Miniature multiband antennas for hand held WIMAX and WiFi application

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Abstract – **This paper presents a MIMO multi-band antenna system designed for WIMAX and WLAN applications. The antenna system includes two receive and one transmit antennas designed to cover the following frequency bands: WiMAX: 2.3-2.4GHz and 2.45-2.7GHz, and WiFi 2.4-2.45GHz. The ntenna system is part of the Software Defined Radio (SDR) platform developed by Sandbridge Technologies.**

1 INTRODUCTION

One of the challenges of the multiple communication protocol systems is the design of the multi-band antenna. Besides the fact that the antenna needs to meet certain gain and directivity properties it also encounters physical size restrictions. Even more, for today's multiple input multiple output (MIMO) mobile systems due to very small form factor the mutual coupling of the antennas plays a significant role.

The purpose of this work was to design a printed circuit board (PCB) MIMO antenna system that minimizes the size and mutual coupling with superior gain and directivity proprieties. The target application is a combined WIMAX - WLAN mobile device with one transmit (TX) and two receive (RX) antennas. The antenna system is part of the Software Defined Radio platform developed by Sandbridge Technologies [1].

2 MICROSTRIP ANTENNA DESIGN

Conforming to WiMAX WAVE II recommendations, the radio frequency front end (RFFE) consists of two RX and one TX chains in time division duplexing (TDD) mode. Since only the receiver or transmitter are turned on for any particular time, in order to minimize the mutual coupling [2] of the three antennas we choose to place the TX antenna in the middle and the two RX antennas at the both sides as illustrated in Figure 1.

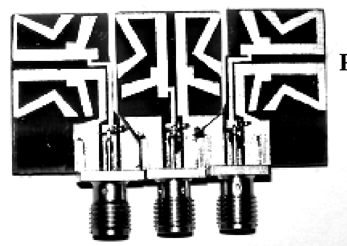

Figure 1: MIMO antennas system.

2.1 PCB layout

We made the following assumptions during the design process:
1. The thickness (h) of the multiplayered PCB dielectric substrate varies between 1.2 and 1.5 mm due to the manufacturing process.
2. The dielectric permittivity (ε_r) of the substrate varies from 3.9 to 4.8.
3. The total available area for the three system antenna is equal or less than 60x30 mm^2

The shape of each antenna is similar to the shape described in our former paper [3].

The antenna is designed on two layers. On the top layer are the feeding point and the impedance adapting circuit. The bottom layer acts as frequency selective reflector, having a similar print as the top layer, with a specified resistive load in the feed point location. In order to reduce the mutual coupling between antennas a free space cut was added in the dielectric substrate near the sides of the TX antenna. In Figure 2 are illustrated the two layers as TOP and BOTOM for the three antenna system.

We applied an iterative measurement-simulation design methodology using the S_{ij} (s-parameters) measurements as feedback for the antenna performance.

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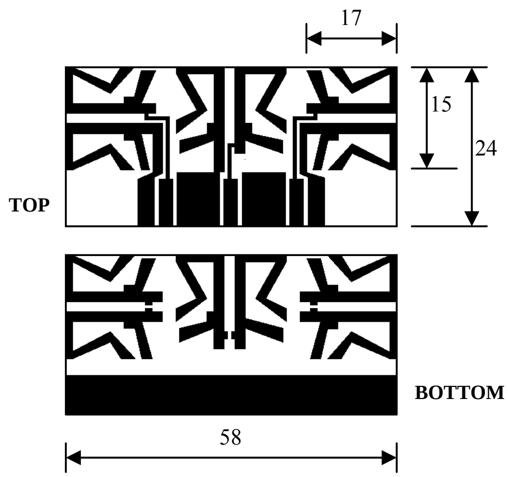

Figure 2: TOP and BOTTOM layers of the antennas (all dimensions are in mm).

The return loss measurement S_{11} was the main feedback parameter used for the antenna design. First, we designed a single antenna then the shape of the antenna was modified to obtain the desired frequency response. Second, we designed a three antenna system and we modified the TOP and BOTOM layers in order to have the desired frequencies response for each antenna. In order to evaluate the decoupling between antennas we have measured the transmission parameter S_{12} between each two pairs of the antennas TX-RX1, TX-RX2 and RX1-RX2.

2.2 Impedance matching circuit

The purpose of the matching circuit, illustrated in Figure 3, is to match the dipole impedance Z_{dip} to the line impedance Z_o. L_1 and C_1 are distributed values due to the PCB and L_2, C_2 are surface mount components. The circuit, is placed on the top layer between the antenna feed point and the line circuit. For convenience C_2 and L_2 are shown in Figure 4 for a single antenna.

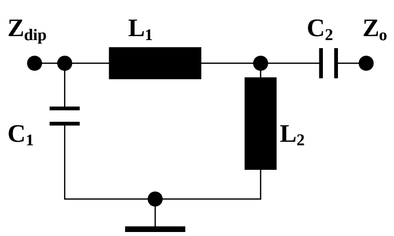

Figure 3: The impedance matching circuit.

The values of the matching circuit component are: Z_{dip}=200 Ω, Z_o=50 Ω, C_1=1 pF, C_2=1.5pF, L_1=5 nH, L_2=15 nH

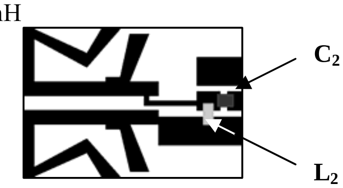

Figure 4: The TOP layer with the impedance matching circuit for a single antenna.

3 ANTENNA MEASUREMENTS

We performed two sets of measurements for the S_{ij} parameters, one set for a single stand alone antenna and the second set for the three antennas. For the S parameters measurement we used the N5230A Agilent Network Analyzer.

For the standing wave ratio calculation we used the following equation [4]:

$$SWR = \frac{1 + |S_{11}|}{1 - |S_{11}|} \quad (1)$$

For a reasonable good antenna the SWR needs to meet the condition SWR ≤ 3.

The gain was computed in transmission mode at $\Phi=90^o$ incidence as shown in Figure 5. The S_{12} parameter was measured using two identical antennas or antennas system.

For the gain computation, the Friis transmission equation was considered with the far-field condition [5]:

$$P_R = \left(\frac{\lambda}{4\pi R} \right)^2 G^2 P_T \quad (2)$$

with: $R \geq 2d^2 / \lambda$.

In the above equation, P_R is the power measured at the receive antenna output port, P_T is the power measured at the transmit antenna input port, G is the gain for both transmit and receive antennas, considered identical, λ is the wavelength, R is the separation between antennas and, d is the largest physical dimension of the antenna. From equation (2), knowing that $S_{12}=S_{21}$, through simple algebraic manipulation, the gain follows:

$$G = -3.779 + 10 \log(R F) + 0.5 (S_{21}) + 2.15 \quad (3)$$

Where the antenna gain G is in dBi, the transmission parameter S_{12} is in dB, R is in cm and F is the frequency in GHz.

The directivity D is the measure of the directional properties of the antenna related to the isotropic antenna. The directivity gain G, related to the isotropic dipole is also defined in [4] as:

$$G = e\,D, \text{ with } 0<e<1 \tag{4}$$

Where e is the radiation efficiency of the antenna. The directive gain of the antenna was measured in the XOY plan, normal to the antenna layers, as shown in Figure 5.

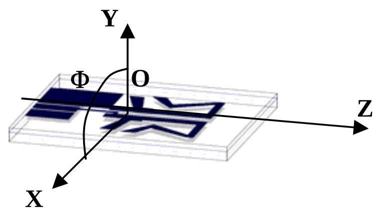

Figure 5: 3D view of the single antenna.

3.1 SWR, G and D charts for a single antenna

The physical parameters of the single antenna are: h=1.5mm, ε_r = 4.6 and total surface area of 14x24 mm^2. The SWR as a function of frequency is illustrated in Figure 6. It can be seen that in the frequency band from 2.2 to 2.6 GHz, the SWR is less than 2 while from 2.14 to 2.7 GHz is less then 3. The gain chart G versus frequencies, illustrated in Figure 7, shows a gain higher then 0dBi in the same frequency range with a maximum gain of 3dBi. Finally, the directive gain is depicted in Figure 8. The antenna has the maximum directive gain of 3dBi at 2.46GHz and $\Phi=81^o$ which is near the OY axis.

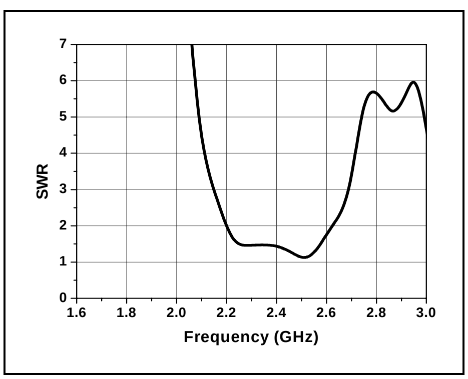

Figure 6: The SWR diagram for a single antenna.

3.2 SWR and G of each antenna in the presence of the other two antennas

For the three antenna system ε_r and h are the same as for the single antenna. There is a w=1mm wide and l=20mm long cut between the TX and RX antennas as previously mentioned. To minimize the mutual coupling, the RX and TX antennas have perpendicular orientation to each other. The SWR versus frequency for each antenna is illustrated in Figure 9 while the gain G is shown in Figure 10. For all the antennas in the system the standing wave ratio SWR<2.5 in the 2.3-2.7 GHz band. The best antenna in the system the RX2 with SWR<1.8 in the entire band and maximum gain of 2.6dBi. It can be seen that the overall gain is higher than -5 dBi for the entire frequency range. The antenna with the best gain is RX2.

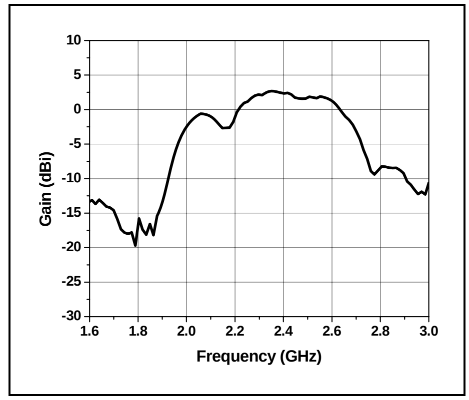

Figure 7: Gain measurement in dBi , $\Phi=90^o$.

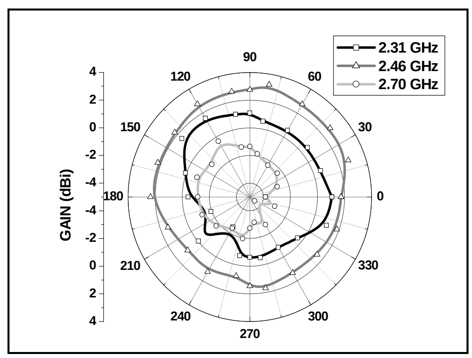

Figure 8: The directive gain diagram, in the electric field plane.

3.3 Mutual coupling measurement

The mutual coupling is directly linked to the isolation of two antennas. Smaller the mutual coupling higher is the isolation between antennas.

We estimated the mutual coupling by using one of the antennas as a transmit antenna and the other two as receive antennas. The isolations between antennas is illustrated in Figure 11. It can be seen an isolation of -17dB to -24dB between TX and RX2, -12dB to -26dB between RX2 and RX1, and -10.5 dB to -15dB between TX and RX1 antennas.

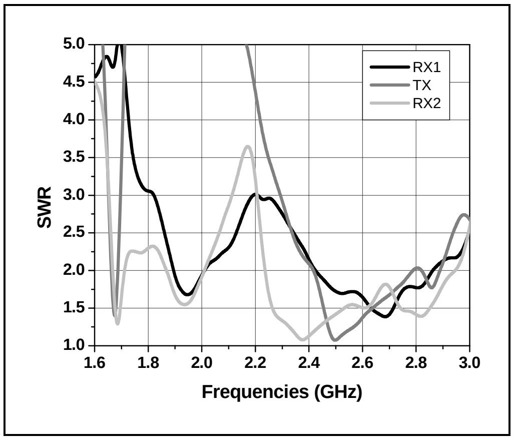

Figure 9: The SWR for each antenna in the system.

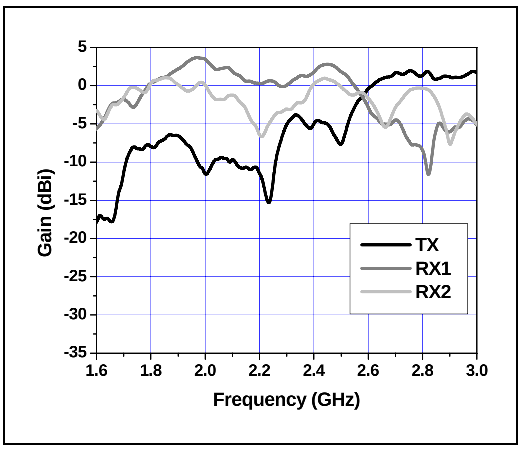

Figure 10: The gain of each antenna in the system.

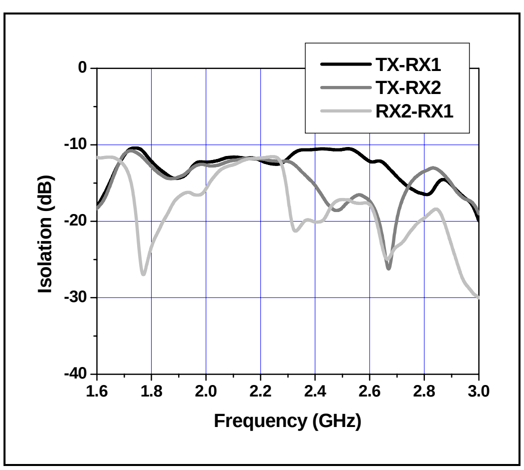

Figure 11: The isolation between antennas as function of frequency.

4. CONCLUSIONS

We presented a multiband antenna system, two RX and one TX antenna capable to cover WIMAX 2.3-2.4 GHz and 2.5-2.7GHz, and WiFi 2.4-2.45 GHz frequency bands. The total area of the antennas of 58x24 mm^2 makes the system suitable for hand-held and PCMCIA devices. We showed that the maximum gain of the antenna system is comparable with the gain of the stand alone antenna. The antenna system is part of the Sandbridge Technologies SDR platform.

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