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Wide-Band Spatially Distributed TE₁₀ Substrate Integrated Waveguide Transition for High-Power Generation at mm-Wave Frequencies

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Abstract—An array of microstrip lines is used for the direct excitation of the spatially distributed TE₁₀ substrate integrated waveguide (SIW) mode. The proposed configuration can generate 4x more power with a 4x smaller form factor relative to a single microstrip-to-SIW transition, while offering a larger bandwidth. This is an important step toward the generation of high power in densely integrated mm-wave antenna systems.

Keywords—Substrate integrated waveguide; spatial power combining; mm-wave systems.

I. INTRODUCTION

The generation and transmission of high power is a major challenge at mm-wave frequencies, since the atmospheric propagation and material losses are significant and increase as frequency increases. This is further exacerbated by the fact that semiconductors reduce in size and deliver less power when moving up into the mm-wave frequency region. Hence, more transistors are needed to overcome these limitations, but will collectively generate more heat. These problems must be overcome to, for instance, enable the high data throughputs that are envisioned for future 5G communication systems.

Substrate integrated waveguide (SIW) technology offers a low-cost low-profile mm-wave integration solution. However, a transition is needed to interface the principal SIW electromagnetic field mode to a single network node, or TEM-type transmission line (TL), so that a circuit component can be connected. A typically employed microstrip-to-SIW transition is shown in Fig. 1(a), where a tapered section is proposed to transform the distributed SIW to the spatially confined microstrip TL mode [1], [2].

We propose a transition that is more compact (no TL tapering needed) by interfacing an array of amplifiers to a single SIW port. This allows to directly feed the spatially distributed TE₁₀ single SIW mode with high power. Note that this is different from the multi-mode concept in [3]. Our transition also exhibits larger impedance bandwidth characteristics. The proposed concept is illustrated in Fig. 1(b).

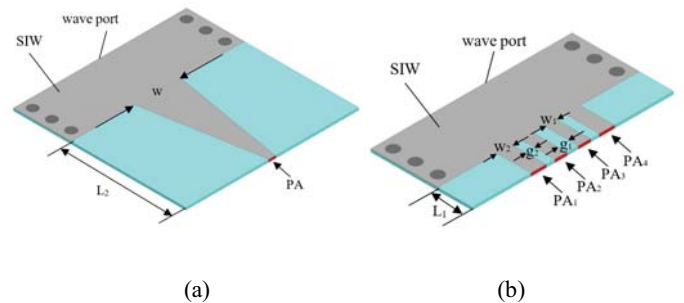


Fig. 1: (a) Classical single microstrip-to-SIW transition; (b) Proposed multi-channel transition and optimization parameters.

II. DESIGN DETAILS

Our design aims at operating in the K/Ka-Band and is based on the proposed concept in Fig. 1(b) with indicated geometrical parameters. The structure is built on an RT5880 laminate with substrate thickness 0.127 mm and relative dielectric constant $\epsilon_r = 2.2$. The low dissipation factor ($\tan \delta @ 10 \text{ GHz} = 0.0009$), thereby extending the applicability of RT5880 to Ka-band and above. Our specific design employs four parallel microstrip lines, each of which is terminated by 50 Ohm to represent the output resistance of a power amplifier. To expedient the simulations, the SIW vias were replaced by conductive side walls. Perfect Electric Conductors were used for the metals. Regarding Fig. 1, the optimized designs for best impedance match are (in mm): $w=2.4$; $L_2=6.5$; $L_1=1.54$; $w_1=0.54$; $w_2=0.68$; $g_1=0.5$; $g_2=0.39$. The SIWs are identical, width=7.11.

III. NUMERICAL RESULTS

Fig. 2 shows the field propagation inside the SIW and the coupled fields to the microstrip TLs when the SIW port is excited by the TE₁₀ mode (i.e. receive mode). When transmitting, the active reflection coefficients of the microstrip TLs should be considered due to the strong electromagnetic coupling between them. The simulated active and passive

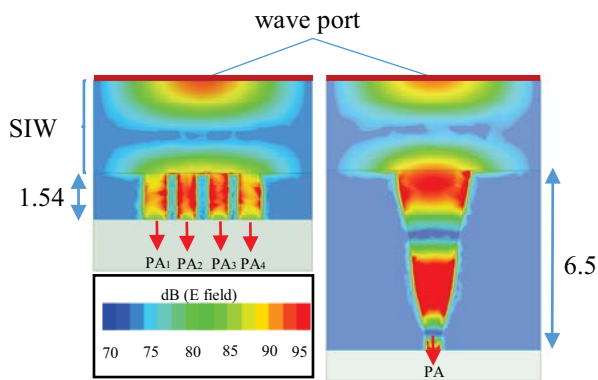


Fig. 2. Magnitude of E -field distribution at 31.5 GHz (real part) and sizes (mm) of the proposed multi-channel transition and the conventional single-channel tapered microstrip transition.

wave port reflection coefficients of both the proposed transition and the conventional single-channel tapered microstrip TL are shown in Fig. 3. The simulated multi-channel transition demonstrates a wide bandwidth performance relative to its single-channel counterpart.

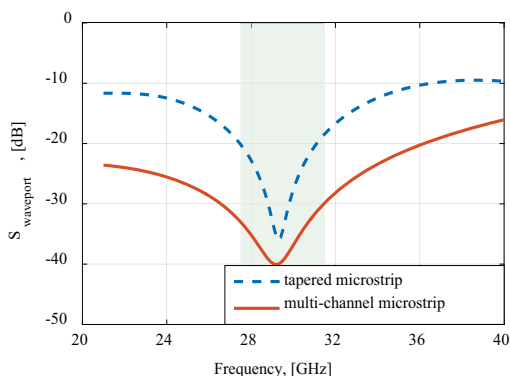


Fig. 3. Simulated wave port reflection coefficient of the proposed multi-channel transition and conventional single-channel tapered microstrip transition.

The simulated active $|\Gamma_i|$ and passive $|S_{ii}|$ reflection coefficient of the $50\text{-}\Omega$ microstrip ports are shown in Fig. 4. The active reflection coefficients are better than -30 dB over the desired frequency range (27.5–31.5 GHz).

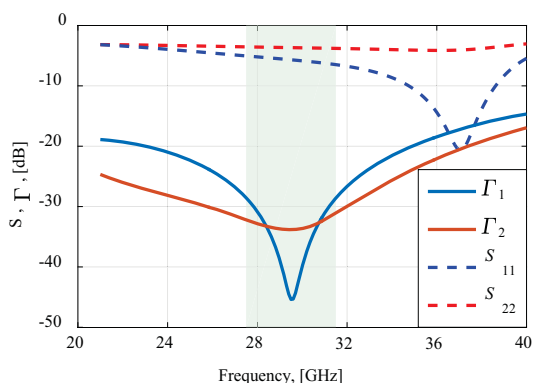


Fig. 4. Simulated active and passive (dashed lines) reflection coefficient of the $50\text{-}\Omega$ microstrip ports of the proposed transition.

The designed four-channel transition is almost four times more compact (Fig. 2) and allows to generate four times higher mm-wave output power as compared to a conventional tapered microstrip transition.

Fig. 5 shows the microstrip port powers when the wave port is excited by 1 W (i.e. receive mode). The power distribution is near uniform (i.e. $< 25\%$ variation, 250 mW is ideal), implying that the power amplifiers in the array are utilized effectively.

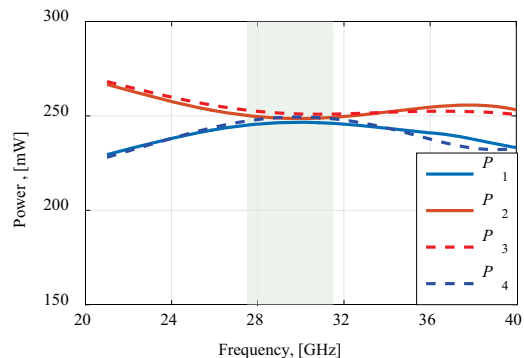


Fig. 5. Simulated power accepted by the microstrip ports when the wave port is excited by 1 W.

IV. CONCLUSIONS

A novel transition concept based on the direct excitation of the TE₁₀ substrate integrated waveguide mode by an array of strongly coupled microstrip lines has been proposed. The simulated active reflection coefficients of the four-channel transition at their microstrip ports and passive reflection coefficient at the wave port of a single transition are better than -30 dB over the desired frequency range (27.5–31.5 GHz). The quad-channel transition is four times more compact and allows to generate four times higher mm-wave output power compared to conventional tapered microstrip transitions. Its relatively short length allows to decrease transition losses and renders the structure suitable for much higher frequencies. The concept is expected to play a determining role in future mm-wave communication systems where both high-power generation and low-loss structures are required.

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