Benefits of Circular Polarization for Mobile Services

A Summary of the Testing Dielectric Performed Over the Last Decade

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Abstract

The success of Mobile TV is dependent upon service reliability. Generally speaking, people accept poor cellular voice service and intermittency. Dropped calls are not a big deal since the information can be repeated on another hopefully successful attempt. Video is much different. Gaps in reception result in a lost experience and will not be acceptable to the viewer.

Testing History

Over the last decade, Dielectric has conducted extensive testing to quantify the benefits of transmitting circular polarization (CP) to a linearly polarized mobile handheld. In 2007, after investigating the fundamental limitations of a handheld, it was concluded that small handheld devices are limited to linear polarization with dipole like performance. This is mainly due to the fact that the small antennas within the device excite the long dimension of the circuit board. At the same time, in order to quantify the benefits of CP, margin improvement; (MI), was defined as the reduction in signal strength variability versus the receiver's location and orientation.

$$MI = (\mu - t) - \sigma \quad (1)$$

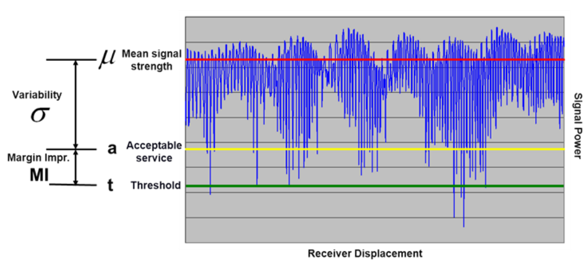

Figure 1: Defining margin improvement (MI).

Testing in a controlled anechoic chamber environment showed that transmitting UHF circular polarization to a linearly polarized receiver in motion provided on average 5dB of margin improvement over transmitting linear polarization to the same linearly polarized receiver. In 2008, testing again in the controlled environment showed that elliptical polarization with a 66% horizontal polarization / 33% vertical polarization power split provided the highest margin improvement in heavy fading depolarized environments compared to CP. Even though the 66%/33% split provided the highest MI, the actual MI vs. percent ellipticity curve has a gentle slope giving the optimum range of H/V splits from 80% / 20% up to 50% / 50% (full CP), all providing more than 4 dB of margin improvement. The reason why the optimum range of ellipticity is biased toward lower percentages of vertical polarization than horizontal polarization is because we live in a vertical world of obstructions. Buildings, trees, etc. all produce heavy scatter in the vertical plane and thus more variability in the received signal strength than the horizontally polarized component of the elliptically polarized signal. Also that year, it was discovered that adding a separate vertically polarized UHF antenna displaced vertically on the tower to an existing horizontally polarized UHF antenna provides on average 2dB of margin improvement over transmitting from the horizontally polarized antenna only. Critics were quick to point out that all of our work had been performed in a controlled anechoic chamber environment and not in the "real world". Taking the next logical step in 2009, field testing in many different indoor and outdoor locations confirmed the results showing that transmitting CP to a linearly polarized receiver in motion provided on average 5dB of MI over transmitting horizontal polarization and provided on average 7.5dB of MI over transmitting vertical polarization. In 2010, the same experiments were performed at VHF in order to understand if circularly polarized VHF transmission provided the same advantages for reliable mobile services as UHF. Field testing showed that transmitting VHF CP to a small linearly polarized handheld provided on average 3.5dB of MI over horizontal polarization. It should be noted that at

VHF, the handheld's antenna is electrically smaller than at UHF which provides less polarization discrimination and greater orientational immunity leading to less variability in received signal strength while the receiver is in motion. The disadvantage is that the electrically small antenna is very inefficient which means lower received signal strength. The comparison measurements between UHF and VHF found that on average VHF provided 2.5dB less variability than UHF but also was at a 19.4dB deficit in mean signal strength to the UHF. This large imbalance gives a net average gain of 16.9dB of MI for UHF over VHF CP transmission to a small linearly polarized receiver in motion. The findings correlate well with the Wheeler limit which defines the fundamental limitation of an electrically small antenna [1]. The max power factor is given by equation (2) where (a) is the antenna volume radius.

$$\rho_{max} = (ka)^3 \qquad (2)$$

$$k = \frac{2\pi}{\lambda}$$

Solving for the max power ratio difference between 210 MHz and 700 MHz dictates that the best VHF/UHF receive ratio for an electrically small antenna will be -15dB.

$$\frac{\rho_v}{\rho_u} = 10log\left[\frac{\left(\frac{2\pi}{\lambda_v}a\right)^3}{\left(\frac{2\pi}{\lambda_u}a\right)^3}\right] = 10log\left(\left(\frac{\lambda_u}{\lambda_v}\right)^3\right) \approx -15dB \quad (3)$$

BER Testing Confirms Benefits of CP

Even though the testing quantified the margin improvement when using circular polarization, there was still concern over the benefits since all the measurements to date were based on signal strength. Many believed that to truly prove the margin benefit gained by circular polarization for digital transmission, the measurements must be based on bit error rate (BER). In March of 2011, in a joint effort with the West Central Florida Group, the opportunity to conduct measurements based on BER became possible. BER is simply the number of bit errors divided by the total number of bits. The relationship between BER and signal to noise ratio (SNR) are inversely related by a waterfall curve; general examples of which can be found in most communication text books. Two BER measurements can be converted to an expected margin improvement as shown.

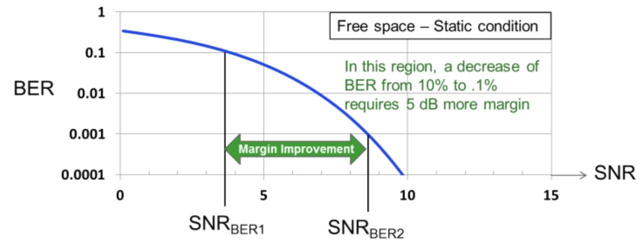

Figure 2: Typical curve for signal to noise ratio vs. bit error rate in a free space, static condition.

These general curves are typically published for free space and static conditions, neither of which is true for real life conditions. In order to be able to relate expected SNR based on BER measurements, the curve must be adjusted for multipath fading and the modulation scheme used within the communication channel. In mobile handheld situations, a fading channel is best represented by a Rayleigh distribution where there is typically no dominant line of site signal. The equipment used in the experiment was an ICOM LMR 450 MHz system which is based on non-coherent 4 level frequency shift keying (4FSK). It can be shown that in a Rayleigh fading environment when using non-coherent 4FSK, the probability of signal is given by:

$$\rho_s = \frac{2^{x-1}}{2^x - 1}\sum_{k=0}^{m-1}\frac{(-1)^{k+1}\binom{m-1}{k}}{1+k(1+SNR)} \quad (5)$$

Where m=4 for 4FSK and:

$$\binom{p}{n} = \frac{p!}{n!(p-n)!} \quad (6)$$

$$x = log_2(m) \quad (7)$$

The expected BER is then given by equation (8).

$$BER = 1 - \rho_s \quad (8)$$

Referring to Figure 3, the BER vs. SNR curve can now be adjusted for the experiment situation and used for determining margin improvement from measured average BER's. It should be noted that this adjustment demonstrates the need for higher SNR in "real life" conditions in order to reduce the BER.

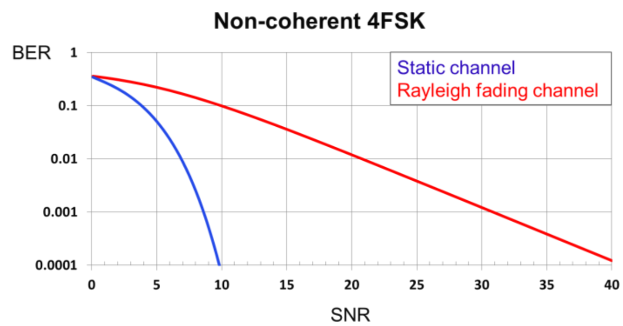

Figure 3: BER vs. SNR curve for a non-coherent 4FSK system in a Rayleigh fading channel.

A circularly polarized antenna was placed next to a vertically polarized antenna at the 800 ft. level on the ATC broadcast tower in Riverview, Florida as shown in Figure 4.

Figure 4: Circularly polarized slotted coaxial antenna placed just above a vertically polarized antenna at the 800' level on the ATC broadcast tower in Riverview FL.

A mobile unit simulating a linearly polarized mobile handheld was constructed as shown in Figure 5. A motorized dipole was used to measure in parallel mode as if the user was holding the handheld in the upright position and perpendicular mode as if the user was holding the handheld horizontal to the ground. While continuously measuring all orientations, the mobile unit was moved over a long run in location. At the base station, a logging program was used to continuously sample the BER and GPS location.

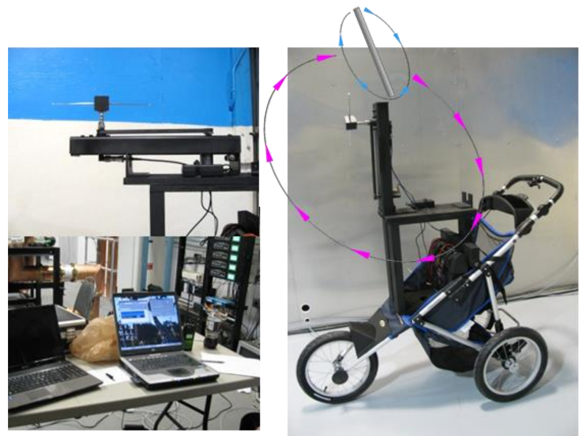

Figure 5: Mobile test unit.

In order to ensure a fair comparison, the circularly polarized antenna was designed to provide similar coverage and ERP on the main beam as the vertically polarized antenna. In doing so, the estimated field strengths per polarization are calculated to be equal from 3 mile out in free space. For this reason, all measurements were taken within 60 degrees of the main azimuthal beam and no closer than 4 miles to the tower. The data was collected in three different environments: outdoor, indoor and driving. Multiple experiments were conducted in each of the three environments including open areas, city, residential, mall, office complex, and inside and outside of a vehicle.

Figure 6: Mobile unit testing in different environments.

During each test run a large number of samples were recorded and the average BER for that run was calculated for both the circular polarization and linear polarization. The margin improvement is then determined by transposing the average BER's onto the BER vs. SNR curve as shown in Figure 7.

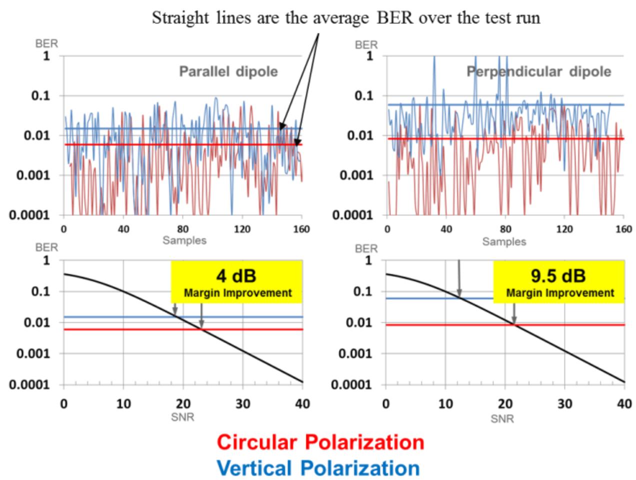

Figure 7: Sample of the test results.

The average margin improvement of circular polarization for all outdoor tests was 8dB in the parallel mode and 7.9dB in the perpendicular mode. It may appear strange that the average margin improvement of the perpendicular mode is not higher than the parallel mode since in the perpendicular mode the receive dipole is held horizontal to the ground and should be completely depolarized from the vertical signal. This is due to the fact that small scale fading has created as much vertical component in the horizontal plane as there is in the vertical plane. Multipath has completely depolarized the signals. If this is the case then logically: If the vertically polarized signals are so depolarized then the received signals should be independent of orientation and location. So why does transmitting circular polarization provide 8dB of margin improvement over transmitting linear polarization? That answer is because circular polarization is made up of two orthogonal polarizations time shifted by 90 degrees. The odds of both polarizations destructively interfering at the same time and same location is much less than a single polarization.

For the indoor cases, the average margin improvement of circular polarization was found to be 6.8dB in the parallel mode and 8.3dB in the perpendicular mode. Note that both the indoor and outdoor measurements produced similar results for both the parallel and perpendicular cases with an overall average margin improvement of 7.5dB. This is explained by understanding that circular polarization primarily helps mitigate the effects of small scale fading which is present both indoors and outdoors. Large scale fading, such as attenuation through structures, tends to only shift the mean signal strength. As the mean signal strength decreases, the BER increases but the margin improvement gap remains the same. This is due to the fact that the effect of Rayleigh fading has flattened out the SNR vs. BER curve in the region of usable operation. Form these measurements, it is shown that the benefits of circular polarization hold true both indoors and outdoors.

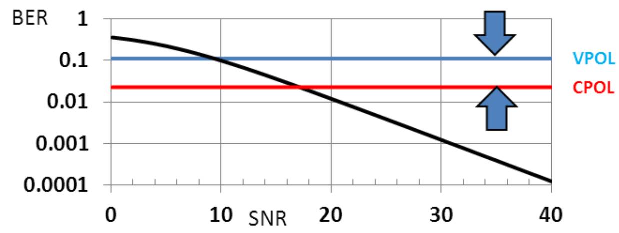

Figure 8: As the mean signal strength decreases, the BER increases, but the MI gap remains the same.

The next tests were performed both inside and outside of a moving vehicle during long drives of 25 to 60 miles. The results form an interesting conclusion. The first test was inside of a hatchback car as shown in Figure 9.

Figure 9: Mobile unit mounted inside a vehicle.

It was found that vertical polarization actually provided on average .5dB more margin improvement than circular polarization. The second test was conducted with a small monopole on top of the car. See Figure 10.

Figure 10: Small monopole mounted on to of vehicle.

The results with the small monopole showed that circular polarization was starting to provide a benefit with the margin improvement being 1.5dB over the vertical polarization. The third test was with a larger monopole farther above the top surface of the vehicle as shown in Figure 11.

Figure 11: Large monopole mounted on top of vehicle.

The margin improvement of this case was found to be 2.5dB. The results provide an interesting insight into why circular polarization does not provide any benefit inside a vehicle and only starts to provide benefit when raised off the surface of the top of the car. The explanation lies in a boundary condition commonly used to solve Maxwell's equations. It states, "The E-field tangent to a ground plane is zero".

$$\eta \; X \; E = 0 \quad (9)$$

Inside a vehicle, there is basically a ground plane above and below the linearly polarized antenna of a mobile handheld. Therefore most of the horizontally polarized signal is filtered out leaving only the vertically polarized component of the incoming circularly polarized signal. When the antenna is placed on top of the vehicle, there is only a ground plane below it. As the antenna is raised higher above the ground plane the circularly polarized signal begins to retain shape. This concept can be demonstrated using high frequency simulation modeling software by launching a circularly polarized wave at a low grazing angle onto a ground plane as shown in Figure 12.

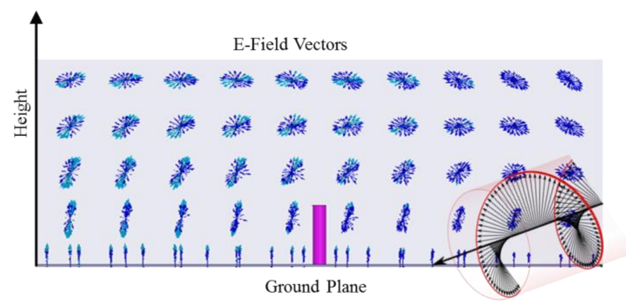

Figure 12: Using high frequency simulation software, the image demonstrates a circularly polarized wave at a low grazing angle onto a ground plane.

Note that only the vertical component exists near the ground plane, but a few wavelengths above the ground plane the circularly polarized signal is fully intact.

It must be mentioned here that this situation should not discourage the use of circular polarization for mobile applications. Who needs margin? It's not the individual inside a vehicle. They have the option to use larger, more efficient external antennas in conjunction with a high power amplifier. The users that need margin are the ones that are carrying small inefficient low power handheld devices and this is where circular polarization provides a significant advantage in reliable connectivity over liner polarization.

Summary

Margin equals reliability. All of Dielectric's testing over the last decade has confirmed that transmitting circular polarization to linearly polarized handheld devices can provide 5-7dB of necessary margin which will be imperative to the success of next generation mobile services.

References

[1] Harold A. Wheeler, "Fundamental Limitations of Small Antennas", Proceeding of the IRE (IEEE), vol 35, pp. 1479-1484, Dec. 1947.