Frequency Calibration for SDRs - Without GPS

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Why Do I need Frequency Calibration?

- **Software Defined Radios usually have a single crystal oscillator**
  - The crystal determines its frequency and frequency step size accuracy
  - While some SDRs have accurate oscillators with low temperature drift, not all do

- **RTL-SDRs typically have large frequency errors**
  - +/- 18 parts per million (ppm) is not uncommon to see
  - At 432 MHz this gives a 7776 Hz error (18*10^-6 * 432*10^6= 7776 Hz)

- **When using SDRs to receive satellite signals, this uncertainty of frequency could slow down the acquisition of our favorite satellite**
  - This is on top of the Doppler uncertainty

- **As we go higher in operating frequency, where you Tx/Rx becomes more important**
  - 18 ppm at 10 GHz is 180 kHz

- **For 10 GHz, even with a accurate downconverter there is a lot of uncertainty**
  - On top of Doppler, setting your frequency could be a challenge

What's a HAM to do?

- **WWV is good, but not available at VHF or higher frequencies**
- **You could buy/borrow test equipment each time you wanted to measure the error !**
- **You could open up the SDR and detect the crystal frequency**
  - Using your general coverage receiver or Test equipment
    - Calibrate your receiver, then use it to measure the frequency error compared with it's markings
- **Have a friend with accurate system transmit on a known frequency while you use your SDR to measure the frequency**
  - The difference in frequency divided by the frequency is the % frequency error
  - Don't forget to do this over your typical operating temperature range (warm vs cold room)
- **Use someone else's signal to calibrate that is always available – ATSC Television!**
  - **Depending on where you live of course**

ATSC (HDTV)

- **ATSC (Advanced Television Systems Committee) sets the specifications for HDTV**
- **To exchange signals (Network to local etc.) the timing has to be standardized**
- **ATSC uses a series of tones to send it's signal in OFDM format**
  - OFDM (Orthogonal Frequency Division Multiplexing)
  - One of the tones is a pilot tone
- **The pilot tone frequency is every 6 MHz starting at the lowest channel, channel 14 at 470,309440.55944056 Hz**
  - "… the pilot frequencies of all transmitters in a network shall be maintained within **±1/2 Hz** of nominal frequency
- **The exact pilot tone frequency is now apparently only a recommendation since the FCC changed it's rules (no NTSC interference issues)**
  - Most TV stations already used an Atomic source as a reference or at least a GPS system

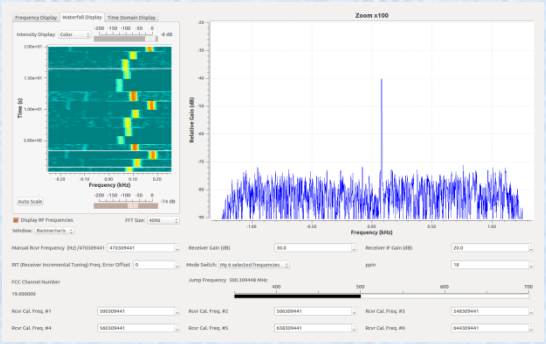
What You Could Do And What I Did

- **You could tune your SDR to channels starting at 470.30944055944056 MHz**
  - The FCC channel assignment does not line up with what your TV station call sign broadcasts
  - Look at all 40 possible frequencies to find the strong ones near you

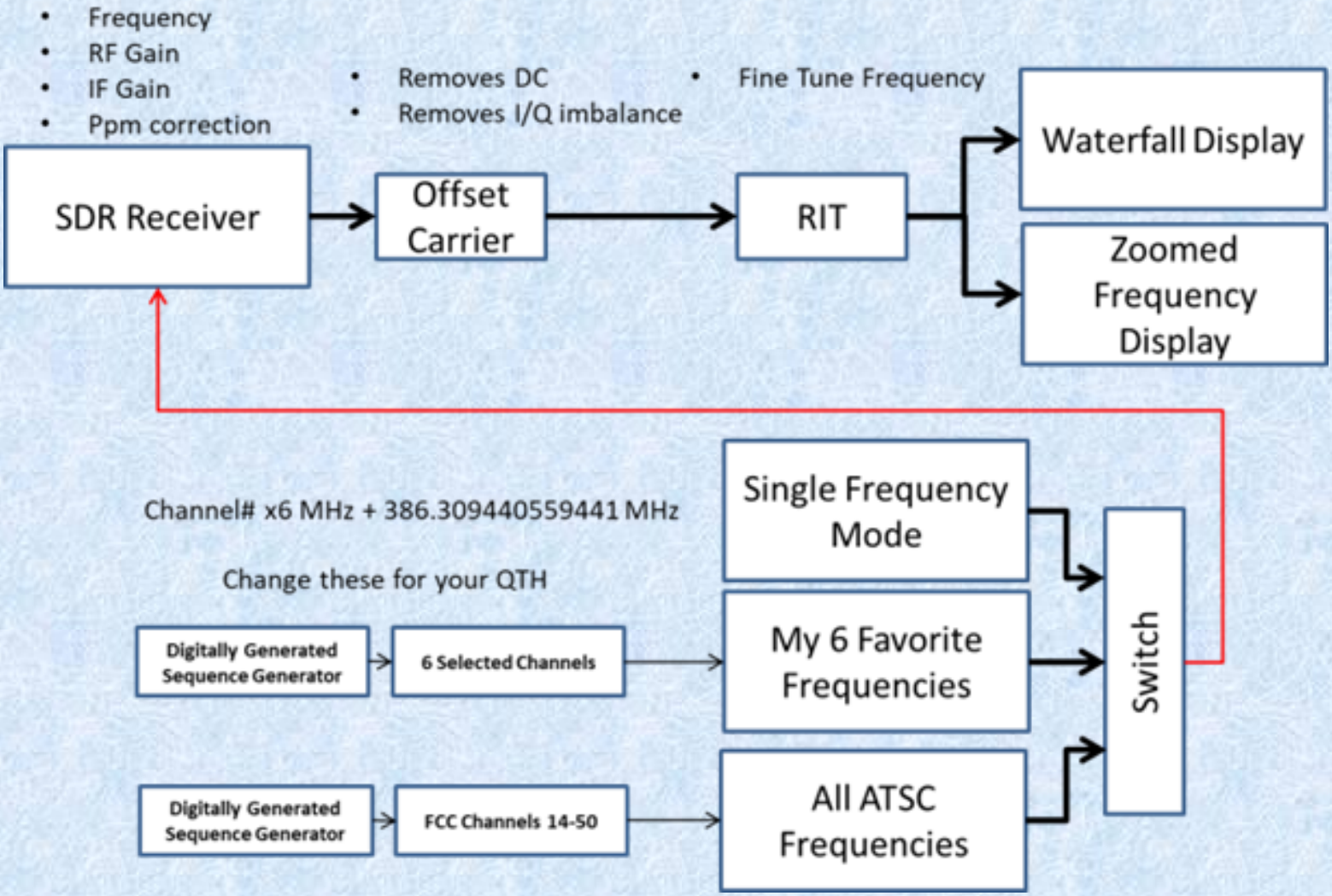
- **Using GNU Radio Companion, I wrote a program that scans all the channels**
  - It lets you pick the top 6 channels and compares the results
  - You can change the ppm setting (assuming a RTL-SDR) and see the effect
  - To get even closer, a RIT function lets you line them up better

https://github.com/WA1CYB/satellite_ground_emulator/tree/master/Ascent/Frequency%20Calibration

- **I recommend downloading the program from the link in the paper**
  - If you don't have GNU Radio, I recommend you 1st download it. Try it, you'll like it
  - GNU Radio is available for LINUX or Windows users (works best under LINUX)
  - There is a packaged version also that does not require a GNU Radio install (LINUX only)

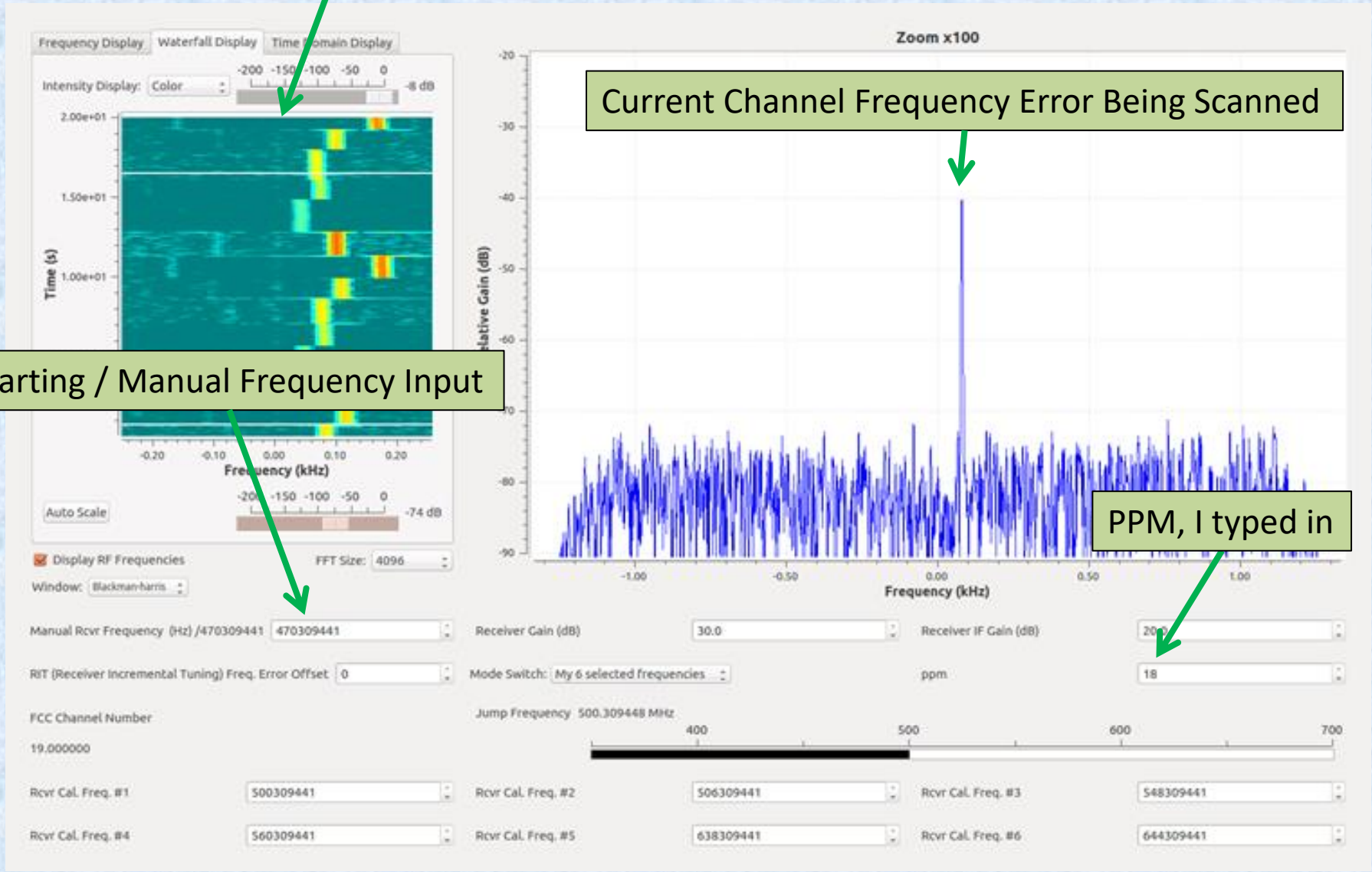


Frequency Calibration Receiver Block Diagram

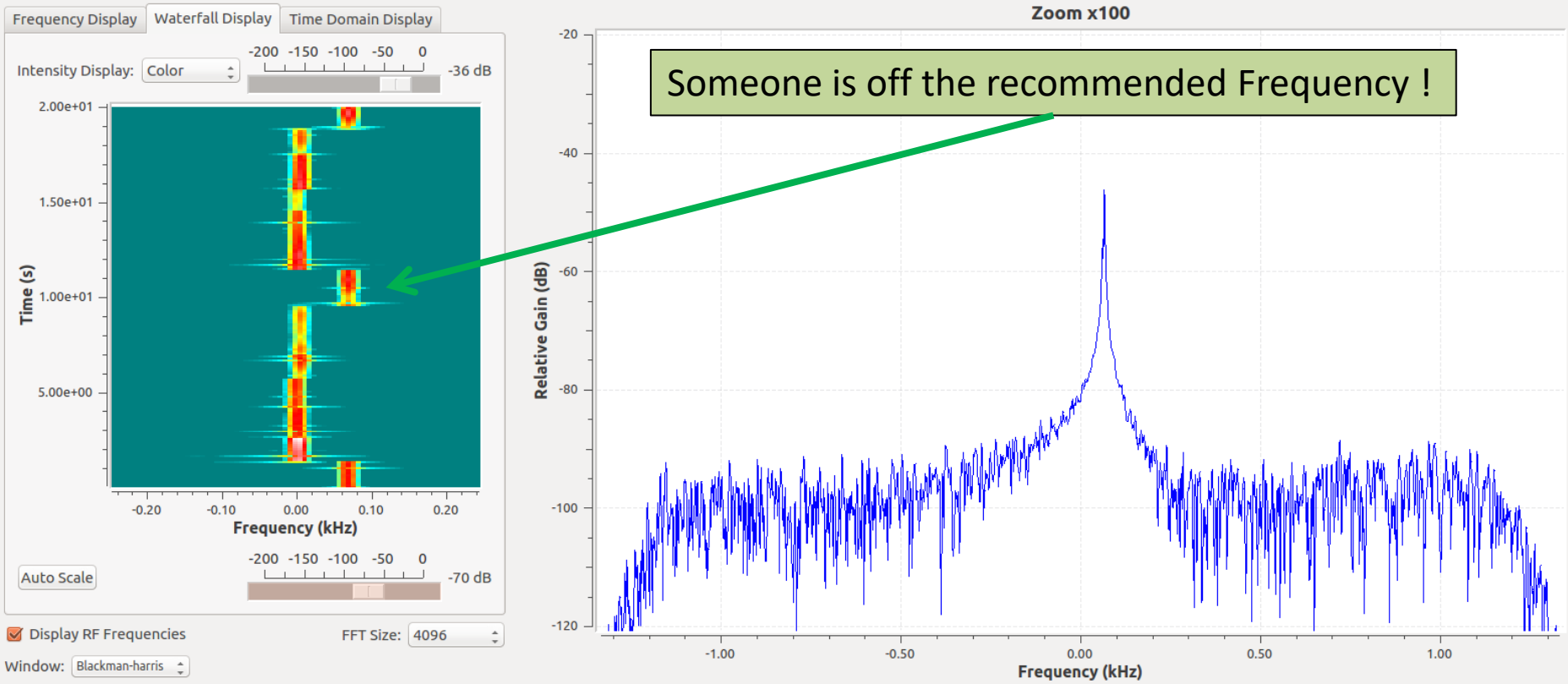


Waterfall Display of My 6 Selected Frequencies

The Result



ETTUS N-210 (un-calibrated) in 6 Selected Frequency Mode



Manual Rcvr Frequency (Hz) /470309441 470309441

Receiver Gain (dB) 30.0

Receiver IF Gain (dB) 20.0

RIT (Receiver Incremental Tuning) Freq. Error Offset 170

Mode Switch: My 6 selected frequencies

ppm 0

FCC Channel Number

42.000000

Jump Frequency 638.309448 MHz

400 500 600 700

Rcvr Cal. Freq. #1 500309441

Rcvr Cal. Freq. #2 506309441

Rcvr Cal. Freq. #3 548309441

Rcvr Cal. Freq. #4 560309441

Rcvr Cal. Freq. #5 638309441

Rcvr Cal. Freq. #6 644309441

Demonstration