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Microstrip Antenna: Basics and Applications

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ABSTRACT

Microstrip antennas are now a well-established type of antenna that designers firmly recommend around the world for various applications, especially when low-profile radiators are required. It is assumed that the microstrip antenna or printed antenna has matured to the point where many tried-and-true approaches may be depended upon and few surprises remain concerning its performance. This article includes some of the important basics of microstrip antennas that each researcher should remember while working with these antennas. Resonant frequency formula for various patch shapes are also included. An attempt is also made to take account of various applications of microstrip antenna such as different type of communication systems that includes mobile communication, wireless communication, satellite communication etc. Applications of microstrip antenna in medical science (Biomedical application), energy harvesting (Rectenna application), textile industry (wearable antenna) are also included.

Keywords: Microstrip antenna, Gain, Resonant frequency, Patch antenna, Array Antenna, Impedance Bandwidth, Gain, Mobile Communication, Wireless applications, Satellite Applications, Biomedical Applications

INTRODUCTION

In recent times, a lot of rapid technological developments have been observed in the cellular, wireless and satellite communication network systems as almost all the people of entire world are connected with these systems directly or indirectly. So all networks operators are persistently strained to optimize their networks to put the maximum amount of facility together with quality coverage and reduced power consumption. Extensive research was started to find innovative solutions particularly for problems related with wireless long distance communication. Antenna engineering technology provides vast solutions for such specific type of problems in wireless communication techniques. It plays a very important role in transmission and reception of signal [1].

In general antenna can broadly be classified in different categories. Array antennas can be put in category I, where a number of radiators positioned spatially to provide anticipated radiation features. The printed antenna can be placed in category II and these can be fabricated using standard photolithography technique. Category III includes wire antenna that can widely be used on top of buildings, automobiles, ships and spacecraft. Aperture antennas comprises of an aperture or a slot in a metal plate and can be put in category IV. Such type of antennas is appropriate at higher frequencies (3-30 GHz). Further for long distances communication and outer space exploration, the reflector antennas are used and can be placed in category V. The lens antennas can be put in last category VI; these antennas are used to collimate the incident divergent energy to prevent it from spreading in undesired directions [2].

Each type of antenna has its own cons and pros. However, due to adjustable features and interoperability, microstrip antenna has long been at the heart of a significant number of communication systems. The basic goal of this article is to evaluate microstrip antenna and technology that includes structural adaptability, feature performance capabilities and design variety. An antenna constructed using microstrip techniques is known as a microstrip antenna (MA) The other popular name of MA are printed antenna or the patch antenna. MA has been a leader among the most inventive themes in antenna structure and theory in recent years, and they continue to find applications in a wide range of modern wireless systems. These antennas are without a doubt the most advanced and efficient antenna technology available [3]. In recent years these antennas have emerged as one of the most cutting-edge subjects in antenna theory and design, and they are progressively being used in a variety of current microwave systems.

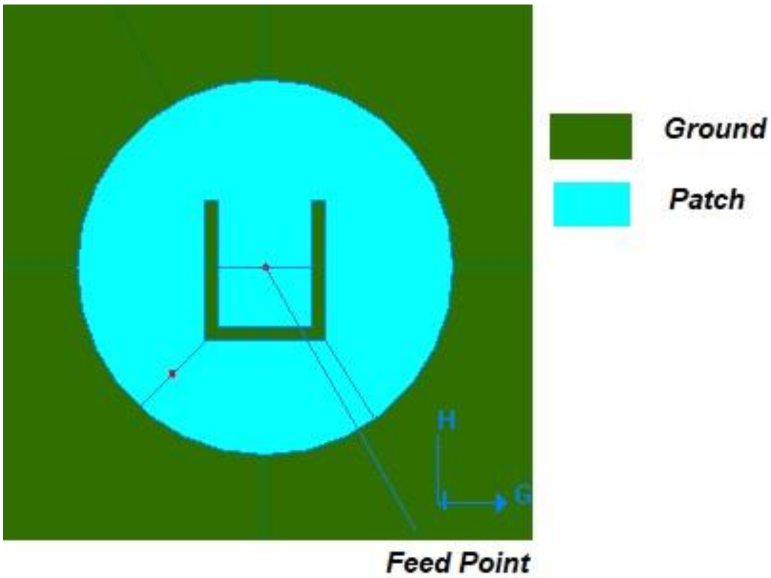

Fig. 1 Circular Shape U –Slot antenna [4]

Grieg and Engleman first presented the notion of Microstrip Antenna (MA) in 1952, while Deschamps designed the first microstrip patch antenna (MPA) configuration in 1953. As shown in Fig. 1, in its most basic form, a MA is made up of a sandwiched dielectric substrate between two thin metallic layers, out of these two metallic layers one is serves as a ground plane and the another one as a radiating patch. In common, the thin metallic layer below the substrate is considered as the ground plane, while the top one is considered the radiating element (patch). These patches can be of any shape includes circular, square, rectangular or elliptical shape [5-6]. After extensive research, it was discovered that the shape/ structure of the metallic patch and the features of the material (substrate) on which the antenna is printed are the primary constraints on the execution and implementation of an MA. As a result, it's possible that with the right material and parameter settings, improved antenna performance can be achieved. Its success is due to well-understood favourable and unquestionable properties, which including low volume and profile, planar structure, easy fabrication and connection and significant flexibility to the extent electromagnetic qualities includes resonant frequency, radiation pattern and polarization etc [7]. In MA's, one characteristic is standardized at the cost of others in a way that is acceptable with the system limitations in place, but the microstrip technology is diluted by other building approaches in order to attain the intended optimization [8].

MA's can work at an extensive range of frequencies, ranging from 1 - 100 GHz in most cases. In any event, MA's do not have only beneficial statuses; they also have certain distinct drawbacks, the most fundamental of which is inborn low impedance bandwidth and gain [9]. In any event, by employing tailored and precise tactics, these drawbacks can be mitigated or even eliminated. The MA can be energized with various type of feed techniques. The advantages and disadvantages of these feeding techniques is presented in Table 1 [10].

Table 1. Advantages and Disadvantages of Various Types of Feeding Techniques

Feed Techniques	Advantages	Disadvantages
Probe feed	Impedance matching is basically achieved by varying the location of probe feed. Higher mode operation possible at suitable probe location. Minimal spurious radiation.	Inductive impedance for thick substrates. Constricted Bandwidth. Generation of cross polarization due to asymmetric probe feed position.
Microstrip line feed	Easy fabrication. Easy impedance matching by changing the location of the feed.	Large Spurious feed radiation. Tapered bandwidth.
Coplanar Waveguide feed	Easy fabrication. Broader bandwidth Good isolation.	High substrate thickness. Existence of Spurious radiation.
Aperture-coupled feed	Optimized feed and antenna substrates Easily integrated with other active devices Non-existence of spurious radiation Less cross polarization	Difficult fabrication Altered input impedance due to Small air gap between the dielectric layers
Proximity Coupling	Enhanced bandwidth in compare to all techniques A lot of degrees of freedoms are available for matching/tuning.	Undeviating radiation from coupling region Difficult to fabricate due to multilayer and proper alignment Altered input impedance because of small air gap between dielectric layers Less Efficient due to lossy bonding material.

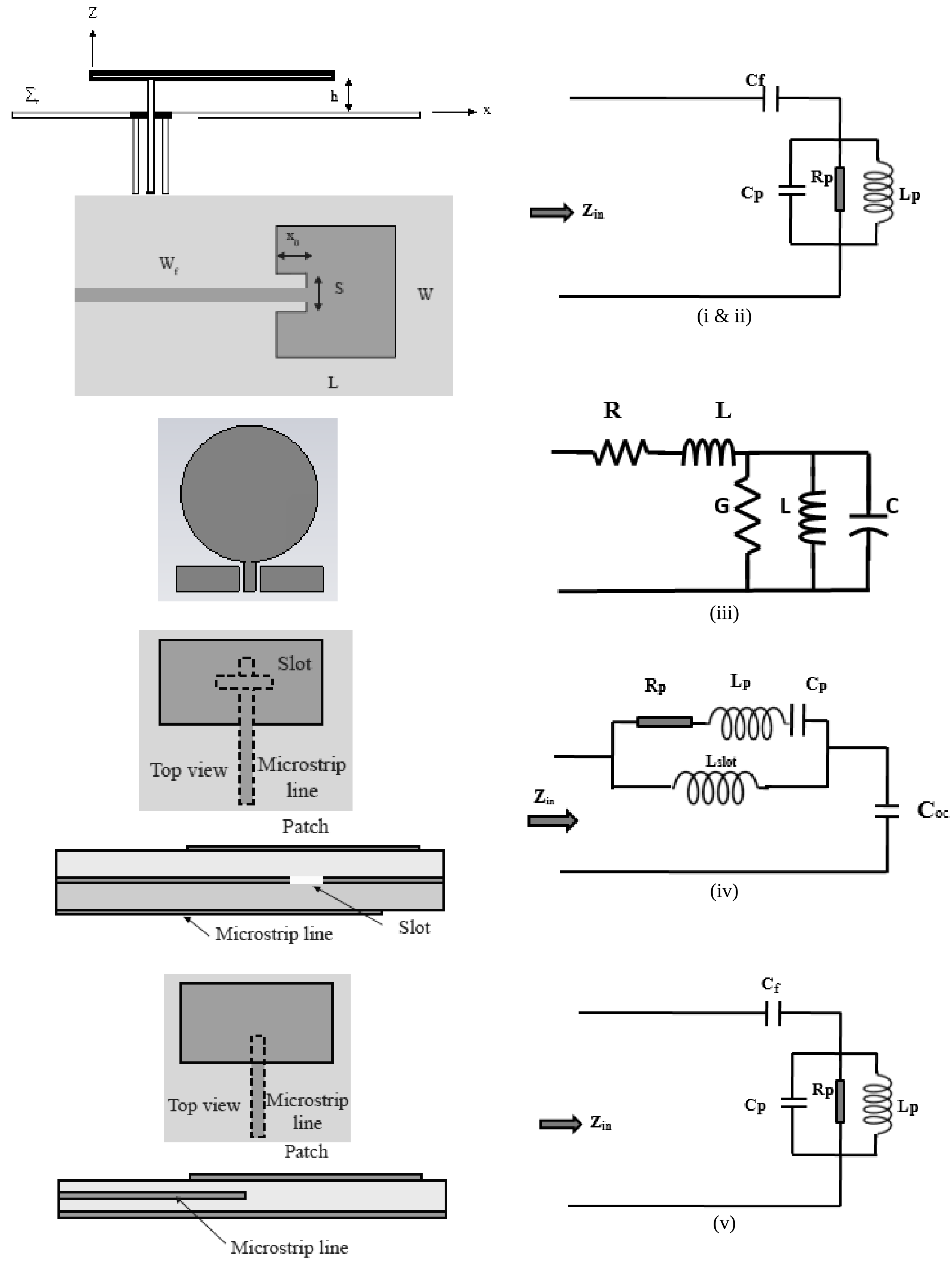

Fig. 2 Demonstration of Feeding Techniques (i) coaxial probe feed (side view) (ii) microstrip line feed (top view) (iii) CPW (iv) aperture-coupled (v) proximity-coupled

MA's are broadly used in a variety of industries and applications, and they are currently growing in the commercial sector. It is also projected that, as patch antennas become more widely used in a wide range of applications, they will eventually supplant traditional antennas for the majority of uses. A MA can be used in a variety of situations. In this article an attempt is made to address some of the important basics and recent applications of microstrip antennas. This paper starts with a brief outline of the MA's along with different feed technique applied to energise the MA's. Before focusing on the most recent applications of microstrip antenna technology a small note is also included about the performance factors of a designed antenna along with the resonant frequency formula for different shape of patch antenna.

THE RESONATING FREQUENCY FORMULA FOR VARIOUS MICROSTRIP ANTENNA SHAPES

For MA having patch shape in rectangular form, the resonating frequency for the TM_{mn} mode is given by [11]

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{reff}}}\left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2\right]^{1/2} \tag{1}$$

Here m and n are the operating mode indices of the MA, along with dimensions L (length) and W (width).

The resonant frequencies formula for TM modes (z-independent) for equilateral triangle of side length 'a' satisfying the boundary condition (for perfect magnetic wall) is given by [12]

$$f_{mn} = \frac{2c}{3a\sqrt{\varepsilon_r}}(m^2 + mn + n^2)^{1/2} \tag{2}$$

Helszain and James [13], suggested that the side length 'a' be replaced by the effective value as given in equation (3), to include the effects of non-perfect magnetic wall effects.

$$a_e = a + t(\varepsilon_r)^{-\frac{1}{2}} \tag{3}$$

The resonant frequency for circular patch antenna is given by [14]

$$(f_r)_{mn0} = \frac{1}{2\pi\sqrt{\mu\epsilon}}\left(\frac{\chi'_{mn}}{a_{eff}}\right) \tag{3}$$

For the first four modes are $TM^z_{110}, TM^z_{210}, TM^z_{010}, TM^z_{310}$ of circular patch antenna, the values of χ'_{mn} of these corresponding modes are, $\chi'_{11} = 1.8412, \chi'_{21} = 3.0542, \chi'_{01} = 3.8318, \chi'_{31} = 4.2012$ (4)

For an elliptical shaped printed patch, the resonant frequency can be considered as-

$$f_r = \frac{\chi'_{mn} c}{2\pi r_e\sqrt{\varepsilon_{eff}}} \tag{5}$$

Here, χ'_{mn} is the mth zero root derivative of Bessel function of order n; c is the velocity of EM wave.

The effective dielectric constant of the dielectric material (substrate) is ε_{eff} and for elliptical shape printed patch, it can be calculated using equation [6]:

$$\varepsilon_{eff} = \varepsilon_r - \frac{0.35\varepsilon_r}{2}\left(\frac{h}{a} + \frac{h}{b} + \frac{h^2}{ab}\right) \tag{6}$$

Here '*h*' is the substrate height and the dimensions of semi major and semi minor axis of ellipse are 'a' and 'b'. In equation (5), r_e is effective radius of equivalent circle of elliptical MA, which is calculated as:

$$r_e = \sqrt{\frac{{a_{eff}}^2 + {b_{eff}}^2}{2}} \tag{7}$$

To account for fringing fields in elliptical MA, the dimensions of semi major and semi minor axis of ellipse 'a' and 'b' are replaced by their effective values a_{eff} and b_{eff} and can be given as:

$$a_{eff} = \{a^2 + \frac{2ha}{\pi\varepsilon_{eff}}[\ln(\frac{a}{2h}) + (1.41\varepsilon_{eff} + 1.77) + \frac{h}{a}(0.268\varepsilon_{eff} + 1.65)]\}^{1/2} \tag{8}$$

$$b_{eff} = \{b^2 + \frac{2hb}{\pi\varepsilon_{eff}}[\ln(\frac{b}{2h}) + (1.41\varepsilon_{eff} + 1.77) + \frac{h}{b}(0.268\varepsilon_{eff} + 1.65)]\}^{1/2} \tag{9}$$

THE PERFORMANCE FACTORS OF A DESIGNED ANTENNA

The checklist for designed antenna performance includes following factors [16]

- Matching, it means how input terminals of designed antenna is matched with source feed
- The qualities of an antenna's gain and beamwidth.
- How much gain is there and how the pattern looks like.
- The alignment and power in side lobes, it should be confined to a predetermined envelope.
- Cross-polar behaviour should be within the desired limit.
- Less wastage of power in antenna structure that is antenna should be highly efficient in terms of antenna and radiation efficiency.
- Bandwidth means the frequency range over which the above features meet the requirements.

Along with these other parameters those are frequently considered for making decisions about antenna performance are its size, weight, and cost. In all these are the major factors to consider antenna performance in relative manner.

APPLICATIONS OF MICROSTRIP ANTENNA

Regardless of the constraints, MA considered the multiple focal points to be incredibly useful in a variety of applications. Radar for surveillance and defence, marine radar, airborne application, satellite communication and remote sensing are all examples of MA widely used in defence systems. Because of its simplicity and ease of manufacture, MA is being used in professional settings (both commercial and personal applications). For the reason that of the improvement and ongoing research in the field of MA, it is expected that in the near future, MA will displace a substantial percentage of the traditional antenna. After evaluating the existing research publications, it is clear that MA is the best contender for a wide range of applications. Table 2 illustrates the IEEE standard frequency allotment for a variety of microwave applications.

Table 2. Various Microwave Bands Assigned by IEEE [17]

Designation of Band	Frequency (GHz)	Application
L-Band	1-2	GSM Mobile Phones, GPS, GPRS, CDMA, DECT
S-Band	2-4	Weather radar systems, Microwave Oven, WCDMA (3G Mobile Services), LTE (4G Services),Wi-Max, WLAN, Wi-Fi, Bluetooth, DVB-(Satellite / Handheld), IMT-2000 extension band.
C-Band	4-8	WLAN, Wi-Fi, Satellite communications Transmissions, Long distance communication
X-Band	8-12	Military communication satellite, Space communication, Amateur Radio(HAM), Motion Detectors used in traffic lights
Ku-Band	12-18	Fixed satellite services, Ttracking and data relay Satellite, Service like Space research, Radio astronomy and mobile service.
K-Band	18-27	Radar and satellite communication, Proximity Warning Systems.
Ka-Band	27-40	Satellite communications, terrestrial microwave communications.

Radar Applications

An array of MA is a credible candidate in radar for marine and surveillance application. This array antenna is used to identify, the speed of sea waves and its trace (position). This application requires a long-term gain and beam breadth, which an array of MA can provide [18]. In another type of application of radar, the ground soil grades are determined by means of Synthetic Aperture Radar (SAR).

Global Positioning System (GPS) Applications

MA's with high permittivity sintered substrates are now employed in global positioning systems. Due to their positioning, these antennas should be circularly polarised. Also these system requires small size and quite inexpensive antennas. It is projected that lots of GPS receivers would be used by the wider populace to precisely locate land vehicles, aircraft, and maritime vessels [19]. MA's is the most suitable candidate that fulfils all these requirements.

Direct Broadcast Satellite (DBS) System Applications

In several nations, the DBS system is providing television services. For this service the ground user antenna essentially has a gain of approximately 30 dBi and operate at a frequency of approximately 12.0GHz. Numerous consumers are currently using traditional parabolic reflector antennas for this application. However, the parabolic reflector, cannot be conveniently disguised or put on an existing structure due to its curved bulky shape. To put it another way, it necessitates the purchase of separate real estate for installation [20]. To ratify this issue, a number of flat microstrip array antennas for DBS can be used. These arrays are lightweight, easy to install on a building wall and low in cost of production. Additional benefit of implementing a flat low-profile antenna over a parabolic reflector is that its performance is less influenced by wind or snow.

Mobile Communication

Most of the mobile applications are mainly composed of portable devices like cell phones, mobile handsets or handheld gadgets [21]. For communication applications, all of this necessitates a compact, low-profile, low-cost antenna. Many MA's such as monopole antennas, folded antennas and planar Inverted-F antennas (PIFA) antennas, can meet this requirement because to their small size, as opposed to any conventional antenna utilised for this purpose. MAs are a type of antenna that can meet these needs, and various MSAs have already been constructed and used for mobile communication systems.

Satellite Communication

In satellite communications, circularly polarised radiation patterns are necessary, and these type of radiation patterns can be generated by means of MA's. For this purpose, patches either in square shape or circular shape with one or two port feeding mechanism like orthogonal or dual feed networks are used.

In practice, parabolic reflector antennas are being used to broadcast communication from satellites. These parabolic reflectors are not only very large in size but also having a primary feed in forward-facing of the reflector. This arrangement increases the effective installation area and that can be ratify with the application of a small array of flat MA elements [22]. An array of MA elements may produce beam patterns (sector beam or / and a multi-beam). Photolithography technique is used on double sided copper-clad dielectric substrate, which can be straightforwardly constructed to make a flat structure, though thousands of components are utilised.

Wireless Communication

In current years cellular and wireless communication technologies have been advanced very expeditiously. In present scenario these communication systems are vastly utilized by the persons in all over the world, for this cellular operators are consistently provoked to enhance their performance to get excellent services with low power consumption [23]. Because of low power handling capabilities and compact design, MA is ideal for communication systems, particularly in wireless devices. The Wi-Max (worldwide interoperability for microwave access) system, according to the "IEEE 802.16 standard, encompasses three main frequency bands: lower band (2.495 to 2.695 GHz), median band (3.25 to 3.85 GHz), and upper band (5.25 to 5.85 GHz)". MA is a good option for this purpose since it can resonate multiple frequencies at once without causing interference [24-25].

Radio Frequency Identification (RFID) Applications

The MA is a typical printed resonant antenna for narrow-band microwave wireless link applications that demand semi-hemispheric coverage, such as RFID devices. A planar antenna for UHF RFID Tags that may be attached to metallic surfaces is proposed in [26]. A short-circuited patch antenna with fractal shape is presented as the radiating structure, culminating in a Tag that is not only cost effective but also compact in size. Such a Tag, with its excellent platform tolerance, is also suited for use on a variety of materials (metal, glass, etc.).

Medical Applications

Recently, there has been a surge in excitement in the use of electromagnetic techniques in healthcare diagnosis and therapy. There is evidence that local and/or full body hyperthermia can be an efficacious therapeutic method for some malignant tumours. Microwave energy is one of the most efficient tools to induce fast hyperthermia, however it is challenging to heat deep buried tissues and a big volume of tissue with it.

In general, a microwave radiator should have the following features: efficient energy accumulation in a particular tissue volume (e.g., in the muscle without overheating the skin), excellent impedance matching, minimal microwave energy outflow into the surrounding area. When properly built, microstrip radiators have the advantages of being compact, low weight, and proficient of adapting to the outline of the body while maintaining qualities equivalent to conventional microwave radiators [27]. MA can be easily implanted inside the human body and utilised to communicate with interior and exterior control systems due to their small size. However, the material used for this purpose becomes a vital parameter, and it must be biocompatible. Telemedicine and wireless body area networks use these MA (annular ring and circular disc).

For Monitoring Different Pathological Changes Relating Breast Cancer

The most common uses for medical diagnostics include stroke detection, water accumulation in the human body, and breast cancer detection, which is the most common type of cancer among women. The optimum model for breast tumour detection is a patch antenna with a wide impedance bandwidth, a good front-to-back ratio, and a steady radiation pattern. The antenna's time-domain characterisation indicates that it is suited for brief pulse radar applications [28].

Telemedicine Application

Telemedicine is growing more important as the demand for remote human vital sign monitoring grows in a variety of applications, including monitoring seniors, tracking post-surgery patients' recovery, and evaluating bodily functioning during exercise [29]. In telemedicine systems, the health measures that can be wirelessly communicated to remote stations (in off body mode) range from simple heart rate, blood pressure, and body temperature to blood glucose levels and ECG waveforms. On-body mode is required for communication between sensory devices placed on or within the patient's body in addition to off-body applications [30]. As a result, for optimal performance, a reliable low-profile antenna is necessary and that is the microstrip antenna only.

A MA that may be worn is suited for a Wireless Body Area Network (WBAN). In comparison to other antennas, the offered antenna [31] has a larger gain and front to back ratio. Along with this it provides a semi-directional radiation pattern, which is favoured in excess of the omni-directional pattern to avoid redundant radiation to the user's body and meets the requirements for on and off-body applications. Telemedicine applications can benefit from an antenna with a gain of 6.7 dB and an F/B ratio of 11.7 dB that resonates at 2.45GHz [31].

Automobile Applications

Two kinds of antennas have been initiated: one for use in the cabin of a vehicle and the other for use on the roof of a vehicle. MSAs can meet these criteria because they are low profile and compact antennas. When an antenna is mounted on the uppermost of the vehicle, the radiation pattern is normally oriented upwards; however, for urban mobile operations, low-angle radiation is desirable. When fitted on the roof of a vehicle, an annular slot is employed to create a low-angle pattern. For the reason that a thick or bulky antenna cannot be put on the roof, MA's flat structure is preferred.

As the antennas with sector radiation patterns are required for mobile communications base stations. Compact size antennas are preferred, as the antenna tower for the base station should be of lower height and require low weight support. Small, lightweight antennas are also required for ships and aircraft, and conformal constructions are sometimes required to permit antennas to be fitted flat on the moving vehicle's body. MA’s are thought to be suitable in such circumstances, and a number of antennas have been constructed and erected. MA’s are thought to be suited for such situations, and a number of antennas have been built and deployed aboard ships and planes [32].

Vehicle to-Vehicle (V2V) and Vehicle to-Infrastructure (V2I) Communication

People have recently become more interested in automobile communication. It can offer drivers with real-time traffic information, allowing them to reduce traffic congestion and avoid accidents. The allocated frequency band for wireless access in vehicle environments (WAVE) is ranges from 5.85 GHz to 5.925 GHz and this frequency span is committed for short range communications. It not only takes account of vehicle to-vehicle communication (V2V) but also for vehicle to-infrastructure (V2I) communication [33]. MA have an extensive variety of applications in the field of vehicle antennas due to its low profile characteristic and good concealment. A regular hexagon microstrip antenna with a low profile and low cost is proposed in [34].

For Pedestrian Applications

This application necessitates extra caution, particularly when the apparatus is carried in a user's pocket or close to the human body. The impact of nearby things on antenna’s act is difficult to avoid; nevertheless, the loss of antenna performance owing to surrounding materials can be decreased by utilising an antenna driven by a magnetic current rather than an electric current. Despite the fact that the ground plane of an MA performances as a protective layer contrary to next to materials like circuit components and other metallic materials, the image of the magnetic current pertaining to the ground plane will be responsible for improved radiation in front of the MA element, resulting in reduced radiation deterioration [35].

Rectenna Application

A rectifying antenna is a unique form of antenna that converts microwave radiation directly into DC power. Antenna, one rectification filter, rectifier, and post rectification filter are the four subsystems that make up a rectenna. To satisfy the demands of long-distance communications, it is required to develop antennas with extremely high directional qualities in rectenna applications. Since the goal of the rectenna is to transfer DC power over great distances via wireless networks, for this purpose the electrical size of antenna is extended.

In [36], the design and experimental verification of a rectenna ("rectifier + antenna") for wireless power reception is presented. The offered rectenna is made up of two main components: a MA and a half-wave rectifier circuit. The MA receives wireless power and the rectifier converts the received radio-frequency power to DC. A matching network is made in between them before they are combined to match the initial harmonic. Around the 2.4 GHz ISM band, a a small number of integrated rectenna are created. Rectenna are flat and compact since they are entirely made of printed circuit boards.

Textile Antenna Applications

Now a day, antenna is being used to observe biometric data from the human body in various applications [37]. To do so, they must remain so near to the human body at all times that they can constantly monitor biometric data and transmit it to the network connected. If the antenna is firm, it will not be able to remain permanently attached to the human body. An microstrip antenna constructed of textile material is safe to wear and can be worn for long periods of time.

Wearable Antenna Applications

Wearable antenna will be useful in fields such as healthcare, recreation, and firefighting. The radiating patch and ground plane of this unique patch antenna are composed of conductive textile material. The textile substrate material has a specified substrate permittivity or dielectric constant. It's termed a textile antenna since it's composed entirely of textile material [38].

Application in Manufacturing Processes

Microstrip antenna research is inextricably linked to manufacturing processes. Numerous machining techniques, such as multilayer printed circuit board, complementary metal oxide semiconductor, low-temperature co-fired ceramics and micro-electromechanical systems, have recently advanced, allowing for the development of novel antennas such as reconfigurable antennas, active antennas, metamaterial-based antennas and THz antennas. Microstrip antennas are becoming more integrated of antenna/array and feed network, and functioning at moderately high frequencies, owing to the wide accessibility of high-precision and high-speed sophisticated manufacturing processes. Researchers propose that microstrip antennas is continually presenting innovative advanced machining techniques [39].

CONCLUSION

The enormous development in growth of wireless communication and information exchange via handsets and personal communications devices has demanded momentous antenna design innovations as a critical component of any wireless system. Based on study, it is observed that these Microstrip antennas are equally applicable not only in bulky base stations but also in portable devices. These MA's come in a variety of shapes and sizes are perhaps the most active research field in antenna applications and development. Microstrip antennas are one special type of antenna that can suit the requirements of almost each wireless systems. These are rapidly being employed in wireless communication systems such as handheld portable device, mobile devices, satellite communication systems, and in biomedical applications due to their multiple advantages.

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