DEVELOPMENT OF A SUPERCONDUCTING INTEGRATED RECEIVER FOR APPLICATION IN IMAGING ARRAYS

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Introduction

An imaging array for the sub-millimeter wavelength region based on a number of light weight and low power consuming devices such as the recently developed superconducting integrated receiver [1], looks very attractive, especially for space applications. Both reproducibility and reliability of the integrated receiver chips are very important to create an imaging array. We have demonstrated recently a noise temperature of 400 K DSB at 450 GHz using an on-chip Flux Flow Oscillator (FFO) as a local oscillator (LO). This was only 30% higher than the best performance obtained by using an external LO [2]. The main reason for the difference between the external and internal pump is lack of the LO power coupled from FFO to the SIS junction.

The experiment with frequency locking of the FFO at about 450 GHz to an external synthesized source of 10 GHz has been performed successfully. An averaged linewidth of about 200 kHz has been recorded [3]. The recent status of an integrated receiver study as well as a number of specific problems associated with the development of an imaging array are reported.

Experimental Details

The all-Nb superconducting integrated receiver on a single crystalline quartz chip of size 4 mm × 4 mm × 0.2 mm contains: a planar double-dipole antenna, SIS mixer, FFO as a local oscillator and all necessary coupling circuitry. The photo of the chip receiver mounted in the mixer block by Al bonding (∅20 μm) is presented in *Fig. 1.*

The transfer of the production process from IREE (Moscow, Russia) to SRON/FDL (Groningen, the Netherlands) has been realized successfully in a short time, which probably means that the integrated receiver chips are reasonably easy to produce world-wide. All the circuits have been redesigned for use of SiO_2 insulation at SRON/FDL instead of SiO used at IREE. A yield of good devices as high as 80% has been achieved in a single batch (12 useful devices from 15 ones available). The data of production yield are presented in *Table 1.*

The optimization of the coupling circuitry between the SIS mixer and the FFO has resulted in considerable improvement of the pumping level of the SIS mixer [4].
The normalized RF voltage $\alpha=eV_{RF}/hf$ as high as $\alpha=2$ has been achieved during preliminary dc-tests in dipstick. In the cryostat the antenna is matched better to the outcoming beam so part of LO power emitted those results in somewhat lower pump level.

The use of μ-metal shield around the housing of the integrated receiver in the cryostat has resulted in the improvement of stability of the FFO in the noisy experimental environment. The recent improvements in the optics (anti-reflection coating on all quartz lenses of the mixer, thin mylar window of the cryostat) have resulted in significant decrease of the receiver DSB noise temperature lower than 150 K. The break-down of the noise for the experimental receiver is presented in *Table 2*.

It has been found that no significant difference occurs for the receiver driven with external or internal LO for both the pump level and the noise temperature of the receiver. The experimental data for the mixer as well as its hot/cold response at about 500 GHz are presented in *Fig. 2*. The plot of the receiver DSB noise temperature with respect to the LO frequency is presented in *Fig. 3*.

The experimental antenna beam pattern of the integrated receiver is presented in *Fig. 4*. The difference in the width of H- and E-pattern is most probably caused by the double-dipole antenna shape which is designed to be used without back-reflector that means longer arms and higher directivity in the vertical plane.

The reported results of the integrated receiver look rather encouraging that allow us to start development of optical concept for integrated image array receiver.

Optical Configuration for an Image Array Receiver

There are several possible optical configurations that could be used in an imaging array. Two different approaches of practical interest to an array are: A) a single dielectric lens antenna (either an elliptical or hyper hemispherical lens, Figure 5a) with an array of antennas (receivers) positioned in the focus of the lens, and B) an array of lenses each with its own receiver positioned in the focus of the lens (fly's eye, Figure 5b). With the single lens concept an additional intervening optical system (mirrors and/or lenses) between the telescope and the dielectric lens antenna is needed to re-image the beams onto the sky, as for the fly's eye concept that depends on the dielectric lens type chosen.

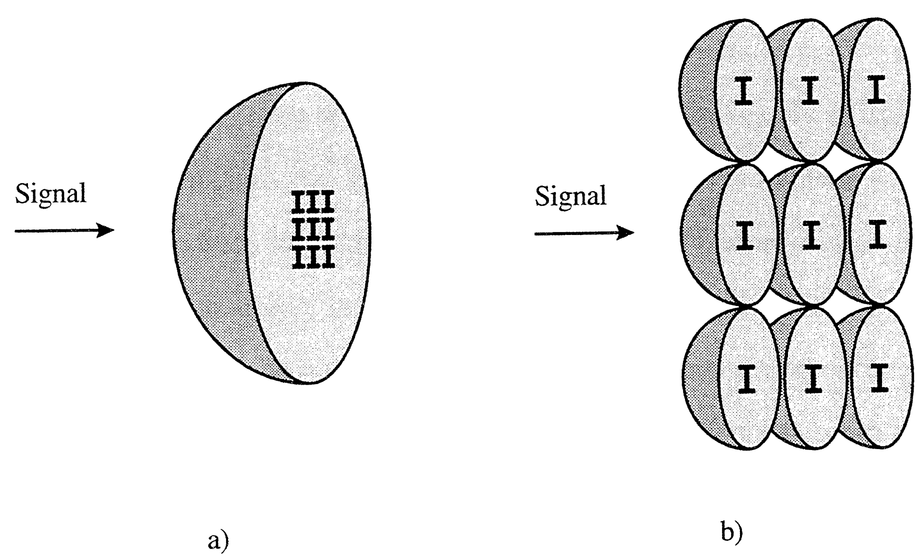

Figure 5. Two different array concepts for 9 pixel image receiver: a) A large single lens with

an array of receivers in its center, and b) an array of lenses, each only having a single element in its center.

Comparison of different optical schemes needs to be based on the performance, such as aperture efficiency, spillover, undersampling (packing density), sidelobe level and Gaussian beam coupling, of each system. Also practical considerations, such as the size of the whole array, the size of the intervening optics and whether there is a need for them, yield in the SIS-junction process, testability and selection of each receiver in the array, play an important role in selection of the best concept for the imaging array.

Both the single lens and the fly's eye concept offer considerable advantages (⊕) as well as disadvantages(Θ), which are more or less reciprocal of one another:

<u>Single lens</u>

⊕ everything on a single chip, superconducting lines for DC and RF connections could be used (including phase-locking signals),

⊕ small size,

⊕ ease of mounting,

Θ the image quality of the off-axis beams distorted due to aberrations,

Θ crosstalk between individual elements,

- mutual coupling (RF),
- intermediate frequency coupling (IF),
- magnetic coupling (DC),
- reflections from the dielectric-air interface,

Θ a large front lens needed,

Θ yield in the SIS manufacturing process might not be high enough to give 9 (10) similar junctions on a single chip (plus FFOs),

Θ broken pixel is non-replaceable since the receivers are manufactured on a single chip.

"Fly's eye"

⊕ all antennas are center elements ⇒ no aberrations,

⊕ possible to match directly to the telescope without any intervening optical system,

⊕ reduced crosstalk between individual elements,

⊕ each of the receivers can separately be tested and replaced, if needed,

⊕ size of the receiver chip much smaller than the lens size ⇒ room for connections,

Θ large array size ⇒ large intervening optics if they are needed (sideband filtering, calibration etc.),

Θ large number of individual lenses and receives ⇒ mounting laborious.

The problems associated in the single lens concept with the integrated receiver, such as crosstalk, packing density and yield in the SIS junctions process are obstacles that could be overcome with thorough study and testing with time. On the other hand, the "fly's eye" concept already offers solution to these problems, and in addition it offers high beam quality for all beams, since there are no aberrations. For the reasons presented we are in favour of the "fly's eye" configuration, but we have not yet completely ruled out the single lens concept either.

Conclusion

The recent results of the integrated receiver test: $T_{rx} < 200$ K, reasonably low antenna sidelobes (-18...-20 dB), and quite high production yield (80%), allow us to start the development of a concept of the integrated image array for radio astronomical application.

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References:

[1] V. P. Koshelets, S. V. Shitov, L. V. Filippenko, A. M. Baryshev, H. Golstein, Th. de Graauw, W. Luinge, H. Schaeffer, H. van de Stadt. "First Implementation of a Superconducting Integrated Receiver at 450 GHz", Appl. Phys. Lett., to be published in 1996.

[2] A. Baryshev, V. Koshelets, S. Shitov, L. Filippenko, Th. de Graauw, W. Luinge, H. van de Stadt, H. Schaeffer. "A Fully Superconducting 500 GHz Receiver with Integrated Flux-Flow Oscillator", Extended Abstracts of ISEC'95, pp. 419-421, 1995

[3] A. V. Shchukin, V. P. Koshelets, S. V. Shitov, L. V. Filippenko, and J. Mygind. "Linewidth of Flux-Flow Oscillators for Sub-mm Wave Receivers", Extended Abstracts of ISEC'95, pp. 416-418, 1995

[4] S. V. Shitov, V. P. Koshelets, L. V. Filippenko, A. M. Baryshev, H. Golstein, Th. de Graauw, W. Luinge, H. Schaeffer, H. van de Stadt. "Recent Development of Integrated Receiver for submm Applications", Conference Digest of XX International Conference on Infrared and Millimeter Waves, pp. 367-368, Orlando, Florida, December 11-15, 1995.

Figures Capture:

Fig. 1 Photo of the chip receiver mounted on the hyper hemispherical lens by bonding.

Fig. 2 Experimental data for the mixer pumped by FFO: autonomous and pumped IV-curves; hot/cold response at about 500 GHz.

Fig. 3 Integrated receiver DSB noise temperature with respect to the FFO frequency.

Fig. 4 Experimental antenna beam pattern of the integrated receiver.

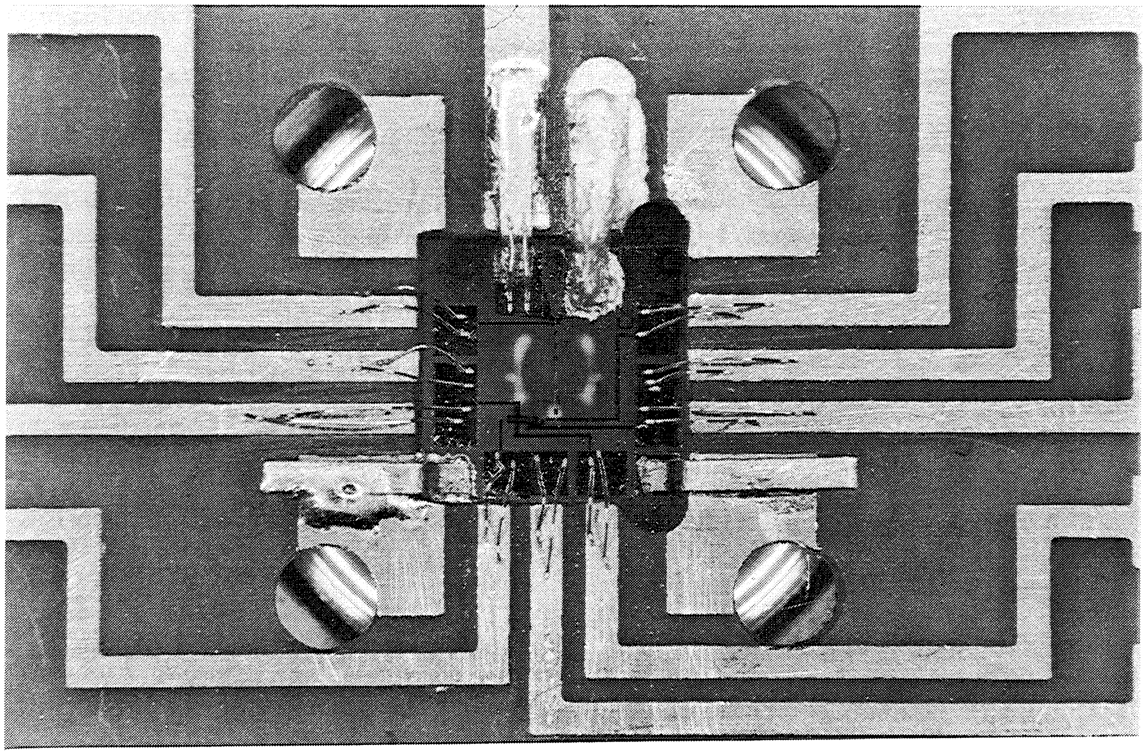
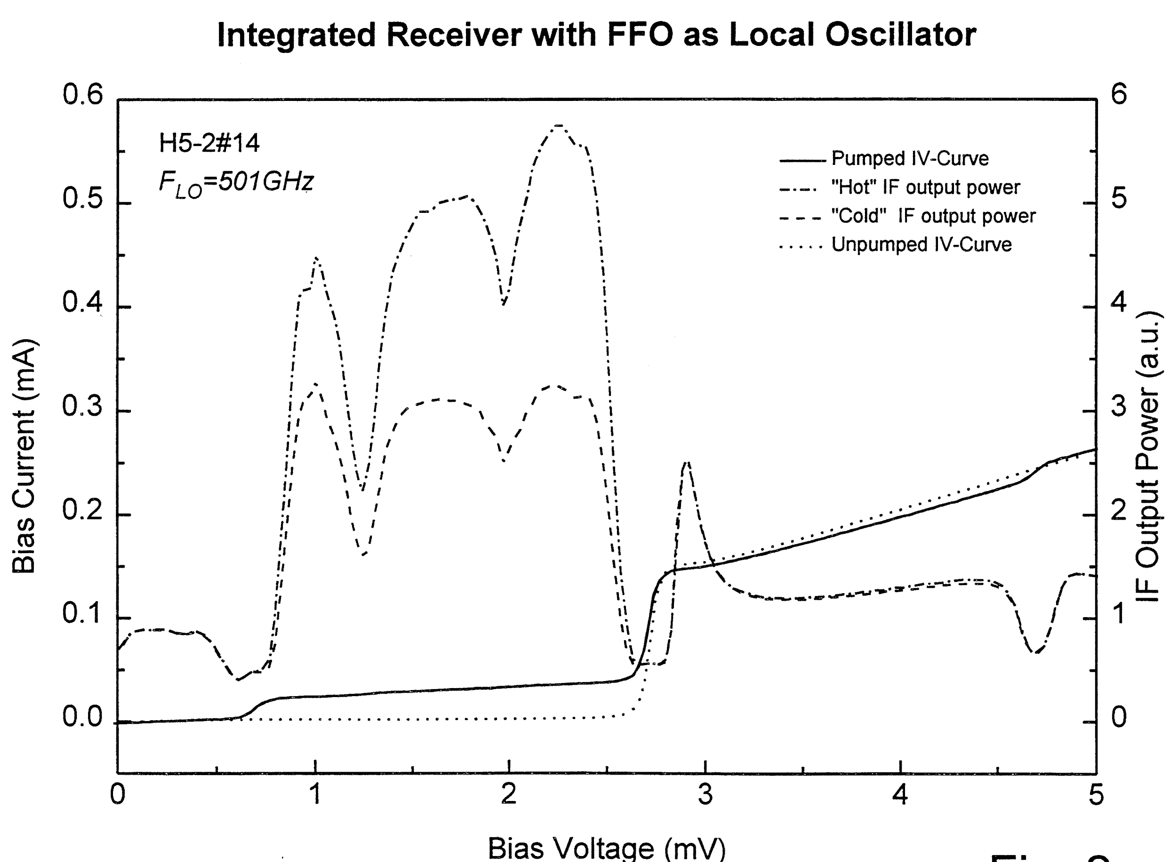


Fig. 1



Integrated Receiver with FFO as Local Oscillator
H5-2#14
F_{LO}=501GHz
Pumped IV-Curve
"Hot" IF output power
"Cold" IF output power
Unpumped IV-Curve
Bias Current (mA)
IF Output Power (a.u.)
Bias Voltage (mV)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
1
2
3
4
5
6

Fig. 2

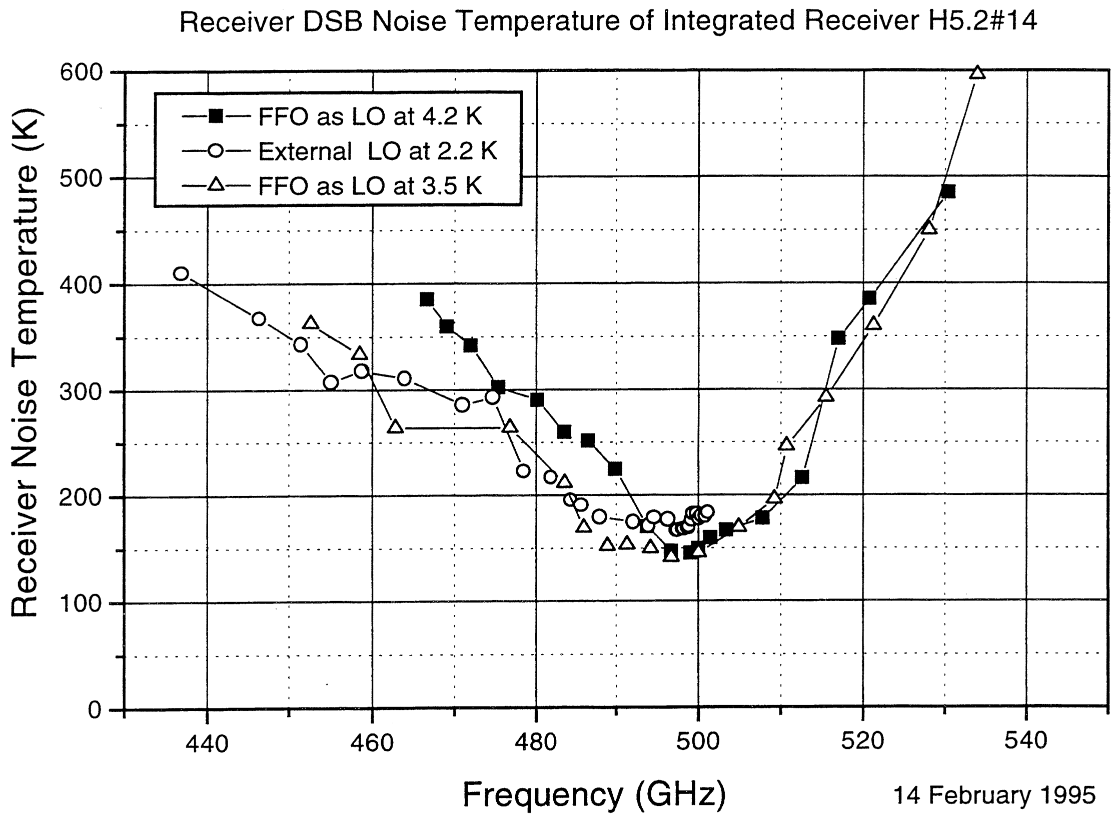

Receiver DSB Noise Temperature of Integrated Receiver H5.2#14
FFO as LO at 4.2 K
External LO at 2.2 K
FFO as LO at 3.5 K
Receiver Noise Temperature (K)
600
500
400
300
200
100
0
440
460
480
500
520
540
Frequency (GHz)
14 February 1995

Fig. 3

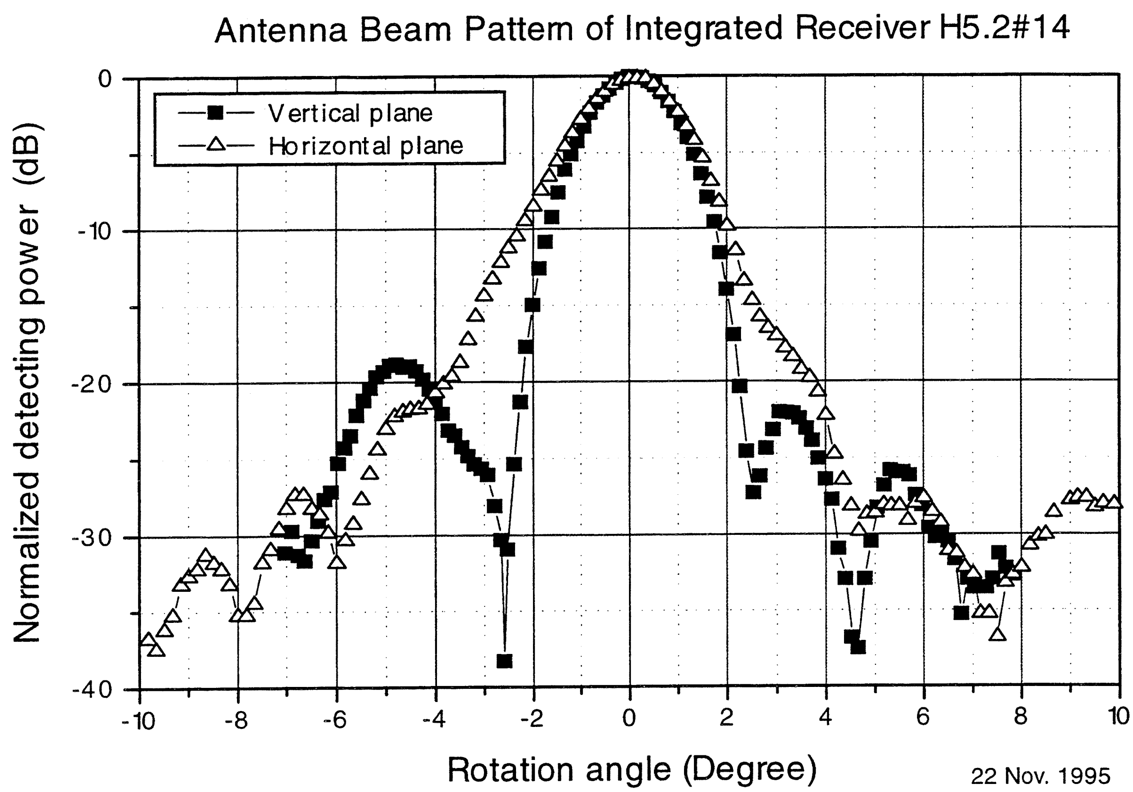

Antenna Beam Pattern of Integrated Receiver H5.2#14
Vertical plane
Horizontal plane
Normalized detecting power (dB)
0
-10
-20
-30
-40
-10
-8
-6
-4
-2
0
2
4
6
8
10
Rotation angle (Degree)
22 Nov. 1995

Fig. 4

Table 1

Results of dc tests of Integrated Receiver Chips H5 (batch #2)

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SIS R_n (Ω)		18	22.5	19.1	15.3	21	17.5	17.3	16.1	20	16	14.5	23.7	19.6	25
SIS R_j/R_n		22	25	19	22	24	31	29	39	31	25	10	35	34	16
SIS V_g (μV)		2800	2800	2800	2800	2800	2830	2830	2825	2825	2780	2830	2835	2840	2800
SIS δV_g (μV)		150	200	200	150	200	120	120	150	140	160	160	130	120	120
SIS CL 1st min/ (mA) 2nd min		50/ 100	60/ -	33/ 77	32/ 76	50/ 100	37/ 80	33/ 68	45/ 93	41/ 88	32/ 68	35/ 60	47/ 98	45/ 91	55/
SIS area (μ^2)		2.1	1.7	2.0	2.4	1.8	2.1	2.1	2.3	1.9	2.3		1.6	1.9	1.5
FFO ΔI_g (mA)		140	126	127	129	124	121	130	130	96	104	104	97	100	102
FFO I_r (mA)		3	3	3.3	3.5	3.3	3.1	3.4	3.3	2.7	2.7	2.7	2.5	3.2	5
FFO I_c (mA)		30	33	30	28	25	27	29	23	27	28	30	27	26	30
FFO V_g (μV)							2805		2825	2820	2830	2835	2835	2840	2810
Flux Flow Steps		+	+	++	++	++	++	++	++	++	++	++	++	++	+
SIS pumping, P.		+	+	+	++	++	++	+	++	++	++	++	++	++	++
V of max P. (μV)		950	990	950	970	970	980	970	980	970	970	970	1100	1050	1050
ΔI SIS at max P.		75	70	60	85	75	85	75	75	85	110	100	80	110	110
minV/maxV(μV) where ΔI SIS > 20 μA		900/ 1060	950/ 1050	920/ 1020	920/ 1030	860/ 1120	860/ 1100		950/ 1100	950/ 1130			950/ 1130	955/ 1135	
# of comments	1	2	3	4	5	6									
Σ	-	+	+	+	+	+	++	+	++	++	++	+-	++	++	+

SIS V_g (μV)	Before modification of the measuring setup V_g was measured by oscilloscope
SIS CL 1st min/2nd min (mA)	Values of the SIS Control Line Current where 1st /and 2nd minimum of SIS critical current occure.
SIS area (μ^2)	Calculated from averaged R_nS value
FFO ΔI_g (mA)	FFO "gap" current.
FFO I_r (mA)	FFO "return" current.
FFO V_g (μV)	Measured at 10 mA.
V of max P. (μV)	FFO voltage where maximum pumping of SIS takes place.
ΔI SIS at max P.	Maximum changing of the SIS current (μA) at 2 mV by FFO pumping.
Σ	Summary Rating (possibility to use for some hf measurements: IntRec, Receiver with External LO, FTS)

Table 2

Noise Figure Breakdown for Quasi-optical Integrated Receiver H5-2#7

	T_{rx} DSB (K)	T_{rx} DSB corrected for beamsplitter 10 μm (K)	T_{rx} DSB corrected for 10% sidelobes (K)	Mixer noise @ input (K)	IF noise @ input (K)	Optics efficiency (dB)	Antenna coupling (dB)	Mixer gain DSB (dB)	IF coupling R_{dvn}= 190Ohm (dB)	T_{IF} (K)
Experimental	150±5	-	-	122±5 [1]	20±5	-0.7±0.3 [2]	-	-3.3±0.5	-	9±3
Theoretical	-	142±5	≈106	54 [3]	22	-0.45	-2.3±0.4	+2.05	-1.8	12

[1] Noise of the optics and sidelobes included

[2] Part of the mixer gain

[3] Quantum noise not included (26 K @ 500 GHz)