UCSD MAS WES268A - Lab 2 Report DRAFT

08NOV2025

Prepared By:
Joshua Hoang
Ryan Shimizu

Contents

1 Part 1: Generation of Passband Noise Waveforms

1.1 Narrative Questions

1.1.2 - The center value of the histograms I and Q is zero. This is because the noise is generated using a Gaussian distribution with a mean of zero.

1.1.3 - From Figure 2, we can see that the IQ spectrums show a flat frequency response indicating that the noise power is uniformly distributed across the frequency range hovering around the -40dB range. This is a characteristic of additive white Gaussian noise, which has equal power across all frequencies. Using an RBW of 50 Hz and one-sided bandwidth of 250kHz, we can calculate the total noise power as follows:

$$P_{\text{noise}} = (10^{-4}) \times B/RBW = (10^{-4}) \times (250,000/50) = 0.5$$

We can verify that this is correct because it is consistent with our value of σ:

$$\sigma_{\text{noise}} = \sqrt{P_{\text{noise}}} = \sqrt{0.5} = 0.7071$$

which matches our set value of σ in the simulation VI seen in Figure 1 and Figure 2.

1.1.4 - Just like in step 3, we can calculate the total noise power using the same method but only for the in-phase component. Using an RBW of 50 Hz, one-sided bandwidth of 250kHz, and a power level of -40dB uniformly distributed across the frequency range, we can calculate the total noise power as follows:

$$P_I = (10^{-4}) \times B/RBW = (10^{-4}) \times (250,000/50) = 0.5$$

Again, we can verify that this is correct because it is consistent with our value of σ:

$$\sigma_I = \sqrt{P_I} = \sqrt{0.5} = 0.7071$$

which matches. LabVIEW only displays the one-sided spectrum for real signals because the negative frequency components mirror the positive frequency components. Therefore, it is redundant to display.

1.2 Figures

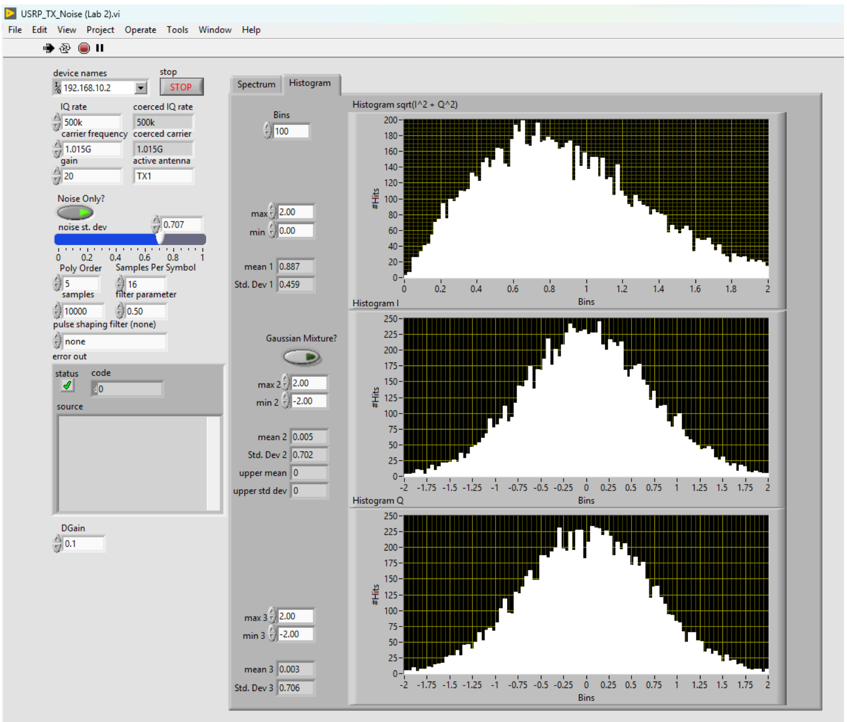


Figure 1: 1.1.2 - Histogram of I and Q components of passband noise

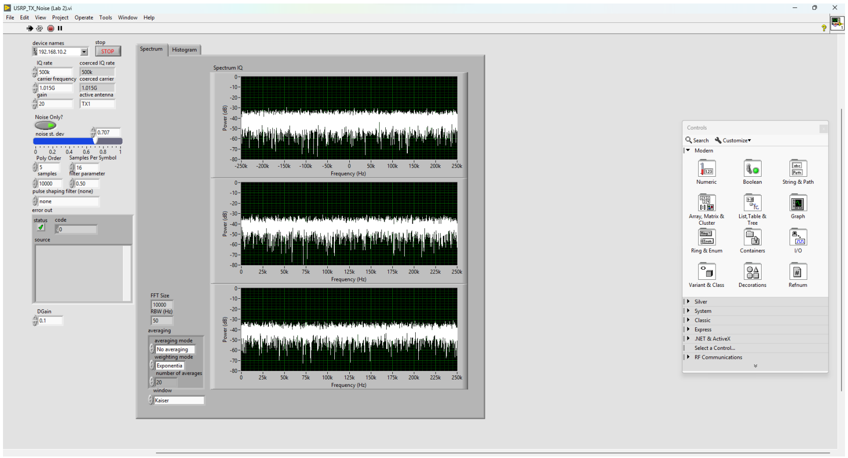


Figure 2: 1.1.3 - Spectrum of I and Q components of passband noise

2 Part 2: Up Sampling and Pulse Shaping

2.1 Narrative Questions

2.1.5 - As we vary the Filter Parameter β of the Root Raised Cosine Filter, we observe changes in the power spectrum of the shaped signal. Specifically, as β increases, the bandwidth of the signal also increases. We can see this in Figure 2. This is because a higher β value results in a wider transition band in the filter's frequency response. Conversely, a lower β value results in a narrower bandwidth.

2.2 Figures

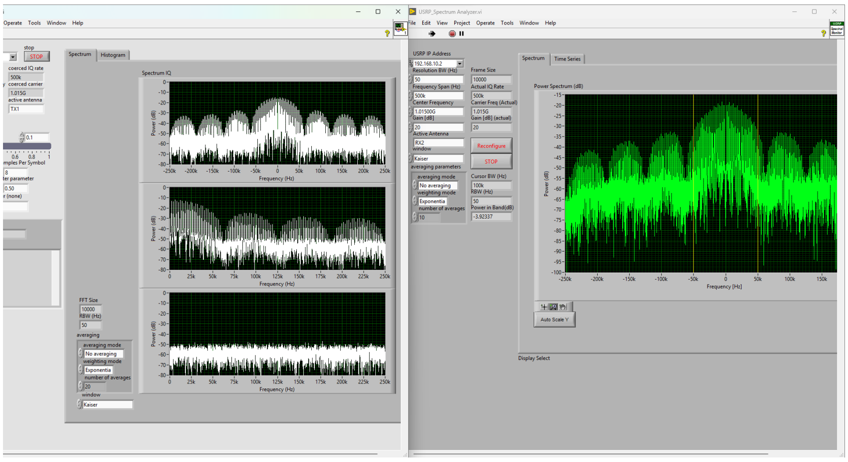


Figure 3: 2.1.3 - Side-by-side TX and RX VI

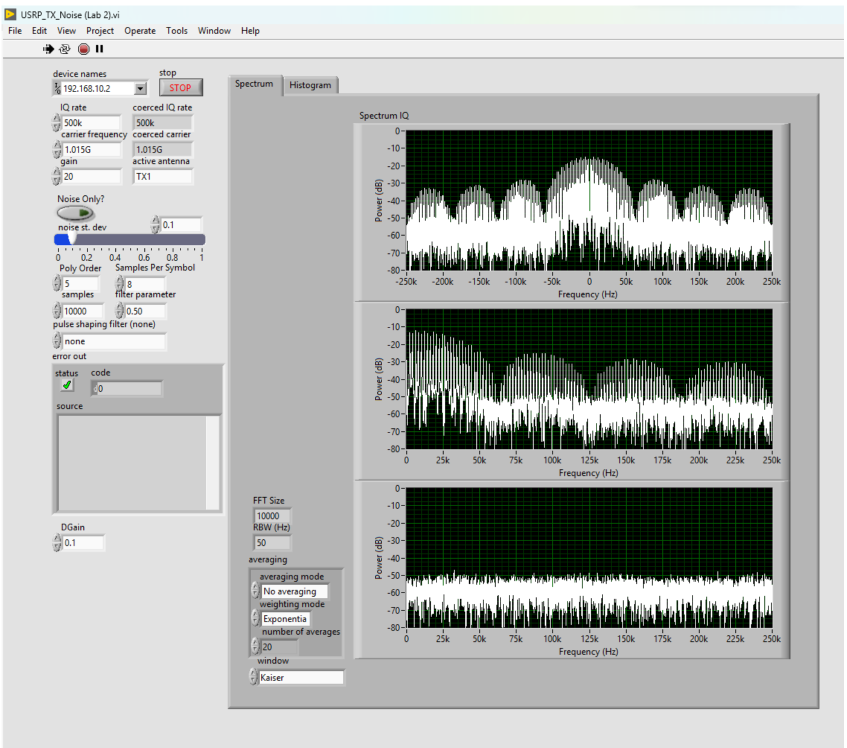


Figure 4: 2.1.4a - Power Spectrum (No filter)

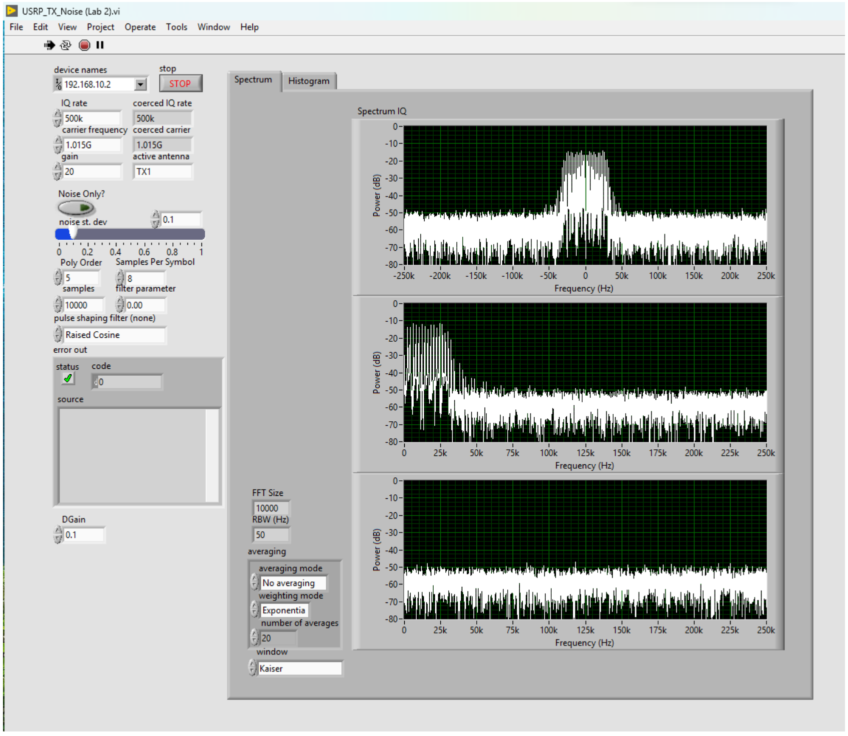


Figure 5: 2.1.4b1 - Power Spectrum of β = 0 (Root Raised Cosine Filter)

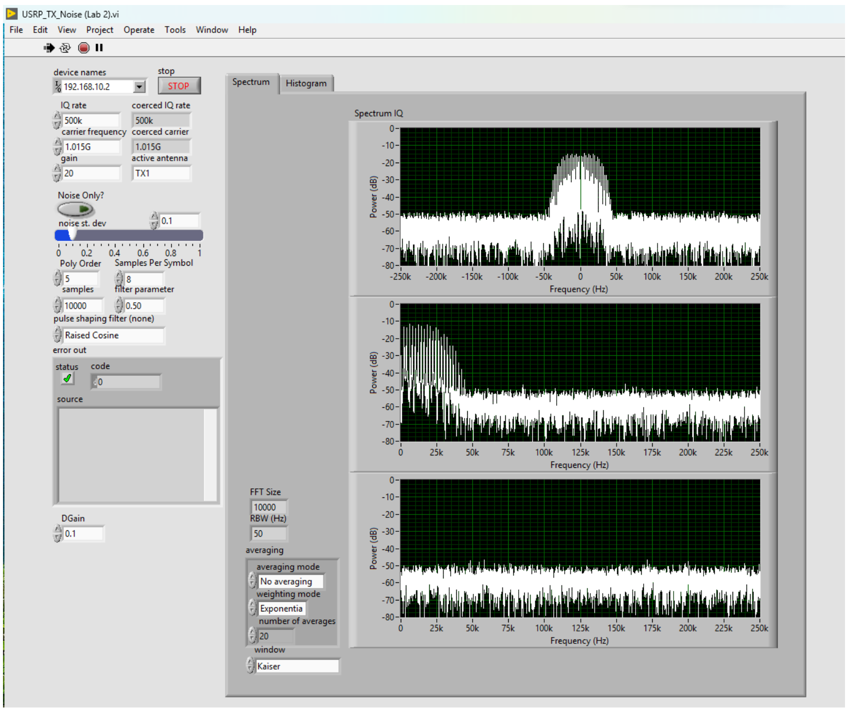


Figure 6: 2.1.4b2 - Power Spectrum of β = 0.5 (Root Raised Cosine Filter)

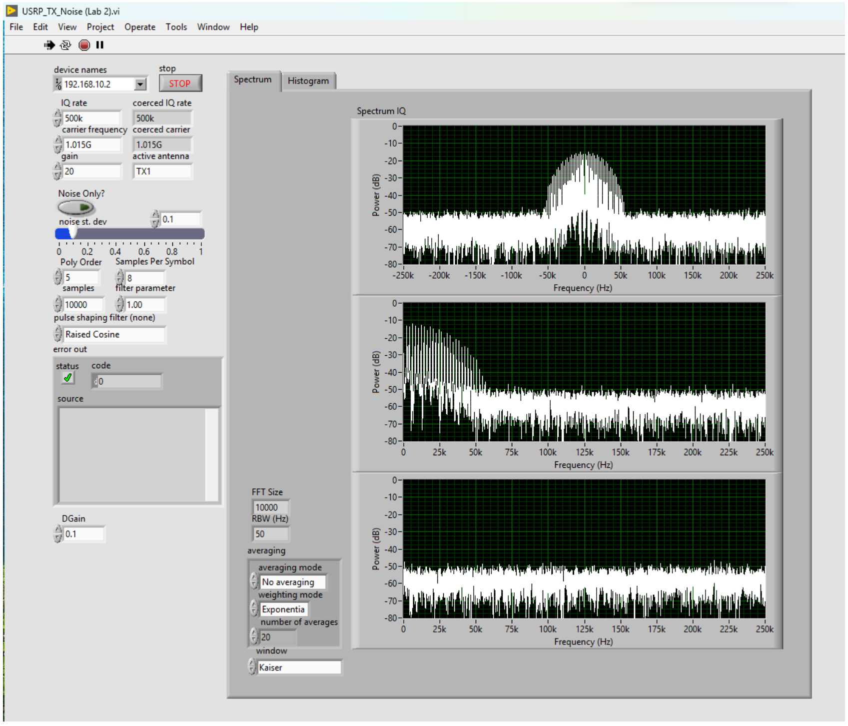


Figure 7: 2.1.4b3 - Power Spectrum of $\beta = 1$ (Root Raised Cosine Filter)

3 Part 3: Generation of Pseudo Random Binary Sequences (PRBS)

3.1 Narrative Questions

3.0.5 - We analyze the power spectrum for this type of signal using a Fourier series expansion to represent the PRBS signal because it is periodic. Since the sequence is pseudo-random, it has a period that repeats depending on the length of the shift registers used to generate it. For our case, with $M = 5$ and $N = 8$, the period is $N \times (2^M - 1) = 248$ samples. This makes a Fourier series expansion appropriate for analyzing the frequency components of the signal.

3.0.6 - The frequency spacing between the spectral lines Δf is approximately 60kHz as seen in Figure 8. The Δf_{null} repeats at 2kHz intervals as seen in Figure 10. We can verify that these are consistent with our calculations in Additional Questions 1:

$$\Delta f = \frac{f_s}{N \times (2^M - 1)} \qquad \Delta f_{\text{null}} = \frac{f_s}{N}$$

where $f_s = 500\text{kHz}$, $N = 8$ and $M = 5$.

$$\Delta f = \frac{500\text{kHz}}{8 \times (2^5 - 1)} \approx 2.016\text{kHz} \qquad \Delta f_{\text{null}} = \frac{500\text{kHz}}{8} = 62.5\text{kHz}$$

3.2 Figures

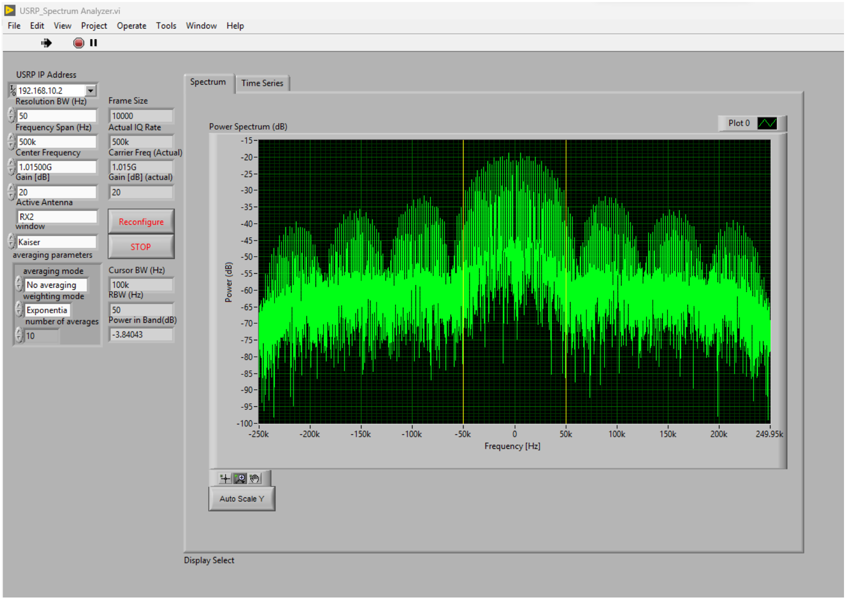


Figure 8: 3.0.3 - Generated Spectrum using USRP Spectrum Analyzer

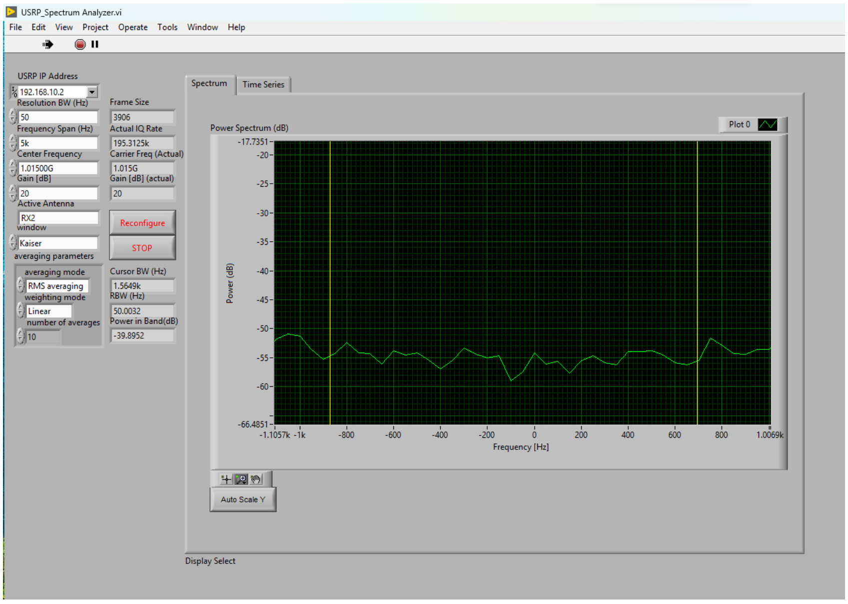


Figure 9: 3.0.4a - DC Component of PRBS Spectrum

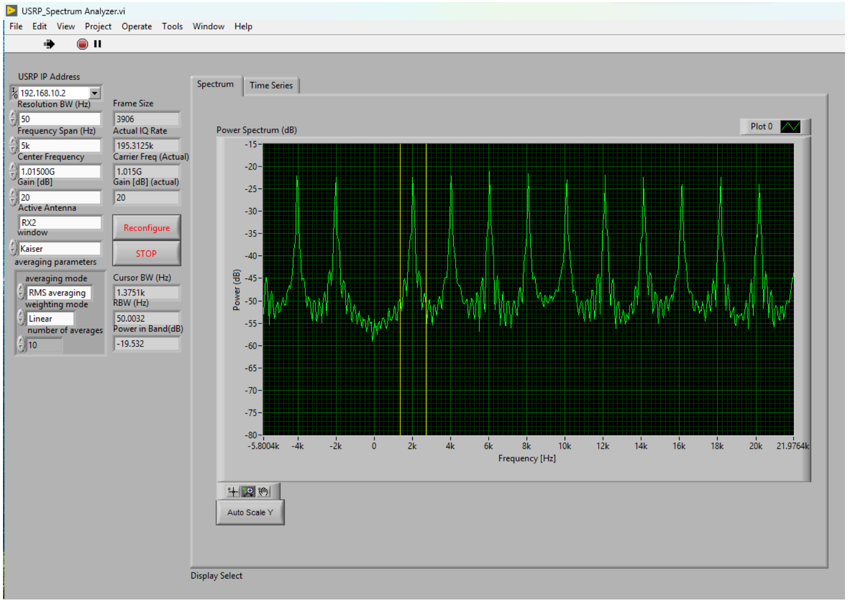


Figure 10: 3.0.6 - Frequency Spacing between spectral lines Δf_{null}

3.3 Autocorrelation Properties of PRBS Sequences (Simulation Only)

3.3.A Narrative Questions

3.1.2 - The results of the MLS, Ones, and Random sequences shown in Figures 11 through 13 match the expected behavior of the three sequences. When the noise standard deviation is set to 0, the MLS sequence achieves a detection rate very close to one because its autocorrelation always gives a single sharp peak at $t = 0$. The Ones sequence has a flat correlation surface so the algorithm rarely singles out $t = 0$, and its detection rate stays near zero. As for the Random sequence, each newly generated pattern is essentially uncorrelated with the stored template, so the peak almost never lands at $t = 0$ and the detection rate likewise remains close to zero.

3.1.4 - Across all three noise levels the MLS sequence delivers the best performance as it consistently shows the highest Packet Detection Rate in Figures 11, 14, 17, 20 and 23 compared to the Ones and Random sequences in Figures 12, 13, 15, 16, 18, 19, 21 and 22.

3.1.5 - Under additive white Gaussian noise the MLS sequence still performs the best. Figure 20 shows that the MLS maintains a clear correlation spike, while the Ones and Random sequences in Figures 21 and 22 lose their peaks first.

3.3.B Figures

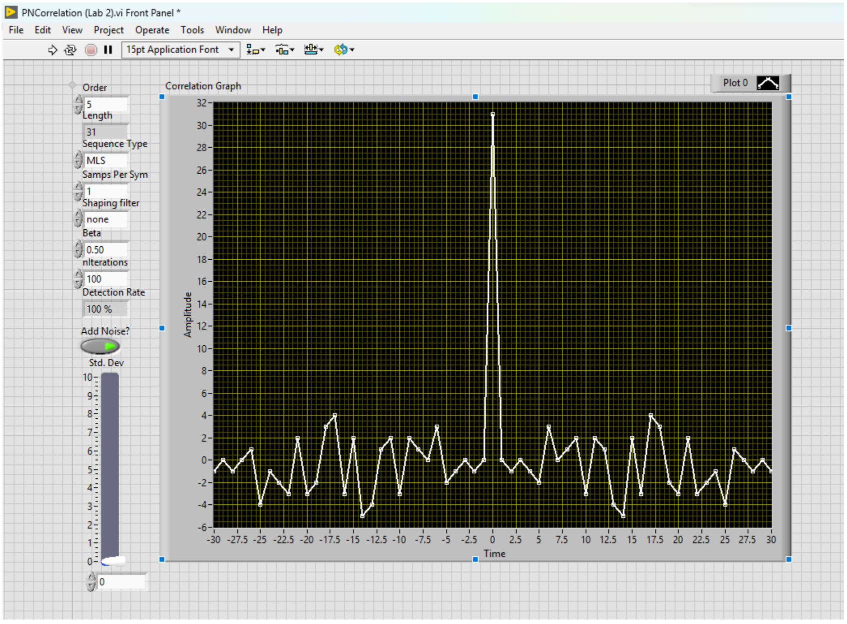


Figure 11: 3.1.2 - Correlation function for MLS

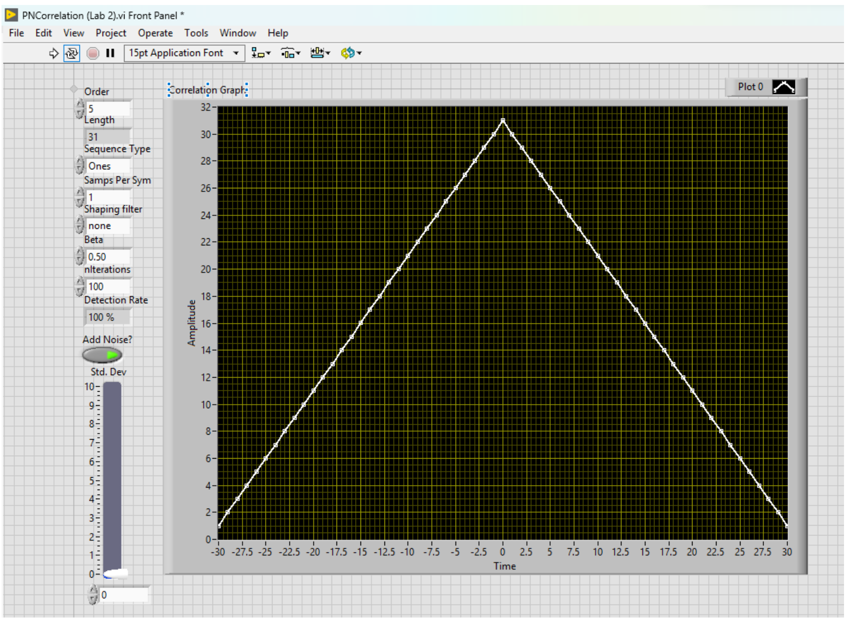


Figure 12: 3.1.2 - Correlation function for Ones

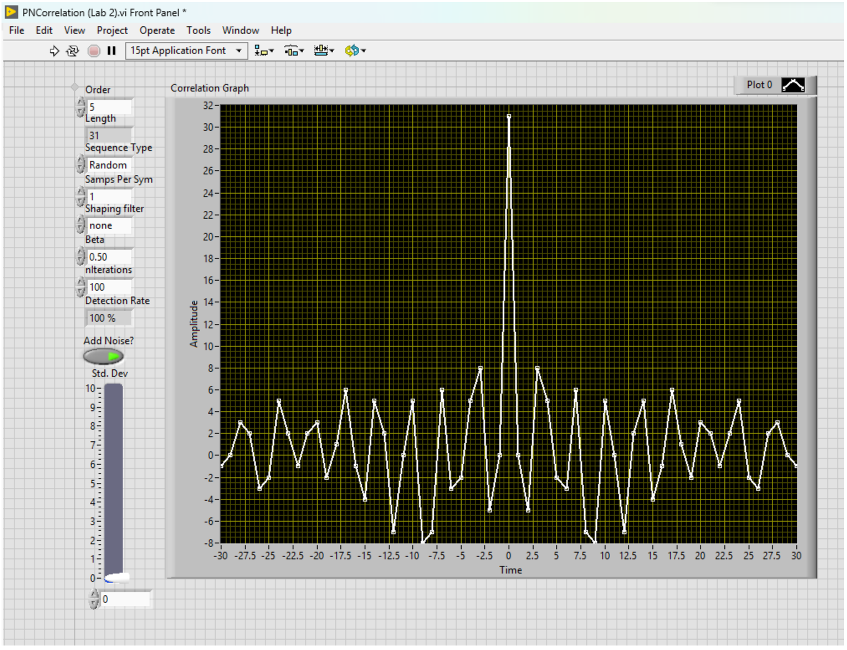


Figure 13: 3.1.2 - Correlation function for Random

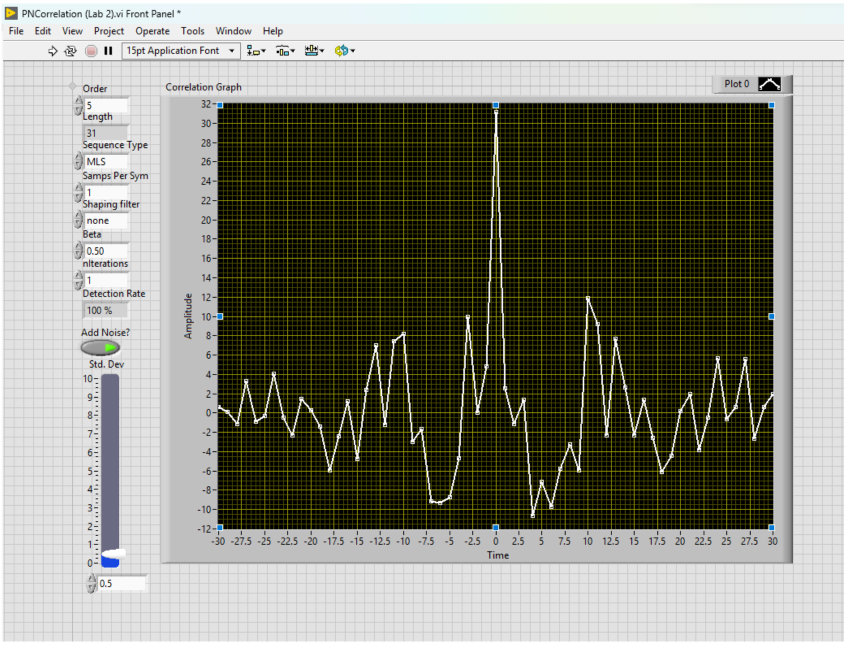


Figure 14: 3.1.4a - Correlation function for MLS with β = 0.5

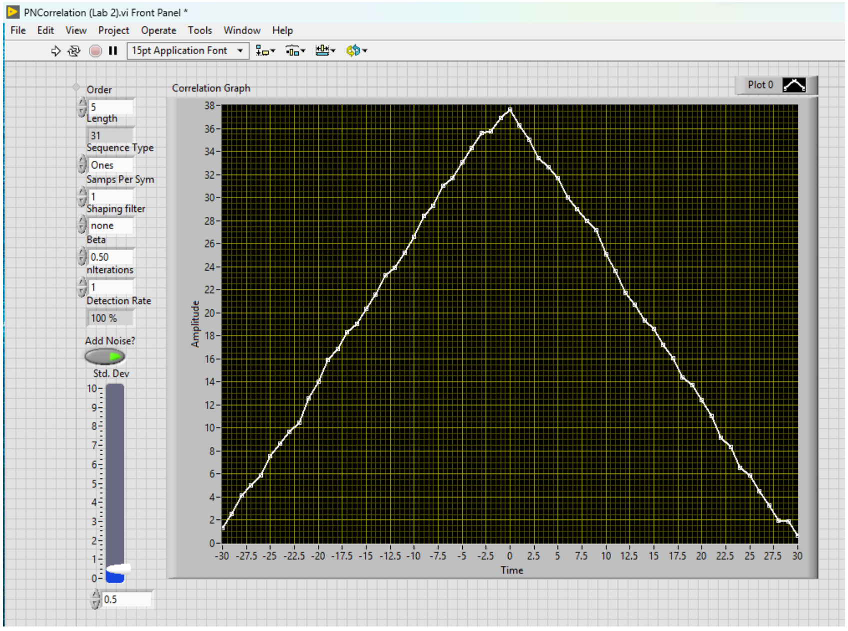


Figure 15: 3.1.4a - Correlation function for Ones with β = 0.5

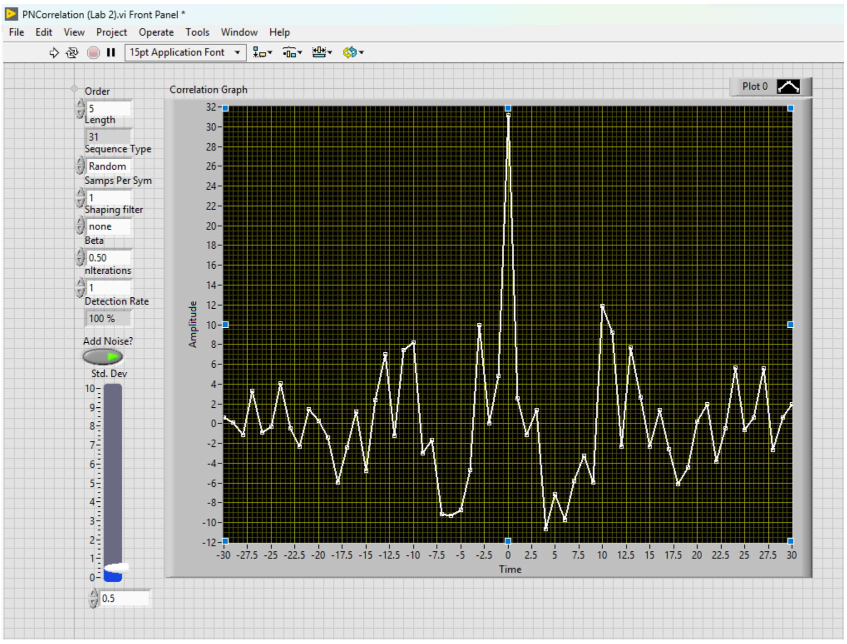


Figure 16: 3.1.4a - Correlation function for Random with β = 0.5

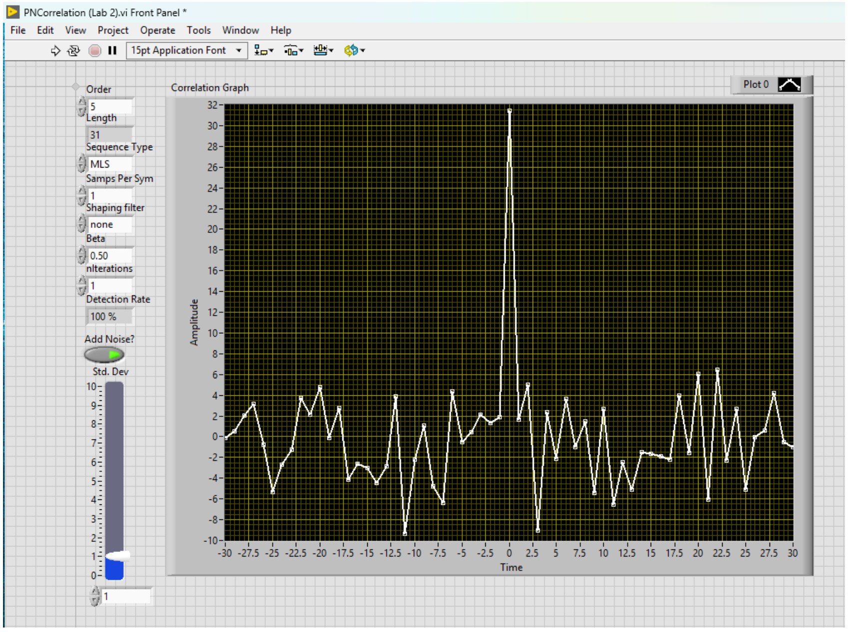


Figure 17: 3.1.4b - Correlation function for MLS with β = 1.0

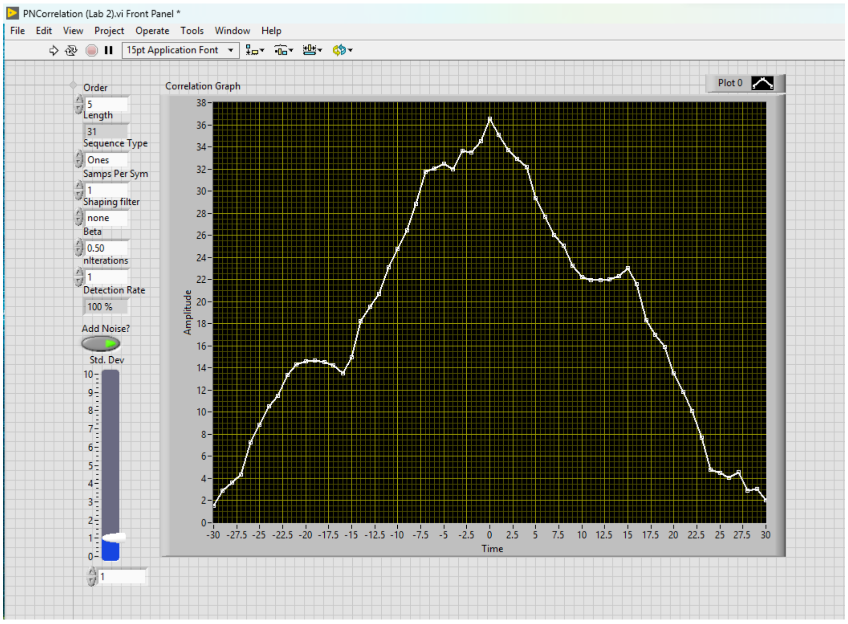


Figure 18: 3.1.4b - Correlation function for Ones with β = 1.0

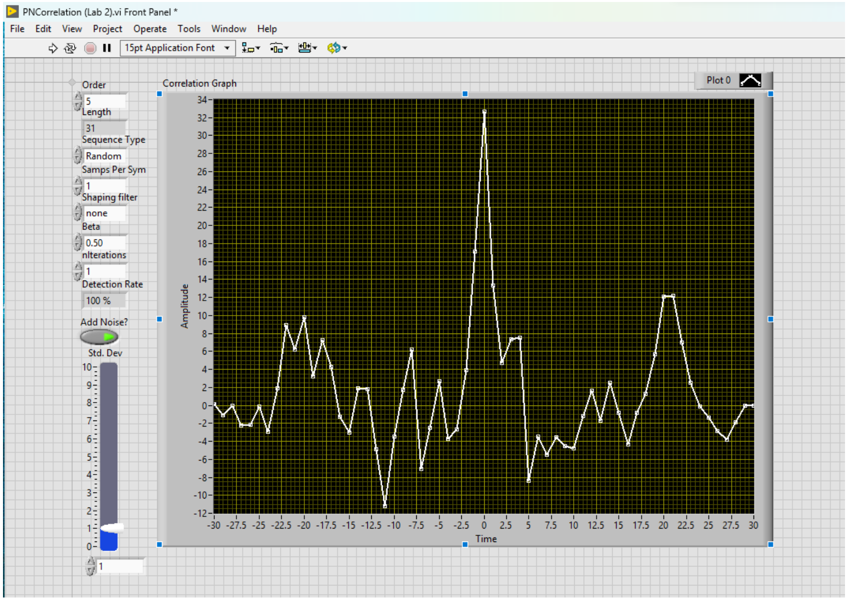


Figure 19: 3.1.4b - Correlation function for Random with β = 1.0

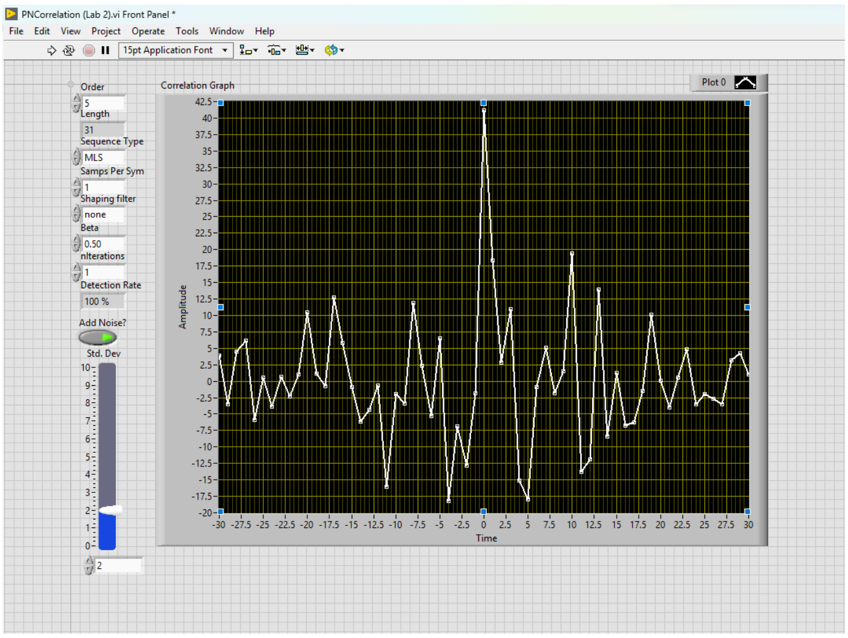


Figure 20: 3.1.4c - Correlation function for MLS with β = 2.0

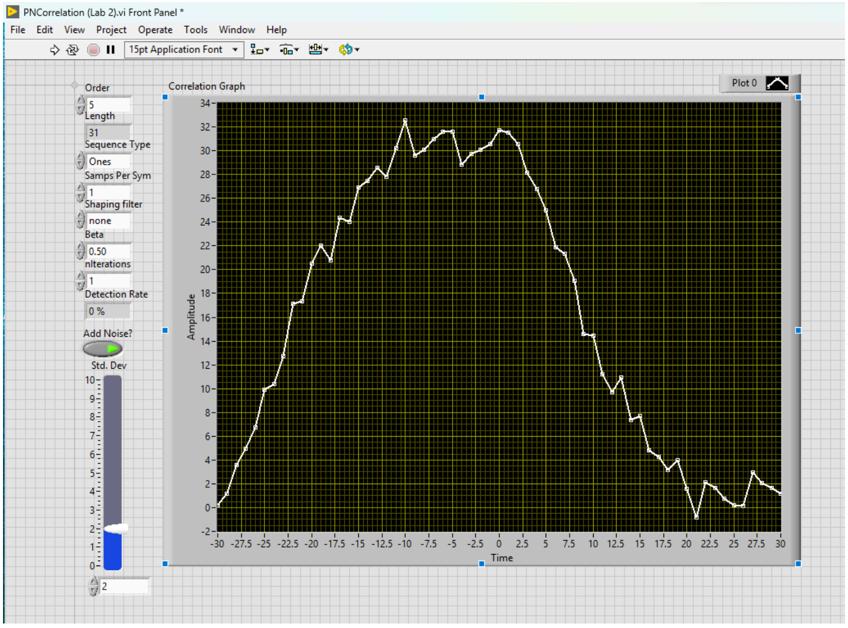


Figure 21: 3.1.4c - Correlation function for Ones with β = 2.0

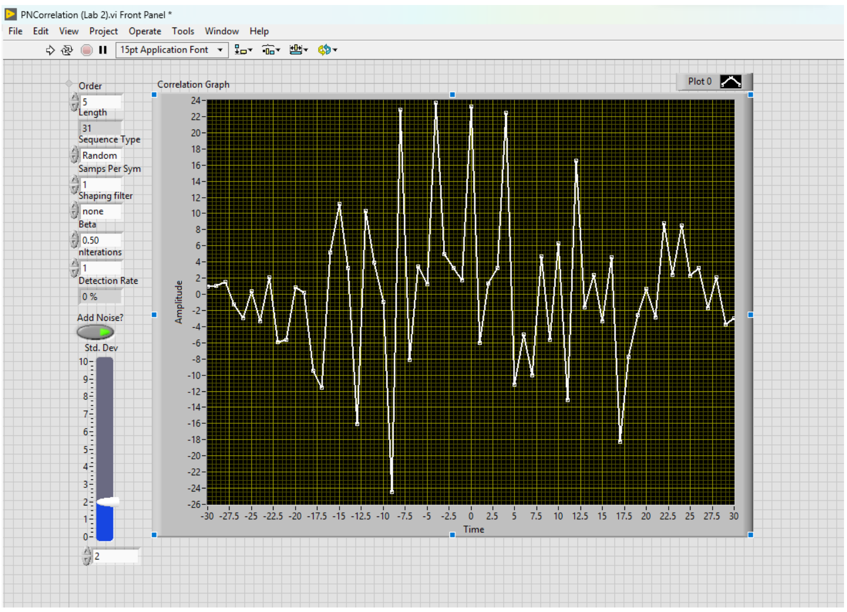


Figure 22: 3.1.4c - Correlation function for Random with β = 2.0

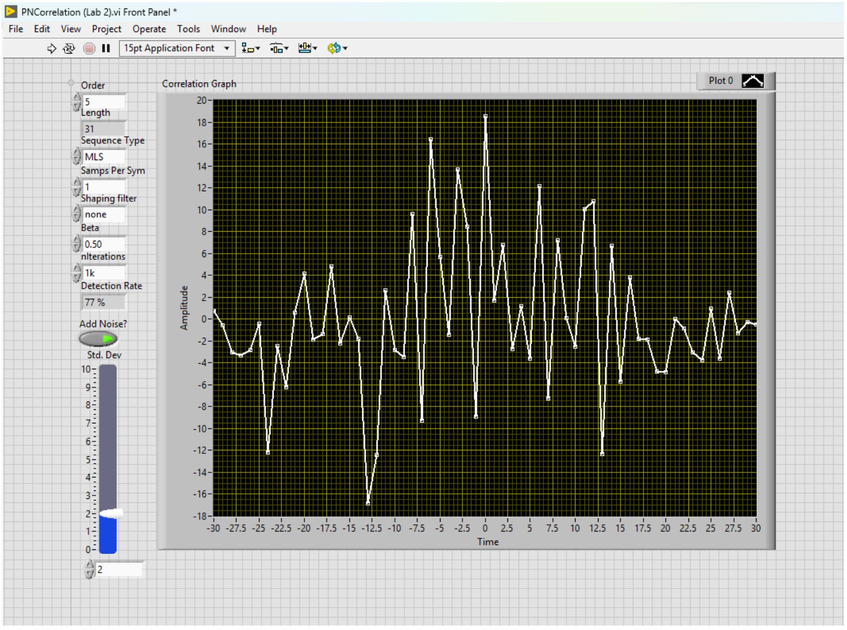


Figure 23: 3.1.5 - Correlation of Best Performing Sequence with $\beta = 2.0$ (MLS)

3.4 Additional Questions

1 -

$$T_{\text{sym}} = \frac{N}{f_s}, \qquad T_{\text{period}} = \frac{N \times (2^M - 1)}{f_s}$$

$$\Delta f = \frac{1}{T_{\text{period}}} = \frac{f_s}{N, (2^M - 1)}, \qquad \Delta f_{\text{null}} = \frac{1}{T_{\text{sym}}} = \frac{f_s}{N}$$

2 - PRBS sequences are used for frame synchronization because it uses a known, repeatable bit pattern whose autocorrelation has one strong, well-defined peak at zero lag. In practical terms this gives a clear correlation spike even at relatively low SNR, so the receiver can find the start of the frame quickly and reliably while still using a preamble with a fairly flat spectrum that stays within emission limits. When a receiver correlates the incoming signal with a locally generated PRBS sequence, the correlation output will produce a distinct peak when the sequences align indicating that a message is currently being sent. These sequences also have very little cross correlation with other sequences, making them useful for distinguishing between different users on the same channel.

4 Part 4: Eye Patterns (Simulation VI)

4.1 Narrative Questions

4.0.4 - Figure 19 shows that the largest value of Zeta occurs when the receiver samples at the centre of the eight-sample symbol, which is the fourth sample position. At that instant Zeta is 9.80653 for a raised-cosine pulse with Beta equal to 1.

4.0.5a - For Beta equal to zero, Zeta plunges from about ten to roughly two within one sample on either side of the optimum in Figures 20 through 22. With Beta equal to one-half the fall-off is even sharper, dropping to almost zero in Figures 23 through 25. By contrast, the broader pulse in Figure 19 with Beta equal to one loses only a fraction of a decibel over the same shift, showing that wider roll-off is far less sensitive to sampling error.

4.0.5b - Beta equal to one-half is the most sensitive to sampling time because Zeta collapses from about 10.35 to essentially zero with a single-sample shift.

4.0.5c - Beta equal to one is the least sensitive. The wider roll-off spreads the pulse energy so inter-symbol interference grows more slowly when the sampling instant moves away from the optimum, leaving Zeta almost unchanged across neighbouring samples, as suggested by the gentle eye opening in Figure 19.

4.0.6a - With no transmit filter the rectangular pulse in Figure 26 gives a peak Zeta of about 9.97. When moving the sampling point a single sample early or late, the eye closes noticeably faster than it does for the raised-cosine pulse with Beta equal to one shown in Figure 19, yet not nearly as abruptly as for the tighter roll-off cases in Figures 20 through 25. As a result, its timing sensitivity resides between those two extremes.

4.0.6b - The peak Zeta of 9.97 for the unfiltered case is only a couple of percent higher than the 9.81 recorded for Beta equal to one in Figure 19, so the two optimal values are practically the same. The key difference is not the height of the peak, but how rapidly Zeta drops when the timing slides away from it.

4.0.7 - At the best sampling instant Zeta is about 10.30 for Beta equal to zero, 10.35 for Beta equal to one half, 9.81 for Beta equal to one, and 9.97 for the unfiltered rectangular pulse. Narrower roll-off factors concentrate more signal energy at the center of the symbol, giving a slightly larger eye opening, but they also tighten the transition slopes so any timing error hurts much more. A wider roll-off sacrifices a small amount of peak Zeta yet offers a more forgiving eye diagram.

4.2 Figures

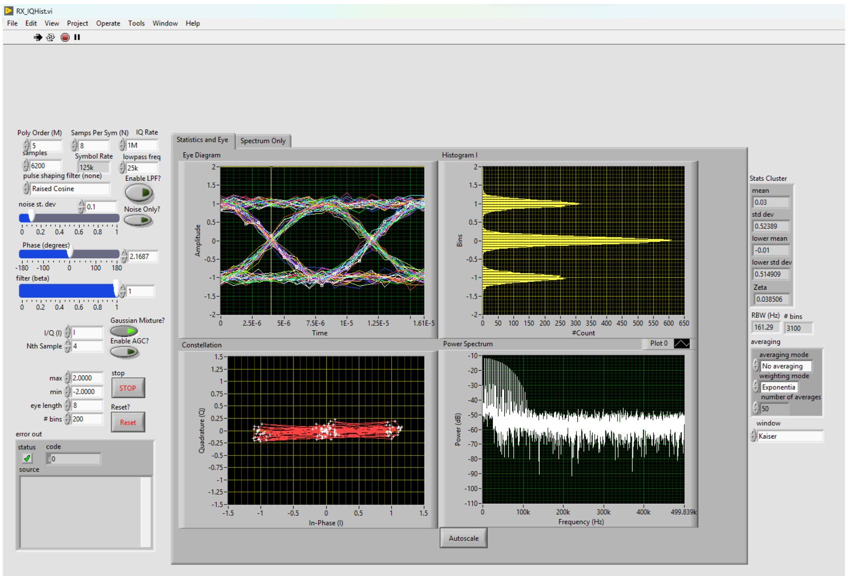


Figure 24: [4.0.3: Nth Sample 4 - Three Histograms]

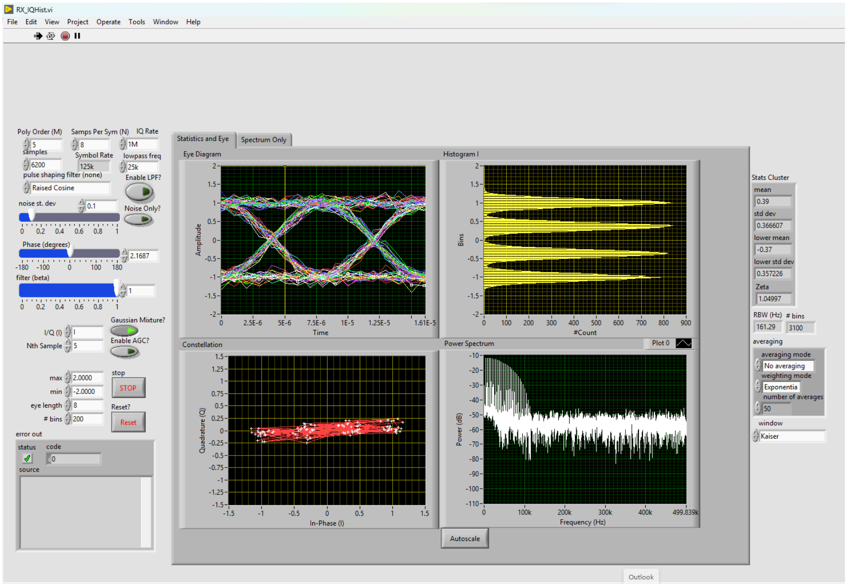


Figure 25: [4.0.3: Nth Sample 5 - Four Histograms]

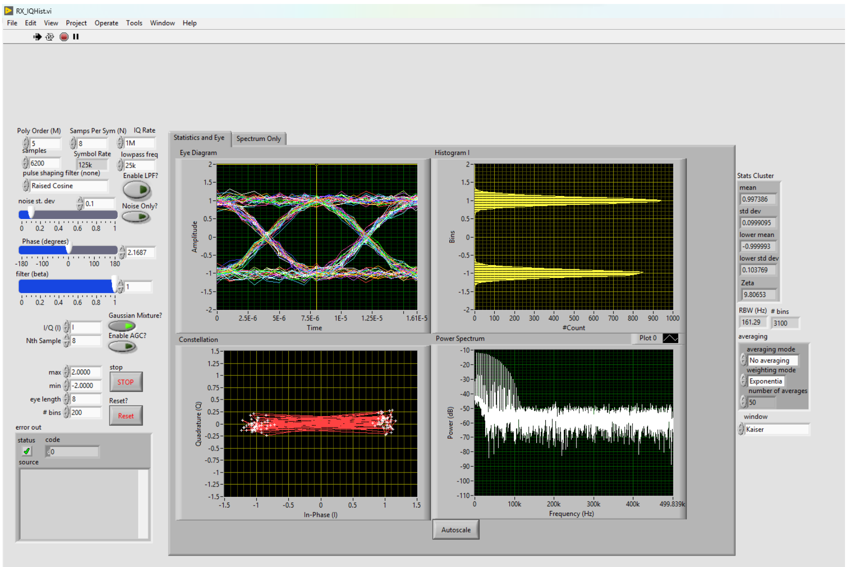


Figure 26: [4.0.4: Eye Trace and Histogram at Optimal Time [Beta = 1 — Zeta = 9.80653]]

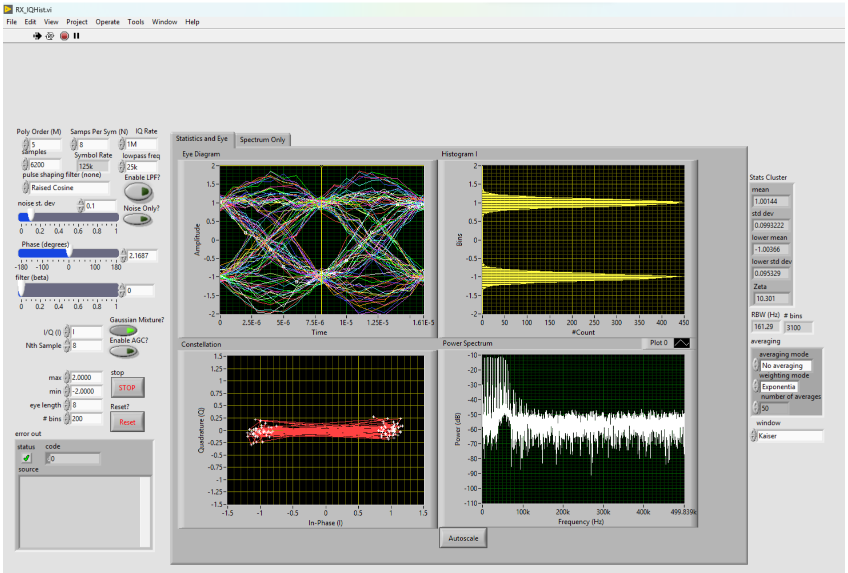


Figure 27: [4.0.5: Two Histograms [Beta = 0 — Zeta = 10.301]]

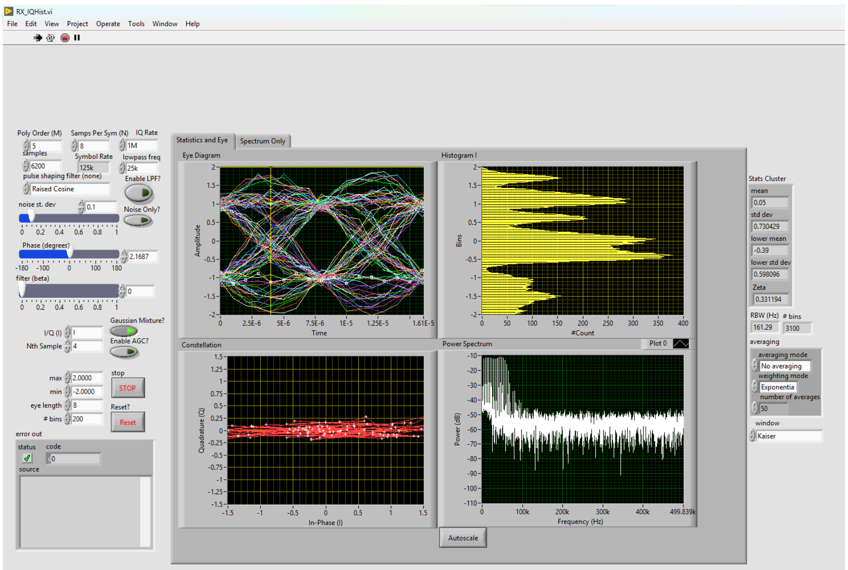


Figure 28: [4.0.5: Three Histograms [Beta = 0 — Zeta = 0.331194]]

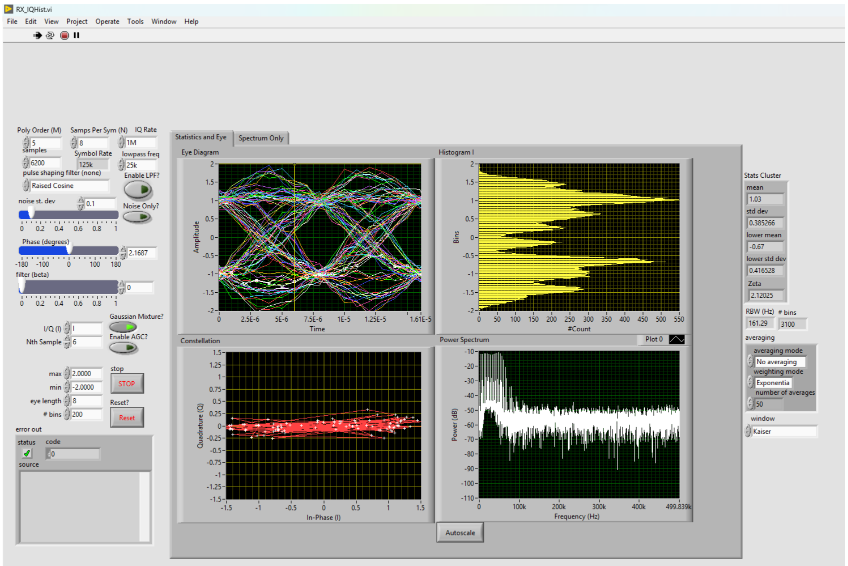


Figure 29: [4.0.5: Four Histograms [Beta = 0 — Zeta = 2.12025]]

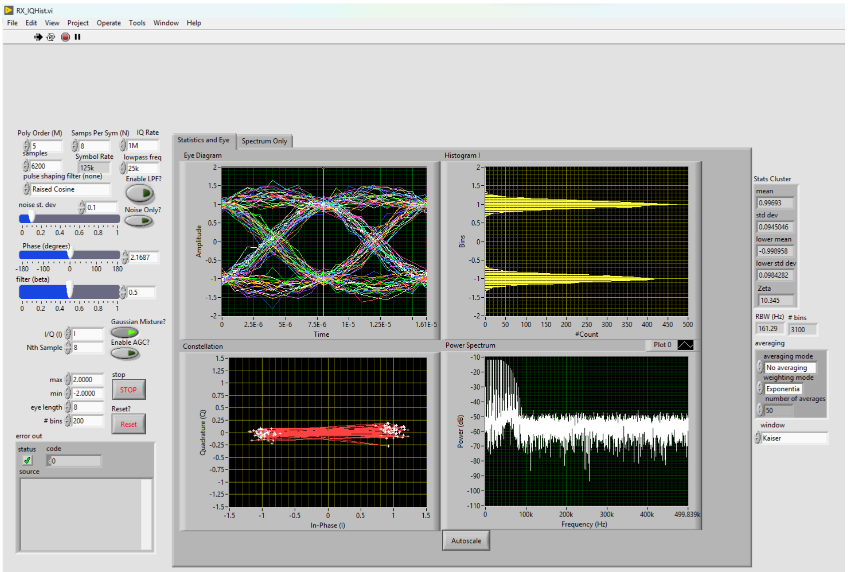


Figure 30: [4.0.5: Two Histograms [Beta = 0.5 — Zeta = 10.345]]

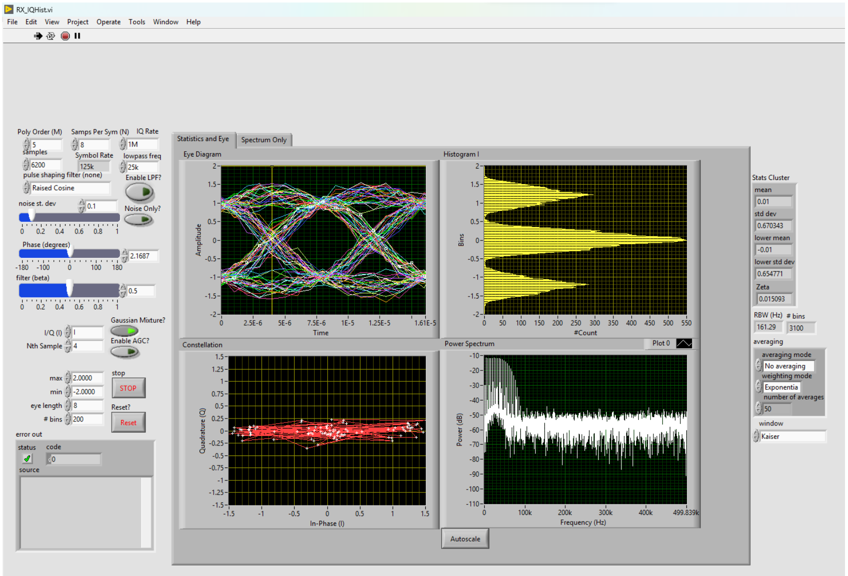


Figure 31: [4.0.5: Three Histograms [Beta = 0.5 — Zeta = 0.015093]]

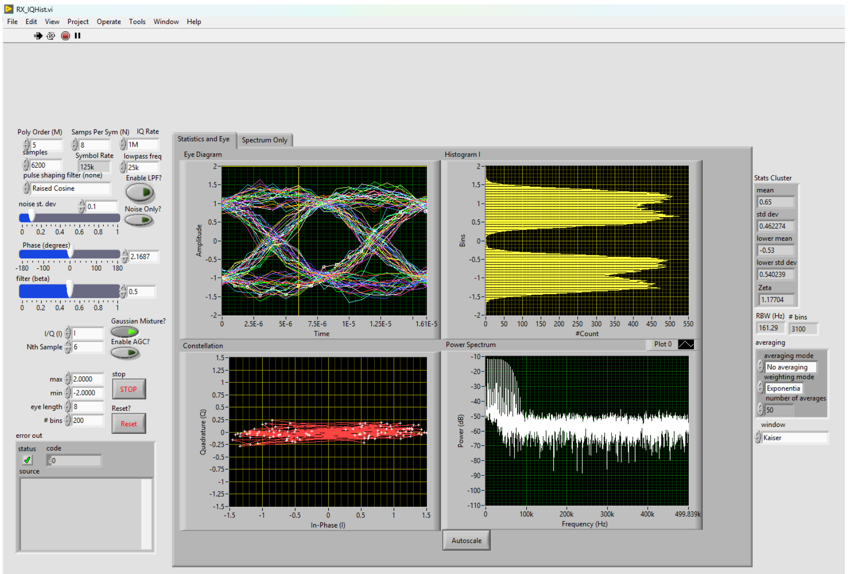


Figure 32: [4.0.5: Four Histograms [Beta = 0.5 — Zeta = 1.17704]]

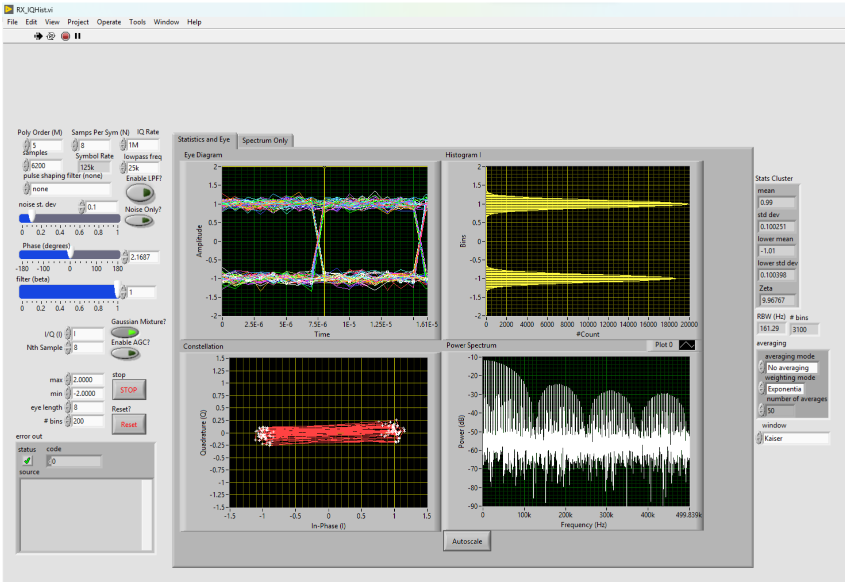


Figure 33: [4.0.6: Transmit Filter None [Zeta = 9.96767]]

4.3 Interference and Low-Pass Filtering

4.3.A Narrative Questions

[4.1.1a] When the Butterworth cut-off sits at two-hundred percent of the symbol rate the eye remains wide and clean in both the raised-cosine capture (Figure 27) and the unfiltered capture (Figure 30). Dropping the cut-off to one-hundred percent trims high-frequency content so the openings shrink noticeably, as seen in Figures 28 and 31. A further drop to fifty percent removes much of the spectrum that separates adjacent symbols; inter-symbol interference smears the crossings and the eyes in Figures 29 and 32 are almost closed. The progressive closure happens because a tighter bandwidth stretches each symbol in time, making successive bits overlap and crowd the decision point.

[4.1.1a.i] The low-pass filter makes the signal more vulnerable to inter-symbol interference than the raised-cosine pulse-shaping alone. The raised-cosine waveform is already designed to satisfy the Nyquist criterion, so even after the extra filtering its eye retains a clearer opening, whereas the unfiltered sequence loses definition much faster at the same cut-off settings.

4.3.B Figures

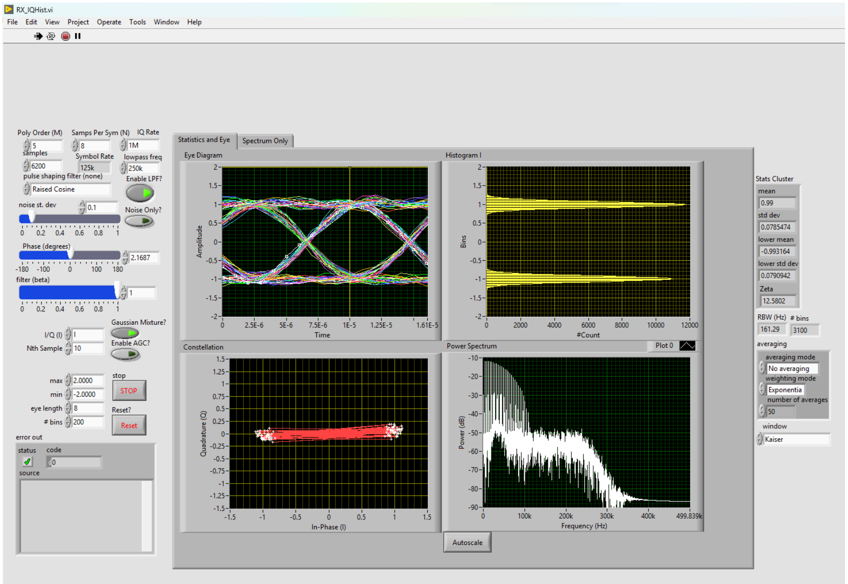


Figure 34: [Cut-Off Frequency 200 Percent - Raised Cosine Filter]

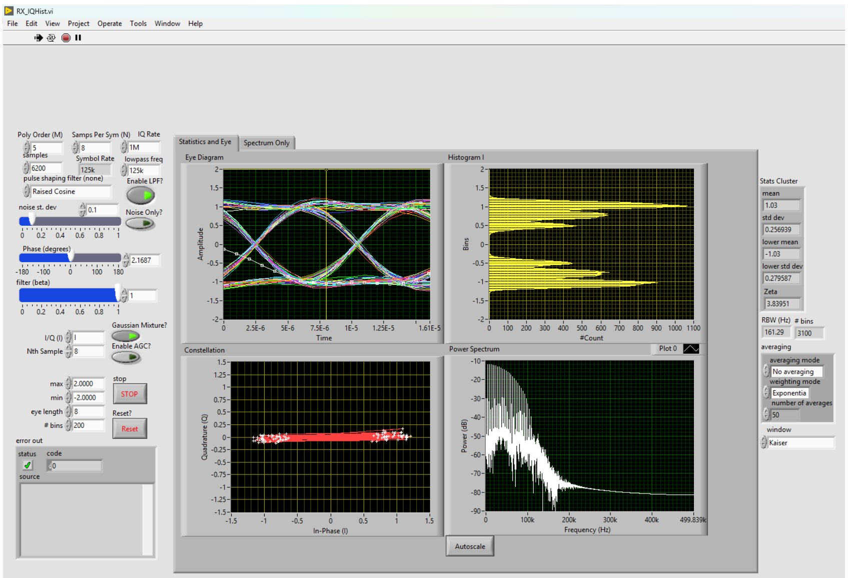


Figure 35: [Cut-Off Frequency 100 Percent - Raised Cosine Filter]

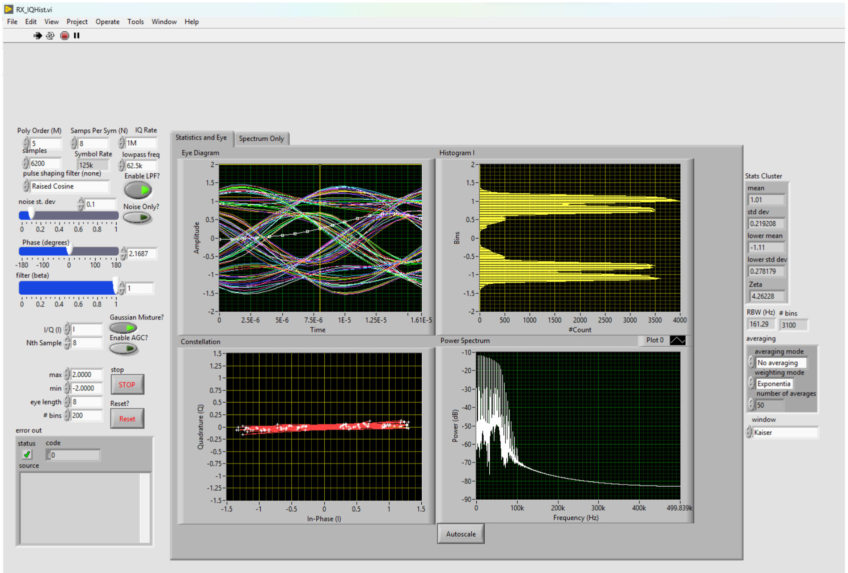


Figure 36: [Cut-Off Frequency 50 Percent - Raised Cosine Filter]

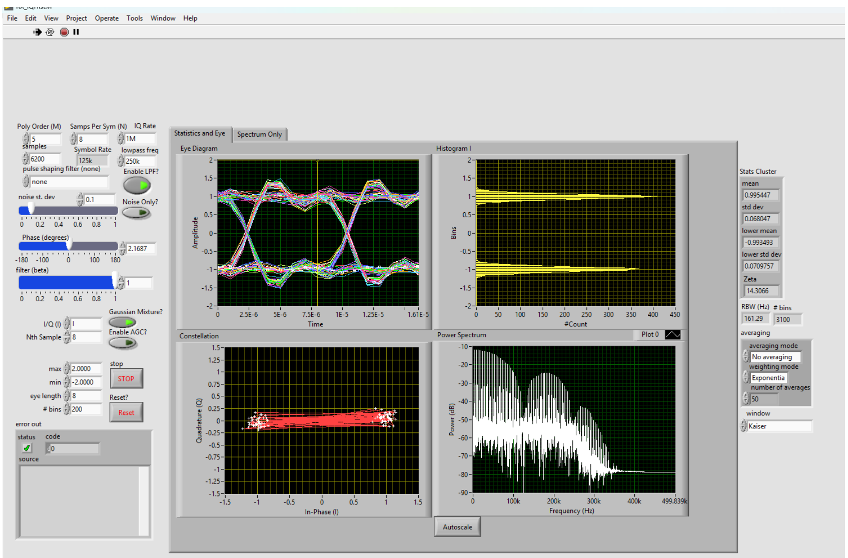


Figure 37: [Cut-Off Frequency 200 Percent - Un-Filtered]

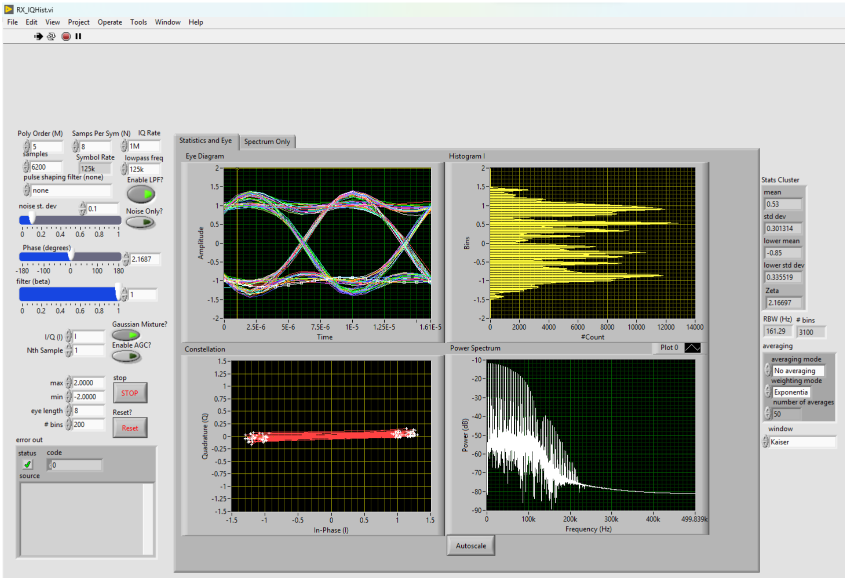


Figure 38: [Cut-Off Frequency 100 Percent - Un-Filtered]

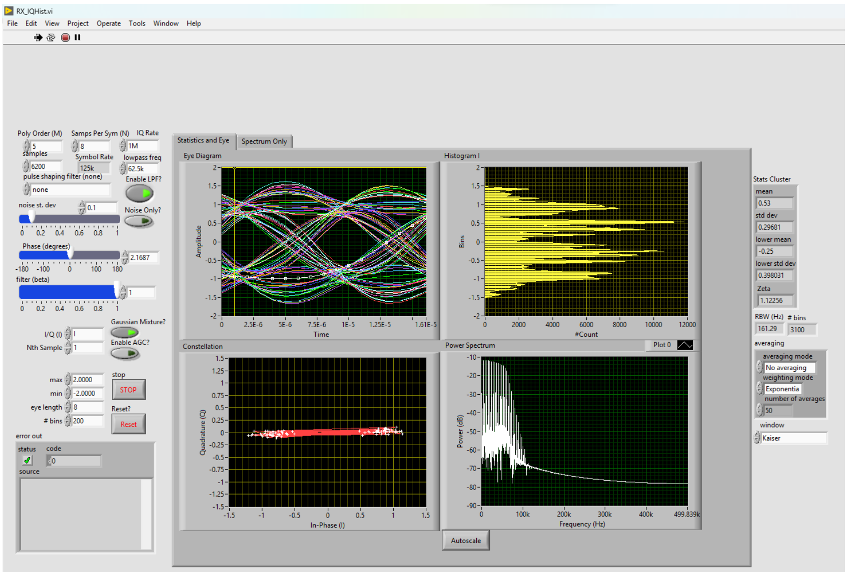
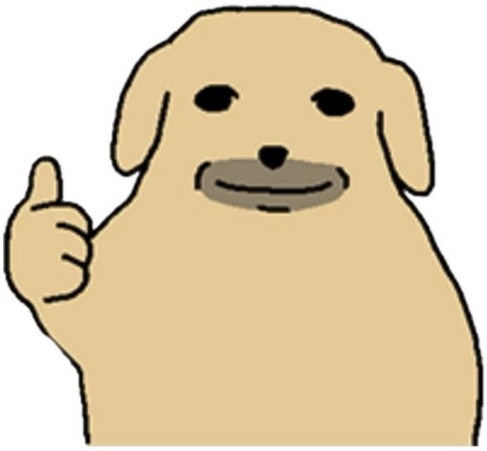


Figure 39: [Cut-Off Frequency 50 Percent - Un-Filtered]



feelsgoodman