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Chapter

# A Review: Circuit Theory of Microstrip Antennas for Dual-, Multi-, and Ultra-Widebands

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## Abstract

In this chapter, a review has been presented on dual-band, multiband, and ultra-wideband (UWB). This review has been classified according to antenna feeding and loading of antennas using slots and notch and coplanar structure. Thereafter a comparison of dual-band, multiband, and ultra-wideband antenna has been presented. The basic geometry of patch antenna has been present along with its equivalent circuit diagram. It has been observed that patch antenna geometry for ultra-wideband is difficult to achieve with normal structure. Ultra-wideband antennas are achieved with two or more techniques; mostly UWB antennas are achieved from coplaner structures.

**Keywords:** dual-band, multiband, ultra-wideband, microstrip patch

## 1. Introduction

Antenna is a device that is used to transmit and receive the information in the form of electromagnetic waves only. Antenna is generally classified according to the frequencies, low-frequency, medium-frequency, and high-frequency antenna. Firstly, low-frequency antenna was proposed by a German physicist H. Hertz, i.e., a dipole antenna; thereafter it took 20 years to practically install this antenna. Marconi preformed an experiment on half-wave dipole to transmit the information from Atlantics and received successfully at the receiver side, i.e., St. John's Newfoundland. It was Marconi who used the theory of Prof. J.C. Bose for successful transmission of information. Later, J.C. Bose was known for his contributions on horn antennas. These transmissions of signal were limited to a 200-m distance, and after that De Forester and Felleming developed vacuum tubes; this leads to the increase in transmission distance till 600 m. This enhances the role of electrical and electronics devices for long-distance communications. Then medium-frequency antenna ranges from 300 to 3000 KHz which was designed in the late 1920s. This antenna was constructed using steel bar supported via wooden bars. Later on all lots of development gone till the 1960s for the improvement of medium-frequency antenna, and various antennas were proposed that satisfied this ranges. High-frequency antennas range from 0.003 to 40 GHz after that it is millimeter waves. High-frequency antennas are aperture antenna (pyramidal horn, circular horn, rectangular waveguide), antenna array (linear or planar arrays) and reflector antennas (parabolic reflectors with horn fed or Cassegrain feed, lens antenna, and microstrip antennas (MSAs)) which comprise of a circular, rectangular, or square conducting patch that is made of grounded substrate. This chapter is focused on the miniaturized high-frequency devices so that it can be used in compact wireless communication devices.

In view of this, high-frequency patch antennas devices are introduced, and an extensive literature survey is performed. High-frequency MSAs are the antennas in which dielectric substrates are between the radiating patch and ground plane [1] and are shown in **Figure 1** along with its equivalent circuit diagram. Patch antenna at high frequency is represented as a parallel combination resistance $R_1$, capacitance $C_1$, and inductance $L_1$. The value and equations of $C_1$, $R_1$, and $L_1$ [1] vary depending

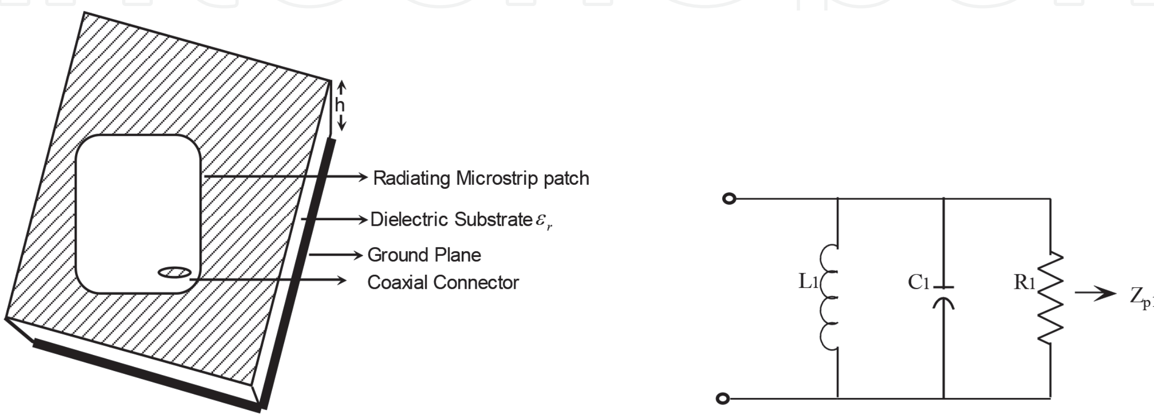


**Figure 1.**
*Configuration of microstrip antenna and its equivalent circuit diagram.*

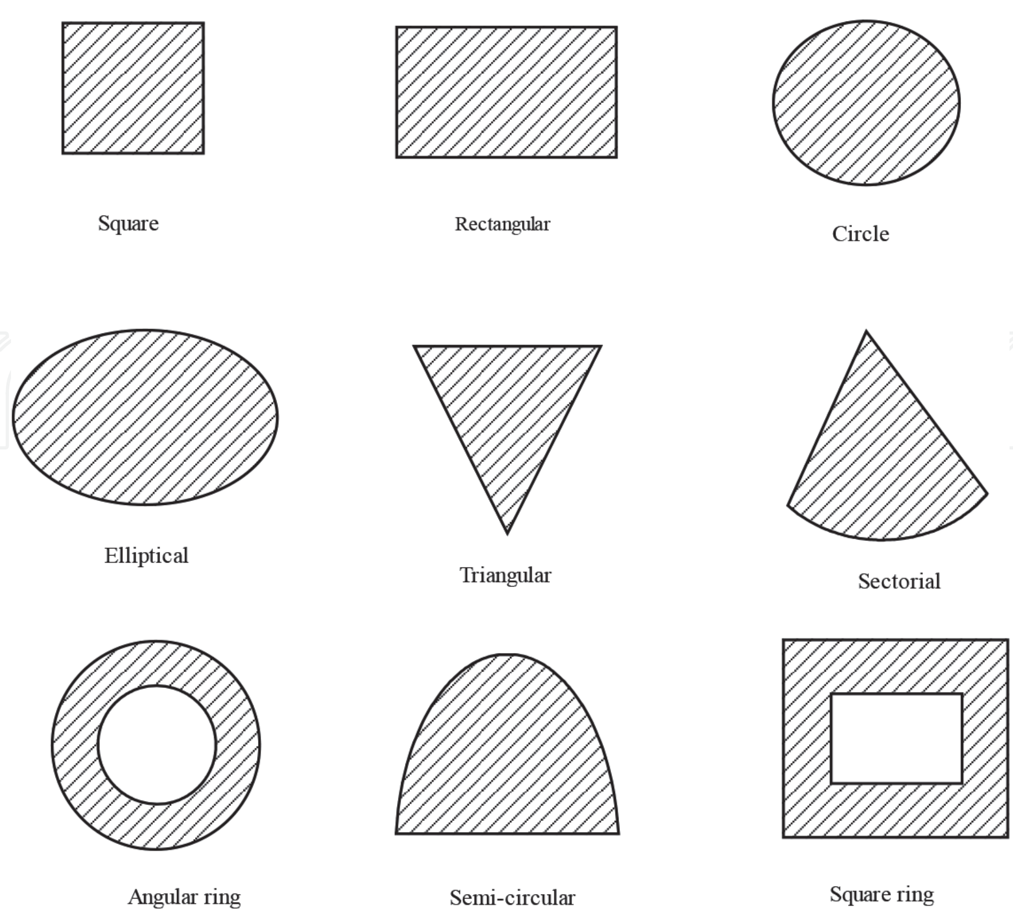


**Figure 2.**
*Different shapes of radiating patches.*

on the shape and size of antennas. Patch antennas can be of any shape [1] and size, as shown in **Figure 2**. **Figure 2** shows different types of existing geometry of antennas such as square, rectangular, circle, elliptical, triangular, sectorial, angular ring, semicircular, and square ring. First microstrip patch antenna was reported by Deschamp [2] in 1953. High-frequency microstrip patch antennas generally are divided according to the frequency bands, i.e., dual-band, multiband, broadband, and ultra-wideband (UWB) [3–5]. To achieve these frequency bands, antennas of different shapes and sizes have been presented. In the next section, these frequency bands are discussed with respect to their shape, size, and feeding techniques. From **Figure 1** the input impedance of patch can be written from its equivalent circuit as

$$Z_{p1} = \frac{1}{\frac{1}{j\omega L_1} + j\omega C_1 + \frac{1}{R_1}} = \frac{j\omega L_2 R_1}{j\omega L_2 - \omega^2 L_1 C_1 R_1 + R_1}, \tag{1}$$

## 2. Dual-band MSAs

Dual-band and multiband microstrip patch antenna can be realized with different techniques such as stacking, coplanar structures (parasitic patches), slots, notches, shorting pin, shorting wall and active devices, etc. Using these techniques several research papers were published by various researchers, and the first dual-band radiator was reported in 1984, using shorting pins in rectangular patches by Wang and Lo [6]. In this section, literature survey of dual-band and multiband is presented on the basis of techniques used to achieve dual or multiband.

### 2.1 Slot loaded MSAs

Slot loaded MSAs can be achieved by etching rectangular or slot of any desired shape in the patch as shown in **Figure 3**. This antenna can be represented as a parallel combination of impedance due to patch ($Z_{p1}$) and impedance due to slot ($Z_{sh}$), and its equivalent is denoted as ($Z_{ps}$), as given in **Figure 3** and calculated as,

$$\frac{1}{Z_{ps}} = \frac{1}{Z_{p1}} + \frac{1}{Z_{sh}}, \tag{2}$$

The slotted loaded MSAs proposed by various researchers are summarized here.

Daniel and Shevgoankar [7] studied rectangular microstrip patch antenna with the slot etched along with the nonradiating edge of the patch antenna for tunable dual-band operation and investigated the effects of the slot parameter on the tuneableness of the RMSA resonant frequencies. Wu [8] demonstrated compact slot loaded triangular patch antenna for wireless application and measured gain as 2.8

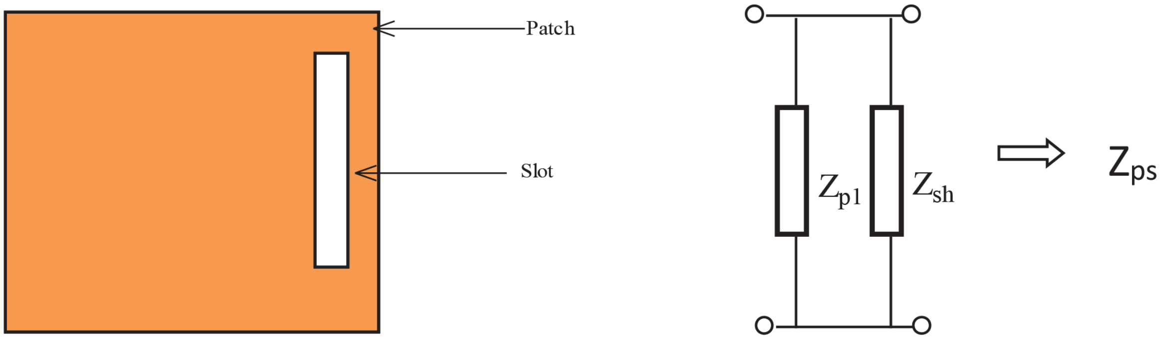


**Figure 3.**
*Top view of slot loaded MSAs and its equivalent circuit diagram.*

and 5 dBi with variations within 1.0 dBi. Vishvakarma and Vishvakarma [9] presented the theoretical analysis of inclined slot loaded rectangular patch antenna for dual-band operation. They given circuit diagram for patch antenna which is similar to **Figure 3** and circuit theory concept was used to calculate reflection loss, variation of slot length and width was also discussed. Lim et al. [10] presented the modeling of dual-band aperture-coupled microstrip patch antenna (ACMPA) with a symmetric crossed slots. Ansari et al. [11] also reported a triple U-shaped slot loaded patch antenna for Bluetooth and wireless local area network (WLAN) application and have explained that by introducing three U-slots in the circular disk, 16.54% of size reduction can be achieved. Lu and Liu [12] proposed a novel planar slot array antenna with high-gain operation for long-term evolution (LTE)/Worldwide Interoperability for Microwave Access (WiMAX) point and measured maximum peak antenna gains and efficiencies of 13.9/14.1 dBi and 86.5/73.5% across 2.6/3.5 GHz bands, respectively, whereas Luo et al. [13] reported an open L-slot antenna for WLAN/WiMAX applications. Ansari et al. [14] reported single W-slot loaded and two dielectric layers microstrip patch antenna using equivalent circuit theory concept and reported the frequency ratio and 1.33 for single-layer patch antenna and 1.38 for two-layer patch antenna. Gupta et al. [15] proposed a microstrip antenna with tunable high-impedance surface with two varactor diodes. Mohammad et al. [16] proposed a U-shaped patch, T-shaped monopole path, and a pentagonal wide slot in the ground plane for multi-input multi-output (MIMO)/diversity applications. Chakraborty et al. [17] designed two different single slotted loaded on rectangular microstrip antennas with slotted ground plane for IEEE 802.11a WLAN application. Tsai [18] investigated a bow tie-shaped CPW-fed slot antenna which consists of a coaxial connector and two conducting strips for wireless communication applications.

### 2.2 Feeding techniques of MSAs

There are different feeding techniques by which dual-band can be achieved such as coplanar waveguide (CPW) fed, coaxial fed, microstrip line-fed, etc. and is shown in **Figure 4**. **Figure 4(a)** shows the CPW fed in which ground plane and excited patch lies on the same plane. **Figure 4(b)** shows microstrip line fed of 50 Ω which is used to excite the patch and ground plane that is on either side of the dielectric substrate. **Figure 4(c)** shows coaxial fed in which coaxial fed feed from bottom of antenna via drilling hole till excited patch. **Figure 4(d)** shows proximity fed which has actually microstip line fed which lies between two dielectric substrate of height $H_1$ and $H_2$. **Figure 4(e)** it has microstrip line fed at bottom of the substrate above that ground plane at height $H_2$ is placed above the ground plane patch is placed with height of the dielectric substrate $H_1$. Different feeding techniques used by various researchers to achieve dual-band are briefly described below.

Liu and Chen [19] proposed a compact patch antenna CPW fed for dual-band operation and obtained that lower band and upper band of antenna can be utilized for short-range wireless application. Sung et al. [20] illustrated a microstrip line dual frequency dielectric resonator antenna printed on a single metal layer. Su et al. [21] presented a rectangular patch antenna surrounded by a ring patch for dual-band operation and observed that two operating bands produce linear polarization. Chen and Hsu [22] proposed broadband radial slot CPW-fed antennas for dual operation and observed that the bandwidth of the lower resonance frequency lies in the range of 2.4–9.7%, while that of the upper frequency ranges from 17.4 to 23.2%. Sze et al. [23] proposed a circular slot antenna fed by a coplanar wave guide with slit back patch, and they observed that broadside far-field pattern at both frequency bands. Huang et al. [24] studied dual-band monopole antenna excited by a

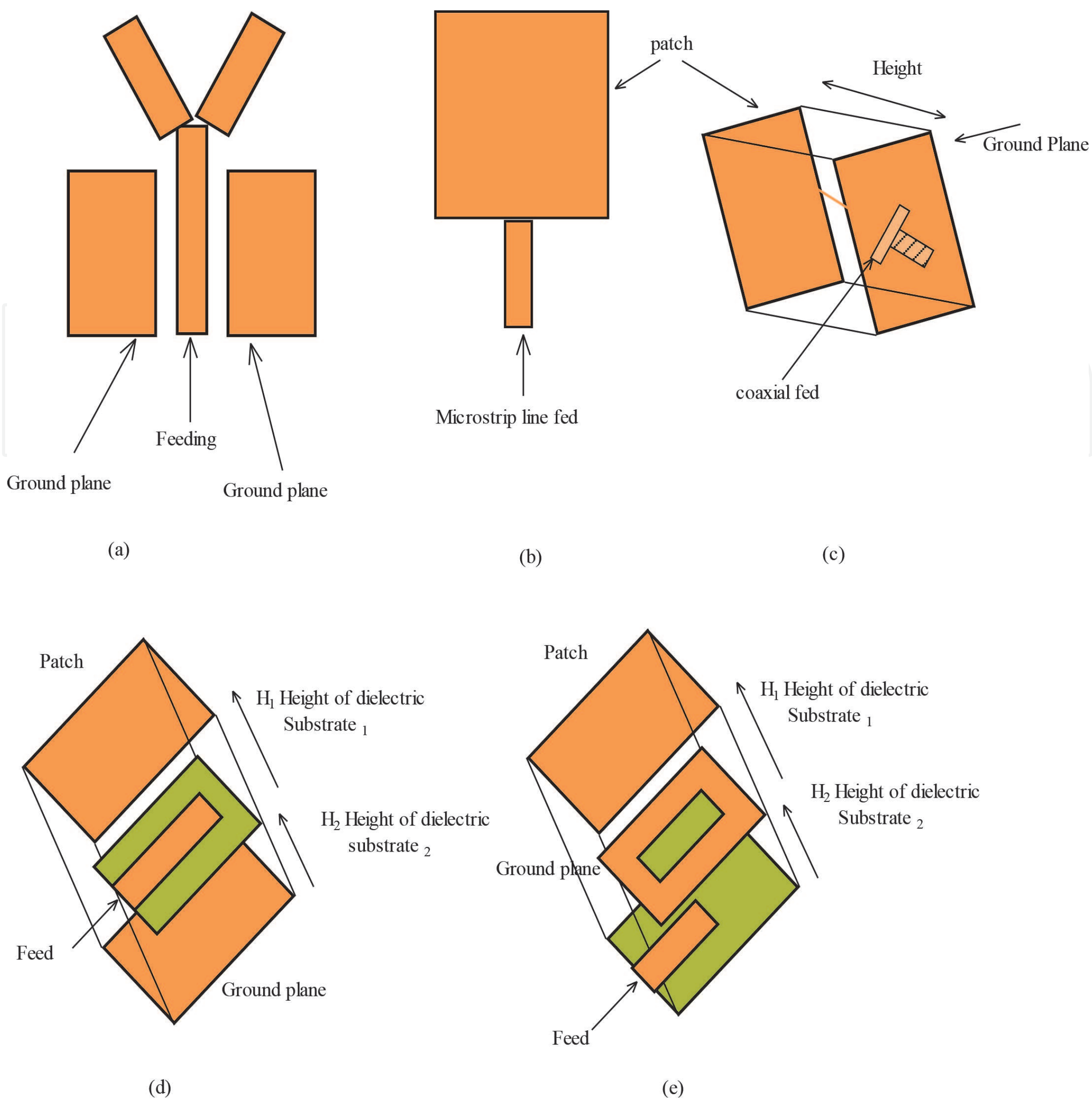


**Figure 4.**
*Different feeding techniques of MSAs. (a) CPW fed, (b) microstrip line fed, (c) coaxial fed, (d) proximity fed, and (e) aperture fed.*

capacitive coupling feed for WLAN application and measured 3.4% and 13% bandwidth for upper and lower resonance frequency. Yoon et al. [25] designed a planar CPW-fed slot antenna and thin substrate for dual-band operation for WLAN applications and measured peak gains 1.37 and 1.7 dBi for lower and upper frequencies, respectively. Lin et al. [26] investigated a compact CPW-fed patch antenna with two embedded slots and found average antenna gain as 1.4 and 5.1 dBi.

Singh et al. [27] published an article on aperture-coupled feeding to achieve dual-band. The antenna was designed in the IE3D simulation software, and results were compared with theoretical result via circuit theory concept. Two resonance frequencies were achieved at 4.39 and 5.55 GHz with a percentage bandwidth of 10.23 and 13.33%. Circuit concept was applied on antenna for analysis of these antenna parameters such as input impedance, reflection coefficient, VSWR, and return loss. Antenna physical parameters were also varied such as dielectric substrate thickness of two dielectric used, width and length of aperture, and dielectric constant of two dielectric used in the design for achieving dual-band characteristics.

Microstrip line fed exciting the gap coupled rectangular and parasitic patch was presented by Singh et al. [28]. Dual-band was achieved through spitted ring resonator (SRR) at ground plane and parasitic patch at 0.9 and 1.8 GHz. They proposed the circuit of design of antenna, and analysis of the antenna was presented theoretically on varying gap between parasitic and fed patch, microstrip width and length, and height of substrate. All these variation was explained in terms of change in inductance and capacitance.

Gulam Nabi Alsath et al. [29] discussed and designed two identical aperture-coupled pattern reconfigurable dielectric resonator antennas (DRAs). Li et al. [30] studied a compact asymmetric coplanar strip (ACS)-fed using loaded capacitance terminations for 2.4/5.8 GHz wireless local area network applications. Moosazadeh and Esmati [31] presented the small planar microstrip-fed square radiator using slotted conductor backed plane for wireless local area network applications. Chen et al. [32] investigated the slot stepped-impedance resonators (SIRs) and CPW feeding for dual-band/tri-band/broadband applications. Emadian and Shokouh [33] investigated CPW-fed slot antenna which consists of a coaxial connector and two conducting strips for wireless communication applications with high increased impedance bandwidth.

Singh et al. [34] designed an antenna with L-strip feed. It is a slightly complicated geometry to be fabricated because it is difficult to create an L-strip fed structure. This fed excite rectangular patch with three rectangular slots. They found that resonating frequency depends on the slot length and width, L-strip length, and width which have a vital role in achieving dual-band.

### 2.3 Stacked MSAs

Stacking of MSAs means having two or more dielectric substrate of different or same thickness that is kept over each other or one can say the toppling of one substrate over the other. Dual-band can also be achieved by stacking as shown in **Figure 5**. From figure, patch is at top of the antenna that is excited through coaxial fed below the excited patch one more patch placed of height $H_2$ (no-excited) after ground plane is there which is ground through coaxial fed. **Figure 5** equivalent circuit represents combination impedance of excited patch $Z_{P1}$, and electromagnetic coupling occurs due mutual inductance and capacitance occurs, i.e., mutual inductance $L_m$, inductance occurs because of patch and other patch $L_{mp}$, capacitance occurs because of patch and other patch $C_{mp}$, and $L_{p1}$ and $C_{p1}$ are inductance due to patch and ground plane. Its equivalent impedance can be given as

$$Z_{St} = \frac{1}{Z_{p1}} + \frac{1}{\left(\frac{1}{L_m} + \frac{1}{L_{p1}}\right) + L_{mp}} + \frac{1}{\left(\frac{1}{C_{mp}} + C_{p1}\right) + C_m}, \quad (3)$$

Karmakar [35] proposed shorted strap tunable stacked patched PIFA and measured bandwidth of 10.8% at 1.8 GHz where shorting and stacked structure plays

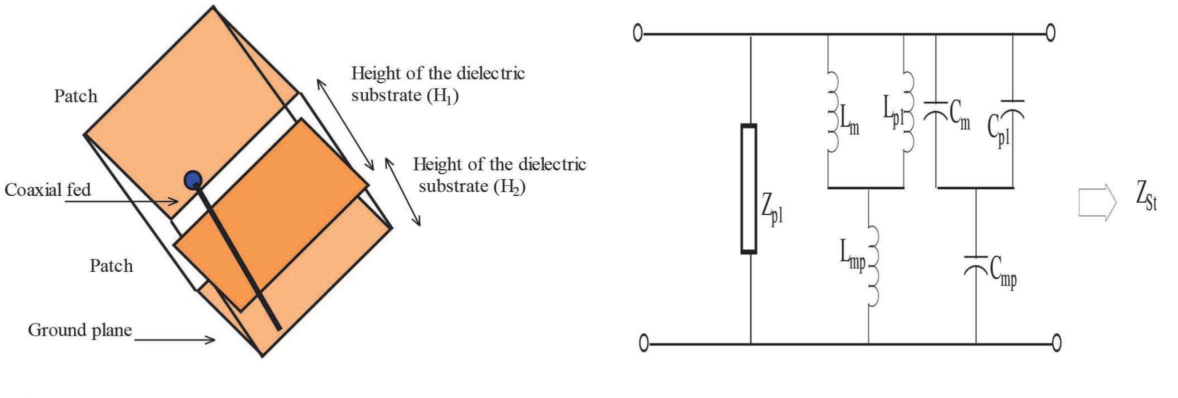


**Figure 5.**
*Side view of stacked MSAs and its equivalent circuit diagram.*

a vital role in achieving 10.8% bandwidth. Pioch and Laheurte [36] investigated a dual-band stacked microstrip based on a small parasitic patch inserted slightly above an EBG patch. Kim et al. [37] presented the design simulations and measured stacked meandered patch antenna for mobile communication and observed that dual-band operation is realized using via holes with 0.3-mm height. Anguera et al. [38] presented stacked microstrip patch antenna using reactive loading and a fractal shape radiating edge. Ansari et al. [39] reported the analysis of U-slot loaded patch stacked with H-shaped parasitic elements. The circuit theory concept was applied by them and presented equivalent input impedance of the designed antenna. Further, they calculated variation of U- and H-shaped slotted on antenna bandwidth. Ma and Row [40] proposed a design of single-fed antenna structure composed of two stacked patches with different polarizations and radiation patterns. Benkouda et al. [41] investigated stacked high $T_c$ superconducting rectangular patches fabricated on a two-layered substrate using a full-wave spectral analysis. Batgerel and Eom [42] presented a stacked microstrip patch antenna structure combined with high-gain dielectric rod and a sleeve-dipole element. Mishra et al. [43] designed the dual- and wideband slot loaded stacked microstrip patch antenna for WLAN/WiMAX applications. The bandwidth of the proposed dual-band antenna at lower resonance frequency is 9.53%, whereas at upper resonance frequency, 6.95% is achieved.

### 2.4 Parasitic MSAs

Parasitic MSAs can be designed as shown in **Figure 6**, with its equivalent circuit diagram. These types of antenna are represented as a combination of gap capacitance ($C_{p1}$ and $C_{p2}$) with patch and in addition to it develop coupling capacitance $C_c$, and the values of $C_{P1}$, $C_{P2}$, and $C_C$ can be calculated as in [1]. Its equivalent impedance can be given as

$$Z_{CC} = j\omega C_g + j\omega C_{P1} + \frac{1}{j\omega C_{p1}}, \quad (4)$$

It has the fed patch and non-fed patch on the same plane of the dielectric substrate. Brief survey of antennas having parasitic elements is described here.

Anguera et al. [44] reported a dual frequency patch antenna based on the Sierpinski fractal geometry with two parasitic patches to enhance the bandwidth of

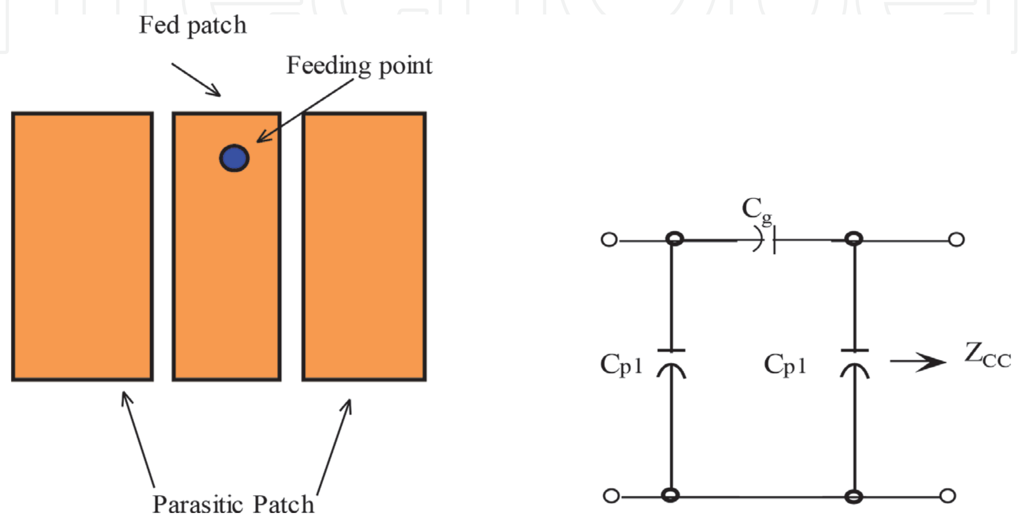


**Figure 6.**
*Top view of parasitic MSAs and its equivalent circuit diagram.*

the antenna. Chen et al. [45] proposed planar antenna, an ungrounded dielectric slab with parasitic reflector for dual-frequency operation and steerable end-fire pattern characteristics. Cho et al. [46] presented a compact internal antenna with parasitic patch for mobile handset and measured the bandwidths of 140 MHz (1740–1880) for which is the within the range of Korean communication service (KPCS) band and 90 MHz (2400–2490) in the Bluetooth devices. Liu et al. [47] presented a triangular patch antenna with parasitic element over a modified ground plane and measured bandwidth greater than 20% at the 2.45 and 5 GHz bands. Peng and Ruan [48] presented microstrip-fed dual-band design patch antenna with two parasitic invert L stubs for 2.4/5-GHz wireless applications, and they found L stub plays important part in achieving dual-band.

### 2.5 Notch-loaded MSAs

Dual-band-notch-loaded MSA geometry is shown in **Figure 7** and its equivalent circuit diagram. The figure shows rectangular patch with coaxial fed having rectangular notch at edges. Due to notches $\Delta L$ and $\Delta C$, inductance and capacitance will be developed, and it is represented as a parallel combination of $R_2$, $L_1 + \Delta L = L_2$, $C_1 + \Delta C = C_2$ which can be calculated [1]. Its equivalent impedance is given as

$$Z_n = \left(\frac{1}{R_2} + \frac{1}{L_1 + \Delta L} + \frac{1}{C_1 + \Delta C}\right) \tag{5}$$

Rectangular and circular notch is etched near the edges of the MSAs as seen in the figure. Depending on the designs of notch-loaded MSAs, brief literature survey is done.

Shivnarayan and Vishvakarma [49] investigated the theoretical analysis of notch-loaded patch antenna for dual-band operation, and they observed that frequency ratio varies from 1.11 to 1.83 with length and width of the notch. Deshmukh and Kumar [50] analyzed various types of dual-band slotted antennas such as U-shape slotted, E-shaped notched, and pair slots. They found the U-shaped and pair of slots help in achieving dual-band and discussed radiation characteristics of the antenna. Mishra et al. [51] presented notch-loaded microstrip patch antenna with shorting pin using cavity model. They achieved dual-band on inserting shorting pin, and variation of notch length and width was also presented. Thomas and Sheernivasan [52] proposed a novel CPW antenna which comprises a rectangular patch and notch cut at lower edge of the patch and measured gain of 2 dBi. A compact-notched CPW-fed wide-slot antenna for WLAN and WiMax

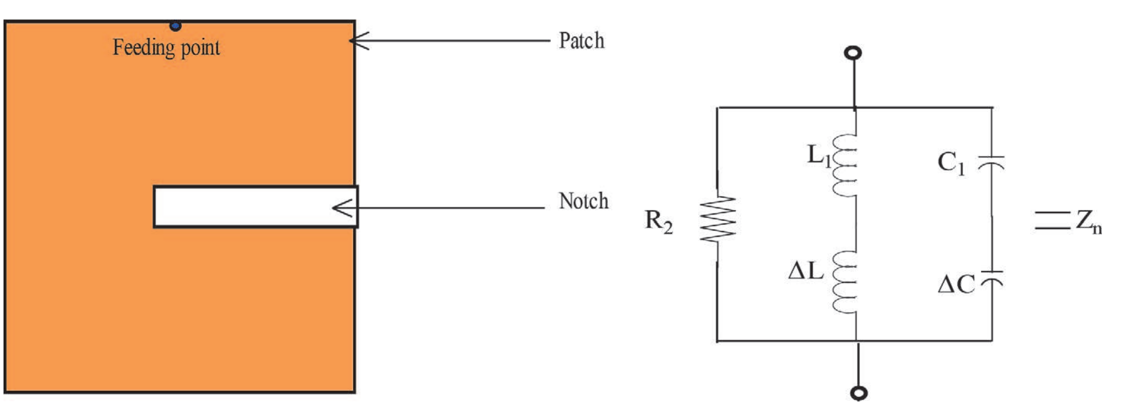


**Figure 7.**
*Top view of notch-loaded MSAs and its equivalent circuit diagram.*

applications was proposed by Lin et al. [53]. Singh et al. [54] presented and analyzed two symmetrical notches and shorting pin-loaded patch antenna using circuit theory concept based on modal expansion cavity model. Variation of symmetrical notches' length and width was shown using circuit theory concept, and parametric analysis of antenna design was also presented. Mishra et al. [55] analyzed L-strip-fed circular disk patch antenna using circuit theory concept and observed that when the notch is etched on the circular disk, patch dual-band behavior shifts towards resonance higher side.

Verma et al. [56] designed and fabricated equilateral triangle antenna with edge-notched at each edge of triangle. Dual-band was achieved at 9.53 and 4.81 GHz. The variation of frequency ratio for side length, substrate thickness, and dielectric constant was presented. Antenna was designed for dual-band that is applicable for the C, X, and Ka band operation.

## 3. Broadband MSAs

Broadband MSAs can be defined as a bandwidth that is greater than 18% for upper and lower resonance frequencies that too band should be −10 dB down. Broadband can be achieved by different techniques such as slots and notches and different feeding techniques such as proximity, aperture, CPW fed, microstrip line, stacked, parasitic elements, etc. In 1979, the first broadband antenna by stacking rectangular patches in two- and three-layered configuration was described by Hall et al. [57]. Long and Walton [3] investigated the stacked microstrip antennas for dual-frequency operation. A brief literature survey of broadband MSAs is presented herein and described according to its feeding techniques, reactive loading, coplanar structures, etc.

### 3.1 Feeding techniques for broadband MSAs

Mestdagh et al. [58] presented a systematic study of aperture-coupled stacked patch antennas fed by coplanar waveguide useful at millimeter wave frequency in the 30 GHz range. They found the antenna bandwidth of 30%. Stevan et al. [59] proposed broadband patch antenna with L-shaped probe and found bandwidth of 35% with a gain of 6 dBi. They achieved 30% reduction in dimension from convention patch antenna. Yuehe [60] proposed a novel two-layer stacked wideband dielectric resonator antenna (DRA) of rectangular shape. Zhang et al. [61] presented a dielectric resonator antenna formed by a U-shaped dielectric resonator and a conformal elliptical patch proposed for wideband communication applications. The measured impedance bandwidth $S11 < -10$ dB was about 72%, covering the frequency range 3.82–8.12 GHz.

### 3.2 Stacked design of MSAs

Natrajan et al. [62] introduced a novel topology of a dual-stacked, U-slot loaded patch antenna and achieved VSWR bandwidth of 65% and peak gain of 9.4 dBi. Lui and Luk [63] in 2005 designed a stacked patch antenna fed by meandering probe and achieved 37% bandwidth. Ghannoun et al. [64] reported a patch antenna with two E-shaped stacked patches and found a bandwidth of 54%. Deshmukh and Kumar [65] presented a compact broadband stacked patch antenna and found 10.9% bandwidth for C-shaped stacked patch and 9.7% for H-shaped stacked patch antenna.

### 3.3 Slot loaded design of MSAs

Wu et al. [66] presents a novel dual-broadband rectangular slot antenna for 2.4 and 5 GHz WLAN. The impedance bandwidth for two operating bands could reach up to 10.6% for the 2.4 GHz band and 33.8% for the 5 GHz band. Deshmukh and Kumar [67] reported a broadband rectangular microstrip antenna with a pair of rectangular. Its bandwidth was further increased either by cutting multiple pairs of slots or by cutting a pair of bowtie slots. Deshmukh and Kumar [68] presented various suspended broadband and compact circular microstrip antennas using variations of U-slot, V-slot, and pair of rectangular slots cut either on the periphery or inside the patch. Fang et al. [69] described a novel microstrip slot antenna backed by a ground plane of large bandwidth and high gain. Chen et al. [70] proposed a novel microstrip line-fed wide-slot antenna. The proposed antenna has a simple symmetric structure and compact size. Mo et al. [71] presented a broadband ultra-high-frequency radio-frequency identification (UHF RFID) tag patch antenna with a pair of U-slots.

Aneesh et al. [72] presented a research article of S-shaped patch antenna on tough form with copper laminated on the front and back side. They applied a multilayer perceptron artificial neural network (MLPANN) for the analysis of antenna design on varying size of notches. The ANN models with several types of algorithm were trained from which Levenberg-Marquardt (LM) algorithm takes less time. S-shaped-type structure is formed by etching two rectangular notches of equal dimension and resonating at 2.64 GHz with a bandwidth of 20.57%.

Aneesh et al. [73] designed an H-shaped rectangular structure on IE3D simulation software and achieved triple band for PCS and WiMAX applications. The design was fed via a microstrip line fed with finite ground plane. They found that measured and simulation results were in close agreement for radiating structure. They observed antenna maximum efficiency and gain at 5.2 GHz, i.e., 95.5% and 7 dBi.

### 3.4 Other techniques of MSAs

Liu and Boyle [74] proposed a bandwidth enhancement of a quarter wavelength slot antenna by capacitive loading to increase its bandwidth. Tang and He [75] proposed a square microstrip patch with a pair of U and T slots which was suitable for attaching to metallic objects. Kimouche et al. [76] presented the monopole antenna with the bandwidth enhancement technique covering the band 3.1–10.6 GHz, which was approved by the federal communication commission as a commercial band for ultra-wideband communication systems, with a measured return loss bandwidth of 7.9 GHz.

## 4. Ultra-wideband MSAs

In the year 2002, the Federal Communication Commission (FCC) defined ultra-wideband as those bands which have first resonance frequency at 3.1 GHz and higher resonance frequency at 10.6 GHz. After FCC defined the bandwidth of ultra-wideband, the lots of papers were published on UWB MSAs. Depending on the designs of patch antenna, a brief literature survey is described in the section.

### 4.1 Slot loaded MSAs for UWB

Liu et al. [77] proposed a microstrip-fed antenna, consisting of a square slot patch with a vertical coupling strip, which only occupies a small size of 15 (L) $\times$ 15

(W) × 1.6 (H) $mm^3$. Ghaderi and Mohajeri [78] proposed a compact wide-slot antenna with microstrip-fed monopole for UWB application. The monopole is composed of an elliptic patch connected to a trapezoid one. Ojaroudi and Ojaroudi [79] presented a novel inverted T-shaped ring slot antenna, surrounded by a C-shaped slot, which provides a wide usable fractional bandwidth of more than 125% (2.71–12.06 GHz). Peng Gao et al. [80] proposed an inverted U-shaped slot on the ground plane and a radiation patch similar to the slot that is fed by a 50-Ω microstrip line. Shinde and Mishra [81] presented L-shaped thin ground plane for lower frequency band stop function and a tapered rectangular vertical slot in radiating patch for upper frequency band stop. Gong et al. [82] presented a compact ultra-wideband antenna with an L-shaped slot. They found that the proposed antenna offers 118% bandwidth when the antenna is fabricated on dielectric constant 4.4 and of dimension of 23.7 × 23.7 × 0.8 $mm^3$. Haraz et al. [83] designed two different slot-coupled vertical microstrip-microstrip transitions for UWB multilayer microwave circuits and simulated the results using two simulation programs with two different numerical techniques.

### 4.2 Notch-loaded MSAs for UWB

Shameena et al. [84] designed and analyzed a compact planar UWB antenna with notch-band ON/OFF control and achieved the UWB response by a microstrip-fed staircase patch with an identical inverted ground plane. Ojaroudi et al. [85] presented a novel printed monopole antenna (PMA) for UWB applications with variable frequency band-notch characteristics. Movahedinia and Azarmanesh [86] presented novel printed monopole antenna for ultra-wideband applications with variable frequency band-notch characteristics. Ojaroudi et al. [87] presented printed monopole antenna with constant gain over a wide bandwidth for ultra-wideband applications with desired notch-band characteristic. Li et al. [88] presented a compact dual-band-notched UWB antenna and showed that the designed antenna is of compact size, has a wide bandwidth covering 3.05–14.2 GHz, realizing dual-notched bands of 5.14–5.36 and 5.74–6.07 GHz. Ojaroudi et al. [89] presented a novel UWB printed monopole antenna for use in a circular cylindrical microwave imaging system. Mehranpour et al. [90] proposed a novel printed monopole antenna for ultra-wideband applications with dual-band-notch function.

Fuguo Zhu et al. [91] proposed novel band-notched antennas suitable for UWB applications with coexisting wireless systems operating over 3.3–3.6, 5.15–5.35, or 5.725–5.825 GHz bands. Mandal and Das [92] presented a printed plaque monopole antenna fed by a microstrip line for UWB width with triple notch band. Natarajamani et al. [93] proposed a compact two-element diversity planar antenna for UWB application with band-notch function. Karimian et al. [94] designed two compact monopole antennas with band-notched characteristics at for ultra-wideband application. Zheng et al. [95] investigated compact optically controlled UWB antenna with reconfigurable band-notched characteristics for cognitive radio (CR) applications. Rajesh Kumar and Raghavan [96] demonstrated a compact microstrip-fed novel U-shaped fractal monopole antenna with enhanced bandwidth and band-notched characteristics for ultra-wideband applications.

Gautam et al. [97] designed UWB antenna for MIMO application. An antenna was excited with microstrip line, and resonating band was observed at 3.1–35 GHz. Within this extended bandwidth, two bands were obtained at 5.1–5.8 GHz and 6.7–7.1 GHz. The variation of antenna design was as presented single and double notches. The center notch frequency $F_n$ was calculated as

$$f_n \approx \frac{c}{4L_f\sqrt{\varepsilon_r + 1/2}}, \tag{6}$$

They also calculated mean effective and diversity gain (DG) and envelope correlation coefficient (ECC) and reflection coefficient (RC)

$$ECC = \frac{\left|S_{11}^{*}S_{12} + S_{21}S_{22}\right|}{\left(1 - |S_{11}|^2 - |S_{21}|^2\right)\left(1 - |S_{22}|^2 - |S_{12}|^2\right)}, \tag{7}$$

$$DG = 10\sqrt{1 - |ECG|^2}, \tag{8}$$

$$RC = \frac{\sqrt{(S_{11} + S_{12})^2 + (S_{21} + S_{22})^2}}{\sqrt{2}}, \tag{9}$$

Measured and simulation results were compared for the reflection and transmission coefficient of the designed antenna.

### 4.3 Different feeding techniques used

Elsadek and Nashaat [98] investigated a new configuration of multiband/ultra-wideband antenna which has a V-shaped patch with unequal arms coupled electromagnetically to single-feed isosceles triangular PIFA thorough two unequal slots. Gayathri et al. [99] proposed a microstrip-fed planar ultra-wideband monopole antenna with band-notch characteristics and consist of an inverted cone as the radiating patch and a tapered ground plane which operates over an extremely wideband of 3–16 GHz. Mandal and Das [100] proposed regular hexagonal monopole antenna fed by a microstrip line for ultra-wide bandwidth. Peng Gao et al. [101] proposed an inverted U-shaped slot on the ground plane and a radiation patch similar to the slot that is fed by a 50-Ω microstrip line. Gautam et al. [102] proposed a novel CPW-fed compact inverted L-strip UWB microstrip antenna operating bandwidth of 2.6–13.04 GHz. Azim et al. [103] designed a microstrip line-fed planar antenna with dual-notched bands and prototyped for UWB communication applications. Telsang and Kakade [104] proposed a compact ultra-wideband microstrip patch antenna fed by a CPW and a microstrip line. Emadian and Ahmadi-Shokouh [33] proposed a very small CPW-fed rectangular slot antenna with dual-bandnotched characteristics for super UWB applications. Patre and Singh [105] demonstrated the simulation and experimental studies on a novel compact and broadband CPW-fed flower-shaped microstrip patch antenna. Singhal et al. [106, 107] presented a compact third-iteration inner-tapered tree-shaped fractal antenna for ultra-wideband applications and found that the bandwidth is enhanced by using CPW ground plane and increasing the number of iterations.

### 4.4 Stacked designs

Matin et al. [108] presented an antenna consisting of a U-slotted rectangular microstrip patch stacked with another patch of a different size on a separate layer and investigated its performance. Kaur et al. [109] proposed an aperture-coupled stacked Sierpinski gasket fractal antenna with a defected ground structure for UWB and wireless local area network applications.

| | Dual-band | Broadband | Ultra-wideband |
|---|---|---|---|
| Bandwidth | Having two or more bands (narrow bands 5–6% bandwidth) [7–18] | Single-band having bandwidth is greater than 20% [3, 56–61] | Single-band bandwidth is greater than 109.4% [79–85] |
| Antenna required | Single antenna can be used as transmission and reception | Dual antennas are required for transmission and reception | Dual antennas are required for transmission and reception |
| Designs of antennas | Easier to achieve dual-band (means any one of the above techniques can be sufficient to achieve dual-band) [10, 11, 14, 17] | More than one design techniques required to achieve broadband [66, 68, 72, 73] | Two or more different techniques are required to achieve ultra-wideband [110] [113–115] |
| Applications | GSM, Wi-Fi, WiMAX, DCS, 2G, 3G, Bluetooth [15, 20–22, 26] | Depending on band achieved, GSM, Wi-Fi, WiMAX, DCS, 2G, 3G, Bluetooth [59, 66] | Satellite communication, DCS, Wi-Fi, WiMax [79–85] |

**Table 1.**
*Summary of dual-band, broadband, and ultra-wideband antennas.*

### 4.5 Parasitic designs

Ojaroudi et al. [110] proposed an inverted T-shaped strip, and by embedding a pair of T-shaped parasitic structures in the ground plane, additional resonances at the higher band are excited which provides a wide usable fractional bandwidth of more than 135%. **Table 1** summarizes the review of dual-band, broadband, and ultra-wideband antennas in this chapter.

## 5. Conclusions

It is observed from the review of the papers that all design of patch antennas can be converted to its equivalent circuits with basic concept high-frequency designing circuits. The proper design of circuit for particular antenna can give the clear pictures of resonating frequencies and reflection coefficient. Using circuit theory of basic structures of patch antennas, the designer can propose there circuit that will be helpful in the analysis of antenna. Further comparison of dual-band [22–55], broadband [3, 57–78], and ultra-wideband [79–110] is present in terms of application, size, bandwidth, and design. Further, it was observed that dual-band and multiband antenna is achieved through microstrip line and coaxial fed, slots, and notch structure. The ultra-wideband was achieved through coplanar structures and defected ground structures.

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## Conflict of interest

The authors declare no conflict of interest.

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