Simulation of transition matrix and strip lines of microwave switch

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Abstract. The method of microwave switch elements simulation in Microwave Office CAD was offered. The calculation method of the ring power divider was developed. The simulation of transmission strip lines, switch matrix and printed circuit board was carried out. Frequency dependences of standing-wave ratio of the input and output signals, the signal attenuation from input to output and between different pins were received. The topological layout of switch elements was given. The comparison of the experimental data with the results of simulation was carried out.

1. Introduction
The signal switch is one of the main nodes of the microwave path. Most switches have low operation speed, large real losses in open channels, limited frequency range, weak channel isolation [1-3].

![Block diagram of the 4x4 microwave switch: PD - power divider, HFS - high frequency switch, A - amplifier.](image)

Figure 1. Block diagram of the 4x4 microwave switch: PD - power divider, HFS - high frequency switch, A - amplifier.
However improved switches are needed to create new generation small-sized complexes for protecting aircrafts of different purposes with electronic intelligence and suppression functions [4-9] with modular technology [10].

It was offered switch that is based on switching chips SW-438TR. The switch is based on 4x4 switch matrix consisting of strip lines, ring power dividers and switching chips. It provides switching of 4 aerials signals from four inputs to any of four outputs. Programming of switching channels is carried out in advance and done via chips EPM7128AET1100-7. The block diagram of the switching device based on the 4×4 transition matrix is shown in figure 1.

Purpose of work is simulation of microwave switch elements.

2. Development of the calculation method of ring power divider

Circuit of power divider is shown in figure 2.

![Figure 2. Circuit of ring power divider.](image)

The elements of the transmission non-normalized A-matrix of such a divider can be determined by multiplying the classical matrices of elementary quadripoles that make it up:

\[
\begin{bmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{bmatrix}
= \begin{bmatrix}
\cos \beta_w \ldots i \rho_1 \sin \beta_w \\
i \sin \beta_w \ldots \cos \beta_w
\end{bmatrix}
\begin{bmatrix}
1 \ldots 0 \\
-1 \ldots 1
\end{bmatrix}
\begin{bmatrix}
\cos \beta_w \ldots i \rho_1 \sin \beta_w \\
i \sin \beta_w \ldots \cos \beta_w
\end{bmatrix},
\]

where \( \beta_w = 2\pi f / \lambda_w \) - frequency parameter, \( \lambda_w = C / f_w \) - wavelength, \( C \) - speed of light, \( f_w \) - frequency in the passband.

After multiplying the matrices of elementary quadripoles, we get the following expressions for the elements of the classical transmission matrix of a single quadripole:

\[
\begin{align*}
a_{11} &= a_{22} = (2 + \rho_1 / \rho_2) \cos^2 \beta_w - 1; \\
a_{12} &= i (2 \rho_1 / \rho_2 \cos \beta_w \sin \beta_w; \\
a_{21} &= i \left( \frac{2 \cos \beta_w \sin \beta_w}{\rho_2 \sin \beta_w} \right)
\end{align*}
\]

The function of operating attenuation \( L_p^n \) was presented:

\[
L_p^n (f_w) = 1 + P(f_w) \cdot \Psi (n, a_{11} (f_w)),
\]

The final expression for the function \( L_p (f_w) \) of a single quadripole has the form:
\[ L_p(f_w) = \left( 2 + \frac{\rho_1}{\rho_2} \right) \cos^2 \beta_w - 1 \right)^2 + \left( \frac{\rho_1}{2 \rho_2} + \frac{1}{\rho_1} \right) \cos \beta_w \sin \beta_w - \frac{\cos^3 \beta_w}{2 \rho_2 \sin \beta_w} \right)^2, \quad (4) \]

where \( \rho_1 = \rho_1 / \rho_0 \), \( \rho_2 = \rho_2 / \rho_0 \) - the normalized wave impedance, \( \rho_0 \) - wave impedance of the transmission lines.

The function \( L_p \), as well as the function \( P(f_w) \) depends on the normalized wave impedances \( \rho_1 \), \( \rho_2 \) and the frequency parameter \( \beta_w \). The function \( P(f_w) \) has an uncertainty of type 0/0. After its elimination, it takes the following form:

\[ P(f_w) = \frac{b_1 \cos^4 \beta_w + b_3 \cos^2 \beta_w + b_5}{b_4 \cos^4 \beta_w + b_5 \cos^2 \beta_w + b_6}, \quad (5) \]

where:

\[
\begin{align*}
  b_1 &= a_2^2 + a_3^2 - a_1^2 - 2a_4a_3, \\
  b_2 &= a_1^2 - 2a_2^2 + 2a_1 + 2a_4a_3, \\
  b_3 &= a_2^2 - 2a_1, \\
  b_4 &= a_1^2, \\
  b_5 &= -a_1^2 - 2a_4, \\
  b_6 &= 2a_4, \\
  a_1 &= 2 + \frac{\rho_1}{\rho_2}, \\
  a_2 &= \frac{\rho_1}{\rho_2} \left( \frac{2}{\rho_2} + 1 / \rho_1 \right), \\
  a_3 &= -1 / 2 \rho_2. 
\end{align*}
\]

When \( \rho_1 = \rho_2 \), coefficients \( b_1, \ldots, b_6 \) can be written in the following form:

\[
\begin{align*}
  b_1 &= 9 \left( \rho_1^2 - 1 \right)^2, \\
  b_2 &= -18 \rho_1^4 + 30 \rho_1^2 - 12, \\
  b_3 &= \left( 3 \rho_1^2 - 2 \right)^2, \\
  b_4 &= 36 \rho_1^2, \\
  b_5 &= -60 \rho_1^2, \\
  b_6 &= 24 \rho_1^2.
\end{align*}
\]

3. Simulation of the transmission strip lines

Simulation and calculations were made in the Microwave Office design environment. Microwave Office is a fully functional software package for the analysis of high-frequency devices, which allows you to automate the process of their design. It allows you to carry out design from technical specification to production without leaving the development environment.

One of the following methods could be used in the simulation: linear modeling, advanced harmonic balance, Volterra series, or 3-dimensional electromagnetic modeling (EM Sight). The results were displayed in various graphical forms and in a table.
The geometry parameters of conductors and wave parameters of RF EHF lines formed by printed wire were modeled after taking into account the dielectric parameters of the substrates and losses in conductors and in dielectrics. The signal delays in the lines, their attenuation along with the dispersion pulse stretching were simulated.

The purpose of the simulation was to verify the calculations and, if necessary, adjust the width and length of strip conductors, as well as the distance between them.

Initial data for simulation: RT/duroid 6002 substrate with dielectric constant 2.94, thickness 0.504 mm, 50-Ohm microstrip line (width 0.35 mm), frequency range 0.7 to 4.0 GHz. The length of transmission line is ¼ λ taking into account effective ε.

Calculation of transmission line parameters was carried out in the txline program, which is an application of the MWOffice program. Initially, the first transmission line to the resistor R1 100 Ohms was calculated.

Figure 3 shows the model of the first ring of transmission line with impedance 50 Ohm. In order to optimize the occupied space on the printed circuit board the line had the shape of a coil.

![Figure 3. Model of the first ring of the 50 Ohm transmission line.](image1)

Figure 4 shows the scheme of simulation of the transmission line.

![Figure 4. Scheme of simulation of the transmission line.](image2)
Figure 4 shows the scheme of simulation of the transmission ring required to plot the VSWR and the shape of the transmission line. Then the second transmission line was modeled. Based on the power divider circuit, 2 parallel identical transmission lines are required. The model of the second ring of the transmission line (50 Ohms) is shown in figure 5.

![Figure 5. Model of the second ring of the transmission line (50 Ohms).](image)

By combining both lines we get a full view of the four channel power divider with transmission microstrip lines 35 micrometers thick. Figure 6 shows the strip lines of the four-channel power divider.

![Figure 6. Transmission microstrip line of the four-channel power divider PD4.](image)

Figures 7-10 present graphs of the standing-wave ratio of the input and output signals and graphs of the signal attenuation from input to output and between the outputs.

![Figure 7. Graph of standing-wave ratio of the input signal.](image)

Based on the foregoing graphs, it can be concluded that the experimental selection of the thickness of 0.35 mm conductive lines was made correctly. The graphs show that in the frequency range of 0.7 – 4.0 GHz, the value of the standing wave ratio of the input and output signal does not exceed the specified in the technical specification, namely 1.3 at a frequency of 2.7 GHz.
4. Conclusion
Simulation and studies of power dividers and strip lines have shown that microwave switch according to the proposed topology must have the following characteristics:

- operating frequency range: 0.7 ... 4Hz;
- current consumption: less than 0.4 A;
- channel switching time: less than 100ns;
- direct losses in open channels: less than 2 dB;
- loss of locking in closed channels: less than 50dB.
5. References

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