Short Papers

A New Mixer Design for 140–220 GHz

ANTHONY R. KERR, ASSOCIATE MEMBER, IEEE,
ROBERT J. MATTAUCH, MEMBER, IEEE, AND
JOHN A. GRANGE

***Abstract*—A new Schottky-diode mixer is described which has low noise and conversion loss in the 140–220-GHz band. At 170 GHz mixer noise temperatures of 1100–1300 K [Single sideboard (SSB)] have been measured, with 6.2–7.2-dB SSB conversion loss. The design should be usable up to ~300 GHz with appropriate scaling. The mixer has been successfully used in airborne radiometers on the NASA Convair 990 and C-141 aircraft.**

I. Introduction

There is a growing demand in the fields of radio astronomy, atmospheric physics, and plasma diagnostics for low-noise mixers above 100 GHz. These mixers are frequently used in spectral line receivers whose overall sensitivity is largely determined by the noise temperature and conversion loss of the mixer. Intermediate frequencies are usually chosen in the range 0.5–10 GHz to satisfy instantaneous bandwidth and noise-figure requirements.

At frequencies above ~100 GHz waveguide dimensions are so small that it becomes impractical to scale down lower frequency mixer designs. Difficulties arise in making very small RF choke structures with acceptable performance at both RF and IF, and in fabricating waveguide sections less than 0.010 in high. Also the waveguide height becomes comparable with the thickness of the diode chip (typically 0.005 in), leaving little room for a contact spring ("whisker") between the diode and the opposite wall of the waveguide.

This short paper describes a mixer design for the 140–220-GHz band which largely overcomes these problems, while giving what is believed to be the best mixer performance so far obtained at these frequencies. An asymmetric split-block mount is used, in which the diode is recessed into the waveguide wall as part of the RF choke structure. Special gallium arsenide Schottky-barrier diodes were fabricated for these mixers, with chip-dimensions 0.005 × 0.009 × 0.005 in thick.

The mixers described have been used successfully in an airborne spectral line radiometer for observations [1] of stratospheric O_3 and H_2O, and to set an upper limit on the stratospheric abundance of ClO. The 183-GHz H_2O line has been detected in the Orion nebula [2]—the first observation of this line in an extraterrestrial source.

II. Electrical Design

In a recent paper by Kerr [3] a design procedure was described for low-noise mixers in the 80–120-GHz band. It was shown that by reducing the waveguide height in the diode mount to one-quarter of the standard height, desirable RF and IF impedance levels might be obtained over a wide range of frequencies. Taking the same approach in the electrical design of the present mixer, the waveguide is reduced in size through a four-step transformer from 0.0510 × 0.0255 in to 0.0510 × 0.0064 in in the vicinity of the diode, a 4:1 height reduction. Because the thickness of the diode chip (0.005 in) is almost as great as the waveguide height, the chip is incorporated into the first low impedance section of the RF choke, leaving the face of the chip flush with the waveguide wall, as shown in Fig. 1.

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A. R. Kerr and J. A. Grange are with the Goddard Institute for Space Studies, New York, NY 10025.
R. J. Mattauch is with the Department of Electrical Engineering, University of Virginia, Charlottesville, VA 22901.

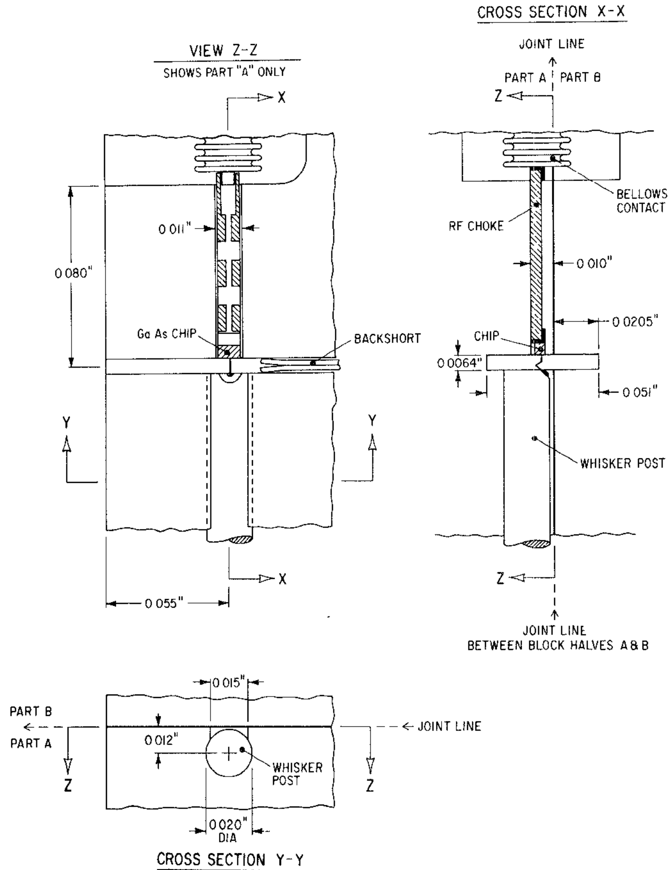

Fig. 1. Details of the asymmetric split-block mount. The diode, RF choke, and whisker post are contained entirely within part A of the block. The fused quartz choke, epoxied into part A, supports the diode chip at its lower end, and is contacted by a spring bellows at the top. The waveguide transformer section is not shown.

The mixer uses gallium arsenide Schottky-barrier diodes similar to those used in [3]. They are 2.5 μm in diameter, fabricated by electroplating platinum anodes on epitaxial GaAs ($N_d = 3 \times 10^{17}$ cm^{-3}). The zero bias capacitance and dc series resistance are 0.007 pF and 8 Ω, respectively, and the ideality factor $\eta = 1.11$.

The RF choke design was optimized using a 100× scale model [4] on which the choke impedance seen from the waveguide could be measured. The choke dimensions and impedance are shown in Fig. 2. The effect of changing the chip dimensions and its position on the choke, each by ±0.0005 in, was measured on the model and found to be small.

III. Construction

Mixer Mount: The diode is mounted across a reduced-height waveguide in an asymmetrically split brass block, as shown in Fig. 1. Normally, in such a design one would avoid current flow

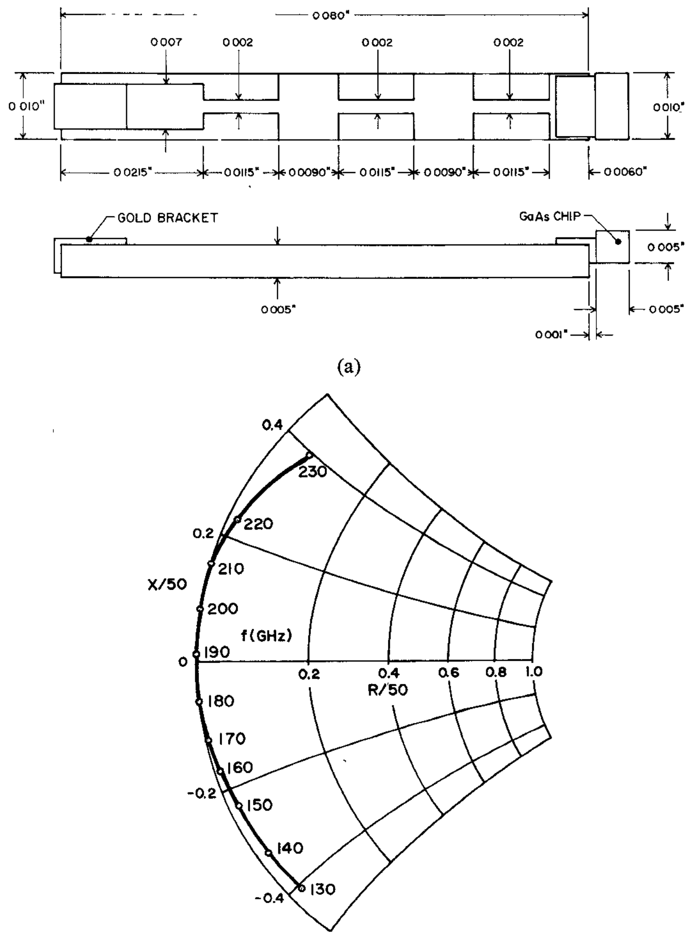

Fig. 2. (a) Dimensions of the RF choke structure. Chip dimensions are not critical within ± 0.0005 in. (b) Input impedance of the choke structure as seen from the waveguide wall. Measurements were made on a 100 × scale model with the left-hand end of the choke terminated in 50 Ω. Impedances are with respect to 50 Ω.

across the joint line by splitting the block down the waveguide center line; however, in this case it was desired to position the diode on the waveguide center line while accommodating the whisker post entirely within one part of the block. This has the following advantages over the configuration described in [3]: 1) easier fabrication, 2) greater mechanical stability, and 3) the diode contacting can be observed in detail through a high-power microscope.

To obtain square waveguide slots with smooth walls and well-controlled dimensions, a tungsten carbide slitting saw was used. Attempts using high-speed steel saws resulted in tapered slots with poor surfaces. The 0.020-in hole for the whisker post was drilled and the 0.015-in gap was then milled along the hole. The hole was reamed to obtain a uniform diameter, a procedure which is necessary to obtain smooth movement of the whisker post while contacting the diode.

All the steps in fabricating the mount were performed on a Bridgeport milling machine. Using carefully developed but simple techniques, tolerances of ±0.002 in were maintained on most of the critical dimensions.

RF Choke: The RF choke is fabricated by photolithography on a 0.005-in fused quartz substrate metallized with 80-Å chromium and 100-μin gold. Small 0.001-in gold brackets are ultrasonically bonded to the ends of the choke, one to contact the springbellows on the center conductor of the SMA connector, the other to support the diode chip which is soldered to it. The choke is glued into the mixer block using Sears Craftsman epoxy No. 9-8059, which has been found to have good adhesion over a wide temperature range [5]. It should be noted that the chip is soldered in place after epoxying the choke into the mount—if the chip is present while the epoxy is curing, the vapor of the epoxy contaminates the surface of the chip and is hard to remove.

Waveguide Transformer: The stepped waveguide transformer is of copper, electroformed on a gold-plated 6061 aluminum mandrel. After electroforming, the mandrel is dissolved in hydrochloric acid leaving the transformer gold plated on the inside.

Backshort: Two heavily gold-plated 0.002-in phosphor–bronze shims are inserted in the waveguide as shown in Fig. 1. Spring fingers ensure contact with the broad walls of the waveguide.

Diode Chips: The diodes are initially fabricated as 0.010-in square dice, 0.005 in thick, by the conventional scribing and breaking process. To reduce their dimensions to 0.005 × 0.009 in as required by the choke design, the chips are soldered to a metal post and hand-lapped under a microscope using grade 3/0 emery paper.

Diode Contacting: The surface of the gallium arsenide chip contains an array of 2.5-μm-diam diodes spaced on 4-μm centers. The anodes of these diodes are deposited through holes in an SiO_2 masking layer, and in the mixer one anode is contacted by a pointed phosphor–bronze whisker as shown in Fig. 1. During the contacting operation it is important that the whisker contact an anode directly without first hitting the SiO_2 layer and then sliding into an anode with further advancement of the whisker post. If sliding occurs the tip of the whisker will be severely deformed and excess capacitance will be introduced in parallel with the diode which will degrade the conversion loss of the mixer. It is also possible to deform the whisker by advancing the post too far after the diode has been correctly contacted.

For these reasons we have found it useful to monitor the contacting process visually with a high-power microscope, with a capacitance bridge, and with a curve-tracer scope. The whisker is advanced in increments of 50 μin using a differential screw, and the position of the whisker tip in relation to the pattern of diodes is observed through the microscope. If necessary the whisker can be bent slightly with a micromanipulator to ensure that it will fall on a diode. The capacitance between the whisker and diode is monitored, and when contact is made a large jump is observed, corresponding to the diode's zero bias capacitance. Fig. 3 shows the capacitance position curve for both well and poorly contacted diodes. After contact is made, the curve tracer is used to check the series resistance and η factor of the diode.

For some years it has been common practice to use a nickel whisker post, typically 0.020-in diameter. We have found that it is difficult to make a nickel post of sufficient uniformity that it will slide smoothly into a tight hole—jumping and creeping frequently occur. For this reason we use a 0.020-in-diam ground steel whisker post, a few microns smaller than the reamed hole in the mixer block. The post is gold plated to achieve the desired degree of interference, the soft gold acting as a lubricating layer between the steel post and the brass block.

IV. Performance

The mixers were measured using the 1.4-GHz IF radiometer/reflectometer apparatus described by Weinreb and Kerr [6]. A noise tube, callibrated at each local oscillator (LO) frequency

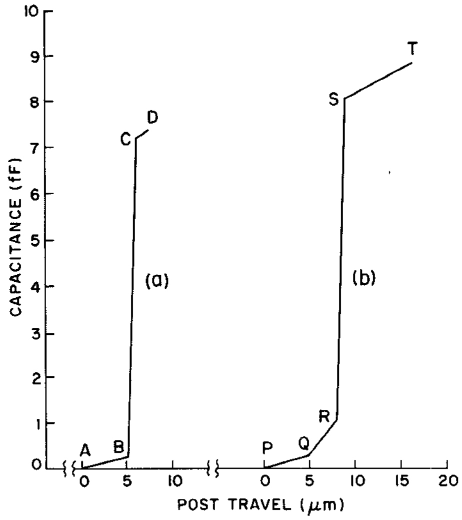

Fig. 3. Capacitance measured at the IF connector during contacting. In curve (a) the whisker approaches the diode (AB), contacts its anode (BC), and deforms slightly (CD) as the post is advanced 1–2 μm further to ensure a stable contact. In curve (b) the whisker lands on the SiO_2 layer between diodes (Q), is forced to skid along the SiO_2 with considerable deformation (QR) until it hits an anode (RS), and is then further deformed (ST) by excessive additional advancement of the post.

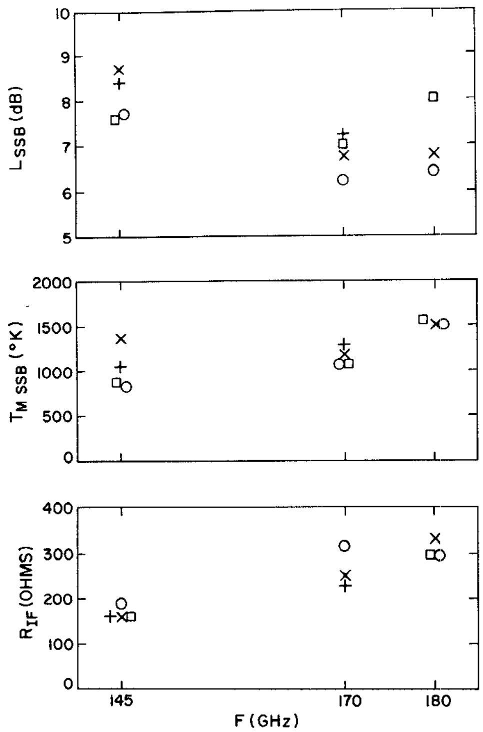

Fig. 4. Measured SSB conversion loss L, mixer noise temperature T_M, and IF impedance R_{IF} for several mixers. L and T_M are referred to the mixer input flange, and have been corrected for IF mismatch. T_M does not include IF amplifier noise. R_{IF} is deduced from the measured IF-port VSWR. Optimum bias was ~0.6 V with $I_{dc} \approx 1.0$ mA.

against hot and cold loads, enables the conversion loss and mixer noise temperature to be determined with respect to the waveguide input flange of the mixer. An IF reflectometer gives the VSWR at the IF port. The LO was injected through a tunable resonant-ring filter having a LO noise rejection of typically 14 dB at the signal and image frequencies (1.4 GHz either side of the LO). For some klystrons the (AM) sideband noise can be many times greater than the input noise temperature of the mixer, and even with 14 dB of sideband rejection the klystron noise may severely degrade the system noise temperature.[1] Our results have been corrected for klystron noise and IF mismatch, and give the performance which would be obtained using a quiet (or well filtered) LO, and an appropriate IF transformer.

In Fig. 4 the measured performance of four mixers is shown. L_{SSB} is the single-sideband conversion loss, and T_M is the effective SSB input noise temperature of the mixer excluding noise from the IF amplifier. The differences between the results for these mixers are caused by variations of diode parameters and mount dimensions. The optimum bias was found to be ~0.6 V with ~1.0-mA dc current. The LO power requirement is estimated to be 1–3 mW. (No power meter was available, and this estimate is based on the klystron manufacturer's figures for our tubes.)

V. Conclusions

A new Schottky-diode mixer has been demonstrated which has low conversion loss and noise in the 140–220-GHz waveguide band. The mixer has an asymmetrical split-block configuration which should be usable up to 300 GHz with appropriate scaling. The diode chip is recessed into the waveguide wall and forms part of the RF choke structure. An improved diode contacting procedure is used.

Acknowledgment

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The Measurement of the Equivalent Admittance of 3-Port Circulators Via an Automated Measurement System

GORDON P. RIBLET, MEMBER, IEEE

***Abstract*—A derivation of the equivalent admittance of symmetrical 3-port circulators is given which is based on the requirement that the *S*-matrix eigenvalues be separated by 120° on the unit circle for perfect circulation. This quantity has the property that if a 2-port matching network is found which matches into this admittance, then the same matching network connected in each circulator arm will match the circulator. It was used in conjunction with a computerized measurement system to determine the optimal single-step transformer matching of a stripline 3.7–4.2-GHz circulator and resulted in a device with performance better than 30 dB over this band.**

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The author is with the Microwave Development Laboratories, Inc., Natick, MA 01760.

[1] For example, our 180-GHz tube, when used as a LO with no sideband filtering, adds about 20 000 K to the system temperature, while our 170-GHz tube only adds 3 000 K. With an LO filter having a sideband rejection of 14 dB, the corresponding contributions to T_{sys} are 800 and 120 K.