

# Aspects of Dedicated Dormant Chip for Intelligent Part Handling by Industrial Robots

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**Abstract:** The identification on spatial location and orientation of objects are strongly enhancing their manipulation by industrial robots performing in manufacturing environments. This paper presents design concepts, geometrical analysis and practical solutions towards the development of a dedicated dormant microchip suggested for such performance. The proposed design is utilized to construct and test the object dedicated dormant chip. Specific circuit design and determination of object identity, location and orientation are presented. The use of signal detection, directional antennae and electromagnetic energy transfer and storage is discussed.

**Keywords:** dormant chip, data transfer, industrial robots

## 1 Introduction

A bar-coding system, used to tag manufactured and handled objects is widely implemented with no ability to define object's location and orientation. Those requirements are vital for improved and efficient manipulation of such objects by industrial robots for assembly and other handling operations.

The GPS system and the Russian GLONA system provide such ability for remote location. Those systems fail in a manufacturing/discrete part production environment, because of accuracy below the required for such operation.

Interferometry on the other hand makes use of very high frequencies to detect the thickness of Silicon layers in epitaxial growing processes. Its accuracy is in the range of a few nano meters. It works good for lengths shorter than  $\lambda$  (1 wavelength). In the manufacturing environment, however, it will not produce a unique solution.

To find the position and orientation in a manufacturing environment, the ability to separate the unreflected received signal from reflected one is vital. The paper proposes a system that provides the ability to determine the identity, the position and the orientation of a remote object, tagged with a dormant chip. This system "filters" out reflected waves through the use of directional antennae.

The work presented describes concepts pertaining to the dormant chip, identifying the chip and finding its position and orientation. An analysis of some parts of the system is discussed. Experimental procedure and some results are included.

## 2 Design Concepts

The system proposed in this paper consists of a number of parts. The main related problem can be summed up as follows: sufficient power must be "transferred" to a dormant chip to allow for the transmission of signals that can be interpreted as data for the identity, position and orientation of the dormant chip. The design concepts are addressed to include appropriate solutions. Such concepts deal with problems related to electromagnetic energy transmission and receiving circuits, data transfer capability and online representation and computations required for position and orientation values.

### 2.1 The Dormant Chip

The purpose of the dormant chip is to transmit information about the identity, position and orientation of the object it

represents, on demand. The dormant chip is most of the time in an "off" state. A magnetic field with a specific frequency "awakens" the dormant chip which "draws" energy from the magnetic field. The magnetic energy is converted to electrical energy and stored in a capacitor till a high enough voltage is available to enable the dormant chip to transmit a frequency modulated (FM) signal.

The top section of Figure 1 shows the magnetic energy conversion to electrical energy and its storage in a capacitor. The frequency is determined by the values of L and C<sub>1</sub> according to

$$f = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C_1}}$$

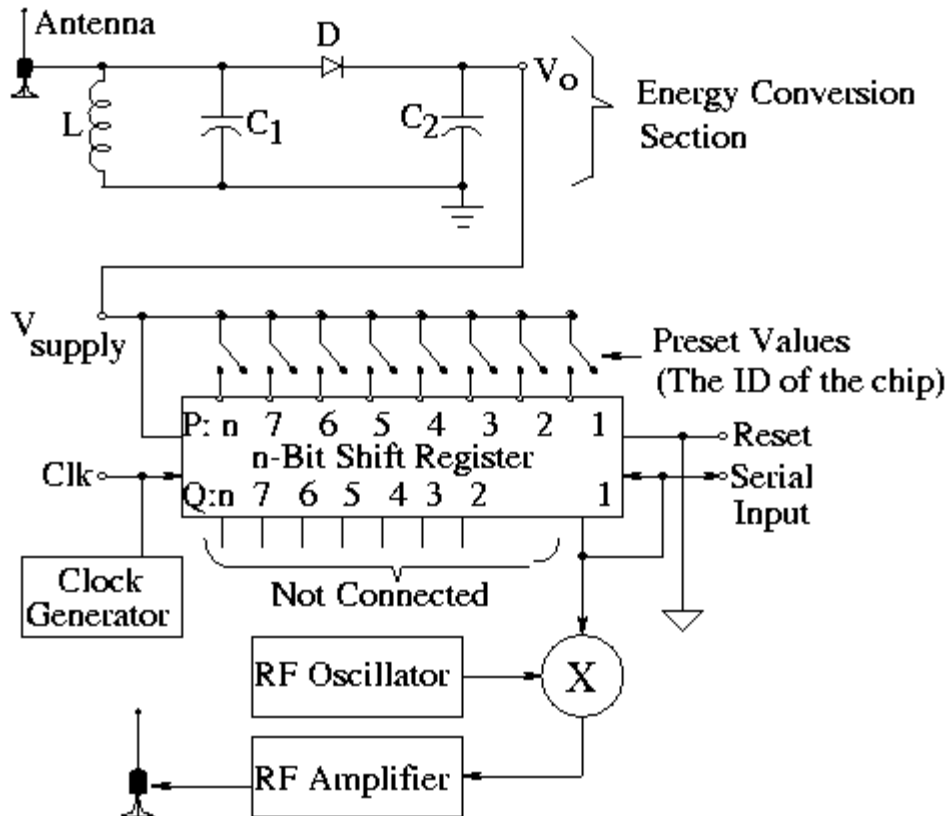


Figure 1: Functional block diagram of the dormant chip with an energy conversion section and a section that contains and transmits identification details (ID).

### 2.2 Part Identification

The FM signal transmitted by the dormant chip contains a digital number unique to each dormant chip, being the ID of the dormant chip. It transmits *only* this code. Other information (such as the type of object, the weight, etc) is encoded in a database under the unique ID of each dormant chip and can be accessed when needed. This concept is practically known. There are already a large number of commercial systems available to *identify* objects remotely.

The proposed ID data storage is included in Figure 1, which shows a functional block diagram of the dormant chip. The dormant chip consists of two main sections: the energy conversion section and the transmitting section. The transmitting section starts transmitting when enough power is available. The ID of the dormant chip (or the preset values) is set during the manufacturing of the dormant chip. With each clock pulse the next bit of the preset values (starting with the value of P1) is

shifted to Q1. The values (a digital 0 or 1) are modulated and transmitted at a different frequency than that of the magnetic field surrounding the dormant chip.

### 2.3 Position finding

Extracting information about the position of the dormant chip from the transmitted signal is required. Determining the position of a radio frequency (RF) transmitter or receiver is simple (in principle) in a large environment, because the distances that the signal travels are long. With long distances the following assumptions can be used without compromising accuracy:

- The time of flight of a signal can be measured sufficiently accurate.
- The effect of reflections from objects in the environment can be ignored.

Systems like the Global Positioning System (GPS) make use of these assumptions to calculate the position of a GPS receiver by measuring the time of flight of signals traveling between satellites and the receiver.

In a manufacturing environment, however, these assumptions are not valid. To calculate the time in which an electromagnetic wave (the transmitted signal) covers a distance of 10m and less, time intervals of 33ns should be measured accurately. To obtain a position, accurate to a few millimeters, time differences of a few Pico seconds need to be counted (e.g.

$$t = \frac{s}{c} = \frac{10mm}{3 \cdot 10^8 m \cdot s^{-1}} = 10ps$$

). This is not yet possible.

Also the reflections in a small environment can not be discarded. If it is assumed that the reflection can be ignored when  $P_D \geq 100 \cdot P_R$ , (where  $P_D$  is the received signal strength of the unreflected wave and  $P_R$  the signal strength of the reflected wave) equation 1 must be true:

$$\frac{K}{r_D^2} \geq 100 \cdot \frac{K}{r_R^2} \quad (1)$$

(Where  $r_D$  is the length of the direct path and  $r_R$  that of the reflected path). Thus

$$r_D \leq \frac{r_R}{10}$$

For a value of  $r_D=3m$ , then  $r_R$  must be larger than 30m. The unreflected path distance can not be assumed to be ten times shorter than all reflected paths in a cell of  $3m^3$  (as in the experimental environment). Even if it is assumed that the reflections can be ignored when  $P_D \geq 10 \cdot P_R$ , equation 2 follows.

$$\frac{K}{r_D^2} \leq \frac{r_R}{\sqrt{10}} \approx \frac{r_R}{3} \quad (2)$$

This means for  $r_D=3m$ ,  $r_R$  must be larger than 9m. This requirement is also not satisfied.

Thus, objects that reflect electromagnetic waves (or RF-signals) have a significant influence in manufacturing environments. Reflected signals and unreflected signals interfere constructively or destructively with each other at the receiving end. Because the time difference between the arrival of the unreflected signal and the first reflected signal is so small, no distinction can be made as to which signal is received first. Thus the reflected signals can not be filtered out electronically.

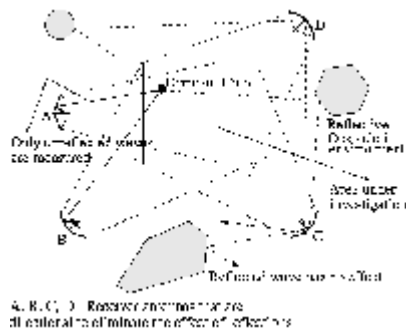


Figure 2: Schematic of the setup when measuring signal strength to calculate position.

Figure 2 shows a schematic representation of the system that measures received signal strength at different points in space equivalent to the distance that the signal traveled. The four receiver antennae "look" only at the square area. The distances are represented by voltages with specific amplitudes, measured at each receiver. A distance can be seen as the radius of a sphere with the center point as the receiver position. With four such radii and the known positions of the four receivers, the equation for each sphere can be obtained. To find the position of the dormant chip in three dimensions the point where all the spheres intersect is calculated (See section 3.1).

By using directional antennae at the receiving end of the system, only a specific defined area is being "looked" at by the receivers' antennae. This greatly reduces the effect of reflected waves. Eliminating reflected waves in this manner, the position of the dormant chip can be determined by measuring the transmitted signal strength at different points in the environment around the area of investigation. The position can also be determined by measuring the phase difference between signals received at different points.

The received signal strength,  $P_r$ , of an electromagnetic wave (See equation 3) is inverse proportional to the square of the distance that the signal traveled.

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The received signal strength,  $P_r$ , of an electromagnetic wave (See equation 3) is inverse proportional to the square of the distance that the signal traveled.

$$P_R = P_T \cdot G_T \cdot G_R \cdot \frac{\lambda^2}{4 \cdot \pi \cdot r^2} = \frac{K}{r^2} \quad (3)$$

$P_r$  = Received signal strength

$P_T$  = Transmitting power

$G_r$  = Receiver antenna gain

$G_T$  = Transmitter antenna gain

$\lambda$  = Wave length

$r$  = Distance between the chip and a receiver.

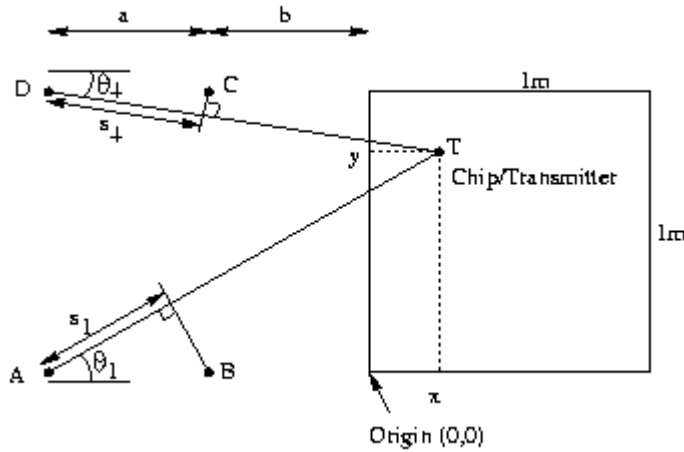


Figure 3: Schematic setup for measuring phase differences to calculate position.

$$r = \sqrt{\frac{K}{P_r}}$$

Thus

Measuring the phase difference between different received signals instead provides a faster numerical method to calculate the position of the dormant chip. Figure 3 shows this system' s setup. The phase differences between receivers A and B ( $\theta_{A-B}$ ) and receivers C and D ( $\theta_{D-C}$ ) are measured (See section 3.2.1). The angles  $\theta_1$ , and  $\theta_4$  are calculated with the phase differences known, since  $s_1$  and  $s_4$  are proportional to the phase differences. From these angles the equations of lines TA and TD can be determined. The intersecting point of these two lines provides the solution for the position of the dormant chip (See section 3.2).

### 2.4 Object Orientation

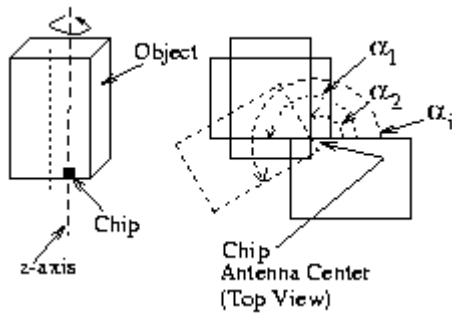


Figure 4: One degree of freedom is needed to find the orientation of an object with one dormant chip on it.

For an object, like the one in Figure 4, with the dormant chip at the indicated place, it can be concluded that the dormant chip is placed on the object, with its position known. An additional degree of freedom is needed to find the orientation of the

object. This degree of freedom is the angle ( $\alpha_i$ ) about the z-axis (in this case) that passes through the center of the dormant chip's antenna.

The best solution, however, requires the location of another similar dormant chip at another location on the same object. With both positions known and their respective locations on the object, the orientation of the object is calculated through calculating the angle of line  $\underline{KL}$  in Figure 5, with the x or y axis of the coordinate system. Thus the problem of finding the orientation of an object reduces to that of finding the position of a RF chip.

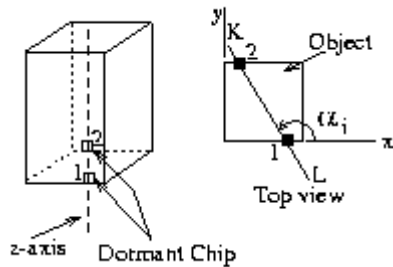


Figure 5: Two dormant chips solve the problem of finding the orientation.

### 3 Analysis

#### 3.1 Signal Strength Method

The signal strength is the amplitude of the measured voltages at the respective receivers. Figure 6 emulates from Figure 2. A, B, C and D are the receivers.  $R_1, R_2, R_3$  and  $R_4$  are the distances between the chip and each receiver, which are represented by the voltage measured at each receiver. These radii are those of four different spheres.

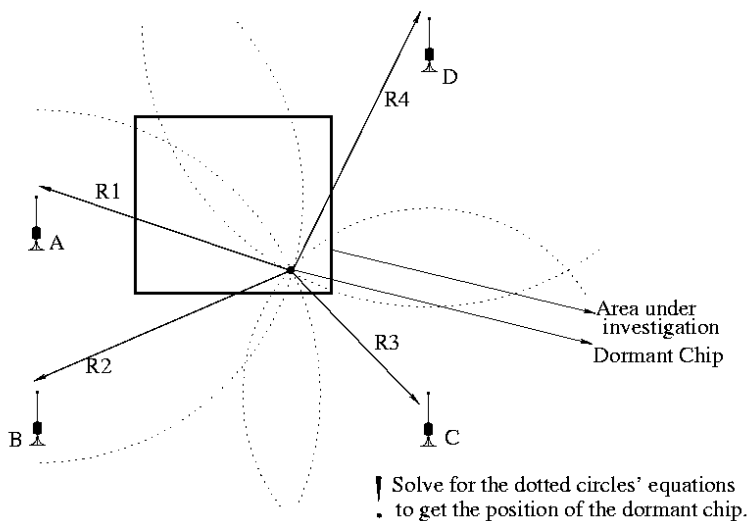


Figure 6: The intersecting point of the four spheres reveals the position of the dormant chip.

Suppose that the points where the receivers are, are given by points 4 to 7, then equations 9 to 12 represent the equations for the four spheres.

$$A(-2,1,2) \quad (4)$$

$$B(-2,-2,2) \quad (5)$$

$$C(4,-2,2) \quad (6)$$

$$D(4,4,2) \quad (7)$$

$$T(X_T, Y_T, Z_T) \quad (8)$$

$$(x - A_x)^2 + (y - A_y)^2 + (z - A_z)^2 = R_1 \quad (9)$$

$$(x - B_x)^2 + (y - B_y)^2 + (z - B_z)^2 = R_2 \quad (10)$$

$$(x - C_x)^2 + (y - C_y)^2 + (z - C_z)^2 = R_3 \quad (11)$$

$$(x - D_x)^2 + (y - D_y)^2 + (z - D_z)^2 = R_4 \quad (12)$$

Subtracting equations 10 from 9, 11 from 10 and 12 from 11, substituting the assumed values of **A**, **B**, **C** and **D** and writing it in matrix format, equation 13 is obtained. The position of the chip ( $T_x, T_y, T_z$ ) can be found by solving for x, y and z in equation 13.

$$\begin{bmatrix} 0 & 6 & 0 \\ -12 & 0 & 0 \\ 0 & -12 & 0 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} R_1 - R_2 - 3 \\ R_2 - R_3 - 12 \\ R_3 - R_4 - 12 \end{bmatrix} \quad (13)$$

This equation represents the set of linear equations that is used to solve for x, y and z simultaneously.

### 3.2 Phase Difference Method

Some receivers' positions in Figure 3 are given in Table 1. In two dimensions the position of the transmitter, ( $T_x, T_y$ ), is determined as follows:

Receivers	Position	Value
A	( $A_x, A_y$ )	$-(a+b), 0$
B	( $B_x, B_y$ )	$(-b, 0)$
C	( $C_x, C_y$ )	$(-b, 1)$
D	( $D_x, D_y$ )	$-(a+b), 1$

Table 1: Receiver positions for two dimensions

$\phi_{A-B}$  and  $\phi_{D-C}$  are measured, where  $\phi_{A-B}$  is the phase difference between the received signals at receivers A and B (See section 3.2.1). The distances  $s_1$  and  $s_4$  are given by equations 14 and 15.

$$s_1 = \frac{\phi_{A-B}}{360^\circ} \cdot \lambda \quad (14)$$

$$s_4 = \frac{\phi_{D-C}}{360^\circ} \cdot \lambda \quad (15)$$

The angles  $\theta_1$  and  $\theta_4$  are calculated in equations 16 and 17.

$$\theta_1 = \cos^{-1}\left(\frac{s_1}{a}\right) \quad (16)$$

$$\theta_4 = \cos^{-1}\left(\frac{s_4}{a}\right) \quad (17)$$

Equations 18 to 23 represent equations needed for lines TA and TD definition.

$$m_1 = \tan^{-1}(\theta_1)$$

$$c_1 = A_y - m_1 \cdot A_x = m_1 \cdot (a + b)$$

$$y_A = m_1 \cdot x + c_1$$

$$m_4 = \tan^{-1}(\theta_4)$$

$$c_4 = D_y - m_4 \cdot D_x = m_4 \cdot (a + b)$$

$$y_D = m_4 \cdot x + c_4$$

For  $y_A = y_D$ , the values of x and y can be calculated from equations 20 and 23. These equations are shown in matrix format in equations 24 and 25.

$$\begin{bmatrix} -m_1 & 1 \\ -m_4 & 1 \end{bmatrix} \cdot \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} c_1 \\ c_4 \end{bmatrix} \quad (24)$$

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} c_1 - c_4 \\ m_4 \cdot c_1 - m_1 \cdot c_4 \end{bmatrix} \quad (25)$$

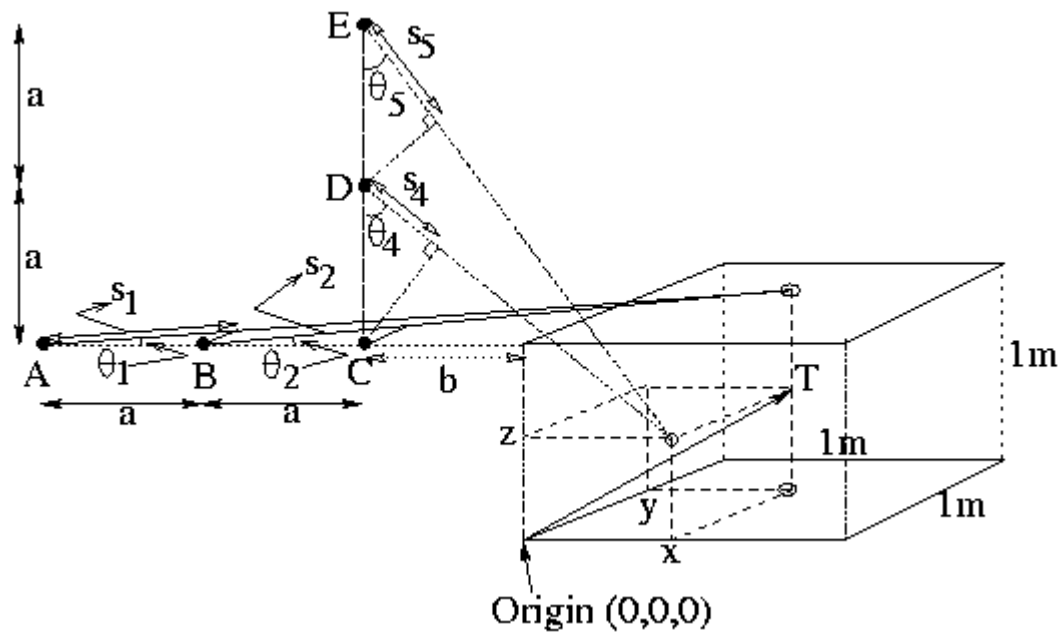


Figure 7: Schematic setup (Figure 3) for a three dimensional case.

Receivers	Position	Value
A	$(x_1, y_1, z_1)$	$(-(2a+b), 0, 1)$
B	$(x_2, y_2, z_2)$	$(-(a+b), 0, 1)$
C	$(x_3, y_3, z_3)$	$(-b, 0, 1)$
D	$(x_4, y_4, z_4)$	$(-b, 0, 1+a)$
E	$(x_5, y_5, z_5)$	$(-b, 0, 1+2a)$

Table 2: Receiver positions for a three-dimensional setup.

Figure 7 indicates schematically the use of this method for a three dimensional case. With receivers' positions given in Table 2 and following the same procedure as in the two-dimensional calculations, equations 26 and 27 are derived to solve for the x, y and z coordinates of the dormant chip.

$$\begin{aligned} \begin{bmatrix} x \\ y \end{bmatrix} &= \begin{bmatrix} 1 & -1 \\ m_2 & -m_1 \end{bmatrix} \cdot \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} \\ &= \begin{bmatrix} c_1 - c_2 \\ m_2 \cdot c_1 - m_1 \cdot c_2 \end{bmatrix} \end{aligned} \quad (26)$$

$$\begin{aligned} \begin{bmatrix} x \\ y \end{bmatrix} &= \begin{bmatrix} 1 & -1 \\ m_5 & -m_4 \end{bmatrix} \cdot \begin{bmatrix} c_4 \\ c_5 \end{bmatrix} \\ &= \begin{bmatrix} c_4 - c_5 \\ m_5 \cdot c_4 - m_4 \cdot c_5 \end{bmatrix} \end{aligned} \quad (27)$$

### 3.2.1 Phase Difference Computation

Figure 8 indicates the calculation of the phase difference between two signals. The two received signals are multiplied and then passed through a low pass filter. If the received signals are  $f_1(t)=A_1 \cos(\omega t)$  and  $f_2(t)=A_2 \cos(\omega t + \phi)$ , the output of the circuit in Figure 8 is  $\frac{1}{2} \cdot A_1 \cdot A_2 \cdot \cos(\phi)$ .

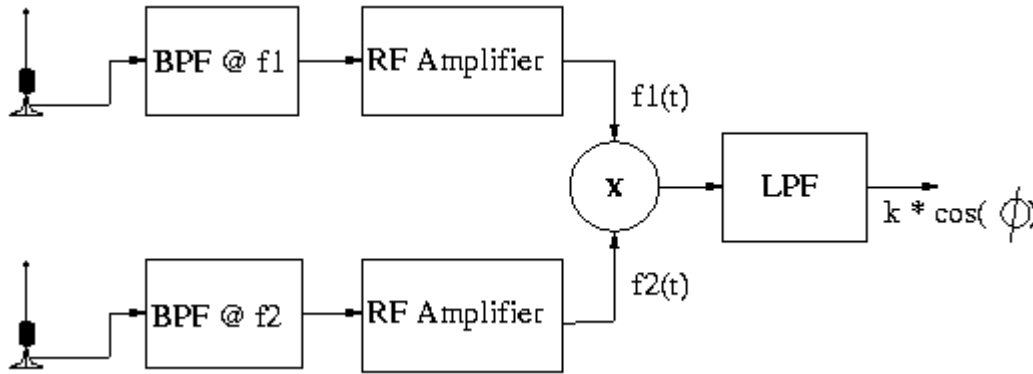


Figure 8: Block diagram for the calculation of the phase difference between two signals.

This result can be obtained by applying Equations 28, 29 and 30 to equation 31 and passing it through a low pass filter.

$$\begin{aligned} \cos(A + B) &= \cos A \cdot \cos B - \sin A \cdot \sin B \\ \cos A \cdot \cos B &= \frac{1}{2} [\cos(A + B) + \cos(A - B)] \\ \sin A \cdot \cos B &= \frac{1}{2} [\sin(A + B) + \sin(A - B)] \\ f_1 \cdot f_2 &= A_1 \cdot A_2 [\cos(at) \cdot \cos(at + \phi)] \end{aligned} \quad (28)...(31)$$

#### 4 Experimental procedure and results

Figure 10 details a flow diagram of the data transfer and data processing of the system that measures phase differences to calculate the position of the dormant chip. The main controller performs all the calculations and functions as a server on the Internet. The control interface is written in JAVA and C.

A low frequency system, functional in two dimensions, has been designed. This systems uses wound loop antennae (Figure 9) to determine the position of a dormant chip. The phase differences between the antennae determine in which quadrant the dormant chip is and the amplitude of the voltages indicate the distances from the center lines of antennae X and Y. Smaller size antennae were build and tested. Experimentation at low frequencies (100-1000kHz) reveals that the range of the loop antennae is only a few centimeters. As the frequency increases, the antennae get more efficient and the range increases.

The low frequency system assumes that the dormant chip is near the plane of the loop antenna.

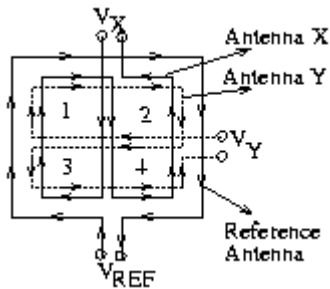


Figure 9: Wind pattern of the loop antennae for a low frequency system

In three dimensions this assumption is invalid because the voltage is *also* a function of the distance between the dormant chip and the antenna plane and the orientation of the dormant chip relative to this plane. Therefore this system would not be useful in a three dimensional environment. This low frequency system can however be implemented together with a RFID system from Philips that has been set up in the laboratory. The latter system works also at a low frequency (125kHz) and makes use of a loop antenna. This implementation is able to determine the *identity* and the two dimensional *position* of a dormant chip.

Higher frequencies enable three-dimensional functionality, but at high frequencies (30MHz and up) circuit design and layout are difficult since nearly every conductor becomes an antenna. Also reflections from obstacles in the environment start to influence measurement. To eliminate these reflections the antennae (not loop antennae any more) would be designed to "look" only at the specific area of interest. This directivity of the antennae forms a basic assumption on which the frequency system functions. A high frequency system with the same functional blocks as in the receiver and dormant chip sections of Figure 10 was designed. These blocks are available for different frequencies except for the part that awakens the dormant chip.

A circuit to test the power transfer to the dormant chip at low frequencies was build and tested. The circuit is similar to the one that forms the energy conversion part of Figure 1 except that it uses a loop antenna.  $L$  and  $C_1$  form an oscillating circuit that oscillates at the frequency of the generated magnetic field. The current in the  $LC_1$ -part of the circuit is rectified and stored in a capacitor ( $C_2$ ). The antennae were scaled down for the experiment. A maximum voltage of 2V was successfully stored in the capacitor.

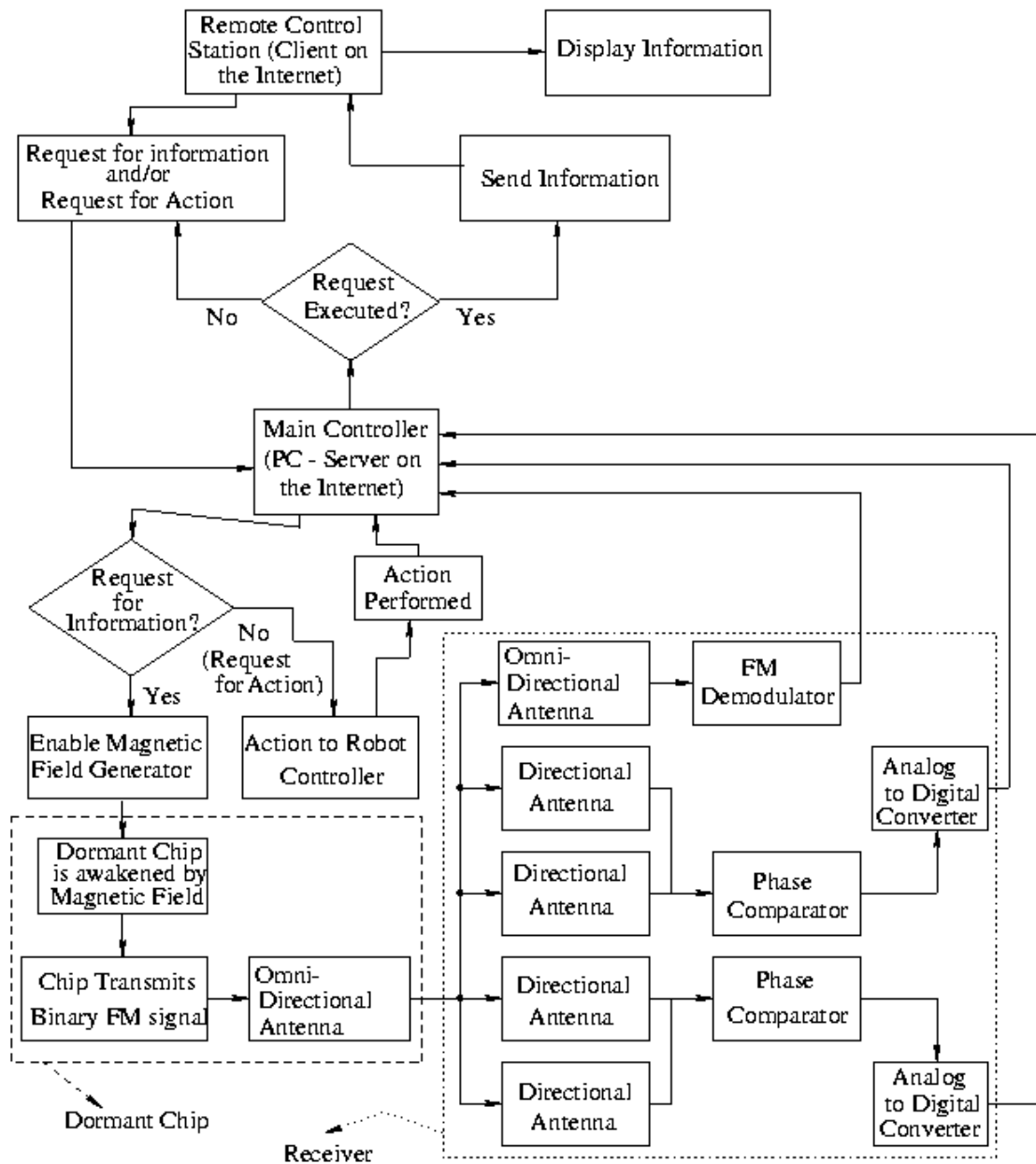


Figure 10: Flow diagram of the data transfer and data processing of the system.

At high frequencies (30MHz and up) circuit layout gets difficult. But at this frequencies antennas can be designed to be very directional. Also the dormant chip antenna can be designed to be smaller, but still effective.

A circuit to test the power transfer to the dormant chip at low frequencies has been build and tested. The antennas were scaled down for the experiment. A maximum voltage of 2V could be stored in capacitor  $C_2$  of figure 1.

## 5 Summary

Remote radio frequency identification (RFID), that makes use of a dormant chip, is nothing new. However, the ability to

sense the position and orientation in a manufacturing environment has not yet been solved satisfactory.

A method to determine the identity, the position and the orientation of an object by means of a dormant chip is being investigated. This system has to deal with the problem of reflected radio frequency waves. The problem is overcome by equipping the receivers with directional antennas. This significantly reduces the effect of reflected waves. The position of the dormant chip is then determined by measuring the strength of the received signal at different points in space or by measuring the phase difference between signals received at different points in space. Although this system requires that line of sight exist between the dormant chip and the receivers, it is developed for applications in the field of industrial robots. The robot need line of sight between the tool center point and the working object to manipulate the object.

Integrating the ability to sense position and orientation into a robot-operating environment will improve robot-related actions. This, for example, will enable a robot, with only the information of a CAD, to "programme" itself. This means that such a system will be able to eliminate the erroneous training time.

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