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Circular Dipole Antenna for Mode 1 UWB Radio with Integrated Balun Utilizing a Flex-rigid Structure

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Abstract—A fully integrated dipole antenna with balun for ultra-wideband (UWB) radio utilizing a flexible and rigid printed circuit board is presented in this paper. The concept in this paper is to take advantage of the respective possibilities of the rigid and the flexible part. The balun utilizes broadside-coupled microstrips and is integrated in the rigid part of the printed circuit board, whereas the radiator is placed in the flexible part. The antenna with the balun covers the Mode 1 UWB frequency-band 3.1-4.8 GHz (with margin) at VSWR<2. Furthermore, good radiation characteristics and a linear phase response are observed with measurements.

Index Terms—Balun, broadside-coupled, circular, dipole antenna, UWB, Ultra-wideband.

I. INTRODUCTION

Ever since the effort to achieve one sole UWB standard halted in early 2006, two dominating UWB specifications have remained as top competitors [1]-[8]. One is based on the direct sequence spread spectrum technique [4], [7]-[8]. The other is based on the multi-band orthogonal frequency division multiplexing technique (Also known as “Wimedia UWB”, supported by Wimedia alliance) [5]-[6], [8]-[9]. The multi-band specification divides the frequency spectrum into 500 MHz sub-bands (528 MHz including guard carriers and 480 MHz without guard carriers, i.e., 100 data carriers and 10 guard carriers). The three first sub-bands centered at 3.432, 3.960, and 4.488 GHz form the so-called Mode 1 band group (3.1-4.8 GHz) [4]-[8].

All the research efforts that have been made during the era of UWB antenna development have resulted in many ideas for good wideband antennas [10]-[19]. However, the general focus has so far been on the antenna element but not so much on how the antenna can be used and integrated in a UWB system. Utilizing a flexible substrate the antenna can be bent and placed in many different ways without a major distortion of the antenna performance [20]. Moreover, for a distortion free UWB communication an omnidirectional pattern and linear phase response are desired [21]-[22]. Small element antennas to which circular dipoles belong exhibit those properties [3], [10]. Using the flex-rigid concept the antenna is made on the flexible part of the flex-rigid structure. In the

rigid part other circuitries are designed and placed as with any other type of regular multi-layer printed circuit boards. To connect the dipole antenna to a 50- Ω single-ended port a balun is needed, and traditionally the balun is built with lumped components [23], [24]. However, in this paper the dipole antenna balun is realized with distributed components and integrated in the rigid part. Interconnect between the antenna and the balun is thus directly routed on the same metal layer, assuring a good electrical interconnect.

II. OVERVIEW OF THE SYSTEM

As shown in Fig. 1 all prototypes were manufactured using a flex-rigid printed circuit board (two metal-layers in the flexible part and four in the rigid part). The rigid and the flexible substrates are processed together in a printed circuit board bonding process, i.e., the adhesive layers are used to bond the polyimide layers.

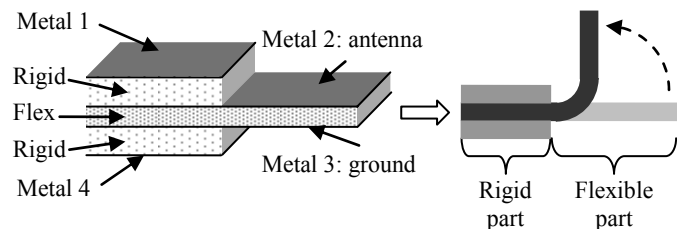


Fig. 1. Flex-rigid printed circuit board structure.

Table 1. Printed circuit board parameters

Parameter (Polyimide)	Dimension
Dielectric constant	3.40±0.05
Dissipation factor	0.004
Parameter (Adhesive)	Dimension
Dielectric constant	3.60±0.10
Dissipation factor	0.020
Parameter (Metal, common)	Dimension
Metal thickness, layer 1, 4	0.038 mm
Metal thickness, layer 2, 3	0.018 mm
Metal conductivity	5.8×10 ⁷ S/m (Copper)
Surface roughness	0.001 mm

Table 1 lists the printed circuit board parameters, with the stack of the printed circuit board layers shown in Fig. 1. Metal layers 1 and 4 are thicker than metal layers 2 and 3 because the two surface layers are plated, when plating vias of the board.

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Table 2. Printed circuit board build-up

Rigid 1	Dimension (mm)
Metal 1	0.0380
Adhesive	0.0254
Polyimide	0.1270
Adhesive	0.0254
Adhesive (Bonds rigid-flex)	0.0254
Coating 1	Dimension (mm)
Polyimide	0.0254
Adhesive	0.0254
Flex	Dimension (mm)
Metal 2	0.0180
Polyimide	0.0508
Adhesive	0.0508
Polyimide	0.0508
Metal 3	0.0180
Coating 2	
Same as Coating 1	
Rigid 2	
Same as Rigid 1, and Metal 4 is identical to Metal 1	

Table 2 shows the detailed specification of the flex-rigid printed circuit board build-up. It is seen in Tables 1 and 2 that the total substrate height between Metal 1 and 2 and between Metal 3 and 4 is 0.2540 mm. It is also seen that the substrate height between Metal 2 and 3 is 0.1524 mm.

A. Circular dipole antenna

Fig. 2 shows a circular dipole antenna realized using the flex-rigid substrate. The antenna is positioned in the x-y plane, and $\phi=0$ (Horizontal plane) is along the x-axis. The radiating antenna element is placed entirely on the flexible part of the substrate. Furthermore, the balun is integrated in the rigid part of the substrate.

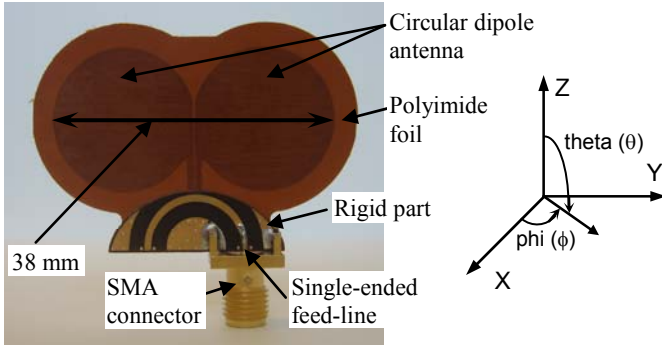


Fig. 2. Photo of the circular dipole antenna, positioned in the x-y plane.

B. Balun used with the dipole antenna

Fig. 3 shows an illustration of the broadside-coupled balun. The balun is used together with the dipole antennas and built with the broadside-coupled microstrips [11]-[13]. By implementing the balun in a multi-layer structure a more compact design is achieved. The single-ended microstrip-line is placed on Metal layer 1. The differential microstrip-line of the balun is placed on Metal layer 2, directly beneath the microstrip-line on Metal-layer 1. The two lines then exhibit a strong broadside-coupling. Since the arm ends of the differential lines are grounded at its ends there is a 180° phase-shift between Port 2 and 3. Metal 2 is also the metal-

layer where the radiator is placed, i.e., the differential feed-line is directly routed to the antenna.

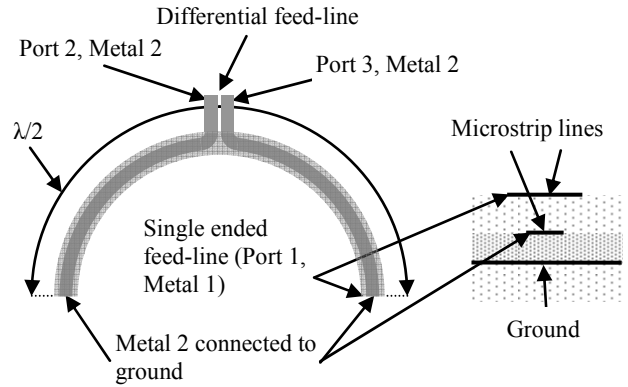


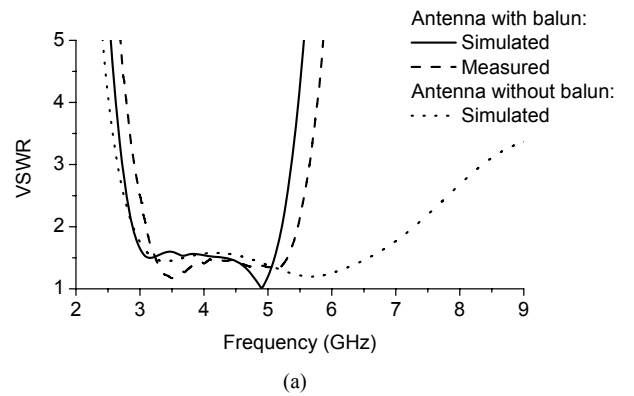
Fig. 3. Layout and cross-section of the broadside-coupled balun.

III. RESULTS

Design and simulation were done with ADS2006A from Agilent Technologies Inc. Electromagnetic simulations were done with Momentum, a built-in 2.5D field solver of method of moment.

A. Circular dipole antenna

Fig. 4 shows voltage standing wave ratio (VSWR) simulation and measurement of a circular dipole antenna on the flex-rigid substrate. The VSWR simulation results from antennas with and without the balun and measurement results from the antenna with the balun are shown. It is seen in Fig. 4a that the circular dipole antenna has a wide impedance bandwidth (VSWR<2.0 with a margin in the entire Mode 1 frequency-band, both with and without balun) using the suggested flex-rigid structure. Moreover, it is seen in Fig. 4b that the VSWR is stable when the antenna is bent (also see Fig. 1) from 0° to 45° and 90° in the entire frequency-band (3.1-4.8 GHz). Furthermore, it is also seen that the balun is the component limiting the bandwidth. A small shift in frequency between simulation and measurement is observed which may attribute to the fact that the simulated phase velocity is lower than the actual one.



(a)

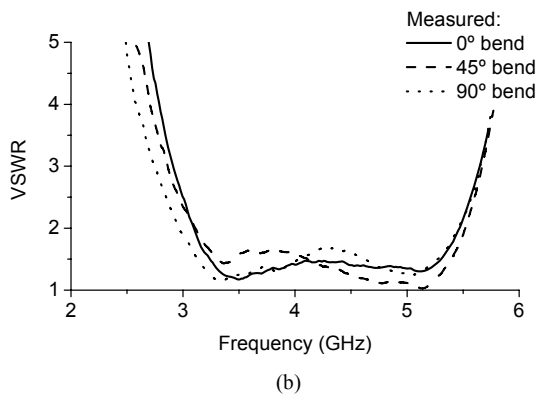


Fig. 4. Circular dipole antenna. (a) VSWR simulation with and without balun and measurement with balun, and (b) Measured VSWR when the antenna is bend 0° , 45° and 90° (bending definition see Fig. 1), respectively.

Fig. 5 shows radiation simulation and measurement of the circular dipole antenna. The radiation patterns are similar in the three sub-bands of 3.432, 3.960, and 4.488 GHz, as seen in Figs 5a-5c. The pattern becomes slightly more focused at higher frequencies, which is expected since the physical size is larger compared to the wavelength at the higher frequencies [24]. Fig. 5d shows the radiation pattern at 3.960 GHz when $\phi=90^\circ$ (Vertical plane). It is seen that the radiation is symmetric as expected from an omnidirectional dipole antenna. Furthermore, the radiation from the cross polarization is higher in the measurement than in the simulation, owing to the fact that any contribution from the balun is not included in the simulated radiation pattern. Fig. 5e shows simulated and measured gain in dBi at the boresight direction. A match between simulation and measurement is seen within the Mode 1 UWB frequency-band (3.1-4.8 GHz), and a gain around 2 dBi is observed. However, some difference between simulation and measurement is seen, especially outside the Mode 1 UWB frequency-band. This is also due to the fact that the effect of the balun is not included in the radiation simulation. The balun is, as shown in Fig. 4a, the component that limits the bandwidth, i.e., giving the bandpass filtering effect below 3.0 and above 5.5 GHz (see section III-B for further information about the balun performance). Fig. 5f shows the measured S_{21} phase response from a transmission between two identical circular dipole antennas, including the contribution from the transmitter antenna to the receiver antenna. It is seen that the established radio link has good phase linearity.

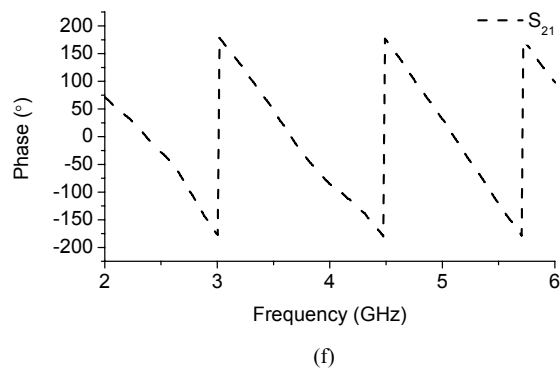
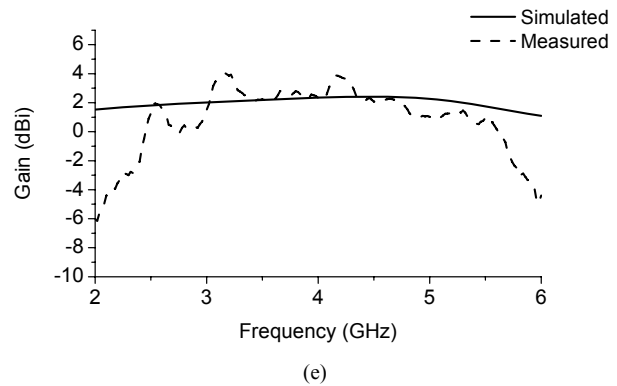
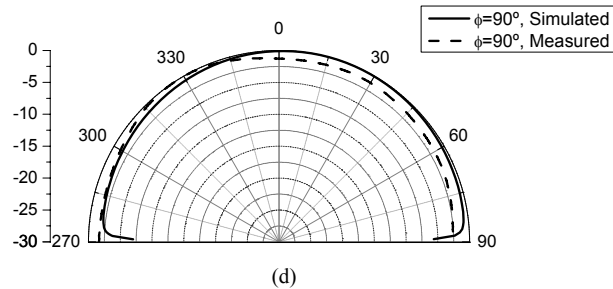
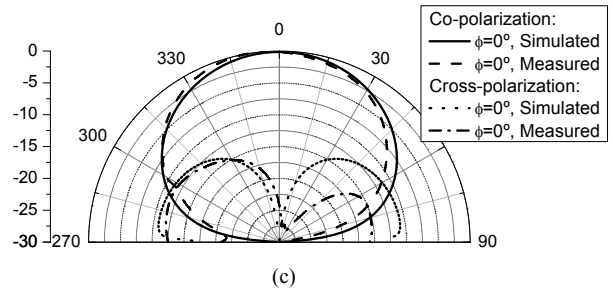
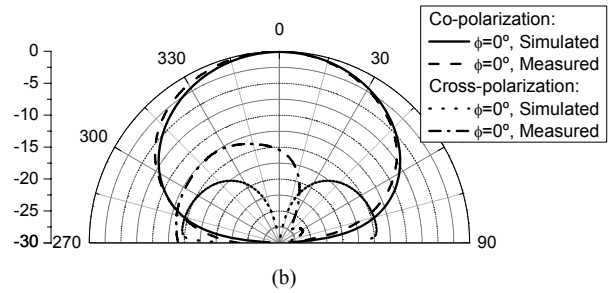
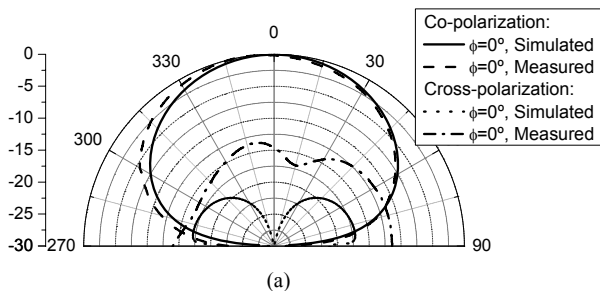


Fig. 5. Simulated and measured results of the antenna: (a) radiation pattern at 3.432 GHz, $\phi=0$, (b) radiation pattern at 3.960 GHz, $\phi=0$, (c) radiation pattern at 4.488 GHz, $\phi=0$, (d) radiation pattern at 3.960 GHz, $\phi=90$, (e) gain in dBi at the boresight, and (f) measured S_{21} phase response (transmission between two circular dipole antennas).

B. Balun used with the dipole antenna

Fig. 6 shows simulations and measurements of the broadside-coupled balun shown in Fig. 3. A balun-only prototype (without antenna) was used, and two SMA-connectors were mounted on the differential port to perform single-ended measurements. It is seen in Fig. 6a that the balun has a simulated differential insertion loss (IL) less than 0.8 dB in the Mode 1 UWB frequency-band. Figs. 6a and 6b show a rather symmetric performance of the two signal paths. S_{21} and S_{31} are single-ended forward transmissions, from Port 1 to Port 2 and 3, respectively. However, it is seen that above the Mode 1 UWB frequency bandwidth (3.1-4.8 GHz) the IL increases. Figs. 6c and 6d show simulated and measured phase response (single-ended S_{21} and S_{31}), respectively. It is seen that the phase shift is linear, and the phase difference is close to 90° between 2.0 to 7.1 GHz from simulation, and 2.0 to 7.5 GHz from measurement. It is noticed that a small notch is seen at 3.05 GHz. This occurs when the total length from the antenna feed-point (Ports 2 and 3 in Fig. 3) to the grounded end of each path of the balun is equal to one quarter wavelength. In this work, the length of the differential antenna feed-line was optimized so that the small notch fell below the Mode 1 UWB frequency-band.

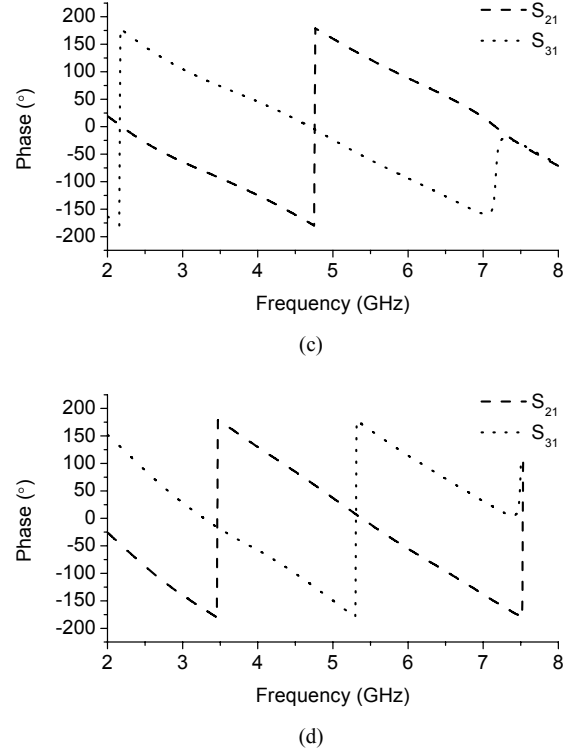
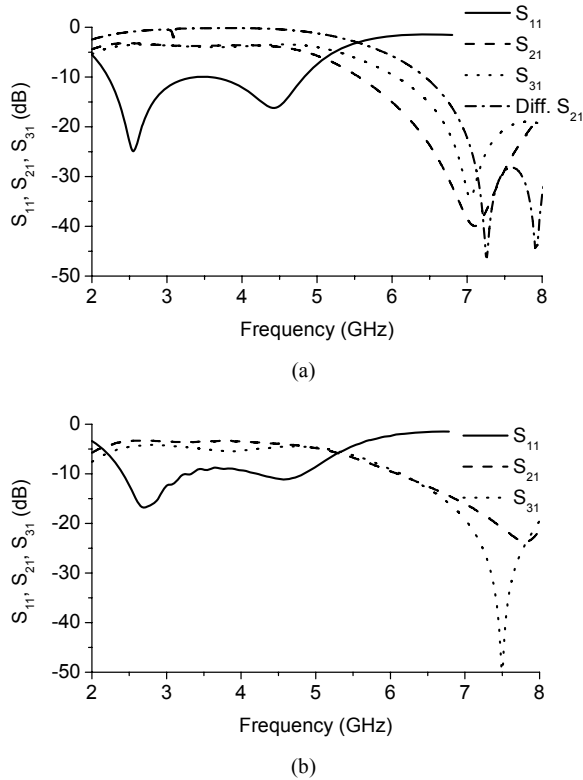


Fig. 6. Balun: (a) simulated forward transmission, single-single and single-differential ports, (b) measured forward transmission, single-single port, (c) simulated phase response, and (d) measured phase response.

IV. DISCUSSION

Space and cost are two unavoidable factors in consumer electronics. The benefit with flex-rigid is that the antenna is integrated on a printed circuit board but it can still be bent to better fit inside a handheld device for instance. Furthermore, since the flex-rigid structure is bonded together to one board good electrical interconnect is maintained between the antenna and the rest of the circuitry. The simulations and measurements of the circular dipole antenna indicate that the antenna has a typical radiation pattern as expected from a common dipole antenna. It is also observed (Fig. 4) that the balun limits the bandwidth if the dipole antenna is used with a single-ended port. However, this antenna with the balun (Fig. 2 and 4) has a good bandpass characteristic, covering the frequency band 3.1-4.8 GHz required by the Mode 1 UWB specification. A general agreement was seen between measurement and simulation. However, some differences are also noticed, mostly in the radiation results. This is due to the fact that the effect of the balun is included only in the VSWR simulations (Fig. 4), but not included in the radiation simulations (Fig. 5). ADS Momentum cannot handle finite-size substrate with different layer stacks. Therefore, the flexible and the rigid parts were simulated as isolated components, each with its respective printed circuit board stack. Since the balun limits the bandwidth, the measured gain (dBi) in Fig. 5e has a sharper passband-like shape (see also Fig. 6a and 6b) compared to the simulation from the antenna without the balun. Moreover, the measured radiation from

cross-polarization is higher than indicated by simulations, due to effect from the balun in the rigid part that is not considered in the simulations. Conclusively, all electrical parameters (VSWR and phase linearity etc.) show good agreement between simulation and measurement for all frequencies, whereas radiation parameters except cross-polarization show good agreement within the Mode 1 UWB frequency band (3.1-4.8 GHz).

V. CONCLUSION

A circular dipole antenna implemented using the flex-rigid substrate including the integrated balun can cover the Mode 1 UWB frequency bandwidth (3.1-4.8 GHz) at a measured VSWR<2.0 (with margin). The radiation pattern is stable within the entire Mode 1 UWB frequency band. Moreover, good phase linearity is observed when the antenna is used in a wireless transmission, i.e., the antenna is used for both transmitting and receiving operations. With these excellent properties the antenna can be either used as a free-stand component or integrated in a UWB system.

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Between 1991 and 1999 he was a senior researcher at the microelectronic institute – Acreo in Sweden. From 2000 to 2001 he was the CTO at a spin-off company from the institute. Since 2002 he has been full professor in communication electronics at Linköping University, Sweden. His main research interest has been communication electronics including RF design, wireless communications and high-speed data transmissions.