A Compact VHF Antenna for Smart Meters

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Abstract— Energy companies have demanded two way communications between the consumer energy meter and the company to ease data collection and enable variable energy tariffs. There are serval bands in use from GSM to ISM bands working at 900, 315, 434 and 868 MHz. In hilly terrains and meters located in basements these frequencies do not propagate well in these bands, however frequencies below 200 MHz are much better. This work describes a narrow band antenna derived from a perturbed microstrip patch working at 169 MHz. Its largest dimension is only 0.07λ at resonant frequency with a $ka = 0.18$. A gain of -1.2 dBi and an SII of -2 dB was achieved. The antenna was designed to fit directly to the smart meter so its radiation pattern was optimised to radiate broadside. It incorporates a novel matching element to allow ease of manufacture. From near field studies it can be described as parasitic resonator excited by a single driven electrode matching 50 ohms. The main method of tuning was by altering the separation of the top fin structures. The antenna was finally tuned to the required resonant frequency when enclosed in an polycarbonate plastic housing.

1. INTRODUCTION

Wireless mBus N-mode was introduced to read residential gas and water meters in Italy and France. The ISM band at 169 MHz with a bandwidth of 75kHz provides cost effective coverage in gathering data from in-building consumption meters minimising path losses caused by building material and partially buried meters [1, 2]. The free space wavelength, of 1775 m makes conventional antennas too large to mount conveniently near the consumer unit. The conventional approach to reducing the antenna size is either by collapsing a whip to a helix or an inverted F both of which require large ground planes to function efficiently. In this work the antenna was required to fit to a consumption meter of overall size of 234 × 158 × 80 mm with a footprint of no bigger than 100 mm × 50 mm.

Taking a conventional patch antenna with an air dielectric Moon in [3] perturbed the top structure and folded the top plates to produce an antenna of size ka of 0.3 at 40 MHz where k is the wavenumber and a the radius of a minimum sphere enclosing the antenna. Its bandwidth was only was only 1.9% and demonstrated a gain of 0.23 dBi. This approach has a number of advantages: it has high gain relative to its size whilst maintaining an omnidirectional pattern; the antenna does not require a ground plane and lastly the construction allows rapid and economic manufacture.

2. DESIGN

Moon's design was developed from a $\lambda/4$ microstrip structure working at 40 MHz. First the structure was perturbed which enabled the top and bottom plates of the patch to be folded reducing the size by a third. Next the structure was reduced further by adding plate loading to increase the

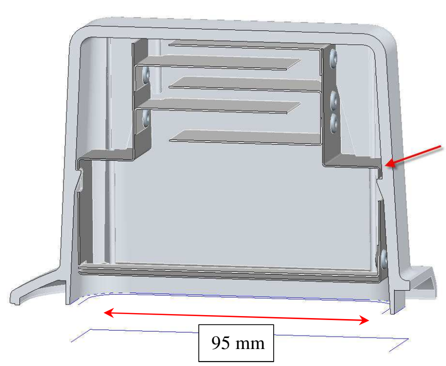

Figure 1: Antenna section within smart meter housing. Arrow indicates method of attachment.

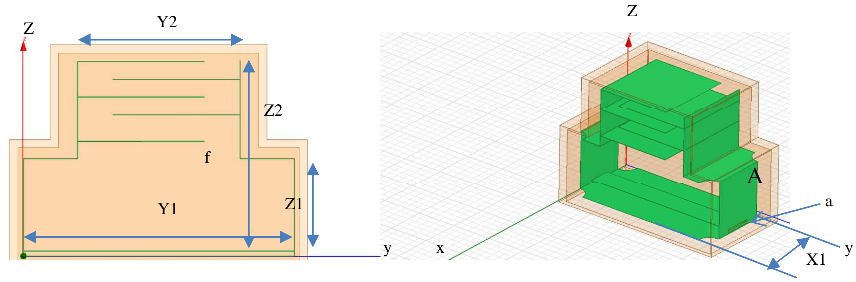

Figure 2: Antenna structure, the fawn coloured boundary surrounding the antenna represents the plastic housing. On the right the feed aperture, a, is on face A.

current path to maintain the operating frequency. A similar technique was employed in developing this design. At 169 MHz the dimensions were: $Y1 = 129$ mm, $Y2 = 60$ mm $X1 = 70$ mm and $Z2 = 72$ mm, Figure 2. This was however was still too large to fit within the required volume.

Whilst maintaining the current path the design was further reduced to $Y1 = 95$ mm, $X1 = 45$ mm whilst keeping $Z2$ to 72 mm and $Y2$ to 60 mm to allow the antenna to fit within the specified housing. The antenna was modeled using HFSS [9] and simulations had shown that reducing $X1$ had a small effect on resonant frequency. This, however, resulted in a resonance 10 MHz above 169 MHz. An additional fin, f, (Figure 2) was added and it's position below the bottom fin of the initial design allowed the structure to the tuned to 169 MHz. The original feed electrode was a circular rod 5.5 mm in diameter fed from an aperture a in z-x plane on face A and terminated on the opposite face. To achieve a match of 50 ohms constrained the height above the base plate to only a few mm so to aid manufacture the electrode was developed to a flat plate of similar surface area, i.e., a width of 15 mm. Fin and electrode attachment had to be low impedance at the working frequency. The first structure was constructed from 0.5 mm copper sheet with fins soldered to the outer structure. Fast and cheap manufacture was the essence of this design and comparison by simulation between a copper structure with soldered fins and aluminium structure with fins and electrode riveted to the vertical walls showed little change in antenna performance in terms of gain and efficiency. So the final design was made from 0.5 mm thick aluminium sheet in which the fins were attached by pop rivets as in Figure 1. The rigidity of the antenna was compromised by the thinness of the aluminium so the structure was supported by a plastic clip on one face, but, small enough not to effect the antenna performance.

3. ANTENNA TUNING AND MATCHING

The 'hot' feed point position, F1, Figure 3, simulated as a lumped port, was varied horizontally from the aperture to the opposite face, from 0 (referenced at A) to 90 mm and the 'cold' connection, G1, from 2–20 mm in the vertical direction and the best match was found to be with $F1 = 2$ mm from face A and G1 at 2 mm. The antenna input impedance is shown in Figure 4. A good match of real 48 ohms was achieved.

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Without altering the feed position, fine tuning of the antenna was achieved by varying the fin size

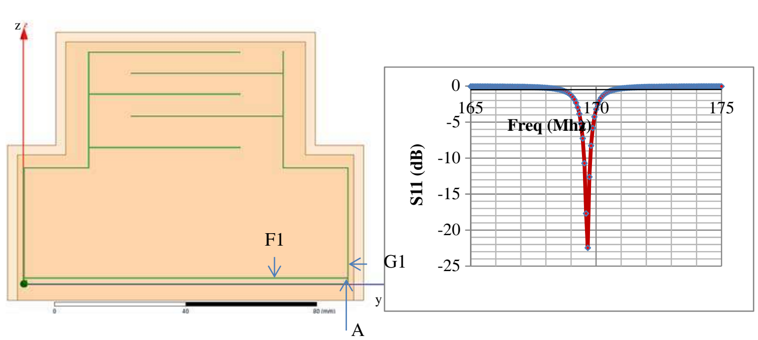

Figure 3: Left feeding points F1 and G1 with A as the reference point, right the return loss at 169.6 MHz of −22 dB at optimum feeding position.

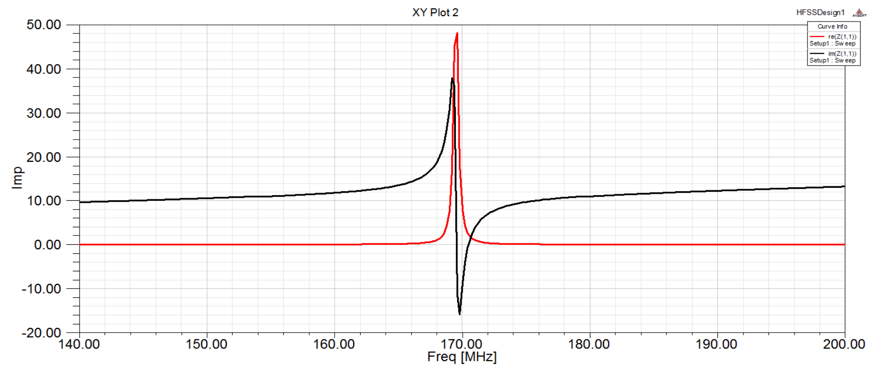

Figure 4: Antenna input impedance, the red line is real and black imaginary impedance.

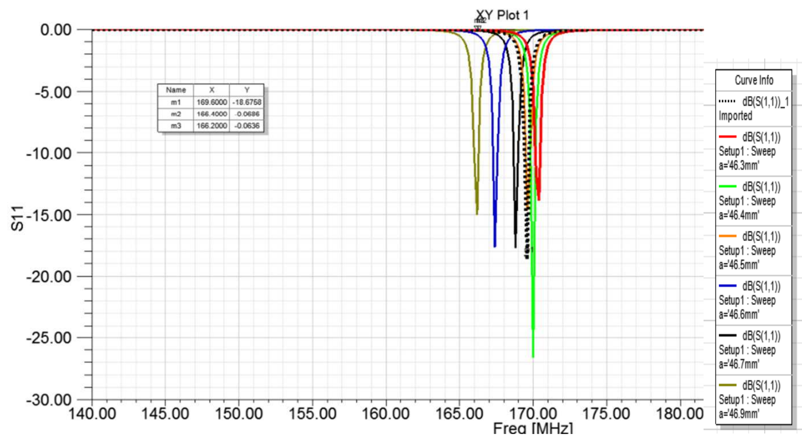

Figure 5: Return loss for fin lengths from 46.3–46.9 mm, dotted, brown = 46.5, red = 46.3, green 46.4, blue 46.6, black = 46.7, beige = 46.9.

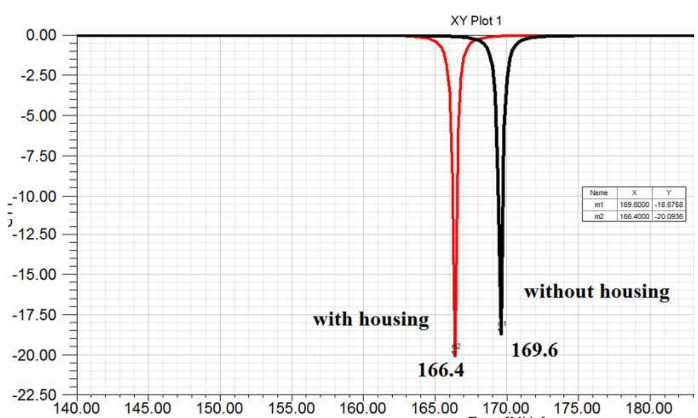

Figure 6: With and without plastic housing.

in y direction, Figure 5. At 169.6 MHz return loss of -18 dBi occurred with fin length = 46.9 mm.

In the final deployment the antenna would be enclosed in a plastic housing. Being a dielectric this would inevitably reduce the operating frequency. A reduction in frequency of 3.2 MHz was found, Figure 5, with a housing, 3 mm thick and a relative dielectric constant of 2.8, mimicking that seen with a housing made of polycarbonate.

The maximum gain simulated was -1.2 dBi omnidirectional in the y-z plane, Figure 7.

4. MEASUREMENTS

The return loss of the antenna constructed in sheet aluminium was measured in an open area with Agilent Network Analyser 8510 with and without hood attached to the gas meter.

For an independent assessment of the efficiency and radiation pattern, the antenna was measured

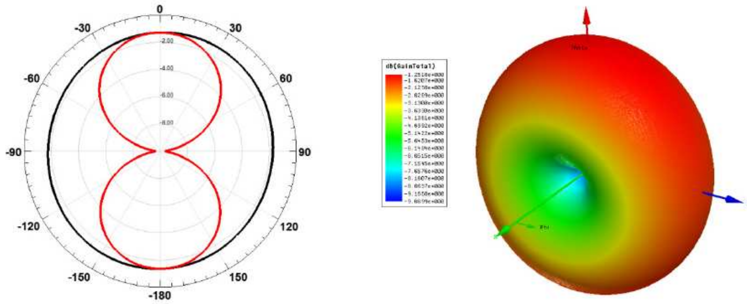

Figure 7: Gain of simulated antenna, on the left red is y-z plane, black is x-z plane, peak gain was -1.2 dBi. On the right 3D spatial gain distribution, RGB scale red $= -1.2$ dBi, blue $= -9.5$ dBi, upper is Z, to the right is Y and isometrically towards the reader on the left is X.

in an anechoic chamber by ProAnt [5]. Differences were found when the meter was attached to copper pipes, improvements in gain and efficiency were found with copper pipes the implying the antenna on its own was deficient in a ground plane.

The measured gain was lower by 0.8 dBi and the efficiency lower, 52%, than predicted, 70%, resulting from the device under test being off tune by about 3 MHz due to the devices supplied being slightly undersize.

The radiation patterns in Figure 11 demonstrate the omnidirectional pattern predicted in the YZ plane in Figure 7, and to a lesser extent the dumb bell shape in the XZ plane. The gain is lower than predicted because the antenna resonance was above 169 MHz. The tilting of the E-plane was probably caused by asymmetric ground plane resulting from the position of the antenna on the gas meter.

5. DISCUSSION

E and H field plots in Figure 12 demonstrate where the fields are positioned at maximum intensity. This can be interpreted as parallel resonant device where the top fin structures representing the capacitance and the lower part, the inductance. Erentok and Ziolkowski [7, 8] in their series of papers on metamaterial inspired antenna developed VHF and UHF antennas from resonant structures

Figure 8: Left bare antenna supported by plastic clip of the left, centre antenna mounted in hood, right antenna housed in assembled gas meter.

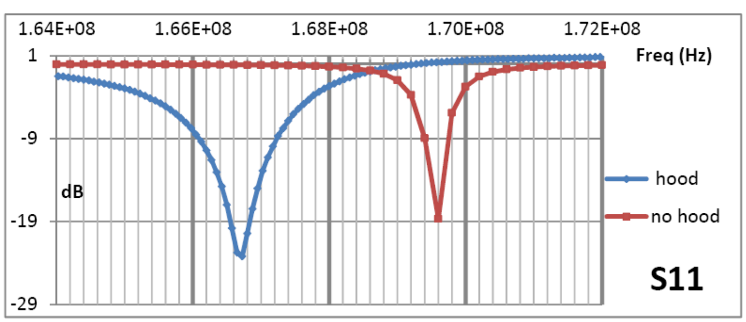

Figure 9: Return loss with and without polycarbonate shroud.

excited by a nearby electrode. However to achieve good gain and efficiency they had to use a large ground plane, comparable in size to $\lambda/4$. In this work the bottom electrode is used to excite the resonant structure in the same way, but the base plate forms the ground plane of only 94×45 mm.

Harrington [4] suggested that the efficiency of antenna is limited by its Q. But as the physical size is decreased, and loaded by capacitance or inductance to maintain a fixed frequency, the Q has to rise to maintain gain and efficiency, The Q however, is limited in practise by the conduction losses in the antenna and the coupling efficiency between the source and the antenna. The Q in this design was 211 unshrouded and 68 shrouded, the latter result from losses in the polycarbonate housing.

The minimum fractional bandwidth (FBW) required of this antenna was $\sim 0.04\%$ whereas the measured FBW was 0.5% with the antenna housing. The FBW predicted by simulation was 0.48. The return loss deepened with the antenna housing shown both by simulation, Figure 6, and measurement, Figure 9. This is to be expected because the antenna shroud is within the radian sphere increasing the energy in the electric field, deepening the return loss but losses in the plastic decrease Q broadening the bandwidth. The Q broadening however is to advantage in

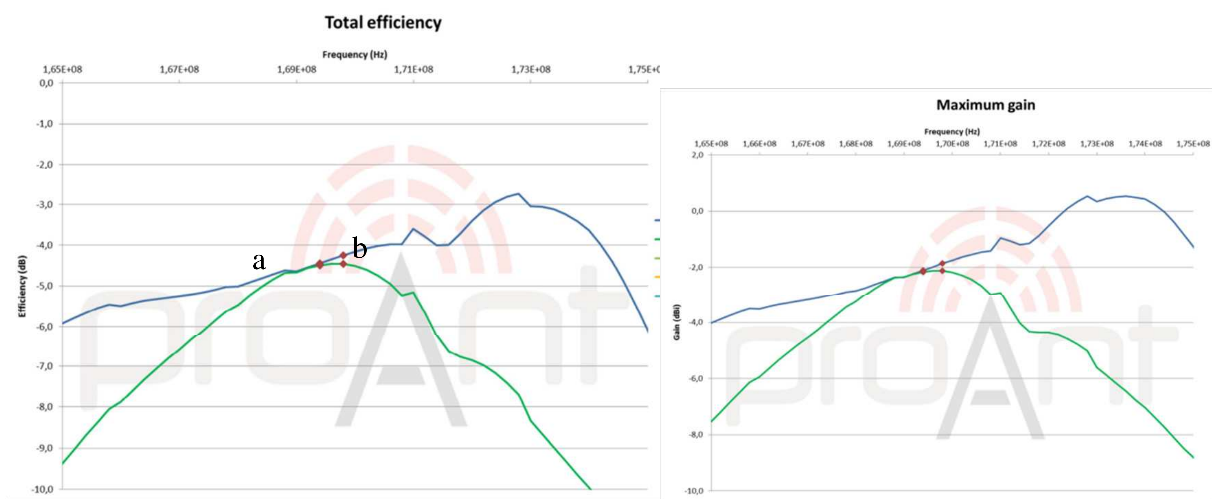

Figure 10: Left antenna efficiency, 0 dB = 100%, peak −2.5 dB (52%) at 173 MHz. Blue curves are this design the green curves are an inverted F antenna for comparison. The right figure is gain plot where maximum gain out of band at 173 MHz is better that 0 dBi Markers $a = 169.4$ MHz, marker $b = 169.8$ MHz.

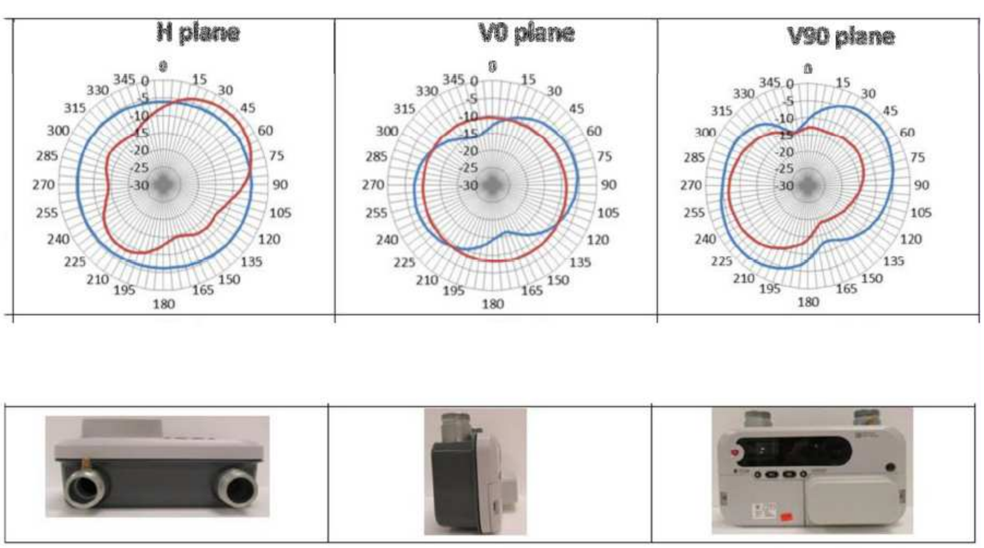

Figure 11: Top three radiation plots at 169 MHz, left H plane centre E plane 0 and right E-plane 90 degrees. The bottom three images indicate orientation of gas meter, blue curve was vertical plane, red was horizontal.

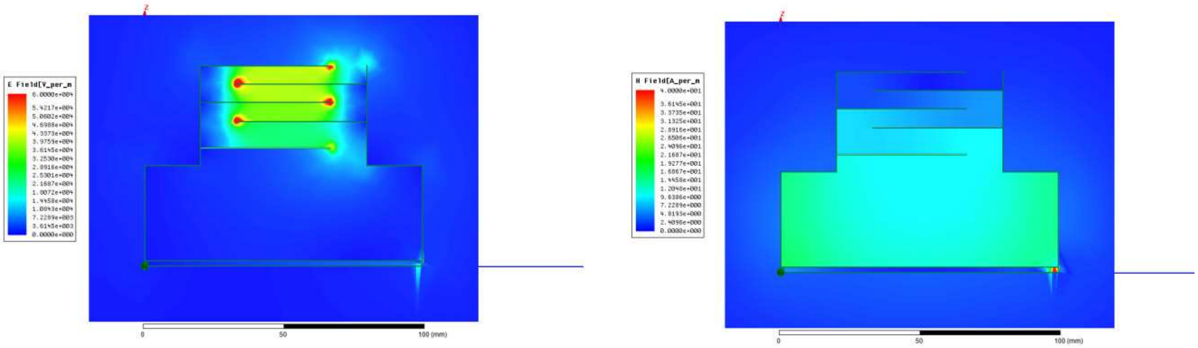

Figure 12: Left electric concentration right magnetic field concentration.

manufacturing.

6. CONCLUSION

A 169 MHz antenna was designed specifically to fit within a specified volume and be manufactured rapidly. The performance achieved exceeded the initial specification will allow the smart meters to be deployed in weak signal areas.

ACKNOWLEDGMENT

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