

Basics of Dual-Polarized Antennas

Definition

Many wireless service providers have discussed the adoption of a polarization diversity scheme in place of a space diversity approach. Like space diversity, polarization diversity relies on the decorrelation of the two receive ports to achieve diversity gain. The diversity gain from polarization diversity is maximized if the dual-polarized antenna has receive and receive diversity ports that receive radiation in a cross-polarized fashion over the desired coverage area with equal field strengths. Stated in another way, in a typical sectorized system, the two receive ports must remain cross-polarized (i.e., orthogonal) and capable of tracking one another over the forward 120-degree sector and into the hand-over area. The orthogonality, combined with tracking ability, is necessary if systems using dual-polarized antennas in a polarization diversity scheme with an advanced combining technique are to perform as well as systems employing vertically polarized antennas in a horizontal space diversity format.

Overview

This tutorial provides an in-depth explanation of antenna pattern measurement techniques used to determine the performance of dual-polarized antennas and of some antenna characteristics that are unique to antennas used in a polarization diversity scheme.

Topics

1. Copolar and Total Power Front-to-Back Measurement
2. Cross-Polar Discrimination
3. Polarization Purity
4. Microstrip Patch Antennas versus Dipole Antennas
5. Further Discussion of XPD
6. Orthogonality for Dipole and Microstrip Patch Antennas
7. Tracking of Antenna Beams
8. Summary

Self-Test

Correct Answers

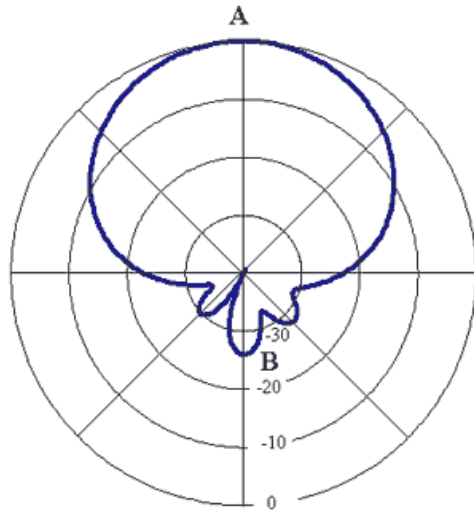
Glossary

1. Copolar and Total Power Front-to-Back Measurement

Characterizing the performance of slant-45 polarization diversity antennas is considerably more involved than vertically polarized space diversity antennas or polarization diversity antennas with vertically and horizontally polarized receive and receive diversity ports. Thus, antenna pattern measurement techniques used to determine the performance of slant-45 dual polarized antennas are likewise more involved. The technique for measuring the performance of vertically and horizontally polarized antennas is well known and quite robust. When these types of antennas are measured properly, the polarization of the source matches the polarization of the antenna being tested for the entire test. This type of measurement is said to be a copolarized measurement. Hence, as the polarization of the source antenna matches that of the antenna-under-test, no coupling loss occurred.

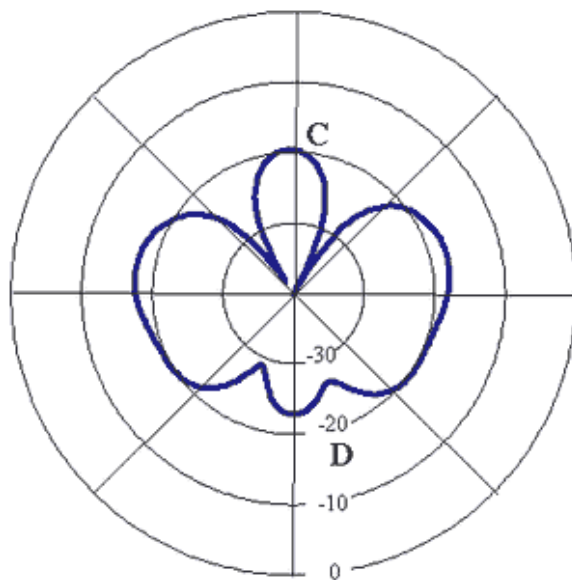
Coupling loss (i.e., the polarization loss factor) is a result of a mismatch in the polarizations of the source antenna and the antenna-under-test. If the polarizations of the two antennas do not match over the entire pattern measurement, then antenna parameters such as gain, horizontal beamwidth, and front-to-back ratio may not be accurately reflected in the antenna pattern measurement. The polarizations of the source and of the antenna-under-test do not match over the entire test with a slant-45 source and a slant-45 antenna. The polarizations of the source and the slant-45 antenna match only at boresite. This type of measurement is not truly copolarized, but is often referred to as copolarized, and is depicted in *Figure 1*.

Figure 1. Copolarized Measurement with a Slant-45 Source on a Slant-45 Antenna



For this single pattern cut with a slant-45 source, the source antenna and the antenna-under-test are copolarized at boresite (see position A in *Figure 1*), cross-polarized in the back (see position B in *Figure 1*), and varyingly noncopolarized elsewhere. The same can be said in converse fashion for a cross-polarized measurement on a slant-45 antenna with a slant-45 source. Such a pattern is shown in *Figure 2*, where the source antenna and the antenna-under-test are cross-polarized at boresite (see position C in *Figure 2*), copolarized in the back (see position D in *Figure 2*), and varyingly noncopolarized elsewhere.

Figure 2. Cross-Polarized Measurement with a Slant-45 Source on a Slant-45 Antenna



The difference in signal strength between position A in *Figure 1* and position D in *Figure 2* is known as the copolarized front-to-back ratio. If the power level at B and D are added together in a linear fashion, this gives the total radiated power in the backward direction. Comparing this total radiated power to that of position A in *Figure 1* gives the total power front-to-back ratio. For this case, the copolarized front-to-back measurement is approximately 22 decibels (dB), whereas the total power front-to-back ratio is approximately 20 dB.

2. Cross-Polar Discrimination

The level of the polarization purity for the polarization diversity antenna should be pushed as high as possible for peak diversity gain performance. The system diversity gain relies on the combining method used by the base station equipment, which in turn relies on decorrelation of the two receive ports to be quite high. This decorrelation is achieved by ensuring that the receive and receive diversity ports of a diversity antenna are highly orthogonal to one another. The orthogonality measurement requires both magnitude and phase measurements to be stored during the testing process. A more simplified approach to ensure orthogonality is to measure the cross-polar discrimination for highly linearly polarized antennas.

The same set of antenna patterns in *Figure 1* and *Figure 2* are also used quite often to obtain the polarization purity and the cross-polar discrimination (XPD) of the slant-45 dual-polarized antenna. For this example, the boresite XPD is obtained by comparing A in *Figure 1* to C in *Figure 2*, yielding a value of 19 dB. The XPD at 30 degrees is about 35 dB, whereas at the sector border (60 degrees), the XPD is back down to 8dB. Measuring the cross-polar discrimination off-boresite is also known as the polarization quality ratio (PQR). As the source and antenna-under-test are neither copolarized nor cross-polarized off-boresite, the use of an alternative set of orthogonal source positions may yield more insight into the polarization purity of the slant-45 antenna off-boresite and, more importantly, at the sector border.

3. Polarization Purity

Using a set of orthogonal source antenna orientations that are copolarized and cross-polarized at boresite may or may not provide easily interpreted results if the polarization of the antenna-under-test changes in polarization with respect to azimuth position. This type of phenomena is quite common with slant-45 antennas and is often the crux of any base station antenna design for slant-45 polarization diversity antennas. Thus, for certain types of antennas that are dual-polarized slant-45 antennas, using certain types of noncopolarized measurements are quite informative for quickly ascertaining the polarization-dependent beamwidth of the slant-45 polarization diversity antenna. Enormous insight into

the polarization purity of the slant-45 antenna can be gleaned from using a set of source positions that are vertically and horizontally polarized.

Two additional pattern measurements per slant-45 antenna port with a horizontal and vertical source position add some additional insight into the performance of the dual-polarized base station antenna. By taking these two pattern cuts on the slant-45 antenna, with the source in the vertical and horizontal position, the amount of polarization loss in the pattern measurement is the same at boresite and directly behind the antenna. In other words, for antenna patterns taken with horizontal and vertical source positions, the amount of variation in the pattern as a result of polarization loss is less than using the slant-45 source position.

Antenna patterns taken with horizontal and vertical source positions demonstrate the stability of the polarization in the horizontal plane. Given a crisp slant-45 signal from the dual-polarized base station antenna, the beamwidth for both of these pattern cuts with vertical and horizontal source positions will be nearly the same. Thus, with well-behaved slant-45 antennas, the horizontal patterns for the vertical source position, the horizontal source position, and one slant-45 copolarized source position will all have approximately the same pattern shape over the forward 120-degree sector. Furthermore, the other slant-45 base station antenna port should have the same antenna patterns for the horizontal and vertical source position and the other slant-45 source position.

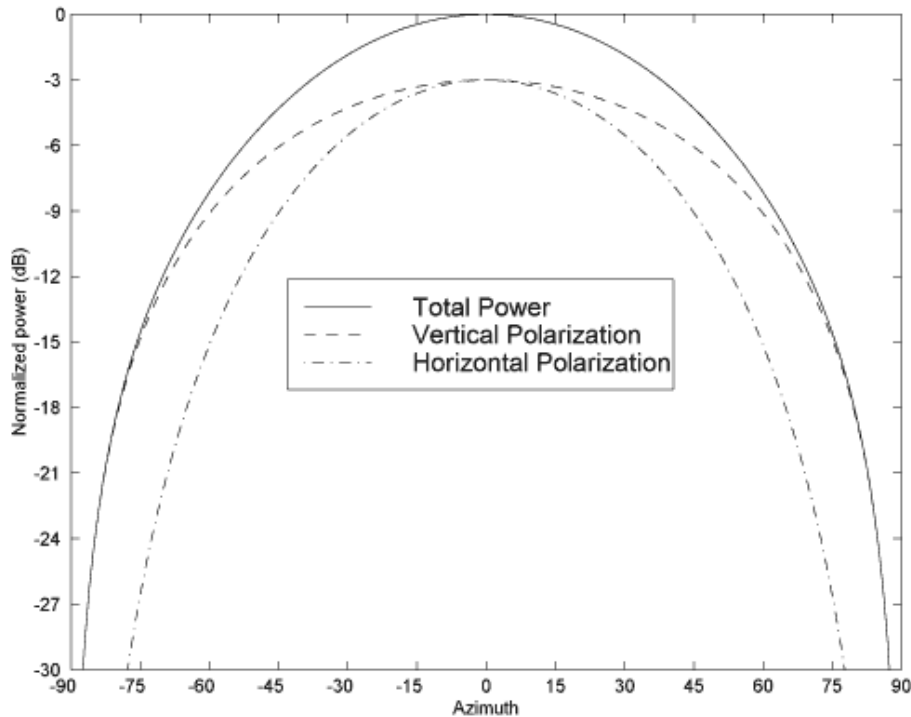
These noncopolarized source position measurements result in an easy method to determine the polarization purity for a slant-45 antenna. If the beamwidths obtained from the horizontal and vertical source position measurements are not the same, then the polarization that has the broadest horizontal beamwidth is the polarization that has the strongest signal, given that the polarization at boresite is truly slant-45. If the pattern cut for the vertical source position shows a broader beamwidth than the one taken for the horizontal source position, then the antenna polarization is less than slant 45, and the polarization of the base station antenna is in fact somewhere in between being vertical and slant-45. If there is any more than a 6dB difference in the gain at a particular azimuth angle between the vertical and horizontal source position measurements, this slant-45 antenna should no longer be considered a polarization diversity antenna but a rather poor vertically polarized antenna for that particular azimuth angle.

4. Microstrip Patch Antennas versus Dipole Antennas

It is interesting to explore the feasibility of using noncopolarized antenna pattern measurements to determine the polarization angle of linearly polarized slant-45 antennas that use dipole and microstrip patch antenna elements. Some numerical results, which have been submitted for publication in a technical

journal, present the theoretical horizontal pattern performance of slant-45 dipole and microstrip patch-based antennas. The patterns for an antenna that uses dipole elements is shown in *Figure 3* for copolarized slant-45 vertical and horizontal source positions.

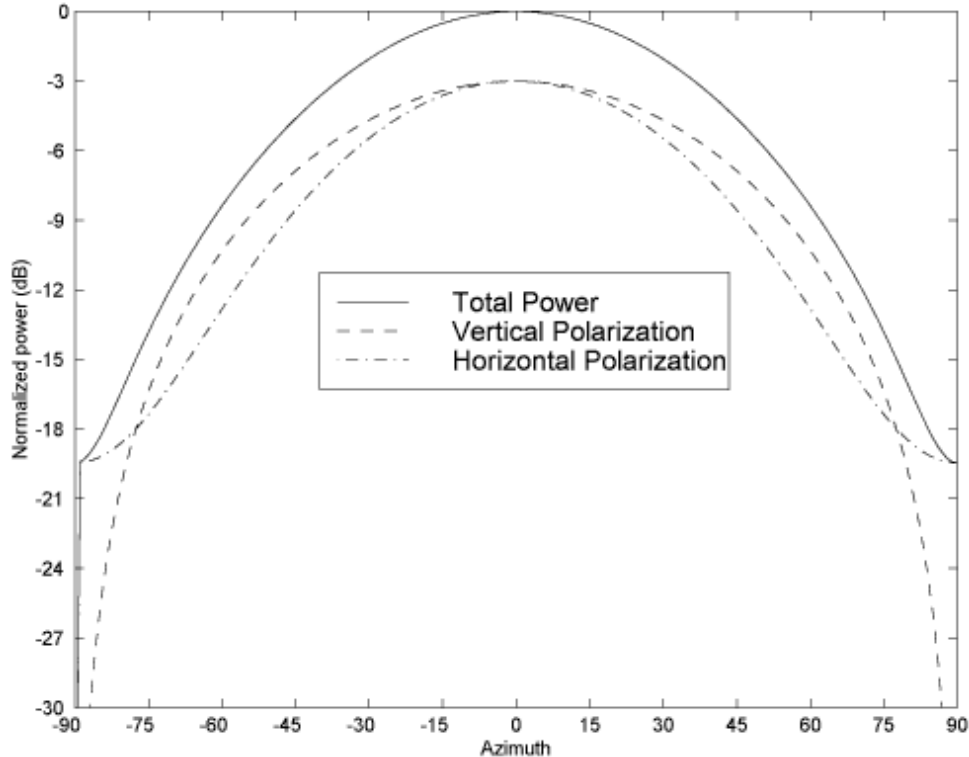
Figure 3. Patterns for a Slant-45 Antenna Using Dipole Elements



As demonstrated in *Figure 3*, the solid line shows the antenna pattern as taken with a slant-45 source. The closely spaced dashed lines show the antenna patterns taken with a vertical source and the dash-dot-dash line for the horizontal source. At boresite, the patterns for the horizontal and vertical source positions show the same gain, which shows that the dipole antenna is indeed slant-45 polarized at boresite, assuming that the phase references for both polarizations are either equal or differ by 180 degrees.

Recognizing that the dipole-based antenna is slant-45 at boresite, *Figure 3* demonstrates that the antenna is not slant-45 at the sector borders. Near 60 degrees on either side of boresite, the difference in the patterns between the vertical and horizontal source positions is quite large—approximately 6 dB. This large difference demonstrates that the signal is becoming more like that from a vertically polarized antenna and less like that from a slant-45 polarized antenna. This conclusion can also be reached by noting that the beamwidth of the antenna pattern for the vertically polarized source is the broadest of the three. The same type of analysis is performed on an antenna that uses microstrip patch elements, as demonstrated in *Figure 4*.

Figure 4. Patterns for a Slant-45 Antenna Using Microstrip Patch Elements



For the patch antenna, the difference between the horizontal and vertical sources is not as dramatic as seen in the dipoles; thus, the radiated signal from the antenna using patch elements remains far closer to a slant-45 polarization over the 120-degree sector than the antenna using dipole elements. Hence, the superior performance of the microstrip patch-based antenna should lead to improved system performance for the wireless network.

5. Further Discussion of XPD

As discussed, the front-to-back ratio, the horizontal beamwidth, and the angle of the polarization of dual-polarized antennas can be determined by comparing antenna patterns obtained from four different source positions. From these measurements, the axial ratio of the antenna can, if necessary, be estimated. The axial ratio is also what is known as the XPD for antennas that are polarized in a near-linear fashion (i.e., vertical, horizontal, and slant-45). As another point of reference, the XPD of perfect circularly polarized antennas is zero, which gives rise to an axial ratio of unity. However, like their linearly polarized counterparts, a good pair of right-handed and left-handed circularly polarized antennas are orthogonal and have good receive diversity performance if they cophase to one another. For perfect orthogonality, the vector addition (i.e., dot product) of the radiation from the two ports from the dual-polarized base station antenna is zero.

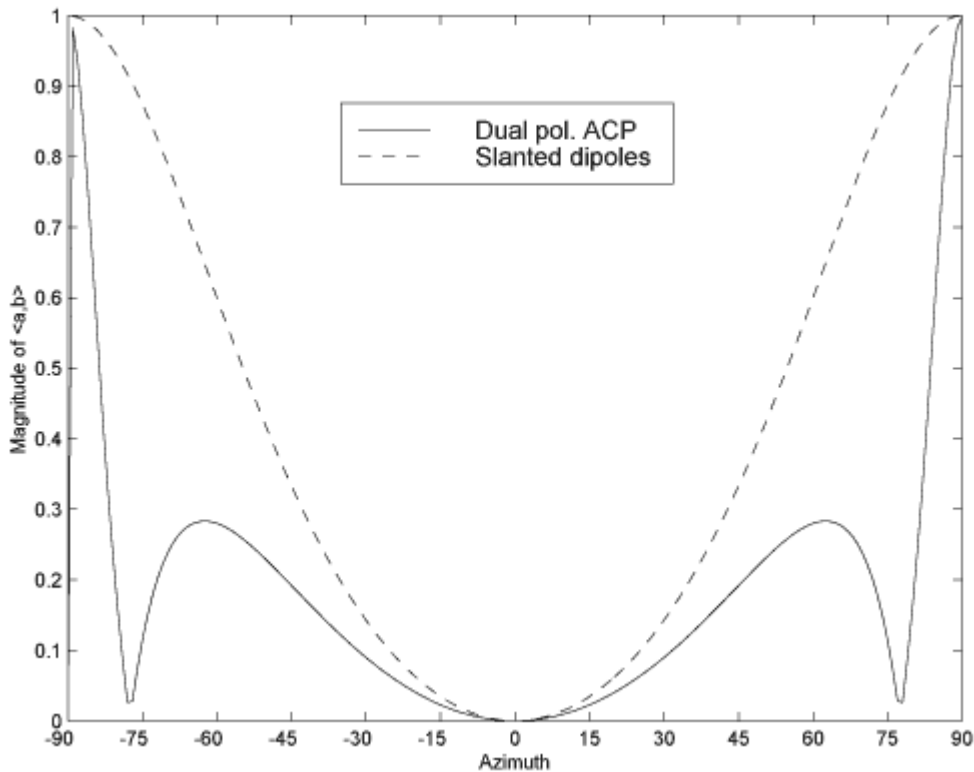
Thus, having a solid XPD over the entire sector face (i.e., PQR) is one way to ensure proper performance for linearly polarized antennas. A more exact method, however, is to inspect the orthogonality of the dual-polarized antennas over the entire coverage area for slant-45 antennas, as a result of polarization changes off-boresite. The orthogonality more accurately describes how well the two receive diversity ports are decorrelated to one another over the entire operating forward sector, but the orthogonality is more involved and tedious.

For antennas that are intended to be linearly polarized, the XPD or PQR is an easier and less complicated way to describe the polarization purity of the antenna. For reference, the XPD of vertically polarized base-station antennas that are used in the space diversity scheme is most often greater than 15 dB. In practice, linearly polarized antennas are never purely linearly polarized but maintain a reasonable XPD of better than 20 dB at boresite. The XPD of slant-45 antennas also tends to be reasonable at boresite and typically decreases in performance away from boresite. Having a reasonable XPD over the entire forward sector is another way of ensuring polarization purity (as opposed to using vertical and horizontal source positions, as previously discussed). Having reasonable XPD at boresite is wonderful in itself, but base station antennas are expected to perform over the entire sector and into the hand-over area. At the sector border, the PQR of some dual-polarized, slant-45 antennas tends to degrade. For these slant-45 antennas, performance near the sector boundaries ceases to be that of a linearly polarized, slant-45 antenna and begins to degenerate to that of poor-quality, vertically polarized antenna.

6. Orthogonality for Dipole and Microstrip Patch Antennas

Another way to approach the polarization purity of dual-polarized slant-45 antennas is to take two sets of antenna patterns with right angle source positions and record the magnitude and phase of the receive power at each azimuth angle. In this way, the previously presented antenna patterns in *Figures 3* and *4* with horizontal and vertical source positions can be used to compute the orthogonality. To investigate the orthogonality for the dipole and microstrip patch antennas, the orthogonality of the dual-polarized slant-45 antennas is computed by using a formula submitted for publication by Lindmark and Nilsson. The results of the orthogonality computations are revealed in *Figure 5*, in which the solid line is for the microstrip patch-based antenna and the dashed line is for the dipole-based antenna.

Figure 5. Results of Orthogonality Computation



This computation shows that the orthogonality is perfect at boresite (zero degrees) for both the dipole and the microstrip patch-based antennas. At 78 degrees, well into the hand-over region, the orthogonality is good again for the microstrip patch-based antenna, but is quite poor for the dipole-based antenna. If *Figure 5* is compared to *Figures 3* and *4*, the results of the orthogonality computation show that the best values for the orthogonality are located where the magnitudes of the horizontal and vertical source position patterns have the same signal strength.

Reviewing *Figures 3* and *4* reveals that the dipole-based antenna has the same gain for the patterns taken with the horizontal and vertical source positions only at boresite. On the other hand, the patch antenna has the same gain at boresite and then again well into the system hand-over area at 78 degrees for the patterns taken with the horizontal and vertical source positions. Hence, when the dual-polarized base-station antenna yields quite similar antenna patterns for the horizontal and vertical source positions, antenna performance for system diversity gain is favorable. Based on the results presented, the system diversity gain will be higher for microstrip patch based antennas compared to dipole-based antennas. This is due to the fact that antenna polarizations from the two receive diversity ports must remain cross-polarized to one another over the 120-degree sector face and into the hand-over area to obtain peak system performance. However, the gain of the two polarization diversity ports must be the same over the intended coverage area as well.

7. Tracking of Antenna Beams

If the azimuth antenna patterns from the two ports do not overlay and sometimes appear to be mirror images of one another, the dual-polarized antenna is said to have a tracking problem. The tracking problem can be polarization-dependent, which may be related to the type of element used in the construction of the antenna. Tracking errors between the receive and receive diversity antenna adversely affect diversity gain (in much the same way as using vertically polarized antennas—in a space diversity scheme—that do not have the same gain or horizontal beamwidth). In both cases, one antenna will continually receive a higher signal strength over a specific portion of the coverage area. The benefit of having the second receive diversity port will be small, due to an imbalance in the gain of the two antennas over similar coverage areas.

8. Summary

In conclusion, dual-polarized antennas in a polarization diversity scheme rely on orthogonality and tracking to perform at the same level as their vertically polarized counterparts, which are used in a space diversity scheme. The orthogonality and tracking of slant-45 dual-polarized antennas is easily investigated by taking antenna patterns with either slant-45 source positions or horizontal and vertical source positions. The patterns taken with the vertical and horizontal source positions nearly overlay and are quite symmetrical for antennas that have superior orthogonality and good tracking characteristics. As a result of this type of investigation, it was discovered that antennas built with microstrip patch elements exhibit better orthogonality over the desired coverage area and hence promote improved system performance compared to antennas that use dipole elements. Without the proper electrical performance of dual-polarized antennas, the system that exploits polarization diversity will not achieve the diversity gain on the uplink that is physically possible for this type of receive diversity scheme. Consequently, the selection criteria for dual-polarized antennas is more extensive than their vertically polarized space diversity counterparts.

Self-Test

1. To measure antenna patterns properly, the polarization of the source must match the polarization of the antenna being tested for the entire revolution of the antenna-under-test.
 - a. true
 - b. false

2. When examining backward radiation measurements (copolarized front-to-back measurements) for a slant-45 antenna, the source polarization must match at boresite and be cross-polarized behind the antenna.
 - a. true
 - b. false
3. When examining backward radiation measurements for a slant-45 antenna, the front-to-back ratio can be obtained from a single antenna pattern measurement.
 - a. true
 - b. false
4. At the sector borders (near 60 degrees), the difference between the vertical and horizontal signal strengths for the dipole-based antenna is approximately _____ dB, which demonstrates that the dipole-based antenna appears to be more like a vertically polarized antenna than a slant-45 antenna.
 - a. 2
 - b. 4
 - c. 6
 - d. 8
5. At the sector borders, the beamwidth of the dipole-based antenna is the broadest for the _____ polarized source position.
 - a. slant-45
 - b. vertically
 - c. horizontally
 - d. slant-30
6. The XPD of perfect circularly polarized antennas is _____ dB, while that of a good linearly polarized base station antenna for space or polarization diversity is better than 15 dB.
 - a. zero
 - b. one

- c. two
 - d. four
7. Measuring antennas that are vertically and horizontally polarized is more involved than measuring slant-45 antennas.
- a. true
 - b. false
8. Polarization quality ratio (PQR) is another name for cross-polar discrimination (XPD) at different azimuth positions and is an easier, more complete way to examine the polarization purity of an antenna.
- a. true
 - b. false
9. If the azimuth antenna patterns from the two receive diversity ports are _____, the dual-polarized antenna is said to have a tracking problem, given that the patterns do not overlay.
- a. identical
 - b. incomplete
 - c. asymmetrical
 - d. abbreviated
10. The orthogonality is perfect at boresite and nearly again at 78 degrees for _____-based antennas.
- a. dipole
 - b. microstrip patch
 - c. both
 - d. neither
11. If patterns are taken on slant-45 antennas with vertical and horizontal source positions, the patterns overlay one another reasonably well if the antenna polarization remains slant-45 over the entire forward sector.
- a. true

b. false

Correct Answers

1. To measure antenna patterns properly, the polarization of the source must match the polarization of the antenna being tested for the entire revolution of the antenna-under-test.

a. true

b. false

See Topic 1.

2. When examining backward radiation measurements (copolarized front-to-back measurements) for a slant-45 antenna, the source polarization must match at boresite and be cross-polarized behind the antenna.

a. true

b. false

See Topic 1.

3. When examining backward radiation measurements for a slant-45 antenna, the front-to-back ratio can be obtained from a single antenna pattern measurement.

a. true

b. false

See Topic 1.

4. At the sector borders (near 60 degrees), the difference between the vertical and horizontal signal strengths for the dipole-based antenna is approximately _____ dB, which demonstrates that the dipole-based antenna appears to be more like a vertically polarized antenna than a slant-45 antenna.

a. 2

b. 4

c. 6

d. 8

See Topic 4.

5. At the sector borders, the beamwidth of the dipole-based antenna is the broadest for the _____ polarized source position.
- a. slant-45
 - b. vertically**
 - c. horizontally
 - d. slant-30

See Topic 4.

6. The XPD of perfect circularly polarized antennas is _____dB, while that of a good linearly polarized base station antenna for space or polarization diversity is better than 15 dB.
- a. zero**
 - b. one
 - c. two
 - d. four

See Topic 5.

7. Measuring antennas that are vertically and horizontally polarized is more involved than measuring slant-45 antennas.
- a. true
 - b. false**

See Topic 1.

8. Polarization quality ratio (PQR) is another name for cross-polar discrimination (XPD) at different azimuth positions and is an easier, more complete way to examine the polarization purity of an antenna.
- a. true**
 - b. false

See Topic 2.

9. If the azimuth antenna patterns from the two receive diversity ports are _____, the dual-polarized antenna is said to have a tracking problem, given that the patterns do not overlay.

- a. identical
- b. incomplete
- c. asymmetrical**
- d. abbreviated

See Topic 7.

10. The orthogonality is perfect at boresite and nearly again at 78 degrees for _____-based antennas.

- a. dipole
- b. microstrip patch**
- c. both
- d. neither

See Topic 6.

11. If patterns are taken on slant-45 antennas with vertical and horizontal source positions, the patterns overlay one another reasonably well if the antenna polarization remains slant-45 over the entire forward sector.

- a. true**
- b. false

See Topic 3.

Glossary

PQR

polarization quality ratio

XPD

cross-polar discrimination