Research Article

A MIMO Reversed Antenna Array Design for gsm1800/td-scdma/lte/wi-max/wiLan/wifi

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A triband MIMO antenna used for gsm1800/td-scdma/lte/wi-max/wiLan/wifi has been proposed in this paper. The design with the size of 32 m * 73.6 mm is fabricated on FR4 substrate (thickness is 1.6 mm). This antenna consists of two reversed monopole meandered radiators and defected ground structure which work together to achieve impedance match and enhance isolation for all operating bands. According to the subsequent measured results, the working frequency domains are at gsm1800 (1.71 GHz–1.88 GHz), td-scdma (1.88 GHz–2.025 GHz), lte (2.1–2.35, 2.48–2.51), wi-max (3.5 GHz, 5.5 GHz), wiLan (5.725 GHz–5.8 GHz), and wifi (5.8 GHz–5.88 GHz) approximately. Besides, the measured radiation patterns (gain total) are also well at these working frequency domains and the omnidirectional performance has been achieved for the reversed MIMO antenna array. Furthermore, the realized isolation is more than 15 dB, 24.2 dB, and 22 dB at the first, the second, and the third working frequency band, respectively.

1. Introduction

Multi-input, multioutput is a technology in wireless communication which can transmit information with high data rate and increase channel capacity with the same channel bandwidth. So the MIMO technology is very important for the next generation wireless communication. With the wireless technology development, the MIMO antenna has been required to have multiband performance, simple structure, relative small size, light weight, and low cost to be easily integrated with complex multifunction RF circuit. Recently, there are several research works focusing on the MIMO antennas, such as the MIMO antenna with H-shaped directive antenna [1], but it can only operate at one frequency band from 4.5 GHz to 6.2 GHz and the isolation is not good. In the literature [2, 3] the MIMO antennas show good performance on compact size. However, the isolation is relatively poor and there are few working coverages. Other MIMO antenna designs for handset application [4–6] are presented for excellent performance of isolation while the size is relatively big. For [7], a simpler MIMO antenna has been proposed whereas the achieved isolation is less than

12 dB for most of the frequency domain and should be improved. The high-isolation (more than 17 dB) and single-band MIMO antenna with wide coverage has been presented in [8]. Nevertheless, it is possible to be interfered by useless signal and the size is not suitable for handset application. In this paper, the novel tri-band MIMO design on the FR4 substrate has been presented. There are two reversed monopole radiators diagonally on the substrate for MIMO performance. The monopole radiator is proposed in my another paper which is now under review by microwave journal. There are two reversed monopole radiators located diagonally on the substrate for MIMO performance. This design can cover three frequency bands simultaneously based on the measured/simulated results and the isolation is also good compared to the listed references. Meanwhile, the planar area size is eligible for handset devices application.

2. Multiband Antenna Design

As is shown in Figure 1 there are two layers for the MIMO antenna in this paper. The dendritic meandered microstrip is

FIGURE 1: The proposed antenna in this paper. (a) The top view. (b) The bottom view.

FIGURE 2: The simulated results for the proposed antenna and design without interdigital slot-line.

located on the top layer and the reversed interdigital slot-line can be seen from the bottom view. On the other hand, the size of this antenna is 32 mm * 73.6 mm * 1.6 mm so that this

FIGURE 3: The copolarization and cross polarization with interdigital slot-line and without interdigital slot-line ($\phi = 90$) at 2.3 GHz.

FIGURE 4: The simulated electric current distribution of the MIMO antenna. (a) 2.3 GHz. (b) 3.45 GHz. (c) 5.4 GHz.

TABLE 1: The detailed size of this design.

$L1$	$L2$	$L3$	$L4$	$L5$	$L6$	$L7$	L	W
2.2	5.8	4	8	9.5	2.2	11.6	73.6	32

design can be used for the wireless handset application. The detailed size of the antenna is presented in Table 1 (unit: mm).

The substrate is FR4 (thickness is 1.6 mm) with a relative permittivity of 4.4 and loss tangent of 0.02. It can be easily known that the structure is simple compared to other MIMO antennas with the same multiband function. The difficulty for MIMO multiband antenna design is to generate multipaths for resonating electric current at multifrequency bands. The two linear polarization radiators located diagonally at substrate can generate three primary resonating current paths below 6 GHz for the multiband performance. The first and second band are created by the top-side dendritic microstrip by realizing the impedance match. The interdigital slot-line can excite the third-band performance and enhance the impedance match at all bands which can be inferred from Figure 2. Besides, interdigital slot-line proposed in my other submitted paper mentioned in Introduction will provide the meandered path for electric current at the first band to increase the cross polarization ratio for diversion transmission/reception application in mobile communication (lte/td-scdma) which can be summarized from Figure 3. These can be also analyzed from Figure 4 where there is distributed resonating electric current around the interdigital slot-line at all bands especially for the first and third band. This demonstrates that the performance of antenna can be influenced and adjusted by the defected ground structure. The resonating electric current can flow on the meandered path imbedded in the interdigital slot-line at the first frequency domain so that the effective radiation length can be increased to 0.14λ and the polarization electromagnetic fields should

be counteracted with each other due to the different current direction. For the second band, the electric current mainly appears on Path d to h (d, h are marked in Figure 1) that is as long as 0.132λ for radiation. When the frequency is moved to the third band electric current with about primary 0.161λ radiation length will not only activate on the top-side but also flow below the interdigital slot-line which shows the interdigital slot-line is important to achieve impedance match at this band for antenna too.

Furthermore, the reversed structure will weaken the mutual coupling effect caused by the defected ground structure between the two monopole radiators. So the structure can enhance the mutual isolation of the two radiators.

The return loss can be derived as the following equation:

$$S_{11} = \frac{Z_0 - Z_{in}}{Z_0 + Z_{in}}, \quad (1)$$

where Z_0 is the port impedance and Z_{in} is the equivalent input impedance of the antenna. When the port impedance is matched to antenna impedance at some frequencies the signal will be transmitted/received with very weak reflection. As for this design, most of the electric current will flow through the corresponding three equivalent paths in the working frequency domains. So the impedance of the equivalent resonating path should be thought to be approximate to Z_0 at corresponding frequencies ($Z_0 \approx Z_{in}$). The equivalent impedance of the top-side radiator which is the shunt and series connections of several microstrips on each path can be obtained based on the basic impedance formula of microstrip [10]:

$$Z_{\text{microstrip}} \approx \frac{87}{\sqrt{\epsilon + 1.41}} \ln \left(\frac{5.98H}{0.8W + L} \right), \quad (2)$$

where ϵ is the dielectric constant of the substrate, H is the thickness, W is the width of microstrip, and L is the total length of microstrip.

FIGURE 5: The fabricated MIMO antenna.

Except for the microstrip part, the coupling capacitance which is influenced by defected ground structure and relative location of two radiators should also be considered into the whole path. The equivalent impedance of capacitance is

$$Z_{\text{capacitance-equivalent}} = \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2}, \quad \omega = 2\pi f, \quad (3)$$

where C_1 is the coupling capacitance between top-side microstrip and ground (influenced by interdigital slot) while C_2 is the coupling capacitance between two monopole radiators. According to the analysis above, impedance of each path should be expressed as sum of $Z_{\text{capacitance-equivalent}}$ and $Z_{\text{top-radiator}}$. So the working frequencies can be calculated and adjusted through the top-side microstrip and DGS (defected ground structure) at bottom side and locations of two radiators.

Consequently, the defected ground structure and the dendritic reverse radiators on top can work together to excite the corresponding frequency bands at 2.1 GHz/3.5 GHz/5.4 GHz in simulation results.

3. Measured Results Analysis

The fabricated antenna has been shown in Figure 5. As can be known the size of this two-layer planar MIMO antenna is 32 mm * 73.6 mm * 1.6 mm and it has been measured for return loss and radiation pattern but there is some discrepancy due to the inaccuracy of simulation and measurement, use of SMA connector, fabrication limitation, and some other random reasons. In addition, the comparison table between this design and some references is provided to prove the good performance of this design on relative compact size, multiband performance, high isolation level, and so on. The measured results tell us that the proposed design can work at gsm1800 (1.71 GHz–1.88 GHz)/td-scdma (1.88 GHz–2.025 GHz)/lte (2.025 GHz–2.35 GHz)/wi-max (3.5 GHz, 5.5 GHz)/wiLan (5.725 GHz–5.8 GHz)/wifi (5.8 GHz–5.88 GHz) simultaneously. The simulation and measurement presented in Figure 6 indicate the isolation is more than 15 dB, 24.2 dB, and 22 dB for the first, second, and third working frequency domain, respectively.

FIGURE 6: The measured S_{11} , S_{21} and simulated S_{11} .

Furthermore, the radiation pattern at three frequency bands is well qualified in Figure 7. The measured radiation pattern can verify the omnidirectional performance of the proposed MIMO antenna in the three frequency bands. Besides, the measured peak gain totals in Table 2 are all bigger than 0 dBi which demonstrate that the radiation efficiency is greater than the ideal radiation antenna so the energy (−20 dB delivered to antenna in this experiment) should be radiated out with relative high efficiency. At last, the comparison information between this paper and other references is presented in Table 2. It is easily inferred from the table that the antenna in this paper has advantages in gain total, relative compact size, multiband working performance, and relative high isolation level compared to previous works. Last but not least, the enveloped correlation can also be derived by [11]

$$\rho_e = \frac{|S_{11} \times S_{12} + S_{21} \times S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}. \quad (4)$$

FIGURE 7: The measured radiation pattern of the MIMO antenna. (a) 1.98 GHz. (b) 2.14 GHz. (c) 3.5 GHz. (d) 5.75 GHz. (e) 5.85 GHz.

TABLE 2: The comparison of the performances between this paper and some references.

Refs	Planar area size (mm*mm)	Measured peak gain (dBi)	Isolation (dB)
This paper	32 * 73.6 (triband)	2.54 (1.81 GHz)/1.97 (1.98 GHz)/3.43 (2.14 GHz)/3.47 (3.5 GHz)/5.99 (5.75 GHz)/5.55 (5.85 GHz)	≥ 14.6 dB (1st band)/ ≥ 24.2 dB (2nd band)/ ≥ 22 dB (3rd band)
[1]	42 * 42 (single-band)	5.2 (5.45 GHz)	≥ 14 dB (in working band)
[4]	110 * 65 (single-band)	1.07 (1.9 GHz)/1.53 (2.1 GHz)/2.73 (2.45 GHz)	≥ 15 dB (in working band)
[7]	60 * 120 (dual-band)	0 (0.9 GHz)/4 (2.5 GHz)	≥ 12 dB (1st band)/ ≥ 11 dB (2nd band)
[9]	35 * 112.5 (dual-band)	2.01 (0.75 GHz)/6.3 (2.15 GHz)	≥ 9.5 dB (1st band)/ ≥ 12 dB (2nd band)

The calculated enveloped correlation using measured data is less than 0.001 at all operating bands. This is very well for MIMO application. In a word, the measured results of this antenna show the qualified performance for most wireless terminus applications.

4. Conclusion

In this paper, a novel MIMO antenna array with two monopole antennas for gsm1800, td-scdma, wi-max, wiLan, wifi is designed and fabricated. The antenna with three main electric current resonating paths consists of dendritic radiator on top and bottom-layer interdigital slot-line. The size of the proposed MIMO antenna is $0.21\lambda * 0.48\lambda * 0.01\lambda$ (λ is the wavelength at 1.98 GHz based on the experimental results) that is eligible for handset device application. The simulated and measured results also prove the design is feasible. Meanwhile, the peak gain and gain total is well which demonstrate the approximate omnidirectional performance and high radiation efficiency for the antenna. Finally, the structure of the designed MIMO array with three bands in this letter is simple and very easy to be implemented so that it can be widely used in wireless communication systems.

Disclosure

Mu Ju is a coauthor.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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