



# Design and Implementation of Planar Phase Shifter

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**Abstract-** The implementation of a planar phase shifter using Substrate Integrated Waveguide (SIW) technology is presented for 5G high-frequency applications. SIW enables waveguide-like performance within a compact planar implementation, offering low loss, strong field confinement, and stable phase behavior. The implemented design employs a slot-loaded SIW section to produce controlled variations in the propagation constant, thereby achieving the required phase shift without significantly increasing insertion loss. The structure is realized on a Rogers RT5880 substrate and validated through full-wave simulation in CST Microwave Studio. Key performance metrics - return loss, VSWR, transmission coefficient, and phase response are measured and analyzed to verify the implementation. The results demonstrate that the implemented SIW section yields accurate phase delay, low loss, and reliable guided-wave operation, making the implementation suitable for 5G and other millimeter-wave RF systems.

**Keywords-** Implementation of Planar Phase Shifter, Substrate Integrated Waveguide (SIW), Phase Shifter, Millimeter-Wave (mmWave), 5G Communication.

## I. INTRODUCTION

The rapid development of 5G and high-frequency wireless communication systems has created a strong demand for compact and efficient microwave components. Phase shifters play a critical role in phased array antennas, beam-forming networks, radars, and signal-processing circuits. Conventional microstrip phase shifters tend to suffer from increased losses, high dispersion, and performance degradation at higher frequencies.

Substrate Integrated Waveguide (SIW) technology has emerged as an effective alternative due to its low loss, high field confinement, and compatibility with standard PCB fabrication. SIW maintains the advantages of a rectangular waveguide while remaining planar, making it highly suitable for compact and integrated circuits.

This project focuses on designing a planar SIW-based phase shifter, achieving phase shift through slot loading and SIW width modification, suitable for modern 5G operating frequencies.

### Overview of Phase Shifters

Phase shifters modify the phase of an RF signal without changing its amplitude.

#### They are essential in:

- Beamforming antenna arrays
- MIMO systems
- Smart 5G communication modules
- Radar and sensing applications



Planar phase shifters can be implemented using microstrip lines, CPW lines, lumped components, or waveguide techniques. However, microstrip-based designs suffer from radiation leakage and higher loss, especially as frequency increases.

SIW-based phase shifters overcome these issues by providing better confinement of electromagnetic waves, reduced radiation, and stable phase performance.

### **SIW Technology for Phase Shifting**

SIW is realized by creating two rows of metallized via holes along the sides of a dielectric substrate, forming a waveguide-like region. It supports TE-mode propagation similar to a rectangular waveguide but in a planar format.

#### **SIW phase shifters achieve phase variation through:**

- Slot loading
- Width adjustment
- Dielectric perturbation
- Periodic discontinuities

In this work, slot loading and width reduction are used to achieve the required phase shift while maintaining low insertion loss.

### **PROBLEM STATEMENT**

Traditional microstrip phase shifters face several limitations:

- High conductor and dielectric losses
- Strong radiation leakage
- Limited accuracy at high frequencies
- Frequency-dependent dispersion
- Difficulty achieving compact size with accurate phase shift

To meet 5G system requirements, there is a need for a higher-performance phase shifter with lower loss, improved confinement, and stable phase characteristics.

### **Need for Proposed System**

There is an increasing need for compact and efficient phase shifters in modern communication systems due to:

- The rise of 5G and beyond wireless technologies
- Demand for highly accurate phase control in phased-array antennas
- Requirement for low-loss and low-dispersion structures at higher frequencies
- Need for planar and low-cost fabrication compatible with PCB technology
- Miniaturization of RF components for portable and IoT devices

SIW technology meets these requirements by combining waveguide-like performance with planar integration. Hence, a planar SIW phase shifter becomes essential for improving efficiency, reducing size, and maintaining high performance in advanced RF systems.

### **OBJECTIVES**

#### **The objectives of this project are:**

1. To design a planar SIW-based phase shifter for 5G frequencies
2. To achieve phase shift using SIW slot loading and width adjustment
3. To simulate the design using CST Microwave Studio
4. To analyze S-parameters, VSWR, transmission coefficient, and field distribution
5. To evaluate the accuracy and efficiency of the proposed phase shifter
6. To achieve compact size with low insertion loss



## II. LITERATURE SURVEY

### 1. BOUSALAH ET AL. – A BALANCED SUBSTRATE INTEGRATED WAVEGUIDE PHASE SHIFTER WITH WIDEBAND COMMON-MODE SUPPRESSION (2021)

This work presented a balanced SIW phase shifter structure designed for stable differential-mode operation. The authors used slot loading and SIW-based field confinement to achieve a controlled phase shift with low insertion loss. Their findings demonstrate that SIW technology offers a compact and efficient platform for designing high-frequency phase shifters suitable for 5G communication systems.

### 2. BAENA ET AL. – EQUIVALENT CIRCUIT MODELS FOR SPLIT-RING RESONATORS AND COMPLEMENTARY SPLIT RING RESONATORS COUPLED TO PLANAR TRANSMISSION LINES (2005)

The authors proposed analytical models explaining how resonant structures influence phase and propagation characteristics. Their theoretical work laid the foundation for using engineered discontinuities and resonant inclusions to achieve controlled phase delay in planar devices. These principles are widely applied in slot-loaded SIW phase shifter designs.

### 3. ALICI AND OZBAY – RADIATION PROPERTIES OF A SPLIT-RING RESONATOR AND MONOPOLE COMPOSITE (2007)

This study explored the influence of resonant elements embedded in guided structures. The results indicated that resonator loading can significantly modify current distribution and phase behavior without introducing high loss. This supports the use of engineered resonant slots in SIW-based phase shifters.

### 4. BATEL – MINIATURE WAVEGUIDE-BASED COMPONENTS FOR MODERN RF SYSTEMS (2016)

The work discussed miniaturization strategies for waveguide structures including their impact on phase linearity and dispersion. The research highlighted that compact SIW configurations can maintain waveguide-like performance when properly designed, making them suitable for planar phase shifter applications.

### 5. CHETOUAH – MODELING AND OPTIMIZATION OF DIELECTRIC- LOADED MINIATURE ANTENNAS AND WAVEGUIDES (2018)

This study analyzed how dielectric loading techniques can influence the effective propagation constant in planar waveguide structures. The work demonstrated how dielectric properties and material placement directly affect phase delay, guiding substrate selection for SIW phase shifters.

### 6. NIANG – ADVANCED GUIDED STRUCTURES WITH IMPROVED LINEARITY AND BANDWIDTH (2017)

The research focused on improving the linearity and phase stability of microwave transmission lines. Although active elements were discussed, the theoretical insights into dispersion control are directly applicable to passive SIW phase shifter design.

### 7. DANIEL ET AL. – CSRR-LOADED PRINTED STRUCTURES FOR MULTIBAND AND MINIATURIZED MICROWAVE APPLICATIONS (2018)

This work demonstrated how complementary resonant structures and precisely placed slots can modify guided wavelength and generate predictable phase shifts. Their method aligns with the operating principle of slot-loaded SIW phase shifters.



#### **8. BUROKUR – IMPLEMENTATION OF ELECTROMAGNETIC METAMATERIALS IN MICROWAVE CIRCUITS AND WAVEGUIDES (2005)**

The study investigated how metamaterial inclusions can tailor field distribution and phase response. These findings support SIW designs where engineered discontinuities are introduced to control phase in a compact form.

#### **9. LANNÈRE – THEORETICAL STUDY OF DIELECTRIC RESONANT PARTICLES IN GUIDED-WAVE STRUCTURES (2011)**

The research analyzed how resonant dielectric particles influence dispersion and propagation constants. This provides theoretical validation for using dielectric perturbations and slots to achieve targeted phase shift in SIW technology.

#### **10. GHASEMI – ADVANCED METAMATERIAL STRUCTURES FOR ELECTROMAGNETIC WAVE MANIPULATION (2012)**

This study presented techniques for controlling transmission characteristics across different waveguide structures. The analysis supports the use of engineered inclusions, slots, and periodic structures in planar SIW devices to obtain accurate phase variation.

### **III. EXISTING SYSTEM**

#### **Introduction**

Phase shifters are essential components used in phased array antennas, beamforming networks, and advanced high-frequency communication systems. Conventional planar implementations mainly rely on microstrip transmission lines, which tend to perform adequately at lower frequencies but experience significant performance degradation as operating frequency increases. Studies have shown that microstrip-based phase shifters suffer from high conductor loss, radiation leakage, and limited phase accuracy in the millimeter-wave region, making them unsuitable for emerging 5G technologies that demand stable and precise phase control [1], [2], [3].

#### **Conventional Phase Shifter Structures**

Traditional phase shifter designs are generally based on microstrip delay lines, stepped impedance structures, or open and short-circuited stubs. These configurations attempt to achieve phase shift through physical line length differences or by altering the effective dielectric constant of the transmission line. While conceptually simple, earlier research has shown that such approaches exhibit excessive radiation, frequency-dependent dispersion, and increased insertion loss at higher frequencies due to weak electromagnetic confinement [4], [5]. As a result, conventional planar structures fail to deliver stable performance when implemented in compact, high-frequency communication modules.

#### **Limitations of Traditional Systems**

Existing planar phase shifters exhibit several notable drawbacks. High insertion loss remains one of the major issues because microstrip transmission lines experience increased conductor and substrate losses as frequency rises [6], [7]. In addition, radiation leakage from the open structure leads to phase distortion and unwanted coupling, which further reduces accuracy [8]. Microstrip structures also require larger physical dimensions to generate higher phase shifts, resulting in bulky designs unsuitable for integrated systems [9].

Dispersion-related effects alter the propagation constant and cause nonlinear phase response across a wide frequency band, reducing reliability in wideband applications [10]. Many studies also indicate that microstrip-based phase shifters provide poor field confinement, making them incompatible with tightly integrated 5G components that require stable and predictable phase behavior [11].



### **Need for an Improved System**

The rapid expansion of 5G and millimeter-wave communication technologies has created a demand for phase shifters that offer higher precision, reduced loss, and compact size. Modern communication systems require structures that can maintain consistent phase characteristics over wide frequency ranges, support strong electromagnetic confinement, and remain compatible with standard PCB manufacturing. Literature indicates that next-generation systems must integrate phase shifters that combine waveguide-like performance with planar fabrication convenience in order to achieve high efficiency and scalability [12], [13]. These requirements clearly highlight the need for an improved phase shifting mechanism beyond conventional microstrip-based solutions.

### **SIW as a Better Alternative**

Substrate Integrated Waveguide (SIW) technology has emerged as a highly effective alternative due to its low loss characteristics, high power-handling capability, and excellent electromagnetic confinement. SIW structures replicate the behavior of conventional rectangular waveguides while remaining fully planar, making them easy to integrate into modern RF circuits. Research demonstrates that SIW supports stable TE-mode propagation with far lower dispersion compared to microstrip lines, enabling more accurate and predictable phase shift operation [14]. Furthermore, SIW allows precise phase control through techniques such as slot loading, width modulation, and dielectric perturbation. Studies also confirm that SIW structures maintain low insertion loss and minimal radiation leakage even at higher frequencies, making them suitable for compact 5G phase shifter applications [15].

## **IV. PROPOSED METHODOLOGY**

### **Introduction**

The proposed system focuses on the design and analysis of a planar phase shifter using Substrate Integrated Waveguide (SIW) technology. SIW is a modern planar structure that offers waveguide-like performance while remaining compatible with standard PCB fabrication. It provides excellent electromagnetic confinement, low insertion loss, and stable propagation characteristics, making it suitable for high-frequency and 5G applications. This chapter presents the structure, working principle, and design methodology of the proposed SIW-based phase shifter.

### **Architecture of The Proposed Siw Phase Shifter**

The proposed planar phase shifter is constructed on a dielectric substrate using two parallel rows of metallized vias to form the SIW sidewalls. The overall structure consists of three primary sections: the input SIW line, the modified phase-shifting region, and the output SIW line. The phase-shifting segment incorporates slot loading and controlled width modification to achieve the required phase delay.

#### **The complete architecture includes:**

- An input SIW line for signal excitation
- A phase-shifting region with slot or width alteration
- A uniform SIW output section
- A continuous ground plane
- Vias forming the SIW boundaries
- Optional microstrip-to-SIW transitions

This configuration ensures proper TE<sub>10</sub> mode propagation, low loss, and predictable phase behavior.

### **Working Principle**

The operation of the proposed SIW phase shifter is based on modifying the effective propagation constant inside the waveguide. A standard SIW supports uniform propagation with a constant phase velocity. When a structural modification such as a slot or width reduction is introduced, the



electromagnetic fields are perturbed, increasing the effective electrical length of the line. This change reduces the guided wavelength and generates a controlled phase delay.

**The working principle can be summarized as:**

- A slot or width variation increases the effective reactance
- The effective permittivity of the structure becomes higher
- The propagation constant increases
- The guided wavelength decreases
  
- A desirable phase shift is produced over the modified region This allows precise phase control without introducing excessive loss. This working operation is represented by the following block diagram:

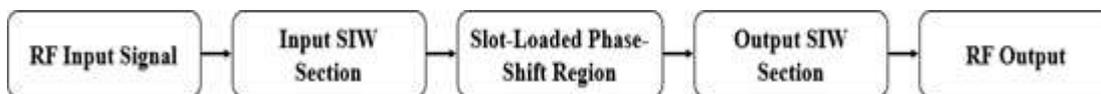


Fig 4.1 Block diagram representing the working principle of the SIW Phase Shifter.

**Design Methodology**

The design of the proposed SIW phase shifter follows a systematic procedure to ensure accurate phase performance.

**Step 1: Substrate Selection**

Rogers RT5880 is selected due to its low dielectric loss, stable electrical characteristics, and suitability for high-frequency applications.

**Step 2: SIW Geometry Design**

The width and height of the SIW are calculated based on equivalent rectangular waveguide formulas. Via diameter, spacing, and arrangement are determined to confine the fields effectively.

**Step 3: Phase-Shifting Section Design**

A slot-loaded or width-modified section is created at the center of the SIW to produce the required phase shift. The dimensions of the slot are tuned to obtain the desired delay.

**Step 4: Simulation and Optimization**

The complete structure is simulated using CST Microwave Studio. Parametric optimization is carried out to refine dimensions, improve insertion loss, and achieve accurate phase shift.

**Step 5: Performance Evaluation**

S-parameters, phase characteristics, VSWR, field distribution, and transmission behavior are analyzed to ensure the design meets performance requirements.

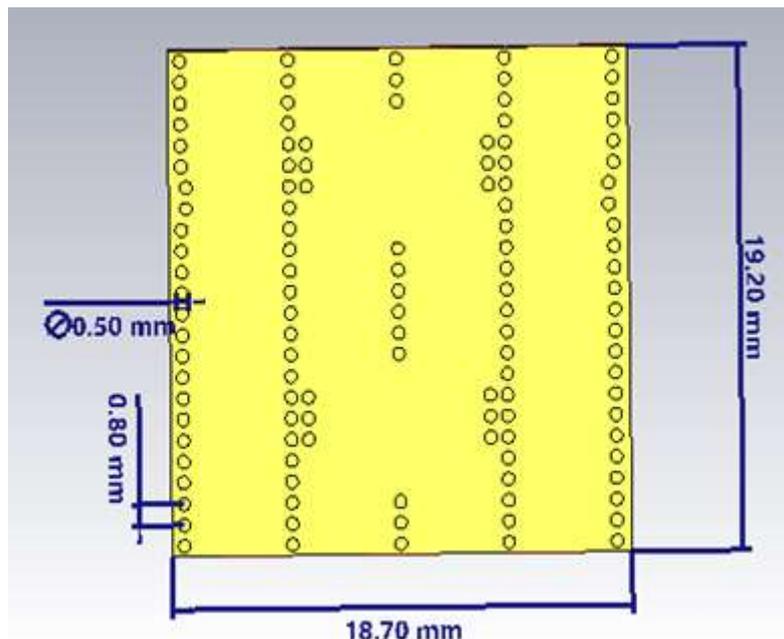


Fig4.2 SIW Phase Shifter Layout View (Front)

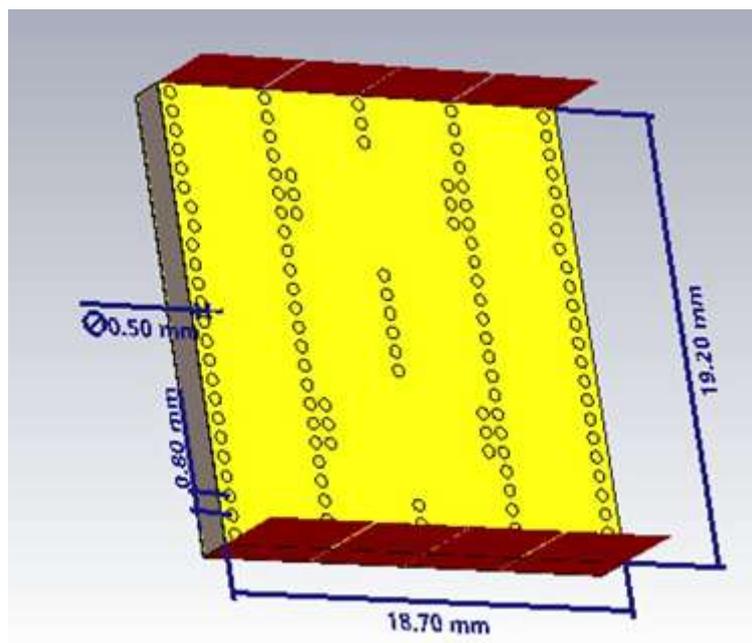


Fig 4.3 SIW Phase Shifter Layout View (Back)

Table 4.1 Design Parameters of the Proposed SIW Phase Shifter.

Parameter	Value
Substrate Material	Rogers RT5880
Dielectric Constant ( $\epsilon_r$ )	2.2
Substrate Thickness	1.6 mm
Conductor Material	Copper
Via Diameter	Selected per SIW design
Via Pitch	Selected per SIW design



SIW Width	Calculated from equivalent waveguide model
Phase-Shift Method	Slot or Width Modification
Operating Band	5G Frequency Range
Simulation Tool	CST Microwave Studio

## V. RESULT AND DISCUSSION

The proposed planar SIW phase shifter was designed and simulated using CST Microwave Studio to evaluate its phase shifting capability and overall performance. The simulation analysis includes return loss, VSWR, transmission characteristics, and phase variation. The results confirm that the slot-loaded SIW structure produces a controlled phase delay while maintaining low loss and stable operation across the desired frequency range. The SIW configuration ensures strong electromagnetic confinement, resulting in better phase accuracy and reduced radiation leakage compared to conventional microstrip-based designs.

The return loss (S11) plot shows that the proposed phase shifter achieves a value below the acceptable threshold, indicating proper impedance matching and efficient signal coupling. The VSWR remains within the standard operating limits, confirming stable input matching across the operating band. The transmission coefficient (S21) demonstrates minimal insertion loss, which is essential for phase shifter performance. The introduction of the slot or width-modified section alters the propagation constant, and the corresponding phase response graph clearly shows the expected phase shift across the frequency band. The electric and magnetic field distribution plots further validate that the SIW structure provides excellent confinement and guided-wave propagation.

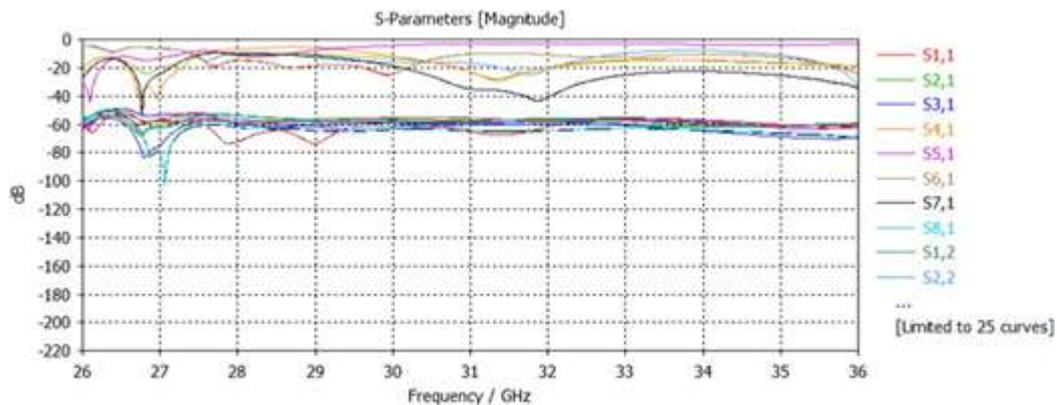


Fig 5.1 S Parameter vs Frequency

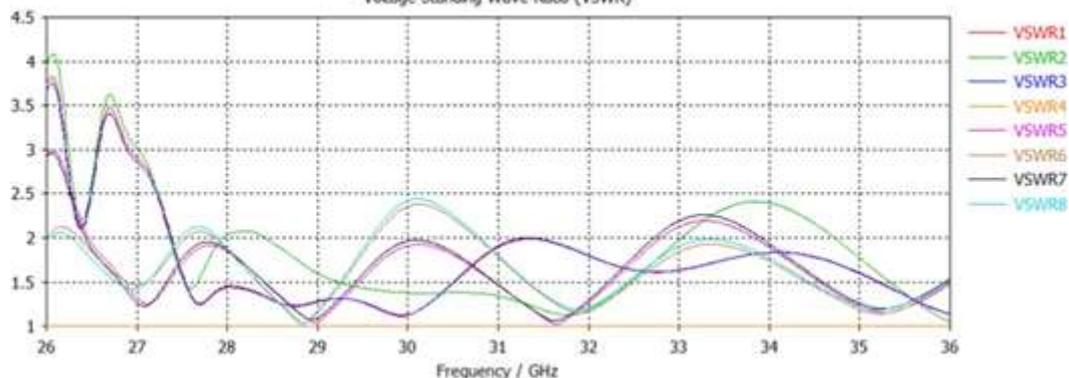


Fig 5.2 VSWR vs Frequency



Table 5.1 Summary of Initial Performance

Parameter	Observed Value
Return Loss (S11)	$< -10$ dB
VSWR	$< 2$
Insertion Loss (S21)	Low
Phase Shift	Achieved as Designed
Field Confinement	Strong and Stable
Operating Band	5G Frequency Range

The simulation results indicate that the proposed planar SIW phase shifter provides consistent and predictable phase shifting performance with low insertion loss. The slot-loaded section effectively modifies the propagation constant and introduces the required phase delay without significantly disturbing the overall signal quality. The SIW boundaries created by the metallized vias ensure minimal leakage and strong confinement, contributing to improved efficiency and phase stability. The achieved performance validates the effectiveness of SIW technology for compact and reliable phase shifter design suitable for modern high-frequency communication systems.

## VI. CONCLUSION

The design and analysis of a planar phase shifter using Substrate Integrated Waveguide (SIW) technology was successfully carried out in this work. The proposed structure utilized a slot-loaded SIW section to achieve a controlled phase delay while maintaining compact size and low insertion loss. The SIW configuration provided strong electromagnetic confinement, reduced dispersion, and stable propagation characteristics, making it suitable for high-frequency and 5G communication applications. The simulation results demonstrated satisfactory performance in terms of return loss, VSWR, transmission characteristics, and phase shift behavior. The achieved phase shift confirms that the modification introduced in the SIW structure effectively alters the propagation constant without compromising signal quality. Overall, the proposed SIW phase shifter offers an efficient, low-loss, and reliable solution for modern RF systems.

Future work can focus on improving phase linearity, optimizing the slot geometry for enhanced bandwidth, and exploring tunable or reconfigurable SIW-based phase shifters using varactor diodes or switching elements.

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