INTEGRATED MICROWAVE FREQUENCY DISCRIMINATOR WITH RAT-RACE 3dB HYBRIDS

Adam Rutkowski*[a], Hubert Stadnik[b]
[a]Military University of Technology, ul. Gen. Sylwestra Kaliskiego 2, 00-908 Warszawa, Poland,
[b]Military University of Aviation, ul. Dywizjonu 303 no. 35, 08-521 Dęblin, Poland

ABSTRACT

The microwave frequency discriminators (MFD) are important part of instantaneous frequency measurement (IFM) receivers. There are known, so-called, single function discriminators (SFMFD) and quadrature discriminators (QMFD). The QMFDs have a more complicated structure but enable achieve, in comparable conditions, a higher frequency measurement resolution. Directional couplers, among other elements, are used for MFD construction. The couplers based on coupled lines provide wide operation frequency band but their fabrication requires more complicated technology. The new structure of quadrature microwave frequency discriminator based on two single-step power dividers and two rat-race 3 dB couplers is proposed in the paper. The correlator of the QMFD was designed and fabricated onto single printed circuit board (PCB). The input port connector and connectors for output microwave detectors were mounted in such way to avoid crossings of the transmission lines on PCB. The middle part of the made discriminator's operation frequency range includes WiFi frequency band. Structure and measured parameters of the developed and fabricated quadrature microwave frequency discriminator were presented in the paper.

Keywords: microwave frequency discriminator (MFD), instantaneous frequency measurement (IFM), directional coupler, rat-race directional coupler

1. INTRODUCTION

The microwave frequency discriminator (MFD) is a passive device that allows for very quick measurement of temporary values of frequency and amplitude (power) of microwave signals. For this reason, it can be the basic component of instantaneous frequency measurement (IFM) receivers[1-6, 7, 8]. The MFD operating principle is based on a comparison of signals' phases propagating through at least two microwave delay lines with different electrical lengths. In addition to microwave phase discriminators (MPhD)[9], microwave frequency discriminators can also be used in reconnaissance stations[10]. The high speed of MFD operation i.e. providing slow-varying voltage proportional to frequency of the input microwave signal, results from the fact that vector operations used to determine the temporary value of frequency are performed on microwave signals by passive elements of relatively small sizes, i.e. comparable to the wavelengths of the analyzed microwave signals. There are so-called single-function discriminators. These are systems with one microwave element of power splitting and one element of microwave signals' vector summation[4, 11, 12]. They can be used where precision is not a main requirement but size of device is the more important parameter. Increasing the measurement accuracy using single-function discriminators very similar to those described in[11] was obtained in multi-channel devices containing several delay lines with different electrical lengths[13, 14, 15]. The so-called quadrature microwave frequency discriminators (QMFD) [1-6, 7, 8] have a higher resolution of frequency measurement, but also a greater complexity of their structures. They contain three elements of signal splitting and two elements of vector summation in their structure. For instance in[4] there were presented one QMFD version based on five rat-race couplers and one structure of QMFD based on five 90° overlap couplers. In[1, 2, 4, 8] it can be found quadrature discriminators with three 3dB/90° directional couplers and two power dividers. The QMFD presented in[7] consists of one power divider, one 180° directional coupler and three quadrature directional couplers. The width of the MFD useful bandwidth is determined by the design solution which were used and the parameters of utilized components. Therefore, research is carried out both in the scope of system modifications as well as aimed at developing microwave elements of the possibly simple design and possible to be carried out without the need for complex technologies. For example, such requirements can accomplish microwave directional couplers of type: slot-line, branch-line and so-called rat-race hybrids[4, 5].

*adam.rutkowski@wat.edu.pl

Radioelectronic Systems Conference 2019, edited by Piotr Kaniewski, Jan Matuszewski, Proc. of SPIE
Vol. 11442, 1144209 · © 2020 SPIE · CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2565284

The novelty of the presented work is the use in the QMFD structure only two rat-race couplers, three single-stage Wilkinson power dividers and one phase shifter. This version of the discriminator in an integrated form may require less space than the one based on five rat-race couplers. The developed printed circuit board has no crossings of microwave transmission lines.

2. MICROWAVE FREQUENCY DISCRIMINATOR BASED ON RAT-RACE COUPLERS

2.1 The general construction

A microwave frequency discriminator in a quadrature version based on microwave ring couplers (rat-race couplers) was developed for the works on methods and devices for monitoring electromagnetic space.

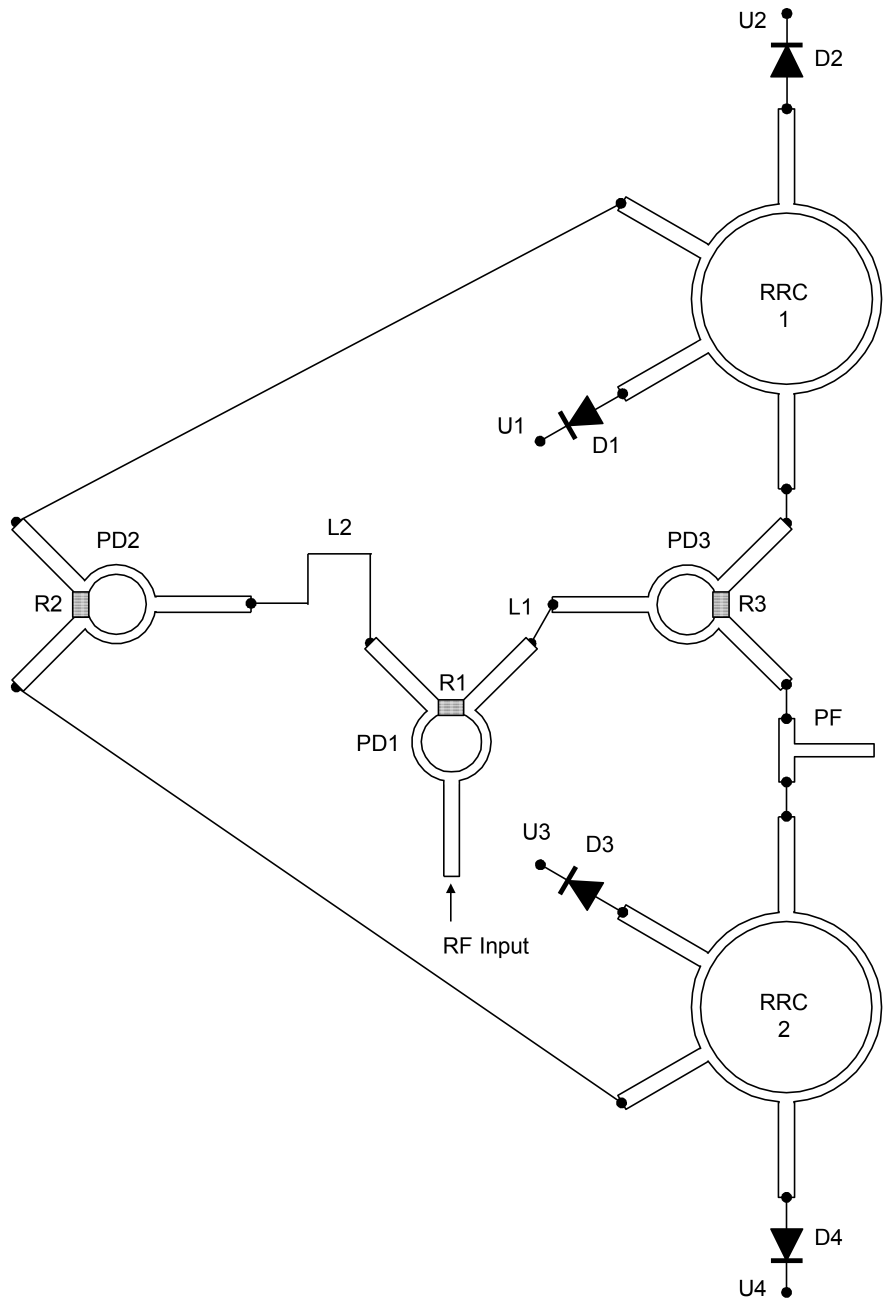

Figure 1. Structural diagram of the integrated quadrature microwave frequency discriminator with rat-race couplers.

The production of this type couplers in the microstripline technique does not require complex technology. Such elements can be made by photolithography or milling. The visual structure of the developed discriminator was shown in Figure 1. A microwave signal of unknown frequency f_{inp} is fed to the RF Input port made as an SMA connector. At next stages, the input signal is divided into several paths by PD1, PD2, PD3 power dividers. These are single-step Wilkinson-type power dividers with resistor R. Then, the rat-race couplers RRC1 and RRC2 perform vector summation of the particular signal pairs. Results of summations from output ports of directional couplers are passed to microwave amplitude detectors D1, D2, D3, D4 which have square transient amplitude characteristics. The voltages U1, U2 U3, U4 from the detectors are proportional to power of directional couplers output microwave signals' and carry an information about frequency f_{inp} of signal feeding RF Input port.

The temporary value of input signal's frequency can be estimated and expressed by the symbol f_m according to formula (1).

$$f_m = f_0 + W_m \cdot atg \frac{k_1 \cdot U1 - k_2 \cdot U2}{k_3 \cdot U3 - k_4 \cdot U4}, \qquad (1)$$

where: f_0 – center frequency of MFD measurement range, W_m, k_1, k_2, k_3, k_4 – coefficients distinctive for given discriminator.

Transmission lines connecting the ports of individual elements are symbolically represented by straight lines in Figure 1. The bands of discriminator's unambiguous frequency measurement is determined by the relation of physical lengths of lines L1 and L2. The greater the difference in the length of these lines, the better the measurement resolution is, but at the same time the width of the discriminator's unambiguous measurement range becomes narrower. The phase shifter PF inserted in front of one of the input ports of rat-race coupler RRC2 enables to achieve a quadrature dependence of voltage differences U1 – U2 and U3 – U4 in reference to frequency f_{inp} of the input signal.

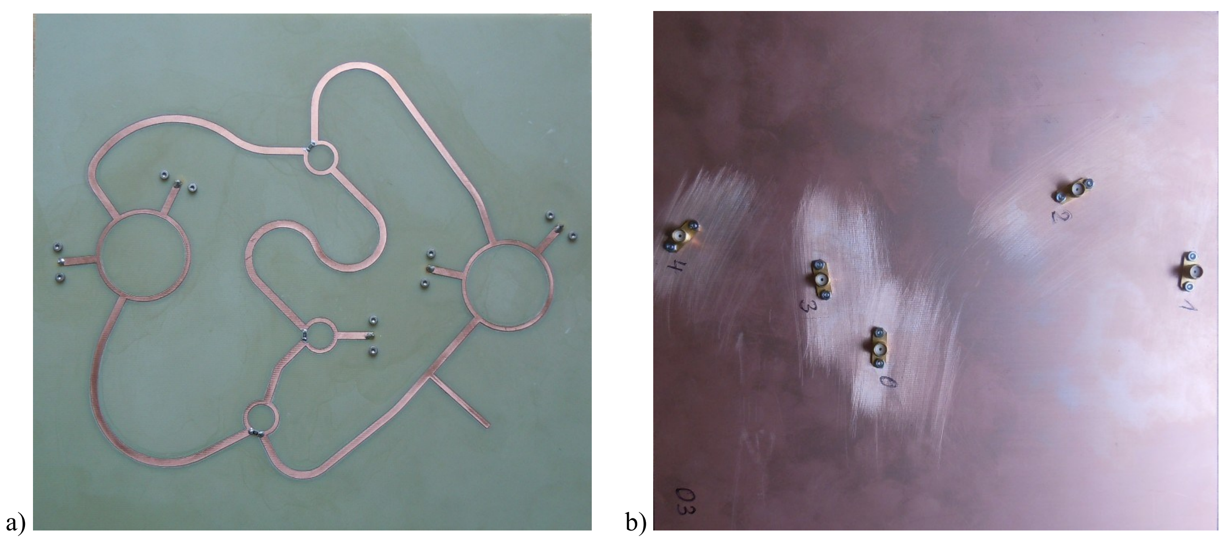

Figure 2. Integrated correlator of microwave frequency discriminator with rat-race couplers, a) view from side of paths, b) view from side of SMA connectors.

The entire discriminator's correlator, i.e. transmission lines, power dividers and ring couplers, was made in an integrated version on one printed circuit board (Figure 2a). Microwave detectors were connected using SMA connectors, which were mounted on the bottom side of PCB (Figure 2b). Thanks to such configuration, crossings of correlator's internal lines were avoided. Method of signal flow graph was used at the initial stage of device development. The final version of PCB was designed using the Genesys RF simulator.

2.2 Selected results of measurements

The measurement results of the developed and fabricated quadrature microwave frequency discriminator with rat-race couplers are presented in Figures 3 – 6. In the Figure 3 there are presented plots of output voltages U1, U2, U3, U4 versus frequency f_{inp} of the input microwave signal. They are close to sine-type waveforms around the designed frequency f_0. ≅ 2.45 GHz. Their shapes below a frequency of around 1.675 GHz and above of 3.145 GHz are unacceptable for instantaneous frequency measurement, but between these frequencies they are appropriate for such purposes. Discriminator's transient characteristic i.e. estimated frequency f_m versus frequency f_{inp} of input signal was shown in Figure 4. As it can be seen, between frequency of 1.675 GHz and of 3.145 GHz, its shape is very close to a straight line. These frequency values are the boundaries of the discriminator's operating frequency band. Over this band measurement of frequency is unambiguous. According to the assumptions, the discriminator can be used to observe and measure the instantaneous frequency of signals used, among others, by 2.45 GHz WiFi systems. The operational bandwidth is close to one octave. The ratio of the upper (f_{up}=3.145 GHz) and lower (f_{lo}=1.675 GHz) frequency of the band (Figure 4) is about of f_{up} / f_{lo} = 1.88. In the frequency range from about of 1.95 GHz to about of 3.145 GHz, the measurement deviation (Figure 5), determined in conditions that the estimation of the f_m value will be made directly without the use of any correction algorithms, is not greater than ±20 MHz. However, around of 1.8 GHz, the frequency measurement deviation increases to around of 60 MHz.

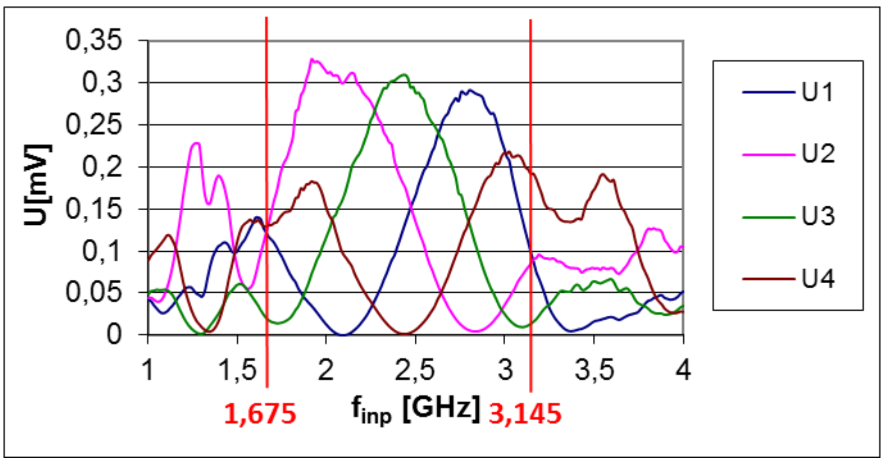

Figure 3. Integrated microwave frequency discriminator's output voltages versus frequency of input microwave signal.

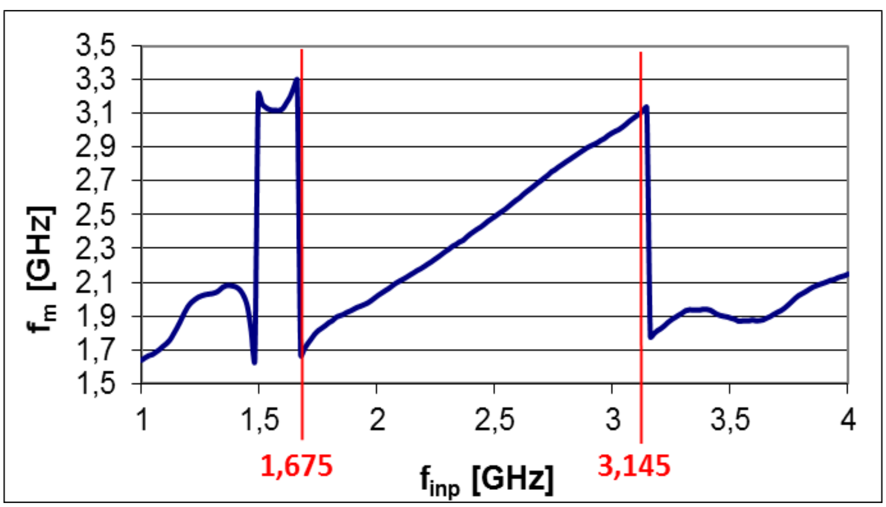

Figure 4. Transient characteristic of the developed quadrature microwave frequency discriminator with rat-race couplers made in the integrated version.

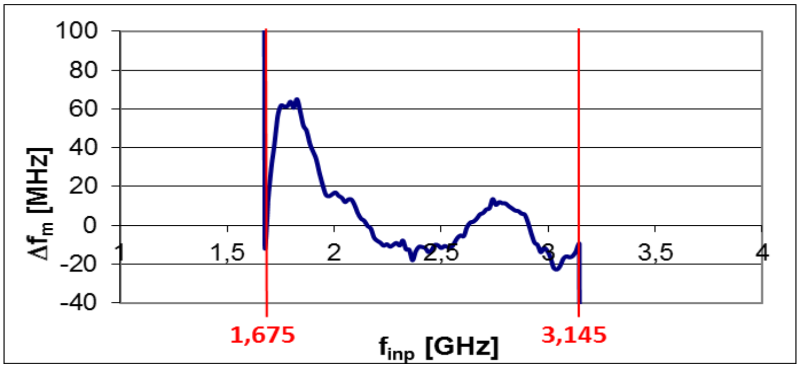

Figure 5. Frequency measurement deviation of the developed integrated quadrature microwave frequency discriminator with rat-race couplers (results of measurement).

Microwave frequency discriminator's properties can be very accurately illustrated by means of polar graph, which was presented in Figure 6.

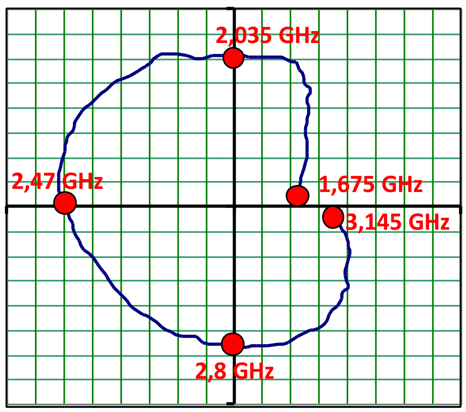

Figure 6. Polar version of transient characteristic of the developed integrated quadrature microwave frequency discriminator with rat-race couplers (results of measurement).

Axis X in this graph was fed by difference U4-U3 but axis Y was fed by difference U2-U1. This kind of visualization of information from MFD provides estimation both of temporary frequency value and of temporary amplitude (strength) value of input signal as well.

3. CONCLUSIONS

The developed quadrature microwave frequency discriminator based on 3 dB rat-race couplers was made on one printed circuit board by milling. This discriminator allows for observation of microwave signals of WiFi band devices and, for example, mobile base stations operating in the DCS 1800 MHz and of LTE bands. The maximum frequency deviation of the model of discriminator, which was made, reaches 60 MHz, but in most of the useful band does not exceed ±20 MHz. This measurement deviation can be significantly reduced by calibration and the use of correction algorithms in unit estimating frequency basing on MFD output voltages.

REFERENCES

[1] Smólski, B., "Analysis and synthesis of microwave instantaneous frequency measurement devices", The Supplement of the Bulletin of Military University of Technology No 7(335) WAT, Warszawa, Poland, (1980), (in Polish).

[2] Stec, B., "Analysis and investigation of the microwave frequency discriminator", The Bulletin of Military University of Technology No 7(431), Warszawa, Poland, July, 29-36, (1988) (in Polish).

[3] Tsui, J.B.–Y., McCormik, W.S., “Instantaneous frequency measurement (IFM) receiver with only two delay lines”, United States Patent 4,963,816, Oct. 16, (1990).
[4] East, P.W., “Fifty years of instantaneous frequency measurement”, IET Radar Sonar Navigation, Vol. 6, Issue 2, 112–122, (2012).
[5] Rutkowski, A., Stadnik, H., “IFM Receiver Based on Microwave Frequency Discriminator That Uses Rat-Race Directional Couplers”, 22nd International Microwave and Radar Conference MIKON 2018, May 15-17, 2018, Poznań, POLAND, Pen drive issue, 865 – 867, (2018).
[6] Chatterjee, D., Blau, K., Hein, M.A., “A wide dynamic range microwave frequency discriminator for cognitive radio”, Proceedings of the 45th European Microwave Conference, France, Paris, September 7-10, 2015, 889-892, (2015).
[7] Kondakov, D., Lavrov, A.P., “Instantaneous Frequency Measurement Receiver Performance Analysis for AM, FM Signals”, Conference: 15th International Conference on Next-Generation Wired/Wireless Advanced Networks and Systems (NEW2AN) and 8th Conference on Internet of Things and Smart Spaces (ruSMART), St Petersburg, RUSSIA, August 26-28, 2015, Book series: Lecture Notes and Computer Science, Volume 9247, 605-611, (2015).
[8] de Moura Barbosa, G.M.C., dos Santos, J.C.A., “2-4 GHz Digital Frequency Discriminator (DFD) Design for Microwave Receivers”, SBMO/IEEE MTT-S International Conference on Microwave and Optoelectronics, 2005, Brasilia, Brazil, July 25-25, 2005, 381-385, (2005).
[9] Stec, B., “Wideband homodyne device for microwave circuits measurement,” V Conference on Microwave Electronics of Solid State, MECS, Poland, Gdańsk, 27-30 October, 1980, 353 – 357, (1980), (in Polish).
[10] Stec, B., “Radioelectronic reconnaissance monopulse station,” International Defence Conference, Abu Dhabi, 19-23 March 1995, 553-567, (1995).
[11] Gruchała, H., Rutkowski, A., “Frequency detector with power combiner dividers”, IEEE Microwave and Guided Wave Letters, Vol. 8, No. 5, May 1998, 179-181, (1998).
[12] Rećko, Cz., Stec, B., “Modification of microwave frequency detector characteristic with the use of phase shifter”, Metrology and Measurement Systems, Vol. 25 (2018) No. 4, 769-777, (2018).
[13] Espinoza-Espinoza, M., de Oliveira, B.G.M., Llamas-Garro, I., de Melo, M.T., “2-Bit, 1-4 GHz Reconfigurable Frequency Measurement Device”, IEEE Microwave and Wireless Components Letters, Vol. 24, No. 8, August 2014, 569-571, (2014).
[14] Espinoza-Espinoza, M., de Oliveira, B.G.M., Llamas-Garro, I., de Melo, M.T., Kim, J.-M., “4-Bit, 1-4 GHz Reconfigurable Discriminator for Frequency Measurement”, Proceedings of the 9th European Microwave Integrated Circuits Conference, Italy, Rome, October 6-7, 2014, 652-655, (2014).
[15] Espinoza-Espinoza, M., de Oliveira, B.G.M., Llamas-Garro, I., de Melo, M.T., Kim, J.-M., “A comparison between 4-bit fixed and reconfigurable microwave discriminators for frequency identification”, Proceedings of the 2016 URSI Asia-Pacific Radio Science Conference, Korea, Seoul, August 21-25, 2016, 1104-1106, (2016).