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DRS Defense Solutions

RAZOR: ADVANCED ARCHITECTURE FOR THUMB-SIZED SOFTWARE-DEFINABLE RADIO

Clark Pope

November 29, 2011

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Outline

- SDR Requirements
- RAZOR Architecture
- Development Tools
- Applications
- Future Work

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History

- DRS has produced multiple generations of SDR technology
- See “Clark Pope and Mike Kessler, “Picoceptor: Advanced Architecture for Miniature Software Definable Radio Systems”, SDR Forum Conference, November 2008.” for a detailed history.
- Razor is our first device aimed at consumer/hobbyists markets
- New opportunity exists because:
  - Low cost processing hardware like Gumstix available
  - Maturity of open source SDR frameworks like Gnuradio
  - RF ASICs and Modules have integrated most radio hardware into low cost packages
  - Significantly less demanding applications have developed, e.g. remote sensing, product line testing, etc.

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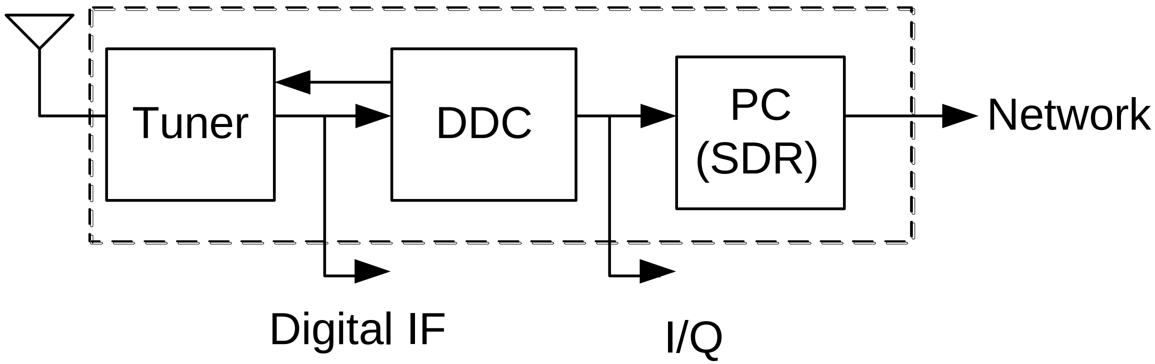
Generic Requirements

- Compatible with any SDR framework if:
  - Digital IF, baseband I/Q, and processed data is available
  - Simple tuner control for frequency, gain, and bandwidth



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Razor Requirements

- Moderate RF performance: Excellent sensitivity, minimal LO leakage, decent dynamic range, moderately low phase noise, and good IF/Image rejection of 60-70 dB
- 1 GHz or more tuning range to cover most ham and hand-held radio traffic
- USB powered (to save space and power supply expense)
- Open source software based (to save NRE)
- COTS module for processing element (since digital technology evolves much faster than RF technology)
- Low cost manufacturability (conventional FR4 with no more than 6 layers)
- Low cost BOM (mostly digikey high volume, in stock parts)
- Simple aluminized housing with acceptable spurious (gasketing cost prohibitive)
- Designed specifically for international export (for volume)

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Razor Requirements

- Fully reconfigurable (OS, FPGA, and application software)
- Extendable and upgradable with minimal effort
- Minimal SWAP to maximize application space
- Configurable for stand-alone operation

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RAZOR Architecture

- RF Front End
- FPGA
- Processing Module
- Software

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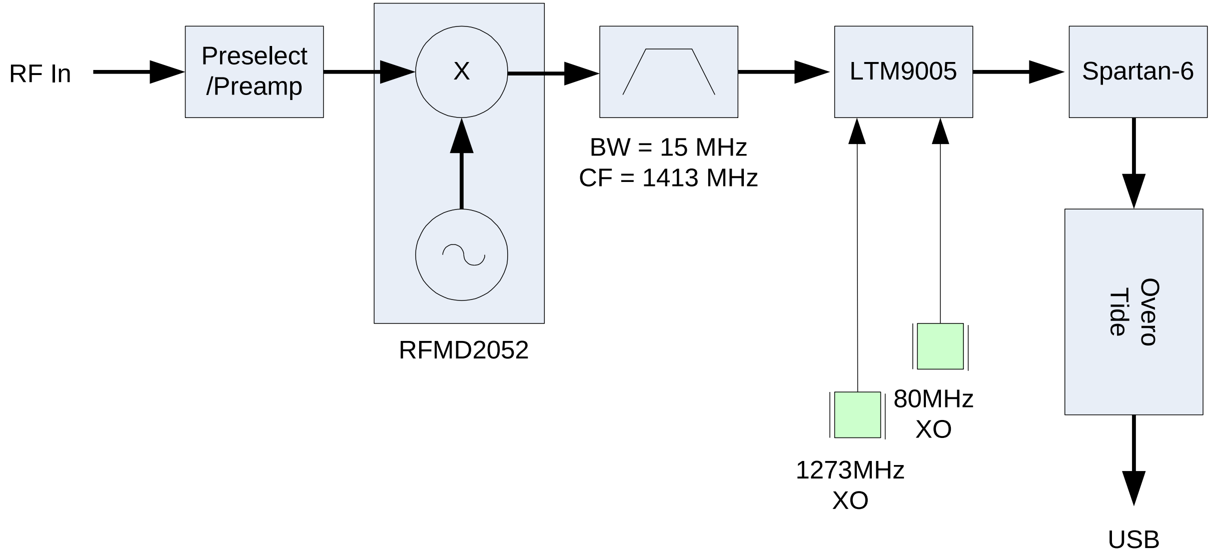
RAZOR Architecture

- Ceramic filter preselector
- Integrated first LO and mixer
- SAW filter IF
- Integrated 2nd Mixer and ADC
- Fixed 2nd LO and ADC clocks
- Spartan-6 FPGA
- Gumstix Overo Tide/Sand



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Razor Architecture

- Costed BOM ~ $300
  - Including $169 Gumstix
- Sell price typically 3-4x cost
- Power consumption 3-4 watts
  - Can be reduced with slower CPU clock
  - Able to power off USB port
  - (Technically USB spec is 2.5W max but most PCs supply more and two ports can be used if necessary)

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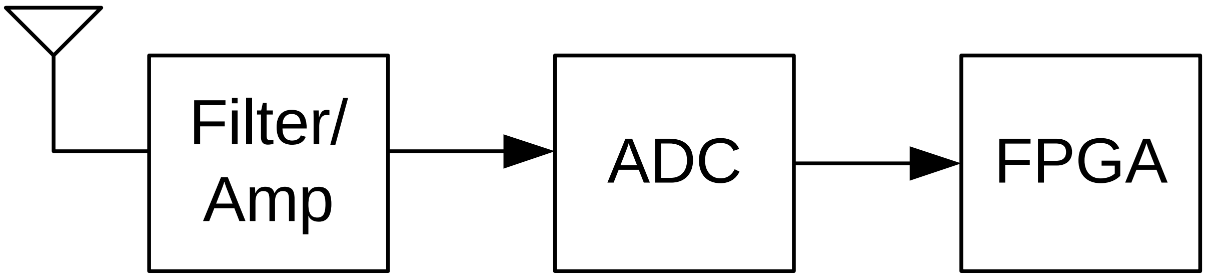
RF Front End Design (Direct Digitization)

- Low cost and relatively high dynamic range
- Limited upper frequency because of nyquist
- Tracking preselector /band select filters needed to prevent aliasing
- High power consumption because of FPGA processing



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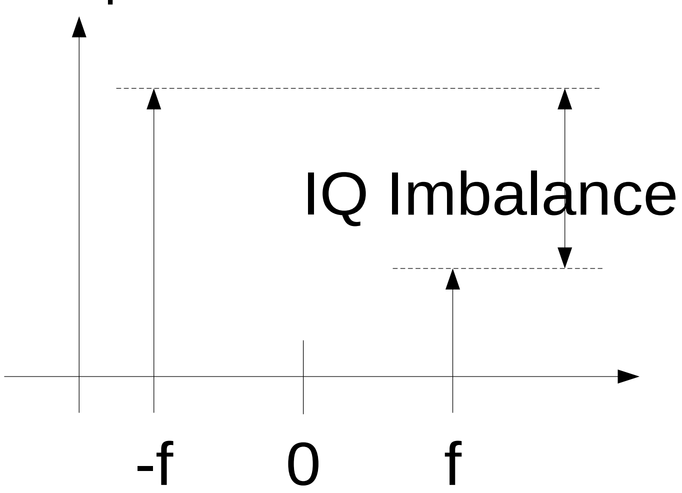
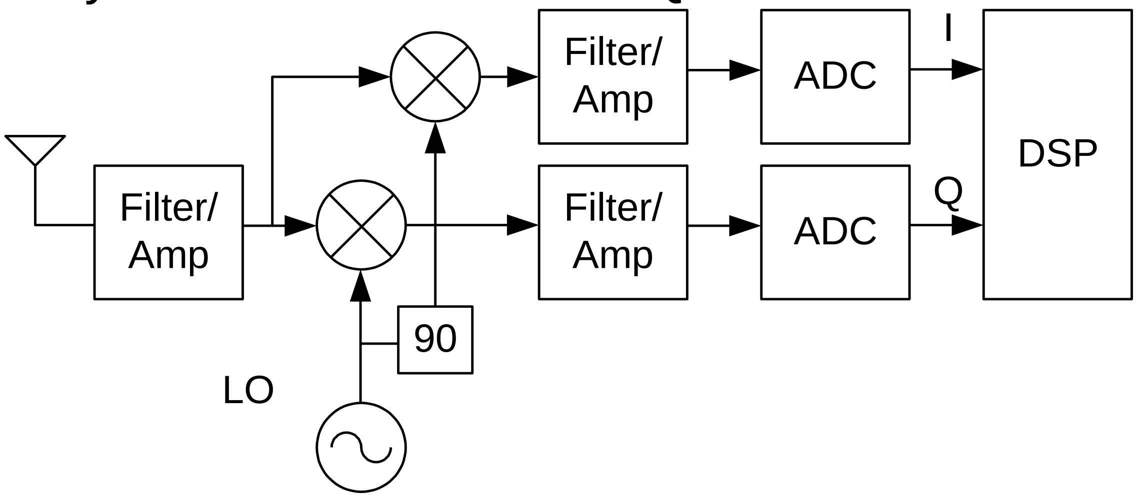
RF Front End Design (Direct Conversion)

- Used in most all RF ASIC based designs
- Very low cost
- High LO reradiation
- IQ imbalance limits dynamic range to 50 or 60 dB WITH elaborate compensation, 30 or 40 dB without
- Entire spectrum hits the first mixer and generates a plethora of intermod
- Integrated LOs usually have higher phase noise than discrete designs
- With suitable preselection fine for single channel systems, not suitable for spectral search or N channel systems because of the IQ imbalance





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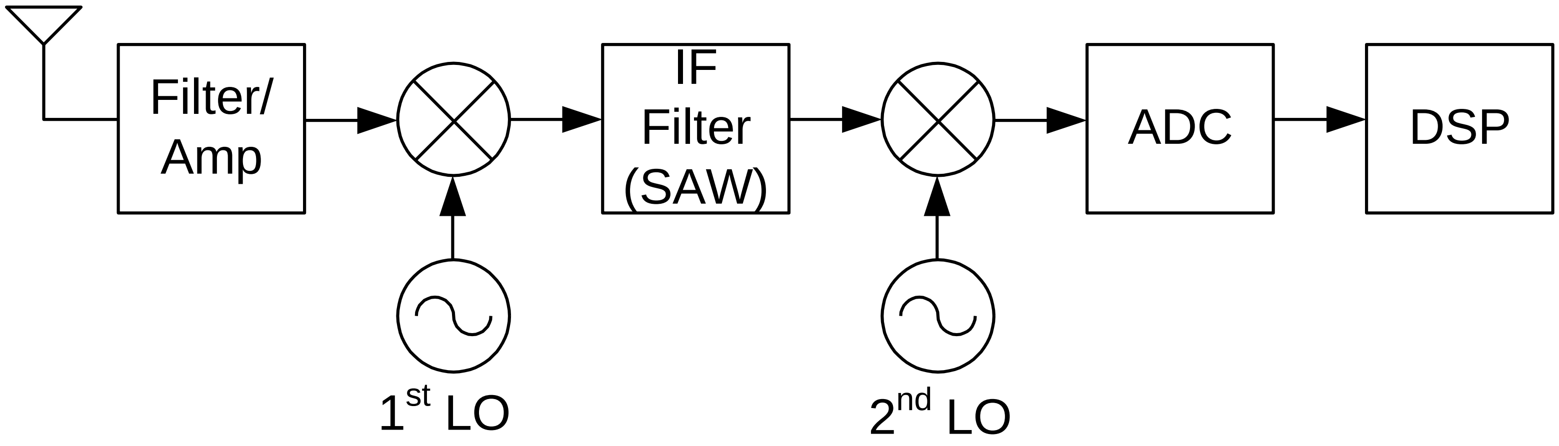
RF Front End Design (Superheterodyne)

- Additional complexity because of second mixer
- Spurious generation more difficult to plan for
- Wide tuning range
- Highest performance
- Minimal LO leakage
- Spur free dynamic range typically limited by ADC which can be 80dB or more
- Main drawback is the input image which requires specific preselection to reject



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Razor Front End

- Superheterodyne
- 20 to 980 MHz
- 1st Mix + LO = RFMD2052
- 2nd Mix + ADC = LTM9005
- Custom oscillators for 2nd LO and ADC Clock

No.	Razor Radio With LMT9005 Stage Description	Stage					Cumulative						
		Gain (dB)	NF (dB)	IIP3 (dBm)	P1 (dBm)	IIP2 (dBm)	Gain (dB)	NF (dB)	IIP3 (dBm)	IIP-NP (dBm)	P1 (dBm)	IIP2 (dBm)
1	Input Protection	-0.5	0.5	99.0	99	99	-0.5	0.5	99.0	98.5		
2	LPF LFCN-1000	-0.9	0.9	99.0	99	99	-1.4	1.4	96.2	94.8		
3	BLANK	0.0	0.0	99.0	99	99	-1.4	1.4	94.8	93.4		
4	PreAmp MGA82563	13.0	2.2	18.0	99	99	11.6	3.6	19.4	15.8		
5	LPF LFCN-1000	-0.9	0.9	99.0	99	99	10.7	3.6	19.4	15.8		
6	Active Mixer RF2052	-2.0	12.0	18.0	99	99	8.7	5.5	7.0	1.5		
7	Diplexer	-0.5	0.5	99.0	99	99	8.2	5.5	7.0	1.5		
8	1st IF SAW Filter TFS 1413	-2.7	2.7	30.0	99	99	5.5	5.7	6.9	1.2		
9	1st IF Amp	13.0	2.2	18.0	99	99	18.5	5.9	5.8	-0.1		
10	1st IF SAW Filter TFS 1413	-1.0	1.0	40.0	99	99	17.5	5.9	6.7	-0.2		
11	2nd Mix/IF/ADC LMT9005	0.0	16.0	17.0	99	99	**17.5**	**6.6**	**-1.4**	**-8.1**		

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FPGA Selection

- XC6SLX16-2FTG256C
- Low power
- $24 in low quantity
- Able to host stock USRP code
- Same pinout as LX9 and LX25
- 2278 slices, 32 BRAM, 32 MPY
- Xilinx ISE Webpack support

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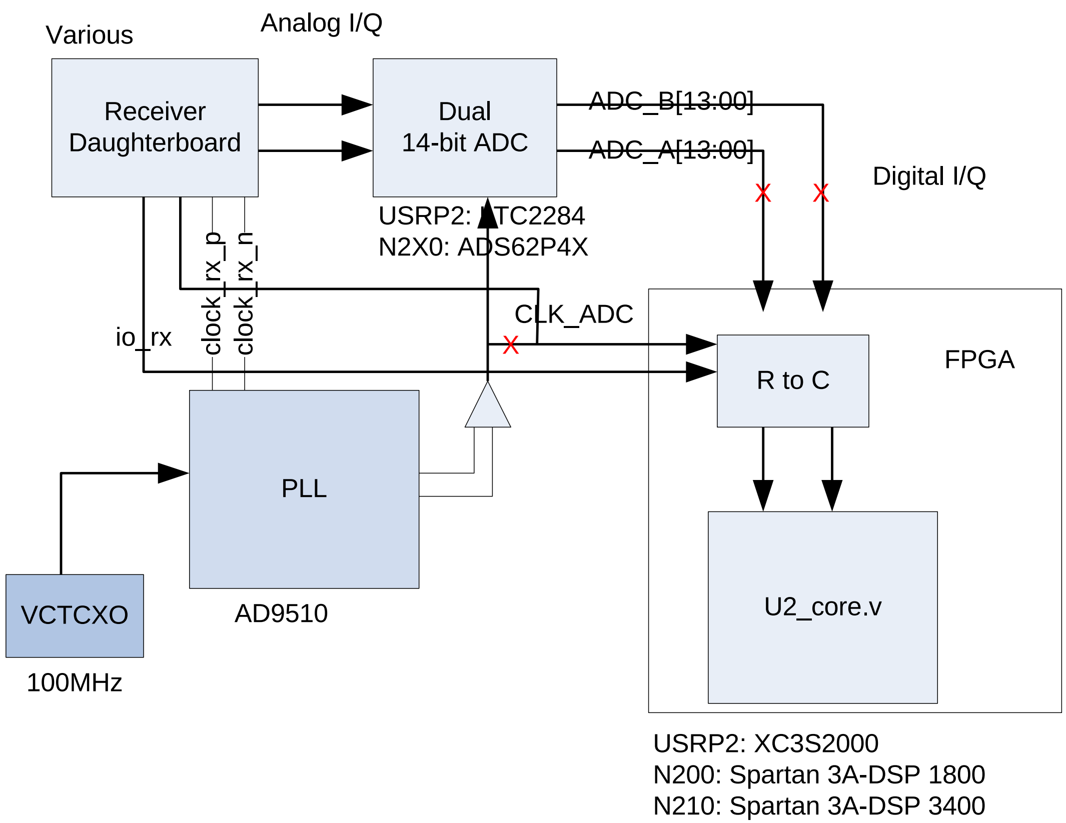
FPGA Modifications

- Stock Ettus USRP FPGA
- w/ digital real to baseband conversion



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Processing Module

- Gumstix Overo Tide
  - 720 MHz OMAP 3530 ARM/C64+ processor
  - Graphics co-processor
  - 512 Mbyte RAM
  - 4Gbyte MicroSD card
  - Standard peripherals (USB OTG, I2C, SPI, UART, etc.)
  - Alternate models plug into same headers
    - Wifi/bluetooth
    - Flash
    - More power and cost

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Software Architecture

- Open Embedded with Angstrom distribution of Linux Kernel, device drivers, root file system, and u-boot bootloader provided by Gumstix
- Bitbake tool pulls cross compiler and package sources from internet then stages, builds, and installs into image
- The stock omap3-desktop-image provides a complete windowed environment
- Opkg for package management
- Includes all standard network tools: ssh, sftp, httpd, xvnc11, etc.
- Gnuradio/GRC is a standard package

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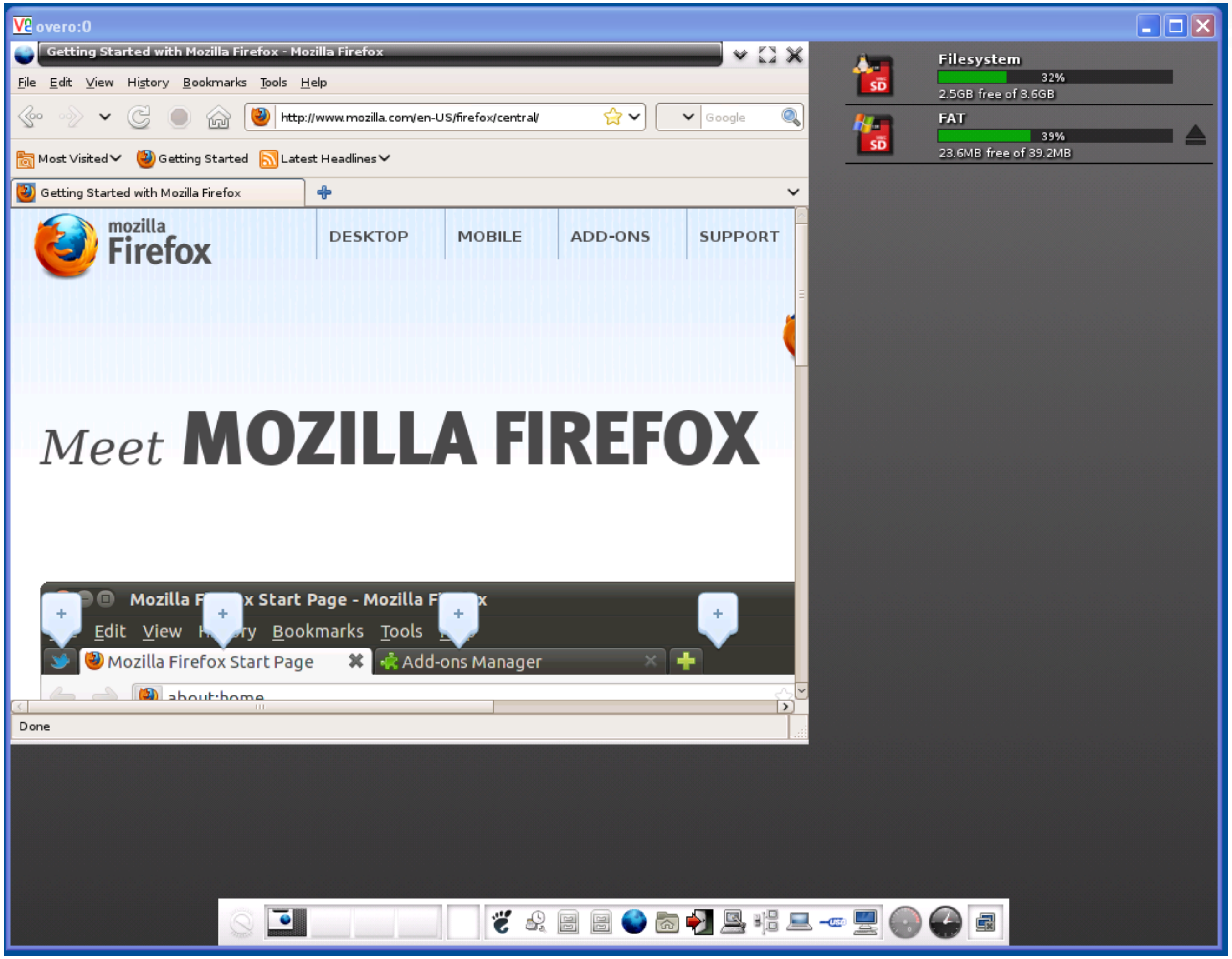
Software Architecture



Software Architecture

- Low-level custom driver to
  - Access FPGA registers
  - Set radio frequency and attenuation
  - Retrieve data for processing
- With driver loaded radio control can be performed via python scripting just like other Gnuradio applications
- Additionally, users can write and install their own custom applications as though Razor were a standard Linux PC

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Development Tools

- Virtual Machine
- PCB123
- eMachineShop
- Gnuradio

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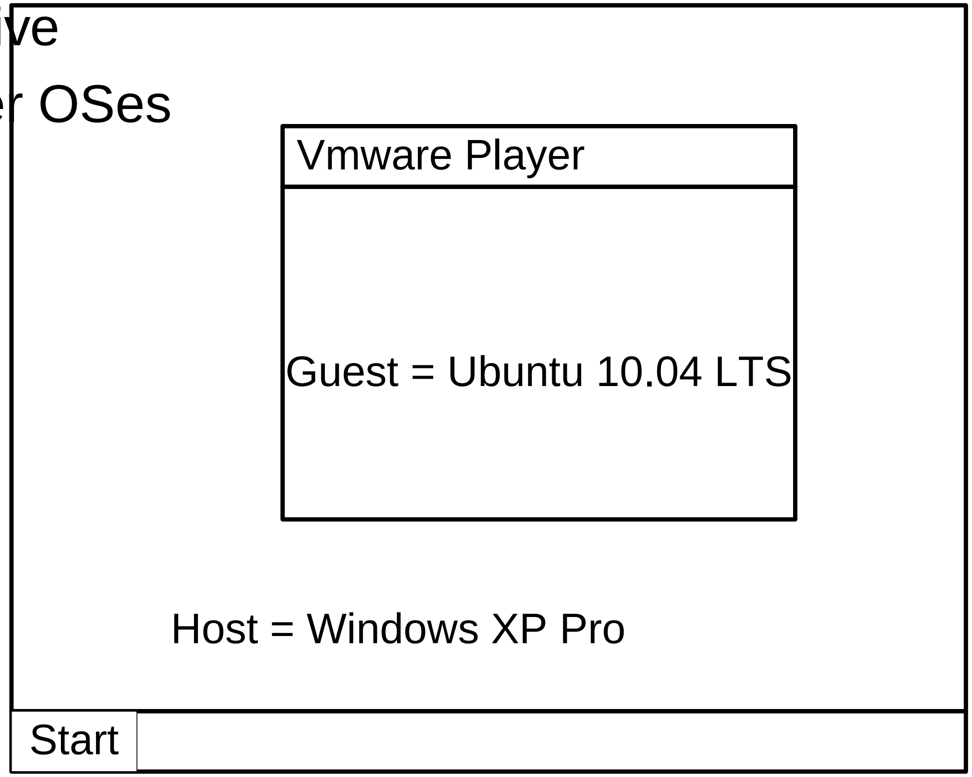
Virtual Machine

- Ubuntu 10.04 LTS
- Contains OpenEmbedded Build System
- Xilinx Webpack with Programmer
- Gnuradio and UHD
- Distributed by portable eSATA drive
- Note: users welcome to user other OSes and toolflows



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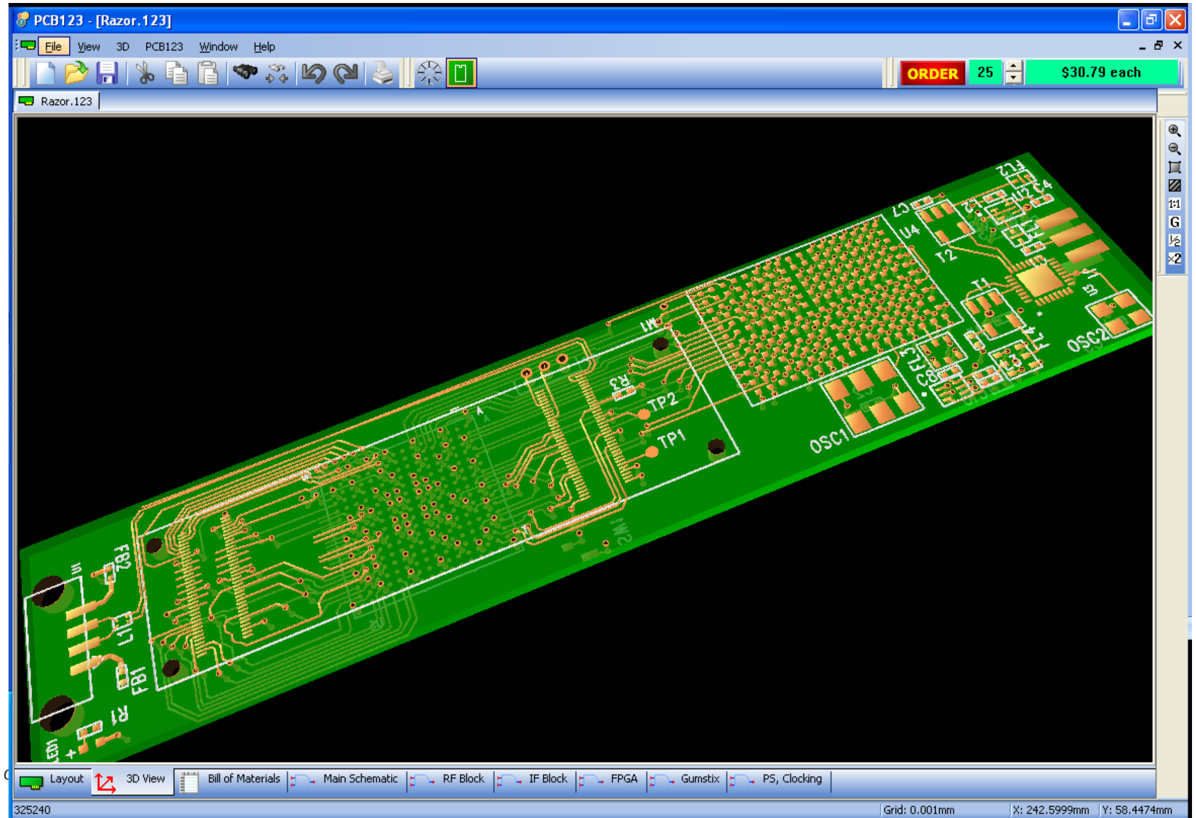
PCB123

- Free CAD Software(Integrated schematic, layout, and BOM tools)
- Built in DRC for low cost manufacturing (limits via sizes, number of layers, fabrication options, etc.)
- Integrate flow to purchase boards and have them assembled
- Gerbers can be purchased for ~$150



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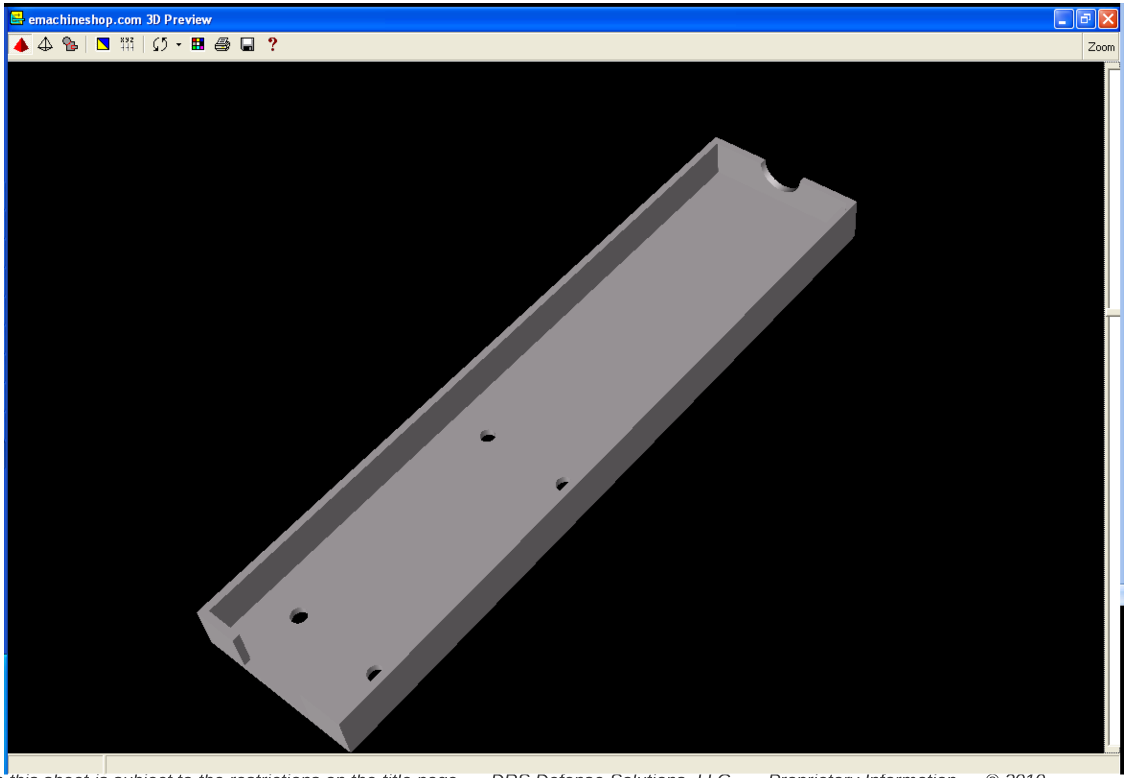
eMachineShop

- Online vendor of 3D printing services
- Free CAD software
- Simple entry (polynomial dimensions and relative heights)
- Online ordering, parts received in about a week
- Dozens of materials from plastic to steel



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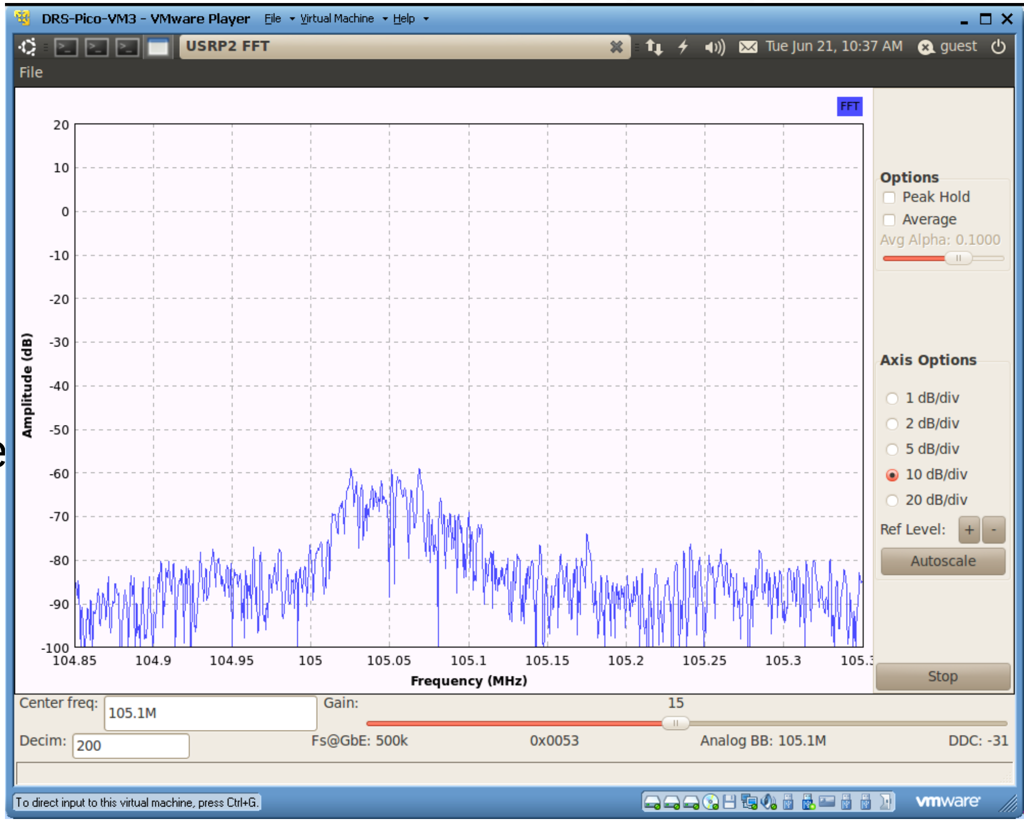
Gnuradio

- A custom SDR software framework is cost prohibitive for a low cost product
- Gnuradio is
  - Widely adopted
  - Open source
  - Already ported to ARM/Gumstix
  - Graphical tools like GRC available
- Razor only requires a custom driver to interface



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Applications

- Commercial/Consumer grade applications
  - No environmentals
  - No ruggedization
  - Moderate performance
- Academic Research
- Production line testing
- Depot Repair
- Ham Radio

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Production Line Tester

- Integrate into ATE for testing cell phones, LMR radios, FRS, etc.
- With good inline preselection the RF is adequate transmitter testing
- Power level measurements
- EVM measurements
- Scripted easily with GNU radio

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Spectrum Analyzer

- Calibration required to find, characterize, and factor out internal spurs.
- Good differential RF measurements when coupled with a suitable RF generator (e.g. quonsetmicrowave)
- Small enough to integrate into handheld configuration for EMC applications
- Note limited scan rate (3GHz/s max theoretical)

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Academic

- Affordable for students
- Study digital communications, cognitive radio, and DSP
- Can be used in lab to record live signal samples for further processing/analysis in Matlab

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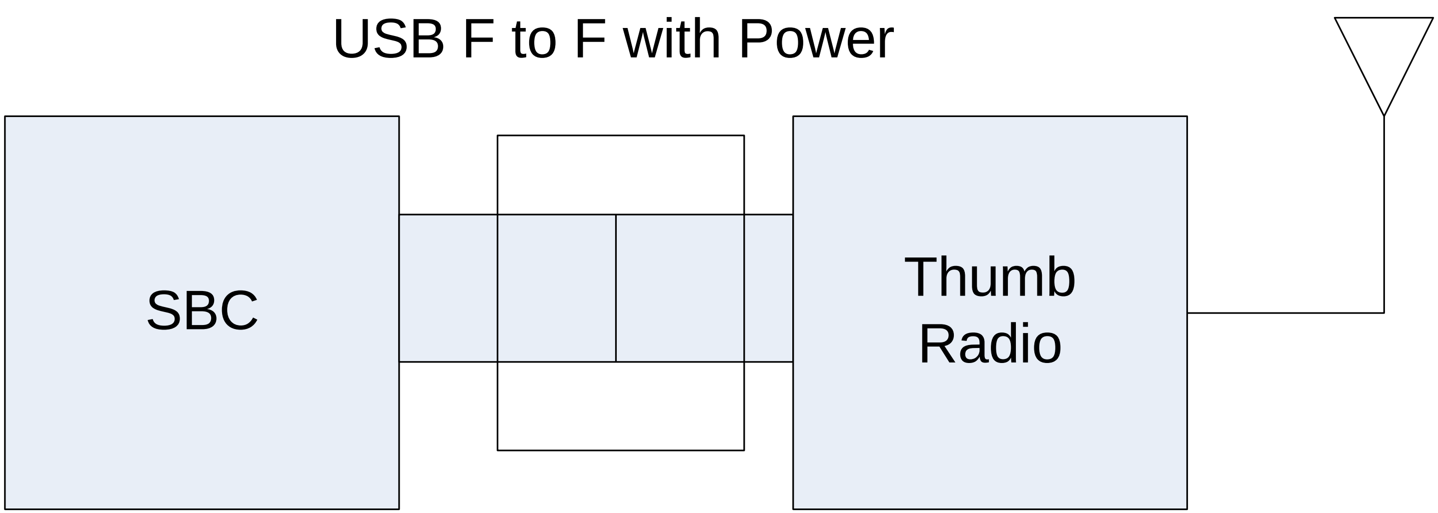
Stand-Alone

- Because of USB host capability other devices can be attached easily(hard drives, modems, displays, SBCs, etc.)
- Creates stand alone sensor node



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Future Work

- More performance testing and optimization
- Wider bandwidths and inclusion of external reference/synchronization for MIMO
- Alternative radio modules(direct conversion, HF, and superheterodyne with alternate frequency ranges)
- Transmitter version
- Lower cost versions: replace gumstix with simple GigE or USB3.0 PHY.

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Conclusions

- Razor is a novel, low cost, moderate performance solution for consumer/commercial/academic applications.
- Author available for questions: cpope@drs-ds.com
- Please visit the DRS booth (#18) on the exhibit floor

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