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Sweep Measurements of Multipath Effects on Cross-Polarized RF-Channels Including Space Diversity

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Summary. *Sweep measurements over a bandwidth of 60 MHz were carried out on a 46.5 km hop in the 7 GHz band. The transmitted signal is sent quasi-simultaneously on the vertical and horizontal polarization and is received by two antennas and in both polarizations. From the measured data, statistics about the behaviour of the different amplitude frequency-response functions and their correlation can be derived.*

1 Introduction

Four years ago, the swiss PTT started the measurement of the transfer function of RF-channels on several hops in Switzerland. With an extended measurement set-up and an improved data acquisition system, the fourth hop is now under investigation. The measured signals allow to study the behaviour of individual channels. Beside this, the correlation between the measured quantities can be deduced.

2 Description of Experiment

The experiment has been in progress since August 1983 on a hop of 46.5 km length *(Fig. 3)* at frequencies in the upper 6 GHz band. It consists of two parts *(Fig. 1)*: the measurement of the transfer functions of a RF-channel and the transmission of 140 Mbit/s.

The first one is an extended version of an earlier experiment [1, 2]. The RF-signal sweeps over a bandwidth of 60 MHz and is transmitted by a circular parabolic dish antenna (3 m ∅) alternately on both polarizations using a latching circulator as a switch. The switch, controlled by the sweep signal, changes every 0.2 second between the horizontal and vertical polarization. The isolation of the latching circulator (Electromagnetic Sciences Inc.) is better than 43 dB after further adjustments. At the receiver site two parabolic dish antennas were installed. The main antenna (3 m ∅) is equipped to receive both polarizations, the diversity antenna (1.2 m ∅) only the vertical one. The magnitudes of the three receive signals are measured by means of logarithmic amplifiers and fed to the data acquisition system. In addition, the two vertically polarized signals from the main and diversity antenna resp. are combined through an in-phase diversity combiner [3]. A link analyzer (model RM-4, Wandel + Goltermann) measures amplitude and group delay of the combined signal and derives the sweep voltage which corresponds to the frequency deviation. All analog signals are fed to the processor. The six analog quantities are sampled at a rate of 200 Hz per channel, digitized and collected in a long term and a short term data base. The long term data base takes two successive sweeps of each of the six signals every 30 s (i.e. one

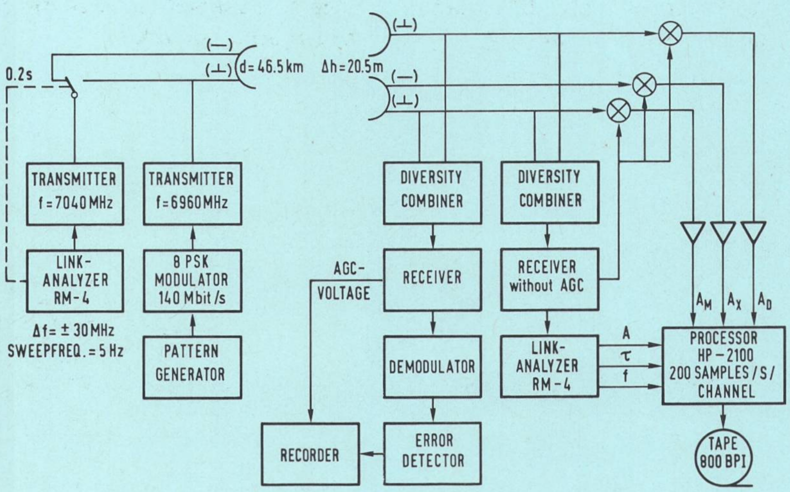
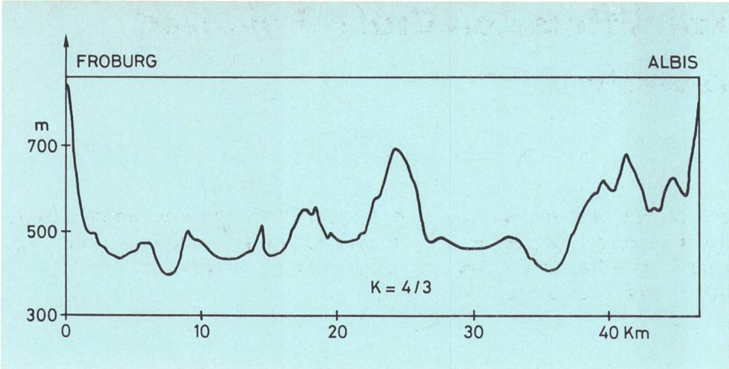


Fig. 1
Block diagramm of the field experiment



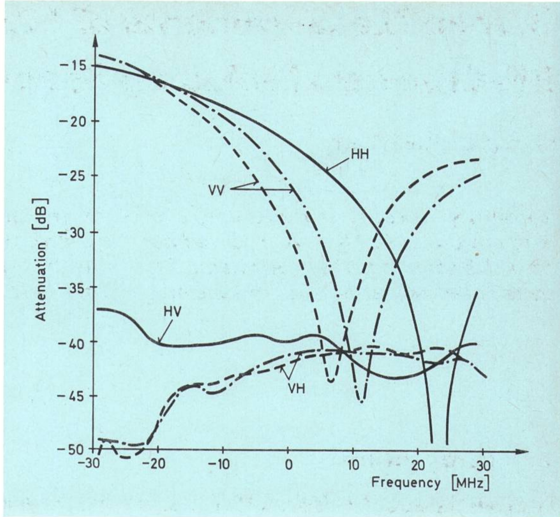


Fig. 2 ▲
Example of successive sweeps

Fig. 3 ►
Path profile

horizontally, the other vertically transmitted) and allows to extract overall monthly statistics. If the variations of the measured values exceed given limits or when the amplitude falls below a given value, the raw data are stored in addition to the long-term values.

The second part of the experiment consists of the transmission of 140 Mbit/s in an adjacent channel (80 MHz spaced). An 8-PSK radio link from NEC was installed in order to prove the validity of an outage prediction method published previously [2]. This method uses the joint probability density function of the linear and parabolic distortions and the signature of the radio link under test.

3 Qualitative Description of the Measured Data

The following examples and results are all taken from the short term data base. The information of the six channels, measured with 200 samples/s each, or 40 samples/sweep respectively, represents:

$A_C(f)$ Amplitude frequency-response of the combined signal (RF-diversity combiner)

$A_M(f)$ Amplitude frequency-response of the main-antenna signal (vertically polarized reception)

$A_D(f)$ Amplitude frequency-response of the diversity-antenna signal (vertically polarized reception)

$A_X(f)$ Amplitude frequency-response of the main-antenna signal (horizontally polarized reception)

$D_C(f)$ Group delay of the combined signal

$V(f)$ Voltage proportional to the transmit frequency

As the polarization of the transmitted signal is changed at every sweep from horizontal to vertical and vice versa, real in-line and quasi-simultaneous cross-polar transfer functions can be derived from the received signals.

Figure 2 shows three successive sweeps during a selective fading. The sweeps No. 28 and 30 correspond to vertically transmitted and received signals (labelled as VV). The two corresponding horizontally received (cross-polarized) signals are denoted as VH. The sweep No. 29 represents a horizontally transmitted signal with the in-line receive signal labelled as HH and the cross-polarized one HV.

Several observations can be made by examining the measured amplitudes:

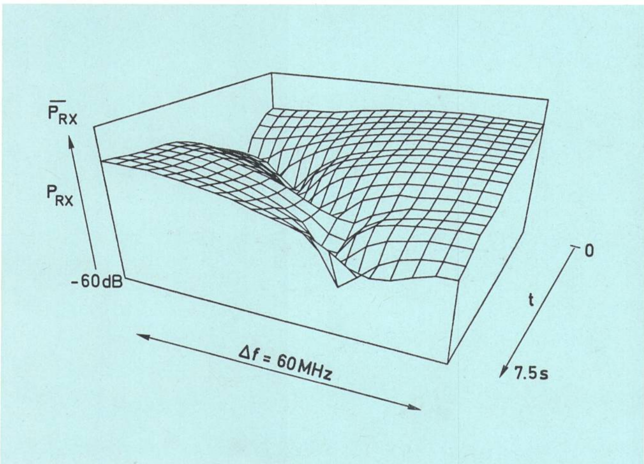


Fig. 4
Main antenna vertical (co-polar) rotated

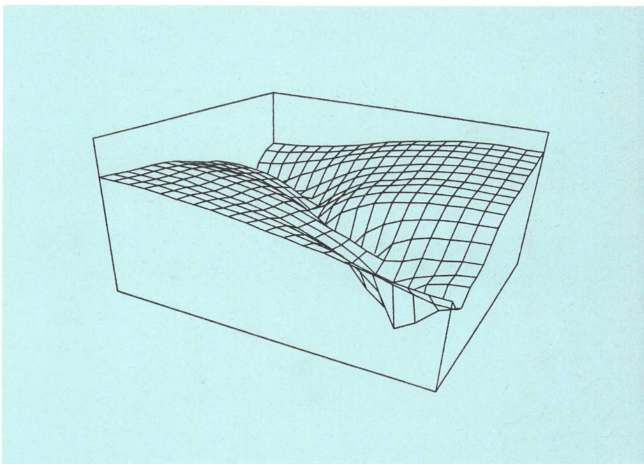


Fig. 5
Main antenna horizontal (co-polar) rotated

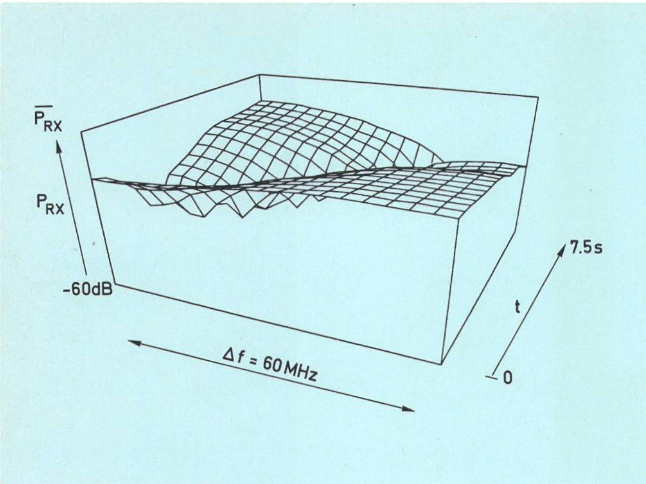


Fig. 6
Main antenna vertical (co-polar)

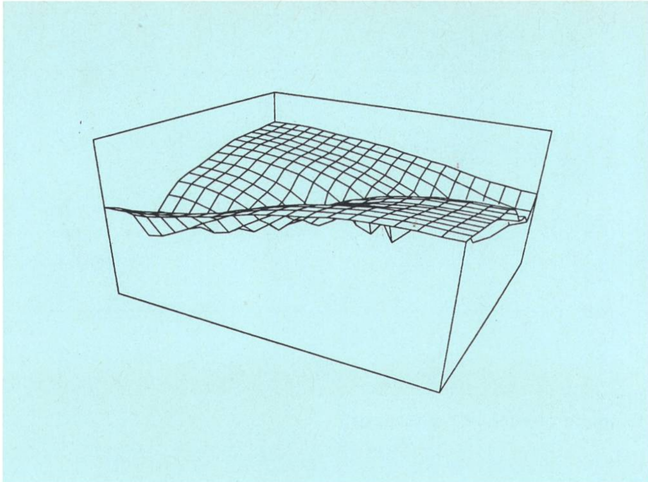


Fig. 7
Main antenna horizontal (co-polar)

- the cross-polarized signals show no notches at the frequency where the in-line signals have deep fades
- the minima of the in-line signals are below the cross-polarized level
- the minima of the two cross-polarized in-line signals (VV and HH) are not simultaneously at the same frequency. Due to the measurement procedure this conclusion derives from comparing sweep No. 29 (HH) with an interpolated curve between the two sweeps 28 and 30 (both VV).

A better overview of the behaviour of the transfer functions versus frequency and time is possible if they are represented in three-dimensional plots. The following Figures 4 to 13 show all the different transfer functions of the same fading (day = 267, time = 6 h 32 m 15 s) presented in Figure 2. The two horizontal axes represent the frequency (−30 MHz to +30 MHz) and the time (0 s to 7.5 s).

The third dimension gives the received level in dB, from the averaged undisturbed level $\overline{P}_{RX}$ down to a level of 60 dB below. In Figures 6 to 13, the time increases from front to back. In *Figures 4* and *5* the time axis is reversed in order to have a better look into the valley produced by the fading. The notch crosses the RF-band with a speed of about 10 MHz/s.

Figures 4 to 7 show the two quasi-simultaneous in-line signals VV and HH. In *Figures 8* and *9*, the cross-polarized signals HV resp. VH are depicted. Both have a relative flat amplitude frequency-response and no deep notches as one can notice at the in-line signals. During the deep fade, the diversity antenna, which is mounted 20.5 m higher than the main antenna, delivered a non-faded signal with a flat amplitude *(Fig. 10)*. The combined signal *(Fig. 11)* of the main and the diversity antenna is mainly determined by the stronger signal and shows also a flat amplitude frequency-response. Its level is 3 dB below that of the diversity antenna, because an in-phase combiner was used. The cross-polarized signal of the diversity antenna and the combined one are likewise flat *(Fig. 12* and *13)*.

The difference of the signals HV and HH resp. VH and VV yields the cross-polar discrimination XPD, which is depicted in *Figures 14* and *15*. The XPD as a function of frequency and time varies between 35 dB and negative values, as already shown in Figure 2. One can notice that the small values of the XPD are mainly caused by a deep fade in the in-line signal.

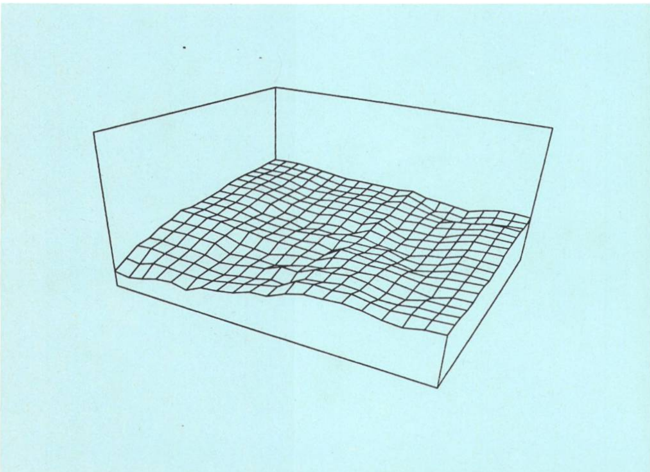


Fig. 8
Main antenna vertical (cross-polar)

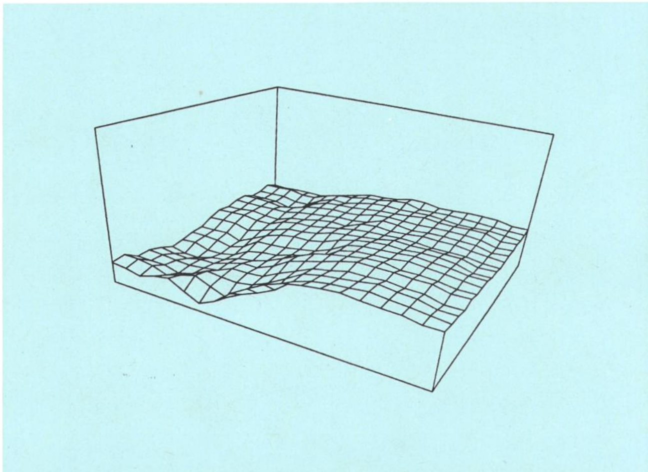


Fig. 9
Main antenna horizontal (cross-polar)

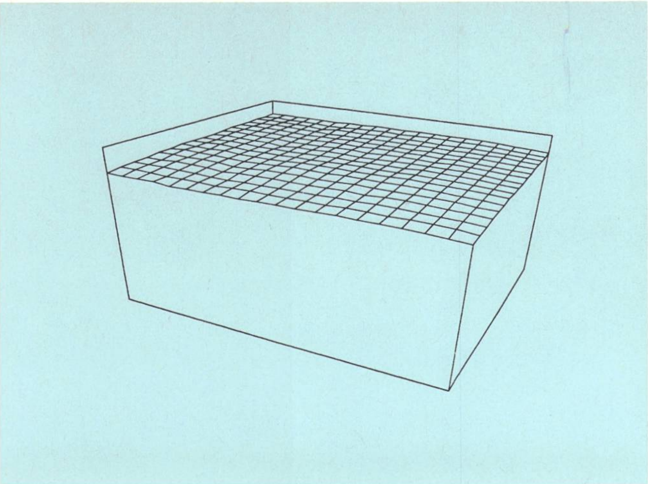


Fig. 10
Diversity antenna vertical (co-polar)

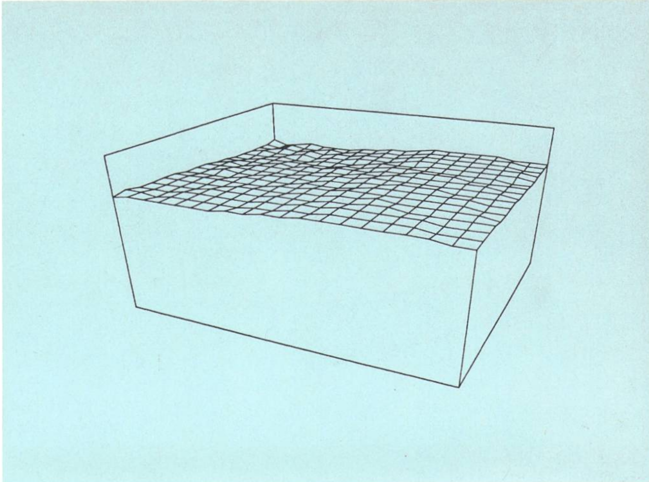


Fig. 11
Combined vertical (co-polar)

4 Statistical Results

During a fading period in the late summer 1983, a data base of 300 000 sweeps with attenuations of more than 10 dB in one of the measured signals was gathered. From this data, one can study, for example, the distortion in the single channels or the correlation between the different signals. The following results are restricted to correlations. Statistics about channel-distortions will be published later.

The three following comparisons are made:

- in-line versus cross-polar signal
- vertical versus horizontal in-line signal (quasi-simultaneous)
- main-antenna versus diversity-antenna signal (both in-line).

A polynomial of second degree, namely, $A(f) = a_0 + a_1f + a_2f^2$, is fitted to the measured received levels in dB. The results are triplets of coefficients (a_0, a_1, a_2) for the four examined signals. The coefficient a_0 denotes the attenuation at the center of the RF-channel in dB, a_1 describes the slope in dB/MHz and a_2 the parabolic distortion in dB/MHz^2. The joint density of pairs of these coefficients gives a measure of correlation between various signals.

41 Correlation Between the In-line and the Cross-polarized Signal

Figure 16 shows the correlation matrix of the linear coefficients (slope) of the vertical in-line signal and the horizontal cross-polarized signal. The magnitude of the coefficients varies between −0.8 dB/MHz to +0.8 dB/MHz. The logarithm of the density function $p(a_{1V}, a_{1H} \mid \text{Tx: vertical})$, which is depicted in the direction of the third axis, indicates the presence of two subsets of pairs (a_{1V}, a_{1H}). The more numerous ones form the «long, slender mountain»: During weak distortions of the in-line signal the cross-polarized one shows non-correlated distortions with four times steeper slopes. The less numerous ones formed by a circular cone about the center indicate that large linear distortions of the in-line signal are not correlated with the linear distortions of the cross-polarized signal.

Similar observations can be made by interpreting *Figure 17*, which describes the correlation matrix of the parabolic distortions.

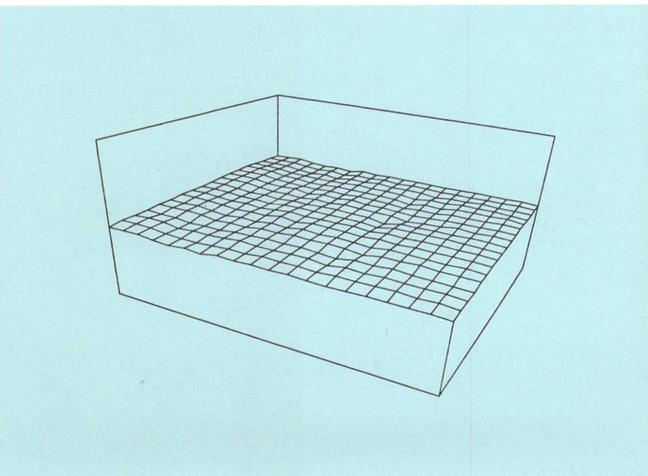


Fig. 12
Diversity antenna vertical (cross-polar)

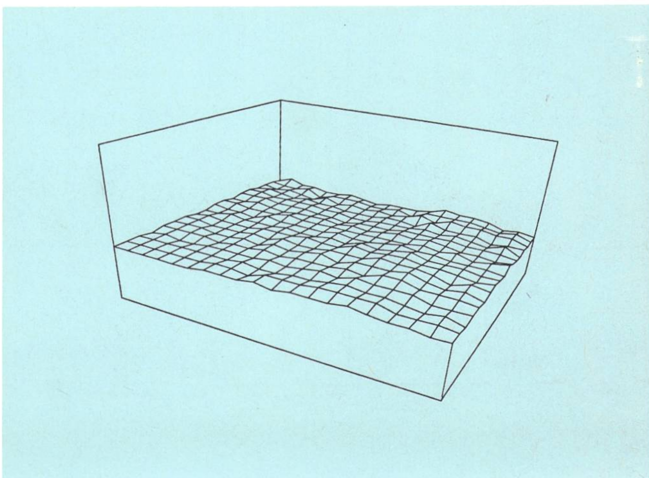


Fig. 13
Combined vertical (cross-polar)

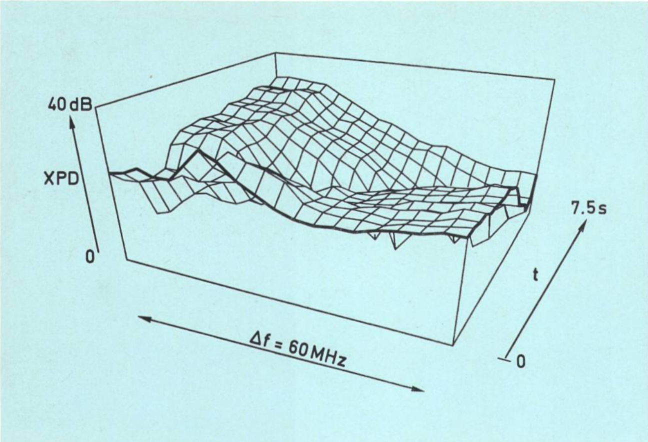


Fig. 14
Cross-polar discrimination
Tx: Horizontal
Rx: Main Antenna (vertical) – main antenna (horizontal)

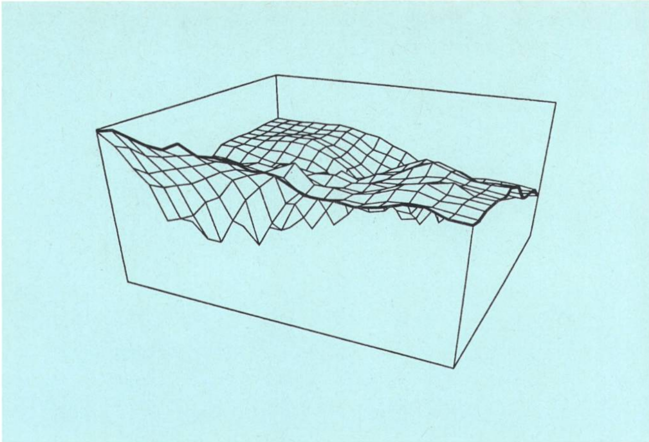


Fig. 15
Cross-polar discrimination
Tx: Vertical
Rx: Main antenna (horizontal) – main antenna (vertical)

42 Correlation Between the Vertical and the Horizontal In-line Signal

The question of the correlation between the two cross-polarized in-line signals becomes more important with the trend to use both polarizations of the same frequency in parallel for simultaneous transmission. The introduction of a cross-polarization interference canceler has shown the need for more information about the distortion of the two channels.

The quasi-simultaneous measurement of the horizontal and the vertical in-line signals yields informations to this subject. *Figure 18* shows the density function $p(a_{1V}(t), a_{1H}(t+0.2s) \mid \text{both in-line})$, i.e., the joint probability of the quasi-simultaneously measured slope of the vertical and horizontal in-line signals. One can see an asymmetrical density function with no correlation between the two polarizations: the slope of the horizontal signal is about twice the slope of the vertical one.

The parabolic distortions *(Fig. 19)* of the two polarizations seems to be equal and non-correlated.

43 Correlation Between the Signals of the Main and the Diversity Antenna

The density function $p(a_{1M}, a_{1D} \mid \text{both in-line})$ *(Fig. 20)* shows a mountain with a cross-shaped ground plane, which indicates that one polarization has strong linear distortions whilst the other shows practically none and vice versa. Strong simultaneous distortions have not been observed until now. The same conclusions can be drawn for the parabolic distortions *(Fig. 21)*.

5 Conclusions

The relatively small data base of 300 000 sweeps allows some qualitative conclusions:

- The horizontally and the vertically polarized in-line signals are simultaneously affected by multipath fading. More detailed studies show that the notches of deep selective fades are not at the same frequency for any given instant.
- The in-line horizontal signal is more distorted than the in-line vertical signal. This result may be special for this hop and needs further investigations.

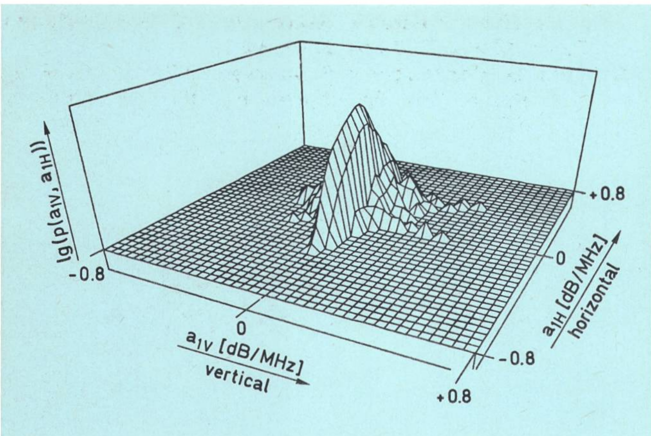


Fig. 16
Comparison
Signals from the vertical vs-signals from the horizontal polarization (vertical is in-line)
Correlation matrix of the linear terms of the fit-polynomials

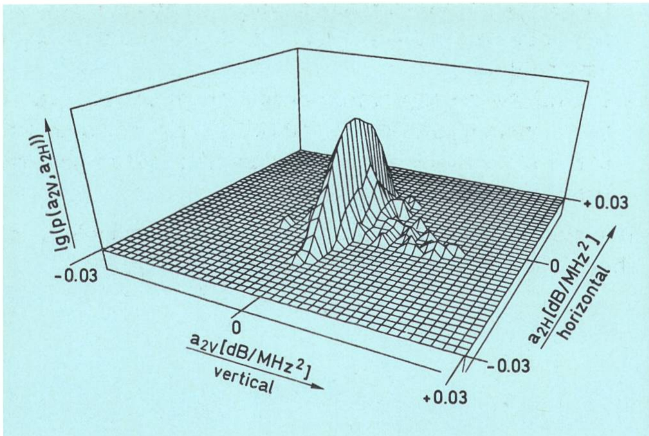


Fig. 17
Comparison
Signals from the vertical vs-signals from the horizontal polarization (vertical is in-line)
Correlation matrix of the parabolic terms of the fit-polynomials

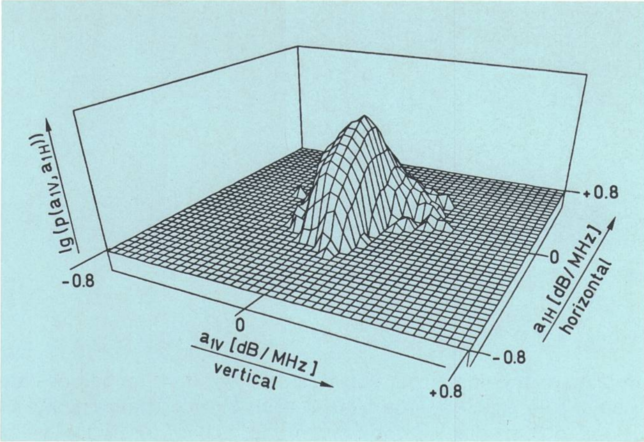


Fig. 18
Comparison
Signals from the vertical vs-signals from the horizontal polarization (both in-line, quasi-simultaneous)
Correlation matrix of the linear terms of the fit-polynomials

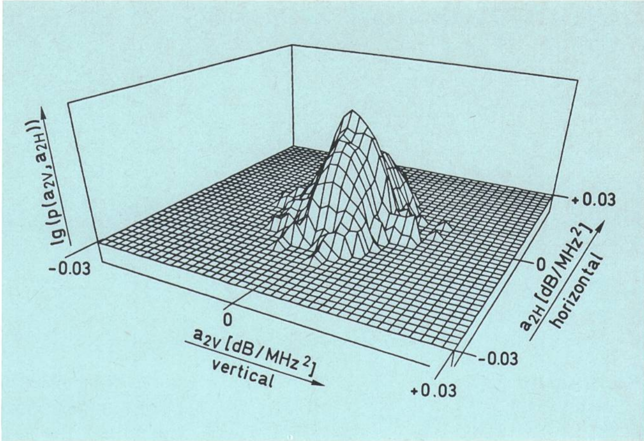


Fig. 19
Comparison
Signals from the vertical vs-signals from the horizontal polarization (both in-line, quasi-simultaneous)
Correlation matrix of the parabolic terms of the fit-polynomials

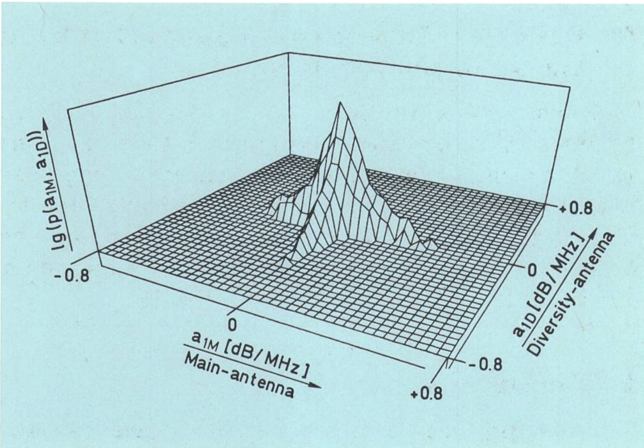


Fig. 20
Comparison
Signals from the main vs-signals from the diversity antenna
Correlation matrix of the linear terms of the fit-polynomials (both in-line)

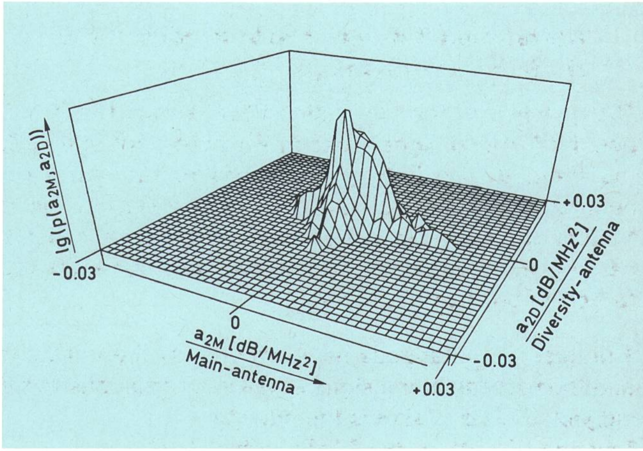


Fig. 21
Comparison
Signals from the main vs-signals from the diversity antenna
Correlation matrix of the parabolic terms of the fit-polynomials (both in-line)

– A small or negative cross-polarization discrimination can occur at instants, when the in-line signal has a selective fade.
– Large distortions of the in-line and cross-polarized signals are not correlated.
– Large simultaneous distortions of the main and diversity antenna signals are not correlated and they occur very seldom.
– During the measurement period no errors occured in the transmission of the 140 MBit/s signal, indicating the improvement obtainable by the space-diversity system.

The measurements are being continued on this hop and should lead to further and improved results.

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