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A Historical Development and Futuristic Trends of Microstrip Antennas

Simerpreet Singh[1], Gaurav Sethi[1] and Jaspal Singh Khinda[2]

[1]*Department of Electronics and Electrical Engineering, Lovely Professional University, Phagwara, Punjab, India*
[2]*Department of Electrical Engineering, Bhai Gurdas Institute of Engineering and Technology, Sangrur, Punjab, India*

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Abstract: This article presents the general overview of the Microstrip Antenna referred as electronic human eye and its design and fabrication considerations.MPA consists of a metal based substrate of any geometrical shape with a copper based microstrip patch on the one side with other side having ground connection. Various Feeding Techniques are presented for feeding the patch and feedline is having ohmic contact with the patch present on the substrate. The MPAs were introduced in 1950s. However, these, at that stage, were having low fraction bandwidth with very low efficiency, and eventually they struck the communication designing market in early 1980s. With its reviewed design after extensive research that elaborates the different geometric patterns with optimized feeding methods results in high fractional bandwidths. With the decline in wideband bandwidth due to excessive application patterns in this era, extensive research is in process for the proposal of usage of Ultra Wide Band frequency patterns for the development of multiple bandwidth based reconfigurable MPAs that provide reliable and high spectrum bandwidth. This article presents the study of MPAs, comparison of different material used for substrates and feeding methods.

Keywords: mm–wave, wide–band, narrow–band, dielectric

1. Introduction

In wireless communication, since from its inception, Antenna plays an integral part. From large broadband Antenna to tiny mobile trans-receiver, Antennas play considerable role for effective communication [1], [2]. In early 19th century,the basic concept revolves around the pair of reflectors, also known as resonators, with multi-strip wired having cylindrical parabolic shape with revolving aerial so arranged that it could rotate in the direction of other resonator that was structured identically and placed at a distance. The history revolves further back when H. Hertz introduces simple Dipole Antenna [3] based on transmitter of induction coil and when this induction coil is energized, it establishes multi-directional loops of polarization [4], [5], [6]. With the spark in inventions for Antennas, Parabolic reflectors [6], Horn Shaped Antennas [6], Lenses as reflectors and Waveguide radiators [6] were also integral part of research study for microwave antennas in early days of their invention. As short wave research taking leaps towards success, the long radio waves based applications were also introduced with voice communications [7], [8]. In 1920s, Aeronautical and navy services utilize the radio wave navigation during long distance movement [1]. With this development, cage antennas [6] were introduced with the insight of dedicated shapes for different applications. The very basic applications, during 1930s to 1960s, were categorized as Broadcasting, Communications, Navigational applications and Research [9]. This phase also observed the advancement of utilization of frequency spectrum that is from Low Frequency Band to Very High Frequency(VHF) to Centimeter and to further millimeter Waves Antenna [10], [11], [12], [13]. This advancement also relates the increase in the applications and utilization of antennas in different fields [5]. Also, in this passage of time, Omni–directional Antennas [6] were also introduced to generalize as an antenna array that overcomes the losses occurring from unidirectional resonator. Therefore, the antenna which was introduced as a simple pair of resonators becomes complex trans-receiver circuit utilized for various applications [14] i.e. from remote control of simple toy car to the multiple features based aircraft [15], [16]. Since it utilizes the wave guides present the atmosphere, ITU (International Telecommunication Union) introduces the Radio Spectrum which contains frequency range from 30 Hz to 300 GHz and is divided into different bands as explained in Table I.

The ITU is governing body which allocates different frequency levels for different applications to overcome the issue of frequency overlapping or interference experienced generally in telecommunications and telemetry based applications [11]. Also, due to increase in the applications, existence of network congestion in one band motivates the researcher to work on higher frequency bands with effective results [17], [18], [19], [20]. As a consequence, whereas the antenna utilized the lower energy bands in early times of its development, modern antennas are utilizing much higher bands i.e. UWB (Ultra-Wide Band) [21], [16], [22] and

E-mail address: s.simerpreet@gmail.com, gaurav.11106@lpu.co.in, jskhinda@gmail.com

TABLE I. Band wise applications

Band Nomenclature	Range of Frequency and wavelength	Applications Type
ELF (Extreme low frequency)	3-30 Hz 100000-10000 Km	Submarines Communications and Mines communications
SLF (Super Low Frequency)	30-300 Hz 10000-1000 Km	Submarine Communications
ULF (Ultra Low Frequency)	300-3000 Hz 1000-100 Km	Time Signals & Submarine Communications, Wireless based Pulse Rate Monitors
VLF (Very Low Frequency)	3-30 KHz 100-10 Km	AM and Radio Broadcasting, Time Signals and Navigation
LF (Low Frequency)	30-300 KHz 10-1 Km	RFID, Radio Broadcasting, Navigation
MF (Medium Frequency)	300-3000 KHz 1000-100 m	Medium wave broadcasting, Storm Beacons
HF (High Frequency)	3-30 MHz 100-10 m	ALE, Radar, Marines, mobile based radio telephony, radio communication
VHF (Very High Frequency)	30-300 MHz 10-1 m	FM broadcasting, Earth-Aircraft Communication, Maritime based communication
UHF (Ultra High Frequency)	300-3000 MHz 1-0.1 m	T.V. broadcasting, ovens (microwave), cellular phones, Lan, Bluetooth, satellite radio etc
SHF (Super High Frequency)	3-30 GHz 100-10 mm	WiMAX, WLAN, radars, satellite television etc
EHF or mm waves	30-300 GHz 10-1 mm	Microwave based remote sensing, mm–wave scanners, radio astronomy, DSRC, WLAN etc

mm (Millimeter) waves [23], [24].As explained earlier, the different selection and designing parameters for antenna were invented in recent times by keeping in view of application based requirement, and therefore antenna with various shapes and sizes exists [25], [26].With the utilization of wide band [27] and Ultra wide band spectrum [28] in multiple application based devices [29], [30], [31], [32], [33], the main challenge was to introduce antennas with larger bandwidths because of lesser availability of frequency spectrum below 6 GHz and requirement of continues high speed connectivity [33], [34]. In fact, with the extensive growth in utilization of 4G spectrum and introduction of 5G [35] based mobile networks [36] which introduces multi–band applications, the design requires miniature but less complex circuits with wideband and ultra wideband [37] based spectrum operations which can be suitable for multiple mobile applications in one go [32]. Moreover, extensive research in biomedical telemetry systems and Earth Station in Motion (ESIM) which requires continues and stable monitoring and multitasking [38], [39] possess the complex challenge for wireless communication [19], [40] and for antenna design due to its utilization in UWB and mm waves [41]. There are many efforts in process to identify and design the different geometrical designs which aim to satisfy the requirements of the users [25]. The design, shape and complexity of antenna also decide the future shape and size of modern wireless system design [42], [43] As different standards are adopted by different countries for Ultra wide Band spectrum range, it can broadly come into the range from 3.1 GHz to 10.6 GHz.

There is commendable continuous development occurred in the field of WB (Wideband) [44], UWB (Ultra-Wide Band) [16], [45] and mm waves [46] in recent years for the efficient and break free multi signal with wider bands which enable antenna to deliver multi-tasking aspects of the signal.

2. Historical Overview

Recently the definition of antenna is further extended due to inclusion of semiconductor materials such as Gallium Arsenide, Gallium Nitride along with metallic devices like metallic rods and wires as trans-receiver. Various geometrical structures of antennas were developed in past according to applications. However, the basic mechanism of trans-reception remains same. Historically, an antenna was developed by Henrich Hertz [6] in 1886 named as Dipole or Whip Antenna. He produced lambda by two dipole antenna in laboratory at 4 meter gap. The various experimental setups with consideration of null ohmic losses resulted in an electrical spark between two ends created an idea for trans-reception of signals. The described antenna was developed for VLF range in initial days. The dipole antenna was further modified to loop antenna [47] by folding the wire in shape of a loop. This modified version of the antenna operated for applications upto 3 GHz. The shapes of loops may be a circle, square, triangular or any other geometry forming loops. Monopole Antenna is derived from combination of dipole antennas with half of total dipole antennas that are required for successful operation. By contrast, as compare to dipole antenna, [48] monopole antenna has a field only for the upper part and no radiation from underneath ground plane whereas in dipole antenna, radiation can be performed from both parts. After development of basic concepts of antenna, various antennas Yagi Uda, horn Biconical [1], [49], Notch [50], Turnstile [51], Microstrip antennas [2], [4], [52], [53], [54] were introduced with consideration of applications. In 1928 Shintaro Uda and Hidetsugu Yagi invented a commercialized antenna for Television named as Yagi Uda antenna. The antenna was designed as array to achieve high gain and unidirectional radiation patterns by using a driven element, a reflector and a number of directors. In 1938, Wilmer Lanier Barrow introduced a waveguide capable to radiate in open space called Horn Antenna [49]. Due to its capability of achieving high gain and its simple design, the antenna was popularized in radar systems to detect enemy aircrafts during World War II. The various designs of Horn antennas include Sectorial H, E-plane, Para-middle and conicle Horn are important shapes. In 1960, Dish Antenna [6] was commercially launched to receive line of sight signals from satellites. Its purpose was to broadcast video signals from a source to multiple receivers. From its visual shape, the antenna is also known as parabolic antenna. These types of antennas are widely used for developing a link between WAN/LAN based data communication systems and also contributing as a keyrole for tracing of aircrafts, missiles, airplanes and satellite. With passage of time, new techniques/ types/revolution in antennas were evolved, and in 1970, the concept of Microstrip Antenna was introduced by Deschamp [6]. Messon and Howers [6]. They demonstrated the first practical microstrip antenna in 1970. This demonstration brings revolution in field of communication due to its small size, low cost, integration of active devices [55], [56] on planer surface of antenna. Further, in 1980, Planer Inverted F–Antenna (PIFA) [43] was evolved by modifying microstrip structures due to revolution in mobile Hand held devices. These antennas makes communication devices more handy as small sized PIFAcan be integrated/housed properly in its structure and also trans-receive Omni-directional radiation. These antennas also offers high data rate with very low favorable Specific Absorption Ratio (SAR) results benefitted in human tissues [57].

Some other application-specific antennas are Spiral Plate Antennas which are also recognized as frequency-independent antennas leading to applicable for larger bandwidths. Total ground-based radiant structures were developed to enhance the design to overcome the electromagnetic field effect developed by the antenna during communication with the contact of the user's body. Mathematical simulations with consideration of human models result in the development of specially designed connectors, transition lines as well as suitable feeding [58] lines, and the complete setup of trans–receiver is termed a Wearable Antenna. The combination of macrocells–based structures termed macro units, which are having continuous and non–continuous sub-wavelength properties, were introduced and termed Meta–material Antennas. These are the realization of distinct materials which have no existence in nature. Some of the structures are introduced, such as SRR (Split Ring Resonators) and Complementary SRR, AMC (Artificial Magnetic Conductors), to improve the quality of service, which includes exceptional radiation properties [59] having high gain, capable of handling the pulse and efficiency provided by antennas. 3D profile-based DRAs (Dielectric Resonance Antenna) were introduced in 1990s and were preferred for most of the applications like Radio and Satellite links development, where very high performance is required. The considerable fact of DRAs is that these are not having any effect on surface waves losses and metal losses due to the use of dielectric materials having very little permittivity and having broad-band signal acceptance because of its special structures which results in considerable performance in both linear as well as circular polarization [60].

With the development of Planer [45] and Printed (2D & 3D) [61], [62] mopole antenna with the aim of supporting the integration requirements of hand held wireless systems as well as fixed base stations and since size remains always a key constraint the printed antennas are maximum utilized for the development of wireless systems. With the antenna technology applied in almost every communication and telemetry-based applications like cars, radios, mobiles, airplanes, ESIMs, etc. [36], [63], [64] printed monopole antennas [65] are preferred having tri–dimensional shapes due to its more reliable circuit development with the spectrum and also their lesser weight portable nature. As this type of antenna technology found more suitable for reduced size antenna fitted equipment, intensive research occurred at various stages to develop multi–band [66] and wide–band monopole printed 2D antennas [62] having notched bands to minimize the interference within the circuit and other systems with similar spectrum structure and supports the effect of polarization which is circular in nature. Most commonly utilized is Microstrip antenna [1], [67]. Because of its smaller size, low profile and having low cost,it has been preferred. In this study, we discuss the effect of different feeding and design techniques for micro strip antennas.

3. Microstrip Patch Antennas (MPAs)

The initial concept of microstrip antenna was purposed by Deschamp [6] in 1953 and in 1970, Munson [6] and Howell [6] demonstrated it in practical form. Afterward, with the passage of time, the researcher community showed a deep interest in it due to its extraordinary advantages of low cost fabrication on printed circuit board, light weight, planer structure that can house active components etc. Due to these advantages, these antennas are more suitable for hand held devices. The structure of microstrip antenna comprises of metallic (i.e. Copper, Gold etc.) radiating patch fed through ground by feeding line, and all these components are placed on insulating materials like Flame Retundent (FR4), Duriode,, Taconic, Polyethylene Terephthalate etc. Since inception of antenna in early age of 1970s by Messon [6] and Howers [6],a very low fractional bandwidth of 7% to 10% was observed, it was unnoticed and assumed as very less compatible for integration in electronics platforms [68], [69], [70]. During decade of 1980s, in order to enhance the bandwidth, the metallic patch was introduced as appropriate modification. The patch may made up of Gold or Copper [6] with non-rusting tin coating on it [1], [2]. The various basic shapes of patch were reported like rectangular [71], [72], circular [73] and even square [73] configurations by placing on insulating materials. This material also separates the patch and ground plane of antenna. The patch is excited through feed line that produces electromagnetic energy [7] to space as illustrated in Figure 1. The dimensions of antenna were mathematically computed [6] and it resonates at predefined frequency [74]. In next 15-20 years, the basic shapes of patches were further modified to different constructive structures and this process continues with the effective enhancement in performance of MPA.

Since earlier staged antennas were not satisfied the ideal transmission requirement for most of the systems due to its narrow spectrum and because of its reluctance over multi–range frequencies, continues attentive research in recent times gives rise to improvement in bandwidth characteristics which aim towards loss free widening of bandwidth spectrum of the antenna [21].

4. Multi–band Antenna Structures

In past decades many antennas [75] were developed for multi–band applications. The frequency range for multi–band applications varies from a short wave to an ultra wideband [32], [47], [76] and further it is extended to millimeter wave [17], [60] in present days. There are also many methods introduced in which tuning of frequencies can be done over a specific range, which is helpful to use the same antenna for different frequency ranges. Many multi–band antennas like dual band [29], triple band [6], [77], quad band, penta–band and many more [6] antennas were introduced under the development of multi–band antenna category [30], [78] and the adjacent bands in multi–band structure is separated by a band rejected frequencies in order to avoid overlapping of desired band of frequencies [31], [62]. The uniqueness of these multi–band antennas is to use the single antenna that can be utilized effectively for trans–reciever purpose.This was a unique feature at earlier development stages and this leads to further research in the field of multi band tunable antennas preferred in different situations.Generally in these situations trans–receiver is required to work in different frequencies having minimum cut-off range or having very low frequencies in between two distinct frequencies, and the two different resonances can also be tuned efficiently.The various multi–band frequencies for specific applications were achieved by developing multi–layer or stack shaped geometry having number of resonators at different layers at the metal patch [79]. The one of adjustment is by providing air gap [6] between two substrates as shown in Figure 2. The upper and lower resonant frequencies of multi–band can easily be adjusted (accommodated) by varying the gap between these substrates [6].

5. Re-Configurable Antenna Structures

As the antenna based resonator circuits starts dominating embedded chipsets, the rapid growth was observed on specific applications. Further, the antennas were miniature with the introduction of VLSI based platforms [10]. More and more stress is emphasized on the suitable replacement for one tunable antenna for many with various frequencies that can be regulated and henceforth it reduces the overall size of chipset [42], [80], [81]. Moreover, additional filter circuits are also required for multiple band antennas on a communication system to avoid interference between them [82]. By introducing a switch on the antenna structure, the parameters can be shifted like polarization, frequency, impedance bandwidth and radiation patterns effectively [83]. Therefore, re–configurable antennas are considered to be subclass of multi–band antennas [6]. These antennas were reconfigured by four main methods such as Electrically [84], [85] Optically, Mechanically [86] and by using properties of met materials [86]. The electronics devices like PIN diodes [81] and FETs [81] were used in order to achieve the electrical switching for various parameters (for frequency bands) of antennas. Similarly, the switching between linear polarization to left hand polarization [3] or right hand polarization [3] and perhaps between left handed and right handed polarization [3], [87] can also be achieved electrically. In case of Optical switching [6], [88] the LASER lights were used to control the switching characteristics of radiation pattern. The radiation patterns were also reconfigured by changing the physical structural properties of antenna that is known as mechanical reconfiguration.

The radiating pattern can also be reconfigured by the changing of its physical structure and this reconstruction is known as Mechanical method [6], but it has the limitation of size. Antennas can be returned by changing the material and its characteristics of the substrate [89]. Different materials like liquid crystals, ferrites, dielectric fluids or meta–surfaces are used to attain such change. These materials reflect differ in their properties with change in some parameters like by change in the voltage level, and the dielectric constant is changed of a liquid crystal.

In case of Frequency Re–configurable antenna's [42] switching between operating frequency bands, by

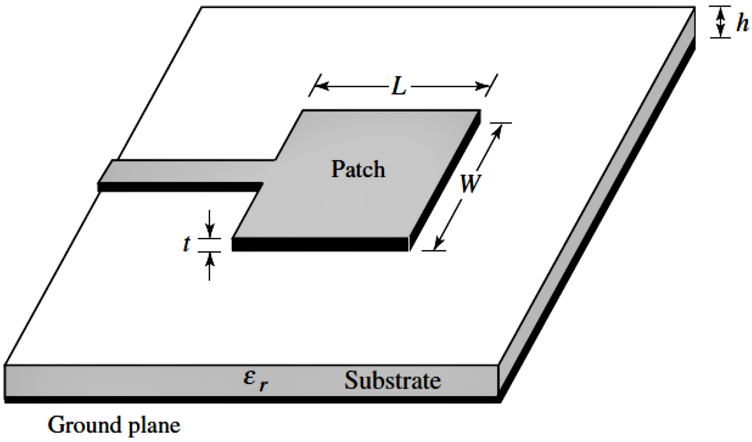

Figure 1. Microstrip Patch Antenna

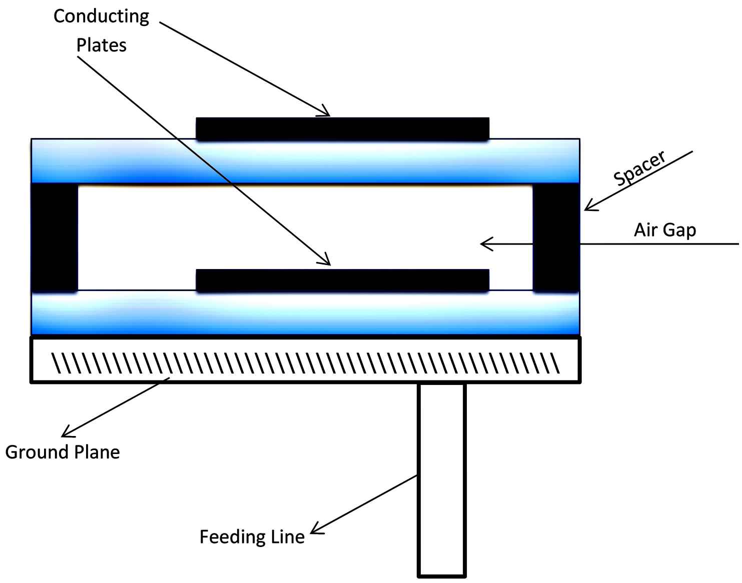

Figure 2. Dual- Frequency MPA

adjusting the operating properties dynamically discussed above, the re–configurable antenna can be classified as Frequency type [42] which can be developed either electrically in which discrete tuning and continues tuning methods are used and can be achieved by varactor diodes or mechanically in which certain impedance tunable material is used [33]. Liquid crystals and meta surface materials are preferred as materials [89]. The antennas which are having rotary structure with the considerable change in the volume distribution of the radiation pattern is termed Pattern Re–configurable Antennas [81], [86]. In Polarization type of re–configurable antenna, switching procedure is applied between different polarization that may include from LP (Linear Polarization) [81] to LHCP (Left Hand Circular Polarization) [81] and RHCP (Right Hand Circular Polarization) [81]. Any mismatch if occurs in the polarization process,the vertical, circular, and horizontal polarization based switching is preferred [81]. The antenna which is utilizing the substantial properties simultaneously of all the above types to tune itself is known as Compound Antenna [81].These types of antennas can be very handy in the applications like MIMO (Multiple Input Multiple Output) [91], Cognitive radios, Satellite Communications and in the field of Biomedical telemetry based devices. Broadband [92] spectrum based antenna is the new approach and also attraction of research. This antenna is a combination of single band and dual band antenna [20] in which the levels of frequency with ON-OFF selection switching can be reselected and reset depending upon the requirement and application. The switching components include a semiconductor based switching for desired characteristics achievement. Since the spectrum is very wide in this case, UWB [18], [90], [93], WB [90] and NB [90] characteristics can easily achieved, and even multi–band operations can also be done with the minor change in physical characteristics. These types of antennas have many applications in advanced communication multi-application based systems. As

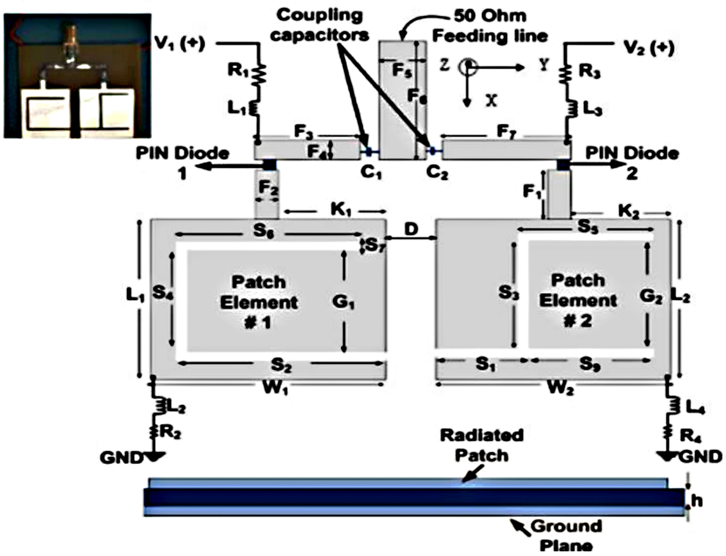

Figure 3. Configuration of Re–configurable Antenna [90].

shown in Figure 3, the re-configurable MPA consists of C–type cut based two parallel patches. Excitation of various modes can be done by upsetting the surface current paths [90]. This type of antennas has three modes of operation i.e. one wideband and other two are dual band modes. A semiconductor based PIN diode is attached on feeding line of every patch. The switching can be observed in ON-ON, ON-OFF and OFF-ON states. The ON-ON is active state defining that electromagnetic signal is appeared at input patch one and others are left open. On the other hand in ON-OFF condition, dual band reaction is analyzed.OFF- ON describes that patch 2 is radiating while others are left open. So it is clear that ON-ON condition can be selected during wideband applications. It is also noted that coupling [94] between two patches must be configured wisely as it has a major role to smoothing the function of these type of antennas. These antennas provide various application based utilization without changing any physical dimensions i.e. all three modes can be utilized by simply switching feeding line through PIN diode. It is also clear from above study that dual band modes offer narrow spectrum as compare to single wide–band mode.

6. Bandwidth Enhancement

At earlier stages, MPAs are limited in use due to their performance metrics which include narrow bandwidth operation.Therefore, a very large proportion of research in MPAs revolves around broadening the bandwidth and increasing gains with the help of geometrical restructuring as well as some logical changes [95]. Although Substrate with higher thickness level was introduced in earlier research, it experiences a large amount of losses, and therefore radiation efficiency was decreased which was again not desirable [78], [96]. There are some techniques which when are applied give out good results in terms of efficiency and broad bandwidth. The impedance matching technique is a very useful technique in which impedance is matched in terms of antenna frequency [49], [96]. The operational frequency range is determined by the impedance variation from 50 ohms which is a standard impedance value for the antenna. Calculated geometry changes, other physical variations and even feeding techniques [76], [97] are also helpful in the impedance matching process, and therefore a large number of shapes were introduced. The combination of stubs connected in shunt with the feeding line also helps to raise the bandwidth [38]. There are also some active elements like negative capacitor or inductor matching networks which were found very much effective [62]. Simple rectangular MPA when connected with negative inductor enhances the bandwidth by almost 20% to 25% and negative capacitor network provides enhancement around 15% to 20% [98]. Defected Ground Structure(DGS) [73], [90] is also a highlighted technique which is having a slot concept, and therefore support enhancement of bandwidth. As compare to earlier technique which was based on logical changes, this technique is based on patch modification with the help of geometrical changes [38] and physical variations. These geometries can be having regular or irregular shapes depending upon its compatibility with integrated chip-sets [38].

7. Patch Size Reduction Methods

In most of the applications, it is desirable to have a smaller patch size. This can be achieved by selecting the material of substrate with large dielectric constant but this results are in narrow bandwidth, and therefore other methods for size reductions were researched and introduced [99], [100]. Shorting wall was introduced and placed across the center point of patch and the resonant length can be halved and the area becomes one-fourth with same aspect ratio. It is also concluded that one fourth wave shorted patch results in wider bandwidths than the half wave and full wave due to lesser energy stored in small volume. However, this conclusion was only limited for air type or foam type

TABLE II. Properties of Different materials used for Substrates

#	Bakelite	FR4	RO4003	Taconic	RT Duriod
Dielectric Constant	4.8	4.4	3.4	3.2	2.2
Water Absorption	0.4%-1.4%	¡0.25%	0.06%	¡0.02%	0.02%
Tensile Strength	60 MPa	¡310 MPa	141 MPa	—-	450 MPa
Loss Tangent	0.03	0.013	0.002	0.002	0.0004
Breakdown Voltage	20-28 kv	55 kv	—-	—-	¿60 kv
Density	1810 kgm3	1850 kgm3	1790 kgm3	—-	2200 kgm3

substrates [9]. Due to surface wave effect of different materials, it was not applicable on material based substrate. Partially Shorted scheme was also implemented which results in dipping the resonant frequency. As in this case the side view appears like an inverted form of F; this phenomenon is also known as PIFA (Planar Inverted F–Antenna) [43]. Another method for patch size reduction is to apply a shorting pin at feeder. This system affects the fields under the effect of patch to revolve around back-and-forth. It tends the field to radiate when the revolving distance approaches half of wavelength and with similar multiple attempts, the size of microstrip patch is reduced. It is also noted that the cross polarization effect is also very high in this type of antenna. Since the cross polarization is very high in both above discussed cases, the folded patch method is applied to reduce the size. The folded patch provides larger current paths which results in larger resonant lengths than the length of the simple patch. Due to its lower cross polarization, this type of method is preferred.

8. Materials used for Dielectric Substrate

Initial design consideration revolves around the selection of Dielectric Substrate material. Bakelite, FR4, RO4003, Taconic, and RT Duriod are some common materials with all are having constant height i.e. 1.6 mm [89]. Some basic parameters are shown below in Table II.

9. Effect of various Geometries in Performance of MPAs

As discussed above, the basic rectangular shaped antenna results in some major setbacks likenarrow bandwidth, small gain, poor impedance matching and bulky size [90]. The easier way to increase the bandwidth of antenna is to increase the thickness of substrate but it leads to increase in surface waves and radon power then decreased which reduces efficiency [73], [98], [101]. There are other different methods applied like by using arrays [102] and multi layered structures ,which reduces the size but the fabrication process will then becomes challenge. So, to overcome these challenges, different adjustments were made.One of the major developments for enhanced antenna was with different possible geometrical structures derived from general structures. Asymmetric antenna was also introduced during this phase of research. To improve the impedance matching, microstrip based feeding line generally tapered or based on CPW (Co–planar Waveguide) [32], [90] having single and several transitions on the notches close to transition area placed in between the ground of plane and radiating monopole. It also possess lesser loss.DGS (Defects in Ground Plane) [73], [90] structures are also preferred for multichannel and multi–band applications by just edging out the shape from a simple ground plane. These designed shapes can be complex or simple. Fractal geometries [52], [66] and patch cutting are other options to design multi–band and wide–band antennas [47]. It is also worth mentioning here that different DGS structures on ground plane results in different ranges of bandwidth and resonant frequencies in a predefined ground space.

There is a long list of articles and books purposing different shapes and modification in basic geometrical shapes that lead to better results like larger bandwidth with high fractional bandwidth is discussed [90]. The basic and common geometry architectures which are used in initial designs are as shown below in Figure 4.

There are considerable changes occur when the design is switched over from basic rectangular shape to some other modified [103] shapes. For example, when the patch is designed in hexadecimal shape, radiation efficiency is achieved by 85% as compared to basic shape which is having lesser efficiency and also the return loss will become notably low. It is also observed that when semi elliptical antenna [62] is proposed as shown in Figure 5, a broad impedance matching is noted i.e.from 2.5 to 15 GHz. It was also noted that by changing the angles [104] or by changing in position [104] of slots vary the band rejection performance. There are some innovative designs, as shown in Figure 6, that were also introduced like T-Stub and U–slot [105]. MPAs are having reduced patch size with lesser return loss that indicates larger bandwidth and also higher impedance bandwidth. There is 164% bandwidth enhancement observed by an M-Shaped [61]

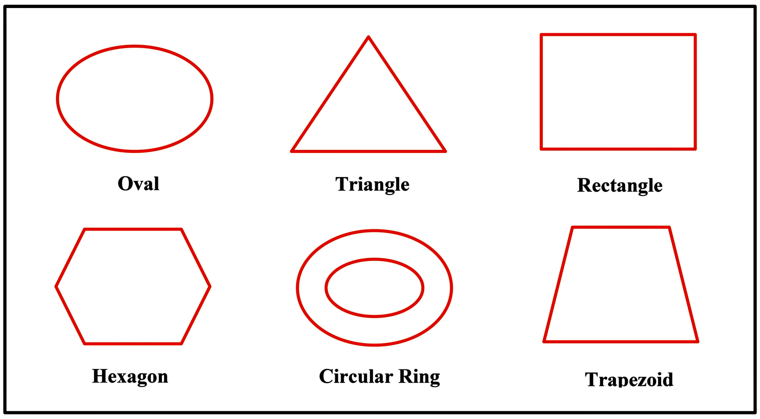

Figure 4. Basic Geometry Shapes

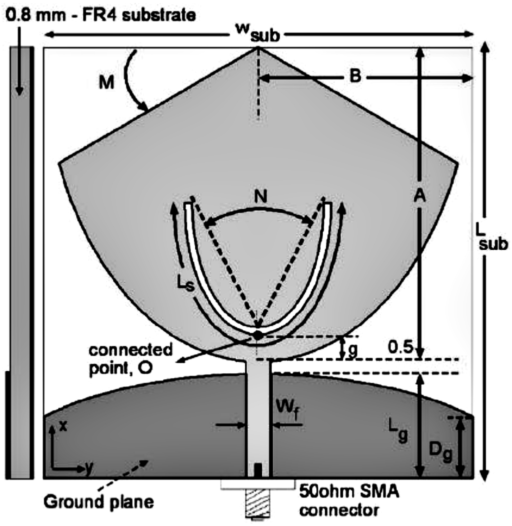

Figure 5. Semi elliptical Shape [62]

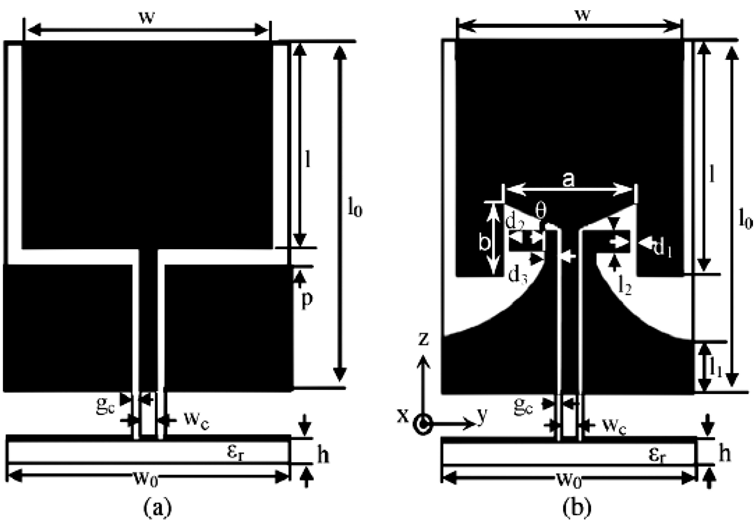

Figure 6. M–shaped notch Printed Antenna [61].

notch also tapered exponentially at the bottom. The tapering found very much effective to achieve multi resonant characteristics on 5 to 16 GHz [61] and therefore this tapered ground [61] also affects the

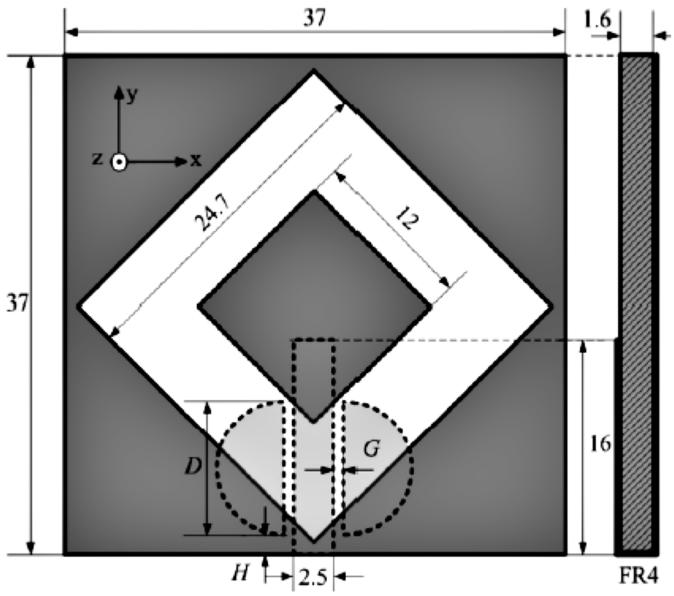

Figure 7. Parasitic Paired Printed Slot Antenna [65]

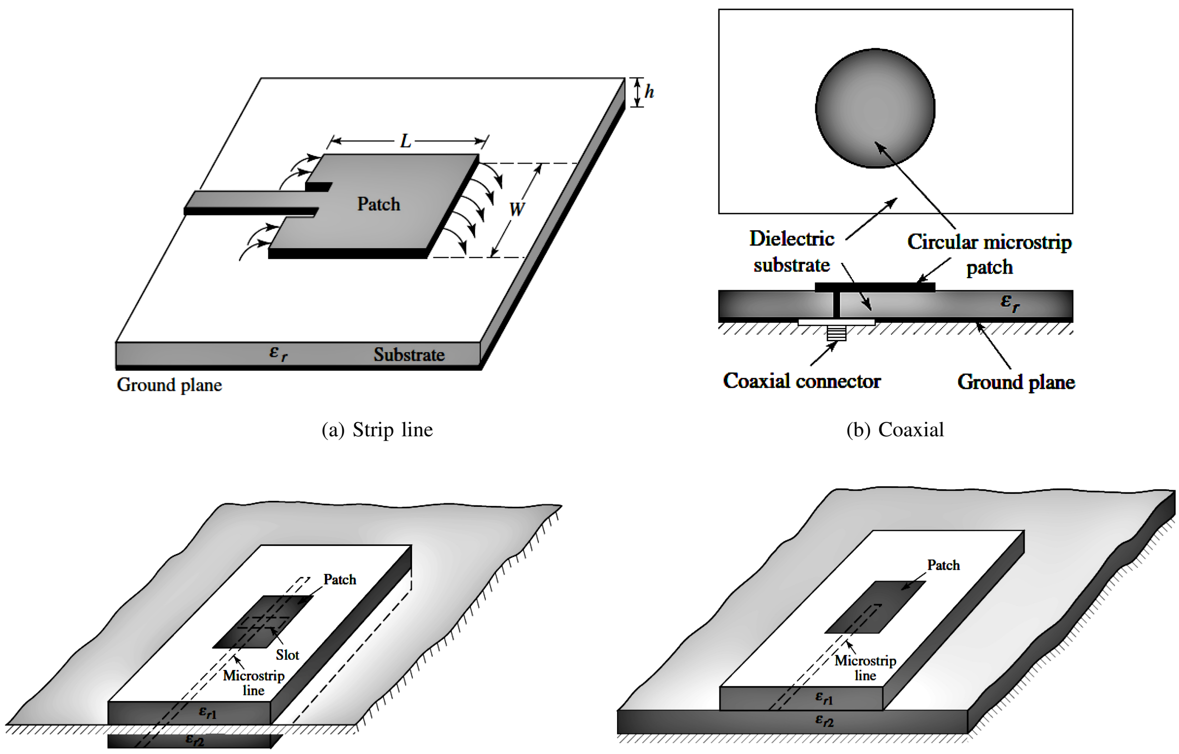

Figure 8. MPA Feeding Methods [6] a)strip line b) Coaxial c) Aperture d) Proximity

performance of distributive matching network. It is also observed that there is a phenomenal improvement in characteristics of impedance when T shaped ground was designed [61]. It is also noted that during these geometrical changes, due to increase in frequency range, the cross polarization also arises because of horizontal variables, and therefore can be ignored for mobile networks [61]. Consequently, there are many parameters which improve the high cut off frequency accordingly in shaping process,such as tapering the ground, shaping the notch and impedance characteristics.It is also observed that return loss is decreased. Bandwidth is enhanced to 136% in the range of 2.1 to 11.1 GHz band by designing a pair of parasitic patches as shown in Figure 7 which observes the excitation of resonance which is helpful in improved impedance matching [65].

TABLE III. Comparison of Feeding Techniques ([97])

Parameter	Feeding Methods			
	Coaxial	Proximity Coupling	Apperture Coupling	Stripline
Fabrication	Easy	Difficult	Difficult	Easy
impedance Matching	Simple	Difficult	Difficult	Simple
Spurious Radiation	Low	Low	Low	High
Modelling	Difficult	Simple	Simple	Simple
Bandwidth	Narrow	High 13%	Narrow	Narrow ¡ 5%

10. MPA Feedings

Once the design is finalized, the next step is to access the feeding method and feeding slot design by assuming all the electromagnetic wave signals which can be transmitted [103], [106]. There are many different feeding techniques such as proximity coupling,Strip line feeding, aperture coupling and coaxial feed lines [6]. Connectors are used with feed lines through which the signal is transferred. In Figure 8 different feeding methods are designed and the constructive difference is clear enough between these four.

The proximity feeding provides almost 13% bandwidth [90] and is considered as largest bandwidth method. In this method, patch width and the length of line act as an important parameter for matching. Stripline method is consisting of conductive strip which is directly connected to the radiating patch having very smaller width as compare to the patch width. In this type of feeding, substrate thickness is increased which results in feed radiation effect and surface waves existence which affects the bandwidth selection limited to less than 5% [90]. The coaxial method includes a co–axial connector which is soldered with patch at impedance location of 50 ohms. This method is difficult to design and having very low spurious radiation. The bandwidth is also very low as compare to proximity coupling. In aperture coupling method, there are two substrates. While upper substrate is used for radiating patch, microstrip feed line is modeled on lower substrate [97], [107]. Also the value of dielectric constant is very high for low substrate and very low for upper substrate. There is a ground plane in between the two substrates which helps to reduce the interference due to spurious based radiations [108]. An effective pattern is hence obtained with purity of polarization. All the other parameters are at optimized state for efficient performance in this case. Because of built in asymmetries and cross polarization effects occurs in strip line and coaxial methods, aperture coupling and proximity coupling are preferred [106]. The comparison for different feeding methods is explained below in Table III.

11. Analytic Parameters

There are numerous factors which can be considered as an analytic parameters which affects the performance of the antenna ([6]). Some of these are discussed as below. a) Antenna Gain:- It can be defined as the ratio of maximum intensity of radiation at the top of core beam to the intensity of radiation in the similar direction generated by an isotropic antenna with same input power. The Gain of Antenna can be expressed as,

1) **Antenna Gain** :- It can be defined as the ratio of maximum intensity of radiation at the top of core beam to the intensity of radiation in the similar direction generated by an isotropic antenna with same input power. The Gain of Antenna can be expressed as,

$$G = 4\pi U(\theta, \phi)/P_{in}, \quad (1)$$

where P_{in} is defined as input power and $U(\theta, \phi)$ is the signal intensity in a particular given direction.

2) **Radiation Pattern**:- It is also called as antenna pattern. It is defined as a graphical response and representation of defined angle of arrival of the wireless signal.

3) **Directivity**:- The Directivity for an antenna is given by

$$D = 4\pi U/P_{rad} \quad (2)$$

Where $4\pi U$ is radiation intensity and P_{rad} is average radiation intensity.

4) **Antenna Efficiency**:- It is represented by 'η' and defined as the ratio of output radiated power of antenna to the input power through source.

$$\eta = P_r/P_{in} \quad (3)$$

5) **VSWR**:-It is defined as Voltage Standing Wave Ratio and expressed as the ratio of maximum Voltage to minimum voltage.

$$VSWR = V_{max}/V_{min} \quad (4)$$

6) **Return Loss**:- It is defined as reflection of power signal from the addition of a device in a communication line.
R_L for a given device can be calculated as R_L = -20 $log_{10}(\Gamma)$ dB.

12. Parameters for Antenna Design

Since it is discussed earlier that the design and fabrication of single layered MPA is very easy, there are many also parameters which we have to take care off. In general, FR4 material is used for substrate due to its supportive properties ([6]). The height and width of the patch have to be formulated. Dielectric Constant, Substrate Height and resonant frequency pattern is also need to be calculated and assumed for efficient design of antenna. The different equations which are required for calculation of various parameters are written below ([6]),

$$W = \frac{c}{2f_c}\sqrt{\frac{2}{\epsilon_r + 1}} \tag{5}$$

Where 'W' is width and 'c' is speed of light. The dielectric constant for various materials used for substrate is given above in Table II.

For the calculation of Length of Microstrip Patch, ϵ_{eff} and L_{eff} i.e. is effective dielectric constant and effective Length respectively which is as below,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-0.5} \tag{6}$$

$$L_{eff} = \frac{c}{2fc\sqrt{\epsilon_{eff}}} \tag{7}$$

$$\Delta L = 0.412h\frac{(\epsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{8}$$

$$L = L_{eff} - 2\Delta L \tag{9}$$

The post authentication of the design parameters and designing process is completed with the help of simulation software available in the market such as Ansoft HFSS [71], ZELAND IE3d [109] etc. which generate ".DXF" or ".BMP" extension files. For final testing procedure, fabrication can be done after successful simulation of the defined parameters.

13. Optimization Techniques for Antenna Designing

A number of parameters are associated with the designing of antenna. For proper tuning of proper design, various optimization techniques are used in High Frequency Structure Simulator (HFSS) software. The list of these techniques are given below:-

1) Random search based Genetic Algorithm
2) Search-based Pattern Search technique
3) Gradient based Quasi Newton and Sequential Nonlinear Programming
4) Gradient and Discrete based Sequential Mixed Integer Nonlinear Programming
5) and MATLAB

The algorithmic flow chart for designing of antenna is illustrated in Figure 9. The flow chart includes various processes used for designing of an antenna.

14. Fabrication

The different methods applied for fabrication [110] of the MPA are discussed below,

1) **Chemical Etching : -** In this type of process, the substrate is treated with material of photo resistance property with the help of air brushing process so that very thin layer of material layer would be formed. Spinner method is also used to raise the uniformity level which is not achieved by air brush. The coating level must not exceed 1.5 microns to 2 microns [111]. After the process of spinning the coated board is heated at a temperature of 100 0C for a small fraction of time (1-2 mins) so that the board will be dried out. In next step with the exposure of UV rays for almost 2-3 mins, once the printed mask (.dxf file)of the geometry of antenna is drafted to the board to remove the photo resist. After that rinsing the substrate board with water and drying it, it is positioned in the FeCl3 (Ferric Chloride) solution for etching. Acetone rinsing is last step to remove any photo resist material or other impurities if left [110], [111].
2) **Photo Lithography: -** This process is based on design developed by computer aided software. The design of the antenna geometry is developed and reverse masking also called negative masking is generated and published on the see-through sheet. Now the substrate having etched patch and copper metallization is carefully chosen [112]. In this process also after initial cleaning with acetone, thin layer of image resist solution with thinner is applied and coated on the Copper (Cu) planes. Spinning technique is again preferred here due its thinner deposition ability. After drying it fully, the mask is applied on the photo resist material and exposed to UV rays which hardened the photo resist material. The substrate is then with dye solution which results in view of photo resist parts on the coating. After again it is washed with FeCl3 and acetone to removal of unwanted deposits [110].
3) **Computer Based Co–ordinatograph:-** This is basically CAD based software tool used for creating the mask of the antenna geometry design system. Gerber file is generated to view the saved antenna geometry and photo plotter is used for mask designing. This mask is copy of the desired geometry design and this mask is again used to be etched on the substrate. Generalized view of fabricated substrate.
4) **Antenna Testing: -** Testing is done to verify the results [112] and simulated design of Antenna geometry. Network Analyzer (NA) is used to test the potential of research. Network analyzer [112] is an instrument designed and used to measure the reflection and transmission levels (S parameters) generally at very high frequency levels because these levels are easy to calculate. It operates on both domains i.e. time and frequency. It is utilized by microwave research labs for observing the response of antenna based

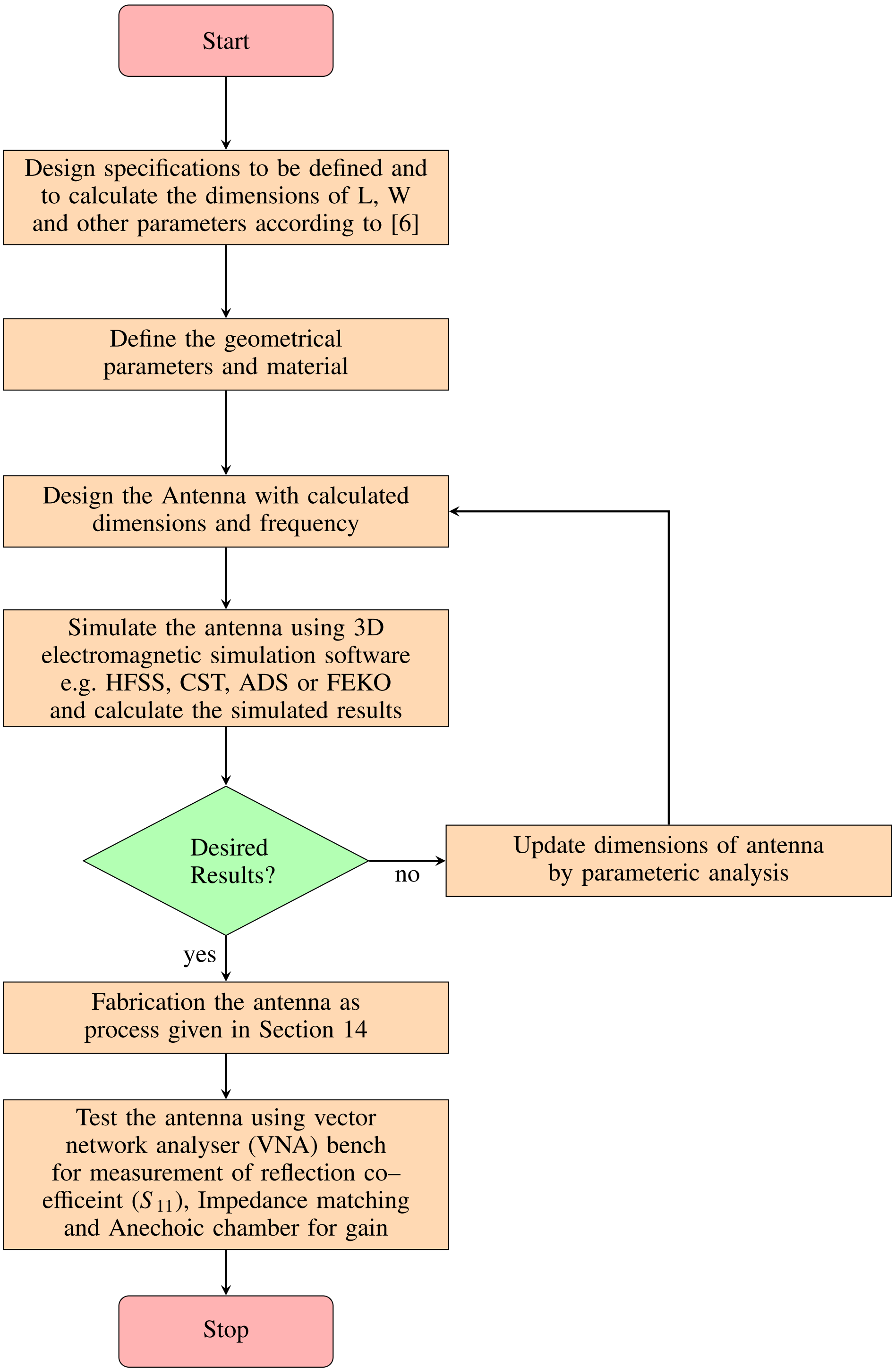

Figure 9. Algorithmic process used for Microstrip Patch Antenna designing

devices [111], filters and mixers for all higher radio frequency levels. By observing the response of the antenna on NA, it is fixed or characterized for its application based system and also the performance of fabricated antenna is revealed. There are three types of NAs are generally used based on different measuring properties. SNA (Scaler Network Analyzer) is a NA used for observing the scaler properties of the antenna and other microwave radiating device, since there is no vector element is there and therefore it is very simplest form of Network analyzer. In this type of Analyzer, it functions as spectrum analyzer with tracking generator. The functioning of tracking generator is to develop a swept signal which is having the similar frequency level of spectrum analyzer and hence output terminal of tracking generator is act as input terminal for spectrum analyzer. The amplitude response according to the frequency change is displayed

TABLE IV. MPAs Advantages and Disadvantages

Sr. no.	Advantages	Disadvantages
1	MPAs are having a low weight as compare to other antenna structures.	MPAs are having a very low efficiency.
2	The Substrates are having a very thin profile.	It is having a very large ohmic loss for the Array feed structure.
3	No cavity backing is required in MPA.	Power Handling capacity is very much low.
4	Both type of polarization is possible i.e. linear and circular.	It has surface wave excitation issue due to its basic structure.
5	Dual and multiband frequency operations are possible.	Polarization purity is very much difficult to achieve.

by spectrum analyzer. VNA (Vector Network Analyzer) is a more useful and powerful network analyzer as its name suggest as compare to SNA as it is having potential of measuring scaler as well as vector elements also like amplitude and phase and hence provides the level of gain also and therefore it is also known as gain-phase meter. It provides the optimum information regarding the design of antenna and other device to get the ideal performance. LSNA (Large Scale Network Analyzer) is designed for very high level signal conditions based devices. It provides detailed view which includes harmonics and nonlinear behavior of device also. This analyzer is generally used for microwave frequencies based devices and it is also known as Microwave Transition Analyzer.

5) **Advantages and Disadvantages of MPAs:-** Above review study broadly explains about MPAs and its applications based on its structure and shapes. There are many advantages to consider about and disadvantages also which motivate to research. Some of these are as follow in Table IV.

15. Conclusion

The basic concept and operational principles of different types of antennas are discussed and understood. The main motivation behind the advance and continues research in the field of antenna is the bandwidth enhancement with improved gain for larger communication based networks and dual band applications with the effective isolation between the two bandwidth levels. Although the initial stage research of microstrip antenna was concentrated only on the defence and aerospace applications, the area of applications became broader with more and more application based research happened and with invention of wireless application based systems MPAs have become backbone of any communication system. In this review article, the design consideration and fabrication process of MPA is discussed. There are different materials used and based on the intense study of different articles, and it is concluded that FR4 is preferred over other materials for substrate. Copper and gold are preferred as the patch and feedline material. The feedline material is a conductive strip attached with Microstrip patch to radiate the signals on the one side and other side is ohmic grounded. It is also concluded that as compare to simple basic patch structure which is rectangular in shape, different geometrical structures were introduced, and by restructuring the rectangular patch into novel shapes, we get enhanced bandwidth which can be from fraction to 180% of the basic rectangular. In this paper, hexadecimal shaped antenna is discussed with which 95% radiation efficiency is achieved with very less return loss. Some other novel shapes, such as, elliptical with increased impedance matching and T-Stub and U Slot MPAs with reduced patch size and bandwidth enhancement, are discussed. The different feeding techniques with the comparison of different considerable parameters are discussed in this paper. It is concluded in this paper that by selecting the different material parameters, we can enhance the fractional bandwidth and also the elliptical and other novel shaped MPAs exhibit better performance as compare to the simple rectangular patch. The different methods of fabrication and testing are also discussed. Concept and application of Network Analyzers also discussed in details. More and more work is in progress in the field of multi–frequency antennas which can play vital role in the field of biomedical and industrial telemetry systems and on different possible geometries to enhance the bandwidth and gain of antenna.

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Simerpreet Singh Simerpreet Singh received his B.E. degree in Instrumentation Engineering and Masters in Technology in Electrical Engineering. He is pursuing his PhD in Electrical Engineering from Lovely Professional University, Punjab, India. His area of interest is wireless communication, Energy Harvesting and process control systems. Currently He is working as Assistant Professor in Department of Electrical Engineering Department in Bhai Gurdas Institute of Engineering and Technology affiliated to IKG Punjab Technical University, Jalandhar, and Punjab, India.

Gaurav Sethi Gaurav Sethi received his Ph.D. degree in Electronics & Communication Engineering from Dr B. R. Ambedkar National Institute of Technology Jalandhar in the area of Biomedical Image Processing. Presently, he is working as Professor in School of Electronics and electrical Engineering at Lovely Professional University, Phagwara, Punjab India. He has 13 years of rich experience of teaching & research and technical education management. His areas of interest are Digital Signal Processing, medical imaging, artificial Intelligence, Image Processing, healthcare services. He is the member of Indian Science Congress, Calcutta and Deputy Dean in Division of admissions.

Jaspal Singh Khinda Jaspal Singh Khinda earned his Ph.D. (2018) in Electronics and Communication Engineering at Amity School of Engineering and Technology, Amity University, NOIDA, Uttar Pradesh, India. He obtained a research Master's degree (2009) in Electronics and Communication Engineering in from the Punjab Technical University, Jalandhar, Punjab, India. He have 18 years rich experience in teaching, research and administration. Presently, he is working with Bhai Gurdas Institute of Engineering and Technology, Sangrur, Punjab, India as Professor in Electrical Department. His research interests include Ultra Wide–band, mm-wave and reconfigurable Microstrip Antennas. He also have filed 6–patents on wide band, mm-wave microstrip antenna. Dr. Khinda's primary research focus is steering major lobes of antenna using Python programming models for high-performance mm-wave applications.