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Design of A Ka Band Microstrip Patch Antenna Integrated with FSS for Military Drone Communication Systems

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Abstract: This project presents the design and simulation of a compact, high performance microstrip patch antenna operating at 32 GHz within the Ka band, specifically tailored for military drone communication systems. The antenna is constructed using Rogers RT/duroid 5880 substrate, characterized by a low dielectric constant (εr = 2.2) and minimal loss tangent (tan δ = 0.0009), ensuring superior radiation efficiency and reduced signal attenuation at millimeter-wave frequencies. To enhance the antenna's performance, a Frequency Selective Surface (FSS) is integrated, serving to improve gain and bandwidth while mitigating electromagnetic interference. The design achieves a peak gain, a return loss better than -17 dB, and a bandwidth exceeding 2 GHz, indicating its efficacy for reliable and secure military drone communications. The antenna's low-profile and lightweight design make it suitable for integration into unmanned aerial vehicles (UAVs), where size and weight constraints are critical. The proposed antenna system holds promise for applications requiring robust, high frequency communication links in compact airborne platforms.

Keywords: Ka-band, Microstrip Patch Antenna, Military Drone Communication, Rogers RT/duroid 5880, Frequency Selective Surface (FSS), Compact Antenna Design, High-Frequency Communication, Lightweight Antenna.

1. Introduction:

In modern military operations, unmanned aerial vehicles (UAVs) have become indispensable for intelligence, surveillance, and reconnaissance missions. The effectiveness of these drones heavily relies on robust, high-frequency communication systems that ensure real-time data transmission and control. The Ka-band, operating between (26.5 - 40GHz), offers substantial bandwidth and high data rates, making it ideal for such applications. In modern military operations, unmanned aerial vehicles (UAVs) have become indispensable for intelligence, surveillance, and reconnaissance missions [1,2]. The effectiveness of these drones heavily relies on robust, high-frequency communication systems that ensure real-time data transmission and control.

The Ka-band, operating between (26.5 - 40GHz), offers substantial bandwidth and high data rates, making it ideal for such applications [3]. Microstrip patch antennas are particularly suited for UAVs due to their low profile, lightweight, and ease of integration into the aircraft's structure [4]. These antennas can be fabricated using photolithographic techniques on printed circuit boards, allowing for compact and efficient designs [5]. However, traditional microstrip antennas often face limitations in gain and bandwidth. To overcome these challenges, integrating Frequency Selective Surfaces (FSS) into the antenna design has proven effective [6,7]. FSS structures can enhance antenna performance by filtering specific frequency bands and improving radiation characteristics.

This project focuses on the design and development of a Ka-band (32GHZ) microstrip patch antenna integrated with an FSS for military drone communication systems. By leveraging the advantages of microstrip technology and the performance enhancements offered by FSS, the proposed antenna aims to provide reliable and efficient communication capabilities for military drones.

1.1 Microstrip patch Antenna

A microstrip patch antenna typically consists of a thin metallic patch mounted on a dielectric substrate, which is backed by a ground plane[Fig1]. The patch can take various shapes, including rectangular, circular, or elliptical, depending on the desired radiation characteristics. The antenna operates by exciting the patch with a feed line, causing it to radiate electromagnetic waves. The simplicity of this structure allows for easy integration with printed circuit boards and other electronic components .

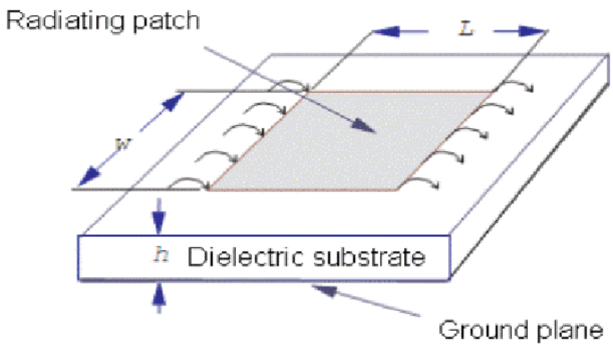

Figure 1: Microstrip patch antenna

1.2 Frequency Selective Surface (FSS)

In antenna systems, FSSs can be positioned as superstrates (above the antenna) or reflectors (below the antenna) to enhance gain, bandwidth, and directivity[Fig2]. For instance, an FSS superstrate can focus the radiated energy, improving the antenna's efficiency and reducing sidelobe levels. Additionally, FSSs can be engineered to suppress unwanted frequencies, mitigating interference and enhancing signal clarity.

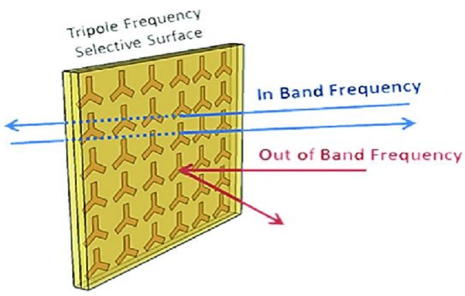

Figure 2: Frequency Selective Surface (FSS)

1.3 Ka -band

The Ka-band is a part of the microwave portion of the electromagnetic spectrum, covering frequencies from 26.5 GHz to 40 GHz. It is commonly used in high-frequency satellite communication systems, especially for applications that require high data rates and compact antennas. The Ka-band is highly valued for its ability to support high-data-rate transmissions, narrow beamwidth, and compact antenna designs, all of which are essential for modern communication systems. The shorter wavelength of Ka-band signals allows for smaller antennas with higher gain, which is ideal for size-constrained platforms like unmanned aerial vehicles (UAVs) and drones.

1.3.1 Military Advantages of Ka-Band

High Data Throughput: Ka-band systems can support gigabit-per-second data rates, enabling the transfer of high-resolution video, sensor data, and command/control signals in real-time—critical for intelligence, surveillance, and reconnaissance (ISR) missions.

Compact Antenna Size: Due to the high frequency, antennas operating at Ka-band can be made smaller and lighter, which is perfect for military drones, satellites, missiles, and handheld systems without compromising performance.

Secure and Directional Communication: Ka-band antennas produce narrower beams, which are harder to intercept or jam. This increases the security and resistance to electronic warfare (EW) such as jamming or spoofing. These directional links are ideal for point-to-point or satellite-ground communication.

Less Congestion: Compared to lower bands (e.g., C, X, or Ku), the Ka-band has more available bandwidth and is less congested, offering clearer channels and less interference for military networks.

Satellite Communication (SATCOM): The Ka-band is extensively used in military satellite communication (MILSATCOM) systems. It supports beyond-line-of-sight (BLOS) communication, enabling forces to maintain contact across continents without relying on terrestrial infrastructure.

Real-Time Battlefield Connectivity: In modern warfare, real-time connectivity between drones, ground stations, command centers, and soldiers is vital. Ka-band links help enable network-centric operations, allowing better decision-making and mission success.

2. Design and Methodology

The design of a Ka-Band (32 GHz) microstrip patch antenna with integrated frequency selective surface (FSS) starts by setting up the antenna structure in ANSYS HFSS. A low-loss substrate like Rogers RT/duroid 5880 is selected, and a rectangular patch is placed on top with a ground plane below. A microstrip feedline is used to excite the antenna, and appropriate boundary conditions and ports are applied. The antenna is simulated to achieve resonance at 32 GHz, and key performance metrics like return loss and gain are analyzed. Next, the FSS unit cell is designed using a periodic metallic pattern and simulated separately using periodic boundary conditions and Floquet ports. Once the FSS shows the desired frequency filtering behaviour, it is positioned behind the patch antenna at a quarter-wavelength distance to improve gain and reduce back radiation. The full structure is then simulated, and the final performance is evaluated. This approach results in a compact, high-gain antenna suitable for military drone communication.

2.1 Design Calculation

Patch Width:

$$\mathrm{W} = \frac{c}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}}$$

$$\mathrm{W} = \frac{3\times10^8}{2\times32\times10^9}\sqrt{\frac{2}{3.2}} = 3.72\mathrm{mm}$$

Patch Length:

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

$$= \frac{3\times10^8}{2\times32\times10^9}\sqrt{2} = 1.41\mathrm{mm}$$

Fringing Effect Correction:

$$\Delta L = 0.412h\frac{(\epsilon_{eff}+0.3)(\frac{w}{h}+0.264)}{(\epsilon_{eff}+0.258)(\frac{w}{h}+0.8)} = 0.07\mathrm{mm}$$

Final Patch Length:

$$L = L_{eff} - 2\Delta L = 1.41 - 2(0.07)$$

Patch Size L=3mm

Ground Plane Dimensions:

$$L_g = 6h + L = (6 \times 0.254) + 3$$

$$= 4.524mm$$

$$W_g = 6h + W = (6 \times 0.254) + 3.72 = 5.244mm$$

Effective Dielectric Constant:

W=3.72mm and h=0.254mm

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \left(\frac{1}{\sqrt{1 + 12\, h/w}} \right) = 1.6 + 0.6 * 0.55 = 2$$

2.2 Microstrip patch antenna design for frequency of 32GHz with FSS .

Ka- band (32GHZ) rectangular microstrip patch antenna

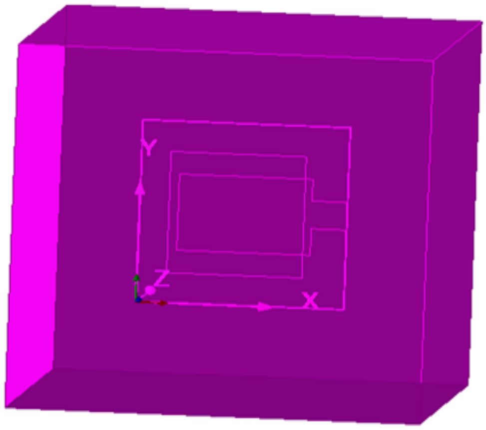

Figure 3: Rectangular microstrip patch antenna with radiation box

Ka-band (32GHZ) Microstrip Patch Antenna with Frequency Selective Surface (FSS)

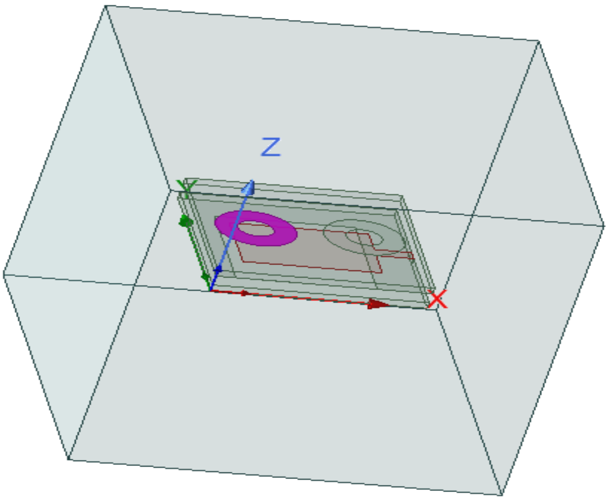

Figure 4: Microstrip patch antenna with Frequency Selective Surface at 32GHz

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3. Proposed Solution

3.1 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna return loss

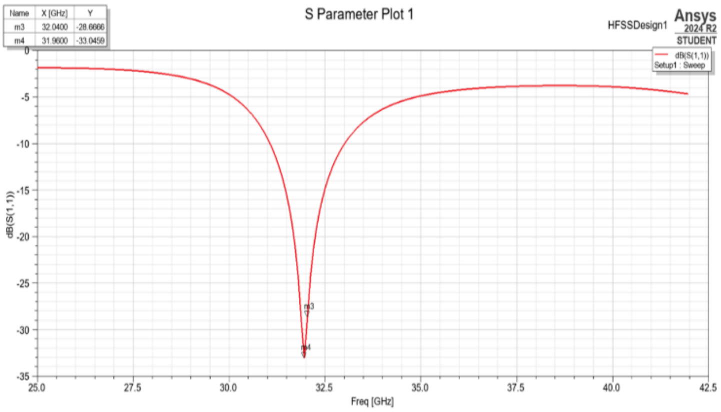

Figure 5: Return loss of -28.66dB

3.2 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna VSWR

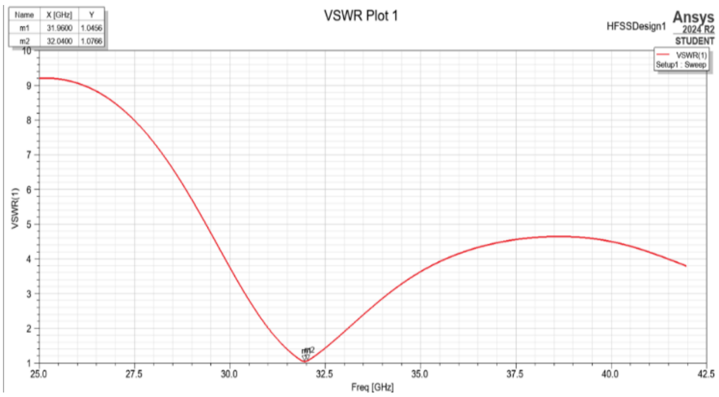

Figure 6: VSWR of 1.07.

3.3 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna gain plot

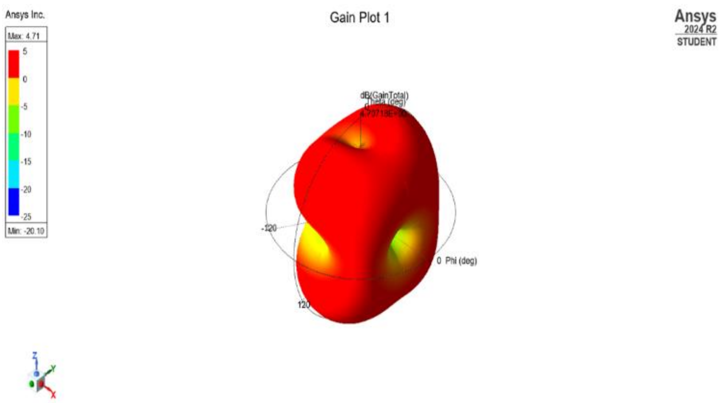

Figure 7: gain of max 4.71 dB

3.4 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna directivity

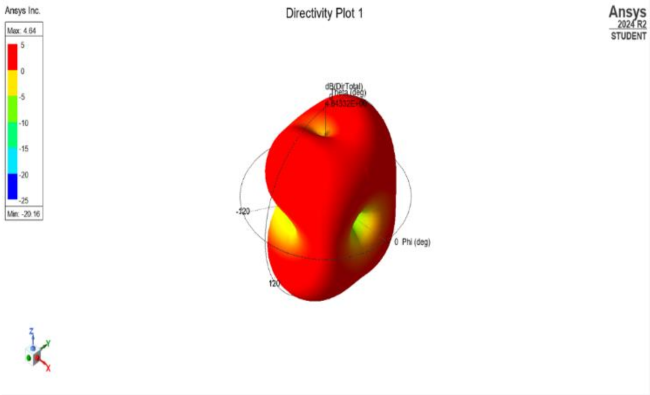

Figure 8: directivity of max 4.64 dB

3.5 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna with Frequency Selective Surface (FSS) Return loss

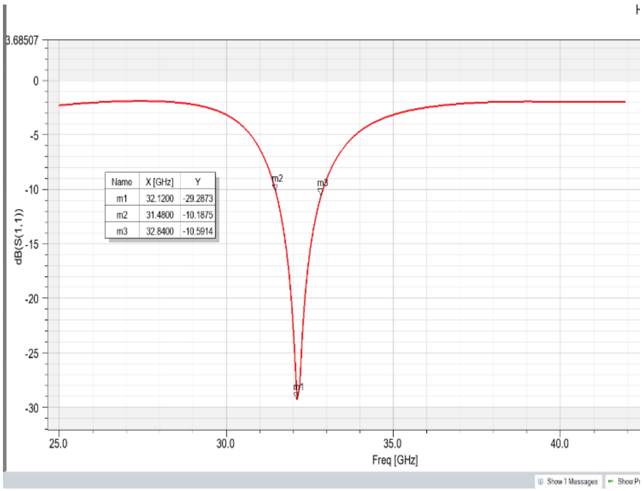

Figure 9: FSS Return loss of -29.28dB.

3.6 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna with Frequency Selective Surface (FSS) VSWR

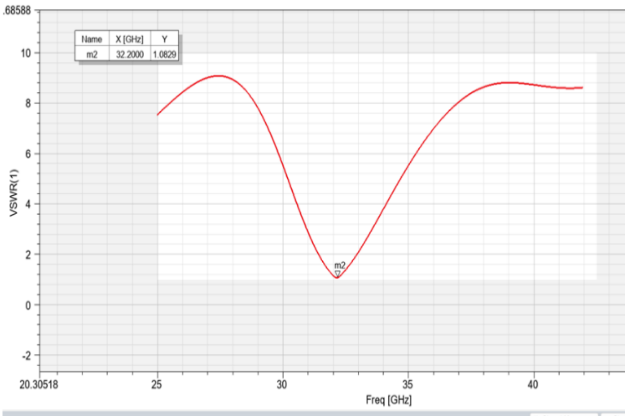

Figure 10: FSS VSWR of 1.082.

3.7 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna with Frequency Selective Surface (FSS) gain plot

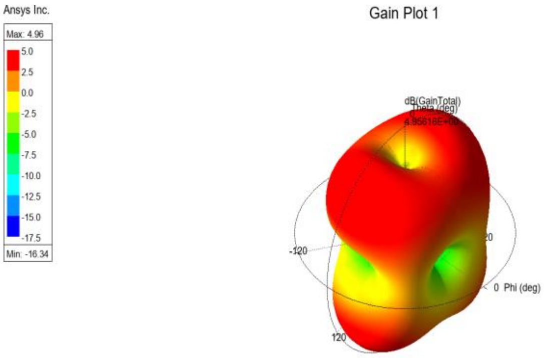

Figure 11: FSS gain plot of max 4.96 dB

3.8 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna with Frequency Selective Surface (FSS) gain directivity

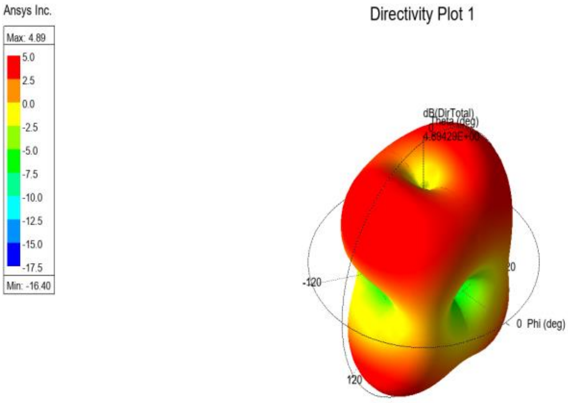

Figure 12: FSS directivity of max 4.89 dB

3.9 The figure shows the graphical representation of Ka- band (32GHZ) Microstrip Patch Antenna with Frequency Selective Surface (FSS) radiation pattern

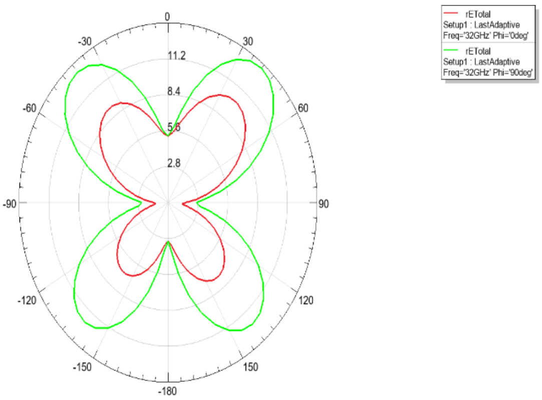

Figure 13: E-field and H-field radiation pattern of the antenna with FSS

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Table 1: Performance Metrices Of KA Band Microstrip Patch Antenna With And Without FSS

Parameters	**Ka-band**	**Ka-band with FSS**
Resonant frequency	32GHz	32GHz
Return loss	-28.6666dB	-29.2873dB
VSWR	1.0766	1.0829
Gain	4.71dB	4.96 dB
Directivity	4.64 dB	4.89 dB

From the above table 3.10, shows integrating an FSS with a Ka-band MPA leads to marginal improvements in return loss, gain, and directivity without affecting the resonant frequency or significantly altering the VSWR. These enhancements suggest that FSS can be beneficial in applications requiring improved antenna performance**.**

4. Conclusion

In this project, a compact and high-performance microstrip patch antenna operating at 32 GHz was successfully designed and integrated with a frequency selective surface (FSS) using ANSYS HFSS. The antenna achieved effective resonance in the Ka-band, meeting the key design goals of high gain, sufficient bandwidth, and low return loss. The integration of the FSS significantly enhanced the antenna's directivity and reduced back radiation, making it more efficient for directional communication. This design is well-suited for military drone communication systems, where low profile, lightweight, and reliable high-frequency antennas are essential. The simulation results confirm that the proposed structure is a strong candidate for use in modern defense and aerospace applications.

5. References

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