An Approach to Digital Demodulation

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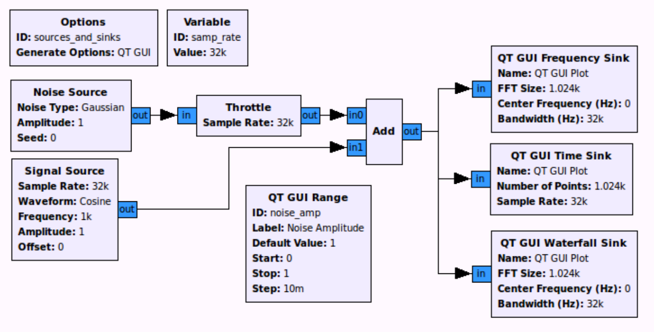
Basics

"The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point."
- Claude Shannon,*A Mathematical Theory of Communication*

Sources and Sinks (quick review)

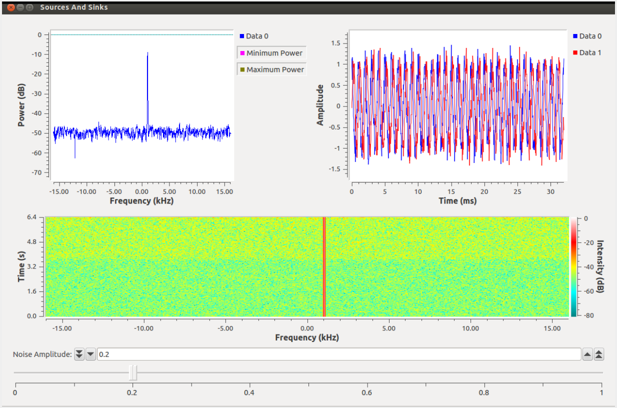
sources_and_sinks.grc



- Demonstration of using multiple sources to create a noisy sine wave and multiple sinks to view it in different domains.

Sources and Sinks (quick review)

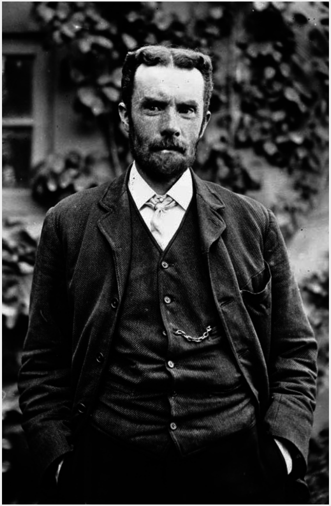
sources_and_sinks.grc - Output



- Showing PSD, spectrogram, and time domain of noisy signal.

Complex Numbers Review

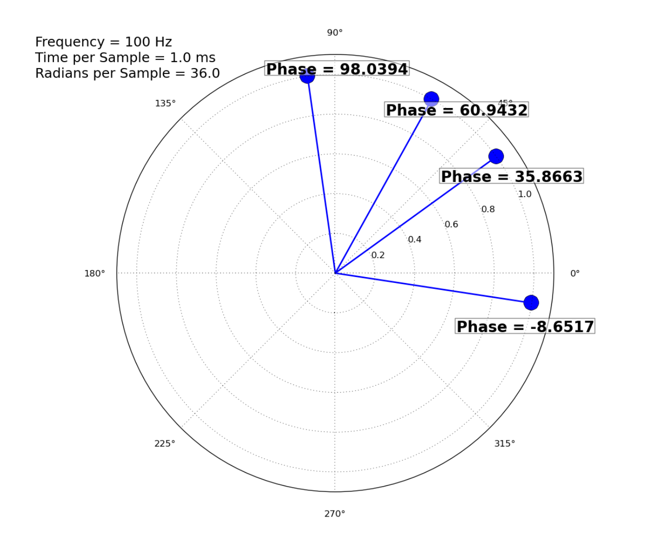
"Am I to refuse to eat because I do not fully understand the mechanism of digestion?"
- Oliver Heaviside



Complex Numbers

- $z(t) = x(t)cos(2\pi f(t)t + \phi(t)) + jy(t)sin(2\pi f(t)t + \phi(t))$
- $z(t) = c(t)e^{-j2\pi f(t)t+\phi(t)}$
- Information can be encoded in $c(t)$, $f(t)$, and $\phi(t)$.

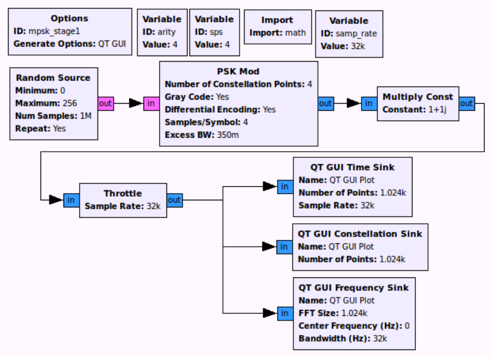
Complex Numbers: Polar Plots



Basic Tx/Rx

Modulating & Transmitting a Signal

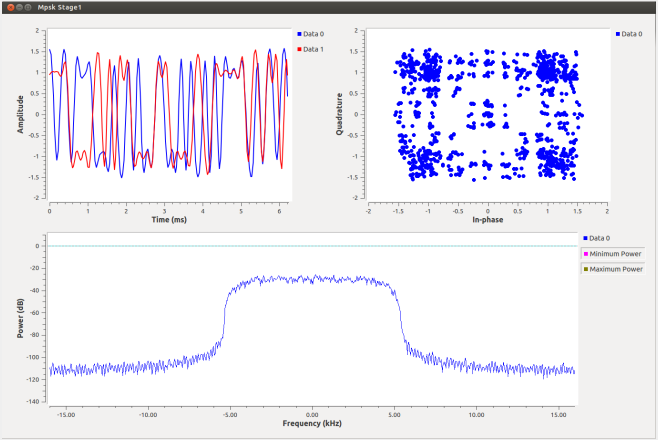
mpsk_stage1.grc



- Using a pre-built PSK modulator block from GNU Radio.

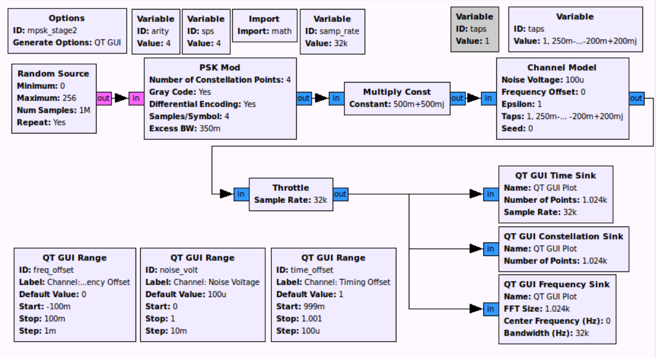
Modulating & Transmitting a Signal

mpsk_stage1 output: Showing ISI introduced by the transmit filter



The Received Signal

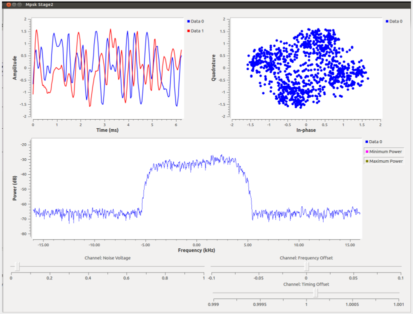
mpsk_stage2.grc



- We can simulate a channel model with noise, frequency and timing offsets, and multipath.

The Received Signal

mpsk_stage2 output: Effects of noise, timing offset, and frequency



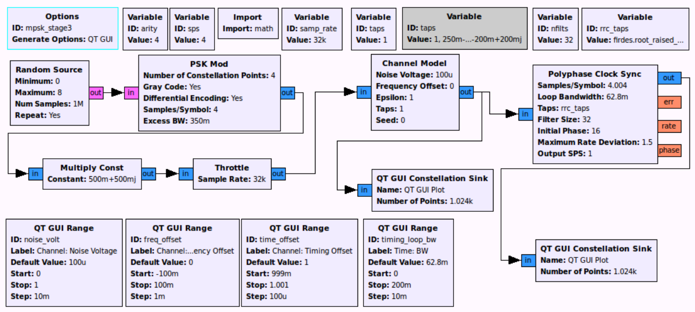
- Signal captured using a multipath channel with some AWGN noise and timing offset. No frequency offset was used.

Timing Recovery

"Some knowledge rises out of information, disorganized but nevertheless true."
- James Crumly, *The Wrong Case*

Timing Recovery

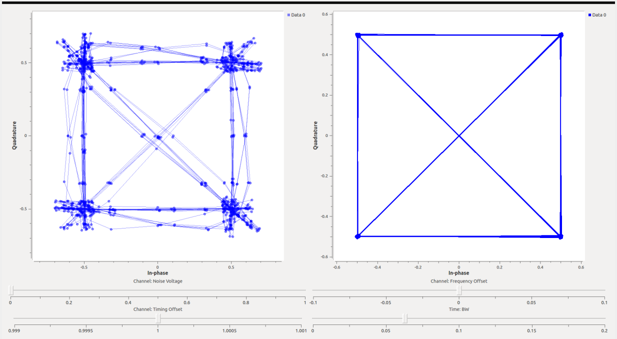
mpsk_stage3.grc



- We use a control loop algorithm to find the right sampling time to fix clock mismatches between the transmitter and receiver.

Timing Recovery

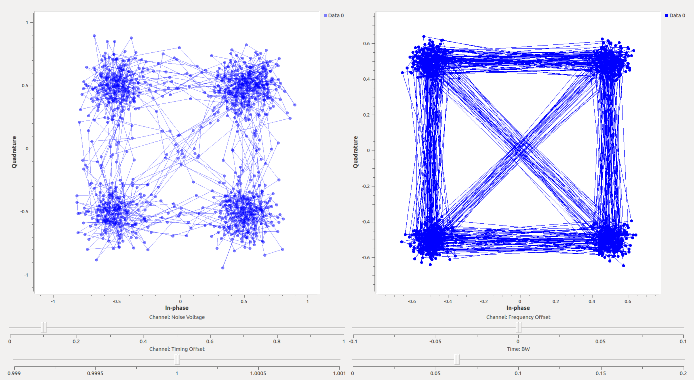
Timing recovery block also runs through the matched filter and down-samples to 1 sps



- Showing a no-noise situation to illustrate ISI (self-interference) issues in the received signal before timing recovery and matched filtering.

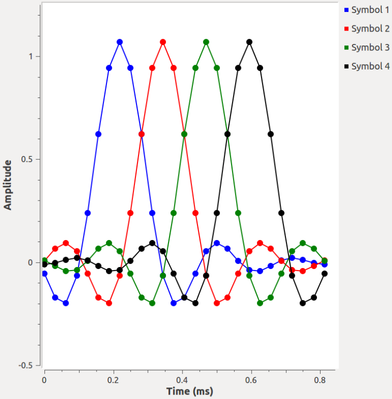
After Timing Recovery - With Noise

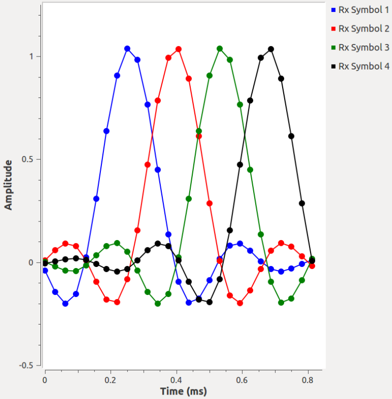
Timing recovery algorithm robust against noise



Understanding Timing Recovery

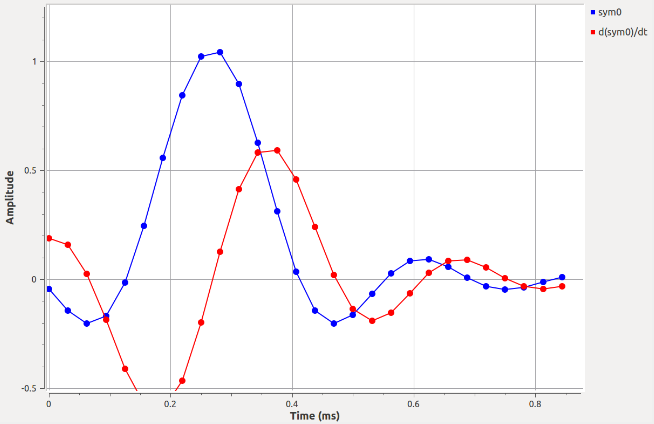
Difference in clocks causes symbol sampling differences





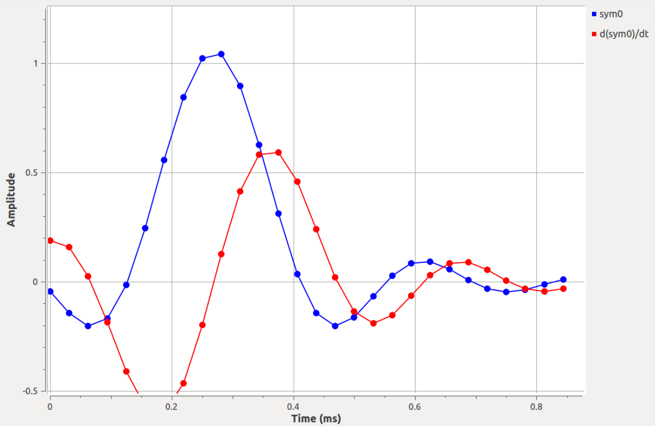
Understanding Timing Recovery

A shift in time is also a shift in phase. Try to find the right phase offset.



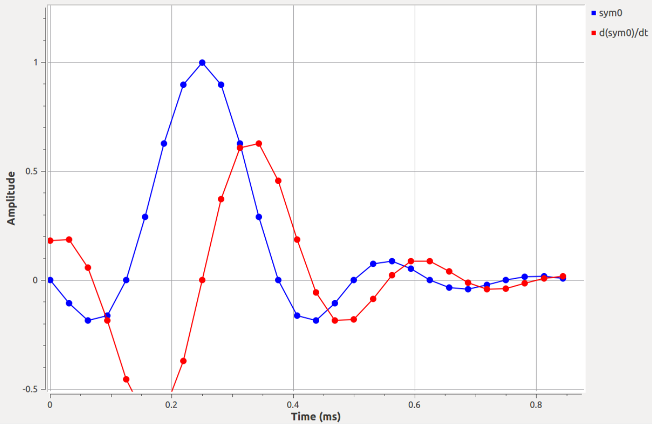
Understanding Timing Recovery

Derivative filter gives us a error value that we can force towards 0.



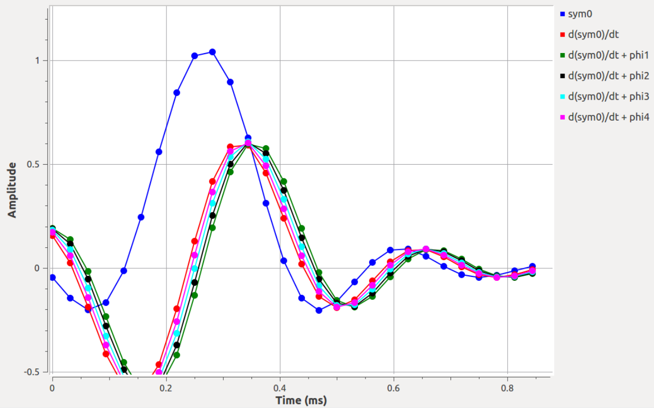
Understanding Timing Recovery

If we find the right offset, the derivative goes to 0, the sampling is at the peak.



Understanding Timing Recovery

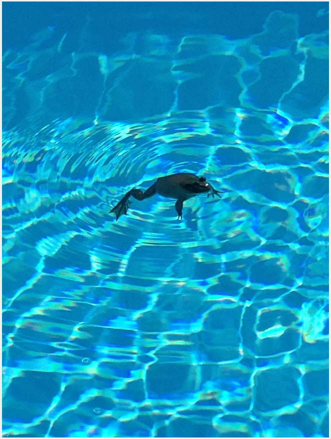
Using a bank of filters of equally-spaced phases, we can search for the nearest filter arm.



Multipath

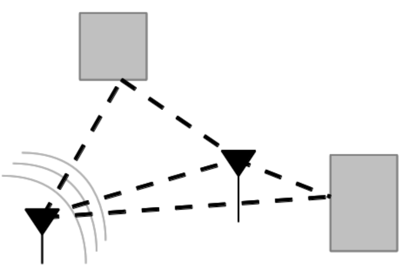
"There is a quaintly modern notion that information will eventually equal knowledge, which is neatly balanced by the cliche that the more one learns, the less one knows."

- James Crumly, *The Wrong Case*



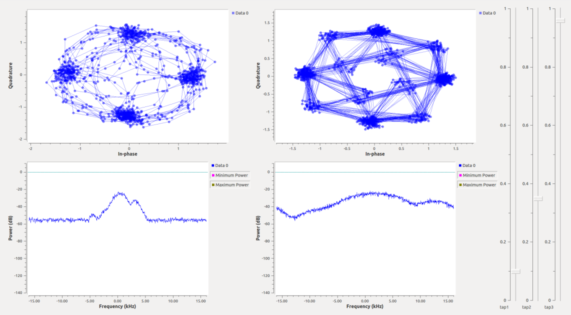
Multipath in Brief

Multipath result from signal bounces hitting the receiver at different times and with different phases



Effects of Multipath

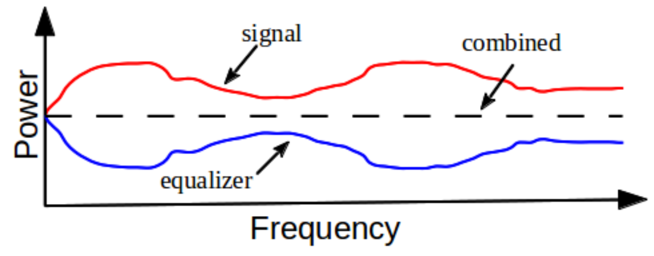
mpsk_multipath.grc



- This simulation allows us to adjust the multipath channel as though we are adjusting a stereo's equalizer.

Equalizing Multipath

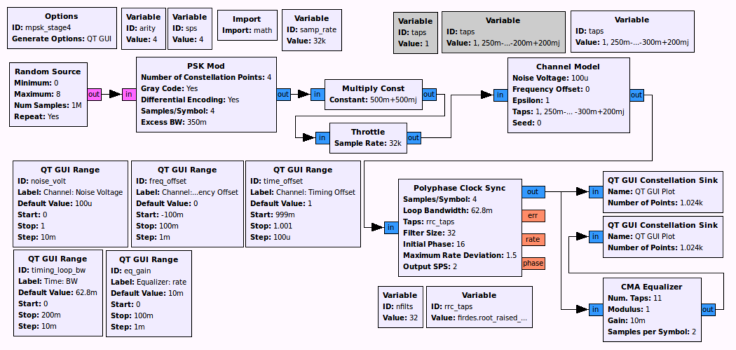
Multipath equalizing cartoon



- Signal corrupted by multipath. Equalizer tries to invert the multipath so that the combination is a flat frequency response.

Equalizing Multipath

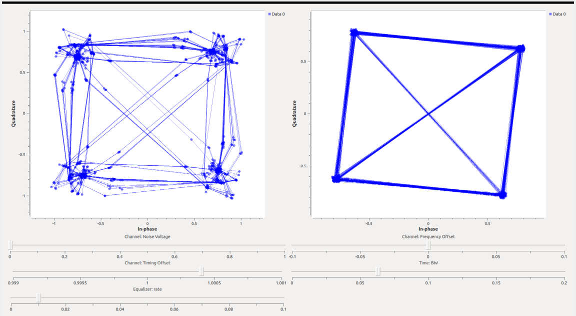
mpsk_stage4.grc



- Using the constant modulus algorithm (CMA) blind equalizer is used here to correct multipath distortion.

Equalizing Multipath

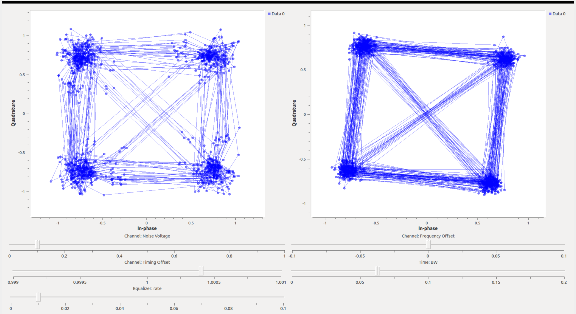
mpsk_stage4.grc



- Note the similarity between the time-synchronized and filtered output with multipath and the ISI of the signal before the matched filter with no multipath.

Equalizing Multipath

Equalizer output of signal with noise

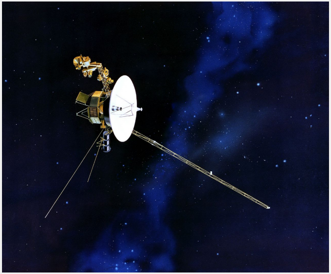


- Equalization working with noise.

Phase & Fine Frequency Lock

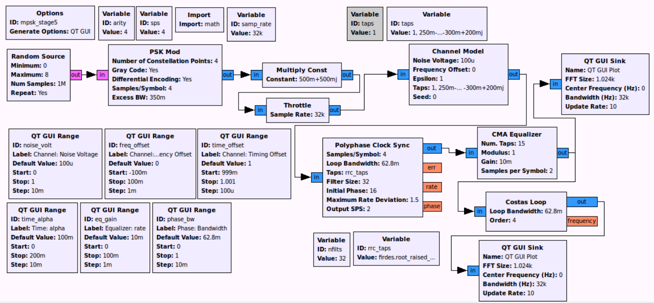
"That receiver had a faulty tracking-loop capacitor... Result: Voyager 2 effectively lost all contact with the mission controllers."

Joel Davis, *Flyby*



Phase Offset Correction

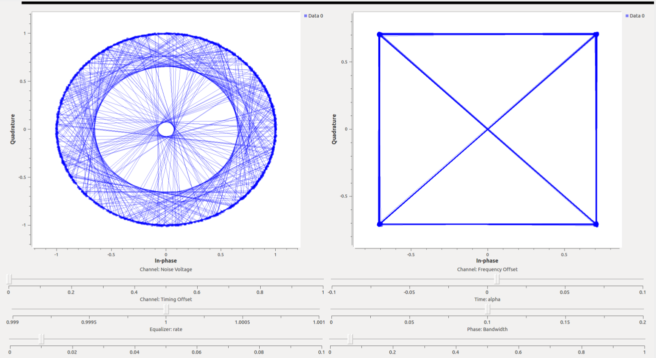
mpsk_stage5.grc



- The transmitter and receiver work off different clocks, so there will be a frequency and phase offset. We need to correct for any small frequency and phase offsets.

After Phase Offset Correction

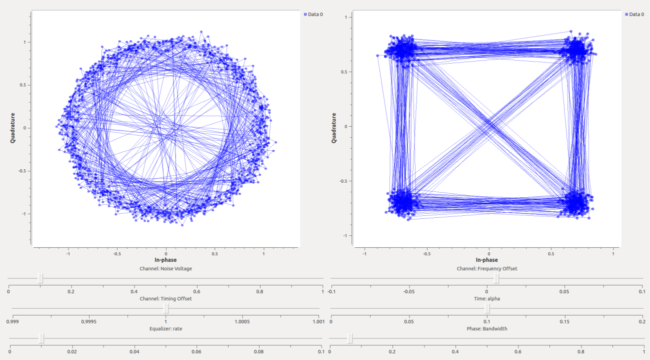
mpsk_stage5 output



- Left figure shows a rotate constellation. The Costas Loop block fixes the offset.

After Phase Offset Correction - With Noise

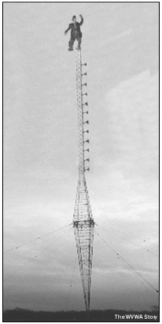
mpsk_stage5 output robust against AWGN



Coarse Frequency Correction

"We can get used to nine-tube screen-grid highboy Philco radios, although that really won't be necessary, inasmuch as the superheterodyne circuit has already been invented"

Philip K. Dick, *Ubik*

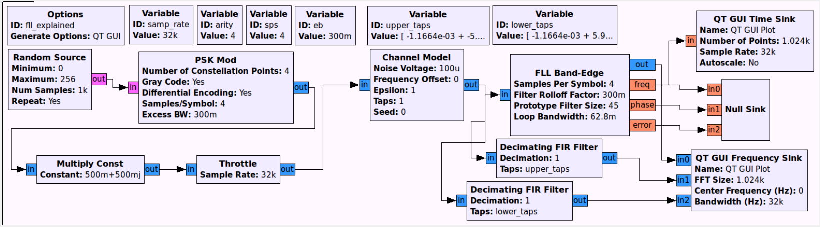


Armstrong atop WVWA-FM

Coarse Frequency Correction

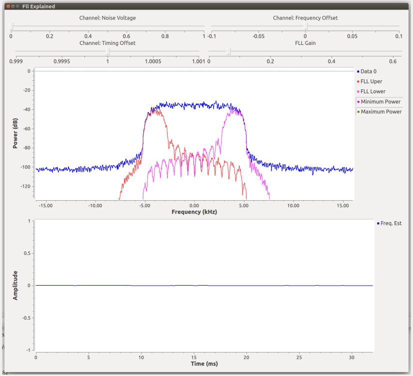
Frequency Lock Loop using band-edge filters

- Given the pulse shaping filter's excess bandwidth.
- Create a filter for each edge of the transmitted signal in frequency.
- The difference in the amount of energy between the two filters is proportional to the coarse frequency offset.
  - $|h_L(t) * x(t)| - |h_u(t) * x(t)| \propto f$



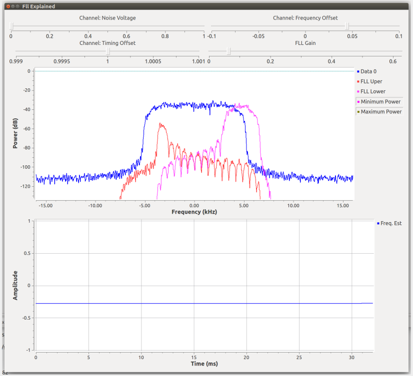
Coarse Frequency Correction

FLL Output: Ideal Tx/Rx Settings



Coarse Frequency Correction

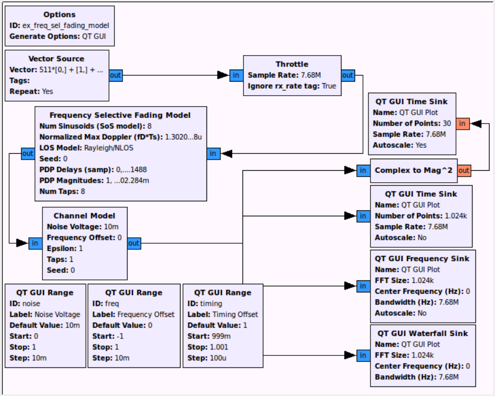
FLL Output: Frequency Offset at near 0.05



Channel Models

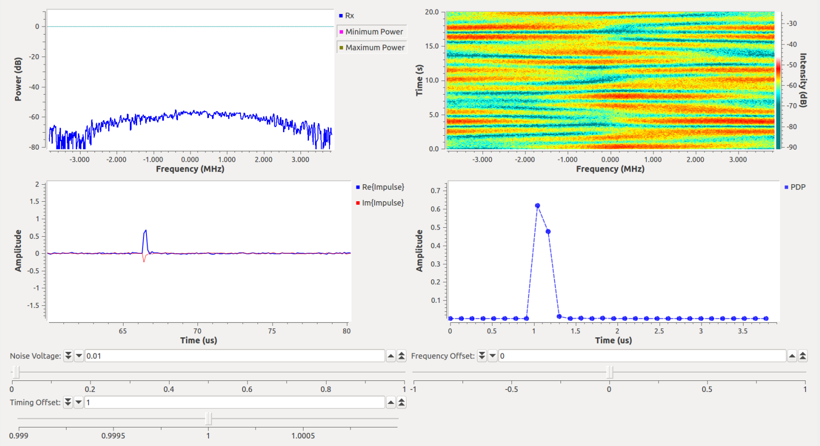
Experimenting with PDPs

Frequency selective fading model shows effect on an impulse



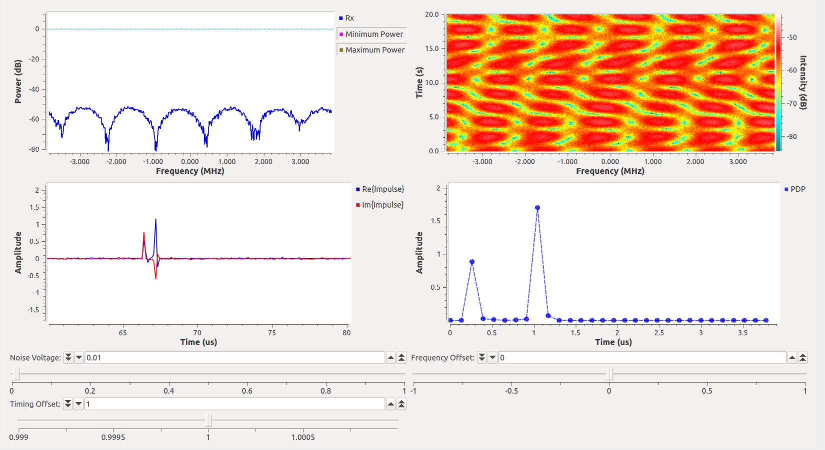
Sample Output: UMTS Pedestrian A

Taken from the 3GPP UMTS Info; Sampled at 7.68 Msps



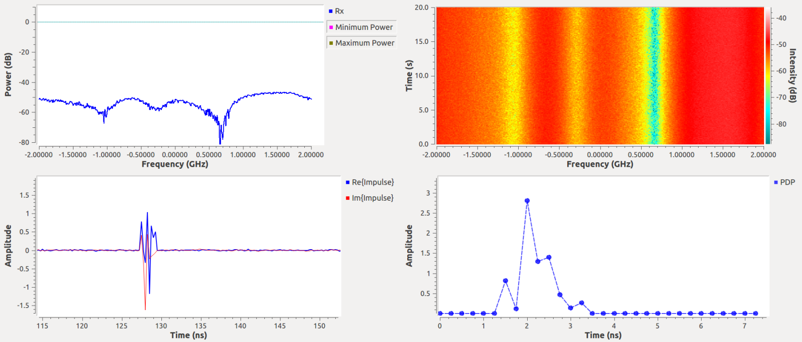
Sample Output: UMTS Pedestrian B

Taken from the 3GPP UMTS Info; Sampled at 7.68 Msps

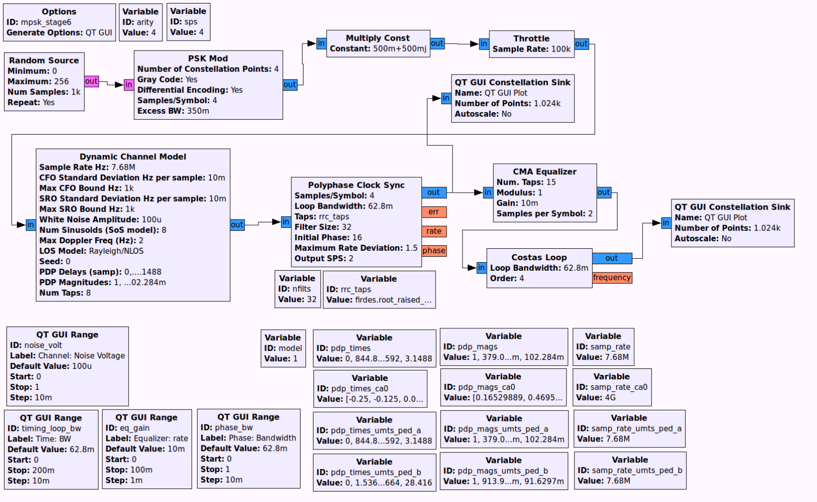


Sample Output: PDP Collected from Chris Anderson (USNA)

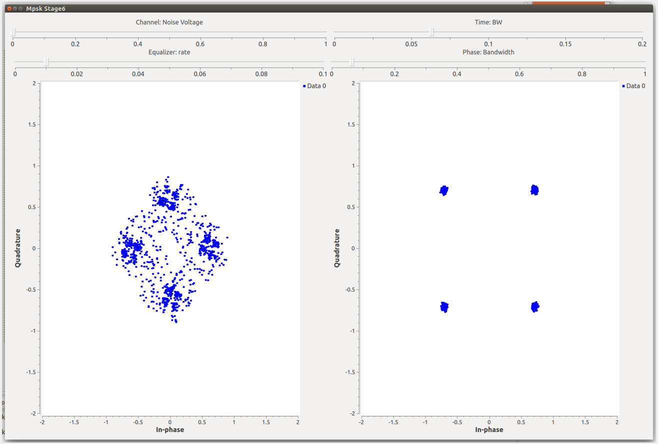
PDP collected at 4 Gsps in office building



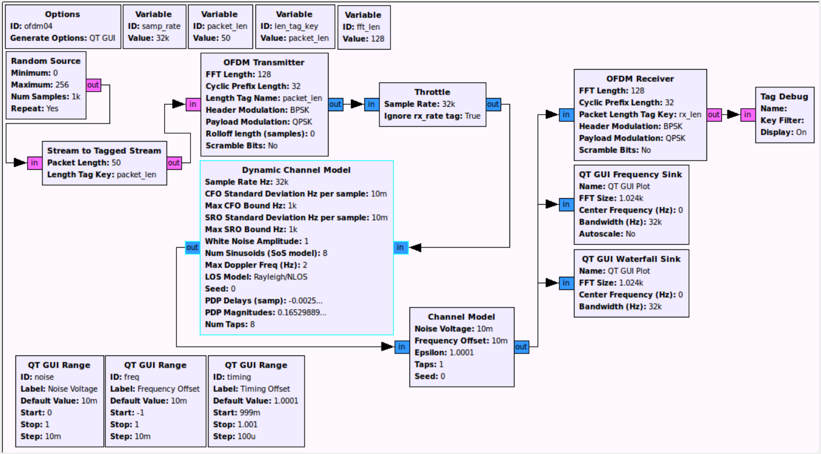
Fading Model Applied to MPSK Sim



Fading Model Applied to MPSK Sim: UMTS Ped. A

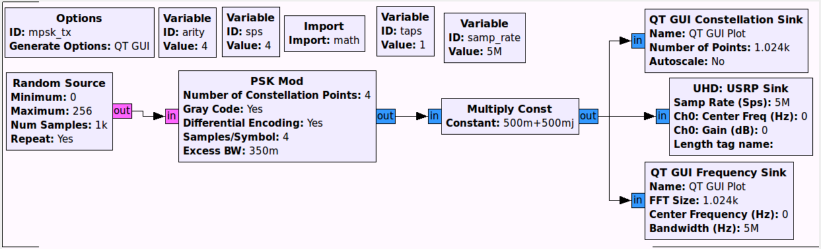


OFDM Through a Fading Model



Split the graph into Tx and Rx

TX: Remove throttle and add HW interface



Split the graph into Tx and Rx

RX: Take second half for receiver; added gain control