

A Novel Polarization Smart Antenna

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Abstract - The wave propagating through the mobile channel becomes partially depolarised by polarization-dependent scattering. Measurements of the amount of depolarization (XPD – cross polarization discrimination) for linear polarizations reveal an energy transfer of -8 to -15 dB to the orthogonal polarization in outdoor propagation, indicating that the wave is essentially polarized. The independent fading of the wave components are commonly interpreted as being randomly polarized but the histogram of the incident wave appears to be bounded by an eccentric ellipse-like shape with an axial-ratio equal to the value of XPD. Moreover, the measured projection of the averaged-in-time polarization of the incident wave is found to be highly correlated over a wide frequency bandwidth. This observation serves as the foundation for a new polarization-matching algorithm, whereby the time-average polarization of the incident wave serves to adjust the polarization of the transmission back to each individual Mobile Station - MS. This process recovers a substantial portion of the polarization-induced transmission losses that may exceed 10 dB, and serves to reduce the forward power control variations and the average transmit power of the Base-Transceiver-Station (BTS), as well as the induced interference. The Paper presents the proof-of-concept *polarization matching* trial, and the analysis of the results. A novel *polarization-matching smart-antenna* system architecture is described.

1 Introduction

Mobile wireless channels are time varying mainly due to the MS motion [1], exhibiting shadowing, fading, Doppler shift, and polarization mismatch that determine the communications link performance. The combination of these greatly affects the average bit error-rate (BER) performance at the receiver-detector output, both for the BTS and the MS, which commands an increase of transmitted power for maintaining the quality of service causing additional interference to other users and degrading the overall system efficiency.

The focus in this work is on the polarization and the discussion applies to general wireless links in outdoor

environments. While the polarization of the wave is preserved through free-space propagation, the polarization-dependent scattering along the multipath of the mobile communication channel induces a transfer of energy to the orthogonal polarization, and uncorrelated fading of these wave components. The time-varying polarization of the wave incident at the receiver is thus mistakenly interpreted as random. However, numerous reports of measured XPD of cellular mobile links, including Non-Line-of-Sight (NLOS), fall in the range of 8 to 15 dB [2], [4], showing that the polarization is greatly preserved in the channel. A histogram indeed shows the wave to be bound by an eccentric ellipse-like shape whose axes ratio is the XPD, and its main axis aligns with the initial polarization. Thus it is important for efficient communications to keep the polarization mismatch between the transmit and receive antennas to a minimum.

Polarization diversity receiving antenna pair used in the cellular service typically consists of two orthogonal linear antennas (either V-H or two slant $\pm 45^\circ$). By employing diversity combining techniques (e.g. maximal-ratio combining (MRC) receiver per MS channel), the two orthogonal polarization components are optimally weighted and combined to achieve the best equivalent polarization [1]. While this process is commonly attributed to a polarization diversity gain, the fact that averaging over a number of fading results in adaptively matching the polarization of the receive antenna to that of the incoming wave from the MS alludes to the *polarization matching gain* as the dominant effect.

Polarization matching on the forward link would require an antenna pair and appropriately two receivers at the MS – an impractical proposition. Generation of the right polarization at the BTS antenna, to match the MS antenna, requires a-priori knowledge of the state of the latter. The 3G cellular standard incorporates provisions to assist the BTS in beamforming its transmission to match the MS position, by appropriate feedback from the latter. This may be used to steer the “polarization” state¹ of the BTS, but it

¹ Since the main objective is to steer a BTS multicolumn array beam, it is doubtful that an additional dimension (i.e. polarization) will benefit from these provisions.

is limited to slow speeds and has to compete on the priority of beam vs. polarization steering.

A novel and by far simpler approach for *forward link polarization matching* is discussed in the following. Recognizing that the time-averaged polarization state is frequency insensitive, the polarization state that is processed by the receiving antennas of the BTS is now applied to the transmit antennas, at the forward link frequency. This process adapts the polarization of transmission for each MS, and is therefore considered a “polarization smart antenna”.

Section 2 describes a field trial for measurement of typical relevant polarization characteristics for various outdoor channels. Section 3 details results from recent field trials. A novel *polarization matching smart antenna*² is proposed, based on the trial results. Section 4. Section 5 summarizes the conclusions.

2 Polarization Matching Trial

The purpose of the field trial that was performed in the 1900 MHz frequency band in sub-urban and rural areas, including NLOS, was threefold: a) Measure the channel XPD statistics. b) Measure the correlation between the (slow varying) mean orientations of the polarizations at two frequencies, which were 100 MHz apart. c) Measure the fast fading characteristics at the two distinct frequencies. The set-up of the trial is depicted in Figure 1.

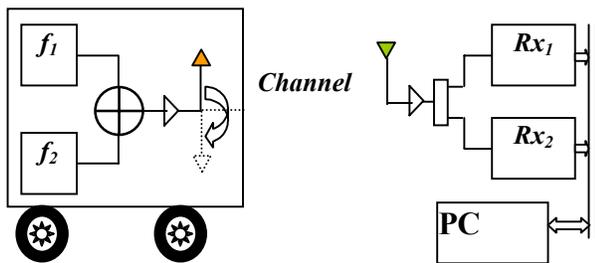


Figure 1: Set-Up of the Polarization Matching Trial

The set-up consisted of a stationary side and a mobile side. Since the channel is reciprocal at a given frequency, a simpler approach was used where the transmission of the two FDD frequencies was from one side of the channel, and the reception of both frequencies was performed at the other side of the channel. The mobile station consisted of a transmitter that operated continuously during the drive-test. Two continuous wave (CW) frequency sources ($f_1=1950$ MHz, $f_2=1850$ MHz) were combined to produce a two-tone signal, which after amplification was

² Patent Pending.

transmitted via a linearly polarized antenna. The antenna consisted of a half-wavelength dipole in front of a conducting back-screen. The whole transmitter-antenna complex (see Figure 2) was rotated in a vertical plane creating a periodically rotating linear polarization. The rate of rotations was 1 cycle per second. The stationary site consisted of a linearly polarized receiving antenna that was connected to a low-noise pre-amplifier (LNA) and then split into two narrow-band receivers, realized by spectrum analyzers, that operated at zero span.



Figure 2: Mobile Transmitter Set-Up

The digitized detected video outputs of the receivers were fed into a personal computer (PC) for later post-processing.

This set-up guaranteed that the two frequencies were transmitted at the same polarization, through the same channel, and were received with the same polarization. The vehicle speed varied between 10 and 70 Km/Hour. It was possible to vary the polarization orientation of the stationary linear antenna.

Several drive-tests were performed in ranges between 1 Km and 10 Km between the mobile and the stationary sites. Since the mobile transmit antenna covered roughly a hemisphere, the mobile was transmitting backwards and driving away from the stationary site in all the test routes.

In all the cases that have been examined, a clear periodic pattern of varying receive power was noticed at the stationary site, at exactly the same rate as the rotation of the mobile antenna. These variations indicate the time varying polarization mismatch loss at the stationary receive station. Figure 3 presents a typical example of the results for a NLOS path. The receive power variations of the two frequencies are highly correlated. The upper plot shows the relative dB level samples of the received signals at the two distinct frequencies as a function of time, measured in samples. The lower plot is the same one, but with one of the received signals shifted upwards. The two signals seem highly correlated.

The dB difference between the consecutive maximum and minimum points is the XPD, and it is in the order of 10 dB. Although the slow varying (mean) changes in receive power are highly correlated between the two frequencies, the fast fading is generally uncorrelated.

These results clearly indicate that the received mean polarizations of two co-polarized transmissions, which are spaced by 100 MHz at 1.9 GHz, are *matching* remarkably.

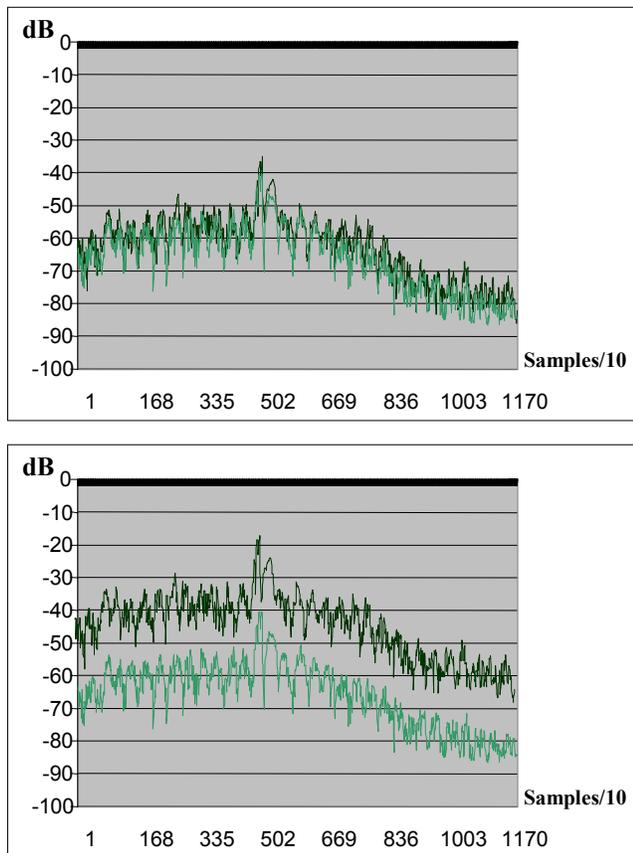


Figure 3: Recorded Receivers' Outputs

This phenomenon may be termed *polarization shadowing*, similar to the shadowing attenuation that is an energy related effect, and is broadband.

3 Analysis of Trial Results

The data that was gathered in several runs of trials as described in the previous section was processed, and indicative results are presented in this section. The data was arranged in blocks of 401 samples per 0.5 second,

and stored as a two-column vector for the receive levels at the two frequencies. Since the polarization cycle duration was 1 second, we used a 15 Hz low-pass filter (LPF) to smooth out the fast fading and leave the slow time-variations, whereas a 10 Hz high-pass filter (HPF) was used to suppress the slow variations and leave the faster fading process.

First, the dB difference between consecutive peaks and valleys were determined and their statistics analyzed. This empirical XPD cumulative distribution function (CDF) is shown in Figure 4.

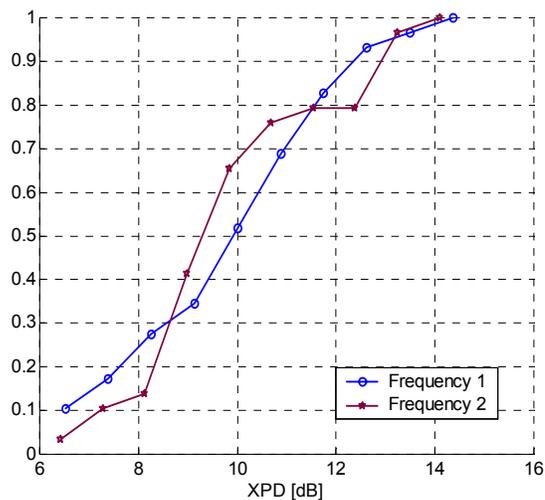


Figure 4: CDF of XPD at f_1 and f_2

The XPD's are in the range of 8 to 14 dB, and are distributed similarly for the two distinct frequencies.

These results are similar to other published results, cf. [2]. Next the correlations between the slow-varying received power time functions at the two frequencies were analyzed. Partial correlations were performed per data blocks of 401 samples, and a CDF of the correlation values was generated. Figure 5 is a typical CDF of the correlations of sub-sections (blocks) between the two slowly varying envelopes at the two frequencies. Note the high correlation between the two power-envelops which is termed here *polarization matching*.

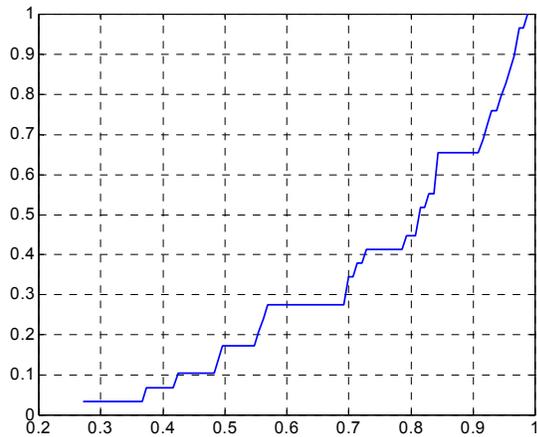


Figure 5: Correlations' CDF of Slow-Varying (LPF) Envelopes

The fast variations at the two frequencies were checked against a Rayleigh CDF, Figure 6. The empirical CDF's practically coincide for the two distinct frequencies.

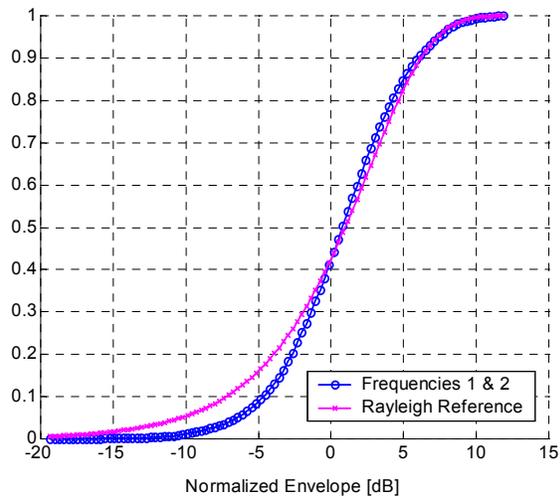


Figure 6: CDF of Fast Fading (HPF) Envelopes

Finally, the cross-correlation between the fast-fading envelopes was tested for blocks of 401 samples, and the CDF of the results was generated, Figure 7. The results correspond to highly uncorrelated (between the two distinct frequencies) fast Rayleigh fading.

This *polarization-matching* phenomenon immediately leads to a polarization smart antenna concept that does not require any feedback information from the MS at the BTS.

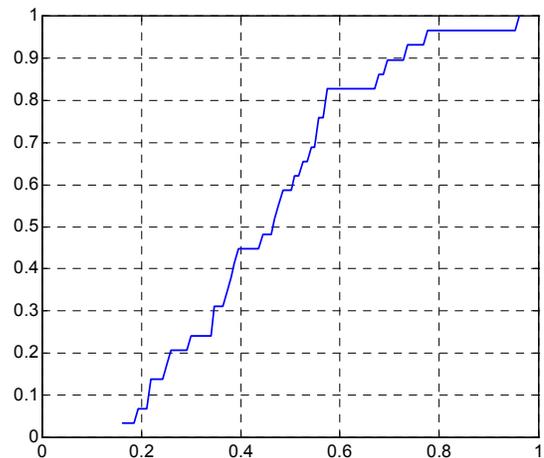


Figure 7: CDF of Cross-Correlation between the Fast Fading (HPF) Envelopes

4 Polarization Matching Smart Antenna

Based on the trial results, a polarization smart antenna is proposed, that utilizes the signal received at the BTS from each MS, to learn about the (slow-varying) mean polarization and transmit back from the BTS to that MS at the estimated polarization. Figure 8 presents the block-diagram of a polarization smart antenna processor³. Such a processor may be implemented at base-band⁴, since it performs the algorithm per channel.

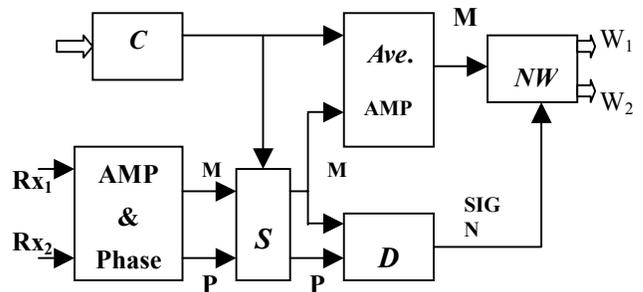


Figure 8: Block Diagram of the Polarization Smart Antenna

Additional transmission considerations are presented in [3].

³ Patent pending

⁴ IF/RF implementations are possible for FDM/TDMA systems.

The general flow in Figure 8 is from left to right. The whole processor applies to one MS. Lines designated with the letter 'M' carry *amplitude* data, and those with 'P' carry *phase* data. The up-link signal received by two cross-polarized antennas is denoted R_{x1} , R_{x2} . The lower-left block processes these signals and estimates the amplitude ratio and relative phase between the two copies of the signal. This is performed by an MRC receiver, and instantaneous magnitude and phase are generated. The block 'S' is a smoothing filter, with its integration time determined according to the channel dynamics. These are determined in the block 'C' based on the received signal. The block 'D' determines the sign of the phase difference to resolve the correct signs of the output weights. The block 'Ave. AMP' further filters the amplitudes and correctors for any calibration. Finally, the block 'NW' produces the normalized weights that determine the weights (including sign) for the transmitted signal to the MS through the cross polarized transmit antennas.

Conclusions

The Paper presented a polarization field trial for a 1900 MHz wireless mobile channel. The trial clearly demonstrated that XPD's around 8 - 10 dB typify such channels. The trial also proved that the correlation between the mean polarizations of two distinct frequency signals transmitted and received by the same antennas through a wireless mobile channel is high, even when the frequencies are 100 MHz apart at 1900 MHz.

Based on the trial result a novel polarization smart antenna concept was presented, that sets the polarization of a signal transmitted from the BTS to a MS based on the mean polarization of the signal received at the BTS from that MS.

Implementation of *polarization matching* at BTS's may save on the average 3 - 4 dB in the total transmitted power, reduce the cellular system self-interference and reduce the size of the power amplifier.

Also, the power variations due to polarization mismatch are reduced, aiding the operation of the forward-link power-control.

Acknowledgement

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