Chapter 14
THz Microstrip Patch Antenna for Wearable Applications

Mehaboob Mujawar and Md. Shakhawat Hossen

Abstract In this chapter, a THz-frequency microstrip patch antenna is constructed and analyzed, with the goal of using it in wearable applications. A novel form of THz wearable antenna is presented for wearable applications. Due to the shortage of spectrum accessible for wireless communication, this chapter was written with the intention of recognizing the needs and expectations of high data rates. As a result, the time has come to seriously consider the higher frequency portions of the electromagnetic spectrum for wireless communications. This chapter considers and analyses the usage of the terahertz frequency band in future compelling systems and devices.

Keywords THz antenna · Wearable · Microstrip · THz Applications · Wearable Applications · Denim · Return loss · Radiation parameters

Introduction to Terahertz (THz) Technology

THz is the frequency range from 300 to 3000 GHz, which is $1mmto100\mu m$ in wavelength, corresponding to the energy of about 1.2 to 12.4 meV and equivalent temperature of about 14 to 140 K. There are various applications for which the frequencies can be used depending on the electromagnetic spectrum. Starting from radio waves, which are used for broadcast radio and TV, going to higher frequencies which is the area of the cell phones then the THz region starts at the 300 GHz up to 3 THz. Going to higher frequencies in the infrared region then visible light region and ultraviolet region which is used in medicinal applications and x-ray imaging at higher frequencies and gamma rays, which are used for cancer therapy because it kills living cells.

M. Mujawar (✉)
Research Scholar, Glocal University, Saharanpur, Uttar Pradesh, India
e-mail: mehaboob311134@gmail.com

Md. S. Hossen
Rajshahi University of Engineering & Technology, Rajshahi 6204, Bangladesh

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Advantages of THz

THz has very strong interaction with all states of matter, i.e. liquid, solid and gases. The strong interaction results in interesting spectral effects. There are certain materials which are transparent in this frequency range such as plastics, ceramics and few dielectric crystals. There are naturally occurring spectral signatures, which have to do with molecular motion and these are mostly apparent when we have light weight gases under low pressure. It has got very high sensitivity for traditional signal detection because the techniques out of the microwave regime can be used. There are aperture advantages that we can compare directly with mm wavelength, we just scale the frequency up for the same antenna diameter and the pixel size or resolution can be scaled down linearly with aperture diameter and that gives real portability advantages. THz is non-ionizing radiation and compared to x-rays they don't cause harm to any genetic material or atomic structure when exposed to it. The optical tolerances are lower than near IR or optical regime. So the antennas don't have to be quite well surfaced even though they might be large. The huge bandwidth available from 300 to 3000 GHz, practically no signal bands in that range that have been assigned in that point of time. For wide dynamic signal range this frequency band is suitable.

THz Constraints

In this wavelength range, the material loss is very high irrespective of the material being plastic, crystalline material. The dielectric loss is very high compared to the optical regime. There is no such thing as the equivalent of optical fiber in the THz range because of the interaction of phone on the mode of dielectrics and because of high ohmic losses in metals. THz energy can be propagated in any material without suffering significant loss, whether it is a waveguide or quartz substrate having low loss. In the atmosphere water and oxygen absorb very heavily and cannot transmit to a very large distances interms of km at the low end of the THz band.

Interaction of THz Waves with Matter

One aspect which determines how THz waves behaves is their attraction with matter. THz waves have certain properties for example they can penetrate through materials which are not transparent for other parts of the electromagnetic spectrum packaging materials such as plastic, ceramic and so on (Failed 2021). Also the energy is very low that does not induce any chemical changes in the chemical structure. It can also be used to create imaging and transmit information.

Generation of THz Radiation

There are certain possibilities for the generation of THz radiation. One way is to do up conversion coming from the lower end of the spectrum and the other possibility is coming from the high end of the spectrum to do down conversion. Each of these waves has its own advantages and disadvantages. In the case of up conversion, electronic sources such as multiplier chains, RTD, transistors and diodes are used. The main advantages are as follows: It is compact, and it is at room temperature but disadvantages include limited bandwidth and limited efficiency. Coming from the upper part of this spectrum, that is for opto-electronics. Bit signal can be created using two lasers and bit signal can be mixed on the photodiode, and it is connected to antenna and then transmit THz radiation. It is tunable because lasers are tunable. It is at room temperature. Power and efficiency are limited.

Applications of THz Antennas

Traditional THz Applications: The investment of THz in the frequency regime has been significant and the reasons behind it mainly come from basically four areas (Plasma diagnostics, non-destructive evaluation, gas spectroscopy and quantum physics, ultra fast chemistry and nonlinear optoelectronics) in the historic development. The first is astrophysics, this is something that comes about because of the particular signatures that can be detected in this wavelength range that are unique, and have to do with molecular motion, especially in regions that are cold and low pressure, as you find outside the stars or in center of galaxies and out of space in general. The people doing plasma work in the early days were using THz for measuring electron zygotron resonance parameters and temperatures of heart gases in fusion reaction systems. There have been several non-destructive evaluation techniques that use THz for their very high sensitivity to order content. **Modern THz Applications**: One of the major applications of THz waves include non-destructive imaging, which can be used for security checks and material analysis. Another application is the analysis of molecules for diclofenac acid (Voltaren), which is a painkiller. The THz radiations can distinguish between two of its chemical forms. Chemical compound differences lie in the THz frequency region. The quick personnel security scanner used in airports and operates between 70 to 80 GHz and can create a 3D picture, which can easily detect suspicious objects. The security scanner consists of approximately 3000 transmitters and 3000 receiver antennas. Each transmit antenna radiates at a certain time successively and the 3000 receive antennas take the picture of the reflected waves at the same time. Which results in the collection of a lot of data and this data needs to be processed. The peak power is very low i.e. only 1mW. **Three main approaches to THz**: The first approach is the traditional radio frequency techniques, where we take microwave, transmission lines, waveguides, antennas, sources, and detector technology and we translate it up in frequency into the THz regime, in order to capture these spectral contents that exists only in the wavelength band. A lot of this technology investment has really confirmed the astrophysics community basically in the 70 s as sources become available in this wavelength range and has undergone continuous development from then. The second approach is another technique that was developed in 1970s involves generating THz signals using Optical sources and using an interweaning crystals or photo-mixers to do optical rectification but narrow band sources like lasers are able to be applied to non linear crystals and down converting from optical into the THz regime became possible with narrow linewidth. The third technique is essential to use for the transform spectroscopy or to generate broadband THz energy through time domain technique using a fast femtosecond laser and the same kind of frequency conversion techniques that optics researchers used in 1980s to generate a very wide signal with microwatt levels of power throughout the THz range by making sure that the laser has pulse width of only few femtosecond, so that very broad THz signal response can be obtained from the fourier transform.

Millimeter Wave Effects on the Body

When THz imaging system comes into picture, in this technique human body is illuminated. When the human body is illuminated it will get heated apart from that, there will be also radiation effects on the body, which is a controversial statement. For many years it was thought that it was therapeutic approach for many diseases as well as for stimulating cells to behave in certain ways. For the frequency range of 60 GHz, which is approved for LAN systems and also used in Military applications for active denial. For the experiment in which rat tissue was exposed to millimeter waves, when the tissue was exposed to millimeter waves for 5 s, the neurons were less affected compared with the same tissue when exposed to 15 s.

Importance of Microstrip Patch Antenna

Antennas are the essential part of any wireless communication device because it is used to radiate and receive electromagnetic radiation preferably in the desired direction. Most of the time we want to radiate or receive from a desired direction. The efficiency of the antenna for the device is very important because without the efficient antenna the device will not be able to create a link with the receiving device or it will not be able to receive the information transmitted by the transmitter. The device bearing the antenna can be handheld, mobile or stationary. The efficiency of the antenna primarily determines the quality of the wireless communication and further the antenna characteristics determine the efficiency of the antenna. The main antenna characteristics which we need to focus on is return loss, gain, bandwidth in which the antenna is working, radiation pattern of the antenna and many other parameters, which we need to examine during the design of the antenna. In general, the most preferred type of antenna is the small size planar antenna or microstrip patch antenna. The general structure of the microstrip patch antenna consists of two parallel conducting planes that are separated by dielectric substrate. The thickness of the conducting planes is very small, therefore we call it as microstrip (Mujawar October 2021). The bottom conducting plane is known as ground plane and the upper conducting plane is known as a radiating plane. The upper part is basically radiating and the lower part is basically spotting the radiation, therefore the ground plane has its own role. The thickness of the substrate and the dielectric constant of the substrate, these are the two major deciding factors of the characteristics of the antenna. The selection of the substrate is very crucial in the field of wearable antennas and flexible antennas. The upper conductor which is named as radiating patch that may have shape of rectangular then will call it as rectangular shaped microstrip patch antenna. Similarly we can have circular patch, square patch or ring type of radiating patch. If we are having fractal type of radiating patch, then will call it as fractal microstrip patch antenna. Depending on the shape of the radiating patch will name the antenna accordingly. The main advantages of microstrip patch antenna are (Mujawar 2021): Microstrip patch antenna are light weight and low volume, so these antennas are very light and the dimensions of the antenna are very compact and we can easily integrate these antennas to the devices. If the weight of the antenna is large, then the device will not be able to carry the antenna. We can easily design these antennas in planar configuration and we can also easily design these antennas which can be hosted on the conformal host surface. The wearable or flexible antennas can be easily designed using the microstrip patch antenna design principles, which can be conformal to the host surface. Many of the fabrication techniques of these antennas are low cost. We can fabricate these antennas with low cost fabrication process. We can integrate these antennas with microwave integrated circuits. In microwave integrated circuits, the antenna will become part of the circuit and some parts will behave as antenna and the other part will work as microwave integrated circuit for the desired function. The very popular application of antenna in the field of microwave integrated circuit is RF energy harvesting. In RF energy harvesting, antenna have been used to collect RF energy and get RF energy. Then we need to provide that energy to rectifier, so we can easily design that integrated rectifier along with antenna, which is very useful for RF energy harvesting applications. These antennas are also capable of multi-band frequency operations, that is we can design antennas which can work on two or more than two bands. So same antenna can be used for different bands.

Introduction to Wearable Antennas

These antennas find a number of applications in the smart devices and smart clothes. The upcoming technology would require that the antenna should be a part of clothing, therefore there is a need of flexible antenna. The interaction of the antenna with people and surrounding should be very easy, therefore there is a need for flexible antenna.

The major applications of the wearable antennas can be in the field of medical applications, for planning time or getting inputs from surrounding. The emerging of IOT applications, this is another reason for a special focus on flexible wearable antennas. For the IOT applications, many times we require that those components should be self powered or we should have energy storage components. So for self powered components, RF energy harvesting antennas are very useful for collecting ambient energy and giving that energy to the IOT device. In general we can say that the upcoming time is of flexible electronics systems. So flexible electronic systems will also require flexible antenna systems, especially interms of IOT. According to different surveys it is projected that billions of the devices will be connected to internet to form the IOT type of network, so these devices will be needing antennas. So these tens of billions of wireless sensing devices will be required in coming years, so all these devices will be required antennas. These antennas should have the properties of conformability or flexibility to mount on non-planar or curved surfaces. IOT is one special segment of application, which need flexible and durable antennas. Most of these antennas will be worned by the humans as part of wearable sensors. **Desirable Features of Wearable Antennas**: These antennas should be low cost, because IOT applications will require billions of wireless sensors or antennas. The cost of the antenna should be so low that it can be comparable to use and throw, disposable type. Flexibility should be large, so there should not be any deformation with the antenna conformal to the host surfaces. Light weight is another concern of the antenna, specially for human wearable devices. The size of the antenna also matters, because if the size of the antenna is large then it will not be easy to integrate that antenna with the wearable devices. Similarly these antenna should be low profile. Mechanically robust antennas are required since they are subjected sometimes to harsh environments, such as continuous change in temperature or other type of variations in physical environment (Hossen et al. 2021, 2020). The radiation characteristics should be desirable. If we have designed antenna for particular application, so even in the different harsh environments they should work desirably and we should be able to control the radiation characteristics of the antenna, so that we can design antenna accordingly for their use. **Applications of flexible wireless antenna**: These are mainly used for bio-medical monitoring / applications. They are also used in Wi-Fi and WLAN applications. They are also used in beam switching detection systems, RF energy harvesting, wearable glasses and UWB applications. **Major issues with wearable antennas**: (a) Non-invasive and invisible: Many of these antennas will be a part of smart clothes, these smart clothes will be interacting with the environment of the person, who is wearing that particular cloth. But at the same time the major challenge is our antenna should be non-invasive and it should be invisible to the user or to the person who is interacting with the user of that smart cloth. Making of invisible antennas is a major issue. (b) Durability of wearable clothes and devices: when antenna is made part of the cloth or wearable particular device, especially in case of clothes that are frequently washed or ironed frequently. The performance of the antenna is also affected. The antenna characteristics should not drift when it is subjected to the different operations interms of clothes. (c) Robustness to operating circumstances: This is another major issue, when the wearable or flexible antenna is a part of smart cloth or it is a part of wearable device. Making antenna independent of the surrounding environment is also a major issue. (d) Drift in antenna RF characteristics due to bending and human body proximity: Since human body is hostile environment interms of antenna performance, so energy is absorbed by the human body, so we need SAR analysis during the design of antenna and our antenna should meet the desired standards which have been set up by different bodies interms of SAR deposition. Similarly how the body affects the performance of the antenna is also a major issue. (e) We cannot generalize the solution approach for flexible wearable antenna, so the design of flexible antenna or wearable antenna will be an application centric approach.

Recent Trends in THz and Wearable Antenna Technology

In this paper (Ghosh et al. 2020), terahertz structures have been designed in the terahertz window. Meander line-based split ring resonator in terahertz has been designed. The subsequent improvement in the structure can be achieved and multiband operation can be obtained operating at four to six distinct frequencies. The co-polarized level is higher compared to the cross polarized. The efficiency of the proposed antenna is around 50%. The return loss obtained by the proposed antenna is around 35 dB in the frequency range of 5 to 6 THz. This antenna finds applications in the field of medicine and point to point communication. In this paper (Zhang et al. 2017), optimization techniques in THz antenna is explained, basically consists of open loop resonator with multiple channels and dual surface. The feed line is wired to the same multiway open-loop resonator on both sides of the antenna substrate. In dual-band microstrip antennas, a T-shaped structure is commonly used. The study presents a unique dual-frequency THz microstrip antenna. In this paper (Paul and Islam 2017), Gain and bandwidth were increased as a result of optimizations. Antenna arrays, in addition to a single microstrip antenna, have greater directionality and gain. THz wireless communication is carried out from the transmitter to the receiver end with the help of THz antennas. Overall system's efficiency has a direct impact because of the effectiveness of the THz antennas. Which basically means that bandwidth will have a direct impact due to THz antenna performance. THz antennas have a good directivity. The unit size is significantly reduced due to the response of THz antenna in the higher band of frequencies. Materials and process methods restrict the packaging of THz antennas. Because of its small size in the high-frequency bands of THz waves, it has a high loss and lower fabrication accuracy. Another difficulty in terahertz antennas is obtaining effective radiation. As a result, THz antennas must meet higher standards with respect to design, operation and fabrication technology. At frequencies of 0.835, 0.635, and 0.1 THz, LCP is used as a substrate. Fabrication for a variety of medical applications, including THz tumour detection and Doppler radar or vitro technology for vital sign detection, may be done on a simple printed circuit board (PCB). However, because THz microstrip antennas have a low gain, researchers are concentrating their efforts on figuring out how to boost the gain. The principle of suppression effect is employed to identify semiconductor features in this study (Failed 2017). TARC Value is also giving the bandwidth from 2 GHz to almost 8 GHz. MEG is almost 0.3. Surface current distributions in different frequency range has been observed, specifically for 2.4 GHz, 6 GHz and 6.425 GHz. For every frequency range the I shaped structure has reduced the coupling current in the second element. After placing the I shaped structure the bandwidth has been increased. Quality factor will be reduced and bandwidth will be increased. The overall gain will also be reduced. Therefore it can be concluded that after placing the I shaped structure gain of the antenna is reduced. So the major disadvantage of this design was with the increase in bandwidth, gain of the antenna reduces. In this paper (Mei et al. 2017), radar cross section of the antenna has been reduced with the help of frequency selective surfaces. The broadband absorber has been placed on the antenna along with periodic strip type of structure to get a notch band. Notch band is working in only vertical polarization. In horizontal polarization there will be only wide absorption band. The absorber structure acts like a ground plane for a dipole antenna. Radar cross section of the antenna has been observed when absorber structure acts like a ground plane for a dipole antenna. The frequency of operation of the antenna is chosen to be overlapping with the notch band of the absorber. Monostatic RCS for vertical polarization and horizontal polarization was observed. For horizontal polarization, the RCS of antenna with and without absorber is seen. The significant reduction in RCS was observed in both in band and out band for the horizontal polarization. For vertical polarization RCS is reduced only in the out band, RCS is not reduced in band. In this paper (Young et al. 1973), meander line polarizer has been discussed. meander line polarizer is a transmission type polarization converter. In meander line polarizer wave is incident diagonally over the polarizer, this incident field is broken into two components, one is E parallel and the other is E perpendicular. E parallel is incident in parallel with the surface of the meander line structure. E perpendicular is striking the meander line surfaces orthogonally. Meander line structures are periodically arranged and their surfaces are spaced at a distance of $\lambda/4$ with respect to each other. The basic approach is to make the array of structure which appeared to be predominantly inductive to one polarizer and predominantly capacitive to orthogonal polarization. In this paper (Syed et al. 2013), the desired axial ratio is achieved with the help of jerusalem cross shaped structure with inductive arms and capacitive coupling among unit cells. The arms are tuned to provide inductive and capacitive coupling between the unit cells, which helps in achieving the polarization conversion. The unit cell sizes are close to $\lambda/2$ at the operating frequency. The wave will be incident at 45 degree to the surface of polarizer and again by adjusting the dimensions of the arms meander line type of response can be obtained. The main disadvantage of this antenna structure is high insertion loss of about -3.1 dB. In this paper (Ayoub et al. 2020), reconfigurable polarization converter has been designed. The designed antenna has periodic array of hexagonal type of structure. This structure basically works in two modes. The incident wave is a linearly polarized wave and transmitted wave is a linearly polarized wave in one state of the converter and it will be circularly polarized wave in another state of the converter. The proposed converter is a reconfigurable polarization converter. The converter is designed on a diclad 880 substrate. The antenna has hexagon type of structure with gap in the middle where PIN diodes are placed. The PIN diode can be operated in two modes. Hexagonal type of structure have been printed on both sides of the diclad substrate having thickness of 60 mil thick. In state 1, diode acts like a short circuit. In state 2, it is a hexagon structure with split in the central arm. In state 1 of the polarization converter, the magnitude of the transmission coefficient for the orthogonal component in the frequency band ranging from 13.6 to 17 GHz are both equal and close to 0 dB and phase difference among them varies between 13.3 to 19 GHz. Since the phase difference is not 90 degrees, it is not circularly polarized mode. For the state 2, magnitude of the orthogonally transmitted components are equivalent and they have phase difference varying from 85 to 100. it is providing circularly polarized wave. In this paper (Ridouane et al. 2017), innovative DGS structure has been used to design the antenna for WiMAX applications. The main aim of this paper is to design antenna which could shift the resonance frequency from 10 GHz to 3.5 GHz. The reduction in frequency can be achieved by using DGS structure. The use of DGS structure also makes the antenna compact. They have designed this antenna for WiMAX applications by shifting the frequency from 10 GHz to 3.5 GHz. In this paper (Arya and Kartikeyan Patnaik 2008), A simple dumbbell-shaped DGS structure has been used to design the antenna. The effect of dumbbell-shaped DGS structure on the antenna was observed. The efficiency of the antenna has been increased by using cavity backed model. The overall size of the antenna was reduced with the introduction of DGS. The antenna has been designed using IE3D software. The resonance frequency has been calculated by varying the structure dimensions. The change in the inductive and capacitive values of the LC circuit used depends on the size and area of the antenna structure. In this paper (Hamad and Gehad 2019), the antenna has been designed using periodic geometry. The use of a DGS structure in the antenna has provide compact antenna having low cost, antenna design involving less complexity and the antenna offering large bandwidth. FR4 substrate has been used to design the antenna. The overall structure of the antenna consists of X-shaped slots on the microstrip patch and it has four slots at the edges of the patch. The designed antenna has bandwidth ranging from 3.1 to 22.9 GHz. This antenna offered gain of 6.01 dB at a frequency of 8.8 GHz. In this paper (Gao et al. 2016), massive MIMO antenna has been designed which is having dual polarization. The designed antenna is having arrays with 132 ports. In the construction of this antenna power splitters have been used. These power splitters have vertically and horizontally connected ports. The ports connected to power splitters acts like feed provided to the antenna structure. The combination of four individual unit cells forms the subarrays in the design. The overall arrays used in the structure constitute for 18 subarrays. Many layers have been stacked one on top of the other to form stacked patch. This antenna design has 7 layers stacked one on top of the other. The metallic coupling strips are located between the two dielectric layers. Also the ground plane is also located between the two dielectric layers. The feeding ports are located at the bottom of the stacked layer. This antenna offers measured bandwidth of 159 MHz (3.55 to 3.80 GHz). The measured transmission coefficient of the antenna is -31 dB. The mutual coupling between the power splitters is observed to be -44 dB. The simulated reflection coefficient of the antenna is -17 dB at 3.75 GHz and the measured reflection coefficient of the antenna is -23 dB at 3.75 GHz. In this paper (Sarkar et al. 2015), monopole antenna loaded with split ring resonator has been discussed. The monopole antenna has also been loaded with an inter-digital capacitor. The split ring resonator has also been loaded with an inter-digital capacitor because of which the antenna structure is offering four bands.but normally monopole offers single resonance. The overall performance of the antenna has been studied by considering four cases of operation. In the first case only the monopole antenna has been considered, which resulted in single resonance. The reflection coefficient for the first case was obtained to be –20 dB at 2.8 GHz. In the second case the monopole antenna was loaded with SRR, which resulted in two resonances. The reflection coefficient for second case was obtained to be –25 dB at 1.8 GHz and –20 dB at 2.8 GHz. In the third case inter digital capacitor has been introduced in the antenna structure, which resulted in two resonances. The reflection coefficient for third case was obtained to be –15 dB at 2.4 GHz and –20 dB at 2.8 GHz. In the fourth case inter-digital capacitor has been introduced along with split ring resonator in the antenna structure, which resulted in four resonances. The reflection coefficient for fourth case was obtained to be –17 dB at 1.8 GHz, –22 dB at 2.4 GHz, –21 dB at 2.7 GHz and –15 dB at 3.3 GHz. When the designed antenna was put on microstrip patch in the form of array of four antenna elements in the orthogonal pattern, the correlation parameters of the antenna reduced compared to the single antenna structure. In this paper (Sarkar et al. 2016), dipole antenna arrays loaded with CSRR have been designed. Two power dividers have been combined and placed on the antenna patch. The two dipoles are not feed with the same because of the additional delay lines introduced in the second power divider. Due to the additional delay line, the phase will be different at both the power divider locations. If the feed is given to port one, then proper radiation patterns are obtained. But if the feed is given to port two, then it can be clearly seen that the power has reduced along + 1 as well as in the x direction. From the radiation patterns at the different frequencies, it was concluded that the designed antenna offered good diversity patterns at 2.36 GHz. The introduction of Complementary split ring resonators in the antenna structure has resulted in making the proposed antenna compact, low profile and increasing the diversity of the antenna. In this paper (Sharma et al. 2015), quad band MIMO antenna has been designed. Two rings have been used to create two bands. The structure of the antenna is in the form of orthogonal style. In order to establish the quad band operation, slots have been created on the microstrip patch. These microstrip slots are loaded with split ring resonators. The proposed antenna finds very good application in WLAN, WiMAX and c-band operations. In this paper (Sharma et al. 2016), dipole antenna has been designed to achieve polarization and pattern diversity in the antenna elements. Two dipole antenna element structures have been created on the patch and in addition to this bottom side of the patch is behaving like reflector. The reflector is like some in fire radiation at the bottom of the patch antenna. The dipoles will radiate under + Y and -Y directions respectively. Circularly polarized patch has been placed at the center of the patch antenna. This patch will be radiating at the CP antenna in the + Z direction. It is also radiating in the linearly polarized wave along the + Y and –Y direction. This three element system is very compact but it has the polarization and pattern diversity. The pattern is not only orthogonal polarization, it is also linearly polarized on one side and circularly polarized antenna on the other side. From the radiation patterns it can be clearly seen that the linearly polarized antenna is radiating in the –Y direction, + Y direction and also the Z direction it is radiating at Right Hand Circular Polarization. In this paper they have integrated pattern diversity and polarization. The simulated results of the reflection coefficient for the designed antennas are obtained to be -20 dB at 5.8 GHz. The measured results of the reflection coefficient for the designed antennas are obtained to be –35 dB at 5.8 GHz. In this paper (Dwivedy and Behera 2020), the antenna has been designed for frequency and CP re-configurability. The overall structure of the antenna consists of rectangular microstrip patch, feed network, varactor diodes. The antenna is fed with microstrip line feeds at port 1 and port 2. The ports are matched with quarter wave transformer. Four varactor diodes have been used to design the antenna. The selection of varactor diodes mainly depends on the capacitance and operating voltage. These varactor diodes are used for capacitance variation as well as frequency alteration. The primary aim of this antenna is to alter its resonant frequency or operating frequency. Therefore four varactor diodes are used to tune its frequency. In order to achieve circular polarization antenna has been fed using two ports. The two ports are fed with equal amplitude signal and 90 degree phase shift. The feeding network basically consists of phase shifting and switching circuit. The switching circuit handles the operation of + 90 or –90 degree phase shift. The proposed antenna offered a band width of –10 dB for the frequency range from 1.9 GHz to 2.5 GHz. The measured transmission coefficient of the antenna is varying from –5 dB to –6.2 dB. In this paper (Kumari et al. 2015), the sequential rotation technique has been used to achieve circular polarization within a wide bandwidth. The proposed antenna structure aims at four types of polarizations within a wide bandwidth. It is very difficult to achieve multiple polarizations with a single structure hence sequential rotation technique has been used to design the antenna. Rogers dielectric substrate has been used for the antenna design having a dielectric constant of 9.2. The radius and height of the DRA are 20 mm and 10 mm respectively. To achieve circular polarization all the four antennas are simultaneously excited from four sides by equal amplitude signals with 90 degree phase shift. The two antennas are excited at the same time with the phase difference of 180 degree to obtain vertical linear polarization. The other pair of antennas are excited with the phase difference of 180 degree to obtain horizontal linear polarization. Hence four types of polarizations are obtained within a wideband. In this paper (Bhattacharya et al. 2012), single band metasurface absorber has been designed. The metallic pattern have been printed on the unit cell of the structure. The substrate used to design this antenna is FR4. The absorption is achieved at a frequency close to 7.46 GHz. The scaling of the metallic structure has been carried out. The periodicity of the structure remains constant and only the dimensions of the structure have been scaled. Super cells have been formed which basically consists of sub-cell 1 and sub-cell 2. Sub cell 1 has been scaled by a factor of 1.2, which is deponent from the scaling factor of sub cell 2 that is 1.3. The designed structure is absorbing and resonating at two distinct frequencies. It has 48

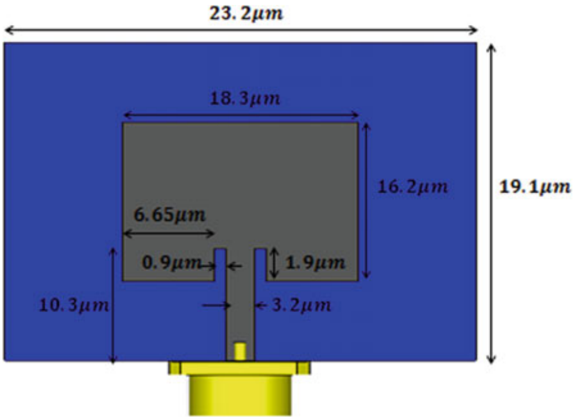

Fig. 14.1 The proposed THz microstrip wearable antenna

unit cells in the X direction and 48 unit cells in the Y direction. The dimensions of the fabricated structure is 230*230. It was observed from the electric field pattern that all the gaps are getting activated at 5.46 GHz. From the second frequency band that is at 9.54 GHz, the gaps are indicating absorption. At 7.40 GHz, the waves are adjacent on the metallic structures. Therefore all the capacitance in the structure gets excited at 7.40 GHz. Hence the structure contributes to triple band absorber.

Geometry of the Proposed THz Wearable Antenna

The suggested THz wearable antenna's top layer is comprised of copper with a thickness of 0.05μm, and it is the antenna's radiating element. The substrate is made of denim, which has a thickness of 0.6μm and a dielectric constant of 1.6. CST software was used to design the antenna. The proposed antenna's ground plane measures 23.2 × 19.1μm^2 and the copper radiating patch measures 18.3 × 16.2μm^2 (Fig. 14.1).

THz Wearable Antenna Simulation Results

At the resonance frequency of 870.3 GHz, the return loss reaches a maximum of –28 dB. At a resonance frequency of 692.7 GHz, the return loss is as low as –26 dB. The tunability of the suggested antenna to resonate at multiple frequencies in the terahertz region, 692.7 GHz, 798.3 GHz, and 870.3 GHz, has been shown. CST was used to build and simulate a terahertz microstrip patch antenna. As a substrate, the suggested antenna uses Denim with a dielectric constant of 1.6 (Figs. 14.2, 14.3, 14.4).

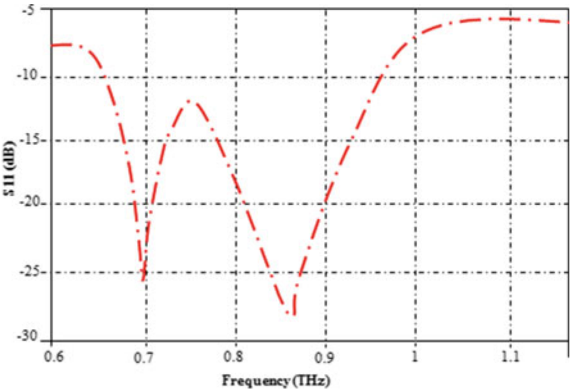

Fig. 14.2 Graph of S11 vs. Frequency

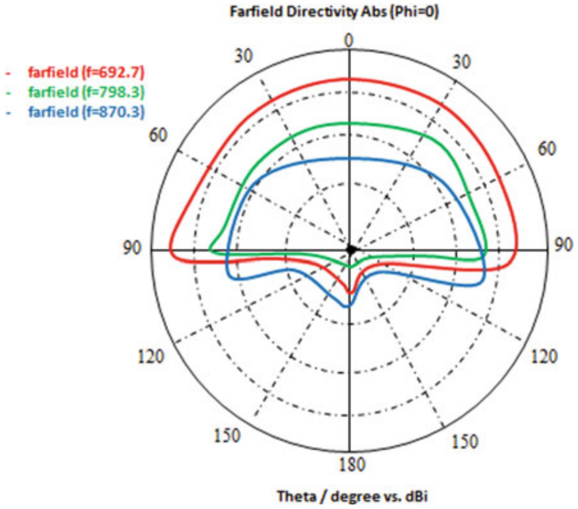

Fig. 14.3 Field radiation patterns in E-plane

SAR Analysis of the Proposed Antenna

The amount of power absorbed by human tissue per unit mass is known as the specific absorption rate. SAR values of all devices must be validated prior to fabrication and before the product is put on the market. The impact of human body interaction on wearable antennas must be investigated. According to the Federal Communications Commission, the SAR value for 1 g of tissue in the United States is 1.6 W/ kg, while the SAR value for 10 g of tissue in Europe is 2.0 W/ kg. CST microwave studio was used to determine the SAR values of the wearable device. The SAR values of the antenna obtained when placed on the forearm are 0.35, 0.61 and 0.72 at frequencies 692.7 GHz, 798.3 GHz, and 870.3 GHz respectively (Fig. 14.5).

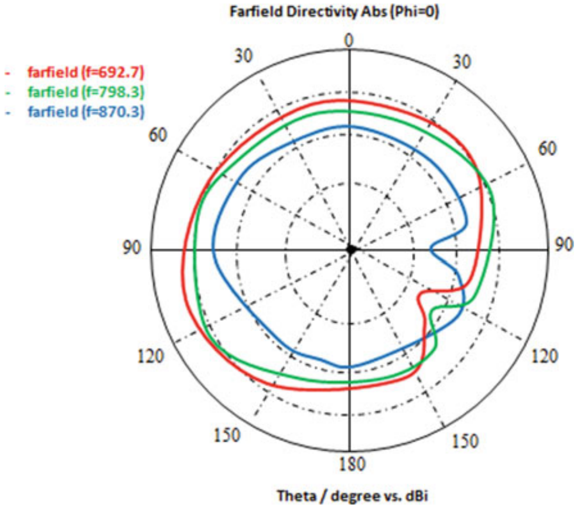

Fig. 14.4 Field radiation patterns in H-plane

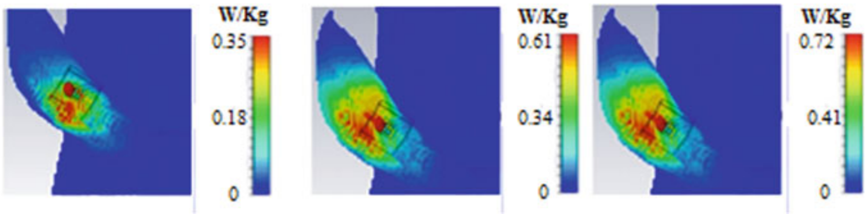

Fig. 14.5 SAR distribution on forearm

Conclusion

This chapter discusses a wearable antenna design that works well at terahertz frequencies. The tunability of the suggested antenna to resonate at multiple frequencies in the terahertz region, 692.7 GHz, 798.3 GHz, and 870.3 GHz, has been shown. CST was used to build and simulate a terahertz microstrip patch antenna. As a substrate, the suggested antenna uses denim with a dielectric constant of 1.6. The antenna reflection coefficient at resonant frequencies was also evaluated by analysis. The developed antenna's performance makes it ideal for wearable applications.

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