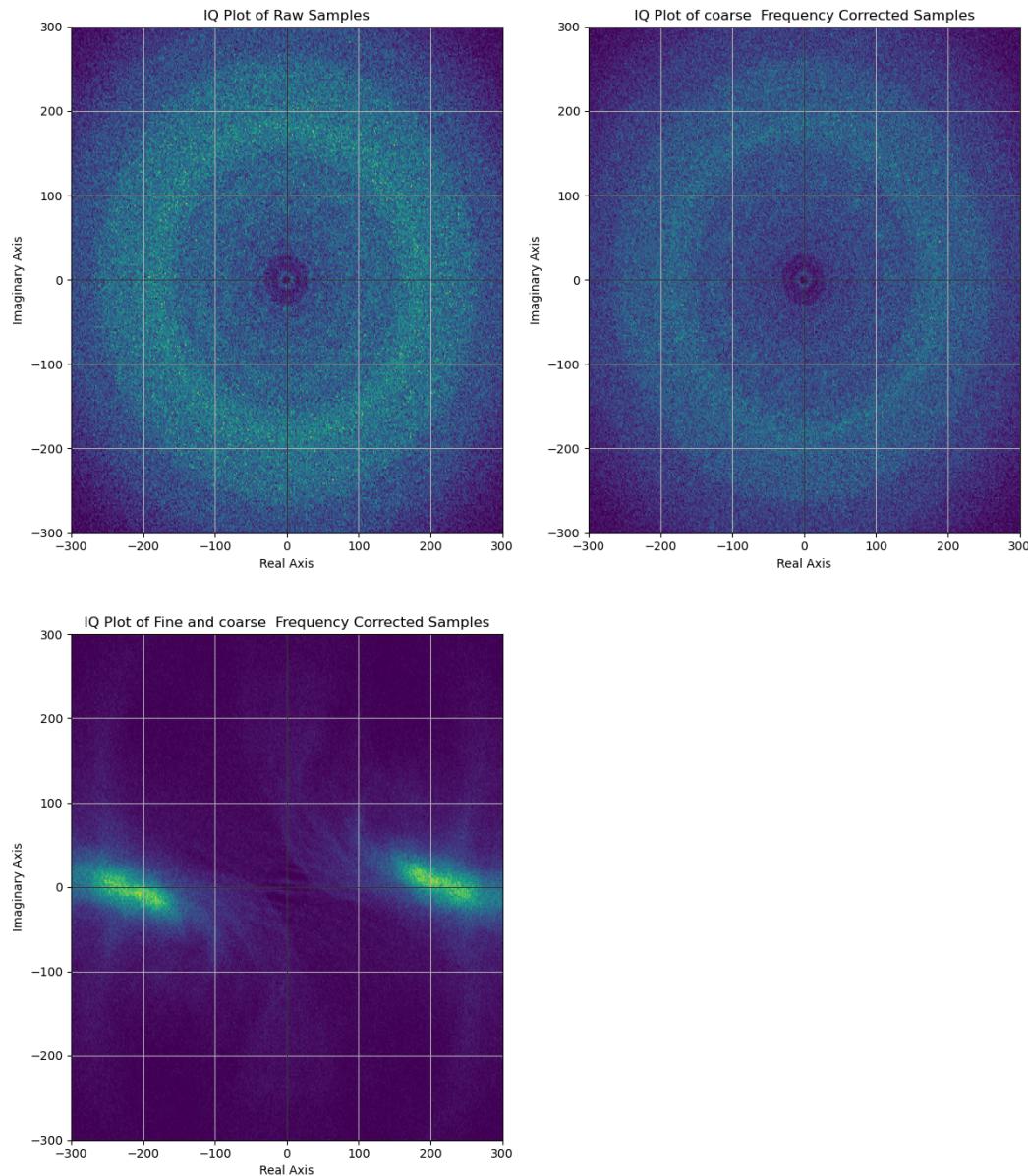


## ECE331X - Module 4

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Module 4 focuses on implementing a digital phase locked loop (DPLL) using a Costas loop to correct the phase rotation found in the binary phase shift keying (BPSK) transmission at 915 MHz. The overall goal of this module is to be able to intercept a signal, record it for processing, then design and implement a phase tracking system that can lock onto the transmission signal despite noise and phase drift. By the end, we were able to extract clear before and after constellation plots that showcased the phase error convergence behavior. In theory, once we have been able to get a lock on the signal we would be able to decode it into actual words or information being transmitted, but in practice we were not so successful.



### **IQ Plot Analysis:**

In the top left, the IQ plot of the raw samples shows a large circular “ring” shape. This happens because the BPSK signal has a phase rotation and frequency offset that we have not coarse corrected yet. Instead of two fixed points, the samples spin around the origin over time, which makes the constellation and the signal itself unreadable. The wide spread in the ring also reflects real-world noise and multipath, since the signal was captured over the air.

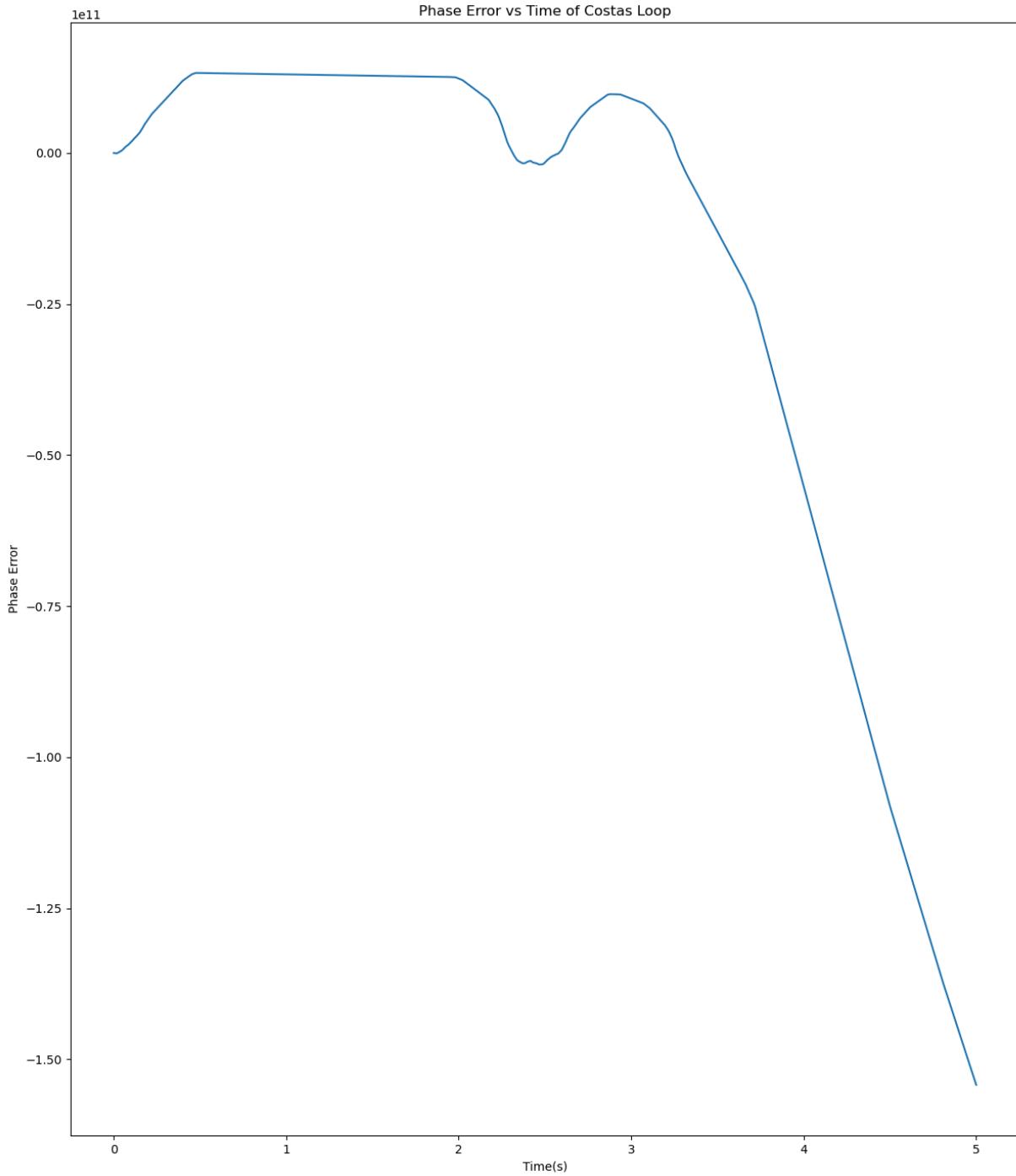
After coarse frequency correction, the top right plot still shows a ring, but the samples rotate more slowly and the distribution looks slightly tighter. This means we removed most of the large frequency offset, but there is still some fine frequency error and phase drift present. At this stage, the signal is improved, but we are still not able to determine the actual location of any given data point so we have no way of decoding the signal. This confirms that we need a Digital Phase Lock Loop to continuously track and correct the remaining phase changes.

Finally, once the DPLL using the Costas loop is applied, the constellation becomes significantly more stable. The plot now shows two clear clusters, which is what we expect for BPSK. There is still some spreading due to noise and small imperfections in the loop tuning, but the signal is now corrected well enough to make symbol decisions. This final result on the bottom left shows that the DPLL successfully locked onto the phase and removed the rotation seen in the earlier plots. We also feel pretty confident in our ‘lock’ because of the phase error graph sloping into an asymptote shown in the graph below.

This is important because a BPSK signal with uncontrolled phase rotation cannot be decoded reliably. By applying this correction and then a DPLL, we stabilize the constellation, so the receiver can correctly recover the transmitted data. Without this phase-locking step, the captured signal would remain unusable. One additional step we corrected for was a static 90 degrees phase offset. This means our timing/synchronization was off, so the clusters appeared on the imaginary axis rather than the real axis. We corrected for this by rotating the output of the Costas loop by 90 degrees, this works because BPSK has a 0 or 180 degree phase offset, so when decoding later on we are able to account for the value of each of the samples.

### **Decoding**

In an effort to try to decode the samples, we tried a combination of different symbol rates. The number of samples per symbol can change the output of an ASCII character greatly. We had some trouble finding anything that seemed to make sense and tried to test different sections of the data as well. We decided the left cluster, or values less than zero, was 0s and the right or positive cluster was 1s, that could also have had an effect. Furthermore, we think that potentially more specific tuning and using a different method to determine the values could help us successfully decode the signal for the next lab.



The above plot shows the phase error reported by the Costas loop over time as it works to lock onto the BPSK signal. At first, the error is extremely large, due to the fact that the loop is not yet synchronized to the carrier. However, as time progresses, the error settles into a narrower band, meaning that the loop is tracking the phase more consistently despite noise causing it to fluctuate moderately. The overall decrease and stabilization in this graph shows that the DPLL has successfully locked on to the signal.

**Who Did What:**

Coarse Frequency Correction - Fiona P.  
Fine Frequency Correction and Filtering - Phil W.  
Graphs - Nathan C., Fiona P., and Phil W.  
Lab Write-Up - Nathan C and Fiona P.  
Attempted decoding - Fiona P. :(