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Circuit Model of Curved Ultra Wideband (UWB) Antenna

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Abstract. This paper studies the effect of curved antenna performance on Ultra Wideband (UWB) characteristics, particularly on impedance bandwidth. A UWB antenna is designed, after which is curved and conformed onto cylindrical radius of 150 mm, 120 mm, 90 mm and 60 mm. The motivation of the study is to study the effectiveness of the antenna to be conformed onto non-planar structure applications, particularly on cylindrical body of air or land vehicles. It is observed that the degradation which occurs when the antenna is curved still adheres to the UWB characteristic of more than 500 MHz bandwidth. A circuit model is developed to understand the physics behind the antenna structure when it is curved or bent. The discontinuity of the antenna structure during the curving effect could be explained with the alteration of capacitive loading of the antenna, which is related to the electrical field of the antenna. The curved antenna proves to be suitable for UWB application and the results of its performance according to the UWB characteristics are discussed in detail.

1 Introduction

Antenna research has garnered great interest especially since the release of Ultra Wideband (UWB) frequency spectrum, which was allocated to be from 3.1 GHz to 10.6 GHz [1]. By definition, UWB refers to signals or systems with more than 500 MHz bandwidth, according to the Federal Communications Commission (FCC) [2]. Recent trend has observed more emphasis on integrating microstrip patch antenna onto curved structure of air or land vehicles because of the space constraints [3]. Related researches have been done on curved antenna. For instance, Taha A. Elwi *et al*. studied the effect of Truncated Sinusoidal Printed Circuit Antenna (TPSCA) in application for biomedical telemetry, resulting in unaffected bandwidth with change in resonant frequency [4]. Georget et al. added resonators on the dual-band antenna on flexible substrate, reporting a shift in resonant frequency, contributed by the coupling between the parasitic elements [5]. Macon et al. modelled a doubly curved conformal microstrip antenna using Green's function, which are investigated based on different orientations of probe feed positions [3]. This research aims to analyse the effect of the curved antenna on UWB characteristic, particularly on its impedance bandwidth. The antenna is designed to operate in the UWB bandwidth, after which is bent or curved on different radius. Besides, equivalent circuit is modelled for the curved antenna to study the perturbation that affects the antenna structure during bending.

2 Ultra Wideband (UWB) antenna

Fig. 1 depicts the antenna geometry, which is designed on a double-sided Roger substrate. The front part of antenna comprises the antenna radiator itself, which is made up of octagonal shape as the larger patch and fed through the feed line which is positioned in the middle of the substrate. The patch antenna is designed as such that each part of the structure would be resonant to the frequency in the return loss graph. The back part is the ground plane, comprising partial step truncated in the middle as well. The design is as such that it improves the impedance matching between the patch and ground plane so that wider bandwidth could be achieved.

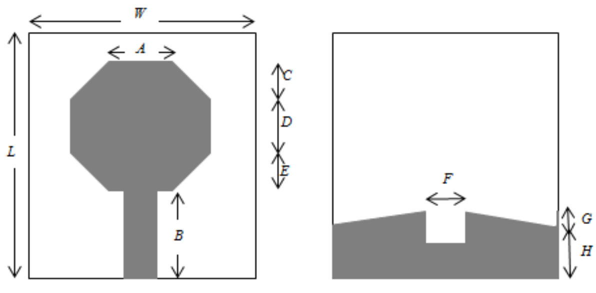

Figure 1. Antenna geometry (a) Patch antenna (b) Ground plane.

Table 1 tabulates the dimension of the antenna geometry based on Fig. 1.

Fig. 2 depicts the antenna's return loss, S11 across the UWB frequency spectrum. Based on electromagnetic simulator, the designed antenna operates with approximately 11 GHz bandwidth, covering UWB spectrum. The first resonant frequency is contributed by the antenna patch length of approximately 0.5 λ, with the S11

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of -35.62 dB at 3.3 GHz, while the second and third are due to truncated step from the patch, 'E' and ground plane, respectively, thereby recording S11 of -37. 22 dB at 6.6 GHz and S11 of -22. 62 dB at 9.53 GHz. The notch at the ground plane and truncated shape of the patch antenna serve as a means to improve the impedance matching and enhancement of the S11 of the graph so that it remains below -10 dB. This is due to the matching of the capacitive coupling between the patch antenna and the ground plane. Meanwhile, the ground plane is designed partially with the notch which serves as a realization of series inductance, validated by Hoefer as a mean to compensate for the excessive capacitance due to abrupt geometry change [6].

Table 1. Antenna Dimensions.

Antenna	Variable	Dimension (mm)
Substrate	*W*	30
	L	33
Patch Antenna	*A*	8
	B	11
	C	5
	D	8
	E	5
Ground Plane	*F*	4
	G	2
	H	9

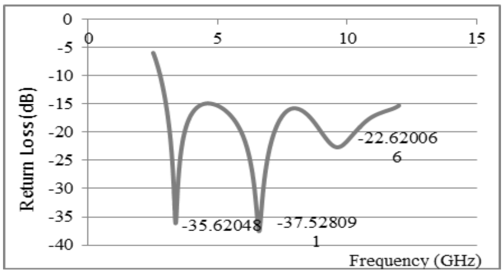

Figure 2. Return Loss of UWB Antenna.

3 Development of circuit model for antenna bending

Lumped element circuit model has been applied in various ways, such as modelling of the antenna, understanding the antenna operation and computation of antenna matching potential [7]. Literatures on such models are more extensive for narrowband antennas, especially on dipoles [8]-[10]. It has also been reported that there is a lack of study on reflection coefficient, S11 results being depicted by equivalent circuit for a wideband antenna, despite the fact that it is the primary parameter to be considered when it comes to qualifying for antenna system requirement [11]. In this paper, the circuit model features the use of lumped elements, which consists of resonant circuit represented by resistor and inductor in series with combination of capacitor and inductor in parallel, as depicted in Fig. 3.

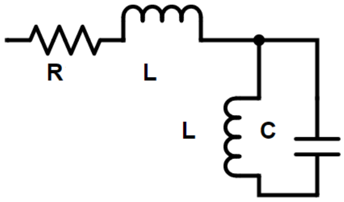

Figure 3. Basic resonant circuit

Based on Fig. 3, the series configuration represents the surface resistance, R and inductance, L, respectively, given by

$$R = \frac{1}{w\sigma_{cond}\,\delta}. \tag{1}$$

$$L = \frac{1}{w\sigma_{cond}\,\omega\delta} \tag{2}$$

where σ_{cond} represents the copper conductivity
δ represents the skin depth

The capacitance is given by the combination of Wheeler's and Schneider's model [12] :

$$C = \varepsilon_{eff}\, 2.85 \frac{1}{\ln\left\{1+\frac{1}{2}\left(\frac{8h}{w_{eff}}\right)\left[\left(\frac{8h}{w_{eff}}\right)+\sqrt{\left(\frac{8h}{w_{eff}}\right)^2+\pi^2}\right]\right\}} \tag{3}$$

where w_{eff} represents the effective width
ε_{eff} represents the effective permittivity

The equivalent circuit model for the designed antenna is as depicted in Fig. 4.

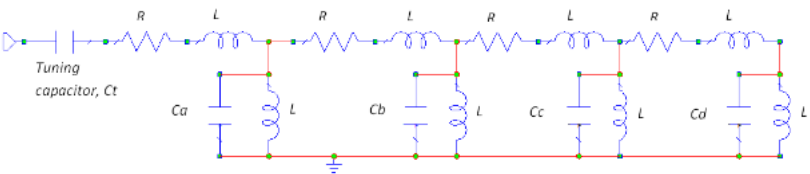

Figure 4. Lumped element circuit model of UWB antenna

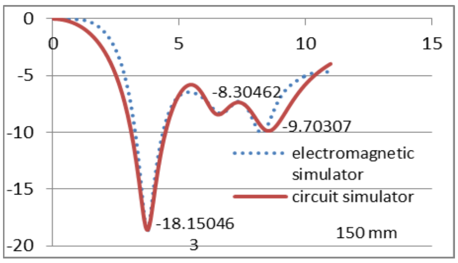

Figure 5. Return loss of curved antenna over radius of 150 mm

As depicted in Fig. 5, the bending effect of the antenna does shift its resonant frequencies, thus affecting the antenna resonant structure [13]. The first resonant frequency is shifted to the right, recording -18.15 dB at 3.73 GHz. Meanwhile, the second resonant frequency is only slightly affected with -8.3 dB at 6.67 GHz. The third resonant frequency due to the ground plane is shifted to the left, stating -9.7 dB at 8.27 GHz. The operating bandwidth is 1.09 GHz. It should be noted that the curved antenna

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adheres to UWB requirement of 500 MHz bandwidth with S11 below -10 dB.

Meanwhile, the radius of which the antenna is conformed onto is then set as 120 mm. The return loss is depicted in Fig. 6, which observes slight difference in the shifting of the resonant frequencies, as the first records -19.04 dB at 3.765 GHz, followed by -7.853 dB at 6.6 GHz and -9.74 dB at 8.38 GHz. The impedance bandwidth recorded is 1.065 GHz.

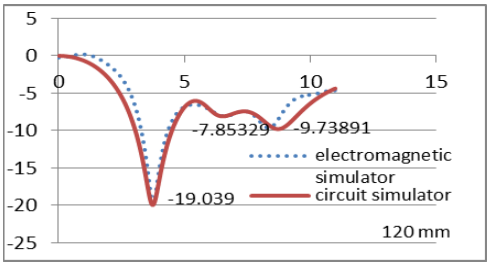

Figure 6. Return Loss of Curved Antenna over Radius of 120 mm

The same behaviour is observed in antenna being conformed onto radius of 90 mm, with minimal shifting of frequencies as depicted in Fig. 7. Recording a bandwidth of 1.11 GHz, the resonant frequencies record negligible change, but its return loss is observed to shift a little; -18.29 dB at 3.75 GHz, -8.05 dB at 6.577 GHz and -9.59 dB at 8.28 GHz.

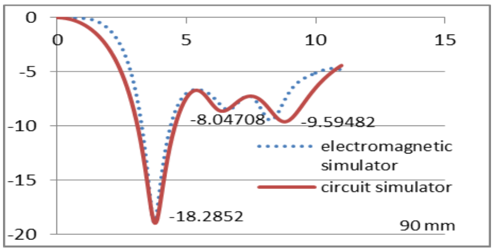

Figure 7. Return loss of curved antenna over radius of 90 mm

Similar expected result could be observed in the antenna being conformed onto radius of 60 mm, as depicted in Fig. 8. The bandwidth is of 1.095 GHz, which is similar to the previous bending. The return loss and its corresponding resonant frequencies are as follow; -18.8 dB at 3.75 GHz, -8.38 dB at 6.59 GHz and -9.28 dB at 8.25 GHz.

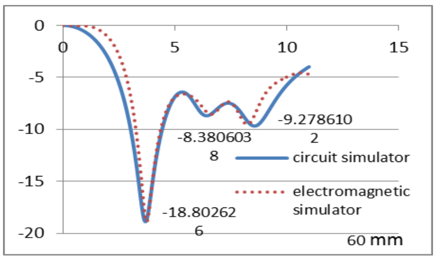

Figure 8. Return loss of curved antenna over radius of 60 mm

From the circuit analysis point of view, the bending changes the electrical field of the antenna, validated by change of the capacitance between the antenna elements [14]. The percentage of capacitance variation is depicted in Fig. 9, with each capacitance being referred to from Fig. 4. The tuning capacitor, denoted as Ct, records a decrease, indicating a decrease in terms of the coupling between the patch antenna and ground plane, therefore the reactance representation is affected. Further decreased angle for the curved antenna does not affect much on the capacitive loading. Similar behaviour could be observed in the capacitance of the patch antenna with the truncated step, as is represented by Cc. A huge spike of capacitance loading, Cb, could be observed at the patch antenna truncated part upon being curved, which then increases in value as the bending radius gets smaller. Similarly, Cd which represents the notched ground plane also records an increase. The notched ground plane structure serves as to provide a better impedance matching for the antenna. The bent antenna brings about change in which the antenna discontinuity is further deteriorated due to the curved nature. This indicates that the electrical field acts the strongest at that part. The inductive loading does not get affected much, thereby the change in magnetic field should be minimal. The development and analysis of the circuit model aid in showing the effect of parameter variation for antenna parameters, and is relatively fast, as compared to other simulators which take on transient time-domain simulations [11].

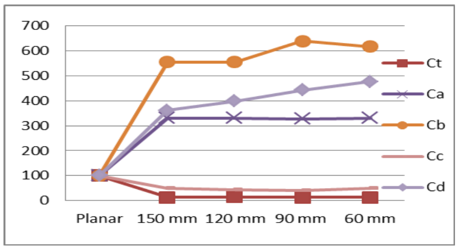

Figure 9. Percentage of capacitance variation for curved antenna

4 Conclusion

This paper analyses the effect of curved or conformal UWB antenna, particularly on the impedance bandwidth and return loss, S11. The designed UWB antenna is compared to its performance when it is conformed onto different radii over a cylindrical shape of 150 mm, 120 mm, 90 mm and 60 mm. The impedance bandwidth is affected, due to the shifting of resonant frequencies as it affects the electrical field of antenna. Nevertheless, the shifting mainly affects the resonances contributed by the patch antenna length and the ground plane. While the bandwidth is affected, it still adheres to the UWB requirement of ≥ 500 MHz.

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