Size Miniaturized Coaxial Probe Fed Antenna for Multiband Applications

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Abstract
A coaxial cable-fed antenna with a combination of L-shaped elements is proposed for multiband applications. The obtained resonances at different frequency bands are realized by adding L-shaped strips with different lengths to the antenna geometry. The antenna is printed on a low-priced FR-4 substrate with overall size of 14×14×1.6 mm3. Experimental results indicate the coverage of 1.32, 1.80, 2.34, 3.30, 3.66, 4.26, 5.28, 7.68, 8.1, 9.72 and 10.38 GHz, compatible with L-band, WLAN, WiMAX, C-band, ITU 8 GHz, and X-band. Suitable radiation properties, multiband functionality, desirable gain values and agreement of simulated and measured results confirm the suitability of the proposed structure for multiband communication applications.

1. Introduction
Paving the way to accommodate the rapid development of wireless communication calls the need for antennas with multiband performance. To this end, a vast variety of researches have been conducted on design of antenna structures with more than one operating band [1-9]. Being able to operate in multi frequency bands, this category of antennas has gained popularity in different applications. For instance, regarding the smartphones and mobile phones antennas has gained popularity in different applications. For instance, crinkle fractal-structure is adopted in [9] to yield a triple-band operation. In [10], a hybrid design of a microstrip-fed parasitic coupled ring fractal monopole antenna with semi-ellipse ground plane is proposed for WLAN and WiMAX applications. Also, other applications could be found in [11-15]. Although interesting outcomes have been reported in the case of recently published and reviewed antenna structures, improving the multiband antennas features in terms of size miniaturization, frequency bands extension, and the compatibility of the obtained frequency bands with applicable and in-service frequency ranges calls the need for further investigations on this context. With the aim of proposing a reliable and efficient antenna design, a compact antenna geometry with L-shaped elements is proposed for L-band/WiMAX/WLAN/C-band/ITU 8 GHz and X-band applications. The main radiating patch of the proposed design consists of several L-shaped elements. Each constituent L-shaped element is responsible for exciting a resonance; thus, by including different L-shaped elements with different lengths, multi resonances are appeared which yields a multiband performance. The obtained results indicate that impedance bandwidths of 230 MHz (1.19-1.42 GHz), 280 MHz (1.70-1.98 GHz), 320 MHz (2.19-2.51 GHz), 680 MHz (3.13-3.82 GHz), 380 MHz (5.28-5.82 GHz), 10.38 GHz (85-95 GHz). The antenna is printed on a low-priced FR-4 substrate with overall size of 14×14×1.6 mm3. Experimental results indicate the coverage of 1.32, 1.80, 2.34, 3.30, 3.66, 4.26, 5.28, 7.68, 8.1, 9.72 and 10.38 GHz, compatible with L-band, WLAN, WiMAX, C-band, ITU 8 GHz, and X-band. Suitable radiation properties, multiband functionality, desirable gain values and agreement of simulated and measured results confirm the suitability of the proposed structure for multiband communication applications.
MHz (4.10-4.48 GHz), 530 MHz (5.07-5.60 GHz), 1310 MHz (7.23-8.54 GHz) and 1150 MHz (9.48-10.63 GHz) to cover the L-band (1-2 GHz), WLAN (2.4 GHz), WiMAX (3.5 GHz), C-band (4 GHz), WLAN (5.2 GHz) and some part of 8 to 12 GHz are covered by the proposed design. It is worth noting that suitable gain and radiation characteristics are observed over all of the operating frequency bands.

2. Antenna design

The schematic view of the proposed antenna is shown in Figure 1(a). Moreover, the fabricated prototype is shown in Figure 1(b). As mentioned earlier, L-shaped elements with wisely tuned dimensions and positions are adopted as the radiating patches. Being different in width, the L-shaped strips resonate at desired frequencies of applicable frequency ranges, resulting in a multiband performance. A 50Ω coaxial feed line, which is placed on the upper side of the substrate, is adopted to feed the antenna. The reported antenna is printed on an inexpensive FR4 substrate with overall size of 14×14×1.6 mm³, relative permittivity of 4.4, and loss tangent of 0.0022. The optimized values of the antenna parameters are reported in Table 1. The proposed antenna is simulated using Ansoft High Frequency Structure Simulator (HFSS) software and the relevant magnitude of the reflection coefficient is plotted in Figure 2. As can be seen, multi resonances are excited in different frequencies which yield a multi band operation at 1.32, 1.80, 2.34, 3.30, 3.66, 4.26, 5.28, 7.68, 8.1, 9.72 and 10.38 GHz, compatible with L-band, WLAN, WiMAX, C-band, ITU 8 GHz, and X-band.

| Lsub | Wsub | hsub |
|------|------|------|
| 14   | 14   | 1.6  |

Figure 2: magnitude of the reflection coefficient for the proposed multi band antenna.

To further explain the antenna design process and reveal the role of each L-shaped element on the antenna performance, the proposed antenna configuration is developed in five steps as shown in Figure 3. The corresponding magnitude of the reflection coefficient is plotted in Figure 4 to reveal the effect of including L-shaped elements in each development step. As it is shown, in Ant. 1, two L-shaped elements are included in antenna body. In this case, seven resonances are excited. Then in Ant. 2, by including two other L-shaped elements, other resonances are excited both at lower and higher frequencies. The displacement of the resonances is mainly due to the fact that the inclusion of the second pair of the L-shaped elements creates a coupling effect with the first pair of the L-shaped elements. In the sequel, by the inclusion of the third, fourth, and fifth pair of the L-shaped elements, other resonances are excited which finally yield a multi band operation.

Figure 3: Design process of the proposed multi band antenna. (a) Ant. 1, (b) Ant. 2, (c) Ant. 3, (d) Ant. 4, (e) Ant. 5.

Figure 4: magnitude of the reflection coefficient for the antennas depicted in Fig.3.

Total radiation efficiency of higher than 50 % is observed for Ant. 4, and Ant. 5 that is indicated in Figure 5. Moreover, to clarify the role of each constituent L-shaped strip on the

Table 1: The optimized dimensions of the proposed antenna.

| W1  | W2  | W3  | W4  | W5  | W6  |
|-----|-----|-----|-----|-----|-----|
| 13  | 10.5| 8.5 | 6.5 | 4.5 | 0.7 |
antenna performance and multiband performance achievement through other analysis methods, nine surface current distribution plots relating to the nine different resonance frequencies are depicted in Figure 6. As mentioned before, each part of the L-shaped structure in the antenna excites one of the existing resonances. It is a well-known fact that the elements with red colors refer to the most current carrying parts on the antenna. For instance, the resonance in 5.4 GHz, yielding WLAN coverage, is obtained by the shortest L-shaped strips on the antenna. As well, some resonances are obtained by more than one strip, such as the one at 1.86 GHz that is obtained by the two longest L-shaped strips.

3. Results and discussion:

To validate the obtained results, the fabricated antenna is measured in antenna chamber as shown in Figure 1(c). Simulated and measured magnitude of the reflection coefficient are given in Figure 7. Close agreement of the results confirms the suitable performance of the antenna. As it is clearly shown in Figure 7, both the simulated and measured results can cover L-band, WLAN, WiMAX, C-band, ITU 8 GHz, and X-band satellite communication applications. Different frequency bands are highlighted with different colors.

Figure 7: Simulated and measured magnitude of the reflection coefficient for the proposed antenna.

The two-dimensional measured radiation patterns in the H-plane (x-z plane) and E-plane (y-z plane) are shown in Figure 8. Six resonance frequencies are selected as sample frequencies of the operating bandwidths. As can be seen, the radiation patterns at both H-plane and E-plane are almost omnidirectional. Moreover, the obtained simulated and measured peak gain values are depicted in Figure 8. Acceptable results are observed over the operating frequency bands.

Figure 8: Measured radiation patterns of the proposed antenna at (a) 1.8, (b) 2.3, (c) 3.6, (d) 5.2, (e) 8.1, and (f) 10.3 GHz at x-z-Plane and x-y-Plane.
Figure 9: Simulated and measured peak gain for the proposed antenna.

Table 2: Summary of the structural and performance features of the antenna in this work and antennas in [1-10].

| Ref | Size (mm²) | Operating bandwidths | Peak Gain (dB) | Efficiency % |
|-----|------------|-----------------------|----------------|--------------|
| [1] | 122.5×60   | GSM900/GSM1800/GSM1900/ LTE2300/LTE2500 | 0.62-2.12/2.38-3.81/3.82-4.79 | 42-54/45-71/>53 |
| [2] | 120×60     | GSM850/GSM900/DCS1800/PCS1900/UMTS/ TDSCDMA/LTE2300/ WLAN | 0.96-2.4/3.2-4.5 | 50-76/57-84 |
| [3] | 80×60      | GSM900/DCS1800/LTE2300/ LTE2600 | 3.0-4.0 | 85-95 |
| [4] | 260×200    | GSM850/GSM900/DCS/PCS/ UMTS | 1.06-1.3/2.15-2.44 | 70/74 |
| [5] | 260×200    | WLAN5.2/WLAN5.8/WiMAX2.5/ WiMAX3.3/ WiMAX5.5 | 4.5/4/8.1 | - |
| [6] | 260×200    | WLAN2.4/WLAN5.2/WLAN5.8/ WiMAX2.5/WiMAX3.5/WiMAX5.5 | 3.2/2.38/2.34 | 76.5/69.5/61.7 |
| [7] | 260×200    | WLAN2.4/WLAN5.2/WLAN5.8/ WiMAX3.5/WiMAX5.5 | - | - |
| [8] | 260×200    | WLAN2.4/WLAN5.2/WLAN5.8/ WiMAX2.5/WiMAX3.5/WiMAX5.5 | 1.2/1.9/2.1/3.6/4.8 | - |
| [9] | 14×14      | DCS/GSM 1800/ WiMAX 3.5/ WLAN 5.2 | 2.7 | - |
| [10] | 14×14     | WiMAX/WLAN | 0.84/1.09/0.89/1.08 | - |
| This | 14×14     | L band/ WLAN2.4/WiMAX3.5/C band/ WLAN 5.2/WLAN 5.8/ITU 8 GHz/ X band | 0.3/0.9/0.95/1.7/2.2/1.9 | 73/49/73/81/81/87 |

4. Comparison

To shed light on the advantages of the proposed design in comparison with some of the previously designed structures, Table 2, summarizes the characteristics of the antenna in this work and the antenna designs in [1-10]. As can be seen, the proposed antenna has the most compact size among the antenna except for the antenna in [9] which is as large as this antenna. Also, gain and efficiency values are included in the table which shows the suitable performance of the proposed antenna. Although having a small size, by suitable placement of the conductive elements and wise tuning of their dimensions, the proposed design covers the frequency bands of L-band (1-2 GHz), WLAN (2.4 GHz), WiMAX (3.5 GHz), C-band (4 GHz), WLAN (5.2 GHZ), and some part of 8 to 12 GHz, including X-band satellite communication applications.

5. Conclusion

A compact L-strip coaxial-fed line antenna is proposed for multiband applications. The several resonances that are excited by the constituent L-shaped elements yields a multiband functionality. The obtained frequency bands include 230 MHz (1.19-1.42 GHz), 280 MHz (1.70-1.98 GHz), 320 MHz (2.19-2.51 GHz), 680 MHz (3.14-3.82 GHz), 380 MHz (4.10-4.48 GHz), 530 MHz (5.07-5.60 GHz), 1310 MHz (7.23-8.54 GHz), and 1150 MHz (9.48-10.63 GHz) to cover the L-band (1-2 GHz), WLAN (2.4
GHz), WiMAX (3.5 GHz), C-band (4 GHz), WLAN (5.2 GHz), and some part of 8 to 12 GHz. Furthermore, the far field radiation patterns are mostly omnidirectional at all operation bands. The obtained results show that the reported antenna has acceptable performances for multiband applications.

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