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Design And Implementation Of Microstrip Patch Antenna For Conformal Surfaces

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Abstract: This research describes a unique conformal antenna design that delivers higher bandwidth and gain while using a compact and mild flexible substrate appropriate for Military aviation Communication. Conformal antennas are widely used in satellite communication because they may be built to adapt to the curvature of the surface, allowing for better aerodynamics and lower drag. The antenna's conformal design allows it to be fitted into a variety of military platforms, offering effective communication and sensor capabilities. The antenna substrate is made of RT5880(lossy) flexible Rogers with a dielectric constant of 2.2 and a loss tangent of unity. Rogers RT/duroid is a high frequency laminate material that is frequently used as an antenna substrate. The material is appropriate for high-frequency applications due to its low dielectric constant, low loss tangent, and great thermal stability. Copper is used to create the Patch and Ground planes. The antenna was measured and simulated with one element powered and the surrounding elements terminated in 50-ohm resistive loads. The microstrip patch antenna components' estimated reflection coefficients suggested a narrowband match at 5.2 GHz. The antenna's performance is optimized during the design process by using electromagnetic simulation software. The radiation pattern, gain, and impedance matching are all evaluated throughout the analysis.

***Index Terms* - Conformal Antenna, CST, Military Application, RT Duroid.**

I. INTRODUCTION

An antenna is a sort of transducer that transforms RF (radio frequency) signals into alternating current (AC). For sending or receiving radio broadcasts, there are receiving and transmission antennas. Antennas are essential to the operation of all radio equipment. They are utilized in satellite communication, mobile telephony, and wireless local area networks. The antenna and its feed line are referred to as an antenna system. Because an antenna is typically connected to a transmission line, the optimum technique to build this connection is of interest, because the signal from the feedline must be radiated into space in an efficient and desired manner. It is preferable to combine the antenna and its feedline in some applications where space is constrained, such as hand portables and aircraft. In other applications such as the reception of TV broadcasting, the antenna is far away from the receiver and a long transmission line must be used.

Undoubtedly, the public has used antennas extensively over the past 10 years for things like cellular, GPS, satellite, wireless LAN for PCs, Bluetooth, radio frequency ID devices, WiMAX, and other things. However, future demands will be even larger when a plethora of antennas are incorporated into autos to meet a variety of communication needs. A microstrip patch antenna is a form of antenna that is made from a tiny, flat metal patch put on a dielectric material substrate. [11] The patch is linked to a transmission line that supplies radio frequency (RF) energy to the antenna. The patch of the microstrip antenna is commonly square or rectangular in form, with a length of one-half to one wavelength of the RF signal being broadcast. The patch is typically put on top of the dielectric substrate, with a ground plane on the bottom. The ground plane acts as a reflector for the antenna, which improves its performance.

Microstrip patch antennas provide various benefits over other antenna designs. One advantage is that they are lightweight and compact, making them appropriate for use in small electrical devices. They are also relatively simple to produce using printed circuit board (PCB) technology, making them cost-effective. Microstrip patch antennas come in many different forms, including rectangular, circular, and triangular. The antenna's shape can influence its performance parameters such as polarization and radiation pattern.

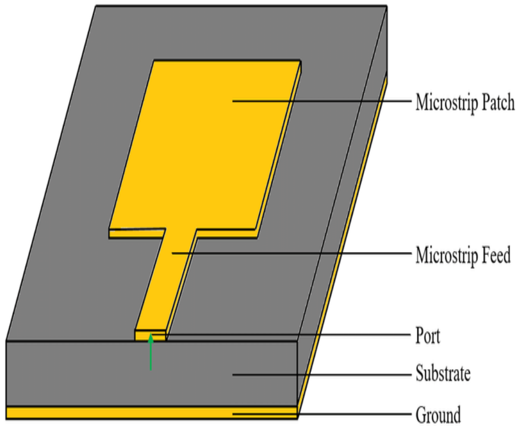

Figure. 1 Microstrip Patch Antenna Layout

II. DESIGN OF CONFORMAL ANTENNA

2.1 Overview

A conformal antenna is one that is designed to adapt to the contour of the object to which it is attached. It is sometimes referred to as a conformal patch antenna or a conformal array antenna. The purpose of a conformal antenna is to minimize the antenna's impact on the aerodynamics or other physical aspects of the item while offering effective communication or sensing capabilities. Conformal antennas can be created in several forms and sizes, such as patches, spirals, or slots, and can function across a wide frequency range. They are frequently employed in radar systems, satellite communication, and wireless networks. One of the primary benefits of conformal antennas is their ability to retain high performance characteristics while being incorporated into the surface of the item on which they are placed. This is especially critical for applications like airplanes or spacecraft because protruding antennas might impair the object's aerodynamics. Conformal antennas can be built to blend in with the surface of an object, lowering drag and reducing the radar cross-section. [12]

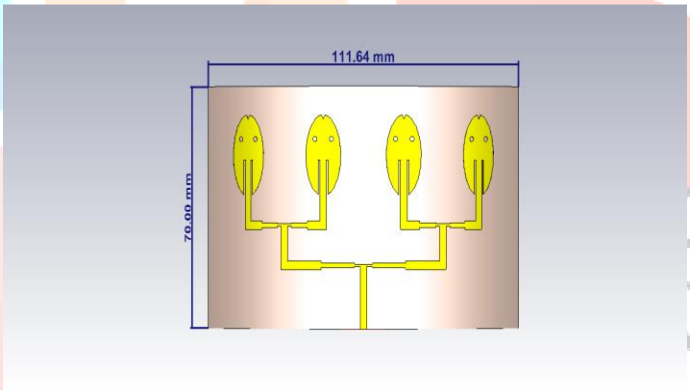

Figure. 2 Front View of the Simulated Antenna

Conformal antennas also have the benefit of providing better coverage than standard antennas. They can give greater coverage over a broader variety of angles and frequencies by adapting to the contour of the item they are installed on. There are various varieties of conformal antennas, each with its own set of pros and limitations. [13] The conformal patch antenna, which consists of a flat patch of metal installed to the surface of the item, is one of the most frequent forms. This sort of antenna is relatively simple to design and produce, and it may be utilized across a large frequency range.

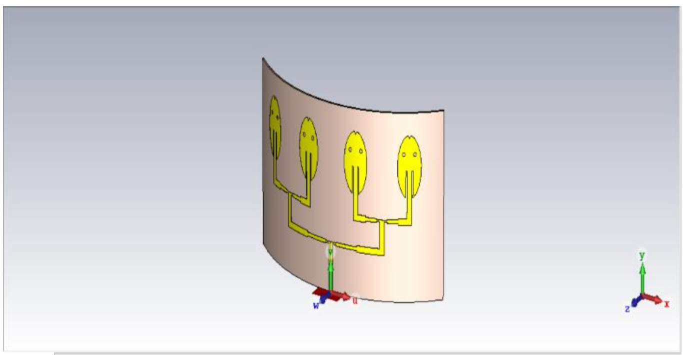
Figure. 3 Perspective View of the Simulated Antenna

2.2 Substrate Material

The application determines the substrate material that is chosen. The conformal antennas require flexible substrates; low frequency antennas require high dielectric constant substrates to reduce the size of the antenna. The first design step is to 7 choose a suitable dielectric substrate of appropriate thickness h and loss tangent. In addition to being mechanically sturdy, a thicker substrate will radiate more power, suffer less conductor loss, and have better impedance bandwidth. However, it will add to the weight, dielectric loss, surface wave loss, and excess radiation of the probe feed. The substrate dielectric constant, like substrate thickness, has an effect. A low substrate dielectric constant raises the fringing field at the patch's edge and, consequently, the radiated power. Therefore, substrates with dielectric constants less than 2.5 are preferred, unless a smaller patch size is necessary. Similar to a decrease in the value of the dielectric constant, an increase in substrate thickness has an impact on antenna properties. Antenna efficiency is lowered by a high loss tangent because it causes more dielectric loss. [11]

2.3 Design of the Antenna

A rectangular patch antenna's attributes are affected by all of its parameters (L, W, h, permittivity). As a result, in order to comprehend the design process, this page provides a general overview of how the parameters affect performance. First, the length of the patch L influences the resonance frequency. This is true for all microstrip antennas, even the more sophisticated ones that wrap around the longest path of the microstrip to control the lowest operational frequency. The patch length and resonance frequency are related by the following equation: [10-13]

$$f_c = \frac{1}{2L\sqrt{\varepsilon_r \varepsilon_0 \mu_0}} \longrightarrow 1$$

Where,

εr=relative permittivity
$\varepsilon 0$=vaccum permittivity
fc=operating frequency
$\mu 0$=permeability

The width W determines the input impedance and the radiation pattern (the radiation equations are available here). The lower the input impedance, the wider the patch becomes. The permittivity εr of the substrate controls the fringing fields - lower permittivity's have wider fringes and therefore better radiation The bandwidth of the antenna is also increased by decreasing permittivity. Efficiency is increased when the permittivity value is lower. Higher permittivity results in an increase in the antenna's impedance. [6] Higher permittivity levels allow for "shrinking" of the patch antenna. Designers are given extremely little room in cell phones and want the antenna to be a half-wavelength long. One method is to employ a substrate with extremely high permittivity. To demonstrate this, answer the equation above for L:

$$L = \frac{1}{2\sqrt{f_c \varepsilon_r \varepsilon_0 \mu_0}} \longrightarrow 2$$

As a result, increasing the permittivity by a factor of four reduces the length required by a factor of two. Higher permittivity values are widely used in antenna miniaturization.
The bandwidth is also controlled by the height of the substrate h; raising the height increases the bandwidth. The general notion that "an antenna occupying more space in a spherical volume will have a wider bandwidth" can be used to explain why increasing the height of a patch antenna increases its bandwidth. [1] The same logic holds true when noting that increasing the thickness of a dipole antenna increases its bandwidth. The antenna's effectiveness also rises with its height. Height increases do cause surface waves to propagate into the substrate (unwanted radiation that may link to other components). The following equation approximates how bandwidth scales with given parameters:

$$B \,\alpha\, \frac{\varepsilon_r - 1}{\varepsilon_r^2}\frac{W}{L}h \longrightarrow 3$$

The following steps are taken to design a rectangular micro strip patch antenna.

Step1: Calculation of width of the Antenna (W):

The width of the micro strip patch antenna (Copper Material) is given by the equation as
W – Width of the patch.
C - Light's velocity in free space, 3 x 10^8 m/s.
$f0$ -The resonance frequency.
εr - The dielectric substrate's relative permittivity.

$$W = \frac{c}{2f_0\sqrt{(\varepsilon_r + 1)/2}} \longrightarrow 4$$

Step 2: Calculation of the Effective Dielectric Constant of the Antenna:
Based on the patch antenna's predicted width, height, and dielectric constant of the dielectric.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \longrightarrow 5$$

Step 3: Calculation of the Effective length of the Antenna *L*:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} \longrightarrow 6$$

Step 4: The length extension of the Antenna L is calculated as follows:
The length extension is provided by the following equation:
h - Thickness
W- width

$$\Delta L = 0.412h\,\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \longrightarrow 7$$

Step 5: Calculation of actual length of the patch of the Antenna:
L – Length of the patch.

$$L = L_{eff} - 2\Delta L \longrightarrow 8$$

2.4 Feeding Technique

The advantage of corporate or parallel fees as excitation networks for microstrip arrays are great design flexibility and ease of vertical integration to form a two-dimensional array. Several examples of microstrip arrays excited by a coplanar corporate feed were demonstrated in the past. One of the key features of these antennas is that corporate feeds were realized with the design of several power splitters based on transmission line theory or the equivalent waveguide model to obtain a specified magnitude and phase distribution for the output currents. [7]

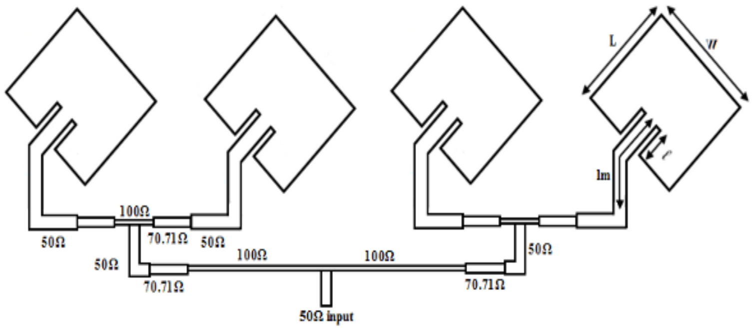

Figure. 4 Corporate Feeding Technique

However, at high frequencies, both methods may show significant deviation from the measured results since they do not rigorously account for discontinuity effects. In this paper, we characterize each discontinuity in the corporate feed using a more accurate full-wave technique. An electric field integral equation is created using the spectral-domain dyadic green's function, which takes both radiation and surface-wave effects into account. The moment approach is then used to determine the current distribution on the microstrips as well as the scattering characteristics of the junctions. In order to synthesize a Dolph-Chebyshev array sum pattern, intensive care is devoted to shaping each junction in the corporate feed such that the currents can reach the output ports in phase and with a desired tapered magnitude distribution. Initially, the corporate feed is built as a mix of various simple multiport microstrip connections such as right-angle bends, T junctions, and cross junctions. All the junctions are connected with the uniform microstrip lines which are assumed to be loss-free transmission lines.

The separation from one junction to another is at least one-half guided wavelength long such that the mutual coupling between any two junctions may be ignored. In this scheme, network theory may be applied to cascade the effects of individual junctions to predict the output current distribution of the corporate feed. The microstrip junctions may need to be shaped, and then the scattering parameters related to the remodeled junctions may need to be calculated, in order to produce the appropriate current distribution in the output ports. For the sake of design flexibility, each junction in a corporate feed is limited to an irregular shape which can be divided into several rectangles. Thus, one can easily modify the junction geometry by adding or removing some rectangles. In the moment-method procedure, we employ the rectangular subdomain functions, a combination of pulse and piecewise sinusoidal functions, to model the electric surface current density in the vicinity of an irregular junction The semi-infinite traveling-wave functions are used to simulate the current distribution along the microstrip lines. Corporate-feed arrays are general and versatile. This approach allows for greater control over each element's feed and is perfect for scanning phased arrays and multiband arrays. In comparison to a series feed array, it offers superior directivity, radiation efficiency, and lowers beam variations over a range of frequencies. Phase shifters can be used to change the phase of each element, and amplifiers or attenuators can be used to change the loudness. [1-4,11,13]

This expansion mechanism allows for the direct solution of the scattering parameters from the method of moments. It has been shown that a microstrip radiator fed by parasitic coupling through the substrate by an embedded microstrip line can be matched Based on this concept, a linear array of microstrip dipoles is ideally suited to a corporate feed because, under the input match condition, there are no reflected currents from the line dipole junctions to cause a disturbance to the feed performance. As an example, we demonstrate a design of an embedded microstrip corporate feed to excite a five element equispaced array of microstrip dipoles.

III. ANALYSIS OF ANTENNA

3.1 Return Loss

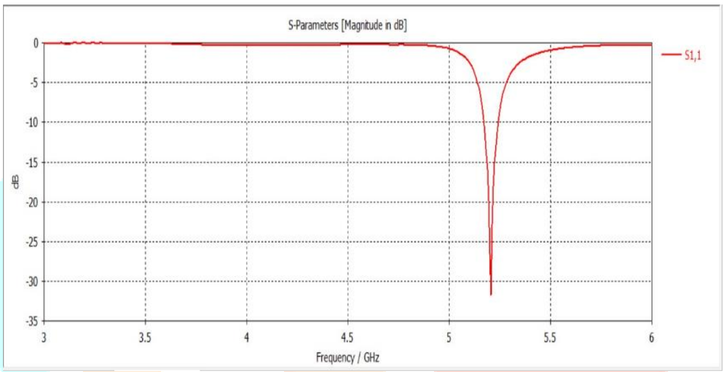

Figure. 5 Return Loss of the Simulated Antenna

Figure 6 shows the S- Parameter (Return loss) of the designed antenna. It indicates that it can be operated at frequency of 5.2 GHz with a return loss of about – 32.2 dB. Generally, bandwidth of the antenna is found from the return loss graph. Bandwidth is obtained from the intersection of return loss graph with - 10dB of the graph. The difference between the upper cutoff frequency and lower cutoff frequency gives the bandwidth of the antenna.

3.2 Gain

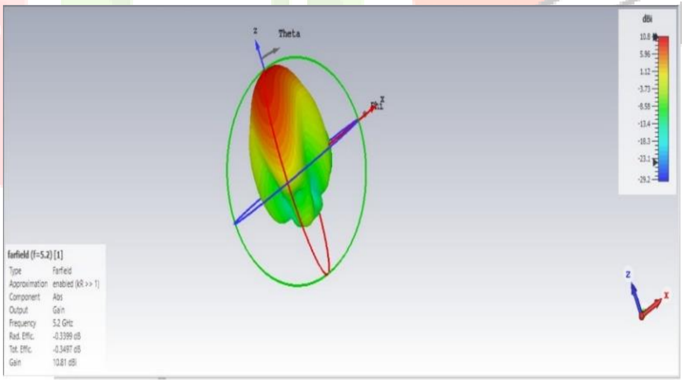

Figure. 6 Farfield at frequency 5.2 GHz of the Simulated Antenna

Gain, often known as 'absolute gain,' is defined as a comparison of radiation intensity in a specific direction to radiation intensity produced if the antenna's absorbed power disappeared isotropically. An isotropic antenna radiates in all directions equally. An isotropic radiator is thought to be completely efficient. An real antenna's gain improves power density in the direction of peak radiation. The gain of the antenna is related to its directivity.

$$Gain = 4\pi \frac{radiation\ intensity}{total\ input\ accepted\ power} \longrightarrow 9$$

Figure represents the 3D radiation patten of gain of the design antenna with substrate as Rogers. The simulated gain of 10.81 dB is obtained for frequency 5.2GHz (Rogers).

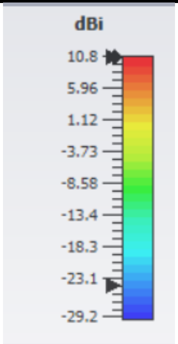

Figure. 7 Measured gain of the Simulated Antenna

3.3 VSWR

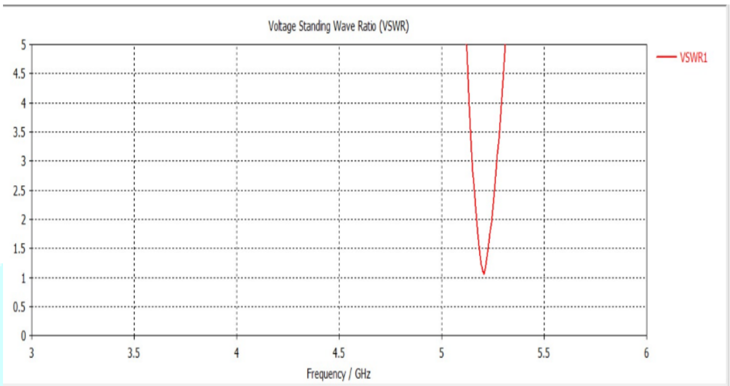

Figure. 8 VSWR of the Simulated Antenna

Voltage Standing Wave Ratio (VSWR) is also known as Standing Wave Ratio (SWR). The reflection coefficient, which represents the power reflected from the antenna, determines VSWR.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \longrightarrow 10$$

where,

Γ- Reflection Coefficient

The reflection coefficient, which describes the power reflected from the antenna, determines VSWR. From the Fig.8 it is seen that the antenna yields minimum VSWR value of 1.105 for the frequency 5.2 GHz.

3.4 Directivity

The degree to which the radiation emitted is focused in a single direction is measured by directivity, which is a parameter of an antenna or optical system. It is the ratio of the intensity of radiation from the antenna in a particular direction to the average intensity of radiation in all directions. As a result, an isotropic radiator has a directivity of 1, or 0 dBi. Simply put, a non-isotropic source's directivity is equal to the proportion of its radiation intensity in any particular direction compared to that of an isotropic source.

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}|F(\theta,\emptyset)|^2 \sin\theta \, d\theta d\emptyset} \longrightarrow 11$$

where,

D – Directivity

F(θ) - Normalized radiation pattern.

Directivity compares the power density radiated by an ideal isotropic radiator radiating the same total power to the power density radiated by the antenna in the direction of the highest emission.

From Fig. 9 , it is seen that the antenna radiates much along the patch side and radiates less along the downside of the antenna. For Rogers, the simulated results show a directivity of 11.15 dBi for frequency 5.2 GHz.

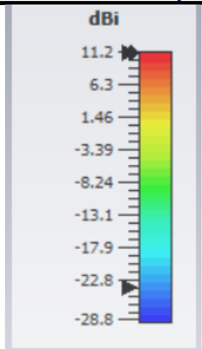

Figure. 9 Directivity of the Simulated Antenna

3.5 Side Lobe Level

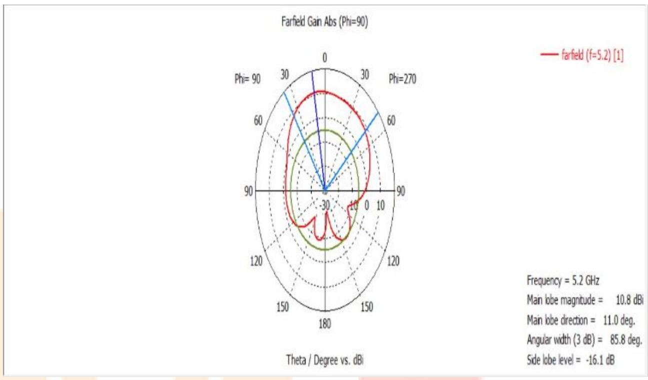

Figure. 10 Farfield Gain Abs of the Simulated Antenna

An antenna's radiation pattern indicates the energy emitted by the antenna. Radiation Patterns are diagrammatic illustrations that depict the distribution of radiated energy in space as an effect of direction. Generally, 2-D graph represents the polar plot. The magnitude of the main lobe and side lobe is obtained from the polar plot. Fig 10 represents the 2D plot for gain for Rogers. Since the main lobe magnitude greater than side lobe level, the antenna has better efficiency.

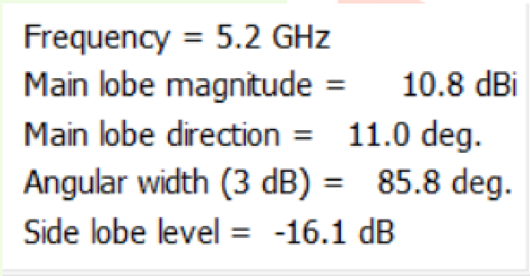

Figure. 11 Side Lobe Level of the Simulated Antenna

IV. Conclusion And Future Scope

Conformal antennas have gained popularity in recent years due to their unique characteristics, which include conformal fitting to complex and curved surfaces, a low profile, and reduced aerodynamic drag. These antennas are used in a variety of fields, including aerospace, military, and communication systems. Here are some potential future projects in conformal antenna research:

1) Conformal Broadband Antennas: A critical research direction is the development of conformal antennas with wideband capabilities. Wideband antennas are needed for a variety of communication and sensing applications, and conformal wideband antennas would be especially beneficial for aircraft and spacecraft.
2) Multiband Conformal Antennas: Another research direction is to develop conformal antennas that can operate on multiple frequency bands. Multiband antennas can provide multiple functions in a single package and can be used in a wide range of applications.
3) Adaptive Conformal Antennas: Adaptive conformal antennas can adjust their radiation properties according to the surrounding environment, making them suitable for dynamic environments such as moving vehicles and aircraft. Developing adaptive conformal antennas would require research in materials science, signal processing, and control systems.
4) Ultra-Thin Conformal Antennas: Developing conformal antennas that are ultra-thin would have significant implications for space applications, where weight and size are critical factors. Achieving ultra-thin antennas would require the development of new materials and fabrication techniques.
5) Conformal Antennas with Integrated Electronics: Integrating electronics into the conformal antenna structure, such as amplifiers, filters, and phase shifters, would result in a compact and low-power antenna system. This would necessitate research in materials science, fabrication techniques, and design.
6) Conformal Antennas for 5G and Beyond: The introduction of 5G and beyond communication systems would necessitate

the use of conformal antennas capable of operating at high frequencies and providing high data rates. Conformal antenna development for 5G and beyond would necessitate research in antenna design, materials, and signal processing.

7) Wearable Conformal Antennas: Wearable antennas are becoming increasingly popular in applications such as health monitoring. Creating conformal antennas that can be worn on the body would necessitate material, design, and signal processing research.

In summary, the future of conformal antenna research entails creating antennas with increased bandwidth, multiband operation, adaptive radiation properties, ultra-thin profiles, integrated electronics, high-frequency operation, and wearable capabilities. To achieve these objectives, research in materials science, fabrication techniques, signal processing, and design would be required. The development of conformal antennas with these characteristics would have far-reaching implications for a variety of applications, including communication, aerospace, and healthcare.

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