Methods of the analysis of microwave circuits with the superdimension scattering matrices

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The main method of analysis of the microwave circuits is evaluation of their characteristics through the parameters of elements of circuits. The procedure of calculation consists in solving of a system of linear equations (SLE), into which the appropriate coupling conditions are substituted.

With solving the SLE in the matrix form it is necessary to operate with matrices, the order of which is commensurable with a number of the connected ports (inputs).

As the superdimension matrices we understand the matrices, whose dimensions are such, that the technical performances of PC don't allow to operate by them.

One of the effective ways to solve this problem is usage of the cyclic algorithms (CA).

CA consist of two main procedures – successive unification of the elements into the desirable circuit and estimation of the circuit parameters for the defined quantity of the cycles from the recurrent formulas.

The consecutive unification of the elements into the circuit can be executed by pairing unification of the element ports (inputs), unification of several ports (inputs) pairs as well as two-step unification of the ports (inputs) pair.

Let consider the two-step CA.

The algorithm is characterized by the fact, that unification of the ports pair is realized in two steps. If the ports k, l are united, the coupling condition $a_l = b_k$ is substituted into the disconnected SLE, and by the second step $a_k = b_l$, where a_k, a_l, b_k, b_l – the incident and reflected waves, respectively.

The relations for calculation are

$$S_{r,s}^{2i+1} = S_{r,s}^{2i} + \frac{S_{r,l}^{2i} S_{k,s}^{2i}}{1 - S_{k,l}^{2i}}, \qquad (1)$$

$$r = 1,2,\ldots,l\ ; \quad r \neq k,$$

$$s = 1,2,\ldots,k\ ;$$

$$k = p + 2(t - i) - 1$$

$$l = p + 2(t - i)$$

$$i = 0,1,2,\ldots,t - 1\ ,$$

with substituting $a_l = b_k$

$$S_{r,s}^{2(i+1)} = S_{r,s}^{2i+1} + \frac{S_{r,l}^{2i+1} S_{l,s}^{2i+1}}{1 - S_{l,k}^{2i+1}}, \qquad (2)$$

$$r, s \in 1,2,\ldots,k - 1\ ,$$

with substituting $a_k = b_l$.

The computation from (1), (2) is drived on the "*i*"-cycle : first, by formula (1) - for the first step, then by formula (2) - the second step; after that – the transfer to κ_i + 1 - cycle.

Expressions (1), (2) permit to calculate the circuit parameters relatively the external ports (inputs) in *t* – cycles. For the last cycle, $i = t-1$, and the factors $S_{r,s}^{2t}$ ($r, s = 1,2,\ldots, p$) – are the required parameters.

Lately, the necessity in study of the electromagnetic processes, taking place inside the circuit, has arisen. Therefore, it is represented as expedient to add the above-described method by the relations, allowing to investigate such processes.

The magnitudes of the *k* and *l* – numbers are the function of a number of *i*-cycle

$$
\begin{aligned}
k &= k(i), \\
l &= l(i).
\end{aligned}
\qquad (3)
$$

Let all t-1 cycles are made, and all intermediate results, during the successive cancellation of a_l and a_k, are stored. Then, waves in the connected ports (inputs) are determined as follows :

$$
a_{p+1} = \frac{1}{1 - S_{p+2,\; p+1}^{2t-1}} \left[S_{p+2,\; s}^{2t-1} \right] \begin{bmatrix} a_1 \\ \vdots \\ a_p \end{bmatrix},
$$

$S = 1, \ldots, p;$

$$
a_{p+2} = \frac{1}{1 - S_{p+1,\; p+2}^{2t-2}} \left[S_{p+1,\; s}^{2t-2} \right] \begin{bmatrix} a_1 \\ \vdots \\ a_p \end{bmatrix} + \frac{S_{p+1,p+1}^{2t-2}}{1 - S_{p+1,p+2}^{2t-1}} a_{p+1},
$$

$S = 1, \ldots, p;$

$$
a_{k(i)} = \frac{1}{1 - S_{l(i),k(i)}^{2i+1}} \left[S_{l(i),\; s}^{2t+1} \right] \begin{bmatrix} a_1 \\ \vdots \\ a_{k(i)-1} \end{bmatrix},
$$

$$
a_{l(i)} = \frac{1}{1 - S_{k(i),l(i)}^{2i}} \left[S_{k(i),\; s}^{2t} \right] \begin{bmatrix} a_1 \\ \vdots \\ a_{k(i)-1} \end{bmatrix} + \frac{S_{k(i),k(i)}^{2i}}{1 - S_{k(i),l(i)}^{2i}} a_{k(i)},
$$

$S \in 1, \ldots, 2, \ldots, k(i) - 1;$

$$a_{k(0)} = \frac{1}{1 - S^{1}_{l(0),k(0)}} \left[S^{1}_{l(0),\,s} \right] \begin{bmatrix} a_1 \\ \vdots \\ a_{k(0)-1} \end{bmatrix},$$

$$a_{l(0)} = \frac{1}{1 - S^{0}_{k(0),l(0)}} \left[S^{0}_{k(0),\,s} \right] \begin{bmatrix} a_1 \\ \vdots \\ a_{k(0)-1} \end{bmatrix} + \frac{S^{0}_{k(0),k(0)}}{1 - S^{0}_{k(0),l(0)}} a_{k(0)}, \tag{4}$$

$S \in 1,\ldots,2,\ldots,k(0)-1.$

The solution of the equations system (4) is obvious. The first equation is substituted into the second one, the result into the third, etc.; and the *S*- factors were calculated earlier from the formulas (1), (2). Notice, that in the expressions (1), (2) cancellation of a_l and a_k is reasonably started from "an inconvenient" equations in order to avoid an appearance in the denominators of formulas (1), (2), – the S_{kk}- or S_{ll}- factors; (in this case, the denominator is written without 1); those in the frequency range can accept values close to zero and result in considerable errors.

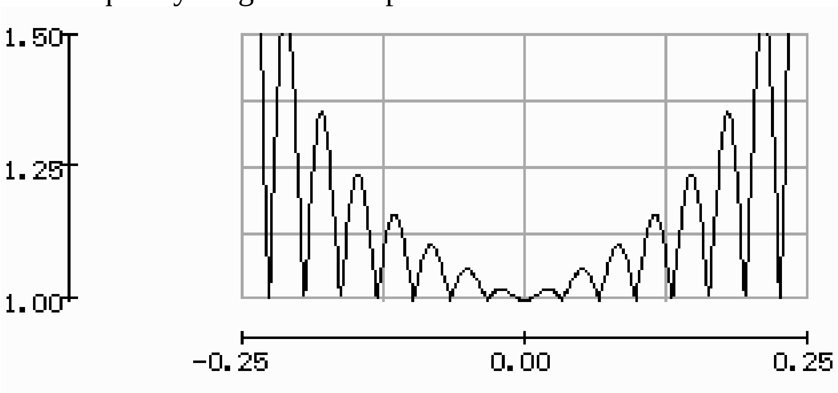

Fig. 1. The frequency characteristic for КСВН-port of the divider into 2^{20} channels (axis of ordinates – is КСВН; axis of abscissae – as relative frequency readjustment).

For a illustration of the CA-efficiency, Fig. 1 shows the frequency characteristic for WSWR-port of the divider into 2^{20} channels. The computation is conducted for 1-2 minutes at several hundreds of the frequency points with Pentium- 166 type PC.