Ascent Ground and Satellite Demonstration

By Ray Roberge (WA1CYB) & Howie DeFelice (AB2S)

Amateur radio operators have not had a high earth orbit (HEO) satellite since the untimely loss of AO-40 in 2004. Allot has changed in the satellite industry since then. It took a multi-national team six years to design and build AO-40 at a cost of several million dollars. It weighed in at 632 Kg, was about 2 meters across and could generate up to 600 Watts of solar power. In the current environment, the most likely affordable launches will be 3U CubeSat's that are about 30 cm across at the longest dimension, have a mass of about 9 Kg and might be able to generate 50Watts of solar power on a good day. Add to this the government mandated restrictions that all but eliminate international cooperation and the picture looks pretty bleak. AMSAT needed a way to take all these lemons and mix up a big batch of lemonade. This is one of the reasons AMSAT formed the ASCENT team, Advanced Satellite Communications and Exploration of New Technology.

The ultimate goal is to place more capable satellites into higher orbits that give more users more access for longer periods of time. This objective requires multiple disciplines working on many fronts to uncover and capitalize on not only new technology but new launch opportunities and new strategic partnerships with industry and academia as well.

One of the first technologies the team turned to was software defined radio and digital modulation. As with most new things, this was more evolutionary than revolutionary. ArrisSat already used software defined radio techniques in its transponder and much of this technology was used and improved in the Fox series of satellites. To get to a true multi-user transponder that can accommodate hundreds of users within a very small footprint with limited power requires a big step up in complexity in terms of digital signal processing capabilities and spacecraft support systems like power generation, attitude control and propulsion. Fortunately, we don't need to make this giant leap in one step. This paper/demo proposes the first step with a new type of programmable transponder that supports multiple linear and non-linear (FM) conversations simultaneously in a single transponder. Each input frequency 'slice' will have a constant power weighting feeding the downlink transmitter. The downlink will be in X band (10.45 GHz.). The demonstration ground terminal will be low cost and incorporate real time Doppler compensation.

Be Flexible:

2 months ago our main goal was to support Ragnarok Industries for its Heimdallr Mission (6U traveling past the moon and returning to orbit the moon). We were not selected for the final 3 slots available. A suggestion was made to put a package on a 3U with a thruster to increase its orbit. We would provide the "science" ala radio based. This demonstration hardware is a concept of what we could do. This paper is written in bullet form since it is a concept demonstration and more words seemed like a waste of time.

Current Focus Goals:

- C-Band Uplink, X-Band Downlink (five and dime)
- Provide Frequency/Time Locking Capability for the Ground Station
- Utilize SDR technology to maximize flexibility to Experiment and Modify Operation
- Optimize Satellite architecture to minimize Ground Station costs

- Provide Output maximum Power Weighting for the downlink to prevent satellite capture
- UHF/VHF/L-Band/S-Band/HF optional Uplinks
- Provide a Digital Downlink of Satellite Data
- Provide a Digital Downlink of ID, Time stamp, Location (ala GPS/Grid Square) and uploaded TLE
- Provide for a DVB-S2 Input & Output when available
- Build in Redundant paths where feasible
- Provide multiple Digital Downlink paths
- Provide multiple Voice Downlink paths with different modulation types
- Provide a Multi-channel In- Single Channel out for contact Initiation and/or emergency channel
- Provide a controlled Ham Band Scanner Survey Downlink Capability

Approach:

- Build and Demonstrate an example Ground and Satellite system that gives the user a sense of what a modern satellite system might look and feel like
- Concentrate on the system, not the implementation
- Incorporate the latest technology that is available and cost effective
- Use hardware and software that is identical or mimics planned future systems
- Make the communication architecture programmable to facilitate experimentation and optimization
- Use COTS SDR(s) likely to be used to facilitate early launch opportunities

The System:

- One Laptop operating as the Satellite Processor and Display. Connected to 2 SDR receiver channels and 1 downlink transmit channel. See Figure 1
- One Laptop operating as the Ground Station Computer and Display. Connected to 2 SDR receiver channels and 1 uplink transmit channel. One of the receiver channels is strictly for demonstration of a local input, in place of a microphone.

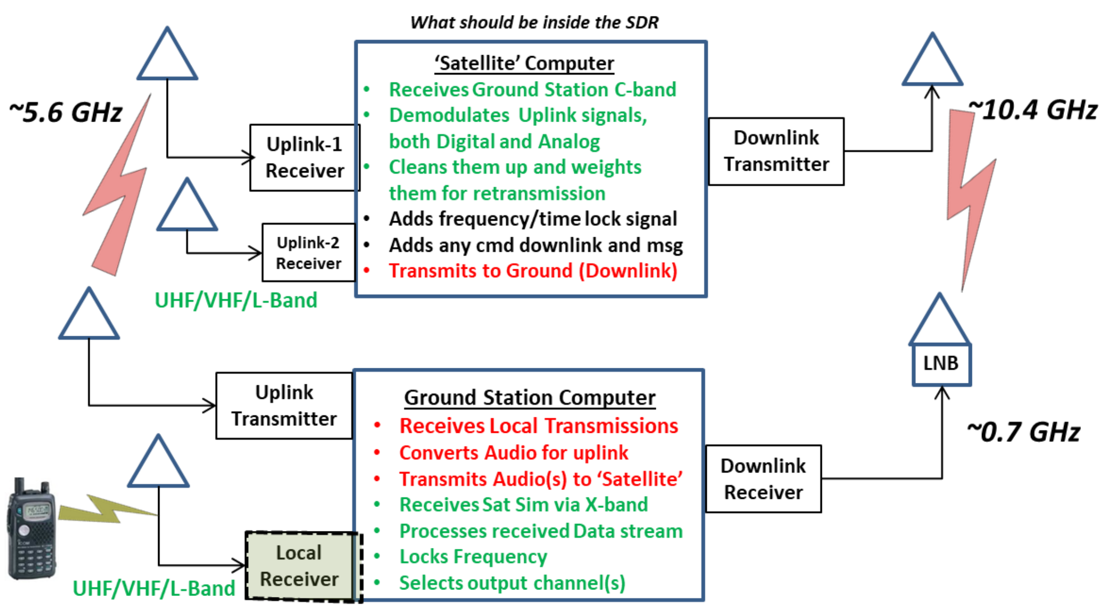


Figure 1 -Basic Communications System Functions

Satellite Communication Processing:

- Requirement is that all ground stations have locked onto the satellites beacon and all transmit uplinks will have Zero Doppler at the satellites input
- Satellite Transmits both a CW beacon and a phase modulated 1 pulse per second timing pulse
- All receivers (2 in this case) are translated to wideband baseband for channel separation
- Input frequencies are shifted and filtered according to the programmable configuration plan
- Each segment of the spectrum (channel) is handled in accordance with its intended modulation use
- All Channels have a separate filtering, AGC and squelch circuity set in accordance with its intended modulation use. (AGC timing and Squelch thresholds are different with mode)
- Channels can be either linear, regenerated or cross-modulated (ex: NBFM in, USB out)
- Channel content can be analog or digital
- **Control Ground station can upload a new channel allocation and processing**
- Figure 2 shows simplified example channel processing

GNU Radio Details:

- Outer Layer of the flow graph has a Pseudo Doppler insertion (input and output) to simulate Satellite Doppler at 3 selected altitudes generating +/-250KHz,+/-150kHz and +/-50kHz with a 10 min pass time
- Receiver sampling rate minimum is set by the maximum Doppler expected plus the bandwidth of the communication spectrum. In this case +/- 250 KHz Doppler and 256 KHz Output Spectrum, so ~2**20 (1,048,576Hz) was selected +/- depending on the SDR used
- Input receiver stream has a frequency offset to shift the IQ imbalance/DC term by ~65kHz
- nbfm Channel is split into 2 nbfm channels with less deviation for no good reason, just experimented with it, besides who doesn't want more channels!
- The base Squelch level is set by the receiver tab. Individual channel levels add or subtract from this level
- mseq_substitute_15.py is a 2**15 bit pseudo random time/ranging waveform heir block. The ground receiver cross correlates this into one PPS (like GPS). It's weighted lower in the output power spectrum since it has 40 dB of processing gain
- The channel filters are definitely not optimized, but are a 1st approximation of the desired response
- The Wideband Digital channel is a linear channel for this Demo as a place holder.
- Hieratical blocks were not used in most of the flow diagram so as to observe the system complexity, See Figure 3
- No python or C++ programming was used to show what can be done with standard GNU Radio
- The demo system has several Tabs and QT displays that would be disabled in a real system since it eats up lots of resources and no one is there to see the display!

You can download the concept demonstration system from here:
https://github.com/WA1CYB/satellite_ground_emulator/tree/master/Ascent/Concept%20Demo%20System

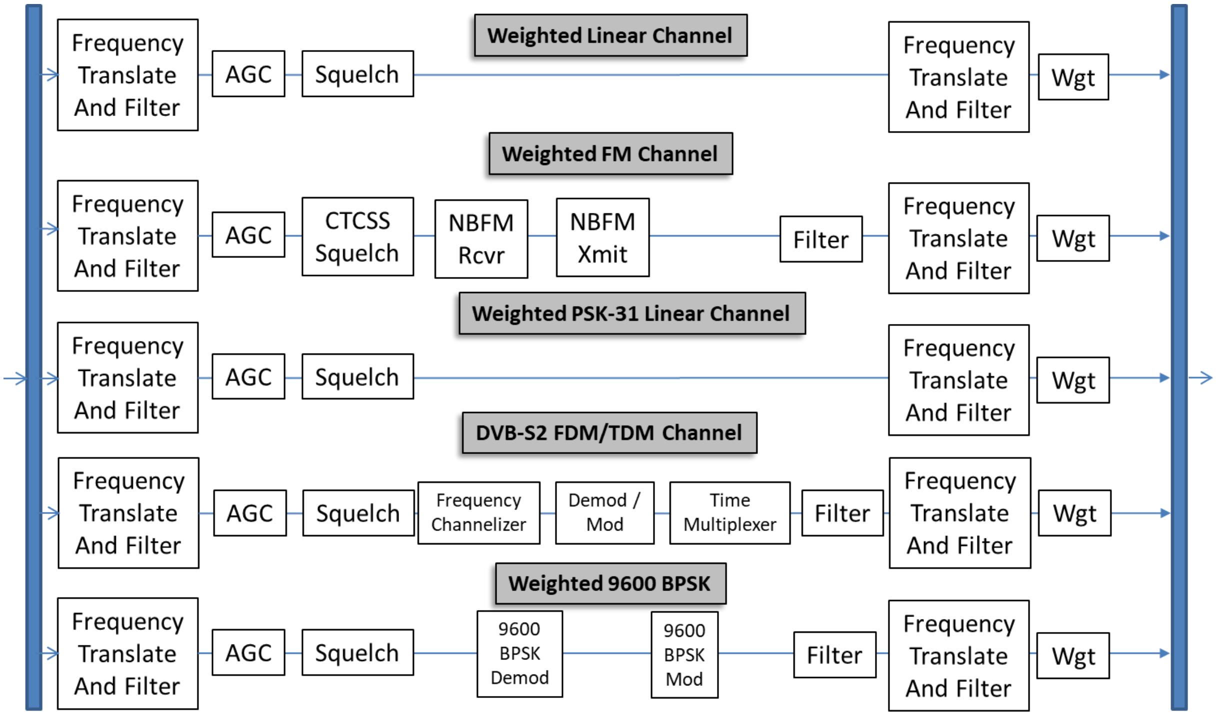


Figure 2 –Satellite Channel Processing Examples

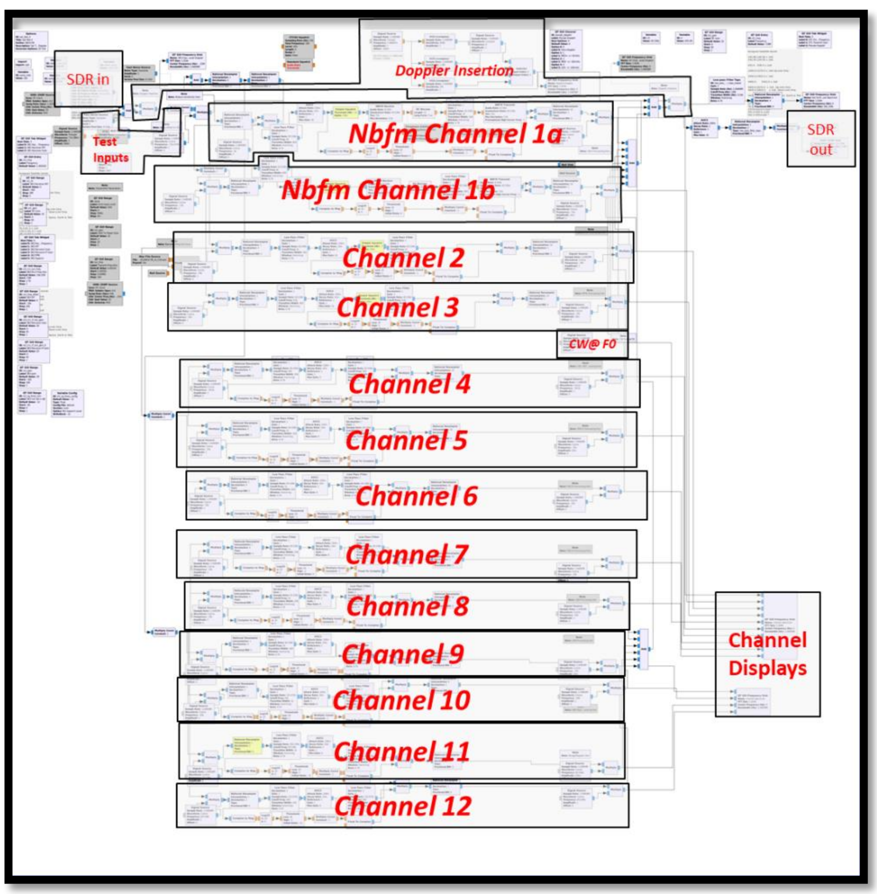


Figure 3 - Typical GNU Radio Flow Graph – Not Pretty

Why Programmable? :

- Because we can! That's the beauty of Software Defined Radios. We can launch with one band plan and set of mode possibilities and later reconfigure the satellite for new modes and band plans.
- We can refocus the satellite resources to assist in emergency situations. For instance digital messaging may be more important than voice. Or a chat with psk31 should be the highest priority and weighting to get the real time status message through with minimal ground equipment, etc.
- It enables a common satellite method that can be used and programmed differently before and after launch
- It enables experiment possibilities of cross band and cross modulation type communication
- Can have selected receive frequencies that are polled on a specific time schedule for emergency use

"Science" Experiment Possibilities:

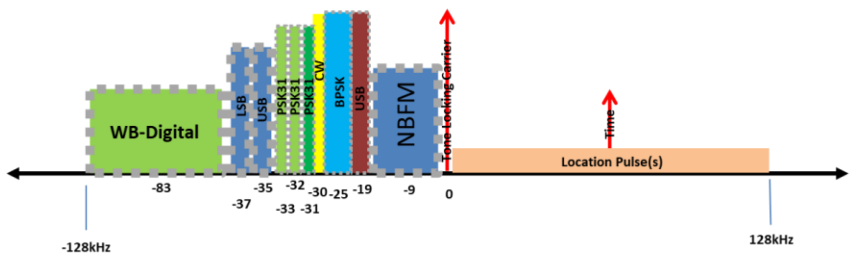
The second receiver can be tasked to do other functions while the main one continues on. The possibilities could be to conduct an Amateur Frequency Survey (multi-bands). Examine propagation via WSPR and WJT modes, upper atmosphere scattering and urban noise sources versus frequency etc. Or, multiple frequency inputs on different bands with common output band channel (Cross band input) for emergency use. Or, Shared Aperture Antenna Steering or Automatic logging of satellite users/peak signal level /vs satellite location or Very weak satellite transmitter power beacon experiments (no power amplifier, straight SDR power) or even more satellite input frequency receivers (1 chip for each 2 frequency bands) or Harmonic beacons for frequencies above x-band…… endless possibilities!

What can we build now you say? :

Everything! (Although it may not work completely just yet). We have provided the framework to simulate the satellite and ground nodes using laptops for the processor, as opposed to the built in SDR processor in some SDRs. Since the ETTUS SDR runs GNU Radio, as does the laptop, its porting should be an easier step than coding its FPGA directly. Using the FPGA makes the system faster and more reliable, so in the end, that's the direction we should go. (My opinion of course).

The demo system:

Figure 4 shows the selected Band plan to demonstrate the concept. It has a dozen functions covering a potential bandwidth of +/- 128 kHz. The satellites output power is set by the combination of the dozen functions. Some functions like NBFM have a constant peak power while others like Lower Sideband have an average power much lower than its peak so to equalize the energy used one can enhance the LSB at the expense of the NBFM. Also the narrow band PSK31 channels are assumed to be higher priority so they are given more of the output energy. Since the entire band plan is predicated on receiving the Tone Locking Carrier, it was given the most power allocation. The location and 1 PPS timing was given less peak power because of the high processing gain.



1. Tone Locking Carrier: Enables Ground Lock of Spectrum when Doppler is present
2. NBFM: Voice Channel(s) Translated from a Low Band
3. USB: Combined Multi-channel In Initiate contact and/or emergency channel down
4. BPSK: ID, Telemetry and data stream from satellite
5. CW: CW Bandwidth(s) Translated from a Low Band
6. PSK31-3: Satellite broadcast of ID, Time stamp, Location (ala GPS) and TLE
7. PSK31-2: Chat Channel #2
8. PSK31-1: Chat Channel #1
9. USB: Channel #3
10. LSB : Channel #4
11. Wide Band Digital: Channel #5
12. Location Pulse(s): Enables Precise Ranging/Location

Figure 4 – Demonstration Downlink Frequency Band Plan- Arbitrary Peak Weighting

Figure 6 shows the Satellite control program output spectrum when one satellite SDR receiver was tuned to 2 meters and the second one was tuned to an ATSC TV station calibration frequency. This screenshot was not from the current flow graph, but one developed on the way. Every 2nd frequency block allocation was attenuated so as to see the band plan. The lower right area shows how one could reallocate the blocks, weighting and frequency offsets and filter bandwidths.

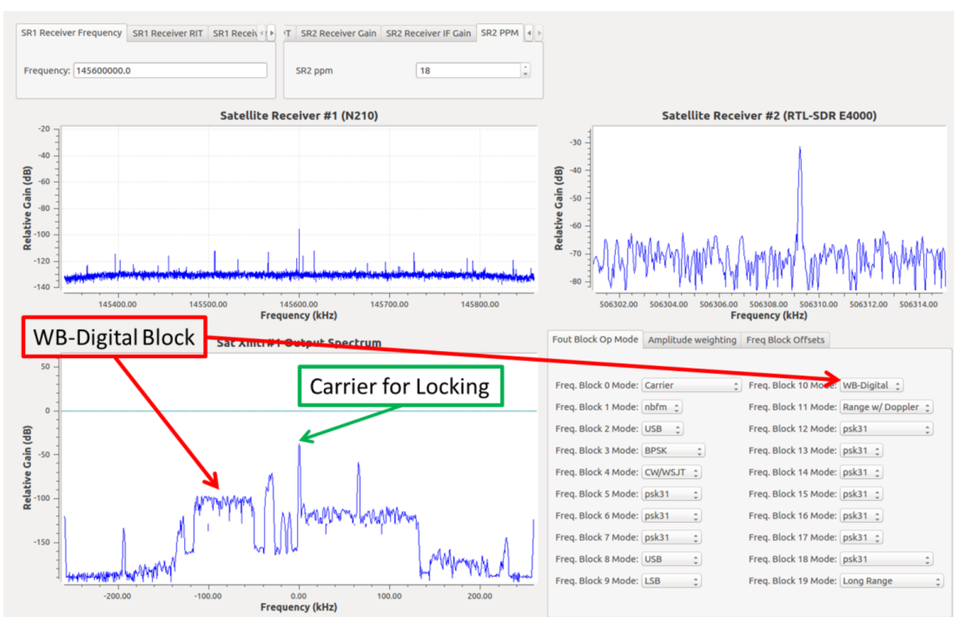


Figure 5 -2 Satellite Receivers Enabled, 1 tuned to 2 meters, the second tuned to a ATSC HD pilot tone

Some may rightly question why even put USB/LSB on the potential modulation types for the channels. Keep in mind even WSJT uses USB to gather it's data for further processing. The ground receivers SDR output can be re-directed to a virtual audio cable which in turn can be picked up by FLDIGI, WSJT-X, other programs we have or remote operation for further processing if desired.

Figure 6 shows the Satellite set up to receive in C-Band for Satellite Receiver #1 and receive in the 432MHz band for the second receiver. The output from the SDR is at C-band, which is then mixed up to X-band for transmission to the Ground Station. Figure 7 shows a test received spectrum using SDR-Console by Simon Brown.

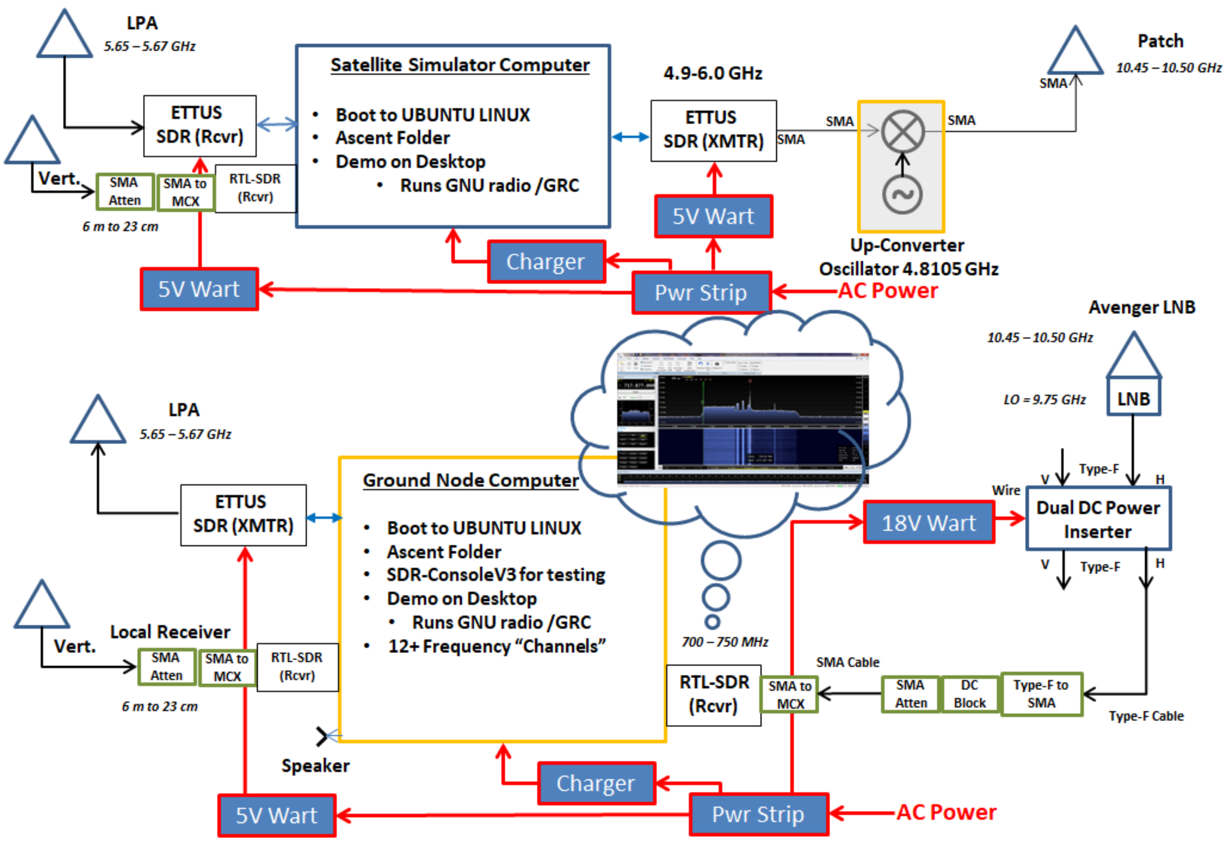


Figure 6 -C-Band and 70 cm band received uplinks with common X-Band downlink

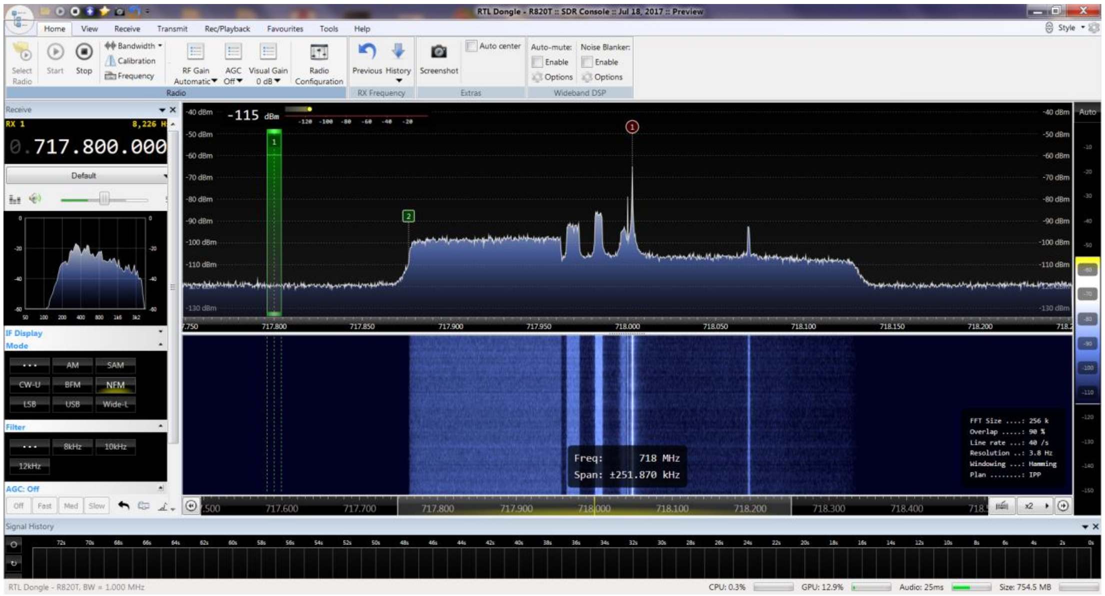


Figure 7 – Received (noise channel inputs) test spectrum- every other channel suppressed

The Ground station:

Figure 8 shows the functional diagram of the barebones demonstration Ground station. A second SDR (RTL-Dongle) was added so as to have a local input (instead of a microphone) that people could utilize locally at the symposium for a input (doesn't everybody carry a HT?). The ground station has recorded uplink messages internally generated. The received signal consists of a chat channel window and a single audio window. Not the prettiest system, but hopefully it gets the point across.

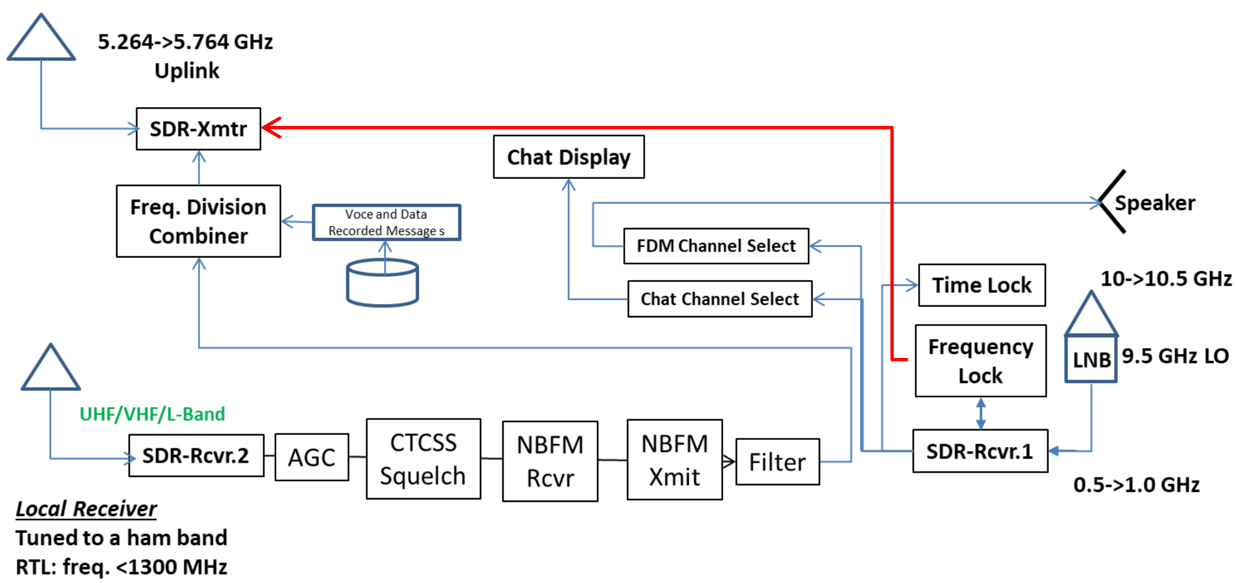


Figure 8 – Simplified Bare Bones Ground Station

Conclusion: We can build it if the opporunity arrises. Flexable programable digital signal processing allows for multiple uses and science experiments.