Dual-Band Magneto-Electric Dipole Antenna with High-Gain for Base-Station Applications

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Abstract:

The paper presents the results of a novel high-gain dual-band magneto-electric dipole (MED) antenna. The antenna comprises two pairs of horizontal metal plates of different heights that are excited by a Γ-shaped feedline structure. The antenna is entirely made of metal plates. Compared to traditional MED antennas the proposed design exhibits dual-band operation with higher radiation gain and whose frequency ratio can be modified by simply adjusting the heights of the two magneto-electric dipole segments. This feature is necessary for cellular base-station applications. The operation and characteristics of the antenna are validated by measurements. The measured results confirm the proposed antenna achieves fractional bandwidths of 13.31% (801.9-916.2 MHz) and 19.76% (1710.7-2085.7 MHz) for $S_{11} \leq$-10 dB. It has stable unidirectional radiation patterns and optimum radiation gains of 9.2 dBi and 7.8 dBi at the first and second operating bands, respectively.

Key words: dual-band antenna, magneto-electric dipole, base station applications.

I. Introduction:

The fundamental MED antenna was first introduced in 2006 [1]. This type of antenna is based on the complementary concepts and composed of a shorted patch and an electric dipole. Due to excellent impedance matching and good radiation behavior, the MED antennas has recently attracted much interest [2-4]. In [2] a circularly polarized MED antenna is proposed that consists of two cross-placed magneto-electric dipoles and a feeding structure. The antenna has a fractional bandwidth of 85.7% (2 to 5 GHz), and a peak gain of approximately 8.3 dBi. Another design example of the MED antenna is investigated in [3] for cellular base stations. This antenna comprises a horizontal slotted electric dipole and a vertical magnetic dipole, which is shorted to the ground. This antenna has a fractional bandwidth of 63.3% (2.05 to 3.95 GHz), and an average gain of 5 dBi. A cavity-backed MED antenna in [4] is employed in the implementation of a 4 × 4 antenna array. The antenna employs substrate integrated waveguide (SIW) aperture as a feed mechanism. This antenna is shown to achieve a fractional bandwidth of 19.1% (30.3 to 36.7 GHz) and a peak gain of about 20 dBi. The aforementioned antennas operate over a single frequency band.

Next generation of wireless communication systems use software-defined radio architecture to enable base-stations to simultaneously support multiple radio standards. Consequently, there is a demand for antennas that are capable of dual-band and/or multiband operation. The use of dual-band antennas decreases the number of antenna elements employed and reduces the cost and installation space for the base-station system. In the last few years, many studies have been carried out on the dual-band MED antennas [5-6]. In [5], a dual-layer structure is used to realize dual-band MED antennas that have fractional bandwidths of 47.5% (1.70-2.76 GHz) and 30.2% (4.50-6.10 GHz), and corresponding peak gains of 9.7 dBi and 8.5 dBi, respectively. In [6], two U-shaped slots etched on the dipole results in dual-band characteristics covering 2.13-2.62 GHz and 4.57-6.28 GHz with a corresponding peak gain of 4.7 dBi and 3 dBi, respectively.

In this paper, we present a novel high-gain magneto-electric dipole antenna that exhibits dual-band characteristics and radiates energy unidirectionally in both bands. The gain performance in both bands is relatively high compared to other MED antennas. The proposed antenna is composed of two pairs of horizontal metal plates of different heights that are excited by a Γ-shaped metal strip. In fact, the upper metal plates determine the frequency of the first band, and the lower metal plate the second frequency band. The proposed antenna is a simple structure that can be easily designed and fabricated.

II. Single-Band MED Antenna Design

Initially a single-band MED antenna was designed, which is based on the traditional MED antenna structure. The geometry of the single-band MED antenna is shown in Fig.1. It consists of two horizontal metal plates that are placed above the metallic ground-plane at a height of ~λ/4, where λ is the wavelength in the free-space at the center of the operating frequency band. The plates are connected to the two vertical short-circuited patched. Horizontal plates act like an electric dipole and the vertical plates as a magnetic dipole. The length of the electric and magnetic dipole is designed close to a quarter-wavelength, corresponding to the desired resonant frequency. A 'Γ-shaped' feed strip is used to excite the electric and magnetic dipoles. The feed strip is connected to the inner pin of the SMA connector that is located under the metallic ground-plane. The equivalent circuit of the single-band MED antenna is shown in Fig.1(d). The feedline is represented by inductor L_f and coupling capacitance between feedline and shorted vertical patches by C_f. The electric dipole consists of 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 represents the magnetic dipole.

A parametric analysis was conducted to understand of how the Γ-shaped feed strip affected the S_{11} performance of the single-band MED antenna. The results of this analysis in Fig.2 shows the frequency of the peak dip in S_{11} decreases from 1950 MHz to 1805 MHz with increase in L_1 length from 24.5 mm to 32.5 mm; however, there is negligible change in the impedance bandwidth. Simulated reflection-coefficient (S_{11}) and peak gain of this antenna for L_1 = 27.5 mm are shown in Fig.3. The single-band MED antenna has a fractional bandwidth of 18.73% (1708.5 to 2061.6 MHz) for S_{11} ≤-10 dB, and average gain of approximately 8 dBi.

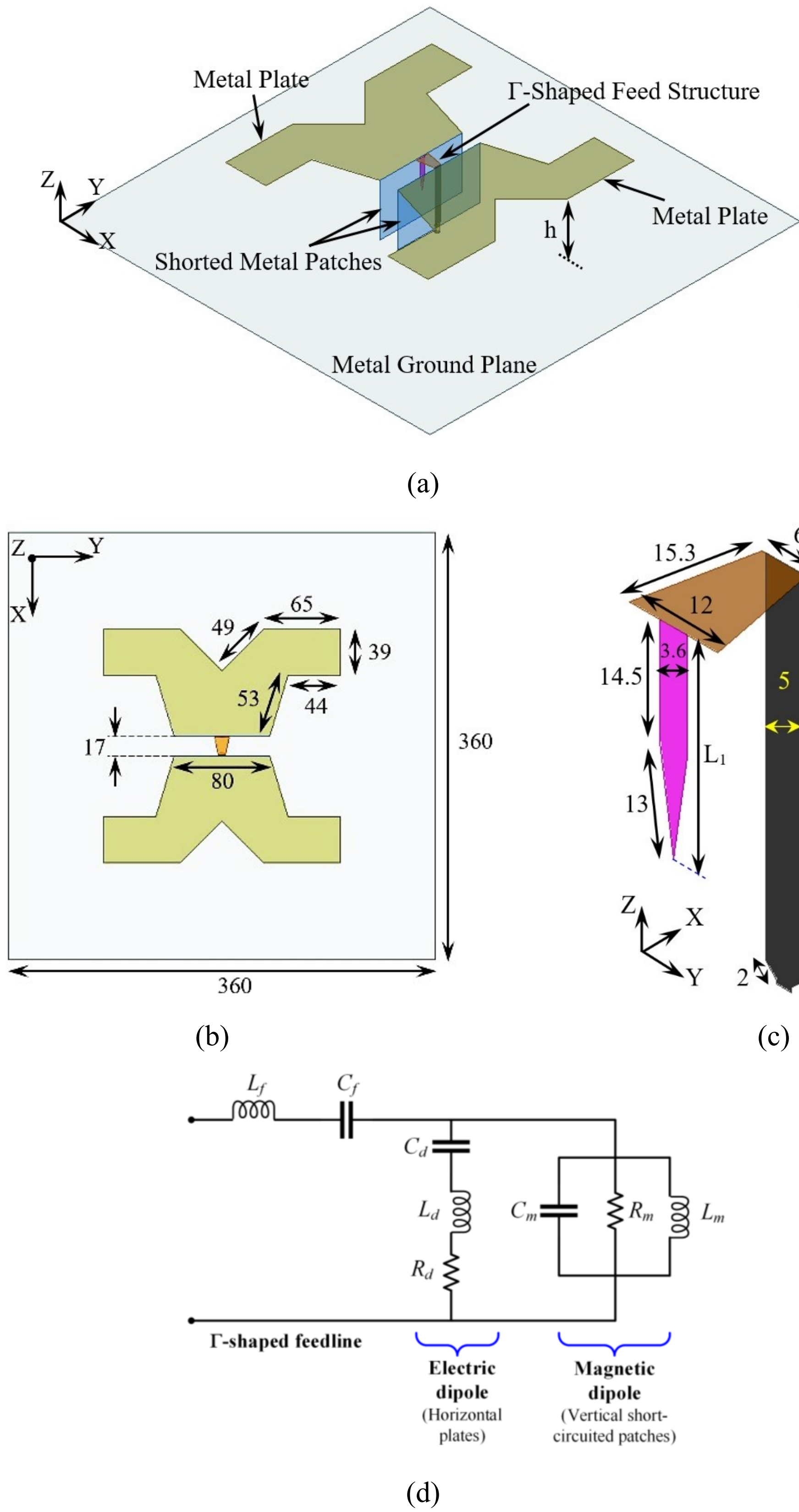

Metal Plate
Γ-Shaped Feed Structure
Z
Y
X
Metal Plate
h
Shorted Metal Patches
Metal Ground Plane
(a)
Z
Y
X
65
49
39
53
44
17
80
360
360
(b)
15.3
6
12
3.6
14.5
5
L1
48
13
Z
X
Y
2
(c)
Lf
Cf
Cd
Ld
Rd
Cm
Rm
Lm
Γ-shaped feedline
Electric dipole
(Horizontal plates)
Magnetic dipole
(Vertical short-circuited patches)
(d)

Fig. 1 Structure of the single-band MED antenna and Γ-shaped feed structure with the antenna results. a) Perspective view, (h = 50 mm), b) Top view, c) Γ-shaped feed structure, (L_1 = 27.5 mm), & d) Equivalent circuit of the single-band MED antenna. (units: mm)

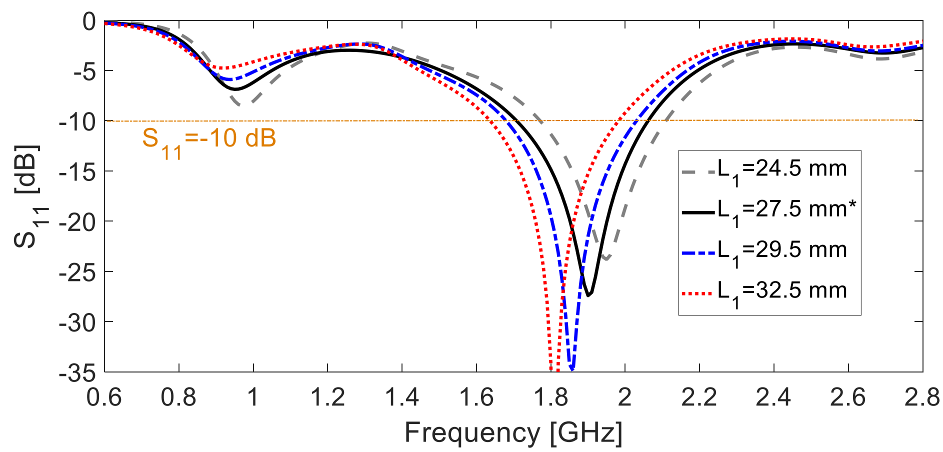


Fig. 2 Simulated reflection-coefficient (S_{11}) response of the single-band MED antenna as a function of Γ-shaped feed strip length L_1.

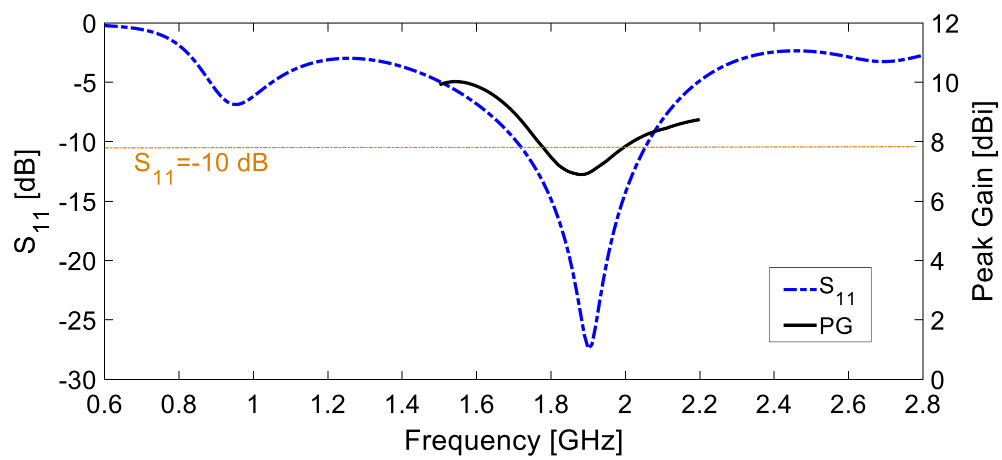
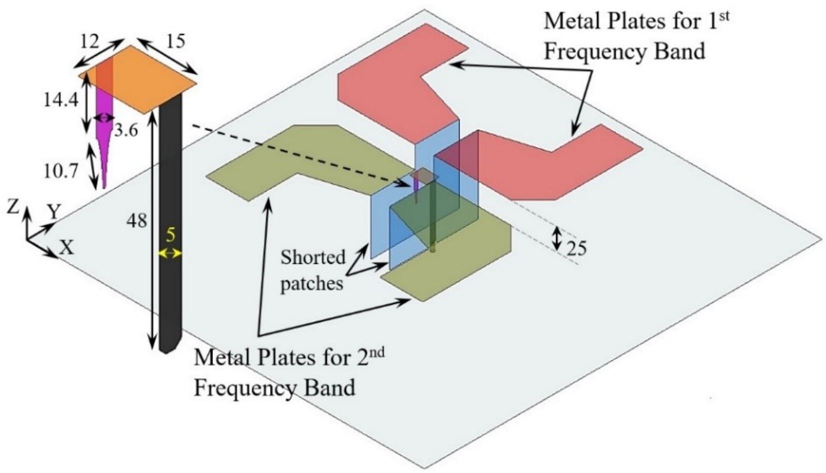


Fig. 3 Simulated reflection-coefficient (S_{11}) and peak gain response of the single-band MED antenna for L_1 = 27.5 mm.

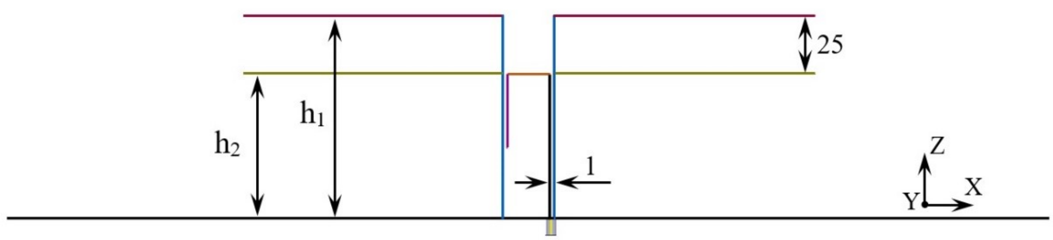
III. Proposed Dual-Band MED Antenna Design

The structure of the proposed dual-band MED antenna is shown in Fig.4. Compared to the single-band antenna structure in Fig.1 each of the horizontal metal plates is divided into two equal segments which are of different heights. Consequently, there are two pairs of horizontal metal plates. To generate two distinct frequency bands, one pair of the metal plates is located at the height of h_1, and the other one positioned at the height of h_2. The frequency ratio between the two bands is determined by the gap between the segment heights. The equivalent circuit of the dual-band MED antenna is shown in Fig.4(c). The gap between the pair of horizontal plates for the desired operating band in this case is 25 mm. A single band antenna can be easily realized by making $h_1 = h_2$.

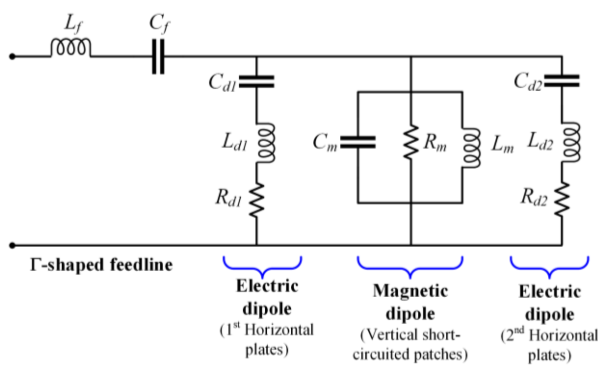
The current distribution over the antenna at its upper and lower operating bands in Fig.5 shows the current to be concentrated predominately at the Γ-shaped feed structure, which consists of three segments. This is not surprising as it is connected to the SMA excitation point. The coupled current over the vertical shorted patch is more intensely distributed than at the horizontal plates.



(a)

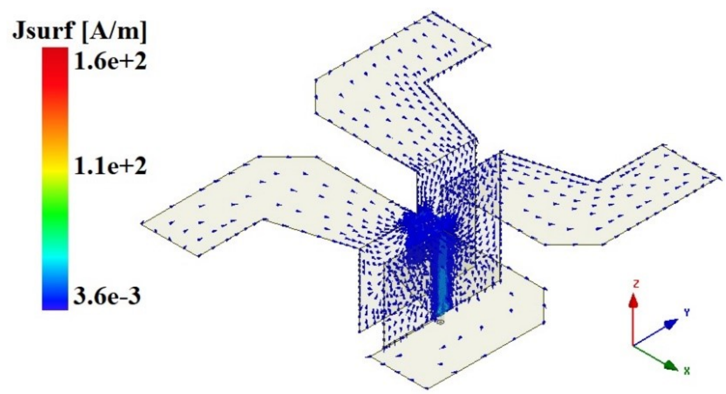


(b)

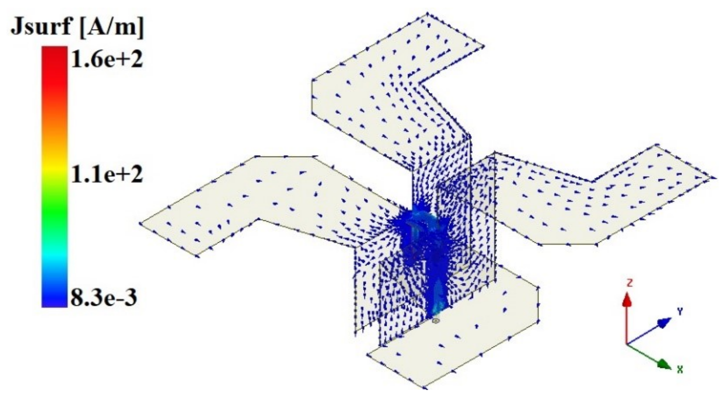


(c)

Fig. 4 Proposed dual-band MED antenna and Γ-shaped feed structure, a) Perspective view of the antenna and Γ-shaped feed strip, b) Side view of the antenna, & c) Equivalent circuit of the dual-band MED antenna. (units: mm)



(a)

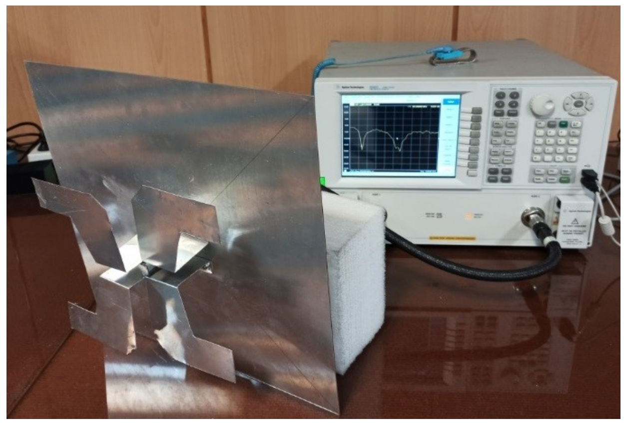


(b)

Fig. 5 Current distribution over the dual-band MED antenna, a) At 850 MHz, & b) At 1800 MHz.

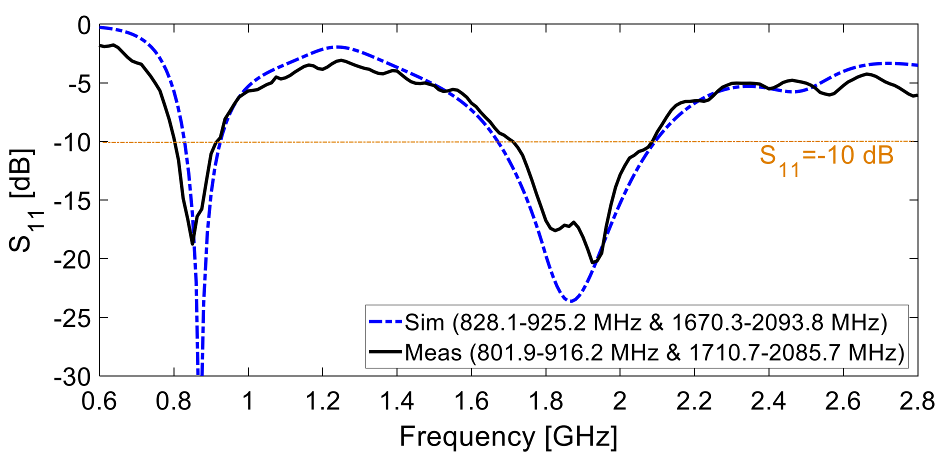
The optimized physical dimensions of the proposed dual-band antenna were obtained through parametric study using 3D electromagnetic simulation tool (HFSS. Ver13). The proposed dual-band MED antenna was fabricated in-house and tested using Agilent's Network Analyzer (E8363C). Fig. 6 shows photographs of the antenna in situ with the measurement setup. Simulated and measured S_{11} response of the proposed antenna are shown in Fig.7(a). The numerical and measured results agree well with each other. According to the measurements, the proposed antenna achieves fractional bandwidth at the lower and upper bands of 13.31% (801.9 to 916.2 MHz) and 19.76% (1710.7 to 2085.7 MHz), respectively, for $S_{11} \leq$-10 dB. The antenna gain is its ability to radiate efficiently relative to an isotropic antenna. Fig.7(b) shows the simulated and measured peak gain response of the antenna. The measured average peak gain is 9.4 dBi at the first frequency band and 7.9 dBi at the second band. The gain at the lower band is unusually higher than at the upper band. This is attributed to the better matching performance at the narrow lower band than at the upper band as evident in Fig.7(a). In the magneto-electric dipole antenna the gain is affected by the electromagnetic coupling between the two magneto-electric dipole segments. As the frequency of the signal increase in the operating band, the interaction of the shorter wavelength signals with the antenna segments increases and causes the gain to fall. This phenomenon is also observed in other published work on dual-band magneto-electric dipole antennas [7, 8]. The antenna's radiation patterns in the H-plane (*yz*-plane) and E-plane (*xz*-plane) at 850 and 1800 MHz are shown in Fig.8. The radiation patterns are stable and unidirectional with very low cross-polarization, and the antenna has a low backward radiation. The antenna's cross-polarization (X-pol) level is better than -20 dB in both H- and E-planes at 850 MHz. At 1800 MHz, the X-pol is better than -20 dB in the H-plane and is approximately -20 dB in the E-plane. The measured half-power beamwidth (HPBW) is 105.4° at 850 MHz and 83.3° at 1800 MHz.

(a)

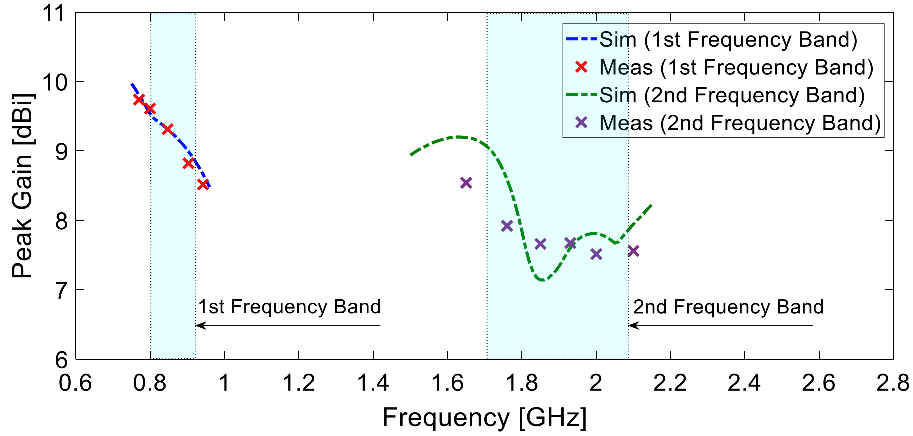


(b)

Fig. 6 Photographs of the fabricated dual-band MED antenna, a) The antenna in anechoic chamber, & b) The antenna connected to the Network Analyzer.

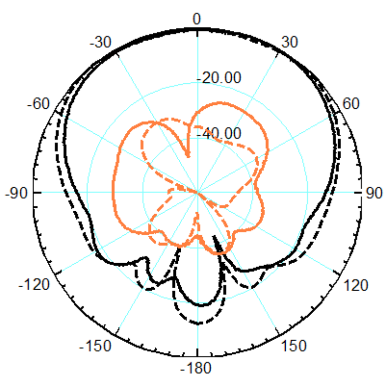


(a)

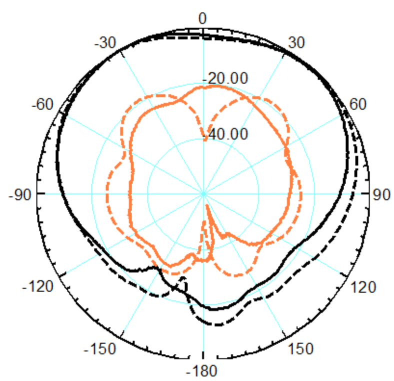


(b)

Fig. 7 Simulated and measured responses of the proposed dual-band MED antenna, a) S_{11} response, & b) Peak gain at direction of $\phi = 0°$ and $\theta=0°$.



(a)



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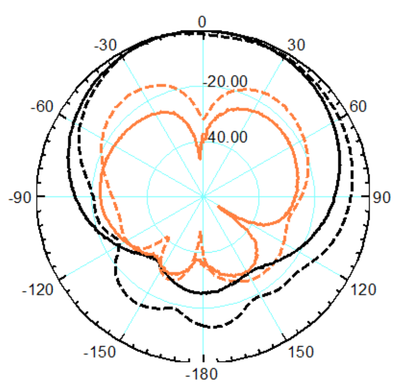

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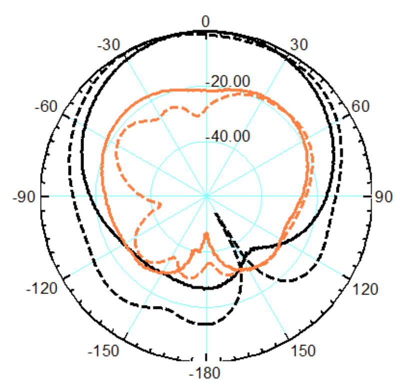

(d)

Fig. 8 Simulated and measured radiation patterns of the proposed dual-band MED antenna at 850 and 1800 MHz. a) H-plane at 850 MHz, b) E-plane at 850 MHz, c) H-plane at 1800 MHz, & d) E-plane at 1800 MHz. (Black lines represent Co-pol and orange lines the X-pol. Measured radiation patterns are shown in solid lines, and simulated patterns in dash lines).

Table 1 shows a comparison between the proposed antenna and other dual-band antennas in terms of operating impedance bandwidth, HPBW, broadside gain, and dimensions. Compared to other dual-band antennas the proposed design has the higher gain performance. In addition, the frequency ratio of the dual-band can be controlled by adjusting the gap between the two magneto-electric dipole segments, and it is much simpler to design and manufacture.

Table 1. Size and performance comparison of dual-band MED antennas

Refs.	Impedance BW (GHz) / FBW (%)	HPBW (deg)	Ave. Gain (dBi)	Dimensions (λ_o^3)
6	2.13-2.62 / 20.6 4.57-6.28 / 31.5	60 104	4	1.80×1.80×0.16
9	1.83-2.92 / 45.9 2.39-2.52 / 5.29	30 56	7	0.95×0.95×0.24
10	0.80-1.10 / 31.6 1.67–2.71 / 47.5	NR NR	3.6	0.64×0.40×0.0025
11	1.68-2.93 / 54.2 3.32-3.64 / 9.2	103 165	6.1	0.71×0.70×0.15
12	0.79–1.01 / 24.4 1.38–2.78 / 67.3	NR NR	7.2 7.5	0.95×1.36×0.35
13	1.67–2.75 / 24.4 3.22–4.13 / 24.7	49 21.5	5.9 4.9	NR
14	0.77–1.15 / 39.6 1.66–2.93 / 55.3	90 85	4.4 4.0	0.97×0.73×0.88
15	4.31–4.71 / 18 5.07–5.89 / 45	84 60	4.4 5.3	0.73×0.73×0.11
This work	0.80-0.92 /13.4 1.71-2.08 / 19.8	105.4 83.3	9.2 7.8	1.03×1.03×0.21

FBW: Fractional Bandwidth, NR: Not Reported

IV. **Conclusion**

Design of an innovative high-gain dual-band MED antenna is verified by measurement. Dual-band functionality is created by employing two pairs of horizontal metal plates of different heights. The magneto-electric dipoles created by the two segments resonate at dual-band that is determined by the dimensions of the segments. The antenna exhibits impedance bandwidths of 13.31% centered at 850 MHz and 19.76% centered at 1900 MHz for $S_{11} \leq$-10 dB. The gain performance in both operating bands is relatively high compared to other MED antennas. The proposed antenna exhibits stable radiation patterns and a low backward radiation, both in the lower and the upper band. The proposed dual-band MED antenna should find application in cellular base-stations.

Acknowledgments

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References

[1] Luk, K M, and Wong, H, "A new wideband unidirectional antenna element," Int. J. Microw. Opt. Technol., 2006, 1, (1), pp. 35–44.

[2] Liang W, Ni T, Li J, Jiao Y-C, "Circularly polarised magneto-electric dipole antenna," Electronics Letters 2014; 50:976–978. doi:10.1049/el.2014.0812.

[3] Idayachandran G, Nakkeeran R, "Compact magneto-electric dipole antenna for LTE femtocell base stations," Electronics Letters 2016; 52:574–576. doi:10.1049/el.2015.3266.

[4] Yang G, Zhang J, Zhou Z, "Low-profile broadband aperture coupled magneto-electric dipole array antenna for millimetre-wave applications," Electronics Letters 2020; 56:271–273. doi:10.1049/el.2019.3514.

[5] Yang M, Zhou J, Lian W, Chen B, "Dual-band dual-polarized magneto-electric dipole antenna with dual-layer structure," Progress in Electromagnetics Research M 2020; 92:193–202. doi: 10.2528/pierm20022708.

[6] Yan S, Soh PJ, Vandenbosch GAE, "Wearable dual-band magneto-electric dipole antenna for WBAN/WLAN applications," IEEE Transactions on Antennas and Propagation 2015; 63:4165–4169. doi:10.1109/tap.2015.2443863.

[7] Yan S, Soh P.J., and Vandenbosch G.AA.E., "Wearable Dual-Band Magneto-Electric Dipole Antenna for WBAN/WLAN Applications," IEEE Trans. on Antennas & Propagation, Vol. 63, No. 9, Sept. 2015:4165-4169.

[8] He K, Gong S-X, and Gao F., "A wideband dual-band magneto-electric dipole antenna with improved feeding structure," IEEE Antennas & Wireless Propagation Letters, Vol. 13, 2014:1729-1732.

[9] Zhai H, Zhang J, Zang Y, Gao Q, Liang C, "An LTE base-station magnetoelectric dipole antenna with anti-interference characteristics and its MIMO System Application," IEEE Antennas and Wireless Propagation Letters 2015; 14:906–909. doi:10.1109/lawp.2014.2384519.

[10] Feng B, Yin S, Li S., "A planar-printed E-shaped omnidirectional magneto-electric dipole antenna for WWAN/LTE applications," Microwave and Optical Technology Letters 2014; 56:1734–1739. doi:10.1002/mop.28441.

[11] Feng B, Chung KL, Lai J, Zeng Q., "A conformal magneto-electric dipole antenna with wide H-plane and band-notch radiation characteristics for sub-6-GHz 5G base-station," IEEE Access 2019; 7:17469–17479. doi:10.1109/access.2019.2896356.
[12] Feng B, Hong W, Li S, An W, Yin S., "A dual-wideband double-layer magnetoelectric dipole antenna with a modified horned reflector for 2G/3G/LTE applications," International Journal of Antennas and Propagation 2013; 2013:1–9. doi:10.1155/2013/509589.
[13] Lai J, Feng B, Zeng Q, Chung K. L., "A low-profile metamaterial magneto-electric dipole antenna with band-notch characteristics for 5-G MIMO base-stations," International Symposium on Antennas and Propagation (ISAP), 2017:1-2.
[14] Zhao Z, Lai J, Feng B, Sim C-Y-D, "A Dual-polarized dual-band antenna with high gain for 2G/3G/LTE indoor communications," IEEE Access, Vol. 6, 2018:61623-61632.
[15] Shuai C-Y, Wang G-M, "Substrate integrated low-profile dual-band magneto-electric dipole antenna," RF and Microwave Computer-Aided Engineering, Vol. 28, Issue 4, Dec. 2017:1-8.