Technical realization of the device for integrated monitoring of the parameters of the microwave path

Yu Gimpilevich, I Afonin, V Vertegel and Yu Tyschuk
Sevastopol State University, 33 Universitetskaya St., Sevastopol, 299053, Crimea

E-mail: y.tyschuk@gmail.com

Abstract. Two designs of a microwave sensor have been developed for a device for built-in monitoring of microwave path parameters, built on the basis of a broadband quadrature measurement method. The first sensor design is made on the basis of a symmetrical strip line, the second - on the basis of a segment of a coaxial line. Each of the microwave sensor designs consists of three parts: a directional coupler and two non-directional measuring probes. The microwave sensor is designed to operate in the 1 - 2 GHz frequency range. The paper also proposes a variant of the circuitry implementation of the built-in microwave control device, which implements the procedure for broadband automatic measurement of the complex reflection coefficient and the power level in the microwave path based on the method of quadrature measurements. The device solves the problem of long-term automatic monitoring of parameters and timely detection of the beginning degradation of the antenna-feeder path.

1. Introduction
Currently, built-in microwave control devices are widely used. For this, as a rule, measuring devices are used, built on the basis of direct detection methods using square-law microwave diodes [1-4]. The principle of operation of these devices is based on the analysis of the amplitude distribution of an electromagnetic wave in a transmission line. Such devices have small dimensions and weight, which allows them to be built in the required amount in various sections of the microwave path without significantly affecting the mass and size characteristics of the latter. The disadvantage of such devices is the low measurement accuracy, since the microwave diodes used for amplitude detection have a small dynamic range of square-law detection (about 30 - 40 dB). This leads to a significant measurement error, as well as to a sharp decrease in accuracy (and even the impossibility of making measurements) when changing the power in the microwave transmission line over a wide range. This drawback is largely overcome in the quadrature measurement method developed by the authors [5-9]. The device [6-8] created on the basis of this method is narrow-band. The creation of a wide-band automatic built-in control device based on the quadrature measurement method is an important and urgent task, which is solved in this article. The main components of the built-in control device are a microwave sensor and an information processing unit. The microwave sensor is implemented in two versions: based on a strip line and based on a coaxial line.

2. A strip microwave sensor for a broadband device for built-in control
In [8], the results of the development of a narrow-band microwave sensor for a device for built-in control of parameters of microwave paths are presented. This sensor is made in a strip-like form on a printed
circuit board with a thickness of 1 mm (dielectric material - FR4). The sensor consists of four main elements: directional coupler, power divider, two non-directional measuring probes. The main disadvantage of the sensor [8] is that it is designed to operate in a narrow frequency band around the central frequency of 1.5 GHz.

On the basis of the developed model of the broadband quadrature measurement method, the authors of this article have created the structure of a new microwave sensor operating in the 1 - 2 GHz frequency band. The main differences of the new structure of the microwave sensor are the following:

- only one quadrature detector was used in the circuit, which made it possible to exclude the power divider;
- a multi-link directional coupler was used, which made it possible to expand its operating frequency band;
- reduced longitudinal dimensions of the sensor due to the placement of non-directional probes in the communication area of the directional coupler.

The topology of the developed microwave sensor based on a strip line is shown in figure 1. The sensor is made on the basis of a symmetrical strip line with a total dielectric thickness (FR4) of 3 mm. Figure 1 shows the following input and output ports: 1 — input of the main microwave path; 2 - output of the main microwave path; 3 - direct wave output of directional coupler (DC); 4 - DC backward wave output connected to matched load; 5 and 6 - outputs of non-directional measuring probes.

Figure 2 shows a model of a microwave stripline sensor. The developed hybrid printed circuit board contains a symmetrical strip line, on the basis of which a directional coupler and non-directional measuring probes are made, as well as elements of an asymmetrical strip line, on which matching attenuators and connections to connectors are made.

Figure 3 shows the exterior of the manufactured strip microwave sensor, which was used for experimental studies.
Figure 2. Model of the printed circuit board of the microwave stripline sensor.

Figure 3. External view of the manufactured strip microwave sensor.

Figure 4 shows the results of modelling (solid lines) and experimental studies (plotted by dots with adjacent numerical values) of the S-parameters of the developed sensor.

Figure 4. Results of modelling and experimental measurements of S-parameters of a microwave stripline sensor.

In the operating frequency band (1-2 GHz), the transient attenuation of the directional coupler varies from $-12$ dB to $-11$ dB, and its directivity is no worse than 20 dB. Attenuation of non-directional measuring probes in the operating frequency band varies in the range from $-25$ to $-32$ dB, which ensures normal operation of quadrature detectors and insignificant shunting effect of the probes on the primary microwave path.

The results of experimental measurements showed that the printed circuit board of the microwave probe performed quite accurately, since the difference between theoretical and experimental results is rather small.
3. **Coaxial microwave sensor for a broadband built-in control device**

The developed coaxial microwave sensor consists of an air-filled coaxial line, in which a directional coupler and two non-directional measuring probes are placed in the gap between the outer and inner conductors. The length of the coaxial sensor is 100 mm. The developed sensor is intended for operation in the frequency range 1 - 2 GHz.

The inner conductor of the coaxial line has a diameter of 3.04 mm, the outer one is 7 mm. N-type connectors are attached to the ends of the coaxial sensor.

A model of a coaxial microwave sensor is shown in figure 5. The designations of the outputs of the coaxial microwave sensor are the same as for the strip microwave sensor.

The secondary line of the directional coupler is made in the form of a piece of wire with a diameter of 1 mm and a length of 50 mm, immersed in the primary transmission line by 0.5 mm.

Non-directional measuring probes are made in the form of wire pieces with a diameter of 1 mm and a length of 1.5 mm, at the submerged ends of which metal disks with a diameter of 3 mm are placed. Metal discs are needed to increase the capacitive coupling of the probes to the field in the transmission line (reduce transient attenuation) at shallower immersion depths.

![Figure 5. Model of a coaxial microwave sensor.](image)

Figure 6 shows the external view of the manufactured coaxial microwave sensor used for experimental studies.

![Figure 6. External view of the manufactured coaxial microwave sensor.](image)

Figure 7 shows the results of modelling (solid lines) and experimental studies (indicated by dots with signed numerical values) of the parameters of the coaxial microwave sensor.

The attenuation in the main channel of the microwave power transmission does not exceed 0.5 dB, which is associated with a small value of the transient attenuation (10 dB) of the directional coupler, which is necessary for the normal operation of the quadrature detector.

The calculated value of the transient attenuation of the directional coupler, as in the case of the microwave stripline sensor, varies from −11 to −10 dB. The experimentally measured values are 1 dB less.
The directivity of the DO is close to 20 dB in the entire operating frequency range. Omnidirectional probes attenuate the branch signal by 25 - 30 dB.

Figure 7 shows that the results of calculation and experiment are close.

4. Block of information processing

The performed development is the development of ideas and approaches described in [8]. Main innovations: expansion of the operating frequency band; autonomy of all operations of mathematical processing of measurement results; periodic correction of the zero drift of the measuring path during the operation of the device. All these innovations are hardware and software provided by the information processing unit, the main unit of which is the analogue-digital processing module.

Unlike the device described in [8], a microwave switch is installed at the input of the information processing unit of the new device, which provides 3 options for connecting the measuring input of the quadrature detector: to probe 1; to probe 2; to a 50-ohm load (built into the microwave switch). This approach makes it possible to exclude one quadrature demodulator from the measurement circuit, which ensures that the parameters of the measurement channel are identical for signals from both measurement probes. In addition, measure and compensate for the zero drift that occurs in the analogue part of the instrument. As a microwave switch, the SKY13414-485LF microcircuit (Skyworks) was used, which has a built-in 50-ohm load and allows signal switching in the frequency range from 0.1 GHz to 3.8 GHz.

The device uses an integrated quadrature demodulator based on the ADL5382ACPZ microcircuit. Two low-pass filters are installed on the quadrature outputs of this microcircuit.

This design uses a differential 24-bit sigma-delta ADC ADS1261BIRHB, with multiple multiplexed input channels and an integrated low-noise differential amplifier with software switchable gain, which allows to expand dynamic range of measured signals.

The microcontroller is implemented on the K1986BE92QI microcircuit. This microcontroller provides control of all elements of the built-in control device, calculation of the determined parameters of the microwave path by solving a system of nonlinear measuring equations.

Based on the approaches and principles described above, a four-layer printed circuit board of the ADC module was developed. Board size: 65x60mm. The 3D model of the board is shown in figure 8 (view from the microcontroller side). Figure 9 shows the external view of the manufactured printed circuit board of the information processing unit (view from the installation side of the quadrature detector).
5. Conclusions

Two designs of a microwave sensor have been developed: strip and coaxial, intended for a broadband device for built-in monitoring of microwave path parameters operating in the 1 - 2 GHz frequency band. The attenuation introduced by each of the sensors into the transmission line does not exceed 0.75 dB. The directivity of the couplers is not worse than 20 dB.

A new hardware structure of the built-in microwave control device is proposed, which differs by the detector path common for the signals of the two probes, the presence of a system for periodic correction of the zero drift and means of mathematical processing and display of information. Such an implementation of the device will improve the accuracy of measuring the parameters of the microwave path under conditions of long-term operation without regular maintenance.

Acknowledgements

This work was supported by the Sevastopol State University, Grant No. 24/06-31.

References

[1] Abubakirov B A, Gudkov K P and Nechaev E V 1984 Measurement of Parameters of Radio Engineering Circuits (Moscow: Radio and communication)

[2] Gimpilevich Yu B and Smailov Yu Y 2005 A Method for measuring of two microwave signals vector ratio Proc. of the 5th IEEE Int. Conf. on Antenna Theory and Techniques 397-98

[3] Gimpilevich Yu B and Noskovich V I 2007 Calibrated complex reflectance meter on the basis of two-channel microwave transducer Telecommunications and Radio Engineering 66(4) 363-71

[4] Gimpilevich Yu B 2008 The estimation of built-in devices measurement error influence on the authenticity of microwave units parameters monitoring Proc. Int. Conf. on Modern Problems of Radio Engineering, Telecommunications and Computer Science, TCSET-2008 518-9

[5] Gimpilevich Yu B and Zebek S E 2014 The mathematical model of a complex reflection coefficient measuring instrument based on a method of direct frequency conversion Proc. of the 24th IEEE Int. Conf. on Microwave & Telecommunication Technology 2 882-3

[6] Gimpilevich Yu B, Vertegel V V and Tischuk Yu N 2020 Mathematical model of the measuring procedure of an automatic device for built-in monitoring of microwave path parameters Proc. of the 7th All-Russian Microwave Conf. 304-6

[7] Gimpilevich Yu B and Tischuk Yu N 2020 Calibration procedure for a quadrature meter of microwave path parameters Proc. of the 7th All-Russian Microwave Conf. 313-5

[8] Gimpilevich Yu B, Tischuk Yu N and Afonin I L 2020 Development, modeling and experimental research of a two-probe microstrip impedance sensor Proc. of the 7th All-Russian Microwave Conf. 310-2

[9] Gimpilevich Yu B and Zebek S E 2020 Proc. of the 7th All-Russian Microwave Conf. 307 - 9