A Dual-Element Folded Strip Monopole with SRR loading for Multiband Handset MIMO Applications

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***Abstract*—A compact, low profile and multiband dual-element folded strip monopole is presented for mobile phone MIMO applications. Both the compactness and the multiband operation are achieved by loading the folded strip with a split ring resonator (SRR). The antenna elements are placed on the same mobile PCB arm in order to achieve angle diversity that enhances ports isolations, especially below 1 GHz. The proposed antenna achieves isolations of higher than 12 dB, enveloped correlation coefficients (ECC) of less than 0.1, apparent diversity gain around 10 dB and total efficiencies of greater than 60 % within the frequency band of interest (GSM 850, DCS1800, PCS 1900 and LTE 2500).**

Index Terms— ***MIMO antennas, multiband antennas, diversity gain, Handset devices.***

I. Introduction

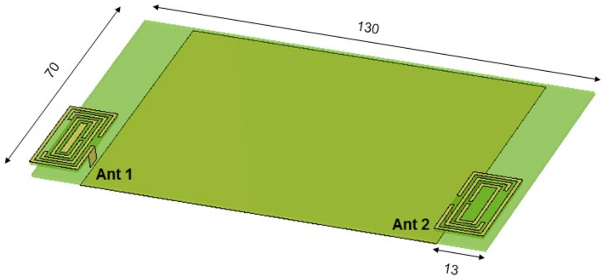
Due to the continuous mobile customer's demands, mobile communications field have witnessed a great evolution; it evolved from 2G, 3G to current generation 4G over the last three decades. Accordingly, a huge evolution has been carried on antennas design for hand portable devices. Such evolution adds new design challenges on smartphones antennas' design. As an example: the introduction of new mobile generations adds new frequency bands ranging between 0.7 GHz up to 2.7 GHz; this makes the design of multiband antennas as an urgent need. Additionally, the mobile devices form factor is changed to slim profile with large LCD display; this increases the needs for low profile antennas with a small footprint area over the system circuit board. Furthermore, as the current 4G technology requires MIMO and antenna diversity schemes, the design of multi-element antennas is highly recommended to increase the system reliability and capacity [1]. All, the aforementioned challenges and goals spurred researchers in both academia and wireless industry to work out to find new antenna solutions to meet the said requirements and challenges. To achieve the benefits of MIMO and diversity technology, several important performance parameters should be met like high port isolation (decoupled antenna elements), very low envelop correlation coefficient between antenna elements and power balance [2].

Several isolation techniques have been proposed [3-12] to reduce coupling between handset mobile antennas. Decoupling networks represents one isolation techniques between MIMO antennas [3, 4]. In [5, 6], parasitic decoupling element technique have been proposed between coupled antenna elements. Although this technique is very effective in achieving excellent antenna isolation over a wide operational bandwidth, it is not suitable for frequencies below 1 GHz as the parasitic decoupling element represents a distributed circuit that resonates based on its dimensions, which are quite large for such frequencies. Good isolation level has been achieved using defected ground plane structures [7-9]. However, such modifications on the ground plane are not acceptable for mobile phone devices as it affects the operation of other circuits and components of the mobile device. Other techniques such as the neutralization line [10,12], and the periodic structures [13] are also investigated and proposed as decoupling techniques for mobile phone antennas. However, all of the aforementioned techniques share common drawbacks such as: a difficulty of realization for frequency applications below 1 GHz, especially, when the space is limited. Also, at lower frequencies (below 1GHz) the ground plane acts as a part of the antenna radiator; this makes the isolation between MIMO antenna elements over the same system ground plane quite difficult due to strong current distribution on the ground plane.

In this paper, based on the antenna design proposed in [14], a new design of dual-element multiband MIMO antenna is proposed. To mitigate antenna's coupling below 1.0 GHz, angle diversity is achieved between the two antenna elements that are as shown in Fig. 1, located on the top and the bottom PCB ground plane edges, respectively. The pattern diversity is achieved by controlling the surface current distribution on the ground plane, in which orthogonal current modes are excited between antenna elements. In Section II, the antenna configuration and the design principle are proposed. Section III presents the prototype and the simulated and measured MIMO performance parameters. Finally, Section IV concludes the paper.

II. Antenna Configuration And Design Principle

The geometry and configuration of the proposed antenna is shown in Fig. 1(a). The two elements are built over a system PCB board made from an FR4 (εr = 4.4 and a loss tangent tan δ = 0.025) substrate whose dimensions are 70×130×1 mm^3. Each antenna element is a folded monopole strip loaded with edge coupled split ring resonators over a free ground plane area of dimensions 13×26 mm^2. Each element is printed on a very small FR4 superstrate at 4.0 mm height above the main PCB board. Fig. 1(b) shows the detailed geometry and dimensions of each antenna elements. The operational mechanism of the proposed antenna element is based on using a coupled split ring resonators (SRR) to first creating more than one resonant frequency to achieve multiband operation and also to provide more antenna loading that can minimize the overall antenna size. More details on the mechanism of operation of this antenna element can be found on [14]. Each element if fed through a coaxial probe feed that is connected through the feeding plate of each. Each antenna element is designed to cover the following frequency bands: GSM 850 MHz (outer ring), PCS 1900 (middle ring) and LTE 2500 (the outer ring). Fig.1 (a) shows that the separation between the MIMO antenna elements (MIMO Antenna 1 and MIMO Antenna 2) is 0.295λ0, which measures 104 mm at 850 MHz. Since the total length of the long edge of the main PCB is a fraction of operational wavelength at 850 MHz (0.37 λ0), this makes the isolation between the antenna elements quite difficult using only spatial diversity.



(a)

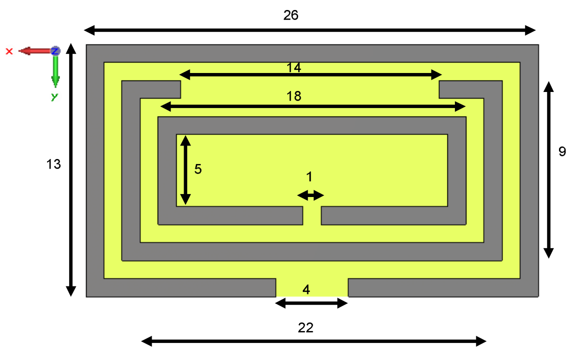


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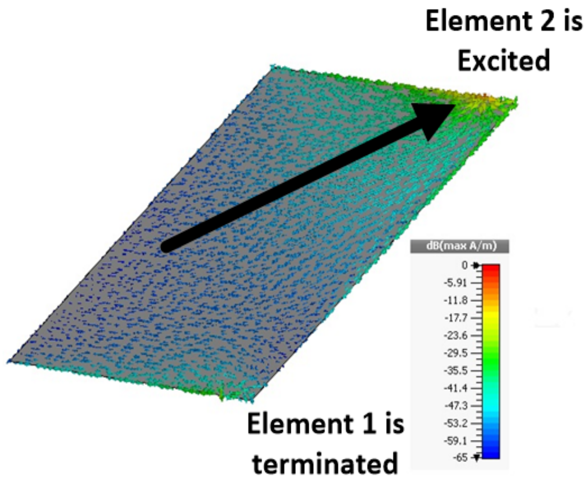
Fig.1. The geometry of the use MIMO antenna: (a) Overall view and (b) detailed dimensions of MIMO antenna element. [units are in mm].

To overcome this, both antenna elements are installed on the same long edge. By doing this, two orthogonal surface current modes are excited on the shared ground plane to reduce coupling. Fig. 2 shows the surface current distribution at 850 MHz when one element is excited and the other is terminated with a matched 50 Ω load. Due to the excited orthogonal current modes, the mutual coupling between the two antenna elements is reduced to below -10 dB at 850 MHz. Additionally, as each antenna elements occupies a very small portion of the top and bottom sides of the PCB, better isolation level obtained as compared to the levels reported [15, 17]. Regarding the higher frequency bands (PCS 1900 and LTE 2500), the isolation is achieved through spatial diversity, as the separation distance at these frequencies is quite high (much more than a half wavelength).



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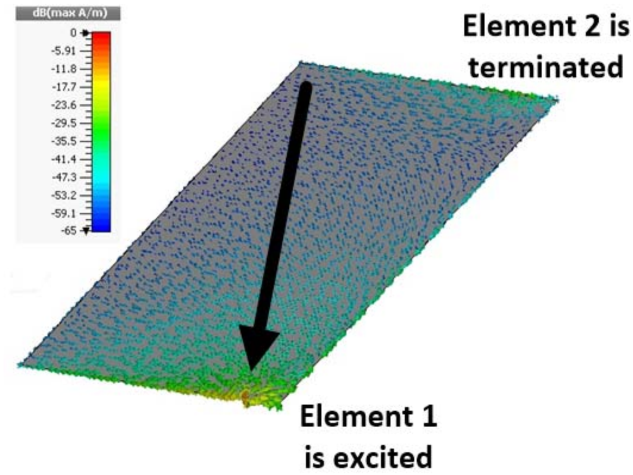


(b)

Fig. 2. Ground plane surface current distributions at 850 MHz: (a) Element 2 is excited, while element 1 is terminated with matched load, (b) Element 1 is excited, while element 2 is terminated with matched load.

III. Simulated And Measured Results

This section includes fully-wave simulated and measured results for the proposed antenna. The diversity characteristics and the MIMO performance of the proposed antenna are presented and discussed. These performance parameters are:

Scattering parameters, far field radiation patterns, total radiation efficiency, the envelope correlation coefficient (ECC), and apparent diversity gain.

Using the methodology presented in the previous section, a dual-elements MIMO antenna is proposed for multiband mobile phone applications, the simulation and the optimization are carried out using CST Microwave Studio [18]. Fig. 3 shows the fabricated prototype of the proposed antenna. The fabricated prototype was tested using the measurement facilities available at the University of Liverpool. The measured S-parameters were collected inside an anechoic chamber (an ideal environment to mimic the free space) and presented as a function of frequency as shown in Fig. 4. The measured impedance bandwidths for all bands, which are defined by 6 dB return loss, are in a very good agreement with the simulated ones. Regarding the mutual coupling level between the two implemented antenna elements, Fig. 4(b) shows that the isolation level is greater than 12 dB for all bands , which is acceptable as it is below the conventional threshold limit of 10 dB.

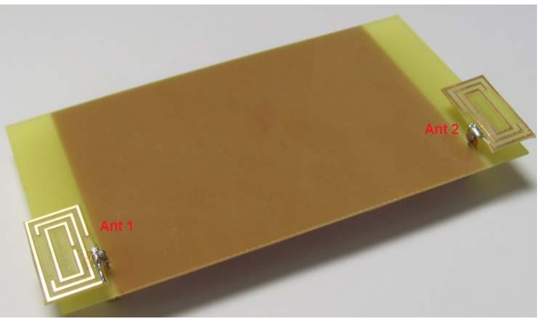
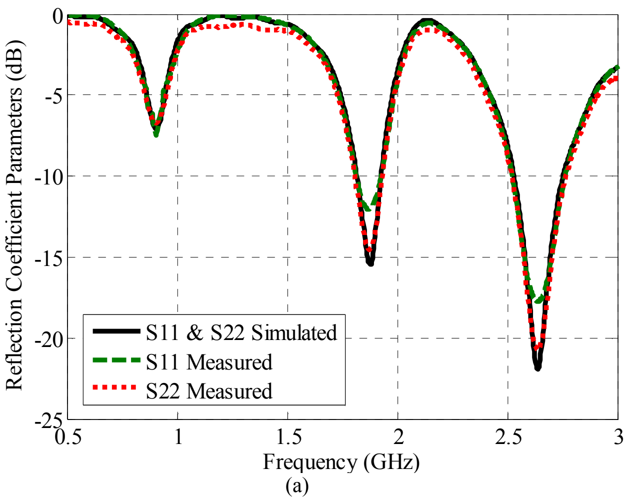


Fig. 3. Proposed dual-element antenna prototype



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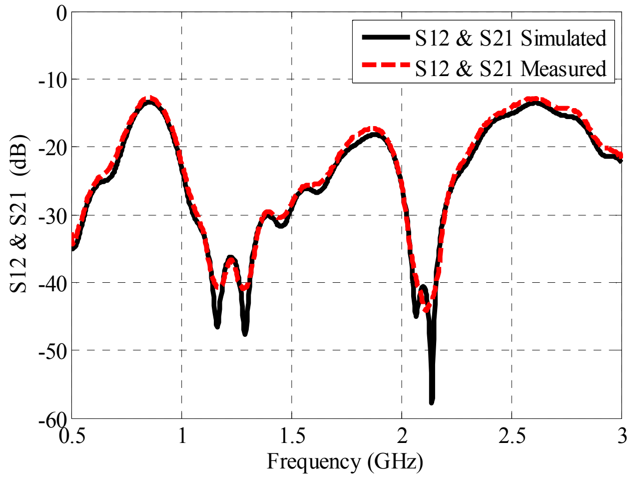


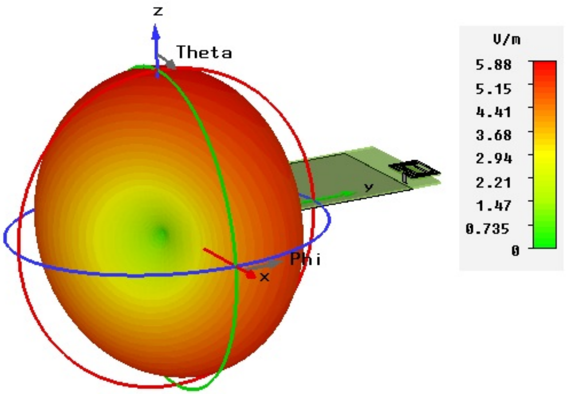
(b)

Fig. 4. Simulated and measured scattering parameters.

Besides the scattering parameters, the active element patterns of the diversity antenna are also studied. As the design has MIMO operation below 1 GHz, which is the main contribution of this work, only the radiation pattern at 850 MHz is studied to explain the achieved good isolation level. Fig. 5 shows the 3D radiation patterns at 850 MHz. It is evident that active element patterns are somehow orthogonal to each other. This contributed to the low coupling obtained between the two antennas.

The MIMO and diversity performance parameters of the proposed antenna are also simulated and measured. These parameters are: the envelope correlation coefficient (ECC), the total efficiencies and the diversity gain. All are discussed next.

As the proposed antenna has an orthogonal surface current on the common ground plane, and a very low isolation level over the bands of interest, the envelope correlation coefficient between the two antenna elements is calculated using the S-parameters and the radiation efficiency as described in [17]. Fig. 6 shows both the simulated and the measured ECC values. Both values are in good agreement and satisfy the diversity ECC condition as they are below 0.1. This is indeed much lower than the recommended value of 0.5.



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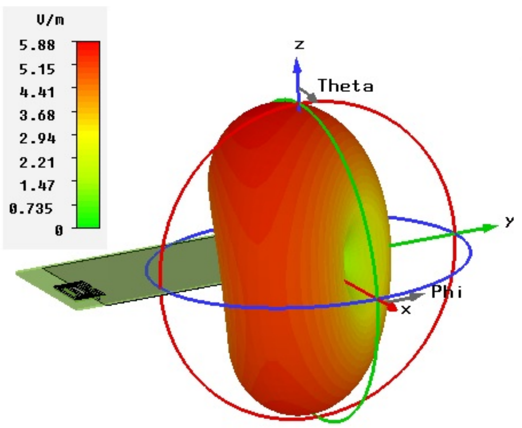


(b)

Fig. 5. 3D Radiation Patterns for the two antenna elements at 850 MHz.

The apparent diversity gain is defined as the difference between the power levels in dB scale at a given cumulative probability level between the CDF of a combined signal and the CDF of a signal at the antenna branch with the strongest average level [17].

The diversity gain and the total radiation efficiency measurements were carried out inside a reverberation chamber at University of the Liverpool. The measurements set up, procedures and post-processing of the collected data can be found in [19, 20]. For accurate results, the measurements were done over three discrete bands as follows: Band 1 (810-970 MHz), Band 2 (1700-2000 MHz) and Band 3 (2300-2700 MHz). Using selection combining MIMO techniques, Fig. 7 shows that the proposed design has apparent diversity gains, for the three discrete bands, of 9.26 dB, 9.71 dB, and 10.44 dB, respectively. The CDF level is 0.01.

From the same collected data, the post-processing of total radiation efficiency is done using MATLAB routine. The calculation of the total efficiency was based on (1). The simulated and the measured efficiencies are matched to each other and depicted in Fig. 8. As element 1 and element 2 are identical and for the purpose of the clarity of the figure data, only one antenna element data is presented. The results demonstrate that the proposed design has total efficiency that ranges between 60-90 %, which is an acceptable total efficiency over the frequency band of operation.

$$\eta_{TOT} = \eta_{Rad}\left(1-|S_{11}|^2-|S_{12}|^2\right) \qquad (1)$$

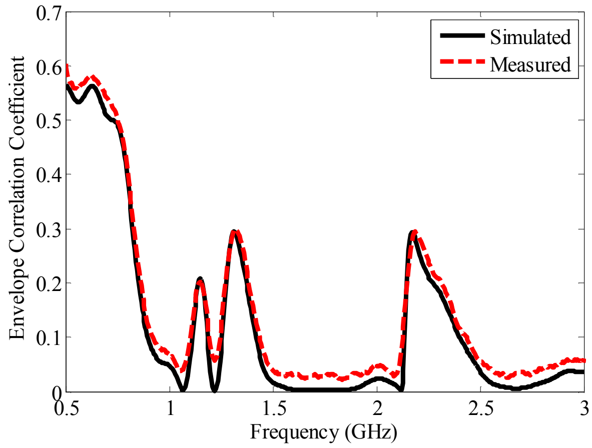
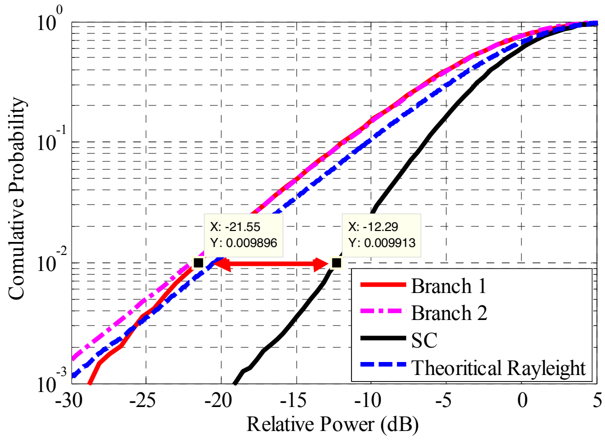
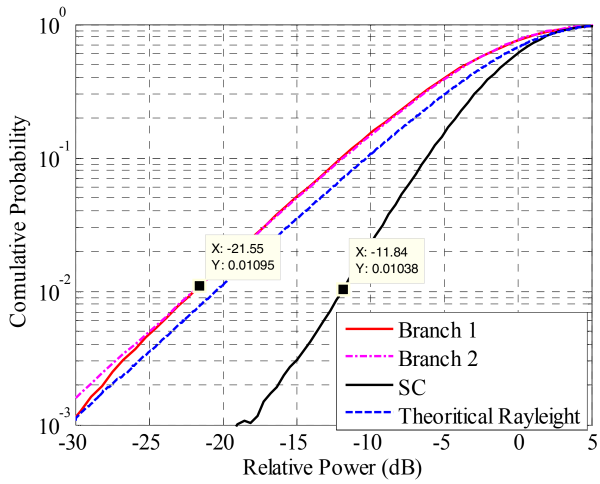


Fig. 6. Envelope Correlation Coefficient



(a)



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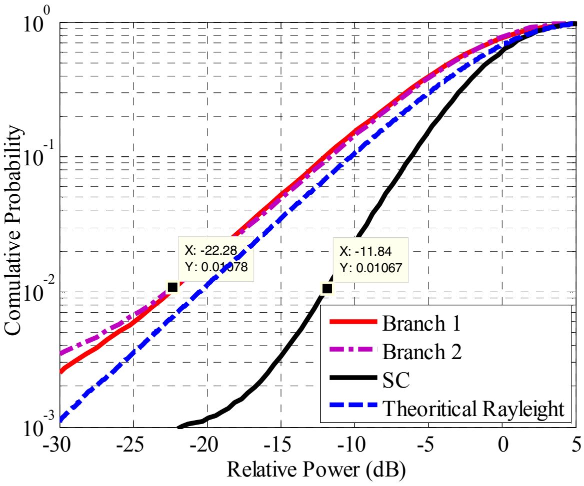

(c)

Fig. 7. CDF function and apparent diversity gain: (a) 810-970 MHz, (b) 1700-2000 MHz and (c) 2300-2700 MHz.

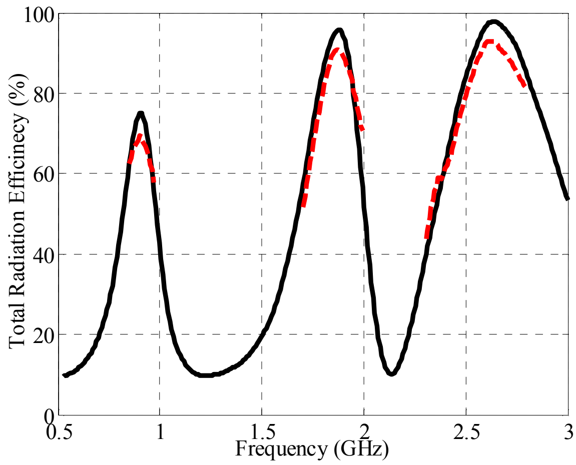

Fig. 8. Measured and simulated total radiation efficiency; solid black line (—) is the simulated total efficiency, and the red dashed line (-----) is the measured total efficiency of both antenna 1 and antenna 2.

IV. Conclusion

A compact, low profile and multiband dual-element folded strip monopole for mobile phone MIMO applications has been proposed. Angle diversity has been used to excite orthogonal surface current modes over the common ground plane. The proposed design was fabricated and tested. It was shown that the isolation levels are acceptable and below the -10dB limit and the enveloped correlation coefficients (ECC) is less than 0.1. The MIMO and diversity parameters were also shown feasible; the achieved apparent diversity gain was around 10 dB and the total efficiencies are greater than 60 within the frequency bands of interest (GSM 850, DCS1800, PCS 1900 and LTE 2500). Overall, the proposed antenna represents a good candidate for multiband mobile phone MIMO applications.

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