Overview of RFID Technology

Article

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1. Introduction

Radio Frequency Identification (RFID) technology utilises electromagnetic radiation in the radio frequency (RF) and microwave ranges to uniquely identify objects without physical contact. All RFID communication systems consists of two components: the reader, or interrogator, and the transponder, or tag. The transponder is embedded in the object that is to be identified, and the reader is used to sense and identify the tag when it enters the reader's interrogation range. RFID technology has been used in various forms for several decades. It has recently become very popular due to prospects of mass production of cheap tags that could be embedded into most everyday items and hence allow manufacturers and distributors a complete and very accurate insight into their supply chains.

All existing RFID communication schemes can broadly be divided into three groups, based on the principle of operation: (1) inductively coupled systems, (2) systems utilising electromagnetic (EM) backscatter, and (3) RF-powered systems. This categorisation does not include RFID systems which support the transfer of only one bit of information from the transponder to the reader. (One-bit RFID systems can only sense if a tag is in the reader's interrogation range, but not extract any information from the tag.) While based on physically sound principles, capacitively-coupled multi-bit RFID systems, and multi-bit RFID systems utilising surface acoustic waves (SAWs) are currently not produced and marketed on a scale that inductively-coupled and backscatter systems are.

Inductive and backscatter RFID tags come in two varieties: passive and active. All power required for the operation and transmission of information in passive tags is supplied by the signal coming from the reader. This is the case for both inductive and backscatter tags. In active tags (both inductive and backscatter), the power required for the operation of circuitry is supplied from an on-board battery. However, the power required for the transmission of information in active tags is always extracted from the received reader power. In the case of RF-powered tags, both the operation and communication power is supplied by an on-board battery.

The quality of performance of any (most certainly wireless) RF or microwave communication system is measured in terms of parameters such as the communication range, signal-to-noise ratio (SNR) and the maximum data transfer rate. It is most influenced by the amount of power which the system uses to transmit information. Given infinite amounts of power, information could be transmitted instantaneously to any point. On the other hand, the physical dimensions of devices used for wireless RF and microwave communications are most affected by the frequency of electromagnetic waves used for communication. Both of these parameters, namely the use of electromagnetic spectrum and the allowed levels of power are strictly regulated.

In Section 2 we outline the most important principles of regulations applicable to RFID systems in Australia. In Sections 3, 4, and 5 we shall present suitable mathematical models of inductive, backscatter, and RF-powered RFID systems.

2. Spectrum Allocation and Power Regulation

The principles of spectrum allocation and power regulation are set out internationally. Each country signatory to those principles ensures that they are implemented within its jurisdiction, and in the best national interest. In Australia, the government agency with executive power in the domain of spectrum allocation and power regulation is the Australian Communication Authority (ACA). Information presented in this brief was collected from various sources, including ACA publications, but it is by no means to be taken as authoritative and final. In case of discrepancies and before operating any radio communication equipment, written advice from ACA must be sought.

RFID systems were envisaged to be operated in unlicensed portions of the electromagnetic spectrum. In particular, they were envisaged to be operated in the so- called Industrial-Scientific-Medical (ISM) bands. In Australia, these bands are between the following frequencies:

(a) 13.533 – 13.567 MHz (centre frequency = 13.55 MHz)
(b) 26.957 – 27.283 MHz (centre frequency = 27.12 MHz)
(c) 40.66 – 40.70 MHz (centre frequency = 40.68 MHz)
(d) 918 – 926 MHz (centre frequency = 922 MHz)
(e) 2.4 – 2.5 GHz (centre frequency = 2.45 GHz)
(f) 5.725 – 5.875 GHz (centre frequency = 5.8 GHz)
24.0 – 24.25 GHz (centre frequency = 24.125 GHz)

RFID systems (and in particular the backscatter systems) may also be operated in some other bands which are not specifically designated as ISM, but for which a licence is also not required (given that proper approval from ACA is obtained). The most significant of these other bands is the 433.92 MHz ultra-high frequency band, used for amateur radio services, telemetry transmitters, cordless telephones, walkie-talkies, short-range radio, keyless entry systems and other similar applications. The suitability of this band has been recognised by some manufacturers of RFID equipment, but the extent of commercial support is not at the same level as in the case of conventional ISM bands.

It is important to realise that in different countries and radio frequency jurisdictions, different frequencies might be preferred for RFID applications (both from the point of view of manufacturers and regulators). For example, the 869.0 MHz band (reserved for 'short-range devices') could be used in Europe, while the 915.0 MHz band could be used in the United States. Furthermore, due to the importance of RFID technology to the Supply Chain Management, most countries, including Australia, are in the process of designating several bands exclusively to RFID systems. It is our belief that those bands will be, at least in Australia, around the 922 MHz ISM frequency band.

Another band very important for the operation of RFID systems (and in particular the inductive systems) is the (heavily-used) band of frequencies below 135 kHz, due to the possibility of working with high magnetic field strengths. This frequency band, similarly to the 433.92 MHz band, is not an ISM band, but it may be used without a paid licence. Typical services that occupy the long-wave band from about 9 to 135 kHz are aeronautical and marine navigational radio services, time signal services, military radio services, and some wire-bound services such as intercoms.

Jurisdiction-to-jurisdiction variations in terms of the amount of power that can be emitted in the ISM bands (and other bands of importance to RFID) could be pronounced. Currently, the power that can be emitted is most commonly in the range of 10 to 100 mW, rarely exceeding 500 mW. Once a specific RFID band is established, it is expected that the allowed power will be much higher, typically of the order of 1 W. The Federal Communication Commission (FCC) in the United States is considering allowing even higher emission levels, of the order of 4 W (in the 915 MHz band). It is expected that Australia will act in a similar way on this issue.

In order to minimise possible discrepancies in the results presented in this brief, and in order to further emphasise the importance of power regulation, we shall consider the performance of backscatter RFID systems with power levels ranging from about 1 mW to about 4 W (0 dBm to 35 dBm). Table below shows the relationship between W's and dBm's.

Power level	Power level in dBm
1 mW	0 dBm
10 mW	10 dBm
100 mW	20 dBm
1 W	30 dBm
2 W	33 dBm
3 W	35 dBm
4 W	36 dBm

Table 2.1: Relationship between (linear) power level in W, and (logarithmic) power level in dBm.

It should be noted here that when specifying the allowed power emission at frequencies below 135 kHz (which are mainly used in inductive RFID systems), the level is usually expressed in terms of the magnetic field at a particular distance from the reader, rather than in terms of the absolute amount of power emitted as is the case at higher frequencies. Expressing the level in terms of the magnetic field strength is more common, but in some cases, such as in the United States, allowed levels are expressed in terms of the electric field strength. In Australia, typical values (which may have to be modified depending on what type of antenna is used), measured at a distance of 10 m from the reader's antenna, are in the range from 42 dBμA/m to 72 dBμA/m.

3. Inductive RFID Systems

An inductively-coupled transponder consists of a data-carrying microchip, and a large-area coil that functions as an antenna. Inductively-coupled transponders are almost always operated passively, meaning that all the energy needed for operation of the microchip has to be provided by the reader. For this purpose, the reader generates a strong electromagnetic field, which penetrates the cross-section of the transponder coil. The transponder antenna coil is also connected to a capacitor, thus forming a resonant circuit. Oscillations in this resonant circuit allow the transponder to draw energy from the reader's electromagnetic field. Once the transponder starts drawing energy from the reader's field, the reader senses it as an additional loading, via a change in the operation of its own antenna. If the transponder microchip can be switched on and off in a pattern that reflects the data stored in it, then the changes in the reader's antenna will also have the same pattern. On the basis of this coded changes in loading, the reader can receive data from the transponder.

Inductive RFID systems will work when the transponder is located somewhere in the near field of the reader's antenna. The extent of the near field (measured from the reader) is approximately given by

$$r_F = \frac{\lambda}{2\pi} \text{ (measured in metres),}$$

where the wavelength λ of electromagnetic radiation can be worked out from its frequency by using

$$\lambda = \frac{c}{f} \text{ (measured in metres),}$$

where $c = 3 \cdot 10^8$ m/s is the speed of light in vacuum. The distance which marks the end of the near field for each of the frequency bands discussed in Section 2 is given in Table 3.1 below. Most inductive RFID systems are designed for, and best operated at frequencies below 40 MHz.

The extent of the near field in inductive RFID systems also depends on the size of the transmitting antenna, D:

$$r_F = 0.62 \frac{\sqrt{D^3}}{\lambda} \text{ (measured in metres),}$$

where λ is the wavelength of electromagnetic radiation. The larger the antenna is, for a given radiation frequency, the larger the extent of the near field is. The larger the extent of the near field is, the larger the potential communication and identification range is.

FREQUENCY	WAVELENGTH	NEAR FIELD RANGE
<135 kHz	>2.22 km	353.68 m
13.55 MHz	22.14 m	3.52 m
27.12 MHz	11.06 m	1.76 m
40.68 MHz	7.37 m	1.17 m
433.92 MHz	69.14 cm	11.00 cm
922 MHz	32.54 cm	5.18 cm
2.45 GHz	12.24 cm	1.95 cm
5.8 GHz	5.17 cm	8.23 mm
24.125 GHz	1.24 cm	1.98 mm

Table 3.1: The extent of the near field for frequencies that could be used for radio frequency identification.

The interrogation range of a typical inductive RFID system is given by

$$x = \sqrt{\sqrt[3]{\left(\frac{I \cdot N \cdot R^2}{2 \cdot H_{\min}}\right)^2} - R^2}, \tag{3.1}$$

where I is the known interrogator antenna current (measured in Amperes), R is the radius of the antenna (measured in metres), N is the number of windings, and H_{min} is the minimum required magnetic field strength for activation of the transponder circuit. If the strength of the magnetic field due to the reader antenna can be measured or estimated at the location of the transponder antenna, and if N and R are known, the current in the coil of the reader antenna can also be calculated. The minimum required interrogation field strength H_{min} is a function of the transponder circuitry and it is usually specified in the reader data sheet.

The following expression can be used to estimate the magnetic field strength produced by an interrogator antenna made up of a coil of radius *R*, with *N* number of windings, and at a distance *x* from the antenna. *I* represents the current flowing through the antenna coil:

$$H = \frac{I \cdot N \cdot R^2}{2\sqrt{\left(R^2 + x^2\right)^3}}.$$

Similar expressions to antennas of other shapes (such as rectangular) can easily be obtained.

The maximum identification range obtainable ultimately depends on many factors, such as the operating frequency, magnetic field strength, tag operating voltage, and the modulation scheme. Once all those factors are taken into account, the operating range of most inductive RFID systems is not more than a couple of metres at best. However, this range is sufficient for typical applications in which inductive RFID system are used. In cases where this limited identification range needs to be extended, the easiest solution is to use active inductive RFID tags. Active inductive RFID tags have an on-board battery which can be used to power the microchip contained in the tag, hence allowing the tag to use all of the interrogation power for producing a response back to the reader. The extension in the identification range that can be obtained is not significant, as most of the interrogation power is already used for responding. However, the cost of an active inductive RFID tag is significantly larger, due to the additional cost of the battery. The presence of an on-board battery increases the size and weight of the tag, and also introduces the need for periodic maintenance.

Inductive RFID systems were one of the first types of RFID systems developed. They have mainly be used in applications such as animal identification and tracking, contactless access control and payment systems, car immobilisers (where RFID tags are embedded in car keys), and item tracking in stores and warehouses. The main issue in all of these applications was not the achievable identification range (in fact, in all of the above applications, the range actually must not be too large), but the low cost of tags. The low cost of passive inductive RFID tags continues to be the main factor influencing their increasing popularity.

4. Inductive RFID Systems

An electromagnetic wave emitted into the surrounding space by an antenna encounters various objects. Part of the high frequency energy that reaches the object is absorbed by the object and converted into heat; the rest is scattered in many directions with varying intensity. A small part of the reflected energy finds its way back to the transmitter antenna. Conventional radar technology uses this reflection to measure the distance and position of distant objects.

In RFID systems, the reflection of electromagnetic waves (backscatter) is used for the transmission of data from a transponder to a reader. Because the reflective properties (or the radar cross section, RCS) of objects generally increase with increasing frequency, these systems are used mainly in the ISM frequency ranges at around 922 MHz, 2.45 GHz, and above.

In passive backscatter RFID systems, all the power required for the operation of the tag comes from the reader. This interrogation power that is received by the tag is used for both the operation of the microchip in the tag, and for responding back to the reader’s interrogation. Hence, the overall identification range in a passive backscatter RFID system depends on how much of the power sent out by the reader is received by the transponder. The more power the transponder receives, the more available power it will have for responding back. The situation is similar in active backscatter

RFID systems. The additional benefit here is that active backscatter RFID systems have an on-board battery used for powering the microchip, thus allowing more power to be used for tag's response.

Let us examine the power relationships in an RFID system. The reader antenna emits an electromagnetic wave with the total transmitted power P_{EIRP}, where EIRP stands for 'effective isotropic radiated power'. The radiation density S that reaches the location of the transponder can be calculated by using

$$S = \frac{P_{EIRP}}{4\pi r^2} = \frac{P_T G_T}{4\pi r^2}, \tag{4.1}$$

where r is the distance from the reader to the transponder, P_T is the actual power emitted by the reader, and G_T is the gain of the reader antenna.. Note that the 'one-way' distance r represents only the first part of the whole communication link. The transponder's antenna reflects (or backscatters) a power P_S that is proportional to the incident power density S and the so-called radar cross section σ. This reflected power will suffer another propagation loss due to going back over the same distance r. After this propagation loss is accounted for, the reader's antenna will only absorb a portion of the backscattered power that reaches is, in proportion to its effective aperture area $A_{e,R}$. Mathematically, we can write this two-way link equation as

$$P = \frac{P_R G_R \cdot \sigma \cdot A_{e,R}}{\left(4\pi r^2\right)^2}, \tag{4.2}$$

where P stands for the power that the reader ultimately detects. Given that $A_{e,R}$ can be written in terms of the reader antenna gain:

$$A_{e,R} = \frac{\lambda^2}{4\pi} \cdot G_R, \tag{4.3}$$

Eq. (4.2) then becomes:

$$P = \frac{P_R \cdot G_R^2 \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot r^4}, \tag{4.4}$$

where the only unknown parameter (or the parameter that is hardest to estimate) is σ. In general, the radar cross-section σ (RCS, or the scatter aperture) is a measure of how well an object reflects electromagnetic waves. The radar cross-section depends upon a range of parameters, such as object size, shape, material, surface structure, but also wavelength and polarisation. The radar cross-section can only be calculated precisely for simple surfaces such as spheres, flat surfaces and the like. The material composition also has a significant influence, as well as the direction of incidence. For example, metal surfaces reflect much better than plastic or composite materials. Fortunately, there are several limiting cases where σ assumes a characteristic value.

If a loading impedance attached to an antenna is matched to the impedance of the antenna itself, then a half of the total power that falls on an antenna is absorbed by the loading impedance, and the other half is reflected back into space. In this case we have the radar cross section σ being equal to the antenna's effective aperture (which measures how much of the incident power an antenna absorbs). Mathematically, this can be written as

$$\sigma = A_e = A_{e,T} = \frac{\lambda^2}{4\pi} \cdot G_T \,, \tag{4.5}$$

where $A_{e,T}$ is the effective aperture of the transponder antenna, and G_T is the gain of the transponder antenna.

If the impedance attached to the antenna equals zero (in other words, if the antenna is short-circuited), the antenna has the largest radar cross section, and backscatters the largest amount of incident power. This can be written as:

$$\sigma_{\max} = 4A_{e,T} = 4 \cdot \frac{\lambda^2}{4\pi} \cdot G_T \,, \tag{4.6}$$

where the radar cross section has been written in terms of the effective area. The smallest radar cross section occurs when an infinite impedance is attached to the antenna. In this case, the antenna reflects no power back:

$$\sigma_{\min} = 0A_{e,T} = 0 \,, \tag{4.7}$$

where we have again written the radar cross section in terms of the transponder effective area. The scatter aperture σ can hence take on any value between 0 and $4A_{e,T}$, depending on the value of the loading impedance, with the characteristic value of $\sigma = A_{e,T}$ taken on when the loading impedance of an antenna matches its actual impedance. This exact property represents the essence of the data transmission mechanism in backscatter RFID systems.

Given the above, we can write Eq. (4.4) as

$$P_{\text{abs}} = \frac{P_R \cdot G_R^2 \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot r^4} = \frac{P_R \cdot G_R^2 \cdot \lambda^2 \cdot k \cdot A_{e,T}}{(4\pi)^3 \cdot r^4} = \frac{k \cdot P_R \cdot G_R^2 \cdot G_T \cdot \lambda^4}{(4\pi r)^4} \,, \tag{4.8}$$

where k can take on any value between 0 and 4. In our calculations, we interpret a passive backscatter RFID system as the case when (ideally) $k = 1$, and an active backscatter RFID system as the case when (ideally) $k = 4$.

Equation (4.8), in which we have taken account of no other losses but the propagation loss, can be written in the logarithmic form as follows:

$$P_{abs} = 10\log P_R + 20\log G_R + 10\log(kG_T) + 40\log\lambda - 40\log(4\pi r) \,, \tag{4.9}$$

where all the symbols have the same meaning as before.

In our estimation of performance of backscatter RFID systems we shall give attention to the losses due to: multipath fading (L_{mpf}), attenuation due to precipitation (falling rain and snow, L_{rain}), propagation through a static layer of snow (L_{layer}), and diffraction (L_{diff}). When these losses are taken into account, Eq. (4.9) becomes:

$$\begin{aligned} P_{abs} &= 10\log P_R + 20\log G_R + 10\log(kG_T) + 40\log\lambda - 40\log(4\pi r) \\ &\quad - L_{mpf} - L_{rain} - L_{layer} \end{aligned}, \tag{4.10}$$

where all loss (L) values are assumed to be in dB. The description of how we calculate each of the losses is given in the sections below.

4.1 Multipath fading loss

Multipath fading loss is most conveniently estimated by the path loss exponent model. According to this model, the multipath fading loss is given by

$$L_{\text{mpf}} = 10\log\left(\frac{r}{r_0}\right)^n = 10n\log\left(\frac{r}{r_0}\right) \text{ (dB)}.$$

In this equation, r_0 is a reference distance in the far field, also referred to as the received power reference point, usually chosen such that it is smaller than any practical distance used in the wireless communication system, and also such that it lies in the far-field region. n is the path loss exponent that depends on the specific environment. Typical values of the exponent are (as used for estimating the performance of mobile communication systems):

Environment	**Path loss exponent *n***
free space	2.0
urban area cellular radio	2.7 to 3.5
shadowed urban radio cellular	3.0 to 5.0
in building line of sight	1.6 to 1.8
obstructed in building	4.0 to 6.0
obstructed in factories	2.0 to 3.0

Table 4.1.1: Exponent values to be used in the calculation of multipath fading loss.

Values presented in Table 4.1.1 have been experimentally. The reference distance r_0 that we used in our calculations at 433.92 MHz is 10 m, while at 922 MHz it is 5 m. We assumed that the path loss exponent for a typical snowy mountainous terrain is in the range of $2.7 - 3.5$.

4.2 Attenuation due to precipitation

Microwaves suffer significant losses due to propagation through precipitation only at frequencies above 10 GHz. At frequencies below about 1 GHz, these losses are generally considered not significant to be included in system performance calculations. In other cases, the attenuation due to rainfall is dependent on the size and distribution of water droplets. Estimation models are created empirically, based on nominal sizes and distributions. In general, the attenuation rate (measured in dB/km) due to a specified rainfall rate can be approximated as

$$\alpha_{\text{rain}} = aR^b \text{ (measured in dB/km)},$$

where a and b are empirically determined constants, and R is the rainfall rate measured in mm/h. Given the same rainfall and snowfall rates, the effect of falling snow on the propagation of microwaves is considered to be smaller than the effect of falling rain. The total loss due to falling rain can be written as

$$L_{rain} = r \cdot \alpha_{rain} \text{ (measured in dB),}$$

as r is the distance of travel, measured in kilometres. As the attenuation due to falling rain can be completely ignored at frequencies below 1 GHz, and as the attenuation at frequencies below 10 GHz is negligible, we conclude that we can safely assume that falling rain does not affect the performance of an RFID system in any way. As the loss due to falling snow is always smaller than the loss due to falling rain, we can also assume that falling snow does not affect the performance of an RFID system in any way. Hence, we can set $L_{rain} = 0$ in Eq. (4.10).

4.3 Loss due to propagation through layers of snow and water

The loss due to an electromagnetic wave travelling through a static layer of snow or water of thickness t (measured in metres) is given by

$$L_{\text{layer}} = -10\log\left[\exp\left(\frac{-4\pi\kappa}{\lambda}\cdot t\right)\right] \text{ (measured in dB),}$$

where λ is the wavelength of radiation as before (measured in metres), and κ is the imaginary part of the refractive index of snow or water (at the given radiation wavelength). Values of κ for the frequency range of our interest and various snow and water conditions are given Table 4.3.1 and Table 4.3.2 respectively. In case where there is no κ value at our precise frequency of interest, we used linear interpolation to obtain the required value.

Frequency (GHz)	Dry snow κ (wetness = 0.05%)	Moist snow κ (wetness = 1%)	Wet snow κ (wetness = 7%)	Watery snow κ (wetness = 25%)
0.6	$2.458 \cdot 10^{-4}$	$2.073 \cdot 10^{-3}$	$9.304 \cdot 10^{-3}$	0.1544
0.8	$2.015 \cdot 10^{-4}$	$1.809 \cdot 10^{-3}$	$1.027 \cdot 10^{-2}$	0.1996
1.0	$1.730 \cdot 10^{-4}$	$1.666 \cdot 10^{-3}$	$1.152 \cdot 10^{-2}$	0.2453
1.6	$1.264 \cdot 10^{-4}$	$1.432 \cdot 10^{-3}$	$1.592 \cdot 10^{-2}$	0.3818
2.0	$1.095 \cdot 10^{-4}$	$1.552 \cdot 10^{-3}$	$1.909 \cdot 10^{-2}$	0.4702
3.0	$8.606 \cdot 10^{-5}$	$1.740 \cdot 10^{-3}$	$2.729 \cdot 10^{-2}$	0.6764
4.0	$7.420 \cdot 10^{-5}$	$2.013 \cdot 10^{-3}$	$3.558 \cdot 10^{-2}$	0.8564
6.0	$6.339 \cdot 10^{-5}$	$2.651 \cdot 10^{-3}$	$5.198 \cdot 10^{-2}$	1.1300

Table 4.3.1: Values of the imaginary part of the refractive index (κ) for various types of snow.

Frequency (GHz)	Water κ at 20 ºC	Water κ at 0 ºC
0.6	0.1713	0.3146
0.8	0.2172	0.4083
1.0	0.2648	0.5031
1.6	0.4105	0.7851

2.0	0.5078	0.9677
3.0	0.7471	1.3940
4.0	0.9771	1.7680
6.0	1.3990	2.3410

Table 4.3.2: Values of the imaginary part of the refractive index (κ) for various types of water.

Considering this type of loss is important when calculating the RFID system performance in cases when the rescuee is lying under a layer of snow, or is covered by water. Water, especially sea water and water at low temperatures, presents a big problem for the propagation of microwaves. The larger the content of water in a layer of material such as snow, the greater are the losses suffered by microwave radiation travelling through it.

4.4 The effect of diffraction

The degradation of performance of a communication system due to diffraction cannot easily be expressed in quantitative terms. Here we qualitatively describe how diffraction might affect the performance of a backscatter RFID system.

Diffraction occurs if the radio beam is partly obstructed by an object on the ground. As illustrated in Fig. 4.4.1, diffraction can cause a second signal to appear at the receiver, and the two signals, depending on their relative phase angles, may cancel each other out to some extent, resulting in the fading of the signal.

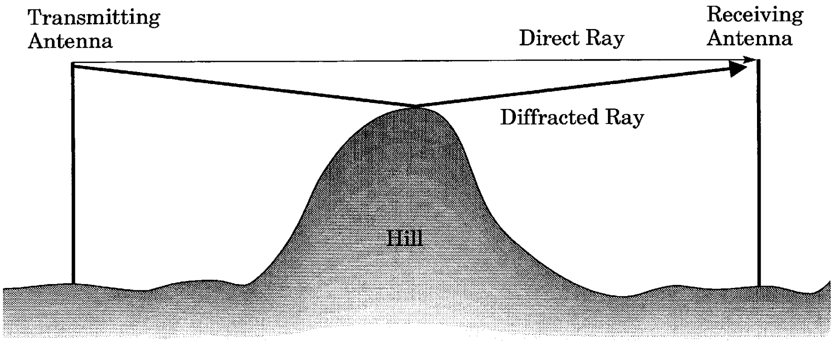


Fig. 4.4.1: Diffraction may cause a second signal to appear at the receiver, and the two signals, depending on their relative phase angles, may cancel each other out.

The effects of diffraction illustrated in Fig. 4.4.1 can be reduced by making sure that the path from transmitting antenna to receiving antenna clears an obstacle by at least 60% of a distance known as the first Fresnel zone. This distance is given by:

$$R_1 = 10.38\sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}}, \tag{4.4.1}$$

where f = frequency in megahertz, d_1 = distance to the antenna nearer the obstacle (in metres), and d_2 = distance to the antenna farther the obstacle (in metres).

Let us consider the case now where the total distance between the reader and transponder is 50 m. Let us assume that there is an obstacle of certain height between the reader and the transponder, such as the hill in Fig. 4.4.1. Figure 4.4.2 shows what the maximum height of that obstacle can be for us to be completely certain that communication will successfully take place between the reader and the tag. If the obstacle is larger, communication may be possible, but with a reduced quality.

In all three cases shown in Fig. 4.4.2, we assumed that the both the reader and the transponder antennas were at a height of 1.5 m. This height approximately corresponds to a person standing upright and carrying the antenna. Figure 4.4.2 shows two trends. First is that larger obstacles can be allowed if the reader and the tag operate at a higher frequency, and if we wish to have good quality communication at all time. Second is that the worst case scenario is if the obstacle is located right in the middle between the reader and the tag. The situation in all three cases will improve in all cases if both the reader and the transponder antennas are at larger heights. Correspondingly, if one or both of the antennas are lower and closer to the ground, then the maximum allowable size of the obstacle will decrease.

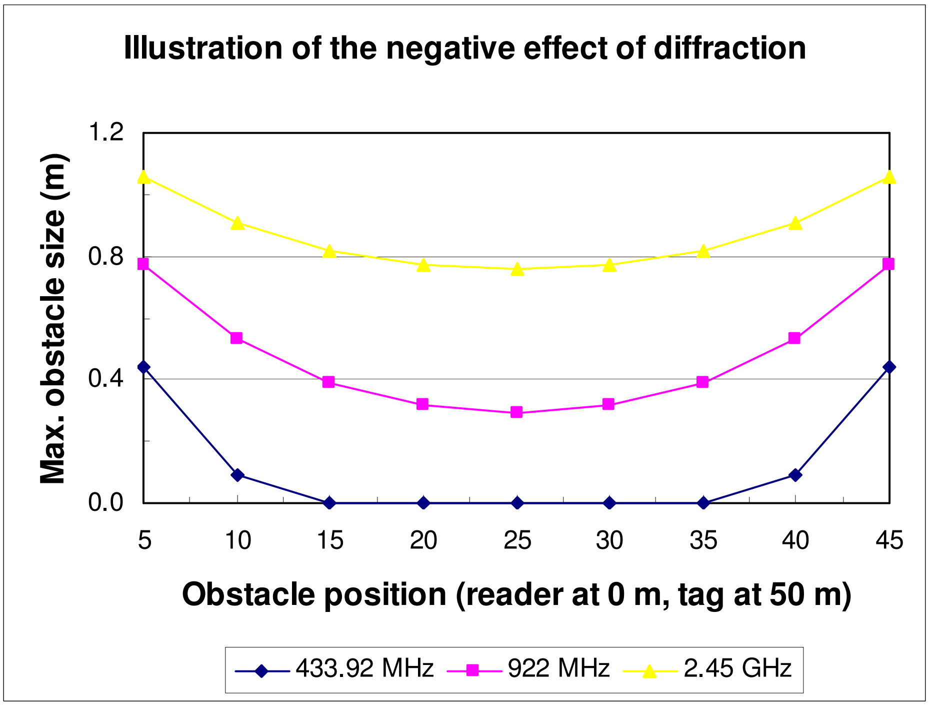
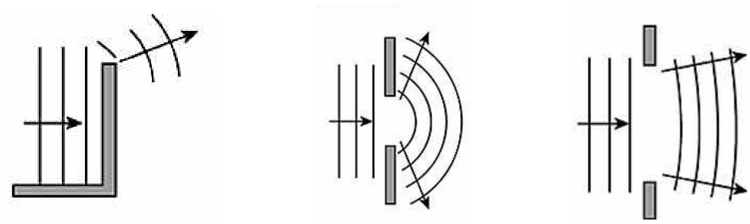


Fig. 4.4.2: Maximum allowed height for an obstacle placed at various positions between the reader (assumed to be at 0 m) and the transponder (assumed to be at 50 m), for three different frequencies: 433.92 MHz, 922 MHz, and 2.45 GHz.

Apart from hindering the perfect reliability of a communication link, diffraction of electromagnetic radiation can also be helpful in some cases. Diffraction essentially represents the bending of radio wave around an obstacle, thus allowing the radiation to get around it, and penetrate into regions not directly in the line of sight. This bending of radio waves around different obstacles is illustrated in Fig. 4.4.3 and Fig 4.4.4.



(a) (b) (c)

Fig 4.4.3: Diffractive bending of light around:
(a) straight edge, (b) narrow obstacle, and (c) wide obstacle.

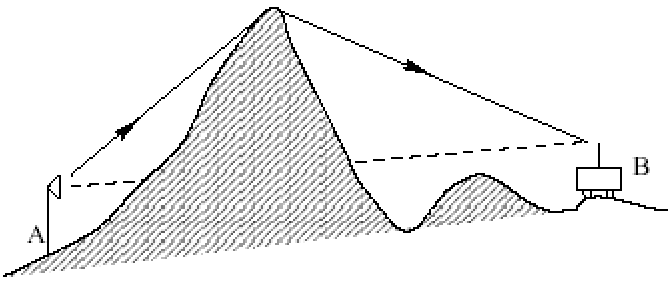


Fig. 4.4.4: Diffractive bending of radio waves around edges can be used to circumvent obstacles and reach regions not in the line of sight. This helpful bending, however, works much better for lower radio wave frequencies.

However, this helpful property of diffraction works much better for lower frequencies than for higher frequencies, as illustrated in Fig. 4.4.5. While Fig. 4.4.2 shows that the 433.92 MHz frequency is worst performing when it comes to clearing obstacles, Fig. 4.4.5 shows that the same frequency works best for getting around obstacles into the shadow region. Since not clearing an obstacle by a sufficient margin means a possible reduction in the quality of communication (due to the interaction of two signals as illustrated in Fig. 4.4.1), the good bending property of lower frequencies makes them better in terms of overall behaviour in the presence of diffraction. Regardless of the frequency, however, the overall performance will worsen if the implicit assumption of polarisation match between the transmitter and the receiver antenna is not true in practice.

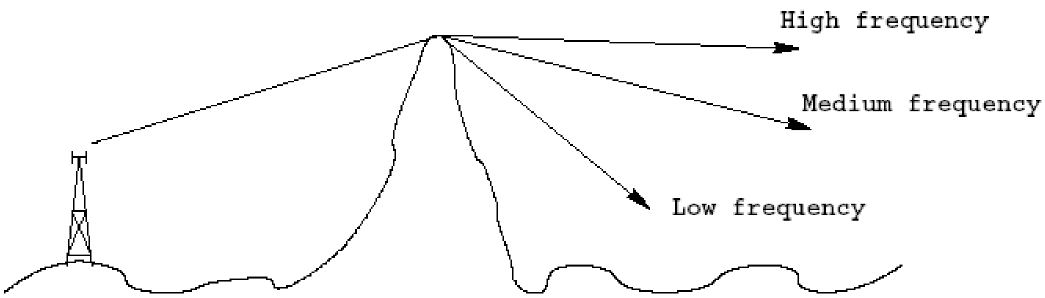


Fig. 4.4.5: The helpful bending property of diffraction works much better at lower than at higher frequencies.

5. RF-Powered Systems

In their principle of operation, RF-powered systems are almost identical to backscatter RFID systems. The only difference is that the RF-powered tag can generate its own RF power and hence does not have to rely on the backscattered signal reaching the reader. As the RF-powered tag can operate independently, it can also initiate communication, which is not the case in backscatter RFID systems.

Given a power of P_R produced by the reader, and a gain of G_R of the reader antenna, such that the effective isotropic radiated power (EIRP) is given by EIRP = $P_R \cdot G_R$, the power reaching the tag is given by

$$\begin{aligned} P_T &= 10\log P_R + 10\log G_R + 20\log\lambda - 20\log(4\pi r) + 10\log G_T \\ &\quad - L_{mpf} - L_{rain} - L_{layer} \end{aligned} , \tag{5.1}$$

where λ is the radiation wavelength, r is the range, G_T is the gain of the transponder antenna, and the L terms are as explained in Sections 4.1, 4.2, and 4.3. If the power reaching the transponder is sufficiently high, and there are no additional sources of noise, the message sent by the reader will be received.

On the other hand, given a power of P_T produced by the reader, and a gain of G_T of the reader antenna, such that the effective isotropic radiated power (EIRP) is given by EIRP = $P_T \cdot G_T$, the power reaching the tag is given by

$$\begin{aligned} P_R &= 10\log P_T + 10\log G_T + 20\log\lambda - 20\log(4\pi r) + 10\log G_R \\ &\quad - L_{mpf} - L_{rain} - L_{layer} \end{aligned} , \tag{5.2}$$

where all the symbols have the same meaning as before. If the power reaching the transponder is sufficiently high, the message sent by the reader will be received.

Depending on the particular parameter values and environmental circumstances, the maximum communication range from the reader to the tag (the ‘downlink’ communication path), and the maximum communication range from the tag to the reader (the ‘uplink’ communication path) may not be the same. While in later sections we shall estimate both ranges, the shorter one is usually taken as the overall range.

The RFID reader in both backscatter and RF-powered RFID schemes can be of the same type. The main difference between the two systems is in the power supply to the tag. In passive backscatter systems, the tag is not independently powered at all; all its power comes from the radiation emitted by the reader. In active backscatter systems the tag battery is only used for the operation of electronic memory chips. In RF-powered tags, the on-board battery is used for the operation of the electronics, as well as for RF communication. Hence, RF-powered tags are much more expensive than the conventional inductive and backscatter RFID tags, they are not mass produced, they are heavier, more complex, and they require more frequent maintenance.

Version history

Version B (04 SEP 2009): Corrected minor errors in text.
Version A (11 JUN 2009): First release