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LOW-NOISE 205GHz SIS MIXERS USING HIGH CURRENT DENSITY Nb AND NbN TUNNEL JUNCTIONS

W.R. McGrath, H.H.S. Javadi, S.R. Cypher, B. Bumble, B.D. Hunt, H.G. LeDuc

Center for Space Microelectronics Technology
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

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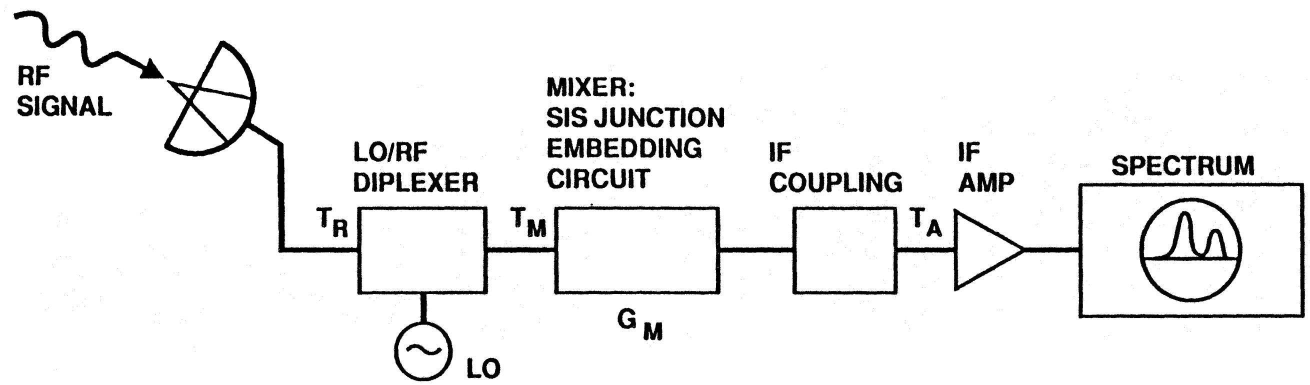
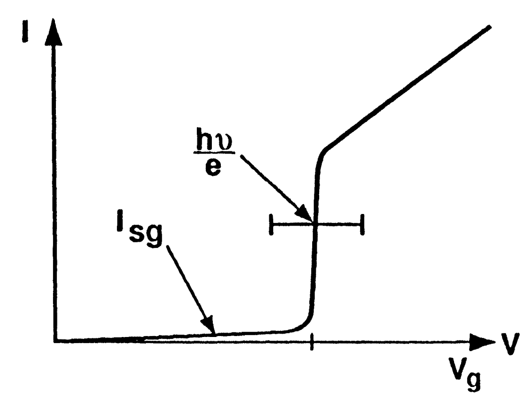


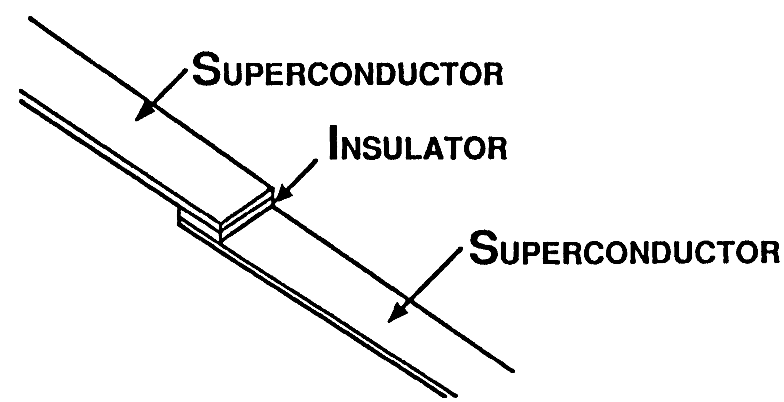
HETERODYNE RECEIVER $T_R = T_M + T_A / G_M$

SIS MIXER: $G_M > 1$, $T_M \rightarrow \frac{h\upsilon}{k}$, $P_{LO} \sim 50$ nW @ 200 GHz

IMPORTANT REQUIREMENTS: (Tucker Theory 1979)

- PROPER RF EMBEDDING CIRCUIT (TUNE OUT JUNCTION CAPACITANCE)
- IMPEDANCE MATCH AT THE IF
- SHARP NONLINEARITY $\frac{h\upsilon}{e} > \Delta V_g$
- LOW SUBGAP CURRENT $I_{sg} << \Delta I$





GOAL: Develop Low Noise SIS Mixers for Submillimeter Wave Applications using High Current Density, Submicron Area, Refractory Metal Tunnel Junctions: NbN, Nb

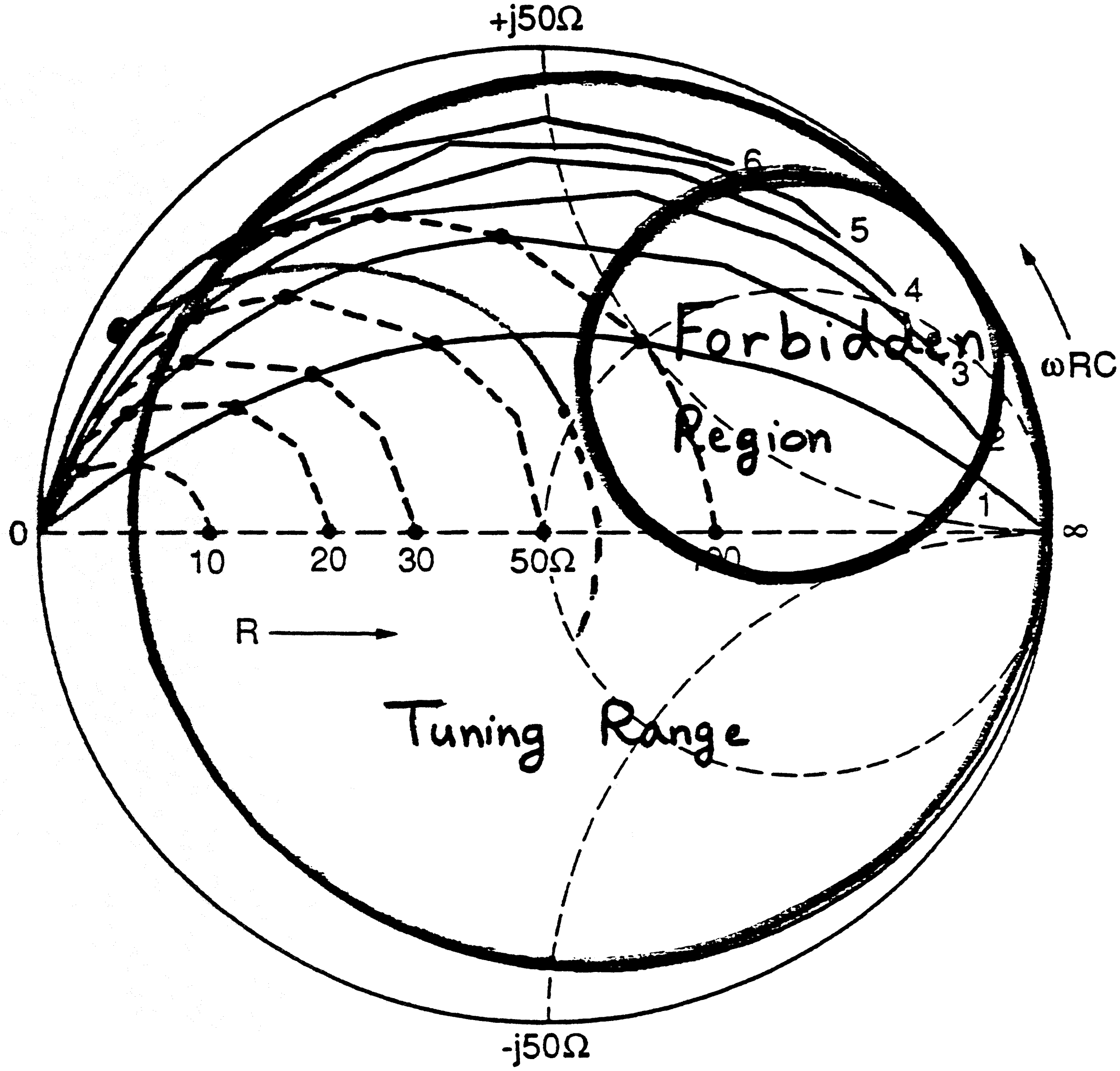
(Ground-based: Caltech, KAO, SMMM)

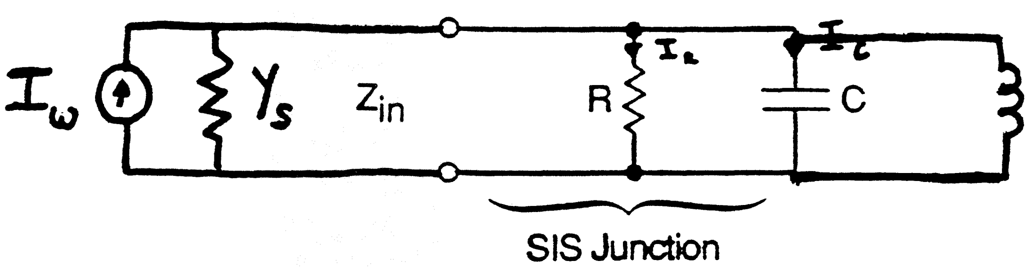
APPROACH:

I.
Area $\geq 1\ \mu^2$
Current Density Jc: moderate to high ($10^3 - 10^4$ A/cm^2)
ωRC: high (8 - 10)
Good Mixer Performance with Integrated Tuning Elements.
(Last year; First Space Terahertz Technology Conference)

II.
Area $<< 1\ \mu^2$ ($0.25\ \mu^2$)
Current Density: high (10^4 A/cm^2))
ωRC: low (2 - 4)
Excellent Mixer Performance without Integrated Tuning Elements.

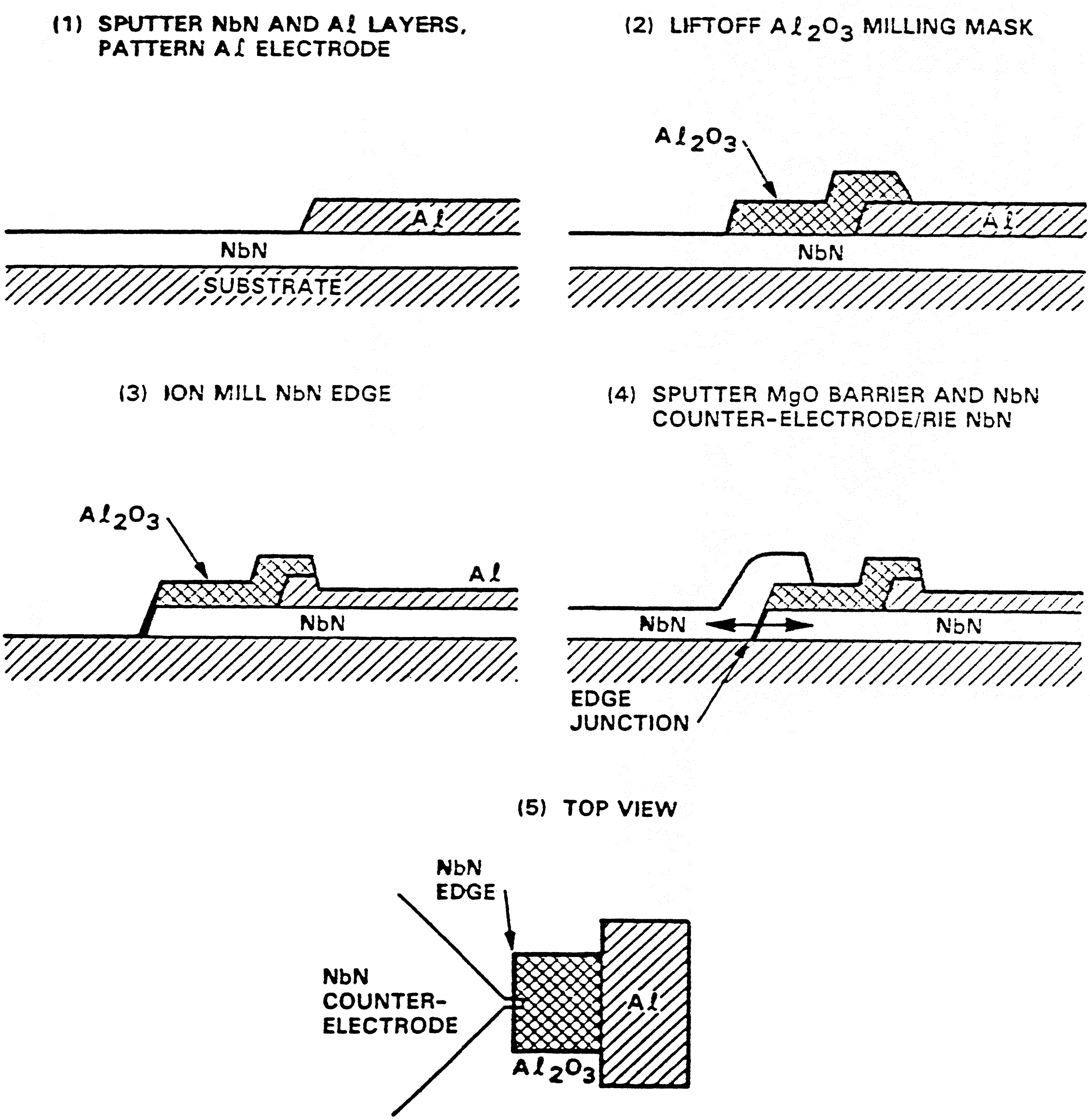
Impedance Smith Chart



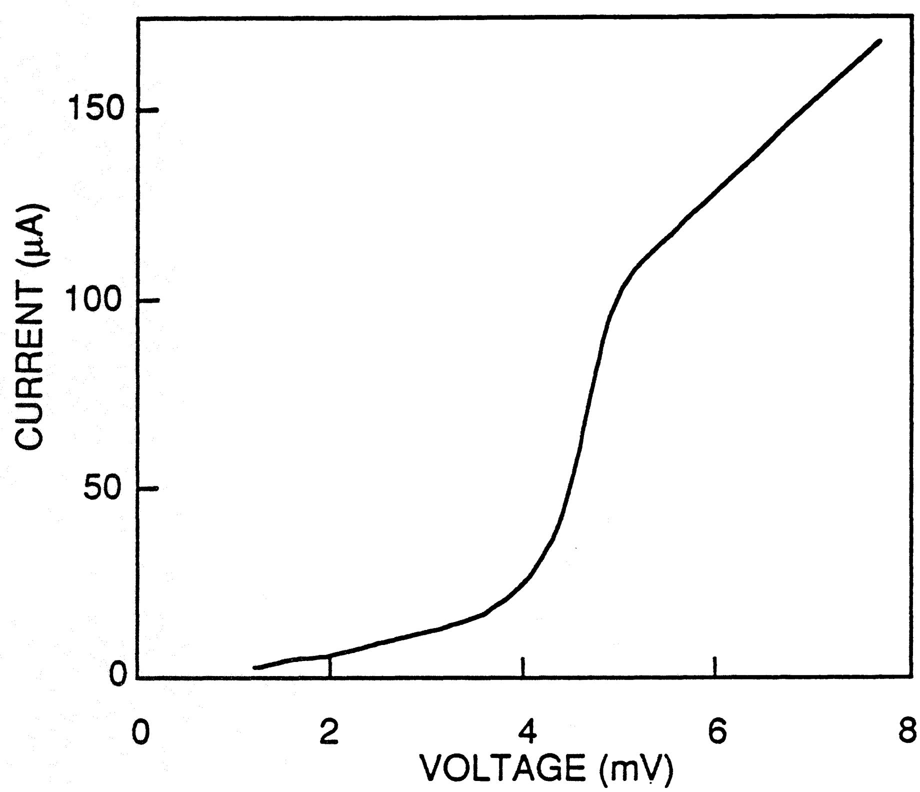


$$\omega R C = \frac{I_c}{I_R} = \frac{\omega}{\Delta\omega}$$

EDGE JUNCTION PROCESS



NbN/MgO/NbN EDGE JUNCTION



TYPICAL JUNCTION PARAMETERS

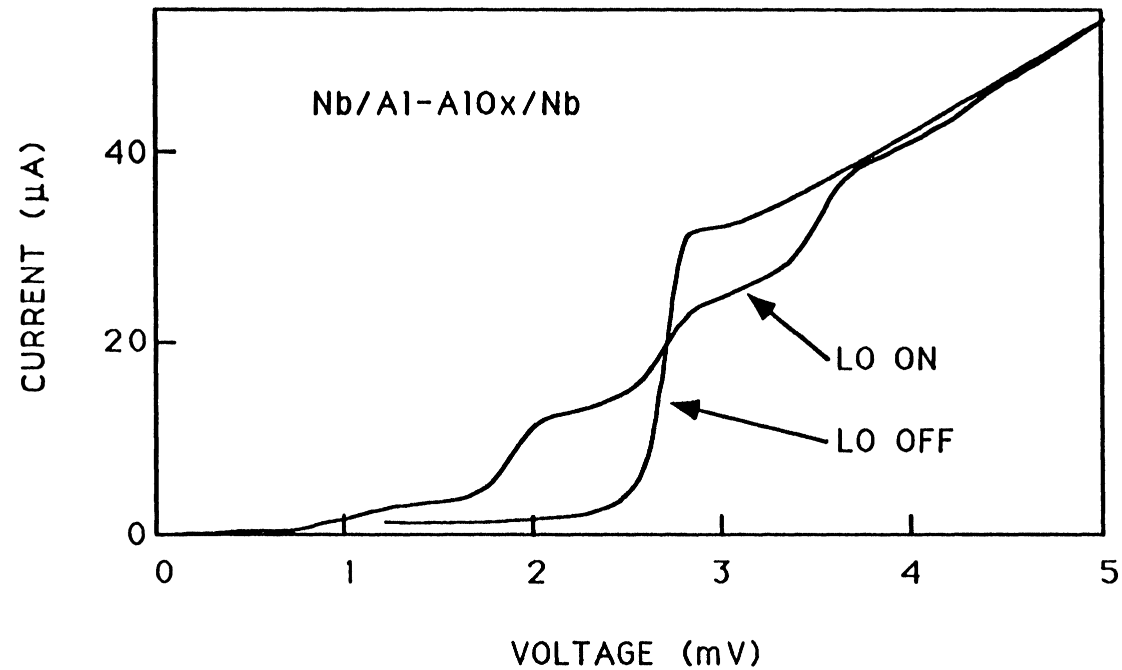
AREA $\approx 0.3\mu^2$ Jc = 18 - 25 kA/cm^2 R = 40 -70 Ω

Vg = 4.8 mV ΔVg $\approx$ 1 -2 mV $\frac{h\nu}{e} \simeq 0.85\,mV \rightarrow \Delta V_g > \frac{h\nu}{e}$

Capacitance $\approx$ 35 - 50 fF ωRC $\approx$ 2.5 - 3.5 @ 205 GHz

For recent improvements in edge junction I-V curves, see:
H.G. LeDuc, A. Judas, S.R. Cypher, B. Bumble, B.D. Hunt, and J.A. Stern
"Submicron Area NbN/MgO/NbN Tunnel Junctions for SIS MIxer Applications"
Applied Superconductivity Conference Proceedings, IEEE Trans. Magn. March 1991.

Nb AlOx - Nb   E-beam 11csq Junction

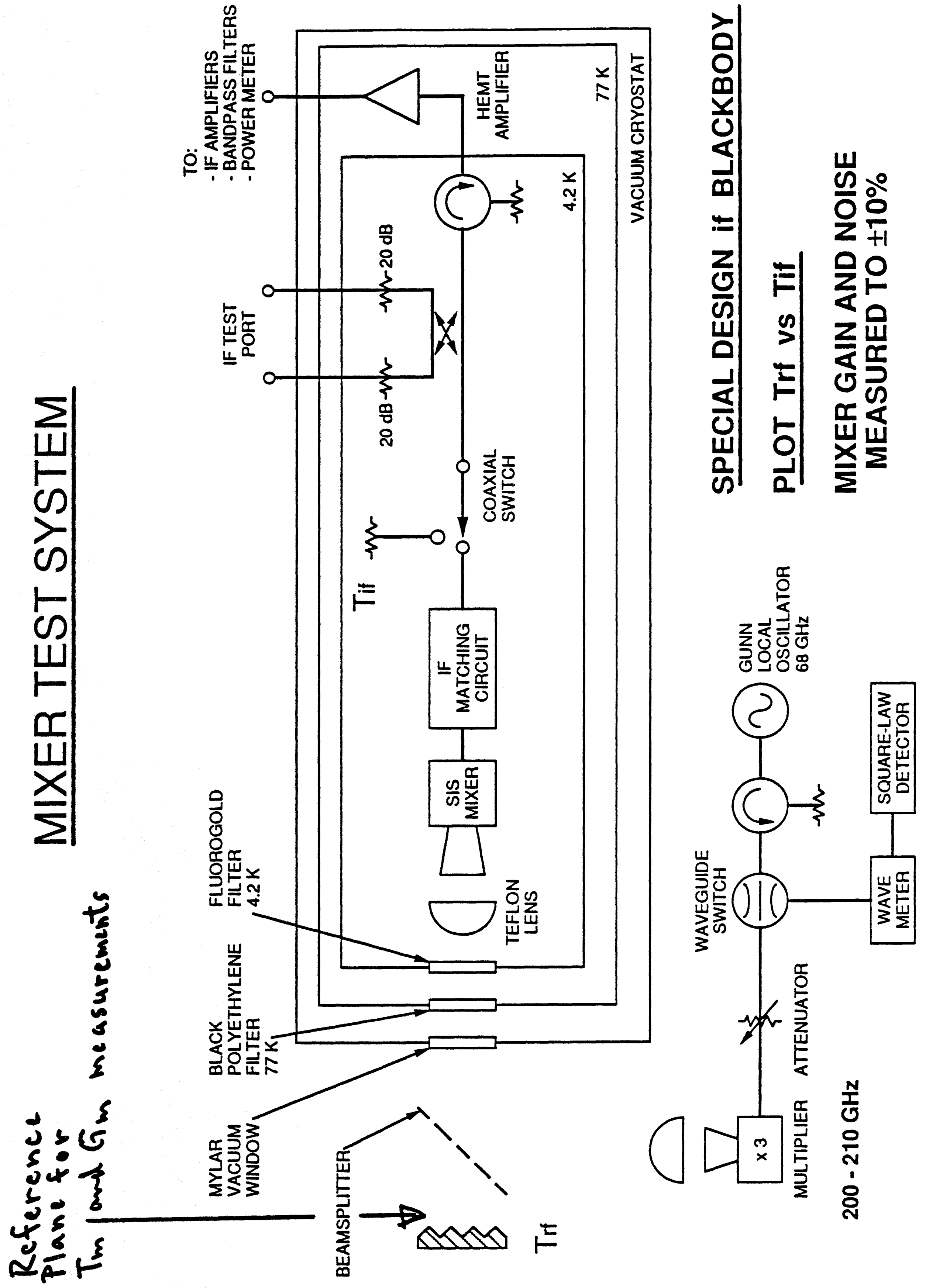


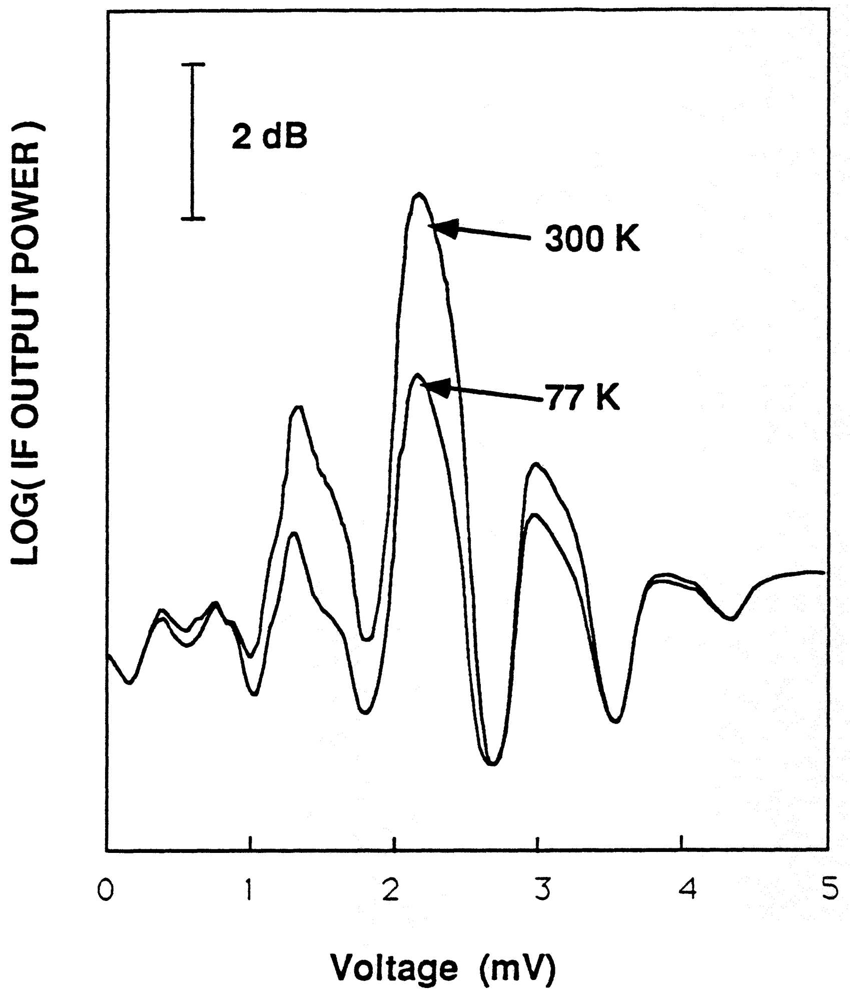
JUNCTION PARAMETERS

AREA $\approx 0.25\ \mu^2$ Jc $\approx$ 10 kA/cm^2 R = 95 Ω

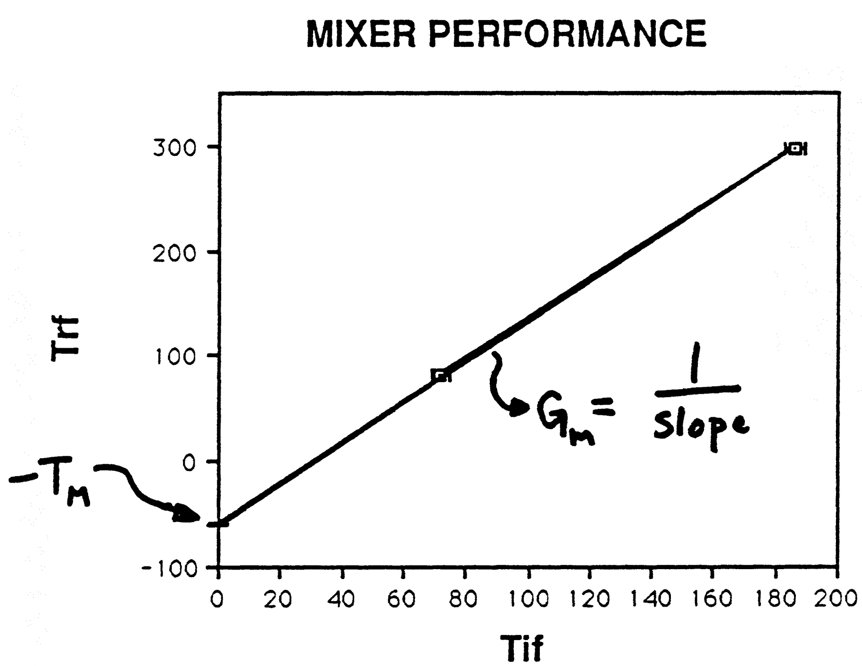
Vg = 2.7 mV ΔVg $\approx$ 0.3 mV   hν/e $\approx$ 0.85 mV ΔVg < hν/e

ωRC $\approx$ 2 @ 205 GHz


MIXER TEST SYSTEM
Reference Plane for Tm and Gm measurements
BEAMSPLITTER
Trf
MYLAR VACUUM WINDOW
BLACK POLYETHYLENE FILTER 77 K
FLUOROGOLD FILTER 4.2 K
TEFLON LENS
SIS MIXER
IF MATCHING CIRCUIT
Tif
COAXIAL SWITCH
20 dB
20 dB
IF TEST PORT
HEMT AMPLIFIER
TO:
- IF AMPLIFIERS
- BANDPASS FILTERS
- POWER METER
4.2 K
77 K
VACUUM CRYOSTAT
x 3
MULTIPLIER
200 - 210 GHz
ATTENUATOR
WAVEGUIDE SWITCH
WAVE METER
SQUARE-LAW DETECTOR
GUNN LOCAL OSCILLATOR 68 GHz
SPECIAL DESIGN if BLACKBODY
PLOT Trf vs Tif
MIXER GAIN AND NOISE MEASURED TO ±10%



2 dB
300 K
77 K
LOG(IF OUTPUT POWER)
0
1
2
3
4
5
Voltage (mV)



MIXER PERFORMANCE
300
200
100
0
-100
Trf
0
20
40
60
80
100
120
140
160
180
200
Tif
$-T_M$
$G_m = \frac{1}{slope}$

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SUMMARY OF BEST RESULTS

JUNCTION TYPE	BATH TEMP.[K]	SIDEBAND RATIO [dB]	T_m [K]	AVAILABLE G_m [dB]	T_R* [K] (T_{IF}=5K)	STUB LENGTH [μ]
Nb MESA (0.25μ²)	4.2	19 ± 3	60 ± 10	-2.1	70	NO STUB
Nb MESA (1μ²)	4.2	***	78 ± 7	-6.5	100	NO STUB
NbN EDGE (0.3μ²)	4.2	0 ± 3	145 ± 10	-10.7	215	NO STUB
NbN MESA**	4.2	0 ± 3	185 ± 10	-12.4	290	80
	1.5	0 ± 3	134 ± 10	-11.2	212	80

* CALCULATED

** W.R. McGrath, K. Jacobs, J. Stern, H.G. LeDuc, R.E. Miller, M.A. Frerking, First Int. Symp. on Space Terahertz Technology, University of Michigan, 1990.

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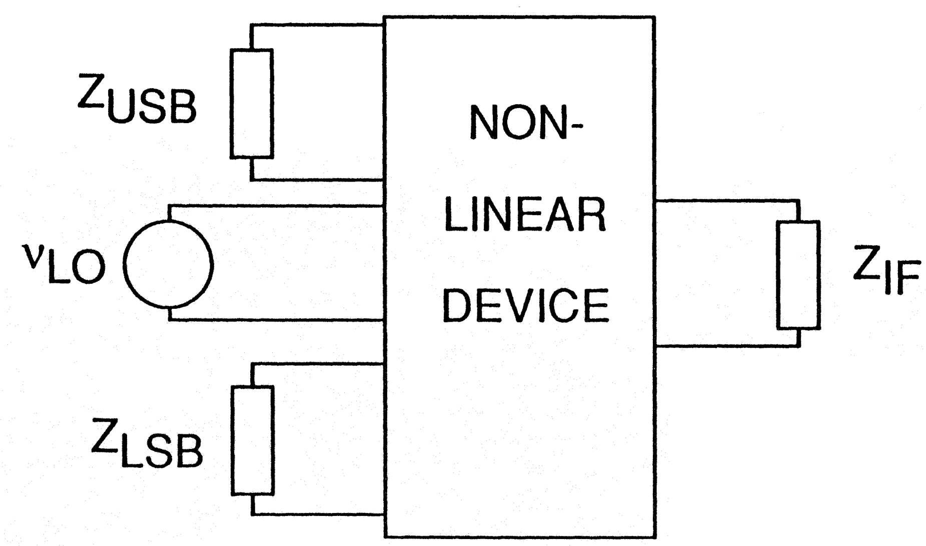
COMPUTER SIMULATION OF MIXER PERFORMANCE

Tucker Theory

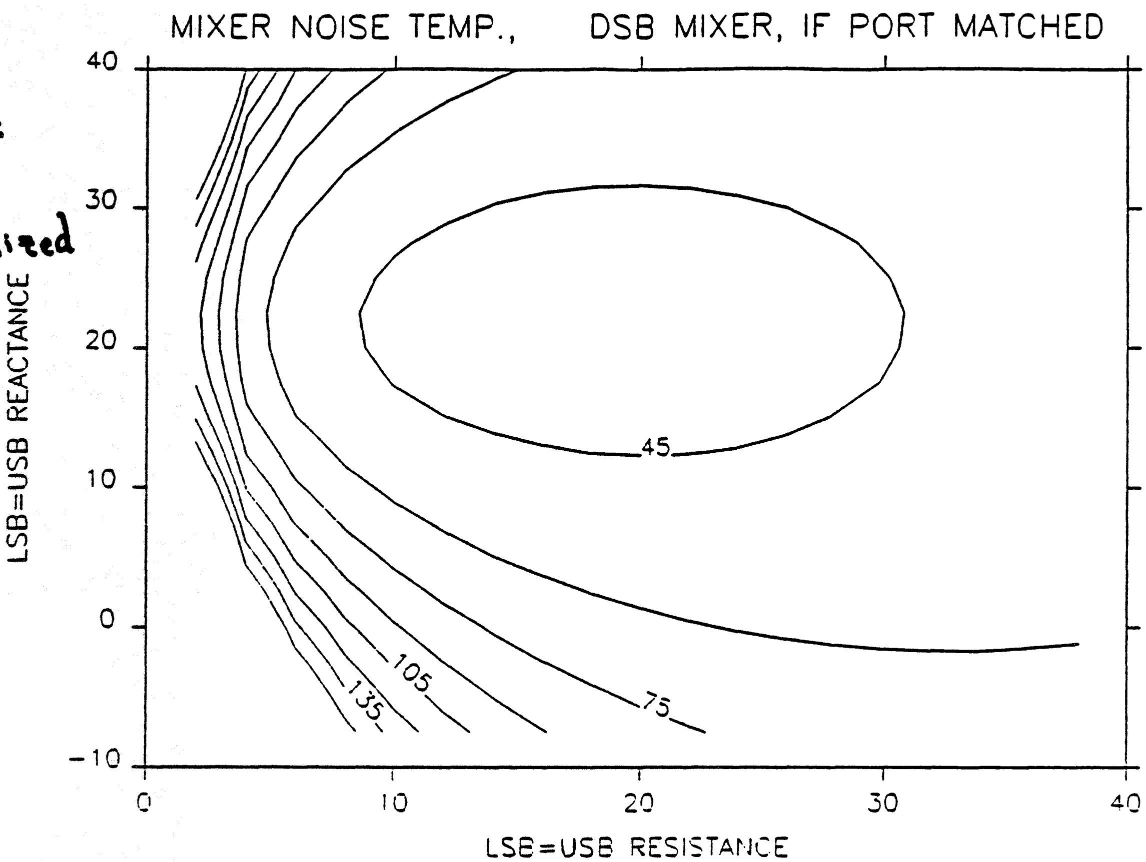
Three - Port Mixer Model

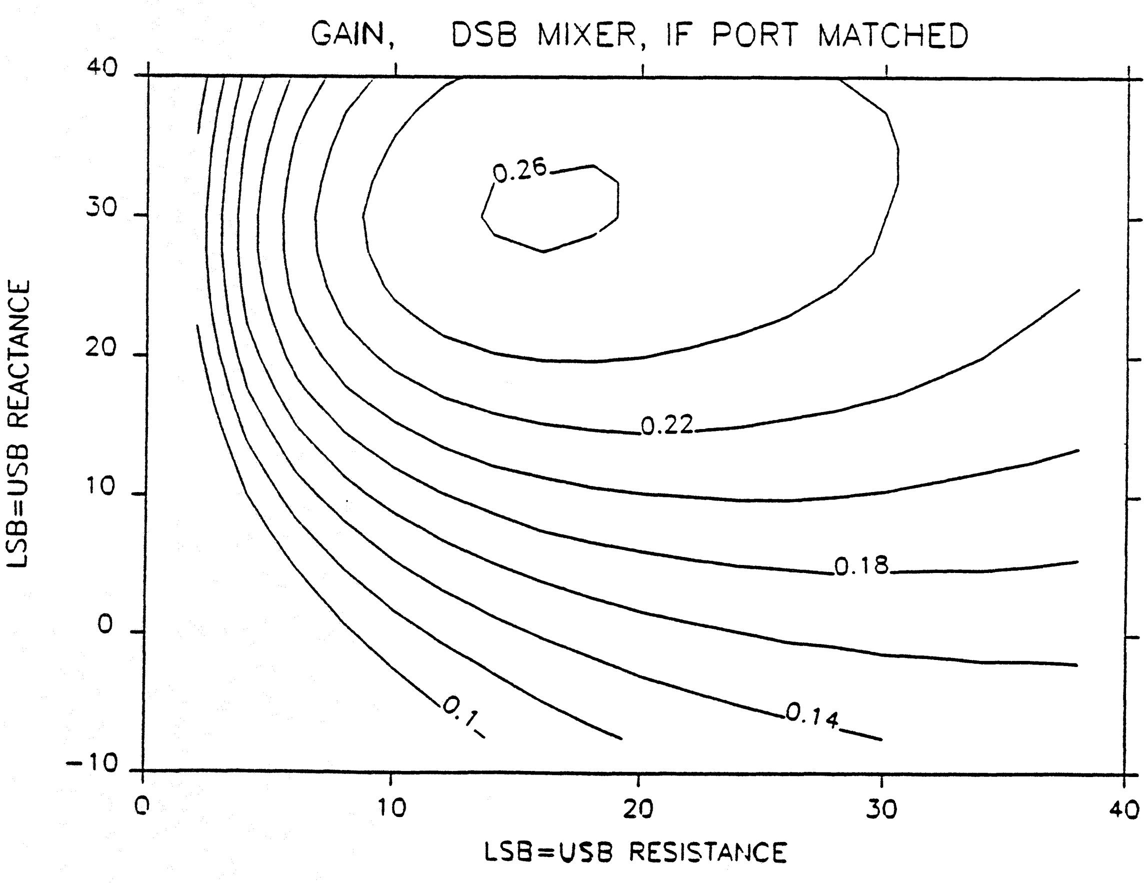
Inputs: DC I-V Curve, V_{dc}, V_{LO}, Z_{USB}, Z_{LSB}, Z_{IF}

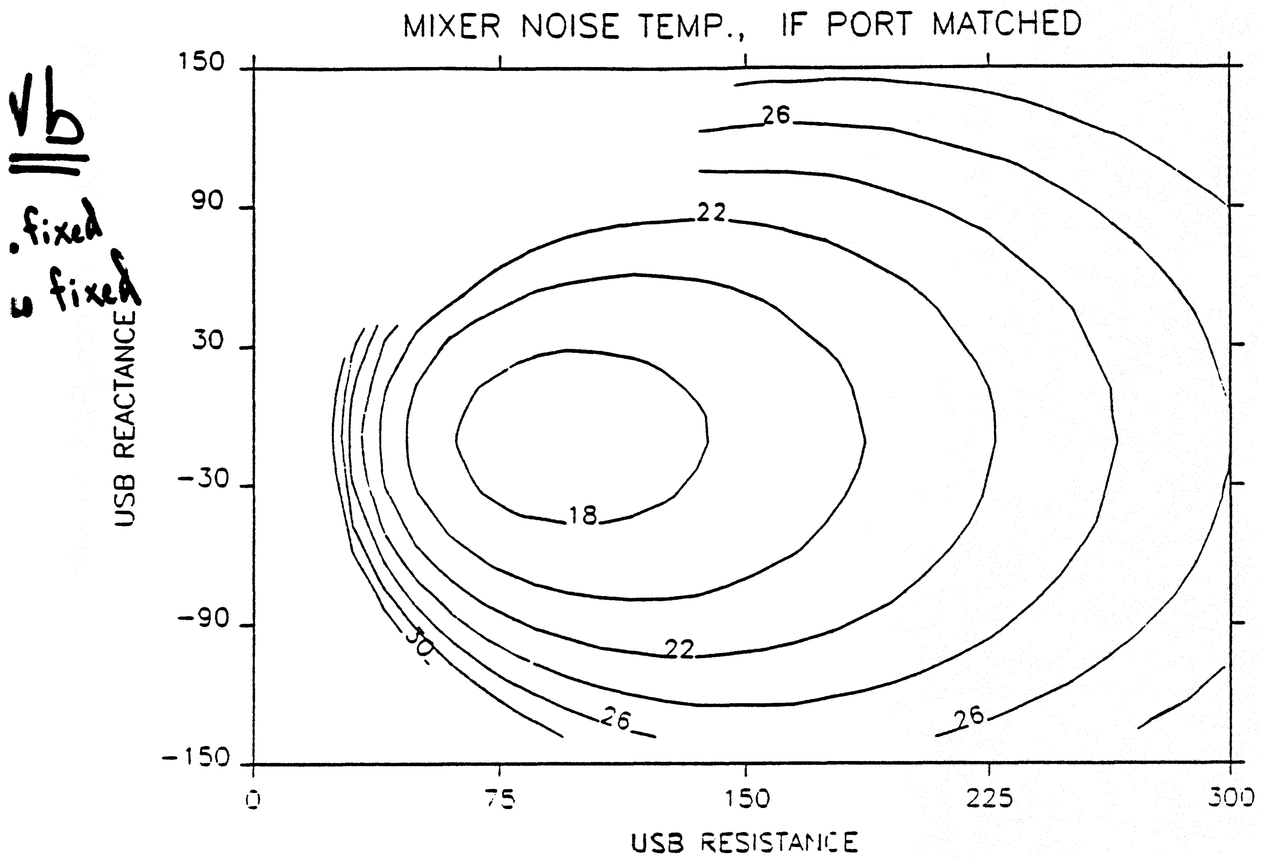
Outputs: Mixer Noise Temperature, Mixer Conversion Efficiency



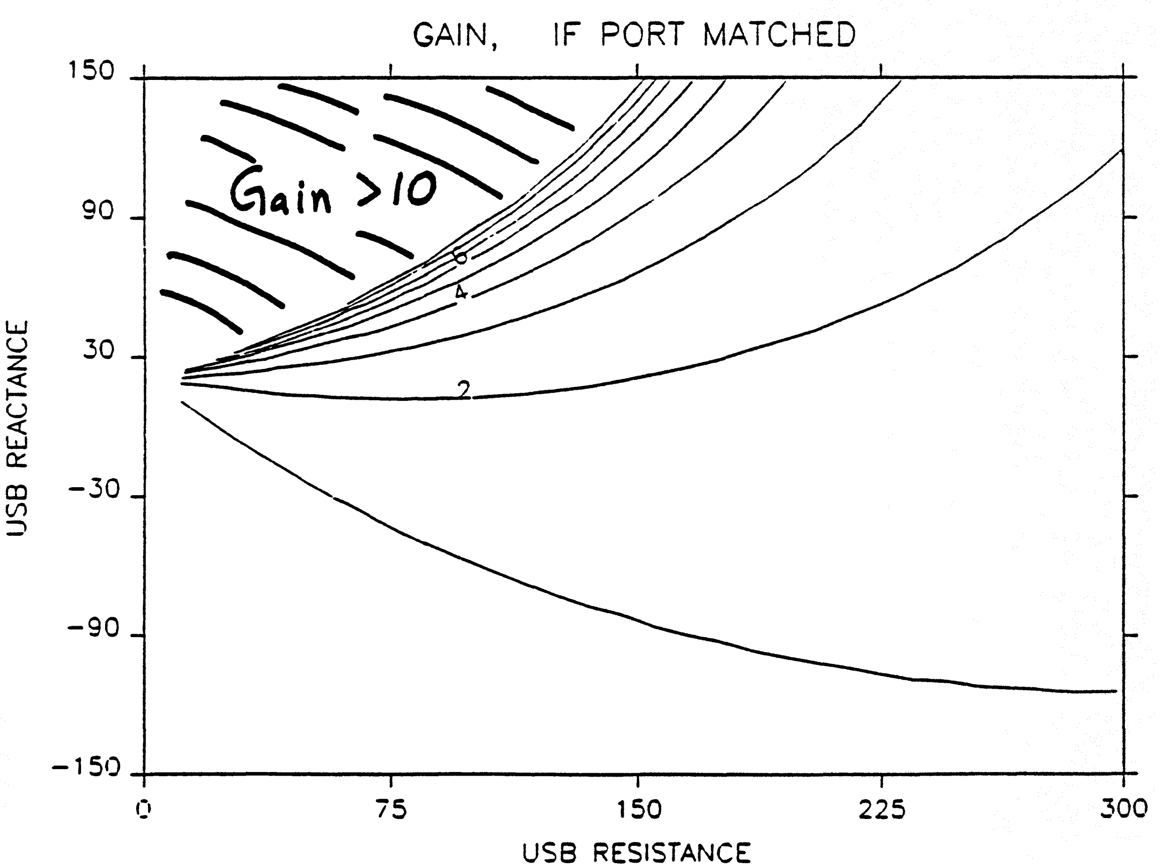
NbN
V_b fixed
V_{LO} Optimized







MIXER NOISE TEMP., IF PORT MATCHED
Vb
.fixed
ω fixed
USB REACTANCE
USB RESISTANCE
150
90
30
-30
-90
-150
0
75
150
225
300
18
22
26
30



GAIN, IF PORT MATCHED
Gain >10
USB REACTANCE
USB RESISTANCE
150
90
30
-30
-90
-150
0
75
150
225
300
6
4
2

Comparison:

	NbN		Nb	
	Gain	T_M	Gain	T_M
Tucker's Theory	-6^{dB}	45	Large	18
Experiment	-11^{dB}	145	-2^{dB}	60

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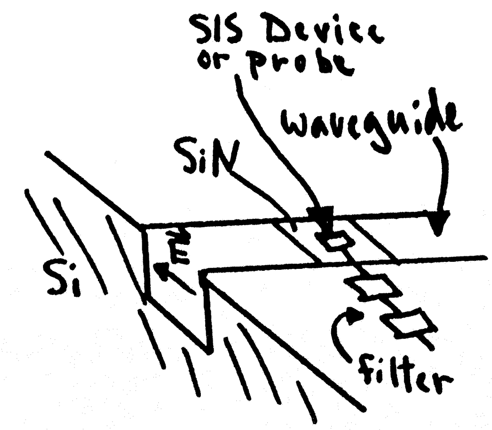
CURRENT PROGRAMS

* 630 GHz SIS MIXER ----- Presently being tested.

  Waveguide Mount
  NbN, Nb Tunnel Junction (JPL)
  Pb-Alloy (R.E. Miller, Bell Labs)

* Si Micromachined Waveguide ----- 1000 GHz

  Y.C. Tai, C. K. Walker, M. Yap: Campus
  W.R. McGrath, H.S. Javadi, H.G. LeDuc: JPL



  Fabricate waveguides with 1μ thick SiN membranes in E-field dir.
  Fabricate SIS junctions or probes directly in the waveguide
  Solves the mounting problem!

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SUMMARY

Fabricated and tested submicron area, refractory tunnel junctions as SIS mixers at 205 GHz.

No integrated tuning elements: $\omega RC \approx 2\text{-}4$.

Accurate measurements of mixer noise and conversion efficiency.

Nb-AlOx-Nb: Tm(SSB) = 60K Gm(SSB) = -2 dB Best to date!

NbN-MgO-NbN: Tm(DSB) = 145K Gm(DSB) = -10.7 dB

Preliminary calculations of mixer performance with the Tucker Theory.

630 GHz SIS mixer currently being tested.

Extenion of waveguide circuits to 1000GHz using Si micromachining techniques.