Over-the-air performance testing of wireless devices with multiple antennas

The proliferation of wireless devices has led to the development of new technologies that combine the use of multiple antennas with special algorithms that can dynamically change the RF performance of the device. Measuring the performance of these new technologies poses signifcant challenges to current test methodologies.

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Over the past several years, methodologies have been developed for over-the-air (OTA) performance testing of active wireless devices such as mobile phones[1, 2]. The goal of such testing is to operate the device in a normal operating mode with near-field impairments, such as a simulated human head, in order to determine the RF performance (both transmit power and receiver sensitivity) of the device when in normal use. For mobile phones currently on the market, the techniques involved are well known and center primarily on combining a traditional spherical antenna pattern measurement (APM) in a fully anechoic environment with the test equipment necessary to establish a voice or data connection to the phone in order to measure transmit power and receiver sensitivity of the phone at each position in the pattern[1-4]. This active measurement is an important part of determining overall device performance since the interaction between the antenna, the body of the phone, the circuitry in the phone, and the near-field environment can result in performance that differs significantly from that predicted by combining conducted radio performance (through a 50 Ω cable) with measured performance of an antenna. The cable used to measure the antenna can have a significant impact on the antenna measurement itself. In addition, detuning of the antenna due to near-field interactions can result in non-linear behaviors in the radio caused by large mismatches, while radiated emissions or immunity issues within the device can de-sensitize the receiver. Since the phone is operating with an active transmitter/receiver, the resulting pattern is in absolute power units (as opposed to a typical relative radiation pattern), so that integration of the surface produces device performance metrics

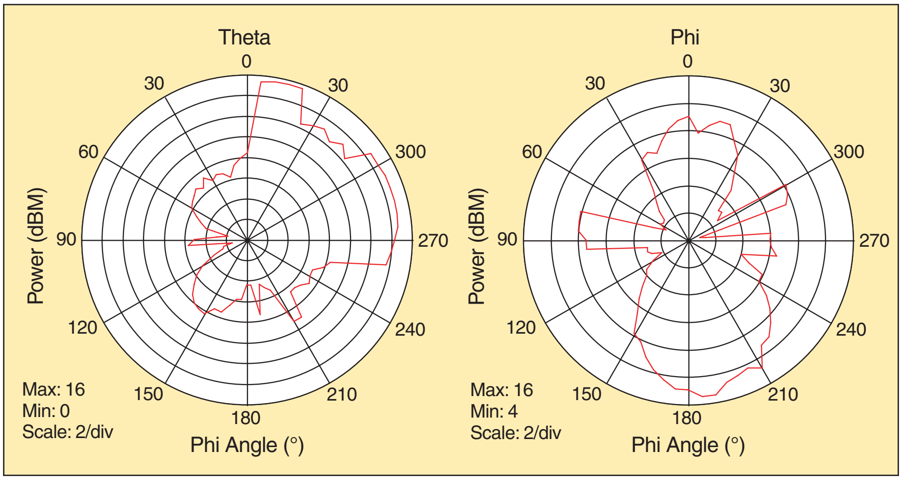

Figure 2. Pattern cut for DUT with switching diversity antennas measured at every 5° using alternating polarizations.

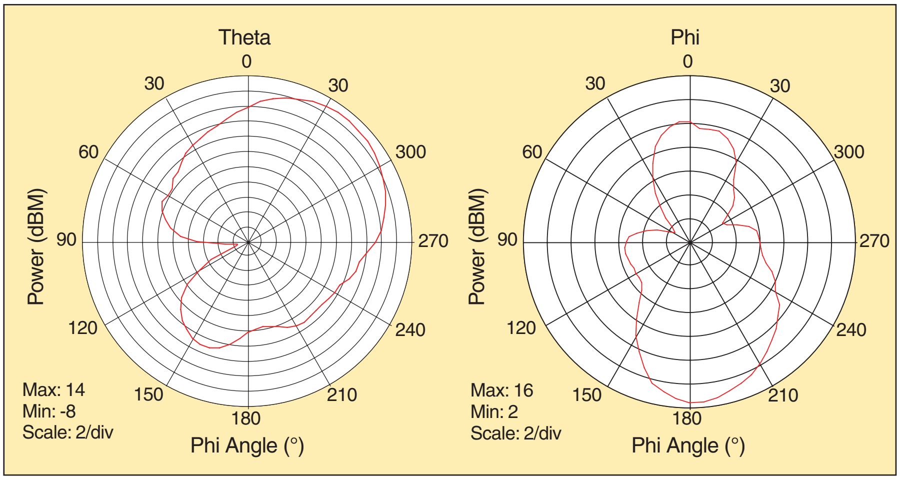

Figure 3. Pattern cut for DUT with switching diversity antennas where each polarization pattern was measured sequentially at every 5°.

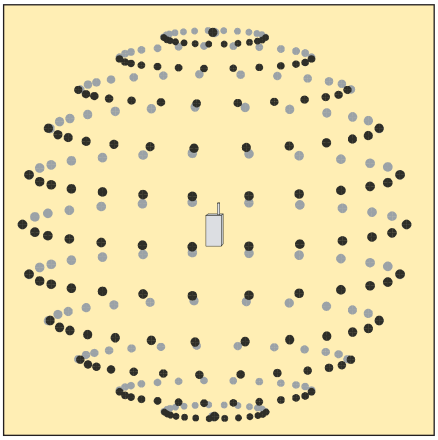

Figure 1. Spherical pattern measurement grid on 15° angular steps.

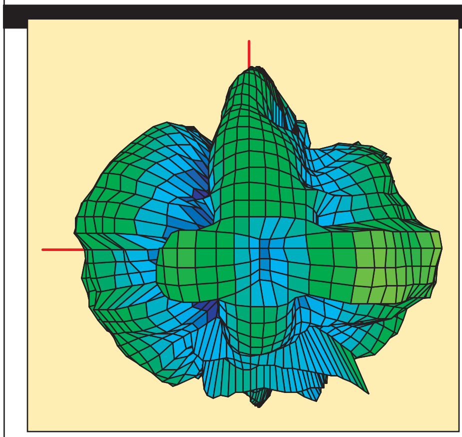

Figure 4. Three-D spherical pattern for DUT with switching diversity antennas illustrating non-optimal selection of the transmit antenna.

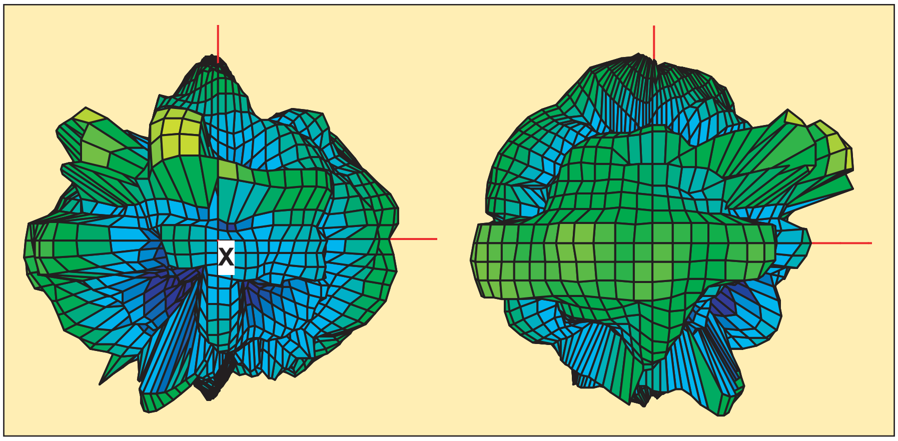

Figure 5. Three-D spherical pattern for DUT with switching diversity antennas illustrating other unnatural measurement artifacts.

such as total radiated power (TRP) and total isotropic sensitivity (TIS).

The proliferation of antennas in all sorts of wireless devices has led to new techniques for improving device performance in real world environments. Operational environment issues such as multipath fading result in sub-optimal conditions for wireless communication. Constructive and destructive interference of the same signal propagating along different paths in the environment result in the potential for field nulls at the location of the device antenna. If the antenna were moved some fraction of a wavelength, it would likely end up receiving a much stronger signal. By adding a second antenna and a mechanism to switch between them for the best signal, overall performance can be improved. This mechanism, known as spatial diversity, is one example of the variety of multiple-antenna designs that introduce an unprecedented level of complexity to the measurement of radiated performance in a controlled test environment. The radiated performance of the device now becomes a function of some set of processing and switching algorithms, as well as the performance of the transmitter, receiver and antennas. This article explores some of the issues involved with measuring these devices.

A later article will propose some solutions for the simpler cases and explore issues with more complicated diversity processing schemes such as diversity combining and maximal ratio combining. Those technologies, as well as the latest multiple-input multiple-output (MIMO) antenna systems and "smart" antenna technologies will require equally innovative measurement technologies to allow measuring RF performance that represents expected real world performance.

Active antenna pattern measurement

While this topic is covered in more detail elsewhere[3, 4], it's useful to recap the current methodology for OTA performance testing. A radiation pattern, or antenna pattern, describes the relative strength of the radiated field in various directions from an antenna, at a fixed (constant) distance. Simple two-dimensional pattern cuts are typically made by placing the device under test (DUT) on an azimuth rotator (turntable) at a fixed distance from the measurement antenna (MA) and then rotating the DUT 360º while measuring the transmission between the DUT and the MA. For omnidirectional antennas like those found in wireless devices, a spherical pattern measurement is normally used, although planar and cylindrical patterns can also be measured. Measuring a spherical antenna pattern just builds on the 2-D pattern cut by adding a second axis of rotation orthogonal to the first. This allows representing pattern data as a function of the two spherical coordinate angles, theta (Θ) and phi (ϕ). Figure 1 illustrates the measurement grid created by measuring pattern data at every 15 degrees in both theta and phi. One can think of the intersection of latitude and longitude lines on a globe as representing evenly spaced angular points to be measured.

At each point on the surface of the sphere, the total field vector is measured, normally by measuring two orthogonal polarizations and computing the resulting field value. Under normal circumstances, it is not necessary to be concerned with field vectors, as the pattern really represents the power density at each point in space. The two orthogonal polarizations of the MA sample the power density at that point such that their (linear) sum always represents the total power available, no matter what the polarization orientation. This is ideal since it means that it is not necessary to assume that the radiation is linearly polarized; elliptically polarized signals will produce equivalent results.

For active devices, a radiation pattern must be measured for transmitted signals and for received signals. For transmit patterns, the DUT normally transmits full power and the received signal is measured at each point on the pattern. Traditionally, it's not necessary for the measurement signal path to be the same as the communication signal path, so that communication traffic may occur between the DUT and a separate communication antenna. For receive patterns, the MA transmits the communication signal and one of several methods is used to determine the receiver performance. The most common is to use a bit or block error rate (BER or BLER) measurement to determine the level of corruption to the digital signal as the RF level from the MA is lowered. When the BER/BLER reaches a specified level, the associated RF level represents the sensitivity for that orientation and polarization. When combining sensitivity values for each polarization, the total is the inverse of the sum of the inverses of each polarization. That is due to the fact that better sensitivity performance is represented by a lower RF power rather than a larger value. Alternatively, if the DUT receiver has the ability to report its received power level

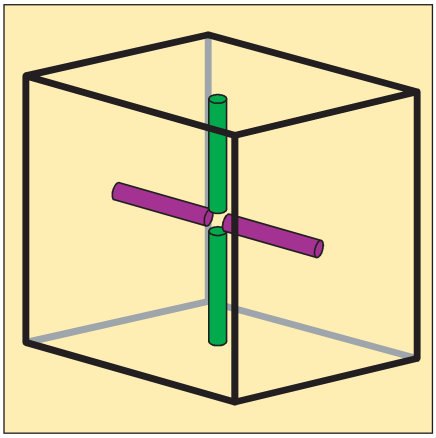

Figure 6. Sample DUT with polarization diversity—two perfect dipoles with identical performance at right angles to each other.

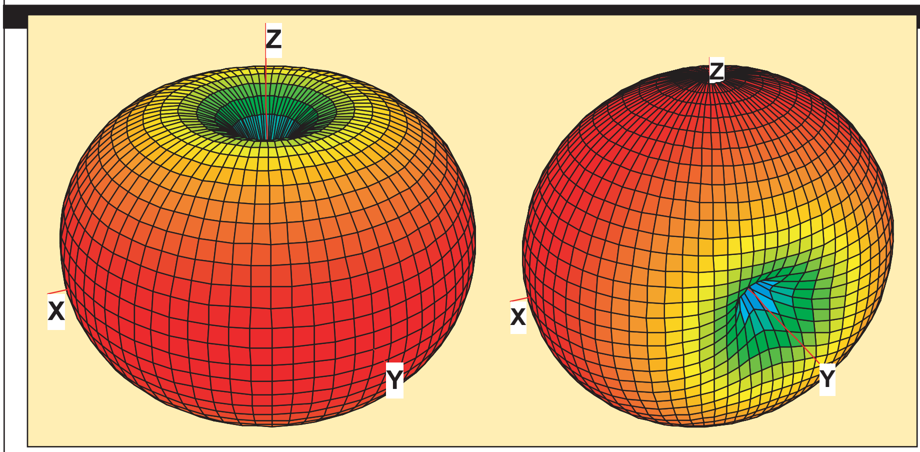

Figure 7. Patterns for each of two perfect dipoles with identical performance at right angles to each other. Scale is 30 dB.

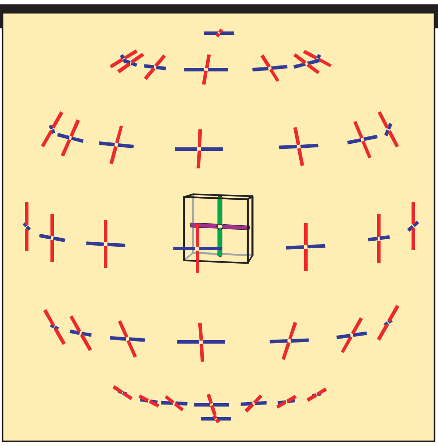

Figure 9. Illustration of measurement antenna positions and polarizations relative to the test DUT with the DUT oriented with its antenna elements parallel to the measurement antenna polarizations.

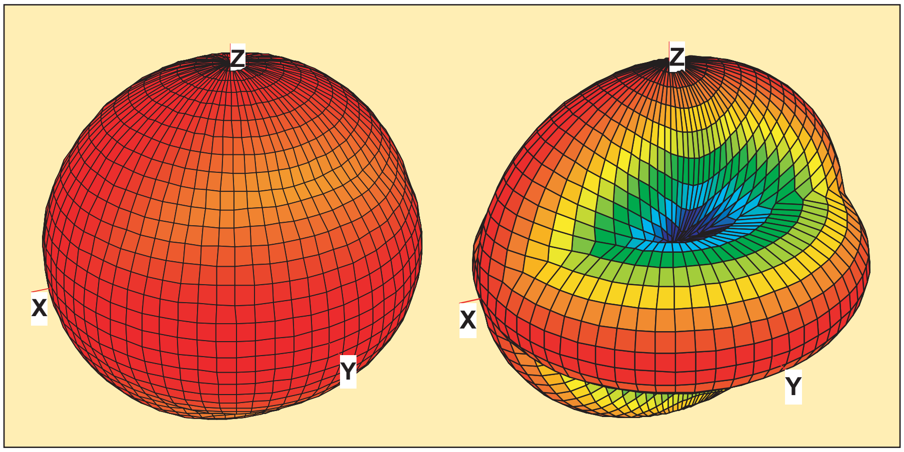

Figure 8. Numerical result of choosing the best performance at each point on the two dipole patterns. The pattern on the left is the original 30 dB scale, while the pattern on the right has been rescaled to 3 dB to show the dual dipole behavior.

(RSSI), that value can be recorded as a function of the pattern position. The RSSI pattern is usually less accurate and still needs to be normalized to an OTA sensitivity value to be able to determine the receiver's actual TIS. Note that for convenience, most of the discussion here will refer to transmit patterns, but in general, the arguments are the same for transmit and receive performance measurements.

Measuring switching diversity antennas

If a device containing two diversity antennas is measured using a typical OTA test system, results shown in Figure 2 are likely to occur.

It's apparent that there is something unusual going on with the measurement. The discontinuous steps in the pattern are not natural RF properties of an antenna. Instead, they're being caused by the diversity algorithm making decisions about which antenna to use. While there are a number of pieces of information that may be used to decide which diversity antenna is used for communication, the decision is typically made by the DUT based on the received signal level or signal quality. Since toggling the polarization of the MA changes the signal level seen by the DUT antenna, the diversity algorithm may choose to switch to the other antenna due to the polarization change. When switching back to the original polarization, there may be no detected advantage that would cause the diversity algorithm to switch back. Thus, the measurement sequence itself affects the measurement. If instead of switching polarizations at each point, a pattern is measured for each polarization in sequence, the patterns shown in Figure 3 are the result.

The resulting pattern certainly looks more realistic, but there are still some issues apparent in the data. In Figure 3, the Phi Polarization plot on the right shows a slight "kink" in the pattern at 165º. Again, this is not a natural phenomenon but is caused by a switch in the diversity antenna. However, the switch decision still appears to be sub-optimal, as it chose to switch

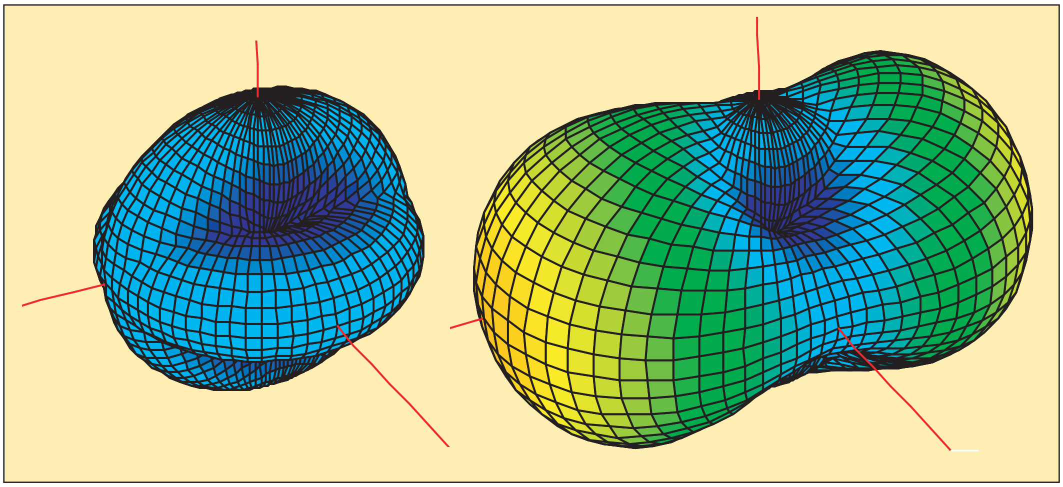

Figure 10. Comparison of "actual" performance of the sample polarization diversity device (left) and result of measurement using dual polarized APM system when the DUT antennas are polarized parallel to the measurement antennas (right) showing an apparent 3 dB increase in performance in the intersecting regions. The plots are on a +3 dB to –3 dB scale.

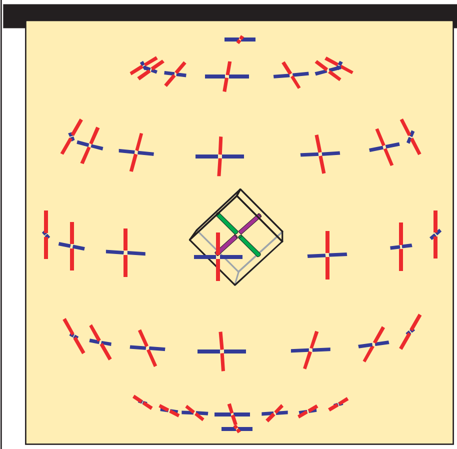

Figure 11. Illustration of measurement antenna positions and polarizations relative to the test DUT with the DUT oriented with its antenna elements angled 45° from the measurement antenna polarizations.

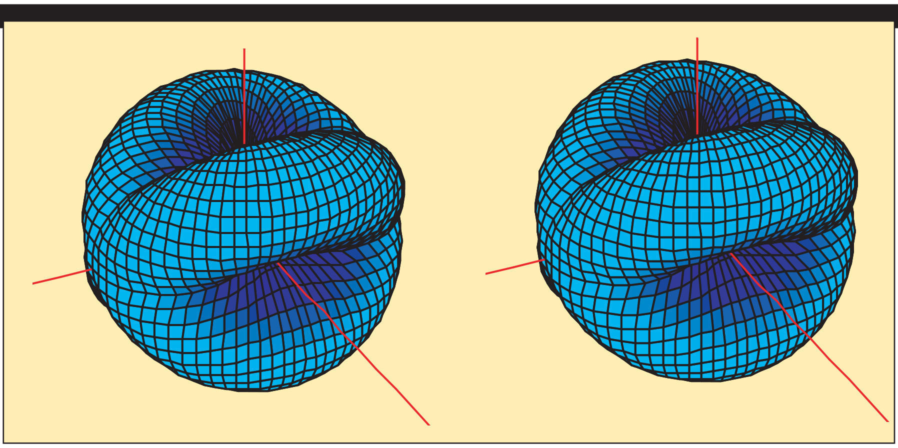

Figure 12. Comparison of "actual" performance of the sample polarization diversity device (left) and result of measurement using dual polarized APM system when the DUT antennas are polarized angled 45° to the measurement antennas (right). In this case, there is no apparent increase in performance. The plots are on the same + 3 dB to – 3 dB scale.

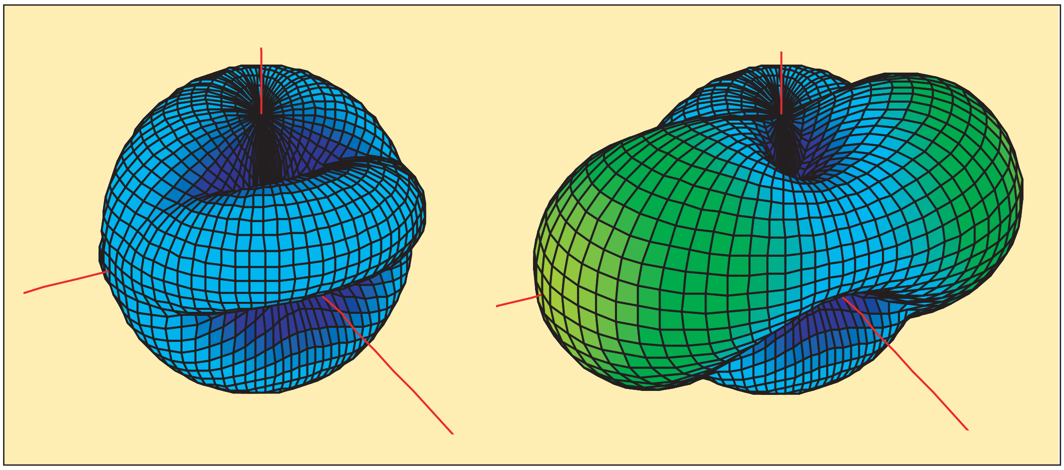

Figure 13. Comparison of "actual" performance of the sample polarization diversity device (left) and result of measurement using dual polarized APM system when the DUT antennas are polarized angled 35° to the measurement antennas (right).

between a signal that was rising rapidly with increasing angle to one that was flatter as a function of angle. The rising lobe from the other antenna would have resulted in a better link budget at the limit of the communication range. Looking at a full 3-D pattern shows this issue more clearly (Figure 4).

From this orientation, it is apparent that the cuts near the top and bottom of this pattern were taken on one antenna while the cuts near the middle were taken on the other. The null right in the middle of the pattern is obviously not the best possible choice given the two antennas. If the best antenna were chosen at each point in this pattern, most of the visible nulls would be expected to have filled in. In the case of this test, no additional effort was spent to ensure that the algorithm was always making the best possible choice. Conceivably, it would be possible to force the DUT to the best antenna by lowering the signal transmitted from the MA to the point where the "worse" antenna was below sensitivity. Thus, the DUT would have no choice but to use the "best" antenna for each measurement point. This behavior, of course, would likely be dependent upon the algorithm used by the DUT.

Even with this possibility in mind, an analysis of the measurement technique used for single antennas will reveal other limitations when evaluating diversity antennas. Figure 5 illustrates the effect of these limitations when looking at other orientations of the same pattern shown above. The discontinuous peaks in the pattern are the result of something more critical than just the DUT's choice of antenna at each data point. The problem is related to the choice of antenna at each polarization, and more fundamentally to the concept of polarization orientation in the measurement system as a whole. Ideally, the radiated power for the "best" antenna for the given propagation direction would be measured at each data point. However, since the typical measurement system measures two orthogonal components in order to numerically compute the total value at each data point, then even under the above conditions, the "best" antenna would be chosen for each measured polarization rather than for each data point. Thus, if a different antenna is chosen for each polarization, the total power calculated from the two components is no longer valid and could represent a level as much as 3 dB higher than the maximum level that the DUT could ever transmit in that direction. This illustrates the crux of the problem in that the measurement system has now (erroneously) altered the result of the measurement.

An example: Polarization diversity

To further illustrate this issue, assume that the DUT consists of two point dipole antennas with identical individual performance that are polarized perpendicular to each other. Thus, each antenna would have an identical pattern, but the orientation of each would be at right angles to the other as shown in Figure 6. Figure 7 illustrates the patterns of those two dipoles oriented at right angles to each other. If we then create a new pattern consisting of the values resulting from choosing the best performance between the two antennas at each data point, we get the pattern shown in Figure 8. This pattern represents the best possible performance of the DUT in all directions, and ideally represents the desired quantity to be measured. The assumption here is that only one antenna can transmit (or receive, in the case of sensitivity measurements) at a time, and that in determining a suitable representation of the device's overall performance, we would choose the best performing antenna at each point on the surface of the pattern measurement sphere. Doing so results in an apparent improvement of TRP or TIS of 1.2 dB. Since the actual output power or sensitivity of the DUT does not change, this appears as an increase in efficiency. However, since the resultant gain remains constant, because the resulting gain of the combined pattern can be no more than the gain of any one antenna, the increase in efficiency is offset by an equivalent decrease in directivity.

Now, let's consider the impact of the measurement system on the above result. If we assume that we are testing a DUT in full operational mode, where the diversity switching algorithm is free to choose the best antenna possible, and we constrain the test to ensure that at each point and polarization, the DUT does in fact switch to the "best" antenna, then we obtain the following results.

Figure 9 illustrates the proposed DUT placed in the middle of the an array of dual polarized measurement antennas representing different measurement points on the spherical surface used to record the pattern data. In this case, the DUT is oriented so that its antennas are parallel to each polarization of the measurement antenna. In this orientation, the DUT will change the communication antenna that's used to be parallel to the active measurement antenna for each polarization that is measured. The result is shown in Figure 10b, where an apparent 3 dB gain is observed with a corresponding improvement in TRP/TIS of ~1.4 dB due to receiving a maximum coupling from each polarization. To be clear, this is an artificial result. Remember, each polarization is measured separately and assumed to be one component of an electric field vector, whether linearly or elliptically polarized. However, the diversity function of the DUT resulted in two completely different field vectors being measured for each polarization.

To verify that this is an artificial result, use the exact same measurement system, but now rotate the DUT by 45º about the axis perpendicular to both antennas as shown in Figure 11. In this case, since the dipoles are identical, there is no polarization advantage to either antenna in the DUT. Put another way, either diversity antenna produces the same magnitude for their components when in the boresight region, so that the sum of the measured components do actually result in the appropriate total field value, but only by chance. This result is shown in Figure 12. Even a change of 10º greatly changes this result as shown in Figure 13.

Conclusion

The complexity of wireless communications devices continues to increase. The introduction of multiple antennas to these devices poses an interesting challenge to determining the overall performance of such a device. The methods used today for performing over-the-air performance testing of wireless devices are not ideally suited to this task. A concept as simple as diversity switching, which introduces the behavior of a software algorithm into what would normally be a simple RF problem, can result in unexpected and blatantly erroneous results. A follow up to this article will present some possible short-term workarounds to these simpler problems we currently face. However, greater issues loom on the horizon. The concept of MIMO is poised to take the world by storm, especially with work in 802.11 TGn rapidly approaching completion. Other smart antenna technologies are also becoming more prevalent. Methods for performance testing of these devices will require considerable more thought in their development before we can expect to see useful results capable of predicting real world performance of these devices. The issues surrounding these technologies will be detailed in an effort to define the problem and point to possible courses of action. RFD

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Michael D. Foegelle received his Ph. D. in Physics from the University of Texas, where he performed theoretical and experimental research in condensed matter physics and electromagnetic compatibility (EMC). He performed contract EMC research with J. D. Gavenda of UT for IBM and RayProof where he helped to develop a semi-anechoic chamber modeling system. In 1994, Foegelle began working for EMCO (now ETS-Lindgren in Cedar Park, Texas), where he is a senior principal design engineer. He has been integral to the development of products, software and test methods for wireless, RF and EMC testing. He is active in standards development, and is involved in the work being done to improve antenna calibrations and site validations per the ANSI C63 standards, as well as the CTIA Certification Program Working Group on over-the-air performance testing of wireless devices and the IEEE 802.11 TGT for wireless performance prediction of WiFi devices. He is co-chair of the CTIA’s Converged Devices ad-hoc group and a member of the Wi-Fi Alliance’s Wi-Fi/Cellular Convergence group. He can be reached at foegelle@ets-lindgren.com.