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Substrate-Less Vertical Chip-to-Waveguide Transition for W-Band Array Antenna Integration

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Summary

This paper presents a vertical transition from a high permittivity GaAs MMIC to rectangular waveguide using bondwires as a coupling structure. The transition is advantageous for the direct integration of any off-the-shelf chip into a waveguide antenna since no modification of the GSG-pad or additional substrate is needed. An EBG structure consisting of pins is used for the packaging of the chip in order to avoid field propagation in undesired directions. The simulations results show that the reflection coefficient is lower than -10 dB and the average insertion loss is better than 0.5 dB from around 87 to 101 GHz (14% relative bandwidth).

1 Introduction

The need for higher data rates has increased the interest on higher frequencies over the last years. Gap waveguide technology has been proven as a low-loss and cost-efficient solution for mm-wave [1]. However, since all the active circuits are based on MMIC technology, it is thus necessary to have an adequate integration of these devices into waveguide based antennas with a good performance in terms of insertion loss and bandwidth. Extensive research has been done on this topic and several transitions from microstrip to waveguide can be found in the literature. Some of these solutions use an additional low-permittivity substrate including a coupling structure. This additional substrate is wire-bonded to the high-permittivity MMIC substrate, making the solution less compact and introducing additional losses. On the other hand, other solutions propose a direct on-chip transition from MMIC to waveguide. Nevertheless, this approach usually has a negative impact on the costs due to the increase in size and also requires the co-design of the chip and the package, which is not always possible.

In this work, a substrate-less vertical transition from chip to waveguide using bondwires as a coupling structure is proposed. The solution is compact and low-loss while showing a good performance in terms of bandwidth. The transition is advantageous for the integration of any off-the-shelf chip with array antennas and the design is suitable for fabrication using standard manufacturing techniques.

2 Design of the transition

The transition is based on the direct connection of the chip to the waveguide metal block using bondwires and the schematic of the proposed solution is shown in Fig.1. The thickness of the GaAs ($\varepsilon_r = 12.94$) substrate used in this work is 100 μm. Due to the high inductance of the wires at these high frequencies, it is important to keep the length as short as possible. However, there is a limit on how narrow the cavity can be so that it can be produced by CNC milling. That is the reason why an additional layer with a narrow etched slot is included in between the two metal blocks. This narrow slot helps coupling the energy into the cavity underneath while reducing the length of the wires.

The wires are placed in a V-shape to reduce the total inductance, thus helping to achieve a wide band impedance matching. The electromagnetic energy is coupled to a $\lambda/4$ cavity placed below. In order to enhance the coupling of the fields to the vertical waveguide, a ridge with a small step is placed on the waveguide. In this way, a secondary resonance is introduced and the overall operation bandwidth of the proposed transition is improved.

A periodic EBG structure consisting of pins is used on both the bottom and top metal layers in order to prevent the fields from leaking in undesired directions when there is a small air gap between the layers. Some pins are placed on top of the chip in order to prevent undesired mode propagation inside the waveguide.

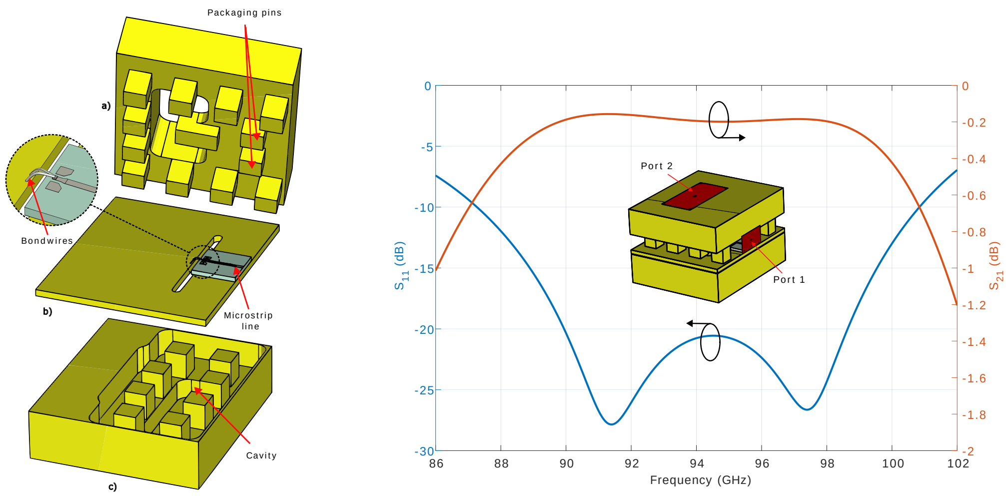

Figure 1. Proposed substrate-less vertical transition between chip and rectangular waveguide (left): (a) Top metal layer with WR10 waveguide and packaging pins. (b) Middle etched layer holding the chip (c) Bottom metal layer including the cavity. Simulation results of the transition (right)

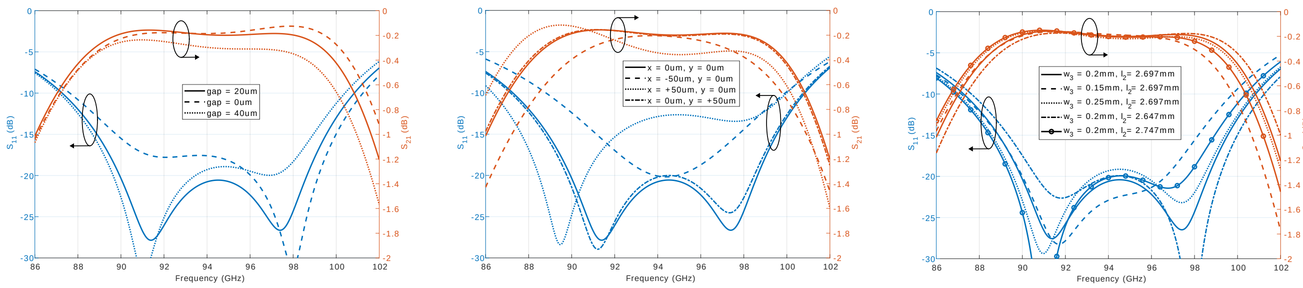

Figure 2. Tolerance analysis of the proposed transition. Air-gap variation between the different metal layers (left), chip position miss-alignment being *x* a displacement across the slot and *y* a displacement along it (middle), variation of the etched slot dimensions (right).

3 Simulation results and tolerance analysis

Lossy aluminum for the metal layers and lossless GaAs substrate for the MMIC are used in the simulation model. The simulation results of the proposed transition are shown in Fig. 1. It can be seen that the reflection coefficient remains lower than -10 dB from around 87 to 101 GHz frequency range (14% relative bandwidth). The losses are, on average, smaller than 0.5 dB in this band of interest. A tolerance analysis of the transition was also performed. The results of the analysis are shown in Fig. 2. It can be seen that the proposed transition is tolerant to variations on both the air-gap between the metal layers and slot dimensions but sensitive to any chip miss-alignment.

4 Conclusion

A vertical substrate-less transition from RF circuit to waveguide by using bondwires has been presented. It can be seen from the simulation results that the transition achieves around 14% relative bandwidth with return losses better than 10 dB and insertion loss lower than 0.5 dB. The transition is advantageous for the integration of RF electronics into a waveguide antenna array since no modification of the MMIC is needed. A back-to-back prototype of the transition will be manufactured in the future in order to confirm with measurements the good performance shown in the simulations.

References

[1] A. Vosoogh et al., "Compact Integrated Full-Duplex Gap Waveguide-Based Radio Front End For Multi-Gbit/s Point-to-Point Backhaul Links at E-Band," in IEEE Transactions on Microwave Theory and Techniques, vol. 67, no. 9, pp. 3783-3797, Sept. 2019, doi: 10.1109/TMTT.2019.2919539.