



### Basic Receiver Fundamentals and Design



Presented by,  
Clark Pope

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### Bio- Clark Pope

- MSEE University of Illinois, 1994
- 13 years at DRS Signal Solutions
- Work History
  - DSP coding for HF product Line
  - Digital Engineer section head
  - System engineer (VXI, slot zero, Pentek DSP)
  - Architect Sunrise SDR
  - Several years on digital demodulators (Qam, Psk, Fsk, etc. Reed-Solomon, Viterbi, BCH. etc.)
  - Architect Pico SDR (FPGA SOC, USB2.0 OTG, Embedded Linux)

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### Outline

- Receiver Fundamentals
  - Definition of a Receiver
  - Basic Block Diagram
  - Building Blocks
  - Superheterodyne Receiver
  - Direct Conversion Receiver
  - Digital Backends and the Software Definable Radio
- Real World Datasheet
- Working as a Radio Engineer
- Questions

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**What is a receiver?**

What does an FM Radio do??

It recovers the transmitted stereo music.

More generally a receiver performs the task of extracting the source information from a transmitted modulated signal that has been corrupted by noise.

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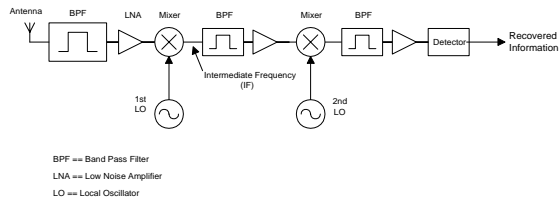
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**Basic Receiver Block Diagram**




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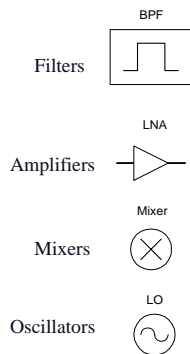
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**Building Blocks**




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**Filters** DRS SIGNAL SOLUTIONS, INC.  
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- Pass desired signals and reject undesired signals.
- Important Characteristics
  - Center Frequency  $f_0$
  - Bandwidth BW
  - Transition Bandwidth BT
  - Insertion Loss IL
  - Rejection REJ
  - Amplitude Ripple AR
  - Phase Ripple
  - Group Delay Ripple GDR

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**Amplifiers** DRS SIGNAL SOLUTIONS, INC.  
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- A device to amplify signals in the signal path in the forward direction.
- Supply reverse isolation to prevent signals from propagating back through a system.
- Important Characteristics
  - Gain - G, in dB:  $G = 10\log(P_{out}/P_{in}) = 20\log(V_{out}/V_{in})$
  - Noise Figure- NF, in dB:  $NF = 10\log(S/N_{in})/(S/N_{out})$
  - 1 dB Compression point: P1
    - The output power at which the gain of the amplifier has decreased by 1 dB.
    - This is a measure of the signal handling and linearity of an amplifier.
  - Output Third Order Intercept Point:  $OIP3 = P1 + 10\text{ dB}$  (approximately)
    - The theoretical output power where the 3rd order product would equal the fundamental output power.
  - Input Third Order Intercept Point:  $IIP3 = OIP3 - G$ 
    - The Output third order intercept point reflected to the input of the amplifier.

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**Nth Order Products** DRS SIGNAL SOLUTIONS, INC.  
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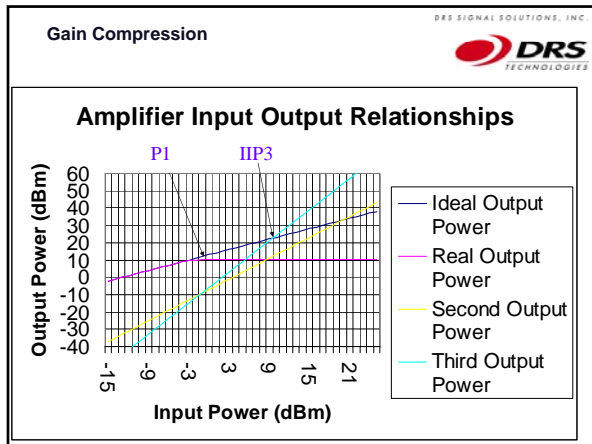
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### Mixers

- Mixer is a three port devices used for frequency translation.
  - $f_{RF}$  is the RF frequency input. (RF is Radio Frequency)
  - $f_{IF}$  is the IF frequency output. (IF is Intermediate Frequency)
  - $f_{LO}$  is the LO frequency input. (LO is the Local Oscillator Frequency)

$$f_{IF} = \pm m f_{RF} \pm n f_{LO} \quad m \text{ and } n = 0, 1, 2, 3, 4, \dots$$

Usually want  $m = n = 1$ :

$$f_{IF} = f_{RF} \pm f_{LO} \quad \text{low side LO}$$

$$f_{IF} = f_{LO} \pm f_{RF} \quad \text{high side LO}$$

$f_{RF}$   
 $\uparrow$

Mixer

- Higher order terms are unwanted and should be avoided.
- Important Characteristics
  - Conversion Loss: (the gain of the mixer) Mixing generally causes the signal level to drop by 6 to 8 dB.
  - Noise Figure- NF, in dB: Usually equal to the conversion loss unless an active mixer is used.
  - Intercept Points: The same as for an amplifier.

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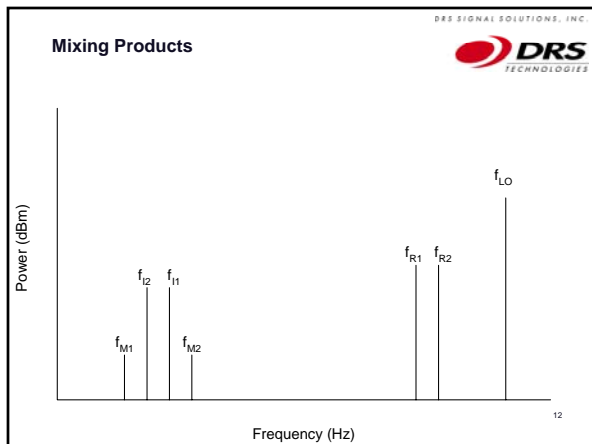
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**Oscillators**



- An oscillator is an electrical device that produces a sinusoid at a specified frequency
- Used in the mixing process.
- Usually phase locked to a very stable and clean crystal reference oscillator
- Important Characteristics
  - Frequency of oscillation.
  - Jitter – short term variation in frequency
  - Tuning characteristics: MHz/V
  - Output Power
  - Phase Noise
    - The phase noise of an oscillator is a measure of the amount of power contained in 1 Hz bandwidth, relative to the carrier power at increasing offsets from the desired carrier frequency. (dBc/Hz)

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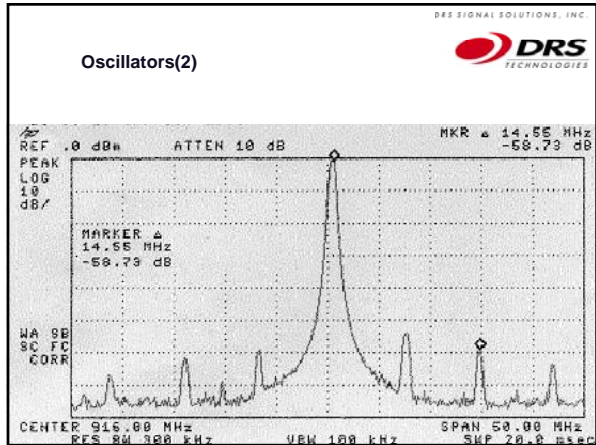
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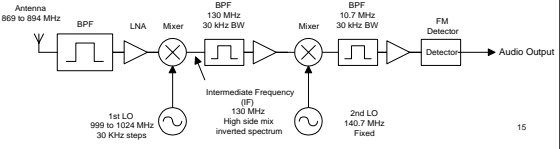
**How does a receiver design start?**



First a frequency plan is established.  
 What are the input frequencies of interest?  
 What first IF will be used to avoid any mixer spurious products?  
 What final IF will be used?

Next the input signal level is defined so that the noise figure and amplifier signal handling capabilities can be defined.

Finally a demodulation type is chosen (given) and audio levels established.



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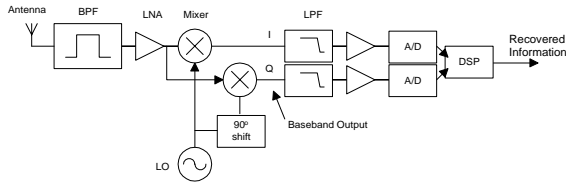
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## Direct Conversion Receiver



This type of receiver is now used in some GSM handsets. It requires less hardware than the Superhetrodyne receiver, most notably the IF filter is removed. In this receiver the input signal is mixed with an LO at the same frequency as the RF carrier. This is then low pass filtered and the information is then extracted by a demodulator.



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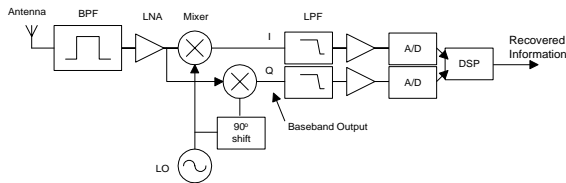
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## Digital Backends and the Software Definable Radio



In the GSM example the baseband I and Q signals are being sampled by an A/D converter. These samples are then used for FM demodulation and subsequent audio generation. This is the earliest type of digital demodulation.



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## What is an A/D Converter?



An A/D converter is an Analog to Digital converter. An input analog signal is sampled at a constant rate and the digital word corresponding to the signal level at that instant is sent out in a digital word.

Table IV. Output Data Format

Input (V)	Condition (V)	Digital Output	OTR
V <sub>INA</sub> - V <sub>INB</sub>	< -V <sub>REF</sub>	0000 0000 0000	1
V <sub>INA</sub> - V <sub>INB</sub>	= -V <sub>REF</sub>	0000 0000 0000	0
V <sub>INA</sub> - V <sub>INB</sub>	= 0	1000 0000 0000	0
V <sub>INA</sub> - V <sub>INB</sub>	= +V <sub>REF</sub> - 1 LSB	1111 1111 1111	0
V <sub>INA</sub> - V <sub>INB</sub>	> +V <sub>REF</sub>	1111 1111 1111	1

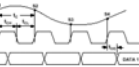


Figure 1. Timing Diagram

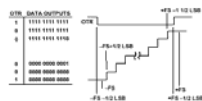


Figure 53. Output Data Format

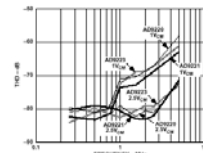


Figure 32a. AD9221/AD9223/AD9220 THD vs Frequency for V<sub>CM</sub> = 2.5 V and 1.0 V (A<sub>CL</sub> = -0.5 dB, Input Span = 2.0 V p-p)

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### Digital Backends and the Software Definable Radio

Newer Software Definable Radio's are sampling large bandwidths of spectrum near baseband. This 1 MHz to 40 MHz band is sampled at 80 MHz and then a single channel of information is extracted with a digital drop receiver (DDR). The digital drop receiver is controlled by a digital signal processor (DSP) and the DSP is also processing the single channel output of the DDR.

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### Digital Backend (Detail)

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### Processes

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## Processes (2)

- There are several control loops in a receiver
  - Automatic Gain Control (AGC) = adjusts the gain stages throughout the receiver for best SNR and to prevent clipping (remember that NF depends on where the gain is applied)
  - Automatic Frequency Control (AFC) = adjusts the tuning to center the signal in the filter
  - Baud Synchronization = resamples the signal at 2x or 4x the baud rate with the samples at "optimal" places in the symbol
  - Equalization = adapts the response of the system to match the response of the channel
  - Carrier Tracking = in digital demodulation, tracks the phase of the signal to keep the constellation upright
  - Channel Scanning = tunes the radio, checks signal strength, if above COR level, dwells for a period, before moving to the next frequency

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## HF-1000/WJ-8711A Datasheet (Handout)

- Tip: If you can explain the specifications on an interviewer's product, you'll probably get a job offer.
- Specifications fall in to broad categories
  - Functional = what the product does
  - Performance = how well the product works
  - Environmental = mechanical configuration and the conditions it operates in



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## Functional Specifications

### Features

- Frequency coverage from 5 kHz to 30 MHz in 1 Hz steps
- High dynamic range: +30 dBm third-order intercept typical
- Digital filtering provides 66 IF bandwidths up to 16 kHz with exceptional shape factors
- AM, SAM, FM, CW, USB, LSB and LSB detection m-Modes Standard
- Fast, flexible scanning with 100 memory channels
- Large readable LED displays and user-friendly controls
- Three variable AGC decay settings
- Noise blanking and passband tuning
- Tunable IF notch filter
- Internal switchable preamplifier and attenuator
- Standard remote interface (optional Multidrop RS-232, RS-485, RS-422, CSMA or IEEE-485)
- Built-in self test
- Optional subaudible preselector
- Optional digital data output

- Systems Engineers compete on functionality and capability. Trying to cram more into the same size, weight, and power (SWAP)

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**Working in Radio Industry (1)** DRS SIGNAL SOLUTIONS, INC.



- General
  - The main markets for radio engineering are:
    - Consumer
      - Examples: bluetooth, wifi, cable modem, am/fm radio
      - Usually a specific band of interest
      - Goal is a low cost integrated solution with acceptable performance
    - Telecom/Professional
      - Ex: cellular networks, point to point microwave, satellite communications
      - Moderately expensive, higher performance systems
      - Business use this technology to make money so performance is often more important than cost since it gets spread over many customers
    - Test and Measurement
      - Ex: signal generators, test radios, production testers
      - Highest performance (standard that the rest are measured against)
      - Very Expensive
    - Military/Government
      - Ex: SIGINT, ELINT, COMINT
      - High Performance
      - Often most expensive because of quantities and mechanical/environmental challenges
      - Most challenging for the engineer
      - All modulations, all frequencies, all bandwidths!

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**Working in Industry(2)** DRS SIGNAL SOLUTIONS, INC.



- Analog Engineers
  - RF = lower frequencies < 1 GHz
  - Microwave = > 1 GHz
  - Toolsets and design methodologies are very different
  - Manufacturing and shielding become major efforts
  - Specialties
    - Synthesizer design (higher frequencies, wider coverage, better phase noise)
    - RF chain design (mixers, amplifiers, filters, better GNFIP, lower cost, fewer spurs)

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**Working in Industry(3)** DRS SIGNAL SOLUTIONS, INC.



- Digital Engineers
  - PCB/HW Engineers
    - Design circuit boards and do general digital design of PLDs and FPGAs
    - Focus on high frequency digital design where the circuits are essentially microwave because of the clock edges
    - PCB signal analysis tools employed heavily
    - Generally cutting edge CPU clocking, DDR2 memories, and so on
  - DSP Engineers
    - Focus on the signal processing algorithms
    - Simulate in matlab
    - Implement in either DSP chip (TI, Freescale, Analog Devices) or FPGA (Xilinx or Altera, usually VHDL)
    - Though technology changes regularly the basic math stays the same

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**Working in Industry (4)**

- Software Engineers
- GUI/System engineers generally write software that integrates several pieces of equipment into a framework that gets presented to the user
  - Use tools like Qt
  - Web based
  - Databases
- Embedded SW engineers work on small microprocessors inside the equipment
  - Mostly C and assembler code
  - Limited OS if any
  - Often develop using a debugger/emulator
  - Work closely with the DSP engineer

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**Advice**

- Subscribe to EE Times and at least one specialty magazine like RF&Microwave
- Team work is over emphasized in school. Often you'll be the only person in your technical area on the project, don't expect a lot of help.
- Learn continuously. Half life of your degree is ~5 years.
- Engineering is more than technical knowledge
  - Time management
  - Communications
  - People skills
  - Attitude
- What you don't realize yet: Engineers create paper, that's all. Schematics, test procedures, program listings, datasheets, etc.

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**Questions?**

- Please see me after class if interested in DRS employment.

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