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RFID Technology: Perspectives and Technical Considerations of Microstrip Antennas for Multi-band RFID Reader Operation

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1. Introduction

This chapter presents a comprehensive review of RFID technology concerning the antennas and propagation for multi-band operation. The technical considerations of antenna parameters are also discussed in details in order to provide a complete realization of the parameters in pragmatic approach to the antenna designing process, which primarily includes scattering parameters and radiation characteristics. The antenna literature is also critically overviewed to identify the possible solutions of the multi-band microstrip antennas to utilize in multi-band RFID reader operation. In the literature dual-band antennas are principally discussed since they are ideal to realize and describe multi-band antenna mechanism. However, it has been seen that these techniques can be combined to enhance multi-band antennas with wider bandwidths. Last but not least, the high gain dual-band antennas and limitations have been described and it is realized that the conventional feeding technique might limit the performance of multi-band antennas to only one frequency.

2. Radio frequency identification

The idea of early radio frequency identification (RFID) system was invented by Scottish physicist Sir Robert Alexander Watson-Watt in 1935. With the supervision of Watson-Watt, the British government developed the first active identify friend or foe (IFF) system. This prototype of RFID concept was modified in 1950s and 60s by using radio frequency (RF) energy for commercialization purpose. The first US patent in this field was published on January 23, 1973 for the invention of an active RFID tag with rewritable memory by M. W. Cardullo (Cardullo 1973). That same year, C. Walton received another RFID patent for a passive transponder used to unlock a door without a key. In the recent days, the low power ultra high frequency (UHF) RFID system research has gained a lot of importance after some of the biggest retailers in the world, e.g., Albertsons, Metro, Target, Tesco, Wal-Mart and the

US Department of Defense, have said they plan to use electronic product code (EPC) technology to track goods in their supply chain (Mitra 2008).
RFID is an emerging technology for the identification of objects and/or personnel. RFID is recognized as one of the technologies capable of realizing a complete ubiquitous computing network due to its strong benefits and advantages over traditional means of identification such as the optical bar code systems. Comparing with barcode, RFID has some advantages of rapid identifying, flexible method and high intelligent degree (Wang et al. 2007; Xiao et al. 2008). Furthermore, it can function under a variety of environmental conditions (Intermec Technologies Corporation 2006). It has recently found a tremendous demand due to emerging as well as already existing applications requiring more and more automatic identification techniques that facilitate management, increase security levels, enhance access control and tracking, and reduce labor force. A brief listing of RFID applications that find use on a daily basis is:

- Warehouse Management Systems
- Retail Inventory Management
- Toll Roads
- Automatic Payment Transactions
- High Value Asset Tracking and Management
- Public Transportation
- Automotive Industry
- Livestock Ranching
- Healthcare and Hospitals
- Pharmaceutical Management Systems
- Military
- Marine Terminal Operation
- Manufacturing
- Anti-counterfeit

2.1 RFID system

Basically RFID is a contact-free non-line-of-sight type identification technology using radio frequency consisting of a RFID transponder (tag), a RFID interrogator (reader) with an antenna and data processing unit (host computer). In case of the handheld RFID reader, the reader itself contains the feature of data processing unit. The typical block diagram of RFID system is shown in Fig. 1.

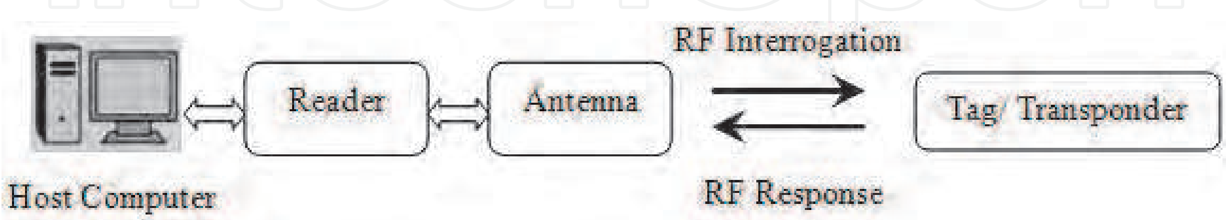


Fig. 1. Block diagram of RFID system

The interrogation signal coming from the reader antenna must have enough power to activate the transponder microchip by energizing the tag antenna, perform data processing and transmit back the data stored in the chip up to the required reading range (typically 0.3–

1m). The reader antenna receives the modulated backscattered signal from the tags in field of antenna and examines the data.

2.1.1 RFID tags

The tag is the basic building block of RFID. Each tag consists of an antenna and a small silicon chip that contains a radio receiver, a radio modulator for sending a response back to the reader, control logic, some amount of memory, and a power system. Tags contain a unique identification number called an Electronic Product Code (EPC), and potentially additional information of interest to manufacturers, healthcare organizations, military organizations, logistics providers, and retailers, or others that need to track the physical location of goods or equipment. All information on RFID tags, such as product attributes, physical dimensions, prices, or laundering requirements, can be scanned wirelessly by a reader at high speed and from a distance of several meters. According to the energizing power system, the tags can be classified into three types:

a. Passive tag - These tags (shown in Fig. 2 (a)) use the signal received from the reader to power the IC, and vary their reflection of this signal to transmit information back to the reader. Passive tags are the most common in cost-sensitive applications, because, having no battery and no transmitter, they are very inexpensive (Dobkin 2007). In this research we will consider only passive tags, the most commonly-encountered, and range-challenged, of the three types.

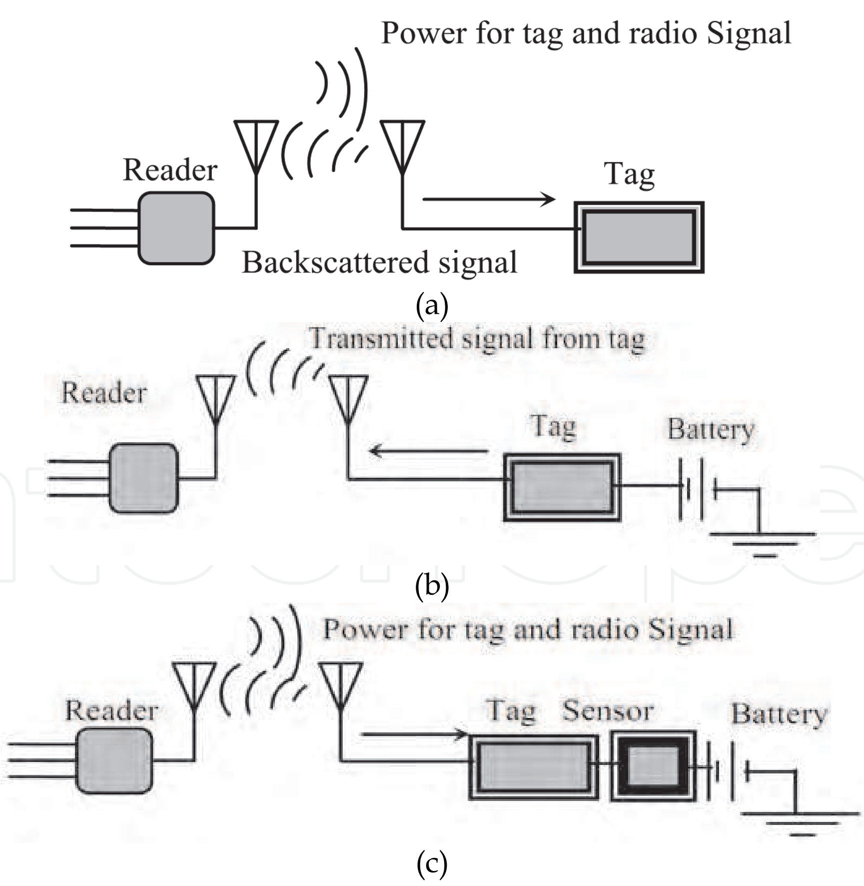


Fig. 2. Communication between (a) reader and passive tag, (b) reader and active tag, (c) reader and semi-passive tag (Khan et al. 2009)

b. Active tags - These tags are full-featured radios with their own transmitting capability independent of the reader. The primary advantages of active tags are their reading range and reliability. The typical communication between the reader and an active tag is shown in Fig. 2 (b). The tags also tend to be more reliable because they do not need a continuous radio signal to power their electronics. But due to the decay of battery life, the active tags have the disadvantage of shorter shelf life than passive tags, normally a few years after manufacturing (Garfinkel & Holtzman 2005).
c. Semi-passive tags - These tags, sometimes known as battery-assisted passive tags, (as shown in Fig. 2 (c)) have a battery, like active tags, but still use the reader's power to transmit a message back to the RFID reader using a technique known as backscatter. These tags thus have the read reliability of an active tag but the read range of a passive tag. They also have a longer shelf life than a tag that is fully active.

2.1.2 RFID reader

The RFID reader sends a pulse of radio energy to the tag and listens for the tag's response. The tag detects this energy and sends back a response that contains the tag's serial number and possibly other information as well. In simple RFID systems, the reader's pulse of energy functioned as an on-off switch; in more sophisticated systems, the reader's RF signal can contain commands to the tag, instructions to read or write memory that the tag contains, and even passwords (Garfinkel & Holtzman 2005).

RFID readers are usually on, continually transmitting radio energy and awaiting any tags that enter their field of operation. However, for some applications, this is unnecessary and could be undesirable in battery-powered devices that need to conserve energy. Thus, it is possible to configure an RFID reader so that it sends the radio pulse only in response to an external event. For example, most electronic toll collection systems have the reader constantly powered up so that every passing car will be recorded. On the other hand, RFID scanners used in veterinarian's offices are frequently equipped with triggers and power up the only when the trigger is pulled.

Like the tags themselves, RFID readers come in many sizes. The largest readers might consist of a desktop personal computer with a special card and multiple antennas connected to the card through shielded cable. Such a reader would typically have a network connection as well so that it could report tags that it reads to other computers. The smallest readers are the size of a postage stamp and are designed to be embedded in mobile telephones.

2.2 Near & far field concept & the selection of RFID operating bands

There are only two possible physics concepts used by RFID technology for the detection of RF tags as depicted in Fig. 3: near field concept (magnetic coupling) and far field concept. In the far field, electric and magnetic fields propagate outward as an electromagnetic wave and are perpendicular to each other and to the direction of propagation. The fields are uniquely related to each other via free-space impedance and decay as $1/r$. In the near field, the field components have different angular and radial dependence (e.g. $1/r^3$). The near field region includes two sub-regions: radiating and reactive. In radiating region, the angular field distribution is dependent on the distance. And in the reactive near field, energy is stored in the electric and magnetic fields very close to the source but not radiated from them. Instead, energy is exchanged between the signal source and the fields (Lecklider 2005).

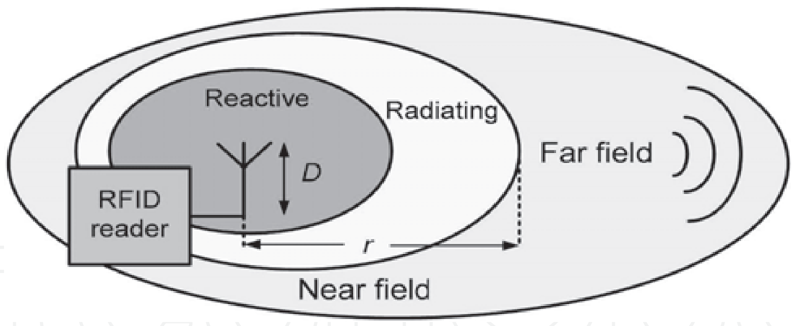


Fig. 3. Antenna near and far field region (Nikitin et al. 2007)

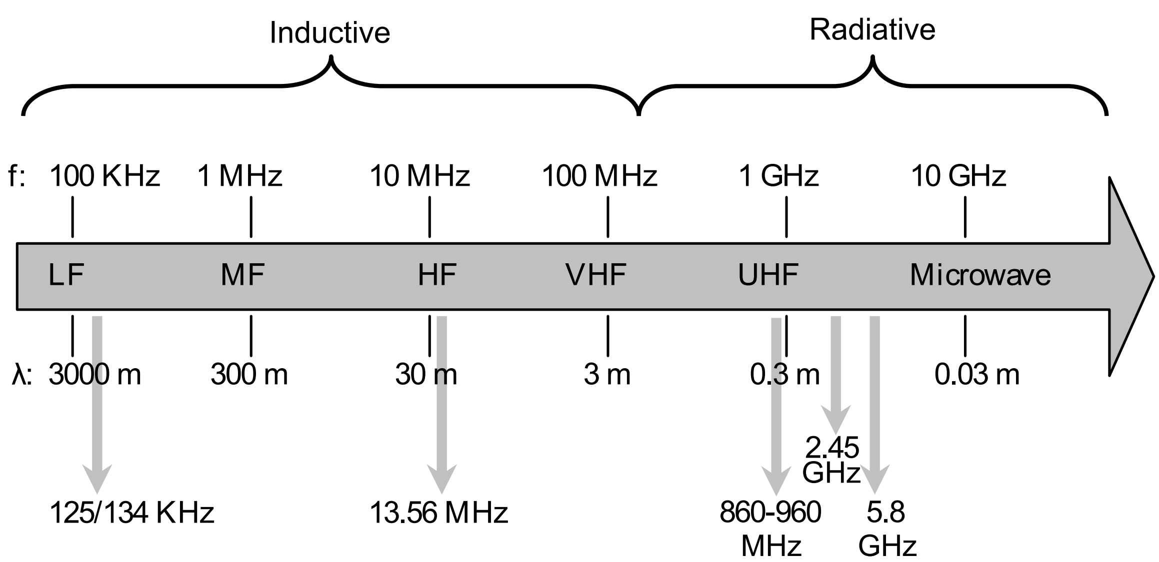


Fig. 4. Frequency-ranges used for RFID-systems

As shown in Fig. 4, several frequency bands have been assigned to RFID applications: 125/134 KHz, 13.56 MHz, 860-960 MHz, 2.450 (2.400–2.483) GHz and 5.800 (5.725–5.875) GHz. Several issues are involved in choosing a frequency of operation (Dobkin 2007).

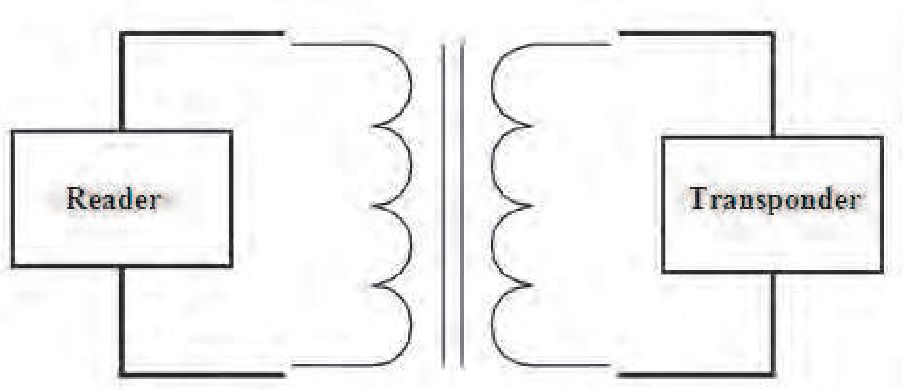


Fig. 5. Inductive coupling or near field detection of RFID reader

The most fundamental, as indicated in the diagram, is whether inductive or radiative coupling will be employed. The distinction is closely related to the side of the antennas to be used relative to the wavelength. When the antennas are very small compared to the wavelength, the effects of the currents flowing in the antenna cancel when viewed from a great distance, so there is no radiation. Only objects so close to the antenna that one part of the antenna appears significantly closer than another part can feel the presence of the current. As depicted in Fig. 5, in case of inductive coupling, the antennas act like transformers and the propagation time from reader to tag is fraction of cycle time. Thus, these systems, which are known as inductively-coupled systems, are limited to short ranges comparable to the size of the antenna. In practice, inductive RFID systems usually use antenna sizes from a few cm to a meter or so, and frequencies of 125/134 KHz (LF) or 13.56 MHz (HF). Thus the wavelength (respectively about 2000 or 20 meters) is much longer than the antenna.

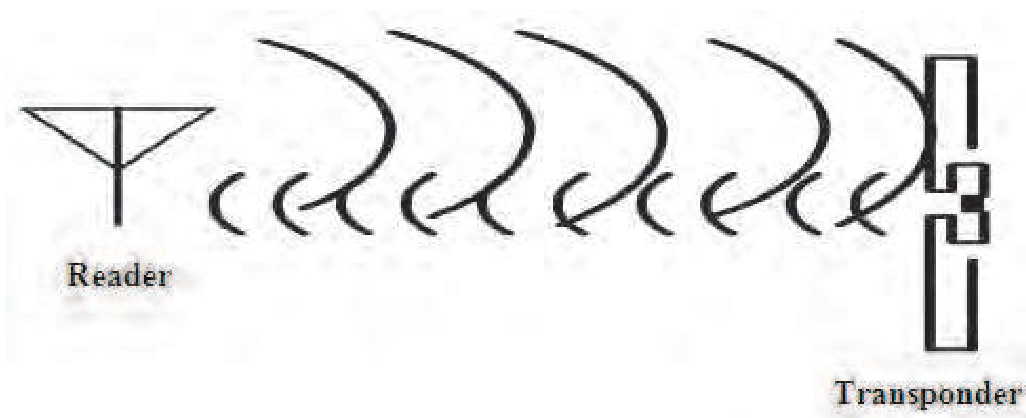


Fig. 6. Radiative coupling or far field detection of RFID reader

Radiative systems use antennas comparable in size to the wavelength. The very common 900 MHz range has wavelengths around 33 cm. Reader antennas vary in size from around 10 to >30 cm, and tags are typically 10-18 cm long. These systems use radiative coupling, and are not limited by reader antenna size but by signal propagation issues. In these systems, the reader antenna launches an electromagnetic wave (exhibited in Fig. 6) and use backscattering from tag to reader. However, the propagation time from reader to tag is longer than a single RF cycle

A second key issue in selection of frequency bands is the allocation of frequencies by regulatory authorities. In essentially every country in the world, the government either directly regulates the use of the radio spectrum, or delegates that authority to related organizations.

RFID systems are typically operated in unlicensed bands. In the US, unlicensed operation is available in the Industrial, Scientific, and Medical (ISM) band at 902-928 MHz, among others. However, for Malaysia the UHF RFID band is 919-923MHz. The UHF RFID frequency allocation statuses are pictured in Fig. 7, where it is realized that, the 900-MHz ISM band is a very common frequency range for UHF RFID readers and tags in all over the world. That's why in this research, the frequency band of 902-928 MHz is aimed for the operation of UHF RFID band.

The practical consequence of UHF band being in proximity to other bands of different wireless applications is the possibility of interference: for example, a nearby cell phone transmitting tower may interfere with the operation of RFID readers, due to the finite ability of the reader receiver to reject the powerful cell signal. (Cellular base stations may sometimes use transmit powers of 10's to hundreds of watts.) Other users of the ISM band may also interfere with RFID readers, or encounter interference due to them: examples are cordless phones and older wireless local area networks.

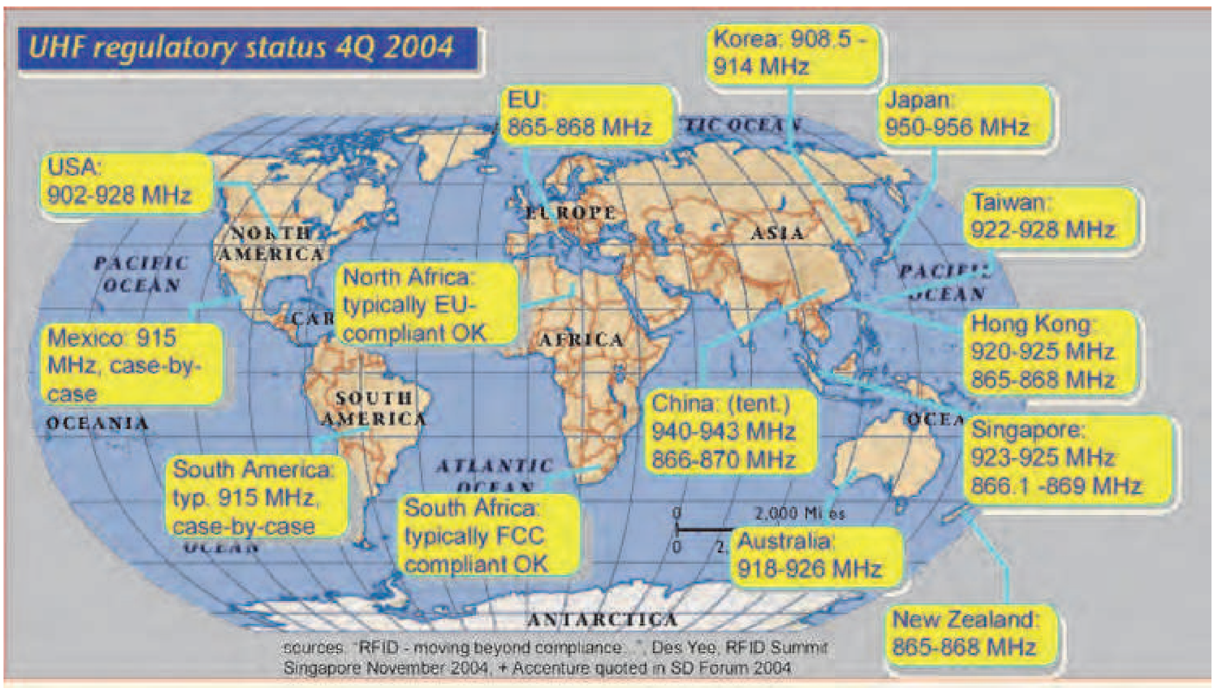


Fig. 7. UHF RFID frequency allocation statuses from 2004 (www.mapquest.com)

Finally, changes in operating frequency affect the propagation characteristics of the resulting radiated fields. Lower frequencies diffract more readily around obstacles, but couple less well to small antennas. Radiated fields are absorbed by many common materials in buildings and the environment, particularly those containing water. The degree of absorption due to water increases gradually with increasing frequency. Tags immersed in water-containing materials (i.e. injected into or swallowed by animals or people) must use very low frequencies to minimize absorption: this is a typical 125 KHz application. For locating large objects or people outdoors, a relatively low frequency may be desirable to avoid obstacle blockage; when a clear line of sight from the antenna to the tag can be assured, a higher frequency may be useful to reduce the size of the antennas.

3. Antenna characteristics

Antennas are the key components of any wireless communication system (Balanis 1996; Kraus 1988). According to The IEEE Standard Definitions of terms for Antennas, an antenna is defined as “a means for radiating or receiving radio waves" (IEEE Std 145-1993 1993). In other words, they are the devices that allow for the transfer of a signal (in a wired system) to waves that, in turn, propagate through space and can be received by another antenna. The receiving antenna is responsible for the reciprocal process, i.e., that of turning an electromagnetic wave into a signal or voltage at its terminals that can subsequently be processed by the receiver.

In the following sections, some of the antenna parameters are described that necessary to fully characterize an antenna and determine whether an antenna is optimized for a certain application.

3.1 Impedance bandwidth, reflection coefficient, VSWR & return loss

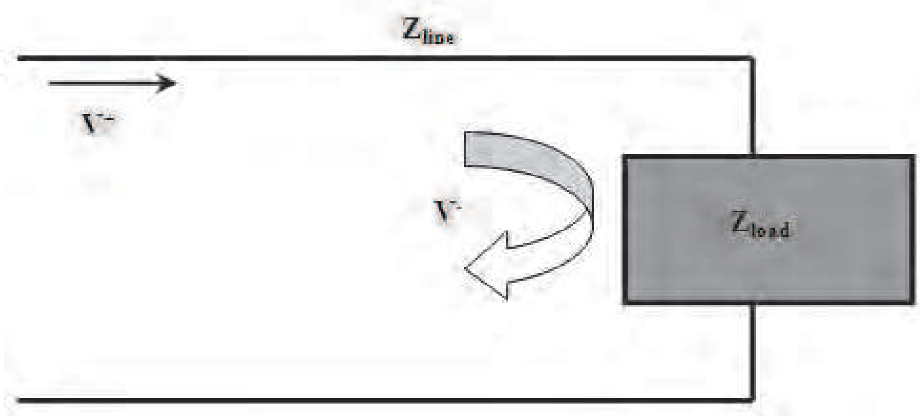


Fig. 8. Transmission line model

Impedance bandwidth indicates the bandwidth for which the antenna is sufficiently matched to its input transmission line such that 10% or less of the incident signal is lost due to reflections. Impedance bandwidth measurements include the characterization of the Voltage Standing Wave Ratio (VSWR) and return loss throughout the band of interest. VSWR and return loss are both dependent on the measurement of the reflection coefficient Γ. Γ is defined as ratio of the reflected wave V_o^- to the incident wave V_o^+ at a transmission line load as shown in Fig. 8. Transmission Line Model, and can be calculated by equation 2.1 (Balanis 1996; Stutzman 1998; Pozar 2001):

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_{line} - Z_{load}}{Z_{line} + Z_{load}} \tag{1}$$

Z_{line} and Z_{load} are the transmission line impedance and the load (antenna) impedance, respectively. The voltage and current through the transmission line as a function of the distance from the load, z, are given as follows:

$$V(z) = V_0^+ e^{-j\beta z} + V_0^- e^{j\beta z} = V_0^+ (e^{-j\beta z} + \Gamma e^{j\beta z}) \tag{2}$$

$$I(z) = 1/Z_0 (V_0^+ e^{-j\beta z} - V_0^- e^{j\beta z}) = V_0^+ / Z_0 (e^{-j\beta z} - \Gamma e^{j\beta z}) \tag{3}$$

where $\beta = 2\pi/\lambda$.
The reflection coefficient Γ is equivalent to the S_{11} parameter of the scattering matrix. A perfect impedance match would be indicated by Γ = 0. The worst impedance match is given by Γ = -1 or 1, corresponding to a load impedance of a short or an open.
Power reflected at the terminals of the antenna is the main concern related to impedance matching. Time-average power flow is usually measured along a transmission line to determine the net average power delivered to the load. The average incident power is given by:

$$P^{i}_{ave} = \frac{|V_0^+|^2}{2Z_0} \tag{4}$$

The reflected power is proportional to the incident power by a multiplicative factor of $|\Gamma|^2$, as follows:

$$P^{r}_{ave} = -|\Gamma|^2 \frac{|V_0^+|^2}{2Z_0} \tag{5}$$

The net average power delivered to the load, then, is the sum of the average incident and average reflected power:

$$P_{ave} = \frac{|V_0^+|^2}{2Z_0}[1-|\Gamma|^2] \tag{6}$$

Since power delivered to the load is proportional to $(1-|\Gamma|^2)$, an acceptable value of Γ that enables only 10% reflected power can be calculated. This result is Γ= 0.3162.
When a load is not perfectly matched to the transmission line, reflections at the load cause a negative traveling wave to propagate down the transmission line. Ultimately, this creates unwanted standing waves in the transmission line. VSWR measures the ratio of the amplitudes of the maximum standing wave to the minimum standing wave, and can be calculated by the equation below:

$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{7}$$

The typically desired value of VSWR to indicate a good impedance match is 2.0 or less. This VSWR limit is derived from the value of Γ calculated above.
Return loss is another measure of impedance match quality, also dependent on the value of Γ, or S_{11}. Antenna return loss is calculated by the following equation:

$$\text{Return Loss} = -10\log|S_{11}|^2 \text{, or } -20\log(|\Gamma|) \tag{8}$$

A good impedance match is indicated by a return loss greater than 10 dB. A summary of desired antenna impedance parameters include Γ<0.3162, VSWR<2, and Return Loss > 10 dB.

3.2 Radiation pattern

One of the most common descriptors of an antenna is its radiation pattern. Radiation pattern can easily indicate an application for which an antenna will be used. For example, fixed indoor RFID reader applications, such as a ware-house, would necessitate a nearly omni-directional antenna which could be hung in the ceiling, since the position of the detectable object might not be known. Therefore, radiation power should be spread out uniformly around the user for optimal reception. However, for high range RFID detection applications, a highly directive antenna would be desired such that the majority of radiated power is directed to a specific, known location. According to the IEEE Standard Definitions of Terms for Antennas, an antenna radiation pattern (or antenna pattern) is defined as: "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far-field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity phase or polarization (IEEE Std 145-1993 1993).

In most cases, it is determined in the far-field region where the spatial (angular) distribution of the radiated power does not depend on the distance. Usually, the pattern describes the normalized field (power) values with respect to the maximum values. The radiation property of most concern is the two-or three-dimensional (2D or 3D) spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. In practice, the three-dimensional pattern is some-times required and can be constructed in a series of two-dimensional patterns. For most practical applications, a few plots of the pattern as a function of ϕ for some particular values of frequency, plus a few plots as a function of frequency for some particular values of θ will provide most of the useful information needed, where ϕ and θ are the two axes in a spherical coordinate.

There are two common portions used to describe the characteristic of a radiation pattern of an antenna:

a. **Co-polar pattern:** diagram representing the radiation pattern of a test antenna when the reference antenna is similarly polarized, scaled in dBi or dB relative to the measured antenna gain
b. **Cross-polar pattern:** diagram representing the radiation pattern of a test antenna when the reference antenna is orthogonally polarized, scaled in dBi, or dB relative to the measured antenna gain

3.3 Antenna polarization

Polarization is a property of a single-frequency electromagnetic wave; it describes the shape and orientation of the locus of the extremity of the field vectors as a function of time. In antenna engineering, the polarization properties of plane waves or waves that can be considered to be planar over the local region of observation are of interest. For plane waves, it is sufficient to specify the polarization properties of the electric field vector since the magnetic field vector is simply related to the electric field vector. The plane containing the electric and magnetic fields is called the plane of polarization and is orthogonal to the direction of propagation (Volakis 2007).

The polarization of an electromagnetic wave may be linear, circular, or elliptical (Kumar & Ray 2003). The instantaneous field of a plane wave, traveling in the negative z -direction, is given by

$$E(z,t) = E_x(z,t)\hat{x} + E_y(z,t)\hat{y} \tag{9}$$

The instantaneous components are related to their complex counter-parts by

$$E_x(z,t) = E_x \cos(\omega t + \beta z + \phi_x) \tag{10}$$

and

$$E_y(z,t) = E_y \cos(\omega t + \beta z + \phi_y) \tag{11}$$

where E_x and E_y are the maximum magnitudes and ϕ_x and ϕ_y are the phase angles of the x and y components, respectively, ω is the angular frequency, and b is the propagation constant. For the wave to be linearly polarized, the phase difference between the two components must be

$$\Delta\phi = \phi_y - \phi_x = n\pi \text{ , where n=0, 1, 2, …} \tag{12}$$

The wave is circularly polarized when the magnitudes of the two components are equal (i.e., $E_x = E_y$) and the phase difference $\Delta\phi$ is an odd multiple of $\pi/2$; in other words,

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} +(2n+1/2)\pi \text{ for } RHCP \\ \quad\quad or \\ -(2n+1/2)\pi \text{ for } LHCP \end{cases} \tag{13}$$

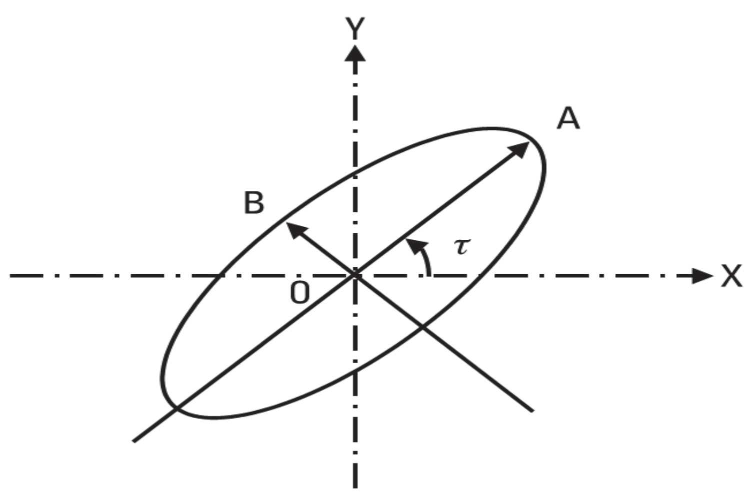


Fig. 9. Elliptically polarized wave

If $E_x \neq E_y$ or $\Delta\phi$ does not satisfy (11) and (12), then the resulting polarization is of elliptical shape as shown in Fig. 9. The performance of a circularly polarized antenna is characterized by its AR. The AR is defined as the ratio of the major axis to the minor axis; in other words,

$$AR = \frac{\text{major axis}}{\text{minor axis}} = \frac{OA}{OB} \tag{14}$$

where

$$OA = \left[\frac{1}{2}\left\{E_x^2 + E_y^2 + \left[E_x^4 + E_y^4 + 2E_x^2E_y^2\cos(2\Delta\phi)\right]^{1/2}\right\}\right]^{1/2} \tag{15}$$

and

$$OB = \left[\frac{1}{2}\left\{E_x^2 + E_y^2 - \left[E_x^4 + E_y^4 + 2E_x^2E_y^2\cos(2\Delta\phi)\right]^{1/2}\right\}\right]^{1/2} \tag{16}$$

The tilt angle τ of the ellipse is given by

$$\tau = \frac{\pi}{2} - \frac{1}{2}\tan^{-1}\left[\frac{2E_x E_y}{E_x^2 - E_y^2}\cos(\Delta\phi)\right] \tag{17}$$

For CP, OA = OB (i.e., AR = 1), whereas for linear polarization, AR → ∞. The deviation of AR from unity puts a limit on the operating frequency range of the circularly polarized antennas. Generally, AR = 3–6 dB (numerical value 1.414 to 2) is acceptable for most of the practical applications.

3.4 Directivity & gain

Directivity of an antenna, D is defined as the ratio of the radiation intensity U in a given direction from the antenna to the radiation intensity averaged over all directions, i.e. an isotropic source. It is introduced to describe the directional properties of antenna radiation pattern. For an isotropic source, the radiation intensity U_0 is equal to the total radiated power P_{rad} divided by 4π. So the directivity can be calculated by:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{18}$$

If not specified, antenna directivity implies its maximum value, i.e. D_0.

$$D_0 = \frac{U|_{\max}}{U_0} - \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{rad}} \tag{19}$$

Antenna gain G is closely related to the directivity, but it takes into account the radiation efficiency e_{rad} of the antenna as well as its directional properties, as given by:

$$G = e_{rad} D \tag{20}$$

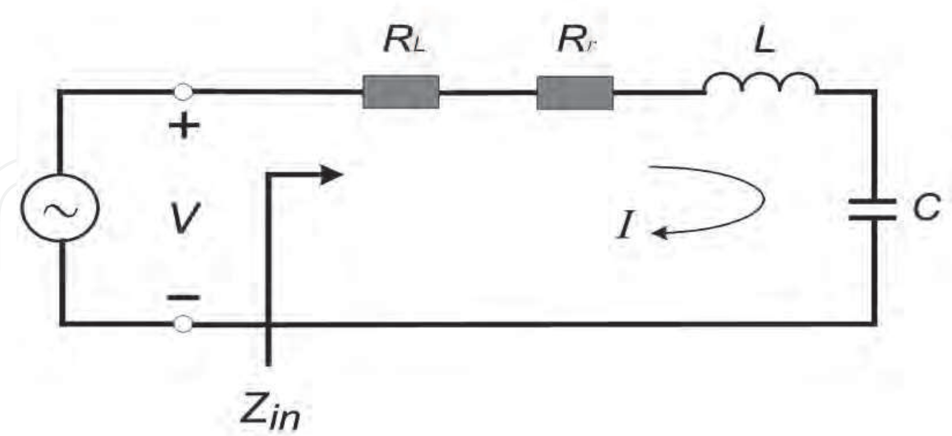


Fig. 10. Equivalent circuit of antenna

Fig. 10 shows the equivalent circuit of the antenna, where R_r, R_L, L and C represent the radiation resistance, loss resistance, inductor and capacitor, respectively. The radiation efficiency e_{rad} is defined as the ratio of the power delivered to the radiation resistance R_r to the power delivered to R_r and R_L. So the radiation efficiency e_{rad} can be written as:

$$e_{rad} = \frac{\frac{1}{2}|I|^2 R_r}{\frac{1}{2}|I|^2 R_r + \frac{1}{2}|I|^2 R_L} = \frac{R_r}{R_r + R_L} \tag{21}$$

According to the IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1993 1993), the antenna absolute gain is "the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically" (IEEE Std 145-1993 1993). The maximum gain G_0 is related the maximum directivity D_0 mathematically as follows:

$$G_0 = e_{rad} D_0 \text{ (Dimensionless)} \tag{22}$$

Also, if the direction of the gain measurement is not indicated, the direction of maximum gain is assumed. The gain measurement is referred to the power at the input terminals rather than the radiated power, so it tends to be a more thorough measurement, which reflects the losses in the antenna structure.

Gain measurement is typically misunderstood in terms of determining the quality of an antenna. A common misconception is that the higher the gain, the better the antenna. This is only true if the application requires a highly directive antenna. Since gain is linearly proportional to directivity, the gain measurement is a direct indication of how directive the antenna is (provided the antenna has adequate radiation efficiency).

4. Multi-band antenna techniques: review

When the antenna operates only at more than one spot frequency, then it is known as a multi-frequency antenna. When it operates over a finite BW at all of the frequencies, it is known as multi-band antenna. When two or more resonance frequencies of a MSA are close to each other, one gets broadband characteristics. When these are significantly separated, dual-band or multi-band operations are obtained. In literature, numerous multi-band antennas are available. However, in order to understand the technique of multi-band operation, it is worthy to understand the mechanism of dual-band antennas which could be extended to more than two bands employing the same or combination of other techniques.

For dual-band operations, various single and multilayer microstrip antennas configurations are possible. In the single-layer microstrip antenna, dual-band operation can be achieved by utilizing the multi-resonance characteristics of a single patch, by reactively loading the patch with quarter-wavelength stubs, by using shorting posts, by cutting slots, and by adding lumped elements, among other techniques. Multi-resonators in both planar and stacked configurations yield dual-band operations. Both electromagnetic as well as aperture coupling mechanisms are used in multilayer configurations (Kumar & Ray 2003).

4.1 Higher order or orthogonal mode microstrip antennas

As is well-known, a simple rectangular patch can be regarded as a cavity with magnetic walls on the radiating edges. The first three modes with the same polarization can be indicated by TM_{100}, TM_{200}, and TM_{300}, where TM denotes the magnetic field transverse with respect to the interface normal. TM_{100} is the mode typically used in practical applications; TM_{200} and TM_{300} are associated with a frequency approximately twice and triple of that of the TM_{100} mode. This provides, in principle, the possibility to operate at multiple frequencies. In practice, the TM_{200} and the TM_{300} modes cannot be used. Indeed, owing to

the behavior of the radiating currents, the TM_{200} pattern has a broadside null, and the TM_{300} pattern has grating lobes.
The simplest way to operate at dual frequencies is to use the first resonance of the two orthogonal dimensions of the rectangular patch, i.e., the TM_{100} and the TM_{101} modes. In this case, the frequency ratio is approximately equal to the ratio between the two orthogonal sides of the patch. The obvious limitation of this approach is that the two different frequencies excite two orthogonal polarizations. This simple method is very useful in low-cost short-range applications, where polarization requirements are not pressing (Maci & Gentili 1997).

4.1.1 Single feed dual-band microstrip antenna

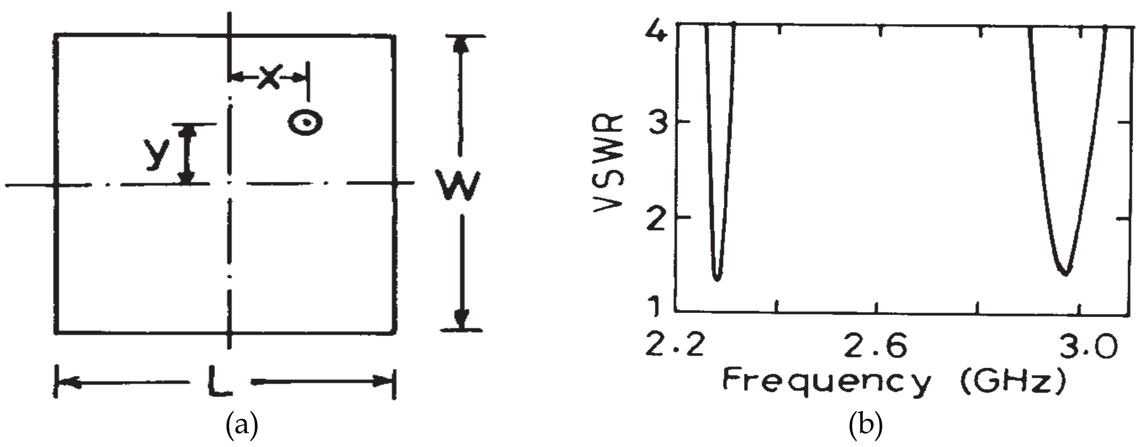


Fig. 11. (a) Rectangular microstrip antenna with a single feed for orthogonal dual-band operation and its and (b) VSWR plots (Chen & Wong 1996)

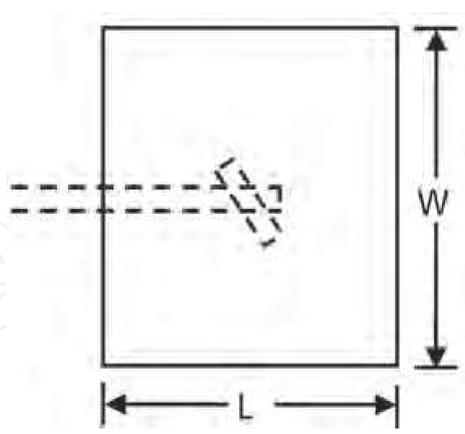


Fig. 12. Aperture coupled RMSA with an inclined slot

An interesting feature of these antennas is their capability of simultaneous matching of the input impedance at the two frequencies with a single feed structure (denoted by "single-point" in Fig. 11). This may be obtained with a probe-fed configuration, which is displaced from the two principal axes of the patch. As demonstrated in literature (Chen & Wong 1996), the performance of this approach in terms of matching level and bandwidth is almost equal to that of the same patch fed separately on the two orthogonal principal axes. This provides

the possibility of using the well-known design formula for standard feeds. It is also worth noting that the simultaneous matching level for structures that provide the same polarizations at the two frequencies is, in general, worse with respect to the case relevant to orthogonal polarization.
Instead of using a single coaxial feed, similar results are obtained by using an aperture coupled rectangular microstrip antenna, in which an inclined slot is cut in the ground plane with respect to the microstrip feed line as shown in Fig. 12 to give proper matching at both the frequencies (Antar et al. 1995). The required slot length and inclination angle can be approximately obtained by projecting the slot onto the two orthogonal directions. The two projections can be thought of as the length of two equivalent slots that excite the patch at the two separate polarizations. The inclination of the slots may also be adjusted, in order to compensate for error introduced by the matching stub, which is designed to be a quarter of a wavelength for only one frequency.

4.1.2 Dual feed microstrip antennas

The use of a circulator or diplexer that should be used in single fed dual-band microstrip antenna to isolate reception from transmission may be avoided by feeding the RMSA at two orthogonal points as shown in Fig. 13(a) (Srinivasan et al. 2000a). Since these feed points are at null locations of the respective orthogonal modes, the loading of one feed point does not affect the input impedance at the other feed point. The isolation between the two modes using orthogonal feeds is nearly 30 dB and 40 dB at the lower and higher resonance frequencies, respectively.

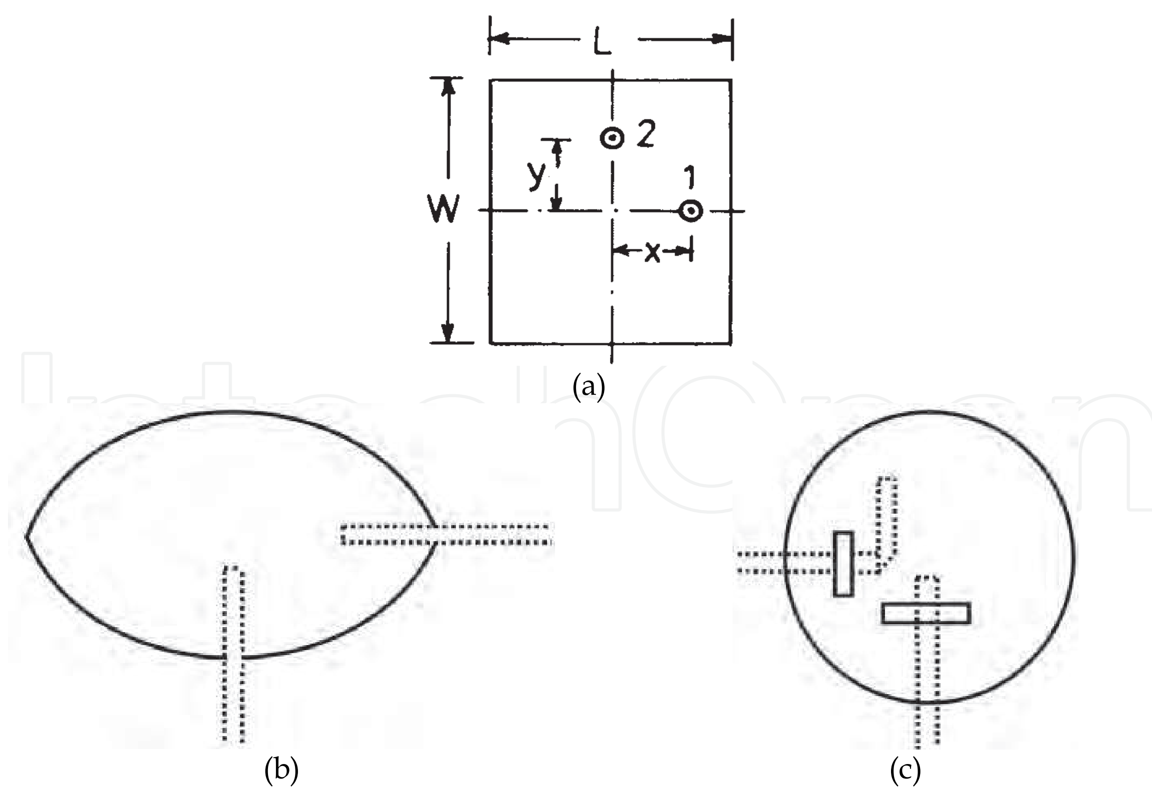


Fig. 13. (a) Rectangular microstrip antenna with two orthogonal feeds for dual-band operation, (b) Elliptical microstrip antenna with two orthogonal feeds, (c) Circular microstrip antenna with two orthogonal slots (Kumar & Ray 2003)

Similar results are obtained for an ellipse with two orthogonal feed points. This configuration is fed with two orthogonal electromagnetically coupled microstrip lines (Deepukumar et al. 1996). As before, the frequency ratio of dual-band operation is approximately equal to the ratio of the orthogonal dimensions in the two planes. The isolation between the two ports is 27 dB.
Another variation using a circular patch is shown in Fig. 13 (c). It is excited by two orthogonal microstrip lines through the two orthogonal slots cut in the ground plane. By changing the slot dimensions, the two orthogonal resonance frequencies can be changed (Murakami et al. 1993).

4.2 Multi-patch antenna design approach

It is also a common practice to utilize two or more patches to accomplish multi-band. This section describes two main multi-patch techniques for dual-band or multi-band antennas.

4.2.1 Multi-patch stacked antennas

The dual-frequency behavior of these antennas is obtained by means of multiple radiating elements, each of them supporting strong currents and radiation at the resonance. This category includes multi-layer stacked patches (Fig. 14) that can use circular (Long & Walton 1979; Dahele & Lee 1982; Bennegueouche et al. 1993; Iwasaki & Suzuki 1995), annular (Dahele et al. 1987; Tagle & Christodoulous 1997), rectangular (Wang, et al. 1990; Yazidi et al. 1993), and triangular (Bhatnagar et al. 1986) patches. These antennas operate with the same polarization at the two frequencies, as well as with a dual polarization.

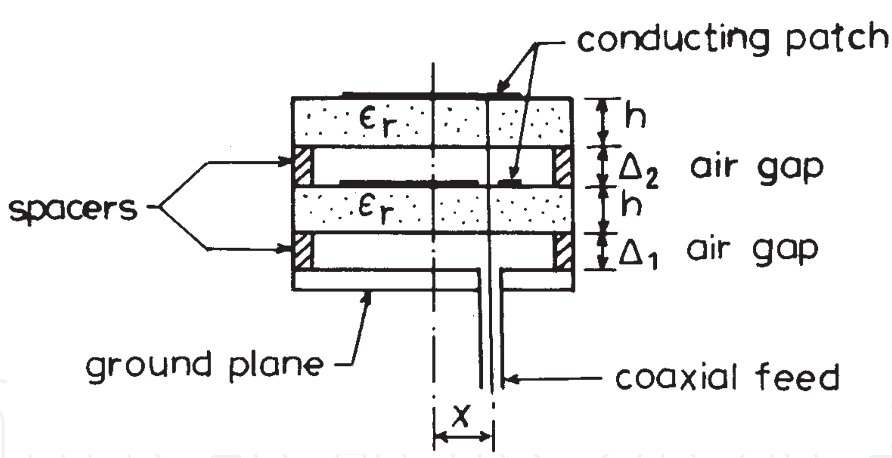


Fig. 14. A dual-frequency stacked circular-disc antenna (Long & Walton 1979)

The same multilayer structures can also be used to broaden the bandwidth of a single-frequency antenna, when the two frequencies are forced to be closely spaced. In this latter case, the lower patch can be fed by a conventional arrangement and the upper patch by proximity coupling with the lower patch (Wang et al. 1990). In order to avoid disappearance of the upper resonance, the sizes of the two patches should be close, so that only a frequency ratio close to unity may be obtained. A direct probe feed for the upper patch may also be used (Long & Walton 1979; Dahele et al. 1987). In this case, the probe passes through a clearance hole in the lower patch, and is electrically connected to the upper patch. This kind of configuration insures one more degree of freedom (the hole radius) in designing the optimum matching at the two frequencies, and allows a wider range of the frequency ratio with respect to the structure in which the upper patch is electromagnetically coupled. In comparison with the resonant frequencies of the two isolated patches, the frequency of the upper (smaller) patch increases, and the frequency of the lower (larger) patch decreases. In any case, due to the strong coupling between the two elements, simple design formulas cannot be found, so that a full-wave analysis is, in general, required in the first phase of the design.

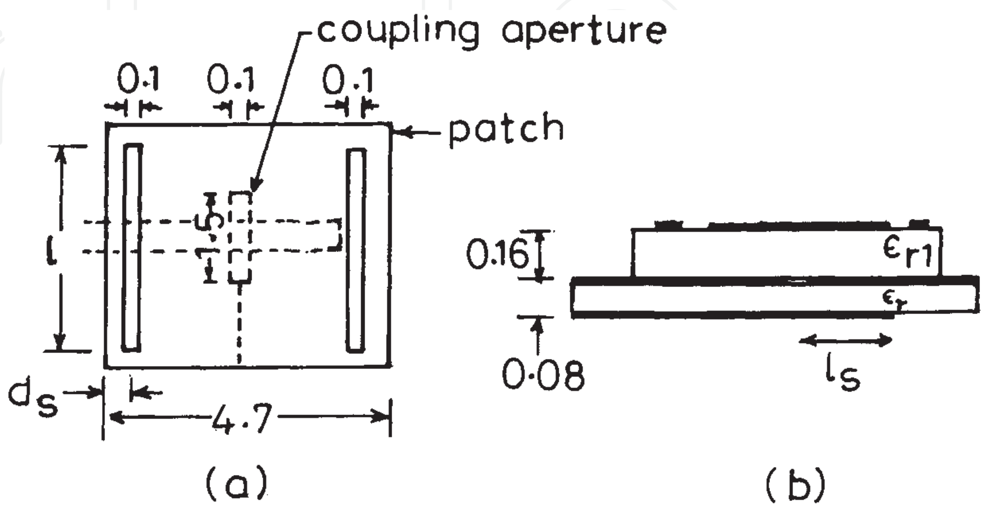


Fig. 15. An aperture-coupled rectangular microstrip antenna with two slots: (a) top and (b) side views (Yazidi et al. 1993)

4.2.2 Multi-patch co-planar antennas

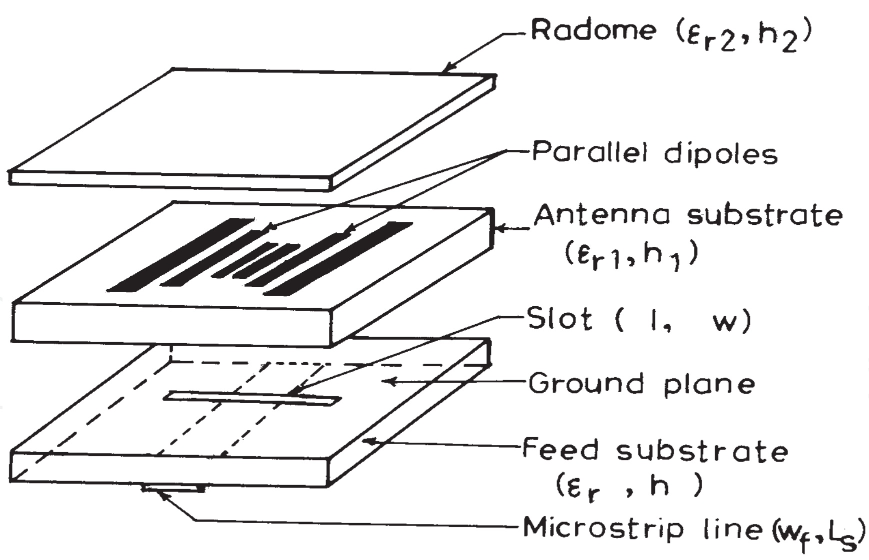


Fig. 16. Aperture-coupled coplanar parallel dipoles for multi-frequency operation (Croq & Pozar 1992)

Coplanar parallel dipoles fed by aperture coupling could be used to obtain multi-frequency operation. The dipoles of different lengths are fed by a microstrip line through a rectangular slot cut in the ground plane. In general, this antenna consists of 2*N* dipoles of *N* different lengths, which are symmetrically excited through the aperture at *N* frequencies (Croq &

Pozar 1992). Either the longest identical pair of dipoles could be placed in the center of the slot and smallest identical pair close to the edges of the slot, or the smallest dipoles could be placed in the center and the longest at the edge. For the latter case, six symmetrical dipoles are shown in Fig. 16. Since there are three pairs of dipoles, there will be three resonance frequencies. The radiation pattern is in the broadside direction at all the three frequencies, and the antenna is attractive for its simplicity.

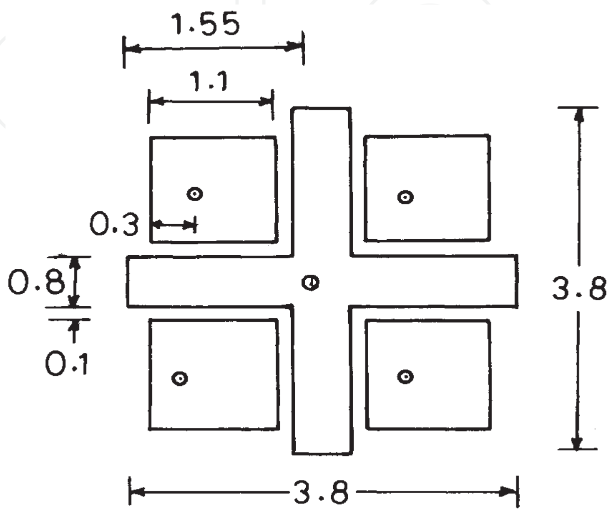


Fig. 17. Dual frequency sub-array microstrip antenna (Salvador et al. 1995)

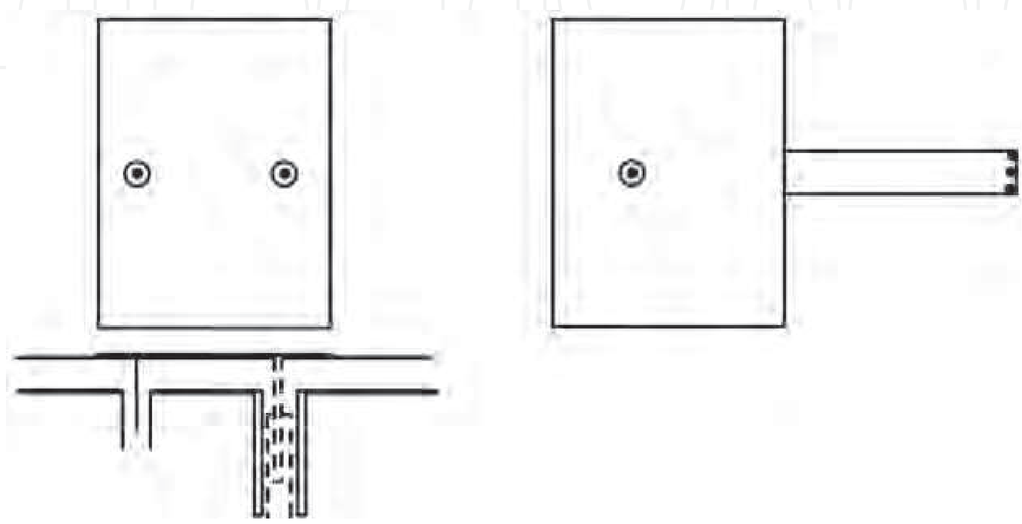
Many radar and communication systems often require a large separation between the two frequencies, so the multi-resonator configuration requires patches of very different resonant lengths. A simple example of this concept is shown in Fig. 17 (Salvador et al. 1995). It consists of a cross-shaped patch at the S-band and a sub-array of four patches at the X-band. The resonance frequency of the cross-patch is only slightly perturbed by the addition of four square patches, since the radiating edges of the cross patch are away from the four square patches. However, the resonance frequency of the square patches is affected by the presence of the cross patch, which causes a reactive loading to the square patch. Therefore, the upper resonance frequency corresponding to the four square patches is slightly lower than that of the isolated square patches. The decrease of this upper frequency is noticeable when the spacing is less than the substrate thickness because of increased gap coupling. In designing the antenna, one should carefully choose the distance between the square patches, which should be less than 0.7l λ_0 to avoid scan blindness at the upper frequency.

4.3 Loaded multi-band antennas

The patch can be loaded for multi-band operation of microstrip antennas. The loading could be primarily stubs, notches, pins, lumped elements like resistors or capacitors and slots. Nevertheless, combination of these loading is also possible. In the following section the load antenna techniques are described in brief.

4.3.1 Stub loaded microstrip antennas

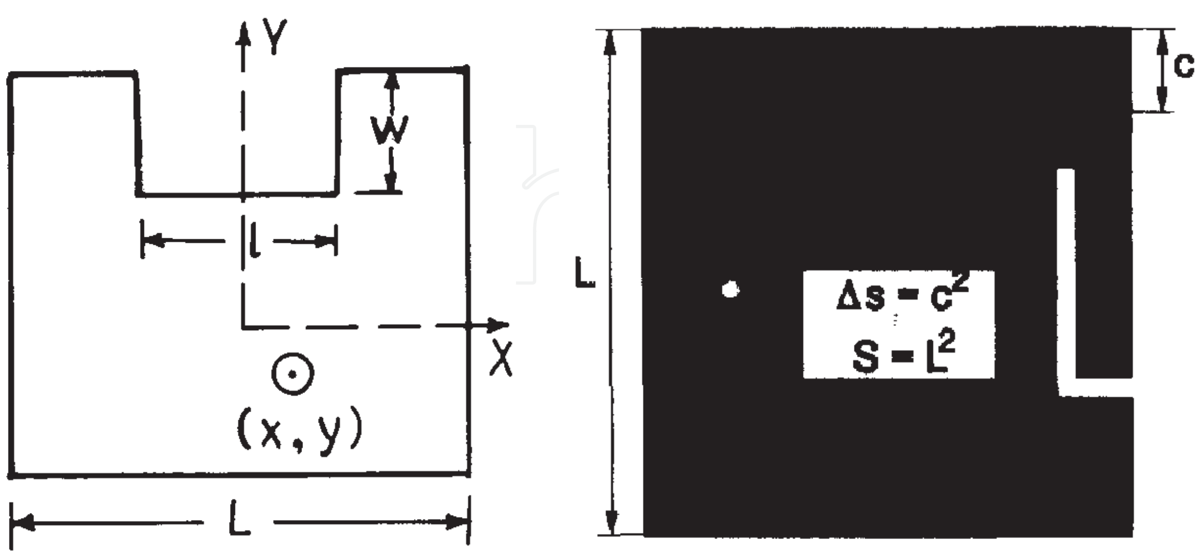
The reactive-loading approach was first used in Richards et al. (1985), where an adjustable coaxial stub was employed. This structure may provide both tuning and design of the frequency ratio in a simple manner; on the other hand, it is encumbering and not well-suited for high frequencies. In Davidson et al. (1985), a more practical configuration is presented, in which the stub is constituted by a microstrip. The tuning of the two frequencies was obtained by changing the length of the short-circuited coaxial line. Instead of short circuited coaxial line, a $\lambda/2$ short-circuited microstrip line is used as shown in Fig. 18(b), which can be etched on the same substrate along with the patch. Antennas with a single stub have slightly higher cross-polar level because it is asymmetrical configuration. To make the configuration symmetrical, not harming dual frequency operation, a λ /4 open-circuited stub is placed along both the radiating edges of the rectangular patch.



(a) (b)

Fig. 18. Various dual-band stub-loaded RMSA configurations: (a) short-circuited coaxial line, (b) short-circuited $\lambda/2$ stub (Kumar & Ray 2003)

4.3.2 Notch-loaded dual-band microstrip antennas

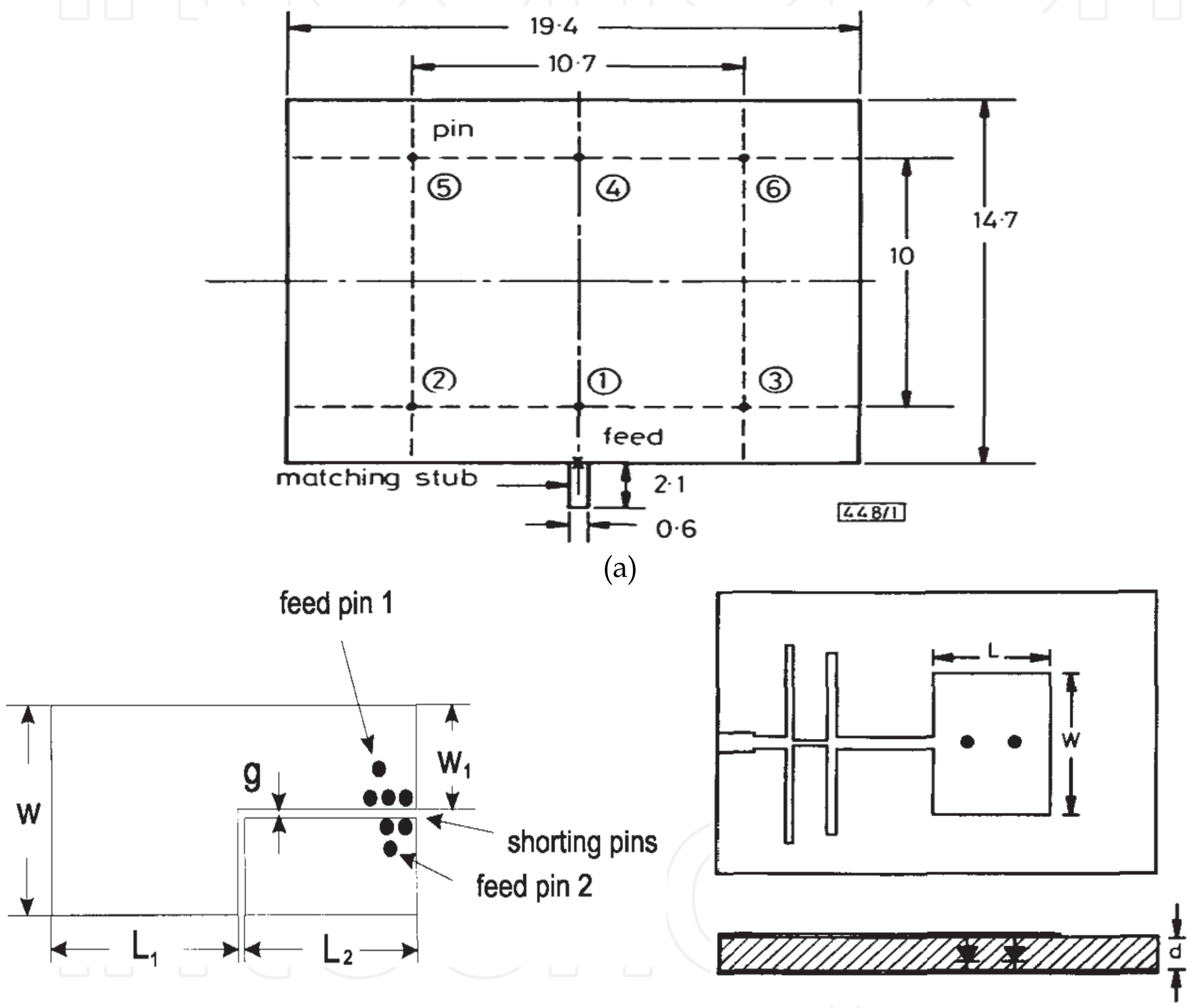


(a) (b)

Fig. 19. (a) Notch loaded square microstrip antenna and (b) Dual-band circularly polarized microstrip patch antenna (Nakano & Vichien 1989; Hernandez & Robertson 1995)

Loading the radiating edge with an inset (Nakano & Vichien 1989; Palit et al. 1998) or a spur-line (Hernandez & Robertson 1995; Hernandez & Robertson 1993; Vaello & Hernandez 1998) ("notch loading") is an alterative way to introduce a dual-frequency behavior that creates the same effect as the microstrip-loading effect, with the advantage of reduced size. However, both with stubs and notches, the frequency ratio cannot be designed to be higher than 1.2 without introducing strong cross-polarization levels or pattern distortion at the additional frequency.

4.3.3 Pins and lumped elements loaded dual-band antenna



(b) (c)

Fig. 20. (a) A rectangular microstrip antenna with shorting posts for dual-band operation, (b) top view of dual-band antenna mounted on the conducting telephone case, (c) Edge-Jed rectangular microstrip patch with double stub matching network and symmetrically loaded with two varactor diodes (Zhong & Lo 1983; Gao et al. 2002; Waterhouse & Shuley 1992)

A rectangular microstrip antenna operating in the TM_{10} and TM_{30} modes has a broadside radiation pattern with the same polarization at the two frequencies. The ratio of their resonance frequencies is approximately three. A shorting post placed at the null position of the TM_{30} mode will not change its corresponding resonance frequency but will have a strong effect on the TM_{10} mode frequency (Zhong & Lo 1983). An RMSA with six shorting posts is shown in Fig. 20 (a). Since all these posts are located at the nulls of the TM_{30} mode, f_2 remains constant at around 1,865 MHz, while f_1 varies from 613 MHz to 891 MHz. The ratio f_2/f_1 varies from 3.0 to 2.1, which could be lowered by using more shorting posts. However similar principle might be seen in other antennas in literature (Gao et al. 2002; Pan & Wong 1998; Liu et al. 1997; Srinivasan et al. 1998). The structure of the antenna might be circular (Tang et al. 1997; Pan & Wong 1997) or triangular. Very high values of the frequency ratio (4-5) can be obtained by means of lumped loaded elements like resistors (Srinivasan et al. 2000b), varactors (Waterhouse & Shuley 1992), connected from the patch to the ground plane.

4.3.4 Slot antenna technique

Another kind of reactive loading can be introduced by etching slots on the patch. The slot loading allows for a strong modification of the resonant mode of a rectangular patch, particularly when the slots are oriented to cut the current lines of the unperturbed mode. In particular, as shown in (Wang & Lo 1984), the simultaneous use of slots and short-circuit vias allows a frequency ratio of from 1.3 to 3, depending on the number of vias. Other kinds of slot-loaded patches have been independently introduced in (Maci et al. 1993) and (Yazidi et al. 1993), and consist of a rectangular patch with two narrow slots etched close to and parallel to the radiating edge. The same configuration has been investigated in ([58] Maci, S., 1995), and extended to dual polarization in (Piazzesi et al. 1995).

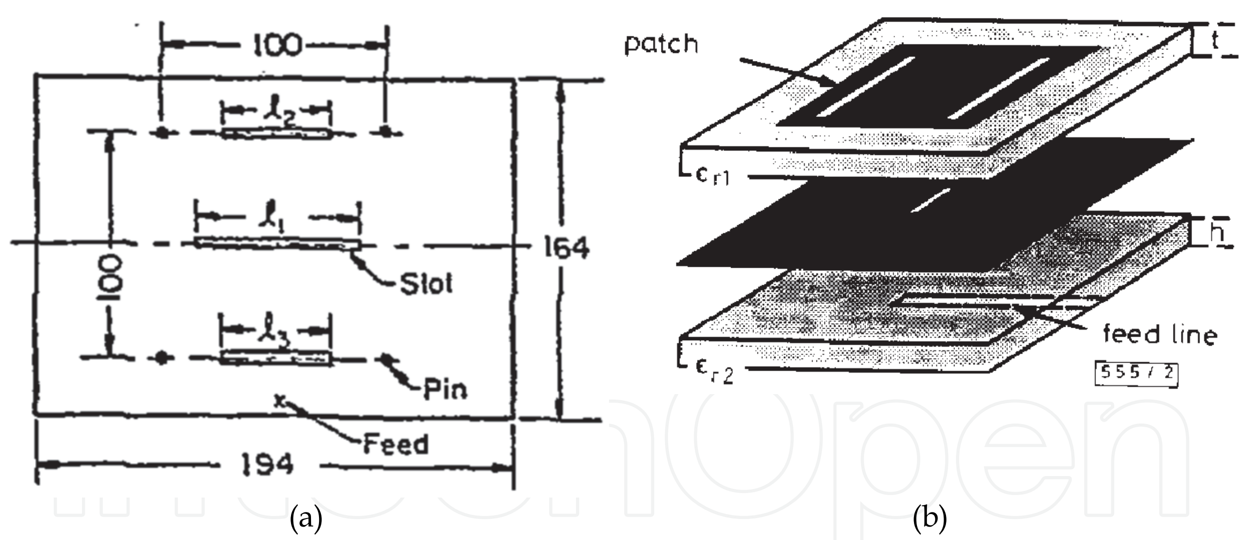


Fig. 21. (a) The microstrip antenna with shorting pins and slot, (b) Aperture coupled microstrip antenna for dual frequency operation (Wang & Lo 1984; Yazidi et al. 1993)

5. Dual-band high gain antennas & limitations

Many dual band antennas are developed and reported in the literature, especially for 2.4/5.8GHz. In order to achieve good radiation characteristics especially high gain, there are a lot of approaches taken. Printed dipoles (Kim et al. 2005; Lin et al. 2003), printed monopole (Wu et al. 2003; Jianhui et al. 2008; Wu et al. 2005), planar (Raj et al. 2005), slot (Wong et al. 2007) antennas are popularly used to provide dual frequency operation. But these antennas have complicated patch structures. Dielectric resonators (Chen et al. 2009; Ding & Leung 2009) and chip antennas (Moon & Park 2003) also provide dual band coverage which are very hard to fabricate. Rectenna (Suh & Chang 2002; Heikkinen & Kivikoski 2003), stacked patch (Yang et al. 2005), aperture coupled antenna (Yang et al. 2008), even though offer these two bands, occupy large space and difficult to integrate with handheld applications. However, the gain of these reported antennas are very low; lower than 7dBi, even printed simple element arrays (Lin et al. 2003; Wu et al. 2003) could not boost the gain higher.

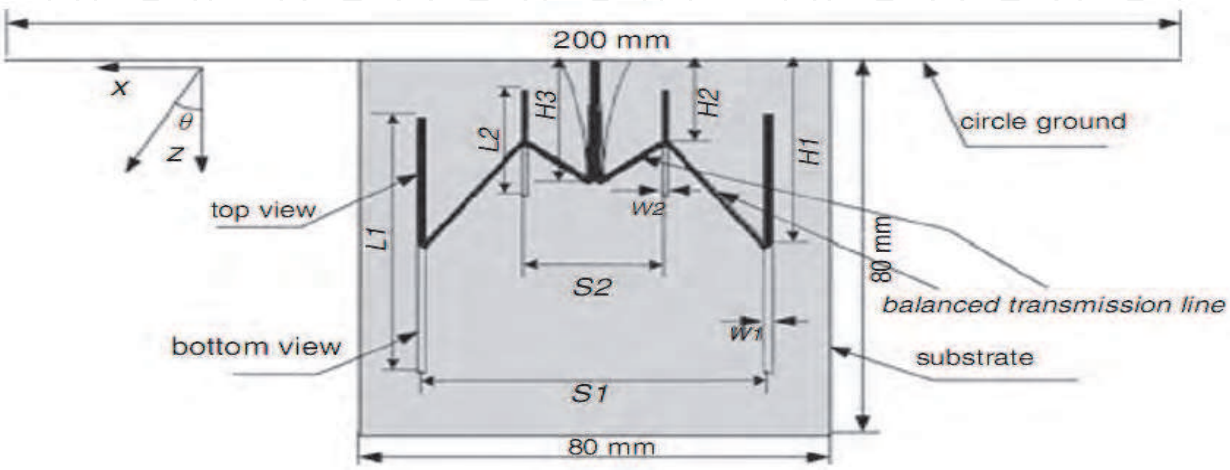


Fig. 22. Geometry of the dual-band bidirectional high gain antenna (Zhang et al. 2009)

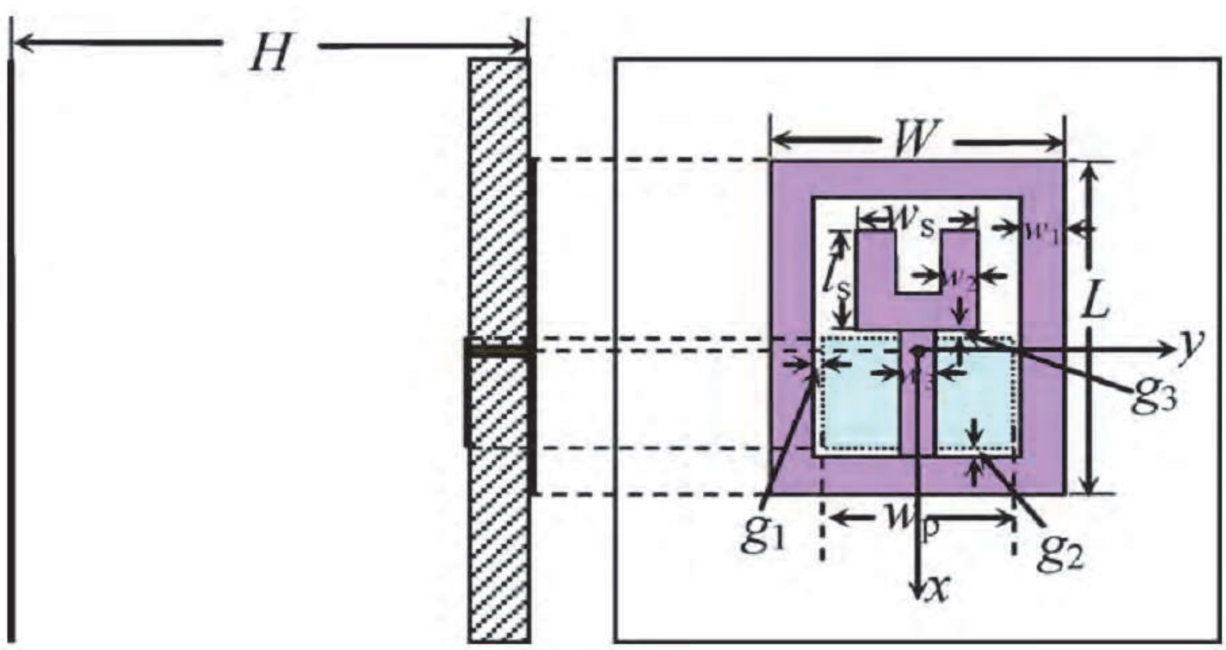
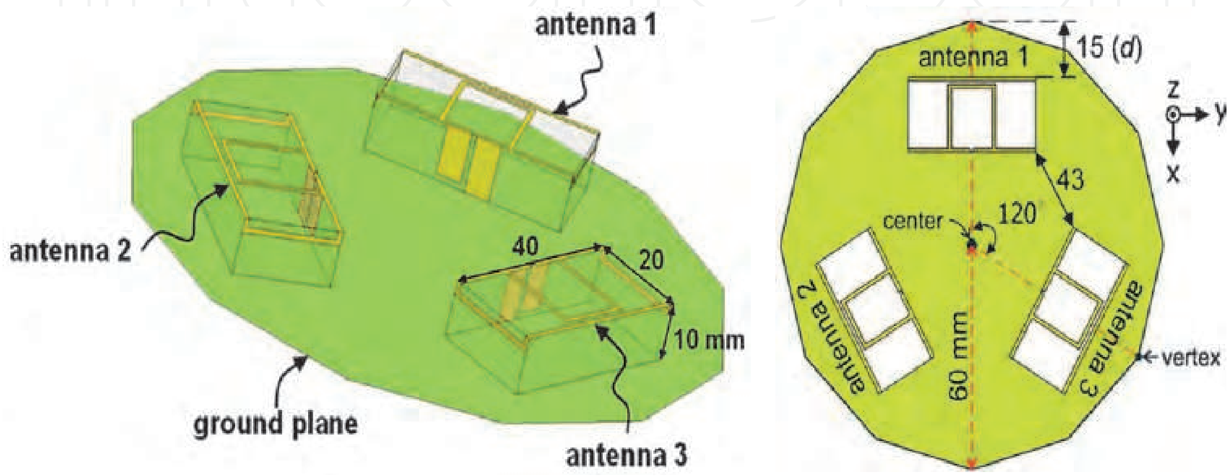


Fig. 23. Configuration of novel high-gain dual-band antenna (He et al. 2009)

Lately, to have high gain in these two bands a four-element printed dipole array antenna with balanced twin transmission line is reported (Zhang et al. 2009). Here the use of vertical patch increases the antenna volume. But still the gains for the 2.4 and 5.8 GHz bands are between 4.8–6 and 6–8.8 dBi, respectively.

Another novel high-gain dual band antenna is reported (He et al. 2009) shortly. The radiator is composed of three parts: the fork-like monopole, the rectangular ring, and the rectangular patch. A metal reflector with the same dimensions as the substrate is used behind the designed antenna, so the directivity/gain of the presented antenna is enhanced for both bands by suppressing the backside radiation. This antenna came up with a good peak gain; but still the antenna is inadequate to achieve desired bandwidth for lower frequencies and gain variation is severe over both the bands with an unlike radiation pattern in frequency bands. However taking the metal reflector into account requires bigger space for the antenna profile.



(a) (b)

Fig. 24. (a) Configuration of the proposed, high-gain, dual-loop antennas for MIMO access-point applications (b) Top view of the proposed, three-antenna MIMO system (Su 2010)

Another novel, high-gain, dual-loop antenna design applied to a three-antenna system for MIMO access point (AP) applications is presented in Fig. 24 (Su 2010). The metal shape of the dual-loop antenna is configured to be affixed to the surfaces of a foam base occupying a moderate size, which allows the antenna to be surface-mountable on the ground plane and to be concealed in the casing of the AP at the height of 10 mm. The proposed design comprises two loop antennas of uniform width, namely a large 2.4-GHz outer loop and a small 5-GHz inner loop, both attached onto the rectangular foam base and operating at 1.0-wavelength resonant mode. Both loops also share common antenna feeding and grounding portions. However, the antenna shows peak gain of 7dBi over the operating bands.

From the literature review, it is realized that previously reported antennas limit good performances only to one frequency band or sometimes lack in consideration of compactness. This can be attributed to the conventional feeding techniques that the antennas are being fed. So it is necessitated to introduce a new feeding technique to have the best performances in the operating bands.

6. Conclusion

A review of RFID technology from the point of antenna specifications in presented in this chapter. The antenna theory is also described for proper convenience of antenna characterization. The parameters are mainly related to scattering parameters including return loss and VSWR as well as radiation characteristics like radiation patterns, antenna gain, polarization and so on. Moreover, a wide literature review has been done in order to identify the techniques to design multi-band microstrip antennas. Mostly dual-frequency operation is discussed since they mean the basics of multi-band operation. However, it has been seen that these techniques can be combined to enhance multi-band antennas with wider bandwidths. Finally, the high gain antennas and limitations have been described and it is realized that the conventional feeding technique might limit the performance of multi-band antennas to only one frequency.

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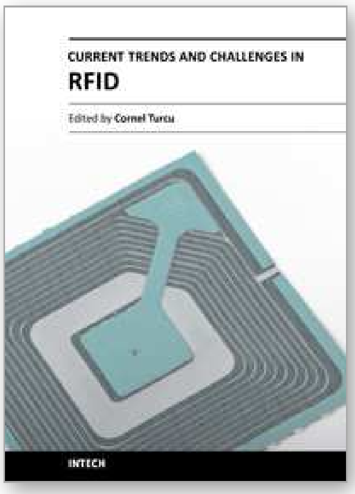

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With the increased adoption of RFID (Radio Frequency Identification) across multiple industries, new research opportunities have arisen among many academic and engineering communities who are currently interested in maximizing the practice potential of this technology and in minimizing all its potential risks. Aiming at providing an outstanding survey of recent advances in RFID technology, this book brings together interesting research results and innovative ideas from scholars and researchers worldwide. Current Trends and Challenges in RFID offers important insights into: RF/RFID Background, RFID Tag/Antennas, RFID Readers, RFID Protocols and Algorithms, RFID Applications and Solutions. Comprehensive enough, the present book is invaluable to engineers, scholars, graduate students, industrial and technology insiders, as well as engineering and technology aficionados.