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ABOUT SOME ELEMENTS FOR DESIGN OF AS/RS SHELVES IN INDUSTRIAL LOGISTICS

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Abstracts: *The objective of this paper is to guide designers of antenna systems for coupling to EPC labeled products in AS/RS shelving using either UHF or HF EPC labeling systems. It does provide an explanation of important physical principles that must be taken into account in the AS/RS shelf antenna design problem.*

Key words: *RFID, industrial logistics, AS/RS shelves, electromagnetic field, tag, antenna.*

1. INTRODUCTION

1.1. Shelf antenna design

In the design of antennas for AS/RS shelves we need to achieve the following:

- create fields of appropriate orientation;
- create fields of reasonable uniformity, so that the dynamic range of tags is not overtaxed;
- our antennas should not be too finicky because they are of too high a quality factor;
- the tags should be easy to manufacture;
- this probably means that they should fit in easily with existing shelf design
- the tags on products should be placed where the best parts of the field are
- for HF systems the antenna and shelf design must allow for a complete flux path, and must surround conduction current, not merely displacement current.

1.2. Case Study at HF – The Quadruple Shelf Pair

The structure we consider here is shown in outline form in Fig. 1 below. The magnetic field lines, which are shown in blue, are created by current, which flows horizontally along the central shelf, and returned via the upright sections to flow in the opposite direction of the topmost and bottom most shelves.

The diagram shows a single feed point space for the injection of current in the center of the metal shelf, but appropriately phased feed points in all shelves may be considered. The structure has the advantage that the field lines are reasonably uniform throughout the region that will be occupied by product, and are totally compatible with a shelf structure in which all horizontal and vertical elements other than the central spine are conducting. The structure has, however, the disadvantage that the magnetic flux path involves not only the shelves facing one supermarket aisle, but also the shelf at corresponding height facing a neighboring aisle. This simple field configurations precludes the use of the conducting mesh back plane almost always present in supermarket shelf configuration, and is for that reason considered to be unlikely to be adopted.

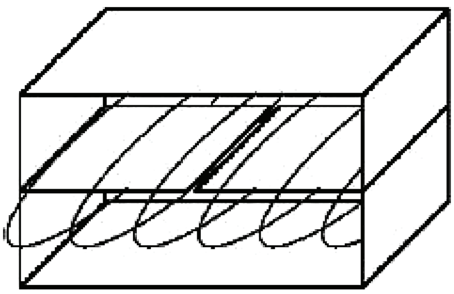

Fig. 1. Quadruple shelf pair.

1.3. Case study at HF – The Forward Facing Loop

An option that can be considered for operation at HF is the installation of a number of loop antennas towards the rear of each shelf, but sufficiently spaced from the conductive mesh which separates the shelves facing one aisle from those facing another, such as is shown in Fig. 2 below.

Several things become clear from examining the figure. One is that a return flux path must be provided behind the conductive loops. Allowing too small space for this flux path will create oppositely phased images of the antennas behind the backing sheet with the result that the field variation in front of the antennas, already substantial, becomes even greater. It is true that the effect can be mitigated to an extent by the use of ferrite material within the return flux path, but this is regarded as a costly solution. Another thing that becomes evident is that the field varies not only significantly in magnitude, but also in direction from point to point, and coupling to product tags that are in a consistent direction cannot always be an assured. We have conducted so far no experiments on this type of structure.

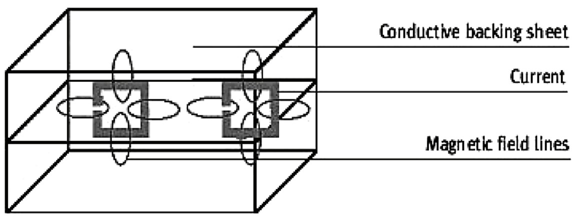

Fig. 2. Forward facing loop.

1.4. Case Study at HF – The Shelf Loop

This antenna structure is suitable for non-metallic shelving. It consists of metallic loop, which occupies the underside edges of a 900 mm wide, and 550 mm deep shelf. A simplified view of this structure and of the resulting magnetic field pattern is shown in Fig. 3 below. A single feed point at the front may be readily tuned and matched to 50 Ω, and a coaxial cable may make connection with the strip and lead to the point of symmetry at the center of the back of the shelf. Such an arrangement maximizes the uniformity of current within the loop.

2. EXPERIMENTAL WORK

2.1. Objectives

The objectives of experimental work reported here were:

- to see whether clear tag replies could be obtained from tags placed in the AS/RS shelf environment with interrogation systems of the type which will satisfy electromagnetic compatibility regulations;
- to obtain some idea of the field coverage, which could be obtained with various interrogator antenna designs.

2.2. Available Equipment

The equipment which could be assembled in a short time and the minimum cost consisted of:

- the AS/RS shelving system previously illustrated;
- an early model UHF interrogator system with prototype tags designed for a waste management system. This system must employ tags with asynchronous on chip oscillators designed to operate at a frequency in the vicinity of 200 kHz, and to employ binary phase shift keying to modulate its reply onto the sub-carrier. The tag operating power is high by current technology standards, so whatever performance we see here is certain to be exceeded by current technology;
- appropriate modifications to the system must be made so that its peak power output was within current FCC regulations for frequency hopping equipment. The antenna system successfully employed with this equipment consisted of a circularly polarized patch antenna with an overall gain of about 5 dB, or 2 dB if one considers the gain from the input terminal to each of the output polarizations;
- a model multiple read HF interrogator system with prototype tags designed for a document management system. In this system a power output of 800 mW to an antenna of quality factor 14 must be employed. This system also employed tags with asynchronous on-chip oscillators designed to operate at sub carrier frequencies of 250 kHz and 400 kHz, in which the tag reply is provided by frequency modulation of the sub-carrier between those two values. The tag operating voltage is high by current technology standards, and EPC tags under development are expected to have performance exceeding those used here. The extent of far field radiation from the loop antennas used in the experiments has not yet been determined

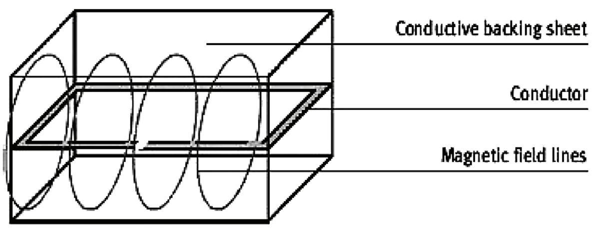

Fig. 3. Shelf loop.

For simplicity in the laboratory, the shelves are single sided, but mostly in supermarkets a single spine supports shelves on two sides. In addition, there are supports provided on each of the front sides, as well as the supports that are provided at the spine.

The uprights supporting the shelves at the front, absent in our structure, were generally found to be at 1800 mm spacing. The upright supports at the spine, as in our structure, are generally found to be at 900 mm spacing. Most shelves were 550 mm deep from front to back. Many shelves had a vertical separation of 420 mm. An exception can be found for goods in which case a vertical shelf spacing of 660 mm was noted.

Most of the shelves were constructed from nickel or chromium plated mesh made from round steel bars separated 20 mm in the width direction and 90 mm in the depth direction. It is assumed that the very common mesh construction has been adopted so that extraneous materials may fall to the floor which is the only surface requiring frequent cleaning. In one of the major chains the mesh gaps were reduced from 20 mm as mentioned above to 10 mm as present in our structure.

However, the shelves not always wire. Some AS/RS employ a small proportion of flat metal shelving, and some use that extensively.

Sometimes shelving is sloped downward to the front edge in order to improve product visibility. A feature of the shelf vertical spacing which was noted was that it was frequently variable and suited to product height, thus obviating the need for unstable stacking of products in order to achieve high display density.

In fact the only products that we found stacked were those for which little damage to people or the products will occur if the products tumbled to the floor.

It is a fortunate fact that such products, are normally electromagnetically highly transparent.

3. ELECTROMAGNETIC COMPATIBILITY ISSUES

We will have space in this report to make only a few remarks about this very large subject.

It is noted that at both UHF and HF, electromagnetic compatibility regulations are enforced in the far field.

In the measurements, reflections from the environment, at least from a ground plane, must be allowed for, in the sense that when such reflections occur, a reduction in the radiated power is required.

At UHF use of interrogator transmitter antennas with high gain is self-defeating, as the regulations are usually written in terms of the radiated power density per unit area, with the result that the use of high gain transmitter antennas requires a corresponding reduction in transmitter power.

Thus quite low gain UHF antennas, i.e. with broad angular coverage are preferred.

The way to obtain good spatial coverage with HF antennas without excessive variation in the amplitude of the field produced over the range of space intended to be occupied by product is to use antennas with physically large areas.

Such antennas are more likely to radiate to the far field, and a compromise on antennas size is required.

Some antenna configurations suitable for use at HF can create strong local fields and diminished radiation to the far field, and should be considered if other aspects of their product coverage are satisfactory.

4. DESIRABLE CHARACTERISTICS

4.1. HF labels

At HF losses in an un-modulated label are small. To avoid finicky labels, it is desirable to keep the quality factor at a sensible level. With that quality factor, we should aim to employ as high a self-inductance and as low a capacitance as is practicable, given the label antenna size.

When the label quality factor is kept to a sensible level, there is some influence on label operating power.

Another issue affecting label design is that of providing adequate dynamic range over which the label will operate successfully, or will not suffer damage. Once this issue is recognized, it has implications for interrogator antenna design. The implications are that conducting surfaces should be made sufficiently large that high current densities, and the associated adjacent high magnetic fields, are avoided. Another implication is that the extreme variation with distance of the magnetic field from a small dipole should where possible be avoided through making the label excitation structures of significant size.

4.2. UHF labels

For UHF labels, we have the possibility of designing a label antenna that responds either to electromagnetic fields (this being the case when the label antenna is reasonably efficient), or primarily to electric field or to magnetic field, (this being possible when the label is very small indeed).

In the normal situation, labels, which are to be placed on products, will be electrically small (this means of a dimension substantially less than a half wavelength), and will only operate with reasonable efficiency over a narrow bandwidth. It is again a consequence that we may wish to avoid labels, which are finicky because they are easily mistuned. This objective has two consequences. One is that we should avoid making labels excessively small. The other is that the labels need to be designed with the knowledge of the immediate environment in which they will be placed, particularly if they are to be placed close to metal surfaces on a product. In the latter case they must be designed so that they will couple well to the magnetic fields, which will be tangential to such surfaces. Fortunately, all this is possible, but such labels will occupy volume, rather than be of negligible thickness.

It is also a notable characteristic that at UHF, the capacitance of the rectifier junction plays an important role in any matching circuit that attempts to optimize the extraction of power from the label antenna.

Very good performance can be obtained when this issue is recognized and exploited.

The question of label dynamic range is, as with HF labels, also important.

5. ILLUSTRATION OF WAVEFORMS

5.1. UHF system

The base band signals observed in the UHF system when labels were moved generally over the field of illumination of UHF system, which was one shelf bay'. Both in phase and quadrature base band signals are shown.

Clearly the base band signals have a very high signal to noise ratio. The intervals of the phase change are very clearly discernible.

5.2. HF system

The base band signals observed in the HF system when labels were moved generally over the field of illumination of HF system, which was one shelf bay.

Again both in phase and quadrature signals are shown.

6. SIMPLE WIRE ANTENNA

Because it is a well-known that almost any piece of wire that has dimensions comparable with or larger than half a wavelength will radiate copiously, an initial exploration using a network analyzer of the field distribution which is obtained beneath the simple wire slung underneath one shelf, was made.

For convenience the wire consisted of an approximately 3 mm diameter aluminum rod and which was fastened by means of an alligator clip to a coaxial connector passing through one of the mounting holes of the shelf bracket. The results were very much as expected. The wire continues to radiate over its whole length, but in a very irregular way. The field distribution beneath the wire shows the characteristics of a many path electromagnetic propagation situation, in which there are both deep nulls and corresponding peaks in the field intensity. This antenna configuration was regarded as useful for confirming expectations, but not highly useful for practical application in the shelf reading context. It provides for no field stirring, so that tags and some locations would not be read. Moreover, some of the radiation is to large volumes of space in which the energy density is too low to be usefully used, even though the total energy radiated thereto is significant. What is needed is a more deliberately focused antenna that would radiate over an appropriately large beam to the shelf region below it, and that can be multiplexed with similar antennas so that null positions can be avoided. Such an antenna is the circularly polarized patch antenna which is normally employed with a model of UHF interrogator used in our experiments.

7. OPERATION WITH PATCH ANTENNA

When the patch antenna and normally used with the UHF interrogator was slung beneath the center of an upper shelf, it was found that tags could be read in almost all regions above the shelf below, with base band signals. Only at the extreme edges and high up, that is in regions, which would be substantially outside of the beam of the antenna, presented any difficulty.

These good results were obtained with tags with their long axis parallel to be mesh back plane of the shelf structure, and also with their long axis perpendicular to that plane. This latter result appears to provide confirmation that the use of a circularly polarized interrogation antenna is beneficial.

Our conclusion is that multiplexed patch antennas slung underneath upper shelves will provide a very good reading mechanism for UHF tags, but more than one patch antenna per meter of shelf length may be required.

In multiplexing a single transmission line to several patch antennas we do not require the usual design of high isolation multiplier. Only a moderate level of isolation will be required, and economy of manufacture will result.

8. USE OF HF LOOP ANTENNA

For the evaluation of tag reading at HF, the grid-like metal shelves were removed from the upright supports of the shelf structure, and electromagnetic transparent shelves (made from particle board) with a single turn rectangular peripheral metal strip antenna, connected to the interrogator was used.

It should be emphasized that the drawing lacks reality in that the drawn in antenna appears to be sitting on the existing rectangular grid metal shelf, but in the experiments the metal shelf had been removed. It was found that HF tag antennas oriented parallel to the back plane off-the-shelf structure could be read at all positions across the shelf below.

9. SHELF FIELD UNIFORMITY

The results of a measurement by means of the network analyzer of the uniformity of the field created by the shelf loop antenna at the height of 160 mm above the shelf appear below.

In interpreting this graph, we note that the vertical axis is linear in reactive power density per unit volume.

The range of values from about 1 down to about 0.2 is only about 5 dB, and is very much less than the expected dynamic operating range of the tag, for which a value of 40 dB is a reasonable aim.

10. CONCLUSIONS

The modern industrial logistics combines the new use of AS/RS with the RFID technology. Suitable objectives for antenna design for UHF

Systems include the achievement of uniform direct interrogation signal illumination of tags without undue dispersal of interrogation energy to areas where it is not useful, and the provision of suitable field stirring to deal with field nulls arising from multi path propagation.

Circularly polarized interrogation antennas have been shown to be helpful, and in phase and quadrature detection of reply signals is regarded as essential.

Suitable objectives for antenna designed for HF systems include the planning of closed flux paths that surround antenna current, and the achievement of field uniformity in magnitude and direction so that dynamic range demands on tag performance are minimized.

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