Compact Microstrip Antenna Design at 120 GHz for Sub Terahertz 6G Applications

P.Aarthi
PG Student
Department of Electronics and Communication Engineering
Alagappa Chettiar Government College of Engineering and Technology, Karaikudi
aarthipichairaj5991@gmail.com

R.Abisha
PG Student
Department of Electronics and Communication Engineering
Alagappa Chettiar Government College of Engineering and Technology, Karaikudi
abishareginald@gmail.com

Dr.D.Helena Margaret
Associate Professor
Department of Electronics and Communication Engineering
Alagappa Chettiar Government College of Engineering and Technology, Karaikudi
helenamargaret@accet.ac.in

Dr.P. Bhuvaneswari
Professor
Department of BME
ACS College of Engineering
Bangalore

Dr. Shanthi P
Associate Professor
Department of E& T
RV College of Engineering
Bangalore

Abstract — **The advancement toward sixth generation (6G) wireless communication systems is driving research into sub terahertz (sub THz) frequency bands, where the 120 GHz spectrum provides substantial bandwidth for ultra high data rate applications. However, antenna design at such extreme frequencies presents significant challenges due to increased propagation losses, dielectric losses, and stringent dimensional constraints. This paper presents the design and simulation of a compact rectangular microstrip patch antenna operating at 120 GHz. The antenna is implemented on a thin Rogers RT/Duroid 5880 substrate (εr = 2.2, h = 0.127 mm) to minimize dielectric loss at millimeter wave frequencies. The proposed design achieves a simulated impedance bandwidth of 5.4 GHz (4.5% fractional bandwidth) with a return loss of −15.4 dB and a VSWR of 1.4. A realized gain of 7.36 dBi is obtained, demonstrating stable radiation performance suitable for short range, high capacity sub THz 6G communication links.**

Keywords — 6G Communication, Sub Terahertz Antenna, 120 GHz, Microstrip Patch Antenna, Millimeter Wave

I. INTRODUCTION

The rapid evolution of wireless communication technologies is driving research toward sixth generation (6G) communication systems. Compared to existing 5G networks, 6G is expected to provide extremely high data rates exceeding 100 Gbps, ultra low latency, high spectral efficiency, and massive connectivity to support future applications such as holographic communication, extended reality (XR), autonomous systems, smart cities, and high resolution sensing systems [1]. Achieving these ambitious performance targets requires the exploration of new spectrum resources beyond the conventional microwave and millimeter wave frequency bands.

In this context, the sub terahertz (sub THz) frequency region above 100 GHz has emerged as a promising candidate for next generation wireless communication systems. The availability of large contiguous bandwidth in this region enables ultra high capacity short range communication links that are essential for future high speed data services [2]. Among the potential candidate bands, the 120 GHz band has attracted significant attention due to its ability to support high data throughput and compact antenna integration within wireless communication modules.

The reduced wavelength at 120 GHz enables the design of highly compact antenna structures, which facilitates dense integration in modern wireless devices and communication systems. However, antenna design at sub THz frequencies introduces several technical challenges. These include increased free space path loss, higher conductor and dielectric losses, surface wave excitation, and increased fabrication sensitivity due to extremely small physical dimensions [3]. Therefore, careful antenna design, substrate selection, and geometrical optimization are required to achieve acceptable impedance matching and radiation performance at these frequencies.

Several antenna structures operating in the millimeter-wave and sub THz frequency bands have been reported in the literature. Planar antenna configurations such as microstrip patch antennas, slot antennas, and integrated on chip antennas have been investigated for operation in the 110–140 GHz range [4]. Microstrip patch antennas remain widely studied due to their low profile structure, simple geometry, low fabrication cost, and compatibility with integrated microwave circuits [5]. Previous studies have also explored advanced design techniques such as antenna arrays, substrate engineering, and bandwidth enhancement methods to improve radiation characteristics and gain performance in sub THz systems [6].

Although these approaches can improve antenna performance, many designs involve complex structures or array configurations that increase design complexity and fabrication difficulty. In addition, maintaining stable impedance matching and radiation efficiency becomes increasingly challenging as the operating frequency approaches the sub THz region.

To address these challenges, this work proposes the design and simulation of a compact rectangular microstrip patch antenna operating at 120 GHz using a thin low loss Rogers RT/Duroid 5880 substrate. The proposed antenna focuses on achieving stable impedance matching and acceptable radiation characteristics while maintaining a structurally simple configuration. Such compact antenna elements can serve as fundamental radiating units for future antenna arrays and integrated sub THz communication modules in emerging 6G wireless systems.

II. ANTENNA DESIGN

The proposed compact microstrip patch antenna was designed and analyzed using the CST Studio suite platform. At sub terahertz frequencies such as 120 GHz, accurate electromagnetic simulation is essential due to high sensitivity to dimensional tolerances and material properties

The antenna consists of three primary layers:

Radiating Patch
Dielectric Substrate
Ground Plane

A rectangular patch configuration was selected due to its structural simplicity and ease of integration with planar circuits. All antenna dimensions were initially calculated using classical transmission line model equations and then optimized through full wave simulation to achieve resonance at 120 GHz.

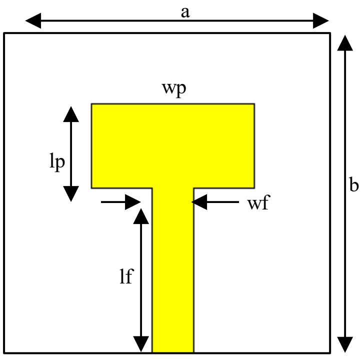

Fig.1. Antenna geometry

The geometric structure of the proposed antenna was modeled in CST Studio Suite, and the antenna layout used for simulation is illustrated in Fig. 1.

The initial dimensions of the antenna were calculated using the following standard microstrip antenna design equations.

A. Width of the Patch

The width of the rectangular patch significantly influences the radiation efficiency and bandwidth of the antenna. The approximate width of the patch can be calculated using

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where,
W_p=width of the patch
c= speed of light in free space (3×10^8 m/s)
f_r= resonant frequency
ε_r= dielectric constant of the substrate

B. Effective Dielectric Constant

Due to the presence of fringing fields around the edges of the patch, the effective dielectric constant must be considered. It can be calculated using

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W_p}\right)^{-1/2}$$

where
h= substrate thickness
W_p= patch width

C. Effective Length of the Patch

The effective length corresponding to the resonant frequency is expressed as,

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}}$$

D. Length Extension

Because of fringing fields, the electrical length of the patch appears slightly larger than its physical length. The extension in length can be estimated as,

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)(W_p/h + 0.264)}{(\varepsilon_{eff} - 0.258)(W_p/h + 0.8)}$$

E. Actual Length of the Patch

The physical length of the patch is obtained by subtracting the fringing field extension from the effective length

$$L_p = L_{eff} - 2\Delta L$$

F. Ground Plane Dimensions

To minimize edge effects and ensure stable radiation characteristics, the ground plane dimensions are typically chosen larger than the patch dimensions. The approximate substrate dimensions can be expressed as

$$L_s = L_p + 6h$$
$$W_s = W_p + 6h$$

where
L_s= substrate length
W_s= substrate width

After analytical calculation and parametric optimization in CST, The optimized antenna dimensions used in the simulation are summarized in Table I.

Table I. Optimized Antenna Parameters

Parameters	**Values**
Substrate Width(a)	2.51 mm
Substrate Length (b)	3.27 mm
Patch Width(wp)	1.20 mm
Patch Length(lp)	0.62 mm
Feed Width(wf)	0.30 mm
Feed Length(lf)	1.26 mm
Substrate Thickness	0.127 mm
Material	Rogers RT/Duroid 5880 (εr = 2.2)

The CST simulation model of the antenna is illustrated in Fig. 2.

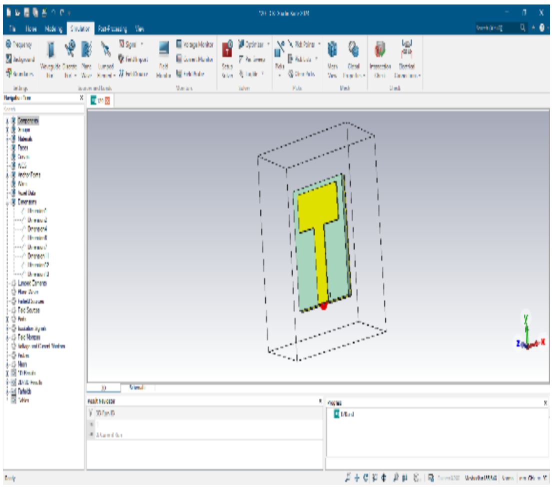

Fig. 2. CST view of the designed antenna

III. RESULT AND PERFORMANCE ANALYSIS

The performance of the proposed 120 GHz microstrip patch antenna was analyzed using CST Studio Suite. The simulation results were evaluated in terms of reflection coefficient (S_{11}), impedance bandwidth, voltage standing wave ratio (VSWR), gain, and radiation characteristics. These parameters are essential to determine the suitability of the antenna for sub terahertz wireless communication systems.

A.Reflection Coefficient (S_{11})

The reflection coefficient (S_{11}) indicates the amount of power reflected back from the antenna input. For efficient antenna operation, the return loss should be below −10 dB.

The simulated reflection coefficient (S_{11}) of the proposed antenna is shown in Fig.3. The simulated S_{11} plot shows that the proposed antenna resonates at 120 GHz with a minimum return loss of −15.4 dB. This confirms that the antenna achieves satisfactory impedance matching at the desired operating frequency.

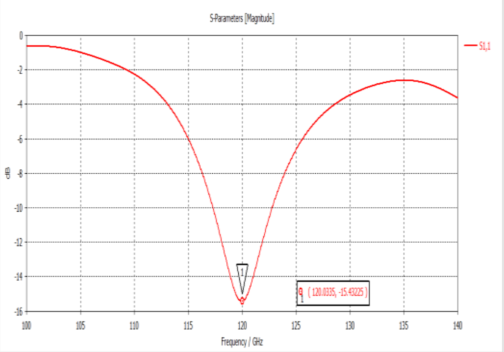

Fig. 3. Return Loss of the designed antenna at 120 GHz

B.Impedance Bandwidth

The impedance bandwidth is defined as the frequency range over which the reflection coefficient remains below −10 dB. From the simulated results, the proposed antenna achieves a bandwidth of 5.4 GHz around the center frequency of 120 GHz.

This corresponds to approximately 4.5% fractional bandwidth, which is typical for conventional rectangular microstrip patch antennas operating in the millimeter wave and sub terahertz frequency regions.

C.Voltage Standing Wave Ratio (VSWR)

The voltage standing wave ratio (VSWR) describes the level of impedance matching between the antenna and the transmission line. For good antenna performance, the VSWR should be less than 2.

The simulated VSWR value at 120 GHz is 1.4 is shown in Fig.4., which indicates efficient power transfer and minimal signal reflection from the antenna input port.

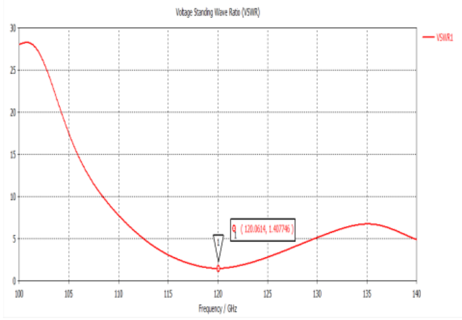

Fig. 4. VSWR of the designed antenna at 120 GHz

D.Gain and Directivity

The simulated radiation performance shows that the antenna achieves a realized gain of 7.36 dBi and a directivity of 7.49 dBi at the operating frequency which shown in Fig.5.

The small difference between gain and directivity indicates low radiation losses and acceptable efficiency for a compact single-element microstrip antenna operating at sub-terahertz frequencies.

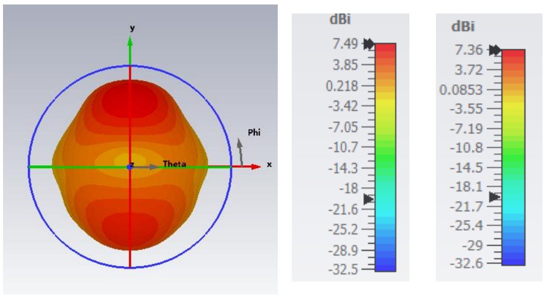

Fig. 5. Gain and Directivity of the designed antenna at 120 GHz

E.Radiation Pattern

The radiation pattern of the proposed antenna is shown in Fig. 6. And Fig.7. which exhibits a stable broadside characteristic, which is typical for rectangular microstrip patch antennas. The antenna radiates primarily perpendicular to the patch surface, making it suitable for integration in planar communication

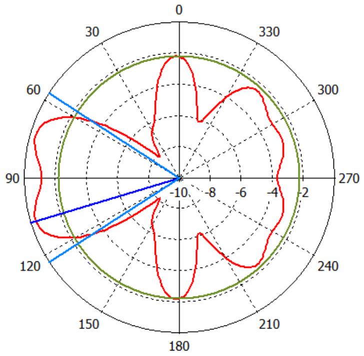

Fig. 6..E-Plane of the designed antenna

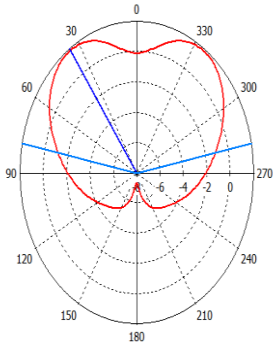

Fig.7.H-Plane of the designed antenna

Simulation summary of the designed antenna are summarized in table II.

Table II. Simulation Summary of the Designed Antenna

Parameter	**Simulated Value**
Resonant Frequency	120 GHz
Return Loss (S11)	−15.4dB
Bandwidth	5.4GHz
Gain of the Designed Antenna	7.36 dBi
Voltage Standing Wave Ratio (VSWR)	1.4

IV. CONCLUSION

In this paper, a compact rectangular microstrip patch antenna operating at 120 GHz has been designed and analyzed for potential sub-terahertz 6G communication applications. The antenna was implemented on a Rogers RT/Duroid 5880 substrate with a dielectric constant of 2.2 and thickness of 0.127 mm to reduce dielectric losses at millimeter wave frequencies. The design was initially calculated using classical transmission line model equations and further optimized using CST Studio Suite simulation.

The simulated results show that the antenna resonates at 120 GHz with a return loss of −15.4 dB and a VSWR of 1.4, indicating good impedance matching. The antenna achieves an impedance bandwidth of 5.4 GHz and provides a realized gain of 7.36 dBi with a directivity of 7.49 dBi. The radiation pattern exhibits stable broadside characteristics suitable for short range high capacity communication links.

The compact size and simple structure make the proposed antenna a suitable candidate for integration in future sub terahertz wireless systems and potential antenna array configurations for 6G communication architectures.

Future work may focus on the practical fabrication and experimental validation of the proposed antenna to verify the simulated performance. Further research can also explore the development of antenna array configurations based on the proposed element to achieve higher gain required for long distance sub terahertz communication links. Additionally, optimization of antenna parameters and integration with beamforming techniques may improve coverage and performance for potential 6G wireless communication systems.

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