Differential and Single Ended Elliptical Antennas for 3.1-10.6 GHz Ultra Wideband Communication

Johnna Powell* and Anantha Chandrakasan
Massachusetts Institute of Technology
50 Vassar St. Rm 38-107, Cambridge, MA 02139
johnna, anantha@mtl.mit.edu

ABSTRACT

This paper introduces differential and single ended antenna designs for Ultra Wideband 3.1-10.6 GHz communication. The primary design is an ultra thin, low profile differential antenna with an incorporated ground plane for use with a UWB IC receiver. The differential capability eases the design complexity of the RF Front-End, and the incorporation of a ground plane enables conformability with small electronic UWB devices. Two single ended designs are also presented for use with a UWB IC transmitter. Both designs result in excellent bandwidth, efficiency, and nearly omnidirectional radiation patterns. 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 ultra thin, low profile, differential elliptical antenna (DEA, Figure 1) will be presented for UWB IC receivers. Two single-ended elliptical antennas (SEA, Figure 2), will also be presented for UWB transmitters and/or single-ended receivers. One SEA incorporates an elliptical radiator with a horizontal elliptical cutout to explore antenna loading bandwidth and frequency effects. 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.

These antenna topologies are derived from the recent work in circular and elliptical disc monopoles (CDM and EDM) [1-4]. While these antennas are extremely broadband, efficient radiators, they are not low

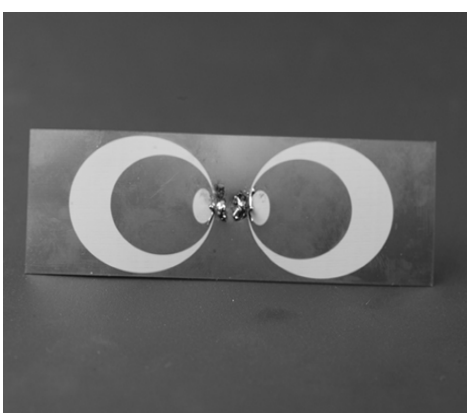

Figure 1. Differential Elliptical Antenna (DEA). Total area = 2.67cm x 4.57cm

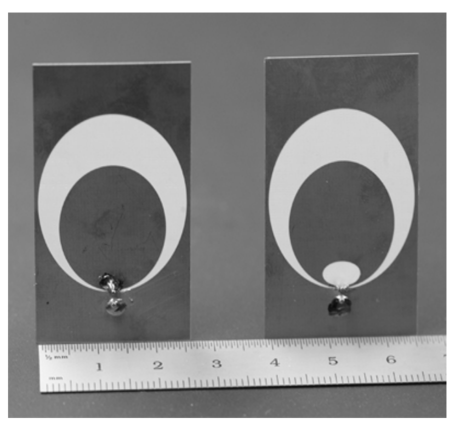

Figure 2. Single Ended Elliptical Antenna (SEA). Left: Unloaded. Right: Loaded (cm)

0-7803-8302-8/04/$20.00 ©2004 IEEE

profile. CDM and EDM antennas protrude perpendicularly from their ground planes, and therefore are not optimally compatible with an integrated circuit receiver. The differential and single ended elliptical antennas presented here are planar and enable easy integration of an IC. Work in single ended elliptical dipoles has also recently been explored [5], and a single ended antenna using a transmission line feed and horizontal elliptical design has also been presented [6].

ANTENNA DESIGN

The key intuition behind the SEA and DEA designs is the understanding of the bandwidth effects at various higher modes within a circular resonator such as a CDM. The roots of the derivative of the Bessel function characterize these closely spaced modes [4]. Since the antenna distance from the ground plane consistently increases symmetrically from the antenna feed, the impedance change from one resonant mode to another resonant mode is very small, and therefore enables a very large bandwidth from the fundamental resonant frequency on through much higher frequencies. The designs presented here differ from that of a CDM in that they are coplanar with their ground planes rather than perpendicular, and they are printed on dielectric substrate. As such, they have tapered clearance area from the ground plane, which increases fringing capacitance and therefore may cause a slight decrease in the fundamental frequency. This has been indicated in simulation. The theoretical lower end frequency for a CDM is given as follows [4]:

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

Where L = disc height (cm), and r =equivalent radius given by $2\pi rL = \pi r^2$. Adjustment for ellipticity is achieved by defining L = 2*y radius (cm) and r = (x radius)/4 (cm). The equivalent radius is derived by equating the planar disc area with that of a cylindrical wire (monopole) of height L. In this research, it has been found that this equation can be applied to the DEA and SEA for quite accurate results in design, simulation and measurements.

Each antenna was designed and simulated using CST Microwave Studio. They were fabricated on RO4350B material, e_r=3.36, $\tan\delta$ = 0.0037, and thickness = 0.004”. Measured results were extremely close to simulated results, and impedance matching was easily achieved with MMCX to SMA adapters at the feed. It was found that slightly increasing the ellipticity ratio enabled a better impedance match with an increase in directivity. Also, better impedance matching for the bandwidth was generally achieved with closer placement of the radiating ellipse to the feed point; however, the optimal match was achieved at approximately 0.010”. In the designs presented, the radiating ellipse was placed 0.005” from the ground plane at the Unloaded SEA feed, and 0.010” from the Loaded SEA and DEA feeds.

The radiating ellipse of each design had an x-radius of 0.360” and a y-radius of 0.405” with a total clearance ellipse of x-radius 0.500” and y-radius 0.575”. The horizontal elliptical slot load placed in the DEA and Loaded SEA had an x-radius of 0.130” and a y-radius of 0.080”. The slot was placed .010” from the feed point in the SEA and 0.005” from the feed point in the DEA. The frequency effects for each of these locations are not negligible, as can be seen in Figure 3, which illustrates the return loss for each of the antennas presented. The lower end theoretical frequency (VSWR ≤ 2) for a CDM of this size is 3.15 GHz. Simulations of a CDM of these dimensions were in agreement with theory (achieving a lower end frequency of 3.13 GHz). The measured lower end frequencies of the antennas presented in this paper were 3.09 GHz for the Loaded SEA, and 3.2 GHz for the Unloaded SEA and DEA. This further solidifies the argument that the CDM equation can be used in designing the planar elliptical antennas. The Loaded SEA seems to have a

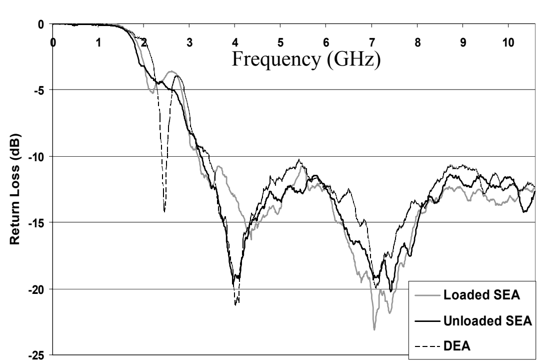

Figure 3. Return Loss plot for SEAs and DEA.

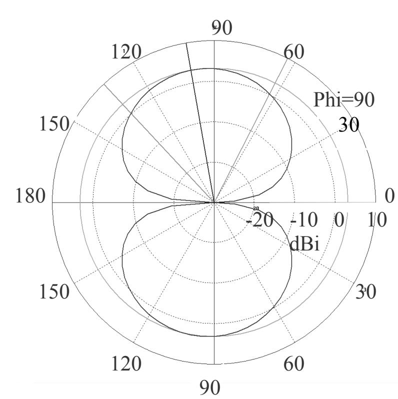

Figure 4. Simulated SEA Radiation pattern.

slight advantage in achieving better impedance matching throughout the UWB frequency band, especially affecting the second mode of resonance at 7.2 GHz, as well as achieving a slightly lower f_o. This suggests that size reduction can be employed with further investigation of antenna loading techniques. The DEA would be expected to achieve similar characteristics as the Loaded SEA; however, the slot load placement is twice the distance from the feed in the DEA than the SEA, and the surrounding metal area also alters its frequency characteristic. Slight differences in the antenna feed could have also caused inconsistency in comparison of the Loaded SEA and DEA. One notable characteristic of the DEA is that it had a resonant point at 2.46 GHz, although not optimally tuned, which suggests that dual mode 802.11b and UWB antennas are certainly achievable. This result was also observed in simulation.

Figure 4 illustrates the simulated radiation pattern for the Unloaded SEA at 4 GHz for varying theta, at position phi = 90 degrees, with directivity = 3.2 dBi and beamwidth = 70 degrees. Notably, the most important features of these designs are the achievement of wide bandwidth throughout the UWB frequency range for all three antennas presented, nearly omnidirectional simulated radiation patterns, and the resonance effects of antenna loading, which could facilitate size reduction.

UWB TRANSMITTER SETUP

The transmitter system used to test the UWB antenna designs is based on a design from Intel labs [7], with block diagram shown in Figure 5.

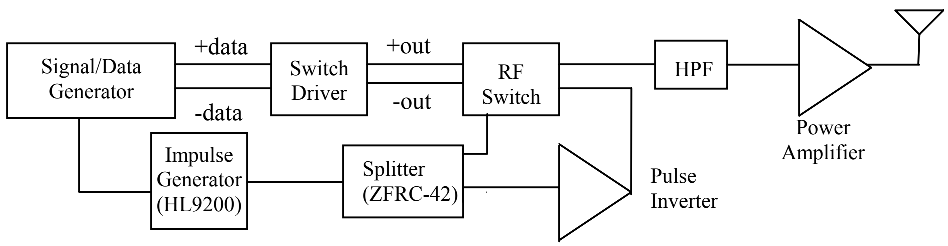

Figure 5: Transmit Block Diagram [7].

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

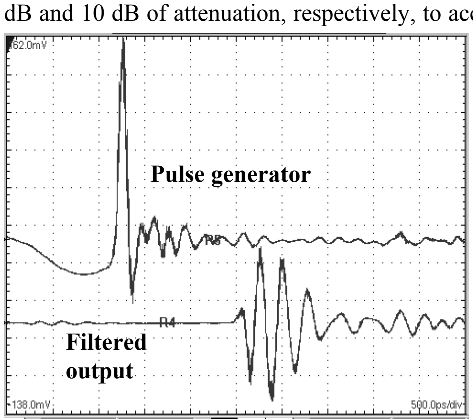

Figure 6: Impulse generator output (top) and filtered pulse output (bottom).

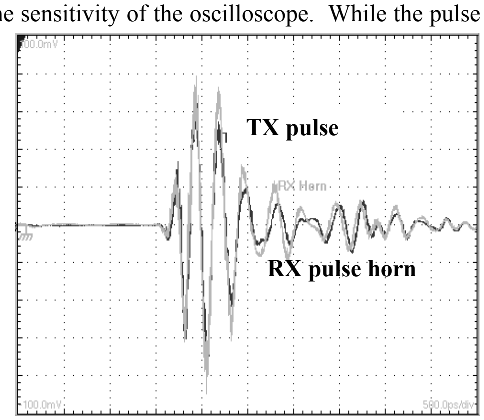

Figure 7: Transmitted pulse superimposed on received horn pulse (gray).

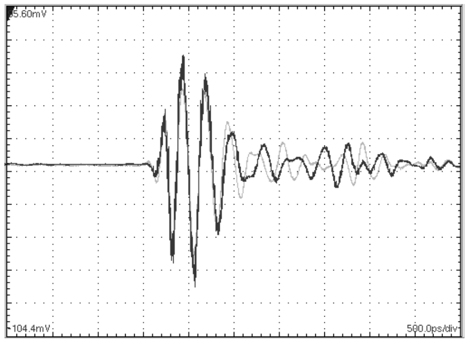

Figure 8: Transmitted pulse superimposed on received pulse from the Loaded SEA (gray).

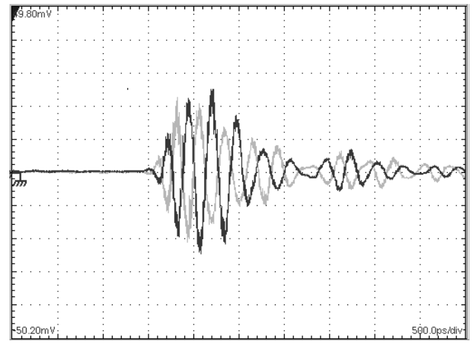

Figure 9: Received pulses from positive and negative terminals of the DEA.

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 and 8 illustrate the transmitted pulse from the horn antenna superimposed on the received pulse from the horn and Loaded SEA, respectively. Pulse reception measurement was similar for the Unloaded SEA and the DEA. 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. Figure 7 shows measurements taken at 20 mV/div. The measurements of the received pulses of Figures 8 and 9 are taken directly at the antenna terminals at 10 mV/div. By the theory of reciprocity, it can be inferred that each antenna transmits the same way it receives.

The differential antenna was optimized for RF Front-End co-design, as the common ground spacing between the positive and negative terminals allow for the IC to be housed. At high frequencies, substrate noise can be a substantial problem, rendering a differential input at the RF Front-End an optimal solution such that common mode noise can be rejected. Figure 9 illustrates the received pulses from the positive and negative terminals of the DEA, indicating that the received pulses are inverses of each other. Further testing will indicate viability of this method.

Each plot shows clearly that very little pulse distortion can be observed from the transmitted pulse to the received pulse. There is very little qualitative difference that can be observed in pulse distortion for the horn vs. the elliptical antennas for line of sight, short-range measurements. Future work will focus on further investigation of antenna loading effects and size reduction.

ACKNOWLEDGEMENT

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] 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 Prop.*, Sapporo, Japan, Sept. 1992, pp. 1145–1148.

[2] Hammoud, M., et al., “Matching the Input Impedance of a Broadband Disc Monopole,” *Electronics Letters*, Vol.29, Feb. 1993, pp. 406-407.

[3] 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.

[4] Kumar, G., Ray, K.P., *Broadband Microstrip Antennas*, Archtech House, Boston, 2003.

[5] Schantz, H., “Planar Elliptical Element Ultra-Wideband Dipole Antennas,” *IEEE Antennas and Propagation Society Int. Symp.,* Vol. 3, 2002.

[6] Kovacs, I., Eggers, P., “Short-range UWB Radio Propagation Investigations Using Small Terminal Antennas,” *International Workshop on Ultra Wideband Systems*, 2003.

[7] Green, Evan R., Manny, Ben. “Ultra Wideband: A Disruptive RF Technology,” *Intel Developer Conference*, February 28, 2002.