Easily Fabricated 60 GHz WR15/MSL Transition to Measure the Apparent Reflection Coefficient of Differentially-fed Patch Antennas

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Easily fabricated 60 GHz WR15/MSL transition to measure apparent reflection coefficient of differentially fed patch antennas

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A new procedure to measure the apparent reflection coefficient of differential patch antennas at 60 GHz is described. The measurement method makes use of two WR15/microstrip-line (MSL) transitions which are simple to realise. The experimental results are compared with simulated results. This comparison emphasises the limited effect of transition losses on measurement accuracy.

Introduction: To keep the benefits of differential amplifiers in radio-frequency (RF) receivers and transmitters, the antenna feeds should be directly compatible with differential input receiver circuits and/or differential output transmitter circuits [1]. Compared with single-ended circuits, differential amplifiers have the advantages of high immunity from cross-talk, improved common mode susceptibility, supply noise suppression, higher dynamic range and compression of even-order harmonic distortion [2]. Differential antennas are widely used in the 57–66 GHz unlicenced band [3] and intense RF engineering efforts have been made for a decade due to the growing demand for high data rates [4–7].

The return loss measurement of most types of published differential antennas (dipole, loop, Yagi, Vivaldi and so on) of about 60 GHz makes use of baluns to avoid differential measurements. However, baluns can either be lossy and prevent a correct de-embedding of the antenna *S*-parameters [4] or create spurious radiations thus altering the actual radiation pattern [5]. In [7], the balun suffered from a ±30° phase imbalance between 55 and 65 GHz. This phase error resulted in common mode excitation which altered the antenna radiation.

This Letter presents a 60 GHz patch antenna with a differential interface which can be connected directly to the amplifier without a dedicated balun. A simple and accurate procedure is proposed to measure the apparent reflection coefficient of differential patch antennas (DPAs). This procedure does not require a probe station as it is based on two WR15/microstrip-line (MSL) transitions designed to excite the DPA ports. The apparent reflection coefficient is extracted from the *S*-parameters of the dual-port DPA once the thru, reflect and line (TRL) de-embedding method has been applied. In spite of the 1.7 dB loss in each transition, good agreement between measurements and simulation is achieved.

Description of WR15/MSL transition: The principle of the WR15/MSL transition was first carried out in [8]. The TE10 mode of a WR15 waveguide is transformed into the quasi-TEM mode of the MSL thanks to a parasitic patch resonator located at the waveguide opening (Fig. 1). The parasitic patch is centred on a slot etched in the MSL ground plane. The slot dimensions are identical to those of the waveguide aperture. In [8], vias reducing the radiation losses connected the ground plane to the metallic pattern on the upper side of the substrate. The same principle of transition is optimised at 60 GHz with vias replaced by two metallic skews to simplify the designs.

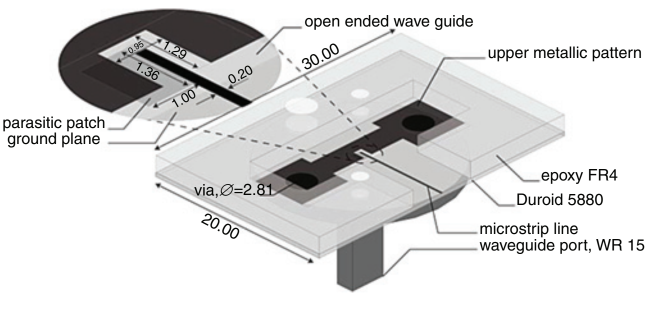

Fig. 1 *WR15/MSL transition showing waveguide aperture, parasitic patch and upper metallic pattern*

The picture of two back-to-back WR/MSL transitions is shown in Fig. 2. The transition is etched on a 254 µm-thick Duroid 5880 substrate ($\varepsilon_r = 2.24$ and tan $\delta = 0.004$ at 60 GHz [9]). To improve the rigidity of the Duroid substrate, a 1.6 mm-thick frame of epoxy substrate is placed on the top of the Duroid substrate. This epoxy frame is screwed through the Duroid substrate to the waveguides. The transition geometry is optimised with the commercial electromagnetic simulator ANSOFT high-frequency structure simulator (HFSS).

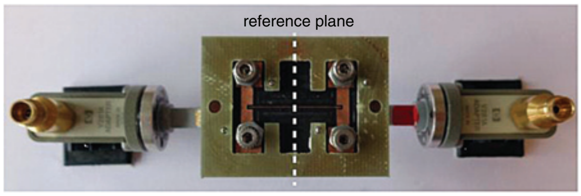

Fig. 2 *Back-to-back WR15/MSL transition*

Transition measurement: The *S*-parameters of the back-to-back transition were first measured. Then, the TRL method [10] was applied to determine the ***S***-matrix of the single transition between the reference plane indicated in Fig. 2 and the coaxial connector. The TRL calibration set makes use of two different line lengths. The first length 1 mm ensures a shift phase lower than 90° at the lower frequency. It is used to determine the MSL propagation constant. The second length 20 mm allows an accurate estimation of the MSL attenuation constant. As the transition is lossy, it is necessary to have a much longer MSL length showing high losses to extract meaningful data.

The *S*-parameters of the transition estimated by the TRL algorithm are depicted in Fig. 3. The minimum transmission loss is 1.7 dB which is much more than that (0.4 dB at 76.5 GHz) observed in [8]. These losses are mainly radiation losses due to the use of screws instead of vias. However, the results are encouraging with regard to the mechanical simplicity of the structure. S_{11} and S_{22} roughly remain below −10 dB between 62 and 67 GHz. Their values are slightly different because the transition is not fully symmetrical.

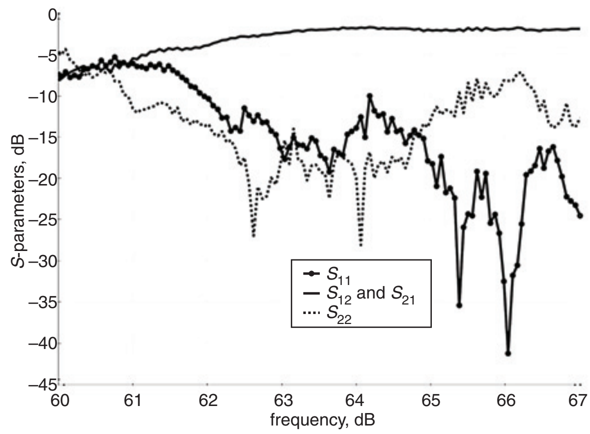

Fig. 3 *Scattering parameters of WR15/MSL transition*

Measurement of differential reflection coefficient of DPA: When a differential feed network is used to excite a differential antenna, the key parameter at the interface between the circuit and the antenna is the odd mode reflection coefficient. This is the apparent reflection coefficient at port 1, when the excitation at port 2 is constrained to be equal in amplitude but perfectly out of phase with the excitation at port 1. The apparent reflection coefficient Γ_{odd} of a DPA can be determined as follows [1]:

$$\Gamma_{odd} = S_{11\,DPA} - S_{12\,DPA} \quad (1)$$

where $S_{11\,DPA}$ and $S_{12\,DPA}$ are extracted from the DPA scattering matrix ($\boldsymbol{S}_{DPA}$) defined by applying in-phase excitations at ports 1 and 2. Let us call $\boldsymbol{T}_T$ the chain matrix of the transition

$$\boldsymbol{T}_T = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \quad (2)$$

The relationship between the chain matrix ($\boldsymbol{T}_{DPA}$) of the DPA alone and the chain matrix ($\boldsymbol{T}_{DAT}$) of the DPA including the WR15/MSL transitions measured previously is given by

$$\boldsymbol{T}_{\text{DAT}} = \begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \cdot \boldsymbol{T}_{\text{DPA}} \cdot \begin{pmatrix} T_{11} & -T_{21} \\ -T_{12} & T_{22} \end{pmatrix} \tag{3}$$

$\boldsymbol{T}_{\text{DPA}}$ is calculated by inverting matrix (3). Then, the DPA scattering matrix ($\boldsymbol{S}_{\text{DPA}}$) is calculated from ($\boldsymbol{T}_{\text{DPA}}$) and Γ_{odd} is deduced from (1).

The dimensions of the DPA were adjusted through HFSS simulations to cover the upper part of the unlicensed band. The simulated resonant frequency 63.5 GHz was obtained with good DPA matching ($\Gamma_{\text{odd}} < -8$ dB) in the bandwidth 62–65 GHz. The DPA was then measured with WR15/MSL transitions (Fig. 4). In Fig. 5, the simulated Γ_{odd} is compared with the experimental value extracted by the TRL calibration. The reference planes are indicated in Fig. 4. Excellent agreement is obtained with the WR15/MSL transitions both for the resonant frequency and the level predictions.

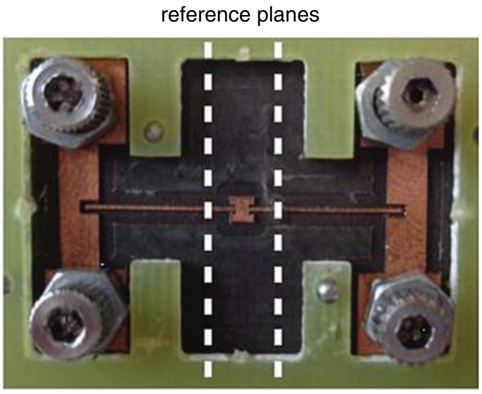

Fig. 4 *DPA connected to WR15/MSL transitions*

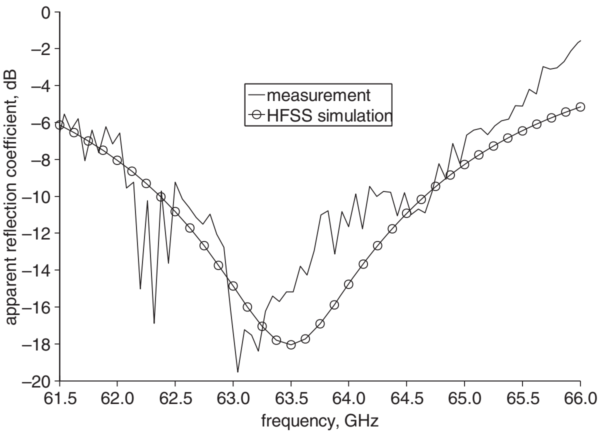

Fig. 5 *Reflection coefficient of DPA*

Conclusion: In this Letter, an experimental procedure has been detailed for an accurate estimation of the apparent reflection coefficient of a DPA at 60 GHz. The procedure combines the use of easy-to-manufacture WR15-to-MSL transitions with the application of a simple method to extract the apparent reflection coefficient from two-port measurements. The validity of the measurements is confirmed by HFSS simulations. The radiation losses from the transitions limit their use to *S*-parameter measurements as the actual radiation pattern of the DPA might be strongly altered.

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One or more of the Figures in this Letter are available in colour online.

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