ULTRA-WIDEBAND DIViders-COMBiners OF PICO- AND NANOSECOND SIGNALS

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Abstract

Specific features of the operation of ultra-wideband power dividers based on coupled lines under the influence of picosecond impulses are considered. The divider consists of seven links: a single-stage splitter on a three-wire strip line and six cascades of quarter-wave transformers on two-wire coupled lines.

The possibility of using dividers as combiners of pulse signals fed to the outputs of the dividers is shown. It is shown that the decoupling of the output ports and the transmission factor between the input port and the output ports, measured in the pulsed mode and under the influence of the chirp signal, are significantly different. Conditions for increasing the decoupling of the divider outputs in the pulsed mode are given. The divider is made on a ceramic substrate with an area of 5.5×1.2 mm and provides decoupling in the frequency band from 10 GHz to 67 GHz not worse than 18 dB, and maximum return losses not worse than 12 dB at insertion loss from −3.5 to −4.4 dB in frequency range.

Keywords: A super-broadband divider, the combiner of impulses, picosecond and nanosecond impulses, divider model as a six-pole, ABCD-matrix of divider/combiner, boundary conditions for the incident and the reflected waves in microwave devices

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I. Introduction

Wilkinson's broadband power dividers are often used in a wide variety of microwave systems. Dividers with filtering properties are described in articles. Fast design method of wideband tapered Wilkinson divider was implemented in. An overview of several types of dividers/combiners discussed in the master thesis. In these and other works the authors considered the frequency characteristics of the dividers.

In paper were presented results of research Wilkinson power combiner when it was tested with a pulse width modulated radio-frequency signal.

The task of developing ultra-wideband devices for dividing and combining pulse signals of pico- and nanosecond ranges became relevant in connection with the development of pulse measurement and control methods. For example, separation of short pulses into two channels is required when controlling electro-optical cells of modulators. These dividers are required to a high decoupling of the outputs and a minimum reflection of the pulses from the input and outputs.

An ultra-wide-band power divider with an upper working frequency of 67 GHz, which is a mutual device and, therefore, can be used as a signal combiner, was described and studied in. The calculated and experimental frequency characteristics of an ultra-wide-band power divider are presented in.

The purpose of the paper is to investigate dividers under the influence of pulse signals to identify features, ensuring the decoupling of the divider outputs and the reflection from the input and outputs. We also give the results of an experimental study of the pulse combining when pulses are fed to the output ports of the divider.

II. Materials and Methods

The design of the ultra-wideband divider 1:2 is described in; its appearance without a cover is shown in Fig. 1. The divider is made on a ceramic substrate with an area of 5.5×1.2 mm$^2$ and provides decoupling in the frequency band from 10 GHz to 67 GHz not worse than 18 dB and maximum return losses not worse than 12 dB at uneven separation from –3, 5 to –4.4 dB.

The schematic diagram of the divider-combiner (D/C) with external loads $Z_1$...$Z_3$ and generators $E_1$...$E_3$ is shown in Fig. 2. The D/C consists of seven links: a single-stage splitter on a three-wire strip line and six cascades of quarter-wave transformers ($\lambda/4$ transformers) on two-wire coupled lines.
Fig. 1: The ultra-wideband divider 1:2 with upper frequency of 67 GHz

Film resistors $R_1...R_{10}$ are included between the segments of strip lines of the splitter and quarter-wave transformers.

Fig. 2: The schematic diagram of the ultra-wideband divider 1:2 with external loads and generators

An equivalent circuit has been developed to analyze the operation of the divider in the frequency domain (Fig. 3). The circuit includes elements supplementing the principal diagram of the device in the form of a three-pole network to the scheme of a six-pole network. This allows determining the transmission matrix of the equivalent circuit $\mathbf{a}_e$ as a product of transmission matrices $\mathbf{a}_i$ of seven D/C links.

Fig. 3: The equivalent circuit of the ultra-wideband divider-combiner as a six-pole network

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The boundary conditions at the inputs of the divider (Fig. 3) are defined as follows:

\[
U_1 = E_1 - Z_1 I_1, \\
U_2 = E_2 - Z_2 I_2,
\]

where \(U_{1,2}, I_{1,2}, E_{1,2}\) are stress and current vectors, open circuit voltage, and diagonal-load matrices \(Z_{1,2}\) on the left (index 1) and on the right (index 2).

The transmission matrix \(a_\Sigma\) of the six-pole network, written in a block form, represents an ABCD-matrix. From here we shall write down the equation for calculating input voltages and currents \(U_1, I_1\) and output voltages and currents \(U_2, I_2\):

\[
\begin{bmatrix}
U_1 \\
I_1
\end{bmatrix}
= 
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}
\cdot
\begin{bmatrix}
U_2 \\
I_2
\end{bmatrix},
\]

(2)

Where \(A, B, C, D\) are matrixes-matrix cell \(a_\Sigma\).

Solving jointly (1) and (2), we find the total currents on the right:

\[
I_2 = \frac{E_1 - (A + Z_1 C)E_2}{A\cdot Z_2 + Z_1 C\cdot Z_2 + B + Z_1 D}.
\]

(3)

Then from (1) and (2) we find \(U_{1,2}, I_1\).

Using boundary conditions (1), we define decreasing \(U_p(t)\) and reflected \(U_o(t)\) voltage at the inputs of the divider:

\[
U_p(t) = E(t)/2, \\
U_o(t) = U(t) - E(t)/2.
\]

(4)

Knowing total voltages, open circuit voltage values, and values of load resistances, it is possible to calculate wave parameters – transmission factors from the input to the output ports, the decoupling of the output ports of the D/C and other parameters depending on the frequency. The results of the calculation and experimental measurements of the separating factor and decoupling of a six-cascade divider are shown in Fig. 4.
Then we define the input action in the form of a pulse $U_1(t)$ and with the help of the Fourier transformation we make the transition from the frequency to the time characteristics and get the response of the device to the signal $U_1(t)$.

The pulse with duration of 40 ps, obtained by the GZ1107DN shaper as part of the experimental setup, was taken as $U_1(t)$.

**III. Experimental Results**

The installation shown in Fig. 5 was used to measure pulse characteristics of the device in the picosecond range. The installation consists of a pulse generator GZ1105DLP2, a picosecond pulse shaper GZ1117DN, a DSA-8300 analyzer, an attenuator of 40 dB, connected by coaxial cables. The generator launched the shaper, which at a frequency of 200 kHz formed test pulses $U_{10}$ of negative polarity with an amplitude of 30 V and a duration of 40 ps at a level of 0.5. Through the attenuator of 40 dB and the coaxial cable, the pulse $U_{10}$, attenuated to the level $U_1$, was applied to the input 1 of the divider when determining the transmission factor from the input 1 to the outputs 2 and 3 of the divider (as shown in Fig. 2). When determining the decoupling, pulse $U_1$ is fed to the output 2 (the output 3 is the output port and the input is loaded at a nominal resistance of 50 ohms. In the combiner mode, the pulses were applied to ports 2 and 3, and port 1 became the output.

Measurements and recordings of the input pulse $U_1$ and pulses $U_{21}$ and $U_{31}$ that passed through the pulse divider were performed using a DSA-8300 analyzer. All ports of the measured divider-combiner are loaded to loads of 50 Ohm.
Fig. 5: The installation for measuring pulse characteristics

The results of the device measurements in the divider mode are shown in Fig. 6. When pulse $U_1$ with amplitude of $-0.41$ V is applied to the input 1, the signals $U_{21}$ and $U_{31}$ (not shown) with amplitude of $-0.26$ V and a delay of 232 ps appear at the inputs 2 and 3. When pulse $U_1$ was applied to the input 2, signal $U_{32}$ with amplitude of $-0.11$ V and a delay of 277 ps with respect to $U_1$ was observed at the output 3.

Fig. 6: The experimental pulse characteristics of the ultra-wideband divider: $U_1$ is the signal at the input 1; $U_{21}$ is the signal at the output 2; $U_{32}$ is the signal at the output 3 when signal $U_1$ is applied to the input 2 (input 1 is loaded for a matched load of 50 ohms)

From the comparison of the dependencies on the time $U_1$, $U_{32}$ (Fig. 6), we see that the supply of the initial pulse $U_1$ to port 2 in the adjacent port 3 of the divider output leads to a low level of decoupling $S_{32}$ between the output ports. If $S_{32}$ is estimated from the maximum values of the voltages $U_{21}$ and $U_{32}$, then we get $S_{32} = -4.1$ dB. This value
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roughly corresponds to the decoupling level, given in for the frequency range up to 4 GHz. Consequently, we conclude that low-frequency harmonics of the spectrum of the initial pulse $U_{1}$ pass from port 2 to port 3. This is also evidenced by the form of the transmitted signal $U_{32}$. To increase the decoupling of the outputs of the investigated divider, it is expedient to use pulses in the spectrum of which the energy of the pulse is concentrated above 8 GHz. These can be, for example, bipolar pulses of the type of differentiated Gauss pulses.

The average length of the $l_{av}$ section of such a divider can be estimated from the formula:

$$l_{av} = \frac{3}{160 f_{\text{min}} \sqrt{\varepsilon_{\text{eff}}}} \text{, m}$$  (5)

Where $f_{\text{min}}$(GHz) is the lower frequency of the pass b and at the decoupling level of $-20$ dB, $\varepsilon_{\text{eff}}$ is the average effective permeability of the substrate.

III. Discussion

The indicated method of increasing the decoupling between the outputs of the divider is implemented by simulating a bipolar pulse applied to the input 1 (Fig. 8). The frequency of the harmonic with the largest amplitude of the synthesized pulse is 14 GHz, the width of the spectrum at 0.5 is 22.5 GHz. When pulse $U_{1}$ with an amplitude of $\pm 0.27$ V is applied to the input 1, signals $U_{21}$ and $U_{31}$ (identical in the shape with $U_{1}$) with an amplitude of $\pm 0.15$ V and a delay of 217 ps appear at the outputs 2 and 3. When pulse $U_{1}$ was applied to the input 2, the signal $U_{32}$ with amplitude of $\pm 0.019$ V and a delay of 247 ps with respect to $U_{1}$ was observed at the output 3.

Fig. 7: The synthesized pulse characteristics of a multi-cascade divider: $U_{1}$ is the signal at the input 1; $U_{21}$ is the signal at the output 2; $U_{31}$ is signal at the output 3 when the signal $U_{1}$ is applied to the input 2 (input 1 is loaded for a matched load of 50 ohms)

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This means that the ratio of the maximum of the "parasitic" signal, which came from one output to another output, has decreased from 0.268 V (Fig. 6) to 0.07 V (Fig. 8), i.e. the decoupling has improved to 15.8 dB.

The summation of pulses was simulated by feeding synchronous pulsed signals from the generators $E_2$, $E_3$ (Fig. 2) to the ports 2 and 3. In Fig. 8 these are the voltages $U_2$ and $U_3$. The resultant pulse $U_1$ with some attenuation was obtained at the input of the combiner 1 (Fig. 7).

![Fig. 8](image)

**Fig. 8:** The summation of synchronous pulses by the device according to the scheme in Fig. 2: $U_2$ and $U_3$ are pulses applied to outputs 2 and 3; $U_1$ is the pulse at the input 1.

![Fig. 9](image)

**Fig. 9:** shows the summation at the input 1 of the delayed relative to each other pulses $U_2$ and $U_3$, fed to the outputs 2 and 3, respectively.

![Fig. 9](image)

**Fig. 9:** The summation of non-synchronous pulses by the device according to the scheme in Fig. 2: $U_2$ and $U_3$ are pulses applied to outputs 2 and 3; $U_1$ is the pulse at the input 1.

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IV. Recommendations

Using as the tiny combiner of picosecond pulse signals of super broadband dividers it is necessary to consider effect of decrease in an outcome in low-frequency area of the used dividers. It is useful to estimate at design (5) average length of section on the lower frequency of bandwidth on outcome level –20 dB.

V. Conclusion

It has been shown that it is possible to use pico-second pulse signals as a combiner for ultra-wideband dividers, but they are subject to increased requirements for decoupling. The presented model of the device allows investigating the passage of any pulse signals, for example, of the Gaussian pulsing type, to calculate both the frequency and pulse characteristics of the device, such as the coefficients of division, decoupling, and returning loss.

The experimental results of the device investigation with the help of pulses with duration of 40 ps have been presented. It has been shown that the decoupling, transmission coefficient and return losses between the input ports output ports, measured in the pulsed mode and the frequency method are significantly different. Therefore, when designing dividers-combiners, one must take into account the effect of reducing the decoupling in the low-frequency region of the dividers used. An estimate for determining the average length of a section at a given lower frequency of the bandwidth by the level of the decoupling of 20 dB has been given.

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