Frequency Detector with Power Combiner Dividers

H. Gruchala and A. Rutkowski

***Abstract*—This letter describes a microwave frequency detector made in microstrip technique. The system consists of two power dividers and three transmission lines. Ratio of amplitudes of output signals determines frequency of input signal. Despite simple structure, the frequency detector has very attractive parameters. Practically made the detectors worked in S and Ku frequency band.**

I. Introduction

MICROWAVE interferometers are usually base circuits of microwave frequency detectors. These interferometers most often consist of 3-dB directional couplers, and 3-dB power combiner divider and transmission lines. Typically, the system contains three couplers and two power dividers [1], [2]. Crossing of transmission lines, applied in these circuits, complicates the structure of interferometers. Systems of "sinus" or "cosines" type do not cause the inconvenience [3]. Also crossing of transmission lines with the structure separation can be applied [4]. The microwave interferometer of frequency detector can consist of two power dividers and three transmission lines only. The system has simple structure but its parameters are fully useful.

II. Principle of Interferometer Operation

The microwave interferometer involves phase shift, which value is a function of input frequency. If we know the value of phase shift and lengths of transmission lines, which involve the phase shift, we can determine frequency of input signal [5]. The system described here consists of input three-way power divider N_1, transmission lines N_3, and output two-way power divider N_2. Its structure is shown in Fig. 1. Input signal is divided in the three-port power divider [6]. Output signals of this divider excite three tracks. The first track, between port 1 and port 2, is the reference channel. This one contains information about power of input signals. The second and third tracks involve phase shifts, which values are proportional to their electrical lengths Θ_1 and Θ_2, respectively. Amplitude of output signal in port 3 depends on electrical lengths of applied transmission lines and parameters of used power dividers only. Transmission coefficient of measurement channel can be determined according to Fig. 2. If we assume full separation between output ports of used power dividers (between ports 3, 4 and 5, 6 in Fig. 2) and equal power dividing in these dividers, their scattering matrices have the form

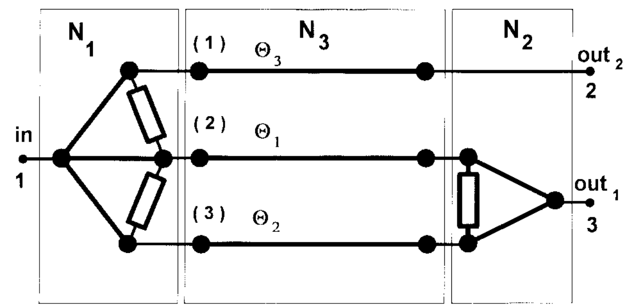

Fig. 1. The structure of the microwave interferometer built on the base of two power dividers.

$$[S^i] = \begin{bmatrix} S_{11}^i & S_{21}^i & S_{21}^i \\ S_{21}^i & S_{22}^i & 0 \\ S_{21}^i & 0 & S_{22}^i \end{bmatrix}. \tag{1}$$

According to this, the scattering matrix of full circuit shown in. Fig. 2 has the form [7]

$$\begin{bmatrix} \mathbf{S}_{pp} & \mathbf{S}_{pc} \\ \mathbf{S}_{cp} & (\Gamma - \mathbf{S}_{cc}) \end{bmatrix} = \begin{bmatrix} S'_{11} & 0 & S'_{21} & S'_{21} & 0 & 0 \\ 0 & S''_{11} & 0 & 0 & S''_{12} & S''_{21} \\ S'_{21} & 0 & -S'_{22} & 0 & 0 & e^{j\Theta_1} \\ S'_{21} & 0 & 0 & -S''_{22} & e^{j\Theta_2} & 0 \\ 0 & S''_{21} & 0 & e^{j\Theta_2} & -S''_{22} & 0 \\ 0 & S''_{21} & e^{j\Theta_1} & 0 & 0 & -S'_{22} \end{bmatrix}. \tag{2}$$

Transmission coefficient from port 1 to port 2 determines the formula [7]

$$[S_p] = [S_{pp}] + [S_{pc}][\Gamma - S_{cc}]^{-1}[S_{cp}]. \tag{3a}$$

Using above two formulas we find (3b), shown at the bottom of the next page, where

$$M_1 = e^{2j\Theta_1} - S'_{11}S''_{11}$$
$$M_2 = e^{2j\Theta_2} - S'_{11}S''_{11}.$$

Manuscript received October 22, 1997.

The authors are with the Military University of Technology, Warsaw 01-489, Poland.

Publisher Item Identifier S 1051-8207(98)03448-5.

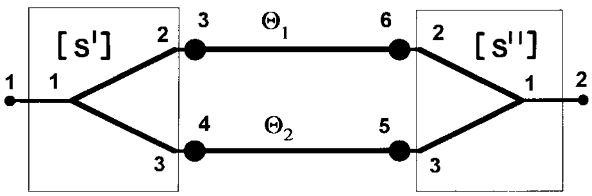

Fig. 2. The measurement channel of the interferometer.

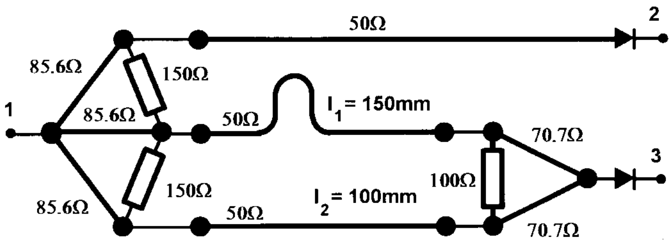

Fig. 3. The full structure of the microwave frequency detector.

For the center frequency of work band of the interferometer ($S^1_{11} = S^{11}_{11} = 0$), transmission coefficient S_{21} is

$$S_{21} = S'_{21}S''_{21}(e^{-j\Theta_1} + e^{-j\Theta_2}). \tag{4}$$

If we put $|S'_{21}| = |S''_{21}| = 1/\sqrt{2}$, then after square detection, the output signal of frequency detector is proportional to the function

$$T = \tfrac{1}{2}[1 + \cos(\Theta_1 - \Theta_2)] = \tfrac{1}{2}\{1 + \cos[\beta(l_1 - l_2)]\} \tag{5}$$

where β is the phase constant and l_1, l_2 are lengths of transmission lines. Extreme values of the function are reached when input frequency is $f = v[n/(I_1 - I_2)]$ and $f = v(1/2 + n)/(l_1 - l_2)$, respectively, where $n = \pm 1, \pm 2, \pm 3, \cdots$ and v is velocity of wave propagation. The circuit operates as a dissipative frequency sensitive detector. Transmission level depends on input frequency in this device. If necessary transmission (attenuation) can be changed with frequency development. The power is dissipated in the resistor of output divider. Power value depends on the resultant phase shift involved by lines connecting these dividers.

III. Structure and Characteristics of Interferometer

The structure of complete microwave frequency detector is shown in Fig. 3. It consists of two power dividers, three transmission lines, and two detectors. Transmission lines (connecting these power dividers) and parameters of applied dividers determine parameters of complete frequency detector.

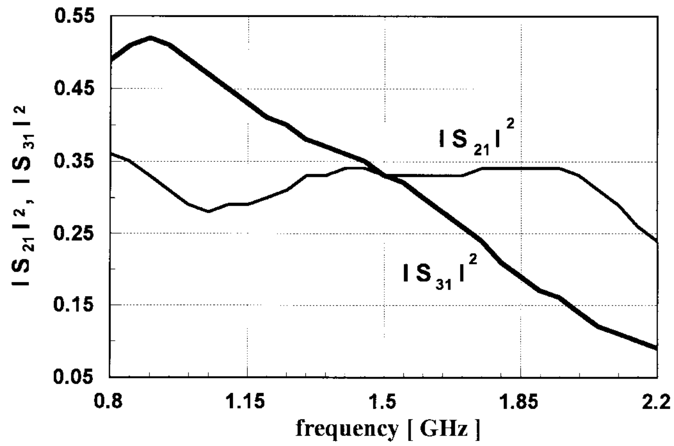

Fig. 4. Transmission characteristic of the reference and measurement channel.

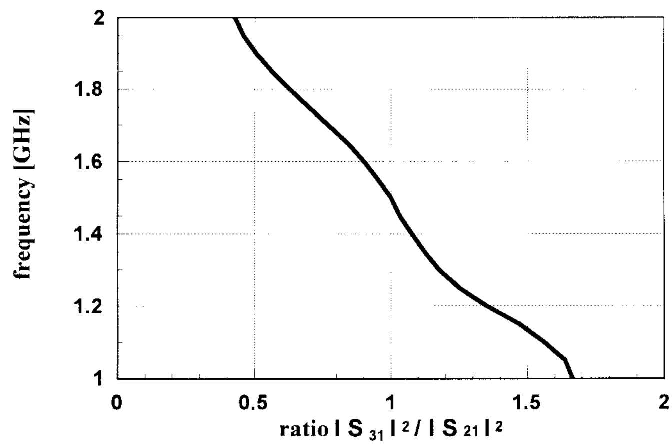

Fig. 5. Characteristics of the frequency detector.

The length difference of transmission lines is equal to 50 mm in this case. It corresponds to frequency $f = 1.5$ GHz, which is the center frequency of work band of this system. All lines have characteristic impedance equal to 50 Ω. Theoretical transmission of the reference and measurement channel is shown in Fig. 4. Experimental results differ not more then 5%. Transmission characteristic $|S_{31}|^2$ diminishes monotonically in frequency band (1–3) GHz. Ratio $|S_{31}|^2/|S_{21}|^2$ determines frequency of input signal according to

$$f = \frac{\mathrm{v}}{2_{\pi}(I_1 - I_2)} \arccos\left[\frac{|S_{31}|^2}{|S_{21}|^2} - 1\right]. \tag{6}$$

Symbols used in this formula are explained above. Dependence between measurement frequency and $|S_{31}|^2/|S_{21}|^2$ is the characteristic of frequency detector. It is shown in Fig. 5.

After analog calculations the measurement error was about 7%. Applying A/D converters and calibration process gave

$$[S_p] = \begin{bmatrix} S'_{11} + (S'_{21})^2 S''_{11}\left(\frac{1}{M_1} + \frac{1}{M_2}\right) & S'_{21}S''_{21}\left(\frac{e^{j\Theta_1}}{M_1} + \frac{e^{j\Theta_2}}{M_2}\right) \\ S'_{21}S''_{21}\left(\frac{e^{j\Theta_1}}{M_1} + \frac{e^{j\Theta_2}}{M_2}\right) & S''_{11} + (S''_{21})^2 S'_{11}\left(\frac{1}{M_1} + \frac{1}{M_2}\right) \end{bmatrix} \tag{3b}$$

error less than 1.5%. Systematic errors were compensated after applying digital technique. Then measurement error was not more than 1%. Return losses are of the order of 11 dB. The value results from parameters of input power divider mainly. Small value of separation between output ports (≤ -11 dB) results from parameters of the divider, too. If we apply multisection power dividers, characteristics of the system will be better (reflected characteristics mainly).

IV. Conclusions

The microwave detector described here belongs to the group of instantaneous frequency monitoring systems. It can be used to coarse frequency measurement of received signals and observe tuning process of such devices as synthesizers, sweep generators, heterodynes, etc. These microwave detectors have the following advantages:

- simple structure;
- attractive electrical parameters;
- possibility of ranging of frequency bandwidth from very narrow to very broad;
- chip making technology;
- possibility of making multichannel systems.

The microwave frequency detectors made according to the above technique confirmed theoretical considerations. They have worked in S and Ku frequency band. These circuits were made on teflon glass and alumina substrates, respectively.

Acknowledgment

The described systems were made for Technical University of Warsaw and Telecommunications Research Institute.

References

[1] S. E. Lipsky, “Measure new threat frequencies instantly,” *Microwaves*, pp. 49–56, May 1971.

[2] B. Stec, “Radioelectronics reconnaissance monopulse station,” in *Proc. Int. Defense Conf. MILCON’95*, Abu Dhabi, Mar. 1995, pp. 553–567.

[3] J. B. LaGrande, W. D. Daniels, and R. L. Lewandowski, “SAW devices: The answer for channelized receivers?,” *Microwave Syst. News*, pp. 87–96, Dec. 1977.

[4] B. Stec and A. Rutkowski, “A planar microwave phase discriminator,” in *Proc. 27th European Microwave Conf.*, Jerusalem, Israel, 1997.

[5] H. Gruchala, C. Recko, A. Rutkowski, and B. Stec, “New kind of frequency detector in microstrip technique,” in *Proc. 10th Int. Microwave Conf.*, Ksiaz, 1994, vol. 1, pp. 117–121.

[6] N. Nagai, E. Maekawa, and K. Kono, “New n-way hybrid power dividers,” *IEEE Trans. Microwave Theory Tech.*, vol. 25, pp. 1008–1012, Dec. 1977.

[7] K. C. Gupta, R. Garg, and R. Chadha, *Computer-Aided Design of Microwave Circuit.* Dedham, MA: Artech House, 1981, pp. 330–371.