

A Novel Matching Technique for Microstrip Feeds using Optimized Tapering

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Abstract – This paper presents an efficient impedance matching technique for microstrip feed structures, providing a practical solution for seamless connector integration in high-frequency systems. Unlike conventional approaches that assume predefined connector compatibility, this method allows adaptation to various connector constraints without requiring major structural modifications. A linearly tapered microstrip feed with tapered substrate is proposed to ensure stable impedance matching, reduce signal reflection, and enhance overall system performance. The technique is demonstrated on a fabricated substrate-integrated waveguide antenna, utilizing a Rogers RT/Duroid 5880 substrate configured for 50 Ω impedance and adapted for integration with a specific coaxial connector. Experimental validation confirms excellent agreement between simulated and measured results, verifying its effectiveness in achieving impedance matching, minimizing return loss, and ensuring seamless integration with the connector while preserving radiation characteristics. This work presents a versatile feed design approach that addresses a key challenge in RF and microwave engineering, paving the way for improved performance and broader applicability in advanced communication systems and integrated circuit applications.

Index Terms – 5G antenna, impedance matching technique, microstrip feed, microstrip transition, substrate-integrated waveguide, tapered microstrip.

I. INTRODUCTION

The increasing demand for high-performance microwave and RF systems has driven extensive research into impedance-matching techniques for microstrip feed structures. Efficient impedance matching is critical for ensuring minimal signal reflection and optimal power transfer, particularly in high-frequency applications. A key challenge arises when microstrip feeds must interface with standard coaxial connectors, such as SMA connectors, whose dimensional constraints often lead to impedance mismatches with conventional microstrip feeds, thereby degrading overall system performance. At high frequencies, the coaxial connector pin becomes too thin for effective connection to the structure due to its small diameter, which prevents the wave from being launched efficiently.

Existing approaches to microstrip-to-coaxial transitions have primarily focused on either waveguide-based transformations or direct microstrip-to-coaxial transitions. Waveguide-based transitions [1–9] offer high performance but may require additional components, leading to increased bulk, sensitivity to manufacturing variations, precise alignment requirements, and added fabrication complexity. Since most electronic systems are equipped with coaxial ports, they are generally preferred over waveguide ports to simplify integration, making a direct microstrip-compatible transition more desirable. However, direct microstrip-to-coaxial transitions [10–11] typically assume predefined connector compatibility,

Table 1: Comparison of transition techniques

Parameter	Waveguide-Based [1–9]	Direct Coaxial [10–11]	Proposed Work
Bandwidth	Narrowband (cutoff-limited)	Wideband (connector-limited)	Wideband (connector-limited)
Adaptability	Fixed dimensions (e.g., WR-90)	Connector specific	Connector-adaptable
Extra components for Impedance Matching	Stepped ridges [9, 12] & impedance transformers [13]	Simple or Radial stubs [14]	None
Fabrication	Complex – requires precise alignment, mode converters, & adapters	Low to Moderate – might involve simple or radial stub etching	Simple
Scalability	Suited to standards (e.g., X-band)	challenges for miniaturization	scalable for next gen. systems
Sensitivity to manufacturing tolerances	High	Low	Low
Connector Compatibility	Low – Need for specialized interfaces	Good – integrates with predefined connectors	High – adaptive for integration with available connectors.

restricting their adaptability to varying design constraints. Moreover, techniques using stepped ridges [9, 12], impedance transformers [13], and radial stubs [14] improve impedance matching but do not specifically address the integration challenges imposed by connector dimensional limitations. Also, fixed connector-specific designs require structural redesign for evolving miniaturized standards (5G/6G), highlighting scalability challenges. This gap motivates the development of a compact, adaptable, and fabrication-friendly impedance-matching technique for microstrip feeds that ensures seamless microstrip-to-coaxial integration without requiring significant structural modifications.

In response, this work introduces a novel impedance-matching technique based on an optimized linearly tapered microstrip transition with tapered substrate. This approach minimizes signal reflection and preserves signal integrity while adapting the feed to the physical constraints imposed by available connectors. The method offers a direct and efficient solution, ensuring wideband performance without adding fabrication complexity. The primary contributions of this study include the development of the optimized tapered transition and the elimination of additional matching components. Experimental validation confirms strong agreement between simulated and measured results. Table 1 presents a comparative summary of different transition techniques.

The remainder of this paper is organized as follows. Section II presents the design methodology and theoretical formulation, detailing the development of the optimized transition. Section III discusses simulation and experimental results that confirm the efficacy of the proposed approach. Finally, section IV concludes the paper with a summary of key findings and future direction.

II. PROPOSED MICROSTRIP FEED DESIGN

In this work, a microstrip feed is designed for integration with a substrate-integrated waveguide (SIW)

antenna fabricated on the same substrate. Among various SIW feed structures [15], the microstrip feed is selected for its extensive use in planar circuit designs and its ability to offer broad bandwidth coverage across the entire SIW spectrum. Design equations from [16] are employed to calculate the microstrip width (w) based on a given substrate height (h) and the targeted port impedance. The conventional microstrip feed, as described in [10], is carefully configured to match the port impedance with its characteristic impedance (Z_o), thereby ensuring optimal power transfer and minimal signal reflection, using the formulations presented in [11]. Specifically, equations from [16] indicate that the microstrip trace width at the port interface should be W_{t1} for a Rogers RT/Duroid 5880 substrate of height h_f and a target impedance of 50Ω . Furthermore, the optimum taper length and corresponding terminal width for the transition to the SIW are computed to be L_{fs} and W_{t2} , respectively, using the formulas from [11]. Figure 1 illustrates the fabricated conventional microstrip feed design integrated with the SIW antenna.

However, the conventional microstrip feed dimensions, W_{t1} and h_f , are incompatible with the available 50Ω SMA840A-0000 connector. To ensure connector compatibility while preserving a 50Ω port impedance, the substrate thickness should be reduced to 20 mils (denoted as h_1), and the corresponding microstrip width is recalculated as W_1 using the formula in [16]. It is essential that the transition to W_1 instead of W_{t1} and from h_f to h_1 occurs gradually rather than abruptly. In pursuit of this, the subsequent formulas and procedures are applied to optimize the tapered length.

A. Secondary taper for microstrip feed

The objective is to design a secondary taper for an already fabricated microstrip feed, which originally tapers from W_{t1} to W_{t2} in width and with a constant substrate height of h_f . The goal is to achieve SMA connector compatibility by applying another taper to reduce the substrate height to h_1 and microstrip width to W_1

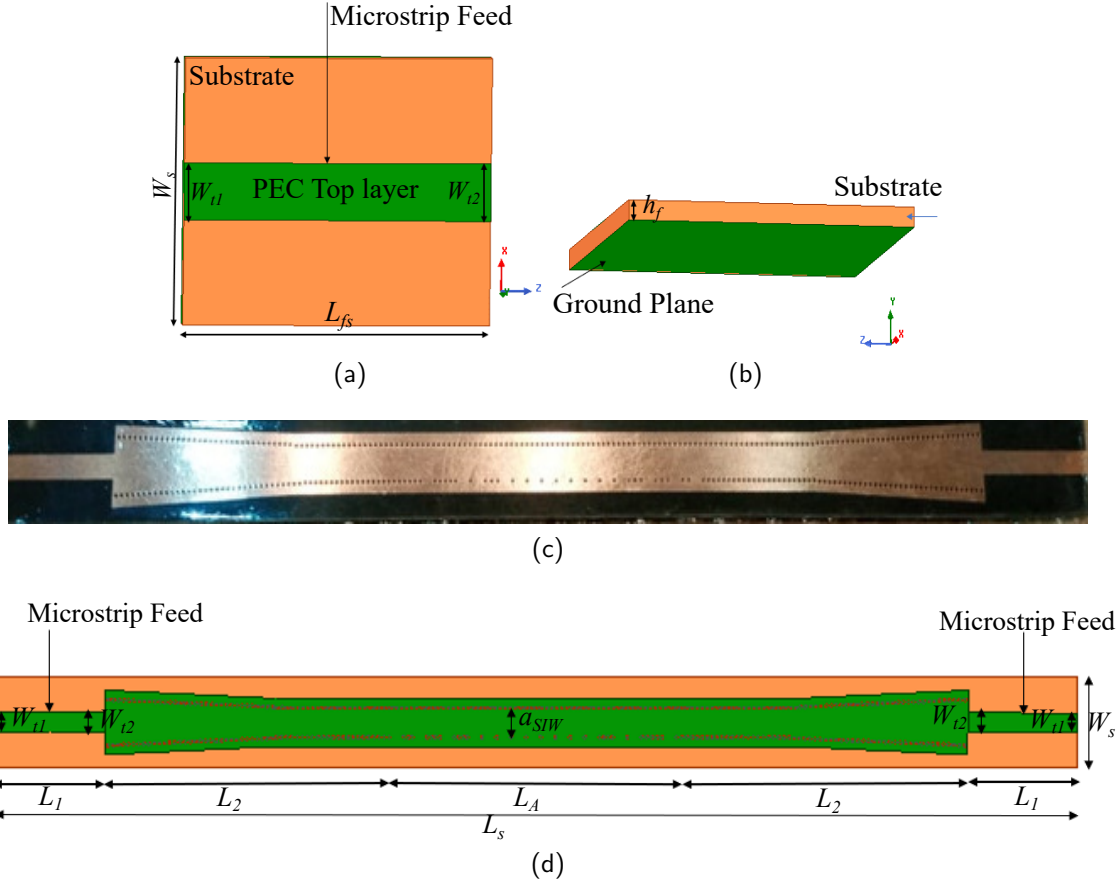


Fig. 1. Conventional simple tapered microstrip feed design to planar rectangular waveguide or SIW: (a) Top view, (b) Oblique View, (c) Fabricated feed integrated with SIW antenna [17], and (d) Feed part indicated by L_1 on both ends of the antenna [17].

gradually, ensuring that the impedance is matched and S_{11} is minimized below -10 dB.

1. Parameters and formulation

- Width at $z = 0$: $W_1 = 1.578$ mm
- Substrate height at $z = 0$: $h_1 = 0.508$ mm
- Width at $z = L$: $W_{t1} \leq w(L) \leq W_{t2}$
- Substrate height at $z = L$: $h_2 = 1.575$ mm
- Length of taper L : Unknown but constrained by $0 < L \leq L_{fp}$
- Microstrip Impedance Formula: The characteristic impedance Z_o for a microstrip line, based on the variable width $w(z)$ and substrate height $h(z)$, is approximated from [16] as follows:

$$Z_o(z) = \begin{cases} \frac{60}{\sqrt{\epsilon_e}} \ln \left(8 \frac{h(z)}{w(z)} + 0.25 \frac{w(z)}{h(z)} \right), & \text{for } \frac{w}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon_e} \left[\frac{w(z)}{h(z)} + 1.393 + 0.667 \ln \left(\frac{w(z)}{h(z)} + 1.444 \right) \right]}, & \text{for } \frac{w}{h} \geq 1 \end{cases} \quad (1)$$

where $w(z)$ is the microstrip width at position z , $h(z)$ is the substrate height at position z , and ϵ_e is the effective dielectric constant of the substrate.

- Linear Taper Functions: The microstrip width and substrate height taper linearly from $z = 0$ to $z = L$ as follows:

$$w(z) = W_1 + \left(\frac{w(L) - W_1}{L} \right) z, \quad (2)$$

where $W_{t1} \leq w(L) \leq W_{t2}$.

$$h(z) = h_1 + \left(\frac{h_2 - h_1}{L} \right) z. \quad (3)$$

- Reflection Coefficient $S_{11}(z)$: $S_{11}(z)$ is based on the mismatch between $Z_o(z)$ along the taper and the 50 Ω SMA connector:

$$S_{11}(z) = \frac{Z_o(z) - 50}{Z_o(z) + 50}. \quad (4)$$

B. Optimization problem

So the optimization problem can be expressed as:

$$\min_{L, w(L)} \int_0^L |S_{11}(z)|^2 dz \quad (5)$$

Table 2: Key design parameters and dimensions

Parameter	Symbol	Value (mm)	Parameter	Symbol	Value (mm)
Substrate Integrated Waveguide Antenna					
Microstrip to SIW transition	L_1	28.22	SIW to antenna section transition	L_2	74
Radiating Section (antenna length)	L_A	75	Substrate Thickness	h_s	1.575
Substrate Length	L_s	279.44	Substrate Width	W_s	23
Ground Plane Length	L_g	L_s	Ground Plane Width	W_g	W_s
SIW width in radiating section	a_{SIW}	8.32			
Simple Tapered Microstrip Feed					
Feed section Length	L_{fs}	L_1	Tapered Section Length	L_t	L_{fs}
Tapered Width (initial)	W_{t1}	4.9	Tapered Width (final)	W_{t2}	5
Tapered section substrate height	h_f	h_s			
Proposed Tapered Microstrip Feed					
Feed section Length	L_{fp}	L_1	Secondary Tapered Section Length	L	~ 10.4 (optimal)
Secondary Tapered section Width (initial)	W_1	1.578	Secondary Tapered section Width (final)	$W_2 = w(L)$	~ 4.932 (optimal)
Secondary Tapered section substrate height (initial)	h_1	0.508	Secondary Tapered section substrate height (final)	h_2	h_s

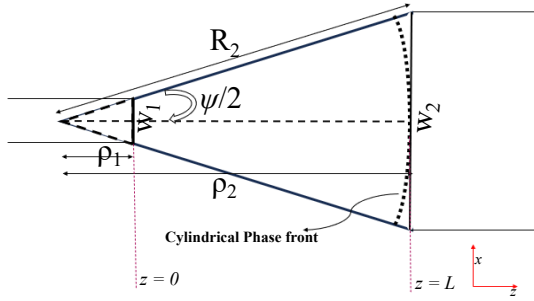


Fig. 2. Top view of E-plane horn-like configuration for proposed tapered microstrip feed.

Subject to:

$$W_{t1} \leq w(L) \leq W_{t2}, \quad (6)$$

$$0 < L \leq L_{fp}, \quad (7)$$

$$S_{11(dB)}(z) < -10 \text{ dB} \quad \forall z \in [0, L], \quad (8)$$

$$\psi \leq \psi_{\max} = 4 \tan^{-1} \left(\frac{\pi}{2k_{\text{eff}}w(L)} \right). \quad (9)$$

where, $k_{\text{eff}} = k_o \sqrt{\epsilon_r}$. k_o is free space wavelength and ϵ_r is the relative permittivity of dielectric.

Constraint (9) is derived to minimize the phase error associated with the cylindrical phase front of the wave launched into the waveguide as the proposed feed resembles an E-plane horn. Referring to Fig. 2, the derivation of (9) is provided in appendix A.

C. Optimization procedure

- Initial Guess: Start with an initial estimate for L and $w(L)$, ensuring $W_{t1} \leq w(L) \leq W_{t2}$.
- Iterative Optimization:
 1. Calculate $Z_o(z)$ along the taper.
 2. Compute $S_{11}(z)$ from impedance mismatch.

3. Adjust L and $w(L)$ iteratively to minimize $S_{11}(z)$.

- Convergence Criteria: Stop when $S_{11}(z)$ stays below -10 dB across the taper, ensuring impedance matching.

This optimization problem can be solved using numerical methods or simulation tools to find the optimal

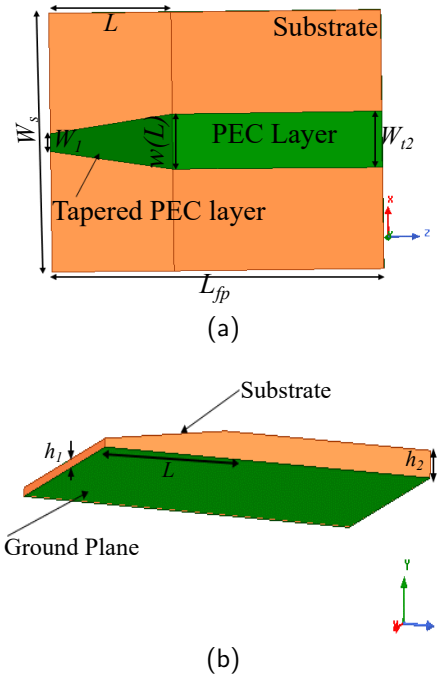


Fig. 3. Proposed tapered microstrip feed design for a planar rectangular waveguide or SIW: (a) Top view and (b) Oblique View.

taper length L that minimizes the impedance mismatch across the taper. The length for this gradual change is determined through optimization conducted in HFSS software, fine-tuning the design for its intended performance, and is found to be 10.4 mm. Figure 3 illustrates the proposed microstrip design along with all dimensions for the SIW antenna fabricated in [17]. Table 2 presents the key design parameters and dimensions across different structures.

III. IMPLEMENTATION AND RESULTS

The proposed microstrip feed is implemented using a cost-effective approach with minimal modifications. The process begins with the selective removal of the copper cladding on the top layer up to a length L . This is followed by carefully reducing the substrate height through mechanical polishing to create a tapered profile over the same length. To restore conductivity in the modified area and ensure continuous signal transmission, readily available materials such as copper strips, foils, or adhesive copper tape are applied. Figure 4 shows the proposed feed design integrated with the SIW antenna, demonstrating its successful implementation and connection to a standard SMA connector, specifically the SMA840A, which is well-suited for high-frequency applications up to 26.5 GHz. It should be noted that the signal pin of the connector is not in contact with the tapered section of the substrate at a single point; instead, it is properly soldered beneath the entire length of the pin.

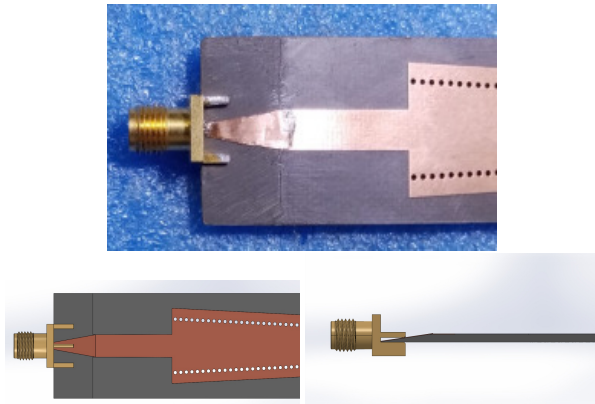


Fig. 4. Visualization of the proposed microstrip feed design for SIW leaky wave antenna fabricated in [17].

The two different feed structures shown in Figs. 1 and 3 are individually simulated using HFSS software, incorporating connector model of specific dimensions. However, when evaluating connector compatibility, it becomes evident that the proposed tapered feed aligns well with the SMA840A connector utilizing a substrate height of 20 mils (h_1) at the port end. In contrast, the simple tapered microstrip feed employs a substrate height

of h_f . Figure 5 (a) illustrates that the simple tapered microstrip feed (SM) performs poorly when connected to the connector, whereas the proposed tapered microstrip feed (TM) excels in this context. The S_{11} parameter of the TM remains well below -10 dB across a wide bandwidth, indicating minimal reflection. In contrast, the SM exhibits S_{11} well above -10 dB, implying higher reflection. Additionally, the S_{21} parameter of the TM is close to 0 dB over the frequency range, signifying efficient power transfer. Conversely, the SM shows S_{21} below -10 dB, indicating minimal power transfer.

Simulated and measured S_{11} for the antenna integrated with the proposed feed and the connector are shown in Fig. 5 (b). It can be observed that S_{11} is below -10 dB for nearly the entire frequency range of beam steering of the antenna, indicating minimal reflection. Radiation characteristics of the antenna, as illustrated in Fig. 6, reveal good agreement between expected and measured normalized directivity (dB). Figure 7 (a) displays the simulated and measured gain of the antenna and demonstrates a consistent trend. Minor discrepancies

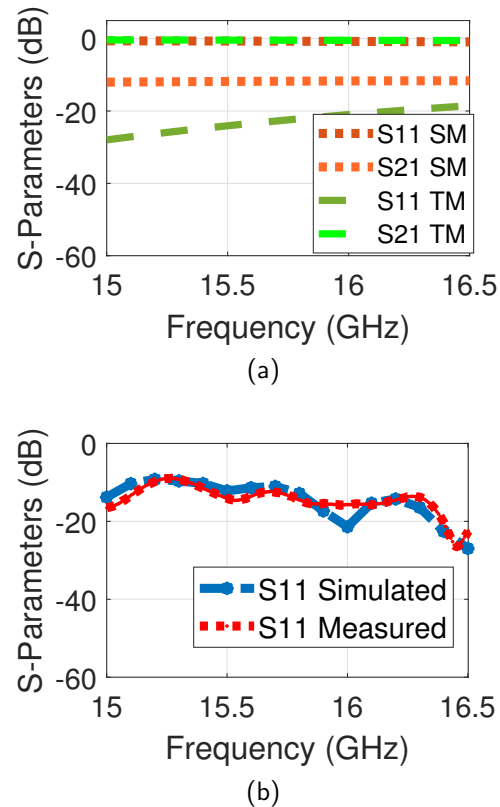


Fig. 5. S-parameters of: (a) simple and the proposed tapered microstrip feed designs (SM and TM) simulated as independent feed structures and (b) the SIW leaky-wave antenna integrated with the proposed feed design (TM).

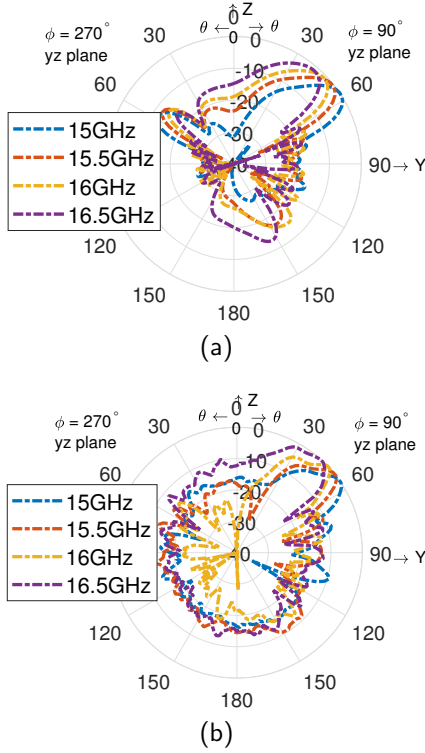


Fig. 6. Radiation patterns in the elevation plane for the SIW leaky-wave antenna demonstrating radiation perseverance: (a) Expected and (b) Measured.

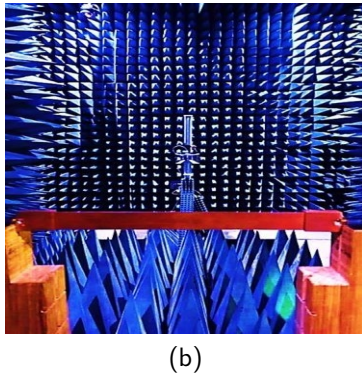
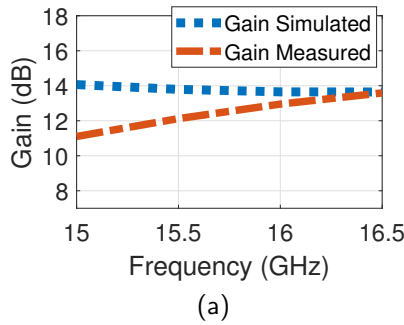


Fig. 7. (a) Simulated and measured gain results and (b) Measurement setup in anechoic chamber.

are due to fabrication tolerances and measurement uncertainties. Figure 7 (b) shows the anechoic chamber setup used for these measurements.

IV. CONCLUSION

This paper presents a microstrip feed design that overcomes connector compatibility challenges, ensuring seamless integration and optimal performance in high-frequency systems. By incorporating a linearly tapered microstrip transition with tapered substrate, the design achieves enhanced impedance matching and reduced signal reflection. Unlike conventional methods that assume predefined connector compatibility, this approach provides a practical and low-cost solution for adapting microstrip feeds to dimensional constraints of connectors without requiring major structural modifications. Demonstrated on a fabricated antenna intended for base station applications, the proposed feed design effectively resolves unforeseen mismatches while maintaining radiation characteristics. Though the study focuses on the SMA840A-0000 connector, the impedance matching approach applies to other connectors intended for specific frequency ranges with suitable parameter adjustments. This ensures broader applicability in RF and microwave systems, including 5G/6G antennas, integrated circuits, and signal interconnects, where precise impedance control and seamless connector integration are critical for reliable performance.

A potential future direction in microstrip design for connector compatibility is to reduce the substrate height by tapering it upward from the ground layer to the top, instead of tapering it downward.

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APPENDIX A

Phase Error Minimization

The constraint (9) arises from the cylindrical phase front of the wave launched into the waveguide. Because the feed resembles an E-plane horn, the wave launched into the waveguide will have a cylindrical phase front. Consequently, adhering to (9) is essential to preserve radiation performance. The radiation pattern resembles that of an aperture with a constant phase field, provided the phase error at the aperture edges does not exceed $\pm \frac{\pi}{4}$ [18].

Referring to Fig. 2, the relationship between the widths and radii of curvature at the taper is established,

leading to the following equations:

$$\rho_1 = \frac{w_1}{2 \tan(\psi/2)}. \quad (\text{A1})$$

$$\rho_2 = \frac{w_2}{2 \tan(\psi/2)}. \quad (\text{A2})$$

From these relationships, the width ratio of the microstrip taper is written:

$$\frac{w_2}{w_1} = \frac{\rho_2}{\rho_1}. \quad (\text{A3})$$

Additionally, the following relationship describes the angle ψ in terms of the radius of curvature R_2 :

$$\frac{w_2}{2R_2} = \sin\left(\frac{\psi}{2}\right). \quad (\text{A4})$$

Substituting the values of R_2 and ρ_2 into inequality from [18]:

$$(R_2 - \rho_2)k_{\text{eff}} \leq \frac{\pi}{4}. \quad (\text{A5})$$

The subsequent constraint for w_2 is as follows:

$$\left(\frac{w_2}{2 \sin(\psi/2)} - \frac{w_2}{2 \tan(\psi/2)}\right)k_{\text{eff}} \leq \frac{\pi}{4}.$$

$$\psi \leq \psi_{\text{max}} = 4 \tan^{-1}\left(\frac{\pi}{2w_2k_{\text{eff}}}\right). \quad (\text{A6})$$

Furthermore, the length of the tapered line from this point can be expressed as:

$$\rho_2 - \rho_1 = \frac{w_2 - w_1}{2 \tan(\psi/2)}. \quad (\text{A7})$$

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