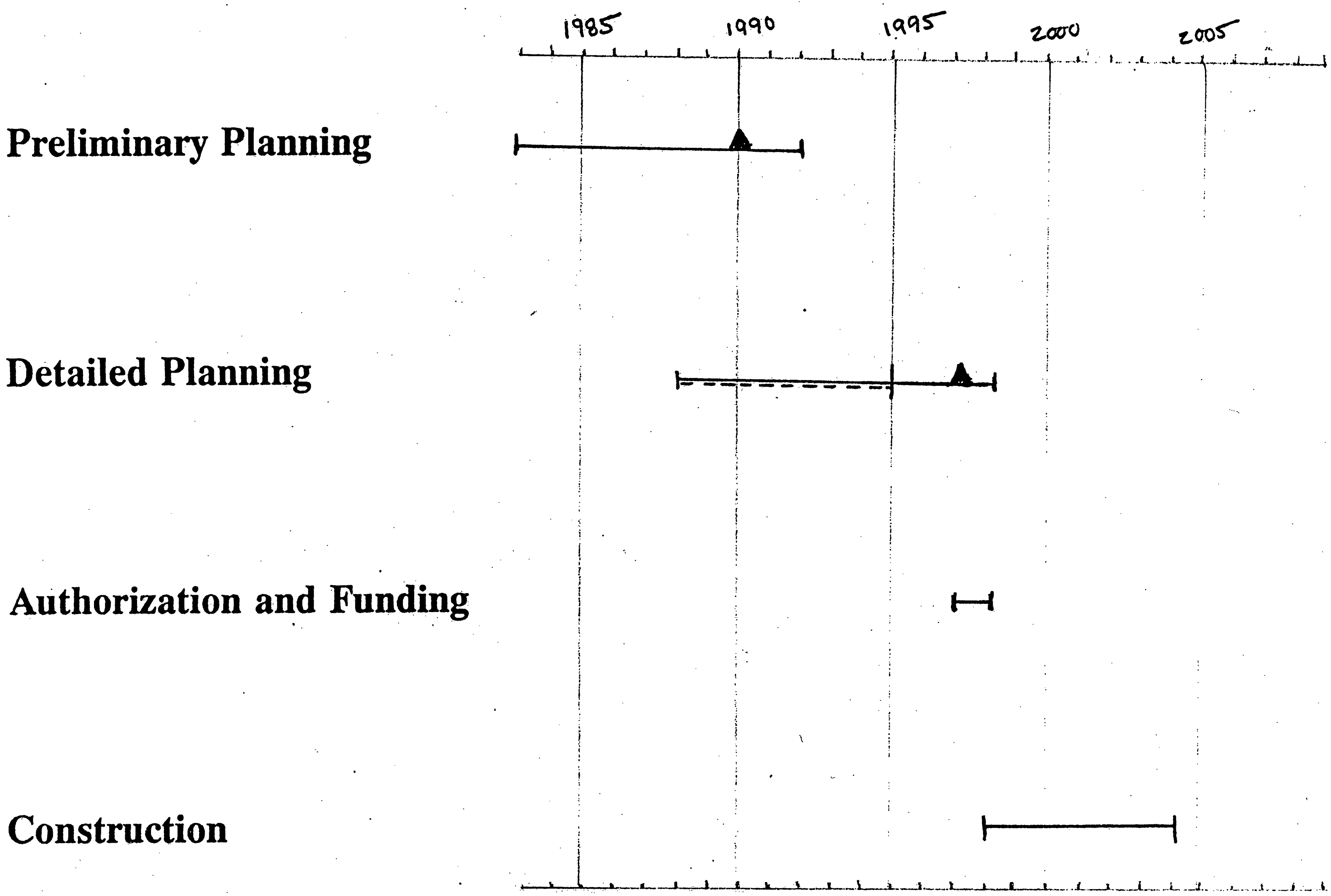
MMA Proposal Chronology

■ 1990 Sept.	AUI Proposal for MMA Submitted to NSF.
■ 1991 Mar.	NSF Site Visit to Review MMA Proposal.
■ 1991 May	NAS Decade Review of Astronomy Recommends MMA as one of Two Major Initiatives in Ground-Based Astronomy for the Decade of the 1990s.
■ 1991 Oct.	MMA Endorsed by NSF Advisory Committee for the Astronomical Sciences in Two Phases: Detailed Design followed by Construction.
■ 1992 Mar.	NSF Division of Astronomical Sciences Asks for a Three-Year Plan for the Detailed Design of the MMA.
■ 1992 Sept.	NRAO Submission of MMA Design and Development Plan.
■ (1995 Jan.	FY 1995: First NSF Astronomy Division Funds for MMA Design.)

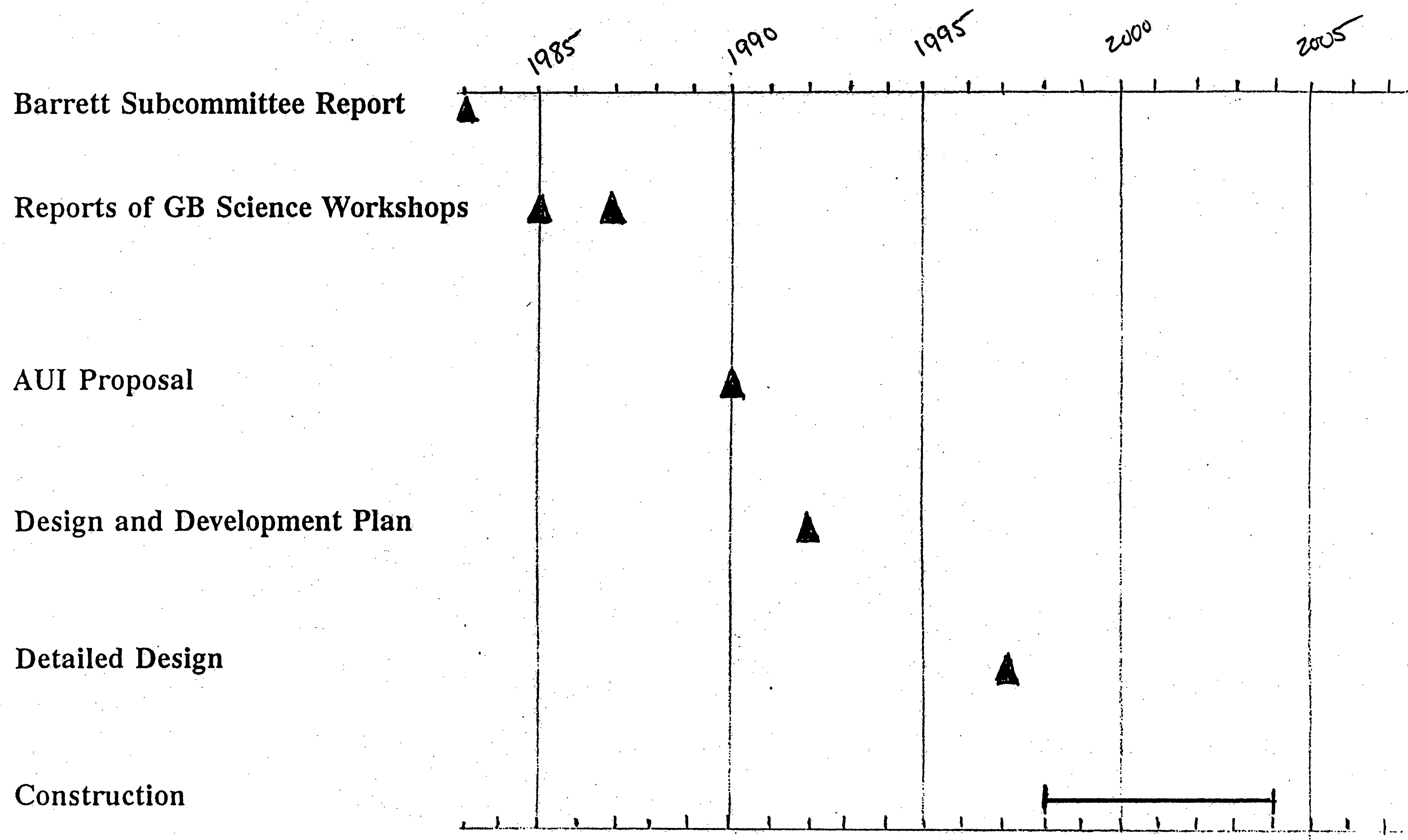
MMA Approval and Funding Process

■	1995 Jan.	FY 1995: First NSF Astronomy Division Funds for MMA Design
■	1996	Continuation, MMA Design and Development
■	1997 Jan.	MMA Final Report Construction Costs Operations Costs Site Continuation, MMA Design and Development
■	1998	Construction
■	2000+	Interim Operation
■	2004/2005	Full Operation

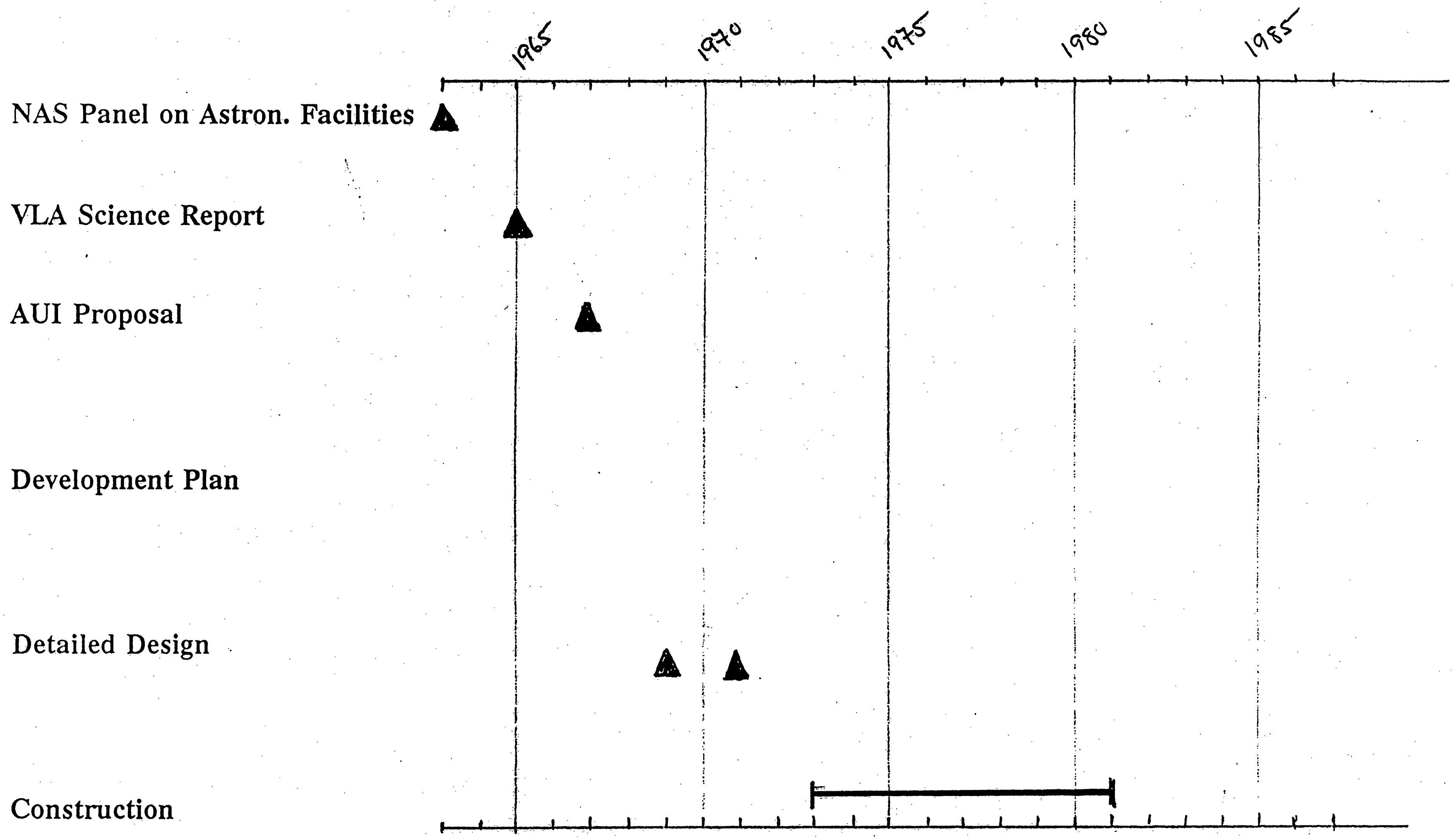
MMA SCHEDULE



Array Reports, Proposal and Documentation: MMA



Array Reports, Proposal and Documentation: VLA



MMA Construction Cost Estimate:

Adjustment for Inflation

1990 Dollars	$120 M	
1993 Dollars	$135 M	(1)
1998 Dollars	$170 M	(2)

Notes

(1) GNP Price Deflator: Source OMB

(2) Projecting Inflation at 4.5% annually

Inflation - Adjusted VLA Construction Cost

Year	Expend ($M)	Index[1]	Cost ('93 $M)	Index[2]	Cost ('98 $M)
1973	$ 2.29	3.213	$ 7.36	4.003	$ 9.17
1974	5.44	2.893	15.74	3.605	19.61
1975	11.79	2.650	31.24	3.302	38.93
1976	16.52	2.506	41.40	3.123	51.59
1977	11.26	2.354	26.51	2.934	33.04
1978	14.01	2.188	30.65	2.727	38.21
1979	10.86	1.963	21.32	2.446	26.56
1980	3.91	1.729	6.76	2.155	8.43
1981	2.17	1.569	3.40	1.955	4.24
TOTAL	**$78.25 M**		**$184.38 M**		**$229.79 M**

Notes:

[1] *Source: OMB*
[2] *Using 4.5% as the annual inflator*

MMA PERSONNEL

MMA Principal Responsibility

J. Cheng
S. Radford
M. Gordon

Millimeter Interferometer Users

H. Liszt
A. Wootten
S. Radford
C. Chandler
G. Fuller
J. Uson
D. Adler
R. Brown
P. Vanden Bout

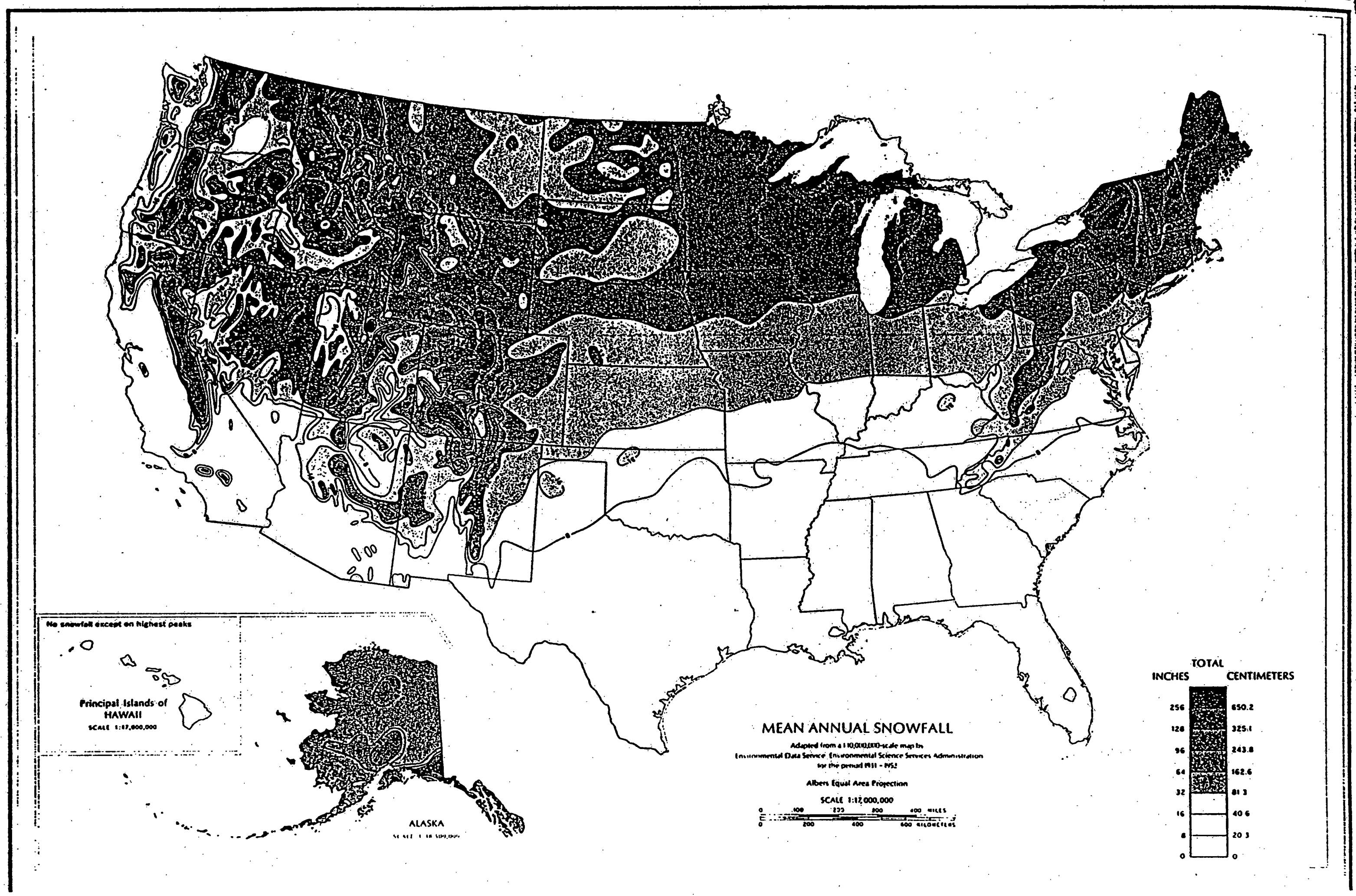
MMA SITE REQUIREMENTS

Principal Criteria

- Elevation at least 9000 feet above MSL
- South of latitude 36 degrees north
- Large enough to accommodate an array 3 x 2 km in extent

Secondary Criteria

- Accessible by existing roads
- In principle, available for scientific use
- Free of hostile activities
- Proximity to support community


No snowfall except on highest peaks
Principal Islands of HAWAII
ALASKA
MEAN ANNUAL SNOWFALL
Albers Equal Area Projection
SCALE 1:17,000,000
0 100 200 300 400 MILES
0 200 400 600 KILOMETERS
TOTAL
INCHES
CENTIMETERS
256 650.2
128 325.1
96 243.8
64 162.6
32 81 3
16 40 6
8 20 3
0 0

MAGDALENA MTNS, NM

	Days With Opacity Less Than Tau			
	τ = 0.05	0.10	0.15	0.20
October 1990	1.2	6.5	13.2	19.3
November 1990	2.6	10.5	17.1	22.3
December 1990	4.4	16.1	22.3	23.3
January 1991	1.7	11.2	19.7	23.5
February 1991	0.7	10.5	18.7	25.3
March 1991	3.6	11.4	17.5	21.8
April 1991	0	9.2	17.8	22.3
May 1991	0	4.5	11.7	18.1
June 1991	0	0.9	4.0	6.9
TOTAL (9 mo.)	14.2	80.8	142.0	182.8
Correct to 12 months	14.8	84.5	150.6	195.9

SPRINGERVILLE, AZ

	Days With Opacity Less Than Tau			
	τ = 0.05	0.10	0.15	0.20
October 1990	0.3	2.8	8.8	14.7
November 1990	0.8	6.7	13.9	19.5
December 1990	0.8	11.8	20.6	22.3
January 1991	0	8.2	16.5	21.5
February 1991	2.3	7.4	15.2	20.0
March 1991	2.9	9.0	17.4	22.3
April 1991	0	6.2	15.6	25.2
May 1991	0	5.3	11.9	18.1
June 1991	0	4.2	6.4	8.6
TOTAL (9 mo.)	7.1	61.6	126.3	172.2
Correct to 12 months	7.3	65.1	133.9	183.9

MAUNA KEA (VLBA SITE)

	Days With Opacity Less Than Tau			
	τ = 0.05	0.10	0.15	0.20
November 1992	3.8	10.9	16.6	21.0
December 1992	0	4.4	8.5	12.3
January 1993	9.7	22.4	27.0	29.8
February 1993	3.6	20.2	23.5	26.6
March 1993	4.0	18.3	25.4	25.4
April 1993	6.0	21.9	27.9	28.8
May 1993	8.0	18.8	26.6	29.5
June 1993	1.8	10.4	23.2	26.0
July 1993	0	0.4	9.2	15.8
August 1993	3.1	7.3	11.3	15.1
TOTAL (10 mo.)	40.0	135.0	199.2	230.3
Correct to 12 months	48.0	162.0	239.0	276.4

SITE SUMMARY

Annual Days With Opacity Less Than TAU

	τ = 0.05	0.10	0.15	0.20
Magdalena Mtns.	15	85	151	196
Springerville, AZ	7	65	134	184
Mauna Kea (VLBA)	48	162	239	276

THE MMA SITE TESTING PROGRAM

1. The Instrument

Radiometer - A room temperature Schottky mixer operating at 225 GHz.
- Two internal temperature-stable loads provide gain calibration.

Optics - A small primary mirror directs the signal into the mixer through a chopper wheel.

2. The Observations

1986-88 - Zenith opacity measurements at the Magdalena Mountains (South Baldy) and at the VLA site.

1989-91 - Zenith opacity, sky temperature fluctuation measurements at Magdalena Mountains and Mauna Kea. Springerville added for 1990-91.

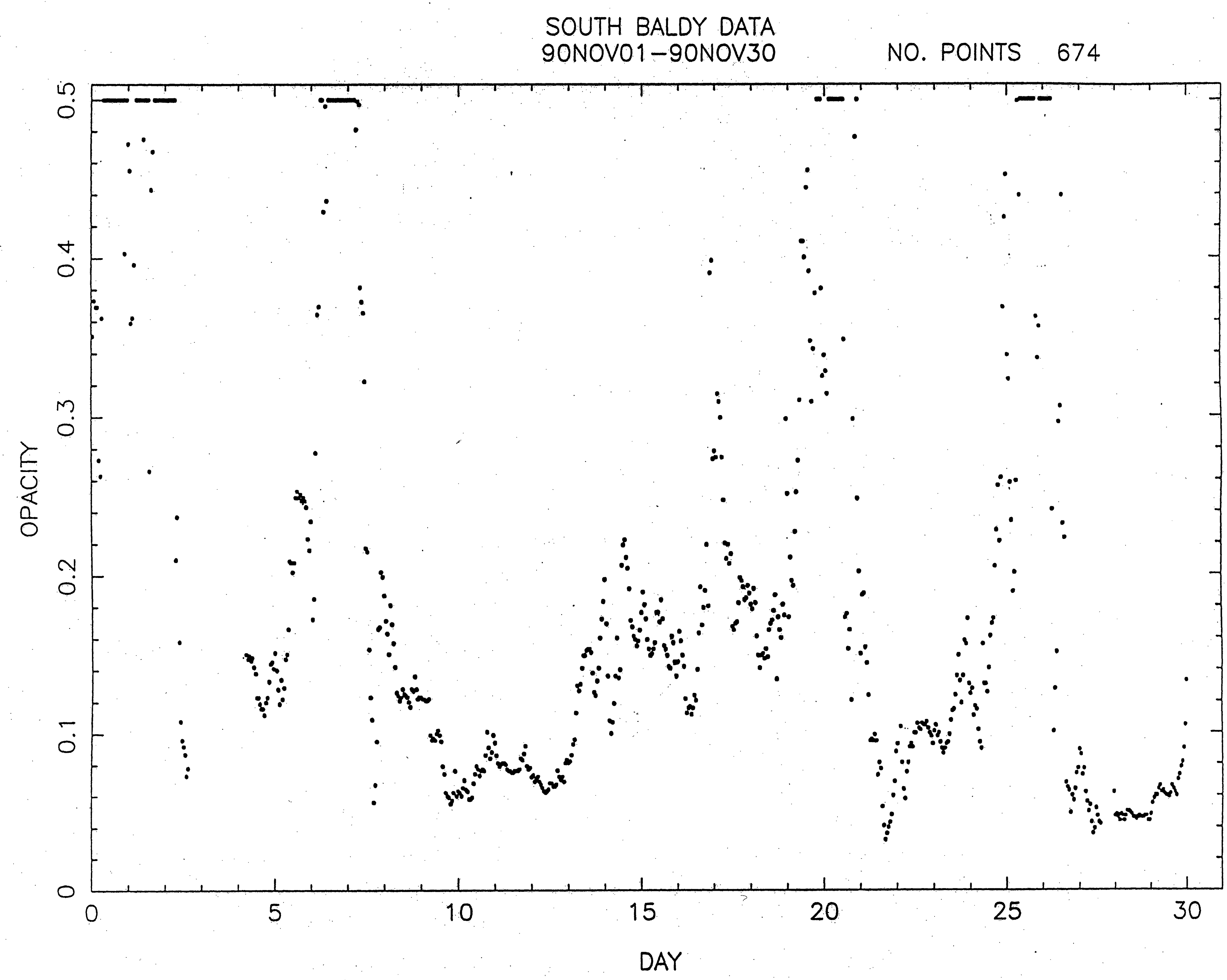
[1992 → Measurements at Mauna Kea—see posters.]

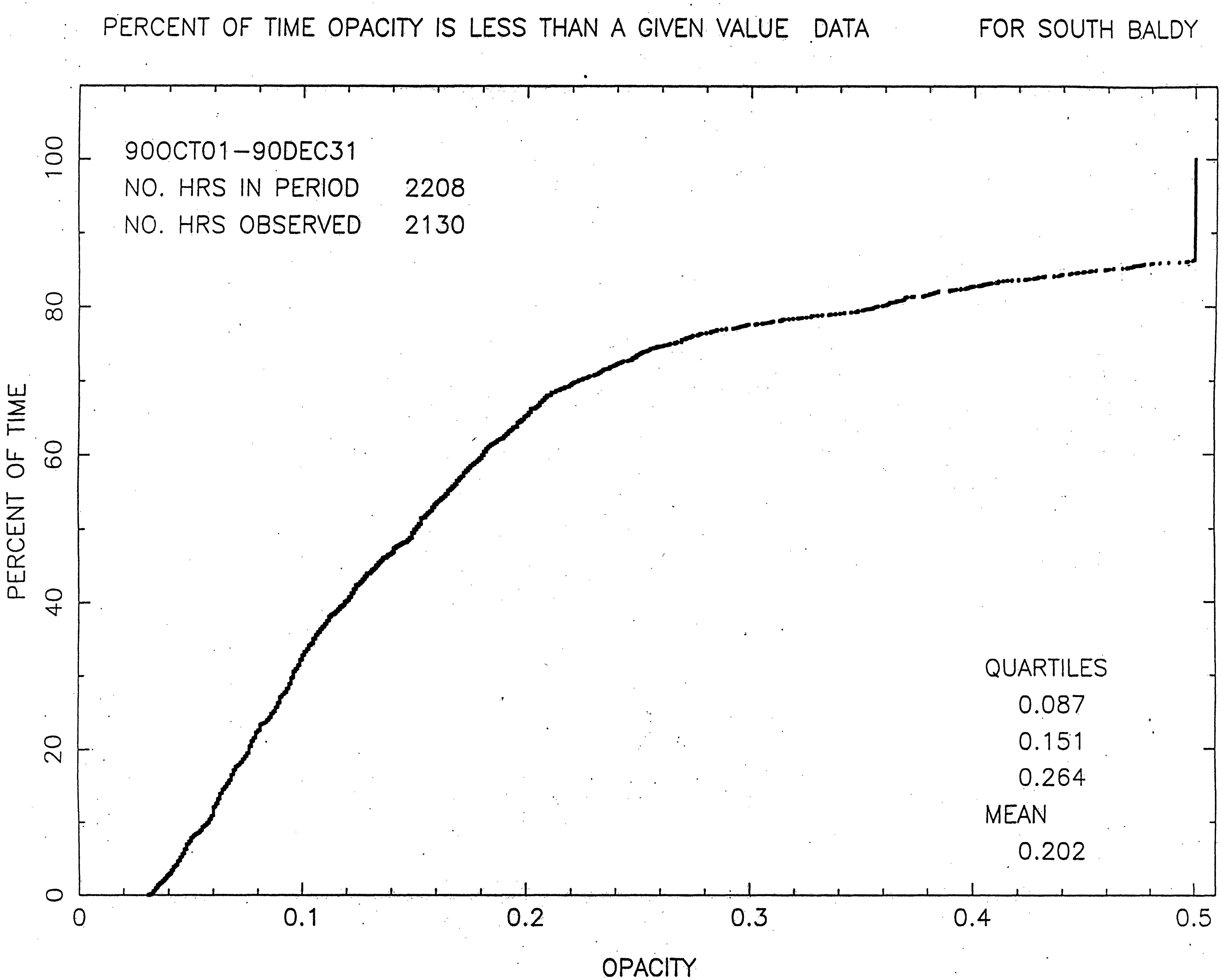
3. Zenith Opacity Measurements

Deduced from an eleven-point tipping curve, made six times each hour.

4. Zenith Sky Temperature Fluctuation Measurements

Deduced from a set of 1024 measurements of sky brightness temperature, the samples taken every 3.5 seconds. The observation requires one hour, and was made every fifth hour.


SOUTH BALDY DATA
90NOV01–90NOV30
NO. POINTS 674
OPACITY
0
0.1
0.2
0.3
0.4
0.5
0
5
10
15
20
25
30
DAY


PERCENT OF TIME OPACITY IS LESS THAN A GIVEN VALUE DATA FOR SOUTH BALDY
90OCT01–90DEC31
NO. HRS IN PERIOD 2208
NO. HRS OBSERVED 2130
QUARTILES
0.087
0.151
0.264
MEAN
0.202
PERCENT OF TIME
0
20
40
60
80
100
OPACITY
0
0.1
0.2
0.3
0.4
0.5

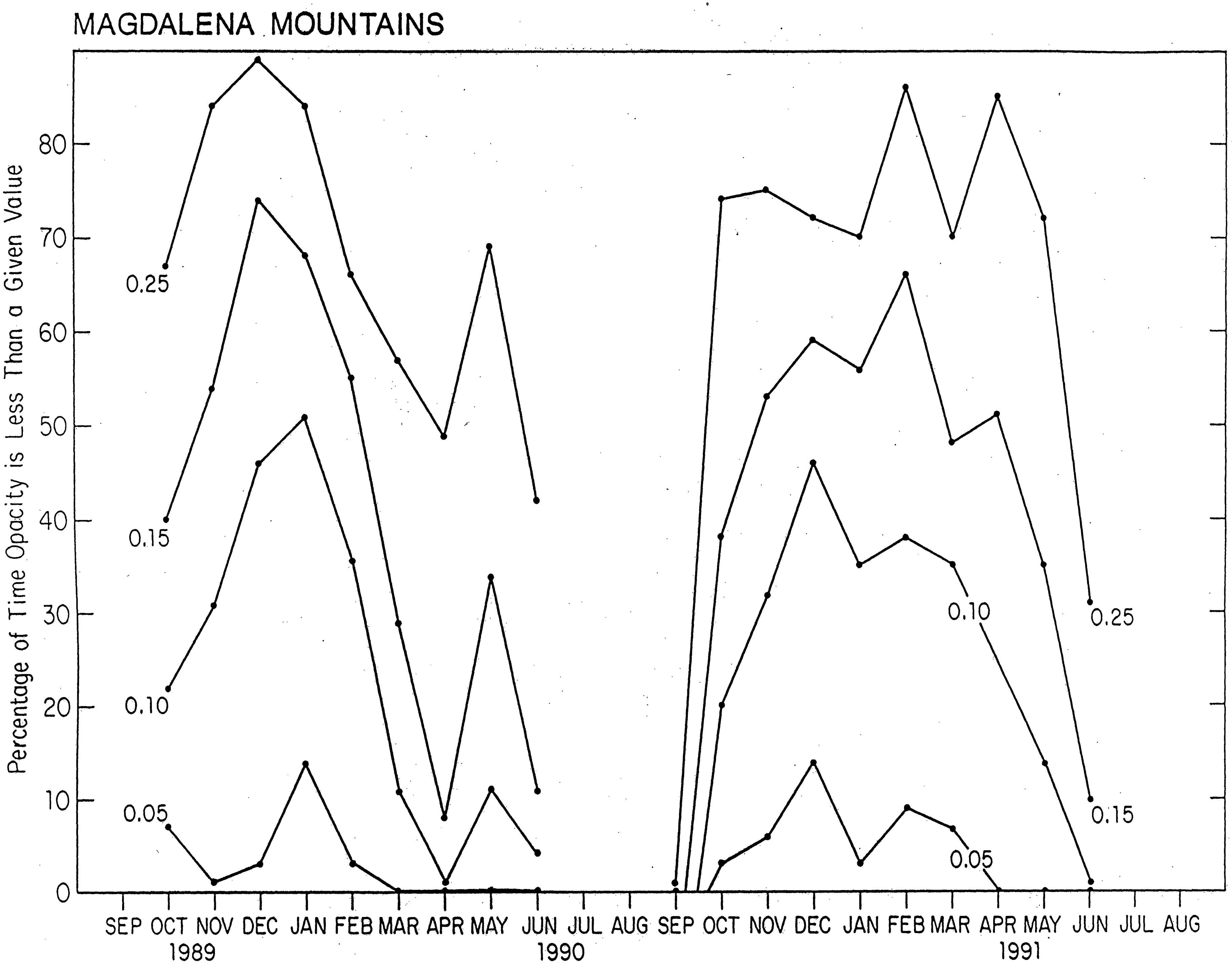

MAGDALENA MOUNTAINS
Percentage of Time Opacity is Less Than a Given Value
0
10
20
30
40
50
60
70
80
0.25
0.15
0.10
0.05
0.10
0.25
0.15
0.05
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG
1989
1990
1991

Figure 3a

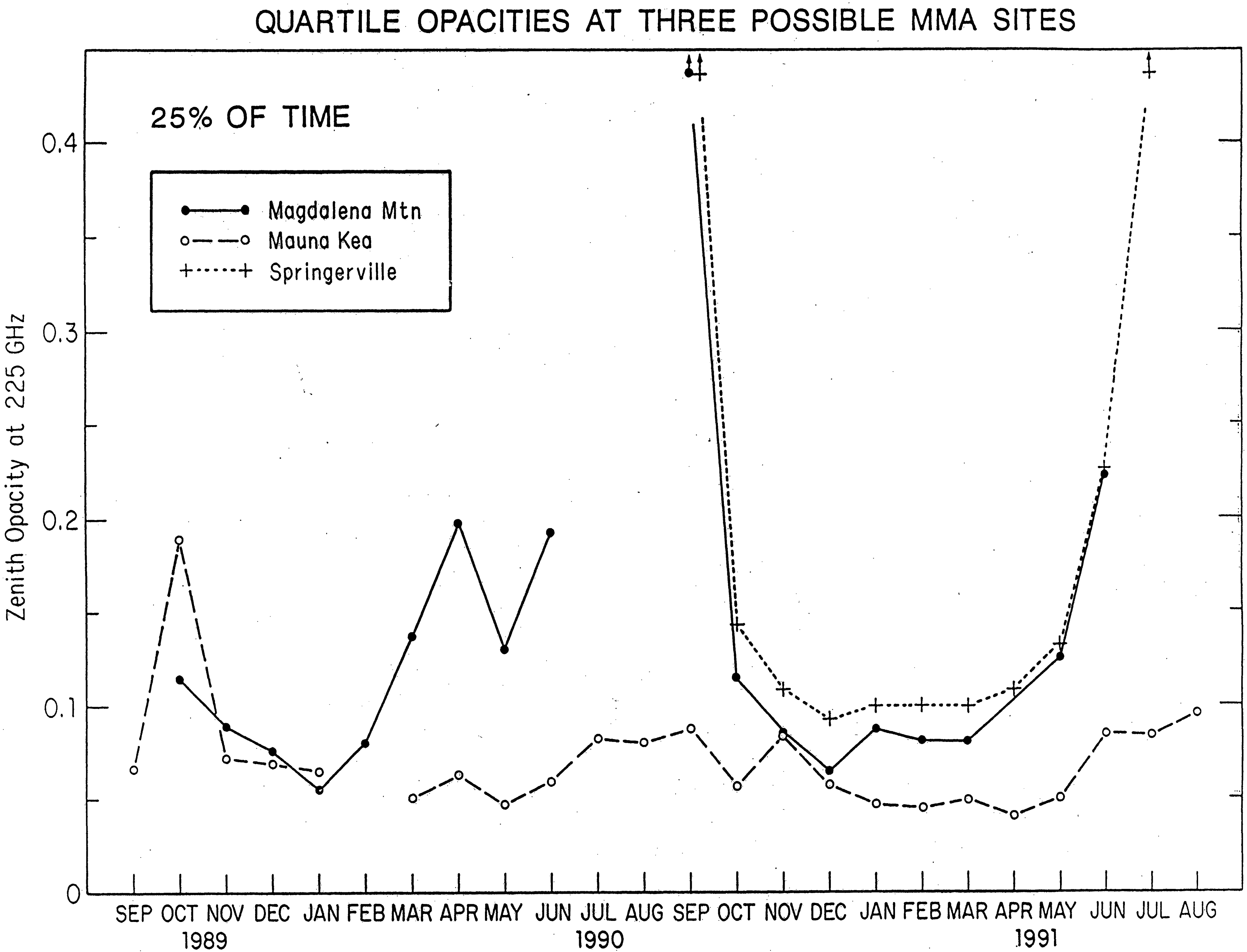

QUARTILE OPACITIES AT THREE POSSIBLE MMA SITES
25% OF TIME
Magdalena Mtn
Mauna Kea
Springerville
Zenith Opacity at 225 GHz
0
0.1
0.2
0.3
0.4
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG
1989
1990
1991

Figure 4a

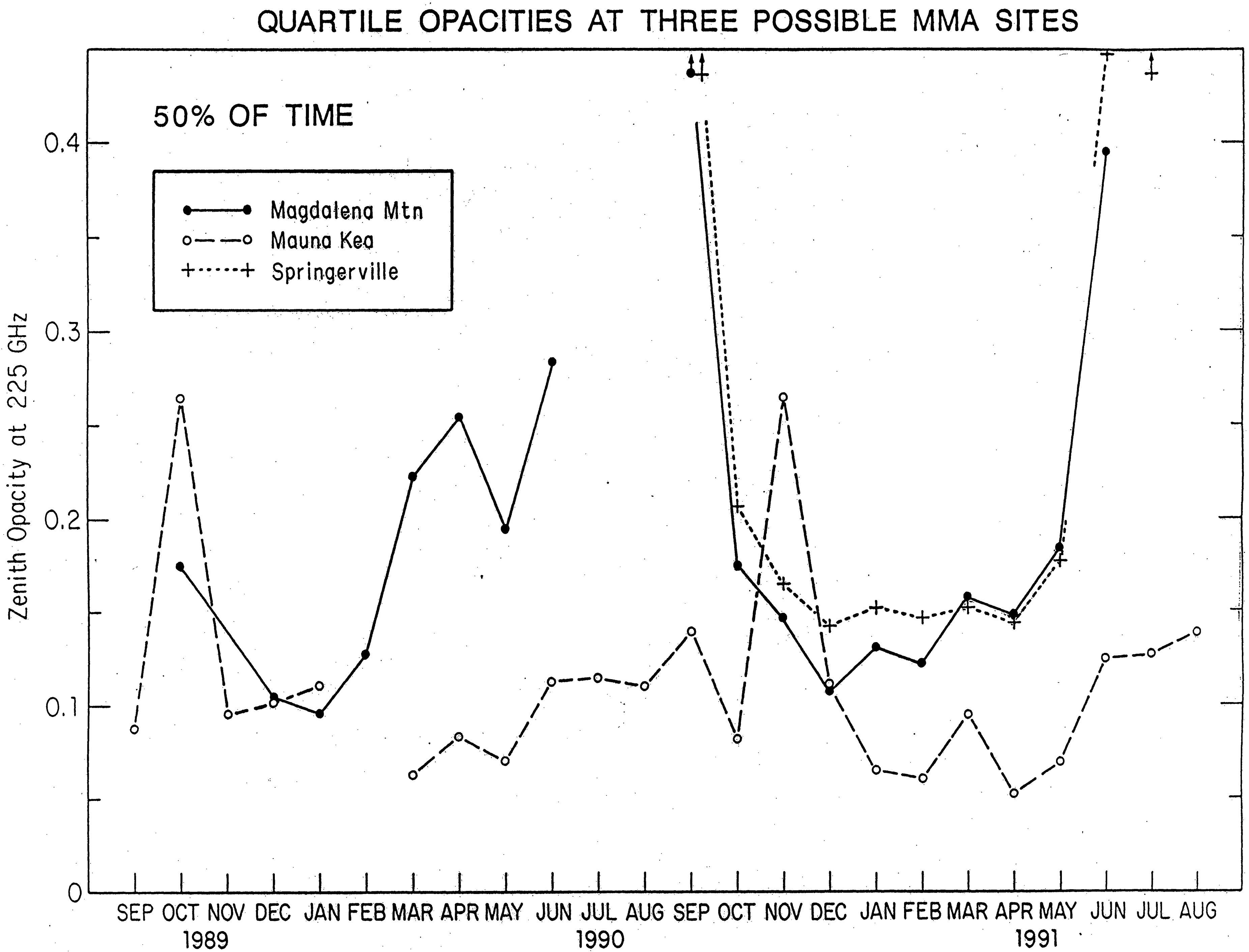

QUARTILE OPACITIES AT THREE POSSIBLE MMA SITES
50% OF TIME
Magdalena Mtn
Mauna Kea
Springerville
Zenith Opacity at 225 GHz
0.4
0.3
0.2
0.1
0
SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG
1989
1990
1991

Figure 4b

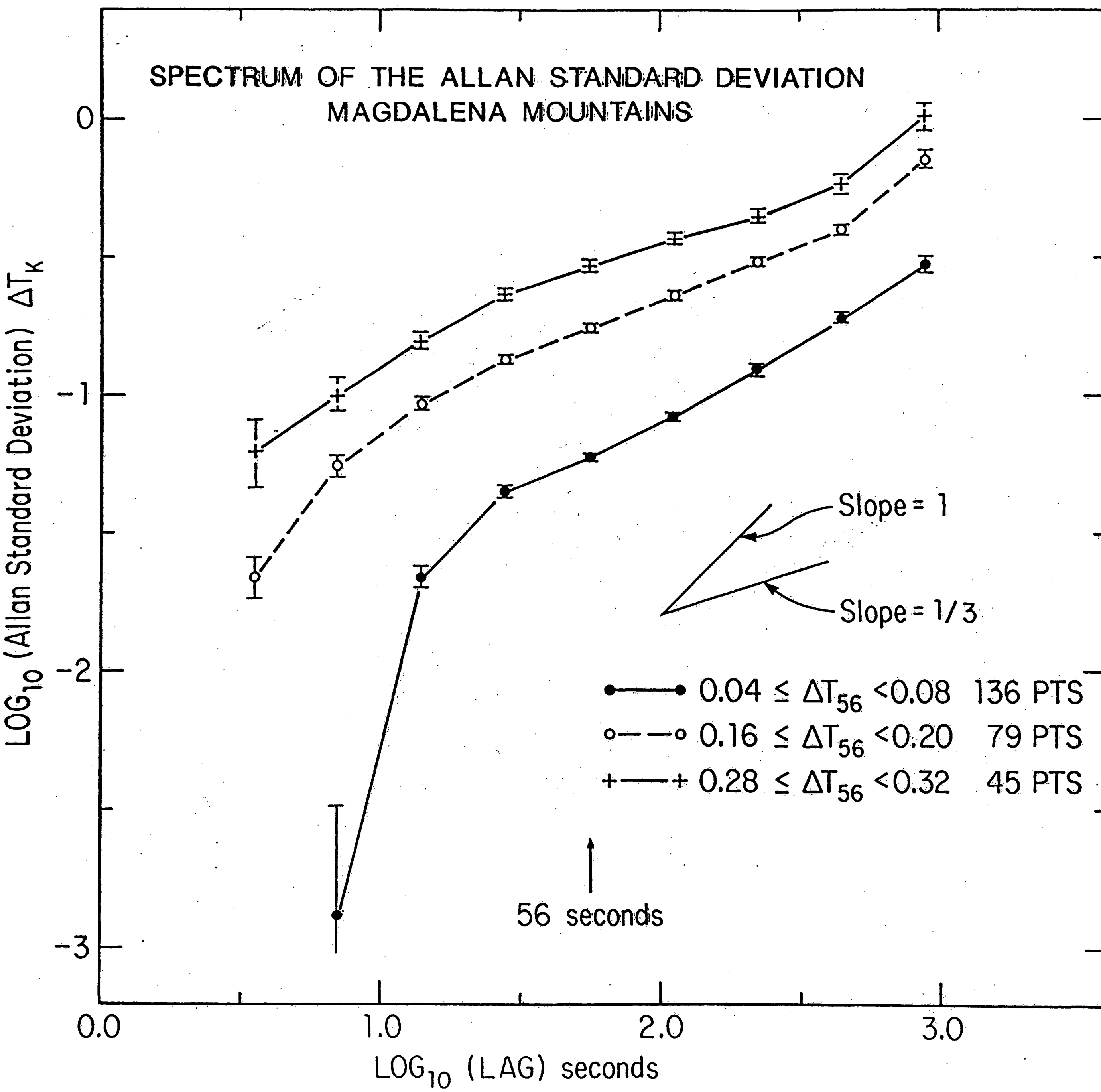

SPECTRUM OF THE ALLAN STANDARD DEVIATION
MAGDALENA MOUNTAINS
0
-1
-2
-3
0.0
1.0
2.0
3.0
LOG10 (Allan Standard Deviation) ΔTK
LOG10 (LAG) seconds
Slope = 1
Slope = 1/3
0.04 ≤ ΔT56 <0.08 136 PTS
0.16 ≤ ΔT56 <0.20 79 PTS
0.28 ≤ ΔT56 <0.32 45 PTS
56 seconds

Figure 6

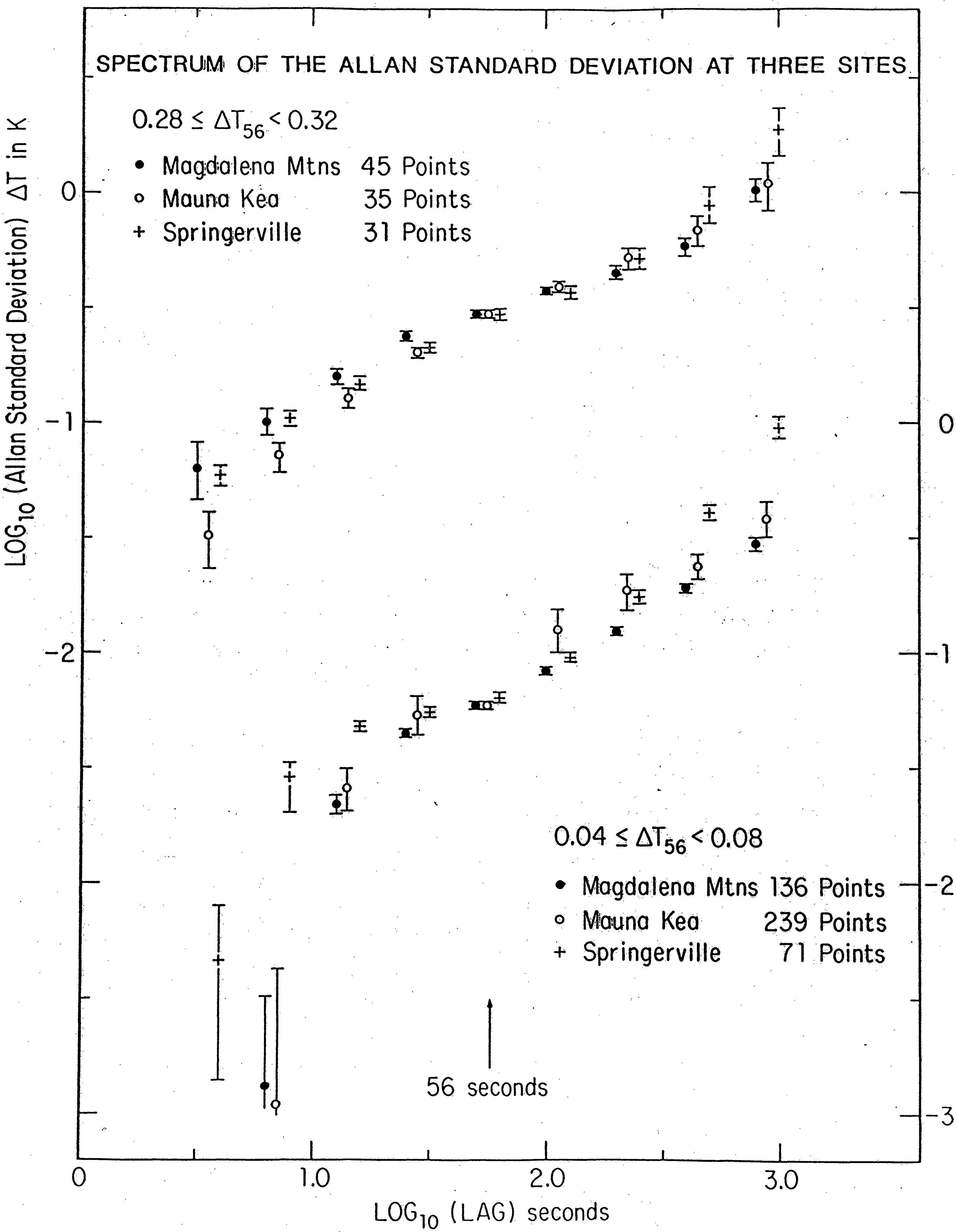

SPECTRUM OF THE ALLAN STANDARD DEVIATION AT THREE SITES
0.28 ≤ ΔT56 < 0.32
• Magdalena Mtns 45 Points
o Mauna Kea 35 Points
+ Springerville 31 Points
0.04 ≤ ΔT56 < 0.08
• Magdalena Mtns 136 Points
o Mauna Kea 239 Points
+ Springerville 71 Points
56 seconds
LOG10 (Allan Standard Deviation) ΔT in K
LOG10 (LAG) seconds
0
-1
-2
-3
0
1.0
2.0
3.0

Figure 7

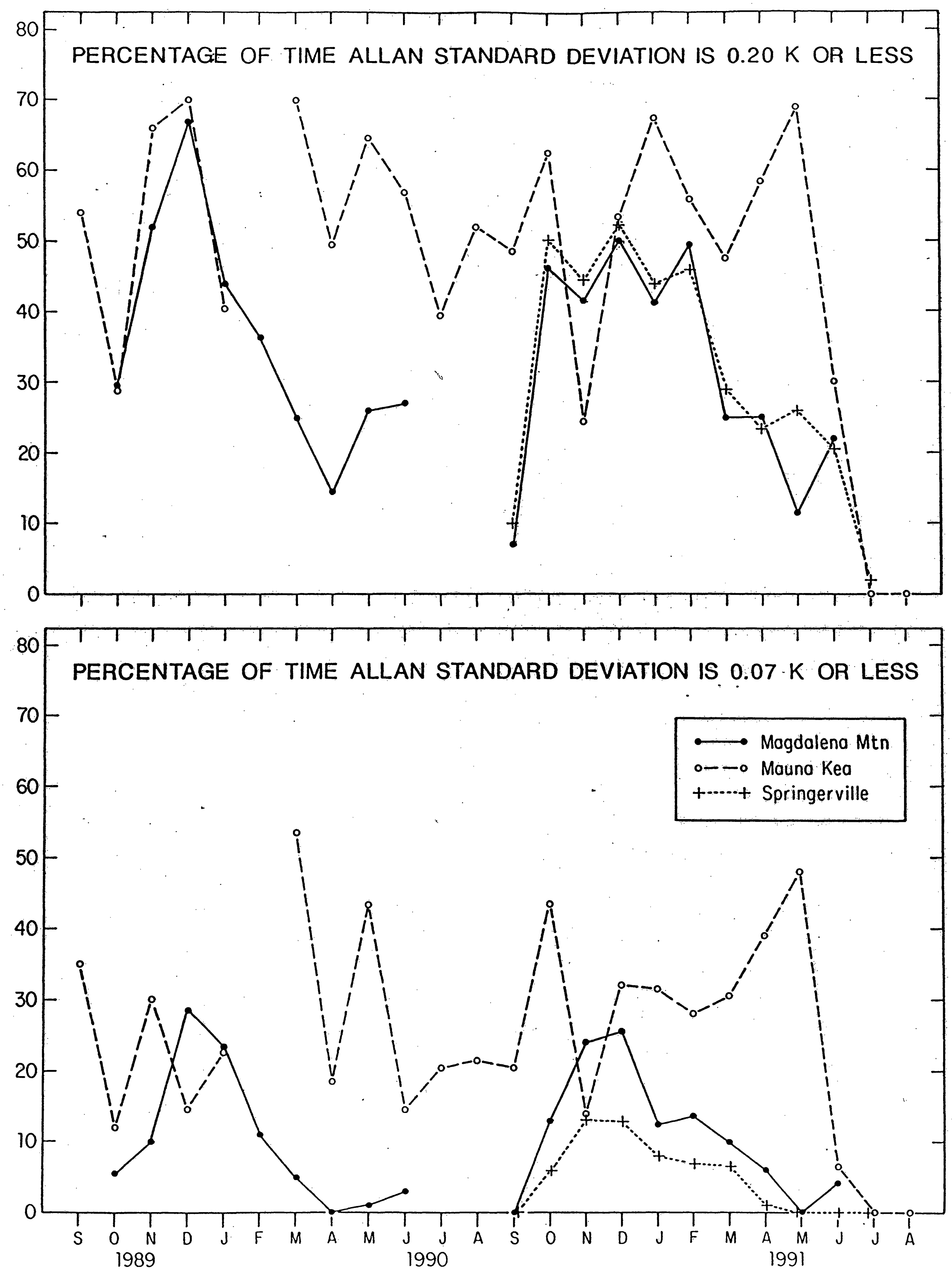

PERCENTAGE OF TIME ALLAN STANDARD DEVIATION IS 0.20 K OR LESS
PERCENTAGE OF TIME ALLAN STANDARD DEVIATION IS 0.07 K OR LESS
Magdalena Mtn
Mauna Kea
Springerville
0
10
20
30
40
50
60
70
80
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
1989
1990
1991

Figure 8

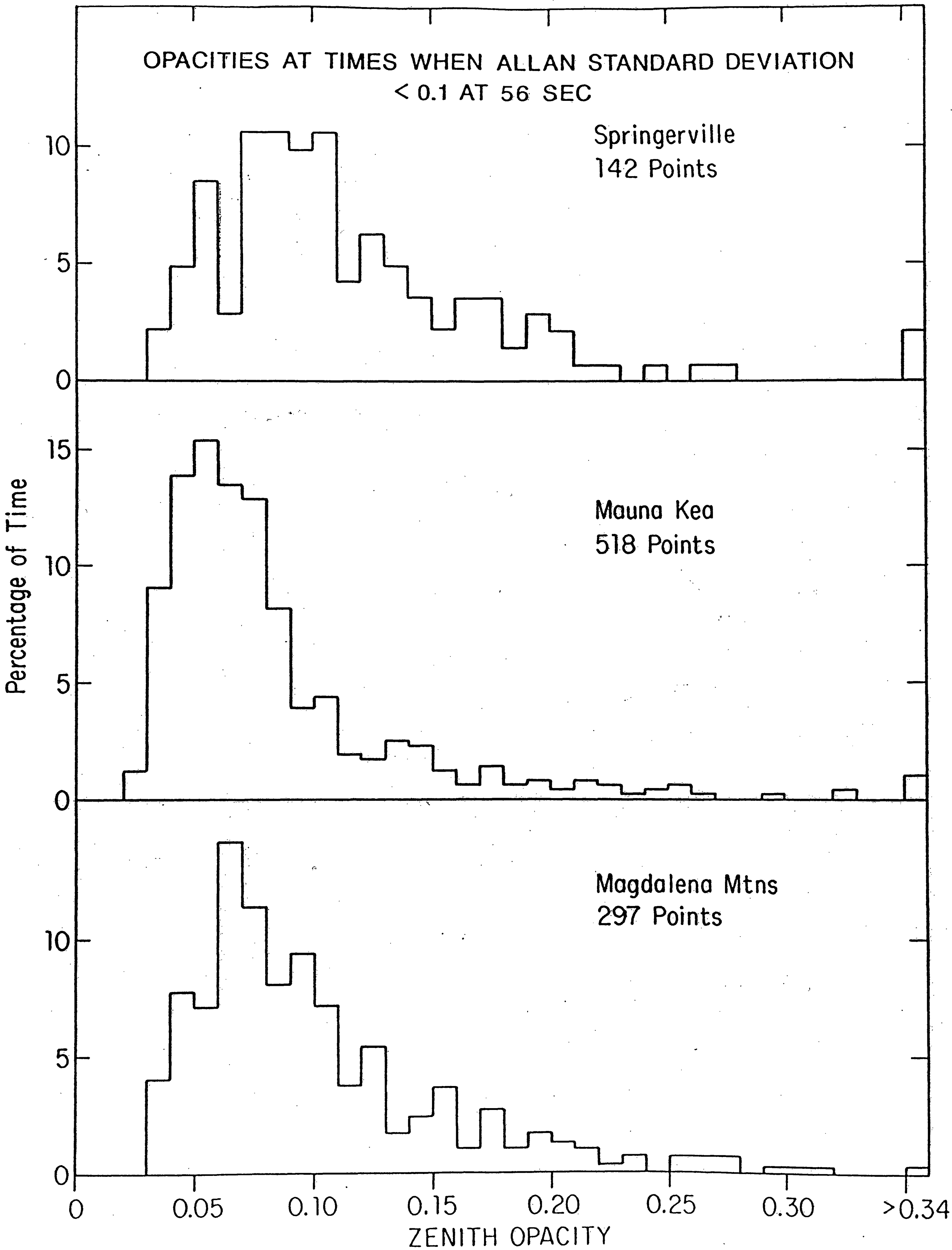

OPACITIES AT TIMES WHEN ALLAN STANDARD DEVIATION
< 0.1 AT 56 SEC
Springerville
142 Points
Mauna Kea
518 Points
Magdalena Mtns
297 Points
Percentage of Time
0
5
10
15
0.05
0.10
0.15
0.20
0.25
0.30
>0.34
ZENITH OPACITY

Figure 9

The Distant Universe

- Image thermal dust emission in evolving galaxies at epochs as early as $z = 10$.
- Yield kiloparsec-resolution images of dust emission in active galaxies & QSOs.
- Detect CO, [C I], [C II] emission lines from galaxies and QSOs. A line luminosity of $10^7 L_\odot$ at $z = \frac{1}{2}$ will be detectable in under 10 minutes.
- Image the microwave decrement in galaxy clusters; together with AXAF observations, this will provide an accurate determination of H_0.
- Resolve regions of particle acceleration in the jets and lobes of radio galaxies.
- The MMA, with the world's largest aperture at λ 1 mm, will be crucial to millimeter-wave VLBI. Accretion disks in galaxies as distant as the Virgo Cluster will be seen at 20 μarcsec resolution.

The Distant Universe: MMA Requirements

- Frequencies: 30-50 GHz for Sunyaev-Zel'dovich effect; 350 GHz for dust continuum from primeval galaxies. VLBA frequencies for high resolution radio maps.
- Bandwidth: 1GHz adequate at useful 9mm band; broad bandwidth for dust continuum experiment sensitivity. >1.5 GHz for high-z CO, [C I], [C II].
- Baselines: Appropriate for VLBA link
- Large angular scale coverage
- Polarization measurements important.
- Site: VLBA link at 90 GHz calls for VLA siting
- Frequency demands: 45% of time above 200 GHz.
- Configuration demands: 35% of time in 1 and 3 km configurations.

The Universe Nearby

- Reveal the masses and kinematics of the optically-obscured nuclei of galaxies, with a resolution equal to HST's.
- Image the distributions of C, N, O, & S, and their isotopes, in galactic disks.
- Observe GMCs in galaxies as distant as 100 Mpc, including all galaxies in the Shapley–Ames catalog.
- Study dependence of spiral structure and galaxy evolution on properties of the ISM.
- Provide unobscured kinematic images of starburst galaxies.
- Detect spectral lines of H_2O and O_2 in distant galaxies, uncontaminated by telluric emission.

The Local Universe: MMA requirements

- Frequency: to 300 GHz for dust continuum, 345 GHz for CO. Low end 70 GHz satisfactory.
- Bandwidth: >1.5 GHz spectral line at 345 GHz; 10 GHz continuum or larger, especially at high end. Simultaneous observation at 115, 230, 345 GHz line, and 1mm, 3mm continuum.
- Baseline: less than 3km; 0.1" resolution at 1.3mm.
- Mosaicing: Weak emission covers several FOVs.
- Frequency demands: 60% of time above 200 GHz.
- Configuration demands: 30% of time in 1 and 3 km configurations.

Star Formation and Molecular Clouds

- Resolve cloud fragments as small as 10 AU and detect fragments a few Jovian masses in size.
- Identify regions of star formation in dark clouds with extensive spatial and kinematic mosaic images.
- Image the chemical, density and velocity structure of pre-planetary disks.
- Reveal the kinematics of the earliest phases of binary star formation.
- Unveil the physical structure of circumstellar disks and determine their role in confining material outflow from protostars.
- Determine the orientation and evolution of the magnetic field in circumstellar disks, from polarization observations of thermal dust emission.

Star Formation and Molecular Clouds: MMA requirements

- Frequency: to 300 GHz for dust continuum, 345 GHz for CO, 366 GHz submm band top. Low end 70 GHz satisfactory; higher if possible.
- Bandwidth: 10 kHz spectral line resolution; 10 GHz continuum or larger, especially at high end. Simultaneous observation at 115, 230, 345 GHz, (CO); 99, 245, 343 GHz (CS) 211-225, 280-300 and 351-366 GHz (H_2CO) line, and 1mm, 3mm continuum.
- Baseline: less than 3km; 0.1" resolution at 1.3mm. 0.2-30" are important angular scales
- Mosaicing: Good for turbulent length scale study, need large Field of View
- Polarization capacity important for dust, masers, and possibly some spectral lines.
- Frequency demands: 60% of time above 200 GHz.
- Configuration demands: 60% of time in 1 and 3 km configurations.

Evolved Stars and Circumstellar Shells

- Measure the molecular abundances and probe the energetics of the outflows from thousands of evolved stars.
- Image (at $0\farcs1$ resolution) hundreds of circumstellar shells.
- Determine the rates and composition of mass-return to the ISM from hot stars, red giants, and supernovae.
- Provide C/O ratios and isotope gradients in circumstellar shells — tracers of the efficacy of stellar C–N–O cycling and carbon dredge-up during He burning.
- Provide sub-arcsecond imaging of all stellar dust shells detectable by SIRTF.
- Measure the crucial $^{12}C/^{13}C$ ratio in the earliest phases of supernova development.

Circumstellar Shells and Evolved Stars: MMA Requirements

- Frequency: At least 230-366 GHz, preferably 100-1000GHz; CO, dust important
- Large IF bandwidth and spectral multiplexing facility for multiple transitions, rotational and vibrational. Maximum continuum sensitivity near 300 GHz (20 GHz bandwidth)
- Map from 0".1 to 1', some facility for resolution to .01".
- Minimum effective area 2000 m^2 at high site.
- Frequency demands: 75% of time above 200 GHz.
- Configuration demands: 60% of time in 1 and 3 km configurations.

Sun and Stars

- Observe stars in every part of the H–R diagram.
- Detect photospheric emission from over 600 stars, in under 10 minutes each; determine temperature gradients, measure positions to astrometric accuracy.
- Detect stellar winds from hundreds of evolved stars and novae.
- Study flare phenomena on the Sun and other stars, and investigate the energy sources in cataclysmic variables and X-ray binaries.
- Reveal physics of particle acceleration in solar flares by combining snapshot MMA images with AXAF (X-ray) and GRID (γ-ray) images.
- Investigate cause of the solar thermal bifurcation by imaging thermal gradients.
- Provide metrology of solar oscillatory modes which will be complementary to GONG and SOHO studies.

The Sun and the Stars: MMA Requirements

- Fast shifting between 1, 3, 9 mm bands; bands near 2mm and 6mm good for thermal continuum.
- Simultaneous multi-frequency observing for flare spectra; High sensitivity, bandwidth > 10 GHz
- Some studies require 35-70 km baselines (thermal stellar continuum images)
- 3' Field Of View at 3mm
- Accurate (<1%) circ polarization
- Fast integration times (<.1 sec); Good snapshots in <1km arrays
- Stellar frequency demands: 67% of time above 200 GHz; solar 50%.
- Stellar Configuration demands: 75% of time in 1 and 3 km configurations; solar 20%.

Planetary Science

- Image the varying atmospheric winds and thermal profiles on Mars and Venus, using CO and its isotopes.
- Resolve phosphine emission in the Great Red Spot, HCN on Titan, and volcanic emission on Io.
- Measure properties of subsurface layers of hundreds of asteroids.
- Image the thermal emission from Pluto and Charon.
- Expand cometary research by providing unobscured images of comet nuclei: study subsurface layers & atmospheric structure; precision astrometry.
- Image impulsive events and sporadic molecular jet emission from comets.
- Detect 'proto-Jupiters' in nearby stellar systems; determine their masses and chemical composition.

Planetary Science: MMA Requirements

- Frequency-.35, .45, .87, 1, 2, 3 mm bands continuum and line; 30-50 GHz continuum only
- Bandwidth larger than 2 GHz; 1. Subdivided into 10 40-80 MHz bands spread to cover entire range. 2. Spectral line: 50-100 kHz resolution 3. Both sidebands (centers and edges of broad lines) 4. Multiband capability (several transitions simultaneously)
- Baselines: ~3km to resolve satellites and outer planets.
- Field of View: Mosaicing crucial for many observations; rapid imaging to monitor atmospheric change.
- Capacity for full polarization measurement
- Higher, drier site than VLA (Moon?)
- Frequency demands: 67% of time above 200 GHz.
- Configuration demands: 50% of time in 1 and 3 km configurations.

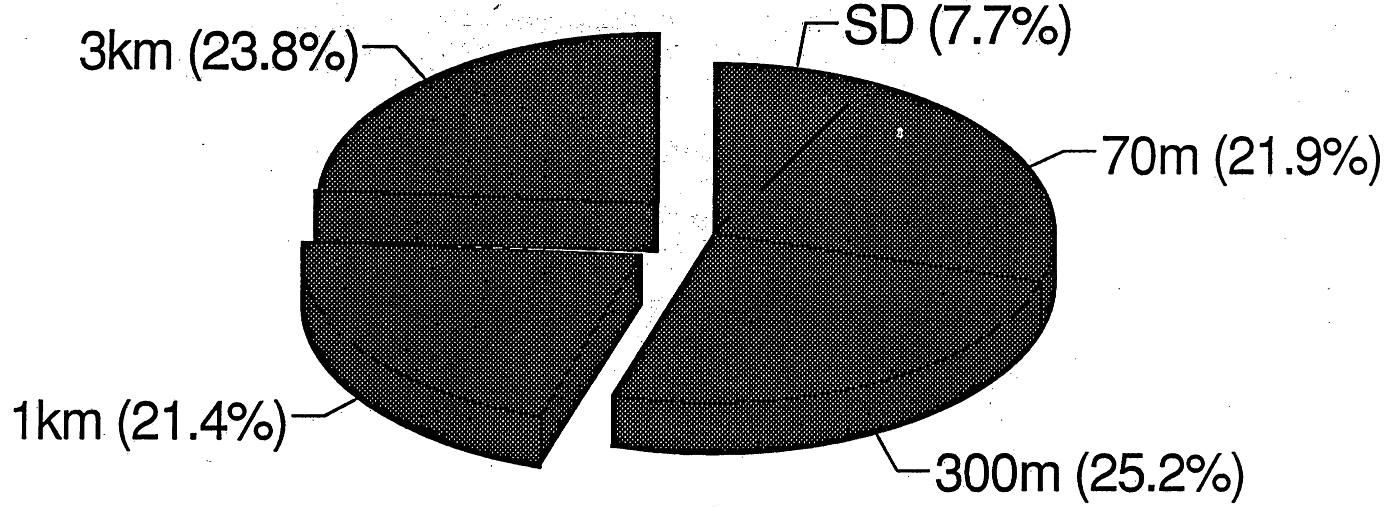
Astrochemistry

- Provide, at $\sim$ 10 AU resolution, images of the chemical gradients in protostellar nebulae for nearby star-forming regions (e.g., in Taurus and Ophiuchus).
- Obtain arcsecond-resolution mosaiced images of molecular abundances throughout GMC complexes; study the changes induced by fragmentation/condensation.
- Yield the spatial variation of dissociative shock chemistry in outflow sources.
- Enable study of photochemical processes via spectral-line images of circumstellar shells.
- Probe dust formation and destruction via emission-line images of the refractory molecules that mark dust catalysis and spallation.
- Provide high-resolution data revealing processes connected with low-temperature chemistry (deuteration and grain-mantle processing) in the cores of dense molecular clouds.

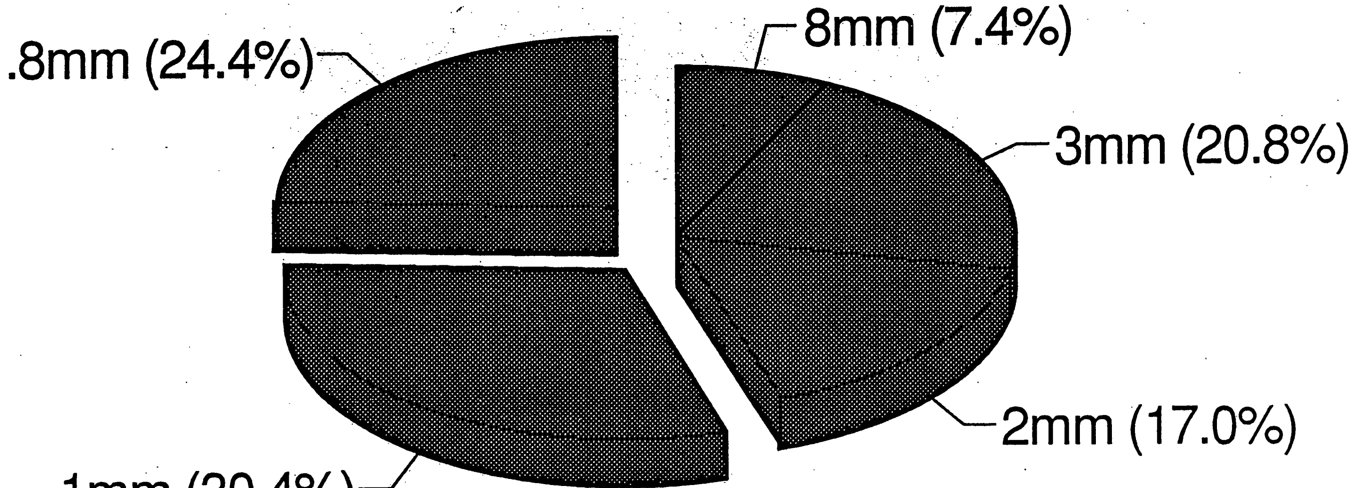
Astrochemistry: MMA Requirements

- Frequency Range: 33 GHz to 366 GHz: 33 GHz for the study of compact, heavy molecules; 366 GHz for study of small, tightly bound refractory molecules.
- Bandwidth Flexibility: Highest frequency resolution: 10 kHz. Greatest bandwidth 3 GHz (for the study of planetary atmospheres). Frequency Agility: E.g., both the upper and lower sidebands.
- Angular Resolution: One arcsecond for the projects discussed.
- Site: The 366 GHz boundary in Item 1 dictates a high, dry site.
- Collecting Area: We can tolerate a minimum collecting area equivalent to that of a 46 meter dish, but we would prefer more. We need the best receivers available.
- Frequency demands: 50% of time above 200 GHz.
- Configuration demands: 30% of time in 1 and 3 km configurations.

MMA Configuration Demand
(Projected)



MMA Band Demand
(Projected)



A.R.T.

MMA Advisory Meeting, Sept. 16-17, 1993

Existing system block diagram: a simple system that meets basic design criteria.
Flexibility and performance can be improved.

Assume, at this time, front ends for < 115 GHz use HFETs. SIS mixers at higher frequencies.
First IF for SIS front ends approx 3-4 GHz. (2.6-3.95 GHz or 3.95-5.85 GHz)

Number of IFs to be processed = 4. (two frequencies and two polarizations)

Total bandwidth transmitted to correlator location shown as 4 GHz per antenna.

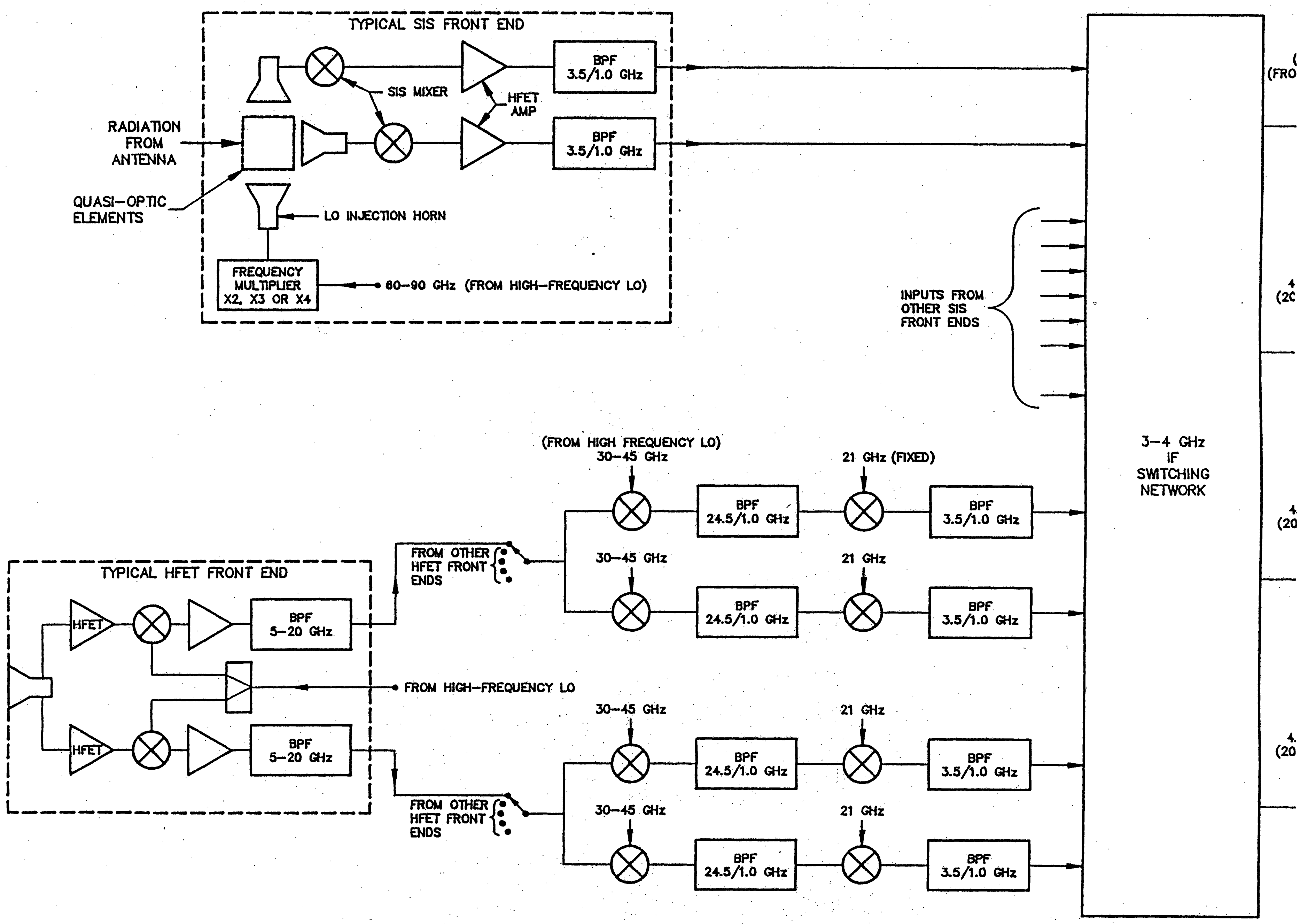
Differential fringe frequency for 500 MHz channel spacing is 0.36 Hz for 3 km baseline.

Channelization: four channels with variable bandwidth for line observation. Four with fixed 500 MHz bandwidth provide for total bandwidth of 4 GHz for continuum.

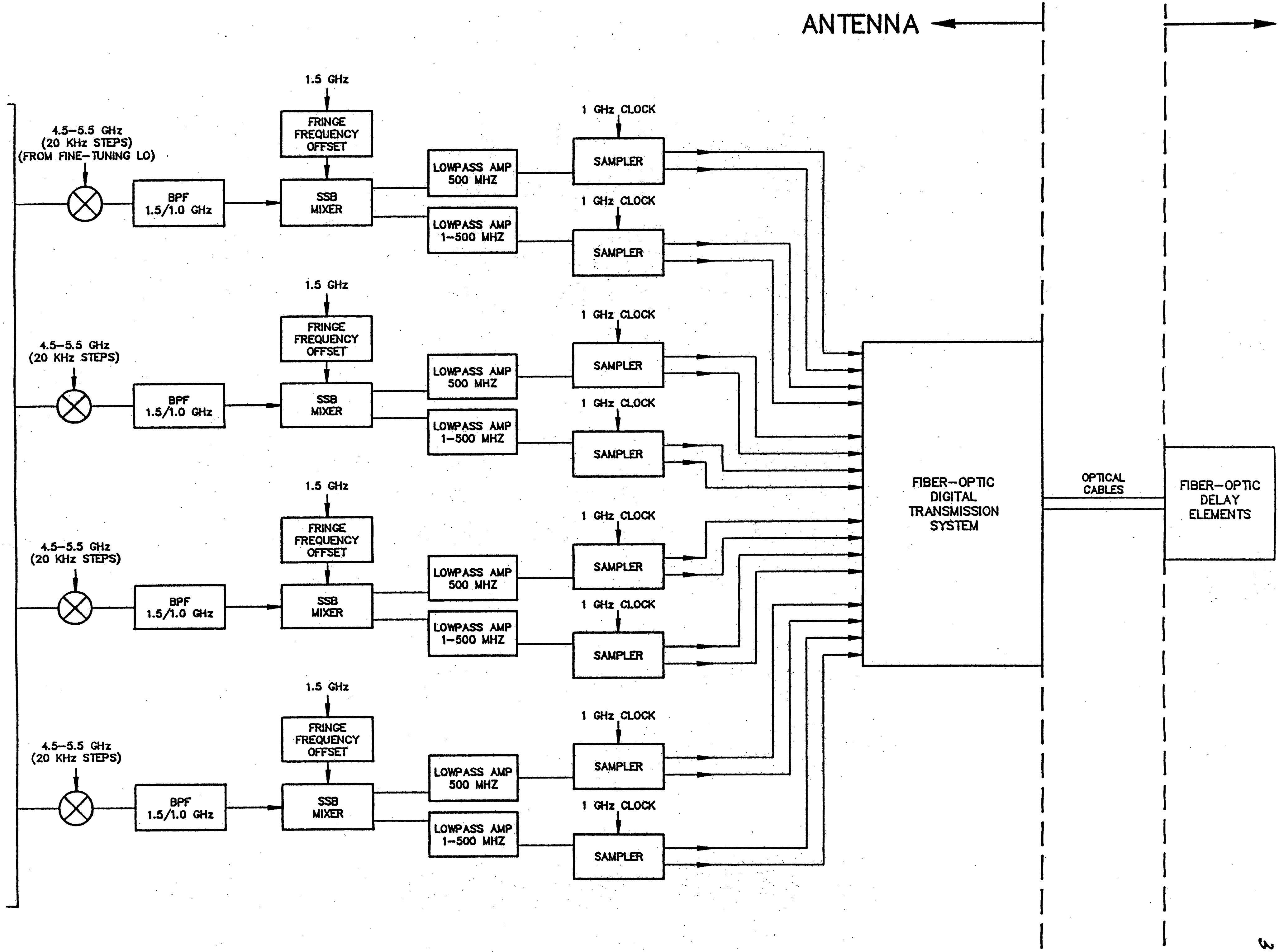
Correlator: possibly 2 GHz bandwidth per antenna, 1000 channels, i.e. 2 MHz frequency resolution at full bandwidth. Highest spectral resolution about 6 kHz. Pre-sampler filtering may need to be as narrow as 6 MHz for a non-recirculating correlator.

Conversion to baseband involves single-sideband mixers or bandpass sampling with filtering to remove unwanted sidebands.

Can we make better use of the wide instantaneous bandwidth of the HFET front ends?



TYPICAL SIS FRONT END
BPF 3.5/1.0 GHz
SIS MIXER
HFET AMP
RADIATION FROM ANTENNA
QUASI-OPTIC ELEMENTS
LO INJECTION HORN
FREQUENCY MULTIPLIER X2, X3 OR X4
60–90 GHz (FROM HIGH-FREQUENCY LO)
INPUTS FROM OTHER SIS FRONT ENDS
3–4 GHz IF SWITCHING NETWORK
(FROM HIGH FREQUENCY LO)
30–45 GHz
21 GHz (FIXED)
21 GHz
BPF 24.5/1.0 GHz
FROM OTHER HFET FRONT ENDS
TYPICAL HFET FRONT END
HFET
BPF 5–20 GHz
FROM HIGH-FREQUENCY LO


ANTENNA
1.5 GHz
FRINGE FREQUENCY OFFSET
SSB MIXER
4.5–5.5 GHz (20 KHz STEPS) (FROM FINE–TUNING LO)
BPF 1.5/1.0 GHz
LOWPASS AMP 500 MHZ
LOWPASS AMP 1–500 MHZ
1 GHz CLOCK
SAMPLER
4.5–5.5 GHz (20 KHz STEPS)
FIBER–OPTIC DIGITAL TRANSMISSION SYSTEM
OPTICAL CABLES
FIBER–OPTIC DELAY ELEMENTS

3

Channelization and Transmission Possibilities.

(1) Analog signal transmission. Analog channelization, frequency conversion, filtering, and sampling at correlator location.

Simplified LO system
Accessibility
Advantages when observing a number of lines simultaneously: bandwidth 5 to 10 GHz per fiber can be transmitted.
Relatively poor bandpass stability: need for bandpass calibration.

(2) Analog filtering and sampling at antennas, digital signal transmission.

Bandpass effects of transmission system eliminated.
More electronics located at antennas.

(3) Digital transmission of 1 GHz bandwidths from antenna to correlator location. D/A conversion, filtering, and sampling again at correlator.

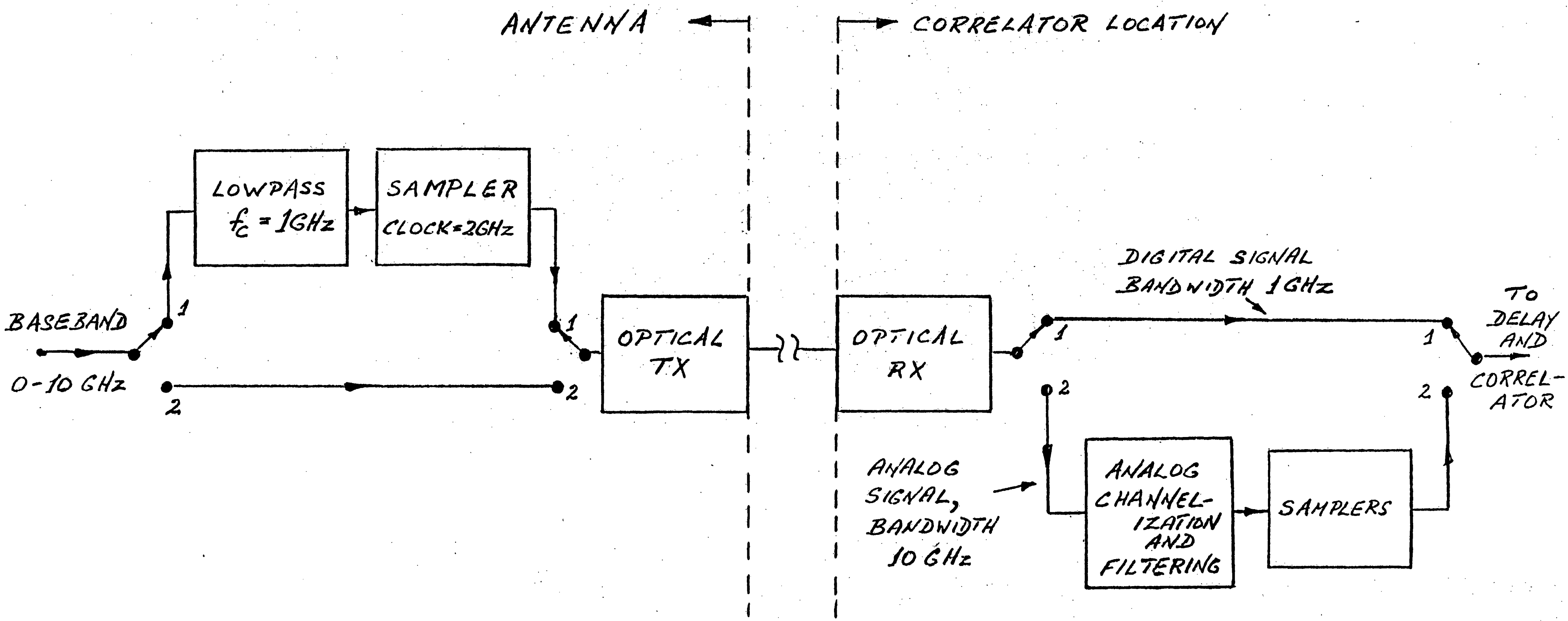
Transmission bandpass effects eliminated.
Less electronics at antennas than (2).
Small increase in overall electronics required.
Sampling occurs twice: need to use several bits per sample to minimize loss of SNR.

(4) Broadband sampling at antennas and digital transmission. Digital processing at correlator location using FFT hardware to get required frequency resolution. See Clark, MMA Memo No. 93.

Minimizes analog processing and associated bandpass. instability effects, i.e. signal digitized as early as possible in the processing.

Notes:

Closure errors in VLA are due mainly to bandpass response and delay errors.
In the wideband analog system correction for fringe frequency differences becomes more important. Could be most easily accomodated in an FX correlator.



<u>Possible MMA Transmission Scheme</u>

4 Transmission systems of this type per antenna.

Switch position 1 principally for continuum, position 2 principally for spectral lines.

System provides:
(1) for continuum, maximum bandpass stability (good dynamic range);
(2) for lines, maximum flexibility with broadband front ends;
(3) channelization and filtering hardware mostly at correlator location,
i.e. simplification of electronics at antennas.

Is double sideband capability desirable?

With SIS front ends with first IF center 3.5 GHz and bandwidth 1 GHz, minimum delay increment should be;

31 ps (clock period/16) for single sideband (rms phase error 2.3°)

4.6 ps for double sideband (1% average decorrelation)

Polarization

Have been assuming that circular polarization rather than linear is the optimum choice. Possibly true, but should re-examine.

Note: For the latest major new instrument (AT) linear was chosen, to allow use of wide frequency bands.

Polarization

Technical difficulties with circular:

(1) waveguide polarizer, bandwidth 15-20% for 1 dB axial ratio.

(2) Martin Puplett interferometer: reflector that introduces differential path length must be set to 9 μm for 1 dB axial ratio, and to 1.6 μm to keep resulting instrumental pol. < 1% (for 300 GHz and two-way signal path).

(3) Frequency diplexing can be more difficult in circular polarization.

Advantages of circularly polarized antennas:
(Assume instrumental polariation small and V very small)

(1) Circular: can map I with one polarization only.

(2) Circular: Q and U can be determined from crossed hands for which output is independent of I.

Linear, need either to

(a) rotate feeds through 45° (not easy with cooled front ends)
or,
(b) calibrate with enhanced accuracy.

(3) Gain calibration (assuming polarization of calibrator is not well known)
Circular: LL and RR can be solved for independently and self cal will give gains for individual antennas.
Linear: can do similar solution for XX+YY, but need to know relative gains of X and Y for each antenna. N.B. AT noise cal. scheme.

Linear feeds

Position angles	Stokes parameters measured	
0°,0°	$I+Q$	Position I
90°,90°	$I-Q$	
0°,90°	$U+jV$	
90°,0°	$U-jV$	
45°,45°	$I+U$	Position II
135°,135°	$I-U$	
45°,135°	$-Q+jV$	
135°,45°	$-Q-jV$	

Circular feeds

Sense of rotation m, n	Stokes parameters
R, R	$I+V$
L, L	$I-V$
R, L	$(U-jQ)$
L, R	$-(U+jQ)$

Polarization (continued)

Typical Calibration Procedure

(1) Variation in electronics gain: observe calibration source (polarization not well known) a few times per hour.

(2) Instrumental polarization (assume constant) and relative phase of crossed channels: observe calibrator with known polarization at least once.

(3) Observe flux calibrator at least once.

(4) For each antenna pair there are:

2 gains
2 phases
4 instrumental polarization parameters

Perform least-squares fit.

How serious is the problem of having I-response summed with Q and U responses?
Circularly polarized feeds seem to be the best bet for measurement of linear pol., but how much worse are linear feeds.?

The best polarization accuracy is likely to be in the lower frequency (HFET) bands because:

Waveguide polarizer has best stability of instrumental polarization,
HFET amplifiers have good gain stability.

MMA will map sources wider than the beam. Is constancy of polarization over the beam and important factor? Does it influence the choice of polarization?

MMA Advisory Committee Meeting
16-17 September 1993

SIS RECEIVERS

MMA Requirements

{1} MMA Operating Frequencies [Ref. MMA Proposal, p.2]
Specification: 30-50 68-115 130-183 195-366 GHz.
Possible Rx Bands for fixed-tuned receivers
Bandwidth limited by: (i) RF circuit design of amplifier or mixer, and (ii), circularly polarized feeds if used (~25%).

{2} Receiver Sensitivity [Ref. MMA Proposal, p.10]
TRx(SSB) = 50, 100, 150 K at 115, 230, and 345 GHz.
This is very close to 9hf/k (SSB).

{3} SIS Receiver Performance – Current performance vs. MMA requirements.

Progress and Plans

{4} Tunable 130-170 GHz SIS mixer
Pan's 580 GHz mixer is similar in concept.

{5} Tunerless 200-300 GHz SIS mixer
Limitation – bias/LO instability.
Equivalent circuit of SIS371 (C_j tuned out)
Embedding impedances (s_{kk} and s_{k0})

{6} New design started
Easier to fabricate
More uniform Z_e's

{7} Saturation (Dynamic range): $f(N_j, \omega_{LO}, b, R_L)$

{8} LO Pwr requirements: $f(N_j, \omega_{LO}, R_{NA})$
LO diplexing and levelling

{9} Input match requirement
Effect on circ. pol.

{10} Choice of IF

{11} Image separation:
Quasi-optical. Add noise from image termination to $T_{R,SSB}$.
Dave Woody's work. Image noise lower, but greater complexity.

{12} Gain stability
John's result: flat to 4 Hz.
Need to measure down to 0.01 Hz (?) on several mixer designs.

{13} Reliability of SIS mixers:
Virtually perfect on telescope
During installation of tested mixers in rockets, and in shipping rockets

to Tucson, we have had 6 failures this year, presumed due to static discharge. Needs to be addressed during MMA preliminary development.

Superconducting Circuit Fabrication

{14} Main concern for MMA receiver development -- SIS circuit fabrication: Our future work on SIS receivers is critically dependent on having a reliable fabricator of SIS devices.

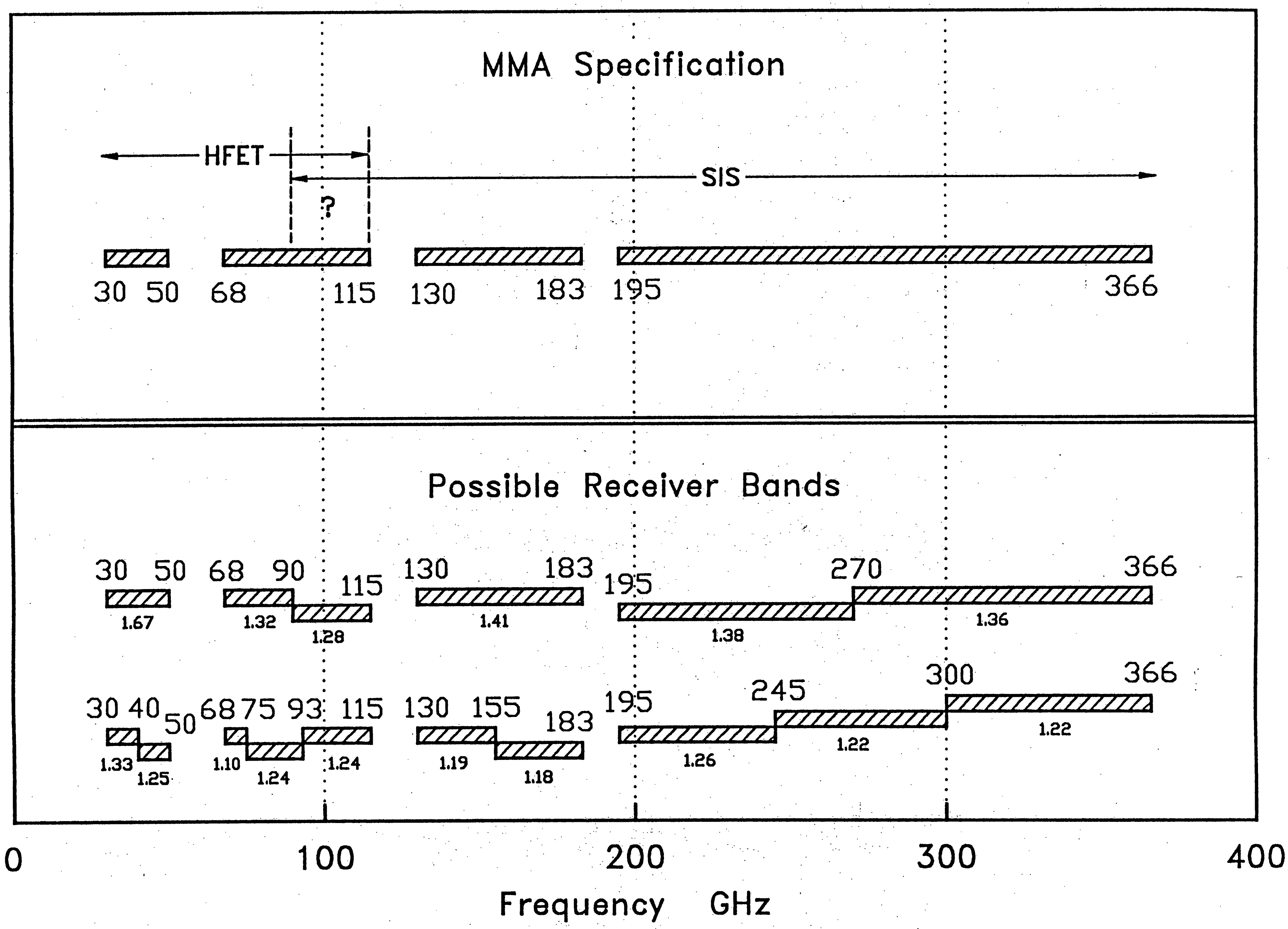
{15} Collaborators: UVa, UI, (Hypres), (IBM/CSE).

{16} Why is it so hard to make such simple circuits?
μm feature sizes with ± 0.1 μm accuracy.
249 process steps (cf., ~10 for Pb shadow-mask junctions (easy to make, but poor mixers)).

{17} Universities vs Industry for SIS fabrication.

{18} Rough estimate of the cost of doing SIS fabrication at NRAO:
$1.6M + $370K/yr in 1992 (almost certainly an underestimate).

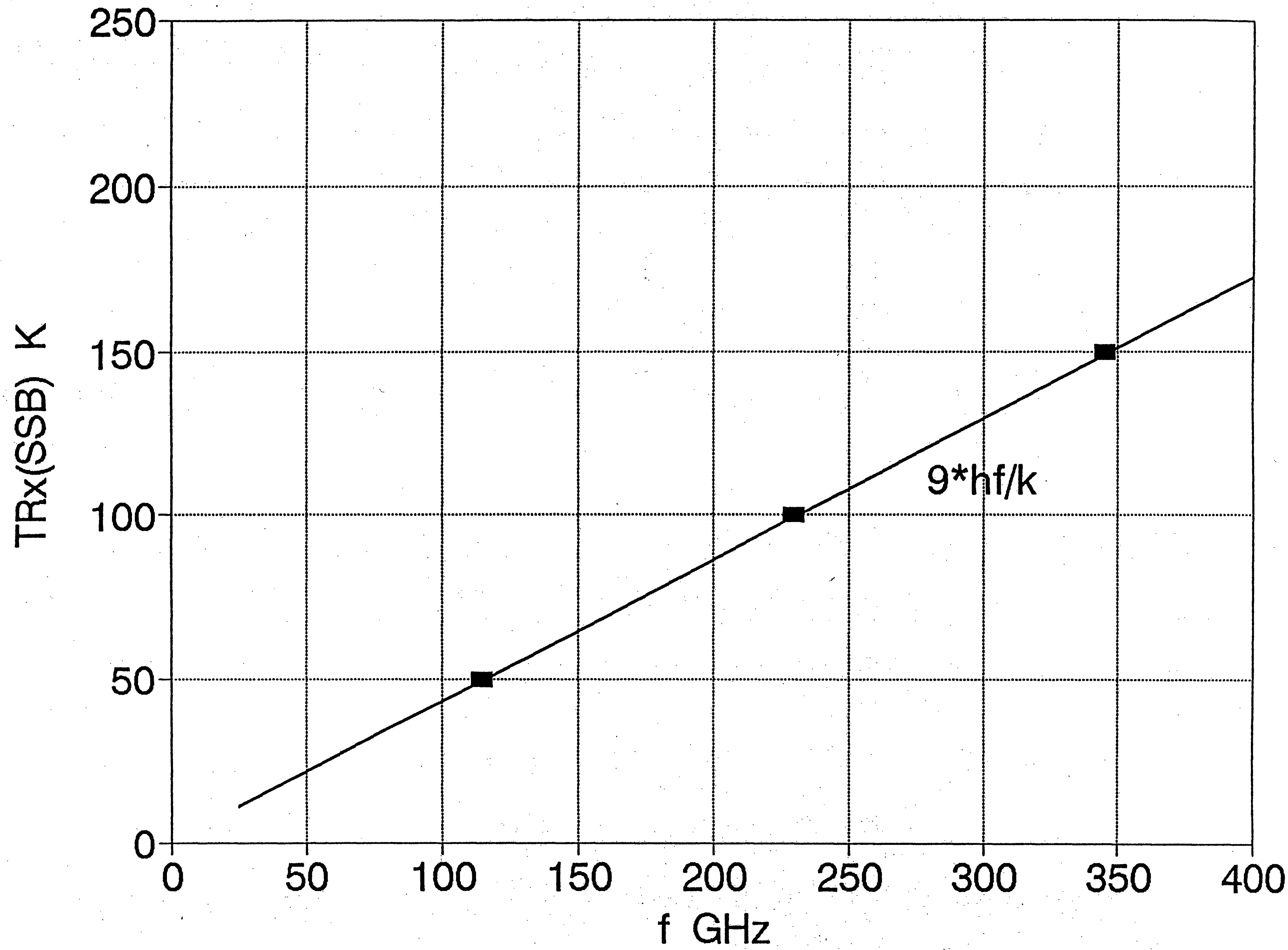
MMA OPERATING FREQUENCIES

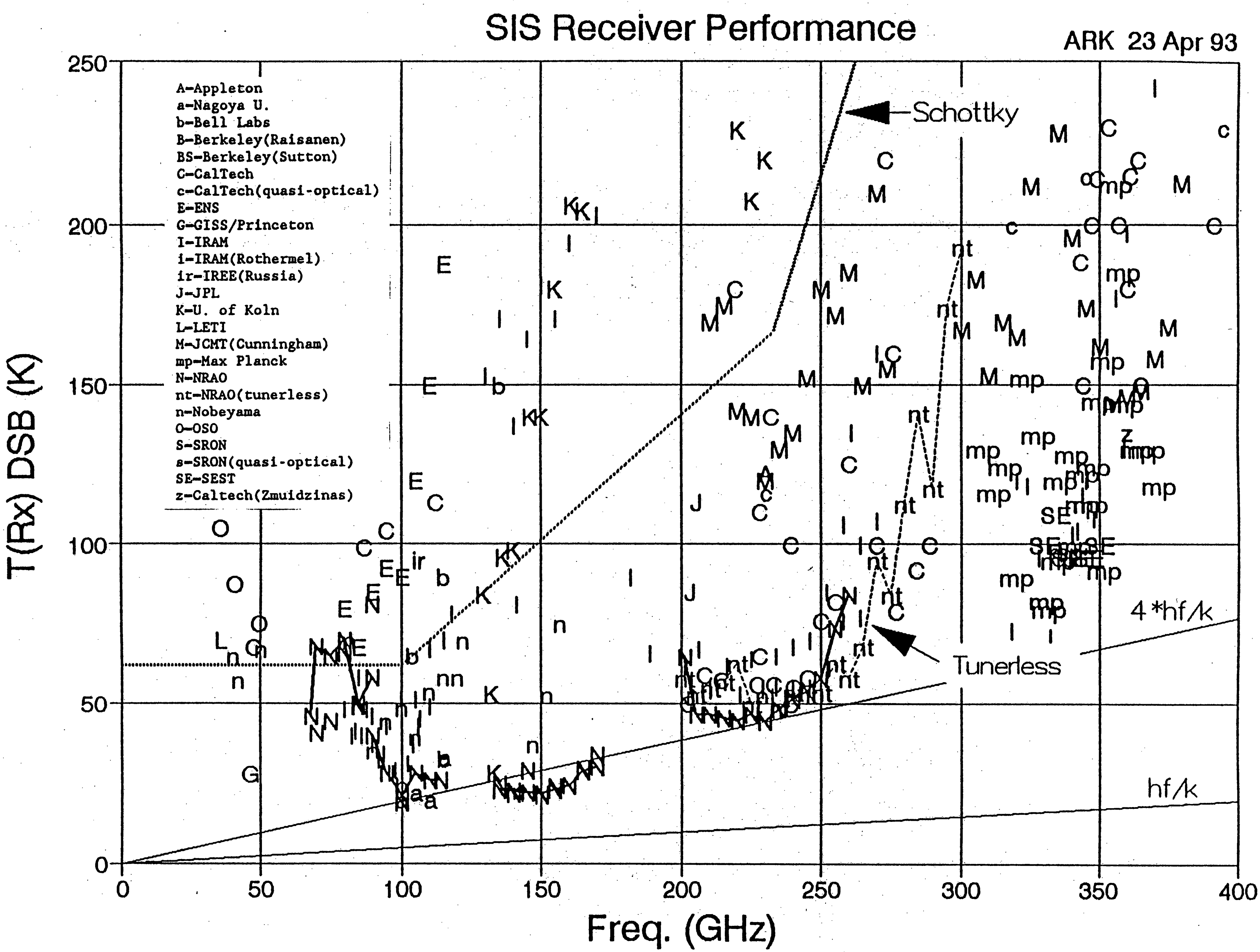


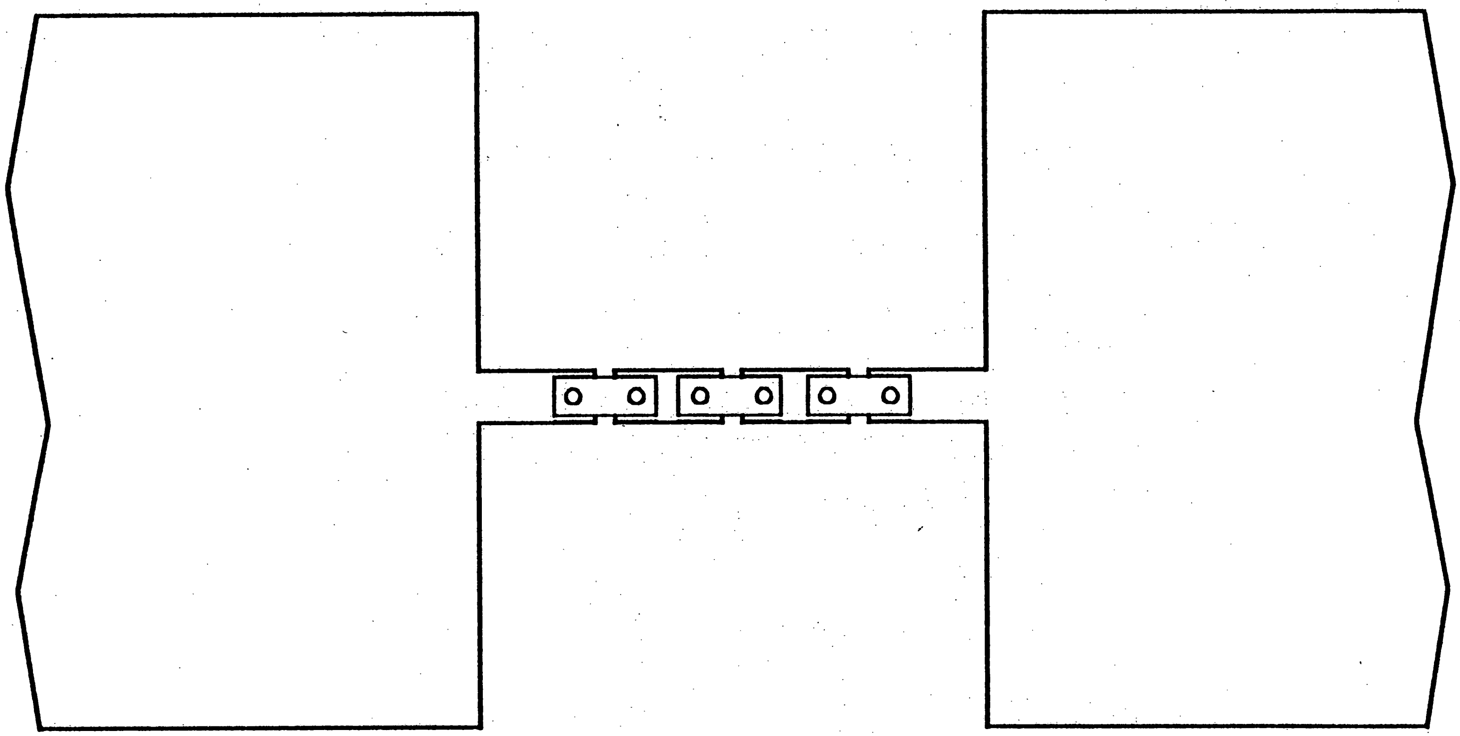
Use LTSCALE = 13

ARK 8 Sep 93 MMA9309A/1

1

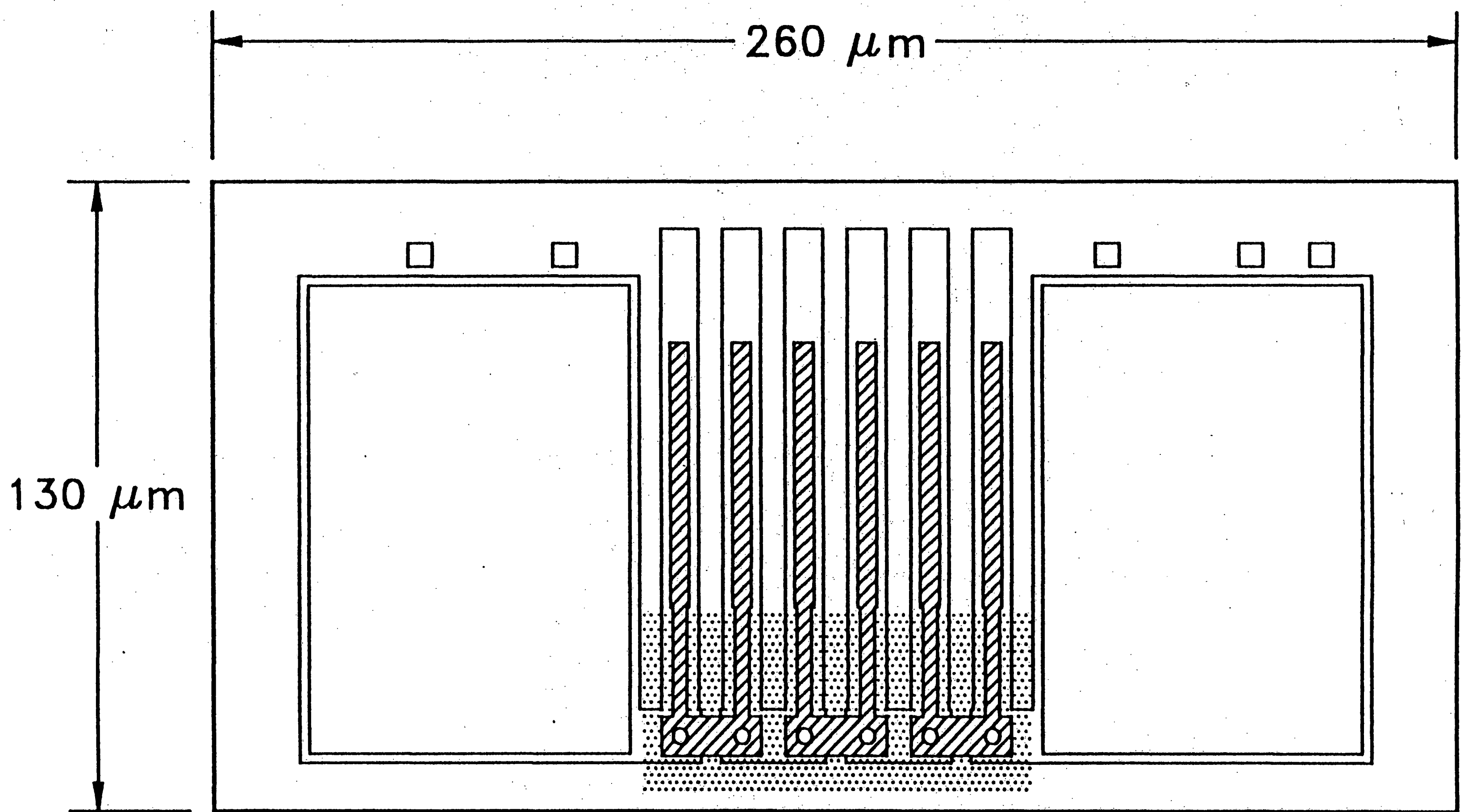

250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
TRx(SSB) K
f GHz
9*hf/k


SIS Receiver Performance
ARK 23 Apr 93
A-Appleton
a-Nagoya U.
b-Bell Labs
B-Berkeley(Raisanen)
BS-Berkeley(Sutton)
C-CalTech
c-CalTech(quasi-optical)
E-ENS
G-GISS/Princeton
I-IRAM
i-IRAM(Rothermel)
ir-IREE(Russia)
J-JPL
K-U. of Koln
L-LETI
M-JCMT(Cunningham)
mp-Max Planck
N-NRAO
nt-NRAO(tunerless)
n-Nobeyama
O-OSO
S-SRON
s-SRON(quasi-optical)
SE-SEST
z-Caltech(Zmuidzinas)
Schottky
Tunerless
4*hf/k
hf/k
T(Rx) DSB (K)
Freq. (GHz)



ARK 16 Mar 93 THZSYM93/VG2

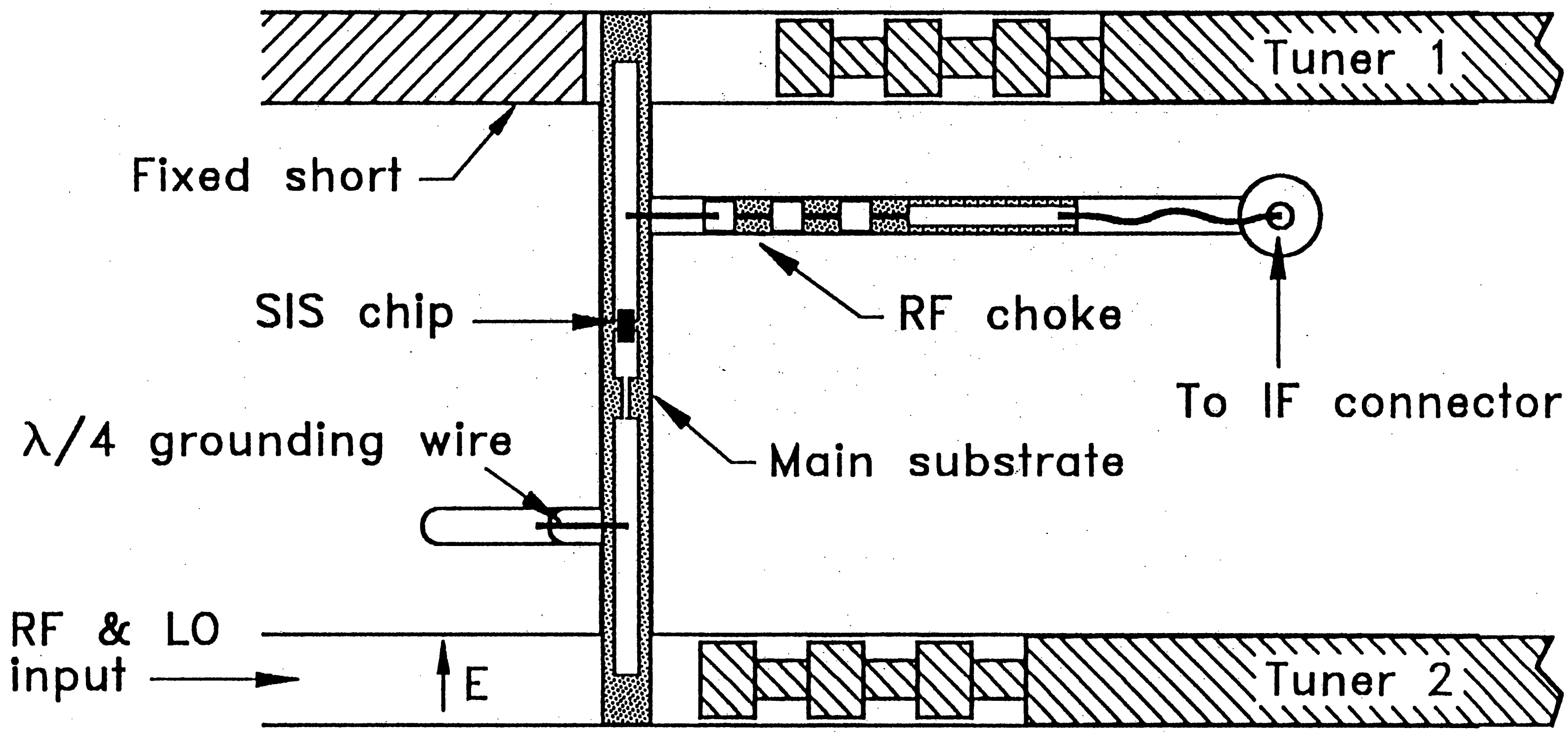
4(a)



LTSCALE = 0.0240

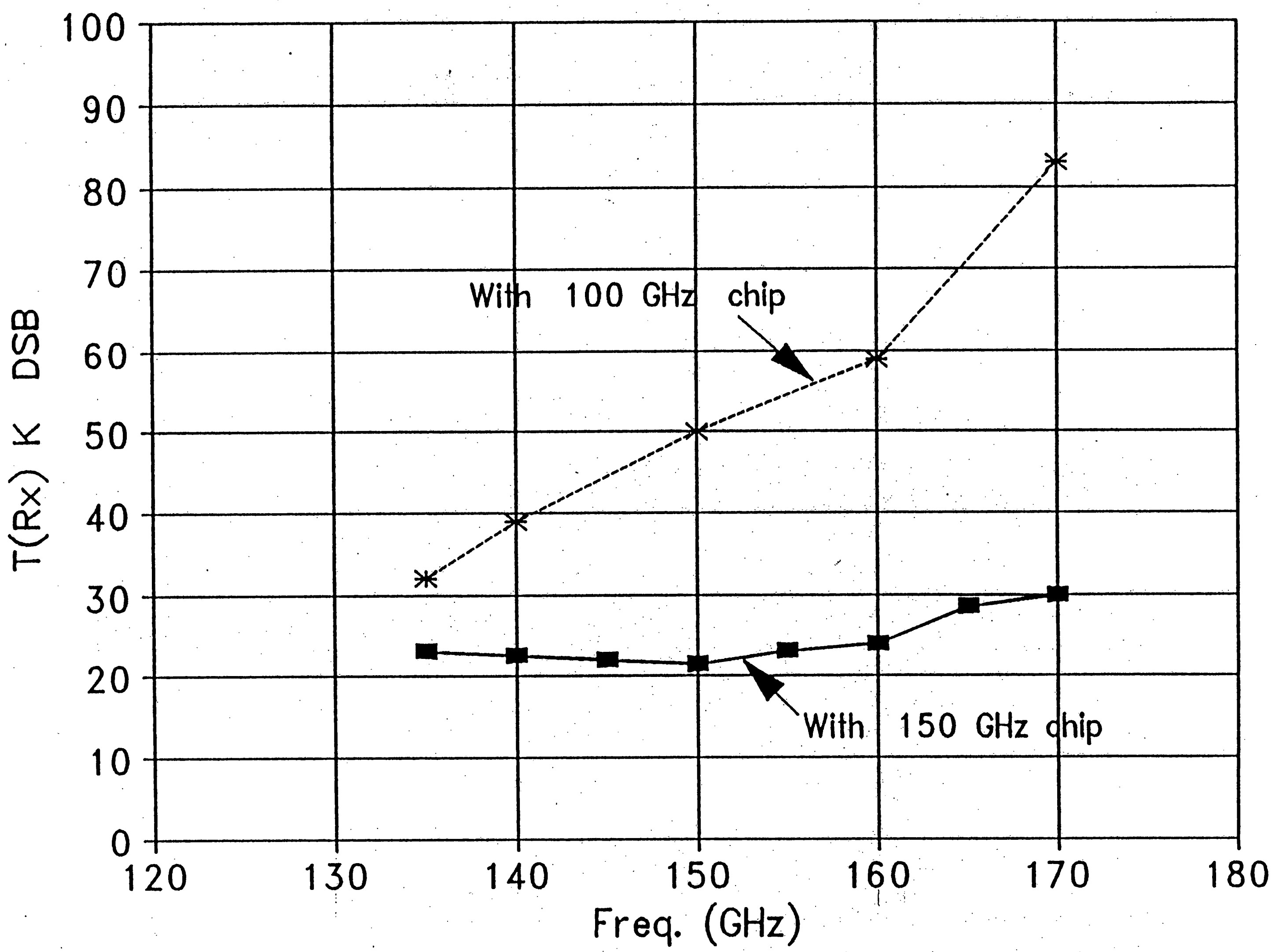
ARK 4 Mar 93 THZSYM93/2

4(b)

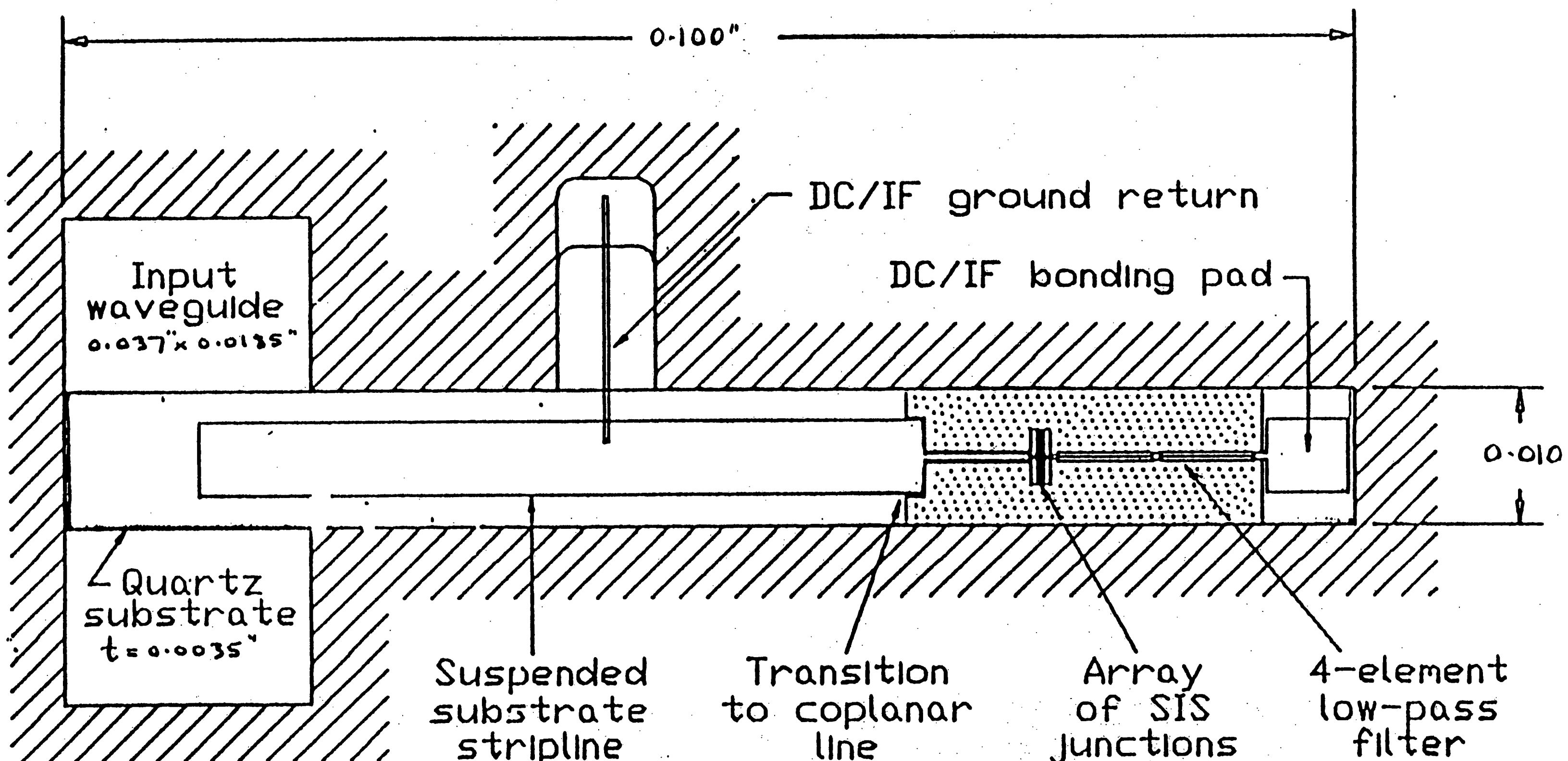


ARK 2 Mar 93 THZSYM93/1

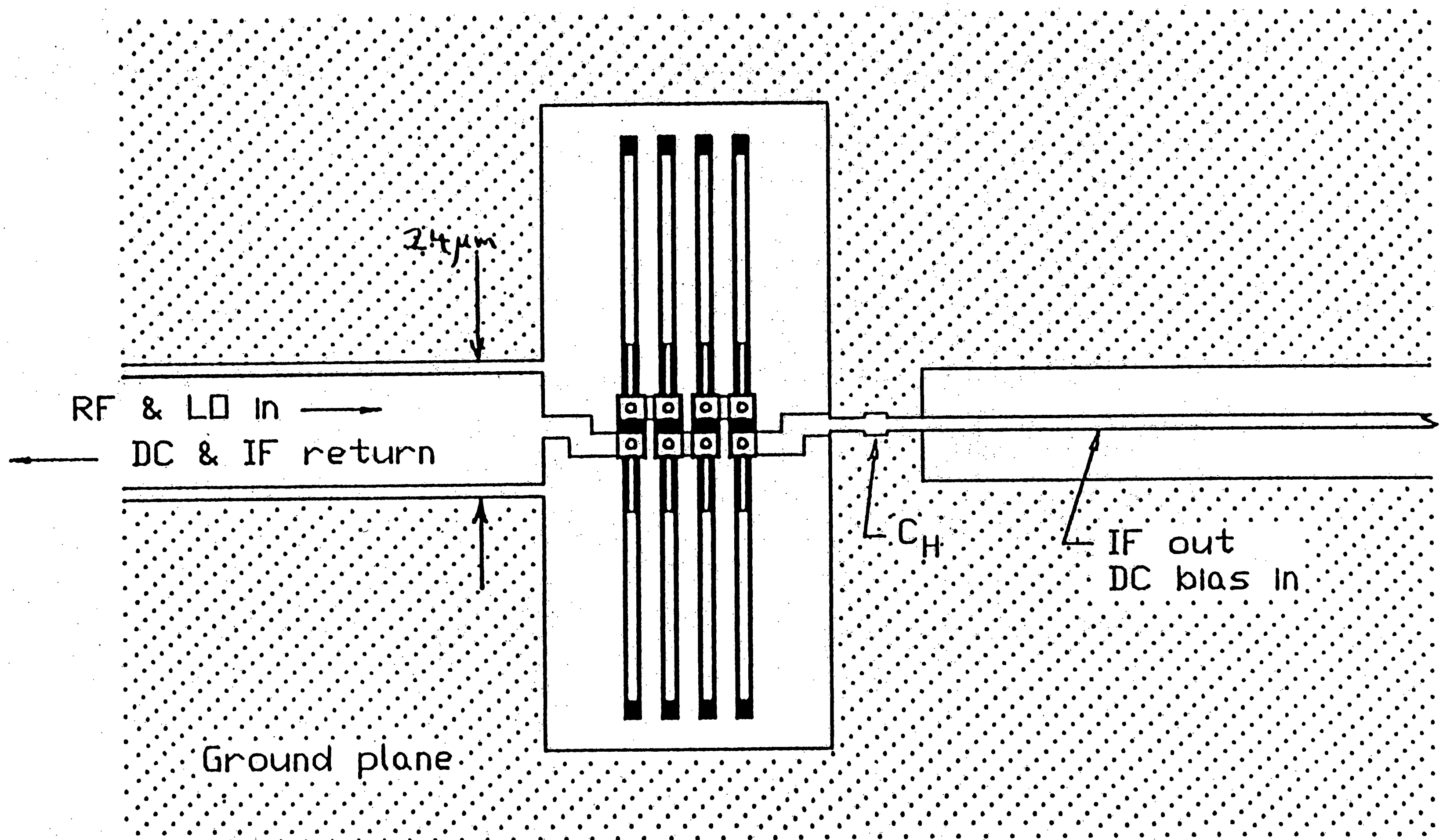
4(c)


100
90
80
70
60
50
40
30
20
10
0
T(Rx) K DSB
With 100 GHz chip
With 150 GHz chip
120
130
140
150
160
170
180
Freq. (GHz)

4 (d)

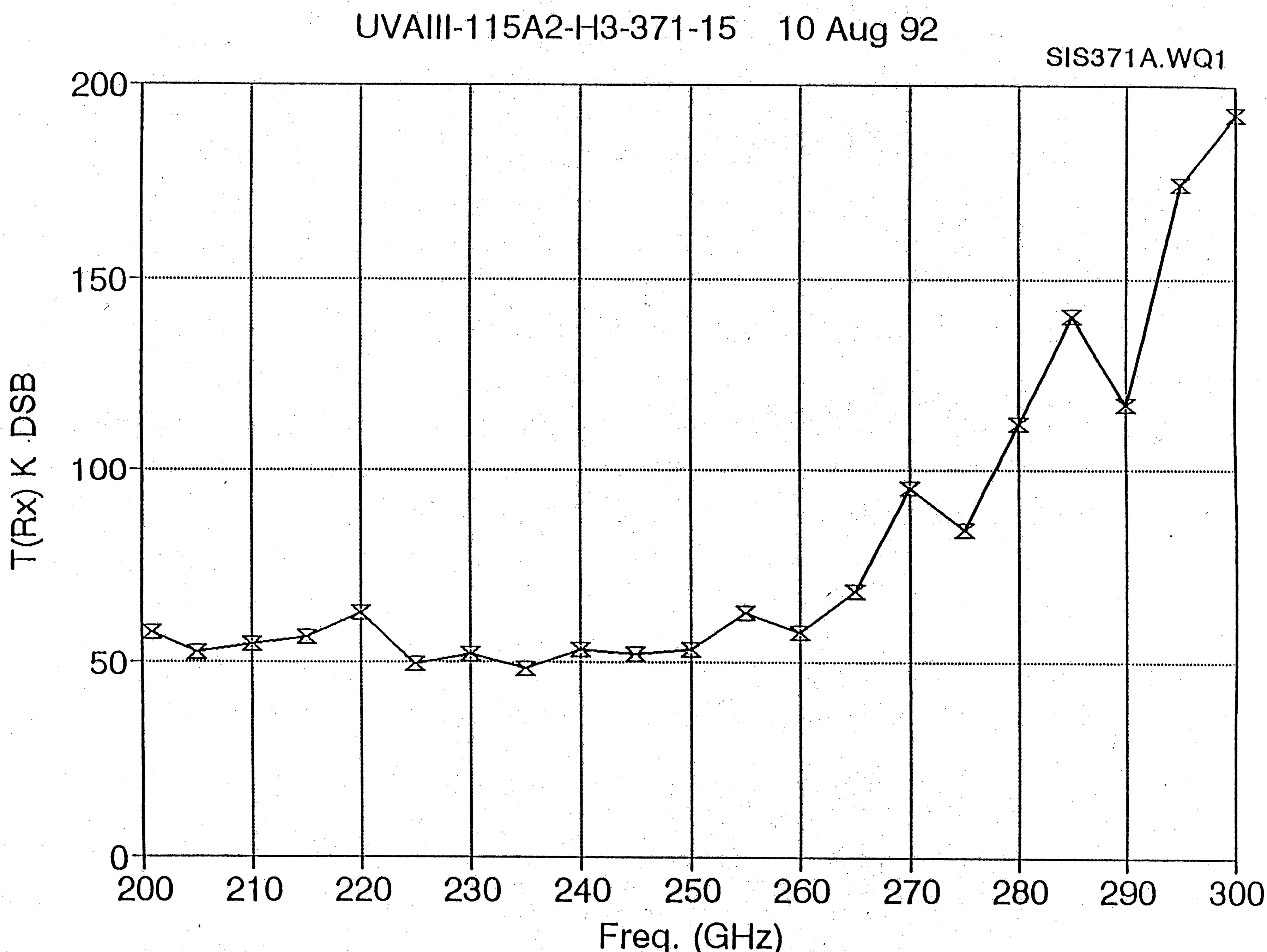

0·100"
DC/IF ground return
DC/IF bonding pad
Input waveguide 0·037" x 0·0185"
0·010"
Quartz substrate t=0·0035"
Suspended substrate stripline
Transition to coplanar line
Array of SIS junctions
4-element low-pass filter

WR-3·7



WR-3.7

5(b)


UVAIII-115A2-H3-371-15 10 Aug 92
SIS371A.WQ1
T(Rx) K DSB
200
150
100
50
0
200
210
220
230
240
250
260
270
280
290
300
Freq. (GHz)

5(c)

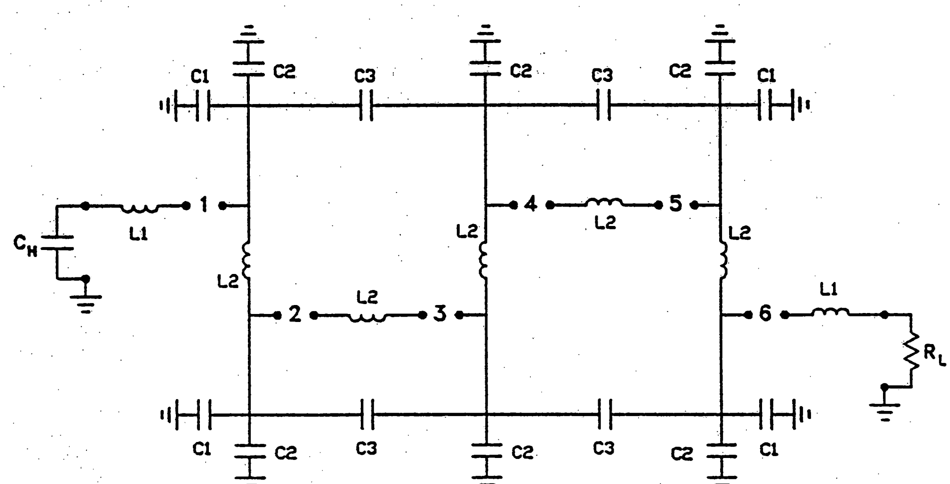
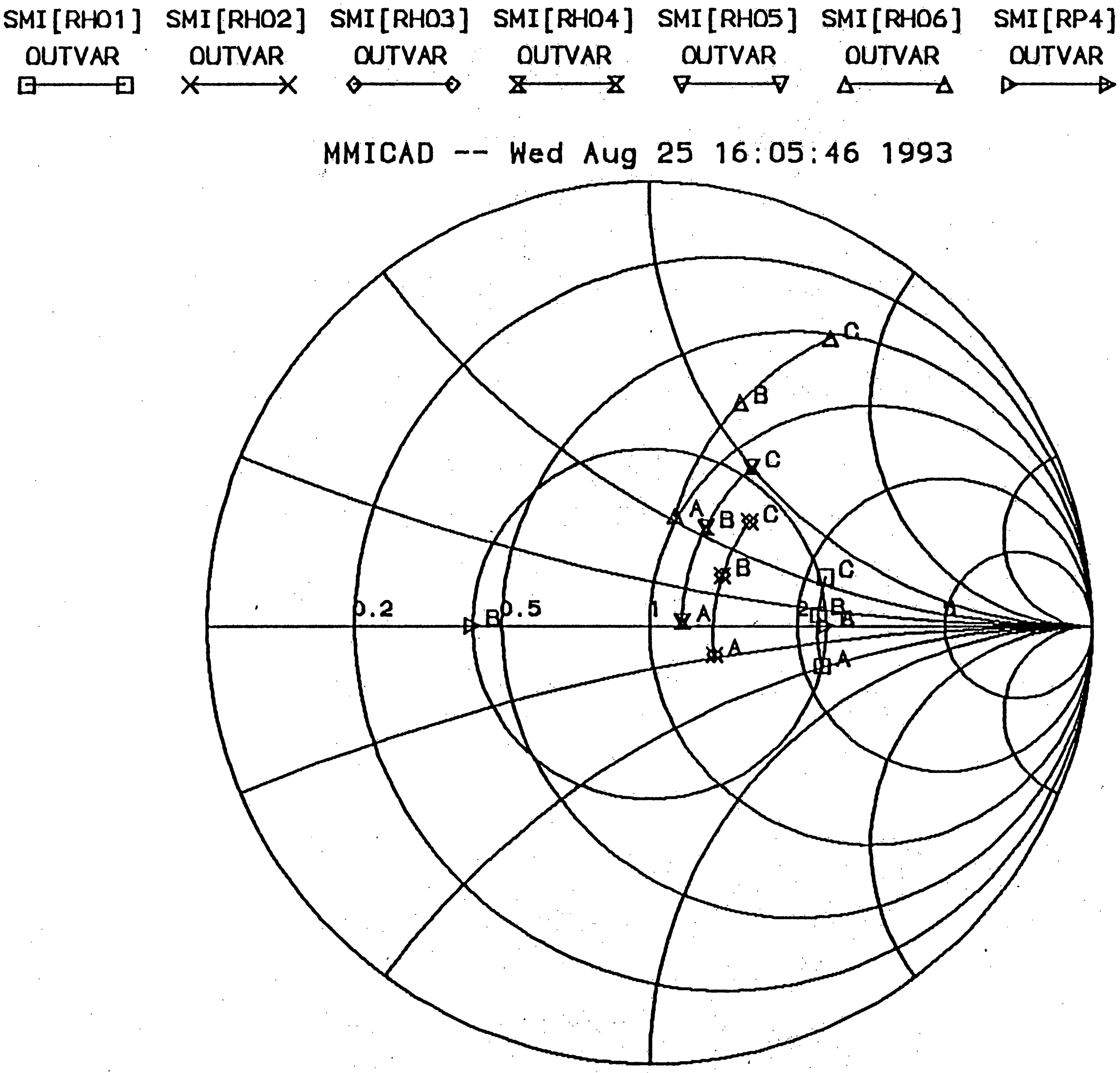


Fig. 10. Equivalent circuit of the embedding circuit. Element values (for the 500 x scale model) are: L1 = 4.98 nH, L2 = 4.48 nH, C1 = 0.507 pF, C2 = 0.613 pF, C3 = 0.00 pF, CH = 4.7 pF.

5(d)

SIS371a1.CKT



MMICAD -- Wed Aug 25 16:05:46 1993

FREQUENCY [GHZ]: 200 - 300

25 Aug 93 (2)

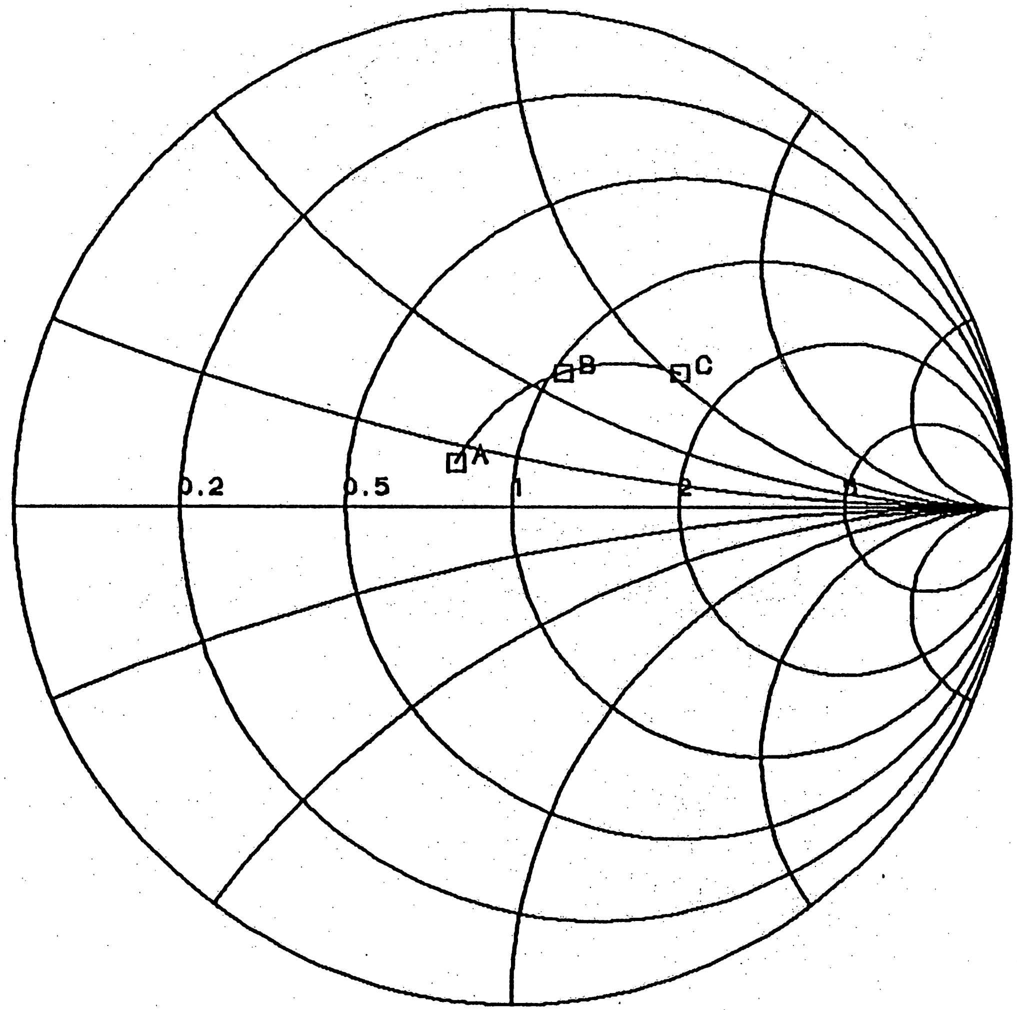
5(e)

SIS371a1.CKT

23 Aug 93 (2)

SMI[ZIN]
OUTVAR

MMICAD -- Wed Aug 25 16:05:31 1993



FREQUENCY [GHZ]: 200 - 300

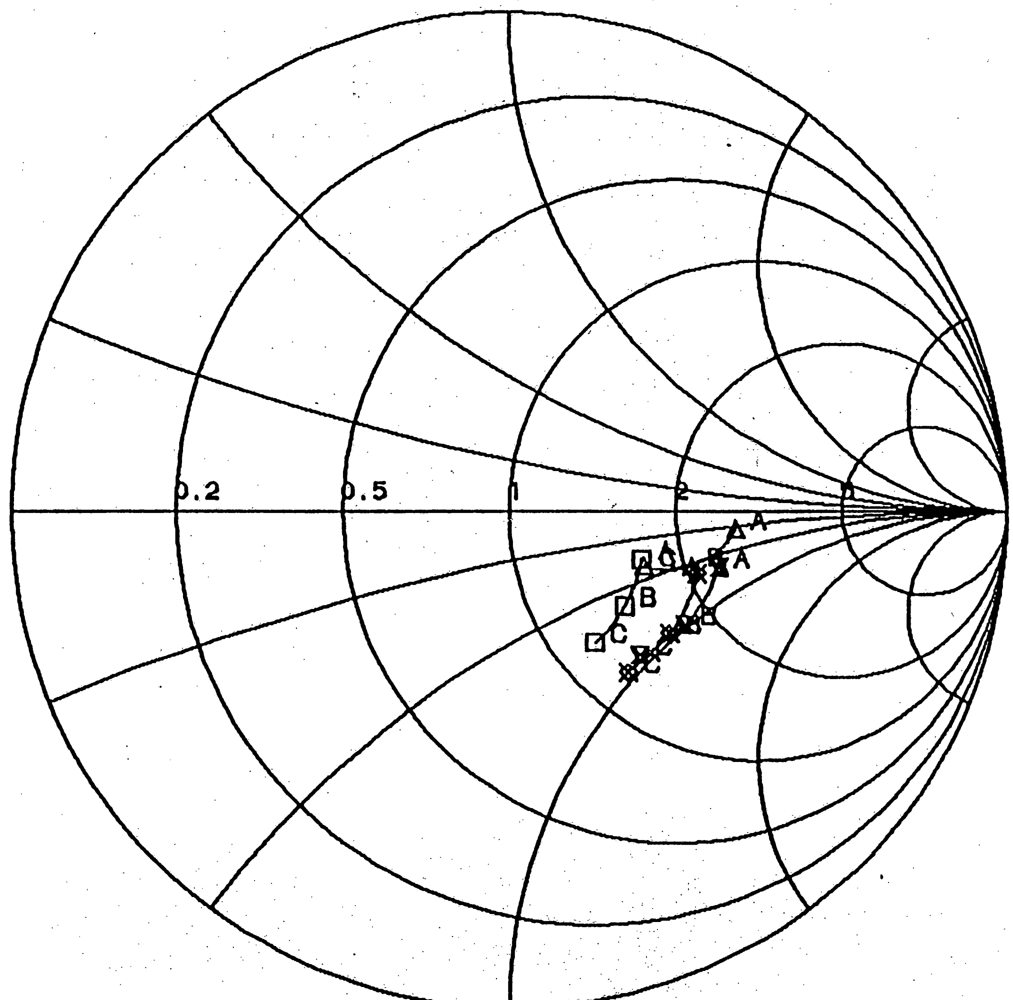
5(f)

23 Aug 93 (2)

SIS371a1.CKT

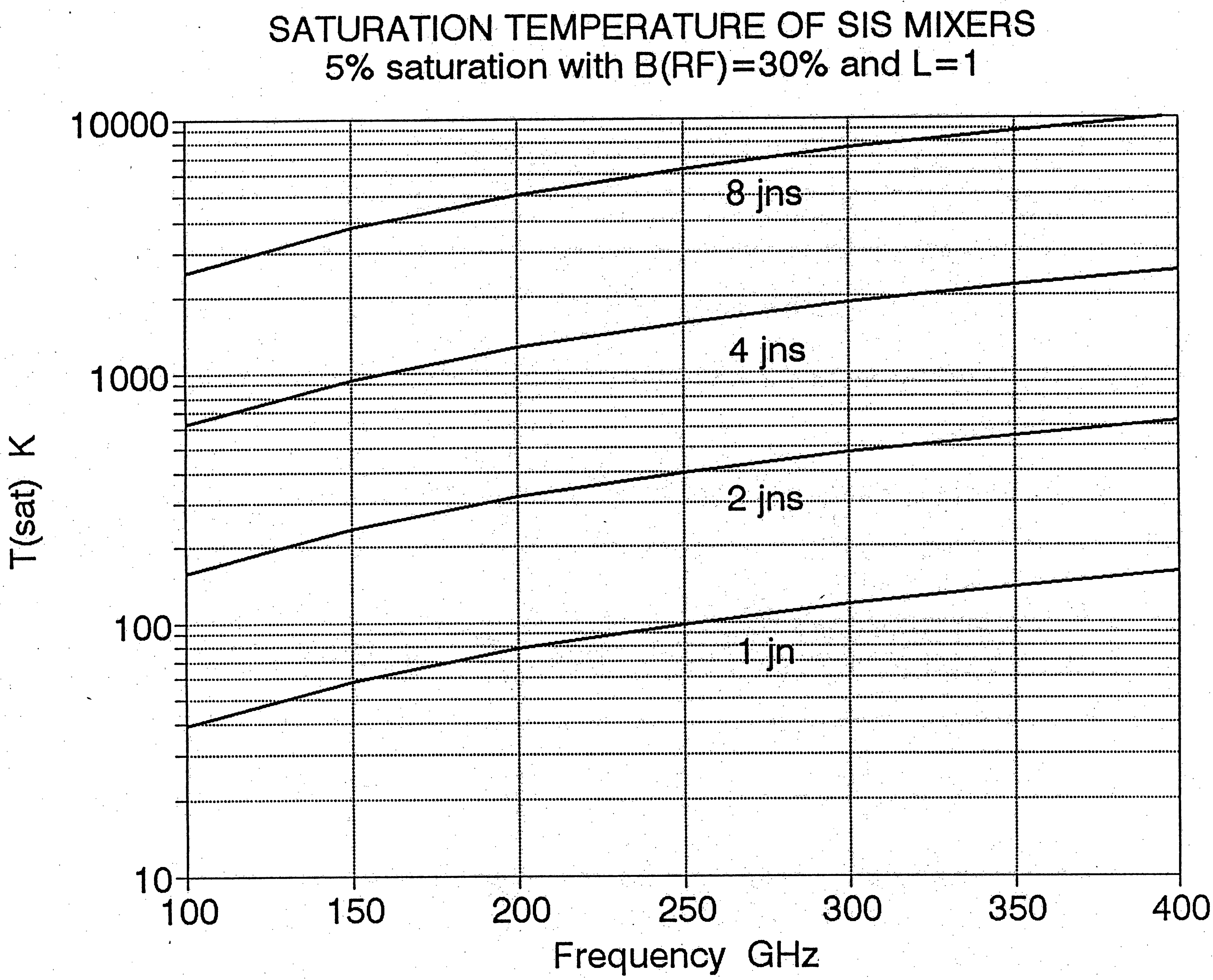
SMI[S17]	SMI[S27]	SMI[S37]	SMI[S47]	SMI[S57]	SMI[S67]
OUTVAR	OUTVAR	OUTVAR	OUTVAR	OUTVAR	OUTVAR

MMICAD -- Wed Aug 25 16:06:02 1993

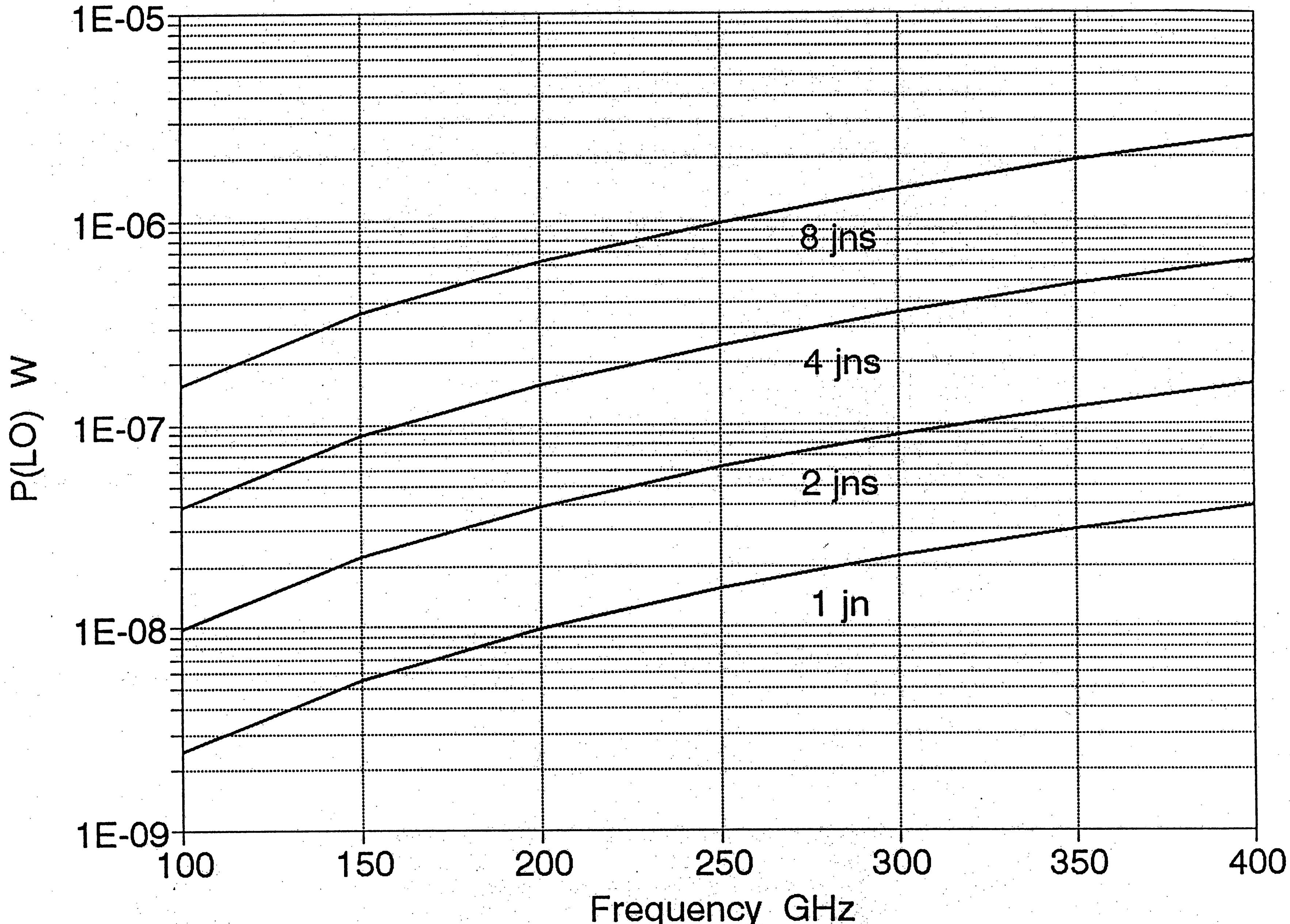


FREQUENCY [GHZ]: 200 - 300

5(g)


SATURATION TEMPERATURE OF SIS MIXERS
5% saturation with B(RF)=30% and L=1
10000
1000
100
10
T(sat) K
100
150
200
250
300
350
400
Frequency GHz
8 jns
4 jns
2 jns
1 jn

LO POWER REQUIREMENTS FOR SIS MIXERS



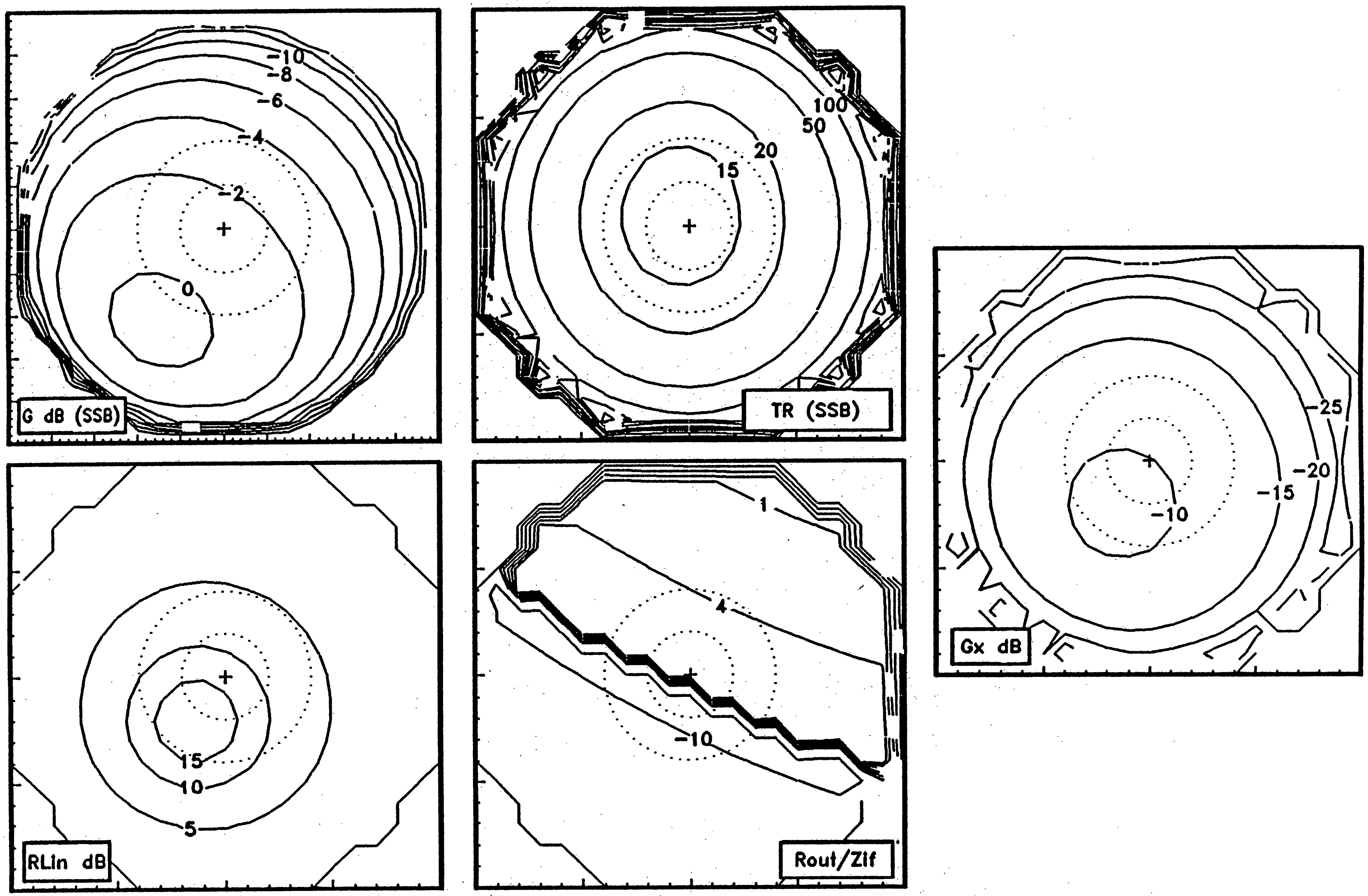


Fig. 7. Contour plots of mixer gain, receiver noise temperature, input return loss, IF VSWR, and signal-to-image conversion gain, for a 230 GHz SIS receiver. The contours are plotted on Smith charts of RF source admittance (*i.e.*, in the $-\rho$ plane). The dotted circles are $|\rho| = 0.2$ and $|\rho| = 0.4$. The receiver includes an IF amplifier with $T_{IF} = 4$ K, and an IF isolator at 4 K. The mixer gain and receiver noise temperature are shown as SSB quantities. (See text for further details.)

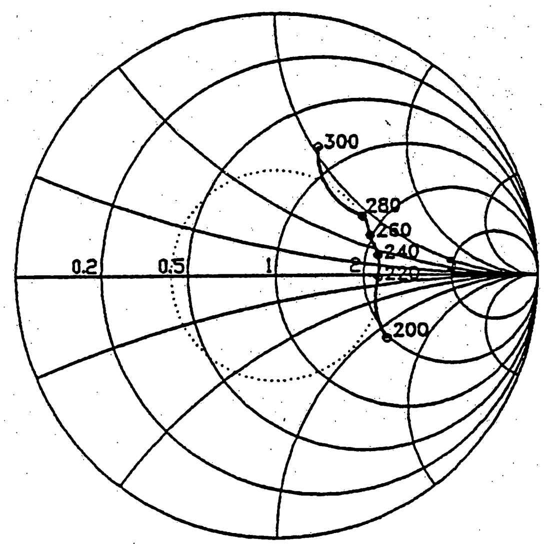


Fig. 11. Embedding admittance of the SIS mixer in Fig. 10 after optimization of the matching network to give the widest possible bandwidth with $|\rho| \leq 0.4$. Admittances are normalized to the RF conductance of the array $1/R = 1/4R_J$. The dotted circle is $|\rho| \leq 0.4$.

9(b)

CHOICE OF 1st IF

Effect of IF on typical SIS receiver

	IF	T_{IF}	T_{Rx}(DSB)
A (Present 12-m Rx.)	1.2-1.8 GHz	3 K	50 K
B	3-4 GHz	5 K	56 K
C	4-6 GHz	6 K	59 K

Bandwidth: 1 GHz (MMA spec.)

Image Rejection (Ref. MMA Memo. # 70)

If QO image suppression is used:

IF	3-4 GHz
Image rejection	≥19 dB
Loss (ideal)	0.05 dB

IF Isolator

1-2 GHz	Not available, large size
3-4 GHz	Available
4-6 GHz	Available

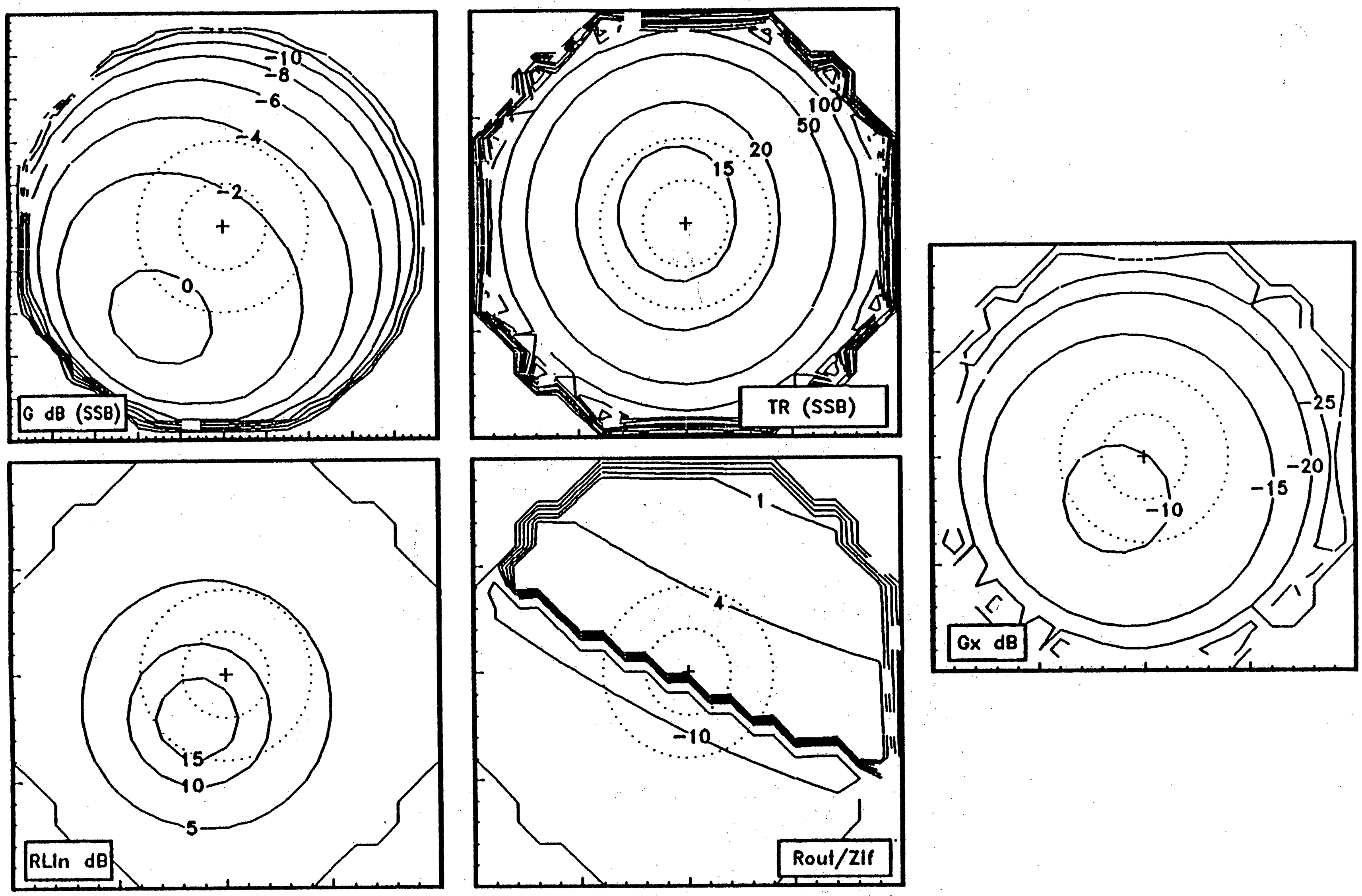


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IMAGE SEPARATION

Quadrature Phase Switching

Should be built into MMA design.
Does not suppress atmospheric noise in image band.

Quasi-Optical

Noise from image cold load adds to T_{RX}(SSB).

Image Separation Mixers (Ref. Woody, *et al.*, 1993 THz Symp.)

Added complexity.

Ref.: R. L. Akeson, J. E. Carlstrom, D. P. Woody, J. Kawamura, A. R. Kerr, S.-K. Pan and K. Wan, "Development of a Sideband Separation Receiver at 100 GHz."

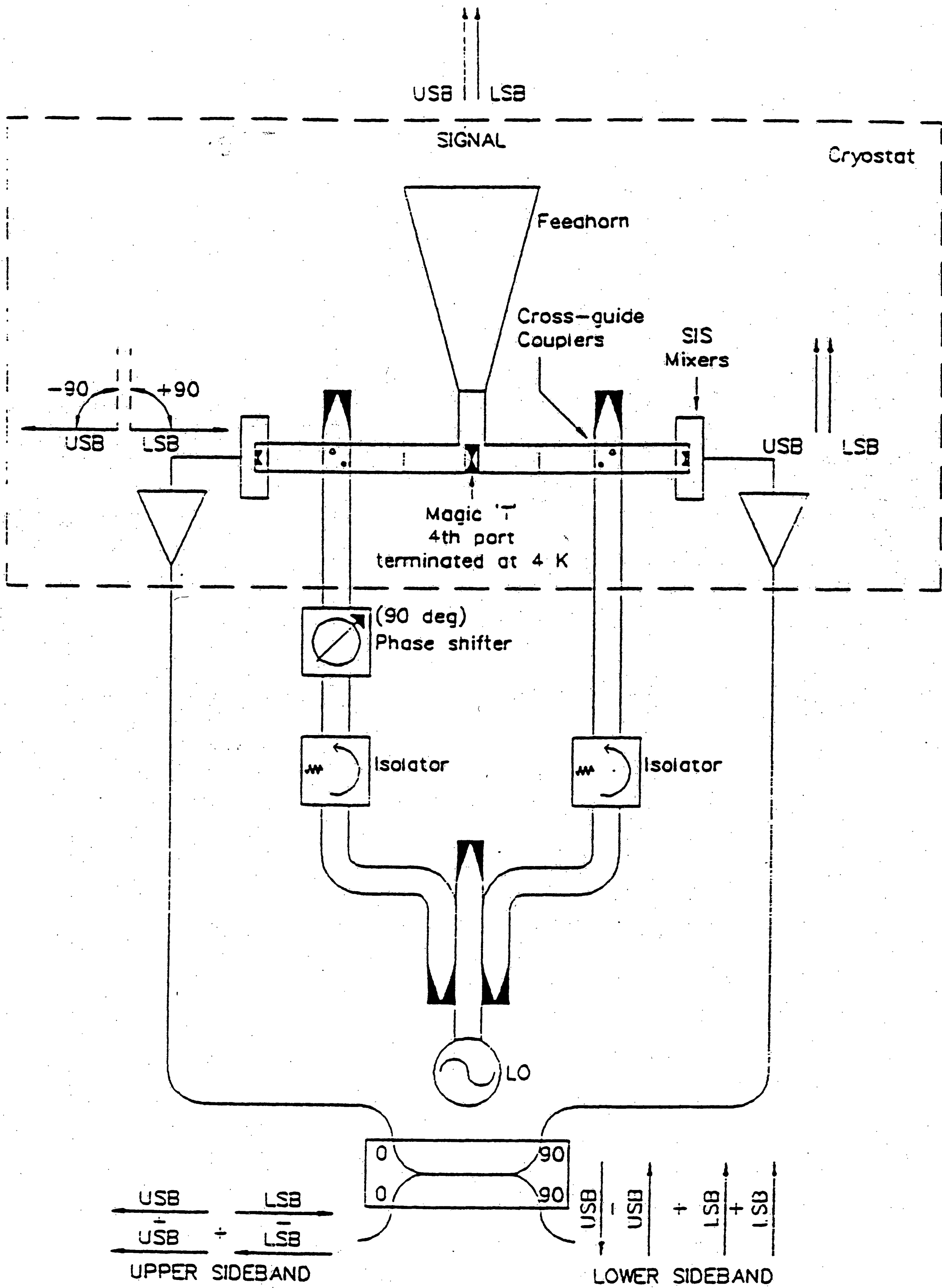

Figure 2: Prototype Sideband Separation Receiver

SUPERCONDUCTING CIRCUIT FABRICATION

The MMA SIS receiver development is critically dependent on having a reliable fabricator of SIS devices.

Collaborators: UVa, UI, (Hypres), (IBM/CSE).

Why is it so hard to make such simple circuits?

μm feature sizes with ±0.1 μm accuracy.

249 process steps (cf., ~10 for Pb shadow-mask junctions (easy to make, but poor mixers)).

Universities vs Industry for SIS fabrication

Cost of doing SIS fabrication at NRAO:

Rough estimate: $1.6M + $370K/yr in 1992 (almost certainly an underestimate).