the slotline. This slotline guides energy between the top and bottom radiating elements, decoupling it cleanly from the antenna so that it can radiate away with minimal reflection.

The process works in reverse when the antenna is receiving. The radiating elements collect energy and the slotline guides it into the balun transformer. The balun transformer couples this energy to the coaxial line. The coaxial line then guides the energy into the RF front end where the energy is made available to the receiver. Ideally, antennas like this could be integrated onto the same board as a complete UWB radio.

3. PERFORMANCE

The prototype bottom fed antenna shown in Figure 1 has been optimized for use with ultra-wideband impulses whose spectral content ranges from about 2.5 GHz to about 6 GHz. The antenna radiates a 500 ps monocycle which becomes roughly a 1 ns waveform once it is received by a matched antenna. The pattern of the antenna is dipole-like: omni with variation no more than 3 dB in the horizontal or azimuthal plane, and a null along the vertical axis. Polarization is linear in the vertical direction. The antenna achieves a VSWR of about 1.5:1 across its operating band with reflection down about -14 dB. Because the elevation pattern of the antenna is a bit tighter than that for a conventional dipole, the antenna achieves a +3 dBi gain. This is about 1 dBi better than a conventional dipole. The phase response of the antenna is linear, so it transmits with minimal distortion. The efficiency of the antenna is on the order of about 90% or better. These characteristics are summarized in the table below, and examined at length in the following sections.

Characteristic:	**Specification:**
Radiated Waveform	*500 ps monocycle*
Pattern	*Omni in azimuth to* ± 1.5 *dB*
Polarization	*Linear (vertical)*
Matching	*VSWR ~1.5:1;* $\lvert S_{11} \rvert \sim -14$ *dB*
Gain	*Nominally ~ 3dBi*
Phase Response	*Linear*
Efficiency	*Nominally >90%*

Table 1: *Performance Summary for a Prototype Bottom Fed Planar Elliptical Dipole Antenna*

3A. PERFORMANCE: WAVEFORM

Impulse radio requires precise timing and clean, non-temporally dispersed waveforms to achieve high performance, accurate ranging, and crisp radar imaging. The antenna used in an impulse radio system must be able to radiate short pulses with minimal ringing. The bottom fed planar elliptical dipole antenna was designed with this requirement in mind.

When excited by a broadband impulse, this antenna radiates a monocycle-like impulse roughly 500 ps in duration. To verify this, a Picosecond Pulse Lab 4050B Pulser with a relatively flat response from 1-6 GHz was used to drive the prototype antenna [6]. A Farr Research Model TEM-2-50 TEM horn was used to receive the radiated impulse [7]. This horn antenna generates a voltage at its terminals that is directly proportional to the incident field. The signal was then captured by an HP 54750 sampling digitizing oscilloscope with a 12.4 GHz bandwidth. Figure 2 shows the measured radiated field. This radiated waveform becomes somewhat more elongated when received by a matched antenna.

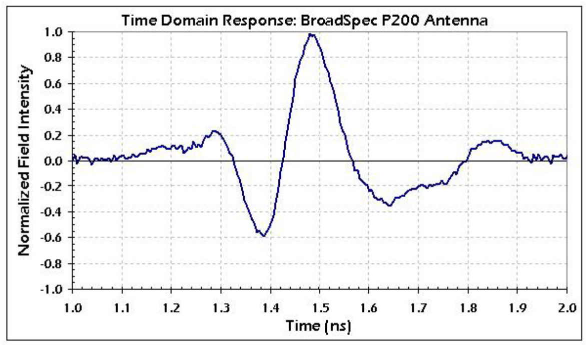

Figure 2: *Measured radiated field from a BroadSpec™ P200 antenna prototype excited by a UWB source.*

3B. PERFORMANCE: PATTERN

The bottom fed planar elliptical dipole antenna has a dipole-like pattern: omni (to within 3 dB). Peak gain for the antenna is about +3 dBi perpendicular to the face of the antenna, front and back. Gain is on the order of +0 dBi edge-on. The antenna has the usual dipole nulls along the axis of the antenna top and bottom. Thus, this antenna provides good coverage in the plane normal to the axis of the antenna, but may have difficulty achieving optimal range directly above or below the antenna. In most cases, an indirect path is likely to exist, however. In typical operation, the antenna is oriented with the long axis positioned vertically. This places the dipole nulls along the vertical axis, and provides best response in the equatorial, azimuthal, or horizontal plane.

Ansoft HFSS (high frequency structure simulator) was used to model the prototype antenna and calculate its radiation pattern. Figure 3 provides a typical result. This view shows the antenna edge-on with the front face of the antenna to the right, and the back face of the antenna oriented to the left. Figure 4 shows the principal planes of the antenna, and Figures 5a-c show peak power patterns in the principal planes.

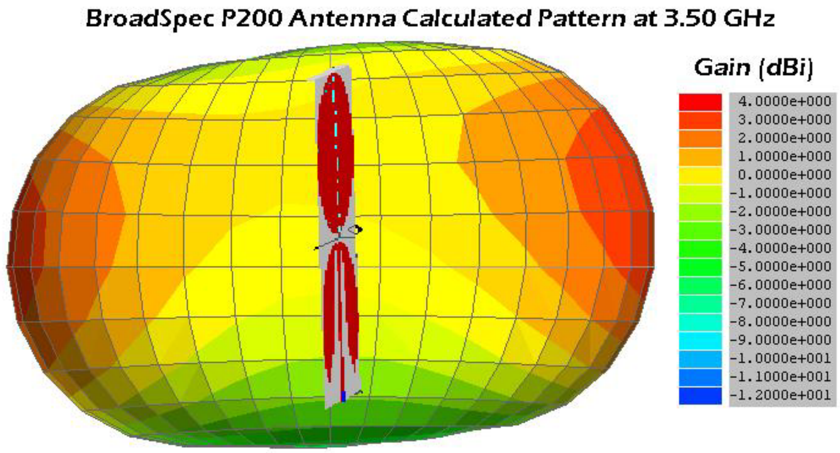

Figure 3: *Gain pattern of a prototype antenna as calculated by Ansoft HFSS at 3.5 GHz.*

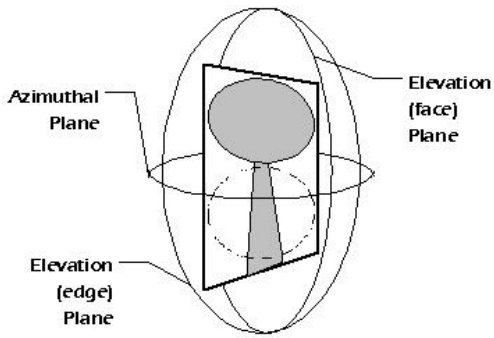

Figure 4: *Principal planes.*

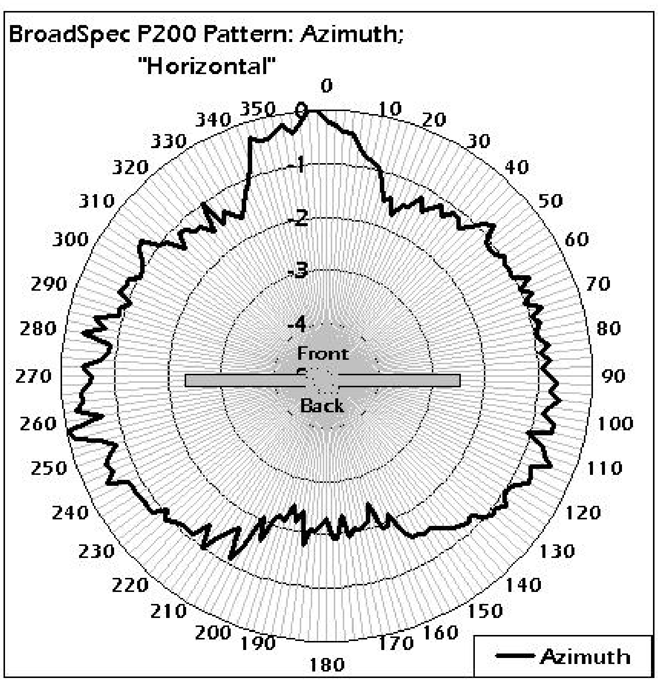

Figure 5a: *Peak power pattern, azimuthal plane.*

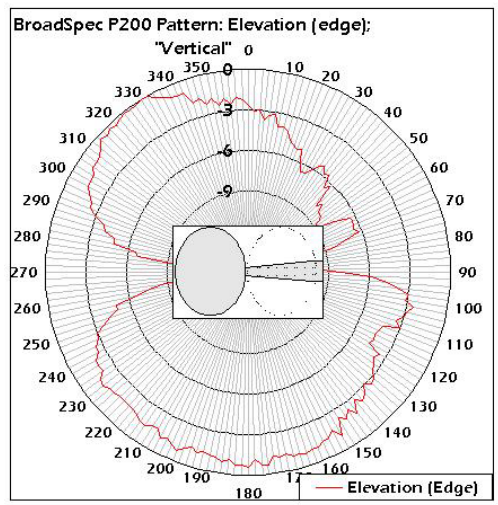

Figure 5b: *Elevation plane (edge-on).*

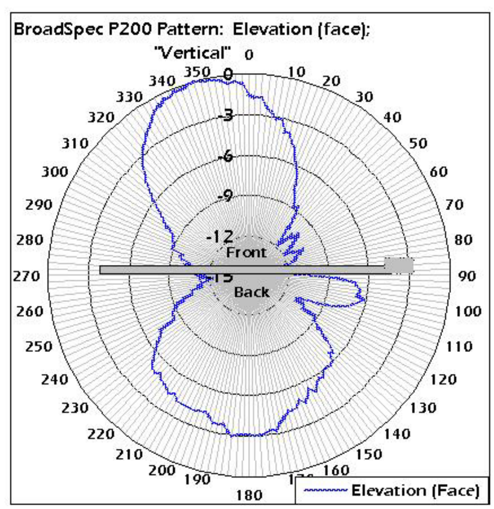

Figure 5c: *Elevation plane (face).*

3C. PERFORMANCE: MATCHING

The bottom fed planar elliptical dipole antenna offers an excellent match to 50 Ω. The voltage standing wave ratio (VSWR) is 1.5:1 or better from just below 3.0 GHz to nearly 5.5 GHz. Reflections from the antenna are down about –14 dB across this same band, thus the antenna accepts 96% of the applied power over these frequencies. Figure 6 shows this matching as a function of frequency from 0-7 GHz in Figure 6. Although optimized for the 3.0-5.5 GHz band, the prototype antenna remains fairly well matched up to beyond 20 GHz with VSWR on the order of 2:1 to 3:1. Figure 7 displays matching from 0-20 GHz. In both cases, matching was measured using a 10 MHz-20 GHz Rohde & Schwartz Vector Network Analyzer Model ZVM.

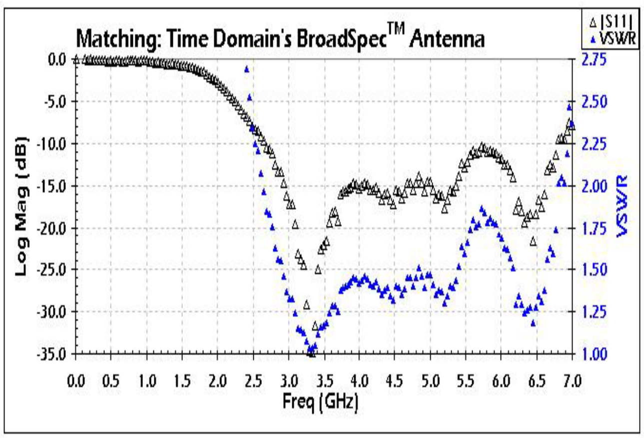

Figure 6: *Matching 0-7 GHz.*

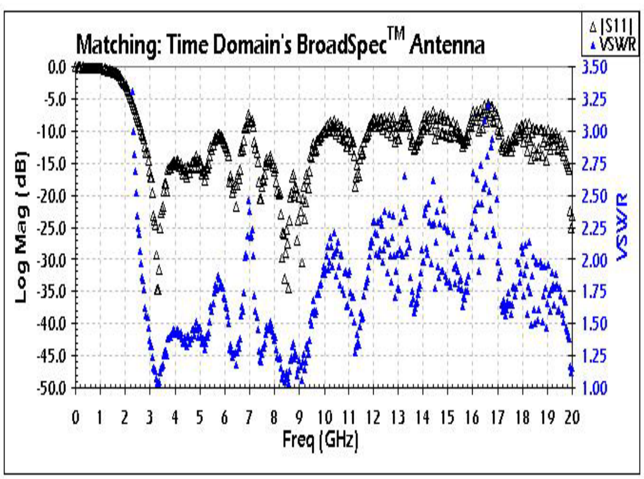

Figure 7: *Matching 0-20 GHz.*

3D. PERFORMANCE: GAIN

The prototype antenna has a nominal gain of about +3 dBi in the direction normal to either face of the antenna. Edge-on gain is on the order of about 0 dBi. These gain numbers are representative of antenna response from 2.5 GHz – 6.0 GHz. Gain was determined from the through response (S_{12}) of a matched pair of antennas using a 10 MHz-20 GHz Rohde & Schwartz Vector Network Analyzer Model ZVM. Figure 8 shows gain for a variety of orientations from 0-7 GHz, and Figure 9 depicts gain from 0-20 GHz. Note that even when the nulls of the antenna were aligned, a gain of about –6 dBi was still obtained. This is likely due to indirect propagation paths between the antennas under test, and represents a worst case scenario.

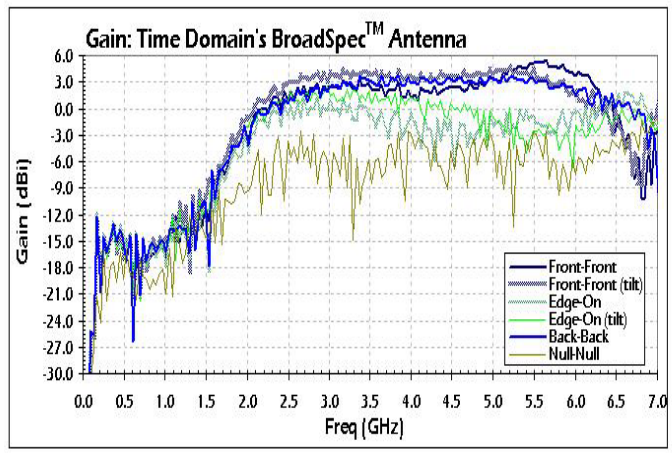

Figure 8: *Gain 0-7 GHz.*

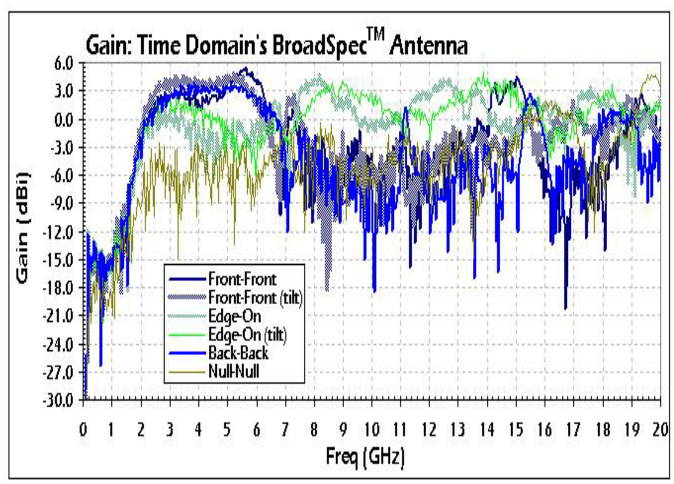

Figure 9: *Gain 0-20 GHz.*

3E. PERFORMANCE: PHASE

The bottom fed planar elliptical dipole antenna offers a very linear phase response. Linearity in phase as a function of frequency means that all frequency components of a signal have the same delay. Thus, a linear phase antenna transmits short pulse and ultra-wideband waveforms without distortion. The phase linearity between a matched pair of prototype antennas was evaluated using a 10 MHz-20 GHz Rohde & Schwartz Vector Network Analyzer Model ZVM. The delay due to the path length between the antennas has been removed. The remaining phase response is due to the delay through the balun transformers and slotlines of the matched pair of antennas. A phase inversion is evident at around 7 GHz, but in-band, phase is remarkably linear. Figure 10 presents these results.

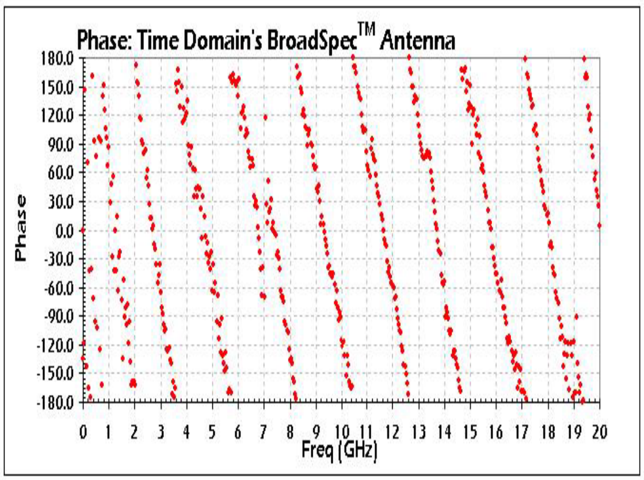

Figure 10: *Phase response, 0-20 GHz.*

3F. PERFORMANCE: EFFICIENCY

As noted in the section on matching, the prototype antenna accepts about 96% of applied power in band. Since the antenna is constructed on a low-loss substrate, and because resistive loading is not employed, virtually all of the accepted energy radiates. Accurate measurement of antenna efficiency across ultra-wide bandwidths poses formidable challenges, since losses in the measurement fixture tend to be much greater than losses in the antenna itself. Figure 11 depicts the result of a measurement of antenna efficiency, but this result probably understates the true efficiency of the antenna. In any event, the prototype antenna very efficiently radiates and receives ultra-wideband signals.

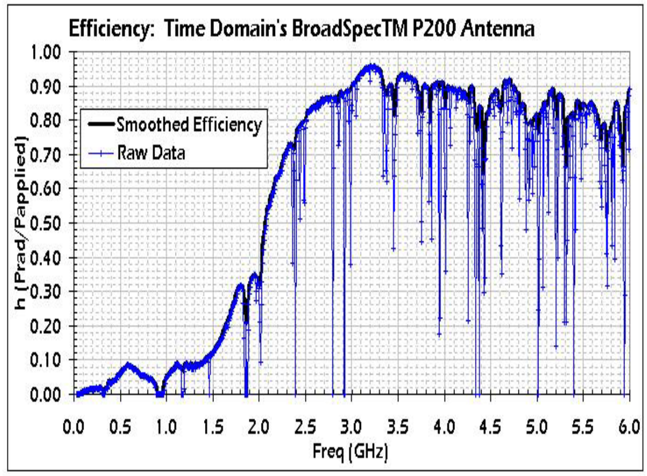

Figure 11: *Efficiency 0-6 GHz.*

4. CONCLUSION

Bottom fed planar elliptical dipoles are well matched and radiation efficient. They are omni-directional and are thus well-suited for ad-hoc networks with arbitrary azimuthal orientations. Furthermore, these antennas are electrically small and inexpensive without compromising on performance. Thus, bottom fed planar elliptical dipoles are well suited for commercial applications.

5. ACKNOWLEDGEMENTS

The work presented in this paper was performed while the author was employed by the Time Domain Corporation. The cooperation and assistance of the Time Domain Corporation are gratefully acknowledged.

6. REFERENCES

[1] H. Schantz, "Planar Elliptical Element Ultra-Wideband Dipole Antennas," IEEE APS 2002.

[2] H. Schantz, "Radiation Efficiency of UWB Antennas," IEEE UWBST 2002.

[3] The Time Domain Corporation markets planar elliptical dipoles under the brand name "BroadSpec™."

[4] Because these antennas are "bottom feeders" their original designation within the Time Domain Corporation was "catfish" antennas.

[5] H. Schantz, "Apparatus for establishing signal coupling between a signal line and an antenna structure" U.S. Patent 6,512,488 (January 28, 2003).

[6] Specifications for the PPL Model 4050B pulser are available at http://www.picosecond.com.

[7] Specifications for the Farr Research Model TEM-2-50 TEM horn are available at http://www.farr-research.com.