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Tuning the Band-Stop Filter Effect 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 (PIFA) 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, but have very high isolation. The slot forms a band-stop filter, creating a large group delay at certain frequencies at a particular anti-resonance frequency. This paper analyzes methods to tune the band-stop filter effect by adjusting the slot width and additional ground connections. The antenna geometry analyzed is similar to a two 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 how to tune the matching and mutual coupling properties of a capacitive slot in one of the antennas in a two antenna system designed for a mobile device with GSM, 3G, and 4G standards. A similar antenna isolation method was discussed by the author in [1] and focused only on the behavior of a capacitive slot where the adjustment of the slot length changed a single bandstop anti-resonance across a wide frequency range. This paper presents two techniques to further fine-tune the single slot $S_{21}$ behavior by adding additional capacitance and inductance in the form of slot widening and additional ground connections, similar to techniques used to adjust the $S_{11}$ properties of a microstrip antenna [2], [3].

A. Methodology & Background

1) Measurements & Simulations: Prototypes were constructed using FR4 PCB, copper tape, and a plastic ABS antenna carrier of dielectric constant $\varepsilon_r = 3.0$. The S-parameters were measured after adjusting for the correct phase delay due to the measurement cables using a Rohde & Schwarz ZVB Vector Network Analyzer. 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 slot behavior.

B. Antenna Description

This paper considers a single two antenna geometry with a meandering slot (or capacitive slot) between the feed and the ground (Figure 1). 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. 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 in order to form the band-stop anti-resonance. By changing the slot width, the slot capacitance changes. The addition of another ground connection (labeled G2) changes the slot inductance and antenna matching (Figure 2).

C. Measurement & Simulation Results

1) Slot vs No Slot: Placing a slot between the feed and ground connections in Antenna 1 has multiple effects: 1) changes the matching for the low-band resonance frequency at $f_1 = 980$ MHz; 2) forms a second resonance in the high-band at $f_2 = 1.84$ GHz with a peak radiation efficiency of 56%; and 3) forms a band-stop anti-resonance at $f_{BSF} = 1.88$ GHz with an $S_{21} = -29$ dB (Figure 3-top). The performance of Antenna 2 remains relatively unchanged with the addition of the slot with a resonance of $f_{A2} = 1.9$ GHz and a peak radiation efficiency of 80%.

2) Slot Capacitance: Increasing the slot width from 1mm to 2mm had no effect on the low-band S-parameters and radiation efficiency. In the high-band for Antenna 1, the increase in slot width results in a better match for the slot resonance, increasing from $f_2 = 1.84$ GHz to $f_2 = 2.0$ GHz with a higher peak efficiency of 67%. The $S_{21}$ band-stop anti-resonance shifts from $f_{BSF} = 1.88$ GHz to $f_{BSF} = 1.92$ GHz (Figure 3-middle). As Figure 4 illustrates, the current strength at $f_2 = 1.9$ GHz within the slot have decreased due to the reduced capacitance of the slot where the resonant frequency is inversely proportional to the equivalent slot capacitance: $f = 1/2\pi\sqrt{LC}$. 

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3) Slot Inductance: The addition of a second ground connection (G2) changes the antenna inductance and has a larger effect on the slot band-stop filter behavior than the change in slot width. If G2 is placed on the same side of the slot as the feed (G2 = 30mm), the mutual coupling increases by 10 dB from $S_{21} = -29\, dB$ to $S_{21} = -20\, dB$ (Figure 3-bottom). When G2 is placed on the same side as the first ground connection, both the matching performance and the radiation efficiency improves in the high-band of Antenna 1. For G2 = 10mm, the Antenna 1 slot resonance increases to by 5% to $f = 2.0\, GHz$ with an increase in efficiency of 18% to $\eta = 74\%$. The $S_{21}$ band-stop anti-resonance increases by over 10% to $f_{BSF} = 2.14\, GHz$, but with an increase in mutual coupling of 10 dB.

II. Conclusions

In this paper two techniques for controlling the band-stop filter effect of a capacitive slot are analyzed. By changing the slot width, the slot parameters can be fine-tuned. In order to control the matching of the slot resonances, a second ground placed on the opposite side of the feed connection has the largest effect. Utilizing the capacitive slot’s band-stop filter properties together with techniques to tune its performance characteristics, multiple antennas can be placed closer together inside future mobile handsets.

REFERENCES

