An Antenna Pattern Measurement Technique Using Wideband Channel Profiles to Resolve Multipath Signal Components

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Abstract

Wideband channel measurements have been used extensively to determine path loss and time dispersion characteristics of radio channels (e.g., [1], [2], [7]). The principles used to temporally resolve individual received signal components for wideband propagation measurements can be applied to antenna pattern measurements to achieve more accurate results. Multipath, a propagation phenomenon which occurs when reflecting or scattering objects exist in an environment, causes inaccuracies in measured patterns when narrowband signals (e.g. continuous-wave) are used to perform far-field antenna measurements. Using the wideband technique described in this paper, the effects of multipath can be completely eliminated from pattern measurements. The method described here is especially useful when antenna range dimensions are limited in space or when multipath signal components caused by distant reflectors are irreducible.

Keywords: Antenna measurements, wideband power delay profiles, sliding correlator, multipath

1. Introduction

Accurate antenna measurements are essential for proper design and maintenance of wireless communication systems. Measured antenna data is often imported into propagation prediction tools to estimate performance for both indoor and outdoor radio channels. Ray tracing and in-building attenuation factor models [3] rely on precise antenna measurements to predict coverage regions for network design and for selection of optimal base station locations. This paper presents a technique for antenna pattern measurement that provides a significant improvement in the accuracy of measurements performed in the presence of multipath signals. This technique provides an excellent way for research groups without dedicated antenna measurement facilities to perform accurate antenna pattern measurements on a non-ideal range (e.g., parking lot or other convenient open space). Furthermore, existing antenna ranges may employ this technique to combat suspected inaccuracies caused by multipath.

Multipath signals are transmissions propagated from a source antenna to a receiver antenna along a path formed by reflection, diffraction, or scattering of electromagnetic waves by objects in an environment [4]. If the receiver antenna is an antenna under test (herein called the test antenna) for pattern measurements, multipath signal components typically distort the measured pattern and, most importantly, corrupt results derived using the pattern. As simulated continuous-wave measurements demonstrate, multipath components in the received signal cause apparent distortion of lobes and filling of pattern nulls.

Figure 1 illustrates a typical problem encountered when performing far-field power pattern measurements using the test antenna as the receiving antenna. The source antenna transmits a continuous-wave (CW) signal within the band of interest and a pedestal rotates the test antenna to produce a plot of signal strength versus angle for a particular planar cut. In the vicinity of the measurement range is a reflecting object which induces a multipath signal component along Path B in addition to the line of sight (LOS) component arriving along Path A. This generic reflecting object may be a wall, building, or even a mountain which causes inaccuracies in most open-air ranges.

The test antenna shown in Figure 1 is rotated on an axis perpendicular to the page to perform a planar cut. The strength of the multipath component relative to the

![Figure 1](image)

Figure 1. The existence of multipath components at the test antenna due to a nearby reflector causes inaccuracies in the measured pattern.
LOS component in the multipath structure of the received signal is dependent upon the orientation of the test antenna. If the LOS component is received along a strong pattern lobe and the multipath component is received along a pattern null, the effect of the multipath component is relatively minor. Also, the excess distance traversed by the multipath component in addition to the imperfect reflectivity of the multipath-causing object will further attenuate the multipath signal compared to the LOS component.

If, however, the multipath component arrives along a strong lobe of the test antenna, the effect can be quite significant (especially in the case where a pattern null of the test antenna is directed toward the source antenna). The multipath component received along Path B now propagates a significant amount of power relative to the total received power at the test antenna. Therefore, "filling" of the pattern nulls and distortion of lobes results, corrupting the measured antenna pattern. Additional multipath-inducing reflectors typically increase the distortion of measured patterns. The same is true for larger transmitter to receiver (T-R) distances, supported by research demonstrating that time dispersion induced by radio channels (e.g., RMS delay spread) generally increases with path loss over a wireless link [5].

A typical method adopted to combat multipath for far-field measurements is to design a large, flat range to eliminate reflections due to terrain. Traditionally, open-air ranges perform well (i.e., eliminate multipath) when highly directional antennas are used. However, emerging mobile communication systems use lower gain antennas making multipath effects more difficult to isolate. Absorbing material and diffractive fences can be used where the cause of multipath is nearly impossible to remove (e.g., the ground) [6]. Also, source antennas can be designed such that reflective areas are not illuminated. A more advanced technique presented here is to distinguish between the LOS component and multipath components using a wideband receiver to retrieve channel delay information.

By extracting the LOS component and only the LOS component from the received signal during antenna measurements, the effect of multipath components on the measured pattern can be eliminated. Several wideband techniques have been developed to resolve multipath for radio channel characterization measurements, including sliding correlation, radio frequency (RF) pulse, and frequency sweep [4]. Sliding correlation measurements, a type of channel sounding, is the technique used for this research. A sliding correlator measurement system produces a profile which shows received power versus propagation delay; this power delay profile represents the impulse response of the measured radio channel.

2. Measurement System

The sliding correlator measurement system has been used extensively in past research to characterize time dispersion and path loss of radio channels in many different types of environments (e.g., [2], [7]) but apparently has not been used to resolve LOS components at antenna ranges. The sliding correlator system is typically used to resolve individual multipath components to determine limitations for high-bandwidth communication systems due to intersymbol interference (ISI). Because of its practical multipath resolution capabilities of 10 ns or less, the sliding correlator system is well-suited for isolating the LOS component which arrives at a test antenna so that a pattern can be measured without influence by received multipath fields. This ability allows antenna measurements to be performed using sites which would likely result in inaccurate patterns if a CW system was used.

![Figure 2. The basic sliding correlator measurement system.](image)

Figure 2 and Figure 3 illustrate the general form of the sliding correlator measurement system. The transmitter in Figure 2 produces a CW carrier in the center of the frequency band to be measured. The carrier is modulated with a pseudo-random binary sequence (often called a pseudo-noise sequence or PN sequence) of length $l$ and chip rate $R_c$. The chip rate $R_c$ is determined by the transmitter chip clock, a second signal generator in the measurement system transmitter. The modulated signal is amplified and transmitted through the radio channel using a source antenna. The null-to-null bandwidth of the transmitted spectrum envelope is twice the chip rate, or

$$B_{RF} = 2R_c$$  \hspace{1cm} (1)

The PN sequence produced at the receiver shown in Figure 3 is clocked at a slightly slower rate compared to the rate of the transmitter PN sequence. The receiver approximates a cross correlation of the transmitted PN sequence with the PN sequence generated locally at the receiver using a mixer and a narrowband filter. Although the transmitter and receiver PN sequences are clocked at different rates, the sequences themselves are exactly the same. Therefore, since the difference in chip rates is small, a cross correlation of the transmitter and receiver
The basic sliding correlator receiver uses DS-SS techniques to realize processing gain. The output is a power delay profile which represents the channel impulse response. PN sequences approximates the autocorrelation function of PN sequences shown in Figure 4.

Since the receiver PN sequence is clocked slightly slower than that at the transmitter, the PN sequences appear to "slide" past each other over time. When a received PN sequence aligns with the PN sequence generated at the receiver, a voltage peak occurs at the output of the detector. During times of complete misalignment, low-level noise (thermal noise and self-noise [8]) exists at the output of the detector. If multiple delayed versions of the transmitted signal are received, then voltage peaks occur as the receiver PN sequence periodically aligns with the individual received sequences. The result is a plot of the received signal components versus delay as seen in the power delay profile shown in Figure 5. In this way individual multipath signal components are identified and measured.

The profile in Figure 5 shows one LOS component and one multipath component. The ordinate is normalized to the power of the LOS component, and the abscissa shows absolute propagation time between the transmitter and receiver. Since electromagnetic energy propagates at 3x10^8 m/s (approximately 1 ft/ns) in air, the profile shows that the T-R separation was approximately 290 feet (88.4 m), and that the excess distance traversed by the multipath was approximately 175 feet (53.3 m). In profiles like this one, measured with an unobstructed LOS path, it is simple to isolate the LOS component so that multipath component can be ignored for antenna pattern measurements.

Several parameters affect the capabilities and performance of the sliding correlator system. Hence, specification of these parameters is dependent upon the requirements of the antenna range and the measurements being performed. The minimum delay by which two signal components must be separated in order to be resolvable is the resolution of the system. The resolution $\Delta \tau$ is determined by the chip rate and is given by $\Delta \tau = 2/R_c$. Signal components separated by more than this will not overlap each other as can be noted in Figure 4. If only the peaks of the components are used to determine the signal component strengths, then the resolution requirement can be relaxed to $\Delta \tau = 1/R_c$ so that component bases do not overlap with adjacent peaks. If components are spaced more closely, then adjacent components interfere with each other in the same way that small-scale fading effects occur in CDMA systems when multiple signal components arrive within one chip period at the receiver.

Given a transmitter chip rate of $R_c$ and a PN sequence of length $l$ chips, the period of the PN sequence is $T_{PN} = l/R_c$ where $T_c$ is the chip period. The period $T_{PN}$ is related to the maximum unambiguous range of the sliding correlator system given by

$$D_{ab} = cT_{PN} = l\frac{T_c}{R_c} = lT_c c$$  

If multipath components travel excess distances greater than $D_{ab}$, then correlation peaks caused by distant reflectors could overlap with the LOS component and cause inaccuracies in the antenna measurements.
Other parameters which affect the performance of the sliding correlator system and descriptions of specific hardware implementations are described in detail in [7].

3. Range Design and Requirements

Range design requirements are related to the sliding correlator measurement system configuration and the specifications of antenna to being measured. Figure 6 illustrates dimensions defined for a basic measurement range. The source antenna and test antenna are mounted on towers of height \( h \) over flat, level ground. The antennas are separated by distance \( d_{LOS} \), and the test antenna rotates on an axis perpendicular to the ground to perform a planar cut.

The reflecting surface nearest to the two antennas is the ground, a common situation for many ranges unless a building or other object is in close proximity. Because the ground component is caused by the closest reflector, it exhibits the least excess delay and is the most difficult to resolve from the LOS component. The total distance along the reflected path is defined to be \( d_{ex} \). The relationships among the distance parameters is expressed as

\[
\left( \frac{d_{ex}}{2} \right)^2 = h^2 + \left( \frac{d_{LOS}}{2} \right)^2 \tag{3}
\]

The difference in distance between the length of the LOS path and the length of the reflected path (i.e., excess distance) is defined to be

\[
\Delta d = d_{ex} - d_{LOS} \tag{4}
\]

The resolution of the system, given by \( \Delta \tau = 1/R_c = T_c \), must be less than the time it takes an electromagnetic wave to propagate along the excess distance \( \Delta d \). Thus, given a chip rate \( R_c \), the excess distance \( \Delta d \) is bounded by

\[
\Delta d \geq \frac{c}{R_c} \tag{5}
\]

By defining a fixed tower height \( h \), the maximum source-to-test antenna separation distance can be calculated using equations (3) and (4). If \( \Delta d_{min} \) is the minimum allowable excess distance, then the antenna separation requirement is expressed as

\[
d_{LOS} \leq \frac{2h^2}{\Delta d_{min}} - \frac{\Delta d_{min}}{2} \tag{6}
\]

If the antennas are spaced farther than the distance bound given by equation (6), then the LOS component and the ground-reflection component will be separated by less than the resolution \( \Delta \tau \); and measurements may be affected by the combination of the signal components. It is helpful to express the antenna separation as a function of the antenna height and chip rate, given by

\[
d_{LOS} \leq \frac{2h^2R_c}{c} - \frac{c}{2R_c} \tag{7}
\]

Figure 6. The dimensions of a simple antenna range can be designed such that the measurement system can resolve the ground reflection between the source and test antennas.

The minimum antenna separation is determined by the far-field distance. The far-field distance is typically expressed as \( r_{ff} = 2D^2/\lambda \), where \( r_{ff} \geq D \), \( r_{ff} \geq \lambda \), and \( D \) is the extent of the antenna [9]. Finally, the fundamental design equation for the range configuration dimensions is

\[
\frac{2D^2}{\lambda} < d_{LOS} \leq \frac{2h^2R_c}{c} - \frac{c}{2R_c} \tag{8}
\]

Figure 7 illustrates design curves for the basic range geometry. Note that the plot can be used to estimate the maximum antenna separation, but the far-field distance criteria must still be applied. For example, suppose measurements are to be performed on a wideband antenna operating at 6 GHz (\( \lambda = 5 \) cm). The maximum extent of the

Figure 7. These curves relate the test and source antenna height to the maximum separation distance which permits separation of the LOS component from the ground reflection component.
antenna \( D = 0.2 \) m is given, and the sliding correlator is operating using a chip rate of 100 Mchips/s (10 ns resolution). If both the source antenna and the test antenna are mounted on 10 ft (3.05m) tall towers, then the maximum separation distance is 15.4 ft (4.7m). By applying the far-field criteria, the minimum separation is calculated to be 5.2 ft (1.6m).

**Figure 8.** This pattern for a biconical antenna was measured in a parking lot at 5.85 GHz using a sliding correlator with \( R_c = 100 \) MHz. (dB vs. \( \theta \))

With the range constructed with the correct geometry and the measurement system configured correctly, power delay profiles are recorded as the test antenna is rotated through 360°. For each incremental change in rotation angle, a power delay profile is recorded. Because the antenna separation is known, the absolute change in rotation angle, a power delay profile is recorded. Because the antenna separation is known, the absolute delay and hence the position of the LOS component in the power delay profile can be identified. Plotting the strength of the LOS component versus rotation angle yields the antenna pattern of the test antenna.

Figure 8 shows an example of a measured antenna pattern using a Watkins-Johnson biconical antenna as the test antenna. The source and test antennas were mounted on two 10 ft towers, and the measurements were performed with a sliding correlator system using a 100 MHz chip rate and a center frequency of 5.85 GHz. For this sample pattern, profiles were recorded for each 5° rotation of the test antenna (a higher angular resolution would be used during typical measurements for finer detail). The power pattern in Figure 8 includes only the contribution of the LOS signal component, excluding all multipath components. The measurements were performed near the Virginia Tech campus in a parking lot surrounded by three concrete buildings and numerous parked cars. Normally, multipath caused by building and car reflections would prevent using such a site for accurate measurements. However, employing a sliding correlator system with a resolution of 10 ns permits using convenient sites for measurements.

4. Simulations

The method of using wideband channel measurements to distinguish the LOS component is appropriate for measurements of relatively wideband test antennas. That is, the characteristics of the antenna which affect the power pattern must remain relatively constant over the bandwidth of the sounding signal used to probe the channel and measure the antenna. With this criteria satisfied, improvement of measurement accuracy in the presence of multipath is demonstrated using the two-component case illustrated by Figure 9.

The test antenna in Figure 9 receives the LOS signal component and a single significant reflected signal. The multipath signal arrives with strength \( 1/A \) of the LOS component and has a phase shift of \( \phi \) relative to the received LOS component. The multipath signal also arrives along a propagation path with an angle of \( \gamma \) relative to the LOS path. In general, assuming a time-invariant channel, the received signal in a multipath environment can be expressed using the vector sum of the individual signal components. Define \( v_{\text{LOS}}(\theta) \) to be the voltage induced at the port of the test antenna during CW pattern measurements in a multipath-free environment, where \( \theta \) is the rotation angle of the test antenna. Then for the case where one multipath component is present at the test antenna as shown in Figure 9, the voltage at the test antenna port \( v(\theta) \) can be expressed as

\[
v(\theta) = v_{\text{LOS}}(\theta) + \frac{1}{A} e^{i\phi} v_{\text{LOS}}(\theta - \gamma)
\]  

(10)

The LOS component is summed with the multipath component (an attenuated, phase-shifted copy of the LOS signal) which arrives at angle \( \gamma \) with respect to the LOS path. The multipath phase shift caused by excess propagation distance and any other phase shifts can be included in the phase term \( e^{i\phi} \).
accuracy can be realized by using a wideband profile technique to implement multipath rejection for pattern measurements, and the amount of improvement depends upon the number and strength of multipath components existing at the receiver.

5. Conclusion

This paper has presented an overview of an antenna measurement technique which employs multipath time delay resolution to eliminate the effect of multipath signal components on pattern measurements. Multipath component discrimination can be implemented using a high-resolution sliding correlator channel sounding system. The technique is especially useful at sites where multipath-inducing objects or terrain cannot be eliminated. Antenna pattern measurement simulations have shown an improvement of patterns produced using only the LOS component versus patterns measured using a CW system. In conclusion, the increased complexity of a wideband measurement system may prove to be a beneficial tradeoff for accurate measurements performed where multipath-free range sites are unavailable.

6. References


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