~6-8-98

# IRAM PROPOSAL:

MM-WAVE RANGE 80-400 GHz.

- Prototyping of LSA technology on next generation of PdB interf. receivers
  - Closed cycle cryocoolers
  - LSA-type focal plane layout
  - Fully automatic remote control & tuning
- Reliability testing under actual working conditions.
- Open to discuss delivery of prototype LSA receiver within framework of LSA dev$^t$ program.

## IRAM CAPABILITIES

- Development and series production of receivers for various telescopes: PdB, PV, SEST
  6x 2ch + 5x 2ch + 1x 2ch
- Low-noise, reproducible, stable receivers, using simple technology
- Automatic tuning under computer control since 8 years on PdBI

Possible organization for LSA receiver development + production

- One central „PI" institution
  (could be existing larger institute or small consortium)
  - overall system design (with receiver WG as advisory committee)
  - interface definition for components
  - coordination of participating inst. documentation

  in construction phase:
  - contracts for mass fabrication (mass fab. in house)
  - receiver assembly
  - receiver testing

- Participating institutes (selection ?)
  - development of components (including parallel developments where sensible)
  - small prototype series fabrication of components to demonstrate mass fab. procedures
  - if possible: mass fabrication (e.g. SIS-junctions and circuits)

Participating institutes ctd.

- support to „PI" institution for system design and mass fab.

ESO delegates management to PI institute (?)

Possible scenario for division of work

A) between US and Europe:

1) common receiver design
(i.e. not separate US and EU receivers)

2) use modularity for division of work
→ division by frequency channels
(and not on component level)

3) Development work on both sides
not excluding parallel work where
productive (e.g. mixer design)

4) complete receiver assembly in
US <u>and</u> EU to share work 50/50
(→ exchange of modules and cryostats)

Needs good definition of interfaces
+ central institution in EU to coordinate
with US/NRAO

Division of work ctd.

B) within Europe:

on component level
(because of distribution of expertise in Europe)

- institutes develop components for some or all receiver modules, to be coordinated + assembled at central institute.

alternative: consortia for complete frequency channel

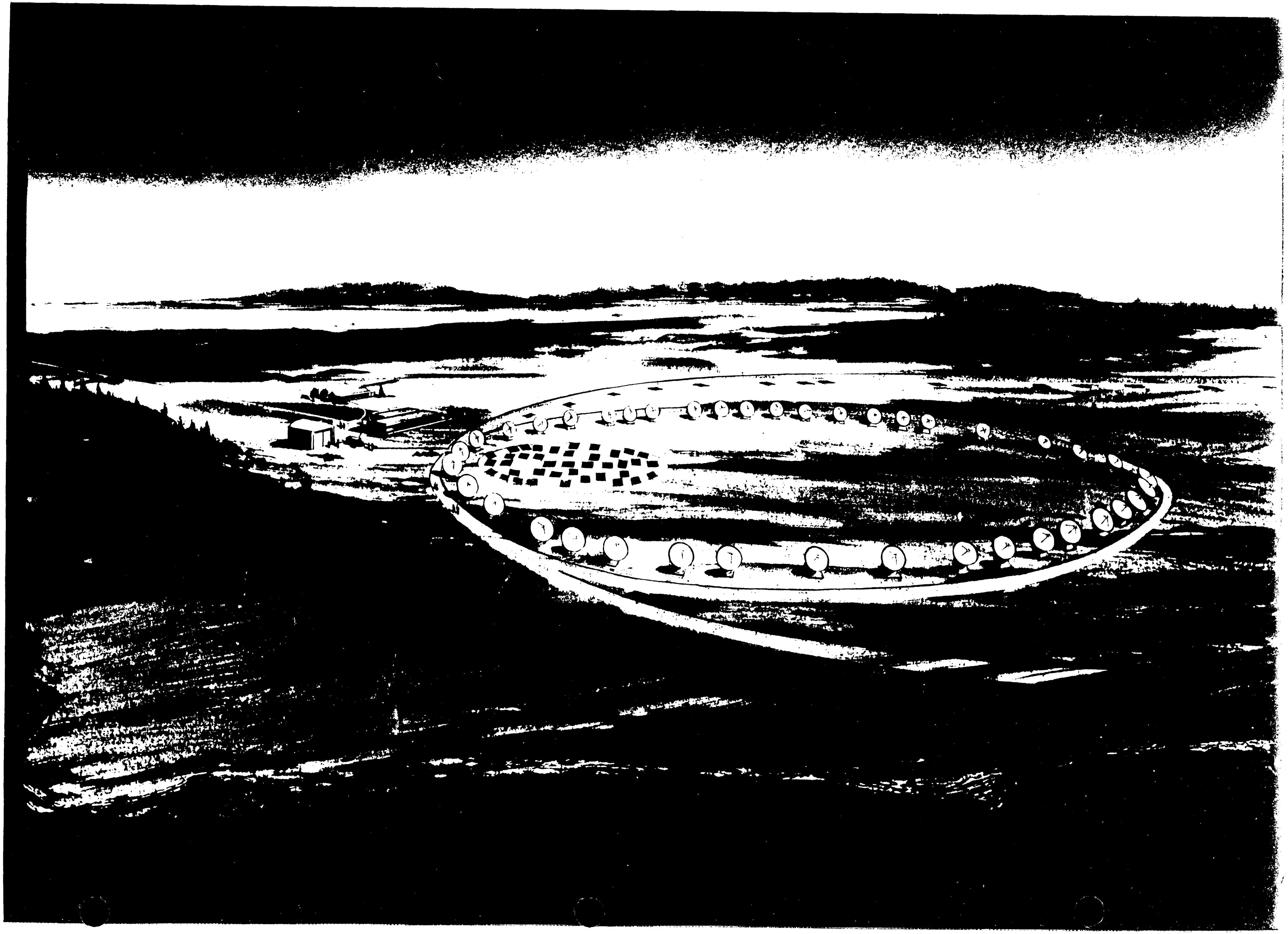
but: - duplication of efforts
(e.g. frequency scalability of mixers is not exploited)

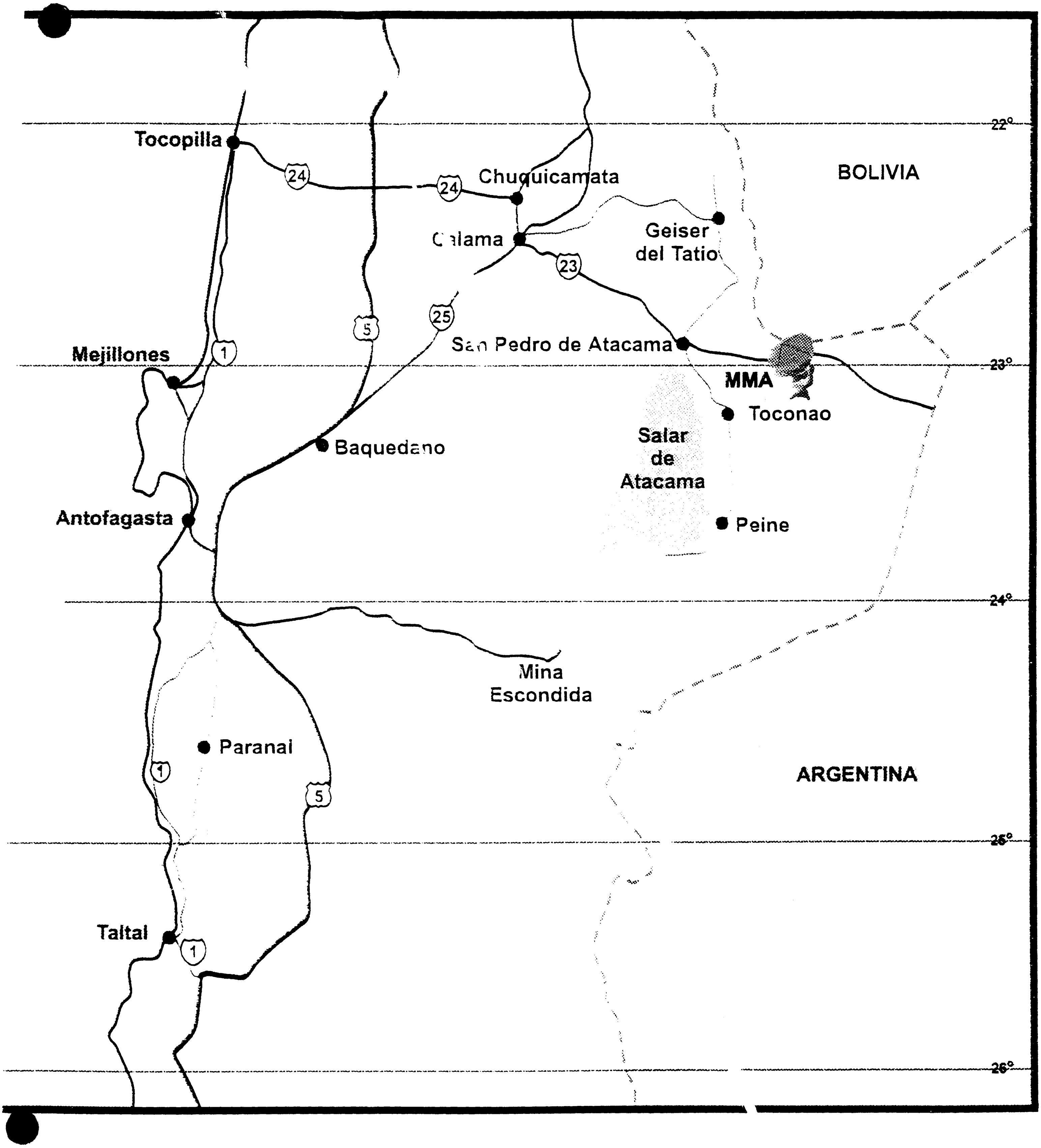
- each consortium needs coordination

| Receiver | $\nu_{low}$ (GHz) | $\nu_{center}$ (GHz) | $\nu_{high}$ (GHz) | WG Band/Detector | comments |
|---|---|---|---|---|---|
| 1 | 30 | 35 | 40 | WR-22 HFET[b] | |
| 2 | 67 | 79 | 90 | WR-12 HFET | |
| 3 | 89 | 103 | 116 | WR-8 HFET or SIS | Pending HFET development |
| 4 | 125 | 144 | 163 | WR-6 SIS | |
| 5 | 163 | 187 | 211 | WR-5 SIS | |
| 6 | 211 | 243 | 275 | n-sc SIS | |
| 7 | 275 | 323 | 370 | n-s SIS | Bandwidth ratio of 1.35 |
| 8 | 385 | 442 | 500 | WR-2.2 SIS | |
| 9[d] | 602 | 660 | 720 | n-s SIS | |
| 10[d] | 787 | 869 | 950 | n-s SIS | |

[a]Band definitions are for good sensitivity degrading increasingly beyond edges
[b]Some sensitivity is needed through the VLBA band. to 45 GHz
[c] n-s means non-standard
[d]Receiver bands #8 and #9 are bandwidth limited by the atmosphere

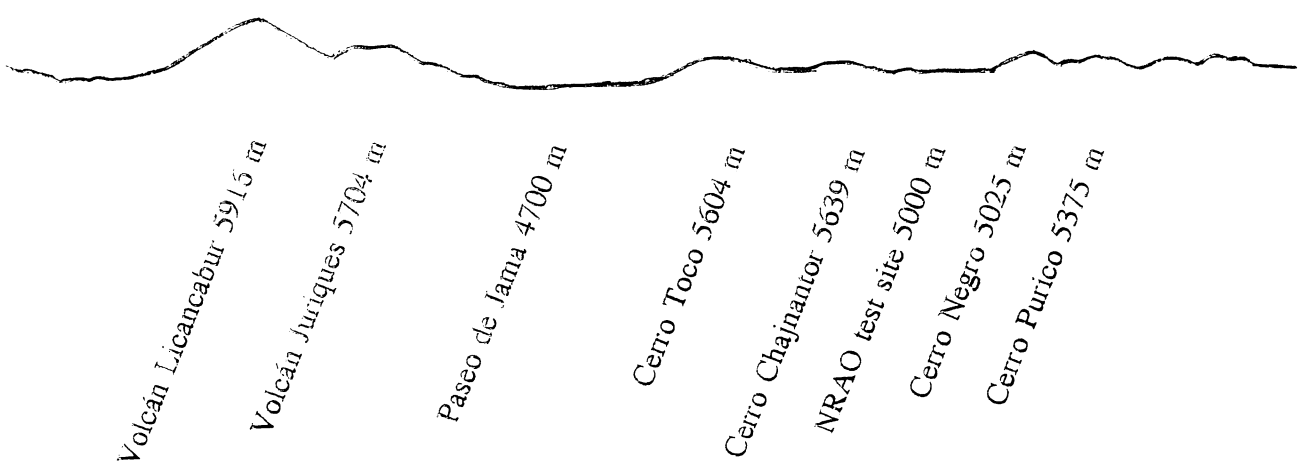
**Table 3:** Recommended Receiver Coverage[a]





Tocopilla
24
Chuquicamata
BOLIVIA
Calama
Geiser
del Tatio
23
22°
Mejillones
1
5
25
San Pedro de Atacama
MMA
23°
Toconao
Baquedano
Salar
de
Atacama
Antofagasta
Peine
24°
Mina
Escondida
Paranal
ARGENTINA
1
5
25°
Taltal
1
26°

# SAN PEDRO DE ATACAMA



NATIONAL RADIO ASTRONOMY OBSERVATORY

# TOPOGRAPHIC MAP OF CONICYT SCIENCE PRESERVE

CONTOUR INTERVAL: 5m

| CONICYT BOUNDARIES | | |
|---|---|---|
| A | N642000 | E7465000 |
| B | N642000 | E7444000 |
| C | N616000 | E7444000 |
| D | N615002 | E7468000 |
| E | N630500 | E7468000 |
| F | N630500 | E7465000 |

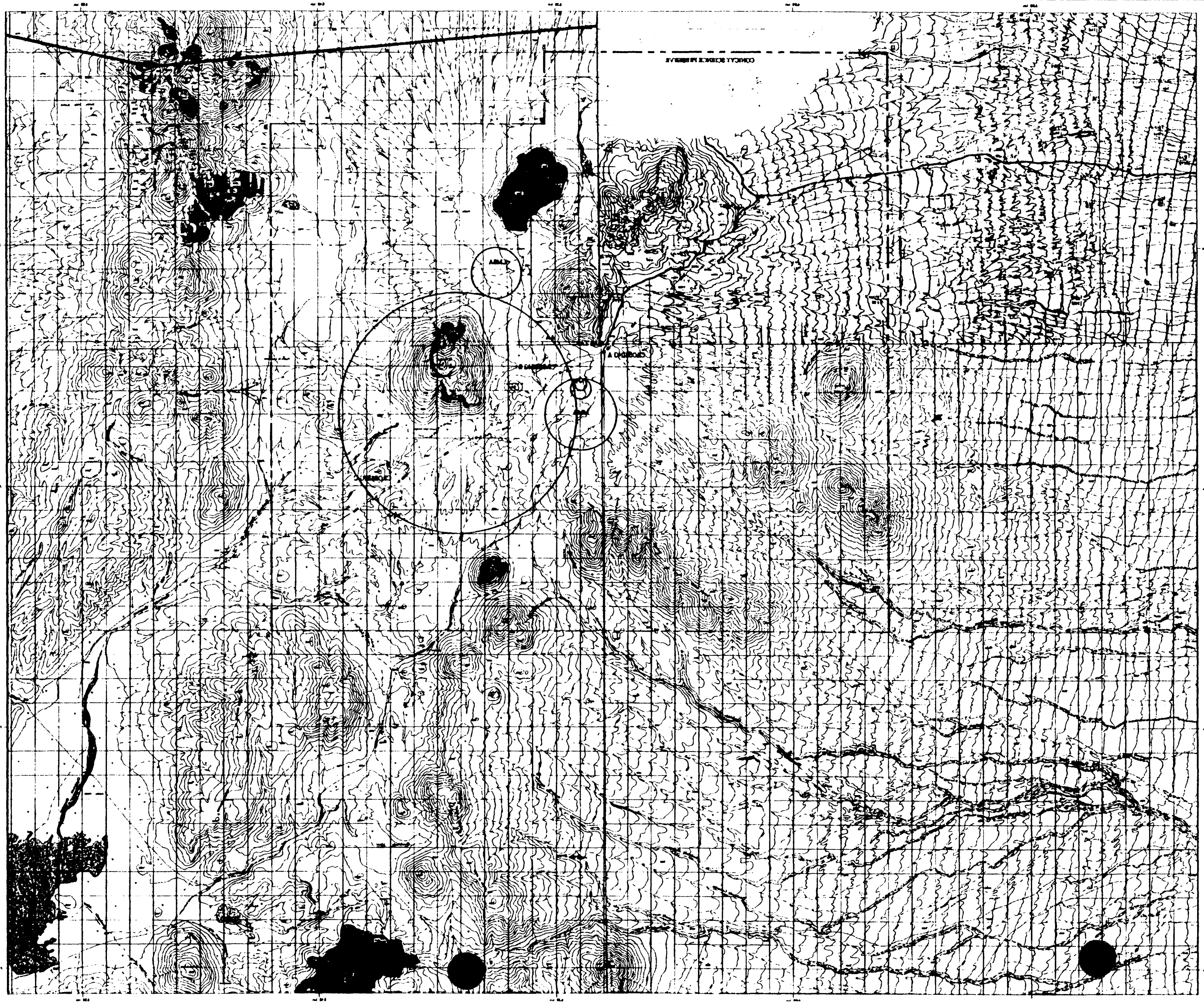
A Array @3000 m 36 Elements
B Array @ 860 m 36 Elements
C Array @ 250 m 36 Elements
D Array @ 85 m 36 Elements
AA Array @ 10,000 m >>36 Elements

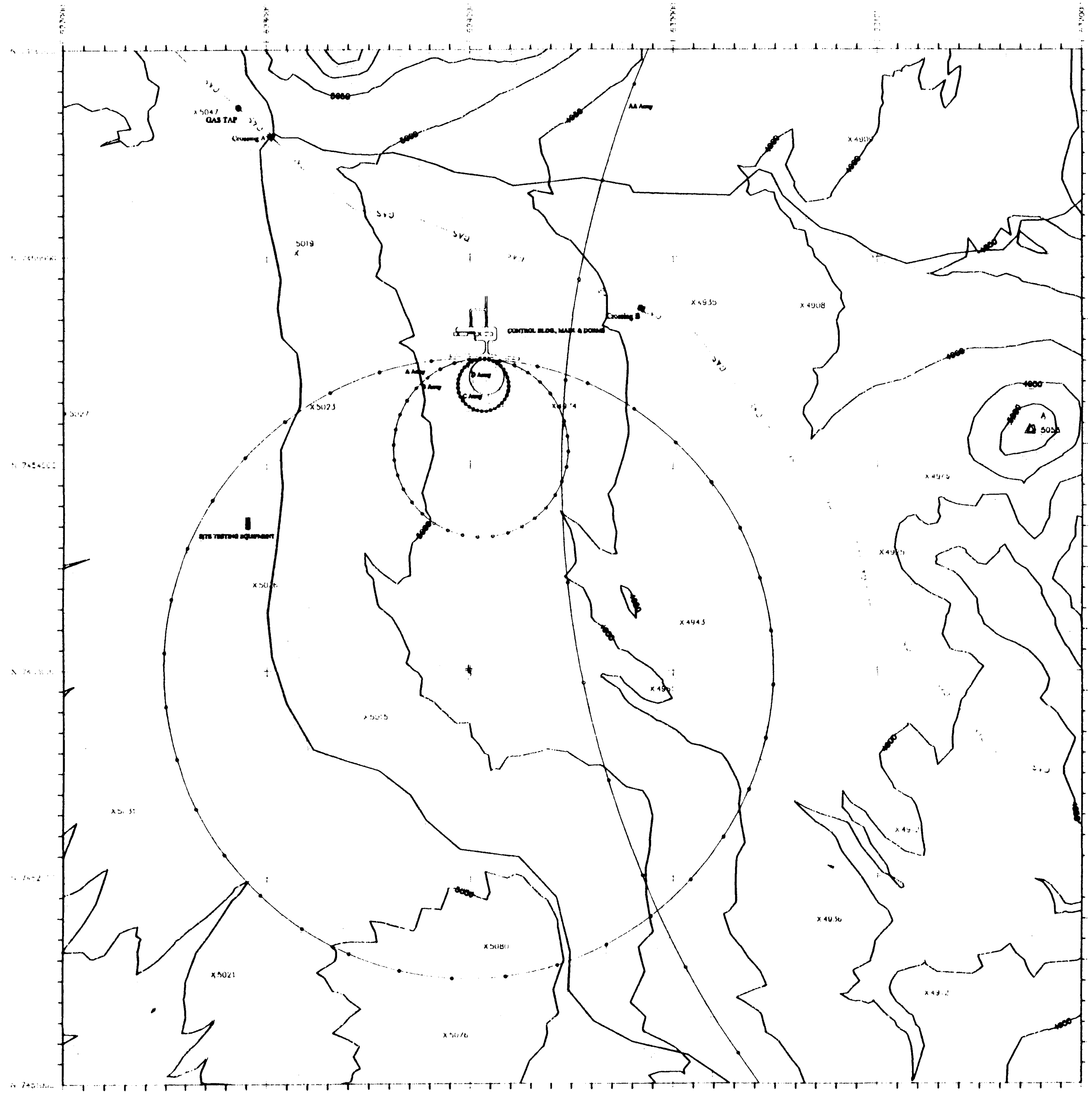
A Array Center N7453009.4 E628991.0

Pipeline Crossing Points
Crossing A N7455582 E628019
Crossing B N7454748 E629841
Crossing C N7450197 E636638

Pipeline Gas Tap Point
TAP N7455720 E627861

See crossing plan drawing & Science Preserve drawing
GA New Pipeline Location Feb. 25, 1998






NATIONAL RADIO ASTRONOMY OBSERVATORY

949 NORTH CHERRY AVENUE
TELEPHONE (520) 882 8250

CAMPUS BUILDING 65
FAX (520) 882 7955

TUCSON, ARIZONA 85721-0655 USA
email: mma@nrao.edu

# TOPOGRAPHIC MAP OF LLANO DE CHAJNANTOR, CHILE

N

CONTOUR INTERVAL: 10m

TOPOGRAPHIC INFORMATION WAS TAKEN FROM AERIAL PHOTOGRAPHY (1981-1982) BY INSTITUTO GEOGRAFICO MILITAR DE CHILE, HAVING A SCALE OF 1:45000 UTM COORDINATES ARE TAKEN FROM THE GEODESIC SA56 MAP PUBLISHED IN 1985.

McLAIN AERIAL, INC.

**A Array Ø3000 m 36 Elements**
**B Array Ø 860 m 36 Elements**
**C Array Ø 250 m 36 Elements**
**D Array Ø 85 m 36 Elements**
**AA Array Ø 10,000 m >>36 Elements**

**A Array Center N7453009.4 E628991.0**

**Pipeline Crossing Points**
**Crossing A N7455582 E628019**
**Crossing B N7454748 E629841**
**Crossing C N7450197 E636638**

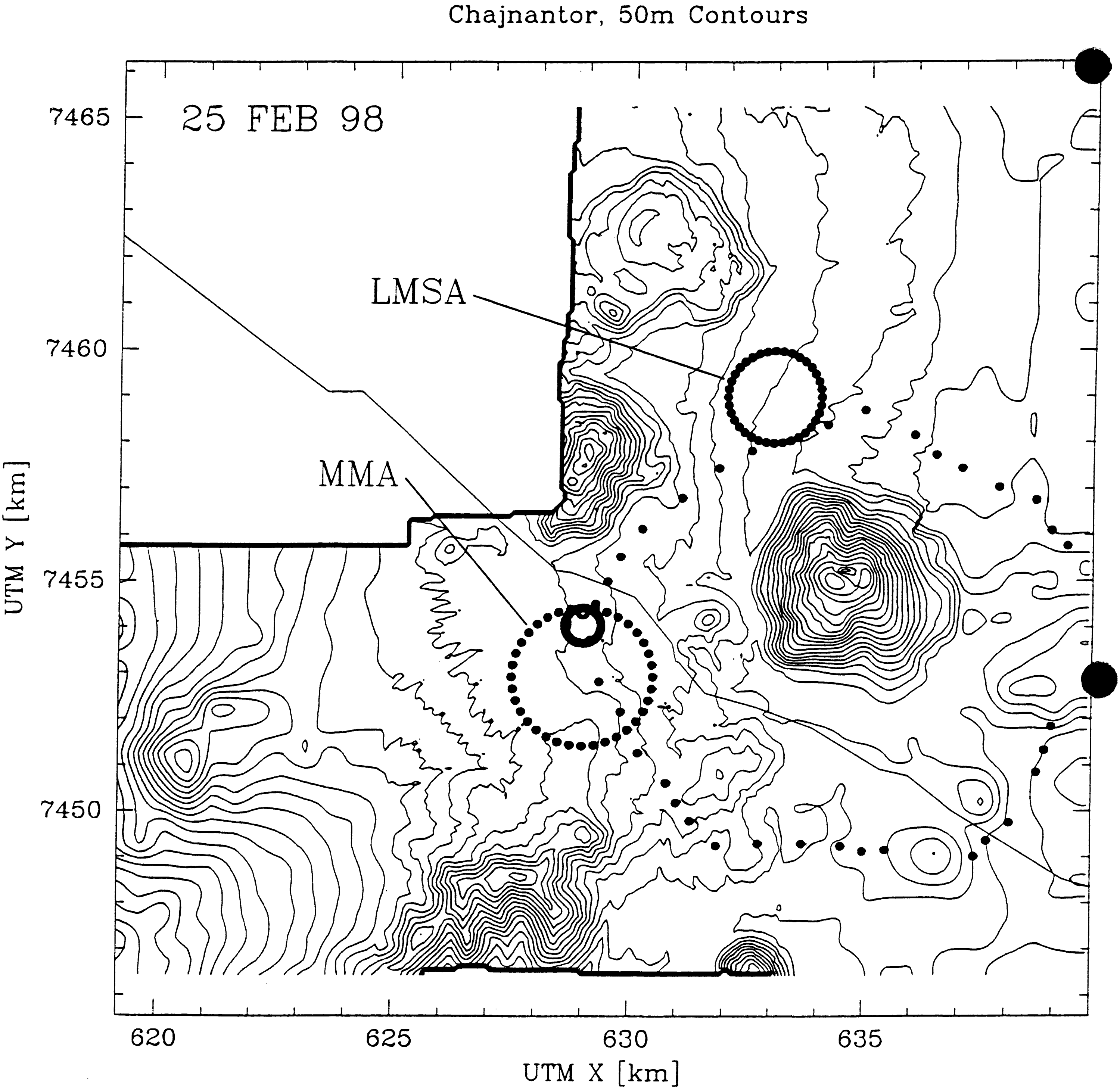
**GAS TAP N7455720 E627861**

**See crossing plan drawing & Science Preserve drawing**

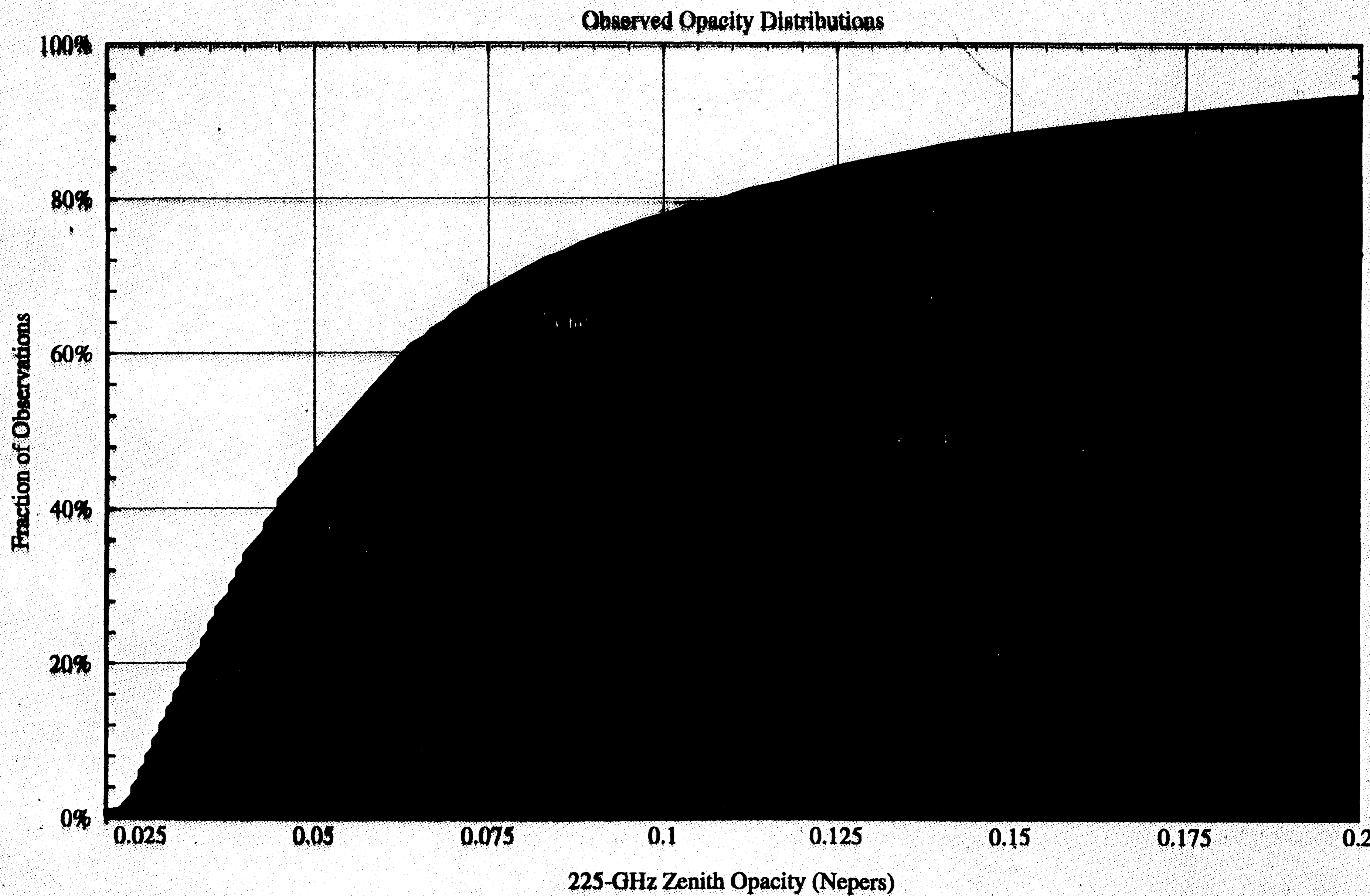
GAS **GA New Pipeline Location Feb. 25, 1998**

1km

FILE: GA1fin.dwg
June 1, 1998
MMADS0004-F



Chajnantor, 50m Contours
25 FEB 98
LMSA
MMA
7465
7460
7455
7450
UTM Y [km]
620
625
630
635
UTM X [km]



Observed Opacity Distributions
100%
80%
60%
40%
20%
0%
Fraction of Observations
0.025
0.05
0.075
0.1
0.125
0.15
0.175
0.2
225-GHz Zenith Opacity (Nepers)

# MMA SENSITIVITY GOALS

**Continuum** - In 60 seconds of integration time the RMS flux density achieved is:

| Frequency (GHz) | ΔS (mJy) |
|---|---|
| 35 | 0.067 |
| 90 | 0.065 |
| 140 | 0.056 |
| 230 | 0.080 |
| 345 | 0.14 |
| 650 | 0.48 |

**Spectroscopic** - In 60 seconds of integration time the RMS flux density achieved with channel widths of 1 km $s^{-1}$ and 25 km $s^{-1}$ respectively is:

| Frequency (GHz) | ΔS (1 km $s^{-1}$) (mJy) | ΔS (25 km $s^{-1}$) (mJy) |
|---|---|---|
| 35 | 18 | 3.5 |
| 90 | 10 | 2.1 |
| 140 | 11 | 2.2 |
| 230 | 13 | 2.6 |
| 345 | 18 | 3.5 |
| 650 | 43 | 8.6 |

## TABLE 4.1 OVERVIEW AND COMPARISON OF MMA INSTRUMENTATION GOALS

| [illegible] | [illegible] | [illegible] |
|---|---|---|
| **ANTENNAS** | | |
| RSS Surface Accuracy | < 25 microns | 30-80 microns |
| **Pointing Precision** | $0''.8$ | > 3" |
| **Fast Switching** | Cycle < 10s | No Capability |
| **Total Power Observing** | Yes | No Capability |
| **RECEIVERS** | | |
| 28-45 GHz HFET | Yes | Special Purpose only |
| 67-95 GHz HFET | Yes | No Capability |
| 91-119 GHz SIS or HFET | Yes | Yes |
| 125-163 GHz SIS | Yes | NRO only |
| 163-211 GHz SIS | Yes | No capability |
| 211-275 GHz SIS | Yes | Yes |
| 275-370 GHz SIS | Yes | No capability |
| 385-500 GHz SIS | Yes | No capability |
| 602-720 GHz SIS | Yes | No capability |
| 787-950 GHz SIS | Planned | No capability |
| SIS Balanced Mixers | Yes | No |
| SIS Image Separating | Yes | No |
| SIS Integrated with IF | Yes | No |
| Dual Polarization | Yes | No |
| IF Bandwidth | 2 x 8 GHz | 2 x 1 GHz |

## MMA: SCHEDULE AND COST

1. **Design and Development Phase FY98-00**

   — Assess prototype hardware for performance;

   — establish an "auditable" cost basis for MMA construction;

   — choose a site;

   — confirm a 25 percent involvement of external (to the NSF) partners in the MMA for construction and operations.

2. **Construction and Cost**

   — Construction is planned for the six years 2001-2006.

   — The construction cost estimate is $200M (1998 dollars).

   — Annual operations cost is estimated to be $8.5M (1998 dollars).

## MMA DESIGN AND DEVELOPMENT
## 1998 – 2001

### GOALS

- Paper design of all major MMA components.
- Prototypes of critical or high-risk instruments.
- Decision of design options.

**ANTENNA**: Prototype designed and built under contract, erected on VLA site.

**RECEIVERS**: Prototype SIS mixers at two bands.

- Image separating.
- Balanced.
- Integrated with IF amplifier.
- Scaleable to all MMA bands.

**LOCAL OSCILLATOR**: Working prototypes of two types and decision.

- Planar vacator multiplier chain.
- Photonic

### CENTRAL LO, IF, AND FIBER OPTICS

- Paper design of major components.
- Breadboards of representative modules

### CORRELATOR

- Single baseline GBT-clone.
- Definition of MMA design.

### COMPUTING

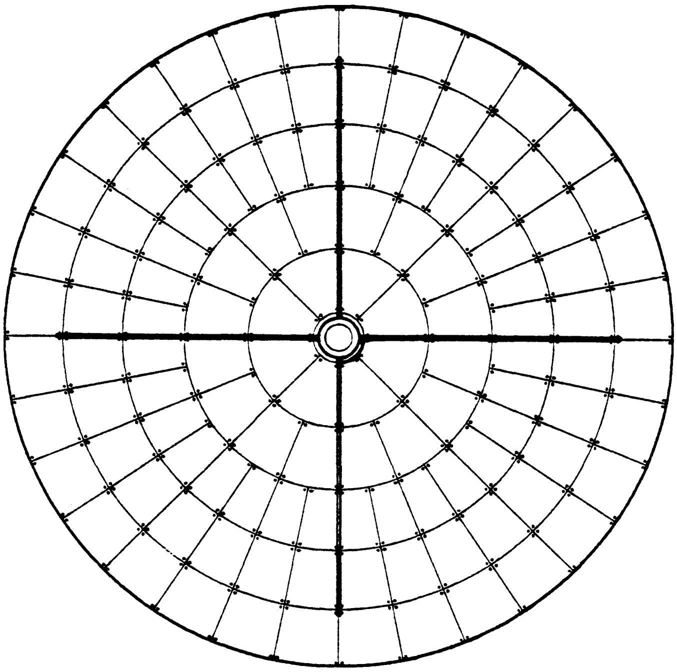
- Support of antenna/interferometer testing.
- Clear set of MMA specs from community.

# MMA TIMELINE

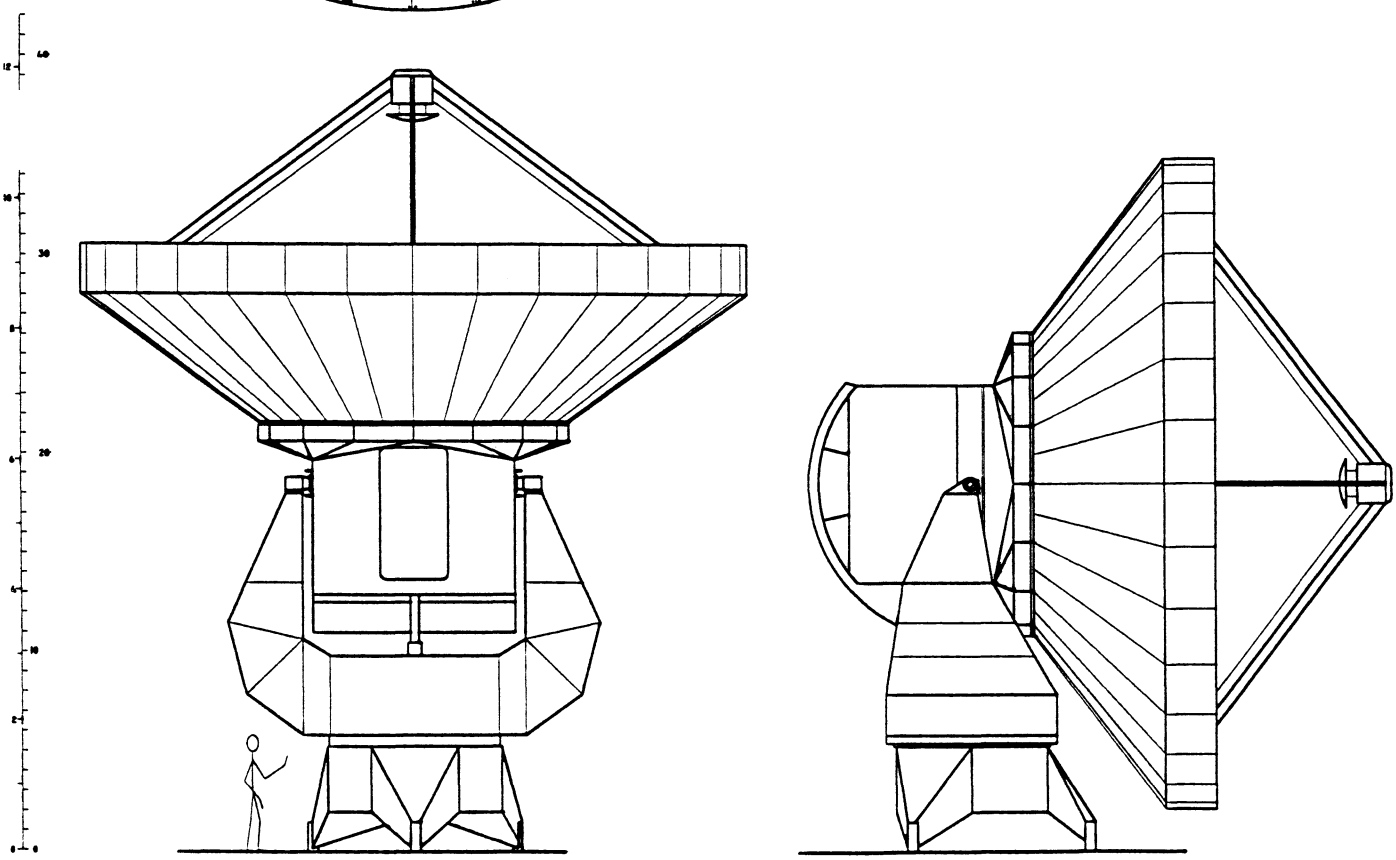
| | |
|---|---|
| 1998 – 2001 | Design and Development<br>• Complete project WBS cost and schedule.<br>• Paper designs and prototypes. |
| 2001 – 2003 | Instrument Evaluation on Test Interferometer<br>Site Engineering and Civil Works<br>OSF Buildings on site and in SPdA.<br>Initiate Production Fabrication |
| 2004 – 2007 | Delivery and Outfitting of Nine (9) Antennas a Year<br>Interim Operations |
| 2008 – 2010 | Commissioning, Retrofits, and Operation |

# MILLIMETER ARRAY

National Radio Astronomy Observatory
A facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.



| Item | Specification | Notes |
|---|---|---|
| Aperature size | 10 Meter | Minimal blockage |
| Number of antennas | 36 | Transportable |
| Site | Cerro Chajnantor, Chile | 5000 meter elevation |
| Frequency Range | 30 GHz to 950 GHz | |
| Surface accuracy | 25 microns RMS | |
| Pointing accuracy | 0.8 arcsec | 1/30 primary beam @ 300 GHz |
| Phase stablity | 10 microns RMS | Median wind conditions |
| Close packing | <1.25D | Minimal baselines |
| Dynamic performance | 1.5° in 1 sec @ 3° pointing | Fast switching for calibration |
| Slew Velocity | 3°/second | Azimuth & elevation |
| Acceleration | 12°/second squared | Azimuth & elevation |
| Resonant frequency | >7 Hz | Lowest mode |
| Subreflector | 3 beamwidths at 86 GHz | Nutation |
| Optics | Cassegrain | Minimal reflections |
| Receiver cabin size | 3 m x 3m x 2.6 m | Rectangular box |
| Cabin Door | 1 m x 2 m | |
| Elevation Range | ±270° from north | |
| Azimuth range | 0° to 95° | |
| Panels | 120 Machined Aluminum | ~1 square meter in size |
| Maximum wind speed | 65 m/sec | Survival |
| Median wind | 9 m/sec | Evaluation of spec. |
| Environment | Full exposure | Volcanic soil & gravel |



**NRAO 10 Meter Design**

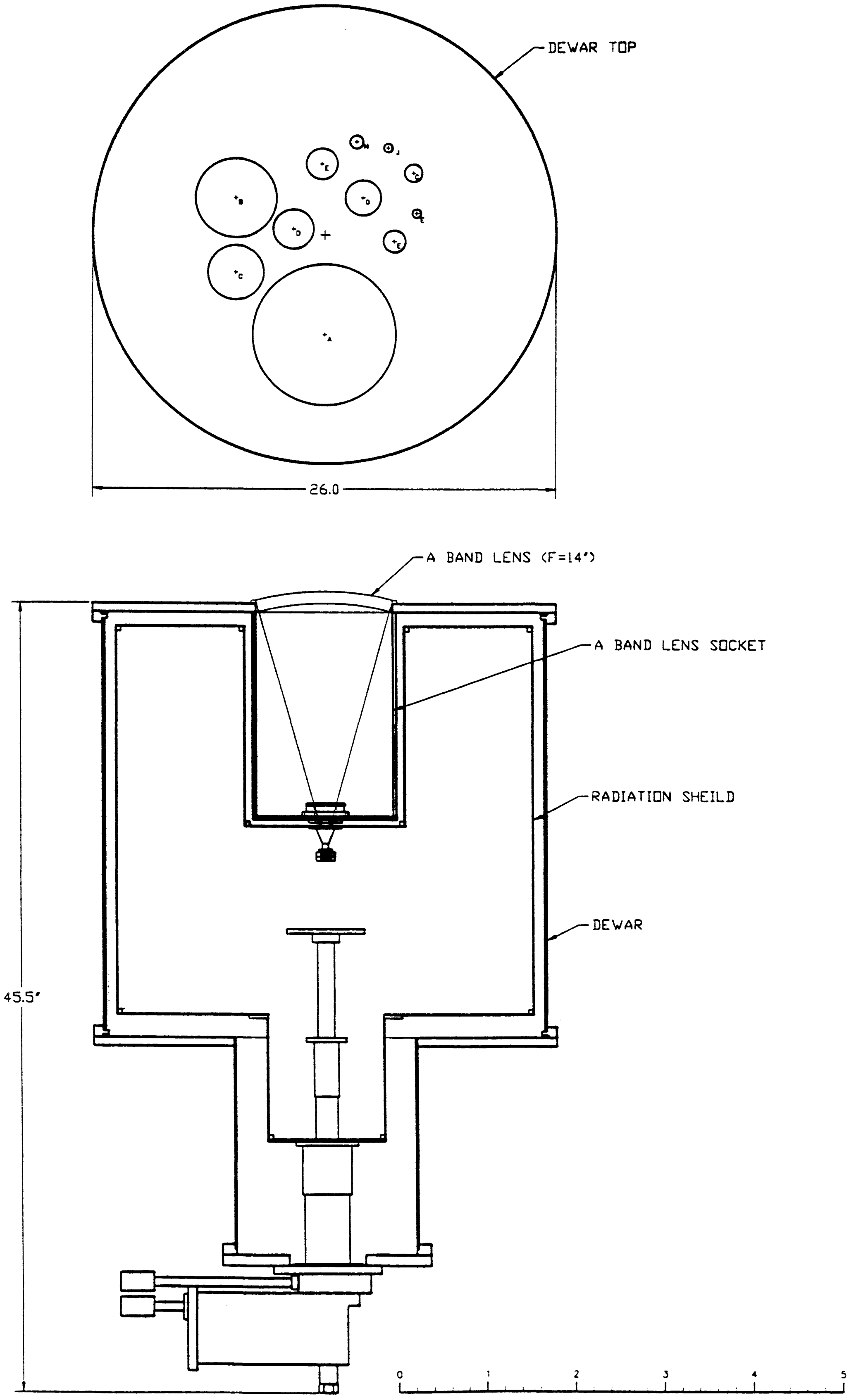
June 2, 1998

Lugten, Kingsley, Cheng & Flemming

# SINGLE DEWAR RECEIVER LAYOUT

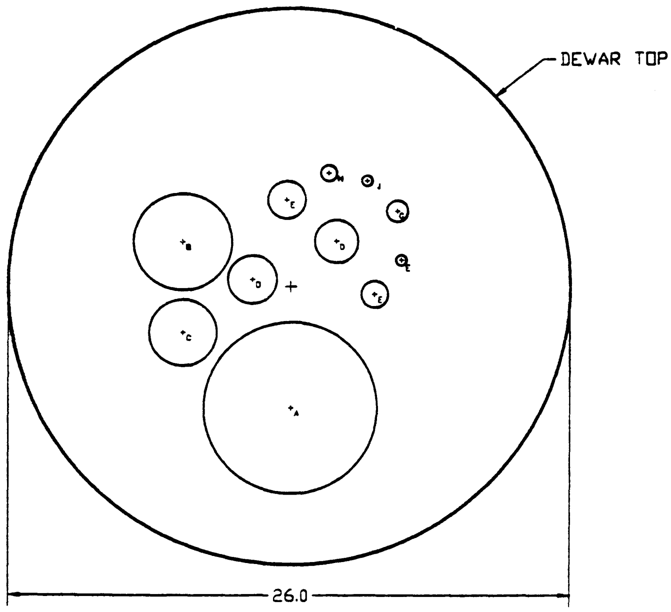
MMA Receiver Group
MARCH 21, 1997

| | |
|---|---|
| A | 30-48 GHz |
| B | 67-95 GHz |
| C | 94-133 GHz |
| D | 132-183 GHz |
| E | 182-236 GHz |
| F | 235-307 GHz |
| G | 305-400 GHz |
| H | 397-517 GHz |
| I | 602-720 GHz |
| J | 787-950 GHz |



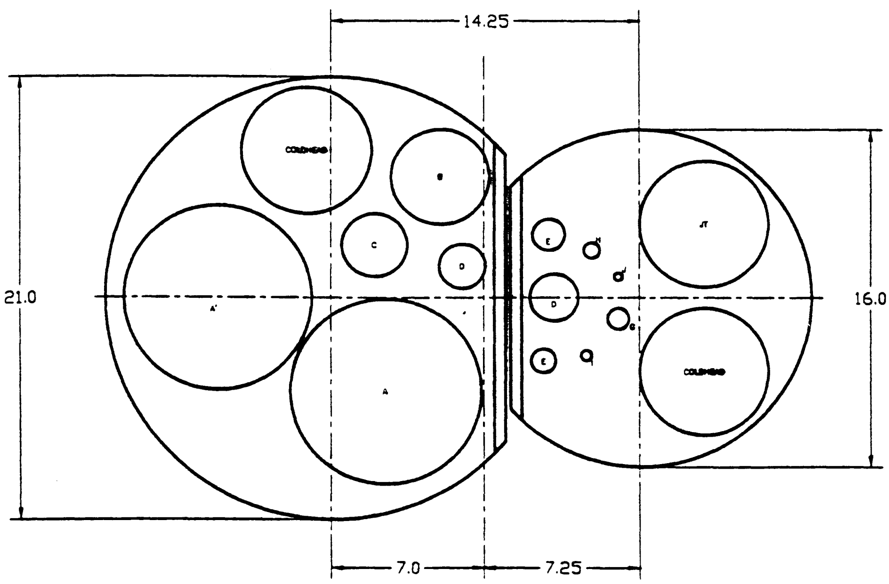
# DEWAR RECEIVER LAYOUTS

MMA Receiver Group
APRIL 15, 1997

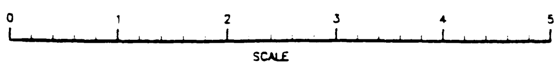



| | |
|---|---|
| A | 30-48 GHz |
| B | 67-95 GHz |
| C | 94-133 GHz |
| D | 132-183 GHz |
| E | 182-236 GHz |
| F | 235-307 GHz |
| G | 305-400 GHz |
| H | 397-517 GHz |
| I | 602-720 GHz |
| J | 787-950 GHz |

PAYNE-KERR-KINGSLEY




LUGTEN-WELCH



# LOCAL OSCILLATORS

## TWO SYSTEMS BEING CONSIDERED

### CONVENTIONAL

Gunn oscillator or YIG oscillator followed by multipliers

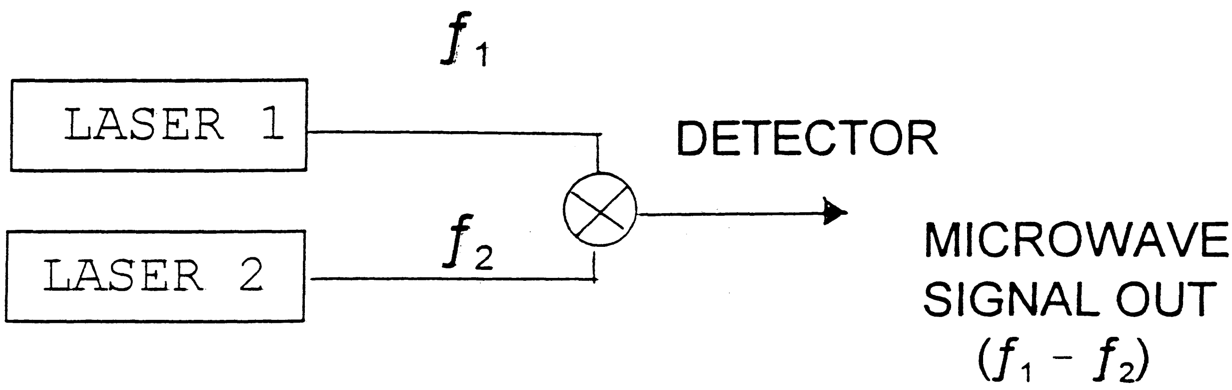
Advantages

- Proven technology
- Will work

Disadvantages

- Expensive
- Very few commercial suppliers
- Several highly specialized devices per band

# BASIS OF METHOD



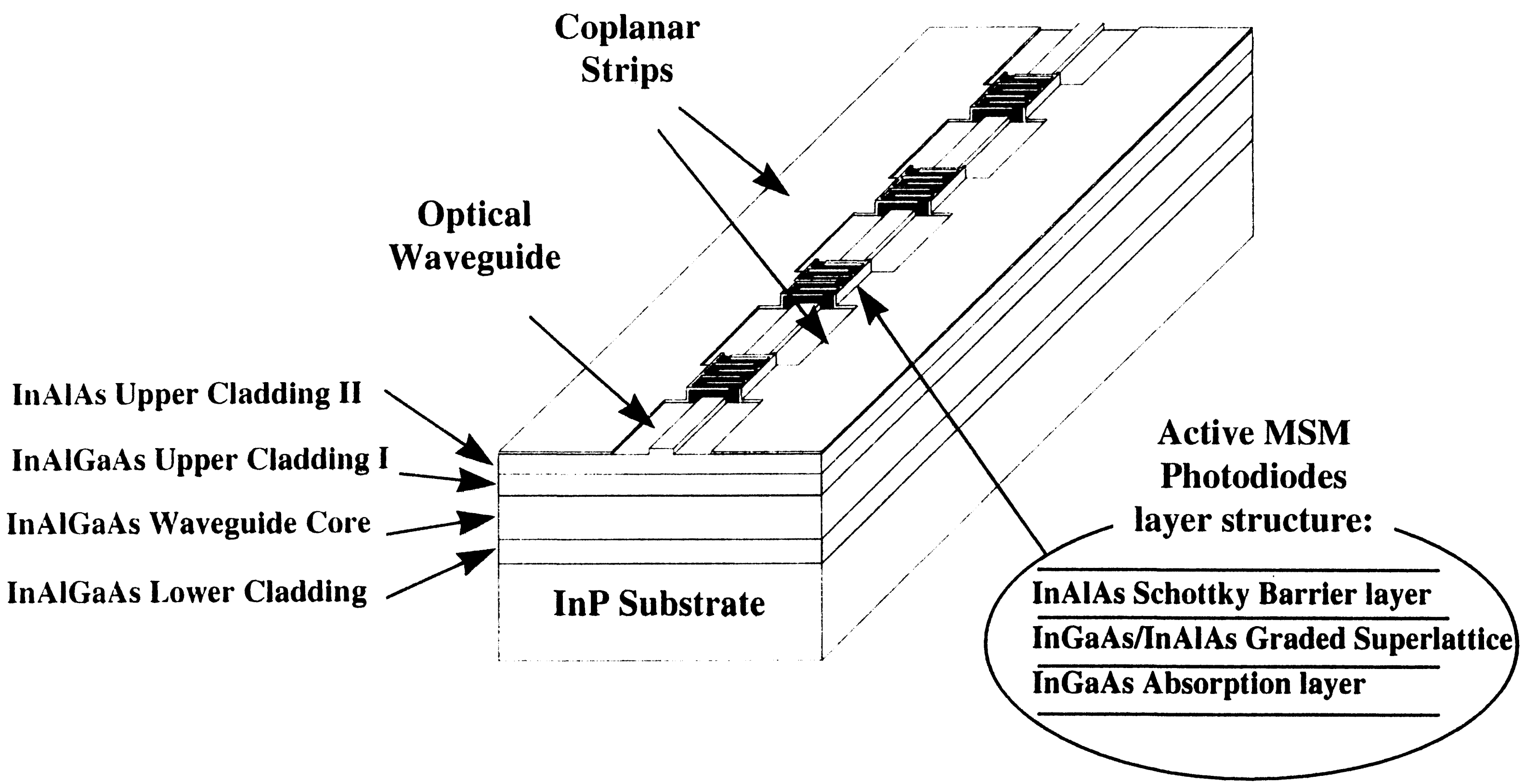

REQUIREMENTS

LASERS

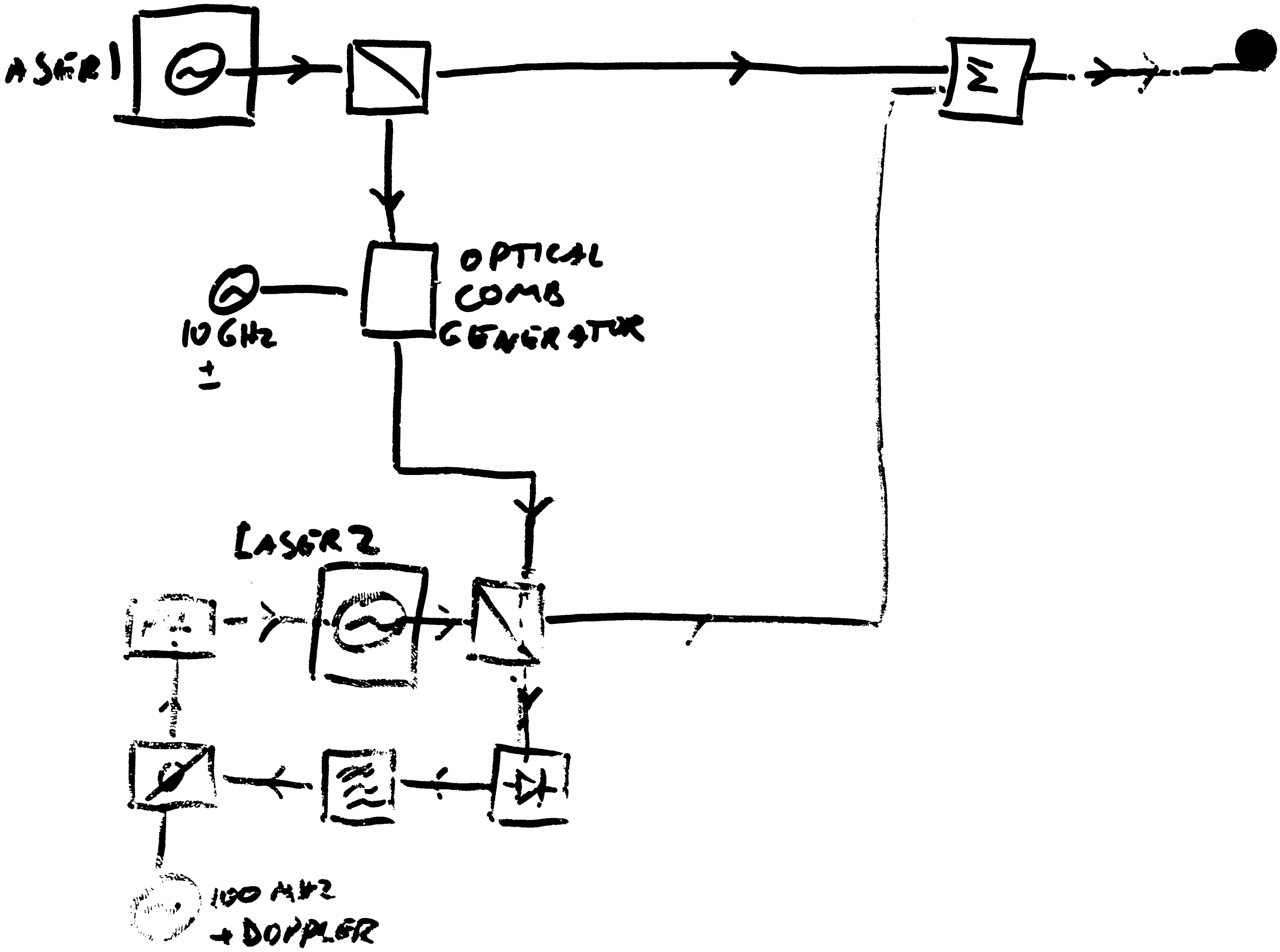
1. $\lambda = 1.5\mu$ (200 THz,) so we can use commercially developed fiber optic components.
2. High spectral purity.
3. Easily incorporated into a phase lock system locked to an external microwave reference.
4. For ease of operation, the lasers should be set-able open loop to a few MHZ.
5. Single mode operation.
6. Linear polarization.

# Schematic of Long Wavelength Velocity-Matched Distributed Photodetector (VMDP)

- Photocurrents add in-phase through a 50Ω coplanar strips microwave transmission line that is velocity-matched to the optical waveguide



# LASER L.O. IN CONTROL ROOM



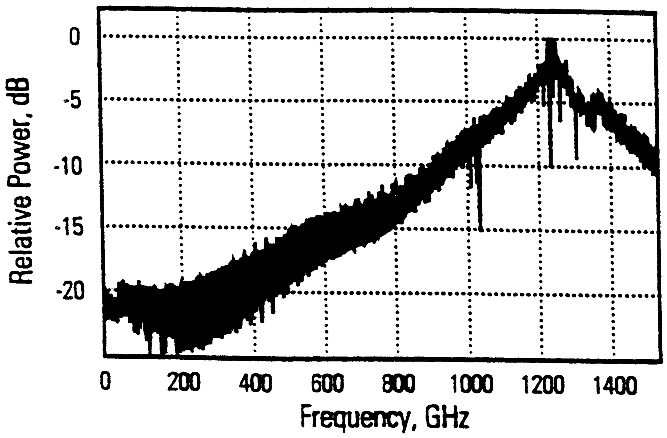
With electro-optic devices, phase modulation is achieved by aligning the optically active axis. New Focus makes proper alignment easy; simply pass the beam through the mechanical apertures.

## TERAHERTZ OPTICAL COMB GENERATOR

Researchers at JILA, University of Colorado and National Institute of Standards and Technology, and New Focus have recently used a prototype Model 4851 that resonated at 10.5 GHz to generate a spectrum of sidebands over 3-THz wide around a stabilized 633-nm HeNe laser source.* (That's over 250 sidebands at 10.5-GHz spacings!) Typically, phase modulation only produces a few sidebands. (See page 42 for a discussion of sideband generation.) However, by combining the efficiency of the Model 4851 with an optical resonator, the researchers were able to produce the spectrum shown in the graph.

Called optical comb generation, this technique produces a series of equally spaced spectral lines that extends over a wide frequency range around a cw optical carrier. One important application of optical comb generators is for high-resolution spectroscopy of various molecular and atomic transitions. These studies are usually performed with a laser locked to a well-known frequency reference, which limits one to studying transitions close in frequency to the laser frequency. In contrast, because optical comb generation enables wide frequency intervals to be coherently linked, a frequency-stabilized laser with an optical comb generator can be used to study transitions that are far from the laser's center frequency. For instance, a stabilized HeNe laser and an optical comb generator can be used to study several molecular iodine absorption lines around 633 nm as well as a neon transition that occurs at 633.6 nm.

*J. Ye, L.-S. Ma, T. Day, and J. L. Hall, "Highly-selective terahertz optical frequency comb generator," *Optics Letters*, **22**, No. 5, (1997).




*The graph shows the output spectrum of the comb generator measured using a Fabry-Perot cavity with a 2-THz free-spectral range.*

KFJ June 98

# Optics for LSA

a first discussion

Demands:
- high efficiency
- Low Loss
- Simple
- mechanically stable

Boundary Conditions:

- telescope design
- frequency selection scheme
- cryogenic rec. design, modularity
- polarization splitting
- LO coupling
- calibration system

⇒ Optical design is a complicated multiparameter problem!

$\boxed{\text{What can be done now ?}}$

LSA ~6-8-98

# Working list for Optics

- work on material characterization for windows, filters, mirrors
- work on LO coupling
- explore WG pol. sep. devices ONC's
- parameter space study for telescope optics
- buildup of powerful ant. range
- definition of a software base for devel. and analysis of optics losses

# <u>Feasability of HEMT-Amplifiers</u>

## 1. Frontend Amplifiers

Amplifiers for cryogenic operation with InP-HEMTs have been developed at the MPIfR for the frequency-bands:

| | | |
|---|---|---|
| 12 | - | 18 GHz |
| 18 | - | 27 GHz |
| 26.5 | - | 40 GHz |
| 33 | - | 50 GHz |

The noise contribution of these amplifiers is < 0.5 RF-Frequency/GHz

The frequency band 50 - 75 GHz can be covered by hybrid amplifiers with existing 0.1 x 40 micron TRW-InP-HEMT devices. Amplifiers for 75 - 100 GHz are presently under development.

The MPIfR is taking part in the JPL/NASA *Cryogenic HEMT Optimization Program* (CHOP) and evaluates single HEMT devices for the development of hybrid amplifiers and cryogenically coolable MMIC's produced by TRW. The institute has a proberstation for 300 K and will soon also have a cryogenic proberstation for the evaluation of HEMTs.

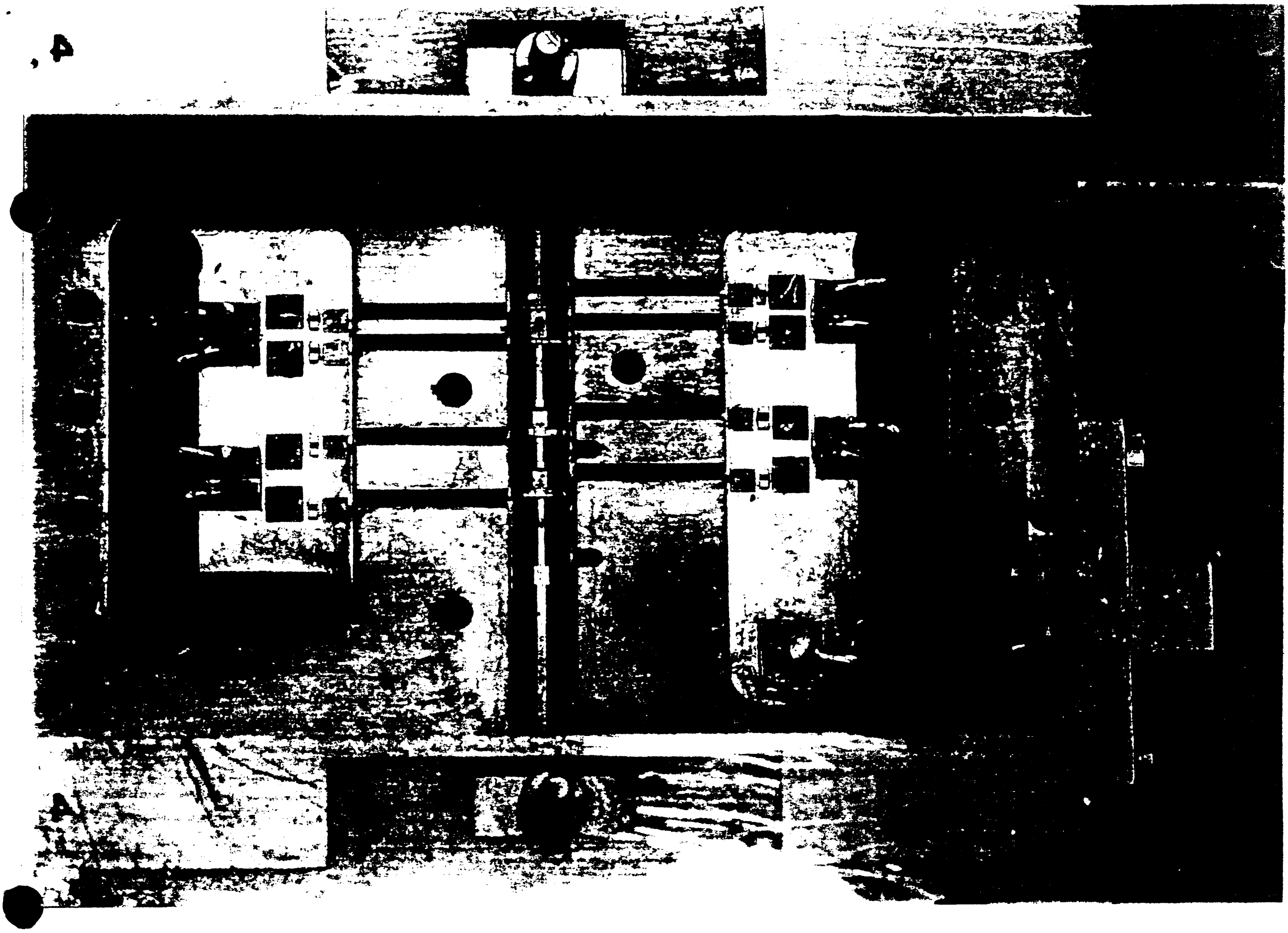
## 2. IF-Amplifiers

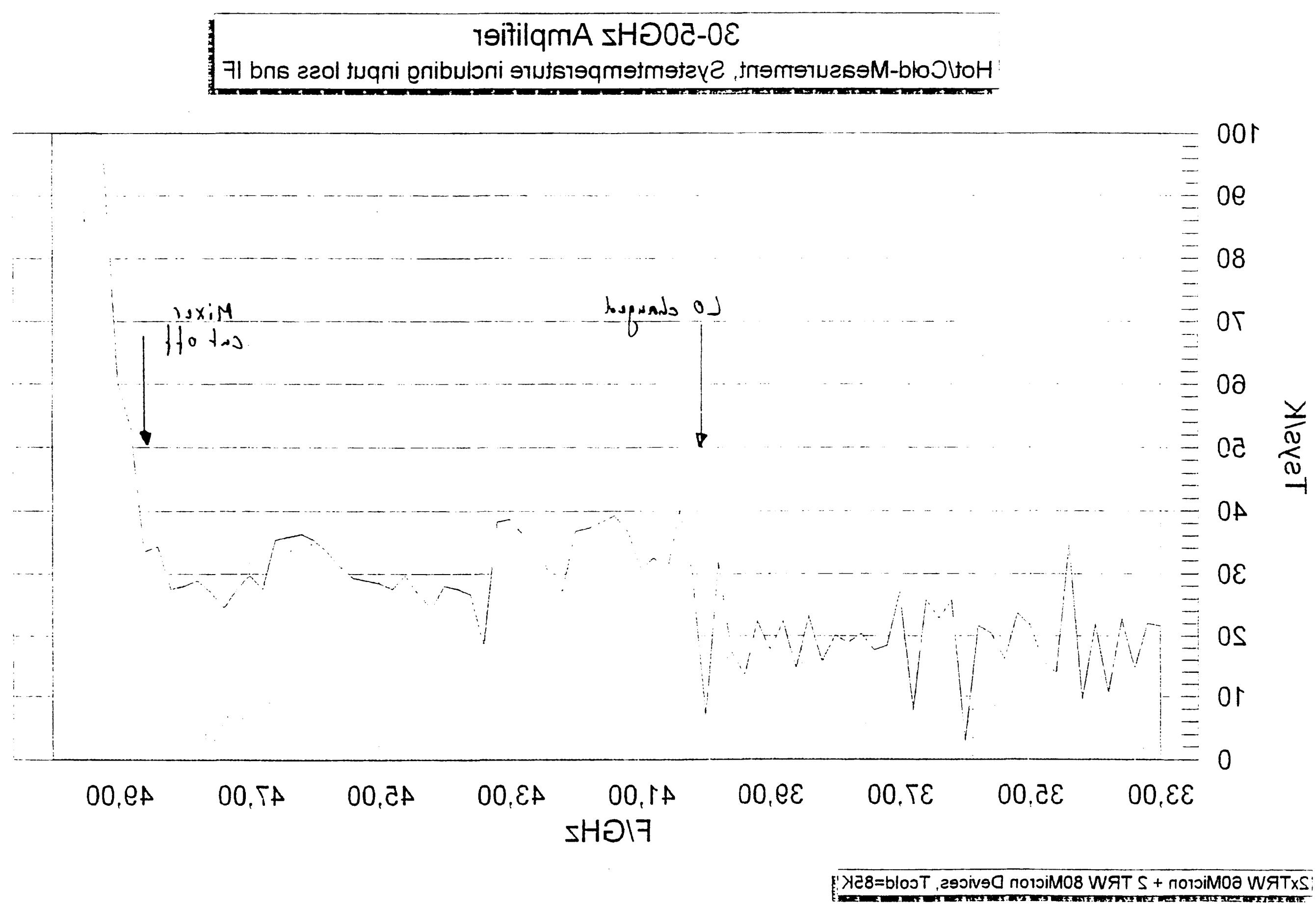
IF-amplifiers covering 4 - 8 GHz or 8 - 16 GHz should be feasable as balanced hybrid amplifiers, thus reducing the influence of the mismatch between SIS-mixer output and amplifier input, provided that the procurement of InP-HEMTs with a 0.1 x 300 micron gate geometry is possible. A development of a balanced IF-amplifier with PHEMTs is currently under way.

With respect to the numerous channels a balanced MMIC solution should also be taken into consideration.

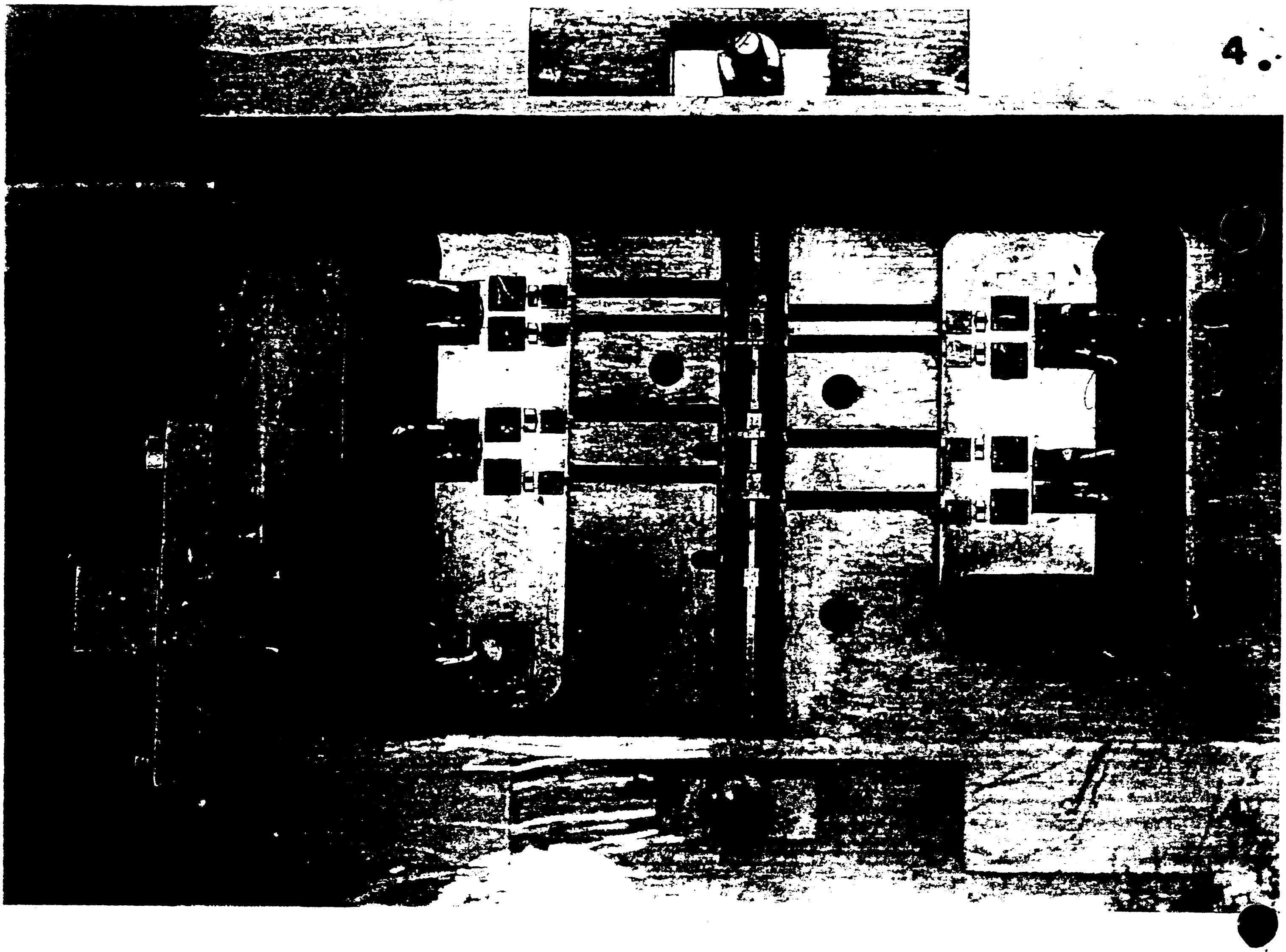
MPIfR

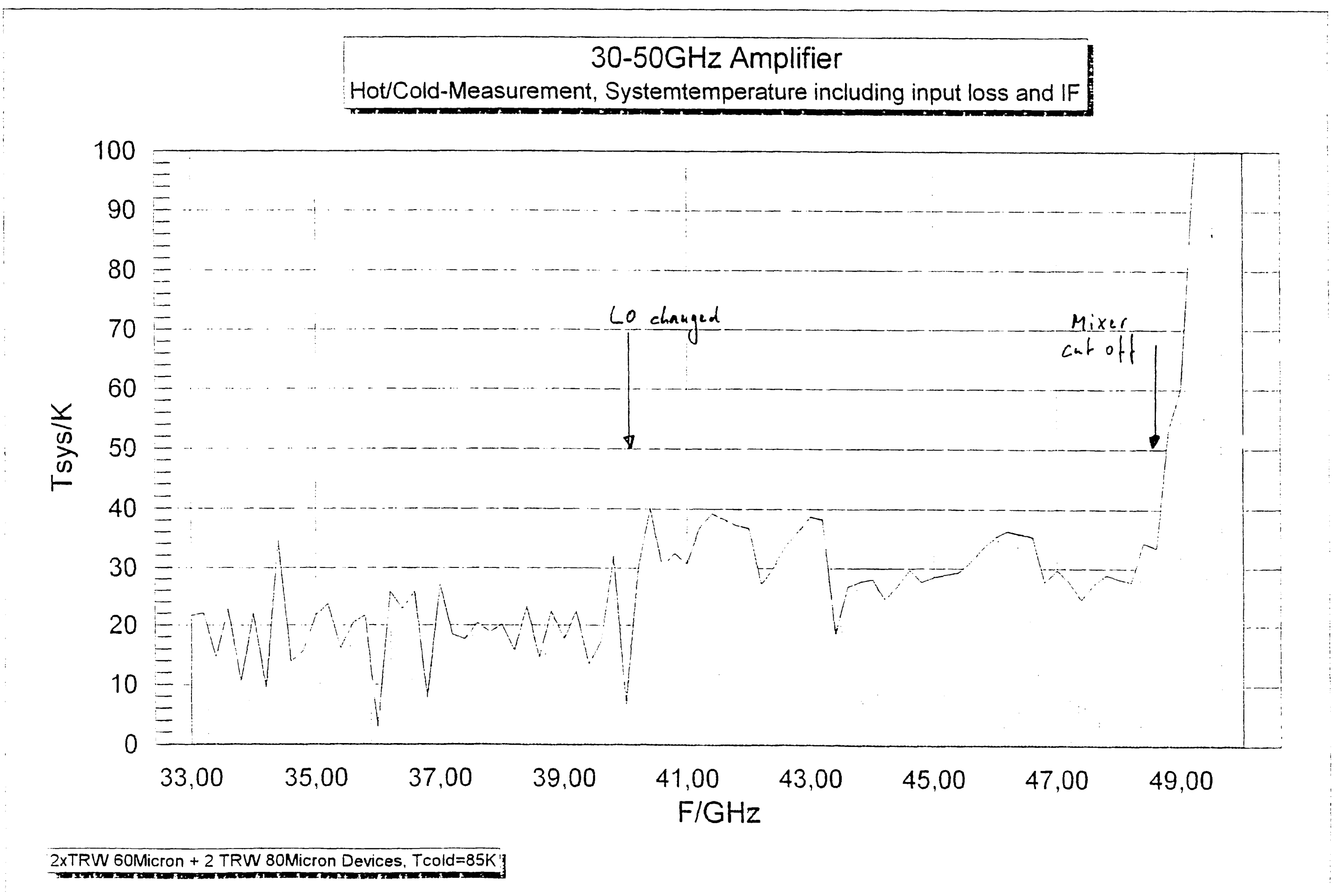
4.

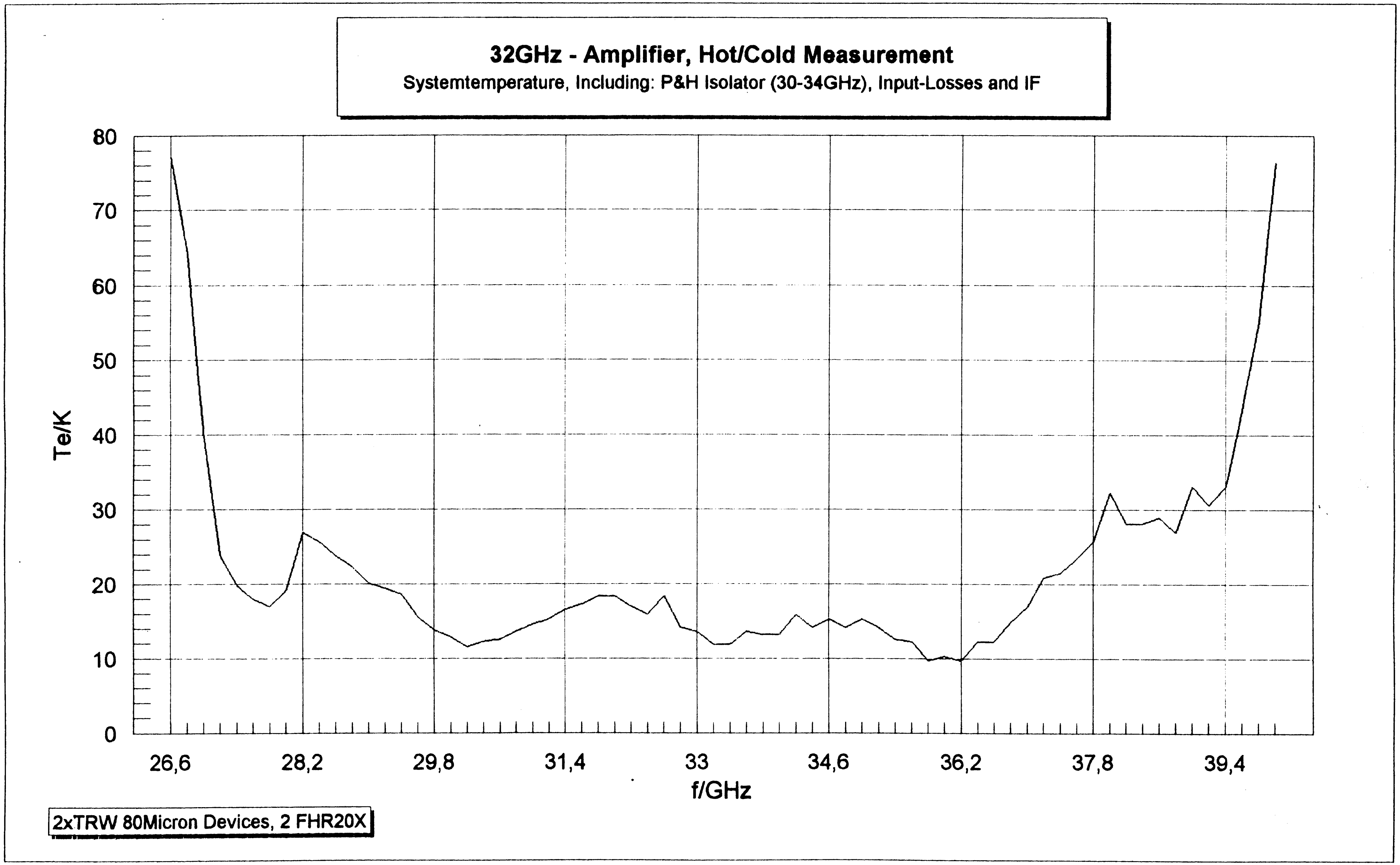




30-50GHz Amplifier
Hot/Cold-Measurement, Systemtemperature including input loss and IF
Tsys/K
0
10
20
30
40
50
60
70
80
90
100
33,00
35,00
37,00
39,00
41,00
43,00
45,00
47,00
49,00
F/GHz
LO changed
Mixer cut off
2xTRW 60Micron + 2 TRW 80Micron Devices, Tcold=85K




30-50GHz Amplifier
Hot/Cold-Measurement, Systemtemperature including input loss and IF
Tsys/K
100
90
80
70
60
50
40
30
20
10
0
33,00
35,00
37,00
39,00
41,00
43,00
45,00
47,00
49,00
F/GHz
LO changed
Mixer cut off
2xTRW 60Micron + 2 TRW 80Micron Devices, Tcold=85K


32GHz - Amplifier, Hot/Cold Measurement
Systemtemperature, Including: P&H Isolator (30-34GHz), Input-Losses and IF
Te/K
80
70
60
50
40
30
20
10
0
26,6
28,2
29,8
31,4
33
34,6
36,2
37,8
39,4
f/GHz
2xTRW 80Micron Devices, 2 FHR20X

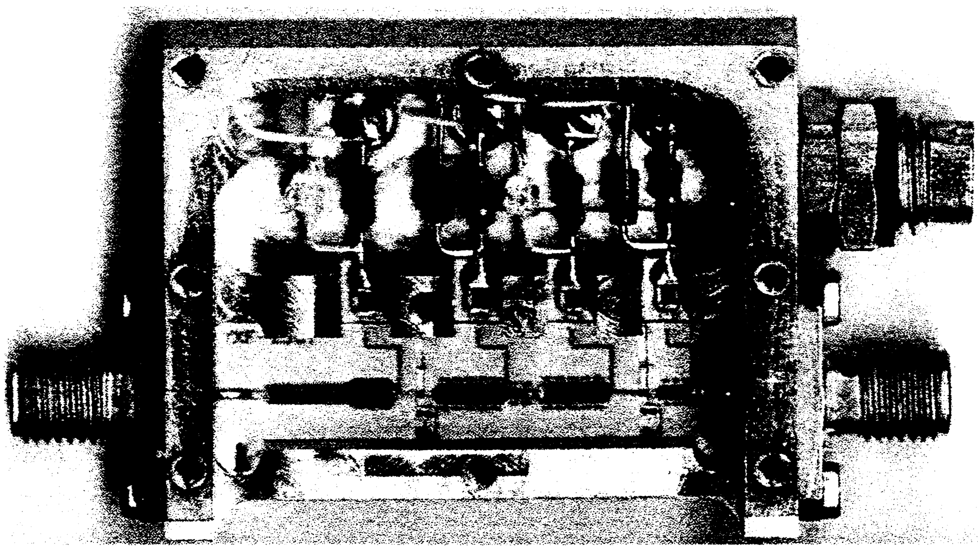
MPIfR 2

CENTRO ASTRONOMICO DE YEBES
OBSERVATORIO ASTRONOMICO NACIONAL
(SPAIN)

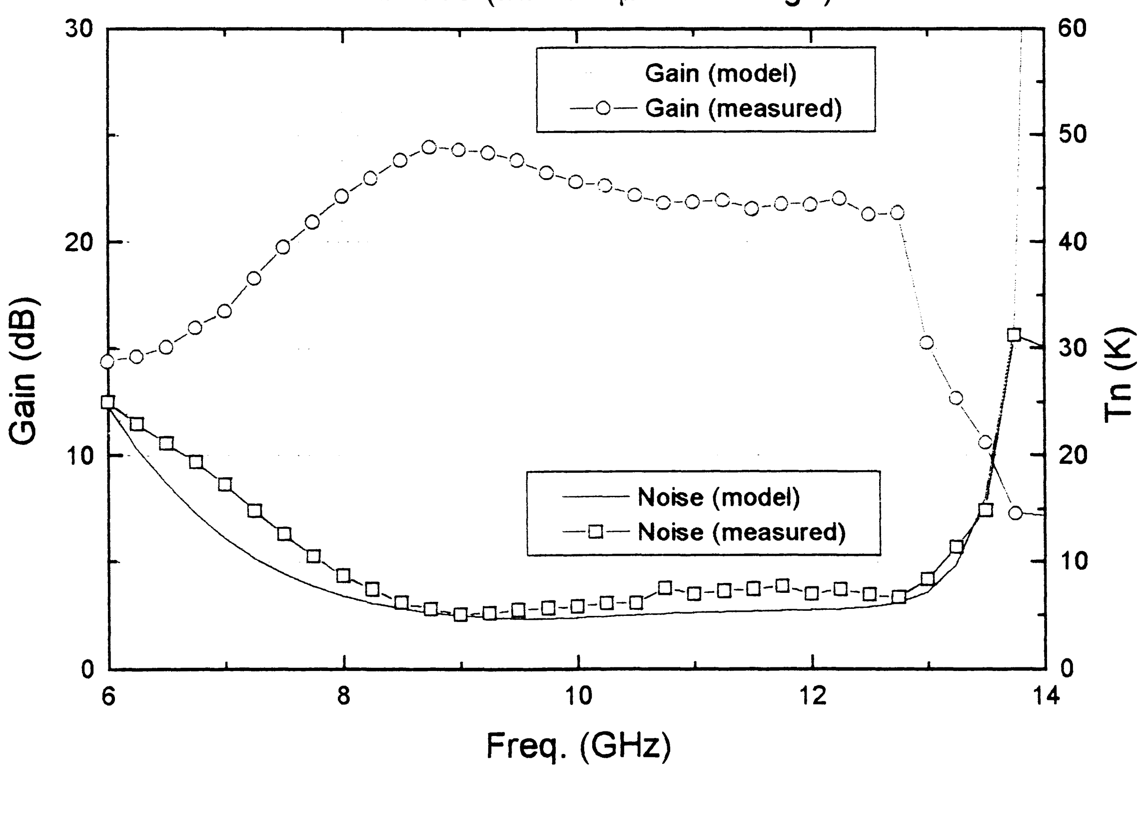
## 8-12 GHz cryogenic amplifier for FIRST with InP (June 98)

Test with InP HEMT only in 1st stage, not optimized for flat gain.

| | |
|---|---|
| transistor type (1st stage): | InP PHEMT, 0.1x160 μm |
| power dissipation (1st stage): | 5 mW (optimum bias) |
| Average Noise Temperature: | 6.5 K (Tamb=15 K) |
| Gain: | ~23 dB |



YXF 003 (InP 160μm 1st stage)

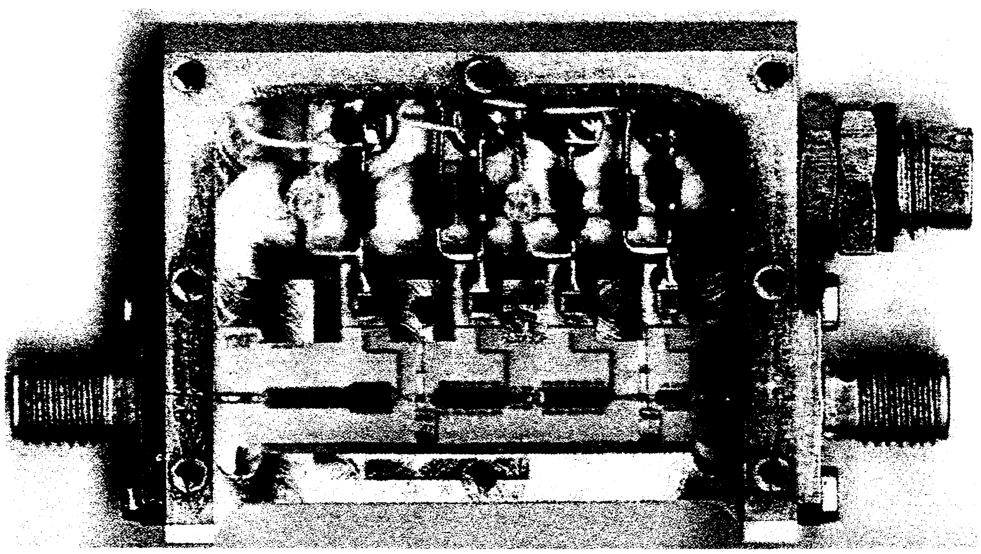


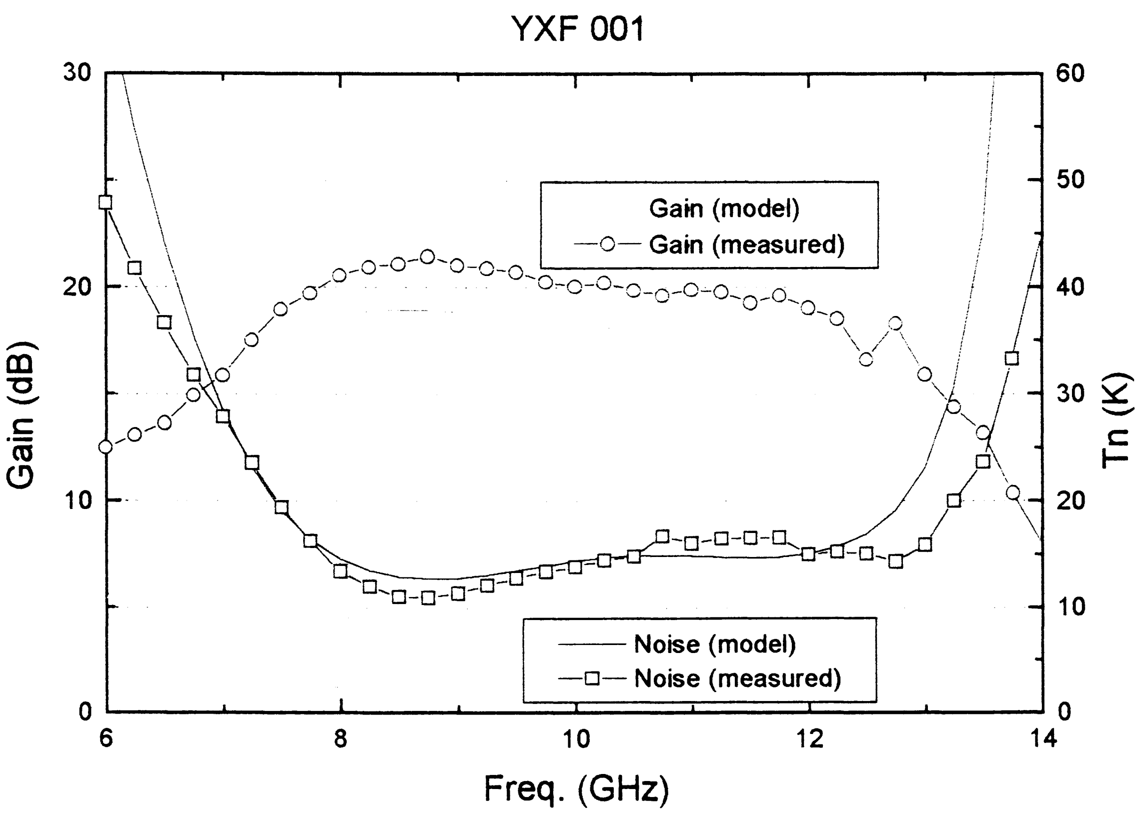
CENTRO ASTRONOMICO DE YEBES
OBSERVATORIO ASTRONOMICO NACIONAL
(SPAIN)

# 8-12 GHz demonstration cryogenic amplifier for FIRST (Feb. 98)

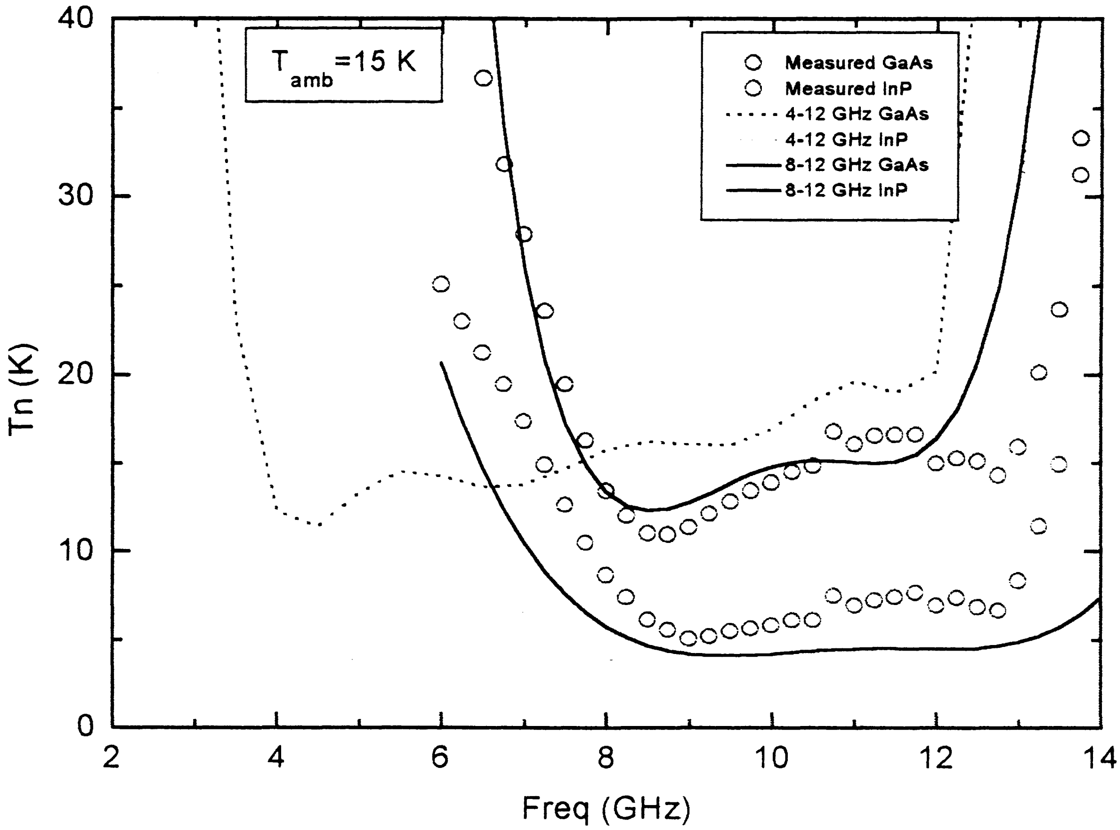
*Isaac López Fernández*
*Juan Daniel Gallego Puyol*

| | |
|---|---|
| transistor type: | GaAs PHEMT, 0.25x200 μm |
| total power dissipation: | 10 mW |
| Average Noise Temperature: | 14 K (Tamb=15 K) |
| Gain: | ~20 dB |





**Noise Temperature of Wideband IF Cryogenic Amplifiers (estimated)**



1300602
N D Whyborn

# Mixer Interfaces

## IF Circuit

Matching : IF bandwidth*/centre frequency, parasitic reactances, impedance levels

* $C_J$ unavoidable, but relatively unimportant at IF ...
* RF circuit can be significantly easier ($f_{RF}/f_{IF} \gg$)
* Fin $R_L \simeq 2 R_N$ (but Kerr has $R_L \simeq R_N$)
* $R_{dyn}$ & $R_{Mix\,out} \gg R_N$ and will vary over RF tuning range (fixed tuned mixer), perhaps −ve.

→ control $R_L$ outside IF band and also to avoid saturation problems

* no isolator? wide IF bandwidth

→ balanced IF amp ??
→ integrated IF amp ?
→ full noise analysis of mixer/IF amp system

* SRON 600−750 GHz mixer has IF band 1−12 GHz
(tested at 1.5 GHz, 4 GHz & 8 GHz $f_{IF}$)

## D. C. Interface

* integrated bias -T

→ separate bias from IF signal (depends on mixer R design)

→ control of out-of-band ~~Z~~ mixer load impedance

→ ESD / EMC protection

## Optical Interface (cont.)

* high F# → larger alignment tolerances
* high efficiency
* wide R.F. bandwidth

→ corrugated feedhorn + off-axis mirror

## Magnetic Interface

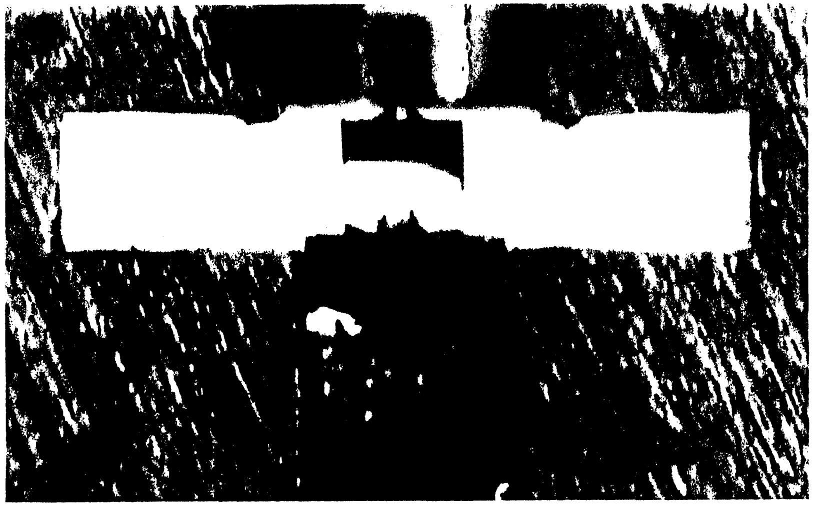
* magnetic field to suppress Josephson noise $f \geq 200$ GHz
* deflux heater ?

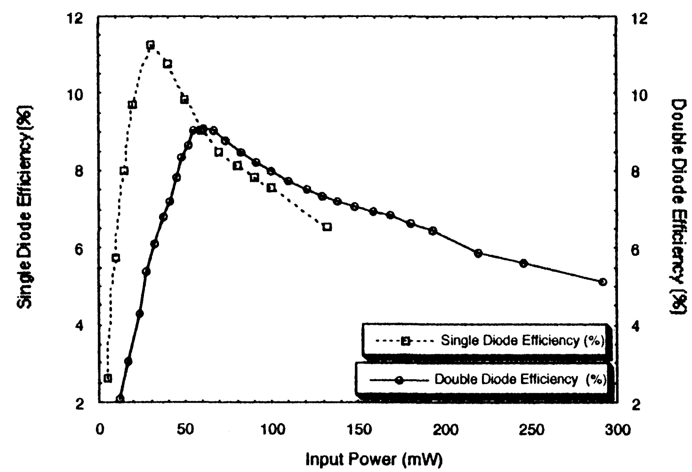
# LSA Local Oscillators

- LOs are a technically demanding and may well be an important instrument driver in a similar way to FIRST.
- Definition of frequency bands required.
- Thought must be given to the best method of signal and LO coupling.
- Simple, proven and reliable systems should be used whenever possible in order to reduce manufacturing cost and increase chances of success.

# MMT Varactor Frequency Multipliers

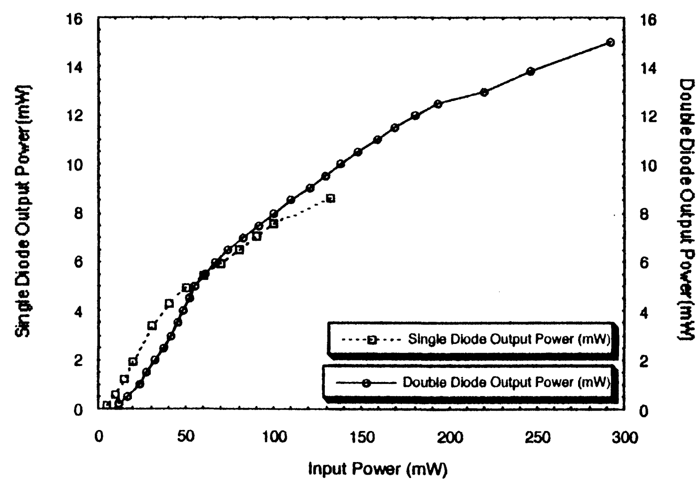
CLRC






Use of the planar whisker has allowed us to combine the output of two 5M4 varactors resulting in record output power

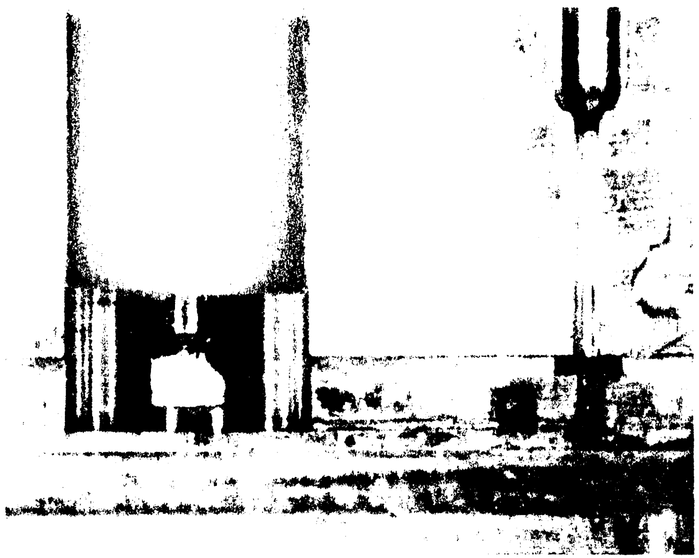
*15mW @ 270GHz,*
*11% efficiencies at 40mW input*



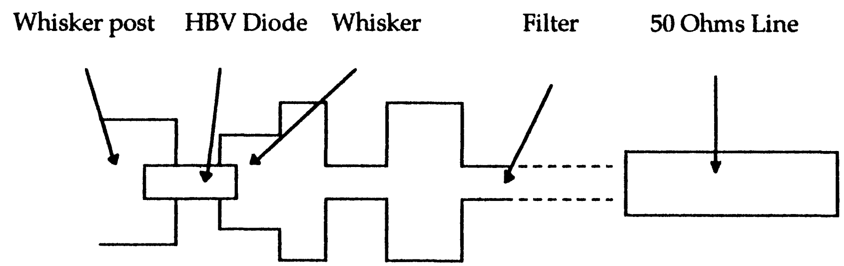
# MMT HBV Frequency Multipliers

*Heterostructure Barrier Varactor Devices for Fixed Tuned Broadband Frequency triplers*

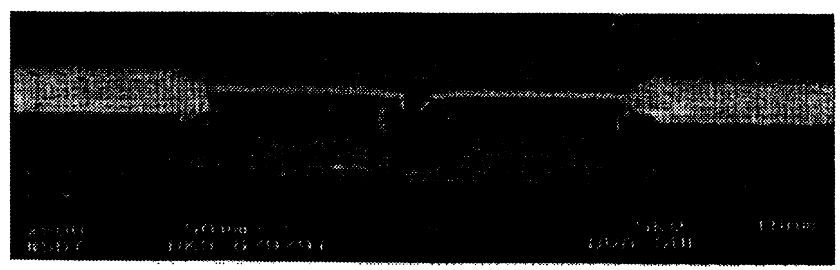
Photograph of the empty block



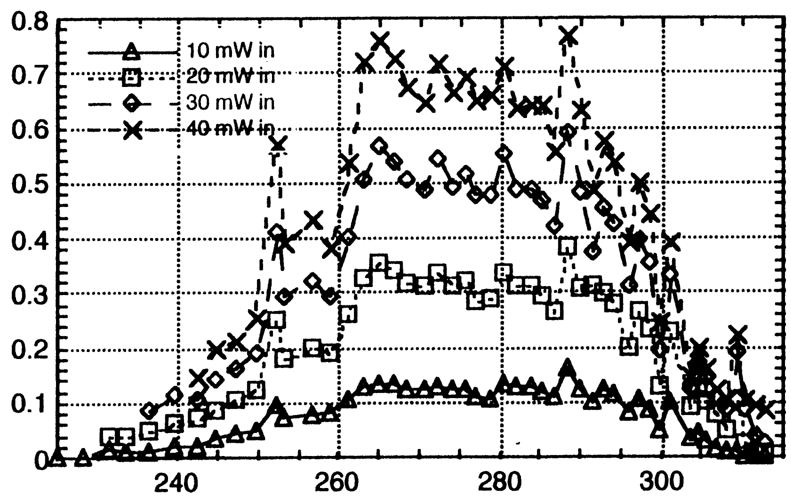
Schematic diagram of the mounting structure
Using a modified 180-220GHz doubler

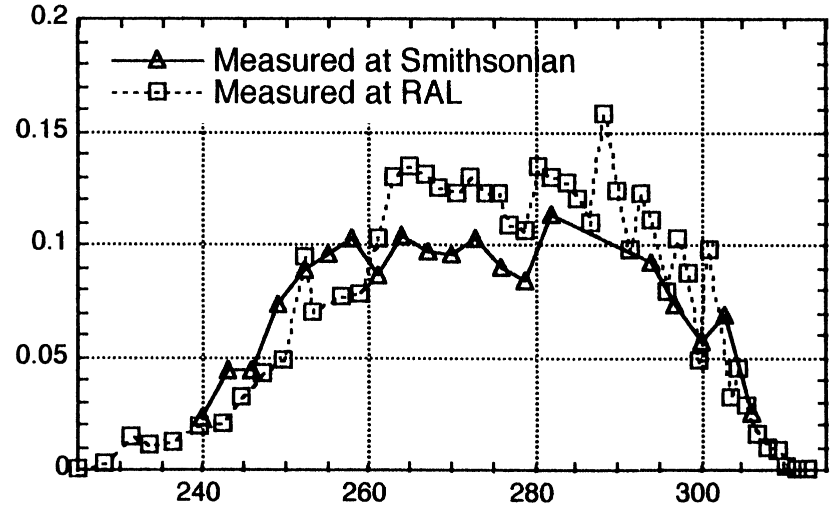



A UVA planar HBV device



# Results for Smithsonian Source Completely Fixed Tuned and Unbiased

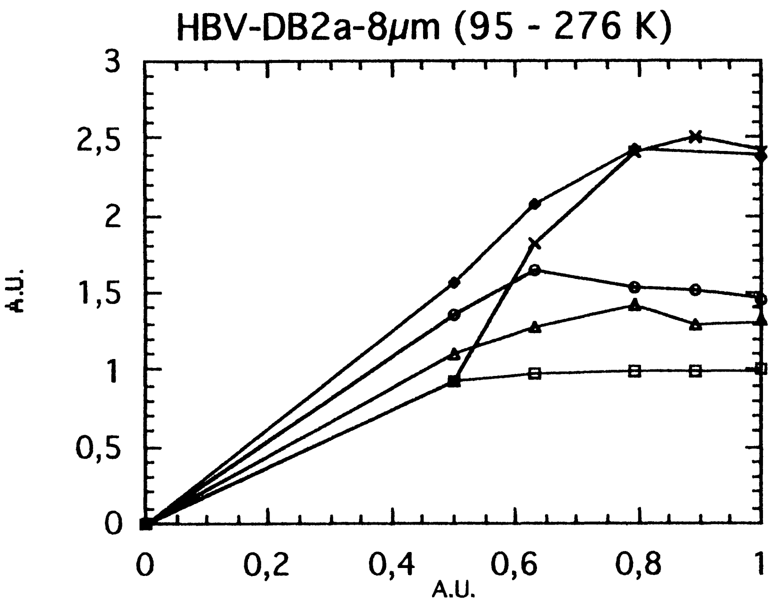


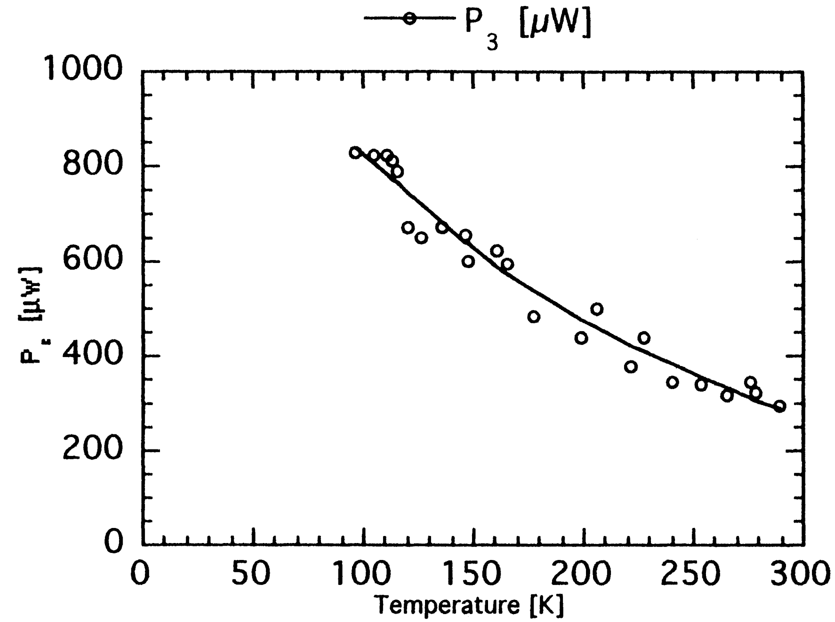




Final measured frequency response as a function of input power (Backshort fixed at 0.45mm)

Final fixed performance for 10 mW input. Comparison of measures made at RAL and the Smithsonian Institute

# HBVs Want to be Cooled




*On cooling to 95K the HBV 255GHz tripler gave a factor of three improvement in efficiency and output power.*

# RECEIVERS FOR GROUND BASED MM WAVE RADIO TELESCOPES

A. Karpov

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## ABSTRACT

We present a study of requirements on the sensitivity of mm and sub millimeter wave receivers for application in radio astronomy. The study is based on the experience of the operation of the SIS receivers at the radio telescopes of IRAM and considers also the conditions of operation at the future radioastronomical instruments such as LSA, MMA and LMSA.

Using a radio telescope and atmospheric model we consider the effect of the receiver sensitivity on the radio telescope operation in terms of observing time. The observing time at a radio telescope depends on the system noise temperature as strongly as on collecting area, which defines nearly all the cost of modern mm and sub mm instruments. As a compromise between the receiver development effort and the system performance we introduce a criterion of an "optimum" receiver noise. A strict requirement on the receiver operation is obtained. For an efficient use of the existing and the future radio telescopes, a 10 - 20 K SSB receiver noise in the mm band and 20-40 K SSB at sub millimeter wavelength are necessary.

Finally the status of development of SIS receiver for mm and sum mm radio astronomy is presented.

**Keywords**: low noise receivers, radio telescope, millimeter wave, SIS receiver.

## 1. INTRODUCTION

Radio astronomy is a domain where the most sensitive millimeter wave receivers are required [1,2]. The performance of the receivers in millimeter wave radio astronomy is based on development of low noise, broad band and stable SIS mixers [1,2]. Having as a basic limitation only the quantum noise limit of $h\upsilon/k$ for the SSB noise temperature they may remain as the basis for the construction of new observing facilities. The inconveniences such as the cooling to the liquid helium temperature and sometimes the mechanical tuning for SSB operation remain less important compared to the strict requirement on the receiver sensitivity for an efficient use of the radio telescopes, impossible with other types of receiver.

A further development of millimeter wave radio astronomy instrumentation is related to the construction of the big interferometers such as the Large Southern Array (LSA)[3], Millimeter Array (MMA)[3], or Large Millimeter and Submillimeter Array (LMSA)[4] planned to integrate 50-60 antennas of 10-15 m in diameter at the high altitude plateau in Chile, at about 5 km of elevation. The new instruments will have a collecting area more than 10-20 time larger than in existing instruments such as the IRAM radio interferometer [6].

In preparing such new instruments for mm and submillimeter wave radio astronomy an important work on the receiver development has to be undertake. One can put forward once more a question about an optimum design of the receivers for these instruments and about their role in the system performance for the existing context of receiver and telescope technology and for the future.

As a starting point for a discussion one can use an example the case of existing radio interferometers, such as the IRAM five 15 meter antenna interferometer in the French Alps at 2500 m altitude. The IRAM radio interferometer at the Plateau de Bure (PdB) is an instrument with the biggest collecting area developed for the radio astronomy observations around 1 mm wavelength [6]. We are using the PdB radio telescopes data as an example of a modern instrument for an estimation of the role of the receivers in the existent context. First we give a presentation of the requirements on the receivers for the IRAM installations based at our IRAM internal report [7]. Then we study the requirements on the receiver sensitivity for the future instruments and present the status of the SIS receiver development in IRAM.





## 2. OPTIMUM NOISE RECEIVERS FOR IRAM RADIO TELESCOPES

The reduction of the receiver noise always reduces the integration time required for an observation. Nevertheless some reasonable minimum of the receiver noise may be evaluated. The requirement on the sensitivity of a receiver may be formulated in terms of the optimization of the radio telescope system performance, including the receiver, the telescope and the atmosphere. As an optimization criterion we can use the relative speed-up of observations at a telescope versus receiver temperature. As a reference value, not affected by the receiver operation, we take the observation time necessary for detection of a certain signal with the same telescope in a hypothetical situation of zero receiver noise. The relative variation of integration time is estimated from the relative variation of the system noise temperature:

$$t/t_o = \{\ T^*_{Sys}(T_{Rec}) / T^*_{Sys}(T_{Rec}=0)\ \}^2 \tag{1}$$

An acceptable increase in observation time has to serve as a compromise between the receiver development effort and the system performance. One can use a 50 % increase in observation time, not negligible indeed, as a criterion for the estimation of the optimum receiver noise for radio telescopes.

The system noise temperature $T^*_{Sys}$ is calculated according to [8]:

$$T^*_{Sys} = \frac{1 + G_i / G_S}{F_{eff} \exp(-A\,\tau_0)} \left[ F_{eff} \cdot T_{Sky} + (1 - F_{eff}) \cdot T_{Amb} + T_{Rec} \right] \tag{2}$$

where $T^*sys$ is the radio telescope system noise temperature at the "star scale" in a reference plane out of the atmosphere; *Tsky*, *Tamb* and *Trec* are respectively the sky antenna temperature, the ambient temperature and the receiver noise temperature; *Gs* and *Gi* are respectively the signal and image band conversion gain, *Feff* is the forward efficiency; $\tau_0$ is the sky zenith opacity.

The sky antenna temperature *Tsky* is calculated as: $T_{Sky} = T_{Atm} \cdot [1 - \exp(-A\,\tau_0)]$

where the airmass $A$ is: $A = \frac{1}{\sin(\alpha)}$ and $\alpha$ is the telescope elevation angle. Comparing (1) and (2) one can mention that the speed-up of observation (1) does not depend on the sideband ratio *Gs/Gi*, but only on the value of *Trec*. So, the requirements on the value of receiver noise listed below concern equally observations with a Double Sideband receiver (Trec DSB) or with Single Sideband receivers (Trec SSB). As the major part of most observations is in SSB mode, we will discuss especially the requirements on Trec SSB.

We selected the different typical frequencies as 90, 230, and 345 GHz and proceed our calculations for several different atmospheric conditions. We studied "good" summer weather (7 mm Precipitable Water Vapor (PWV)), the "average" winter/good summer conditions (4 mm PWV) and "good" winter weather (2 mm the PWV). At 345 GHz we consider also an "excellent" winter weather (0.5 mm PWV). This estimation concerns both the IRAM Plateau de Bure Interferometer and the 30 m IRAM Pico Veleta (PV) telescope for the following reasons. The forward efficiencies of the two types of antennas are the same within 1%, at least in the 3 mm (90%) and 1.3 mm bands (86 %). The estimation at 345 GHz concerns first the 30 m radio telescope with a 75% forward efficiency. The typical values of the atmospheric opacity are also similar at the two sites [9].

An example for a frequency of 90 GHz is shown in the figure 1. Here the relative fraction of the system noise due to a non zero receiver noise *{T*sys(Trec)-T*sys(Trec=0)}/T*sys(Trec)* is plotted against *Trec* at the left. First we can say that the receiver noise gives a significant part of the system noise and the receiver noise may easily dominate in the system operation.

We obtain a more clear presentation of the receiver noise role by estimating the time required for the detection of an astronomical signal, determining the number of the astronomical project one can schedule at the telescope. In the right part of the figure 1 is plotted the relative increase of the radio telescope observation time (1) versus the receiver noise. One can see that in typical weather the observation time of a modern radio telescope strongly depends on the receiver noise. With a moderate 50 K receiver noise the observation time has to be 4 time longer, than the minimum at a zero receiver noise. This corresponds to the loss of a half of the radio telescope collecting area, or, what is nearly the same, the loss of the half of the funding for a radio telescope. Only by approaching an "optimum" $T_{Rec\ Opt}$=10 K receiver noise one can achieve an observation time only 50% longer than the minimum.

This "optimum " receiver noise of 10 K SSB required at 90 GHz for the existing radio telescopes is far better the best published results of 60 K SSB of an SIS receiver at NRAO Keat Peak radio telescope [10]. In our recent SIS receiver prepared for installation at the PdB interferometer the SSB receiver noise ranges between 30 K and 48 K in the 80-120 GHz band (figure 6).

The estimation of observation speed-up versus receiver noise is plotted in the figure 2 for frequencies of 230 GHz and 345 GHz. In this typical condition even with a bigger atmospheric opacity the time required for the detection of an astronomical signal strongly depends on the receiver noise. The 150% threshold compared to the minimum observation time can only reached with a 20 K SSB receiver noise at 230 GHz and 30 K SSB at 345 GHz. For the moment the best SSB receiver noise at these frequencies is about 50 K (figure 6).

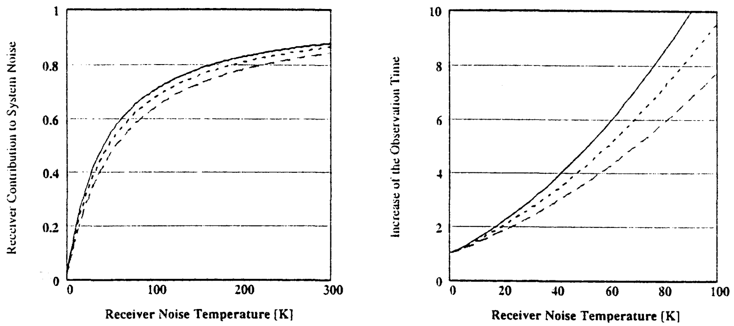


Figure 1. The contribution of a receiver to a modern mm wave radio telescope system noise temperature (left) and the influence of the receiver noise at the time of observation (right) at 90 GHz. We are using an example of the IRAM 30 m radio telescope at Pico Veleta or IRAM 15 m radio telescopes of the Plateau de Bure interferometer. The antenna is at 45° elevation, forward efficiency is 92% and the altitude is 2500-2800 m. A solid line represents an average summer weather (7 mm PWV), a dotted line - a good summer/average winter weather with 4 mm PWV and a dashed line - a good winter weather with 2 mm PWV. In a typical weather the mm wave receiver noise may easily dominate the operation of a modern radio telescope and to increase strongly the observation time. With a 10 K receiver noise a time required for an observation is still longer than the minimum by 50%.

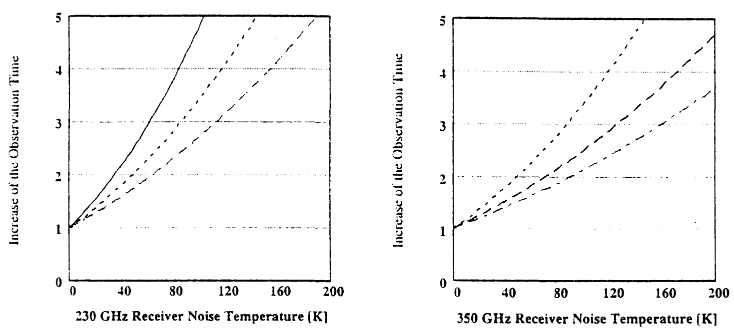


Figure 2. Estimation of a relative increase of the radio telescope observation time at 230 GHz (left) and 350 GHz (right). The Forward efficiency at 230 GHz is 86% and 75% at 350 GHz. The conditions are the same as in the figure. For the 350 GHz data we add an estimation in "excellent" winter weather with 0.5 mm PWV (dotted-dashed line). In a good weather, when the observations are the most rapid, the observation time strongly depends on the receiver sensitivity, until we reach a 20 K receiver noise at 230 GHz and 30 K at 350 GHz.



*ESA Workshop on Millimeter Wave Technology and Applications.*
May 27-29, 1998, Millilab, Espoo, Finland

## 3. RECEIVER FOR THE LSA/MMA SITE OBSERVING CONDITIONS

At about 5000 m altitude at a new site studied for the LSA/MMA/LSMA projects the weather is much better than at the existing radio telescope locations. Here the PWV below 0.5 mm is observed about 25-30 % of the time ("good" weather) and for about 75% of the time the PWV is below 1.5 mm ("average" weather) [4,11]. For comparison at the IRAM radio telescopes only in "good" winter time weather the is PWV below 1.5 mm for about 25% of the time and below 5 mm 75% of the time in "average" weather. In these new conditions the requirements on the receiver sensitivity are even more severe and demand further progress in sensitivity.

The transmission through the atmosphere with 0.5 mm, 1.5 mm and 5 mm PWV is plotted with the typical values of the forward efficiency $F_{Eff}$ existing at IRAM radio telescopes in the figure 3. The loss in the radio telescope ($F_{Eff}$) is a minor contribution in the total loss at the IRAM radio telescopes in "average" weather with 5 mm PWV, and gives just half of the total loss in "good" weather. At the new site this level of the loss will dominate loss in the atmosphere and can not to be accepted.

One can expect that with progress in technology $F_{Eff}$ will be increased up to the maximum existing now at 100 GHz, of about 92%. Below we will use this value for the estimations for a 60 GHz - 550 GHz frequency range.

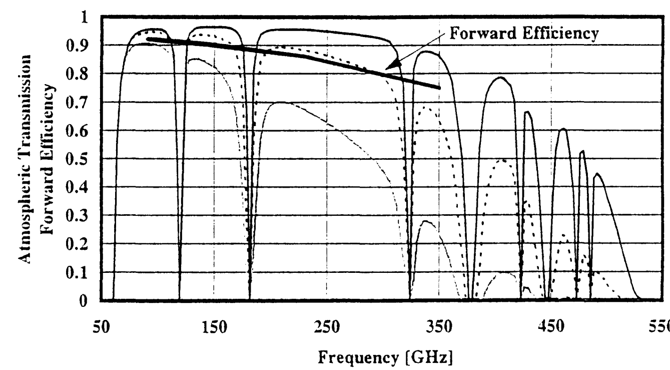


Figure 3. The atmospheric transmission with 0.5 mm, 1.5 mm, and 5 mm PWV (from upper to lower curve) and the forward efficiency at the IRAM 30 m radio telescope. The PWV level is below 1.5 mm at the 30 m telescope site about 25% of winter time, and about 75% of the winter time below 5 mm PWV. At the LSA site the PWV is below 0.5 mm during the 25% of observing time and below 1.5 mm PWV during 75 % of the time. At the existing radio telescope the loss related to the forward efficiency is not dominating the atmospheric loss, but at the LSA site the forward efficiency may be the main limiting factor of the system sensitivity.

The "optimum" receiver noise $T_{Rec\ Opt}$ required for the atmospheric conditions of figure 3 is summarized in the figure 4. Here we are using for $T_{Rec\ Opt}$ the relation (3) obtained from (1) and (2) for a relative increase of observation time $t/t_0$=1.5.

$$T_{RecOpt} = (\sqrt{1.5} - 1)(F_{Eff} T_{Sky} + (1 - F_{Eff}) T_{Amb}) \quad (3)$$

The "optimum" receiver noise depends on the forward efficiency, and through the sky antenna temperature on the zenith opacity. For a fixed $F_{Eff}$ the minimum $T_{Rec\ Opt}$ required with a zero zenith opacity is:

$$Min(T_{RecOpt}) = (\sqrt{1.5} - 1)(1 - F_{Eff}) T_{Amb}, \quad (4)$$

about 6 K with $F_{Eff}$=92%. Under the same conditions the maximum of the $T_{Rec\ Opt}$ corresponds to an important atmospheric opacity, and is about 60 K, independent of the frequency:

$$Max(T_{RecOpt}) = (\sqrt{1.5} - 1)(T_{Amb} - F_{Eff}(T_{Amb} - T_{Atm})) \quad (5)$$

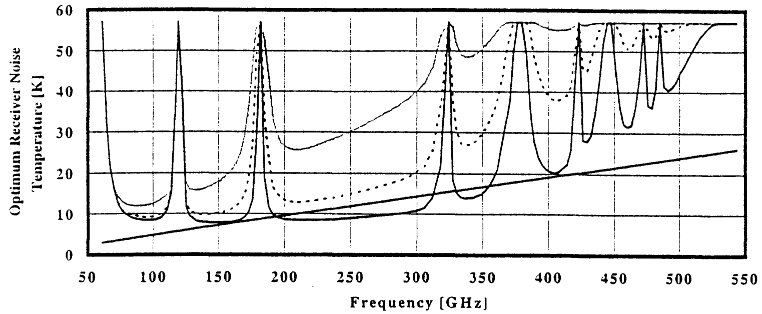


Figure 4. The "optimum" receiver noise temperature required for the LSA/MMA project. The weather conditions are as in figure 3. The radio telescope elevation is 45° and the forward efficiency is supposed to be 92% at all the frequencies. The straight line corresponds to the quantum limit of the receiver SSB noise temperature hν/k. If the receiver sensitivity required for the average winter weather of IRAM radio telescope (gray line) ranges between 13 K SSB at 100 GHz and 50 K SSB at 345 GHz, at the new LSA/MMA/LSAM site it become 10 K - 30 K SSB.

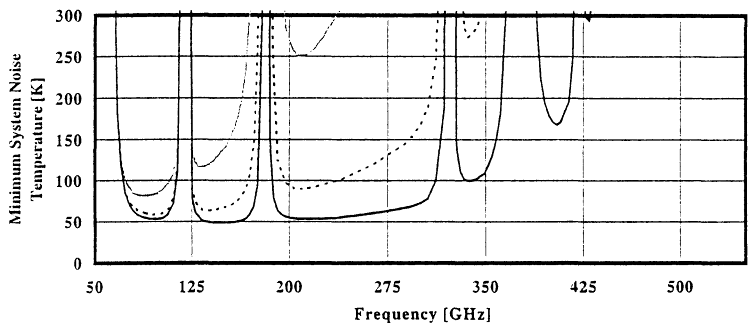


Figure 5. The minimum system noise temperature of a radio telescope at the LSA site with the "optimum" receiver noise temperature. The conditions are the same, as in the figure 4.

## 4. THE STATUS OF THE MM WAVE SIS RECEIVER DEVELOPMENT IN IRAM

The status of the mm wave SIS mixer heterodyne receiver development in IRAM is presented in Figure 6. The minimum SSB receiver noise achieved around 345 GHz is 48 K, about 2.8 hν/k, around 230 GHz the minimum DSB receiver noise is about 50 K and 30 K at 90 GHz. The motivation of this development is the optimization of sensitivity of existing radio telescopes and the preparation of a new generation receiver at the level of requirements for the future instruments like LSA and MMA, or LSMA.

## 5. CONCLUSION

The requirements for the sensitivity of mm wave receivers for ground based radio telescopes have been discussed. Using a radio telescope and atmospheric model we consider the effect of the receiver sensitivity on the radio telescope operation in terms of the observing time. The observing time at a radio telescope depends on the system noise temperature as strongly as on collecting area, which defines nearly all the cost of modern mm and sub mm instruments. As a compromise between the receiver development effort and the system performance we introduce a criterion of an "optimum" receiver noise allowing to obtain the detection time 50% longer than with zero receiver noise.





Applying the criteria of an "optimum" receiver noise to the typical conditions of the existing mm wave radio telescopes, one need the receivers with the 10-20K SSB noise in the mm band, and the 30-40 K in the submm band. For the futures radio telescopes the requirements are more strict, and become 10 K SSB in the mm band and 15-40 K at the submm wavelength.

The sensitivity of the existing SIS receivers developed in IRAM for radio astronomy is between 30 K SSB and 50 K SSB in the 100 GHz - 350 GHz band and must be further improved for application in the future projects discussed above.

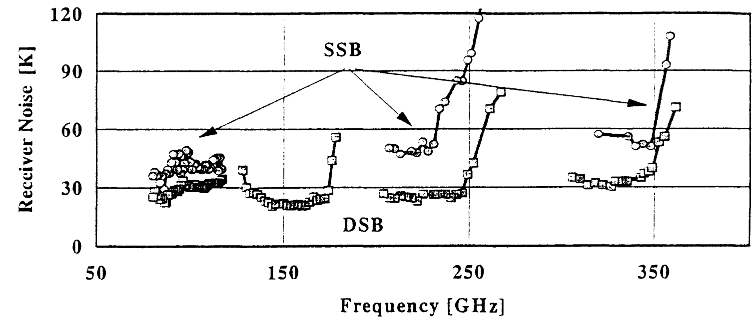


Figure 6. The measured receiver noise temperature of the SSB and DSB SIS receivers developed in IRAM [12-15]. The SSB receiver noise is given by the round points ○ and the DSB noise - with the square points □.

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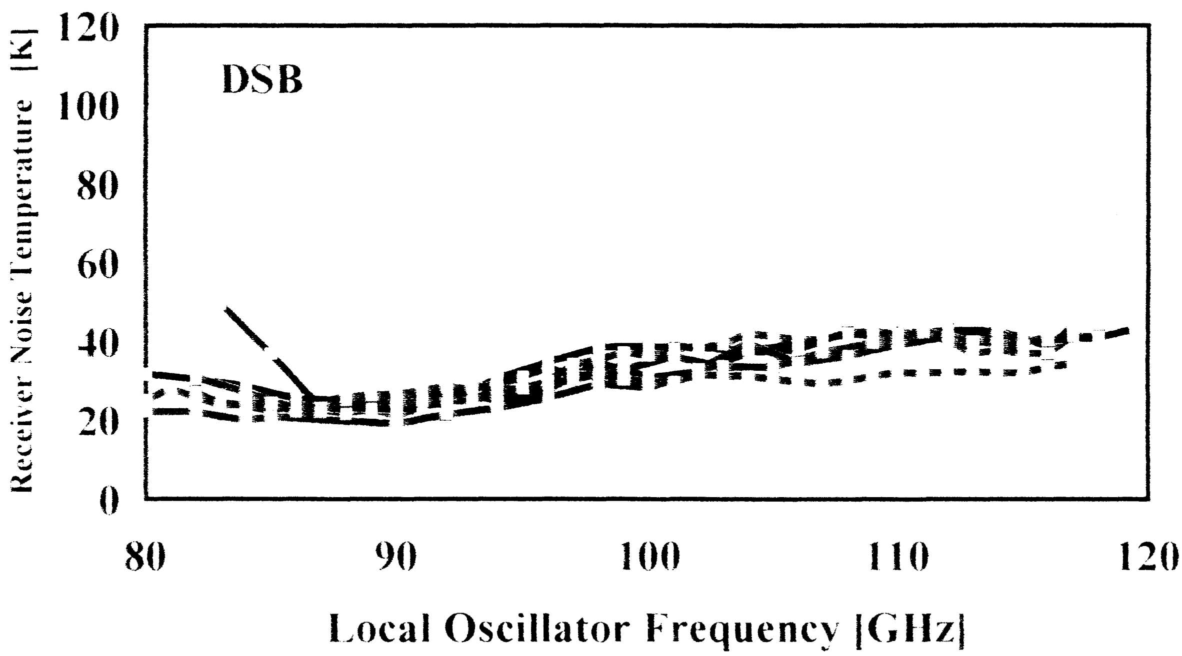
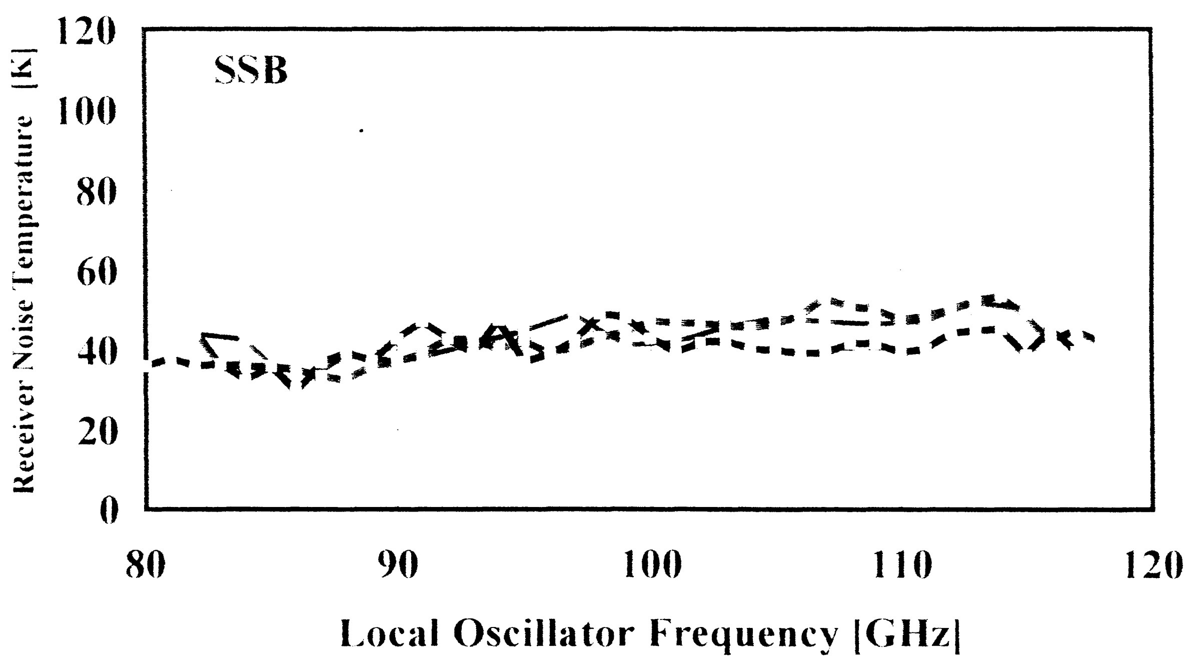
## Requirements for the receivers at mm wave radio interferometer

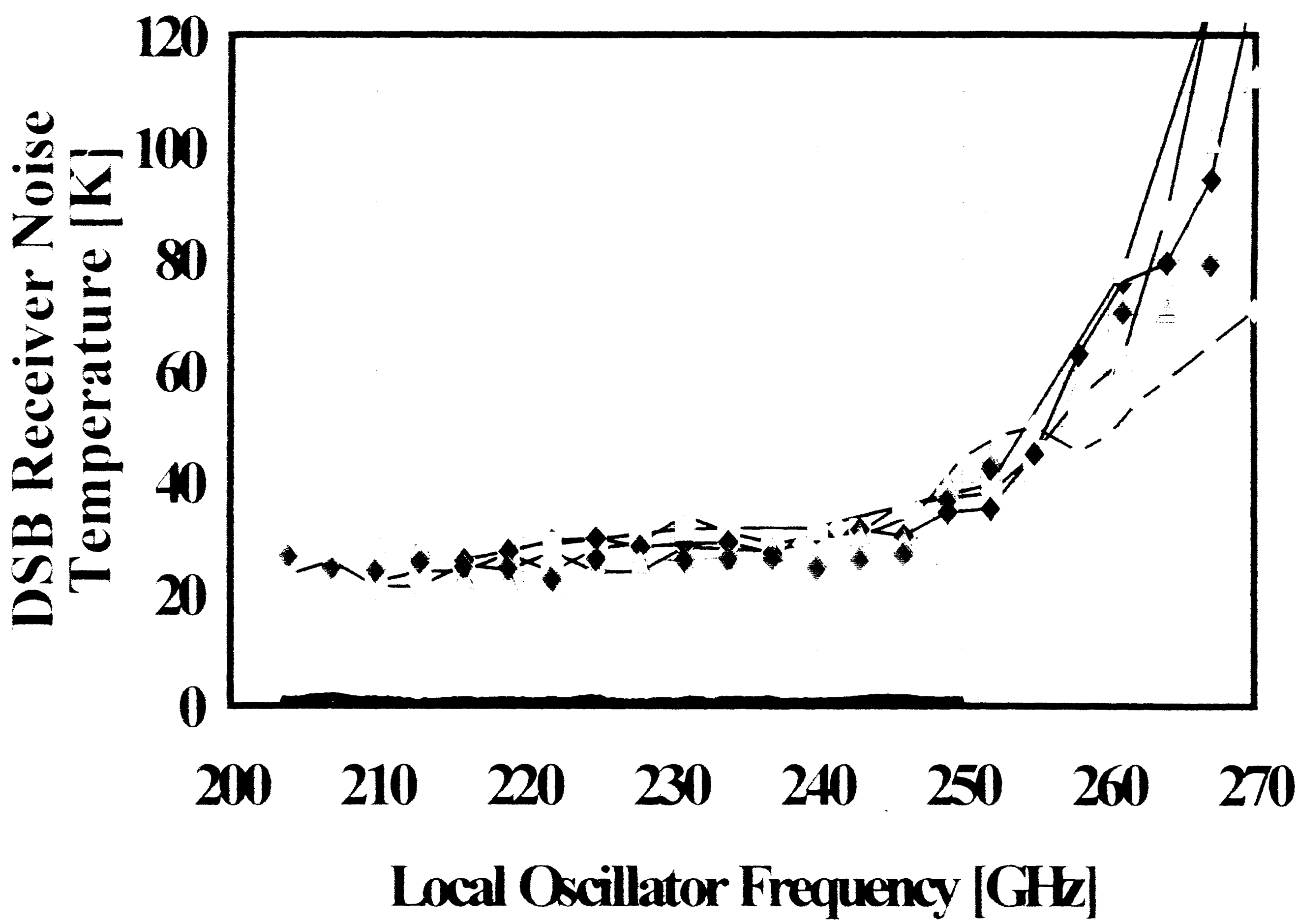
- Identical in all antennas. Example of 100 GHz SIS mixers.



## Requirements for the receivers at mm wave radio interferometer

- Identical in all antennas. Example of the 230 GHz mixers for Plateau de Bure Interferometer (205 - 250 GHz)



# Dutch participation in LSA/MMA

## Motivation

- Enthusiasm about science
  - formation and evolution of high-z galaxies
  - formation of stars and planets : physics and chemistry

  Natural complement to VLT/VLTI, HST, FIRST, .....

- Natural successor to JCMT, ISO

- Long tradition in interferometry

Dutch community currently has no access to millimeter interferometry

~ 2000 : very limited access through JCMT-SMA connection

# NOVA

- NOVA : Nederlandse Onderzoekschool voor Astronomie
  Dutch graduate school for Astronomy

- Collaboration between astronomy institutes of Amsterdam, Leiden, Utrecht and Groningen, plus group at Free University of Amsterdam

- Close ties with NWO foundations ASTRON and SRON

Director: P.T. de Zeeuw, Leiden

Chair of Board: E.P.J. van den Heuvel, Amsterdam

# NOVA's Mission

Train young astronomers at the highest international level

Carry out frontline astronomical research in the Netherlands

# NOVA's research program

## The life cycle of stars and galaxies

- Fundamental problems in science
- Leading scientists in this field
- Technology now available for breakthroughs
- Wide cultural appeal

# Instrumentation program

- Maximize scientific exploitation of the Very Large Telescope
- Take active role in development of new millimeter interferometer array, through construction of prototype receivers

In collaboration with experts as ASTRON, SRON, and other groups

This will provide:

**Priority access to world-class facilities**
**Increased level of technical expertise at universities**
**First-class training of next generation of astronomers**

# NOVA proposal

| | |
|---|---|
| • Spring 1997 : | call by minister of education for proposals for "top-research" schools<br>Mfl. 3-10 / year for 10 years (5+5)<br><u>all</u> disciplines |
| • Summer 1997 : | preparation NOVA phase I proposal<br>instrumentation for VLT(I) + LSA/M<br>top priority |
| • Dec. 1997 : | 11 of 36 proposals selected for phase II |
| • Jan. 1998 : | NOVA phase II submitted |
| • Feb. 1998 : | Interview with committee |
| • March 1998 : | committee ranks NOVA no. 1 |
| • May 1998 : | official letter from minister<br>Mfl. 46 over first 5 years |

## Proposed NOVA LSA/MMA Receiver Development

-ASSUMPTIONS AND CONSIDERATIONS

- PHASES IN THE LSA/MMA PROGRAMME

- RECEIVER PRODUCT TREE

- NOVA DEVELOPMENT ACTIVITIES
  - ACTIVITIES
  - PROGRAMMATICS

## ASSUMPTIONS AND CONSIDERATIONS

- LSA/MMA ORGANISATION T.B.D.

- RECEIVER DEVELOPMENT AND CONSTRUCTION CARRIED OUT IN USA AND EU

- EU RECEIVER EFFORT IS A COORDINATED DEVELOPMENT AND CONSTRUCTION: REQUIRES ONE INTERFACE TO LSA/MMA; NOVA EFFORT PART OF IT

- US MMA RECEIVER DEVELOPMENT ALREADY STARTED; NOVA INITIATIVE ALLOWS EU TO START AS WELL

- DETAILED RECEIVER WORKPLAN AND ORGANISATIONAL SETTING TO BE ARRANGED IN SECOND HALF OF 1998.

- INVOLVED PARTIES: RECEIVER WORKING GROUPS AND LSA/MMA PROJECT

## PHASES IN THE NOVA LSA/MMA RECEIVER PROGRAMME

- NOVA HAS FUNDING FOR 10 YEAR RECEIVER DEVELOPMENT FOR THE LSA/MMA

- COVERING FIRST DAY RECEIVERS AND SECOND GENERATION

- COVERING RESEARCH AND TECHNOLOGY DEVELOPMENT

- FUNDING STOPS AFTER DEMO MODELS, WHERE "MASS" PRODUCTION STARTS

- NL MAY BE A CANDIDATE "PI" INSTITUTE

# NOVA LSA/MMA RECEIVER PROGRAMMATICS

- EMBEDDED IN FIRST-HIFI DEVELOPMENT
- MIXER DEVELOPMENT AT SRON/RUG
- JUNCTION DEVELOPMENT AT RUG/APPL.PHYS.DEPT
  (COLLABORATION EXISTS OVER 10 YEARS)
- SMALL TEAM OF EXTRA MANPOWER SUPPORTED BY EXISTING SRON/RUG TEAM
- LEAD BY "PARTICIPATING" PROJECT MANAGER
- DIRECTED BY RECEIVER STEERING GROUP
  (INCLUDES LSA/MMA RWG/PROJECT)
- REPORTING TO NOVA AND TO LSA/MMA RWG/PROJECT
- INTIMATE COLLABORATION NEEDED WITH CRYO-AMP AND LO GROUPS
- INITIAL PHASE OF DEVELOPMENT FOR THREE YEARS

<u>**LSA/MMA FRONT-END PRODUCT TREE**</u>

**LSA/MMA FRONT-END:**

- FRONT-END FRAME
  AND CABLE WRAP

- CONTROL/BIAS ELECTRONICS

- MICROWAVE INFRASTRUCTURE
  (IF AMP AND LO)

*FREQUENCY DEPENDENT:*

- CRYOSTAT 1

- CRYOSTAT 2 . . . .

    - CRYOSTAT WITH CABLING AND WINDOWS
    - OPTICS
    - CALIBRATION UNIT
    - MECHANICAL STRUCTURE

    ***FOR EACH FREQUENCY BAND:***

    - MIXER MODULE WITH 1ST STAGES PRE-AMP
    - LO MODULE (OUTSIDE)

- POWER COMBINER WITH CRYO-AMP MODULE

- **DUTCH DEVELOPMENT ACTIVITIES:**

- **MIXER DEVELOPMENT AT HIGHER FREQUENCIES LEADING TO PROTO-TYPE MIXER**

  **- MIXERS:**

  - BROAD IF BANDWIDTH
  - TUNERLESS
  - SSB OPERATION
  - FABRICATION ASPECTS

  **- JUNCTIONS:**

  - JUNCTION MATERIALS FOR QLP ATHIGH FREQUENCIES
  - PRODUCTION YIELD AND PERFORMANCE BANDWIDTH
  -

- **DESIGN AND DEVELOPMENT PROTOTYPE CRYOSTAT**

  - INPUT OPTICS
  - LO COUPLING AND LOCATION LO
  - MECHANICAL /THERMAL LAY-OUT
  - IF-AMP MODULE
  - BIAS MODULE (ASICS DEVELOPMENT)(LOCATION OUTSIDE)
  - RELIABILITY/SERVICING

- **PREPARATION FOR INDUSTRIAL PROCUREMENT OF MIXER AND OTHER RECEIVER COMPONENTS**

  - PILOT PRODUCTION RUNS
  - SURVEY AND IDENTIFY INDUSTRIAL PARTNERS (ADDITIONAL FUNDING SOURCES?)

- **DEVELOPMENT OF INTEGRATION AND TEST PLAN**

  - POSSIBLE SCENARIOS
  - BUDGET ESTIMATES

## SYNERGETICS LSA/MMA AND HIFI PROJECTS

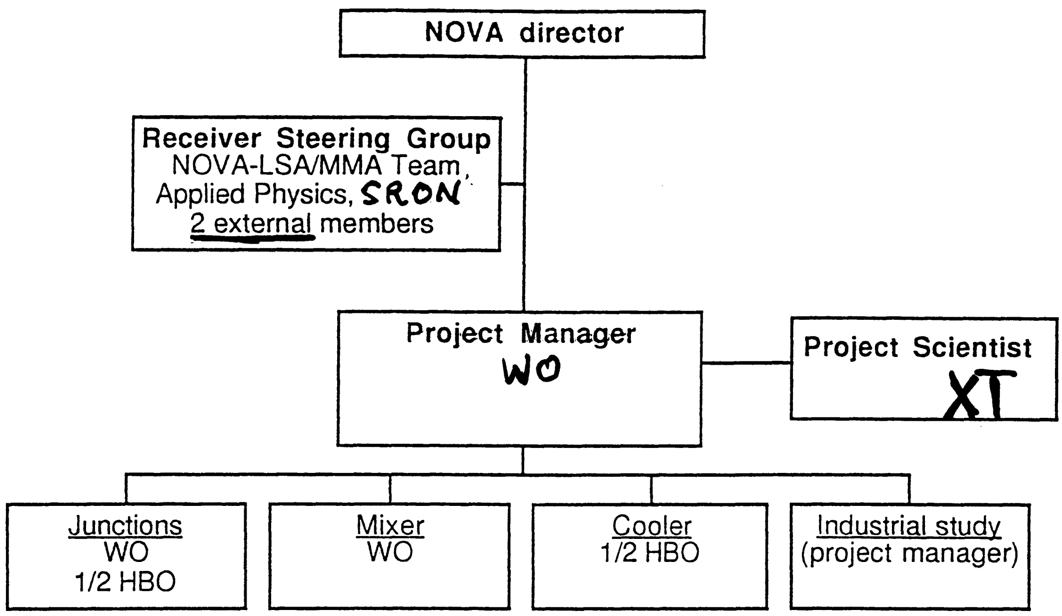
| | **LSA/MMA** | **FIRST-HIFI** |
|---|---|---|
| **FREQUENCY** RANGE | 70- 950 GHz | 480-2700 GHz |
| IF CENTER | T.B.D. | 4 OR 10 GHz |
| IF BANDWIDTH | 4-8 GHz | 4 GHz |
| **MIXER** TYPE | WAVEGUIDE<br>CORRUGATED HORN | WAVEGUIDE/QO<br>CORRUGATED HORN |
| SIDE BAND | SSB | DSB |
| TUNERLESS | YES | YES |
| **JUNCTION** TYPE | SIS Nb/AlO2/Nb | SIS Nb/AlO2/Nb |
| TUNING STRUCTURE | NbTiN | NbTiN |
| QUAL. LEVEL | HIGH | SPACE |
| MODULAR DESIGN | Y | Y |

## COMMON CHARACTERISTICS:

- **NEED FOR MODULARITY: ASICS DEVELOPMENT**
- **COUPLING OF MANY LO'S INTO CRYOSTAT:WINDOW DEVELOPMENT**
- **COMPUTERIZED TESTING AND CONTROL: EASY RESET OF RECEIVERS**
- **EFFICIENT AND RELIABLE OPERATION**
- **LARGE MTBF REQUIREMENT**

# NOVA LSA/MMA Receiver Project

## Management Structure




Personnel: Project manager (WO), 2 WO's, 2 HBO (halftime), project scientist.

Scientist Engineer

Cost to NOVA: 4.3 million guilders

LSA rcvr group mtg. in Leiden

HFET developments in Europe - lots of working groups

Materials: mostly GaAs etc. for power applications - commercial
Zurich: some InP/InAlAs/InGaAs room temp
SiGe/Si for power

Zurich: 12 GHz 0.9 dB NF @ 300K, 19 dB gain in InP

Alberto Barcia: TRW devices through JPL via FIRST
0.1 × 160 μm 23 dB gain 8-12 GHz, NF 5-8K at 15K
using InP only in 1st stage, GaAs
input return loss ~3 dB
Predict: should be able to do 4-12 GHz with 4-5 K NF

Hartmut Mattes' group: 12-18, 18-27, 27-40, 33-50 with <0.5K/GHz
developing balanced design 4-12 GHz

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SIS

tries to dominate discussions - doesn't know how to summarize anything

Alexandre Karpov: should not exclude use of mechanically tuned back shorts - go for lowest possible noise
Jacobs: at higher frequencies, fixed tuned is better
IRAM @ 230 GHz ~45K SSB ; @ 90 GHz, ~40K SSB

Lots of dissension - first time group has been assembled.

## SIS fabrication

Consistency of Nb wafers is always a limiting factor.
For mass production, some development is needed in Europe.
Need expansion of capabilities including diagnosis.

Some discussion of necessity of simplifying assembly —
may trade a little performance for the sake of
simplicity and reliability.

Integrated IF (Nick Whyborn)
SRON 600-750 GHz mixer has IF band 1-12 GHz,
used with 3 GHz instantaneous bandwidth
RF: favors off-axis mirror + corrugated feedhorn (rather than lens)
Barcia: PAMTECH 8-12 GHz cryogenic isolator contributes ~1K

Is flux trapping a problem?

## Local Oscillators

Brian Ellison — list of criteria — all familiar
Discussed use of UVA whisker-contacted diode assembly
Tripler 250-300 >50μW, peak 120μW w/ 10 mW input
(can put in up to 40mW?, efficiency 11% at center)
Zimerman thinks planar diodes doubtful above 500 GHz
Few sources of devices in Europe. No one working on photonics.

ESO thinks having a "P.I." institution designated too early could be a political problem. Jacobs thinks one is essential.

Jacobs: MMA/LSA cooperation considerations:

1. common receiver design
2. modularity by frequency band
3. development work on both sides
4. complete receiver assembly on both sides (implies exchange of modules & cryostats)

Need good definition of interfaces + a central coordinating institution in Europe.

Booth: might set up a new institution with staff contributed by participating organizations.

NFRA is in the process of installing 1 new rcvr per month, with a staff of 12. All parts are made & tested – dewar and electronics must be assembled, tested, installed. This is low frequency stuff.

LSA rcvr group mtg. in Leiden

[Ambrosini: info on Quickwave, Ka band amplifier drawings]

Ewine: NOVA for graduate education in astronomy, 10-yr duration
Selected in May 98 for 46 Mfl over 5 years
Consortium of universities interested in developing
prototype mm receivers for LSA/MMA
Allocating Mfl 3.4 ≈ $1.7M for sub-mm receivers
Tielens: coordinate development with US effort (X.T. is NOVA Project Scientist)
need detailed workplan in second half of 1998 - say in 6 mos.
Funding is for development only - not production
Plan: Front end:
frame & cable wrap
control/bias electronics (ASICs for SIS, HFET?)
IF amp & LO
Cryostat & contents
Want to develop tunerless SSB mixers for one band (no mention of balanced)
Prototype cryostat - optics, LO coupling, IF amp etc.
Think about production organization - looking to industry
Will develop NbTiN so they can go to 950 GHz
Closely associated with FIRST/HIFI development
Will add to staff at SRON/RUG, Groningen for mixer development - about 5 FTE
First phase lasts 3 years
Haven't decided what band to develop first

Discussion: Booth: lots of development going on - Dutch should concentrate
their efforts and not scatter over multiple topics
Same comments from several participants
Tielens: see several months of planning after a program manager is hired

European problem: how to organize and evaluate priorities when only one group has serious money? Appoint a small group to produce a report, then discuss in a big group.

Karpov brought in the KGB.

Jacobs: list of development items

1) LO system
   - specifications
   - might get a European photonics group interested (RAL, MPIfR will look)
   - multipliers/amplifiers: some overlap with FIRST (RPG, ETH, RAL)
2) Integrated SSB mixers
   - specifications (including reliability - don't exclude mechanical tuning a priori, but evaluate it - # of cycles etc.)
   - circuit design
   - maximizing sensitivity
   - device optimization (uniformity, stability)

   (SRON, IRAM, OSO, HIA, DEMIRM, MPIfR, KOSMA, RAL, NRAO)
3) Optics
   - low noise input optics — calibration
     - polarization
     - feed horns/lenses
   - LO coupling if needed

   (IRAM, NRAO, U Calgary, Arcetri, SRON
4) Industrialization/mass production
   - identify suitable components — testing
   - identify suppliers (business partners)

   (SRON, OSO, IRAM, RPG?)
5) Receiver system specifications

   (everybody - form a small working group?)
6) Cryogenics (RAL, SRON, IRAM, HIA
   - temperature — reliability — specifications
   - required stability — new developments

Management: how to develop a plan for ESO? May need money.
Some urgency – ESO council meeting soon to authorize
production of a proposal

Bernard : possible IRAM contribution
- Prototyping LSA technology up to 400 GHz (80-400)
  - JT refrigerators
  - focal plane layout
  - automatic control & tuning
- Reliability testing (won't install until 2001 on PdB)
- Willing to discuss delivery of a prototype LSA receiver (using conventional LO) at a specified band; expect to take ~2 years to develop. Expect SSB with mechanical backshort tuning, L-band IF (1 GHz anyway).

How to form a working committee without causing some nationalities or institutions to feel excluded? Leave it to Karl Jacobs. Receiver working group may be largest of the LSA groups.

Another meeting of the whole group would discuss the draft plan generated by the small group – maybe late Fall?

## INTECSA

General engineering company — interested in MMA infrastructure. (Involved with Rubbiatron method of isotope disposal / energy gen.) Power generation. ~300 people, half technical. Big construction — synchrotron at Grenoble, various facilities. Civil engineering. Normally work with a large team in international projects — do design but not construction.

## INGEMETAL

Antenna specialists. Normally do construction as sub for antenna designers (or other large metal structures). Have done some design work. Might find a sub that could machine panels. Did a power plant in northern Chile. $10M /yr revenue. ~50 people. Get large machining projects done in major machine shops in Zaragossa.