PROCEEDINGS OF ISAP '96, CHIBA, JAPAN

DETERMINATION OF DEVICE PARAMETERS IN H-WAVEGUIDE STRUCTURE

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1. Introduction

The motivation of the presented investigations was necessity of design of original H-waveguide integrated circuits [1], [2]. Due to special features these integrated circuits allow to achieve extremely low losses at millimeter-wave frequency range and may be successfully applied for various microwave devices: low noise amplifiers, mixers, oscillators. For design of the mentioned integrated circuits it is desirable to use active device parameters measured in the same transmission line. In this connection the problem concerning measurement and calculation of device parameters in H-waveguide structure is very important.

This paper presents our investigations on the problem concerning determination of impedance of various microwave and millimeter wave devices (diodes, transistors, etc.) mounted on a lateral side of H-waveguide ridges. The necessary measurement procedures and calculation techniques will be described. The extension of the method to optimum noise parameters is proposed.

2. Principle of measurements

The device impedance is determined using a new measurement method developed by us [3]. Let us consider the main idea of this method. The method is based on a measurement of standing wave minimum shift. It is proved that relative shifts of the minimum $\Delta l/\lambda$ in a rectangular waveguide and H-waveguide are equal. Let us consider two regular transmission lines: $x_0 - x_2$ and $x_3 - x_5$ (Fig.1), joined smoothly by irregular line $x_2 - x_3$.

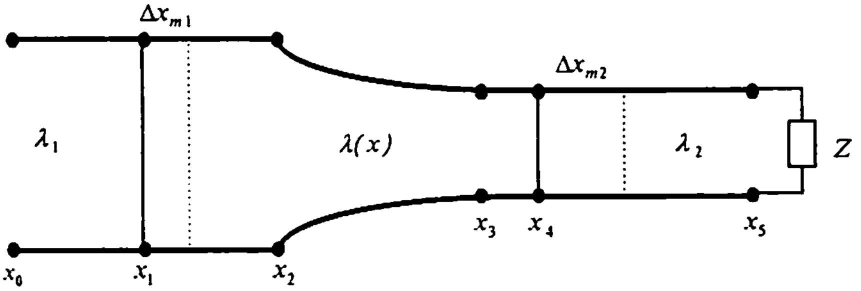

Fig. 1 Smooth transition

Assume that a standing wave minimum of the second regular transmission line is at the point x_4, and the corresponding minimum of the first transmission line is at the point x_1. As it takes place, the phase difference φ between the points x_4 and x_1 may be conceived as follows:

$$\varphi = \frac{2\pi(x_2 - x_1)}{\lambda_1} + \int_{x_2}^{x_3} \frac{2\pi}{\lambda(x)} dx + \frac{2\pi(x_4 - x_3)}{\lambda_2},$$

where: λ_1, λ_2 are wavelengths of the first and the second transmission lines respectively; $\lambda(x)$ is a x - dependence of wavelength of the irregular transmission line.

Let us assume that a load impedance of the second regular line Z being changed in such a way that the point of the minimum shifted to Δx_{m2}. Due to that the shift of the minimum in the first regular line Δx_{m1} is determined under the condition that φ is constant:

$$\frac{2\pi(x_2-x_1)}{\lambda_1}+\int_{x_2}^{x_3}\frac{2\pi}{\lambda(x)}dx+\frac{2\pi(x_4-x_3)}{\lambda_2} =$$

$$\frac{2\pi(x_2-(x_1+\Delta x_{m1}))}{\lambda_1}+\int_{x_2}^{x_3}\frac{2\pi}{\lambda(x)}dx+\frac{2\pi(x_4+\Delta x_{m2}-x_3)}{\lambda_2}.$$

After simple manipulations it follows: $\Delta x_{m1}/\lambda_1=\Delta x_{m2}/\lambda_2$. It enables to determine the shift of the minimum in the H-waveguide for a measured shift of the minimum in the standard rectangular waveguide of slotted line:

$$\Delta l_H = \Delta l_R \frac{\lambda_H}{\lambda_R} .$$

That allows to calculate the unknown impedance Z with the following formula:

$$Z = Z_H\left[\frac{K(1+tg^2 2\pi\Delta l_R/\lambda_R)}{K^2+tg^2 2\pi\Delta l_R/\lambda_R}+i\frac{(K^2-1)tg^2 2\pi\Delta l_R/\lambda_R)}{K^2+tg^2 2\pi\Delta l_R/\lambda_R}\right], \qquad (1)$$

where: Z_H is the wave impedance of the H-waveguide (the second regular line); K is VSWR; $\Delta l_R/\lambda_R$ is the relative shift of the minimum in the standard rectangular slotted waveguide (the first regular line).

3. Calculation of measuring section and measurement procedure

The proposed measurement technique is realized through a special H-waveguide measuring section. It consists of rectangular waveguide section with an inserting plate that formed H-waveguide ridges. There are two inserting plates. The first one (Fig. 2) is a metal substrate with a thin filmed passive integrated circuit and a device under test (field-effect transistor, diode, etc.). The plate forms a smooth transition from the rectangular

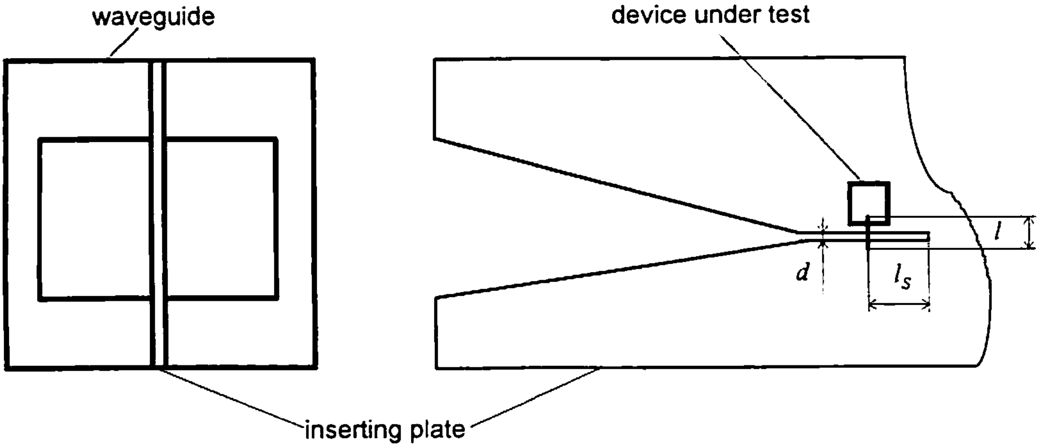

Fig. 2 Inserting plate with a device under test

waveguide to the H-waveguide. The second plate is a short-circuiting switch. The configuration of the second plate is similar to the first one, but it is shorted at the point of input (output) of the device under test.

The measuring section must provide a smooth transition from the rectangular waveguide to the H-waveguide under minor irregularity. The Chebyshev transition has the minimum reflection under the fixed length. The exponential compensative transition has the most appropriate approximating it to the Chebyshev one. The wave impedance dependence of the relative length of the exponential compensative transition is calculated with the following formula:

$$Z(x/l) = Z_0 exp\left[ln\frac{Z(l)}{Z(0)}\left(\frac{x}{l} - 0.133sin\frac{2\pi x}{l}\right)\right],$$

where l is the length of exponential compensative transition.

The wave impedance and the wavelength in the H-waveguide may be calculated with the help of various techniques, for example using closed-form expressions given in [4]. From those expressions it is inferred that the wave impedance of H-waveguide depends on the clearance between its ridges. Therefore, from the known $Z(x/l)$ dependence we are able to found $d(x/l)$ dependence, where d is the distance between the ridges, and to calculate the constructional proportions of smooth transition. However, as the clearance d changes the H-waveguide wavelength also changes. Therefore, it ought to take the dispersion into account. Calculation of the smooth transition is effected by as follows:

1. The necessary data are set: the rectangular waveguide section dimensions, the H-waveguide ridges thickness, the smooth transition length, the frequency of operation and the corresponding wave impedance.
2. $Z(x/l)$ is computed.
3. $d(x/l)$ and $\lambda_H(x/l)$ are computed with the closed-form expressions [4].
4. The smooth transition length l is broken up into n sections of the same length Δx_l. The real geometric length of this sections x_i is calculated being regard to dispersion for each of them: $x_i = \Delta x_l \ \lambda_H / l$.
5. $d(x_i)$ dependence is calculated at n points.

The measurement procedure is based on the measurements of standing wave minimum shifts and VSWR for the inserting plates described above. Measurements of the standing wave minimum are carried out for the each inserting plate (with the measured device and the short-circuiting switch) under strict observing the identical measurement conditions. At the same time VSWR is measured for the plate with the device under test.

The extension of this method to optimum noise parameters of field-effect transistors is proposed. For determination of optimum noise parameters the usage of set of inserting plates with various configuration is proposed. The active component of input transistor impedance is determined with the distance between ridges of H-waveguide by appropriate choice of slot width cut off in the metal plate. The reactive one is compensated by appropriate selection of length of shorting stub. The noise figure of the H-waveguide measuring section with the various inserting plates is measured. The optimum noise parameters are determined for the plate with the minimal noise figure.

4. Calculation of input (output) impedance

Calculation of input (output) device impedance is effected by as follows:

1. The standing wave minimum shift in the rectangular waveguide is determined: $\Delta l_R = x_{SC} - x_D$, where: x_{SC}, x_D are minimums of standing wave for corresponding plates.
2. The measuring section impedance $Z = R + iX$ is calculated with the proposed above formula (1).

3. The inserting plate elements are calculated with the help of schematic diagram shown in Fig. 3, where: B_S, X_L are parameters of shorting stub and inductive conductor

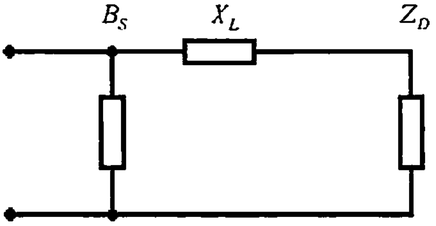

Fig. 3 Equivalent schematic diagram

respectively; $B_S = 1/Z_H\, tg(\beta l_S)$; $\beta = 2\pi/\lambda_H$; Z_H, λ_H are the wave impedance and the wavelength in the H-waveguide; l_S is the length of the shorting stub;

$$X_L = 0.4\pi f l \left(ln\frac{4l}{D} - 1 \right) \cdot 10^{-6},$$

where: f is the testing frequency; l, D are the length and the diameter of round conductor.

5. The input (output) device impedance Z_D is calculated with the following formula:

$$Z_D = \frac{R}{1+2XB_S+B_S^2\left(R^2+X^2\right)} + i\left(\frac{X+B_S\left(R^2+X^2\right)}{1+2XB_S+B_S^2\left(R^2+X^2\right)} - X_L \right).$$

5. Calculation of optimum noise parameters

The necessary impedance Z_N in the plane of device under test (field-effect transistor) for minimum noise figure is calculated with the following formula:

$$Z_N = \frac{1/Z_H}{1/Z_H^2+B_S^2} + i\left(X_L - \frac{B_S}{1/Z_H^2+B_S^2} \right),$$

where: Z_H, B_S, X_L are determined for the inserting plate with minimal noise figure.

6. Conclusion

The proposed method was developed for determination of impedance of various microwave devices and optimum noise parameters of field-effect transistors mounted on a lateral side of H-waveguide ridges. The parameters determined by described techniques may be used for design of integrated circuits based on H-waveguide transmission line.

7. References

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