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Comments on "A Method for Measurement of Losses in the Noise-Matching Microwave Network While Measuring Transistor Noise Parameters"

MARIAN W POSPIESZALSKI

In the above[1] paper, expressions (1), (2), and (3) appear to be correct only if the physical temperature T_a of the tuner is equal to the standard temperature $T_0 = 290$ K. The expression (1) for $T_a \neq T_0 = 290$ K should read

$$F_m(\Gamma_{ns}) = \frac{T_a}{T_0}\left[\alpha_{\Gamma_s}(\Gamma_{ns}) - 1\right] + 1 + \alpha_{\Gamma_s}(\Gamma_{ns})\left[F(\Gamma_s) - 1 + \frac{F_i(S'_{22}) - 1}{G_a(\Gamma_s)}\right] \quad (1)$$

using the notation of the paper. Generally valid versions of expressions (2) and (3) follow in a straightforward manner. The error caused by the limited validity of expressions (1), (2), and (3) in the subject paper may be quite significant, even for room temperature measurement. For instance, for the tuner losses of 1.5 dB (worst case in the example discussed), each kelvin of a difference between physical temperature of a tuner and standard temperature T_0 will contribute 0.4 K of an error.

Also, the remaining nonreferenced expressions in the subject paper (i.e., (5) through (9)), which deal with the noise temperature of a receiver with isolator at the input, are derived in the Appendix ((A1) through (A14)) in an unnecessarily complicated way. In order to demonstrate this point, let us refer to the equivalent circuit of Fig. 1. This equivalent circuit is valid for a receiver preceded by an isolator having $S_{12} = 0$ and a physical temperature T_a. In this case, a nonideal isolator is modeled by a cascade connection of lossless reciprocal two-port, followed by an ideal isolator and lossy reciprocal two-port.

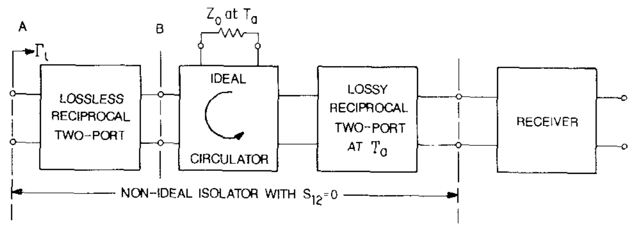

Fig 1 Equivalent circuit of a receiver with nonideal isolator at its input.

It has been brought to the attention of the authors of the subject paper [1] and also discussed in some greater detail in [2] that at plane B (refer to Fig. 1), the noise parameters of such a system are

$$T_{min} = T_R^B(\Gamma_g = 0), \qquad \Gamma_{opt} = 0, \qquad N = \frac{T_a + T_{min}}{4T_0}. \quad (2)$$

It follows immediately from the invariant properties of T_{min} and N [3] that at plane A the noise parameters are

$$T_{min} = T_R^A(\Gamma_g = \Gamma_i^*) = T_R^B(\Gamma_g = 0), \qquad \Gamma_{opt} = \Gamma_i^*,$$
$$N = \frac{T_a + T_{min}}{4T_0}. \quad (3)$$

The relations (2) and (3) follow in a straightforward manner from those published many years ago [4], [5]. The expressions (5), (7), and (8) in the subject paper can be easily obtained by substitution of noise parameters given by (3) into standard expression for equivalent noise temperature (noise figure).

The relations (3) also clearly demonstrate why, for a full noise description of a receiver with isolator ($S_{12} = 0$) at the input, only single noise measurement will suffice if the input reflection coefficient Γ_i and physical temperature of the isolator are known.

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Reply[2] by G. Martines and M. Sannino[3]

I. Premise

Before replying in detail to the above comments, we would like to reassure experimenters working in the field of transistor noise measurements that the questions raised do not affect to any

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extent the effectiveness of the method proposed by us. This statement holds not only as far as measuring principles and experimental procedures are concerned, but also from the viewpoint of the numerical results, i.e., the accuracy. Actually, the influence of the room temperature (25°C nominal) is completely negligible.

In other words, the comments by M. W. Pospieszalski regarding the ambient temperature T_a are unnecessary, as was true of the comments by the same author on a previous paper of ours [6], to which we have already replied [1].

Pospieszalski has repeated his criticism after carrying out some calculations on the "error" due to the simplifying assumption made by us. He writes: "the error may be quite significant even at room temperature." However our considerations do not support this position.

II. Reply

We recall that the above referenced paper regards an original method for determining the (available power) losses α_{Γ_s} of the tuner which is connected with the noise source in a transistor noise parameter test-set in order to vary (or tune for searching the optimum condition) the reflection coefficient Γ_s of the source.

Following the method, the determination of α_{Γ_s} for each configuration of the tuner requires measurements of the receiver noise figure F_r for each Γ_s, i.e., with the source connected to the receiver through the tuner, and the measurement of $F_r(0)$, with the receiver connected to the source directly ($\Gamma_s = 0$), i.e. without the tuner, as shown in Fig. 2. The measurement of $F_r(0)$ is performed only once for each frequency and is already a step of the calibration procedure [7], [8]. Comparing the values of $F_r(0)$ as computed by $F_r(\Gamma_s)$ and the one as measured, the values of α_{Γ_s} for each Γ_s are derived by difference (in dB). The main advantages of the method are that it requires the same instrumentation employed for the transistor noise parameter determination and that its experimental procedure can be easily inserted into the more complex procedure of a computer-controlled test set for determining noise, gain, and scattering parameters through noise figure measurements only, shown in Fig. 3 [6].

Probably, because of his experience, Pospieszalski pays particular attention to the effects of the (low) temperatures of the device under test.

Actually, his first comment concerns the effect of the ambient temperature on the tuner losses. This comment, valid for any method, was already proposed by Pospieszalski with reference to a former paper of ours [6]. Therefore we reply in the same way [1]: "the comments of M. W. Pospieszalski are correct, but, as stated, do not affect noise characterization of transistors at room temperature with which we are dealing."

Actually comparison between $F_m(\Gamma_s)$ by Pospieszalski and (1) in our paper, rewritten here for convenience in the form

$$F_m(\Gamma_s) = \alpha_{\Gamma_s}(\Gamma_{ns})\left[F(\Gamma_s) + \frac{F_r(S_{22}') - 1}{G_a(\Gamma_s)}\right] + \left[\alpha_{\Gamma_s}(\Gamma_{ns}) - 1\right]\left(\frac{T_a}{T_0} - 1\right) \quad (4)$$

gives a difference

$$\Delta F_m(\Gamma_s) = \frac{\left[\alpha_{\Gamma_s}(\Gamma_{ns}) - 1\right]}{T_0}(T_a - T_0) \quad (5)$$

which for $\alpha_{\Gamma_s} = 1.5$ dB (see the example discussed by

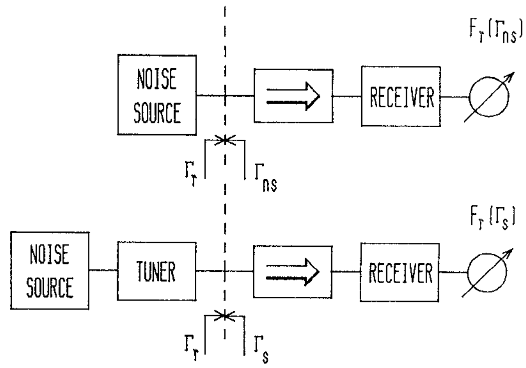

Fig 2. The two different configurations of the measuring system for determining tuner loss through noise figure measurements.

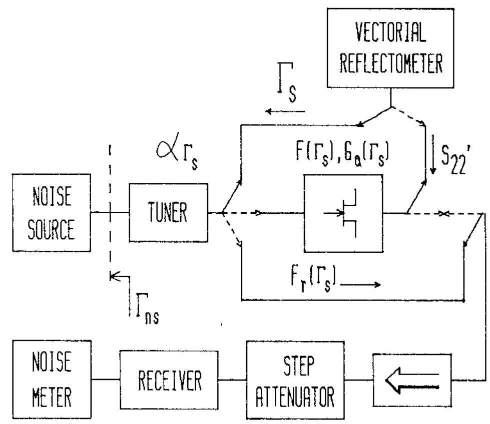

Fig 3 Simplified block diagram of the transistor noise, gain, and scattering test-set

Pospieszalski) furnishes

$$\Delta F_m(\Gamma_s) = \frac{0.4}{T_0}(T_a - T_0) = 0.00142(T_a - T_0) \quad (6)$$

i.e., an error of 0.00142 (in terms of noise figure) for each degree K of difference between the ambient temperature T_a and the standard one $T_0 = 290$ K. In a transistor noise measuring system the microwave (double stub or slide screw) tuner is always at room temperature (nominal 25°C) also when the device is tested at low temperatures by introducing it into a thermostatic camera. Thus we have $F_m = 0.011$!

In conclusion, the relationships reported in the paper do not contain T_a as far as the noise of the tuner is concerned because its effect is negligible. This is not valid for the noise of the isolator since the mismatch factor (μ' in the paper) may be so high that the contribution of T_a may not be negligible.

On the second comment, we first notice that the expressions from (5) to (9) in the subject paper are not referenced because they are derived by us (in the Appendix). The way they are derived is not, in our opinion, unnecessarily complicated, as Pospieszalski states; it is simply a way which employs the relationships which we usually use for experimental data processing, without recalling other concepts which would unnecessarily complicate the analytical procedure.

Thus the procedure proposed by Pospieszalski is conventional and, consequently, correct. Pospieszalski says that the receiver noise figure $F_r(\Gamma_s)$ can be computed for each Γ_s (as for any two-port) through the four noise parameters of the receiver.

In practice, what is proposed by Pospieszalski, expressed in terms of noise figure, requires the measurements of $F_r(\Gamma_i^*)$ and of the input reflection coefficient of the receiver Γ_i (Γ_r for us in Fig. 2). The noise figure $F_i(\Gamma_s)$ is then computed through the four noise parameters of the receiver, which, for $T_a = T_0$, become

$$F_{\rm opt} = F_r(\Gamma_i^*) \qquad \Gamma_{\rm opt} = \Gamma_i^* \qquad N = F_i(\Gamma_i^*)/4. \tag{7}$$

Alternatively, following the procedure reported in our paper the noise figure $F_i(\Gamma_s)$ is computed from $F_r(0)$, i.e., in the input matched condition (50 Ω, the impedance of the noise source), according to the relationship [6]–[8]

$$F_r(\Gamma_s) = F_r(0)\frac{|1-\Gamma_s\Gamma_r|^2}{1-|\Gamma_s|^2} \tag{8}$$

where Γ_i is the input reflection coefficient of the receiver.

The procedures are equivalent from both the theoretical and the experimental point of view. The only small difference regards that which needs to be measured. Actually, our procedure requires the measurements of $F_r(0)$ and Γ_s (or S_{22}' in a transistor test set [6], [8]), both of which are already part of the experimental procedure for determining the noise, gain, and scattering parameters of a transistor [8].

For the sake of accuracy, we note that the above question has never "been brought to the attention of the authors of the subject paper." Actually the subject paper was submitted to the editor before the publication of the paper quoted by Pospieszalski [1].

In any case, we would not have changed our data processing procedure, because, as already stated, it is more convenient.

Rebuttal[4] to Authors' Reply

Regretfully, the form and style of the authors' reply suggest a strong disagreement with my comments, while close examination of its technical content proves precisely the opposite.

First, the authors do concede that the expressions (1), (2), and (3) in the subject paper are valid only if $T_a = T_0 = 290$ K, which is especially striking since the remaining expressions in their paper deal with the noise figure of the receiver with input isolator at arbitrary temperature T_a. Contrary to their statements, their calculations and mine of an error caused by limited validity of the expressions for the example of a tuner with 1.5 dB loss give precisely the same number: 0.4 K of an error in measured noise temperature for each kelvin of a difference between the temperature of a tuner and standard temperature T_0. The best room temperature HEMT devices now exhibit noise temperatures around 40 K in X-band. The error discussed could be about 4 K (for $T_a = 300$ K), and, therefore, is no longer insignificant. Obviously the problems with accuracy could become much more severe upon cooling of the device (noise temperatures less than 10 K at X-band) and/or tuner.

Next, the authors do agree that the two-line derivation of the remaining expressions in their paper presented in my comments is "conventional" and "correct." Unfortunately, that makes their derivation appear unnecessarily complicated. The authors also acknowledge the existence of the exchange of comments concerning precisely the same problem published in the IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, which was conspicuously absent from the list of references in the subject paper.

As a final note, the authors, calling my comments on their papers unnecessary, in striking contradiction have devoted a large portion of the subject paper to my first comment [1] and have elaborated copiously above on my second comment. The ultimate judgement, however, should be left to the interested readers of the TRANSACTIONS.

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