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Band-Stop Filter Effect of Multiple Slots in Mobile Phone Antennas

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Abstract—A slot placed between the feed and the ground connections of a single shorted microstrip antenna in a two antenna system can produce a band-stop filter effect in one of the frequency bands where both antennas radiate at the same frequency. This band-stop filter effect creates a large group delay at a particular frequency anti-resonance and depends on the slot parameters and the feed/ground placement relative to the second antenna. This paper will show that a second slot can produce an additional band-stop anti-resonance to create two bandstop frequencies. The antenna geometry analyzed is a two planar inverted-F antenna system inside a mobile device where the first antenna with slots has both lower band and high band resonances (quad-band GSM or dual-band LTE) and the second antenna is a wide-band single frequency antenna at LTE/3G/WiMAX.

I. INTRODUCTION

This paper analyzes an antenna modification of two long slots adjacent to the feed location in one of the antennas in a two antenna element system designed for a mobile phone with GSM, 3G, and 4G standards. A similar antenna isolation method was discussed by the author in the IEEE APS 2011 conference [1]. The antenna geometry presented in that conference focused only on the behavior of a single slot for PIFAs where the adjustment of the slot length changed a single band-stop anti-resonance. Others papers [2]-[4] use different techniques to create a single anti-resonance, whereas this paper develops a technique to form two anti-resonances with the addition of a second slot.

A. Methodology & Background

1) Measurements & Simulations: Prototypes were constructed using FR4 PCB, copper tape, and a plastic ABS antenna carrier of dielectric constant $\epsilon_r = 3.0$ The S-parameters were measured after adjusting for the correct phase delay due to the measurement cables using both a Rohde & Schwarz ZVB Vector Network Analyzer and an Agilent E5071C. For the antenna radiation efficiency measurements, the RF cable is routed through the PCB prototype and exits the PCB in an area that causes the least disturbance to the electromagnetic field distribution of the antenna. Port 2 is terminated by a 50 Ohm load when measuring Port 1 and visa versa for the Port 2 measurement. A Satimo Starlab system was used to measure the total antenna radiation efficiency $\eta$. CST Microwave Studio was used to visualize the current distributions for the antennas in order to illustrate the physical behavior of the $S_{21}$ band-stop anti-resonances.

2) Group Delay Calculations: The parallel RLC circuit (created by the slot geometry) forms a band-stop filter with a notch at the $S_{21}$ anti-resonance and is often characterized as having high group delay in that region. The group delay is the negative derivative of the phase response as a function of frequency: $S_{21}' = -\partial S_{21}\angle /\partial f$ where $S_{21}\angle$ is the unwrapped phase response.

In addition to measuring the signal distortion, group delay can be used to characterize the $S_{21}$, or mutual coupling between antennas. Antenna structures with a very sharp $S_{21}$ anti-resonance at particular frequencies (i.e. $S_{21} < -30$ dB) all have a group delay at that frequency that is much greater than for the rest of the signal bandwidth, indicating that part of the antenna geometry acts as a bandstop filter [1]-[4].

B. Antenna Description

This paper considers three sets of antenna geometries with two antennas. Antenna 1 is larger and has dual band operation in the lower (~1 GHz) and upper (~2 GHz) frequency bands while antenna 2 is a wide-band antenna in the 1.8-2.3 GHz band. The first antenna set has no slots in Antenna 1; the second set has a single L-shaped slot in Antenna 1; and the third set has two slots in Antenna 1 (as illustrated in Figure 1). As described in [1], the feed is placed between the the slot in Antenna 1 and Antenna 2 with the ground connection on the opposite side and this slot geometry forms a band-stop filter.

C. Measurement & Simulation Results

1) S-Parameters Measurements: The Antenna 1 low-band S11 resonance remains unchanged for all three antenna geometries at $f_1 = 1$ GHz (Figure 2). The no-slot antenna geometry does not have a resonance in the upper band. When a single slot of length $l_1 = 30$ mm, a second resonance forms at $f_{1S} = 1.9$ GHz. The addition of a second slot of length $l_2 = 35$ mm loads the first slot resonance, decreasing it to $f_{1S} = 1.6$ GHz and forms a second slot resonance at $f_{2S} = 2.0$ GHz. While the first slot has no effect on the $S_{22}$
resonance, the second slot shifts $S_{22}$ from $f_{ant2} = 1.82\,GHz$ to $f_{ant2} = 1.88\,GHz$.

The single-slot antenna forms a $S_{21}$ bandstop anti-resonance at $f_{BSF1} = 1.74\,GHz$ (BSF is band-stop filter). The $f_{BSF1}$ anti-resonance can be controlled by varying the length of the slot. The second slot creates another separate bandstop anti-resonance at $f_{BSF2} = 1.9\,GHz$ while shifting the single-slot anti-resonance from $f_{BSF1} = 1.74\,GHz$ to $f_{BSF1} = 1.52\,GHz$ (Figure 3). As the length of the second slot increases to $l_{S2} = 50\,mm$, the anti-resonances further decrease to $f_{BSF1} = 1.30\,GHz$ and $f_{BSF2} = 1.75\,GHz$.

2) Group Delay Calculations: The group delay for the antenna geometry without slots is below 1 ns for the entire frequency band (0.8 to 2.5 GHz). The single-slot antenna geometry creates a single group delay peak of 6 ns at 1.74 GHz. Two slots form two group delay peaks of 5 ns at 1.52 GHz and 11 ns at 1.9 GHz.

3) Radiation Efficiency Measurements: For all three antenna geometries, the low band radiation efficiency is relatively unchanged at $\eta = 82$ – 88% (Figure 2). In the upper frequency band for Antenna 1, the efficiency for a single slot at 1.9 GHz is 60% and the dual-slot further increases the efficiency to 82% in the same frequency band; whereas Antenna 2 efficiency is only marginally affected by 2%.

4) Electromagnetic Field Simulations: The current distribution at $f = 1.9\,GHz$ on Antenna 1 without slots is relatively uniform (Figure 4). For the single-slot, the uniform current distribution at $f_{BSF1} = 1.74\,GHz$ is interrupted and forms a new resonance within the slot (dependent on the slot length). The second slot in the two slot geometry forms a third antenna resonance with current flowing in phase with the currents in the first slot at $f_{BSF2} = 1.90\,GHz$.

II. CONCLUSIONS

In this paper, multiple slots with a specific feed and ground placement are proposed as a method to reduce isolation at a more than one frequency. The slots create additional slot resonances within the PIFA and can be adjusted to match the same resonance as the adjacent antenna.

REFERENCES


