Research Article

Ram Horn-Shaped Inspired Folded Compact Antenna for 4G LTE-A and WLAN Portable Mobile Applications

Jeremiah O. Abolade and Dominic B. O. Konditi

1Department of Electrical Engineering, Pan African University, Institute for Basic Sciences, Technology and Innovation, Nairobi, Kenya
2School of Electrical and Electronic Engineering, The Technical University of Kenya, Nairobi, Kenya

Correspondence should be addressed to Jeremiah O. Abolade; aboladejeremiah@yahoo.com

Received 28 May 2021; Revised 7 July 2021; Accepted 2 November 2021; Published 18 November 2021

A compact dual-band ram horn-like folded antenna is presented in this work. The antenna is based on a ram horn-like folded strip, asymmetric microstrip feeding (AMF) technique, partial ground, and protruding stub at the ground plane. The dimension of the proposed antenna is 0.11λg × 0.17λg at 2.3GHz (10 × 15mm²). The proposed shape is achieved through the combination of two circular arcs with different radii. The antenna operates at 2.3GHz and 5.8GHz with a measured bandwidth of 100MHz and 820MHz, a gain of 0.62dBi and 2.2dBi, and radiation efficiency of 93.67% and 99.87%, respectively. The prototype of the proposed antenna is fabricated and measured. The measured result shows a good agreement with the simulated result. A parametric study of the proposed antenna is performed and results are presented. Besides, a comparative study between the antennas proposed in this work and the state-of-the-art is performed and presented. The proposed antenna is comparatively small in size than all the recently reported works in the literature while ensuring good radiation characteristics. Therefore, the antenna proposed in this work is a better candidate for future portable sub-6GHz fifth-generation (5G), Advance Long-term Evolution (LTE-A), Worldwide Interoperability for Microwave Access (WiMAX), and Wireless Local Area Network (WLAN) applications.

1. Introduction

The compact multiband antenna has become the darling of the wireless communication community because of the need for miniaturized devices on the part of both the manufacturers and users [1–4]. Many microwave system researchers have invested effort in realizing compact antennas such as [5–10]. Techniques such as meandering, slotting, slitting, shorting pin/plate, lumped elements, and metamaterial/metasurface [11–15] have been exploited. The main goal of slotting, slitting, shorting pin/plate, and lumped element techniques is to make the antenna effective length longer than its physical length [16–18]. However, the meandering technique ensures maxima use of the antenna space [19]. For example, authors in [9] used a meandering strip and shorting pin to achieve a compact antenna (36 × 15 mm²) operating at 2.4 GHz. The same meandering technique has been recently exploited by authors in [5–8]. Furthermore, the slotting technique has been used by authors in [2, 20–25]. For example, authors in [20] used the Audi logo-shaped as a slot on a rectangular patch on a 20 × 12 mm² FR-4 substrate to achieve a triband antenna operating at 3.9 GHz, 5.0 GHz, and 7.1 GHz, respectively. Also, authors in [22] use circular nested square slots comparative to an ancient coins symbol in China. The radiating patch was etched on an 88.5 × 60 mm² FR-4 substrate and the operating frequencies of the antenna are 1.6 GHz, 2.6 GHz, 3.7 GHz, and 5.3 GHz. In addition, authors in [14] reported the use of metamaterial for the antenna miniaturization. The authors used a double negative metamaterial based on the rectangular split ring resonator as the slot on the ground plane of the proposed antenna to achieve a 50% miniaturization. In the same light, authors in [15] have also used metasurface to achieve 67% miniaturization. In recent times, folded monopole antenna
has attracted antenna design engineers due to its ability to reduce overall antenna size [25–34]. Folded monopole antenna uses the principle of space filling to miniaturize the antenna radiating patch. For example, authors in [34] proposed three folded-rectangular strip branches radiating patch etched on a $20 \times 18 \text{mm}^2$ FR-4 substrate.

2.3GHz band is one of the most useful communication bands. It was designated International Mobile Telecommunication (IMT) by the ITU. Even though it was originally used for WiMAX applications, it has been generally adopted for the deployment of 4G LTE applications. For example, Singtel Optus, STC, and Telkom in Australia, Saudi Arabia, and South Africa, respectively, are performing 5G trials in this band. In the same light, the 5GHz band is also one of the commonly used bands in wireless communication such as the 5GHz band WLAN and ISM. Therefore, the miniaturization of the antenna operating in these bands is of importance for future communication.

Therefore, in this work, an ultracompact ram horn-like folded dual-band antenna is proposed. The proposed antenna is fed with a 50 Ω asymmetric microstrip feedline. The contribution of this work is the proposal of an ultracompact dual-band antenna suitable for LTE and WLAN applications compared to the recently published works in the open literature.

The remaining section of this paper is divided as follows. The detailed design and analysis of the proposed antenna are presented in Section 2. The results and discussion, which includes $S_{11}$, a parametric study of some design parameters, radiation pattern, gain, and efficiency, are presented in Section 3. The proposed antenna is compared with the recently published works in the literature and presented in Section 4, and the conclusion is presented in Section 5.

### 2. Antenna Design and Analysis

The radiating patch of the proposed antenna is a strip folded in a ram horn-like shape, fed with a 50 Ω asymmetric microstrip feedline, and a partial ground with a protruding stub made up the ground plane, as shown in Figure 1. The ram horn-like shape is realized through the concatenation of two slit rings, as shown in Figure 1(c). The antenna is built on a $10 \times 15 \text{mm}^2$ duroid5880 substrate of 1.57 mm thickness. The detailed configuration is given in Figure 1, and the optimized parameters are given in Table 1. The distance between the edge of the radiating patch and the substrate is 1 mm at the two sides and 0.75 mm at the top. The frequency of a quarter-wavelength strip can be determined by using equation (1) [2, 35]. Therefore, the expected fundamental mode resonance of the strip can be predicted. The equivalent (total) length of the strip that made up the ram horn is determined from equation (2). The first term at the RHS of equation (3) denotes the circumference of a circle, while the second term denotes the length of the slit of ith ring:

$$f_r \approx \frac{C_o}{4L_t \sqrt{(\varepsilon_r + 1)/2}},$$  \hspace{1cm} (1)

where

$$L_t = L_{R_1} + L_{R_2},$$  \hspace{1cm} (2)

and

$$L_{R_i} = 2\pi r_i - S_i, \quad \text{for } i = 1 \text{ and } 2,$$  \hspace{1cm} (3)

where

$$S_i = \frac{\theta - \varphi_i}{\theta} \times 2\pi r_i,$$  \hspace{1cm} (4)

$$r_i = R_i + w_r.$$

The AMF width ($w_f$) is calculated using the standard microstrip line equations (5)–(9) [35, 36]:

$$Z_0 = \begin{cases} \frac{120\pi}{\sqrt{\varepsilon_{eff}}} \left[ w_f/h + 1.393 + 0.677 \ln( w_f/h + 1.444) \right], & \text{for } \frac{w_f}{h} \leq 1, \\ \frac{60}{\sqrt{\varepsilon_{eff}}} \ln \left( \frac{8h}{w_f} + \frac{w_f}{4h} \right), & \text{for } \frac{w_f}{h} \geq 1, \end{cases}$$  \hspace{1cm} (5)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{1}{\sqrt{1 + 12(h/w_f)}} \right),$$  \hspace{1cm} (6)

Since the value of the characteristic impedance is known in this case to be 50 Ω, the width of the microstrip line can be calculated using...
\[ \phi_1 = 241.9^\circ \text{ and } \phi_2 = 170.1^\circ. \]

**Figure 1:** Configuration of the proposed ram horn-like folded antenna: (a) top view, (b) bottom-view, and (c) concatenated slit rings.

**Table 1:** Optimized design parameter of the proposed ram horn-like folded antenna, \( \phi_1 = 241.9^\circ \) and \( \phi_2 = 170.1^\circ \).

| Parameter | \( w_{\text{sub}} \) | \( w_g \) | \( w_{\text{gs}} \) | \( w_f \) | \( w_s \) | \( L_{\text{sub}} \) | \( L_{\text{gs}} \) | \( L_g \) |
|---|---|---|---|---|---|---|---|---|
| Value (mm) | 10 | 8.5 | 1 | 2.9 | 0.6 | 15 | 2 | 1.5 |

\[
A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{\varepsilon_r}} + \frac{\varepsilon_r - 1}{2 \varepsilon_r} \left( 0.23 + \frac{0.11}{\varepsilon_r} \right) \quad \text{for } \frac{w_f}{h} > 2
\]

\[
B = \frac{377 \pi}{2Z_0 \sqrt{\varepsilon_r}} \quad \text{for } \frac{w_f}{h} < 2
\]

where \( \varepsilon_r \) is the permittivity of the substrate, and \( \varepsilon_{\text{eff}} \) is the effective permittivity.
3. Results and Discussion

3.1. Reflection Coefficient (S11). The fabrication of the prototype of the proposed ram horn-like folded antenna is shown in Figure 2, which demonstrates the practicability of the proposed antenna radiating patch shape. Figure 3 shows the measured and simulated S11 results of the antenna proposed in this work. It can be observed that, for both simulated and measured results, two modes are excited which implies that the proposed antenna is a dual-band antenna. It can also be observed that, for simulation, the two resonances are 2.3 GHz and 5.7 GHz with a -10 dB bandwidth of 70 MHz and 481 MHz and a return loss of 15.42 dB and 17.6 dB, respectively. It can be observed that there is a shift toward the lower frequency, while the resonance at the upper frequency of the measured S11 is maintained. That is, the measured resonances are 2.3 GHz (2.298 GHz) and 5.8 GHz, respectively. It can also be observed that the measured -10 dB bandwidth is 100 MHz and 820 MHz at lower and upper bands, respectively. In terms of return loss, the measured reflection coefficient at the lower and the upper bands is 13.3 dB and 23.36 dB, respectively. The variation in the results could be traced to the effect of cable and connector losses as well as the fabrication errors. It can be deduced that this antenna can be used in WiMAX and 5 GHz band WLAN applications. In other to study the effect of the ground plane and its protruding stub, the parametric study is done and presented in the next section.

3.2. Parametric Study. The parametric study of the proposed ram horn-inspired shape antenna is carried out to understand the impact of some design parameters and justify the optimized values of the parameter presented in Table 1. The parametric study specifically focused on the ground plane effect on the resonance behavior of the antenna proposed.

3.2.1. Effect of \( w_g \). Figure 4 shows the effect of \( w_g \) on the resonance behavior of the proposed antenna. It can be observed that an increase in the value of \( w_g \) leads to a tuning effect towards lower frequency at the upper band. It can also be noticed that, as \( w_g \) increases from 6 mm, aside from shifting the resonant frequency downward, the impedance matching is also enhanced until 7 mm after which the reflection coefficient starts increasing. 5.8 GHz is the desired frequency at the upper band; therefore, 8.5 mm is taken as the optimized value of \( g_w \) in the proposed configuration. It can also be observed that variation in \( w_g \) has no significant frequency tuning effect at the lower band, but it has a pronounced effect on its impedance matching, as shown in Figure 4. The tuning and impedance matching effect of \( w_g \) is more pronounced at the upper band of the proposed ram horn-like folded antenna than at the lower band. Conclusively, \( g_w \) can be used to both tune the upper band resonant frequency as well as the impedance matching of both lower and upper bands.

3.2.2. Effect of \( L_g \). As can be seen in Figure 5, \( L_g \) significantly affects the impedance matching of the proposed ram horn-like folded antenna at both bands. It can be observed that as \( L_g \) increases, the reflection coefficient increases which implies that 1 mm has the best impedance matching at both frequency bands as shown in Figure 5. Nonetheless, to ensure good ground plane support for the proposed antenna, 1.5 mm has been taken as the optimized value in the proposed configuration. As can be noticed from Figure 5, the highest suitable length of the ground plane to achieve a 10 dB return loss in both frequency bands is 2 mm. Therefore, ground length has a tremendous effect on the impedance matching of the proposed structure at both frequencies.

3.2.3. Effect of \( L.gs \). Figure 6 shows how S11 changes with \( L.gs \). It can be observed that an increase in \( L.gs \) not only reduces the impedance matching at both bands but also results in frequency tuning at the upper band. As shown in Figure 6, to ensure a 10 dB return loss at the lower band, the maximum value of \( L.gs \) should be 4 mm. Although 1 mm has the best impedance matching at the upper band, it does not have the best S11 at the lower band. Therefore, for a reasonable reflection coefficient at both resonant frequencies, 2 mm is chosen as the optimal value in this paper.

3.2.4. Effect of \( w.gs \). \( w.gs \) does not have a significant effect on the resonant frequency of the proposed antenna, but a small variation can be seen in the reflection coefficient of the antenna as it increases. Although 0.5 mm has the best S11 at both frequencies, this is more pronounced at the lower band as can be seen in Figure 7. It can be observed that 1 mm has a comparative S11 with 0.5 mm at both resonant frequencies. Besides, to avoid significant fabrication error and to further enhance the ground plane support of the proposed antenna, 1 mm was chosen as the optimized value in the proposed configuration.

3.3. Radiation Pattern, Gain, and Radiation Efficiency. As shown in Figure 8(a), the radiation pattern at E-plane and H-plane is bidirectional and omnidirectional, respectively, at 2.3 GHz with a peak of −1.5 dB at 10° and a 3 dB beamwidth of 70°. The E-plane and H-plane radiation pattern at 5.8 GHz is a dumbbell and omnidirectional pattern, respectively, with a peak of 2.36 dB at 180° and a 3 dB beamwidth of 130°, as shown in Figure 8(b). As shown in Figure 9, a peak gain of 0.62 dBi and 2.2 dBi is achieved at the lower and upper bands, respectively. The peak efficiency at the lower and the upper band is 93.67% and 99.87%, respectively, as shown in Figure 9. With this analysis, the ram horn-like folded antenna proposed shows an acceptable performance despite its compactness.

3.4. Current Distribution. To understand the mode of operation of the proposed antenna, the vector current distributions at the two resonant frequencies are plotted and analyzed. As can be seen in Figure 10(a), a high current concentration is noticed on the folded strip and the feeding branch except at the strip-tip where there is mode cancelation at 2.3 GHz. It can also be observed that the ground
Figure 2: Prototype of the proposed ram horn-like folded antenna. (a) Top view. (b) Ground plane.

Figure 3: Simulated and measured S11 of the proposed ram horn-like folded antenna.

Figure 4: S11 variation due to $g_w$. 

---

International Journal of Antennas and Propagation
Figure 5: S11 variation due to \( L_g \).

Figure 6: S11 variation due to \( L_{gs} \).

Figure 7: S11 variation due to \( w_{gs} \).
plane does not contribute much to the resonant frequency at 2.3 GHz. These validate the fundamental mode frequency predicted by equation (1) and the results of the parametric study. At 5.8 GHz, a high current concentration is observed around the feedline-branch strip and some part of the folded strip. It can also be observed in Figure 10(b) that there is a
significant current around the edge of the ground plane which shows that the ground plane plays an important role in the resonance at the upper band. This is in agreement with the parametric study presented before.

4. Comparative Study

To validate the compactness of the ram horn-like folded antenna proposed in this work, a comparative analysis along with the recently published works is carried out and presented in Table 2. Guided wavelength size at the lowest resonant frequency has been used for normalization purposes. It can be observed that the proposed antenna is comparatively compact than the recently reported works in literature. It can also be observed that the proposed antenna shows competitive performance in terms of size, gain, and efficiency when compared with the recent works, as shown in Table 2.

5. Conclusion

A compact ram horn-like folded dual-band antenna for LTE-A and WLAN applications is proposed in this work. The proposed antenna design is based on a folded monopole, partial ground, AMF, and protruding stub. The overall antenna footprint is $15 \times 10 \text{ mm}^2$, and it operates at 2.3 GHz and 5.8 GHz with a gain of 0.62 dBi and 2.2 dBi, and radiation efficiency of 93.67% and 99.87%, respectively. The comparative analysis of the antenna proposed in this work with the state of the art shows that the proposed antenna is the smallest yet maintaining good radiation characteristics.

Therefore, the antenna proposed in this work is a competitive candidate for future portable wireless communication.

Data Availability

The data supporting the findings of this study are all presented within the article.

Conflicts of Interest

There are no conflicts of interest among the authors.

Acknowledgments

This work was sponsored and supported by the African Union through the Pan African University Institute of Basic Sciences, Technology, and Innovation.

References

[1] W.-Y. Chiang, C.-H. Ku, C.-A. Chen et al., “A power-efficient multiband planar USB dongle antenna for wireless sensor networks,” Sensors, vol. 19, no. 11, Article ID 2568, 2019.
[2] J. O. Abolade, D. B. O. Konditi, and V. M. Dharmadhikary, “Compact hexa-band bio-inspired antenna using asymmetric microstrip feeding technique for wireless applications,” Heliyon, vol. 7, no. 2, Article ID e06247, 2021.
[3] B. Fady, J. Terhzaz, A. Tribak, and F. Riouch, “Integrated miniature multiband Antenna designed for WWD and SAR assessment for human exposure,” International Journal of Antennas and Propagation, vol. 2021, Article ID 5548834, 15 pages, 2021.

| Ref  | Size ($\lambda_0^2$) | Freq. (GHz) | Gain | Eff. (%) | Approach                  | Complexity |
|------|----------------------|-------------|------|----------|---------------------------|------------|
| [6]  | 0.70 \times 0.70     | 2.5/4.5/5.6/6.8 | 0.5–4.5 dB | 84/90/89/96 | Meandering and DGS         | High       |
| [12] | 0.50 \times 0.52     | 2.4/3.5      | 2.25/0.88 (dBi) | 76/85  | Metamaterial               | High       |
| [13] | 0.44 \times 0.49     | 1.22/1.57/2.45/3.6/4.5 | 1.75/3.6/3(dBi) | 73/63/86/57 | Multiple slots             | High       |
| [15] | 0.55 \times 0.35     | 4.0          | 5.1 dB | 71.6     | Metasurface                | High       |
| [23] | 0.38 \times 0.38     | 2.23(3.49/5.48/7.48) | 7.85 dB | NR      | Balloon and rectangular    | High       |
| [10] | 0.41 \times 0.19     | 2.5/5.4      | 2.23/3.48 dB | 97.2/99.9 | Semileaf shaped with slit  | High       |
| [26] | 0.73 \times 0.25     | 0.9/1.95/5.8 | 3.2/3.8/9.2dB | 67–95  | Folded branch with slit    | High       |
| [32] | 0.42 \times 0.77     | 0.85/1.8/2.6 | 10 dB $^*$ | 60–90$^*$ | Folded monopole with SRR   | Medium     |
| [33] | 0.22 \times 0.20     | 1.57/2.9/3.5/4.8/5.5 | 2.2/2.8/3.2/4.5/4.4 dB | 50/78/84/92/94 | Loaded IFA with Via        | High       |
| [36] | 0.38 \times 0.42     | 2.48/3.49    | 2.4/3.5 (dB) | NR      | Meandering, SSR, and CPW   | High       |
| [37] | 0.95 \times 0.95     | 3.9          | 4.15 dBc | 87.32    | R-DRA, aperture coupled    | High       |
| [38] | 0.26 \times 0.17     | 1.22/6.06    | 0.99/37.2 dB | 57/91.8 | CRLH-TL and CPW            | High       |
| [39] | 0.31 \times 0.14     | 2.5/3.35/5.7 | 1.7/1.5/2.05 | 81.1/79.6/81.5 | Multiple resonator         | High       |
| [40] | 0.35 \times 0.35     | 3.3/5.01/7.6/9.48 | 0.4/0.28/4.19/2.05 | 46.6/50.8/72.2/50.9 | Metamaterial               | High       |
| [41] | 0.42 \times 0.49     | 3.59/5.53$^*$ | 3/3.6 dB | 93/87    | C-SRR, H-CRR, and ACGP     | Medium     |
| [42] | 0.96 \times 0.56     | 1.45/2.45/3.85/5.13/5.8 | 2/4.8/4.1/2.5/4.2 | NR      | Window grille shape        | High       |
| This work | 0.11 \times 0.17     | 2.3/5.8      | 0.62/2.2dB $^*$ | 93/76/99.8/74$^*$ | Ram horn shaped, AMF, ground protruding stub | Medium     |

$^*$ peak value; $^*$ range; $^*$ diversity gain; $^*$ extracted from the comparative table; NR, not reported; C-SRR, circular split ring resonator; H-CRR, hexagonal closed ring resonator; ACGP, asymmetric coplanar ground plane; CRLH-TL, composite right-/left-handed transmission line; R-DRA, rectangular-dielectric resonator antenna; SSR, square split ring; MTM, metamaterial; DGS, defected ground structure; CPW, coplanar waveguide.
[4] M. Alibakhshikenari, B. S. Virdee, A. Ali, and E. Limiti, "Extended aperture miniature antenna based on CRLH metamaterials for wireless communication systems operating over UHF to C-band," Radio Science, vol. 53, no. 2, pp. 154–165, 2018.

[5] F. Majeed and D. V. Thiel, “An Optimized circuit in plastic meander line antenna for 2.45 GHz applications,” International Journal of Antennas and Propagation, vol. 2016, Article ID 7398567, 7 pages, 2016.

[6] R. Patel, T. Upadhyaya, A. Desai, and M. Palandoken, “Low profile multiband meander antenna for LTE/WiMAX/WLAN and INSAT-C application,” AEU - International Journal of Electronics and Communications, vol. 102, pp. 90–98, 2019.

[7] T. K. Das, B. Dwivedy, and S. K. Behera, “Design of a meandered line microstrip antenna with a slotted ground plane for RFID applications,” AEU—International Journal of Electronics and Communications, vol. 118, Article ID 153130, 2020.

[8] S. Bhaskar and A. K. Singh, "Meandered cross-shaped slot circularly polarised antenna for handheld UHF RFID reader," AEU - International Journal of Electronics and Communications, vol. 100, pp. 106–113, 2019.

[9] C. Y. Cheung, J. S. M. Yuen, and S. W. Y. Mung, “Miniaturized printed inverted-F antenna for internet of things: a design on PCB with a meandering line and shorting strip,” International Journal of Antennas and Propagation, vol. 2018, Article ID 5172960, 5 pages, 2018.

[10] J. O. Abolade, D. B. O. Konditi, and V. M. Dharmadhikary, “Ultra-compact hexa-band bio-inspired antenna for 2G, 3G, 4G and 5G wireless applications,” International Journal on Communications Antenna and Propagation, vol. 11, no. 3, pp. 1–13, 2021.

[11] M. Alibakhshikenari, B. S. Virdee, L. Azpilicueta et al., “A comprehensive survey of "metamaterial transmission-line based antennas: design, challenges, and applications’’,’ IEEE Access, vol. 8, pp. 144778–144808, 2020.

[12] M. Hasan, M. Rahman, M. Faruque, M. Islam, and M. Khandaker, "Electrically compact srr-loaded metamaterial inspired quad band antenna for bluetooth/wifi/wlan/wimax system,” Electronics, vol. 8, no. 7, pp. 790–7, 2019.

[13] B. B. Q. Elias, P. J. Soh, A. A. Al-Hadi, R. Joshi, Y. Li, and R. C. Biradar, “Compact audi-shaped slotted multiband Antenna for WiMAX/WLAN/X-band Applications,” in Proceedings of the 2018 Second International Conference on Advances in Electronics, Computers and Communications (ICAEC), pp. 1–6, Bangalore, India, February 2018.

[14] K. D. Prasad, T. Ali, and R. C. Biradar, ”A compact slotted multiband antenna for L-band and WLAN applications,” in Proceedings of the 2017 2nd IEEE International Conference on Recent Trends in Electronics, Information and Communication Technology (RTEICT), pp. 820–823, Bangalore, India, May 2017.

[15] Z. Yu, J. Yu, X. Ran, and C. Zhu, “A novel ancient coin-like fractal multiband Antenna for wireless applications,” International Journal of Antennas and Propagation, vol. 17 pages, Article ID 6676689, 2021.

[16] H. Liu, X. Liu, S. Gao et al., “Compact wideband folded dipole antenna with multi-resonant modes,” IEEE Transactions on Antennas and Propagation, vol. 67, no. 11, pp. 6789–6799, 2019.

[17] J. Cui, A. Zhang, and X. Chen, “An omnidirectional multiband Antenna for railway application,” IEEE Antennas and Wireless Propagation Letters, vol. 19, no. 1, pp. 54–58, 2020.

[18] J. R. Panda and R. S. Kshetrimayum, “A printed 2.4 GHz/5.8 GHz dual-band monopole antenna for WLAN and RFID applications with a protruding stub in the ground plane,” in Proceedings of the 2011 National Conference on Communications (NCC), pp. 1–5, Bangalore India, January 2011.

[19] Z. Yang, Y. Cui, X. Mo, and R. Li, “A wideband crossed-dipole antenna for lte700/gsm850/gsm900 base stations,” in Proceedings of the 2019 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), pp. 30–33, Granada, Spain, September 2019.

[20] Z. Tang, J. Liu, R. Lian, Y. Li, and Y. Yin,”Wideband differentially fed dual-polarized planar antenna and its array with high common-mode suppression,” IEEE Transactions on Antennas and Propagation, vol. 67, no. 1, pp. 131–139, 2019.

[21] H. Liu, B. Lu, and L. Li, “Novel miniaturized octaband Antenna for LTE smart handset applications,” International Journal of Antennas and Propagation, vol. 2015, pp. 1–8, 2015.

[22] B. Sonny and C. Morlaas, “Usage of characteristic modes with specific boundary conditions for wideband Antenna design: application to a cage loaded monopole antenna,” IEEE
[33] S. S. Alja‘Afreh, Q. Xu, L. Xing, Y. Huang, C. Song, and E. Almajali, “A dual-element folded strip monopole with SRR loading for multiband handset MIMO applications,” in Proceedings of the 2020 14th European Conference on Antennas and Propagation (EuCAP), pp. 1–5, Copenhagen, Denmark, March 2020.

[34] A. Chatterjee, M. Midya, L. P. Mishra, and M. Mitra, "Branch line strip loaded compact printed inverted-F antenna (IFA) for penta-band applications," AEU - International Journal of Electronics and Communications, vol. 93, pp. 103–108, 2018.

[35] R. Kumar Naik, "Asymmetric CPW-fed SRR patch antenna for WLAN/WiMAX applications," AEU - International Journal of Electronics and Communications, vol. 93, pp. 103–108, 2018.

[36] R. Kumar, S. R. Thummaluru, and R. K. Chaudhary, "Improvements in wi-MAX reception: a new dual-mode wide-band circularly polarized dielectric resonator antenna," IEEE Antennas and Propagation Magazine, vol. 61, no. 1, pp. 41–49, 2019.

[37] J. Kulkarni and C.-Y.-D. Sim, "Low-profile, compact multiband monopole antenna for futuristic wireless applications," in Proceedings of the 2020 IEEE International Conference on Electronics, Computing and Communication Technologies (CONENCT), pp. 1–6, Bangalore, India, July 2020.