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RESEARCH IN MILLIMETER WAVE TECHNIQUES

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

R. E. Forsythe
ProjectDirector/Principal Investigator

J. L. King
Project Monitor for NASA/GSFC

Report Period 15 December 1978 – 15 June 1979

15 July 1979

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station
Atlanta, Georgia 30332

1979

Semi-Annual Status Report

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FOREWORD

This is the tenth semi-annual status report on NASA Grant NSG-5012. The grant period is from June 15, 1974 to January 31, 1980 and includes seven extensions and increases to the scope and funding of the programs. The total funding to date is $586,433 of NASA funds and $30,171 in Georgia Tech cost-sharing funds, for a total of $616,604. Current grant funding is at a level of $35,000 with Georgia Tech providing $1,840, and the current grant period extends through January 31, 1980.

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 these monthly reports for the current period (fifty-three through fifty-seven) are contained in Appendix I. This tenth semi-annual report will replace the fifty-eighth monthly letter (since this semi-annual report is being furnished during the time the fifty-eighth monthly report would normally be written).

Responsibility for technical effort on this grant lies in the Electromagnetics Laboratory, under the general supervision of J. W. Dees, 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, and the Electro-Optics Division, responsible for radiometric measurements, quasi-optical techniques, and analysis.

Contributors to the technical effort and/or these reports during the eight six-month periods include: V. T. Brady, J. W. Dees, J. J. Gallagher, D. O. Gallentine, J.B. Langley, R. W. McMillan, H. Muzika, W. M. Penn, J. H. Rainwater, J. M. Schuchardt, R. G. Shackelford, R. E. Forsythe, G. T. Wrixon (consultant), and Students Assistants C. H. Branch, A. M. Cook, H. Homayun, N. K. O'Rourke, E. Rodrigues, D. Zacharias, J. Shaver, W. Feath, and D. H. Smith.

The following paper, based on work supported wholly by this grant, has been presented and accepted for publication during the period covered by this report.

R. E. Forsythe, V. T. Brady, and G. T. Wrixon, "Development of a 183 GHz Subharmonic Mixer," Proceedings of the 1979 IEEE-MTT Symposium, Orlando, Florida, April/May, 1979.

During the period covered by this semi-annual report, a trip was made by R. E. Forsythe to present the above mentioned paper at the 1979 Orlando meeting of the IEEE-MTT symposium. Other attendees from the Electromagnetics Laborabory of Georgia Tech were J. W. Dees, J. M. Schuchardt and J. A. Stratigos. These trips were related to the areas of technology covered by the grant but not charged to it.

1.0 INTRODUCTION

During the past six months, efforts on this project have been devoted to: (1) obtaining a reliable 183 GHz subharmonic mixer using a new body design, (2) improving whisker etching techniques, (3) developing a broadband 183 GHz fundamental mixer, (4) assembly and testing of mixers to be used on the B-57 flights of a 94/183 GHz radiometer during the summer and fall of 1979, (5) improving mixer backshort techniques, (6) assembly of the $\omega/4$ subharmonic mixer, (7) development of a precise noise figure tuning and test set-up for testing mixers, and (8) calculations of wire grid array interferometer performance. Significant events during the past six months include: (1) development of a reliable 183 GHz subharmonic mixer, (2) development of a precision noise figure test set-up, (3) cancellation of the order for the 183 GHz IMPATT source from Hughes Aircraft, (4) successful deposition of SiO_2 on a noncontacting backshort, and (5) development of sturdier whisker points used for diode contacting. Each of these areas of effort and achievement are treated in this report.

2.0 MIXER DEVELOPMENT

2.1 Fundamental Mixers

Two fundamental mixers, one a 94 GHz wafer type mixer and the other a 183 GHz split block mixer both designed by Dr. G. T. Wrixon of University College, Cork, Ireland, have been used on the first high altitude test flights of the 94/183 GHz B-57 radiometer. These mixers have been developed under this program. The advances achieved in the performance of these mixers in the past six months are due to (1) the use of a low power diode developed by Dr. Wrixon requiring only about 400 μWatts of LO at 183 GHz for optimum noise figure performance allowing the use of a solid state local oscillator when the LO power is coupled with a new low loss directional filter and (2) the development of an IF matching network for the 94 GHz wafer type mixer. The efforts made on these mixers under this program during this six month period have been directed towards improved performance and reliability as well as mixer noise figure characterization.

The 183 GHz mixer failed prior to the B-57 flight test after an unfortunate accident in which an engineer's finger got caught in the chopper blade. The 183 GHz RF system was sent back for repair. The diode kept losing contact and seemed to degrade with time after each contact. An apparently solid contact was finally made but the noise figure was about 2 to 3 dB worse than before.

The mixer was shipped back to Texas for the test flights but the diode had again degraded beyond usefulness. Upon return of the system to Georgia Tech an SEM photograph, shown in Figure 1, was taken of the contacted diode chip. Dried blood can be seen surrounding the tip of the whisker in this figure. Figures 2 and 3 show SEM photographs of the diode and whisker after a thorough cleaning by forcing warm soapy water through the waveguide. The tip of the whisker had been completely dissolved. This mixer has been recontacted and is now functioning normally with about a 7-8 dB mixer noise figure.

After the accident a degradation of the Δt_{min} of the 94 GHz channel was also observed. Upon return of this system to Georgia Tech a large piece of blood was found in the mixer waveguide prior to the diode. This mixer has been cleaned and is again operating normally with about a 5-6 dB noise figure.

New techniques are currently being investigated under this program to improve mixer backshorts and whisker etching techniques. Blunter whiskers have been made using KOH and square wave etching. Figure 4 shows an SEM photograph of a whisker etched in 10% KOH using about 3.4 V 100 Hz square wave etching. This effort will require more investigations to develop reliable etching techniques. Noncontacting backshorts are also being developed for evaluation purposes at 183 GHz for quarter height waveguide.

A new 183 GHz fundamental mixer designed by the author is being built which allows broad IF matching by placing the matching network as

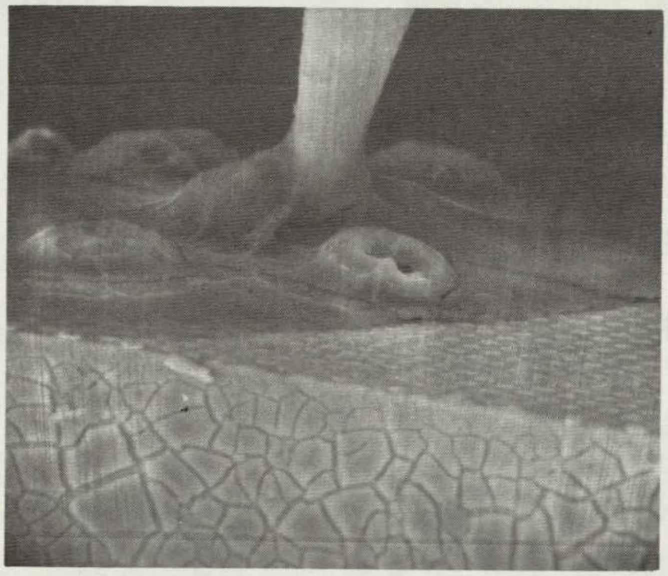


Figure 1. SEM Photograph of Dried Blood on 183 GHz Mixer Diode, 1150X

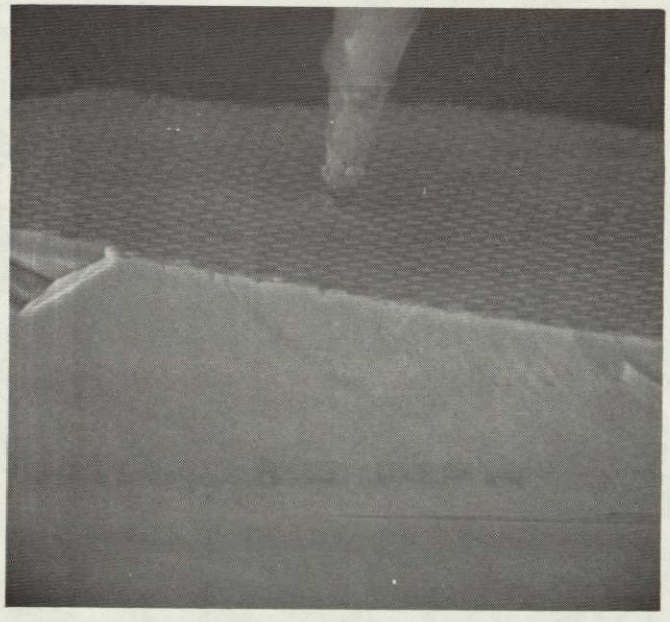


Figure 2. SEM Photograph of 183 GHz Mixer Diode after Cleaning, 1150X

Figure 3. Same as Figure 2 Except the Magnification is About 5300X

Figure 4. SEM Photograph of Successfully Etched Whisker, 5700X.

close to the diode as possible. This task is being done to improve the 183 GHz B-57 system performance particularly at the higher IF frequencies. This body is currently being machined and will hopefully be available as an alternate 183 GHz mixer for the B-57 flights.

2.2 Subharmonic Mixers

The primary thrust during the past six months has been to develop a reliable 183 GHz subharmonic mixer. The excellent results achieved last fall and presented at the IEEE-MTT symposium in Orlando, May 1979, (see Appendix II) have solicited this concentrated effort to repeat those results and ruggedize the mixer for use in a flight radiometer. Previous 183 GHz subharmonic mixers showed reliability problems in which the whiskers would lose the diode contact possibly due to some small motion of the parts of the mixer body.

The first diode contacts with the new ruggedized body showed good noise figures (~8 dB) but again the contact on one of the diodes was intermittent. The mixer was then assembled using a dummy diode and observed for several days under an SEM to locate the cause of the apparent motion. No motion was detected after several days. The mixer was then refrigerated and then dipped into LN_2 for 30 seconds. The mixer was also placed in a 10^{-4} Torr vacuum several times. The diode remained contacted throughout these tests. The mixer was again assembled on June 26, 1979, using Wrixon's low power diodes. The first set of diodes contacted were damaged due to sparking. A second set was contacted by running in the pins a little further. These have been tested and have shown about an 8.5 dB noise figure at a 1-2 GHz IF with no IF matching. About 3 dB IF mismatch was observed. This added about 3 dB to the mixer noise figure. An IF matching network would probably improve the noise figure to about 5 to 6 dB. These diodes have retained solid contacts ever since. Mild temperature cycling between 10°C and 64°C was done on this set of contacted diodes. The diodes remained contacted when cooled to 10°C. They both lost contact when heated to 65°C but the curves returned at about 35°C. The substrate circuit was slightly misaligned and damaged during assembly causing excess LO loss. As a result the typical LO power required for best noise figure in this assembly attempt increased from 10 mW to about 30 mW. Diode selection for optimum performance will begin upon arrival of the spare body made at NASA/GSFC. The subharmonic mixer mounts for the B-57 flight radiometer are being made. A direct comparison of the fundamental and subharmonic mixers will soon be made.

The $\omega/4$ subharmonic mixer is awaiting the suspended substrate stripline circuits from R. Lamb of NASA/GSFC. The body has been gold plated and polished. The report on the model stripline circuits developed for this mixer is contained in Appendix III. Another circuit has been developed to improve the bandwidth of this mixer. The basic mixer circuit functions are shown in Figure 5. The improved bandwidth is due primarily to the increased bandwidth of the LO x 4 short circuit caused by the quarterwave low impedance transmission line. This filter shown in Figure 6 is a cascade of a low pass and a bandstop filter. The bandstop filter presents an open circuit to the diodes at the 2 x LO frequency thus suppressing the unwanted mixing components. The low pass filter presents a short circuit to the diode pair at the signal frequency. This filter replaces the LO filter shown in Figure 5. Both filters are being made and will be compared in the 183 GHz mixer. A mixer similar to this one has been proposed for another program at 230 GHz as a direct consequence of the successes that have occurred during the past six months on this program.

2.3 Mixer Performance and Evaluation

One of the tasks under this program is that of characterizing mixer performance. The current noise figure test set-up consists of a lab radiometer with a divider network to tune for minimum system temperature (T_{sys}). The divider network takes the output of an RMS voltmeter and divides it by the output voltage of the radiometer. This value is

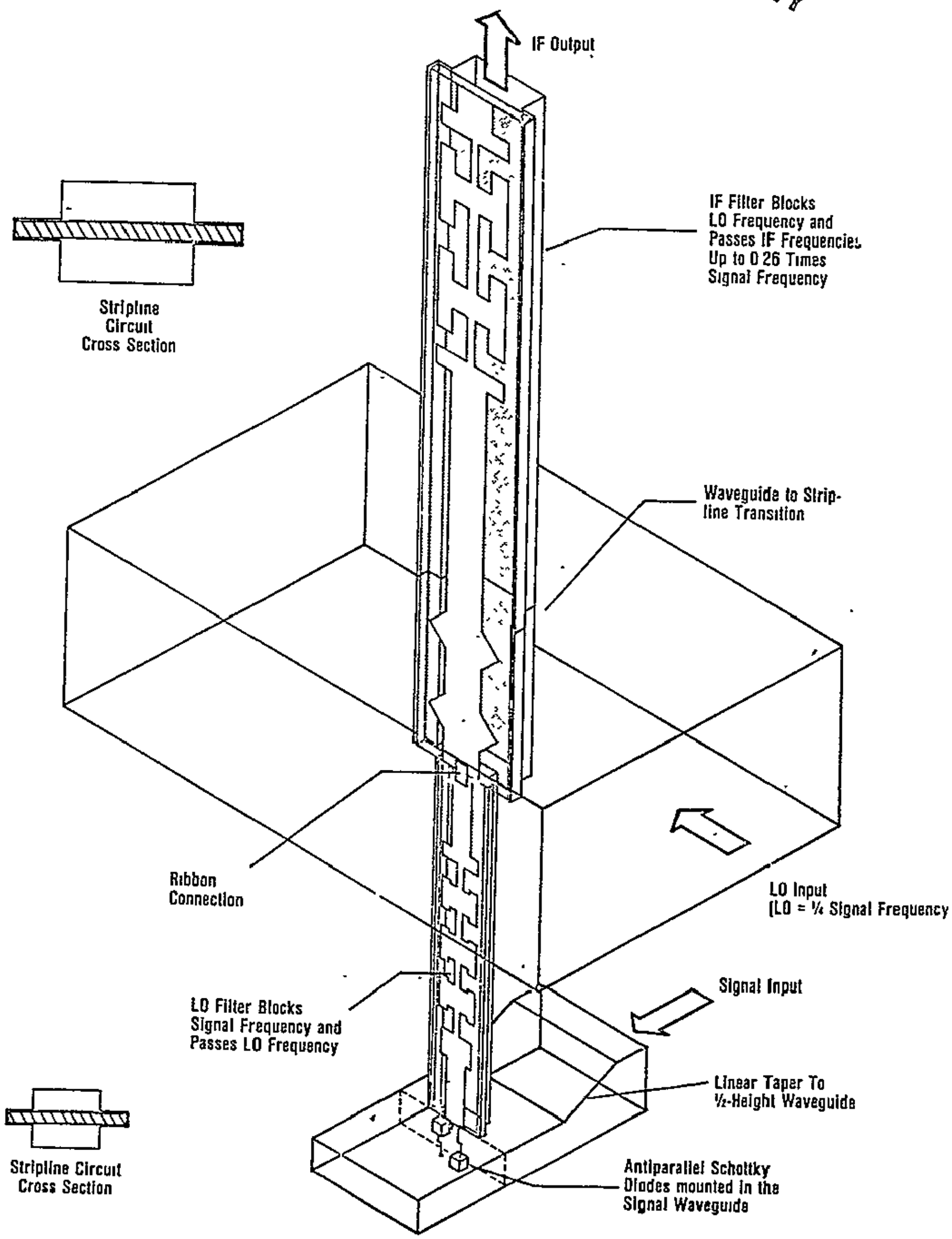


Figure 5. Fourth Harmonic Mixer Layout.

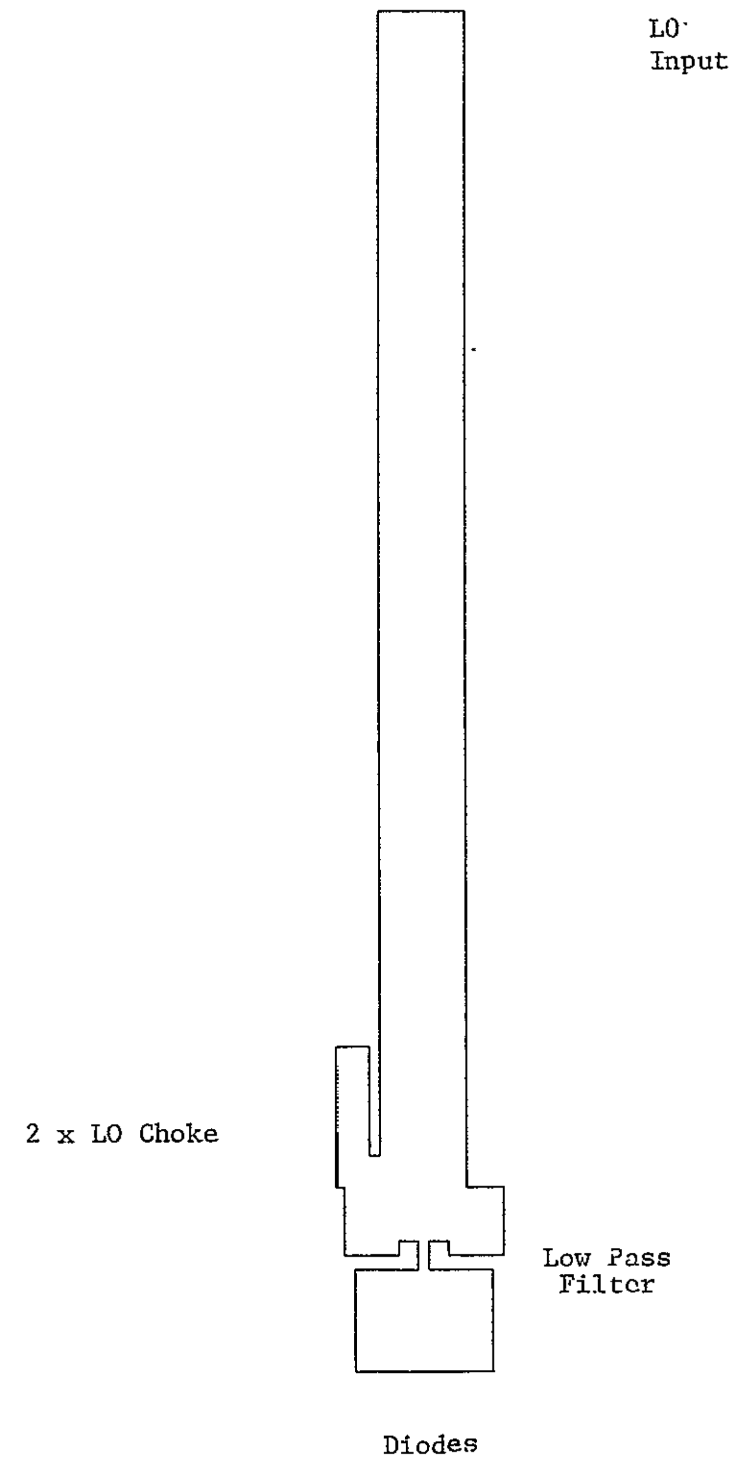


Figure 6. Broadband LO Filter for Fourth Harmonic

proportional to T_{sys}. The actual system temperature is then measured by a Y-factor method using either a hot-cold load (room temperature to LN_2) or a noise tube with the system shown in Figure 7. This system can measure Y-factors of 0.01 dB or more.

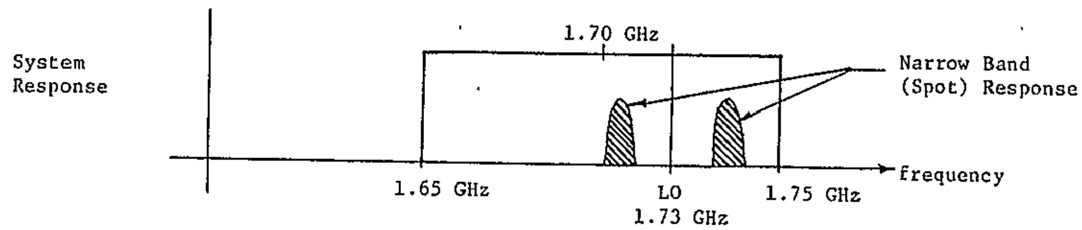
Another recent improvement in lab equipment is the acquisition by Georgia Tech of a 75-100 GHz IMPATT sweeper allowing swept conversion loss measurements at these frequencies. The IMPATT can also be used as a local oscillator to examine LO noise cancellation in the subharmonic mixer.

Hughes has not been able to deliver the 183 GHz locked IMPATT source, therefore this order has been cancelled and the money unencumbered. This has resulted in an additional $25,000 being available for mixer development during this grant period.

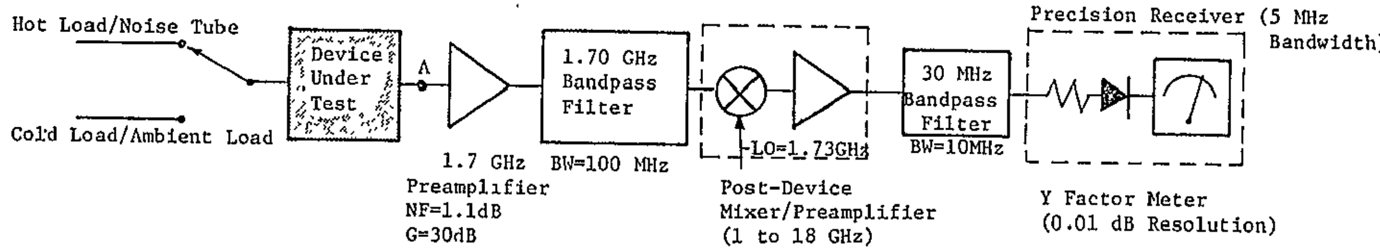
3.0 QUASI-OPTICAL RESEARCH

The early calculations made on transmissivity and reflectivity of wire grid arrays at millimeter wave frequencies were based on the reference direction being chosen to be perpendicular to the actual wire direction. To make these calculations conform to the results obtained by other authors, the transmission and reflection matrices were modified so that the orientation direction is now defined as being parallel to the wires. This change is also expected to reduce the complexity of the overall transmission and reflection equations derived during the program.

The purpose of making the change discussed above was to rederive the transmission and reflection equations derived earlier with the hope that this change will result in some simplification that will allow for extension of this earlier work to more general cases. This work has not been pursued further, but it is expected that it will be continued during the remainder of the current grant period.



a) Frequency Band of Interest.



b) Block Diagram

Notes: 1. When using the total system, a spot noise figure is measured. The spot noise figure frequency response can be examined over the 1.65 to 1.75 GHz band by tuning the LO.

2. To check the device under test in other frequency bands between 1 and 18 GHz, other preamplifiers are used.

3. To check millimeter wave mixer performance, point A is connected to the mixer IF port.

Figure 7. Precision Noise Figure Measurement Facility

4.0 EFFORTS PLANNED FOR THE LAST HALF OF 1979

4.1 Component Development

Efforts will continue in the area of subharmonic and fundamental mixer development. Diode selection will begin for the 183 GHz subharmonic mixer. The 183 GHz fourth harmonic mixer assembly will continue. The broad IF 183 GHz fundamental mixer will be built and tested.

4.2 Quasi-Optical Research

The calculations of wire grid array transmission and reflection, discussed in Section 3.0, will be pursued further. In particular, attempts will be made to generalize the results obtained earlier to arbitary grid orientations and phase shifts.

APPENDIX I

Monthly Progress Reports

Fifty-Three through Fifty-seven

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Fifty-third Monthly Progress Report

Report Period
15 January through 15 February 1979

Report Prepared

14 February 1979

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

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

Georgia Institute of Technology
Engineering Experiment Station
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Atlanta, Georgia 30332

SUMMARY OF WORK

1.0 MIXERS

The new low power Wrixon diodes were mounted in the split block mixer and the subharmonic mixer. Tests on the split block mixer indicate an improvement of about 1.0 dB in noise figure. The subharmonic mixer was successfully contacted but the diodes lost contact before any measurements could be made. One of the Wrixon diodes was lost upon disassembly of the subharmonic mixer. A new back short was made which looks as good as the original one. It was used in this assembly attempt.

New etching methods have been developed during this period through discussions with both Tony Kerr and Jerry Lamb to produce blunter whiskers which should ease the recontacting procedure for the subharmonic mixer. PCE and PNE were used as etchants and both ac and dc voltages were used to etch the whiskers (dc voltages produced the best whiskers so far).

The 4th subharmonic circuit diagrams were sent to Jerry Lamb along with sputtered substrates so that the new circuits may be made. The 4th subharmonic mixer body was polished and is ready for gold plating. The second subharmonic body drawings were sent to NASA/GSFC so that two new mixer bodies could be made using brass.

The 45-90 GHz Gunn doubler was received. Tests indicate that both frequency and power specifications are slightly different from those stated by TRG and are not optimum for use with the 183 GHz doubler.

A paper was written and accepted for presentation at the May 1979 IEEE-MTT microwave symposium in Orlando. The results obtained last October with the 183 GHz subharmonic mixer are presented along with some model measurements. The authors are R. Forsythe, V. Brady and G. Wrixon.

2.0 NOISE FIGURE MEASUREMENTS

A new low noise (1 dB noise figure) IF amplifier was received. This amplifier has been married into a noise figure measurement system for total power noise figure measurements. It has a 1.7 GHz center frequency with a 100 MHz bandwidth. The dc power supplies, a 30 MHz mixer-amplifier and filters have all been mounted on a permanent bracket. This system has been tested and has a noise figure of 1.1 dB. The precision receiver has been modified by placing a large capacitor on the input of the meter. This increases the sensitivity of the system.

3.0 QUASI-OPTICAL CALCULATIONS

The transmission and reflection matrices for individual grids have been modified so that the grid angles are defined parallel to the wires instead of perpendicular as before. The modified matrices for a grid oriented at angle θ are then

$$T_\theta = t_\theta \begin{bmatrix} \sin^2\theta & -\sin\theta\cos\theta \\ -\cos\theta\sin\theta & \cos^2\theta \end{bmatrix} ,$$

$$R_\theta = r_\theta \begin{bmatrix} \cos^2\theta & \sin\theta\cos\theta \\ \cos\theta\sin\theta & \sin^2\theta \end{bmatrix} ,$$

where t_θ and r_θ represent the fractions of incident power transmitted and reflected for polarization perpendicular and parallel to the wires, respectively.

As might be expected, the only effect on the hierarchy of grid equations derived thus far is to replace the angle θ by $\theta-90°$, and the other grid angle α by $\alpha-90°$, so that $\sin\theta$ becomes $\cos\theta$ and $\cos\theta$ becomes $-\sin\theta$, with similar substitutions for α. The transmission equation for a two-grid array was rederived to verify these relations. This change is expected to reduce confusion in future grid calculations as well as to make our quasi-optical definitions agree with those of other workers without making cumbersome substitutions.

4.0 PLANS FOR NEXT PERIOD

The subharmonic mixer will be recontacted using blunter whiskers. This will increase the chance of recontacting in case that the diodes lose contact. The new Wrixon diode may be cut in half to form a new pair of diodes. Gerry Wrixon will be contacted to see if a new pair may be obtained. The 4th subharmonic mixer body will be plated.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Fifty-fourth Monthly Progress Report

Report Period
15 February through 15 March 1979

Report Prepared

19 March 1979

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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Engineering Experiment Station
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SUMMARY OF WORK

1.0 Mixers

The subharmonic mixer is currently being assembled for another run-in attempt. This try will be made with diodes obtained from Bob Mattauch. Blunter whiskers are being used in this attempt. The run-in process is currently going on. The mixer is allowed to rest a few days prior to the final contacting of the diodes to allow the body to relax and help prevent the diodes from losing contact due to possible shifts between the two parts of the body holding the pins and the substrate.

2.0 Noise Figure Measurements

New broadband (0.5 to 12.5 GHz) bias tees have been received from Alpha/TRG. These tees will allow testing of the mixers at IF frequencies to 12.5 GHz with a single bias tee. A Y-factor measurement was made with the 183 GHz split block mixer using the new noise figure test set-up. The double side band noise figure of this mixer at 1.7 GHz IF was measured to be 8.0 dB using this method.

3.0 Plans for Next Period

The 183 GHz subharmonic mixer will be recontacted and tested. Work will continue in whisker etching research.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Fifty-fifth Monthly Progress Report

Report Period
15 March through 15 April 1979

Report Prepared

15 April 1979

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

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

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

SUMMARY OF WORK

1.0 Mixers

The 183 GHz subharmonic mixer was recontacted during this period. The diodes lost contact after a few hours. The mixer was tested during this time but showed poor noise figure due to the fact that the klystron power supply was accidentally left on internal 1 kHz modulation during the tests. Recontacting was successful for only limited periods of time. The 183 GHz subharmonic mixer is currently being reassembled for another run-in attempt. Another new mixer body is being made in the machine shop at Georgia Tech. This new body should help solve most of the reliability problems currently being experienced in the old mixer body. The 4th subharmonic mixer body is currently being polished in anticipation of the arrival of the circuits from Jerry Lamb. Gerry Wrixon's low power diode was split to form a new diode pair.

2.0 Plans for Next Period

The 183 GHz 4th subharmonic mixer circuits should arrive and assembly will begin. The 183 GHz subharmonic mixer will be recontacted. A paper will be presented at the IEEE-MTTS in May 1979 showing the results achieved with the 183 GHz subharmonic mixer.

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Fifty-sixth Monthly Progress Report

Report Period
15 April through 15 May 1979

Report Prepared

15 May 1979

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

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

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

SUMMARY OF WORK

1.0 Mixers

The new 2nd subharmonic mixer body has been machined. Metalized substrates have been sent to NASA/GSFC for fabrication of the circuits to be used in the new body. The improvements made in this new mixer body are outlined below.

1. The body is made of brass instead of copper increasing the strength of the structure.
2. The holes in which the pins holding a diode and a whisker are pressed have been drilled directly in the body rather than being drilled into a plug and then inserted in the body.
3. The pins line up with the substrate better than in the old body easing contacting and whisker mounting procedures.
4. The back shorts can be removed without having to take the body apart. This puts less pressure between the parts of the mixer body.
5. One waveguide junction and about one inch of WR-5 waveguide has been eliminated in the new structure by connecting the antenna directly to the mixer rather than use an adapter between the antenna and mixer thus reducing RF losses.
6. More screws and larger screws are being used to hold the body together.

These improvements (most of which were already incorporated in the $\omega/4$ mixer body) should solve the problems currently being experienced when using the old body.

The circuits for the $\omega/4$ body have not yet been received from NASA/GSFC. Hopefully they will arrive soon. The $\omega/4$ body is completed and awaiting the circuits for the final finishing touches.

Due to IF matching and bandwidth problems with the current 183 GHz split block mixer a new single-ended split block mixer has been designed and drawn up for construction in the machine shop. Figure 1 is a functional diagram showing the basic layout of the mixer. The highlights of this mixer compared to the one currently being flown on the B-57 are outlined below.

1. The diode is only 0.030 inches away from a microstrip matching network made on a low loss 1/32" duroid substrate allowing broad band matching of the IF impedance.
2. The RF choke is a three element coaxial Chebyshev filter with 0.5 dB

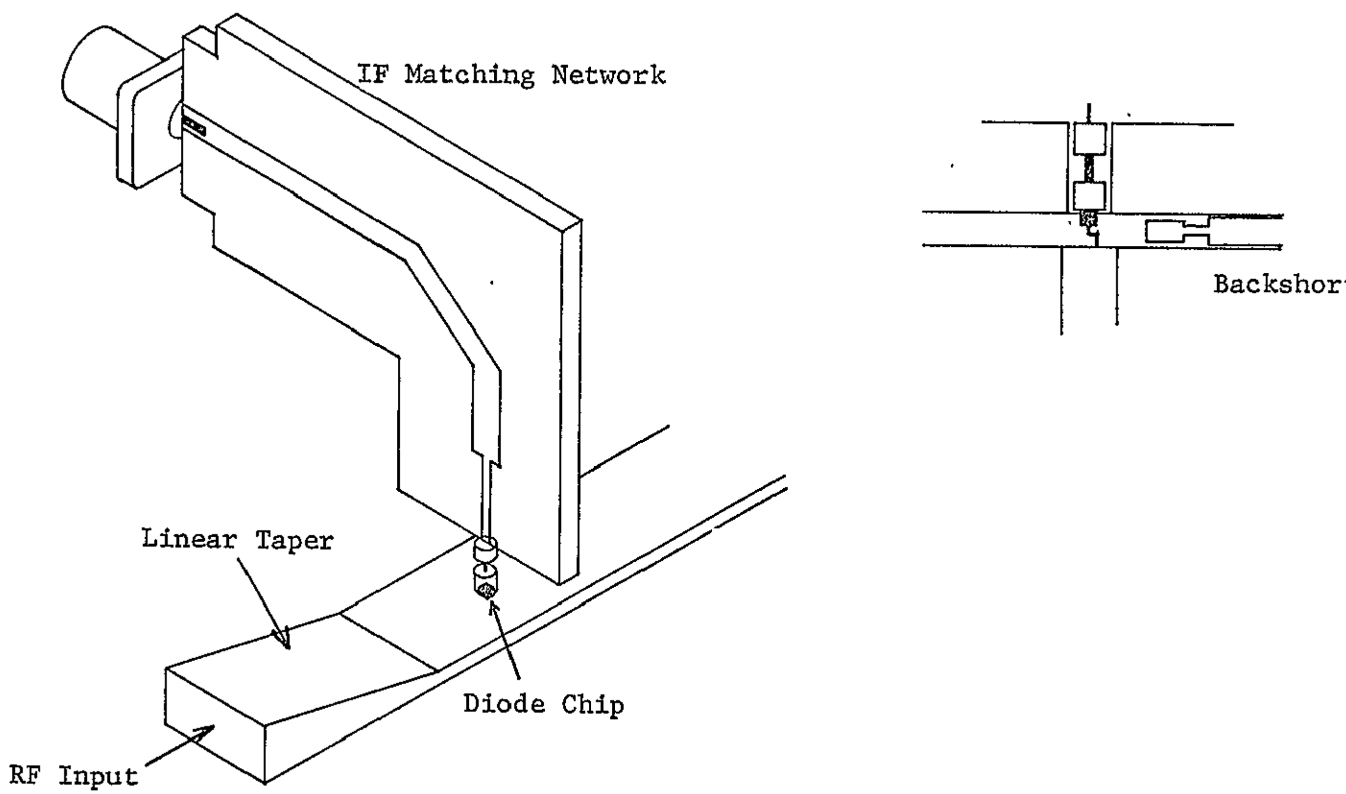

Figure 1. 183 GHz Split Block Mixer with Broadband Matching Network

ripple and a cutoff frequency of 91.65 GHz. The dimensions of this filter have been chosen to assure that no waveguide modes propagate through the coaxial choke and the lengths of the elements are a quarter wavelength long at 183 GHz.

3 A linear taper to quarter height WR-5 waveguide is being used to improve RF matching.

4 A quarter size diode, 0.005" x 0.005" x 0.005", is used in this structure and will be recessed about 0.002" inside the coax choke.

5 A non-contacting back short (discussed below) will be used.

Non-contacting back shorts are being developed for use at 183 GHz for both the subharmonic and fundamental mixers. The current contacting back shorts show erratic response and may be losing significant amounts of energy due to the loose contact with the waveguide walls. This back short will consist of two quarter wave chokes as shown in Figure 2. The choke structure will be coated with a dielectric material to prevent contact. A thin layer of quartz will be sputtered onto the back short (made of phosphor bronze or berylium copper) during the first attempts. These back shorts will be tried in both the half height and quarter height waveguide 183 GHz mixers. They can easily be compared by simply replacing the back shorts and measuring the RF response of the mixer.

The RF choke has been made by cutting a 0.010" diameter copper wire with an Exacto knife to form the three element filter. This filter will be epoxied in place. The diode will then be mounted on the end of the first element.

A paper was presented during this period at the IEEE/MTT Symposium in Orland Florida explaining the results achieved last fall with the 183 GHz subharmonic mixer.

2.0 Plans For Next Period

Fabrication of the new split block mixer body will begin . Work will continue on the assembly of the subharmonic mixers as soon as the new circuits are received. Run in jigs will be fabricated for the new bodies.

The new back shorts will be built and tested when the new mixers are available.

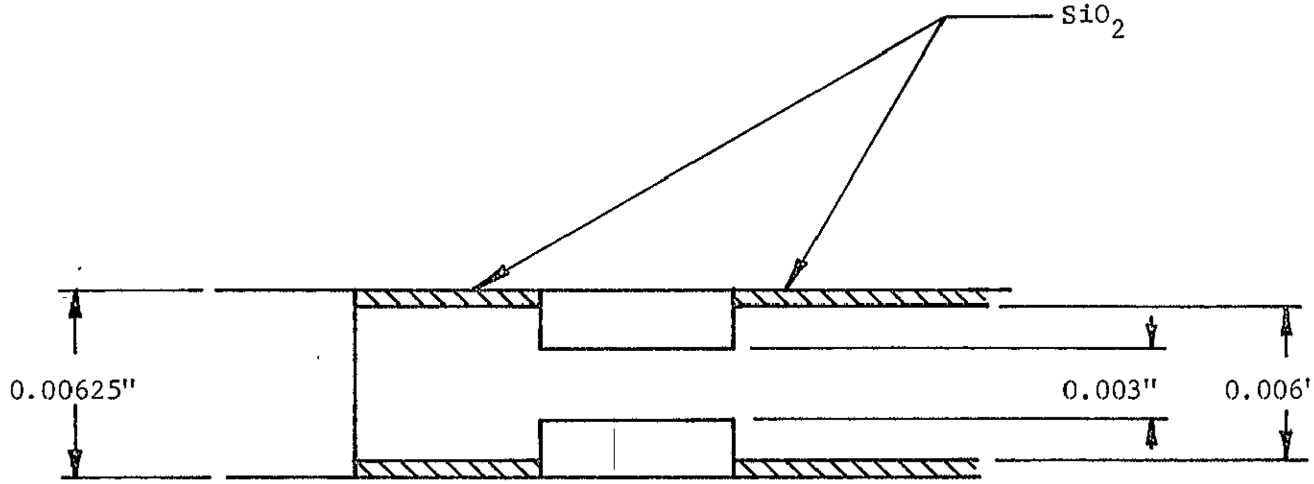

Figure 2. Non-Contacting Backshort

RESEARCH IN MILLIMETER WAVE TECHNIQUES

Fifty-seventh Monthly Progress Report

Report Period
15 May through 15 June 1979

Report Prepared

15 June 1979

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 subharmonic mixer has been contacted using R. Mattauch's diodes and the new brass mixer body built at Georgia Tech. In this attempt the pin with the diode mounted on it was made of beryllium copper and the pin with the whisker mounted on it was made of nickel. The pins were pressed into the body until contact was imminent and then the mixer was allowed to relax over the weekend. The diodes were then examined and it was found that the beryllium copper pin with the diode mounted on it had relaxed too much and had contacted over the weekend. The contact was extremely poor and damage had apparently occurred to the whisker on the substrate. The pin was pulled out slightly and a good diode curve was obtained. The other pin was pressed in and an antiparallel diode pair was formed. Testing the mixer showed about a 13 dB system noise figure with a 2 dB IF contribution over a 1-2 GHz IF bandwidth. A 3 dB IF mismatch was also measured. About 10 mW of LO power was required. The poor system noise figure was assumed to be caused primarily by the damaged whisker on the substrate. After two days the diode mounted on the beryllium copper pin had lost contact. Again the pin was pulled slightly and another diode curve was obtained. The mixer was then temperature cycled. The diodes remained contacted after one hour at 10°C however the diode on the pin lost contact after half an hour at 0°C and ice formed on the mixer body. The top of the body that contained neither the pins nor the substrate was removed. No change was observed in the dc characteristics during this operation. The diodes were then observed under the SEM. The continuous loss of contact of the diode mounted on the pin indicates a problem exists possibly due to some motion too small to observe with an optical microscope. Currently tests are being made on the mixer to determine the cause of the motion. SEM photographs are being taken of a dummy diode contacting the whisker mounted on the substrate. Motion of the pin, diode, whisker, substrate and the mixer body sections will be observed. The first test is being made with beryllium copper pins. The second will be made using nickel pins.

A noncontacting backshort described in the previous monthly progress report was successfully made using 0.006 inch brass shimstock. The high impedance section was made by carving the shim stock with an X-Acto knife. The short was then coated with quartz by depositing SiO_2 at 330°C in a deposition chamber.

The drawings for the broadband 183 GHz single-ended mixer body are complete and the machining has begun. Matching networks are being developed using a computer analysis/optimization program called COMPACT.

2.0 Plans for Next Period

The 183 GHz subharmonic mixer will be recontacted after the testing for the cause of the lost diode contact is completed. The 94 and 183 GHz mixers flown on the RB-57 will be examined and repaired as needed. The assembly of noncontacting backshorts will begin for some of the mixers for RF testing. The machining of the broadband 183 GHz mixer body will be completed. Experimentation in etching blunter whisker points will begin again.

APPENDIX II

Development of a 183 GHz Subharmonic Mixer

DEVELOPMENT OF A 183 GHz SUBHARMONIC MIXER

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Abstract

Experimental results are presented for a 183.3 GHz subharmonic mixer operating in a broad IF (0.75 GHz-10.0 GHz) radiometer system. The results are compared to a low frequency (6.8 GHz) mixer model. Results from a similarly designed fourth harmonic low frequency model are also presented.

Introduction

Antiparallel diodes, when used as a subharmonically pumped mixing network, have several advantages over single diode mixers particularly for millimeter wave applications.[1-3] Pumping at half the frequency allows the use of lower cost or solid state local oscillators at millimeter wave frequencies while having similar mixer conversion loss characteristics to single ended mixers. Local oscillator AM noise cancellation occurs due to the nature of the antiparallel diode circuit.[4] Also, a dc bias is not required for mixer operation.

The use of Schottky barrier diodes placed in the signal waveguide and a specially designed suspended substrate circuit have extended this concept for use at 183 GHz. Preliminary results based on measurements made with a Dicke radiometer using this device are given in this paper.

Description

The mixer diagram shown in Figure 1 shows the functions of the stripline circuit and diode placement. This mixer was modeled at 6.8 GHz for circuit optimization and directly scaled using electromagnetic scaling techniques to 183 GHz. Great care was taken to model the actual mixer by choosing diodes with scaled cut-off frequencies. The size of the diodes was also scaled by using brass blocks in the waveguide. The IF filter consists of a low pass filter designed to reject the LO and pass the IF frequencies. The LO filter is another low pass filter designed to pass the LO but block the RF energy from leaking into the LO waveguide. The stripline circuit provides a broadband RF match to the diode pair, allows LO injection and provides an IF output port. The quartz substrate is 0.003" thick with a Cr-Au vacuum deposited center conductor. The circuit is etched by common photolithographic methods. The signal waveguide has a linear taper to half-height WR-5 waveguide to improve the RF match.

The mixer has two orthogonal waveguides, WR-10 for the LO, and half-height WR-5 for the signal. These two waveguides are connected by a channel that supports the suspended substrate filter. One diode and one whisker are mounted on one end of the filter, the LO transition from waveguide to stripline is in the middle of the filter and the IF connection is made to the other end of the filter. Across the WR-5 waveguide from the end of the filter where a diode and whisker are mounted, two pins are inserted on which the other whisker and diode are mounted. When the two diodes are contacted, the antiparallel diode pair is formed inside the WR-5 waveguide. The diodes are 0.005" x 0.01" GaAs diode chips which contain arrays of 2μm Schottky barrier diodes.

The body itself is divided into three parts. One part holds both pins, one holds the IF filter, and the last contains the linear taper from full to half-height WR-5 waveguide.

Assembly

First a pre-shaped whisker is mounted on the end of the LO filter using normal solder. The whisker is then etched to 0.007" in a 10% solution of NaOH at 2 Vac. The diode chip is then epoxied to the thin edge of the filter and a fillet of 90°C solder is added for the electrical connection. The filter is then mounted in the filter channel in the block using Loctite 404. The SMA connector is then attached and a piece of gold ribbon is soldered between the connector and the filter. When the diode chip is mounted on the diode pin, a glass cover slip is used to press it into a thin layer of low temperature, 90°C, solder. The preshaped whisker is mounted on the pin using normal solder and etched to the same length as the whisker on the filter. All soldering is done using Supersafe #30 flux.

The filter block is then bolted to the pin block and both of the pins are pressed into the block. A micrometer is used to position both pins to 0.005" from their final positions. The waveguide transition block is now bolted to the other two and one diode at a time is contacted while being monitored on a curve tracer.

Performance

The design and testing was performed primarily to develop a 183 GHz mixer with a 20 GHz RF bandwidth to be used on a radiometer with three IF channels spanning a 0.75 GHz to 10.0 GHz IF. This radiometer and its system requirements have been set by the study of the water vapor absorption line at 183 GHz. This broad IF prohibits the use of standard IF matching techniques.

The mixer shown prior to assembly in Figure 2 was tested in a radiometer system. The signal was modulated by a Dicke chopper alternately viewing liquid-nitrogen or room temperature distributed loads and a reference load. This modulated signal is then mixed down to between 0.75 GHz and 10.0 GHz by the subharmonically pumped mixer with a 91.65 GHz LO. The IF signal was amplified and then detected using square law detectors and a lock-in amplifier.

An RC time constant of 1.25 seconds was used to get the scale factor for determining the minimum detectable temperature by alternately viewing the room temperature and liquid nitrogen loads and reading the output of a DVM. This time constant corresponds to an integration time (τ) of 2.5 seconds for a simple RC integrator.[5] The RMS fluctuations were measured by graphic analysis of the radiometer output recorded on a chart recorder. The measurements were used to get the minimum detectable temperature (ΔT_{min}) for the system using

$$\Delta T_{min} = \left[(T_{RT} - T_C) / (V_{RT} - V_C)\right] \times V_{RMS}.$$

where

T_{RT} = Room Temperature (°K)

T_C = Temperature seen by antenna when viewing the cold load (°K)

V_{RT} = Voltage output of radiometer when viewing room temperature load

V_C = Voltage output of radiometer when viewing cold load

V_{RMS} = Measured standard deviation of radiometer output.

The system noise temperatures, frequencies, double sideband mixer noise figures (F_M) and bandwidths are summarized in Table 1. These numbers were achieved using no specialized matching networks and represent actual results obtained with a 183.3 GHz double sideband radiometer system.

Summary

These results show the feasibility of using subharmonic mixers with Schottky barrier diodes for system applications in the millimeter wave region. This design is adequate for frequencies up to 360 GHz by using the same scaling techniques.

A fourth harmonic mixer for use at 183.3 GHz is also being developed. Results from the model mixers (shown in Figure 3) show that with carefully designed stripline circuits comparable performance to the second subharmonic mixer may be obtained. Results from the 183 GHz version of this mixer should be available soon.

Acknowledgments

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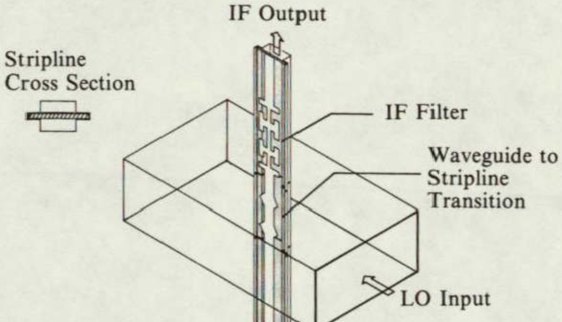

Figure 1. Functional Schematic of Subharmonic Mixer.

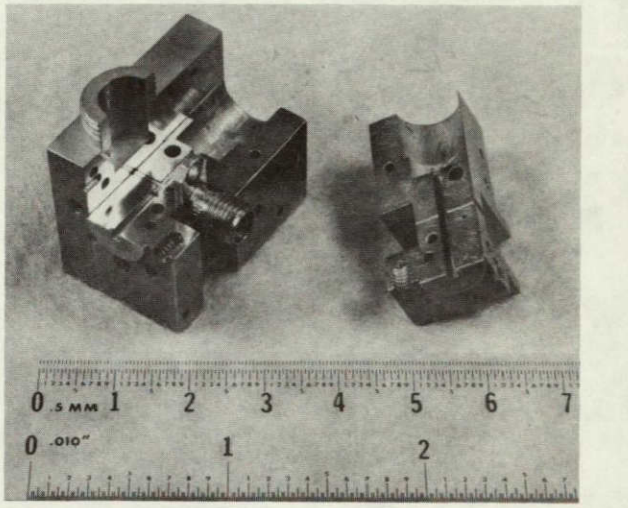

Figure 2. Photograph of Partially Disassembled 183 GHz Subharmonic Mixer.

TABLE I

NOISE FIGURE SUMMARY

IF CHANNEL (f_o)	ΔT_{min}	IF Bandwidth (B)	IF Noise Figure (F_{IF})	T_{SYS}	F_M
1.0 GHz	0.22°K	0.5 GHz	4.0 dB	3536°K	4.9 dB
5.0 GHz	0.25°K	1.0 GHz	5.0 dB	5680°K	5.9 dB
8.75 GHz	0.25°K	2.5 GHz	5.0 dB	8984°K	7.9 dB

where:

$$\Delta T_{min} = \frac{2.2\, T_{SYS}}{\sqrt{B\tau}}$$

$$T_{SYS} = T_A + (a-1)290 + a(F_m-1)290 + aL_C(F_{IF}-1)290$$

$$T_A = 290°K,\ a = \text{RF losses} = 2.0\text{ dB},\ \tau = 2.5\text{ sec.}$$

and assuming,[6] $LC = F_M$ (Noise Ratio ≈ 1)

$$F_M = \frac{T_{SYS}}{a\,290\,F_{IF}}$$

$$f_{LO} = 91.65\text{ GHz} \quad f_{SIG} = 183.3 \pm 10\text{ GHz}$$

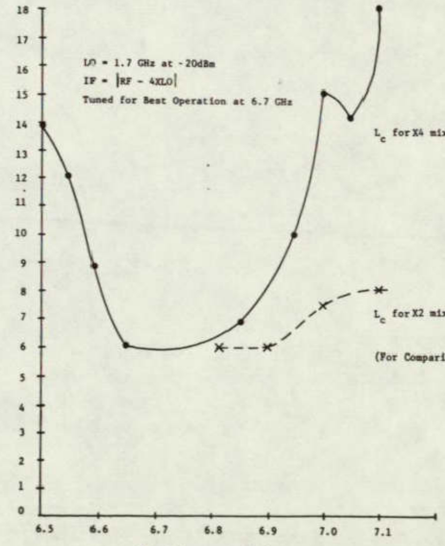

Figure 3. Measured Conversion Loss (L_c) versus Signal Frequency of Fourth Harmonic Mixer Model (Scaled 26.9:1)

APPENDIX III

Fourth Harmonic Model Mixer

Filters and Mixer Data

Preliminary Test Report

SUSPENDED SUBSTRATE
STRIPLINE
FILTERS
FOR MIXER APPLICATIONS

Part III
Fourth Harmonic Model Mixer Filters and Mixer Data

January, 1978

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Reviewed by:
James M. Schuchardt

ABSTRACT

This paper is the third part* of a series of reports on the progress of the 183.3 GHz subharmonic mixer [1,2]. This report covers the design of the fourth harmonic mixer using the scaled mixer model (26.9:1 up in size). It includes individual filter data as well as measured mixer performance using the scaled model.

*Part one covered individual filter design and measurements. Part two covered X2 mixer measurements and the integration of all the circuits.

INTRODUCTION

The fourth harmonic (X4) mixer is even more attractive than the second harmonic (X2) mixer when considering the cost and performance of available LO sources. Further, the performance of stripline used for the LO injection circuit is increased due to less loss at the lower LO frequency. The LO frequency would be 45.825 GHz for X4 pumping and 91.65 GHz for X2 pumping for a fundamental frequency of 183.3 GHz. The conversion loss and noise figure of a fourth harmonic mixer can be made almost as low as that of a second harmonic mixer by adjusting the placement of the LO filter so that the diodes see an open circuit at twice the LO frequency [3]. This requires that a new LO filter be made which cuts off at less than half the signal frequency (183.3 GHz) and continues to be a good low pass filter past the highest signal frequency. The required LO and IF filter responses are shown in Figure 1.

Filter	Scaled f_{cs}	Actual f_c	Insertion Loss $IL_{Sig.}$	IL_{LO}	Insertion Loss IL_{2XLO}	IL_{IF}
IF	0.9 GHz	24 GHz	--	39dB	--	0.1
LO	2.8 GHz	75 GHz	50dB	0.1dB	30dB	0.1

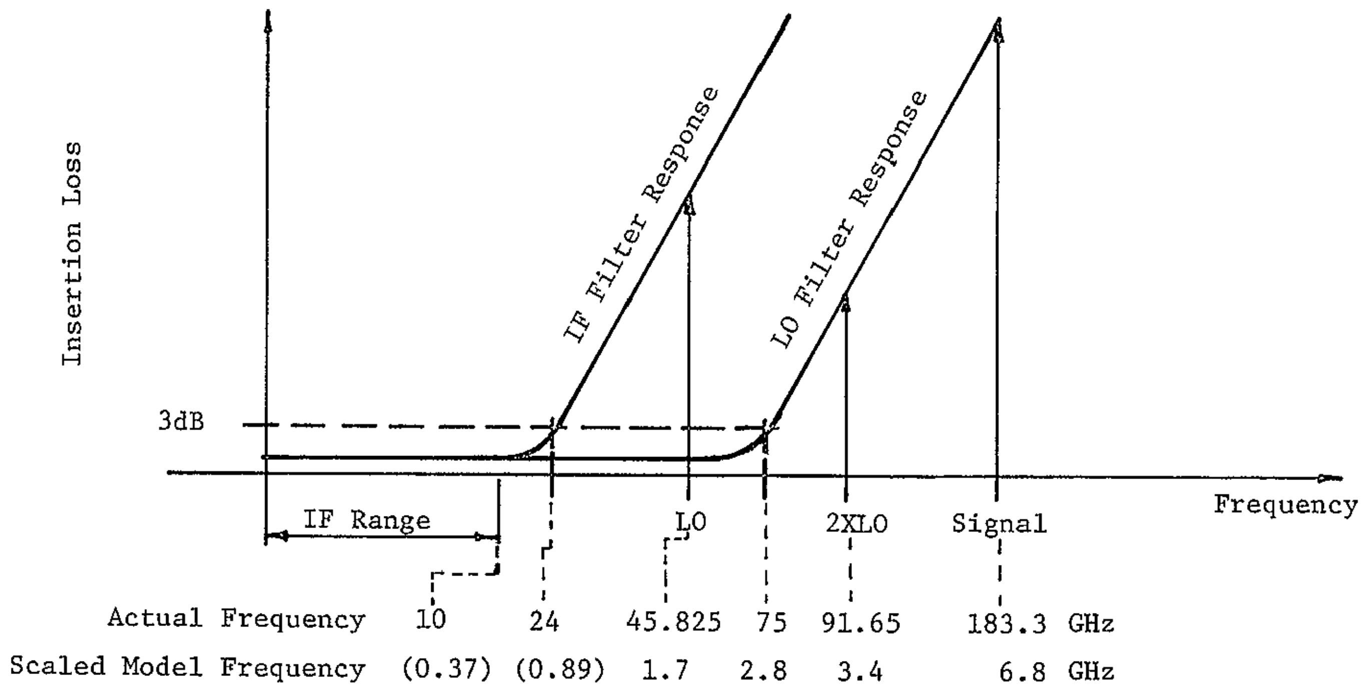

Figure 1. Filter Parameters and Data

DESIGN and RESULTS

A diagram of the X4 mixer filter (IF and LO) is given in Figure 2. The IF filter passes the mixer generated IF to the output while channeling the LO to the mixer diodes. The LO filter passes the LO signal to the mixer diodes, acts as a choke to the RF signal and passes the IF with ideally no effect.

Reducing the LO frequency in the X4 model to 1.7 GHz requires the IF filter to also have a lower cutoff frequency than the X2 mixer model. The new cutoff frequency is 0.89 GHz which is down from 1.78 GHz as used in the X2 mixer. To achieve this lower cutoff frequency, it is necessary to make the filter L and C sections (high impedance and low impedance sections) physically larger than those used in the X2 mixer. Since the relationship between the IF filter parameters for the X2 and X4 mixers is exactly two times, all dimensions of the IF filter for the X4 mixer were obtained by doubling dimensions of the X2 mixer IF filter. These dimensions are given later (see Figure 9), however in developing the LO filter circuit it was expedient to not use an IF filter that was directly scaled. The reason for this is it would have required a quartz structure about 1.7 inches wide and restructuring the model mixer. Obtaining this material would have caused a significant project delay. An alternate approach was used to provide adequate IF filtering so that the LO filter parameters could be developed. Basically the test IF filter used was designed to provide only about 15 dB of LO rejection as opposed to the more desirable value of 39 dB that will be obtained by direct filter scaling. This lower LO rejection was obtainable with L-C sections that could fit on a quartz structure 0.83 inches wide that was readily available from the X2 mixer work.

In order to provide good stop-band performance with the LO filter at the signal frequency which is about three times the LO filter cutoff frequency, it is necessary to not permit the LO filter channel width to increase over that used in the X2 mixer. This avoids higher order stripline and waveguide modes that can degrade the stop-band performance

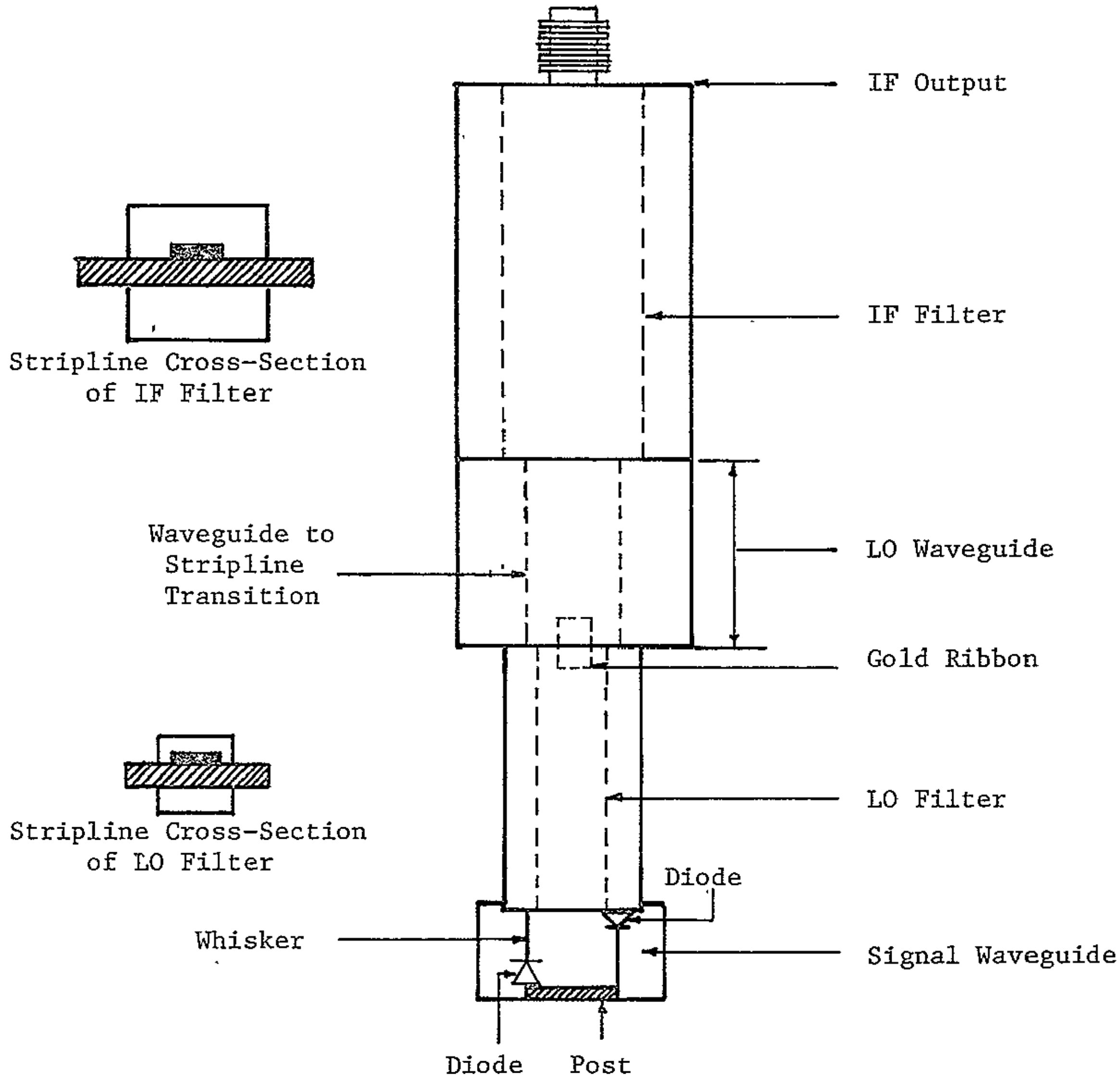

Figure 2. Functional Diagram of Fourth Harmonic Mixer

The geometry of the combination of IF and LO filters as shown in Figure 2 is practically implemented by using two separate pieces of quartz, one for each filter. The two filters are then connected during assembly by soldering a gold ribbon between the two center conductors. It can be observed that this abrupt junction only affects the LO propagation path since the IF is much lower in frequency and the LO filter keeps the signal itself in the waveguide. Some problems might occur due to small reflections at the ribbon connection between the circuits but these should be minimal compared to the problems faced in fabricating a circuit with the dimensions required using a single filter circuit.

The IF and LO transition section of the 183.3 GHz mixer circuit is shown in Figure 3. Its filter characteristics have been investigated earlier [1]. The dimensions of this portion of the circuit were determined by using a scaling factor of 13.45 on the corresponding section of the second harmonic model mixer circuit. This scaling will make this part of the circuit perform the same function as the second harmonic circuit, but at half the frequency, thus acting as an LO injection mechanism for the fourth harmonic pumping frequency. The cutoff frequency (24 GHz) is still well above the IF frequency range as indicated in Figure 1.

LO Filter

The LO filter for the fourth harmonic model mixer is a nine element low pass filter which has been empirically derived. It is shown in Figure 4. Its filter response is given in Figure 5. Its cutoff frequency is about 2.8 GHz. This corresponds to a 75 GHz cutoff frequency for the mm-wave version. This filter was moved up and down in the stripline channel until the optimum model mixer characteristics were measured.

Mixer Measurements

The model mixer was tested to optimize the placement of the LO filter. The other sections have already been tested in the second harmonic mixer. The model mixer circuit was built on a single quartz substrate to make use

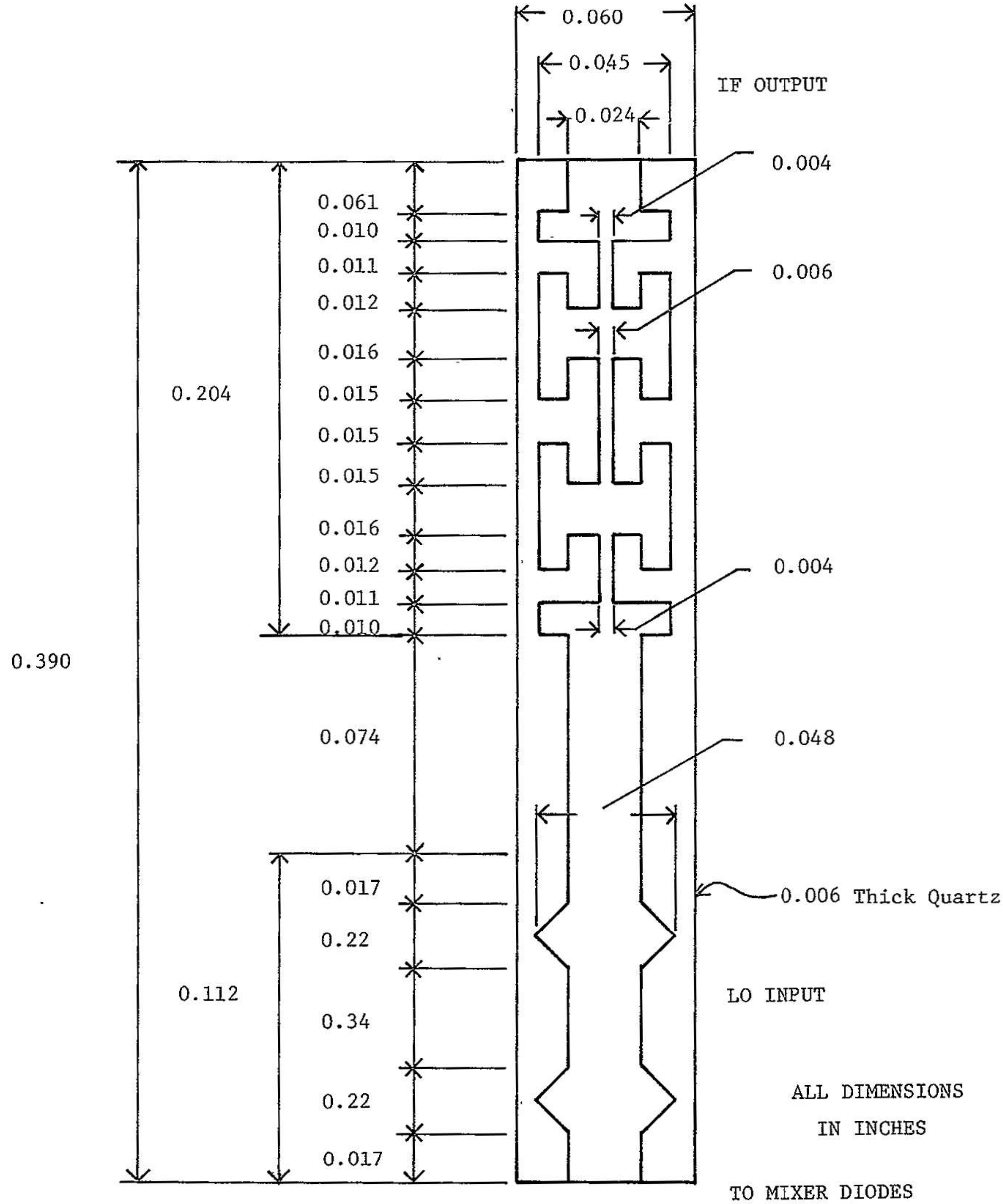

Figure 3. IF Filter and LO Transition for 183.3 GHz Fourth Harmonic Mixer

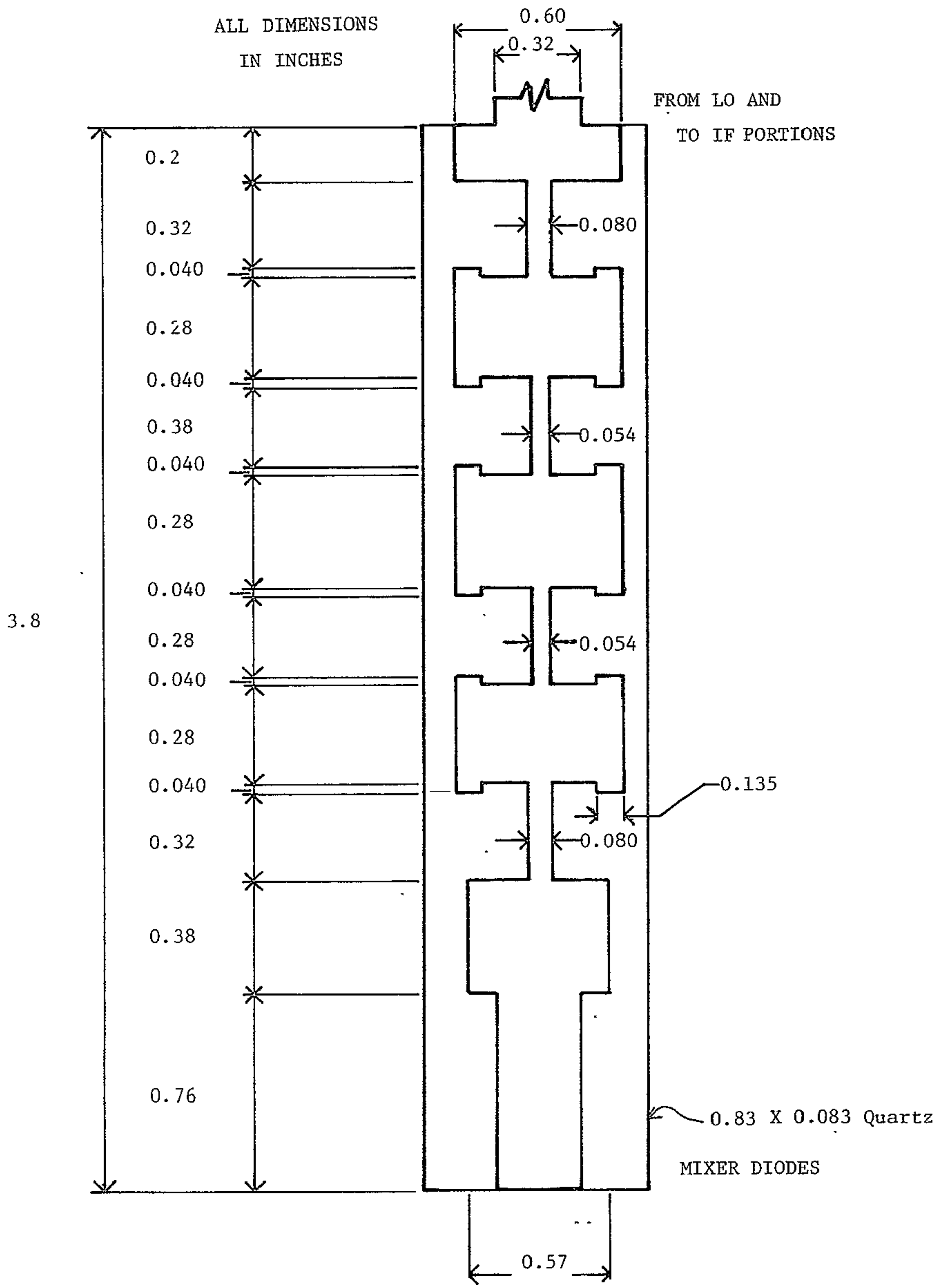

Figure 4. LO Filter for Fourth Harmonic Mixer Model (Scaled 26.9 to 1)

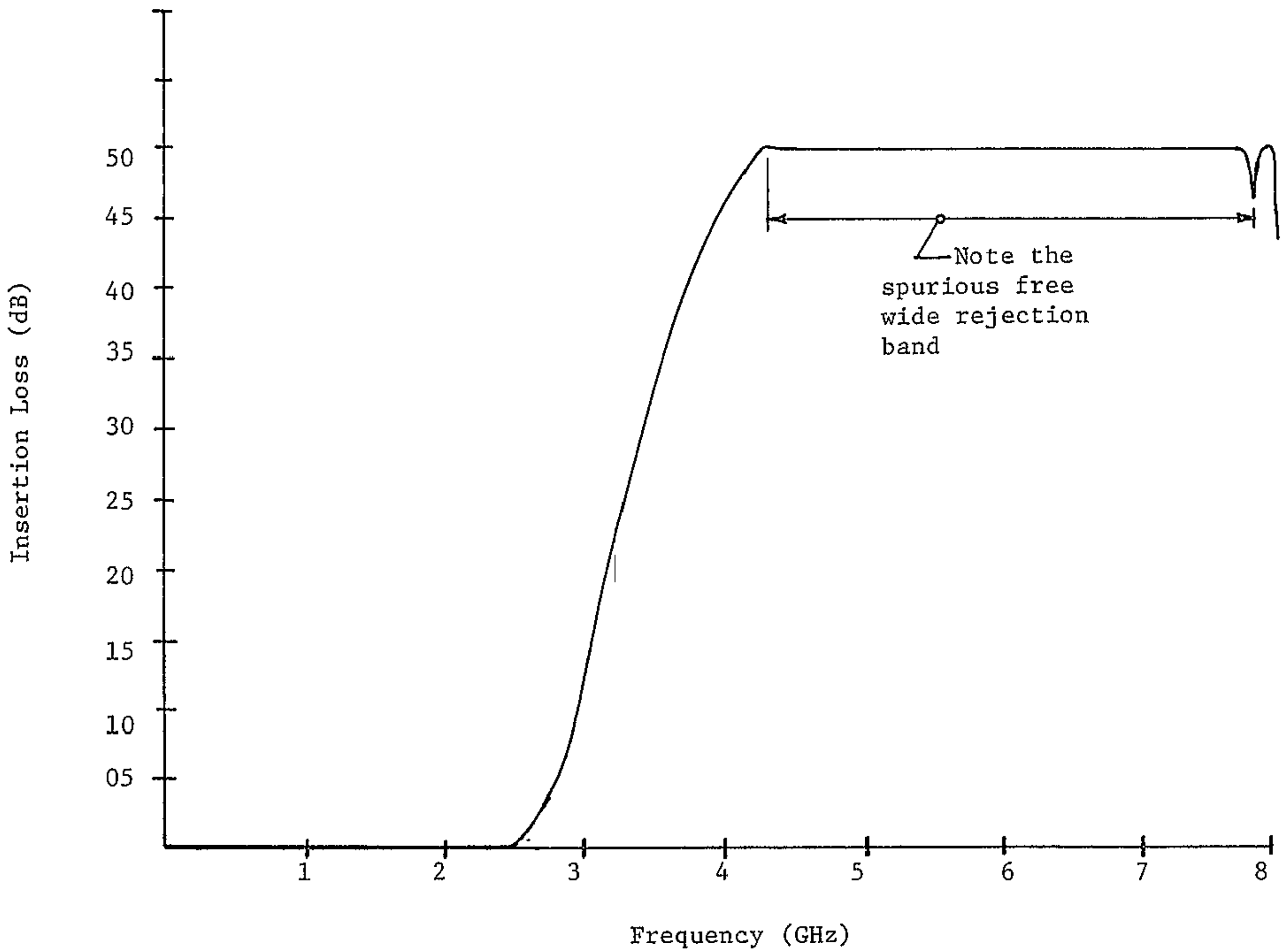

Figure 5. Measured Insertion Loss of the LO Filter for the Fourth Harmonic Mixer Model

of the available mixer model and the quartz substrates. The test IF filter provided the minimum insertion loss (15 dB) at the LO frequency. The circuit, however, did serve its purpose in supplying the diodes with the required LO power and passing the IF power out of the mixer. The LO filter was then moved up and down the channel until the best mixer performance was measured. Plots of the mixer performance are shown in Figures 6 through 8. Conversion losses as low as 6 dB and noise figures as low as 9.5 dB were measured. The noise figure includes a 2 dB noise figure for the IF amplifier.

The circuit layout for the finalized 183.3 GHz mixer is given in Figure 9. This design is made so that the larger circuit will butt up against the sidewall of the LO waveguide. This will ease fabrication problems. A short taper will be added to decrease any stray capacitance caused by the sidewalls.

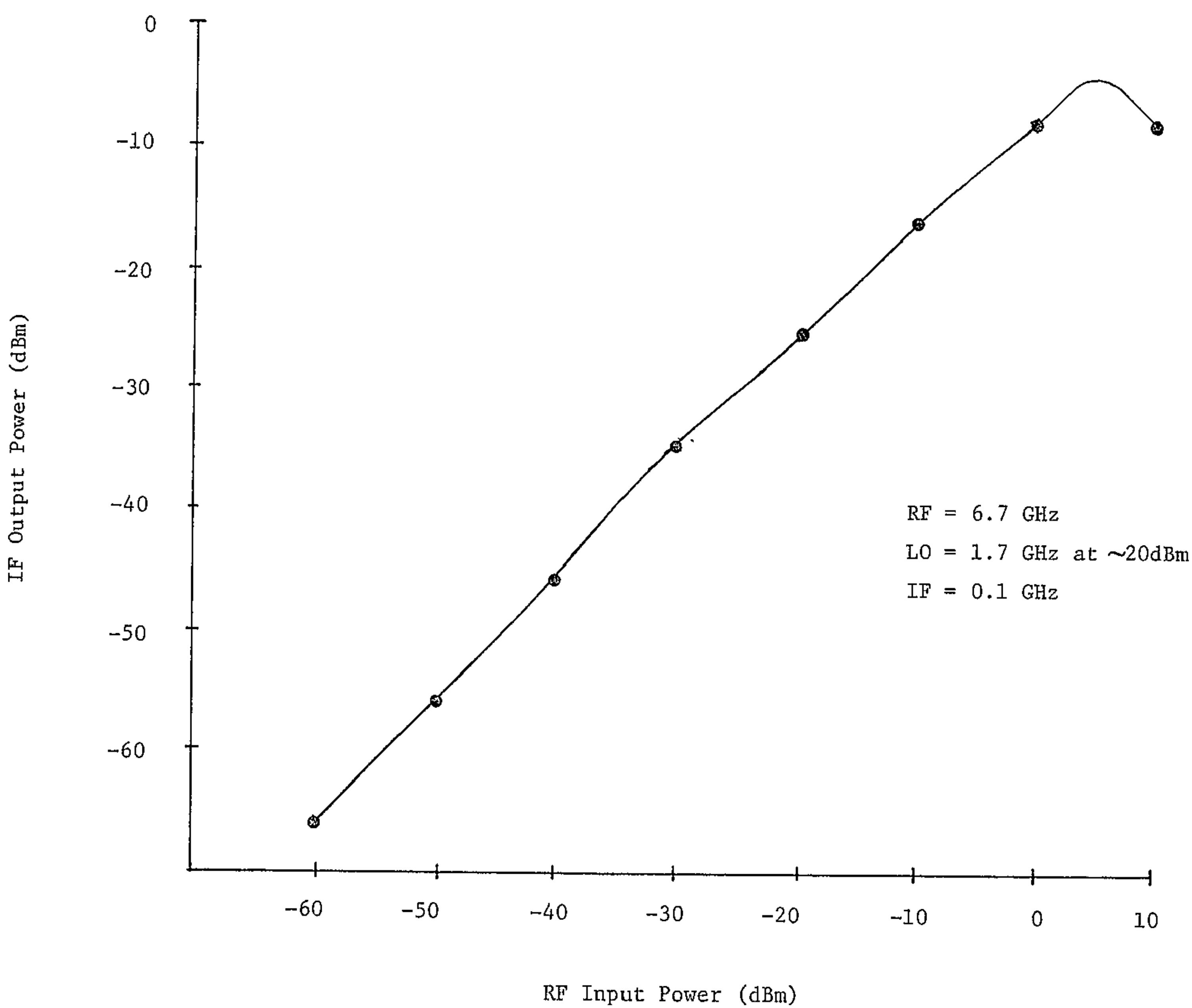

Figure 6. IF vs. RF Power for Fourth Harmonic Mixer (Scaled 26.9 to 1)

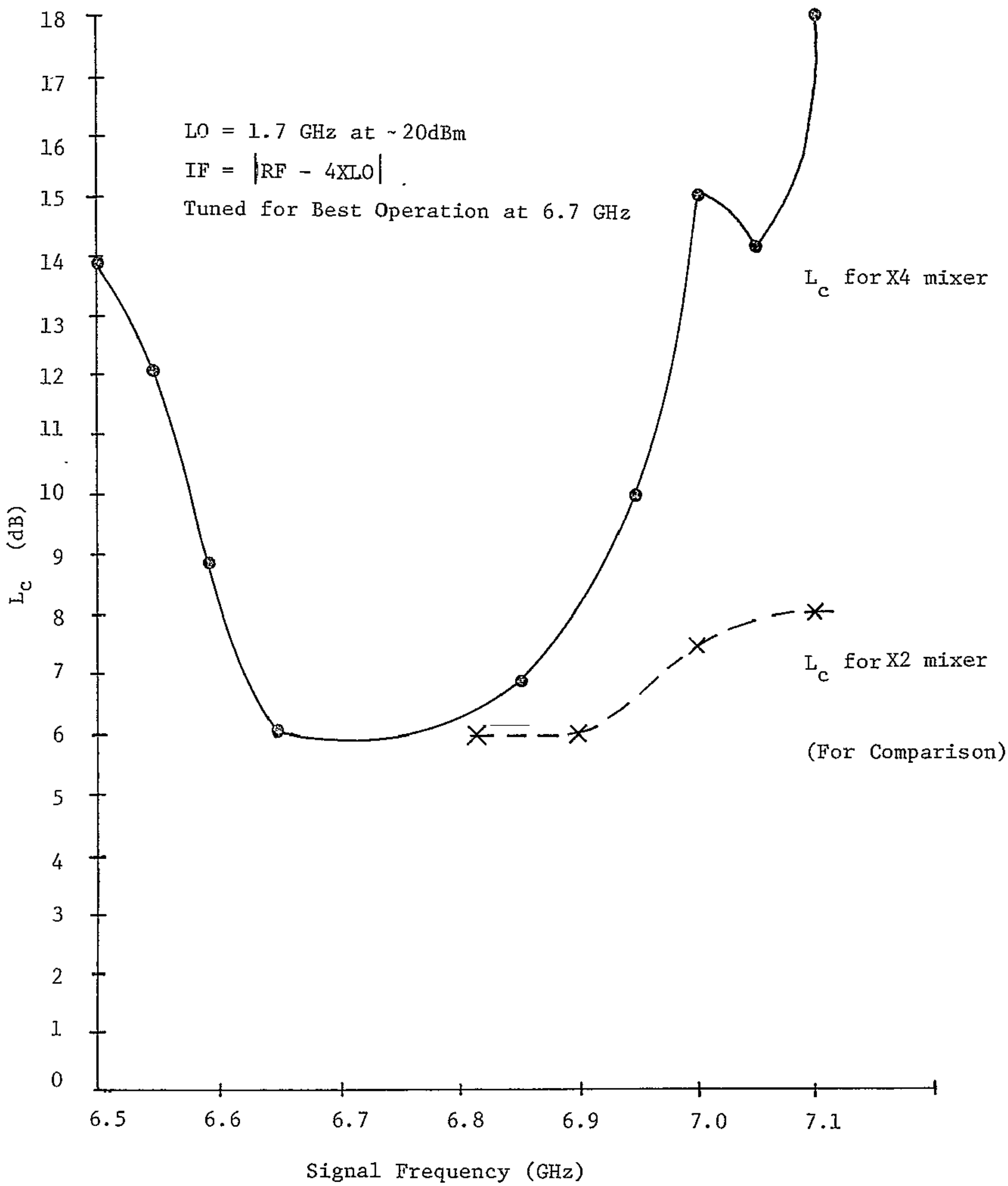

Figure 7. Measured Conversion Loss (L_c) versus Signal Frequency of the Fourth Harmonic Mixer Model (Scaled 26.9:1)

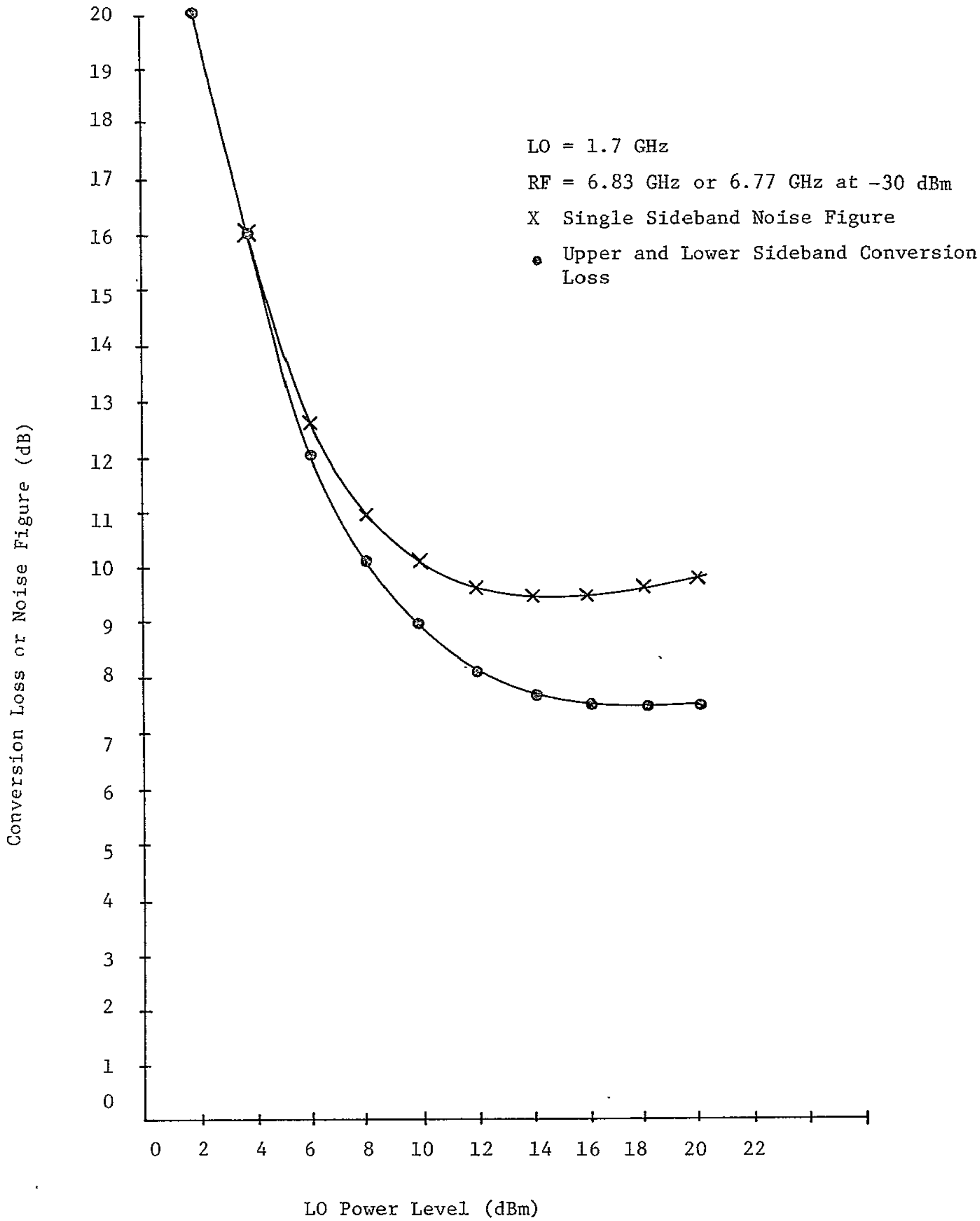

Figure 8. Measured Conversion Loss and Total System Noise Figure of the Fourth Harmonic Mixer Model versus LO power

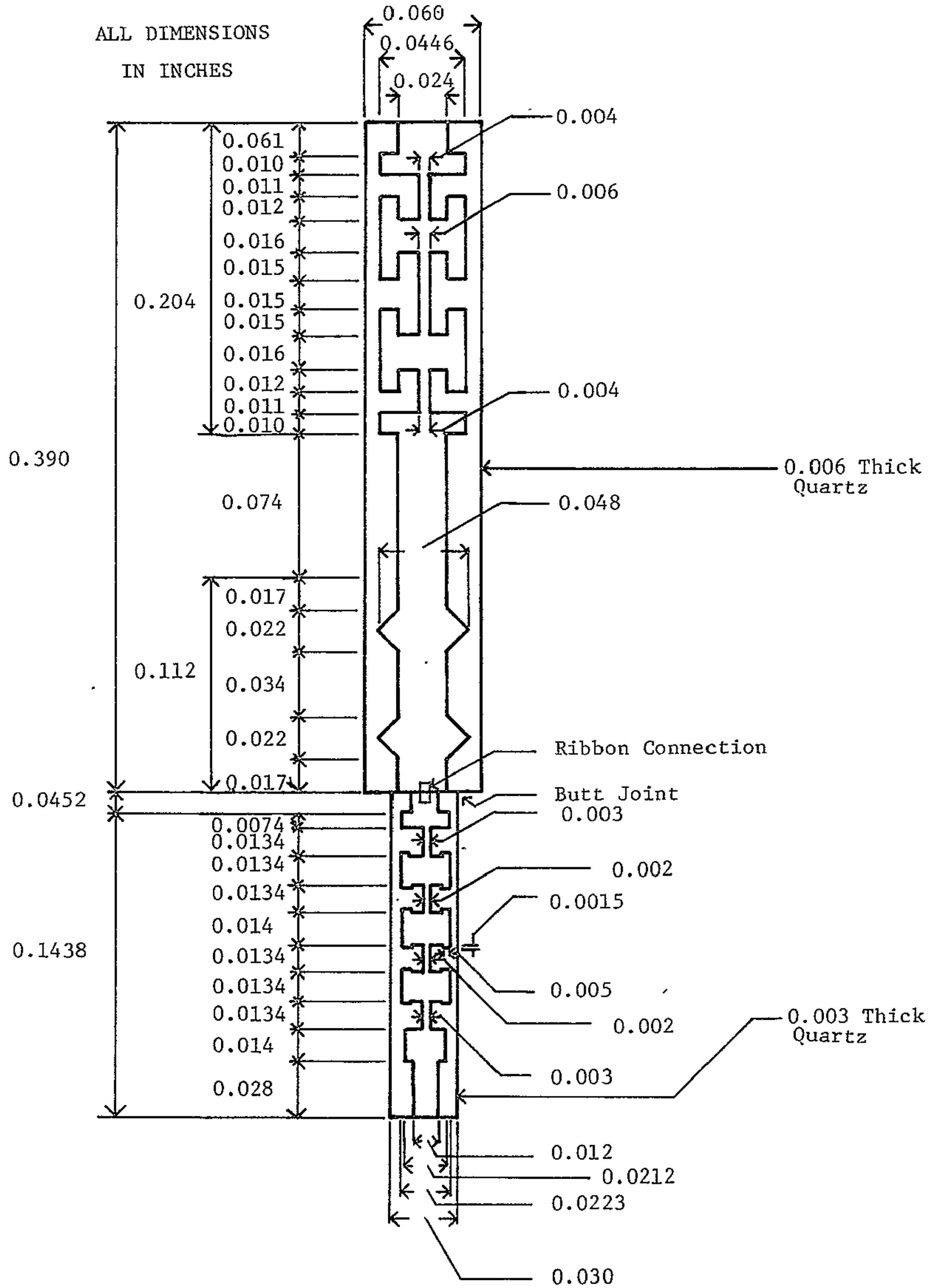

Figure 9. Layout of Fourth Harmonic Mixer Circuit for 183.3 GHz Mixer

CONCLUSIONS

The measured mixer data show a possible decrease in the usable bandwidth of the fourth harmonic mixer when compared to that obtained with the second harmonic mixer. This can be attributed to the circuit itself. Phase measurements on the LO filter indicate that the filter looks like a short circuit at the first element nearest the diodes at both the signal frequency and 2XLO frequency. The diodes will see an open circuit at the 2XLO frequency and a short circuit at the signal frequency (which is required for optimum performance of the fourth harmonic mixer) if the filter is moved back a half wavelength at the signal frequency (quarter wavelength at 2XLO frequency). Moving the filter back up the channel causes the decrease in the bandwidth of the mixer. A different LO filter geometry, one which can exhibit a broadband short circuit to the diodes at the signal frequency while looking like an open circuit at half that frequency, will improve this bandwidth. An effort to develop potential filter geometries is continuing through computer aided analysis using COMPACT.

Different diodes from the ones used for the second harmonic mixer were used for the measurements of this mixer. Previous measurements with the X2 mixer used Alpha pill package diodes (Type DMK 6601). These diodes were degraded during direct current measurements and were further degraded by numerous soldering cycles. The new diodes used in the X4 mixer were Aertech (A25602) glass case package diodes. These diodes had nearly the same capacitance and cutoff frequency as the pill package diodes. Although some minor circuit performance differences can be attributed to these glass case package diodes, these were judged to be small and measurements with new pill package diodes are not planned.

The next step in the mixer investigation will be to develop a X4 mixer operating directly at 183 GHz. Figure 10 is a mechanical drawing of the X4 mixer body that will be fabricated in the near future.

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