A Comparison of Solid, Mesh, and Segmented Broad Dipoles in Biological Environments

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***Abstract*—Solid and mesh broad dipole antennas (30 mm half-length at 2 GHz) show similar S_{11} and bandwidth in air, but the current is distributed differently. Further, when the mesh dipole is placed onto a conductive material (pork loin), the current distribution moves from edges toward the center, changing the overall performance of the antenna. Low conductivity, segmented dipoles are also presented showing an increase in resonant frequency from 3.4 GHz to 4.0 GHz as the segment gap increases from 0.1 mm to 0.3 mm. The segmentation also increases the bandwidth from 19% to 25%. The segmented dipole is placed onto conductive pork loin and resonant frequency decreases from 1.7 GHz to 1.1 GHz as the gap decreases from 0.3 mm to 0.1 mm.**

Keywords—Implantable Antennas; Mesh Dipoles, Segmented Dipoles

I. INTRODUCTION

Wireless telemetry for implanted medical devices is necessary to monitor battery level, device health, and patient well-being. These implanted antennas must operate within a lossy environment, severely reducing their efficiency and changing their operating parameters [1]. Recent work has concentrated on making these antennas smaller [2], more robust, and making them from conductive ink [3]. Implantable antennas commonly operate in the low-GHz region at the MICS band (402-406 MHz) or an ISM band (915 MHz, 2.45 GHz). This work considers dipole antennas that operate near the 2.45 GHz region.

Fabricated dipole antennas have slightly different behavior compared to the ideal Hertzian dipole due to each dipole arm having a width and a thickness, which creates additional paths for current. If the dipole antenna is made from a very thin material ($< \lambda_c/10$), but has an arm width of 20-30% of the arm length, such a dipole is referred to as a 'broad dipole'. Broad dipole antennas display more wideband characteristics and have resonant frequency below that of an equivalent Hertzian dipole as predicted by the cylindrical dipole model in [4]. This work examines three types of broad dipole antennas: solid copper, meshed copper, and segmented copper.

II. BROAD DIPOLE

A. Free Space

An ideal dipole with half-length of 30 mm in air is expected to resonate at 2.5 GHz. In free space both the broad solid dipole and broad mesh dipole have a resonant frequency just above 2 GHz. The insets in Fig. 1 show the fabricated broad dipole antennas. Fig. 1 (a) shows the copper tape dipole (0.036 mm thickness) and Fig. 1 (b) shows the copper mesh (0.28 mm thickness). The peak resonance of the copper tape dipole is measured at -38 dB at 2.2 GHz and simulated at -18.2 dB at 2.1 GHz. The peak resonance of the mesh dipole is measured at -32 dB at 2.0 GHz and simulated at -21 dB at 2.0 GHz.

Although the dipoles have nearly the same resonant frequency, the current distribution is different as seen in Fig. 2. Fig. 2 (a) shows the current peaking along the center axis of the copper tape dipole, while in Fig. 2 (b) the current peaks along the copper mesh edges.

B. Biological Environment

When the copper mesh dipole is placed directly onto pork loin the simulated resonant frequency drops to 0.68 GHz. The pork loin is much more conductive than free space (σ = 0.82 S/m) and acts to short the current and provide new current paths. The current distribution is changed so that it is concentrated closer to the feed point and away from upper and lower edges. This current distribution is shown in Fig. 2 (c).

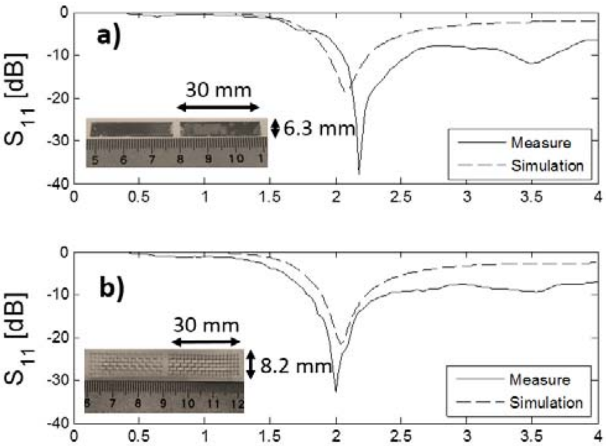

Fig. 1 S_{11} of the (a) broad dipole (made from 1oz. Copper tape) and (b) the broad mesh dipole (made from 0.28 mm wire, 1.68 mm^2 square openings) in free space. The inset for each plot shows the antenna geometry.

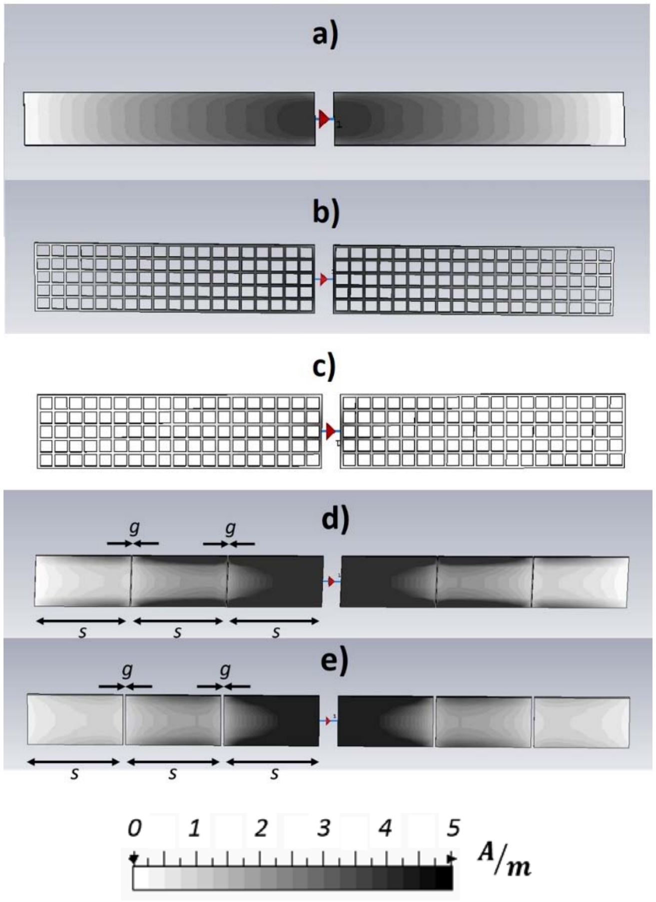

Fig. 2 Current distribution of the broad dipole antennas. (a) The current distribution of the copper dipole in free space. (b) The current distribution of the copper mesh dipole in free space. (c) The current distribution of the copper mesh dipole on pork loin. (d) The current distribution of the segmented dipole with gap, *g* = 0.1 mm, and segment length, *s* = 10.33 mm. (e) The current distribution of the segmented dipole with gap, *g* = 0.3 mm, and segment length *s* = 10.2 mm

III. SEGMENTED DIPOLE

A. Free Space

Segmented dipole antennas are low conductivity dipole antennas in which dipole arms are divided into smaller sections with uniform gaps between each section. The segmented dipole offers a simple approach to understanding low conductivity antennas and in a biomedical application the segmentation may also provide additional benefits, such as enhanced patient comfort.

Two segmented dipoles in free space with different gap sizes (0.3 mm and 0.1 mm) are simulated in CST, as shown in Fig. 2 (d) and (e). The gap sizes represent a very small fraction ($<\lambda_c/100$) of the wavelength at the center frequency. The S_{11} of the segmented dipoles are compared to the S_{11} of a broad dipole with half-length equal to $3s+2g$ as in Fig. *2*. The solid dipole, 0.1 mm gap, and 0.3 mm gap segmented dipoles have simulated resonant frequencies of 2 GHz, 3.35 GHz, and 4 GHz, respectively, with 10 dB bandwidths of 16%, 19%, and 25%. Increasing the segment gap increases both resonant frequency and bandwidth. When the segmented dipoles are compared to a solid dipole with half-length equal to a single segment (10.2 mm and 10.3 mm) it is seen that the solid dipole resonates at 4.8 GHz, much higher than either segmented dipole. Thus, it appears that the segments are coupled, which is confirmed by the current distributions in Fig. 2 (d) and (e).

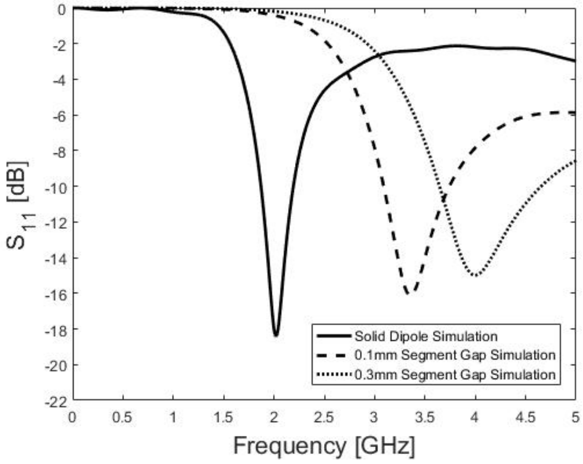

Fig. 3 S_{11} comparison of solid and segmented dipoles

B. Biological Environment

When compared with segmented dipoles in free space, identical models simulated on pork have a wider bandwidth and lower resonant frequencies of 1.74 GHz for a 0.3 mm gap and 1.13 GHz for a 0.1 mm gap. As the segment gap size decreases the resonant frequency decreases and the bandwidth increases. In free space, current concentrates on the upper and lower edges of each segment while on the pork loin the current concentrates at the feed and away from the upper and lower edges of each segment.

IV. CONCLUSION

Broad dipoles made from solid or mesh conductive materials demonstrate similar S_{11} properties, but different current distribution. When the mesh dipole is placed in a biological environment the current distribution adjusts accordingly. Segmented dipoles act as low conductivity antennas. In free space the bandwidth and frequency increases as segment gap increases. When the segmented dipole is placed in a biological environment the current distribution also changes and resonant frequency decreases as the segment gap decreases.

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