Correspondence

Noise Performance of Traveling-Wave Masers*

In this communication, a review of the noise performance of traveling-wave masers (TWM) is given. It is shown in particular that when the gain per unit length of structure is low, the equivalent noise temperature of the TWM can become appreciable.

The expression for noise temperature of a TWM has been derived by many investigators, and we shall here use the form given by Siegman,[1]

$$T_m = \frac{G-1}{G}\left[\frac{\alpha_s T_s}{\alpha_s - \alpha_0} + \frac{\alpha_0 T_0}{\alpha_s - \alpha_0}\right], \quad (1)$$

where

T_s = spin temperature,
T_0 = structure temperature,
α_s = gain coefficient per unit length of the TWM,
α_0 = loss coefficient per unit length of the TWM,
$G = e^{(\alpha_s - \alpha_0)L}$ = net gain for a TWM of length L.

The usual assumption made in the discussion of TWM is that, generally, $G \gg 1$ and $\alpha_s \gg \alpha_0$. Then it is seen that (1) becomes

$$T_m \cong T_s. \quad (2)$$

Since T_s is generally a fraction of the bath temperature, *i.e.*,

$$T_s \simeq \frac{f_s}{f_p - f_s}, \qquad T_0 = \rho T_0, \quad (3)$$

where f_s = signal frequency and f_p = pump frequency, it is seen that T_m can be very small. The system noise contribution originates in the input transmission line losses and in the follow-up receiver. (These latter quantities are to be added in the usual way.)

These results are a consequence of the assumption of high gain per unit length of structure. This assumption is a reasonable one for ruby masers operating at 1.5 to 2.5°K, but it is not necessarily valid for operation at 4.2°K or higher temperatures. At the latter temperatures it is still possible to obtain high net gain, G; however, the gain per unit length is small and a long structure is necessary. Eq. (1) now takes the approximate form

$$T_m \simeq \frac{\alpha_s T_s}{\alpha_s - \alpha_0} + \frac{\alpha_0 T_0}{\alpha_s - \alpha_0} = T_0 \frac{\rho + \beta}{1 - \beta}, \quad (4)$$

where $\beta = \alpha_0/\alpha_s$.

It is noted from (4) that if the coefficient for net gain per unit length $\alpha_s - \alpha_0$ is small then T_m could become appreciable.

Fig. 1 shows graphically the behavior of T_m/T_0 as a function of β for different values of ρ. The usual approximation is given by taking $\beta = 0$ in Fig. 1.

The foregoing discussion indicates the need for careful design of a TWM when operating at elevated temperatures (4.2°K or higher) which the present state-of-art in closed-cycle refrigerators, unfortunately, requires. Particularly important is the need to reduce the forward loss of the structure.

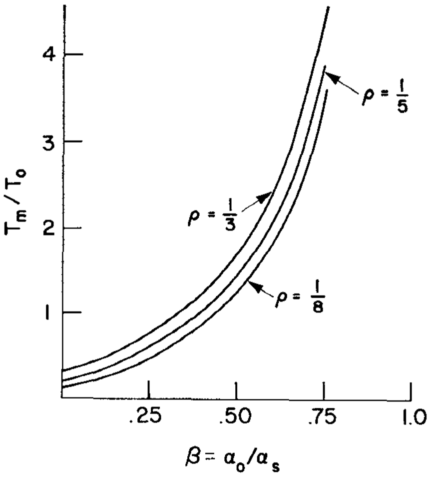

Fig. 1—Ratio of TWM temperature to bath temperature as a function of β (ratio of loss per unit length to electronic gain per unit length).

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[1] A. E. Siegman, "Thermal noise in microwave systems," *Microwave J.*, vol. 4, pp. 66–73; April, 1961.

Millimeter Frequency Multiplication with an In-Line Harmonic Generator*

When building a crystal frequency multiplier to generate harmonics in the millimeter region, one may improve conversion efficiencies by one of two basic techniques: selecting an improved nonlinear junction, or improving the physical and electrical environment of that junction. This communication will describe an in-line frequency multiplier designed to facilitate changing semiconductors and whiskers to evaluate their efficacy in generating the third and fourth harmonics of a 22-Gc drive signal. In addition, the test results on several different semiconductors will be presented.

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In-Line Harmonic Generator

The harmonic generator has been designed for simplicity and rapid whisker and crystal changeability; these goals have been achieved in conjunction with electrical effectiveness by abandoning the crossed-guide structure[1] for a coplanar arrangement, which is evident in the E-plane section of Fig. 1. This multiplier has a WR-42 input waveguide and WR-12 output waveguide. As Fig. 2 shows, these two guides are in line, and perpendicular to them are two tunable shorts located symmetrically with respect to the crystal site. The region between the input and output guides is tapered so that in the immediate vicinity of the crystal, the waveguide has a 0.420×0.050-inch cross section, and the two tuners also have a guide height of 0.050 inch.

The low guide allows the use of a short, relatively rigid whisker which, in comparison with the crossed-guide unit, is very easily replaced, since there is no necessity for threading a long whisker through a small hole between fundamental and harmonic guides. In practice, the short whisker can be changed in a few minutes.

Electrically the in-line frequency multiplier has a slightly different circuit from the more common crossed-guide multiplier. Fig. 3 shows both circuits. The crossed-guide multiplier has a circuit that approximates a series connection of the crystal; the in-line circuit is approximately a shunt connection of the crystal and the input and output circuits. The radical aspect ratio of the waveguide (8.4:1) in the immediate vicinity of the multiplying junction leads to very low integrated input and output impedances,[2] of the order of 90 ohms. According to the formulas of Leeson and Weinreb[3] applied to a typical point contact crystal, these guide impedances are of the right order of magnitude for matching reactive generation of the third and fourth harmonics when the second is suppressed. However, this match depends upon the power level.

The low guide height also limits the effects of standing waves on the whisker. Measurements made by Swago on a large in-line harmonic generator of variable guide height showed high and consistent output for heights less than approximately $\frac{3}{8}$ of the harmonic wavelength; beyond that, the output was an erratic function of the guide height.[4] In the frequency multiplier described here, the height is 0.28 λ for the third

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[3] D. B. Leeson and S. Weinreb, "Frequency multiplication with non-linear capacitors—a circuit analysis," Proc. IRE, vol. 47, pp. 2076–2084; December, 1959.
[4] A. W. Swago, "Crystal Multipliers," Quarterly Progress Report Number 11, Research and Investigation Leading to Methods of Generating Radiation in the 100 to 1000 Micron Range of the Spectrum, University of Illinois, Urbana, USAEC Contract AT(11-1)-392, p. 46; March 31, 1959.