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Back-ends for THz heterodyne systems:

Fast Fourier Transform Spectrometer (FFTS)

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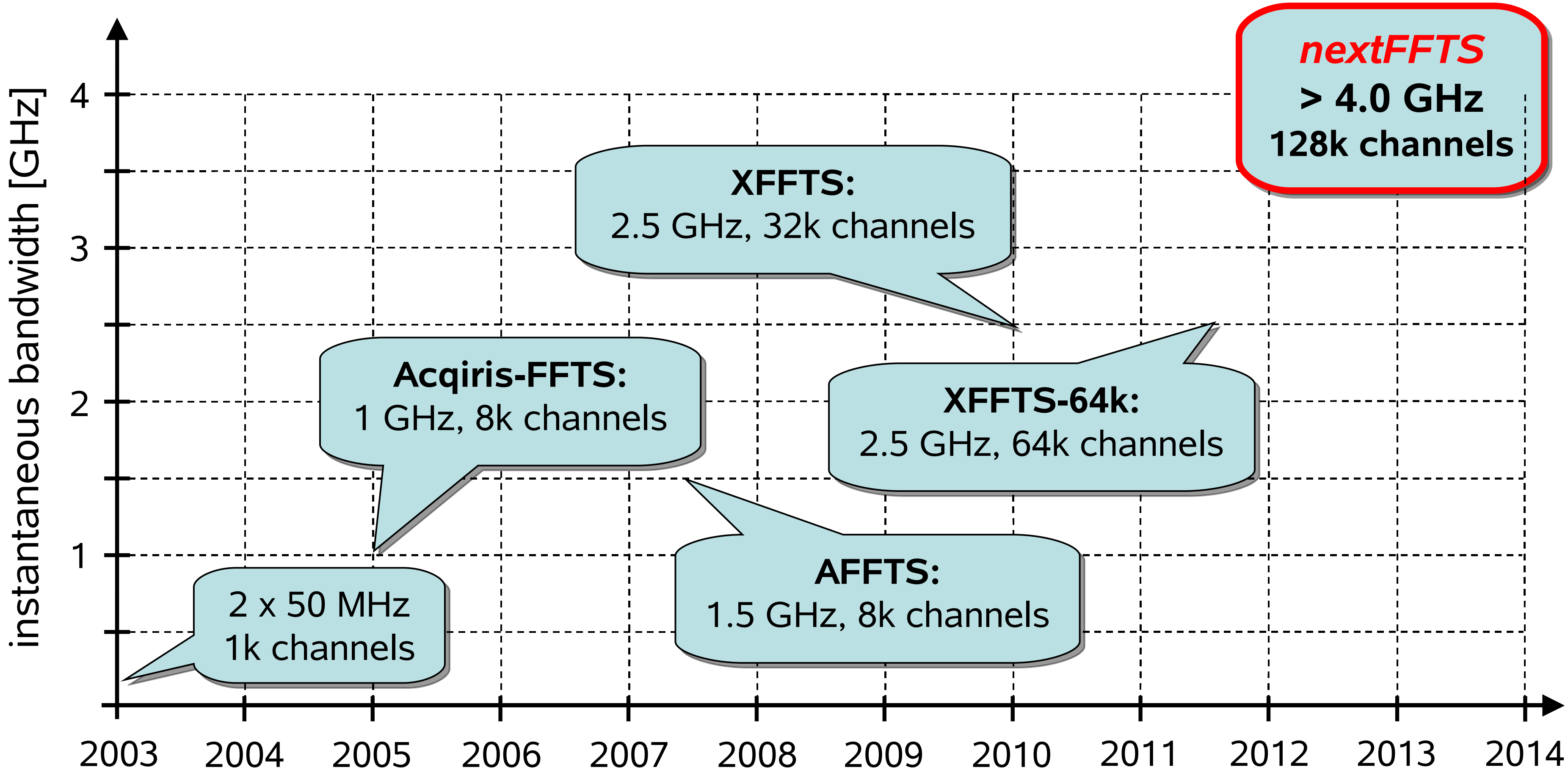
2014-01-20

FFTS development history



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FFTS Generations

Fast Fourier Transform Spectrometer (FFTS)

1. Generation: AFFTS – 1.5 GHz BW, 8K channels

2. Generation: XFFTS – 2.5 GHz BW, 32K channels
XFFTS2 – 2.5 GHz BW, 64K channels

3. Generation: *nextFFTS* – 4 GHz BW, 128K channels
+ IF sampling (4 – 8 GHz)
+ digital sideband separation

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APEX :: AFFTS & XFFTS

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Atacama Pathfinder EXperiment APEX

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APEX :: Flash$^+$ + XIF + XFFTS / XFFTS2

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Atacama Pathfinder EXperiment APEX

- ***FLASH$^+$ 345:* 4 x XFFTS2 → 4 x 2.5 GHz BW, 4 x 64K channels**
- ***FLASH$^+$ 460:* 4 x XFFTS → 4 x 2.5 GHz BW, 4 x 32K channels**

APEX :: Flash^{+}345 + XIF + XFFTS2

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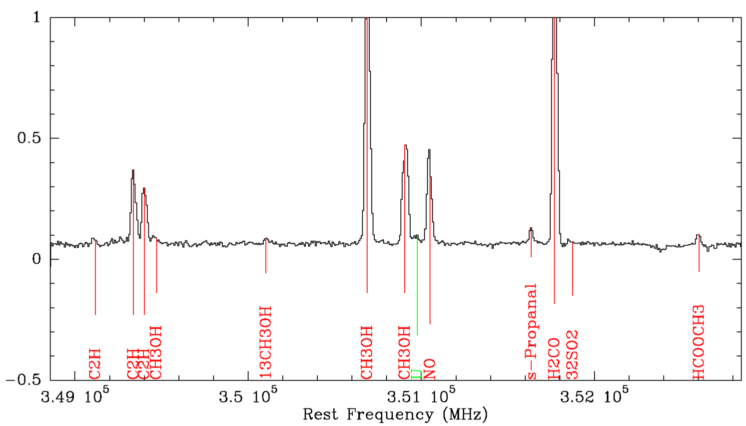
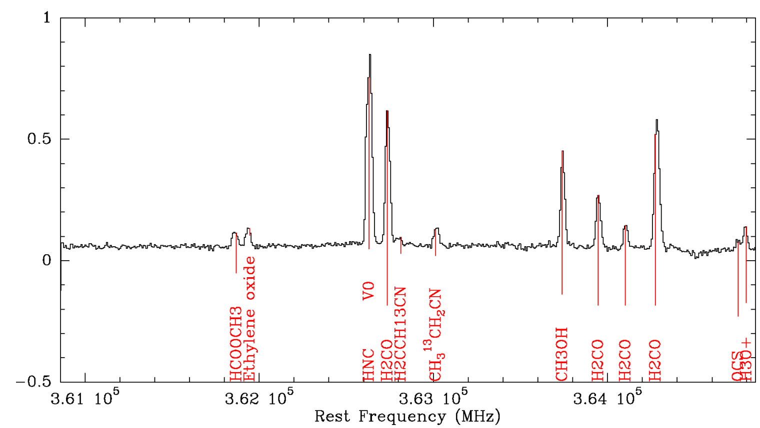
Atacama Pathfinder Experiment APEX

► *8 GHz of bandwidth and ~210'000 spectral channels* ◄

lower sideband | ***upper sideband***

← 4 GHz bandwidth → | ← 4 GHz bandwidth →





← **12 GHz spacing** →

Flash^{+}345: updated receiver with IRAM 2SB SIS mixer

iram Institut de Radioastronomie Millimétrique

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SOFIA / GREAT :: XFFTS

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SOFIA / GREAT :: XFFTS

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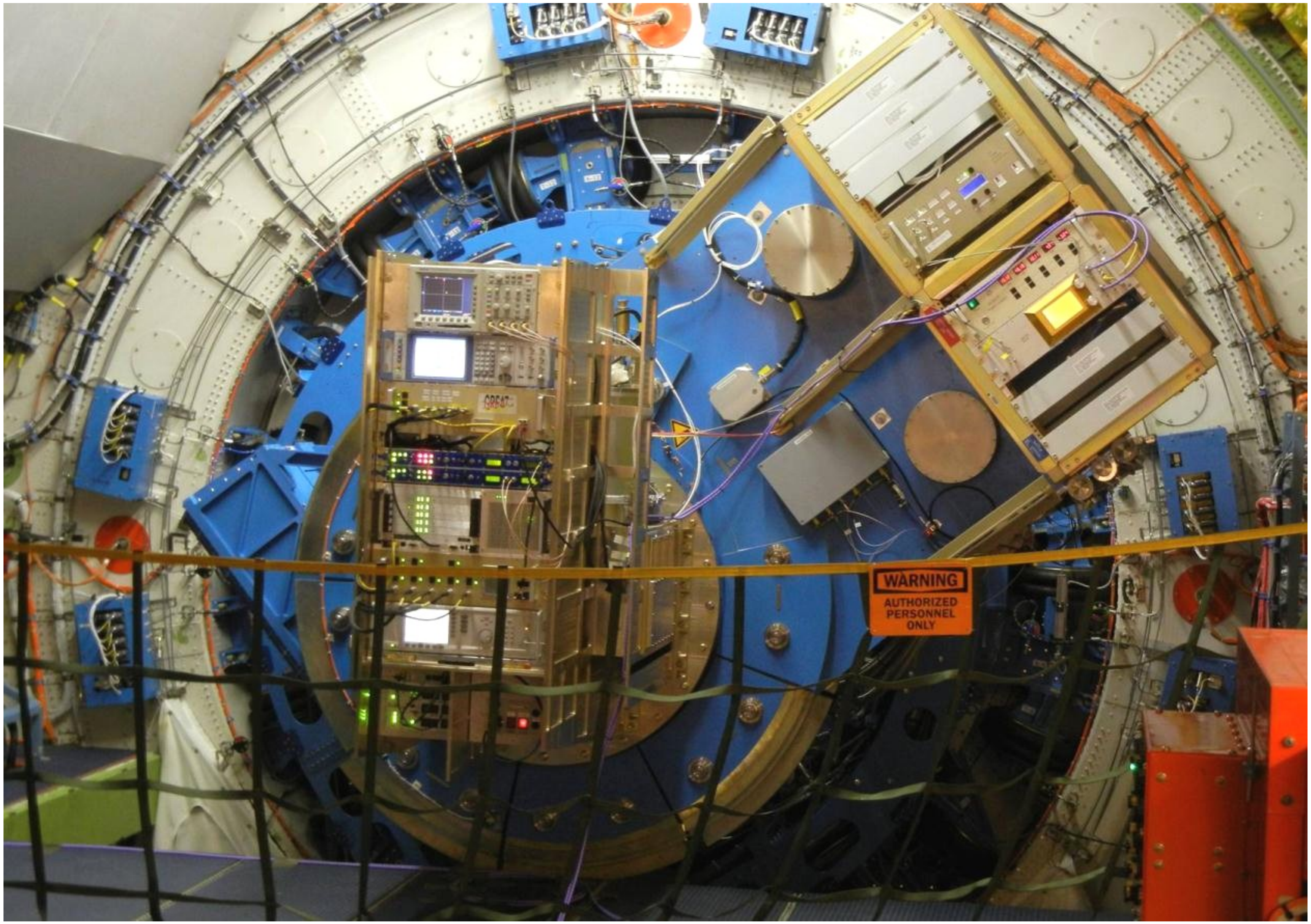

XFFTS2 :: 64k spectral channels

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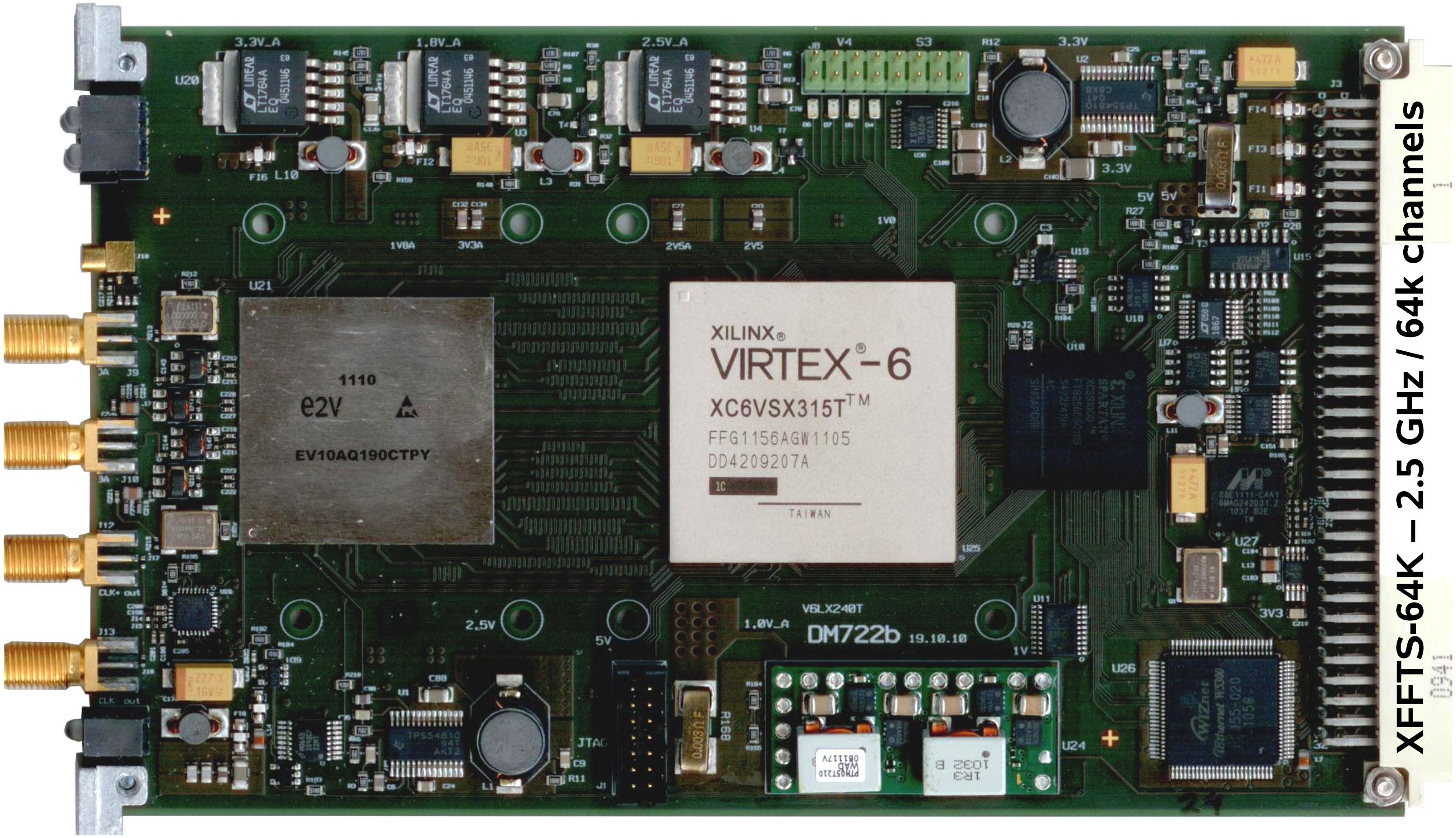
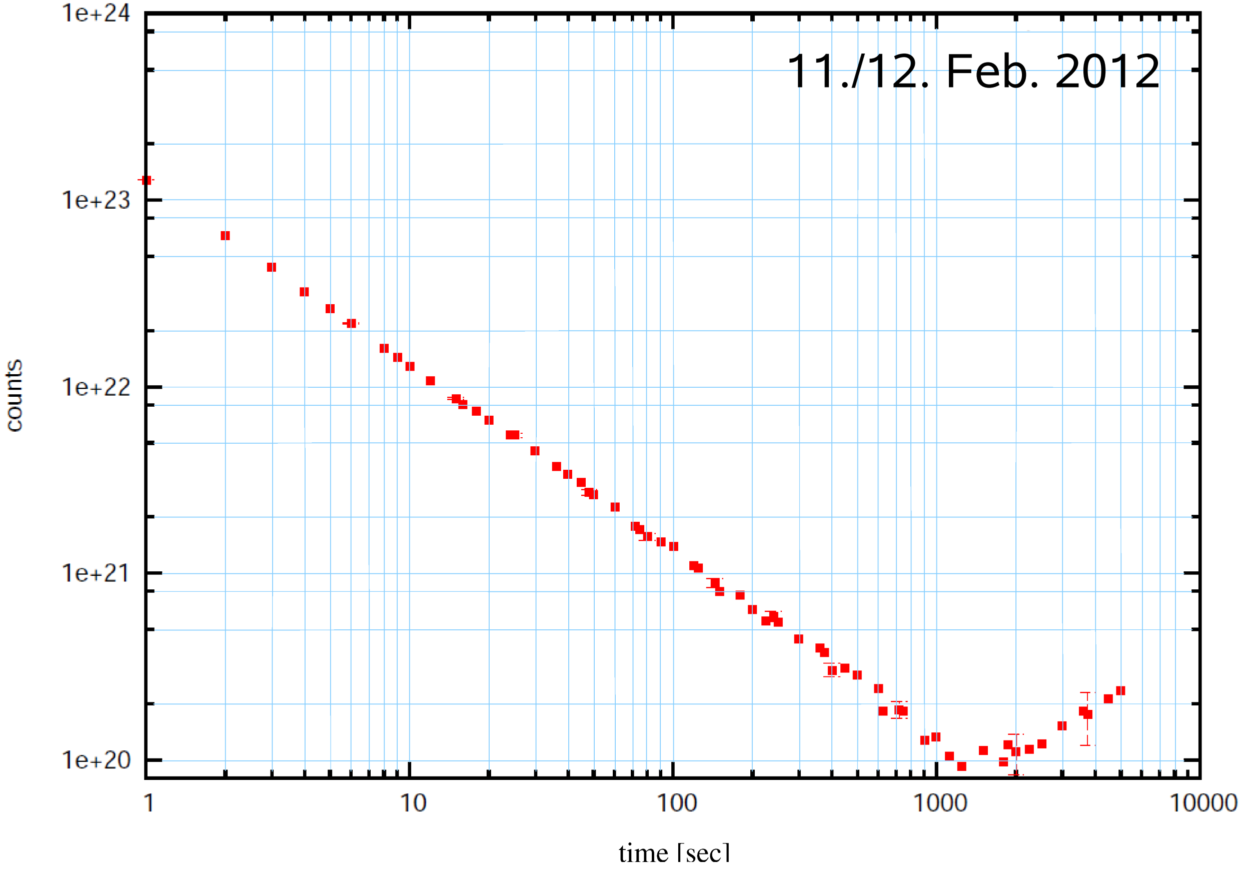
GREAT

XFFTS2: 2.5 GHz bandwidth / 65536 channels (ENBW 44 kHz)



XFFTS2 :: Allan stability



The spectroscopic Allan variance between two 1.2 MHz broad channels, separated by 1.8 GHz within the band, was determined to be stable on a timescale of >1000 s.

Fast Fourier Transform Spectrometer (FFTS)

1. Generation: AFFTS – 1.5 GHz BW, 8K channels

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XFFTS2 – 2.5 GHz BW, 64K channels

3. Generation: *nextFFTS* – 4 GHz BW, 128K channels

+ IF sampling (4 – 8 GHz)

+ digital sideband separation

3. Generation : *nextFFTS*

Development Goals:

- 4 – 5 GHz instantaneous bandwidth,
- 128k channels, 4-tap polyphase filter bank, ENBW: ~ 35 kHz @ 4 GHz bandwidth
- direct IF sampling of the 4 – 8 GHz band
- support for digital sideband separation
- 8-bit ADC, ENOB: ≥ 6 bit
- 100 MBits/s and 1 Gbit/s Ethernet interface
- high-resolution continuum mode
- power dissipation: < 35 W @ 128k channels

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3. Generation : *nextFFTS*

Hittite MICROWAVE CORPORATION v00.0709

HMC5448

8-BIT, 5 GS/s ANALOG-TO-DIGITAL CONVERTER

► Monolithic ADC

Typical Applications

The HMC5448 is ideal for:

- RF Test Instruments and ATE
- Digital Sampling Oscilloscopes
- Radar / Lidar Systems
- Software Defined Radio and Digital Receivers

Features

8-bit Resolution

>6 GHz Input Bandwidth

>5 GS/s Sampling Rate

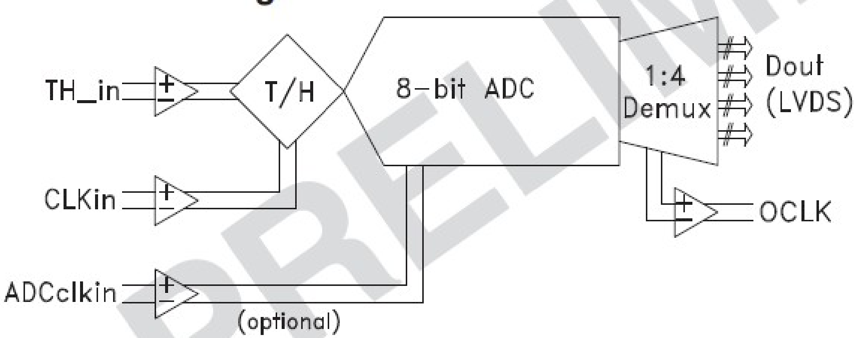
Direct-coupled Differential Signal, Clock Inputs

1:4 LVDS-compatible Output Data Demux

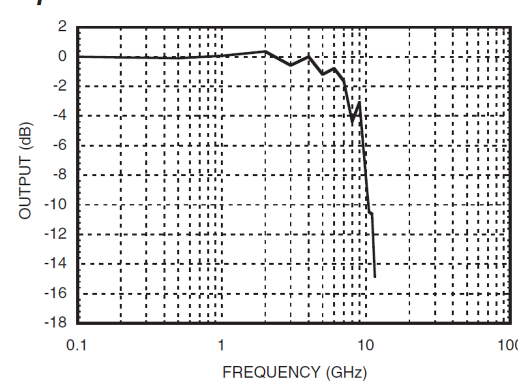
Synchronous Output Clock, Over-range Bit

16 x 16 pin (17 x 17 mm²) BGA Package

Functional Diagram



Input Bandwidth [1]



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3. Generation : *nextFFTS*

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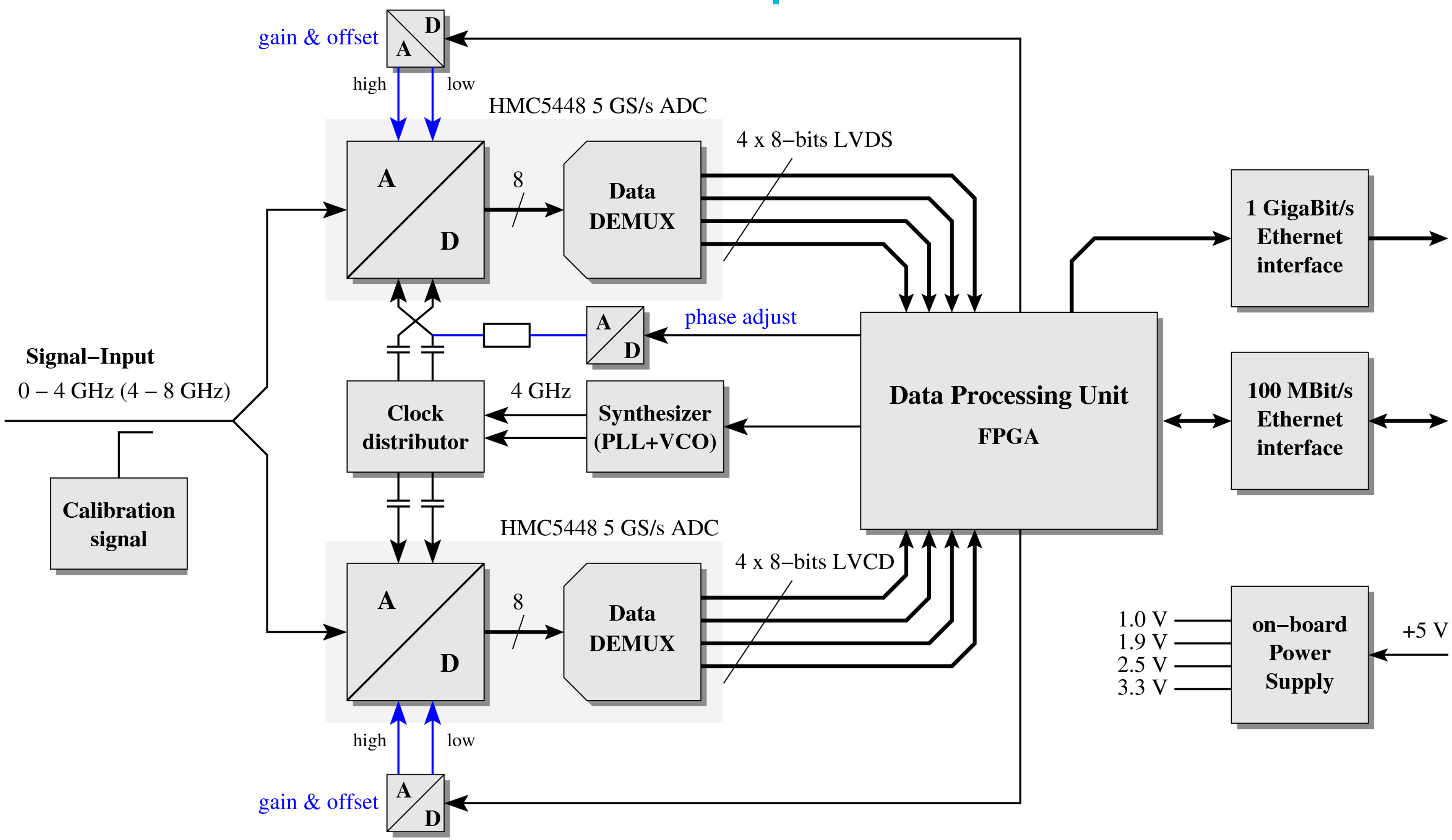
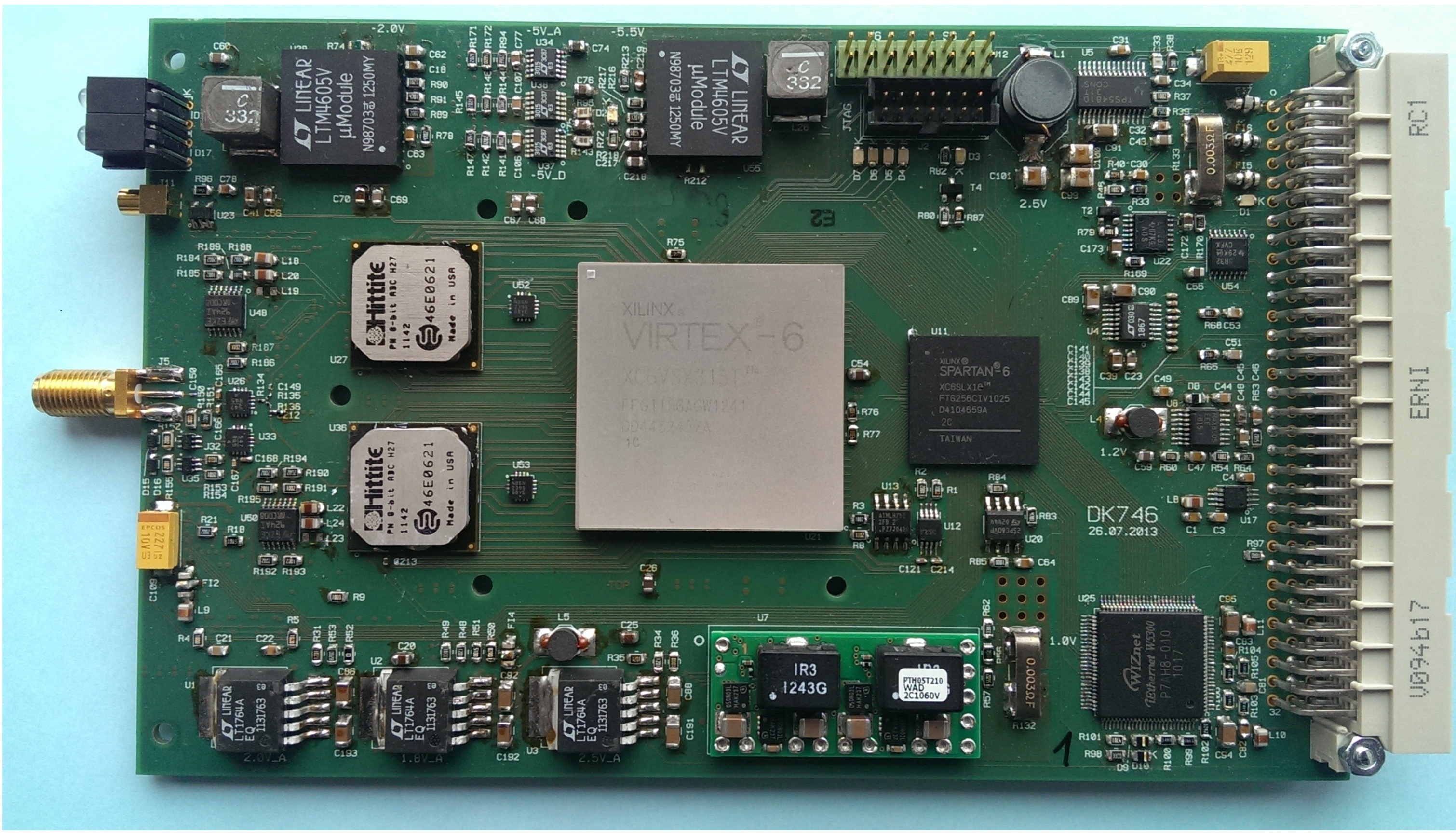
Concept



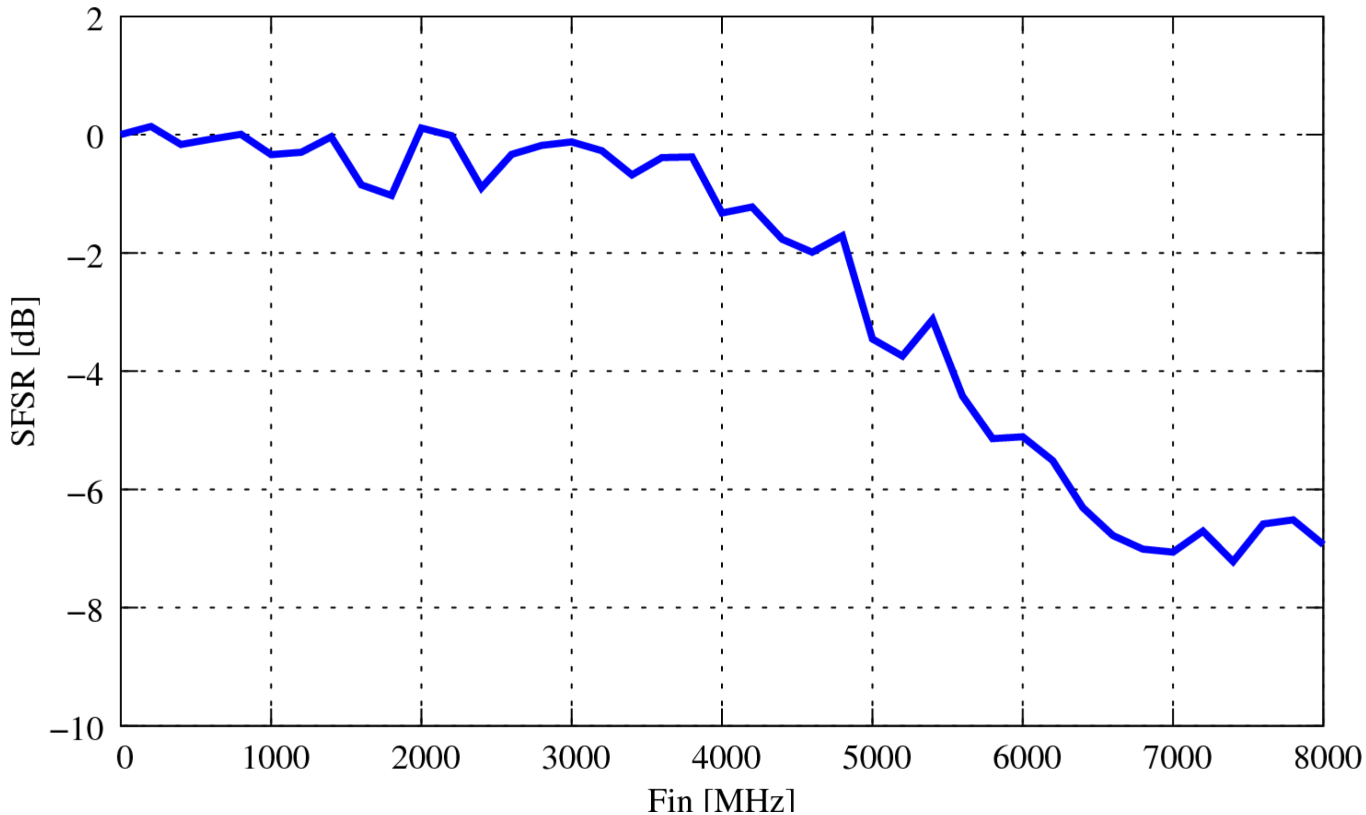
3. Generation : *nextFFTS*

Photo of the Prototype Board (December 2013)



3. Generation : *nextFFTS*

Measured Normalized Full Power Input Bandwidth (f_{samp} = 4 GHz)



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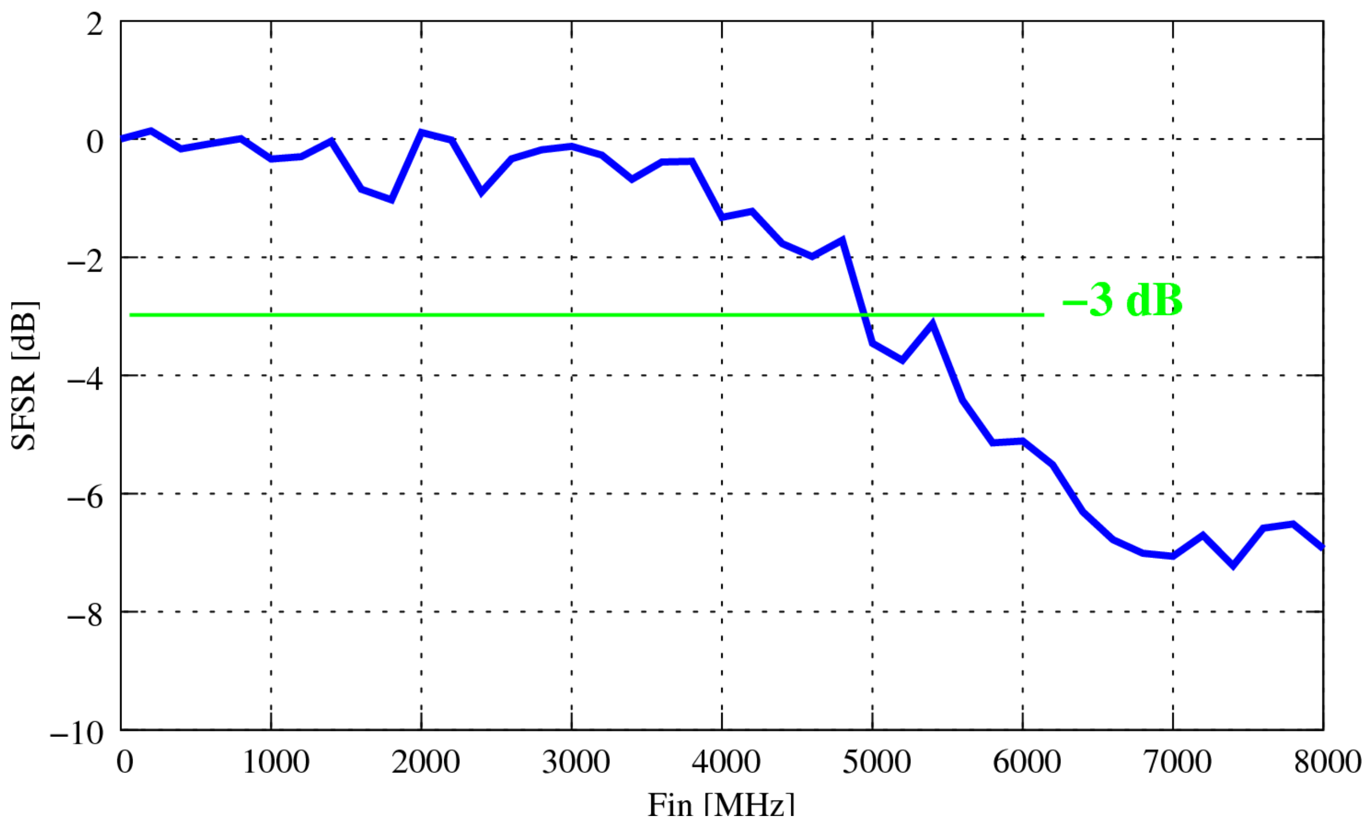

3. Generation : *nextFFTS*

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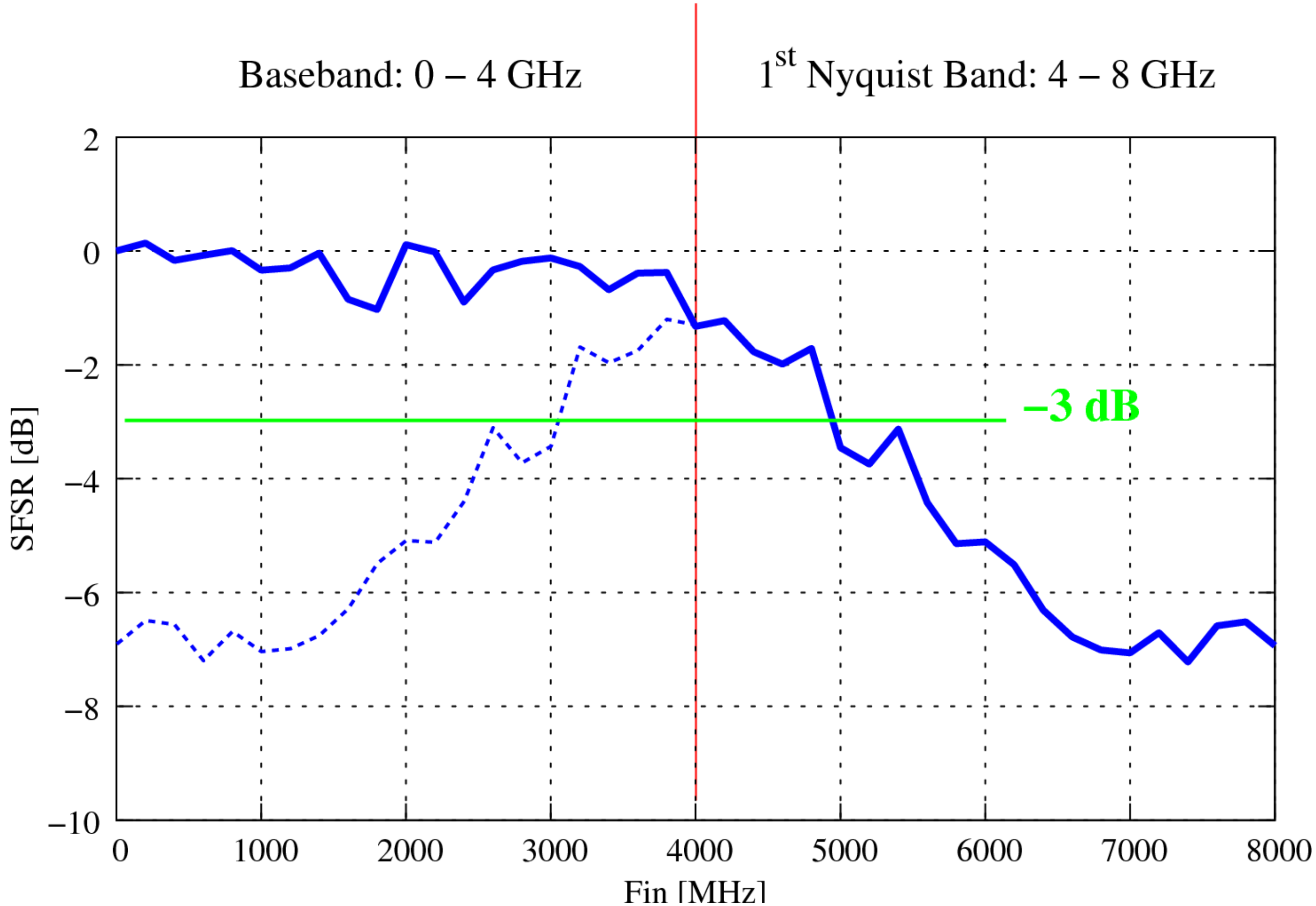
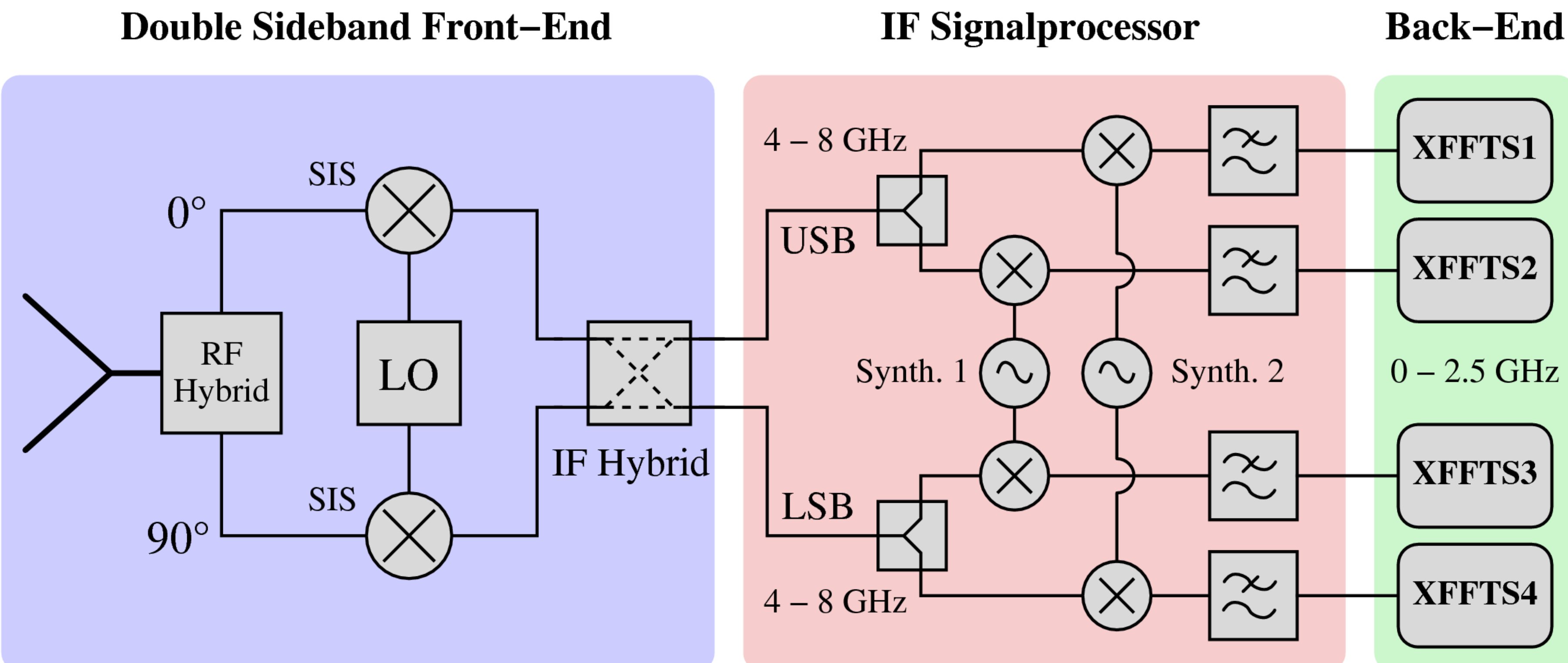


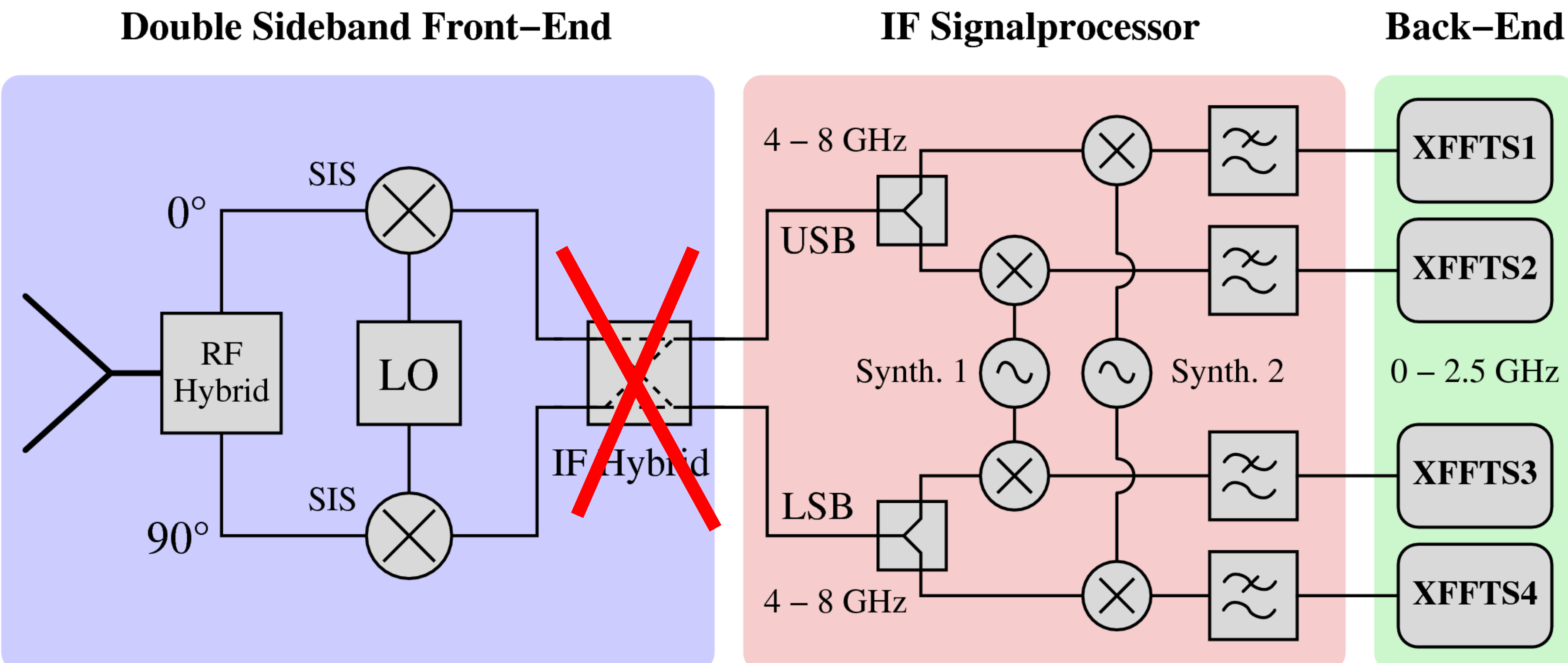
Classical Heterodyne system :: APEX / FLASH+



- Problem: amplitude and phase imbalances limit the sideband separation ratio to 10 - 15 dB.
- An analog IF system can become very complex, expensive and unstable.

3. Generation : *nextFFTS*

Classical Heterodyne system :: APEX / FLASH+



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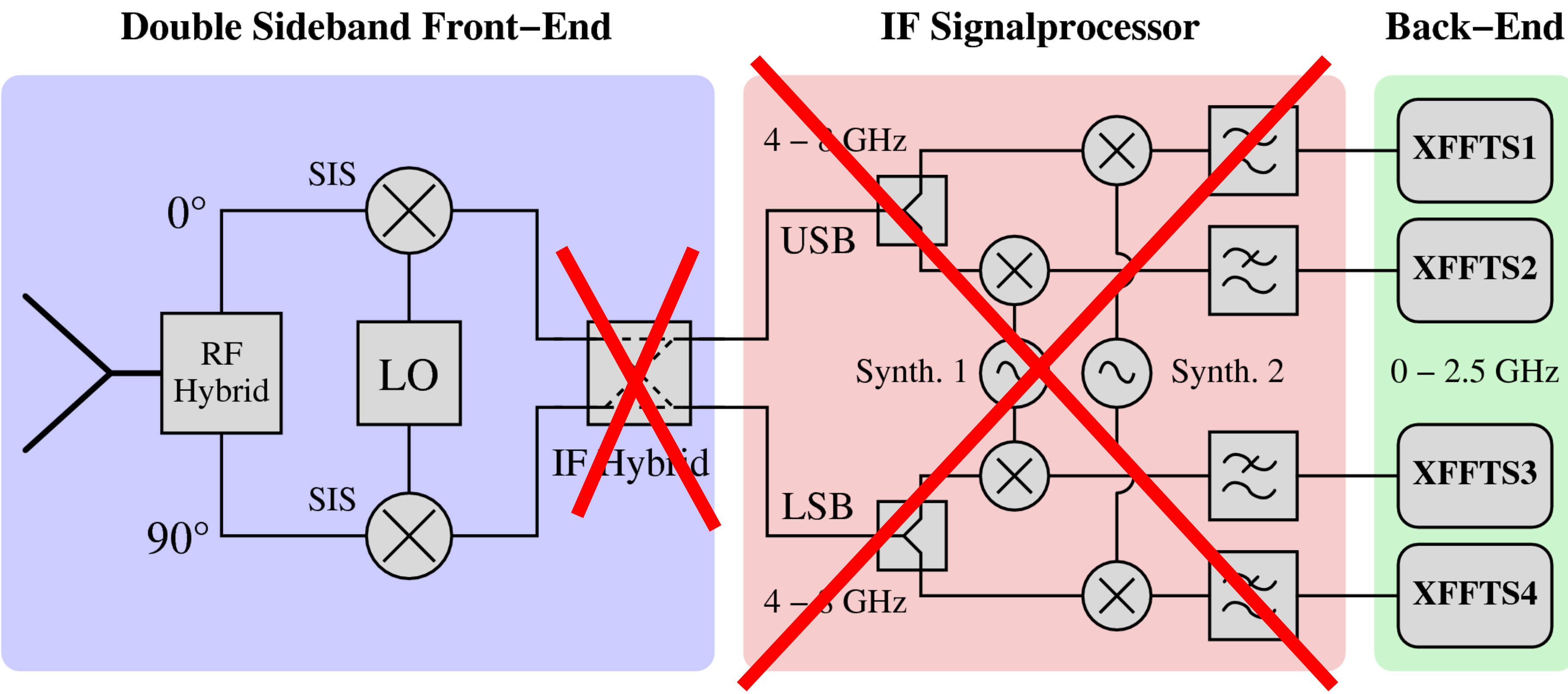

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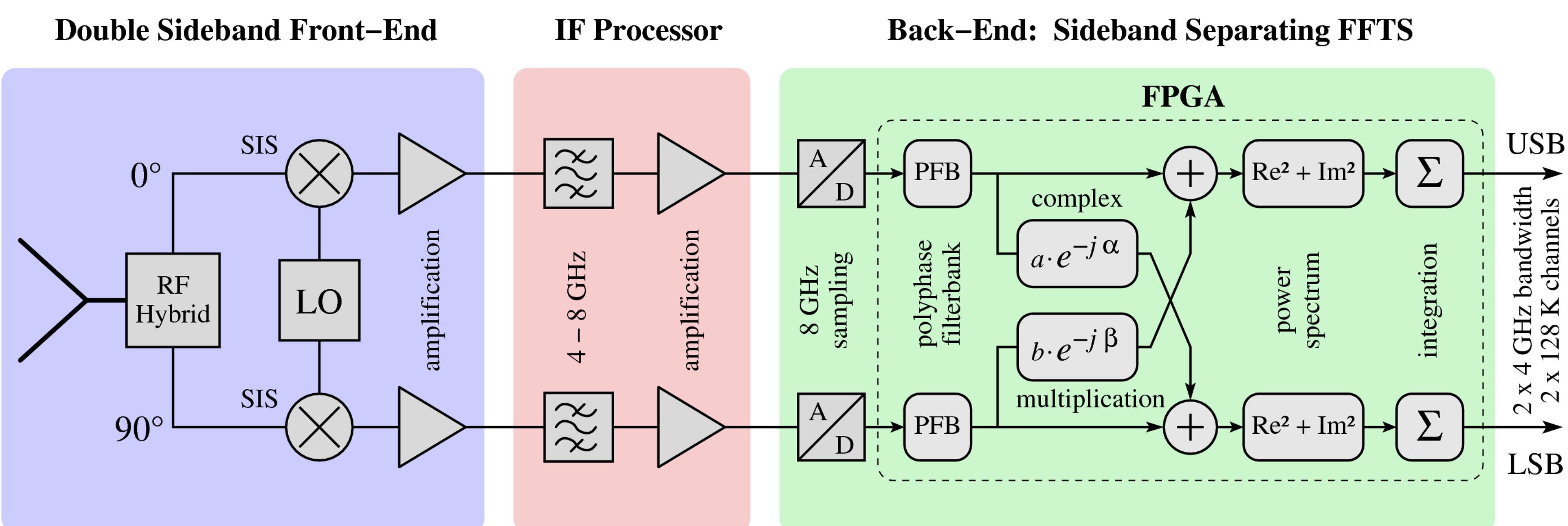
New concept for Heterodyne Receiver



- Front-End without an IF-hybrid.
- 90° phase shift is implemented by the FFTS for each spectral channel.
- IF processor as simple as possible.
- Undersampling techniques (digital down mixing) instead of analog base-band mixing.
- IF sampling at 8 GS/s to process an instantaneous bandwidth of 4 GHz.

FFT-Spectrometer :: *Summary*

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Advantages of our new generation of compact FFT spectrometers:

- ✓ FFTS offer high instantaneous bandwidth up to > 4 GHz with many thousands frequency channels, thus offering wide-band observations with high spectral resolution without the complexity of the IF processing in a hybrid configuration.
- ✓ They provide very high stability by exclusive digital signal processing. Allan stability times of > 1000 seconds have been demonstrated routinely.
- ✓ Our optimized polyphase FFT signal processing pipeline provides a nearly loss-free time to frequency transformation with significant reduced frequency scallop, less noise bandwidth expansion, and faster side lobe fall-off.
- ✓ Field-operations of our FFTS over the last 8 years have proven to be very reliable, with calibration- and aging-free digital processing boards.
- ✓ Low space and power requirements – thus safe to use at high altitude (e.g. APEX at 5100-m) as well as on spacecrafts (SOFIA) and future satellites (Millimetron?).
- ✓ Production cost are low compared to traditional spectrometers through use of only commercial components.

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FFTS/XFFTS :: *Contact, Distribution*

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Contact:

For further information about the MPIfR FFT spectrometer, future developments and applications, please contact
Dr. Rolf Güsten (rguesten@mpifr.de) or
Prof. Bernd Klein (bklein@mpifr.de) at the
Max-Planck-Institut für Radioastronomie in Bonn, Germany.

Distribution:

Radiometer Physics GmbH

http://www.radiometer-physics.de