

# National Radio Astronomy Observatory Electronics Division Technical Note 198

## Mixer-Preamp Noise

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Analysis of the noise temperature of a mixer connected to a mismatched IF preamplifier often causes confusion, particularly if the mixer has a large or negative IF output resistance as can occur in an SIS mixer [1]. The noise analysis is actually quite straightforward if one considers separately the noise power at the output of the amplifier engendered by the mixer and by the IF preamplifier.

Fig. 1 shows the preamplifier connected to a source impedance  $Z$ , which may have a negative real part. If  $G_{A,P}$  is the power gain<sup>1</sup> of the amplifier, then its transducer gain<sup>2</sup> when connected to a source impedance  $Z$  is  $G_{A,Tr} = (1-|\rho_Z|^2)G_{A,P}$ , where the reflection coefficient  $\rho_Z = (Z_{A,in} - Z^*)/(Z_{A,in} + Z)$ . If  $T_{A,Z}$  is the noise temperature of the amplifier when connected to source impedance  $Z$ , then the power spectral density of the output noise engendered by the amplifier is

$$P_{out} = kT_{A,Z} G_{A,Tr} = kT_{A,Z} (1-|\rho_Z|^2) G_{A,P} \quad \text{W/Hz}, \quad (1)$$

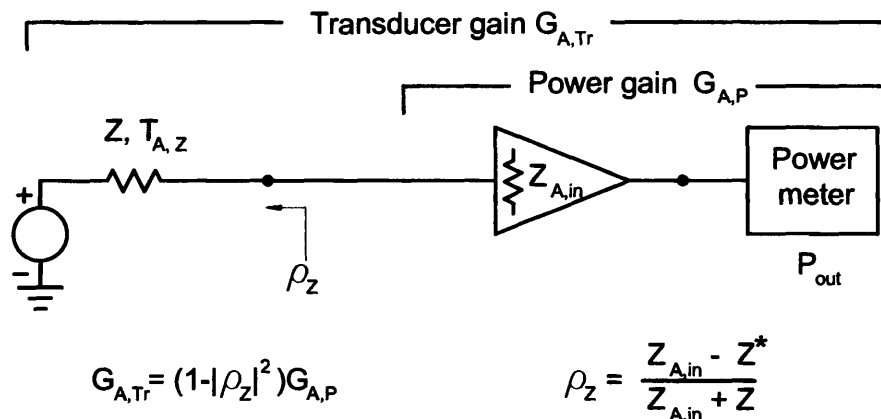


Fig. 1.

<sup>1</sup> The *power gain* is the ratio of the power *delivered* to the load to the power *delivered* to the input of the amplifier [2].

<sup>2</sup> The *transducer gain* is the ratio of the power *delivered* to the load to the *available* power of the source [2] and is a function of the source impedance. If the source impedance has a negative real part, the *exchangeable* power is used in place of the available power. The exchangeable power of a source with open circuit voltage  $v$  and impedance  $R + jX$  is  $v^2/4R$ . When  $R$  is positive, the exchangeable power is the same as the available power.

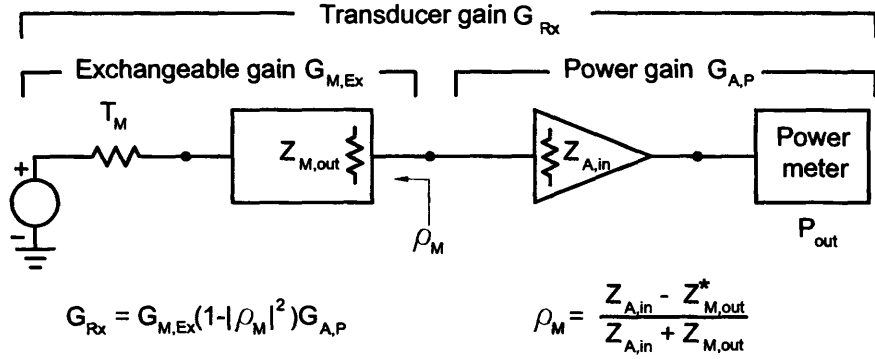
where [3]

$$T_{A,Z} = T_{\min} + 4NT_0 \frac{|\Gamma_Z - \Gamma_{opt}|^2}{(1 - |\Gamma_Z|^2)(1 - |\Gamma_{opt}|^2)} . \quad (2)$$

$T_{\min}$  is the minimum noise temperature of the amplifier,  $\Gamma_{opt}$  is the reflection coefficient of the optimum source impedance of the amplifier and  $\Gamma_Z$  is the reflection coefficient of the source impedance  $Z$  ( $\Gamma_Z$  and  $\Gamma_{opt}$  are referred to the same arbitrary reference impedance  $Z_0$ , normally  $50 \Omega$ ).

In Fig. 2, the amplifier is connected to a mixer whose output impedance is  $Z_{M,out}$ , which may be large or negative in the case of an SIS mixer. If the exchangeable gain<sup>3</sup> of the mixer is  $G_{M,Ex}$ , then the (transducer) gain of the receiver  $G_{Rx} = G_{M,Ex}(1 - |\rho_M|^2)G_{A,P}$ , where  $\rho_M = (Z_{A,in} - Z_{M,out}^*) / (Z_{A,in} + Z_{M,out})$ . The contribution of the mixer noise temperature  $T_M$  to the output power spectral density of the receiver is

$$P_{out} = kT_M G_{Rx} = kT_M G_{M,Ex} (1 - |\rho_M|^2) G_{A,P} \text{ W/Hz}. \quad (3)$$



**Fig. 2.**

From (1) and (3), the total power spectral density at the receiver output due to the mixer noise and the amplifier noise (which are not correlated) is therefore

$$P_{out} = kT_M G_{M,Ex} (1 - |\rho_M|^2) G_{A,P} + kT_{A,Z_{M,out}} (1 - |\rho_M|^2) G_{A,P} \text{ W/Hz}. \quad (4)$$

The receiver noise temperature  $T_{Rx} = P_{out} / kG_{Rx}$ , where (from above)  $G_{Rx} = G_{M,Ex} (1 - |\rho_M|^2) G_{A,P}$ , so

$$T_{Rx} = T_M + T_{A,Z_{M,out}} / G_{M,Ex} , \quad (5)$$

where  $T_{A,Z_{M,out}}$  is the noise temperature of the amplifier when connected to source impedance  $Z_{M,out}$ , the output impedance of the mixer.

<sup>3</sup> The *exchangeable gain* of a two port network is defined as [4]: (exchangeable power at the output)/(exchangeable power of the source), and is a function of the source impedance. The exchangeable gain is the extension of the concept of *available gain* to include circuits which contain negative resistances. If all resistances are positive, the exchangeable gain is the same as the available gain.

In SIS mixers, the IF output impedance  $Z_{M,out}$  may have a real part which is large, infinite, or even large and negative. When operated with such a high source impedance, the noise temperature of the IF amplifier  $T_{A,ZM,out}$  as given by equation (2) is large. In equation (4), this would seem to indicate a high receiver noise temperature. However, when the mixer has a high output impedance, its available (exchangeable) gain  $G_{M,Ex}$  is also large [1]. The result is that the term  $T_{A,ZM,out}/G_{M,Ex}$  is not indeterminate but has a finite value, so the receiver noise temperature can be low despite the large value of  $T_{A,ZM,out}$ . Likewise, the receiver gain  $G_{Rx} = G_{M,Ex}(1-|\rho_M|^2)G_{A,P}$  can be well behaved because a large value of  $G_{M,Ex}$  is offset by the small value of  $(1-|\rho_M|^2)$  when the mixer has a large output impedance.

To avoid the conceptual difficulty associated with the infinite quantities  $T_{A,ZM,out}$  and  $G_{M,Ex}$  when the mixer has high output impedance, the mixer-preamp combination can be visualized as shown in Fig. 3. The output of the mixer is represented by its Norton equivalent circuit and the noise of the IF amplifier is represented by its (partially correlated) outgoing and ingoing noise waves [5,6]. At the high impedance mixer output, the noise wave  $T_{A,out}$  is reflected and enters the amplifier with the noise wave  $T_{A,in}$ . The output of the mixer looks like a (finite) current source which delivers finite power to the IF amplifier. The magnitude and correlation of the noise waves can be deduced from the amplifier parameters  $T_{min}$  and  $\Gamma_{opt}$ .

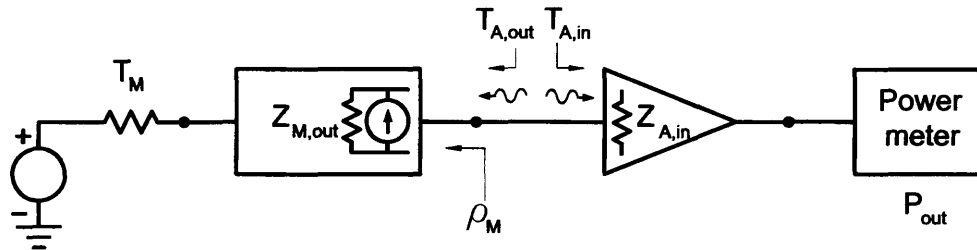


Fig. 3.

### SSB and DSB quantities

The above analysis applies equally to double-sideband and single-sideband quantities. The mixer and receiver noise temperatures  $T_M$  and  $T_{Rx}$ , receiver gain  $G_{Rx}$ , and the mixer's exchangeable gain  $G_{M,Ex}$  can be either DSB or SSB quantities. If the upper- and lower-sideband mixer gains are not equal, that must be taken into account in converting between DSB and SSB quantities.

### Sideband-Separating Mixers

In the case of a sideband-separating mixer, the mixer noise temperature  $T_M$  includes thermal noise from the (internal) image termination. The above analysis applies as long as this internal noise is included in  $T_M$ .

## References

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