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30 GHz COMMUNICATIONS SATELLITE LOW NOISE RECEIVER

BY

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&

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LNR COMMUNICATIONS, INC.

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

OCTOBER 1983

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16. Abstract

A Ka-band low noise "front-end" in Proof-of-Concept (POC) model form for ultimate spaceborne communications receiver deployment has been developed. The low noise receiver consists of a 27.5-30.0 GHz image-enhanced mixer integrated with a 3.7-6.2 GHz FET low noise IF amplifier and driven by a self-contained 23.8 GHz phase-locked local oscillator source. The measured level of receiver performance over the 27.5-30.0 GHz RF/3.7-6.2 GHz IF band includes 5.5 to 6.5 dB (typ) SSB noise figure, 20.5 $\pm$1.5 dB conversion gain and +23 dBm minimum third order two-tone intermodulation output intercept point.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

FIGURES

LIST OF TABLES

TABLE

1.0 SUMMARY

Three proof-of-concept (POC) models of a 30 GHz low noise receiver "front end" design which is intended for ultimate spacecraft usage, has been developed and demonstrated. Said "front end", consists of the closely integrated combination of a 27.5-30 GHz image-enhanced mixer, coupled to a 3.7-6.2 GHz FET low noise IF amplifier and driven by a self-contained 23.8 GHz phase-locked LO source. The image enhanced mixer, designed for less than 6 dB overall "front-end" SSB noise figure, utilizes a balanced pair of LNR high quality hermetically sealable GaAs Schottky mixer diodes embedded in composite waveguide/TEM balanced mixer structure. The three stage FET IF amplifier implemented in a single-ended isolator-coupled microstrip configuration utilizing readily-available packaged FET's, typically exhibits 25 ±0.4 dB gain and 1.7 to 2.2 dB noise figure over the 3.7-6.2 GHz band. The LO source, consisting of a C-band high power FET VCO, phase locked to an external 500 MHz crystal reference, and driving a C-to-K-band varactor quadrupler, provides over 40 mW LO drive at 23.8 GHz. High quality large-signal LNR GaAs varactors are utilized in both the VCO and quadrupler.

The overall POC model receiver is packaged in an EMI-shielded, milled-out 8.75"x6.5"x2.5" enclosure along with associated self-contained DC bias regulators and EMI filters. The measured level of receiver performance over the 27.5-30 GHz RF/3.7-6.2 GHz IF band includes 5.5 to 6.5 dB (typ.) SSB noise figure, 20.5 ±1.5 dB conversion gain and +23 dBm minimum third order two tone intermodulation output intercept point.

2.0 INTRODUCTION

Studies of the growth in satellite communcations traffic indicate that the frequency spectrum allocated to fixed service satellites at C and Ku bands will reach saturation by the early 1990's. The K/Ka band (30/20 GHz) region with an uplink frequency band at 27.5 - 30.0 GHz and down link frequency band at 17.7 - 20.2 GHz is the next higher frequency band allocated for this purpose. Current plans for the development of satellite systems to implement these frequency bands includes the NASA ACTS demonstration satellite in the mid-1980's. Systems studies have identified the use of multiple-beam antenna systems as a major factor in achieving minimum cost and efficient use of frequency and orbital resources, such multibeam systems require reliable efficient lightweight low noise receivers which have been identified as one of the key areas in which technology development was needed.

This final report summarizes the results of a two-year program to develop a 30 GHz receiver which demonstrates the feasibility of providing low-noise, reliable, lightweight receivers provide a proof-of-concept (POC) design for a flight qualified receiver to be flown on a 30/20 GHz communications demonstration system, and provide an advanced data base for use in communications payload definitions and design studies. The successful completion of the program culminated in the delivery of 3 fully tested 30 GHz proof-of-concept (POC) receiver assemblies to NASA Lewis Research Center.

A photograph of the space-qualifiable 30 GHz (POC) receiver is shown in Figure 1. It consists of the closely integrated combination of a 27.5 - 30.0 GHz uncooled image-enhanced mixer driver by a self-contained 23.8 GHz phase-locked local oscillator, and coupled to a 3.7 - 6.2 GHz FET low noise IF amplifier.

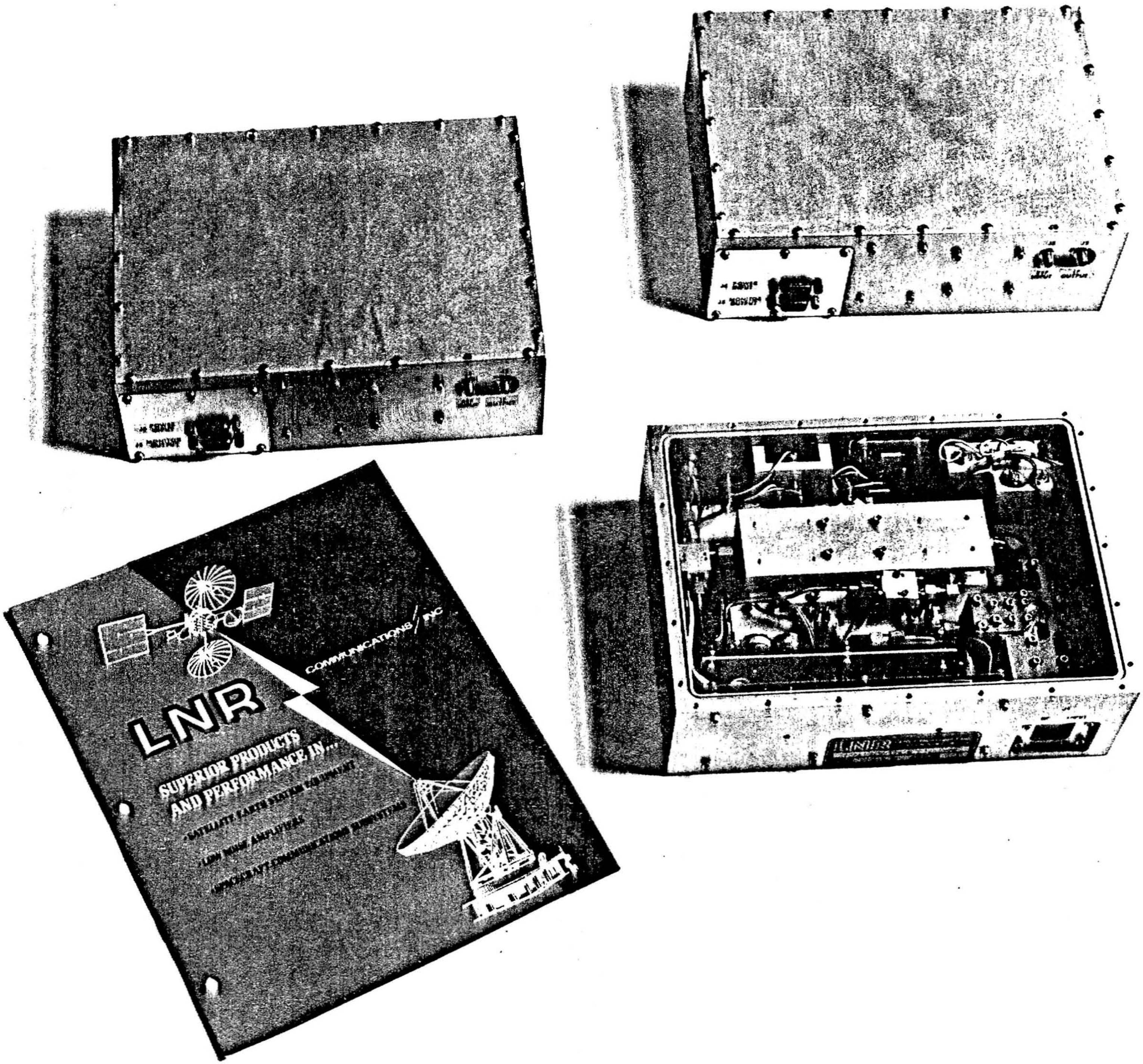

Figure 1 30 GHz PROOF-of-CONCEPT MODEL RECEIVERS

Typical measured RF/IF gain and input SSB noise figure characteristics of the 30 GHz receiver are presented in Figure 2. In addition to the RF functional performance testing conducted on three POC receivers, functional thermal/vacuum tests and special dynamic range testing, including pulse recovery measurements, were performed on one receiver assembly. A detailed summary of the measured receiver performance is presented in section 6.0.

Table 1 presents a summary of the program tasks of the subject 30 GHz low noise receiver contract. Summarized below are the pertinent results and/or conclusions derived from several tasks. These tasks are discussed and summarized in more detail in subsequent sections.

Task 1. 30 GHz Receiver Design, 1982 Technology

In order to select the POC Model design approach to be developed during the course of the program, the current and projected state-of-the-art of various millimeter wave "front-end" technologies was reviewed. In particuliar, available broad band mixer/IF amplifiers and potential improvements with image enhancement techniques, cooled and uncooled paramps and the rapidly emerging low noise FET technology were assessed. As a result of this overall assessment, it was concluded that the best approach to a space qualifiable design for a 1982 time frame deployment was the image enhanced mixer/IF amplifier receiver configuration. This receiver design task also determined the image enhanced mixer configuration, mixer diode requirements, optimum IF frequency range, and local oscillator approach and configuration.

Task 2. ALTERNATE 30 GHz Receivers Designs, 1987 Technology

Three alternate 30 GHz receiver designs were evaluated that would meet or exceed the RF performance requirements and utilize advanced technology of anticipated availability in the 1987 time frame. These technologies are: cooled mixer technology, using spaceborne passive cooling techniques, low noise 30 GHz FET

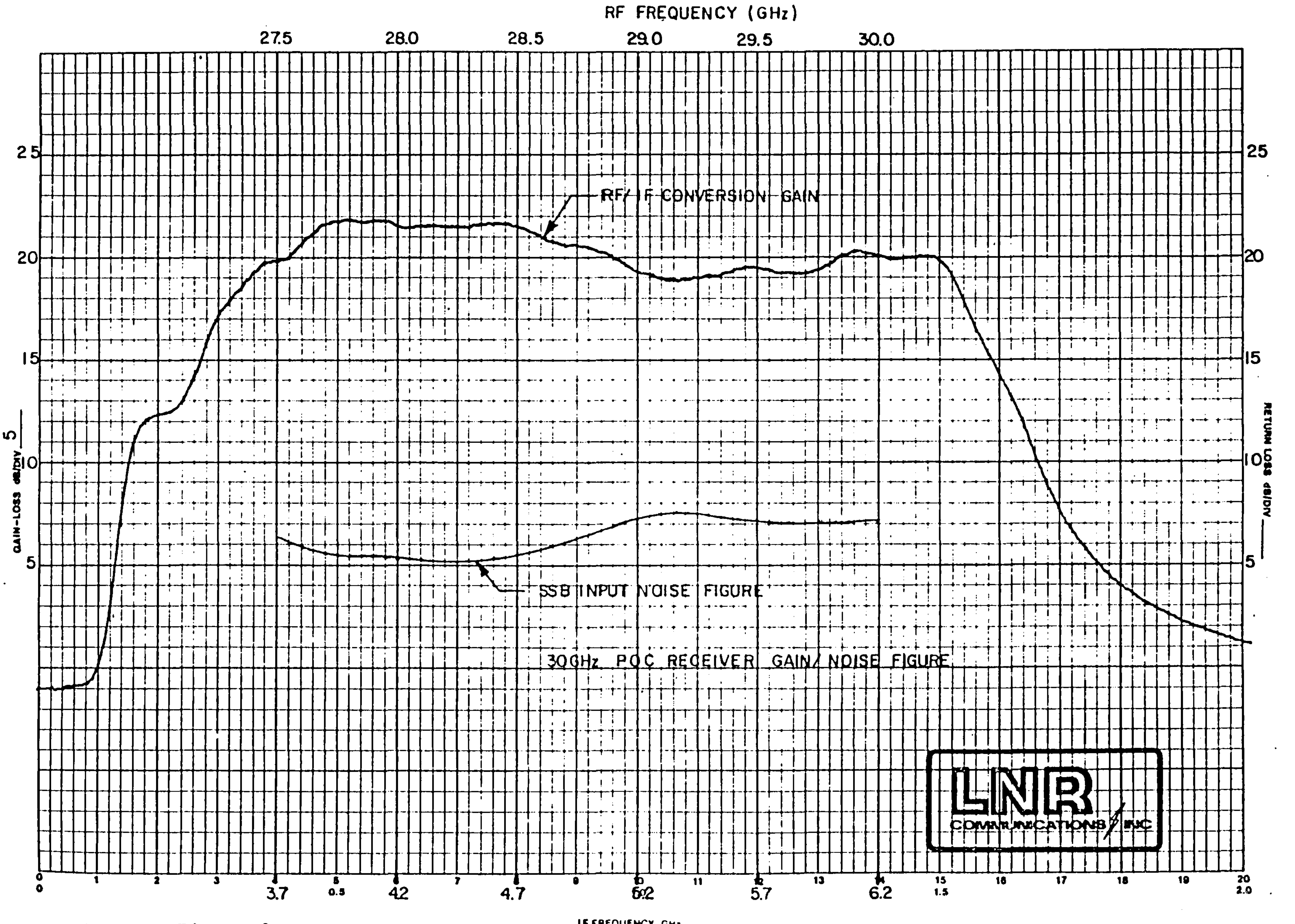
RF FREQUENCY (GHz)
27.5
28.0
28.5
29.0
29.5
30.0
RF/IF CONVERSION GAIN
SSB INPUT NOISE FIGURE
30GHz POC RECEIVER GAIN/NOISE FIGURE
GAIN-LOSS dB/DIV 5
RETURN LOSS dB/DIV
25
20
15
10
5
3.7
4.2
4.7
5.2
5.7
6.2
IF FREQUENCY GHz
LNR
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Figure 2

TABLE 1

PROGRAM TASK SUMMARY

TASK	DESCRIPTION
1	30 GHz Receiver Design Using 1982 Technology
2	Alternate 30 GHz Receiver Design Using 1987 Technology
3	Breadboard Development of Receiver Technology
4	POC Model Planning and Specifications
5	POC Model Design
6	Fabrication of POC Models
7	POC Receiver Testing
8	Reliability Projections for Flight Hardware
9	Product Assurance
10	Work Plan
11	Reporting
12	Requirements Document and Development Plan for Flight Hardware

amplifier technology and GaAs monolithic integrated circuit technology. A parametric trade-off analysis has confirmed that the perferred approach to the implementation of a 30 GHz spaceborne low noise receiver utilizing 1987 technology is the discrete microwave-integrated-circuit (MIC) "front-end" incorporating a 30 GHz MIC FET LNA.

Task 3. Breadboard Development of Receiver Technology

The image-enhanced mixer, phase locked LO source, and the IF amplifier assembly were all receiver technology areas that required preliminary breadboard fabrication and testing prior to the initiation of the POC Model design. The realization of the lowest input noise figure in a mixer/IF amplifier "front-end" required advances in image-enhanced mixer technology at 30 GHz. It has long been known that proper reactive termination of the image frequency along with that of higher order idler frequencies can reduce the mixer single sideband conversion loss by typically 1 to 2 dB compared to a conventional wide band mixer. LNR Communications in-house semiconductor processing facility provided the capability for fabricating high quality, low parasitic content GaAs Schottky chip mixer diodes in a "controlled" optimum embedding and hermetically sealable geometry which provided the necessary RF circuit functions at the key mixer conversion frequencies. The processing facility also provided two special GaAs varactor designs that were required for the voltage controlled oscillator and the times 4 multiplier, which are part of the 23.8 GHz phase-locked local oscillator chain.

Based upon the results of the breadboard component development is was projected that the input single sideband noise figure of the POC receiver would range between 5.5 and 7.0 dB over the RF bandwidth of 27.5 to 30.0 GHz.

Task 4. POC Model Plan and Specifications

In order to insure the successful development and testing of the 30 GHz POC Model receivers, a detailed development plan was generated. Based upon the results of the breadboard development phase, a revised set of performance specifications for the POC Model design was also generated.

Task 5,6 POC Model Design and Fabrication

The physical embodiment of the POC Model design was derived from LNR's development and manufacturing experience on operational "Hi-Rel" microwave receiver "front-ends". The receiver design approach is modular in concept and consists of an optimum mix of pre-tested and replaceable "Hi-Rel Worthy" microwave and DC components. The receiver assembly is contained in a completely shielded enclosure, with EMI filters on all DC input/output lines. The receiver design is capable of antenna feed mounting and will withstand, without degradation of RF performance, those mechanical (shock and vibration), electromagnetic, thermal and radiation stresses incurred during pre-launch handling to long term operation in synchronous orbit environments, including baseplate temperatures ranges of 10° to $50^{\circ}C$ and vacuum less than $5x10^{-5}$ torr.

Task 7 POC Receiver Testing

Full RF functional testing was performed on the three deliverable POC receivers; this included RF/IF conversion gain, input noise figure, 1dB gain compression, and input/output VSWR. The thermal-vacuum performance of one receiver was measured by monitoring the conversion gain characteristics of the receiver when it was mounted in a vacuum chamber, while the baseplate mounting temperature was varied over a range of $10^{\circ}C$ to $50^{\circ}C$.

In addition to the above, additional tests were conducted on one receiver assembly to determine its dynamic range characteristics.

This testing included suceptability to large signal interference, inter modulation characteristics, AM-PM conversion, and amplitude and phase pulse recovery characteristics. There were no POC model failures encountered during testing, and all RF performance parameters fell within the anticipated ranges.

Task 8 Reliability Projections for Flight Hardware.

A special test and analysis program for predicting the reliability and lifetime expectancy of a flight model of the 30 GHz POC receiver is not required because the selection of device types used in the POC receiver has a sufficient data base for reliability analysis.

The reliability analysis of the 30 GHz receiver design indicates a 0.9079 probability of success for a 10 year mission at a baseplate temperature of 120^{o}F (50^{o}C). The total failure rate for the 30 GHz low noise receiver is 1.103 failures per million hours, which is equivalent to an MTBF of 906,450 hours. This, MTBF, is in excess of 100 years for the receiver operating continuously in an unattended spacecraft environment.

Task 12. Requirements Document and Development Plan for Flight Hardware.

In support of a future flight hardware program, a requirements document has been generated which defines the specifications and tasks required for the design, development, production, test and delivery of 30 GHz low noise receivers. This specification covers Engineering, Qualification, and Flight model receivers. A detailed development plan in support of a 27 month flight hardware program in the 1983-85 timespan has also been completed.

3.0 30 GHz SATELLITE RECEIVER DESIGN

The fast growing use of the satellite-allocated frequency spectrum will soon result in saturation of these frequency bands. In order to continue this expansion, new technological solutions are needed so that new bands can be utilized. The operational implementation of the K/Ka-Band spectrum will provide a new band of frequencies that can be used to satisfy this ever increasing demand for communication services. Studies have already identified specific areas of technology in the 20/30 GHz band that need rapid development so that they will be available for mid 1980 usage. One of these specific technological areas is the 30 GHz spaceborne receiver.

A summary of the RF performance objectives is presented in Table 2. The general requirements which the 30 GHz Low Noise Receiver Proof-of-Concept Model must meet are:

- ELECTRICAL/RF PERFORMANCE SPECIFICATIONS
- SPACE-QUALIFIABLE DESIGN 1982 TIME FRAME
- PROVIDE FULLY QUALIFIED FLIGHT UNIT BY 1985 TIME FRAME
- RELIABILITY - 10 YEAR OPERATIONAL LIFE
- CONSISTENT WITH SPACECRAFT DEPLOYMENT RELATIVE TO: SIZE
  WEIGHT
  POWER DRAIN
  ANTENNA MOUNTING

TABLE 2

30 GHz RECEIVER PERFORMANCE

	REQUIREMENT	MEASURED
Input RF Band	27.5-30.0GHz	27.5-30.0GHz
Output IF	2.5GHz Bandwidth In Range 3.0-8.0 GHz	3.7-6.2GHz
SSB Noise Figure	5dB (max)	5.5-6.5dB (typ) 7.5dB (max)
RF/IF Conversion Gain	21± 1dB	20.5± 1.5dB
Gain Variation Over Temperture (+10°C to +50°C in Vacuum)	TBD	±0.7dB (max)
Gain Slope (max/10MHz)	±0.5dB	±0.2dB
In-Band Overdrive with no performance degradation	-10dBm Input	+5dB Input
VSWR Input	1.25:1 (max)	1.50:1 (max)
VSWR Output	1.8:1 (max)	1.6:1 (max)
Group Delay per 100MHz	±0.1ns/MHz^2 (max) 5ns P-P (max)	$\ll$0.1ms/MHz^2 (CALC.) $<$1ns P-P (CALC.)
Image Rejection	15dB (min)	$>$ 40dB
AM-PM Conversion	1.0°/db for inputs up to -70dBm	0.5°/dB for inputs up to -5 dBm
Input 1dB gain Compression	TBD	-5 to -7 dBm
Two-tone Output Intercept Point	TBD	+23dBm (min)
Input Reference Frequency	≤2GHz	500MHz @ +17dBm
LO Stability	±1 Part in 10^7/24Hr.	$<$ ±1 Port in 10^7/24Hr.
LO Phase Noise	-	-83dBc/Hz max. at 150KHz offset
DC Power	+28VDC±10%	±5,-15VDC @ ±7% (7 watts total,typ)

In order to select the first-order POC Model design approach to be developed during the course of the program, LNR considered the current and projected state-of-the-art for the various millimeter wave "front-end" technologies enumerated in Table 3. In particular, currently available broadband mixer/ IF Amplifiers and potential improvements with image enhancement techniques, cooled and uncooled paramps and rapidly emerging low noise FET technology were assessed. The results of this study, relative to noise factor, are summarized in Figure 3. As shown, all of the foregoing receiver approaches with the exception of the conventional broadband mixer/IFA, can be developed to meet the 5 dB overall noise performance requirement.

In the opinion of LNR, all paramps as well as other subassemblies requiring advances in spaceborne cooling techniques via therma-electric ($\sim 200^{\circ}K$), closed cycle liquid N_2 ($\sim 77^{\circ}K$) or radiational equivalent thermal methods should also be eliminated from further first-order design consideration. Use of these technologies may yield increased performance at the unnecessary expense of size, weight, power drain and overall assembly complexity. Increases in the latter, in turn, have a negative impact on overall system reliability and 10 year operational life.

The decision as to which 30 GHz receiver approach will best meet the POC model requirements, therefore, narrows down to a choice between an uncooled FET amplifier and image enhanced mixer/IFA. Low noise FET amplifier technology is steadily advancing into the millimeter wave frequency range, utilizing GaAs FET devices with gate lengths currently of 0.5 um and in the future as low as 0.25 um (Figure 4). Demonstrated spot performance of low noise FET's (as of 1980) includes 2.5 dB NF device with 7 dB associated gain at 18 GHz and 6 dB NF amplifier

TABLE 3

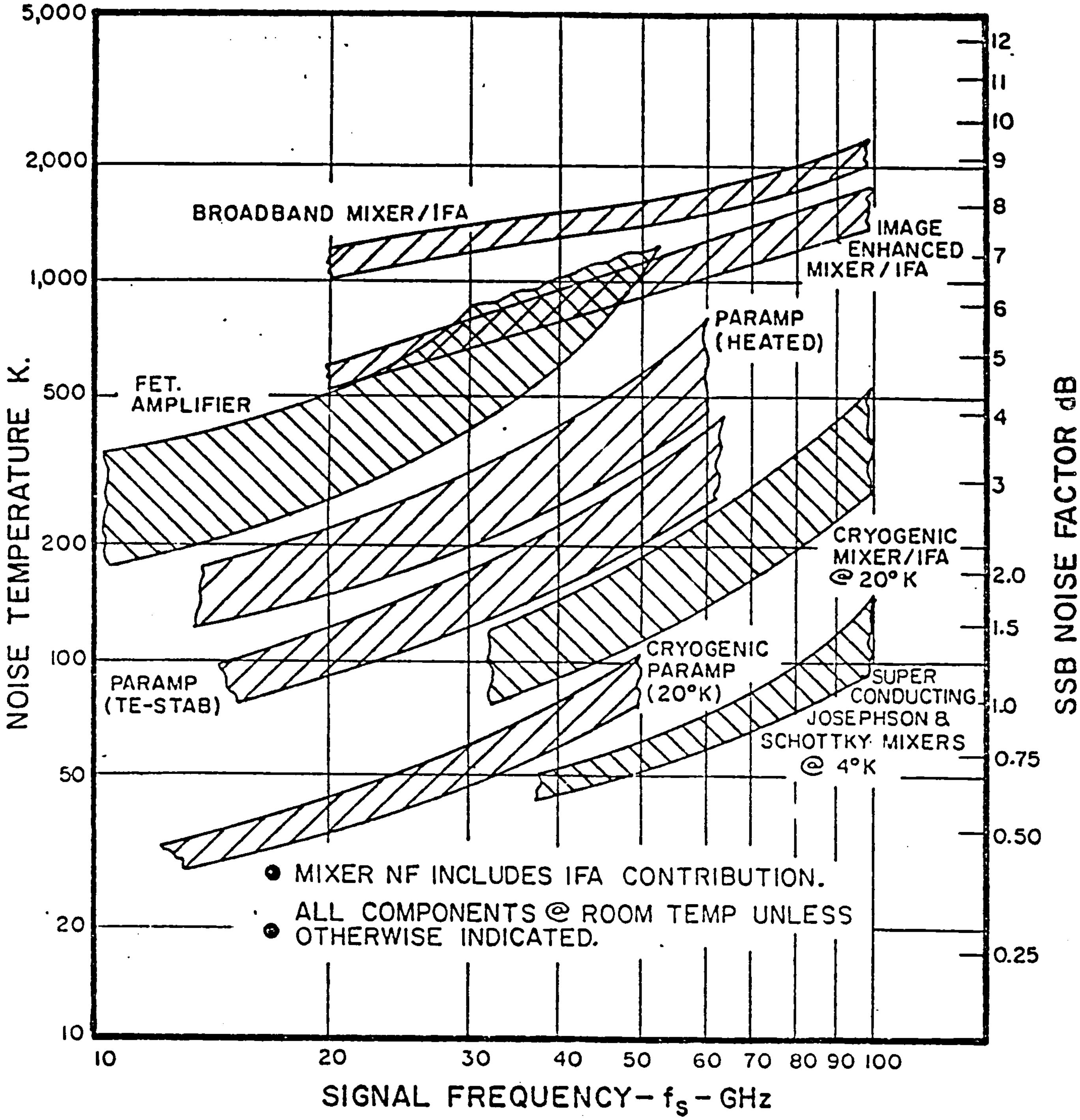
30 GHz RECEIVER ALTERNATIVES

A. ALTERNATIVE CONFIGURATIONS

- PARAMETRIC AMPLIFIER FRONT END
- FET AMPLIFIER FRONT END
- IMAGE-INHANCED MIXER/IFA

B. DEGREE OF PHYSICAL COOLING

- NON, HEATED OR PASSIVELY COMPENSATED TEMPERATURE STABILIZATION (320° - 360°K)
- THERMOELECTRICALLY STABILIZED (200-250°K)
- CLOSED CYCLE LIQUID N_2 CRYO COOLED (80°K)
- CLOSED CYCLE LIQUID H_2 CRYO COOLED (20°K)
- PASSIVE RADIATION COOLING (100°K)



CURRENT AND PROJECTED STATE OF THE ART NOISE TEMPERATURE COMPARISON OF VARIOUS MILLIMETER WAVE "FRONT-ENDS"

FIGURE 3

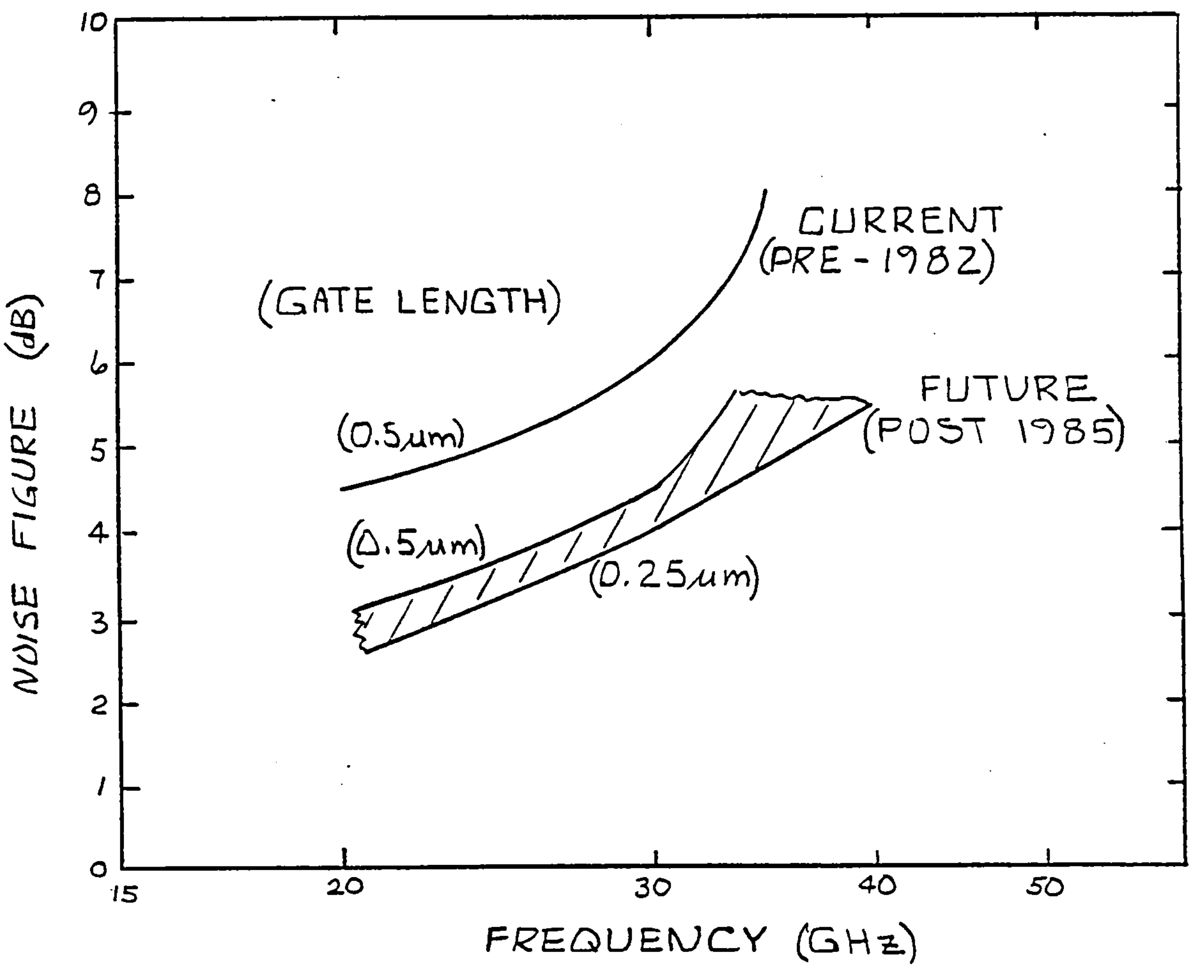


FIGURE 4 CURRENT AND PROJECTED FET AMPLIFIER NOISE PERFORMANCE STATE-OF-ART

with 6 dB gain at 30 GHz (Hughes). Other manufactures (Plessey), have produced devices having 3.0 to 3.5 dB NF at 18 GHz. Plessey has reported the fabrication of 0.2 μm devices with predicted NF of 4.5 dB at 40 GHz and Hughes has on-going development of GaAs FET, with gates $\leq$ 0.25 μm.

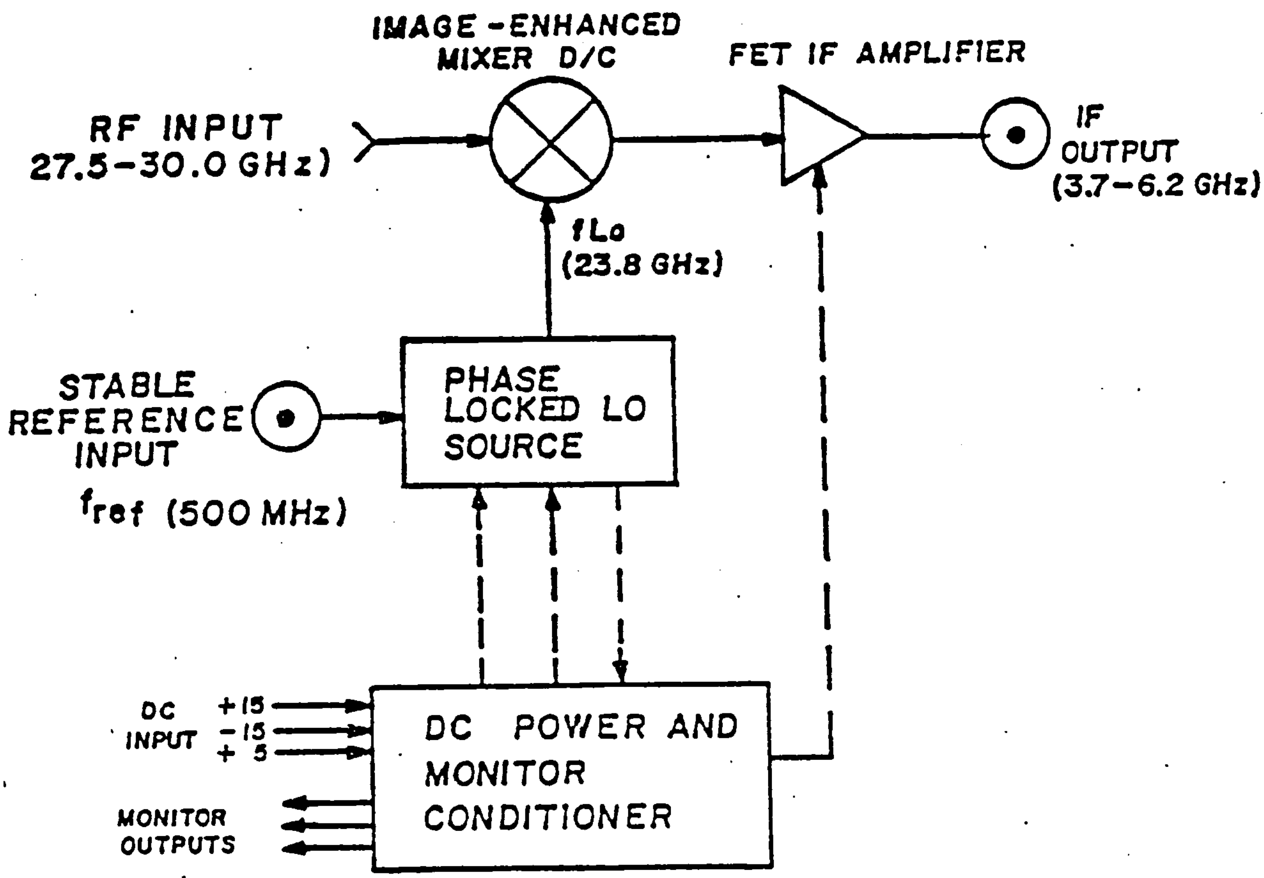
For the far term, theoretical results predict noise figures of 2 dB at 20 GHz, 2.5 dB at 30 GHz and 3.5 dB at 40 GHz for 0.25 um GaAs MESFETS. However, these results are based on the analytical optimization of material and geometric parameters and do not address the fabrication and implementation problems. Availability of these advanced FET devices in a time frame for 1982 POC Model development and, in fully qualified form, for 1985 demonstration satellite system development seems highly unlikely.

As a result of this overall assessment, LNR concluded that the best approach for 1982 time frame deployment which meets all of the requirements as outlined in the previous section, is the image enhanced mixer/IFA.

The POC Model design configuration is shown in Figure 5 and consists of :

- Low noise image-enhanced mixer in a compact composite waveguide/TEM line dual diode embodiment wherein a matched pair of high quality LNR GaAs Schottky diodes are embedded in a unique circuit-functional mounting structure. Fundamentally rather than subharmonically pumped LO (at 23.8 GHz) used so as not to compromise ability to achieve best possible conversion loss over full specified bandwidth.
- Sophisticated, low power-drain advanced technology low phase-noise phase locked LO source, at 23.8 GHz, in miniaturized planar embodiments in conjunction with high quality phase lock loop components such as offset mixer, digital dividers, phase detector and baseband operational amplifier/filter, all integrated in a compact self-contained structure.
- Low noise 3-stage FET IF amplifier.
- Compact DC power and monitor conditioning circuits including DC bias postregulators and monitor circuit providing DC outputs indicative of critical currents and voltages.

The highlights of this design are summarized in Table 4.



FUNCTIONAL BLOCK DIAGRAM OF 30 GHz POC MODEL

FIGURE 5

TABLE 4

HIGHLIGHTS OF PREFERRED 30 GHz
RECEIVER DESIGN APPROACH

1) IMAGE ENHANCED MIXER

- DUAL DIODE "BALANCED" CONFIGURATION WITH INHERENT RF/LO ISOLATION
- HIGH QUALITY LNR LOW PARASITIC, ENCAPSULATED GaAs SCHOTTKY MIXER DIODES
- RF INPUT PRESELECTION FOR WIDE-BAND REACTIVE IMAGE TERMINATION

2) PHASE-LOCKED LO SOURCE

- LOW PHASE NOISE C-BAND FET VCO
- LOW LOSS VARACTOR X4 OUTPUT MULTIPLIER, USIGN HIGH QUALITY LNR GaAs VARACTOR
- HETERODYNED IF PHASE COMPARISON CIRCUIT, OPERATING OFF EXTERNAL 500 MHz XTAL REFERENCE
- AUTOMATIC PLL LOCK ACQUISITION AND STATUS MONITOR CAPABILITY

3) FET IF AMPLIFIER

- IF CHOSEN FOR BEST TRADE BETWEEN NF, IMAGE ENHANCEMENT AND SPURIOUS REJECTION
- USES READILY AVAILABLE LOW NOISE FET'S

Rationale for the selection of the balanced common-junction mixer mount as the preferred approach is summarized in Table 5. It is seen, therein, that the doubly-balanced mixer type is not a viable alternative due to both local oscillator power requirement and implementation difficulty. No known doubly-balanced mixer has been realized at the upper microwave or millimeter wave frequencies in an image enhancement deployment. The common-junction balanced mixer achieves RF-local oscillator isolation via circuit symmetry. This avoids the use of filters to achieve LO-RF diplexing. This advantage is deemed to be crucial when implementing an image enhanced millimeter mixer with a broadband microwave IF. The selection of the preferred 3.7 - 6.2 GHz IF frequency range for best tradeoff between single tone spurious suppression and image location, noise figure, etc., is based upon the analysis summarized in Figure 6. Key features of the preferred mixer design are summarized in Table 6.

The preferred phase locked LO source design, utilizing a heterodyne phase locked loop (PLL) for phase comparison, is shown in block diagram form in Figure 7. As shown in this figure, the basic source is divided into the following four major segments:

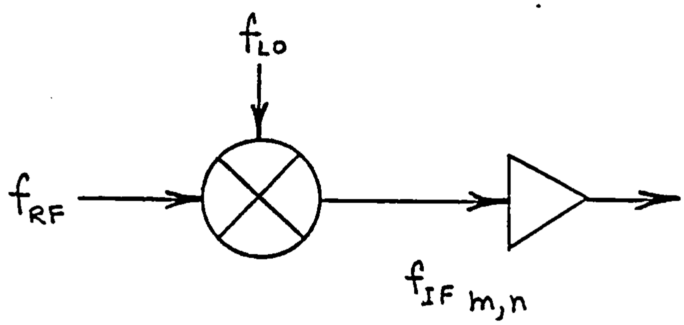
- microwave source
- reference source
- IF phase comparator
- baseband loop filter/acquisition circuit

In the microwave source, the basic phase-locked oscillator (PLO) is a FET voltage controlled oscillator (VCO) that nominally oscillates at 5.950 GHz. This oscillator provides a voltage tuning capability of $\pm$ 25 MHz about 5.950 GHz, and a power output capability of 0.5 Watts. The voltage controlled oscillator includes at its output, an integrated sampling power divider which energizes the PLL via the reference source sampling mixer and IF phase/frequency detector. The oscillator feeds a 10 percent efficient

TABLE 5

COMPARISON OF ALTERNATIVE MIXER MOUNTS

Type	No. of Diodes	Inherent LO-RF Isolation (dB)	LO Power Requirement (mW)	Input 1 dB Compression Level (dBm)	Relative Implementation Difficulty
Single-Ended	1 or 2	None	5 to 10	-10 to -5	Medium
Balanced Hybrid-Coupled	2	15 to 20	15 to 30	- 7 to - 2	Medium/High
Balanced Common Junction	2	15 to 20	10 to 20	- 7 to - 2	Medium
Double - Balanced	4	10 to 15	25 to 50	- 5 to 0	High



- $f_{IFm,n} = / nf_{RF} - mf_{LO} /$
- m,n = 1,2,3 ....
- DESIRED OUTPUT n=m=1 : $f_{IF} \pm = f_{RF} \pm - f_{LO}$
- GIVEN F_{RF} = 27.5 - 30 GHz
- SPUR APPEARS IF CHOICE OF f_{LO} IS SUCH THAT

$$f_{RF}^{-} - f_{LO} \leq f_{IFmn} \leq f_{RF}^{+} - f_{LO}$$

f_{LO} GHz	f_{IF}^{-} GHz	f_{IF}^{+} GHz	LOWEST-ORDER PASSBAND SPUR m	n	IMAGE RANGE GHz	REMARKS
22	5.5	8	3	2	14-16.5	. INSUFF SPUR REJ . HIGH F_{IF}
22.5	5.0	7.5	4	3	15-17.5	. HIGH SPUR REJECTION . HIGH f_{IF}
23	4.5	7.0	4	3	16-18.5	
23.8	3.7	6.2	4	3	17.6-20.1	BEST TRADE . SPUR REJ . F_{IF} . IMAGE LOC.
24	3.5	6.0	4	3	18-20.5	IMAGE BAND TOO CLOSE TO RF
24.5	3.0	5.5	5	4	19-21.5	

FIGURE 6 SUMMARY OF MIXER SINGLE-TONE SPURIOUS ANALYSIS

TABLE 6

KEY FEATURES OF PREFERRED 30 GHz
IMAGE ENHANCED MIXER DESIGN

1) DUAL DIODE COMMON JUNCTION "BALANCED" MIXER

2) INHERENT MUTUALLY ISOLATED SIGNAL/IMAGE AND LO/IF/SUM

3) HIGH QUALITY LNR GaAs SCHOTTKY MIXER DIODES

4) OPTIMUM DIODE MOUNTING GEOMETRY

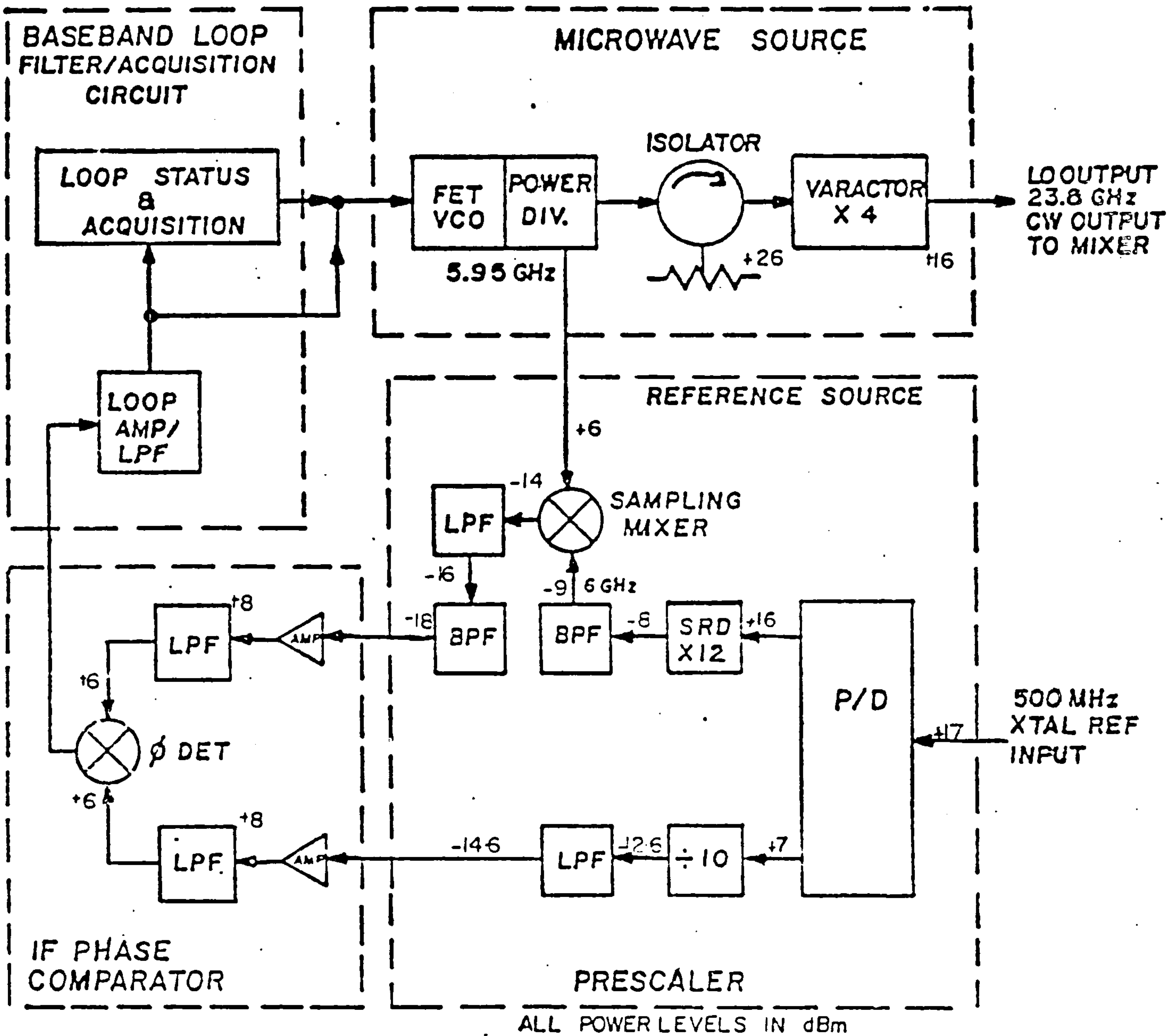
5) SIMPLE RF-MATCHED/IMAGE REJECT PRESELECTOR

6) OPTIMUM CHOICE OF IF AS TRADEOFF BETWEEN BEST IFA NF, SPURIOUS REJECTION AND IMAGE ENHANCEMENT

7) COMMON-JUNCTION LO/IF DIPLEXER @ DIODE MIDPOINT

8) CAD OF APPROPRIATE MATCHING NW'S @ APPROPRIATE ACCESSIBLE MIXER PORTS

9) PRECISION CONSTRUCTION FOR REPRODUCABLE PERFORMANCE



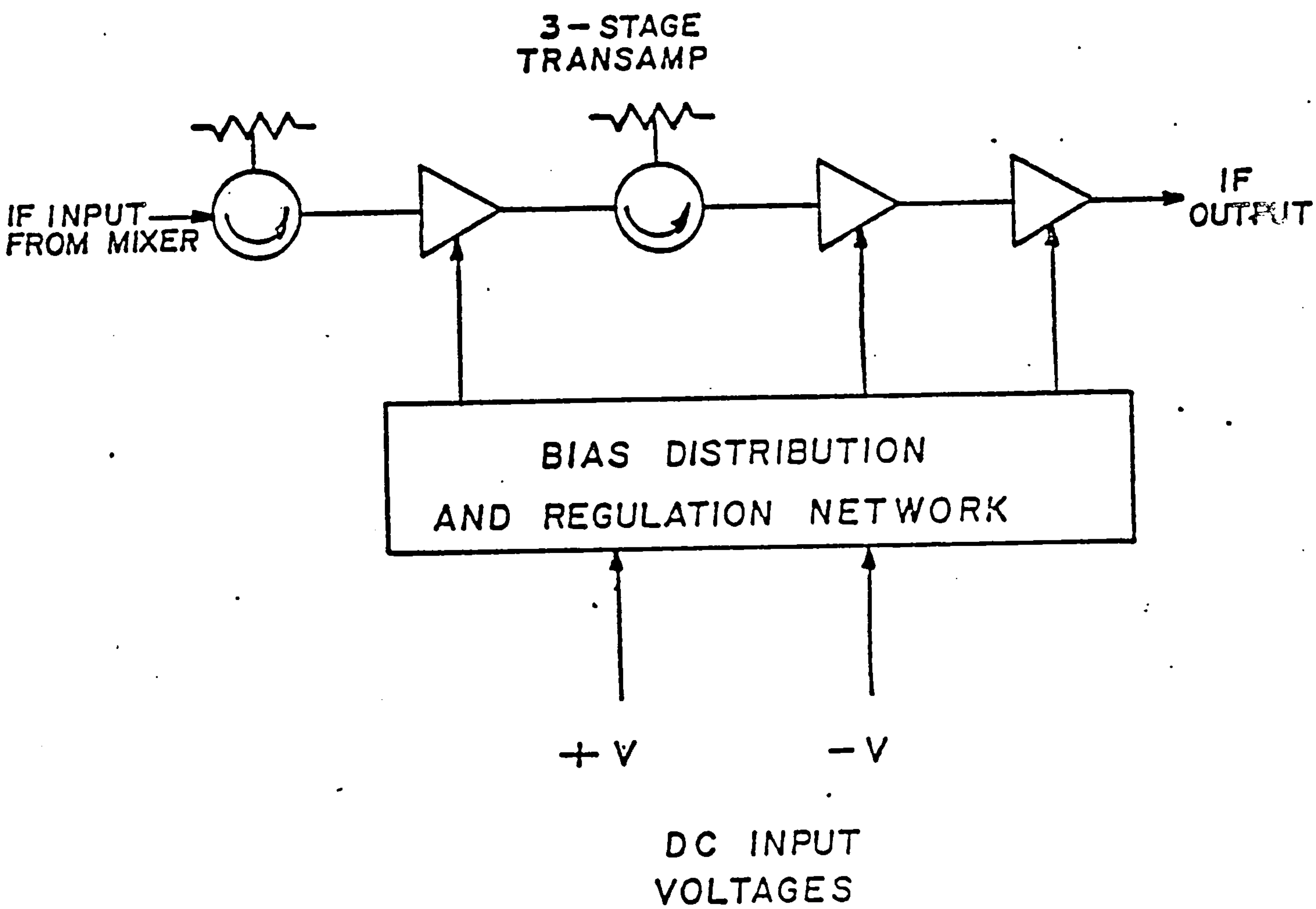
PHASE-LOCKED LO SOURCE
BLOCK DIAGRAM

FIGURE 7

C-to K-band varactor X4 multiplier. The latter, utilizing integral "drop in" circulators where required, and incorporating a K-band output bandpass filter (BPF) for rejection provides at its output, the required LO input to the receiver image enhanced mixer. The microwave source output will typically be a power level of +16 dBm and at a stabilized frequency of 23.8 GHz.

The locking action of the PLL segments is activated by the externally supplied, highly stable, 500 MHz crystal reference source. The output of the phase - frequency detector is passed through the baseband loop filter so as to complete the phase locked loop and lock the fundamental FET VCO output frequency to exactly 119 times 50 MHz or the required 5950 MHz. (As previously described, further multiplication by four produces the required output frequency of 23.8 GHz). The basic phase locked loop bandwidth is designed to be greater than 100 KHz so as to easily enclose the close-in noise of the fundamental oscillator.

For the POC model to meet the RF performance requirements of an input noise figure of 5 dB or less and an RF to IF gain of 20 dB min., an IF amplifier with a noise figure of 2 dB or less and an overall gain of typically 25 dB is required over a 2.5 GHz bandwidth in an IF frequency range between 3.7 to 6.2 GHz. Based upon the results of a FET device/circuit trade-off analysis, the IF amplifier utilizes a three stage single-ended design wherein, the first FET stage is optimized for low noise figure performance and the second and third stage are optimized for maximum gain and minimum output VSWR. A block diagram of the three-stage IF amplifier design is presented in Figure 8. The bias distribution network will provide mutually-isolated drain and gate bias boltages to each transamp stage. The design of the amplifier utilizes input, output, and interstage matching over the entirety of the amplifier passband with heavy use of computer aided design (CAD) techniques.



BLOCK DIAGRAM OF IF AMPLIFIER (3.7-6.2 GHz)

FIGURE 8

4.0 ALTERNATE RECEIVER DESIGNS, 1987 TECHNOLOGY

The LNR design for a 30 GHz space qualifiable receiver, which was implemented for the 1982 time frame Proof of Concept (POC) model, was derived after extensive research into the current and projected state-of-the-art of receiver technology. This research has uncovered several areas of technology which although not developed enough for incorporation in the current (1982) POC model, do offer the potential for utilization in the future post-1987 time frame. This section defines those technologies, which in the opinion of LNR, can be sufficiently advanced during the next seven years to provide further improved alternatives to the current receiver design. In addition, performance characteristics are projected for each of these alternatives and a parametric trade-off analysis relative to the POC model design is presented.

The main criteria used to select exactly which designs were to be considered was their ability to meet or exceed the required performance parameters and the confidence factor relative to their projected availability in 1987. Availability was judged on the basis of projected status of in-house and industry at large state-of-the-art and/or the requirement for additional formal research and development programs to develop the needed technologies between 1983 and 1987.

A. Rationale for Selection of Alternate Designs

A review of the projected state of the art for various millimeter wave "front-end" technologies indicates that there are three major technology categories which should be available in the 1987 time frame. These technologies are: spaceborne cooling techniques, low noise FET amplifier technology, and GaAs monolithic integrated circuit technology. Therefore, LNR has chosen three alternate 30 GHz receiver designs, each utilizing one of the technologies stated above, for a parametric trade-off analysis relative to the POC model receiver. A summary of the rationale for selection of alternate future (1987) technology 30 GHz receiver designs is presented in Table 7. The parametric amplifier, which has the capability of achieving the lowest noise performance of the various receiver "front-ends", was not considered because of its excessive size, weight, power drain and overall assembly complexity in relation to the performance requirements of the 30 GHz receiver.

B. Functional Block Diagrams

Figure 9 presents the functional block diagram of a cooled mixer front-end. The millimeter wave portion of the receiver consists of an image enhanced mixer integrated with a low-noise FET IF amplifier. The mixer IFA assembly (otherwise similar to that specified in the POC model receiver design) is cooled to an operating temperature of approximately 100°K utilizing spacecraft radiation cooling techniques. In order to maximize the efficiency of cooling, the mixer - IFA assembly must be thermally isolated from all surrounding structures and interconnections. The phase locked LO source (a more advanced design than that specified in the current POC model) comprises a FET VCO/doubler, the 6 GHz output of which is multiplied up to the LO frequency of 24 GHz by a FET multiplier. The fundamental 3 GHz output of the VCO is divided down to 100 MHz where it is compared to a stable reference input for generating the pahse locked loop error voltage. The loop status/acquisition circuit provides an indication of the phase locked loop status, in or out of lock, and a sweep voltage to reacquire phase lock if an out of lock condition occurs.

The second alternate receiver design considered utilizes the capabilities of projected achievements in low noise 30 GHz FET amplifier technology. A functional block diagram of this receiver configuration is presented in Figure 10. The input LNA consists of a three stage, low noise, 30 GHz FET amplifier. The RF performance of the mixer following the LNA in this receiver approach can be relaxed because of the presence of the medium gain LNA, and

TABLE 7

RATIONALE FOR SELECTION OF ALTERNATE

FUTURE (1987) TECHNOLOGY 30 GHz RECEIVER DESIGNS

1) COOLED MIXER/FET IFA

- CONSIDERABLE IMPROVEMENT IN NF
- SIMPLE CONFIGURATION
- HIGH DYNAMIC RANGE

2) DISCRETE MIC-FET "FRONT-END"

- CONSIDERABLE IMPROVEMENT IN NF
- COMPACT, LIGHT-WEIGHT CONFIGURATION
- NON-CRITICAL DESIGN

3) MONOLITHIC MIC FET "FRONT-ENT

- SMALLEST, LIGHTEST WEIGHT CONFIGURATION
- POTENTIAL LOW COST MASS REPRODUCABILITY
- MOST SUITABLE FOR MULTIPLE RECEIVER DEPLOYMENT IN MULTI-APERTURE ANTENNA ARRAY
- NON-CRITICAL DESIGN
- SOME IMPROVEMENT IN NF

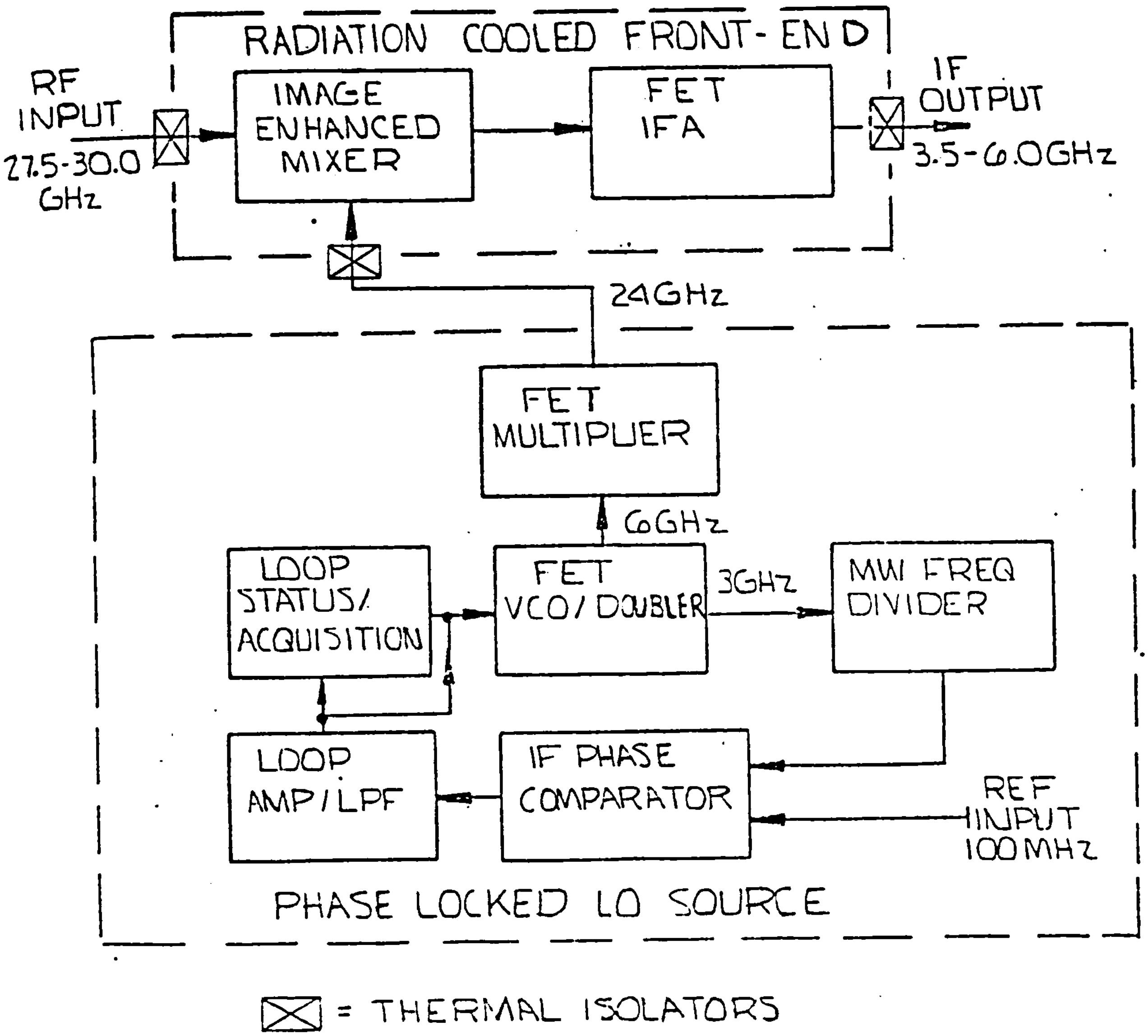


FIGURE 9 COOLED MIXER FRONT-END, FUNCTIONAL BLOCK DIAGRAM

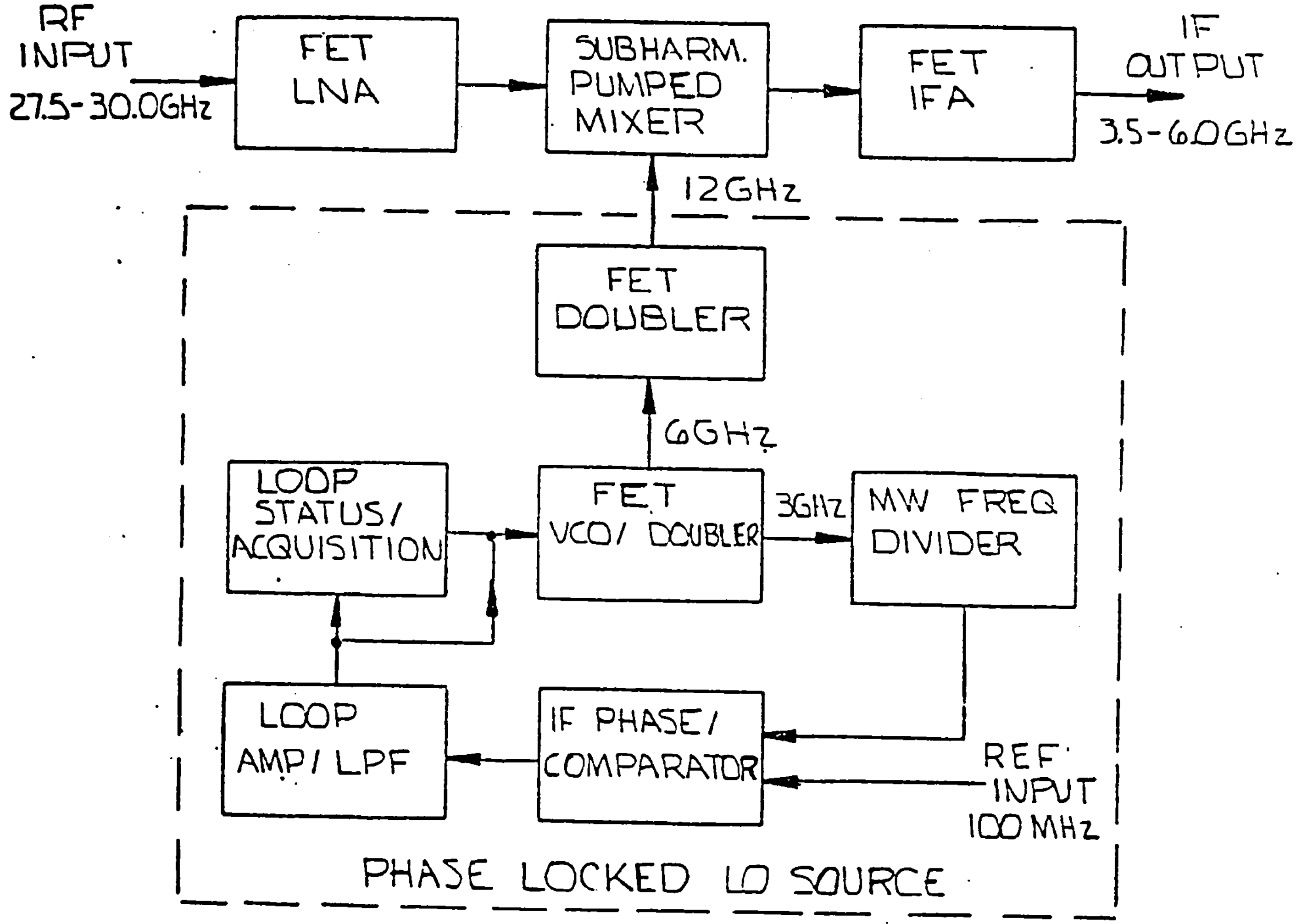


FIGURE 10 DISCRETE/MIC - FET FRONT END FUNCTIONAL BLOCK DIAGRAM

can therefore be a single sideband (but not image enhanced) subharmonically pumped mixer. The phase locked source is identical to the one used in the cooled-mixer approach except that the output multiplier to the LO frequency is a FET doubler rather than a FET x4 multiplier. The FET IF amplifier is generically the same as the one used in the cooled mixer configuration, except it will be operating at an ambient temperature of approximately 320^{o}K.

The third 1987 time-frame receiver design considered utilizes GaAs monolithic integrated circuit technology, as presented in Figure 11. This ultimate design configuration incorporates all of the discrete module functions (LNA, MIXER, IFA, PLO) on a single monolithic e.g., selectively doped, metallized, semi-insulating GaAs substrate, with the exception of the lower frequency portion of the phase-locked-loop, which is realized on a companion silicon monolithic chip.

C. Achievable RF Performance of Alternative Designs

Summarized in Table 8 are the projected RF performance budgets for the three alternate 1987-technology 30 GHz receiver designs. Each design is capable of meeting the noise-figure requirement of 5 dB Max. with various degrees of margin.

D. Parametric Trade-Off Comparisons

A summary of the major RF performance parameters associated with the 1987 alternate receiver designs compared to the POC Model design is presented in Table 9. It can be seen therein that the major differences in performance are in the areas of noise figure, gain variation, image rejection, and output 1 dB gain compression capabilities. It should also be noted that for the radiation cooled (100^{o}K) mixer/IFA approach, if just the mixer assembly is cooled or just the IF amplifier is cooled the improvement in input noise figure would only be 0.5 to 0.75 dB. Cooling the

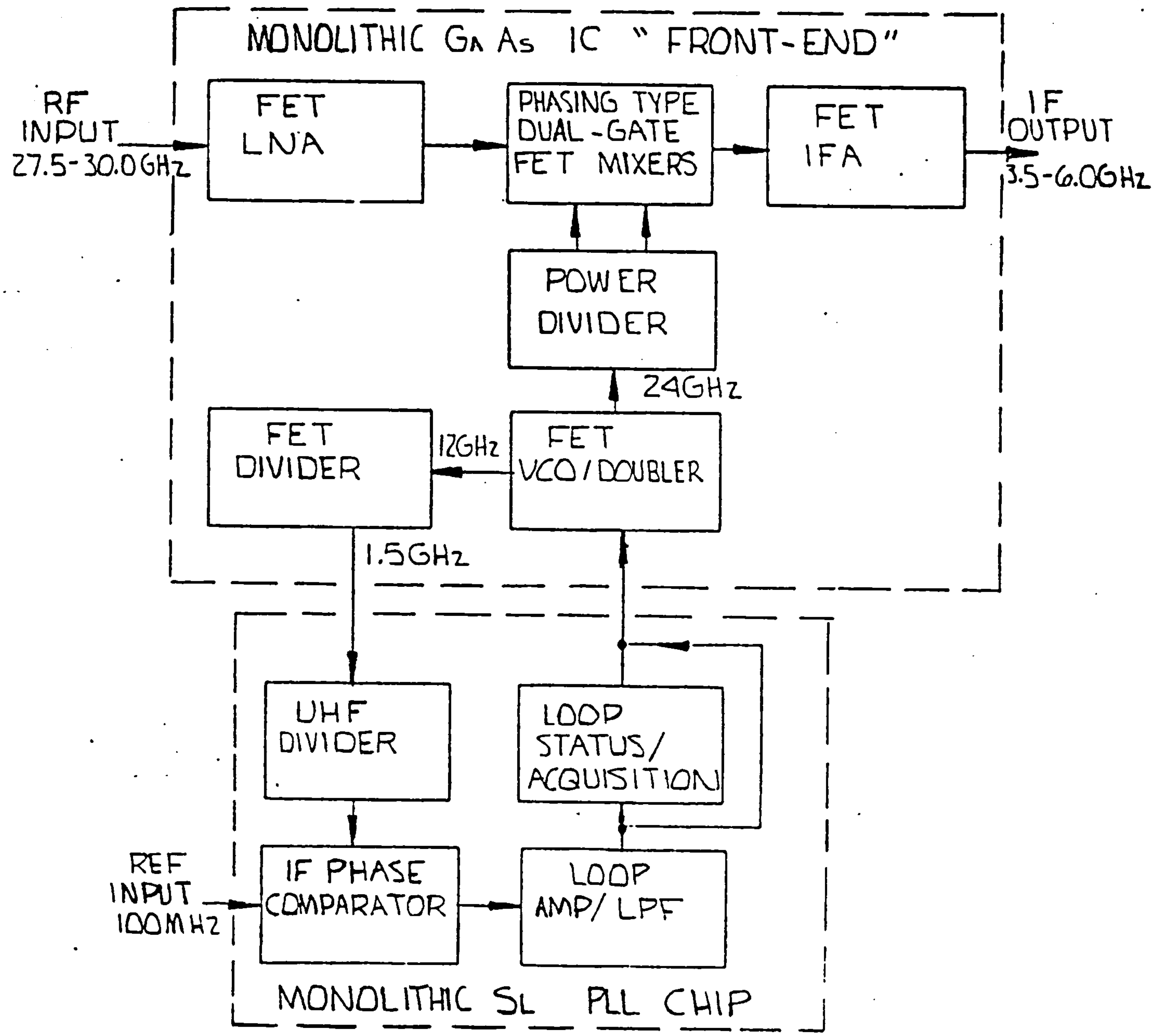
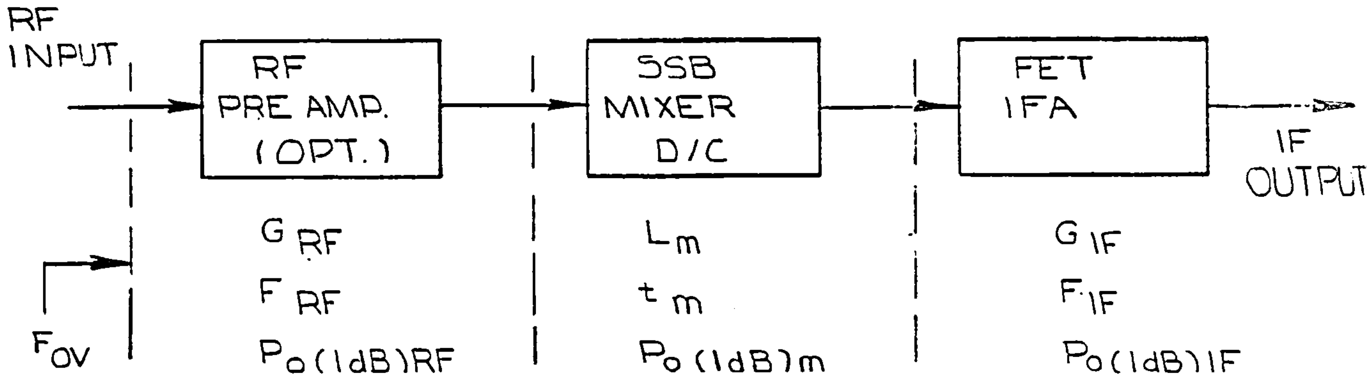


FIGURE 11 MONOLITHIC FRONT END FUNCTIONAL BLOCK DIAGRAM

TABLE 8

PERFORMANCE BUDGETS FOR FUTURE (1987) TECHNOLOGY 30 GHz RECEIVER DESIGNS



CASE / PARAMETER	COOLED MIXER FET IFA	DISCRETE MIC FET "FRONT-END"	MONOLITHIC MIC FET "FRONT-END"
G_{RF}	0 dB	16 dB	14 dB
F_{RF}	0 dB	3 dB	4 dB
$P_{o(1dB)RF}$	∞	-10 dBm	-13 dBm
L_m	3 dB	6 dB	7 dB
t_m	1.5	1.0	1.0
$P_{o(1dB)m}$	0 dBm	0 dBm	0 dBm
G_{IF}	28 dB	15 dB	18 dB
F_{IF}	0.8 dB	1.5 dB	2.5 dB
$P_{o(1dB)IF}$	+10 dBm	+10 dBm	+7 dBm
PHYSICAL TEMPERATURE T_o (°K)	100 °K (RADIATION COOLING)	320 °K	320 °K
G_{ov}	25 dB	25 dB	25 dB
F_{ov}	3.2 dB	3.3 dB	4.5 dB
$P_{o(1dB)OV}$	+10 dBm	-1 dBm	-2 dBm

TABLE 9

RF PERFORMANCE COMPARISON

Receiver Requirements	POC Model Design	1987 Alternate Receiver Designs		
		Cooled Mixer	Discrete MIC	Monolithic MIC
Input RF Band 27.5-30.o GHz 2.5 GHz BW	27.5-30.0	27.5-30.0	27.5-30.0	27.5-30.0
Output IF BAnd (3-8 GHz range)	3.7-6.2	3.5-6.0	3.5-6.0	3.5-6.0
Noise Figure 5 dB Max.	4.8	3.2	3.3	4.5
RF to IF Gain 20 dB Min.	25	25	25	25
In-Band Overdrive -10dB Input	-10	-10	-20	±1.0
Gain Variation ±1.0dB Max.	±0.8	±0.8	±1.0	±1.0
VSWR Input 1.25 Max.	1.25:1	1.25:1	1.25:1	1.25:1
VSWR Output 1.80 Max.	1.6:1	1.6:1	1.6:1	1.8:1
Image Rejection 15dB Min.	20	20	23	15
Output Power @1dB Compression (dBm)	+10	+10	-1	-2

integrated mixer/IF amplifier module to 100°K achieves the maximum improvement in input noise figure of approximately 1.5 dB over the capabilities of the POC Model design. A summary of the physical attributes of the various receiver designs is presented in Table 10.

E. Technology Readiness - 1987

Each of the three alternate designs, as shown in the previous trade-off analysis, offers distinct advantages which must be carefully evaluated relative to improved receiver performance verse implementation problems. A key area to be considered is the amount of new development now in process and the additional allocation of funds and manpower required for practical flight hardware deployment.

The cooled mixer/FET IF amplifier approach offers considerable improvement in noise figure but requires use of advanced cooling techniques for successful implimentation. The required technology is capable of being developed by 1987 but not in a form which is within practical size, weight and power drain specifications. After consideration of the amount of development required and the ultimate capabilities of various physical cooling methods such as solid cryo, passive radiation, thermo-electric and mechanical refrigeration, LNR has concluded that the cooled mixer/FET IF amplifier does not present a viable alternative for 1987. The only way such an approach would be appropriate is if the spacecraft design were to include a cooling mechanism required elsewhere which could in addition be utilized by the receiver.

The discrete MIC FET "front end" offers, perhaps, the most promising alternative design for 1987 implementation. Low noise FET amplifier technology has been steadily advancing into the millimeter wave frequency range, utilizing GaAs FET devices with gate lengths currently of 0.5 um and in the future as low as 0.2 um.

TABLE 10

SUMMARY OF RECEIVER PHYSICAL ATTRIBUTES

	POC Mod.	Cooled MXR	Disc MIC	Monol. MIC.
Volume (in^3)	90	*10,000 70	80	6
Weight (lbs)	3.2	*45 2.4	2.7	0.5
Power Drain (W)	10	9	8	3
Required Major New Technology	Image Enhanced Mixer	Radiation cooler	30 GHz GaAS FET ampl[illegible]	Monolithic 30 GHz GaAs FET front end
Relative Complexity	low	high	medium	medium
Development cost	low	high	medium	high

* estimate of radiation cooler

Demonstrated spot performance of low noise FETs includes 2.5 dB NF device with 7 dB associated gain at 18 GHz and 6 dB NF amplifier with 6 dB gain at 30 GHz. With the proper allocation of reasonable resources it is conceivable that the discrete MIC FET "front end" will be well within the state-of-the-art for 1987.

The monolithic MIC FET "front end" is the ultimate concept which is feasible for development by 1987. Research is in process within the industry at C and X band and it is possible to advance to K band within the required time frame. Extensive funding would, however, be required to assure this result; the amount of funding required at this time is probably excessive relative to the receiver improvement (size/weight rather than performance) which may be achieved.

F. CONCLUSIONS

As indicated in the preceding sections, the preferred approaches to the implementation of a 30 GHz spaceborne low noise receiver "front end" are:

- uncooled image-enhanced mixer/FET IF amplifier for development of qualifiable POC model using 1982 technology and for deployment of fully flight qualified units on demonstration satellite in 1985 time frame
- discrete MIC FET LNA "front end", for advanced development utilizing 1987 technology and for spacecraft deployment of fully qualified units in the post 1990 time frame

In addition to the above, it may be worthwhile to undertake monolithic all-FET 30 GHz receiver development to address the pothential application of multiple aperture receiving antenna arrays and associated multiple receivers on post 1990 30/20 GHz communications satellites in view of their projected ultimate small size, light weight, low cost quantity reproducability.

5.0 BREADBOARD DEVELOPMENT

The breadboard development task on the 30 GHz POC model receiver program consisted of the development of an optimum image-enhanced 30 GHz mixer assembly including LNR gallium arsenide (GaAs) Schottky mixer diodes, a 3.7 to 6.2 GHz low noise FET IF amplifier, and a 23.8 GHz phase-locked local oscillator source, as described in more detail in the following paragraphs.

A. 30 GHz Image-Enhanced Mixer

A detailed tradeoff analysis reaffirmed the selection of the dual diode common junction balanced mixer mount as the preferred 30 GHz image enhanced mixer configuration. A functional block diagram of this configuration is shown in Figure 12. Heavy emphasis was placed on computer aided modelling of the mixer design supported by scale model circuit/structure simulation measurements for optimizing the design dimensions such as to provide the proper reactive terminations to the mixer diodes over the image and sum frequency bands, as required to achieve image-enhancement.

A photograph of the image-enhanced mixer structure is shown in Figure 13. The packaged mixer diodes are mounted in each half of the housing and are contacted by the cross-bar which is situated midway between the top and bottom walls of the input waveguide, transverse to the direction of propagation. The local oscillator drive is coupled to the diodes through the cross-bar which, at one end, forms a probe coupled interface with the LO waveguide. The other end of the crossbar provides the IF output as a coaxial TEM structure which transforms the mixer diode impedance to the 50Ω output IF impedance line. Matching of the diode impedance to the input waveguide impedance is achieved by a multi-quarter wavelength impedance transformer which is located in the RF input waveguide. The latter is below cutoff over the image band (17.6-20.1 GHz), thus serving as an RF input preselector and providing the required reactive image termination.

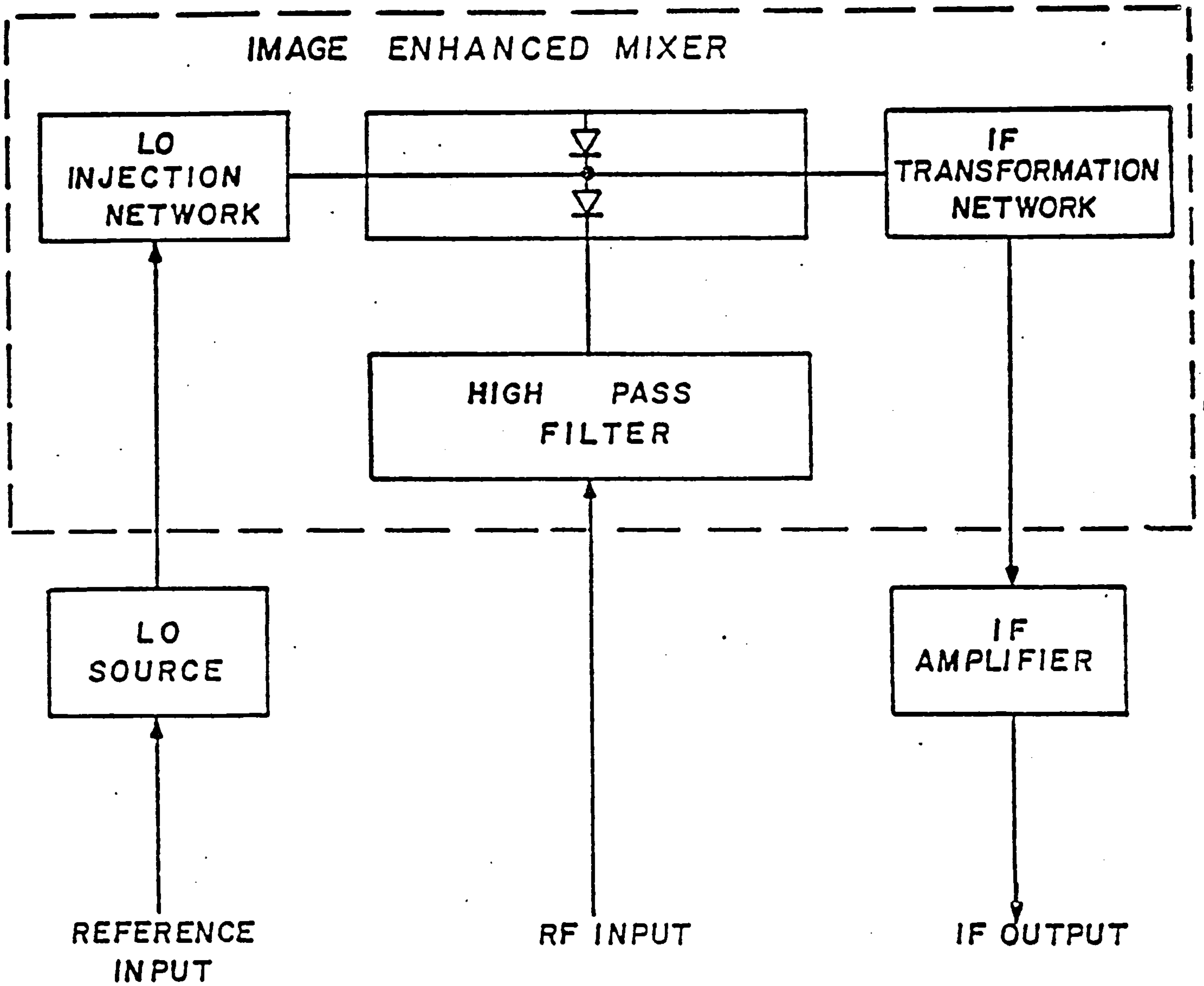


IMAGE ENHANCED MIXER CONFIGURATION

FIGURE 12

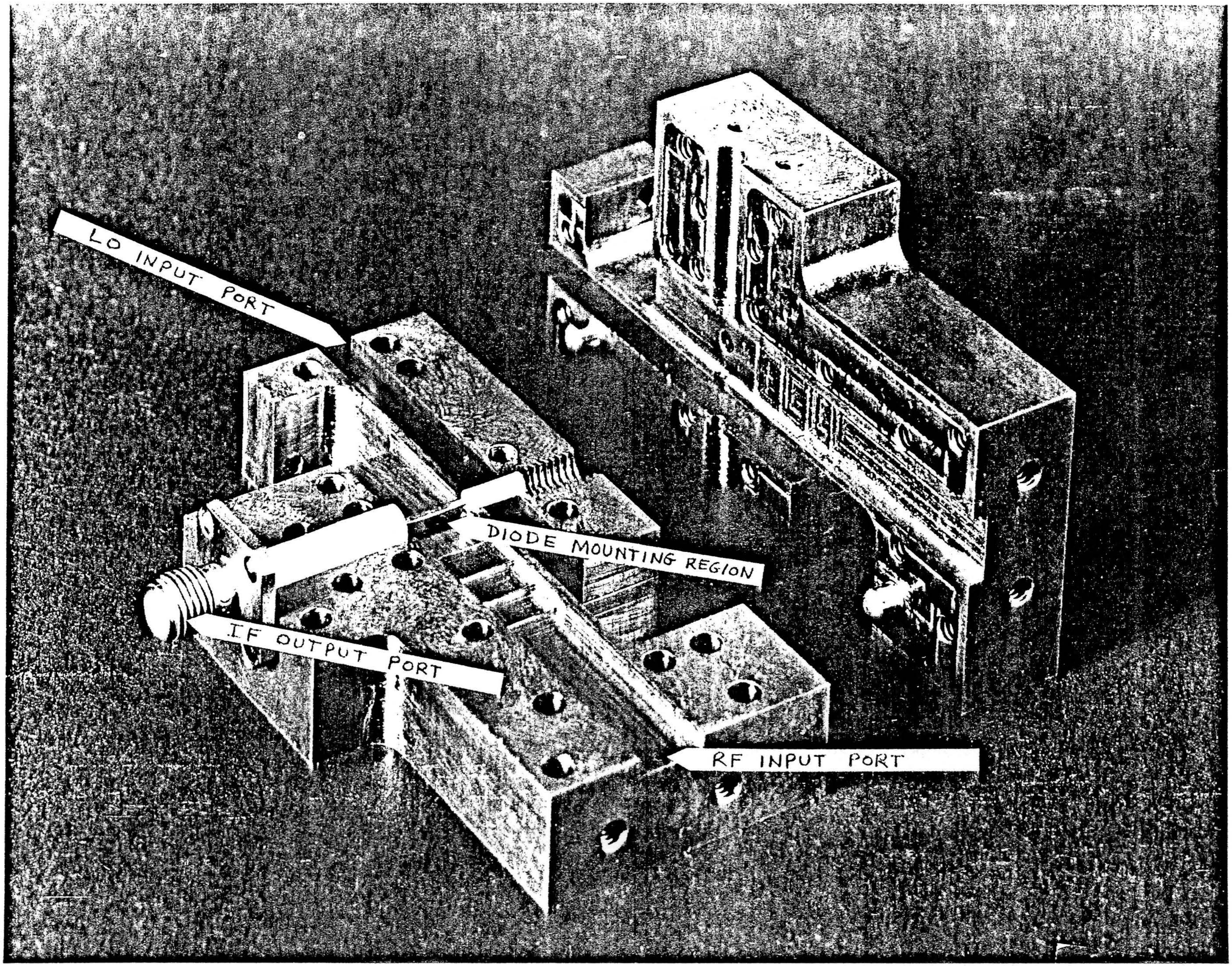


FIGURE 13 OPEN VIEW OF 30 GHz IMAGE ENHANCED MIXER STRUCTURE

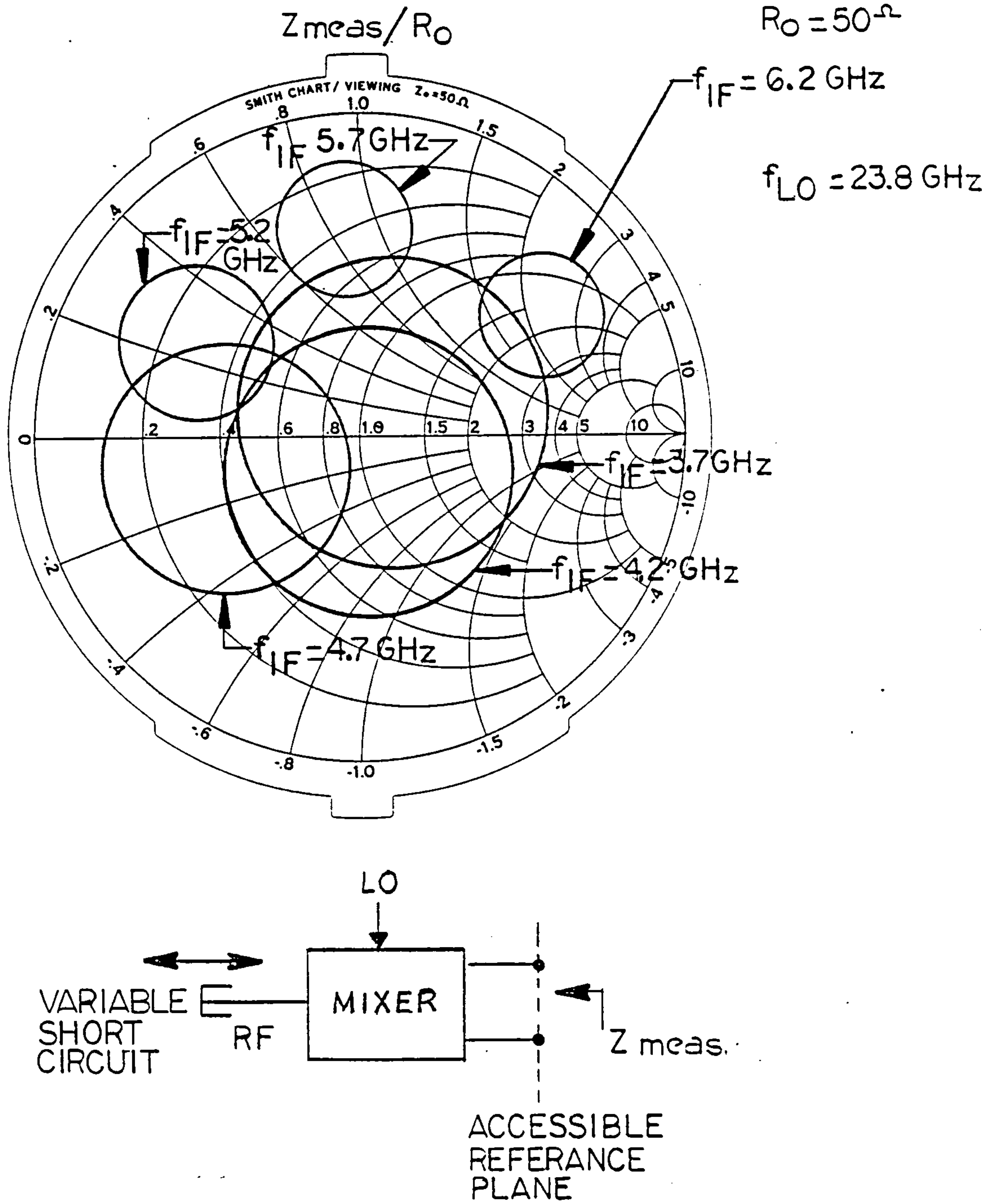
The mixer diode assemblies, which are fabricated at LNR, consist of high quality GaAs Schottky chips embedded in customized hermetically-sealable packages which contain controlled parasitics and incorporate built-in reactive circuit elements for achieving the required reactive terminations at higher harmonic conversion products. The Schottky chips exhibit zero bias junction capacitance of 0.06 pF and an estimated cutoff frequency greater than 1000 GHz.

The conversion loss of the breadboard mixer assembly was evaluated utilizing the loss-circle technique. This technique measures the return loss at the IF mixer port when the RF port is terminated in a sliding short circuit load. The results of these measurements are shown in Figure 14. The relative size of the loss-circle at each frequency is a measure of the minimum conversion loss of the mixer assembly when both the RF and IF port are terminated in biconjugately matched impedances. These measurements indicate a minimum conversion loss of 3.2 to 4.5 dB over the 27.5 to 30.0 GHz RF bandwidth. In the breadboard implementation of the mixer, an additional conversion loss component of 1.0-2.0 dB was introduced by departure from biconjugate match at the RF and IF ports.

B. 3.7-6.2 GHz IF Amplifier

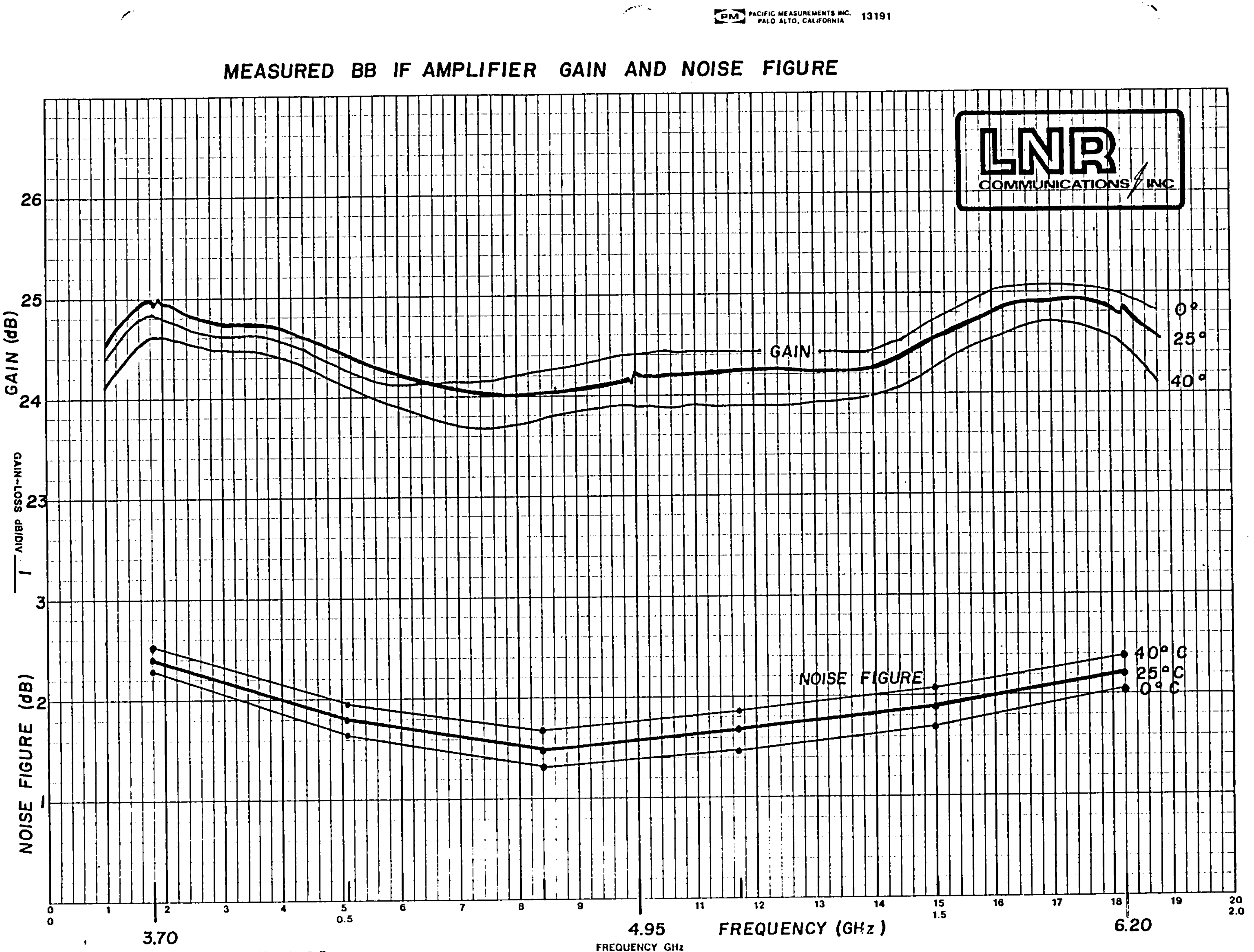
For the POC model receiver to meet its RF performance requirements, a FET IF amplifier with a noise figure of 2 dB or less and an overall gain of typically 25 dB was required over a 2.5 GHz bandwidth encompassing the selected 3.7 to 6.2 GHz IF range. The selected FET amplifier design is a 3 stage single ended configuration using NEC packaged FET's embedded in a duroid based substrate microstrip transmission line structure.

The gain and noise figure of the breadboard IF amplifier measured over the 0-40^{o}C temperature range is shown in Figure 15, demonstrating that the gain and noise figure variation over termperature was reasonably small.



TYPICAL MEASURED IF LOSS CIRCLE
FOR
BREADBOARD IMAGE-ENHANCED MIXER

FIGURE 14



PM PACIFIC MEASUREMENTS INC. PALO ALTO, CALIFORNIA 13191
MEASURED BB IF AMPLIFIER GAIN AND NOISE FIGURE
LNR COMMUNICATIONS INC
GAIN (dB)
26
25
24
23
3
2
1
NOISE FIGURE (dB)
GAIN-LOSS dB/DIV
RETURN LOSS dB/DIV
GAIN
0°
25°
40°
NOISE FIGURE
40° C
25° C
0° C
3.70
4.95
6.20
FREQUENCY (GHz)
FREQUENCY GHz

FIGURE 15

Based upon the measured noise performance of the cascaded breadboard mixer/IF amplifier, the input noise figure performance of the POC receiver was projected to be between 5.5 to 6.5 dB over 80 percent of the 27.5-30 GHz RF input band, and a maximum of 7 dB at the high end of the band.

C. <u>23.8 GHz Phase-Locked LO Source</u>

The major portion of the breadboard effort on the 23.8 GHz phase-locked LO source was directed toward the design and development of the medium power 5.95 GHz VCO and the C to K-band varactor X4 multiplier.

The measured performance of the breadboard VCO showed an output power capability of approximately 0.45 watts at an efficiency of 26%, and a voltage tuning capability of greater than ±25 MHz. This measured performance is summarized in Figure 16. The frequency tuning requirement of ±25 MHz was dictated by the tunability required of the VCO to compensate, via phase locking, for the measured oscillator frequency drift over temperature.

The measured performance of the C to K-band varactor multiplier is shown in Figure 17. The 40 mW output power capability of the multiplier was sufficient as a local oscillator source for the image-enhanced mixer.

The remaining portions of the phase-locked loop were also breadboarded, and the dynamic characteristics of the loop were adjusted for optimum performence in conjunction with the FET VCO. The loop bandwidth was designed for approximately 100 KHz as the best tradeoff between short term frequency stability and sideband phase noise reduction.

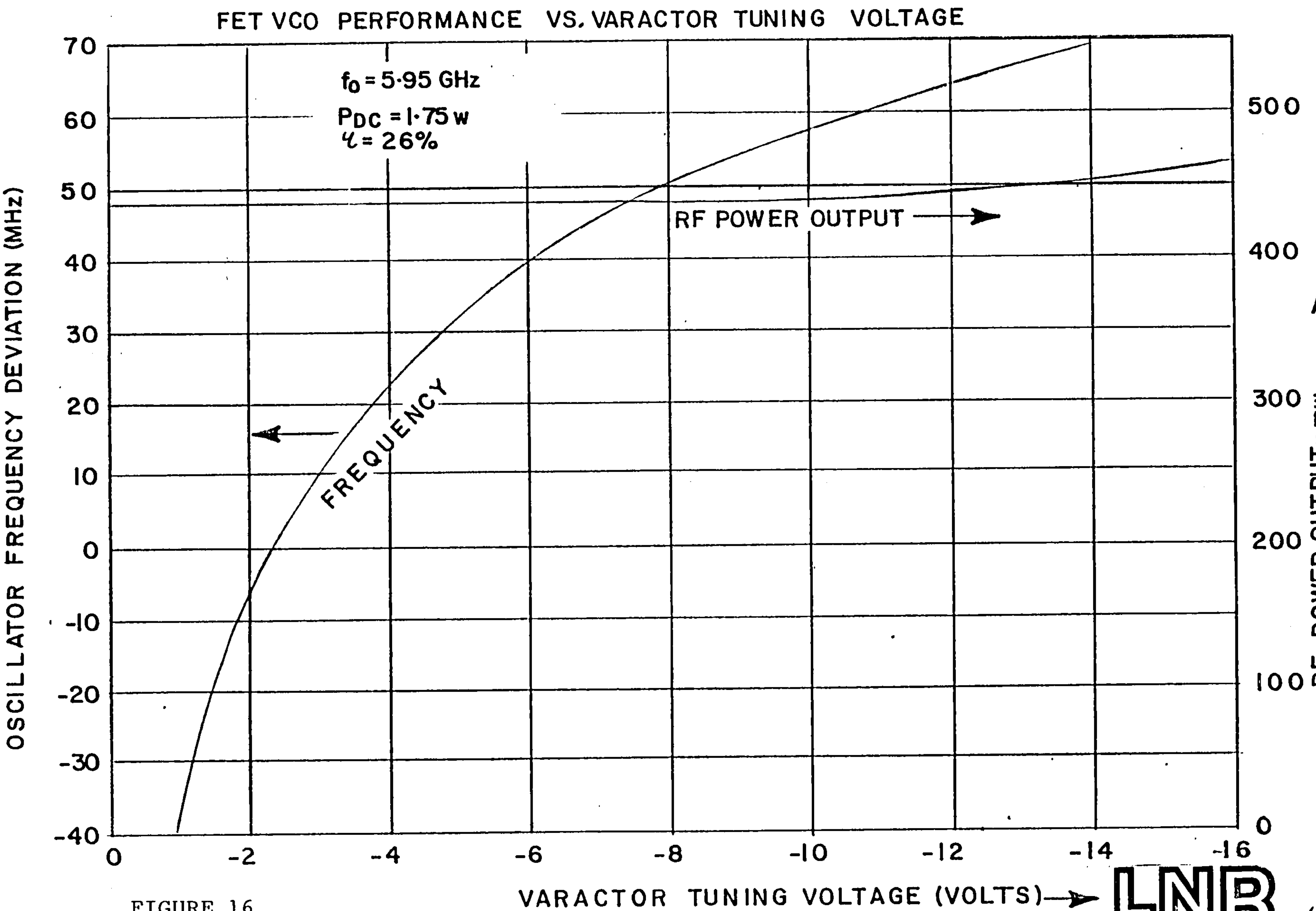


FIGURE 16

LNR COMMUNICATIONS INC

QUADRUPLER RF OUTPUT POWER AND CONVERSION EFFICIENCY VS. OUTPUT FREQUENCY

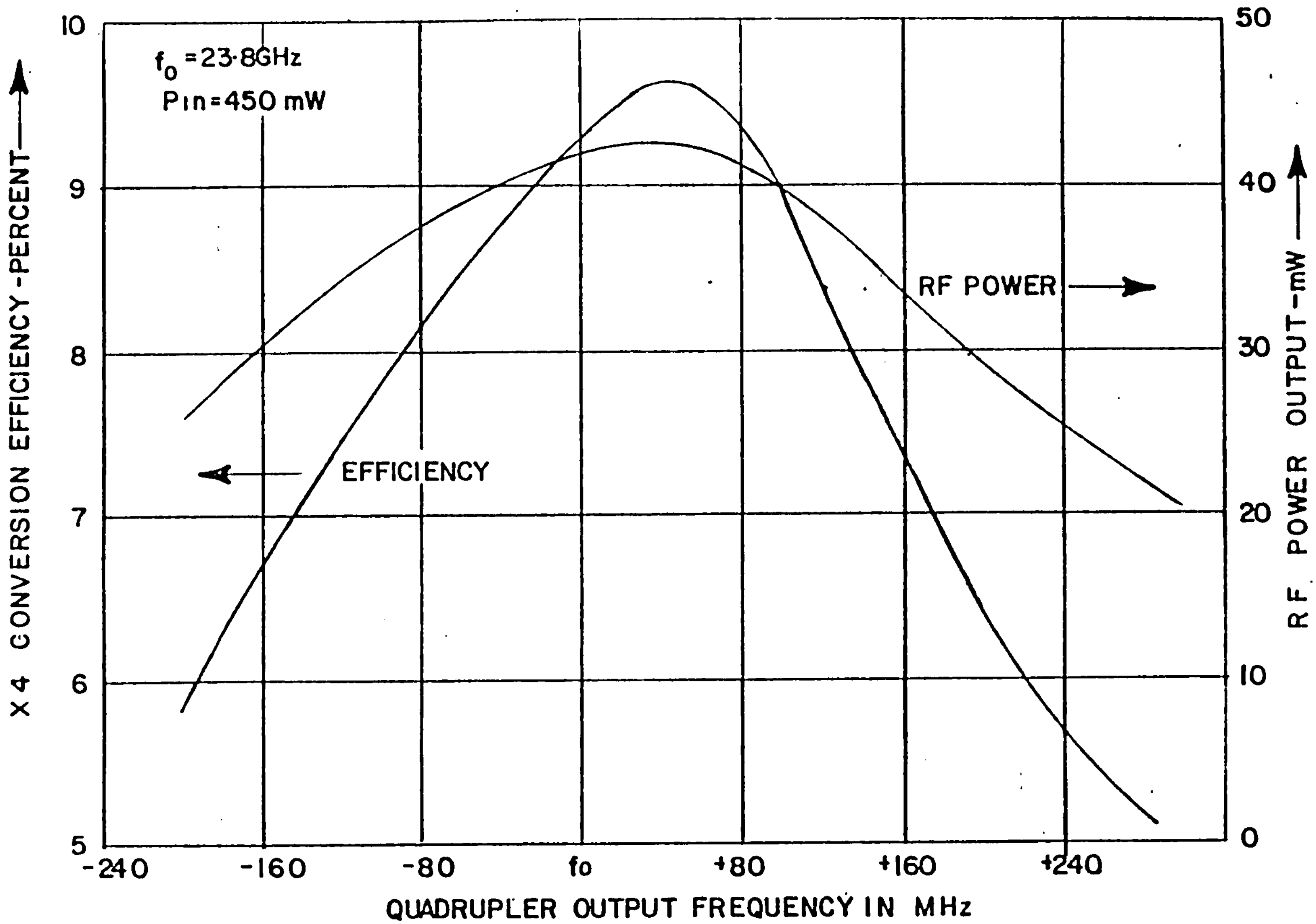


FIGURE 17

6.0 POC MODEL PERFORMANCE

This section summarizes the measured performance of the final deliverable 30 GHz POC model receivers. The parameters measured were:

A) Ambient Functional

- RF/IF Gain-Bandwidth
- Input Noise Figure
- VSWR Input/Output
- In-Band Overdrive
- Phase-Locked LO Source Phase Noise
- DC Power Requirements

B) Thermal-Vacuum Characteristics

- RF/IF Gain-Bandwidth
- Phase-Locked LO Source Stability

C) Dynamic Range Characteristics

- Input-1 dB Gain Compression Point
- Two-Tone Intermodulation Product Output Intercept Point
- In-Band Small Signal Suppression/Desensitization
- Out-of-Band Large Signal Interference
- AM/PM Conversion
- Pulse Recovery Time - Amplitude and Phase

Ambient Functional

The measured RF/IF conversion gain and input single sideband noise figure of the three POC model receivers is shown in Figures 18 A, B and C. The nominal performance of these three receivers over the 27.5-30 GHz/3.7-6.2 GHz instantaneous RF input/IF output bands includes 18 to 22 dB conversion gain and 5 to 8 dB SSB noise figure. Specific observations on the foregoing measured performance of these receivers are summarized as follows:

- The 6 dB "notch" in gain of POC S/N 001 at an RF input frequency of 27.95 GHZ is caused by a spurious resonance in the low pass filter choke that is used as the DC return for mixer diode current monitoring. This filter choke design was modified for the additional two POC receivers to eliminate this resonance.

- The reduction of gain and increase in noise figure at the high end of the RF band is directly attributable to a corresponding upper bandedge increase in the conversion loss of the image enhanced mixer, because the measured gain of the FET IF amplifiers is extremely flat over the 3.7-6.2 GHz IF band (25.0 ± 0.4 dB) and the amplifier noise figure varies from 1.6 dB at midband to 2.2 dB at the band edges. In addition, "minimum available" conversion loss measurements on the three mixers under the condition of perfect match at both the RF and IF ports, yielded results of 3.5 to 4.5 dB over the full 27.5-30 GHz/3.7-6.2 GHz RF/IF band. Further measurements indicated that the additional $\sim$1 to 2 dB increment in upper bandedge conversion loss exhibited by each POC mixer results from upper bandedge mismatch at the IF port of the mixer assembly. This can be corrected in future iterations to achieve RF/IF conversion gain $\sim$1-2 dB higher and a noise figure approximately 1-2 dB lower than reported above at the high end of the RF band.

The in-band signal overdrive test was performed at an RF input level of +5 dBm, which is approximately 10 dB above the input 1 dB gain compression level. The swept RF/IF gain response of the receivers was monitored before and after application of the overdrive signal with no decernable difference noted.

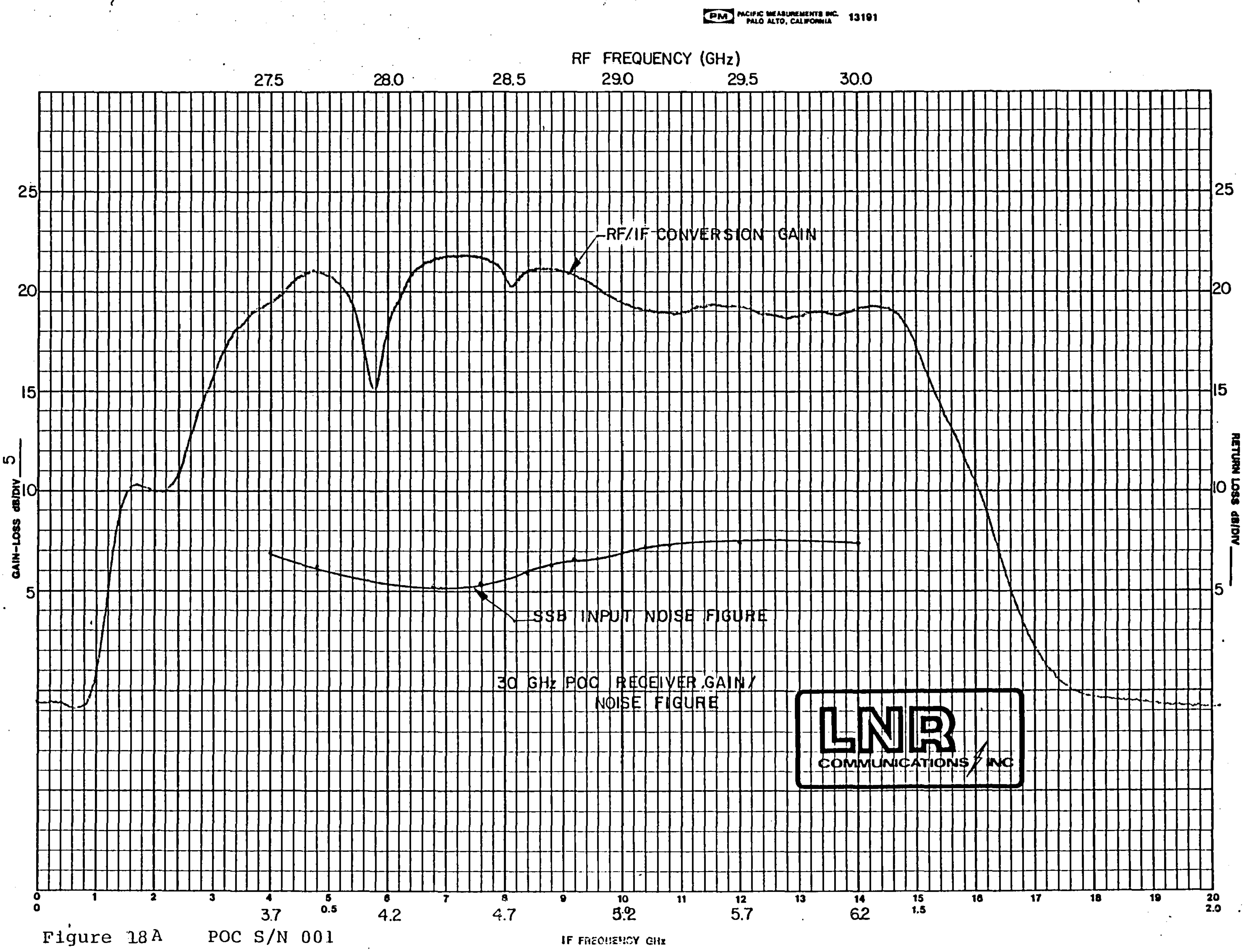


Figure 18A POC S/N 001

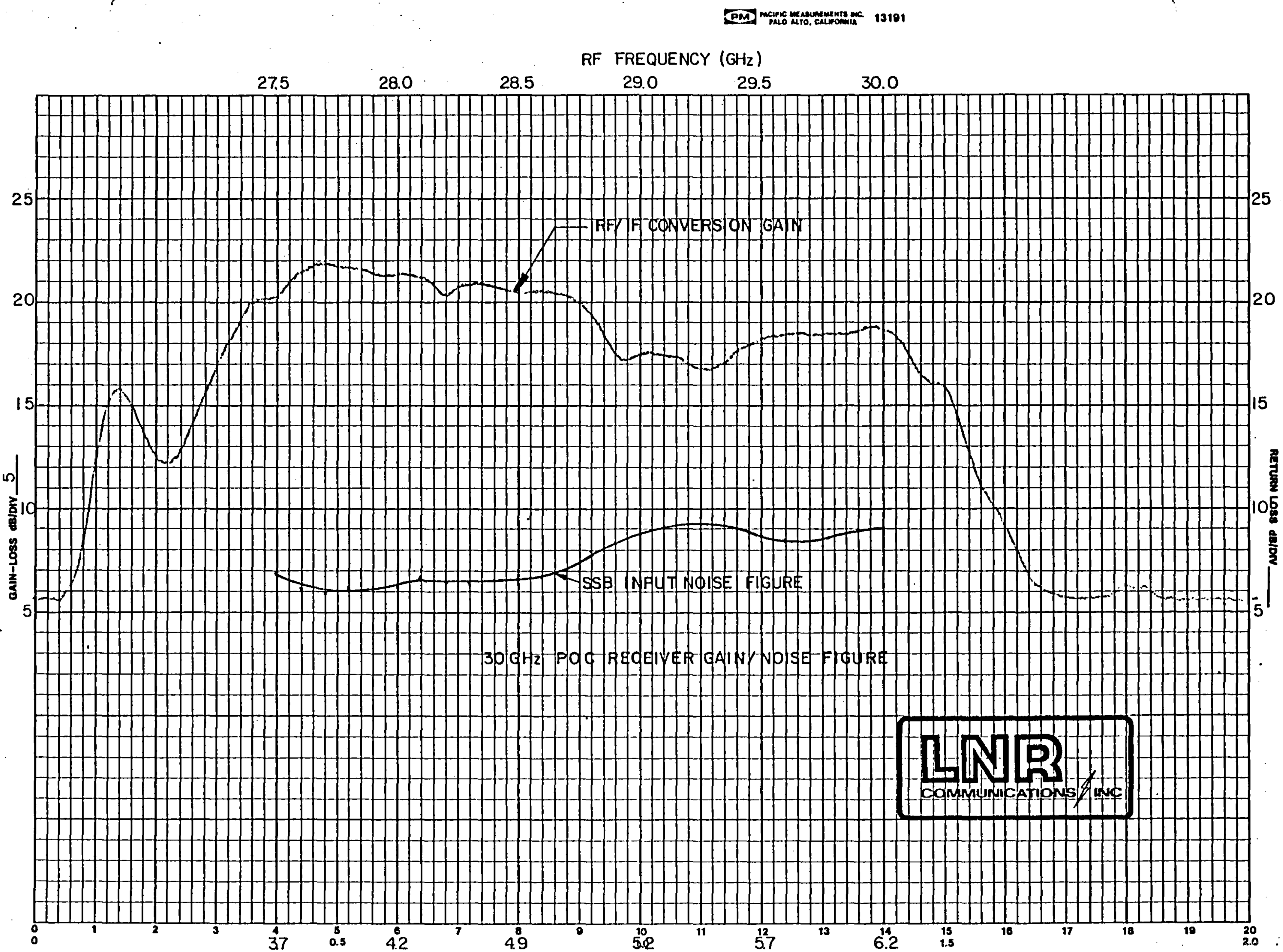


Figure 18B POC S/N 002

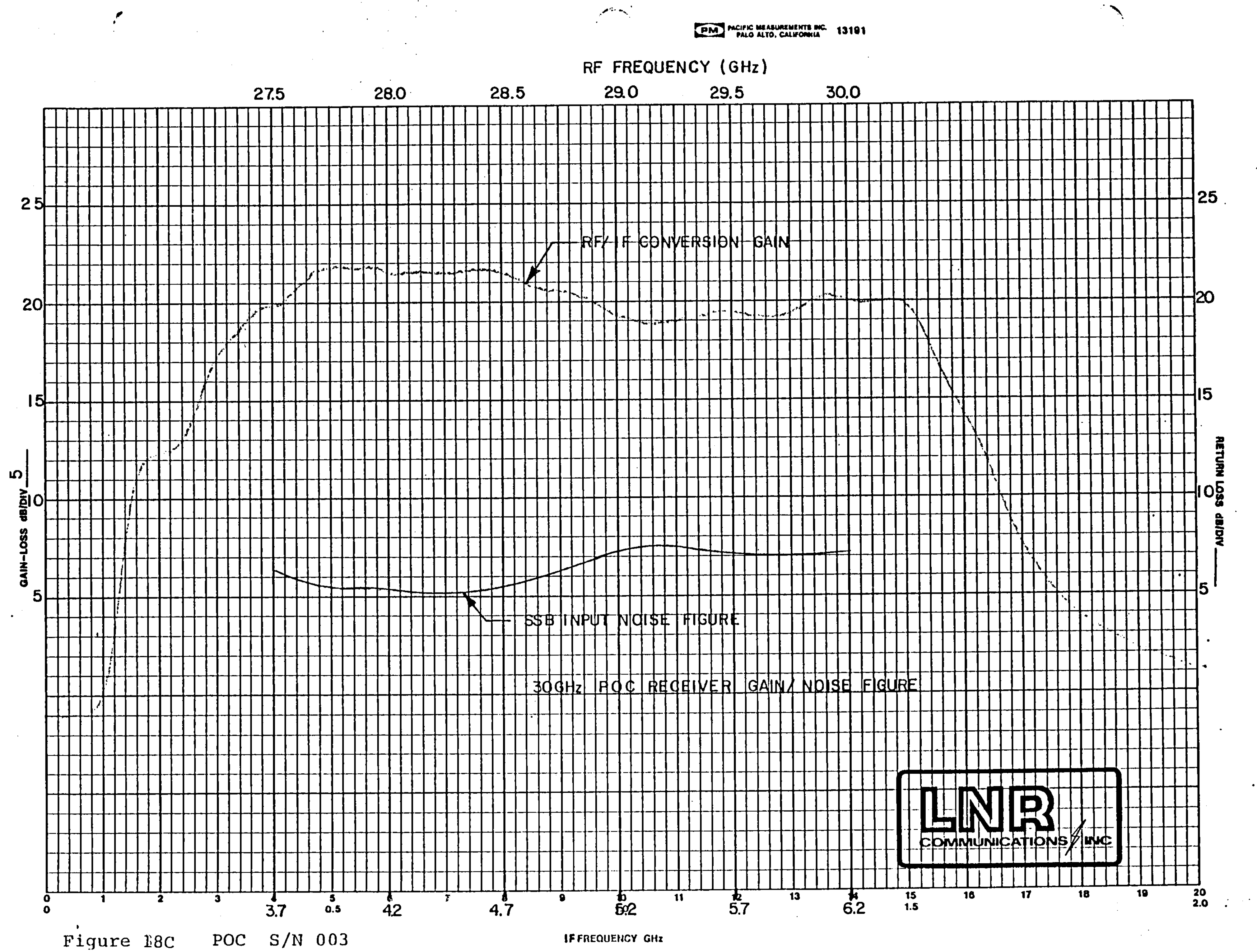


Figure 18C POC S/N 003

The measured phase noise spectrum of the POC receiver, as sampled at the output of the phase locked 5.95 GHz voltage controlled oscillator (which, in combination with a x4 varactor multiplier, comprises the 23.8 GHz mixer LO source) is shown in Figure 19. At offset frequencies from the carrier of 10 KHz to 10 MHz, the highest sideband phase noise density occurs at approximately the phase-locked-loop bandwidth of 150 KHz and is typically -95 dBc/Hz. At the local oscillator frequency of 23.8 GHz (and consequently at the receiver output) this phase noise density will be increased by 12 dB, because of the x4 multiplier, and be at a level of -83 dBc/Hz. Within the loop bandwidth, the phase noise will replicate that of the 500 MHz crystal input reference source increased by 34 dB. The low LO source phase noise spectral characteristics imparted to the receiver, is considered essential for wide band data communications.

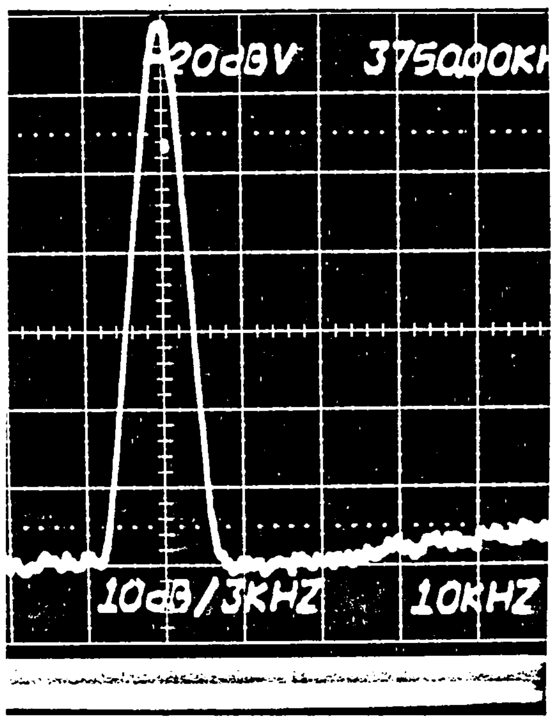
The DC prime power drain exhibited by each of the three POC receivers ranged between 6 and 8 watts. This variation is caused by the variation in efficiency of the medium power FET transistor used in the 5.95 GHz VCO. For future units a DC power requirement of 7 watts maximum can be achieved by additional screenings of the FET transistor characteristics.

Because of the degree of difficulty envolved in measuring the group delay characteristics of the POC receiver, an analytical technique was used to calculate the group delay of the three stage IF amplifier. This approach is made possible due to the minimum reactance functional relationship of the amplification process and by an accuate model used to represent the amplifier. In addition to the above, the group delay of the IF amplifier was calculated based upon the measured transmission phase of the amplifier. A 20 point curve fit computer program was then used to calculate the various components of group delay across the full 2.5 GHz bandwidth.

A comparison of the group delay coefficients obtained by the two methods described above show very close correlation for the linear, parabolic, and ripple components. It should be noted that the group delay characteristics were calculated for the full 2.5GHz bandwidth. The parabolic and ripple components for a 100MHz segment of the passband will be much smaller than calculated, and even the calculated coefficients are well within the specification of less than +0.1 nS/MHz^2 and 5nS peak-peak ripple.

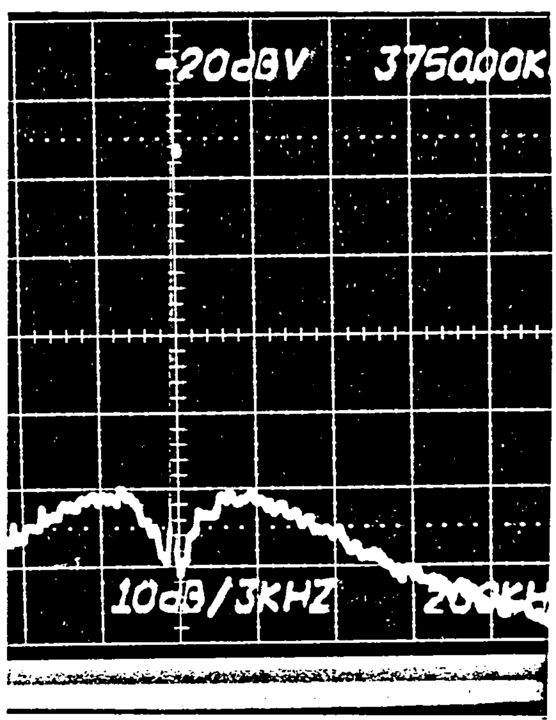
MEASURED PHASE LOCKED 5.95 GHz VCO PHASE NOISE SPECTRUM

RF Power
Density
dBc/3 KHz BW
10 dB/div



Frequency Offset
10 KHz/div

RF Power
Density
dBc/3 KHz BW
10 dB/div



Frequency Offset
200 KHz/Div

FIGURE 19

Thermal-Vacuum Characteristics

The thermal-vacuum performance of the receiver was measured by monitoring the conversion gain characterisitcs of the receiver while it was mounted in a vacuum chamber. This test was conducted on one POC receiver. A photograph of the thermal-vac test station is shown in Figure 20. It should be noted that coupling a 30 GHz signal in waveguide into a thermal-vacuum chamber creates major interface problems; several waveguide-to-coax transitions had to be used which introduced considerable amplitude ripple on the 30 GHz input signal. However, since primarily the variation in RF/IF conversion gain versus baseplate temperature was of interest, the absolute shape of the gain response was not important. Also, to eliminate the effects of RF input signal variations, reference plots of the input signal level were taken at all data points. A summary of the measured relative RF/IF gain variation of the POC receiver versus baseplate temperature at several discrete frequencies is presented in Table 11. It can be seen from the data that the maximum peak-to-peak relative gain variation at any frequency is 1.4 dB over a baseplate temperature range of 10°C to 50°C.

Additionally, the characteristics of the phase locked 5.95 GHz VCO was continuously monitored during the thermal-vacuum testing, using the spectrum analyzer depicted on the right side of the photograph in Figure 20. Phase lock was acquired immediately after application of DC power, and no loss-of-lock was observed during the testing.

FIGURE 20 THERMAL-VAC TEST STATION

TABLE 11

BP TEMP. PRESSURE	RF SIGNAL FREQUENCY (GHz)					
	27.5	28.0	28.5	29.0	29.5	30.0
27°C-AMB.	20.9	19.5	24.0	21.4	20.0	22.8
27°C-VAC.	21.1	19.1	24.1	20.8	19.4	21.9
50°C-VAC.	21.0	20.5	23.5	20.4	19.8	21.8
10°C-VAC.	20.0	20.0	24.5	21.5	19.4	22.4
27°C-VAC.	21.3	19.8	24.8	21.8	20.2	22.7
27°C-AMB.	20.6	19.9	23.9	20.8	19.7	22.8

RELATIVE RF/IF CONVERSION GAIN (dB)
THERMAL-VACUUM

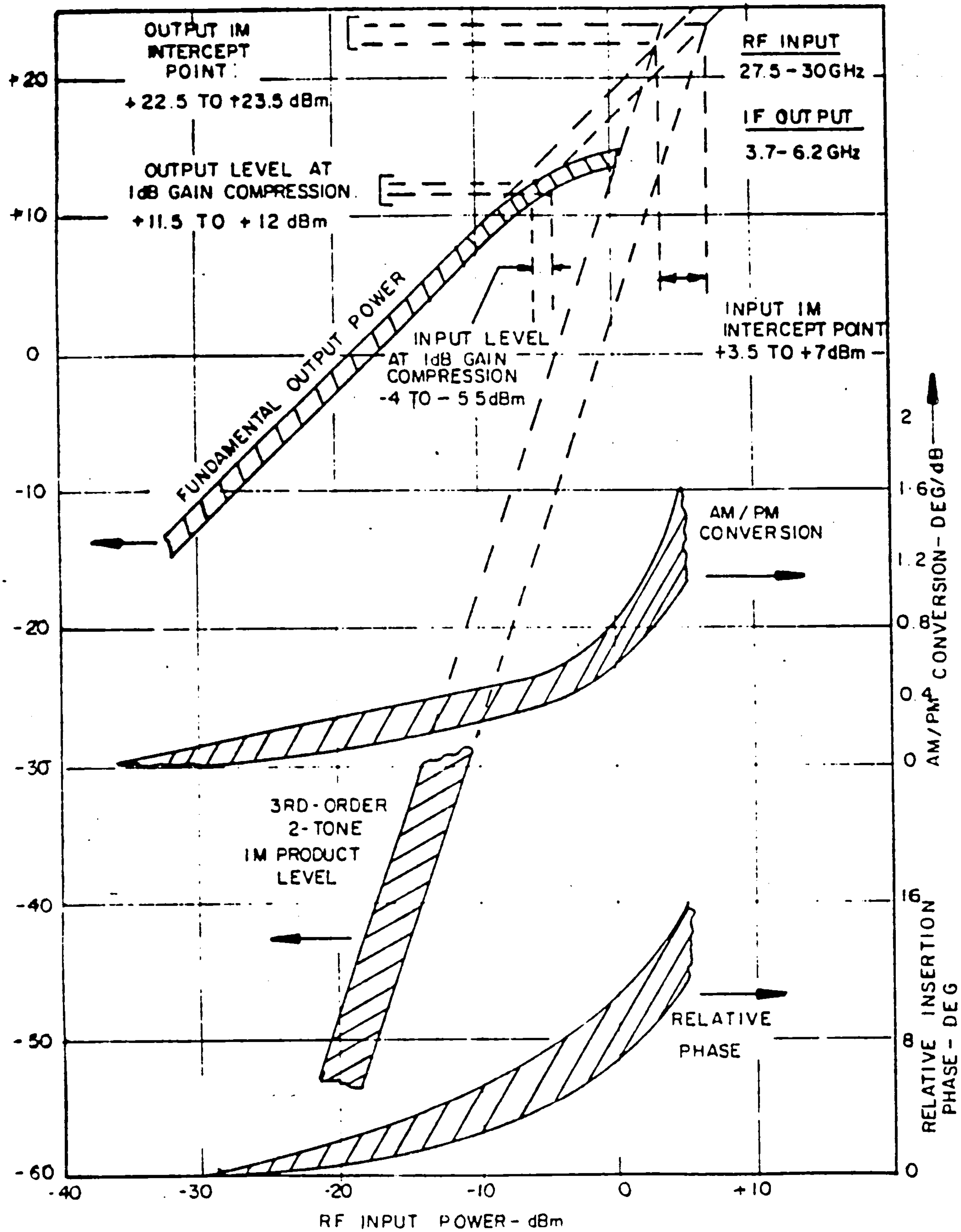
Dynamic Range Characteristics

A summary of the measured POC receiver dynamic range characteristics is presented in Figure 21 . The output -1 dB gain compression point is basically controlled by the IF amplifier output stage FET compression point. Hence, the receiver output 1 dB compression point could be increased by utilizing a higher power FET in the output stage if required, under which condition the two tone output intercept point and the AM/PM conversion characteristics would be increased correspondingly.

With large and small in-band CW carriers simultaneously incident at the input of the receiver, the output level of the small signal was suppressed by 3 dB for a large signal input level of -2 dBm; the latter being approximately 3 dB higher than the input -1 dB compression point. Moreover, the effect of an out-of-band interfering signal on POC receiver performance was simulated by applying a +5 dBm CW signal level to the receiver input at 34GHz and observing the increasing degree of suppression of a small in-band signal as the frequency of the large signal was brought closer to the 27.5 to 30.0 GHz passband. The 3 dB suppression points of the receiver passband small signal gain response was observed at large signal interferor frequencies of 26.35 and 31.00 GHz.

The amplitude and phase recovery of the receiver after being subjected to an in-band, high level, pulsed RF signal was measured utilizing a pulse-biased PIN diode waveguide switch to generate the interfering pulsed signal. The pulsed RF signal was applied at a peak power level of +5 dBm, with a pulse width of 20 nsec and a rise and fall time of 2 nsec. The amplitude recovery of a small signal to within 1 dB of its non-pulsed value was measured at 0.8 usec relative to the trailing edge of the pulse. The pulsed signal level was reduced until the recovery time decreased to 5 nS; this input pulsed RF level was +2 dBm. The phase recovery response of the small signal was such that the maximum phase deviation did not exceed 6 degrees after removal of the pulsed signal at a level of +5 dBm.

The general performance of the POC receivers is summarized in Table 2.



MEASURED DYNAMIC RANGE CHARACTERISTIC OF 30GHz POC MODEL RECEIVER

FIGURE 21

7.0 Conclusions and Recommendations

This final report summarizes the results of a two year program conducted by LNR Communications, Inc. to design, develop and implement in proof-of-concept (POC) model form, a space-qualifiable 27.5 - 30.0 GHz low noise communications receiver "front-end" for ultimate spacecraft deployment. The specific accomplishments of the program included demonstration of:

- Wide bandwidth image-enhanced mixer performance at 30 GHz.
- Low-noise 2.5 GHz bandwidth IF amplifier performance.
- Low phase noise, phase-locked, local oscillator source at 23.8 GHz.
- High dynamic range EHF receiver capability.
- Thermal-vacuum receiver performance integerity.

Improvements in the 30 GHz receiver gain and noise performance can be anticipated for future iterations of the receiver design based upon the current availability of lower noise figure microwave FET devices and refinements in impedance matching of the mixer RF and IF ports.

The projected level of performance for an improved front-end design is an RF/IF conversion gain of 20 ± 0.5 dB and an input noise figure of 4.5 to 5.5 dB over the 27.5 - 30.0/3.7 - 6.2 GHz instantaneous RF input/IF output band.

For ultimate spacecraft useage, the low-noise "front-end" can be configured in a 8"x6"x2 enclosure, requiring less than 7 watts of DC prime power, and weighing a total of 3lbs.

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