Zeitschrift: Technische Mitteilungen / Schweizerische Post-, Telefon- und Telegrafenbetriebe = Bulletin technique / Entreprise des postes, téléphones et télégraphes suisses = Bollettino tecnico / Azienda delle poste, dei telefoni e dei telegrafi svizzeri

Herausgeber: Schweizerische Post-, Telefon- und Telegrafenbetriebe

Band: 66 (1988)

Heft: 7

Artikel: Multipath delay spread in a hilly region at 210 MHz

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DOI: https://doi.org/10.5169/seals-876255

Multipath delay spread in a hilly region at 210 MHz

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Summary. Investigations of multipath propagation in hilly terrain show that the delay spread between the first and the last significant path may be greater than 30 microseconds. The method of measurement is described and the propagation conditions are illustrated by representative examples.

1 Introduction

The capacity of radio communication channels *(fig. 1)* is determined by the characteristics of the transmitter, the transmitting medium and the receiver. Due to substantial progress in technology, wideband equipment is available and sophisticated encoding and modulation methods have been proposed. For these reasons, more detailed data for the frequency dependence of the radio channel are required.

At frequencies between 50 MHz and 1000 MHz, the tropospheric propagation of electromagnetic waves can be affected by free space attenuation, by diffractions and by reflections from the terrain (as well as from buildings, trees, etc.). With path lengths of less than 50 km, meteorological effects can be ignored. Experiments clearly show that propagation conditions are considerably affected by the type of terrain. In order to reinvestigate the possibilities of wideband communication in the frequency bands from 50 MHz to 1000 MHz, an experimental study was carried out at the Main Division Research and Development (V) of the Swiss PTT.

First, a suitable technique to determine the RF-transfer function and/or the individual delay profiles of reflections had to be developed. The method adopted [1, 2] is described in section 2. It was tested in a hilly region of Switzerland. Considering the results given in section 4, the frequency dependence of the RF-transfer function needs further experimental and theoretical investigation.

2 Measuring method

If the transmitted RF-signal is known, then distortions due to multipath propagation can be determined by analysing the received RF-signal. The transmitted RF-signal and the received RF-signal are denoted by the real parts of $\{\underline{x}(t) \cdot \exp(j2\pi f_o t)\}$ and $\{\underline{y}(t)\exp(j2\pi f_o t)\}$, respectively. The lowpass signals $\underline{x}(t)$ and $\underline{y}(t)$ are the complex envelopes, their magnitudes are the amplitude and their arguments the phase modulation. The relation between the transmitted and the received RF-signal is given by the relation between their complex envelopes $\underline{x}(t)$ and $\underline{y}(t)$:

$$\underline{y}\,(t) = \int_0^\infty \underline{x}\,(t-\tau) \cdot \underline{h}\,(\tau)\,d\,\tau \tag{1}$$

where $\underline{h}(\tau)$ is the complex lowpass impulse response of the transmission channel and τ the time delay. The delay for the direct signal is set to 0. The Fourier transform $\underline{H}(f)$ of $\underline{h}(\tau)$ is the RF-transfer function shifted to low frequencies by the carrier frequency f_o.

The received signal is demodulated to the inphase and quadrature signal. The inphase component shall be considered as the real part and the quadrature component as the imaginary part of a complex function $\underline{z}(t)$. As the inphase and quadrature signal are linear combinations of the real and the imaginary part of $\underline{y}(t)$, the functions $\underline{h}(\tau)$ and $\underline{H}(f)$ can be determined by analysing $\underline{z}(t)$.

The difference between the reference signal $\underline{z}_o(t)$ in the case of single path propagation and $\underline{z}(t)$ in the case of multipath propagation is due to echoes. Thus, if $\underline{Z}(f)$ and $\underline{Z}_o(f)$ are the Fourier transforms of $\underline{z}(t)$ and $\underline{z}_o(t)$, then

$$\underline{H}\,(f) = \frac{\underline{Z}\,(f)}{\underline{Z}_o\,(f)} \tag{2}$$

and $\underline{h}(\tau)$ is its inverse Fourier transform. There is no need to exactly know elements of the measuring system such as RF-filters, IF-filters, etc., because their influence is eliminated by calibration of $\underline{Z}_o(f)$ in equation (2).

A TV-transmitter was used as the signal source. The necessary transmitted wideband signal is obtained by a pseudorandom sequence (8 bit shift register, 4.9 MHz clock) [1, 2] modulated on two successive test lines. The modulations of these two lines are identical. Assuming that all delays are shorter than 64 µs, the modulation in the second line can be treated to be a periodic process and FFT algorithms can be used to evaluate $\underline{h}(\tau)$. The signal $\underline{z}(t)$ was recorded by a transient recorder with a sampling rate of 20 MHz and an accuracy in amplitude better than 1 percent.

In the examples shown, the complex impulse response $\underline{h}(\tau)$ is characterized by its envelope and the transfer function $\underline{H}(f)$ by its magnitude and group delay. The data correspond to an assumed receiver bandwidth of 4 MHz and the S/N-ratio is about 30 dB.

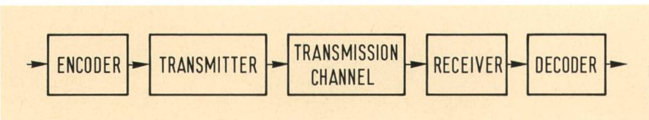

Fig. 1
Simplified diagram of a communication channel

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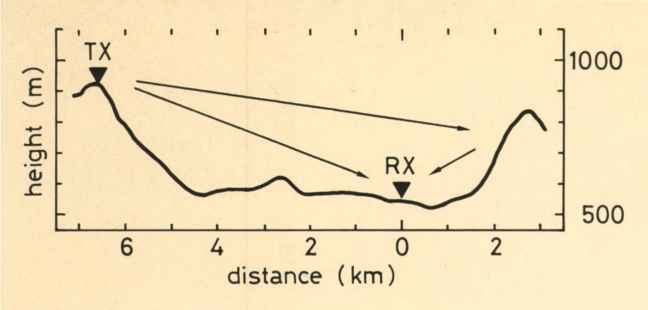

Fig. 2
Typical profile of the terrain

3 Topographic description of the region

The measurements were carried out in the city and the outskirts of Berne, i.e. one of the hilly regions of Switzerland. The nearest mountains of the Lower Alps and the Jura are more than 25 km away from Berne. Thus only the nearby surrounding terrain with altitudes ranging from 500 m to 950 m above sea level is of any influence *(fig. 2)*. The distance between the individual hills or small mountains is 5 km to 10 km. Such a terrain with variations in altitude of 450 m can be found in many countries.

In the first series of experiments, measurements were made at 28 locations at distances of 4 km to 13 km from the transmitter. The presumable distortions due to multipath propagation are mainly determined by the ratio of the amplitudes of the 'direct' and the reflected signals and the delay spread between the first and the last significant path. The propagation conditions may be roughly assigned to the following three categories:

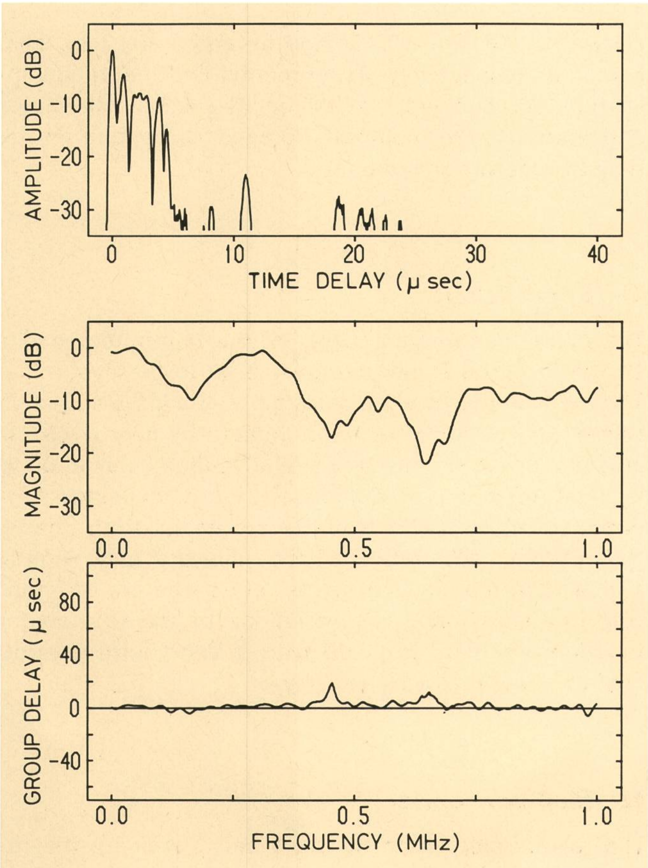

Fig. 3
Typical delay profile and transfer function in the city of Berne. The transfer function is described by the magnitude and the group delay as functions of frequency f

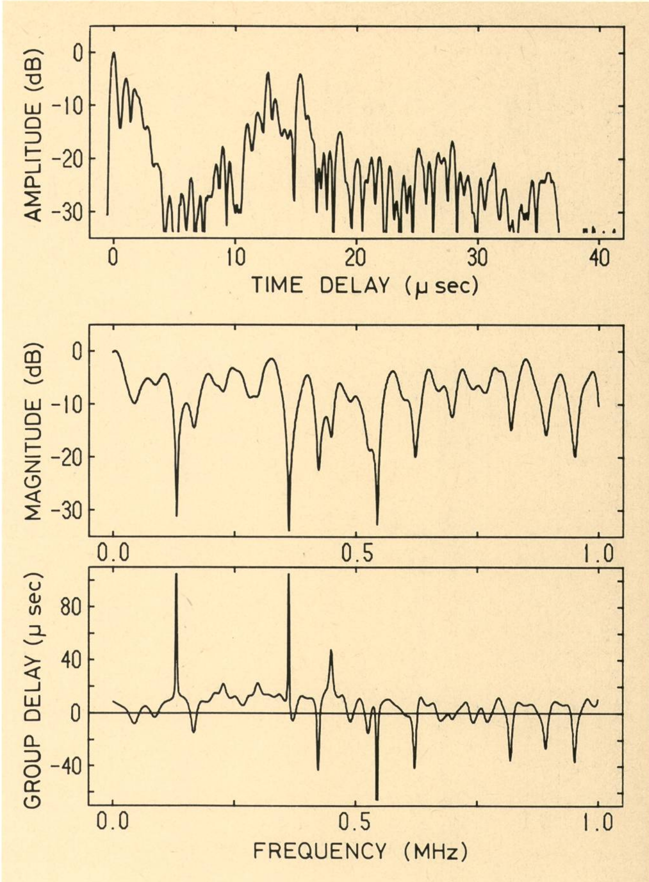

Fig. 4
Delay profile and transfer function in a hilly region. Possible influence of reflections from hills (location Elfenau I)

a) Short delays: Signals with a delay greater than 7 μs are more than 15 dB lower than the direct signal. The transfer function $\underline{H}(f)$ varies relatively slowly with the frequency f *(fig. 3)*.

b) Medium delays: Reflections delayed by more than 10 μs and 20 μs are, respectively, more than 10 dB and 20 dB lower than the 'direct' signal; the direct signal may be slightly attenuated by small obstacles such as one-family houses. Reflections from hills are received with considerable amplitudes. The variations of the transfer function $\underline{H}(f)$ with frequency f are moderate *(fig. 4* and *5)*.

c) Large delays: The 'direct wave' is significantly attenuated, and numerous reflections from distant hills are present. Reflections that are delayed by more than 20 μs may differ from the 'direct signal' by less than 10 dB. The transfer function $\underline{H}(f)$ is highly frequency-dependent *(fig. 6)*.

In the following text typical examples of these propagation conditions are discussed. Attention is paid to the data as well as to the assumed propagation mechanisms. The possible variety of individual delay profiles

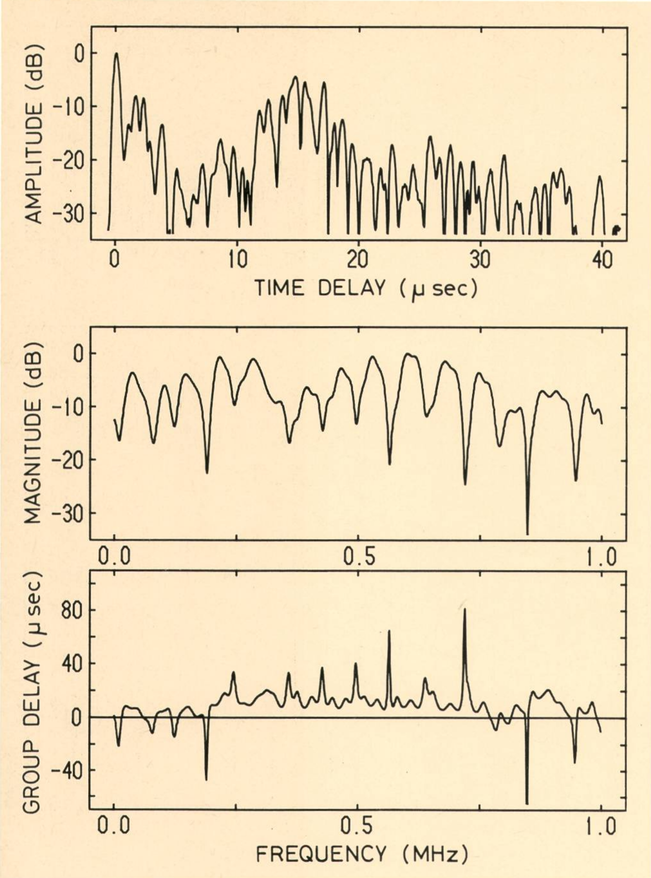

Fig. 5
Delay profile and transfer function in a hilly region. Possible influence of reflections from hills (location Elfenau II)

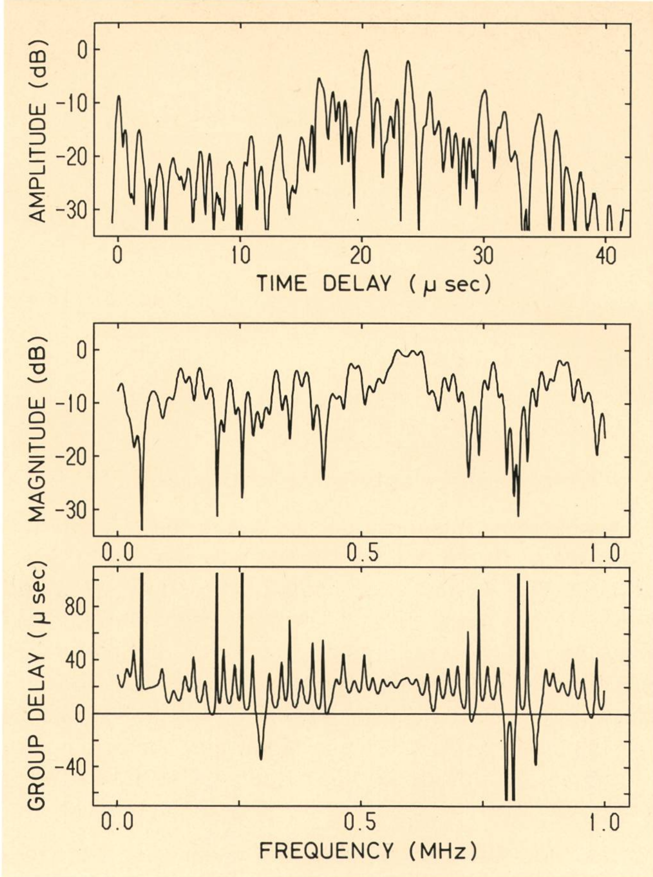

Fig. 6
Unfavourable delay profile and transfer function in a hilly region (location Muri/Berne)

and RF-transfer functions is demonstrated by representative examples.

4 Typical results

Signals of a TV-transmitter operating in channel 10 (209 MHz to 216 MHz) were analysed to determine the transfer functions. The transmitter station Bantiger is situated on the highest point in this region at 947 m above sea level. As the 'direct wave' is generally lower than the received reflections when the transmitter's altitude is reduced, the observed significant delay spreads would have been higher, if a transmitter at a lower altitude had been used. For reception tests, only locations for which the mobile radio service should be assured were taken into consideration. The omnidirectional receiving aerial was 2.5 m above the ground.

Typical results are shown in figures 3 to 6. Each figure consists of three parts: At the top, the amplitudes (−30 dB...0 dB) of the received signals $|\underline{h}(t)|$ as a function of delay (0 μs...40 μs) are plotted. In the middle, the computed magnitude (−30 dB...0 dB) of the transfer function $\underline{H}(f)$ as a function of the frequency deviation (0 MHz...1 MHz) is given. At the bottom of the figures, the group delay (−40 μs... +80 μs) i.e. $\{(-1/2\pi)\ d(\text{phase of } \underline{H})/df\}$ versus frequency is shown.

The experimental results may be classified into different groups by taking into account the 'multipath spread T_M' as defined in [5]. The multipath spreads T_M of the results shown on the figures 3, (4 and 5), and 6 are 2 μs, 9 μs, and 12 μs respectively. Experimental and theoretical investigations showed that the relative echo amplitudes and therefore the multipath spreads T_M depend on the type of receiver environment.

41 Short delays

The conditions characterized by the computed results shown in figure 3 may be considered to be favourable. The measurements were carried out at a large square in Berne. The direct wave is attenuated by nearby obstacles. Scattered signals with a relative time delay of up to 6 μs are reflections from façades of large buildings. Signals delayed by 10 μs to 25 μs are echos from nearby hills. As the silhouettes of the hills are only slightly higher than the sky-line, these reflections are of relatively low amplitude. The variations of the RF-transfer function are 10 dB to 20 dB with a 'short-term periodicity' of about 0.25 MHz = 1/4 μs.

42 Medium delays

The results plotted on figures 4 and 5 indicate the receiving conditions at two points separated by only 1.7 m. The topographic configuration is shown in figure 2. The receiver is located 6.6 km from the transmitter and clearly within the so called 'radio horizon'. It is a suburb of Berne with one-family houses and gardens. The waves reflected from a hill are received without additional attenuation at this location. The profile of the terrain shows that similar configurations exist at many other places in hilly regions.

Signals with a relative delay of less than 5 µs (see upper diagrams of figures 4 and 5) are due to scattering by nearby obstacles. The most significant echos delayed by 10 µs to 18 µs are reflections from the mountain shown on figure 2. Accordingly, the apparent 'short-term periodicity' of the RF-transfer function is about 0.07 MHz = 1/14 µs. Thus, the variations of the transfer function are clearly more accentuated than in the former case 41. Comparing figure 4 with figure 5 it becomes evident that the individual delay profile and the transfer function may vary considerably within a short distance (= 1.7 m).

In order to describe the propagation conditions in a statistical way, about 35 single measurements at equally spaced points on a line of 60 m in length were carried out at each location. The distribution of the reflected signals with a predefined delay could be approximated by a Rayleigh distribution. Concerning the location of case 42, *figure 7* shows the signal amplitudes that are exceeded with the probabilities of 16 p.c., 50 p.c., and 84 p.c. versus the time delay.

43 Large delays

Data describing unfavourable receiving conditions are given in figure 6. The geometric configuration of this location is comparable to case 42. However, the direct wave is attenuated by diffraction due to a well-treed area. Numerous significant reflections from different hills are received. The delay spread is greater than 17 µs (upper part of figure 6). For these reasons, the linear distortions are considerable and the RF-transfer function depends highly on the frequency.

5 Conclusions

Since wideband radio communication is affected by multipath propagation, a method for determining delay profiles and transfer functions was developed. As the transmitter used for the propagation tests was situated at the highest point in the region, the amplitudes of the 'direct' signals were relatively high in comparison with reflections from the terrain. Nevertheless, important delay spreads could be observed. Nearby hills can hardly be seen from the streets of Berne. Thus – as in many other towns – the delay spread is generally less than 5 µs (fig. 3).

In suburbs and the outskirts of towns, however, distant hills may be visible from the receiver's location. Thus, significant distant echoes are received and relative time delays of more than 15 µs can be observed (figures 4 to 6). Examinations of the topographic conditions in hilly regions show that such situations occur quite frequently. Obviously, even higher delay spreads can be measured in mountainous areas.

Digital speech transmission requires bit rates of 16 kbit/s to 64 kbit/s, thus severe intersymbol interferences can occur. To overcome this difficulty, adaptive equalizers may be used. For moving receivers, the possible variations of the transfer function $\underline{H}(f)$ from point to point should be taken into account (fig. 4 and 5).

The delay profiles observed in the streets of the city, in the suburbs and in the outskirts were quite different from each other. Consequently, a statistical description of the conditions in hilly regions should be based on a model with many parameters and should take into account a great number of experimental data. In order to give some preliminary information, the possible problems have been illustrated by the selection of a few representative results.

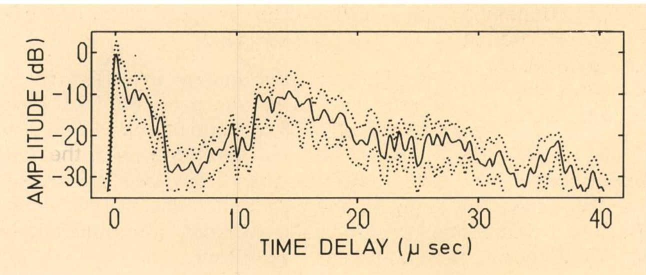

Fig. 7
Signal amplitudes exceeded with probabilities of 16 percent, 50 percent and 84 percent at predefined time delays at the location of case 42

Acknowledgments

The author is grateful to the Main Division Development and Research of the Swiss PTT for the possibility to conduct this study in the group for wave propagation. He wishes to thank Mr. W. E. Debrunner and Mr. H. Gysel for stimulating discussions and support.

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