Double Dipole Antenna SIS Receivers at Frequencies above 500 GHz*

J. Mees[a], A. Skalare[a], M.M.T.M. Dierichs[a,b], H. van de Stadt[a], R.A. Panhuyzen[a], Th. de Graauw[a], T.M. Klapwijk[b], and E. Armandillo[c]

a) Space Research Organisation Netherlands (SRON), Postbox 800, 9700 AV Groningen, The Netherlands
b) Dept. of Applied Physics and Materials Science Center, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands
c) ESTEC, Postbox 299, 2200 AG Noordwijk, The Netherlands

Abstract

Resonances of simple tuning circuits up to 1 THz coupled to SIS tunnel junctions were obtained by means of FTS measurements and compared with calculations based on the Mattis-Bardeen theory. We developed a new sort of devices for frequencies above 700 GHz using gold instead of Nb for the rf-parts. First measurements of the video and heterodyne response of all-Nb SIS receivers have been made at frequencies between 720 and 890 GHz. We measured a possible heterodyne response of 1.1 dB due to a hot/cold load at 830 GHz. The video response of the unpumped junction was 0.3 dB due to the hot/cold load.

Introduction

Planar double dipole antennas consisting out of two half-wave dipoles are well suited for the construction of sensitive broad band heterodyne SIS-receivers. Previously published results [1,2,4] with small area Nb-tunnel junctions including simple tuning structures have shown an excellent performance at frequencies up to 500 GHz. In order to develop mixers above the gap frequency of Nb up to 1 THz we are investigating in several items.

Resonances of open-ended tuning stubs coupled to SIS-tunnel junctions are studied and compared with calculations based on the Mattis-Bardeen theory. Since the conductivity of Nb decreases strongly above the superconducting gap frequency we are proposing improved performance using instead of Nb films made out of a normal conductor. We are developing therefore devices with antennas and integrated tuning network out of gold and Nb-tunnel junctions as detection elements. First results of these new devices are promising.

Besides this we are investigating in measurements of all-Nb elements above 500 GHz. Resonances of the integrated tuning network above the gap frequency could be obtained by means of measurements with a Fourier-Transform-Spectrometer (FTS). First measurements of the video and heterodyne response have been carried out at frequencies between 700 and 900 GHz.

---

* Proceedings of the 4. International Symposium Space TeraHertz Technology (1993), Los Angeles

Resonances of the Integrated Tuning Network

Integrated tuning network is necessary to compensate for the junction capacitance or to transform its impedance to the antenna impedance. This is especially true for SIS-mixer receivers based on planar antennas since there is no other tuning possibility available. In order to understand the frequency dependent behavior of superconducting transmissionlines we measured the video response of SIS-junctions coupled to open-ended stubs by means of an Fourier-Transform-Spectrometer. We used an array of 2 junctions in a log-periodic antenna each coupled to one stub. Multiple resonances (Fig. 1) up to the gap frequency of Nb were detected. The solid line Fig. 1 shows the result for an all-Nb microstrip and the dashed line for the same geometry but with a upper conductor out of gold instead. For better comparison the curves in Fig. 1 are fitted to at the same height in the first resonance. The splitting of the first resonance of the Nb-line is presumably due to unsymmetry in the junction sizes or widths of the microstrip lines.

These measurements show again that the conductivity of Niobium is superior than of gold for frequencies below 700 GHz. The lower conductivity of gold results in a more washed out shape of the resonances in Fig. 1. There is an offset in the minima and the maxima of the gold measurements does not reach the same height as in the Nb measurements.

We made also calculations to model the measurements of Fig. 1. They are based on the Mattis-Bardeen theory (MB-theory) for the conductivity of the Nb-films and formulas of Kautz and Matick for the performance of superconducting and normal conducting striplines. They also includes terms out of Tuckers theory for the video response for the detector. The comparison of the Nb case and the calculations shows good agreement of measurements and theory in the frequency dependence of the resonances. That means the dispersion of the line and the general shape of the sensitivity. Nevertheless there is a significant difference in the height of the resonances which is increasing to higher frequencies. This is presumably due to radiation losses of the microstrip or to losses in the dielectric (sputtered SiO_2) which separates the upper and lower conductor. A more detailed discussion can be found in [3].

These results fit very well with the common picture of the conductivity of gold and Nb at high frequencies. Fig. 2 shows the calculated attenuation of superconducting striplines (MB-theory) out of Nb and NbN based on literature values for the conductivity. We measured the DC-conductivity of sputtered gold films as those used in the FTS-measurements and calculated the high frequency performance of such a stripline shown in Fig. 2. Due to our production process the conductivity of gold is less than in literature. Nevertheless there will be a clear advantage in the use of gold or other good conductors like copper for antennas and transmissionlines at frequencies above ~ 670 GHz.

Gold Antennas

The discussion in the chapter before has led us to the development of SIS-mixers with gold antennas and microstrips for frequencies above 700 GHz. As shown in Fig. 3 two small pads of trilayer are deposited on one side of the antenna for the SIS-junction and the lumped capacitor. The actual size of those is defined by two (smaller) windows in the SiO_2. The wiring layer with the other half of the antenna is deposited on top of that. Fig. 4 shows the cross-section with upper and lower conductor out of gold and in-between the trilayer with the junction in the middle. A new recipe has had to be developed for the production of these devices. First results are very promising. Measurements of the DC-IV-curves show clearly self-resonant steps at around 700 GHz.

Resonances above the Gap

Besides the development of the gold devices we are still investigating in all-Nb elements. We have been able to obtain for the first time second harmonic resonances of several devices above the gap frequency of Nb. An example for a lumped element tuning circuit (like in Fig. 3) is shown in Fig. 5 with the second resonance at 830 GHz. The dip at 560 GHz in the first resonance is due to an absorbing waterline since the FTS was not evaporated. The dashed line shows the probable shape of the resonance without waterline.

Video and Heterodyne Response above 700 GHz

Since there was no device available with a first resonance peak above 700 GHz we investigated in measurements of the video and heterodyne response of the device shown in Fig. 5. The experimental setup is shown in Fig. 6. We used a carcinotron with a frequency range from 830-930 GHz as local oscillator. The radiation from the hot/cold load (300 K / 77 K) was coupled into the cryostat by means of a 60 μm thick mylar beamsplitter. Two lenses focused the radiation of the carcinotron on a hemispherical lens. The antenna was mounted on the back side of the hemispherical lens with a quarter-lambda thick metalized plate on the back as reflector. A more detailed description of the receiver setup is given by [1,4].

We measured the video response of to different devices at frequencies ranging from 700 GHz to 900 GHz. Fig. 7 and 8 show the video response at 720 GHz and 830 GHz, respectively. We used a 350 GHz carcinotron together with a doubler for the measurements at 720 GHz. The device measured in Fig. 7 shows a much higher leakage current than that shown in Fig. 8, which is the same as in Fig. 5 and 9. The measurements were hardly influenced by the Josephson effect, although we could not suppress it completely. At 720 GHz the width of the responsivity steps in the subgap is already smaller than the width of one photon step hf/e. This is due to the interfering effect of the photon steps from the positive and negative parts of the IV-curve at zero volt. This effect is much more severe at 830 GHz (Fig. 8).

First measurements of the heterodyne response were done at frequencies between 830 GHz and 890 GHz. The best performance was obtained at 830 GHz. Fig. 9 shows the hot/cold response of the IF-line at 830 GHz together with the pumped DC-IV curve. The best hot/cold response was measured at about 1.4 mV. The shape of the IF-curve here is reasonable good. At the lower end this region is limited by the self-resonant step at ~ 1 mV and at the upper end through the AC-Josephson effect at ~ 1.8 mV that could not be completely suppressed. The structure below 1 mV is due to the interfering effect of photon steps of the positive and negative part of the IV-curve.

The junction area was 1.75 μm^2 and the normal resistance R_N=16 Ω. The best measured Y-factor was Y=1.1 dB. Assuming heterodyne response, this would correspond to a receiver noise temperature of T_{DSB}~670 K. This is not corrected for losses due to the 60 μm thick mylar beamsplitter which has a transmission of about 60%. The hot and cold load was assumed to be 300 K and 77 K, respectively. The video response of the unpumped junction was 0.3 dB at the same bias point.

These very first results of heterodyne and video experiments at frequencies above the gap frequency of Nb are very promising, although the interpretation is not yet clear. More work has to be done to verify and analyze the quasiparticle heterodyne response, e.g. with line measurements, and distinguish the quasiparticle heterodyne detection from Josephson and video effects.

Conclusions

Resonances of all-Nb and mixed Nb-gold open-ended stubs were measured up to the gap frequency. Calculations based on the Mattis-Bardeen theory agree fairly good with the measurements. Differences in the height of the resonances at higher frequencies are probably due to losses in the sputtered SiO_2 or to radiation losses of the microstrip.

For mixers above the gap frequencies a new sort of devices with gold antennas were developed. DC-IV curves from first devices show self-resonant steps at ~ 700 GHz.

Measurements of all-Nb elements were performed at frequencies above 700 GHz. FTS measurements of several devices show 2. resonances of the tuning structures at frequencies between 800 and 1000 GHz. We measured a possible heterodyne response due to a hot/cold load of Y=1.1 dB at 830 GHz. Assuming a quasiparticle heterodyne response this would correspond to a receiver noise temperature of T_{DSB}=670 K The video response for the unpumped junction was 0.3 dB. Further analysis has to be done.

Acknowledgments

This work was supported by the European Space Agency under contract No. 7898/88/NL/PB(SC), the Stichting Technische Wetenschappen and the Stichting voor Fundamenteel Onderzoek der Materie. We acknowledge the assistance of H. Golstein, H. Schaffer and J. Wezelman for helpful discussions and in the preparation of the experiments.

References

[1] A. Skalare, H. van de Stadt, Th. de Graauw, R.A. Panhuyzen, and M.M.T.M. Dierichs, 3. International Symposium Space TeraHertz Technology (1992)

[2] A. Skalare, H. van de Stadt, Th. de Graauw, Microwave and Optical Letters, Vol. 4(1), (1991)

[3] M.M.T.M. Dierichs, C.E. Honingh, R.A. Panhuyzen, B.J. Feenstra, A. Skalare, J.J. Wijnbergen, H. van de Stadt, Th. de Graauw, IEEE Trans. Microwave Theory Tech., to be published in March 1993.

[4] A. Skalare, M.M.T.M. Dierichs, J. Mees, H. van de Stadt, R.A. Panhuyzen, Th. de Graauw, T.M. Klapwijk, 4. International Symposium Space TeraHertz Technology (1993)

Figure Captions

Fig. 1: Measured resonances of a series of 2 SIS-junctions coupled to an open-ended stub each: a) upper and lower conductor are Nb and b) upper conductor is gold.

Fig. 2: Calculated attenuation (MB-theory) of microstrips out of Nb and NbN. The dashed line represents calculations for a line completely out of gold based on measurements of the DC-conductivity of sputtered films.

Fig. 3: The geometry of the gold antennas

Fig. 4: Cross-section of the new devices. The trilayer with the SIS-junctions is shown in the middle.

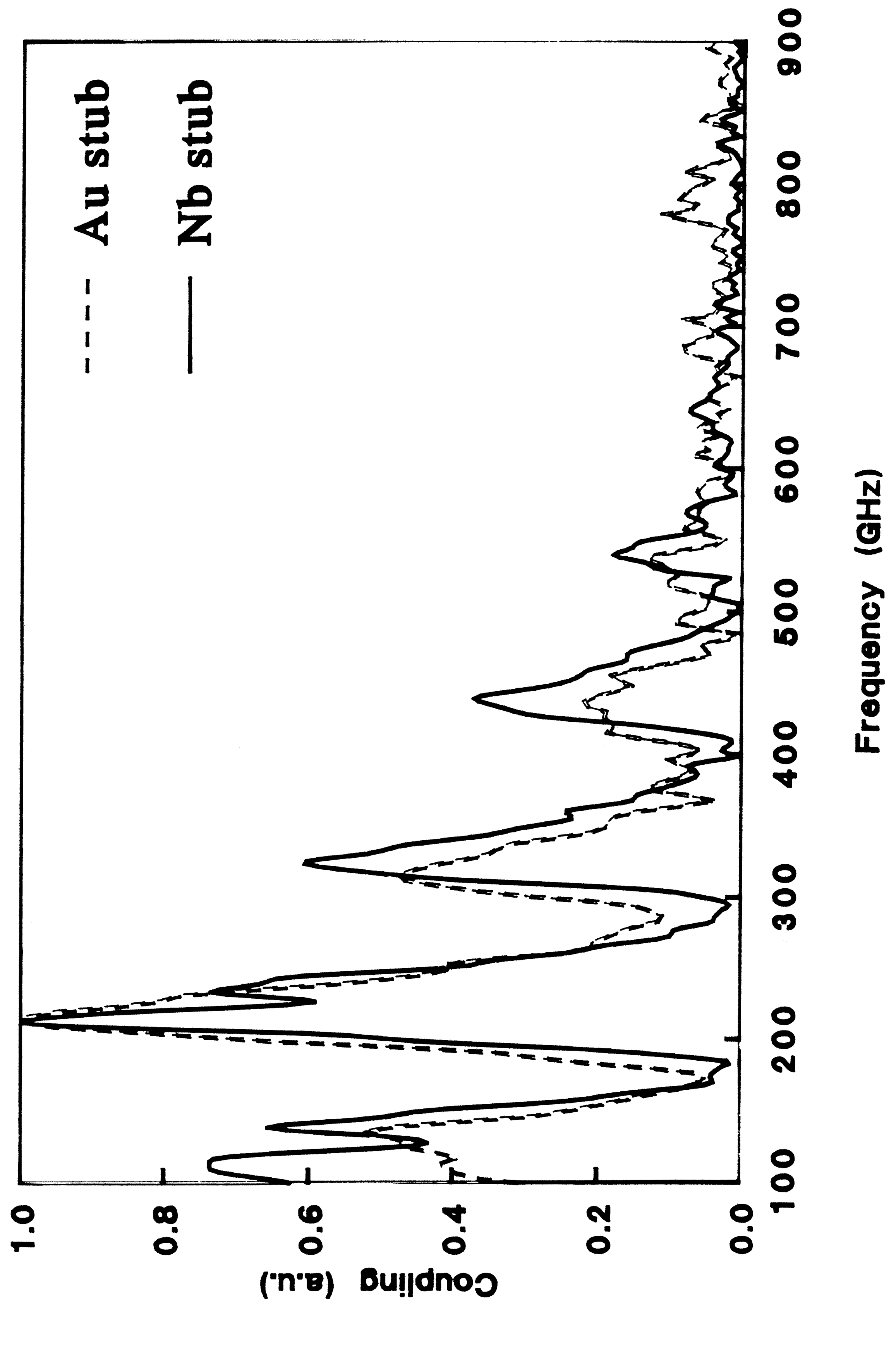
Fig. 5: The Fourier-Transform-Spectrum of a lumped element circuit shows the rf-coupling of the junction to the antenna. The second resonant peak at ~ 830 GHz was used for video and heterodyne measurements.

Fig. 6: Experimental setup for video and heterodyne measurements.

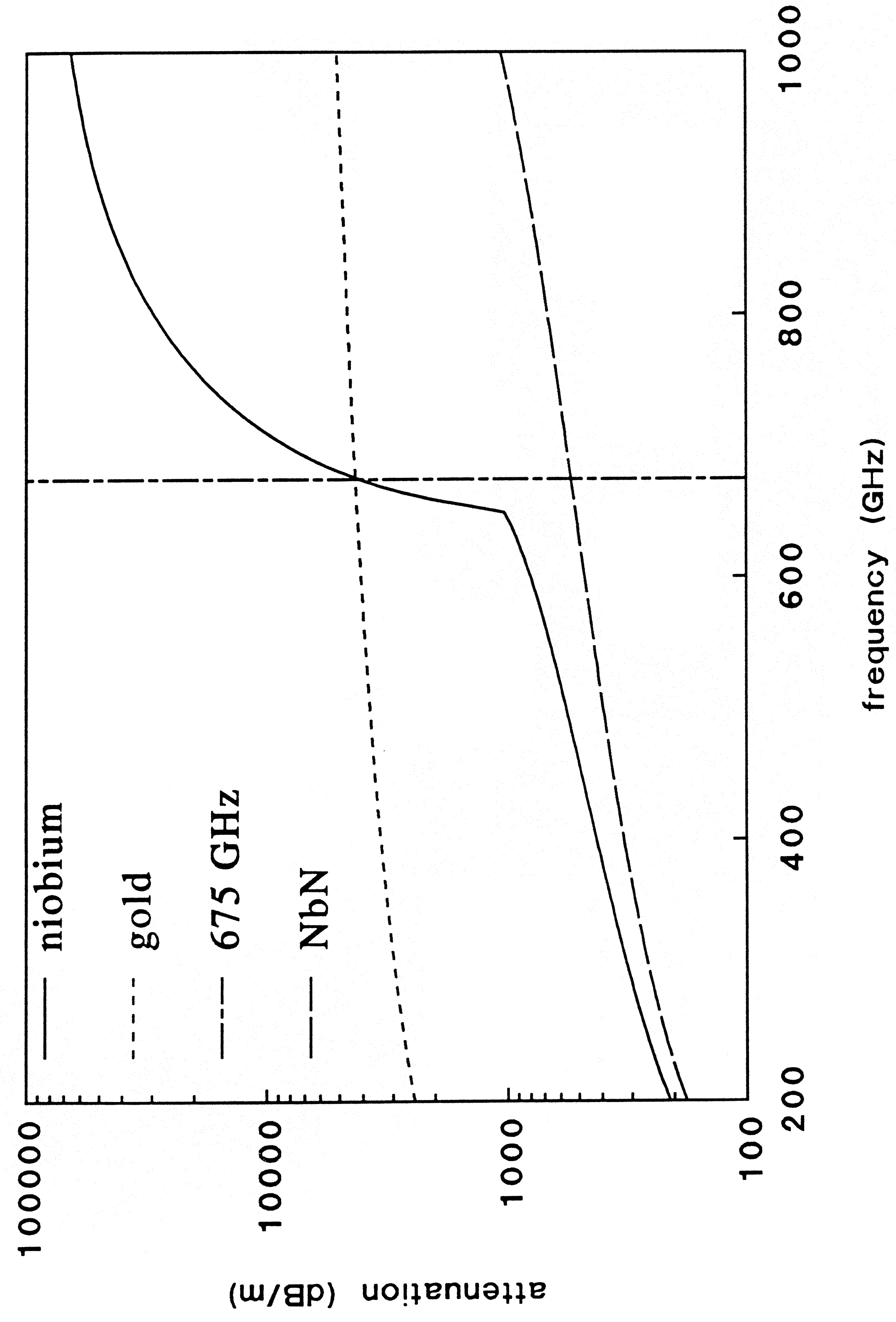
Fig. 7: Video response at 720 GHz. (Different device with a higher leakage current than that in Fig. 5, 8 and 9)

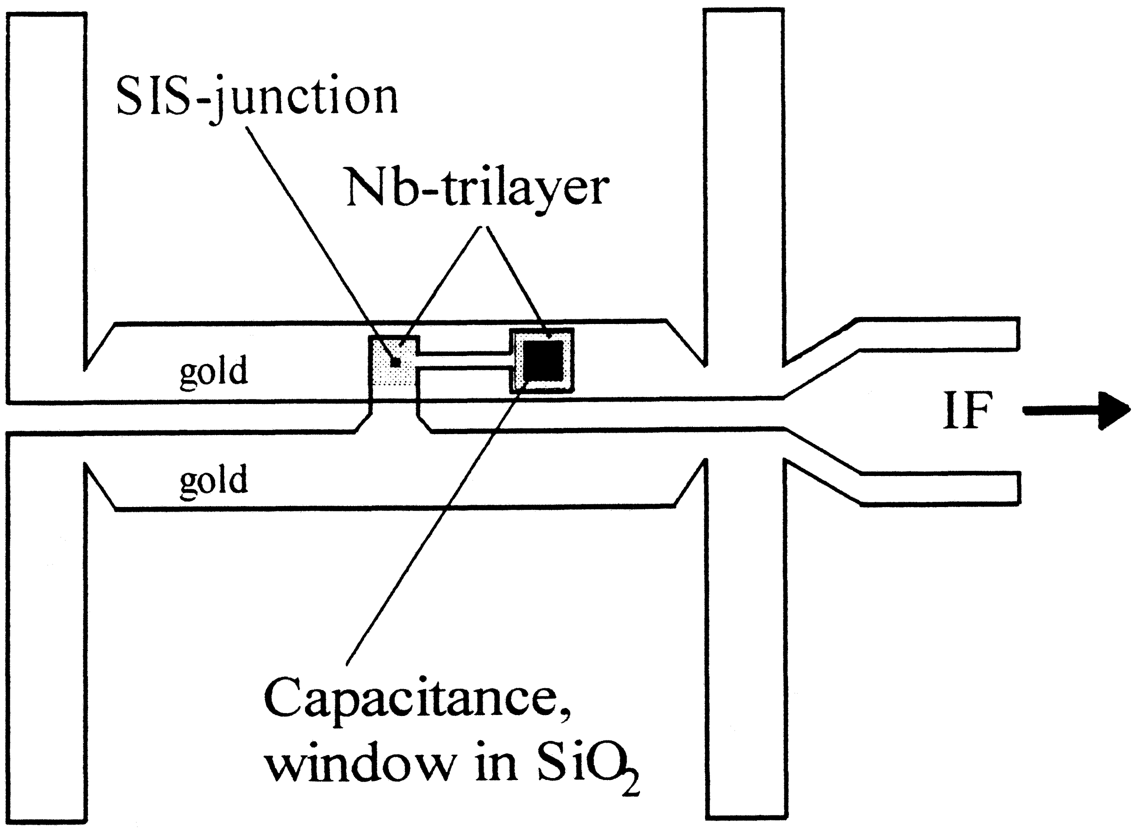
Fig. 8: Video response at 830 GHz. (Same device than in Fig. 5)

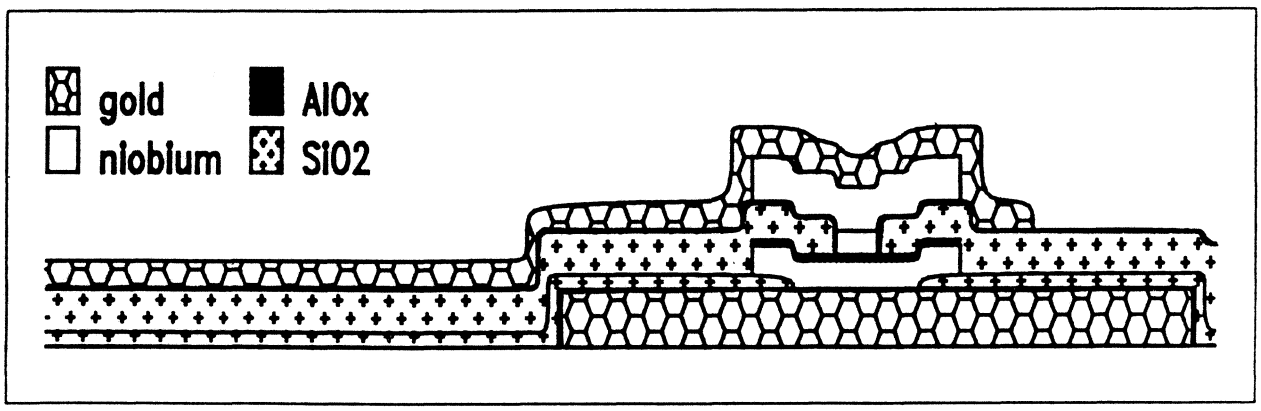
Fig. 9: Hot/cold response of a pumped junction at 830 GHz. The Josephson effect at ~ 1.75 mV could not be suppressed completely. Also visible is the self-resonance at ~ 1 mV, corresponding to the first resonance at ~ 510 GHz. (Same device than in Fig. 5)



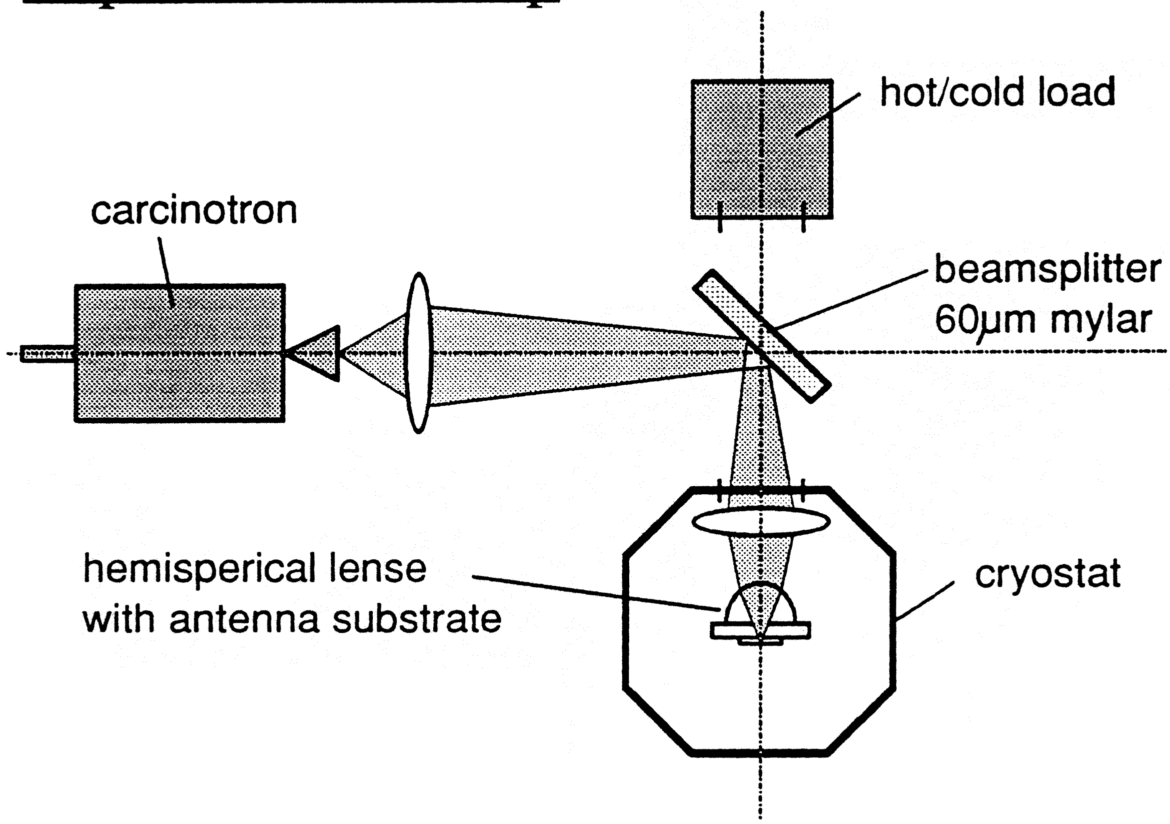
Au stub
Nb stub
Coupling (a.u.)
0.0
0.2
0.4
0.6
0.8
1.0
Frequency (GHz)
100
200
300
400
500
600
700
800
900

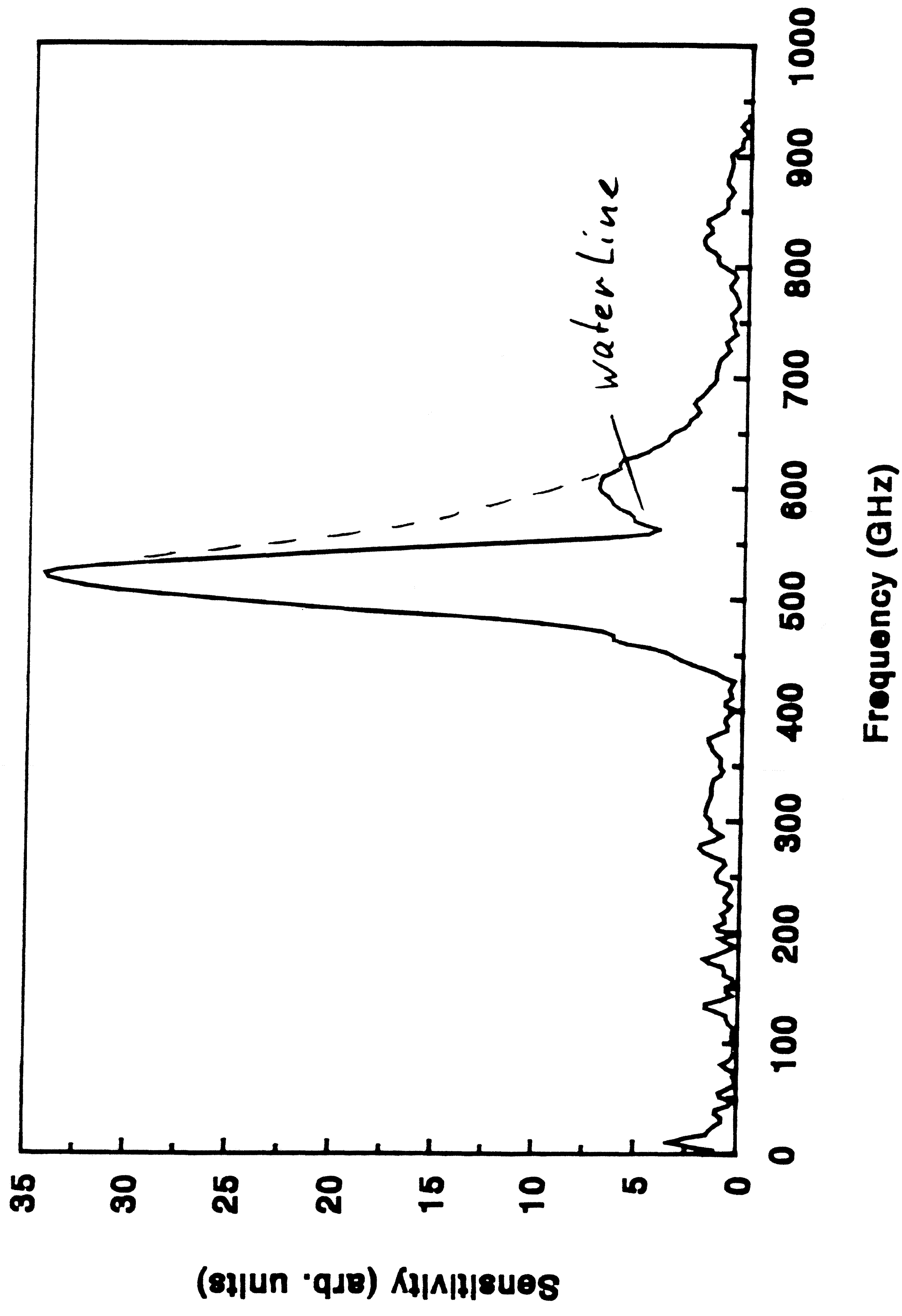

niobium
gold
675 GHz
NbN
frequency (GHz)
attenuation (dB/m)
200
400
600
800
1000
100
1000
10000
100000

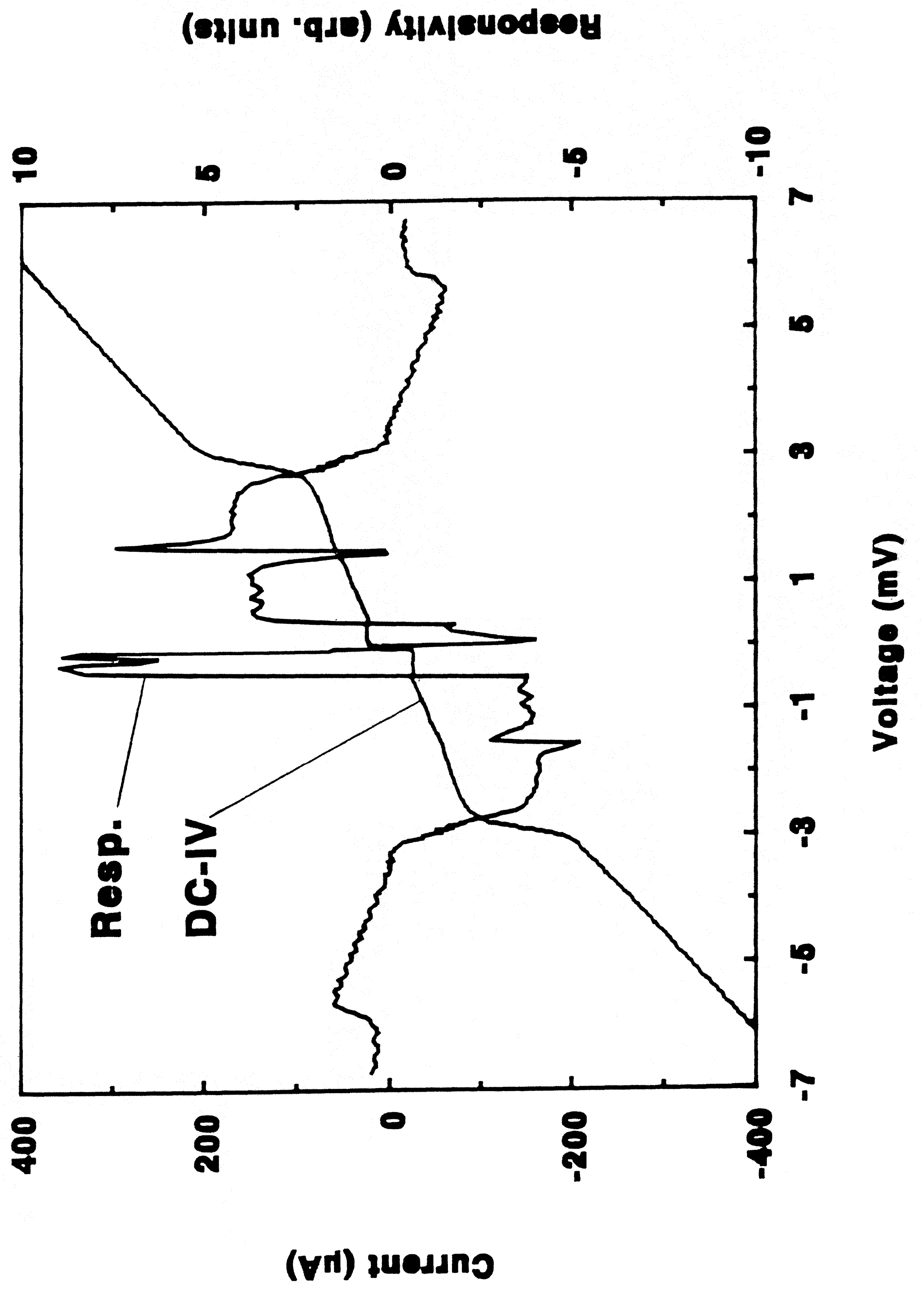

SIS-junction
Nb-trilayer
gold
gold
IF
Capacitance,
window in SiO_2

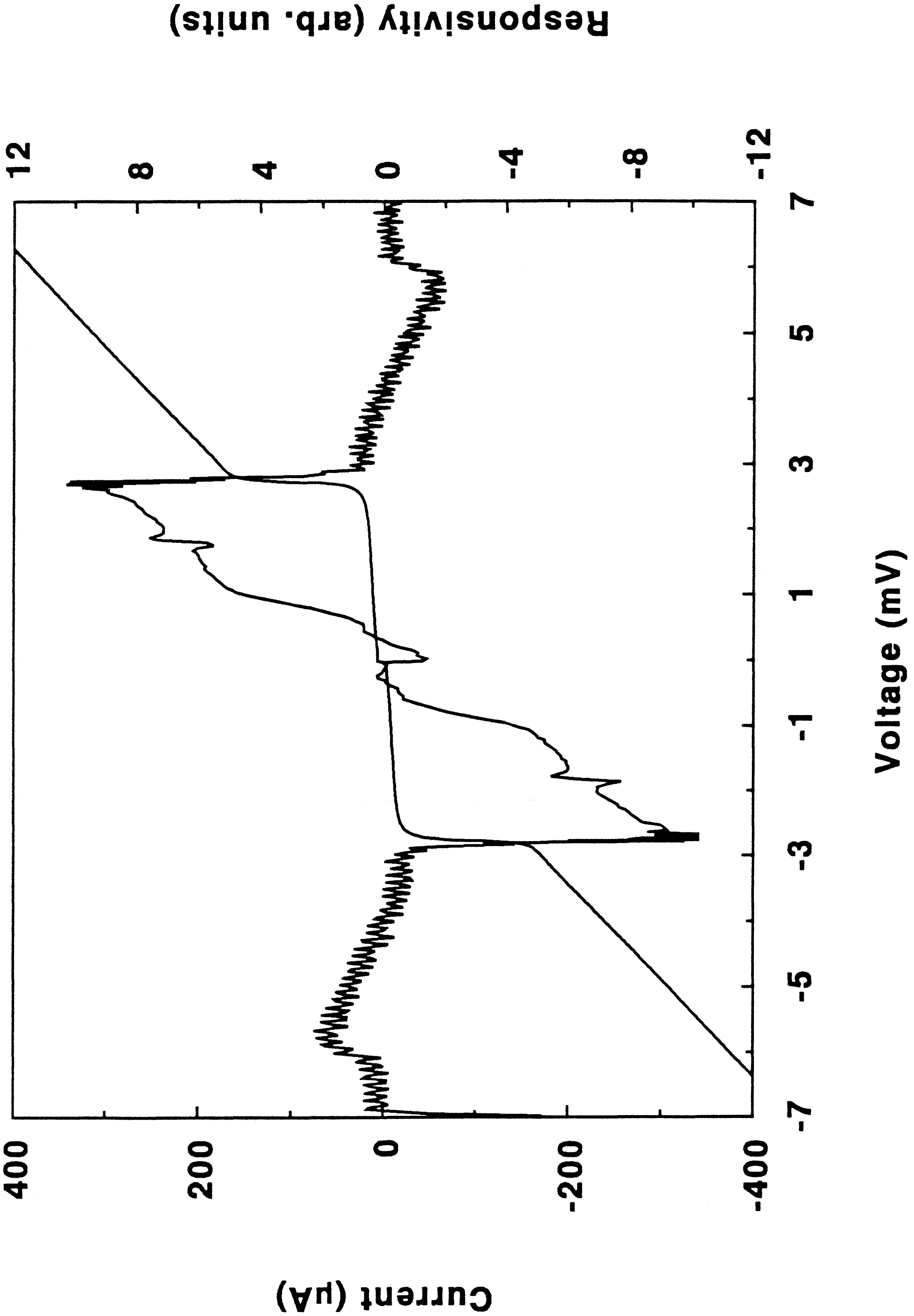

gold
AlOx
niobium
SiO2

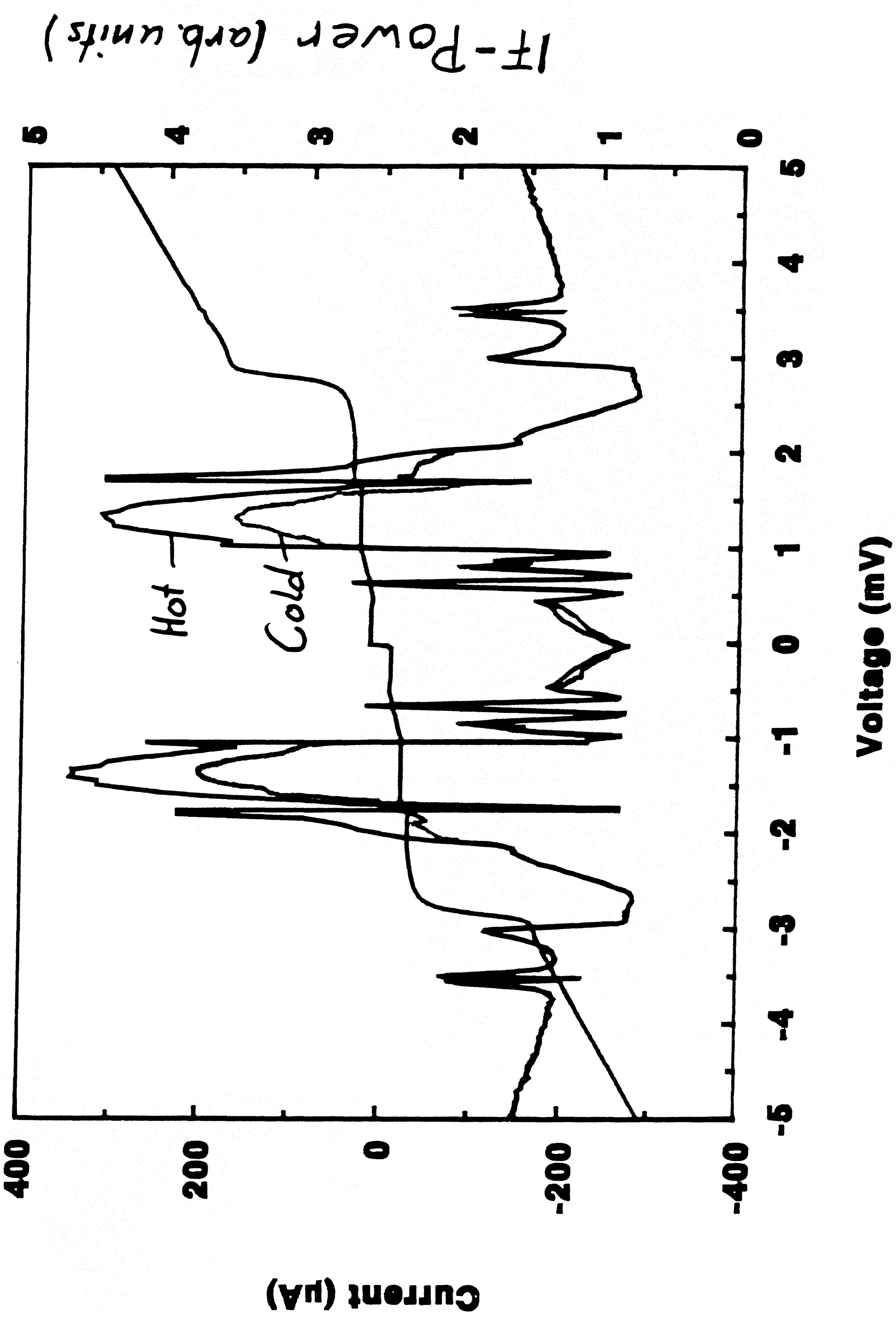
Experimental Setup




Sensitivity (arb. units)
Frequency (GHz)
water Line
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
700
800
900
1000


Responsivity (arb. units)
10
5
0
-5
-10
400
200
0
-200
-400
Current (µA)
-7
-5
-3
-1
1
3
5
7
Voltage (mV)
Resp.
DC-IV


Responsivity (arb. units)
12
8
4
0
-4
-8
-12
400
200
0
-200
-400
Current (μA)
-7
-5
-3
-1
1
3
5
7
Voltage (mV)


IF-Power (arb. units)
Hot
Cold
Voltage (mV)
Current (μA)
400
200
0
-200
-400
-5
-4
-3
-2
-1
0
1
2
3
4
5