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Post-Amplifier Noise Temperature Contribution in a Low-Noise Receiving System

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A derivation is given for the equivalent noise temperature of an amplifier terminated in a nonstandard temperature in terms of a noise-figure meter reading. The result is applied to the measurement of the post-amplifier noise temperature contribution in a low-noise receiving system.

The noise temperature instrumentation for a low-noise (maser) receiving system as used in planetary radar experiments or space probe communications[1,2] usually consists of cooled microwave terminations, low-loss switches, and gas-tube noise sources. The equivalent noise temperature of the system is typically measured by the Y-factor method where a precision attenuator is adjusted so that a power-level indicator has the same reading when the noise tube coupled into the maser amplifier is fired and not fired. Although theoretical calculations[3] and measurements of the maser amplifier noise temperature are performed, a precise breakdown of the contributions to the total system temperature requires[4] independent measurements of antenna temperature, transmission line losses, maser temperature and gain, and post-amplifier noise temperature. The contribution of the post-amplifier to the system temperature is found by dividing its equivalent noise temperature by the maser gain.

A simple technique to measure the contribution of the post-amplifier is to determine the change of system temperature with maser gain. The post-amplifier temperature T_r can be calculated from two separate system measurements T_1 and T_2 obtained with maser gains of G_1 and G_2 from the formula

$$T_r = \frac{T_1 - T_2}{1/G_1 - 1/G_2}. \tag{1}$$

This method requires a means of measuring and carefully controlling the maser gain (the latter is very difficult in a typical maser amplifier) in a stable manner and is inaccurate when the post-amplifier noise contribution is small.

Another technique is to measure the post-amplifier noise temperature with an automatic noise-figure meter through a directional coupler. A correction[5] must be made for the noise-figure meter reading since the post-amplifier is not terminated in an ambient load. It is also necessary to refer the noise temperature to the input of the directional coupler since this is the temperature as seen by the maser.

Referring to Fig. 1, define the following terms:

T_0 = 290°K (standard ambient temperature)
T_r = equivalent noise temperature of post-amplifier

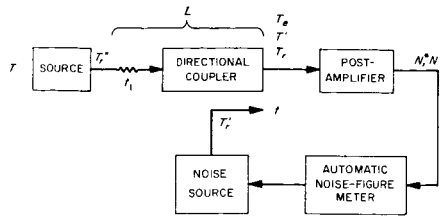

Fig. 1—Block diagram of receiving system with a nonambient source termination used for evaluation of noise temperature in terms of an automatic noise-figure meter reading.

T_r' = equivalent noise temperature of post-amplifier referred to the input of the side arm of the directional coupler as measured by noise-figure meter
T_r'' = equivalent noise temperature of post-amplifier referred to the input of the main arm of the directional coupler
T_e = excess noise of noise source delivered to post-amplifier input
T = termination temperature
T' = equivalent termination temperature referred to post-amplifier input
t = power coupling coefficient of coupler (less than 1)
t_1 = resistive power transmission coefficient of coupler (less than 1)
L = total coupler insertion loss
N = noise power output with noise source off (delivered to noise-figure meter)
N^* = noise power output with noise source on (delivered to noise-figure meter)
F = noise-figure meter reading (ratio).

At the input of the side arm of the directional coupler

$$\frac{N^*}{N} = \frac{T_0 + T_r' + T_e/t}{T_0 + T_r'}. \tag{2}$$

Using $T_r' = T_0(F-1)$ gives

$$\frac{N^*}{N} = \frac{FT_0 + T_e/t}{FT_0}. \tag{3}$$

However, referred to the input of the post-amplifier

$$\frac{N^*}{N} = \frac{T_r + T_e + T' + T_0 t}{T_r + T' + T_0 t}. \tag{4}$$

Setting (4) equal to (3),

$$T_r = tT_0F - T' - T_0t. \tag{5}$$

The total equivalent noise temperature referred to the termination is

$$L(T_r + T' + T_0t) \tag{6}$$

so that

$$T_r'' = L(T_r + T' + T_0t) - T. \tag{7}$$

Substituting for T_r from (5),

$$T_r'' = LtT_0F - T. \tag{8}$$

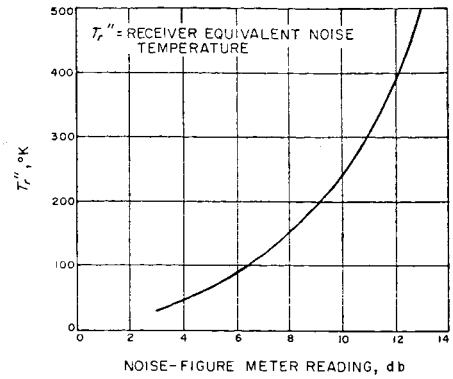

Fig. 2—Typical plot of post-amplifier temperature referred to maser output in terms of automatic noise-figure meter reading with 10-db directional coupler corrected for nonambient source termination.

As an example, consider a low-noise receiving system using a 10-db coupler with 0.5-db insertion loss between the maser and the post-amplifier. Assume a source temperature T of 20°K. This is calculated from the transmission line loss between the maser and post-amplifier, maser bath temperature, maser-off insertion loss, and maser input termination temperature. The noise-figure meter is read with the maser off. Then

$$L = 0.891$$
$$t = 0.1$$
$$T = 20°\text{K}$$
$$T_0 = 290°\text{K}.$$

A plot of receiver temperature vs automatic noise-figure meter reading as calculated from (8) is shown in Fig. 2. With a maser gain of 30 db, a measurement error of 100°K (20 per cent) in a 500°K post-amplifier results in an error of only 0.1°K in the estimated contribution to the system noise temperature.

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