

# Spiral Slot Patch Antenna and Circular Disc Monopole Antenna for 3.1-10.6 GHz Ultra Wideband Communication

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## ABSTRACT

This paper introduces two antenna designs for Ultra Wideband 3.1-10.6 GHz communication. The primary antenna design is an equiangular spiral slot patch antenna with an outer radius of 2.25 cm. The incorporation of a ground plane enables conformability with small electronic UWB devices. Also, a circular disc monopole is designed and tested. Viability of these antennas is tested with a UWB pulse transmitter. Time domain responses are compared to that of a commercial 1-18GHz double ridged waveguide horn.

## INTRODUCTION

The recent allocation of the 3.1-10.6 GHz frequency spectrum by the Federal Communications Commission (FCC) for Ultra Wideband (UWB) radio applications has presented a myriad of exciting opportunities and challenges for antenna designers. Pulsed UWB, by definition, refers to any radio or wireless device that uses narrow pulses (on the order of a few nanoseconds or less) for sensing and communication. Successful transmission and reception of UWB pulses entails minimization of ringing, spreading and distortion of the pulse. This requires sufficient impedance matching and near constant group delay (ie. linear ungrouped phase) throughout the entire bandwidth.

In this paper, an equiangular spiral slot antenna design and a circular disc monopole (CDM) design will be presented for UWB applications. Time domain pulse reception from these antennas will be qualitatively compared against a standard wideband double ridged waveguide horn antenna with 1-18 GHz bandwidth and nominally 10dBi gain throughout the UWB band. We propose that pulse differentiation, distortion, dispersion etc. should not occur during transmission and reception of the pulses within the UWB band. The pulse that is transmitted should ideally be the same pulse that is received, such that correct detection can be employed at the digital backend of the UWB receiver.

The spiral slot patch antenna was designed and simulated in Remcom's XFDTD electromagnetic simulator and fabricated on Rogers TMM10i PCB material,  $\epsilon_r=9.8$ ,  $\tan\delta = 0.002$ , thickness = 0.5cm, as shown in Figure 1. The circular monopole antenna was simulated in CST Microwave Studio and fabricated with standard copper material, as shown in Figure 2.

## ANTENNA DESIGN

The spiral topology has long been known to achieve broadband impedance matching [1-3], as first introduced by Rumsey's theory of frequency independent geometry. A significant amount of research has been conducted on the spiral antenna topology since Rumsey's first discovery; however, the recent allocation of the UWB spectrum by the FCC has piqued new

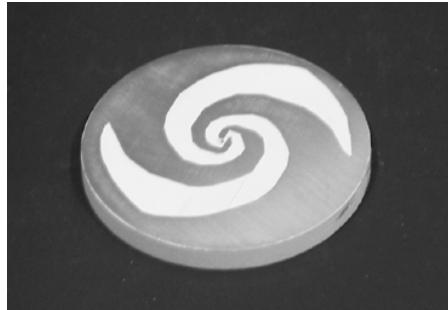


Figure 1: Photograph of the equiangular spiral slot patch antenna.

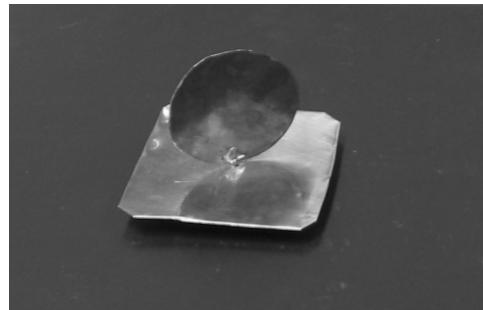


Figure 2: Illustration of circular disk monopole.

interest in this antenna area. [4-6] Key motivation for this research includes compact size, low profile and low pulse distortion upon transmission and reception. The spiral was constructed by the equation  $\mathbf{r} = \mathbf{r}_o e^{a(\mathbf{q}-\mathbf{q}_0)}$ , where  $\mathbf{r}$  and  $\mathbf{r}_o$  are the radial distance and initial radial distance for each arm of the spiral, respectively;  $\mathbf{q}$  and  $\mathbf{q}_0$  represent the angular position and initial angular position, respectively, and  $a$  is the expansion rate. The spiral was designed with an expansion rate of 0.38, initial inner radius of 1.5mm, total arm length of 6cm, outer radius of 2.25cm and arm slot ratio of 0.65. The total arm length was chosen for optimization of polarization and impedance bandwidth for the lower end frequency, while the other parameters were also optimized for bandwidth through simulation. When the spiral arm length equals approximately one wavelength, the impedance begins to match the feedline and the radiated wave achieves circular polarization (CP), which is desirable for optimal reception [7]. The chosen spiral arm length theoretically enables CP and impedance matching at 1.6 GHz and higher; however, the simulated and measured results indicated a better match at approximately 3.0 and 2.8 GHz, respectively. This is most likely due to the grounding effects of the spiral slot antenna, which reduce the bandwidth.

The key to this spiral design is that it is low profile and conformable to small electronic devices. Most spirals incorporate an absorptive back cavity, which significantly thickens the size of the antenna and decreases its efficiency; they also incorporate a balun feed, which increases design complexity and can harm the radiation pattern. In this design, neither an absorptive cavity nor a balun is used. A balanced feed is achieved with an MMCX to SMA connector with positive and negative terminals each attached to a spiral arm. Ground plane spacing is also minimized. Antennas held over ground planes require at least  $\lambda/4$  spacing at the lowest operating frequency such that image currents created by the ground plane do not cancel the radiation of the antenna. This required spacing is approximately 2.5 cm in free space at 3.1 GHz, the UWB lower end frequency. The design presented in this research uses high dielectric constant material, which enables size miniaturization and also lengthens the electrical distance from the spiral element to the ground plane, at the cost of reduced radiation efficiency. At a spacing of 0.5cm, a profile five times thinner than that required of a spiral radiating in free space is achieved.

The CDM antenna has been proposed to have a very large impedance bandwidth pattern and circular polarization [8-9]. In this research, a CDM is designed with a radius of 2.54cm and a ground plane 7.6cm x 7.6cm, the theoretical lower end frequency is given by [9]

$$f = c/\lambda = (30 * .24)/(l + r) \text{ GHz}$$

Where  $l$  = disc height (cm), and  $r$  = equivalent radius given by  $2\pi rl = \pi r^2$ . The equivalent radius is derived by equating the planar disc area with that of a cylindrical wire (monopole) of height  $l$ . The theoretical lower frequency is 1.28 GHz, and the measured lower frequency value is 1.45 GHz. While this design is not particularly low profile or planar, other properties such as circular polarization, demonstrable wide bandwidth and easy construction make it an interesting candidate to study pulse reception properties against the spiral antenna.

Figures 3 and 4 show the VSWR and delay plots of the spiral, the CDM antenna and the

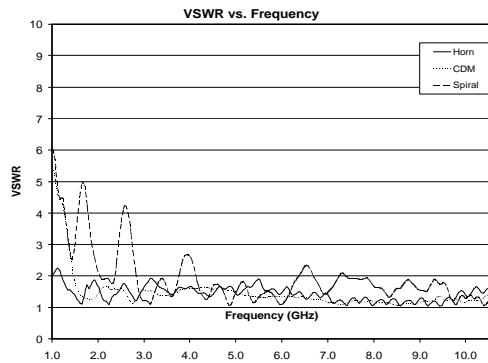


Figure 3: VSWR vs. Frequency for the horn antenna, CDM and Spiral.

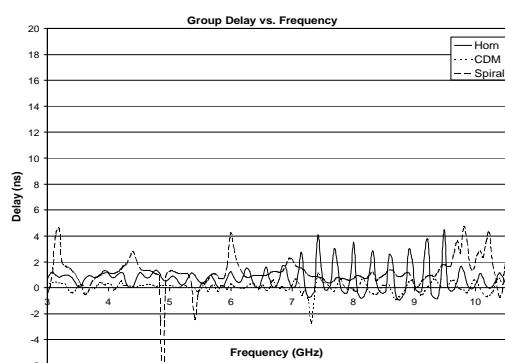


Figure 4: Group Delay vs. Frequency for the Horn Antenna, CDM and Spiral.

horn antenna. Figure 3 indicates  $VSWR \leq 2$  for the horn and CDM for the entire UWB bandwidth of 3.1-10.6 GHz. The spiral antenna only slightly reaches above  $VSWR=2$  line at three points throughout the bandwidth, indicating an acceptable impedance match for the UWB band. The group delay of the CDM is relatively constant compared to the horn and spiral. The horn exhibits group delay inconsistency with increasing frequency, while the spiral shows spikes of group delay inconsistency at certain frequencies. The spiral shows significant group delay improvement over the horn at higher frequencies, while it performs more poorly at lower frequencies.

## UWB TRANSMITTER SETUP

The transmitter system used to test the UWB antenna designs is based on a design from Intel labs [10], with block diagram shown in Figure 5.

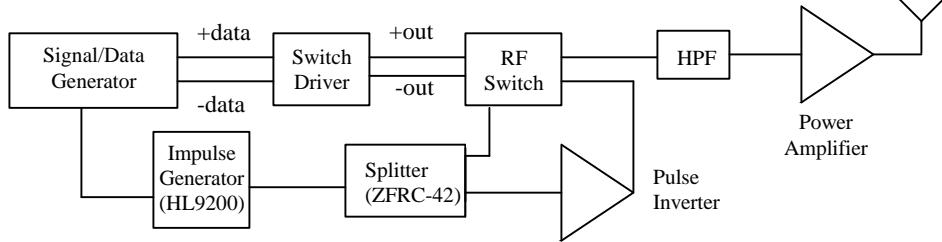


Figure 5: Transmit Block Diagram [10].

This system uses a clock and data generator, which provides a 100 MHz clock and data synchronized with the clock. This corresponds to a pulse repetition rate (prf) of 10ns. The clock is fed to an impulse generator, which generates sub-nanosecond pulses. The impulse generator is split into positive and negative pulses via a power splitter and pulse inverter. The positive and negative pulses are then fed to an RF switch, driven by a circuit that provides a -5V drive voltage. Thus, the RF switch produces positive and negative pulses at its output depending on the data that the RF switch driver receives. The switch output is then filtered through a high pass filter with a 3 GHz cutoff to provide transmission in the UWB frequency range. The signal is then amplified via a power amplifier, and then transmitted through a 1-18 GHz horn antenna.

Figure 6 shows the output from the impulse generator and the filtered UWB pulse, both measured on a digitizing oscilloscope at 500 ps/div and 30mV/div. The pulse output and filtered output required 20 dB and 10 dB of attenuation, respectively, to account for the sensitivity of the oscilloscope. While the pulse output and filtered pulse are not ideal and both show some level of ringing at the tail end, this does not disturb the main objective of this research, which is to receive the pulse that is transmitted with a minimal level of pulse shape distortion.

## RESULTS AND CONCLUSIONS

Figures 7, 8 and 9 illustrate the transmitted pulse from the horn antenna superimposed on

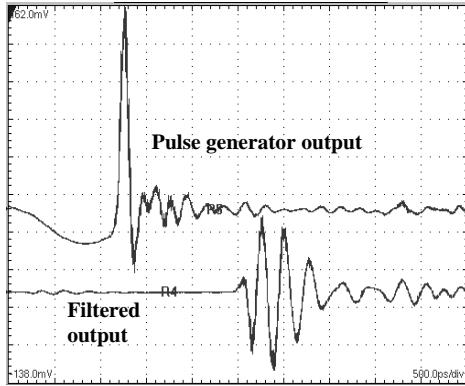


Figure 6: Impulse generator output (top) and filtered pulse output (bottom).

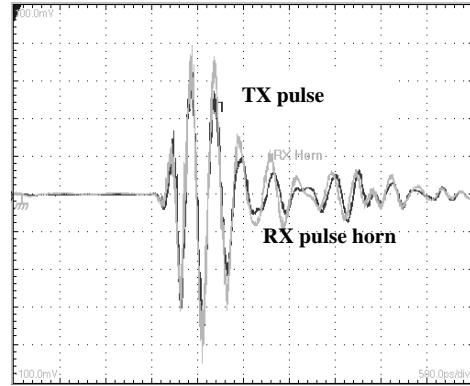


Figure 7: Transmitted pulse superimposed on received horn pulse.

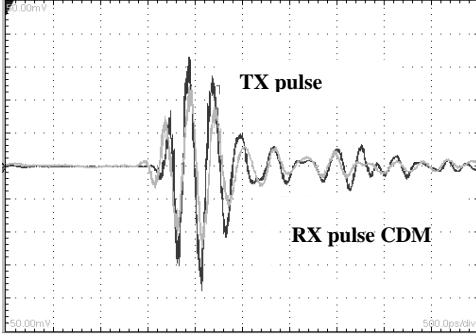


Figure 8: Transmitted pulse superimposed on received pulse from the CDM.

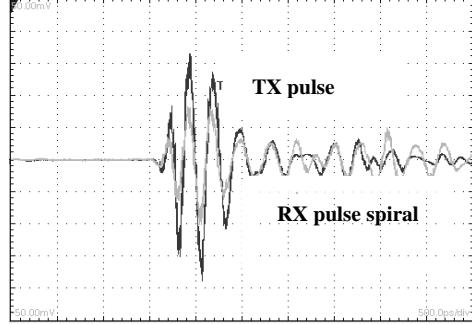


Figure 9: Transmitted pulse superimposed on received pulse from the spiral.

the received pulse from the horn, CDM and spiral, respectively. This test setup was conducted in a typical multipath lab environment, and the reception distance was approximately 1.5m. The transmitted pulse was measured directly at the amplifier terminals with a 30 dB attenuator. Each measurement was taken on a timescale of 500 ps/div and voltage level 20 mV/div, except for that of the spiral received pulse measurement, which was taken at 10 mV/div to better illustrate the pulse shape. By the theory of reciprocity, it can be inferred that each antenna is reciprocal in that it transmits the same way it receives.

Each plot shows clearly that very little pulse distortion can be observed from the transmitted pulse to the received pulse. Although the received pulse of the spiral antenna is significantly more attenuated than that of the CDM and horn antennas due to decreased radiation efficiency, it retains the pertinent pulse information, which is imperative for successful back-end processing. The spiral slot patch antenna and CDM antenna show very little difference in pulse shaping effects than that of the horn antenna, a known standard for transmitting wideband signals. While the CDM performs very well for UWB, the profile of the spiral antenna is more promising for UWB applications. Future work will focus on improvement of the spiral design, including further size reduction and improvement of radiation efficiency.

#### ACKNOWLEDGEMENT

The authors would like to acknowledge Michael Garcia-Webb and the Bioinstrumentation Laboratory at MIT for help with the spiral antenna fabrication. This work is sponsored by Hewlett-Packard under the HP/MIT Alliance and the NSF under contract ANI-0335256. Johnna Powell is supported by an NSF Graduate Fellowship. Any views expressed in this paper are those of the authors and do not necessarily reflect the views of the NSF.

#### REFERENCES

- [1] V.H. Rumsey, "Frequency Independent Antennas," *1957 IRE National Convention Record*, pt. 1, pp. 114-118.
- [2] J.D. Dyson, "The equiangular spiral antenna," *IRE Trans. Antennas Propagat.*, vol AP-7, pp.181-187, Apr 1959.
- [3] J. Wang, V. Tripp, "Design of Multi octave Spiral-Mode Microstrip Antennas", *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 3, March 1991.
- [4] Paulino, N, "Design of a Spiral-Mode Microstrip Antenna and Matching Circuitry for Ultra-Wide-Band Receivers," *IEEE International Symposium on Circuits and Systems*, vol. 3, 2002.
- [5] Liu, Bosui, A.M. Ferendeci, "Broadband Spiral Antennas with Thin Dielectric Substrates", *IEEE Radio and Wireless Conference, 2002 (RAWCON 2002)*, August 2002.
- [6] Asfar, M.N., Wang, Yong, Hanvi, D., "A New Wideband Cavity-Backed Spiral Antenna", *IEEE Antennas and Propagation Society International Symposium*, Vol. 4, July 2001.
- [7] C.A. Balanis, *Antenna Theory and Analysis*, 2<sup>nd</sup> ed., Wiley, New York, 1997.
- [8] S. Honda, M. Ito, H. Seki, and Y. Jingo, "A disc monopole antenna with 1:8 impedance bandwidth and omnidirectional radiation pattern," *Proceedings of the International Symp. Antennas Propagation.*, Sapporo, Japan, Sept. 1992, pp. 1145-1148.
- [9] Agrawall N. P. ,Kumar G.,Ray. K.P., Wideband planar monopole antennas", *IEEE Transactions on Antennas and Propagation*, vol. AP-46(2),pp.294-295,1998.
- [10.] Green, Evan R., Manny, Ben. "Ultra Wideband: A Disruptive RF Technology," *Intel Developer Conference*, February 28, 2002.