WIDELY TUNABLE MILLIMETER-WAVE MIXERS USING BEAM-LEAD DIODES

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SUMMARY

Newly developed GaAs beam-lead diodes have been used in mixers covering the millimeter bands of 35 to 50 GHz, 70 to 90, and 90 to 120 GHz. The mixers were tested at room temperature and achieved the following single sideband conversion losses: 4 to 4.5 dB from 35 to 50 GHz, 5 to 7 dB from 70 to 90 GHz, 4.5 to 6.5 dB from 90 to 120 GHz. SSB mixer noise temperature from 90 to 120 GHz ranged from 494 K to 1200 K. Room and cryogenic noise temperature measurements for the other mixers are in progress.

INTRODUCTION

A series of high-performance tunable mixers covering 35 to 50 GHz, 70 to 90 GHz, and 90 to 120 GHz have been successfully configured to employ state-of-the-art high cutoff frequency beam-lead diodes developed at the Eaton Corporation AIL Division. The performance of these units is among the best reported to date in both conversion loss and noise temperature. The mixers utilize 5000-GHz zero bias cutoff frequency, low parasitic, Mott barrier, beam-lead diodes suitable for high-rel operation. These diodes have been successfully operated at laboratory environments and in cryogenic temperatures (20 K), as well as in a high-vibration vehicle without degradation or failure. These high performance mixers represent a significant advance in characteristics over previously reported tunable mixers (which employed whisker-type diodes with less severe vibration constraint), and are more cost-effective, reliable, and able to withstand severe operational environmental conditions. Some of the highlights of these mixers are:

- SSB conversion losses, and noise figures (4.3 dB, when operated at 296 K at 92 GHz) are among the best results for mixers employing beam-lead and whisker diodes (references 1 - 4).
- They employ beam-lead diodes that are batch processed.
- A biphase configuration that has an inherent instantanous IF bandwidth of 26 GHz.* These units were developed for the Tokyo Astronomical Observatory and can be readily utilized in high data rate communication systems as well as EW applications.

DESIGN CONSIDERATIONS

The beam-lead diode was developed at Eaton Corporation AIL Division (reference 5). It has a Quasi-Mott barrier** with zero bias capacitance in the 0.003 to 0.01 pf range. Typically, the diodes have a parasitic capacitance near 0.015 pf, an ideality factor below 1.08, and a zero bias cutoff frequency in excess of 5000 GHz. The very low series and thermal resistance is realized through the definition of the ohmic contact within 2 um of the junction periphery. The junction area is rectangular, typically 1 x 8 um, and is shown in Figure 1. The diodes have been bonded onto quartz circuits and pins which were in turn installed in biphase mixer housings.

Figure 1. GaAs Beam-Lead Diode

The biphase mixer configuration (reference 6) was chosen with the following in mind:

- Convenient biasing for low LO power
- Convenient IF isolation - resulting in a 50-ohm coaxial circuit unrestricted from dc to 26 GHz
- Optimum as well as wide-band RF embedding impedance for beam-lead diodes from 35 to 120 GHz
- Mechanically suitable at cryogenic temperatures

The additional mixer assembly specifications were:

- Minimum image rejection greater than 18 dB
- Minimum of 2-GHz instantaneous IF band centered at 10 GHz (23-GHz IF for 105 to 117 GHz mixer intended for a dual frequency system)
- Maximum SSB conversion loss of 4.5 dB from 35 to 50 GHz and 6 dB from 70 to 120 GHz
- Maximum diplexer-image filter loss of 0.6 dB

Four mixer types were developed to meet the above specifications and each was designed to cover customer specified RF/IF band. The schematic diagrams in Figure 2 show the four configurations. Each schematic shows the LO diplexing and image rejection scheme.

The 35 to 50 GHz mixer operates the RF below the LO frequency and utilizes the backshort to reject the image. Two couplers separated by a three-position, high-pass waveguide filter are employed to diplex the LO and RF energy.

The 70 to 120 GHz mixers operate the RF band above the LO frequency. They use tunable ring filters to inject LO power and multiposition cutoff waveguide sections to reject the image. The location of the image filter (Figure 2b versus Figure 2c) depends on the ring filter image frequency characteristics.

*Instantaneous 2-GHz mixer bands were designed to be used with 2-GHz wide cryogenics paramps. However 10-GHz mixer instantaneous bandwidth was measured for the broadband (image not rejected) mixers.

**Approaching Mott barriers.

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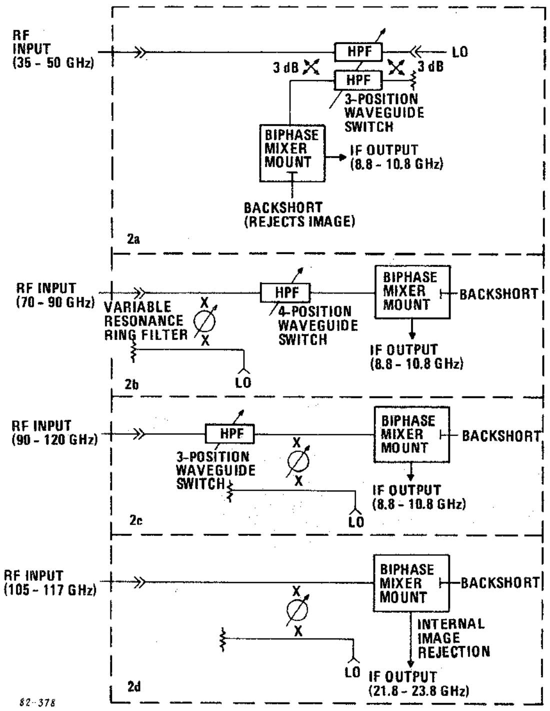

Figure 2. Image Rejection Mixers Block Diagram

Figure 3 shows the assembled 35 to 50 GHz mixer. The biphase mixer with its micrometer driven backshort is bolted through a four section transformer to the LO/RF diplexer. The diplexer scheme, similar to one used for a different application (reference 7), is designed to operate over the 35 to 60 GHz RF/LO band. The 3-dB couplers, each 7/8-inch long, utilize an etched iris pressed in an H-plane split housing. The high-pass filter utilizes three cutoff guide sections that are well matched, and are switched into position every 5 GHz. The RF reflects off the filter into the mixer port with a 0.5 dB loss throughout its band, while the LO passes through both couplers and filter to the mixer port with a maximum of 2 dB loss. The overall SSB conversion loss of the assembly was uniform, 5 dB, and LO power was typically +5 dBm.

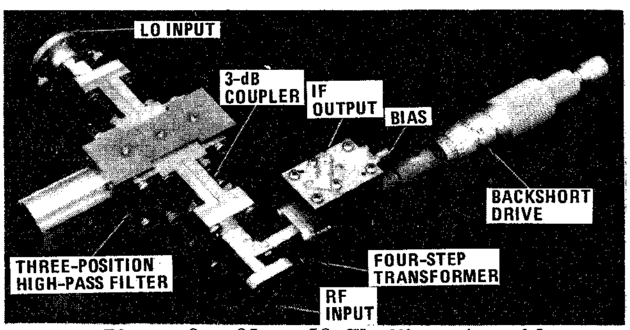

Figure 3. 35 to 50 GHz Mixer Assembly

Figure 4 shows the typical 70 to 120 GHz component makeup as was described in Figure 2. The mixer diode mount, the ring filter diplexer, and the image reject filter are shown.

The diode mount is made out of three sections. The main two consist of reduced height waveguide, transformers to full height guide, and the coaxial IF output. The third section consists of the bias tee. The mixer housing is formed through a hobbing technique that greatly reduces the fabrication cost while improving waveguide finishes.

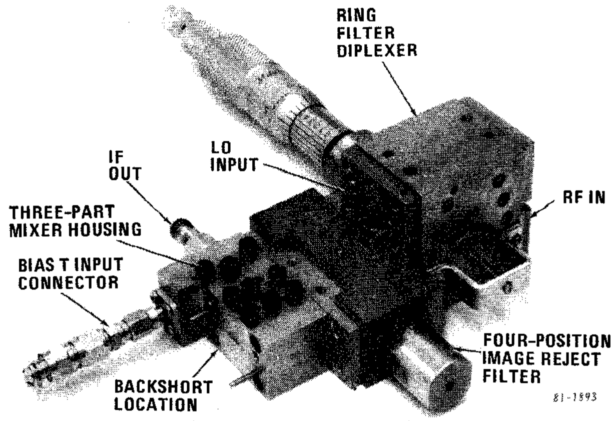

Figure 4. 70 to 90 GHz Mixer Assembly (Typical 70 to 120 GHz Assembly)

The ring filters are similar in construction to the one described in reference 8. Three units were designed each tailored toward the specific RF and IF bands (Figure 2). The RF and LO losses were typically at 0.3 dB and 5 dB, respectively. The 70 to 90 GHz and 105 to 117 GHz ring filters could not be optimized for image performance. The image filters was placed in front of the diode mixer. This eliminated the need of the ring filter to perform at the image.

The image filters use waveguide sections that are each switched into position. The RF loss is typically 0.3 dB. The relative position of the image filter from the mixer diodes' reference plane was found to greatly affect the mixer's RF performance. However, changing the diodes operating current and voltage has always restored performance.

RESULTS

Room temperature SSB conversion loss, input/output VSWR, and LO drive power were measured for each of the four described mixers under the following conditions:

- 2-GHz* instantaneous IF band
- Optimized backshort, bias current, and LO power for each 2-GHz band
- Fixed backshort (for the 90 to 120 GHz only)
- Excluding diplexer/image filter loss
- Including diplexer and image filter losses

Mixer temperature was measured for the room temperature 90 to 120 GHz mixer through the excess noise ratio technique and through the hot/cold method. Both methods were found to be in close agreement and results ranged from 406 K versus 494 K at 92 GHz, to 1130 K versus 1144 K at 119 GHz through the "t" and the hot/cold techniques, respectively.

Figure 5 summarizes the measured results of the mixer covering the 35 to 50 GHz band. The close-in backshort provides a wide bandwidth image termination resulting in near 4-dB SSB conversion loss over the full RF band. We would like to stress that the RF below LO mixer design contributed greatly to the close-in backshort mixer performance. LO power level of 1 to 2 mw was used to drive the two diodes. The dotted line conversion results are given for the full assembly case where the combined IF and RF VSWR remains below 2.5:1 and overall RF to IF conversion losses vary from 4.5 dB to 5.5 dB over the band.

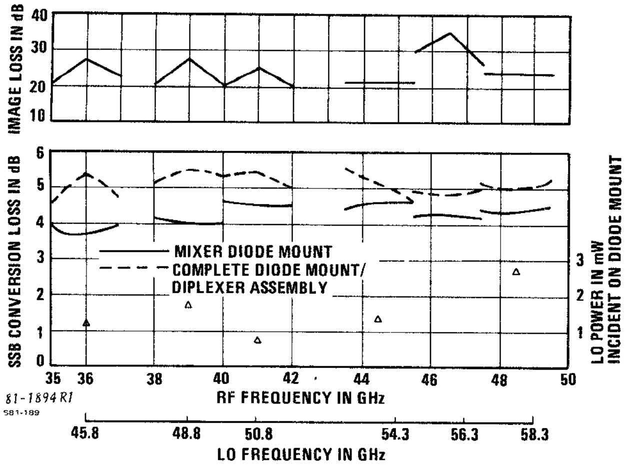

Figure 5. Measured Results of 35 to 50 GHz Mixer

Figure 6 summarizes the measured results of the mixer covering the 70 to 90 GHz band. The mixer's operating bias current was about 2.5 ma per diode and the voltage was about 0.4 volt. The mixer's input and output match, though acceptable, was near the design specification limit and caused the SSB conversion loss to range from 5.5 to 7 dB. Average LO power level of 2.5 mw was used to drive the two diodes.

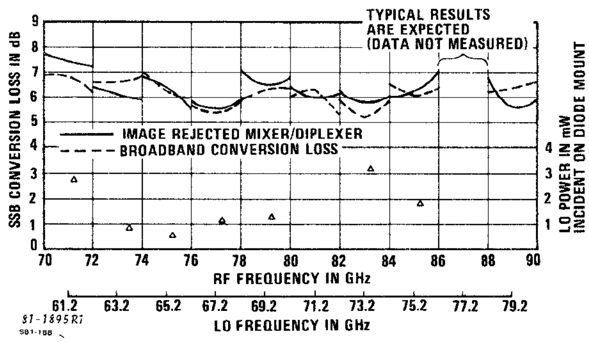

Figure 6. Measured Results of 70 to 90 GHz Mixer

The input and output match of the 90 to 120 GHz mixer was near 1.5:1 and the SSB conversion locs was 4.4 to 5.5 dB from 90 to 109 GHz. This allowed us to evaluate the beam-lead diodes without making corrections for mismatch losses. SSB conversion loss of 6.5 dB and 2:1 to 2.5:1 input and output VSWR were measured at 120 GHz. Figure 7 summarizes the broadband mixer diode mount SSB conversion loss data over the 2-GHz instantaneous IF bandwidth. The data is compared to the performance of the fully assembled image rejected mixer. The fully assembled image rejected mixer has an additional loss of 0.5 to 1 dB throughout its operating band. As in the 70 to 90 GHz mixer, the image filter installation required readjustment of the operating bias and the LO drive levels. In addition, the broadband mixer-diplexer assembly has been operated with a fixed backshort without significant deterioration in passband performance resulting.

A 150 K, 8.8 to 10.8 GHz, liquid nitrogen cooled FET followed by an AILTECH preamplifier mixer was used to measure the mixer's noise temperature. Figure 8 shows the room temperature tabulations. The excess noise ratio ranged from 0.871 at 92 GHz to 1.13 at 120 GHz. However, the deteriorated IF match at the operating RF, which ranged from 108 GHz to 120 GHz, influences our belief that the average excess noise temperature is near 0.9.

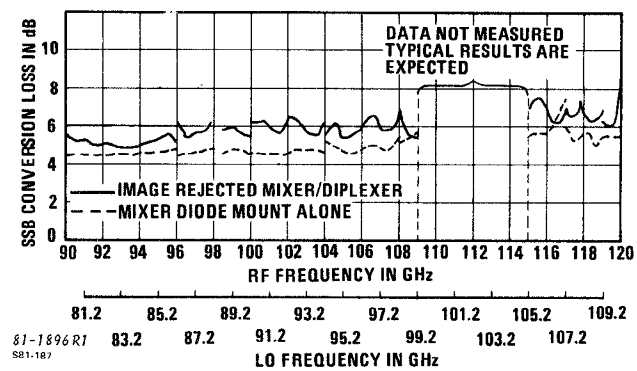

Figure 7. Conversion Loss Data Over a 2 GHz IF Bandwidth

RF (GHz)	RF CONVERSION LOSS (dB) (DIODE MOUNT)	MEASURED t (EXCESS NOISE RATIO)	"t" METHOD SSB (K) T = 290 (Lt-1)	HOT/COLD LOAD SSB	
				$TM_{SSB} = TR_{SSB} - L_S T_{IF}$	NF (dB)
92	4.45	0.871	406	493 5 K	4 3
94	4.25	0.898	406	630 K	5 0
107	5 0	0.989	606	626 K	5.0
118	6.9	1.131	1304	825 K	5.8
119	6.5	1.108	1130	1144 K	6.94

82-431 Figure 8. 90 to 120 GHz Room Temperature Noise Data Summary

CONCLUSION

High-performance beam-lead diodes have been used in deliverable hardware to downconvert from 35 to 120 GHz to an IF centered at 10 GHz and 23 GHz. State-of-the-art SSB conversion losses and noise temperatures have been achieved reliably over 35 percent RF bands, and image rejected performance demonstrated over instantaneous 2-GHz IF bands.

Unique low-loss diplexing, and image control and rejection techniques have been described. The described hardware is capable of cryogenic as well as room temperature operation, and the wide instantaneous IF bandwidth achieved through the biphase mixer makes it very useful in EW receivers. Cryogenic measurements will be reported on in the near future.

ACKNOWLEDGEMENT

The work reported herein was done at Eaton Corporation AIL Division for the Tokyo Astronomical Observatory represented by Professor M. Morimoto. The advice and direction of S. Becker, J. J. Taub, J. Whelehan, G. Irvin, and F. Parini are gratefully acknowledged. Our warmest gratitude is extended to A. R. Kerr of the Goddard Institute of Space Studies for providing us with his 115-GHz ring filter drawings.

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