Cryogenic IF Amplifiers for Focal Plane Arrays

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• Previous work by others (NRAO, CALTECH, BIMA....)

• Possible SIS-Amplifier connection schemes:
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  – Tradeoff between $T_n-S_{11}$ in a 4-12 GHz amplifier
  – Balanced Amplifier

• Open “TBDs”
  – Decisions which need to be taken

• Deliverables to EC

• Use of FP7 funds by FG-IGN
Previous work

• Theoretical work:
  – “SIS Mixer HEMT Amplifier Optimum Coupling Network”; Weinreb S.; MTT, 1987

• Experimental work:
  – “A 200-300 GHz SIS Mixer-Preamplifier with 8 GHz IF Bandwidth”; Lauria E. F., et. al.; MTT-S Digest, 2001 (ALMA Memo 378)
  – "Simple 1 mm receivers with fixed tuned double sideband SIS mixer and wideband InP MMIC amplifier"; Engargiola G., et. al.; Berkeley Astronomy Dep., Internal Report, 2004
• 250 µm GaAs and 300 µm InP
• SIS and first stage IF-Amplifier integrated in the same unit
• No 50 Ω intermediate matching. IF port of mixer provides real part of $Z_{\text{OPT}}$ (~200 Ω) and imaginary part is provided by a spiral chip inductor (high for induction from bonding wire)
• 205-270 GHz LO, 1-5 GHz IF-Band

“An Integrated SIS Mixer and HEMT IF Amplifier”; Padin S., et. al.; MTT, 1996
IF-Amplifier gain and noise temperature measured with 50 $\Omega$ input impedance.

Receiver noise temperature and gain across the IF-Band

Circles are for a 250 $\mu$m GaAs HEMT. Crosses are for a 300 $\mu$m InP HEMT. Dashed lines are for model predictions for the GaAs HEMT.
• InP transistors
• Different units for SIS and IF-Amplifier (independent testing)
• Uses 50 Ω intermediate matching
• Simulated results show better overall performance than with Isolator (ideal, 4 K) but with important gain and noise ripple
• 200-300 GHz LO, 4-12 GHz IF-Band

“A 200-300 GHz SIS Mixer-Preamplifier with 8 GHz IF Bandwidth”; Lauria E. F., et. al.; MTT-S Digest, 2001 (ALMA Memo 378)
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Noise temperature and gain outside of the Dewar IF with LO frequency of 230 GHz

Noise temperature outside of the Dewar IF with LO frequency as a parameter

Triangles for DSB receiver noise temperature and squares for gain

Double-sideband receiver noise temperature, measured outside the Dewar, with LO frequency as parameter

• Same design as Lauria et. al. (2001) with improved SIS 50 Ω IF output impedance
• Separate units for SIS and IF-Amplifier (independent testing)
• IF-Amplifier at 4.2 K with 50 Ω source presents ~4.5 K noise temperature, 35 dB gain
• 84-116 GHz LO, 4-12 GHz IF-Band. Scalable to other ALMA Bands

**DSB noise temperature of the receiver**

Measurement outside the receiver Dewar, LO frequency as a parameter

Simulated (blue) and measured (magenta), LO frequency of 100 GHz
"Simple 1 mm receivers with fixed tuned double sideband SIS mixer and wideband InP MMIC amplifier"; Engargiola G., et. al.; Berkeley Astronomy Dep., Internal Report, 2004

- Different approaches using MMIC amplifiers (3-11 GHz) using 100 µm InP transistors
- 215-240 GHz LO, 1-5 GHz IF-Band

SIS followed by WBA13 MMIC

SIS integrated with WBA12 MMIC

Thermally split integrated SIS and WBA13 MMIC
"Simple 1 mm receivers with fixed tuned double sideband SIS mixer and wideband InP MMIC amplifier"; Engargiola G., et. al.; Berkeley Astronomy Dep., Internal Report, 2004

• SIS followed by WBA13 MMIC
  – Coaxial Amplifier module with 50 Ω intermediate matching
  – Important ripple in noise temperature and gain

Measured output power for 240 GHz LO frequency

Measured noise temperature for 240 GHz LO frequency
"Simple 1 mm receivers with fixed tuned double sideband SIS mixer and wideband InP MMIC amplifier"; Engargiola G., et. al.; Berkeley Astronomy Dep., Internal Report, 2004

- SIS integrated with WBA12 MMIC
  - 50 Ω intermediate matching and ~25 dB amplifier gain
  - Noise temperature and gain ripple improvements over previous design

Measured output power for 240 GHz LO frequency

Measured noise temperature for 240 GHz LO frequency
"Simple 1 mm receivers with fixed tuned double sideband SIS mixer and wideband InP MMIC amplifier"; Engargiola G., et. al.; Berkeley Astronomy Dep., Internal Report, 2004

- Thermally split integrated SIS and WBA13 MMIC
  - Different MMIC temperature lets better bias stability.
  - Low Noise temperature and gain ripple
SIS-Amplifier connection

• Direct connection of present designs:
  – Theoretical simulation
  – IRAM 3mm + CAY 4-12 GHz
  – High ripple obtained at some LOs

• Tradeoff between $T_n - S_{11}$ in a 4-12 GHz amplifier
  – Goal: -10 dB (50 Ohm ref.)
  – Other reference impedance?

• Balanced Amplifier
  – Interesting electrical properties
  – Is it an option?
Direct connection of present designs

• Simulation:
  – Amplifier modeled using HRL InP HEMT (0.1x150 µm) @ 15 K
  – ALMA 4-12 GHz Amplifier model
  – Amplifier reference plane at microstrip line (no SMA input connector)
  – SIS reference plane at the edge of mixer substrate.
  – 4.5 K Ideal Isolator between SIS and Amplifier when present
  – Simulations realized inserting calculated SIS output impedance as source impedance for Amplifier
  – Performance with two LO freq are compared: 88 and 103 GHz

• SIS model data provided by Doris Maier

• A complete model for Gain-Tn of the overall system is needed!
Direct connection

Amplifier

50 Ω Source Impedance

Gain & $T_{REC}$
Direct connection

\( f_{LO} \ 103 \text{ GHz} \)

SIS output impedance

Gain & \( T_{REC} \) - No-Isolator configuration

Gain & \( T_{REC} \) - Isolator configuration
Direct connection

\( f_{\text{LO}} \) 88 GHz

SIS output impedance

Gain & \( T_{\text{REC}} \) - No-Isolator configuration

Gain & \( T_{\text{REC}} \) - Isolator configuration

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AMSTAR+ Grenoble
Tradeoff between $T_n - S_{11}$

Initial

IRL & ORL

Gain & $T_n$
Tradeoff between $T_n$ - $S_{11}$

Optimized $S_{11}$ (Goal: -10 dB)

IRL & ORL

Gain & $T_n$
Balanced Amplifier

Schematic of a balanced amplifier

Theoretical noise temperature*

Measure of the noise temperature of the balanced amplifier inside a cryostat

YXA 1025&1026 - Balanced Amplifier - ISO+Amplifier

- 33% of noise temperature improvement comparing to input isolator configuration.
- Input matching better than -15dB.
- Reduced degradation of the noise for mismatched input terminations.
- Higher complexity and dissipation.
- Hybrid substrate dimensions: 21.4x16 mm.

Open “TBDs”

• Decisions which need to be taken:
  – Maximum dimensions (footprint)
  – Number of stages / gain
  – Bandwidth (4-12 GHz)
  – Maximum power dissipated
    • HIFI: 2mW/stage ; ALMA: 3mW/stage
  – Maximum number of bias wires per pixel
  – Electrical / mechanical interface
    • Microstrip, Coaxial, K-conn. bead?
Things to explore

- Is the balanced configuration an option?
- Should the reference impedance be 50 Ω?
- Is it possible to self bias reliably the HEMTs?
- Do we need to fine tune bias of each device at amplifier level? How?
Deliverables (EC)

- Design study mixer- IF integration (T3 month 21)
- Design report of optimal coupling (T2 month 24)
- Design and test report of integrated 2SB mixer and LNA pixel (T2 month 42)
- Design study report on sub-THz Array infrastructure, (T3 month 42)
Use of FP7 funds by FG-IGN

• A person will be hired. The founding comes from:
  – 1/3 APRICOT
  – 1/3 AMSTAR+ (IRAM WP)
  – 1/3 AMSTAR+ (SRON WP)

• Travel reimbursements (meetings, etc)