0.01-50 GHz Power Detector MMICs

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***Abstract*—This work presents a pass-type ultrawideband power detector MMICs designed for operation from 10 MHz to 50 GHz in a wide dynamic range from -40 dBm to +25 dBm which were fabricated using GaAs zero bias diode process. Directional and non-directional detector designes are reviwed. For good wideband matching with transmission line, bonding wires parameters were taken into account at the stage of MMIC design. Result of this work includes on-wafer measurements of MMICs S-parameters and transfer characteristics.**

Keywords — zero bias diode; microwave integrated circuits; microwave sensors; directional detector.

I. INTRODUCTION

The power is one of the most important parameters in RF and microwave techniques. Thermocouples and semiconductor diodes are widely used as a sensitive element in modern power sensors. The main advantage of diode detectors over thermocouple sensors is their fast response to the input power level shifts. Also diodes are suitable for broadband devices and allow power detection in a wide dynamic range. There are few types of diodes that can be used in power detectors defining device performance and its final design. The most widely used diodes are GaAs and Si high-barrier, medium-barrier, low-barrier and zero bias Schottky diodes [1] – [3].

Modern power sensors work as a broadband load and measure RF signal power dissipated on the 50Ω load. However, in some cases it is important to control the RF signal power passing in transmission lines without disconnection of the load from the signal source. Directional couplers with detection unit or directional power detectors are often used for such applications. This work presents directional and non-directional broadband power detector MMICs with low insertion loss.

II. PROBLEM STATEMENT

There are few well-known methods to measure RF signal power in a transmission line: use of directional coupler equipped with an absorbed power detector, calorimetric method and capacitive method [4]. These methods have some disadvantages: complexity of low frequency implementation for directional couplers or long response time to the input RF signal shifts for calorimetric detectors. Pass-type diode power detector is not burdened with these limitations. It demonstrates fast response to the input signal and can function at rather low frequencies. It should be noted that diode-based detectors also have the advantage over the transistor-based detectors, namely they have a lower noise level.

There are a lot of pass-type power detectors implemented with use of MMIC technologies which are commercially available, but they either have a relatively narrow frequency band or a small dynamic range. The need of pass-type detectors that demonstrate both ultra-wide frequency range and wide dynamic range causes the relevance of the this work.

III. DIODES

At the first stage of this work zero bias diode ZB-28 [5] was fabricated on GaAs Micran fab. Fig. 1 shows the photo of this diode in a beam lead edition. IV-curves and a few parameters of fabricated diode are presented in Fig. 2 and Table 1 in comparison with the well-known Avago HSCH-9161 zero bias diode [6]. Power detector MMICs described below were designed using ZB-28 diode.

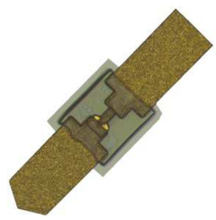

Fig. 1. Beam lead edition of ZB-28 diode

TABLE I. DIODE PARAMETERS

Parameter	ZB-28	Avago HSCH-9161
Junction capacitance at zero bias Cj, fF	24	35
Video resistance, kΩ	1.6 - 2.0	2.5 - 7.5

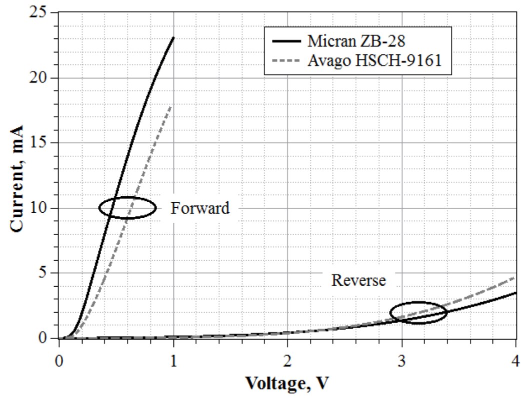

Fig. 2. IV-curves of zero bias diode

SPICE-parameters and additional characteristics of ZB-28 diode are presented in [5].

IV. Directional Detector MMIC

Pass-type detector can detect incident RF power both from input and output ports. So it can detect the power of passing signal (direct mode, from detector input to output) and the power of reflected signal (invert mode, from detector output to input) simultaneously. In many cases it is important to reduce the influence of unwanted reflected signal on a measurement of passing signal power. Directional detectors are used in these cases. Directivity of the detector is determined by the ratio of the output voltage in the direct mode to the output voltage in the invert mode. Directivity can be provided by directional couplers or directional bridges.

Simplified circuit of the directional power detector presented in this work is shown in the Fig. 3.

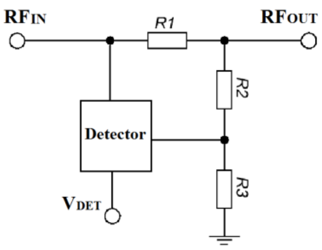

Fig. 3. Simplified circuit of the directional power detector

The values of R1-R3 resistors determine the insertion loss and coupling. For ideal circuit calculated RF_{IN}-RF_{OUT} insertion loss is 0.9 dB, and coupling is 15 dB. Photo of fabricated directional power detector MMIC is shown in Fig. 4.

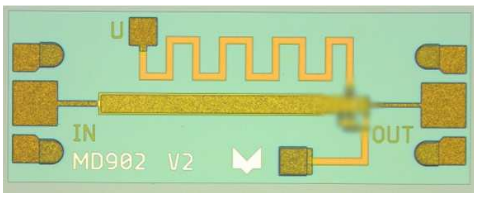

Fig. 4. MD902 directional power detector MMIC layout

S-parameter measurement results for MD902 are shown in Fig. 5 and Fig. 6.

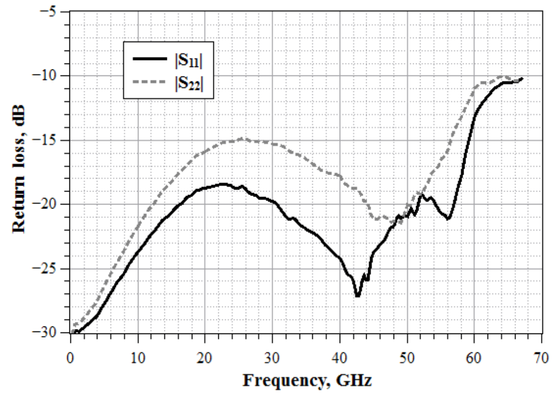

Fig. 5. MD902 return loss

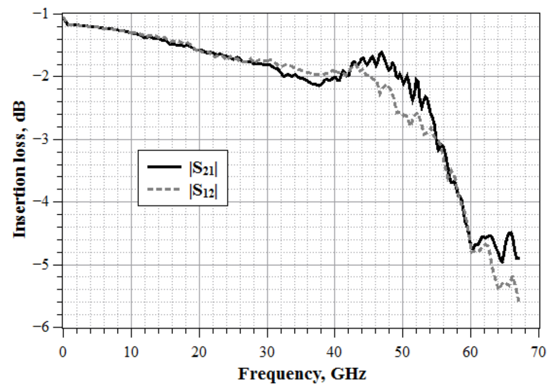

Fig. 6. MD902 insertion loss

One of the main things that have impact on S-parameters of hybrid integrated devices at millimeter wave frequencies is electrical connections between MMIC and transmission lines. Bonding wires (Fig. 7) or foil strip are usually used for this connection. For good MMIC broadband matching their RF parameters should be determined and then taken into account at the stage of MMIC layout design. The simplified equivalent circuit of bonding wires shown in Fig. 7 represents series connection of inductance and resistance.

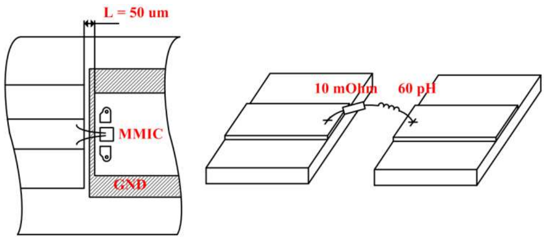

Fig. 7. MMIC connection with transmission line and bonding wires parameters

Compensation of bonding wires parasitics were performed by increasing the area of input and output RF contact pads. The Smith chart, illustrating result of bonding wires matching, is shown in Fig. 8. S-parameters shown in Fig. 5 and Fig.6 represent on-wafer measurements of MD902 with added bonding wires.

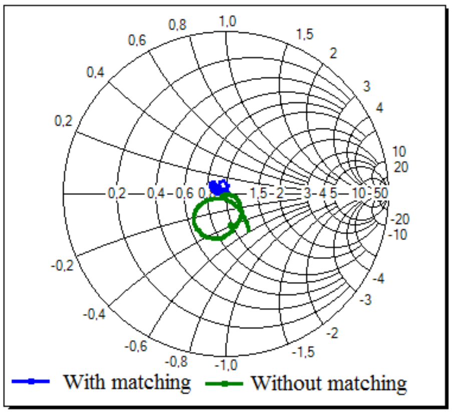

Fig. 8. The result of bonding wires matching

The transfer characteristic (output voltage vs. input RF power) for MD902 is shown in Fig. 9. Measurements have been performed at frequency 10 GHz, using scalar network analyzer R2M-18A (Micran). V_{DET} output of MMIC was loaded with 30 kΩ. The absolute maximum input RF power is 30 dBm in condition of low output VSWR (less than 1.2). Fig. 10 shows the square law deviation diagram corresponding to transfer characteristic Fig. 9.

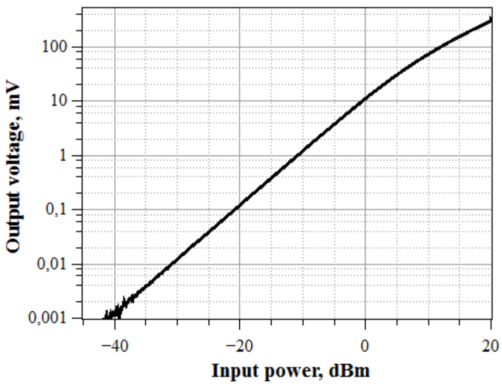

Fig. 9. MMIC MD902 transfer characteristic

Dynamic range of detectable input power is about 65 dB (from -40 dBm to +25 dBm). Since low frequency detection can meet some difficulties at output voltage less than 10 µV, usable dynamic range of this detector MMIC is limited to 55 dB (from -30 dBm to +25 dBm).

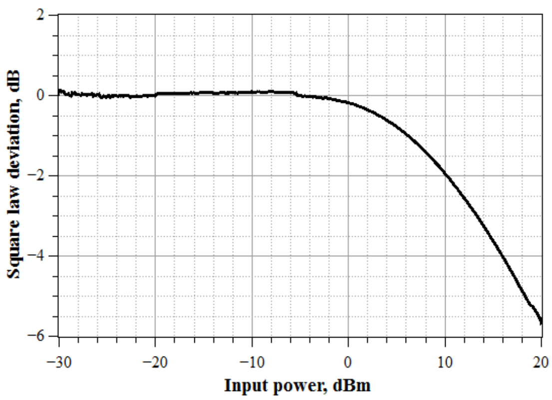

Fig. 10. MD902 square law deviation

Test RF module designed for MD902 characterization is shown in the Fig. 11.

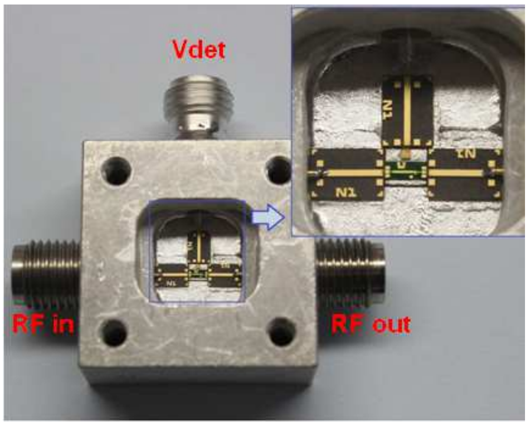

Fig. 11. Test RF module with MD902

Microstrip lines are fabricated on 0.254 mm alumina substrate. Coaxial connectors are Anritsu K102, 2.9 mm (RF_{IN} and RF_{OUT}). For output V_{DET} an SMA-type coaxial connector is used.

Output voltage versus frequency in direct and invert operation modes is shown in Fig. 12. Both curves were obtained at +10 dBm power at input (direct mode) and at ouput (invert mode). The directivity of the detector is not less than 10dB in frequency range from 100 MHz to 35 GHz.

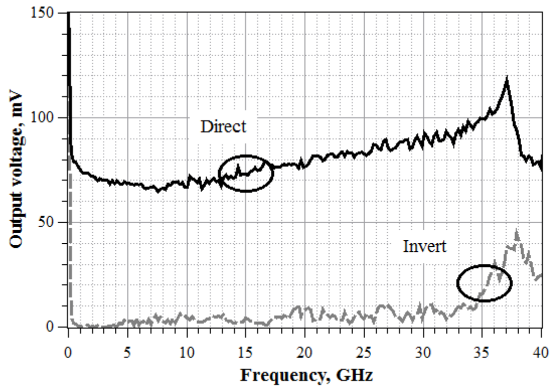

Fig. 12. Output voltage vs frequency for direct and invert modes at +10 dBm

Table 2 contains general technical data of MD902 in comparison with similar MMIC's from Avago Tehnologies and Hittite (subsidiary of Analog Devices).

TABLE II. MMICs Comparison

MMIC	Frequency range, GHz	Dynamic range, dBm	Return loss, dB	Insertion loss, dB
VMMK3313	15 … 33	-10 … 25	-20	0.7
VMMK3413	25 … 45	-10 … 25	-19	1.1
VMMK3213	6 … 18	-5 … 27	-18	0.5
MD902	0.01 … 50	-30 … 25	-15	2.2
HMC7447	71 … 86	-0.5 … 23.5	-15	0.45

V. Non-Directional Detector MMIC

The insertion loss of MD902 start from 1 dB at low frequencies and reach 2.2 dB at high frequencies. Such high loss are mostly caused by resistance R1 connected to transmission line in series (Fig. 3). For some applications insertion loss are essential and non-directional detectors which demonstrate low insertion loss can be used. The simplified circuit of detector which has a minimal influence on transmission line is shown in Fig. 13.

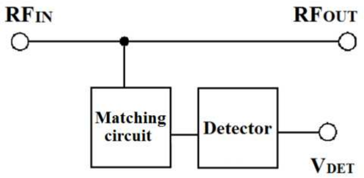

Fig. 13. Simplified circuit of non-directional detector

Photo of fabricated non-directional power detector MMIC is shown in Fig. 14.

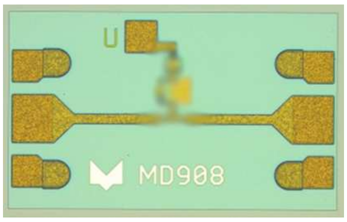

Fig. 14. MD908 non-directional power detector MMIC layout

S-parameter measurement results for MD908 are shown in Fig. 15 and Fig. 16.

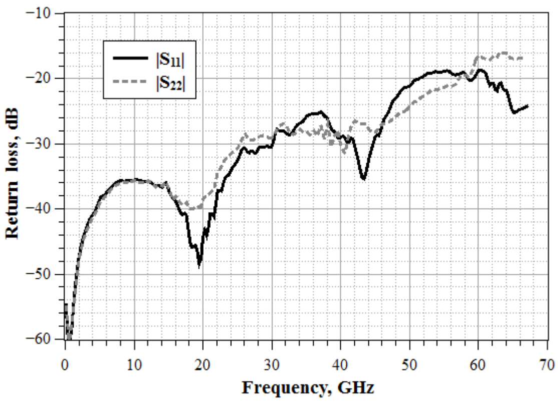

Fig. 15. MD908 return loss

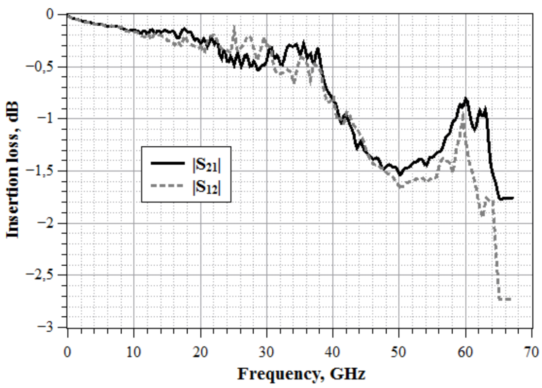

Fig. 16. MD908 insertion loss

The transfer characteristic for MD908 is shown in Fig. 17.

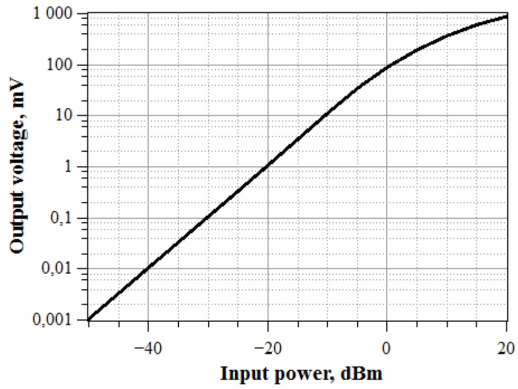

Fig. 17. MD908 transfer characteristic

The return loss of MD908 is less than -20 dB in frequency range up to 50 GHz. Insertion loss in frequency range from 10 MHz to 20GHz is less than 0.3 dB, and from 20 GHz to 50 GHz is less than 1.7 dB. In addition, MD908 non-directional detector demonstrates better sensitivity in comparison with MD902 directional detector. However, non-matched load or signal source for non-directional detector reduces measurement accuracy due to detection of reflected signal power.

All measurements were performed on probe station Karl Suss PA200 using a vector network analyzer PNA-X (Keysight Technologies), with SOLT on-wafer calibration.

VI. Conclusion.

Pass-type power detectors are widely used in the microwave monitoring systems, for building automatic gain control circuits. Presented detector MMICs can be used in measuring equipment with frequency range from 10 MHz to 50 GHz and above. Directional detector MMIC can be used instead of directional coupler with absorbed power detector. Wide dynamic and frequency ranges have been achieved in comparison with commercially available MMICs. Directional detector MMIC provides power measurement from -30 dBm to +25 dBm, non-directional detector MMIC from -40 dBm to +20 dBm.

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