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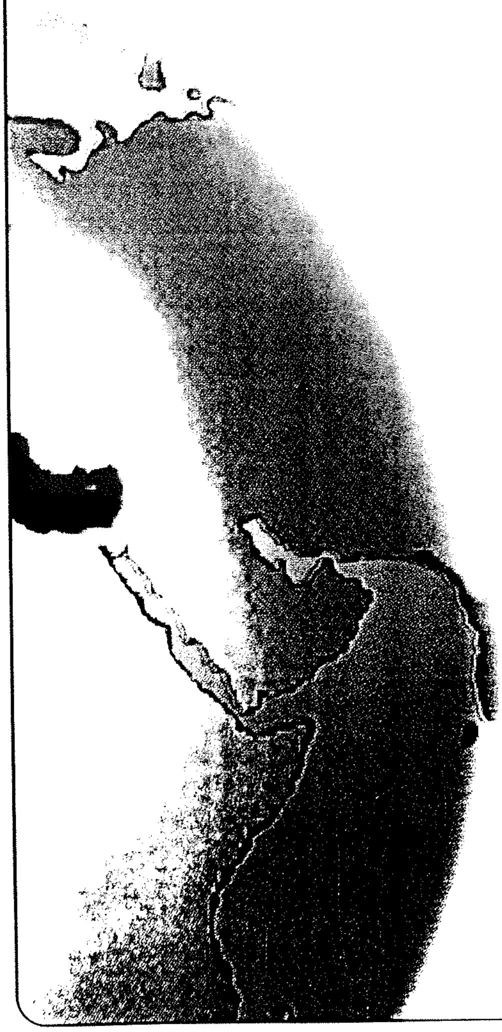

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Magnetic resonant sensors for remote identification of objects

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Abstract

This article deals with the use of **M**agnetic **R**esonant **S**ensors (M.R.S.) for the realisation of an identification system. Nowadays, the market of I.D. system evolves versus magnetic tags as they bring some advantages like remote identification and removal of the need of handling. M.R.S. tags present an alternative to micro-chip as their production cost will be much smaller. The coding capabilities of M.R.S. tags is discussed widely. The principle of the dial code technique is presented with practical results : A prototype system which achieves a code span of 1001000 has been realised and tested successfully.

1 Introduction

Identification is a very important business in industry. The need for object identification exists almost everywhere. Just imagine a production cycle of an object. Identification may be required at all stages : production , assembling, packaging, storage, retailing, recycling,...etc

Humans represent the first method of identification (ID). Today human people are still employed for identification purposes where replacement by automatic systems is not yet possible. This is still often the case when the identification process is complex and requires intelligence or when the amount of objects to identify is low. There are three important drawbacks to the human identification. Firstly human identification is costly. Secondly Human ID is not always possible ; Often the case in individual identification of similar objects. Thirdly, ID work in itself is not interesting as a job.

Consequently, automatic identification systems have rapidly evolved. Tags have been associated to the object to identify. They have evolved from written paper to optical bar code label. This solution has the advantage of always being able to give an identity to any object. The price of such a solution is low for the tag support and writing, but may be higher when the object needs manipulation for accessing the tag. Moreover, the tag may be damaged by transportation and extra bits are required to ensure correct reading.

New technologies are being developed to overcome these problems. Some use microchips for storing data electronically and communicate with an identification system through radio frequency or hyper frequency electromagnetic signals. The problem of these solutions is the cost of the tag which significantly reduces the number of applications.

However the use of electromagnetic fields is a breakthrough in tag technology. The tags are now inserted inside the package and are protected from damage during the manipulation of the object. They can then be read at distance without contact nor optical link between the object and the reader. The technology presented in this paper uses the magnetic field for data transmission but aims at a tag price much lower than the chip tag. This would enable its use in a very large number of applications. Our work has concentrated on **M**agnetic **R**esonant **S**ensors (M.R.S.) whose characteristics, described hereafter, bring a very original and inexpensive solution to the identification market.

This article deals with the use of M.R.S. for the realisation of an identification system..The coding capabilities of M.R.S. tags is discussed widely. The principle of the dial code technique [1] is presented with practical results [2,3] : A prototype system which achieves a code span of 1,001,000 has been realised and tested successfully.

2 Magnetic resonant sensors

The Magnetic Resonant Sensors (M.R.S.) studied here are resonators that use the non linearity of some physical characteristics as a function of a static or quasi-static bias magnetic fields. These physical characteristics drive the resonant frequency of the M.R.S. These resonators can be made in two different ways : L.C. resonators and M.E. (Magneto-elastic) resonators [2].

2.1 M.R.S. characteristics

Whatever the method used to make an M.R.S., their form as they are built now is principally in one direction. The characteristic of frequency versus bias field is valuable only for the tangential component of the bias field.

The tests performed [3] in order to look for any influence of orthogonal component of the bias field have shown that there is no effect on the measured frequencies in the range of used bias magnitude.
Different types of M.R.S. can be easily designed by shifting their characteristic in the frequency domain (Fig.1). This enables not only the detection of their presence in a detection area, but also the recognition of different kinds of objects (as will be explained hereafter).

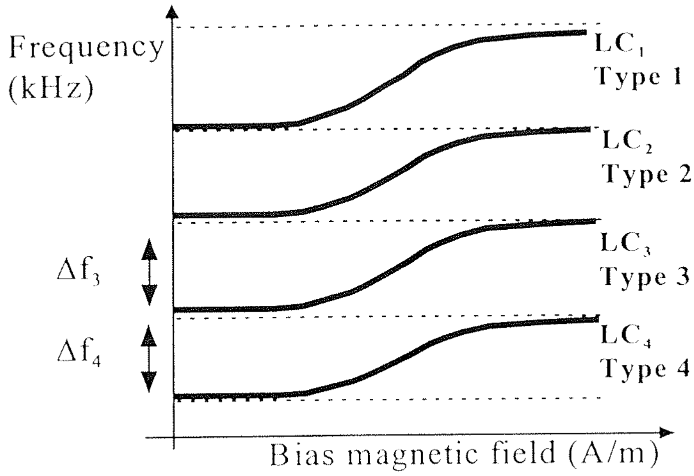

Figure 1 : Characteristics of 4 M.R.S. types

2.2 Detection of M.R.S.

M.R.S. can be detected remotely through magnetic fields (Fig.2). They need a certain amount energy that can be brought by the reading device with an exciting field. They then resonate at their eigen frequency and generate a responding magnetic field which is detected by the reading device.

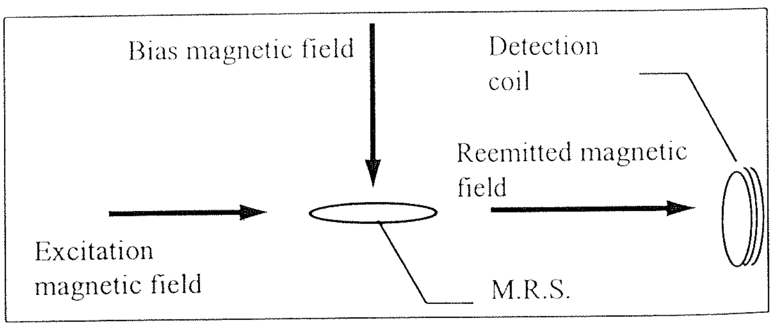

Figure 2 : Principle of detection

3 Object identification with M.R.S.

3.1 Identification with the M.R.S. type

An M.R.S. associated with an object enables to detect magnetically the presence of the object. In this way, M.R.S. can be used for anti-theft systems or counting devices. Commercial systems, using quite the same principles already exist on the market [4].
Additionally, for both ways of making resonators, different types of resonators can be designed. Simply changing the capacitor of the L.C. resonator changes the range of resonant frequencies. For this kind of resonator, the value of the inductance can also be varied and the design of the magnetic core also enables us to vary the shape of the resonator characteristic. In the same way, the characteristic of M.E. resonators

can be divided into different ranges thanks to the control of the ribbon dimensions and the amorphous magnetic properties.

Consequently, the use of M.R.S. can be extended for identification simply by using a specific type of resonator for each kind of object to identify. For example, the generation of 20 types of resonator enables us to identify 20 different objects. Used directly this way, the technique does not yet allow the design of a very large number of identities.

3.2 Identification with M.R.S. tags

In order to achieve a larger code span, more than one M.R.S. can be included in each identity tag (Fig.3). The first idea is to use the set of M.R.S. types as a binary coding. Each resonator type would then represent one digit of a binary number. When the resonator type is present, the digit is set to 1. Otherwise it is set to 0. Assuming the number of available types is N_t the number of identities would then be set to

$$C_t = 2^{N_t} \tag{1}$$

Assuming that N_t can be set to 20, the code range thus obtained is about 10^6.

With such coding, the identification process has to deal with tags made of various number of resonators from 0 to N_t . This may have two drawbacks. Firstly, the number of resonators to identify may vary a lot. This makes the decoding sequence vary according to the tag identity. Secondly, as the number of resonators in each tag is not known in advance, the reliability of the decoding may be uncertain. While a given number of M.R.S. types have been detected in a tag, what would ensure that no other non-detected resonator exists in the tag ? The well known solution to this problem consists of using a part of the bits to make a key code which ensures some security in the identification process. The disadvantage of this solution is the reduction of the code range, since for a given N_t, some of the resonator types are not used for the coding.

Developing the idea and in order to increase the homogeneity of the decoding process, one may restrict the number of resonators in a tag to a given number : N_r . Then, the code range C_t is reduced to the combination of N_r resonator type taken among a set of N_t possible types *i.e.*

$$C_t = \mathcal{C}_{N_t}^{N_r} = \frac{N_t!}{N_r!(N_t - N_r)!} \tag{2}$$

Assuming that N_t and N_r can be respectively set to 20 and 6, the code range thus obtained is about $3*10^4$.

3.3 Identification through tag configuration

The code range of M.R.S. tags can be further extended thanks to the full and clever use of their characteristics. It has been reported previously that M.R.S. are sensible to the tangential component of the magnetic field. This enables M.R.S. to be sensible to both the magnetic field magnitude and its orientation. Consequently, the signal generated by the M.R.S. depends on their position and orientation in the tag. This effect can be used in order to enhance the coding capabilities (Fig.3).

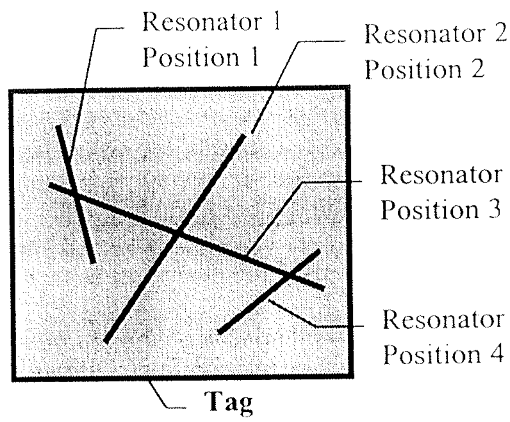

***Figure 3** : Composition of a tag*

Assuming that the tag is referenced both in position and orientation, a co-ordinate system $\mathcal{R}_{tag}$ can be defined and M.R.S. position and orientation can be computed in $\mathcal{R}_{tag}$. Now, make the identification code depends on the position and orientation of each M.R.S. in the tag. The number of possible configurations of tag is greatly increased. In order to better understand, an example is taken. Suppose that 3 degrees of freedom for the positioning of each M.R.S. in the tag are available and that there exists 10 possible positions for all three of them. The number of configurations is then multiplied by

$$C_a = (10^3)^{N_r} \quad (3)$$

thanks to the orientations configuration. With $N_r = 6$ (Six M.R.S. in the tag), the total number of combinations is multiplied by 10^{18}. With a total number of type set to 20, the total number of combinations C taking also into account the combination on the resonator type, is then

$$C = C_t * C_a \quad (4)$$

and can be evaluated to be about 10^{22}.

3.4 Identification capabilities

Now lets come down to earth. Even if all the assumptions made above seem realistic, the computation of actual coding capabilities is a little more complex in the real hard world. Nevertheless, the presented results show how the combination can explode rapidly and can lead to very large code span using only 6 M.R.S. per tag. What should be reminded about these examples is whatever the code range achieved today, the combination explosion is such that a few small and almost insignificant improvements make the usable code range increase sharply.

It was assumed previously that there are three degrees of freedom for the position of each M.R.S. Actually, the number of degrees of freedom for the positioning of a solid object is 6 : 3 for the position of the centre and 3 for the orientation of the solid in space. Among these 6 degrees of freedom, one has to be suppressed : The rotation along the longitudinal axis of the M.R.S. Their response does not vary when a rotation is performed along this axis. This means that there are five relevant degrees of freedom instead of three as assumed above. This leads us to consider that the computations performed above may be under estimated.

However, other considerations still restrict the code range capabilities. Although these are more related to the specifications of the user of identification systems. These specifications correspond to constraints on the tag dimensions and/or on the conditions of measurements that are usually asked for. They are not compulsory, but they are highly probable and taking them into account should significantly increase the number of applications which require such an ID system. These specifications are detailed in the next chapter.

3.5 Usual specifications of users of identification systems

As was explained at the beginning of the article, the use of magnetic tags is interesting as they can be protected inside the packaging of an object and identified remotely through magnetic data transfer. In this case the tag may be hidden and its position not known. Consequently it seems natural that the requirements are to detect the tag whatever its position or orientation in the identification area. This, along with the remote detection significantly increases the difficulty of identification, but brings a second big advantage to such a magnetic tag ; that is no special manipulation is required during the identification process. This advantage is all the more interesting when the object to identify is heavy or difficult to handle.

A second usual specification concerns the size of the tag. A first obvious requirement may be that the tag does not change the volume of the object to identify. In these conditions, the tag volume can be equalled with the volume of the object to identify. However, for practical tag manipulation reasons, and certainly also due to the comparison with the bar code tag, a flat tag as small as possible is often asked for. This specification also significantly increases the identification difficulty and also widens importantly the number of applications. A tag can be ever more used if it is small and thus does not change the associated object volume.

Three other important specifications are often required. They do not change the code span as directly as the first two ones, but they may have an indirect influence on it.
The third specification concerns the cost of the tag. It should of course be as low as possible.
The fourth specification concerns the detection time. It should be as low as possible too.
Then the fifth specification concerns the number of items that can be detected simultaneously. Multi-tag reading is possible since the response of M.R.S. is dependant from their position in the detection area. For example, two tags positioned at different place on different objects responds with different signals even if they are of the same code. They, hence, can be both identified. Of course, the number of tags read simultaneously should be as high as possible.

3.6 Consequences of the specifications on the code span possibilities

The fact that the tag can be positioned anywhere at any orientation implies that absolute positioning of M.R.S. cannot be the basis of the coding. One has to rely only on relative positioning which means using a reference of the tag position in the identification area. One solution is the use of some of the M.R.S. to make the reference. With three M.R.S., one can get a full co-ordinate system [3]. However, the drawback of such a solution is either the need for more M.R.S. in each tag to perform this function, or the reduction of the code span if the total number of M.R.S. in the tag is fixed. This drawback can be reduced noting that the third resonator is not required since the third axis orientation can be computed from the direction of the first two ones. In fact according to the coding needs, only one or two reference M.R.S. are necessary.

The use of a flat tag directly removes two degrees of freedom for the positioning of M.R.S. in the tag which reduces the number of degrees of freedom from five to three. Unfortunately the requirement of a tag as small as possible again reduces two degrees of freedom as all M.R.S are compacted at the same position. This leaves only one degree of freedom for the coding : The M.R.S. orientation angle in the tag plane. This kind of coding leads to a special angular coding which has been named the dial code.

3.7 Dial code

The dial code (Fig.4) is a principle that has been invented and patented by C.Tyren [1]. It consists in using the angle of orientation of linear elements to form a code which is much more powerful than a binary coding. The number of codes achievable by this kind of coding depends on several parameters.

- The angular resolution of the identification system, α_r
- The total angle range used for the coding, A_t
- The number of coding elements, N_r

As has been seen previously, a reference element is required for omnidirectional identification. Consequently the dial code span is given by

$$C_a = (\frac{A_t}{\alpha_r} + 1)^{(N_r - 1)} \tag{5}$$

Using a coding sector of 90° with an angular resolution of 10° and six M.R.S. per tag, the code range obtained is 100 thousand possibilities. Combining this result with the combination of resonator types, the code span can be evaluated to be more than 10^9 which provides already a great amount of possibilities.

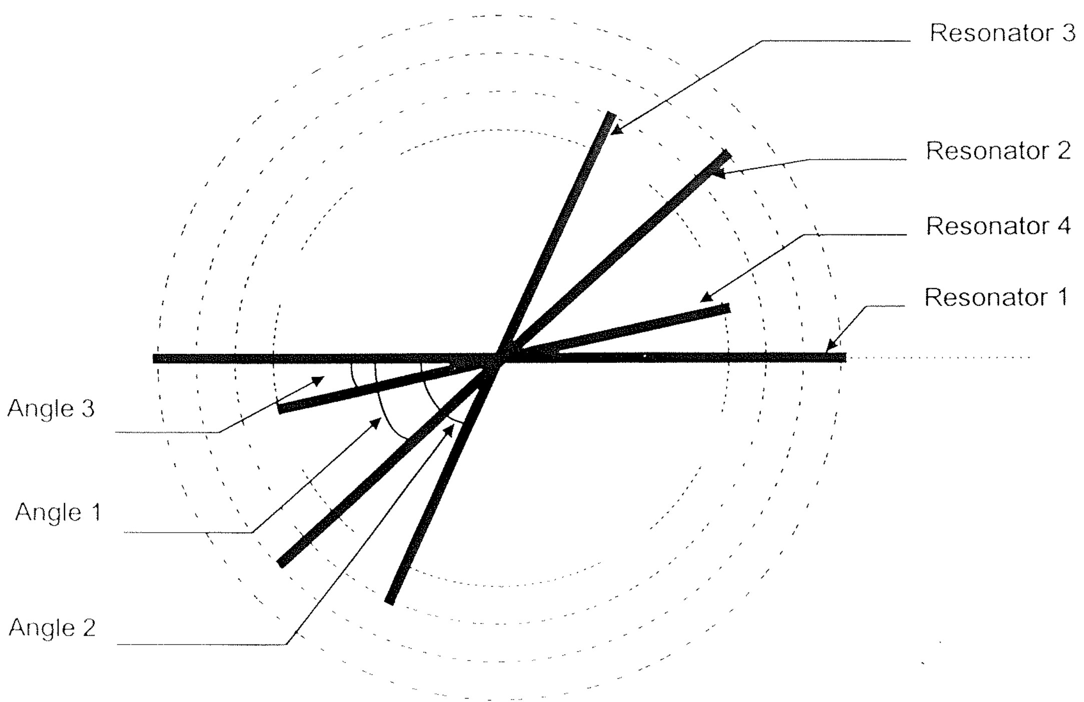

***Figure 4** : Dial code principle*

4 Tests of the principle

In the framework of the Brite Euram MUSIC project [5], a prototype of identification system [2,3] has been built and enables us to realise a software which performs the decoding of such tags. Tests have been realised with L.C. tags (Fig. 5). The parameters chosen are N_t = 14 (Table 1), N_r = 4, A_t =90°, α_r = 10°.It gives C_t = 1001 and C_a = 1000 and enables the realisation of a code span of $C = C_t * C_a$ = 1,001,000. Tests of identification sequences using a computer to generate random numbers to decode have been performed successfully.

Figure 5 : *L.C. M.R.S. resonator (View at scale 1 : 1)*

M.R.S. types	1	2	3	4	5	6	7	8	9	10	11	12	13	14
L (μH)	970	990	1033	830	747	855	830	732	786	870	838	801	960	956
C (nF)	28.0	19.6	14.7	12.5	11.0	7.6	6.2	5.5	4.0	2.9	2.16	1.77	1.15	0.91
f_0 (kHz)	30.5	36.1	40.8	49.4	55.5	62.4	70.2	79.3	89.8	100	118	134	151	171
$\Delta f/f_0$ (%)	10.0	9.7	9.5	8.9	9.2	8.1	8.1	7.6	10.0	11.4	6.3	7.9	6.8	6.9

Table 1 : *Set of experimental MRS types used for tests.*

5 Conclusion

The identification market which has already greatly developed, still needs to significantly improve the identification efficiency by using smarter tags. The system existing today is the bar code label. It is very cheap, but presents some drawbacks ; handling of the packages is necessary so that the tag can be read and, as the tag is positioned at the package surface, it may be damaged during the manipulations. For some time, research has been focussed on electromagnetic reading of tags in order to overcome these problems. However, solutions using micro-chips are much too expensive.

The Magnetic Resonant Sensor (M.R.S.) are resonators whose resonant frequency can be driven by a magnetic bias field. As their response is sensible to the magnetic field, for both magnitude and orientation, they can be used in order to form a magnetic tag. The main advantage of the use of the M.R.S. is that they can be produced in huge quantities at a very low price as they do not need extremely sophisticated factories such as a micro-chip may require.

Looking at the ways M.R.S. can be used for realising different identities, the number of configurations is quite important and the number of attainable identities extremely large. However, the specifications of users of identification systems, such as dimensions and conditions on the identification process lead us to decrease the achievable code span to much lower but more realistic values.

In the framework of the MUSIC project, a test of the principle has been performed using L .C. tags whose code span is 1,001,000. The low cost of tags made with magneto-elastic M.R.S and using the dial code technique, added to the advantages of magnetic reading should ensure the successful growth of M.R.S. in the market of I.D. systems.

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[5] MUSIC : **MU**ltiple **SI**multaneous **C**ode ; Brite Euram project n° BRPR-CT96-0218; Partnership : IKANO, GOTTHARDS, IKEA, VACUUMSCHMELZE, DEGREANE, CEDRAT RECHERCHE, UNIVERSIDAD COMPLUTENSE DE MADRID, BRANDENBURGISCHE TECHNISCHE UNIVERSITÄT COTTBUS.

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