PROBLEM OF TESTING HIGH-FREQUENCY PHASE METERS

(UDC 621.317,77,029.5,089.6)

A. M. Prokhorov

Translated from Izmeritel'naya Tekhnika, No. 7, pp. 47-51, July, 1966

The problem of testing phase meters, especially of the high-frequency variety, has not as yet been completely solved. Reference phase-angle standards have not as yet been adopted in the testing practice. Methods for checking phase meters are complicated and require a personnel with a relatively high qualification. In this connection, the finding of simple methods for evaluating phase-meter errors, at least for several tested angles, is of considerable interest.

One of these methods is dealt with in this article. It is based on using phase shifters which are calibrated at a single frequency directly by means of the tested phase meter. By selecting a given set of frequencies it becomes possible, as it will be shown later, to evaluate the error of phase meters at multiples of $\pi/2$.

Such phase shifters may consist of sections of long lines. The utilization of lines (including coaxial cables) as phase shifters is not a new idea, and it is widely used in various branches of radio technology. Long lines have not as yet been used as reference phase shifters because the parameters of lines (especially coaxial cables) and of loads cannot be determined with the required degree of precision. However, provided certain conditions are met, long lines can be used as reference phase shifters whose phase shifts are multiples of $\pi/2$.

Moreover, such line sections can also be used for other purposes when it is necessary to obtain precise phase-shift multiples of $\pi/2$. Let us prove this assertion. From the theory of long lines it is known that the relationship between the voltage across the load of a line and across its input can be represented by

$$U_1 = U_2 \cos \gamma l + \frac{I_2}{G} \sin \gamma l,$$

where $U_1$ is the voltage at the input of the line, $U_2$ is the voltage across the load of the line, $I_2$ is the current through the line load, $\gamma$ is the propagation constant of the line, and $l$ is the physical length of the line.

The transmission constant of the line is

$$K = \frac{U_2}{U_1} = \frac{1}{\cos \gamma l + \frac{G}{R} \sin \gamma l},$$

where $G$ is the admittance of the load.

Taking into consideration that $\gamma = \beta + j\alpha$ and $G = 1/R - j1/X$ ($R$ and $X$ are the real and imaginary components of the load in a parallel equivalent circuit). We find, after simple operations, that

$$K = \frac{1}{\cos \alpha l + \frac{W}{X} \sin \alpha l + \frac{W}{R} \sin \alpha l + \frac{W}{R} \sin \alpha l + \frac{W}{R} \sin \alpha l + \frac{W}{R} \sin \alpha l}.$$

The phase shift in the line is

$$\tan \varphi = \frac{\frac{W}{X} \sin \alpha l - \left(\frac{W}{R} \sin \alpha l + \frac{W}{R} \sin \alpha l\right)}{\cos \alpha l + \frac{W}{X} \sin \alpha l + \frac{W}{R} \sin \alpha l + \frac{W}{R} \sin \alpha l}.$$

918
Let us assume that there are no losses in the line, i.e., that $\beta = 0$,

$$\varphi = -\arctan \frac{\frac{W}{R} \sin \alpha l}{\frac{W}{X} \sin \alpha l},$$

It will be seen from (5) that, assuming the electrical length of the line to be $\alpha l = \pi m$ ($m = 0, 1, 2, \ldots$), its phase shift $\varphi$ will also be equal to $\pi m$, but with the opposite sign. However, if $\alpha l = \pi (m + \frac{1}{2})$, the phase shift in the line will be

$$\varphi = -\arctan \frac{X}{R} = -\left[ \pi \left( m + \frac{1}{2} \right) - \arctan \frac{R}{X} \right].$$

Thus, the phase shift $\varphi$ in a line with an electrical length of $\alpha l = \pi m$ is equal precisely to $\alpha l$, and for $\alpha l = \pi (m + \frac{1}{2})$ it differs from $\alpha l$ by $\arctan \frac{R}{X}$ (or $\arctan \frac{R}{X}$ for a small value of $R/X$) independently of the matching between the line and its load. This circumstance makes it possible to use lengths of line as reference phase shifters for testing phase meters over a wide frequency range.

The testing is done in the following manner. A tentative estimation is made of a line length which is a multiple of $2\pi n$ at the upper operating frequency of the phase meter. In this case, the higher the value of $n$, the larger will be the number of frequencies at which the phase meter can be tested. This length of line is then measured by means of the tested phase meter and the operating frequency is adjusted until the phase-meter readings become equal to zero. The electrical length of the line will then be equal precisely to $2\pi n$. The operating frequency $f_0$ should be measured on a frequency meter with an error determined by that of the reference phase meter which will be described below. By setting the test frequencies at intervals of $f_0/4n$ we can obtain phase angle values of $2\pi n - m\pi/2$, i.e., in steps of $90^\circ$, with values of 0 and $\pm 180^\circ$ being precise, and those of $\pm 90^\circ$ having a correction of $\Delta \varphi \approx R/X$. The error of correction $\delta \varphi_c$ is determined by the error of resistance ($R$) and reactance ($X$) which constitute the load. Since the reactive component $X$ is, as a rule, capacitive, we find that the phase-shift error at points $\pm 90^\circ$ decreases proportionately to frequency.

Let us now examine the possible error of a line section used as a phase shifter. The sources of errors consist of an inaccurate setting of operating frequencies and line nonuniformities and losses.

If the frequency measurement error is equal to $\delta f$, the error in setting the initial frequency $f_0$ will be $\delta f \cdot f_0$, and the maximum error in setting a multiple frequency $f_m = f_0/m$ will be $2\delta f \cdot f_0/m$. Since the electrical length of the line is proportional to frequency, the phase angle error will be $\delta \varphi_f = 2\pi m \delta \varphi_f / m$. It is obvious that $\delta \varphi_f$ will have a maximum value at $m = 1$, i.e., near $f_0$. In the limit for $m = 1$ we have $\delta \varphi_f = 4\pi \delta f$. The number of $n$ is determined by the number of test frequencies, which is equal to $4n - 1$, since the initial frequency $f_0$ is not used for testing.

Let us now evaluate the error due to line irregularities. Let us assume that the line has an irregularity in the form of a lumped admittance $G_0$ at a distance $S$ from the beginning of the line (see figure).

After simple calculations we obtain an expression for the transmission constant of the line in the following form:

$$K = \frac{U_2}{U_1} = \frac{1}{ch \gamma l + G_0 W \sinh \gamma l + G_0 W \sinh S \left[ ch \gamma (l - S) + G_0 W \sinh (l - S) \right]}.$$  

Let us simplify this expression by adopting the following conditions. First, let us assume that there are no losses in the line, since, in actual lines, the losses are small and their effect on the error is also small. Second, it is possible to neglect the reactive component of the load, since, according to the test conditions, it is also small and has no noticeable effect on results. By taking these assumptions into consideration and denoting $G_0 = 1/\rho_0 - j/\rho_0$, we obtain

$$K = \frac{1}{\cos \alpha l + \frac{\frac{W}{R} \sin \alpha l}{\frac{1 - j}{\rho_0}}} W \sin S \times \left[ \cos \alpha (l - S) + j \frac{W}{R} \sin \alpha (l - S) \right].$$

919