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Decoupling of TX and RX Antennas in a Full-duplex Mobile Terminal

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***Abstract*—In this paper, a Full-duplex (FD) antenna system is presented with a high isolation between the TX and RX antennas. The isolation method is based on utilizing balanced antennas to localize the current on the ground plane and single mode excitation of the ground plane with capacitive coupling elements. The simulation results show a promising isolation level of 75 dB. User impact investigation on the antenna isolation, antenna matching and efficiency is presented. The isolation level varies from 60 dB to 30 dB in the worst user scenarios. The proposed antenna system can be used in a MISO/SIMO FD system.**

***Index Terms*—Full-duplex, User interaction, Theory of characteristic modes, Antenna Decoupling.**

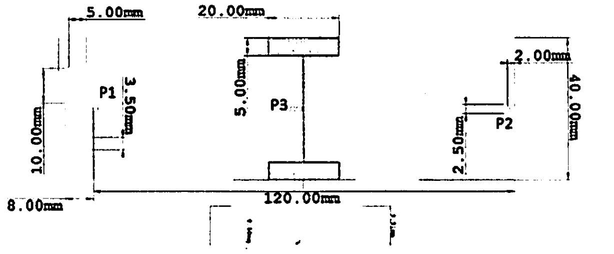

Figure 1: Antenna system and its dimensions (top and side view). The ground plane and the balanced dipoles are printed on a 0.5 mm FR-4 substrate.

1. Introduction

Advanced communication systems aim at maximizing the throughput due to the growing demand from users to access more data. A promising technology where the throughput can be doubled for a given bandwidth is Full-Duplex (FD) which allows a radio terminal to transmit and receive simultaneously on the same frequency. To enable an FD transmission, a high level of decoupling between the TX and RX antennas is required [1]. For small-form-factor devices, designing multiple antennas with high isolation is very challenging, due to the strict limitation on space and size. Current flowing on the ground plane is the main source of coupling between the multiple antennas. Excitation of the orthogonal currents on the ground plane which leads to pattern diversity can be used to achieve antenna isolation [2], [3]. In this paper, we use a combination of balanced antennas with capacitive coupling elements to achieve pattern diversity. We use the Theory of Characteristic Modes (TCM) which first introduced in [4], to find an optimum location for the coupling elements to excite a single mode. Self-resonant balanced antennas are used to localized the current flowing on the ground plane [5]. A three-port antenna system consisting of two balanced dipoles (TX antennas) and coupling elements (RX antennas) is presented. The results of the proposed design show a very high isolation level of 75 dB between the TX and RX antennas in free space. Moreover, the performance of the antenna system under the influence of the user in investigated by conducting simulations of the system in three different user scenarios, i.e. data mode, talk mode and landscape mode.

2. Antenna System

Fig.1 shows the antenna system configuration and its dimensions. Two balanced dipoles are located on the short edges of the chassis. To excite the dipole antennas, two T-slot are introduced in the ground plane. Two capacitive coupling elements are located on the center of the long edge of the chassis, since the full-wavelength current of the chassis has its minimum values at the center of the chassis. A simple T-splitter is used as a feeding network to excite the coupling elements in-phase. In this manner, a selective excitation of the full-wavelength current mode of the chassis can be achieved. On the other hand, the balanced dipole antennas excite the half-wavelength current flowing on the short edge of the chassis. The dipole elements are assigned as TX antennas (port 1 and 2) and the port 3 is assigned to the RX antenna. Fig.1 shows the antenna system configuration and its dimensions. Two balanced dipoles are located on the short edges of the chassis. To excite the dipole antennas, two T-slot are introduced in the ground plane. Two capacitive coupling elements are located on the center of the long edge of the chassis, since the full-wavelength current of the chassis has its minimum values at the center of the chassis. A simple T-splitter is used as a feeding network to excite the coupling elements in-phase. In this manner, a selective excitation of the full-wavelength current mode of the chassis can be achieved. On the other hand, the balanced dipole antennas excite the half-wavelength current flowing on the short edge of the chassis. The dipole elements are assigned as TX antennas (port 1 and 2) and the port 3 is assigned to the RX antenna.

3. Results

The antenna system is simulated using CST Microwave studio. The performance of the antennas is simulated in four scenarios, as follows: free space; talk mode, referred to Head and Hand (HH); data mode, referred to One Hand (OH); landscape mode, referred to Two Hands

Case / Efficiency,dB	Free Space			Head and Hand			One Hand			Two Hands		
	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3	P_1	P_2	P_3
η_{rad}	-3.2	-3.2	-0.7	-3.2	-3.2	-0.7	-3.2	-3.2	-0.7	-3.2	-3.2	-0.7
η_{em}	-0.06	-0.06	-0.99	-0.1	-0.13	-0.38	-0.1	-0.03	-0.2	-0.15	-0.15	-1.04
η_{bl}	0	0	0	-2.6	-3.3	-8.8	-1.3	-0.9	-3.7	-7.2	-7.2	-1.2
η_{tot}	-3.26	-3.26	-1.7	-5.9	-6.63	-9.8	-4.6	-4.13	-4.6	-10.5	-10.5	-2.94

TABLE 1: Measured efficiencies of the antennas at the center frequency (2.37 GHz) for different user scenarios. Port 1 and 2 corresponds to monopole and balanced dipole antennas, respectively.

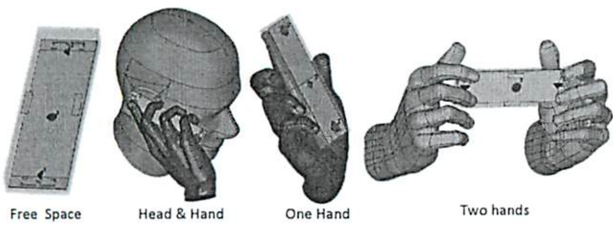

Figure 2: The antenna simulation setup in free space, head and hand, one hand and two hands user scenarios.

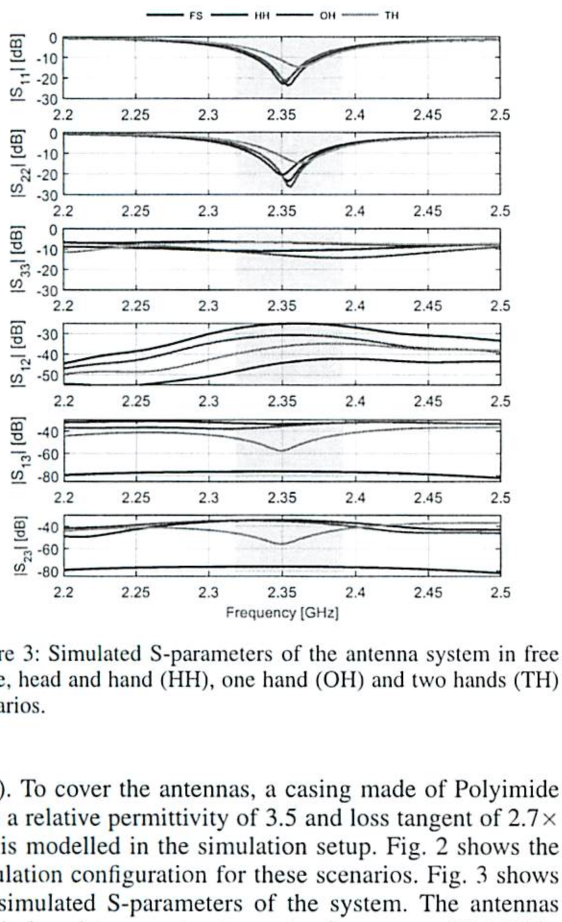

Figure 3: Simulated S-parameters of the antenna system in free space, head and hand (HH), one hand (OH) and two hands (TH) scenarios.

(TH). To cover the antennas, a casing made of Polyimide with a relative permittivity of 3.5 and loss tangent of 2.7×10^3 is modelled in the simulation setup. Fig. 2 shows the simulation configuration for these scenarios. Fig. 3 shows the simulated S-parameters of the system. The antennas are designed to operate at a center frequency of 2.4 GHz. However, the dielectric loading of the antennas with the casing shift the center frequency to 2.35 GHz. The user has more impact on the balanced antennas frequency shift compared to the port 3. This is due to the fact that port 3 has a wider operating bandwidth and it is using the entire chassis for radiation. In free space, the system has a very high isolation value of 75 dB between the TX and RX antennas over the operating bandwidth. However, the user has a high influence on the isolation between the antennas. It can be seen that the isolation varies between 60 dB to 30 dB between the TX and RX antennas. While for TX pairs this variation is between 25 dB to 40 dB. To investigate the body losses, we extracted the efficiency terms from the total efficiency of the antennas. Table. 1 presents the simulated total efficiency η_{tot}, radiation efficiency η_{rad}, embedded miss-match efficiency η_{em} , and body loss efficiency η_{bl} of the three-port system. Where the embedded mismatch efficiency for each port can be calculated from S-parameters ($\eta_{em,i} = 1 - \sum_{j=1}^{3} \mid S_{i,j} \mid^2$).

In the worst scenario (TH), the user's hands absorbed 10.5 dB of the radiated power from the balanced dipole antennas. In this scenario, the dipole elements are covered by the hands. The worst scenario for port 3 is the talk mode where the head and hand absorbs 4 dB and 4.6 dB of the radiated power from port 3. It can be concluded in talk mode and data mode, the user's hand has a higher impact on port 3 performance compared to the balanced antennas.

4. CONCLUSION

In this paper, we presented a three-port antenna system with high isolation between the TX and RX antennas. The isolation method is based on using balanced antennas to localized the current on the ground plane and single mode excitation of the ground plane with coupling elements. The simulated results of the proposed system show a very high isolation between the ports in free space with 75 dB isolation between TX and RX antennas. However, the isolation varies between 30 to 60 dB with the influence of the user. This antenna system can be used in an FD MISO/SIMO system.

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