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Design of a Magneto-Electric Dipole Antenna for FM Radio Broadcasting Base Station Antenna Implementation

Thunyawat Limpiti*, Ajalawit Chantaveerod, and Wijittra Petchakit

Abstract—This work presents the design of a magneto-electric dipole (MED) antenna for the base station antenna of FM radio broadcasting implementation. The advantages of MED antenna are high gain, stable and symmetrical radiation patterns in both electric and magnetic planes, and low back lobe radiation pattern. The antenna was designed and studied to achieve the optimal dimensions of configuration parameters. The prototype antenna was fabricated and measured to validate its S_{11}, radiation patterns, and gain. The impedance bandwidth was 33.49%, and the average gain was 7.78 dBi at the entire operating frequency (88–108 MHz). The measured results are in good agreement with the simulated ones.

1. INTRODUCTION

In recent years, the rapid growth of technologies in wireless communications for many applications, such as digital television, analog and digital radio broadcastings, GSM/3G/4G/LTE mobile communications, WLAN, and WiMAX, causes the finite radio-frequency spectrum significantly congested. Among these applications, analog radio broadcasting, especially FM radio, is one of the most essential missions which confront the severe problem. This problem is the interference between FM radio stations and the interference to the aeronautical radio communications [1]. This type of interference is called "intermodulation" [2]. To solve this problem, various works have been published [3–6]. One of the promising candidates is more inclined towards designing the antenna whose radiation patterns and gain are stable to replace the conventional base station antennas. Normally, dipole antennas are exploited for base station antennas because of their advantages of simple structure and easy fabrication, but they suffer from poor radiation patterns. Several types of antennas having directional radiation patterns, i.e., Yagi-Uda antenna, log-periodic antenna, reflector antenna, and horn antenna, are interesting. However, they are not suitable for being used as base station antennas because of their complex and bulky geometries [7]. Although microstrip patch antenna with the advantages of low profile, light weight, and easy fabrication is a popular one, its radiation pattern is not stable in the entire wide bandwidth.

In order to obtain stable and symmetrical radiation patterns, the concept of complementary antenna firstly revealed by Clavin [8, 9] is raised as the most challenging choice for base station implementation since its excellent characteristics such as symmetrical radiation pattern in both electric and magnetic planes, stable gain at the entire frequency of interest, and low back lobe radiation pattern. This concept has been further applied to develop a simple structure based on the magneto-electric dipole (MED) antenna and proposed by Luk and Wong [10, 11]. Many works concerning magneto-electric dipole antennas have been published [12–17], including base station antennas [18, 19]. In addition, the applied concept of MED with optimal synthesis of the reconfigurable antenna would be a promising candidate for radar applications [20, 21].

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Consequently, this paper presents the implementation of a magneto-electric dipole (MED) antenna for the base station antenna of FM radio broadcasting. This designed antenna is able to cover the frequency range of 88–108 MHz with good directional radiation pattern, low cross polarization, and stable gain. The configuration parameters of the antenna are studied and optimized. Finally, a prototype antenna was fabricated and measured to validate the designed antenna by comparing the simulated and measured results.

2. PRINCIPLE

The concept of MED antenna based on the complementary antenna is simultaneously exciting an electric dipole and a magnetic dipole in order to provide identical E- and H- planes of radiation patterns as illustrated in Fig. 1 in which a planar dipole represents the electric dipole while a vertical quarter wavelength shorted patch represents the magnetic dipole. The electric dipole provides an 8-figure and an O-figure radiation patterns in its E- and H-planes, respectively. On the contrary, the magnetic dipole gives an O-figure and an 8-figure radiation patterns in its E- and H-planes, respectively. An equivalent circuit of MED antenna with L-probe feed is demonstrated as shown in Fig. 2. The L-probe feed can be realized by an inductor L_f and a capacitor C_f. For the electric dipole, a resistor R_d is in series with an inductor L_d and a capacitor C_d, whereas a resistor R_m is in parallel with an inductor L_m and a capacitor C_m for the magnetic dipole. The input admittance of this equivalent circuit can be calculated from

$$Y_{in} = \left[\frac{1}{R_d} + \frac{1}{R_m}\right] - j\left[\left(\omega L_d - \frac{1}{\omega C_d}\right)\frac{1}{R_d^2} - \left(\omega C_m - \frac{1}{\omega L_m}\right)\right] \tag{1}$$

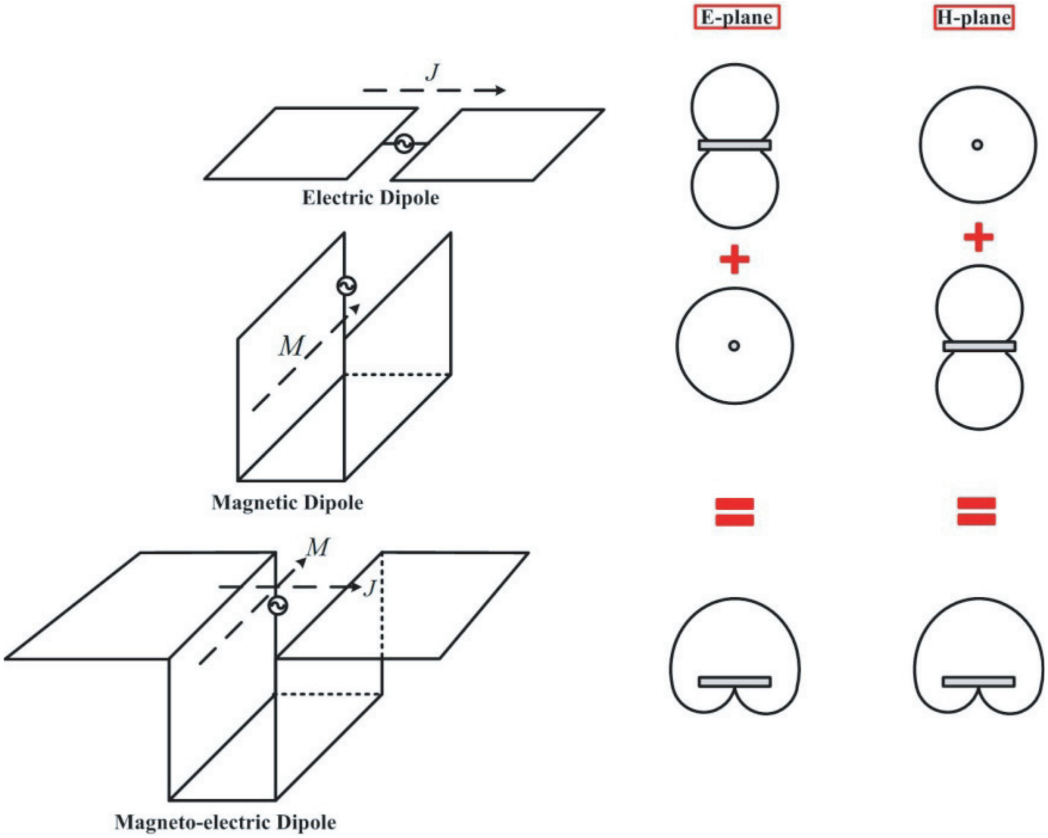


Figure 1. Radiation patterns of magneto-electric dipole antenna.

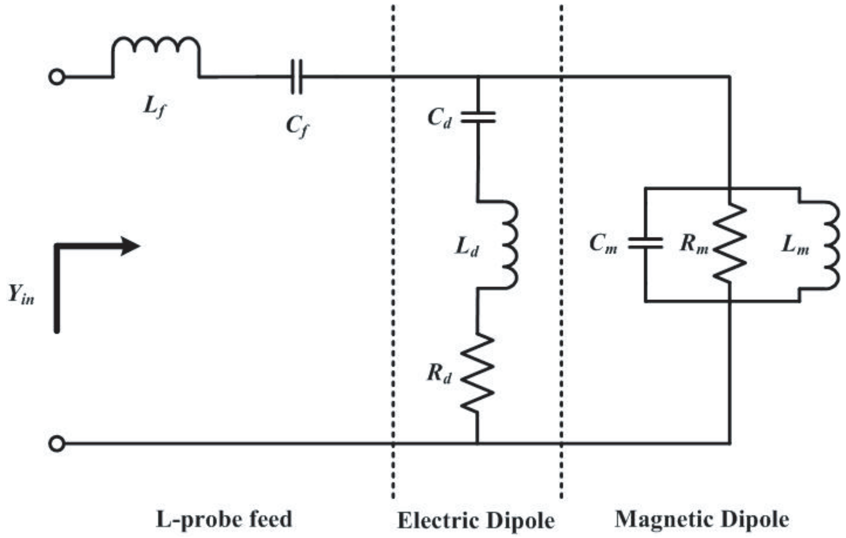


Figure 2. Equivalent circuit of magneto-electric dipole antenna with L-probe feed.

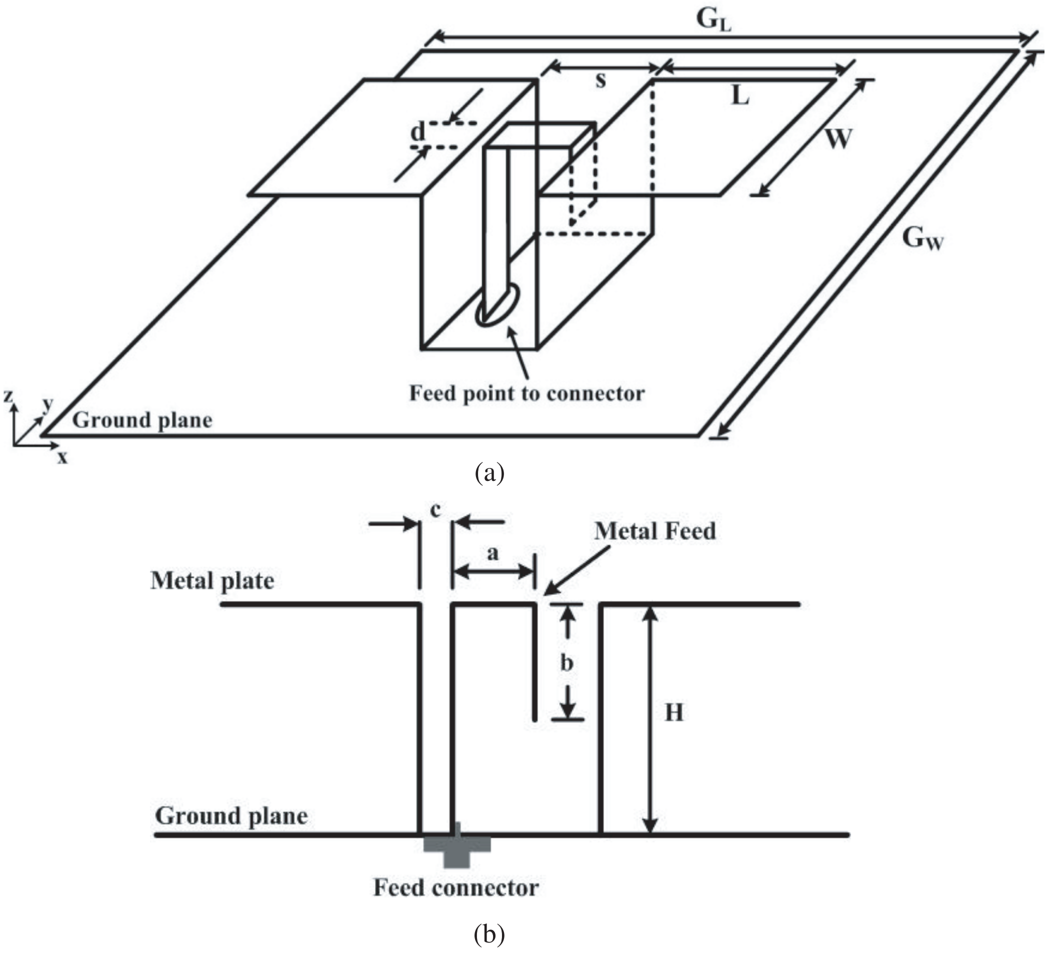
3. DESIGN AND PARAMETERS STUDY

The configuration of the MED antenna with its parameters is depicted in Fig. 3. It consists of a planar dipole, a vertical quarter wavelength shorted patch, a Γ-shaped strip fed by a connector, and a ground plane. This antenna is designed to cover the frequency range of 88–108 MHz. Initially, the dimensions of three parameters of the antenna concerning a part of the planar dipole and the vertical quarter wavelength shorted patch: the planar dipole length $L = 765\,\text{mm}$ (0.25λ), planar dipole width $W = 1530\,\text{mm}$ (0.5λ), and shorted patch length $H = 765\,\text{mm}$ (0.25λ) were calculated at the center frequency of 98 MHz. For the feeding part, the mechanism of Γ-shaped strip feed is composed of three portions: a transmission line, a coupled strip, and a open stub strip. The first portion is a vertical transmission line that acts as a microstrip line whose characteristic impedance is equal to 50 Ω connected to a connector below the ground plane. The second portion horizontally located and connected to the first portion is an important part acting as an electrical energy source to couple the signal to both planar dipole and shorted patch. The last portion is connected to the second portion to form the open stub. The dimension of ground plane ($G_L \times G_W$) is equal to $1\lambda \times 1\lambda$.

The initial dimensions of the antenna were incorporated with the Γ-shaped strip feed to further study the effect of five parameters: the width of Γ-shaped strip feed d, length of coupled strip a, distance between the transmission line and planar dipole c, distance between open stub strip and planar dipole $(s-(a+c))$, and length of open stub strip. The studied parameters were simulated using a commercial electromagnetic software [22] to get the optimal dimensions that are best for FM radio broadcasting antenna.

3.1. Effect of Γ-Shaped Strip Feed Width (d)

The effect of the width of Γ-shaped strip feed d was studied by varying in the range of 42.4–122.4 mm and considering S_{11} as shown in Fig. 4. It is obviously noticed that when the width of Γ-shaped strip feed decreases from 122.4 mm to 102.4 mm, S_{11} and frequency bandwidth are lower and slightly wider, respectively. For the case that d equals 82.4, S_{11} is much lower than $-25\,\text{dB}$, but the frequency bandwidth is much narrower. Moreover, when d is lower than 82.4 mm, S_{11} increases, and it is more than $-10\,\text{dB}$ in the case that d equals 42.4 mm. The optimal dimension of this parameter is 102.4 mm which provides the widest frequency bandwidth of 31.65 MHz (70.75–102.4 MHz).



(a)

(b)

Figure 3. Magneto-electric dipole antenna configuration. (a) 3D view. (b) Side view.

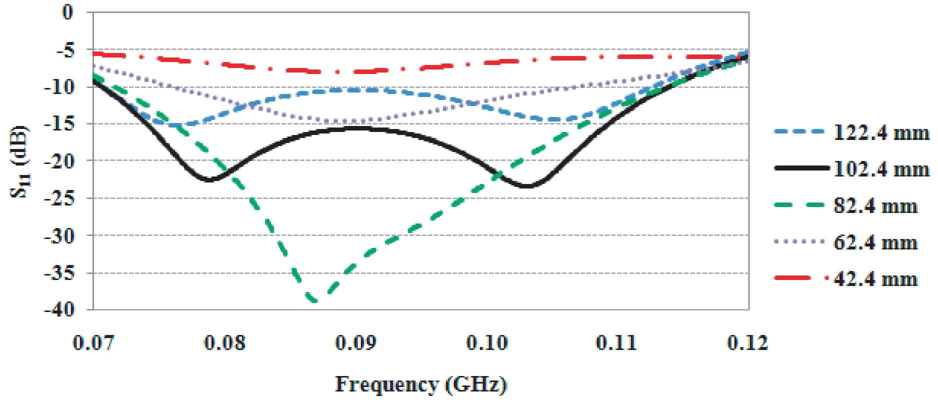


Figure 4. Effect of Γ-shaped strip feed width versus S_{11}.

3.2. Effect of Distance between Transmission Line and Planar Dipole (c)

The effect of distance between the transmission line portion of Γ-shaped strip feed and the near-ended planar dipole c was studied by varying in the range of 24.5–104.5 mm and considering S_{11} as illustrated in Fig. 5 in which parameter d is assumed 102.4 mm. It is obviously seen that parameter c at the distances of 24.5 mm and 44.5 mm provides $S_{11} < -10$ dB covering the frequency range of 88–108 MHz.

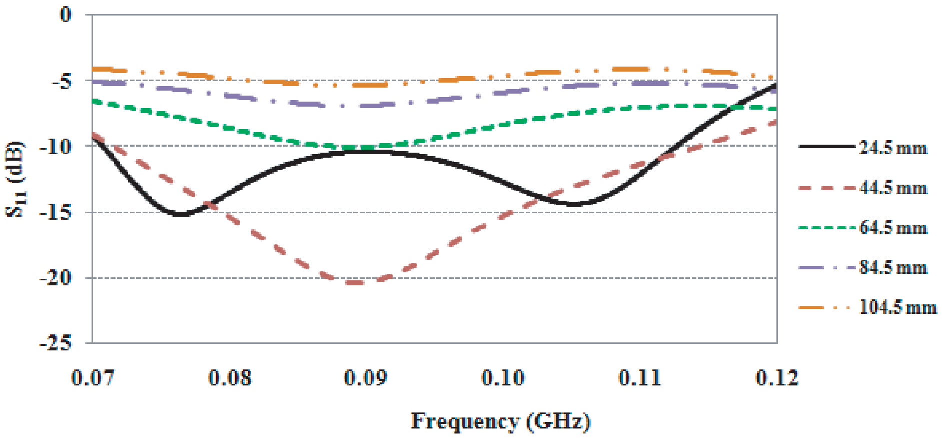


Figure 5. Effect of distance between transmission line and planar dipole versus S_{11}.

For the case that c equals 24.5 mm, the frequency bandwidth is 41.9 MHz (70.75–112.65 MHz) whereas it is 43 MHz (71.45–114.45 MHz) for the case that c equals 44.5 mm. However, when c increases more than 44.5 mm, S_{11} becomes higher than -10 dB in the entire frequency range of interest.

3.3. Effect of Coupled Strip Length (a)

According to the study of parameter c, the optimal dimension was 24.5 mm, which was equal to $0.008\lambda_0$. It is obviously noticed that the magnitude level of coupled signal from the coupling feed to the planar dipole depends on the distance between feed and planar dipole, and the length of coupled strip. Normally, the length of coupled strip of planar dipole is in the range of $0.05\lambda_0$–$0.1\lambda_0$. Thus, the effect of the length of coupled strip portion of Γ-shaped strip feed a was studied by varying in the range of 161.7–261.7 mm and considering S_{11} as depicted in Fig. 6, in which parameters d and c are respectively assumed to be 102.4 mm and 24.5 mm. It can be observed that S_{11} decreases as the length of coupled strip increases, but the frequency bandwidth shifts to the lower frequency. The optimal dimension of this parameter is equal to 241.7 mm.

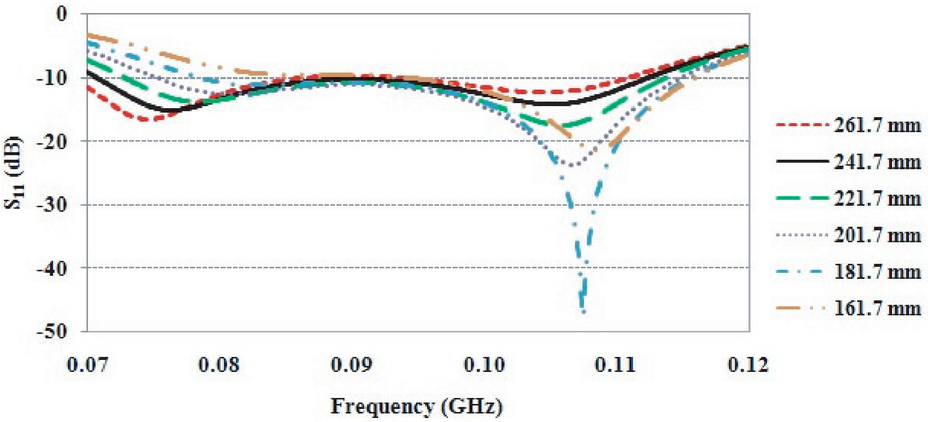


Figure 6. Effect of coupled strip length versus S_{11}.

3.4. Effect of Distance between Open Stub Strip and Planar Dipole ($s-(a+c)$)

The effect of the distance between the transmission line and the far-ended planar dipole $s-(a+c)$ was studied by varying in the range of 77.7–177.7 mm and considering S_{11} as illustrated in Fig. 7 in which parameters d, c and a are respectively assumed to be 102.4 mm, 24.5 mm, and 500 mm. It is clearly

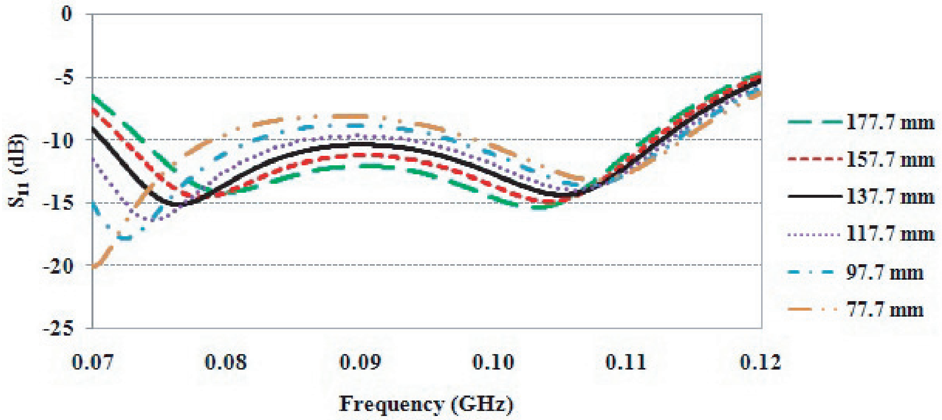


Figure 7. Effect of distance between each side of planar dipole versus S_{11}.

seen that S_{11} increases as the distance decreases. The optimal dimension of this parameter is equal to 137.7 mm.

3.5. Effect of Open Stub Strip Length (b)

The effect of the length of open stub strip b was studied by varying in the range of 500–620 mm and considering S_{11} as depicted in Fig. 8 in which parameters d, c, a, and $s-(a+c)$ are respectively assumed to be 102.4 mm, 24.5 mm, 241.7 mm, and 137.7 mm. It is obviously observed that when the length of open stub strip is equal to 500 mm, the frequency bandwidth is 43.35 MHz (75.3–118.65 MHz). The frequency shift inclines to the lower frequency as the length of the coupled strip increases. However, S_{11} for all coupled strip lengths in the middle range of the wide frequency bandwidth are almost equal to -10 dB.

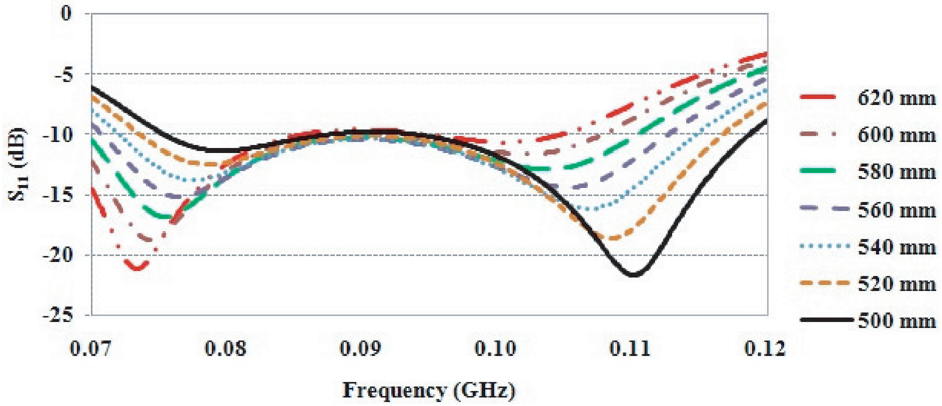


Figure 8. Effect of coupled strip length versus S_{11}.

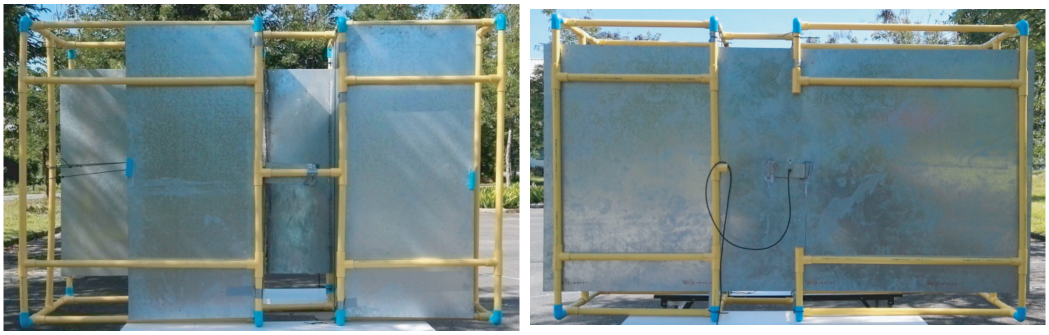
According to the parameters studies, the optimized dimensions of antenna configuration parameters are listed in Table 1. These optimal dimensions are then used in fabricating the prototype which will be described in the next section.

4. EXPERIMENTAL RESULTS

To validate the designed antenna, a prototype antenna with the optimal dimensions as tabulated in Table 1 is fabricated and illustrated in Fig. 9. The fabricated antenna was made of galvanized iron sheets with 1 mm thickness and fed by 50 Ω N-type connector. The prototype antenna was measured to

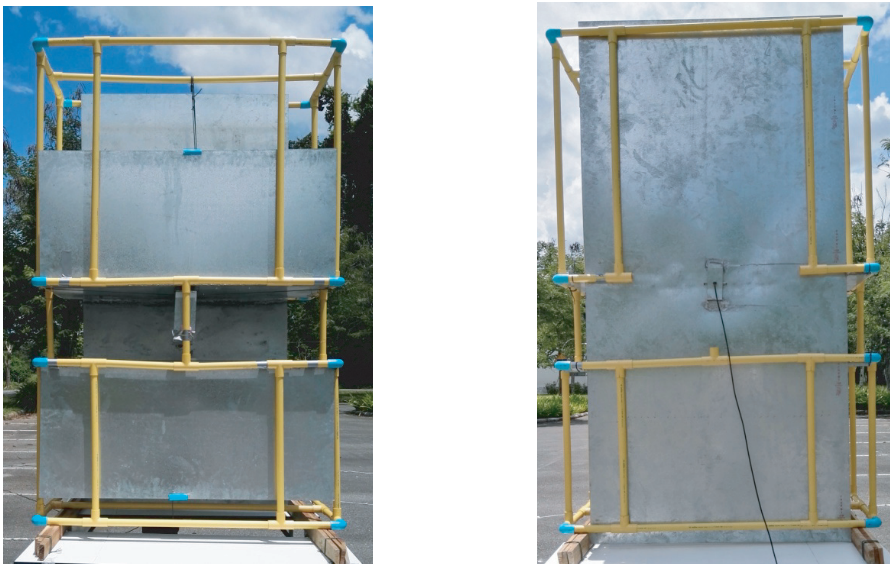
Table 1. Optimal dimensions of designed antenna.

Parameters	Values (mm)	Parameters	Values (mm)
a	241.7 ($0.08\lambda_0$)	H	765 ($0.25\lambda_0$)
b	500 ($0.16\lambda_0$)	W	1440 ($0.47\lambda_0$)
c	24.5 ($0.008\lambda_0$)	L	645 ($0.21\lambda_0$)
d	102.4 ($0.03\lambda_0$)	G_W	3410 (λ_0)
$s-(c+a)$	137.7 ($0.045\lambda_0$)	G_L	3410 (λ_0)



front view back view

(a)



front view back view

(b)

Figure 9. Prototype antenna with plastic supporter. (a) Horizontal alignment. (b) Vertical alignment.

verify the reflection coefficient (S_{11}) by a Keysight E5063A ENA Series network analyzer, whereas the measurements of radiation patterns and gain were set up in the open space area by using a Keysight N5173B analog signal generator and a Keysight N9340B handheld spectrum analyzer. The comparison of measured and simulated S_{11} is shown in Fig. 10. It is clearly seen that the impedance bandwidth is 33.49% ($S_{11} \leq -10$) covering 84.4–118.35 MHz, which is narrower than the simulated one. The deviation between the measured and simulated results might result from the increasing mismatch caused by errors from prototype fabrication, which sum up the insertion loss of discontinuity of antenna structure, connector soldering and connecting cable. In addition, the inherent resistance characteristic of material used in prototype fabrication differs from the perfect electric conductor (PEC) material used in simulation. The radiation patterns in both E-plane (xz-plane) and H-plane (yz-plane) were measured at frequencies of 88, 98, and 108 MHz and compared with the simulated ones as illustrated in Fig. 11. It can be seen that the measured radiation patterns are broadside which are symmetric and stable in the entire operating frequencies. The half power beamwidths at the center frequency of 98 MHz in E- and H-planes are respectively 70° and 79°. Moreover, the measured E-plane patterns are

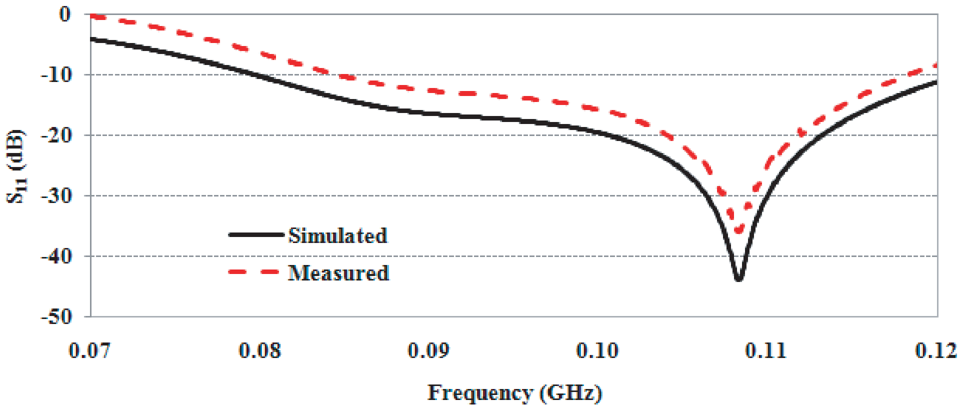
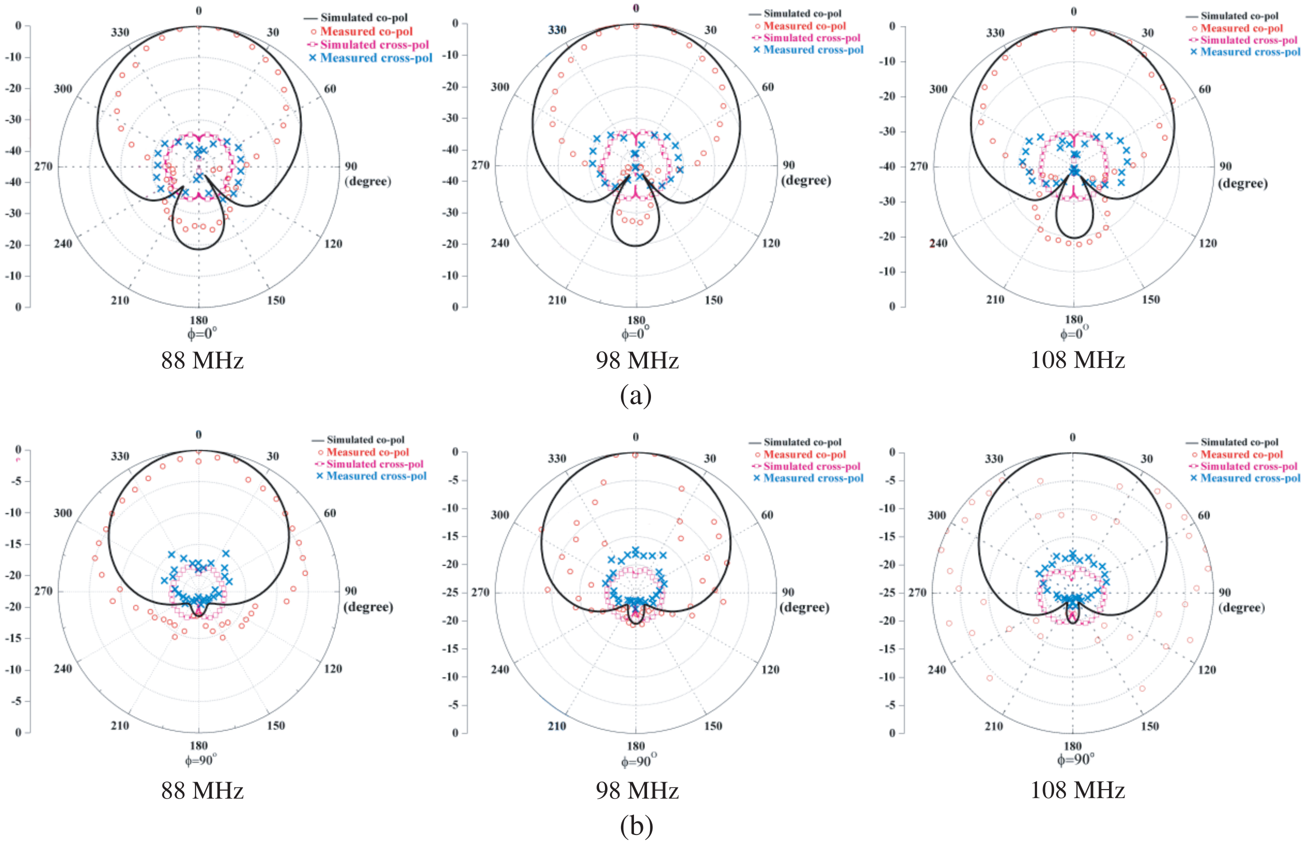


Figure 10. Simulated and measured S_{11}.



88 MHz 98 MHz 108 MHz

(a)

88 MHz 98 MHz 108 MHz

(b)

Figure 11. Simulated and measured radiation patterns. (a) xz plane. (b) yz plane.

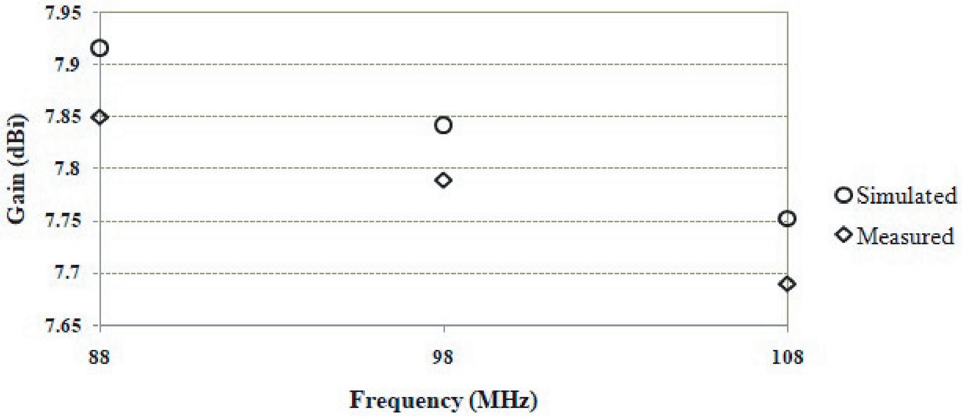


Figure 12. Comparison of simulated and measured gain.

narrower than the simulated results for all frequencies, but the measured H-plane patterns are wider than the simulated results. The cross-polarization radiation patterns in both planes are at low level as depicted in Fig. 11. Note that the much difference between the measured and simulated results might be caused by the scattering from surroundings, i.e., ground, plastic supporter, and tables where the radiation patterns were tested. Since the antenna was so bulky, the measurement was unable to be done in an anechoic chamber. The simulated and measured gains were measured at the frequencies of 88 MHz, 98 MHz, and 108 MHz and compared as shown in Fig. 12. The measured gains were slightly lower than the simulated ones. The average measured gain of this prototype antenna is 7.78 dBi.

5. CONCLUSION

The design of a magneto-electric dipole antenna for the base station antenna of FM radio broadcasting implementation was presented. The antenna design and parameter studies to achieve optimal dimensions were also described. The prototype antenna was fabricated and measured to validate its S_{11}, radiation patterns, and gain. The impedance bandwidth was 33.49%, and the average gain was 7.78 dBi covering the entire operating frequency (88–108 MHz). The measured results are in good agreement with the simulated ones. The advantages of this presented antenna are high gain, stable and symmetrical radiation patterns in both electric and magnetic planes, and low back lobe radiation pattern. However, it still has a limitation in the bulky configuration issue for the practical usage, which will be further improved.

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