SEMI–ANNUAL STATUS REPORT

RESEARCH IN MILLIMETER WAVE TECHNIQUES

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NASA GRANT NO. NSG–5012
GT/EES PROJECT NO. A–1642

R. E. Forsythe
Project Director/Principal Investigator

J. L. King
Project Monitor for NASA/GSFC

Report Period 15 July – 15 January 1982

January 1982

GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Engineering Experiment Station
Atlanta, Georgia 30332

Semiannual Status Report

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January 1982

Georgia Institute of Technology
Engineering Experiment Station
Electromagnetics Laboratory
Atlanta, Georgia 30332

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FOREWORD

This is the fifteenth semiannual status report on NASA Grant NSG-5012. The grant period is from June 15, 1974 to January 31, 1982 and includes nine extensions and increases to the scope and funding of the program. The total funding to date is $696,433 of NASA funds and $35,961 in Georgia Tech cost-sharing funds, for a total of $732,394. Current grant funding is at a level of $60,000 with Georgia Tech providing $3,158. The current grant period extends through January 31, 1982.

As indicated in previous reports, and although not required by the grant, informal monthly letter type reports have been written and furnished to the NASA/GSFC technical monitor, J. Larry King in order to keep him abreast of project activities on a current basis. We believe this provides a better opportunity for NASA to direct the technical efforts of the program for the maximum benefit of the government. Copies of each of the monthly reports for the current period (eighty-three through eighty-seven) are contained in Appendix A. This fifteenth semiannual report will replace the eighty-eighth monthly letter (since this semiannual report is being furnished during the time the eighty-eighth monthly report would normally be written).

Responsibility for technical effort on this grant lies in the Electromagnetics Laboratory, under the general supervision of R.G. Shackelford, Director. R.E. Forsythe has been appointed Principal Investigator of this program, which has the internal project number, A-1642. The program technical effort is divided between the Radiation Systems Division, responsible for source and mixer development, the Electro-Optics Division, responsible for radiometric measurements, quasioptical techniques, and analysis, and the Solid State Sciences Division, responsible for mm-wave mixer diode development.

Contributors to the technical effort and/or this report during the past six month period include: J.J. McSheehy, D.O. Gallentine, R.W. McMillian, G.N. Hill, J.M. Schuchardt, R.G. Shackelford, S.M. Halpern, and Student Assistants: C. Grizzle, J. Shaver, A. Miller, and B. Crawford.

1.0 INTRODUCTION

During the past six months, efforts on this project have been devoted to: 1) the assembly and testing of 183 and 220 GHz X2 subharmonically pumped mixers; 2) the development of a computerized version of the automatic noise figure measurement system, and 3) the investigation of impedance matching techniques suitable for these types of mixers.

Significant events during the past six months include:

1) Design of narrow and broadband (one octave) matching networks for the subharmonic mixers;
2) The completion of the automatic mixer noise figure test facility;
3) The evaluation and characterization of subharmonic mixers and systems that use them at 183 and 220 GHz; and
4) The publication of these results at the IEEE-MTT International Conference on IR and MM-Waves during December 1981 at Miami Beach, Florida (see Appendix B).

2.0 MIXERS

2.1 Noise Figure Measurements

Noise figure measurements of several systems using subharmonically pumped mixers at 183 and 220 GHz have been made during the past six months. A summary of these measurements is presented in Table 1. Some of these systems have been delivered to other U.S. Government agencies that helped support some of this work.

The measurements shown in this table represent levels of performance achieved under various conditions. Some measurements were made with cleaner local oscillators than others. Some were made using different IF amplifiers and different IF frequencies. Some were made with IF matching networks. Also, different types of corrugated horn antennas with different lengths of waveguide runs prior to the mixer were used during these measurements. A summary of easily achievable system noise figures and bandwidths using these types of mixers under the best set of conditions is given in Table 2.

2.2 IF Impedance Measurements

Measurements of IF impedance and system noise figure for a 225 GHz X2 subharmonically pumped mixer were made as the LO power was turned up using a LO level set attenuator. The graph in Figure 1 shows a summary of the results. The horizontal axis is the micrometer reading on the LO attenuator and LO power is increased as the reading increases.

The IF measurement was done using an IF reflectometer and sweeper. The system noise figure was measured using a manual Y factor measurement. This set of measurements shows that an optimum LO level for this mixer had not been reached on this particular set of measurements. This graph illustrates the effect of IF mismatch on the system noise figure. The system noise figure remains the same as the LO power is increased while the loss due to IF mismatch goes up. This graph shows that the system noise figure cam be improved by IF matching, and that more LO power is needed for optimum mixer operation. This graph also indicates how much improvement can be obtained with matching, and can also be used to determine the IF impedance at the antiparallel diode pair. These data can then be used to design the matching network. It is significant that this set of data took almost a full day to compile using these particular measurement methods.

Table 1

MEASURED SYSTEM NOISE FIGURES USING SUBHARMONICALLY PUMPED MIXERS

Mixer Type	RF Frequency (GHz)	IF Frequency (GHz)	IF Noise Figure (dB)	DSB System Noise Figure (dB)
X2	220	2–4	2.5	13.0
X2	183	0.75–1.00	2.0	9.2
X2	183	1.65–1.75	2.5	8.7
X2	220	1–2	2.0	12.0
X2	183	1.5–3.0	2.5	11.0
X4	225	0.5–1.0	2.0	12.0

Table 2

ACHIEVABLE* SYSTEM NOISE FIGURES USING SUBHARMONICALLY PUMPED MIXERS

Mixer Type	RF Frequency (GHz)	IF Frequency (GHz)	IF Noise Figure (dB)	DSB System Noise Figure (dB)
X2	183	1-2	1.6	7.5
X2	220	1-2	1.6	10.0
X2	220	2-4	2.0	11.0
X4	225	0.5-1.0	1.5	11.0
X2	183	0.5-1.0	1.5	7.0

*Assuming following conditions: Low Loss Horn, State of the Art IF Amplifier, Clean LO, and Matched IF.

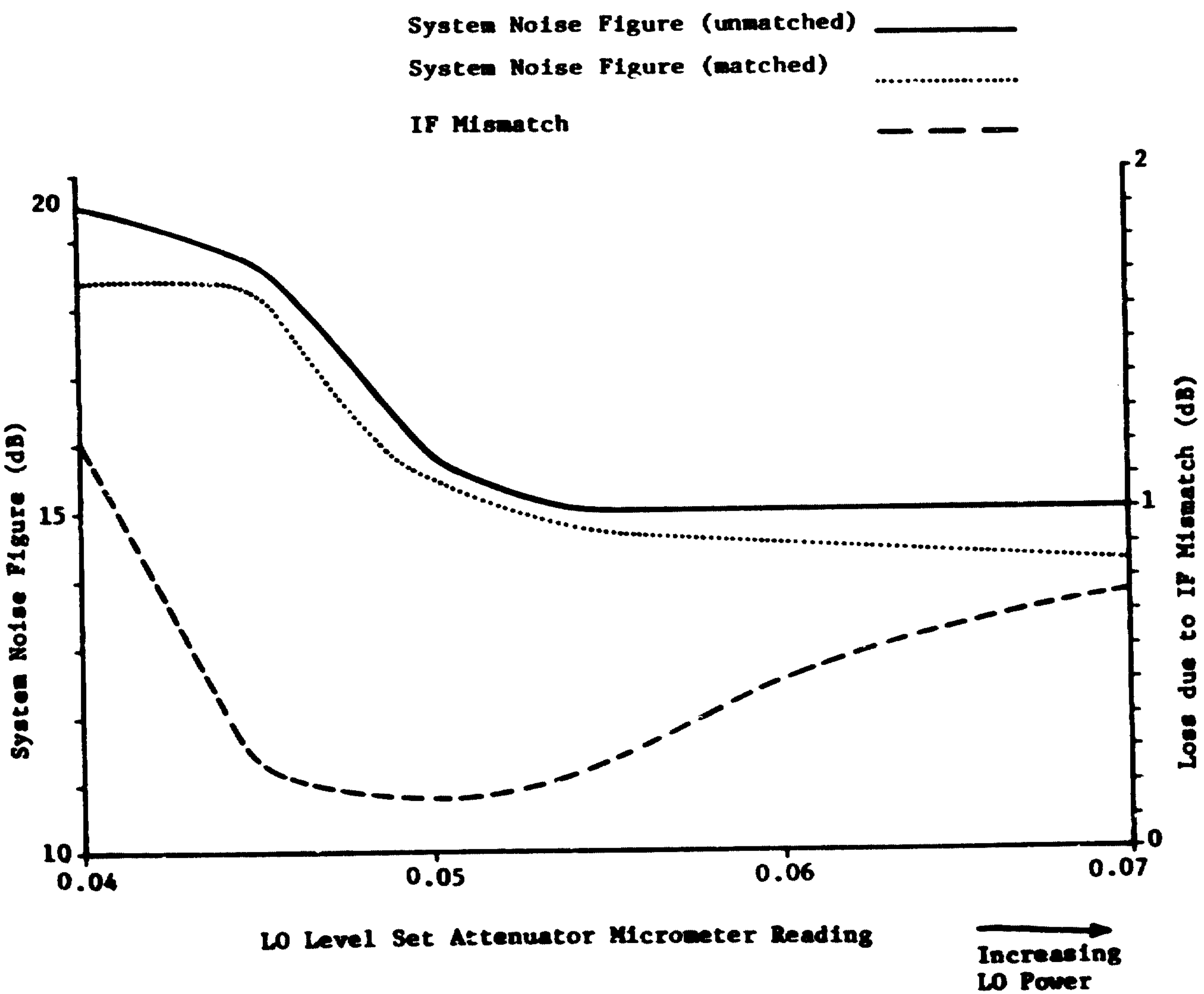

Figure 1. System Noise Figure and IF Mismatch Versus LO Power for a 220 GHz X4 Subharmonically Pumped Mixer

However, it would have taken much longer to determine the optimum operating point for the mixer using an iterative procedure in which the system noise figure is optimized; the IF mismatch is measured; and the system noise figure is then optimized with an IF matching network (made to match the previously measured IF impedance). This procedure would continue until the best possible noise figure is obtained.

Figure 2 shows another set of data taken in just one hour using the automatic noise figure measurement facility, which is described in more detail later. These data were taken using a 183 GHz X2 subharmonically pumped mixer with an IF frequency of 2.0 to 4.0 GHz.

2.3 Impedance Matching Techniques

The types of impedance measurements that were just described are valuable tools for mixer evaluation and optimization. These measurements using this automatic noise figure test facility do not contain any phase information which is needed for impedance matching. Fortunately, these measurements can be combined with a mixer IF equivalent circuit to obtain the phase information needed to design the IF matching networks. The equivalent circuit simply consists of a high impedance load at the end of a short section of 50 Ohm transmission line (~0.4 inches). The magnitude of the high impedance load can be determined directly from the IF mismatch measurements that are made with the automatic noise figure test facility. Currently, two techniques are being examined for IF matching. The first involves adding a length of 50 Ohm transmission line until the IF impedance is a real value at the center frequency of the IF band. Then a single or double stage quarter wave transformer is used to match this impedance to 50 Ohms. The second technique also involves adding enough transmission line to get the mixer impedance at the center frequency of the IF band to exhibit a real value. Then a resonant circuit is used to transform the IF impedance over the IF band of interest into a smaller circle around this real impedance. A quarter wave transformer is then used to match this set of impedances to 50 Ohms. The second technique is expected to perform better with the broad bandwidths required for these mixers.

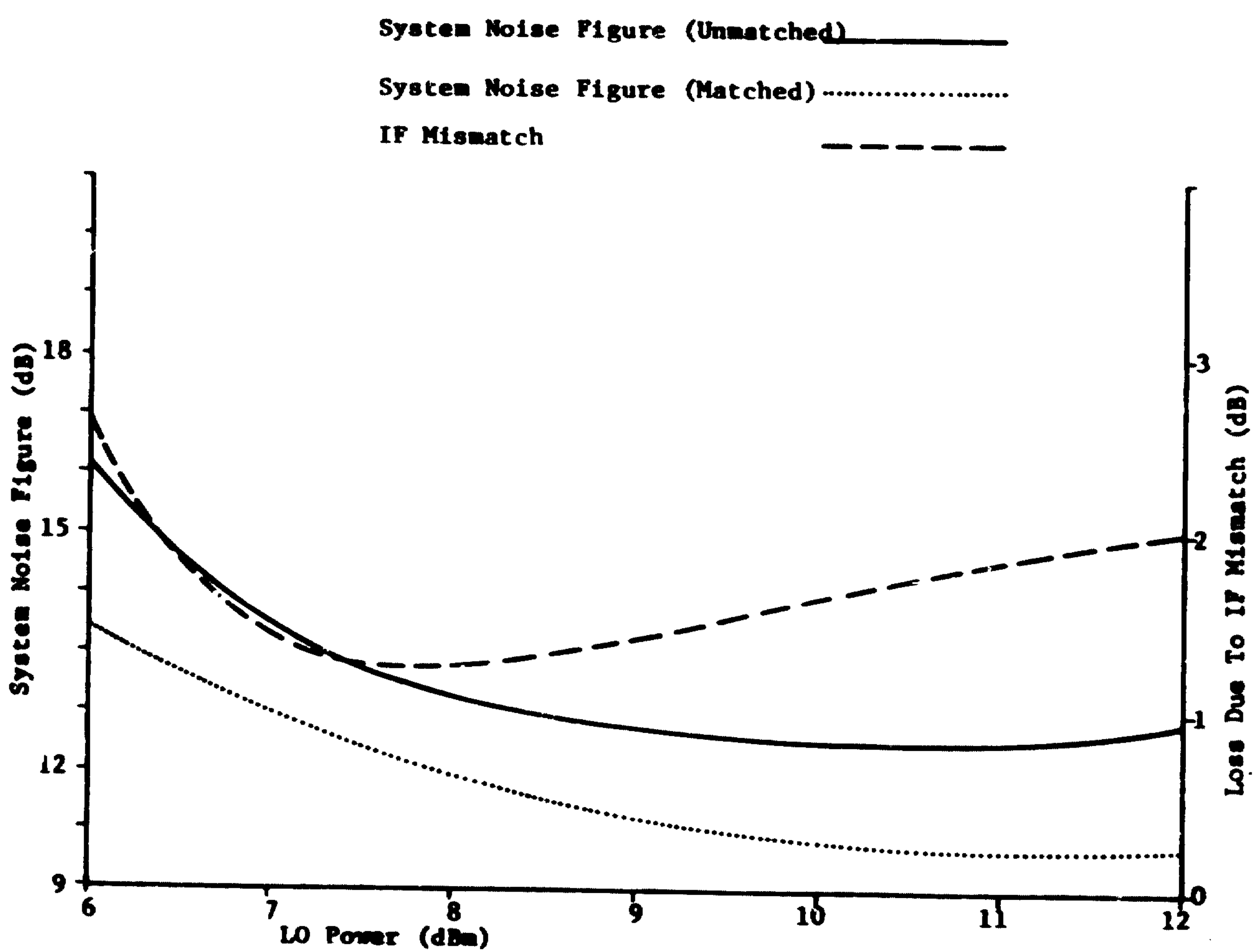

Figure 2. System Noise Figure and IF Mismatch Versus LO Power for a 183 GHz X2 Subharmonically Pumped Mixer.

3.0 AUTOMATIC NOISE FIGURE MEASUREMENT SYSTEM

3.1 System Description

The automatic noise figure measurement system currently consists of two versions, analog and digital. The block diagram of this system is shown in Figure 3. Both versions measure the system noise figure and the mismatch to the mixer at the IF port. A square wave voltage is present at the output of the square law detector at a frequency corresponding to REF 1. This signal is generated by a fan blade chopper switch that causes the receiver or mixer under test to alternately view an LN_2 or room temperature, free space, absorbing load. The LN_2 load is enclosed in a styrofoam container and has been calculated and measured to exhibit a 100 K brightness temperature.

The IF mismatch is measured using a noise diode that is injected at the IF port via a 20 dB coupler. This noise diode, when switched on and off at a frequency corresponding to REF 2, generates another square wave voltage that is superimposed on the previous one, and can be used to calculate the IF mismatch. The analog system automatically switches the noise diode on and off at the frequency REF 2 which can be switched between one fourth and one tenth of the frequency of REF 1. System noise figure, mixer noise figure, and IF mismatch are then measured and displayed continuously on the three front panel meters. This analog version is especially convenient for tuning and optimization of the mixer.

The digital system goes one step further and actually calculates the values of the Y factor, IF mismatch, system temperature, system noise figure, and gain (in K/volt). This version uses an HP digital voltmeter with an HPIB compatible output connector to measure the square wave voltages corresponding to the system temperature and IF mismatch. This voltmeter is controlled by an HP 85 programmable computer with a printout capability. The program that controls the measurement is a user oriented program that asks for the input parameters as given in Table 3, and, to some extent, will tell you what to do if, and when, you key in the wrong data.

This measurement program has several modes. These are:

1) setup;
2) tuning;

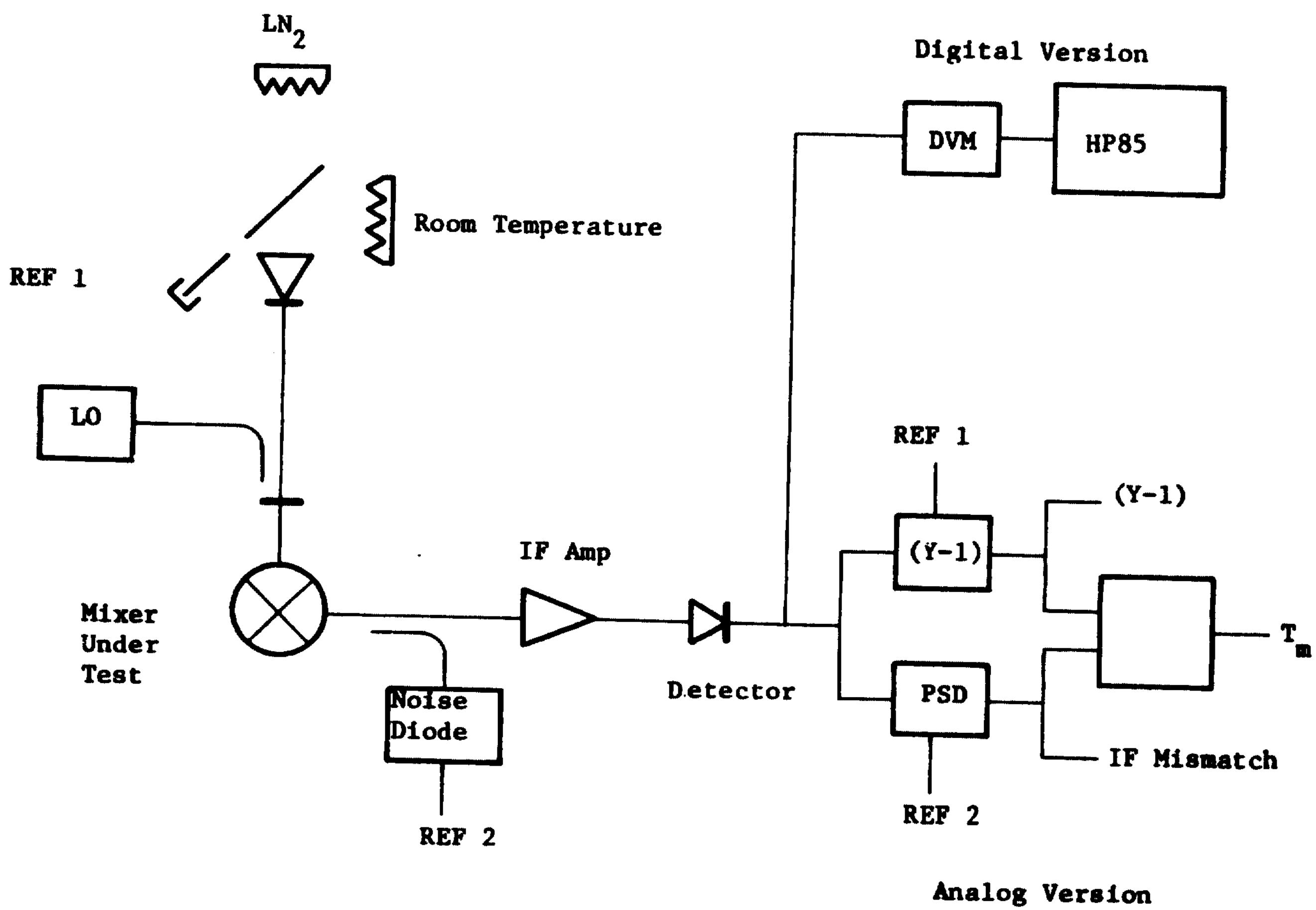

Figure 3. Block Diagram of Automatic Noise Figure Test Set-up

Table 3

INPUT PARAMETERS FOR NOISE FIGURE MEASUREMENT

Current Parameters

1.	Mixer I.D. #	= 6/183/3/3
2.	Chopper Frequency	= 25.0 Hz
3.	Hot Load Temperature	= 290.0 K
4.	Cold Load Temperature	= 100.0 K
5.	IF Gain	= 60.0 dB
6.	IF Bandwidth	= 1.0 GHz
7.	IF Noise Figure	= 3.0 dB
8.	RF Losses	= .75 dB
9.	Noise Diode ENR	= -4.8 dB
10.	Video Amp Gain	= N/A
11.	Square Law Detector Factor	= 800 V/W

Changes ?, Enter # or Ø for Exit ?

3) IF mismatch; and

4) Parameter input.

Setup must be done first. This mode simply asks for the date of the experiment to be entered. Then the parameter input mode is engaged to provide the necessary information to the program so that it may perform the calculations. The tuning routine is a repetitive measurement of noise figure that updates itself at about one second intervals. IF mismatch is not measured in this mode.

The IF mismatch mode is a one time measurement of IF mismatch, system noise figure, and mixer noise figure. Once the mixer is tuned, the LO power can be varied to obtain plots similar to those shown earlier. Sample outputs of these two types of measurements are given in Table 4. (A paper describing this system has been accepted for presentation at the May 1982 SPIE meeting in Washington, D.C.)

3.2 Noise Figure/IF Mismatch Calculations

The receiver alternately views an LN_2 load through a styrofoam container and a room temperature load. A chopper is used to switch between the two loads, a square wave voltage is then generated at the output of the receiver. The computer uses these two voltages as well as the dc offset voltage (measured with the IF amplifier turned off) to determine the system noise figure. The equations for this measurement are:

$$1)\quad Y = \frac{V_H - V_o}{V_c - V_o} \quad ;$$

$$2)\quad F_{sys} = \frac{T_H - YT_c}{Y - 1} \quad ;$$

and

$$3)\quad F_{sys} = 10 \log \left(\frac{T_{sys}}{290} + 1\right)$$

Where:

T_H = 290K;

T_c = 100K;

Y = Y factor;

F_{sys} = System Noise Figure (dB);

Table 4

OUTPUT OF DIGITAL AUTOMATIC NOISE FIGURE MEASUREMENT SYSTEM

Mixer I.D. #	= 6	IF Mismatch Mode
IF Mismatch	= 1.6 dB	
Mixer Noise Figure	= 5.8 dB	
Y Factor	= 1.050	
T_{sys}	= 3714 K	
System NF	= 11.4 dB	
Gain	= 2007 K/V	
Mixer I.D. #	= 6	
Y Factor	= 1.049	Tuning Mode
T_{sys}	= 3781 K	
System NF	= 11.5 dB	

T_{sys} = System Noise Temperature (K);

V_H = Output voltage when viewing room temperature load;

V_c = Output voltage when viewing cold load;

and V_o = Offset voltage when IF amplifier is off.

IF mismatch is measured using a one time measurement. Noise is injected into the mixer IF port with a noise diode and a 20 dB coupler. The reflected noise is then measured as a dc shift in the output voltage of the receiver. The loss due to IF mismatch is then calculated using:

$$M = \frac{V_{on} - V_o}{V_{off} - V_o} \quad ;$$

and

$$L_{IF} = ENR - 10 \log [E - F_{IF}(M - 1)]$$

where:

V_{on} = Output voltage with noise diode on;

V_{off} = Output voltage with noise diode off;

L_{IF} = Loss due to IF mismatch;

ENR = Excess noise ratio of diode (dB);

E = Excess noise ratio of diode (ratio);

and F_{IF} = IF noise factor.

Mixer noise figure is then calculated using:*

$$F_m = F_{sys} - L_{RF} - L_{IF} - F_{IF}$$

where:

F_m = Mixer Noise Figure (dB);

L_{RF} = RF losses prior to mixer (dB).

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*These calculations assume a mixer diode noise ratio of 1.

4.0 EFFORTS PLANNED FOR THE FIRST HALF OF 1982

The work planned for the next six months will consist of a continuation of the work that has been described in this report, with the addition of some tasks. In particular, work will begin on the integration of IF preamplifiers with these subharmonic mixers. Also, more X4 220 GHz mixer bodies will be machined so that research can continue with these mixers.

APPENDIX A

Monthly Progress Reports

Eighty-three through Eighty-seven

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Eighty-Third Monthly Progress Report

Report Period
1 July-31 July 1981

Report Prepared
August 1981

NASA Grant No. NSG-5012
GT/EES Project No. A-1642

Principal Investigator: R. E. Forsythe
Project Monitor: J. L. King

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1.0 MIXERS

Several X2 220 GHz mixers were assembled and tested during this period. One exhibited a system noise figure (DSB) of 13 dB over a 2-4 GHz IF bandwidth. This indicates a 9 dB mixer noise figure with a 1-2 dB improvement expected using an IF matching network. This improvement is due primarily to the better LO noise cancellation properties of this particular mixer and careful tuning of the 108 GHz Gunn/tripler used for the LO. The LO was tuned for maximum output with minimum noise using a single ended mixer. The IF was displayed on a spectrum analyzer to monitor LO noise while the rectified dc current was monitored to measure the power output of the LO.

2.0 Work to be Performed During the Next Period

Measurements on and assembly of these mixers (both X2 and X4) will continue.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Eighty-Fourth Monthly Progress Report

Report Period
1 August-31 August 1981

Report Prepared
September 1981

NASA Grant No. NSG-5012
GT/EES Project No. A-1642

Principal Investigator: R. E. Forsythe
Project Monitor: J. L. King

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1.0 Mixers

One of the X4 mixers which was assembled and tested during this month exhibited a 12 dB system noise figure (DSB) over a 0.75-1.00 GHz IF bandwidth. The mixer noise figure was determined to be 8.5 during this measurement. A special IF matching network was made to help match the IF output port. IF impedance and system noise figure measurements versus LO power were made to determine the optimum operating point for the mixer. A matching network was then made to match the IF impedance that occurs at that point.

2.0 Work to be Performed During the Next Period

Assembly, testing and evaluation of these mixers will continue.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Eighty-fifth Monthly Progress Report

Report Period
September 1 through September 30, 1981

Report Prepared

October 15, 1981

NASA Grant No. NSG-5012
GT/EES Project No. A-1642

Principal Investigator: R.E. Forsythe
Project Monitor: J.L. King

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SUMMARY OF WORK

1.0 Mixers

The 183 GHz front end and IF components were removed from the B-57 radiometer system for testing and evaluation. The IF noise figure contributions at each channel were measured with and without the FEL triplexer using a noise diode. A summary of the IF noise figures is shown in Table 1. The main problems with the triplexer are that the crossover frequencies are off almost 500 MHz on the two lower bands and the overall insertion loss in the passband is slightly higher than expected. These problems will be investigated and solved prior to the next set of flights by NASA/GSFC.

Measurements of system noise figures at 183 GHz (using the X2 subharmonic mixer) were made with a radiometer assembled in the lab. The noise figures measured during this test are summarized in Table 2. An IF matching network was made at 1.7 GHz to show the effect of matching on system noise figure. A 2 dB improvement in noise figure has been achieved through IF matching. This implies that a 7.2 dB system noise figure at 750-1250 MHz is achievable since 9.2 dB was measured without a matching network.

These measurements were made with the only mixer available during this period. Substrate circuits have been in short supply. These are not the best noise figures that have been measured and better noise figures are expected with these mixers. The lens and triplexer were not used during this test. The system noise figures are DSB and include contributions from the horn, RF waveguide, RF mismatch, LO noise, mixer, IF preamp and

Table 1

IF NOISE FIGURE CONTRIBUTIONS

Channel	IF Amp	Noise Figure (dB) Triplexer	Cable	Total
1.5 - 3.0	2.5	1.5	0.8	4.8
4.0 - 6.0	3.2	2.0	1.0	6.2
7.5 - 10.0	5.2	0.5	1.9	7.6

Table 2

183 GHz RADIOMETER SYSTEM NOISE FIGURES

IF Frequency	IF Noise Figure	System Noise Figure
0.75 - 1.0 GHz	2.0 dB	9.2 dB
1.5 - 3.0 GHz	2.5 dB	11.0 dB
1.65 - 1.75 GHz*	2.5 dB	8.7 dB

*Measured with an IF Matching Network

and IF mismatch. More substrates have been received and other mixers can be tested when assembled.

2.0 Plans for Next Period

Efforts to lower system noise figures at 183 GHz will continue. The next step is to make a broadband matching network. More 183 GHz subharmonic mixers will be assembled and tested. A solution to the triplexer problem will be investigated.

Eighty-Sixth Monthly Technical Report

Report Period
1 October through 31 October 1981

Report Prepared on
15 November 1981

RESEARCH IN MILLIMETER WAVE TECHNIQUES

R. E. Forsythe

NASA Grant No. NSG-5012
EES Project A-1642

Effective Date: 15 June 1974
Expiration Date: 31 January 1982

Prepared for

NASA/GSFC
Greenbelt, MD

Prepared by

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Georgia Institute of Technology
Atlanta, Georgia 30332

1.0 MIXERS

Mixer assembly and evaluation has continued during this period. However, no noise figures better than those previously reported have been achieved. A 1-2 GHz matching network has been designed and is being fabricated for use with the subharmonic mixers.

The problems that occurred with the mixers during the flights of the B-57 radiometer have apparently been solved. A subharmonic mixer with the new NiAuro whiskers has been flying in the Arctic region over the past three months, taking 220 GHz passive imaging data. It has been exposed to many large temperature cycles and vibrations during these flights, and has not degraded in performance, showing remarkable reliability.

2.0 WORK TO BE PERFORMED DURING THE NEXT PERIOD

Assembly evaluation and testing the subharmonic mixers will continue.

Eighty-Seventh Monthly Technical Report

Report Period
1 November through 30 November, 1981

Report Prepared on
15 December 1981

RESEARCH IN MILLIMETER WAVE TECHNIQUES

R. E. Forsythe

NASA Grant No. NSG-5012
EES Project A-1642

Effective Date: 15 June 1974
Expiration Date: 31 January 1982

Prepared for

NASA/GSFC
Greenbelt, MD

Prepared by
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Atlanta, Georgia 30332

1.0 MIXERS

During this next period, several papers will be presented at the IEEE International Conference on IR and MM Waves in Miami [1-5]. These papers describe the results obtained with mixers originally designed and/or developed under this grant. Systems in which these subharmonic mixers were used and some data obtained with these systems will be described and presented at this conference.

2.0 MIXER EVALUATION TECHNIQUES

Also during this period a computerized version of the automatic noise figure meter was perfected. This version calculates system noise figure, IF mismatch, and mixer noise figure using an HP 85 computer and a DVM with an HPIB compatible output. A tuning routine has also been developed.

3.0 WORK TO BE PERFORMED DURING THE NEXT PERIOD

The semiannual report will be prepared. Mixer assembly and testing will continue.

4.0 REFERENCES

[1] J. P. Hollinger, M. F. Hartman, R. E. Forsythe, and J. J. McSheehy, "An Airborne Imaging System at 140 and 220 GHz," IEEE Conf. on IR and MM Waves, Miami, December 1981.

[2] R. E. Forsythe, "A Coherent 225 GHz Receiver," IEEE Conf. on IR and MM Waves, Miami, December 1981.

[3] R. E. Forsythe and S. M. Halpern, "Subharmonic Mixers for 183-225 GHz," IEEE Conf. on IR and MM Waves, Miami, December 1981.

[4] J. A. Gagliano and J. J. McSheehy, "Airborne Millimeter Wave Radiometer for 94/183 GHz High Altitude Atmospheric Measurements," IEEE Conf. on IR and MM Waves, Miami, December 1981.

[5] C. W. Trussell, R. W. McMillan, R. E. Forsythe, and R. A. Bohlander, "225 GHz Radar System," IEEE Conf. on IR and MM Waves, Miami, December 1981.

APPENDIX B

Recent Publications

ORIGINAL PAGE IS
OF POOR QUALITY

A COHERENT 225 GHz RECEIVER

W-3-9

R. E. Forsythe
Georgia Institute of Technology
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Atlanta, Georgia 30332

Abstract

A receiver for use at 225 GHz has been designed and built. It uses a low noise, subharmonically pumped, balanced mixer that requires a local oscillator (LO) at only one fourth the signal frequency. The local oscillator is a commercially available 56 GHz phase locked Gunn oscillator with a 50 mW power output. Preliminary results indicate a 12 dB system noise figure (DSB).

Introduction

A low noise, fourth harmonic balanced mixer employing antiparallel diodes was developed because of the desirability of having an all solid state coherent receiver at 225 GHz. Because phase locked Gunn LOs are not available above 100 GHz, the decision was made to develop a new mixer for use at 225 GHz. Subharmonic mixers have found many useful applications for mm-wave systems because of their low noise, broadband frequency conversion properties [1]. They have been used as receivers and radiometers for both airborne and ground based systems [2-4]. This report presents preliminary results on the development of a coherent receiver which uses a relatively low frequency, solid state, local oscillator and a fourth harmonic mixer to form a low noise, superheterodyne receiver at 225 GHz.

225 GHz Receiver Description

The receiver, shown in Figure 1, consists of a corrugated horn, a fourth harmonic mixer, a variable attenuator, a solid state phase locked Gunn LO, and an IF preamp. The corrugated conical horn is of a standard design scaled for use at 225 GHz. It contains a circular to WR-4 waveguide transition and a WR-4 to WR-5 waveguide transition. The mixer, shown in Figure 2, is from a design developed at Georgia Tech and uses a combination of suspended substrate stripline and waveguides to achieve low loss [5]. A diagram of this mixer is shown in Figure 3. The signal input is WR-5 waveguide and the LO input is WR-19 waveguide. These are connected via a stripline channel. The diodes are located in the signal waveguide so that no signal is transmitted through the stripline channel. A low pass filter is located above the diodes to reflect the signal energy (225 GHz), pass the LO to the diodes, prevent the generation of second harmonic mixing and help match the diodes to the signal energy. Another low pass filter, on a larger stripline circuit, is located above this circuit at the LO waveguide. It prevents the LO energy (56 GHz) from backshort is used to maximize the coupling of the LO to the diodes. The signal backshort is used to help match the 225 GHz energy to the diodes. The mixer is followed by an IF preamp with a gain of 30 dB. This device has a 2 dB noise figure over a 500-1000 MHz frequency range. It is followed by another IF amplifier and filtered with a 780 MHz bandpass filter having a 78 MHz bandwidth.

Results and Conclusions

The total system noise figure (DSB), based on a Y-factor measurement using free space absorbers at LN_2 and room temperature, has been measured to be 12 dB with a 500-1000 MHz IF. A breakdown of the system noise figure contributions is given in Table I. The LO power required for optimum performance of the receiver is about 20 mW. The noise figure degrades very little when using a 2-4 GHz IF bandwidth. This indicates that broadband systems are easily achieved with this front end technique.

This receiver is believed to be the only one of its kind in existence and represents a significant breakthrough in receiver technology. Future efforts will focus on higher frequency devices and optimization of the current devices that have now been developed. Although low noise figures have already been achieved, further improvements are anticipated because these are only the first devices of their kind at these frequencies. This receiver is part of a larger system being developed at Georgia Tech for field use by NVL [6].

Acknowlegments

The author would like to acknowledge the following people for their contributions to this effort: D. O. Gallentine (mechanical design); S. M. Halpern and J. A. Shaver (mixer assembly); and J. Lamb, NASA/GSFC (circuit fabrication). This work was supported by NASA/GSFC (NSG-5012) and NVL Contract No. DAAK70-79-C-0108. Diodes for these devices were provided by the Georgia Institute of Technology (Meeks), the University of Cork (Wrixon), and the University of Virginia (Mattauch).

References

[1] M. Cohn, J. Degenford, and B. Newman, "Harmonic Mixing with an Antiparallel Diode Pair," IEEE-MTT, Vol. MTT-8, pp. 667-673, August 1975.
[2] J. P. Hollinger, M. F. Hartman, R. E. Forsythe, and J. J. McSheehy, "An Airborne Imaging System at 140 and 220 GHz," IEEE

BLACK AND WHITE PHOTOGRAPH

going out the IF port and directs it to the diodes. Both filters pass the IF frequency to the IF output port which is an SMA connector whose center conductor is connected to the stripline using a soldered gold ribbon. Both waveguides have variable backshorts. The LO

[4] J. A. Gagliano, et al., "94/133 GHz Aircraft Radiometer for Project Storm Fury," Final Report, NASA/GSFC, Contract NAS5-23710, April 1980.

[5] R. E. Forsythe, "Research in Millimeter Wave Techniques," Semi-Annual Reports, NASA/GSFC, NASA Grant NSG-5012, January 1979 to July 1981.

[6] R. W. McMillan, et al., "Near MM-Wave Radar Technology," Phase I, Interim Report, NVL Contract No. DAAK70-79-C-0108, January 1980.

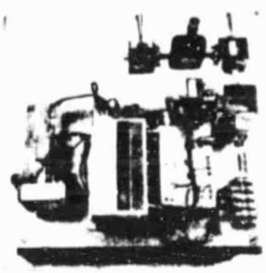

Figure 1. Photograph of 225 GHz Receiver.

Figure 2. Photograph of 225 GHz Fourth Subharmonic Mixer.

Conf. on IR and MM Waves, December 1981.

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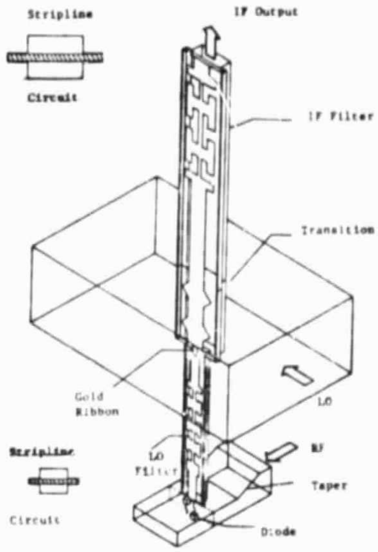

Figure 3. Fourth Harmonic Mixer Diagram.

Table I

225 GHz RECEIVER NOISE FIGURE SUMMARY

Item	Measured
Horn/Transition Loss*	1.5 dB
Mixer Noise Figure (DSB)	8.5 dB
IF Preamp Noise Figure	2.0 dB
Total Noise Figure	12.0 dB

*Estimated

AN AIRBORNE IMAGING SYSTEM AT 140 and 220 GHz

J.P. Hollinger*, M.F. Hartman**, R.E. Forsythe*** and J. J. McSheehy***

Abstract

A dual-frequency passive millimeter-wave airborne imaging system has been assembled and flight tested using the Naval Research Laboratory RP-3A aircraft. The system incorporates a 140/220 GHz radiometer built by the Georgia Institute of Technology, and a scanning mirror and a microprocessor controlled data acquisition unit built by the Naval Research Laboratory. The system will be described and selected measurements presented.

Introduction

Millimeter waves are of great interest for surveillance and targeting applications because they offer the advantages of being covert, passive, low power and difficult to jam compared to radar and provide nearly all-weather and day/night operation compared to infrared and optical systems. Millimeter waves are an attractive and viable compromise in the trade-off between increased resolution, obtainable at shorter wavelengths, and decreased weather penetration. Airborne systems have been demonstrated at 90 GHz (1) and target/clutter measurement made (2). The system described here successfully extends airborne imaging to the atmospheric windows in the region of 140 and 220 GHz.

140/220 GHz Radiometer

The 140/220 GHz radiometer is a low noise, broadband, solid state, total power radiometer. A block diagram of this radiometer is shown in Figure 1 [3]. It consists of two main parts. The remotely located, temperature controlled portion, shown in Figure 2, contains the RF, IF, and video components as well as a regulator/switching network for the local oscillators. The control unit contains a dc to dc converter, main power filters, and a temperature controller. It also controls system operation. On the front panel the temperature of the remote portion is set, the 140 GHz mixer bias and Gunn current are monitored, and a dc offset control and adjustable integration time switch are provided. Video bandwidths up to 40 KHz are provided as outputs for fast sampling times. The radiometer provides an analog voltage which is proportional to the brightness temperature that the antenna is viewing. The RF is downconvereted to a 2-4 GHz IF frequency. A square law detector is used after IF amplification to convert the IF to a dc voltage. This voltage is amplified by an ultra low noise dc amplifier and then low pass filtered to provide a clean radiometric signal. The system is operated by turning on three switches on the front panel of the control unit (power, Gunn, and heater). Operation at 140 or 220 GHz is chosen by the use of the 140/220 GHz select switch. The antenna consists of a six inch TPX lens illuminated by both the 140 and 220 GHz corrugated feed horns using a polarization diplexer. The diplexer is a parallel grid of etched metallic lines on a thin mylar sheet. It is oriented to reflect vertical (220 GHz) and transmit horizontal (140 GHz) polarization. It is placed at a 45° angle to the lens so that the 140 GHz horn is in line with the lens while the 220 GHz horn is at a 90° angle to the lens/140 GHz horn combination. The 140 GHz front end consists of a wafer type single ended mixer/preamp. An automatic bias network provides mixer bias when the system is switched on. The LO and signal are coupled to the mixer using a directional filter. The directional filter is a cylindrical resonant cavity which acts as a bandstop filter (centered at the LO frequency of 135 GHz) for the horn/mixer path and a bandpass filter for the LO mixer path. It cleans up the LO power, exhibiting only 4 dB LO loss and 0.75 dB signal loss to the mixer. The LO is a solid state 67.5 GHz Gunn and 135 GHz doubler providing 10 mW output at 135 GHz. The 220 GHz downconverter consists of a subharmonically pumped balanced mixer/ preamp [4]. This device uses a combination of specially designed suspended substrate circuits and waveguide to provide low loss, broadband downconversion. The LO is a solid state 36 GHz Gunn followed by a 108 GHz tripler with 28 mW power output at 108 GHz. These front ends share common post IF/ video electronics via a SPDT IF switch. Summaries of system performance levels and system noise figures are given in Table 1. This radiometer has been built to operate in the P-3 aircraft environment. Four power filtering circuits have been provided to protect the radiometers' electronics and front end components and to insure a clean radiometer signal during data flights. The system has also been ruggedized to withstand vibrations, shocks, power surges and power interrupts. RFI shielding has also been provided to prevent interference at the IF frequencies.

Scanner and Data Aquisition

The antenna electrical axis and the mirror rotational axis are collinear and parallel to the flight direction. The elliptical mirror is mounted at 45° to its rotational axis thus projecting the same circular aspect to the antenna at all scan angles. This geometry minimizes variations with scan angle due to spillover of the antenna reception pattern past the mirror. The antenna beam is scanned perpendicular to the flight direction at a constant angular rate of 1200°/sec over a 90° field of view centered on the ground track; successive scans generating a raster over the ground with aircraft motion. The mirror is then accelerated and deaccelerated over the remaining part of a revolution by a specially designed gear mechanism such that the 270° sector is scanned in the same time as the 90° sector. This scheme allows contiguous scans of the antenna beam from one half the air-

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craft altitude, and hence twice the surface resolution, or alternately a 1.5 db improvement in signal-to-noise at the same altitude, as would be obtained with a constant scan. The radiometer output is sampled each 0.5°, a 2.4 KHz rate, during the 90° scene sector after being passed through a 1.2 KHz low pass filter. The noise per sample, is therefore, 49 times that listed for a one second integration in Table 1. During the 270° sector 16 samples are taken as the antenna successively views two absorbers at different temperatures to provide an absolute temperature calibration of the overall system. Each sample is digitized with 12-bit precision and recorded on magnetic tape. Also recorded are the absorber temperatures, the pitch, roll, drift angle and heading of the aircraft, the latitude, longitude, ground speed, altitude, time, thermal infrared temperature of the surface, air temperature and dew point. The most recent 320 scans are also displayed real-time on an onboard color monitor.

Results

Post flight processing of the raw data begins with conversion of the output samples to absolute antenna temperature using the absorber calibration temperatures. Corrections are then applied for antenna spillover to obtain absolute brightness temperatures and these data resampled to correct for v/h effects, geometrical projection distortion and aircraft roll. An example of a raw image taken from the onboard monitor is given in Figure 3. This is a 140 GHz image taken from an altitude of 1800 m while overpassing a NAVY P3-A aircraft at a relative altitude of approximately 100 m. An example of processed data is given in Figure 4. This is a 140 GHz image taken from 3600 m through a solid 300 to 600 m cloud layer. A fine mist or drizzle was being experienced on the surface at the time. This demonstrates the weather penetration still possible at frequencies as high as 140 GHz.

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Item	140 GHz	220 GHz
LO Frequency	135 GHz	108 GHz (216 GHz virtual LO)
IF Frequency Range	2.0-4.0 GHz	2.0-4.0 GHz
Radiometer Output	2.5 mV/K	1.0 mV/K
Total System Noise Figure (DSB)	10.25 dB	14.5 dB
Total System Noise Temperature (DSB)	2,7[illegible]2 K	7,883 K
ΔT_{min} at τ = 1 sec	0.06 K	0.18 K
Antenna Beamwidth	1°	0.64 °

Table 1. 140/220 GHz RADIOMETER PERFORMANCE SUMMARY

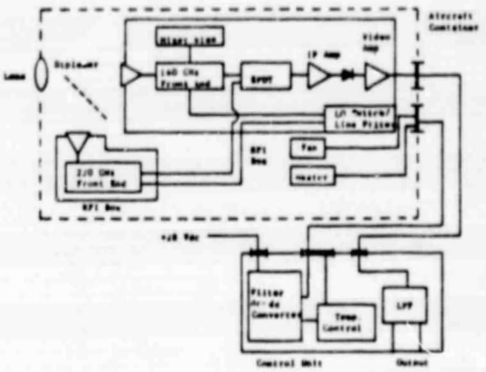

Figure 1. 140/220 GHz RADIOMETER BLOCK DIAGRAM

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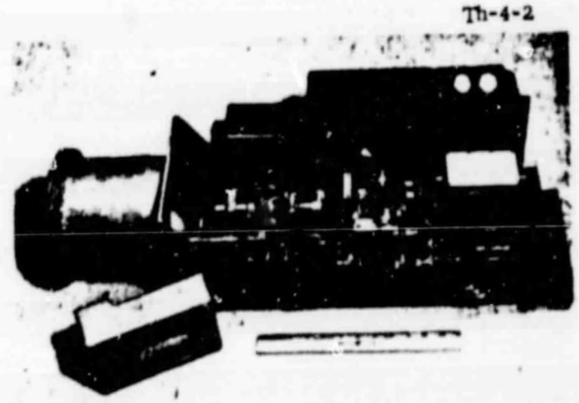

Figure 2. 140/220 GHz RADIOMETER

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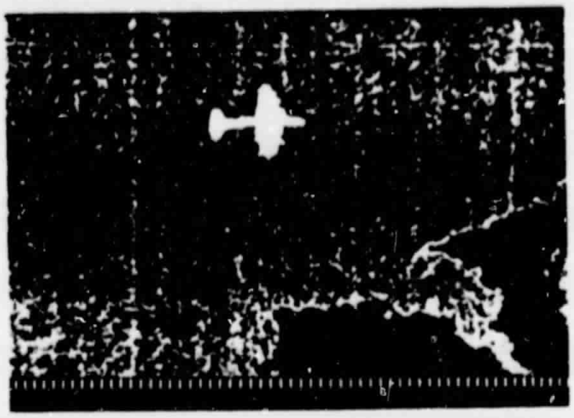

Figure 3. 140 GHz IMAGE OF A P3-A AIRCRAFT

Figure 4. 140 GHz IMAGE THROUGH CLOUDS

SUBHARMONIC MIXERS FOR 183-225 GHz

T-S-2

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Abstract

Subharmonically pumped, balanced mixers have been developed for field measurement systems at 183-225 GHz. These mixers are second and fourth harmonic (X2 and X4) mixers and are designed for use with solid state local oscillators. Preliminary measurements indicate mixer noise figures (DSB) as low as 4.5 dB have been achieved with these devices.

Introduction

Subharmonic mixers employing antiparallel diodes are highly desirable for low noise, broadband system applications. Some of their most noted features are that they have low noise, low loss, LO am noise cancellation and no need for external bias circuitry [1,2]. Most importantly, they require only one half or one fourth the signal frequency as sources for local oscillators. Mixers of this type have been developed at Georgia Tech particularly for use at 183-225 GHz, and the preliminary results are presented here. Nine such mixers (six X2 and three X4) have been machined and are being assembled and tested to insure reliability and performance. Two have been used on flight radiometers for NASA and NRL [3-5]. These are X2 versions. One operates at 183 GHz in an imaging radiometer taking high altitude water vapor profile data and storm images, and the other operates at 220 GHz taking low altitude, high resolution, radiometric images on board a P-3 aircraft. Others will be used on ground based systems for passive imaging of targets and clutter at 220 GHz (also a X2 version) and as part of a coherent receiver at 225 GHz (a X4 version) for NVL [6-8].

Mixer Description

The X2 mixer is an upgraded version of a mixer described in an earlier publication [9]. The main differences are that the signal waveguide has been shortened, thinner quartz substrates are used, the circuit has been scaled to a higher frequency, and the LO waveguide input port is interchangeable with the LO backshort so the mixer can be oriented in different systems in the most convenient way. In addition, the diode contacting procedure is done in an open structure and monitored visually using a microscope. This allows the user to have more control over the different variables that effect mixer performance.

The mixers shown in Figures 1 and 2 were originally designed with a low frequency (6.8 GHz) the edge of the circuit can be seen when looking down this waveguide. The LO is then reflected by the IF filter and passed by the LO filter to the antiparallel diode pair. An adjustable LO backshort is provided for maximum coupling of the LO energy to the diodes. The signal waveguide is linearly tapered to half height WR-5 waveguide. The diodes are mounted in this waveguide. An adjustable backshort is provided for RF matching of the diodes to the signal. The LO filter reflects the signal energy and prevents it from leaving the signal waveguide. It also helps match the diodes to the signal. The IF is passed by both filters to the IF output port which is an SMA connector whose center conductor is connected to the substrate's center conductor by a soldered gold ribbon.

The diodes are Schottky barrier diodes formed in a planar array on the face of a 0.010" by 0.005" by 0.005" GaAs chip. The circuit is completed by an ohmic contact made by a 0.0005" Niauro whisker etched to a fine point. Two chips are used. One is placed on top of the signal waveguide facing down and the other is on the bottom facing up. Separate contact of one diode on each chip is made in the following manner. A whisker and diode chip are carefully mounted on the end of a substrate which has been glued in place in the body structure. Another whisker is mounted on a 0.032" diameter pin and another diode chip is mounted on a separate pin. These pins are then pushed into the mixer body from the bottom. When the diodes are close to the whiskers, the pins are pushed in with a differential micrometer while being viewed with a microscope. The circuit is electrically monitored for dc characteristics with a curve tracer and the ohmic contacts are examined under an SEM. The mixer body is then assembled and tested for noise figure in an automatic noise figure test set-up.

The fourth harmonic mixers are of similar design except that the LO filter blocks the second harmonic mixing product as well. Also, a larger circuit is used for the LO diplexing and coupling. This larger circuit is connected to the 0.0025" circuit with a soldered gold ribbon.

Results and Conclusions

The results obtained with these mixers so far are summarized in Table I. These measurements were made using a Y-factor measurement as the mixers viewed liquid nitrogen or room temperature free space absorbing loads. The results are

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model and scaled according to electromagnetic scaling laws. The mixer is a hybrid structure which consists of two waveguides (LO and RF) and a suspended substrate stripline circuit oriented orthogonally to each other, as shown in Figure 3. This circuit is oriented in the center of the E-plane of the LO waveguide. Only are currently being investigated and significant improvements in system performance for solid state receivers using these mixers (particularly with the X2 version at 220 GHz) are expected. Mixer work at Georgia Tech is currently focused on optimization of whisker lengths, diode type/size, diode placement, and the integration of IF preamps.

Acknowledgments

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double sideband mixer noise figures and include LO noise, IF mismatch and RF mismatch contributions. Typical improvements of 1-2 dB can be obtained by matching the IF port. LO noise contributions can be significant. For this reason, the LO type is included in the table. Techniques for cleaning up LO noise

Figure 1. Photograph of 183-220 GHz X2 Subharmonic Mixer.

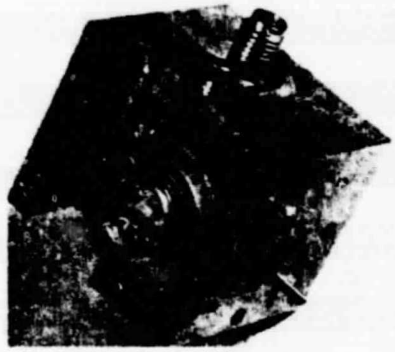

Figure 2. Photograph of 183-225 GHz X4 Subharmonic Mixer.

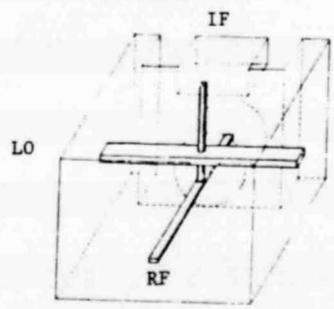

Figure 3. Subharmonic Mixer Diagram.

Table I

MIXER PERFORMANCE SUMMARY

Mixer Type	RF Frequency (GHz)	LO Frequency (GHz)	DSB Mixer Noise Figure (dB)	IF Frequency (GHz)
X2	183	91.65 (1)	4.5	0.75-1.0
X2	220	108 (2)	9.0	2.0 -4.0
X2	220	108 (1)	8.0	2.0 -4.0
X4	225	56 (2)	8.5	0.75-1.0
X4	225	55 (2)	10.0	2.0 -4.0

(1) Klystron
(2) Solid State Gunn or Gunn/Multiplier