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MODIFICATION OF MIROWAVE FREQUENCY DETECTOR CHARACTERISTIC WITH THE USE OF PHASE SHIFTER

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Abstract

Microwave frequency detectors enable immediate determination of an unknown microwave signal frequency. Measurement is possible if the output characteristic of a frequency detector is unequivocal in a selected band of operation. The paper presents a method for obtaining unequivocal output characteristics for a given band of frequency detector operation.

Keywords: frequency detector, phase detector, diode ring.

1. Introduction

Measurement of microwave signal frequency in the surrounding area provides information concerning sorts and types of the working radio-electronic devices. A measurement can be carried out with the use of *Microwave Frequency Detector* (MFD). Its great advantage is possibility to measure even a single microwave signal pulse. The output voltage depends on frequency. The accuracy of its determination depends on the number of the used detectors. Measurement with the use of only one detector may result in obtaining a rough value which, in many cases, may be sufficient. Measurement consists in assigning each value of the output voltage to its corresponding frequency. The output characteristic may be described with a sine or cosine function, depending on the detector structure. The characteristic may be ambiguous in a selected range of operation frequency. Application of an additional element, in the form of a phase shifter, in the detector system enables to obtain an unambiguous and monotonic characteristic in an arbitrarily selected range of frequencies.

2. Frequency detector structure

Depending on type of the function describing the behaviour of the output voltage, there are distinguished the "sine" and "cosine" types of *Single-function Frequency Detectors* (SFDs). In order to simplify the procedure of SFD and the processing system as well as to obtain a wide band of operation in a built detector, a diode ring was used. A frequency detector is composed of two main blocks: a *System of Developing a Proportional Phase Difference* (SDPPD) and a *Phase-Sensitive Detector* (PSD) [1–6].

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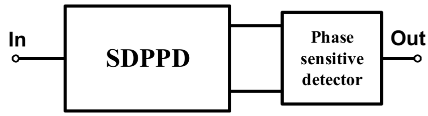

Fig. 1. A block diagram of a frequency detector with a ring phase-sensitive detector.

The purpose of SDPPD is to generate two output voltages with a phase difference between them proportional to their frequencies. The difference of phases between Output 1 and Output 2 is due to application of sections of lines with various electrical lengths.

The range of device operation is unequivocally determined by the difference in lengths of transmission lines l_1 and l_2 as well as by operation bands of the power share system and the ring phase sensitive detector. A time lapse introduced by a single transmission line is defined by the dependency (1):

$$\Phi = 2 \cdot \pi \cdot \frac{l}{\lambda_f}. \tag{1}$$

The difference of phases $\Phi_1 - \Phi_2$ for the SDPPD system presented in Fig. 2 is defined with (2), assuming that the power share system does not introduce an addition phase shift between those signals:

$$\Phi_1 - \Phi_2 = \frac{2 \cdot \pi}{\lambda_f} \cdot (l_1 - l_2). \tag{2}$$

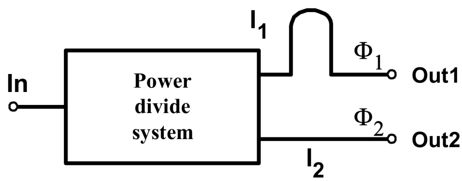

Fig. 2. A block diagram of System of Developing a Proportional Phase Difference.

If a difference of phases $\Phi_1 - \Phi_2$ on a lower frequency f_L is marked with a symbol α_L and a difference of phases on an upper frequency f_U with α_U, then a phase difference can be written as:

$$\alpha_L = \frac{2 \cdot \pi}{v_f} \cdot f_L \cdot (l_1 - l_2), \tag{3}$$

$$\alpha_U = \frac{2 \cdot \pi}{v_f} \cdot f_U \cdot (l_1 - l_2). \tag{4}$$

Having values α_L and α_U defined, it is possible to introduce another variable K_α, which is defined as follows:

$$K_\alpha = \frac{\alpha_U}{\alpha_L} = \frac{f_U}{f_L}. \tag{5}$$

This dependency is applied to calculate the operation ranges of SFD of a “sine” or “cosine” type.

3. Phase sensitive detector

A diagram of a ring microwave phase-sensitive detector is presented in Fig. 3.

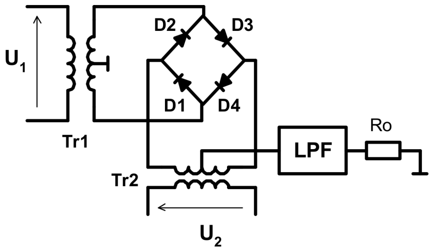

Fig. 3. A schematic diagram of a phase-sensitive detector with a diode ring.

For the output of the ring phase sensitive detector, there are given voltages described with the following equations:

$$u_1 = Um_1 \cos(\omega t + \Phi_1), \tag{6}$$

$$u_2 = Um_2 \cos(\omega t + \Phi_2), \tag{7}$$

where: Φ_1 – an initial phase of the first voltage; Φ_2 – an initial phase of the second voltage; Tr1 and Tr2 transformers perform the function of balancing transformers with a 1:1 gear. Voltages on the individual diodes are described with the following dependencies:

$$u_{D1} = ((u_1/2) + (u_2/2)), \tag{8}$$

$$u_{D2} = ((u_1/2) - (u_2/2)), \tag{9}$$

$$u_{D3} = (-(u_1/2) - (u_2/2)), \tag{10}$$

$$u_{D4} = (-(u_1/2) + (u_2/2). \tag{11}$$

The diode current may be determined, for the need of analysis, by first three expressions of the power series:

$$i_{\text{out}} = a_0 + a_1 u + a_2 u^2. \tag{12}$$

As a result of summation and subtraction of individual currents flowing through the constant component diodes the basic component signals are subject to compensation. The output current, after taking into consideration a low-pass filter at the output, is described with the following dependence:

$$i_{\text{out}} = a_2 U_{m1} U_{m2} \cos(\Phi_1 - \Phi_2). \tag{13}$$

The output voltage of the detector is a function of the difference of output signal phases and amplitudes of input voltages. Hence, the detector is defined as phase-sensitive.

4. Single-function frequency detector of “cosine” type

A block diagram of a “cosine type” SFD is presented in Fig. 4. The power divider acts as a power dividing system [3, 6].

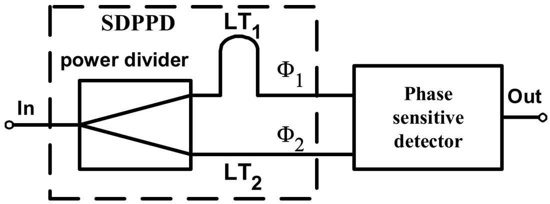

Fig. 4. A block diagram of a "cosine" type SFD.

Output voltage as a function of phase difference at the output of the ring phase-sensitive detector is described with the following dependence:

$$U_{\mathrm{OUT}} = k \cdot \cos(\Phi), \tag{14}$$

where: k – a detection coefficient; $\Phi = \Phi_1 - \Phi_2$ – a difference of signal phases at the first and second inputs of the phase-sensitive detector.

The full range of an unambiguous reading of phase differences for a ring phase-sensitive detector of "cosine" type is equal to π. It is possible to determine, in an unambiguous way, the input phase signal frequency for phase fluctuations in ranges: $0-\pi$, $\pi-2\pi$, $2\pi-3\pi$, *etc*. In general, it can be stated that the unambiguous determination of frequency is possible if the phase fluctuates in a range $n\pi \div (n+1)\pi$, where $n = 0, 1, 2, 3 \ldots$

$$K_\alpha(n) = \frac{n+1}{n} = \frac{\alpha_U}{\alpha_L}, \quad \text{where} \;\; n = 0, 1, 2, \ldots\,. \tag{15}$$

It results from the dependence (15) that $K_\alpha(n)$ may assume only specific values. For $n = 0$, $K_\alpha(0) = \infty$ is obtained, for $n = 1$ – $K_\alpha(1) = 2$, *etc*. Difference of lengths of transmission lines can be calculated from the dependence (16):

$$l_1 - l_2 = \frac{c}{2 \cdot \sqrt{\varepsilon_r}(f_U - f_L)}\,. \tag{16}$$

Graphic plots for an unambiguous reading of frequency are presented in Fig. 5.

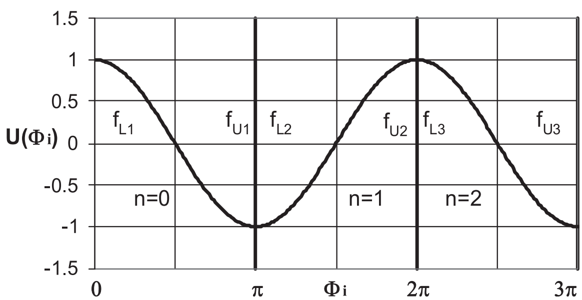

Fig. 5. Ranges of unambiguous reading of frequency by a "cosine" type frequency detector.

It is often required to obtain an unambiguous output characteristic in the range of frequencies for which the characteristic is ambiguous. The problem can be solved by changing the structure of the "cosine" type SFD by adding a phase shifter with a shift φ_p, which enables to obtain K_α of any value [5]. The shifter may be placed in both lower or upper line of SDPPD.

If the phase shifter is placed in the upper line of SDPPD, then:

$$K_\alpha(n) = \frac{(n+1)\cdot\pi - \varphi_p}{n\cdot\pi - \varphi_p}, \quad \text{where } n = 0, 1, 2. \tag{17}$$

If the phase shifter is placed in the lower line, the dependence describing K_α has the following form:

$$K_\alpha(n) = \frac{(n+1)\cdot\pi + \varphi_p}{n\cdot\pi + \varphi_p}, \quad \text{where } n = 0, 1, 2. \tag{18}$$

Having given the values of both upper f_U and lower f_L frequencies, it is possible to calculate the required shift introduced by the phase shifter. For the phase shifter located in the upper line:

$$\varphi_p = \pi\cdot\frac{n(K_\alpha(n)-1)-1}{K_\alpha(n)-1}, \quad \text{where } n = 0, 1, 2. \tag{19}$$

Whereas for the phase shifter located in the lower line of SDPPD, the equation has the following form:

$$\varphi_p = \pi\cdot\frac{n(K_\alpha(n)-1)-1}{1-K_\alpha(n)}, \quad \text{where } n = 0, 1, 2. \tag{20}$$

The difference of lengths of transmission lines may be calculated from the dependence (16).

Table 1 compares the shift values of the phase shifter for its locations in the upper and lower lines in dependence on n.

Table 1. The shift values of the phase shifter for its locations in the upper and lower lines in dependence on n (cosine).

***n* value**	**0**	**1**	**2**
upper line	–225°	–45°	135°
lower line	225°	45°	–135°

The real system can be obtained for positive shift values of the phase shifter. Fig. 7 presents an example of input voltage characteristic for a "cosine" type SFD operating in a range of 1–1.8 GHz ($n = 1$).

The shift introduced by the phase shifter in the operation band of SFD is 45 degrees and is placed in the lower line of SDPPD (Fig. 6a).

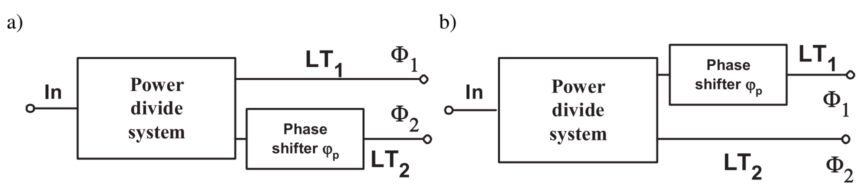

Fig. 6. Modifications of the system of developing a proportional phase difference.

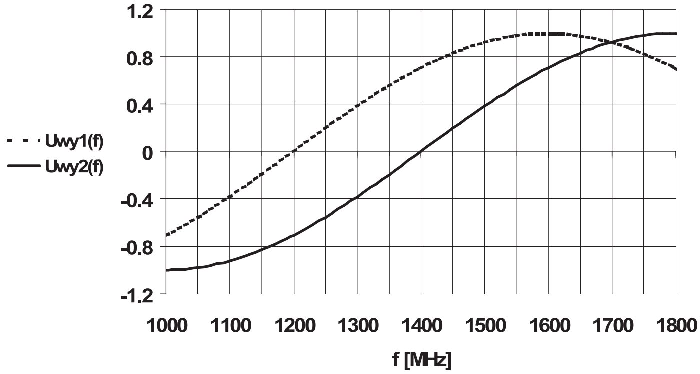

Fig. 7. Characteristics of input voltage for a "cosine" type SFD operating in a range of 1–1.8 GHz without a phase shifter and with a phase shifter with a shift of 45 degrees for $n = 1$ (solid line – a curve of SFD output voltage with a phase shifter, dashed line – a curve of output voltage without a phase shifter –).

5. Single-function frequency detector of "sine" type

The structure of a frequency detector of this type is similar to that of a "cosine" type frequency detector [5]. The difference between them consists in the application of a power share system introducing constants in the function of frequency at a phase shift of 90°. The output voltage of the frequency detector is described by a sine function. A 3 dB/90° coupler may function as a power share system with a phase shift. A block diagram of the system is presented in Fig. 8.

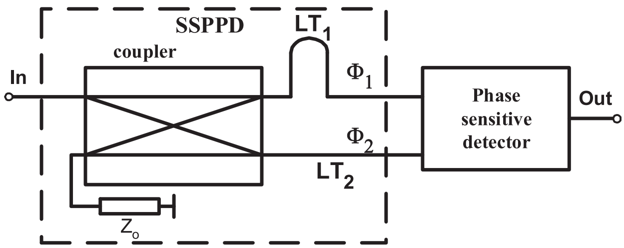

Fig. 8. A block diagram of a "sine" type frequency detector.

The full range of an unambiguous reading of frequencies for this type of detector is equal to π. The value of $K_\alpha(n)$ may be calculated from the formula (21):

$$K_\alpha(n) = \frac{3+2n}{1+2n}, \quad \text{where } n = 0, 1, 2. \tag{21}$$

Ranges of an unambiguous reading of frequencies for a "sine" type detector of frequency are presented in Fig. 9.

The difference of lengths of transmission lines can be calculated form (16). The given dependencies do not include the initial range of characteristic in the range of phase fluctuations of $0 \div \pi/2$, although it can also be used. The application of a phase shifter in one of the SDPPD

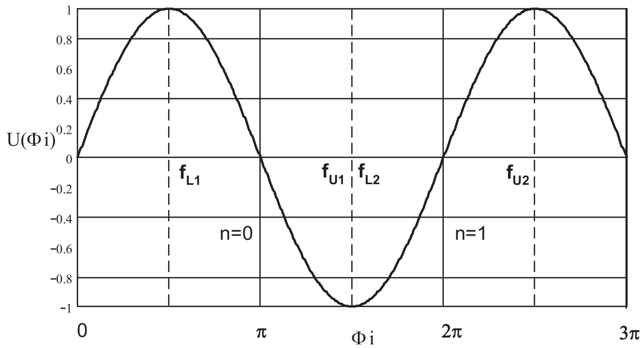

Fig. 9. Ranges of an unambiguous reading of frequencies for a “sine” type detector of frequency.

lines enables to obtain $K\alpha(n)$ of any value. It is described for the upper line with the following dependence:

$$K_\alpha(n) = \frac{\left(n+\frac{3}{2}\right)\cdot\pi - \varphi_p}{\pi\cdot\left(n+\frac{1}{2}\right) - \varphi_p}, \quad \text{where } n = 0,1,2,\ldots \tag{22}$$

whereas for the lower line with:

$$K_\alpha(n) = \frac{\left(n+\frac{3}{2}\right)\cdot\pi + \varphi_p}{\pi\cdot\left(n+\frac{1}{2}\right) + \varphi_p}, \quad \text{where } n = 0,1,2,\ldots \tag{23}$$

For specified values of upper f_U and lower f_L frequencies, the value of shift in the upper line is expressed with the following formula (24):

$$\varphi_p = \pi\cdot\frac{K_\alpha(n)\cdot\left(n+\frac{1}{2}\right) - \left(n+\frac{3}{2}\right)}{K_\alpha(n)-1}, \quad \text{where } n = 0,1,2,\ldots \tag{24}$$

Whereas that for the lower line is expressed with:

$$\varphi_p = \pi\cdot\frac{K_\alpha(n)\cdot\left(n+\frac{1}{2}\right) - \left(n+\frac{3}{2}\right)}{1-K_\alpha(n)}, \quad \text{where } n = 0,1,2,\ldots \tag{25}$$

Table 2 compares shift values of the phase shifter depending on the line in which the shifter is placed and on the value of n. Similarly as in the case of the “cosine” type SFD, the real system can be obtained for positive phase shift values of the shifter.

Figure 10 presents an example of the output voltage characteristic for a “sine” type frequency detector operating in a frequency range 1–1.8 GHz.

A shift introduced by the phase shifter in the operation band of SFD is 45 degrees and is placed in the upper line of SDPPD (Fig. 6b). The application of the phase shifter provides, as

Table 2. The shift values of the phase shifter for its locations in the upper and lower lines in dependence on n (sine).

***n* value**	**0**	**1**	**2**
upper line	−135°	45°	225°
lower line	135°	−45°	−225°

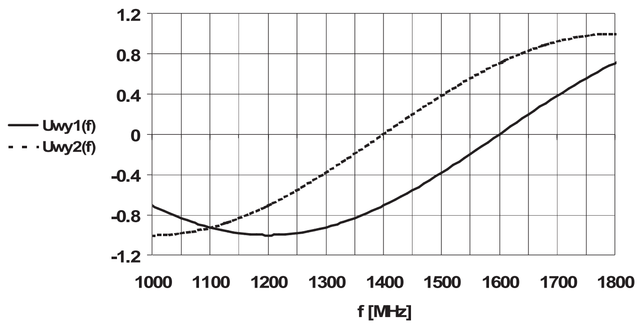

Fig. 10. Characteristics of output voltages for a "sine" type SFD without a phase shifter and with a phase shifter for $n = 1$ (solid line – a curve of output voltage for the frequency detector without any interference in the SDPPD structure, dashed line – a curve of output voltage for the detector after introducing a phase shifter).

in the case of the "cosine" type detector, a possibility of designing a frequency detector for a selected operation band along with an unambiguous form of the output characteristic of the detector. However, obtaining a wide operation band with the use of a "sine" type detector may be difficult due to the fact that both the shifter and a coupler with a wide operation band have to be applied.

6. Conclusions

An approximate frequency value may be defined with an amplitude method with the use of only one SFD of either "sine" or "cosine" type. The output voltage of a frequency detector is a function of frequency and power level at the input of the detector. Based on its value, it is possible to approximately estimate the frequency. In order to eliminate the influence of an input power level on the measurement result, it is required to apply a reference channel. A power level at the output of the reference channel is not a function of frequency. In the case of determining the frequency with the amplitude method, obtaining an unambiguous characteristic of the output voltage in a given frequency band may pose a problem. What is expected is a monotonic increasing or decreasing characteristic of output voltage as a function of frequency. If increasing or decreasing sections occur in the operation band, then ambiguities of frequency determination appear. For various values of frequency, the voltages of the same value occur. The application of a phase shifter in the frequency detector structure enables to obtain a shift of the output characteristic as a function of frequency. As a result, the output voltage characteristic of the detector is monotonic, increasing or decreasing, in the full assumed range of frequencies. An advantage of this solution is the use of the full range of SFD output voltage fluctuations.

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