Millimeter wave contactless microstrip-gap waveguide transition suitable for integration of RF MMIC with gap waveguide array antenna

Millimeter Wave Contactless Microstrip-Gap Waveguide Transition Suitable for Integration of RF MMIC with Gap Waveguide Array Antenna

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Abstract—**A new simple transition from a microstrip to gap waveguides has been proposed in this paper. The transition has been implemented for ridge gap waveguide and a groove gap waveguide. The cavity coupling is used to couple the waves between the microstrip and the gap waveguides. This cavity acts as a backshort in the transition region and the microstrip lies inside the waveguide, which provides a solution to integration of RF MMIC circuits with the feed-network of the gap waveguide array antenna. Roger 3010 ($\epsilon_r = 10.2$) was used as the microstrip substrate for these transitions. The optimised back-to-back Ridge Gap Waveguide (RGW)-microstrip transition shows relative bandwidth of 21% for $S_{11} < -20\ dB$ and Groove Gap Waveguide (GGW)-microstrip transition shows relative bandwidth of 20% for $S_{11} < -17\ dB$. The insertion losses are better than 0.5 dB in the designed frequency bands for both the RGW and GGW transitions.**

I. Introduction

The lower frequency communication bands have now become crowded. Hence, there is a paradigm shift towards higher frequency in order to meet the increasing demand of high data rate and high resolution video transfer. However, losses at circuit interconnects, high path loss and low penetrating capacity at higher frequencies needs to be dealt with to extensively use millimeter wave frequencies for communication purpose. Several solutions like compact and closely placed Tx/Rx module, high gain antenna, beam steering and massive MIMO have been proposed to overcome these limitations [1], [2]. Gap wave technology seems to be very promising in high frequency applications. Gap wave technologies have been used for packaging of millimeter wave circuits [3], [4] and making band pass filters [5]. Several high gain array antenna using gap waveguide have already been produced which overcomes the limitations of traditional microstrip and rectangular waveguide array antennas [6]–[9]. The split block architecture of these gap waveguide array antenna is suitable for integration and packaging of RF (Monolithic Microwave Integrated Circuit) MMIC circuits. Not only will such integration make the entire Tx/Rx module compact, but also will enable beam steering through integration of phase shifters and power amplifiers circuits. Concepts like massive MIMO can also be implemented by integrating several Tx/Rx module in the feed-network of such antennas. Hence, integration is a key aspect which need to be realised for the extensive use of millimeter wave frequencies for communication.

Several transitions have been designed so far for different gap waveguides. Transition from coaxial lines to ridge gap waveguide had been designed earlier [10]. However, such transition is not suitable for integrating MMIC chips with gap waveguide antennas and coaxial line have high losses for millimeter wave frequencies. Direct pressure contact between the ridge and the microstrip to make transition has also been proposed in [11]. However, the thickness of the microstrip substrate for this transition had to be the same as the air gap between the ridge and the top metal plate. Moreover, a direct contact is not a very suitable option as it could damage the MMIC circuit and it becomes extremely difficult to have a good contact at higher frequencies. Contactless transition from microstrip to gap waveguide had also been proposed where quarter wavelength of the ridge is overlapped with microstrip patch with air gap in between [12], [13]. However, this transition was very sensitive to the gap between the ridge and the patch. Tolerance analysis suggested that it had a tolerance level of only $10\mu m$. Manufacturing and assembling the PCB with this accuracy level is challenging and hence the measured results were not in line with the simulated results. In this paper, a new simple method to make transitions from microstrip to gap waveguides transition is proposed. These transitions are suitable for integrating and packaging of MMIC chips with gap waveguide array antennas.

II. Proposed Transitions

The proposed transition presented in this paper is based on the principal of electromagnetic coupling with the help of a rectangular cavity. The depth of the cavity is a quarter wavelength which acts as a backshort in the transition region. On one side of the cavity it is possible to have the desired waveguide such as Ridge Gap Waveguide (RGW) or Groove Gap Waveguide (GGW). On the other side of the cavity a microstrip probe extending over half the cavity width is placed in order to couple the signal to the microstrip line. Impedance matching for the transition can be done by optimizing the dimensions of the cavity and dimensions of the structure in the transition region. The microstrip is in the same plane as that of the pins and lies inside the waveguide. Hence, this transition is ideal for integrating and packaging of MMIC chip with gap waveguide antennas. In the subsection below the proposed

RGW-microstrip and GGW-microstrip transitions using this backshort cavity method are presented.

A. RGW-Microstrip Transition

Fig. 1 shows the proposed back-to-back RGW-microstrip transition. The impedance of the RGW can be estimated with microstrip line with substrate as air. For $1\ mm$ ridge width and $0.25\ mm$ air gap between the ridge and the top metal plate the impedance is approximately 50 Ω. Whereas the wave impedance of the cavity region can be approximated as impedance of TE_{10} mode of rectangular waveguide. This is approximately 550 Ω at 60 GHz. As seen in Fig. 1, impedance matching is done by Chebychev transform with steps in the ridge. The length of each step is quarter wavelength where impedance is increased from 50 Ω to 550 Ω by decreasing the height of the ridge. As there is a space constrain in the feed-network of array antenna only two steps have been used. However, a better matching can be achieved by increasing the number of steps in the transition region. Optimization for the RGW-microstrip transition was done by changing the dimensions of the steps, dimensions of the cavity, the width of the triangular probe and the extent to which this probe goes into the cavity. The transition had been optimised for V-band and the dimensions were in line with the theoretically predicted results. Fig. 2 shows the S parameters for the back-to-back transition after optimization. As seen in Fig. 2 the return loss is better than 20 dB for the transition over 55.8-68.8 GHz which is 21% relative bandwidth. The insertion loss is better than 0.5 dB over the same frequency band.

B. GGW-Microstrip Transition

The concept of backshort cavity has also been used to design GGW-microstrip transition as shown in Fig. 3. In this design, the width of the GGW is same as that of WR-15 flange (3.8 mm) used for V-band. Impedance matching between the groove and the microstrip is done by changing the position of the first two pair of pins just after the cavity, the dimensions of the cavity and the dimensions of the triangular probe. The cavity occupies entire width of the groove in order to have impedance similar to that of GGW. The distance of

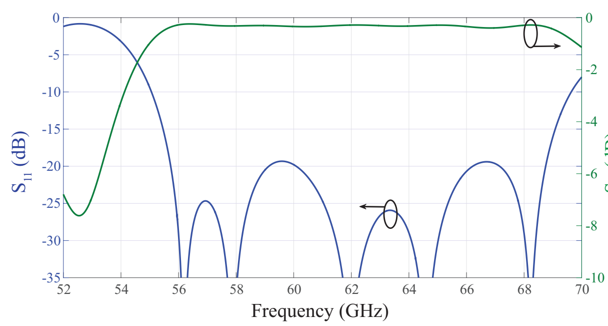

Fig. 2. S parameters for the back to back proposed transition from Ridge Gap Waveguide (RGW) to microstrip.

this pair of pins from the transition region is approximately quarter wavelength. This helps to minimize the reflection through destructive interference of waves from the pins and the transition region. It also acts as an inductive iris and helps to cancel out the capacitance present in the transition region. Fig. 4 shows the achieved S-parameters after optimization. A return loss better than 17 dB is achieved over the frequency range from 55.6-67.4 GHz which is 20% relative bandwidth. The insertion loss in this band is better than 0.5 dB.

Roger 3010 was used as microstrip substrate for making these RGW and GGW transitions. The relative permittivity of such substrate is 10.2 which is close to that of MMIC substrate. Perfect electric conductor (PEC) had been used as the material for the waveguides. It is also worth mentioning that if the microstrip substrate width is greater than a certain limit (approximately $\lambda/2$) the coupling of waves through the probe will not be effective. This is because the waves can then travel as TE_{10} modes of GGW instead of quasi TEM mode through the microstrip. Hence, if transitions with wide substrate width is required, additional pins from the top metal plate needs to be placed above the microstrip substrate. This will help to suppress unwanted modes above the microstrip substrate. The dimensions of the microstrip substrate used in simulation both for the RGW and GGW transition was approximately (4 mm × 1.5 mm). This dimensions are similar

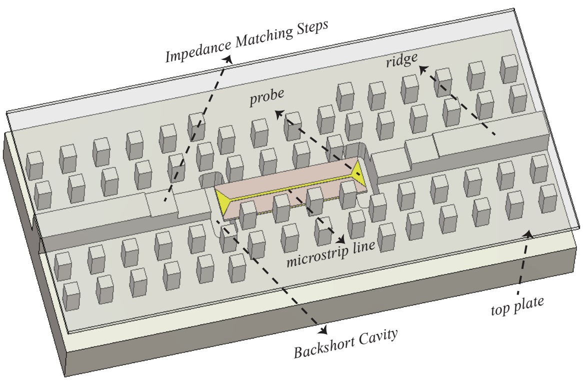

Fig. 1. Proposed back to back Ridge Gap Waveguide (RGW) to microstrip transition using back short cavity.

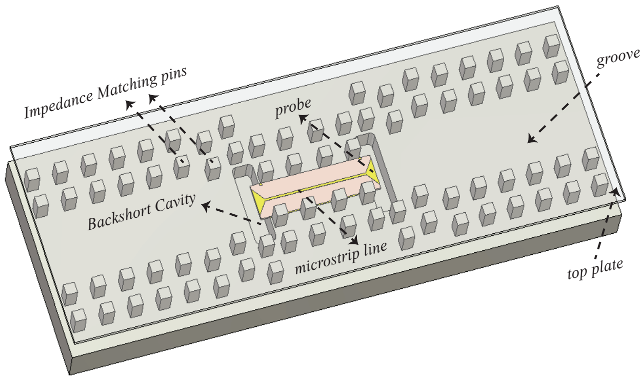

Fig. 3. Proposed back to back Groove Gap Waveguide (GGW) to microstrip transition using back short cavity.

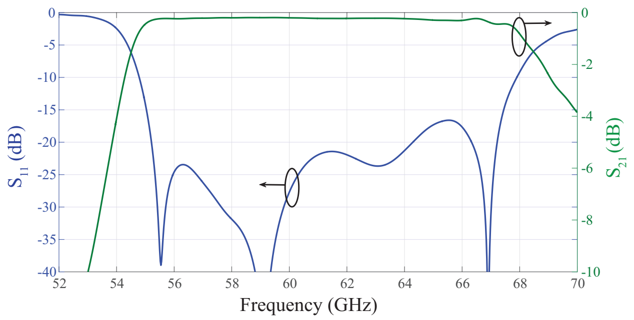

Fig. 4. S parameters for the back to back proposed transition from Groove Gap Waveguide (GGW) to Microstrip.

to the typical dimension of MMIC circuit for millimeter waves. As there is a space constrain in the feed network of the array antenna rectangular cavity was used. The achieved bandwidth using such cavity are slightly more than 20%. However, if there is no space constrains elliptical cavity can be used in order to achieve bandwidth greater than 30%.

III. Conclusion

A new and simple contactless microstrip line to gap waveguide transition have been proposed. This transition is based on electromagnetic coupling using a rectangular cavity. This method of transition is verified for ridge gap waveguide-microstrip and groove gap waveguide microstrip transitions. The Ridge gap waveguide-microstrip transition had 21% relative bandwidth with $S_{11} < -20\ dB$ whereas the groove gap waveguide-microstrip had 20% relative bandwidth with $S_{11} < -17\ dB$. The microstrip lies on the plane of the pins and inside the waveguides which is ideal for integrating MMIC chips with gap waveguide array antenna.

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