Field-Replaceable Waveguide Connectors Reaching 110 GHz

Alexander Chen
Eravant, USA
achen@eravant.com

Yonghui Shu
Eravant, USA
yshu@eravant.com

***Abstract*— This paper presents an improved design of the originally proposed waveguide connector described in [2], aimed at making the field replacement more practical. The enhanced waveguide connectors support operation from 50 to 110 GHz in three upper millimeter-wave frequency bands, V-band (50–75 GHz), E-band (60–90 GHz), and W-band (75–110 GHz). The products are designed, manufactured, tested and released to the industry. The electrical performance of these waveguide connectors is compared with that of standard 1.0 mm coaxial connectors. Results indicate that the waveguide connectors offer comparable performance to their coaxial counterparts, making them suitable for a range of applications. Additionally, the paper presents an application example using W-band waveguide connectors in a W-band low-noise amplifier. The results show that the amplifier exhibits similar noise figure and gain performance whether using 1.0 mm connectors or W-band waveguide connectors.**

***Keywords*— Millimeter-wave, waveguide connector, Uni-guide, coaxial connector, amplifier, field-replaceable, WR-15, WR-12, WR-10, 1.0 mm, packaging, hermetical seal, glass bead**

I. Introduction

In the millimeter-wave frequency range, rectangular waveguides are widely employed as transmission-line media due to their low loss characteristics and high power-handling capability. Unlike coaxial cables, waveguide interfaces are inherently rigid and polarized, making custom port orientations and positions frequently necessary for system-level integration. Moreover, hermetically sealed waveguide windows are often required for environmental isolation, but such windows are typically difficult to implement and costly to produce [1].

To address these limitations, a waveguide connector interface (Uni-Guide™) was proposed by Y. Shu et al. [2]. This solution enables hermetic sealing through standard glass bead feedthroughs, thereby preserving the environmental integrity of the device housing. Furthermore, the connector introduces a user-friendly coaxial-style interface for waveguides, facilitating reduced packaging variation, simplified inventory management, and cost savings. Specifically, the use of standard enclosures originally developed for coaxial connectors eliminates the need for custom-designed waveguide housing, resulting in reduced manufacturing complexity and shorter development cycles [3].

Although the original design supported field-replaceable configurations, the enhanced waveguide connector presented in this work significantly improves practical deployment and extends the operational frequency up to 110 GHz. Three variants have been developed, corresponding to the following waveguide bands:

- V-band (WR-15): 50–75 GHz
- E-band (WR-12): 60–90 GHz
- W-band (WR-10): 75–110 GHz

The electrical performance of the waveguide connectors has been characterized and benchmarked against standard 1.0 mm coaxial connectors. Measurement results indicate comparable insertion loss and return loss, confirming the viability of the proposed interface for a wide range of high-frequency applications.

As an application case study, the W-band waveguide connector was implemented in a W-band low-noise amplifier (LNA). Measured results show that the LNA exhibits similar noise figure and gain performance when using either 1.0 mm coaxial connectors or the proposed W-band waveguide connectors. Additionally, performance is consistent with expectations based on waveguide-to-microstrip transition design simulations, validating the connector's utility in transitional and hybrid packaging architectures.

II. Enhanced Waveguide Connector

The internal configuration of the enhanced waveguide connectors is shown in Figure 1. While the overall design remains similar to the original waveguide connector described in [2], several key improvements have been implemented.

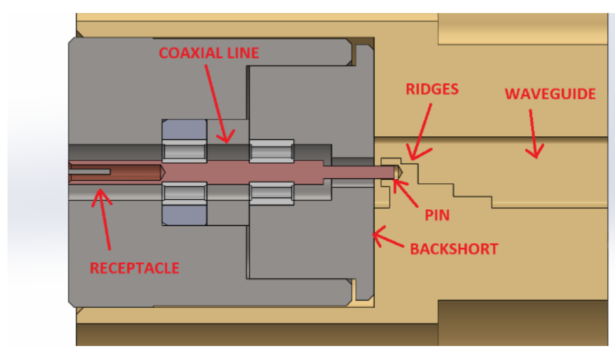

Fig. 1. The inner structure of the enhanced waveguide connector

The first improvement is that the receptacle is now flush with the end of the coaxial line transition. This modification enables the use of standard glass-beads with pin lengths of 0.030" to 0.060", eliminating the need for custom-length pins (typically 0.090" to 0.125") required in the original design. Since most standard coaxial connectors from leading manufacturers accommodate a maximum pin length of 0.065" or less, many housings and glass-beads are designed accordingly. As a result, the original waveguide connector was not fully compatible with existing packages.

The second improvement integrates the backshort and receptacle into the coaxial line transition piece itself, rather than assembling them separately with the waveguide connector body. This integration simplifies assembly and ensures more consistent unit-to-unit performance.

The finalized waveguide connectors for the V, E, and W bands are shown in Figure 2. These connectors are compatible with 0.009" diameter glass-bead pins and are field-replaceable on packages with the standard 2-hole flange 1.0 mm connector footprint, such as Southwest Microwave's model 2414-01SF.

Fig. 2. V, E, W band waveguide connector prototypes

III. WAVEGUIDE CONNECTOR TEST RESULTS

For each of the three models, a sample size of five units was tested using a back-to-back configuration on a vector network analyser. The approximate single-unit performance, presented in Figures 3 through 5, was derived by halving the measured back-to-back insertion loss and applying mathematical post-processing to the return loss data. Across all models, the typical single-unit insertion loss (blue curves in Figures 3–5) ranged from approximately 0.8 to 1.0 dB, while the return loss (brown curves in Figures 3–5) was typically between 18 and 20 dB. The results indicate a high level of unit-to-unit consistency in performance.

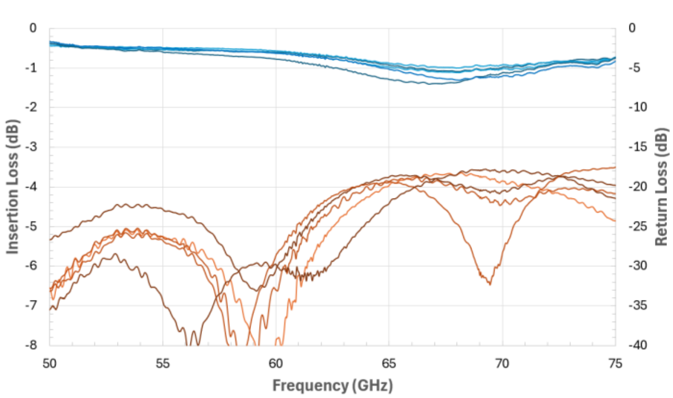

Fig. 3. Single Unit Performance Results of the WR-15 waveguide connector

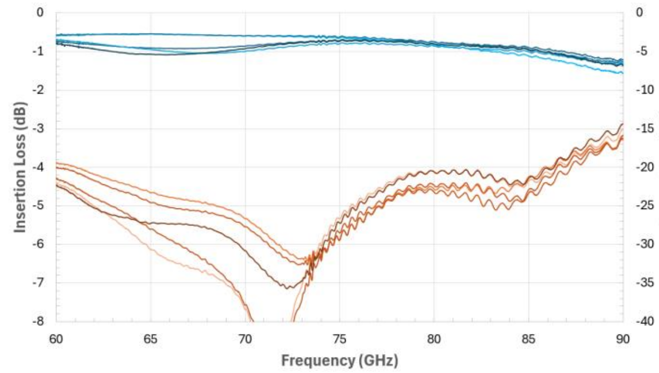

Fig. 4. Single Unit Performance Results of the WR-12 waveguide connector

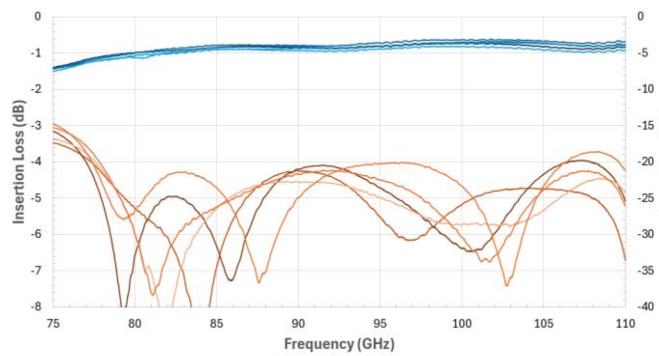

Fig. 5. Single Unit Performance Results of the WR-10 Waveguide Connector

Additionally, a performance comparison in the E-band was conducted between a standard 1.0 mm coaxial connector and the WR-12 waveguide connector, as shown in Figure 6. The typical 1.0 mm connector data was referenced here [4], while the WR-12 waveguide connector data represents an average-performing unit from the tested sample lot. The comparison shows that replacing the 1.0 mm connector with the E-band waveguide connector results in higher insertion loss and worse return loss.

This performance degradation is expected, as the waveguide connector must convert the dominant TE_{10} waveguide mode to the dominant TEM coaxial mode, introducing additional loss and impedance mismatch. In contrast, the 1.0 mm coaxial connector operates entirely in the TEM mode without requiring mode conversion.

The key advantage of the waveguide connector lies in its ability to preserve the hermetic seal of a coaxial housing while enabling seamless conversion to waveguide ports. Traditionally, achieving waveguide ports on a hermetically sealed package required custom waveguide housing with dielectric pressure windows and waveguide-to-microstrip transitions—solutions that often introduce comparable or even greater insertion loss and mismatch. Furthermore, such custom designs increase complexity, lead time, cost, and inventory management burden.

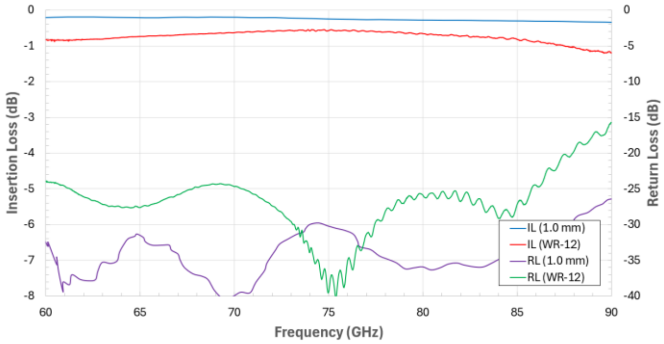

Fig. 6. 1.0 mm connector vs WR-12 waveguide connector performance

IV. FIELD-REPLACEABLE APPLICATION RESULTS

For the field-replaceable application case study, a W-band low noise amplifier (LNA) with standard 1.0 mm connector interfaces was selected. After establishing the baseline performance of the LNA, the 1.0 mm connectors were removed and replaced with the W-band waveguide connectors, as shown in Figure 7.

Fig. 7. W-Band Coaxial Amplifier with 1.0 mm and waveguide connectors

Since the same amplifier was tested with both the 1.0 mm coaxial connectors and the newly developed W-band waveguide connectors, a direct performance comparison was possible. The results for gain, noise figure, output power at 1 dB compression (P_{1dB}), and return loss are shown in Figures 8 through 11. Based on the measured data, the waveguide connector demonstrated performance comparable to that of the 1.0 mm connector across all key parameters for this amplifier.

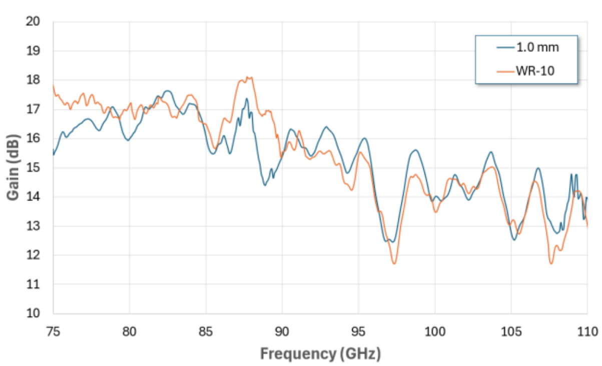

Fig. 8. Gain, 1.0 mm vs WR-10 waveguide connector

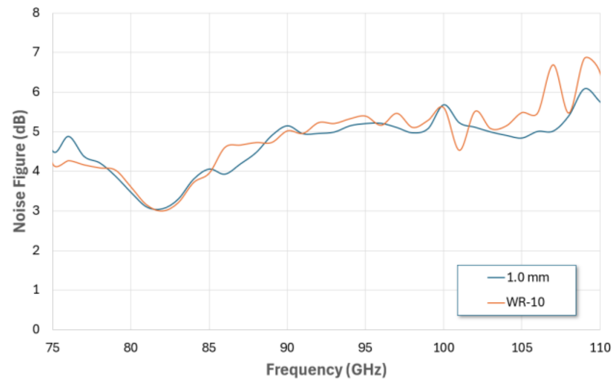

Fig. 9. Noise Figure, 1.0 mm vs WR-10 waveguide connector

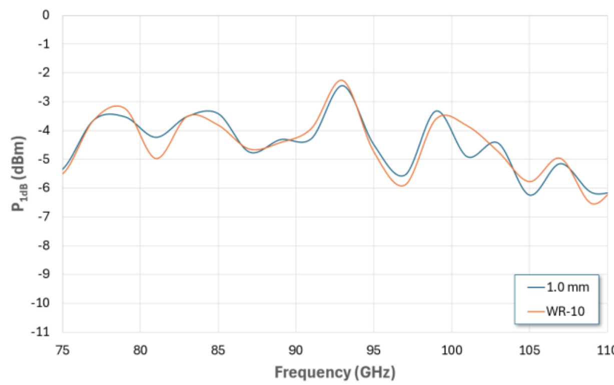

Fig. 10. P_{1dB}, 1.0 mm vs WR-10 waveguide connector

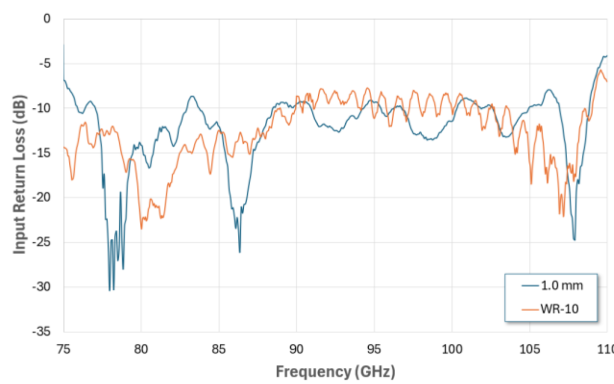

Fig. 11. Input Return Loss, 1.0 mm vs WR-10 waveguide connector

The performance of the coaxial amplifier with W-band waveguide connectors was compared to that of a traditional inline waveguide amplifier, as shown in Figure 12. Both amplifiers utilized the same internal LNA MMIC chip model and layout design; however, the traditional waveguide package design uses custom-designed waveguide-to-microstrip line mode transitions, whereas the coaxial package with the waveguide connectors installed uses standard glass beads and coaxial line to microstrip line transitions. This comparison essentially evaluates two different transition technologies: waveguide-to-microstrip via an E-plane probe versus coax-to-microstrip transition. The waveguide connector approach provides a convenient and practical solution for waveguide interfacing by leveraging standard housings to satisfy hermeticity requirements.

Based on the results presented in Figures 13 through 15, the waveguide connector-based packaging demonstrates performance comparable to that of conventional waveguide-to-microstrip transition-based packaging, in terms of gain, output power, and noise figure. While the analysis reveals some data inconsistencies and the findings are based on a single prototype, the results suggest that the developed waveguide connectors represent an effective and alternative solution for millimeter-wave packaging applications with their unique advantages.

Fig. 12. W-Band Waveguide Amplifier Package

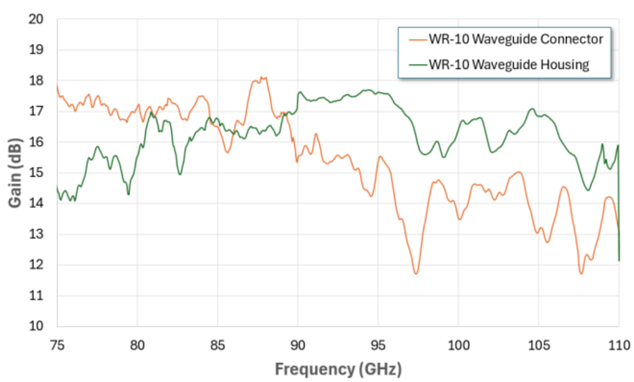

Fig. 13. Gain, WR-10 waveguide connector on Coaxial Housing vs WR-10 Waveguide Housing

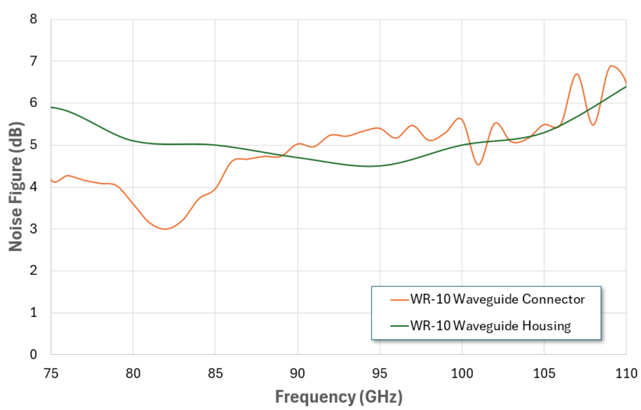

Fig. 14. Noise Figure, WR-10 waveguide connector on Coaxial Housing vs WR-10 Waveguide Housing

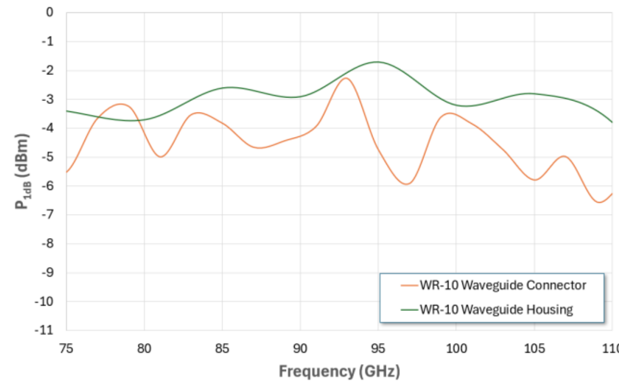

Fig. 15. P_{1dB}, WR-10 waveguide connector on Coaxial Housing vs WR-10 Waveguide Housing

V. Conclusion

Enhanced waveguide connectors for three millimeter-wave frequency bands (V, E and W-bands) that cover a combined range from 50 to 110 GHz have been designed, tested, and evaluated against the industry-standard 1.0 mm coaxial connector. The waveguide connector demonstrated comparable performance to the 1.0 mm connector in a real-world application involving a W-band coaxial low noise amplifier. The results suggest that the developed waveguide connectors represent an effective and alternative solution for millimeter-wave packaging applications with their unique advantages.

Acknowledgment

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