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WIDE-BAND QUASI-OPTICAL SIS MIXERS FOR INTEGRATED RECEIVERS UP TO 1200 GHZ

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Introduction

Recently demonstrated integrated receiver [1] comprising a planar-antenna SIS mixer and a superconducting local oscillator based on FFO (Flux-Flow Oscillator), is limited in its frequency range by the SIS mixer as well as by the FFO. The coupling between FFO and mixer determines the effective bandwidth and could potentially be several hundreds of GHz. Recent development of all-Nb superconducting integrated receivers has demonstrated that the frequency of a single FFO can be tuned from 200 to 700 GHz [1],[2], i.e. up to the gap frequency of Nb. If the material with higher gap frequency (NbN for example) is used, the FFO can be running up to nearly two times this frequency, so up to 1200 GHz. However, the coupling of signal into SIS mixers with Nb tuning structures is found to be decreased rapidly above the gap frequency (about 700 GHz for Nb). This problem can be solved by using a normal metal such as aluminium for the coupling structures [3], [4]. In this contribution we present both calculated and experimental results of Nb-based SIS mixers in combination with a double dipole planar antenna for the highest possible frequencies. Special attention is paid for an expansion of the SIS mixer instantaneous bandwidth towards the frequency range of FFO.

Numerical Simulation

The numerical simulation of both single junction mixer and twin junction mixer has been performed for the frequency range of 300-1200 GHz using Mathcad™. The layouts of the double-dipole SIS mixers with single- and twin-junction are presented in *Fig. 1a, 1b.* A numerical model of an SIS mixer with Al stripline has been developed. The calculation indicates an advantage of the twin-junction mixer in both the signal coupling and its instantaneous bandwidth over the conventional end-loaded mixer employing the same kind of normal metal in the tuning circuit. The twin-junction mixer employing junctions of the same size ($A \approx 1\ \mu m^2$ each) occurs to be about 3 times more broad-band. The numerical comparison for the two types of mixers is presented for two most important cases: *Fig. 2a* for the frequency range below the gap frequency of Nb; *Fig. 2b* for the 1 THz frequency region (Al-added stripline with surface resistance 0.1 Ω is assumed). The improvement in the instantaneous bandwidth for the lower frequency band is caused by presence of 3 arbitrary independent tuners in the twin-junction mixer: 1) the tuning inductor (in the center), 2) $\lambda/4$ transformer, and 3) the resonant dipole antenna. The improvement at high frequency is expected because of much higher impedance of the optimal transformer in the twin-junction mixer that leads to lower *RF* current density in the transformer's stripline.

Experimental samples

All the experimental samples are based on standard all-Nb trilayer $Nb/Al/AlO_x/Nb$. The typical IV-curve of the "low frequency" twin-junction mixer (300-700 GHz) is shown in *Fig. 3*. The complex resonant structure on the IV-curve indicates the wide tuning range of the mixer.

The Al-added striplines are fabricated using UHV evaporation of 150 nm of pure Al onto Nb bottom electrode of the stripline. The RF sputtering of 200 nm of Al is used beneath of the Nb wiring that results in structure $Nb/Al/Nb/Al/AlO_x/Al/Nb$. The Nb wiring is used to avoid series resistance in the structure. The probable influence of Nb film on the Al-added stripline property will be discussed below. The IV-curve of Al-added mixer is shown in *Fig. 4*.

Experimental Details

The experimental study has been performed in the same quasi-optical mixer block as used for the integrated receiver study [2] just replacing the sample on the back of quartz hyper hemispherical lens. The Fourier Transform Spectrometer has been used for preliminary test of the mixers in video-detection mode. The heterodyne test over a frequency ranges 430-500 GHz and 830-890 GHz have been performed for all-Nb and Al-added mixers correspondingly.

The comparison of the experimental FTS response and the calculated coupling below the gap frequency is presented in *Fig. 5*. The data are in a reasonable agreement between the computed and measured frequency response. However, the two side peaks are somewhat lower than the middle one. It is caused probably by decreasing of the optical coupling of the double-dipole antenna that occur far from its center frequency. Nevertheless the flatness of about ±1 dB is available within the bandwidth of 300 GHz.

To improve the signal coupling at the central frequency, a back-reflector at a distance of $\lambda/4$ could be used. The back-reflector provides coupling of the back-lobe of the antenna (about 28% of available power for the quartz lens) to the main lobe. The FTS data obtained for the same sample with and without the back-reflector are presented in *Fig. 6*. The receiver DSB noise temperature for these two cases is plotted in *Fig. 7*. The flat response at the level of 200-250 K occurs for no back reflector used. For the case of back reflector the region of the best response gets narrower, but the receiver DSB noise temperature drops down to about 120-130 K.

The FTS response for Al-added mixer is shown in *Fig. 8*. The design value for tuning frequency for this particular device is about 750 GHz. However, the cut-off of Nb stripline at about 700 GHz is clearly seen as an extra to the broad peak centred at 750-800 GHz. The qualitative analysis allows to conclude that there might be both Nb and Al influencing the RF current in the tuning circuit. The SQUID-like behaviour of the critical current vs. magnetic field is one more evidence that superconducting Nb is possibly penetrating the 150 nm of Al film producing the superconducting loop of the SQUID. The DSB noise temperature of the Al-added mixer has been measured within 830-890 GHz as about 5000-10000 K (corrected to 60 μm thick mylar beamsplitter). The reasons of that low sensitivity are under investigation. The evaluation of properties of Al/Nb film sandwich looks rather important.

Conclusion

The wide-band quasi-optical SIS mixers have been tested experimentally showing good agreement with the numerical simulation within the frequency range below the gap of Nb. The wide-band operation regime with DSB noise temperature of about 100-150 K and instantaneous bandwidth of 250-300 GHz is expected for the properly fabricated mixers that fits well to the tuning range of the integrated superconducting oscillator (FFO) available. The twin-junction mixer design with Al-added stripline tuner for THz frequency range still needs to be evaluated accurately.

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References:

[1] J. Mygind et al. “Properties of Autonomous and Injection Locked Flux Flow Oscillators”. IEEE Trans on Appl. Supecond., v. 5, No 2, pp. 2951-2954, 1995

[2].V.P. Koshelets et al.“First Implementation of a Superconducting Integrated Receiver at 450 GHz”, Appl. Phys. Lett., to be published in 1996.

[3] H. van de Stadt et al. “A 1 THz Nb SIS Heterodyne Mixer with Normal Metal Tuning Structure”, Proceedings of the 6th THz Symposium, pp. 66-77, March 1995, Pasadena.

[4] M. Bin et al. "THz SIS Mixers with Normal Metal Al Tuning Circuits", Extended Abstracts of ISEC '95, pp. 402-404.

[5] V. Yu. Belitsky et al. "0.5 THz SIS Receiver with Twin Junction Tuning circuit", Proceedings of IV Int. Conf. on Space Terahertz Technology, 1993, Los Angeles, pp. 538.

Figures Capture:

Fig. 1 Layout of the double-dipole SIS mixers with single- and twin-junction structure.

Fig. 2 Numerical comparison for the two types of mixers for two most important cases: a) for the frequency range below the gap frequency of Nb; b) for the 1 THz frequency region (Al-added stripline with surface resistance 0.1 Ω is assumed).

Fig. 3 Typical IV-curve of the "low frequency" twin-junction mixer (300-700 GHz). The complex resonant structure on the IV-curve indicates the wide tuning range of the mixer.

Fig. 4 Unpumped and pumped IV-curves of Al-added mixer for 750 GHz frequency region. Chopped hot/cold response at 890 GHz is shown.

Fig. 5 Comparison of the experimental FTS response and the calculated coupling efficiency for the twin-junction mixer below the gap frequency of Nb.

Fig. 6 FTS data obtained for the same sample *with* and *without* the back-reflector.

Fig. 7 Receiver DSB noise temperature is dependent on presence of the back-reflector.

Fig. 8 The FTS response for Al-added mixer.

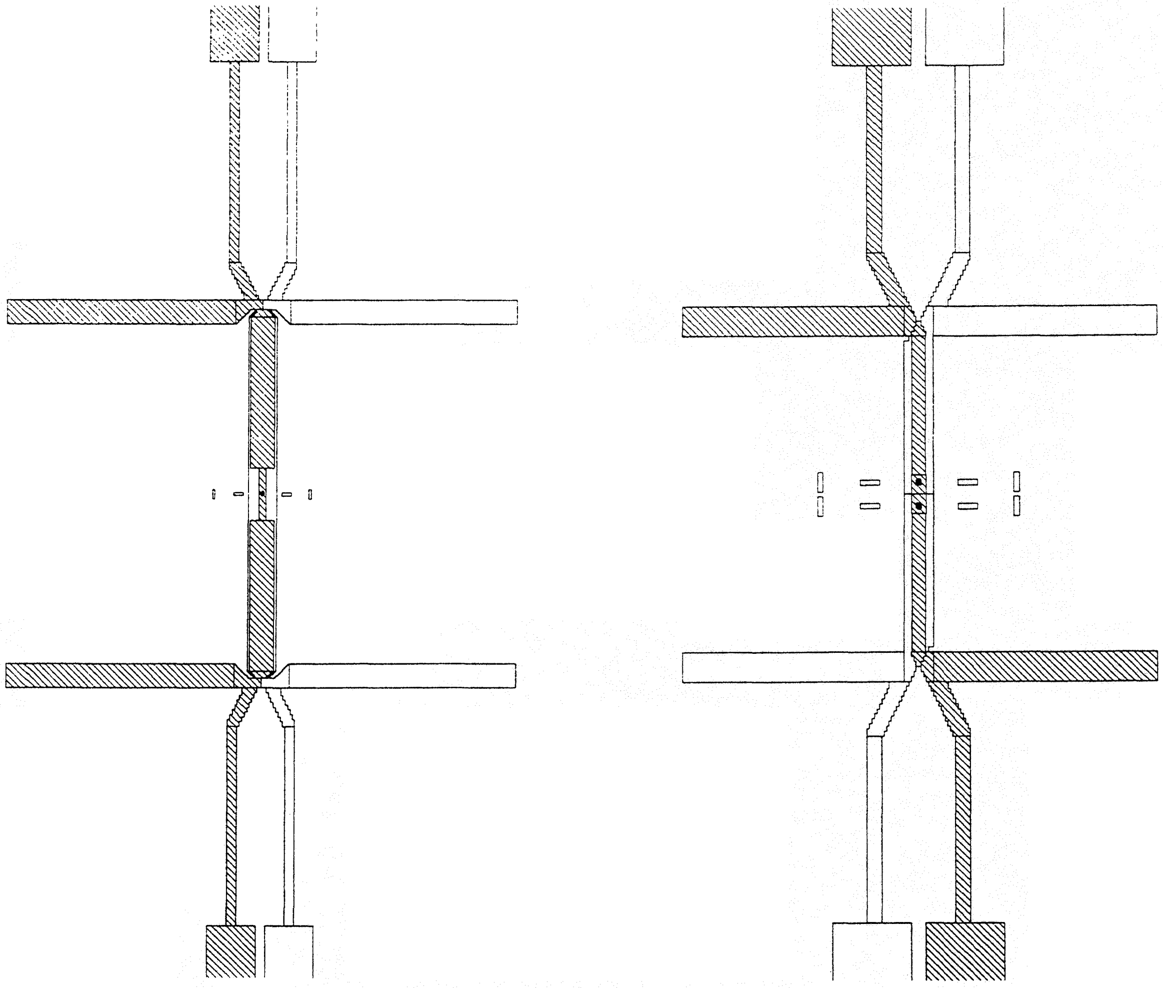

Fig. 1

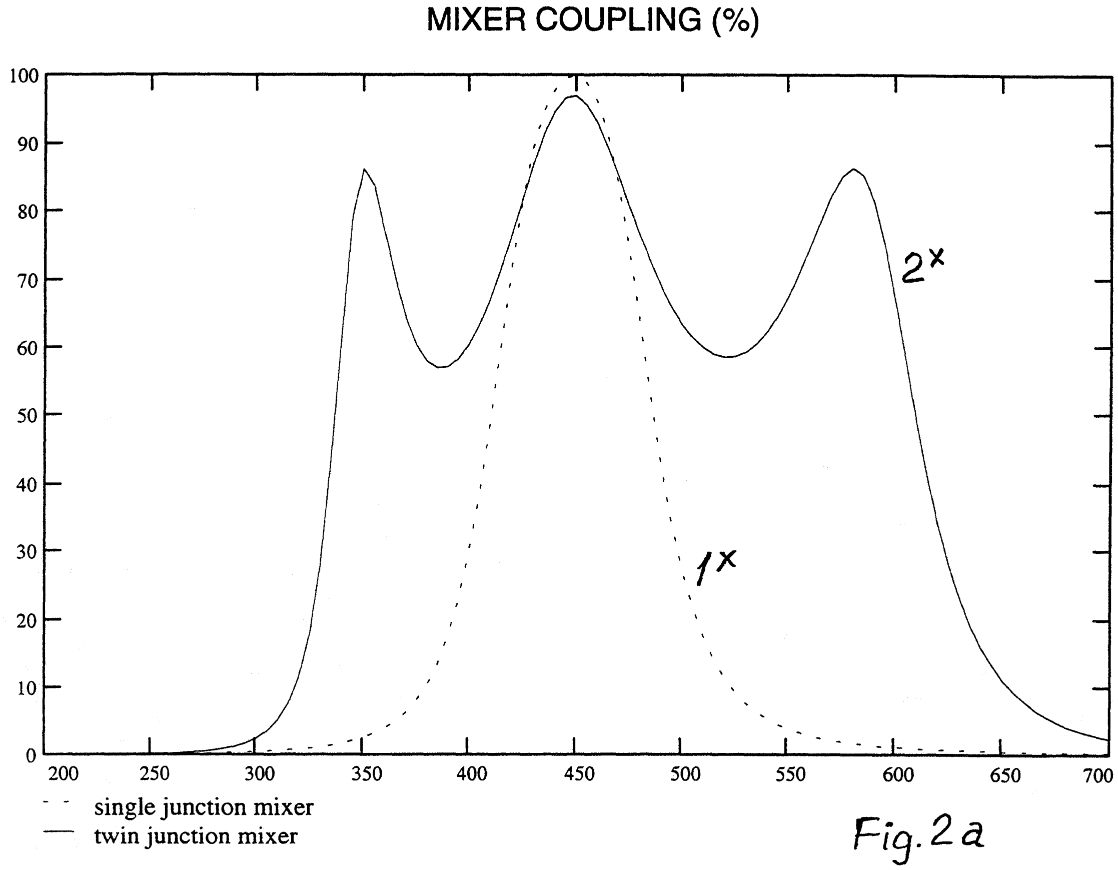

Fig. 2a

FIG. Comparison of instantaneous bandwidth for the two different mixer designs.

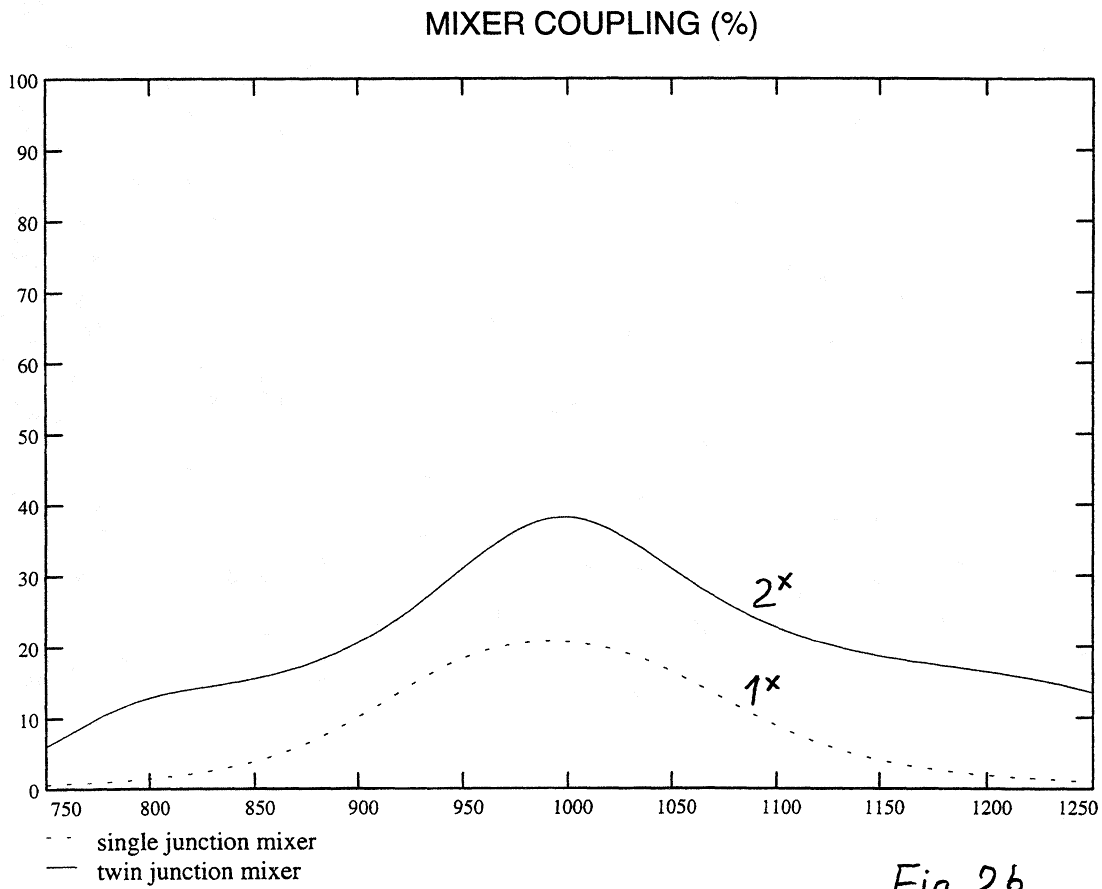

Fig. 2b

FIG. Comparison of instantaneous bandwidth for the two different mixer designs within frequency range above the gap frequency (normal metal tuners).

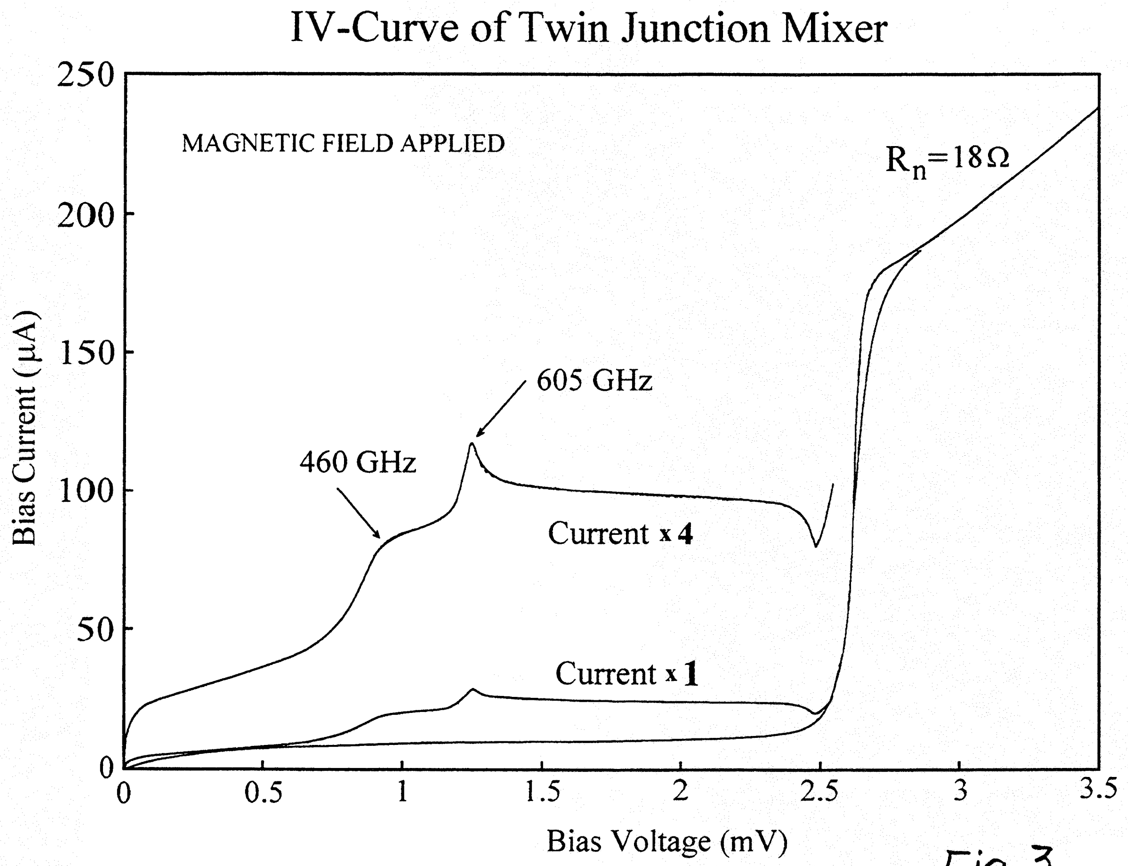
IV-Curve of Twin Junction Mixer
MAGNETIC FIELD APPLIED
R_n=18Ω
605 GHz
460 GHz
Current x 4
Current x 1
Bias Current (μA)
0
50
100
150
200
250
0
0.5
1
1.5
2
2.5
3
3.5
Bias Voltage (mV)

Fig. 3

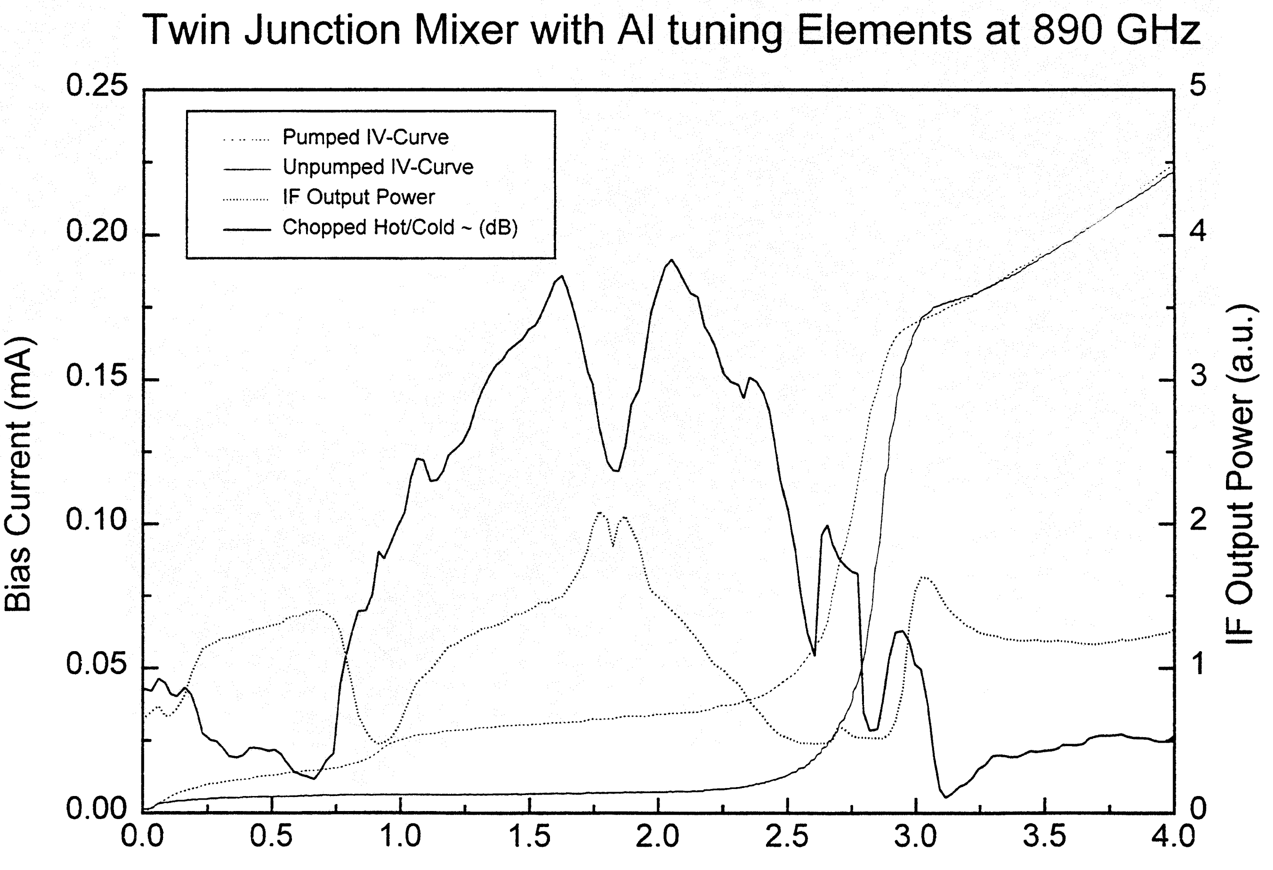
Twin Junction Mixer with Al tuning Elements at 890 GHz
Pumped IV-Curve
Unpumped IV-Curve
IF Output Power
Chopped Hot/Cold ~ (dB)
Bias Current (mA)
IF Output Power (a.u.)
0.00
0.05
0.10
0.15
0.20
0.25
0
1
2
3
4
5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Bias Voltage (mV)

Fig. 4

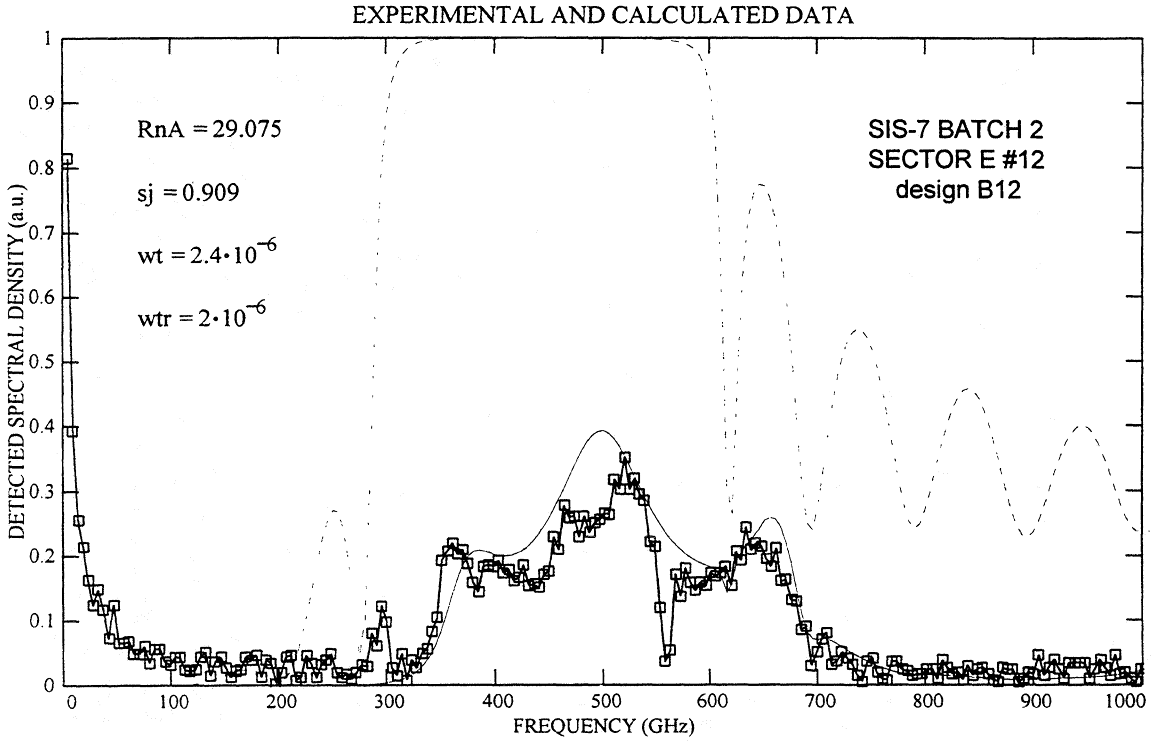
EXPERIMENTAL AND CALCULATED DATA
RnA = 29.075
sj = 0.909
wt = $2.4 \cdot 10^{-6}$
wtr = $2 \cdot 10^{-6}$
SIS-7 BATCH 2
SECTOR E #12
design B12
DETECTED SPECTRAL DENSITY (a.u.)
FREQUENCY (GHz)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
100
200
300
400
500
600
700
800
900
1000

Fig. 5

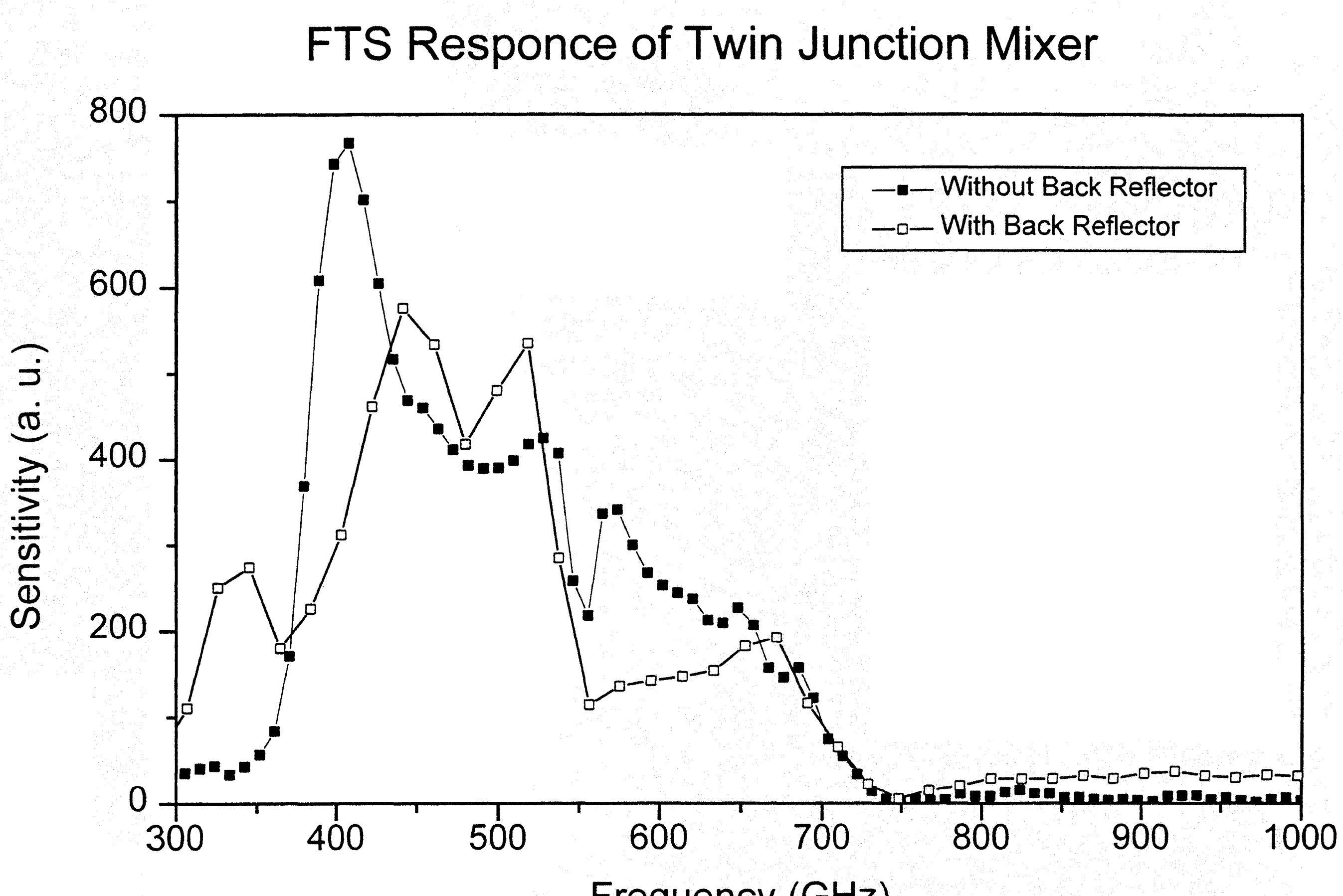
FTS Responce of Twin Junction Mixer

Fig.6

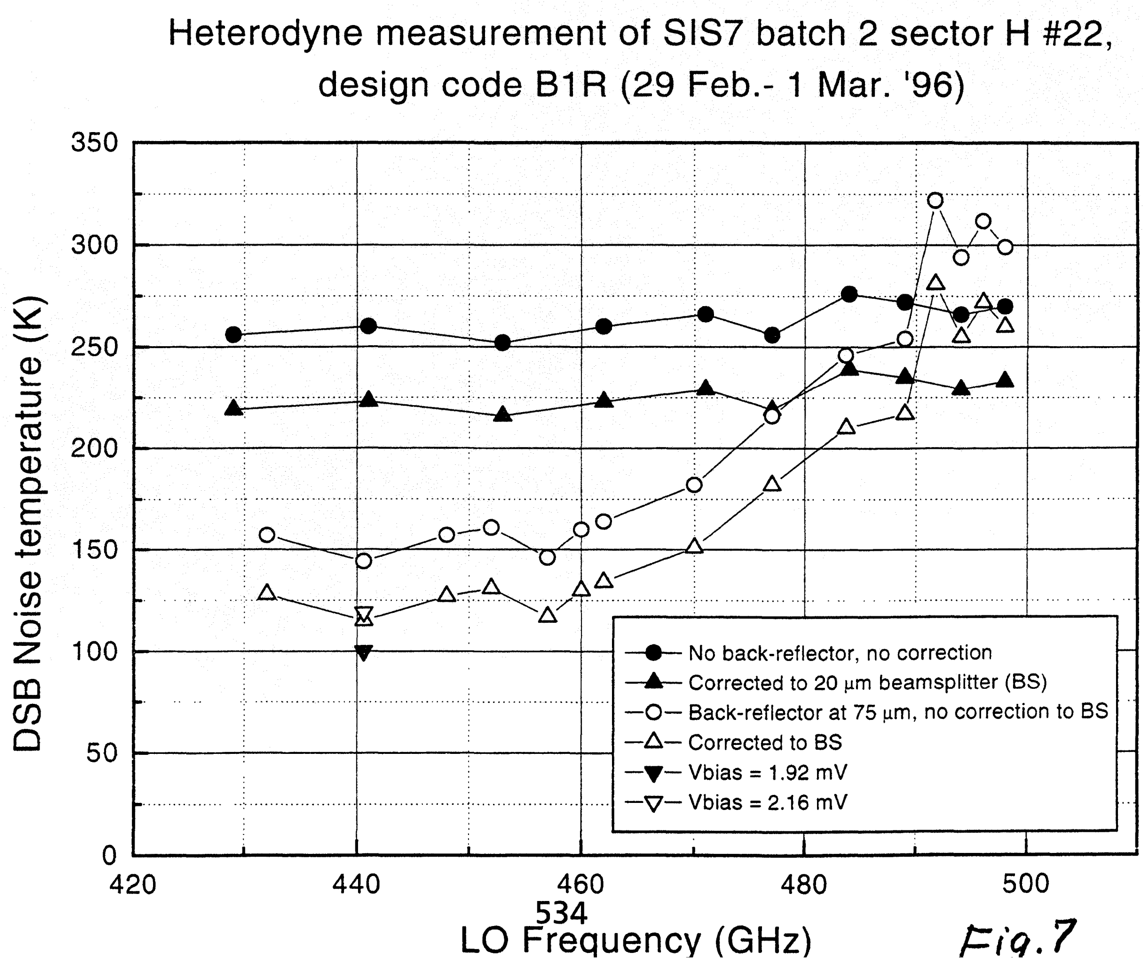
Heterodyne measurement of SIS7 batch 2 sector H #22, design code B1R (29 Feb.- 1 Mar. '96)

Fig.7

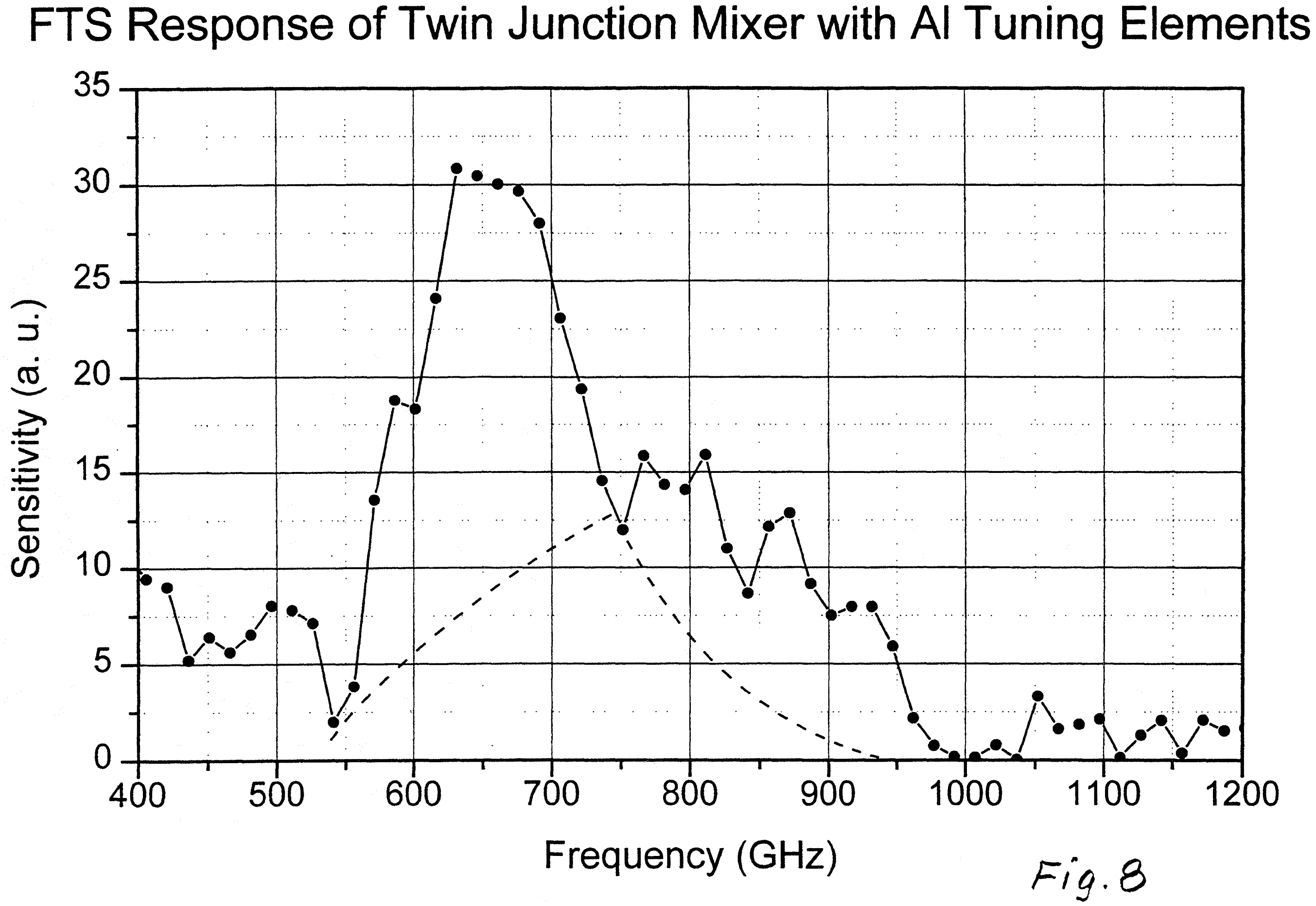
FTS Response of Twin Junction Mixer with Al Tuning Elements
Sensitivity (a. u.)
0
5
10
15
20
25
30
35
400
500
600
700
800
900
1000
1100
1200
Frequency (GHz)

Fig. 8