Homebrewing A Software Defined Radio (SDR)

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NAØTC - 285 TechConnect Radio Club
http://www.naøtc.org/
Goal

• Stimulate Interest in Homebrewing
  • Simple projects
  • High performance SDR transceivers
What We Will Cover

• How to Get Started
• Who offers kits for ham radio applications
• What is a Software Defined Radio
• Who offers Software Defined Radio Kits
  1. Beginner
  2. Intermediate
  3. Experienced

Genesis G59 HF SDR Transceiver: Project Overview
  1. Goals
  2. Approach
  3. Overview of Design
  4. Performance summary
  5. Lessons Learned

Summary
What We Will Cover

• How to Get Started
• Who offers kits for ham radio applications
• What is a Software Defined Radio
• Who offers Software Defined Radio Kits

1. Beginner
2. Intermediate

This discussion will focus on receivers

1. Goals
2. Approach
3. Overview of Design
4. Performance summary
5. Lessons Learned

• Summary
How to Get Started

• Identify Goals
  • Homebrewing can cost more than buying used

• Assess Complexity
  • Review build instructions before purchasing a kit
  • A SDR may not be the best choice for a first time builder
    • Building a SDR can require:
      • Circuit design knowledge (digital, analog and RF)
      • Build experience (probably SMD experience)
      • Test/troubleshooting experience
      • Knowledge of how to set up software applications
      • A variety of test equipment
      • Need for technical support

• Support
  • Find an Elmer
    • The TechConnect Radio Club has a list on their website
  • Internet based support groups
    • Yahoo Groups
  • Can you send your item to someone to get it working?
How to Get Started – cont’d

• Who offers kits for *amateur radio* applications (*short* list):
  
  • Elecraft
  • Communications Concepts Inc
  • Fox Delta
  • Softrock
  • Genesis
  • Emtech
  • Small Wonders Lab
  • Almost-All-Digital-Electronics
  • Vectronics
  • Lazy Dog Engineering
  • Cross Country Wireless
  • Ten Tec
  • HFprojects (K5OOR)
  • Kits and Parts
  • Ramsey
  • Wilderness Radio

• For those with some homebrewing experience:
  “Experimental Methods in RF Design”, Hayward, et al
What is a Software Defined Radio?

A **Software Defined Radio (SDR)** is a radio which has been designed to allow some, or all, of the *traditional functionality* of a radio to be handled in software/firmware on a computer, rather than in hardware.

- Note that SDR **does not mean** control of a radio using software

- SDR **means** the *implementation* of a radio *in firmware or software*
  - Implies “Digital Signal Processing” (DSP)
  - Debate continues among the “experts” as to what constitutes “implementation of a radio”
    - RF based DSP
    - IF based DSP
    - Analog to digital conversion at the antenna (Flex 6000)
Signal Processing

• What is **Signal Processing**?: Anything intentionally done to improve the recovery of signal information
  • Amplification
  • Filtering
  • Noise Limiter
  • Detection
  • Demodulation
  • Automatic Gain Control
Signal Processing

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  - Detection
  - Demodulation
  - Automatic Gain Control
  - ...
  - ...

Analog Signal Processing (ASP)
Digital Signal Processing (DSP)

• Amplification
• Filtering
  • “Brickwall” Filters*
  • Auto Notch
  • Tracking Notch
• Noise Limiter
• Noise Reduction*
• Detection
• Demodulation
• Automatic Gain Control

*: Not achievable with analog signal processors
Digital Signal Processing (DSP)

- Amplification
- Filtering
  - “Brickwall” Filters*
  - Auto Notch
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- Noise Limiter
- Noise Reduction*
- Detection
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- Automatic Gain Control

*: Not achievable with analog signal processors

1. DSP is simply the newest technique for implementing traditional functionality
2. DSP offers some features not available with Analog Signal Processing
Analog vs. Digital *Signal Processing*

**RF Signal (Analog)**
- Analog Frequency Conversion
- Analog Signal Processor

**Audio (Analog) Output**

**Digital Receiver (SDR)**
- Frequency Conversion
- Analog To Digital Conversion
- Digital Signal Processor
- Digital To Analog Conversion

**Audio (Analog) Output**

**Traditional Analog Receiver**
- ASP

**Digital Receiver (SDR)**
- DSP
Analog vs. Digital Signal Processing

Traditional Analog Receiver

Analog Frequency Conversion

Analog Signal Processor

Audio (Analog) Output

RF Signal (Analog)

ASP

Digital Receiver (SDR)

Frequency Conversion

Digital Signal Processor

ADC

Digital Receiver (SDR)

DAC

Audio (Analog) Output
Analog Frequency Converter (AFC)

- When $F_{LO} = F_{IN}$ => $F_{IF} = 0$ Hz (DC) => “Direct Conversion”
- No Image rejection => **BIG** problem
- Output is frequently referred to as being at “Baseband”
Analog Direct Conversion

• CW input signal at 3.750 MHz, $F_{LO}$ tuned to 3.750

• Input signal at 3.751 MHz, $F_{LO}$ tuned to 3.750

• Input signal at 3.749 MHz, $F_{LO}$ tuned to 3.750
Analog Direct Conversion

• USB input signal at 3.750 MHz, $F_{LO}$ tuned to 3.750 MHz

• Rejection of unwanted images is important
  • Using **Quadrature (I & Q) Conversion** can be a good solution
    • >60 dB rejection is achievable
      • Usually requires *both* hardware & software techniques
    • **Direct Digital Conversion** gives the best image rejection (>80 dB)

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8/23/2012
Types of SDRs

• **Two Basic Types:**
  • **Quadrature Sampling Conversion (QSC)**
    • aka “Direct Conversion”
      • A direct conversion radio may or may not be an SDR
    • Uses a **Quadrature Sampling Detector (QSD)** for down conversion to baseband
      • Direct conversion process that **generates two (I & Q) baseband signals**
      • Design challenge: rejection of unwanted image and sideband
    • Softrock "Ensemble II", Genesis G59/G11
  • **Direct Digital Conversion (DDC)**
    • **Direct conversion from RF to bits**
      • “No IF frequency used” => not strictly true
      • Design challenges:
        • Extremely high data rates => Cost
        • Rejection of unwanted “Aliasing” signals
          • Easier problem to solve than image rejection
    • Perseus, QuickSilver, Flex 6000 series radios
Quadrature Sampling Conversion (QSC)

- Identical Analog Signals
- 90 degrees out of phase
- “Quadrature”
- “Complex” signals
Quadrature Sampling Conversion (QSC)

- RF IN
- Power Splitters
- Mixer
- Power Splitters
- OSC
- 0°
- 90°
- Identical Analog Signals
- 90 degrees out of phase
- “Quadrature”
- “Complex” signals

A QSC = Two AFC’s:
- Oscillator
- 90° phase shifter
- Two power splitters
- Two mixers
Quadrature Sampling Detector (QSD)
(aka: “Tayloe Detector”)

- Identical Analog Signals
- 90 degrees out of phase
  - “Quadrature”
  - “Complex” signals

**Block Diagram:**

- **RF\_IN**
- **Power Splitter (0°)**
- **Mixer**
- **Power Splitter (90°)**
- **Mixer**
- **OSC**
- **Quadrature Sampling Converter**

**Outputs:**
- I
- Q
Quadrature Sampling Conversion (QSC)

- Why go to all of this effort to generate two identical signals?
  1. Can completely remove unwanted image (theoretically)
  2. “Give me I & Q and I can demodulate any signal”
  • Note: Demodulation is done in software
- Theoretically, the QSD can be located anywhere in the signal path:
  • RF
  • IF
  • Audio

Quadrature Sampling Detector (QSD) (aka: “Tayloe Detector”)

RF

IN

Q

0

90

Power Splitter

Mixer

Mixer
Quadrature Sampling Receiver

QSC

Power Splitter

Power Splitter

$0^\circ$

$90^\circ$

I

Q
Quadrature Sampling Receiver

Filter

Power Splitter

Power Splitter

QSC

QSD

I

Q

90°

0°
Gain = -10 dB

Quadrature Sampling Receiver

Filter → Power Splitter → QSD

QSC

Gain = -10 dB

Quadrature Sampling Receiver
Baseband Amps need to have:
- Moderate gain
- Low Noise
- High Dynamic Range
Quadrature Sampling Receiver

- Filter
- Power Splitter
- QSD
- Power Splitter
- OSC
- USB I/F
- To Computer
- QSC
- 90°
- 0°
- I
- Q
- Baseband Amps
- Analog
- To Computer

Diagram showing the components of a quadrature sampling receiver, including filters, power splitters, oscillators, USB interface, and baseband amplifiers.
“Softrock” Receiver

- Softrock receiver = Filter + QSC + 2 op amps + I/F
- Softrock I & Q outputs are **Analog** signals
"Softrock" Receiver

- Softrock Receiver = Filter + QSC + 2 op amps + I/F
- Softrock I & Q outputs are Analog signals

This is not a complete SDR receiver!
“Softrock” Receiver

- Softrock receiver = Filter + QSC + 2 op amps + I/F

- Softrock I & Q outputs are Analog signals

This is not a complete SDR receiver!

- Most of a SDR is in the software
- All we have here is two analog, low gain, direct conversion receiver front ends
“Softrock” Receiving System

- Additional hardware required
- Word size: 16, 24 bits
- Sample rate: 48, 96, 192 Ksps
- Data rate < 5Mbps
“Softrock” Receiving System

Additional hardware required
“Softrock” Receiving System

Additional software required
Quadrature Sampling SDR (SDR Cube)

No external computer, display or sound card required
Direct Digital Conversion (DDC)

Analog $\xrightarrow{RF_{IN}}$ $F_{IN}$ $\xrightarrow{F_{CLOCK}}$ ADC

$\xrightarrow{\text{DDC}}$ OSC
- $F_{CLOCK}$ must be greater than $2 \times F_{IN}$ (Nyquist criteria)
  - $F_{CLOCK}$ is usually a fixed frequency

- **Very high** data rates
- Theoretically only one channel is needed
  - Two channels (I & Q) often used for implementation reasons
Typical Direct Digital Conversion (DDC)

- Two DIGITAL words
- 90 degrees out of phase
- “Quadrature”
Typical Direct Digital Conversion (DDC)

- **Perseus**: 14 bits, 80 Msps, Data rate ~ 2Gbps
- **QuickSilver QSR1**: 16 bits, 130 Msps, Data rate ~ 4Gbps
- **Flex 6000**: 16 bits, 490 Msps, Data rate ~ 8Gbps

- No kits likely in the near future (other than HPSDR)
- Desktop computers won’t work
Direct Digital Conversion (DDC) SDR

Flex 6xxx architecture

DDC/DUC (Direct Down Conversion, Direct Up Conversion)
Some Important Considerations for SDR Projects

• Computer Hardware Requirements:
  • Very important:
    • Processor speed
    • Dual or quad core processor
    • Amount of RAM
    • High speed (2.0) USB ports
    • Sound card interface

• Audio Amplifier(s)
  • Many kits require an external audio amp(s)
    • Amplified computer speakers work well
Some Important Considerations for SDR Projects

• **Sound Cards:**
  - Sound card interface
    - PCI vs PCIe vs USB vs Firewire vs Ethernet?
  - What **sensitivity** is needed?
    - 16 bits (96dB DR) may be ok, but 24 bits (144dB DR) is best
  - What **display** bandwidth is needed?
    - Sample rate determines maximum achievable display bandwidth
      - 48, 96, 192 Ksps => 48, 96, 192 KHz

• **Recommendations from the Genesis reflector:**
  - Sound card choice depend on desired **Bandwidth** (sample rate) and **Sensitivity** (bits)
  - Asus Xonar DX series (cheap)
  - Asus Essence STX (expensive)
  - EMU 0202 or 0204 (USB external). Older cards can be bought very cheaply
  - Edirol FA-66 (expensive and Firewire may not work well)
  - All of these cards work fine for SDR applications in any supported Windows OS
  - How much to invest for Sensitivity depends on how "radio quiet" your location is **and** the quality of your PC components (power supply and motherboard are critical)
  - For beginners: try an older Audigy 2ZS (cheap 24bit/96KHz card)
Some Important Considerations for SDR Projects

• **Software:**
  • *Free* SDR Applications:
    • “Rocky”
    • Flex “Power SDR”
    • “WinRad”
    • “HDSDR” (not H P SDR)
    • “GSDR” (Genesis software based upon Flex “Power SDR”)
      • *Not* based upon the latest version of Power SDR!
  • **Computer Operating Systems**
    • Windows:
      • XP (good all around choice)
      • Vista (no!)
      • 7 (be careful)
        • Early SDR applications designed for use with XP
          • They may, or may not work with W7
        • Run XP on W7 machine may be an option
    • Mac (be *very* careful)
    • Linux (be *very*, *very* careful)
Receiver Performance Comparisons

• Dynamic Range:
  • Traditional Methods (ie, IMD) used for analog radios don’t accurately represent digital radios
    • Hard limiting in A/D converters
    • Digital radios have spurious signals that don’t occur in analog radios

• Unwanted image/sideband rejection:
  • DDC receivers have a big advantage

• QSD vs. DDC vs. Superhet Performance Comparison:
  • https://sites.google.com/site/lofturj/comparison_of_sdr_vs_superhet
  • Also has good discussion of 16 bit vs. 24 bit sound cards
Receiver Performance Comparisons

- Rob Sherwood rankings ([http://www.sherweng.com/table.html](http://www.sherweng.com/table.html))
- Measured SDR receiver performance:

<table>
<thead>
<tr>
<th>Item</th>
<th>Mfg</th>
<th>Model</th>
<th>Blocking dB</th>
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<th>Filter Ultimate dB</th>
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<td>123</td>
<td>98</td>
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*DDC architecture*
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<td>98</td>
<td>96</td>
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• Predicted receiver performance:

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<td>FLEX-6xxx*</td>
<td>-</td>
<td>147</td>
<td>-</td>
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*DDC architecture
SDR Kits

- **Softrock**: http://kb9yig.com/
- **Lazy Dog**: http://www.lazydogengineering.com
- **Crosscountry Wireless**: www.crosscountrywireless.net/
- **SDR CUBE**: http://www.sdr-cube.com/
- **HPSDR**: http://openhpsdr.org/
- **PM-SDR (Italy)**: http://www.iw3aut.altervista.org/
- ?
- ?
- ?
SDR Kits – cont’d

• **Beginner:**
  - Tiny SDR ([http://www.qrz.lt/ly1gp/SDR/Intermediate](http://www.qrz.lt/ly1gp/SDR/Intermediate)):
    - Very simple hardware (receiver only) but *not a kit*
    - All parts must be procured individually

• **Softrock:**
  - Excellent choice for first time SDR builder
  - *Some (~25) surface mount components*
  - Runs on any of several SDR software applications:
    - Power SDR (Flex software)
    - Rocky
    - **HDSDR**
  - Over 12,000 sold worldwide
  - Good website based support
  - May have to wait to purchase one
Intermediate Experience:

- **SDR Cube:**
  - Integrated architecture
  - Embedded DSP processor
  - No external computer required
  - No external display required
  - Single band HF transceiver
  - Built around a Softrock RF front end
  - **Mostly SMT components**

- **Genesis:**
  - High performance transceivers
    - G59 (no longer offered)
    - **G11**
      - G6 (Direct Digital Sample - Fall of 2012)
        - Fully assembled (not a kit and ~$1000)
  - Good website based support
• **Highly Experienced:**
  - HPSDR

**13-16 Different** Subsystems:

- Atlas
- Ozy
- Mercury
- Alex
- Penelope
- Pennywhistle
- Alex
- Excalibur
- Janus
- LPU
- Alexiars
- Metis
- Hercules

HPSDR Architecture

• Built around a six slot Backplane (ATLAS)
Tiny SDR

Only 20 components!

http://www.qrz.lt/ly1gp/SDR/Intermediate
Tiny SDR

http://www.qrz.lt/ly1gp/SDR/Intermediate
Tiny SDR

Filter

http://www.qrz.lt/ly1gp/SDR/Intermediate
Tiny SDR

Note: No amplifiers in signal path

http://www.qrz.lt/ly1gp/SDR/Intermediate
What is a “Softrock”? 

“Softrock” is a term for a software defined radio (SDR) which consists of three major building blocks:

- The **SDR hardware** (e.g., one of the Softrock kits) offered by **Tony Parks (KB9YIG)**: [http://kb9yig.com/](http://kb9yig.com/)

- A **PC** running SDR software, and

- **Stereo soundcard(s)**
  - One stereo input (“Line IN”) for RX, and
  - A second stereo output (“Line OUT”) for TX

**Documentation**: found at [http://www.wb5rvz.com/sdr/](http://www.wb5rvz.com/sdr/)

- Robby Robson (WB5RVZ)
Softrock Kits

- **SoftRock_40_R** receiver kit $21.00 each
- **SoftRock HF** Receiver Kit $67.00 each
- **SoftRock 6m/4m/2m RX Ensemble** Receiver Kit $68.00 each
- **SoftRock RXTX Ensemble** Transceiver Kit $89.00 each

  - The SoftRock RXTX Ensemble Transceiver Kit provides a 1 watt SDR transceiver that can be built for one of the following four band groups: 160m, 80m/40m, 30m/20m/17m or 15m/12m/10m

- *When kits do become available, they can sell out within 24-48 hours*
Softrock "Ensemble II"

"Ensemble II" RX Specs:

- Coverage in 4 bands:
  
  **HF:**
  
  - Band 0: 160M - Continuous coverage from 1.8 to 4.0 MHz
  - Band 1: 80M and 40M - Continuous coverage from 4.0 to 8.0 MHz
  - Band 2: 30M, 20M, and 17M - Continuous coverage from 8.0 to 16 MHz
  - Band 3: 15M, 12M, and 10M - Continuous coverage from 16 to 30 MHz

  **LF:**

  - 180 KHz to 3.0 MHz in four bands

- All parts needed for either HF or LF option are supplied in kit
- Runs on external 12 VDC supply (not supplied)
- Good sensitivity
- Front end easily overloaded
- Makes an excellent Panadapter
- HDSDR can run on a small Laptop or Netbook that has **stereo** "Line IN"
  
  - Many older Laptops do not have stereo

**A TX/RX version is also available**
Softrock "Ensemble II" – cont’d

- Filter
- Power Splitter
- OSC
- Power Splitter
- USB I/F
- QSD
- 0°, 90°
- Analog
- I
- Q
- Baseband Amps
- Softrock Receiver
Softrock "Ensemble II" – cont’d
Softrock "Ensemble II" – cont’d

RF In

Filters

QSD

Op Amps

To Sound Card
Softrock "Ensemble II" – cont’d
Softrock "Ensemble II" – cont’d

+5 V Supply

+3.3 V Supply

Osc

USB I/F

Freq Dividers
Softrock "Ensemble II" Receiver
Softrock "Ensemble II" Receiver – cont’d

~25 Surface Mount (SMD) Parts
Softrock "Ensemble II" Display (Power SDR)
Softrock "Ensemble II" Display (HDSDR)
**SDR Cube Transceiver**

- **Single band** HF transceiver
- Built around a Softrock RF front end
- All DSP processing is accomplished by an *embedded* DSP processor
  - No external computer or display required
- LCD display *with Bandscope* (+/- 4 KHz bandwidth)
- Transmit output power ? (5 watts?)
- $434 US (Kit) ($293 w/o Softrock Tx/Rx)
Instead of this ...

The SDR Cube Does THIS

Embedded DSP

Graphic User Interface

Softrock RXTX 6.3
“We don’t need no stinkin’ PC!”

Instead of this ...

The SDR Cube Does THIS

- Embedded DSP
- Graphic User Interface

Softrock RXTX 6.3
SDR Cube Transceiver – cont’d

3-PCB BOARD SET

I/O Board

DSP Board

Controls Board
SDR Cube Transceiver – cont’d

3-PCB BOARD SET

Note: Mostly SMD parts

I/O Board  DSP Board  Controls Board
Figure 3: SDR Cube Hardware Architecture
Illustrates designed-in controls, graphic display, and tight integration with NUE-PSK Digital Modem
The TLV320AIC23B is a relatively old codec. The main reason we used this particular part was the accumulated SW experiences how to control it. The TLV320AIC23B also provides handy adjustable input amplifiers, mic amplifier and head phone amplifiers. Most part of the audio signal routing is done with the codec mux block and codec driver sw. Only the PSK modem audio needed external switching.

The TLV320AIC23B provides 24-bit ADC output. Our processing happens in 16-bit resolution but we can benefit from the 24 bits by selecting the magnitude that we use from it. If we start from bit 22 instead of bit 23 we get 6dB gain and so on. S/N ratio gets worse on every bit reduction. Practical numbers are 1 to 3 bits. More can be used, yielding 6 to 18dB of "free gain".

SDR Cube Transceiver – cont’d
SDR Cube Transceiver – cont’d
Genesis

• **What is Genesis?**
  • Small group (~4) of hams that sell high performance SDR kits
    • Bus Mgr, H/W Engr, S/W Engr, Tech Support

• **Kits offered:**
  • **G59 HF Transceiver** (*no longer offered*)
    • GPA-10: 10 watt power amp for 160-6 M (*no longer offered*)
  • **G11 HF Transceiver**
  • **G6 HF Transceiver** (*available Fall 2012*)
    • Direct Digital Sample
    • *Not a kit* (fully assembled)
    • Key features:
      - band coverage: 138KHz-450MHz
      - A/D and D/A convertors built in
      - 32 bit CPU
      - USB 2.0 connection
      - 10W output power
      - SMD technology
  • Kits are periodically built in batches and *can sell out quickly*

• **Websites:**
  • Yahoo Reflector: [http://groups.yahoo.com/group/GenesisRadio/](http://groups.yahoo.com/group/GenesisRadio/)
Genesis – cont’d

• **G11 Transceiver Kit:**
  - All SMT parts (600+) are *factory installed*
  - Thru-hole parts (~50) need to be installed by purchaser
  - Average assembly time ~8 hrs
  
- Operates **all modes on 5 user selected bands**
  - Option for 160-6 M available ($139)
  
- **10 watt** RF output power
  
- Schematics can be downloaded from website
  - *No charge*
  
- Build instructions can be downloaded from website
  - *No charge*
  
- GSDR software can be downloaded from website
  - Based on Flex Power SDR
  - *No charge*
  
• **Cost:** $299 US
Genesis G11 – cont’d

Genesis G11 Block Diagram

USB

Rx QSD

Tx QSD

- Pout: 20W
- RF Amp, A: 43 dB
- Pin: 10 mW
- A: 12 dB
- LPF 30 kHz

\( \begin{align*}
\text{ATT} & : 17\, \text{dB} \\
\text{SI570} & : \text{VLF Option} \\
\text{I/4} & : \text{or} \\
\end{align*} \)
Genesis G11 Specifications:

1. **LF version**: 137 KHz or 500 KHz (RX 50KHz – 2MHz)
   - **HF version**: covers up to 5 HF bands (1.8-30 MHz), depending on BP/LP filters selection
     - 160 M monoband
     - 6 M monoband

2. Min synthesizer step: **1Hz**, adjustable
3. All-mode **CW/SSB/FM/ DIGITAL** *
4. **IIP3 30-32dBm** *
5. **MDS** is -116 to -122dBm * RF preamplifier on: MDS is from **-130 to -133dBm** *
6. Image rejection: -35 to -60 dB [hardware], better than 60dB [software]
7. **RX sensitivity**: 0.15-0.2uV for 10 dB S/N ratio. Max S/N measured: 70dB.
8. SFDR (Spurious free dynamic range) is 93-100dB these results are with signals spaced 5 kHz or more.
9. Receiver 1dB compression point is +5dBm
10. **Second antenna RX2 input**
11. **Support for transverter** with split RX input
12. Transmitter output power is **10W min** (5W on 6m) and it is adjustable in software to almost 0W
   - Transmission is possible only on amateur bands
13. TX carrier suppression: 45-60dBc [hardware]
14. Image rejection: -35dBc to -50dBc [hardware], 60dB with GSDR SDR software
15. Built in microphone preamplifier with adjustable 2 position gain to enable operation with single-input sound card [LINE IN or MIC in]
16. **Built in IAMBIC CW keyer with independent CW monitor**
17. Control circuit for keying RF linear power amplifier
18. Power requirements: +12V to +14V @3.5A
19. Specified operating temperature range is from 0°C to +55deg C
20. Dimensions 240 x 240 x 88mm weight 1.5kg
21. Kit assembly: 5-8 hours **
22. **G11 control via USB connection with GSDR software running on XP, Vista or WIN7 OS**
   - * Software or sound card dependant/related
   - ** enclosure, power supply, sound card and PC supplied by owner!
The G11 enclosure is ready for board installation
All holes punched & labeled
$60
Genesis GSDR Display
Genesis GSDR Display

- Waterfall
- Spectrum
- Oscilloscope

Gain Controls:
- RF Amp
- AF Amp
- Attenuator

Memory
- VFOs

Modes Select
- Analog or Digital S Meter

Bandwidth select
- Display Zoom (up to x32)

Display Control
- Noise Reduction
- Auto Notch
- Noise Blankers (2)

Main RX

TX

Band Select

Sub RX
Genesis GSDR Display

- Waterfall
- Spectrum
- Oscilloscope
- RX VFOs
- Memory
- Noise Reduction
- Auto Notch
- Noise Blankers (2)
- Gain Controls
- AGC
- RF Amp
- AF Amp
- Attenuator
- TX
- Bands Select
- Modes Select
- Display Control
- Display Zoom (up to x32)
- Analog or Digital S Meter
- Main RX
- Sub RX

Note: No second receiver or dual watch
Panadapter Displays

GSDR (96 Ksps)

Wide

Narrow

14.150 MHz
-70 dBm (S9+3dB)
100% AM @ 1KHz
Panadapter Displays

GSDR (96 Ksps)

IC-7600

14.150 MHz
-70 dBm (S9+3dB)
100% AM @ 1KHz

The 7600 can display up to 500 KHz

Wide

Narrow

96KHz
3KHz

100KHz
5KHz
Genesis G59 Transceiver

Genesis G59
160 - 6m SDR Transceiver
Genesis G59 Project

• **Goals:**
  • Build a high performance 100 watt SDR transceiver for *daily ops*

• **Approach:**
  • Use parts from junk box as much as possible
  • Packaging: Ease of servicing more important than small size
  • Use Genesis G59 transceiver as the core
  • Use an EM-U 1212 sound card (24 bits & 192 Ksps)
  • Build HF power amp capable of 100 watts continuous duty
  • 7 Bands: 160M, 80M, 40M, 20M, 15, 17M, 10M

• Separate into two chassis:
  • **Chassis 1:** G59 SDR Transceiver + High Gain RF Amps
    • Don’t want high sensitivity circuits in same chassis with 200 watt power amp
    • Use linear power supplies
  • **Chassis 2:** RF Driver Amp + High Power RF Amp
    • Use IRF-510 FETs for driver amp
    • Input 0.5 watt for 20 watts out
    • Use CCI 200 watt kit for final amp
    • Add SWR & Thermal protection circuits
    • Use self contained switching power supply
  • Use “RF tight” enclosures for both chassis
Genesis G59 Project

Computer
Genesis G59 Project

G59 & RF Power Amp Front Panels

RF Power Amps

G59 Chassis
G59 High Gain RF Amps & T/R Switch
Knobs

Flex 5000
Knobs

Flex 5000

“We don’t need no stinkin’ knobs!”
“I do need those stinkin’ knobs!”
(... and meters, and switches, and lights, and ...)
**G59 Panel Layouts**

- **SWR Protect**
- **Over Temp**
- **Audio Gain**
- **Frequency Tune**
  - Tune knob
  - Point & Click
- **IC**
- **SWR**
- **P_{OUT}**
- **RF Drive**
- **Mic Gain**
- **Filter Select**
  - Auto Select
- **Audio Gain**
- **RF Drive**
- **Over Temp**
- **IC**
- **SWR**
- **P_{OUT}**
- **Filter Select**
  - **Auto Select**
- **Mic Gain**
# Receiver Performance - Sensitivity

**Estimated Sensitivity**

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Sensitivity (μV)</th>
<th>Equivalent dBm (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC-7600</td>
<td>0.15</td>
<td>-123</td>
</tr>
<tr>
<td>TS-930S</td>
<td>0.2</td>
<td>-121 (S1)</td>
</tr>
<tr>
<td>G59</td>
<td>~0.8</td>
<td>-109 (S2)</td>
</tr>
<tr>
<td>G59</td>
<td>&lt;0.1</td>
<td>-127 &lt; S1</td>
</tr>
<tr>
<td>Ensemble II</td>
<td>~2</td>
<td>-101 (S4)</td>
</tr>
</tbody>
</table>

**Notes:**
1. ~10 dB output (S+N)/N using maximum RF preamp gain (BW=2.4KHz)
2. Measurements made with Preamp 2 ON (spec = 0.15 uV)
3. Preamp OFF
4. Using custom RF Preamp
5. Has no RF Preamp
G59 Custom RF Preamp

- Noise Figure ~3 dB
- Net gain ~26 dB
Receiver Performance – Dynamic Range

• Dynamic Range is hard to measure for digital receivers
  • Traditional methods such as IP3 can be inaccurate and mis-leading
  • Digital radios can have unwanted spurs even at low signal levels that analog radios do not have
  • Overloading the ADC causes **serious** problems
    • Example: G59 Overload (RF Preamp OFF)

![Dynamic Range Graph](image)
Receiver Performance – Dynamic Range

• Dynamic Range is hard to measure for digital receivers
  • Traditional methods such as IP3 can be inaccurate and mis-leading
• Digital radios can have unwanted spurs even at low signal levels that analog radios do not have
  • Overloading the ADC causes serious problems
  • Example: G59 Overload (RF Preamp OFF)
Receiver Performance – Dynamic Range

• Dynamic Range is hard to measure for digital receivers
  • Traditional methods such as IP3 can be inaccurate and misleading
  • Digital radios have unwanted spurs even at low signal levels
  • Overloading the ADC causes serious problems

Note: $+1 \text{ dBm} = \text{S9} + 74 \text{ dB}$

• Example: G59 Overload (RF Preamp OFF)
Receiver Performance – Dynamic Range

G59

S9+60 dB

Not a spur (common with Direct Conversion Receivers)
Receiver Performance – Dynamic Range

- The IC-7600 does not exhibit hard limiting
- It has a **hardware AGC** that the G59 does not have

**S9+60 dB**

**G59**

Not a spur (common with Direct Conversion Receivers)

**IC-7600**
Receiver Performance – Dynamic Range

• The IC-7600 does not exhibit hard limiting
• It has a hardware AGC that the G59 does not have

S9+60 dB

Which receiver is better???

Not a spur (common with Direct Conversion Receivers)
Receiver Performance – Dynamic Range

• The Ensemble II/ACER Notebook *combination* overload:

S9+13 dB
Receiver Performance – Dynamic Range

• The Ensemble II/ACER Notebook *combination* overload:

  S9+13 dB

  S9+14 dB
Receiver Performance – Dynamic Range

• The Ensemble II/ACER Notebook combination overload:

- S9+13 dB
- S9+14 dB

• The Ensemble II looks good up to -15 dBm (S9+58 dB)
Receiver Performance – Dynamic Range

• The Ensemble II/ACER Notebook combination overload:

  - S9+13 dB
  - S9+14 dB

• The Ensemble II looks good up to -15 dBm (S9+58 dB)
• This overload problem is in the ACER Netbook
Receiver Performance – G59 Image Rejection

- No Rejection
- H/W Only Rejection: 37 dB
- H/W + S/W Rejection: 80 dB
G59 Transmitter Performance

Image (unwanted sideband) Rejection at G59 Output:
G59 Transmitter Performance

• Image (unwanted sideband) Rejection at G59 Output:

All unwanted spurious down >60 dB
Transmitter (RF Power Amplifiers)

Goals:

• Gain \( \geq 43 \) dB (0.01 watt to 200 watts)
  • Split into 20 dB & 23 dB => separate enclosures

• Bands: 160M, 80M, 40M, 20M, 15/17M, 10M
  • Dedicated filter for each band
  • Auto filter select via G59

• Adequate filtering to meet FCC harmonics requirements
  • >40 dB second harmonic rejection

• IMD down >30 dB

• Two stage SWR protection
  • Fast response (ie, ALC based upon Reflected Power)
  • Latch after 1 sec delay
  • Front panel Threshold Adjust and Reset

• Thermal
  • Design for full 100% duty cycle at 100 watts output
  • Over Temp protection
RF Power Amplifier Chassis

- SWR Protect
- Filters
- RF Driver
- RF Power Amp
- TR Switch
- AC On/Off
- Switching Pwr Sup
- SWR/Power Meter
- Fans
RF Power Amplifier Back Panel

- Shielded air intake for fans
- Shielded air exhaust (on top)
Note: Running this amp over 30 W output with the top cover off crashes the SDR computer.
RF Driver Amp

• Design: “A Broadband HF Amplifier Using Low-Cost Power MOSFETs”  
  By Mike Kossor, WA2EBY  
  March 1999  
  QST
• Uses two inexpensive ($0.70 ea) IRF-510 switching FETs in push-pull  
• Easy to burn out FETs at high SWR  
• $P_{IN} > 30$ watts ($P_{IN} = 1W$) from 2-30 MHz
Final Amp

• Based upon Motorola App Note AN-762
  • Parts and documentation available from:
    • Communications Concepts Inc
      • http://www.communication-concepts.com/
    • Solid state amplifier kits for 20 W to 1 KW power levels
• 2-30 MHz
• Uses two MRF-421 bipolar transistors in push-pull
• 180 watt output with 15 watt input
Transmitter Performance Summary

• Tests done at 14.15 MHz

• G59 Final Amplifier:
  • Output Power:
    • 100 watts with 10 watts input
    • Capable of ~200 watts with 20 watts input

• IMD Performance Comparison at 100 watts:
  • G59: -30 dB
    • Bipolar transistors
    • Motorola predicted -30 dB
  • 7600: -25 dB
    • FET transistors
    • Not spec’d
Output Filters

• FCC requires all harmonics to be $> 40$ dB below the PEP output
• Started with Comm Concepts Inc lowpass filter kits
  • Some needed tuning to center operating bandwidth
  • One (15/17M) needed to be re-designed to cover two bands:
Output Filters

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• Started with Comm Concepts Inc lowpass filter kits
  • Some needed tuning to center operating bandwidth
  • One (15/17M) needed to be re-designed to cover two bands:

These filters can take a great deal of time & effort!
LPF Circuits

RF In

1. Coil
   K1

2. 160M

3. Coil
   K3

4. 80M
   K4

5. Coil
   K5

6. 40
   K6

7. Coil
   K7

8. 20
   K8

9. Coil
   K9

10. 15/17M
    K10

11. 10
    K11

12. 13.5 VDC

RF Out

50 Ω

Coil 1

Coil 2

Coil 3

Coil 4

Coil 5

Coil 6

Coil 7

Coil 8

Coil 9

Coil 10

Coil 11

Coil 12

8/23/2012
SWR Protection

RF Driver \rightarrow HPA \rightarrow RF Sensor (Rev) \rightarrow Filters

SWR Protection Circuits:
- Shutdown
- Foldback Threshold
- +5 VDC
- +8 VDC
- +13.5 VDC (Power Supply)

Input: +13.5 VDC

Output: Power Supply
Note: These are the most important circuits in the entire transceiver.
Basic SWR Protection Circuit

Rev (BLK)

LM324

1.1K

100K

1N3600 x3

2N3501

390 ½ W

To SWR Shutdown

To +13.5 VDC

To +8 VDC

To +5 VDC

0.1 uF

Foldback Threshold

To +5 VDC

To +8 VDC

To +13.5 VDC

2N3501

SWR LED

Radio Shack 276-0017
Note: This circuit needs to be well shielded & filtered from RF

Basic SWR Protection Circuit

- **1N3600 x3**
- **2N3501**
- **390 ½ W**
- **100K**
- **1.1K**

Foldback Treshold

- **0.1 uF**
- **To +5 VDC**
- **To +8 VDC**

To SWR Shutdown

SWR LED
Radio Shack
276-0017

To +13.5 VDC
SWR Protection Circuits

\[ V_{LATCH} \text{ set to } 75 \text{ mV} \]

\[ V_{LATCH} = \text{Reflected Power} \]

\[ \sim 0.5 - 10 \text{ sec Delay to Latch} \]

C* is ten 1.0 \( \mu \)F ceramic caps in parallel

\[ V_{LATCH2} \text{ set to ? V} \]

\[ V_{THD} \]

\[ V_{LATCH2} \]

\[ \text{LATCH} \text{ set to 75 mV} \]

\[ \text{Foldback Treshold} \]

\[ \text{Relay: Omron G6A-234P-ST-US} \]

\[ \text{700 ohm coil} \]

\[ \text{17 mA @ 12 VDC} \]

\[ \text{Coil polarity critical} \]
RF Power Amp – Switching Power Supply

MegaWatt Model S-400-12

• **9.5 to 15.5 VDC**

• **36 amps** (90% D.C.) 41 amp peak
  • A 90% duty cycle means 30 minutes at 36 amps and 3 minutes at 30 amps to cool down for another run at 36 amps.

• These units are designed for powering HAM radio equipment
  • The output section of the power supply is highly filtered to eliminate RF in the output voltage (**no noise observed**)

• Input 120/240 VAC

• Cost: **$60** thru eBay or [http://www.12voltpowersupplies.us/](http://www.12voltpowersupplies.us/)
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• Cost: $60 thru eBay or [http://www.12voltpowersupplies.us/](http://www.12voltpowersupplies.us/)

Crowbar protection needed?
RF Power Amp – Switching Power Supply

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• Input 120/240 VAC

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Maximum $V_{CE}$ for MRF421 = 20V
From ARRL Handbook 2004 page 11.39

Fig 14-54 - Schematic diagram of the overvoltage protection circuit. Resistors are 1/4-W, 5% carbon types unless noted.

D3 — TBD 1/2 W Zener (NTE 5036A or equiv.).
Q6 — NPN Transistor (2N2222A or equiv.).
Q7 — 100 V, 25 A SCR (NTE 5522 or equiv.).
RF Isolation

• Important to Prevent:
  • Degraded out of band rejection of harmonics
  • Unwanted parasitic oscillations in power amps
  • Computer being unusable

• Filter Layout
  • Short leads on inputs and outputs
  • Wide separation between input and output relays/connectors
  • Ground inactive filter inputs and outputs

• TX/RX Relays
  • Use small (and fast) relays
    • 3A rating for 100 watt switching
  • Insure that isolation is >10 dB more than:
    • Filter isolation
    • Net gain of switched amplifiers

• Aluminum coatings (Alodine, etc) are poor conductors
• Ferrite beads on all lines (non-RF) IN & OUT of the chassis
  • Ferroxcube (old P/N VK200 09 3B)
• Metal screens advisable for large openings
Summary

• Many options are available for homebrewing for all experience levels

• SDR homebrewing options are available for all performance and experience levels at attractive prices
  
  • *Do your homework first!*

• Don’t be intimidated by “Digital” or “DSP”
  
  • You don’t need to be an expert in either to build/operate a SDR
  
  • Most of the “Digital” is in the computer/sound card
  
  • All of the ”DSP” is in the computer software/firmware

• With SDRs, low cost does *not* mean poor performance