A low noise 410-495 heterodyne two tuner mixer, using submicron $Nb/Al_2O_3/Nb$ Tunneljunctions

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A 410-495 GHz Heterodyne receiver, with an array of two $Nb/Al_2O_3/Nb$ tunneljunctions as mixing element is described. The noise temperature of this receiver is below 230 K (DSB) over the whole frequency range, and has lowest values of 160 K in the 435-460 GHz range. The calculated DSB mixergain over the whole frequency range varies from -11.9 ± 0.6 dB to -12.6 ± 0.6 dB and the mixer noise is 90 ± 30 K.

Introduction

SIS-mixers are currently being used as heterodyne receivers up to submillimeter wavelengths [1][2]. Two different types of mixers are used to achieve low noise receivers: quasi-optical mixers, with a fixed tuned broadband planar antenna, and waveguide mixers, with one or two tuning elements.

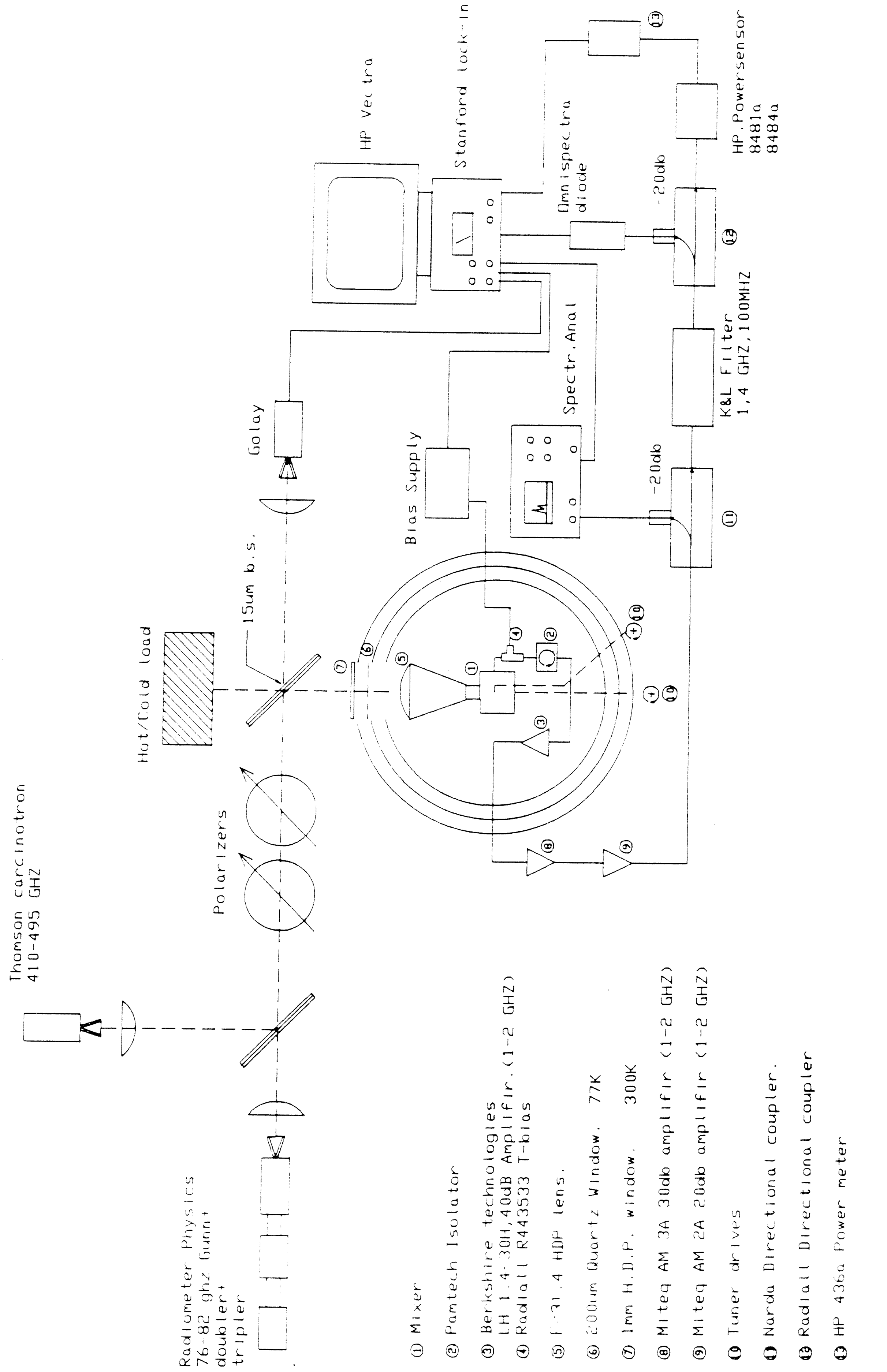
In this paper a two tuner waveguide mixer designed for the 400-500 GHz range is described. The used mixing elements are two different arrays of two $Nb/Al_2O_3/Nb$ tunneljunctions. This mixer is the second frequency step towards our goal to make a THz receiver (350-490-750-1000 GHz). At these high frequencies the dimensions of a waveguide structure become very small (100-400 μm) and it is unclear how far losses due to surface irregularities deteriorate the mixer performance.

The laboratory tests of the mixer show that in the 400 to 500 GHz frequency range, waveguide mixers can still achieve low noise temperatures (as low as 160 K DSB), and the flat response over the band indicates that the current design can be scaled up to higher frequencies.

The behaviour of SIS-mixers is well described by theory [3][4]. An extensive comparison between theory and measurements has been performed at 345 GHz [5] and this comparison is started in the 410-490 GHz range. First results show a good agreement between calculated and measured IV-curves, from which the electromagnetic environment of the junction is deduced.
This paper describes the design of the mixer, the results from the two different arrays of junctions and some preliminary analysis of the mixer performance.

Receiver design

The mixer block design for 400-500 GHz is a scaled version of the 345 GHz mixer described by Honingh et al.[6].
The mixer system is placed inside an Infrared Laboratories HD 3 cryostat. The signal and LO-power enter the cryostat via a 1 mm thick HDP window of 3 cm diameter. On the 77 K radiation shield a 200 μm thick quartz plate serves as heat filter.
A diagonal horn with an aperture size of 4.5 mm, a length of 12 mm and a flare angle of 11 degrees is used. Laboratory tests of this horn showed a good gaussian beam-coupling (side lobes <-15db), equal beamwidth in E-,D- and H- planes and a low cross-polarisation (<-15 dB). In front of the horn a F=31.4 mm HDP lens is used. The lens is mounted in a holder which can be directly mounted on the mixerblock. The mixerblock is cut in OFHC. The full height waveguide with dimensions 0.44*0.22 mm, has a cut off frequency of 340 GHz. The waveguide system has two moving shorts as tuning elements, each with a quarter wave choke section to improve the quality of the short. In order to suppress the Josephson currents in the junction, a coil with 10.000 turns of 0.1 mm Nb wire is placed around the horn, in front of the mixerblock. The IF-chain consists of a Radiall R443533 T-bias, a Pamtech LTE 1290 isolator and a Berkshire Technologies L-1.4-30H IF-amplifier.


Radiometer Physics
76-82 ghz Gunn+
doubler+
tripler
Thomson carcinotron
410-495 GHZ
Polarizers
Hot/Cold load
15um b.s.
Golay
HP Vectra
Stanford lock-in
Bias Supply
Spectr. Anal
Omnispectra
diode
-20db
-20db
K&L Filter
1,4 GHZ,100MHZ
HP. Powersensor
8481a
8484a
1 Mixer
2 Pamtech Isolator
3 Berkshire technologies
LH 1.4-30H,40dB Amplifir. (1-2 GHZ)
4 Radiall R443533 T-bias
5 F:31.4 HDP lens.
6 200um Quartz Window. 77K
7 1mm H.D.P. window. 300K
8 Miteq AM 3A 30db amplifir (1-2 GHZ)
9 Miteq AM 2A 20db amplifir (1-2 GHZ)
10 Tuner drives
11 Narda Directional coupler.
12 Radiall Directional coupler
13 HP 436a Power meter

SIS-junctions

The fabrication of the used junction arrays, is described elsewhere [7]. Up to now two different types of arrays have been used. The arrays differ in junction area, current density, RF-filterstructure and gapvoltage. An overview is given in table 1.

Junction array	Q34	Q35
A (1 junction) (μm^2)	0.8	2
I_c (A/cm^2)	7000	12.000
R_n (Ω)	100	22
RF-filter	Chebychev	¼ λ
Gap-voltage (mV)	2.7	2.4

Table 1. Overview of the 2 different junction arrays.

The lower gapvoltage of junctions Q35 is caused by a higher oxygen background pressure during sputter deposition of the trilayer.

Measurement set-up

A schematic diagram of the measurement set-up is given in Fig. 1. The use of two coherent sources, in combination with a spectrum analyser allow to analyse the mixer performance at the LO and the upper and lower sideband frequencies. In the measurements the carcinotron acted as LO-source.

The noise temperature of the mixer was measured by using the well known "Y-factor" method. The measurements were corrected for the loss of the beamsplitter (15 μm mylar, 95% transmission).

Results

The DSB noise temperature of the receiver is shown in Fig. 2 for two different junction arrays. Array Q34 (Rn = 100 Ω, A = 0.8 μm^2, Chebychev RF-filter) has noise temperatures below 230 K over the whole 410-495 GHz range. The lowest value measured was 160 K at 445 GHz. Array Q35 (Rn = 22 Ω, 2 μm^2 ,1/4 λ RF-filter) has noise temperatures between 260 K to 220 K in the frequency range 445-495 GHz. The noise temperature increases sharply below 445 GHz, due to leakage of the RF-filter.

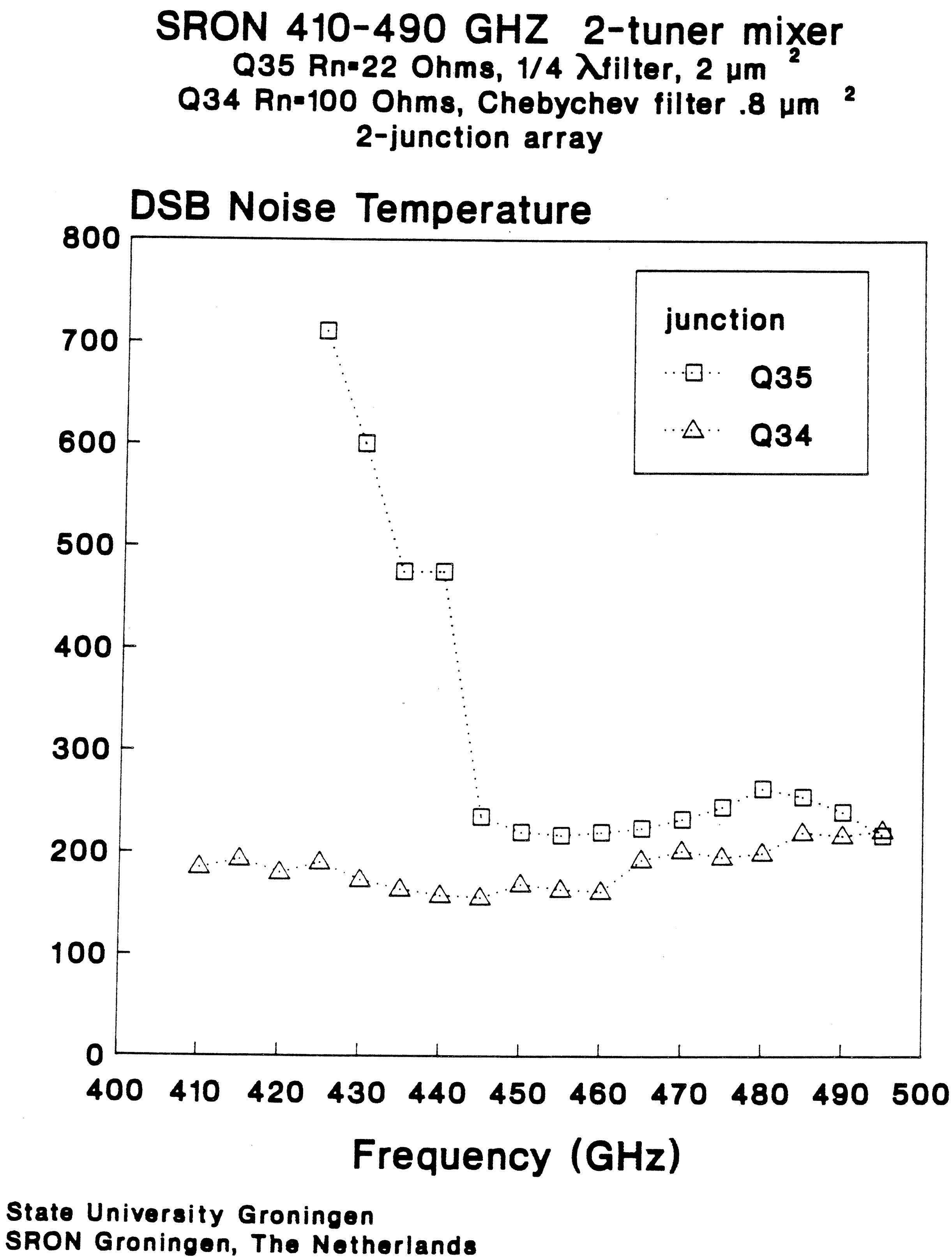

SRON 410-490 GHZ 2-tuner mixer
Q35 Rn=22 Ohms, 1/4 λ filter, 2 μm²
Q34 Rn=100 Ohms, Chebychev filter .8 μm²
2-junction array
DSB Noise Temperature
800
700
600
500
400
300
200
100
0
400 410 420 430 440 450 460 470 480 490 500
Frequency (GHz)
junction
Q35
Q34
State University Groningen
SRON Groningen, The Netherlands

Fig. 2

SRON 490 GHZ 2-tuner mixer
Tuned and instantaneous bandwidth
Q34 Rn=100 Ohms ,Chebychev-filter

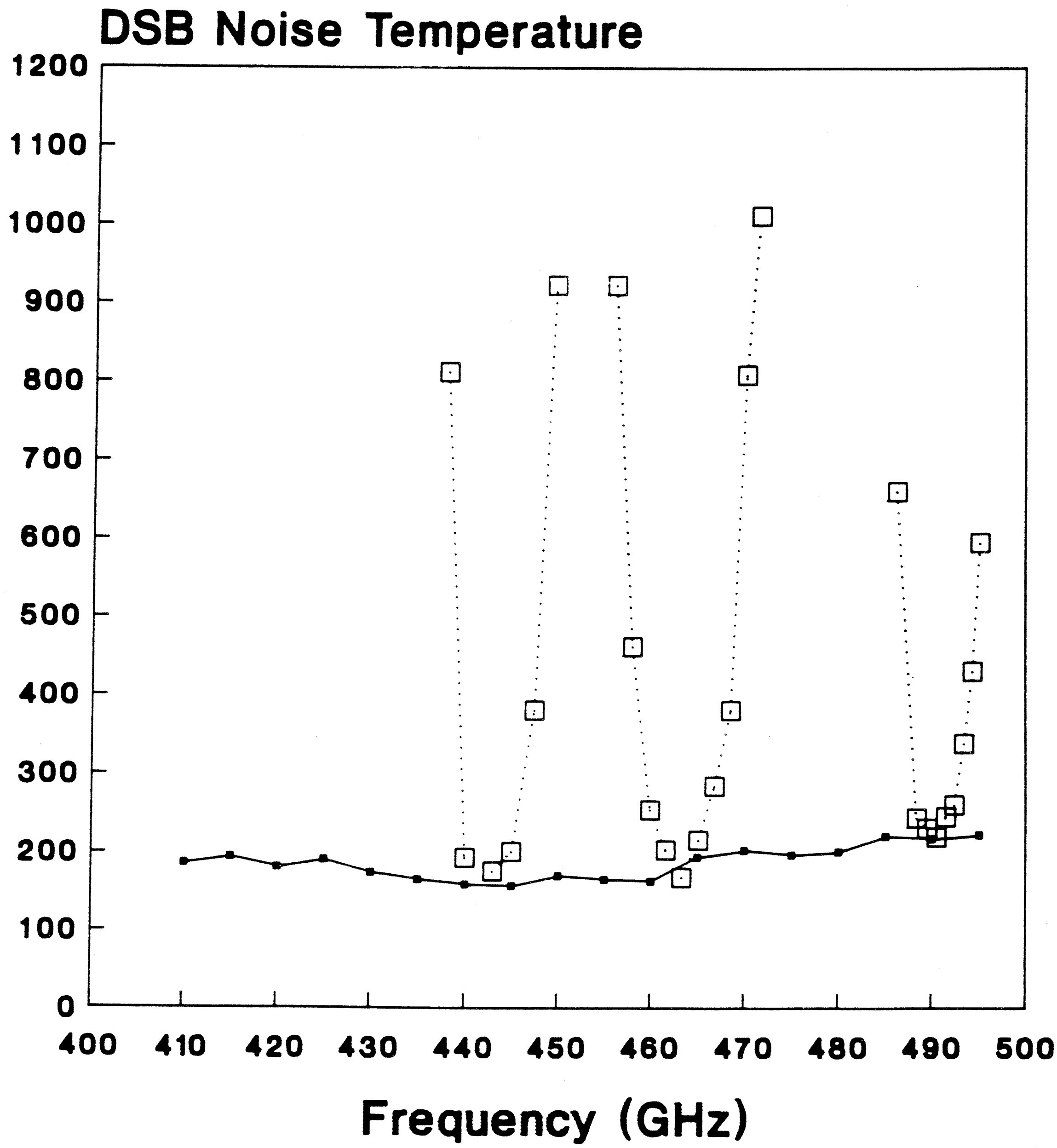


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Fig. 3

The instantaneous bandwidth of junction Q34 is shown in Fig. 3. Here the frequency was changed without adjusting the tuners, only the pump power was adjusted for optimum H/C response.

The unpumped and pumped IV-curves of the two arrays at two different frequencies are shown in Fig. 4. Array Q34 has a low leakage current, a gap voltage of 2.7 mV (1 junction) and a well defined photon step above the gap. The gap voltage of array Q35 is 2.4 mV and it is clearly observed that if the LO-power is radiated on the junction the gap voltage decreases due to heating. The shape of the photon step above the gap also indicates heating effects occur in the junction.

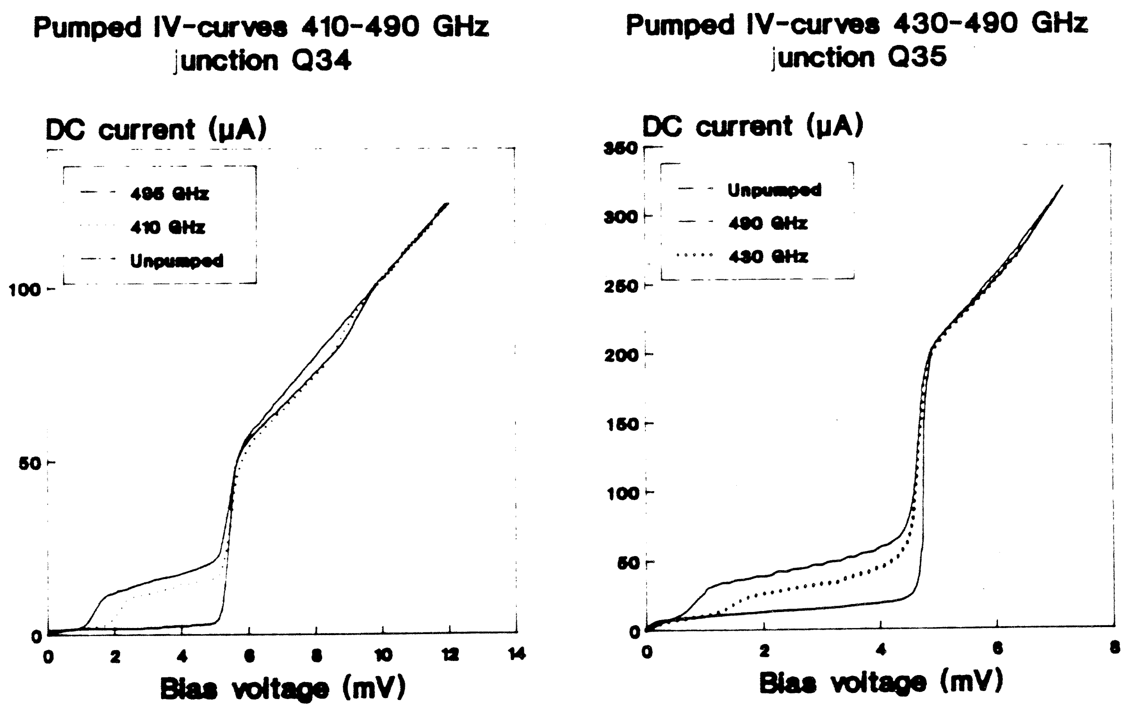


Fig. 4 Pumped and unpumped IV-curves of the two junction arrays

Fig. 5 shows the IF power output at two LO-frequencies, when a hot or cold load are placed in front of the junction. The smooth curves indicate that the Josephson current is suppressed sufficiently. The structure (at 3 mV) in the IF-output seen at 495 GHz is due to the fact that the second photonstep from the negative bias voltage range "creeps" into the first photonstep at the positive voltage range.

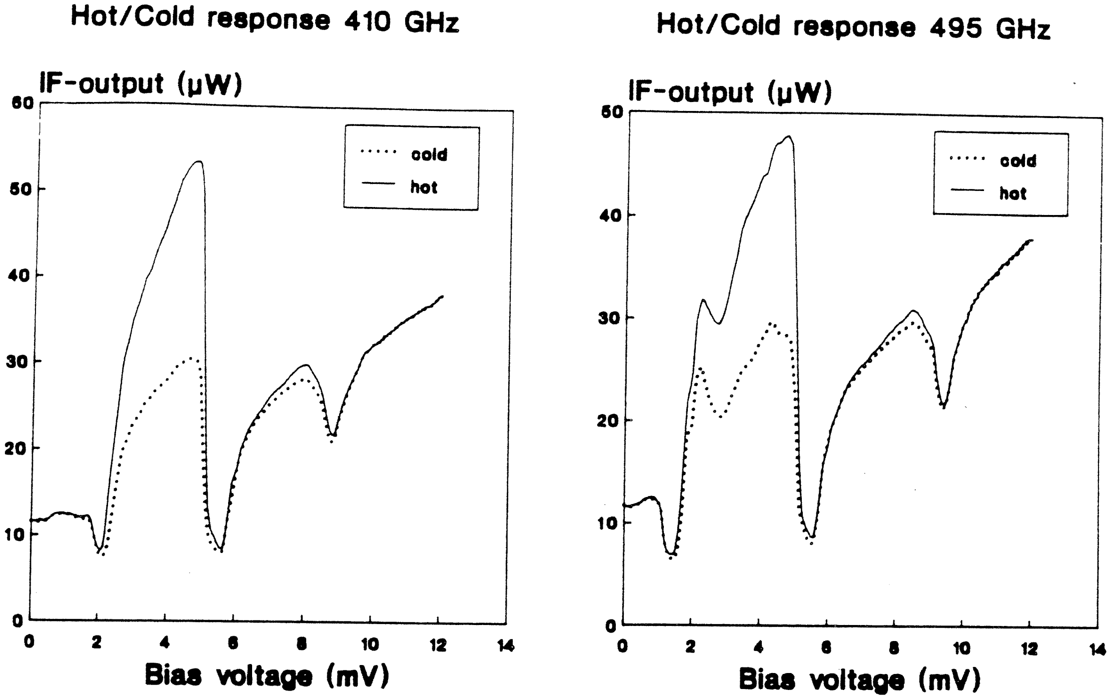


Fig. 5 IF-output with hot and cold signal

Analysis

In the analysis of the noise temperatures, the receiver is divided into three elements: the RF-input, the mixer and the IF-output. A schematic diagram of the whole receiver is given in Fig. 6. Each of these elements contributes to the total receiever noise and gain.

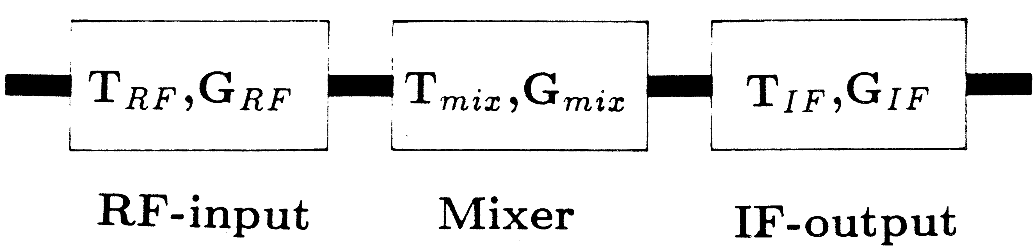


Fig. 6 Schematic representation of the noise and gain contributions in the receiver

For the analysis of the contribution of the IF chain (T-bias, isolator, IF-amplifiers), the shotnoise of an unpumped junction is used. With the known shotnoise of an unpumped junction a Y-factor measurement on the IF-chain is performed. The total power at the end of the IF-chain is given by (1). Here Γ is the reflection coefficient between the 50 Ω line and the junction. P_{junc},P_{isol} and P_{IF} are the noise powers coming from the junction, the isolator load and the IF-amplifier. G_{IF},G_{isol} and G_{T-bias} are the gains from the various components. The noisepower from an unpumped array of two junctions is given by (2), where B is the bandwidth, R_{dyn} is the dynamic resistance of the array and V is the voltage over the entire array.

$$P_{out} = (P_{junc}\Gamma + P_{isol}(1-\Gamma) + \frac{P_{IF}}{G_{isol}G_{T-bias}})G_{IF}G_{isol}G_{T-bias} \qquad (1)$$

$$P_{junc} = \frac{1}{8} < I_0^2 > R_{dyn} = \frac{1}{8} 2eB\coth(\frac{eV}{4k_BT})I(V)R_{dyn} \qquad (2)$$

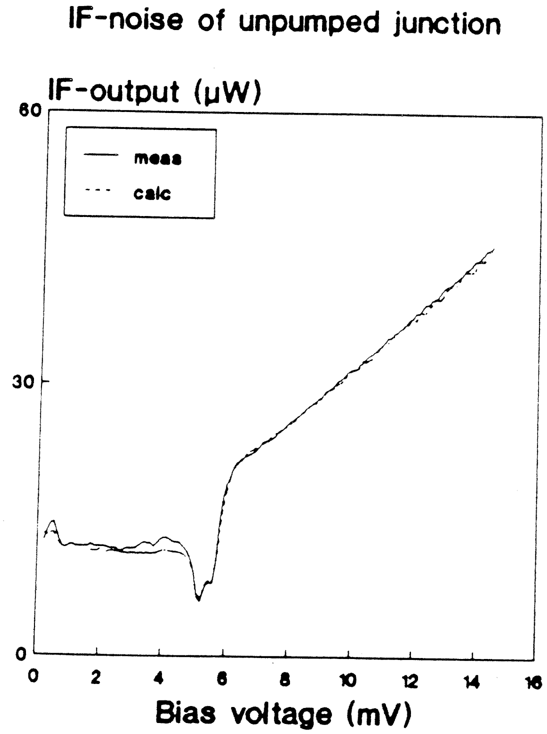
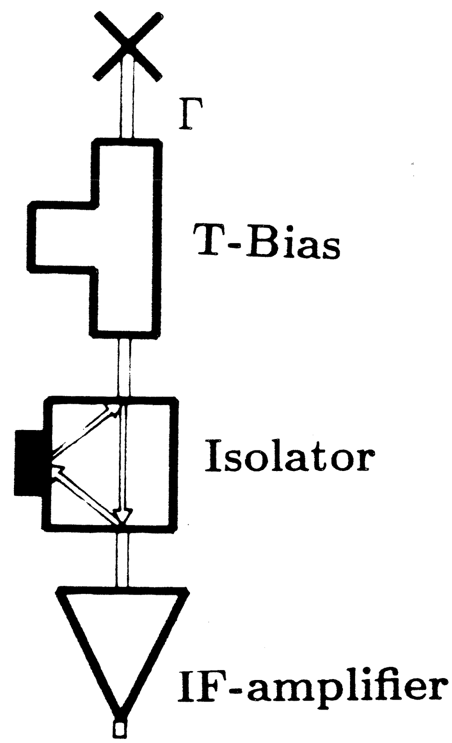


Fig. 7 Measured and calculated noisepower output of an unpumped array of two junctions



Schematic Diagram of junction and IF-chain

Fig. 7 shows the experimental and fitted curves. The values for the gain and noise contributions of the IF-chain are: G_{IF}=88.4 ± 0.1 dB, T_{IF}=4.8 ± 0.2 K.

The gain and noise contributions of the RF input (beamsplitter, HDP-window, quartz-filter, lens, horn, waveguide and tuners) are difficult to estimate. Several elements were measured seperately, but reflections at the horn waveguide transition and losses in the waveguide and the two tuners are difficult to find. The total gain and noise at the RF-input are: G_{RF}=0.77 ± 0.1 and T_{RF}=56 ± 20 K.

The mixer noise and gain are now calculated with (3) and (4), where δP_{out} is measured power difference at the IF-frequency and δP_{in} is the difference in input power from the hot and the cold load. T_{rec} is the measured total receiver noise temperature.

$$G_{mix} = \frac{\delta P_{out}}{G_{RF} G_{IF} \delta P_{in}} \tag{3}$$

$$T_{mix} = T_{rec} G_{RF} - T_{RF} G_{RF} - \frac{T_{IF}}{G_{mix}} \tag{4}$$

The gain and noise of the mixer are, just as the receiver noise temperature, nearly constant over the 400-500 GHz band. Typical values for the contributions in the receiver DSB gain and noise are: G_{mix}= -12.5 dB ± 0.6 dB and T_{mix}= 90 ± 30 K.

For a complete calculation of the mixer performance it is necessary to know the embedding admittances at the LO and the upper and lower sideband frequencies. These admittances are found by fitting a calculated pumped IV-curve to a measured pumped IV-curve. An example of the quality of this fit at two different frequencies is shown in Fig. 8.

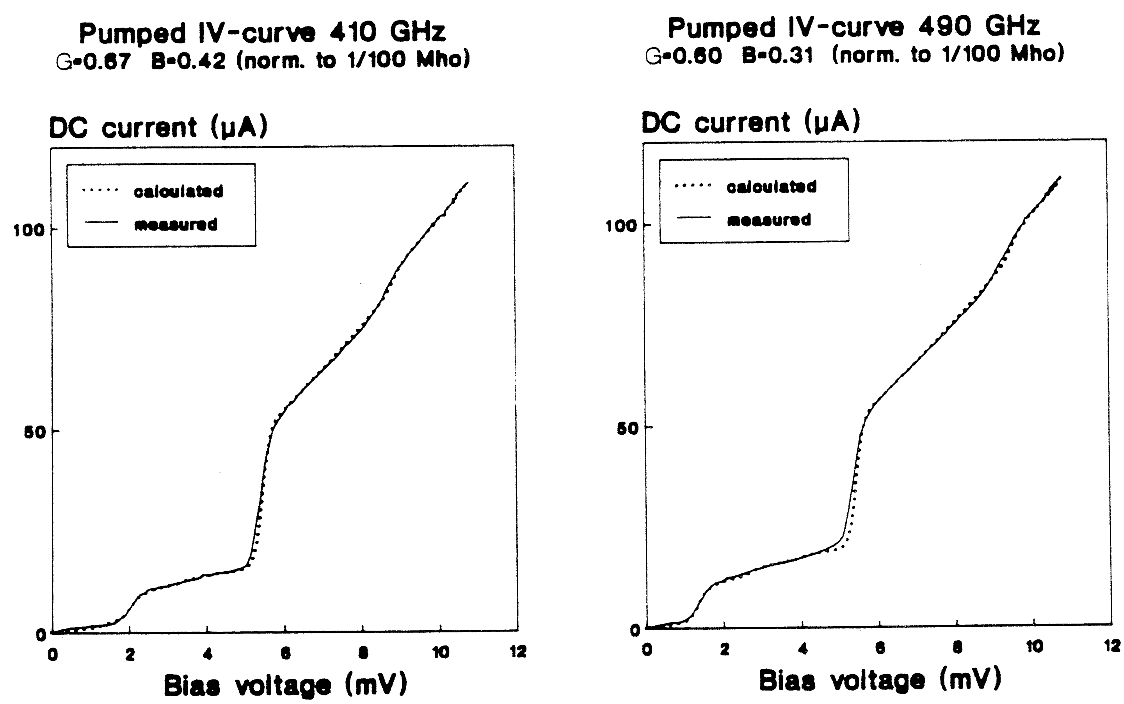


Fig. 8 Measured and calculated IV-curves. The embedding parameters are shown in the header

It is observed that the quality of the fit is good, except for the discrepancy near the gap, which is due to heating and difficult to model. The derived embedding admittances indicate that the tuning elements are able to compensate the junction capacitance. Unfortunately the sideband admittances are not yet calculated and a full analysis cannot be performed at the moment. The result of a calculation of the mixergain, under the assumption that the sideband admittances are equal to the LO-admitance, is shown in Fig. 10.

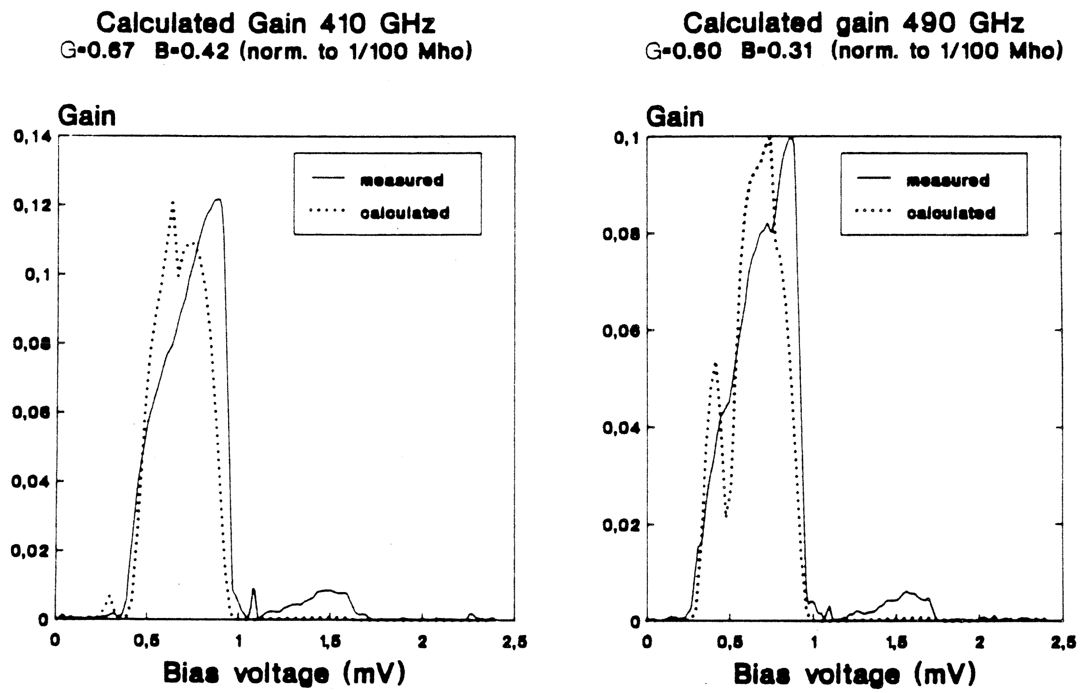


Fig. 10 Measured and calculated mixer gain

In this figure the calculated and measured gain are normalized to each other. One observes a big discrepancy between the measured and calculated gain, which indicates that the LO and sideband frequencies differ significantly.

In both the calculated and the measured gain, some fine structure on the first photonstep region is observed, indicating that the calculation method is working properly, but the input parameters are wrong.

Summary

Measurements were performed in the 400-500 GHz range with a two tuner waveguide mixer. The measured (receiver) noise temperatures are amongst the lowest values measured at these frequencies. The results show that an array of two junctions is suitable in achieving a low noise receiver in the 400-500 GHz range. It is also found that a qualitatively "bad" junction with a low gap-voltage can still serve as a low noise mixer element. The preliminary comparisons between theory and measurement show a good agreement between calculated and measured pumped IV-curves. Gain calculations indicate that the measured noise temperatures are not fully DSB measurements. Further analysis is needed to determine the USB and LSB gain and noise contributions.

Acknowledgements:
This work was supported by ESA under contract No. 7898/88/NL/PB(SC), the Stichting Technische Wetenschappen and the Stichting voor Fundamenteel Onderzoek der Materie.

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