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LF Indoor Location and Identification System

Antti Ropponen, Matti Linnavuo, Raimo Sepponen

Helsinki University of Technology
Department of Electronics
PL 3340, 02015 TKK Finland
Emails: antti.j.ropponen@tkk.fi, matti.linnavuo@tkk.fi, raimo.sepponen@tkk.fi

Abstract In this paper, a low-frequency RFID location system based on a matrix of quad antennae placed under a floor surface is described. A prototype system was used for parameterisation and feasibility tests. The results show that it is possible to build a location system using floor quad antennae.

Index terms*:* RFID, Low-Frequency, Indoor location, near field imaging

I. INTRODUCTION

A. Location and identification systems

In care for the elderly, the identification, localisation, and other surveillance of persons are increasingly needed to make the care more effective and safer. There are several methods which can be used.

In principle, two groups of methods can be used for localisation: active methods, in which the person is tagged with a transponder [1, 2, 3, 4] and passive methods, in which observations rely on the physical properties of the person [5, 6, 7, 8, 9].

In care for the elderly, active methods are unacceptable because of the significant maintenance and attention requirements of the transponder. There are many challenges in ubiquitous computing systems, one of which is the requirement of invisibility. This requirement is fulfilled by having sensors embedded in the walls or floor [9].

B. NFI system

This study is based on a human localisation system using near field imaging (NFI). This NFI system is mainly used in care for the elderly to help carers. There are also other applications, e.g. tracking and localisation needs in building automation and security systems and ergonomic, usability, and marketing research [9].

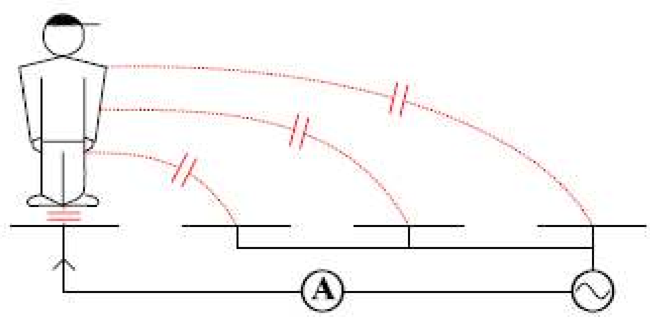

Fig. 1. The current flow of a single element is affected by a person. The whole element matrix is scanned sequentially.

The measurement principle of the localisation function is illustrated in Fig. 1. The area to be monitored is equipped with floor-mounted sensors consisting of plastic-protected thick metal film areas. Each sensor measures approx. 300 x 300 mm. The sensors come in strips 500 mm wide and up to 7 m long. The sensor strip is designed to allow use on floors up to 14 m in width and of any length. A carrier signal is fed sequentially to each sensor element, while the others are grounded, providing a return path for the signal. Using the carrier, the impedance between the active and grounded sensors can easily be measured. The impedance has a component relative to the coupling between the sensors and the conductive object and the resistive properties of the conductive object. A conductive object near the sensor array will show an impedance variation compared to the normal situation and can thereby be detected. The total area is monitored by sequentially scanning every thick film sensor matrix element [9].

The sensor system described can be covered with virtually any dielectric floor covering material, such as wood, carpeting, or linoleum.

The main benefit of the NFI system is that it is person-independent. All persons are detected, irrespective of any tags or other signal sources attached to them. However, there are cases where the system would benefit from identifying the persons localised by NFI. In facilities for the care of the elderly it could be important to distinguish between staff and residents. Locating certain non-human objects, such as equipment, tools, or wheelchairs could also make a beneficial addition to the functionality of the basic NFI system.

C. Purpose of the study

One basic idea in the NFI system is the indiscernibility for the person. Thus identification methods requiring any kind of registration, such as fingerprint detection, must be excluded. Video-based or other biometric identification systems are widely used [5] but they perform point identification. Here the identification should occur everywhere. One solution, which is of wide area and invisible and can be applied to a variety of objects, is an RFID (Radio Frequency Identification) system. It identifies and locates tags attached to objects. There are various RFID solutions to locate objects, for example the LANDMARC system [1], the Ekahau Positioning Engine based on WLAN (Wireless Local Area Network) [2], and the Cricket Indoor Location System, which uses ultrasonic pulses to locate the tags [4].

The requirements stated for the NFI identification system could be fulfilled by any of the aforementioned solutions. However, given the NFI system, there might be other solutions which utilise the NFI hardware and thus could be designed to be simpler in terms of hard- and software. In the design of the NFI sensor, some thoughts of additional RFID functionality were realised in that the sensor strips were equipped with simple antenna loops. This work aims to utilise these for communication.

II. MATERIALS AND METHODS

A. System

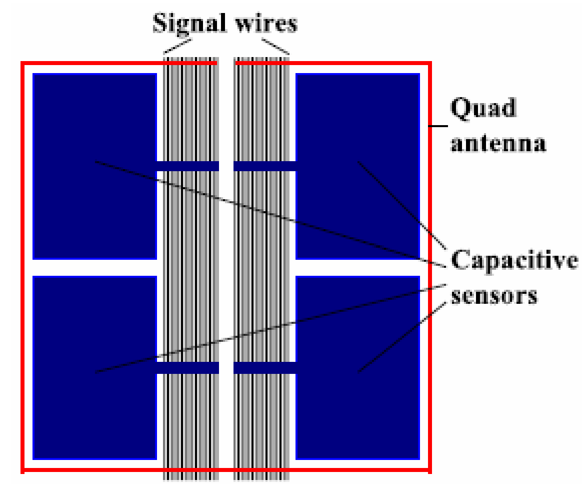

Fig. 2. A schematic picture of an NFI sensor element. A quad antenna surrounds the electric field sensors and signal wires. Up to 10 elements can be linked together in a row.

The NFI sensor element version 9.0 (see Fig. 2) provides a quad antenna that can be used to create a magnetic field. Hence the NFI-RFID system could use this antenna matrix to locate RFID tags.

The size of the quad antenna is 440 x 480 mm. The antennae are made of metal which is printed on two isolated layers. The sensor assembly is covered with a plastic laminate. The thickness of the sensor is 160 μm [9]. The signal wires in the middle of the laminate allow sensor strips of 7 metres in length. The sensors can be placed adjacent to each other, thus allowing arbitrary width, as shown in Fig. 3.

A typical RFID system uses an excitation RF signal to activate the tag. The tag transmits its ID and other information by another signal. This provides the identification of the tag. To localise the tag, various methods may be used, such as signal strength measurement, time-of-flight measurement, or triangulation [10].

The system presented here should utilise the location capabilities of the NFI system. One solution would be the system illustrated in Fig. 3. Each quad antenna is sequentially fed with a coordinate specific code (red signal). The tag transmits the coordinate and a tag-specific ID to the system (blue signal).

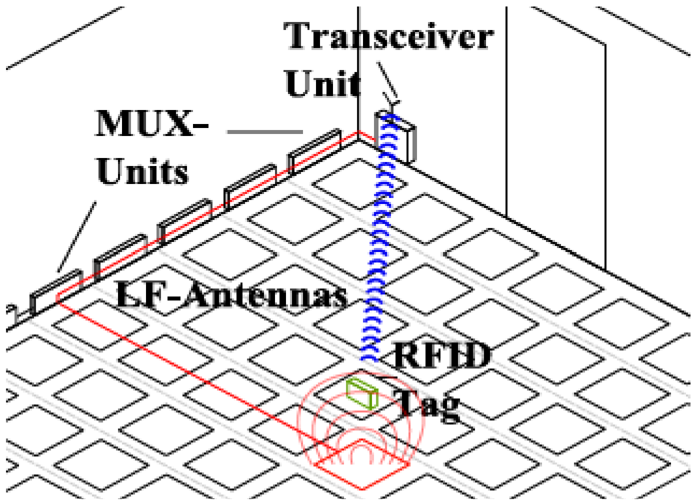

Fig. 3. *NFI-RFID routing. Red lines: low-frequency signal and induced magnetic field, blue lines: high-frequency signal. Grey lines: borders of different NFI element carpets.*

The tag excitation frequency should be high enough to allow an acceptable data rate. However, the frequency is limited by the wiring properties of the sensor element. The sensor wiring layout neither forms a transmission line nor is shielded. Shielding is not possible, because the wires are printed on one layer of the plastic foil. The signal wiring of an NFI sensor may be up to 7 metres.

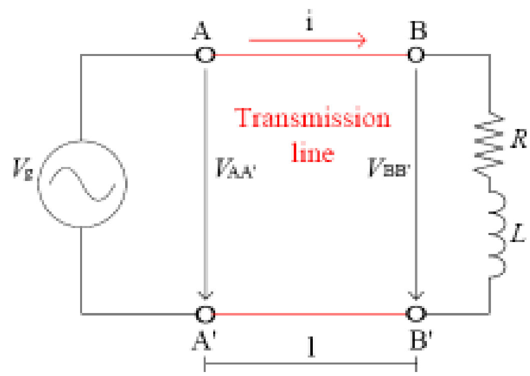

Fig. 4. Transmission line

One of the transmission line effects in relatively long transmission lines is reflection from the load towards the generator and power loss on the line. However, they can be ignored if the length l of the transmission line is short enough compared to the wavelength λ of the signal, as can be seen in Equation 1 [11]:

$$\frac{l}{\lambda} \leq 0.01 \qquad (1)$$

Hence the wavelength has to be longer than 700 metres or the carrier frequency below 430 kHz. This does not mean that the signal does not induce current to the other wires but it is a fact that has to be lived with.

Equation 2 defines the boundary r_f where the far field of an antenna begins (l means the length of the antenna quad and λ the wave length of the carrier frequency):

$$r_f > \frac{2l^2}{\lambda} \qquad (2)$$

When l is 1.8 m and λ is 3 kilometres the boundary r_f gets a value of 2 mm. That means that the tag always receives the data in the far field of a quad antenna [12].

Because all the values have been measured from the far field the magnetic field H is calculated from the electric field E with Equation 3, which describes the wave resistance of free space [13]:

$$\frac{E}{H} = 377\Omega \qquad (3)$$

The benefit of the low frequency is that the disturbance caused by objects and structures is minimal because of the near field condition. It is normally difficult to build an indoor location system because of the instability of the environmental dynamics. For example, with a frequency of 2.4 GHz (which, for example, WLAN uses), people, the different position of the doors, and humidity affect the radio signal and have a deleterious effect on the accuracy of the localisation [14].

B. Tests

In the prototype phase, the general feasibility and location range are of interest.

The location range is relative to the dimensions of the quad antenna field. The small quad antenna field pattern has a zero downright to the antenna plane (Fig. 5). The resulting field pattern is nearly a sphere surrounding the antenna [12]. Thus increasing the vertical sensitivity also increases the horizontal range. The detecting area could be made more vertical by using a group of several antennae. Increasing the carrier frequency would make the horizontal area smaller [15] but it would create too many losses in the wiring.

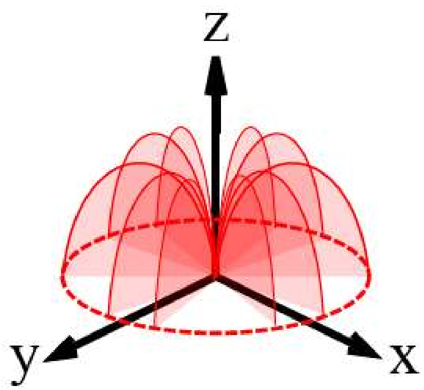

Fig. 5. Radiation pattern of a small loop antenna. Antenna lies on the XY-plane.

Fig. 6 shows the directional gain of 440 x 480-mm loop antennae with different frequencies between 0-300 MHz. The figure was created with the IE3D simulation program. As we can see from the figure, the directional gain increases very rapidly between 0 and 150 MHz [16].

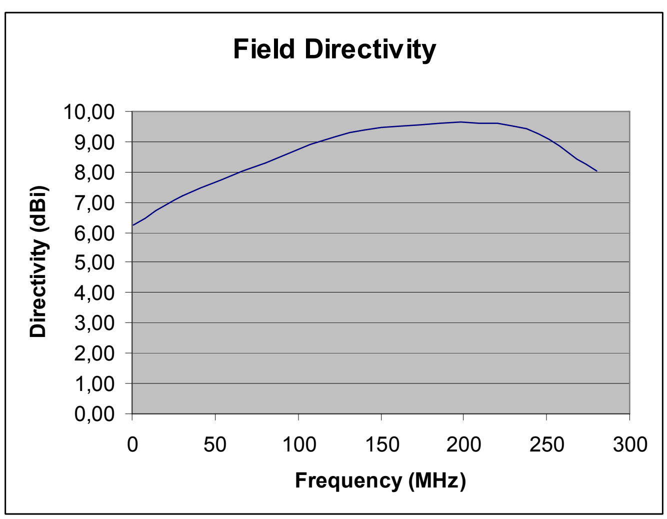

Fig. 6. Field directivity of the quad antenna

The main target of the prototype tests is to measure the coverage area where the signal is received. The coverage area has to be wide enough to reach a tag on the person's chest. Then it is easy to adjust the signal to the desired level. It was decided that the frequency should be well below the 430-kHz limit (that was calculated from Equation 1) and thus a frequency in the 70-119-kHz frequency band was selected.

It should also be verified that the strength of the magnetic field is within the recommendations. The ERC (European Radiocommunications Committee) recommendation ERC/REC 70-03 relating to the use of short-range devices makes it clear that transmission is allowed in the 70-119 kHz frequency band if the magnetic field of the antenna stays below 42 dBμA/m at a range of 10 metres. The transmission duty cycle has no restrictions [17].

III. RESULTS

A. System

A prototype system was constructed to verify the feasibility and functionality of the planned RFID system. A limited-range low-frequency magnetic field is created sequentially by each quad antenna. The Transceiver Unit sends a unique code to each antenna using multiplexers (MUX units).

When the unique code of an antenna is detected by a tag's LF channel it relays the code and its own ID number to the Transceiver Unit using the HF channel. Thus the tag can be both identified and located. The LF channel works with 100 kHz and the frequency of the HF channel is 2.4 GHz.

The theoretical bit rate with a 100-kHz carrier frequency using ASK keying is about 10 kb/s [18]. In actual systems the rate is below 4 kb/s. However, the rate is enough to send short location messages. For example, with an 8-bit address space it takes about 200 ms to go through all 256 antennae.

Each room or corridor in the system service area has at least one transceiver unit. A unit has an HF radio to communicate with the whole system and an LF transmitter to create the location signal. The transceiver unit also controls the MUX units (multiplexers). If the transceiver receives information from the HF network to start searching for tags the unit creates the location signal and routes it to each quad antenna sequentially. The MUX units are controlled with an 8-bit parallel port. 4 bits are used to select the right MUX unit and 4 bits to select the right quad antenna. The location code consists of this address. If a tag is in the antenna's coverage area it receives the location code. In Figure 3 this would mean that the address the tag received would be 0101 0101 because the transmitting quad antenna is the fifth antenna of the fifth MUX unit. Then the tag transmits the location address and its own ID number back to the transceiver unit. With this information the system knows where a person or an item is.

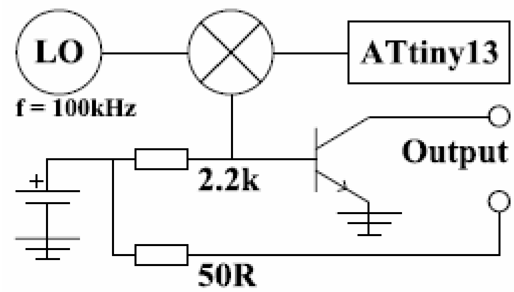

Fig. 7. Early prototype's LF transmitter unit

Figure 7 illustrates the prototype's transmitter unit. A local oscillator creates a 100-kHz signal which is modulated using ASK keying. The modulator is an ATtiny13 microcontroller (Atmel). The transmitter sends one byte at a time continuously. A 50Ω resistor sets the maximum output current to 100 mA. The current was calculated in such a way as to create a magnetic field of 22 mA/m in the middle of the antenna.

RFID tags can be divided into active and passive ones. Passive ones get all the energy they need from the transmitter's electromagnetic field. Active ones use their own battery and are usually more complicated than passive ones [19]. In this prototype the tag was selected to be active because it has to function at relatively long distances from the transmitter, so it would have been hard to get all the energy needed to decode the signal and transmit it on to the HF receiver.

The intention was to test three different low-frequency receivers: Micro Analog System's MAS9180 [24], Atmel's ATA5282 wake-up receiver [20], and Austria Micro Systems' AS3931 ASK receiver [21].

Table 1: Thee different LF receivers

	MAS9180	**ATA5282**	**AS3931**
Sensitivity	0.4µVrms	2.8mVpp	350µVpp
Baud Rate	Very low	4 kbps	2.731 kbps
Freq Range	40-100 kHz	100-150 kHz	19-150 kHz
Rcv. Cur.	40 µA	4 µA	7.2 µA
StandbyCur.	0.1 µA	2 µA	7 µA

As we can see from Table 1 the MAS9180 has far greater sensitivity than the two other receivers. The problem is that its data rate is not provided in the data sheet. The receiver is used in solutions like DCF77, which has an extremely low data rate: the system sends one bit in a second.

MAS9180's carrier frequency is selected with a crystal attached to the chip's crystal filter. Of course the receiver antenna has to be tuned to the same frequency. Because of the crystal filter the receiver has a high Q value, which also explains its high sensitivity. However, the high Q value leads to a lower data rate. Figure 8 illustrates the spectrum of the ASK-keyed signal. The carrier signal's sidebands $f_0 - f_m$ and $f_0 + f_m$ have to fit inside the filter's -3dB band. Thus with a higher Q value the data rate is lower [18].

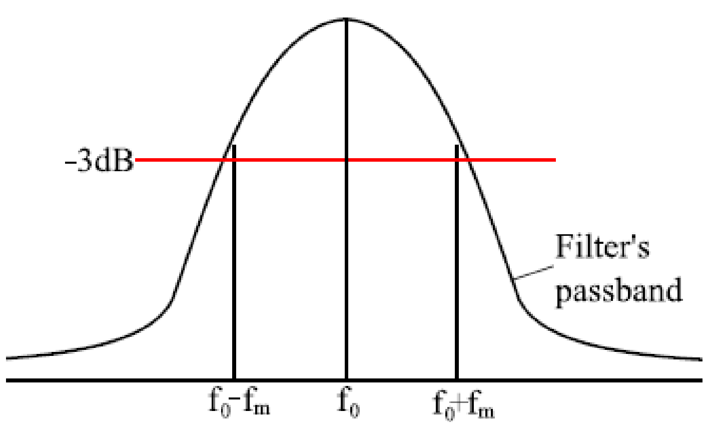

Fig. 8. ASK-keyed signal sidebands and Q value

After testing it was found that the highest data rate achieved with the MAS9180 was about 16 bps. The data rate is far too slow because with an 8-bit address space it takes about 128 seconds to scan through all the antennae.

The ATA5282 and AS3931 do not have crystal filters. The received interference is much higher than with the MAS9180. But the two receivers awaken only when a certain kind of data pattern has been received. The advantage when the selectivity is not achieved with a high Q value is faster data rates. Atmel promises a baud rate of 4 kbps [20] and Austria Micro Systems a rate of 2.731 kbps [21]. In this case the actual data rate is lower because the wake-up pattern has to be sent before every separate data transfer to the different antennae because unless it receives the wake-up pattern the receiver does not react to the data transfer. When the transferred data bursts are very short, for example 8-16 bits, the wake-up pattern's proportion of the data transfer time can be relatively large. Fig. 9 shows the wake-up pattern of the AS3931 between the first two red verticals. Between the second and third verticals is the Manchester-coded 8-bit data byte. As we can see, the wake-up pattern takes 67% of the transfer time. From Fig. 9 it can be calculated that the actual achieved data rate of the AS3931 in this system with an 8-bit address is about 530 bps. At this rate the address space would be searched through in 4 seconds, which is fast enough.

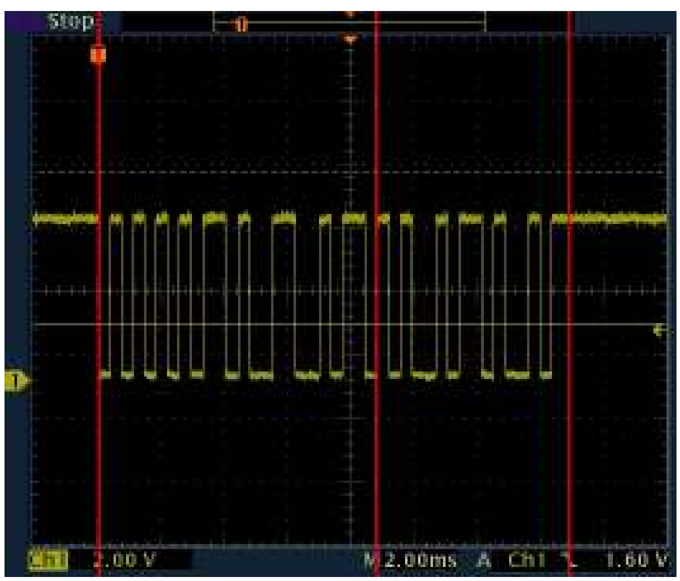

Fig. 9. Header and 8-bits of Manchester coded data to AS3931

The wake-up header of the ATA5282 is shorter than that of the AS3931. It takes about 4 ms to start the data transmission. The data do not have to be sent Manchester coded so the transmission time is also faster. The problem with the ATA5282 for this kind of system, where many different signals with wake-up patterns come after one another, is that the protocol has 20 ms of time at the end of the transmission during which no data are sent [20]. The AS3931 does not have this kind of protocol. When the data have been received the wake pin has to be set through an SPI (Serial Peripheral Interface Bus), which takes under 20 µs [21]. So in fact, even if the header and data transmission times are faster with the ATA5282 than with the AS3931, the whole transmission time is slower. The ATA5282's sensitivity is also inferior to that of Austria's (

Table 1). This leads to the fact that the AS3931 is a better choice for this LF application. If the Atmel chip was used the power levels of the transmitter would have become much higher than with the AS3931.

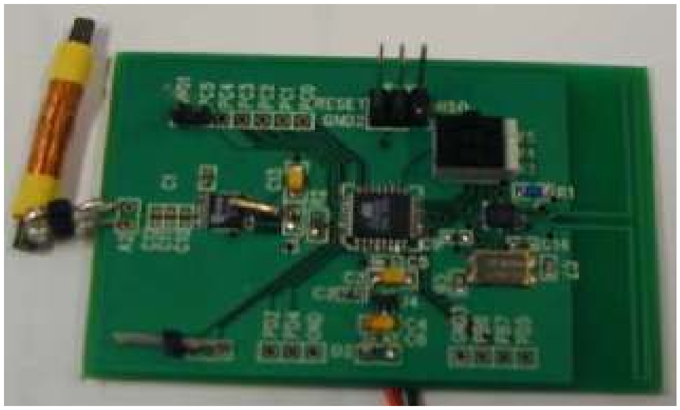

Fig. 10. The first prototype tag. LF ferrite coil antenna and MAS9180 receiver on the left, ATMega88 microcontroller in the middle, and CC2500 transceiver unit and its antenna on the right.

In consequence there were two choices left as to which LF receiver to use: the very slow but very sensitive MAS9180 and the faster but less sensitive AS3931. The superior sensitivity mattered more, because it was not known how wide-ranging the coverage area of the quad antenna is and thus the MAS9180 was selected to be the LF transceiver in the first prototype (Fig. 10).

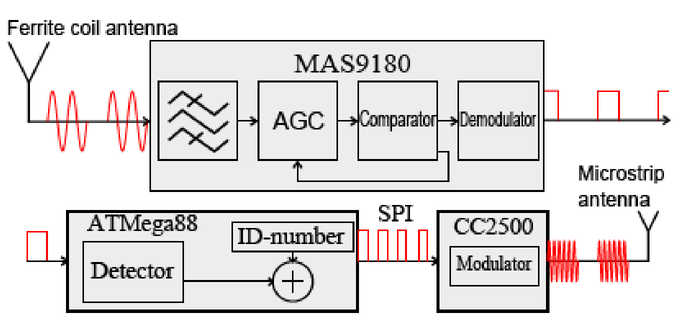

Fig. 11. Tag prototypes block diagram

The MAS9180 consists of a crystal filter, an automatic gain control (AGC), a comparator, and a demodulator. It is a low-power receiver that consumes a current of about 67µA with a 3V input voltage. The MAS9180 decodes the incoming signal and gives out a logical 0 when it receives the carrier frequency and a logical 1 when it does not. The AGC can be locked to a fixed level. This helps to limit the range in which the receiver reacts to the transmitted signal.

The problem with the MAS9180 is that it is designed to receive extremely low data rate signals, for example the DCF-77 signal that is used to tell the time value in different kinds of devices. The data rate of the DCF-77 is about 1bit/s. That is why the highest possible data rate gained with the MAS9180 is far below the possible data rate with a 100-kHz carrier frequency.

If the MAS9180 receives the carrier frequency it sets its output to a logical 0. Otherwise the output stays high [24]. The ATMega88 microcontroller [22] receives these data to its digital input and decodes them. The ATMega88 also controls the CC2500 transceiver (Fig. 11). For prototype testing, the tag has a UART (Universal Serial Receiver/Transmitter) so it can be used as a receiver to connect the system with a PC. There are also extra connectors on the board to help testing.

The CC2500 is a low-power transceiver which uses the 2.4-2.4835 ISM/SRD frequency band. It was selected to be the tag (Fig. 10 and Fig. 11) because of its low power consumption (3.3V: 92µA power down, about 20mA RX and TX) and because it is easy to use with an SPI bus [23].

B. Tests

The system was tested with a simple arrangement. The LF transmitter unit sent 8-bit data continuously to one quad antenna. The tag in Fig. 10 was used to receive the LF signal and to transmit it back to the system.

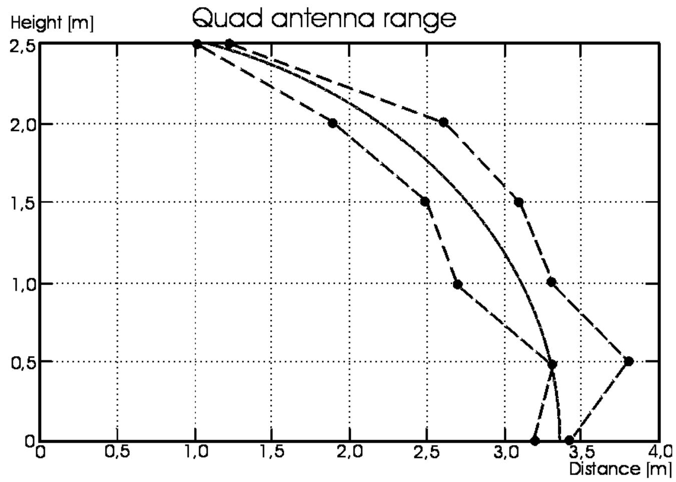

Fig. 12. Possible coverage area of one quad antenna. MAS9180 and a ferrite antenna are used for receiving. Right dotted line: receiving stops, left dotted line: receiving starts

Figure 12 shows the maximum coverage area of one quad antenna when the data have been received with the MAS9180 [24] receiver with the automatic gain control on. The coverage area of the quad antenna was measured by moving the tag slowly away from the antenna at different heights. The right-hand dotted line illustrates the distance at which the tag stopped receiving data. A current of 100 mA went through the antenna.

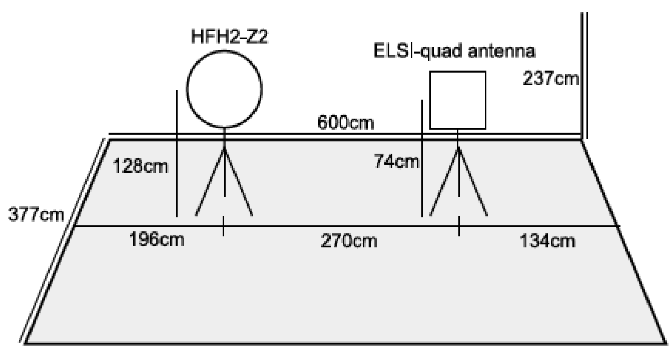

Fig. 13. Arrangement to measure electric field caused by the transmitter system

The electric field transmitted was measured in a shielded room, where the noise level was about 20dBμV/m in the selected 200kHz band. In the department's corridor the noise level in that band was about 90dBμV/m. Fig. 13 illustrates the arrangement of the measurement. The quad antenna and the transmitter lay on a table that did not have any magnetic parts in it. The receiver was Rohde & Schwarz's ESCS 30 and the antenna was a big HFH2-Z2 loop antenna.

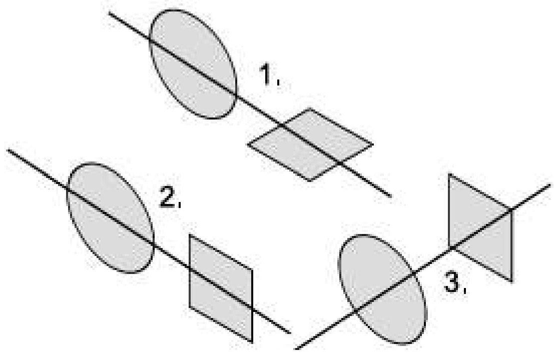

Fig. 14. Three different measurement alignments. The round one is the receiving antenna.

The field was measured three times when the transmitting quad antenna was in three different alignments towards the receiving antenna (Fig. 14). The measured values and the related values of the magnetic field that are calculated from Equation 3 can be found in Table 2.

Table 2: Measured values of the electric field of the antenna and calculated values of the magnetic field

	Electric Field / dBµV/m	**Magnetic Field / dBµA/m**
1.	42	-9.5
2.	47	-4.5
3.	32	-19.5

IV. DISCUSSION

As we can see from Table 2, the magnetic field was at its most powerful at -4.5 dBμA/m at a distance of 2.7 metres from the centre of the antenna. So the magnetic field is far below the recommended maximum value, even when the coverage area of the antenna is too wide.

Even though the coverage area of one quad antenna is wide, there are some ways to improve the localisation estimate. For example, when the system starts to search for the tags an LF signal is sent with a selected maximum power level. This means that the quad antenna has the widest coverage area and all the tags in the service area will reply. It also means that the location accuracy is the poorest. But after the full-power scanning the tags that are found can be searched for in a limited area with lower power levels and the location becomes more accurate.

It is much faster to scan the service area with selected maximum power because then there is no need to transmit with every quad antenna because the coverage areas overlap with each other. For example, every third quad antenna on every third row can be used (Fig. 15), which makes the search much faster. The maximum power level should also be used to find the tags that are vertically high in the room. As mentioned before, if the coverage area is increased vertically it also increases horizontally.

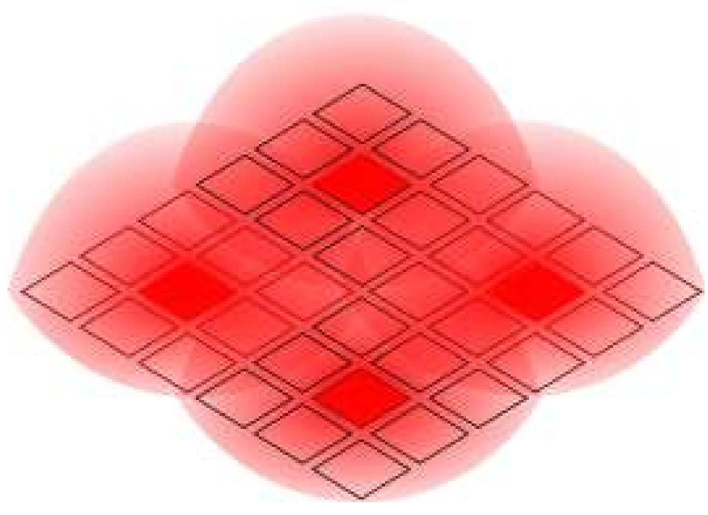

Fig. 15. With selected maximum power the coverage areas of the quad antennae overlap with each other and thus, for example, every third antenna can be used to cover the whole service area.

After a tag is found the location estimate can be adjusted by lowering the transmitter's power. With a lower power level the coverage area gets smaller and the localisation estimate more precise. Additionally, with the MAS9180 the coverage area can be made smaller by setting the AGC to the desired level [24]. If the coverage area is controlled with the transmitter's power the receiver should be more sensitive, which would lead to a greater amount of disturbance. The only problem is that with lower power levels the tag might not be found because it is held too high. That is why it might be better to use the selected full power rate and to add the location data of two or more antennae together.

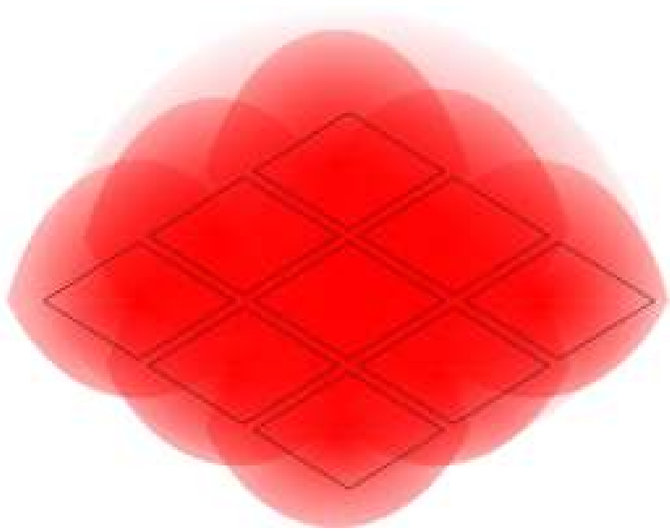

Fig. 16. After a tag has been found in the maximum coverage area of the central antenna all the antennae in the area can be used to locate the tag more accurately with lower power levels

To make a more accurate location estimate more than one quad antenna can be used. For example, the Region of Confidence (RoC) algorithm uses aliasing signal domains to form smaller areas called an RoC, where the tag exists [25].

Fig. 17 presents one type of RoC to estimate the location. If the tag has responded to three different LF signals from different antennae the overlapping coverage areas generates three crossing points, A, B, and C, called triangulation points. The centroid of the triangle whose vertices are the crossing points is calculated. The region of confidence is the circular area whose radius is from the centroid of the triangle to the crossing point which is farthest away from the centroid. The RoC area is much smaller than the coverage area of one quad antenna [25].

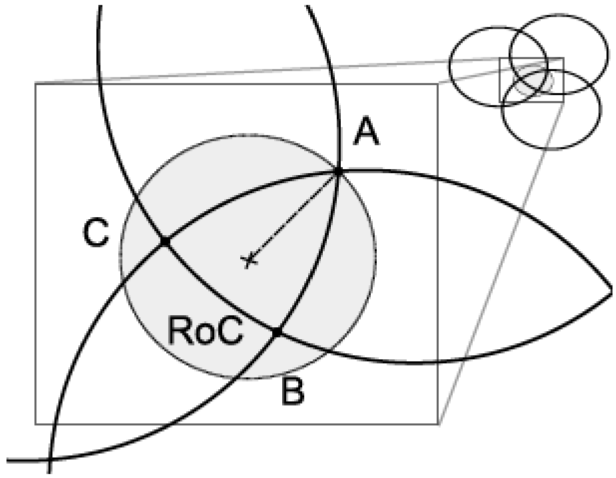

Fig. 17. RoC: A, B, and C form a triangle whose centroid is calculated. The circle whose radius is the line segment from the centroid to A is the region of confidence.

V. CONCLUSIONS

The RFID system will have three separate ways to localise and identify tags for different purposes (Fig. 18): search the whole service area when it is necessary to make an inventory of the tags in the building; search for a certain tag and stop scanning after its detection to find a particular person or item or find out after capacitive detection which person is lying or standing on the floor. The detection can be triggered automatically or by the user.

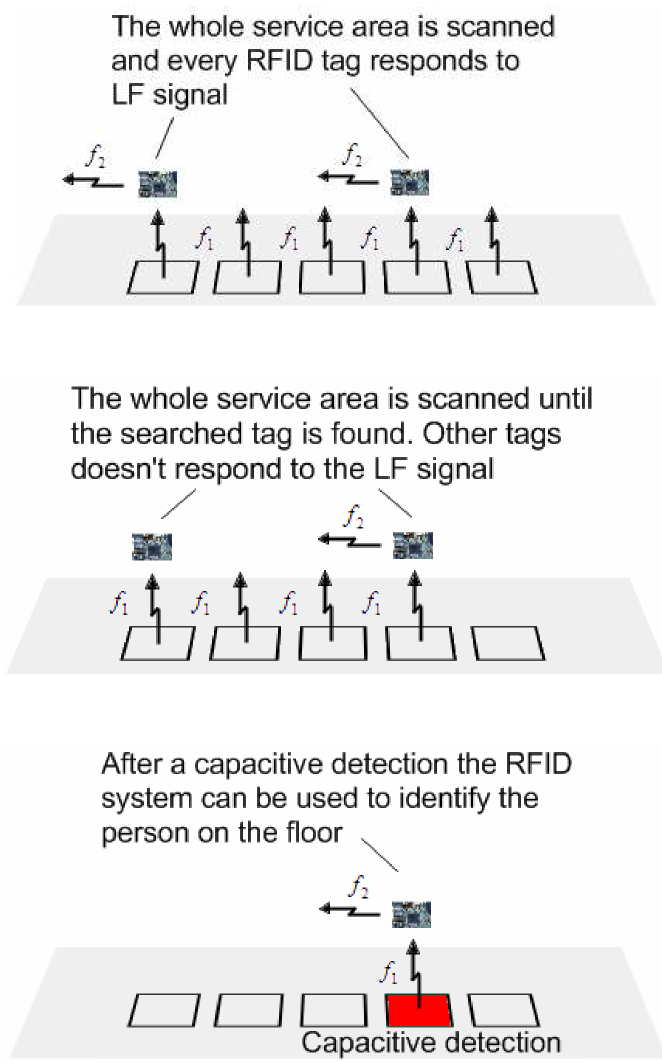

Fig. 18. Three different ways to use RFID localisation. f_1 is the LF signal and f_2 the HF signal

The simple prototype showed that it is possible to build a location system with floor quad antennas. The next step is to build a better prototype which uses the MUX units and has an LF data rate closer to 4 kbit/s. There is also a need to create a network and controlling system that would bond the rooms with NFI-RFID together. At the moment the NFI system uses CAN (Controller Area Network) to connect the rooms with the central unit [9].

Since the coverage area of the LF antenna was so wide when the MAS9180 was used it was decided that the next prototype will be built with the AS3931 as its LF transceiver so as to achieve better data rates. With a better receiving antenna the coverage area of the LF system should be wide enough.

VI. ACKNOWLEDGEMENTS

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