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SINGLE PARALLEL STUBS AS BROADBAND MICROWAVE PHASE SHIFTERS

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Abstract

Structures and characteristics of wideband small-size phase shifters made with the use of single parallel stubs are presented in this paper. The stubs can be short-circuited or open-circuited on termination. Such devices are well known, but are primarily used as components of filters or matching circuits. The novelty, then, comes from the establishment of simple, but helpful formulae, which enable to describe the insertion phase shift and differential phase shift of a line with short and open stubs connected in parallel. These equations can be very useful for designing complex microwave multi-ports. The results of simulations and measurements of the devices, which were designed and made, are shown herein. It was also proved that the presented devices have several usable operating frequency sub-bands, and that the differential phase shift values in the higher sub-bands are greater than those in the lower operating frequency ranges. Thanks to this, the described phase shifters can be used in more than one frequency sub-band. It was stated that in the conditions under analysis, larger phase shifts can be achieved using open-circuited stubs rather than short-circuited stubs. However, the phase shifters with shorted parallel stubs can operate in a wider frequency band.

Keywords: phase shift, differential phase shift, microwave phase shifter, parallel stub, instantaneous frequency measurement, IFM.

1. Introduction

Wideband phase shifters are necessary components of many complex microwave devices used in radar-based techniques, and in radio-electronic reconnaissance. The microwave phase shifters are two-port devices, which change the phase of the signal fed into their input port. The simplest phase shifter is a transmission line. The phase shift inserted by a microwave transmission line is determined, among other things, by its physical length, as well as the frequency and wavelength of the signal propagating within it. This type of solution can be applied in narrow-band microwave assemblies working with monochromatic signals, or signals which are called complex, but are limited to a relatively narrow waveband. Any phase shifters used in broadband systems should also be broadband capable. This implies, among other things, that the modulus of their transmittances should have possibly great values, and versus frequency they should be constant or, at the very least, change within acceptable limits over the whole required frequency range. The argument (insertion phase shift) Φ_M of transmittance S_M of a broadband phase shifter, as in other microwave devices, can be described, for example, with function (1) including the component Φ_f dependent on the frequency (this dependency is most often linear), as well as the component Φ_{PhS}, which is typically independent of or little dependent on frequency.

$$\Phi_M(f) = \Phi_f(f) + \Phi_{\mathrm{PhS}} . \tag{1}$$

If a microwave signal is brought to the input port of a phase shifter and simultaneously to the microwave reference track (Fig. 1) which has the argument (insertion phase shift) Φ_{Ref} of this track transmittance S_{Ref}, then the phases of the signals in their output ports differ from each other by $\Delta\Phi_{MR}$. The expression (2) describes this difference.

$$\Delta\Phi_{MR}(f) = \Phi_M(f) - \Phi_{\mathrm{Ref}}(f). \tag{2}$$

In turn, when:

$$\Phi_{Ref}(f) = \Phi_f(f), \tag{3}$$

then, according to (1) and (3), it is possible to write down:

$$\Delta\Phi_{MR}(f) = const = \Phi_{\mathrm{PhS}} . \tag{4}$$

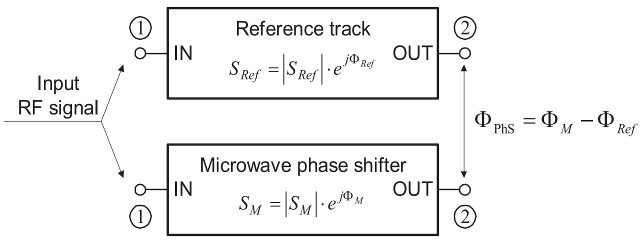

Fig. 1. A symbolic composition of a microwave phase shifter and a reference track to demonstrate *differential phase shift* Φ_{PhS}.

Therefore, in such conditions, the phases of the signals at the output port (number 2) of a microwave phase shifter, as well as at the output port of a reference track may be functions of frequency, but their difference $\Delta\Phi_{MR}$ will be independent of frequency, and be equal to Φ_{PhS}. For this reason, the component Φ_{PhS} is called a *differential phase shift* [1, 2], which means the value of the phase of the signal from the phase shifter output port related to the phase of the signal from the reference track output port, which phase characteristic fulfils equality (3). This effect is used in the design, for example, of broadband microwave multi-ports, to form directional characteristics of the polycell antenna systems. Examples of broadband phase shifters include, for instance, the circuits described in [3–6]. These circuits, called Schiffman's phase shifters, are based on coupled lines. Other designs, such as Wilds' phase shifters [7–10], consist of a combination of parallel stubs with shorted and open ends, and the main transmission line with the characteristic impedance smaller than the characteristic impedance of a microwave route, in which this phase shifter is connected in series. The Burns', Holden's, Tang's shifter [11, 12] is another interesting design, made up from two stubs shorted at the end, engaged to a microwave path in parallel in distance of $\lambda/4$ apart. All of these designs are very useful, but their dimensions can be too large for complex designs comprising thousands of channels. For these reasons, the author is interested in components,

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phase shifters among them, which occupy a very little area on a *printed circuit board* (PCB). In addition, it is necessary to emphasize that for many applications, differential phase shifts of microwave multi-ports' channels are more considerably valid than their insertion phase shifts. The analyses performed show that the differential phase shift, which is approximately constant over a wide frequency band, can be achieved using only a single parallel stub with a short or open end. These types of components, *i.e*. parallel stubs, are often used in so-called matching networks for impedance matching of microwave devices. The presented simple devices are very useful as the broadband phase shifters for various purposes, such as correction of transition (especially phase) characteristics of *instantaneous phase measurement* (IPhM) devices, the signal's *instantaneous frequency measurement* (IFM) devices [13] or measurement multiports [14].

2. Phase shifter with single parallel open-circuited stub

A scheme of the phase shifter with a single parallel open-circuited stub is presented in Fig. 2. In the centre of the transmission line (the so-called main line) with the characteristic impedance Z_0, physical length l_R and wavelength within it of λ_R for current frequency f, there is connected in parallel a transmission line (stub) with the characteristic impedance Z_{0R}, wavelength within it of λ_{SR}, and physical length l_{SR}.

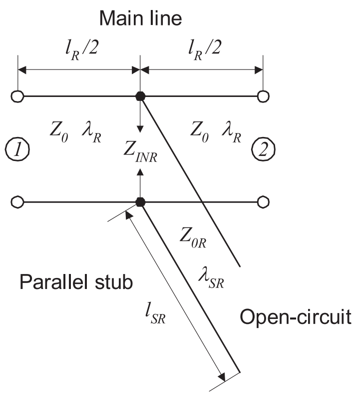

Fig. 2. A microwave phase shifter with a single parallel open-circuited stub.

The transmittance S_R of the phase shifter shown in Fig. 2, is described by a complex volume given in the form [2, 15]:

$$S_R = S_{21} = \frac{2 \cdot Z_{INR}}{2 \cdot Z_{INR} + Z_0} \cdot \exp\left(-j \cdot \frac{2 \cdot \pi}{\lambda_R} \cdot l_R\right). \tag{5}$$

The characteristic impedance Z_0 is real in the frequency band of interest. For lossfree openstub the input impedance Z_{INR} is defined as:

$$Z_{INR} = -j \cdot Z_{0R} \cdot \cot\left(\frac{2 \cdot \pi}{\lambda_{SR}} \cdot l_{SR}\right). \tag{6}$$

Because the wavelength λ_{SR} is dependent on frequency, in accordance with (6) the value of input impedance Z_{INR} is also an imaginary number being a function of frequency f. Therefore, the argument (insertion phase shift) Φ_R of transmittance S_R of the circuit presented in Fig. 2 is determined not only by the parameters of main line, but also by the parameters of the stub, as it is expressed by the following relationship (7):

$$\Phi_R = \arctan\left[-\frac{Z_0}{2 \cdot Z_{0R}} \cdot \tan\left(\frac{\pi \cdot f}{2 \cdot f_{0R}}\right)\right] - \frac{2 \cdot \pi}{\lambda_R} \cdot l_R\,, \tag{7}$$

where: f_{0R} – the frequency of the signal, at which the electric length of open stub amounts to $\pi/2$ radians.

The insertion phase shift Φ_R can be approximated with a linear function Φ_{TR} of frequency f, expressed as follows:

$$\Phi_{TR} = -\frac{\pi \cdot Z_0}{4 \cdot Z_{0R}} \cdot \frac{f}{f_{0R}} + 2 \cdot n_{PR} \cdot \frac{\pi \cdot Z_0}{4 \cdot Z_{0R}} - \frac{2 \cdot \pi}{\lambda_R} \cdot l_R\,, \tag{8}$$

where: n_{PR} – the number of the operating frequency sub-band ($n_{PR} = 0, 1, 2, \ldots$).

When the reference track is a non-dispersive transmission line providing an insertion phase shift Φ_{RefR} defined as:

$$\Phi_{RefR} = -\frac{\pi \cdot Z_0}{4 \cdot Z_{0R}} \cdot \frac{f}{f_{0R}} - \frac{2 \cdot \pi}{\lambda_R} \cdot l_R\,, \tag{9}$$

then a differential phase shift Φ_{PhSR} of the phase shifter with a single parallel open stub, for discrete values of frequency f_{nR} appointed by the relationship:

$$f_{nR} = 2 \cdot n_{PR} \cdot f_{0R}\,, \tag{10}$$

according to (2) and (4) is described by formula (11).

$$\Phi_{\mathrm{PhSR}}\,(f = f_{nR}) = \Phi_{TR} - \Phi_{RefR} = n_{PR} \cdot \frac{\pi}{2} \cdot \frac{Z_0}{Z_{0R}}\,. \tag{11}$$

For frequencies different from f_{nR}, the phase shift Φ_{PhSR} will change, but more slowly than the insertion phase shift of the main transmission line with length l_R (Fig. 2) without a stub connected in parallel. The coefficient n_{PR} is the number of an operation sub-band of the phase shifter shown in Fig. 2, and can be a non-negative integer value. Frequencies f_{nR} are sub-band centres with numbers n_{PR}. According to relation (11), for the same parameter values of the reference track, various values of differential phase shifts can be obtained in sequential sub-bands of operation. These sequential values of differential phase shifts are integers of the multiplicity of the differential phase shift found in a sub-band with number $n_{PR} = 1$.

3. Phase shifter with single parallel short-circuited stub

A structure of the phase shifter with a single parallel short-circuited stub is presented in Fig. 3. Similarly to the circuit shown in Fig. 2, the stub connected in parallel can be found in the midpoint of the main transmission line, but in this case, the design has an ideal short-circuit at its end.

The parameters characterizing this main transmission line are as follows: characteristic impedance Z_0, wavelength inside it of λ_Z, and physical length of l_Z. For requirements of analysis of phase shifter parameters, the stub is described by: characteristic impedance Z_{0Z}, wavelength within it of λ_{SZ}, and physical length l_{SZ}. The equations given below are very similar to the

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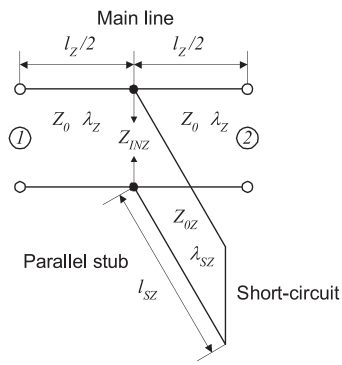

Fig. 3. A microwave phase shifter with a single parallel short-circuited stub.

equations presented in Section 2, but they are different from them because of the stub being short-circuited at its end.

The transmittance S_Z of the phase shifter presented in Fig. 3 is described by the relationship (12) [2, 15]:

$$S_Z = S_{21} = \frac{2 \cdot Z_{INZ}}{2 \cdot Z_{INZ} + Z_0} \cdot \exp\left(-j \cdot \frac{2 \cdot \pi}{\lambda_Z} \cdot l_Z\right). \tag{12}$$

The input impedance Z_{INZ} of the short-circuited stub is described by (13).

$$Z_{INZ} = j \cdot Z_{0Z} \cdot \tan\left(\frac{2 \cdot \pi}{\lambda_{SZ}} \cdot l_{SZ}\right). \tag{13}$$

The wavelength λ_{SZ} in relation (13) is a function of frequency f. In relation to this, the impedance Z_{INZ} is an imaginary number, which changes with frequency. As a result, the argument Φ_Z of transmittance S_Z of the phase shifter presented in Fig. 3 will be determined both by the parameters of the main line, see relation (12), and by the parameters of the stub, what arises from the relationship (14):

$$\Phi_Z = \arctan\left[\frac{Z_0}{2 \cdot Z_{0Z}} \cdot \cot\left(\frac{\pi \cdot f}{2 \cdot f_{0Z}}\right)\right] - \frac{2 \cdot \pi}{\lambda_Z} \cdot l_Z, \tag{14}$$

where: f_{0Z} – the frequency of the signal, at which the electric length of short-circuited stub amounts to $\pi/2$ radians.

The insertion phase shift (argument) Φ_Z can be approximated with a linear function Φ_{TZ} of frequency f defined as:

$$\Phi_{TZ} = -\frac{\pi \cdot Z_0}{4 \cdot Z_{0Z}} \cdot \frac{f}{f_{0Z}} + (2 \cdot n_Z + 1) \cdot \frac{\pi \cdot Z_0}{4 \cdot Z_{0Z}} - \frac{2 \cdot \pi}{\lambda_Z} \cdot l_Z, \tag{15}$$

where: n_{PZ} – the number of an operating frequency sub-band ($n_{PZ} = 0, 1, 2, \ldots$).

When the role of a reference track is performed by a non-dispersive transmission line entering the insertion phase shift Φ_{RefZ} expressed as follows:

$$\Phi_{RefZ} = -\frac{\pi \cdot Z_0}{4 \cdot Z_{0Z}} \cdot \frac{f}{f_{0Z}} - \frac{2 \cdot \pi}{\lambda_Z} \cdot l_Z, \tag{16}$$

then the differential phase shift Φ_{PhSZ} of the phase shifter with a single parallel stub shorted at the end, for a discrete frequency value of f_{nZ}, described by the relationship:

$$f_{nZ} = (2 \cdot n_{PZ} + 1) \cdot f_{0Z}\,, \tag{17}$$

is expressed by formula (18):

$$\Phi_{\mathrm{PhSZ}}\,(f = f_{nZ}) = \Phi_{TZ} - \Phi_{RefZ} = (2 \cdot n_{PZ} + 1) \cdot \frac{\pi}{4} \cdot \frac{Z_0}{Z_{0Z}}\,. \tag{18}$$

One should note that for frequencies f, which are different from f_{nZ}, the differential phase shift Φ_{PhSZ} will change, but considerably slower than the insertion phase shift introduced via the main transmission line with physical length l_Z (Fig. 3) without a shorted stub connected in parallel. The coefficient n_{PZ} is an integer number, which is greater than or equal to zero. Similarly to the equations presented in Section 2, the coefficient n_{PZ} is the number of an operating sub-band of the phase shifter, but in the case shown in Fig. 3 it means the phase shifter with a parallel stub shorted at the end. Frequencies f_{nZ} are the centres of the sub-bands with numbers n_{PZ}. The relationship (18) shows that for the same parameters of the reference track, subsequent operating sub-bands have different phase shift values. These values are integers, and odd multiplicities of phase shift value are brought in an operation sub-band with the number $n_{PZ} = 0$.

4. Results of simulations

The examples – results of simulations of the microwave phase shifters' parameters with parallel stubs are presented in Figs 4–7. The simulating models of phase shifters were examined in a frequency range from 500 MHz up to 6 GHz (for versions with an open-circuited stub) and up to 9 GHz (for versions with a short-circuited stub). Stub lengths were picked specifically so that the fundamental operating frequency sub-bands (numbers: $n_{PR} = 1$, $n_{PZ} = 0$) were near the region of the WiFi frequency band (2.3–2.5 GHz). TEM transmission lines with air dielectric and of physical length L_{Ref} were used as reference tracks for calculations of differential phase shifts Φ_{PhSR} and Φ_{PhSZ}.

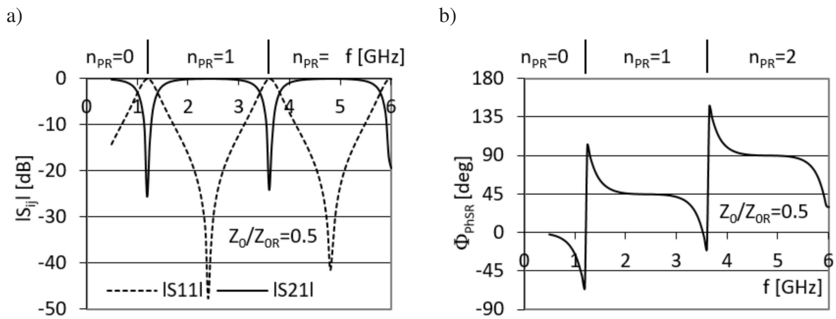

Fig. 4. The amplitude characteristics (a), and the differential phase shift Φ_{PhSR} (b), of a microwave phase shifter with a parallel open-circuited stub for $Z_0/Z_{0R} = 0.5$ (results of simulations, $L_{Ref} = 74.5$ mm).

Over the examined frequency interval, the phase shifter with an open-circuited stub had two well-marked usable sub-bands in the microwave range (Figs 4 and 5). The first one, called the fundamental sub-band (number $n_{PR} = 1$), was situated in the surroundings of frequency

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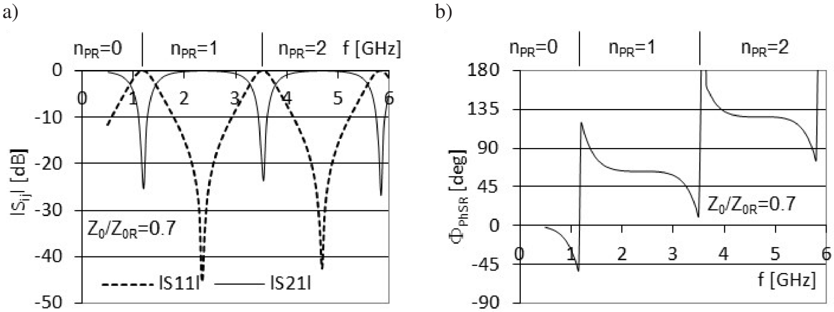

Fig. 5. The amplitude characteristics (a), and the differential phase shift Φ_{PhSR} (b), of a microwave phase shifter with a parallel open-circuited stub for Z_0/Z_{0R} = 0.7 (results of simulations, L_{Ref} = 80 mm).

$f_{nR} \approx 2.45$ GHz, and the second one, $n_{PR} = 2$, was found near a frequency $f_{nR} \approx 4.9$ GHz. The sub-band $n_{PR} = 0$ for this phase shifter is not usable.

Inside the sub-band $n_{PR} = 1$, the transmittance modulus of the phase shifter based on an open-circuited stub with a ratio of impedances $Z_0/Z_{0R} = 0.5$ was greater than −0.4 dB in a frequency range from about 1.7 GHz up to about 3.15 GHz (Fig. 4). The modulus of the reflection coefficient in this sub-band was very good, *i.e.* it was lower than −10 dB. The differential phase shift in this frequency range affected the value by about (45 ± 6) degrees. The frequency boundaries of the sub-band $n_{PR} = 2$, also appointed by a −10 dB value of the reflection coefficient modulus, were at approximately 4.15 GHz and 5.5 GHz.

In this frequency interval, the differential phase shift, in accordance with (11), was two times greater than for $n_{PR} = 1$ and was contained in a range of about (90 ± 4) degrees. As it is shown in Fig. 5, for a larger impedance ratio, *i.e.* for $Z_0/Z_{0R} = 0.7$, the phase shift Φ_{PhSR} increased to about 63 degrees in the middle of the fundamental sub-band ($n_{PR} = 1$) and to about 126 degrees at the central frequency of the sub-band $n_{PR} = 2$.

Over the examined frequency interval, the phase shifter with a short-circuited stub had two well-marked usable sub-bands with numbers $n_{PZ} = 0$ (fundamental sub-band) and $n_{PZ} = 1$ (Fig. 6 and 7).

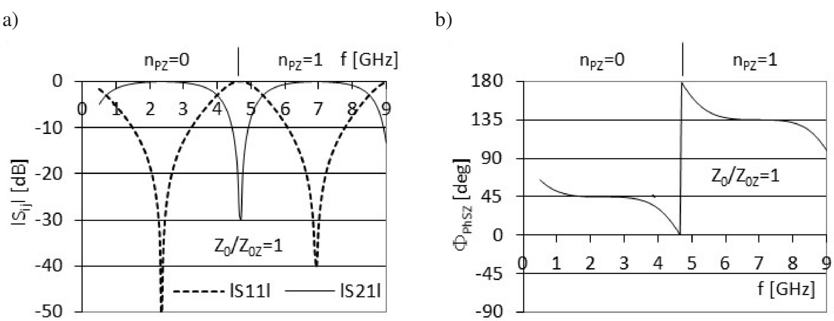

Fig. 6. The amplitude characteristics (a), and the differential phase shift Φ_{PhSZ} (b), of a microwave phase shifter with a parallel short-circuited stub for Z_0/Z_{0Z} = 1 (results of simulations, L_{Ref} = 74.5 mm).

The fundamental sub-band ($n_{PZ} = 0$) was situated in the surroundings of a frequency $f_{nZ} \approx 2.3$ GHz, and the second one, $n_{PZ} = 1$, was placed at a frequency of $f_{nZ} \approx 6.9$ GHz.

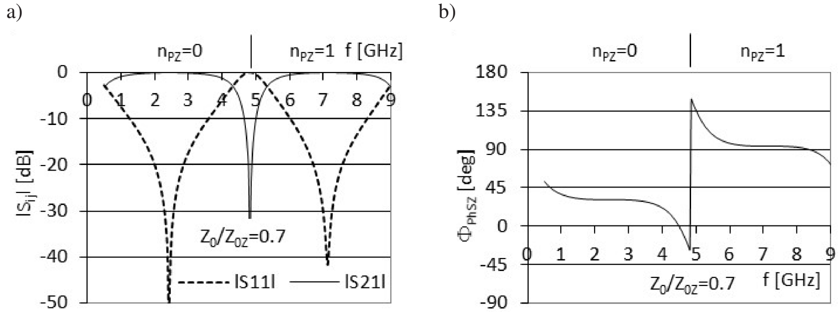

Fig. 7. The amplitude characteristics (a), and the differential phase shift Φ_{PhSZ} (b), of a microwave phase shifter with a parallel short-circuited stub for Z_0/Z_{0Z} = 0.7 (results of simulations, L_{Ref} = 70 mm).

Inside the sub-band n_{PZ} = 0, the transmittance modulus of the phase shifter based on a short-circuited stub with a ratio of impedances Z_0/Z_{0Z} = 1 was greater than −0.5 dB in a frequency range from about 1.5 GHz up to about 3.3 GHz (Fig. 6). The modulus of the reflection coefficient inside this sub-band was lower than −10 dB. The differential phase shift in this frequency range affected the value by about (45 ± 2) degrees. The same differential phase shift was provided by the phase shifter with an open stub, but for a ratio of impedances Z_0/Z_{0R} = 0.5 (Fig. 4b). The borders of the sub-band n_{PZ} = 1 also defined by the value of the reflection coefficient modulus not greater than −10 dB, were of about 6.1 GHz and of about 7.8 GHz. Between these frequencies, the differential phase shift was contained in a range of about (135 ± 2) degrees. This value is three times greater than the phase shift in the sub-band n_{PZ} = 0, what is consistent with formula (18).

After reducing the ratio Z_0/Z_{0Z} down to 0.7, the phase shift Φ_{PhSZ} decreased to about 31 degrees in the middle of the sub-band n_{PZ} = 0 and to about 93 degrees at the central frequency of the sub-band n_{PZ} = 1 (Fig. 7).

5. Results of experiments

The experimental versions of phase shifters described above were designed, manufactured and tested. The circuits were fabricated in microstrip technology using FR4 laminate with thickness of 1.57 mm, dielectric constant of 4.6 and loss tangent of 0.025. The main lines of every phase shifters had a width of w_{ML} = 2.73 mm, characteristic impedance Z_0 = 50 Ω and length l_R = l_Z = 30 mm. A TEM type transmission line with air dielectric and of length L_{Ref} was used as a reference track for measurements of differential phase shifts Φ_{PhSR} and Φ_{PhSZ}. This line was implemented inside a vector network analyser HP8720C used for tests. Schemes of the constructed and tested phase shifters are presented in Fig. 8, and the measurement setup structure is shown in Fig. 9.

The results of measurements are shown in Figs 10–13. The results of simulation of differential phase shifts are inserted in these figures to provide additional information for comparison.

According to Figs 12 and 13 the phase shifts Φ_{PhSZ} in higher sub-bands are somewhat lower than designed. Greater values of phase shifts in lower and higher frequency sub-bands can be achieved through changing width w_{SZ} or longitudinal extension of the reference track (reference line). Examples of Φ_{PhSR} and Φ_{PhSZ} plots achieved using reference lines with various lengths are shown in Figs 14 and 15.

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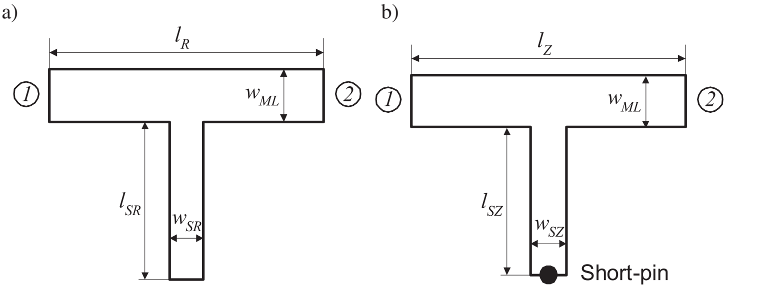

Fig. 8. Schematic views of the phase shifters with single parallel stubs made in microstrip technology, a) with an open-circuit stub; b) with a short-circuit stub.

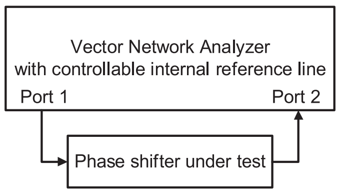

Fig. 9. A schematic block diagram of the measurement setup of phase shifters.

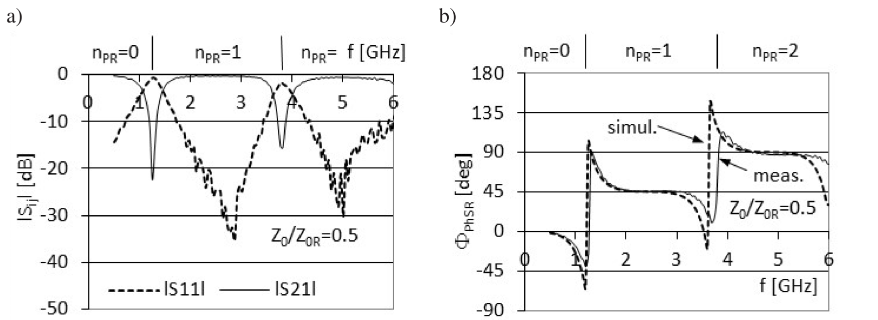

Fig. 10. The measured amplitude characteristics (a), and the differential phase shift Φ_{PhSR} (b), of a microwave phase shifter with a parallel open-circuited stub for $Z_0/Z_{0R} = 0.5$ ($w_{SR} = 0.68$ mm, $L_{SR} = 35$ mm, $L_{Ref} = 74.5$ mm).

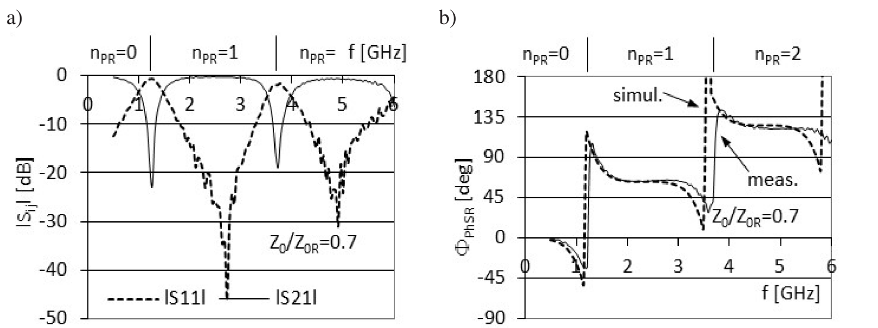

Fig. 11. The measured amplitude characteristics (a), and the differential phase shift Φ_{PhSR} (b), of a microwave phase shifter with a parallel open-circuited stub for $Z_0/Z_{0R} = 0.7$ ($w_{SR} = 1.37$ mm, $L_{SR} = 35$ mm, $L_{Ref} = 80$ mm).

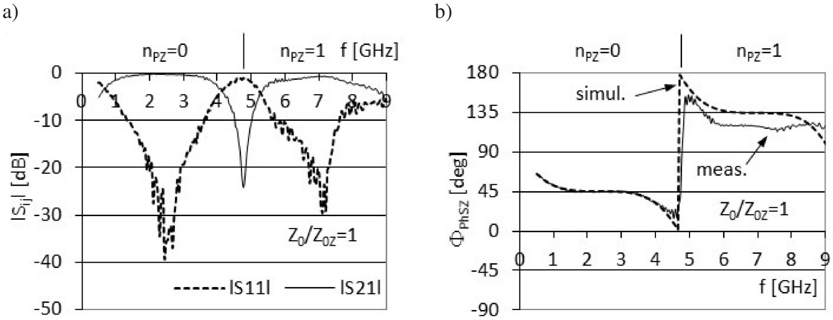

Fig. 12. The measured amplitude characteristics (a), and the differential phase shift Φ_{PhSZ} (b), of a microwave phase shifter with a parallel short-circuited stub for $Z_0/Z_{0Z} = 1$ ($w_{SZ} = 2.73$ mm, $L_{SZ} = 17$ mm, $L_{Ref} = 74.5$ mm).

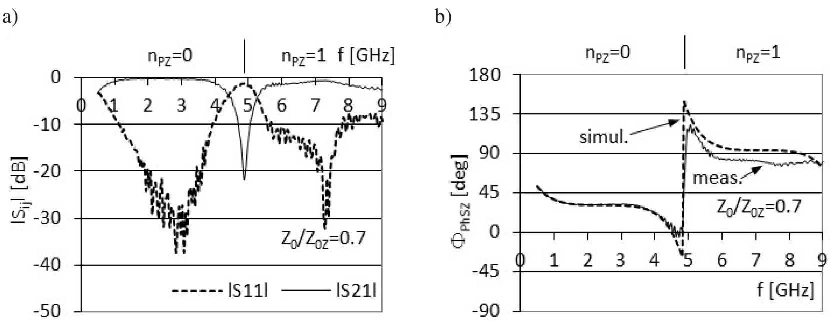

Fig. 13. The measured amplitude characteristics (a), and the differential phase shift Φ_{PhSZ} (b), of a microwave phase shifter with a parallel short-circuited stub for $Z_0/Z_{0Z} = 0.7$ ($w_{SZ} = 1.36$ mm, $L_{SZ} = 17$ mm, $L_{Ref} = 70$ mm).

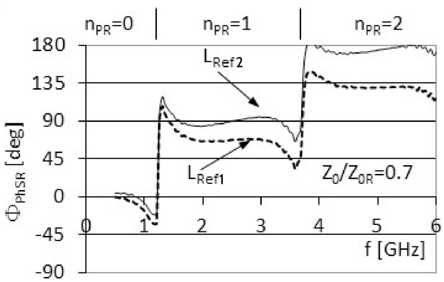

Fig. 14. The measured differential phase shift Φ_{PhSR} of a microwave phase shifter with a parallel open-circuited stub for $Z_0/Z_{0R} = 0.7$ and for two various reference line lengths ($L_{Ref1} = 80$ mm, $L_{Ref2} = 88.7$ mm).

For the longer reference line ($L_{Ref2} = 88.7$ mm) the phase shift of the device with an open-circuited stub for $Z_0/Z_{0R} = 0.7$ was increased up to (90 ± 5) degrees in the sub-band $n_{PR} = 1$ and up to (175 ± 5) degrees in the sub-band $n_{PR} = 2$ (Fig. 14), whereas the differential phase shift of the shifter with a short-circuited stub for $Z_0/Z_{0Z} = 1$ and for $L_{Ref2} = 80.5$ mm rose up to about (62 ± 5) degrees in the sub-band $n_{PZ} = 0$ and to about (175 ± 8) degrees in the sub-band

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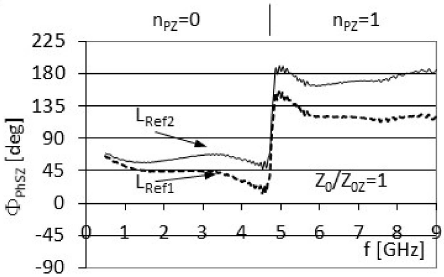

Fig. 15. The measured differential phase shift Φ_{PhSZ} of a microwave phase shifter with a parallel short-circuited stub for $Z_0/Z_{0Z} = 1$ and for two various reference line lengths ($L_{Ref1} = 74.5$ mm, $L_{Ref2} = 80.5$ mm).

$n_{PZ} = 1$ (Fig. 15). The amplitude characteristics of these phase shifters maintained the shapes shown in Figs 11a and 12a, respectively.

6. Conclusions

The novelty of this work lies in the proof that simple, small devices with a single open-circuit stub and with a single short-circuit stub not only have the properties of band-pass filters, but also can be used as wideband phase shifters with interesting differential phase shift values. The value of the differential phase shift provided by both of the described kinds of phase shifters is determined by a ratio of the characteristic impedance of the main transmission line to the characteristic impedance of the stub. The differential phase shift value is proportional to this ratio. Moreover, it was shown that both of the described devices have more than one operating frequency sub-band. In the work, these sub-bands were numbered beginning from zero. The differential phase shifts in every sub-band differ from each other. The width of a sub-band with a greater number (with a greater central frequency value) is smaller, but simultaneously the differential phase shift within it is significantly greater than in a sub-band with a lower central frequency (with a smaller sub-band's number). This effect is a consequence of the electrical properties of the transmission line versus frequency, which have a periodical nature. A good consistency of measurement and calculation results was obtained, especially in the case of phase shifters with a parallel open-circuited stub. The measured and simulated phase shifts of the phase shifters with short stubs agreed in the fundamental sub-bands (for $n_{PZ} = 0$) but they were a little biased in the sub-bands' number $n_{PZ} = 1$. This phenomenon is most probably caused by the loss value of FR4 substrate used for manufacturing the phase shifters and imprecise construction of the short-circuit component. The phase shifters with single parallel open-circuited or short-circuited stubs occupy a small area on the surface of a *printed circuit board* (PCB), and therefore may be used in a large number of pieces, which is particularly useful in integrated multi-channel microwave arrangements. Simultaneously, for the greater values of stub impedance the transmittance modulus changes more slowly versus frequency. The work provides formulae, which enable to calculate the length of reference track for the cases where the differential phase shift characteristic versus frequency at the middle of the phase shifter's operating sub-band has a so-called inflection point. For greater lengths of the reference track, the inflection point of the differential phase shift plot in the sub-band centre disappears, and the characteristic of the differential phase shift moves upward. This denotes the differential phase shift enlargement. Oscillations of the phase characteristic of the phase shifter accompany this effect, but at the same time it increases the frequency bandwidth, in which the differential phase shift is within acceptable limits. The simulations were carried out using AWR program of National Instruments, and a vector network analyser HP8720C of Hewlett Packard was used for measurements. The described phase shifters are designed for use, among other, in Butler matrices with more than 4 ports, wideband *beam forming networks* (BFNs), phased antenna arrays and in multi-channel IFM devices.

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