The journal returns to the theme of multifunctional methods of measurement in the microwave band (see Izmeritel'naya Tekhnika, No. 3, 52-66, 1994). This set of papers presents the results of investigations of a microwave multimeter, developed by specialists at the VNIIFTRI, examples of its application and experience in using the instrument for metrological purposes.

STABILITY OF MICROWAVE MULTIMETER ALGORITHMS

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Apparatus-program methods of increasing the stability of microwave multimeter algorithm are considered.

Experience in using microwave multimeters and automatic microwave-circuit analyzers confirms that their measurement error varies considerably over the frequency band, and at certain frequencies exceeds severalfold the error of the standard, which is calibrated using a similar multifunctional instrument. Hence it is not always possible to predict what parts of the operating frequency band are so affected that the instrument is no longer in its class of accuracy. For automatic measurements this manifests itself in instability of the algorithms, in the sense that small perturbations in the initial data lead to unacceptably large errors.

Below we consider the reasons for the instability of the operation of multifunctional microwave instruments and propose apparatus and algorithmic improvements which eliminate this drawback.

The phenomenon investigated can be illustrated physically using the example of a microwave multimeter in which a multiprobe feed-through power converter is used [1]. If the periodicity in the arrangement of the pickups along the waveguide is identical with the periodicity of the standing-wave pattern in the waveguide, all pickups will give the same signals and it is not possible to establish the field pattern. Mathematically this manifests itself in degeneracy of the algebraic system of equations and in the fact that there is an infinite number of solutions. If the periodicities are not the same but are close to one another, a solution exists, but it is of low stability since small errors in the readouts of the individual probes considerably perturb this solution, i.e. considerably distort the measured parameters of the electromagnetic oscillations (the power) and the load (the complex reflection coefficient). This manifests itself mathematically in a high conditionality number of the algebraic system of equations.

In the ideal case, the error of a microwave multimeter is equal to the errors of the standards by means of which it is calibrated. In fact the instrument compares the measured physical quantity with the physical quantity reproduced by the standard, i.e. it acts as a comparator and has its own comparison error, which, together with the error of the standard, makes up the resultant error of the measurements.

What factors affect the comparison error and what apparatus and algorithmic measures can be taken to minimize it? The answer to this question enables us to optimize the construction of the instrument and the software and should also provide a basis for standardizing its metrological characteristics.

We will analyze the operation of a microwave multimeter which contains a four-pickup transmission converter [2], and we will then generalize the results to a larger number of pickups. A simplified block diagram of the instrument is shown in Fig. 1. It includes a waveguide transmission converter and electronic processing indicator instruments. The figure also shows the pattern of the field-strength amplitude of the hybrid wave along the waveguide channel (l_i are the distances from the i-th pickup to the first and P_i are the readouts taken from the pickups).
By considering the converter as a cascade connection of point power pickups [3], we can write the signals from the pickups in the form

\[ P_i = \sigma_i P_0 \left[ 1 + \left( S_i e^{i \varphi} \right)^2 + 2 S_i e^{i \varphi} \cos \left( \frac{4 \pi l_i}{\lambda} + \varphi_i - \varphi \right) \right], \quad i = 1, 2, 3, 4, \]

where \( P_0 \) is the power of the electromagnetic oscillations applied to the input of the converter, \( \Gamma \) and \( \varphi \) are the modulus and phase of the reflection coefficient of the load connected to the output of the converter, \( \alpha_i \) is a coefficient which takes into account the coupling of the \( i \)-th pickup with the channel, and \( S_i \) and \( \varphi_i \) are amplitude and phase coefficients which take into account the shunting action of the pickups (in the ideal case of pickups without losses \( S_i = 1, \varphi_i = 0 \)).

We will introduce an auxiliary quantity, namely, the weighted sum of the readouts

\[ P_w = P_1 + k_1 P_2 + k_2 P_3 + P_4, \]

where the coefficients \( k_1 \) and \( k_2 \) are defined in such a way that \( P_w \) is independent of the phase \( \varphi \). It can be shown that this requirement is satisfied if

\[
\begin{align*}
    k_1 &= \left[ -\sigma_1 S_1 \sin \left( 4 \pi l_1 / \lambda + \psi_1 - \psi_2 \right) + \sigma_2 S_2 \sin \left[ 4 \pi (l_1 - l_2) / \lambda + \psi_3 - \psi_4 \right] \right] - 1; \\
    k_2 &= \left[ \sigma_1 S_1 \sin \left( 4 \pi l_2 / \lambda + \psi_2 - \psi_3 \right) - \sigma_2 S_2 \sin \left[ 4 \pi (l_2 - l_3) / \lambda + \psi_4 - \psi_1 \right] \right] - 1.
\end{align*}
\]

The normalized signal of the \( i \)-th pickup is

\[ U_i = P_i \left( \alpha_i + k_1 \alpha_2 + k_2 \alpha_3 + \alpha_4 \right) + \Gamma^2 \left( \alpha_1 S_1^2 + \alpha_2 S_2^2 + \alpha_3 S_3^2 + \alpha_4 S_4^2 \right) + \left( \alpha_i (P_1 + k_1 P_2 + k_2 P_3 + P_4) \right)^{-1}. \]

Substituting (1) into (5) we obtain

\[ U_i = 1 + \left( S_i e^{i \varphi} \right)^2 + 2 S_i e^{i \varphi} \cos \left( 4 \pi l_i / \lambda + \psi_i - \varphi \right), \quad i = 1, 2, 3, 4. \]

The purpose of these and subsequent transformations is to solve the system of transcendental equations (1) for \( P_0, \Gamma \) and \( \varphi \) by successively eliminating \( P_0 \) and \( \varphi \) and by constructing an iterative formula for \( \Gamma \), which can be analyzed for stability.

We multiply each of the equations of (6) by a factor such that the amplitudes of the harmonic terms are equal to one another in all four equations. We will denote these terms by \( V_i \):