ANOMALOUS NOISE IN SCHOTTKY DIODE MIXERS AT MILLIMETER WAVELENGTHS

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Abstract

Measurements on state-of-the-art 85 GHz mixers using GaAs Schottky-barrier diodes give high values of noise temperature ratio (~1.3) and loss temperature (~500°K) despite low conversion loss (~5dB SSB) and input noise temperature (~600°K SSB). The source of this noise has not yet been identified.

Introduction

When considering the noise behavior of mixers use is frequently made of the partial analogy between a mixer and a resistive attenuator with an inbuilt lossless frequency converter. For a mixer whose noise temperature ratio[1] $t \gtreqless 1$ the physical temperature of the analogous attenuator $T_L \gtreqless 290°K$. For a good mixer it is usually expected that $T \approx 1.0$, corresponding to $T_L \approx 290°K$.

In an attempt to determine the source of the excess noise in cryogenically cooled mixers[2] we have made careful noise measurements on low-noise 85 GHz mixers at room temperature. Despite their low conversion loss (~5dB SSB) and input noise temperature (~600°K SSB), the value of T_L has been found to be consistently high (~500°K).

The sources of noise usually considered in mixers are:

i) Shot noise from current flowing across the depletion region of the diode. For a diode at room temperature, T_0, this noise is equivalent to the thermal noise from the junction resistance $R_j = \frac{\eta k T_0}{qi}$, at a temperature[3] $T_{equiv} = \eta T_0 / 2$.

ii) Thermal noise from the series resistance, R_s, of the diode.

iii) Thermal noise from lossy terminations at the sideband frequencies $nf_{LO} \pm f_{IF}$, $n = 2, 3, \ldots \infty$.

iv) Noise from the LO at the signal and image frequencies.

v) Excess thermal noise due to LO power heating the diode.

In our experiments LO noise was eliminated by a filter. Calculations of diode heating due to LO power dissipation indicate a relatively small effect. The remaining sources of noise all have temperatures less than or equal to ambient. It has been shown by Dragone[4] that if the noise sources in a mixer all have an equivalent noise temperature T, the available noise at any port cannot exceed that from a simple time-invariant network at temperature T. We thus expect a room temperature mixer to have an equivalent loss temperature $T_L \leq T_0$, the ambient temperature.

Measurement of T_L

To determine the value of T_L from measurements of conversion loss and noise temperature it is necessary to distinguish between the component of the conversion loss due to RF mismatch and that due to actual dissipative loss in the mixer. Because small-signal measurement of the input VSWR is awkward to perform on millimeter-wave mixers,* a technique is used which enables T_L to be deduced from conversion loss and noise measurements on the mixer at a number of different backshort settings. For many mixers the RF port cannot be matched by adjusting the backshort alone, and this technique is particularly useful in such cases.

Consider a broadband mixer adjusted for minimum conversion loss, as shown in Fig. 1(a). The IF port is matched, and the RF port is nearly matched.* L is the single-sideband (SSB) conversion loss at the signal and image frequencies. T_s and T_i are the signal and image source temperatures, and T_M is the equivalent SSB input noise temperature of the mixer. T_L is the temperature of the analogous resistive attenuator with loss L, which produces the observed mixer noise.

For a simple resistive attenuator of loss L, at physical temperature T the equivalent input noise temperature is (L-1)T. For a broadband mixer it is simply shown that the equivalent SSB input noise temperature is

$$T_M = (L-2)T_L \quad . \tag{1}$$

In terms of the noise temperature ratio[1], t, of the mixer, we have

$$t = \frac{T_L}{T_0} + \frac{2}{L}\left(1 - \frac{T_L}{T_0}\right), \tag{2}$$

or

$$t = \frac{1}{L}\left(\frac{T_M}{T_0} + 2\right), \tag{3}$$

where $T_0 = 290°K$.

Consider next the case of the mixer of Fig. 1(a), but with its RF port mismatched. Fig. 1(b) shows the mismatched mixer represented as a reflective nondissipative obstacle ahead of the optimized mixer of Fig. 1(a). For the mismatched mixer the quantities L', T_M', T_L' and t' may be defined, corresponding to L, T_M, T_L and t for the optimized mixer† :

$$L' = L \frac{1}{1 - |\rho|^2} \tag{4}$$

$$T_M' = T_M \frac{1}{1 - |\rho|^2} \tag{5}$$

$$T_L' = T_L \frac{L-2}{L - 2(1-|\rho|^2)} \tag{6}$$

$$t' = t - \frac{2|\rho|^2}{L} \tag{7}$$

The effect of the mismatch, ρ, on mixer performance is shown graphically in Figures 2 and 3.

To determine T_L for a waveguide mixer it is convenient to measure L' and T_L' as functions of $|\rho|^2$ by varying the backshort position while maintaining con-

*Note that the small-signal VSWR at the signal and image frequencies is not the same as the large-signal LO VSWR of the mixer, no matter how low the IF frequency.

*For minimum conversion loss the RF port of a broadband mixer is not necessarily matched--see ref. 5--although in practical mixers the mismatch is usually small.

†The reflective obstacle will have an effect of the IF output impedance of the mixer. This effect is small for practical mixers, provided $|\rho|^2$ is small, and is therefore neglected here.

stant LO drive to the diode (i.e. constant DC diode current). A value of T_L can then be found by trial and error for which the points $(T_L'/T_L, L')$ best fit one of the family of curves in Fig. 2.

Experimental Results

Measurements were made on a number of low-noise GaAs Schottky diode mixers. The design of the mixers, shown in Fig. 4, is described elsewhere[6]; the characteristics of the diodes are given in Table I.* The measurements were made using the 1.4 GHz IF radiometer/reflectometer[2] shown in Fig. 5. This instrument enables the IF port noise temperature and match to be measured directly. Noise readings taken with the RF noise tube on and off enable the parameters L', T_L', T_M' and t' to be calculated.

A typical set of results is shown in Fig. 6 for an 85 GHz mixer, with the backshort position as the independent variable. The measured values of T_L' and L' give a best fit to the curve for L=5 dB in Fig. 2 when T_L= 500°K. The resulting points are shown as triangles.

Interpretation and Conclusion

The unexpectedly high value of $T_L \simeq 500°K$ is of great interest. It must originate in the diode, either by a direct noise generation mechanism, or possibly by parametric action of the junction capacitance. Reverse breakdown of the diode seems unlikely to be the cause since the breakdown voltage is ~8 volts for the diodes used in these experiments.

The mixers used for this work represent the current state of the art at 85 GHz. If the source of the anomalous noise can be found and eliminated the input noise temperature, T_M, may be reduced by a factor of almost 2, which would represent a significant advance in mixer performance.

*The diodes used in this work were supplied by R. J. Mattauch of the University of Virginia.

TABLE I: TYPICAL CHARACTERISTICS OF THE GALLIUM ARSENIDE SCHOTTKY-BARRIER DIODES AT ROOM TEMPERATURE

EPI-LAYER	Doping	3×10^{17} cm^{-3}
	Thickness	0.5 ± 0.25 μ
SUBSTRATE	Orientation	(1 0 0)
	Type	n
	Doping	2-3 x 10^{8} cm^{-3}
DIODE	Diameter	2.5μ
	η	1.11
	R_s (measured at DC)	8.0 Ω
	C_d (at 0.0V, 1MHz)	0.007 pF
	f_c (at 0.0 V)	2800 GHz
	V_b at 0.1μA	8 V

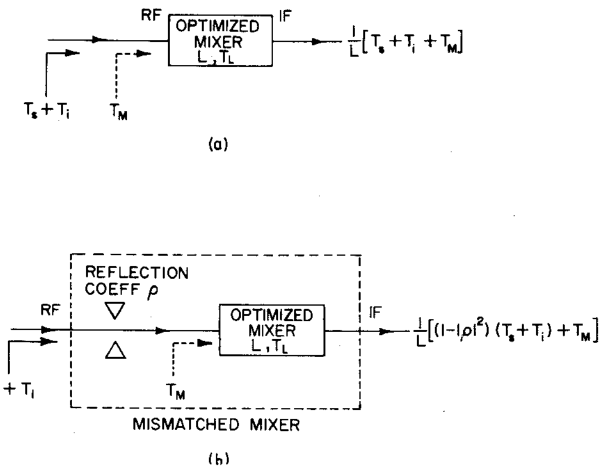

FIG. 1 (a) The optimized mixer. (b) The mismatched mixer comprising the optimized mixer and a lossless reflecting obstacle at the RF port.

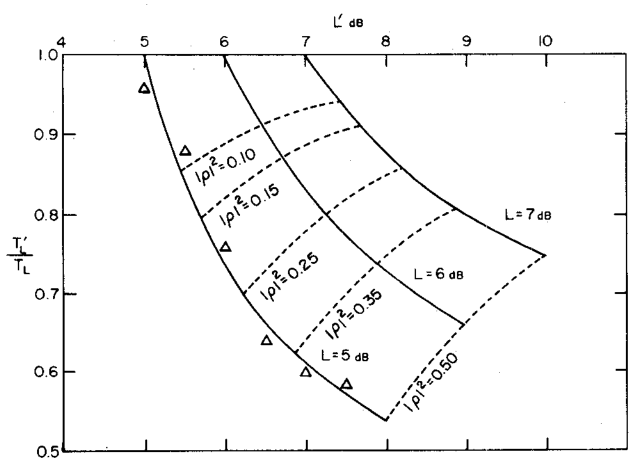

FIG. 2 Curves giving mixer parameters L' and T_L'/T_L as functions of L and $|\rho|^2$. L is the conversion loss of the optimally adjusted mixer, and ρ is the input (RF) reflection coefficient. Points marked (Δ) calculated from measurements on an 85 GHz mixer when a value of T_L = 500°K is assumed.

References

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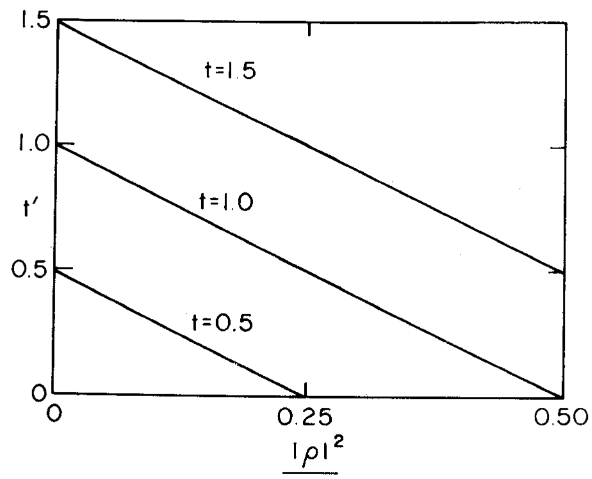

FIG. 3 Curves of the noise temperature ratio, t', as a function of t and $|\rho|^2/L$.

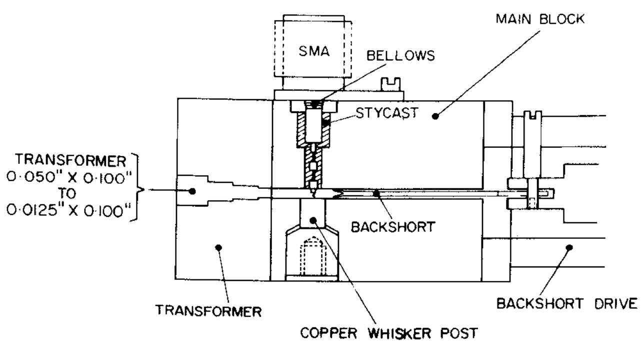

FIG. 4 Cross-section of the 85 GHz mixer--not to scale.

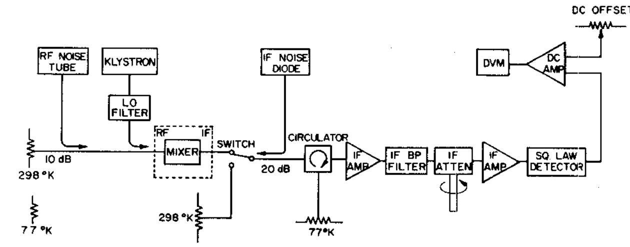

FIG. 5 IF noise radiometer/reflectometer. The DVM reads directly the absolute temperature of the mixer's IF port. The IF noise diode directionally injects noise at ~6000°K, enabling the IF port mismatch of the mixer to be measured.

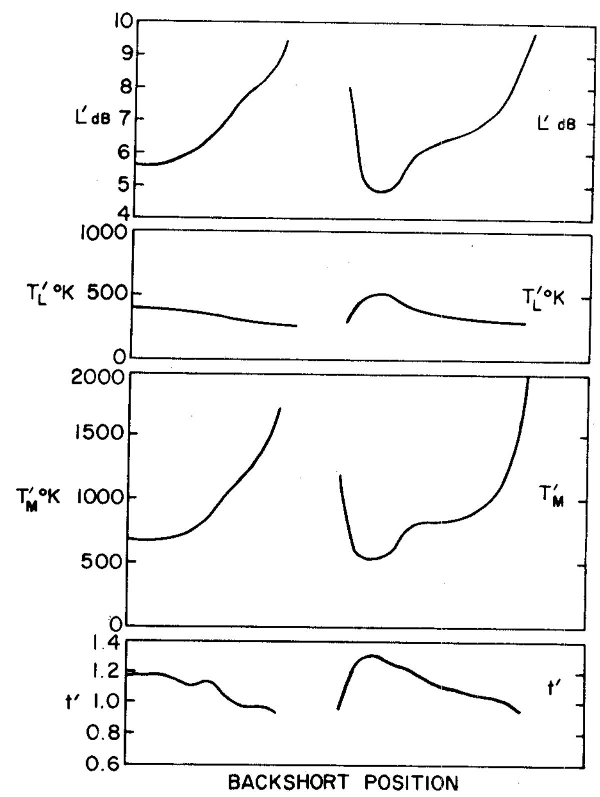

FIG. 6 Measured values of the SSB conversion loss L', loss temperature T_L', SSB input noise temperature T_M' (which does not include any IF amplifier contribution), and noise temperature ratio t', for the 85 GHz mixer operating with 0.5 V bias and 2 mA DC current.