Utilizing Everyday Metallic Structures as UHF RFID Antennas

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***Abstract*—This paper introduces a technique where everyday metallic objects can be made resonant at a frequency of interest and to function as an antenna. This is achieved by the coupling of parallel resonant devices referred to as "Linear Resonators" to a metallic structure, where the Linear Resonator fundamentally operates as a passive frequency selective switch. Presented here is an initial proof of concept design targeted at the European RFID band. The design performance is evaluated both by simulation and practical measurements on various tubular structures.**

***Index Terms*—Antenna, RFID, Linear Resonator, Traps, Assistive Technology**

I. Introduction

The modern built environment offers many metallic materials, structures and objects that could be utilized as antennas for integrated wireless technologies. The challenge is not to mechanically modify these elements and compromise their structural integrity, whilst at the same time applying techniques where these elements of random length and different materials can be made resonant at a frequency of interest, while at the same time couple RF energy efficiently.

Inserting passive frequency selective switches known as "traps" is a known technique for the multi-band operation from a single λ/2 dipole element [1-3], particularly for high frequency applications. The dipole would be resonant at the lowest frequency of interest with trap pairs placed accordingly to achieve higher frequency resonances. Traps have also more recently been incorporated in frequency selective surfaces (FSS) [4-6] to provide dual-band, band-stop and band-pass operation. Although traps are effective they require physical breaks to be inserted in the conductor.

This paper presents a technique introduced by Moxon [7] for high frequency applications where a frequency selective high impedance switch based on trap technology known as a "Linear Resonator" (LR) can be incorporated on a metallic conductor without physically breaking it. In [7] the connection is made directly, while here we propose it could be a simple clip, or even a capacitive connection for insulated materials.

II. Theory of Operation

A. The Linear Resonator

In the case of a metallic tube of length greater than λ/2 at the frequency of interest, by isolating the unwanted section of tube this can be made to resonate at the wanted frequency, Fig 1. This is achieved by the inclusion of traps which would require the mechanical modification of the tube.

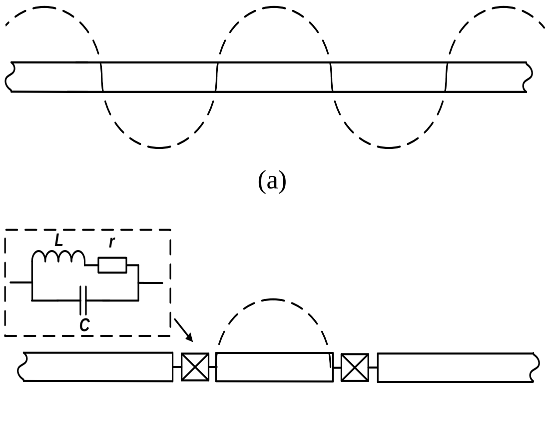
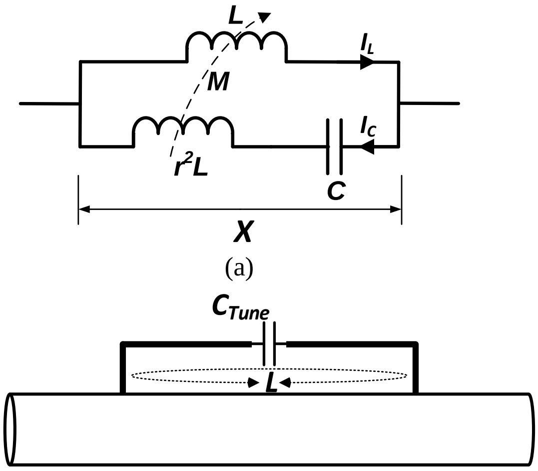


Fig. 1. Current distribution on a random length of conductor, non-resonant at the frequency of interest (a). Same length of conductor brought to resonance by the inclusion of traps in (b).

Fig 2(a) shows the equivalent circuit of a linear resonator. Since a trap is comprised of a parallel LC tuned circuit, part of the metallic structure itself can provide some of the required inductance, with the remainder formed by the connections to the capacitor that complete the tuned circuit. This negates the need to break the conductor. The resonator is designed with

(1)-(4), where *r* is the turns ratio, *k* the coupling factor and $y = \omega LC$. Practical values are k = 0.2-0.5, r = 1.0-1.3. Fig. 2(b) shows how the resonator might be implemented on a metallic tube to form a high impedance switch at the wanted frequency.



(b)

(a) Linear resonator equivalent circuit and implementation on a length of tube in (b).

$$X = \omega L \left[\frac{yr^2\,(1-k^2) - 1}{yr\,(r-2k) + y - 1} \right] \quad (1)$$

Parallel resonance ($X = \infty$) is given by:

$$y_p = \frac{1}{2r^2\,(1-k)} \quad (2)$$

Series resonance ($X = 0$) is given by:

$$y_s = \frac{1}{r^2\,(1-k^2)} \quad (3)$$

The frequency at which $I_L = 0$ is obtained by:

$$y_0 = \frac{1}{r^2\,(1-kr)} \quad (4)$$

I. Design and Simulations

A. Feed and Linear Resonator Design

As the focus of this work is UHF RFID, so the European band of 865-868 MHz was selected for preliminary antenna design incorporating linear resonators. Being a readily available standard size in the UK, both aluminium and copper structures using 22 mm outer diameter tube with a wall thickness of ~1 mm were the chosen platform for initial experiments.

Coupling and matching the RFID device to the tube is achieved by the use of a T-match [8]. This is an established technique that enables the required impedance transformation between chip and antenna whilst also cancelling the capacitive reactance of the device. The RFID device in this case is the Alien Higgs 3 with an input impedance of 27 – j195 Ω at 866 MHz and sensitivity of -15 dBm.

Using CST Microwave Studio^{TM} (CST MWS^{TM}) the required physical dimensions were assessed for both the feed arrangement and also the linear resonators, based on the aluminium tube, with 1.5 mm tin-plated copper wire forming the T-match, and with the same construction used for the LR design. To simplify the process, a λ/2 length of tube was initially used to model the T-match as the parameters would remain constant and transferable to tubes of greater length providing the linear resonators are positioned appropriately. The linear resonators were designed by selecting reactances of ~250 Ω, which compares with the values published for conventional LC traps [1]. Values of 46 nH and 0.73 pF at 866 MHz for the LR.

B. Model and Simulations

Fig. 3 shows the structure resulting from our CST MWS™ model, where L_1 = 40 mm, L_2 = 30 mm, H = 8 mm, *O.D.* = 1.5 mm, and C_{Tune} = *0.73* pF. Simulated, return-loss, surface current, and far field radiation plots are shown in Fig. 4(a), (b) and (c) respectively.

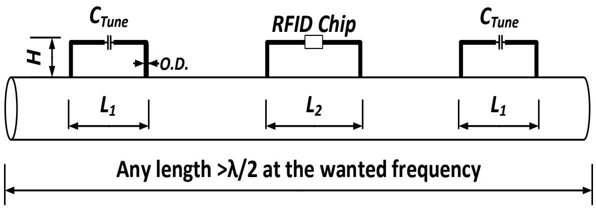


Fig. 2. Topology of the experimental structure.

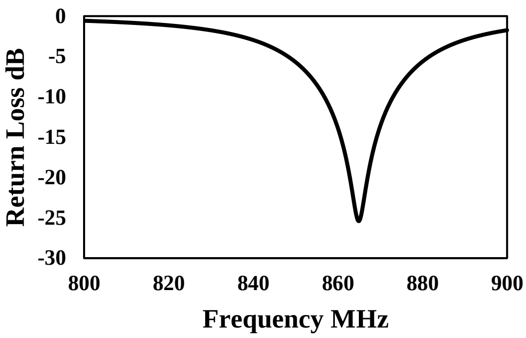
II. Construction and Measurements

For expediency and the convenience of being able to attach the design onto different structures for testing, metallic clips were used to attach the LRs and feed to the test platform. These are sprung steel metal clips (typically bright zinc plated) used to hold or clip onto cylindrical objects.

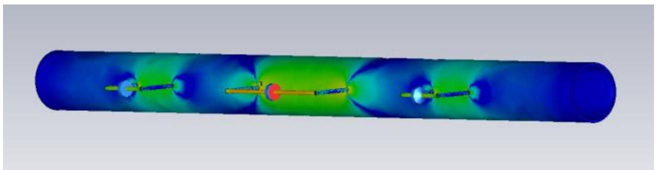
A. Feed and Linear Resonator Design

As with the simulations, a λ/2 (150 mm) length of 22 mm diameter aluminium tube was used to verify the feed arrangement with the RFID device connected. This was measured using a Voyantic UHF RFID measurement system and the results are shown in Fig. 5. Similarly, the LR design was attached to a length of tube greater than itself and was resonated at 867MHz using a small coupling loop attached to a Vector Network Analyzer (VNA). For convenience and to allow for tolerances in construction, small trimmer capacitors of value 0.4 - 2.5 pF enabled precise adjustment of the LRs.
Taking a 1 m length of tube, the feed was clipped on centrally and both LRs placed equidistant at 75 mm from the tube center. Link coupling the VNA to the structure at about its feed-point confirmed the system to be resonant at ~ 868 MHz. The Voyantic measurement system indicated an RFID read range of 12 m as shown in Fig. 5.

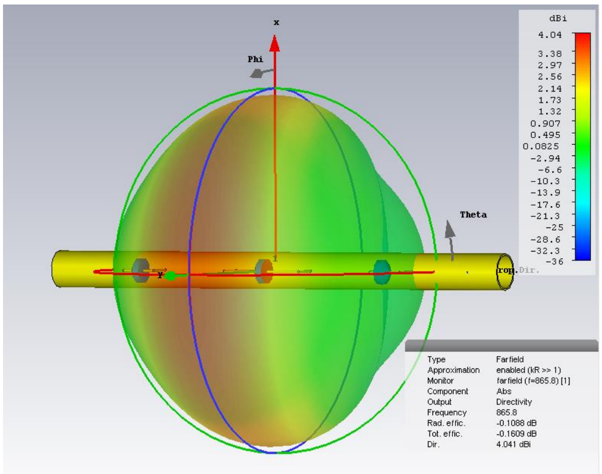
Additionally, an experiment was carried out to confirm that the system would function if capacitively coupled to its target platform. A single layer of PVC tape was used as the dielectric, insulating the clip from the tube. A capacitance measurement yielded a value of 200 pF, resulting in a capacitive reactance of ~1 Ω at 866 MHz.



(a)



(b)



(c)

Fig. 3. CST MWS^{TM} simulations for the experimental design showing, (a) return loss , (b) surface current at 866MHz and far field radiation plot in (c).

B. Field Measurements

Fig. 6(a) shows the complete design attached to different objects for initial testing. The initial proposed application is for the collaborative EPSRC funded research project "Adaptive Assistive Rehabilitative Technologies Beyond the Clinic" (AART-BC) [9], and so a walking frame was selected as a target platform for this project.

The design was clipped onto a vertical section of the walking frame, Fig 6(b), and resonance at the wanted frequency was confirmed with the link coupled VNA arrangement. Subsequently, a Thing Magic M6E development RFID reader on the European band gave read ranges of ~10 m for direct line-of-sight (LOS) to the reader antenna. Rotating the frame through 180° caused about a 1 m loss in read range. Similar results were obtained for the same prototype clipped onto the upper horizontal section of the frame. Of note, this particular frame carries no paint or insulation on its tubes, therefore resulting in a direct connection between the frame and clips.

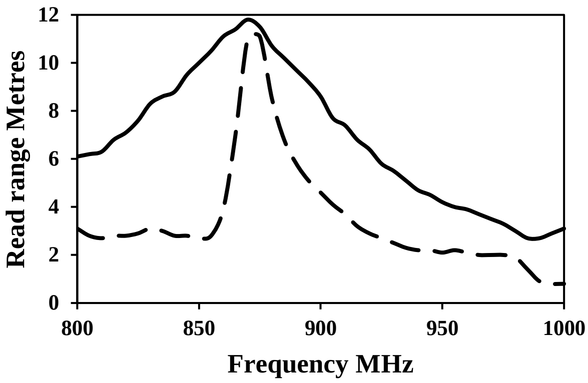
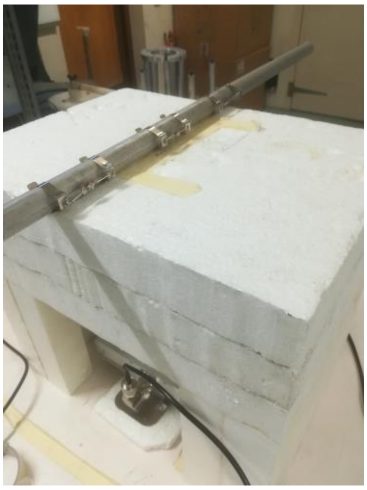


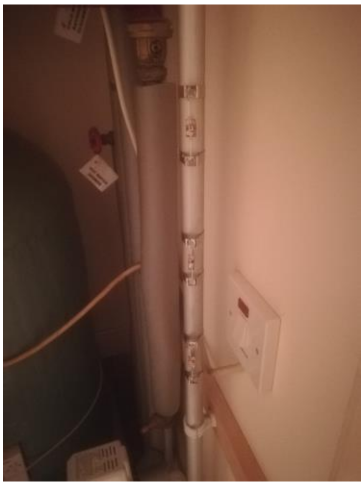
Fig. 4. Voyantic read range measurements for, —— feed arrangement coupled to a $\lambda/2$ length of tube, and ------ the complete assembly incorporating LRs.

As noted previously a direct connection to the structure is not necessarily required if capacitive coupling can be achieved. Fig. 6(c) shows a situation where this is the case with the LR design clipped onto a domestic plumbing system, made up of 22 mm copper tubing which has been previously painted and consequently insulated from the clips. Connecting the system to the plumbing and link coupling the VNA at its feed-point, confirmed the system to be resonant at ~868MHz. Read range measurements were obtained and distances of ~5 m were achieved, though these were limited by the size of the room that housed the piping, and a predominantly non-LOS between target and reader.



(a)

(b)



(c)

Fig. 5. Initial testing of the design using the Voyantic mesurement system is shown in (a). The design clipped onto the walking frame in (b) and a domestic plumbling installation in (c).

III. RESULTS

A. Discussion

An efficient match of S_{11} = -25 dB was achieved for our design using the Alien Higgs 3 (27 – j195Ω) RFID device. No other devices were tried at this stage so the full range of impedance transformation has yet to be evaluated. A limitation might be the case for very low impedance devices, where the T-Match connection points narrow to the extent where insufficient inductance can be realized to cancel the capacitive reactance of the RFID device.

The surface current diagram of Fig. 4(b) shows the current to be contained around the feed-point and within the bounds of the two LRs. Once tuned and on frequency, during simulations it was noted that modifying the length of the conductor beyond the LRs had no effect on operation. This was confirmed in the practical measurements, where the same performance was maintained when physically touching the structure either side outward of the LRs, or adding additional metallic items of random length.

The far-field plot of Fig 4(c) indicates the radiation efficiency to be 98% with a directional pattern of some 4 dBi. It is assumed that the large step in size between the tube to the feed-point, and LR structures is the main contributory factor, where a part of the structure provides a parasitic reflector function. Interestingly the directivity was not as pronounced for the real measurements. In practice, the walking frame would be occasionally masked by the body for wall mounted readers and a ceiling mounted reader would offer the best RF coverage footprint.

It is shown in Fig. 5 that the LR design has a relatively narrow frequency response when compared to a resonant non-LR design incorporating the same T-match feed. This is due to the high *Q* nature of the LR offering a narrow-band response. However, the design still performs in its target band and could be tuned for any of the other international RFID bands. By reducing the LR *Q*, a wider bandwidth design covering multiple bands is feasible, at the possibility of introducing losses and consequently reduced read ranges.

IV. CONCLUSIONS

This paper has investigated Linear Resonators to define UHF RFID antennas both through computer simulation and practical measurements. A prototype targeted at the European RFID band has been designed, constructed and evaluated, which includes, not only ideal laboratory measurements but some platforms on which such devices might be used. Performance of the prototype was in good agreement with computer simulations and also to the performance of standard commercially available RFID tags when mounted in air.

A proof of concept was realized on a metal walking frame, and continuing work will consider techniques to reduce the antenna profile, cost and ease of implementation on a wide range of structures and for other wireless technologies.

ACKNOWLEDGMENT

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