowband noise sources (short-wave radio broadcast) and broadband noise. In Figures 3, 4, and 5, the time dependencies of the accumulated noise power have been visualised at frequencies of 4MHz, 8MHz, and the 31M-band broadcast (9.5MHz - 9.9MHz). We choose 4MHz because the effect of electrical equipment is clearly noticeable at frequencies typically up to 5MHz, and no narrowband noise source was noticeably present. 8MHz was chosen because no narrowband noise source was present at this frequency, and thus a clear view of the behaviour of broadband noise sources can be formed.

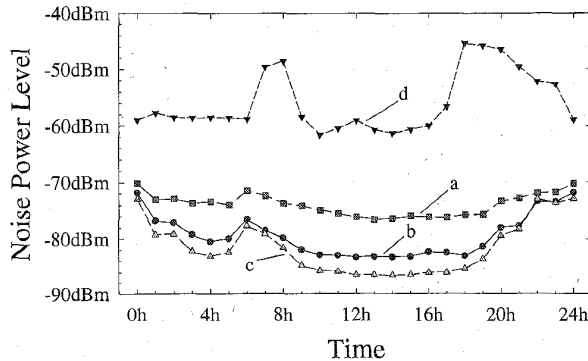


Figure 3: Time dependency of the accumulated noise signal [4] during one day, averaged over one week, at 4MHz in: a) district A1; b) district A2; c) trunk network A; d) network B.

To form a view of the behaviour of narrowband noise sources, we averaged all samples in the 31M-band. We note that the resolution bandwidth of the spectrum analyser was set at 300kHz. Thus the results presented here have to be regarded as the averaged noise power level in a window of 300kHz around the mentioned frequencies.

A clear periodicity was found at 4MHz (Figure 3), but at 8MHz most time dependency had vanished (Figure 4). This except for network B where still a small variation was found at 8MHz. In general, we found that time dependency decreased as frequency increased [1,4].

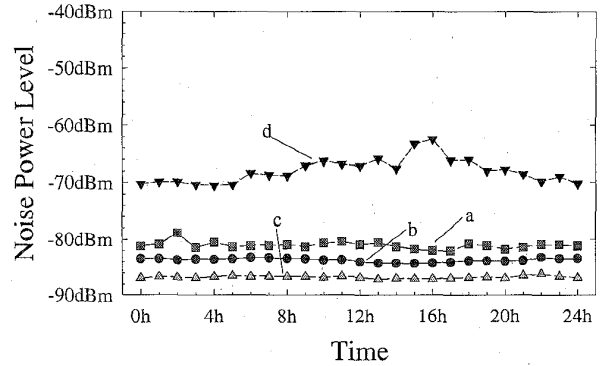


Figure 4: Time dependency of the accumulated noise signal [4] during one day, averaged over one week, at 8MHz in: a) district A1; b) district A2; c) trunk network A; d) network B.

We note that the variation in noise power level is greater in the trunk of network A than in districts A1 and A2 (Figure 3). At night, the noise level in the trunk reaches about the same level as the noise level measured in districts A1 and A2. This indicates that during the night noise induced by subscribers is deafened by other sources. Very likely these sources are far remote sources whose signals can travel a long way due to good propagation conditions at night. This indicates that ingress noise results from both subscriber related and unrelated noise sources. The fact that subscriber unrelated sources contribute significantly to the noise level implies that CATV-networks themselves are not robust with regards to ingress noise. This indication explains the results measured in network B. As mentioned, network B is extra vulnerable for noise from outside sources because the cable infrastructure is not underground.

We also note that the difference in noise power between districts A1 and A2 is not continuously 2dB, which can be caused by the variation in the contribution of the trunk. Another cause can be the difference in noise source activity between the two districts. Minor industries, shops, and offices are settled in district A1, causing a more continuous lapse of the noise power. No industries, shops, etc. are present within district A2, only ordinary houses.

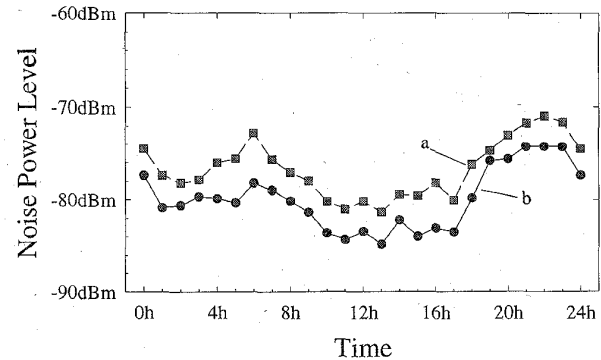


Figure 5: Time dependency of the accumulated interference caused by short-wave broadcast between 9.5MHz and 9.9MHz, during one day, averaged over one week in: a) district A1; b) district A2.

Narrowband noise sources (short-wave radio broadcast) also showed a time dependency (Figure 5). The accumulated level is relatively high in the morning, late afternoon, and evening, times most short-wave broadcasts are scheduled. These effects were observed to be equal in the networks A and B. We observed that the difference between the districts A1 and A2 is varying between 0.5dB and 4dB, which can be due to the fact that not all induced signals from one source are added exactly in-phase.

VI. Channel Availability

Based on long term measurements, channel availability at 4MHz, 8MHz, and 31m-band has been visualised in Figure 6 and Figure 7. A distinction has been made between channel availability during office hours (9.00AM - 17.00PM) and leisure hours (17.00PM - 9.00AM). This distinction has been made because of the difference in the activities of people. A clear difference between the channel availability in these two time periods was found. Generally, this difference could best be noticed at frequencies up to 5MHz. Also a difference was noticed at frequencies reserved for short-wave broadcasting. This results from the fact that many short-wave transmissions are scheduled during leisure hours, and that signal propagation during leisure hours is relatively good.

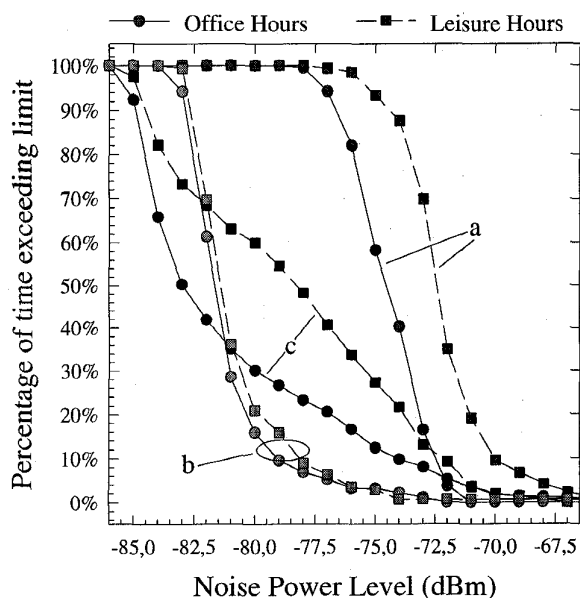


Figure 6: Channel availability as measured in district A1 at: a) 4MHz; b) 8MHz; c) 31m-band.

Generally, channel availability is better during office hours. Whether this is an advantage, is a point of discussion. Note the difference between the channel availability at frequencies reserved for broadcast applications and the other frequencies.

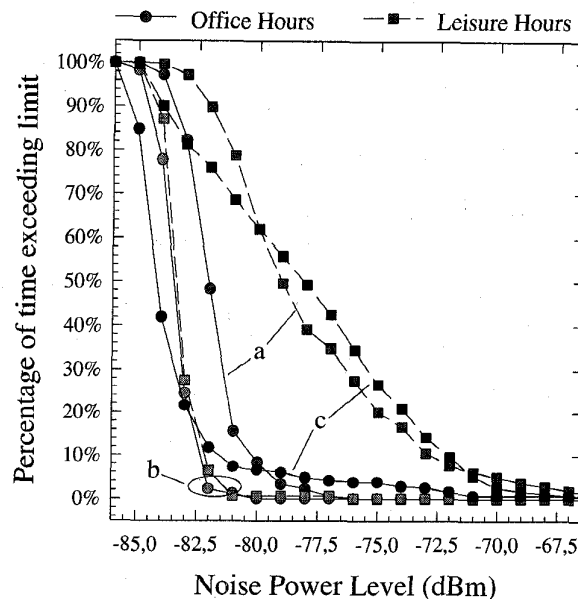


Figure 7: Channel availability as measured in district A2 at: a) 4MHz; b) 8MHz; c) 31m-band.

VII. Conclusions.

Severe channel contamination due to noise accumulation was found in the upstream path of CATV-networks. A distinction can be made between inside sources, outside narrowband sources, and outside broadband sources. In our results, narrowband outside sources can be clearly distinguished from the others. Broadband noise sources show a relatively relaxed behaving noise signature at frequencies higher than 5MHz. Lower frequencies behaved less relaxed, but are commonly not used for upstream communication. Narrowband noise sources, typically short-wave radio broadcast stations, are characterised by a clearly distinguishable noise signature, which behaves less relaxed compared to broadband sources. Noise power levels caused by outside narrowband sources were up to 20dB higher than the level caused by broadband sources.

At times the accumulated upstream interference level rises above a certain level, upstream traffic might be impossible because certain modulation/multi-access methods require a typical signal-to-noise ratio.

Theoretically, all noise and channel disturbances can be overcome by ensuring that signal-to-noise ratio is sufficient. In CATV-networks however, upstream signal power at the subscribers premises is limited because of saturation effects of the TV-receiver. As a result, the frequency regions assigned to short-wave radio broadcast might be useless during several periods a day, especially in the morning and evening. This can pose serious limitations on systems which are not capable of a flexible allocation of bandwidth resources. Finally, we would like to remark that also effects of amplitude and phase distortions in the upstream transmission path, as well as reflections have to be taken into account.

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