Measurement of the Polarisation State of Satellite to Mobile Signals in Scattering Environments

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ABSTRACT

This paper details a measurement campaign which was undertaken to investigate the effects of buildings and trees on signal depolarisation within a personal satellite communications environment. The satellite environment was simulated using a circular polarised transmit antenna elevated above the buildings, with a dual linear polarised receive antenna with separate receivers for the vertical and horizontal components of the signal. The received signal was sampled and digitally stored for processing at a later stage. Data was collected at a number of different sites, such that the effects of diffraction and reflection from both buildings and trees were observed, along with effects within urban corridor situations.

The presented results show a clear indication that there is considerable potential diversity gain available in areas where the signal is greatly diffracted or where the main signal is a reflected one. Diversity gains of around 10dB have been observed and are presented here. There is however an adverse effect of up to 3dB due to the noise from the second receiver when comparing the signal to noise ratios from maximum ratio diversity combining with a standard circular polarised antenna in areas where the two signals are not decorrelated, such as line of sight situations or areas where there is little shadowing or multipath effect..

A pre detection weighting system could be a potential solution to the performance degradation in line of sight situations by applying complex weights to the two signals and summing them prior to the receiver rather applying them after the receiver chain at baseband. There are however complexity penalties which may make this solution not practical or realisable as training sequences which are too long and time consuming may be required to optimise the output signal to noise ratio.

INTRODUCTION

The newly proposed and deployed Satellite Personal Communication Networks (SPCN) will offer seamless communication of high quality to handheld terminal users around the globe.

The satellite to mobile downlink signal has right hand circular polarisation (RCP) at the source, a little depolarisation is caused by the various effects within the environment[1]. Diffraction and scattering from the trees in rural environments, diffraction and reflections from building edges and surfaces in urban environments are expected to have a considerably greater effect on the polarisation state of the downlink[2]. This will introduce extra losses in the link budget deteriorating the system performance. The level of these losses depends on the polarisation mismatch of the antenna on the mobile terminal with the incoming signal.

The aim of the measurement campaign reported in this contribution, was to measure and then model these depolarisation phenomena. This information can then be used to either recalculate the downlink budget including the polarisation losses or to form new requirements for the antenna on the mobile terminal in order to adjust to the polarisation characteristics of the propagation environment.

An antenna system that is able to adjust its polarisation to that of the received signal could achieve significant extra gain, depending on the level of polarisation matching. Furthermore, an antenna which can switch from circular to linear polarisation, or the two linear components of elliptical polarisation, can establish communication in all situations : circular polarisation for line of sight, linear when in shadow receiving the diffracted (elliptical co-polar) or the reflected (elliptical co- or cross-polar) signal, or even the opposite hand of circular polarisation when receiving reflected signals.

The potential benefits of using a diversity scheme such as maximum ratio diversity combining are presented along with a possible disadvantages in terms of received signal to noise ratio in line of sight environments. A potential solution to these disadvantages is also presented.

THE DEPOLARISATION MEASUREMENT CAMPAIGN

The aim of the depolarisation measurement campaign was to measure and record the different polarisation components of the received signal at a number of locations of various types in a satellite communications environment.

A transmitting antenna with right hand circular polarisation (RCP) was placed on a stationary elevated position illuminating a number of different types of environment, trees, building surfaces, building edges and combinations of the above. The two linear wave components perpendicular to the direction of propagation, nominally horizontal and vertical, were collected by a dual linear patch antenna which was attached to mobile receivers. The two signals were mixed down to a manageable frequency (IF), digitally sampled and stored. These measurements were made at a number of different locations around the campus of The University of Surrey.

Equipment

The equipment used in the measurements (Figure 1) consisted of a carrier wave source at 2.385GHz, which was transmitted via an RCP antenna with 7dBi gain at boresight and a 3dB beamwidth of 80°. The receive antenna, a dual linear polarised patch antenna with 13dBi boresight gain was orientated at a number of different elevation angles towards either the diffracting or the reflecting object. The two received signals were fed into custom built RF receivers which filtered and mixed the frequency down to an IF of 8kHz. These IFs were sampled simultaneously using parallel 16bit analogue to digital converters at a rate of 32kS/s and the resultant samples stored on a computer. As well as the received signals, trigger pulses from a 5th wheel were recorded. The 5th wheel gave pulses approximately every 10th of a wavelength as the mobile receive platform moved through the environment under observation.

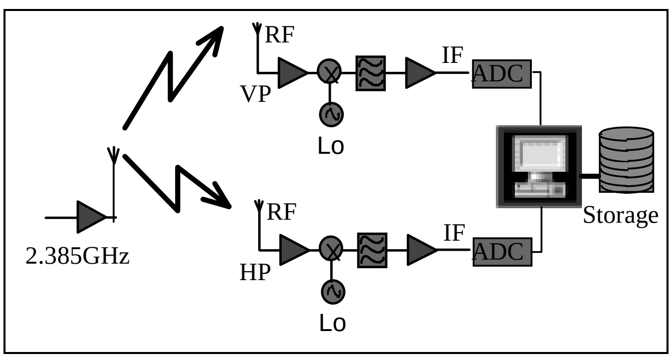


Figure 1:Measurement equipment

Subsequent off line processing was undertaken which digitally mixed the stored data down to a complex baseband signal, filtered and decimated it to a smaller and more manageable 1kS/s time based data. The stored trigger pulses from the 5th wheel were used to sample the data so that position based results which were independent of mobile speed could be obtained in addition to the time based ones. This has the advantage of removing any effect caused by the variation in speed of the receiving platform, giving further clarification during the analysis of the results.

Measurements

Measurements were made in a number of different locations which fulfilled the requirements of the campaign objectives, in terms of the position of buildings and trees, such that the measured signal variations could be attributed solely to the one diffracting or one reflecting object.

Figure 2 shows the measurement setup. The mobile receiver station, consisting of the multiple receivers, antennas, common local oscillator source, data acquisition and storage system and the 5th wheel trigger was moved along a path parallel with the diffracting or reflecting building or line of trees. The path lengths ranged from a few tens of metres up to one hundred metres depending on the surrounding area. Measurements were made at various distances from the building with the elevation of the patch set to a number of different angles.

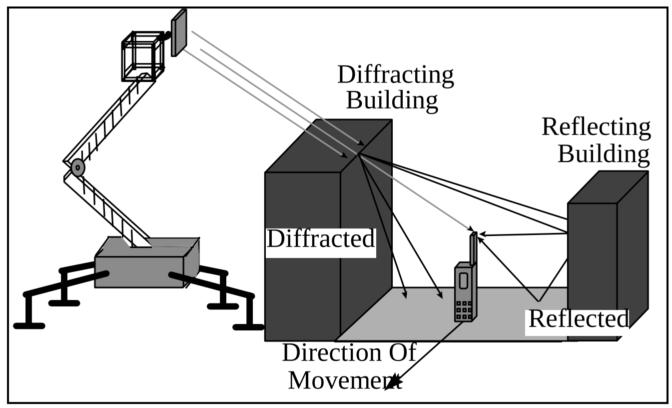


Figure 2: The measurement system

RESULTS

Analysis Methods

The results presented in this section are primarily based on comparison between cumulative distribution functions (cdfs) of the probability of receiving a signal to noise ratio less than the abscissa in the different environments and scenarios.

There are four different scenarios in which the data is analysed, the two independent and orthogonal polarised signals from the patch antenna, termed horizontal and nominally vertical are taken individually. These two polarised signals are phased with a 90° phase difference to simulate the received signal from a circular polarised antenna. The remaining two scenarios are both diversity techniques, the first is selection combining and the second, maximum ratio combining (MRC), both of which are taken calculated as a post detection system[4].

It is important to note that the results presented are a simulation for a circular polarised receive antenna and not for a post detection weighted system optimised for CP. If this were the case then the results for CP would be 3dB lower due to the extra noise from the second receiver thus showing an improvement in available diversity gain. All of the diversity gains quoted in this paper are based on the 1% probability that the signal is less than the abscissa.

Selection combining is chosen as the optimum condition for switch combining as there is prior knowledge of the signals in this case. MRC is the best diversity scheme for obtaining maximum signal to noise ratio so this indicates the absolute best available diversity gain from the two signals when employing a post detection weighting system. It is theoretically possible to obtain up to an extra 3dB of diversity gain when using a pre detection weighting system.

It is assumed in all the analysis, that the received voltages are independent of noise due to the fact that the received signals have a large signal to noise ratio. This was determined by closely examining the level of the received signal relative to the level of the noise floor of the receiver system and assuming that the contributing noise of the system comes predominantly from the receiver chains.

During the off line processing some calibration of the receivers was undertaken and the effective differences between different receivers were extracted from the data, this include both phase and amplitude differences between the receiver chains. A through calibration of received voltage to expected received power was not however incorporated into the analysis as all the results in this paper are based on comparison between different signals and diversity techniques so absolute received power and consequently signal to noise ratios are not necessary. No account for free space loss has been taken into account therefore different locations should not be directly compared in terms of power levels, thus indications of power on graphs within this paper should only be taken comparatively and not as an absolute received power from the system.

Results

Figure 3 and Figure 4 show example cdfs for received diffracted and reflected signals from one particular building, however they are indicative of findings at other locations. In the case of both diffraction and reflection, it can be seen that the result for a CP receive antenna is considerably inferior to that of the MRC case. In these regions, it can be noted that a CP antenna would perform worse than a simple vertical polarised antenna by a couple of dBs, the reason for this is that the horizontal component of the signal is attenuated significantly more by the process of diffraction and reflection. Thus the signal is no longer circular polarised, in fact it is considerably elliptical in polarisation and there is a polarisation mismatch.

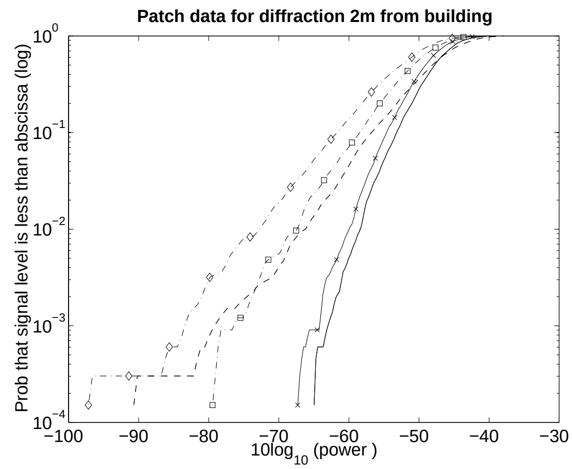
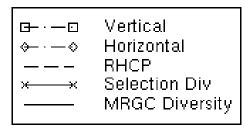


Figure 3: Example cdf in a region of diffraction



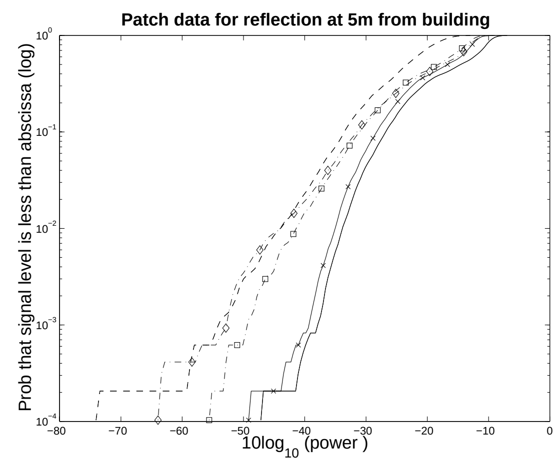


Figure 4: Example cdf in a region of reflected signals

It can be seen from both Figure 3 and Figure 4, that there is significant diversity gain available from using MRC at these specific locations and distances. A better understanding of the available diversity gain in these environments can be seen from the diversity gain versus distance from the building graphs in Figure 5 and Figure 6.

These graphs present the different forms of diversity and diversity gain relative to that obtained by an RCP receive antenna (referenced to 0dB on the graphs). In Figure 5 it can be seen that MRC does not produce diversity gain over an RCP antenna at all distances from the building. At around 14 metres a line of sight between the transmitting antenna and the receiving patch antenna was established. It is seen that diversity gain is obtained at distances less than 11m from the building. It is however within these regions of deep shadow that the signal is most attenuated by diffraction and that the diversity gain is beneficial in maintaining the link budget.

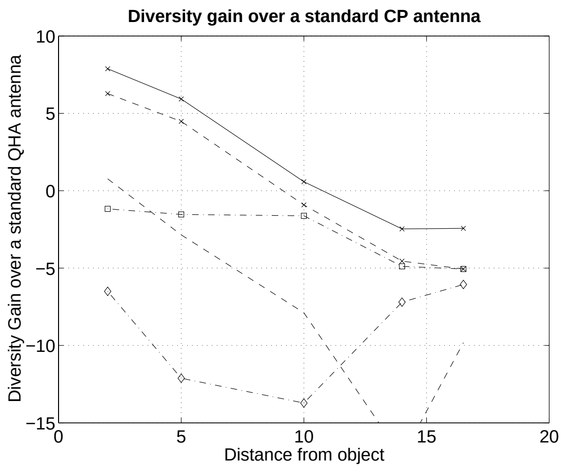


Figure 5: Diversity gain versus distance from a diffracting building

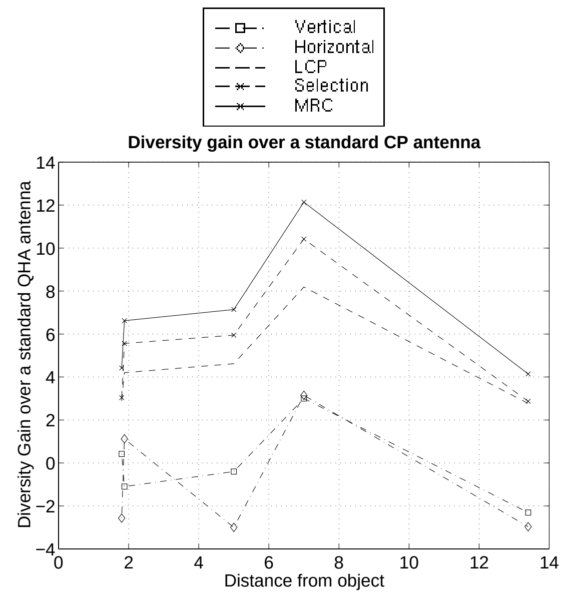


Figure 6: Diversity gain versus distance from a reflecting building

In the case of reflection (Figure 6) even the linear polarised signals have diversity gain over an RCP antenna for a small range of distances of the mobile receiver from the building. It can also be seen that the dominant circular polarisation is in fact LCP in this case, due to the sense of rotation of the wave being swapped upon reflection. This is related to the Brewster angle[3]. At low elevation angles of the satellite, the angle of incidence will be similar to that used this study. Figure 6 indicates that MRC will achieve diversity gain at all distances measured in this study when the signal is reflected by a building. MRC would still give significant diversity gain over an LCP antenna in this situation.

Discussion of Results

It is clear from the values of diversity gain obtained that the presence of a building in the path of low elevation satellite signals can have a serious impact on the polarisation state of the received signal. The fact that good diversity gain is obtained indicates that there is a significant amount of decorrelation between the horizontal and vertical components of the received signal in these situations.

The inferior performance of an MRC post detection weighting system in an area where the mobile is not in deep shadow or in open cases where there may well be in a line of sight link with the satellite is a disadvantage to this type of system. There may well be arguments that a 3dB degradation in a line of sight performance is a reasonable price to pay for diversity gain of around 10dB in regions of deep shadow such as urban areas. The answer to this may well be specific to each individual satellite communications provider based on the system and the link margin which is designed into it.

There is however another alternative which alleviates the problem of the MRC signal being inferior to that of a CP antenna in a line of sight situation. This solution is to use a pre detection weighting system. In this kind of system, the two signals are weighted at RF, combined and then fed into the receiver, thus there is only one receiver which is the dominant source of noise, thus the signal to noise ratio of the system is dependent on one source of noise not two. This has the effect of increasing the SNR of the MRC system by up to 3dB.

There are some side effects of this pre detection weighting system, namely that phase and amplitude weighting circuits need to be implemented at RF rather than a much lower IF. Optimising these weights at RF frequencies with only one receiver output is much more difficult and time consuming, and thus longer training periods are required to get the optimum SNR from the system. From a mobile terminal point of view, however there is the added advantage in terms of size and power consumption of having only one receiver.

CONCLUSIONS

The potential benefits of using a polarisation diversity technique based on maximum ratio gain combining has been presented. Benefits in areas of deep shadow or urban environments have been indicated in the region of up to 10dB of diversity gain. The possible disadvantages of a diversity system have also been highlighted in terms of performance degradation in line of sight environments and the added complexity of the mobile receiver in terms of size, weight and power consumption, all of which are very critical in design of mobile handsets nowadays.

Potential benefits of diversity without the system performance degradation and with hopefully less impact on the size, weight and battery life problem have also been alluded to. A trade off must be made between additional diversity gain available and the complexity and ease of realisation of an industrially viable product.

ACKNOWLEDGEMENTS

The authors acknowledge the support of Nokia Mobile Phones and Mobile VCE, a collaborative venture of more than 20 industrial companies and 7 UK Universities, with the financial support of the UK government.

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