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Compact Multiband Sensing MIMO Antenna Array for Cognitive Radio System

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Abstract—**This paper presents a new design for a multiband sensing MIMO antenna system that can be used in cognitive radio communication for a mobile platform. The antenna system consists of two identical small-size multiband antennas with dimensions 29.5 x 17 x 5 mm^3 and each of them is comprised of a driven strip monopole and a coupled parasitic shorted strip. These antennas are located diagonally to limit the mutual coupling and antenna correlation at low frequencies. The obtained operating bands are 698 - 990 MHz and 1710 - 5530 MHz, which include most of the LTE and Wi-Fi frequency bands. A prototype was fabricated and the measured results indicate that the realized efficiency is acceptable for a mobile application considering the compact size.**

Index Terms - MIMO, mobile phone antennas, internal antennas, antenna array, multiband antennas, small antennas, cognitve radio, LTE, Wi-Fi.

I. Introduction

The explosive growth in the wireless communication service over the past several years requires improving the efficiency of use of the available radio spectrum. Recent investigations have shown that a significant part of the licensed frequency bands remains underutilized or unused for a long period of time (about 90 % of the time) [1]. This has led to the need for development and introduction of new ways to improve the efficiency in the utilization of the spectrum. Cognitive Radio (CR) is a concept which offers a solution using an approach known as opportunistic spectrum sharing [2].

Opportunistic spectrum sharing improves the usability of the spectrum by allowing unlicensed radio users to dynamically access the licensed spectrum bands allocated to licensed users [3]. Thus, exploiting the underutilized and unoccupied spectrum resources through the ability of switching among different bands provides better utilization of the licensed bands. However, it is necessary that cognitive users do not interfere significantly the existing primary ones. This means that the transmitted power of the secondary users has to be low enough so that the interference caused to the primary users is below a certain threshold. Thereby, the quality of service of the licensed users is not reduced, while that of the unlicensed users is maintained high enough [4]. Furthermore, in such a scenario with limited transmit power, the antenna efficiency is paramount for the quality of the communication link.

A cognitive radio system can use two types of antennas - sensing and reconfigurable antennas. By using this set of antennas a CR system is capable to find the unoccupied parts of the spectrum and reconfigure itself in such a way that an efficient communication and spectrum use are achieved [5]. The sensing antenna is necessary to be wideband to "sense" the availability of the spectrum of interest. For mobile devices, the antenna volume is serious constraint. Thus, the realization of wideband antennas, which are bigger than narrowband ones, constitutes a challenge. Apart from this, when the antenna is small compared to the wavelength i.e. it is electrically small, the increasing of the bandwidth results in the decreasing of the efficiency and therefore deterioration in the sensitivity [6]. The reconfigurable antenna has to tune its operating frequency for communication. Realization of a such antenna which can be reconfigured to operate over a wide band is a serious challenge [7]. In addition, the two types of antennas must be placed into the same substrate and the coupling between them must be as low as possible. An alternative to this configuration is the classical use of only wideband antennas and passband filtering after the antenna to limit the interference. This approach is followed in this paper.

Over the last years different types of antennas have been studied for CR applications. In [2] a wideband conformal antenna array has been presented. The proposed array comprises of six E-patch antennas and the covered bandwidth is approximately 25% centered at 2400 MHz. A reconfigurable antenna has been proposed in [8]. The band which can be covered with this microstrip patch antenna by tuning is from 1390 MHz to 2360 MHz. Design of a channel sensing antenna and a frequency reconfigurable antenna embedded into the same substrate has been presented in [5]. The sensing antenna is a slotted polygon-shaped patch and covers the frequency range 3.1 - 11 GHz while the reconfigurable antenna is a triangular-shaped patch and can be tuned in the ranges 3.4 - 4.85 GHz and 5.3 - 9.15 GHz.

One of the key features of the 4G wireless communication standards is the use of MIMO technology. Multiple-input multiple-output (MIMO) systems increase the channel capacity without requiring more spectrum and power, but the price of this improvement in the communication performance is the use of multiple antennas at the both ends of the radio link [9]. In [10] has been presented a sensing antenna and a dual-element MIMO antenna on a single substrate. For frequency reconfigurability has been used p-i-n and varactor diodes integrated with the two elements of the MIMO antenna system. The UWB antenna covers frequencies from 720 MHz to 3440 MHz, while the reconfigurable antenna covers various frequency bands between them. Two MIMO based reconfigurable filtennas for cognitive radio have been proposed in [11].

In this paper, we present an internal mobile phone MIMO antenna system for cognitive radio which can do MIMO trans-

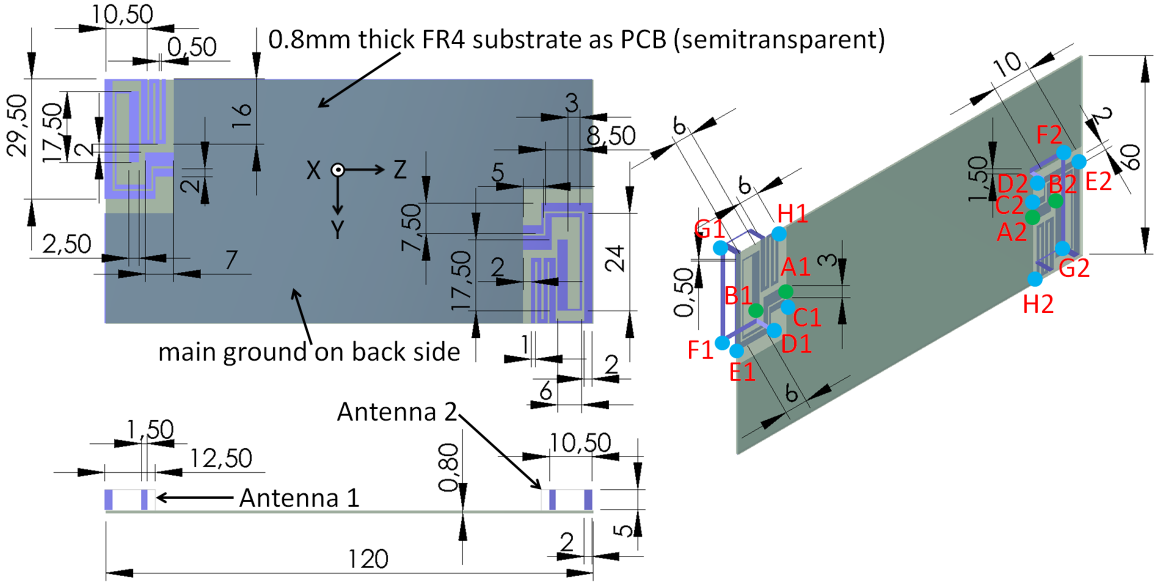

Fig. 1: Geometry of the proposed antenna without the casing.

mission and reception when it is sensed that the channel is free. In addition to the cognitive radio, the antennas can be used for MIMO realization of LTE and Wi-Fi communications. The system comprises of two identical antennas placed diagonally and each of them has a small occupied volume of only 29.5 x 17 x 5 mm^3, thereby only small areas are used at the top and bottom edge of the printed circuit board (PCB). The compact integration of these antennas along with the small areas without ground used under them (the cutback areas of 33 x 17 mm^2) enable effective planning of the board space on the PCB. The proposed antennas are formed by a driven strip monopole and a parasitic shorted strip with a capacitive coupling between them. By combining the fundamental and higher-order resonant modes of these elements a wideband operation is achieved covering almost all LTE and Wi-Fi bands. The details of the operating principle of the proposed system are described in Section II and the measured results of the prototype are presented and discussed in Section III.

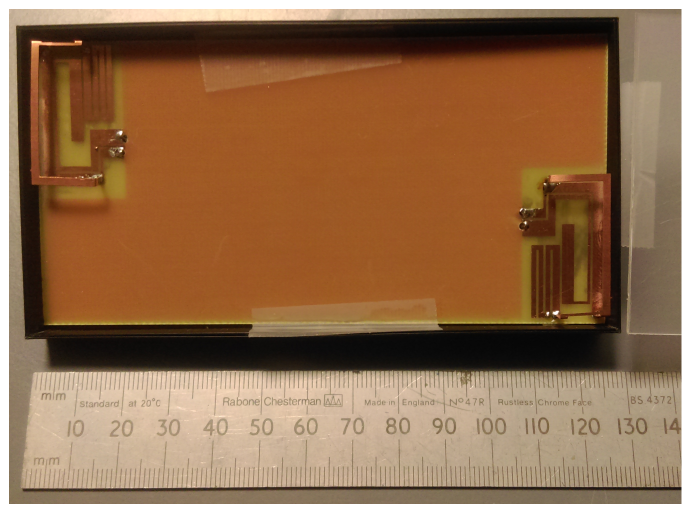

Fig. 2: The antenna prototype with the top lid opened.

II. Proposed MIMO Antenna System

The geometry of the proposed antenna system is illustrated in fig. 1. For the PCB is used a 0.8 mm thick FR4 substrate of length 120 mm and width 60 mm with relative permittivity 4.4 and conductivity 0.02 S/m. The PCB is further enclosed by a plastic housing with thickness 1 mm and with total volume 124 x 64 x 10 mm^3 and with relative permittivity 2.1 and loss tangent 0.002, which plays the role of the mobile phone housing. The ground plane is printed on the back side of the PCB and there is a small cutback area under each antenna with dimensions 33 x 17 mm^2. The volume occupied by each antenna is 29.5 x 17 x 5 mm^3 and the two antennas are placed diagonally as one of them is located on the left corner of the bottom edge and the another one on the right corner of the top edge. This placement is chosen in order to achieve a low envelope correlation coefficient (ECC). It is generally preferred that the antennas are aligned on the same side of the PCB, due to the diagonal chassis-mode [12]. However, the value of the ECC depends not only of the placement but also of the antennas design and excitation mode. For the antenna design presented in this paper the diagonal topology provides a lower correlation.

Each of the proposed antennas comprises two elements: a driven strip monopole (A1-B1 and A2-B2) and a long parasitic shorted strip (C1-D1-E1-G1-H1 and C2-D2-E2-G2-H2). The parasitic strips surround the driven monopoles to obtain a compact structure by loading the antenna impedance through the mutual coupling between the two resonators. The points A1 and A2 of the monopoles are the antennas feeding points and the points C1 and C2 of the parasitic shorted strips are short circuited to the ground plane. Each of the driven strip monopoles has a length of 68.5 mm, which is about 0.25 wavelength at 1100 MHz and this is its fundamental resonant mode. This resonance is shifted to a lower frequency when the parasitic strip is added due to the coupling between these two strips. Each of the parasitic shorted strips has an additional line connected to it (D1-F1-G1 and D2-F2-G2 each with length of 40 mm), which leads to an enlargement of the covered frequency bands. The length of each parasitic shorted strips is 120 mm which is about 0.25 wavelength at 625 MHz. The parasitic shorted strip is excited through capacitive coupling to the driven monopole. The fundamental resonant modes of these elements provide coverage of the frequency range 698 - 990 MHz. The higher-order resonant modes of the monopoles and shorted strips are combined and thus the frequency range 1710 - 5530 MHz is covered. Therefore, each antenna of the system can operate in most of the LTE and Wi-Fi bands.

III. Results and Discussion

The proposed antenna system was fabricated and studied. The photo of the prototype is shown in fig. 2. The measured return loss of each antenna are illustrated in fig. 3. To limit the amplifiers mismatching, for mobile phones around 3:1 VSWR or -6-dB return loss is considered acceptable. The results show that each antenna has a wideband operation and covers almost all LTE and Wi-Fi bands. There are small discrepancies between measured return loss for each antenna which are mainly due to the fabrication inaccuracy of the prototype.

From fig. 3 can be seen that in the low operating band 698 - 990 MHz there are two resonant modes. The one at about 760 MHz is contributed by the parasitic shorted strip and the another one at about 950 MHz is excited by the driven strip monopole. As mentioned above the fundamental resonant mode of the driven strip monopole is shifted to lower frequencies due to the coupling between it and the shorted strip. Seven higher-order resonant modes are generated either by the driven strip monopole or parasitic shorted strip at about 2070 MHz, 2470 MHz, 2830 MHz, 3210 MHz, 3610 MHz, 4890 MHz and 5320 MHz. By incorporating these resonant modes a wideband operation from 1710 MHz to 5530 MHz is obtained. Thus, by combining the fundamental and higher-order resonant modes of these elements, two wideband antennas are obtained.

The measured isolation between the two antennas is also presented in fig. 3. For the mobile phones the acceptable upper limit of the isolation is around -10-dB which limits the coupling losses and indicates a reasonable decorrelation. As can be seen from this figure the isolation between the pair of antennas meets the requirement for all frequency bands of interest, which makes this system appropriate for MIMO applications.

In fig. 4 are shown the simulated surface current distributions at the resonant frequencies, only for one of the antennas due to their symmetry. They are obtained using CST Microwave Studio version 2014 [13]. It can be seen that the resonance at about 760 MHz is the fundamental mode of the parasitic shorted strip, while this for the driven strip monopole is at about 950 MHz. At high frequencies large surface currents can be seen on the both elements, which are due to the strong coupling between them.

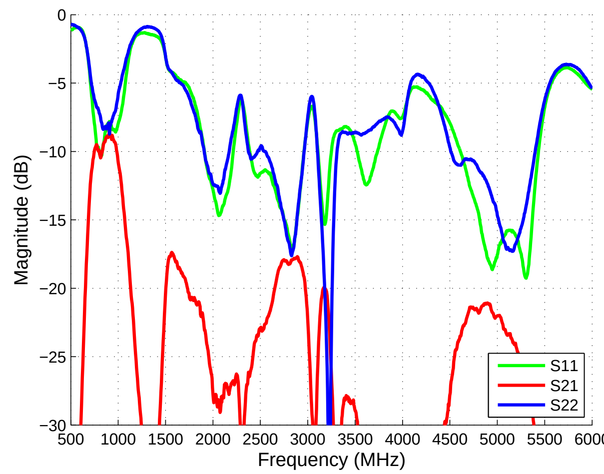

Fig. 3: Measured S-parameters of the proposed antennas.

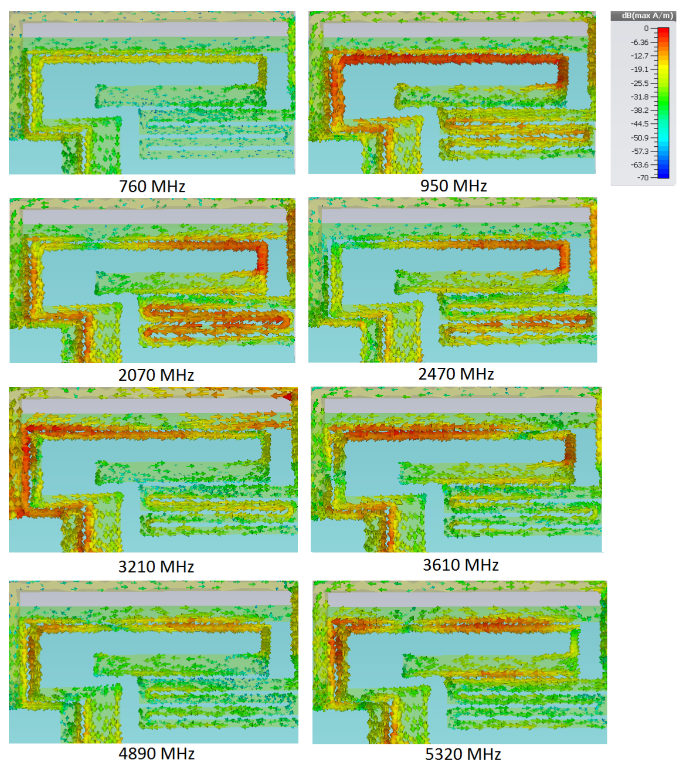

Fig. 4: Current distribution for one of the antennas.

The measured total efficiency (includes return loss, isolation and radiation efficiency) for each antenna of the proposed compact system is shown in fig. 5. For frequencies in the low band, the efficiency varies from 39 % to 58 %. Over the higher frequency band the same parameter ranges from 24 % to 78 %. These results show that the total efficiency of each antenna is high enough for mobile applications in all of the covered frequency bands, despite the small size and the fact that it is optimized mainly for the low band.

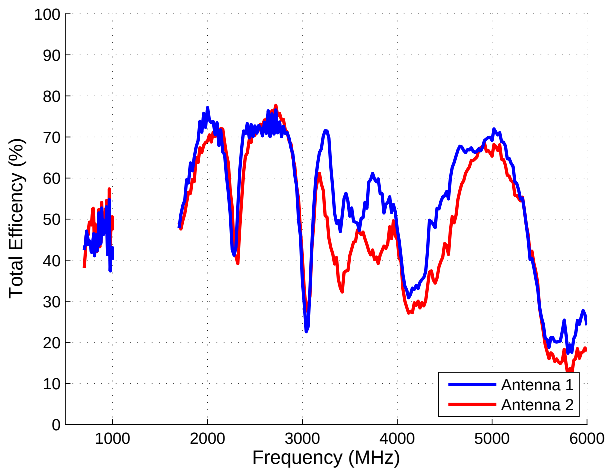

Fig. 5: Measured total efficiency of the two antennas.

In fig. 6 are presented the results of the measured and simulated envelope correlation coefficient, calculated through the 3D E-field radiation patterns of the dual-element MIMO antenna array for isotropic incoming power spectrum. This figure shows that the correlation is slightly higher in the low band, due to the small distance between the antennas compared to the wavelength and slight pattern difference, varying from about 0.8 to 0.6. For the high band it is lower than 0.03 because the distance between the antennas compared to the wavelength is large enough for obtaining a low correlation.

In fig. 7 are illustrated the XZ and YZ cuts of the measured radiation patterns of the two antennas. In fig. 7(a) and fig. 7(b) we can observe the similarity of the gain patterns at 700 MHz and the gradual change across frequencies leading to a smaller correlation in the 800 and 900 MHz case. For the high band case, fig. 7(c)-(f), an expected clear pattern diversity leading to a very low correlation can be observed.

IV. Conclusion

In this paper, a new MIMO mobile phone antenna array consisting of two compact multiband antennas is presented. The proposed antennas cover almost all LTE and Wi-Fi bands and can be used for channel sensing for the goals of the cognitive radio and MIMO transmission and reception. A prototype was fabricated and tested as the achieved results for return loss, isolation and total efficiency are good enough for mobile applications. This antenna system can be a possible candidate for MIMO communications.

The user's body effect is crucial for antenna performance in every mobile device. Therefore, our further work will be

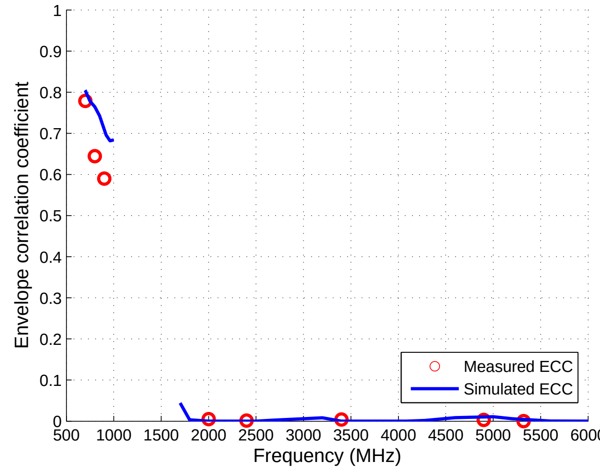

Fig. 6: Measured and simulated envelope correlation coefficient.

focused on an investigation of the user's body effect on this MIMO antenna array. In addition, the high band performance must be optimized to increase the efficiency across the band.

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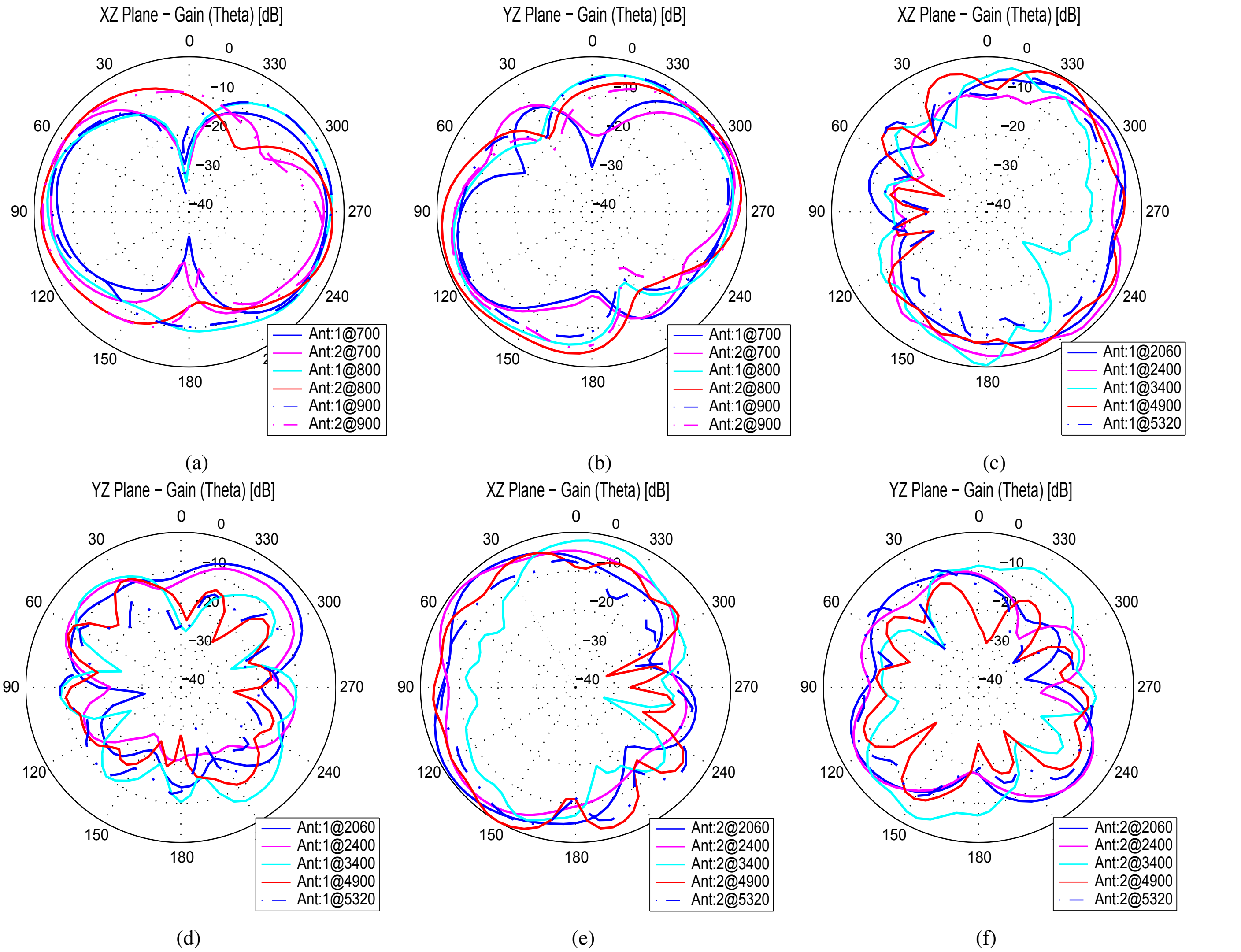

Fig. 7: Measured radiattion patterns: (a) low band XZ-cut of the two antennas; (b) low band YZ-cut of the two antennas; (c) high band XZ-cut of the antenna 1; (d) high band YZ-cut of the antenna 1; (e) high band XZ-cut of the antenna 2; (f) high band YZ-cut of the antenna 2.

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