ANALYSIS OF A MICROWAVE RADIOMETER FOR PRECISE STANDARDIZATION OF NOISE SOURCES

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It is possible to derive a very general expression for the voltage wave emergent from one part of a multiport microwave junction, which itself contains sources, and to the arms of which are connected general microwave two-ports themselves terminated by active sources. This expression may be specialized to a class of microwave radiometers, consisting of a three-port junction, to the arms of which are connected, through general microwave two-ports used for measurement, respectively a microwave source to be measured, a standard source in terms of which the measurement is made, and a receiver. The analysis is sufficiently complete to identify clearly many conditions which bear on the accuracy of measurement of the unknown source, and to quantitatively evaluate them, or to keep them below some tolerable contribution.

In particular, noise arising from lossy elements anywhere in the microwave network can be explicitly taken into account. The familiar result obtains, namely that the noise associated with the excess of the source temperature over the radiometer temperature is observed; but this result is now subject to the important condition that all lossy elements of the radiometer proper be at the same temperature. Adequate isolation among arms is required to avoid contributions from arms other than the desired ones. Departures from ideal impedance match in the microwave arms cause

error which are here carried to second order in small quantities; this analysis constitutes the main quantitative result of the paper. For radiometers designed for rapid comparison of two sources, exactly opposite phase in the switching or modulation is necessary. Isolation against impedance changes in each arm becomes necessary for valid measurement. Correct treatment of the image response of the receiver is also necessary.

An analysis of fluctuations extends previous results for radiometers which are designed for the continuous observation of a source, and which therefore have low pass filters after the second detector. The extension applies to radiometers which are designed for rapid comparison of two sources by switching or modulation, and which therefore have band pass filters after the second detector. The sensitivity to source temperature change is dependent on the receiver noise factor, the limiting IF bandwidth, and the low frequency filter bandwidth in the same way as previously. The sensitivity of radiometers with a third detector operating on the signal at the switching or modulation frequency depends on the particular combination of linear or quadratic second and third detectors used. The spectral distribution of the fluctuations at various circuit points is useful as an aid to understanding and design.

A general balance equation for the instrument, subject to explicit simplifying conditions, may be derived and specialized to three convenient modes of operation in order to account for constants of the instrument appropriate to the two input paths. These modes are (a) substitution of a standard source for an unknown source on a particular arm, (b) interchange of a standard source

and an unknown source on the two arms, and (c) calibration of the instrument so as to allow immediate comparison of an unknown source with a permanently affixed standard. Measurement is accomplished in terms of only the s_{21} (or p_{11}) element of the equivalent scattering (or cascading) matrix of the measurement arm.

Errors of measurement are explicitly given in terms of a relatively few pertinent reflection coefficients and scattering matrix elements. These expressions may be used either to correct the observations or to keep the errors within acceptable limits. Typically, reflection coefficient magnitudes of a few hundredths cause error of a few hundredths db. An important result is that mismatch of the standard and unknown sources to the waveguide transmission line causes error only as the difference of the absolute squares of their reflection coefficients, and so may often reduce the severity of error if the sources are similarly mismatched.

Radiometers in use at the National Bureau of Standards, to which this analysis is applicable, have been previously described by Estin, Trembath, Wells, and Daywitt (1960), and by Wells, Daywitt, and Miller (1962).

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