Application Note
Receiving HF Signals with a USRP Device
Ettus Research

## Introduction

The electromagnetic (EM) spectrum between 3 and 30 MHz is commonly referred to as the HF band. Due to the propagation characteristics of signals in this band, HF is often used for long range, over-the-horizon communication. The Ettus Research USRP™ (Universal Software Radio Peripheral) is an ideal candidate for experimentation with HF communications, as it can directly sample the entire HF band. The USRP software defined radio is also supported by several software frameworks, including LabVIEW™, GNU Radio, Simulink™ and others. Using the USRP hardware and available software, it is possible to experiment in several different application areas, including:

- Reception of worldwide shortwave radio broadcasts
- Two-way voice and data communications in SSB, CW, RTTY and other modes
- International timing broadcasts
- Scientific purposes, including ionospheric characterization and space weather

These applications can be of interested to educators, amateur radio operators, military and many other types of users.

The following section outlines the components required to assemble a capable, flexible receiver. Future application notes will discuss the implementation of a full, two-way capable HF rig.

## The Hardware

The USRP N200 was used with a LFRX daughterboard for this application note. The USRP N200 includes a 100 MSPS, 14-bit ADC and a 400 MSPS, 16-bit DAC. It can stream up to 25 MSPS of complex baseband signals in the receive and transmit directions simultaneously.

The LFRX daughterboard utilizes two high-speed operational amplifiers to provide two differential signals from SMA connectors. These signals can be processed by the USRP radio as a passband signal, or combined to form a complex baseband signal. The operational amplifiers are configured as a low pass filter with a 30 MHz cutoff frequency. This provides up to 60 MHz of bandwidth if used in a complex baseband mode. Within the BW of the LPF's, the LFRX provides unity gain from the SMA connectors to the ADC.

The ADCs of a software radio provide a relatively high noise figure (NF) – in the order of 20-30 dB. In order to improve the overall NF of the receiver, an external low noise amplifier (LNA) was integrated. In this particular experiment, the LNA was installed at the coaxial input to the USRP. Ideally, the LNA should be connected as directly to the antenna. Fortunately, the losses in the cable are low at these frequencies.

In addition to external amplification, a variety of filters were used to improve the overall selectivity and dynamic range of the receiver. While the LFRX does provide some rejection of signals above 30 MHz, additional filtering provides additional attenuation of in-band and out-of-band interferes that are substantially stronger than the weak signals that can potentially be received in the HF band. Examples of interferes include FM and AM broadcast, television broadcast, etc. These signals are produced with hundreds of kW's of power, and are within a hundred miles of the receiver. Thus, they are significantly stronger than the weak HF signals we're attempting to receive, which arrive from thousands of miles away.

Table 1 shows the filters used in this apparatus and the frequencies they pass. The DC-32 MHz filter was used to provide the most flexibility, but allows strong in-band interferes to pass leading to reduce dynamic range in the receiver. The best results were achieved with the SBP-30+ filter – 27, which provides access to several signals of interest, including the amateur 10 Meter band. The cascaded NF of the cabling, BPF, LNA and USRP hardware is approximately 14 dB. HF atmospheric noise is significantly higher than the natural, thermal noise floor, so a very low noise figure is generally not useful.

| Filter | Passband Frequency |
|---|---|
| SLP-30+ | **DC-32 MHz** |
| SLP-30+ | **27-33 MHz** |
| SBP-21.4+ | **19.2-23.6 MHz** |

*Table 1- Tested Filters*

A photo of the one of the filters and LNA used in this setup can be seen in Figure 1.

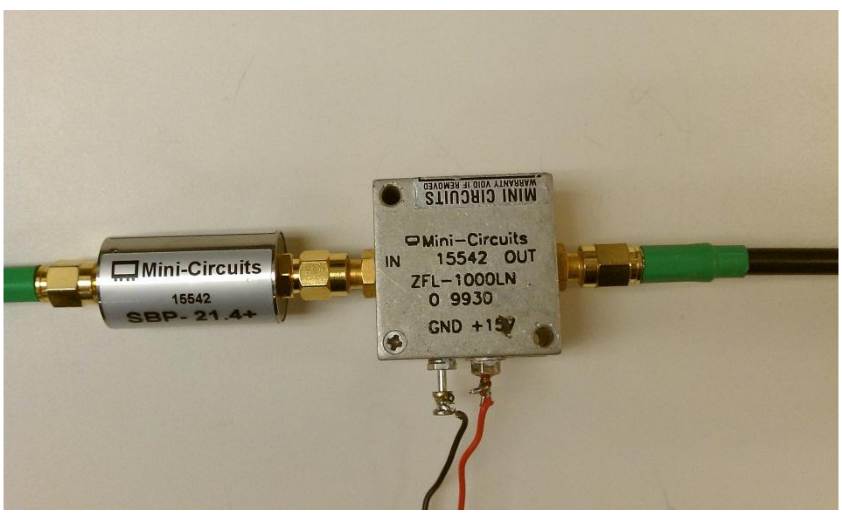


*Figure 1- HF BPF and Combined with Wideband LNA*

In order to experiment easily and quickly, an antenna present on the Ettus Research lab roof was used for this testing. This is a discone antenna intended for operation between 50 MHz and 1 GHz. Although the antenna was not optimized for HF reception, it is still more than capable of receiving interesting signals.

## The Software

In order to demonstrate the flexibility, and low time investment required to experiment with a variety of transmission modes, GNU Radio software was utilized to perform the digital signal processing necessary to receive, demodulated and display the signals of interest. A modified version of the SSB receiver designed by *OZ9AEC, Alexander Csete,* was used for this experiment, further proving that USRP radio operators can benefit from the open source environment. Csete's GNU Radio Companion (GRC) flowgraph was modified to use the UHD (USRP Hardware Driver) source, providing the greatest flexibility for use with all USRP models.

The final flow graph, which can be downloaded from the Ettus Research website, can be seen in Figure 2. Due to screen size resolutions, some graphical components of the flowgraph are cutoff, but the primary DSP blocks are all visible.

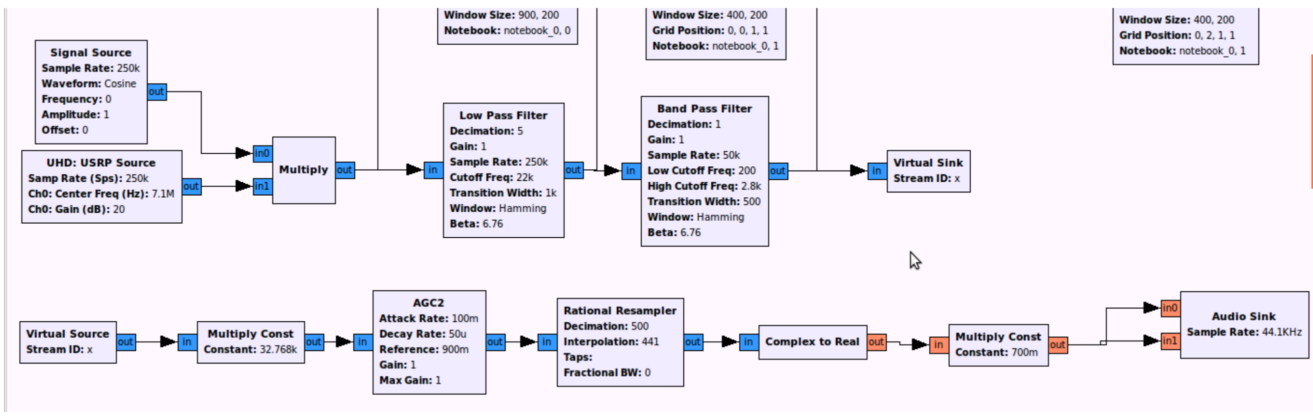


*Figure 2-Simple GRC Flowgraph - This was used to implement a very capable HF receiver. Due to screen resolution limitations, some processing blocks are clipped, but the most important blocks are shown.*

## The Experiment

As mentioned, the HF band provides access to a wide variety of signals from around the world. The signals received during this experiment included amateur radio operators, shortwave broadcasts from the UK and South America, and beacons that are to test the propagation within the HF band at several different frequencies. Screenshots of the receiver application implemented in Figure 2 can be seen in Figure 3 and Figure 4. Figure 3 shows the reception of upper-sideband (USB) voice transmissions. Figure 4 shows reception of a CW broadcast from the W6WX beacon. The symbols (dots and dashes) are clearly seen in the waterfall plot. A map showing the several locations of receive transmissions is displayed below.

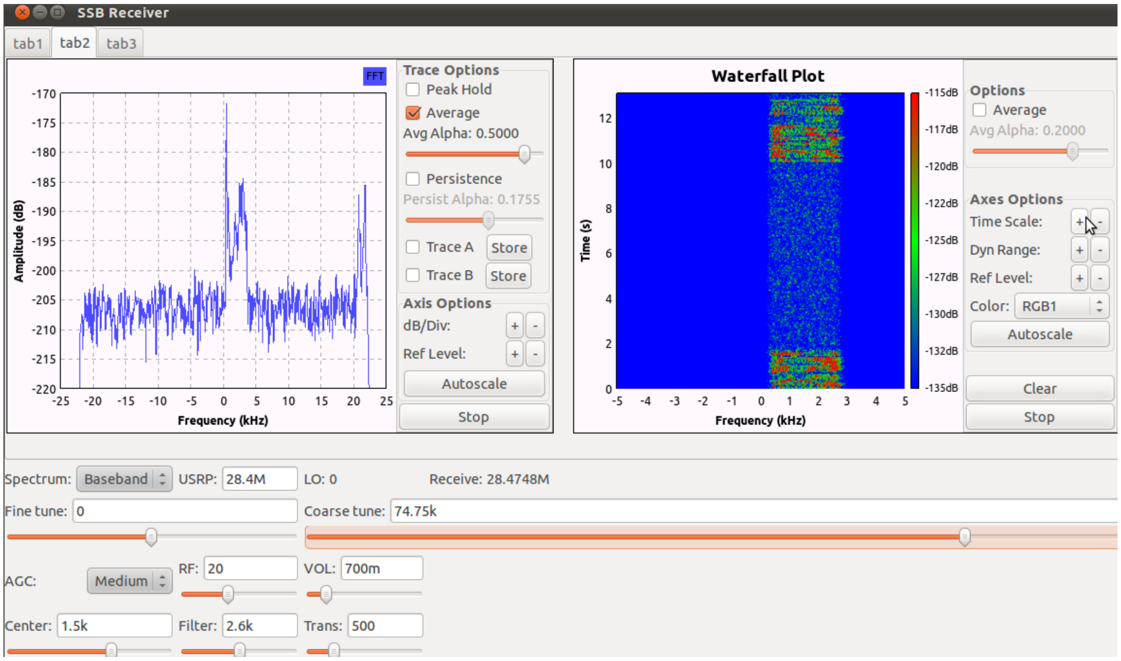


*Figure 3-50 kHz of FFT and Waterfall with USB Filter Applied. This shows speech/audio with waterfall FFT. USB applied at 1.5 kHz and ~2.6 kHz BW. Strong CW carrier shown in FFT (left) is easily rejected by software defined filter with steep rolloff.*

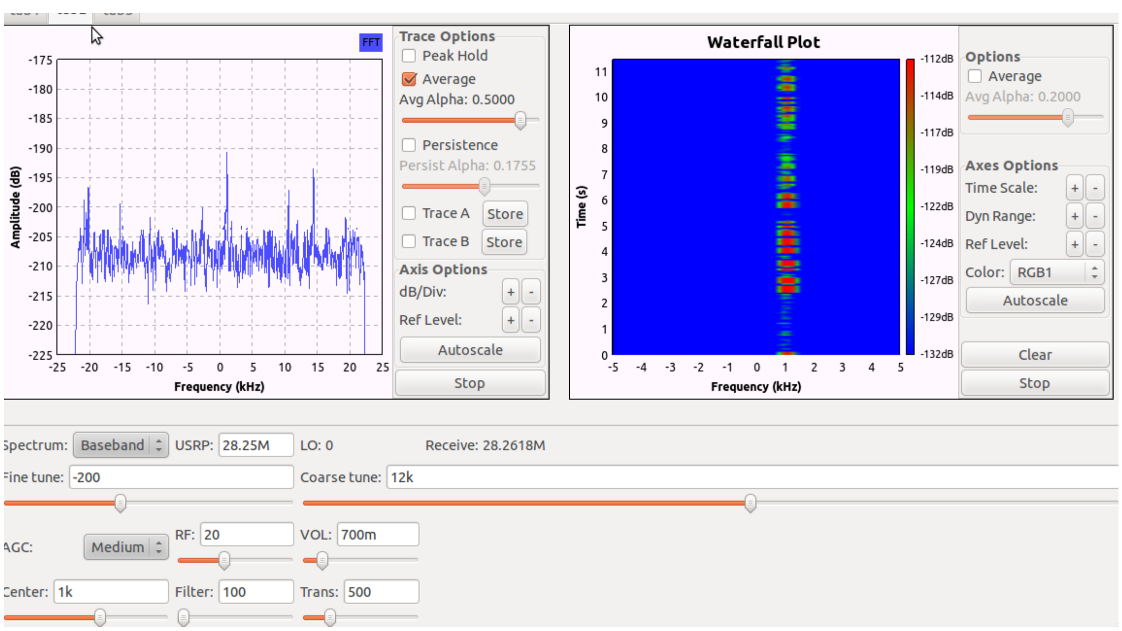


*Figure 4- GNU Radio application showing CW Reception with 1 kHz Offset. Waterfall FFT bin count was lowered to "widen" the appearance of the CW signal for better visibility of the narrow CW tone. Dots and dashes can be seen across time domain of the Waterfall FFT.*

It is interesting to note that signals were received from up to 2347 miles away, even with the non-ideal antenna used for this experiment. Substantially better performance is expected when an HF antenna is matched to this apparatus. A map showing some of the stations received can be seen in Figure 5. Figure 6 shows the high level of traffic in the 10 Meter band, which provides many signals of interest when the band is "open." This is in a one 250 kHz slice of spectrum. There are many more signals received and within the BW of the USRP radio not shown in the USRP. The USRP hardware is capable of digitizing and passing 25 MHz of the HF band to the host PC.

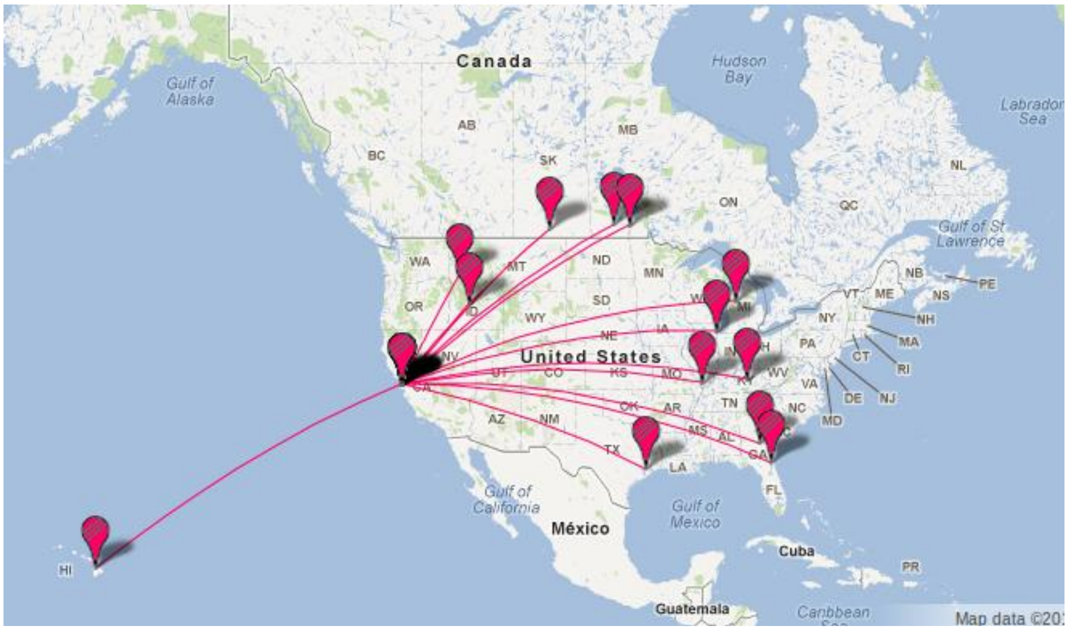


*Figure 5 - Map showing some of the received station locations from first HF experiment.*

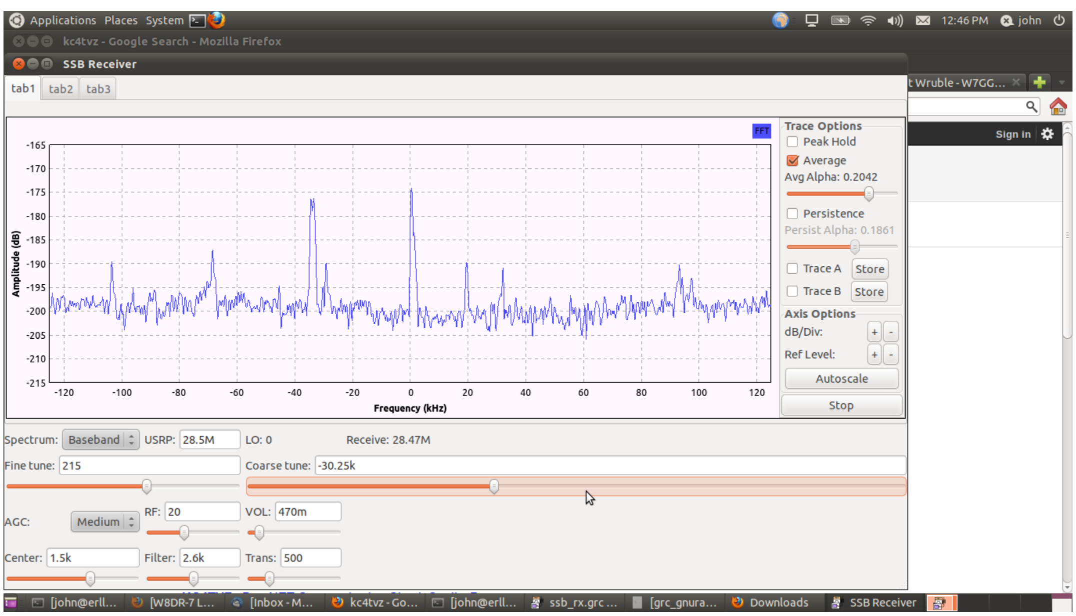


*Figure 6 - 250 kHz FFT Screenshot with a wider BW view showing several signals of interest in a 250 kHz. There are many more outside the BW of this FFT. When at 10 Meter, this high level of activity provides many opportunities to receive various stations.*

The best results were achieved with the filter, which provides access to the amateur 10 Meter band. The 10 Meter band is also of substantial interest in this particular application because it allows Technician and Novice Class operators to access HF. All other HF bands require a general or extra class license. This is also at the upper end of the HF frequency range, thus providing lower wavelength and smaller antennas for mobile operation.

**Downloadable Flowgraph and Bill of Materials**

If you would like to build this receiver, a bill of materials showing the respective manufacturer is shown below.

| Item | Part Number | Manufacturer |
|---|---|---|
| Software Radio | UN200-KIT | Ettus Research |
| RF Front End | LFRX | Ettus Research |
| Band Select Filter | SPB-30+* | Mini-Circuits |
| Low Noise Amplifier | ZFL-1000LN | Mini-Circuits |
| Antenna | Antenna** | |

*Table 2 - HF Receiver Bill of Materials*

**SPB-30+ BPF recommended for 10 Meter operation.*

***Recommend using antenna tuned for band of operation*

It is important to note the addition of an HF amplifier, an antenna switch and simple software updates convert this to a two-way communications radio. The GRC file for this flowgraph can be found at:

http://files.ettus.com/app_notes/hf_rx/ssb_rx.grc

**Other Considerations and Options for Users**

While the USRP N200 was used for this development, UHD provides the flexibility of using any other USRP model, including the USRP B100, USRP E100/E110 embedded model or the USRP1 radios. The USRP1 and USRP B100 are ideal for users looking for a lower cost solution, while the E100/E110 is interesting for users wanting an embedded or standalone configuration. It is possible to use the E100/E110 as a full-feature PC with keyboard, monitors and audio in/out.

Also, the filters and amplifiers were selected based on availability with the Ettus Research labs. It is possible to find filters and amplifiers optimized for a particular band with the HF range. Mini-Circuits is a good general source for these components.

As mentioned, this setup would benefit from an antenna designed for HF operation. However, the reception performance and range of the contacts received is still noteworthy. Users can purchase an antenna, build one or use one that is readily available.

## Conclusion

This application note showed a simple HF receiver built with the Ettus Research USRP software defined radio and a few external components.  A GRC flowgraph was developed to demodulate signals of various types, including SSB, CW and AM.  Signals were receive from respectable distances exceeded 2000 miles.  If you have any questions on this application note, please send them to support@ettus.com.