LOW-NOISE, FIXED TUNED, BROADBAND MIXER FOR 200-270 GHz

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Abstract

A cryogenic, single-ended, fundamental frequency mixer is reported. Contrary to common practice, the mixer utilizes a Schottky diode with high zero bias capacitance of 7 fF and a very short whisker (less than 90 μm). This unusual approach together with a careful design and optimization have yielded an extremely broadband, low-noise mixer which, when fixed tuned and cooled to 21K, has a single sideband (SSB) mixer temperature less than 600K for a local oscillator frequency range of greater than 200 GHz to 270 GHz.

Introduction

To reduce the conversion loss and mixer noise temperature of a Schottky diode mixer, as the frequency is increased, it has been well established that it is necessary to use diodes with higher cutoff frequency, $f_c = 1/2\pi R_s C_o$. This implies reduction of the area of the diode, resulting in lower parasitic conversion losses, L_p, associated with the junction capacitance C_o and the series resistance R_s. However, the intrinsic conversion loss of the mixer, L_o, arising from the mixing processes within the nonlinear diode resistance, can increase rapidly as the area is reduced (1), because firstly, the dynamic range of the nonlinear element is limited and secondly, it becomes more difficult to match the lower capacitance diode to the mount embedding structure. It has been shown (2) that for a given operating frequency, there is an "optimum" diode size which minimizes conversion losses, irrespective of the cutoff frequency f_c. This "optimum" diode size does not necessarily yield low mixer noise temperature because reduction of the area of a GaAs Schottky diode generally causes higher hot electron noise. This can be seen by monitoring equivalent noise temperature of the D.C. biased diode, T_D, while the diode is cooled down. Using our computerized test setup (3), we have found that in most presently available small area GaAs Schottky diodes this effect is significant and results in the noise performance not improving significantly upon cooling when the diode diameter is less than about 1.5 μm ($C_j(0)$ ~ 2-3 fF).

Mixer Development

In order to obtain low-noise broadband operation of a fixed tuned, cooled mixer, we found it desirable to utilize GaAs Schottky diodes with higher zero bias junction capacitance ($C_j(0)$ ~ 6-7 fF) because: 1) diodes with larger area usually exhibit much better noise reduction when cryogenically cooled, and 2) it enables one to resonate the junction capacitance with much smaller whisker inductance, thus permitting proper impedance transformation and matching over a wider frequency range using a fixed backshort. In the presented mixer the whisker length and configuration were selected in such a way that the whisker inductance series resonates the diode capacitance 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 toward the fixed backshort, as the frequency is varied.

The mixer, shown schematically in Fig. 1, is a single-ended, fixed tuned mount with integral scalar feed, developed from an earlier design (4). It comprises a whisker contacted Schottky diode mounted in reduced height waveguide of dimension 0.122 mm x 0.975 mm. A five-section, circular to rectangular waveguide step transition couples power from the feed to the reduced height waveguide. The GaAs Schottky barrier diode, fabricated by R. Mattauch at the University of Virginia (designated type 2P9-300), has a zero bias capacitance C_o = 7fF, a D.C. series resistance R_s = 12 Ω, a saturation current $I_s = 2.7 \cdot 10^{-17}$A, ΔV = 66.5 mV and ideality factor η = 1.113 at 300K. The diode is soldered to a 0.076 mm thick crystalline quartz dielectric microstrip 10-section R.F. choke which is epoxied in a 0.203 mm x 0.203 mm channel in the diode block so that the diode is partially recessed into the channel, itself forming the first capacitive section of the choke.

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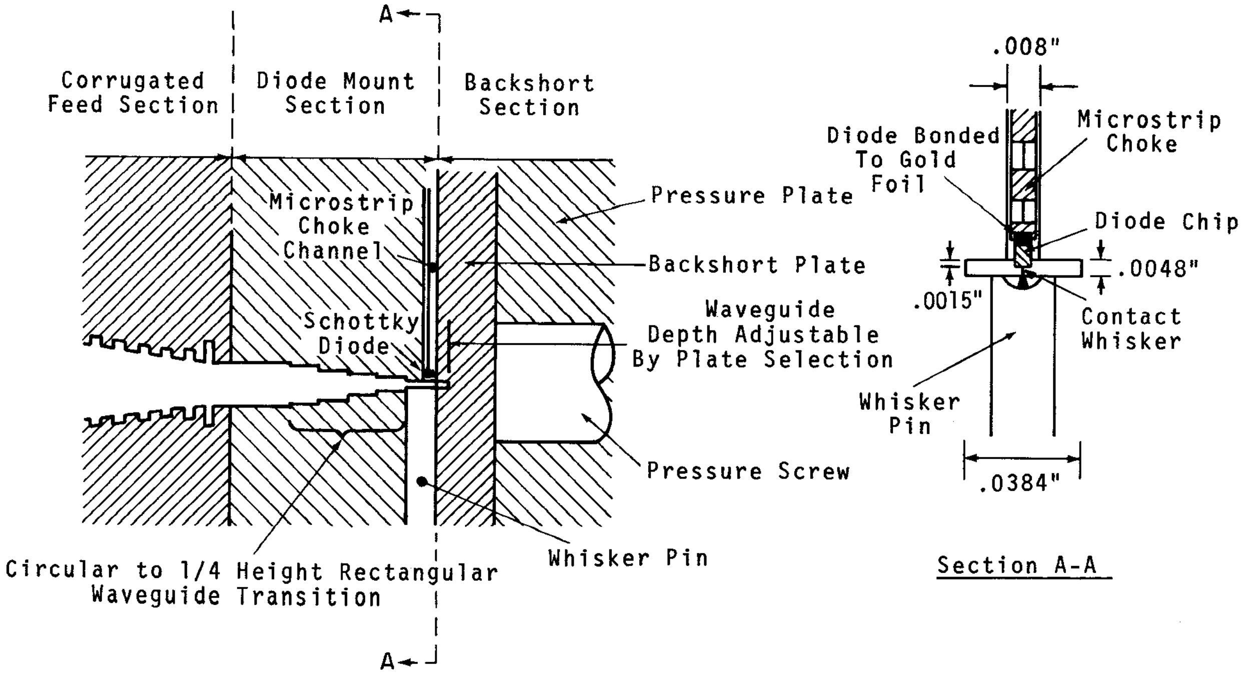
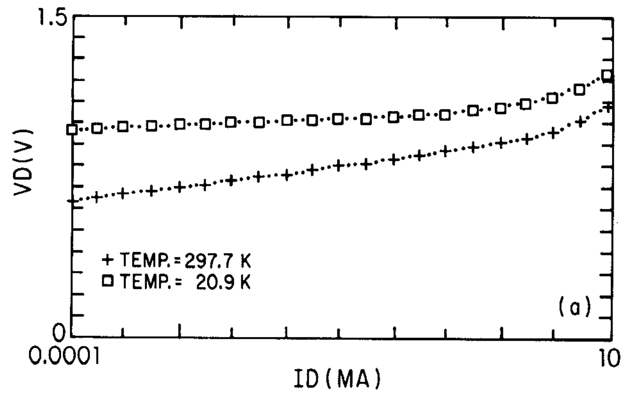


Fig. 1. A sketch of the mixer mount in partial cross-section (not to scale) shows the principal features of the design.

To obtain the desired performance of the mixer, the diode had to be contacted with a whisker of only 88.9 μm unbent length. The whisker was made from a 12.7 μm diameter phosphor bronze wire electrochemically thinned to 6.35 μm and then gold-plated and attached to a 0.51 mm diameter gold-plated BeCu alloy pin which is an interference fit in the mixer body. The pin is made to sit flush with the guide wall after contacting the diode. The fixed backshort was set 0.3556 mm from the diode plane.

Results

The mixer was cooled to 21K and its performance was measured using a computer-controlled, 1-2 GHz I.F. radiometer/reflectometer (3), in conjunction with a quasi-optical local oscillator injection and filtering system. The local oscillator source used for the measurements was a frequency tripled klystron (5). At 21K the diode had R_s = 15.9 Ω, $I_s = 1.5 \cdot 10^{-51}$ A, ΔV = 23.5 mV, and η = 5.27. Its equivalent noise temperature T_D (Fig. 2) was 48K and 59K at D.C. bias current 10 μA and 300 μA, respectively. The mixer performance, uncorrected for the R.F. signal loss associated with the diplexer, is summarized in Table 1 and Figure 3. All SSB mixer parameters quoted assume equal sideband losses and are based on DSB measurements. The SSB mixer noise temperature remains between 500K and 600K, with the corresponding SSB conversion losses between 8 dB and 9 dB (including a loss of approximately 0.6 dB in the quasi-optical L.O. injection system) in the frequency range from 200 GHz to 270 GHz. This is believed to be the low-noise, fixed



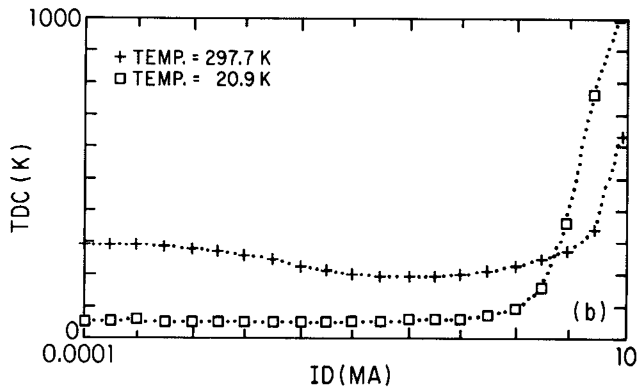


Fig. 2. (a) I-V characteristic of the diode.
(b) Equivalent noise temperature of the D.C. biased diode (I.F. = 1.4 GHz, Δf_{IF} = 60 MHz).

Table 1. SSB mixer noise temperature T_{MXR} and SSB conversion losses L (including ~ 0.6 dB loss in quasi-optical diplexer). Temp. = 21K, I.F. ≈ 1.4 GHz, Δf_{IF} = 60 MHz, equal sideband losses.

F_{LO} [GHz]	T_{MXR} [K]	L [dB]
202.0	537.5	8.38
205.0	548.3	8.57
209.0	601.7	8.92
218.0	592.6	8.42
226.0	511.7	8.04
236.0	537.7	8.26
246.0	528.4	8.35
256.0	503.5	8.15
266.0	554.0	8.25
270.0	596.7	8.55
271.0	699.3	8.95
272.0	789.3	9.03
273.0	876.9	9.56
276.0	2196.6	12.30

tuned mixer with the widest frequency bandwidth so far reported at this frequency range. With an appropriately designed I.F. system and a broader bandwidth L.O. injection scheme, very wide instantaneous receiver bandwidths should be achievable (up to 10 GHz) with relatively flat low-noise performance over the full operating band.

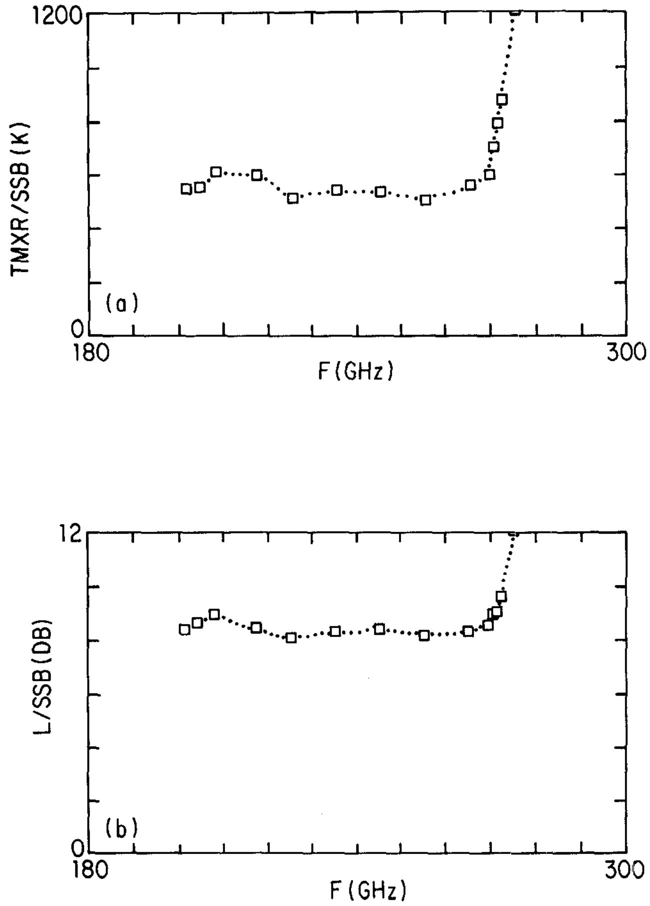


Fig. 3. (a) Single sideband equivalent input noise temperature of the mixer, T_{MXR}.
(b) Corresponding mixer single sideband conversion losses, L (temp. = 21K, I.F. = 1.4 GHz, Δf_{IF} = 60 MHz, equal sideband losses, no corrections for diplexer losses applied).

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