# Current Status of the Highest-GHz-Frequency RFID Systems (Also Highest-Frequency RFIC)

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## Extended Abstract

1. Definition

RFID is an electronic tagging/identification technology which facilitates automatic identification without any contact and line of sight by exchange of electromagnetic signals (radio frequencies) between readers and tags. RFID technology can be broadly divided into passive tags that have no energy source and draw their operating power from the RFID reader, and active tags that include a power source, such as a battery in the tag. Frequency plays an important role in the design of an RFID system; it can affect aspects of the system such as operating range and line of sight requirements. Frequency is a large determinant of range and speed. It also plays a major role in the ability of RF waves to penetrate RF hostile materials such as water and metal (6). It is generally safe to assume that a higher frequency equates to a faster data transfer rate and longer read ranges, but also more sensitivity to environmental factors such as liquid and metal that can interfere with radio waves.

RFID systems are designed to operate over a variety of frequency ranges. Low-frequency (LF): 125 to 134.2 kHz and 140 to 148.5 kHz have shorter read range (< 0.5m or 1.5 ft) and slower read speed. They have strongest ability to read tags on objects with high water or metal content. High-frequency (HF): 13.56MHz has greater read range and higher read speed than LF systems. The read range of ultra-high-frequency (UHF): 860 to 960MHz is up to 3m (9.5 ft) and the data transfer rate is faster than HF systems (1). The final frequency option is the microwave band, 2.45GHz, 5.8GHz and above. Though microwave based RFID systems offer the highest data read rates, they are the most expensive systems and have a limited read range of up to 1 m (3 ft) (8). The inductive coupling used at 125 kHz and 13.56 MHz limits the reading range to below 1 m. At higher frequencies the reading distance increases to 2 m or more (RFID system in Europe). For these systems the reading distance is proportional to the wavelength. Passive RFID systems at the 869 or 915 MHz can reach reading distances up to 8 m. However, the most commonly used RFID chips target reading ranges between 2 and 4 m (12).

1.1 Ultra Wideband (UWB). They range from 3.1 to 10.6 GHz. These are short pulse electromagnetic waves with few RF cycles, having large fractional bandwidth, extremely low duty cycles and high multipath immunity (14). This technology has been used in real time location systems (RTLS) as it provides higher read range and better accuracy.

2. Importance of the topic and its applications

Enhancing read rate, data rate and read ranges are some o0f the present challenges which can only be achieved if the rfid system focuses on higher frequency ranges in GHz frequencies. Active tags operating at 7.2 GHz are being used for real time location system (RTLS). New 2.45 GHz RFID systems are certified for use in all industrialized countries in Europe, America and Asia. They read at up to 6 m range and at passage speeds up to 400 km/hour. They can read several tags simultaneously and use multi-channel technology to allow for an in practice unlimited number of readers in each installation area without interference problem (2). These properties of GHz make it suitable for applications like electronic toll collection, applications involving high data transmission rate like some distribution or logistics, high speed objects(train, vehicle) tracking. Some of the special characteristics of 2.45 GHz systems are by directional reading, long reading range, and high passage speed, good immunity to electromagnetic interference (EMI) and very high tolerance to dirt. High frequency systems at 2.45 GHz is the best choice when a long reading range and high passage speed is needed in combination with a moderate cost for the data carriers. 2.45 GHz works excellent in dirty environments, with freedom to choose between read-write and read-only data carriers, and the reader and tag multiplicity give very high installation flexibility. Applications range from manufacturing to distribution/logistics and access control for people and vehicles. 2.45 GHz RFID also provides excellent opportunities to design RFID systems with advanced characteristics (2). A system operating at 5.8 GHz frequency has improved properties as compared to 2.45 GHz frequency and higher frequencies operating at 24.125 GHz and 60.65 GHz are under research.

## 3. Theoretical basis

The reader initiates the identification process by generating an RF field at a specific frequency defined for the particular system, thereby causing a voltage difference at the tag antenna end points via inductive or capacitive coupling. The tag detects this change and after optionally authenticating the reader via a challenge response mechanism, responds by transmitting the identifier that it holds. RFID tags can be passive or active depending on whether they are completely powered by the RF signal transmitted by the reader or they also carry an additional embedded power source (9). Low frequency systems (125 kHz), high frequency systems (13.56 MHz) operate in magnetic regime and use magnetic coupling to communicate between the tag and the reader. Whereas systems operating at higher frequencies- UHF (860 – 960 MHz), Microwave (2.45 GHz, 5.8 GHz, 7.2 GHz and higher GHz frequencies) operate in the electro magnetic regime and communicate on the principle of back scattering.

However the issues around magnetic coupling are that the frequency is low, the energizing field is very much stronger than the returned data field strength, or in other words it is difficult to create filters with sufficient tuning to separate the transmit and received signal while both are present, that the tags have very limited energy storage capability, meaning that the energizing field needs to be applied in a uniform continuous manner, or data can be received back in that short period of time after the energizing field is removed (2).

For low frequency systems (e.g., 100 kHz - 30 MHz) the tag is typically in the near-field of the reader. Loop antennas are often used to inductively couple the reader and the tag for such systems. Direct inductive coupling (i.e., using loop antennas) may not be the best choice for high frequency systems as for high-frequency RFID systems the tag is often in the far-field of the reader. Such high-frequency systems typically use resonant-type antennas to communicate. The communication channel between the reader and tag for such systems is sometimes described in terms of the radar cross-section $\sigma$ - which is also referred to as the scatter aperture (13).

Generally operating at frequencies typically in the order of 125 KHz, the magnetic coupled transponders are characterised by antenna systems that comprise of numerous turns of a fine wire around a coil former to collect energy from a reader's magnetic field. Due to the magnetic method of coupling, range is limited generally to a number of inches, being determined by the fields generated between the effective north and south pole of the reader.

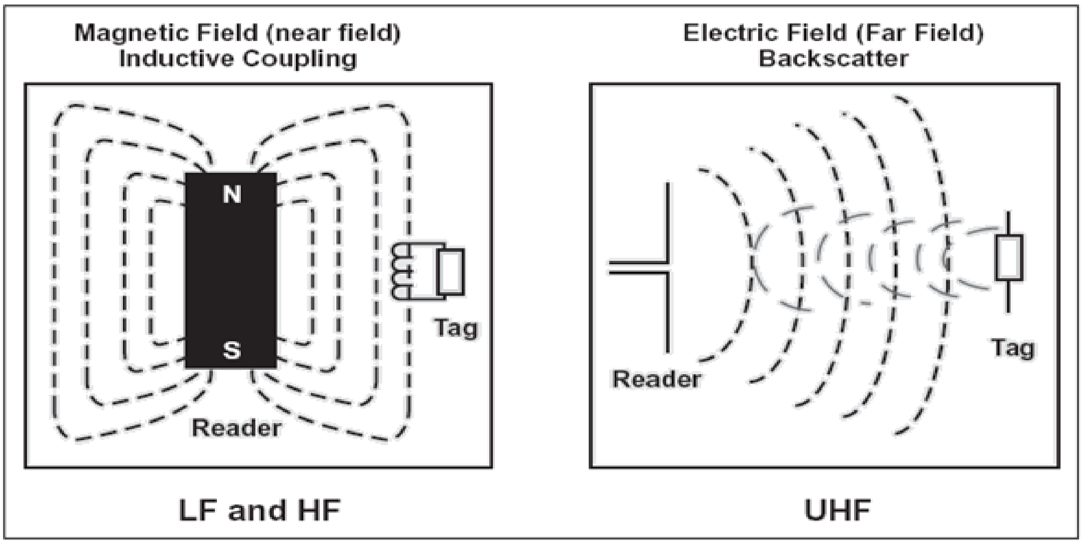



**Fig.** Two types of Antenna/Tag coupling (33) .Magnetic field (near field) coupling is present in low frequency (125 kHz) & high frequency (13.56 MHz) whereas electric field (far field) backscatter is present in ultra high freq. (860-960 MHz) & microwave (2.45 GHz, 5.8 GHz, other higher freq.).

### 3.1 Performance Criteria

3.1.1 Read Range. The most important tag performance characteristic is read range—the maximum distance at which RFID reader can detect the backscattered signal from the tag. Because reader sensitivity is typically high in comparison with tag, the read range is defined by the tag response threshold. Read range is also sensitive to the tag orientation, the material the tag is placed on, and to the propagation environment. The read range can be calculated using Friis free-space formula as

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \quad [1]$$

Where, λ is the wavelength, Pt is the power transmitted by the reader, Gt is the gain of the transmitting antenna, Gr is the gain of the gain of the receiving tag antenna, $P_{th}$ is minimum threshold power necessary to provide enough power to the RFID tag chip, and τ is the power transmission coefficient given by

$$\frac{4R_cR_a}{|Z_c+Z_a|^2},\ 0 \leq \tau \leq 1 \quad [2]$$

Where, Zc = Rc + jXc is chip impedance and Za = Ra + jXa is antenna impedance (5).

3.1.2 Data Rate. RFID systems operating in the LF band have relatively low data rates, on the order of Kbits/s. Data rates increase with frequency of operation, reaching the Mbit/s range at microwave frequencies (33).

3.1.3 Antenna Size and Type. The RFID tag antenna design process involves inevitable tradeoffs between antenna gain, impedance, and bandwidth. RFID tag antenna performance strongly depends on the frequency- dependent complex impedance presented by the chip. Tag read range must be closely monitored in the design process in order to satisfy design requirements (5).

Due to the long wavelengths of low frequency radio signals, the antennas of LF and HF systems have to be made much larger than UHF and microwave antennas in order to achieve comparable signal gain. Frequency of operation will also dictate the type of antenna used in an RF system. At LF and HF, inductive coupling and inductive antennas are used, which are usually loop-type antennas. At UHF and microwave frequencies, capacitive coupling is used and the antennas are of the dipole type (34).

Proper impedance match between the antenna and the chip is of paramount importance in RFID. Adding an external matching network with lumped elements is usually prohibitive in RFID tags due to cost and fabrication issues. To overcome this situation, antenna can be directly matched to the ASIC which has complex impedance varying with the frequency and the input power applied to the chip. Several papers have been published on the designing of RFID antennas for both passive and active tags, including covered slot antenna design, circular patch antenna analysis, Miniaturized Meander-Line Antennas for RFID applications, meander antenna optimization, planar inverted F-antenna, folded dipole antenna (10).

UWB active tags has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size. Passive transponders working on very high frequency is still under research. State of the art RFID technology is utilizing silicon RFID chip technology and silver ink printed antennas, and the current work consequently focus on multilayered antennas using this technology platform (12).

## 4. Current status

The wide-band 2.4 GHz ISM band is available worldwide and the allowed transmit power is 4 W. 2.4 – 2.483 GHz & 5.725 – 5.875 GHz frequency bands used in RFID systems are based on ISO 18000-4 and ISO 18000-5 standards. High frequency systems at 2.45 GHz is the best choice when a long reading range and high passage speed is needed in combination with a moderate cost for the data carriers. 2.45 GHz works excellent in dirty environments, with freedom to choose between read-write, read-only data carriers, and the reader and tag multiplicity give very high installation flexibility (2). The size of tags is getting reduced to a great limit by using GHz frequency. So far the smallest tag that has been developed is 0.4 mm x 0.4mm x 0.15mm in dimension. It's a passive transponder which operates at 2.45 GHz with a reading distance of 30 cm (20).

State of the art RFID technology is utilising silicon RFID chip technology and silver ink printed antennas, and the current work consequently focuses on multilayered antennas using this technology platform (18). Various antennas for the GHz frequency system has been proposed like a coplanar waveguide (CPW)-fed capacitive folded-slot antenna is proposed for the radio frequency identification (RFID) application at 5.8 GHz (6).

Companies like Multi Spectral Solutions Inc. are utilising frequency from 6-6.5 GHz preventing interference and opening up much needed spectrum. New 2.45 GHz RFID systems are certified for use in all industrialised countries in Europe, America and Asia. They read at up to 6 m range and at passage speeds up to 400 km/hour. They can read several tags simultaneously and use multi channel technology to allow for an in practice unlimited number of readers in each installation area without interference problem (22).

Vendor: (Multispectral Solutions): Sapphire DART tags operate under Part 15.250 regulations, permitting both indoor and outdoor use. The FCC Part 15.250 band spans from 5.925-7.250 GHz. The Ubitags and readers operate from 5.8 to 7.2 GHz, though UWB systems can operate from 3.1 GHz to 10.6 GHz. UWB tags transmit a signal over multiple bands of frequencies simultaneously. Unlike conventional RFID systems, which operate on single bands of the radio spectrum, UWB transmits a signal over multiple bands of frequencies simultaneously, from 3.1 GHz to 10.6 GHz (22).

UWB active tags can be used for RTLS applications as well. UWB active tag technology for RFID and RTLS applications has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size. UWB systems work well indoors because the short bursts of radio pulses emitted from UWB tags are easier to filter from multi path reflections. Ubisense uses active tags, which the company calls Ubitags operating from 5.8 to 7.2 GHz (22).

The most commonly used RFID chips targets reading ranges between 2 and 4 m (12). Line-of-sight transmission is required for passive tags at high frequencies. Passive transponders working on very high frequency like 24.125 GHz and 60.65 GHz frequencies are still under research. The key issues for long reading distances are the antenna gain of the tag and the rectifier efficiency and power consumption of the RFID chip. State of the art RFID technology is utilizing silicon RFID chip technology and silver ink printed antennas, and the current work consequently focus on multilayered antennas using this technology platform (12). Various applications have been using active rfid tags opetrating at 5.8 GHz – 7.2 GHz frequency and Ultra Wide Band (UWB) technology for real time location systems (RTLS) as these are more accurate in location sensing and have higher success rate. Current read range of 2.45 GHz systems is around 10 feets and usually active tags are used. Some of the applications include electronic toll collection system and other application involving higher data rates and accuracy.

5. Present challenges

5.1 Cost minimization. High cost and high RFID system integration costs are some of the challenges that restrict the growth of the RFID. Costs incurred in data processing, online handling of huge amount of streaming data, storage, network bandwidths and systems are other constraints. Improving read write capabilities and providing anti counterfeiting and tampering proof tags are few of the current challenges.

5.2 High power consumption. The chip used in the tag gets costlier on increasing the GHz frequency because one cannot use silicon anymore for fabrication of IC as the substrate silicon losses are high and high power transmission losses occur. Costly non-silicon materials like SiGe have to be used which are even very difficult to make.

5.3 Security Concerns. Ethical threats concerning privacy of life are possible. Unauthorised access to the important data is possible by the third party using hidden readers, which give rise to serious concern to the privacy norms.

5.4 Spectrum Congestion. RFID systems should be moved to higher GHz frequencies as the UHF band and other 850 MHz –1 GHz bands are highly congested due to the sharing of frequency band by various radio wireless communication systems.

5.5 Antenna problems. As the frequency of choice for RFID devices rises into the microwave region, the problem of designing antennas to match the devices on the protected object becomes more acute (4). The challenges in RFID antenna design are related to robustness. A single layered RFID antenna is very sensitive to the environment where it is placed. Reflecting and lossy materials provide severe reduction in reading distance. (12). In addition, poor impedance match will result in transmission loss between the antenna and ASIC (10).

5.6 Environmental Elements. Interference from metals and RF noise can degrade the performance of an RFID signal. Metals and liquids tend to absorb RF waves (6).

5.7 Range. Though range increases as the frequency increases from few kHz to 13.6 MHz but the range decreases with increasing frequency as frequency becomes very large (GHz). Ability to penetrate through metal and water content decreases as the frequency increases. Low frequency RFID systems are least effected whereas microwave and ultra high frequency RFID systems are most sensitive to metal and water content and are not able to penetrate through such objects (8).

5.8 Effects of local structure. When a hand-held device is used, the radiation pattern of both the interrogator antenna and the tag antenna will be seriously distorted by the large number of other objects which are also present (4).

6. Solutions to present challenges

6.1 Solutions in UHF. Using state-of-the-art analysis and design techniques, a SOS 0.5-m CMOS technology and inductive matching between the antenna and the transponder, an operating range of 12 m with 4 W EIRP transmitted power was achieved. At this distance, the available power for the transponder is 2.7 micro W which means about 37% global efficiency for the rectifier since the estimated (simulation) power consumption of the whole system is approximately 1 micro Watt. Using silicon-on-sapphire in conjunction with state-of-the-art RF design allowed us to reach an operating range of 12 m (3).

6.2 Suitable Antenna designing. A suitable tag antenna must have following characteristics: has good impedance match, be robust, be very cheap, and be small enough to be attached the required object, has omnidirectional or hemispherical coverage and normally has linear polarization or dual polarization depending upon requirement (10).

6.3 Use of multiple antennas for robustness. The challenges in RFID antenna design are related to robustness. A single layered RFID antenna is very sensitive to the environment where it is placed. Reflecting and lossy materials provide severe reduction in reading distance. One solution is to use multilayered antennas which are much less sensitive to the material that it is attached to. Use of multiple antennas reduces the problem of reflection, diffraction and the formation of null points in the space resulted from the destructive interference of the reflected radio waves.

6.4 Use of isolator materials to mitigate the effect of environmental. Interference from metals and RF noise can degrade the performance of an RFID signal. Metals and liquids tend to absorb RF waves. This is often mitigated through antenna design and/or by applying a buffer or isolator material between the tag and the hostile material. The use of these spacers can lift the tag off the metal.

7. Future outlook

Plan is to take advantage of UWB RF pulses to encompass longer range of tag interrogation, given equal average power from the interrogator (or conversely, greater range in sensitivity); more immunity to signal degradation and multipath effects; a higher degree of security and immunity to eavesdropping; a greater potential for anti-collision in multi-tag environments; more uniform coverage of a volume of space; and the ability to focus the tag interrogation to a localized point in space (12).

UWB active tags can be used for RTLS applications also and UWB active tag technology for RFID and RTLS applications and has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size. Due to spectrum congestion around 1GHz frequency, and improved characteristics has pushed the RFID research towards higher GHz frequencies and 24.125 GHz and 60.65 GHz are going to be the future operating frequency of RFID tags. Various research projects have been going on reducing the cost of silicon technology which is a major problem for large scale RFID deployment. New manufacturing technology: inline printing of electronics devices is under research. Use of organic semiconductors (example: polymers) has increased and printing of polymer chips and antennas using R2R technology is taking place. It has the potential of significant cost reduction (24). Due to spectrum congestion around 1GHz frequency, and improved characteristics has pushed the RFID research towards higher GHz frequencies and 24.125 GHz and 60.65 GHz are going to be the future operating frequency of RFID tags.

## 1. Introduction

### 1.1 Definition

Radio frequency identification (RFID) is a method of remotely storing and retrieving data using devices called RFID tags which facilitates automatic identification without any contact and line of sight by exchange of electromagnetic signals (radio frequencies) between readers and tags. Rfid systems has been guided by the frequency at which they operate and it plays important role in the designing of an RFID system; it can affect aspects of the system such as read rate, ranges, data rates, accuracy and speed of the system. It also plays a major role in the ability of RF waves to penetrate RF hostile materials such as water and metal (6).

RFID systems are designed to operate over a variety of frequency ranges.

1.1.1 Low-frequency (LF). Ranging from 125 to 134.2 kHz and 140 to 148.5 kHz, these have shorter read range (< 0.5m or 1.5 ft) and slower read speed. They have strongest ability to read tags on objects with high water or metal content. This is an uncrowded and unregulated frequency band (hence, easier licensing).

1.1.2 High-frequency (HF). Operating around 13.56MHz, it has greater read range and higher read speed than LF systems. Operate in the magnetic regime based on magnetic coupling.

1.1.3 Ultra-high-frequency (UHF). Covering a range of 860 to 960MHz, the read range is up to 3m (9.5 ft) and the data transfer rate is faster than HF systems (1). It has higher high read and location range and high read and write rate. It has relatively smaller antenna.

1.1.4 Microwave band. These work at 2.45GHz, 5.8GHz and above. Though microwave based RFID systems offer the highest data read rates, they are the most expensive systems and have a limited read range of up to 1 m (3 ft) (8). The inductive coupling used at 125 kHz and 13.56 MHz limits the reading range to below 1 m. At higher frequencies the reading distance increases to 2 m or more (RFID system in Europe). For these systems the reading distance is proportional to the wavelength. Passive RFID systems at the 869 or 915 MHz can reach reading distances up to 8 m. However, the most commonly used RFID chips target reading ranges between 2 and 4 m (12).

1.1.5 Ultra Wideband (UWB). They range from 3.1 to 10.6 GHz. These are short pulse electromagnetic waves with few RF cycles, having large fractional bandwidth, extremely low duty cycles and high multipath immunity (14). This technology has been used in real time location systems (RTLS) as it provides higher read range and better accuracy.

An LF system is considered appropriate in applications which are very industrialized and need RFID to operate under very harsh conditions. The LF is immune to electrical noise in the environment and having encryption technology designed into the IC enables communication distances of up to 1.5m to be reached. LF is also suitable for liquids, organic materials and metal applications (1).A HF system is considered appropriate in applications where items are tagged and read and write ranges of up to 1.5m are required. Encryption algorithms allow for protected data on the IC and EAS features in the tag, making anti-theft prevention possible.

A UHF system is typically used today for applications where great read ranges are required, with distances of several meters. As UHF is the youngest RFID technology solution for tagging items in the supply chain environment as well as EAS, however, such solutions are still under development (1). At UHF, wireless power transmission is more suitable and the backscattering principle offers a reliable communication link (2). A small transponder size, which is mainly determined by the antenna size, is ensured by choosing a high operating frequency. Furthermore, the wide-band 2.4 GHz ISM band is available worldwide and the allowed transmit power is 4 W.

### 1.2 Importance of the topic and its applications

1.2.1 Importance. UWB tags have the advantage of low average power densities (low interference), high energy efficiencies (extended battery life), high RTLS accuracy, high read rates at extended ranges and high multipath immunity (14).

Enhancing read rate, data rate and read ranges are some o0f the present challenges which can only be achieved if the rfid system focuses on higher frequency ranges in GHz frequencies. Active tags operating at 7.2 GHz are being used for real time location system (RTLS). New 2.45 GHz RFID systems are certified for use in all industrialized countries in Europe, America and Asia. They read at up to 6 m range and at passage speeds up to 400 km/hour. They can read several tags simultaneously and use multi-channel technology to allow for an in practice unlimited number of readers in each installation area without interference problem (2). These properties of GHz make it suitable for applications like electronic toll collection, applications involving high data transmission rate like some distribution or logistics, high speed objects(train, vehicle) tracking. Some of the special characteristics of 2.45 GHz systems are by directional reading, long reading range, and high passage speed, good immunity to electromagnetic interference (EMI) and very high tolerance to dirt. High frequency systems at 2.45 GHz is the best choice when a long reading range and high passage speed is needed in combination with a moderate cost for the data carriers. 2.45 GHz works excellent in dirty environments, with freedom to choose between read-write and read-only data carriers, and the reader and tag multiplicity give very high installation flexibility. Applications range from manufacturing to distribution/logistics and access control for people and vehicles. 2.45 GHz RFID also provides excellent opportunities to design RFID systems with advanced characteristics (2). A system operating at 5.8 GHz frequency has improved properties as compared to 2.45 GHz frequency and higher frequencies operating at 24.125 GHz and 60.65 GHz are under research.

1.2.2 Applications. Range from manufacturing to distribution/logistics and access control for people and vehicles. 2.45 GHz RFID also provides excellent opportunities to design RFID systems with advanced characteristics (2). UWB application areas are: real time location systems (RTLS), radar sensors, ranging sensors and wireless communication networks (14). Microwave frequency bannd have been used in electronic toll collection systems.

## 1.3 Theoretical Review

RFID technology can be broadly divided into passive tags that have no energy source and draw their operating power from the RFID reader, and active tags that include a power source, such as a battery in the tag. The reader initiates the identification process by generating an RF field at a specific frequency defined for the particular system, thereby causing a voltage difference at the tag antenna end points via inductive or capacitive coupling. Electromagnetic energy created by the reader impinges on the tag, which is typically comprised of an antenna and special circuitry. The tag typically uses the energy in some fashion to identify itself and communicate with the reader. The precise way in which this communication occurs depends on the type of RFID system that is used. There are many characteristics which are used to distinguish RFID systems. Two of those are the power source of the tag (passive, active or semi-passive) and the frequency of operation (13). The tag detects this change and after optionally authenticating the reader via a challenge response mechanism, responds by transmitting the identifier that it holds. RFID tags can be passive or active depending on whether they are completely powered by the RF signal transmitted by the reader or they also carry an additional embedded power source (9).

Passive RFID systems are those in which all of the energy needed by the tag to identify itself and communicate with the reader is harvested from the energy sent to the tag by the reader. In such systems the antenna of the tag is typically connected to a rectifier circuit which then provides power to the tag circuitry. The tag circuitry is designed in such a way that the tag can identify itself, and (depending on the type of system) also provide additional information to the reader (13). Most of the passive and Semi passive RFID systems that operate in the ultra-high-frequency (UHF) or microwave range exploit modulation of the backscattered radiation to transmit data from transponder to reader .

Active and semi-passive (or battery assisted) tags have a source of energy on the tag. Active tags use the on-board energy to power the tag circuitry as well as to communicate with the reader. Semi-passive (or battery-assisted) tags typically use the on-board energy to power the tag circuitry, but communicate with the reader using the harvested energy (13).

For low frequency systems (e.g., 100 kHz - 30 MHz) the tag is typically in the near-field of the reader. Loop antennas are often used to inductively couple the reader and the tag for such systems.

Direct inductive coupling (i.e., using loop antennas) may not be the best choice for high frequency systems as for high-frequency RFID systems the tag is often in the far-field of the reader. Such high-frequency systems typically use resonant-type antennas to communicate. The communication channel between the reader and tag for such systems is sometimes described in terms of the radar cross-section $\sigma$ - which is also referred to as the scatter aperture (13).

1.3.1 Different types of coupling for RFID Systems. Electric field coupled transponders use the electric field propagation properties of radio communication which radiate out from the energizing antenna, quartering in signal strength every doubling of distance travelled, to convey energy and data from the reader to the transponder and data from the transponder to the reader. Electric field propagation requires antenna systems that operate on high frequencies like 2.5 GHz, 5.8GHz, etc. However the electric field tags need to operate in an ordered spectrum management system as their radiated energy (particularly from the reader) can be detected by other sensitive receivers far away and cause possible interference. These tags are passive, have no onboard tuned circuits, and are read only, consist of a single integrated circuit and a simple antenna, operate at any of a range of frequencies, temperature insensitive, and broadcast a large data value when illuminated by a reader's energizing field. In such a system the reader is complex because it provides the frequency stability, the energy of the system, and the receiver selectivity to receive the weak return communications, but the tags are very cheap (2).

Generally operating at frequencies typically in the order of 125 KHz, the magnetic coupled transponders are characterised by antenna systems that comprise of numerous turns of a fine wire around a coil former to collect energy from a reader's magnetic field. Due to the magnetic method of coupling, range is limited generally to a number of inches, being determined by the fields generated between the effective north and south pole of the reader.

1.3.2 RFICs. The most commonly used RFID chips targets reading ranges between 2 and 4 m (12). Line-of-sight transmission is required for passive tags at high frequencies. UWB active tags has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size. Passive transponders working on very high frequency is still under research. State of the art RFID technology is utilizing silicon RFID chip technology and silver ink printed antennas, and the current work consequently focus on multilayered antennas using this technology platform (12).

Sapphire DART (Multispectral Solutions) tags operate under Part 15.250 regulations, permitting both indoor and outdoor use. The FCC Part 15.250 band spans from 5.925-7.250 GHz. European regulators are currently considering the authorization of UWB-based RFID and RTLS systems within the 6.0-9.0 GHz, overlapping allocations within the U.S.Ubisense uses active tags operating from 5.8 to 7.2 GHz. The Ubitags and readers operate from 5.8 to 7.2 GHz, though UWB systems can operate from 3.1 GHz to 10.6 GHz. UWB tags transmit a signal over multiple bands of frequencies simultaneously.

## 1.4 Current challenges

Higher operating frequencies require more expensive components and lose the ability to transfer energy at a rate of the inverse of the wavelength squared. (A 2.45GHz system would need seven times the energising fields needed by a 915 MHz system) (2).

1.4.1 Antenna problems. As the frequency of choice for RFID devices rises into the microwave region, the problem of designing antennas to match the devices on the protected object becomes more acute (4). The challenges in RFID antenna design are related to robustness. A single layered RFID antenna is very sensitive to the environment where it is placed. Reflecting and lossy materials provide severe reduction in reading distance. (12). In addition, poor impedance match will result in transmission loss between the antenna and ASIC (10).

1.4.2 Environmental Elements. Interference from metals and RF noise can degrade the performance of an RFID signal. Metals and liquids tend to absorb RF waves (6).

1.4.3 Range. Though range increases as the frequency increases from few kHz to 13.6 MHz but the range decreases with increasing frequency as frequency becomes very large (GHz). Ability to penetrate through metal and water content decreases as the frequency increases microwave and ultra high frequency RFID systems are most sensitive to metal and water content and are not able to penetrate through such objects (8). The key issues for long reading distances are the antenna gain of the tag and the rectifier efficiency and power consumption of the RFID chip.

1.5 Scope for Future Work

Passive transponders working on very high frequency is still under research. Research focus is to take advantage of UWB RF pulses to encompass longer range of tag interrogation, given equal average power from the interrogator (or conversely, greater range in sensitivity); more immunity to signal degradation and multipath effects; a higher degree of security and immunity to eavesdropping; a greater potential for anti-collision in multi-tag environments; more uniform coverage of a volume of space; and the ability to focus the tag interrogation to a localized point in space (12).

Future work in RFID focuses on reducing the cost and size of RFID tags further. The frequency of operation of RFID systems is aimed to be moved to higher GHz frequencies so that operation speed of the system can be increased and less interference is encountered. In addition to passive and active RFID tags, the idea is to develop extremely small, disposable RFID tags; tags that had enough processing power and memory to almost be very small computers.

The objectives for the future antenna are: antennas must be small enough to be attached to the required object and have omnidirectional or hemispherical coverage must provide maximum possible signal to the ASIC, have a polarization such as to match the enquiry signal regardless of the physical orientation of the protected object, be robust. It should use multilayered antennas which are much less sensitive to the material that it is attached to (12). The high gain, broad beam-width, low cross polarization and isolation from the input ports are the factors to be considered.

## 2. Theory

2.1 Operating Principles

RFID technology can be broadly divided into passive tags that have no energy source and draw their operating power from the RFID reader, and active tags that include a power source, such as a battery in the tag. The reader initiates the identification process by generating an RF field at a specific frequency defined for the particular system, thereby causing a voltage difference at the tag antenna end points via inductive or capacitive coupling. Electromagnetic energy created by the reader impinges on the tag, which is typically comprised of an antenna and special circuitry (13). In HF systems, the magnetic field powers up an RFID tag through a process known as induction. A magnetic field is created as a result of electrical current flow in a closed loop of electrically conductive material (e.g. copper tubing, copper tape, etc.) acting as an antenna. The magnetic field induces an electric current flowing on the antenna of an RFID tag that is within the magnetic field (also a closed conductive loop). This induced electric current is then used to power the RFID tag's circuitry, enabling the interpretation of and response to commands that are sent to it from a reader. In UHF systems the electric field powers up an RFID tag that enters an area within this field of energy. The power of the electric field is used for the RFID tag's circuitry in a fashion similar to what occurs with HF tags, but using capacitive coupling.

Passive RFID systems are those in which all of the energy needed by the tag to identify itself and communicate with the reader is harvested from the energy sent to the tag by the reader. Active tags use the on-board energy to power the tag circuitry as well as to communicate with the reader. Semi-passive (or battery-assisted) tags typically use the on-board energy to power the tag circuitry, but communicate with the reader using the harvested energy (13).

For low frequency systems (e.g., 100 kHz - 30 MHz) the tag is typically in the near-field of the reader. Loop antennas are often used to inductively couple the reader and the tag for such systems. Direct inductive coupling (i.e., using loop antennas) may not be the best choice for high frequency systems as for high-frequency

RFID systems the tag is often in the far-field of the reader. Such high-frequency systems typically use resonant-type antennas to communicate. The communication channel between the reader and tag for such systems is sometimes described in terms of the radar cross-section $\sigma$ - which is also referred to as the scatter aperture (13).

2.1.1 Different types of coupling for RFID Systems. Electric field coupled transponders use the electric field propagation properties of radio communication which radiate out from the energizing antenna, quartering in signal strength every doubling of distance travelled, to convey energy and data from the reader to the transponder and data from the transponder to the reader. Electric field propagation requires antenna systems that operate on high frequencies like 2.5 GHz, 5.8GHz, etc. However the electric field tags need to operate in an ordered spectrum management system as their radiated energy (particularly from the reader) can be detected by other sensitive receivers far away and cause possible interference. These tags are passive, have no onboard tuned circuits, and are read only, consist of a single integrated circuit and a simple antenna, operate at any of a range of frequencies, temperature insensitive, and broadcast a large data value when illuminated by a reader's energizing field. In such a system the reader is complex because it provides the frequency stability, the energy of the system, and the receiver selectivity to receive the weak return communications, but the tags are very cheap (2).

Generally operating at frequencies typically in the order of 125 KHz, the magnetic coupled transponders are characterised by antenna systems that comprise of numerous turns of a fine wire around a coil former to collect energy from a reader's magnetic field. Due to the magnetic method of coupling, range is limited generally to a number of inches, being determined by the fields generated between the effective north and south pole of the reader.

2.2 Performance Criteria

2.3.1 Read Range. The most important tag performance characteristic is read range—the maximum distance at which RFID reader can detect the backscattered signal from the tag. Because reader sensitivity is typically high in comparison with tag, the read range is defined by the tag response threshold. Read range is also sensitive to the tag orientation, the material the tag is placed on, and to the propagation environment. The read range can be calculated using Friis free-space formula as

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \qquad [1]$$

Where, **λ** is the wavelength, Pt is the power transmitted by the reader, Gt is the gain of the transmitting antenna, Gr is the gain of the gain of the receiving tag antenna, $P_{th}$ is minimum threshold power necessary to provide enough power to the RFID tag chip, and τ is the power transmission coefficient given by

$$\frac{4R_c R_a}{|Z_c + Z_a|^2},\ 0 \le \tau \le 1 \qquad [2]$$

Where, Zc = Rc + jXc is chip impedance and Za = Ra + jXa is antenna impedance (5).

2.2.2 Data Rate. RFID systems operating in the LF band have relatively low data rates, on the order of Kbits/s. Data rates increase with frequency of operation, reaching the Mbit/s range at microwave frequencies (33).

2.2.3 Antenna Size and Type. The RFID tag antenna design process involves inevitable tradeoffs between antenna gain, impedance, and bandwidth.

RFID tag antenna performance strongly depends on the frequency- dependent complex impedance presented by the chip. Tag read range must be closely monitored in the design process in order to satisfy design requirements. Since antenna size and frequency of operation impose limitations on maximum attainable gain and bandwidth compromises have to be made to obtain optimum tag performance to satisfy design requirements. Often a tunable antenna design is preferable to provide tolerance for tag fabrication variations and for optimizing antenna performance on different materials in different frequency bands (5).

Due to the long wavelengths of low frequency radio signals, the antennas of LF and HF systems have to be made much larger than UHF and microwave antennas in order to achieve comparable signal gain. Frequency of operation will also dictate the type of antenna used in an RF system. At LF and HF, inductive coupling and inductive antennas are used, which are usually loop-type antennas. At UHF and microwave frequencies, capacitive coupling is used and the antennas are of the dipole type (34).

Dipole antennas used at the UHF and microwave frequencies, operate by spot beaming signals from transmitter to receiver. This, in addition to the relatively short wavelengths of high frequency UHF and microwave signals, gives rise to small ripples in a UHF or microwave interrogator's read zone, so that signal strength will not be uniform from one end of a read zone to the other and will even diminish to zero at some points, creating "nulls," or invisible spots. RFID tags positioned in these null spots are rendered effectively invisible to an RF interrogator, which can cause problems in UHF and microwave systems (34).

Proper impedance match between the antenna and the chip is of paramount importance in RFID. Adding an external matching network with lumped elements is usually prohibitive in RFID tags due to cost and fabrication issues. To overcome this situation, antenna can be directly matched to the ASIC which has complex impedance varying with the frequency and the input power applied to the chip. Several papers have been published on the designing of RFID antennas for both passive and active tags, including covered slot antenna design, circular patch antenna analysis, Miniaturized Meander-Line Antennas for RFID applications, meander antenna optimization, planar inverted F-antenna, folded dipole antenna (10). Meander class of antennas provides the largest size reduction at a given frequency at the expense of a narrow bandwidth and a low gain especially when the antenna surface needs to be contained in a few centimetre-side square (less than 4x4cm$^2$) for control of small objects). Meandering allowed the antenna to be compact and to provide omnidirectional performance in the plane perpendicular to the axis. Designs of antennas for different GHz frequencies has been proposed like K – band microstrip patch antenna array for 24.125 GHz, folded dipole antenna for 2.5GHz. In the UHF band, printed dipoles or patch antennas are normally used for the tag.

Qualitative behavior of antenna impedance, chip impedance, and read range as functions of frequency for a typical RFID tag is illustrated in Fig. 4. The frequency of the peak range is reffered as the tag resonance. The tag range bandwidth can be defined as the frequency band in which the tag offers an acceptable minimum read range over that band. From (6) one can see that read range is determined by the product of the reader (transmitter EIRP), tag antenna gain, and transmission coefficient (τ). Typically τ is dominant in frequency dependence and primarily determines the tag resonance which happens at the frequency of the best impedance match between chip and antenna. This frequency is different from the resonant frequency of antenna loaded with 50 Ohm and the antenna self-resonance. The range in (6) can be normalized with a factor ro=$\boldsymbol{\lambda}/4\pi \sqrt{P_t G_t / P_{th}}$ . This factor is the range of the tag with 0 dBi antenna perfectly matched to the chip impedance at a fixed frequency (5).

2.2.4 RFICs. The most commonly used RFID chips targets reading ranges between 2 and 4 m (12). Line-of-sight transmission is required for passive tags at high frequencies. UWB active tags has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size. Passive transponders working on very high frequency is still under research. State of the art RFID technology is utilizing silicon RFID chip technology and silver ink printed antennas, and the current work consequently focus on multilayered antennas using this technology platform (12).

2.2.5 Chip Architecture Fig. 1 shows the block diagram of the RFID tag chip. The power generation block produces the required DC power from 2.45-GHz carrier for all the circuit blocks, while maintaining the rectified voltage VDD, below its safe operating limits. The operating voltage is typically kept low at 1V to minimize the power consumption of the chip, i.e., 20pW during read and 120pW during write. As non-volatile memory circuit requires higher operating voltage, a DC-DC converter is used to accommodate that during memory operation. For the same reason, a logic translator is used as an interface between digital circuits and memory. The modem block is used for demodulating downlink and modulating uplink signals at 200kbps and 100kbps respectively with Manchester encoded On-Off- Keying (OOK) modulation scheme. The digital block governs the overall power management of the chip with careful timing to minimize instantaneous power consumption. It also provides anti-collision, command control and memory control logics. Other circuit blocks\ includes a low-power current reference, a programmable oscillator and a power-on-reset circuit that generates reset pulses under a wide range of power supply conditions (35).

| Frequency Band | LF 125KHz | HF 13.56MHZ | UHF 860–960MHZ | Microwave 2.5GHz and Up |
|---|---|---|---|---|
| Read Range (Passive Tags) | <2 Feet | <3 Feet | <10–30 Feet | ~10 Feet |
| Tag Power Source | Generally passive | Generally passive | *Generally active* but Passive Also | *Generally active* but Passive Also |
| Tag Cost | Relatively expensive | *Expensive*, but less So Than LF | Potential to Be very cheap | Potential to Be very cheap |
| Typical Applications | Keyless entry, animal tracking, vehicle immobilizers, POS | "Smart" cards, item-level track such as baggage handling, libraries | Pallet tracking, electronic toll collection, baggage handling | Electronic toll collection |
| Data Rate | Slower | | | Faster |
| Performance Near Metal or Liquids | Better | | | Worse |
| Passive Tag Size | Larger | | | Smaller |

**Fig I.** RFID system characteristics at different frequencies (33). This table clearly depicts the read ranges, relative costs, applications and relative data rates and performance in an environment of metals.

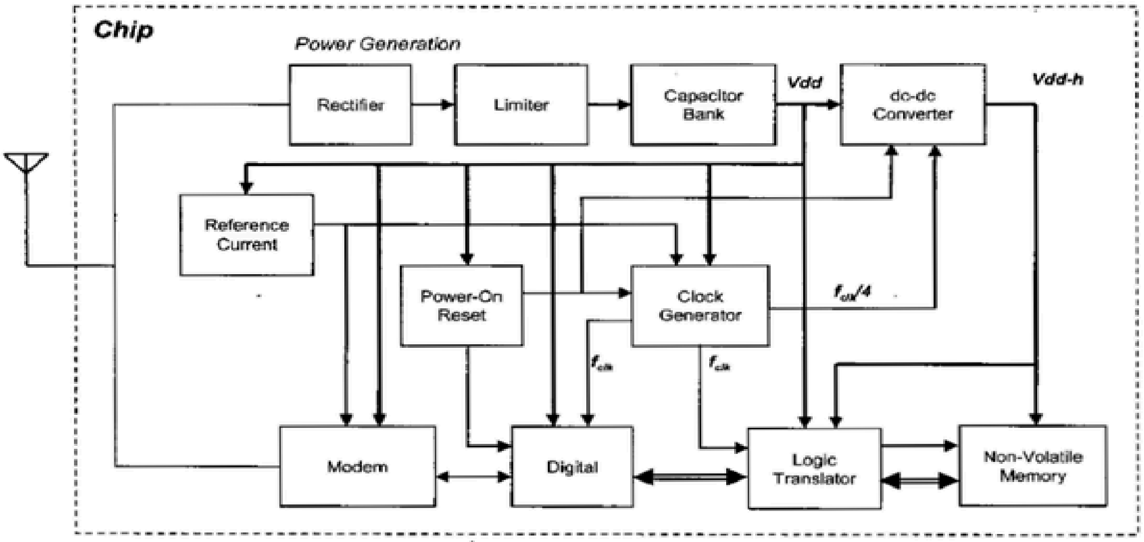



**Fig.2** Block Diagram of RFID Tag IC (35). The figure shows the block representation of various components present within the chip architecture.

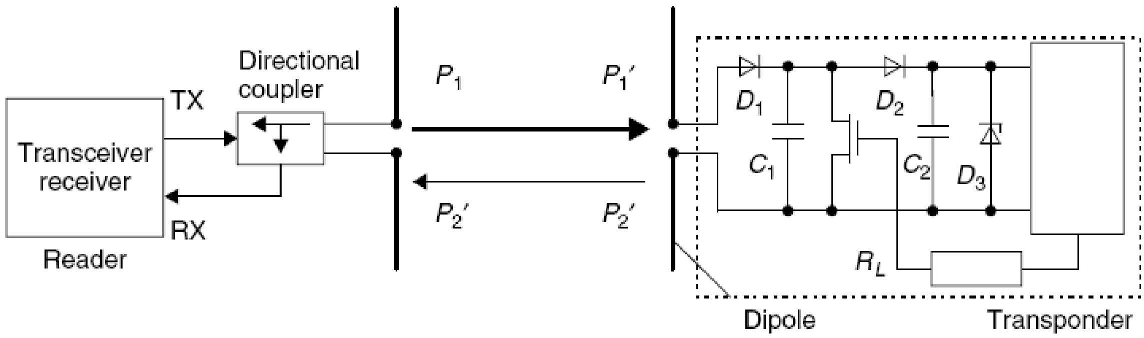



Fig. 3(a) Operating principle of a backscatter transponder. The impedance of the chip is 'modulated' by switching the chip's FET. Electric field (far field) backscatter is present in ultra high freq. (860-960 MHz) & microwave (2.45 GHz, 5.8 GHz, other higher freq.) (36).

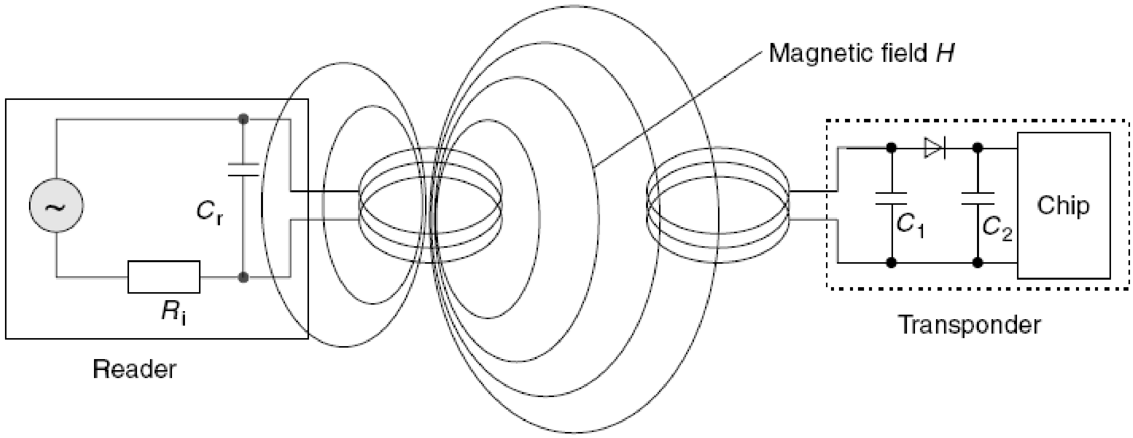



**Fig.3 (b)** Power supply to an inductively coupled transponder from the energy of the energy generated by the alternating field generated by the reader. Magnetic field (near field) coupling is present in low frequency (125 kHz) & high frequency (13.56 MHz) whereas electric field (far field) backscatter is present in ultra high freq. (860-960 MHz) & microwave (2.45 GHz, 5.8 GHz, other higher freq.) (36).

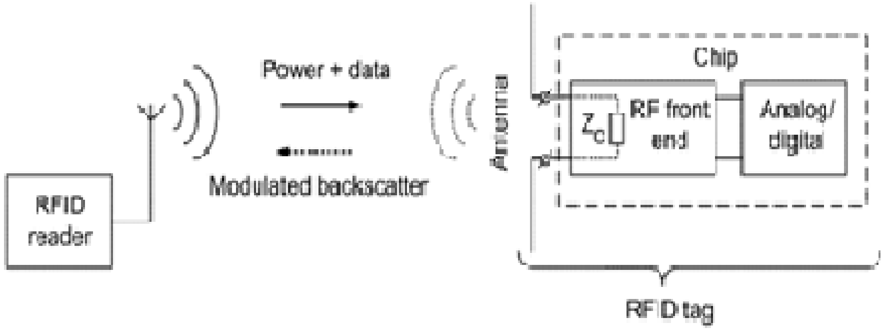



**Fig.4** RFID system operation. The backscattered signal is modulated by changes in chip impedance $Z_c$ (5). GHz frequency systems operate in the Electro Magnetic regime and use modulated backscattering principle to communicate with the tag (chip) and the reader.

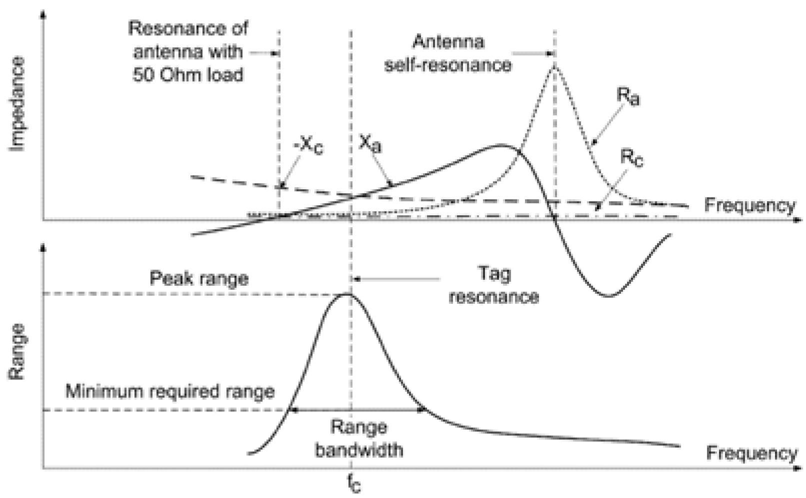



**Fig.5** Antenna impedance, chip impedance and ranges as functions of frequency for a typical RFID tag (5). The range of a particular rfid system is maximum for the resonant frequency (frequency at which maximum impedance matching takes place).

## 3. Technological Details and System Set-Up

### 3.1 RFID system architecture

The architecture of a RFID system is normally composed of two parts –one is the architecture for RFID readers and one for the RF'ID tags (or transponders). The two parts are connected by RF transmissions. On the reader side, the modulator modulates the binary sequences from the memory unit into analog waveforms. Proper coding (Manchester) and modulation (ASK, FSK**)** schemes will he selected by the modulator. The oscillator adds a carrier frequency to the analog waveforms and the amplifier will amplify the signals and send them out through the antenna. The clock module provides clocks to the digital circuits and the power module provides enough energy to drive the circuit. Demodulators on both sides will convert the transmitted signal to binary sequences for the digital circuits (15).

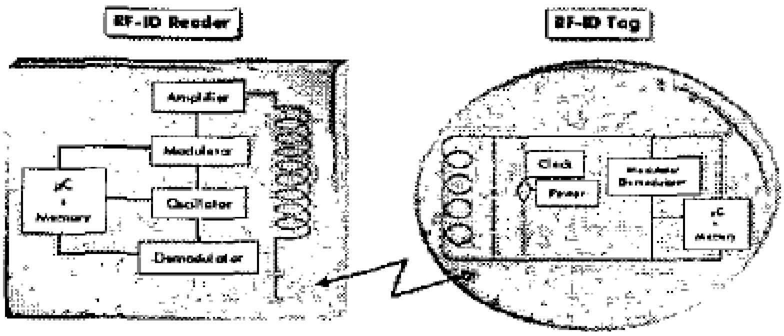



**Fig6**. Structure of RFID system (16). RFID reader structure consists of the amplifier, modulator, oscillator, demodulator and the memory and the rfid tag consists of the chip, antenna designed for matching circuit, clock, memory and modulator .

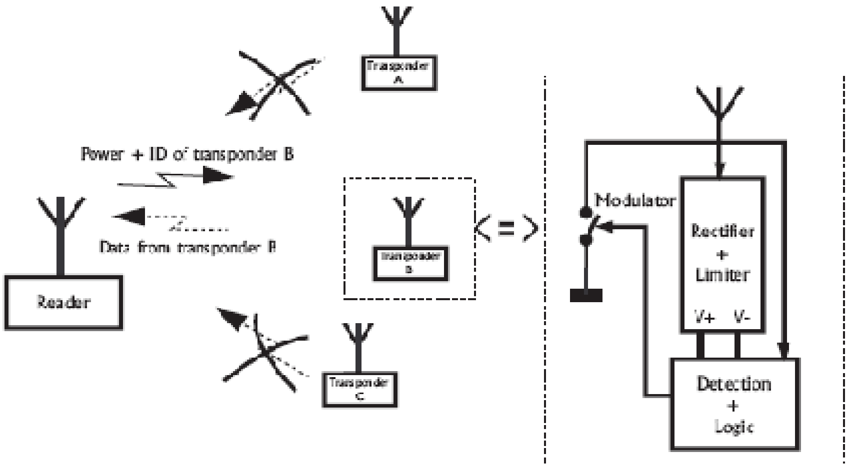



**Fig2.** RFID Operating principle (15). The figure shows the backscattered modulation of the system to operate in the electro magnetic regime to communicate between tag and the reader.

3.2 <u>Transponder</u>

Transponder is the central part of a RFID system. A transponder is a wireless communications, monitoring, or control device that picks up and automatically responds to an incoming signal (16). A transponder stores data which are needed by the base station. It also has two parts – an antenna and an electronic chip. A transponder may even have a battery. Most transponders are not equipped with a battery – they are called passive transponders. Such kinds of transponders must absorb energy from base stations in order to drive their inner circuit (16).

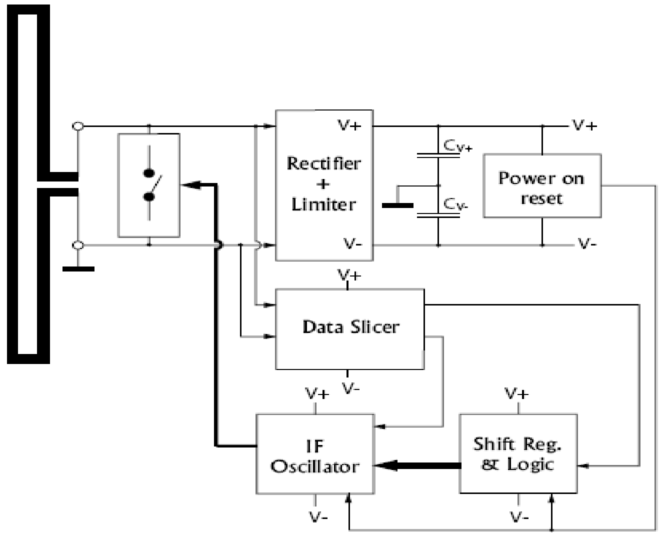



**Fig7**. Transponder system architecture (15). Transponder is the same as the tag and consists of the antenna and the chip and is the basic unit for the rfid systems.

The reader-tag communication link is implemented using a tiny pulse width demodulator. The backscattering technique is used to enable the tag-reader communication link. Because of the 1/*f* noise that occurs, the tag data are modulated at an Intermediate Frequency (IF) rate. The IF frequency is generated by a typical relaxation oscillator structure (15).Transponders can work at different frequencies. The current assignments of the frequencies to the ID tags are 125 KHz, 1356 MHz and 2.45 GHz (16).

3.3 Rectifier

A typical two stage modified-Greinacher structure is shown in Fig. below. The use of low threshold voltage and low reverse current diodes and capacitors makes it possible to obtain a relatively high output voltage f (1-2 V) given a sinusoidal input signal of about 200 mV. These values depend on the received power, the DC output current delivered to the load, and the impedance matching quality between the antenna and the rectifier's input. The model allows the prediction of the power needed to supply a given DC output current at a constant output DC voltage. Furthermore, it provides the rectifier input and output impedance (15). If the input capacitance *C*in is inductively compensated, the input voltage amplitude $V_{in}$ is equal to

$$v_{in} = 2\sqrt{2P_A R_{ant}} \frac{R_{in}}{R_{in} + R_{ant}} \quad [1]$$

Where, $P_{AV}$ is the available power from the antenna and $R_{ant}$ is its impedance real part. From Eq. 1 , it is clear that to increase $R_{ant}$ while simultaneously keeping $R_{in} = R_{ant}$, i.e. power match. This is necessary in order to increase the performance of the rectifier (15).

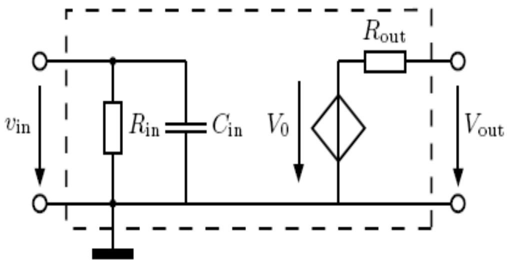



**Fig8**. Equivalent circuit for the rectifier (15).

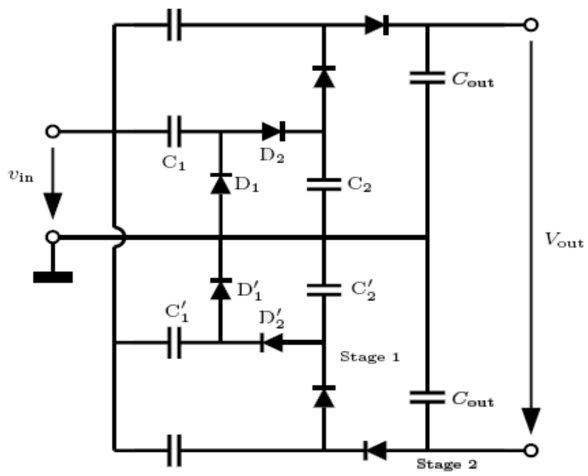



**Fig9.** 2-stage modified-Greinacher full-wave rectifier (15).

3.4 Modulator

The backscattering modulation technique is based on the variation of the reflection coefficient Γ at the input of a transponder. The power part being reflected enables tag to- reader communication. Γ can vary either in amplitude or in phase. As a result, two modulation types are possible: ASK (AM) and PSK (PM). The modulation type choice is a strict trade-off between the power dedicated to the tag operations and power devoted to the communication. In ASK, the modulator switches the input impedance between a matched state and a reflection state, whereas in PSK, it switches the impedance reactive part seen by the antenna between two complex conjugate values. The available power to the tag is thus kept constant during the PSK modulation states. This could be seen as an advantage of PSK over ASK but, it can be shown that there exists an optimum for both modulation in terms of Bit Error Rate (*BER*), average available power and voltage amplitude at the tag input (15).

3.5 Antennas

In RFID system antenna plays a pivotal role. One of the desirable features of tag antennas is that they should be as small as possible. Generally the antenna length is proportional to tag's operating wavelength. Some antennas are discussed below. At first Double or dual dipole antennas features is presented.

3.5.1 Dipole antennas. A dipole antenna has a straight electric conductor interrupted at the centre. In this case the total length of the antenna is half the wavelength of the frequency. There are several variants. A dual dipole antenna has two dipoles. It improves the readability of the tag by the reader. Dipole antenna consisting of two or more straight parallel and connected electric conductors is also possible. Each of the conductors is half the length of the operating wavelength. Figure 4 presents different types of dipole antennas schematically (8).

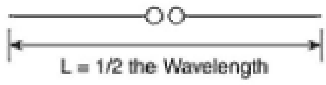



**Fig10**. Dipole antenna (8)

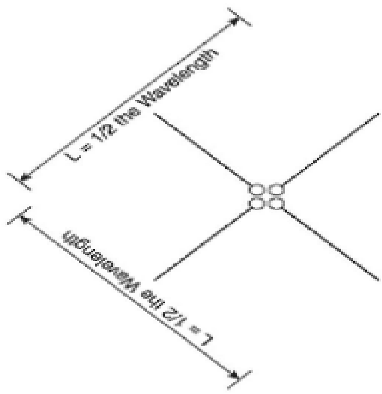



**Fig11**. Dual dipole antenna (8).

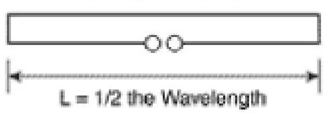



**Fig12**. 2 – Wire folded dipole antenna (8).

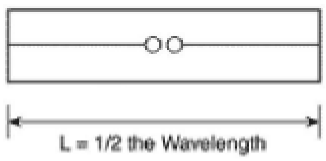
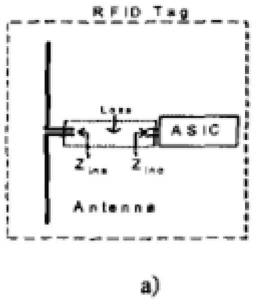



**Fig13.** 3 – Wire folded dipole antenna (8).

Because of its simplicity and omni-directionality, it is preferred in most of the cases. The dipole can be folded to reduce the size. Simulation software can be used to visualize the capacitive and inductive coupling of this type of tag antennas (8).

3.5.2 Folded Dipole Antenna (2.45GHz). The proposed folded dipole antenna is shown in Fig.2. Two folded wires are used to replace the straight wires of dipole antenna. The proposed antenna is not a closed loop, its folded ends are still opened and this open ends folded structure provides great freedom for impedance adjustment, especially for $X_{in}$ this is very important for conjugate impedance design. Fig.3 shows the simulated input impedance as a function of L1, R and X,, increase when LI changes from 24mm to 52mm (corresponds to 0.196**λ** to 0.425**λ**, for 2.45GHz) (10).



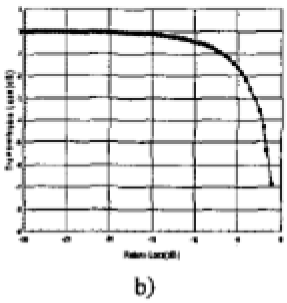




**Fig14.** A) Tag configuration (10). B) Transmission loss caused by mismatch (10).

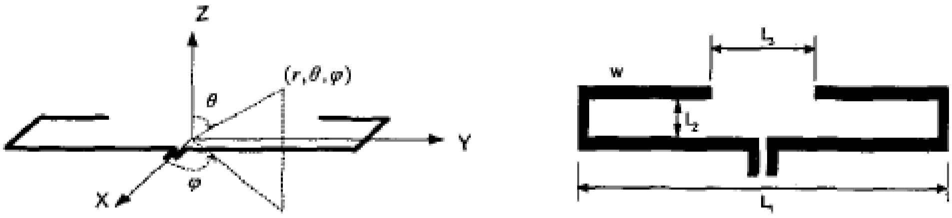



**Fig15.** Configuration and coordinate system of the proposed antenna (10).

3.5.3 Patch Antenna. The advantage of the patch antenna is that, it can be applied to any kind of material, reflecting or lossy material, and still provide good antenna function. However, the patch antenna efficiency is strongly dependent on the material used. The key issues for long reading distances are the antenna gain of the tag and the rectifier efficiency and power consumption of the RFID chip. State of the art RFID technology is utilising silicon RFID chip technology and silver ink printed antennas and the current work consequently focuses on multilayered antennas using this technology platform. Here, multilayered antenna called patch antennas for 2.45 GHz RFID tags is presented (12).

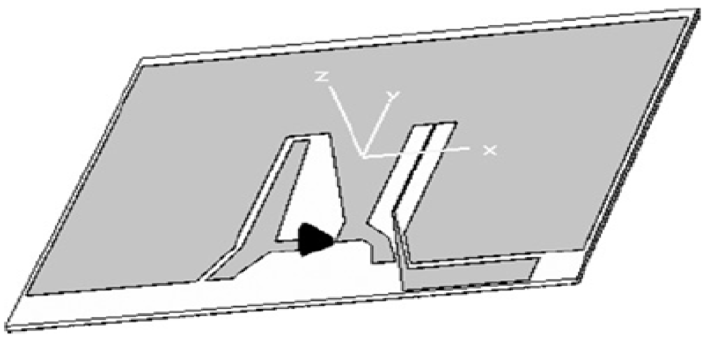
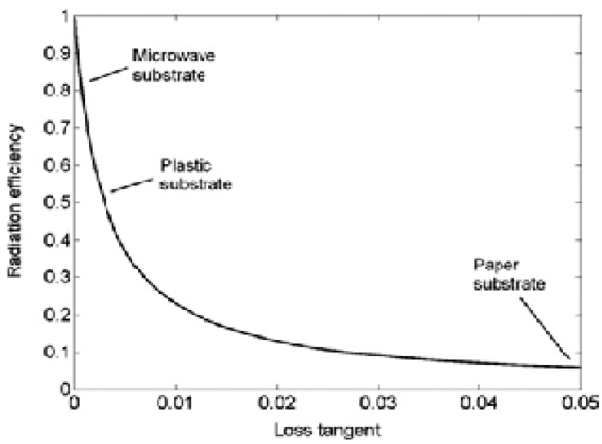



**Fig16.** Schematic picture of patch antenna (12).

In Fig. 3, the radiation efficiency of patch antennas is plotted as a function of dielectric loss tangent and in Fig. 4 the radiation efficiency is plotted as a function of conductor conductance. It is clear that the patch antennas are very sensitive to losses both in the dielectric layer and in the conductor layers (12).



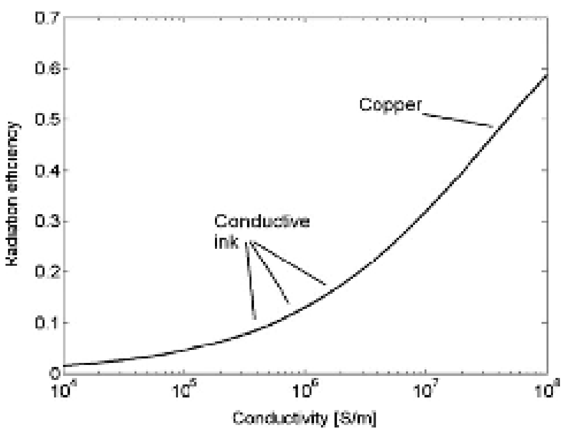



**Fig17.** Radiation efficiency as a function of loss Tangent obtained using the cavity model (12).

**Fig18.** Radiation efficiency as a function of Conductance obtained using the cavity model (12).

3.5.4 Experimental setup for patch antenna. The patch antennas were produced using a simple screen printing technique with silver-based conductive inks. Different substrate materials are used. Both water and solvent-based inks were tried, with the best adhesive and bending performance using the solvent-based ink. The ink layers were approximately 25 mm with a sheet resistance of approximately 20 mV (corresponding to a conductance of 2 $X10^6$ S/m. The dimensions of the antenna were designed according to the permittivity of introduced substrates to provide impedance matching to the excitation circuits used and the design was evaluated using a standard network analyser configuration. For the polyethylene low density (PELD) substrate the width of the patch antenna was 44 mm, the length 37 mm and the quarter wavelength feed was 18.5 mm long. For other materials the dimensions were scaled to provide the same electrical size for all materials (scaling by the square root of the dielectric constant). The phase modulation of the tag was measured as the phase difference of the antenna impedance for the case of biased and unbiased Schottky modulators (12).

The reading distance of the tags has been evaluated in free space using the Tag Master reader according to the setup presented in Fig. 5. A periodic backscattering from the antenna was introduced using a 32 kHz and 3 V square wave modulation of the impedance of the RF Schottky diode located at the feed point of the patch antenna. The amplitude of the demodulated analog backscattered signal was recorded by the reader for different tags to reader distances (12).

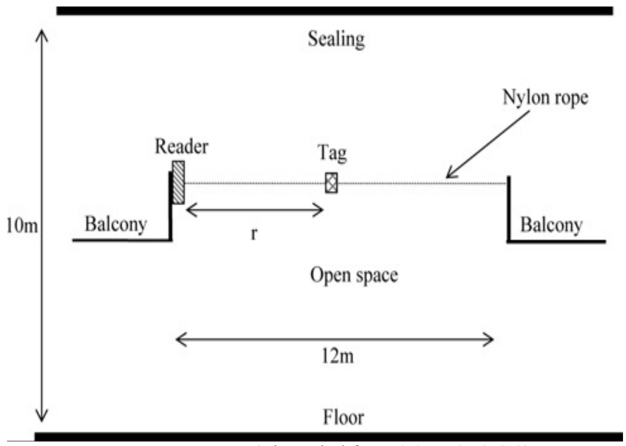



**Fig 19.** Measurement set-up (r is varied from 0.2 to 6 m) (12).

The antenna should be designed to provide the largest possible phase modulation at the frequency where the patch has the highest radiation efficiency. The quarter wavelength feeding the Tag Master antenna ensures rapid phase variations close to the resonance point. The matching condition is to have as large backscattering and phase modulation as possible at the reader frequency. In Figs. 6a and b, the phase modulation of an antenna printed on PELD plastics is presented, both in a Smith chart and in X–Y diagram (12).

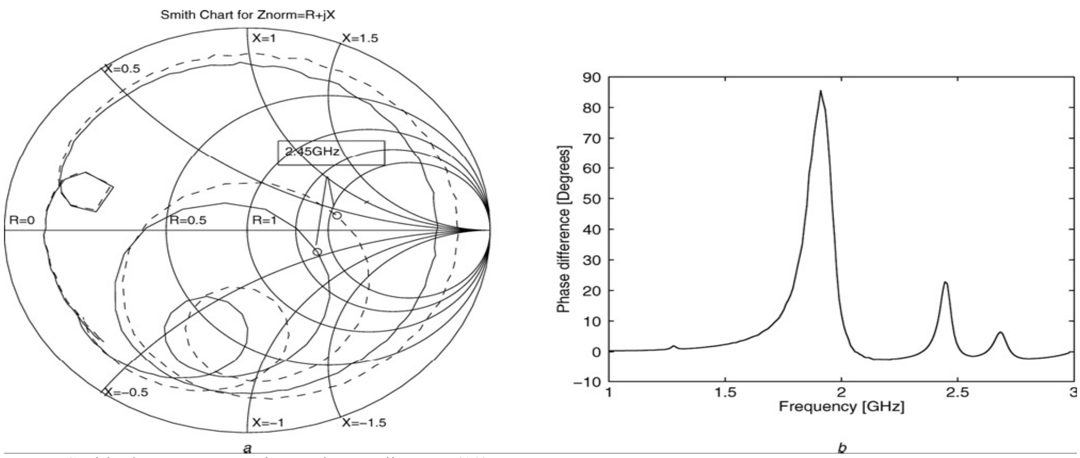



**Fig20.** Smith chart representation and X–Y diagram (12).

3.5.5 CPW-fed folded-slot antenna for 5.8 GHz RFID tags. A coplanar waveguide (CPW)-fed capacitive folded-slot antenna is proposed for the radio frequency identification (RFID) application at 5.8 GHz. The antenna is fabricated on a 30X30 mm substrate. The measured bandwidth and antenna gain are 7.5% and 4.2 dBi, respectively. Radiation patterns are almost omnidirectional in the H-plane. These properties and the compact and uniplanar structure make the antennas suitable for use as RFID tags (6).

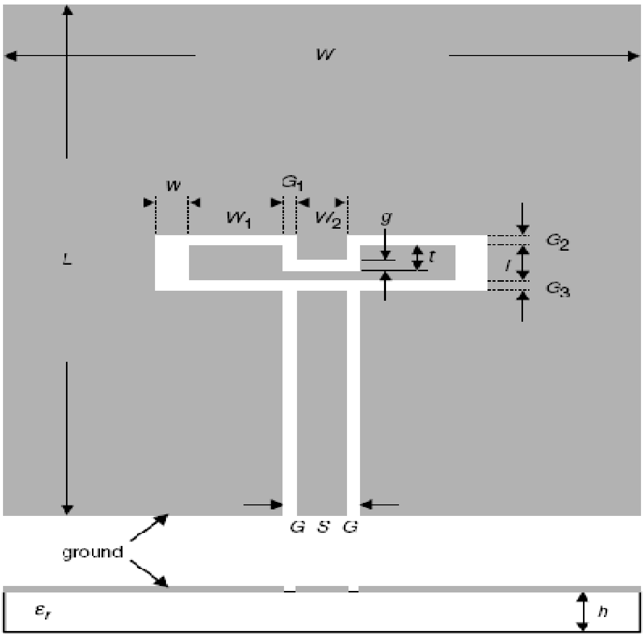



**Fig21.** Geometry of CPW – fed capacitive folded – Losses of prototype antenna (6).

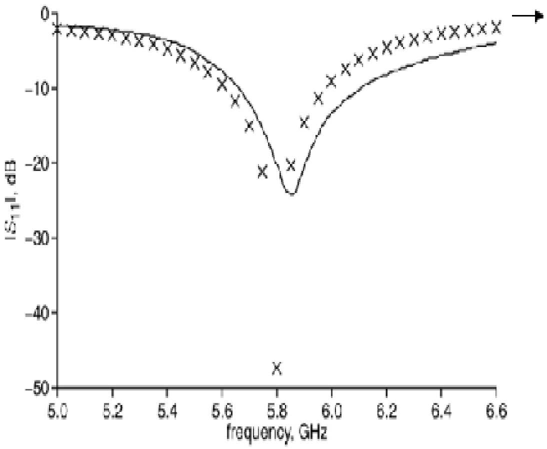



**Fig22.** Simulated and measured input return slot antenna (6).
Xx simulated
----- measured

This antenna has a simple structure with only one layer of dielectric substrate and metallisation. The feeding CPW, of which the central strip is truncated at the lower edge of the folded slot, is capacitively coupled into the folded-slot antenna. The total length of the folded slot will be approximately equal to a guided wavelength of the slot line at resonance. The input return loss level and the resonant frequency of the proposed design will vary with total length L and total width W of the substrate. To facilitate the design and fabrication processes, L and W are both fixed at 30 mm, which is slightly longer than a half wavelength in free space at resonance (6).

A 5.8 GHz prototype antenna is implemented with the substrate size L X W = 30 X 30 mm and is fabricated on an FR-4 substrate with dielectric constant $\varepsilon_r = 4.3$, loss tangent tan $\delta$=0.02, and thickness h=1.5 mm. The design parameters are: $W_1$ =3.6 mm, $W_2$=3.0 mm, w= 1.2mm, $G_1=G_2=G_3=g$=0.3 mm, t=1.6 mm and l=1.3 mm. The widths of the strip and slot of the 50Ω CPW feed line, S and G, are chosen to be 3.0 and 0.3 mm, respectively (6).

## 36. **Merits and Demerits**

New 2.45 GHz RFID systems are certified for use in all industrialized countries in Europe, America and Asia. They read at up to 6 m range and at passage speeds up to 400 km/hour. They can read several tags simultaneously and use multi-channel technology to allow for an in practice unlimited number of readers in each installation area without interference problem. 2.45 GHz systems are characterized by directional reading, long reading range, and high passage speed, good immunity to electromagnetic interference (EMI) and very high tolerance to dirt (15). High frequency systems at 2.45 GHz is the best choice when a long reading range and high passage speed is needed in combination with a moderate cost for the data carriers. 2.45 GHz works excellent in dirty environments, with freedom to choose between read-write and read-only data carriers, and the reader and tag multiplicity give very high installation flexibility. Applications range from manufacturing to distribution/logistics and access control for people and vehicles. 2.45 GHz RFID also provides excellent opportunities to design RFID systems with advanced characteristics (15).

Unlike inductive RFID systems, it is possible to design tags that work flat on metallic objects. Line of sight transmission is not required for operation. UHF and microwave signals easily penetrate wood, paper, cardboard, clothing, paint, dirt, and similar materials. Additionally, because of the short wavelength of the radio signal and reflective properties of metallic objects, reader systems can be designed to have high reliability reading in regions with high metallic object content. Compared to the low frequency inductive systems, the UHF and microwave systems can have longer range, higher data rates, smaller antennas, and more flexibility in form factors and antenna designs (7).

Unlike inductive RFID tags which require substantial surface area, many turns of wire, or magnetic core material to collect the magnetic field, UHF and microwave tags can be very small. The tag's thickness is limited only by the thickness of the chip as the antenna can be fabricated on thin flexible materials. Since tags operating in the E field do not require antennas with extremely low impedances, inexpensive flexible antennas able to withstand considerable bending are achievable (7).

High frequency means high transmitting rate. And with the increase of the frequency, the antenna becomes smaller and smaller, which makes it possible to produce very tiny transponders working at very high frequency.

4.1 Performance advantages of using UWB (Ultra wide Band, 3.1 GHz – 10.6 GHz)

UWB RFID solutions have high RTLS accuracy (10-30cm accuracy and solution), high multipath immunity and have high read rates at extended ranges. UWB tags are highly energy efficient and have extended battery life.

4.2 Antenna design problems

A*s* the frequency of choice for RFID devices rises into the microwave region, the problem of designing antennas to match the devices on the protected object becomes more acute (4). Higher operating frequencies require more expensive components and loose the ability to transfer energy at a rate of the inverse of the wavelength squared (A 2.45GHz system would need seven times the energising fields needed by a 915 MHz system) (15). When RFID frequency rise into the microwave region, the tag antenna must be carefully designed to match the free space and to the following ASIC. This must be made to maximize the transfer of power in and out of the RFID system. This is especially important in a passive RFID system where the ASIC's power supply is only from the interrogating radio wave. In addition, poor impedance match will result in transmission loss between the antenna and ASIC (10).

4.3 Environmental Elements.

UHF and microwave signals are attenuated and reflected by materials containing water or human tissue, and are reflected by metallic objects (7). Interference from metals and RF noise can degrade the performance of an RFID signal. Metals and liquids tend to absorb RF waves (7). Ability to penetrate through metal and water content: decreases as the frequency increases. Low frequency RFID systems are least effected whereas microwave & ultra high frequency RFID systems are most sensitive to metal and water content and are not able to penetrate through such objects (4). HF technology's near field inductive coupling reduces potential wireless interference issues because no real power is being radiated. Therefore, HF technology has an excellent immunity to environmental noise and electrical interference. UHF's far-field technology does radiate real power and its higher signal strength makes it more prone to electrical interference (17).

4.4 Range

The gain of the RFID antenna and whether or not there is a battery will affect the usable range of the RFID tags (4).

4.5 Impedance Problems

For maximum power transfer, the input impedance of the following ASIC should be the same *as* that of the antenna. Another problem is that an object close by the antenna can degrade the Return Loss. This is particularly true for omnidirectional antennas, such *as* dipoles; In addition, items which are dielectrics rather than metal change the frequency of resonance. A plastic bottle of water lowers the frequency of minimum Return Loss point by 16% (4).

Frequency is a large determinant of range and speed. It also plays a major role in the ability of RF waves to penetrate RF hostile materials such as water and metal. Communications protocol between tag and reader affects throughput and accuracy. Orientation sensitivity is largely a factor between antenna design of tags and antenna deployment of readers. This will determine in large part the read accuracy of tags passing through the interrogation zone in a different manner (vertically, horizontally, etc) (8). The key issues for long reading distances are the antenna gain of the tag and the rectifier efficiency and power consumption of the RFID chip.

## 5. Current status

The wide-band 2.4 GHz ISM band is available worldwide and the allowed transmit power is 4 W. 2.4 – 2.483 GHz & 5.725 – 5.875 GHz frequency bands used in RFID systems are based on ISO 18000-4 and ISO 18000-5 standards. 2.45 GHz systems are characterised by directional reading, long read range, and high passage speed, good immunity to electromagnetic interference (EMI) and very high tolerance to dirt (2). These systems are based on the principle of modulated back scattered signal detection. High frequency systems at 2.45 GHz is the best choice when a long reading range and high passage speed is needed in combination with a moderate cost for the data carriers. 2.45 GHz works excellent in dirty environments, with freedom to choose between read-write, read-only data carriers, and the reader and tag multiplicity give very high installation flexibility (2). The size of tags is getting reduced to a great limit by using GHz frequency. So far the smallest tag that has been developed is 0.4 mm x 0.4mm x 0.15mm in dimension. It's a passive transponder which operates at 2.45 GHz with a reading distance of 30 cm (20).

State of the art RFID technology is utilising silicon RFID chip technology and silver ink printed antennas, and the current work consequently focuses on multilayered antennas using this technology platform (18). Various antennas for the GHz frequency system has been proposed like a coplanar waveguide (CPW)-fed capacitive folded-slot antenna is proposed for the radio frequency identification (RFID) application at 5.8 GHz (6). In the UHF band, printed dipoles or patch antennas are normally used for the tag but they have a large resonant size especially for operating frequencies below 1 GHz. For the purpose of reducing the tag sizes, a meander line antenna (MLA) is an attractive choice (11). Antenna designs like novel design of a dual linearly polarized aperture coupled circular microstrip patch antenna operating at C-band (5.8 GHz) has been proposed (12). The high gain, broad beam-width, low cross polarisation and isolation from the input ports make it very suitable for RFID systems. The microstrip patch antenna was designed at S band (2.45 GHz). Another type of antenna is slot antenna. A new approach for microstrip-fed slot antenna for millimetre-wave RFID system operating at 24 GHz has also been approached.

Paratek company dealing with RF antenna designing has proposed the "near field focused, scanning phased array(NFA) antennas in which antenna power is surgically directed and focused at RFID tag with increasing power levels in the near field without polluting spectrum in the far field. Hence, more signal power is delivered at the tag and read and writing ability of tags is dramatically improved. Multi path and interference problem is reduced (24).

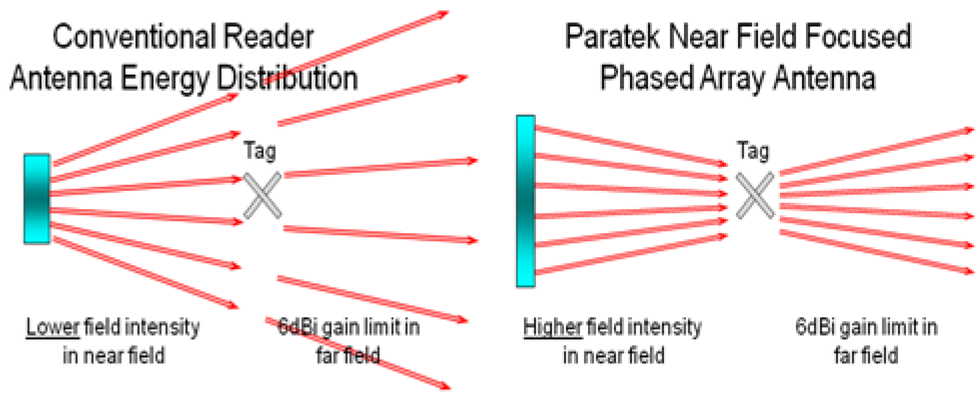



**Fig. 23** Comparison of energy distribution between the conventional reader antenna and Paratek phased array antenna. The figure clearly shows that the higher field intensity is observed by the tag in near field in case of paratek near field focused phased array antenna as compared to the conventional reader antenna (24).

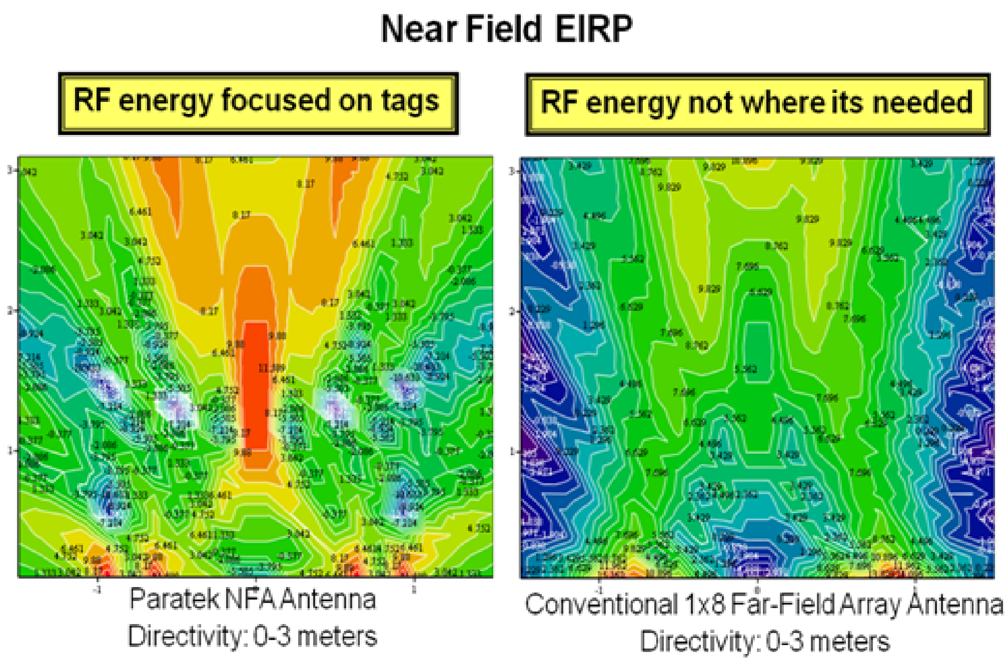



**Fig 24.** Near field EIRP (Equivalent isotropically radiated power). The figure depicts the fact that when paratek near field focused phased array antenna is used, RF energy is more focused on the tags as compared to the situation when conventional reader antenna is used and the rf energy is not focused where it is needed (24).

Companies like Multi Spectral Solutions Inc. are utilising frequency from 6-6.5 GHz preventing interference and opening up much needed spectrum. New 2.45 GHz RFID systems are certified for use in all industrialised countries in Europe, America and Asia. They read at up to 6 m range and at passage speeds up to 400 km/hour. They can read several tags simultaneously and use multi channel technology to allow for an in practice unlimited number of readers in each installation area without interference problem (22).

A back-scattered RFID system developed at both 900 MHz and 2.45 GHz at Intermec Technologies Corporation has the following key features:

1. A single programmable chip with low power digital circuitry together with schottky diodes.
2. Identify and communicate with multiple tags in the field.
3. Read from and write to individual tags.
4. Broadcast information to all tags in the field.
5. Permanently lockable memory
6. Select a subgroup of tags to identify or communicate based on information stored in the tag (25).

Vendor: (Multispectral Solutions): Sapphire DART tags operate under Part 15.250 regulations, permitting both indoor and outdoor use. The FCC Part 15.250 band spans from 5.925-7.250 GHz. European regulators are currently considering the authorization of UWB-based RFID and RTLS systems within the 6.0-9.0 GHz, overlapping allocations within the U.S. With read ranges in excess of 200 meters (650 feet), resolution and accuracies of better than 30 cm (1 foot), battery lifetimes in excess of 5 years, robust operation in severe multi path environments and micro miniature tag sizes, Sapphire DART represents the state-of-the-art in RTLS (23).

The Ubitags and readers operate from 5.8 to 7.2 GHz, though UWB systems can operate from 3.1 GHz to 10.6 GHz. UWB tags transmit a signal over multiple bands of frequencies simultaneously. Unlike conventional RFID systems, which operate on single bands of the radio spectrum, UWB transmits a signal over multiple bands of frequencies simultaneously, from 3.1 GHz to 10.6 GHz (22).

UWB active tags can be used for RTLS applications as well. UWB active tag technology for RFID and RTLS applications has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size. UWB systems work well indoors because the short bursts of radio pulses emitted from UWB tags are easier to filter from multi path reflections. Ubisense uses active tags, which the company calls Ubitags operating from 5.8 to 7.2 GHz (22).

## 6. Present Challenges

6.1 Cost minimization

High cost and high RFID system integration costs are some of the challenges that restrict the growth of the RFID. Tag prices are still high and need to be reduced and should be brought down to (5 cents) for the full deployment in the day-to-day life. Although the price of 2.45 GHz RFID has dropped dramatically, they are still more expensive than low frequency RFID (125 kHz, 13.56 MHz). Costs incurred in data processing, online handling of huge amount of streaming data, storage, network bandwidths and systems are other constraints. Improving read write capabilities and providing anti counterfeiting and tampering proof tags are few of the current challenges.

6.2 High power consumption

The chip used in the tag gets costlier on increasing the GHz frequency because one cannot use silicon anymore for fabrication of IC as the substrate silicon losses are high and high power transmission losses occur. Costly non-silicon materials like SiGe have to be used which are even very difficult to make.

6.3 Security Concerns

Ethical threats concerning privacy of life are possible. Unauthorised access to the important data is possible by the third party using hidden readers, which give rise to serious concern to the privacy norms. For secure implementation of the system, system should be developed such that the tag should not give the entire information and rather reveals the highest level of authenticated information and specifies level of security and/or amount of energy required from the authentic reader and reader proceeds at that level of security to maintain secure system (24).

6.4 Spectrum Congestion

RFID systems should be moved to higher GHz frequencies as the UHF band and other 850 MHz –1 GHz bands are highly congested due to the sharing of frequency band by various radio wireless communication systems.

6.5 Technical Challenges

Since Si process is used for the tags; the power received at the tag ($P_t$) is limited. Various standards defined by the government have put up various limiting factors for passive RFID tags like reader transmitter power ($P_r$) and reader antenna gain ($G_r$). Higher operating frequencies require more expensive components and lose the ability to transfer energy at a rate of the inverse of the wavelength squared. (A 2.45GHz system would need seven times the energising fields needed by a 915 MHz system). Since, at GHz frequency due to far field propagation, the received power of tags ($P_t$) is inversely proportional to the square of the distance from the reader (d) and as a result, doubling read range requires 4X the transmitter power.

$$P_t \alpha \frac{1}{d^2} \quad [1]$$

Where, $P_t$ is the received power of the tag, d is the read range (distance of the tag from the reader) (18).In addition, the energy density of a signal radiated using electric field coupling decreases as the inverse of the distance squared between the source and the transponder.

$$E_{density} \propto \frac{1}{x^2} \quad [2]$$

Whereas sensitive receivers can compensate for this loss of energy for the data communications over long distances, passive transponders which use the reader's energising field as a source of power are practically limited to 10 to 15 meters. Beyond that distance (which reduces drastically with increased frequency to less than 1 meter at 2.5GHz) it is necessary for the tags to use an external battery as a source of power (hence become active transponders). Due to the physical size constraints of the RFID tags; the tag antenna gain ($G_t$) is small because of reduced antenna size. Also, at larger distances and higher frequencies reader receiver sensitivity ($S_r$) and tag modular efficiency ($E_t$) limitations dominate (24).

Antenna performance degrades due to the losses of silicon substrate and relatively thin metal layers. Metal structures near antennas can change input impedances and phase of received signals. Another concern is the interference effects between the transmitted signal and nearby circuits and between the transmitted/received signal and switching noise of nearby circuits (19). The challenges in RFID antenna design are related to robustness. A single layered RFID antenna is very sensitive to the environment where it is placed. Reflecting and lossy materials provide severe reduction in reading distance. However, multi-layer antennas could be used which are less sensitive to the material, but such antennas are considerably thicker than a single layered solution and might increase the cost through the use of low loss microwave substrates (12). Also, designing of antennas with arbitrary input impedance (other than 50 ohm or 75 ohm) with the constraints like small size, low cost etc. is a difficult task. Also, the tag antenna orientation affects radio wave reception. Orientation, distance and height of the antenna affect performance (10).

### 6.6 Environmental influence

Interference from metals and RF noise can degrade the performance of an RFID signal. Metals and liquids tend to absorb RF waves. This effect is most prominent in higher frequencies especially, frequencies in GHz. As a result, RFID communication becomes difficult at high GHz frequencies and signal attenuates rapidly due the interference of metal, water and other materials. Tag attaching material- paper, wood, plastics, metal, liquid affect the performance of the RFID system. Noise from other systems communicating within the designated frequency range is another environmental consideration that can affect range, speed and accuracy (4).

### 6.7 Standard Challenges

6.7.1 Lack of a unified RFID standard. Various standards have been adopted by various countries. The tolerated power levels and regulations for RFID systems vary from country to country. For example, the maximum permitted legal power level (the power level at which the interrogator is set at) for 2.45 GHz in the U.S. is 100 times higher than that in the Europe. This creates a huge difference in read range – a 1 meter range in the U.S. may only be a 1 centimetre range in Europe, all others being equal. These differences hamper the interoperability of RFID systems (18).

6.7.2 Lack of consistent UHF spectrum allocation for RFID. Different frequency bands are assigned for the use of RFID applications in different countries of the world. RFID hardware performance is changed with different central frequency. There is a lack of consistent unified UHF spectrum allocation around the globe.

The lack of a complete and international unified standard is causing many enterprises to hesitate in adopting RFID systems.

### 6.8 Reader collision Problem

As the RFID systems move to higher frequency and due to the presence of multiple tags, the reader – reader interference and reader–tag interference become a matter of concern for the efficient use of RFID system. Collision is caused by simultaneous radio transmission. Proper anti-collision mechanisms need to be introduced to read multiple tags simultaneously.

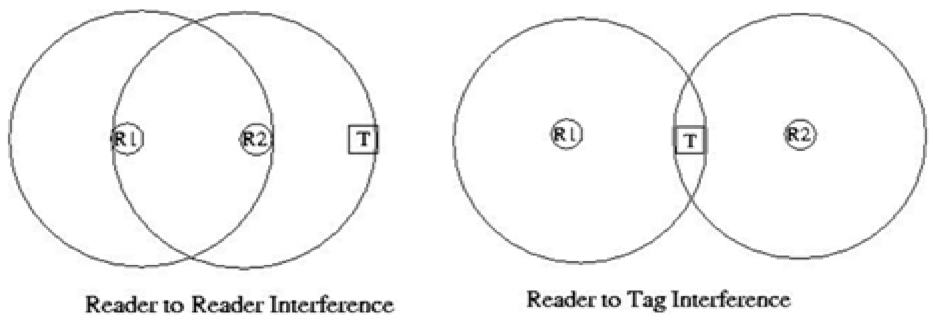



**Fig 25.** Reader to reader interference and reader to tag interference. The figure shows that how reader to reader interference is possible in case of close of proximity of two antennas and the reader to tag interference when multiple tags and multiple readers are present (24).

## 7. Discussion

RFID is an electronic tagging/identification technology which facilitates automatic identification without any contact and line of sight by exchange of electromagnetic signals (radio frequencies) between readers and tags (8). RFID systems have two parts: the tag and the reader. An RFID tag consists of a microcontroller, an antenna (either wire or printed using conductive carbon ink), and polymer-encapsulating material that wraps around the antenna and processor. The reader initiates the identification process by generating an RF field at a specific frequency defined for the particular system, thereby causing a voltage difference at the tag antenna end points via inductive or capacitive coupling. The tag detects this change and, after optionally authenticating the reader via a challenge-response mechanism, responds by transmitting the identifier that it holds (9).

There are many characteristics which are used to distinguish RFID systems. Two of those are the power source of the tag (passive, active or semi-passive) and the frequency of operation (13).

RFID systems currently operate in the Low Frequency (LF), High Frequency (HF) and Ultrahigh Frequency (UHF) bands, microwave & ultra wide band. Each frequency has advantages and disadvantages relative to its capabilities. Generally a lower frequency means a lower read range and slower data read rate, but increased capabilities for reading near or on metal or liquid surfaces.

The microwave band consists of 2.45GHz or 5.8GHz or other higher frequencies like 7.2 GHz. Though microwave based RFID systems offer the highest data read rates, they are the most expensive systems and have a limited read range of up to 1m (3 ft). Additionally, microwave based systems are not able to penetrate objects with high water or metal content which makes it unsuitable for many applications (7).The wide-band 2.4 GHz ISM band is available worldwide and the allowed transmit power is 4 W. 2.4 – 2.483 GHz & 5.725 – 5.875 GHz frequency bands used in RFID systems are based on ISO 18000-4 and ISO 18000-5 standards.

State of the art RFID technology is utilising silicon RFID chip technology and silver ink printed antennas, and the current work consequently focus on multilayered antennas using this technology platform (18). Active RFID ultra wide band tags operate in the frequency range 3.1 – 10.6 GHz. These are short pulse electromagnetic waves with few RF cycles, having large fractional bandwidth, extremely low duty cycles and high multipath immunity.

The most important advantage of the use of higher GHz frequency is that the higher frequency has higher data transfer rate, speed and longer read ranges, but also more sensitivity to environmental factors such as liquid and metal that can interfere with radio waves. These GHz systems are typically used today for applications where high read ranges are required, with distances of several meters. And with the increase of the frequency, the antenna becomes smaller and smaller, which makes it possible to produce very tiny transponders working at very high frequency. But while the frequency is in the microwave range, no penetration will be with the transmission, which means the line-of-sight transmission is required.

However, the GHz frequency radio signals are very prone to the environmental conditions and are easily absorbed by water or the thinnest layer of metal. At UHF and GHz frequencies, wireless power transmission is more suitable and the backscattering principle offers a reliable communication link. A small transponder size, which is mainly determined by the antenna size, is ensured by choosing a high operating frequency. Furthermore, the wide-band 2.4 GHz ISM band is available worldwide and the allowed transmit power is 4 W.

## 8. Solutions to present challenges

8.1 Solutions in UHF

Using state-of-the-art analysis and design techniques, a SOS 0.5-m CMOS technology and inductive matching between the antenna and the transponder, an operating range of 12 m with 4 W EIRP transmitted power was achieved. At this distance, the available power for the transponder is 2.7 micro W, which means about 37% global efficiency for the rectifier since the estimated (simulation) power consumption of the whole system is approximately 1 micro Watt. Using silicon-on-sapphire in conjunction with state-of-the-art RF design allowed reaching an operating range of 12 m (3).

8.2 Suitable Antenna designing

A suitable tag antenna must have following characteristics: has good impedance match, be robust, be very cheap, and be small enough to be attached the required object, has omnidirectional or hemispherical coverage and normally has linear polarization or dual polarization depending upon requirement (10).

When RFID frequency rise into the microwave region, the tag antenna must be carefully designed to match the free space and to the following ASIC. This must be made to maximize the transfer of power in and out of the RFID system. This is especially important in a passive RFID system where the ASIC's power supply is only from the interrogating radio wave. In addition, poor impedance match will result in transmission loss between the antenna and ASIC. For example, assume the antenna doesn't match well to ASIC, its return loss is -1.25dB, the resulted transmission loss will be -6dB, that means the detection range of the tag will reduce to half. For maximum power transfer, the input impedance of the tag antenna must be the conjugate of input impedance of the ASIC, that means the required tag antenna impedance may be an arbitrary value as well; it's a challenge to design the antenna that will have arbitrary input impedance with the constraints like small size, low cost etc (10).

The antenna must be small enough to be attached to the required object and have omnidirectional or hemispherical coverage, must provide maximum possible signal to the ASIC, have a polarization such as to match the enquiry signal regardless of the physical orientation of the protected object like novel design of a dual linearly polarized aperture coupled circular microstrip patch antenna operating at C-band (5.8 GHz).It should use multilayered antennas which are much less sensitive to the material that it is attached to (2). The high gain, broad beam-width, low cross polarization and isolation from the input ports make it very suitable for RFID systems. A coplanar wave (CPW)-fed capacitive folded slot antenna for RFID at C-band (5.8 GHz). It has good and omni directional radiation patterns, high gain and bandwidth suitable for RFID deployment. Micro strip-fed slot antenna for millimetre-wave RFID system operating at 24 GHz has also been developed (6). In the UHF band, printed dipoles or patch antennas are normally used for the tag but they have a large resonant size especially for operating frequencies below 1GHz. For the purpose of reducing the tag sizes**,** a meander line antenna (MLA) is an attractive choice (11).

Since, at GHz frequency due to far field propagation, the received power of tags ($P_t$) is inversely proportional to the square of the distance from the reader (d) and as a result, doubling read range requires 4X the transmitter power.

$$P_t \, \alpha \, \frac{1}{d^2} \quad [1]$$

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$$E_{density} \propto \frac{1}{x^2} \quad [2]$$

Whereas sensitive receivers can compensate for this loss of energy for the data communications over long distances, passive transponders which use the reader's energising field as a source of power are practically limited to 10 to 15 meters. Beyond that distance (which reduces drastically with increased frequency to less than 1 meter at 2.5GHz) it is necessary for the tags to use an external battery as a source of power (hence become active transponders). Due to the physical size constraints of the RFID tags; the tag antenna gain ($G_t$) is small because of reduced antenna size. Also, at larger distances and higher frequencies reader receiver sensitivity ($S_r$) and tag modular efficiency ($E_t$) limitations dominate (24). Hence, focused phased array antennas (as given in the section-5, fig24 & 25) are used that direct and focus signal power to work efficiently. Multipath and interference problems can also be reduced by using near field focussed, scanning phased array antennas in which antenna power is surgically directed and focused at RFID tag with increasing power levels in the near field without polluting spectrum in the far field. Hence, more signal power is delivered at the tag and read and writing ability of tags is dramatically improved (6).

8.3 Use of multiple antennas for robustness

The challenges in RFID antenna design are related to robustness. A single layered RFID antenna is very sensitive to the environment where it is placed. Reflecting and lossy materials provide severe reduction in reading distance. One solution is to use multilayered antennas which are much less sensitive to the material that it is attached to. Use of multiple antennas reduces the problem of reflection, diffraction and the formation of null points in the space resulted from the destructive interference of the reflected radio waves. Earlier work has proposed patch antennas using low loss microwave substrates and planar inverted-F antennas for passive RFID on metallic surfaces .These solutions provide antennas considerably thicker than a single layered solution and might increase cost through the use of low loss microwave substrates (15).

8.4 Use of isolator materials to mitigate the effect of environmental

Interference from metals and RF noise can degrade the performance of an RFID signal. Metals and liquids tend to absorb RF waves. This is often mitigated through antenna design and/or by applying a buffer or isolator material between the tag and the hostile material. The use of these spacers can lift the tag off the metal. However, these spacers are usually thick which is unsightly and can often cause damage to the tag with slight contact (30). Metal structures near antennas can change input impedances and phase of received signals. To deal with this, design guidelines to exclude the interference structures, which significantly change the input impedance, have been suggested.

8.5 Security Concerns

Ethical threats concerning privacy of life are possible. Unauthorised access to the important data is possible by the third party using hidden readers, which give rise to serious concern to the privacy norms. For secure implementation of the system, system should be developed such that the tag should not give the entire information and rather reveals the highest level of authenticated information and specifies level of security and/or amount of energy required from the authentic reader and reader proceeds at that level of security to maintain secure system. Various other approaches like faraday cage approach (RFID tag placed in a protective cage); kill tag approach (kill tag while leaving the store) and tag encryption approach (tag cycles through several pseudonyms) can be used for secure implementation of the system (24). High security encryption algorithms such as DES, RSA must be Applied (16).

8.6 Reader collision Problem

As the RFID systems move to higher frequency and due to the presence of multiple tags, the reader – reader interference and reader–tag interference become a matter of concern for the efficient use of RFID system. Proper anti-collision mechanisms need to be introduced to read multiple tags simultaneously, so that the collisions do not take place due to simultaneous radio transmission. Various collision avoidance mechanisms such as probabilistic (tags return at random time); deterministic (reader searches for specific tags) approaches can be used (6).

## 9. Future outlook

Plan is to take advantage of UWB RF pulses to encompass longer range of tag interrogation, given equal average power from the interrogator (or conversely, greater range in sensitivity); more immunity to signal degradation and multipath effects; a higher degree of security and immunity to eavesdropping; a greater potential for anti-collision in multi-tag environments; more uniform coverage of a volume of space; and the ability to focus the tag interrogation to a localized point in space (2).

Due to spectrum congestion around 1GHz frequency, and improved characteristics has pushed the RFID research towards higher GHz frequencies and 24.125 GHz and 60.65 GHz are going to be the future operating frequency of RFID tags. Passive transponders and passive tags working on very high GHz frequency are still under research, though, active tags are being used for UWB (Ultra Wide band 3.1 – 10.6 GHz) and other higher frequencies like 7.2GHz, RTLS tags operating at GHz frequencies. Companies like Multi Spectral Solutions Inc. are utilising frequency from 6-6.5 GHz preventing interference and opening up much needed spectrum.

Various research projects have been going on reducing the cost of silicon technology which is a major problem for large scale RFID deployment. New manufacturing technology: inline printing of electronics devices is under research. Use of organic semiconductors (example: polymers) has increased and printing of polymer chips and antennas using R2R technology is taking place. It has the potential of significant cost reduction (24).There is currently a large interesting roll to roll production of RFID tags and silver-based inks have been developed for use in printed RFID antennas. Silver ink based single layer antennas work well and provide 70–80% of the reading range compared to copper solutions. However, more advanced antennas are needed to provide less sensitivity to the environment of RFID tags that is need for placing tags on metal or near water.

Vendor: (Multispectral Solutions): Sapphire DART tags operate under Part 15.250 regulations, permitting both indoor and outdoor use. The FCC Part 15.250 band spans from 5.925-7.250 GHz. With read ranges in excess of 200 meters (650 feet), resolution and accuracies of better than 30 cm (1 foot), battery lifetimes in excess of 5 years, robust operation in severe multi path environments and micro miniature tag sizes, Sapphire DART represents the state-of-the-art in RTLS (27).

The Ubitags and readers operate from 5.8 to 7.2 GHz, though UWB systems can operate from 3.1 GHz to 10.6 GHz. UWB tags transmit a signal over multiple bands of frequencies simultaneously. Unlike conventional RFID systems, which operate on single bands of the radio spectrum, UWB transmits a signal over multiple bands of frequencies simultaneously, from 3.1 GHz to 10.6 GHz (28).

UWB active tags can be used for RTLS applications also and UWB active tag technology for RFID and RTLS applications and has demonstrated key performance advantages including long read ranges, sub-foot localization in dense industrial environments, extended battery life, high throughput and extremely small physical size (26).

The feasibility of integrating compact antennas and required circuits for implementing wireless interconnections in foundry digital CMOS technologies has been demonstrated. A 3-mm long zigzag dipole antenna on a 20-Omega-cm substrate should have efficiency up to approximately 25% at 24 GHz and cost 1-2 cents. These antennas can be used to implement a radio for 100-kb/s communication up to about 10 m. By lowering the operation frequency to 5.8 GHz and using a monopole structure, which occupies approximately 30% more area, the communication range can be increased by three times or more. This technology, as well as in a true single-chip radio, can be used for intra- and inter-chip data communication, intra- and inter-chip clock distribution, beacons, radars, RFID tags, and contact less high-frequency testing (29).

## 10. Conclusions

The RFID systems are going to move to higher GHz frequencies in future and it has been estimated that the RFID systems will be operating at 24.125 GHz frequencies within next 5 years and 60.65 GHz is considered to be the frequency of the future RFID applications going to be implemented in next 8 years.

The current emphasis is on developing ultra thin flexible silicon IC (20μm). Polymer electronics based EPC global compatible RFID tags are expected to be in use by 2012. More and more printing processes are going to be in use and low-cost, sustainability and good conductivity ink are some of the challenges. The other concerns for the RFID systems are related to the privacy and security problems (24). Health concerns to humans is another issue which needs to be sort out before moving RFID systems to higher frequencies as electromagnetic waves at higher frequencies could poses serious threats to the humans and as a result, most regulating bodies, such as the FCC, have posed power limits on UHF and microwave systems and this has reduced the read range of these high frequency systems to 10 to 30 feet on average in the case of passive tags.

The technological research includes miniature tags with increased reading ranges, smart systems, small sized antennas for readers and printed polymer batteries & fuel cells (24). In the lower frequency bands, the read ranges of passive tags are no more than a couple feet, due primarily to poor antenna gain. (At low frequencies, electromagnetic wavelengths are very high, on the order of several miles sometimes, and much longer than the dimensions of the antennas integrated into RFID tags. Antenna gain is directly proportional to antenna size relative to wavelength. Hence, antenna gain at these frequencies is very low.) At higher frequencies, the read range typically increases, especially where active tags are used.

Read range is also sensitive to the tag orientation, the material the tag is placed on, and to the propagation environment. The read range can be calculated using Friis free-space formula As

$$r = \frac{\lambda}{4\pi}\sqrt{\frac{P_t G_t G_r \tau}{P_{th}}} \qquad [3]$$

Where, **λ** is the wavelength, Pt is the power transmitted by the reader, Gt is the gain of the transmitting antenna, Gr is the gain of the gain of the receiving tag antenna, $P_{th}$ is minimum threshold power necessary to provide enough power to the RFID tag chip, and τ is the power transmission coefficient given by

$$\frac{4R_c R_a}{|Z_c + Z_a|^2}, \quad 0 \le \tau \le 1 \qquad [4]$$

Where, Zc = Rc + jXc is chip impedance and Za = Ra + jXa is antenna impedance.

Interference from metals and RF noise can degrade the performance of an RFID signal operating at very high frequencies like few GHz. Metals and liquids tend to absorb RF waves. Noise from other systems communicating within the designated frequency range is another environmental consideration that can affect range, speed, and accuracy. Most problems with both types of interference issues can be addressed through a thoughtful systems design. Optimizing the selection of tags, readers, and frequency of use is the chief factor affecting interference. Frequency is a large determinant of range and speed. It also plays a major role in the ability of RF waves to penetrate RF hostile materials such as water and metal. Communications protocol between tag and reader affects throughput and accuracy. Orientation sensitivity is largely a factor between antenna design of tags and antenna deployment of readers.

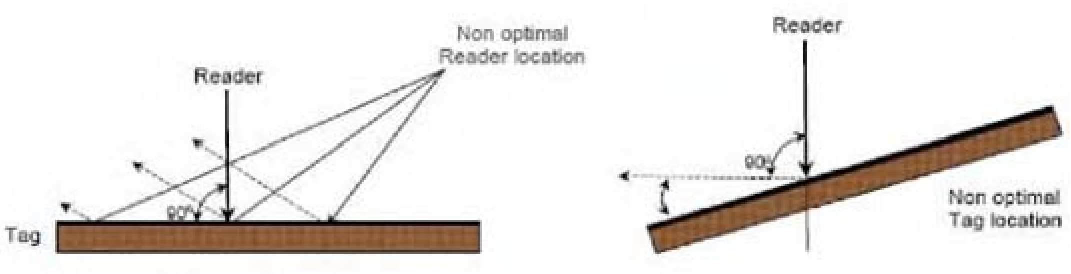


**Fig 27.** Reader orientation for optimal performance (8). The orientation sensitivity is a major factor for the antenna design in high frequency systems because of null points in the space in electro magnetic region. UHF and microwave systems are more sensitive to differences in antenna Orientation. Dipole antennas have a more highly directive gain and significant differences in field strength at a given distance will exist between points in front of the dipole and above it. For UHF and microwave tags oriented top-up to the interrogator, signal strengths might not be high enough to enable communication.

The advantage of radio frequency identification (RFID) tags is that they use a memory storage device to store a certain amount of data such as the product identification number, price, cost, manufacture date, location, and inventory on hand. This information can quickly be read by a wireless scanner, so RFID can process large volumes of multiple data sets at the same time and improve efficiency of operations by using identification tags to accurately monitor processes for time, place and person. Radio frequency identification (RFID) is increasingly being used in retail, pharmaceuticals, transportation, and defence. RFID can provide great value in terms of track and trace, pedigree tracking, forecasting, obsolescence reduction, pharmaceuticals recalls, and efficiency in the entire supply chain infrastructure. However, the usual concerns of security, scalability, availability, reliability, distributed management, and performance are as relevant to RFID as they are in other domains (24).

Using compact antennas in an integrated circuit reduces the radio size, greatly simplifies its use, reduces assembly cost, and eliminates the need for external transmission line connections. These should radically reduce the cost of wireless systems.

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## Tables & Figures

**Table I.** Comparison between the performance of high frequency (2.45 GHz) and low frequency (125 kHz, 13.56 MHz) contactless technologies for different parameters (2).

| **Contactless ID technologies** | **high frequency (2.45 GHz)** | **low frequency (125 kHz, 13.5 MHz)** |
|---|---|---|
| **Parameter** | | |
| Reading range | very good | moderate |
| Passage speed | very high | low |
| Read-write data carriers | yes | yes |
| Directional readers | yes no | No |
| Reads through glass, clothes, wood etc | yes | Yes |
| Resistance against dirt | good | Good |
| Resistance against wear | good | Good |
| Resistance against interference | good | Low |
| Reading of multiple data carriers | yes | Yes |
| Readers close to each other | yes | No |
| Insensitive to metal mounting | yes | No |
| Reader cost | moderate | Low |
| Data carrier cost | moderate | low |

**Table II.** Different frequency bands and their relevance for RFID systems.

| Band Name | Frequency Range | Wavelength Range | Technical Details | Relation with RFID systems |
|---|---|---|---|---|
| HF (High Frequency) | 3–30 MHz | 100–10 m | coastal radar systems, over-the-horizon radar (OTH) radars; 'high frequency'<br>7.4 – 8.8 MHz: medium frequency, used for EAS (electronic article surveillance).<br>13.553 – 13.567 MHz: medium frequency (13.56 MHz, ISM), inductive coupling, most suitable for RFID applications. Example applications are library books, laundry identification, access control and employee IDs. | 6.765 – 6.795 MHz<br>7.4 – 8.8 MHz: medium frequency, used for EAS (electronic article surveillance).<br>100pW maximum allowed EIRP.<br>13.55 – 13.57 MHz: Based on ISO 18000-3 standards. Used in common applications of RFID, generally passive tags only. Slower data rate but better ability to read near metal or wet surfaces.<br>26.96 – 27.28 MHz used in special applications only.<br>Medium read range. |

| | | | | |
|---|---|---|---|---|
| P | < 300 MHz | 1 m+ | 'P' for 'previous', applied retrospectively to early radar systems | |
| VHF (Very High Frequency) | 50–300 MHz | 10 – 1m | very long range, ground penetrating; 'very high frequency'<br>UHF (ISM), backscatter coupling, rarely used for RFID. | |
| UHF (Ultra High Frequency) | 300–3000 MHz | 100cm-10 cm | 868-915 MHz: Active tags with integral battery or passive tags using capacitive storage, E- field coupling.<br>2.4 – 2.483 GHz: ISM , backscatter coupling.<br>2.446 – 2.454 GHz: RFID and AVI (automatic vehicle identification)<br>very long range (e.g. ballistic missile early warning), ground penetrating, foliage penetrating; 'ultra high frequency' | 433 MHz: Based on ISO 18000-7 standards, used in active RFID tags in Asia.<br>860 – 960 MHz: Based on EPC Global Gen2 standards, used world wide for RFID applications. High data rate.<br>2.4 – 2.483 GHz: Based on ISO 18000-4 standards. 2W maximum EIRP allowed. Long read range, higher reading speed, line of sight required and expensive. Poor ability to read through metal or wet surface. |
| SHF (Super High Frequency) | 3 – 30GHz | 10 -1 cm | 5.725 – 5.875 GHz: backscatter coupling, used in RFID systems, Railroad car monitoring, Toll collection systems, Active tags with integral battery or passive tags using capacitive storage, E-field coupling. | 5. 725 – 5.875 GHz: Based on ISO 18000-5 standards, presently rarely used in passive RFID and used for active RFID in UWB tags but in future tags will operate at this frequency because of higher data rate, read rate.<br>2W maximum EIRP allowed.<br>Line of sight required and higher read rate and range. Very poor ability to read through metal or wet surface. |
| L | 1–2 GHz | 30 – 15 cm | long range air traffic control and surveillance; 'L' for 'long'<br>used in optical communications,<br>Used by some of the communication satellites. | |
| S | 2–4 GHz | 7.5–15 cm | terminal air traffic control, long-range weather, marine radar; 'S' for 'short' | |
| C | 4–8 GHz | 3.75-7.5 cm | Satellite transponders; a compromise (hence 'C') between X and S bands; weather | |
| X | 8–12 GHz | 2.5-3.75 cm | Missile guidance, marine radar, weather, medium-resolution mapping and ground surveillance; in the USA the narrow range 10.525 GHz ±25 MHz is used for airport radar. Named X band because the frequency was a secret during WW2. | |
| $K_u$ | 12–18 GHz | 1.67-2.5 cm | high-resolution mapping, satellite altimetry; frequency just under K band (hence 'u') | |
| K | 18–27 GHz | 1.11-1.67 cm | From German *kurz*, meaning 'short'; limited use due to absorption by water vapour, so $K_u$ and $K_a$ were used instead for surveillance. K-band is used for detecting clouds by meteorologists, and by police for detecting speeding motorists. K-band radar guns operate at 24.150 ± 0.100 GHz. | 24.0 – 24.25 GHz: Research going on to utilize this higher frequency in future to improve data read rate, range etc. It has been estimated that this frequency will be available for RFID applications in next 5 years.<br>1W maximum EIRP allowed. Worst ability to read through metal or wet surface. Very expensive tags but very high data rate. |
| EHF (Extremely High Frequency) | 30 – 300 GHz | 10 – 1 mm | Shorter wavelengths hence, smaller antennas with high directivity & high gain.<br>Radio signals prone to atmospheric attenuation, not suitable for long distance communication, Commonly used in radio astronomy and remote sensing. | |
| $K_a$ | 27–40 GHz | 0.75-1.11 cm | mapping, short range, airport surveillance; frequency just above K band (hence 'a') Photo radar, used to | |

| | | | | |
|---|---|---|---|---|
| | | | trigger cameras which take pictures of license plates of cars running red lights, operates at 34.300 ± 0.100 GHz. | |
| Mm | 40–300 GHz | 7.5 mm – 1 mm | millimetre band, subdivided as below. The letter designators appear to be random, and the frequency ranges dependent on waveguide size. Multiple letters are assigned to these bands by different groups. These are from Baytron, a now defunct company that made test equipment. | |
| Q | 40–60 GHz | 7.5 mm – 5 mm | Used for Military communication. | |
| V | 50–75 GHz | 6.0–4 mm | Very strongly absorbed by the atmosphere. | |
| E | 60–90 GHz | 6.0–3.33 mm | | 60.65 GHz is considered to be the future RFID frequency and it has been estimated to be available for RFID applications in next 8 years. |
| W | 75–110 GHz | 2.7 – 4.0 mm | used as a visual sensor for experimental autonomous vehicles, high-resolution meteorological observation, and imaging. | |
| U mm | 300 – 3000 GHz | 1mm - .1mm | | |

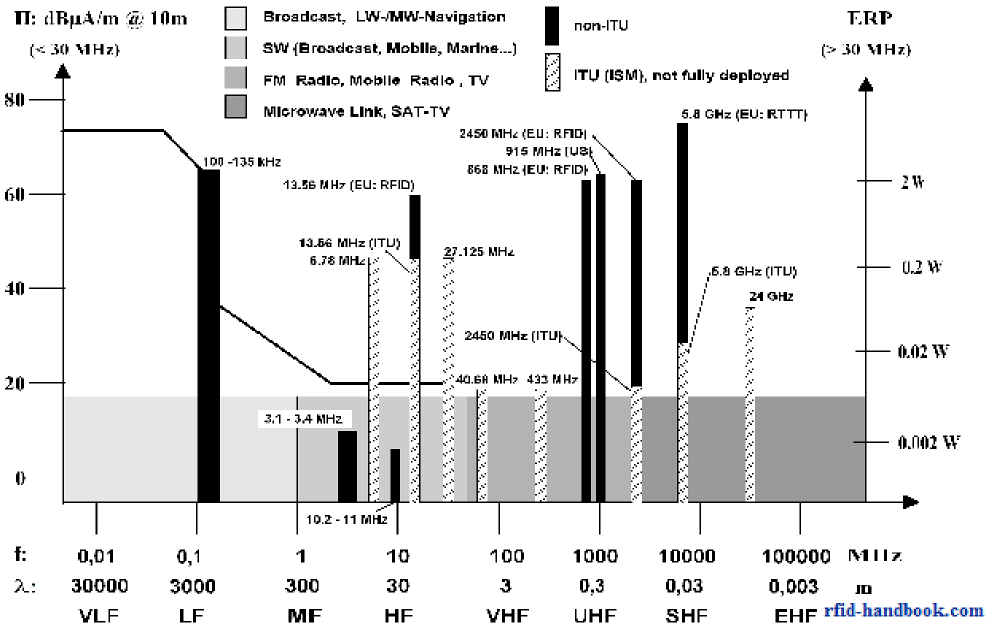

**Fig 28.** Frequency-ranges used for RFID-systems shown with the corresponding field strength and power levels (31).

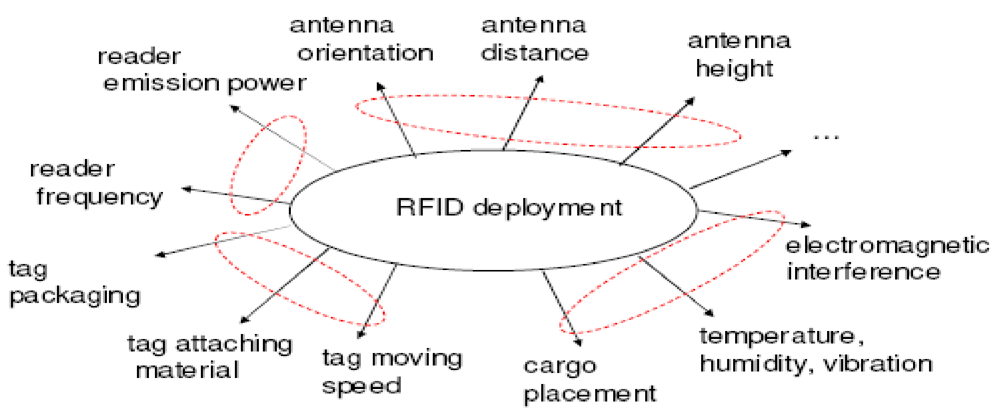

**Fig 29.** Different factors important for the RFID deployment and sustainable and efficient implementation of the RFID system (32).

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