Development of Millimeter-wave Spectroscopic Array Receiver (SSAR)

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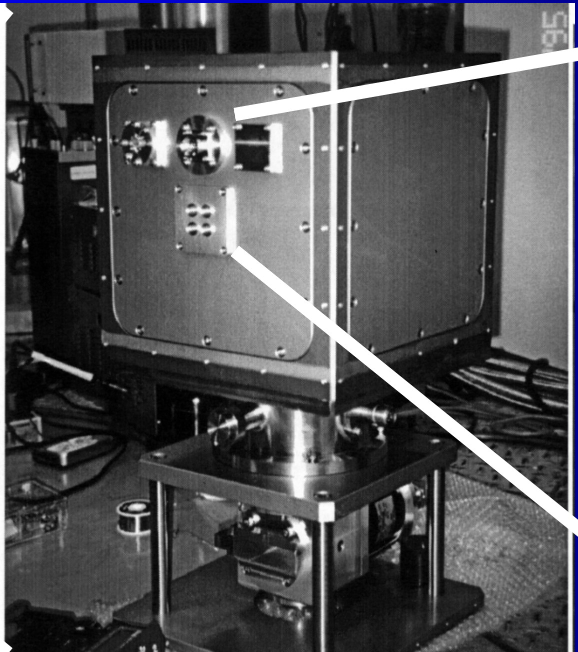
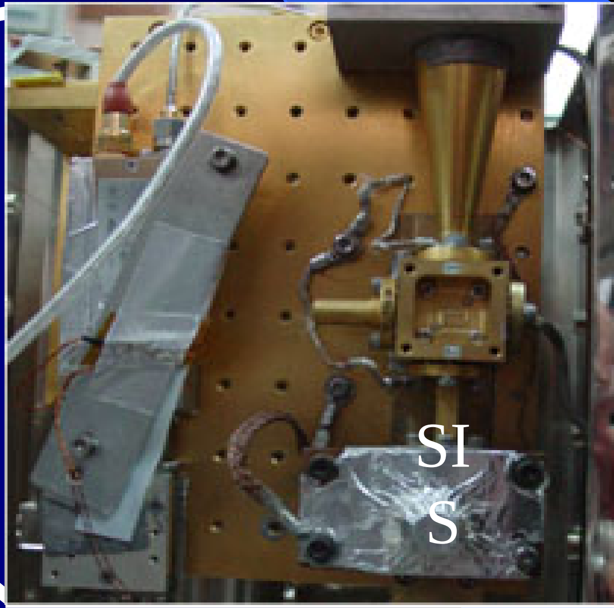
The Delingha (Nexans) Millimeter-wave Radio Telescope Qinghai Radio Astronomy Observatory, Purple Mountain Observatory

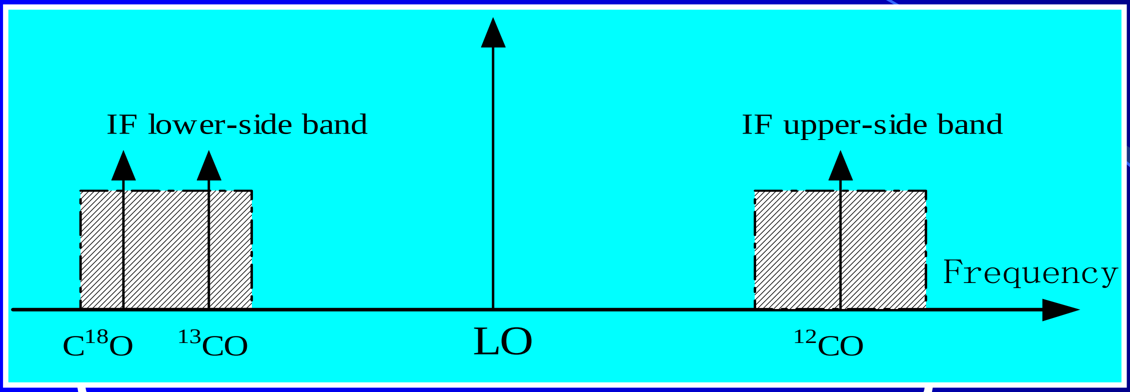
- **97°33′.6E, 37°22′.4N**
- **3200 m**
- **35 km east of Delingha City, Qinghai Province**

- **Cold in Winter (-10 ~ -25 °C)**
- **Dry (3~5mm PWV)**
- **Operation: Sept-June**

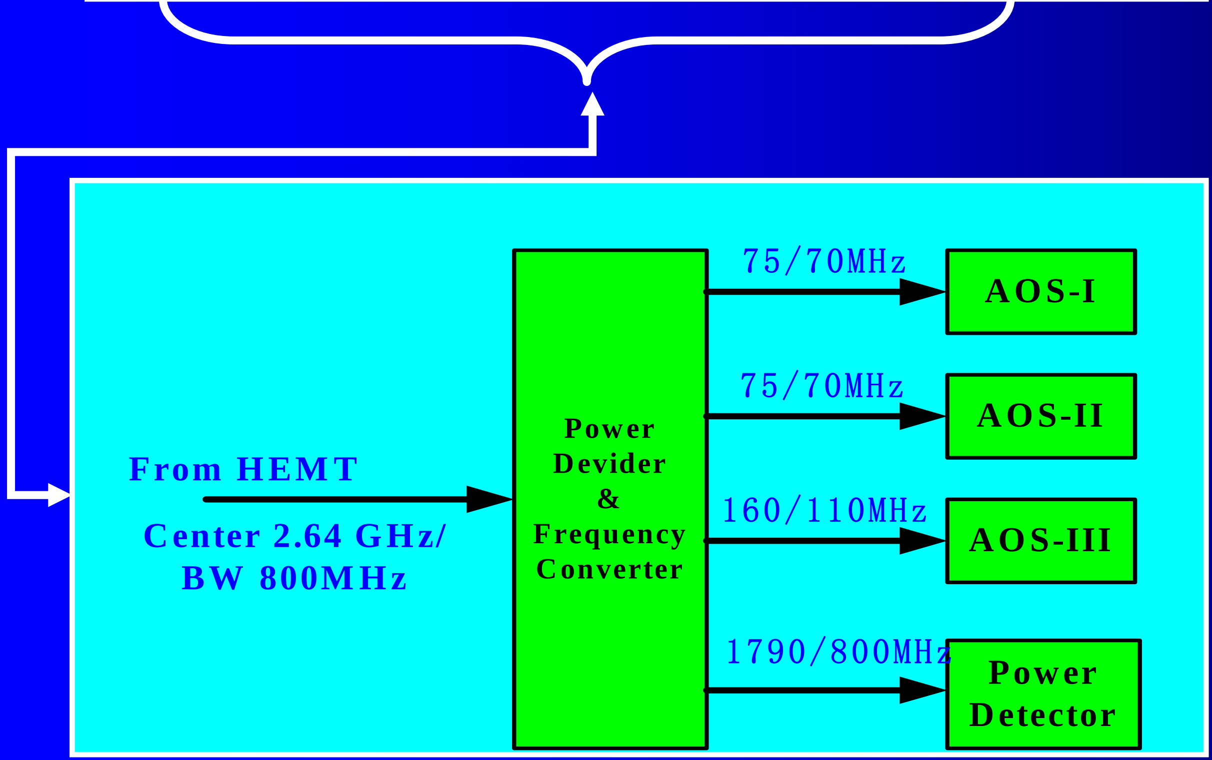




The 3mm Band Multi-line System: Principle

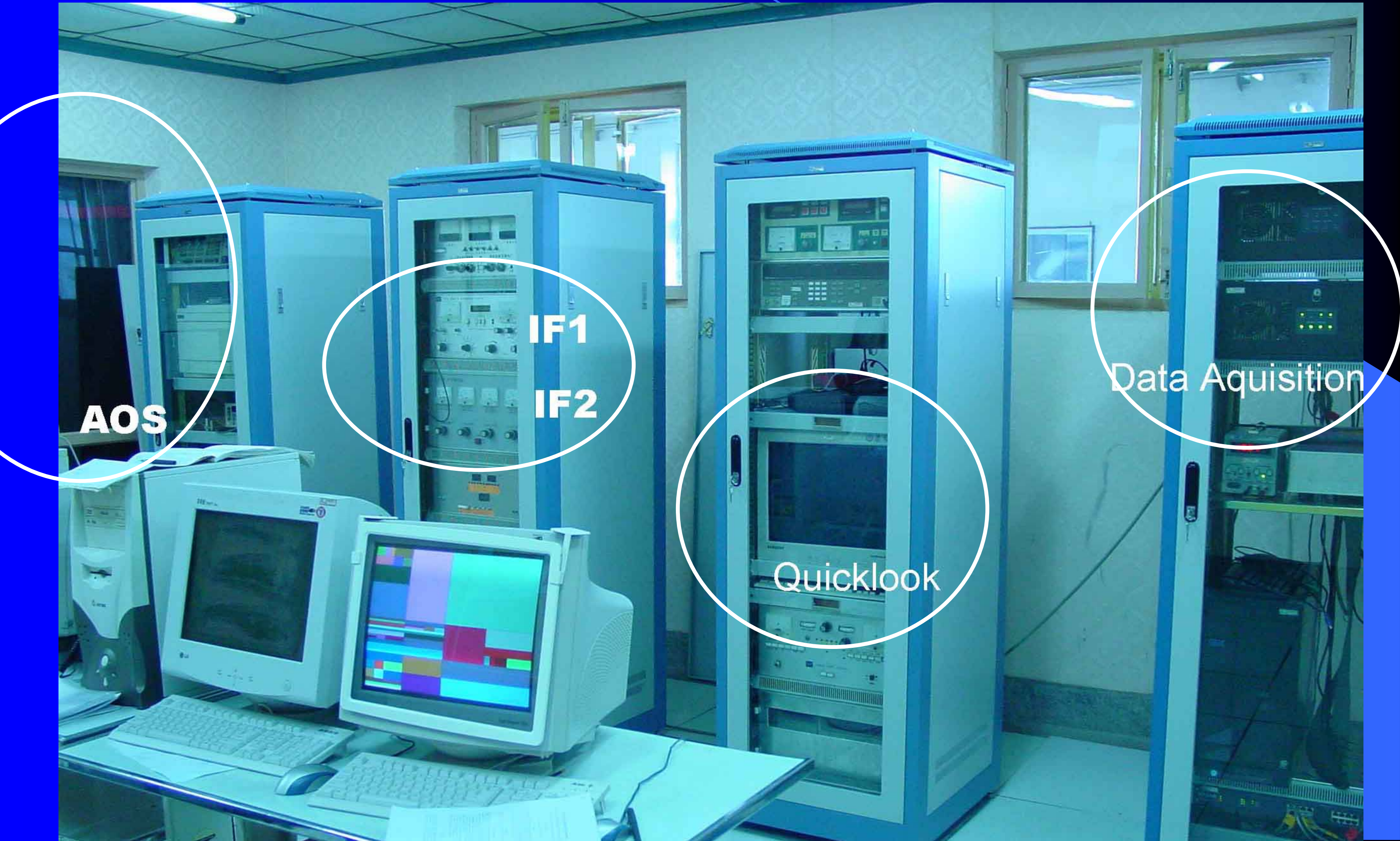


A single SIS front-end in double sideband (DSB) receiving mode



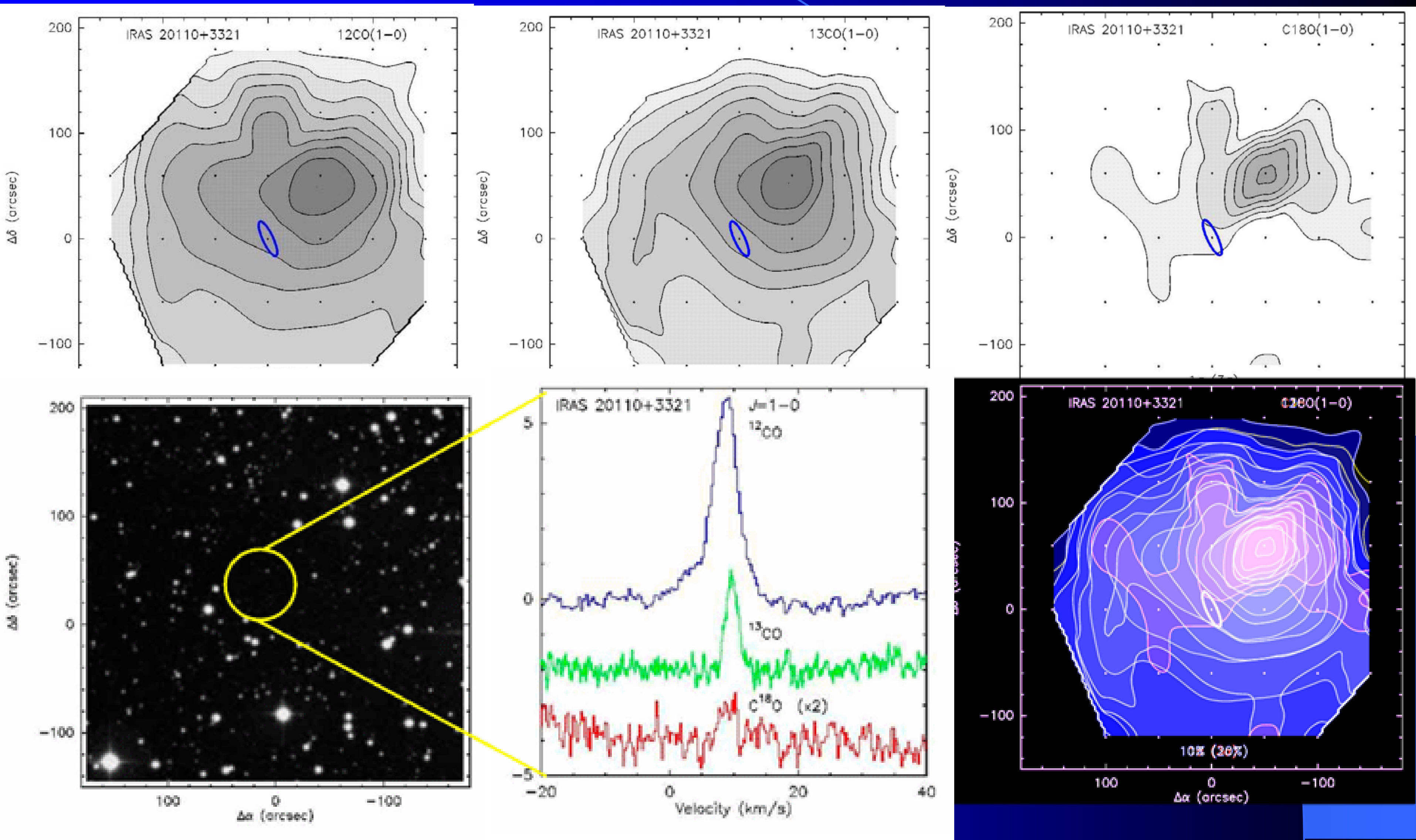
3-line spectroscopic backend

The 3mm multi-line banckend system: operation since 2002

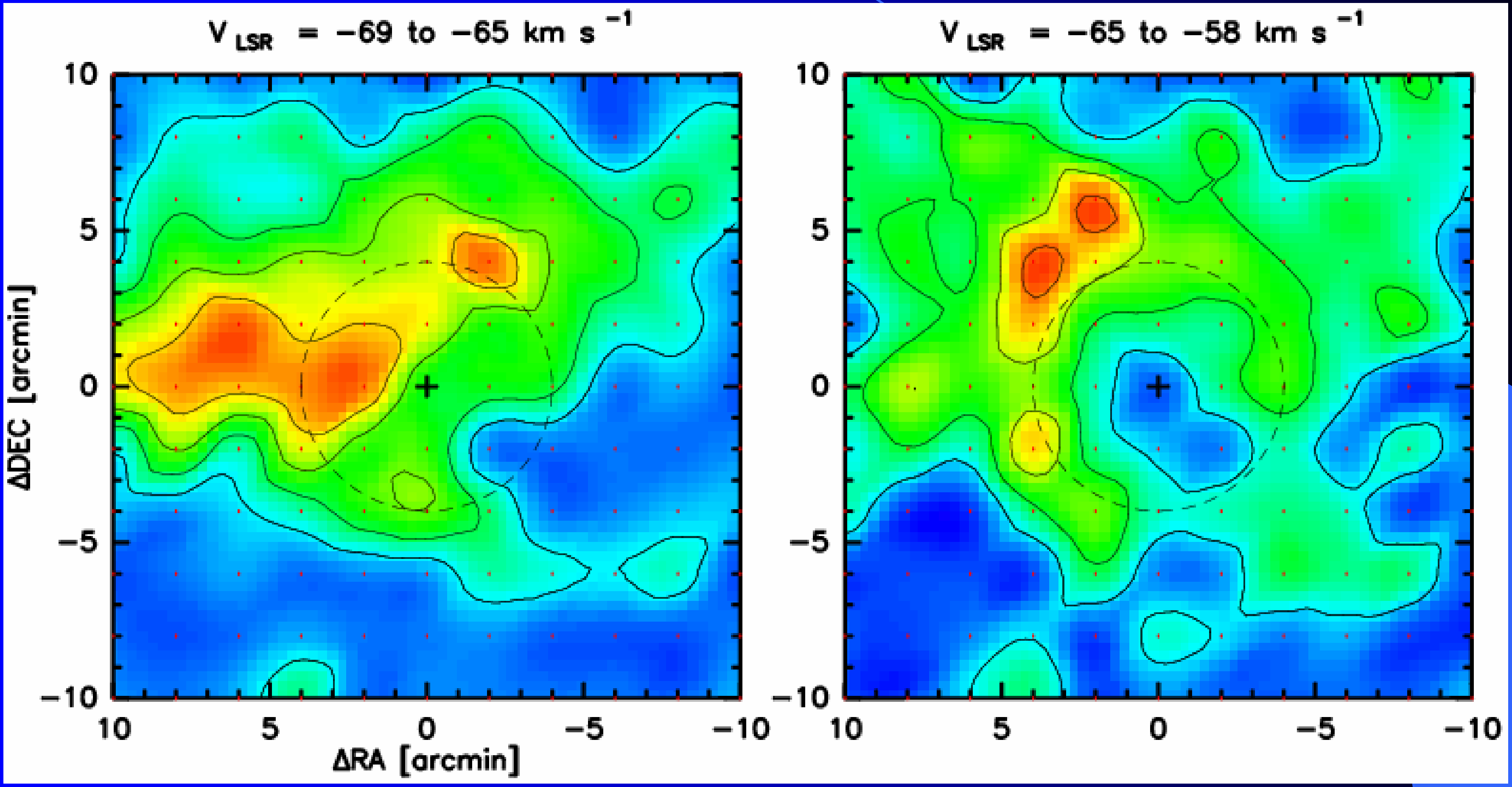


Mapping sample : The massive core associated with IRAS 20110+3321

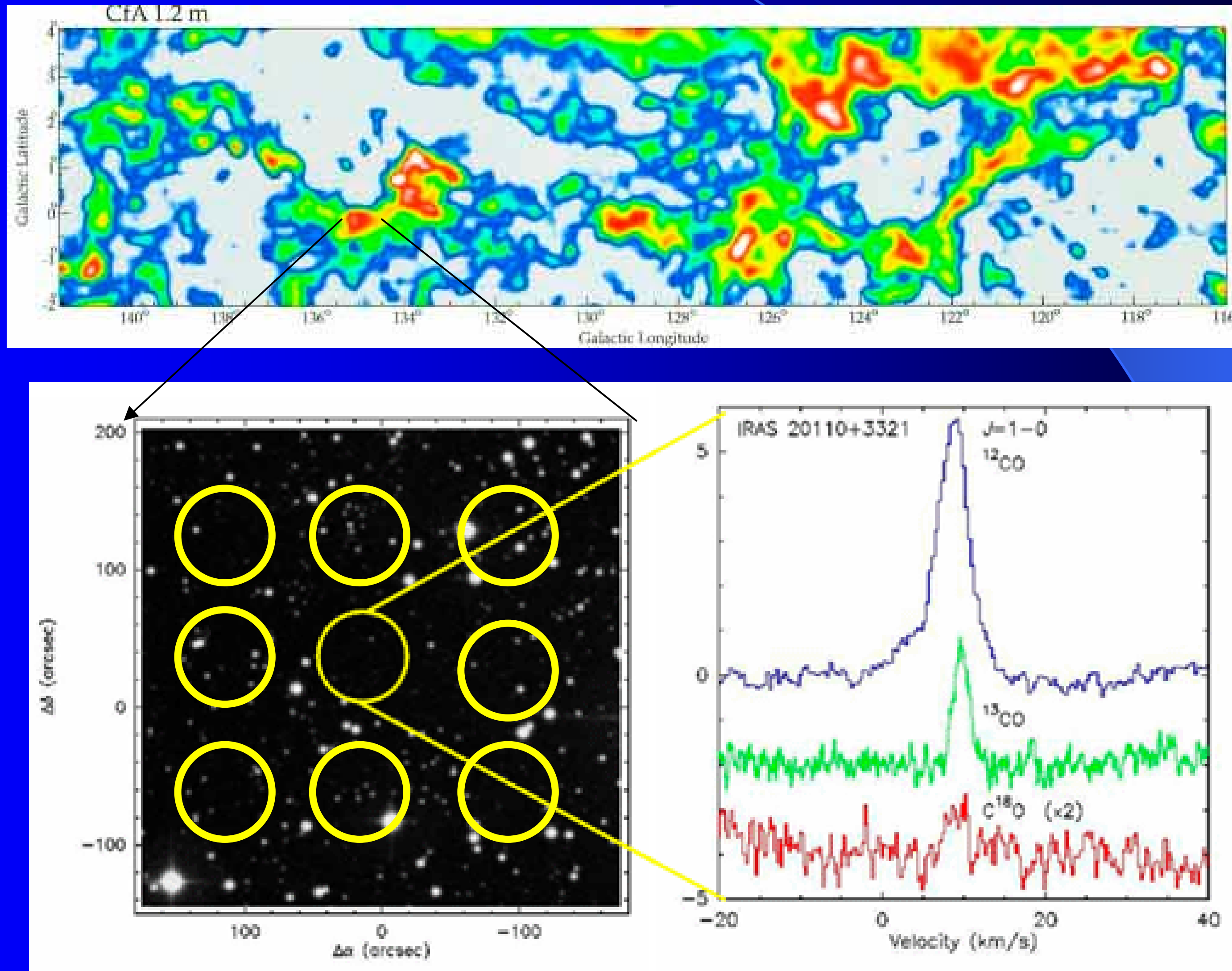
^{12}CO ^{13}CO $C^{18}O$



CO Emission from SN1572 (Tycho's SNR)



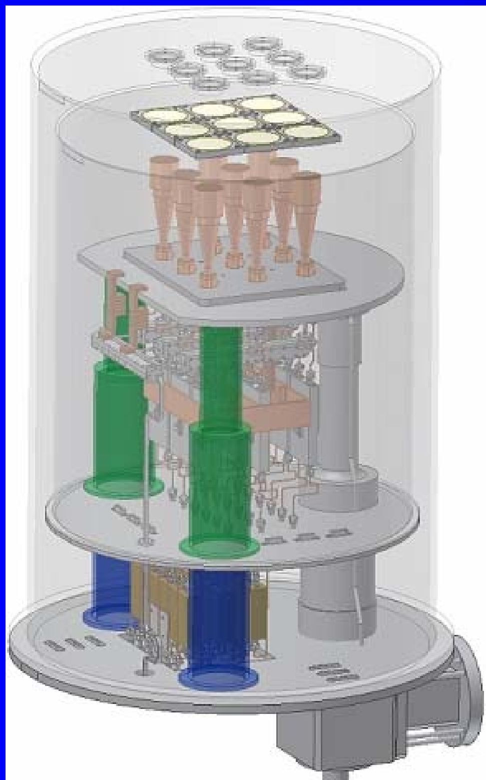
Requirements on large sky coverage & quick imaging spectroscopy: an array receiver as a solution



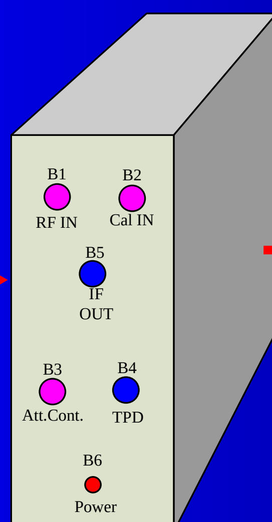
The Superconducting Spectroscopic Array Receiver (SSAR) : Basic Facts

- Array elements: 3×3 pixels
- Working frequency range: 85-116 GHz
- Receiving mode: Sideband Separation (2SB)
- Receiver noise temperature: ≤60 K
- Sideband rejection ratio: ≥ 10 dB
- IF range: 2.64±500 MHz
- Spectrometer: 1 GHz bandwidth,
  16k channels each

Scheme of SSAR



Cryogenic
Multi-beam
RF Front-end



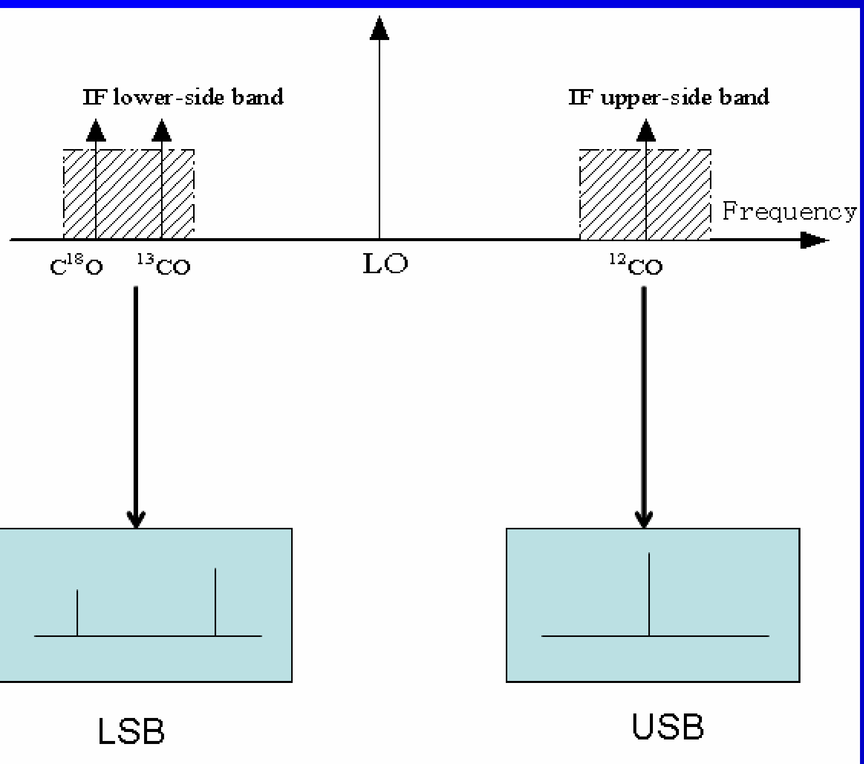
IF signal manipulation
1 GHz BW @ 2.64 GHz
18modules

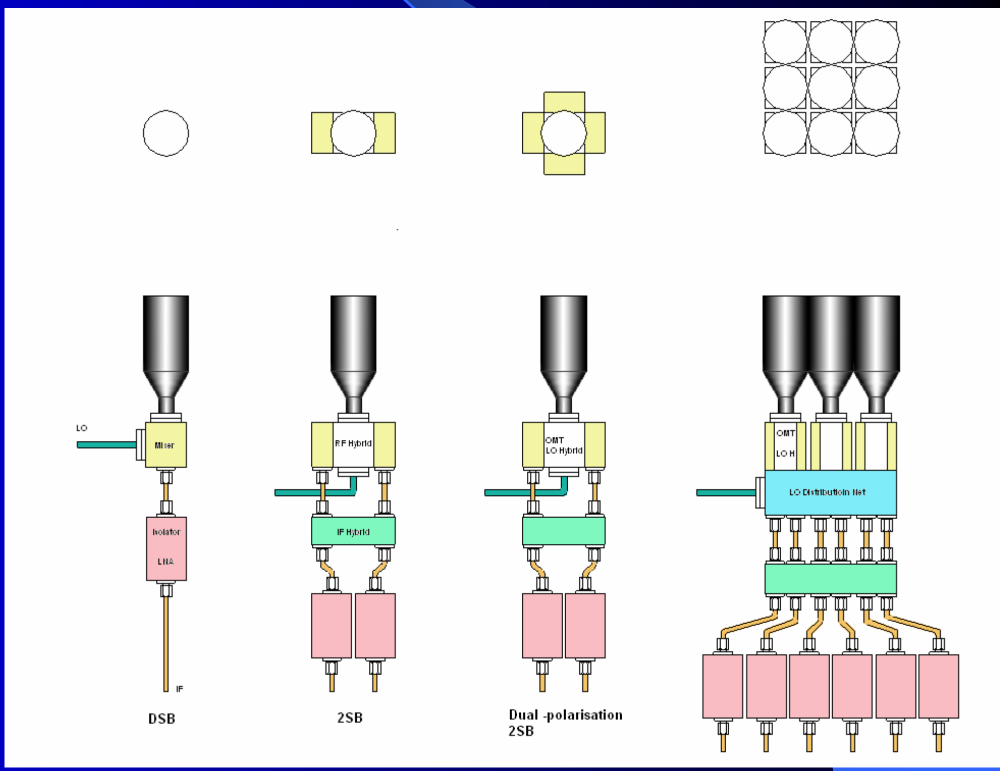
Digital Signal
Processing Backend
18×1 GHz, 16384 pts each

Key Technological Challenges

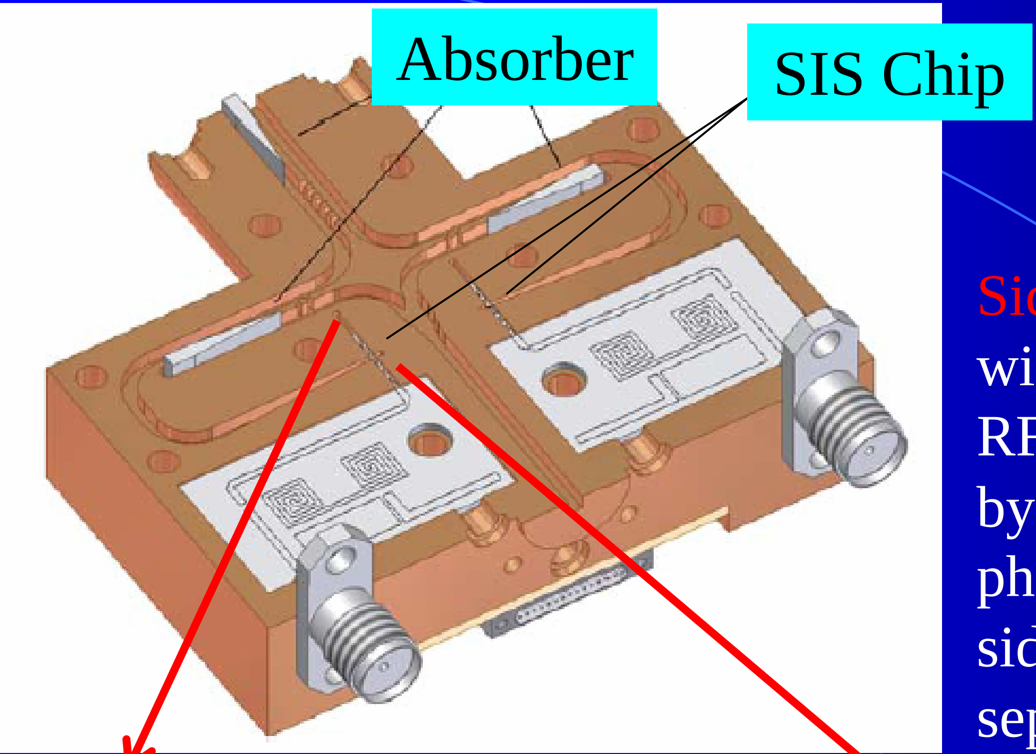
- Design of sideband separation (2SB) mixer unit
- 4K-stage layout and integration of multi-pixels
- LO power distribution
- Cryogenic design and optical coupling
- Design of digital bias network for intelligent control
- FFT Digital spectrometers for 18 channels

Application of sideband separation scheme (2SB): simultaneous receiving of ^{12}CO (USB), ^{13}CO & $C^{18}O$ (LSB)

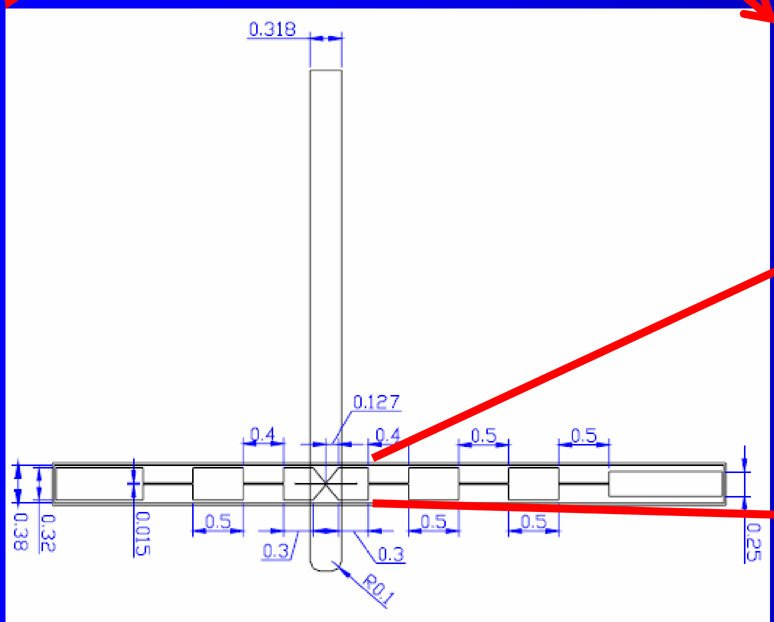


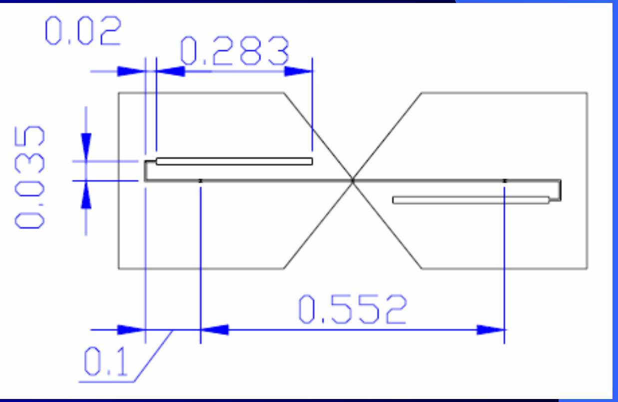


Design of SIS Mixer and Junction

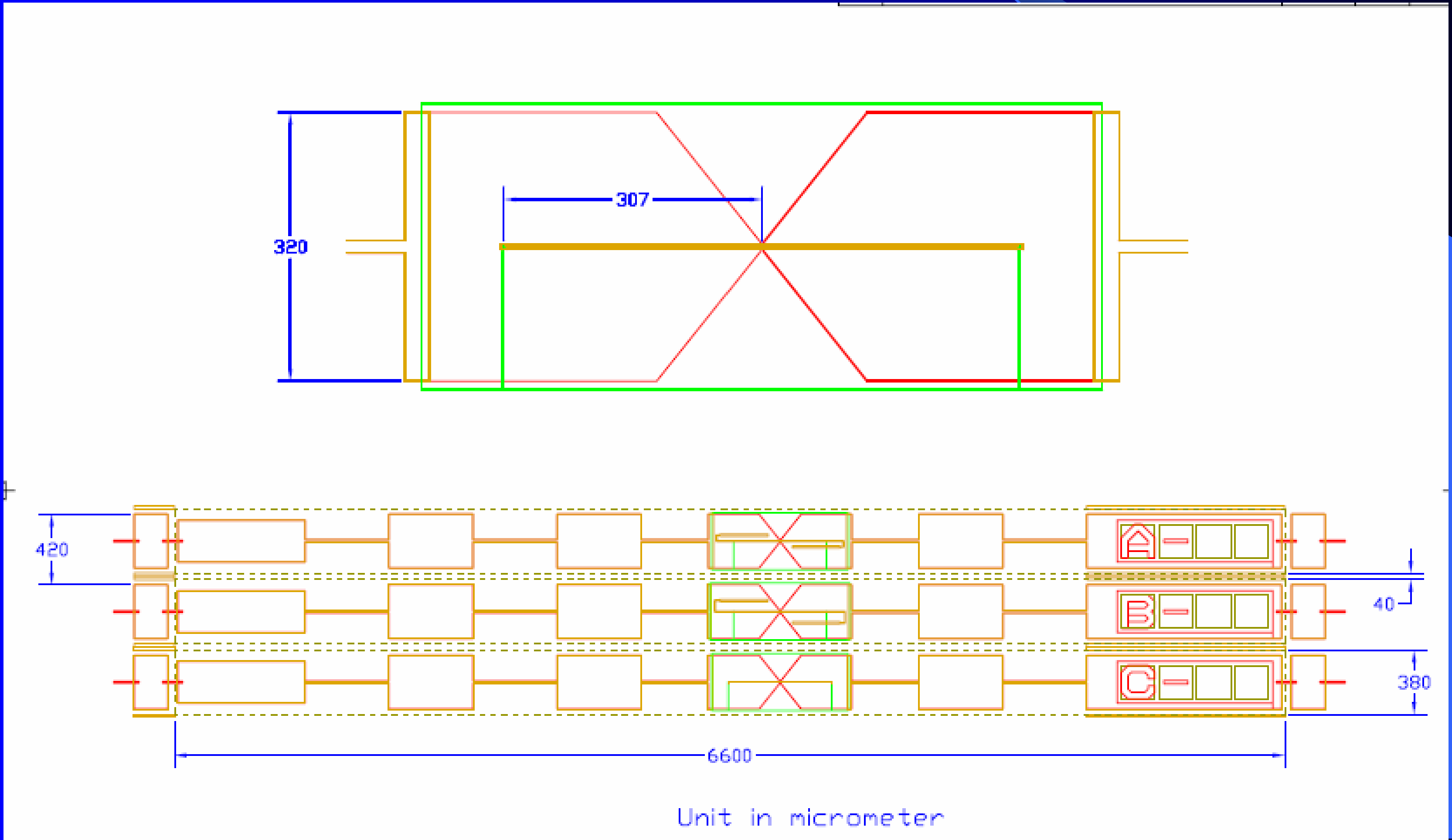


Sideband Separation Mixing Scheme will be used for the mixers. Incident RF signal is fed into two DSB mixers by waveguide RF hybrid with 90° phase shift. The upper- and lower sideband signal are subsequently separated by an IF hybrid.

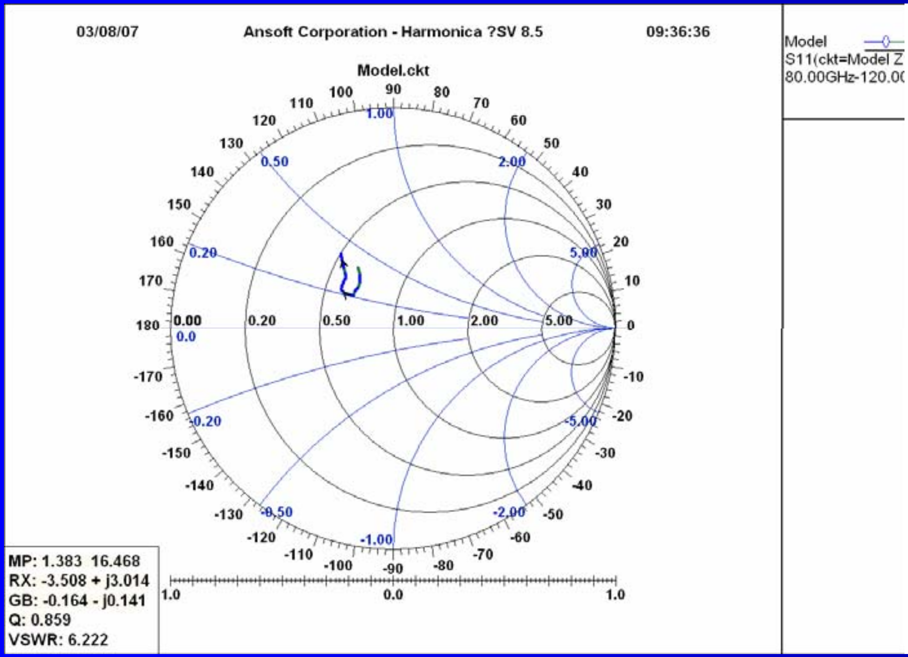


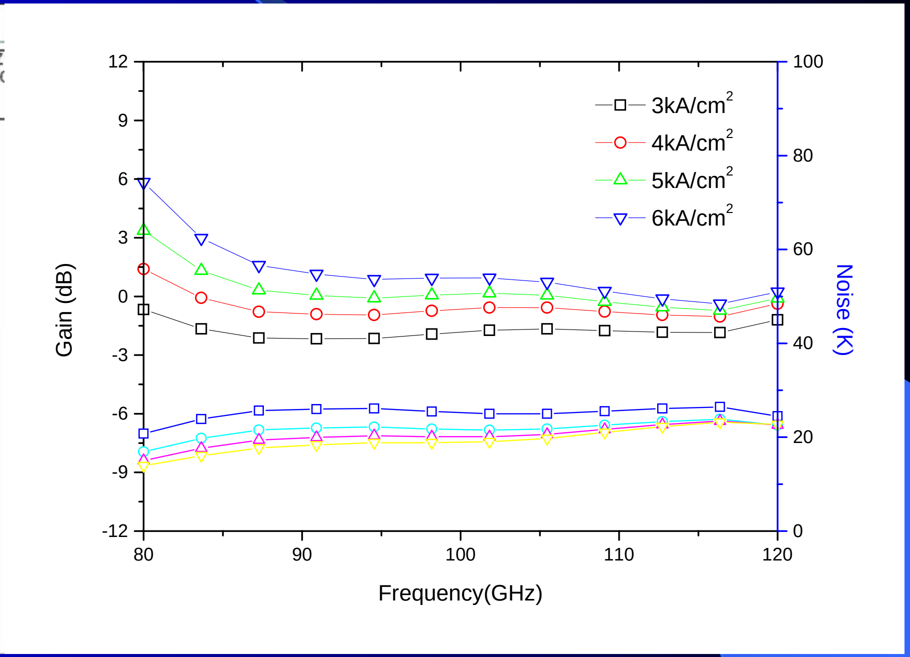


Mirrored Single SIS Junction Design: junction tuned by parallel-connected inductance (Type A and B) & end-loaded design (Type C) (Shan, et al. 2008, in preparation)



Noise Performance of the Superconducting SIS Mixer

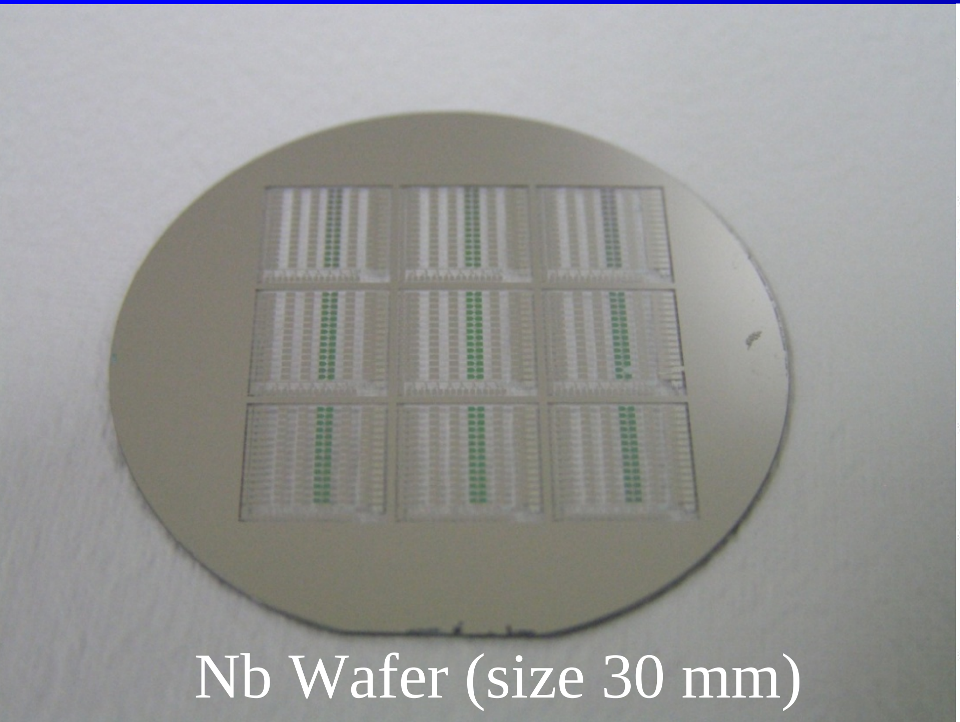




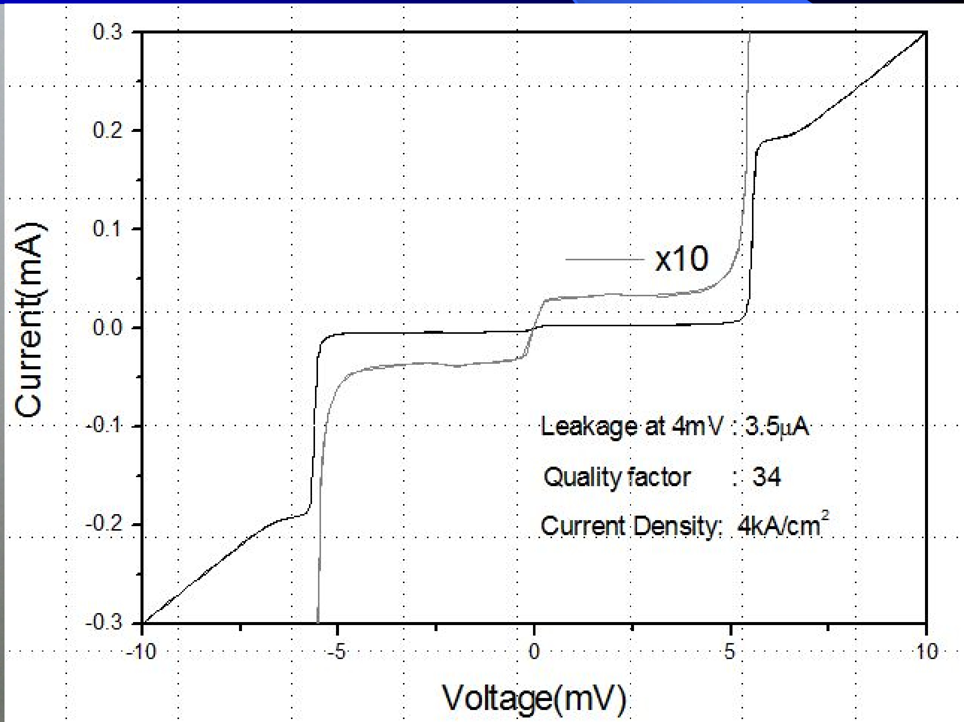
According to the design, the sideband separation ratio will be > 10 dB and the SIS noise level is to be of 20-30 K over the 80-120 GHz band

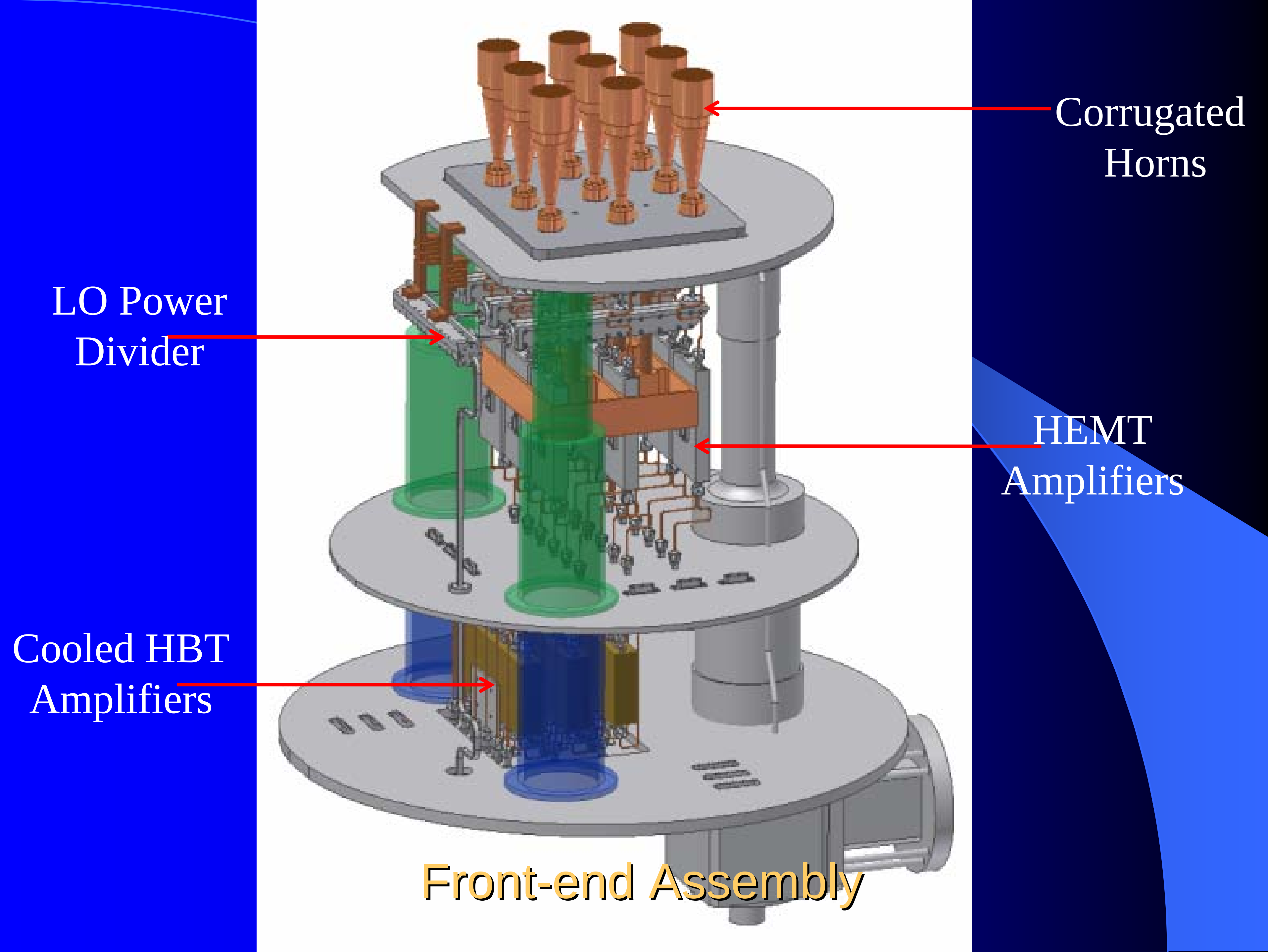
Niobium SIS chip & I-V characteristics

- I-line segmented exposure, shared with the superconducting facilities of NAOJ at Mitaka;
- Mirrored Single Junction， junction size 2μm×2μm, current density 4 kA/cm^2， Leakage 3.5μA;
- 4 wafers, 9 sectors per wafer, and 17 junctions per sector
- yield~30%.



Nb Wafer (size 30 mm)

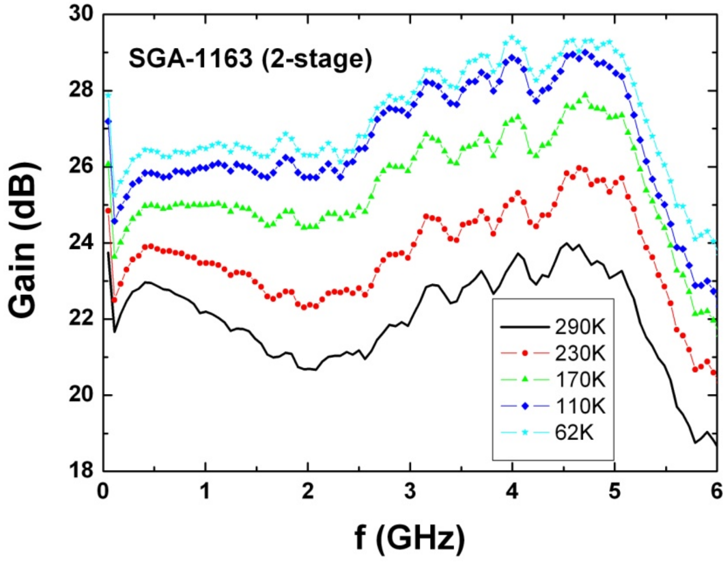


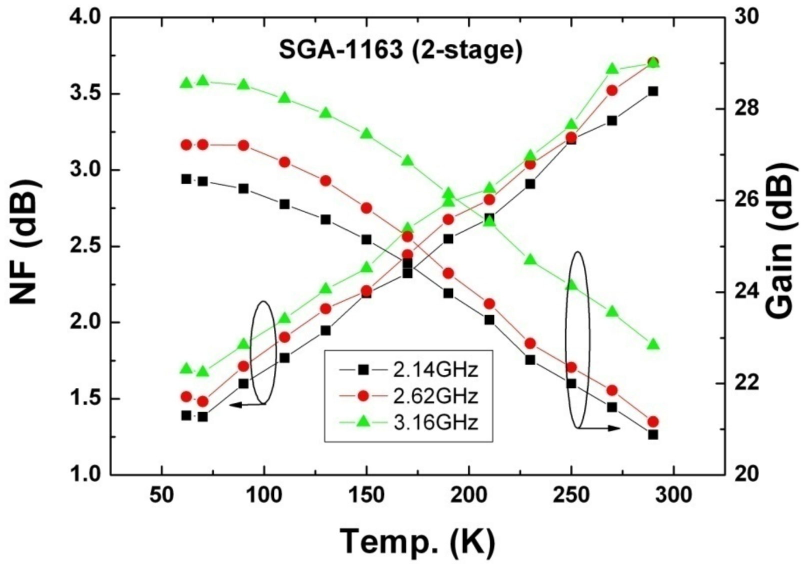


Front-end Assembly

Cooled HBT Amplifiers in 1st IF sector

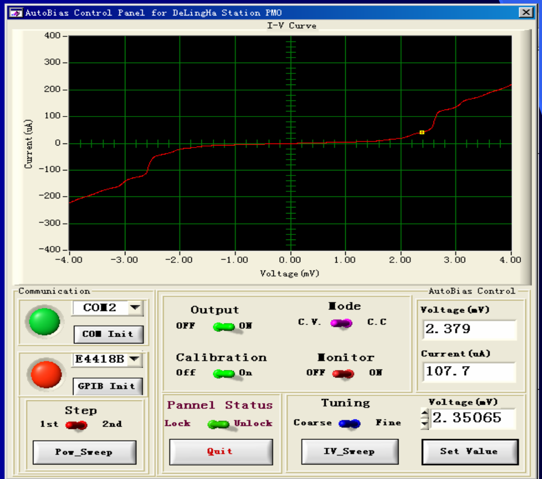
- SiGe HBT amp (Sirenza Microdevices SGA-1163), 2 stages
- NF dropped by 2.2dB and gain increased by 6dB when cooled from 290K to 70K at 2.62GHz.
- Characterization and performance (Cao, A. et al. GSMM2008)





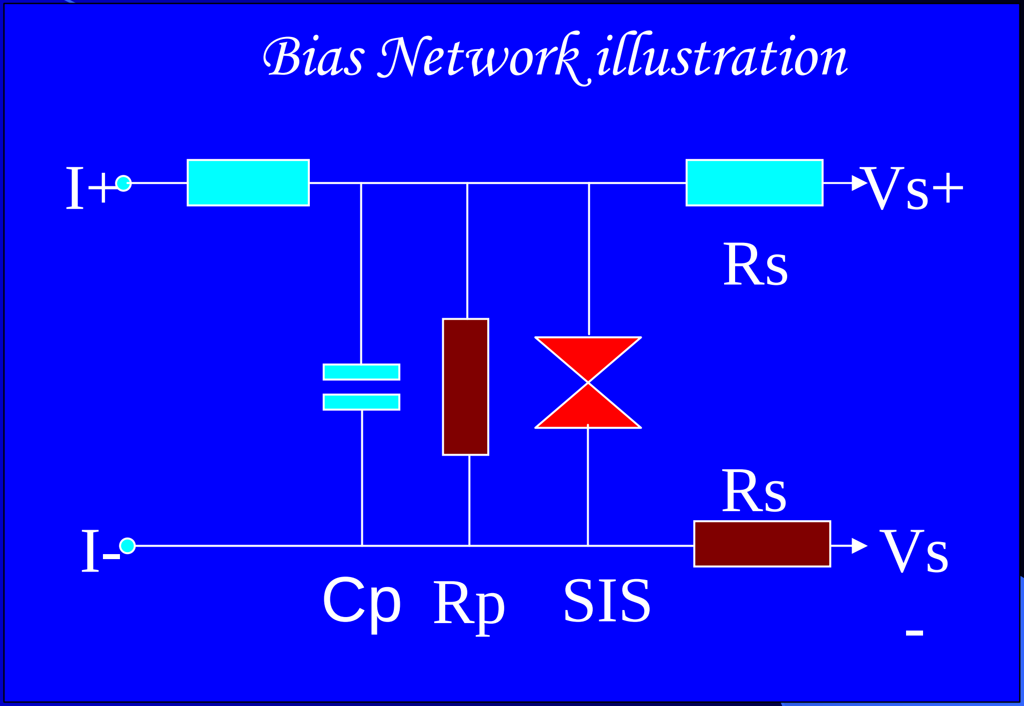
Digital Bias Network (DBN)

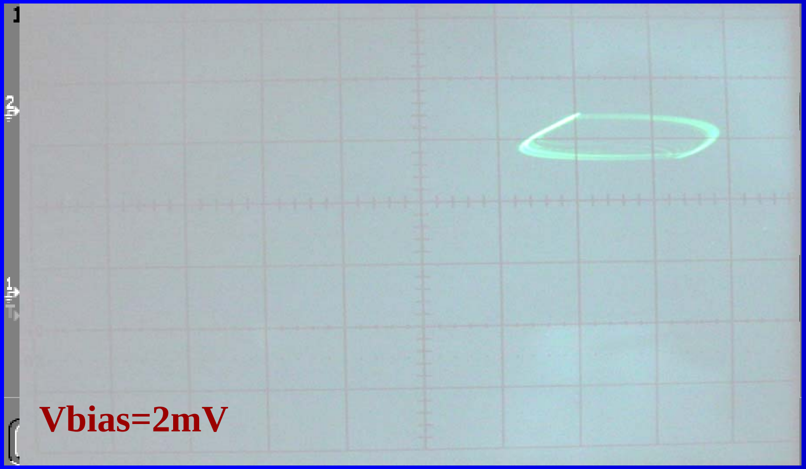
- Using digital Bias source to replace the existing analog bias
- Simultaneous and automatic turning of SIS bias for each array element
- Low noise and High Stability

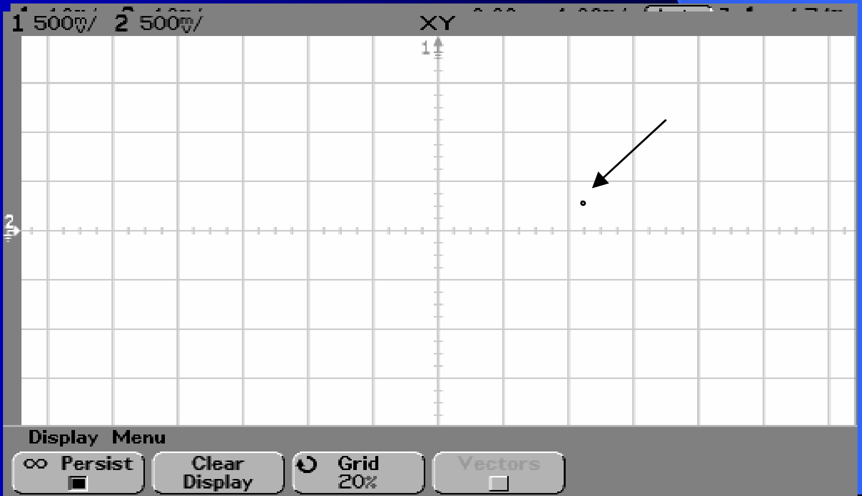


Technological Approaches for the Digital Bias

- **Balanced voltage sensing circuit for reduced read-back noise**
- **Shunt resistor to improve the stability of bias voltage**

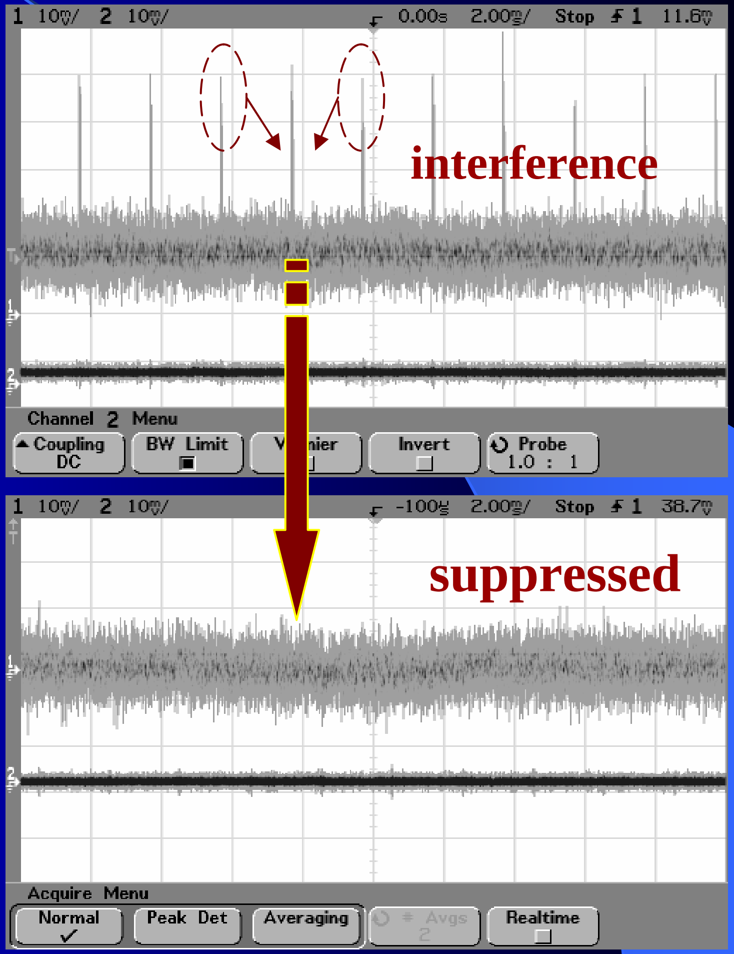






Other Technological Approaches for Digital Bias Network

- Optimized Circuit Layout
  - Integrate OP amp into PCB
  - External DC driving
- Improved electronic isolations
  - Gold-coating connectors
  - photo-optical isolations
- Sophisticated RFI shielding
- Optimized communication scheme



New Digital FFT Spectrometer

Transition from AOS to Digital FFT spectrometers

Features: Wide bandwidth, High dynamic range, High resolution, High stability, Flexible Configuration

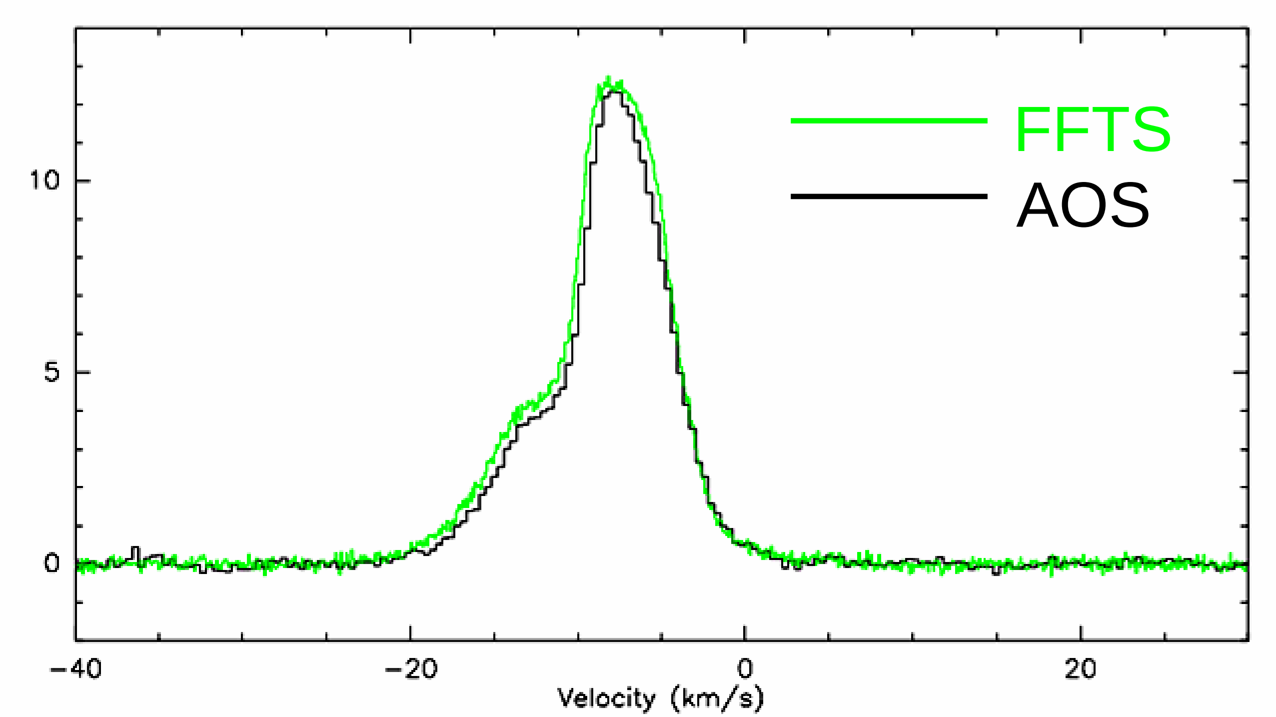
Parameters	FFTS(AC240)	AOS-I/II/III(DLH)
ADC	8bit@2 x 1GS/s	16bit@1MS/s
Bandwidth (MHz)	200/250/500/1000	42/43/145
Channels	16384	1024
Freq resolution (KHz)	16/18/36/74	80/86/209
Dynamic Range (dB)	38 dB	<20
Integratiion (s)	0.001~70,000	0.02~255
Allan time (s)	3000	~100
I/O	cPCI -BUS 32bit	PCI-BUS 32bit
Configuration	reconfigurable	fixed

- 2006 March Start system hardware
- 2007 April Installation and testing observations
- 2007 Sept- Open use

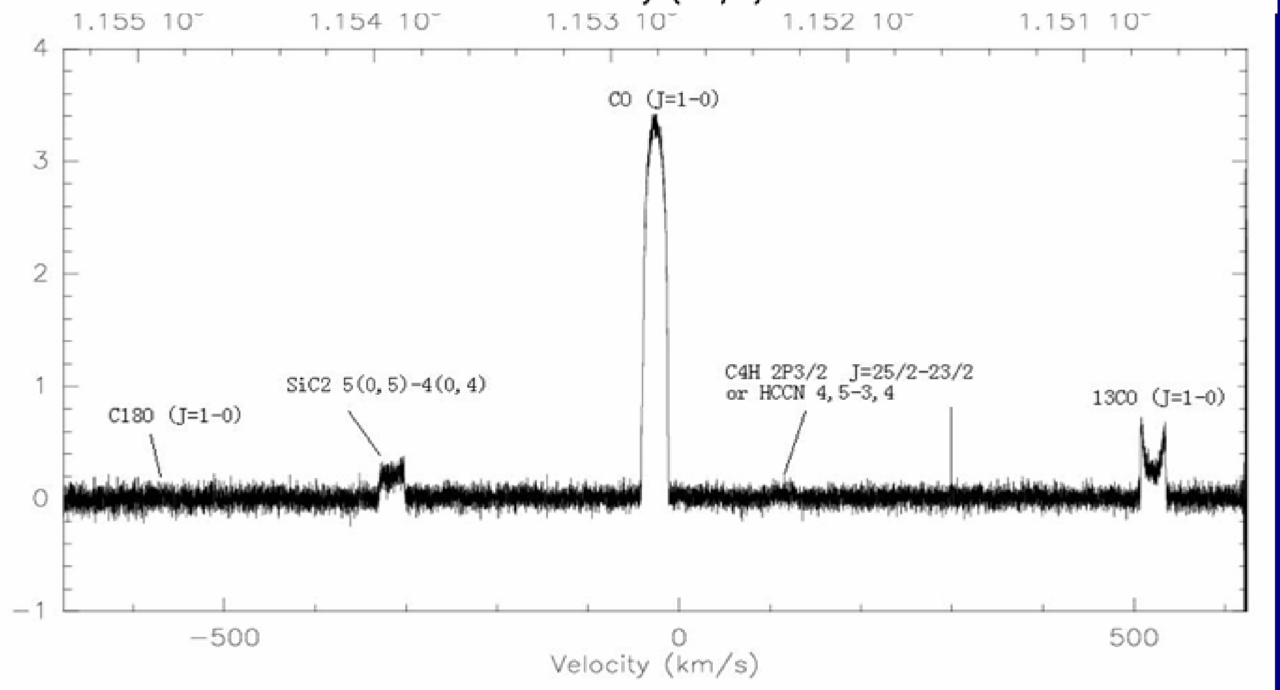
System Development for the Digital FFT Spectrometer:

1 GHz Bandwidth
8 bit sampling
16384 channels

Baseline Quality for Spectra taken by FFTS



S140 500 MHz



IRC+10216 500 MHz

Optical Schemes for Antenna Coupling

A. With Relay Optics with Focusing Mirrors

Drawback: beam obscuration

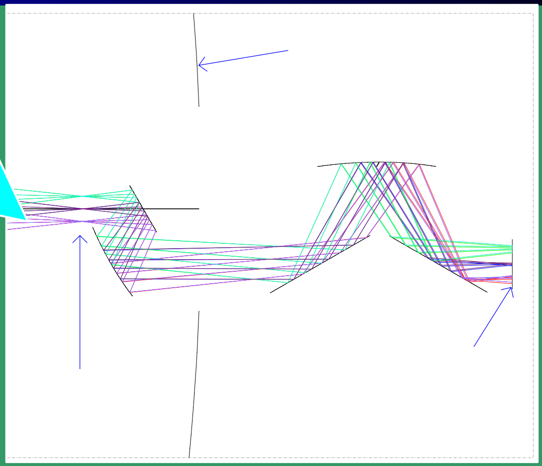
B. With Relay Optics with Focusing Lenses

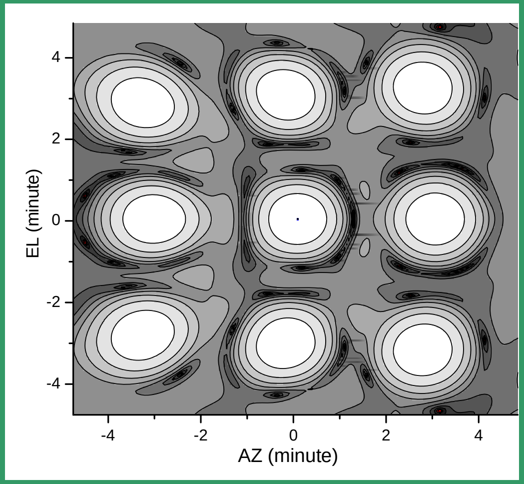
Drawback: reflections between the lenses

C. Without Relay Optics, reshaping sub-refl.

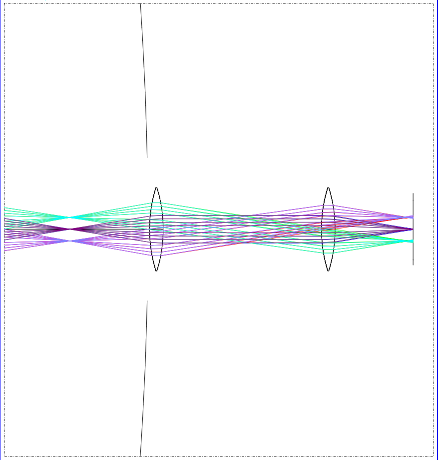
Performance almost ideal

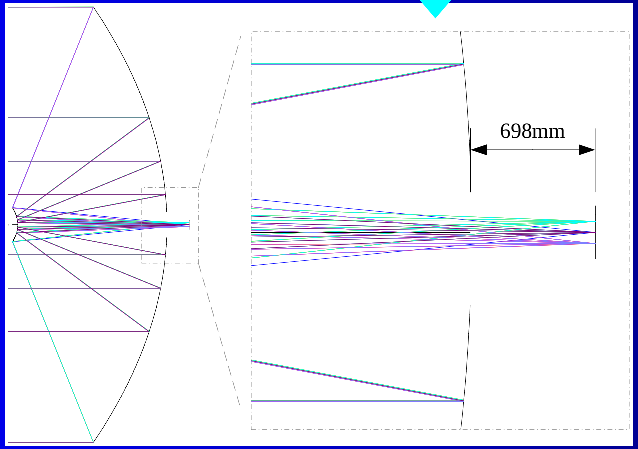
Drawback: inconvenience of field rotation





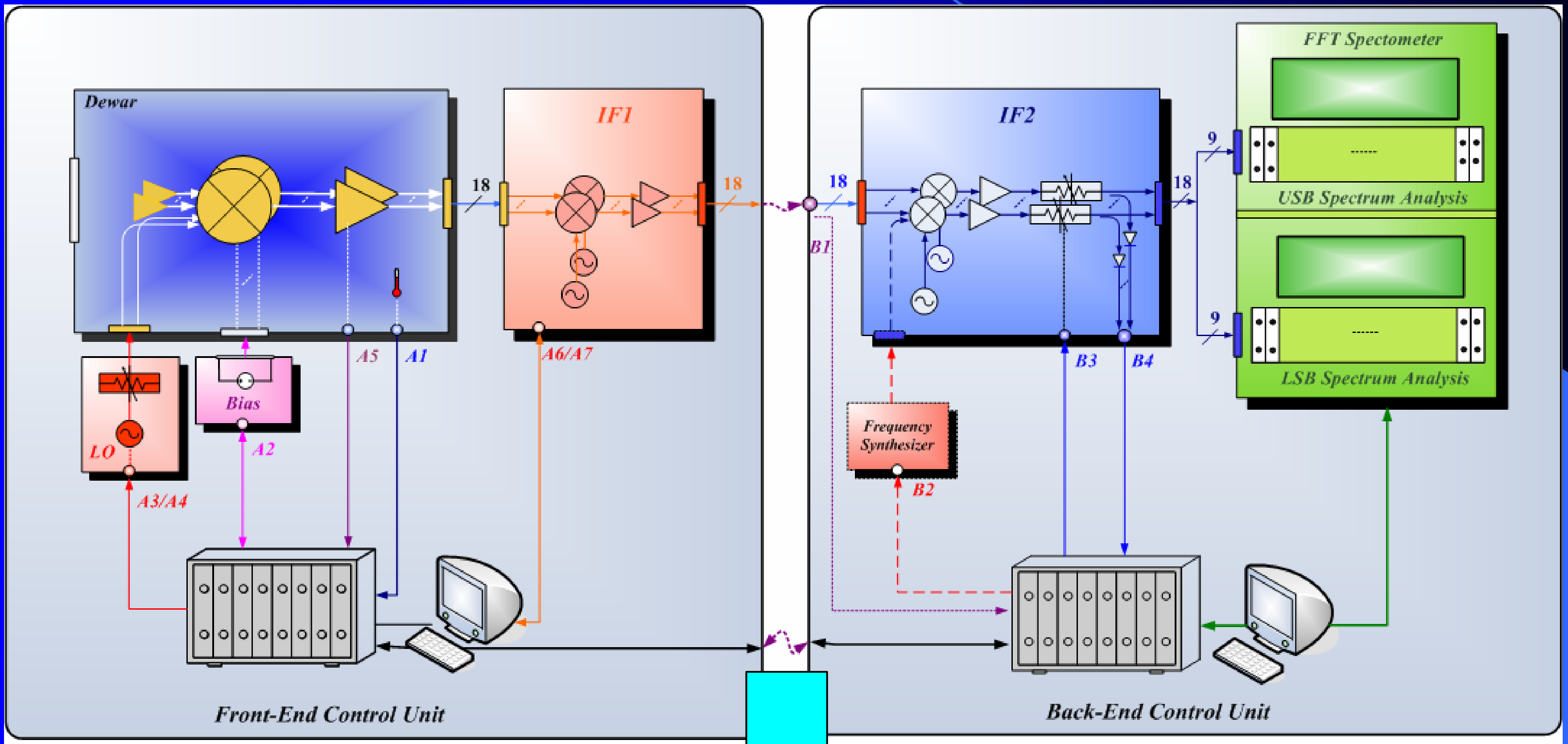
GRASP9 Simulation





Zuo, et al. GSMM2008

Instrument Operation Mode: Outdoor & Indoor

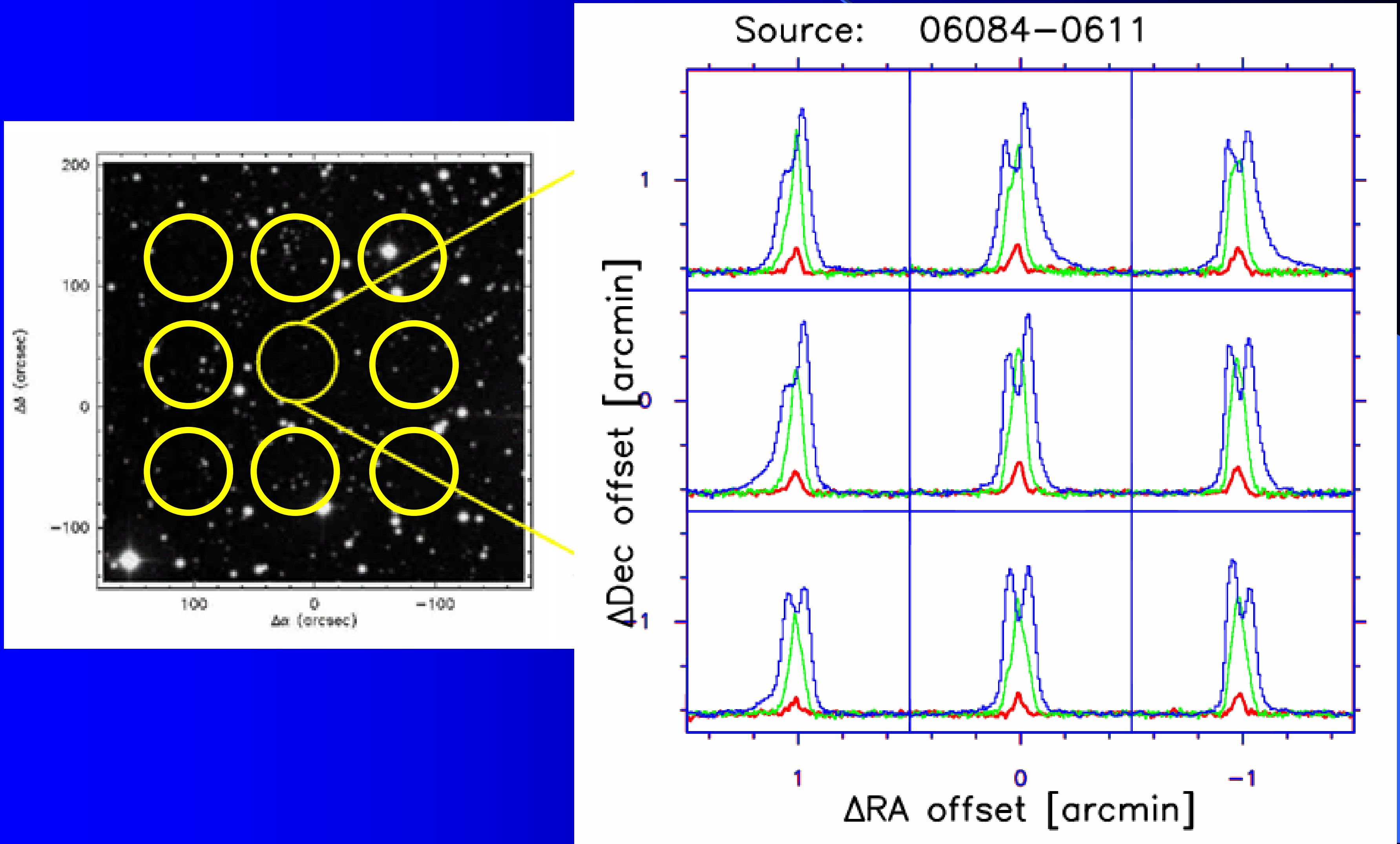


Astronomical Data Output

Major Scientific Capabilities for SSAR

- Galactic plane survey in $^{12}CO/^{13}CO/C^{18}O$ combination: formation and evolution of molecular clouds;
- Physics of high-mass star formation: dense cores, infall motions and outflows;
- Follow-up Studies from Spitzer, Herschel, etc.
- Galactic SNRs;
- $^{12}CO/^{13}CO/C^{18}O$ & high-density gas tracers in nearby galaxies

Simulation for a single pointing of SSAR: order of magnitude improvement w.r.t. the current system

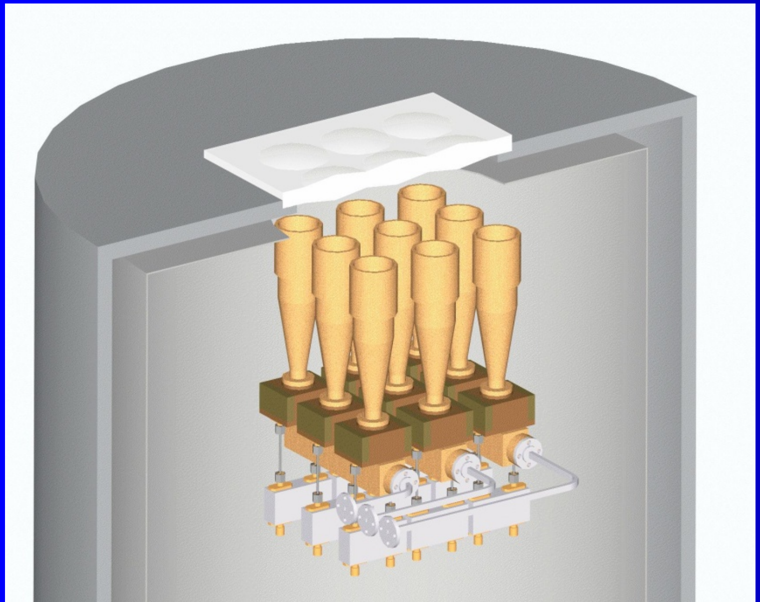


Science Case:
Galactic Plane in ^{12}CO, ^{13}CO, & $C^{18}O$

- Mapping speed: (2-4) $\times 10^6$ spectra/year
- Sky coverage: 15°×20°/year
- Lines: $^{12}CO/^{13}CO/C^{18}O$ (J=1-0)
- Density probing range: 10^{2-4} cm^{-3}
- Line sensitivity: 0.2-0.3 K
- Velocity coverage: 2700 km s^{-1}
- Spectral resolution: 61 kHz (0.17 km s^{-1} @ 110 GHz)

Timeline

- 2004-2005 System Concept
- 2005-2006 Key technological demonstration
- 2006 Project funded
- 2007-2008 Hardware design and development
- 2009 Installation & Testing
- 2010- Open use



Invite collaborations in science programs which make use of the new instrument.

Summary

- 3mm multi-line backend configuration at Delingha telescope has been proved to be an effective configuration in the studies on Galactic star forming regions;
- A Superconducting Spectroscopic Array Receiver (SSAR) , inheriting the advantage of multi-line observations, has been designed to meet the increasing observational demands;
- New electronic designs and advanced approaches, such as the Side-band Separation (2SB) scheme, the digital FFT spectrometry, and the digital bias have been employed in the system;
- The receiver is under development. After completion, it will provide a powerful instrument for surveys of star forming regions in the Milky Way and nearby galaxies. A full coverage of b=±5° of the northern galactic plane can be finished within 6 years.