# Second Quarterly Report

for

# High-Sensitivity Infrared Receiver Development

Contract No.: NAS5 - 10156

AIL Report No. 0323-I-2


Prepared by

AIRBORNE INSTRUMENTS LABORATORY
A DIVISION OF CUTLER-HAMMER, INC.
Deer Park, New York 11729


1 July 1966 through 30 September 1966

for

Goddard Space Flight Center
Greenbelt, Maryland

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by

F. Arams, F. Pace, B. Peyton and E. Sard

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## ABSTRACT

This is the second quarterly report on a program to develop a 10.6-micron infrared heterodyne mixer 'and associated IF preamplifier combining as high a sensitivity and as large an IF bandwidth as possible.

~~During the second quarter,~~ expressions for the conversion gain, noise equivalent power, and quantum noise factor of the photomixer in terms of the measureu I-V characteristics were derived. Using measured I-V characteristics of a high-speed Ge:Cu mixer element with laser local-oscillator power incident, the conversion gain, noise equivalent power, and quantum noise factor under various IF preamplifier conditions have been calculated. A conversion gain of 12.4 db, NEP of $6.72 \times 10^{-20}$ watt/Hz$^{\frac{1}{2}}$ and a QF of 5.54 db have been calculated for a matched mixer and a 3-db IF noise factor. The mixer had a measured dynamic resistance of only 1000 ohms. Using a 50-ohm IF preamplifier to improve high-frepuency response, calculated NEP stays about the same; $6.83 \times 10^{-20}$ watt/Hz$^{\frac{1}{2}}$.

Calculations were made of the mixer carrier lifetime from the detector response, and values shorter than 1 nanosecond were calculated--0.825 and 0.165 nanoseconds for assumed. mobilities of 10,000 and 50,000 cm$^2$/volt-sec, respectively,

Based on the above, it is estimated that the high-speed Ge:Cu mixer with 7 milliwatt of laser LO power has low-noise capabilities, which extend to beyond 1 GHz, due to a combination of optimum semiconductor lifetime, transit time, dynamic resistance, and circuit RC product.

Mixing action has been obtained in a Ge:Cu bulk semiconductor for element at 10.6 microns using signals from

two $CO_2$ gas lasers. A sinusoidal variation up to several megahertz in the mixer output voltage, caused by the beat frequency between the local oscillator and signal was observed.

A new high-speed Ge:Cu mixing element compensated with $5 \times 10^{14}$ antimony atoms per cc was tested. A 20 to 30 MHz driver for an infrared modulator has been built and tested.

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# SECTION I

## INTRODUCTION

This is the second quarterly progress report on a program having as its objective the development of a 10.6-micron infrared heterodyne mixer and associated IF preamplifier, combining substantially increased sensitivity compared with envelope detectors and maximum IF bandwidth. Specific objectives are a noise equivalent power (NEP) near $4 \times 10^{-20}$ watt/Hz$^{\frac{1}{2}}$ and an IF bandwidth of at least 400 MHz.

## SECTION II

## PERFORMANCE OF HIGH-SPEED Ge:Cu MIXER DERIVED FROM I-V CHARACTERISTICS

### A. INTRODUCTION

During the first quarter, a theoretical analysis was presented and equations were derived for the conversion gain, noise equivalent power, and quantum noise factor of a 10.6-micron photoconductive mixer.

Values for various physical parameters were then substituted in the equations to obtain values for G, NEP, and QF for a high-speed Ge:Cu mixer in a coaxial high-frequency mount.

In the case of microwave mixers, it was found expedient to predict and determine conversion gain and noise factor directly from the mixer I-V curve, as a means of gaining engineering insight into optimum mixer design and operation.

An analogous approach is now presented for the infrared photomixer. Equations are derived. Values for conversion gain, noise equivalent power, and quantum noise factor are calculated in terms of the mixer I-V characteristic, including such parameters as DC bias polarity, laser local-oscillator drive power, bias current, IF amplifier input resistance, and IF noise factor.

### B. DERIVATION OF I-V FORMULAS FOR INFRARED PHOTOMIXER PERFORMANCE

In this section an expression is derived for the conversion gain of the photomixer in terms of its measured I-V characteristics at various power levels. This method of estimating conversion gain depends on relatively simple measurements and is useful within the IF pass band of the photomixer. A representative I–V characteristic is given in Figure 1; an AC load line has been superimposed, The simplified circuit of Figure 2 is assumed with values of load resistance, R, and bias voltage $V_{bb}$, chosen to give constant current bias.

From the I–V characteristics, the total current, I, in the photomixer can be written as a function of the incident radiation, P, and the voltage, V, developed across it:

$$I = f(P,V) \tag{1}$$

For an incremental change in power ($\Delta P$) or voltage ($\Delta V$) the concomitant change in current ($\Delta I$) is expressed as:

$$\Delta I = \left(\frac{\partial I}{\partial P}\right)_V \Delta P + \left(\frac{\partial I}{\partial V}\right)_P \Delta V \tag{2}$$

where

$\left(\frac{\partial I}{\partial P}\right)_V$ = rate of change of current with power for constant voltage

$\left(\frac{\partial I}{\partial V}\right)_P$ = rate of change of current with voltage for constant power

An incremental voltage appears across the load resistor $R_L$ with sign conventions defined by

$$\Delta V = -R_L \Delta I \tag{3}$$

Eliminating $\Delta V$ from equations 2 and 3 gives:

$$\Delta I = \left(\frac{\partial I}{\partial P}\right)_V \Delta P \left[\frac{1}{1 + R_L \left(\frac{\partial I}{\partial V}\right)_P}\right] \tag{4}$$

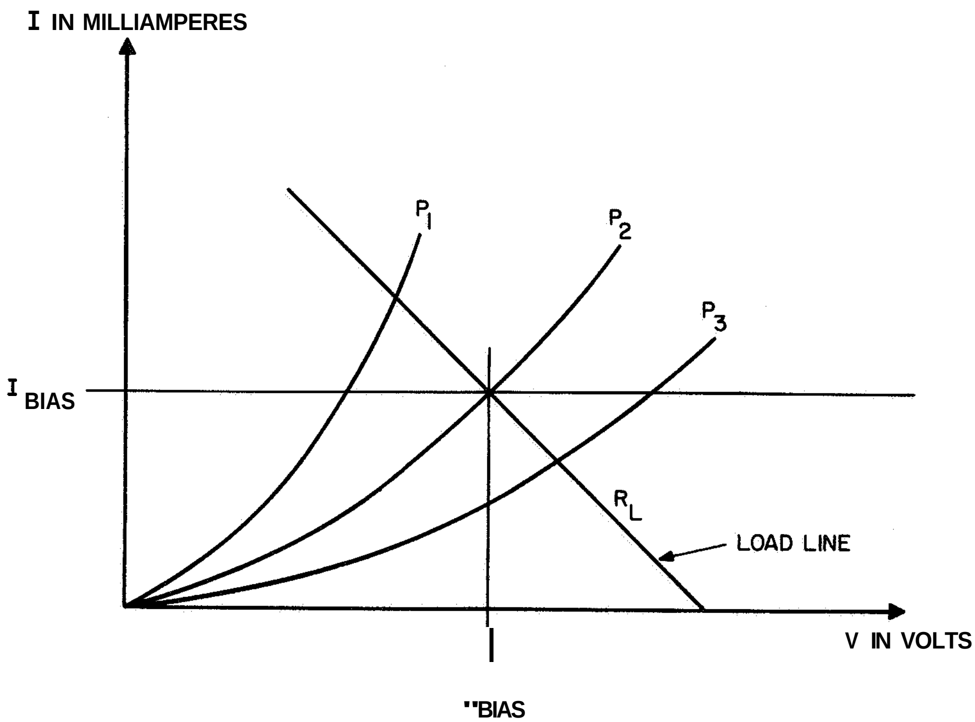
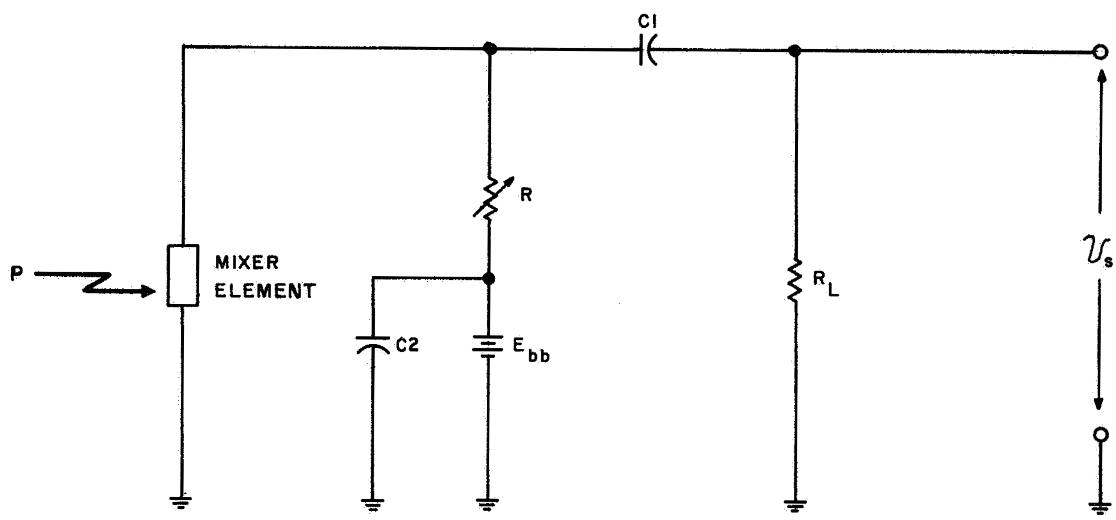



FIGURE 1, I-V CHARACTERISTIC FOR Ge:Cu MIXER ELEMENT WITH APPLJED LASER POWER AS A PARAMETER




$$P = P_{LO} + P_{sig}$$

$$V_{bb} \gg \mathcal{V}_s$$

$$P_{LO} \gg P_{sig}$$

FIGURE 2, SIMPLIFIED MIXER CIRCUIT

The bracketed term in equation 4 pertains to the dynamic impedance of the photomixer and the load resistor, It can be shown that for maximum power transfer to the load (matched conditions):

$$\frac{\partial I}{\partial V} = \frac{1}{R_L} \tag{5}$$

For matched conditions, equation 4 therefore becomes

$$\Delta I = \frac{1}{2}\left(\frac{\partial I}{\partial P}\right)_V \Delta P \tag{6}$$

Since the case of interest here has sinusoidal variations in IF current due to the beat frequency between the local oscillator and the signal, equation 6 is rewritten to display the peak-to-peak values of the IF current and the optical envelope power.

$$(\Delta I)_{p-p} = \frac{1}{2}\left(\frac{\partial I}{\partial P}\right)_V (\Delta P)_{p-p} \tag{7}$$

Consider now the incident illumination which consists of collinear local oscillator and signal beams, whose amplitudes are given respectively by:

$$\sqrt{2}\, E_o \sin(\omega_o t)$$

and

$$\sqrt{2}\, E_s \sin(\omega_s t + \emptyset)$$

where

$E_o >> E_s$,

$\omega_s - \omega_o =$

$=$ an arbitrary phase angle

The photomixer responds only to the envelope of the sum of these two beams. Neglecting second-order terms in $E_s$, the envelope amplitude is given by $\sqrt{2}\left[E_o + E_s \cos(\omega_{IF} t + \phi)\right]$; the IF power across the load is:

$$P_{IF} = \left[E_o + E_s \cos(\omega_{IF} t + \phi)\right]^2 \frac{R_L}{\left[R_L + 1/\left(\frac{\partial I}{\partial V}\right)_P\right]^2}$$

From this expression we compute that the peak-to-peak variation in the IF power is:

$$(\Delta P)_{p-p} = \left[ (E_o+E_s)^2 - (E_o-E_s)^2 \right] \frac{R_L}{\left[R_L+1/\left(\frac{\partial I}{\partial V}\right)_P\right]^2}$$

$$= 4E_oE_s \frac{R_L}{\left[R_L + 1/\left(\frac{\partial I}{\partial V}\right)_P\right]^2} \tag{8}$$

The signal power and LO power in the load when taken independently are:

$$P_{sig} = \frac{E_s^2 R_L}{\left[R_L+1/\left(\frac{\partial I}{\partial V}\right)_P\right]^2}, \quad P_{LO} = \frac{E_o^2 R_L}{\left[R_L+1/\left(\frac{\partial I}{\partial V}\right)_P\right]^2} \tag{9}$$

Combining equations 8 and 9 gives:

$$(\Delta P)_{p-p} = 4\sqrt{P_{sig} P_{LO}} \tag{10}$$

Since the IF signal is sinusoidal, the peak-to-peak current can be expressed as:

$$(\Delta I)_{p-p} = \sqrt{\frac{8 P_{IF}}{R_L}} \tag{11}$$

We now define the available conversion gain as the ratio of IF power under matched conditions to the signal power:

$$G = \frac{P_{IF}}{P_{sig}} \tag{12}$$

Finally, combining equations 5, 7, 10, 11 and 12 gives:

$$G = \frac{P_{LO}\left(\frac{\partial I}{\partial P}\right)_V^2}{2\left(\frac{\partial I}{\partial V}\right)_P} \tag{13}$$

This expression can now be used in the computation of the conversion gain (G), the noise equivalent power (NEP), and the quantum noise factor (QF) of the Ge:Cu photomixer for a variety of conditions.

## C. PREDICTED MIXER PERFORMANCE FROM I-V CHARACTERISTICS

The measured I-V characteristic (Figures 14 and 15 of Reference 1) reported in the First Quarterly Report has been used to predict the expected mixer performance. The procedure used is as follows:

1. Select an $I_{bias}$ and a curve of constant LO power. Their intersection establishes the operating point,
2. The voltage $V_{bias}$ at the operating point is used to compute $R_o = \frac{V_{bias}}{I_{bias}}$,
3. $P_{LO}$ is then computed from equation 11 of Reference 2 under the conditions that:

$$h\nu_{LO} = 1.875 \times 10^{-20} \text{ joule},$$
$$L = 0.0088 \text{ inches}$$
$$\eta \approx 0.56,$$
$$q = 1.602 \times 10^{-14} \text{ coulomb},$$

$\mu\tau = 8.25 \times 10^{-6}$ cm$^2$/volt (obtained from N), and $R_o$, as computed above, is obtained graphically from the I-V characteristic.

4. $\left.\frac{\partial I}{\partial P}\right|_{V_{bias}}$ = constant

5. $\left.\frac{\partial I}{\partial V}\right|_{P_{LO}}$ = constant is obtained graphically from the I-V characteristic

6. $R_L = \left(\frac{\partial I}{\partial V}\right)^{-1}$ for matched conditions

7. G is computed from equation 13,

8. NEP is computed for a variety of preamplifier noise temperature using equation 20 of Reference 1, Under the conditions $\Delta F$ = 1 Hz, and $T_M \approx 5^oK$,

9. QF is computed for each of the above values of NEP by equation 21 of Reference 1.

Under some system conditions, it may be expedient to sacrifice NEP for extended frequency performance. This tradeoff is obtained by deliberate mismatching. When the photomixer and the preamplifier are mismatched, an effective conversion gain is computed as:

$$G_{eff} = G \times \frac{4R_L \left(\frac{\partial I}{\partial V}\right)}{\left(1 + R_L \frac{\partial I}{\partial V}\right)^2} \qquad (14)$$

Under mismatched conditions the value of $G_{eff}$ shows the degradation in overall mixer gain,

Some sample computations have been performed for both matched and mismatched conditions. The results are tabulated in Table I,

Four different operating conditions are compared in Table I, Cases 1 and 2 compare the expected results for a low-voltage bias in the forward and reverse directions under matched conditions. As can be seen from Table I, the forward bias condition has about 5 db more conversion gain, a 20 percent lower NEP and 1-db lower quantum factor (QF) for an IF noise figure of 3 db.

The resultant mixer performance degradation due to a degraded IF noise figure is also shown. As can be seen, the QF for the forward bias case only degraded 3.25 db for a 3-db degradation in IF noise figure but the reverse bias mixer QF degraded 10 db for the same IF noise figure degradation.

Cases 3 and 4 compare matched and mismatched forward bias mixers with a substantially larger bias drive. An NEP $\approx 6.8 \times 10^{-20}$ watt/Hz$^{\frac{1}{2}}$, corresponding to QF $\approx$ 5.6 db, is calculated for a local-oscillator drive near 7 milliwatts and 30-volt DC bias, yielding conversion gains of 12.4 and 4.9 db, for IF input resistances (load resistances) of 1000 and 50 ohms, respectively.

These calculated results are extremely encouraging, since they indicate that large IF-bandwidth high-sensitivity heterodyne mixer operation is achievable with realizable laser, semiconductor, and IF amplifier components. The effective conversion gain for the mismatched case was reduced by 7.6 db for a 3-db IF noise figure but the NEP was only degraded by 1.6 percent and the QF was degraded by less than a tenth of one db when compared with the matched condition.

It is therefore concluded that it is possible to realize good mixer operation even with deliberate IF mismatch for large local-oscillator power and high current bias. Another interesting result from Table I is that for both cases 3 and 4, the NEP and QF degrade negligibly for a 3-db degradation in the IF noise figure.

Finally, the frequency response of the IF amplifier network increases inversely with $R_L$ so that the mismatched mixer (case 4) has an upper frequency limit for the circuit which is twenty times higher than would be obtained for the matched condition (case 3).

# TABLE I

## CALCULATIONS OF CONVERSION GAIN, NEP, AND QUANTUM FACTOR OF Ge:Cu PHOTOMIXER FROM MEASURED I-V CHARACTERISTICS

| Data Source | $I_{BIAS}$ (ma) | $V_{BIAS}$ (Volts) | $\left(\frac{\partial I}{\partial V}\right)^{-1}$ (Ohms) | $R_L$ (Ohms) | $R_o$ (Ohms) | $P_{LO}$ (mw) | $\left(\frac{\partial I}{\partial P}\right)^{-1}$ (Volts) | G (Numeric) | G (db) | Match Factor (Numeric) | $G_{eff}$ (Numeric) | $G_{eff}$ (db) | NEP $\times 10^{-20}$ (Watts) @$F_{IF}$=3 db | NEP $\times 10^{-20}$ (Watts) @$F_{IF}$=7 db | QF (db) @$F_{IF}$=3 db | QF (db) @$F_{IF}$=7 db |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Middle LO Power Trace of Figure 14A (Reference 1) | +0.5 | +3.0 | 5850 | 450 | 6000 | 2.21 | 0.24 | 0.37 | -4.3 | 1 | 0.37 | -4.3 | 7.80 | 11.05 | 6.20 | 7.72 |
| Middle LO Power Trace of Figure 14B (Reference 1) | -0.5 | [redacted] | [redacted] | 2780 | 5660 | 2.36 | 0.19 | 0.12 | -9.2 | 1 | 0.12 | -9.2 | 10.08 | 20.1 | 7.30 | 10.3 |
| Highest LO Power Trace of Figure 15A (Reference 1) | +16 | [redacted] | [redacted] | 10[redacted] | 1875 | 7.07 | 2.21 | 17.3 | 12.4 | 1 | 7.3 | 12.4 | 6.72 | 6.79 | 5.54 | 5.59 |
| Highest LO Power Trace of Figure 15A (Reference 1) | +16 | +30 | 100 | [illegible] | 13[illegible] | 7.07 | 2.21 | 17.3 | 12.4 | [illegible] | 3.12 | 4.0 | 6.9 | 7.15 | 5.68 | 5.82 |

Conditions, $h\nu_{LO} = 1.875 \times 10^{-20}$ joules, $\eta \sim 0.56$, $T_M \sim 5^{o}K$, $\omega\tau << 1$.

## SECTION III
## MIXING EXPERIMENT

### A. GENERAL

Three approaches have been considered to investigate mixing in the 10.6-micron region: (1) homodyne, (2) two-laser, and (3) single multimode laser. Each approach is briefly outlined below:

#### 1. HOMODYNE

The homodyne approach uses a single laser that is split into two beams and later recombined at the mixer element. The signal beam can be independently modulated and attenuated.

The mixer is usually followed by a narrow band video amplifier tuned to the modulation frequency.

#### 2. TWO-LASER MIXING

Mixing using two single-mode lasers imposes the most stringent alignment requirements of the approaches considered. The signal laser beam is independently attenuated and made collinear with the LO laser beam by proper selection and alignment of the optical components.

The mixer is followed by a broad-band high-gain IF amplifier. A number of amplifiers can be used to cover the video bandwidth to beyond 1000 MHz. The IF amplifier can also be followed by a spectrum analyzer to view the RF beat spectrum. Two-laser mixing is the most direct approach to mixing and offers the most promise for the accurate measment of conversion loss, NEP, and IF response.

The two-laser approach has the advantage that it most realistically approaches the operational communications situation. This is because in the one-laser approach, signal and LO are derived from the same source in which case side-bands or extra modes present in the laser could degrade mixer NEP.

3. MULTI-MODE LASER

Beats can be readily observed in a single laser oscillating simultaneously in two modes. The modes involved could be $TEM_{00}$ longitudinal modes, higher-order off-axis modes, or (in the case of $CO_2$) two frequencies can be generated by simultaneous oscillations in two rotational transitions of $CO_2$. The latter are generally spaced about 46 GHz or more.

The longitudinal modes of a two-mirror laser resonator have a frequency separation given by:

$$\Delta f = \frac{C}{2L} \tag{15}$$

where $\Delta f$ = frequency spacing between modes
C = velocity of light
L = mirror spacing

A 4-meter long $CO_2$ laser cavity, for example, will have a mode spacing near 37 MHz. Therefore, there can be two longitudinal modes present within the amplification bandwidth of the $CO_2$ gas (typically 52 MHz).

The single, multi-mode laser approach simplifies the alignment problem but has the distinct disadvantage that the signal and local oscillator beams cannot be independently modulated and attenuated.

For approaches 1 and 2, the threshold sensitivity level of the mixer can be determined by decreasing the signal level until the system is noise limited. This is not true in approach 3.

## B. SETUP FOR TWO-LASER HETERODYNE EXPERIMENT

Initial experiments on the two-laser heterodyne approach were performed during this report period. A diagram of the experimental setup is shown in Figure 3. The local-oscillator beam passes directly through a sodium chloride beamsplitter, and is focused by a spherical mirror onto the mixer. The need for a spherical mirror was discussed in the First Quarterly Report. Signal power which need only be low-power, comes from the second laser and is reflected off the front surface of the beamsplitter. Signal power is varied using thin-film attenuators deposited on a polyethylene substrate.

The experimental setup is aligned using a visible He-Ne laser with the mixer element at room temperature. This can be done because all infrared windows and optical components are transparent in the visible. The path of the visible beam is shown by the dashed lines in Figure 3, The beam is divided by the beamsplitter into the components, each of which traverses one of the $CO_2$ laser tubes, The reflections off the flat rear mirrors of the $CO_2$ lasers are recombined at the mixer. The alignment requires great care, Final alignment is made with the $CO_2$ lasers operating, by peaking the precision mirror mounts while monitoring the mixer V-I characteristic on a transistor curve tracer or by observing the IF output response of the mixing element.

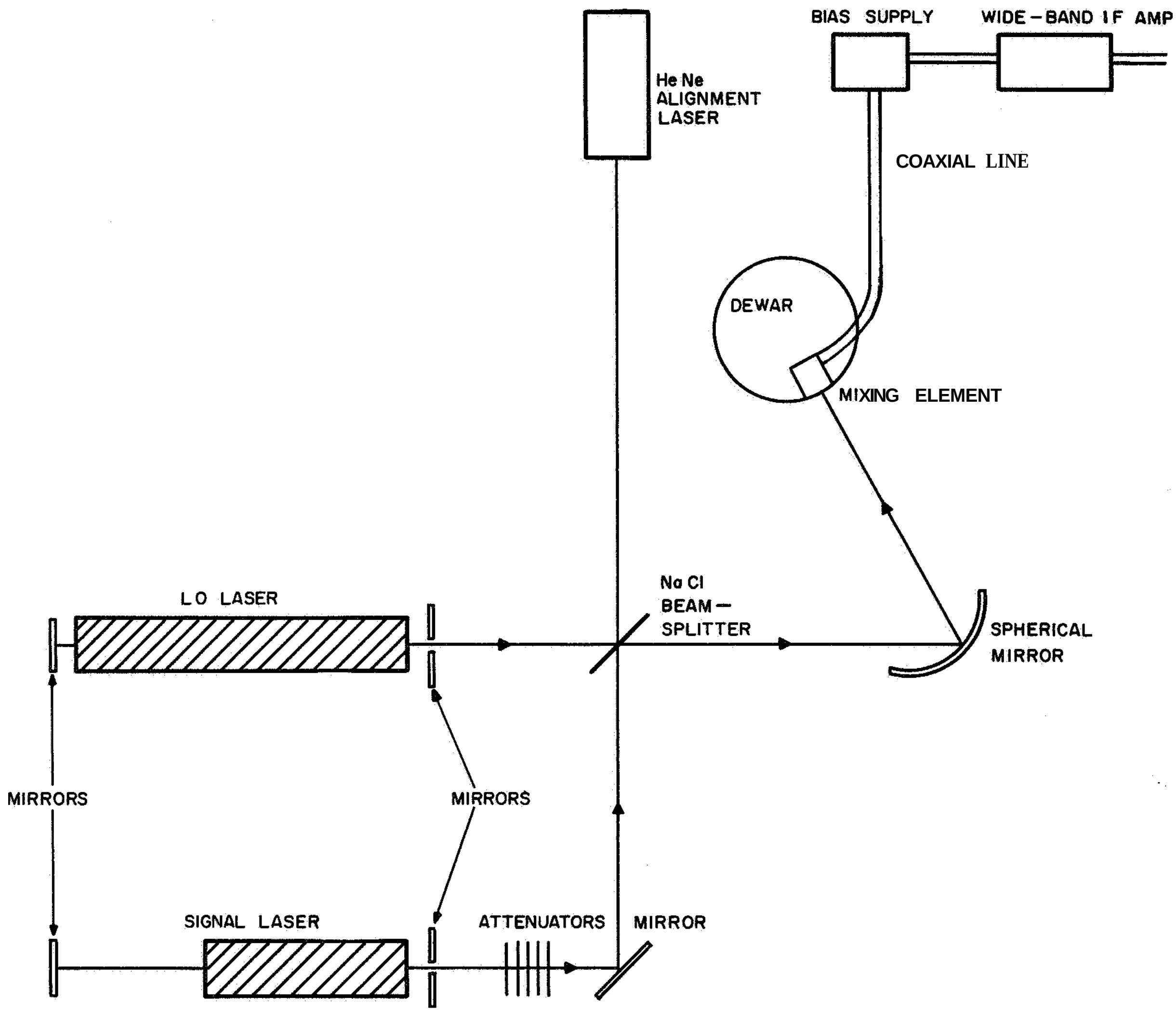



FIGURE 3. BLOCK DIAGRAM OF EXPERIMENTAL SETUP FOR TWO LASER HETERODYNE MEASUREMENTS

## C. RUGGEDIZED $CO_2$ LASER

The LO laser mount has been ruggedized to improve the overall system stability. The new laser housing is shown in Figure 4. The laser tube is conductively cooled by heat-sinking to an aluminum channel using a high thermal conductivity grease. Three muffin fans can be used to cool the tube and heat sink,

The laser table and evacuation pump have been shock mounted to minimize system vibrations. The pump is connected through a small ballast tank to reduce pressure variations.

Further stability improvement was obtained by using a voltage-regulated power supply, Fluke Model 408B. The stability of this system showed an order of magnitude improvement over the previous setup.

## D. EXPERIMENTAL RESULTS

The two-laser measurement setup illustrated in Figure 3 was used to observe mixing at 10.6 microns, The mixer and bias supply were followed by a high-gain oscilloscope. The heterodyning of signal and local oscillator generated a difference frequency beat in the mixer, During the initial experiments, difference frequencies as high as 3 MHz have been observed on an oscilloscope.

Further work in the next report period will be aimed toward improving the measurement setup and measuring the mixer performance in detail.

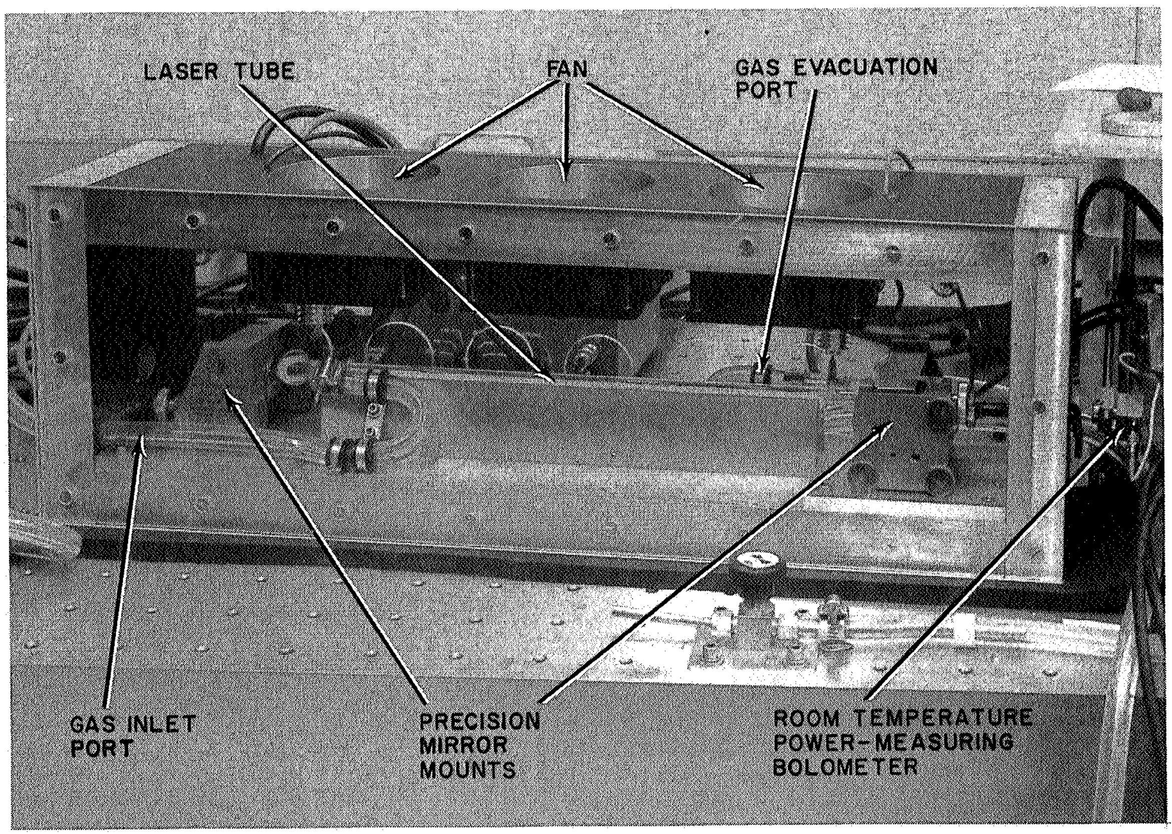



FIGURE 4. RUGGEDIZED HOUSING FOR $CO_2$ LASER CAVITY

## SECTION IV

## DERIVATION OF MIXER IF RESPONSE FROM DETECTOR RESPONSE

For a photoconductive detector of dark resistance $R_C$, connected in series with a voltage bias source $V_{bb}$, and load resistance $R_L$ (Figure 2), the signal voltage, $v_s$, is in general given by:

$$v_s = V_{bb} \frac{R_L R_C}{(R_L + R_C)^2} \frac{G\tau}{n} \qquad (16)$$

where

$G$ = Generation rate of free carriers by the signal radiation,

$\tau$ = Free-carrier lifetime,

$n$ = Total free-carrier density at thermal equilibrium,

$R_L$ = Load resistance,

$R_C$ = Detector resistance.

For a signal sinusoidally modulated at an angular frequency, $\omega$, the generation rate is

$$G = \frac{\eta Q A}{\left[1 + (\omega\tau)^2\right]^{1/2}} \qquad (17)$$

where

$\eta$ = Quantum efficiency

$Q$ = Signal radiant flux density in photons/cm2/sec,

$A$ = Detector area in $cm^2$, as shown in Figure 5.

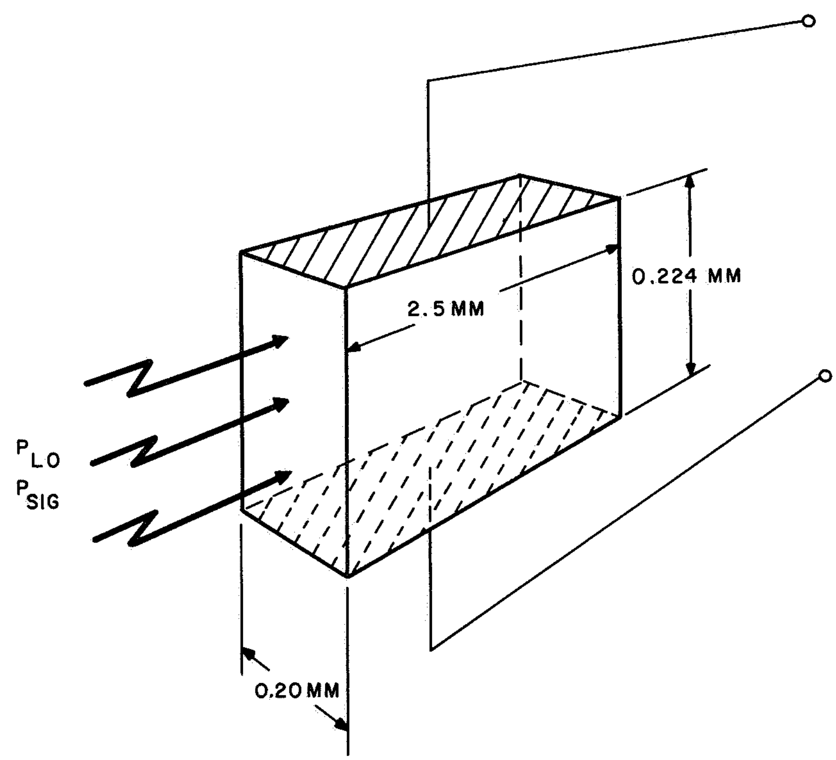



FIGURE 5. DIMENSIONS OF MIXER ELMENT

Substituting equation 17 into equation 16, for $\omega\tau << 1$, we obtain

$$v_s \approx V_{bb} \frac{R_L R_C}{(R_L + R_C)^2} \frac{\eta Q A \tau}{n} \qquad (18)$$

For the Ge:Cu high-speed mixer element under test, we use the experimental values measured with a small-signal black-body source:

$v_s = 1.283 \times 10^{-5}$ volt,

$V_{bb} = 7.5$ volts,

$R_L = 100$ kilohms,

$A = 4.6 \times 10^{-4}$ cm$^2$ (0.2 × 0.23 mm$^2$),

$Q = 9.65 \times 10^{13}$ photons/cm$^2$/sec,

and we take the calculated value $\eta = 56$ percent.

Substituting these values into the above equation, we obtain the numerical value for the Ge:Cu high-speed mixer element

$$\frac{\tau}{n} \approx 3.9 \times 10^{-16}$$

Now, the free-carrier density is given by

$$n = \frac{\sigma \ell a}{q\mu} = \frac{1}{q\mu} \frac{\ell^2}{R_C} \qquad (19)$$

where

$\sigma$ = Conductivity of the mixer element,

$a$ = Cross-sectional area of the element (perpendicular to current flow)

$\ell$ = length of the sensor element between contacts = 0.02 cm (Figure 5)

q = electronic charge = $1.6 \times 10^{-19}$ coulomb,

$\mu$ = mobility of the carriers.

All values required to calculate lifetime from equations 18 and 19 are known, except the carrier mobility. Two assumed values are used with the actual value believed to be in between these:

| Assumed Mobility ($cm^2$/volt-sec) | Number of Free carriers | Transit Time (Sec) | Carrier Lifetime (sec) | Frequency Where Roll-Off Begins |
|---|---|---|---|---|
| 10,000 | $4.3 \times 10^{5}$ | $5.33 \times 10^{-9}$ | $8.25 \times 10^{-10}$ | 193 MHz |
| 50,000 | $2.1 \times 10^{6}$ | $1.07 \times 10^{-9}$ | $1.65 \times 10^{-10}$ | 965 MHz |

When considerable laser power is incident on the detector, the lifetime may get even shorter. The frequency where roll-off begins is obtained from the lifetime $\tau$ by the expression $f = 1/2\pi\tau$.

The preceding lifetime values are significantly shorter than the value given by Yardley and Moore (Reference 2), and indicate the potential high-frequency capability of the antimony-compensated Ge:Cu high-speed material,.

As shown in the First Quarterly Report, NEP remains low to frequencies considerably beyond the roll-off frequencies given.

## SECTION V
## OTHER MIXER MATERIALS

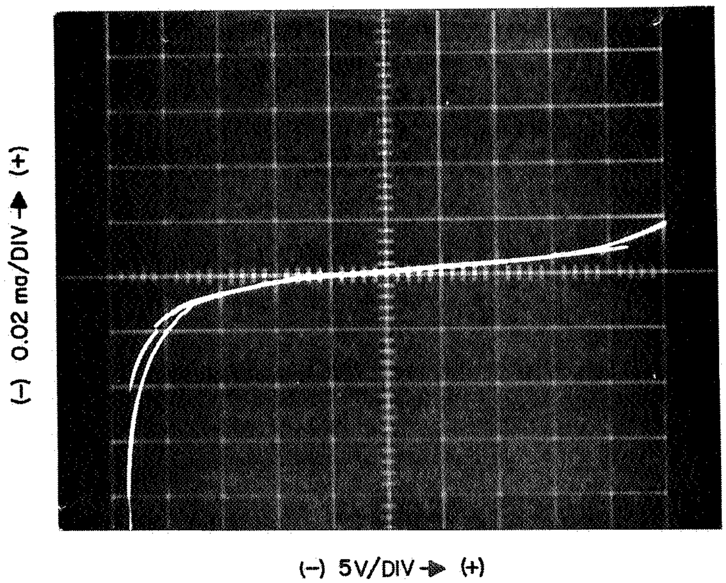
### A. INITIAL TESTS OF A NEW Ge:Cu MIXER ELEMENT

Ge:Cu detector material grown at Bell Telephone Laboratories has been obtained during this report period. This is high-speed material containing $10^{16}$ copper atoms per cc compensated with $5 \times 10^{14}$ atoms per cc of antimony. An element was cut, mounted in a high-frequency coaxial mount, and tested at liquid helium temperature. Initial results were as follows:

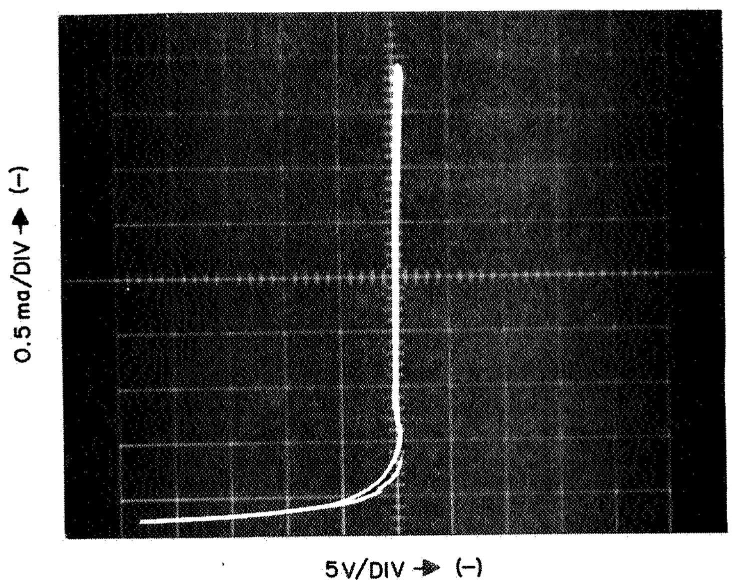
1. Detector resistance, without laser power applied, was 220,000 ohms.
2. Breakdown voltage was near 20 volts.
3. Measured I-V curves are shown in Figure 6,

### B. MERCURY-DOPED GERMANIUM

A mixer element of high-speed Ge:Hg in a high-frequency coaxial mount is ready for test.




*A. I-V CHARACTERISTIC*




*B. EXPANDED NEGATIVE VOLTAGE*

FIGURE 6. I-V CHARACTERISTICS OF HIGH-SPEED Ge:Cu MIXER NO. 2 WITHOUT LASER POWER APPLIED AT 4.2°K

## SECTION VI
## DRIVER FOR GaAs MODULATOR

An infrared GaAs modulator has been obtained on loan from GSFC. Although this modulator is designed primarily for the 1 to 3 micron region, we have been considering its potential usefulness for generating a low-level 10.6-micron phase-modulated signal, by removing the polarizer and quarter-wave plate, which are opaque at 10.6 microns,

Manufacturer's data on the modulator indicates that 40 percent modulation in the near infrared can be realized with a 400-volt RMS applied electric field. At 10.6 microns, the modulation depth would be proportionately lower.

In an attempt to increase the modulation depth, a special driver has been developed (Figure 7). A single 807 Class C amplifier with a high-Q tank circuit was designed, which provides a 1200-volt peak-to-peak swing across the GaAs crystal and is tunable from 20 to 30 MHz.

This supply could be used to drive the modulator at 10.6 microns.

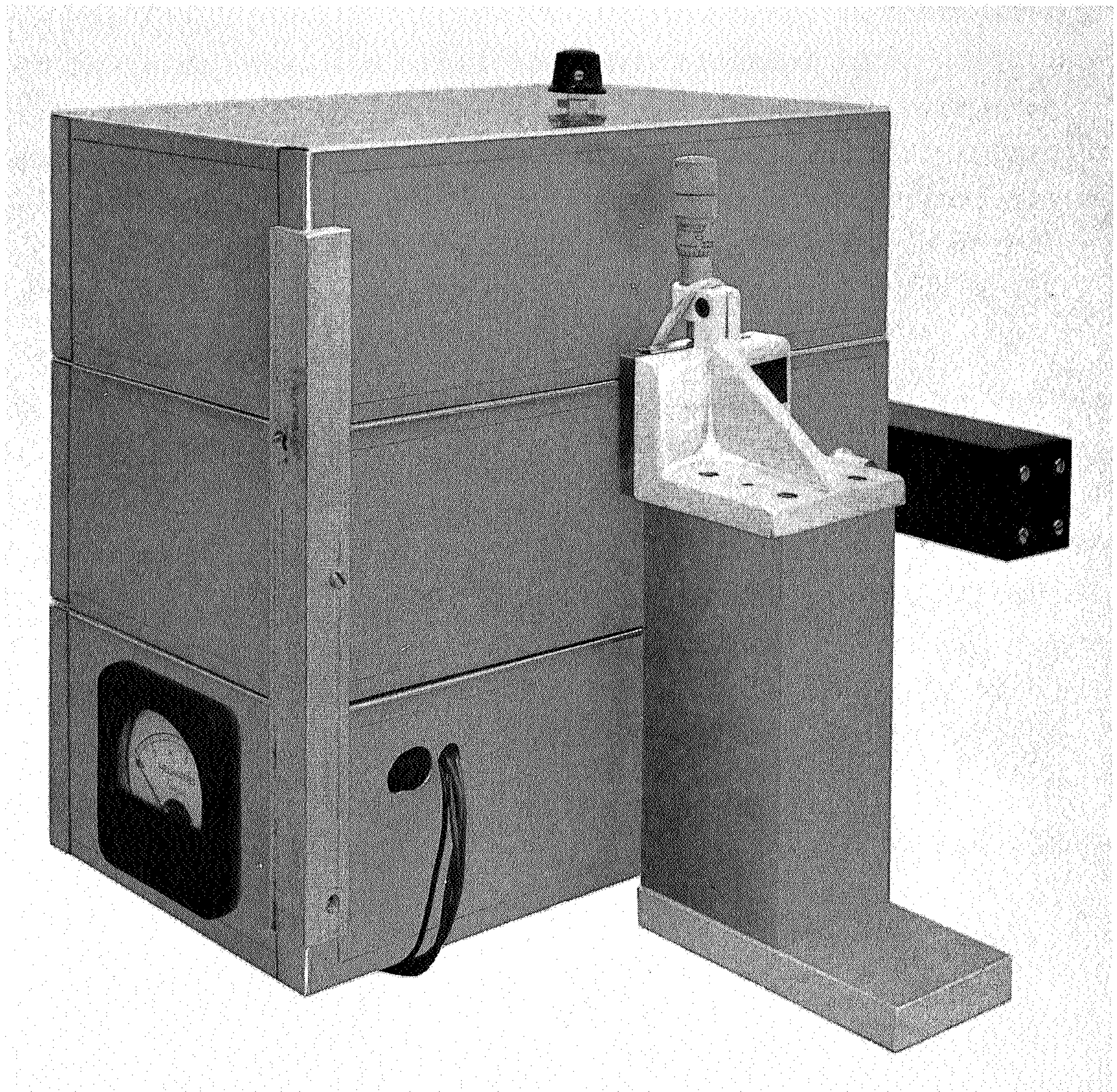


FIGURE 7, DRIVES FOR GaAs MODULATOR

## SECTION VII
## NEW TECHNOLOGY

At this phase in the program, no new technology is believed to be reportable.

## SECTION VIII
## ANALYSIS OF PROGRAM STATUS

### A, PROGRESS DURING SECOND QUARTER

During the second quarter, expressions for the conversion gain, noise equivalent power and quantum noise factor of the photomixer in terms of the measured I-V characteristics were derived. Using measured I-V characteristics of a high-speed Ge:Cu mixer element with laser local-oscillator power incident, the conversion gain, noise equivalent power, and quantum noise factor under various IF preamplifier conditions have been calculated. A conversion gain of 12.4 db, NEP of $6.72 \times 10^{-20}$ watt/Hz$^{\frac{1}{2}}$, and a QF of 5.54 db have been calculated for a matched mixer and a 3-db IF noise factor. The mixer had a measured dynamic resistance of only 1000 ohms. Using a 50-ohm IF preamplifier to improve high-frequency response, calculated NEP stays about the same: $6.83 \times 10^{-20}$ watt/Hz$^{\frac{1}{2}}$!

Calculations were made of the mixer carrier lifetime from the detector response, and values shorter than 1 nanosecond were calculated--0.83 and 0.17 nanosecond for assumed mobilities of 10,000 and 50,000 cm$^2$/volt-sec, respectively.

Based on the above, it is estimated that the light-speed Ge:Cu mixer with 7 milliwatt of laser LO power has low-noise capabilities, which extend to beyond 1 GHz, due to a combination of optimum semiconductor lifetime, transit time, dynamic resistance and circuit RC product.

Mixing action has been obtained in a Ge:Cu bulk semiconductor element at 10.6 microns. The experimental setup used two $CO_2$ gas lasers whose outputs combined through a beamsplitter, and a high-gain oscilloscope at the output. A sinusoidal variation up to several megahertz in the mixer output voltage, caused by the beat frequency between the local oscillator and signal, was observed.

A new high-speed Ge:Cu mixing element, compensated with $5 \times 10^{-14}$ antimony atoms per cc was tested. A 20 to 30 MHz driver for an infrared modulator has been built and tested.

## B. PLANS FOR THIRD QUARTER

Our plans for the third quarter are:

1. Continue mixing experiments in high-speed Ge:Cu mixers and measure performance characteristics.
2. Evaluate high-speed Ge:Hg mixer in high frequency coaxial mount,
3. Give further consideration to shot-noise spectrum measurements.
4. Continue theoretical analyses.
5. Improve laser stability.

## SECTION IX
## REFERENCES

1. F. Arams and E, Sard, "High-Sensitivity Infrared Receiver", Report No. 0323-I-1, Airborne Instruments Laboratory, First Quarterly Progress Report on Contract NAS-5-10156, July 1966.

2. J, T. Yardley and C. B, Moore "Response Times of Ge:Cu Infrared Detectors". Applied Physics Letters, p. 311, 312, 1 December 1965.