HIFAS: Wide-band spectrometer ASIC

Anders Emrich, Stefan Andersson, Johan Dahlberg,
Magnus Hjorth, Omnisys Instruments AB
Torgil Kjellberg, Chalmers University Of Technology

Microelectronics Presentation Days 2010

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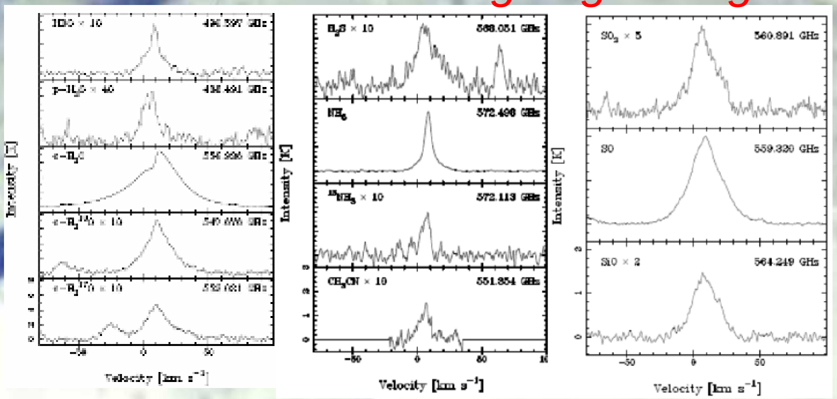
Omnisys

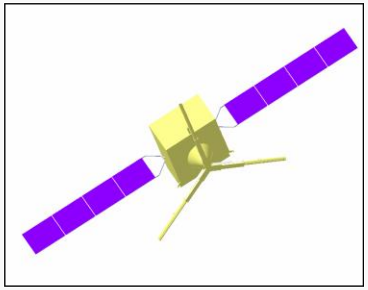
8+ years in space
- still going strong



courtesy of the Odin team

OMNISYS
INSTRUMENTS

Omnisys Instruments



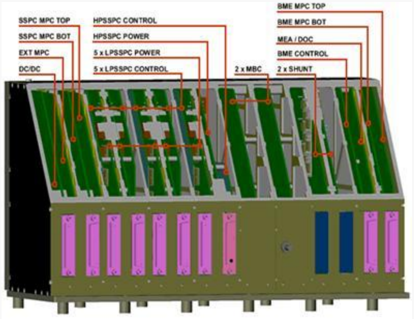
- Founded in 1992, today 21 employees

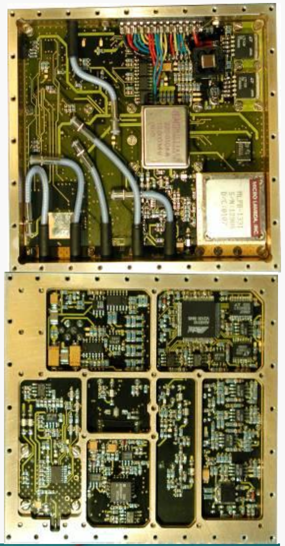
- Past projects:
  - Correlation spectrometer for the Odin research satellite
  - Power system for SMART-1
  - PLL system for the Smiles instrument
  - FFT Spectrometers for several universities in US and Europe.
- Current projects:
  - Interferometer hardware for the ESA GAS demonstrator in collaboration with RUAG.
  - 183 GHz water vapour radiometers (58 units!) for ALMA
  - Back-end for ESA 54 GHz radiometer breadboard (Astrium subcontr.)
  - Power systems for the PRISMA satellites (scheduled launch: April 13)
  - MMIC development in collaboration with Chalmers University
  - Cross-correlator development
  - ...and more

Products

OMNISYS INSTRUMENTS

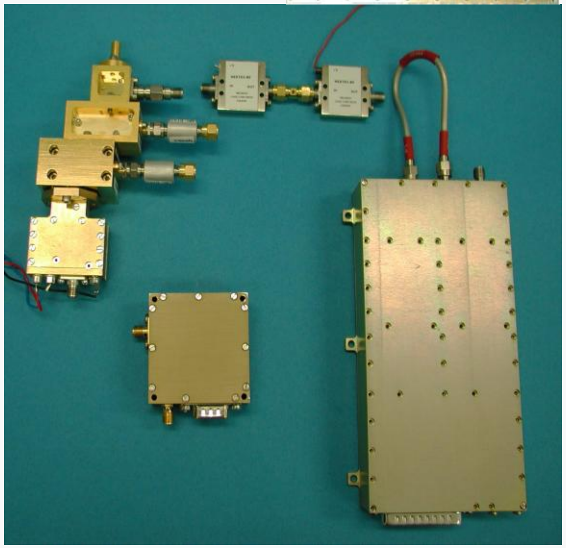
- Scientific instrumentation/Radiometer Systems
- Power Control Systems
- Radiometer front-end systems and subsystems
- Signal Processing Equipment
  - Cross correlation equipment
  - Auto Correlation Spectrometers
  - FFT spectrometers
- Component development
  - LNA:s, mixers, multiplier

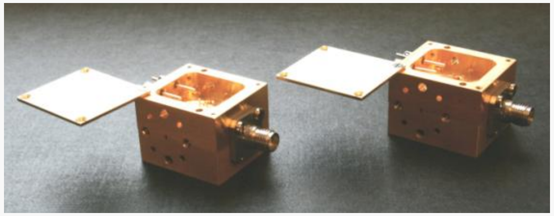




SMILES

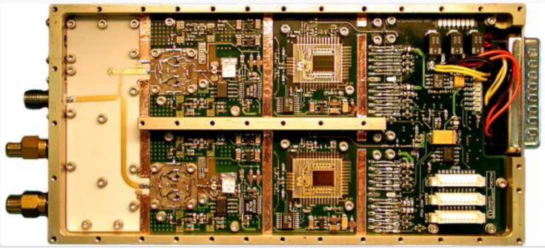
340 GHz Radiometer





340 GHz mixers

6 GHz /4096 ch spectrometer



Correlation spectrometers

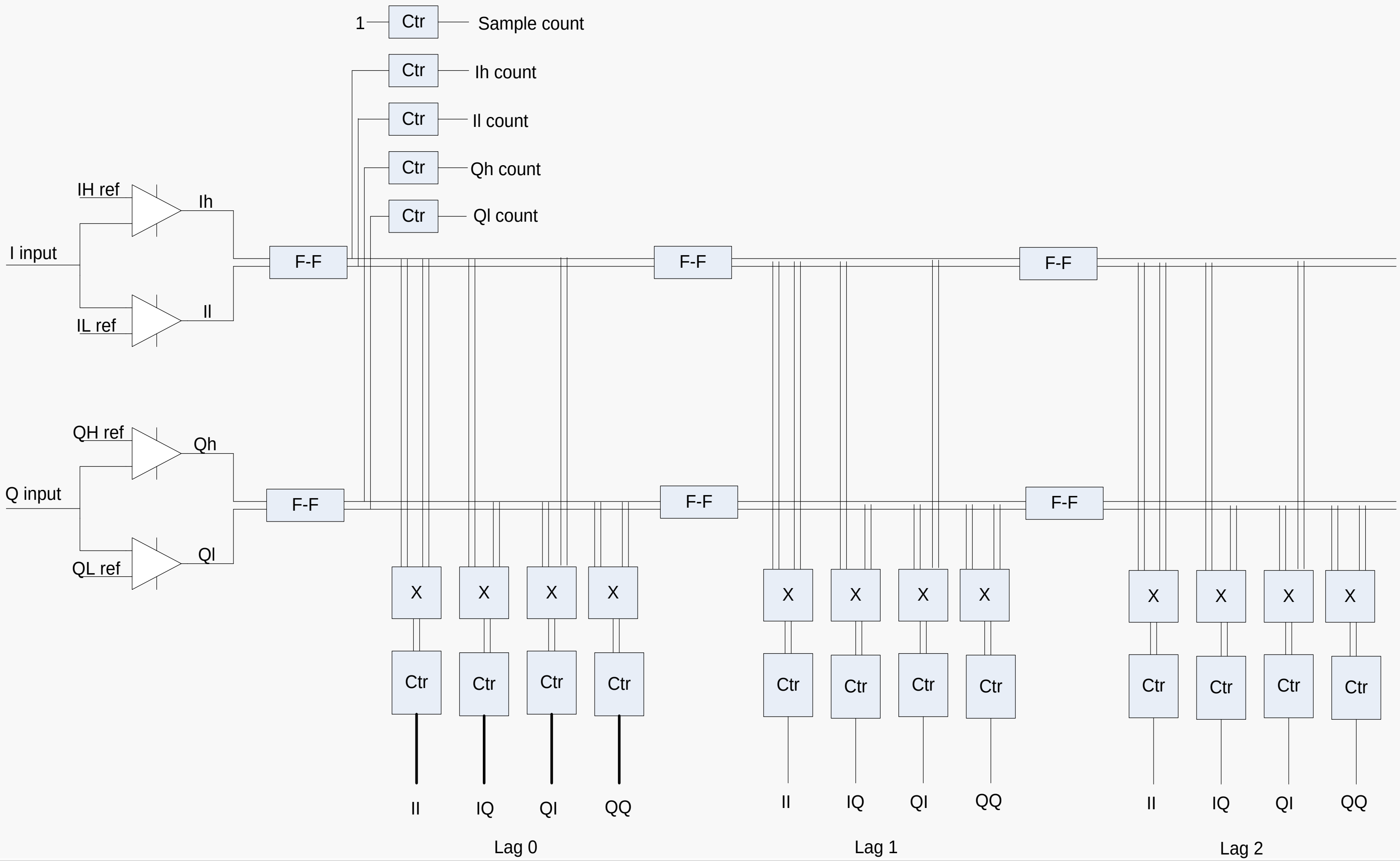
- Spectrometers measure power spectral density of radio signals.
- Used in astronomy, climate research, and other fields...
- Integration times ranging from milliseconds to hours.

- Different measurement principles
  - Digital filterbank (special case: FFT spectrometer)
  - Digital autocorrelator
  - Acousto-Optical
  - Chirp Transform
  - Analog filterbank
  - Analog autocorrelator

- Advantages of the digital autocorrelation spectrometer:
  - Compact, efficient, low power consumption
  - Flexible in terms of bandwidth, integration time, switching
  - CMOS logic, i.e. well-known technology, Moore's law

Omnisys DACS Architecture

- Digital complex autocorrelator with 3-level quantization:



Omnisys DACS history

- 1997: 2:nd generation chipset
  - Separate sampler and correlator chips
  - 100 MHz bandwidth per chip, 96 channels, 0.4 W.
  - Used on the SSC ODIN satellite
  - Flight proven, 8 years of operation in LEO aboard ODIN.
- 1999: 3:rd generation chipset
  - 600 MHz bandwidth, 256 channels, 1.1 W
  - Used in the DLR TELIS spectrometer
- 2002: 4:th generation chipset
  - 2000 MHz bandwidth, 1024 channels, 1.8 W
- 2009: HIFAS

HIFAS Design Drivers

- One of the main drivers for HIFAS development has been the STEAMR concept
  - Limb sounding instrument
  - Linear array of 14 receivers measuring simultaneously the atmosphere at different altitudes
  - HUGE simultaneous measured bandwidth, >150 GHz

- Focus on increasing processed bandwidth (i.e. Increasing the sample rate) per correlator to reduce IF complexity and make the instrument feasible.
  - 4 GHz BW spec, 8 GHz BW design goal

- Interface between sampler and correlator becomes critical
  - For 4 GHz bandwidth, we get 16 Gbit/s data between the sampler and correlator. This data interface starts dominating the ADC power consumption and makes integration tough.
  - Moving to a BiCMOS process and integrating the A/D converter and correlator core on one chip solves this problem, at the expense of slightly slower CMOS.

HIFAS Key Characteristics

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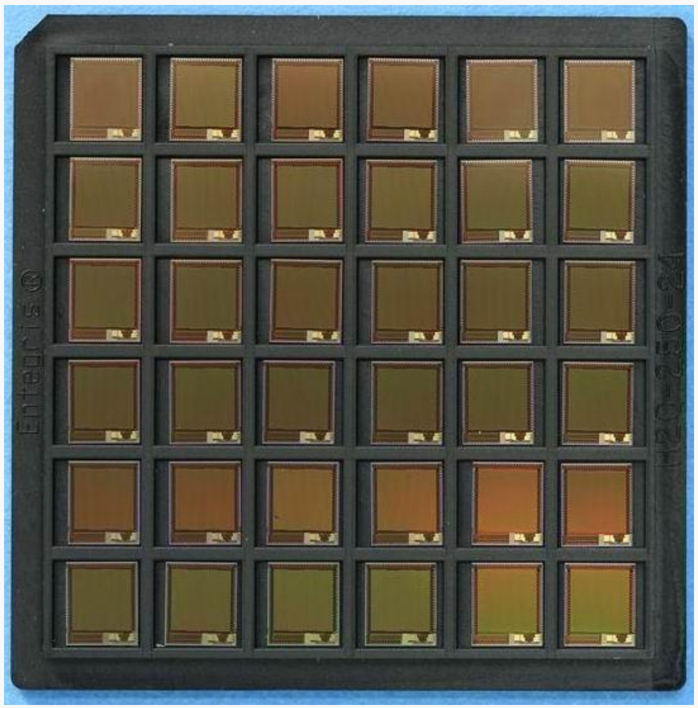
- Integrated ADC and Correlator on one chip.
- Two sampler input modes, Complex (I&Q), and Real (I&I) for flexible IF interfacing
  - In complex mode, I & Q inputs sampled at the same time.
  - In real mode, the two inputs are sampled at opposite sample clock phase.
- Correlator part divided into four banks to allow operation with different resolution.
  - 128/256/384/512 complex lags (II,IQ,QI,QQ) in complex mode.
  - 256/512/768/1024 lags in real mode.
- The two input modes are equivalent in terms of power consumption, bandwidth and resolution.

- The different modes can be a bit confusing. Rules of thumb:
  - Sample clock frequency equals RF bandwidth in both modes.
  - Each complex channel results in two frequency ”bins” (both sidebands) so the spectral resolution is the same in both modes (~1000 channels at max res.).

HIFAS Implementation

OMNISYS INSTRUMENTS

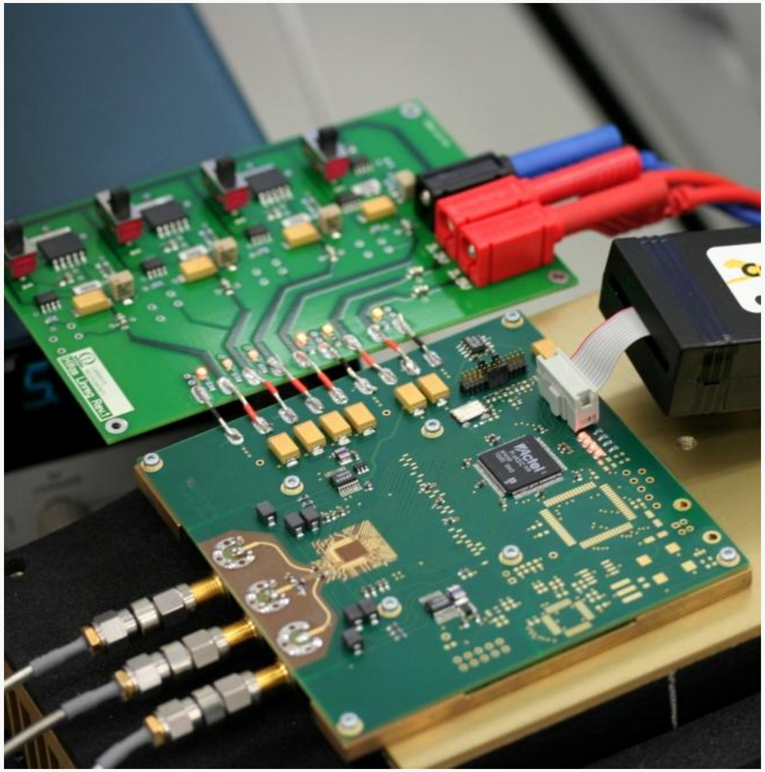


- Overall chip details
  - IBM 7WL 180 nm SiGE BiCMOS process
  - Physical size: 5.2x6 mm
  - Bond pads for analog input and digital I/O
- Chip parts
  - Analog inputs
  - Digitiser
  - Correlator
  - Read-out logic
  - Digital I/O

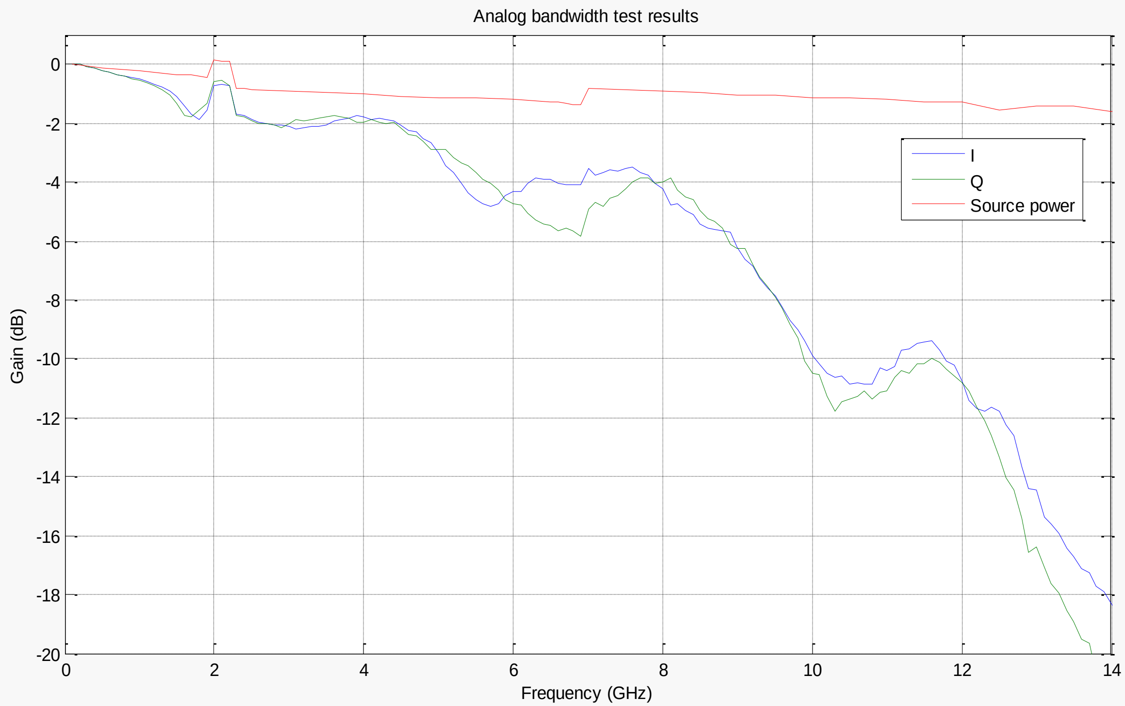
Lab testing

- The chip wire-bonded onto a test board.

- Tested for:
  - Functionality
  - Maximum clock rate
  - Power consumption
  - Analog response
  - Temperature
  - SEU Sensitivity (ESA CASE)
  - Total dose

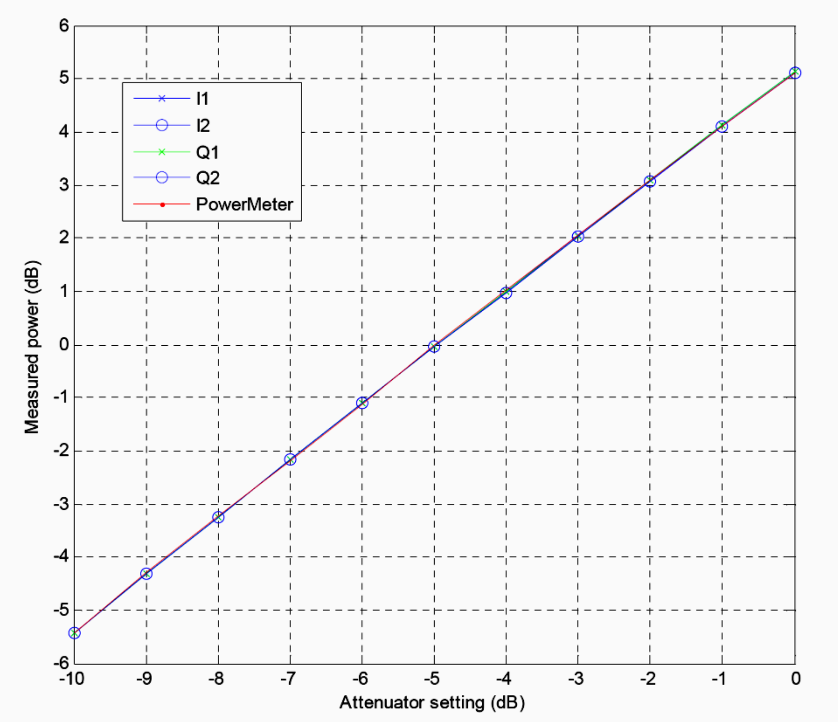


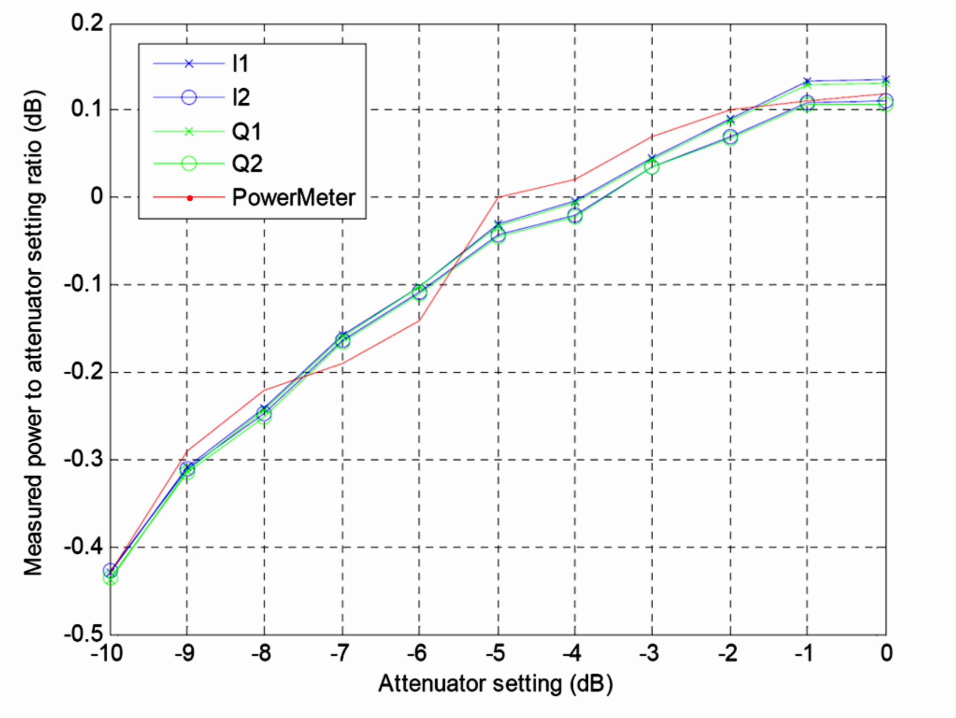
Analog response



- Comparing CW source power estimated using HIFAS with power meter results(red).
  - 3 dB-bandwidth of 5 GHz measured
  - Some SWR caused by test board, improvements are possible
- Analog response limits the maximum useful clock rate of the real input mode
  - Complex mode uses only half the IF BW, so not as critical there.

Total power dynamic range





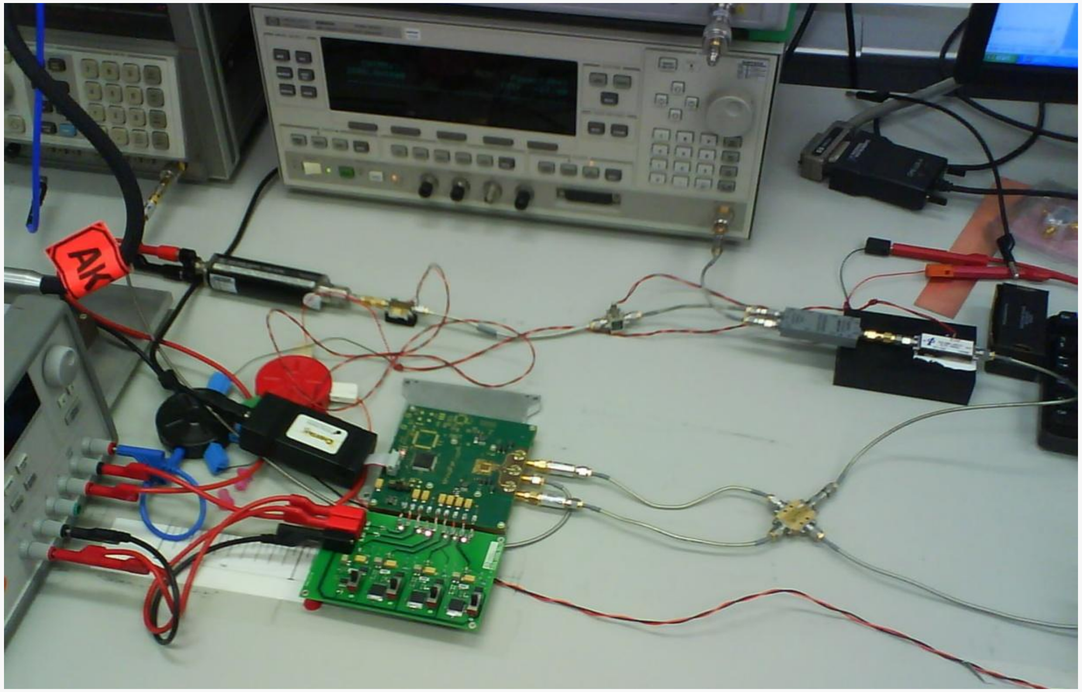
- Comparing wideband noise source total power estimated using HIFAS with power meter results(red).
  - Results match within 0.05 dB over 10 dB range, power meter precision.

Maximum speed and power

- Maximum speed determined experimentally by adjusting clock frequency and checking that the data is correct
  - Up to 5 GHz at full resolution and 6 GHz at half resolution works.
  - Possibility to stretch further to 7-8 GHz but requires increasing CMOS supply voltage above spec.

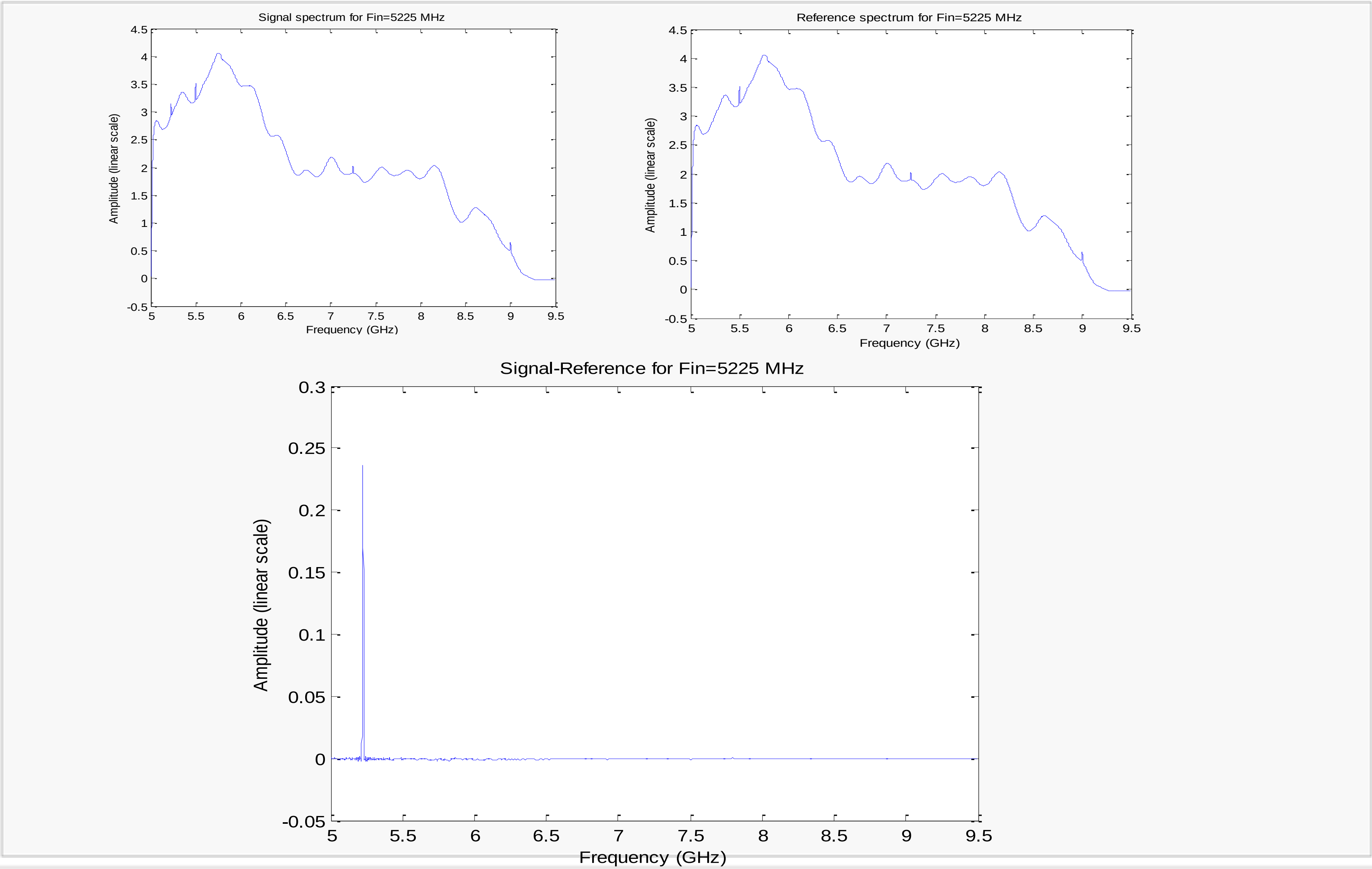
- Sampler consumption almost constant, 270-300 mW
- Correlator consumption increases with sample frequency and number of channels.
- Some typical figures measured:
  - 1 GHz clock, ¼ resolution: 0.5 W total
  - 1 GHz clock, full resolution: 0.7 W total
  - 5 GHz clock, ¼ resolution: 0.9 W total
  - 5 GHz clock, full resolution: 2.2 W total
  - 6 GHz clock, ¼ resolution: 1.1 W total (current baseline for STEAM)
  - 6 GHz clock, full resolution: 3.3 W total (with increased voltage)
- Does not include margins for power conditioning etc.
- This is NOT a data sheet!

Switched Measurements



- Adding CW and noise with power combiner. Switching CW on and off.
- Sensitive lab setup (SWR issues, many cables/interfaces)

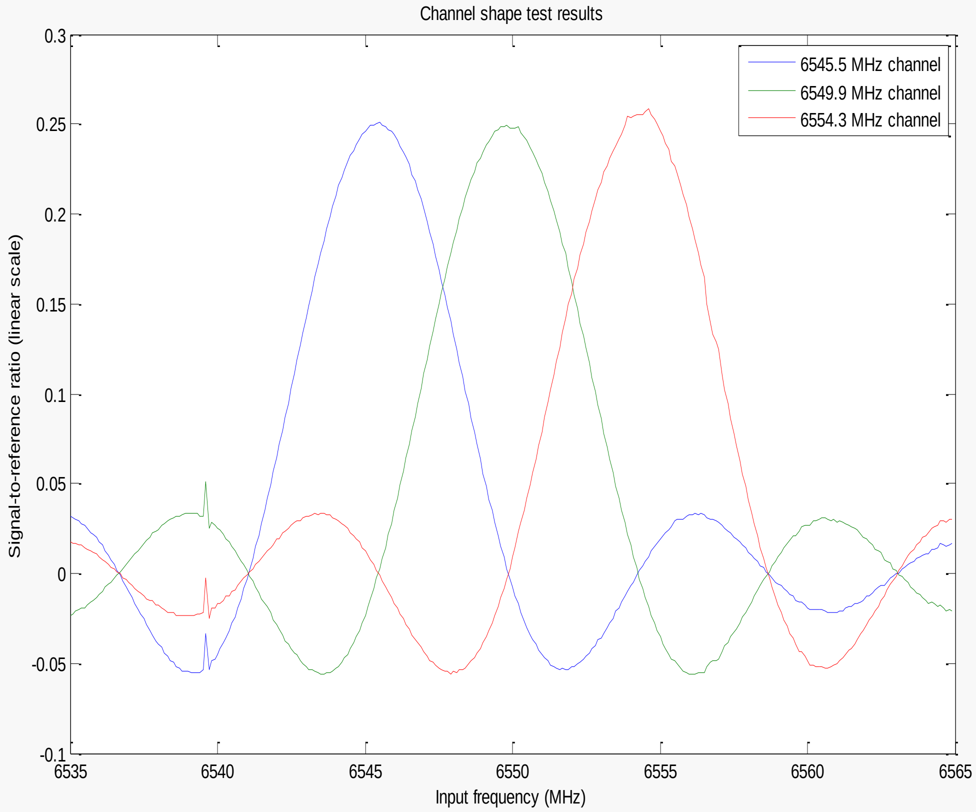
Switched Measurement Examples



Switched Measurements (cont)

- Around 20 dB signal peak to spur peak ratio.
- Expect to increase this to 25-30 dB with integrated IF system.

Channel shape



SteamR early breadboard tests

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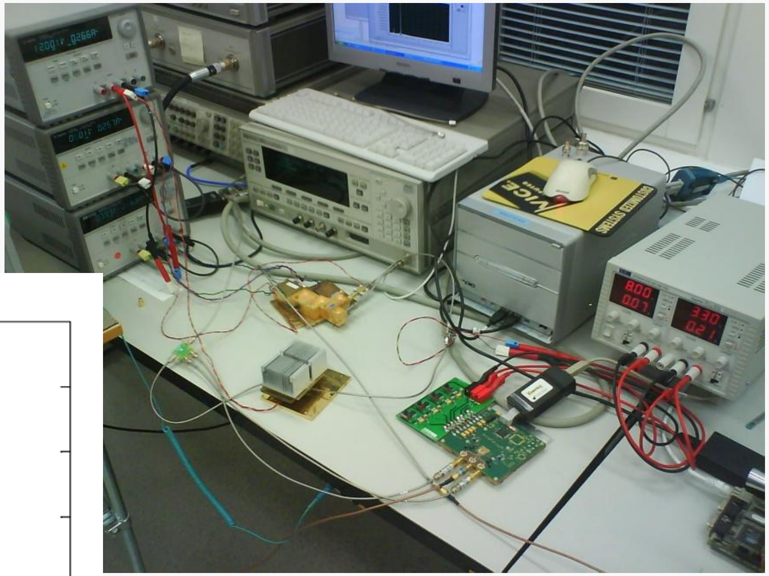
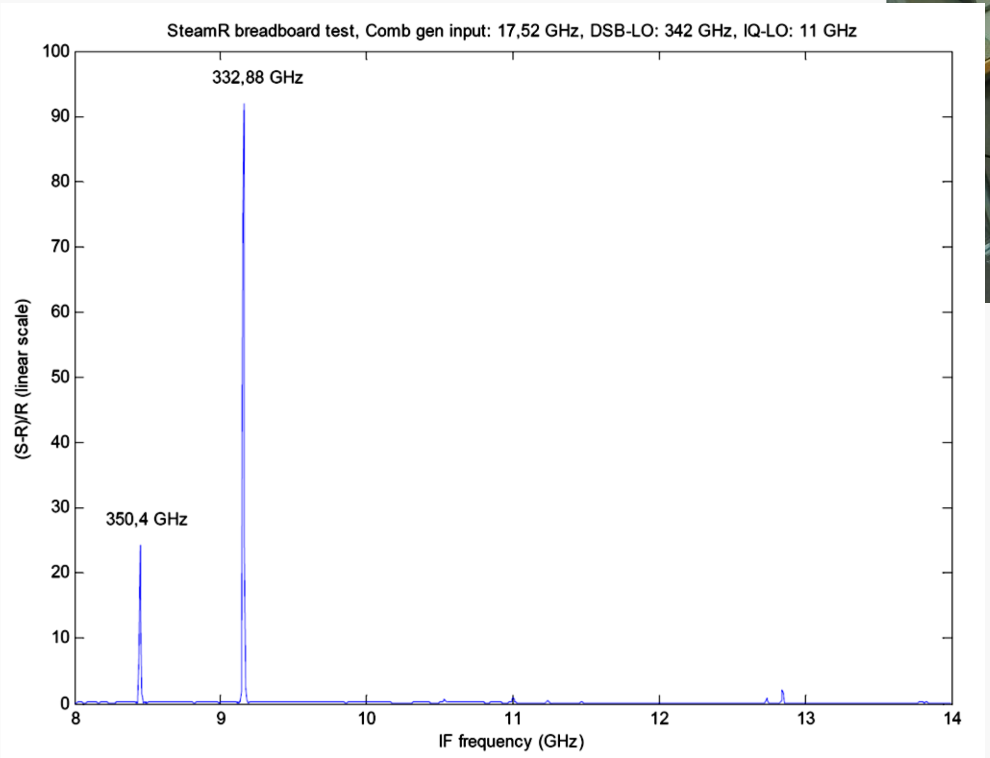
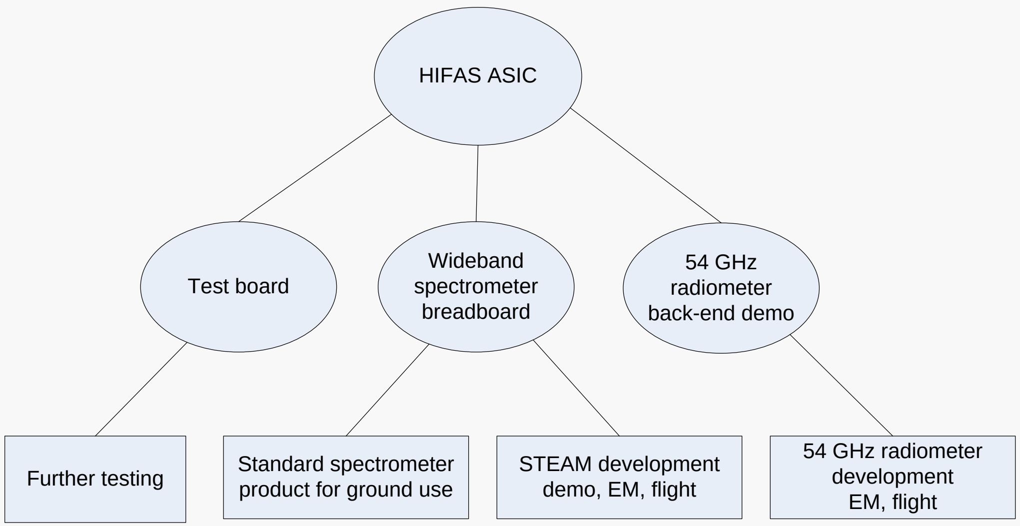
- Test with 330-350 GHz receiver chain
- Comb generator as signal source
- HIFAS test board as back-end





Planned uses for HIFAS



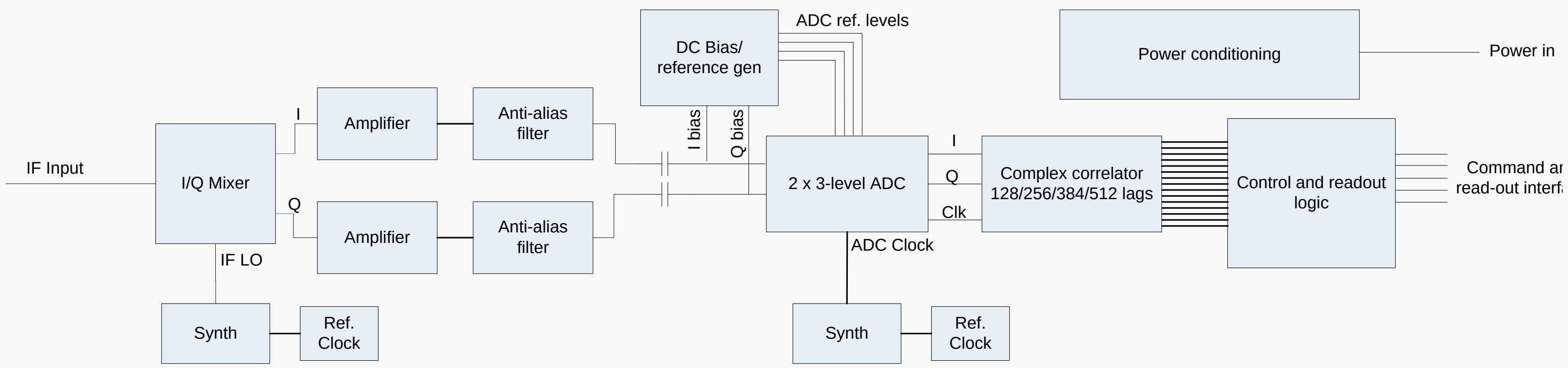
- The chip will be used in:
  - Flight spectrometer development projects
  - Boxed spectrometer product for ground use, marketed by OI
- Omnisys does not plan to sell the ASIC by itself.

ESA 54GHz radiometer demonstrator

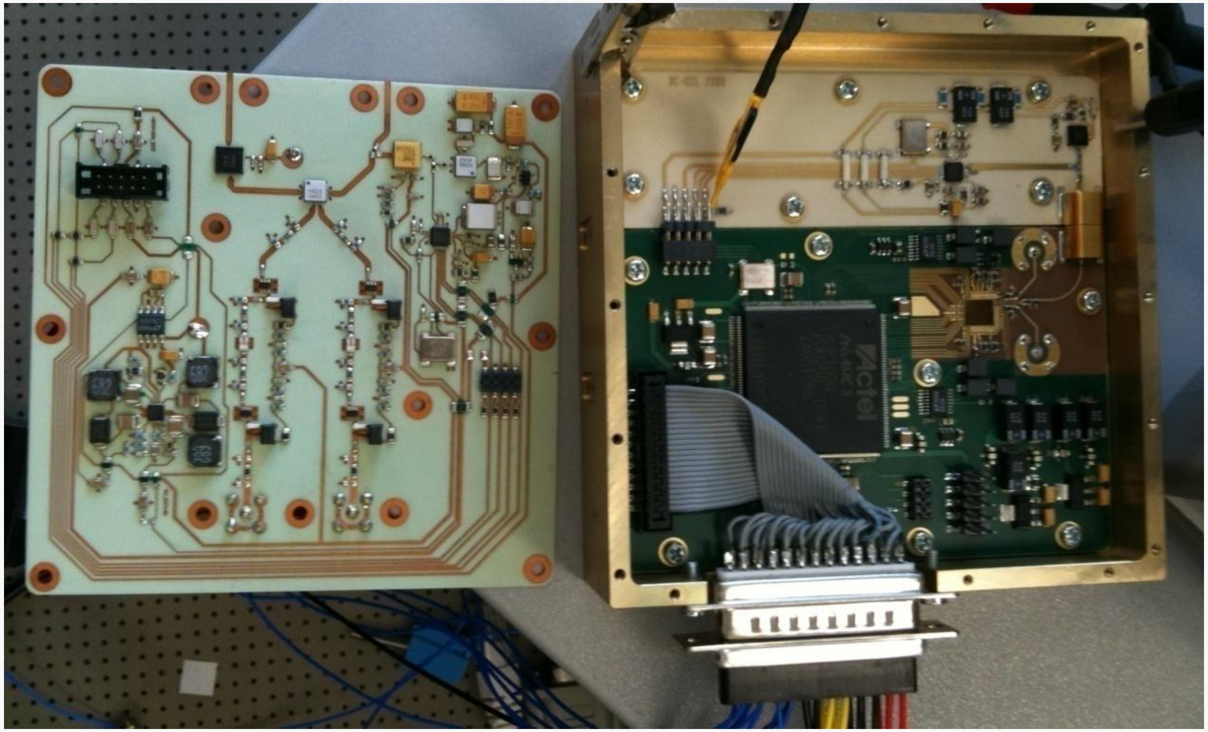
- Background
  - Demand for increased sensitivity at 54 GHz for future meteorology (Post-EPS).
  - Accomplish this by running several receivers in parallell in a single reflector focal plane.
- Demonstrate the feasibility of a low-noise, compact receiver at 54 GHz.
- Omnisys will build the back-end part for this demonstrator with Astrium as prime.
- Early stage, project started a few months ago.

Wideband spectrometer breadboard

- Wideband spectrometer breadboard
  - Single box with integrated IQ mixer, IF conditioning, correlator, LO and sample clock generation, power & control.
  - Finished in December 2009

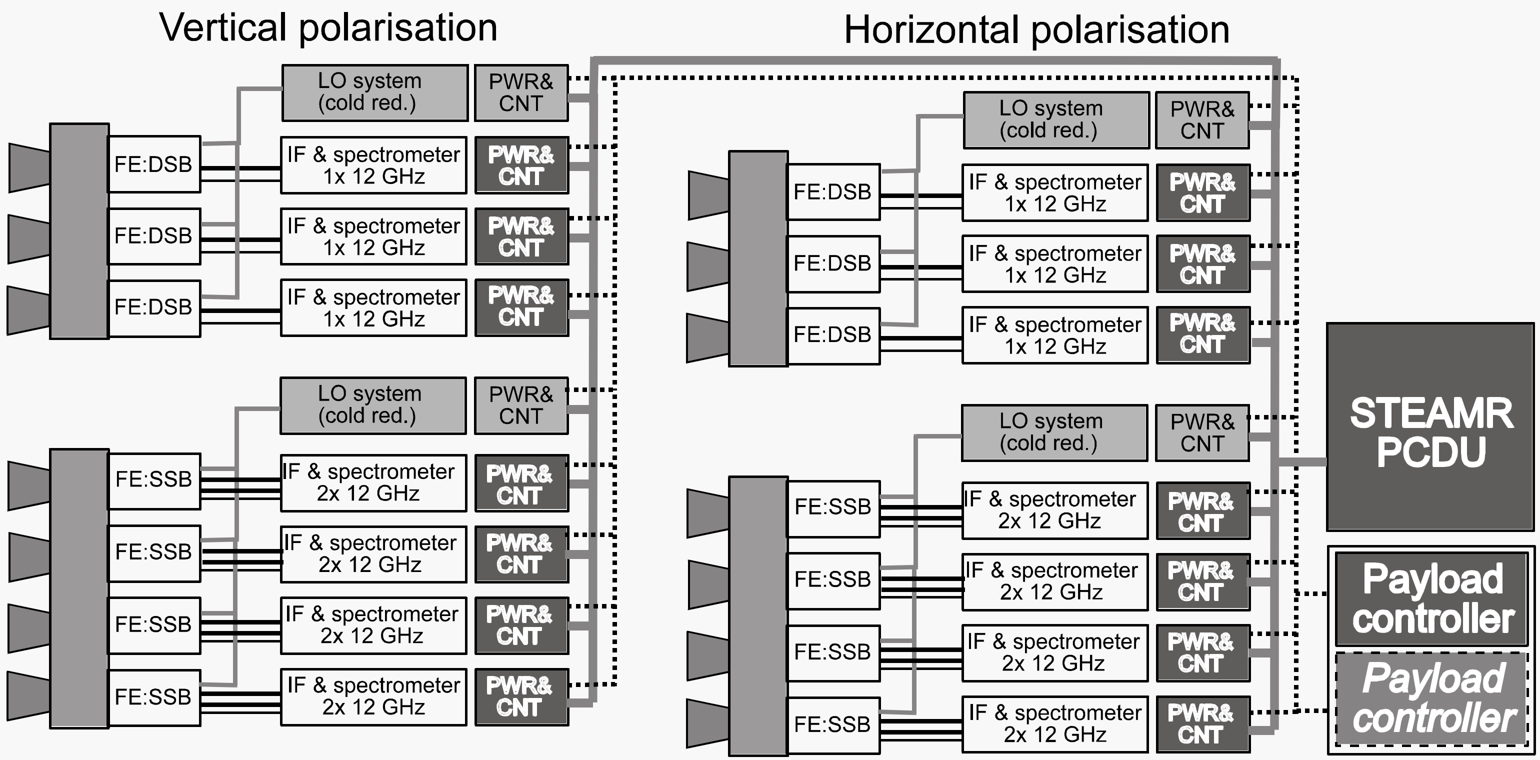


Spectrometer



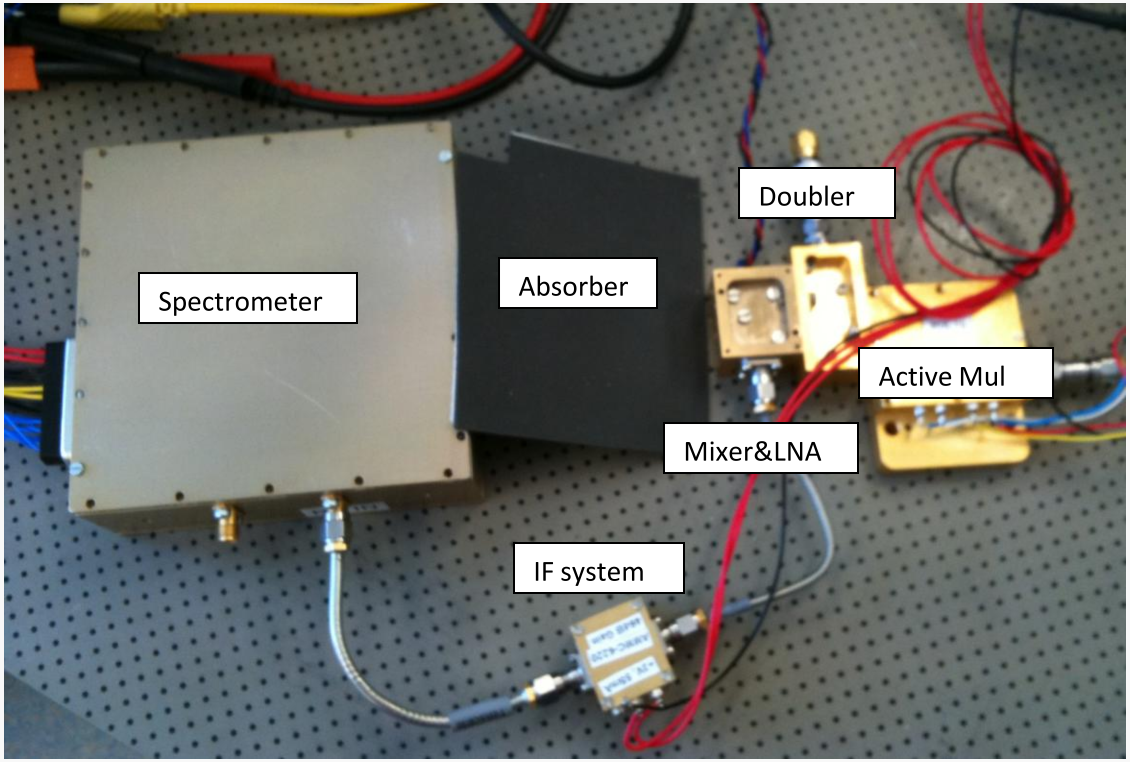
- Different IF board are being tested over 4-18 GHz

STEAMR

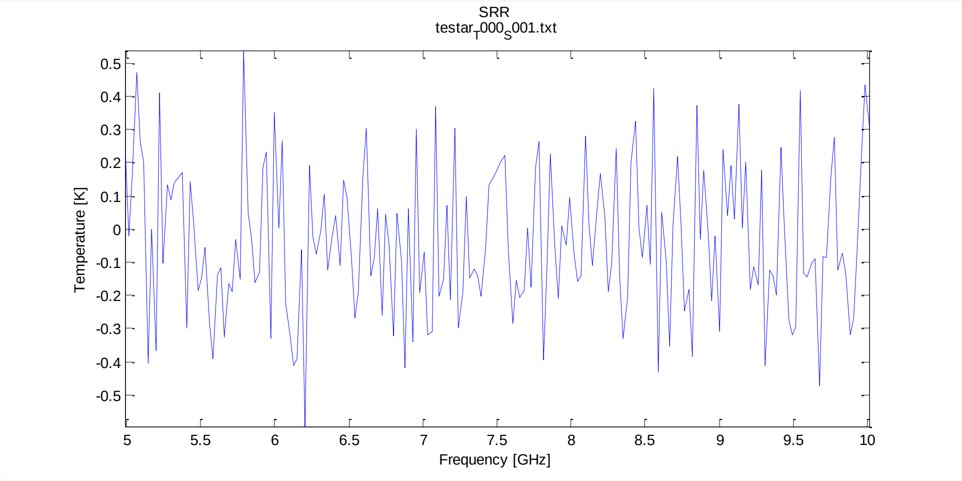


- Herschel HIFI instrument spectrometer bandwidth: 4 GHz : 200 W
- STEAMR spectrometer bandwidth: 200 GHz : 50 W

STEAMR tests at 340 GHz



STEAMR


SRR
testar_T000_S001.txt
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Frequency [GHz]
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0.3
0.2
0.1
0
-0.1
-0.2
-0.3
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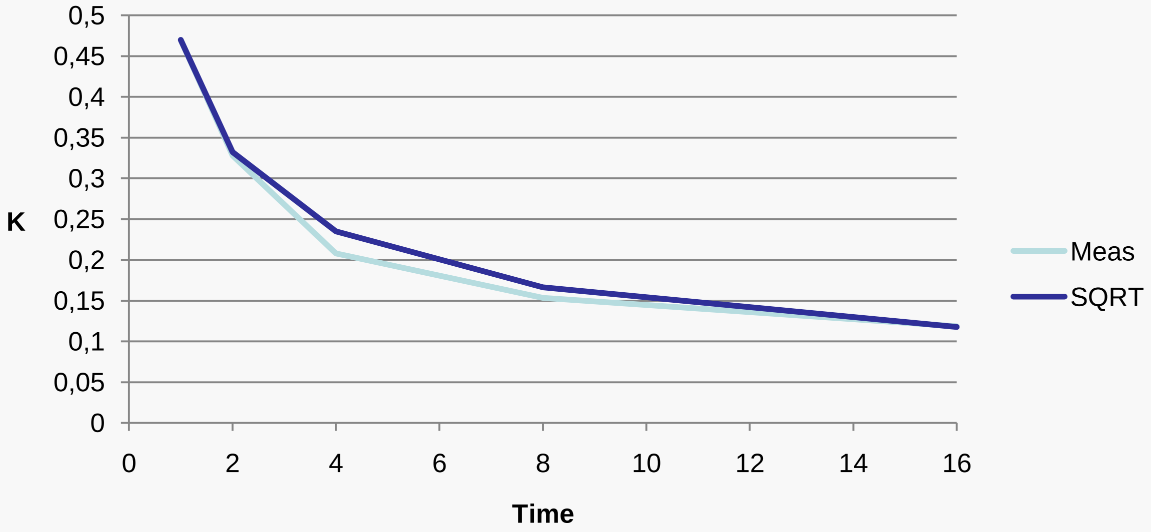
-0.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10


K
Time
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0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
0
2
4
6
8
10
12
14
16
Meas
SQRT

The end.

- Thank you for listening!