A Novel Multiband Planar Antenna for GSM/UMTS/LTE/Zigbee/RFID Mobile Devices

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***Abstract*—A new multiband planar antenna with a compact size is designed and developed for mobile devices. The proposed antenna consists of a two-strip monopole and a meandered strip antenna which occupy a compact area of only 15 mm × 42 mm. This planar antenna has a bandwidth of ~42% at the 900 MHz band and ~53% at the 1900-MHz band. The wide bandwidth at the low frequency is attributed to the mutual coupling of an S-shaped strip and an inverted-F strip which are separately printed on the two sides of a thin substrate, forming a two-strip monopole configuration. The bandwidth at the high frequency is enhanced by inserting a meandered strip which improves the impedance matching for the high-frequency band. The experimental results verify the simulations. The featured broad bandwidths over two frequency bands and the miniaturized size of the proposed antenna make it very promising for applications in wireless communication and wireless sensing devices.**

***Index Terms*—Broadband antenna, mobile devices, multiband antenna, planar antenna, wireless communications.**

I. INTRODUCTION

MULTIBAND internal antennas have become a necessity for the state-of-the-art multifunction "smart phones" and wireless sensor modules for the mobile devices. Such internal antennas are generally required to be capable of covering the frequency bands of GSM- 850/900/1800/1900 and UMTS (824–894/890–960/1710–1880/1850–1990/1920–2170 MHz). In addition, the ever increasing implementation of 4G devices further increases the bandwidth requirement in order to cover the LTE2300 (2305–2400 MHz) and LTE2500 (2500–2690 MHz) bands. The integration of global-operability RFID readers and RFID-enabled wireless sensors Zigbee-based controllers in state-of-the-art "smart-phones" necessitate the antenna operability over the additional bands 860–956 MHz and 2.2–2.3 GHz bands. It should be noted that the size of the multiband internal antennas inside mobile devices has to be as small as possible and preferably below the size of a credit card. Recently, many antennas have been designed to satisfy such stringent requirements. Nevertheless most of them with a miniaturized size fail to cover the required entire frequency bands, especially at the lower frequency band due to the narrower bandwidth [1]–[6]. Antennas with sufficient bandwidths typically require a considerable antenna size or thickness, which usually makes them difficult to integrate within mobile devices or portable wireless modules [7]–[10].

In this paper, we propose a novel multiband internal antenna with the size of 15 mm × 42 mm and a thickness of only 0.5 mm. This antenna is capable of generating two wide operating bands that effectively cover the GSM/UMTS/LTE/Zigbee/RFID operations in mobile devices and wireless sensors, which includes the GSM850 (824–894), GSM900 (890–960), GSM1800 (1710–1880), GSM1900 (1850–1990), UMTS (1920–2170), LTE2300 (2305–2400), and LTE2500 (2500–2690 MHz) bands. It is well known that electromagnetic coupling and two-strip configurations are two very effective methods for increasing the bandwidth of a compact antenna structure [11]–[14]. To achieve the wide bandwidth in the lower frequencies, we use two printed strips with appropriately optimized electromagnetic coupling. An additional shorter meander branch is added for the operation around 2.1 GHz. The mutual coupling among the three strips significantly enhances the bandwidth around the higher frequency band, without affecting the performance in the lower frequency band. There is no shorting via involved in the antenna structure, something that facilitates the fabrication and integration of such an antenna topology in a fully photolithographic technology. The configuration and performance of the multiband antenna is described in Section II. A parametric study is presented in Section III and experimental results are given in Section IV.

II. ANTENNA CONFIGURATION AND PERFORMANCE

The configuration of the presented multiband antenna is illustrated in Fig. 1. The design of the antenna is based on a TLY-5 substrate, which has a dielectric constant of $\varepsilon_{\mathrm{r}} = 2.2$ and a thickness of $\mathrm{t} = 0.5$ mm. The proposed antenna consists of a two-strip monopole and a meandered strip. The two-strip monopole includes an S-shaped strip and an inverted-F strip. The inverted-F and the meandered strips are printed on the front side of the substrate and are fed by a 50-Ω microstrip line while the S-shaped strip is etched on the backside of the substrate and terminated at a ground plane. The upper section of the inverted-F strip is printed inside the area surrounded by the upper section of the S-shaped strip, while the lower section of the inverted-F strip overlaps with the lower section of the S-shaped strip, forming a two-strip line. The width (wf) of the 50-Ω feed line is 1.5

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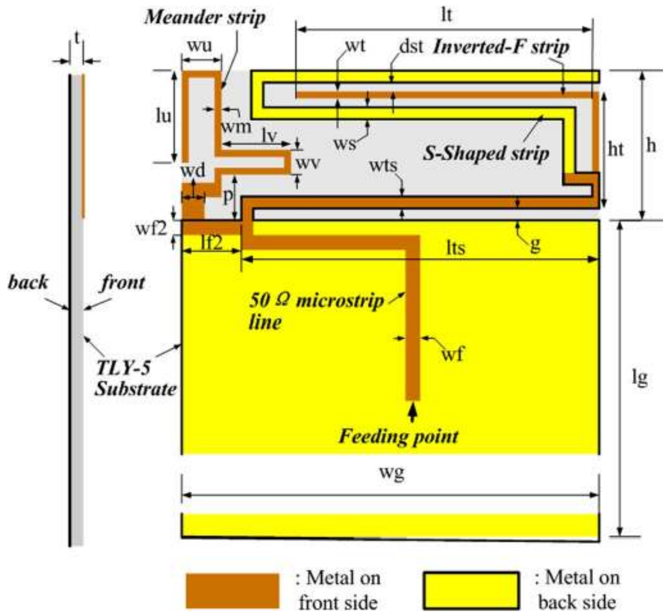


Fig. 1. Geometry of the multiband planar antenna which consists of a two-strip monopole for the 900-MHz band and a meandered strip for the 1900-MHz band.

mm while the width (wts) of the two-strip lines is 1.2 mm. The meander strip is connected to the feed line through a narrower microstrip line with a width (wf2) of 1mm. The width of the strip line of each branch is optimized by simulation in order to achieve better impedance matching over the desired frequency ranges. The height (h) of the two-strip line is the same as the total height of the antenna which is equal to 15 mm.

The multiband antenna was simulated using Ansoft simulation software HFSS v11. The first step of the design involved the optimization of the branches that control the lower frequency band. To achieve a wide bandwidth which can cover the 824–960 MHz frequency band, we use a driven inverted-F strip with a total length of 80 mm and a coupled S-shaped strip with a total length of 120 mm. The length of the two strips is designed to make them resonate around the lower-band frequencies of 800 and 900 MHz, respectively. The distance (dst) between the two strips is carefully chosen to optimize the mutual electromagnetic coupling for a good impedance matching over the whole band. More design details are discussed in the Section III. It can be seen from Fig. 2 that the two-strip antenna generates two dual-resonant modes around 1.2 and 2.4 GHz. The dual-resonant modes at lower frequency provide a wide operating bandwidth for the 824–960 MHz band. However, the dual-resonant modes around 2.4 GHz cannot cover the whole 1.7–2.7 GHz band. The dual-resonant modes can be tuned by the length of the inverted-F branch and the S-shaped strip. As their lengths increase, the cutoff frequencies of both the first-order mode and the higher order mode generated by them shift down.

In order to enhance the bandwidth around the higher frequencies, we add a meander strip to generate an additional resonance at around 2.1 GHz. The total length of the meandered strip is about 40 mm which is approximately a quarter wavelength at 2.1 GHz. To make use of the available space, the horizontal part of the meander line is extended to the unfilled region below the branch of the two-strip line. The center resonant frequency can be adjusted by tuning the length (lv) of the horizontal part. The combination of the additional mode of the meander line at 2.1 GHz with the higher-order modes of the two-strip line effectively forms a wide bandwidth that can easily cover the 1.7–2.7 GHz frequency band. On the other hand, the meander line has almost negligible effects on the lower-frequency bandwidth around 900 MHz, allowing for an easy geometrical optimization to cover specific operation bands depending on the choice of the respective communication and sensing applications.

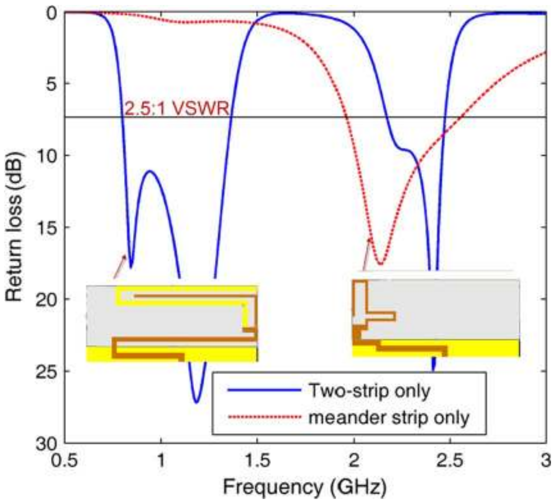


Fig. 2. Comparison of the return loss between the two-strip monopole for the 900-MHz band and the meandered strip for the 1900-MHz band (the geometric parameters used are listed in Table I).

To enable the multi-band antenna with a good impedance matching and a sufficiently wide bandwidth around the 900-MHz and 2-GHz bands, the geometric parameters of the antenna listed in Table I need to be optimized. The optimization design was carried out with the help of numerous simulations. The optimized values for the geometric parameters are listed in Table I. In the rest of the paper, all geometric parameters assume the values in this table unless they are given specifically. Fig. 6 shows the comparison between the measured and simulated results for return loss of the optimized multiband antenna. It is found that the simulated bandwidths (for VSWR $\leqslant 2.5$) around the 900-MHz and 2-GHz frequency bands are 36% (0.8 GHz–1.16 GHz) and 50% (1.70 GHz–2.83 GHz), respectively.

III. PARAMETRIC STUDY

The dual-resonant modes generated by the two-strip monopole are very critical to the realization of the broadband feature of the antenna. As illustrated in [14], the two-strip monopole can be represented by two equivalent circuits electromagnetically coupled with each other. The frequency behavior of the two-strip monopole can be manipulated by tuning the resonances of its two branches and the electromagnetic coupling between them in order to achieve a broad bandwidth impedance matching. Through numerous HFSS simulations we found that the distance (dst) between the two strips has an significant effect on the mutual coupling. Fig. 3 shows the effect of the

TABLE I
OPTIMIZED VALUES FOR THE GEOMETRIC PARAMETERS OF THE MULTIBAND PLANAR ANTENNA

Parameter	Value	Parameter	Value
h	15 mm	wu	4 mm
lts	36 mm	lu	9.2 mm
ht	10.5 mm	wv	2.5 mm
lt	30 mm	wm	0.7 mm
wt	0.7 mm	wd	2.3 mm
ws	1.2 mm	p	4.6 mm
wf	1.5 mm	lv	7.5 mm
wf2	1 mm	lg	100 mm
lf2	6 mm	g	1.2 mm
wg	42 mm	t	0.5 mm
dst	0.7 mm	wts	1.2 mm

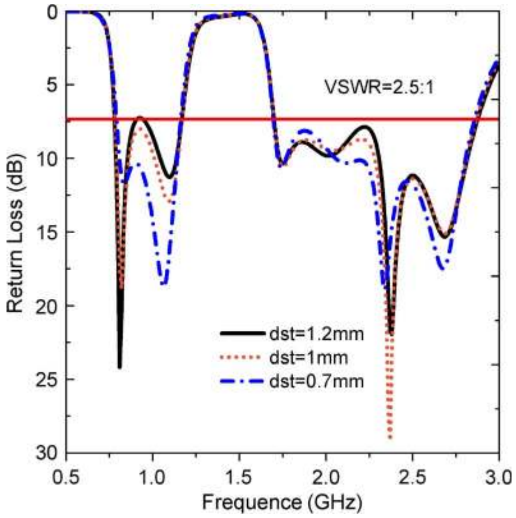


Fig. 3. Effect of the distance (dst) between the s-strip and invert-F strip on the return loss of the multiband planar antenna, where dst was changed from $\mathrm{dst} = 0.7$ mm to $\mathrm{dst} = 1.2$ mm. The optimized value for dst is ∼0.7 mm.

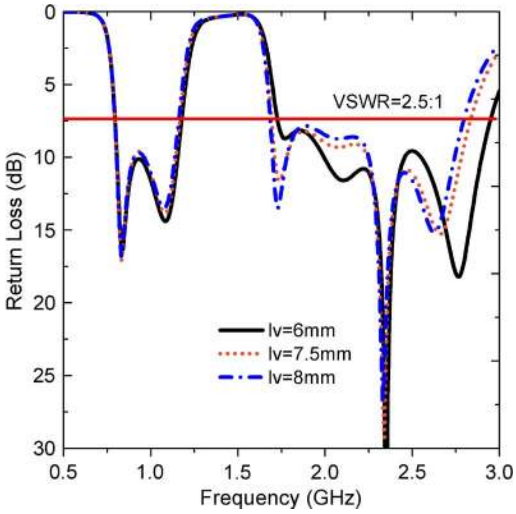
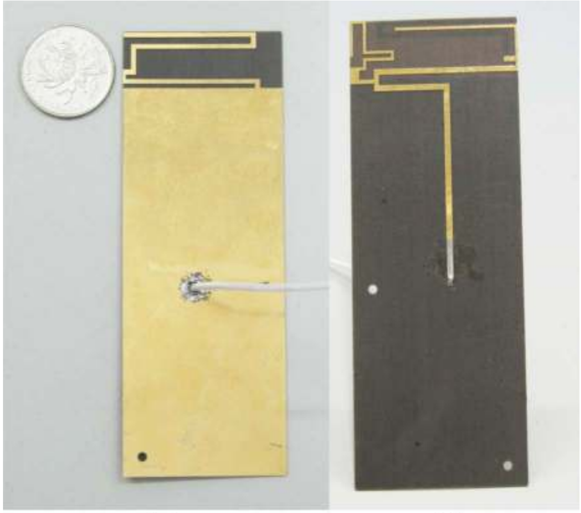


Fig. 4. Effect of the length (lv) of meandered strip on the return loss of the multiband planar antenna, where lv was changed from $\mathrm{lv} = 6$ mm to $\mathrm{lv} = 8$ mm. The optimized value for lv is ∼7.5 mm.

distance (dst) on the impedance matching when dst varies from 1.2–0.7 mm. As the distance between the S-shaped strip and invert-F strip decreases, the mutual coupling is enhanced and the impedance matching around 900 and 2200 MHz become better. Thus, by selecting a proper length for dst, the return loss over the whole operating band can be improved.



(a) (b)

Fig. 5. Photographs of the multiband planar antenna with the optimized geometric parameters. (a) Front view. (b) Back view.

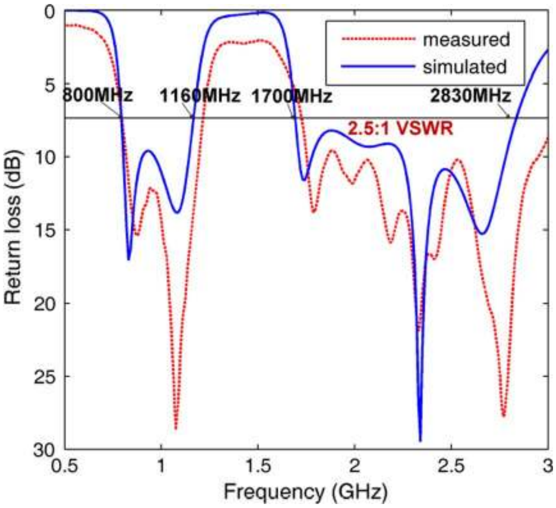
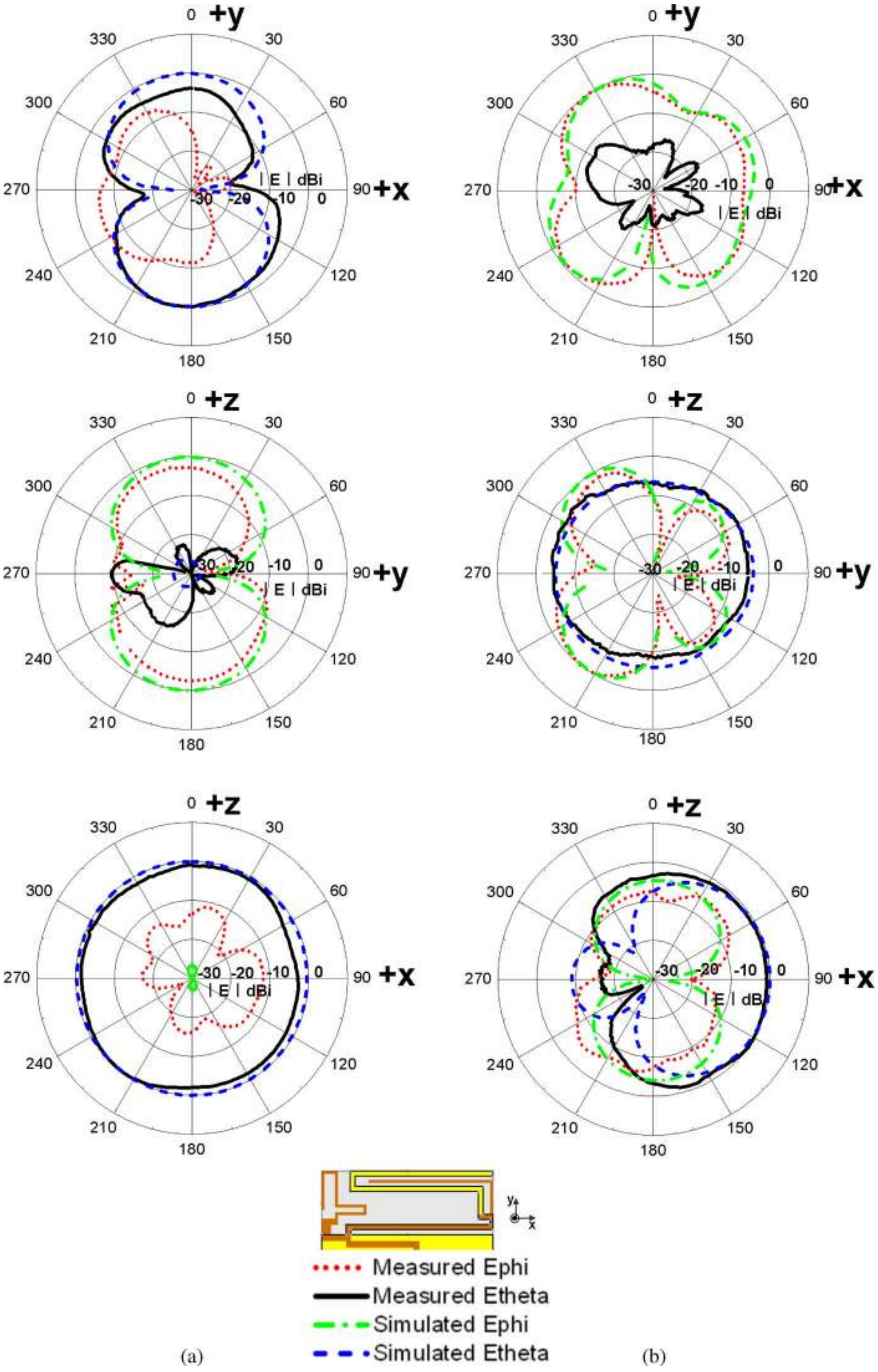


Fig. 6. Comparison between the measured and simulated result for return loss of the multiband planar antenna.

The impedance matching over the high frequency band can be tuned independently by lv. Fig. 4 shows the simulated return loss for the proposed antenna as a function of lv for values between 6–8 mm. Although little difference is observed for the lower band, the frequency range for the upper band varies with lv. As the total length of the meandered strip increases (lv increases), the resonant frequency shifts down, thus enhancing the impedance matching around the 1. 7 GHz and deteriorating the impedance match around 2.1 and 2.6 GHz.

The size of the ground plane also affects the performance of the antenna. The length (lg) of the ground plane has a more obvious impact on the lower band. When the length decreases, the impedance matching over the lower frequency band deteriorates. However, the impedance matching over the high frequency becomes better when the length increases to 120 mm or



(a) (b)

Fig. 7. Radiation patterns of the multiband planar antenna. (a) At 900 MHz. (b) at 1900 MHz.

decreases to 40 mm. The width (wg) of the ground plane has little effect on the antenna performance. As the width increases, the cutoff frequencies of the lower and higher bands shift down a little bit.

IV. EXPERIMENTAL RESULTS

To verify the performance of the multiband planar antenna, a prototype was fabricated and measured. The antenna was fabricated on a $\mathrm{t} = 0.5$ mm TLY-5 substrate with 0.2 oz copper on both sides. Two photographs of the antenna prototype are displayed in Fig. 5 showing the front view and the back view of the planar antenna. For the purpose of measurement, the antenna is connected to a coaxial cable in the middle section of the ground plane. The measured return loss (RL) is presented in Fig. 6. It is clearly seen that two wide operating bandwidths are obtained. The lower frequency bandwidth, defined by a VSWR of 2.5:1, is 425 MHz (42%) and covers the GSM band (824–960 MHz). The bandwidth for a VSWR of 2:1 is found to be 818 MHz–1190 MHz, which is also wide enough to cover the GSM band (824–960 MHz). On the other hand, the upper band has a bandwidth as large as 1275 MHz (53%) (VSWR2.5:1) and covers the GSM1800 (1710–1880 MHz),

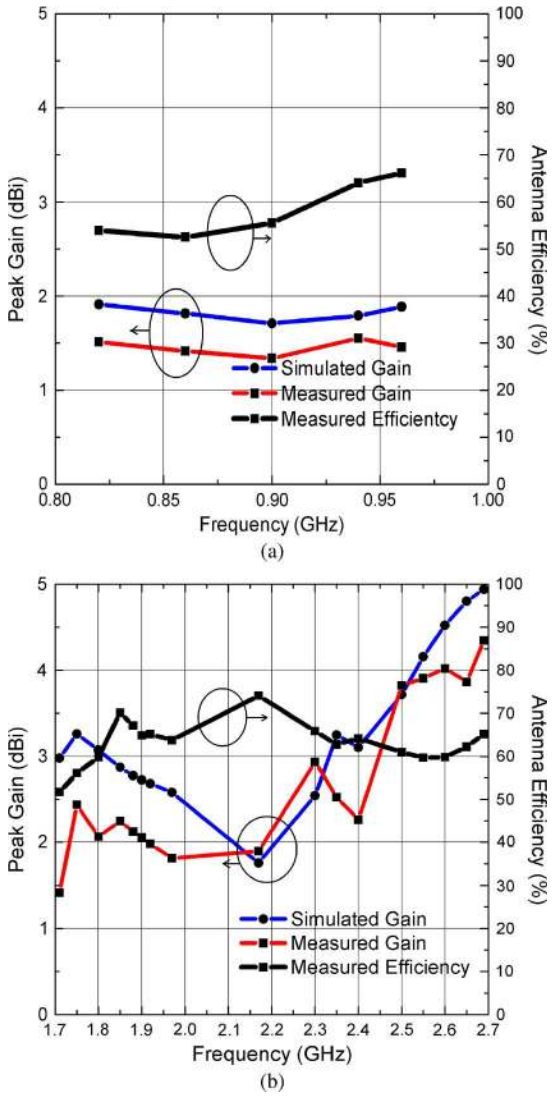


Fig. 8. Comparison between the measured and simulated results for peak gain of the multiband planar antenna and the measured antenna efficiency. (a) In lower band. (b) in higher band.

GSM1900 (1850–1990 MHz), UMTS (1920–2170 MHz), LTE2300 (2305–2400 MHz), and LTE2500 (2500–2690 MHz) bands. The radiation patterns of the proposed antenna at the center frequencies for lower and higher bands are plotted in Fig. 7. At 900 MHz, the radiation pattern with almost omnidirectional radiation in the azimuth plane ($x-z$ plane) is observed. At 1900 MHz, some variations for the radiation pattern appear due to the higher modes. The measured and simulated values for the peak gain at the frequency bands of (824–960 MHz) and (1710–2690 MHz) are exhibited in Fig. 8, featuring good agreement between the measured and simulated results. The measured antenna efficiency is also depicted in Fig. 8. It can be seen that the antenna efficiency is higher than 50% in both of the lower band and the higher band.

V. CONCLUSION

A novel multiband planar antenna is proposed. The proposed planar antenna has two wide frequency bands which cover the lower frequency range of 818–1190 MHz for the GSM850/GSM900 and the higher frequency range of 1710–3000 MHz for the GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), UMTS (1920–2170 MHz), LTE2300 (2305–2400 MHz), and LTE2500 (2500–2690 MHz) bands. The multiband planar antenna is suitable for applications as an internal antenna for wireless mobile and sensors devices.

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