Printed-Circuit Monopole Antenna for Super-Wideband Applications

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***Abstract*—A novel super-wideband (SWB) antenna is presented. It is designed in microstrip technology based on planar monopole antenna theory. In order to achieve acceptable high-frequency return loss, a gap is added between the radiator and the ground plane, and the microstrip line is narrowed down at the feeding point. The prototype is fabricated on standard Rogers 5880 substrate with thickness of 0.254 mm and ε_r = 2.2. Measurements of the return loss up to 110 GHz and measured patterns and gain up to 40 GHz show good agreement with results from full-wave simulations.**

***Index Terms*—super-wideband antenna, planar monopole antenna, microstrip antenna.**

I. INTRODUCTION

High data rate wireless communication systems have expanded during the past decade and entered into the millimeter-wave spectrum beyond 100 GHz. In recent years, different wireless communications have been introduced such as spread spectrum, ultra-wideband (UWB) and Wi-Gig. Moreover, increasing the operational frequency is vital in imaging applications when enhanced resolution is required. Dual-band and multi-band wireless systems, operating in the mm-wave range, can employ widely different operational frequencies [1], and designing an antenna which covers the entire frequency range can be challenging. Applications like spectrum sensing require an antenna which covers a wide frequency band and is compact for integration with other RF building blocks in a fairly small size. Therefore, many different super-wideband (SWB) antennas have been introduced.

Microstrip or coplanar waveguide (CPW) technology is the preferred choice for antenna designers because of their ability to be integrated with other components and integrated circuits at usually low cost.

Typical monopole antennas are 3D radiators fed by transmission lines. They can be modified to have wide bandwidth and fairly good radiation characteristics [2] - [5]. However, 3D antennas are not immediately suitable to be embedded in a wireless system and integrated with other components. Therefore, planar monopole antennas in microstrip technology have been introduced [6] - [11]. They consist of a metal patch on one face of a dielectric board where the feed is normally provided through a microstrip line or coplanar waveguide (CPW) [2].

A large variety of SWB monopole antennas, covering a frequency ratio of 10:1 and higher, have been introduced in printed-circuit technology. For instance, an elliptical monopole is presented in [7] where the radiator is fed by a CPW line. It has an operating frequency range of 1.02 GHz to 24.1 GHz with an omnidirectional pattern at low frequencies whereas, as the frequency increases, the H-plane pattern moves upwards due to horizontal surface currents. The antenna in [11] is composed of an asymmetric trapezoid ground plane and a modified rectangular monopole patch. The 2:1 VSWR bandwidth extends from 1.05 GHz to 32.7 GHz. Radiation patterns are measured up 15 GHz and show omnidirectional behavior with increasing cross polarization levels at higher frequencies. A microstrip and two CPW monopole antennas are designed in [10] for bandwidths of 3 – 30 GHz and 3 – 60 GHz. However, they have not been prototyped. In [6] a new microstrip monopole antenna fed by an exponentially tapered line is presented with 80 GHz bandwidth. This antenna has a return loss of 10 dB over the entire bandwidth.

In this paper, we present a novel super-wideband microstrip monopole antenna which has the highest measured bandwidth, up to 110 GHz, reported in the literature. The main advantage of this antenna over previous designs is that it provides high frequency linearly polarized radiation (measured up to 40 GHz) where most monopole antennas show increasing levels of cross polarization as the frequency increases. Moreover, the gain is relatively flat up to 40 GHz and the return loss is better than 10 dB for most frequencies up to 85 GHz

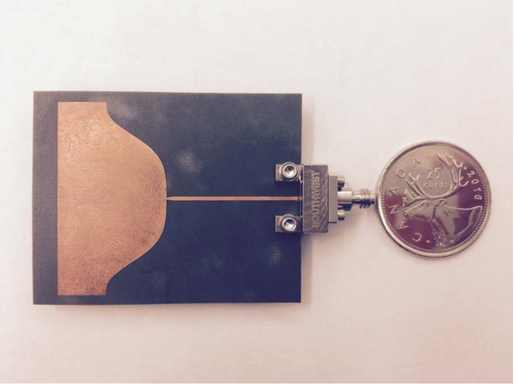


Fig. 1. 3 GHz to 110 GHz SWB antenna prototype with W-band end-launch connector and comparison with a Canadian Quarter coin.

II. ANTENNA DESIGN

The prototype SWB antenna is shown in Fig. 1, including a Southwest Microwave W-band end-launch connector, next to a Canadian Quarter. It is fabricated on Rogers RT/duroid 5880 substrate with $\varepsilon_r = 2.2$ which is a proper option for high frequency applications.

The antenna design proceeds as follows:

Preventing surface waves from excitation is a concern which limits the substrate height. Therefore, to ensure that the next higher order mode is not excited up to 150 GHz, the maximum height can be derived from

$$f_{c-sw} = \frac{c}{4h\sqrt{\varepsilon_r - 1}} < 150\text{ GHz} \tag{1}$$

where c is the speed of light in free space and h is the substrate height. This leads to $h < 456$ µm, and the next available thinner standard substrate height is 254 µm (10 mil).

The next step is to design the shape of the microstrip mono-pole radiator.

Numerous design methods have been proposed in the literature, e.g. [2], [6], [12] - [14]. For the current design, two methods from [2] and [6] are used simultaneously. By choosing the lower operating frequency as $f_l = 2.5$ GHz (note that an even lower frequency will result in a larger structure which will lead to mechanical stability problems if fabricated on such a thin substrate), the antenna dimensions can be found from [2] and [12] as

$$f_l = 0.24c/(L + r) \tag{2}$$

where L is the length of the radiator and r is the radius of an equivalent cylindrical monopole antenna [12].

To calculate the equivalent radius r for a planar monopole antenna (PMA), its area is considered to be equal to the area of the side of a cylindrical monopole of radius r. For example, for a rectangular PMA with sides $2W$

$$2\pi rL = 2WL \quad \text{or} \quad r = W/\pi \tag{3}$$

Due to the effect of the substrate on the monopole, (2) can be modified as [14]

$$f_l = \frac{0.24c}{k(L + r + p)} \tag{4}$$

where p is the length of the gap between the radiator and the ground plane which is added to increase the bandwidth, and $k = 1.1$ is a correction factor. Based on (3) and (4), by choosing $2W = 35$ mm and $p = 1$ mm, the radiator length will be $L = 19.6$ mm.

There are different ways to match the monopole to a standard 50 Ω line. In [2], different types of transformers have been introduced such as two, three and four step, convex, beveled and concave ones which can provide bandwidths of 50 GHz for 3D monopole antennas. Furthermore, [6] presents a triangular tapered line which provides 80 GHz bandwidth for a microstrip monopole. In this design, we use a Hanning function which is a window function in signal processing applications introduced in [15] as a tapering profile to match the load over a wide range of frequencies. The Hanning function is defined as

$$f(z) = 0.5 - 0.5\cos\left(\frac{2\pi z}{L_1}\right), \tag{5}$$

the impedance is

$$Z(z) = e^{\int_0^z f(z)dz} = 0.5z - \frac{L}{4\pi}\sin\left(\frac{2\pi z}{L_1}\right), \tag{6}$$

and the microstrip line is tapered to the radiator using (6) and $L_1 = 11$ mm.

This initial structure was simulated in CST Microwave Studio and HFSS, and dimensions were optimized to have wider bandwidth. Considering the fact that the antenna behaves like a tapered antipodal slot radiator at higher frequencies, we can improve the reflection coefficient by narrowing down the microstrip line at the feeding point that improves radiation and reduces reflection.

After fine optimization, the final dimensions are $2W = 36$ mm, $L = 20$ mm and $p = 0.1$ mm which shows that the initial design based on monopole antenna theory is viable. Fig. 2 shows the antenna profile and the final dimensions.

III. RESULTS

The reflection coefficient of the SWB microstrip antenna prototype of Fig. 1 was measured up to 110 GHz, and good agreement between simulated and measured results is demonstrated in Fig. 3. Note that the dimensions of the end-launch connector were included in the simulations. The measured return loss is better than 10 dB for most frequencies up to 85 GHz. Towards higher frequencies, the reflection coefficient is degraded mostly due to the non-ideal frequency response of the end-launch connector which is included in the measurements. The variation of the actual position of the pin from the exact center of the microstrip line is another reason for slightly higher reflection towards the end of the W-band.

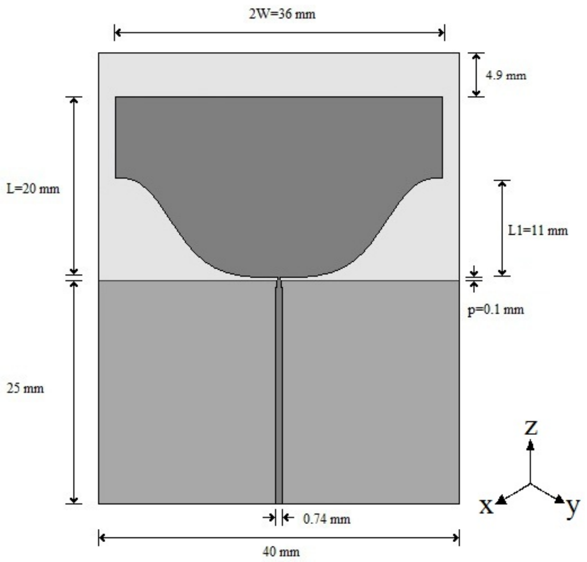


Fig. 2. Dimensions of the SWB antenna based on design by Hanning tapering and coordinate system for pattern measurements.

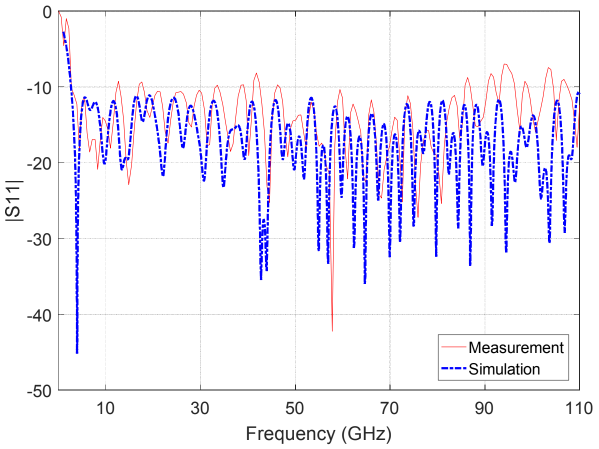


Fig. 3. Simulated and measured reflection coefficient of the SWB antenna.

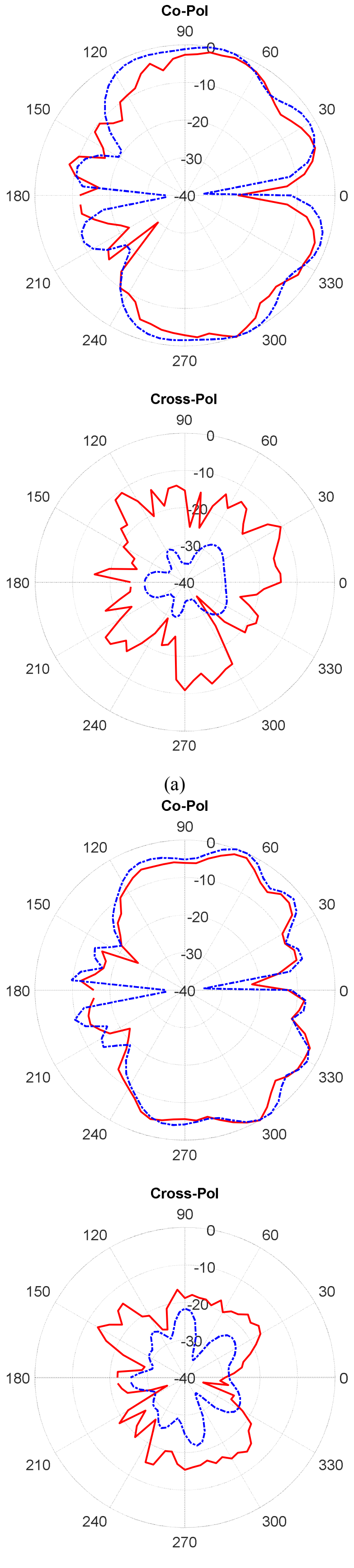
The antenna functions as a linearly polarized radiator. Therefore, the co-pol and cross-pol components are measured as E_θ (yz plane, Fig. 2) and E_ϕ (xy plane, Fig. 2), respectively. Pattern measurements, using an end-launch K-connector, are performed up to 40 GHz. Fig. 4 shows the measured and simulated co-pol and cross-pol radiation patterns at four different frequencies. Good agreement with simulations is observed. The simulation results for patterns at higher frequencies are shown in Fig. 5.

The experimental results verify that in contrast to most planar mono-pole antennas, the proposed antenna is linearly polarized even at high frequencies up to 40 GHz because of its proper vertical current distribution.

Based on the measured transmitted and received powers, the gain of the standard horns, and using Friis transmission equation, the antenna's gain is determined and shown in Fig. 6 together with simulated results. Compared to simulations, the measured gain is slightly higher at low frequencies and lower towards higher frequencies, showing overall a relatively flat response with much less variation than previously published SWB antennas [7, 10, 12] of similar or comparable bandwidth. The simulated gain increases towards 100 GHz as the antenna's apertures act as tapered antipodal slot antennas.

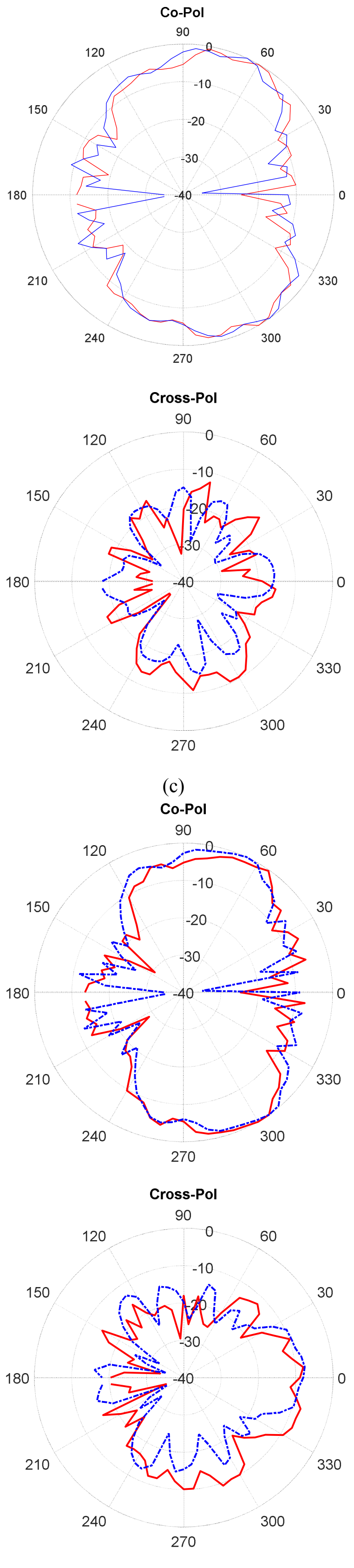
IV. CONCLUSIONS

A super wideband antenna is designed based on planar monopole antenna theory and optimized for wider bandwidth. The reflection coefficient is measured up to 110 GHz and is in good agreement with simulated results. Pattern and gain measurements are performed up to 40 GHz, showing good agreement with full-wave simulations. The operational bandwidth of 2.5 GHz to 110 GHz, the compact size of 40 mm × 50 mm and its low profile make this antenna an excellent option for all types of wireless communication systems requiring wideband antennas.



(a)

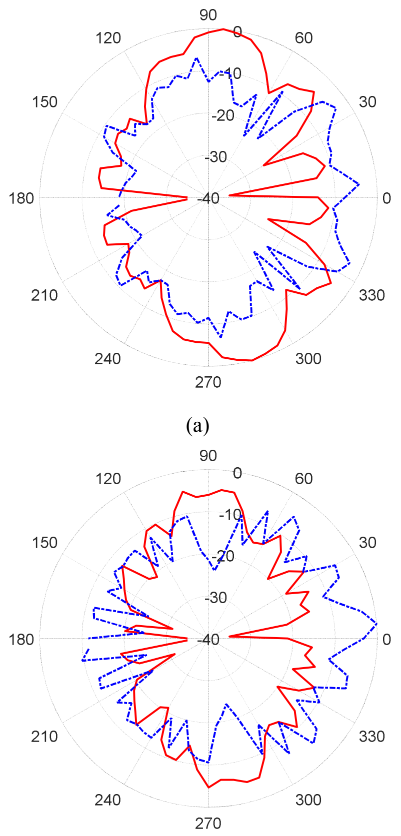
(b)



(c)

(d)

Fig. 4. Normalized simulated (blue) and measured (red) co-pol and cross-pol radiation patterns: (a) 10 GHz, (b) 20 GHz, (c) 30 GHz, (d) 40 GHz.



(a)

(b)

Fig. 5. Normalized simulated co-pol (red) and cross-pol (blue) radiation patterns: (a) 75 GHz, (b) 100 GHz.

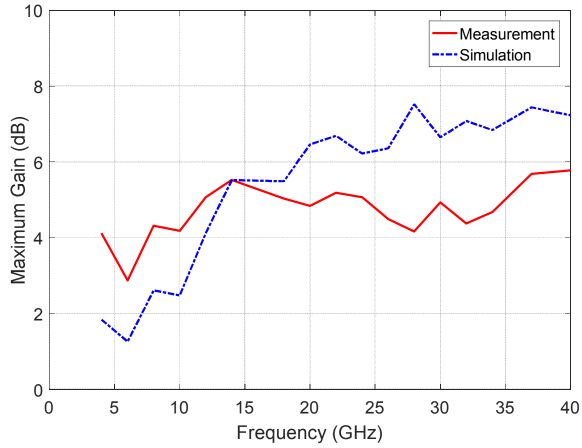


Fig. 6. Measured and simulated gain of the SWB antenna.

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