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The Practical Feasibility of Using RFID in a Metal Environment

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***Abstract*— Passive Radio Frequency Identification (RFID) has revolutionized the way in which products are identified. This paper considers the effect of metals on the performance of RFID at ultra high frequency (UHF).**

The paper establishes read patterns in space, highlighting the interference of RF waves due to three different metals, one ferrous and the other two non ferrous, when placed behind a transponder. The effect of thickness of the metal plate is also examined. Different metals have been found to have different interference effects although there are some similarities in their read patterns related to their material properties. Also experiments have been carried out to identify and establish various methods of improving this performance.

Finally, differences between performance-measuring parameters, namely attenuating transmitted power and calculating read rate at a fixed attenuation are established and possible reasons of these observations are presented.

I. INTRODUCTION

Radio Frequency Identification (RFID) Technology is receiving considerable attention as an enabling technology that can improve supply chain asset tracking and inventory control. RFID is an automatic identification technology whereby digital data encoded in a transponder is captured by a reader using radio waves. The communication process between the transponder and the reader involves the transmitting of energy by the reader's antenna, which is picked up by transponder's antenna and some of it reflected back using backscattering modulation. Nonetheless RFID is still a relatively immature technology and many of its characteristics in real-life industrial scenarios are not yet fully understood. For example, the performance of RFID can be severely hampered by the presence of metals and liquids in the tagged product or extreme conditions in the environment. Hence it is important to examine the practical feasibility of RFID in harsher surroundings. This research is an attempt to examine the practical issues associated with using RFID in a complex metal environment and the interference of RF waves caused by metals in particular. The work also highlights various methods which when applied can improve the performance of RFID significantly.

II. PROBLEM

The problem at ultra high frequency (UHF) or 865.6-867.6 MHz is in two parts. One is near field and second is far field of reader antenna. This transition from near-field to far-field is not abrupt but a good estimate is given by the Rayleigh distance or far field distance. It is taken to be:

$$r > \frac{2D^2}{\lambda}$$

where D is the maximum dimension of the radiating structure, r is the Rayleigh distance and λ is the wavelength of propagating wave[1]. This r in our case comes out to be 26 cm, using D as $15\sqrt{2}$ cm (for a square face of size 15 cm of reader's antenna). We choose our work field to be from 5 cm to 95 cm away from the transponder to observe the effects at both near field and far field.

A. Problem in Near Field of reader's antenna

Very close to the reader's antenna, the reactive component (inductive or capacitive) of the field predominates. When this antenna is close to the transponder with metal in background, it causes transponder coupling [2] and gets detuned by the metal, thus reducing the overall effectiveness of the RFID system. Within the Rayleigh distance lies the radiating near field, where the angular distribution of energy radiated varies with distance [2]. In this region the field has a very complex distribution with distance from the source. In both these regions, conductors present in the near field of transponder's antenna as well can affect its radiation pattern.

B. Problem in Far Field of reader's antenna

At greater distances from the source the angular field distribution is virtually independent of the distance [1]. Energy radiates from the source only in the radial direction. Firstly, conductors present in the near field of transponder can have an effect on the radiation pattern of its antenna in the far field. The other problem in far field is with the reflections and interferences of RF waves. Whenever two out of phase waves meet, their components sum and the result can be greater than, less than, or equal to the magnitude of the fields in the original waves. These interfering waves are mainly due to reflections from the environment. Thus normally any reflections are unwanted because they create an uncertainty in the performance of RFID. Metals when present are big contributors being major reflectors.

Having looked at the problem from theoretical point of view in both near field and far field of the reader's antenna, we conducted experiments to plot the read patterns when the transponder is placed at the center of various metal sheets. The effect of interference of RF waves caused by various metals became clear by these plots. In the end, we discuss the reason of variations in the plots with two performance-measuring methods namely attenuating the reader's transmitted power and read rate.

III. Methodology

A. Workspace

Axes were defined as shown in Figure 1: the metal plate with the transponder lies in the XZ plane where Z is vertical. Measurements were made over a volume $90 \times 90 \times 21$ cm^3 at 3 cm increments in the X and Z directions and 5 cm increments in the Y, for a total of 3,780 points. We term the cross-sections in the workspace parallel to the ground as slices, with slice 1 being the top one or at the maximum height. Along the 30 points in the X direction, the transponder is placed in front of the 17^{th} point.

B. Performance Measurement

The most comprehensive way of measuring the performance between the transponder and reader would be to measure the field strength at both ends. While installing and using an RFID system, however, it is only desirable to know how it will perform in that working environment with the installed system. Therefore it is appropriate to measure the performance of the system as a whole. This can be achieved by measuring the number of responses of the transponder for a fixed number of interrogations by the reader [4] and knowing to what extent the reader's power can be attenuated while the transponder is still read. The latter is a measure of sensitivity of the system to the noise level or in other words, of how far above the noise threshold the signal is [5].

Two experiments were performed corresponding to each experimental set-up. In the first the transponder was interrogated with the transmitted power attenuated by 16 dB. The attenuation was reduced in 2 dB steps until the transponder was detected. At this point, both the value of attenuation and read rate is noted. In the second experiment the transponder was interrogated with no attenuation and the read rate was recorded.

C. Experimental Setup

The transponder was attached to a 30×30 cm^2 metal sheet at a height of 160 cm above ground level, supported by a wooden column, which minimally interferes with the RF waves, inside the lab. The minimum distance between the transponder and the reader's antenna was 5 cm.

1) Equipment Used: We used Wisteq UHF Metal RFID transponders, WTUG-127, which use the EPC Global Class 1 Generation 2 protocol. The Reader used was an Alien technology, ALR-8780, Generation 2 reader [6]. The antennas used were bi-static[1] and circularly polarized as provided with the Alien reader. Circularly polarized antennas ensure that the transponder's orientation in the plane parallel to reader's antenna has minimal effect on its performance.

[1]Bi-static antennas include two antennas, where one antenna is dedicated to transmitting, and the other antenna is dedicated to receiving

2) Use of Automation: To cover the test space with good accuracy, a Fanuc M-16iB/T robot [7] was used. The reader's antennas were attached to it using an end effector, which was made of Perspex®, again which minimally interferes with RF waves. The use of a robot ensures high accuracy in moving to any specific position and also high repeatability in motion. To minimize and evenly spread the influence of any uncontrolled changes in the environment, affecting the output data, the ordering of various points in space which the robot traverses was randomized, i.e. robot moved over a random permutation of all 3,780 points.

3) Statistical Planning: To eliminate any time varying factor and to provide reliability to the output data, specific experiments were conducted. These included, collecting initial dataset. With same experimental set-up, another experiment was performed to look for any time varying factors affecting output and a second dataset was collected. No time varying factor was seen to be prominent as the two datasets strikingly similar and were within 3.2% of each other. Finally at a few selected evenly spaced points, 100 observations were made in a cyclic manner. In general if observations during any experiment are taken more than 30 times, the sample variance s^2 is close to variance of population. The larger the sample size, the closer the distribution of the sample means will be to a normal distribution. It is a result of sampling simulations involving the Central Limit Theorem, from different parent populations (Uniform, Inverse, Normal, Exponential, Triangular), that distribution of the means becomes normal when the sample size reaches 30. [8]. With 100 observations, our data were seen to be more tightly packed than normal distribution. At 67% of points, more than 80% of output data lie within one standand deviation of the mean. This confirmed that the

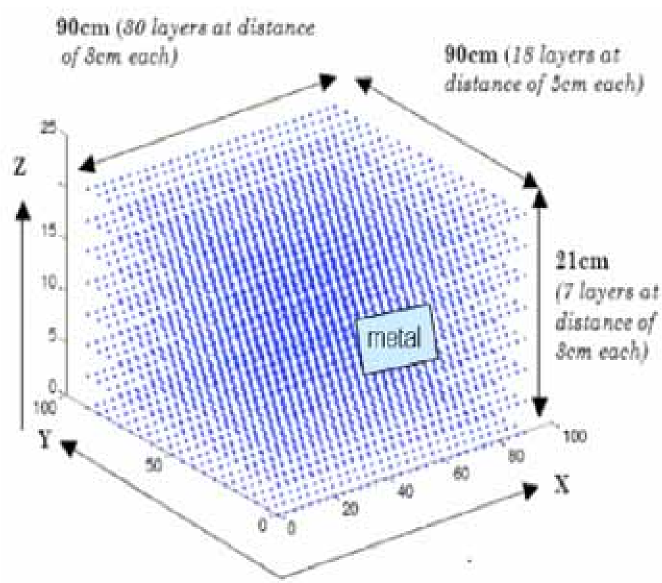

Fig. 1. above shows the total volume scanned by the reader's antenna with each dot in the diagram being a test point. The transponder is attached to the center of the sheet of metal

data were acceptably repeatable. Hence with no time varying factor affecting output and confirmed repeatability of data, the results are reproducible.

4) Account of Environmental factors: To keep an account of environmental conditions, temperatures were noted twice during every experiment, at the beginning and at the conclusion.

IV. RESULTS

Various plots showing points where the transponder could be read (non black spots/regions) were plotted, with brighter spots implying that the transponder could be read even at higher attenuation value in the experiments with varying attenuation of transmitted power and higher read rates in other experiments. Slice 2 of results is presented in paper which is the one where the reader's receiver antenna was straight in front of the transponder. Note the transponder has been provided with an offset towards the left side when viewed, facing it.

A. Interference due to different metals

It is seen that the difference between the plots from experiments of three different metals is very prominent. Though in near field, non ferrous metals have same read pattern. Each slice is found to have circular read region (or the region where transponder is detected by reader, and is marked by bright region on plots shown) with maximum diameter in the slice where the reader's receiver antenna is straight in front of the transponder. This diameter of slices decreases as the vertical distance is increased from this slice.

Brass highly impairs the performance of RFID with a read range no more than 50 cm as in Figure 2. In fact, in case of brass the transponder was read at roughly 15% of all points inspected. In case of Aluminium the read range roughly falls just outside 95 cm as is illustrated in Figure 3. In this case, 43% of inspected space could be read. Finally mild steel causes least radiation losses as the read range extends to well outside the region we investigated as can be seen in Figure 4. However, in this case, in 77% of space transponder could be read. The shape of field in all the three cases is similar being spherical. It is also noted that in the read region of each slice a few spots, where the transponder could not be read (dark spots), are not placed following any pattern. These spots are called nulls (because at these points the RF waves have destructively interfered to give significantly low field) and their positioning cannot be predetermined. Thus the occurence of these nulls is associated with uncertainty of performance. Note that the brightest spots in the figure indicates read rate of over 50%.

This difference in interference of RF waves can be explained as below:

- Near Field: Ferrite provides a very good shielding in a metallic environment. Ferromagnetic substances including iron have relative magnetic permeabilities greatly in excess of unity. Other metals have permeability close to 1. Another main characteristic of ferrite is its high specific electrical resistance [3]. Both of these properties largely prevent the occurence of eddy currents, which minimizes the reduction in magnetic field of the reader antenna near the transponder. This does not happen with non ferromagnetic substances like copper, brass, aluminium lead etc [9]. This property is also used in metal transponders by inserting a highly magnetically permeable ferrite between the tranponder's coil and the metal surface.
- Far Field: It has been noted that in a region far off from the transponder, the effect of three different metals is quite different in terms of read ranges. The main reason is difference in radiation losses due to different electrical conductivities of metals. It is known that electrical conductivity of brass ($5.88 \times 10^7/\Omega m$) is maximum and that of mild steel ($1.02 \times 10^7/\Omega m$) is minimum among the three metals used. Hence maximum radiation losses occur due to brass and more restricted is its read range. More conductive metals have better reflective properties, implying brass causes maximum interference of RF waves.

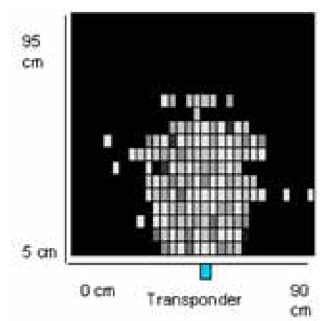

Fig. 2. above shows the plot of transponder directly mounted on Brass. Slice 2 in which the reader's receiver antenna was straight in front of the transponder is shown.

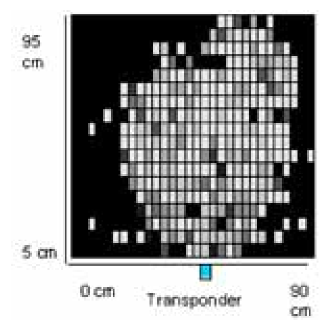

Fig. 3. above shows the plot of transponder directly mounted on Aluminium. Slice 2 in which the reader's receiver antenna was straight in front of the transponder is shown.

B. Effect of thickness of metal plates

Experiments performed involved two different thickness of mild steel, 1 mm and 1.5 mm, with the transponder mounted on center of the metal plate in each case. The effect of

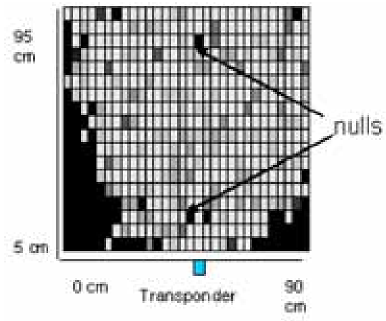

Fig. 4. above shows the plot of transponder directly mounted on mild steel. Slice 2 in which the reader's receiver antenna was straight in front of the transponder is shown.

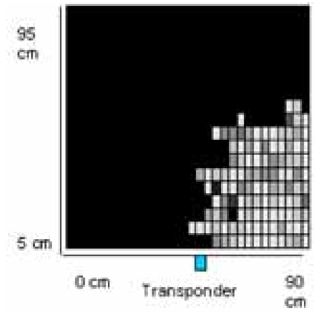

Fig. 6. above shows the plot of transponder directly mounted on mild steel with reader's antenna rotated by 45 degree about its vertical axis. Slice 2 in which the reader's receiver antenna was straight in front of the transponder is shown.

thickness of the metal is seen to be quite prominent. Thicker metal is seen to adversely affect the performance by limiting the read range severely as is visible from Figure 5. Also there are large number of prominent spots which gave high performance (high read rate and read at high attenuation of reader's transmitted power) with a thinner metal and have become either nulls or show very poor performance with the thicker metal. With thicker mild steel the transponder could be read in 45% of space under consideration compared to 77% with a thin metal.

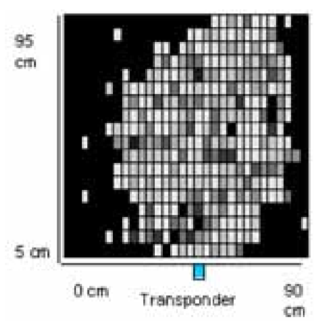

Fig. 5. above shows the plot of transponder directly mounted on 1.5 mm mild steel. Corresponding plot of 1 mm mild steel is shown in Fig 3

C. Orientation sensitivity

In order to test the response of the reader to irregular transponder placements, this experiment was performed with the reader's antenna rotated by 45 ° through its vertical axis. Note that with reader's antenna and transponder oriented at an angle to each other, reads are detected only at one side of the transponder. Figure 6 shows that the reader is able to detect the transponder only from those locations where the reader's antenna faces it (which in this case happens only on one side of the transponder). This is because more RF waves are incident on the transponder in this manner than when the antenna faces the other side of the transponder. So orientation of the transponder with respect to the reader's antenna is a critical factor in the implementation of RFID.

D. Performance Improving methods

We tested three different ways of improving the performance of RFID.

1) Using a spacer between the transponder and metal: Since all concern is due to the metal being in background of the transponder, its distance from the metal is increased by introducing a 10 mm thick Perspex®spacer between them. It is indeed found that there is a huge improvement in performance of RFID, as the read range increases and fewer nulls are found to exist (as can be seen in Figure 7). Another experiment was conducted with the same experimental set-up but changing the spacer thickness to 5 mm. Thicker spacers produced increasing differences between experiments, with and without spacer, apparently reducing the effect of the metal on the transponder. In fact with 10 mm thick spacer, 94.7% of all points in space were read while only 91.6% of points were read with 5 mm thick spacer compared to 77.6% when no spacer was used.

2) Providing Offset to transponder: In this experiment the transponder was positioned so that half was in contact with the metal plate and the other half extended over the edge, with only the wooden support post behind it. Again read region in each slice is seen to increase in diameter, which means the read range expands out. But here a peculiar big null is seen which is perhaps due to the change in reflections from metal due to the relative shift between the metal and the transponder (Figure 7).

3) Angled transponder (lifting the transponder from one end): The transponder was lifted from one end by a small angle of 4.76° using an angled perspex spacer. The other end of it still touches the metal plate in the background. The result shows that this method also improves the performance by significant margin as the read range improves, the number of bright spots increases and the number of nulls are largely reduced as in Figure 7, indicating less interference in RFID performance due to the metal in the background.

All three methods appear to reduce the role of the metal by either increasing the distance of transponder from it or by avoiding full metal background. They are cheap, easy to

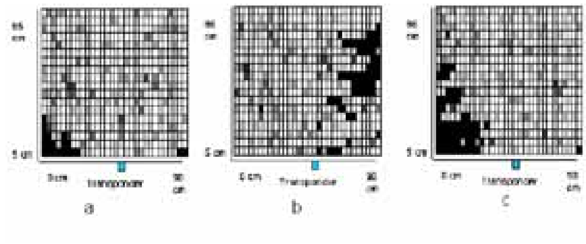

Fig. 7. above shows the plots of performance improving methods with mild steel. a is the plot with spacer, b with offset, and c with angled transponder.

apply and practical solutions to the problem of interference with metals.

E. Comparing Attenuation of transmitted power and Read Rate

The first and foremost difference found between these two ways as performance measuring tools is that results at any point with the varying attenuation of transmitted power are more repeatable than with the read rates. Data of read rate fluctuates within limits and has a little more standard deviation. But there are other aspects to this comparison as well. Before we proceed it should be noted that the brightness of corresponding spots from two plots, of read rate as in Figure 8 and corresponding plot of varying attenuation as in Figure 4, are not to be compared as they represent different parameters with different ranges. Also, the brightest points in the plot with varying attenuation represent attenuation value of greater than equal to 16 dB, and can be anything. The overall shape of two plots is similar but there are a lot many nulls in the plot of read rate, far more than with varying attenuation values. Secondly, there are a lot of points in plot with varying attenuation with high brightness (indicating it is even read at high attenuation) which actually become nulls in other plot. Though we would have expected, when the transmitted power is increased (or its attenuation decreased), any given point in space would be read with a higher read rate.

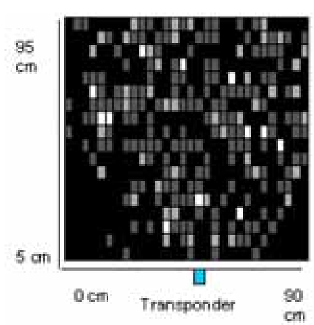

Fig. 8. above shows the plot of read rate with transponder directly mounted on mild steel. Can be compared with corresponding plot of attenuation Fig 3

Possible reasons of above observations are that with varying attenuation, number of interrogations with transponder is more at any given point, since the program decreases the attenuation until the transponder is read. But this is not the case when the read rate is calculated. In fact, the experiment with the read rates took nearly constant time of around four hours for completion against ten to fourteen hours with varying attenuation value. What this implies is that the number of nulls which represent uncertainty in RFID performance gets largely reduced when performance is measured with different attenuations of transmitted power at any point. The second observation can be explained on the basis of redistribution of nulls with change in attenuation of transmitted power. It is known that RF field contracts when attenuation of power transmitted is increased. Perhaps this causes redistribution of the nulls as well, implying the points where nulls are formed (due to some reflection by the metal or surroundings) may also become part of points where transponder can be detected, but at a different attenuated power. Now we have a very strong tool in our hand, instead of just reading the transponder at a given transmitted power, at any point in space, if we change the attenuation of the transmitted power as well, we have a better chance of reading it even from the null points.

V. CONCLUSION & FUTURE WORK

This paper discusses the detrimental effect of nearby metals on the performance of RFID transponders. We considered three different metals, one ferrous and other two non ferrous and have presented their read patterns in space highlighting their different interference effects. In addition, various performance improving methods have been established. It is also found that experiments with varying attenuation of transmitted power though take far more time but cover the read region more extensively than experiments with read rate. In future we would like to extend the study to industrial products with metal environment.

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