

Methods for Measuring a D-band GaAs IPD Patch Array Using a Flip-Chip SIW Interconnect Transition to a WR6 Waveguide

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Abstract—This paper proposes a D-band GaAs Integrated Passive Device (IPD) antenna measurement methodology employing a WR6 waveguide for antenna performance evaluation. By incorporating a novel flip-chip Substrate Integrated Waveguide (SIW) interconnect transition and a high-precision alignment fixture, the method enables accurate characterization of a GaAs IPD microstrip patch array. The proposed Over-the-Air (OTA) measurement technique is versatile and applicable to D-band antenna-integrated systems with either boardside-radiating or end-fire-radiating antennas.

Keywords—Sub-THz, patch antenna, integrated passive device (IPD), Substrate Integrated waveguide (SIW), Flip-chip

I. INTRODUCTION

In recent years, advancements in 6G, radar, and space communication technologies have driven an increasing demand for D-band antennas, accelerating the development of more efficient and precise design techniques. The small physical size of D-band antennas necessitates high precision in circuit fabrication, where substrate loss and the choice of stacking environment have become critical parameters in determining antenna performance. The GaAs-based Integrated Passive Device (IPD) provides a substrate environment that is particularly advantageous for meeting the circuit requirements of D-band systems. Recent studies have highlighted its exceptional performance in radio-frequency passive circuits and system integration [1]-[2]. Due to the small size of D-band antennas, their characteristics can be measured using probing methods. However, the interference introduced by the probing environment can affect the measurement results, presenting additional challenges that must be addressed. Over-the-Air (OTA) antenna measurements offer a more accurate characterization of antenna performance. Nonetheless, for measurements involving significant size differences, such as between the waveguide ports of a vector network analyzer and the feed ports of the D-band antenna on the GaAs IPD, this paper proposes a design for substrate-integrated waveguide (SIW) interconnects, which can serve as a method for performing OTA measurements on such IPD antennas.

II. SIW INTERCONNECT TRANSITION DESIGN

Fig. 1 illustrates the proposed SIW interconnect transition design for measuring the GaAs IPD patch array. The transition consists of a WR6 waveguide-to-SIW section and an SIW-to-

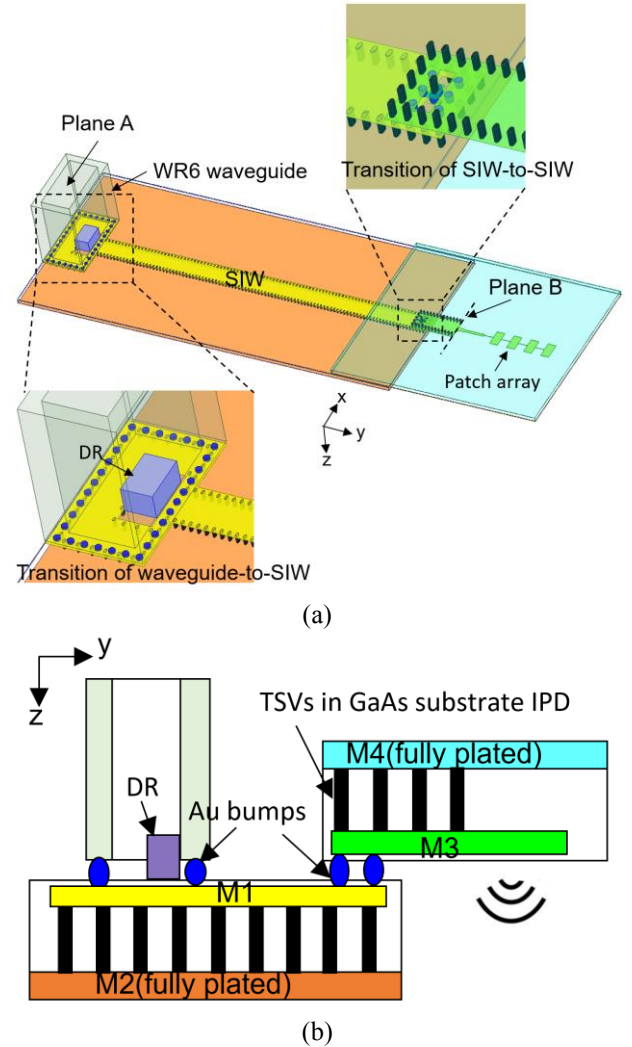


Fig. 1. (a) 3D view and (b) cross-sectional view (not to scale) of the proposed SIW interconnect transition design for measuring GaAs IPD patch array.

SIW section. To mitigate the narrowband characteristics with a high Q-factor resulting from the high dielectric constant ($\epsilon_r = 12.9$) of the GaAs substrate, the bandwidth of the waveguide-to-

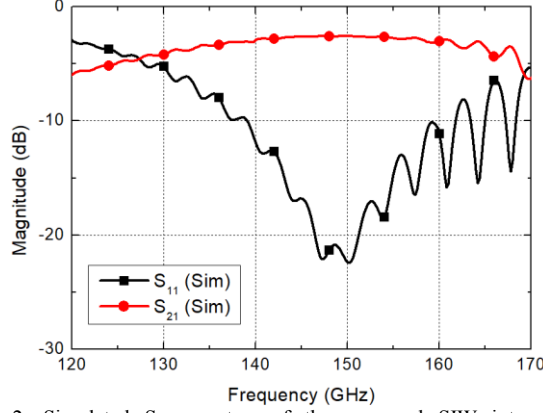


Fig. 2. Simulated S-parameters of the proposed SIW interconnect transition, evaluated between reference planes A and B, as depicted in Fig. 1(a).

SIW transition is enhanced by incorporating a quartz dielectric resonator (DR) with a low dielectric constant ($\epsilon_r = 3.79$). Au bumps are fabricated on the GaAs substrate pads to interface with the waveguide. The SIW structure is formed by the frontside metal, backside metal, and through-silicon vias (TSVs) of the GaAs IPD. The backside metal of the GaAs IPD typically requires full plating, as shown by M2 and M4 in Fig. 1(b). During measurement, the antenna radiation direction must be opposite to that of the waveguide. Therefore, a vertical transition of SIW-to-SIW between the two IPD substrates is realized. By using Au bumps and TSVs to construct a coaxial cable-like structure, the transition supports the propagation of TEM and TE_{10} modes, thereby improving the bandwidth. The integration of the two IPD substrates is achieved through Au-Au flip-chip assembly technology.

III. SIMULATION AND MEASUREMENT RESULTS

Fig. 2 presents the simulated S-parameters of the proposed SIW interconnect transition, evaluated between reference planes A and B as depicted in Fig. 1(a). The reflection coefficient bandwidth spans from 139 GHz to 162 GHz, with a minimum insertion loss of 2.6 dB at 150 GHz. The fabrication of the IPD patch array, including the SIW interconnect transition and its integration with the alignment fixture, is shown in Fig. 3. Plastic screws are employed primarily to ensure proper compression of the gold bumps on the IPD substrate against the waveguide metal while preventing damage to the thin GaAs substrate during the locking process. Fig. 4 compares the simulated and measured reflection coefficients, along with the simulated gain, of the patch array fed by the WR6 waveguide through the SIW transition. The measurements were carried out using a Keysight N5242B vector network analyzer with two OML V05VNA2 frequency extenders, covering the frequency range of 140 to 220 GHz. The measured reflection coefficient bandwidth ranges from 144 GHz to 158 GHz, showing excellent agreement with the simulations.

IV. CONCLUSION

This paper presents an SIW interconnect transition developed using flip-chip technology, achieving the integration

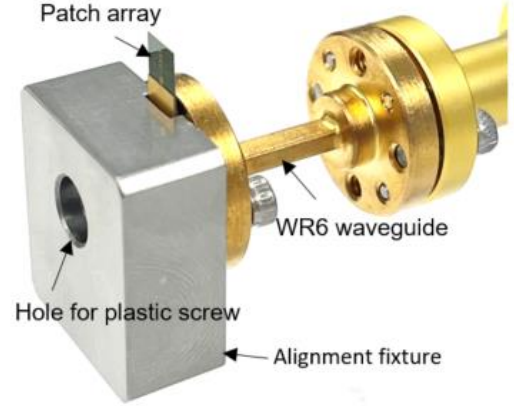


Fig. 3. Fabrication of the IPD patch array, including SIW interconnect transition and integration with the alignment fixture.

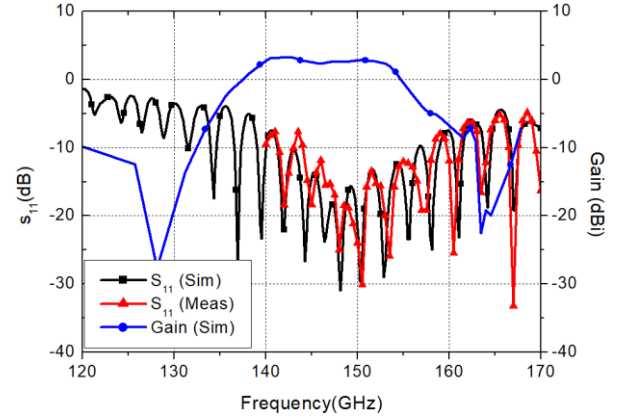


Fig. 4. Simulated and measured reflection coefficients, along with the simulated gain, of the patch array fed by the WR6 waveguide through the SIW transition.

of two IPD substrates. The proposed transition design allows for precise measurements of IPD microstrip antenna arrays, demonstrating strong consistency between simulation and experimental results. This technique offers a dependable and low-interference solution for antenna measurements.

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