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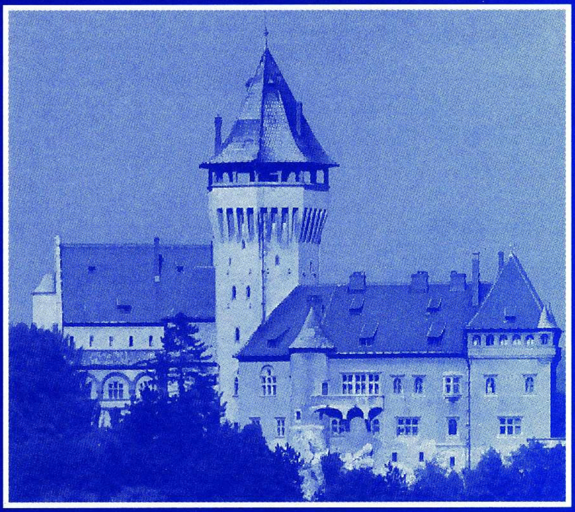

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Coplanar Waveguide Modeling Based on Scattering Parameter Measurements

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There is presented method for verification of important coplanar waveguide parameters in this article. It employs simplex optimization algorithm for transmission line model identification from on-wafer S-parameter measurements in wide frequency range. Method was implemented in control program for automated S-parameter measurements and applied for characterization of micromachined AlGaAs and InGaP coplanar waveguides.

1. Introduction

Transmission lines are very important passive elements for high frequency circuit design. They are often used for microwave signal transmission on chip, but they can be used for another purposes e.g. distributed elements construction. In recent time, the coplanar waveguide (CPW) is very important structure for use in microwave monolithic integrated circuits due to low loss as well as low dispersion in comparison with another microstrip line types. However, it is very important to identify properties of designed CPW used in particular design. This article deals with the transmission line model identification from measured S-parameters. A method of model parameter extraction was implemented as internal procedure in automated vector network analyzer (VNA) control program for S-parameters measurement and data processing called MAMS (Microwave Automated Measurement System) [1]. Program was used for characteristic impedance and propagation constant extraction of CPW from on-wafer S-parameters measurements in frequency range up to 20 GHz. Used methodology is in more details described below.

2. CPW model

At high frequencies the signal wavelength is comparable to physical dimensions of transmission lines. Voltage and current vary along the transmission line due to distributed line inductance and capacitance. Characteristic impedance Z_0 and propagation constant γ derived from wave equations are generally known.

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \qquad (1)$$

$$\gamma = \sqrt{(R + j\omega L).(G + j\omega C)} \qquad (2)$$

Basic parameters R, L, C and G are the resistance, inductance, capacitance and conductance per unit length of transmission line. However this simple model can be used for limited frequency range only due to influence of skin effect and frequency dependency of dielectric losses. This lossy line behavior is possible to approximate by additional terms R_s and G_d [2].

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$$R(f) \cong R_0 + \sqrt{f}(1+j)R_s \tag{3}$$

$$G_d(f) \cong G_0 + fG_d \tag{4}$$

R_0 is DC resistance and R_s characterize resistance caused by skin effect. G_0 models the shunt current due to free electrons in imperfect dielectrics and G_d models the power loss due to rotation of dipoles under the alternating field. From impedance and propagation constant of transmission line is easy to express four scattering parameters [3]. However VNA non-idealities must be taken into account. Let's consider situation shown in Fig. 1. Deviations from ideal 50Ω VNA characteristic impedance are transformed by measured transmission line. For comparison with measured S parameters we have to take these imperfections into account and include them into reflection coefficients at both ports.

$$S_{11}' = S_{11} + \frac{S_{12}.S_{21}.\Gamma_2}{1 - S_{22}.\Gamma_2} \tag{5}$$

$$S_{22}' = S_{22} + \frac{S_{12}.S_{21}.\Gamma_1}{1 - S_{11}.\Gamma_1} \tag{6}$$

S_{11}, S_{12}, S_{21}, S_{22} are transmission line scattering parameters. Γ_1 and Γ_2 are reflection coefficients caused by differences from ideal 50Ω VNA impedance at appropriate port. They could be obtained by measurement of ideal THRU element with characteristic impedance $Z_0=50\Omega$. S_{11}' and S_{22}' are reflection coefficients measured by VNA.

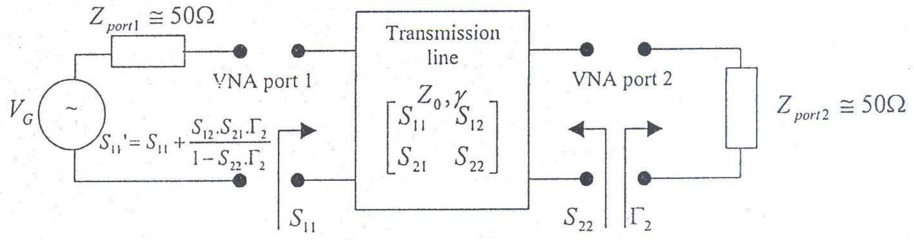

Fig. 1. Transformation of reflection coefficient caused by imperfection of VNA via transmission line

3. S-parameters measurements of CPW

CPW's S-parameters were taken using HP8408B VNA with extension set for on-wafer measurements described in [4]. VNA was calibrated using standard SOLT calibration method in frequency range 100 MHz up to 20 GHz with the frequency step 100 MHz.

4. Optimization

Progress in high-speed computers enables application of novel and high-efficient optimization methods for microelectronic elements and circuits design. These methods could serve for dual purpose. They are suitable for microelectronic device parameters improvement, but they could be applied for microwave as well as optoelectronic devices model identification. Another purpose is described in this section. In this case the main goal of optimization process is minimization of deviation between S-parameters measured and calculated from specific device model. Application of optional optimization method type for model identification requires creation of cost function.

$$Q = f(p_1, p_2, \ldots, p_n) \tag{7}$$

Cost function determines which combination of model parameters $p_1, p_2, \ldots, p_n$ is better according to specified criteria. It should return real non-negative number for optional combination of input model parameters. It is desirable to construct cost function such way, that it returns lower values for better solutions. After that the optimization process changes to finding global minimum of cost function. One of many possible ways of fitting computed curves to measured data is to use the least square method [5]. Least square method is suitable for minimization of total deviation $\rho(f,\varphi)$ between function $f(x)$ given by table in m measured points and chosen approximation function $\varphi(x)$. Weight coefficient w_i in equation (8) enables to emphasize data influence at specific points. It is applicable in real case if the input data are measured with different precision. In most cases the w_i is set to one.

$$\rho(f,\varphi) = \sqrt{\sum_{i=0}^{m} \left| f(x_i) - \varphi(x_i) \right|^2 . w_i} \tag{8}$$

There are two problems of straightforward application of least square method as a cost function. First problem is, that S parameters are complex numbers. Second one is that we need to fit several curves that corresponds to measurement of several scattering parameters for modeled device. Both problems are solved by modification of equation (8).

$$Q(S_M, S_C) = \sum_{i=0}^{m} \left| S_{Mi} - S_{Ci} \right| . w_i \tag{9}$$

Equation (9) means that complex numbers related to measured S_M and calculated S_C scattering parameters are subtracted and difference is than converted into absolute value at all measured points. S_C is computed using transmission line model in section 2. Weight coefficients $w_i > 0$ for $i = 0, 1, \ldots, m$ enables to emphasize data measured with higher precision. In most cases several curves have to be fitted, so cost function is calculated as a total sum of partial errors determined for each S parameter set separately using equation (9).

Many methods were published for finding minimum of cost function of several variables [6]. Classical optimization methods use direct application of mathematic analysis and algebra. They could be distinguished as gradient and non-gradient methods. When good starting point is chosen, gradient methods are usually quite fast, but they often find only local minimum. In opposite non-gradient methods are a little bit slower, but they are not so sensitive for a local minima. Very progressive optimization methods at present are so called evolution algorithms. They follow optimization processes originated in nature. We have chosen simplex optimization method for coplanar waveguide model identification from S-parameter measurements due to its reliability and easy implementation.

5. Results

Chosen CPW's model was applied for approximation of AlGaAs and InGaP transmission line parameters. Model was constructed at physical base, so model parameters can be considered very close to physical transmission line parameters. DC resistance was verified by DC measurements. Higher losses of InGaP CPW than AlGaAs CPW was observed. It was caused by material properties mainly by higher InGaP conductivity.

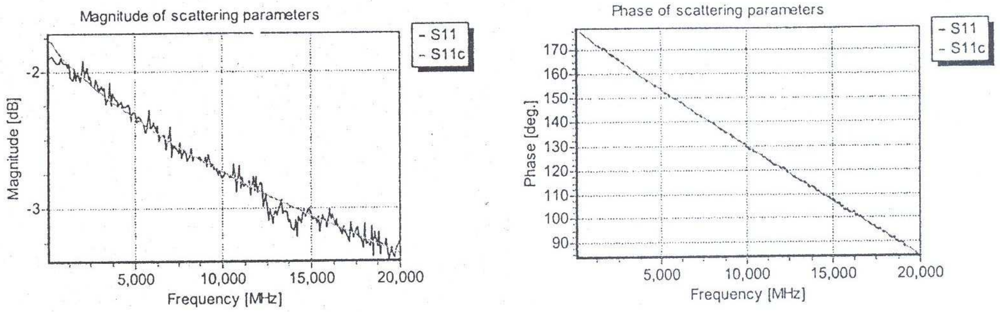

Fig. 2. Comparison between measured (noisy line) and modeled reflection coefficient for 800 μm short terminated AlGaAs CPW.

6. Conclusion

We have described simple, but effective method for identification of basic transmission lines properties from S-parameter measurements. Technique successfully employs optimization method for calculation of chosen transmission line model parameters. Cost function for optimization method was assembled in order to minimize deviations between measured and computed S-parameters from chosen model. Modeled S-parameters using skin effect transmission line model very precisely fits measured curves in measured frequency range. Then model parameters can be considered as correct and it could be used for simulations of more complicated devices. Described method was implemented as an integral part of program for automated S-parameter measurement, which was verified by identification of InGaP and AlGaAs coplanar waveguides. It could be supposed, that another high frequency and optoelectronic devices is possible to characterize by similar way.

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