

Modeling and Application of Microwave Detector Diodes

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Abstract - The results of modeling of the ZB-27 microwave detector diode (produced by "Micran" research & production company) using SPICE parameters are represented in this paper. The simulation results include current-voltage characteristic of the diode at different temperatures and also S-parameters at fixed input power. In addition, possible applications of diodes in the measurement equipment with a frequency range up to 40 GHz are shown.

Index Terms – Detector diode, SPICE-parameters, gallium arsenide, RF power detection, power sensor.

I. INTRODUCTION

Radio Frequency (RF) diode detectors are widely used for power measuring, or in the network analyzers. The other types of power sensors: calorimetric and bolometric – are known. Compared to them, diode detectors have a higher rate of measurements, which allows using them for pulse power measuring. In addition, modern detectors have a dynamic range of about 90 dB and are able to measure signals with a frequency range of 9 kHz to 40 GHz and above [1]. For this reason, diode detectors have become conventional in the problems of measuring the RF power. However, at frequencies above 40 GHz, as a rule, measurers on the thermocouple basis are applied.

This work is devoted to the detector ZB-27 diodes, produced by "Micran." The diodes are manufactured on a semiconductor structure, which is grown using molecular beam epitaxy on a semi-insulating substrate of gallium arsenide (GaAs) [2]. ZB-27 is illustrated in Fig.1. The diodes are intended for zero bias detecting applications at frequencies through 115 GHz. A short description of production technology, the basic parameters and the equivalent circuit of the diode are given in [2].

II. PROBLEM DEFINITION

The aim of this paper is a presentation of the ZB-27 diode model and variants of ZB-27 application in measurement equipment. The model is based on the use of SPICE-parameters which are obtained by extracting them from the static characteristics of diodes, and their temperature and frequency dependencies. Possible variants of applications are considered by the example of detector assemblies "Micran" operating mode with zero offset.

III. USE SPICE FOR NONLINEAR COMPONENTS MODELING

While developing devices and components, computer modeling became widely spread. SPICE (Simulation Program with Integrated Circuit Emphasis) has got a significant popularity

in Russia and abroad. For ease of modeling, the majority of manufacturers of electronic components provide necessary

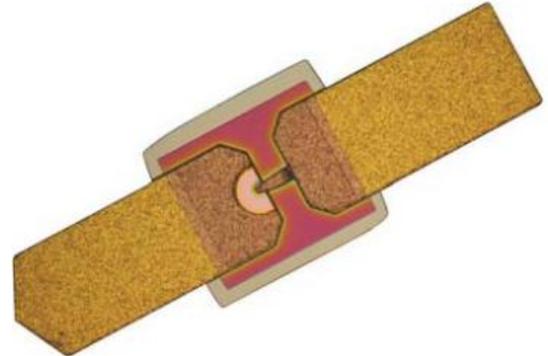


Fig. 1. Diode ZB-27 Photo.

SPICE-models or the individual parameters for the modeling. SPICE is a common name for the modeling programs of electronic circuits. Using SPICE it is possible to count on regimes of DC schemes, frequency, transients and noise characteristics, to analyze the effect of temperature and so on. For nonlinear elements in the language, a list of special parameters that reflect the characteristics of different modes of operation is provided. For example, number of parameters for such diodes exceeds 50 [3]. Most manufacturers are limited by 5-7 indicating parameters that reflect major dependencies which lead to problems in the design of apparatus. In this paper we consider ZB-27 as parallel connected diodes and specify more than 10 SPICE-parameters.

IV. EXPERIMENTAL RESULTS

For a sample of ZB-27 diodes, main working characteristics were measured. Experimental results were used for SPICE-parameters extraction. Diode model is an anti-parallel connection of two diodes (Fig. 2).

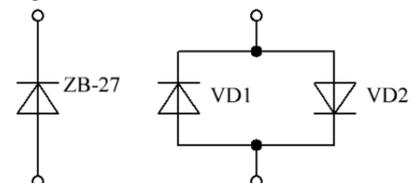


Fig. 2. Diode's model with opposite-parallel connection two diodes

Two diodes are used due to comparatively large values of the reverse current. In the model in Fig.2 diodes VD1 and VD2 characterizes the diode operation under forward and reverse bias, respectively. SPICE-parameters are presented in the table 1. Measured current-voltage characteristics (I-V) of 20 diodes and the resulting model based on extracted SPICE-parameters are shown on Fig.3.

TABLE I
ZB-27 MODEL SPICE-PARAMETERS

Name	Description	Units	VD1	VD2
I_S	Saturation Current	μA	34.64	62.32
R_S	Ohmic Resistance	Ω	30	62.3
N	Emission Coefficient		1.35	21.5
C_D	Linear capacitance	fF	11	11
C_{JO}	Zero-bias Junction capacitance	fF	0.030	0.030
$P_B(V_j)$	Junction Potential	B	0.19	0.19
M	Grading Coefficient		0.5	0.5
B_V	Reverse breakdown voltage	V	10	10
I_{BV}	Current at reverse breakdown voltage	pA	10	10
E_G	Energy gap	eV	1.42	1.42
$P_T(XTI)$	Saturation-current temperature exponent		2	2
T_{RS}	R_s linear temperature coefficient	$1/^\circ\text{C}$	0.005	0.007

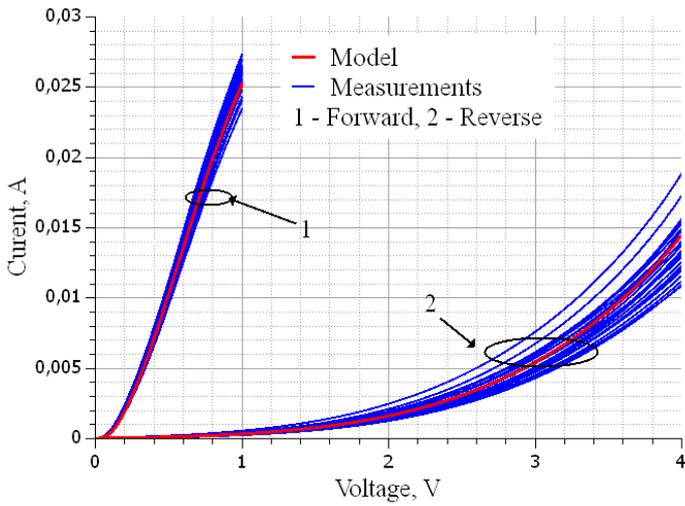


Fig. 3. Current-voltage characteristics of ZB-27 diode

SPICE diode model also allows the modeling of the current-voltage characteristics with temperature dependence. It is possible to achieve a good convergence of calculated and measured I-V curves in a temperature range from -50°C to 50°C . The use of the model for a temperature of 100°C is also possible. Calculated and measured I-V curves of forward biased diode and a model at different temperatures are shown in Fig. 4.

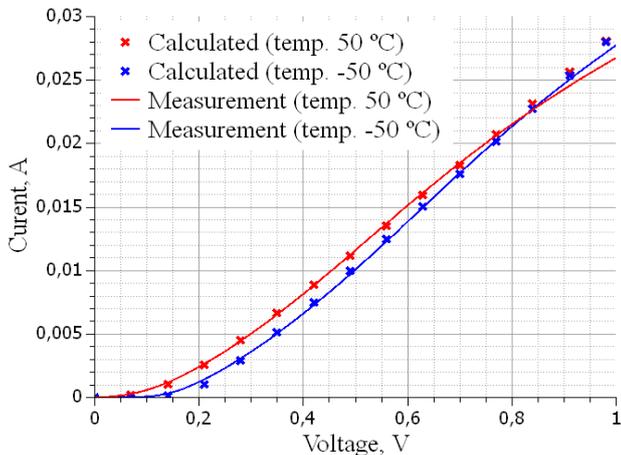


Fig. 4. ZB-27 I-V curve in forward bias at -50°C and 50°C

It should be noted that presented diode model describes temperature dependence the slope of current-voltage characteristics. It allows modeling the deviation of S-parameters with the temperature changes; that allows taking into account the temperature changes at the stage of modeling devices. S-parameters measurement of diodes was performed at an input RF power of 0 dBm. A comparison of experimental and simulated S-parameters is shown in Fig. 5 and Fig. 6.

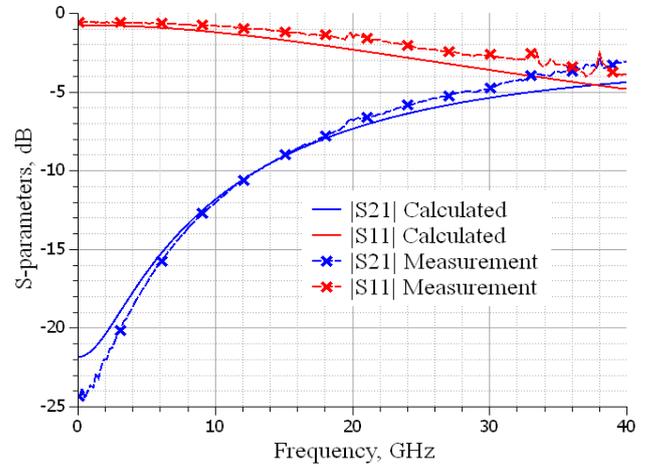


Fig. 5. Calculated and measured S-parameters magnitude

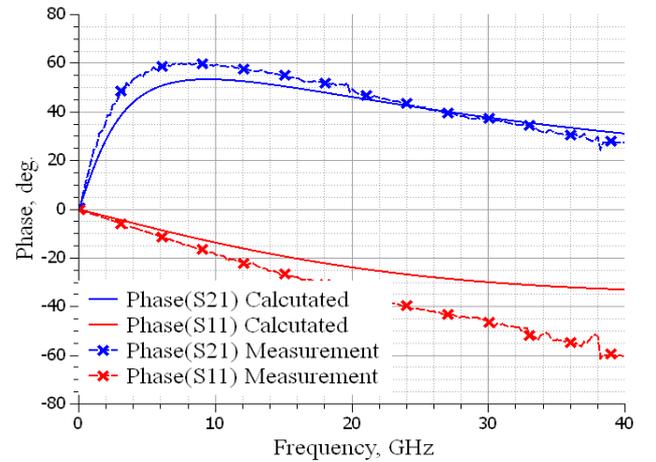


Fig. 6. Calculated and measured S-parameters phase

The small signal linear equivalent circuit of the diode in a small-signal mode is shown in Fig. 7, where $R_s = 30 \Omega$; $C_p = 11 \text{ fF}$; $C_j = 35 \text{ fF}$; $r_j = 0.9 \text{ k}\Omega$.

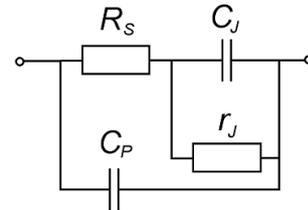


Fig. 7. Equivalent circuit of the diode

V. THE USE OF DIODES

The use of ZB-27 model will be shown by the example of an amplitude diode detector of RF power. Its schematic diagram is shown in Fig. 8. In this circuit, C1 is a split capacitor, resistor R1 is used to match the input impedance of the detector with input line impedance (50Ω).

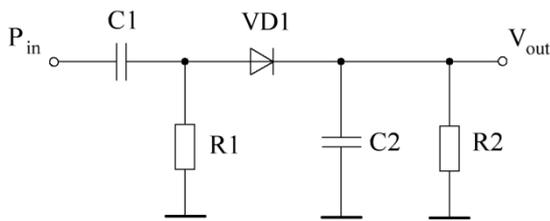


Fig. 8. The basic schematic of the amplitude detector.

The active element is a VD1 diode, a low-pass filter is formed by the C2 capacitor, R2 and load resistance. The scheme illustrated at Fig. 8 is used in D5A-20 detector produced by "Micran" company. The dependence of the output voltage detector from a level of input power, which is called a detector characteristic, is shown in Fig. 9.

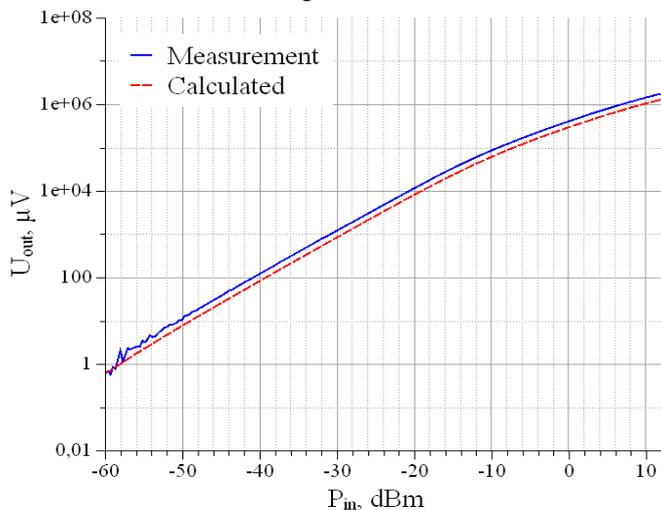


Fig. 9. Output voltage vs. input power

The dependence (Fig. 9) was measured at an input frequency of 1 GHz. The figure shows that used model is correct for modeling of dynamic characteristics. Fig. 10 shows a photograph D5A-20 detector used in the experiment.

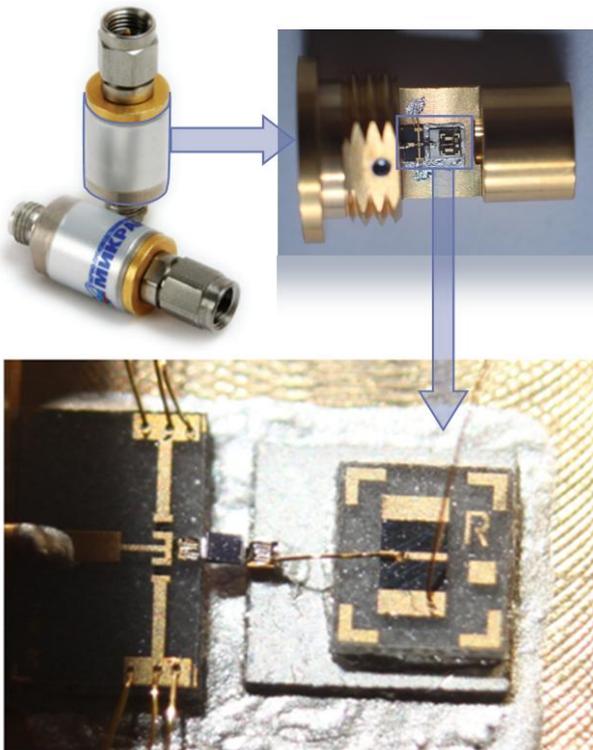


Fig. 10. D5A-20 Detector

Diodes ZB-27 is also a part of the detectors, VSWR sensors and power sensors [4] (Fig. 11).



Fig. 11. Devices with ZB-27 detector diode produced by "Micran"

The main characteristics of devices are presented in Table II.

TABLE II
MAIN CHARACTERISTICS OF DEVICES

RF Detector D42-20	Frequency range, GHz	0,01 .. 20
	Measurable power range, dBm	-50 .. +20
	Max input VSWR	1.2
RF Detector D42-50	Frequency range, GHz	0,01 .. 40
	Measurable power range, dBm	-50 .. +20
	Max input VSWR	1.5
VSWR sensor DK6-40	Frequency range, GHz	0,01 .. 20
	Directivity, dB	30
RF Power meter M3M-18	Frequency range, GHz	0,01 .. 20
	Measurable power range, dBm	-50 .. +20

V. CONCLUSION

The result of the work is the diode ZB-27 model, based on SPICE parameters. This model represents the current-voltage characteristic of the diodes, its changes at different temperatures and S-parameters for fixed input power 0 dBm. To demonstrate the diode model, a modeling of a simple amplitude detector using developed diode model was conducted. The diodes are used in commercially-manufactured products of "Micran". ZB-27 diodes can be used in different detector devices with frequency range up to 40 GHz and above. Diodes provide dynamic range up to 90 dB. Presented model based on SPICE-parameters greatly simplify development process.

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