Multiband Microstrip Antennas for GPS Applications

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***Abstract*— In this report, the multiband microstrip antenna for GPS application was studied. Different studies are investigated and discussed, and the different models of these antennas are analyzed. In this paper, which is the main purpose of investigate the methods of increasing bandwidth in microstrip antennas, microstrip antennas in terms of structure and their analysis methods such as transmission line, Cavity, and moment (in short) have been investigated. Among microstrip antennas, circular and rectangular microstrip antennas are among the most widely used. Rectangular microstrip antenna is used due to having more parameters for design and is also easier to design and analyze.**

Keywords—multiband microstrip antennas, global positioning system, GPS applications

I. INTRODUCTION

An important functional element in communication and radar systems, as well as wireless devices, is the antenna. The antenna may be defined as the transducer between an electromagnetic wave (EM) propagating along a transmission line and an EM wave propagating in an infinite environment (usually open space) or vice versa. An antenna is required to transmit or receive EM energy with proper direction and polarization characteristics for the intended application. The microstrip antenna is a contemporary invention in some degree. This antenna was invented to allow easy integration of an antenna and other excitation circuits of a communication system on a commonly printed circuit board or a semiconductor chip. In addition to other advantages, integrated circuit technology for antenna construction allows high dimensional accuracy, which was difficult to achieve in traditional manufacturing methods. The geometry of a microstrip antenna consists of a dielectric substrate with a certain thickness d, on one of its surfaces of which there is complete metallization, and on the other side it has a metal "patch". The bed is usually thin. The metal patch on the front surface can take many forms, although a rectangular shape is usually used. The antenna may be actuated in a variety of ways. One common method of feeding is from a microstrip line, which connects the microstrip antenna in the center of one of its edges. The microstrip line may be connected to a power supply circuit or powered straight in connecting a signal source across the microstrip line and ground.

An antenna is a telecommunication device which converts electrical signals into electromagnetic waves (in transmit mode) and converts electromagnetic waves into electrical signals (in receiving mode). Antennas have a variety of structures that are determined by the application. One of the simplest possible structures for an antenna is a wired antenna. Each antenna is amplified at a certain frequency and produces the maximum voltage (in the receiving state). If the length of the antenna is proportional to the received wavelength, the wave will fit completely in the antenna and the so-called "antenna is amplified". Or "the antenna is amplified." That is, the antenna is synchronized with the received wave, and in this case, the voltage generated by the antenna is the maximum. Of course, the antenna length does not have to be equal to the received wavelength; Because the inductor can be added to the antenna with one or two capacitors to create an intensification mode in the antenna. The operational performance of the antenna affects the whole system performance directly. The requirements of bandwidth, gain, beamwidth, polarization, and multiple frequency operability may change according to the application area of the antenna. Circularly polarized multiband low-profile antennas are preferred in many wireless communication systems [1].

“GNSS” covers all satellite-based navigation systems such as GPS, GLONASS, and Galileo. These satellite systems generate circularly polarized radio navigation signals. The polarization of the electromagnetic waves changes due to ionized gases or the earth's magnetic field. This effect, known as Faraday Rotation, causes rotation in the orientation of the linear polarized wave. In order to minimize this effect, Right Hand Circularly Polarized (RHCP) signals are used in satellite navigation systems [2].

GPS is the first GNSS constellation developed by the US Department of Defense (DoD). GPS has 24 satellites in 6 orbits around the earth at an altitude of 20200 km. Civil navigation signals were composed of L1 (1575.42 MHz) and L2 (1227.60 MHz) until 2014. After 2014, with the usage of the next-generation GPS satellite “GPS BlockIIF”, L5 (1176.45 MHz) frequency is activated to be used as pre-operational Civil Navigation (CNAV) by civilian users [3].

GLONASS constellation is another navigation satellite system developed by the Union of Soviet Socialist Republics (USSR). It is fully operational orbiting around the earth with 24 satellites since 1996. GLONASS supplies two kinds of navigation service as “standard positioning service” which is open to civilian usage and “precise positioning service” which is only used by military applications. There are three operating GLONASS frequency bands as G1 (1602 MHz), G2 (1246 MHz), and G3 (1204.704 MHz). G1 and G2 frequency bands are open to civilian usage since 1996 [4].

Galileo constellation is another GNSS that has been developed by European Space

Agency (ESA) since May 1999. The complete system will comprise 30 satellites (24 operational and 6 spares for each orbital plane). Five frequency bands are used for navigational signal transmission. Galileo will have four different service choices as Open Service, Commercial Service, Safe-of-life Service, and Public Regulated Service. E5a, E5b, and E1 frequency bands will be open to free usage in Open Service [4].

Combinational usage of the GNSS signals improves the accuracy and robustness of all navigation systems. Additionally, multiband GNSS usage also makes the system robust against jamming signals. Therefore, using multi navigational signal usage becomes more important to improve the reliability of positioning [4][5].

II. Microstrip Patch Antenna

The microstrip patch antenna is one of best candidates to meet the multiple frequency operability, circular polarization, and low-profile requirements for a GPS antenna. When a specific patch geometry is used to generate desired modes. On the other hand, microstrip patch antennas have some disadvantages like low efficiency, spurious feed radiation, and very narrow bandwidth. However, there are some methods to minimize these disadvantages, for instance, increasing the thickness of the substrate can increase the bandwidth and efficiency. But increasing the thickness can also introduce unwanted surface waves which degrade the radiation performance of the antenna [6]. Surface wave degradations can be minimized by using some photonic bandgap structures [7]. In addition to the use of a thicker substrate, there are some methods to increase bandwidth such as slot-loading on patches, different feeding techniques (i.e. aperture coupled feed), stacked structures, parasitic patches, and other multimodal techniques [7].

As shown in Figure 1, microstrip antennas consist of three main layers as ground, substrate, and conducting patch. The thickness of the substrate is usually a small fraction of the wavelength ($0.003\lambda \leqslant h \leqslant 0.05\lambda$). The geometry of the conducting patch can be rectangular, circular, or any other geometrical shape. For a rectangular conducting patch, the length of the patch is usually in the interval of $\lambda/3 < h < \lambda/2$. Substrates are dielectric materials, and their dielectric constants are usually in the range of 2. . The bandwidth of the antenna decreases with the increase of the dielectric constant of the substrate [8].

There are four common feeding methods as a microstrip line, coaxial probe, aperture coupling, and proximity coupling for microstrip antennas. These feeding structures are shown in Figure 2. Despite the low bandwidth, the feeding techniques of the coaxial probe and microstrip line are implemented more frequently [10].

III. Circular Polarization In Microstrip Antennas

In linearly polarized systems, transmission losses can occur because of misalignment of the transmitting and receiving antennas. If the electrical fields are vertically or horizontally oriented above the earth, the polarization of the antenna is called vertical or horizontal polarized, respectively. Both vertical and horizontal polarizations are called as linear polarization.

For circular polarization, two orthogonal components of the electric field which have the same amplitudes and 90° phase difference between orthogonal components are required in the far field region. For a circularly polarized wave, the trace of the electric field vector at a given point in space as a function of time is a circle as shown in Figure 3.

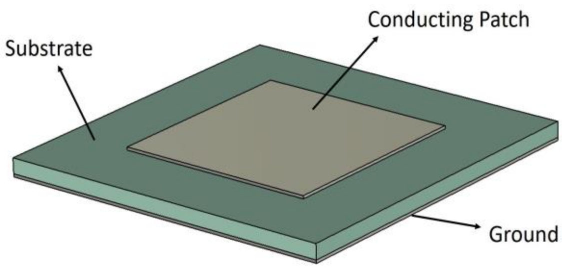

Fig. 1. Structure of microstrip antenna [9]

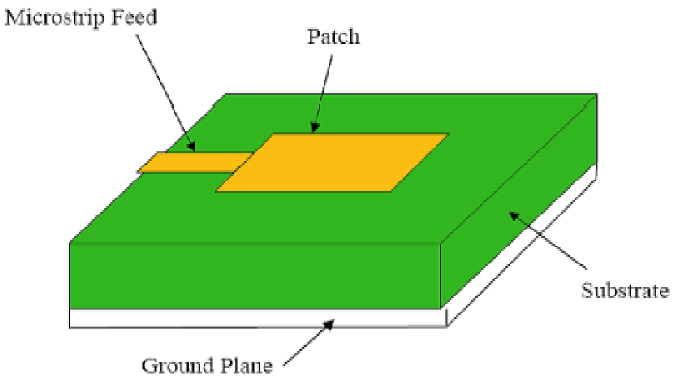

Fig. 2. Feeding methods of microstrip antennas [11]

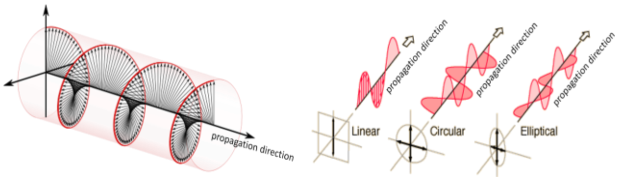

Fig. 3. Representation of circularly polarized wave [12]

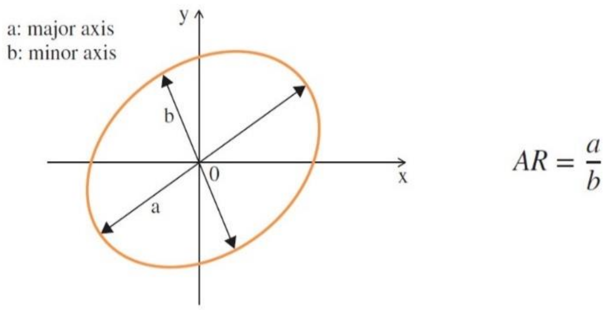

Fig. 4. Trace of the tip of electric field vectors for elliptical polarization.

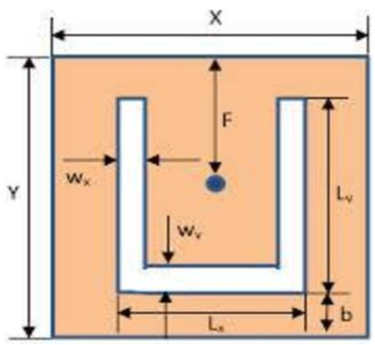

Fig. 5. Double fed CP microstrip antenna configurations for rectangular patches [14]

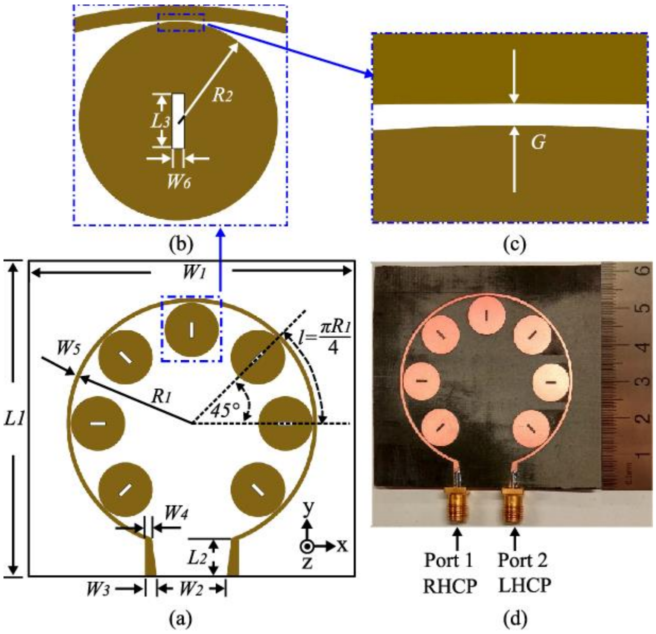

Fig. 6. Double fed CP microstrip antenna configuration for circular patches [15]

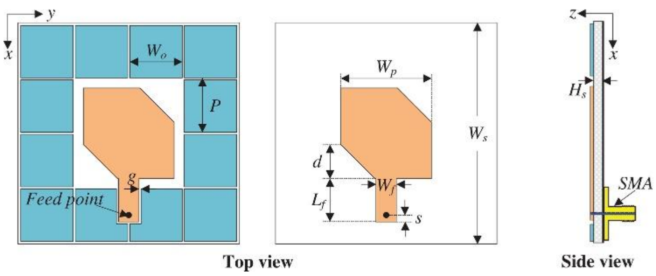

Fig. 7. Single Fed Circularly Polarized Patch Geometries [16]

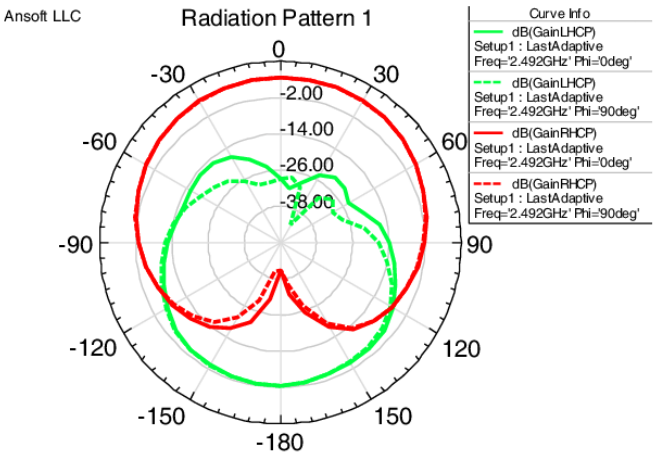

Fig. 8. Patch configurations for RHCP and LHCP on nearly square patches [18]

Shown in Fig.4 is called elliptical polarization [13]. Circular polarization can be achieved in microstrip patch antennas with two different feed configurations as single fed and double fed. 90◦ phase difference between two orthogonal modes is provided with an external passive microwave component (power divider, hybrid coupler, etc.) in double-fed circularly polarized microstrip antennas. TM10 and TM01 modes are used as orthogonal modes for rectangular patch geometries as shown in Figure 5. Double fed configuration can also be used in circular patches as shown in Figure 6. TM11 mode is used to get circular polarization on circular patches. Some of the patches are shown in Figure 7. In single-fed circularly polarized rectangular patches, orthogonal modes (TM10 and TM01 modes) are needed to be excited with 90◦ phase difference from a single point. If a square patch is fed diagonally, orthogonal modes are excited in phase.

The length of the vertical and horizontal edges are changed slightly to get 90◦ phase difference between orthogonal modes and the square patch becomes nearly square [17]. The patch configurations that provide RHCP and LHCP are given in Figure 8.

Circular patches can be made elliptical by changing the axis length of the circle to obtain 90◦ phase difference in the single-fed configuration [19].

U-slot loading is known as a method of increasing bandwidth in microstrip antennas. Asymmetrical U-slot is obtained by changing the length of one arm of the U-slot. If the left arm of the U-slot is longer than the right one, LHCP is obtained; if the right arm of the U-slot is longer than the left one, RHCP is obtained.

The loading of an E-shaped slot on a rectangular patch is another method to increase the bandwidth in microstrip antennas [20]. The loading of asymmetric slots on rectangular patches is another method for circular polarization [21]. In these studies, slightly varying circular slots are placed along diagonal directions to get circular polarization.

The asymmetrical cross-shaped slot is placed at the center of the patch to obtain circular polarization. RHCP [22] and LHCP can be obtained according to which slot is longer as given in Figure 9.

Most of the previously mentioned patch antennas have low axial ratio bandwidth. Slit and slot loaded patches have a 3 dB axial ratio bandwidth smaller than 1%. Corner truncated, nearly square diagonally fed and circular patch geometries have approximately 3 dB axial ratio bandwidth of 1%. In order to increase the axial ratio bandwidth, U-slot and E-slot patches are used and these patch configurations achieved approximately 3 dB axial ratio bandwidth of 4%. S

ingle fed circularly polarized microstrip antennas are preferred in many safety critical applications which have strict mechanical requirements as compared to double fed circularly polarized microstrip antennas, because of their compact sizes and less complexity. From the viewpoint of cost, single fed antennas are also less expensive than double fed ones, because they do not need any extra passive components.

IV. MULTIBAND OPERATION IN MICROSTRIP ANTENNA

Many wireless communication systems use different frequency bands. Single frequency operating antennas can be used for each frequency band separately. However, this case will lead to a large size, mass, and high cost. Therefore, multiband antennas are preferred in multiband operating applications.

Stacking method is applied by stacking microstrip layers on each other as shown in Figure 10. In this configuration, the coaxial probe is connected to the upper patch, the lower patch is coupled electromagnetically (parasitically) with the upper patch. Each microstrip layer operates its own resonant frequency and the whole antenna with two layers operates multiband.

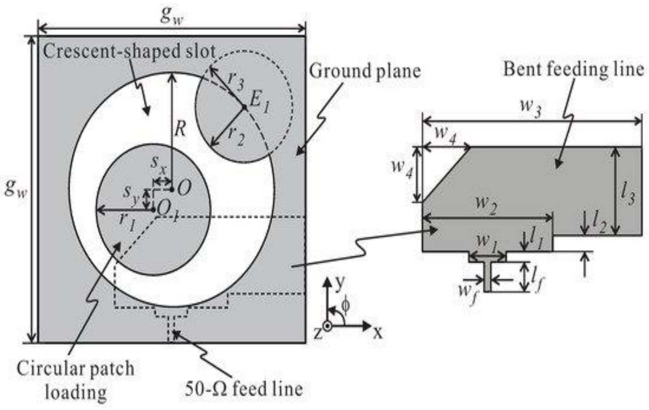

Fig. 9. Patch configurations for RHCP and LHCP on asymmetrical cross-shaped slot patch [20]

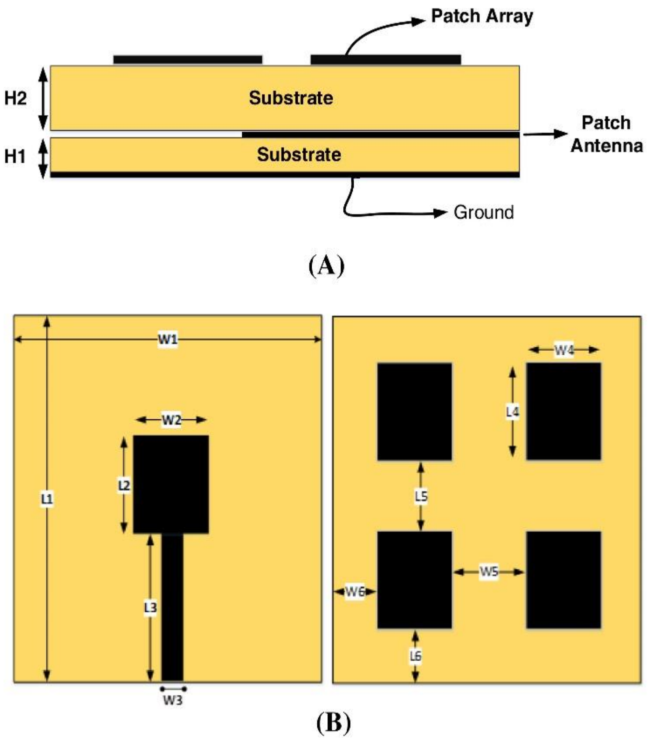

Fig. 10. Structure of stacked microstrip patch antenna for multiband operations [23]

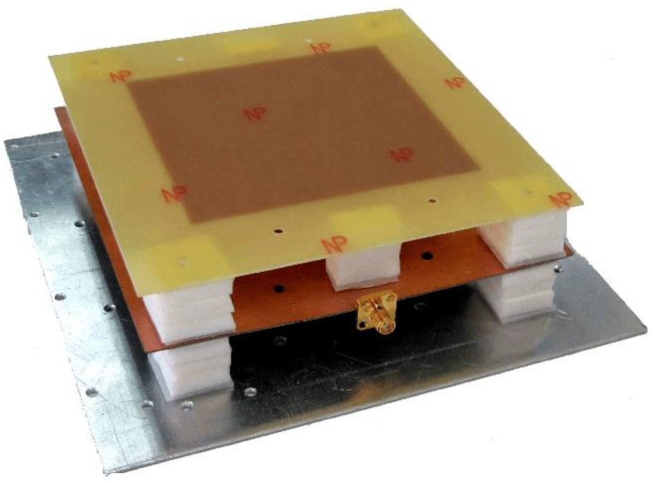

Fig. 11. Stacked microstrip antenna with an air gap

There are several studies on the stacking method to get multiband operations in microstrip antennas. Stacked antennas have broader impedance bandwidth and axial ratio bandwidth than loaded microstrip antennas. Having a small frequency ratio between operating frequencies is quite a challenging issue for loaded microstrip antennas, but stacked antennas can achieve dualband operations with a frequency ratio smaller than 1.5. Stacked antennas can be also used to increase the bandwidth with stacking patches that operate at close frequencies.

The air gap can be used in stacked antennas to get good impedance matching and increase the bandwidth and efficiency of the antenna. Stacked antenna with an air gap is shown in Figure 12.

Loading method is used on the patches for size reduction, control of polarization, control of radiation pattern, and dualband operations in microstrip antennas. The patch can be loaded with stubs, slots, shorting vias, and capacitors to obtain the required resonance frequency, radiation pattern, polarization, bandwidth, and so on.

Dualband operation is obtained with perturbation of TM10 and TM30 modes on dual edge slot loaded patch. If slots are placed close to radiating edges, TM10 mode is perturbed slightly. Therefore, the resonance frequency of TM10 mode changes slightly. The current distribution of TM10 is given in Figure 13-(a). The second resonance frequency is obtained with perturbation of TM30 mode. Slots are placed where the unperturbed TM30 mode current is significant as shown in Figure 13(b). Therefore, the perturbed TM30 mode becomes like TM10 mode. The resonance frequency of TM30 mode decreases and has boresight radiation with no sidelobe. This radiation mechanism also explains the way of obtaining multiband operations on other patch geometries which have slots close to edges.

The loading of multiple U-slot on rectangular patches is another method to get multiband operability in microstrip antennas. Linearly polarized triband is obtained with double U-slot loaded configuration.

Slot loading can also be used on circular patches. TM11 and TM12 modes are used for boresight dualband operations. In a circular slot loaded patch, the circular patch is divided into inner and outer patches which have their own resonance frequencies.

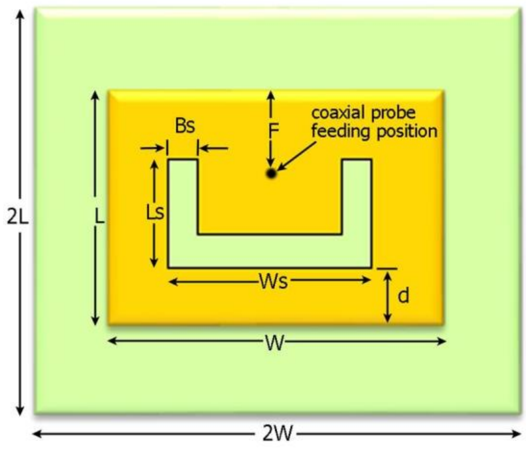

Fig. 12. Multiband slot loaded patches.

V. Multiband And Circularly Polarized Microstrip Antennas

In previous sections, the ways of getting circular polarization and multiband operations on microstrip antennas are given separately. In this section, circularly polarized multiband microstrip antennas are examined and presented.

It is needed to merge the methods of circular polarization and multiband operation to design circularly polarized multiband microstrip antennas. First, the number of feed points is chosen to get circular polarization. A passive component or circuit that provides 90◦ phase difference is needed in the double fed antennas. In single fed antennas, 90◦ phase difference is obtained with perturbation of orthogonal modes. After the decision on the number of feeds, the technique of multiband operation is chosen. Both stacking and slot loading methods are suitable for single feed configurations. Therefore, single fed circularly polarized multiband antennas are researched in the literature survey.

Two truncated patch antennas are stacked as operating at 1575.4 MHz and 1227.6 MHz (L1 and L2 GPS bands, respectively). Corner truncation is used for circular polarization at each frequency band. The air layer is used to tune the frequency ratio. Antenna is fed by a single coaxial probe which is soldered to the upper patch and the lower patch is fed parasitically. According to measurement results, 15 MHz and 17 MHz circular polarization bandwidth is obtained at L2 and L1 bands, respectively.

A triband corner truncated antenna is designed to operate at GPS L1/Galileo E1 (1.575 GHz), Galileo E5b (1.207 GHz), and GPS L5/Galileo E5a (1.176 GHz) frequency bands. Corner truncation is used for circular polarization at each frequency. Antenna is fed by a single coaxial cable which is soldered to the upper patch. Middle and lower patches are fed parasitically. According to the given simulation results, 3 dB axial ratio bandwidth of 12.6 MHz (0.8%), 4.83 MHz, and 94 MHz (8%) are obtained at the center frequencies of GPS L1/Galileo E1, Galileo E5b, and GPS L5/Galileo E5a bands, respectively.

An L1 and L2 GPS band operating truncated patch antenna are designed and measured. Corner truncation is used for circular polarization at each frequency. Antenna is fed by a single coaxial probe which is soldered to the lower patch. The upper patch is placed with an air gap from the lower substrate and excited parasitically. The height of the air gap is used to tune the frequency ratio. According to the results, if the height of the air gap increases, the frequency ratio decreases.

Three square patches are stacked with different geometries. Antenna is designed to operate at L1, L2, and L5 GPS frequency bands. Antenna is fed by a single coaxial probe that is soldered to the top patch. Other patches are fed parasitically. Circular polarization is obtained with corner truncation on the upper patch for L1 band operation. Four symmetric cross-shaped slots are used to get circular polarization on the middle patch for L2 band operation. Symmetric slits are placed on the corner of the lower patch to obtain circular polarization for L5 band operation.

Multiband operation is obtained with the loading of slots and circular polarization is obtained with perturbation of the patch geometry. Dualband is obtained with slots close to edges (edge slots) and circular polarization is obtained with the center cross slot and diagonal feed. Antenna is designed to operate circularly polarized at 1575.4 MHz and 1227.6 MHz. The length of the edge slots controls the resonance frequency of the TM30 mode. However, there is a limited place on the patch. Therefore, the patch is loaded with short circuit stubs from the edges of the patch to decrease the frequency ratio.

Contrubition of the Authors

The contributions of the authors to the article are equal.

Conflict of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were observed in this study.

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