SDR from DC to (almost) Daylight

Tom McDermott, N5EG

tapr.org/~n5eg

Medford, Oregon

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Outline

- SDR Applications.

- Amateur SDR Generations:
  - 1st generation – analog Direct Conversion IQ technology.
  - 2nd generation – digital Direct Conversion IQ technology.
  - 3rd generation – hybrid conversion IQ technology.

- HF, VHF/UHF, & Millimeter Wave Technologies

- References.

Some Applications of SDR

1. Local radio (of course).
   - From Headless (computer GUI) to Full-knobbed box.

2. Remote radio.
   - Internet transceiver, spectrum display (graphics compression).
   - Reverse Beacon Network (RBN) receiver / CW skimmer (many / all bands simultaneously).

3. Ionospheric Echo Sounding.
   - Passive or Active sounding.

4. HF Vector Network Analyzer.
   - Coherent receiver → good dynamic range.

5. AMSAT Phase 4 satellite ground stations.

6. High Speed data linking.
   - UHF & above, typically Ethernet.

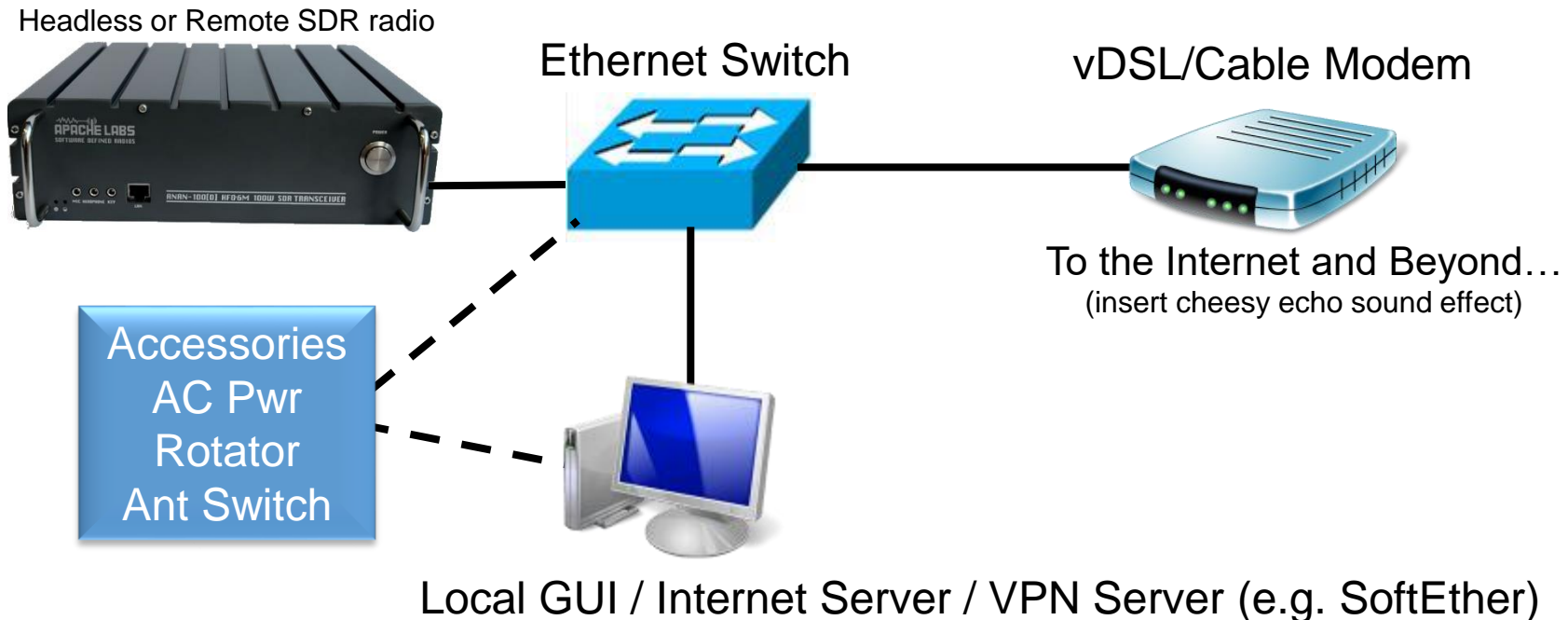# Local SDR Radios – Headless to Fully Knobbed

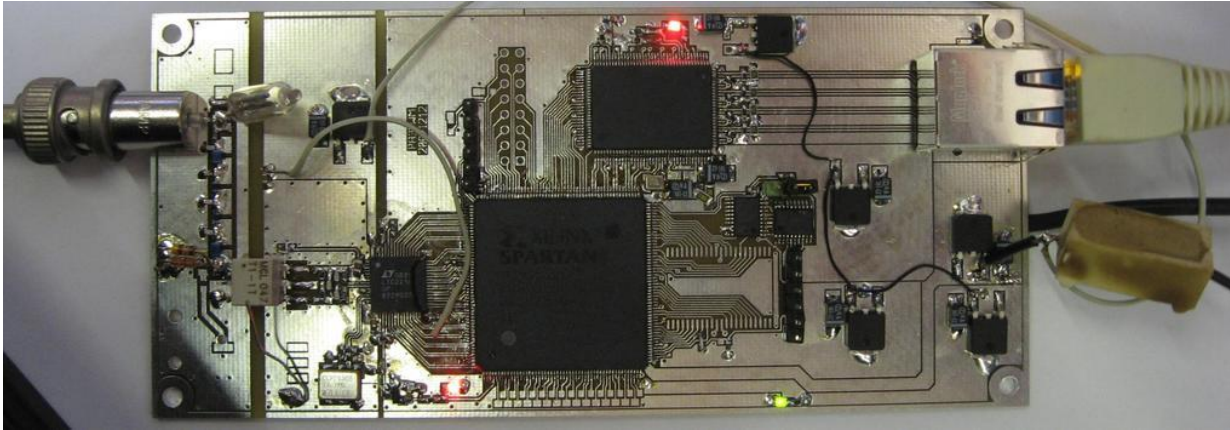
"Headless"

"Partially / Remotely Knobbed"

"Fully Knobbed"

Local / Remote SDR

- Ethernet network makes remoting an SDR possible, but some issues:
    - Internet Server function may be needed (normally not in the radio).
    - Latency (for remote transceiver).
    - Audio Processing (from raw SDR data stream).
    - Graphics compression may be needed for spectral display.
    - Fail-safe Transmit time-out, High SWR lockout, etc.
    - Accessory control (AC Power, Rotator, Antenna switch, etc.)

Headless or Remote SDR radio

Ethernet Switch

vDSL/Cable Modem

To the Internet and Beyond…
(insert cheesy echo sound effect)

Accessories
AC Pwr
Rotator
Ant Switch

Local GUI / Internet Server / VPN Server (e.g. SoftEther)

Well Known Web SDR

Supports more than two hundred simultaneous users – each receiving a different channel.
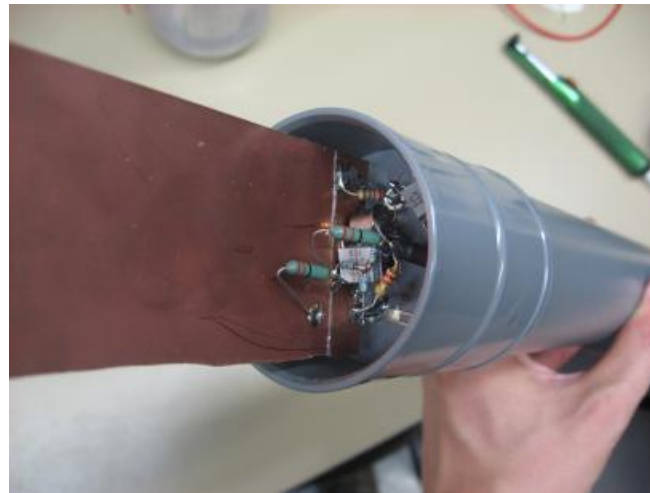
Wideband Receive Antenna

University of Twente
The Netherlands

SDR Web Servers

- SDR server allows client(s) to access your SDR over local network or Internet.
  - Many packages available providing varying functionality. Most usually fit into one of two basic groupings:
    1. Many clients, many narrowband streams. Each client statically sets frequency of their own narrowband receiver, or
    2. Few clients, high functionality. Spectrum display, interactive tunable receiver, transmitter. Mobile device support, etc.
  - Wide range of servers, from high-end desktop to Raspberry Pi. Some examples:
    1. ghpsdr3 (John Melton G0ORX/N6LYT). Linux server for OpenHPSDR devices, others radios have been added.
    2. OpenWebRX (Andras Retzler, HA7ILM) Open Source. Linux based. http://sdr.hu/openwebrx
    3. Numerous pages on Raspberry Pi as web server. GIYF (google is your friend).

- http://websdr.org/ Links to hundreds of SDR servers (receivers) you can listen to in real time.
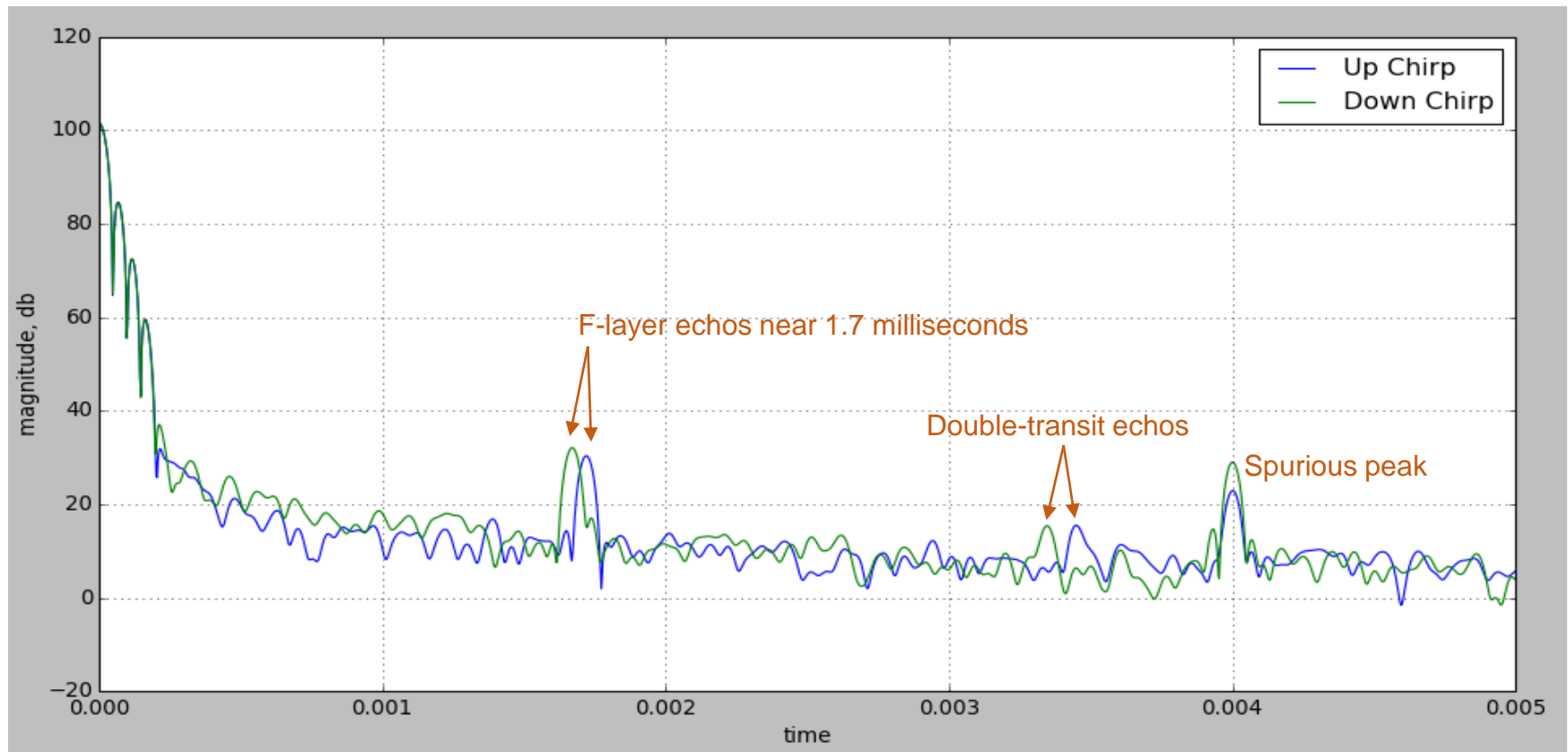
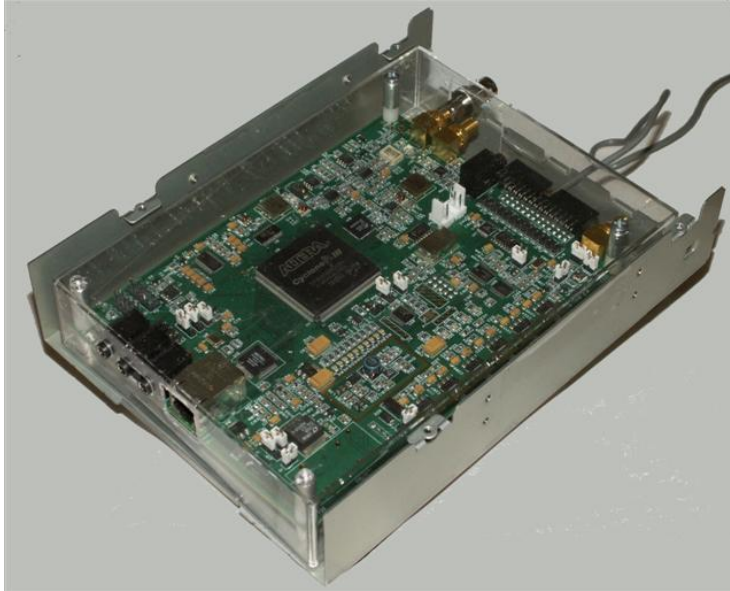# SDR Echosounding Setup
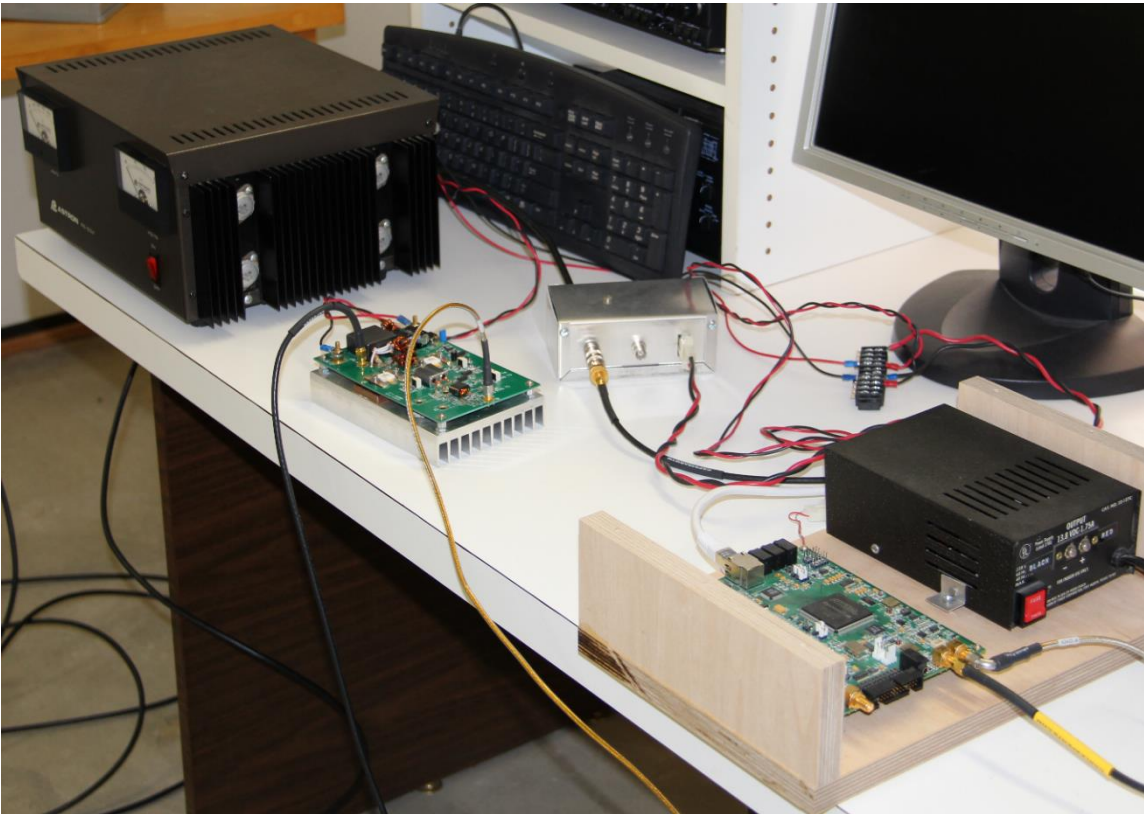
SDR Ionospheric Echosounding Diagram
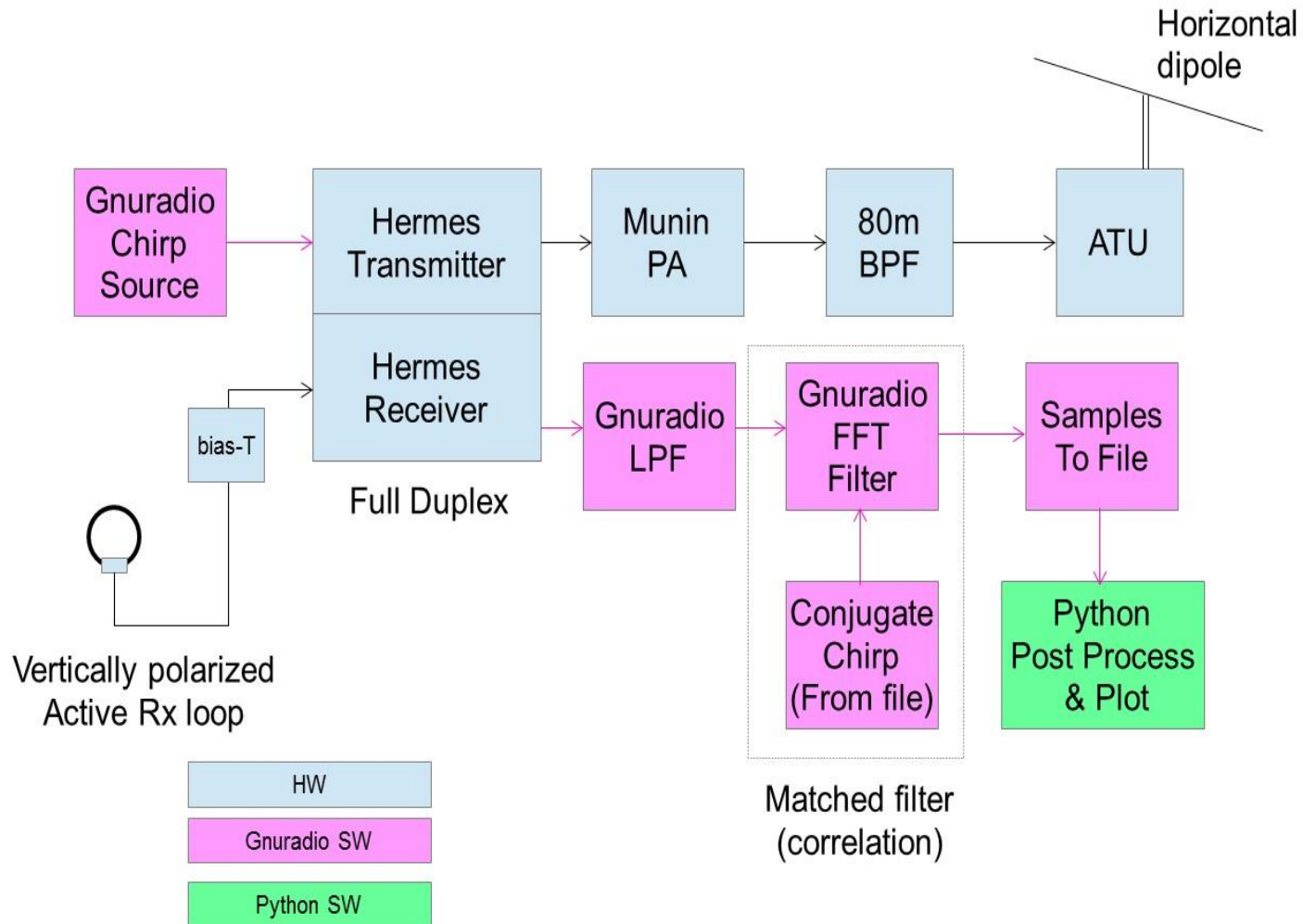
N5EG – DCC 2015

SDR Echos - 3.6 MHz. Evening

- F layer echos near 1.7 milliseconds. -0.38 Hz Doppler shift.

- Double-transmit echos near 3.4 milliseconds

- Height: 254 km. Vertical Velocity: +15.4 m/sec. Artifact at 4 milliseconds

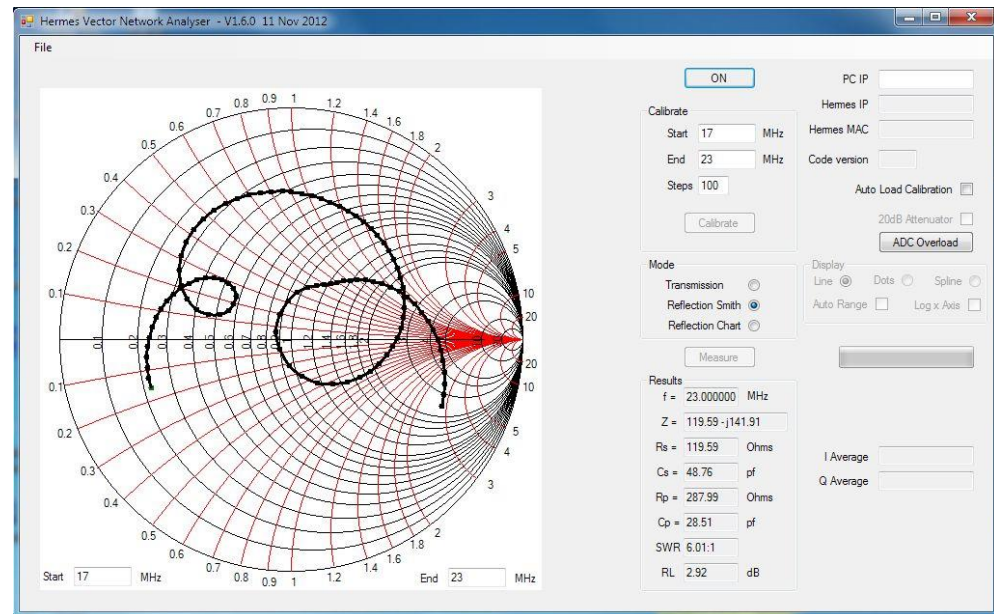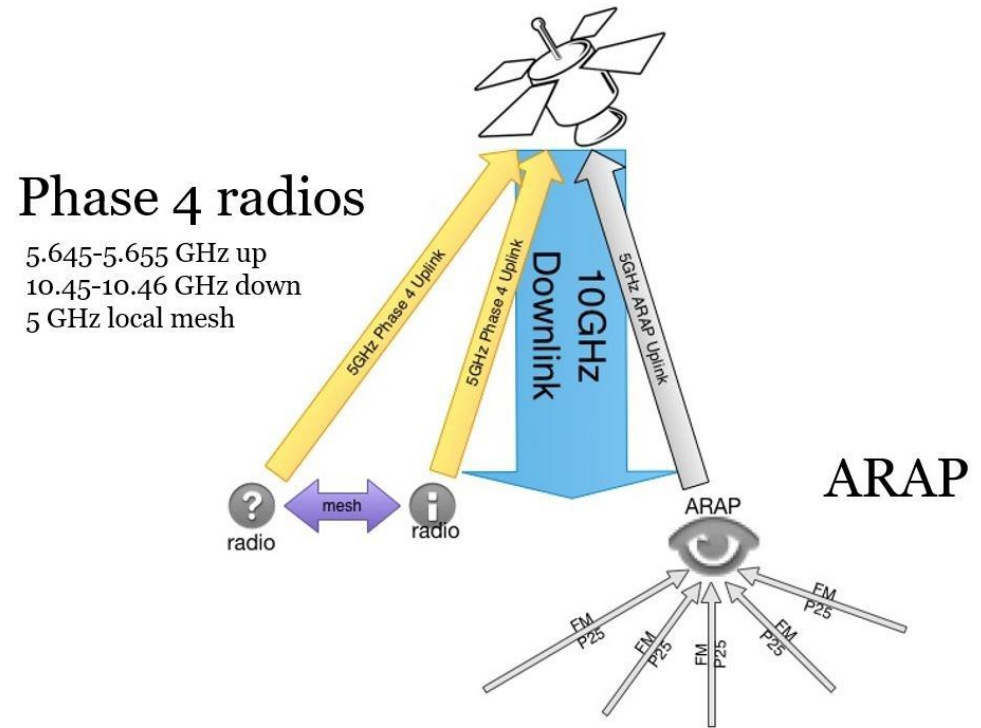# SDR Vector Network Analyzer

SDR Transmitter & Receiver

+

Reflection Bridge
(for S11 measurements)

AMSAT Phase 4 – High Speed SDR Datalinks

- Ground stations multiplex various user traffic, uplink composite digital data to satellite at 5.6 GHz using SDR radios.

- Ground stations downlink composite digital data stream at 10.45 GHz, demultiplex, distribute to users.

- Users don't directly communicate with the satellite.

Phase 4 radios

5.645-5.655 GHz up
10.45-10.46 GHz down
5 GHz local mesh

5GHz Phase 4 Uplink
5GHz Phase 4 Uplink
10GHz Downlink
5GHz ARAP Uplink

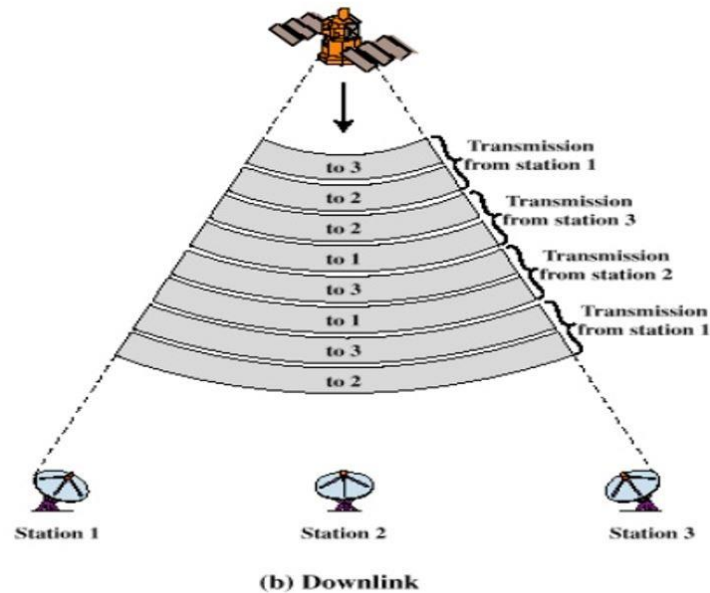? radio ← mesh → i radio

ARAP

ARAP

FM P25

Phase 4 – Uplink and Downlink Concepts

- FDMA uplink – each ground station transmits on a different channel.
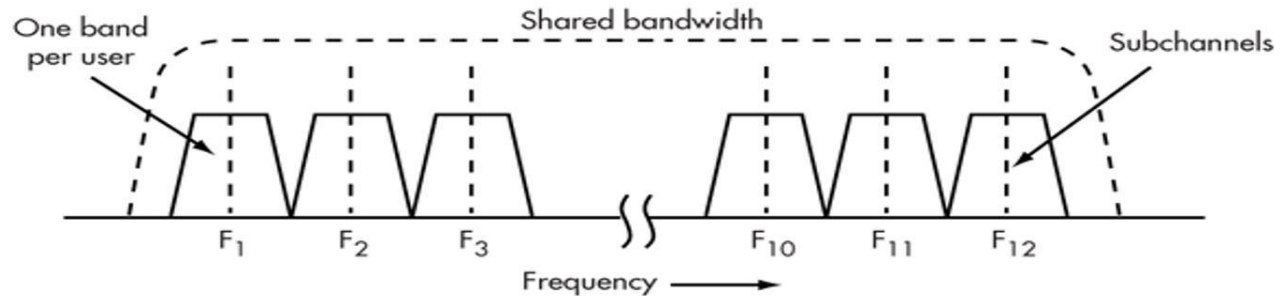

- TDMA downlink – traffic destined for each ground station on a different time slot.

- All ground stations can hear all downlink timeslots (broadcast).

Experiments in progress with Ettus, HackRF, BladeRF SDR radios
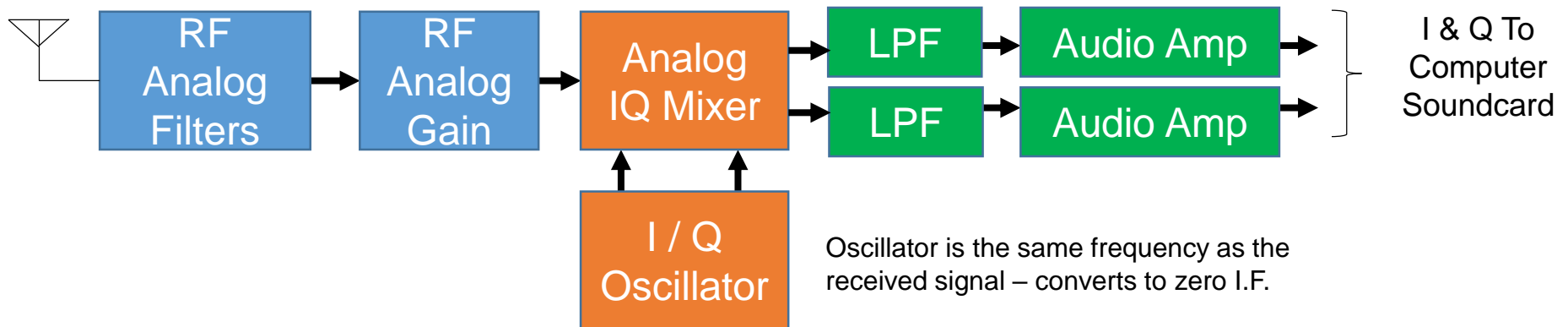
High Speed Datalinks

- UHF+ SDR units well suited to high-speed point-to-point data links.

- Quadrature Amplitude Modulation (QAM) and Forward Error Correction (FEC) → high throughput.

- Adaptive equalization can combat multi-path distortion.

- GNU Radio is an excellent platform for prototyping and testing.

  - Pre-built modules for:

    - Frequency locking

    - Timing recovery

    - Filtering, Equalization

    - Modulation / Demodulation

    - FEC coding / decoding.

Scatter Plot
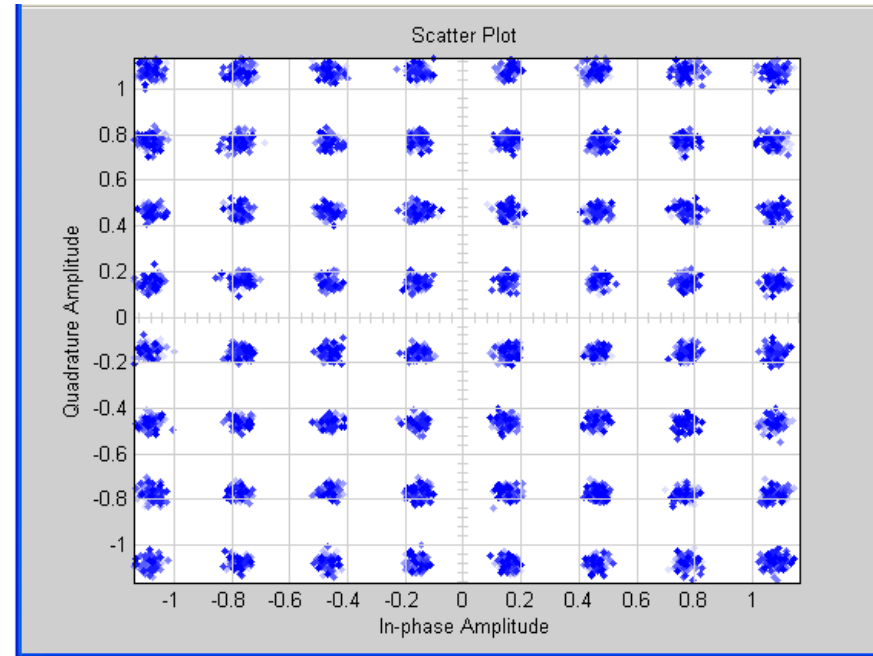
Some Common SDR Architectures

1. Homodyne Analog.

2. Homodyne Digital.
   - Direct firehose.
   - Digitally down-converted.

3. Hybrid (Heterodyne) Digital.
   - Analog down-conversion to lower speed I.F. which can be digitized economically.
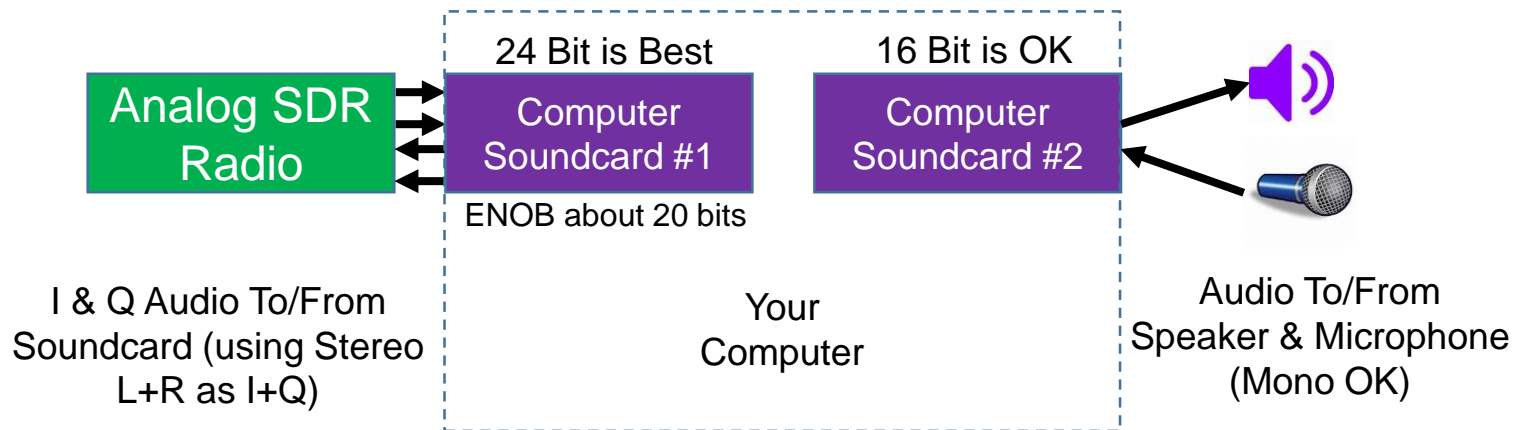
1. Homodyne Analog SDR Receiver

RF Analog Filters → RF Analog Gain → Analog IQ Mixer → LPF → Audio Amp → (I & Q To Computer Soundcard)

Analog IQ Mixer → LPF → Audio Amp

I / Q Oscillator

Oscillator is the same frequency as the received signal – converts to zero I.F.

- Essentially a Direct-Conversion receiver.
- Down convert R.F. to Zero I.F. (Softrock, FlexRadio 1k, 3k, 5k series, etc.).
  - SSB & CW don't require demodulation – just filter and send to speaker.
    - Need a way to reject opposite sideband (negative frequencies):
      - Weaver method, Complex Filter method, Phasing method (Hilbert).
  - FM requires demodulation, AM usually best when demodulated.
- Typical Passband: Minus 24 KHz to Plus 24 KHz. of the channel center frequency using 48ks/s soundcard.
  - Imperfect Mixer, LPF, and Soundcard response all degrade opposite sideband rejection in this approach.

Multiple Soundcards

- Analog SDR requires two soundcards (or equivalent).
  - One to send/receive baseband I & Q samples to the radio from the computer. Normally 24-bit very high performance card is needed.
  - Second to send/receive audio to the headphones (or speaker) and from the microphone. 16-bit lower performance card works just fine.
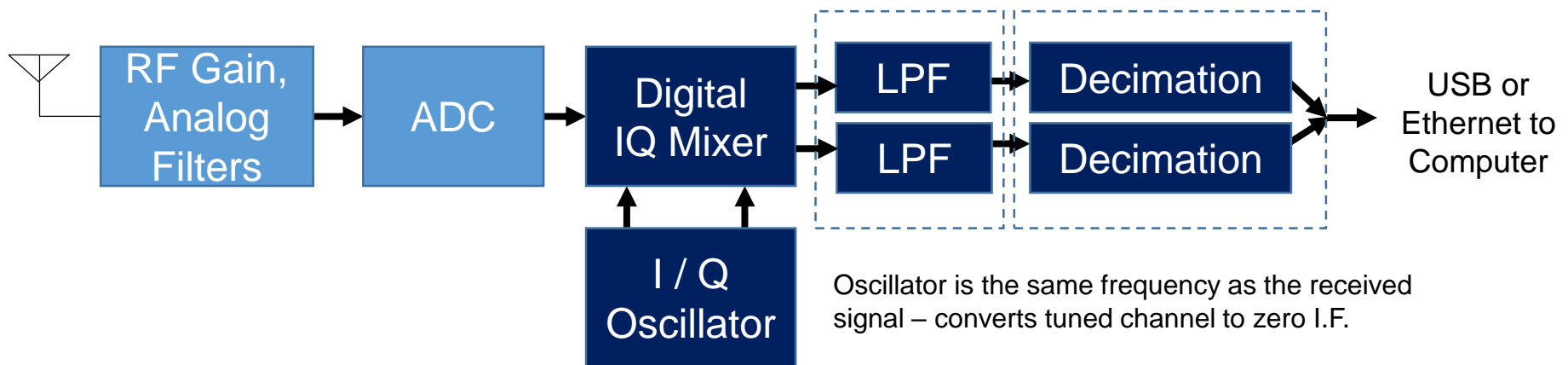 - USB headsets have the soundcard functionality built into the headset itself.

24 Bit is Best   16 Bit is OK

| Analog SDR Radio | Computer Soundcard #1 | Computer Soundcard #2 |

ENOB about 20 bits

I & Q Audio To/From Soundcard (using Stereo L+R as I+Q)

Your Computer

Audio To/From Speaker & Microphone (Mono OK)

A Simple Digital SDR

RF Gain, Analog Filters → ADC → Ethernet IF → 3 x Gigabit Ethernet, or (probably) 10G Ethernet to Computer

- Why Not ?
  - Let's say … DC ~ 6 meters.
  - Spurious Free Dynamic Range ~ 100 dB.   LTC2208 ADC 16 bits.
  - Nyquist criteria: Fsample > 2 * maximum frequency.
    - Fsample > 54 MHz * 2 = 108 Ms/s.
    - Common sample rate: 122.88 Ms/s (harmonically related to 48K).
  - 16 bits * 122.88 MHz = 1.966 Gigabits / second to the computer.
  - Add in IP & Ethernet overhead: 3 x Gigabit Ethernet, or 1 x 10GE.
  - It's a FIREHOSE !!
    - Whoa !   Gulp.   Help.   Open the pod bay doors, HAL.
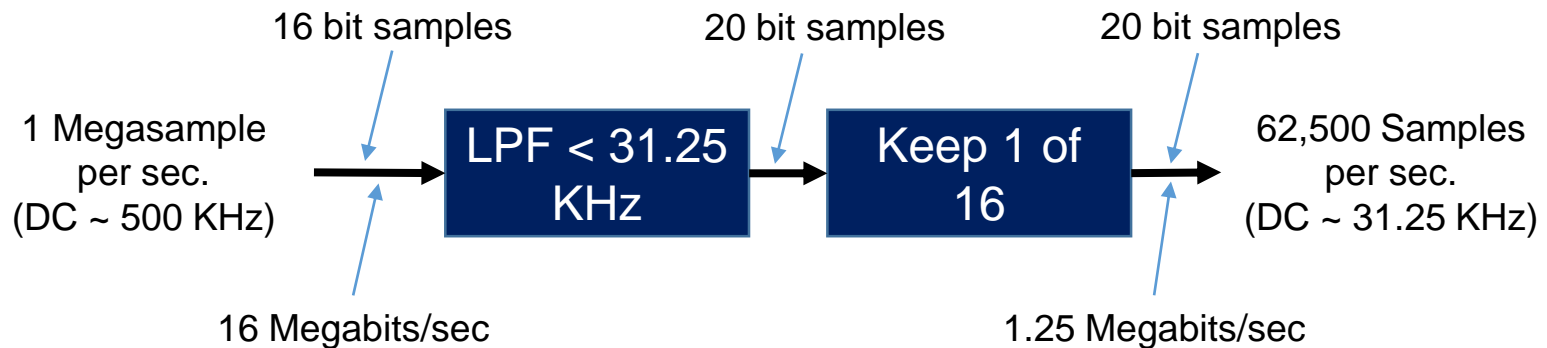
2. Homodyne Digital SDR Receiver

Oscillator is the same frequency as the received signal – converts tuned channel to zero I.F.

- Essentially a Direct-Conversion receiver.
- Down convert R.F. to Zero I.F. (Open HPSDR, Flex 6000, many others).
  - SSB & CW don't require demodulation – filter, decimate, and send to speaker.
    - Need a way to reject opposite sideband (negative frequencies):
      - Weaver method, Complex Filter method, Phasing method (Hilbert).
  - FM requires demodulation, AM usually best when demodulated.
- Typical Passband: Minus 192 KHz to Plus 192 KHz. of the channel. Selectable via Decimation Ratio.
- Typical ADC: 14 or 16 bits.   Baseband is ~24 bits (achieved via decimation).
- Very high opposite sideband rejection without adjustment.
- I/O to Computer: 384 Ksps → about 19 Megabits/sec
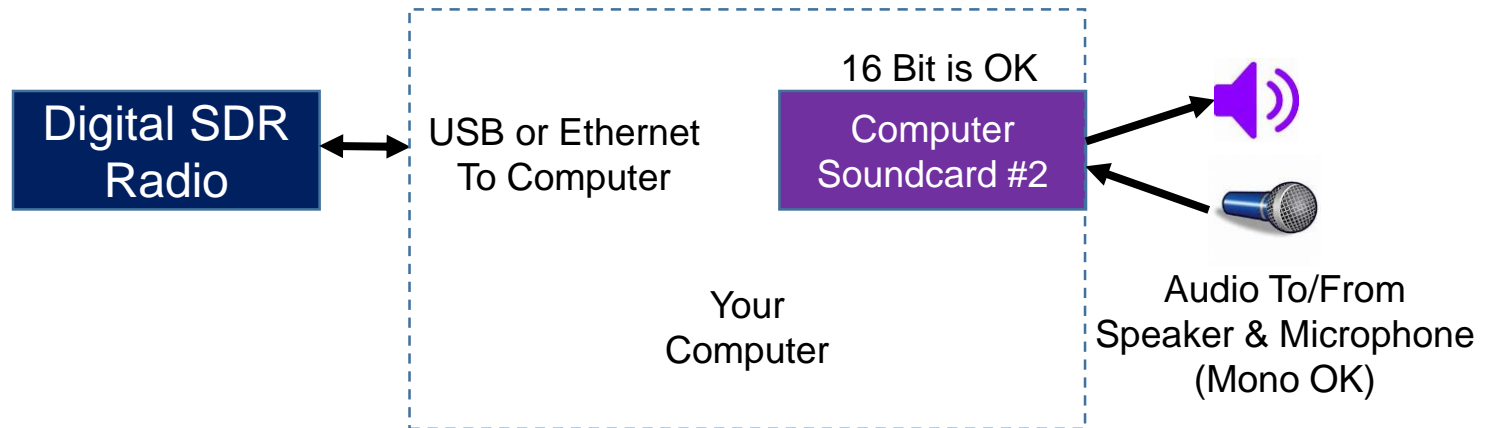
Decimation

- Reduce the sample rate of a digital data stream.
    1. Low Pass Filter the data below the output Nyquist rate.
    2. Then throw away most samples, just keep 1 out of every N.

- Example: Decimate by 16.
    - Peak signal increases by 16 times, i.e. 4 more bits needed.
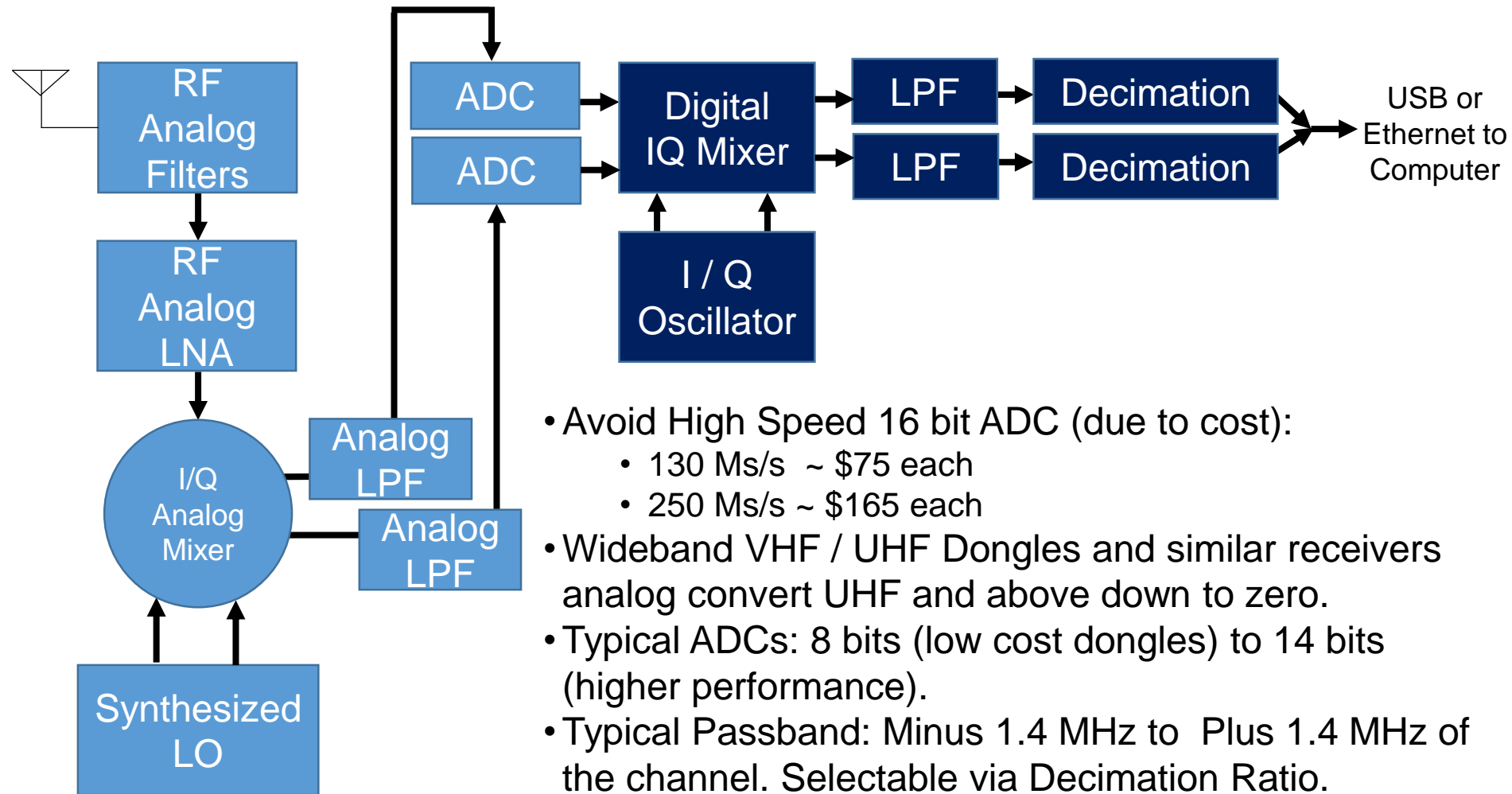   - Signal-to-Noise-Ratio improves by sqrt(16), i.e. 2 bits.

16 bit samples   20 bit samples   20 bit samples

1 Megasample per sec. (DC ~ 500 KHz) → | LPF < 31.25 KHz | → | Keep 1 of 16 | → 62,500 Samples per sec. (DC ~ 31.25 KHz)

16 Megabits/sec   1.25 Megabits/sec

Ratio of 500,000 to 16 = 31,250

Single Soundcard

- Digital SDR eliminates the need for the first soundcard.

Digital SDR Radio ← USB or Ethernet To Computer → 16 Bit is OK / Computer Soundcard #2 → Audio To/From Speaker & Microphone (Mono OK)

Your Computer

3. Hybrid Conversion SDR Receiver

RF Analog Filters → RF Analog LNA → I/Q Analog Mixer → Analog LPF / Analog LPF → ADC / ADC → Digital IQ Mixer → LPF / LPF → Decimation / Decimation → USB or Ethernet to Computer

I / Q Oscillator → Digital IQ Mixer

Synthesized LO → I/Q Analog Mixer

- Avoid High Speed 16 bit ADC (due to cost):
  - 130 Ms/s ~ $75 each
  - 250 Ms/s ~ $165 each
- Wideband VHF / UHF Dongles and similar receivers analog convert UHF and above down to zero.
- Typical ADCs: 8 bits (low cost dongles) to 14 bits (higher performance).
- Typical Passband: Minus 1.4 MHz to Plus 1.4 MHz of the channel. Selectable via Decimation Ratio.
- Used for coherent high-data-rate optical fiber (optical mixing and DSP) [Almost Daylight]
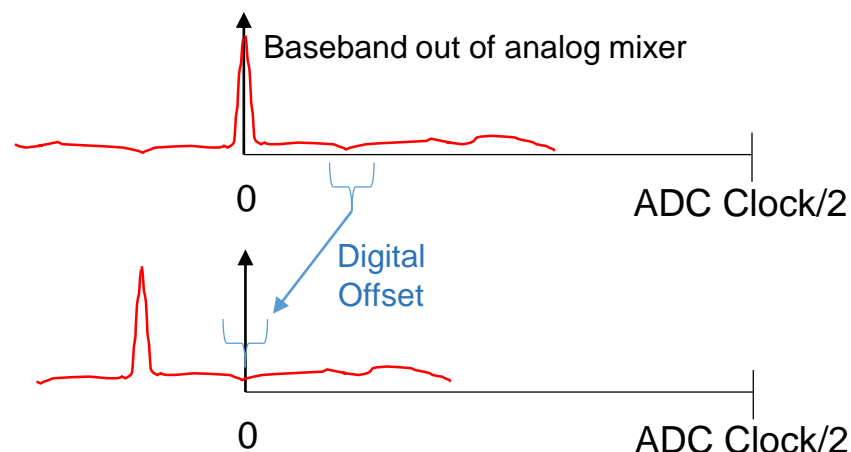
The Spike

- ADC DC offset creates a spike at zero Hertz.
  - Digitally downconvert or offset away from the spike

- Analog mixer LO leakage causes DC offset – a spike at the channel center (zero).
  1. Reduce LO/Mixer image via calibration.
  2. Offset away from the spike.

Homodyne Digital Rx

ADC

DC

ADC Clock/2

IQ Digital Downconversion

0
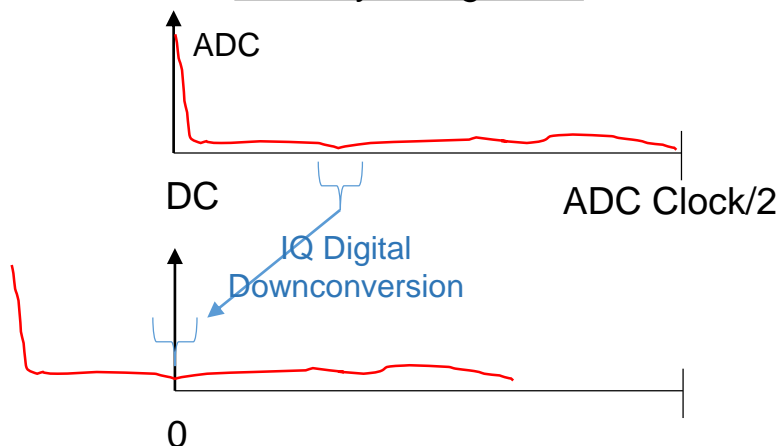
Digital downconversion moves the spike way off frequency

Analog or Hybrid Conversion Rx

Baseband out of analog mixer

0

ADC Clock/2

Digital Offset

0

ADC Clock/2

Digital offset moves the spike outside desired passband

A few SDR Radios used by Hams

The list of available SDR radios is huge and growing…

- ## RTL2800 dongle and cousins – VHF/UHF receiver.
  - Low cost, but poor dynamic range.
  - Many are web connected.
  - Can be used for ADSB reception at 1090 MHz (aircraft status). Networked via websites such as flightradar24.com

- ## Flex Radio Analog (1k, 3k, 5k series) and Digital (6k series) Radios.
  - Performance span from good to 'best measured' (Sherwood).

- ## OpenHPSDR / ANAN Digital Radios.
  - Groundbreaking design, excellent performance, open source.

- ## Red Pitaya, SDRPlay, many many others.
  - Typically lower-cost, low-to-moderate performance.

- ## Incrementally Icom / Kenwood / Yaesu are becoming more SDR-like.

New CMOS Silicon

- Integrated RF/Mixer + LO synthesizer chips becoming available.
    - Analog Devices, Lime Micro, Mirics to name a few.
- Provide range of input frequencies.
    - Mirics: 150 KHz – 2 GHz. [used in SDRPlay]
    - Analog Devices: 100 MHz – 6 GHz [used in Ettus SDR radios]
    - Lime Micro: up to 12 GHz (multi chip solution).
- Some paired with dual ADC + DSP + Host interface chip (USB typical).
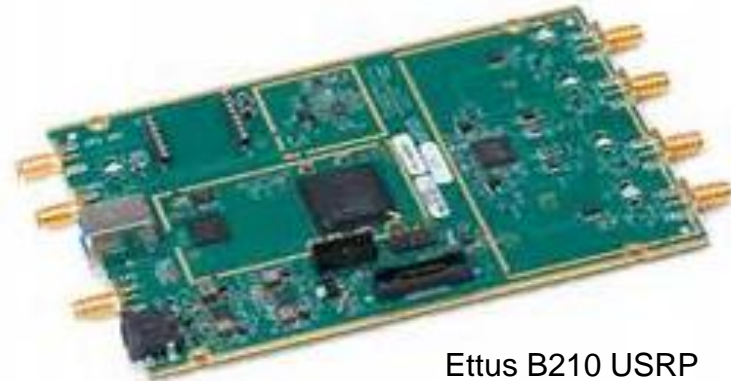- Some provide AGC, typically not for SSB.
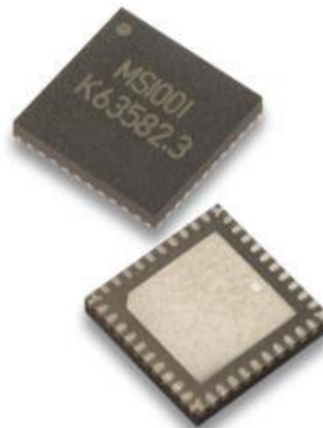
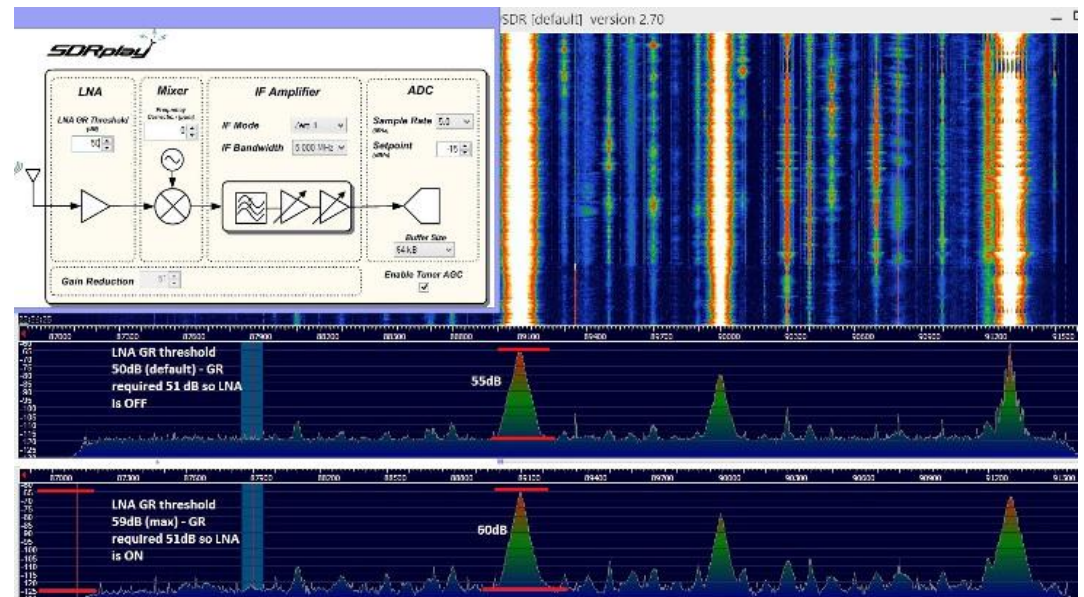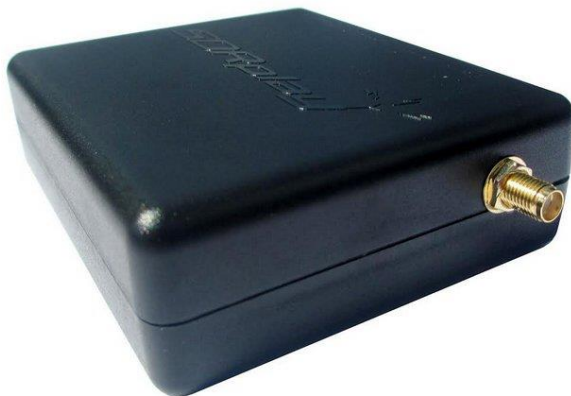Mirics MSi001
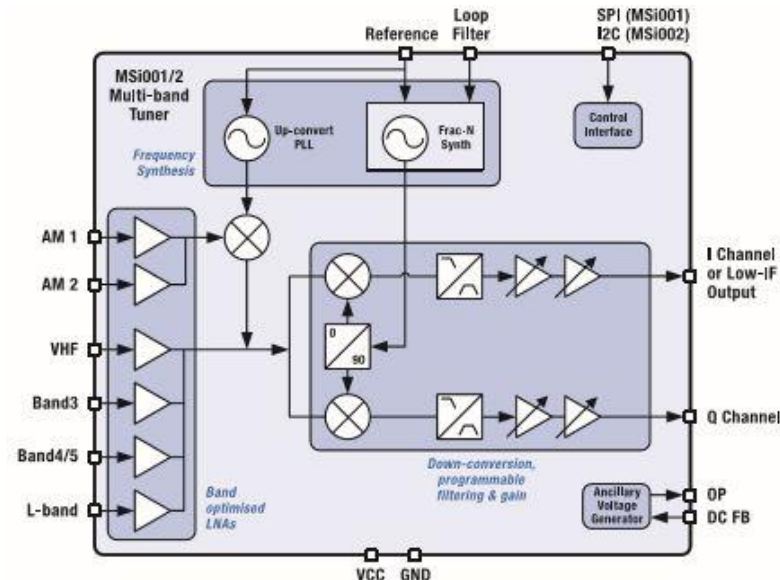
Analog Devices AD9361
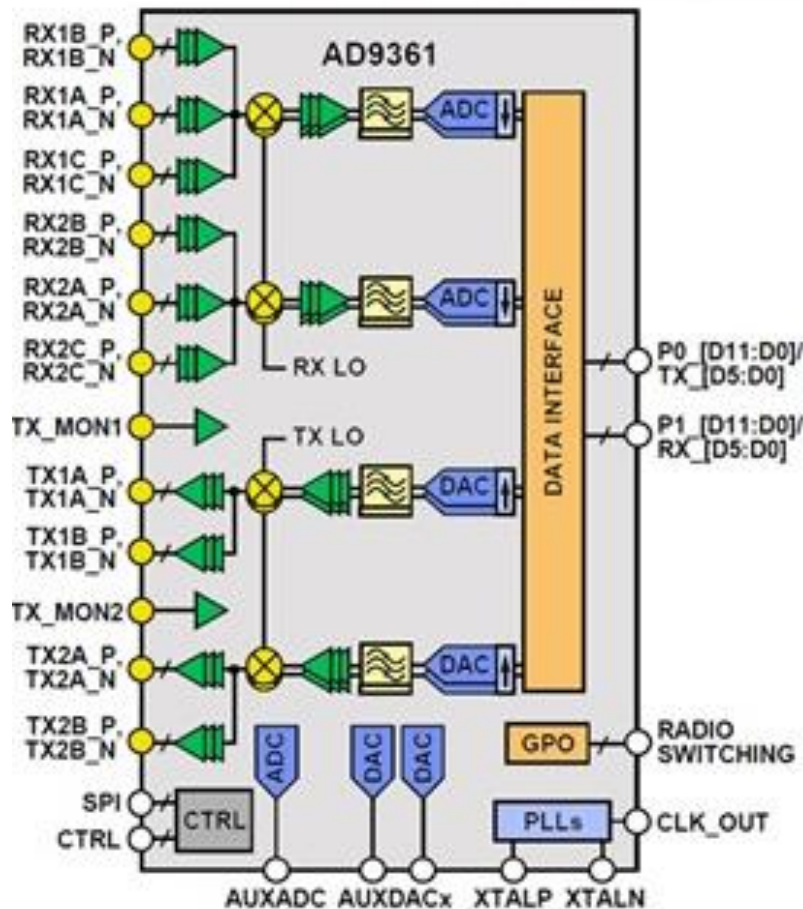
- Single Chip 70 MHz – 6 GHz.
- 2 Rx + 2 Tx (2x2 MIMO)
- 12-bit ADCs and DACs
- Channel BW: 200 KHz to 56 MHz
- Includes LNAs, LO Synthesizer, and RF AGC.
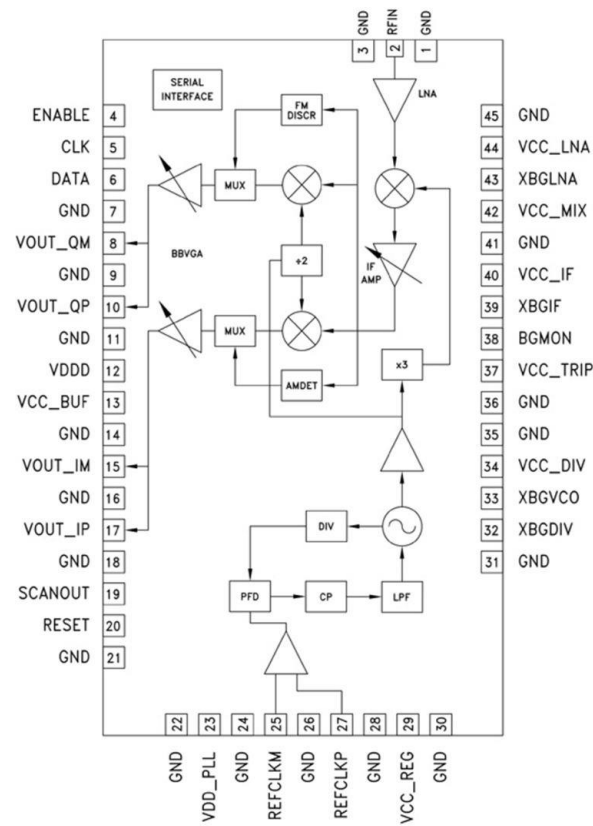

Ettus B210 USRP

SDR Play

- 150 KHz ~ 2 GHz. Like an upgraded RTL2800.
- AGC most useful with AM / FM. Improves overload issue common in some VHF / UHF very-low-cost receivers.
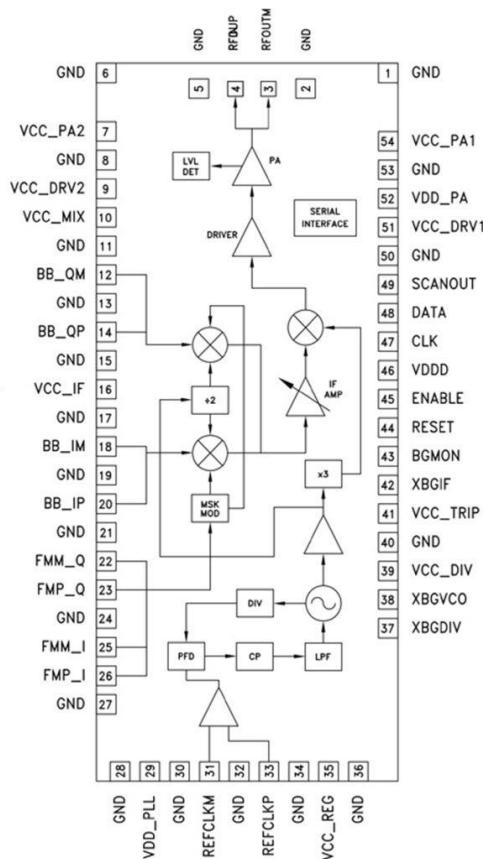- Uses Mirics chip set. 8 MHz. maximum BW.
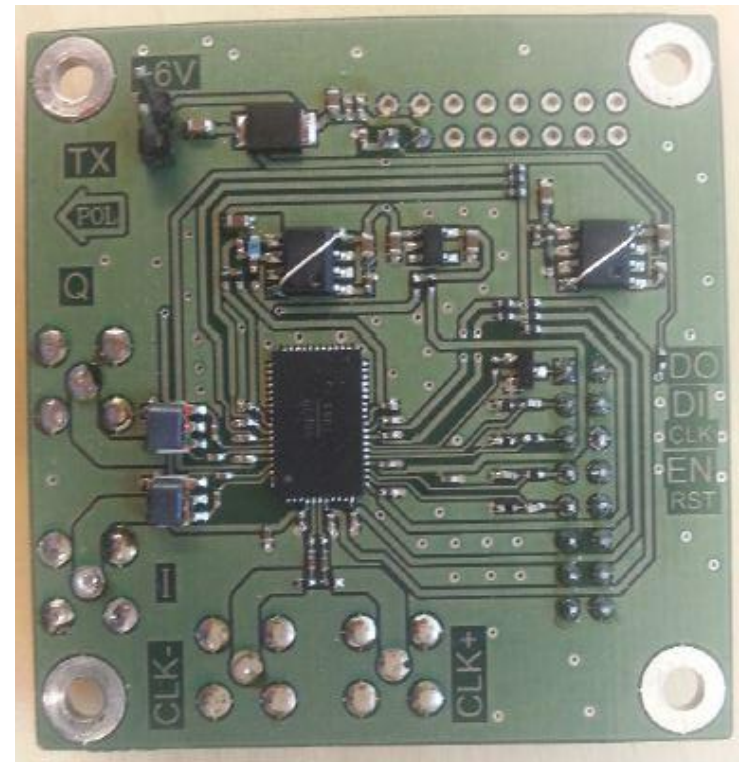
60+ GHz SDR Chipsets

- Growing interest in millimeter wave for 5G. Chipsets for 60-80 GHz available.

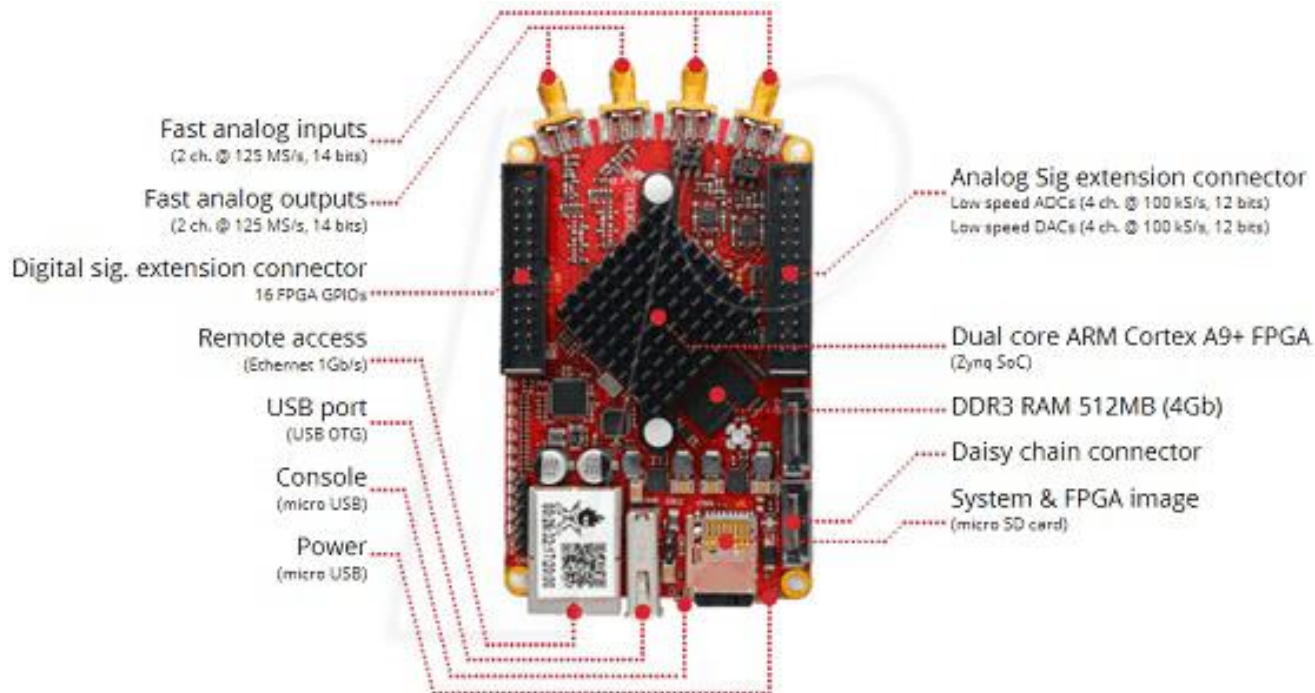- Open source Gnuradio / Hittite drivers: Per Zetterberg.

HMC6001 Rx   HMC6000 Tx

60 GHz Transmitter board.

Red Pitaya

- Marketed as low cost programmable test equipment (Scope, Spec Analyzer, Bode plotter, etc.)
- HPSDR, HDSDR, PowerSDR, Gnuradio available.
- Xilinx Zynq : FPGA + Dual core ARM A9 : Linux
- Two 14-bit ADCs + Two 14-bit DACs // 125 Ms/s

Red Pitaya SDR Measurements

- Ger Metselaar http://www.pa0aer.com/projecten/red-pitaya
- Pavel Demin http://pavel-demin.github.io/red-pitaya-notes/
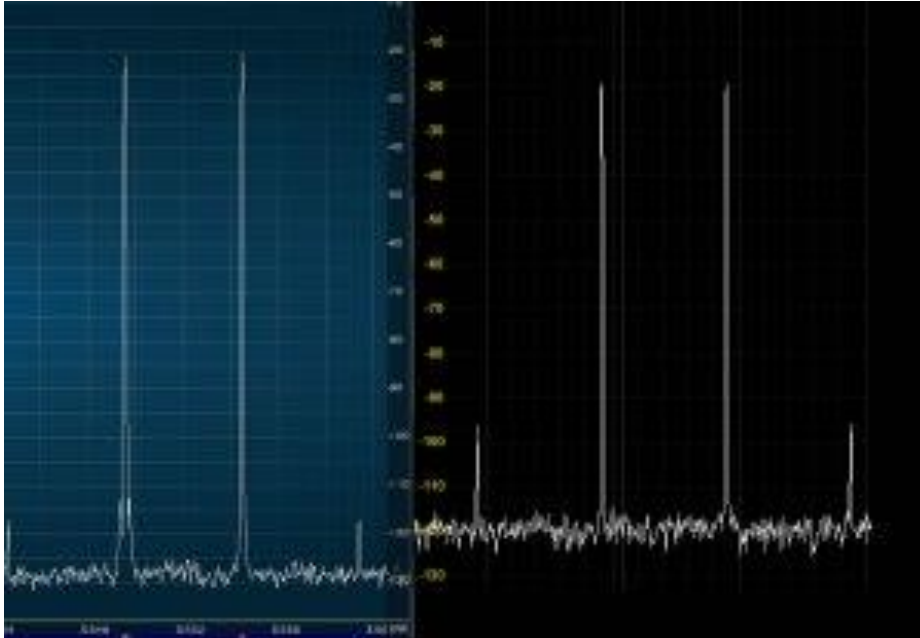
Sensitivity and Dynamic range poorer than Flex 6500.

Red Pitaya has response roll-off at 50 MHz according to Ger webpage.

Characteristic	Flex 6500	Red Pitaya
Noise Floor	-130 dbm	-120 dbm
3rd order IM suppression	97 db	75 db

Summary

- Digital and Analog CMOS, FPGA and Computer DSP enable very high performance and/or very low cost SDR radios.

- Initially SDR emulated a traditional radio.
  - SDR applications now reach far beyond just traditional radio communications.

- SDR can be highly configurable.

- SDR forms the basis of low-cost, high performance test equipment.

References

- http://websdr.org – links to many SDR receivers available on the web.
- https://softether.org – Free, very capable VPN software packages. Windows, Linux, Raspberry Pi 3.
- http://websdr.ewi.utwente.nl:8901/ - runs SDR receiver in your browser (no need to install any software).
- http://redpitaya.com/ - Red Pitaya website.
- http://openhpsdr.org/ - Open HPSDR website.
- http://www.tapr.org/~n5eg – *This presentation*, Echo sounding experiments, links, other presentations.
- https://github.com/Tom-McDermott - GNU Radio drivers for OpenHPSDR, other source code.
- http://w7fu.com/ - John Petrich's "Ham-Friendly DSP" site.
- http://www.tapr.org/conferences.html - ARRL / TAPR Digital Communications Conference (DCC). All things SDR and more.