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MODIFIED TWO FIELDS PROBLEM APPROACH IN SIMULATION OF MICROSTRIPE PIC ELEMENTS

In this paper Modified Two Fields Problem Approach is presented. This method is based on FIT (Finite Integration Technique), on replacement of 3D (three-dimensional) analysis with 2D analysis and on empirical formulas. The starting point to create this method was desire to reduce order models, to decrease computation time and needed computation power. The proposed method is a hybrid method, which essential element is to use new, empirical formulas of p.u.l. (per unit length) capacitance. The method is applied to compute p.u.l. R (resistance), L (inductance), C (capacitance), G (conductance) and propagation quantities like effective dielectric permittivity εeff, attenuation α, characteristic impedance Zo of passive IC (integrated circuits) elements working at high frequency. Usefulness and effectiveness of the method was verified through results comparison with commercial software and with 3D FIT method. Comparison was made on example of Microstripe PIC (Photonic Integrated Circuit) structure.

1. INTRODUCTION

Nowadays we can observe tremendous shrinking of IC size and at the same time increase of their complexity. In case of ICs, which are working at high frequencies (HF) these facts have important consequences in process of design and simulation.

It is also observed, that niche devices and technologies are being modified to became more common. Such examples are PIC devices, based on InP (Indium Phosphide) substrate and BCB (Benzocyclobutene). It is expected, that in the following years, the PIC devices will be used more commonly and will find applications in much broader areas than it is today. It is possible due to the fact of cost production reduction. The PIC devices are becoming cheaper and cheaper, which means that their prices are more competitive to typical electronic IC, based on Silicon (Si).

Dissemination of the PIC devices will effect, that they will be used in variety of electronic devices. Which means, that new, robust, accurate, cost-effective methods of design and simulation of the PIC should be created and implemented in EDA (Electronic Design Automation) software for the PIC. To create such

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methods it is necessary to overcome miniaturisation issues, skin and parasitic effects, which are playing very important role in IC devices working at HF (high frequency). Models of the IC devices working at HF are complex and large, this is why the design methods should be based on model order reduction technique. One way to cope with these issues is mapping of existing solutions, methods for standard IC, based on Si to the PIC devices problems. Such approach is also presented in this paper. Existing method, which is called 2FPA (Two Fields Problem Approach) was modified to make it useful for the PIC design. Modification relies on to use new, analytical formulas, which include properties of PIC structures. New modified formulas and also modified Two Fields Problem Approach are the paper novelty.

New method was implemented in chamy software [1], thus it can be used as EDA tool for the PIC. The chamy software and presented in the article methods, are used to compute p.u.l. R (resistance), L (inductance), C (capacitance), G (conductance) and propagation quantities like the effective dielectric permittivity εeff, the attenuation α, the characteristic impedance Zo of the passive IC elements working at the high frequency.

Results of new methods were verified by fully commercial EDA software, by analytical formulas and by Full-wave 3D FIT solver. The tests are made in limited frequency range, from 1GHz up to 50GHz.

2. MODIFIED TWO FIELDS PROBLEM APPROACH

New method is a modification of the standard Two Fields Problem Approach. This 2FPA is based on solving of two field problems, one which describes the transversal behavior of the Microstripe (MS) line, from which the Microstripe line admittance is extracted and a second one which describes the longitudinal behavior of the Microstripe line and from which the line impedance is extracted. The first problem is dedicated to the computation of the transversal parameters and it uses a 2D transversal electro-quasi-static (EQS) field in dielectrics, considering the line wires as perfect conductor with given voltage. The second problem focuses on the longitudinal electric and the generated transversal magnetic field [2].

Modification of the 2FPA method relies on admittance Y_{EQS} computation not from solving field problem, which describes the transversal behaviour of the Microstripe line but with the use of formulas for per unit length capacitance (p.u.l. C) and p.u.l. G (conductance). These formulas are analytical and are paper novelty. Especially important is the formula for p.u.l. C, due to the fact that the formula for p.u.l. G is dependent from the p.u.l. C formula.

The admittance Y_{EQS}, computed with the use of p.u.l. C and G, is following:

$$Y_{EQS} = (G + j\omega C)\Delta l \qquad (1)$$

where Δl is Microstripe length.

The admittance Y_{EQS} is computed analytically, when impedance Z_{MQS} is computed by solving problem, which is related to the longitudinal electric field and the transversal magnetic field. This problem will be called the TM (transversal magnetic) simulation in what follows. In this model the electric field is 3D, but the magnetic field is 2D (TM, so there is no longitudinal component of the magnetic field along the line). However, the p.u.l. impedance (and consequently, the p.u.l. resistance and inductance) can be extracted from a magneto-quasi-static (MQS) simulation, and not from a TM simulation. Since the TM simulation includes the effects of transversal conductance and capacitance as well, we should subtract the EQS component out of the TM simulation to obtain the MQS component [3].

For the TM simulation is used the Full-Wave FIT solver, with a 2D magnetic mesh. Thus, the TM simulation gives the impedance Z_{TM}, that corresponds to a line segment of length Δl. In order to compute the "longitudinal" MQS impedance, the pi topology is used.

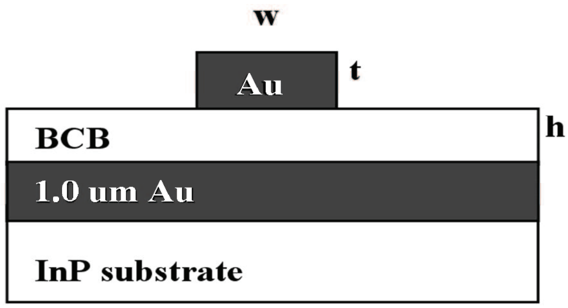

Fig. 1. Cross section of Microstripe line element, where w - metallization width, t – metallization thickness, h – dielectric height

The "longitudinal" MQS impedance Z_{MQS} is:

$$Z_{MQS} = (Z_{TM}^{-1} - \frac{1}{2} Y_{MQS})^{-1} \quad (2)$$

The p.u.l. impedance can be computed from the MQS impedance as:

$$Z = Z_{MQS} / \Delta l \quad (3)$$

and then the p.u.l. resistance R and the p.u.l. inductance L are:

$$R = Re(Z) \quad (4)$$

$$L = \frac{1}{\omega} Im(Z) \quad (5)$$

The M2FPA (Modified Two Fields Problem Approach) is used to compute p.u.l. RLCG values and propagation quantities of Microstripe presented on Fig.1.

3. NEW P.U.L. CAPACITANCE FORMULA

As it was mentioned in the previous chapter the M2FPA is using analytical formulas for p.u.l. C and p.u.l. G. For this method, new formula of p.u.l. C was created. New formula is a modification of formulas obtained with the use of Conformal Mapping technique [4], [5]. The modification relies on introduction to the standard formula the modification coefficient pC. This coefficient was matched by empirical, in such a way to the greatest extent possible to substitute for EQS simulations. Modified p.u.l. C formula is following:

$$C = (\frac{\varepsilon\varepsilon_0 w}{h} + 0.3 \cdot 4\ln(2)\frac{\varepsilon\varepsilon_0}{\pi} + 0.69C_{top} + 0.69C_v)pC \quad (6)$$

where pC is new modification coefficient and is paper novelty, C_{top} is the capacitance of top side of the MS and C_v is the vertical side wall of the MS [4].

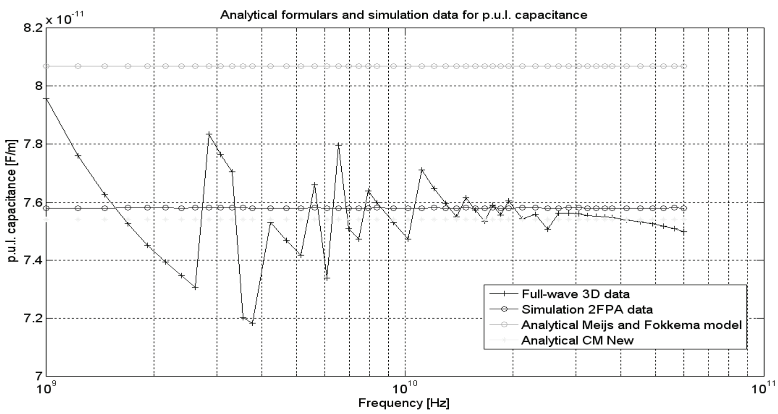

Fig. 2. Comparison of p.u.l. C using 3D, standard 2FPA, new CM formula and analytical Meijs Fokema model [6]

The coefficient pC was created by comparison of p.u.l. C values obtained from Full-wave 3D and 2FPA method. Fig. 2 is presenting this comparison. The coefficient pC is a polynomial and depends from t(thickness) and h(height) of Microstripe, Fig. 1. The polynomial form of pC coefficient is following:

$$\begin{aligned} pC(t,h) = 1.16214 - 0.0373758 \cdot 10^6 t + 0.0625856 \cdot 10^6 h \\ + 0.000520058 \cdot 10^{12} th - 0.0036498 \cdot 10^{12} h^2 \end{aligned} \quad (7)$$

The pC formula is the paper novelty and was used as basis in M2FPA.

The p.u.l. G is computed in the standard way but with essential modification, that C is from modified formula (6) with new pC. The p.u.l. G is:

$$G = C \cdot 2\pi f \cdot \tan\delta \quad (8)$$

4. PROPAGATION QUANTITIES

In our research two ways of computing propagation quantities values were used. First one considers that p.u.l. C, L, G, R are known and the impedance Z_o, effective dielectric permittivity ε_{eff} and losses α are calculated with the use of these p.u.l. values in standard Transmission Line formulas, which were presented in [5]. The second one considers to use S-parameters in order to find propagation quantities values.

Scattering parameters are commonly in use because they provide a complete description of the device. Below is depicted formulas extraction for propagation quantities with the use of S-parameters. First transforming of S-parameters into ABCD matrices form.

$$A = \frac{(1+S_{11})(1-S_{22})+S_{12}S_{21}}{2S_{21}} \tag{9}$$

$$B = Z_0\frac{(1+S_{11})(1+S_{22})-S_{12}S_{21}}{2S_{21}} \tag{10}$$

$$C = \frac{1}{Z_0}\frac{(1-S_{11})(1-S_{22})-S_{12}S_{21}}{2S_{21}} \tag{11}$$

From (9) and (10) the characteristic impedance is:

$$Z_0 = \sqrt{\frac{B}{C}} \tag{12}$$

Propagation constant γ is calculated using following formula:

$$\gamma = \frac{\operatorname{arcosh}(A)}{length} \tag{13}$$

Effective dielectric permittivity ε_{eff} and losses α are calculated:

$$\varepsilon_{eff} = \left(\frac{Im(\gamma)}{k_o}\right)^2 \tag{14}$$

$$\alpha = 8.68\,Re(\gamma)length \tag{15}$$

with commonly used notations: $k_o=2\pi f/c_o$, $c_o=3\cdot10^8$ m/s where k_o is wave number of a plane wave in free space, c_o is a velocity of light.

5. RESULTS

Test structure of Microstripe is depicted on Fig. 1, it is thin-film element, which has on the top metallization layer performed from Au (with width w = 5 um and thickness t = 1 um), below there is dielectric layer (with height h = 4.5 um) made from BCB. Under BCB is ground metalization, made from Au (thickness 1um) and below InP substrate. Tests were made in frequency domain up to 50 GHz.

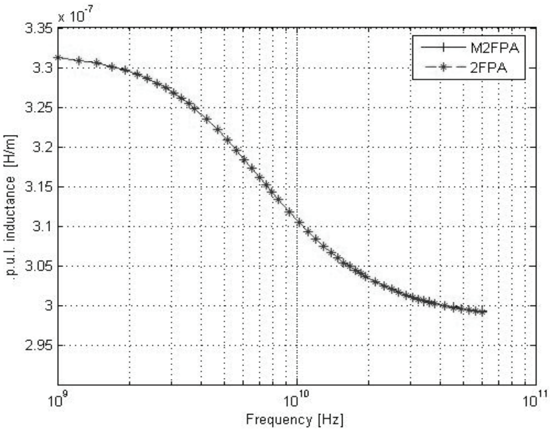

Fig. 3. Comparison of p.u.l. L in new and old two fields problem approach

The p.u.l. parameters have been extracted first with the 2FPA and then with the modified method. Both methods have been implemented in Chamy tool developed in Matlab in the frame of the European Project Chameleon-RF. Fig. 3 and Fig. 4 show the comparison of the p.u.l. L and p.u.l. R extracted from 2FPA and those extracted from M2FPA simulations. As it can be seen the difference between these approaches is almost neglectable, which means that new M2FPA has almost the same accuracy as 2FPA. At the same time M2FPA is faster than 2FPA, due to using analytical formulas, instead of EQS simulations.

Fig. 5 depicts comparison of propagation quantities using Full-wave 3D, EDA commercial software and new M2FPA method.

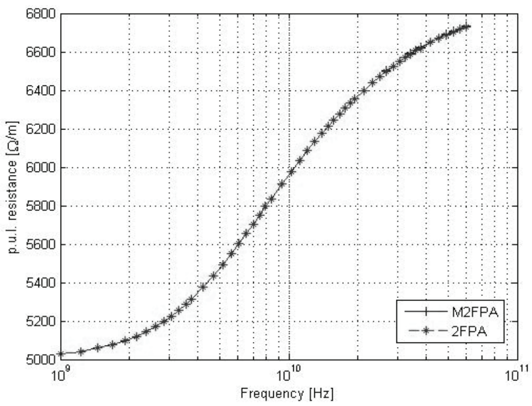

Fig. 4. Comparison of p.u.l. R in new and old two fields problem approach

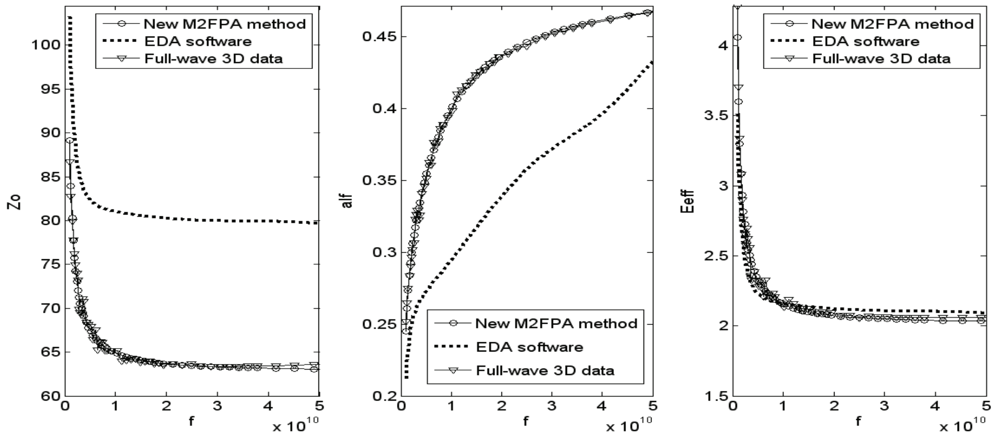

Fig. 5. Comparison of Zo, attenuation alf, Eeff using 3D, EDA commercial software and new M2FPA, where f is frequency

6. CONCLUSIONS

In this paper is presented effective method to extract p.u.l. RLCG and propagation quantities of MS elements built-in PIC devices. The M2FPA method, based on new analytical formulas is the paper novelty. New solutions were compared with commercial EDA and Full-wave 3D method. On this basis, it can be concluded that M2FPA is giving valid, robust and accurate results.

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