

Intelligent Adaptation And Cognitive Networking

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Media

- Wired
 - Can react to local conditions near speed of light
 - Generally reactive systems rather than predictive work “good enough”
- Wireless
 - Much slower sensory and response time
 - Multiple systems can react simultaneously, and not see each other’s effects
 - Broadcast costs and power generally cause a greedy, best-effort scheme

Frequency and Spectrum Usage

- In USA, limited legal usage of wireless frequency (~2.4 and 5 GHz most used)
- ISM (Industrial, Scientific, Medical) bands tend to get overloaded
- Open areas rarely utilized, due to standardization of use

Charts courtesy of commandline.net:

Remote Control Airplanes

27 MHZ Air and Land Use		50 MHZ FCC License Required		72 MHZ Aircraft Only		75 MHZ Land Use Only	
Ch	Freq	Ch	Freq	Ch	Freq	Ch	Freq
A1	26.995	00	50.800	11	72.010	61	75.410
A2	27.045	01	50.820	12	72.030	62	75.430
A3	27.095	02	50.840	13	72.050	63	75.450
A4	27.145	03	50.860	14	72.070	64	75.470
A5	27.195	04	50.880	15	72.090	65	75.490
A6	27.255	05	50.900	16	72.110	66	75.510
		06	50.920	17	72.130	67	75.530
		07	50.940	18	72.150	68	75.550
		08	50.960	19	72.170	69	75.570
		09	50.980	20	72.190	70	75.590
				21	72.210	71	75.610
				22	72.230	72	75.630

HAM Radio

Medium Frequency (MF) (300 kHz to 3 MHz)
High Frequency (HF) (3.0 - 30.0 MHz)
Very High Frequency (VHF) (30 to 300 MHz)
Ultra High Frequency (UHF) (300 MHz to 3 GHz)
Super High Frequency (SHF) (3 to 30 GHz)
Extremely High Frequency (EHF) (30 to 300 GHz)

Through ITU (International Telecommunication Union) agreement bandwidth has been set aside for amateur transmissions. Amateurs use a variety of transmission modes, including Morse code, radio teletype, data, and voice. Specific frequency allocations are a matter of record and vary from country to country and region to region, but the frequency allocations in the USA are:

Medium Frequency (MF) (300 kHz to 3 MHz)
160 metres (1.8 - 2.0 MHz)

High Frequency (HF) (3.0 - 30.0 MHz)
80 metres (3.5 - 4.0 MHz)
60 metres
 (five USB voice channels: 5.332, 5.348, 5.368, 5.373, 5.405 MHz)
40 metres (7.0 - 7.3 MHz)
30 metres (10.100 - 10.150 MHz)
20 metres (14.000 - 14.350 MHz)
17 metres (18.068 - 18.168 MHz)
15 metres (21.000 - 21.450 MHz)
12 metres (24.890 - 24.990 MHz)
10 metres (28.0 - 29.7 MHz)

Very High Frequency (VHF) (30 to 300 MHz)
6 metres (50 - 54 MHz)
2 metres (144 - 148 MHz)
1.25 metres (222 - 225 MHz)

Ultra High Frequency (UHF) (300 MHz to 3 GHz)
70 centimetres (420 - 450 MHz)
33 centimetres (902 - 928 MHz)

Commercial Radio	ISM industrial-scientific-medical frequency band		Wireless Internet
88-108 MHz	902-928 MHz, 2400-2483 MHz, 5725-5780 MHz		2400 - 2 483.5 MHz 2 layers
	Description	Freq	
	Cordless Phone	43-50 MHz 900 MHz-2.4Ghz DSS	

Bluetooth

**2402 - 2480 MHz
with 79 1-MHz RF channels**

Generally, small handhelds like the palm, and most new macintosh computers use "bluetooth" as a means of exchanging data within 30 feet. It enables users to connect a wide range of computing and telecommunications devices easily and simply, without the need to buy, carry, or connect cables.

It uses the 2.4 ghz spectrum to communicate a 1 megabit connection between 2 devices for both a voice channel and a 768k data channel. The entire channel has a total capacity of 1 megabit per second (Mbps). Headers and handshaking information consume about 20 percent of this capacity.

In the United States and Europe, the frequency range is 2,400 to 2,483.5 MHz, with 79 1-MHz radio frequency (RF) channels.

In practice, the range is 2,402 MHz to 2,480 MHz. In Japan, the frequency range is 2,472 to 2,497 MHz with 23 1-MHz RF channels.

A data channel hops randomly 1,600 times per second between the 79 (or 23) RF channels. Each channel is divided into time slots 625 microseconds long. A piconet has a master and up to seven slaves. The master transmits in even time slots, slaves in odd time slots. Packets can be up to five time slots wide. Data in a packet can be up to 2,745 bits in length.

Television

VHF

The general services in the VHF band are:

30-46 MHz: Licensed 2-way land mobile communication

30-88 MHz: Military VHF-FM, including SINCGARS

46-50 MHz: Cordless telephones, "49 MHz" FM walkie-talkies, and mixed 2-way mobile communication

50-54 MHz: Amateur radio "6-meter" band

54-72 MHz: TV channels 2, 3, and 4

72-76 MHz: Remote Control devices

76-88 MHz: TV channels 5 and 6

88-108 MHz: FM broadcasting (88-92 non-commercial, 92-108 commercial)

108-118 MHz: Air navigation beacons VOR

108-132 MHz: Air Traffic Control (AM), 121.5 MHz is emergency frequency

132-144 MHz: Auxiliary civil services, satellite, space research, and other miscellaneous services

144-148 MHz: Amateur "2-meter" band

148-174 MHz: "VHF Business Band", the new unlicensed Multi-Use Radio Service (MURS), and other 2-way land mobile, FM

156-174 MHz VHF Marine Radio FM

162.40-162.55: NOAA Weather Stations, FM

174-216 MHz: TV channels 7 through 13, and professional wireless microphones (low power, certain exact frequencies only)

216-222 MHz: mixed services

222-225 MHz: Amateur "1-1/4-meter" band

above 225 MHz: Federal services, including military aircraft radio (225-400 MHz) AM, including HAVEQUICK

UHF

brief summary of some UHF frequency usage:

300 - 420 MHz: government use, including meteorology

420 - 450 MHz: radiolocation and Amateur "70 cm" band

450 - 470 MHz: UHF business band, GMRS, and FRS 2-way "walkie-talkies"

470 - 512 MHz: TV channels 14-20, public safety

512 - 806 MHz: TV channels 21-69 (channels 53-69 to be auctioned)

806 - 824 MHz: pocket pagers and Nextel SMR band

824 - 849 MHz: cellular phones, A & B franchises, mobile phone

849 - 869 MHz: public safety 2-way (fire, police, ambulance)

869 - 894 MHz: cellular phones, A & B franchises, base station

902 - 928 MHz: ISM band: cordless phones and stereo, datalinks

928 - 960 MHz: mixed Studio-Transmitter Links, mobile 2-way, other

1240 - 1300 MHz: Amateur radio

1850 - 1910 MHz: PCS mobile phone - note below

1930 - 1990 MHz: PCS base stations - note below note: order is A,D,B,E,F,C blocks. A,B,C = 15 MHz; D,E,F = 5 MHz

2310 - 2360 MHz: Satellite radio Sirius and XM

2390 - 2450 MHz: Amateur radio, shared with below:

2400 - 2483.5 MHz: ISM, IEEE 802.11, 802.11b, 802.11g Wireless LAN

around 2450 MHz: Microwave oven

UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

- ADVENTIST MOBILE HYPER SATELLITE RADIOASTRONOMY
- ADVENTIST WIRELESS SATELLITE LAND MOBILE RADIOIMMUNONUCLIDE AND THERMAL SIGNAL
- ADVENTIST RADIOIMMUNONUCLIDE LAND MOBILE SATELLITE RADIOLLOCATION
- MARINE MARITIME MOBILE RADIOLOCATION SATELLITE
- MARITIME SATELLITE MARITIME SATELLITE RADIOIMMUNONUCLIDE
- BIODIVERSITY BROADCASTING MARINE RADIOIMMUNONUCLIDE
- BIODIVERSITY SATELLITE METEOROLOGICAL SPACE OPERATOR
- BROADCASTING SATELLITE METEOROLOGICAL SATELLITE SPACE OPERATOR
- DATA DISTRIBUTION DATA DISTRIBUTION SATELLITE SPACE OPERATOR
- FIXED MOBILE RADIOIMMUNONUCLIDE AND THERMAL SIGNAL
- FIXED SATELLITE MOBILE SATELLITE RADIOIMMUNONUCLIDE AND THERMAL SIGNAL
- GOVERNMENT DECLASSIFIED GOVERNMENT NON-DECLASSIFIED
- NON-DEPARTMENT DECLASSIFIED NON-DEPARTMENT NON-DECLASSIFIED

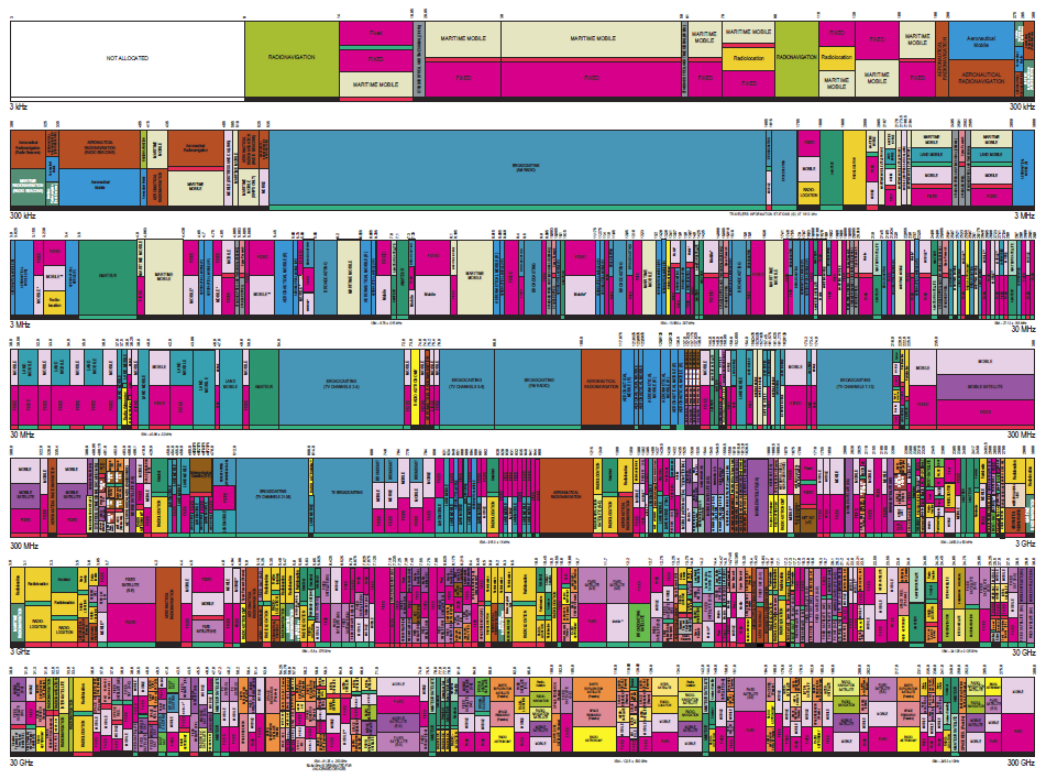
ACTIVITY CODE

- GOVERNMENT DECLASSIFIED GOVERNMENT NON-DECLASSIFIED
- NON-DEPARTMENT DECLASSIFIED NON-DEPARTMENT NON-DECLASSIFIED

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Priority	FIXED	Fixed Station
Secondary	MOBILE	Land Mobile and Other Land Mobile Services

The chart is a graphic representation of the portion of the Table of Frequency Allocations used by the Federal Government for the radio spectrum in the United States. It is not intended to be a legal document. The chart is the property of the U.S. Department of Commerce, National Telecommunications and Information Administration, Office of Spectrum Management.



As shown in the table, the 200 MHz allocations for the radio spectrum in the United States are not intended to be a legal document.

Basic Questions

- How to better use available spectrum?
 - Bluetooth uses Frequency Hopping over 80 channels
 - Wi-Fi splits into 2 to 5 channels (depending on country)
- How to optimally use the assigned channels?
 - FDM, TDM, CDM, SDM within channel
 - Frequency-Division Multiplexing further splits channel
 - Time-Division Multiplexing assigns valid time intervals to connections
 - Code-Division Multiplexing assigns chipping sequences
 - Space-Division Multiplexing uses directional waves to bypass others

Channel Usage

- Statistical usage rates
 - Historically, a particular connection is only active 10% of the time
 - Not true in modern networks, but still less than 100% utilization
- Priority usage, QoS
 - Some users and data in a particular frequency range are more important
 - Real time data vs delayed
 - In-order delivery (video?) vs reliable accuracy (file transfer?)

Change the Way

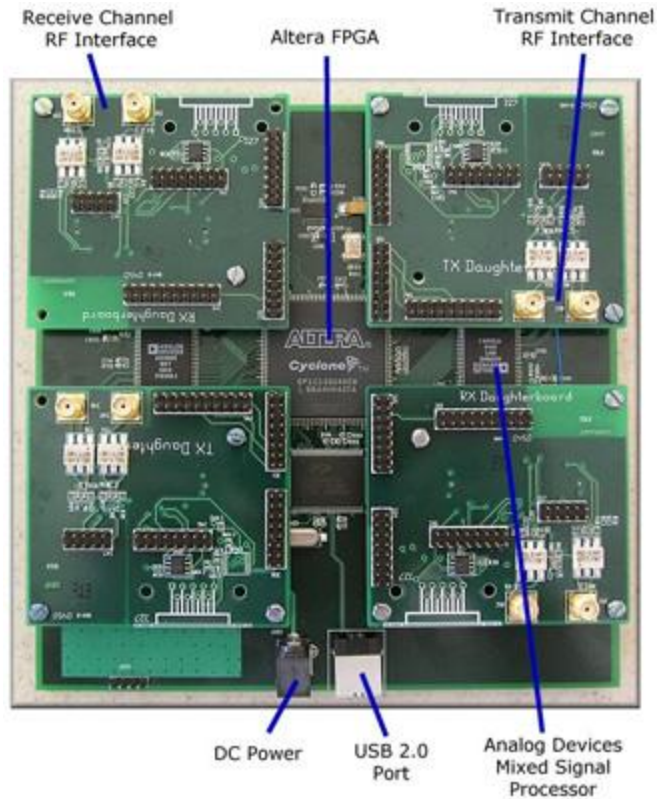
- Allow software to control network connections
 - (Instead of strict hardware, designed for singular device speed)
 - Slower individual speed, better network throughput
- SAN: Software Adaptable Network
- SDR: Software Defined Radio
- GNU Radio
 - Open source software radio package
- USRP: Universal Software Radio Peripheral
 - Hardware designed to use GNU Radio
 - Ettus research labs <http://www.ettus.com>

Cognitive Radio vs Cognitive Networks

- Radio concentrates on single-link range adaptation
 - Primary / Secondary user scheme
 - Sense patterns and usage rates in available channels
 - Secondary users transmit only on channels not used by Primary users and/or in same channels when Primary are idle
 - Tune: Frequency, Power, Modulation, etc...
 - SDR is a Radio-level concept
- Network level communicates a larger topology
 - Both wired and wireless
 - Network flow max, rather than local usage max
 - Top-level users and data, rather than just primary user(s)
 - Optimize and use Machine Learning across multiple OSI layers

Cognitive Radio

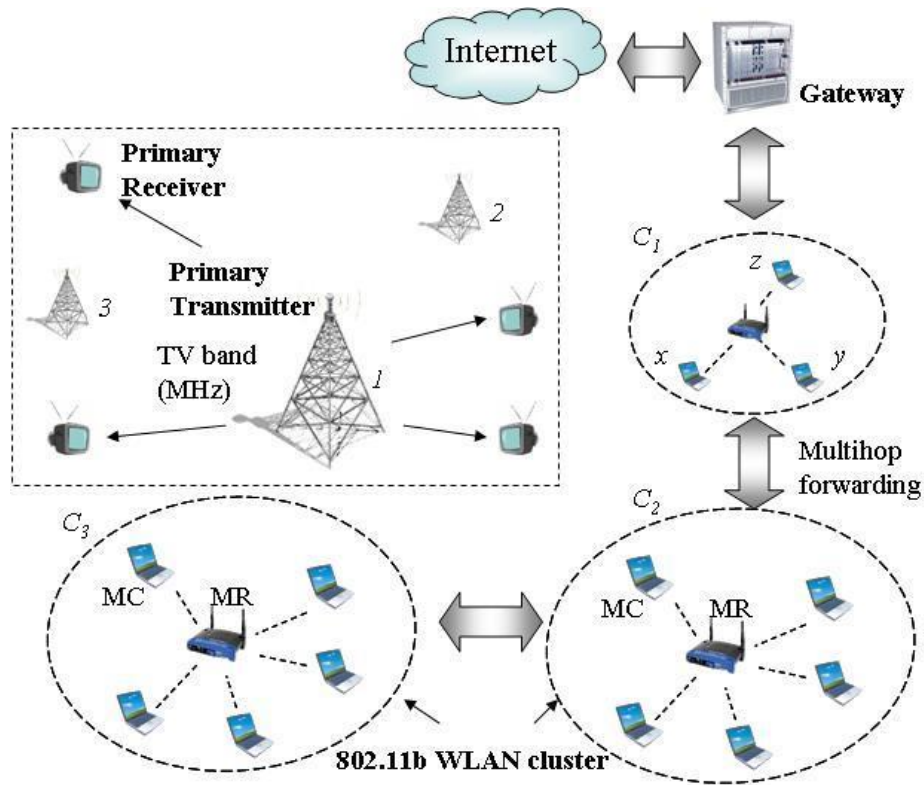
- Spectrum sensing
 - If a given channel or set of channels in use, use another one
 - Requires 2 devices to either:
 - Switch in same pattern at same time
 - Communicate from sensing device to other
 - One device able to listen / receive on multiple channels
 - Bluetooth does this automatically on an 80 channel band
 - SDR can define more channels of varying widths
- Channel sensing and prediction
 - Monitor a specific channel for general or primary user use
 - Predict lulls in activity, and use



<http://www.ettus.com> (Ettus USRP)

Cognitive Networks

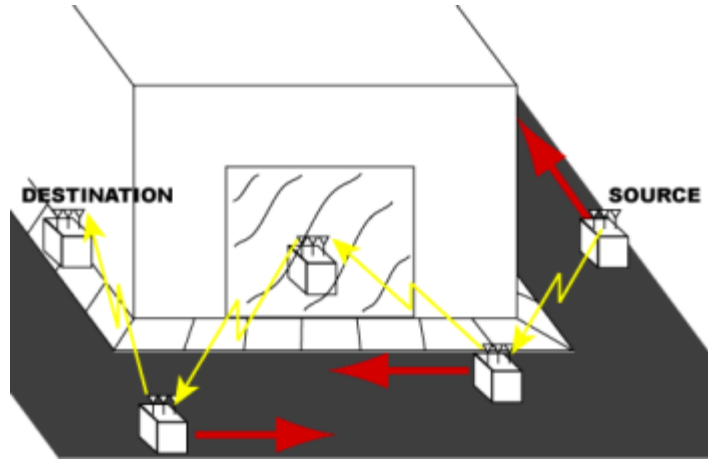
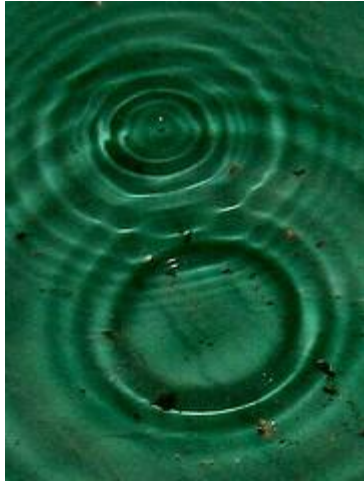
- Natural progression of flow requirements
 - Quality of Service
 - End-to-End
 - Reliable delivery
 - In-Order delivery
 - Best-Effort
- Maximize flow over end-to-end nodes on OSI Mac/Phy through Application
- Slow... multi-node graph processing
- Dynamic: QoS of Users and Applications change flow priorities



Cognitive Mesh (Chowdhury, GA Tech ECE)

Intelligent Adaptation

- Hidden terminals, multi-path, etc.
 - Detect, predict, and share information with neighboring nodes
 - Alter own broadcast patterns, even when no problem exists immediately
- Multiple primary users, hidden primary users
 - Attempt to guarantee priority data, at cost of secondary data
- Enact a virtual data structure across multiple OSI levels to model learned information (SDR, SAN)
- Machine Learning
 - With or Without neighbors participating, or blind primary users, use principles of Machine Learning to alter SDR/SAN.
 - Genetic Algorithms



Wave Interference :: Obstructed Path

Genetic Algorithms in Cognitive Radio

- Chromosomes defined over all available SDR aspects
- Target / Goal state / Fitness function optimizes:
 - maximum data flow, within the Constraints of Primary / Top-level users and applications
 - minimum spectral occupancy for other devices to use
- Small changes (mutations) and combinations (crossovers) in [Power / Frequency / Shape / Symbol Rate / Modulation] test against Fitness function.
- Optimize over multiple generations of testing

Table 7. Simulation Test Results

Radio Parameter	Weights			
	Minimize spectral occupancy	Maximize throughput	Interference avoidance	
	(a)	(b)	(c)	(d)
Power (dBm)	18	28	29	23
Frequency (MHz)	2440	2430	2436	2436
Symbol Rate (Mps)	1	18	3	8
PSF roll-off	0.05	0.33	0.04	0.04
PSF order	46	20	18	13
Modulation, type	PSK	QAM	PSK	QAM
Modulation, M	2	16	4	8
BER	0	0	0	0.12
Data Rate (Mbps)	1	72	6	24

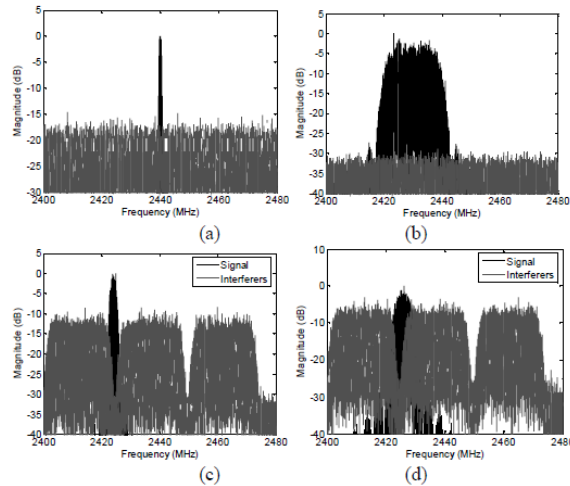


Fig. 3. Spectrum Plots for scenarios of Table 6.

Table 6. Simulation Test Conditions

Functions	Weights		
	Minimize spectral occupancy	Maximize throughput	Interference avoidance
BER	255	100	200
BW	255	10	255
Spectral Efficiency	100	200	200
Power	225	10	200
Data Rate	100	255	100
Interference	0	0	255

Table 1. WSGA Genetic Parameters

Parameter	Value
Crossover Rate	90 %
Mutation Rate	5 %
Population Size	30
Replacement Size	20
Max Generations	50

GRC - Editing: /home/jblum/proj/gnuradio/grc/examples/usrp/usrp_wbfn_receive.grc*

File Edit Build Options Help

dial_tone x usrp_wbfn_receive* x

Options

ID: top_block
 Title: USRP WBFM Receive
 Author: Example
 Description: WBFM Receive with Basic RX o...
 Window Size: 1280, 1024
 Generate Options: WX GUI

Variable
 ID: decim
 Value: 200

Variable Slider
 ID: volume
 Label: Volume
 Default Value: 1
 Minimum: 0
 Maximum: 10
 Num Steps: 100
 Slider Type: Horizontal
 Grid Position: 1, 1, 1, 2

Variable Slider
 ID: freq
 Label: Frequency
 Default Value: 100
 Minimum: 87.5
 Maximum: 108
 Num Steps: 1000
 Slider Type: Horizontal
 Grid Position: 0, 0, 1, 2

```

graph LR
    USRP[USRP Source] -- out --> WBFM[WBFM Receive]
    WBFM -- out --> Mult[Multiply Const]
    Mult -- out --> Audio[Audio Sink]
    FFT[FFT Sink]
  
```

USRP Source
 Unit Number: 0
 Subdev Spec: Auto
 Frequency: 100000000
 Decimation: 200
 Gain: 20
 Mux: 0x0
 Auto T/R: Ignore
 RX Antenna: Ignore

WBFM Receive
 Quadrature Rate: 320000
 Audio Decimation: 10

FFT Sink
 Title: FFT Plot
 Sample Rate: 320000
 Baseband Freq: 0
 Y per Div: 10
 Y Divs: 8
 Reference Level: 50
 FFT Size: 512
 Refresh Rate: 15
 Average Alpha: 0
 Average: No
 Peak Hold: No
 Grid Position: 2, 0, 2, 4

Multiply Const
 Constant: 1

Audio Sink
 Sample Rate: 32KHz
 Device Name:
 OK to Block: Yes

Blocks

- [Sources]
- [Sinks]
- [Graphical Sinks]
- [Operators]
- [Type Conversions]
- [Stream Conversions]
- [Misc Conversions]
- [Synchronizers]
- [Level Controls]
- [Filters]
- ▾ [Modulators]
 - VCO
 - Frequency Mod
 - Phase Mod
 - Quadrature Demod
 - CPFSK
 - Differential Phasor
 - Constellation Decoder
 - Differential Encoder
 - Differential Decoder
 - WBFM Transmit
 - WBFM Receive**
 - WBFM Receive PLL
 - NBFM Transmit

+ Add

Showing: ~/home/jblum/proj/gnuradio/grc/examples/usrp/usrp_wbfn_receive.grc*

Showing: ~/home/jblum/proj/gnuradio/grc/examples/usrp/usrp_two_tone_loopback.grc*

Showing: ~/home/jblum/proj/gnuradio/grc/examples/usrp/usrp_wbfn_receive.grc*

GRC example from <http://www.ioshknows.com>