This method is also applicable when instead of a cavity for measuring $|S_{11}|$ one employs a measurement line and a moving short-circuit, between which the four-terminal network is placed [1]. In order to calculate the corrections in (4), the losses may be determined by the impedance method [1] and the loss angle from

$$\sin \gamma = \frac{k_{\text{max}} - k_{\text{min}}}{4|S_{11}|(k_{\text{max}} + 1)(k_{\text{min}} + 1)},$$

where $k_{\text{max}}$ and $k_{\text{min}}$ are the maximum and minimum values of $K_{\text{STU}}$ observed at the input of the network on moving the short circuit.

With slight additional complication, the method is applicable when the moduli of the reflection coefficients at the inputs of the network are not equal but differ by not more than 10%.

The modified method of measuring the modulus of the reflection coefficient for a network with small losses by reference to points on the minimum-displacement curve retains the high accuracy while reducing by a substantial factor the effort involved by comparison with the standard one. It is useful in monitoring and checking measurement lines by reference to $K_{\text{STU}}$ and also in examining the degree of matching between various uhf devices with small losses.

LITERATURE CITED


STABILITY IN CALORIMETRIC CIRCULATION TRANSDUCERS IN UHF WATTMETERS

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Studies on the accuracy and stability [1] indicate that it is necessary to improve the metrological parameters of calorimetric wattmeters for high uhf power ($10^{-10} \text{ W}$). A study has been made [2] of the effects of various factors on the systematic error of primary circulation calorimetric transducers CCT in these wattmeters. Here we examine some of the sources of error that influence the long-term stability of the CCT and give experimental results.

We consider a CCT with parallel flow division, which is the commonest form and which employs periodic comparison, while we note the features of other types of CCT. In these CCT, there is an error due to inexact hydrothermal balance in the differential part $\delta_b$. Temperature instability in the coolant results in a temperature difference between the inlet and outlet of the calorimetric part $\Delta T$, which in general is determined by the liquid displacement time $\tau_L$ in this part [3] and by the dynamic thermal loss $P_T(\tau)$:

$$\Delta T(\tau) = \frac{P_T(\tau)}{Gc} + \frac{\Delta t(\tau)}{c} \cdot \tau_L,$$

(1)

where $G$ is the flow rate of the coolant in kg/sec, $c$ is the specific heat of this in J/kg·°K, and $\Delta t(\tau)$ is the derivative with respect to time of the difference $\Delta T(\tau)$ between the current and initial temperatures of the coolant at the inlet.

The power $P_T(\tau)$ for $\tau > (1-2)$ min can be put as

$$P_T(\tau) \approx C_\Delta \Delta t(\tau) + K\Delta T(\tau),$$

(2)

where $C_e$ is the effective specific heat of the calorimetric part that influences the heat transfer and $X$ is the heat-transfer coefficient of that part.

In this form of CCT, $\delta_b$ by definition takes the form

$$
\delta_b = \frac{\Delta T_w - \Delta T_o}{\Delta T_w} - \frac{\Delta T_w - \Delta T_o}{\Delta T_w},
$$

(3)

where $\Delta T_w^c$ is the temperature difference in the coolant in the calorimetric part due to the measured $p_m$ and calibration $p_c$ power levels, while the indices $w$ and $o$ relate respectively to the working and reference arms of the differential part of the CCT.

Substitution of (1) and (2) into (3) and transformation gives

$$
\delta_b = h_1 \left[ \frac{\Delta t (\tau c)}{p_c} - \frac{\Delta t (\tau m)}{p_m} \right] + \Delta_2 \left[ \frac{\Delta t (\nu w)}{p_c} - \frac{\Delta t (\nu o)}{p_m} \right],
$$

(4)

$$
\Delta_1 = C_w - C^o w + C^o (\nu w - \nu o) = \Delta C_0 + \Delta t,
$$

$$
\Delta_2 = K_w - K^o w o,
$$

(5)

where $\nu_w = Q^w/Q^o$ is the arm unbalance parameter in terms of the flow rate $Q$, $C^o_w$ is the specific heat of the liquid in the reference arm, and $\nu^w = V^w/V^o$ is the arm unbalance parameter for the volume of liquid flowing $V$.

Therefore, $\Delta_1$ and $\Delta_2$ are parameters of the differential part that characterize the inaccuracy in hydrothermal balancing of the arms in relation to $\Delta t(\tau)$ and $\Delta t(\tau)$, whose relationship to the power dissipated in the CCT can be put as

$$
\Delta t(\tau) = a_0 p + a_1 p^2, \quad \Delta t(\tau) = b_0 p + b_1 p^2,
$$

(6)

where $a_0 < 0$, $b_0 < 0$ are CCT parameters characterizing the nonlinear features of the heat-transfer system in the coolant temperature range. Substitution of (6) into (4) and transformation gives

$$
\delta_b = -PC (M - 1) (\Delta_1 + \Delta_2),
$$

(7)

where $M = p_m/p_c$.

The error $\delta_b$ is mainly of systematic character for constant values of $\Delta_1$ and $\Delta_2$ and with a deterministic measurement process. However, these parameters can vary under real conditions, which means that $\delta_b$ is unstable. The instability in $a_1$ and $b_1$ is due to the randomness in the uninformative parameters of the measurement process, in particular the times for which the calibration power is supplied $\tau c$ and the measurement power $\tau m$, the interval between them $\tau c,m$, and the interval between the measurement and the last calibration $\tau m,c$. Then $a_1$ and $b_1$ are correlated, since they are related to the common factors $p_m$ and $p_c$. The largest deviations from the average values of $a_1$ and $b_1$ occurs when the calibration is performed during the establishment of the coolant temperature after the measured power has been removed, i.e., when $\tau m,c < (3-4) \tau t$, where $\tau t$ is the settling time-constant for the coolant temperature at the inlet to the differential part of the CCT. Usually, $\tau t = 2.5-6$ min in accordance with the properties of the heat-transfer system. For $\tau m,c \geq (3-4) \tau t$ with $\tau c,m$ and $\tau m,c$ in the range 5-10 min, the deviation of $\delta_b$ from the mean does not exceed $\pm (0.2-0.3)$.

If $Q$ is small (small input powers), the stability of $\Delta_1$ is affected mainly by adsorption contamination of the differential part by particles due to erosion of the material in the system, which increases $v_Q$ and correspondingly reduces $|\Delta_1|$, which occurs firstly because the coolant temperature in the working arm may be much higher than that in the reference one, which favors flushing in the working arm, and secondly reduction in the flow rate in the reference arm favors increase in the contamination. It follows from (5) that the relative change in flow rate in the working arm $\delta_Q^w$ for constant $Q$ of course is an absolute change

$$
\Delta (\Delta_1) = -\delta_Q^w v_Q (1 + v_Q) (C^o_w + C^o),
$$

587