УДК 621.382.2

A.S. KASHTALIAN
Khmelnitsky National University, Khmelnitsky, Ukraine

INVESTIGATION OF LOW POWER SCHOTTKY DIODE I-V CHARACTERISTICS

Abstract. I-V characteristics of semiconductor ultrahigh frequency diode are considered in articles, such diodes are used for detection of an electromagnetic field and measurement of its density. The equivalent scheme of the ultrahigh frequency semiconductor diode, its parameters and its influence on the I-V characteristics are examined. Approximation of I-V curves of such class particular diodes is performed. Characteristics are divided into separate quadratic and linear zones for this purpose. Possibility of obtaining I-V curve parameters by means of linear regression is offered.

Key words: microwave diode, approximation, equivalent scheme, volt-ampere characteristics, linear regression.

А.С. КАШТАЛЬЯН
Хмельницький національний університет, Україна

ДОСЛІДЖЕННЯ ВОЛЬТ-АМПЕРНИХ ХАРАКТЕРИСТИК МАЛОПОТУЖНИХ ДІОДІВ ШОТКІ

В статті розглянуто вольт-амперні характеристики напівпровідникових надвисокочастотних діодів, що використовуються для детектування електромагнітних полів та вимірювання їх інтенсивності. Досліджено еквівалентну схему надвисокочастотного напівпровідникового діода, її параметри та їх вплив на вольт-амперну характеристику. Виконано апроксимацію вольт-амперних характеристик окремих діодів такого типу, для чого характеристики розбиті на квадратичну та лінійну ділянки. Запропоновано можливість отримання параметрів вольт-амперної характеристики із застосуванням лінійної регресії.

Ключові слова: надвисокочастотний діод, апроксимація, еквівалентна схема, вольт-амперна характеристика, лінійна регресія.

Problem definition and analysis of research and publications. Diode ultrahigh frequency (UHF) converters have broad application in the measuring devices, the automated systems, medical and biological instrumentation technology and other areas of science and technology for measurement of UHF signal power. Sources of electromagnetic radiation in UHF range are the equipment of cell communication (base stations and mobile modules), microwave process equipment, medical microwave equipment and means of radio-frequency identification [1]. This equipment demands information-measuring systems of electromagnetic field density for activity safety. Semiconductor diodes take the special place among electromagnetic field sensors. The positive properties of measuring diode UHF converters are high speed and sensitivity, almost ideal zero stability, lack of need for preliminary warming. Diode converters can be used as measuring sensors owing to improvement of manufacturing techniques which allows to receive semiconductor junctions with stable characteristics, and also usage of structural methods of precision increase, in particular [2,3]. Schottky diodes, the turned diodes and others produced serially are usually used in practical tasks. It is necessary to determine measuring conversion factor of diode sensor, to estimate an additive component of error, to define the probable range of measurement with the greatest possible accuracy for usage the diode as the electromagnetic field detector or the measuring converter. Diode sensor is selected for concrete measuring system based on these parameters. The approach based on circuit theory with electrodynamics elements application, harmonious balance and semiconductor devices physics is the basic for research of diodes [4]. The parameters of converter equivalent circuit and volt-ampere characteristics (I-V characteristics) are used as primary data. Detector diode represents the device, which consists of Schottky diode (the turned diode) and design details. Each of these elements carries out a certain influence on diode characteristics.

Equivalent semiconductor microwave diode scheme. Equivalent circuits proposed by various researchers differ significantly. But the equivalent circuit of diode (fig. 1) which considers the main features of work in the UHF range is used for an assessment of these influences. Here C_{jun} - capacity of Schottky junction; r_{ser} - serial resistance, which consists of semiconductor layer resistance, contact connections and outlets resistance; C_{pac} - constructional capacity, which includes capacities of package and outlets joining Schottky junction; L_{ser} - serial inductance. The certain perfect Schottky junction is labeled by letter *D*, it differs from practical one by condition $C_{jun} = r_{ser} = 0$.

If C_{pac} and L_{ser} are neglected, then at a first approximation:

$$U_1 = U \Big/ \sqrt{1 + (2\pi)^2 f^2 C_{jun}^2 r_{ser}^2} \ .$$

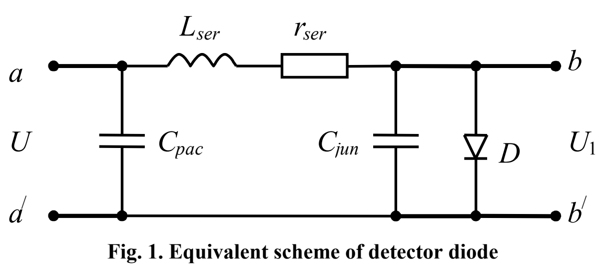


Fig. 1. Equivalent scheme of detector diode

The one of key diode parameters is current sensitivity β_I , it is the relation of straightened current I_{st} to the power of microwave signal, which is leaded to input of detector convertor with incident power P_{inc} :

$$\beta_I = I_{st} / P_{inc} \ .$$

The particular value β_I depends on properties of real semiconductor contact, equivalent scheme parameters, signal frequency and resistance in diode circuit. It is theoretically established, that at small resistance in a diode circuit and without parasitic parameters of the equivalent circuit $\beta_{I\max} = q/2nkT \approx$20μA/μW, here q- electron charge; T- temperature; k- Boltzmann's constant; n-nonideality factor.

With parasitic parameters of the equivalent circuit

$$\beta_I = q/2nkT\left(1 + 4\pi^2 f^2 C_{jun}^2 r_{ser}^2 R_D\right)^2 .$$

It is obvious, that always $\beta_I < \beta_{I\max}$, $q/2nkT$ is theoretical limit for β_I, which answers real conditions. Parameter β_I reaches the best value, if the direct current of straight shift I_{st} runs via the diode. β_I =1…10μA/μW for the majority of modern detector diodes.

Semiconductor diode volt-ampere characteristic approximation. Diode I-V characteristics can be approximated by piecewise-linear function for enough large-scale signals. Piecewise-linear approximation is widely used in converters calculation, including diode converters. However characteristics calculation on such approximation basic is rough and it can conducts to significant errors with small input signal amplitude.

Quadratic approximation is more prevalent and used type of approximation for semiconductor diodes. This type of approximation has great importance as the requirement of quadratic function form is imposed. In this case rectified current and voltage on loading resistance are proportional to UHF signal power, which is leaded to converter input. Semiconductor diode I-V characteristics has appearance: $I = KU^2$.

Exponential approximation is applicable to many types of semiconductor diodes; it permits to receive enough simple expressions for currents and voltages and provides good accuracy for majority of technical tasks. I-V characteristics in exponential form has appearance: $I = I_p \exp[\alpha(U - U_{sh})]$, here $\alpha = \alpha_T/n$, $\alpha_T = q/kT$ =39 1/V – theoretical coefficient value for 300K; I_p and U_{sh} - current and voltage of one I-V characteristics point, which is picked out in working area proceeding from the best compliance to the approximation of real I-V characteristics.

The largest precision can be provided with polynomial approximation in case the n-th order (degree, trigonometric, exponential, etc) polynoms are used as approximating functions. It must be kept in mind that this approximation causes to more difficult results; on account of it is seldom used in practice.

The special attention should be paid to quadratic conversion, which is wildly used in radio engineering, electronics and measuring equipment, generally in ultra high and super high frequency ranges. The characteristic of measuring diode converter can be presented by second degree polynom [5]:

$$i = a + bu + cu^2 \tag{1}$$

If monochromatic signal comes to an input of diode convertor in a look

$$u(t) = U\cos\omega t .$$

That with (1) it is received at the output of diode with quadratic approximated I-V curve

$$i = a + bU\cos\omega t + cU^2\cos\omega t .$$

Executing transformations and considering that $\cos^2\alpha = \frac{1}{2}(1 + \cos 2\alpha)$, we will have created at the output of the semiconductor diode voltage which can be written down in a look

$$u(t) = a + \frac{cU^2}{2} + bU\cos\omega t + U^2\cos 2\omega t \tag{2}$$

Constant component of the equation (2) $\left(a_0 + \frac{cU^2}{2}\right)$ is proportional to the power of an input signal.

The analysis and experimental research show prospects of the measuring diode converters which are realized on turned tunnel diodes, and also on detector diodes with Schottky barrier and with working point shift.

Current through Schottky diode is defined by expression $I = i_0[\exp(\alpha U) - 1]$, here i_0, α - diode parameters; $U = U_0 + U_m(t)$ – voltage applied to the diode; U_0 - voltage of constant shift; $U_m(t)$ - voltage of investigated signal.

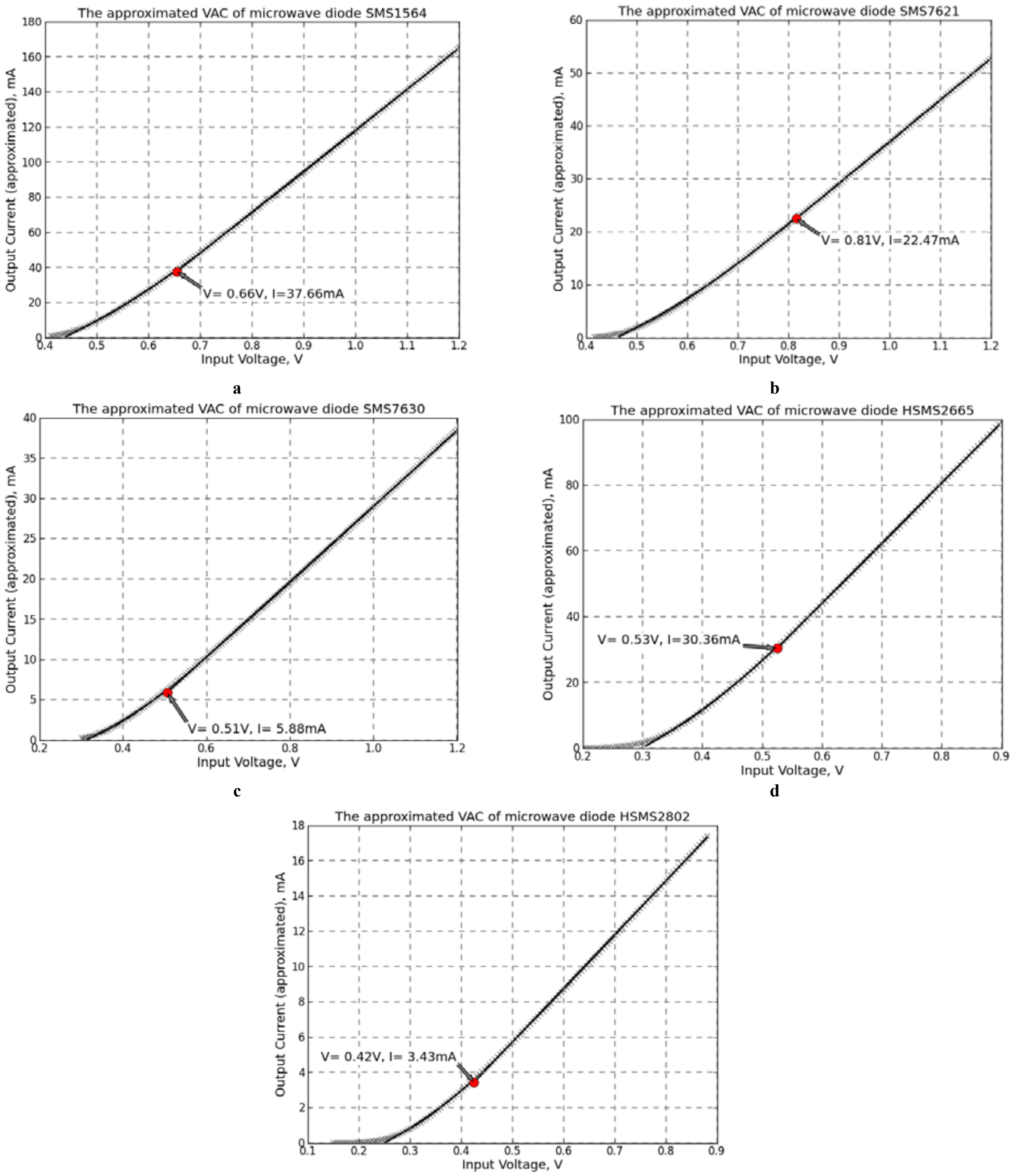
I-V characteristics of Schottky diode is approximated by row (1) for small signal. Abridging the most significant members of a row, it is possible to write down:

$$i = \frac{b}{2}\cdot\frac{U^2}{1 + aR_L} \approx KU^2 .$$

Here $K = \frac{1}{2}\cdot\frac{b}{1 + aR_L}$; R_L - diode loading resistance, and power

$$P \approx \frac{a}{2}U^2 \Big/ R_L .$$

In process of detecting of UHF signal by diode average value of diode current coincides with current i_0 at lack of an input signal. In the presence of an input signal current differs at a value $\Delta i = \frac{a}{2} E^2$, here E represents electromagnetic field intensity. Thus constant voltage is equal $i_0 R$ at lack of the UHF signal, and at presence - $(i_0 + \Delta i)R$.



e

Fig. 2. Approximated UHF diode I-V characteristics: SMS1564 (a), SMS7621 (b), SMS7630 (c), HSMS2665 (d), HSMS2802 (e)

Linear regression model of diode volt-ampere characteristic. Linear regression model with one variable is used for obtaining parameters of I-V characteristics. Data of diodes SMS1564, SMS7621, SMS7630, HSMS2665, HSMS2802 are experimentally received. These diodes belong to a class of semiconductor UHF low power diodes with Schottky barrier. I-V characteristics are divided into quadratic and linear sections.

The small signal area of I-V curve is approximated by quadratic dependence. The objective of linear regression is to minimize the cost function

$$J(\theta) = \frac{1}{2m} \sum_{i=1}^{m} \left(h_\theta \left(x^{(i)} \right) - y^{(i)} \right)^2 . \quad (3)$$

Here the hypothesis $h_\theta(x)$ is given by the quadratic model

$$h_\theta(x) = \theta^T x = \theta_0 + \theta_2 x^2 .$$

The parameters of linear regression model are the θ_j values. These values have to be adjusted to minimize $J(\theta)$ cost. One way to do this is to use batch gradient descent algorithm. In batch gradient descent each iteration performs the update

$$\theta_j = \theta_j - \alpha \frac{1}{m} \sum_{i=1}^{m} \left(h_\theta\left(x^{(i)}\right) - y^{(i)} \right) x_j^{(i)} \quad \text{(Simultaneously update } \theta_j \text{ for all } j) \quad (4)$$

With each step of gradient descent, parameters θ_j come closer to the optimal values that will achieve the lowest cost $J(\theta)$.

Parameter θ_0 represents additive error on quadratic zone; parameter θ_2 corresponds to diode current sensitivity in this zone.

The large signal area of I-V characteristics is approximated by linear dependence. The cost function is the same (3) at this section. The parameters are adjusted with using batch gradient descent (4). But the hypothesis $h_\theta(x)$ is given by linear model:

$$h_\theta(x) = \theta^T x = \theta_0 + \theta_2 x^2 .$$

Parameter θ_0 reflects additive part of error on linear section; parameter θ_2 is diode current sensitivity on this section of I-V curve.

Experimental and approximated I-V curves are displayed in figure 1. Diode I-V characteristics have a nonlinear section in the field of very small signal. On this section it is possible to carry out approximation by high degree polynoms. Each of considered diodes has a quadratic zone in the field of small signals. In the field of large signal I-V characteristics becomes linear. The border between quadratic and linear zones differs for each certain UHF diode, since it depends on its parameters; it is visible on the considered characteristics. The mean quadratic error of approximation does not exceed 3%. Numerical values of limits between quadratic and linear sections, diode current sensitivity for quadratic and liner sections are given in table 1.

Table 1

Diode type	Top limit voltage of quadratic zone, V	Top limit current of quadratic zone, mA	Sensitivity on quadratic zone, mA/V^2	Sensitivity on linear zone, mA/V^2
SMS1564	0,66	37,66	162,03	233,18
SMS7621	0,81	22,47	50,40	78,46
SMS7630	0,51	5,88	39,32	46,75
HSMS2665	0,53	30,36	166,08	183,05
HSMS2802	0,42	3,43	30,24	30.43

Conclusions. The analysis shows that the I-V characteristic of the ultrahigh frequency low-power Schottky diode has a typical appearance that allows standardizing approach to estimation of parameters of different diodes of this class. Linear regression model satisfies this purpose. Such evaluation permit to determine ranges of quadratic and linear detecting of the input UHF signal, to estimate diode current sensitivity on quadratic and linear sections. These data can be used for preliminary installation of conversion coefficient and other required parameters in measuring systems with diode sensors for achievement of higher measurement precision of the sensor.

References

1. Webster J.G. The measurement, instrumentation and sensors handbook/ Webster J.G. – United States, CRC Press LLC, 1999 – 2617 pp.

2. Vodotovka V.I. Automatic monitoring system of diffused UHF electromagnetic field: invariant sensor of radiation from microwave process equipment/ Vodotovka V.I., Mostavliuk A.S.// Vinnyca polytechnic institute visnyk – Vinnica, 2007. – №1 – C. 22-26. [in Ukrainian]

3. Vodotovka V.I. Achivement of metrological reliability of the UHF diode measuring converter/ Vodotovka V. I., Mostavliuk A.S.// Khmelnitsky national university visnyk. Technical science. – Khmelnitsky, 2007. – №3. – T.1. – C.153-157. [in Ukrainian]

4. Neamen, Donald A. Semiconductor physics and devices: basic principles/ Donald A. Neamen – United States, Mc Graw Hill, 2003 – 731pp.

5. Fantom A. Radio frequency and microwave power measurement. I. Microwave. Measurement/ Fantom A. – United Kingdom, Peter Peregrinus Ltd., 1990. – 278 pp.

Рецензія/Peer review : 11.7.2014 р. Надрукована/Printed : 12.7.2014 р.