An Equivalent Circuit Model of Miniature Double E-Shaped Meander Line Printed Monopole Antenna

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***Abstract*—An equivalent circuit model of the UHF miniature double E-shaped meander line printed monopole antenna is presented. The proposed antenna has a simple structure and small antenna size of 46.8 mm x 74 mm or 0.137λ_0 x 0.217λ_0 at 878 MHz resonant frequency. Advanced Design System (ADS) software is used to develop the antenna circuit model. Each section of the antenna structure is represented by the inductance and capacitance circuit with their values are depending on the width and length of the structure. The circuit model is developed based on common discontinuities in the microstrip line. The performance of the circuit model in terms of return loss is compared with the CST simulation for a validation. The printed monopole antenna is having similar radiation characteristics as an ideal wire monopole where it radiates uniformly in all directions.**

***Index Terms*—Equivalent Circuit Model; Printed Monopole Antenna; Lumped Element; Meander Line.**

I. Introduction

In advance of science and technology in the contemporary world today, wireless communication systems have been universally developed in order to accomplish the requirements for numerous applications. Antenna is one of the crucial components in the wireless communication system that functions as the interface between electromagnetic radiation and electrical signals. An antenna is a mechanism to transmit and receives radio waves where it converts a guided wave in transmission lines into electromagnetic waves or vice versa [1]. The selection of the antenna type relies upon the application and the situation where the particular wireless communication system is used [2]. The antenna miniaturization and integration into modern portable devices is quite challenging on low frequency antenna including ultra-high frequency (UHF) band antenna.

UHF monopole antenna loaded with a few numbers of thin stubs at specific positions has been proven to reduce the length of the radiating element. The antenna is used in ground-based and vehicular communication systems [3] and forward scatter radar (FSR) sensor [4]. However, the monopole radiator is positioned on the large ground plane exhibits larger antenna size in overall, plus the antenna structure encounters constraint for printed circuit integration.

The classical monopole antenna experienced modifications from wire monopole to planar and printed monopole structure for some purposes. For instance, the wire monopole is replaced by the planar monopole to improve the antenna bandwidth [5], [6] while the printed monopole antenna is constructed with the aim of producing an omnidirectional antenna with a compact size and feasibility to integrate with modern circuit devices [7], [8].

In designing an antenna, there are some theoretical parts must be followed. As a matter of fact, antennas are represented by equivalent circuit model. When the structures of the antenna are changed, the electrical circuit models of the antenna are changed as well.

The previous study has shown that an equivalent circuit model of circular slotted microstrip patch antenna can be derived using parallel *RLC* circuits [9]. Eight series-connected parallel *RLC* circuits act as a band pass filter where it passes certain frequency bands while other frequency bands are restricted. A series connection of parallel *RLC* circuits also has been used to serve the rectangular and E-shaped microstrip antenna in [10].

Badjian et al. [11] derived the circuit model for UWB patch antenna by dividing the antenna structure into the feed line, steps, and radiating patch. Series and parallel RLC circuit represent each divided structure. Similar circuit model has been developed in [12] to perform the rectangular printed disc monopole antenna but with added series LC circuit due to the slot. The accuracy of the circuit model was obtained by comparing the return loss between CST simulation and circuit model.

The development of the electrical circuit model is significant to enhance the understanding of the antenna structure. In addition, it is also useful for mathematical equation derivation. However, this study emphasis on the equivalent circuit model only where the mathematical equation will not be covered in this study.

II. Antenna Design and Approach

A miniature double E-shaped meander line printed monopole antenna is presented in Figure 1 with the meander line structure is enlarged for visibility. The antenna design has been simulated using Computer Simulation Technology (CST) software and fabricated on the low-cost FR-4 substrate with dielectric constant, ε_r and thickness, h of 4.3 and 1.6 mm respectively. A 50Ω microstrip line is used to feed the proposed antenna which partially backed by a defected ground plane. The proposed antenna has smaller and compact size of only 46.8 mm x 74 mm corresponding to 0.137λ_0 x 0.217λ_0 where λ_0 is a free-space wavelength at 878 MHz.

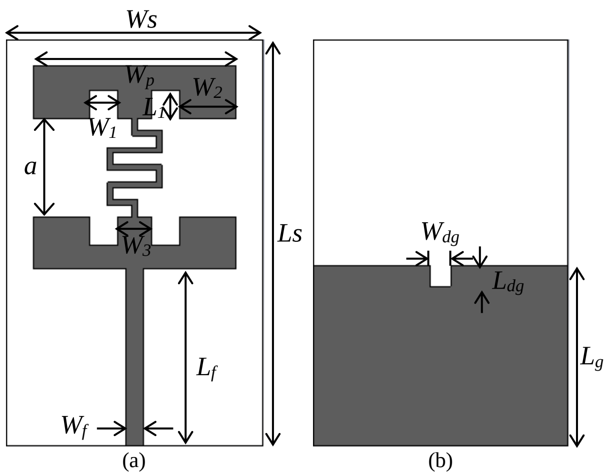


Figure 1: Configuration of the proposed antenna (a) front view (b) back view

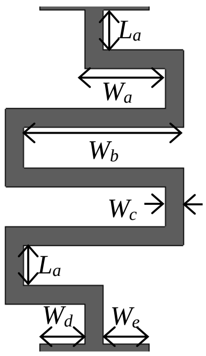


Figure 2: Meander line configuration is enlarged for visibility

The dimensions of the proposed antenna are organised in Table 1 where all the parameters are listed in millimetre (mm).

Table 1
Proposed Antenna Parameters

Parameters	Unit (mm)	Parameters	Unit (mm)
Ws	46.8	*La*	2.18
Ls	74.0	*Wa*	4.8
Wp	37.2	*Wb*	9.6
L_1	5.2	*Wc*	1.0
W_1	5.2	*Wd*	2.6
W_2	10.3	*We*	2.6
W_3	6.2	*Wdg*	3.7
a	18.1	*Ldg*	3.7
Wf	3.0	*Lg*	32.63
Lf	32.0		

III. Results and Discussions

Advanced Design System (ADS) software is used to carry out the modelling circuit. The equivalent lumped element circuit is generated based on the antenna input impedance where the input impedance of the antenna is considered as a two terminal device comprising an arbitrary set of lumped resistors, *R*, capacitors, *C*, and inductors, *L* connected either in series or parallel [13]. The development of an equivalent circuit model provides a better understanding of the antenna characteristics and expose the physics behind the structure [14]. The effects of varying the antenna structures on the frequency response can be studied from the circuit model. Comparison between the CST simulation results and the circuit model is obtained. The comparison is made based on the return loss. The capacitance *C* and inductance *L* in the equivalent circuit model is calculated based on equation below

$$l_c = \frac{\lambda_L \omega C Z_L}{2\pi} \tag{1}$$

$$l_L = \frac{\lambda_H \omega L}{2\pi Z_h} \tag{2}$$

$$\lambda_{L,H} = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{3}$$

where; Z_l is the lowest realisable characteristic impedances in the medium and Z_h is the highest realisable characteristic impedances in the medium. While λ_L and λ_H are the corresponding wavelengths related to the free space wavelength λ_0, ω is an angular frequency which equals to 2πf.

One of the most commonly used transmission lines in microwave design is a planar structure which can be constructed using a low-cost printed circuit board technology. A microstrip line is most frequently used in microwave circuits due to its good mechanical support, ease of integration with solid-state devices, and easy to fabricate using various processes [15], [16].

An alteration of the microstrip will lead to a discontinuity where a modification on the conducting patch affects the inductor while the changes in the cross-section area between the patch and ground plane affects the capacitance. Consequently, electric and magnetic field distributions are modified near the discontinuity. The inductance and capacitance in a circuit model essentially reveal the property of resonance circuits in many applications [17]–[19].

A meander line in an antenna structure can be represented as a combination of several bend segments in Figure 3 [20]. The meander line provides a small and compact size of design area where it allows patch radiator to be compressed and folded yet produces similar performances regarding resonant frequency and return loss. The configuration of the meander line can be translated into lumped element circuit model as shown in Figure 4. Each section is presented by the two inductors and one capacitor connected in parallel.

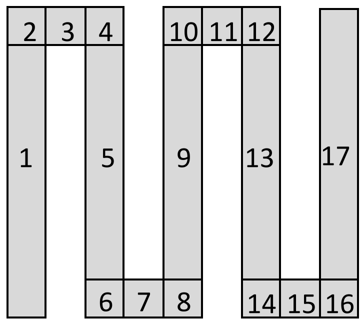


Figure 3: Segmented representation of meander line [20]

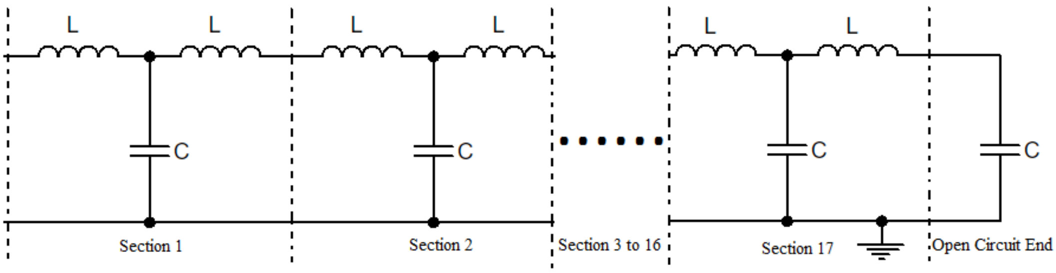


Figure 4: Lumped element circuit model of meander line structure [20]

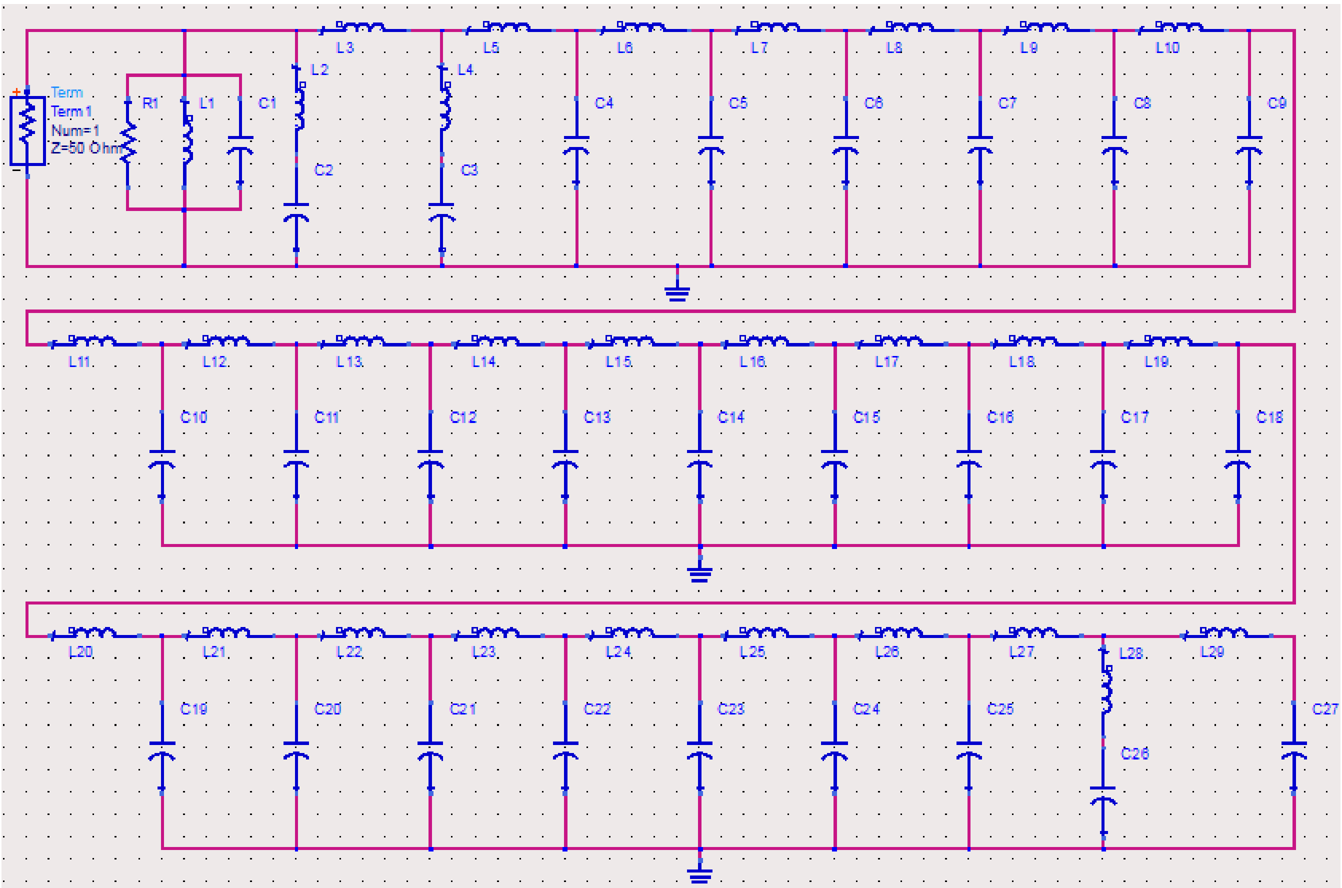


Figure 5: Equivalent Circuit Model of Miniature Double E-shaped Meander Line Printed Monopole Antenna

An equivalent circuit model of the proposed UHF antenna is illustrated in Figure 5. The components of the circuit model are arranged in parallel with the value of all components are organised in Table 2.

Response from the circuit model is compared with the response from CST simulation as depicted in Figure 6. From this result, we can see that both graphs are agreeing well with each other. Both responses produce return loss of -40.47 dB at 878 MHz resonant frequency.

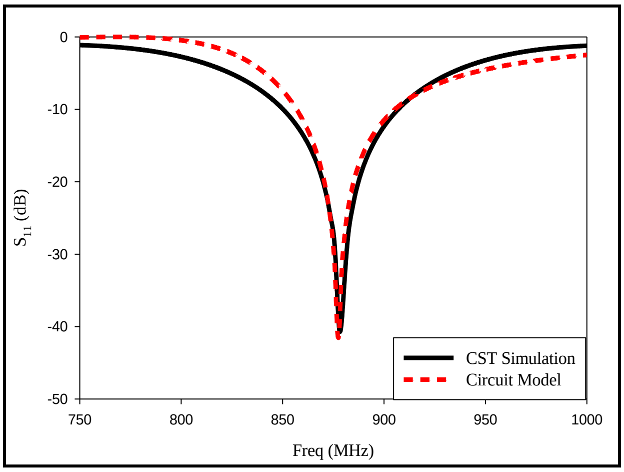
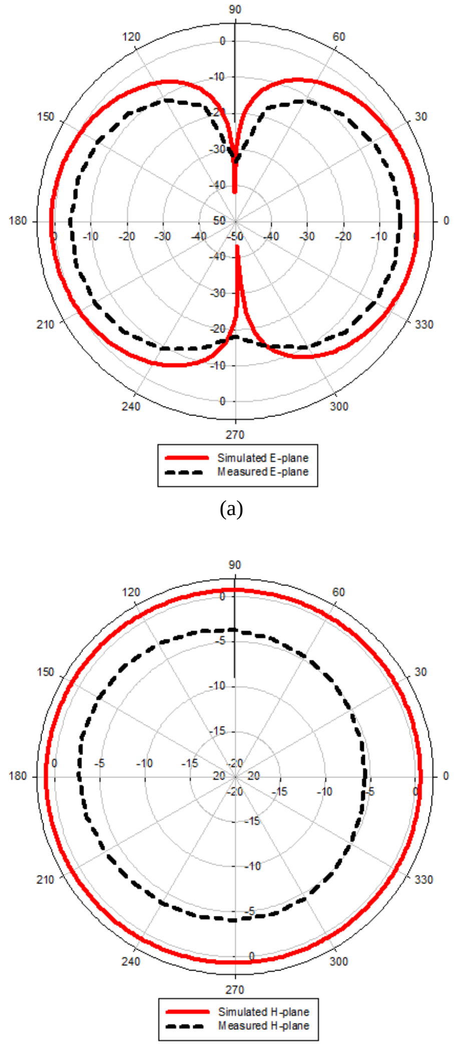


Figure 6: Comparison of antenna return loss between CST simulation and ADS circuit model

Table 2
Components' Value of the Proposed Antenna

Components	Values
R1	49.1 Ω
L1	13.9 nH
L2	4.1 nH
L3	2.3 nH
L4	2.3 nH
L5	2.3 nH
L6	1.0 nH
L7	1.4 nH
L8	2.1 nH
L9	2.1 nH
L10	1.4 nH
L11	1.4 nH
L12	4.2 nH
L13	4.2 nH
L14	1.4 nH
L15	1.4 nH
L16	4.2 nH
L17	4.2 nH
L18	1.4 nH
L19	1.4 nH
L20	4.2 nH
L21	4.2 nH
L22	1.4 nH
L23	1.4 nH
L24	2.1 nH
L25	2.1 nH
L26	1.4 nH
L27	3.2 nH
L28	2.3 nH
L29	2.3 nH
C1	4.3 pF
C2	1.3 pF
C3	0.7 pF
C4	4.3 pF
C5	0.3 pF
C6	0.1 pF
C7	0.5 pF
C8	0.1 pF
C9	0.3 pF
C10	0.1 pF
C11	1.2 pF
C12	0.1 pF
C13	0.3 pF
C14	0.1 pF
C15	1.2 pF
C16	0.1 pF
C17	0.3 pF
C18	0.1 pF
C19	1.2 pF
C20	0.1 pF
C21	0.3 pF
C22	0.1 pF
C23	0.5 pF
C24	0.1 pF
C25	0.3 pF
C26	0.7 pF
C27	5.9 pF

The proposed antenna has similar radiation characteristics as an ideal wire monopole where it radiates with an omnidirectional radiation pattern as plotted in Figure 7. Figure 7 (a) and (b) show the simulated and measured radiation pattern in E-plane and H-plane, respectively.



(a)

(b)

Figure 7: Simulated and measured radiation pattern of the proposed antenna in (a) E-plane (b) H-plane

IV. CONCLUSIONS

A miniature double E-shaped meander line printed monopole antenna has been successfully presented by equivalent circuit model. The equivalent circuit model is developed based on the circuit model of the discontinuities in the microstrip line. Each antenna structure is represented by inductance and capacitance circuit in which all circuits are connected in parallel. The return loss from the ADS circuit model and CST simulation has been compared to validating the circuit. It is proven that the proposed equivalent circuit model serves as the proposed double E-shaped meander line printed monopole antenna.

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