F-band Low-loss Tapered Slot Transition for Millimeter-wave System Packaging

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***Abstract* — This work presents a packaging solution at F-band (90 - 140 GHz) using on-chip waveguide transition. The transition is realized using a Linearly Tapered Slot (LTS) implemented in a commercial Gallium Arsenide (GaAs) Monolithic Microwave Integrated Circuit (MMIC) technology. The LTS is mounted in the E-plane of a split-block waveguide module and fed through a microstrip line. The transition is experimentally verified using a back-to-back test structure and it exhibits an average insertion loss of 1.7 dB over the frequency range extending from 100 to 135 GHz. This work presents an on-chip packaging technique to realize the interface between MMICs and standard waveguides at millimeter-wave (mmW) frequencies and hence addressing one of the main integration challenging facing systems operating at that range.**

***Keywords* — waveguide transition, tapered slot, F-band, millimeter-waves, GaAs.**

I. INTRODUCTION

The increasing demand for high-speed communication systems has been pushing integrated circuits towards higher frequencies in the mmW range [1], [2], [3]. This trend is also fueled by modern high-resolution imaging and product inspection systems. However, the realization of such systems has been always challenged by the lack of low-loss convenient packaging solutions.

Various approaches are proposed in literature to address such challenges. One suggestion is to realize interconnectivity using a microstrip to Substrate Integrated Waveguide (SIW) transition [4]. However, SIWs do not provide direct standard connectivity and an extra transition needs to be designed to interface and match to the impedance of standard air-filled waveguides. Such approach would increase the overall loss and the complexity of packaging. Moreover, SIWs suffer from dielectric loss and would not be suitable for certain technologies that utilize lossy substrate materials.

Another approach is to use separate waveguide transitions and use wire-bonding to the MMIC [5], [6]. However, this approach does not provide high integration and bondwires show highly inductive behavior at mmW frequencies which requires compensation techniques that might not have wideband performance and hence would not make full use of the high bandwidth available at the mmW range [7].

Packaging technologies such as Embedded Wafer Level Ball Grid Array (eWLB) has been widely used for mmW packaging. Moreover, techniques to utilize the technology above 100 GHz by implementing radiating structures are proposed in [8], [9]. However, the presented approaches are more suitable for high-volume production and the technology faces scaling challenges as frequency is being pushed towards the THz range while MMIC technologies provide such capabilities nowadays.

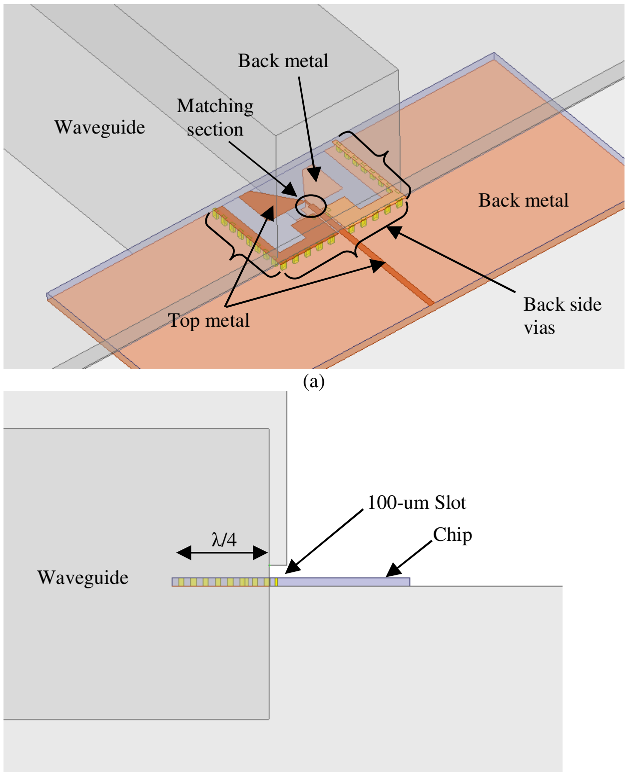
An attractive solution that suggests integrating a MMIC-to-waveguide transition on chip is proposed in [10]. The solution proposes implementing an LTS [11] radiating directly to a standard air-filled waveguide, however, the structure's performance was not experimentally verified. Simulation results showed that the transition exhibits wideband low-loss performance above 100 GHz and could be useful for addressing the needs of high-speed systems as discussed earlier. The F-band offers a wide spectrum ranging from 90 to 140 GHz that can be used for applications such as fixed radio links, future automotive sensing systems, security imaging, ..etc. and hence can be used to demonstrate and verify the proposed solution as a packaging approach for wideband high-speed mmW systems.

In this work, an LTS structure is implemented and fabricated in a commercial GaAs MMIC technology and its performance is verified at F-band. The transition provides direct coupling to the waveguide without the need of any intermediate solutions and it does not impose any limitations on MMIC size nor shape. The solution also eliminates the need for wire-bonding and provides an on-chip packaging solution paving the way towards higher integration above 100 GHz.

The paper is organized as follows: Section II describes the design of the proposed transition and the split-block waveguide module. In section III, measurement results are presented and compared to simulations along with an analysis of the transition's performance. Finally, Section IV concludes and summarizes the presented work.

II. TRANSITION DESIGN

The transition design is shown in Fig. 1. The LTS structure is implemented on a 50-um-thick GaAs substrate in a commercially available MMIC technology. The test chip is mounted in the E-plane of a split-block waveguide module and is inserted inside the waveguide channel through a 100-um slot in the waveguide's back and sidewalls. That way, the chip can have any arbitrary size and its width is not limited by the waveguide dimensions unlike other techniques that pose limitations on the size and/or shape of the chip [12], [13]. The

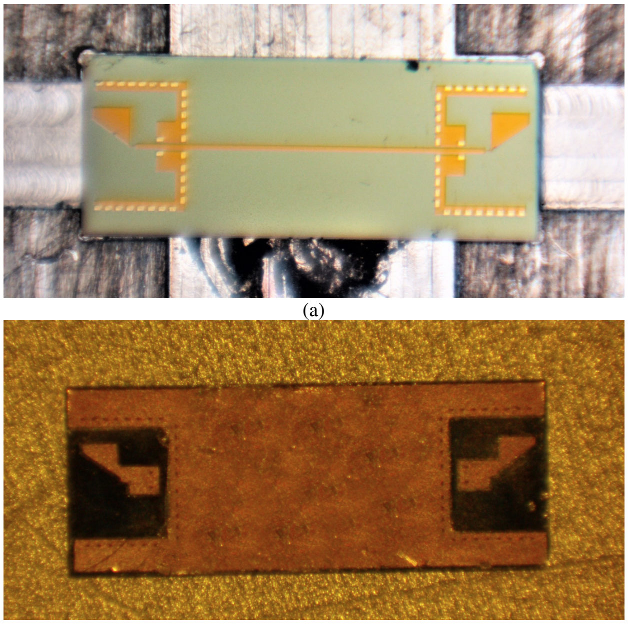


(a)

(b)

Fig. 1. The proposed LTS transition (a) 3D-view (b) Side view

chip is placed at a quarter-wave distance from the waveguide's back-short to avoid back-radiation. A wall of through substrate Back Side Vias (BSV) surround the LTS radiator as shown in Fig. 1 to stop any field leakage through the substrate. The spacing between the BSVs is chosen to be much smaller than the wavelength at F-band.



(a)

(b)

Fig. 2. Photo of the fabricated chip (a) Top view housed in the split-block waveguide module (b) Backside view of the chip

The back end of line (BEOL) includes two top metal layers and one back metal layers with the possibility to pattern the back metallization. This feature enabled the implementation of one side of the tapered slot on the top metal while implementing the other one on the back side. It also allowed using a microstrip feed for the transition and eliminated the need of a Balun to transform the feed from the differential line usually needed for tapered slots to a single ended feed and hence made the overall design more compact. The LTS is fed using a 50-Ohm microstrip line and a matching section was employed between the feedline and the LTS to provide better matching as shown in Fig. 1(a).

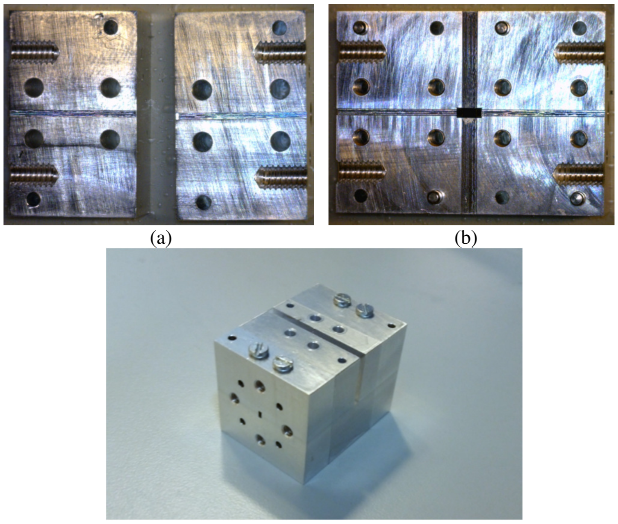
In section III, experimental results are presented and compared to simulations and an analysis of the transition loss is provided.

III. MEASUREMENT RESULTS

The fabricated LTS chip is shown in Fig. 2. The transition is implemented as a back-to-back structure to make the characterization of its performance and the calibration of the test setup more straightforward. The machined split-block waveguide module used to house the chip is shown in Fig. 3. The chip is mounted on the bottom part of the module and is inserted by a quarter-wave distance into the waveguide channel as shown in Fig. 3(b). The waveguide channel is split in the E-plane and a waveguide flange is machined on the sides of the module to provide standard connectivity as shown in Fig 3(c).

The measurement setup for the transition is shown in Fig. 4. The module was measured by connecting it to a pair of F-band frequency extenders at both the input and output ports which in turn are connected to a Vector Network Analyzer (VNA). Two-port calibration was performed to the waveguide interfaces of the frequency extenders.

Measurement results show that the single transition exhibits an average insertion loss of 1.7 dB across the



(a)

(b)

(c)

Fig. 3. Photo of the fabricated waveguide split-block module (a) Top parts (b) Bottom part (c) Assembled module

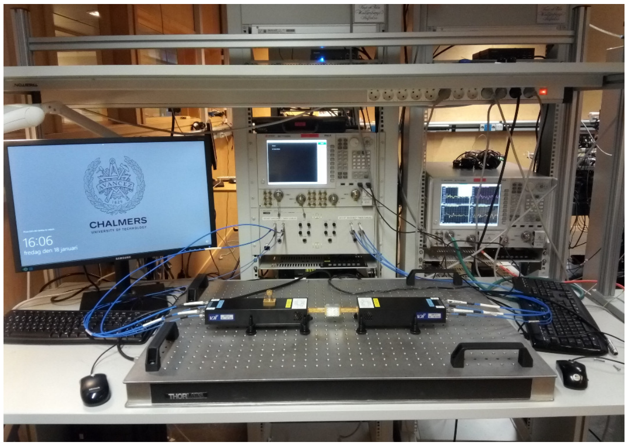


Fig. 4. Measurement setup for the back-to-back transition

frequency range 100-135 GHz as shown in Fig. 5. Measurement results are also compared to 3D electromagnetic (EM) simulations and results show that the average simulated loss is ~1 dB. It is noteworthy that loss of the microstrip transmission line connecting the back-to-back transition is deembedded in the presented results.

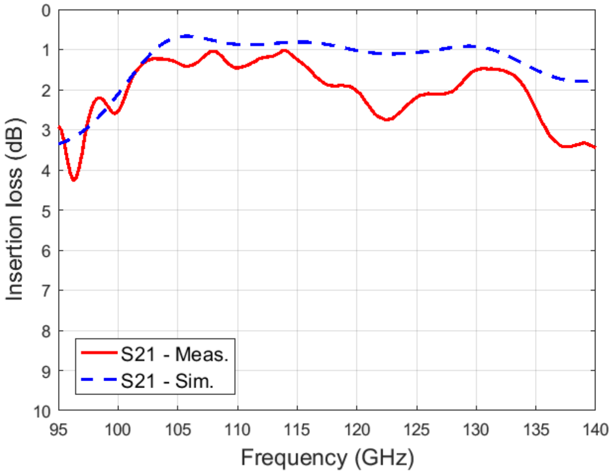


Fig. 5. Insertion loss of a single LTS transition

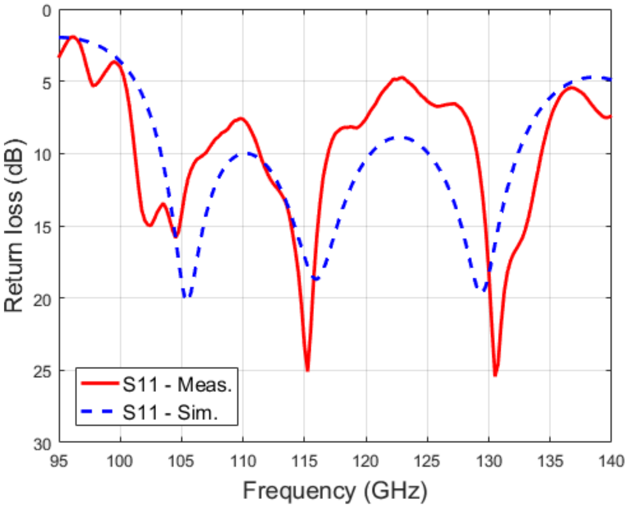


Fig. 6. Input return loss of the LTS transition

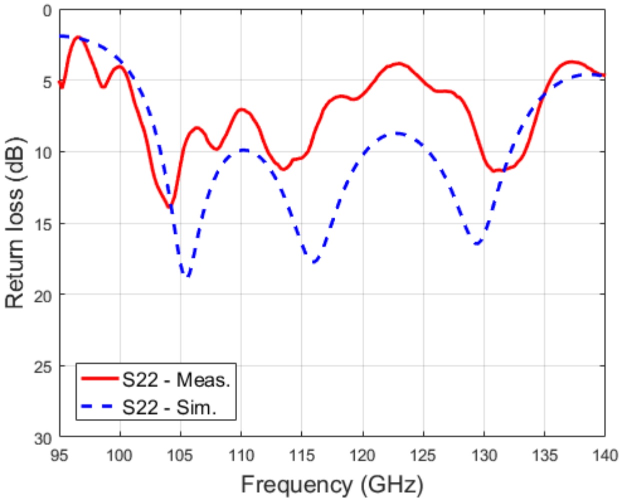


Fig. 7. Output return loss of the LTS transition

The return loss of the transition at both the input and output ports are shown in Fig. 6 and 7 respectively. It is noteworthy that the fabricated transition shows poorer return loss than estimated through simulations in the higher part of the band. This degradation was investigated, and it was found to be due to the discontinuity in the back-metallization that can be seen in Fig. 2(b) which had to be implemented to comply with a design rule imposed by the manufacturer regarding patterning of the back-metal layer and was not part of the original design. This caused an impedance mismatch along the microstrip line feeding the LTS although it should be noted that the chip is mounted on a metal surface and attached to it using conductive epoxy. The degradation of the return loss also coincides with the relatively higher measured insertion loss at the same frequency. A different feeding approach for the LTS or using a technology that provides a different BEOL would help mitigate the issue.

E-field simulation was also performed as shown in Fig. 8. The results show that the E-field is confined in the waveguide direction and no significant back radiation is present.

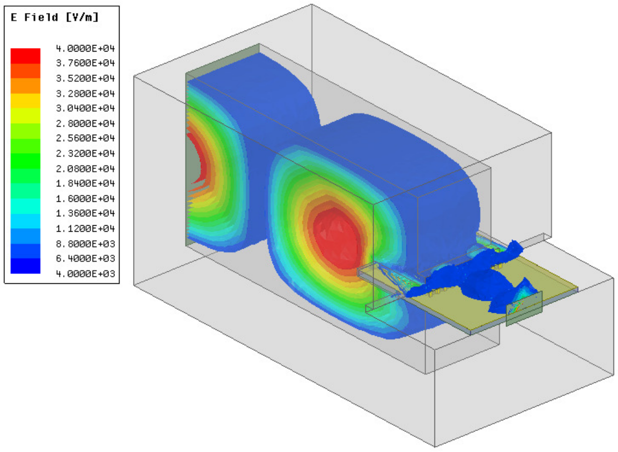


Fig. 8. E-field magnitude distribution

IV. CONCLUSION

An F-band chip-to-waveguide transition based on LTS was presented. The transition is implemented in a commercial GaAs MMIC technology. Experimental results show that the transition achieves an average insertion loss of 1.7 dB over the frequency range 100-135 GHz. The presented transition eliminates the need of bondwire interfaces and provides an on-chip packaging solution for mmW systems and hence addresses one of the main challenges facing the full realization and commercialization of such systems.

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REFERENCES

[1] J. Edstam, J. Hansryd, S. Carpenter, T. Emanuelsson, Y. Li, H. Zirath, "Microwave backhaul evolution", 2017 *Ericsson Technology Review*, vol. 95, pp. 24-36.

[2] Peter H. Siegel, “Terahertz Technology,” *IEEE Trans. Microw. Theory Tech.,* vol. 50, no. 3, March 2002

[3] R. Wu *et al.*, "Ultra-high-data-rate 60-GHz CMOS transceiver for future radio access network," *2017 IEEE 12th International Conference on ASIC (ASICON)*, Guiyang, China, 2017, pp. 1025-1028.

[4] Z. Kordiboroujeni and J. Bornemann, "New Wideband Transition from Microstrip Line to Substrate Integrated Waveguide," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 62, no. 12, pp. 2983-2989, Dec. 2014.

[5] V. Vassilev et al., "Integrated front-ends up to 200 GHz," 2011 IEEE MTT-S International Microwave Workshop Series on Millimeter Wave Integration Technologies, Sitges, 2011, pp. 57-60.

[6] L. Samoska et al., "Miniature packaging concept for LNAs in the 200–300 GHz range," *2016 IEEE MTT-S International Microwave Symposium (IMS)*, San Francisco, CA, 2016, pp. 1-4.

[7] S. Beer et al., "Design and measurement of matched wire bond and flip chip interconnects for D-band system-in-package applications," *2011 IEEE MTT-S International Microwave Symposium,* Baltimore, MD, 2011, pp. 1-4.

[8] A. Hassona *et al.*, "A non-galvanic D-band MMIC-to-waveguide transition using eWLB packaging technology," *2017 IEEE MTT-S International Microwave Symposium (IMS)*, Honololu, HI, 2017, pp. 510-512.

[9] A. Hassona, V. Vassilev, Z. S. He, C. Mariotti, F. Dielacher and H. Zirath, "Silicon Taper Based D-Band Chip to Waveguide Interconnect for Millimeter-Wave Systems," in *IEEE Microwave and Wireless Components Letters*, vol. 27, no. 12, pp. 1092-1094, Dec. 2017.

[10] A. Hassona, Z. S. He, V. Vassilev and H. Zirath, "D-band waveguide transition based on Linearly Tapered Slot Antenna," *2017 IMAPS Nordic Conference on Microelectronics Packaging (NordPac)*, Gothenburg, 2017, pp. 64-67.

[11] Prasad, S.N., and S. Mahapatra, “A New MIC Slotline Antenna for Short Range Radar,” *17th International Electronics Convention and Exhibition,* Univ. of New South Wales, 27-31 Apr 1979, pp. 5-8.

[12] K. J. Lee, D. H. Lee, J. S. Rieh and M. Kim, "A V-Band Waveguide Transition Design Appropriate for Monolithic Integration," *2007 Asia-Pacific Microwave Conference*, Bangkok, 2007, pp. 1-4.

[13] A. Tessmann *et al.*, "A 600 GHz low-noise amplifier module," *2014 IEEE MTT-S International Microwave Symposium (IMS2014)*, Tampa, FL, 2014, pp. 1-3.