A Miniature Double E-Shaped Meander Line Monopole Antenna for VHF Applications

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***Abstract*—A miniature double E-shaped meander line monopole antenna with Defected Ground Structure (DGS) is proposed for Very High Frequency (VHF) Applications. The proposed antenna is a results of a few antenna evolutions. The combination of slots and meander line lead to a novel structure of the patch and resulting in reduction of antenna resonant frequency. The DGS is introduced on the partial ground plane to improve the reflection coefficient of the proposed design. Overall size of the antenna has been reduced up to 89% after implementing the proposed method. A broad parametric analysis have been conducted to optimize the performances of the antenna and to observe the effects of various dimensional parameters. Experiments have been accomplished to validate the proposed antenna performances where simulated and measured results are agree well with each other. The physical area of the proposed antenna is only 181 x 251 mm^2 at 151 MHz resonant frequency. The proposed antenna produces an omnidirectional radiation pattern with 1.364 dBi measured gain.**

***Index Terms*— Meander Line; Omnidirectional; Partial Ground Plane; Patch Antenna; VHF (Very High Frequency).**

I. Introduction

Up till now, printed monopole antennas are extensively used in communication systems due to their uniqueness such as low cost, low profile, ease of manufacturing, robust and omnidirectional radiation pattern characteristic. Recently, the printed monopole antenna is used to replace the typical monopole antenna due to its ability to be integrated with printed circuit board especially for low frequency band applications. Despite of its advantages, the printed monopole antenna possess extremely large size when operating in low frequency band like Very High Frequency (VHF) band.

Normally, VHF systems are extremely large because of the bulky size of the antenna. The size of the antennas at low frequency such as conventional dipole and monopole are extremely large due to their large wavelength. The large size of the conventional antennas limiting many practical applications especially portable and mobile communication systems.

Numerous approaches have been proposed to reduce the antenna size as reported in literatures. Choi *et al.* proposed small folded dipole antenna for low VHF applications [1]. Folded technique is used to reducing the physical size of the antenna. In [2], Ultra-wideband (UWB) antenna was miniaturized based on metamaterial approach for WLAN and WiMax applications. The size of the UWB antenna was reduced about 63.48% using fractalization of the radiating edge and slotted ground structure.

A coplanar waveguide (CPW)-fed antipodal Vivaldi antenna was miniaturized using elliptically shaped strip conductors in [3]. Two elliptical shaped strip conductors reduce the antenna operating frequency that lead to reduction in antenna size.

Slot technique has been widely utilized by antenna designers to reduce the size of the antenna especially for low frequency applications as reported in [4]–[10]. Various shapes slot were proposed in the literatures such as ring slot, X-shaped slot, T-shaped slot, L-shaped slot and U-shaped slot. The slots were introduced on the radiating patch to reduce the resonant frequency of the antenna before the size of the antenna was decreased.

In this study, the combination of several slots, meander line and DGS create a novel patch structure of double E-shaped meander line monopole antenna operates at VHF band. The slots and meander line are utilized to reduce the resonant frequency of the antenna to the lower band. Meanwhile, the DGS is utilized to enhance the reflection coefficient and input impedance of the antenna. The proposed antenna possess an omnidirectional radiation pattern.

II. Design Approach

The evolution of the double E-shaped meander line antenna is presented clearly in Figure 1. Initially, a square monopole patch antenna as demonstrated in Figure 1 (a) is constructed according to the standard design procedure to define the antenna dimension for 155 MHz resonant frequency. Slots on the right and left side of the patch are inserted as shown in Figure 1 (b) to disturb the surface current path to increase the effective inductance of the antenna. More slots are introduced to further increase the strongest current path on the patch as displayed in Figure 1 (c). Next, the antenna circumference is enhanced more by inserting a meander line on the middle of the patch as shown in Figure 1 (d). All antenna designs were constructed on the low cost FR-4 substrate with relative permittivity, ε_r of 4.3; substrate thickness, h of 1.6mm; and loss tangent, $tan\delta$ of 0.025. All antenna structures are backed by partial ground planes that produce omnidirectional radiation patterns. Patches and ground planes are made of copper with thickness of 0.035 mm. There are fed by 50Ω microstrip line. In this study, all designs were simulated and optimized using Computer Simulation Technology (CST) software.

The objective of the design method is to miniaturizing the antenna size for VHF applications. Before the size of the antenna can be miniaturized, the resonant frequency need to be reduced first. By introducing slots and meander line, the resonant frequency has been shifted to the lower frequency band.

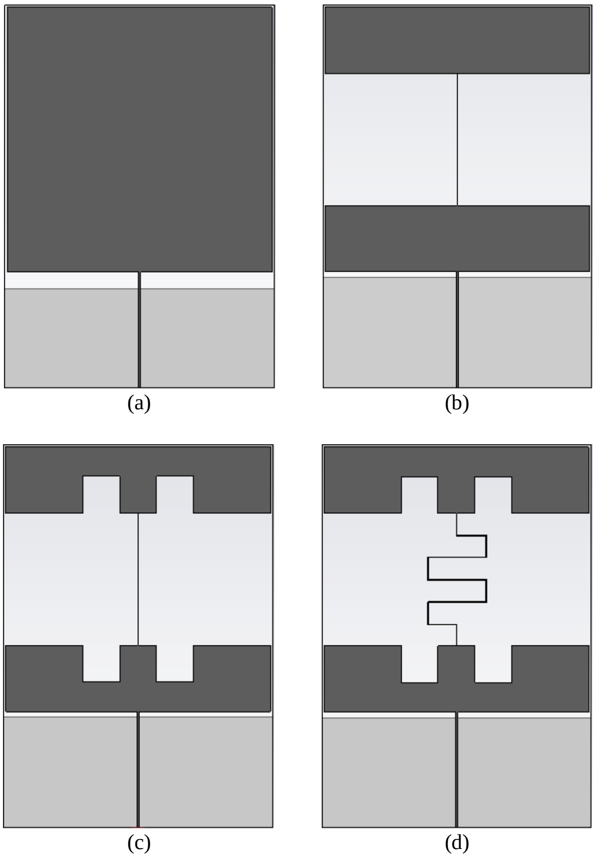


Figure 1: Evolution of double E-shaped meander line antenna (a) reference antenna (b) I-shaped antenna (c) Double E-shaped antenna (d) Double E-shaped meander line antenna

The combination of several slots and meander line produce a novel antenna structure of double E-shaped meander line monopole antenna as shown in Figure 2. In the figure, the configuration of the meander line is enlarged for visibility.

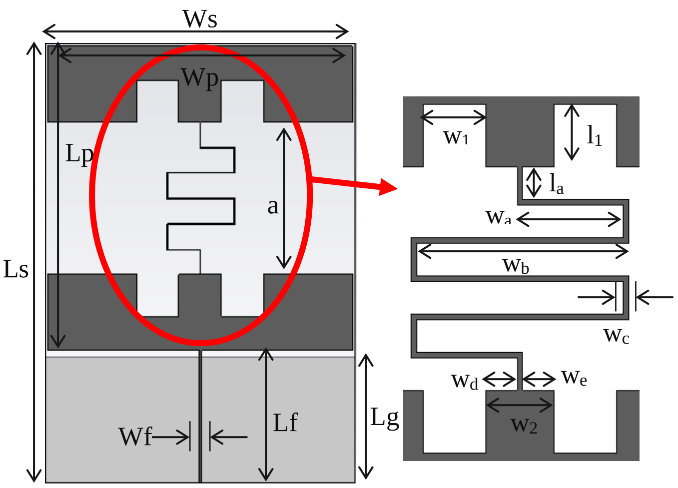


Figure 2: Configuration of the double E-shaped meander line antenna with the meander line configuration is enlarged for visibility

The dimensional parameters of the antenna as listed in Table 1 were optimized using Genetic Algorithm (GA). All parameters' values are set in millimeter (mm). The physical size of the antenna is 543.10 x 771.60 mm^2 covering VHF band.

Table 1
Double E-shaped Meander Line Antenna Dimension

Parameters	Value (mm)	Parameters	Value (mm)
Ws	543.10	w_1	74.20
Ls	771.60	w_2	1.00
Wp	533.50	la	44.00
Lp	533.50	wa	60.90
Wf	3.22	wb	118.80
Lf	233.40	wc	1.00
Lg	222.20	wd	36.80
a	266.20	we	36.80
l_1	74.20		

III. PARAMETRIC ANALYSIS

The analysis of the antennas were performed using Genetic Algorithm (GA) in CST software. While particular parameter of the antenna is optimized, the other parameters are kept fixed. The optimization is carried out to achieve reduction in antenna frequency which will lead to size reduction.

Typical antenna in Figure 1 (a) is considered as a reference antenna. The length of the ground plane, *Lg* is varied to observe its effects on the simulated reflection coefficient and impedance matching as presented in Figure 3. From the graph, it is observed that as the *Lg* increased, the simulated reflection coefficient becomes optimum where the S_{11} value is less than 20 dB.

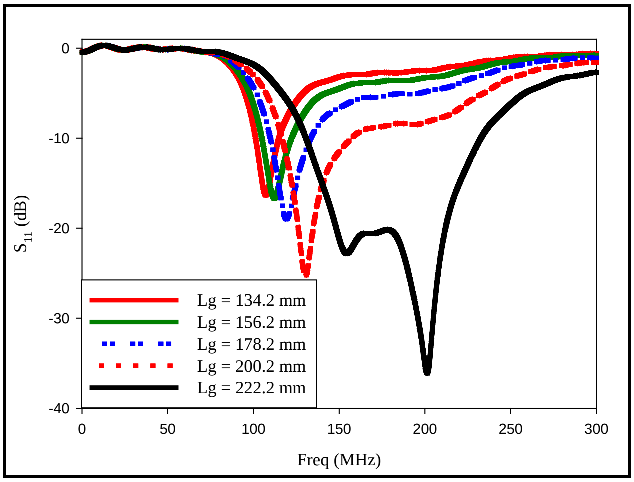


Figure 3: Simulated reflection coefficient of various ground plane length *Lg*

By inserting slots on both side of the patch, the structures changes from square patch to I-shaped patch. The width and length of the slots, *a* in I-shaped monopole patch antenna is varied as in Figure 4. The presence of the slots lead to the increment of the effective capacitance and inductance which reducing the resonant frequency. It is clearly shown in the graph that as *a* increased to 266.2 mm, the resonant frequency of the antenna decreased to 88 MHz where this relationship is in agreement with equation 1.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

where; f_r is resonant frequency, L is inductance and C is capacitance.

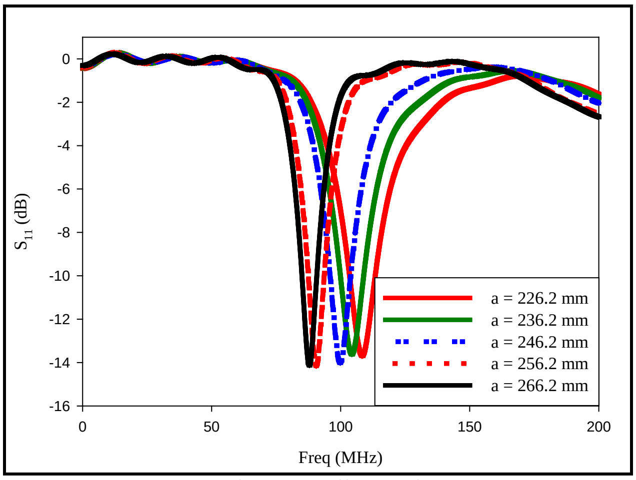


Figure 4: Simulated reflection coefficient of various slot width *a*

The effect of the added slots on the simulated reflection coefficient is explored in Figure 5. It is noticed that various slot width w_1 perform similar pattern on the reflection coefficient. Meanwhile, various slot length l_1 perform slightly different resonant frequencies as shown in Figure 6. It is found that the length of the slot is optimum at l_1 = 74.2 mm where the antenna resonates at 83 MHz. This is due to the increment of the surface current distribution along the length l_1 when l_1 is increased, while the current distribution along the width w_1 is not affected by increasing w_1.

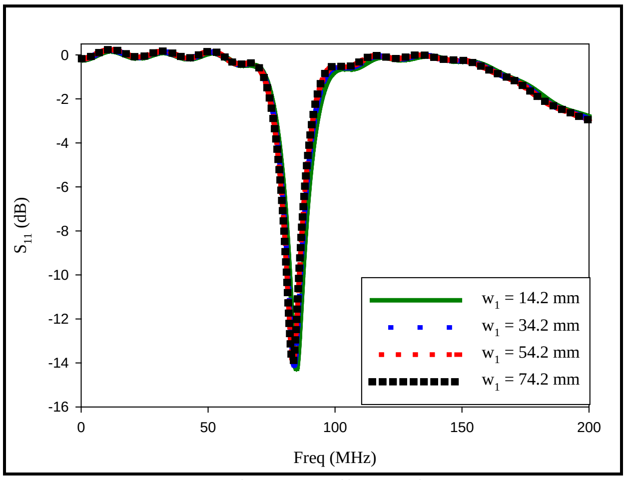


Figure 5: Simulated reflection coefficient of various slot width w_1

Figure 7 shows the effects of the various meander line width w_a on the simulated reflection coefficient. From the graph, the resonant frequency shifted to the lower frequency band when w_a increased. The circumferences of the radiating area is increased by increasing w_a which lead to the reduction in resonant frequency.

The performances of the antenna evolutions as in Figure 1 are displayed in Figure 8. The simulated reflection coefficient of the double E-shaped meander line monopole antenna is presented by a black solid line. Even though the antenna produce narrow bandwidth characteristic, it is not affecting the target applications where the antenna size is more important for VHF applications especially for public safety or radar network. Several slots on the radiating patch disturb the surface current distribution of the antenna which causes narrow bandwidth.

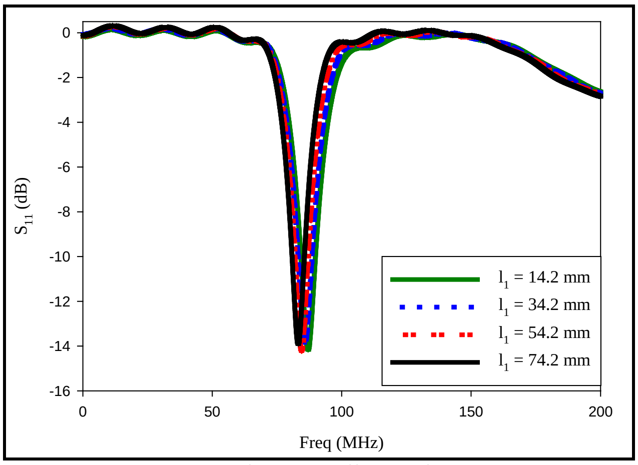


Figure 6: Simulated reflection coefficient of various slot length l_1

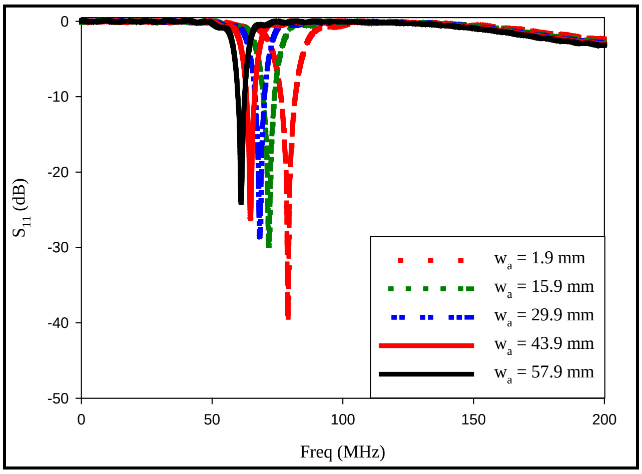


Figure 7: Simulated reflection coefficient of various meander line width w_a

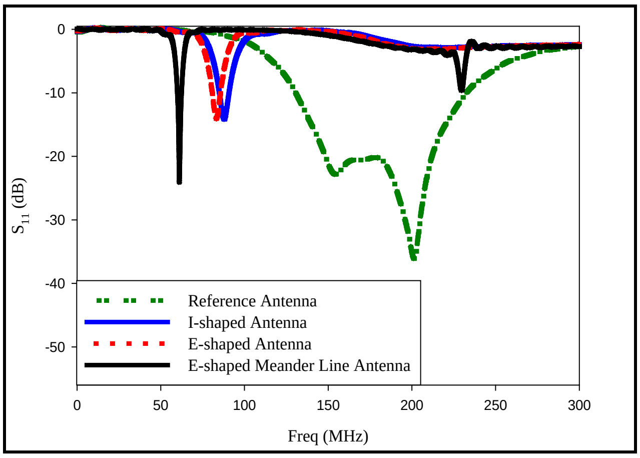


Figure 8: Simulated reflection coefficient of various antenna structures

IV. Final Results and Discussion

The aim of this study is to design miniature printed monopole antenna for VHF applications. The combination of slots and meander line reduce the resonant frequency of the double E-shaped meander line antenna compared to the reference antenna. The size of the antenna is then reduced in order to obtain the targeted resonant frequency band. 89% size reduction has been achieved in this study with a little trade off of other antenna performances. The percentage reduction of the proposed antenna has been calculated by;

$$reduction\ (\%) = \frac{ref.antenna\ size - prop.antenna\ size}{ref.antenna\ size} x\ 100$$

$$reduction\ (\%) = \frac{(543.1mm\ x\ 771.6mm) - (181mm\ x\ 251mm)}{(543.1mm\ x\ 771.6mm)} x\ 100$$

Figure 9 displays the configuration of the miniaturized double E-shaped meander line antenna with DGS on the partial ground plane. The overall size of the antenna has been reduced from 543.10 x 771.60 mm^2 to 181 x 251 mm^2 covering 155 MHz. Figure 9 (b) demonstrates the back view of the proposed antenna. Rectangular shaped DGS with *wg* and length *lg* is inserted on the partial ground plane to improve the reflection coefficient of the antenna. The dimensional parameters of the proposed antenna are organized in Table 2 with their values presented in millimeter (mm).

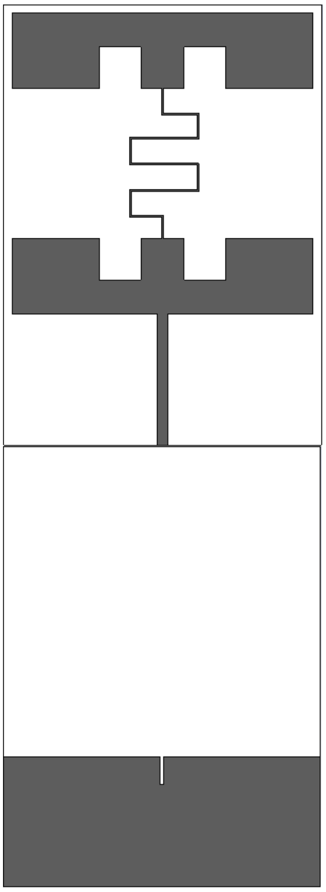


Figure 9: Configuration of the proposed antenna (a) front view (b) back view

Table 2
Proposed Antenna Dimension

Parameters	Value (mm)	Parameters	Value (mm)
Ws	181	w_2	25
Ls	251	la	14
Wp	171	wa	18
Lp	171	wb	37
Wf	6	wc	1.00
Lf	75	wd	12
Lg	74	we	12
a	85	wg	2
l_1	24	lg	16
w_1	25		

The performances of the reference antenna and proposed antenna in term of reflection coefficient are presented in Figure 10. Both antennas covering 155 MHz frequency band, but with different bandwidth characteristic. The proposed antenna due to its small size and modification on the patch produces narrow bandwidth, whereas, the reference antenna produces wide bandwidth. As a matter of fact, most of VHF systems require narrow band antennas, especially for the public safety or radar network.

The miniaturized double E-shaped meander line with DGS structure is referred to as proposed antenna. Experimental work has been carried out to validate and verify the performances of the proposed antenna. The proposed antenna has been fabricated on a low cost FR-4 substrate and tested using the Vector Network Analyzer (VNA) in Anechoic Chamber. The photograph of the fabricated proposed antenna is shown in Figure 11.

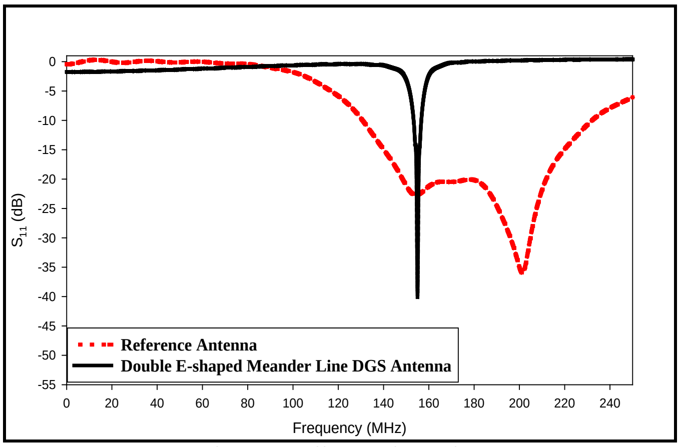
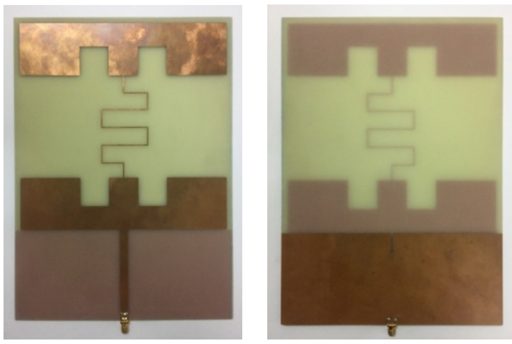


Figure 10: Simulated reflection coefficient of the reference antenna and the proposed antenna



(a) (b)

Figure 11: Photograph of the fabricated antenna (a) front view (b) back view

Figure 12 shows the simulated and measured reflection coefficient of the proposed antenna. It is clearly shown in the graph that the simulated and measured results agree well with each other.

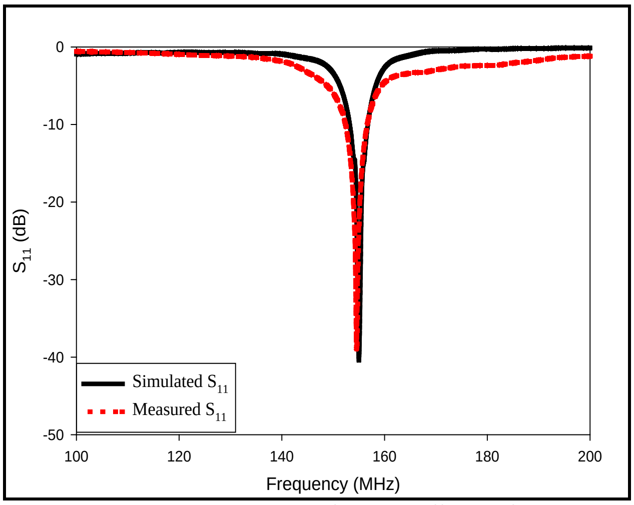


Figure 12: Simulated and measured reflection coefficient of the proposed antenna

Figure 13 shows the simulated and measured Voltage Standing Wave Ratio (VSWR) of the proposed antenna. Both results present good agreement with VSWR less than 1.5.

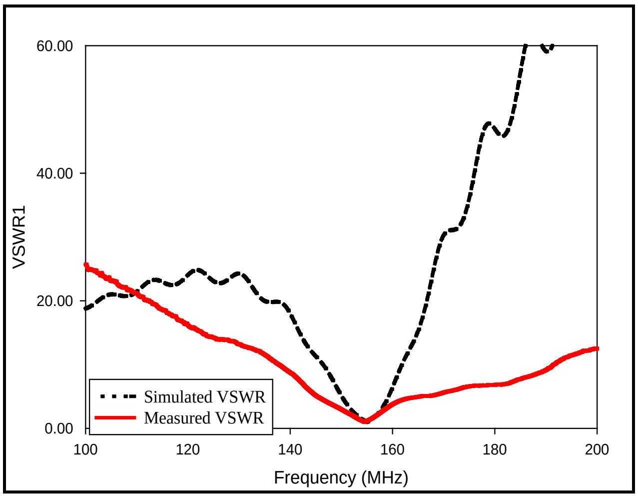


Figure 13: Simulated and measured VSWR of the proposed antenna

The DGS was introduced on the design to improve the reflection coefficient of the design. In addition, the DGS has improved the input impedance of the proposed antenna as well. The input impedance of the proposed antenna is demonstrated in Figure 14 with Z_{in} = 49.06 + j0.07 Ω.

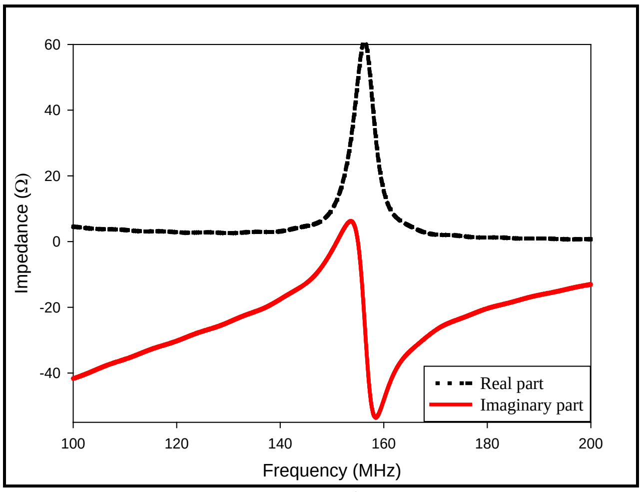


Figure 14: Input impedance of the proposed antenna

The proposed antenna radiates with omnidirectional radiation pattern similar to the reference antenna. 2-D H-plane radiation patterns are presented in Figure 15. Both simulated and measured radiation pattern produce omnidirectional behaviour. Meanwhile, the simulated and measured E-plane radiation pattern are presented in Figure 16 with a slight difference between both results.

Comparison on the antenna performances in simulation and measurement are organized in Table 3. In simulation, the proposed antenna resonates at 155 MHz while in measurement, the antenna resonates at 154.6 MHz. The simulated and measured impedance bandwidth are 2.3% and 2.8%, respectively. The simulated and measured antenna gain are 1.36 dBi and 1.26 dBi, respectively. For antenna that approaching electrically small size, the antenna gain is slightly reduced. However, the proposed antenna gain is sufficient for the targeted applications. The proposed antenna is very efficient both in simulation and measurement. There is a little discrepancies between simulated and measured performances which might due to the fabrication and measurement tolerances.

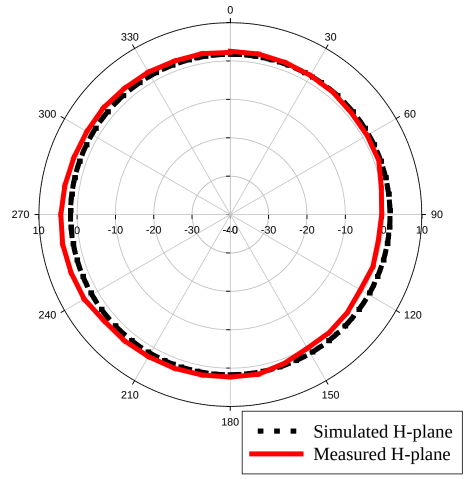


Figure 15: Simulated and measured H-plane radiation pattern

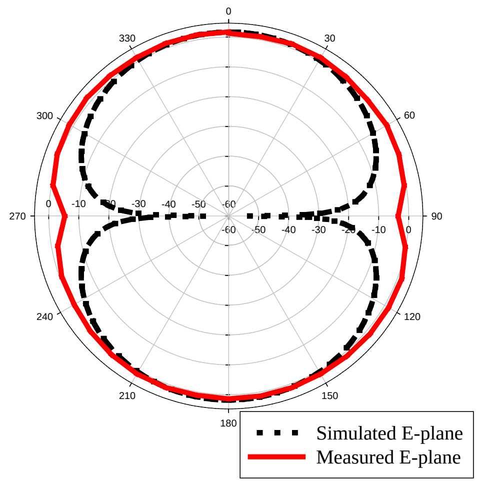


Figure 16: Simulated and measured E-plane radiation pattern

Table 3
Comparison of the Simulated and Measured Results of the Proposed Antenna

Performance	Simulated Proposed Antenna	Measured Proposed Antenna
Resonant Frequency (MHz)	155	154.6
S_{11} (dB)	-40.45	-38.31
Impedance Bandwidth (%)	2.3	2.8
VSWR	1.02	1.03
Gain (dBi)	1.36	1.26
Efficiency (%)	88	97

V. Conclusions

A miniature double E-shaped meander line monopole antenna was designed, fabricated, optimized and measured for VHF applications. A comprehensive parametric analysis has been performed to optimize the performances of the antenna and to observe the effects of various dimensional parameters. The combination of the proposed methods produce novel structure with low frequency band. The size of the antenna has been successfully reduced up to 89% to obtain the desired frequency band with a omnidirectional antenna gain of 1.26 dBi. The proposed antenna possess a very small size without degrading other antenna performances.

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