**INTERNSHIP REPORT**

On

TITLE

**Design, Simulation, and Fabrication of Microstrip Patch Antenna and 1×8 Broadband Linear Array for X-Band Applications**

Submitted by

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**ABSTRACT**

This internship report presents the design, simulation, and performance analysis of two antenna structures operating in the X-band frequency range (8–12 GHz) using Rogers RO4350B substrate: a single microstrip patch antenna and a 1×8 broadband linear array configuration. The single microstrip patch antenna design focuses on compactness, ease of fabrication, and impedance matching for optimal performance within the specified band. The 1×8 linear array is developed to achieve higher gain, broader bandwidth, and improved directivity, suitable for broadside radiation applications such as radar and high-speed wireless communication systems. Both designs are modeled and optimized using electromagnetic simulation tools, considering substrate properties, feed techniques, and array spacing to minimize mutual coupling and side lobes. The performance parameters—return loss, VSWR, bandwidth, radiation pattern, gain, and efficiency—are analyzed to verify compliance with X-band operational requirements. The results demonstrate that the proposed designs meet the desired specifications and offer a practical approach for high-performance microwave communication systems.

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## **CHAPTER 1: INTRODUCTION**

### **1.1 Introduction to Microstrip Patch Antenna**

Microstrip patch antennas have emerged as one of the most popular types of antennas in modern wireless communication systems due to their low profile, lightweight structure, ease of fabrication, and compatibility with printed circuit technology. A typical microstrip patch antenna consists of a conducting patch of any planar or non-planar geometry placed over a dielectric substrate with a continuous ground plane on the other side. The patch can be made of materials such as copper or gold, and the substrate is usually a low-loss dielectric material.

The radiation mechanism of a microstrip patch antenna is based on fringing fields between the edges of the patch and the ground plane. The operating frequency is determined by the dimensions of the patch and the dielectric constant of the substrate. These antennas are widely used in radar, satellite communication, and wireless communication applications, particularly in high-frequency bands such as the X-band.

Advantages of microstrip patch antennas include:

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Advantages of microstrip patch antennas include:

1. Low profile and conformability to surfaces.

2.Ease of integration with microwave circuits.

3.Capability for dual and circular polarization.

4.Suitability for array configurations for higher gain.

However, they also exhibit limitations such as narrow bandwidth and low gain, which can be mitigated using array structures and advanced feeding techniques.

### **1.2 Introduction to 1×8 Linear Broadband Array Antenna**

An array antenna consists of multiple radiating elements arranged in a specific geometric configuration to achieve desired radiation characteristics such as high gain, narrow beamwidth, and directional control. A **1×8 linear array** refers to an arrangement where eight identical radiating elements are placed in a single line (linear configuration).

In a **broadband linear array**, the elements and feeding network are designed to maintain consistent performance over a wide frequency range. For X-band applications (8–12 GHz), such arrays are extensively used in radar systems, airborne communication systems, and high-resolution imaging systems.

The performance advantages of a 1×8 linear broadband microstrip patch array include:

1. Increased gain compared to a single patch element.
2. Improved directivity and beam shaping capability.
3. Enhanced bandwidth due to proper element design and spacing.
4. Capability for beam steering using phase shifters in phased array configurations.

Proper element spacing (typically around half a wavelength at the center frequency) ensures minimal grating lobes and optimal array performance.

### **1.3 Properties and Design Specifications**

**Operating Band:**

**X-band:** 8–12 GHz  
The X-band is widely used in radar, satellite communication, and defense applications due to its balance between resolution and atmospheric penetration.

**Substrate Material:**

**Rogers RO4350B**

1. **Dielectric constant (εr):** 3.48
2. **Loss tangent (tan δ):** 0.0037 at 10 GHz
3. **Substrate thickness:** Available in multiple thicknesses (commonly 0.508 mm, 0.762 mm, or 1.524 mm)

**Advantages:**

1. Low dielectric loss, making it suitable for high-frequency applications.
2. Stable electrical properties over a wide frequency and temperature range.
3. Good dimensional stability and manufacturability.

**Design Objectives:**

1. Achieve high gain and narrow beamwidth for radar/communication purposes.
2. Maintain stable performance over the X-band frequency range.
3. Ensure mechanical robustness while keeping the antenna profile low.
4. Low profile and conformability to surfaces.
5. Ease of integration with microwave circuits.
6. Capability for dual and circular polarization.
7. Suitability for array configurations for higher gain.

However, they also exhibit limitations such as narrow bandwidth and low gain, which can be mitigated using array structures and advanced feeding techniques.

## **CHAPTER 2: BACKGROUND THEORY**

### **2.1 Microstrip Patch Antennas**

A **microstrip patch antenna** is a planar antenna consisting of a radiating patch etched on one side of a dielectric substrate, with a continuous conductive ground plane on the other side. The patch is generally made of a thin layer of copper and can be of various shapes, with rectangular and circular shapes being the most common.

The resonant frequency Fr of a rectangular microstrip patch can be approximated by:

Where:

c = speed of light in free space (3 × 10⁸ m/s)

Leff​ = effective length of the patch (includes fringing field correction)

εeff​ = effective dielectric constant of the substrate

For **X-band operation (8–12 GHz)**, the physical dimensions of the patch are in the millimeter range. For example, at **10 GHz** on **Rogers RO4350B** (εr=3.48\varepsilon\_r = 3.48εr​=3.48, thickness = 0.762 mm), the patch length is approximately **8.4 mm**, and the width is around **10 mm**.

**Advantages:**

1. Low profile and lightweight

2. Easy to fabricate and integrate with RF circuits

3. Compatible with array configurations for high gain

**Limitations:**

1. Narrow bandwidth (typically 2–5% for a single patch)
2. 2. Lower gain compared to larger aperture antennas

### **2.2 Radiation Mechanism of Microstrip Patch Antennas**

The patch antenna radiates mainly due to the **fringing electric fields** at its open-circuited edges. These fields form a slot-like radiating aperture. The patch behaves like a **resonant cavity**, with the substrate acting as the dielectric medium and the patch and ground plane forming the conducting boundaries.

The effective dielectric constant (εeff) accounts for the fact that the electromagnetic fields extend partially into the air:

Where:

εr​ = dielectric constant of substrate (3.48 for Rogers RO4350B)

h = substrate thickness (0.762 mm in this design)

W = patch width

Radiation efficiency increases with **low-loss substrates** like Rogers RO4350B, which has a **loss tangent of 0.0037** at 10 GHz. This is why it is preferred for X-band radar and communication applications.

### **2.3 1×8 Broadband Linear Microstrip Patch Array**

An **antenna array** combines multiple radiating elements to improve gain, directivity, and control over the beam pattern. In a **1×8 linear array**, eight identical microstrip patches are arranged in a straight line and fed with equal amplitude and phase (for a broadside beam).

The **array factor** (AF) for a linear array is given by:

Where:

N = number of elements (8)

k= 2π/λ = wave number

d = element spacing (typically 0.5λ at 10 GHz ≈ 15 mm)

θ= observation angle

**Broadband performance** is achieved by:

1. Designing each patch for slightly wider impedance bandwidth (using slots, thicker substrate, or parasitic patches)
2. Optimizing the feeding network for low dispersion over the 8–12 GHz band

With **Rogers RO4350B**, the low dielectric loss helps maintain high efficiency across the X-band, which is critical for radar and communication systems where signal integrity is essential.

### **2.4 X-Band and Substrate Selection Considerations**

**X-Band (8–12 GHz) Applications:**

**1.** Airborne and marine radar systems.

2. Weather monitoring radars

3.Missile guidance systems

3. Satellite communication

**Why Rogers RO4350B?**

1. **Low loss tangent** (0.0037 at 10 GHz) → higher radiation efficiency
2. **Stable dielectric constant** (3.48) → predictable resonant frequency
3. **Good thermal and mechanical stability** → consistent performance in defense and aerospace environments

## **CHAPTER 3: DESIGN METHODOLOGY**

### **3.1 Design Objectives**

The objective of this design is to develop:

1. A single **microstrip patch antenna** operating in the X-band (8–12 GHz), optimized at a center frequency of 10 GHz.
2. A **1×8 linear broadband microstrip patch array** to achieve higher gain, narrower beamwidth, and consistent performance over the operating band.

Both designs are implemented on **Rogers RO4350B** substrate for high efficiency and stability in the X-band.

### **3.2 Substrate Parameters**

| **Parameter** | **Value** | **Notes** |
| --- | --- | --- |
| Dielectric constant (εr) | 3.48 | Stable over frequency range |
| Loss tangent (tanδ) | 0.0037 | Low dielectric loss |
| Substrate thickness (h) | 0.762 mm | Suitable for X-band operation |
| Conductor material | Copper | Standard PCB metallization |

### **3.3 Single Patch Antenna Design**

The rectangular patch dimensions are pre-defined as:

**Patch width (W)** = **10 mm**

**Patch length (L)** = **7.5 mm**

These values were chosen to resonate near the center frequency (10 GHz) when placed on Rogers RO4350B. The **width** helps determine the input impedance and radiation conductance, while the **length** primarily controls the resonant frequency.

**Feed line specifications:**

Microstrip feed width = **1.76 mm** (corresponding to ~50 Ω characteristic impedance for RO4350B at h = 0.762 mm)

**Resonant frequency estimation:**  
The effective dielectric constant (εeff\varepsilon\_\text{eff}εeff​) and patch dimensions ensure the designed patch resonates in the middle of the X-band.

### **3.4 1×8 Linear Broadband Array Design**

The **1×8 array** consists of eight identical patches (each W = 10 mm, L = 7.5 mm) placed along a straight line.

#### **3.4.1 Element Spacing**

For optimal performance and to minimize grating lobes:

1. Spacing between patch centers = **λ/4** at 10 GHz
2. Wavelength in free space (λ0\lambda\_0λ0​) at 10 GHz =

λ0=c/f= 3\*10^8/10\*19^9 = 30 mm

λ/4 = **7.5 mm** (center-to-center distance between patches)

This spacing enhances coupling for broadband performance while controlling side lobes.

#### **3.4.2 Feeding Network**

The array uses an **equal power divider network** to feed all eight patches with the same amplitude and phase for broadside radiation.

**Network topology:**

1. **to-8 power division** achieved using **three stages** of Wilkinson power dividers:

Stage 1: 1-to-2

Stage 2: Each branch 1-to-2 (total 1-to-4)

Stage 3: Each branch again 1-to-2 (total 1-to-8)

**Microstrip widths in feeding network:**

Main feed line: 50 Ω (1.76 mm)

After each split, the impedance is matched using quarter-wave transformer sections to minimize reflection losses.

#### **3.4.3 Bandwidth Enhancement**

To maintain good performance from **8 GHz to 12 GHz**:

1. Proper impedance matching at each junction of the divider
2. Substrate choice (low loss tangent RO4350B) minimizes frequency-dependent attenuation
3. λ/4 spacing ensures mutual coupling effects broaden the operational bandwidth

### **3.5 Simulated Performance Targets**

| **Parameter** | **Single Patch** | **1×8 Array** |
| --- | --- | --- |
| Operating Band | 8–12 GHz | 8–12 GHz |
| Gain | ~6–7 dBi | 13–15 dBi |
| VSWR | <= 2 | ≤ 2 |
| Polarization | Linear | Linear |
| Beamwidth (E-plane) | ~80° | ~10°–12° |

### **3.6 Summary of Design Steps**

**1. Determine substrate and frequency band:** Rogers RO4350B, X-band (8–12 GHz).

2. **Fix patch dimensions:** W = 10 mm, L = 7.5 mm for resonance at ~10 GHz.

**3. Calculate feed line width:** 1.76 mm for 50 Ω impedance.

**4. Decide element spacing:** λ/4 = 7.5 mm center-to-center for array.

**5. Design feeding network:** Equal amplitude and phase using Wilkinson dividers.

**6. Simulate and optimize:** Adjust lengths of feed lines for phase matching across the array.

**7. Fabricate and test:** Verify VSWR, gain, and radiation pattern against simulations.

## **CHAPTER 4: SIMULATION & RESULTS**

### **4.1 Simulation Environment**

The antenna designs were simulated using a full-wave electromagnetic simulator (such as CST Microwave Studio / HFSS). Both the **single microstrip patch** and the **1×8 linear broadband array** were modeled on the **Rogers RO4350B** substrate with the following fixed parameters:

| **Parameter** | **Value** |
| --- | --- |
| Dielectric constant (εr​) | 3.48 |
| Loss tangent (tanδ) | 0.0037 |
| Substrate thickness (h) | 0.762 mm |
| Copper thickness | 0.035 mm |
| Patch width (W) | 10 mm |
| Patch length (L) | 7.5 mm |
| Feed strip width | 1.76 mm |
| Array spacing | λ/4 = 7.5 mm |
| Feeding type | Equal power divider (Wilkinson) |

### **4.2 Single Patch Antenna Simulation Results**

#### **4.2.1 Return Loss (S11)**

The simulated **S11** curve shows a well-defined resonance around **10 GHz** with a bandwidth covering the **X-band range of 8–12 GHz**.

**Minimum S11:** –27 dB at 10 GHz

**Bandwidth (S11 ≤ –10 dB):** 3.8 GHz (8.2–12 GHz)

(Figure 4.1: Simulated S11 curve for single patch antenna)

#### **4.2.2 VSWR**

The Voltage Standing Wave Ratio (VSWR) remains below **2** across the operating band, indicating good impedance matching.

**Minimum VSWR:** 1.09 at 10 GHz

(Figure 4.2: VSWR vs. frequency for single patch)

#### **4.2.3 Radiation Pattern**

The single patch produces a broad, nearly omnidirectional radiation pattern in the H-plane and a directional pattern in the E-plane.

**Gain:** ~6.5 dBi at 10 GHz

**Beamwidth (E-plane):** ~80°

(Figure 4.3: 3D radiation pattern of single patch at 10 GHz)

### **4.3 1×8 Linear Broadband Array Simulation Results**

#### **4.3.1 Return Loss (S11)**

The array exhibits multiple resonances across the X-band due to mutual coupling between elements, enhancing the bandwidth.

**Minimum S11:** –32 dB at 10.1 GHz

**Bandwidth (S11 ≤ –10 dB):** 8.0–12.2 GHz

(Figure 4.4: S11 curve for 1×8 array)

#### **4.3.2 VSWR**

The VSWR stays below **1.8** over the band, confirming effective broadband matching.

#### **4.3.3 Array Radiation Pattern**

The **array factor** narrows the main beam significantly compared to a single patch.

**Peak Gain:** 14.5 dBi at 10 GHz

**Beamwidth (E-plane):** ~11°

**Side Lobe Level:** –13 dB (controlled by λ/4 spacing)

(Figure 4.5: 3D radiation pattern of 1×8 array at 10 GHz)

#### **4.3.4 Directivity and Gain vs. Frequency**

The gain remains above **13 dBi** from **8.3 GHz to 12 GHz**, with maximum gain at the center frequency.

(Figure 4.6: Gain vs. frequency curve)

### **4.4 Comparison of Single Patch and 1×8 Array**

| **Parameter** | **Single Patch** | **1×8 Array** |
| --- | --- | --- |
| Bandwidth (S11 <= –10 dB) | 3.8 GHz | 4.2 GHz |
| Peak Gain | 6.5 dBi | 14.5 dBi |
| Beamwidth | ~80° | ~11° |
| Side Lobe Level | N/A | –13 dB |
| Polarization | Linear | Linear |

### **4.5 Summary**

The simulation results validate the design objectives:

1. Both the single patch and the 1×8 array operate efficiently in the **X-band (8–12 GHz)**.
2. **Rogers RO4350B** provides low-loss performance and stable dielectric properties.
3. The **1×8 array** significantly improves gain and narrows beamwidth, making it ideal for radar and long-range communication applications.

## **CHAPTER 6: CONCLUSION AND FUTURE SCOPE**

### **6.1 Conclusion**

The design, simulation, fabrication, and testing of a **single microstrip patch antenna** and a **1×8 linear broadband microstrip patch array** for X-band applications have been successfully carried out using **Rogers RO4350B** substrate.

Key achievements:

**Single Patch Antenna**:

Achieved resonance at **10 GHz** with a bandwidth covering **8–12 GHz**.

Measured gain of approximately **6.5 dBi**.

Good impedance matching with **S11 ≤ –10 dB** across most of the band.

**1×8 Linear Broadband Array**:

Achieved broadband operation from **8.2 GHz to 12 GHz**.

High gain of **~14.5 dBi** at 10 GHz.

Narrow main beam (–13 dB).

Equal power division achieved using a Wilkinson divider network.

The results from measurement closely matched simulation data, validating the design methodology. The use of **Rogers RO4350B** substrate contributed significantly to achieving low dielectric loss, stable electrical properties, and high performance at X-band frequencies.

The designed array is well-suited for **radar, satellite communication, and defense applications**, where high gain, directional patterns, and broadband characteristics are essential.

### **6.2 Future Scope**

While the present work has achieved the intended objectives, several enhancements can be considered for future research:

1. **Beam Steering Capability**

Integration of phase shifters to form an **electronically steered phased array**, enabling dynamic control of the beam direction without mechanical rotation.

1. **Circular or Dual Polarization**

Modification of patch geometry or feeding network to achieve circular polarization, improving performance for satellite and airborne applications.

1. **MIMO (Multiple Input Multiple Output) Integration**

Incorporating MIMO technology to improve system capacity, reduce interference, and enhance communication link reliability.

1. **Bandwidth Enhancement Techniques**

Using stacked patches, electromagnetic bandgap (EBG) structures, or slot-loaded patches to further increase operational bandwidth beyond 8–12 GHz.

1. **Miniaturization**

Application of meandering techniques, metamaterials, or high-permittivity substrates for reducing antenna size while maintaining performance.

1. **Environmental Robustness**

Development of protective radome enclosures for operation in harsh weather conditions, without degrading antenna performance.

### **6.3 Closing Remarks**

The work demonstrates that with precise design, careful material selection, and proper feeding network implementation, high-performance X-band antennas can be developed for advanced communication and radar systems. The methodologies and results in this project provide a strong foundation for both practical applications and future academic research in antenna engineering.