Human Activity Tracking using RFID Tags

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ABSTRACT:
Human activity tracking using RFID tags is attractive for many applications since it allows unobtrusive and passive estimation of people's activities. This paper focus on how to customize commonly available RFID technology to obtain orientation estimates of human activity in the field of RFID emitter coils. This enables the accurate estimation of human activity tracking for application domains such as retail, home-care, work place-safety, military, manufacturing and others.
Keywords: RFID, Tracking Systems, Security Systems, Surveillance Systems

1. Introduction:

Successful applications of human activity tracking approaches are becoming more and more widespread. For example, tracking of surveillance has emerged as a feasible and reliable technology and has firmly established itself in the security industry.
Unfortunately, for many applications for which passive human activity tracking would be of great interest, the development of reliable solutions is still difficult. Examples of such applications are theft prevention retail stores, fraud prevention in casinos, workplace safety monitoring, image guided assembly, quality assurance in manufacturing and self-medication monitoring in elder care.
This paper presents the human activity tracking with Radio Frequency Identification (RFID) tag technology that helps in tracking the human motion. RFID tags are inexpensive, bar-code sized stickers that contain an antenna and a microchip that can be sensed wirelessly by an RFID reader.

Information on RFID tags usually contains at least a unique id. The information can be
read and sometimes written at distances of up to 30 feet, depending on the system. RFID has become widespread in retail and shipping where it is used as an alternative to bar codes to detect and identify products and shipments.
An RFID-based detector determines the presence and activity of human beings (equipped with RFID tags) in the field of view of one or more RF field emitter coils.

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2. Reader, Interrogator:

RFID reader is used to activate passive tag with RF energy and to extract information from the tag.
For this function, the reader includes RF transmission, receiving and data decoding sections. In addition, the reader includes a serial (RS-232) capability to communicate with the host computer. Depending on the complexity and purpose of applications, the reader's price range can vary from ten dollars to a few thousand of dollars worth of components and packaging.
The RF transmission section includes and RF carrier generator, antenna and a tuning circuit. The antenna and its tuning circuit must be properly designed and tuned for the best performance.
Data decoding for the received signal is accomplished using a microcontroller. The firmware algorithm in the microcontroller is written in such a way to transmit the RF signal, decode the incoming data and communicate with the host computer.
Typically reader is always read only device, while the reader for read and write device is often called interrogator. Unlike the reader for read only device, the interrogator uses command pulses to communicate with the tag for reading and writing data.

3. TAG:

Tag consists of a silicon device and antenna circuit.
The purpose of the antenna circuit is to reduce an energizing signal and to send a modulated RF signal. The read range of tag largely depends upon the antenna circuit and size.
The antenna circuit of tag is made of LC resonant circuit or E-field dipole antenna, depending on the carrier frequency. The LC resonant circuit is used for the frequency less than 100 MHz. In this frequency band, the communication between the reader and tag takes place with magnetic coupling between the two antennas through magnetic field. The antenna utilizing the inductive coupling is often called magnetic dipole antenna.
The antenna circuit must be designed such a way to maximize the magnetic coupling between them. This can be achieved with the following parameters:

a) LC circuit must be tuned to the carrier frequency of the reader.
b) Maximize Q of the tuned circuit.
c) Maximize antenna size within physical limit application requirement.

When the frequency goes above 100 MHz, the requirement of LC values for its resonant frequency becomes too small to realize with discrete L and C components. As frequency increases, the wavelength is getting shorter. In this case, a true E-field antenna can be made of a simple conductor that has linear dimension less than or equivalent to half (1/2) the wavelength of the signal. The antenna that is made of a simple conductor is called electric dipole antenna. The electric dipole antenna utilizes surface current that is generated by an electric field (E field). The surface current on the current produces voltage at load. This voltage is used to energize the silicon device. Relatively simple antenna structure is formed for the higher frequency compared to the lower frequency.

4. Read-Only Device, Read/Write Device:

For the read only device, the information that is in the memory can’t be changed by RF command once it has been written.

Read only devices are programmed as follows: (a) in the factory as a part of manufacturing process, (b) contactlessly programmed one time after the manufacturing or (c) ca be programmed and also reprogrammed in contact mode.

A device with memory cells that can be reprogrammed by RF commands is called read/write device. The information in the memory can be reprogrammed by Interrogator command.

Memory in today’s RFID device is made of (a) CMOS or (b) FRAM array. The CMOS memory cell needs higher voltage for writing than reading. In the passive read/write device, the programming voltage is generated by multiplying the rectified voltage. The voltage multiplier circuit is often called a Charge pumper. In addition to the programming voltage the read/write device needs command decoder and other controller logics. As a result the read/write device needs more circuit building blocks than that of the read only device. Therefore, the device size is larger and cost more than a read only device. The FRAM device needs the same voltage for reading and writing. However, its manufacturing cost is much higher than CMOS technology. Most of RFID device available today’s market place are CMOS based device.

5. Read/Write Range:

Read/write range is a communication distance between the reader (interrogator) and tag. Specifically, the read range is a maximum distance to read data out from the tag and write range is the maximum distance to write data from the interrogator to tag. The read/write range is related to:

(1) Electromagnetic coupling of the reader (interrogator) and tag antennas,
(2) RF output power level of reader (interrogator),
(3) Carrier frequency bands,
(4) Power consumption of device etc.,

The electromagnetic coupling of reader and tag antennas increases using similar size of antenna with higher Q in both sides. The read range is improved by increasing the carrier frequency. This is due to the gain in the radiation efficiency of the antenna as the frequency increases. However, the disadvantage of high frequency (900 MHz-2.4 GHz) application is shallow skin depth and narrower antenna beam width. These cause less penetration and more directional problem, respectively. Low frequency application, on the other hand has advantage in the penetration and directional, but a disadvantage in the antenna performance.

The read range increases by reducing the current consumptions in the silicon device. This is because additional radiating power is available by reducing the power dissipation in the silicon device.

6. Modulation Protocol:

The passive RFID tag uses backscattering of the carrier frequency for sending data from the tag to reader. The amplitude of backscattering signal is modulated with modulation data of the tag device. The modulation data can be encoded in the form of ASK (NRZ or Manchester), FSK or PSK. Therefore, the modulation signal from the tag is Amplitude-Amplitude, Amplitude-FSK and Amplitude-PSK.

7. Carrier:

Carrier is the transmitting radio frequency of reader (interrogator). This RF carrier provides energy to the tag device, and is used to detect modulation data from the tag using backscattering. In read/write device, the carrier is also used to deliver interrogator’s command and data to the tag.

Typical carrier frequencies are:

a) 125 kHz-400 kHz
b) 4 MHz-24 MHz
c) 900 MHz-2.45 GHz.
d) The frequency bands must be selected carefully for applications because each one has its own advantages and disadvantages. Table 1 shows the characteristic of each frequency bands.

TABLE 1:

Frequency Bands	**Antenna components**	**Read Range(typical)**	**Penetration(skin depth)**	**Orientation (directionality)**	**Usability in metal or humid environment**	**Applications (typical)**
Low Frequency (125-400)kHz	Coil(>100 turns) and capacitor	Proximity (8”)	Best	Least	Possible	Proximity
Medium Frequency (4-24 MHz)	Coil(<10 turns) and capacitor	Medium (15”)	Good	Not much	Possible	Low cost and high volume
High Frequency (>900 MHz)	E-field dipole (a piece of conductor)	Long (>1m)	Poor	Very high	Difficult	Line of sight with long range

8. System Handshake:

Typical handshake of a tag and reader (interrogator) is as follows:

A. Read Only Tag:

1. The reader continuously transmits RF signal and watches always for modulated backscattering signal.
2. Once the tag has received sufficient energy to operate correctly, it begins clocking its data to a modulation transistor, which is connected across the antenna circuit.
3. The tag’s modulation transistor shorts the antenna circuit, sequentially corresponding to the data which is being clocked out of the memory array.
4. Shorting and releasing the antenna circuit accordingly to the modulation data causes amplitude fluctuation of antenna voltage across the antenna circuit.
5. The reader detects the amplitude variation of the tag and uses a peak-detector to extract the modulation data.

B. Read and Write Tag

1. The interrogator sends a command to initiate communication with tags in the fields. This command signal is also used for energizing the passive device.
2. Once the tag has received sufficient energy and command, it responses back with its ID for acknowledgement.
3. The interrogator now knows which tag is in the field. The interrogator sends a command to the identified tag for what to do next: processing (read or write) or sleep.
4. If the tag receive processing and reading commands it transmits a specified block data and waits for the next command.
5. If the tag receives the processing and writing commands along with the block data, it writes the block data into the specified memory block, and transmits the written block data for verification.
6. After the processing, the interrogator sends an “end” command to send the tag into the sleep (“silent”) mode.
7. If the device receives “end” command after processing, it sends an acknowledgement (8-bit preamble) and stays in sleep mode. During the sleep mode, the device reminds in non-modulating (detuned) condition as along as it remains in the power- up. This time the handshake is over.
8. The interrogator is now looking for the next tag for processing, establishes a handshake and repeats the processing.

9. Backscatter Modulation:

This terminology refers to the communication method used by a passive RFID tag to send data to the reader using the same reader's carrier signal. The incoming RF carrier signal to the tag is transmitted back to the reader with tags data.
The RF voltage induced in the tags antenna is amplitude-modulated by the modulation signal (data) of tag device. This amplitude-modulation can be achieved by using a modulation transistor across LC resonant circuit or partially across the resonant circuit.
The changes in the voltage amplitude of tags antenna can effect on the voltage of the reader antenna. By monitoring the changes in the reader antenna voltage (due to the tags, modulation data), the data in the tag can be reconstructed.
The RF voltage link between reader and tag antennas are often compared to weakly coupled transformer coils; as the secondary winding (tag coil) is momentarily shunted, the primary winding (reader coil) experiences a momentary voltage drop.

10. Data Encoding:

Data encoding refers to processing or altering the data bit stream in-between the time it is retrieved from the RFID chips data array and its transmission back to the reader. The various encoding algorithms effect error recovery cost of implementation, bandwidth synchronization capability and other aspects of the system design. Entire text books are written in the subject, but there are several popular methods used in RFID tagging today:

1. **NRZ (Non-Return to Zero) Direct**: In this method no data encoding is done at all; the 1's and 0's are clocked from the data array directly to the output transistor. A low in the peak-detected modulation is a "0" and a high is a "1".
2. **Differential Biphase**. Several different forms of differential biphase are used, but in general the bit stream being clocked out of data array is modified so that a transition always occurs on every clock edge, and 1's and 0's are distinguished by the transition within the middle of the clock period. This method is used to embed clocking information to help synchronize the reader to the bit stream. Because it always has a transition at a clock edge, it inherently provides some error correction capability. Any clock edge that does not contain a transition in the data stream is in error and can be used to reconstruct the data.
3. **Biphase_L (Manchester):** This is a variation of Biphase encoding in which there is not always a transition at the clock edge.

11. DATA MODULATION FOR 125 Khz DEVICES:

Although all the data is transferred to the host by amplitude-modulating the carrier (backscatter modulation), the actual modulation of 1's and 0's is accomplished with three additional modulation methods:

1. Direct: In direct modulation, the Amplitude modulation of the backscatter approach is the only modulation used. A high in the envelope is a '1' and a low is a '0'. Direct modulation can provide a high data rate but low noise immunity.
2. FSK (Frequency Shift Keying): This form of modulation uses two different frequencies for data transfer; the most common FSK mode is FC/8/10. In other words, a '0'is transmitted as amplitude-modulated clock cycle with period corresponding to the carrier frequency divided by 8, and a '1' is transmitted as an amplitude-modulated clock cycle period corresponding to the carrier frequency divided by 10. The amplitude modulation of the carrier thus switches from FC/8 to FC/10 corresponding to 0's and 1's in the bit stream and the reader has only to count cycles between the peak-detected clock edges to decode the data. FSK allows for a simple reader design, provides very strong noise immunity, but suffers from a lower data rate than some other forms of data modulation.
3. PSK (Phase Shift Keying): This method of data modulation is similar to FSK, except only one frequency is used, and shift between 1's and 0's is accomplished by shifting the phase of the back scatter clock by 180^0. Two common types of PSK are:
   - Change phase at any '0', or
   - Change phase at any data change (0 to 1 or 1 to 0).

PSK provides fairly god noise immunity, a moderately simple reader design, and a faster data rate than FSK. Typical applications utilize a backscatter clock of FC/2.

12. Anti Collision:

In many existing applications, a single-read RFID tag is sufficient and even necessary: animal tagging and access control are examples. However, in a growing number of new applications, simultaneous reading of several tags in the same RF field absolutely critical: library books, airline baggage, garment and retail applications are a few. In order to read multiple tags simultaneously, the tag and reader must be designed to detect the condition that more than one tag is active. Otherwise, the tags will all backscatter carriers at the same time and the amplitude-modulated waveforms. This is referred to as collision.

No data would be transferred to the reader. The tag/reader interface is similar to a serial bus, even though the "bus" travels through the air. In a wired serial bus application, arbitration is necessary to prevent bus contention. The RFID interface also requires arbitration so that only one tag transmits data over the "bus" at one time.
A number of different methods are in use and in development today for preventing collisions; most are patented or patent pending. Yet, all are related to making sure that only one tag "talks" (backscatters) at any one time.

13. RFID Activity Recognition System (Prototype):

The purpose of the RFID tracking unit is to detect the presence, movements and orientation of RFID tags in 3D space. The components required to obtain this information are one or more RF coil antennas, each aligned to a plane, an off the shelf RFID reading system and some custom circuitry. RFID reader is modified to obtain the Voltage level values emitted from the RFID tags.

RFID tags serves as small capacitors, where the antenna field energy is used to charge the tag. The antennas periodically switch off, during which the energy in the tags is used to emit data back to the field coils. The release of the energy is modulated and communicates the tag serial number to the reading unit. The amount of charge that each RFID tag receives depends on the tag normal with respect to the antenna field. If the tag normal is parallel to the antenna coils it receives the maximum amount of energy. If it is perpendicular it receives no energy. Based on this dependency the received signal will be captured to roughly estimate the position and orientation of RFID tags.

The orientation estimate of tags increases with the number of used antennas. With only a single antenna, only a single angle of the tag relative to the antenna plane can be estimated. With four antennas, the orientation of a tag can be determined completely.

The system requires the following Hardware & Software to detect the signals from the Tag coming from different directions:

Hardware:
RFID Reader unit,
Tag (employee)
Digital Storage Oscilloscope (To record the signal strength)
Personal Computer or Laptop

Software:
Keil uv2 IDE,
A51 assembler
RFID Reader consists of:
AT 89s52
CLRC 632 Multiple Protocol Contact less Reader IC
Antenna Circuit

14. Practical Observations:

Passive RFID tags work in such a way that they are actually powered by an external signal, which, in most cases is the carrier signal from the tag reader circuit. These tags are fairly simple and are comprised of merely an L-C antenna. The reader and tag communicate using magnetic coupling since their respective antennas can sense changes in magnetic field, which is observed as a change in voltage in the reader circuit.

The tags operate at a 125 KHz carrier frequency and it could have a tag size anywhere between 26 and 128 bits long.

The modulation type used in the cards is Frequency Shift Keying (FSK), one of the more common ways used in RFID. FSK modulates the signal by essentially multiplying a lower amplitude, lower frequency signal with the carrier signal, creating an AM-like effect; the lower frequency enveloping the carrier frequency. To switch between a "1" and a "0", the tag switches the modulating frequency. The two frequencies used by the cards were 12.5 KHz (125 KHz/10) and 15.625 KHz (125 KHz/8), which correspond to 1 and 0 respectively. The modulation produces an effect that looks similar to the figure below:

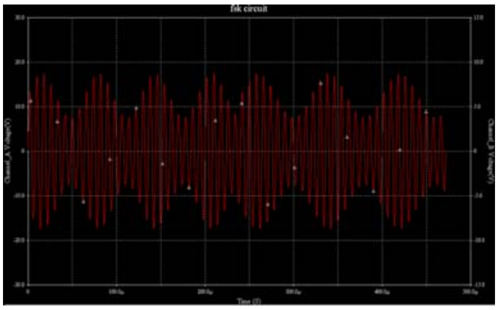


Fig 1: Simulation of FSK Modulation with Modulation Frequencies of 12.5 and 15.625 KHz and Carrier Frequency of 125 KHz

The job of the reader circuit is to provide the 125 KHz carrier frequency, transmit that to the tag, and detect the magnetic coupling from the tag, which should look like the figure above. In order to interpret this data, the carrier frequency must be removed, and the enveloping frequencies must be magnified into something measurable.

When the RFID tag approaches the reader, the amplitude of the received signal will be high when compared to the amplitude of the same as the RFID tag moves away from the reader.

The following signals are recorded for four different positions of the RFID tag from the RFID reader and we can very clear observe the variations in the received signal amplitude.

Case 1: The amplitude of the received signal by the RFID reader is maximum since the tag is at very close proximity to the reader.(See Fig 2) Measured Values: Vpp = 10.1 volts Distance of the tag from the reader= 5cm

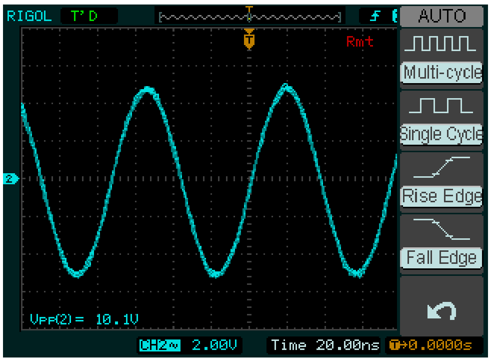


Fig 2: Modulated carrier signal when the RFID tag is brought near to the RFID reader.

Case 2: The amplitude of the received signal decreases as the tag moves away from the reader. (see Fig 3)
Measured Values:
Vpp = 9.92 volts
Distance of the tag from the reader= 8cm

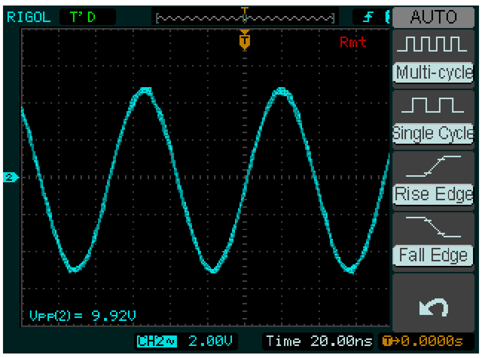


Fig 3: Modulated carrier signal when the RFID tag is moving away from the RFID reader

Case 3: The amplitude of the received signal decreases as the tag moves away from the reader. (See Fig 4)
Measured Values:
Vpp = 8.32 volts
Distance of the tag from the reader= 11cm

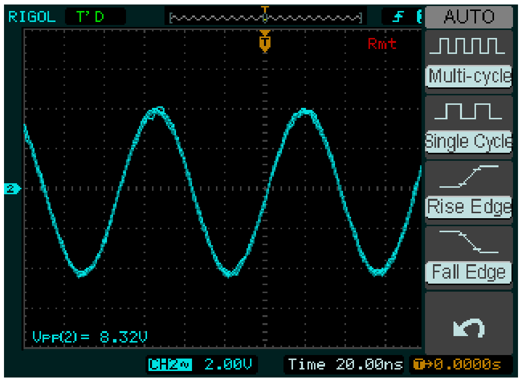


Fig 4: Modulated carrier signal when the RFID tag is moving away from the RFID reader

Case 4: The amplitude of the received signal decreases as the tag moves away from the reader. (See Fig 5)
Measured Values:
Vpp = 6.88volts
Distance of the tag from the reader= 14cm

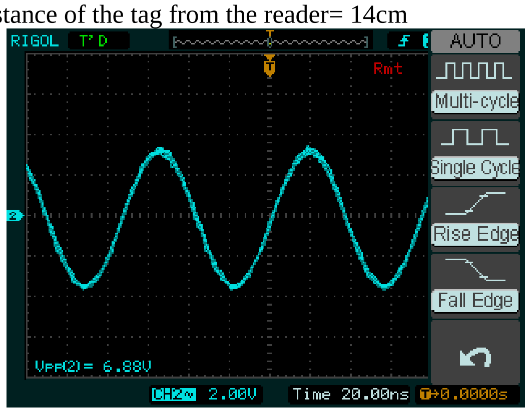


Fig 5: Modulated carrier signal when the RFID tag is moving away from the RFID reader

Case 5: The amplitude of the received signal again increases as the tag moves to the reader from different direction. (See Fig 5)
Measured Values:
V_{pp} = 9.92 volts
Distance of the tag from the reader= 5.5cm

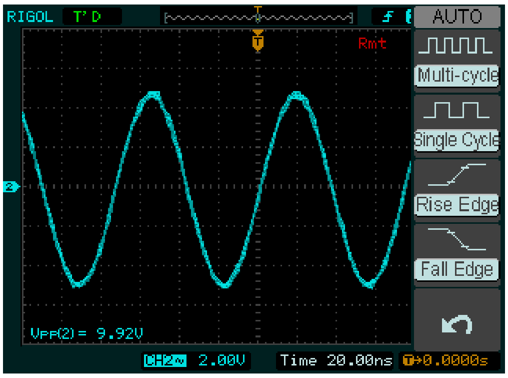
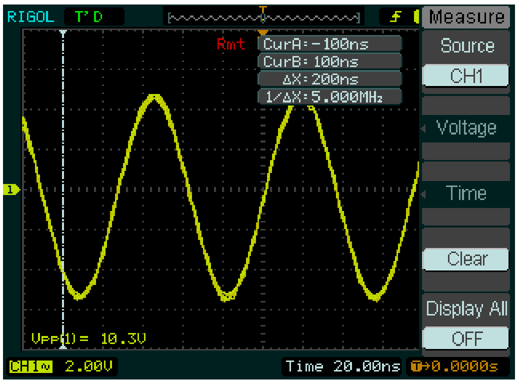


Fig 5: Modulated carrier signal when the RFID tag is brought near to the RFID reader in other direction.

Case 6: The amplitude of the received signal by the RFID reader is maximum since the tag is at very close proximity to the reader.(See Fig 6) Measured Values: V_{pp} = 10.3 volts Distance of the tag from the reader= 5cm



Case 7: The amplitude of the received signal decreases as the tag moves away from the reader. (See Fig 7)
Measured Values:
V_{pp} = 8.80 volts
Distance of the tag from the reader= 11cm

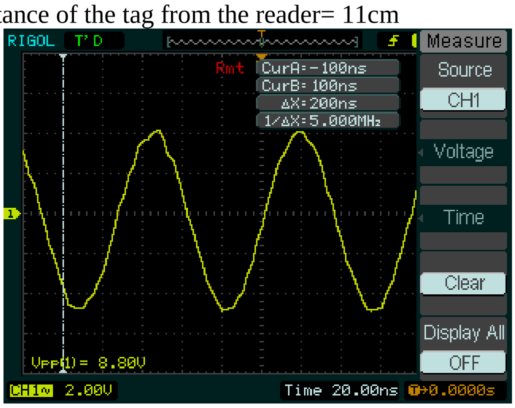
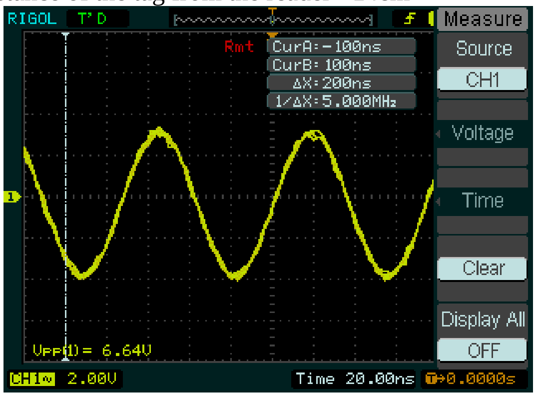
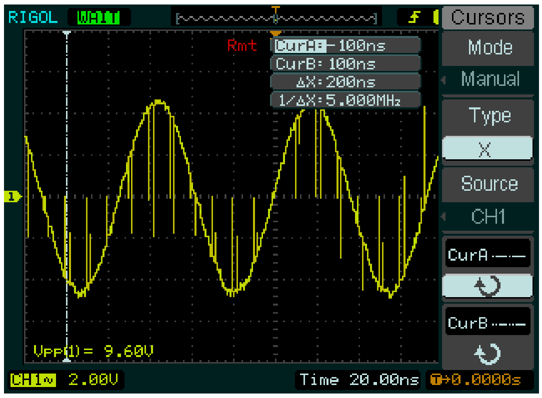


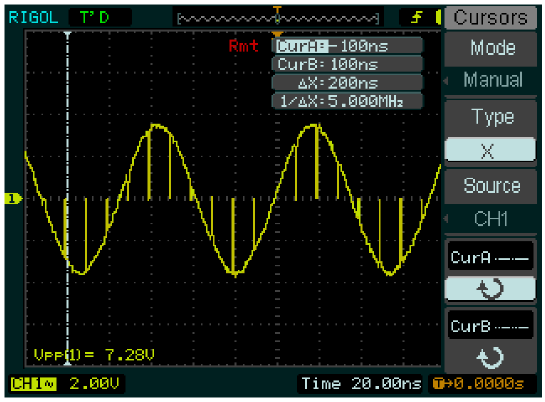
Fig 7: Modulated carrier signal when the RFID tag is moving away from the RFID reader

Case 8: The amplitude of the received signal decreases as the tag moves away from the reader. (See Fig 8)
Measured Values:
V_{pp} = 6.64volts
Distance of the tag from the reader= 14cm



The following two figures show the carrier along with the data retrieved from the tag (PAM).

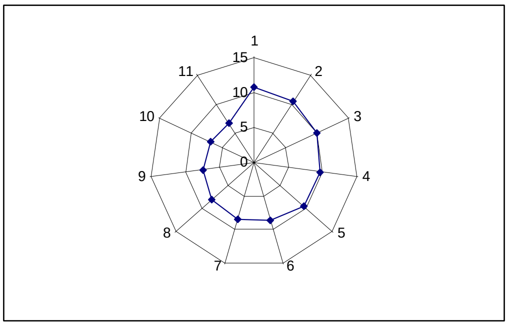


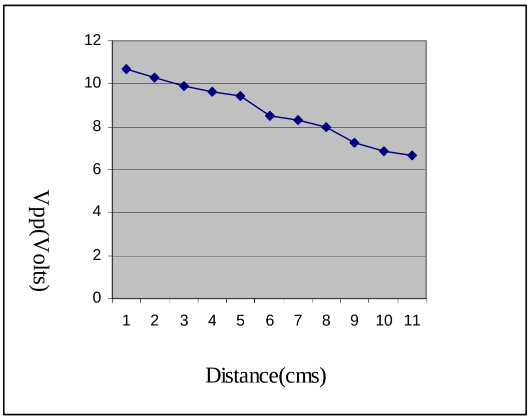


Results obtained from two different tags moving in different directions are tabulated as shown below:

Tag 1		Tag 2	
Distance	**V_{pp}**	**Distance**	**V_{pp}**
5 cm	10.1 V	14 cm	6.42 V
8 cm	9.92 V	11 cm	8.20V
11 cm	8.32 V	8 cm	9.45 V
14 cm	6.88 V	5.5 cm	10.02 V
5.5 cm	9.92 V	5 cm	10.5 V
5 cm	10.3 V	8 cm	9.45 V
11 cm	8.80V	11cm	8.2V
14 cm	6.4 V	14 cm	6.42 V

If a graph is plotted between the signal strength received from the tag and distance, the figures looks as shown below:





15. Conclusions

Displaying a composite power spectrum on a host computer for different tags and selecting the Signal of Interest from spectral display will make the system to calculate the Angle of Arrival of the signal from different tags moving in different direction.

Based on the angle of arrival of the signal from a particular tag, one can track the Human activity very accurately.

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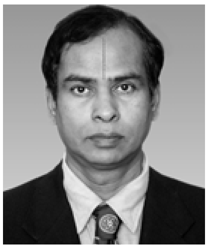

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