Eliminating multipath fading improves wireless signal reception

George W. Webb, Igor Minin, and Oleg Minin

By controlling the beam phase of desired signals, destructive interference and multipath fading can be avoided.

Dropped mobile phone connections, missing wireless data packets, and lost radio reception at traffic lights are all examples of the problems that can result from multipath fading (MPF).1 This phenomenon can also produce ‘ghost’ images in analog television and impair the accuracy of Global Positioning System (GPS) receivers. Previous attempts to eliminate it have not been completely successful, so we developed a new technique2,3 that can drastically reduce MPF and improve signal power by a factor of more than 10^3.

MPF can occur when an antenna receives a transmitted signal that is the sum of the desired line-of-sight (LOS) signal plus one or more non-line-of-sight (NLOS) signals. (NLOS signals are caused by reflections off of structures and diffraction off of obstacles.) In the example in Figure 1(a), the receiving antenna is assumed to be directional while the transmitting one has no restrictions. If the LOS and NLOS signals are received with nearly equal amplitude and 180° out of phase, destructive interference occurs, which results in a loss of carrier power to the receiver feed: see Figure 1(b).

Traditionally, designers have used diversity techniques, such as space, polarization, frequency, spread-spectrum, time, and angle diversity, to combat MPF.4 In these schemes, signals arriving from independent paths are combined in order to reduce fading.

Our approach is based on the discovery of a free parameter in the design of Fresnel zone plate (FZP)5–9 and other antennas.10 Since the 19th century, zone plates have been designed with a specific value for a parameter that could be referred to as the reference radius5 or reference phase (θ_{ref}).6 When non-standard values are used, aspects of antenna performance improve and zone plate antennas gain new functionality.6,7 We have established (both experimentally, at 39GHz, and theoretically) that varying the θ_{ref} shifts the LOS beam phase with a linear slope through 360° (see Figure 2) with only slight changes in antenna gain.5,7 Importantly, the 20° off-axis phase of the NLOS signals does not change by an equivalent amount, or it can vary with negative slope at large NLOS angles. We exploited this difference in phase sensitivity to θ_{ref} in order to eliminate MPF.

Figure 3 shows the combined signal power of the LOS and NLOS signals at the receiver feed as a function of phase reference. Here P_{avg} is the average power over a carrier period.

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The variation of phase of the LOS signal ($\theta_{\text{LOS}}$) is $360^\circ$ for a $360^\circ$ variation of $\theta_{\text{ref}}$ both calculated and measured,\textsuperscript{6,7} while the phase of the NLOS signal is different.

Plotting the average power ($P_{\text{avg}}$) over a carrier period (solid line) and instantaneous total power ($P_{\text{inst}}$) at $t=0$ (dotted line) of the LOS and NLOS signals combined at the receiver feed vs. phase reference ($\theta_{\text{ref}}$) reveals power variation of more than 30dB.

$P_{\text{inst}}$ is the instantaneous power at $t=0$. In this example, the LOS signal impinging on the antenna is assumed to be attenuated by a factor of about twelve, producing a strong signal fade near $\theta_{\text{ref}} = 0^\circ$. (The power of the attenuated LOS signal alone is 0dB.)

Attenuation in LOS amplitude occurs when the signal is partially obscured or scattered. The net combined signal power at the receiver is less than -30dB for the standard value of $\theta_{\text{ref}} = 0^\circ$, demonstrating strong multipath fading. However, a static change of the phase reference increases the average power to $P_{\text{avg}} > 0$ dB for the broad range $30^\circ < \theta_{\text{ref}} < 330^\circ$, thus eliminating MPF.

Alternatively, $\theta_{\text{ref}}$ can be given a continuous dynamic variation, $\theta_{\text{ref}} = 2\pi t / T$, which is a linear ‘ramp’ phase modulation.\textsuperscript{3} This is equivalent, modulo $360^\circ$, to a sawtooth modulation of period T and angular frequency $\omega_0 = 2\pi / T$, and thus $\theta_{\text{ref}} = \omega_0 t$.

Calculated intermediate frequency (IF) signal time traces for (a) LOS signal at $0^\circ$, (b) NLOS signal at $20^\circ$, and (c) combined signals. The rms value of the combined multi-path signal is 0.068, which is greater than that of the LOS signal, so multipath fading was eliminated.
Modulating $\theta_{\text{ref}}$ at frequency $\omega_0$ produces a time variation of the FZP pattern at frequency $\omega_c$. Thus, the phase variation for the radiation through the antenna has two parts: one due to the high frequency of the carrier ($\omega_c$), and the second due to the time variation (which is effectively phase modulation of the carrier $\omega_0$ at frequency $\omega_c$). For simplicity, it is assumed that $\omega_0 << \omega_c$.

After the combined signal is demodulated with a local oscillator frequency of $\omega_c$ and filtered, the intermediate frequency (IF) is independent of the carrier. However, due to phase modulation, the IF is strongly time varying, as shown in Figure 4(c). For comparison, Figures 4(a) and (b) show the LOS and NLOS component signals. The rms value of the combined multi-path signal is 0.068, which is greater than that of the LOS signal alone. Thus, MPF is eliminated by modulating $\theta_{\text{ref}}$.

Our research shows that destructive interference and multipath fading can be eliminated by using a reference phase control to phase out LOS beam phase. Although we used a FZP antenna with alternating opaque zones, this technique applies to any type of focusing antenna that allows direct preferential control of LOS phase over NLOS directions. We are now investigating reference phase modulation, which causes the power in the NLOS signal (essentially an antenna sidelobe) to be spread over a wide frequency spectrum. (The main-beam LOS signal is not effected.) With narrow band or synchronous detection, these antenna sidelobes can be suppressed, which could be an advantage for many applications.

Author Information

George W. Webb
University of California San Diego
La Jolla, CA

George W. Webb holds a PhD in physics and is a research physicist VII at the Institute for Pure and Applied Physical Sciences, University of California at San Diego. Previously he was CEO at two high tech companies, and from 1969-1974 he was with the David Sarnoff Research Center (Princeton, NJ) where he received the RCA Outstanding Achievement Award. He is a member of SPIE and the American Physical Society.

Igor V. Minin
Novosibirsk State Technical University
Novosibirsk, Russia

Igor V. Minin has a PhD in physics and is a professor in the Department of Information Protection at Novosibirsk State Technical University, Russia. He is a member of SPIE and has written numerous papers for SPIE conferences.

Oleg Minin
Novosibirsk State Technical University
Novosibirsk, Russia

Oleg V. Minin holds a PhD in physics and is currently a professor at the department of information protection of Novosibirsk State Technical University, Russia. He is a Member of SPIE and has contributed to numerous SPIE conferences.

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