Practical Application of Software Defined Radio

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Includes material from presentations by
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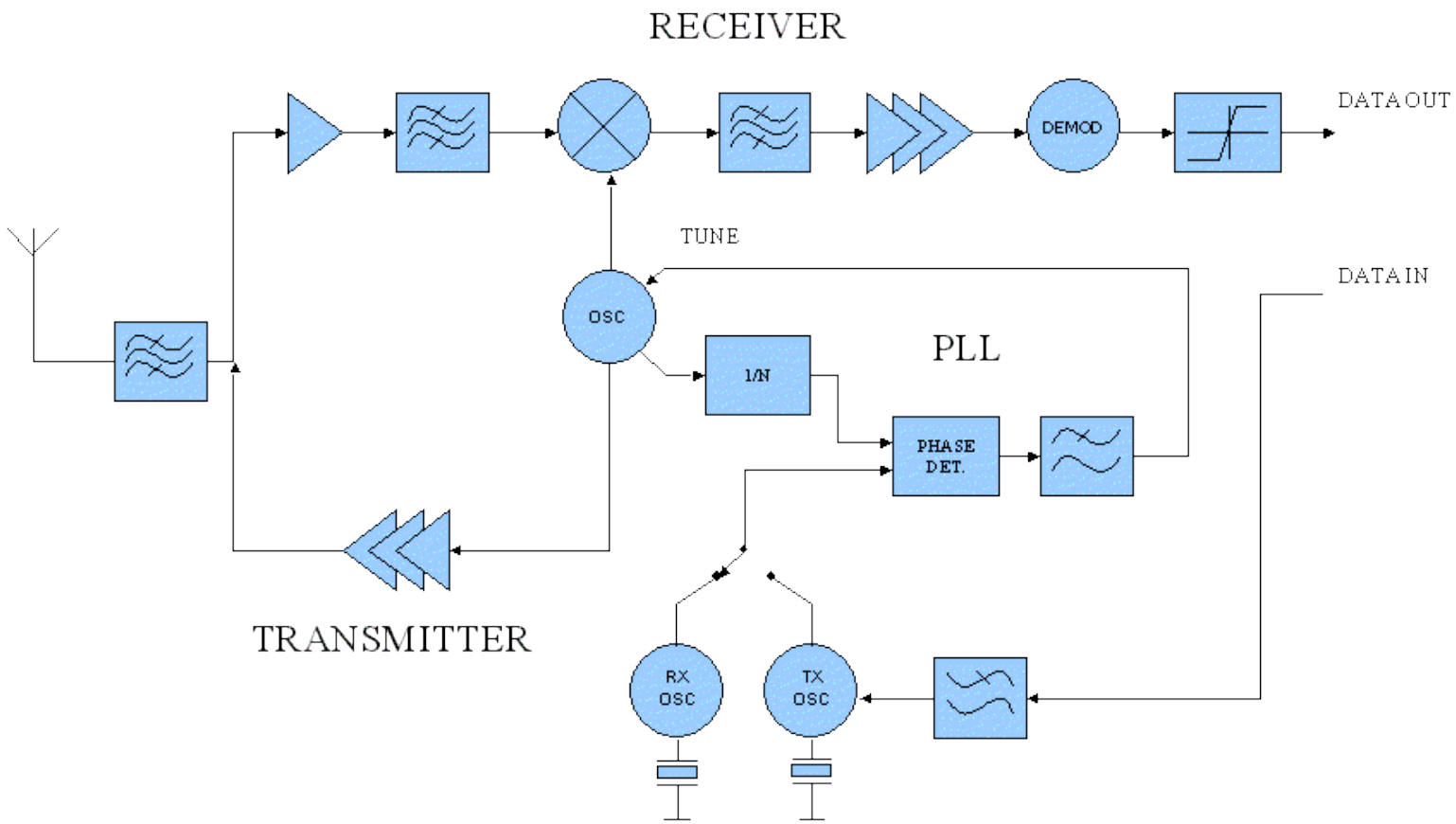
Bob N4HY and Tom K3IO,
and Lyle KK7P

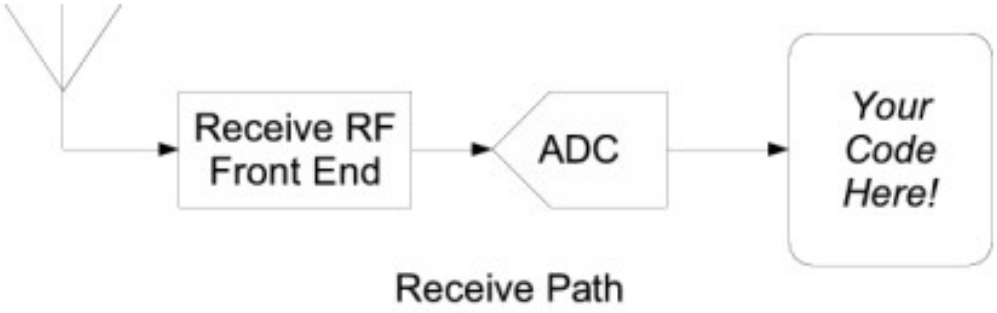
Agenda

- Software Defined Radio
- GNU Radio
- The Politics of Open Source SDR
- Interesting Hardware
  - Sound Card Interfaces
  - USRP, HPSDR, etc
- GNU Radio examples and demos!

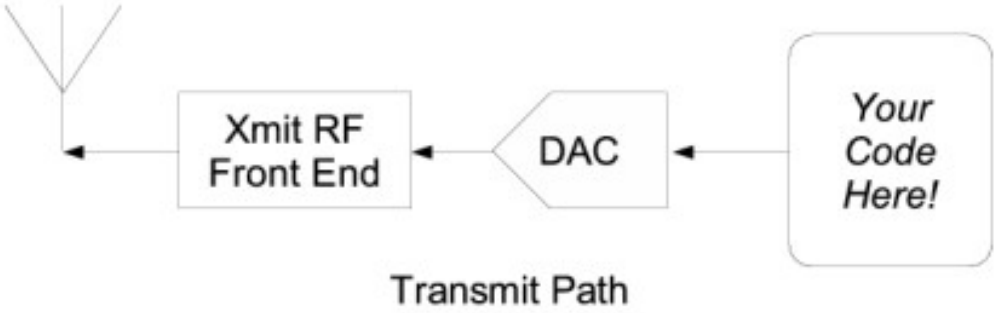
Typical (Data) Transceiver



Sofware Radio Block Diagram



Receive Path



Transmit Path

What can I do with SDR?

- Conventional radio stuff
  - Continuous enhancements
  - Performance not possible in analog circuits
- Use more bandwidth or time instead of power
- Spectrum monitoring
- Multi channel / Multi mode
- Better spectrum utilization
- Cognitive radio

"Used SDR-1000s do not exist. You get a brand new radio every time you download the latest software." Willi, SM6OMH

What's GNU Radio?

- **Free software** toolkit for:
  - **Building** and **deploying software radios**
  - **Learning** about DSP and **communication systems**
  - **Creating new** kinds of **radios**, modulations, protocols, development environments...
  - Exploring!

Architecture / Implementation

- **Data flow** abstraction
  - Signal processing blocks and connections between them
- Hybrid **C++** / **Python** system
- Stitching blocks together to prototype new “radios” in Python is pretty easy, and the body of available examples keeps growing
- Creating new blocks is more involved

Signal Processing Blocks

- **Input streams** and **output streams**
- I/O signature
  - **Type** of each stream is **specified**
  - Blocks specifies constraints on # of streams
- Relative i/o rates
  - **Fixed** 1:1, Fixed interp 1:N, Fixed decim N:1
  - **Variable**

Hello World

```
#!/usr/bin/env python

from gnuradio import gr
from gnuradio import audio

def build_graph ():
    sampling_freq = 32000
    ampl = 0.1

    fg = gr.flow_graph ()
    src0 = gr.sig_source_f (sampling_freq, gr.GR_SIN_WAVE, 350,
ampl)
    src1 = gr.sig_source_f (sampling_freq, gr.GR_SIN_WAVE, 440,
ampl)
    dst = audio.sink (sampling_freq)
    fg.connect (src0, (dst, 0))
    fg.connect (src1, (dst, 1))

    return fg

if __name__ == '__main__':
    fg = build_graph ()
    fg.start ()
    raw_input ('Press Enter to quit: ')
    fg.stop ()
```

Political Layer

- **Innovation** vs **Control, Encumbents** vs I**nnovators**
- "**Broadcast Flag**"
  - MPAA vs the rest of us
  - Though shalt not copy **broadcast TV!**
  - Restrictions on HDTV receivers
  - No provision for "Fair use"
  - Court ruled FCC can not regulate beyond reception...
- **FCC** / regulatory situation
  - SDR Good: Solution to spectrum utilization problems
  - SDR Bad: How to control / type certify / rogue radios

HDTV

Interface to Real World

- How to get samples in / out?
- Analog to Digital and Digital to Analog
- Getting RF up and down converted to IF

- Two main approaches...
  - Sound Card Interfaces
  - Direct Data Interfaces (like USB 2.0)

Sound Card Interfacing

- Relatively low sampling rate
  - 48 kHz or 96 kHz, 16 or 24 bits
- Good for audio input and output
- Can be used with narrow and low IF
- Examples
  - PSK-31 (RigBlaster, etc)
  - Narrow band HF (SDR 1000)

SDR-1000 Features and Specs

- 11Khz – 65Mhz General Coverage Receiver
- 160M – 6M (2M optional) Ham Bands TX
- TX 100W HF, 500mW 6M ... Optional ATU
- 99dB 2Khz Two Tone Dynamic Range
- Brick Wall Filters – 1.05:1 SF @ 500hz
  - No Ring 25hz CW receive filter
- Software features evolving rapidly


FlexRadio Systems
Software Defined Radios
SDR-1000
MIC

Next Gen SDR-1000, Software Skins

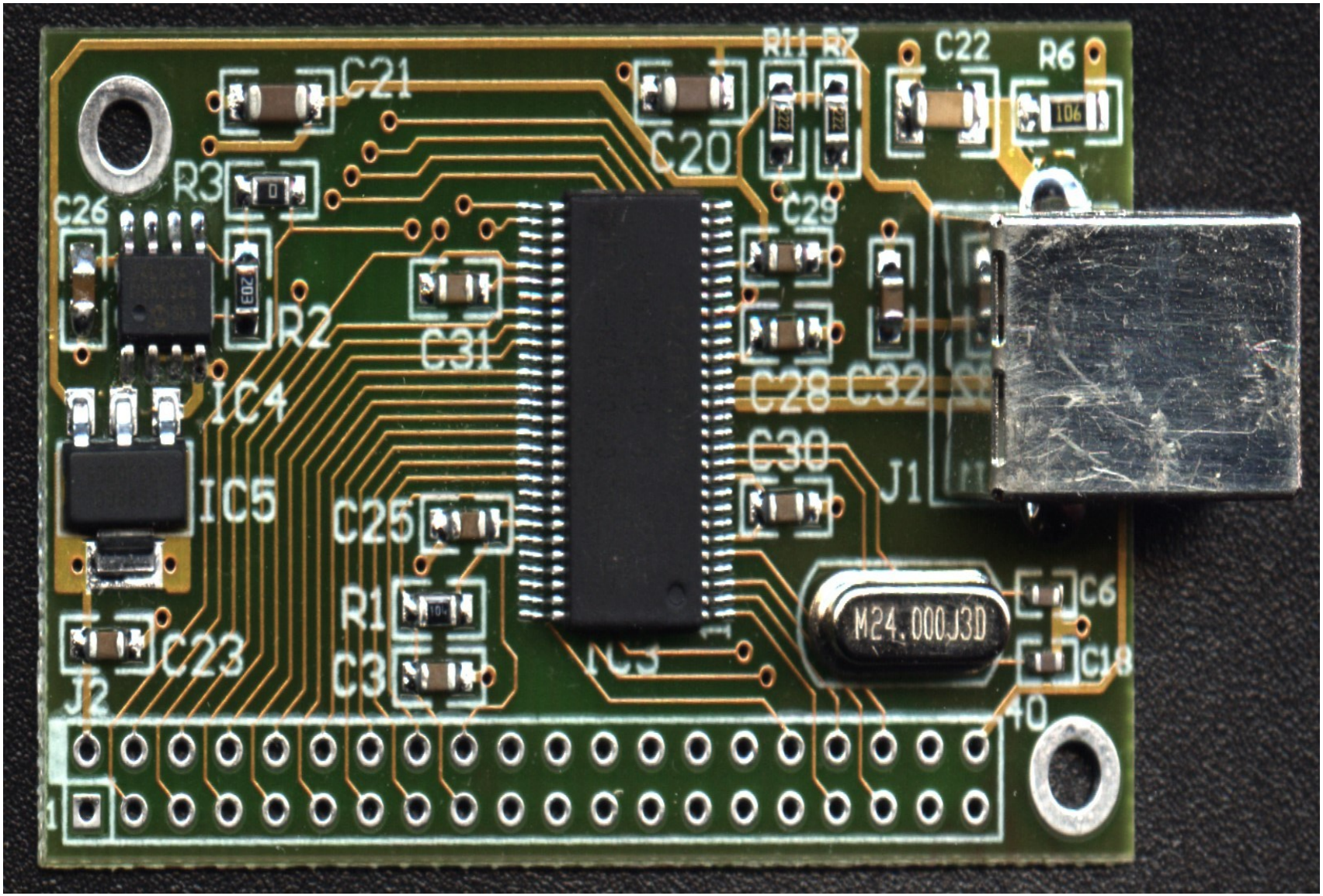
Wide Band I/O

- PCI A/D and D/A Cards
  - Good Bus Bandwidth
  - Expensive to Very Expensive ($1k - $10k)
  - Still need RF Front End

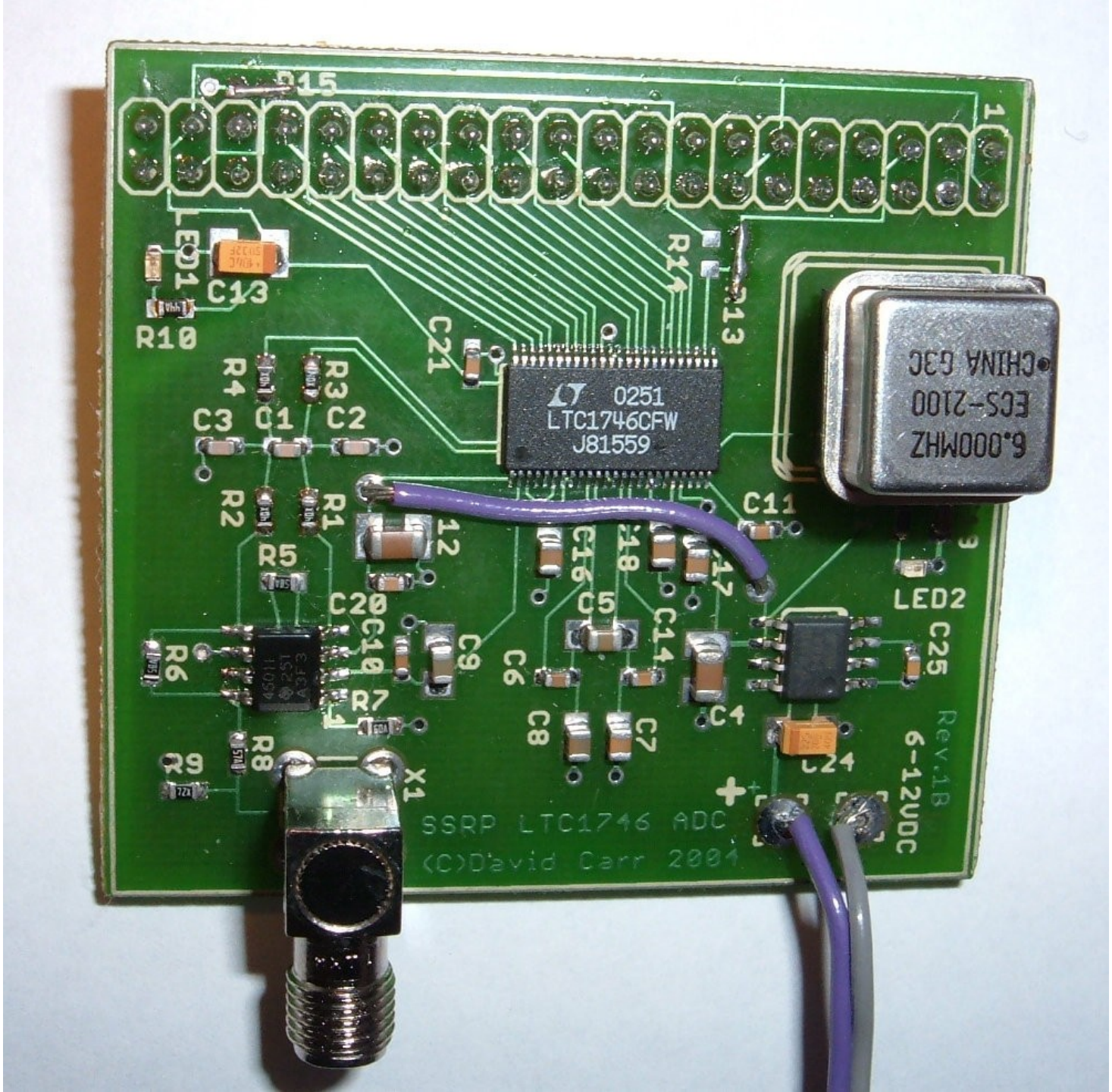
USB 2.0 Interfaces

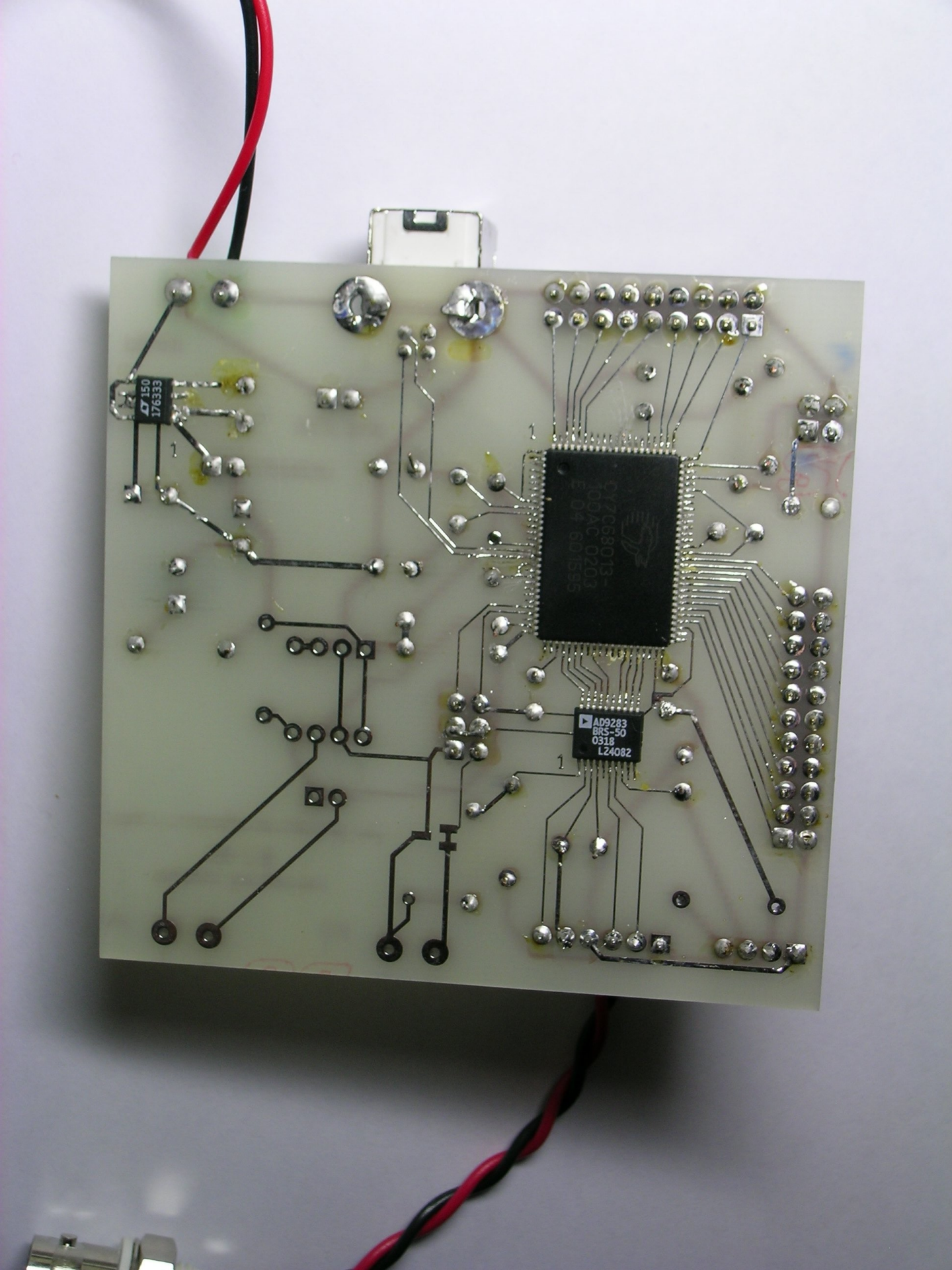
- SSRP kit from David Carr
- SR design by Vladimir Dergachev
- USRP by Matt Ettus
- HPSDR

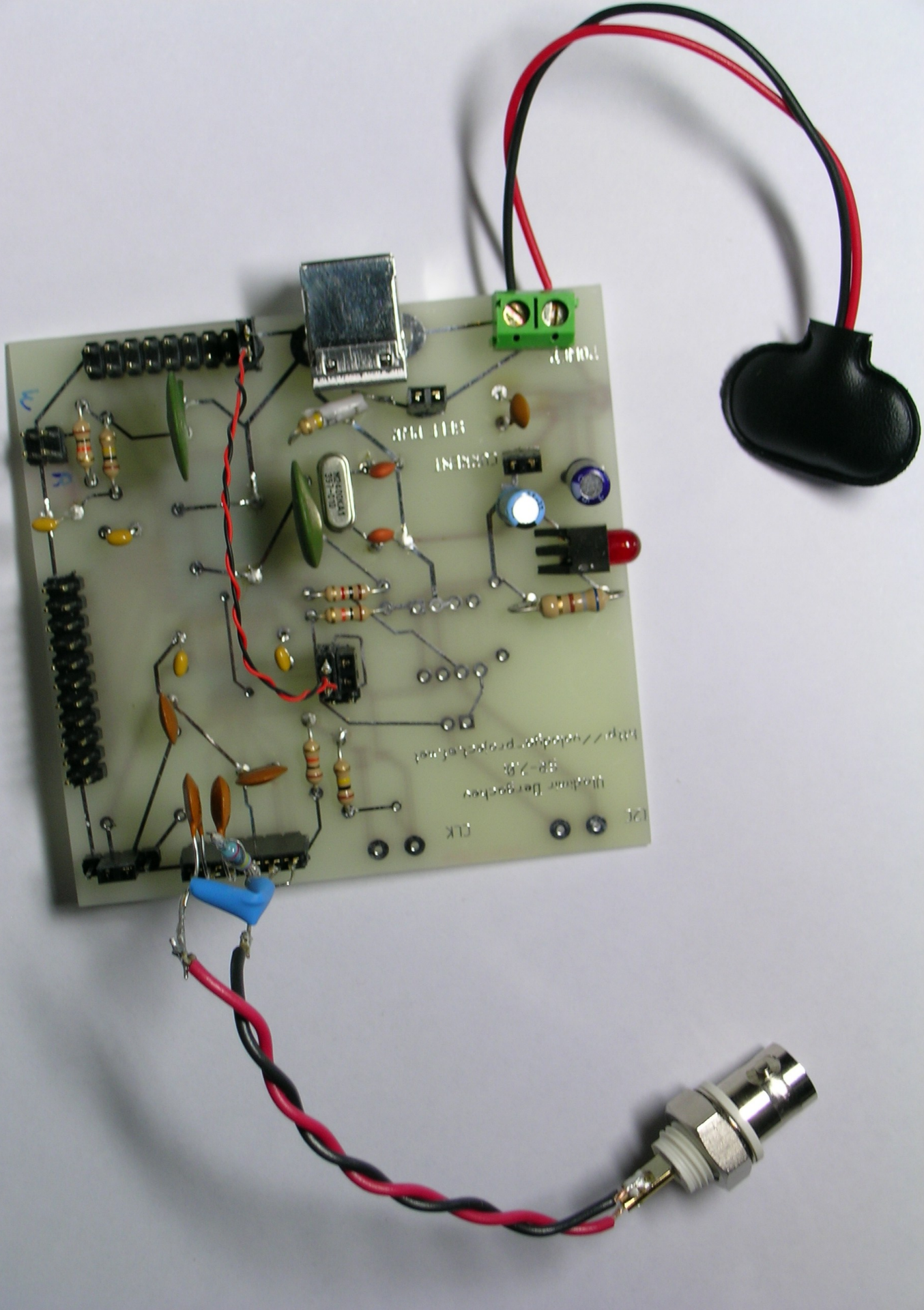
USB 2.0 Interface Board - SSRP



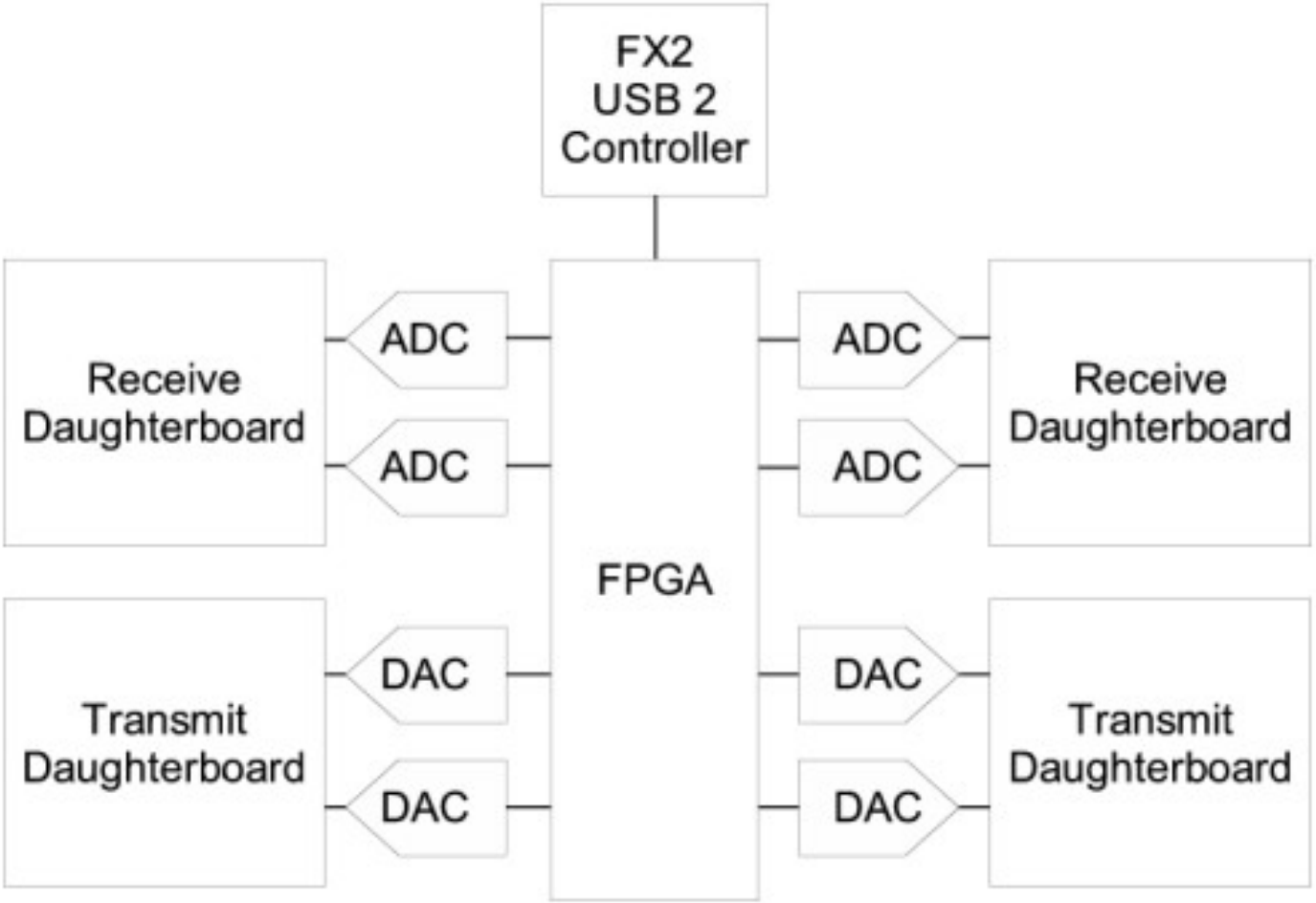
SSRP

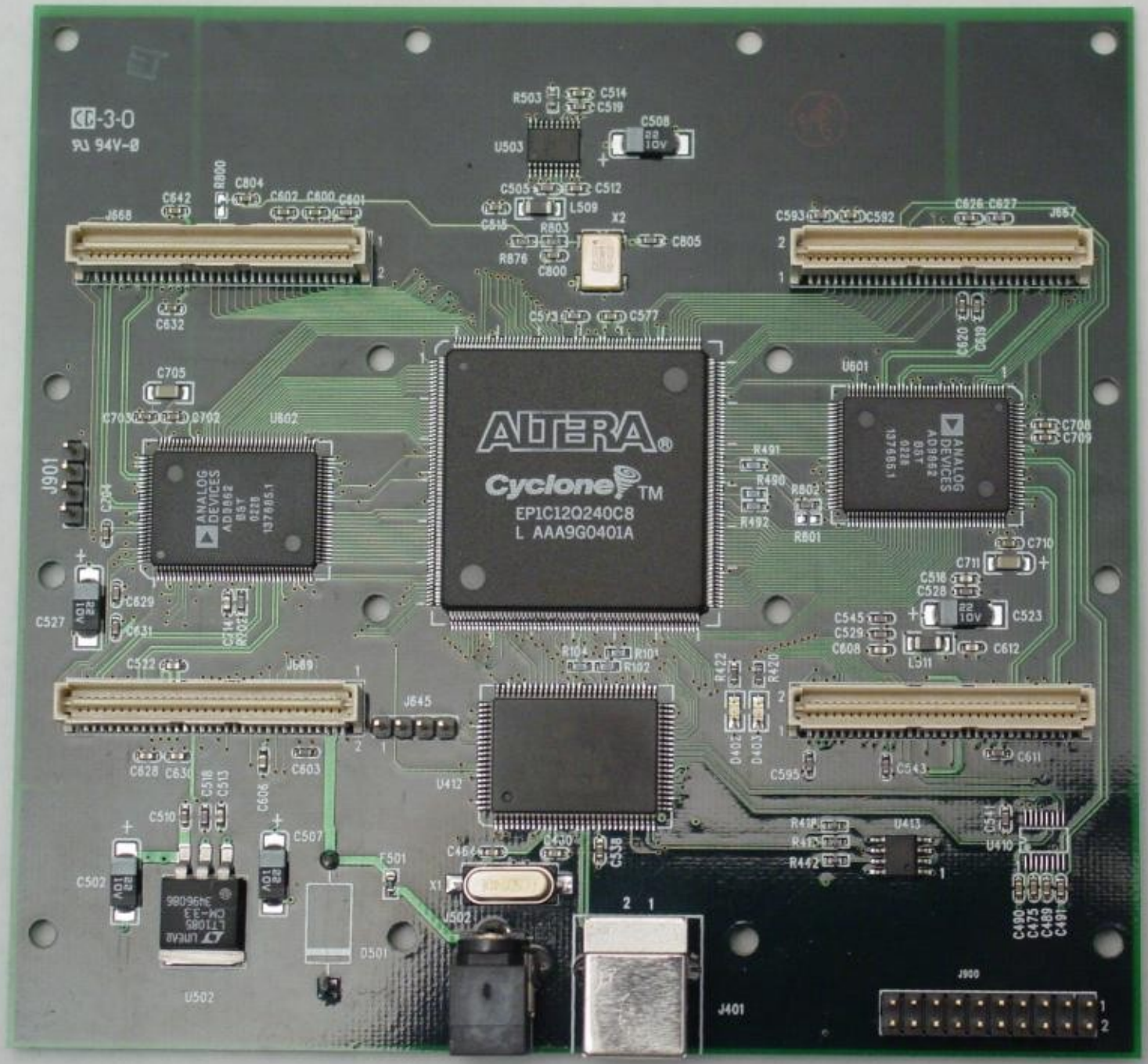

SSRP LTC1746 ADC
(C)David Carr 2001
LTC1746CFW
J81559
6.000MHZ
ECS-2100
CHINA 03C
Rev.1B
6-12VDC
LED1
LED2
X1


AD9283
BRS-50
0318
L24082



USRP Block Diagram




ALTERA
Cyclone TM
EP1C12Q240C8
L AAA9G0401A
ANALOG DEVICES
U601
U602
U412
U413
U502
U503
J668
J657
J689
J645
J901
J401
J900
X1
X2
L509
L511
F501
D501
D402
D403
C514
C519
C508
C505
C512
C642
C804
C602
C600
C601
C632
C593
C582
C626
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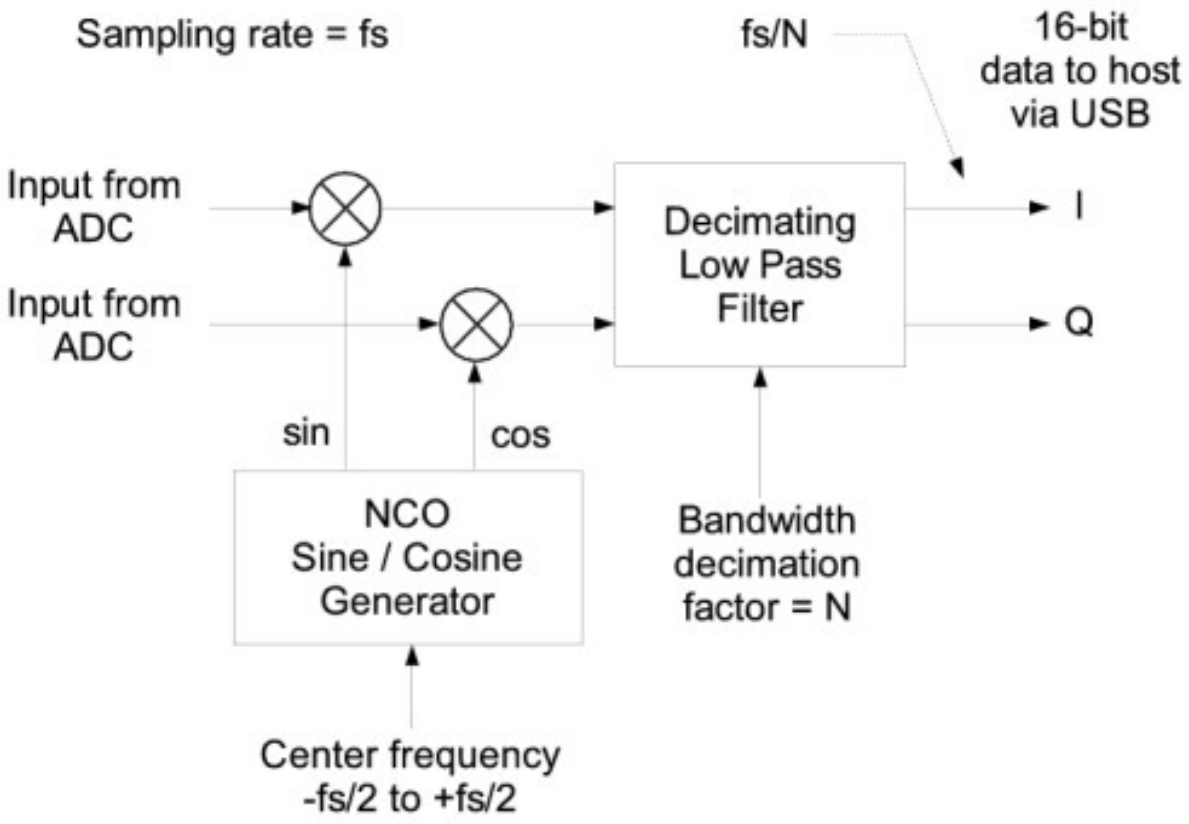
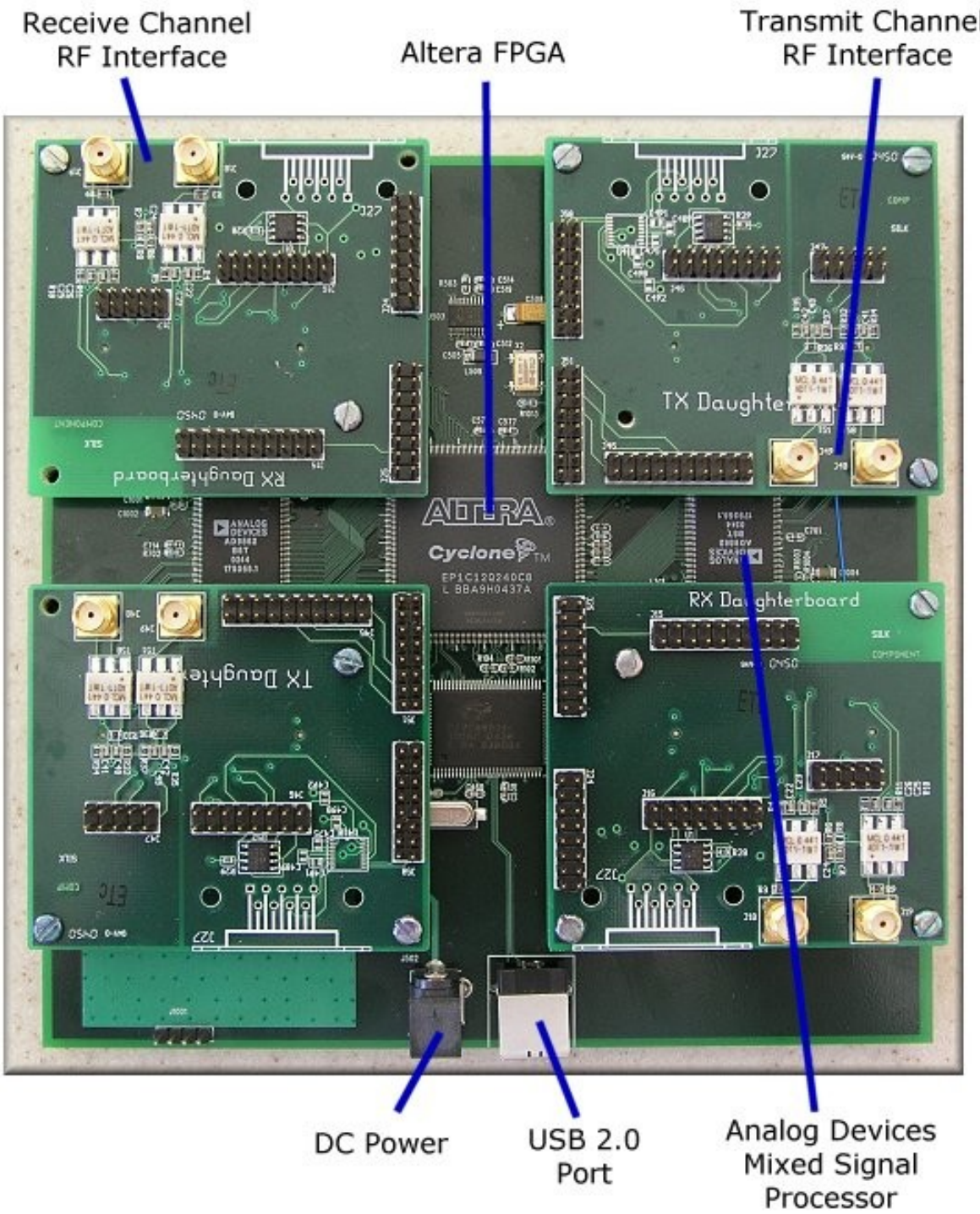
C595
C611
C464
C438
C440
C400
C475
C469
C491
R503
R800
R803
R876
C800
C805
R491
R490
R492
R802
R801
R104
R102
R422
R420
R418
R417
R442
C284
C614
R602

Partial FPGA Contents




Receive Channel
RF Interface
Altera FPGA
Transmit Channel
RF Interface
DC Power
USB 2.0
Port
Analog Devices
Mixed Signal
Processor

High Performance Software Defined Radio

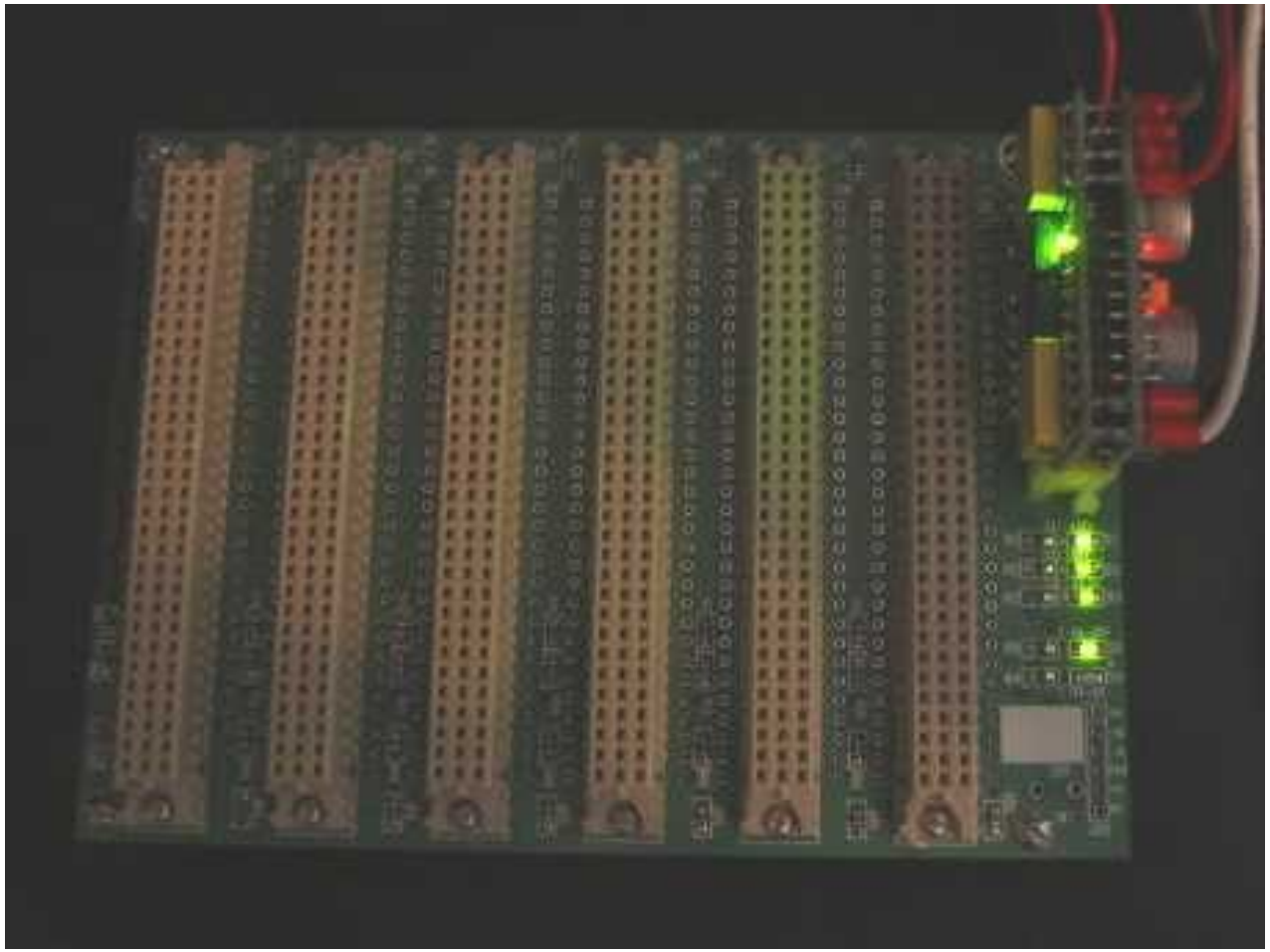
HPSDR: What's It All About?

- The High Performance Software Defined Radio (HPSDR) is an All-Volunteer Project to Create High Tech Modules for Experimentation and Advancing the Radio Art.
- The designs are Open Source.
  - Software
  - Hardware
  - Programmable Logic (FPGA, CPLD)
- Translation: A Bunch of Geeks Having a Good Time.

Open Source Hardware?

- Many Hams are Familiar with the GNU Public License for Software
  - The source code is freely available to anyone who asks
  - Any changes you make must be made freely available to anyone who asks – you can't alter it and make it "proprietary"
- HPSDR is Providing Hardware and Logic Designs Under the Same Provisions
  - Designs are freely available to anyone who asks
  - Any changes made must be freely available to anyone who asks – you can't alter it and make it "proprietary"

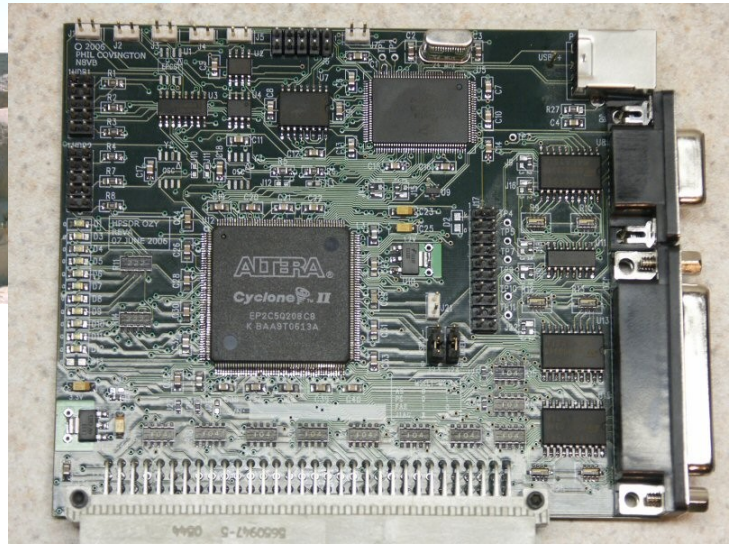
ATLAS – Foundation



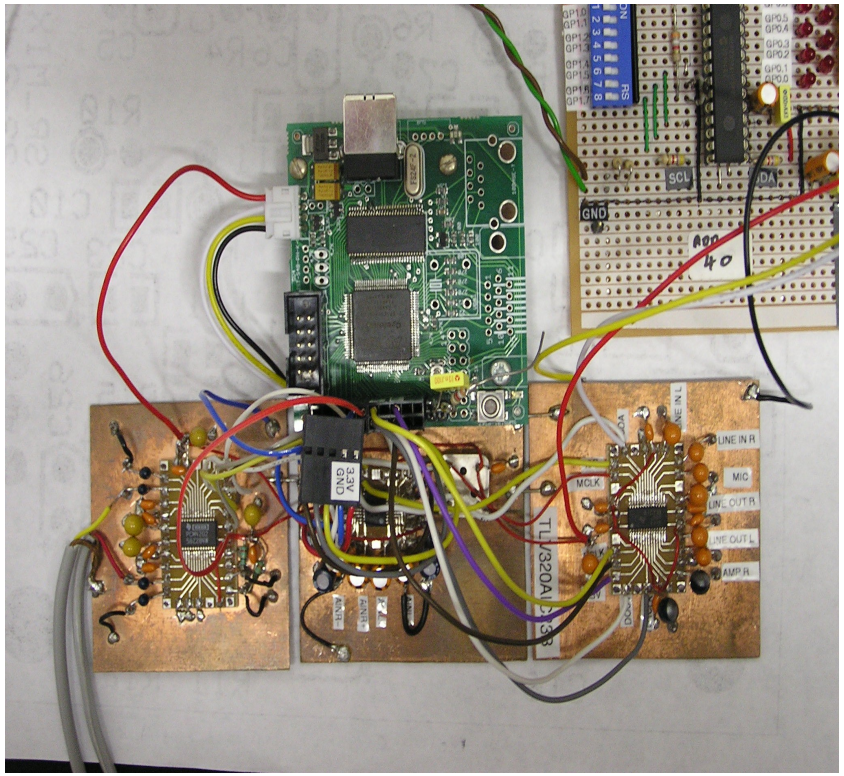
- ATLAS is a passive backplane that all other modules plug into.
- ATX 20 pin Power Connector
  - Recycle that Old PC
- DIN 41612 96-pin Connectors
- First Module
  - No Software!
  - But is it SDR?
- Designer: N8VB

Ozymandias – Ruler

- Ozymandias was a King in Ancient Times.
- OZY is the Module that Controls the Initial HPSDR Systems.
- USB 2.0 PC Interface
  - Cypress FX2 Controller
  - 8051 Processor Core
  - 35 Megabytes/Second
- Altera Cyclone II FPGA
  - User Definable Logic
- Loosely based on:
  - Xylo (http://www.fpga4fun.com)
  - USRP (http://www.comsec.com/wiki?UniversalSoftwareRadioPeripheral)
- Designer: N8VB



Janus - Having It Both Ways



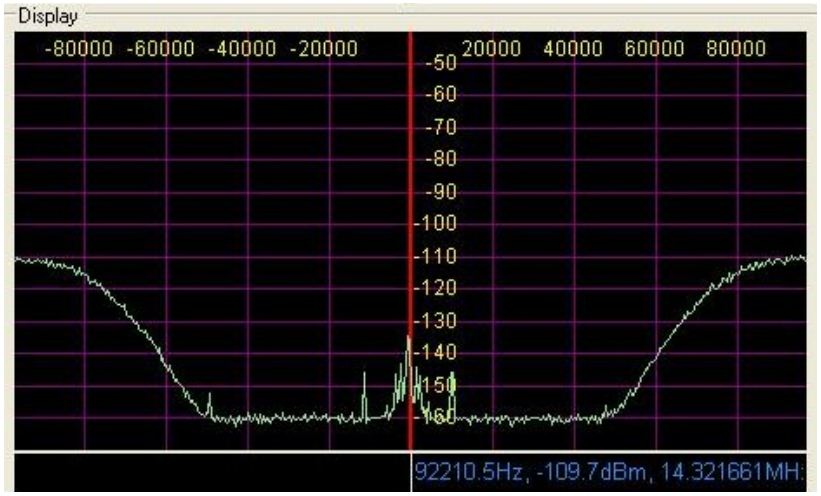
- Analog -> Digital
  - Very High Performance
  - QSD
- Digital -> Analog
  - QSE
- Full Duplex
- International Design Team
  - Phil, VK6APH (Hardware, Verilog)
  - Bill, KD5TFD (Software)
  - Support from KK7P, N8VB

JANUS: What's So Important About a Sound Card?

- QSD, QSE and SDR
- Several currently available Open Source SDRs use a Quadrature Sampling Detector
  - This means that the ADC is all-important for receiver performance
  - Software running on a PC needs ADC Hardware
  - Most Sound Cards are OK for non-critical applications,
    - Games
    - MP3 files
    - VoIP Phones and Conferencing
    - Audio tracks on Movies
  - Most Sound Cards are Disgustingly Poor for QSD/SDR Work
    - Motherboard
    - Turtle Beach (PCI)
    - Delta-44 (PCI)
    - Presonus (Firewire)
- HPSDR Project Early Goal: World-Class Sound Card Performance over USB

JANUS: Some 192 kHz ADC Test Results

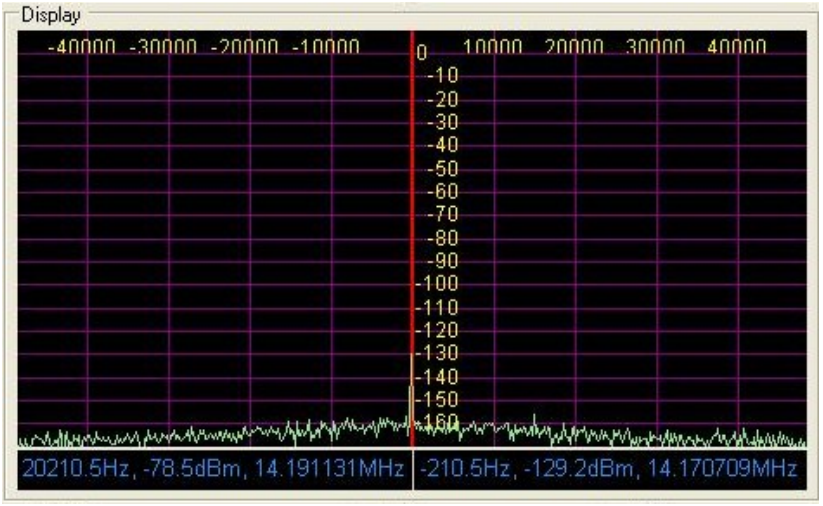
- Here are the Wolfson and TI ADCs at 192 kHz…

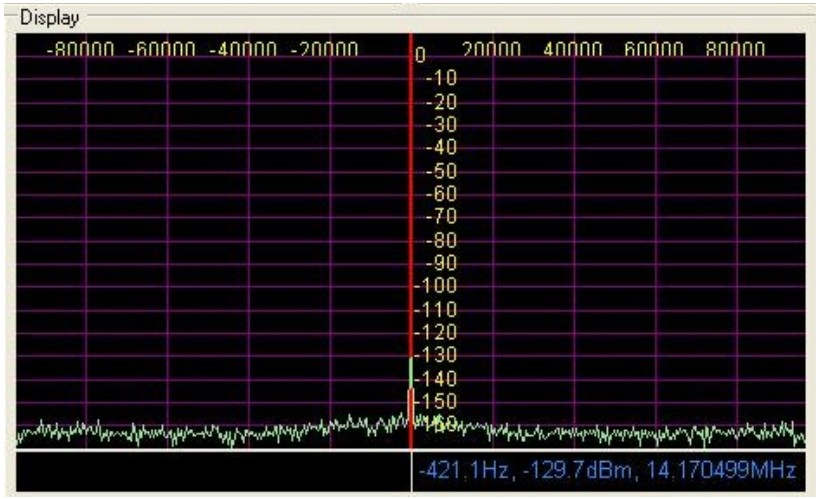


- Clearly, this Performance is Not Acceptable!

JANUS: AK5394A

- Here are the Results at 96 kHz and 192 kHz.

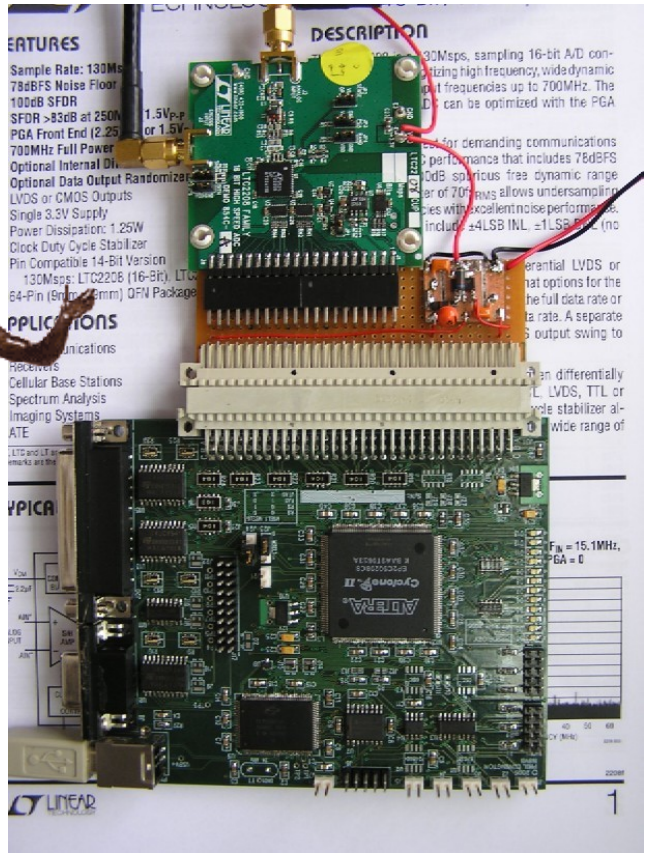




- We Have a Winner!

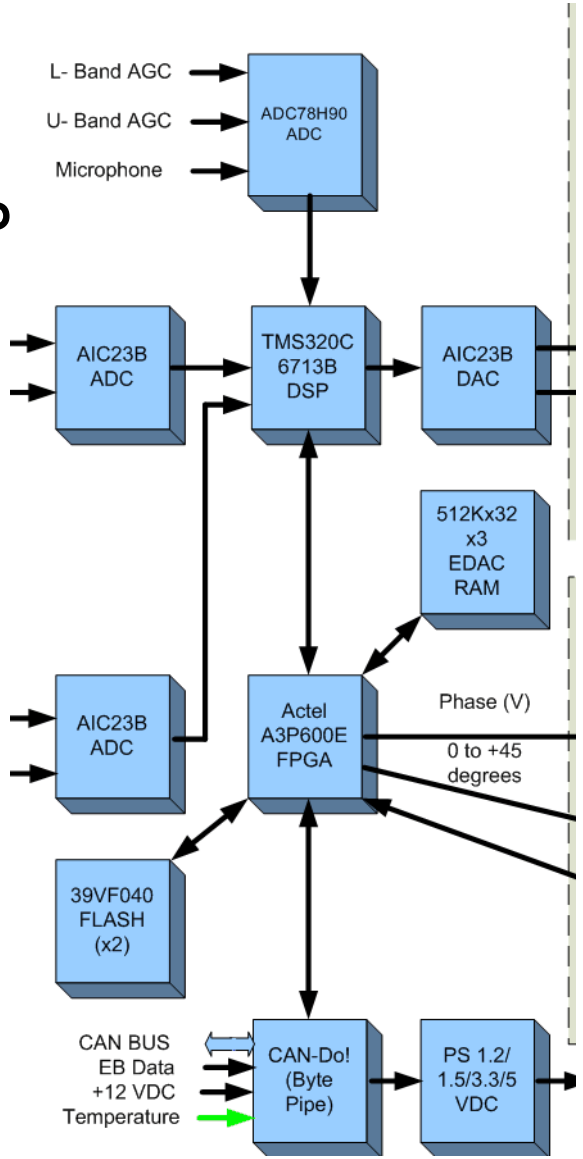
Mercury – That Dude is Fast!

- 16-bit ADC Running at 130 MHz!
  - Linear Technology LTC2208 ADC
  - Sample entire HF Spectrum in Real Time
- Cyclone II FPGA
  - Digital Down Converter
    - Typical BW Reduction to 200 kHz
  - User Defined Features
- USB
  - On-board FX2
- Prototype measures:
  - Max Input Signal +9 dBm
  - MDS (500 Hz BW) -120 dBm
- Designers: N8VB and VK6APH



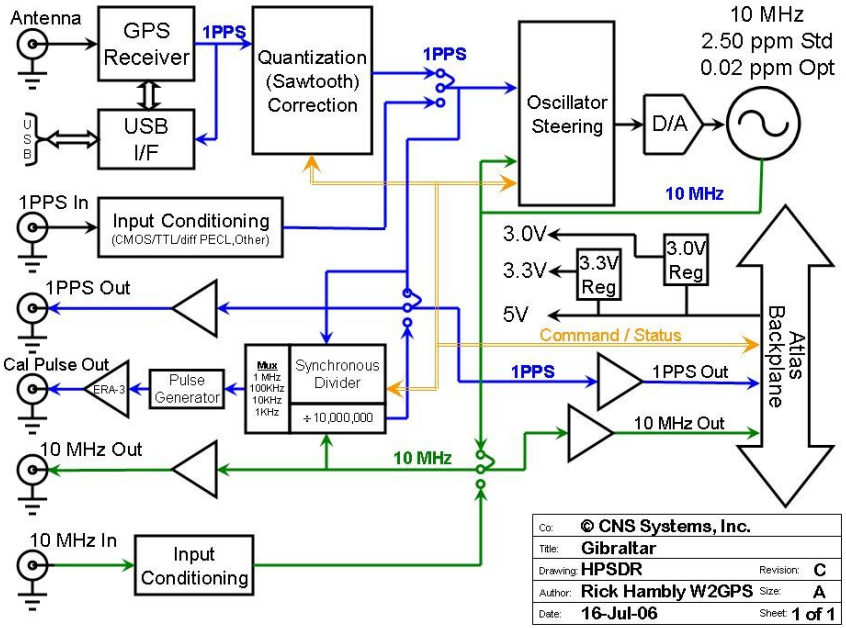
Sasquatch – Big and Bad

- Based on AMSAT SDX Core
- High Performance Floating Point DSP
  - TI TMS320C6726
  - Don't Need No Stinkin' PC
- Flash Memory
  - No Other Controller Required
  - Standalone Applications
- Analog and Digital I/O
  - Analog For QSD/QSE
  - Digital for EER
- FPGA
  - Envelope Elimination and Restoration
  - HELAPS to AMSATters
  - Super High Efficiency Transmitters
- Designer: KK7P



Gibraltar – Stable as a Rock

- System Reference Oscillator
  - 10 MHz Output
  - Additional Frequencies Simultaneously
  - Ovenized Oscillator
- GPS Disciplined
  - Long Term Accuracy
- Pending OHL
- Designer: Rick, W2GPS



Proteus – Have It Your Way!
Pinocchio – The Extender

- Proteus is a Breadboard for ATLAS
  - Makes it Easy to Prototype *Your* Designs
  - Module with
    - IC Footprints
    - Power Supply Regulators
    - ATLAS Bus Connector
- Pinocchio is an ATLAS-based Extender Card
  - Allows Probing and Troubleshooting While Operating

HPSDR can be Even More

- Several other modules have been proposed
- Designs aren't limited to the Atlas backplane physical structure, at least one HPSDR project will introduce a dedicated “product” form factor
  - Odyssey – a Handheld SDR for SuitSat-2?
- TAPR has agreed to make kits and boards available

HPSDR: Your Radio

- This is a Community Effort
- Designed by Hams in the Traditional Amateur Spirit
  - Time and Talent Freely Given
  - Anyone Can Participate
  - Everyone Can Learn
  - International Participation
- Support Especially from The Usual Suspects
  - AMSAT
    - $1,000,000 of Shared Development Tool Licenses
  - TAPR
    - Development Funds
    - Board Distribution

Future AMSAT Missions: Phase 3E and Eagle

Tom Clark, K3IO

&

Bob McGwier, N4HY

AMSAT ANNUAL Meeting

October 6, 2006

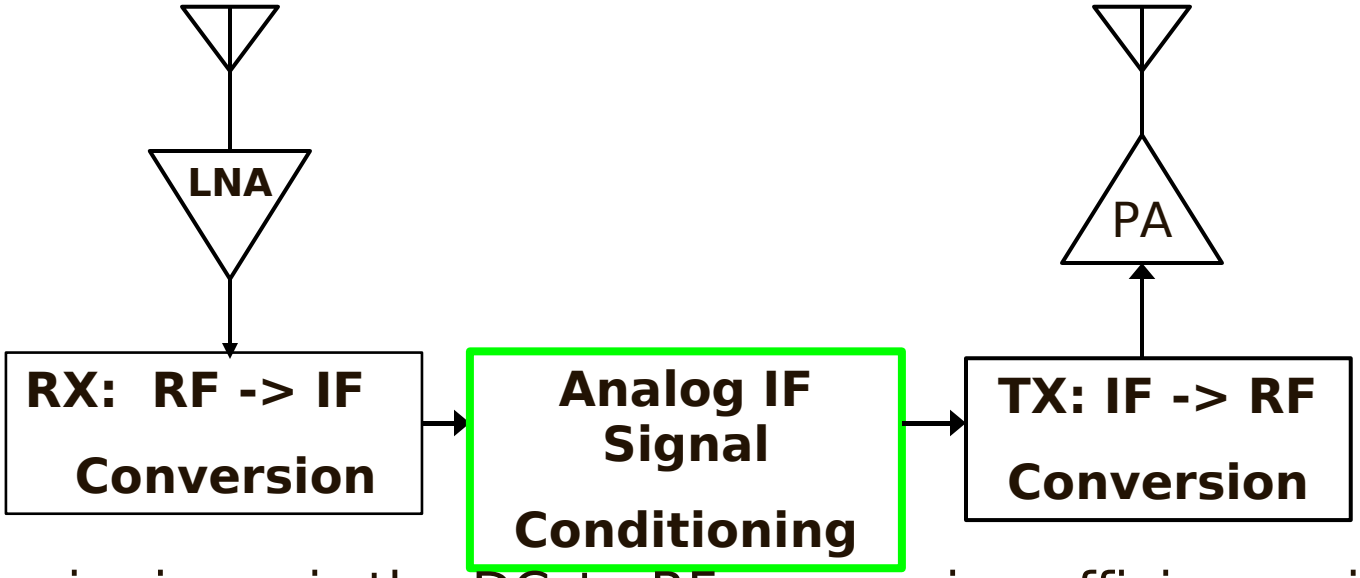
AMSAT-NA Vision Statement

Our Vision is to deploy high earth orbit satellite systems that offer daily coverage by 2009 and continuous coverage by 2012. AMSAT will continue active participation in human space missions and support a stream of LEO satellites developed in cooperation with the educational community and other amateur satellite groups.

The Eagle Project

- Eagle is the next generation high earth orbit satellite under construction now by AMSAT-NA. Eagle will provide many services and reliable communications on bands previously not available, and will build upon technology developed by AMSAT-NA for use in P3E.
- The Eagle satellite is being built to support the AMSAT vision statement and will be designed to carry a set of payloads that will support the primary needs of the worldwide AMSAT community while providing both the builders and the users challenging, exciting, and

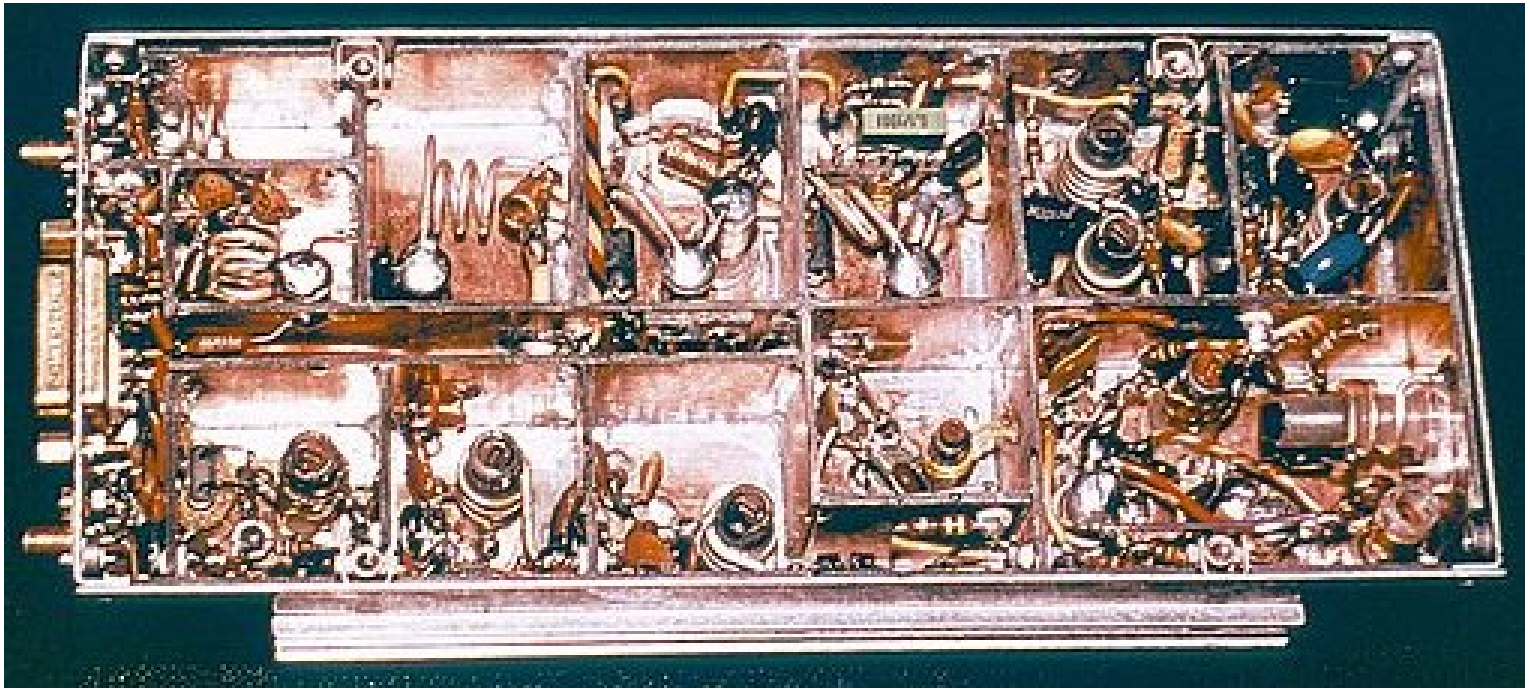
“Old” Spacecraft Linear Transponders:



- A major issue is the DC–to-RF conversion efficiency since power in space is a precious commodity.

- A secondary consideration is dynamic range. Previous satellite transponders have been plagued with a lot of intermod; noise floor has been as poor as -26 dB below peak.

An “old” Transponder: AO-7’s Mode B

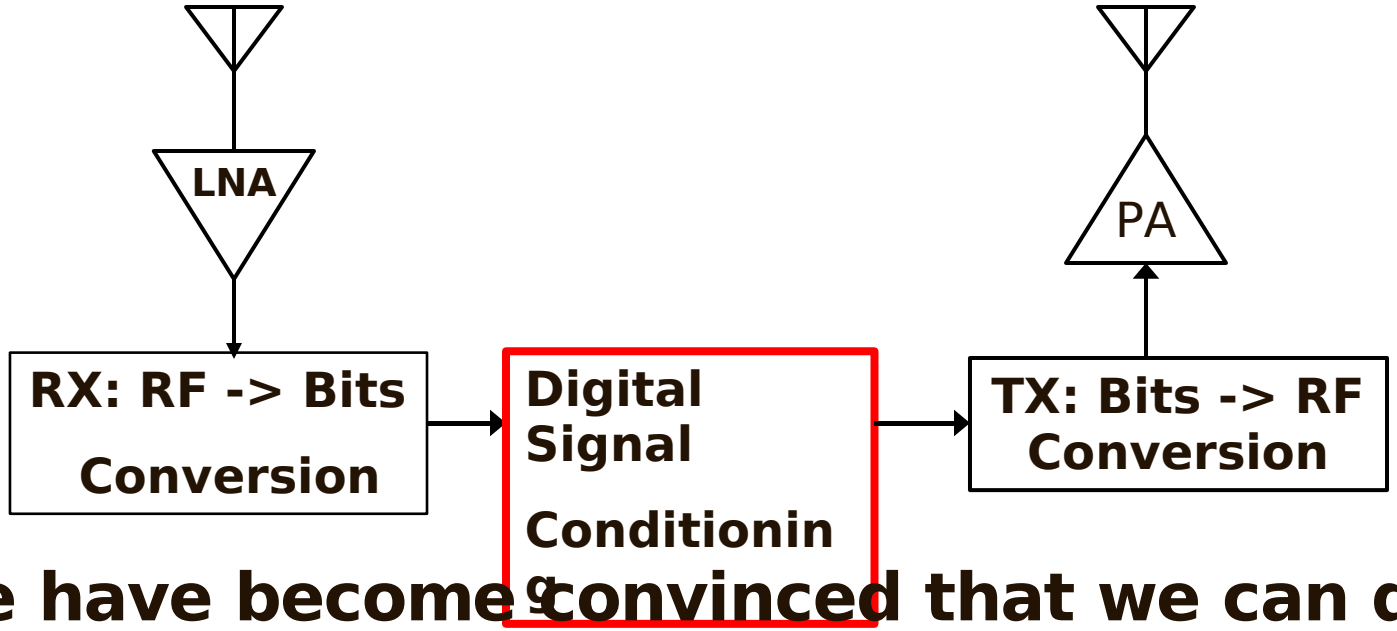


This transponder achieved high DC -> RF efficiency by using DJ4ZC’s “**HELAPS**” technique, but with ~26 dB dynamic range.

Definition: HELAPS

- **HELAPS = DJ4ZC's High Efficiency Linear Amplifier by Parametric Synthesis**
  - **Part of signal (the Phase data) is clipped and fed into a Class-C power amplifier.**
  - **Meanwhile, the Amplitude component is fed into a switching power supply which is used as a Class-D amplifier.**
  - **The Amplitude signal is used to "Plate Modulate" the Class-C Phase amplifier.**
- **HELAPS requires very careful adjustment of both the amplitude and phase signal paths.**
- **The unavoidable intermod limits the dynamic range (typically peak power is <30 dB above the passband noise level).**

“New” Software Defined Transponders (SDX):

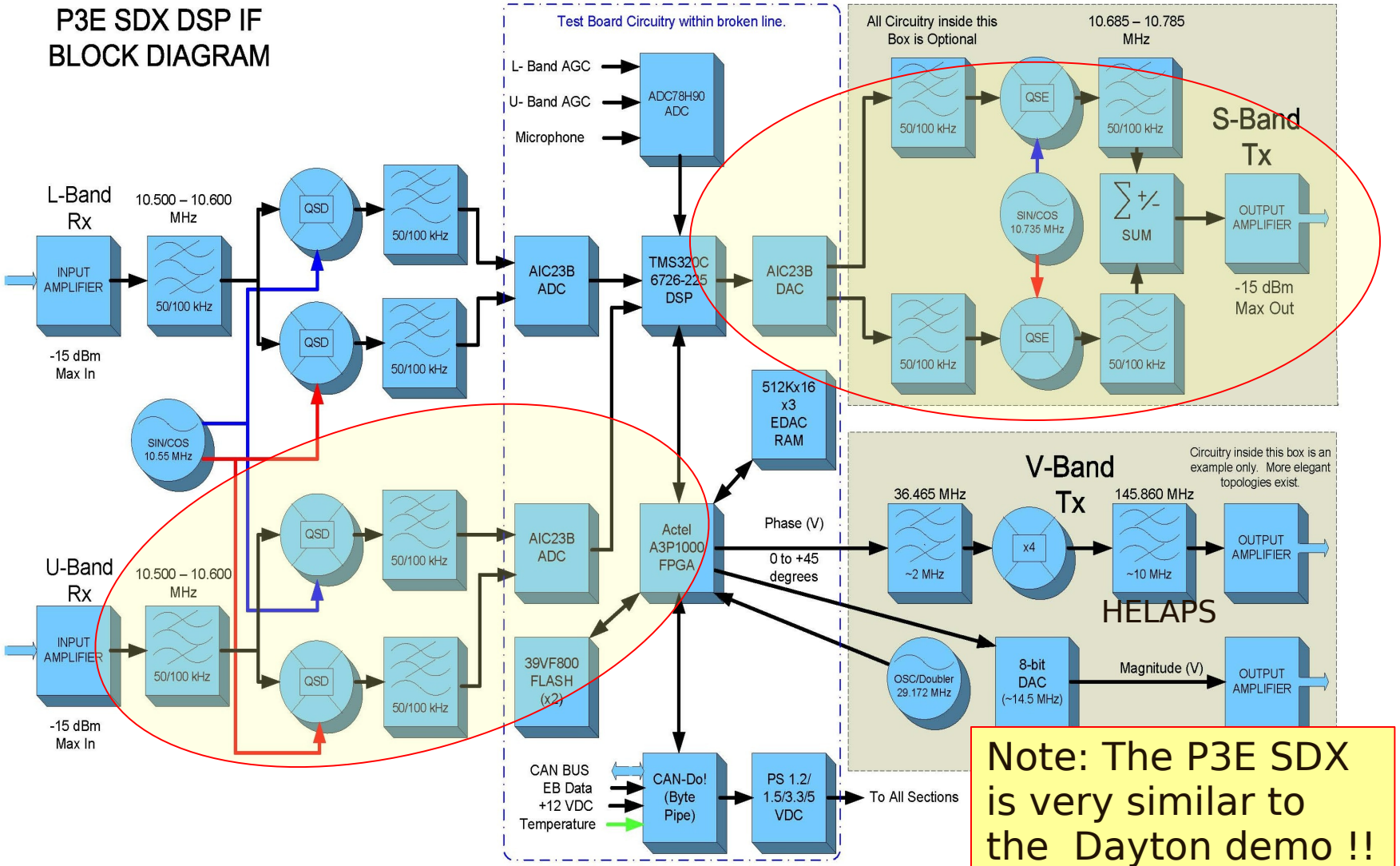


We have become convinced that we can do a much better job by doing the signal conditioning tasks in DSP hardware. Signal Conditioning can include selective AGC, linearizing HELAPS, and mixing of modes.

Prototype SDX as shown @ Dayton:

- The SDX was 96 kHz wide with 400 BPS PSK beacon @ center.
- Dynamic range was ~85 dB despite Dayton QRM
- Everybody commented on how “sweet” it sounded.

SDX with HELAPS for P3E



Note: The P3E SDX is very similar to the Dayton demo !!

Eagle Satellite Project Goals

- Bring HEO satellite communications capability to those who can’t use satellites today (apartment dwellers, covenants, etc).
- Minimize the need for large expensive antennas and the steering and frequency tracking mechanisms and high power amplifiers.
- Amateurs need to occupy the microwave bands to protect them as a resource.
- These are goals that drove our design of the Advanced Communications Payload (ACP).

We identified several generic classes of users:

- **Class 0 User**
  - The traditional linear transponder user.
- **Class 1 User**
  - Low data rate “SMS-like” text messaging to hand-held ground station. This could be quite valuable in rapid response to emergencies.
- **Class 2A User**
  - Digital Voice with electronically aimed patch array (and perhaps minimal mechanical steering).
- **Class 2B User**
  - Digital Voice with steerable 60cm dish.
- **Class 3 User**
  - Digital video or wideband data with 1.8m steerable dish.

San Diego Meeting Conclusions

- We will support the **Class 0 & Class 1** users with a high power U/V/L/S systems. We want to use SDX because:
  - Digital HELAPS technology
  - Similar to P3E's Mode-B Transponder
  - Will provide SMS (text messaging) with no antenna pointing necessary. This mode will support mobile and portable operation as well as Disaster operations.
  - Will support all traditional linear modes.
- The SDX shown by AMSAT at Dayton was the sweetest sounding transponder ever heard and it wasn't killed by alligators and Howard G6LVB is doing GREAT work on this.

San Diego Meeting Conclusions

- ACP functions will be provided to **Class 2 & 3** users by a mode S2/L(up) & C(down) digital transponder using an adaptive phased array:
  - Capable of supporting ~20 conference grade digital voice channels and other services with a 60 cm dish and a dual band feed.
  - Can support 2 streaming video channels (or any other wideband application) with a 1.8 meter dish on the ground.
  - The presence of a 9 cm uplink will help us continue to claim that band. Aussie Telecom ministry recently CITED AMSAT WEB SITE AS SHOWING WE HAVE NO INTEREST.

San Diego Meeting Conclusions

- EAGLE hardware & software are being developed with a GNU-like open architecture philosophy.
  - EAGLEPEDIA on http://www.amsat.org is the major technology exchange forum
  - There are no secrets!
- AMSAT will take the lead in developing & proving the new User Class 0, 1, 2 & 3 hardware in parallel with the spacecraft
  - The Spacecraft & User stations are considered as parts of a full system.
- TAPR (especially the TNC-2) is a model on how to disseminate technology and we might do it with them (we have before).
- Heavy overlaps with HPSDR & GNU Radio efforts

EME on 1296 Mhz

- Communicating with other amateur radio stations by bouncing signals off the Moon...
- Home-brew Az/El pointing of 3m TVRO dish
- OK1DFC septum polarizer + waveguide feed
- GPS-sync'ed HP 58503A master oscillator
- USRP
- Down East Microwave 28-1296 transverter
- 0.28dB NF preamp from LNA Technology
- 75 watt solid-state amplifier for now...
- ~500 watt water-cooled TH-328 amp (soon)

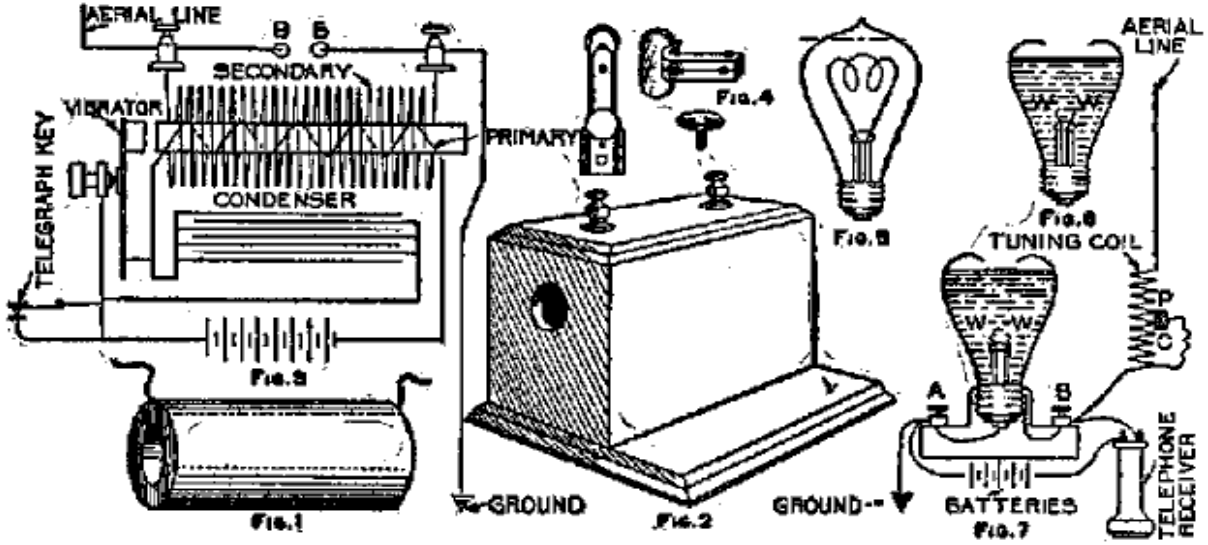

RIGrunner 4012


436A POWER METER
HEWLETT-PACKARD
TS-790A

For Further Information

- GNU Radio
  - http://www.gnu.org/software/gnuradio/
- USRP
  - http://ettus.com/
- HPSDR
  - http://hpsdr.org/
- TAPR
  - http://tapr.org/
- AMSAT Eagle
  - http://www.amsat.org/amsat-new/eagle/
  - Please donate to the AMSAT-NA Eagle fund!

Questions?


AERIAL LINE
SECONDARY
VIBRATOR
PRIMARY
CONDENSER
TELEGRAPH KEY
Fig.1
Fig.2
Fig.3
Fig.4
Fig.5
Fig.6
Fig.7
TUNING COIL
AERIAL LINE
GROUND
GROUND
BATTERIES
TELEPHONE RECEIVER


invent