Naval Information Warfare Center PACIFIC

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Low Earth Orbit Communications Channel Emulator for Small Satellites using Software Defined Radios

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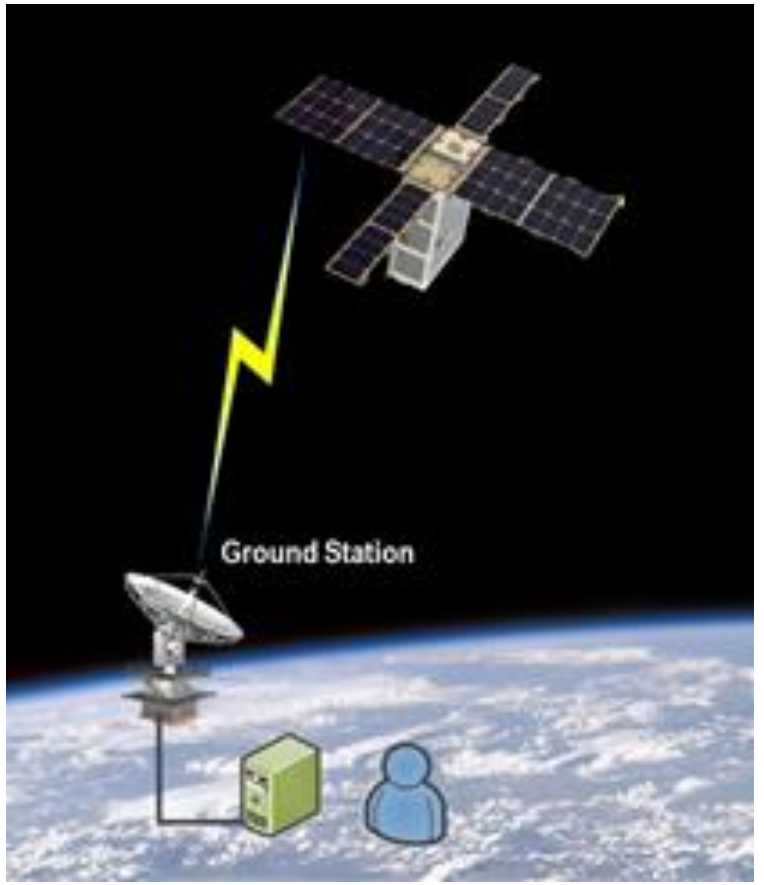
Background

- Satellite communications encounter various channel conditions that could degrade signal integrity
  - RF communications encounter channel conditions such as Doppler shift, free space loss, packet delay or signal interference
  - These artifacts, if not addressed, can potentially interrupt satellite communications to our ground station.
- Two of the main types of Channel conditions of interest at NIWC Pacific are Doppler Shift and Free Space Loss
  - Doppler Shift
  - Free Space Loss (attenuation)



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Motivation

- Our goal is to find a way to test communication subsystems before they are integrated into a satellite or before launch
  - Because “over-the-air” testing is sometimes not feasible, space teams are limited to basing results from cabled, lab-bench tests or vendor specs
- In order to test our hardware components, we would need to acquire and use an ***RF channel simulator***
  - Channel simulators simulate different channel artifacts and conditions, such as Doppler shift and free space loss (FSPL), during end-to-end testing
  - **PROBLEM?** RF channel simulators are **COSTLY!** And are not optimal for low budget satellite projects

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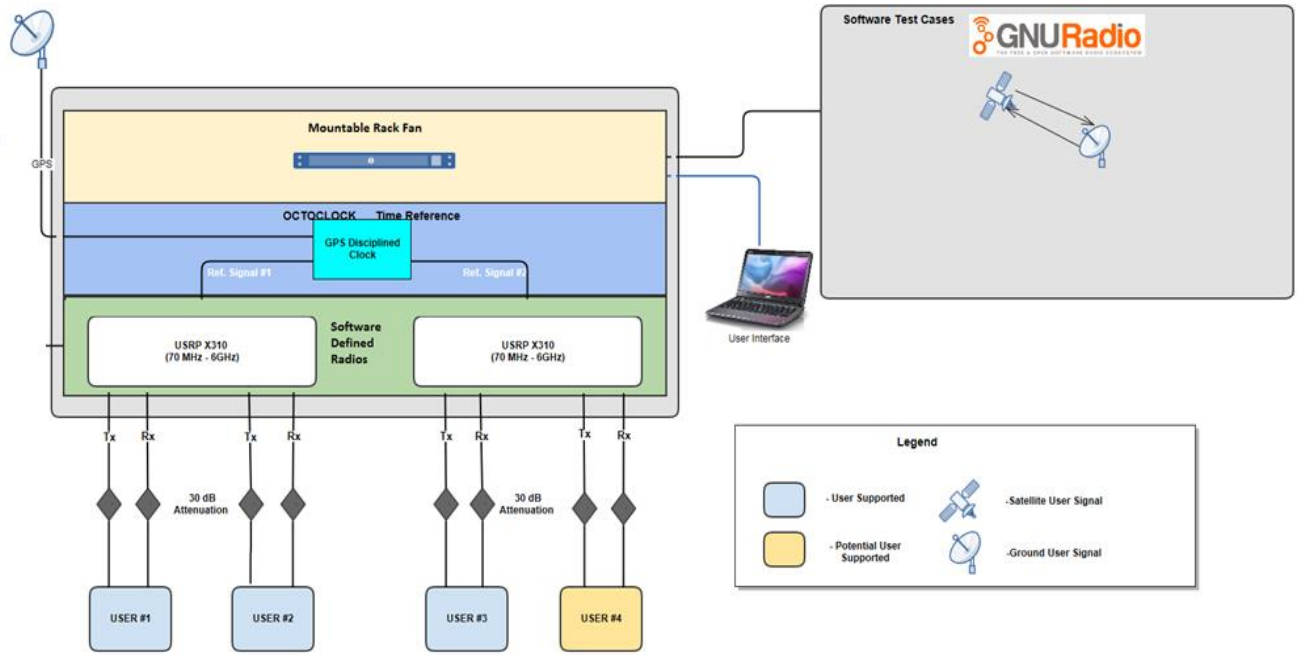
NIWC Pacific's LEO Channel Simulator

- As an alternative solution to procuring an RF channel simulator, NIWC Pacific built an RF channel simulator with COTS hardware and Open source software
  - The RF channel simulator can introduce LEO based Doppler shifts and free space loss
  - It has the capacity of providing Doppler and FSPL values for flyovers and real-time LEO orbits
- What does this alternative channel simulator consist of?
  - 2 x COTS software defined radios (SDR)
  - GNU Radio open-source software
  - Physical RF Attenuators



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Hardware: USRP Software Defined Radios

- What are USRP Software defined radios?
  - Universal Serial Radio Peripheral (USRP) radios are high performance software defined radios used to design communication systems
  - These SDR's provide the analog up/down conversion and filtering needed before signal modification occurs
- NIWC Pacific's RF Channel simulator will have two USRP X310 radios, which are higher end SDR's, however , this concept can also be done on cheaper SDR models (i.e. USRP B210)
  - Channel Bandwidth: Up to 120 MHz per channel
  - Frequency range: 70 MHz to 6GHz
  - Each SDR can support 2 full-duplex radios

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Software: GNU Radio software

What is the GNU Radio software?

- GNU Radio is a free software development toolkit that provides signal processing blocks to implement software-defined radios and signal-processing systems. It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment
- The GNU Radio infrastructure is written entirely in C++, and many of the user tools are written in Python

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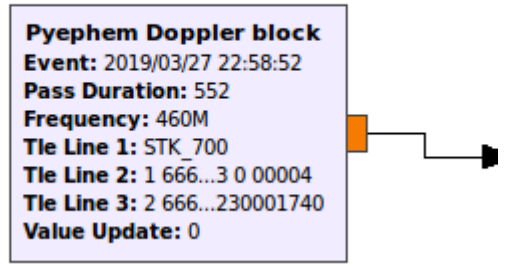
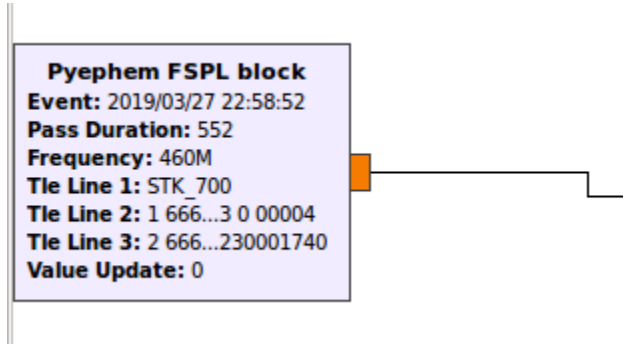
LEO Channel Simulator implementation

- This RF channel simulator used GNU Radio to implement the actual channel simulation of a LEO orbit
  - We developed two out-of-tree (OOT) modules, which are signal-processing blocks not included with GNU Radio, that will introduce
    - LEO orbit downlink and uplink Doppler shifts
    - LEO orbit Free space loss values in dB
  - Both OOT blocks were made using Python programing language and the PyEphem libraries.
  - PyEphem provides basic astronomical computations for Python given a date and location on the Earth's surface





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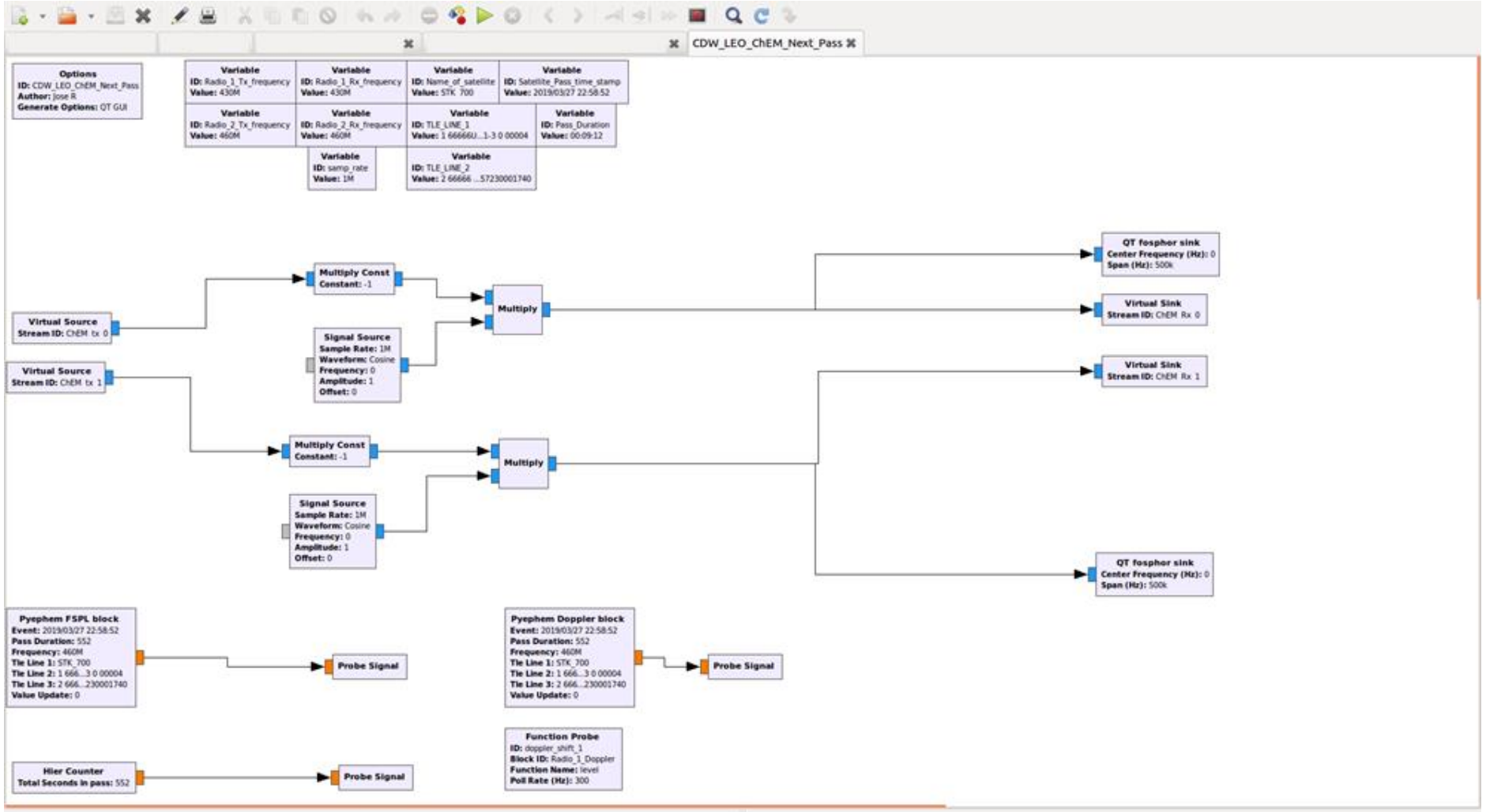
LEO Channel Simulator implementation



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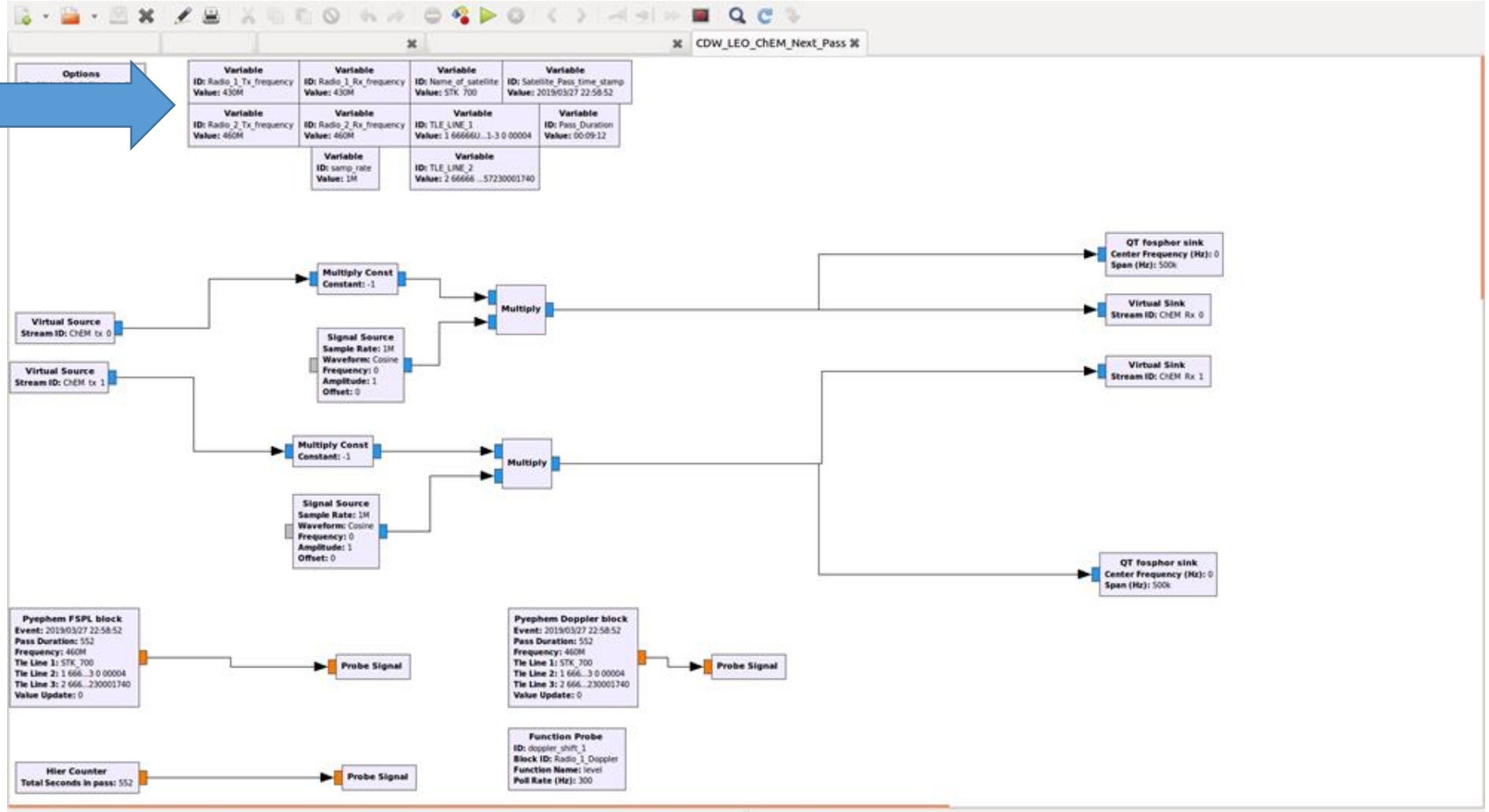
LEO Channel Simulator implementation

User Settings



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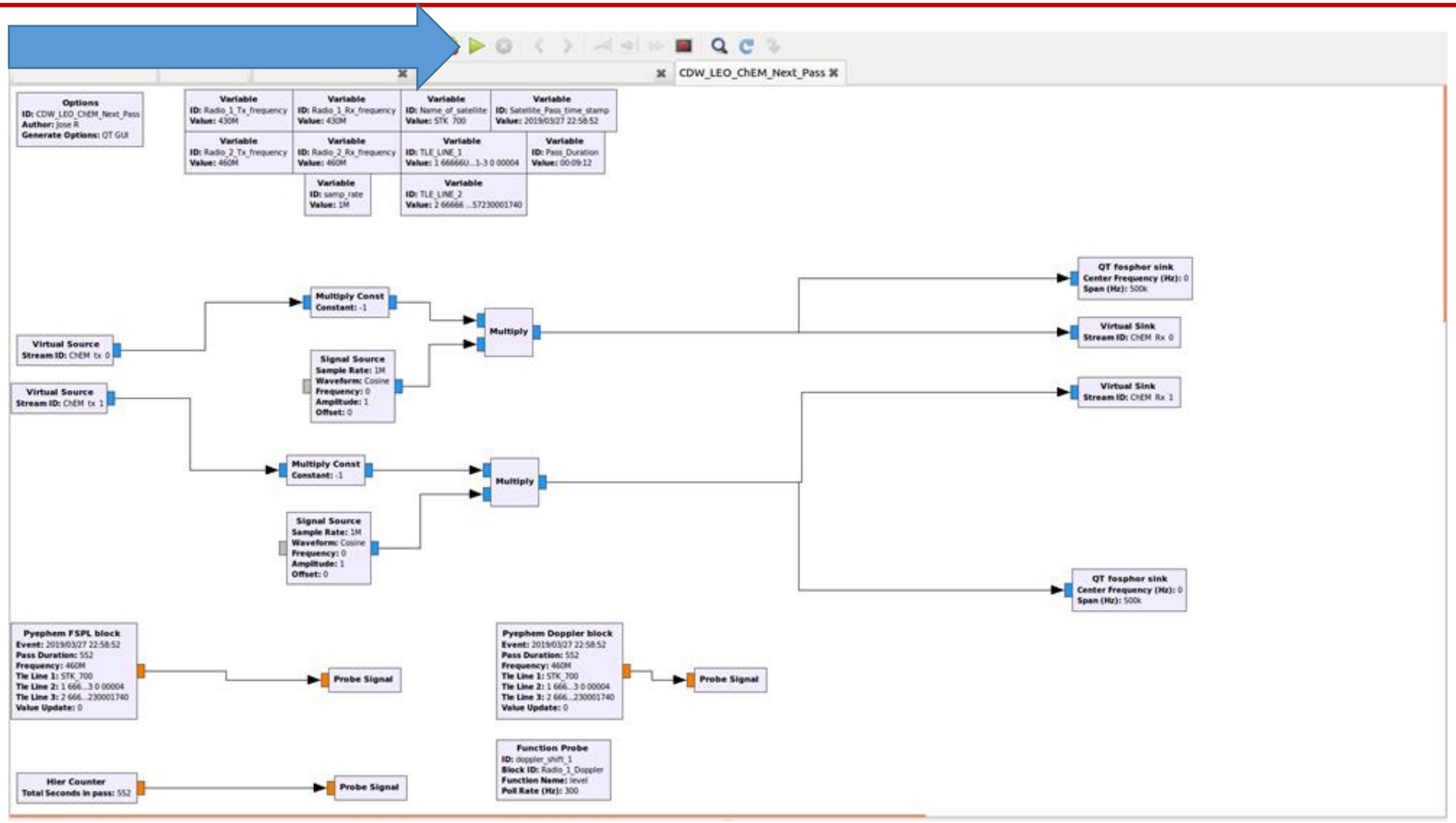
LEO Channel Simulator implementation

Run Simulator



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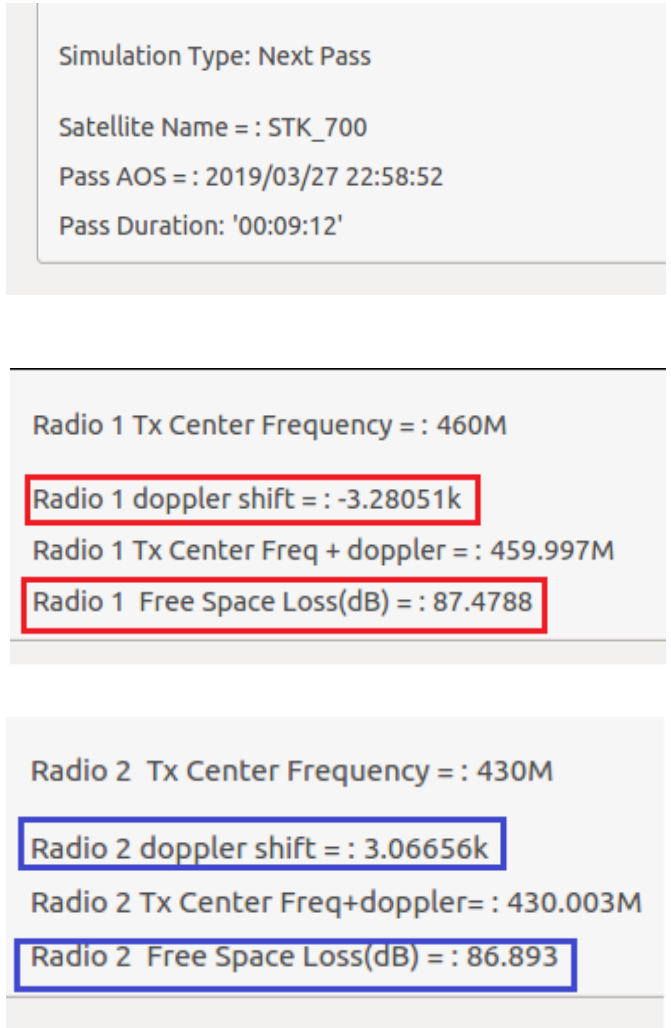
LEO Channel Simulator implementation

- When we run the RF channel simulator a plot displays showing the user a few interesting things
  - Satellite RF signal being affected by
    - LEO orbit Downlink Doppler shift (Red)
    - LEO orbit Uplink Doppler shifts (Blue)
    - LEO orbit Free space loss values in dB
  - Aside from actual channel values, the simulator displays the flyover pass timestamp, the name of the satellite and the duration of the pass currently being tested
  - All this information gives the tester the ability to monitor the RF communication link in real-time



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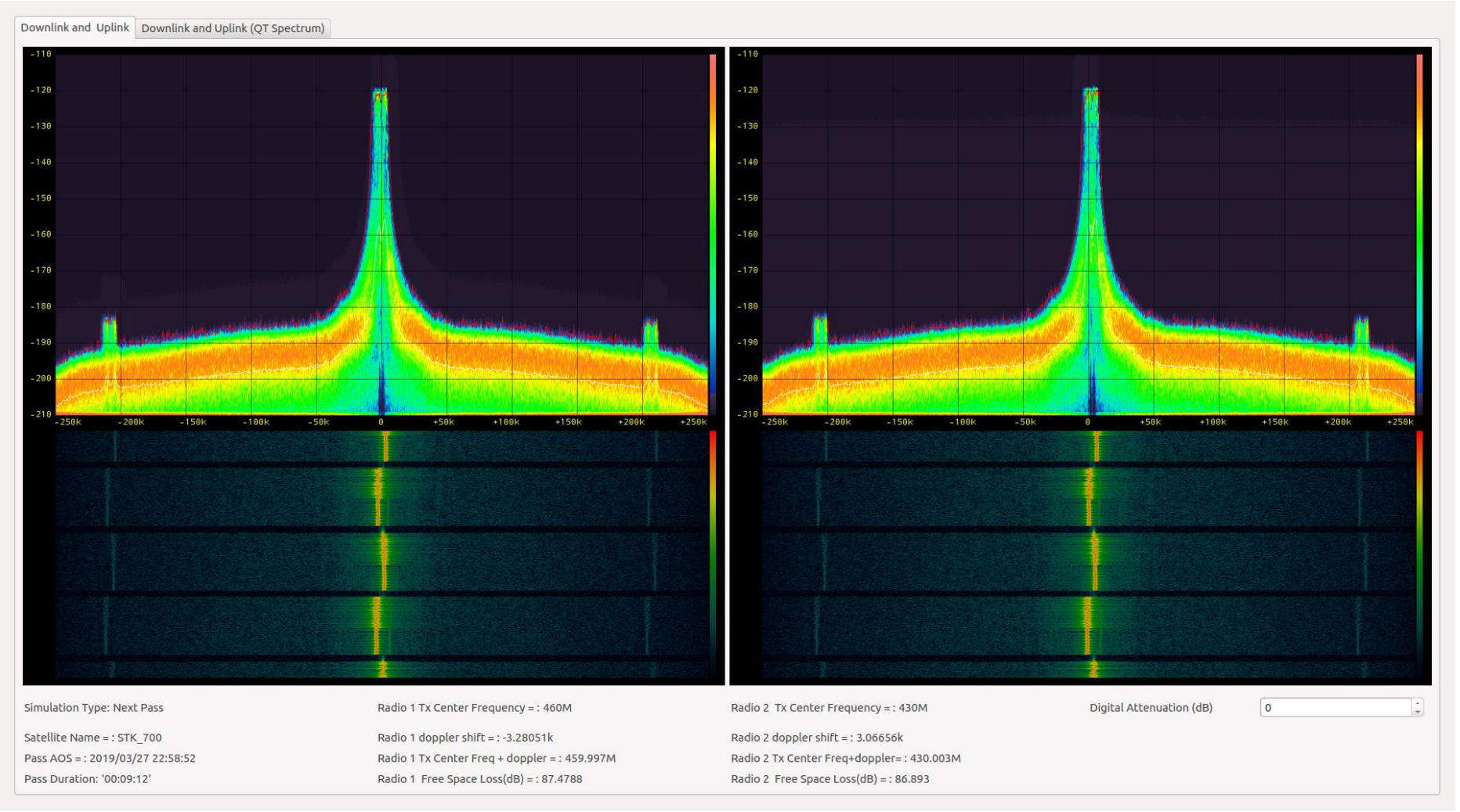
LEO Channel Simulator implementation



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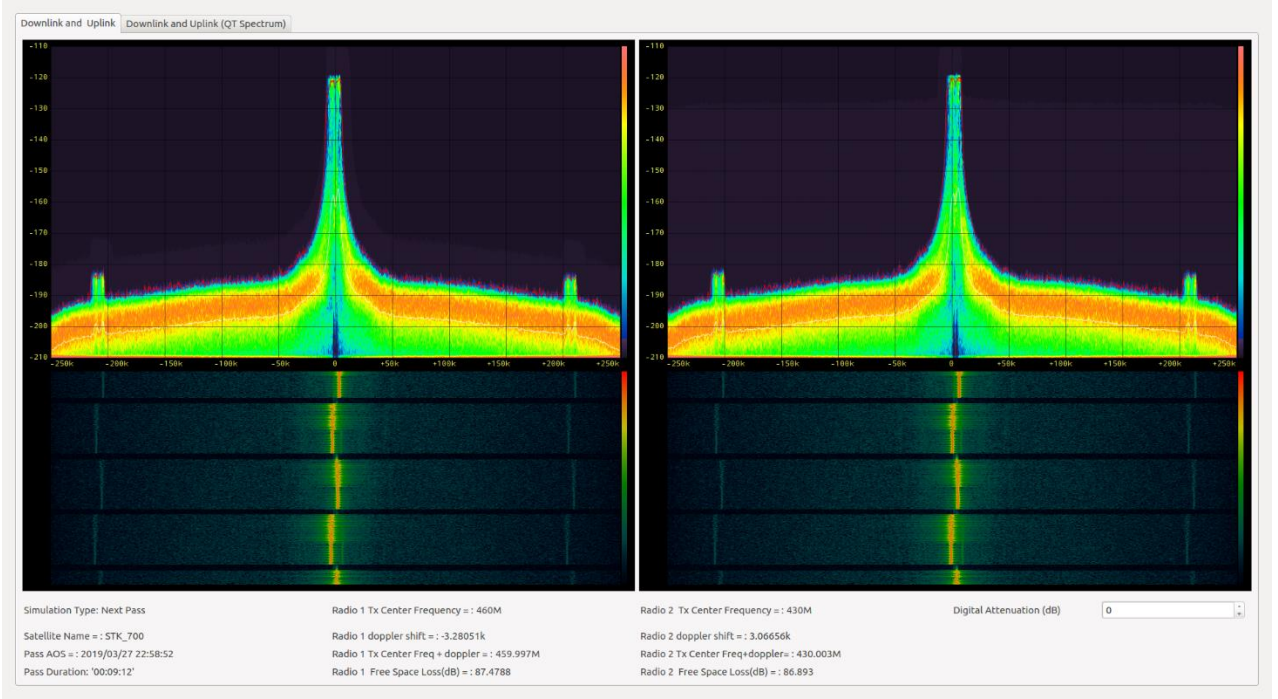
LEO Channel Simulator Testing

- Currently, we are testing various UHF Engineering Model radio hardware's on our LEO RF channel simulator to see how they handle Doppler shifts in LEO
  - We only used one X310 SDR for this test (one channel for the satellite radio, second channel for the ground radio)
  - For our tests, we simulated a LEO orbit at an altitude of 400km and passing over San Diego, CA
  - We used Satellite Tool Kit (STK) to generate TLE's
  - With the generated TLE's, time stamp of the next satellite pass and time of that pass, we finalized the setup of the simulator



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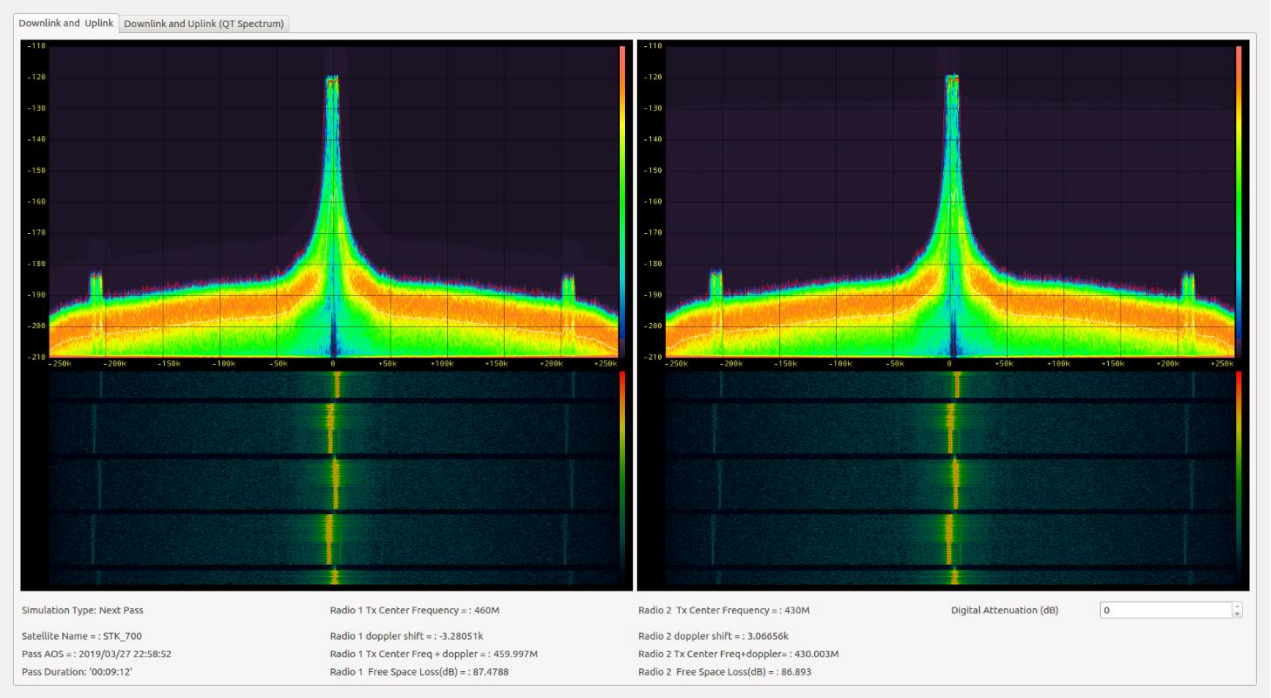
LEO Channel Simulator Testing

- What is the goal of our testing?
  - We want to make sure that devices under test (DUT) can withstand Doppler shifts and attenuation values during low earth orbit while still maintaining RF link
  - Altitude values and ground station parameters currently used are orbit parameters used in previous missions
- Our results showed that at least the first hardware we tested, could withstand a LEO orbit with Doppler shifts which range from +/- 7kHz over a 9 minute pass
  - Note that Free space loss attenuation ranged between 89 to 86 dB
  - Our testing is also verifying that the LEO channel simulator can actually attenuate and shift the signal as it is passing over a desired location



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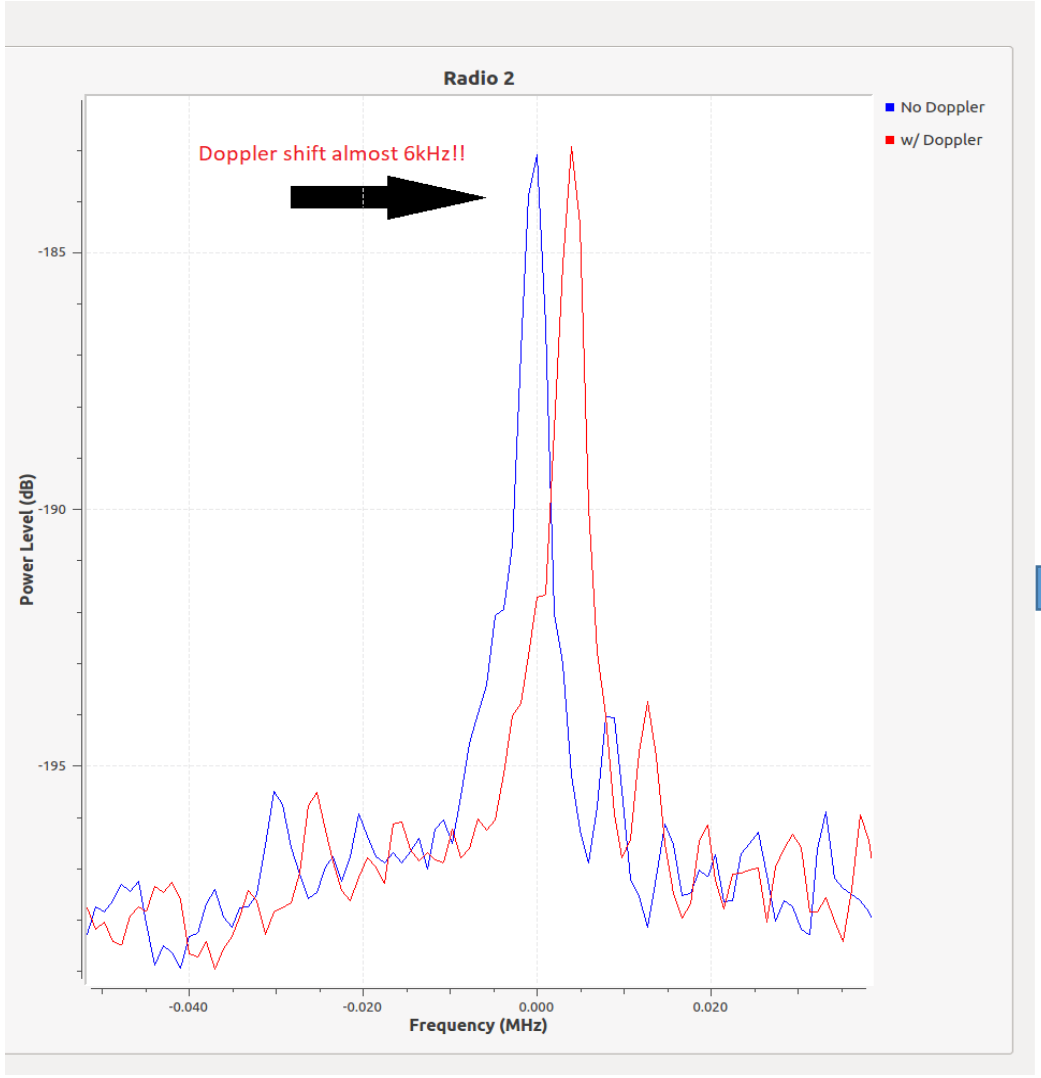
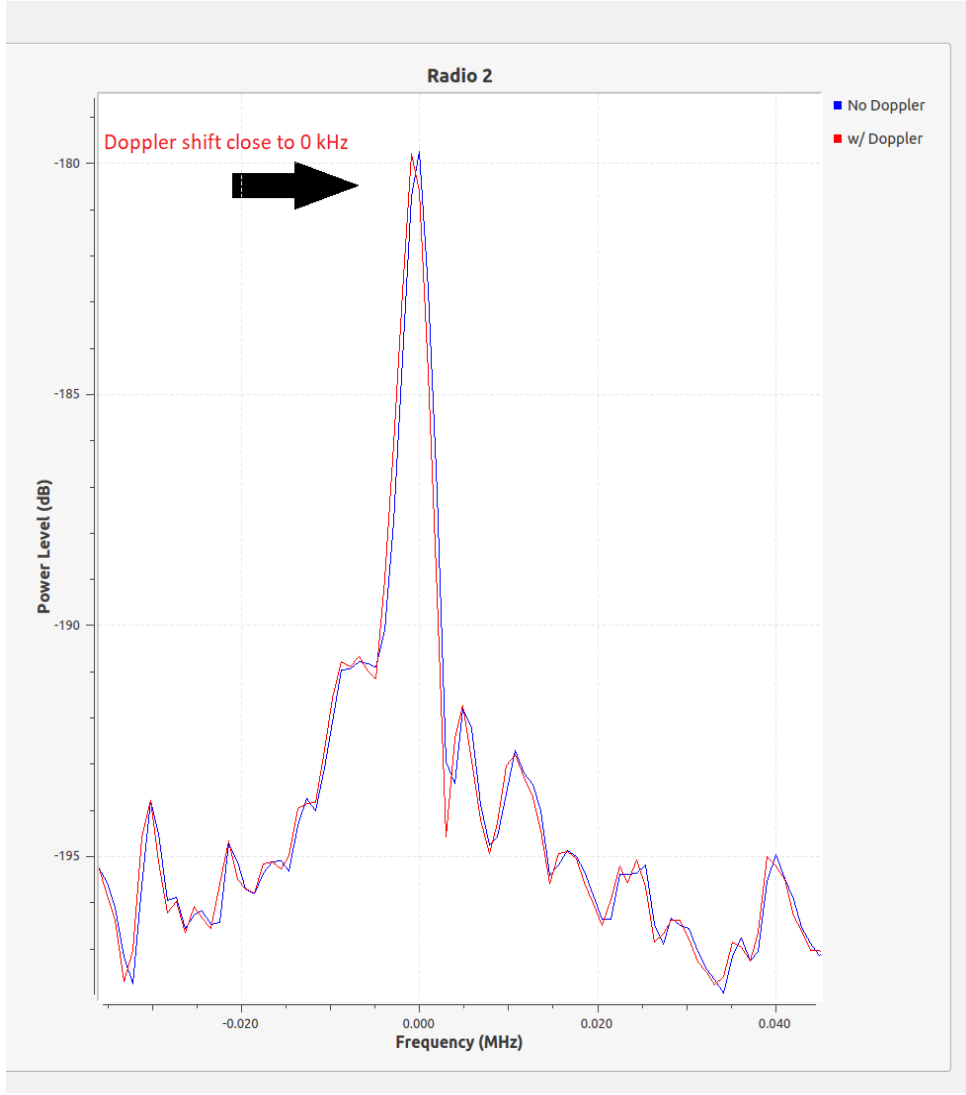
LEO Channel Simulator Test: Doppler Shift



Halfway through flyover pass



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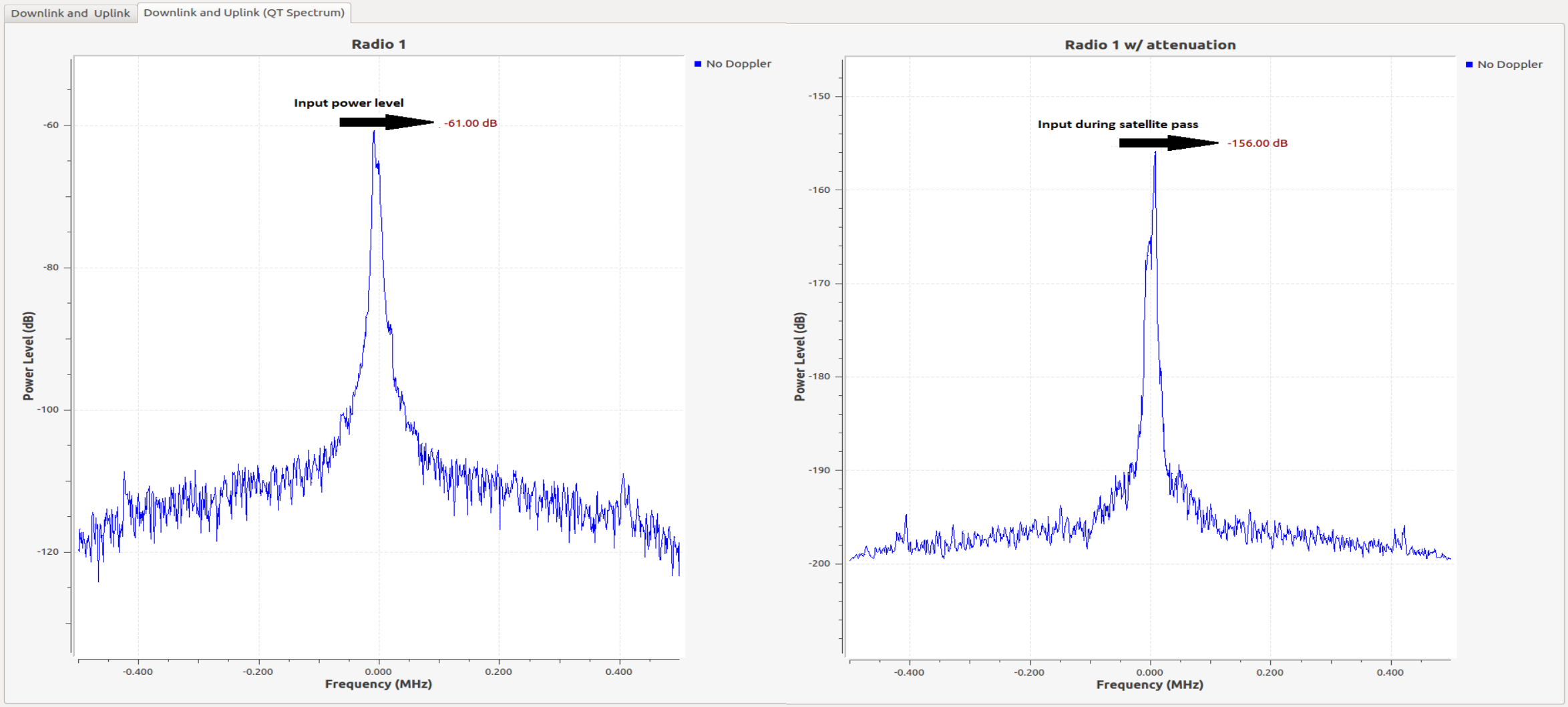
LEO Channel Simulator Test: Attenuation



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LEO Channel Simulator Advantages and Disadvantages

Advantages of NIWC Pacific's LEO RF channel simulator

- Provides Doppler shift for real-time or fly-over LEO orbits
- Provides FSPL (attenuation and channel noise) for real-time or fly-over LEO orbits
- Can support up to 4 radios under test (2 satellites, 2 ground radios or 1 satellite radio, 3 ground radios etc.)
- Software is open-source, can download on Ubuntu machine from the internet right now
- Can modify test cases according to the user's need without any cost (i.e. Add an interference signal or AWGN noise)
- Total cost of hardware for our LEO channel simulator < $12,000*

Disadvantages of NIWC Pacific's LEO RF Channel Simulator

- Cannot implement a channel with a specific time delay with GNU Radio unless FPGA implementation is added
- SDR hardware *may* introduce unwanted hardware impairments (i.e. DC offset or extra attenuation)
- *Need a pair of TLE's for it to work*. May not be optimal if satellite is not on orbit or one does not have STK
- Currently *cannot extract data* and port it to CSV or other format

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References

- GNU Radio: https://wiki.gnuradio.org/index.php/Main_Page
- USRP website: https://www.ettus.com/
- Pyephem website: https://rhodesmill.org/pyephem/

Questions?