EE 340 Communication Lab

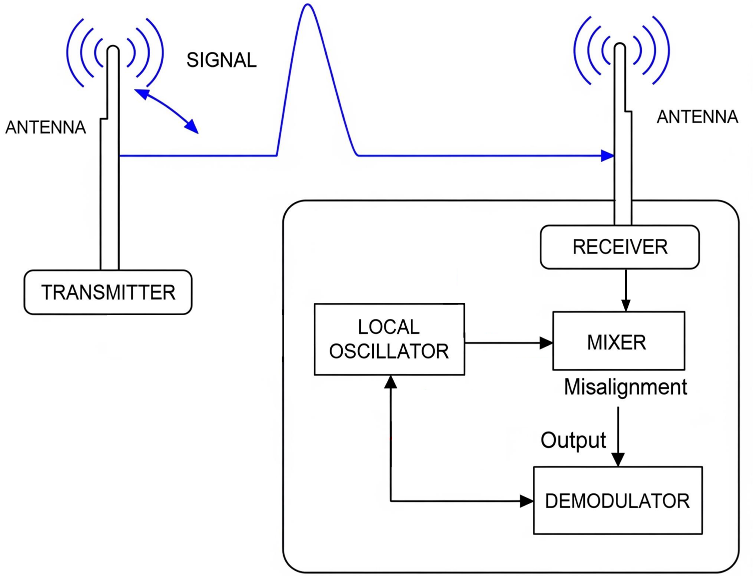
Lab 8

Carrier Frequency and **Phase Synchronization** in Communication Links

Outline

- Why Frequency Synchronization?
- Costas Loop
- Viterbi–Viterbi Algorithm
- Differential Coding

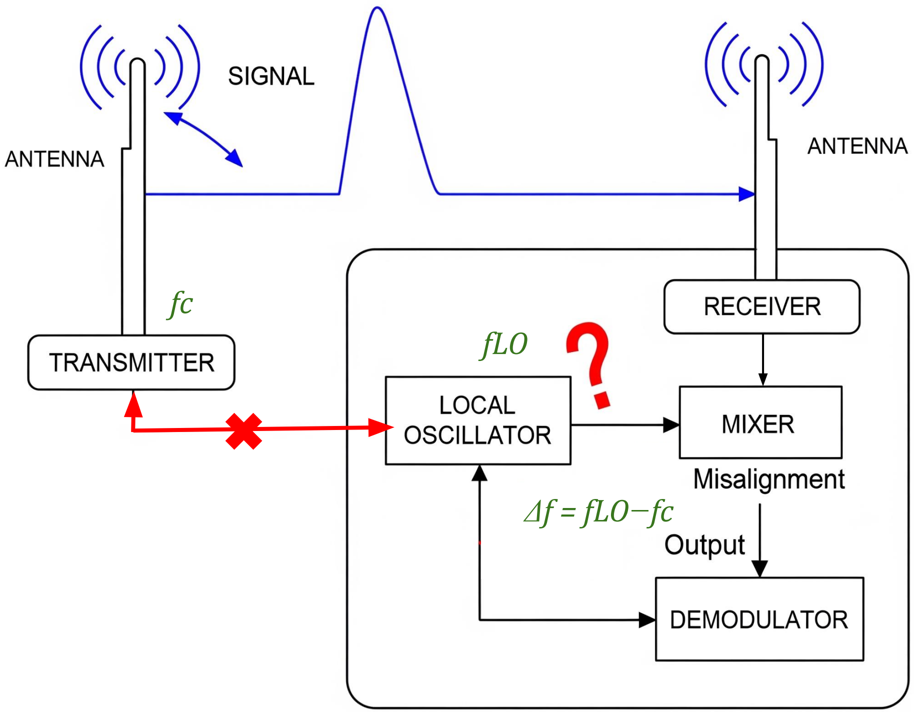
Why Synchronization ?



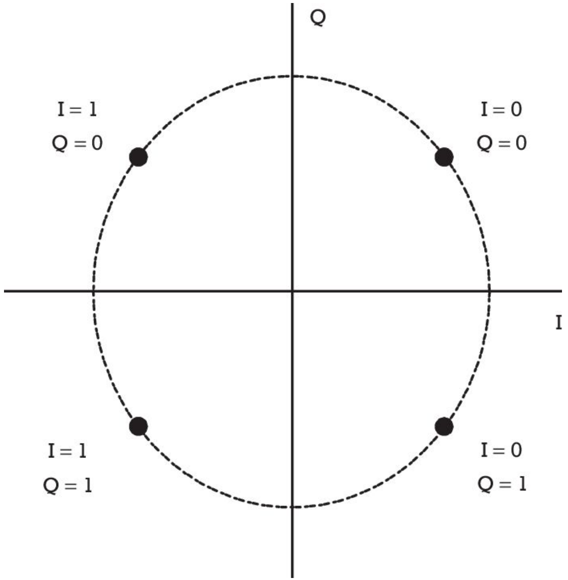
- Modern digital communication techniques use phase modulation (BPSK, QPSK,8-PSK etc.)
- Demodulation often relies on coherent techniques
- Requires the receiver to know or derive the carrier wave's phase and frequency precisely

Why Synchronization ?

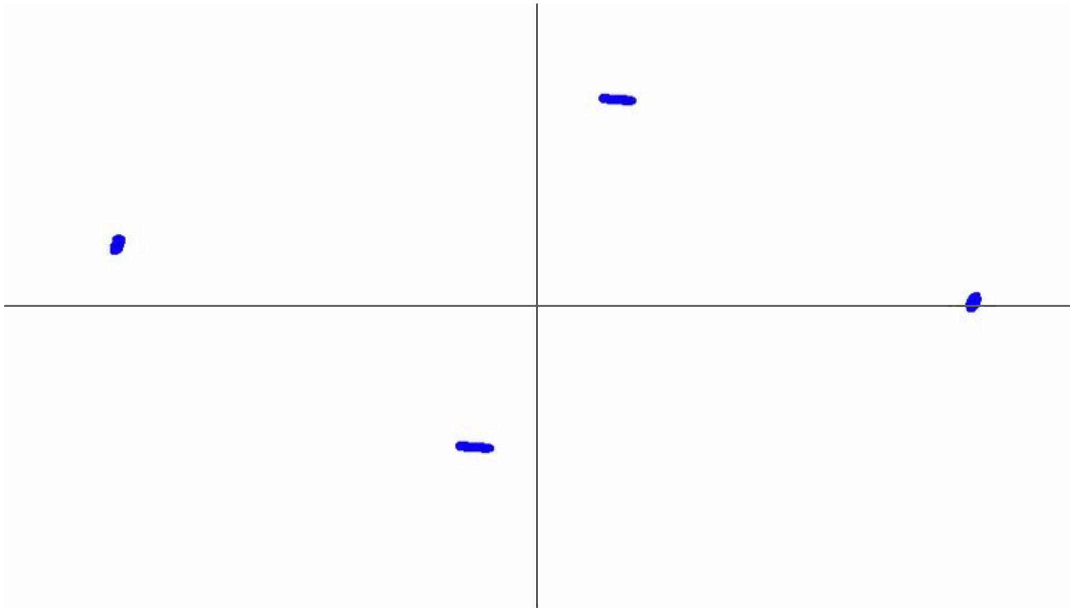
- Receiver uses a local oscillator (LO) generated from a separate reference.
- This LO naturally has a non-zero frequency and phase offset compared to the incoming carrier.
- When RF signal is down-converted using this offset frequency, the resultant baseband signal still contains the **undesired carrier frequency (and phase) offset**



Carrier Offset Observation



Expected Constellation

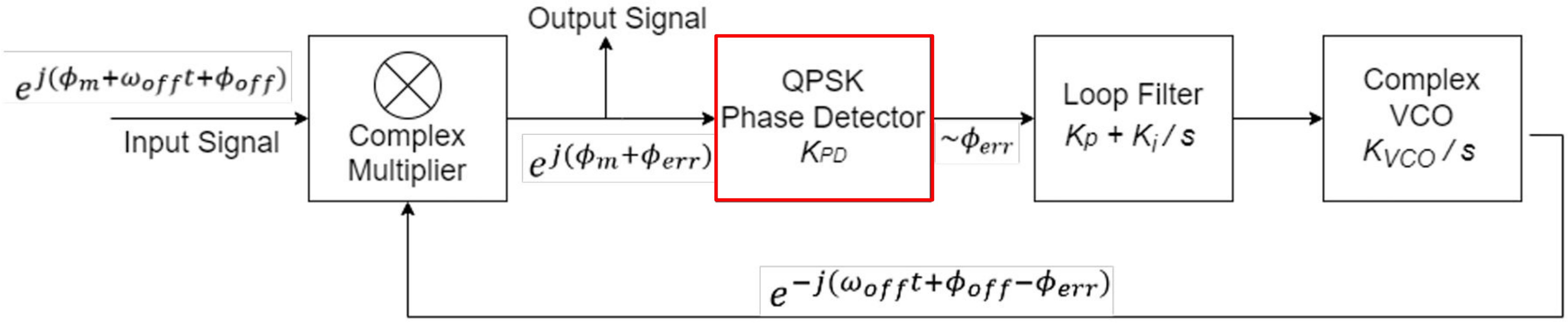


Observed constellation with frequency offset (rotating points)

Motivation

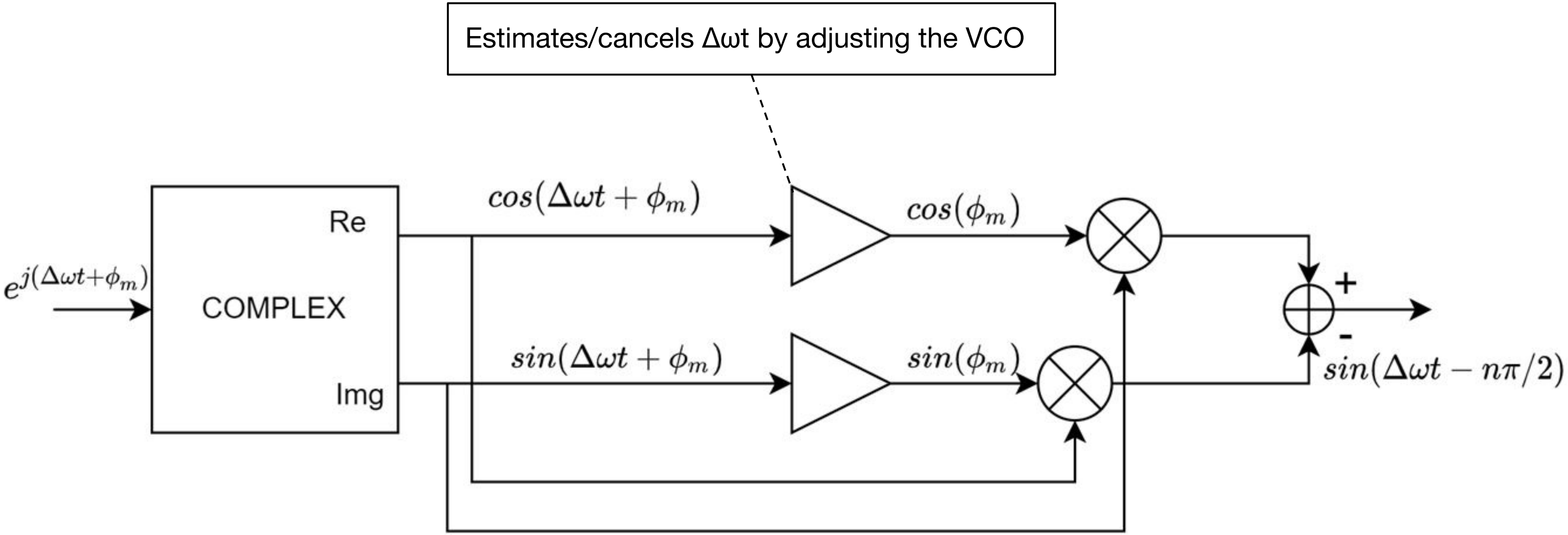
- We need techniques to remove these offsets from the signal (settles the constellation to the desired pattern)
- This lab explores two main techniques:
  – Costas Loop
  – Viterbi–Viterbi Algorithm

Costas Loop

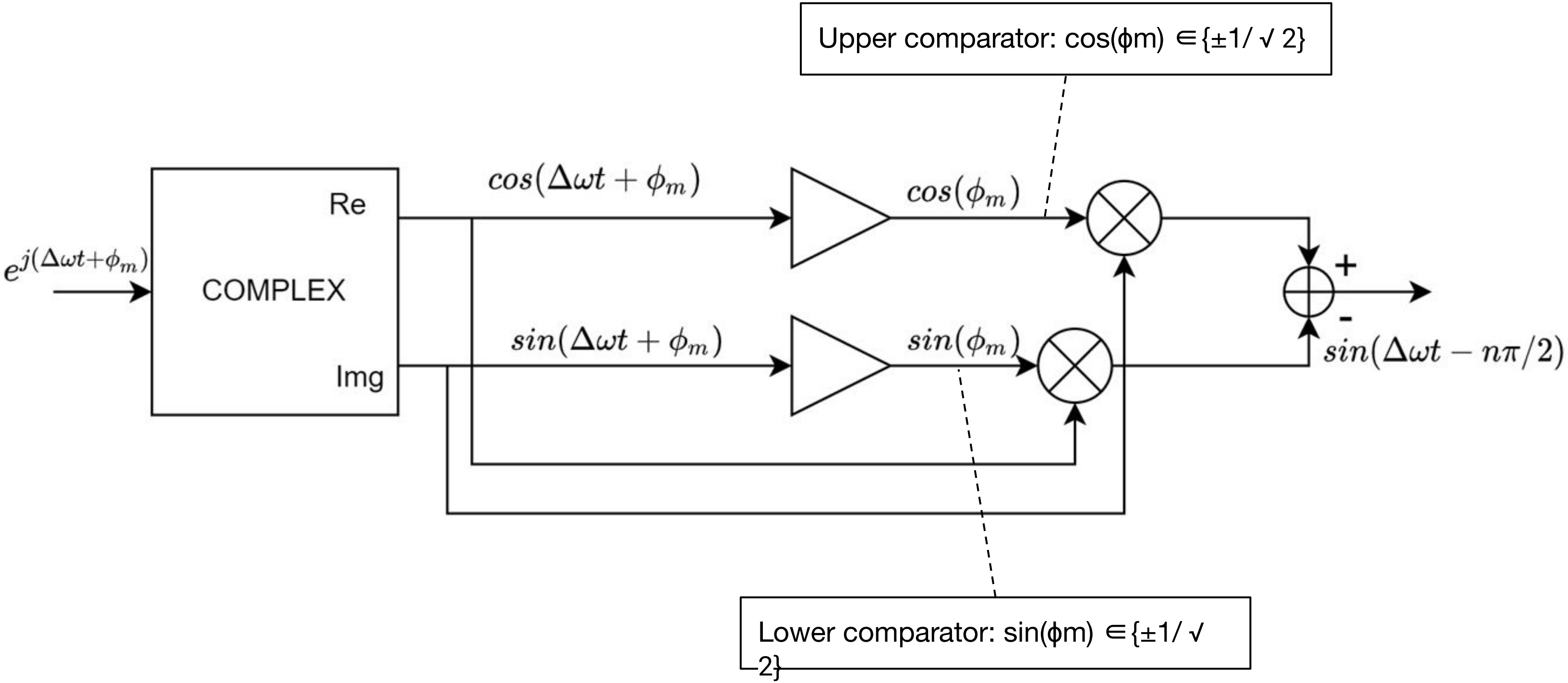


- Costas Loop is fundamentally a Phase Locked Loop (PLL).
- Uses a specialized **phase detector** capable of generating the carrier phase error
- Assumption: Phase error lies within ±π/4.

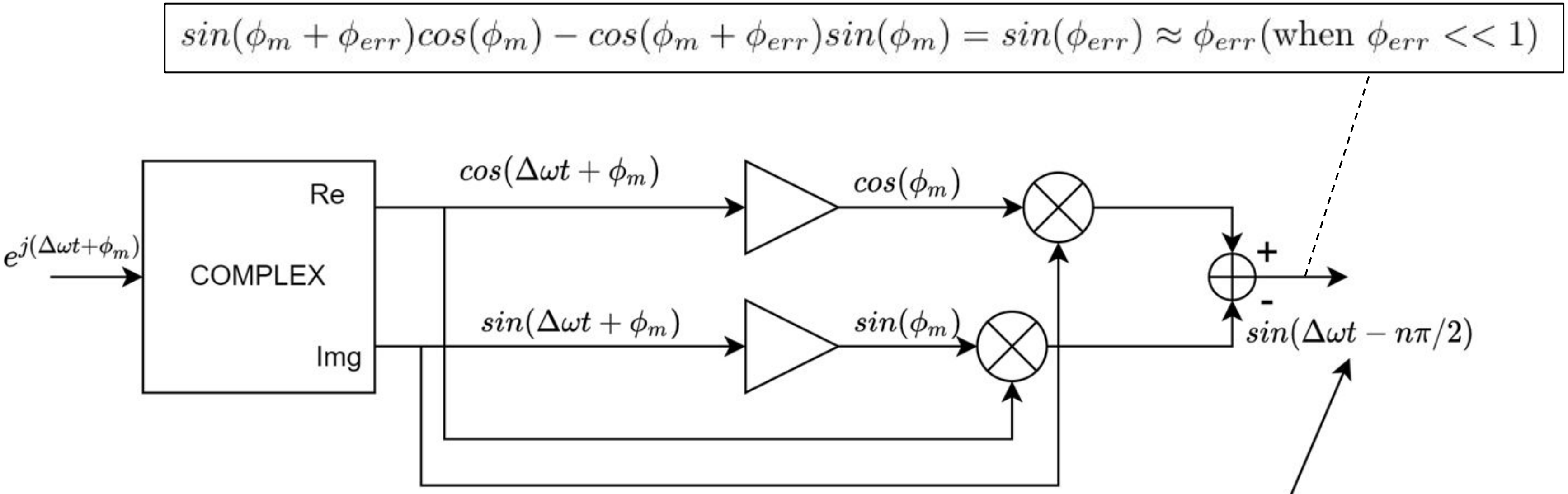
QPSK Phase Detector



How the Detector Generates Error



How the Detector Generates Error



Assuming ϕ_m is $\pm(\frac{\pi}{2} \pm \frac{\pi}{4})$, and the comparators generate $\pm 1/\sqrt{2}$, we get this output.

Here n is such that $-\frac{\pi}{4} < \Delta\omega t - n\frac{\pi}{2} < \frac{\pi}{4}$.

Demapping

- If the phase error exceeds $\pm\pi/4$, an ambiguity of $\pm n\pi/2$ is added to ϕm
- Does this ambiguity change the constellation diagram?

  No
- This $\pm n\pi/2$ ambiguity is removed later using **demapping**
- Mapping between transmitted and received symbol constellations via known bit sequences

Results

Constellation with frequency offset (before Costas Loop)

Constellation with frequency offset (after Costas Loop)

Viterbi-Viterbi Algorithm

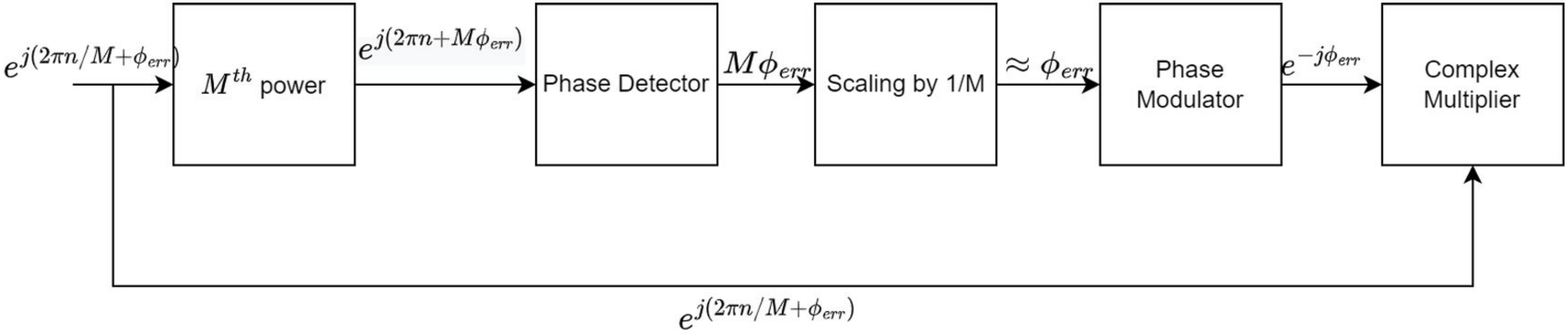
- Viterbi-Viterbi algorithm is a non-data aided mechanism designed for estimating the carrier phase of **M-PSK signals** (M=1,2,4 etc.)

Mechanism for M-PSK Signals

- **Mth Power:** The M-PSK signal $\left(e^{j\left(\frac{2\pi n}{M}+\phi_{err}\right)}\right)$ is taken to its Mth power
  - This step removes the M-ary modulation.
  - Crucially, this results in an M-fold multiplication of the phase error. (For 8-PSK, M=8)
- **Phase Detector:** The argument of the resulting signal is taken (i.e., arctan Real/Img), which yields the estimated phase error

$$\hat{\phi}_{err} = \frac{1}{M}\arctan(e^{j(\frac{2\pi n}{M}+\phi_{err})M})$$

Mechanism for M-PSK Signals

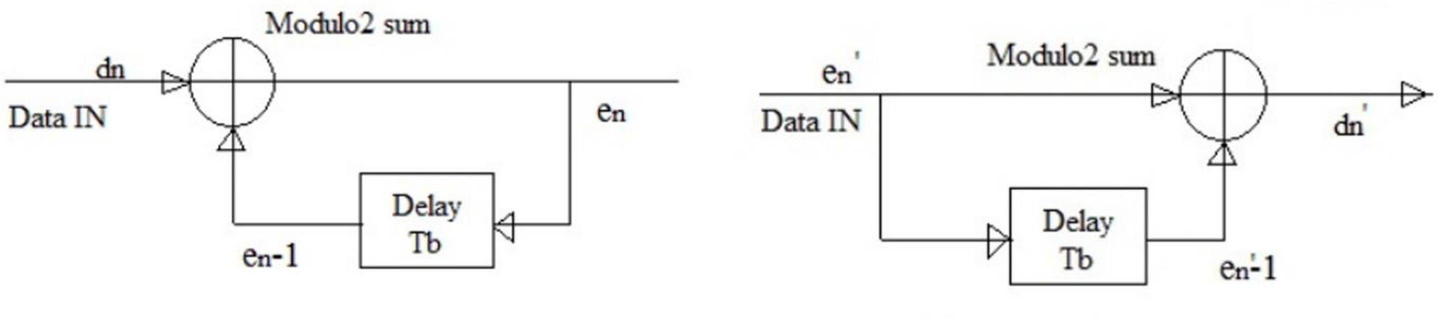


The **Costas loop is a feedback-based phase tracking system**, while the **Viterbi-Viterbi algorithm is a feedforward phase estimation method.**

Differential Demodulation

- The maximum allowable phase error is ±π/M.
- If the phase error exceeds this limit, the constellation point drifts to a neighboring decision region, causing errors during symbol demodulation
- To resolve the issue of drift, the differential of the phase may be demodulated
- *(Recall from FM demodulation)* Multiply the received signal with its delayed and phase-conjugated copy. The argument of this output gives the differential of the phase.
- This technique is used to estimate the frequency offset in 8-PSK signals using: `arg(s[n]*s[n-1])`.
- This frequency offset value is then used to control a Complex VCO to generate the appropriate error signal

Differential Coding



- Differential coding is a separate technique used to ensure **unambiguous** signal reception for certain modulation schemes.
- It is necessary because various factors can unintentionally cause **inversion of bits** in the binary waveform.
- **Mechanism:** When differential encoding is used, the data that is transmitted depends on:

  1. The **current** signal state/symbol.

  2. The **previous** signal state/symbol

Differential Coding: Example

Let's say the raw data bits are: 1 0 1 1

Assume the initial transmitted symbol is 0,

Now encode each bit:

Data Bit	Previous Symbol	Encoded Symbol
1	0	1
0	1	1
1	1	0
1	0	1

So the transmitted sequence becomes: 1 1 0 1

Suppose during transmission, the signal undergoes a **180° phase shift** This flips the symbols:

Received: 0 0 1 0

Current	Previous	Decoded Bit
0	(initial) 0	— (ignored)
0	0	0
1	0	1
0	1	1

Decoded bits: 0 1 1
First bit is lost (needs a reference).