Vertical vs. Horizontal Separations for Diversity Antennas

Learn how to combine two received signals from two separated antennas to reduce signal fading.

By William C. Y. Lee

Many cellular engineers have asked: Why does the horizontal antenna separation have better diversity performance than vertical separation at a cell site? There is an important reason why. In mobile radio environments, signal fading caused by multipath degrades reception performance. Therefore, a popular method called space diversity is used to combine two received signals from separate antennas in order to overcome the effect of the signal fading. The greater the antenna separation, the less likely the fades of the two received signals will occur simultaneously. Thus, the diversity "gain" for reducing the effect of the fades increases as the separation increases. It is based upon the concept that the signal strength of two signals should be nearly equal. If the two received signal strengths are not equal, the diversity gain cannot be achieved regardless of the requirements of antenna separation.

Designing a diversity antenna scheme is based on the parameter η. However, the value depends on the real antenna height

Lee is vice president of research and technology for PacTel Cellular, Irvine, CA.

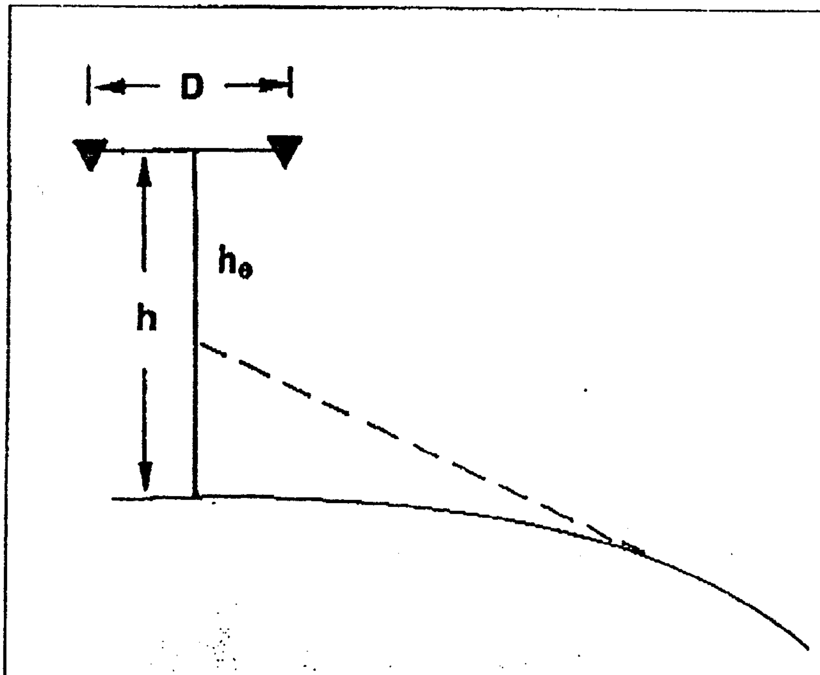

Figure 1. Horizontal antenna separation.

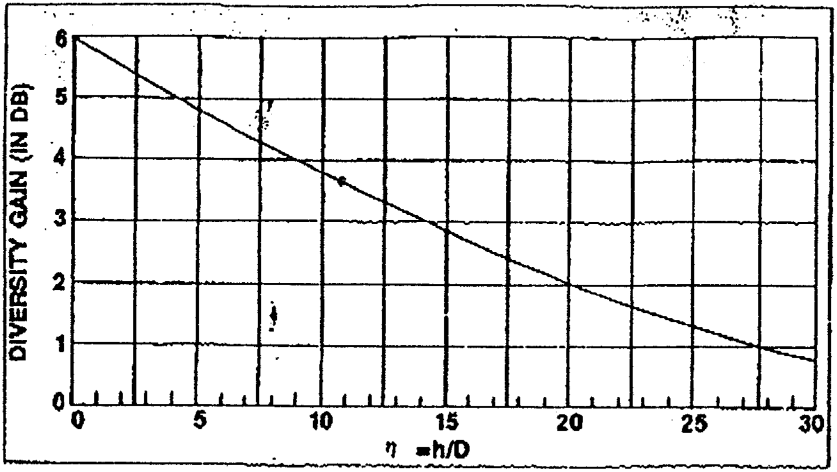

Figure 2. Diversity gain vs. η.

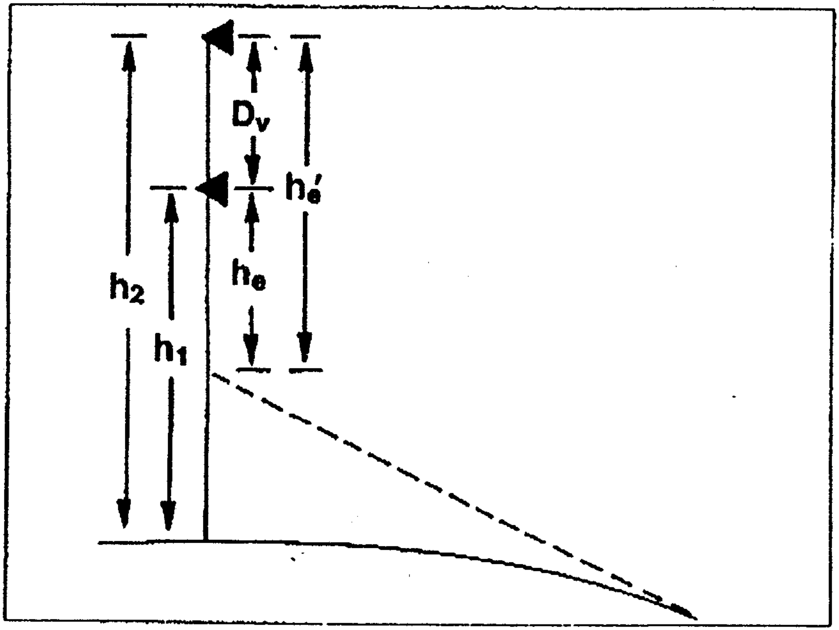

Figure 3. Vertical antenna separation.

(h) and the antenna separation (D)[1]:

$$\eta = \frac{h}{D}$$

Horizontal separation

The parameter is a function of h and D. It has been determined experimentally that the optimum value of eta is 11 for horizontal antenna separation[1]

$$\eta = \frac{h}{D} = 11$$

For example, if the antenna h is 100 feet, the optimum D is 9 feet. Therefore, the higher the antenna, the more separation you will need for optimum diversity gain. Incidentally, the h is the antenna height at the cell site when you design the system.

In a real-world environment, vehicles and portable units are at various ground elevations in all directions from the cell site. Because of this, the effective antenna height (h_e) measured at the cell site varies, based on the real-time locations of vehicles and portables. The same actual antenna height may have two different effective antenna heights according to two different vehicle or portable units. For a specific base-to-mobile/portable transmission, when h_e is less than the h, the signal received by the vehicle will be weaker[2]:

$$\Delta G = 20 \log_{10} \frac{h_e}{h} \quad \text{(dB)}$$

Thus, the gain (G) is −dB when referring to the h. However, if the h_e is greater than the h, the received signal strength will be stronger, and therefore, G will be +dB.

During system operation, the value of η will vary depending upon the present

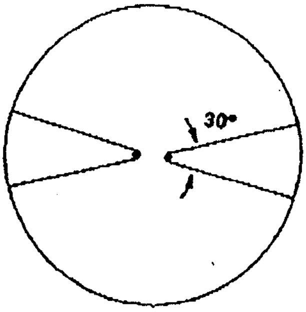

Figure 4. No diversity regions for horizontal antenna separation.

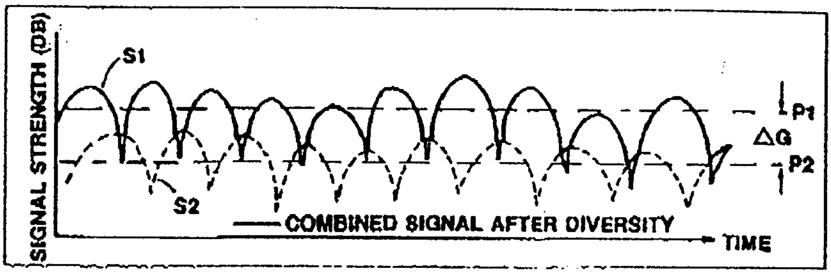

Figure 5. Illustration of two unequal signals combining.

location of the vehicle or portable units. (See Figure 1.)

When the h_e is less than the h, the value of η_e becomes less than 11. As the value of η_e decreases, the diversity gain increases. (See Figure 2.) On the other hand, when h_e is greater than h, the value of η_e is larger than 11. And the diversity gain decreases. Therefore, you can see the advantage of using horizontal separation. When the h_e is smaller than the h, the signal strength from a single antenna at the cell site is weaker. In this instance, you need the diversity gain, which is there. The weaker the signal strength from a single antenna, the greater the diversity gain while the antenna separation remains unchanged. From a design standpoint, this is a good approach.

Vertical separation

You may also use a vertical separation between two cell-site antennas for a diversity application. Usually the vertical antenna separation is greater than the horizontal antenna separation for achieving a given diversity gain.[2] Let the antenna height of the lower antenna be h_1 and the antenna height of the higher antenna be h_2. The vertical separation is D_v, according to a given diversity gain.

When a vehicle is at the location shown in Figure 3, the received signal strengths from both antennas are weaker because the effective antenna heights of both antennas are less than their actual heights. In this case, you need diversity gain. To achieve a greater diversity gain, two requirements are needed:

1. The value of η_e becomes smaller. It is achieved when the h_e is smaller than the h.
2. The signal strengths of two received signals should be relatively equal.

The second condition is hard to meet when you use vertical separation. (See Figure 5.) The difference in reception gain Δg between two effective antenna heights of two antennas can be found by using the following equation:

$$\Delta g = 20 \log_{10} \frac{h_e'}{h_e} = 20 \log_{10}\left(1 + \frac{D_v}{h_e}\right)$$

h_e and h_e' = effective antenna heights of two vertically separated antennas.
D_v = vertical separation.
h_1 = actual antenna height of the lower antenna.

For example, you may find this situation when the difference in Δg is 4dB. Then:

$$1 + \frac{D_v}{h_e} = 10^{\frac{4}{20}}$$

or

$$D_v = 0.58\ h_e$$

It shows that if the D_v is arranged to be 15 feet and h_e of the lower antenna is 26 feet according to the vehicle location, then no diversity gain can be seen regardless of the value of η_e. In this scenario, it is 1.73, which is a small value. (See Figure 3.) Therefore, for vertical separation, when the h_e is smaller than the h, the received signal strengths from the two antennas are weaker. Therefore, you need diversity gain. However, because the ΔG also increased because the condition of the h_e was greater than h, the diversity gain reduces. In both of these vertical-separating antenna arrangements, you need diversity gain because of the reception of the weak signal. However, if it is not there, you do not need the gain due to the reception of the strong signal it provides. This poor arrangement is why we do not encourage its use.

Although the horizontal-separation antennas can provide higher diversity gain when you need it, it has two limitations. (See Figure 4.) When vehicles are in certain areas, no diversity gains are observed.[1] To overcome this situation, line up the two antennas to the areas that do not need diversity gains and to those areas that do — the areas in which the h_e is greater than the h and ΔG is +dB. (See Figure 6.) As long as the received G is greater for the vehicles in those areas, no diversity gains are needed. Of course, no diversity can be provided in those areas either.

Choosing the areas that do not need diversity gain and serving the rest of the areas that do need the diversity gain is the best policy.

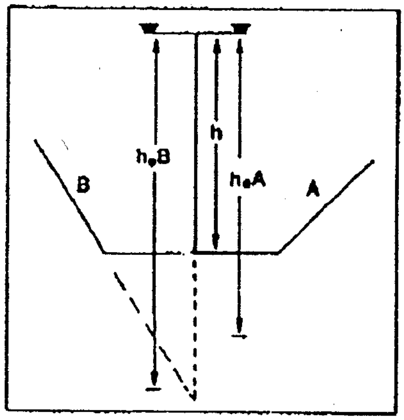

Figure 6. A good way to orient horizontally separated antennas.

Conclusion

The advantage to horizontal separation antennas is when a vehicle (or portable unit) needs diversity gain because of a weak signal — you will always observe the gain. The less the received signal strength, the stronger the diversity gain. The disadvantage is that for the vehicles in the areas in which the two antennas are in-line as shown in Figure 6, the diversity gain is not provided. Therefore, it is essential for you to have proper orientation of the two antennas.

The advantage of two vertically separated antennas is that there is no restriction to the vehicles in any direction around the antenna. However, the disadvantage is that when the received signal is weaker, the diversity gain is also lower. Therefore, it is not a desired approach.

The diversity scheme is used in the analog system today and will continued to be used in digital systems in the future. When everything is said and done, the diversity scheme is really the ideal.

Footnotes

[1] W.C.Y. Lee, "Mobile Radio Signal Correlation vs. Antenna Height and Spacing," IEEE Trans on Vehicular Technology, August 1977, pp. 290-292

[2] W.C.Y. Lee, "Mobile Communications Design Fundamentals," Howard W. Sams and Co., 1986, page 204.

[3] W.C.Y. Lee, "Mobile Communication Engineering," McGraw Hill Book Co., 1982, Page 300.