Quarter-Elliptical Antenna with a Complementary Ground Slot for Wideband Applications

Ashkan Boldaji[1], Marek E. Bialkowski[2]

School of ITEE, University of Queensland
St Lucia, QLD 4072, Australia
[1]ashkan@uq.edu.au
[2]meb@itee.uq.edu.au

***Abstract*— This paper presents the design of a novel compact, printed antenna with a 6dB return loss performance exceeding the 800MHz - 6GHz frequency bandwidth. This wideband operation is achieved using a planar quarter-elliptical monopole accompanied by a quarter-elliptical slot in a finite ground plane. Computer simulations show that the proposed radiating structure achieves better than 10dB return loss within the GSM, DCS, PCS, UMTS, GPS, 3.5GHz WiMAX and 5GHz WLAN bands. This performance is confirmed by measurements on the manufactured antenna which also show that the 6dB return loss reference is met between 750MHz and 6GHz. Because of its planar format, the designed antenna is suitable for integration in compact portable wireless devices aiming for multi-band support of modern wireless standards.**

I. Introduction

In recent times there has been a significant trend towards integrating communication systems within portable and fixed consumer devices. While mobile phones have traditionally offered voice services while "on the go", they are now capable of exchanging data and media with a computer via WLAN or Bluetooth. Laptops and modern e-book readers on the other hand are increasingly supporting cellular communications to provide Internet access while away from the home or office. GPS support is also becoming standard, as location data is essential for popular navigation and map-related applications. In addition, some modern broadband modems offer a cellular fallback option when the primary link, such as ADSL, is unavailable.

The common theme in these applications is the need for the radio circuitry of the portable or embedded device to operate in an increased number of frequency bands. The same requirement applies to an antenna which acts as a transducer between the radio transceiver and the signal propagation medium. As there is a trend for smaller and thinner devices for aesthetic and portability reasons, there is a challenge in achieving multi-band support within a small antenna volume.

Modern embedded antennas typically employ designs based on an inverted-F configuration, in the form of three-dimensional or planar structures for multi-band support [1]-[2]. These designs aim to achieve specific resonances for the bands of interest with the use of single or multiple radiating arms. However when significantly wide bandwidth is desired, UWB designs are of special interest. Planar UWB monopoles have been the focus of significant research [3]-[4] in recent years due the allocation of the 3.1-10.6GHz bands for unlicensed use in the U.S. Although attractive due to their wide-band performance, most UWB designs found in literature are not aimed at operation below 3GHz, preventing them from being directly used for cellular communication bands. An indirect use of UWB antenna design methodology was applied by the authors in [5] for the design of a compact elliptical monopole capable of operating between 1.5 and 3.5GHz. This antenna covers the upper bands of GSM/UMTS, GPS, and 2.4GHz WLAN. This paper presents a considerable progression of this earlier design to obtain even wider operational bandwidth. By incorporating a complementary (to the primary radiator) quarter-elliptical ground slot, the new antenna is able to operate from about 800MHz to 6GHz within the 6dB return loss reference. Full design details of this antenna for use with portable wireless transceivers are presented.

II. Configuration

In [5], a quarter-elliptical monopole was placed above a ground plane in a corner placement configuration with side coaxial feed. That configuration is shown in Fig. 1.

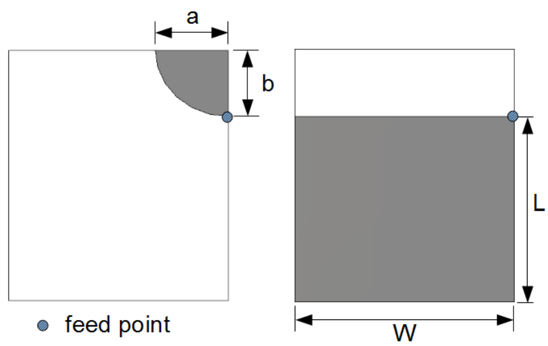

Fig. 1 Original Configuration. Left to Right: Top and Bottom Layers

The resonance at the lowest frequency of 1.5GHz was accomplished by careful adjustment of the ground plane width. However, further lowering the operational frequency using this approach has been unsuccessful. In the new approach which is presented here, instead of relying on the width of the ground plane to lower the operational frequency, an alternative is to promote a different current path within the ground plane. This can be achieved with a suitable use of a ground slot. The newly proposed antenna is shown in Fig. 2.

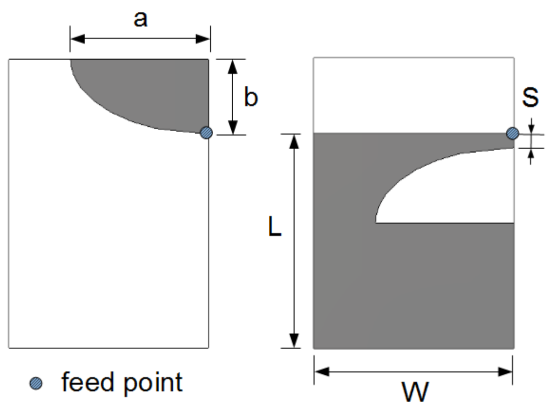

Fig. 2 Proposed Design. Left to Right: Top and Bottom Layers

It consists of a quarter-elliptical element as in [5], but with an additional partially complementary slot in the ground plane. The lack of conductor to the right of the slot prevents the slot from being fully complementary, but this configuration is necessary for side or corner placement in a device. The slot is also slightly offset from the top of the ground plane to provide space for attaching a feed cable.

The configuration in Fig. 2 has the following parameters. The ellipse dimensions are a = 38mm, b = 21mm. The ground width/length are W = 55mm, L = 90mm, and slot offset S = 2mm. The chosen ground size is typical for compact wireless transceivers. A substrate of dielectric constant 3.55 and thickness 0.5mm is assumed in the design. A zero-thickness Perfect Electric Conductor (PEC) is used in simulation.

III. SIMULATION RESULTS

The antenna is modelled and simulated in both Ansoft HFSS and CST Microwave Studio to obtain reliable results. The desired return loss is usually 10dB (VSWR 2:1) in the bands of interest. However a return loss of 6dB (VSWR 3:1) is used in many compact embedded designs where a large number of bands have to be supported [6]-[7]. The simulated return loss result from DC up to 6GHz is shown in Fig. 3.

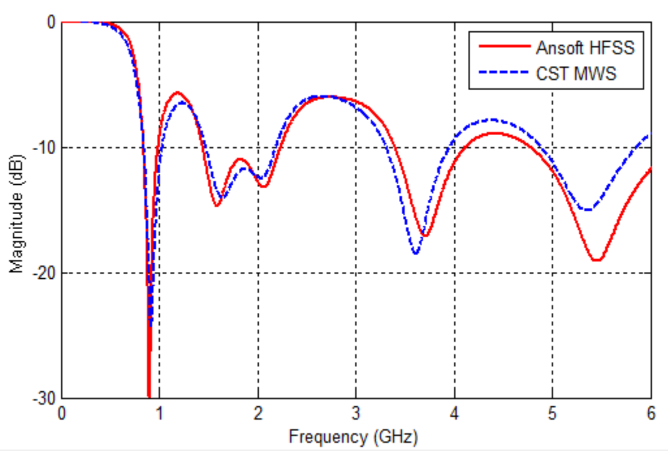

Fig. 3 Simulated Return Loss

Both electromagnetic solvers show a 6dB return loss window starting at 800MHz and maintained through to 6GHz. The 10dB return loss reference is met from roughly 840 to 1000MHz, 1450 to 2200MHz, and most of the 3GHz and 5GHz range where the 3.5GHz WiMAX and 5.2/5.7 WLAN bands reside. A surface current-density plot at a frequency of 900MHz is shown in Fig. 4. It can be seen that a distinct current path is promoted around the quarter-elliptical slot, avoiding the requirement for increasing the ground plane size for a low-frequency operation [8].

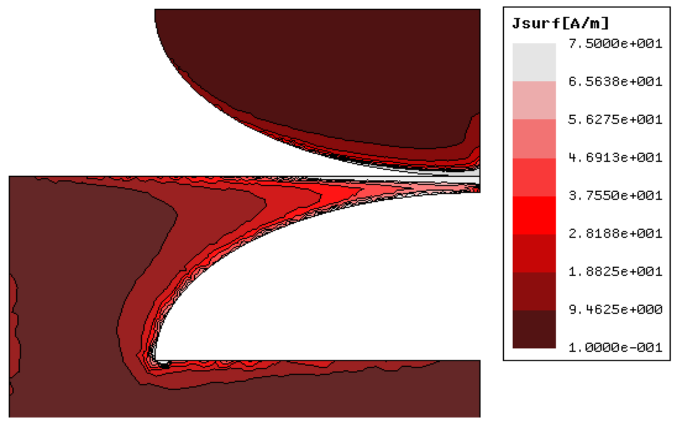

Fig. 4 Simulated Surface Current at 900MHz

By neglecting Specific Absorption Rate (SAR) considerations, a portable device should cooperate with the base station or wireless access point for an arbitrary device's orientation. Hence the antenna should ideally produce an omni-directional or uniform three-dimensional radiation pattern. The radiation pattern of the proposed antenna was simulated in CST Microwave Studio and Ansoft HFSS at frequencies of 900, 1800, 3500 and 5500MHz, with three-dimensional plots shown in Fig. 5.

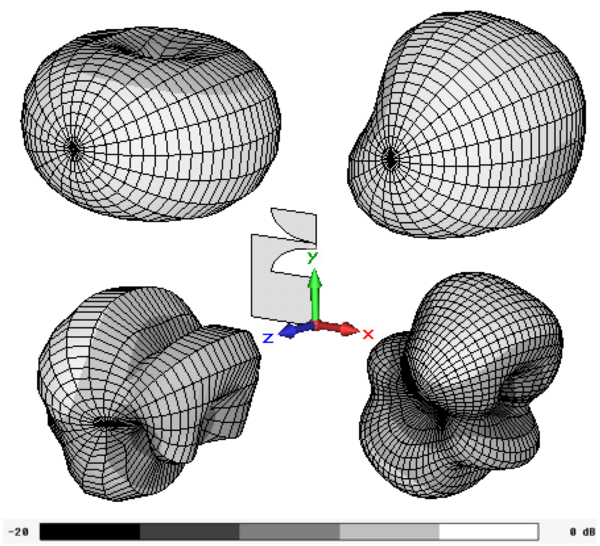

Fig. 5 Simulated 3-D Radiation Patterns (Clockwise from Top-Left: 0.9, 1.8, 3.5, 5.5GHz)

Polar plots of the radiation patterns are presented in Fig. 6, showing the directivity for both co- and cross-polarization in the Z-X plane starting at the z-axis.

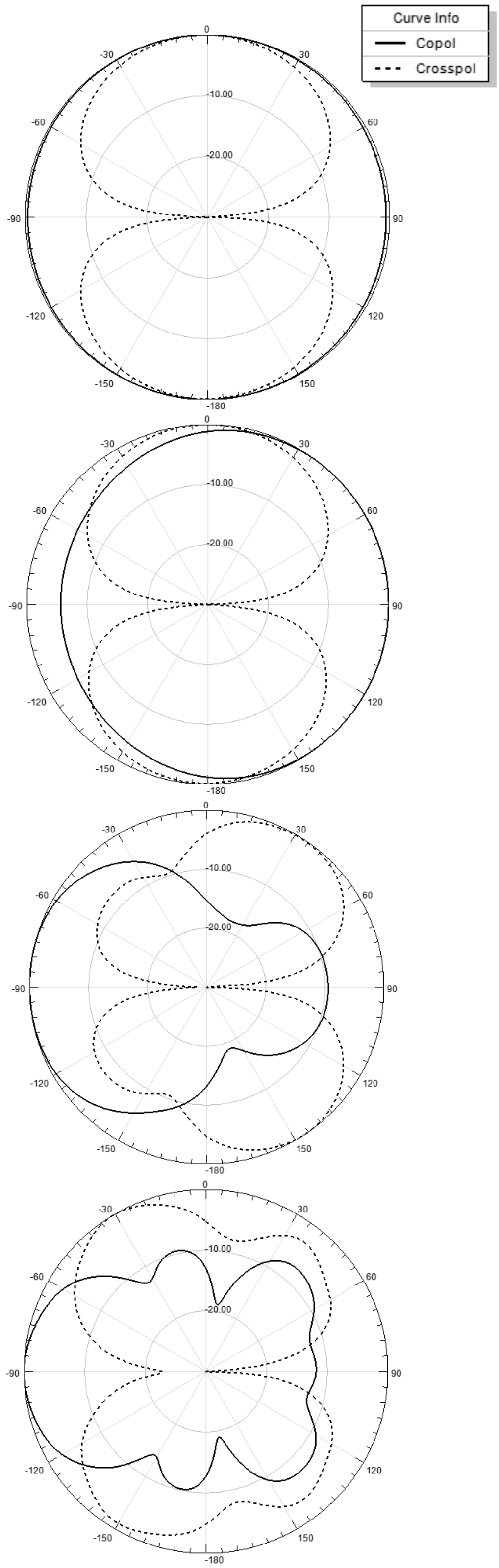

Fig. 6 Simulated 2-D Radiation Patterns (Top to Bottom: 0.9, 1.8, 3.5, 5.5GHz)

The 900 and 1800MHz patterns are found to be more uniform than those at the higher frequencies of 3500 and 5500MHz. This is the expected behaviour of this antenna operating over an increased operational bandwidth.

IV. MEASUREMENT RESULTS

The proposed antenna was fabricated on a Rogers RO4003 laminate with a Hirose miniature coaxial cable soldered directly to the feed point. A photo of the manufactured antenna is shown in Fig. 7.

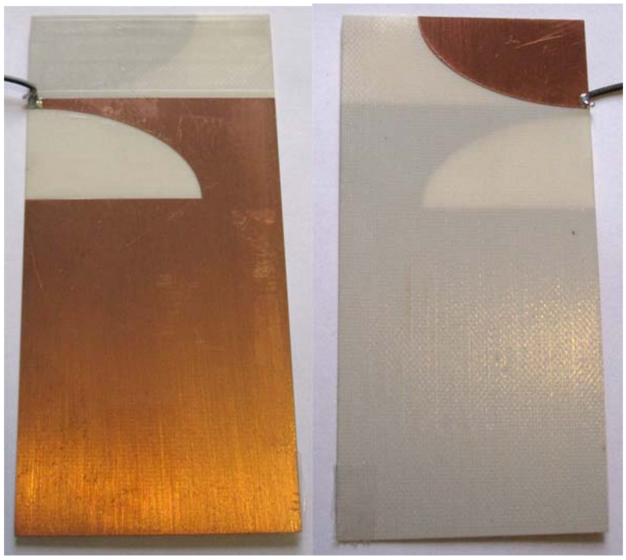

Fig. 7 Manufactured Antenna (Bottom Layer, Top Layer)

The return loss measurements were performed using a vector network analyzer. A comparison of the measured and simulated results is shown in Fig. 8.

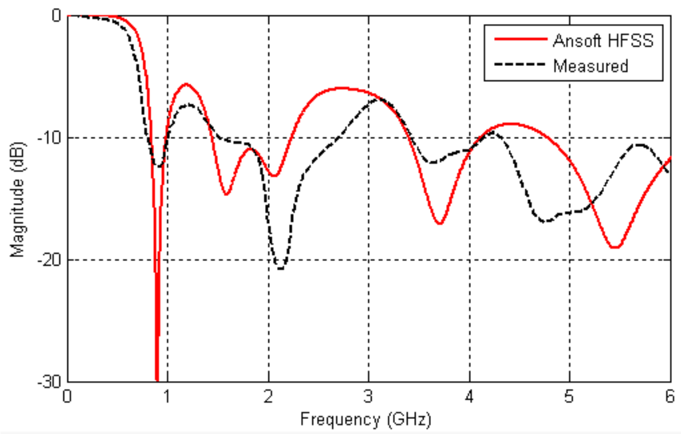

Fig. 8 Return Loss in Measurement and Simulation

Measured results show that the proposed radiating structure achieves better than 10dB return loss within the GSM, DCS, PCS, UMTS, GPS, 3.5GHz WiMAX and 5GHz WLAN bands. A reasonable agreement between the simulations and measurements from the first resonance at about 800MHz up to

6GHz is obtained. Discrepancies can be explained by the fact that in CST and HFSS simulations a line feeding source for the antenna was assumed while during measurements, a cable of 15cm was used. The attempt was made to minimize the cable's impact on return loss and radiation characteristics. This was accomplished by running it close to ground before connecting it to the VNA. However, even this arrangement still faces its limitations, which is the well-known problem in testing small antennas [8]-[9].

The measured results show 6dB return loss starting at a lower frequency of around 750MHz. The manufactured antenna exceeds the simulated 10dB bandwidth in the UMTS bands centered around 2GHz. The return loss in the 3.5 GHz WiMAX and 5.2/5.7GHz WLAN bands also meets the 10dB reference observed in simulations. Hence the wide-band performance of the antenna is confirmed in both simulation and experiment.

V. Conclusions

In this paper, a compact printed wide-band antenna for modern multi-band wireless devices has been presented. A quarter-elliptical design, described earlier by the authors, in conjunction with a partially complementary slot in the ground plane has been adapted to further increase an operational bandwidth, especially with respect to low-frequency bands. Computer simulations have shown the operation of the new antenna from 800 to 6000MHz with respect to a 6dB return loss reference. Additionally, the 10dB return loss reference has been met in the GSM, GPS, DCS, PCS, UMTS, 3.5GHz WiMAX and 5.2/5.7GHz WLAN bands. The antenna has been manufactured and its experimental tests have shown that it is able to cover a 750MHz to 6GHz frequency range with respect to a 6dB return loss reference, while meeting the 10dB reference in the bands predicted by computer simulations. These results show that the presented antenna is suitable for many portable wireless devices meeting the multi-band support for modern wireless standards.

References

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