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Generic Jig for Testing Mixing Performance of Millimeter Wave Schottky Diodes

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Abstract— **In this paper a generic mixer test jig for millimeter wave Schottky diode testing is presented. The test jig enables relatively easy changing of the diode under test and thus testing and comparison of different mixer diodes in realistic operating conditions. The diode under test is mounted on a substrate and flexible RF and LO impedance matching is performed with integrated low-loss waveguide EH-tuner. The feasibility of the mixer test jig is tested with a commercial Schottky diode. The measured double side band (DSB) conversion loss is 4.6 dB and the DSB mixer noise temperature 650 K. The test jig is designed for the nominal RF frequency of 183 GHz.**

Keywords-component; millimeter waves, mixers, Schottky diodes

I. INTRODUCTION

The interest and need for the use of millimeter and submillimeter wavelengths have increased and sensitive receivers, for example for Earth observation and space missions are required [1]. A mixer based on Schottky diodes is one of the most important components in today's millimeter and submillimeter wave receivers, therefore the characterisation of Schottky diodes is important [2, 3].

Usually Schottky diodes are characterised by traditional current-voltage (I-V) and capacitance-voltage (C-V) measurements. Sometimes, the diode under test is mounted on a test carrier and is also characterized using S-parameter measurements. Based on the measurement results a parameter extraction and an equivalent circuit modelling are performed [4]. However, a comprehensive, uniform, and reliable way to compare different Schottky diodes based on the mixer operation in the actual operating environment would be desirable.

In this paper a generic mixer test jig for single-anode Schottky diodes is presented. In the test jig the operation (conversion loss and noise temperature) of different Schottky diodes can be tested and compared. The feasibility of the mixer test jig is tested with a commercial Schottky diode.

The diode is mounted on a substrate without impedance matching with only a waveguide-to-suspended microstrip line transition. The RF and LO matching of different diodes is performed with integrated low-loss waveguide tuners. The IF impedance can be matched with an external coaxial tuner. The waveguide block is the same for all diodes. The diodes are mounted on similar substrates and the substrate with the diode can be changed. The structure of the mixer test jig is simple and the DC and IF connections are provided in a way that the substrate and the diode can be easily changed. The nominal RF frequency of the mixer test jig is 183 GHz.

II. STRUCTURE OF THE MIXER TEST JIG

Fig. 1 shows a photograph of the mixer test jig. A 3D-illustration of the mixer test jig lower waveguide block is shown in Fig. 2. The mixer test jig consists of a split-waveguide block, of which the lower block further consists of two parts. The EH-tuner, substrate channel, and IF structures are milled in the same waveguide structure. The waveguide block is made of brass and the substrate is 100 µm thick quartz (ε_r = 3.8). The quartz chip includes a waveguide-to-suspended microstrip transition, a diode mounting gap, an RF/LO ground filter, and a DC/IF low-pass filter.

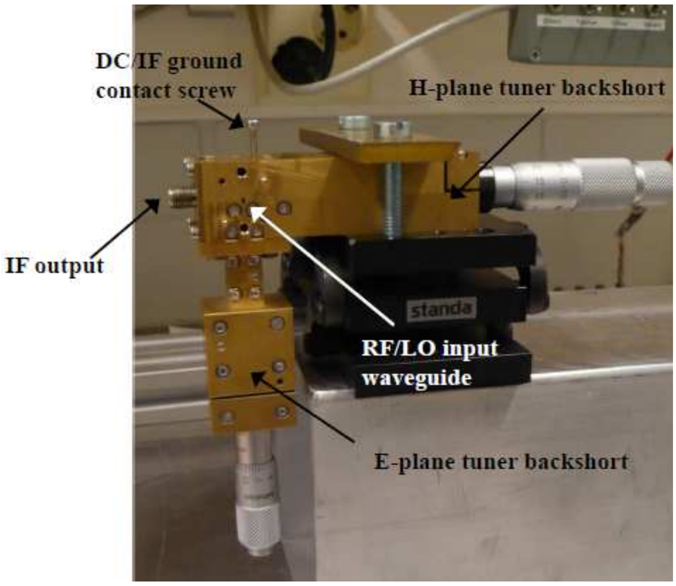

Figure 1. A photograph of the mixer test jig on a supporting device.

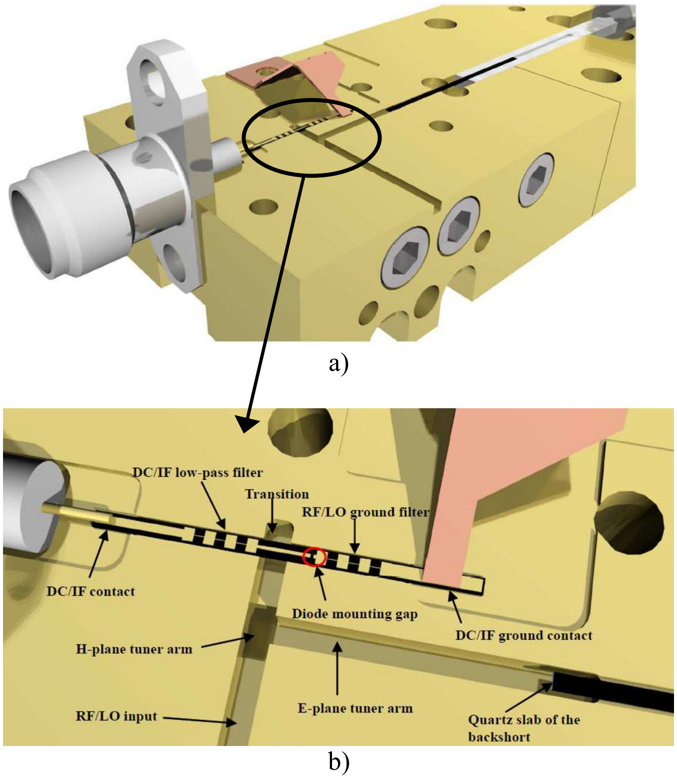

Figure 2. 3D-model of the lower waveguide block of the mixer test jig. a) Wider view, b) closer view.

In the mixer test jig design the mixer simulations and optimisations are done with High Frequency Structure Simulator (HFSS), which is a 3D-simulator, and with Agilent Advanced Design System (ADS) circuit simulator using measured diode parameters. The design and operation of the EH-tuner and the dielectric-based backshorts for the tuner are described in [5]. The design and operation of the waveguide-to-suspended microstrip transition with the DC/IF low-pass filter are presented in [6].

The DC/IF contact and ground contact are designed so that the quartz substrate with the diode can be changed and the contacts can be repeated reliably several times. The DC/IF contact is realized with a miniature SMA connector and the DC/IF ground contact after the diode is made with a copper plate, which is pressed down with a screw through the upper waveguide block. The mixer test jig enables relatively easy changing of the diode and the tested diodes or quartz substrates are not destroyed during the process.

III. Measurements

A. Noise measurement based determination of DSB conversion loss and mixer DSB noise temperature

The feasibility of the mixer test jig is tested with VDI-SC2T6 diode. The noise measurement based determination of the double side band (DSB) conversion loss and mixer DSB noise temperature [7] is carried out. Fig. 3 shows the measurement setup. A backward wave oscillator (BWO) OB-66 is used as the LO source. The RF source is an absorber plate in the room temperature (hot load) and in the liquid nitrogen (cold load). The temperature of the hot load is 295 K and the temperature of the cold load is 77 K. The RF signal is coupled with a combination of a horn antenna and a waveguide.

Because of the BWO noise that is mixed to the IF frequency disturbs the measurements, the noise filtering and combining of the RF and LO signals are done with a simple quasi optical diplexer. Unfortunately the losses in the diplexer reduce the Y-factor and thus the measurement accuracy is decreased. Also the available LO power is limited approximately to 2 mW due to the losses in the diplexer and coupling waveguides.

The IF chain used in the measurements is shown in Fig. 4 and it is packaged in order to avoid mechanical and RF interference. The noise temperature of the IF chain, T_{IF} is measured at different adjustments of the variable attenuator of the IF chain using HP 8970A Noise Figure Meter with HP 346C noise diode. The EH-tuner and bias current are adjusted for the best conversion loss at the signal frequency using Agilent PNA 5250A Vector Network Analyzer as the RF source.

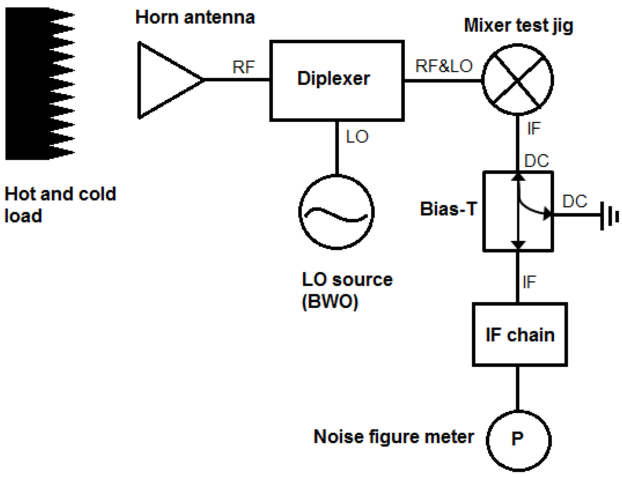

Figure 3. Measurement setup for noise-based measurements.

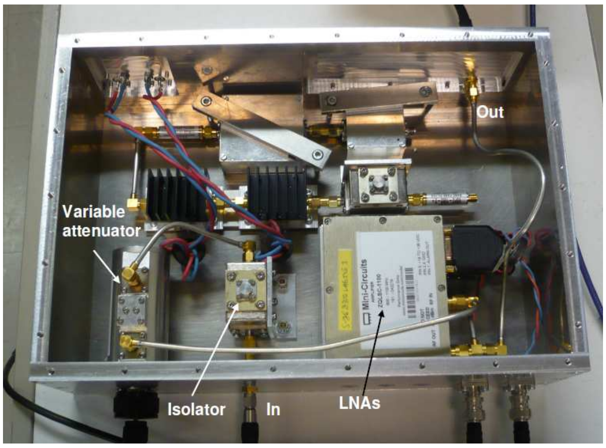

Figure 4. IF chain used in the noise-based measurements.

The noise power of the whole measurement setup is measured with hot and cold loads with the same adjustments of the variable attenuator as the noise temperature of the IF chain is measured. The noise power is measured with a noise figure meter. The noise temperature of the whole setup, T_e is linearly related to the noise temperature of the IF chain

$$T_e = T_M + L_{DSB} T_{IF}\ , \qquad (1)$$

where the DSB noise temperature of the mixer T_M and DSB conversion loss L_{DSB} can be solved by plotting the noise temperature of the whole setup against the noise temperature of the IF chain at the attenuation points of the variable attenuator. This is illustrated in Fig. 5. A straight line is fitted to the measurement results and the mixer DSB noise temperature is the intersection point of the y-axis and the DSB conversion loss is the slope of the line.

The used IF frequency is 1.05 GHz, LO frequency is 182.6 GHz and LO power is 2.1 mW. The measured DSB conversion loss and mixer DSB noise temperature with and without an IF tuner are shown in Table 1, where also the DSB conversion loss results with the PNA as the RF source (otherwise exactly the same measurement setup) are presented for comparison. The IF tuner is placed after the bias-T and it is used to improve the mixer performance by matching the IF impedance to the mixer impedance. The DSB conversion loss values of the PNA measurements are calculated from the measured single side band (SSB) conversion losses using equation

$$L_{DSB} = \frac{L_S L_i}{Ls + L_i}\ , \qquad (2)$$

where L_S is the conversion loss at the signal frequency and L_i the conversion loss at the image frequency. The noise temperature of the IF chain with the IF tuner is defined so that the S-parameters of every component of the IF chain and the noise figures of the LNAs are measured separately and then the noise temperature of the whole IF chain is simulated in ADS using the measured component values and measured IF impedance of the mixer as the input impedance of the ADS circuit. This is done, because the reflections due the mismatch between the IF tuner and noise diode reduce the accuracy of the conventional noise measurement.

TABLE I. MIXER MEASUREMENT RESULTS

	PNA measurements			Noise measurements	
Measurement	L_S [dB]	L_i [dB]	L_{DSB} [dB]	L_{DSB} [dB]	T_M [K]
Without IF tuner	7.5	8.5	5.0	4.9	780
With IF tuner	6.5	7.7	4.1	4.6	650

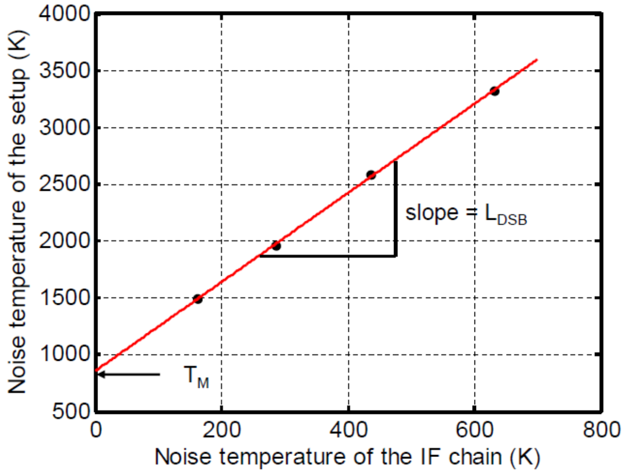

Figure 5. Measured noise temperature of the measurement setup as a function of measured noise temperature of the IF chain at various IF attenuator settings (black dots) and the fitted line (red line). The DSB conversion loss is the slope of the fitted line and the mixer DSB noise temperature is the intersection point of the y-axis.

B. *SSB conversion loss measurements*

The operation of the mixer test jig with more LO power is demonstrated by measuring the SSB conversion loss, when the RF and LO signals are combined with a directional coupler (Aerowave 05-3000) in a place of the diplexer to obtain more LO power. The PNA is used as the RF source, the BWO is used as the LO source and the IF chain is not used. The IF output power is measured with HP 8481D power sensor and the IF frequency is measured with Tektronix 2782 spectrum analyzer. The LO frequency is 182 GHz and the RF frequency is 183 GHz, which gives an IF frequency of 1 GHz.

The SSB conversion loss at the signal frequency is measured to be 7.8 dB and at the image frequency of 181 GHz 8.5 dB, when the LO power is 2.3 mW and the bias current is 3 mA. The EH-tuner and bias current are adjusted for minimum conversion loss at the signal frequency. The SSB conversion loss is improved by 1 dB, when the IF tuner is used.

The SSB conversion loss is measured as a function of LO power at the signal frequency. The LO power is changed with an adjustable attenuator (Aerowave 05-2220). During the measurement the EH-tuner and bias current are adjusted for the minimum SSB conversion loss separately for every LO power level. The measurement and simulation results are shown in Fig. 6.

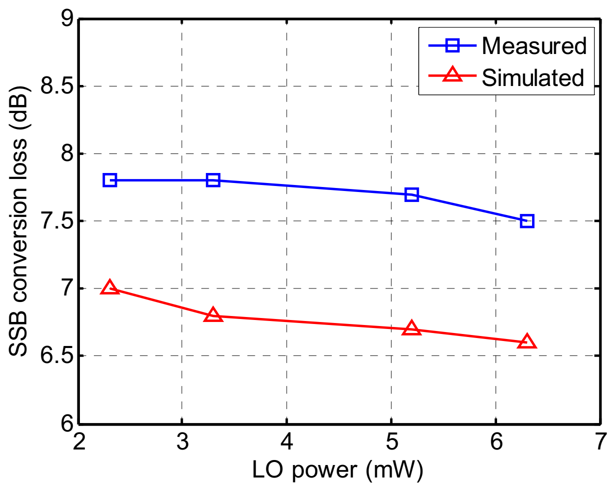

Figure 6. Measured (blue squares) and simulated (red triangles) minimum SSB conversion loss at signal frequency as a function of the LO power.

IV. Conclusions

In this paper a generic mixer test jig for millimeter wave Schottky diode testing is presented. The simulated and measured results of the test jig are shown. The test jig enables relatively easy changing of the diode under test and allows the comparative evaluation of different discrete Schottky diodes in their normal operating environment. Comparative mixer measurements are considered to be a useful addition to the traditional IV- CV- and S-parameter measurements in the characterization of Schottky diodes. The tuning of the embedding impedances of the diode is straightforward with an integrated EH-tuner and the IF impedance can be matched with an external coaxial tuner.

The feasibility of the mixer test jig is tested with a commercial Schottky diode. With noise measurement based determination of DSB conversion loss and noise temperature with the IF tuner, the DSB conversion loss is measured to be 4.6 dB and the DSB noise temperature is measured to be 650 K using 2.1 mW LO power. The measured minimum SSB conversion loss at the signal frequency of 183 GHz is 7.5 dB with 6.3 mW LO power. Using of an IF tuner with the test jig the SSB conversion loss is improved by 1 dB. As the mixer test jig operates at the fundamental frequency, the stability and noise of the LO source (BWO) are a challenge and a performance improvement is expected if the BWO is replaced by a solid-state source. The problems caused by the LO source can be also alleviated by replacing the fundamental mixer test jig with a subharmonic mixer test jig, where the LO is pumped at a frequency that is about half of the RF frequency.

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