Combiner Space Diversity in Long Haul Microwave Radio Networks

Abstract

Long-haul and short-haul microwave radio systems deployed by telecommunication carriers must meet extremely high availability and performance targets. Long-haul microwave radios typically form the backbone of the operator's network carrying mission-critical data and services. In certain geographic locations, such as over water and in deserts, multipath propagation poses an impediment to long-haul radio performance in the form of intolerable link outages. To compensate, a protection scheme must be applied. *Space Diversity* is one such widely implemented protection scheme that improves the performance of long-distance microwave radio links. In long-haul microwave radio systems, *Combiner Space Diversity* provides significant advantages over common Space Diversity schemes. Its superiority is the subject of this paper.

Terrestrial Microwave Propagation

Point-to-point microwave radios are commonly deployed in telecommunication networks. High-capacity microwave links are a cost-effective and very practical alternative to other transport media such as fiber cable. They must be designed to meet very high performance objectives determined by international standardization bodies such as the International Telecommunication Union (ITU). Long-haul microwave links are commonly used in licensed frequency bands from 2 to 40 GHz with somewhat different characteristics and applicability at different bands. As microwave signals are transmitted through the atmosphere, they are subject to free-space loss, atmospheric loss (such as attenuation due to precipitation) and the multipath propagation effect. These phenomena affect the received signal level and quality.

Free-space loss creates fixed attenuation dependent on frequency band and path length.

$$\text{FSL [dB]} = 92.45 + 20\log(d*f)$$

where d is path length in km and f is the frequency band in GHz

The resulting receive level minus the threshold of the receiver equipment gives us the *fading margin*. This fading margin must be dimensioned by microwave link designers in consideration of such variable factors as atmospheric loss and multipath propagation. For atmospheric loss, signal attenuation occurs primarily due to precipitation (rain). During heavy rain, rain drops cause scattering and absorption of electromagnetic waves resulting in possible attenuation. The degree of attenuation varies with the size of the rain drops (rain intensity) and the microwave wavelengths (frequency).

At link frequencies above 10 GHz, the path length of the link is limited by fading due to the occurrence of precipitation, while at link frequencies below 10 GHz rain attenuation has a limited effect on the path length. For this reason, frequencies below 10 GHz are best suited for long-haul communication networks. However, even in these preferred long-haul frequencies, path length and link availability can be limited by another phenomenon—fading caused by multipath propagation.

The probability of fading due to multipath propagation is dependent upon geographic factors such as the locale, the terrain over which the radio waves propagate and the path inclination (angle). The path length itself also has an effect since the likelihood of multipath propagation increases as the path length increases.

In general, multipath propagation is more likely to occur in tropical areas, desert areas and in links over large bodies of water.

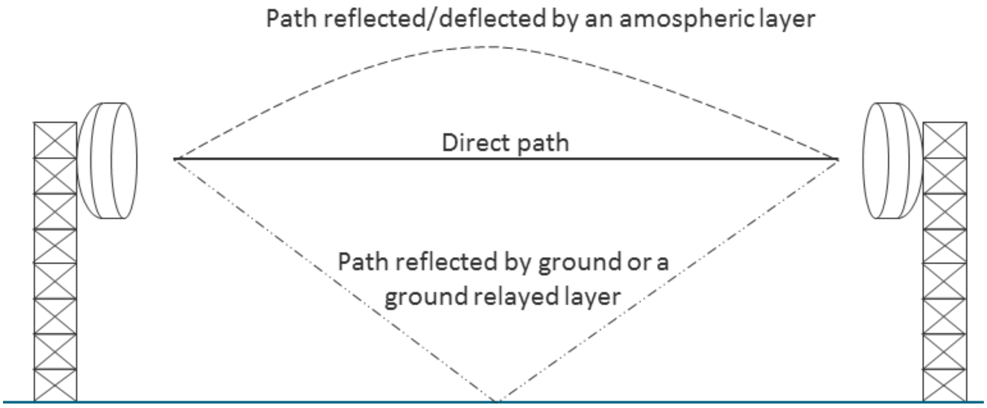

Figure 1 – Principle of multipath propagation

Multipath propagation occurs as a result of one or more waves that are sent out from the transmitting antenna being reflected or deflected back onto a path that leads to the receiving antenna. The reflected/deflected wave is received in addition to the direct path wave.

The received signal is the vector sum of all of these waves following their various paths to the receiver. As each of these paths has a different transmission length, the signal is summarized with different propagation delays (i.e., different phase), causing potential deformation or even cancellation of the received signal.

Figure 2 shows the transfer function of two waves combined with different delays caused by each traveling on a different path, together with the 28 MHz transmitted spectrum. At certain frequencies, the two waves may be combined with a phase difference of 180 degrees causing cancellation of the signal, while at other frequencies the waves may be combined in-phase resulting in an amplified receive signal. When one of the cancellation points falls within the transmitted signal spectrum, the receive signal will be deformed. This effect is called (selective) *fading*.

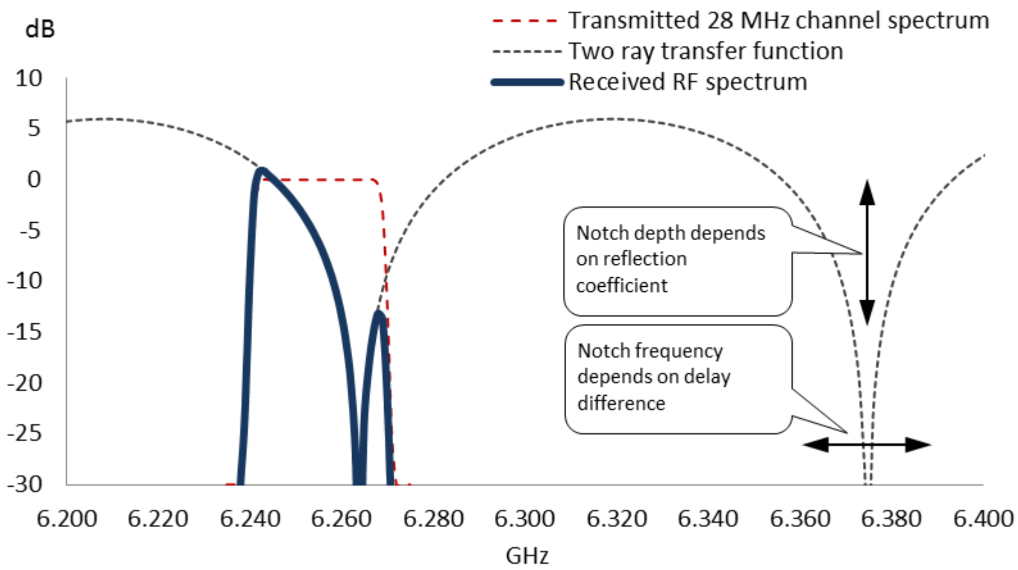

Figure 2 – Distortion of received signal in a two-ray propagation model

Counteracting Multipath Propagation Fading

As the multipath transmission is typically caused by fluctual layers in the atmosphere or at ground level, the delay difference between the direct path and the reflected/deflected paths vary over time. Also, the reflection coefficient (strength of the reflection/deflection) varies over time resulting in erratic fading behavior.

By putting a second receive antenna on the tower, with a vertical separation from the first antenna, we create a second set of delay combinations. This technique is called *Space Diversity*.

As described below, selective fading will occur at different frequency notches in the two received signals (one at each antenna) due to different delays, resulting in a significantly higher probability of receiving an undistorted signal.

Figure 3 – Space Diversity antenna arrangement

In today's microwave radio equipment, two receivers, one for each antenna, are used to receive the signals and select the better of the two. The selection mechanism can be based on a "switch" which selects the better of the two received signals (based on signal strength) or a more advanced technique where the two received signals are combined into one received signal. This more advanced technique is called *Combiner Space Diversity* and it offers a number of advantages.

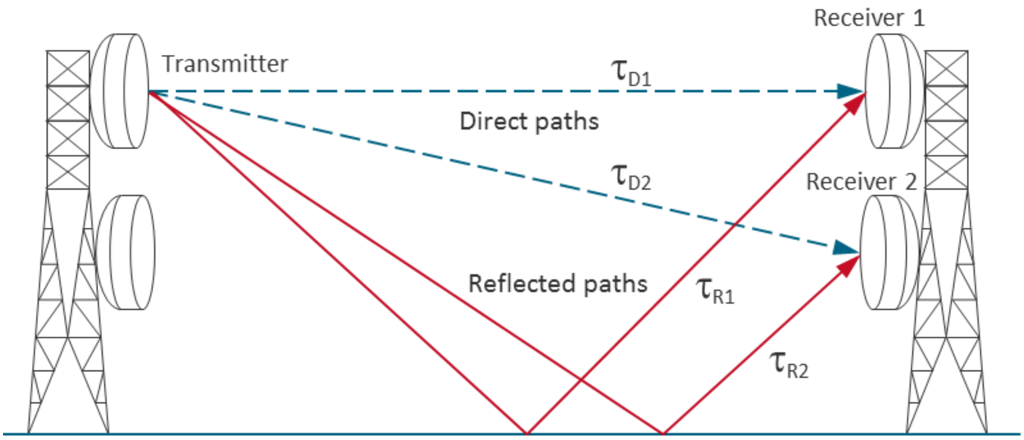

Figure 4 – Multipath space diversity arrangement (one direction shown)

In Figure 4, all four transmission paths have different transmission delays. The two receiver antennas will receive signals with different delays $(\tau_{D1} - \tau_{R1}) \neq (\tau_{D2} - \tau_{R2})$. As a result, if one of the two receivers should receive a signal with a frequency notch (distortion), it is very unlikely that the other will have a notch (distortion) at the same frequency. If we then combine the signals (RF spectra) received by the two antennas, in phase, the spectrum notch will be significantly reduced. If a spectrum notch (selective fade) appears on only one of the signals, the notch in the combined signal will be significantly reduced at this point.

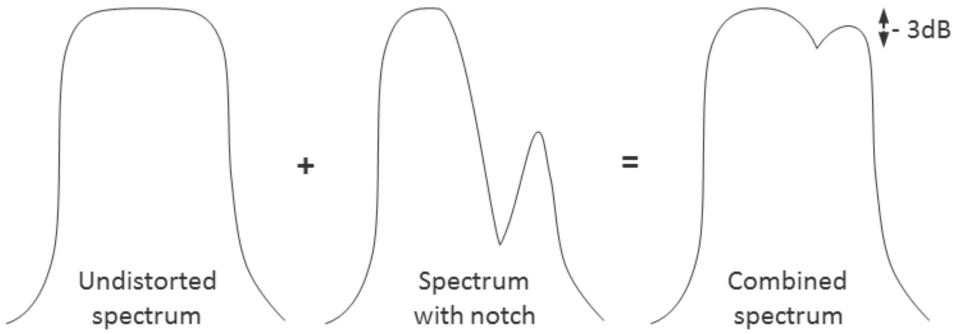

Figure 5 – Combining RF spectrums showing reduced notch of the combined spectrum

An additional advantage of combining the two received signals in phase is an improvement in the flat-fade receiver threshold. The combination of two correlated signals when the thermal noise in the two receivers is non-correlated results in a 3dB lower BER receiver threshold when flat fading occurs simultaneously in both antennas.

In simpler space diversity techniques, a “switch” is used in the receive chain to merely select the better of the two received signals. While this simpler space diversity technique provides some benefit, it does not enjoy the advantages of combining the received RF spectrums nor improvements in receiver threshold as described above. Although propagation models and most common propagation planning software packages do not distinguish between the two techniques, it is clear that Combiner Space Diversity is more effective and provides better results than the simpler switch/selection technique.

Another disadvantage of simpler space diversity techniques is that a multi-channel long-haul radio system will need to be implemented in n+n (like 4+4) configuration to provide the necessary receiver redundancy making it much more costly to implement than the same long-haul radio system using Combiner Space Diversity.

Space Diversity Combiner Technology Implementation

In order to enjoy the benefit of combined received spectrum, the two signals must be combined perfectly (and dynamically) in-phase with each other. To achieve this, the receiving equipment must first align the two signals in time by inserting a fixed delay that compensates for differences in waveguide length and other fixed delays.

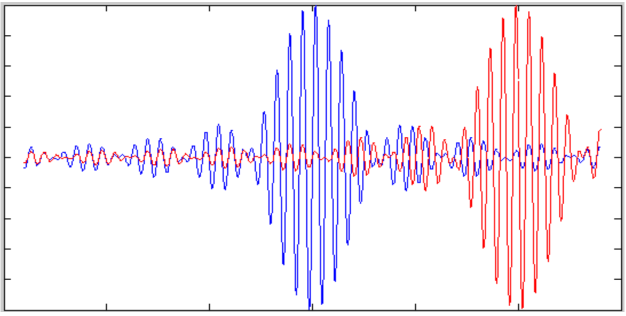

Figure 6 – The two received signals before delay compensation

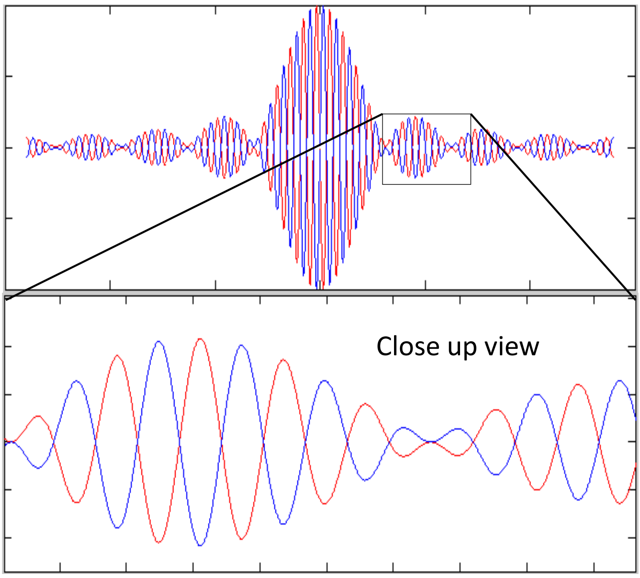

Figure 7 – The two received signals after delay compensation
(Amplitude variation shows the modulation symbols)

In order to dynamically combine the two received signals in phase, a ±180 degree, controllable phase-shift is introduced into one of the two signals before the combination takes place. Spectrum monitoring circuits and control logic manipulate the phase-shift ensuring that the two waves are in-phase before they are combined in the summary signal. They can select among different algorithms (such as maximum power, minimum dispersion, etc.) for the best combined result given the condition of the two received waves.

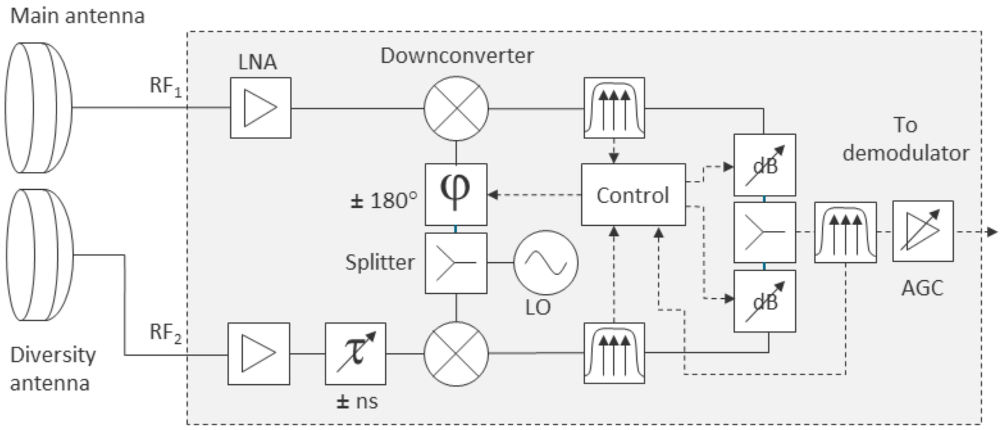

Figure 8 – Principle block diagram of an IF combiner space diversity receiver

The theoretical improvement factor in the performance of a space diversity technique is described in several ITU-R reports and recommendations, as well as in text books on microwave path engineering. From several practical field tests and longtime monitoring of operational links, we have found that the expected significant improvement factors have been verified and the experience is applied in the microwave path engineering conducted by our professional long-haul microwave design engineers. The improvement factor depends on several factors such as fade margin, path length and selective fade probability, and can typically range from a factor of 10 to a factor of 1000.

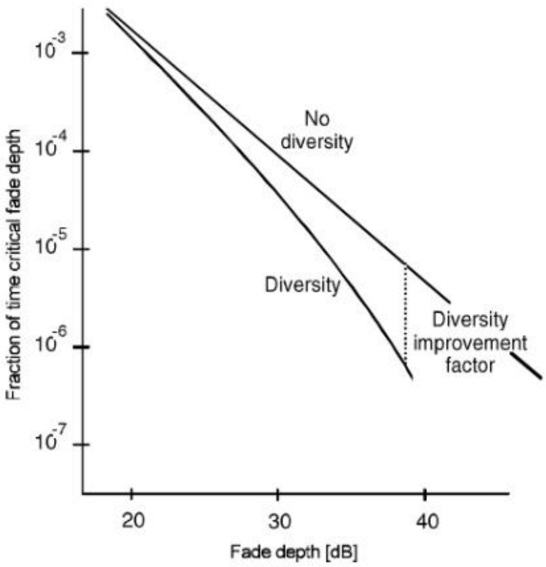

Figure 9 – Space Diversity improvement vs. fade depth

Summary

Combiner Space Diversity is not a new technology. It has been deployed and measured in many generations of high-capacity microwave radio systems. It is one of the unique factors that separate a long-haul microwave radio system designed for challenging and difficult propagation conditions from other alternatives designed for access applications, but then applied in long-haul networks.

In general we can observe that, as demand for higher capacity drives up the modulation used in the microwave links resulting in reduced fade margins, the use of Combiner Space Diversity becomes an increasingly crucial factor in meeting the performance targets of the carrier network.

Combined with other technological innovations such as Multicarrier Adaptive Bandwidth Control (MC-ABC), 1024QAM adaptive modulation and a high-power radio for outdoor installation, the modern long-haul radio today forms an ultra-high capacity transmission system suitable to the transmission needs of telecom operators operating in challenging environments where fiber cable is not viable or as a backup solution to fiber cable.

Ceragon has more than 65 years of experience with microwave radio communications and our innovative Evolution Long Haul radio systems are recognized in the industry as the leading microwave solution for long-haul communications.