A VERY LOW-NOISE, FIXED-TUNED MIXER FOR 240-270 GHz

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ABSTRACT

A cryogenic, single-ended, fundamental frequency mixer is reported. The use of a small-area Schottky barrier diode (C_o = 4 fF) having low series resistance, together with a careful design and optimization, have yielded a very low-noise, broadband mixer which, when fixed-tuned and cooled to 20K, has a single-sideband noise temperature less than 400K for a local oscillator frequency between 242 and 272 GHz. At 266 GHz the mixer has only 6.4 dB of conversion loss and its SSB noise temperature is only 275K. This is the lowest noise temperature ever reported for a Schottky diode mixer in this frequency range.

INTRODUCTION

The fixed-tuned, broadband mixer reported in this paper has been developed to upgrade performance of a low-noise receiver which is currently in use on the NRAO 12-m diameter radio telescope on Kitt Peak, Arizona. The receiver (1) was intended to provide continuous spectral coverage from 200 to 345 GHz using four fixed-tuned, cryogenically cooled mixers individually optimized for operation in the sub-bands 200-240 GHz, 240-270 GHz, 200-300 GHz and 300-345 GHz. For ease of maintenance and to allow mixer upgrading with minimal disturbance to the cryogenic operation of other mixers in the receiver, each mixer and its individual I.F. amplifier is mounted in a separate cryogenic sub-dewar, which can be individually cooled to 20K via one of the mechanical heat switches connected to a single closed-cycle refrigerator.

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MIXER DEVELOPMENT

The mixer, shown schematically in Figures 1 and 2, is a single-ended, fundamental frequency mount developed from an earlier design (2). That design featured a fixed tuning of the mixer and a scalar feed integrated with the mixer block. Such an approach has many advantages. Integrating the feed horn with the diode mount results in a lower loss for the mixer/feed assembly by eliminating unnecessary flanges and lengths of waveguide. Fixed tuning allows the reduction of mixer conversion losses by lowering the ohmic losses and eliminating the reflection coefficient frequency dependence associated with the typical adjustable backshort structures. The use of a fixed-tuned mixer enables one to construct a receiver which is simple to operate and maintain, and can offer good repeatability and stability. However, for such a fixed-tuned device to be useful, broad instantaneous bandwidth must be achieved so that the mixer competes with the frequency domain flexibility available with the more common tuneable mount.

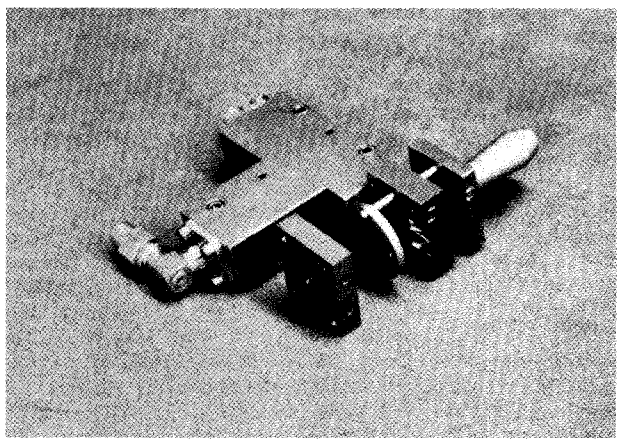

Fig. 1. A photograph of the mixer showing the assembly of major mixer parts.

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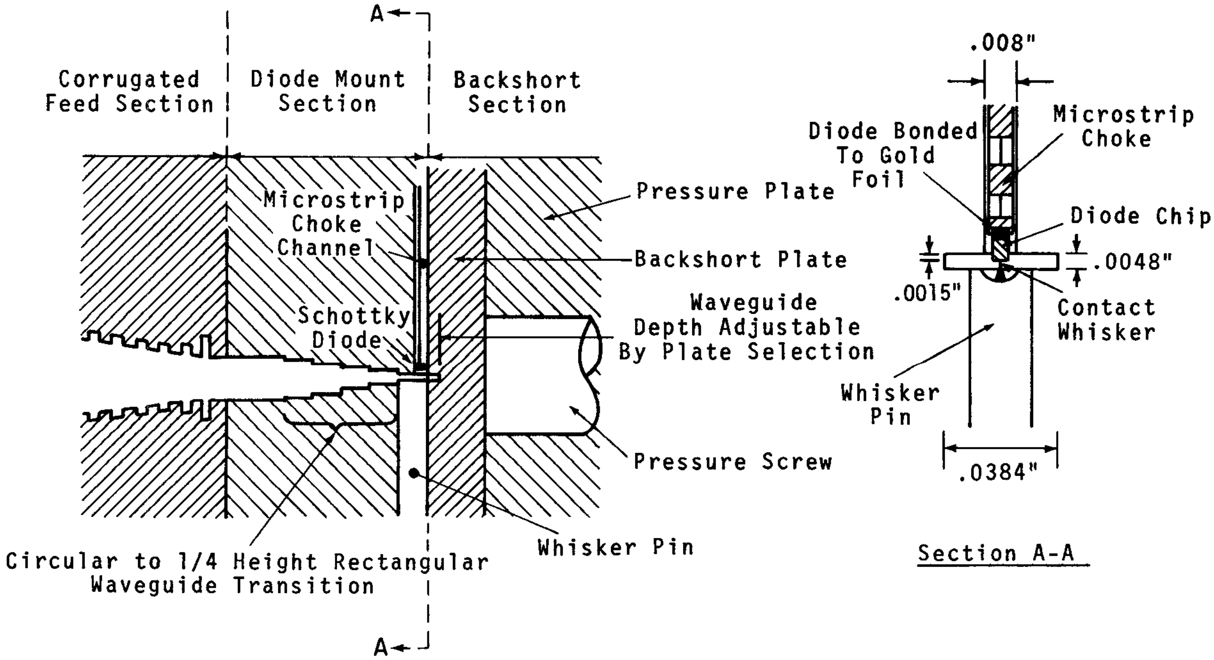

Fig. 2. A sketch of the mixer mount in partial cross-section (not to scale) showing the principal features of the design.

Mixer Mount

The feed horn and waveguide structures of the mixer mount were all electroformed in copper on disposable aluminum mandrels. The feed horn incorporated in the mixer of Figure 2 is a corrugated scalar feed of flare angle 4.57° and aperture diameter 4.79 mm. A five-section, quarter-wave step transformer couples the 1.25 mm diameter circular waveguide at the throat of the horn to a reduced height rectangular waveguide in which a whisker contacted diode is mounted. The reduction in waveguide height to 1/4 of the standard value in the vicinity of the diode (guide dimensions 0.122 mm x 0.975 mm) lowers the impedance of the waveguide, thus making it easier to match the diode to its R.F. embedding network over a broad bandwidth. The I.F. output impedance is also reduced as a consequence of the lower R.F. impedance (3), making broader bandwidth I.F. matching feasible.

The 0.09 mm square x 0.12mm thick diode chip is soldered to a 0.076 mm thick crystalline quartz dielectric microstrip R.F. choke. The choke is epoxied in a 0.203 mm x 0.203 mm channel in the diode block, so that the diode is partially recessed in the channel, itself forming the first capacitive section of the choke. The choke is comprised of a 10-section, high/low impedance design and theoretically presents a short circuit to the diode at 300 GHz while appearing as a small capacitive reactance between 200-270 GHz. At higher frequencies, at least up to the second harmonic of the highest local oscillator frequency, the choke structure remains single moded and presents a reactive termination to the diode, as is required for optimum mixer performance (3).

The fixed backshort is implemented with the aid of a section of short circuited waveguide electroformed into a backing plate. The backshort plate is held in place adjacent to the block containing the diode by a clamping block attached to guide pins and screws which pass through the mixer body (see Figure 1).

The mixer I.F. output is connected to an integral I.F. impedance matching transformer (2), bias tee and D.C. block, which result in an I.F. output VSWR of less than 1.2:1 between 1.2 and 1.8 GHz when the mixer is operated at optimum L.O. and D.C. bias levels.

Mixer Diode

The GaAs Schottky barrier diode used in the mixer, fabricated at the University of Virginia (designated type 1E3), has a zero bias junction capacitance C_o = 4 fF, a D.C. series resistance R_s = 7.9 Ω, a saturation current $I_s = 2.0 \cdot 10^{-15}$ A, ΔV = 74.0 mV and an ideality factor η = 1.374 at 300K. The diode was primarily intended, and hence optimized, for room temperature operation at 240-270 GHz. The higher epilayer doping resulted in higher saturation current, higher ΔV and higher ideality factor as compared with an "optimum" Schottky diode for cooled operation (4), (5). On the other hand, higher doping resulted in the exceptionally low series resistance for such a small area device.

It was very challenging to use this diode in a cryogenic mixer, because it could yield a very low noise mixer if the diode embedding circuit was properly optimized. Low R_s, small C_o and lower R.F. impedance could enable minimization of parametric effects and increases in mixer noise temperature and conversion loss due to higher harmonics effects.

In order to obtain the desired performance of the mixer, the whisker length and configuration were empirically selected in such a way that the whisker inductance series resonates the combined capacitance of choke and diode at a frequency above the highest mixer operating frequency. In this case, changes in the impedance (capacitive) of the diode/whisker combination compensate for changes of the inductive reactance seen towards the fixed backshort, as the frequency is varied. To obtain this behavior, the diode was contacted with a 6.35 µm diameter phosphor-bronze whisker of 114.3 µm, unbent length. The whisker was bent so that the end of the whisker pin sat flush with the guide wall after contacting the diode. The fixed backshort was set 0.4064 mm from the diode plane.

RESULTS

The mixer was cooled to 20K and its performance was measured using a computer controlled measurement system (6) employing a 1-2 GHz I.F. radiometer/reflectometer and a polarizing interferometer/diplexer for L.O./R.F. combining and filtering. The local oscillator source used for the measurements was a frequency-tripled klystron (7). The hot/cold load technique was utilized in the measurements with 300K and 77K R.F. loads provided using Eccosorb AN-72 formed into a pyramidal shape for minimal error due to reflections from the terminations.

As expected for such a small-area, highly-doped device (8), the noise performance of the diode did not improve significantly upon cooling (an equivalent I.F. noise temperature with D.C. bias only, T_{DC} = 190K at bias current of 300 µA). At a temperature of 20K the diode had distinctly non-ideal I-V response characterized by $I_s = 4.4 \bullet 10^{-31}$ A, ΔV = 45.9 mV and η = 9.57. But the diode D.C. series resistance increased to only 10.2 Ω.

Mixer performance was characterized as a function of L.O. and I.F. frequency. The D.C. bias of the diode was kept constant at 0.94 V while L.O. level was optimized at each L.O. frequency (D.C. diode current of 0.4-0.6 mA). I.F. measurement bandwidth was 60 MHz in all measurements. All single-sideband (SSB) values quoted assume equal sideband losses and are based on double-sideband measurements. The sideband losses for the mixer reported here have been measured and found to be equal to within five percent. The accuracy of the reported results is estimated to be ± 3K and ± 0.1 dB in SSB mixer noise temperature and conversion loss, respectively.

At each L.O. frequency mixer noise temperature and conversion loss were measured as a function of I.F. frequency. The computer printout resulting from measurements at 266 GHz is shown in Figure 3. The I.F. response at other L.O. frequencies within the operating range of the mixer is similarly broad.

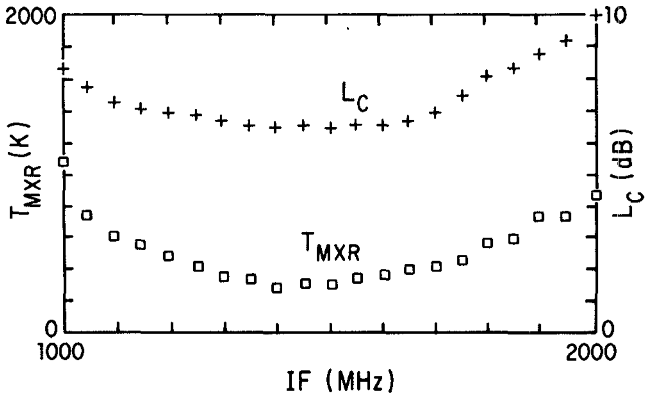

Fig. 3. Single-sideband mixer noise temperature, T_{MXR}, and corresponding single-sideband conversion loss, L_c, of the mixer versus I.F. frequency. (Temp. = 20K, f_{LO} = 266 GHz, Δf_{IF} = 60 MHz, V_D = 0.94 V, I_{MXR} = 0.41 mA, equal sideband losses.)

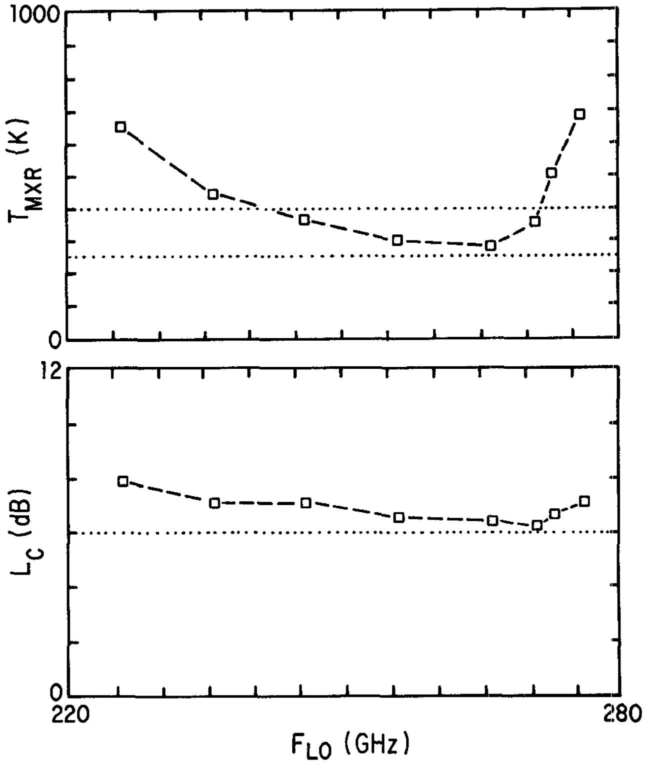

Fig. 4. Single-sideband mixer noise temperature, T_{MXR}, and corresponding single-sideband conversion loss, L_c, of the mixer versus L.O. frequency. (Temp. = 20K, I.F. = 1.4 GHz, Δf_{IF} = 60 MHz, V_D = 0.94 V, equal sideband losses.)

Table 1. SSB mixer noise temperature T_{MXR} and corresponding SSB conversion loss L_c. (Temp. = 20K, I.F. = 1.4 GHz, Δf_{IF} = 60 MHz, V_D = 0.94 V, equal sideband losses.

F_{LO} [GHz]	T_{MXR} [K]	L_c [dB]
226.0	650	7.9
236.0	446	7.1
246.0	363	7.1
256.0	294	6.5
266.0	275	6.4
271.0	352	6.2
273.0	503	6.6
276.0	686	7.1

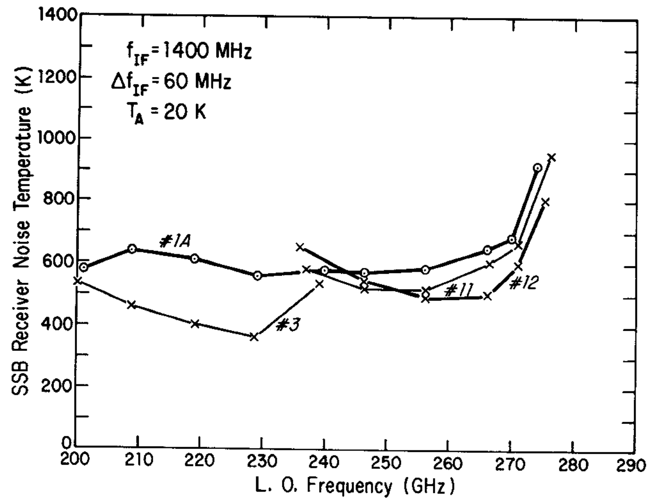

Fig. 5. SSB receiver noise temperature as a function of L.O. frequency for four different fixed-tuned, cryogenically cooled mixers in the 200-280 GHz band. Mixer #12 is reported in this paper; mixers #3 and #11 were reported in (1); mixer #1A in (8). The best SSB receiver noise temperatures obtained at three L.O. frequencies are 370K at 228 GHz, 500K at 246 GHz and 520K at 266 GHz.

The R.F. performance of the mixer is summarized in Table 1 and illustrated in Figure 4. The SSB mixer noise temperature is less than 400K between 242 and 272 GHz with a corresponding SSB conversion loss of less than 7.1 dB. At 266 GHz the mixer has only 6.4 dB of conversion loss and its SSB noise temperature is only 275K. This is the lowest noise temperature ever reported for a Schottky diode mixer in this frequency range. The result obtained shows that, through very careful design, development and optimization, it is possible to construct a Schottky diode mixer in which mixer noise is determined almost entirely by the noise generated in the diode, i.e., the diode series resistance and parametric effects due to the diode non-linear capacitance are negligible, higher harmonics are almost reactively terminated, and correlated shot-noise components from higher harmonics are minimized.

Figure 5 shows the receiver performance measured with the present mixer (#12) and with mixers reported previously (1), (8). A significant improvement in SSB receiver noise temperature was observed at frequencies above 260 GHz, in particular at 266 GHz, SSB receiver noise temperature was decreased to 520 K.

ACKNOWLEDGEMENTS

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REFERENCES

(1) J. W. Archer, "A Multiple Mixer, Cryogenic Receiver for 200-350 GHz," Rev. of Sci. Instruments, vol. 54, no. 10, p. 1371, October 1983.

(2) J. W. Archer, "All Solid-State, Low-Noise Receivers for 210-240 GHz," IEEE Trans. on MTT, vol. MTT-30, no. 8, p. 1247, August 1982.

(3) D. N. Held and A. R. Kerr, "Conversion Loss and Noise of Microwave and Millimeter-Wave Mixers," IEEE Trans. on MTT, vol. MTT-26, no. 2, p. 49, February 1978.

(4) T. J. Viola and R. J. Mattauch, "Unified Theory of High Frequency Noise in Schottky Barriers," J. Appl. Phys., vol. 44, no. 6, p. 2805, June 1973.

(5) S. Weinreb and A. R. Kerr, "Cryogenic Cooling of Mixers for Millimeter and Centimeter Wavelengths," IEEE J. Solid-State Circuits, vol. SC-8, no. 2, p. 58, February 1973.

(6) M. T. Faber and J. W. Archer, "Computer-Aided Testing of Mixers Between 90 GHz and 350 GHz," submitted for publication in IEEE Trans. on MTT, January 1985.

(7) J. W. Archer, "An Efficient 200-290 GHz Frequency Tripler Incorporating a Novel Stripline Structure," IEEE Trans. on MTT, vol. MTT-32, no. 4, p. 416, April 1984.

(8) J. W. Archer and M. T. Faber, "Low-Noise, Fixed-Tuned, Broadband Mixer for 200-270 GHz," IEEE MTT-S Int. Microwave Symp. Dig., p. 557, May 1984.