CERAGON

WHITE PAPER

ADVANCED SPACE DIVERSITY

Improved system gain, longer reach & higher capacity

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INTRODUCTION

The ever-growing demand for capacity is often accompanied by the ever-growing need for increased availability. To meet capacity and availability requirements, network operators such as mobile carriers, ISP utility companies and public safety agencies, strive to modernize their networks including their wireless-backhaul infrastructure.

This increased capacity also leads to the transition to high modulations such as 2048 QAM and 4096 QAM, and higher channel spacing such as 56/60MHz and 80/112MHz, which are more sensitive to selective and flat fading. In addition to these demands, tower space and real-estate resources have become more expensive, particularly in urban aggregation sites.

Space diversity is an essential tool for achieving availability goals on wireless backhaul links. The current trend of using higher modulations and wider channels creates a need for advanced space diversity techniques. In a classic space diversity application, this requires deploying four antennas per link which means additional expenses and tower space for network operators.

Ceragon's unique Advanced Space Diversity (ASD) offers a wide range of solutions for these challenges and helps reduce the number of radios and antennas by 25%.

Beam-Forming Space Diversity (BFSD) is an alternative to ASD. It uses a four-radio and antenna constellation to provide an extra system gain of 9dB, an extra diversity effect and improved resiliency for ducting effects. This is achieved while maintaining the same performance and availability figures as in a classic space diversity configuration. This paper includes information about the implementation and performance figures related to this technology.

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AVAILABILITY & RESILIENCY EVERYWHERE

The evolution of mobile networks towards 5G has resulted in more and more services used to communicate over these networks. The huge promise of 5G technology includes applications such as IoT, Tactile Internet, M2M and IIoT. However, unlike current mobile applications, they require high availability and resiliency throughout the network. This makes mobile infrastructures similar in terms of availability demands to other mission-critical networks such as public-safety and utilities infrastructures.

Mobile network operators strive to modernize their network infrastructure to accommodate the new availability demands and use several techniques and mechanisms to improve their network availability and reliability.

Space diversity is one of the most common methods for improved availability at hard-to-reach, remote sites.

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TERRESTRIAL MICROWAVE PROPAGATION

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.

FSL [dB] = 92.45 + 20log(d*f)
where d is path length in km and f is the frequency band in GHz

The subtracting of the receiver threshold from the receive level results in the fading margin. This must be dimensioned by microwave link designers while considering factors such as atmospheric loss and multi-path propagation.

During atmospheric loss signal attenuation occurs primarily due to precipitation (rain). The degree of attenuation varies according to the size of the rain drops (rain intensity) and the link's wavelengths (frequency).

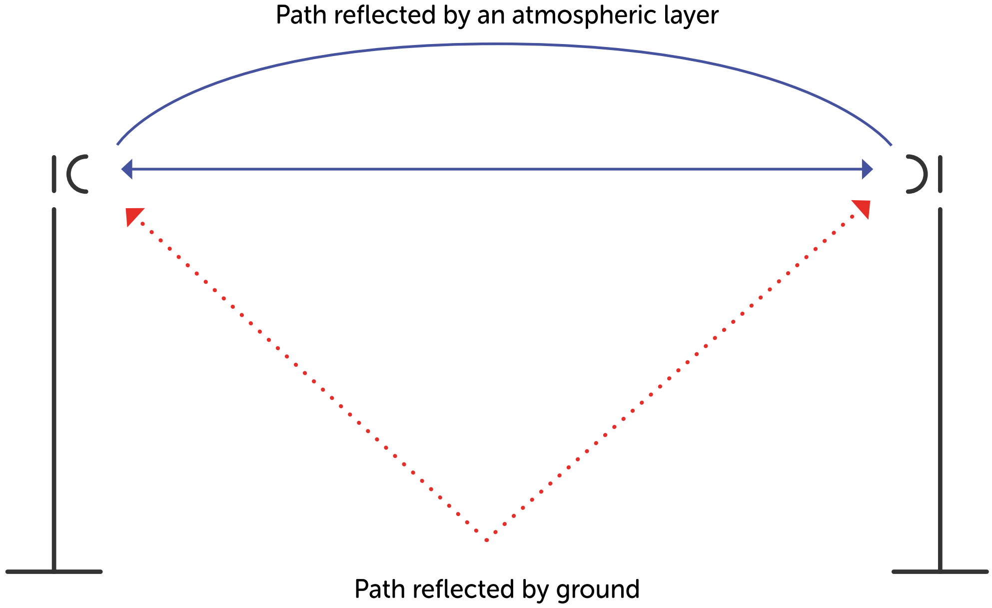
Rain attenuation has a limited effect on a path's length at link frequencies below 10 GHz. For this reason, such frequencies are best suited for long-haul communication networks. However, even in these preferred long-haul frequencies, path length and link availability can be limited by another phenomenon – fading caused by multipath propagation.

The probability of fading due to multipath propagation depends on geographic factors such as the location, the terrain over which the radio waves propagate, and the path's inclination (angle). In addition, the likelihood of multipath propagation increases as the path's length increases.

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

FIGURE 1

Multipath propagation



Multipath propagation is the result of a signal reflection by a surface or atmospheric layer in parallel to the direct signal path towards the receiver.

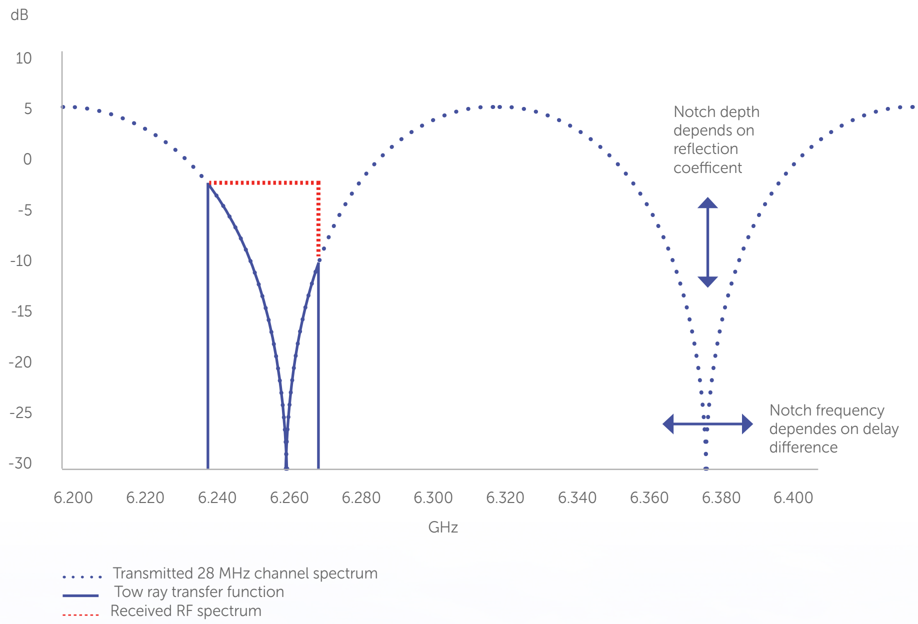
The received signal is the vector sum of these waves following their various paths to the receiver. Since each path has a different transmission length, the signal is summarized with different propagation delays (i.e., different phase), causing potential deformation or even cancellation of the received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

Figure 2 illustrates 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 specific frequencies the two waves may be combined with a phase difference of 180 degrees causing cancellation of the signal. In other frequencies the waves may be combined in-phase resulting in an amplified receive signal. When a cancellation point falls within the transmitted signal spectrum, the received signal will be deformed. This effect is called Selective Fading.

Selective Fading occurs in one or more dimensions and may appear in a specific frequency, at a specific time and/or at a specific location. Therefore, to generate diversity and overcome the fading effect, different types of diversity such as time, frequency and space need to be generated.

FIGURE 2

Distortion of received signal in a two-way propagation model



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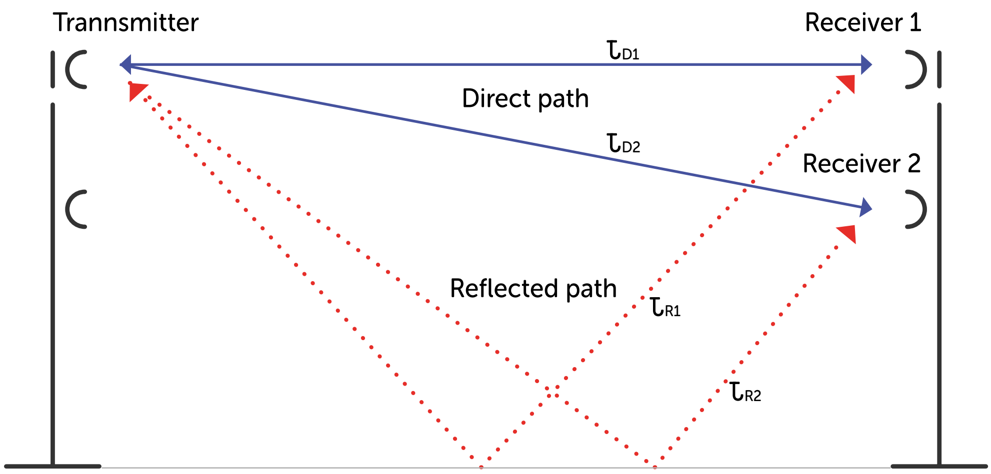
SPACE DIVERSITY

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

Installing a second receive antenna on the tower with a vertical separation relative to the first antenna creates a second set of delay combinations that is uncorrelated to the first antenna. This means that when one antenna receives a selective faded signal, the other receives a regular one. This method is called Space Diversity.

FIGURE 3

Space Diversity



THERE ARE SEVERAL METHODS FOR DEPLOYING SPACE DIVERSITY:

BASE BAND SWITCHING (BBS)

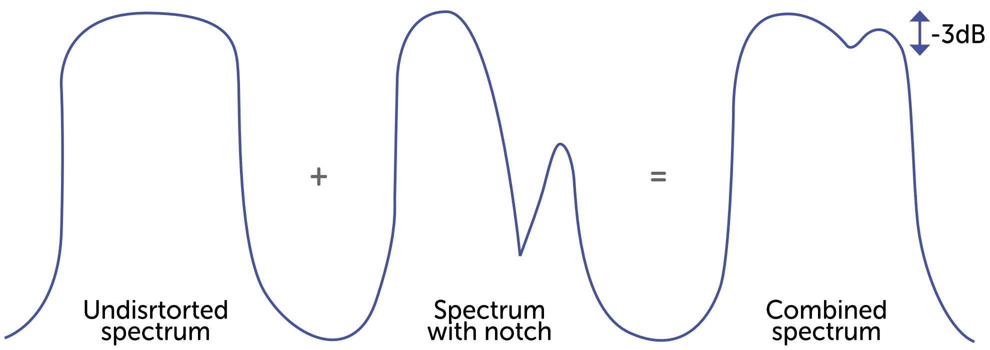
in this method a separate receiver is connected to its own main and diversity antennas at each site. The system monitors the quality of the received signal in each antenna and uses this information when selecting each point in time in the bit-stream from the best active receiver. This method does not provide an additional system gain since it utilizes a single signal path at any given time, which means less resistance to flat fading events.

IF COMBINING

in this traditional method, a smart analog signal combination is used to construct a single signal from the main and diversity signals received from both antennas. If a spectrum notch (selective fade) appears on only one signal, then the notch in the combined signals is significantly reduced at this point. Figure 4 depicts a possible combination and output.

FIGURE 4

Combining RF Spectrum – Reduced Notch



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ADVANCED SPACE DIVERSITY (ASD)

Space Diversity has its limitation, with the main one being the requirement for additional equipment, including antennas and radios at each site of the link. This increases the link's CAPEX and also significantly complicate site-acquisition and installation processes.

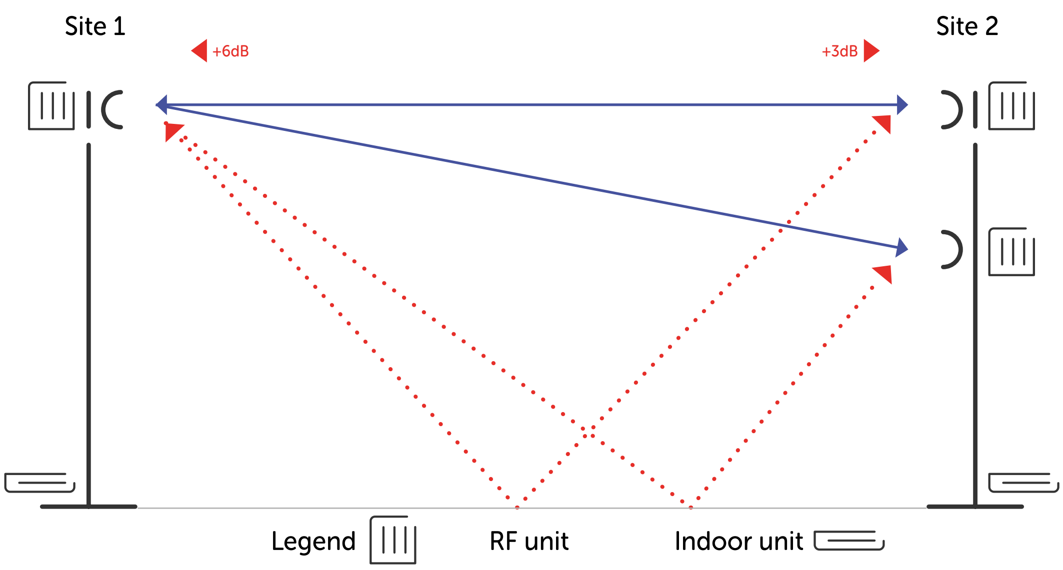
One of the main constraints encountered during a network densification process is the lack of tower space at aggregation sites. In these situations, operators are forced to implement space diversity only in one direction of the link (asymmetrical space diversity). This compromises the availability targets of a network and provided services.

Advanced Space Diversity (ASD) solves these issues as it enables operators to implement space diversity with only three radios and antennas. In this manner, they can select a site where only one antenna is required to overcome the lack of tower space in aggregation sites, which in turn saves CAPEX and reduces installation time and costs.

The implementation of ASD combines standard space diversity in one direction and a phase- synchronize beam forming mechanism in the other direction, as shown in Figure 5.

FIGURE 5

Advanced Space Diversity (Option 1)



As shown in the diagram, Site 1 has one radio and one antenna, and Site 2 has either two radios or one multicore radio and two antennas.

The data path from Site 1 to Site 2 is similar to that of a standard space diversity configuration. Signal transmitted from Site 1 is received by the main and diversity radios in Site 2 (Rx diversity). The signals are Base Band and are combined to overcome any fading conditions. Using Base Band Combining (BBC) rather than Base Band Switching adds 3dB to the system's gain since the signal practically doubles its level as it is received phase-synchronized by two radios.

Formulating this non-coherent combination is comprehensive. Assuming the received power of the two antennas is P1 and P2 and since the signal is identical, $P_1 = P_2$. This indicates a receive power of P1+P2 = 2xP1, which is a 3dB gain.

The data path from Site 2 involves the same signals transmitted from both the main and the diversity radios (Tx diversity), utilizing beam forming technology to achieve optimal reception on Site 1. In this direction there are two radio transmitters and two antennas which quadruple the signal's strength, leading to a 6dB gain and resilience to selective fading.

Formulating the gain of this direction involves a coherent-combination. Since $P \propto V^2$ and the two signals are combined over the air, the combined signals power is $V_1^2+V_2^2+2V_1V_2\cos(\Phi1-\Phi2)$, where $\Phi1- \Phi2$ is the difference in phases between the two signals. In this case V1 = V2.

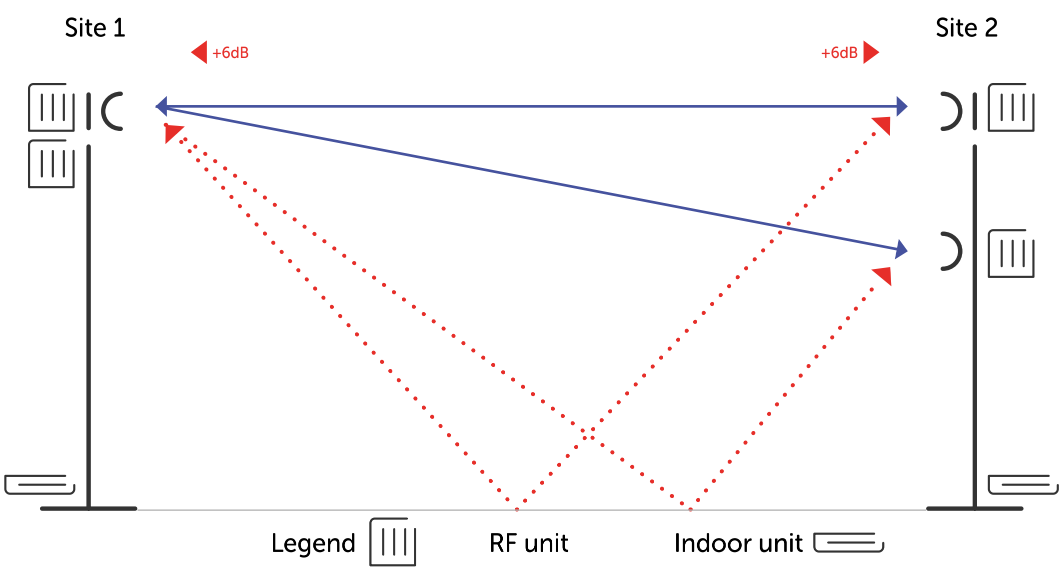
Thanks to the beam-forming mechanism the signals are phase-synchronized and $\Phi1$-$\Phi2$. The received power is $V_1^2+V_1^2+2V_1V_1\cos(0) = 4V_1^2$ and four times the power means an additional system gain of 6dB.

While ASD offers significant savings in CAPEX by reducing the number of radios and antennas by 25%, this technology also allows operators to reduce antenna size, extend a link's reach and increase availability.

To better leverage the benefits of additional system gain, an extra radio can be used in Site 1, as illustrated in Figure 6.

FIGURE 6

Advanced Space Diversity (Option 2)



In Option 2, the architecture remains the same but an additional RF unit is added in Site 1, which doubles the power of the transmitted signal. This results in an additional 3dB gain in the direction from Site 1 to Site 2 and a total gain of 6dB in both directions, offering an even greater reduction in antenna size. Considering the cost of larger antennas and their related transportation and installation costs, the use of smaller antennas is a more cost-effective solution.

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ASD TRIAL IN SOUTH KOREA

The ASD technology was tested in South Korea. Figure 7 depicts the simulated configuration (Option 1) that was set up between two islands to create the complex environment of an over-water link:

LINK DISTANCE:
28.8 km (17.9 miles)

TESTED CONFIGURATION:
2+0, XPIC

CHANNELS USED:
6.74 GHz and 7.08 GHz

CHANNELS BANDWIDTH:
28 MHz

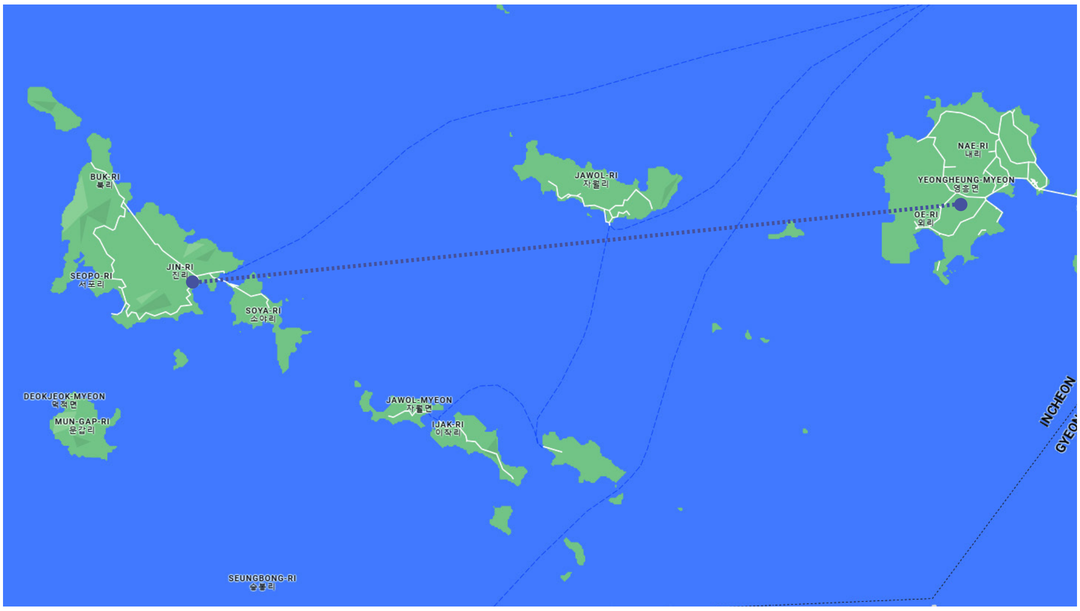
Tx POWER:
23 dBm

RSL:
-38 dBm and -40 dBm

ANTENNA SEPARATION ON BOTH ENDS OF THE LINK:
21 m (69 ft)

FIGURE 7

Test Location (Yellow Sea, South Korea)



The antenna separation on the DJD island site was 21 m (69 ft), implementing Tx diversity, while the YHD island site featured a single antenna, implementing BBC RX diversity.

The RSL level measured over the test period proved the system's theoretical gain advantage. An additional 6dB gain was measured in the Tx diversity direction versus an additional 3dB gain in the Rx diversity direction, as depicted in Figure 8.

FIGURE 8

Tx Diversity Receiver RSL

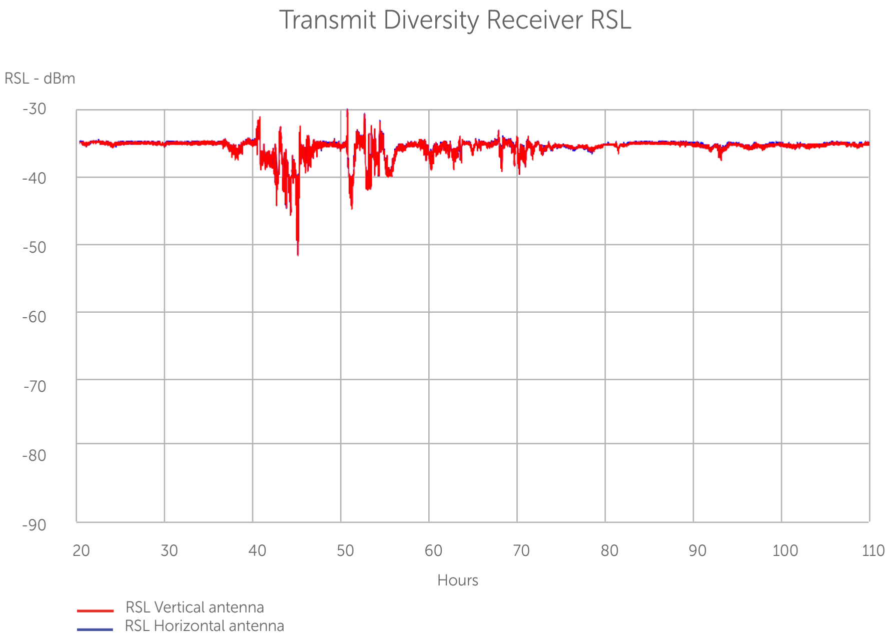
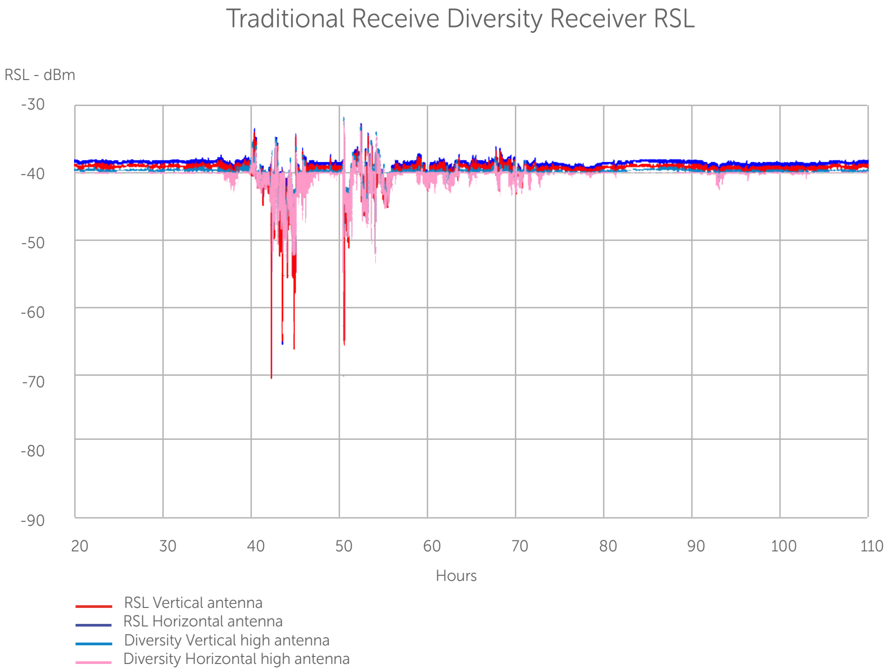


FIGURE 9

Rx Diversity Receiver RSL



Moreover, the Tx diversity mechanism proved to be resilient to selective fading, showing low RSL variance in selective fading events. An additional example of the effectiveness of this mechanism is the number of errors received in each direction.

FIGURE 10

Tx Diversity Receiver Errors

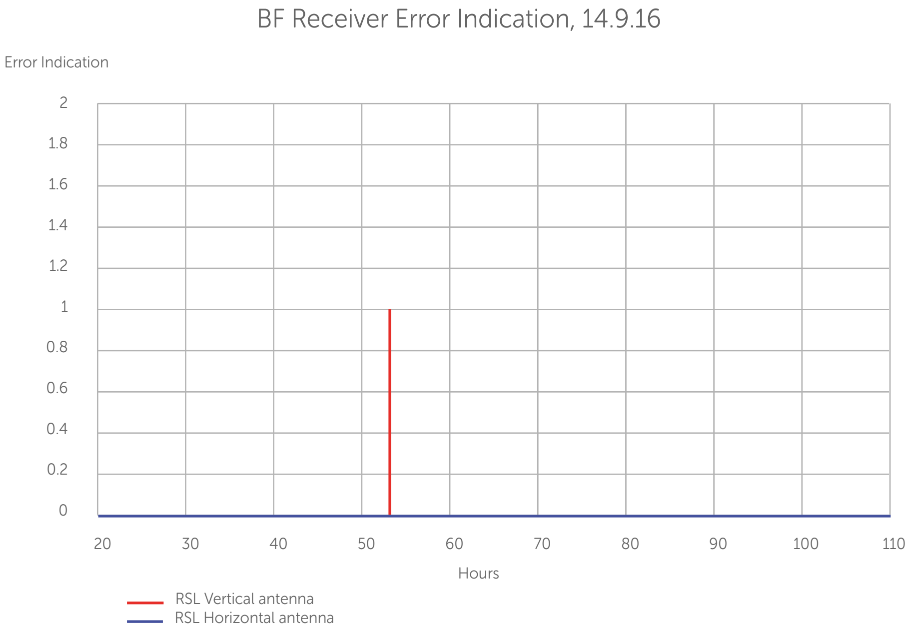
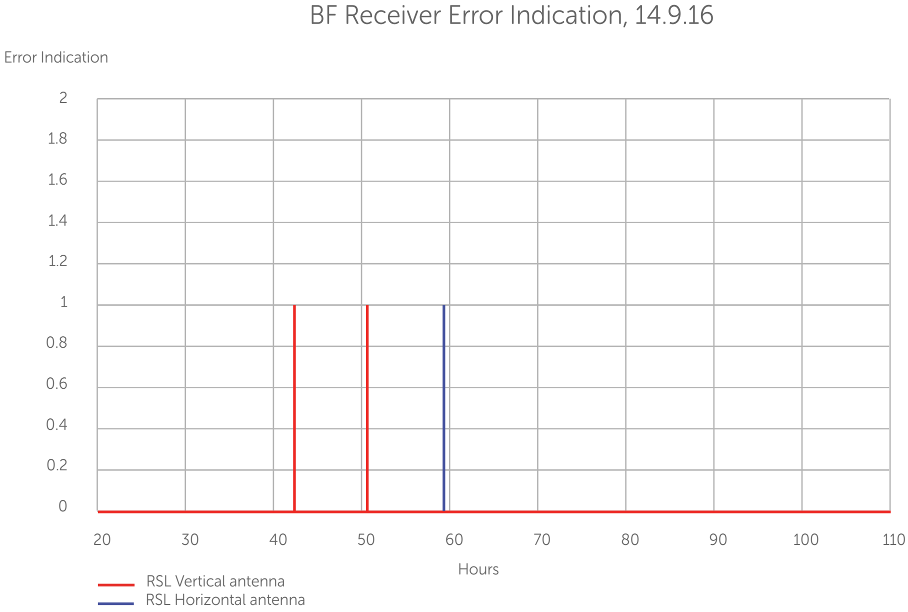


FIGURE 11

Rx Diversity
Receiver Errors



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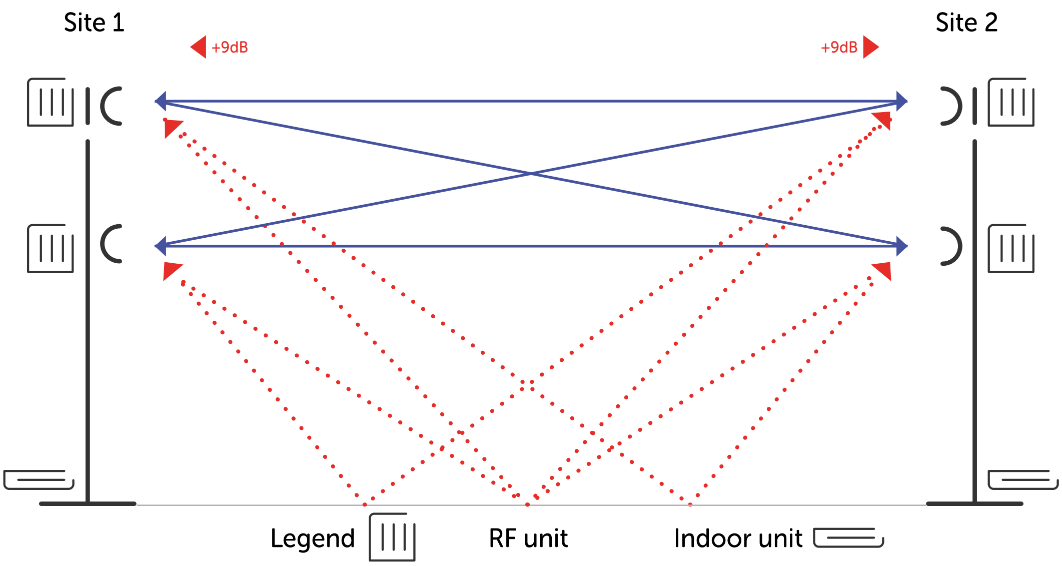
BEAM-FORMING SPACE DIVERSITY (BFSD)

Savings in antenna size are sometimes more significant than savings in the number of antennas and radios deployed. In these situations a four-antenna configuration can be built by combining 6dB and 3dB gains in both directions, as illustrated in Figure 12.

FIGURE 12

Beam-Forming Space Diversity (ASD Option 3)



In this configuration, the increase in system gain enables massive reduction in antenna sizes. Beam-Forming Space Diversity (BFSD) provides a 9dB gain and offers customers many benefits, including:

- Upgrading installed base links to a higher modulation and channel spacing.
- Reducing the size of all four antennas in a link by at least one size.
- Increased availability due to the flat fading effect.
- Increased space diversity effects due to Rx diversity between the two antennas being above the Tx diversity generated by the remote Tx antennas. This also increases availability through selective fading, simplifies link design and minimizes risk of a dominant reflecting surface, especially in over-water links, as shown in Figure 13.

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REFLECTION EFFECT OPTIMIZATION

The four transmitting and receiving radios and antennas allow both manual and automatic post installation reflection effect optimization. Reflection coefficients change according to weather, temperature, tide, and other parameters. Transmit diversity (two transmitters and one receiver) or receive diversity (two receivers and one transmitter) may generate notches in main and diverse links when phases between main and reflection paths differ from 1800 in both links. See Figures 8 and 9.

FIGURE 13

Tx Diversity Paths

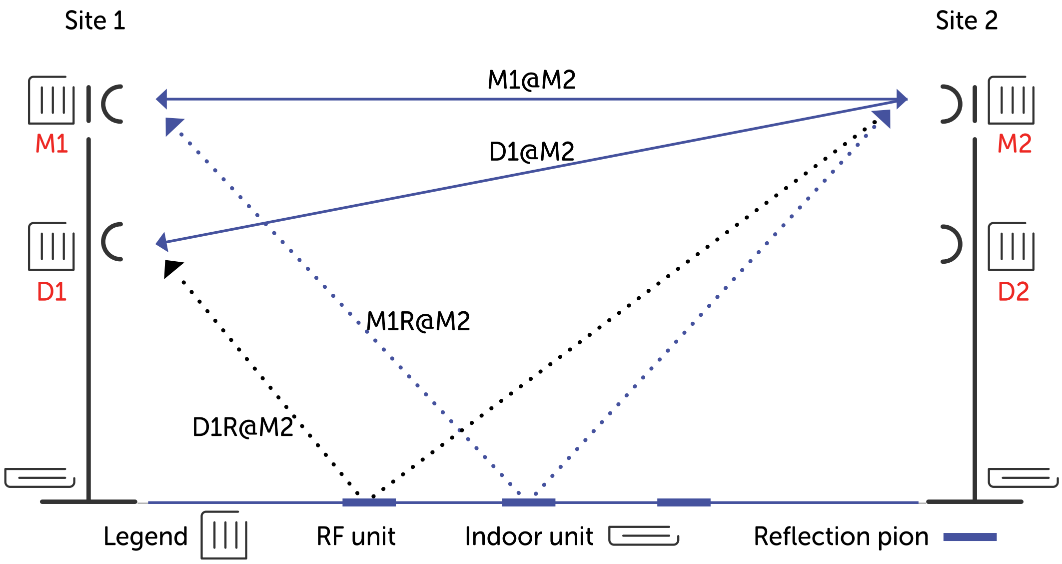
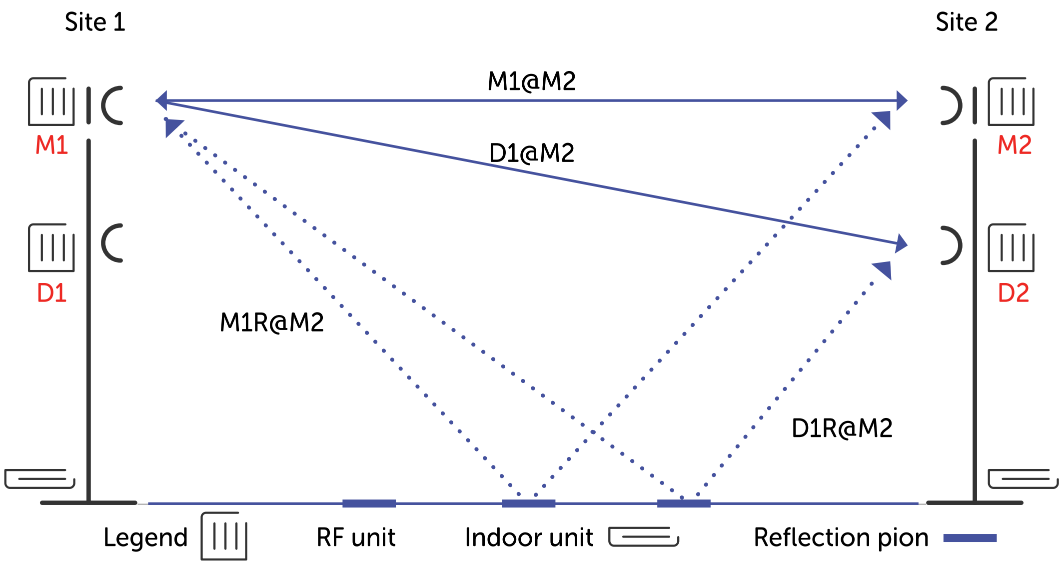


FIGURE 14

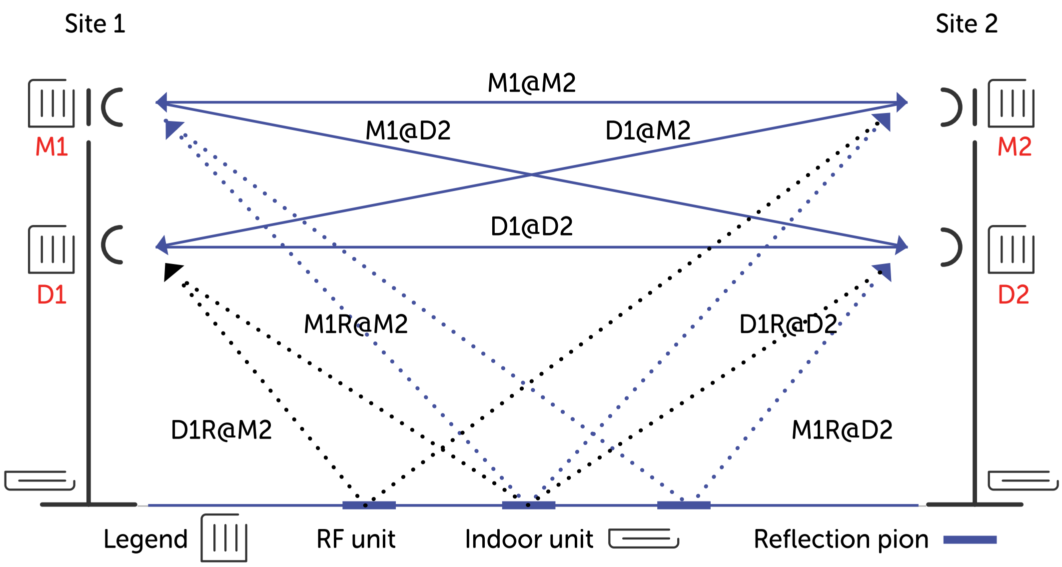
Rx Diversity Paths



With BFSD, twice the number of paths is used (two transmitters and two receivers) and as a result, the chance of notch in all paths is significantly reduced.

FIGURE 15

BFSD Paths



Another way to further reduce the chance of fading is to change the antenna separation on one of the link's ends. In this way the paths in both directions become asymmetrical which improves the overall diversity effect and flexibility.

FIGURE 16

Rx Diversity Paths

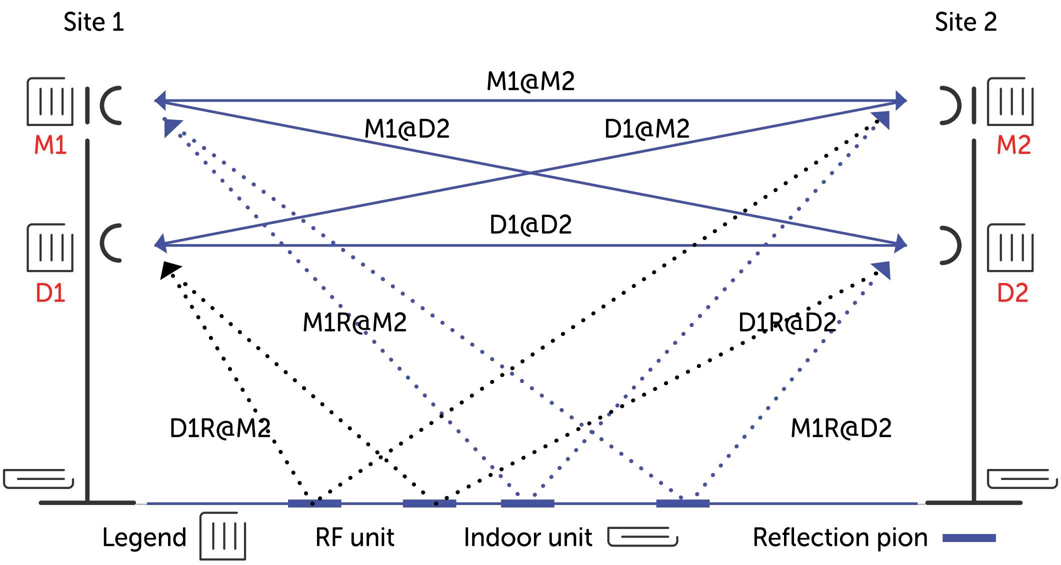
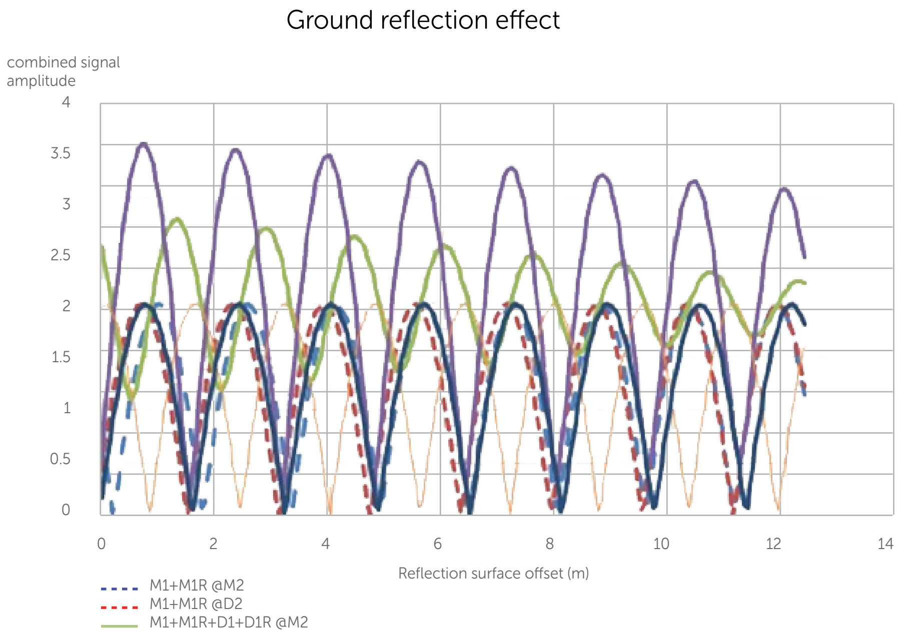


Figure 17 depicts the outcome of a BFSD test case reflecting the above diversity scenarios.

FIGURE 17

Reflection Effect



It is easy to see that while TX diversity or RX diversity implementation have severe notches in several reflection surfaces offsets, the BFSD architecture provides significantly higher resiliency to this effect.

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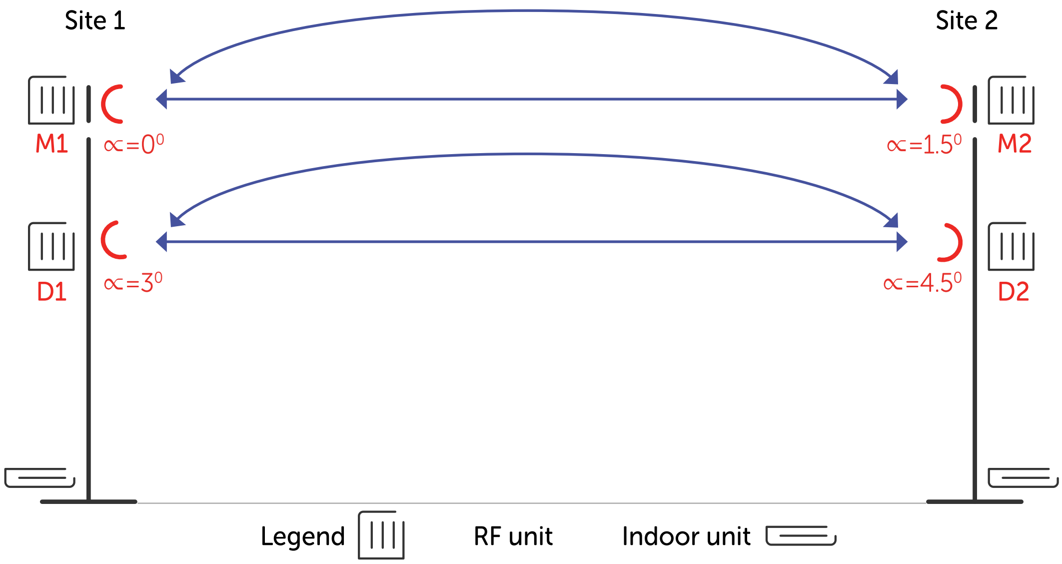
ANGLE DIVERSITY

Another phenomenon that affects the link performance is the ducting effect which is the outcome of changes in the density of different atmospheric layers and can result in a signal angular offset. BFSD architecture uses angle diversity to effectively mitigate the ducting effect. Figure 18 illustrates a BFSD configuration with angle diversity.

FIGURE 18

Angle Diversity



In a 6ft antenna an offset with an incremental 1.5 degree per antenna can overcome an offset of 4.5 degree in antenna alignment due to ducting.

In this case the system's gain will be reduced by up to 7dB compared to a reduction of 30dB in a SISO implementation, as illustrated in the following figure.

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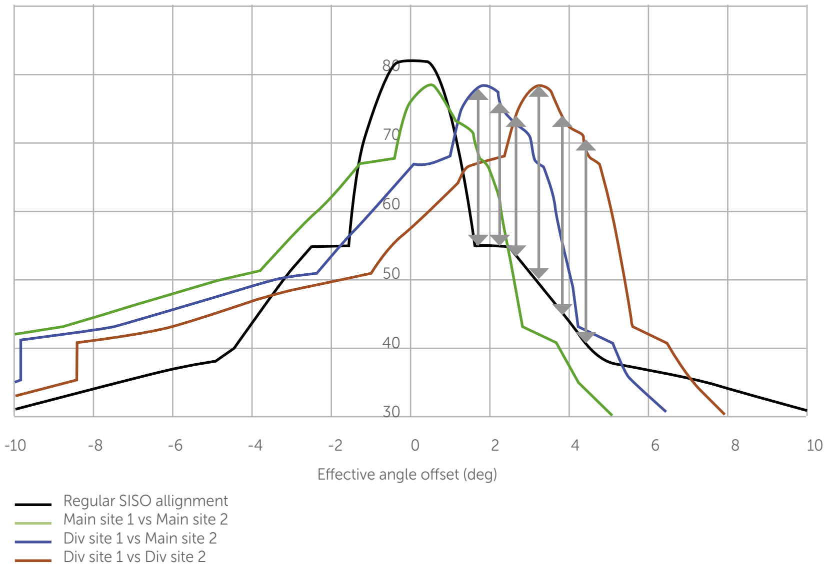
FIGURE 19

Angle Diversity

Link antenna system gain vs angle offset due to ducting effective erth radius effect



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ADVANCED BASEBAND COMBINING (ABBC)

The Advanced Baseband Combining (ABBC) method supports high correlation selective-fading on both antennas, lower non-optimal separation between antennas in tower-space constraints and simultaneous handling of two notches on both antennas.

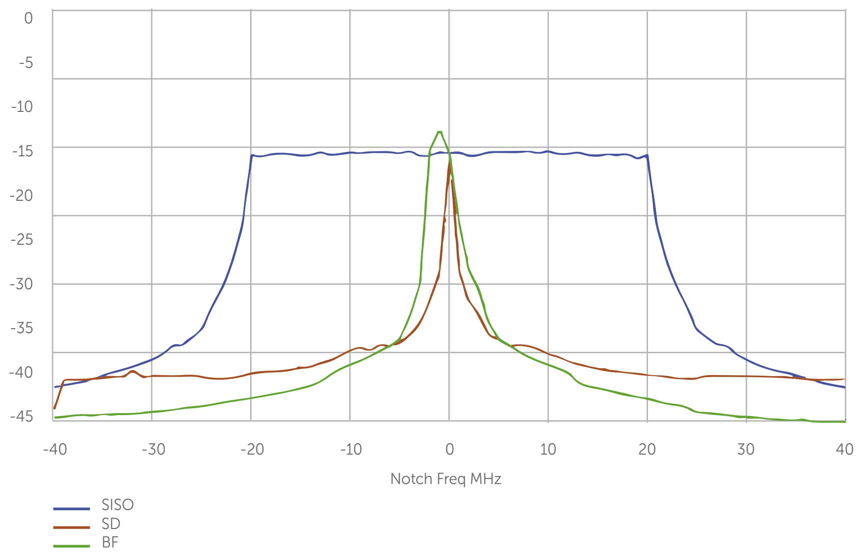
Figure 20 depicts the Mean Square Error during two instances of selective fading on the main and diversity antennas. The X axis represents the frequency difference between the notch on the main antenna and the one on the diversity antenna. The Y axis represents the MSE on the receiver. The simulation was implemented on the 28MHz signal.

This shows that as long as the two notches are not on the same frequency in both antennas, the mechanism leads to MSE of nearly -40dB compared to a SISO implementation.

FIGURE 20

System Gain vs. Antenna Separation

MSE vs Notches -50 - 50 MHz



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CONCLUSIONS

Ceragon's Advanced Space Diversity, accomplished utilizing the unique multicore architecture of the IP-20 platform, allows operators to reduce the number of radios and antennas required for a space-diversity link from four to three (25%), while maintaining the same performance and availability figures as in previous space diversity configurations.

In addition, the system gain achieved with this technology offers a cost-effective solution for CAPEX antenna costs and OPEX transportation and installation, which are extremely significant in long-haul environments.

ABOUT
CERAGON NETWORKS

Ceragon Networks Ltd. (NASDAQ: CRNT) is the global innovator and leading solutions provider of 5G wireless transport. We help operators and other service providers worldwide increase operational efficiency and enhance end customers' quality of experience with innovative wireless backhaul and fronthaul solutions. Our customers include service providers, public safety organizations, government agencies and utility companies, which use our solutions to deliver 5G & 4G broadband wireless connectivity, mission-critical multimedia services, stabilized communications, and other applications at high reliability and speed.

Ceragon's unique multicore technology and disaggregated approach to wireless transport provides highly reliable, fast to deploy, high-capacity wireless transport for 5G and 4G networks with minimal use of spectrum, power, real estate, and labor resources. It enables increased productivity, as well as simple and quick network modernization, positioning Ceragon as a leading solutions provider for the 5G era. We deliver a complete portfolio of turnkey end-to-end AI-based managed and professional services that ensure efficient network rollout and optimization to achieve the highest value for our customers. Our solutions are deployed by more than 400 service providers, as well as more than 800 private network owners, in more than 150 countries. For more information please visit: www.ceragon.com