# A MILLIMETER WAVE MIXER

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# 1.0 INTRODUCTION

## 1.1 GENERAL DESCRIPTION

### 1.1.1 Physical

The mixer consists of a small metallic wafer, in which are embedded the semiconductor diodes, the waveguide mount used to couple the diode wafer to the signal circuit, an RF tuning element, and a 3 mm coaxial connector for the IF output terminal. Figure 1 is an outline drawing of the mixer mount with the wafer diode in place. The cross-sectional dimension is that of the waveguide flange (19 mm x 19 mm, 0.75" x 0.75"), the overall length is nominally 25 mm (1.0 inch).

### 1.1.2 Functional

This component is to be used as a single-ended RF mixer with four replacement mixer diodes, operating in the three millimeter wavelength band, and which can be installed as necessary in the field (at MSFC) without unreasonably complex procedures, tests, or equipment. This mixer is to be a portion of a superheterodyne radiometer which will be employed in radio astronomical observations of transient events in the sun.

## 1.2 OPERATING REQUIREMENTS

This component is designed strictly for laboratory environment operation. Although this type of mixer body and wafer diodes have been successfully subjected to shock, vibration, and temperature testing, these were survival rather than operational tests. No guarantee is given or implied that they will survive other than standard laboratory environment and handling.

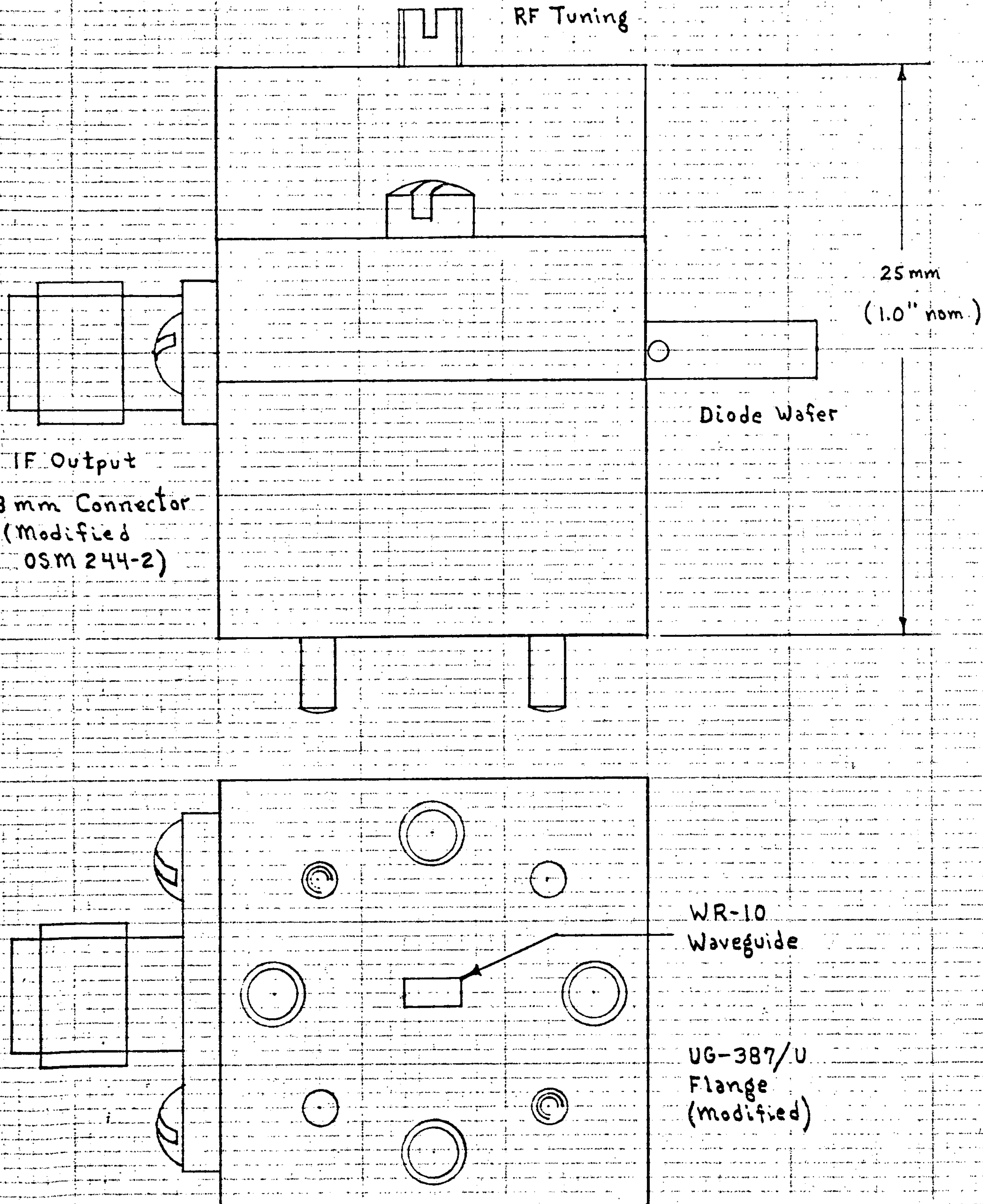



Figure 1. Outline of 95 GHz Mixer

Personnel operating the equipment should be familiar with standard procedures of operating millimeter wave mixers.

## 1.3 EQUIPMENT CHARACTERISTICS

All operational characteristics and specifications are included in the data sheets in Section 3.

## 2.0 MIXER DESIGN

The design of the 95 GHz mixer follows the design techniques already well established[1] and verified at Westinghouse. The approach being taken is centered around the use of a replaceable wafer type diode holder. The wafer contains a unique double diode structure which virtually eliminates RF signal and LO leakage out the IF terminal while minimizing the capacitive loading of the IF terminal (which loading usually comes from a by-pass capacitor or choke and limits the possible IF bandwidth). This unique diode development has made possible[2] a mixer conversion loss at 70 GHz as low as 5 dB. This same type of structure has been used at Westinghouse as the varactor for an ultra-low noise X-band parametric amplifier[3,4] pumped at 70 GHz which had a noise figure of 0.85 dB, gain of 15 dB, and bandwidth of 500 MHz.

The conversion loss initially taken to be 7.0 dB was a number set as a very reasonable goal. Much data had already been taken in the 60 to 70 GHz range with a value of 5.0 dB being attained. This 5.0 dB was actual measured transducer loss and represented not only diode conversion loss but all waveguide and coax transmission line and reflection losses. These values are very close to the theoretically expected values. The mixer frequency cutoff of the diodes, $f_{cm}$, is given as[5]

$$f_{cm} = \frac{1}{2\pi R_s C_j} \quad , \qquad (1)$$

where $R_s$ and $C_j$ are the series spreading resistance and the average junction capacitance respectively, and both quantities must be defined at the operating point of the diode.

The conversion loss is then given as

$$L_c = L_o L_i \quad , \tag{2}$$

where

$$L_i = 1 + 2\frac{f}{f_{cm}} \quad . \tag{3}$$

Here, $L_o$ is the conversion loss of a properly matched, lossless mixer ($R_s = 0$). The $L_i$ term is a multiplicative factor that arises due to the existence of both the $R_s$ and $C_j$. As shown, $L_i$ is given for the case of optimum LO drive; which case requires that under optimum LO drive

$$R_j = \frac{1}{2\pi f C_j} \quad , \tag{4}$$

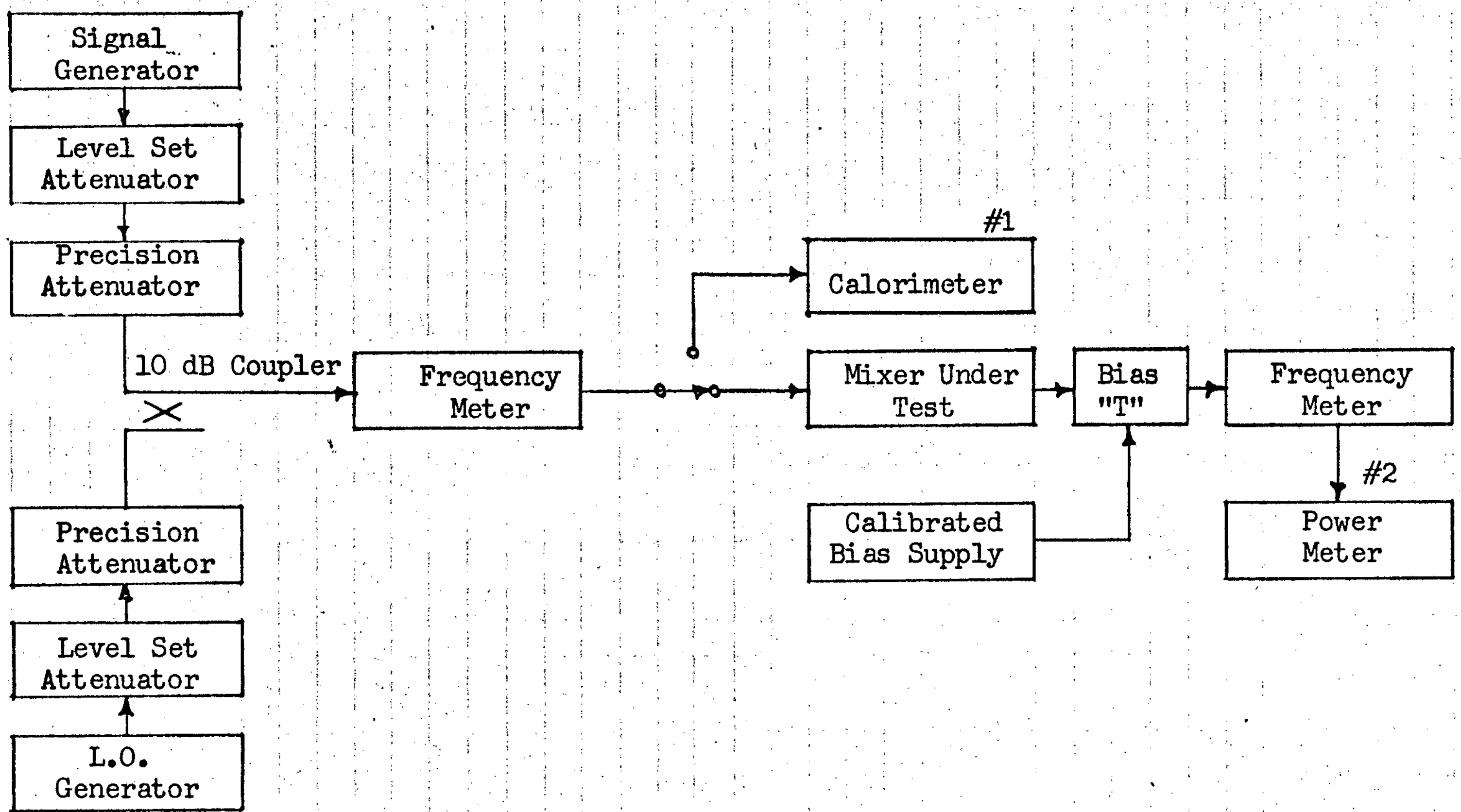
where $R_j$ is the signal resistance referred to the junction terminals and $C_j$ is the average value of the junction capacitance. For the broadband case, where the image and signal impedances are essentially equal, $L_o = 4.5$ dB. It is assumed that an LO duty cycle (conduction angle/2 ) of about 25% is had.[6] The Schottky junctions to be used for this 95 GHz mixer have a junction diameter of 4.0 microns. The measured zero bias parameters of $R_s = 6.5$ ohms and $C_j(o) = .03$ pf which yields a cutoff at zero bias of about 800 GHz. The bias voltage at the optimum operating point is about +.6 volts forward, which would reduce the cutoff frequency to about 700 GHz. By the use of equation 3, and $f_{cm} = 700$ GHz, it is seen that an additional 1.0 dB must be added to $L_o$. As the measured value of $f_{co}$ already included waveguide and mount losses, then $L_c = 5.5$ dB, which is in the range of the measured values. The tuned RF impedance of a single diode is about 160 ohms for the junction parameters given and the junction being driven with a duty cycle of 25%; and the IF impedance is about 90 ohms. With the Westinghouse diode configuration, the two diodes are in series to the RF and thus yield a good match to the waveguide impedance. But the two diodes are in parallel to the IF yielding an effective impedance of 45 ohms which is a good match to the IF output coax. As the match to the RF and IF is simultaneously obtained, no IF transformer is needed. If some mismatch occurs, the LO power and/or bias is readjusted as needed to obtain the desired RF and IF match. As no impedance transformation is required on the IF port, the IF terminal represents no problem on bandwidth.

## 3.0 MIXER TEST/DATA

The measurement and test set-up used for the measurement of conversion loss is shown in Figure 2. The conversion loss is measured by use of a klystron local oscillator set at 95 GHz and a BWO for the signal generator. A waveguide level set attenuator followed by a precision (rotary-vane) attenuator is used to obtain a precise and controllable power level. A TRG Water Calorimeter, Model 980, is used as an absolute power indicator. A General Microwaves, Thermoelectric Power Meter, Model 454A, is used to measure the IF power. The switch at the input to the "Mixer Under Test" block in Figure 2 is only for conceptual purposes. In practice, an actual waveguide disconnect is performed and the calorimeter directly substituted for the mixer for calibration purposes so as to avoid any waveguide switch losses. The calibration was performed before and after each measurement to ensure accuracy.

Figure 3 shows a schematic of a constant current power supply of the type suitable for biasing the millimeter mixers. It will regulate the output current over a wide range of input voltage, and the output is adjustable nominally over the range 1.0-10.0 ma.

Table 1 presents the results of the measurements on the five delivered mixer wafers, Nos. 107, 108, 110, 111, 120. The power into the Local Oscillator port was set to 3 mW (nom. 5 dBm). The bias current was adjusted for minimum conversion loss (as was the RF tuning screw behind the wafer. The measured values of conversion loss, $L_c$, DC bias current, and IF port VSWR for three IF frequencies were recorded and presented in Table 1. The DC bias currents given are the nominal




#1. TRG Calorimeter Model 980.

#2. General Microwaves Thermoelectric Power Meter Model 454A.

Figure 2. Measurement Set-up for 95 GHz Mixers.

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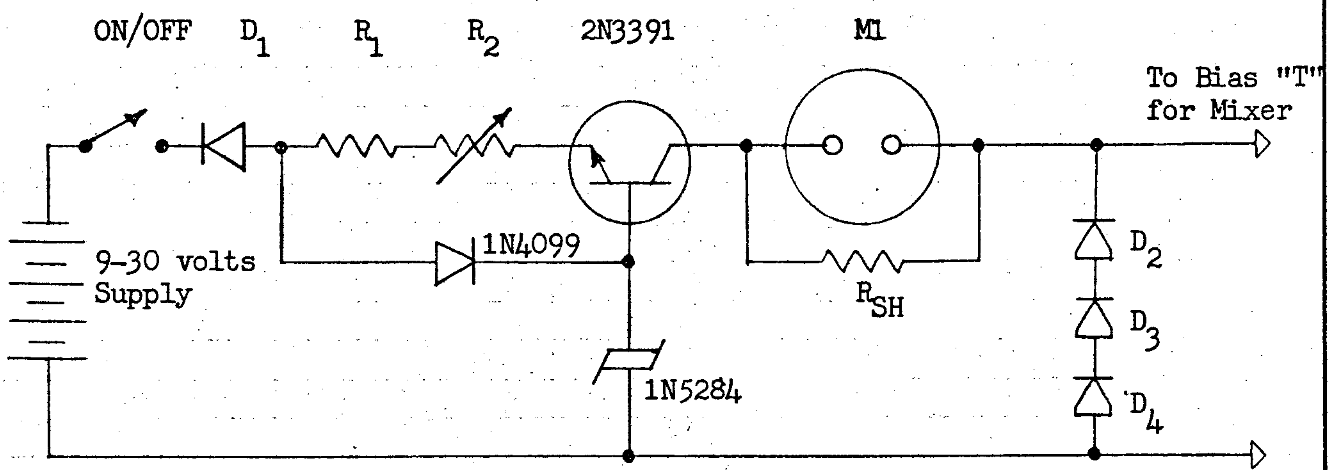


$R_1$ = 560 ohms, $\frac{1}{4}$ watt

$R_2$ = 5 K ohms, 10 turn Potentiometer

$R_3 \cong$ 10 ohms, adjust for 10 ma, full scale

M1 - Simpson Mod. 1622, $R_{int}$ = 1K, $I_{fs}$ = .1 ma

$D_1$, $D_2$, $D_3$ - 1N4154

Figure 3. Constant Current Bias Supply

| $F_{SIG}$ = 92 GHz $F_{LO}$ = 95 GHz $P_{LO}$ = 3 mW. | | | | | |
|---|---|---|---|---|---|
| Diode No. | DC Bias (ma.) | IF Port VSWR | | | $L_c$(dB) |
| | | $f_{IF}$ = 2 GHz | 3 GHz | 4 GHz | |
| 107 | 3.4 | 1.27 | 1.50 | 1.70 | 6.8 |
| 108 | ~5.0 | 1.26 | 1.43 | 1.50 | 4.9 |
| 110 | 3.1 | 1.40 | 1.85 | 1.90 | 5.8 |
| 111 | 3.0 | 1.37 | 1.78 | 1.85 | 5.8 |
| 120 | ~4.0 | 1.20 | 1.26 | 1.38 | 6.5 |

Table 1. Mixer Operating Parameters for $P_{LO}$ = 3 mW.

values, but for three values, plus or minus 0.5 ma, there is little change in $L_c$.

Figure 4 presents additional information in the form of conversion loss as a function Local Oscillator power. The initial tuning was done at an LO power level of +5 dBm. The bias was optimally set and the waveguide (RF) tuner was adjusted. Then the LO power was varied and bias adjusted for minimum $L_c$; the RF tuner was not readjusted at each LO power level. Notice that at the +10 dBm LO level, all five diode wafers showed a conversion loss of $5.2 \pm 0.3$ dB; and in fact all of the nine wafers tested fell within $5.3 \pm 0.5$ dB.

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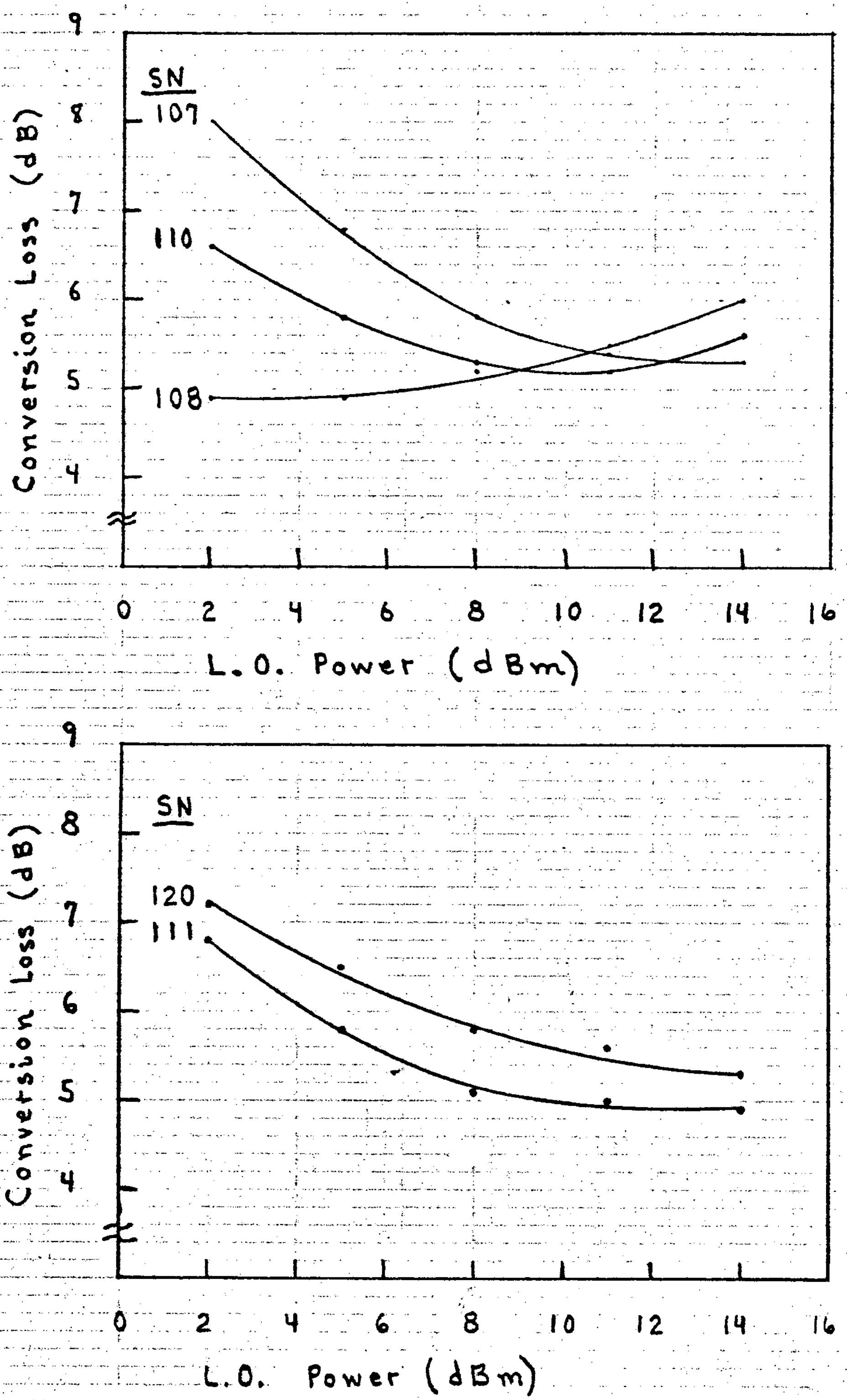


Figure 4. Conversion Loss of 95 GHz Mixer as Function of LO Power

## 4.0 REFERENCES


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