Design of Monopole Antennas for UWB Applications

Ahmad, W., Tarczynski, A. and Budimir, D.

This is a copy of the author's accepted version of a paper subsequently published in the proceedings of the 2017 IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS2017).

It is available online at:

https://dx.doi.org/10.1109/APUSNCURSINRSM.2017.8073204

Design of Monopole Antennas for UWB Applications

Waqas Ahmad, Andrzej Tarczynski, Djuradj Budimir
Wireless Communications Research Group, University of Westminster
London, United Kingdom
waqas.ahmad@my.westminster.ac.uk; tarczya@westminster.ac.uk; d.budimir@wmin.ac.uk

***Abstract*—Presented are the design method, equations, and results of a broadband monopole antenna for UWB applications. The antenna is a fat monopole; made of rectangular and circular patches. Measured results show a passband of 2.8–11.97 GHz. Parametric studies of the effects of the ground plane and the gap between the radiating element and the ground plane were done and their results given. The gain and efficiency are also provided; with average values of 4.34 dBi and 96% respectively. The obtained radiation patterns show bi-directional patterns in the E-plane and omni-directional patterns in the H-plane.**

Keywords—broadband; monopoles; antennas; uwb.

I. Introduction

To utilise the large bandwidth of UWB applications, broadband antennas are needed. Besides wideband features, planar broadband monopole antennas have several benefits; such as, simple structure design, small size, low-cost, low-weight and easy fabrication. Hence, various structures have been proposed; such as elliptic [1], square [2], and crescent patches [3]. However, in these works, the actual design method or equations are not given. Thus, it is only possible to see the given results without knowing how they came to be about. This work presents the detailed design and operating mechanism of broadband monopole antennas which are able to operate across an UWB range. The design is validated by developing an antenna based on the process and presenting its results. The antenna consists of a feed network, a finite ground plane, and various radiating patches which form a radiating element.

II. Design and Operating Mechanism of the Antenna

To design broadband monopole antennas, their operating mechanism needs to be understood first. A broadband monopole antenna is given in Fig. 1. A finite ground plane starts on the bottom edge of the feed line and ends just before the radiating element; thus leaving a gap. Antennas with a finite ground plane are able to operate at multiple resonant modes instead of only one mode as in the case of conventional patch antennas with a complete ground plane. When these multiple closely-spaced resonant modes overlap each other, a wide bandwidth is obtained. Such antennas essentially consist of many wire antennas. The presence of numerous possible currents modes in each of these wire antennas explains the reason of the wide bandwidth. The current modes which can exist in the radiating elements of these antennas are in the form of higher order Bessel functions of the first kind [4]–[5], where the currents are small at the centre of the elements and mostly concentrated on the boundaries.

The frequency of the first resonant mode can be determined by the size of the radiating element. At the first resonance, f_1, the antenna behaves like a quarter-wavelength monopole antenna. Thus, the length of the entire element is λ/4 at the first resonant frequency. The higher order modes, i.e. f_2, f_3… f_N, are harmonics of the first mode. After optimisation, width of the ground plane, W_G, is very close to twice the width of the first patch, W_{P1}, connected to the feed line [3]–[4] and given by (1).

$$W_G \approx 2W_{P1} \tag{1}$$

The gap between the finite ground plane and the feed line is a very important parameter in the design of these antennas. The gap affects the impedance matching between the feed line and the radiating patch. The size of the gap is directly related to the length of the finite ground plane. In all designs, the size will be such that the length of the feed line will always be slightly more than the length of the ground plane. The size of the gap can be determined using full-wave electromagnetic solvers.

Most of the current flow in broadband monopole antennas is concentrated on the boundary of the antennas; as if a wire antenna is running along the perimeters of the radiating patches. For broadband design, the first resonant frequency should be slightly higher than the lower band boundary. The perimeter of the radiating element should have a length of about one wavelength at the lowest in-band frequency. Practically, this frequency should be slightly less than the lower passband limit so as to compensate for variations in the environment. Since the perimeter of the radiating element is close to one wavelength of the average medium of radiation, this relation can be used to calculate the lower passband limit [3]–[4]. The expression is given in (2); where f_L is lower passband limit in GHz, p is perimeter of the element in mm and ε_r is relative dielectric permittivity. The perimeter can be calculated for a desired lower passband limit by reversing (2).

$$f_L = 300/p\left(\sqrt{0.5\varepsilon_r + 0.5}\right) \tag{2}$$

These antennas can be fed using various methods; such as microstrip line feed. Width of the feed line can be calculated according to the required system's characteristic impedance.

Antenna dimensions were determined for a sample UWB 3–12 GHz range using the above design method and equations.

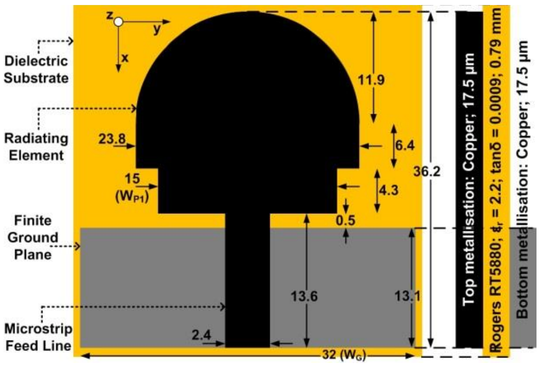

Fig. 1. Top and cross-sectional views of the antenna (dimensions in mm).

III. Results

The antenna was simulated using *Sonnet* and measured using Agilent E8361A Network Analyser. The return loss is given in Fig. 2 (a). The simulated passband is 2.89–11.87 GHz. The three resonant modes of the antenna are present at 3.72 GHz, 6.5 GHz, and 9.65 GHz. All three modes are sharp. The measured passband of 2.8–11.97 GHz is in a reasonable agreement with the simulated result. The three modes are at 3.59 GHz, 6.66 GHz, and 9.5 GHz. The first two modes are sharp and at a higher return loss than the third mode which is flatter. The shifts in frequencies between the two results and the lower measured return loss at higher frequencies is due to losses incurred in the SMA connector which was not modelled in the simulation and the substrate losses. Overall, the antenna exhibits a broadband impedance bandwidth in both results.

The simulated gain and efficiency is given in Fig. 2 (b). The gain varies from a minimum of 2.66 dBi to a maximum of 5.25 dBi. Variance in the gain is within 2.75 dBi and the average is 4.34 dBi. The average efficiency (excluding metallisation losses) is about 96.2%.

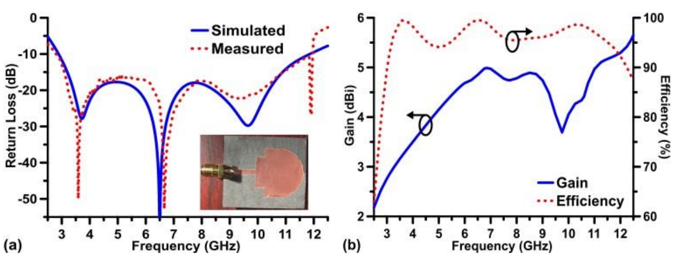

Fig. 2. (a) Return loss and (b) gain and efficiency of the antenna.

To gain a better insight of how the finite ground plane and the gap between ground plane and radiating element affect the performance, parametric studies were done. First, the ground plane width was varied. The results in Fig. 3 (a) show that as it changes from the 32 mm final value, the upper passband limit also changes. But this is at the cost of return loss deterioration. Amongst the plots, the two best are 28 mm and 32 mm. From (1), the width should be roughly 30 mm. This value is amid the two best values. After further software iterations, 32 mm was found to be the better and optimal value. Secondly, the gap between the ground plane and radiating element was varied. The results in Fig. 3 (b) show that while the passband limits are not affected, the passband matching is very sensitive and significantly affected. So, by tuning the gap, impedance matching between the radiating element and feed line can be controlled to get the best possible passband. When the gap is altered from the 0.5 mm final value, the resonant modes start becoming flatter very quickly and the passband matching starts deteriorating. At extreme high and low values, especially when the ground plane overlaps the feed line (negative values), then S_{11} < 10 dB. The best and optimal value of 0.5 mm was obtained from multiple electromagnetic analysis iterations.

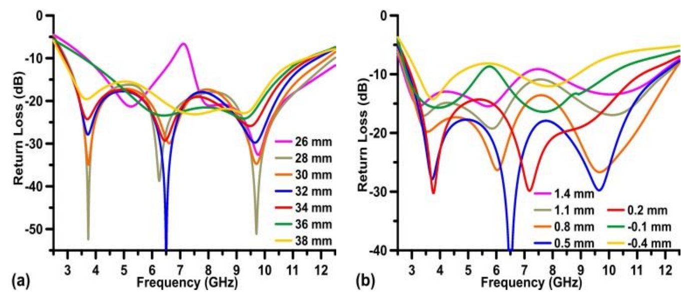

Fig. 3. Performance with varying width of the (a) grounnd plane and (b) gap.

Radiation patterns in E-plane and H-plane are given in Fig. 4. Stable bidirectional patterns in E-plane and omnidirectional patterns in H-plane are seen at the lower frequencies. At the higher frequency, the E-plane pattern is slightly deteriorated.

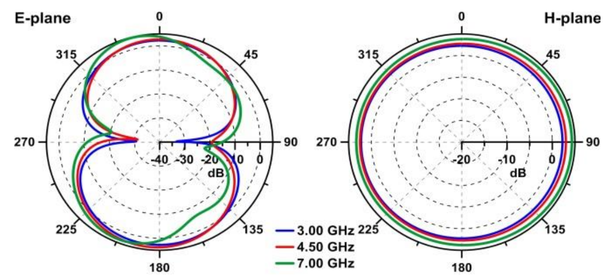

Fig. 4. Radiation patterns of the antenna.

IV. Conclusion

A broadband monopole antenna for UWB applications is proposed. The detailed design method and equations are given. The antenna shows a full UWB passband. Parametric studies of important parameters were also done and their results given. Other important results are also provided. The design process can be adapted for similar antennas. Moreover, the antenna can be integrated with filters for rejecting interfering signals.

References

[1] M. Tang and R. Ziolkowski, "Planar uwb antennas with improved performance," *IEEE Tran. on Antennas and Prop.*, pp. 61–69, Jan. 2016.

[2] M. Nabi and M. Kanagasabai, "Compact uwb monopole antenna," *IEEE Trans. on Antennas and Prop.*, vol. 63, no. 9, pp. 4204–4208, Sep. 2015.

[3] N. Azenui and H. Yang, "A printed antenna for UWB applications," *IEEE Antennas and Wireless Prop. Lett.*, vol. 6, pp. 113–116, 2007.

[4] O. Haraz and A-R Sebak, "UWB antennas for wireless applications," in *Advancement in Microstrip Antennas*, InTech, 2013, ch. 6, pp. 125–152.

[5] C. A. Balanis, *Antenna Theory*, USA: John Wiley & Sons, Inc., 2005.