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Integrated Antenna-Battery for Low-profile Short Range Communications

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Abstract—An integrated antenna-battery was designed in order to function at 2.45GHz, with short range Bluetooth applications considered. The model was derived from a previous study in which an integrated system was first explored. The $\tan \delta$ was investigated for the substrate and this new structure was found to give favourable gains and efficiencies compared to the previous study. Experimental parameters were also applied to the model in the presence of a dielectric material. These experimental parameters gave improved results over the initial assumptions.

Index Terms—antenna, low-profile, battery, short range.

I. INTRODUCTION

With the advent of new proximity location systems operating with Bluetooth links to smart phones, for instance the ‘Tile’ tag [1], there is interest in creating extreme low-profile and integrated antenna/battery components for use at 2.45GHz. The battery and antenna are typically the bulkiest components in a transceiver system and it is therefore of interest to combine them and ideally use novel digital fabrication technologies to realize them using low profile conducting polymer films.

A standard lithium ion battery is comprised of two electrodes, an anode and cathode. Lithium ions will be transported between the two via an electrolyte solution [2]. Metallic current collectors present either side of the two electrodes allow for connection to an external circuit.

A requirement for the new low-profile integrated battery is that it be non-metallic. This means that the battery cannot have the metallic hermetic seal that is standard, and thus the metallic current collectors must be replaced with another highly conductive material, with conducting polymers being the main consideration. Conducting polymers are already in use in batteries and have shown promising results thus far [3]. One polymer of keen interest in electronics is PEDOT:PSS, a copolymer which has demonstrated conductivities of over 3000 S/cm in some cases upon treatment with sulphuric acid [4]. With conductivity values just a few orders below those of bulk metals such as copper, polymer electrolytes such as PEDOT:PSS are a viable alternative as current collectors in a non-metallic battery.

II. INTEGRATED BATTERY-ANTENNA STRUCTURE

Our antenna design is a symmetric slot antenna cut into a conducting film, with an electrolyte substrate underneath, followed by a second conducting layer, also with slots present. The conducting films are used to represent the anode and cathode of a solid state battery. Furthermore, they will also act as the battery terminals, providing the electrical conductivity needed for the battery to function.

Fig. 1 shows the integrated battery/antenna design proposed.

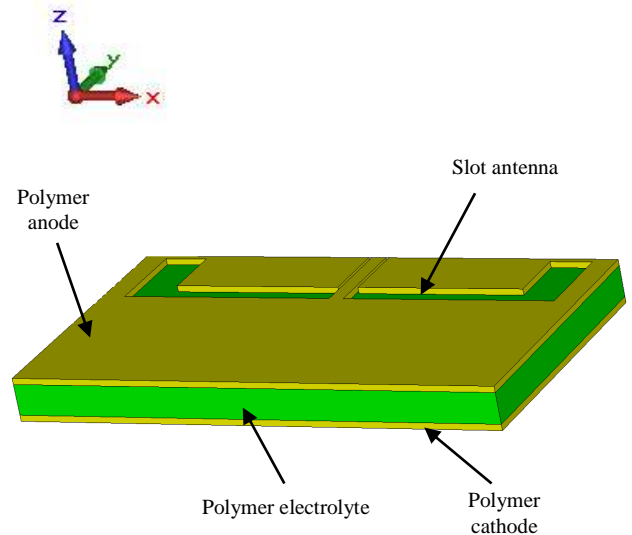
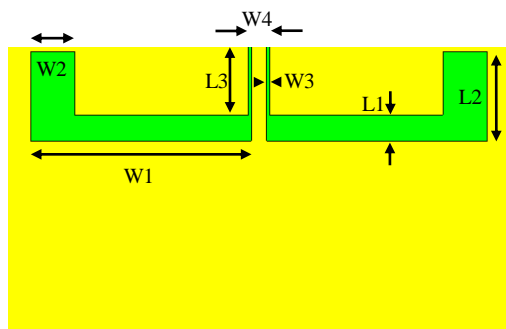
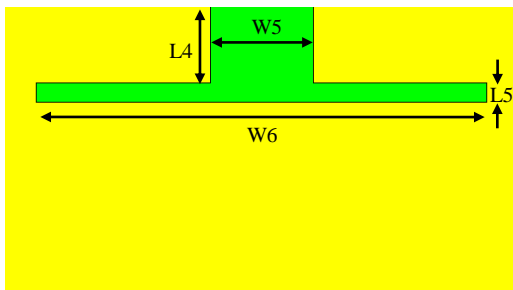


Fig. 1: Integrated battery/antenna design for Bluetooth application.

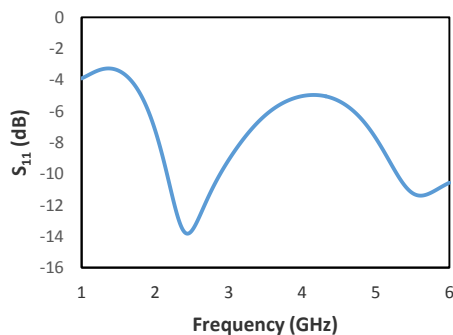
The CST (Computer Simulation Technology) Microwave Studio package transient solver was used to perform the required simulations for this investigation. The slot dipole antenna consisted of two symmetric slots cut into an upper conducting plane. The antenna structure is derived from that of [5], and is based on Nithisopa’s CPW-fed slot dipole [6], and redesigned for the 2.45GHz band. The substrate was of a thickness of 0.3mm, with a relative permittivity (ϵ_r) of 3.



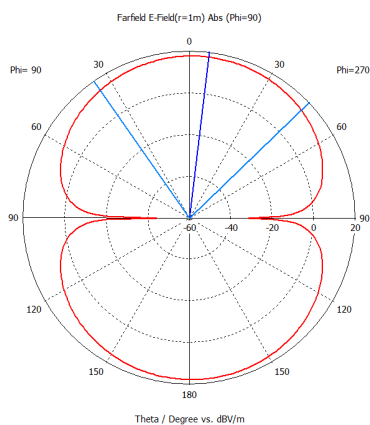
(a)



(b)



(c)



(d)

Fig. 2: (a) Dimensions for slot antenna, top plane (b) and bottom plane, (c) Simulated S_{11} and (d) Simulated far-field at 2.45GHz.

Both the upper and lower ground planes had a thickness of 0.018mm. The dipole slots in this particular structure were symmetrical, with a width and length (W_1) and (L_1), of 35mm and 4.1mm respectively. The end caps, or folded sections, on each slot were each of length (L_2) and width (W_2), 14.1mm and 7mm. The width of the feed slots (W_3) was 0.5mm, with the gap between the two (W_4) being 2.4mm. The CPW feed line for the antenna consisted of a length (L_3) of 11mm. Slots were also present on the bottom ground plane with the slot beneath the co-planar wave guide feed of a length (L_4) of 12mm and width (W_5) of 16mm. The slot beneath the dipole was of a length (L_5) 3mm and width (W_6) 70mm.

The antenna itself had an overall width of 80 mm with an overall length of 45mm. The substrate was initially simulated with a low-loss $\tan \delta$ value of 0.0009. A conductivity value of 1000 S/m was applied to the two conducting planes as might be expected for a good conducting polymer electrolyte. Figure 2 (a) and (b) show the upper and lower plane views of the structure along with the associated length and width parameters, followed by (c), the simulated S_{11} results, and (d) the associated far-field results at 2.45GHz.

From the S_{11} results, we can see that the structure is noticeably lossy with an out of band loss of about 4dB. However, with our low range application in mind, this is not a concern. The -10dB fractional bandwidth was calculated to be about 28% and the antenna simulated total efficiency was -2.3dB with a gain of 2.8dB. This can be compared to that of [5] where efficiencies of about -2.2dB and gains of about 3.3dB at 2.6GHz were obtained.

The loss tangent of the substrate was then altered from 0.0009 to 0.9, as might be anticipated for a battery electrolyte. Here, we observed a reduction in gain to 0.3dB and a reduction in efficiency to -4.8dB. Once again, comparing this to [5] where an efficiency of -7.3dB at 2.6GHz was simulated for a loss tangent of 0.9, a noticeable improvement was achieved. Table I shows a summary of the results obtained from the initial structure of Fig. 2 compared with the results obtained from the previous study [5].

This low profile slotted design is affected by dielectric loading when mounted on structures and a simulated investigation was carried out to ascertain how the antenna match and efficiency were altered when the antenna-battery was placed on a dielectric block of relative permittivity 2.3 and $\tan \delta$ 0.09.

The antenna bandwidth and efficiency underwent a change upon dielectric loading and a few adjustments were made to the antenna in order to allow it to function again at 2.45GHz. The width of the antenna was reduced from 80mm to 75mm, while the width of the slots (W_6) beneath the dipole were reduced from 70mm to 55mm. The substrate material parameters were kept constant with the $\tan \delta$ at 0.9. When mounted onto the dielectric with the altered dimensions, a bandwidth of 55% was observed, with an efficiency of -6.3dB and a gain of -1.7dB. This still gives a slight improvement in gain and efficiencies compared to the results of [5] in which the structure was not mounted onto any dielectric material.

TABLE I
EFFECT OF LOSS TANGENT OF SUBSTRATE UPON
BANDWIDTH, GAIN AND EFFICIENCY

Tan δ	Fractional Bandwidth (%)	Gain (dB) (Fig.2)	Efficiency (dB) (Fig.2)	Gain (dB) [5]	Efficiency (dB) [5]
0.0009	28	2.8	-2.3	3.3	-2.2
0.9	44	0.3	-4.8	-1.8	-7.3

III. SAMPLE MEASUREMENT

It was desirable to create a sample of material as would be used in the polymer battery to form an electrode. A pellet of PEDOT:PSS, a highly conductive polymer electrolyte, was synthesized for this purpose. Aliquots (~30ml) of conductive grade PEDOT-PSS (3% weight dispersion in water) were pipetted into five separate sample dishes. The samples were dried for 48 hours at 55°C under atmospheric pressure. The precipitate was collected from each sample and processed within a ball-mill (800rpm, 40mins). A fine powdered sample was produced and subsequently pressed into a pellet by use of a 25mm pellet-press. The dimensions of the pellet were a width of 25mm and a thickness of 3mm.

The permittivity of the PEDOT:PSS sample was measured by placing a Coplanar Waveguide (CPW) track on top of the material. This was achieved by etching a 24 mm long CPW line onto a Mylar (polyester) sheet which was then placed directly on top of the sample. The gap between the signal and ground lines was set to 1.5 mm to ensure good penetration of the field into the material at the frequency range of measurement. An Anritsu 37397C network analyser with on-wafer calibration was used to measure the S-parameters up to 20GHz. The line proved to be well matched to 50 Ω allowing the phase constant and effective permittivity of the line to be calculated directly from the S_{21} measurement. Using the approximation that the effective permittivity of a CPW is the average of the air and dielectric region allowed a figure of $\epsilon_r = 4.3$ and $\tan \delta = 0.13$ for the relative permittivity and loss tangent to be obtained.

These measured material values were applied to the battery/antenna substrate and simulated. The underlying dielectric material was still present and remained unchanged. The permittivity of the antenna substrate was increased from 3 to 4.3, while the $\tan \delta$ value of 0.9 was reduced to 0.13. The main observations were a slight reduction in bandwidth, which is to be expected when decreasing the loss tangent. More importantly, an improvement in efficiency with a value of -4.63dB was observed, with an increase in gain to 0.02dB. Table II gives a summary of the comparison of simulation results for the antenna mounted onto the dielectric block with

both the initial assumptions and the results obtained from the experimental data.

TABLE II
COMPARISON OF INITIAL ASSUMPTIONS FOR ANTENNA
WITH PARAMETERS OBTAINED FROM EXPERIMENT IN THE
PRESENCE OF DIELECTRIC MATERIAL

Permittivity (ϵ_r)	Tan δ	Bandwidth (%)	Gain (dB)	Efficiency (dB)
3	0.9	55	-1.7	-6.3
4.3	0.13	44	0.02	-4.6

IV. CONCLUSION

The feasibility of producing extremely low profile composite polymer-battery antenna devices for active short range systems such as blue tooth has been indicated by simulation. Material measurements of a candidate polymer sample indicate that losses may not be prohibitively high, though further studies using appropriately treated polymer samples will be required before validation with antenna structures. This technology is proposed for use in short range location finding and security applications where very low profile or covert tags may be beneficial.

IV. ACKNOWLEDGMENT

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