FFT Spectrometer

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Topics

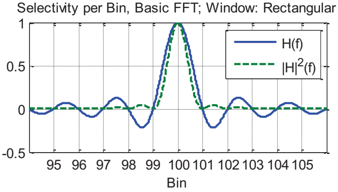
- Summary of different FFTS models used at IAP
- Alternative observing modes with COSPAN
- Problem areas of the Acqiris AC240
- New developments in collaboration with FHNW, ETHZ and Agilent
- Low-cost Software Defined Radio (SDR) options for narrow bandwidth

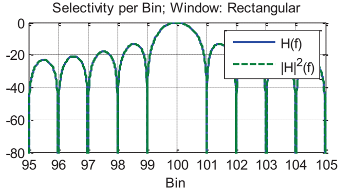
FFT Spectrometers used at IAP

Manufacturer/Model	Bandwidth GHz	Channels	Resolution kHz	ADC Bit
RPG AFFTS	1.5	8192	212	8
(MPI Bonn, B. Klein)	0.1	16384	7	
Agilent AC240 FFTS	1.0	16384	61	8
Agilent AC240 COSPAN	1.0	32768	31	8
Agilent M9703 NEW!	4×1.6	32768	49	12
Omnisys HIFAS	6.6	255	26MHz	1.5
autocorrelator		(511)	13MHz	

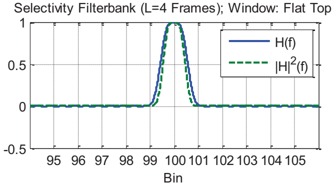
Channel Response Functions

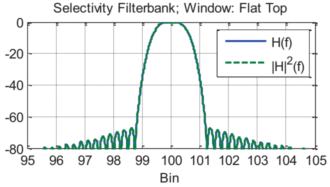
- FFT spectrometer $\left|\frac{\sin(x)}{x}\right|^2$, Autocorrelator $\frac{\sin(x)}{x}$
  Additional window function degrades resolution and noise





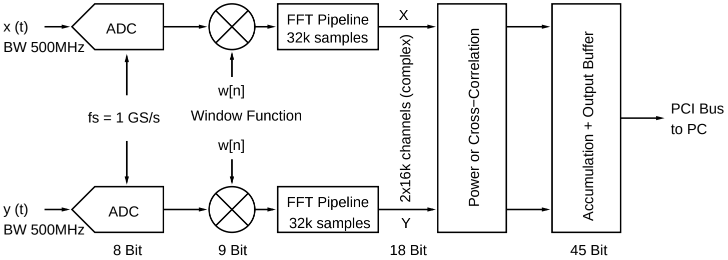
- Polyphase Filterbank (RPG, New Agilent FFTS)
  Superior channel separation without any drawbacks





FFTS firmware for Acqiris AC240

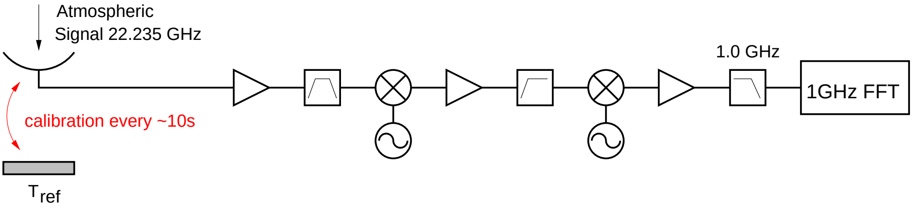
- **Original Agilent FFTS firmware**:
  2GS/s sampling rate by interleaving two 1GS/s ADCs
  Offsets between the ADCs produce spurious artifacts, which can be reduced by ADC calibration (at operational temperatures!).
- **COSPAN firmware at IAP**:
  Both inputs are digitized simultaneously at 1GS/s
  differnt observation options after the FFT



COSPAN Modes

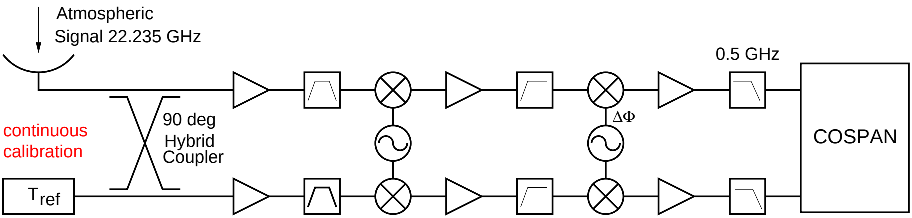
- **Total Power Mode**
  $P_{xx} = |X|^2$ and $P_{yy} = |Y|^2$
- **Correlation Mode**
  $P_{xy} = X^* Y$ (real and imaginary parts)
  $\Rightarrow$ cross-correlation spectrum of $x(t)$ and $y(t)$
- **Sum & Difference Modes** (I/Q Sideband Separation)
  $P_{x+y} = |X + Y|^2$ and $P_{x-y} = |X - Y|^2$ or
  $P_{x+jy} = |X + jY|^2$ and $P_{x-jy} = |X - jY|^2$
- **Bypass Mode**
  $x(t)$ and $y(t)$ of a single frame

Total Power Radiometer with FFT Spectrometer



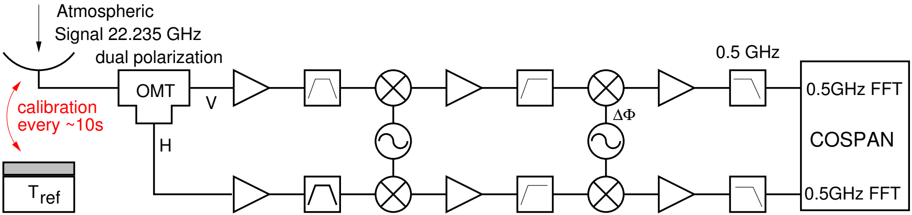
- Bad SNR: line amplitude <1K, receiver noise >100K
- Gain variations require frequent calibration ($\tau \sim 10$s)
- Loss of integration time, but still sensitive to gain fluctuations

Correlation Receiver with COSPAN



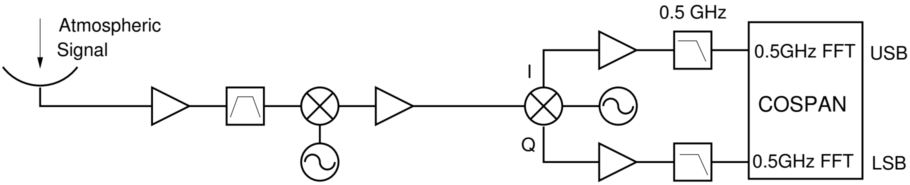
- New correlation receiver MIAWARA-C with COSPAN
- Continuous comparison of the atmospheric signal with an internal reference signal
- Receiver noise after the 90° waveguide hybrid is uncorrelated and does not contribute to the accumulated spectra
- Most efficient use of the integration time, less sensitive to gain variations.

Dual Polarization Receiver with COSPAN



- Since 2010 dual-polarization receiver instead of correlation
- Simultaneous observation of 2 polarizations with OMT
- Lower noise than correlation mode

I/Q Sideband Separation with COSPAN

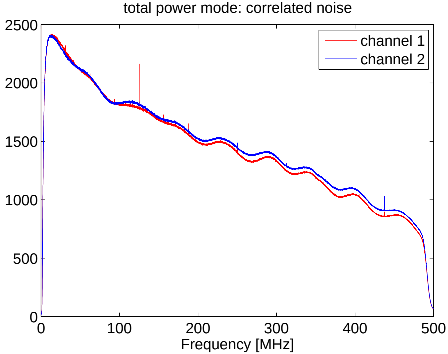


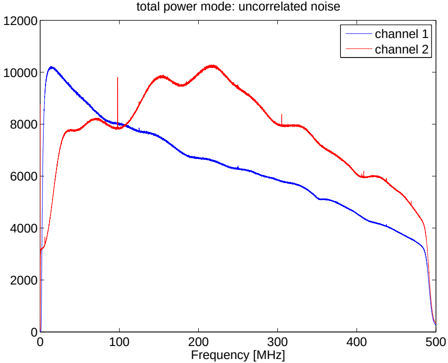
- I/Q Mixer with two IF outputs with zero and $\pm 90^\circ$ phase
- Allows to seperate USB and LSB, image rejection depends on amplitude and phase balance
- Advantages compared to interleaved 2GS/s mode:
  - Same bandwidth, twice the resolution
  - Conversion from IF to baseband requires no steep bandpass filter
- Can be used also with an I/Q mixer at RF

Test Conditions

- Uncorrelated noise: two independent noise sources with 500 MHz lowpass filter.
- Correlated noise: single noise source, in-phase power splitter, 500 MHz lowpass filter
- CW Signal: Agilent Synthesizer
- AC240 analyzer in ADLink cPCI crate
- AC240 input setting 5V without filters, rectangular FFT window

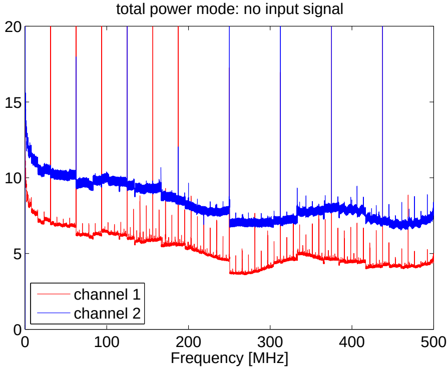
Total Power Mode

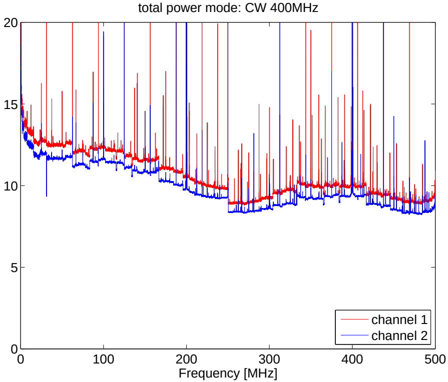




- Similar to original 1GS/s firmware
- $2\times$ 500 MHz bandwidth with twice the resolution

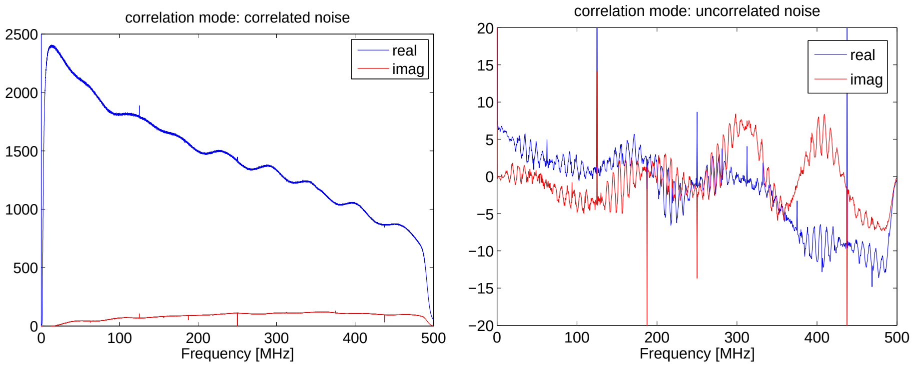
Total Power Mode, Background





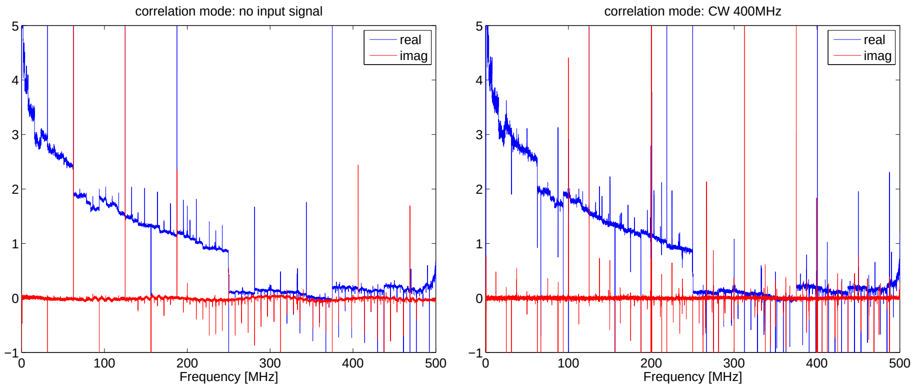
- Spurious signals from FPGA clock
- Offset with platforming and systematic ripple from FFT truncation
- Offset is sensitive to ADC offset

Correlation Mode



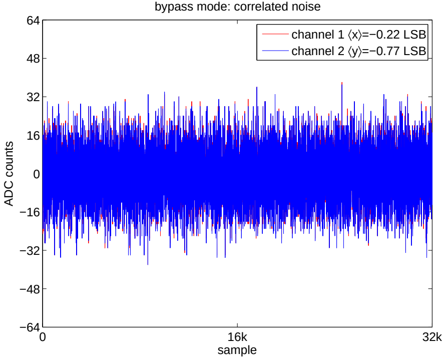
- Correlated noise:
  Spurious imaginary component from AC240 phase unbalance
- Uncorrelated noise:
  Artifacts from the crosstalk between the AC240 inputs

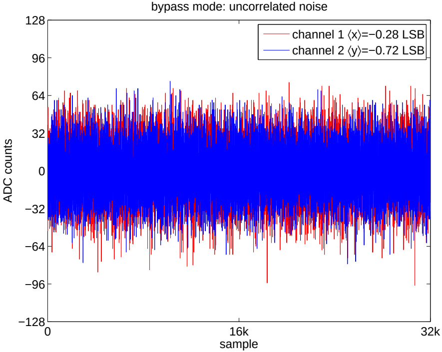
Correlation Mode, Background



- Offset with platforming and systematic ripple from FFT truncation, mostly on the real component.
- Can be corrected partly by inversion of the time domain data within COSPAN

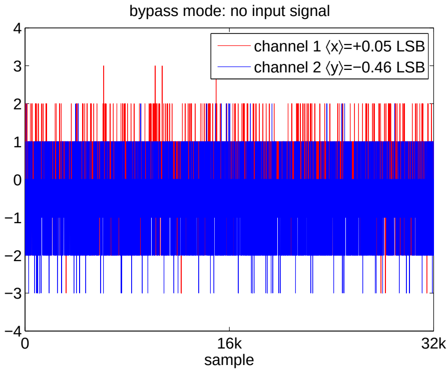
Bypass Mode



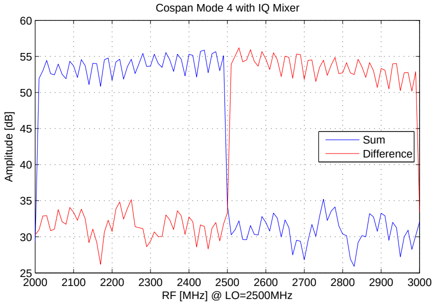


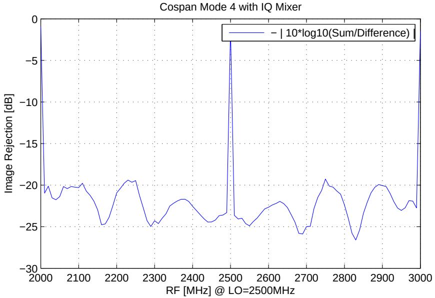
- Allows to determine ADC offset and statistics
- Optimum RF level uses full ADC range without clipping

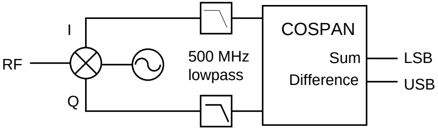
Bypass Mode, Background



Sum & Difference Mode

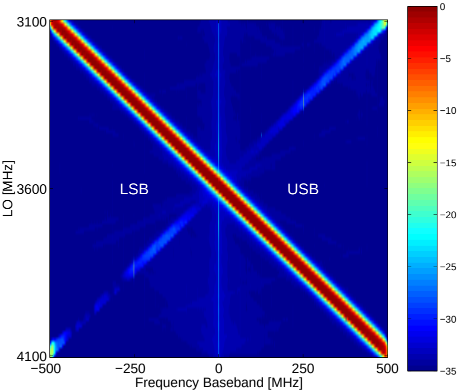


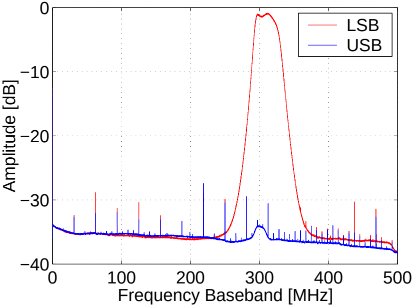




- Test setup: 1.5-4.5GHz IQ mixer, LO 2.5GHz, RF 2-3GHz CW
- Allows to separate upper and lower sideband of an IQ mixer
- Image rejection depends on amplitude and phase balance
- Higher resolution and more flexibility than 1GS/s firmware

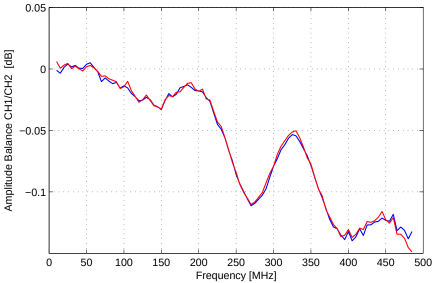
Sum & Difference Mode (Noise Input)

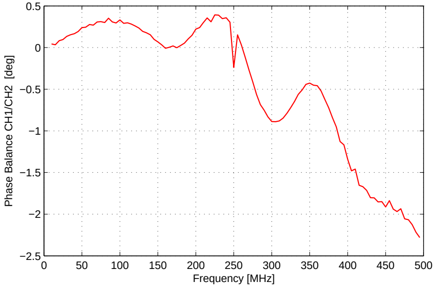




- Test setup: 1.5-4.5GHz IQ mixer (Marki), LO 3.1–4.1GHz, bandlimited noise input 3.6GHz±30MHz

AC240 Amplitude and Phase Balance

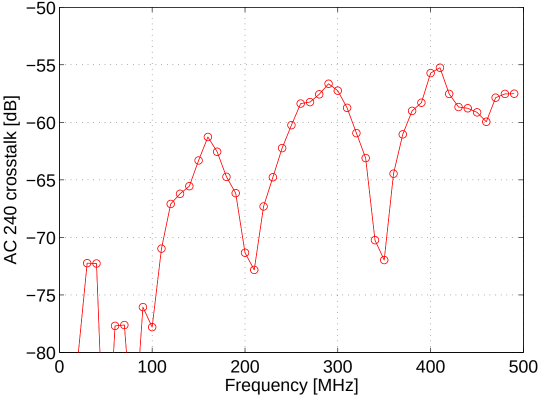




- Tests with 0-500 MHz CW signal and in phase power splitter.
- Amplitude balance from total power mode, phase balance from correlation mode.
- Reversing the inputs allows to distinguish between unbalance of AC240 and test setup

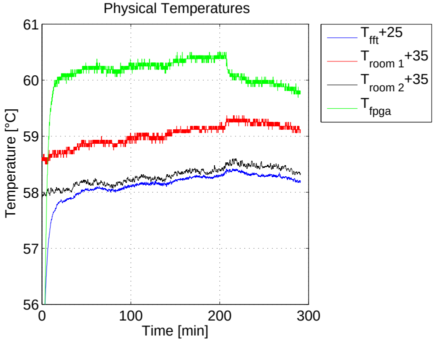
AC240 Crosstalk

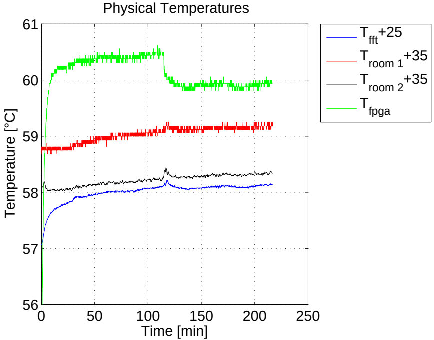
- Very critical for correlation and sideband separating modes.
- -60dB produces significant systematic errors
- Test setup: 0-500MHz CW at CH1, matched load at CH2.



AC240 Thermal Effects

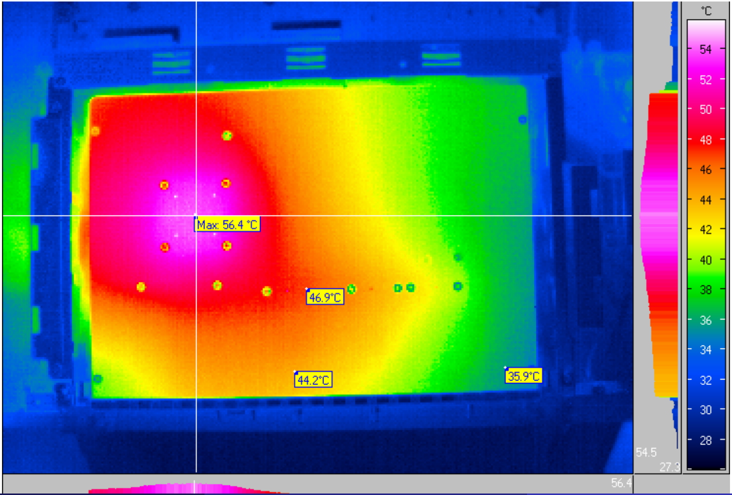
- FPGA load varies between different modes
- FPGA Temperature variation with RF level
- Test setup: FFT started at t=0,
  RF power is reduced by 10dB after 200 or 120 min.





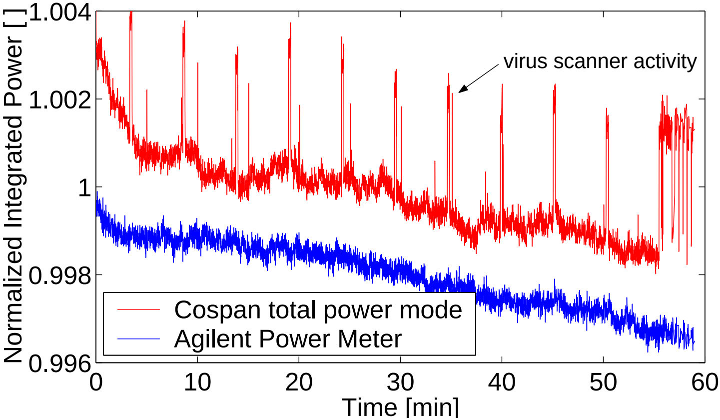
AC240 Thermal Effects

- Problem: ADC and PGA on same heat sink as FPGA
- Ideally analog parts should be temperature stabilized
- IR image of AC240 board shows strong temperature gradients



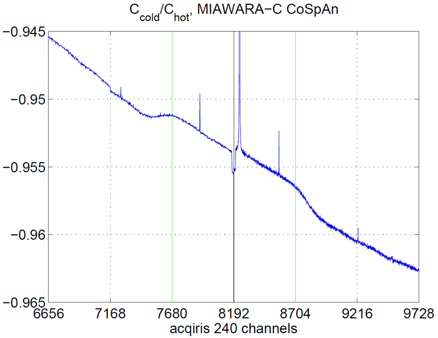
AC240 Instability from Host PC

- Virus scanner activity leads to periodic gain fluctuations
- Drop of V_{bias} in ADlink crate? .

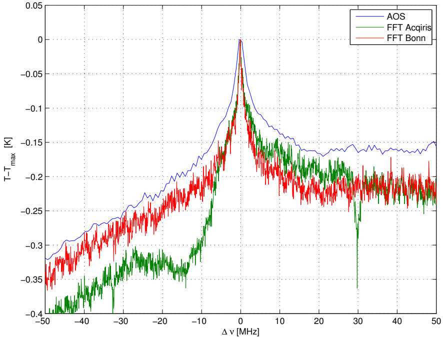


AC240 Nonlinearities

- Original 1GHz FFTS and COSPAN show systematic nonlinearties in different parts of the spectrum
- Most disturbing are shoulders around band center



Linearity test with COSPAN



Comparison calibrated H2O line with FFT AC240, FFT Bonn and AOS

AC240 Problem Areas

- Nonlinearity caused by numeric truncation in the FFT
- Crosstalk between channel 1 and 2
- Amplitude & Phase balance: important for sideband separating mode
- Insufficient cooling for high altitudes (FPGA $\sim 60^\circ$C in Bern)
- FPGA, PGA and ADC share same heat sink
  $\Rightarrow$ stability problems
- Gain variations with temperature and PC activity
- RFI: Spurious signals from FPGA and other clocks

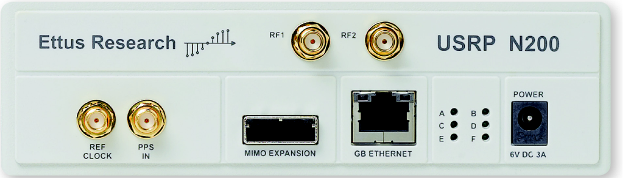
New Agilent M9703 FFTS

- Modular system with different bandwidth options up to 8×1.6 GS/s
- Polyphase filterbank for better channel separation
- Statistical Kurtosis analysis for RFI mitigation
- Similar observation modes as COSPAN (but now also in parallel)
- I/Q error correction for improved sideband separation
- Highly improved linearity (no more truncation artifacts)

Current AXIe version, smaller 2×1.6GS/s for PCIe expected during 2013.

USRP Software Defined Radio

- Universal Software Defined Radio from www.ettus.com
- Dual 100MHz 14Bit ADC, dual 400MS/s 16Bit DAC, Xilinx FPGA
- RF transceiver daughterboards from 1MHz to 4.4GHz
- Software development with GnuRadio (Open Source) or Labview
- CPU calculates FFT, max. bandwidth 5-10MHz (25MHz?)
- Relatively low-cost (1500 US$)



USRP Software Defined Radio at IAP

- Used for radio astronomy and O2 Zeeman splitting (TEMPERA)
- Can be also abused to listen to several radio stations in parallel