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EH-Impedance Tuner with Dielectric-Based Backshorts for Millimetre Wave Diode Testing

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***Abstract*— In this paper, we present a waveguide EH-impedance tuner utilizing dielectric-based backshorts. The tuner is directly machined and the used design can be easily integrated in a waveguide block with other waveguide components. The tuner offers low losses, excellent input impedance coverage and accurate tuning over the frequency range of 140 – 190 GHz, where the maximum measured reflection coefficient is 0.92 (VSWR = 24) at 148 GHz. Our tuner is designed to be a part of a millimetre wave diode testing platform, but it can also be used as a normal stand-alone tuning device in many millimetre wave applications. Design is validated with G-band (140 – 220 GHz) measurement results.**

I. INTRODUCTION

For a mixer or detector diode manufacturer, it is important to have your product properly tested. To a large extent, the diodes can be characterised by traditional I-V, C-V and noise measurements [1]-[3], but how to ensure the correct behaviour at the operation frequency? Obviously, the logical choice is to design a test device, which is measured in an environment similar or very close to that of the intended real application.

For a millimetre wave mixer diode, this might be a quartz substrate embedded in a waveguide channel [4], [5]. If measurements can confirm the predicted results, everything is fine and the diodes are working properly. However, more often than not, a measurement of a millimetre wave device does not provide results that are identical with the simulation results. Usually, the losses in the measurements are larger than in the simulations. When this happens, how to be sure if the reason is in the design or manufacturing of the test device, in the measurement setup or in the diode itself?

In this paper, we describe a waveguide EH-tuner that will be the core of a measurement platform that can isolate the effect of the diode under test. Our tuner design is based on a machined Magic-T junction with previously published dielectric-based backshorts [6],[7] as E- and H-arm tuning elements. We have previously demonstrated the performance of these backshorts in a W-band (75 -110 GHz) double stub tuner with two E-plane arms in [8]. In this paper we extend the design to G-band frequencies and to a more complicated Magic-T structure. We are using our design instead of a commercial EH-tuner for two reasons. First, the dielectric backshorts provide more accurate tuning [6], [7] than the traditional backshorts and second, with directly machined waveguide blocks, we can integrate other millimetre wave devices in close proximity of the tuner. The advantages of the second point will be explained in the paper. Our tuner offers large maximum reflection coefficient, excellent input impedance coverage and accurate tuning over the frequency range of 140 – 190 GHz. In order to validate the design, we have performed network analyser measurements at G-band (140 – 220 GHz).

II. TOPOLOGY OF TEST PLATFORM AND EH-TUNER

A. The Test Platform

The authors are building a test platform for millimetre wave single anode mixer diodes pumped with fundamental LO frequency. The designed RF frequency is namely 183 GHz (water vapour absorption peak), but the platform is limited mainly by the feasible bandwidth of the EH-tuner. The platform includes the diode on a quartz substrate embedded in a suspended microstrip line channel, a waveguide-to-suspended microstrip line transition and the tuning element, which is the waveguide EH-tuner presented in the paper.

The idea is to use the mixer diodes in their normal operation environment, but at the same time offer flexible matching for the diode at RF, LO and IF frequencies (the RF and LO matching is performed by the EH-tuner, and a separate stand-alone coaxial tuner is used to optimize the IF embedding impedance).

B. EH-Tuner

A 3D-illustration of the EH-tuner presented in this work is shown in Fig. 1 and a photograph of the fabricated tuner is shown in Fig. 2. This tuner is a test structure of the tuner that will be integrated in the test platform. The tuner is based on a well-known EH-junction (or Magic-T junction) [9] with dielectric-based waveguide backshorts at E- and H-arms. The dielectric backshorts are described in detail in [6]-[8]. In short, a dielectric backshort is a combination of a dielectric slab and

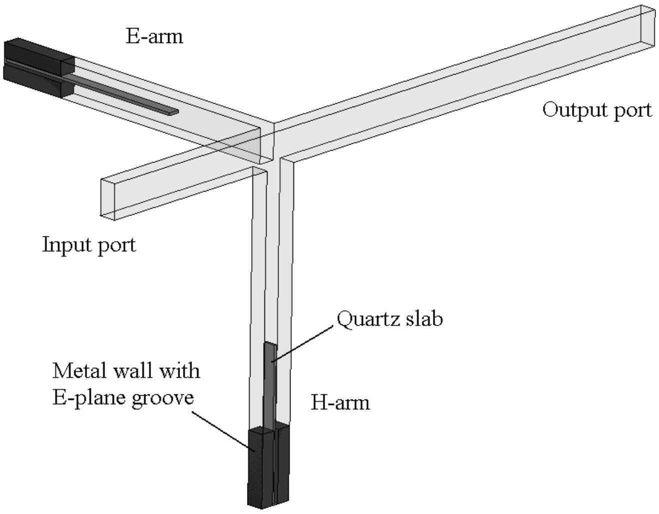

Fig. 1. 3D – illustration of the EH-tuner with the dielectric slabs inserted into the E- and H-arms through the grooves in the E-plane of the waveguides.

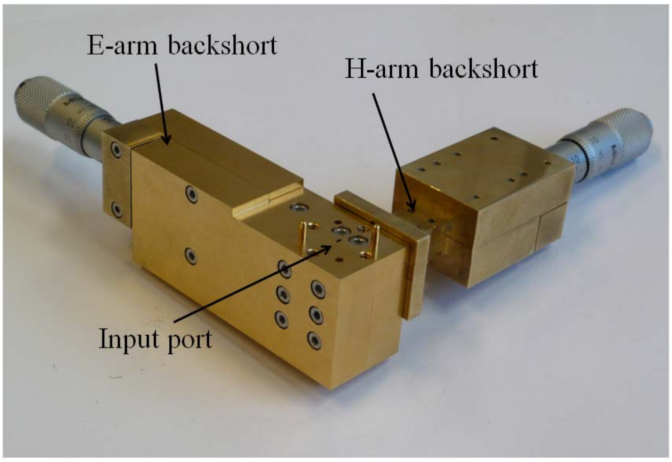

Fig. 2. Photograph of the EH-tuner with the H-arm dielectric backshort attached.

a metal wall with a narrow groove from which the slab is inserted into the waveguide (Fig. 1). The dielectric in the waveguide then changes the effective propagation constant of the waveguide and thus the phase of the reflection coefficient. The dielectric backshort offers more accurate tuning than a traditional backshort, because the phase changes slower as a function of the movement of the micrometer spindle. In a traditional backshort, the spindle moves directly the backshort reference plane and in our tuner it moves only the quartz slab.

As an example, at 180 GHz, the reflection phase of a traditional backshort changes between 0^o to 360^o with about 1.1 mm movement of the micrometer spindle. In our case, where only the quartz slab is moving in the waveguide, the 0^o to 360^o phase change is obtained with 5.5 mm movement of the micrometer spindle. The tuning is thus about 5 times more accurate. On the other hand, this is also a disadvantage in applications requiring as small dimensions as possible.

The tuner is assembled from three directly machined waveguide blocks. The dimensions and material parameters of the waveguide structure and the quartz slabs are given in Table 1. The input and output waveguide length difference is 10 mm. This allows us to estimate the losses of the straight waveguide sections of the tuner. With direct machining, it is possible to integrate other waveguide components, such as waveguide-to-suspended microstrip line transition very close to the tuner. In the mixer platform, this enables the positioning of the diode approximately only one wavelength away from the tuner. With a commercial stand-alone tuner this is not possible.

There are two significant advantages in having the matching element close to the mixer diode. First, RF and LO losses are minimized. This is even more the case, if there is a large mismatch and thus a large voltage standing wave ratio between the diode and the embedding circuit. Second, in a fundamental mixer the RF and LO frequencies are quite close to each other (nominal IF frequency for the platform is 1 GHz) and thus have impedances quite close to each other and can be matched simultaneously with the tuner. If an electrically long RF path would exist between the tuner and mixer diode, the RF and LO embedding impedances would be increasingly far apart.

TABLE I
DIMENSIONS AND MATERIAL PARAMETERS OF THE EH-TUNER

Parameter		**Value**
waveguide width	w	1.37 mm
waveguide height	h	0.65 mm
Input waveguide length	l_I	8.0 mm
Output waveguide length	l_O	18 mm
E-arm length	l_E	9.35 mm
H-arm length	l_H	9.35 mm
Waveguide metal (brass) conductivity	σ	$1.5x10^7$ S/m
Quartz slab width	w_Q	450 µm
Quartz slab thickness	t_Q	100 µm
Quartz dielectric constant	ε_r	3.8

III. ELECTRICAL OPERATION OF THE EH-JUNCTION

In Fig. 3 simulations with Ansoft High Frequency Structure Simulator (HFSS) show coupling from the input port of an EH-junction to the output port and to the matched E- and H-arms of the junction. The simulation results are in line with measured and simulated behaviour that was observed in [10], [11] at lower frequencies, showing that the coupling from input to output is increased as a function of the frequency. For this reason, to achieve a large value of the input reflection coefficient at higher frequencies, larger VSWR in the E- and H-arms of the tuner is needed. Large VSWR means more losses in the E- and H-arms and smaller maximum input reflection coefficient, respectively. Also the tuning sensitivity is affected. With large VSWR in the tuner arms, it is evident that a small change in the reflection phase of a backshort creates large changes in the input reflection coefficient.

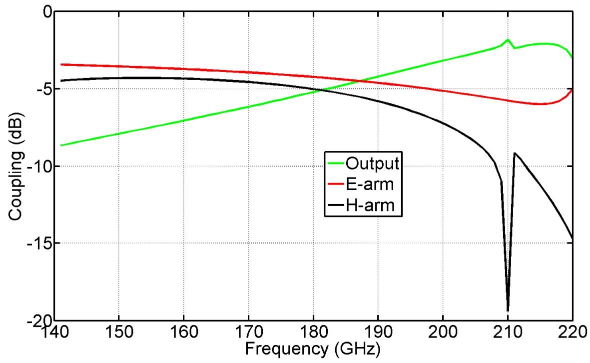

Fig. 3. Simulated coupling from the EH-tuner input port to the output, E-arm and to the H-arm, when ports are matched.

IV. Results

For the 2-port measurements of the EH-tuner, we used Agilent PNA Millimeter-Wave Network Analyser with Oleson V05VNA2-T/R-A extension units for the G-band. Before the measurements, the network analyser was calibrated with 2-port thru-reflect-line (TRL) calibration using Oleson WR05 Waveguide Calibration Kit. All the simulations for this work have been done with Ansoft HFSS version 11.2.

In order to check the quality of the design and fabrication steps of the waveguide blocks, the tuner was measured with both quartz slabs drawn away from the waveguides. The frequency sweep of the input reflection coefficient for the empty waveguide structure is shown in Fig. 4. It can be seen that the losses of the structure and the maxima and minima of the input reflection coefficient are very well predicted by the simulator. The parameters used in the simulation are the same as in Table 1 and in addition, the loss tangent for quartz, tan δ = 0.001 and the metal surface roughness of 0.2 µm were used in all simulations.

The measurement procedure was the following. Quartz slabs in E- and H-arms were moved in 1 mm steps from 0 to 7 mm. This corresponds to 64 different input reflection coefficients. A frequency sweep over the G-band was performed at every step. The maximum reflection coefficient as a function of the frequency is shown in Fig. 5.

The same procedure was followed in the simulations, only now 225 different positions were simulated with the step size of 0.5 mm. The input impedance coverage at the nominal design frequency of 183 GHz is shown in Fig. 6. The largest measured reflection coefficient at 183 GHz is 0.875. In comparison, the largest simulated one is 0.891.

It should be noted here that these reflection coefficients are valid if the tuner is used as a stand-alone unit. However, in the planned mixer diode test platform, the waveguide length between the tuner and the diode is reduced to 1 mm (7 mm reduction). Based on the comparison of measured input and output reflection coefficient, we estimate that the reflection losses are close to 0.06 dB/mm at the center frequency of the G-band, 180 GHz. This means that for the mixer platform application, the tuner losses are reduced about 0.4 dB. Moreover, these first measurements are for brass blocks without gold plating. It is expected that after the blocks are gold plated, the losses are further reduced.

It is a difficult task to define the feasible operation bandwidth of the tuner, as it depends on the application. If the only figure of merit would be the maximum reflection coefficient, the tuner could be used perhaps up to 210 GHz. This is the case for example in noise parameter measurements [12], where four different reflection coefficients are needed for the extraction of the parameters.

However, for our test platform, we also need accurate tuning and excellent impedance coverage. Our estimation is that up to approximately 190 GHz, the tuner offers tuning sensitivity, impedance coverage and good enough maximum reflection coefficient for the test platform.

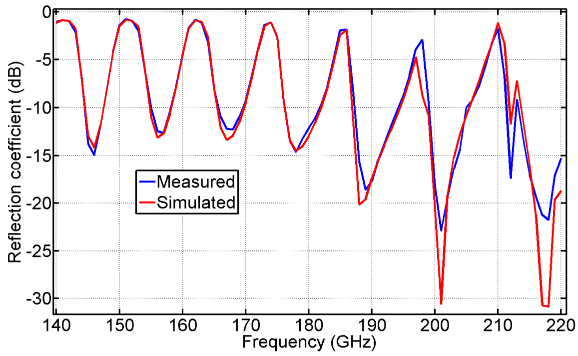

Fig. 4. Measurement and HFSS simulation results of the input reflection coefficient of the tuner structure, when quartz slabs have been drawn away from the waveguide.

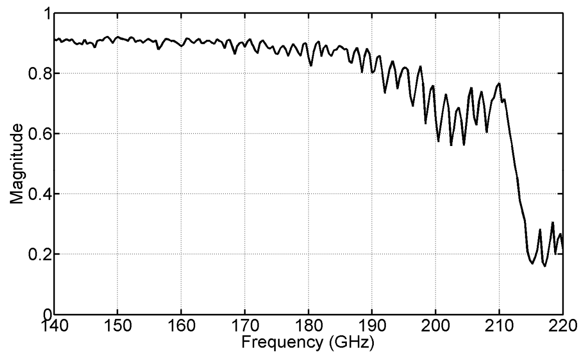

Fig. 5. Largest measured input reflection coefficient as a function of the frequency. The largest value from 64 measurements with different quartz slab positions was chosen.

V. Conclusions and Future Plans

We have presented a waveguide EH-impedance tuner for millimetre wave diode testing. The tuner offers excellent input impedance coverage, low losses and accurate tuning over the bandwidth of 140 – 190 GHz. The tuner can be used as a stand-alone impedance tuner in many millimetre wave applications, but our goal is to integrate it in a waveguide block in close proximity with other waveguide components in order to use it as a tuning element for RF and LO signals in a mixer diode test platform.

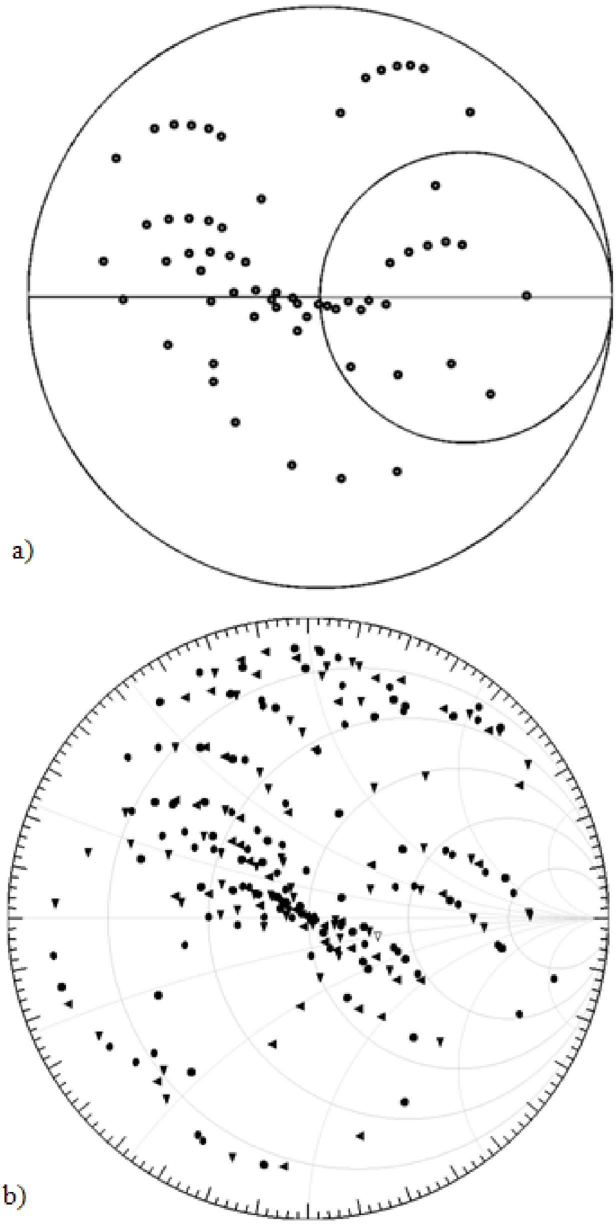

Fig. 6. Input impedance coverage at 183 GHz. In a) 64 different measured impedance points are shown, and in b) 225 points from HFSS simulation are shown.

VI. Acknowledgements

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