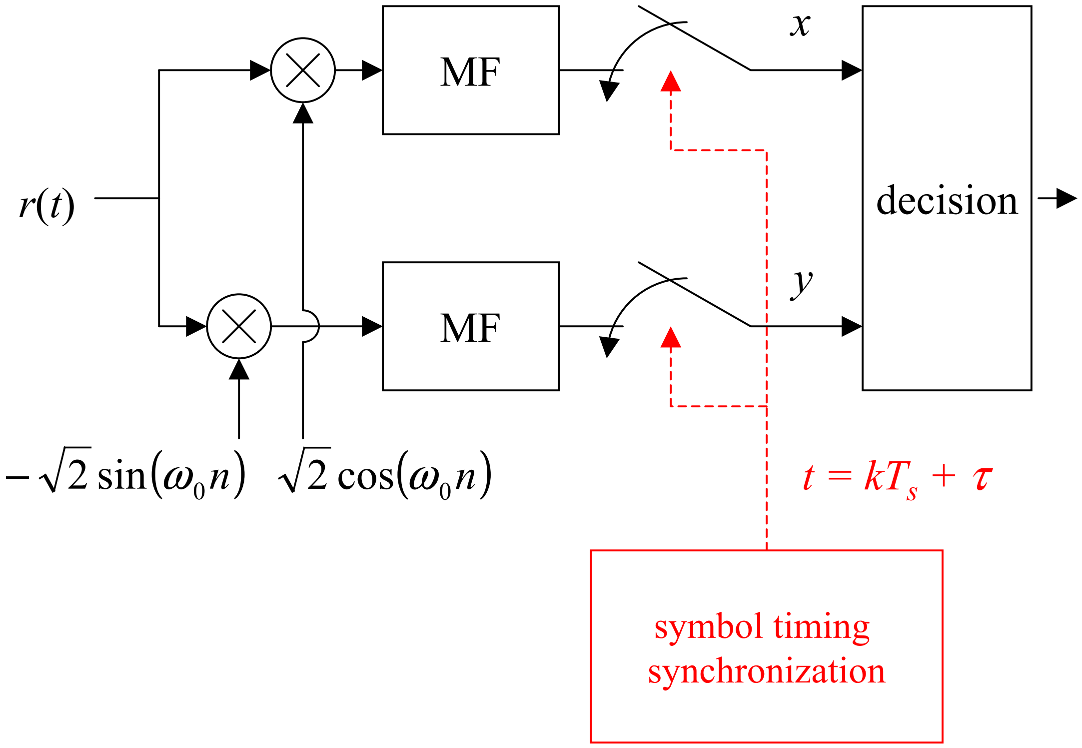
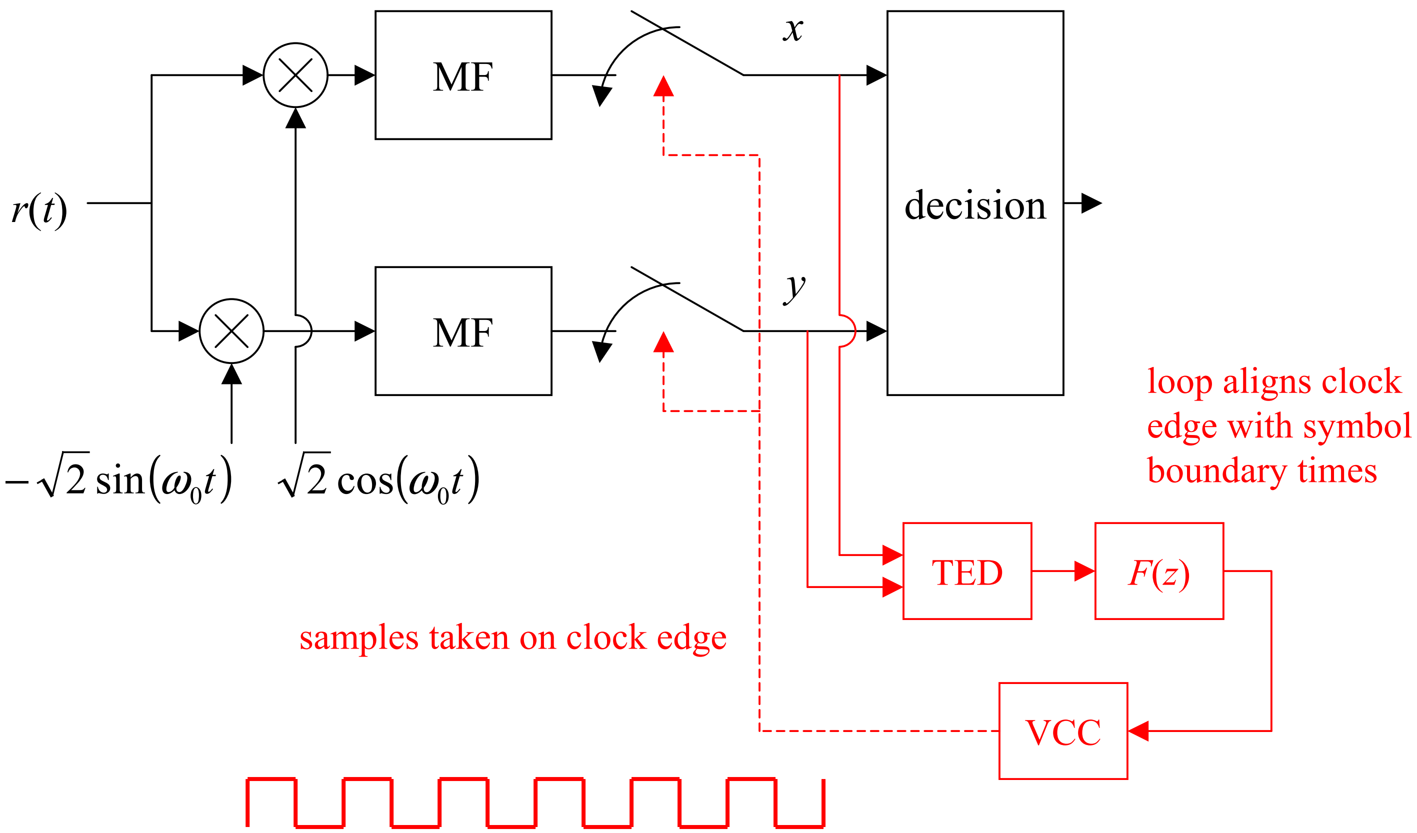
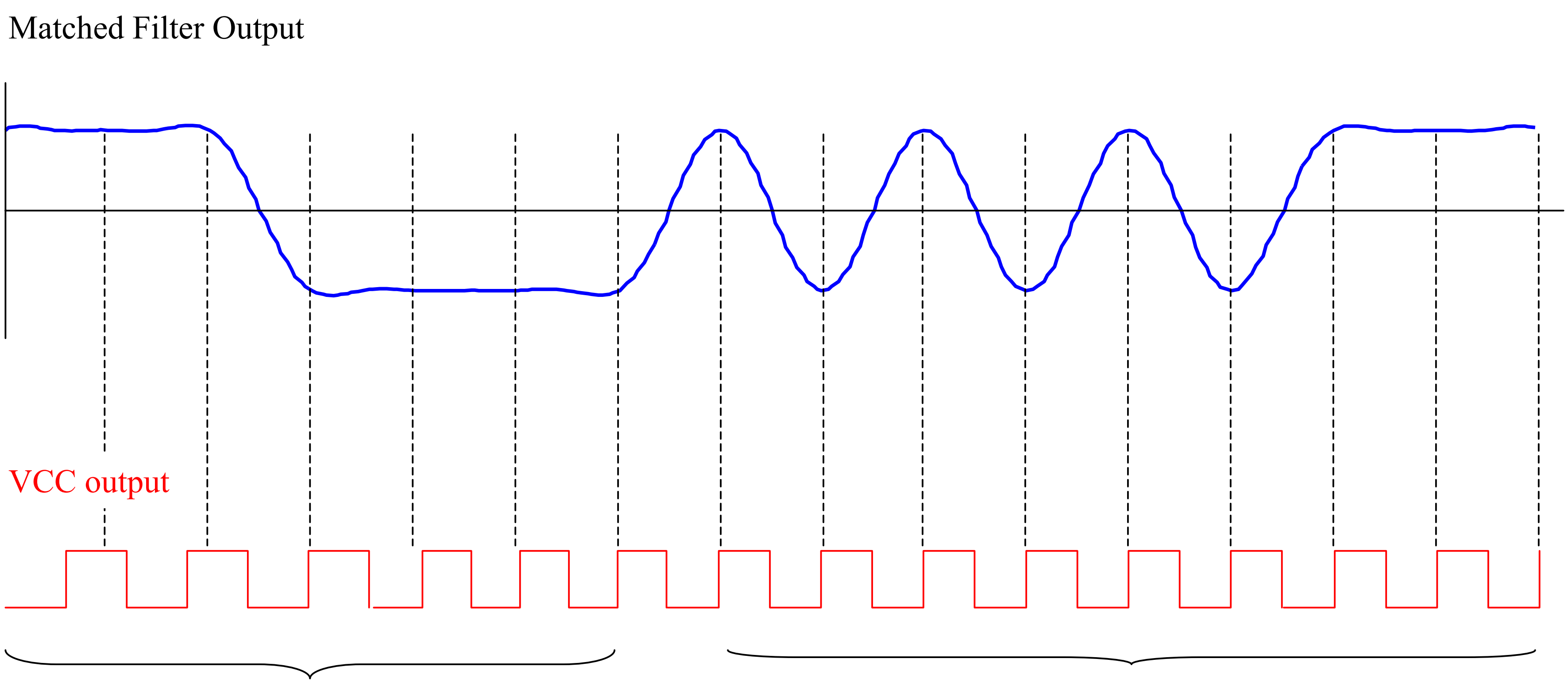
# Symbol Timing Synchronization



# Symbol Timing Synchronization in Analog Systems



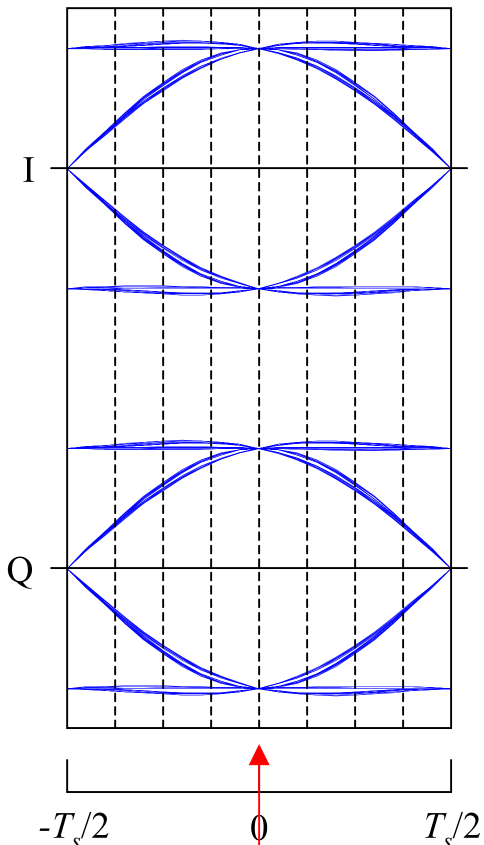
# Symbol Timing Synchronization in Analog Systems

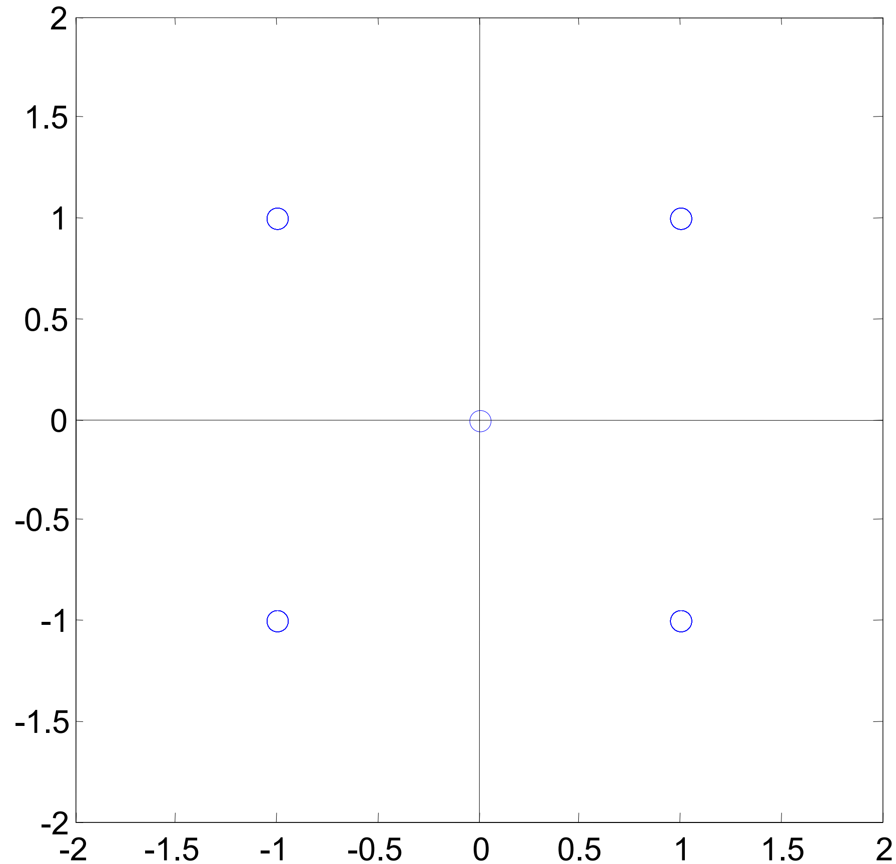



clock edges occur too late so loop increases frequency of VCC

clock edges are aligned with optimum sampling instants

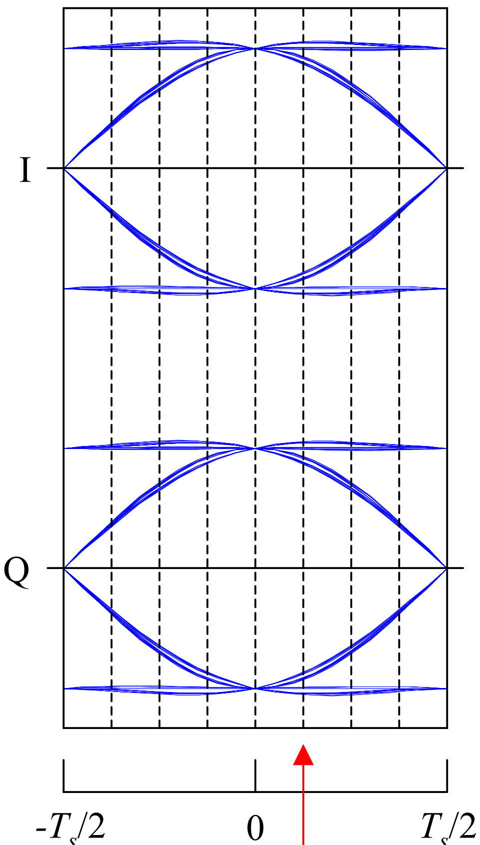
# The Eye Diagram and the Effects of Symbol Timing Offset for QPSK

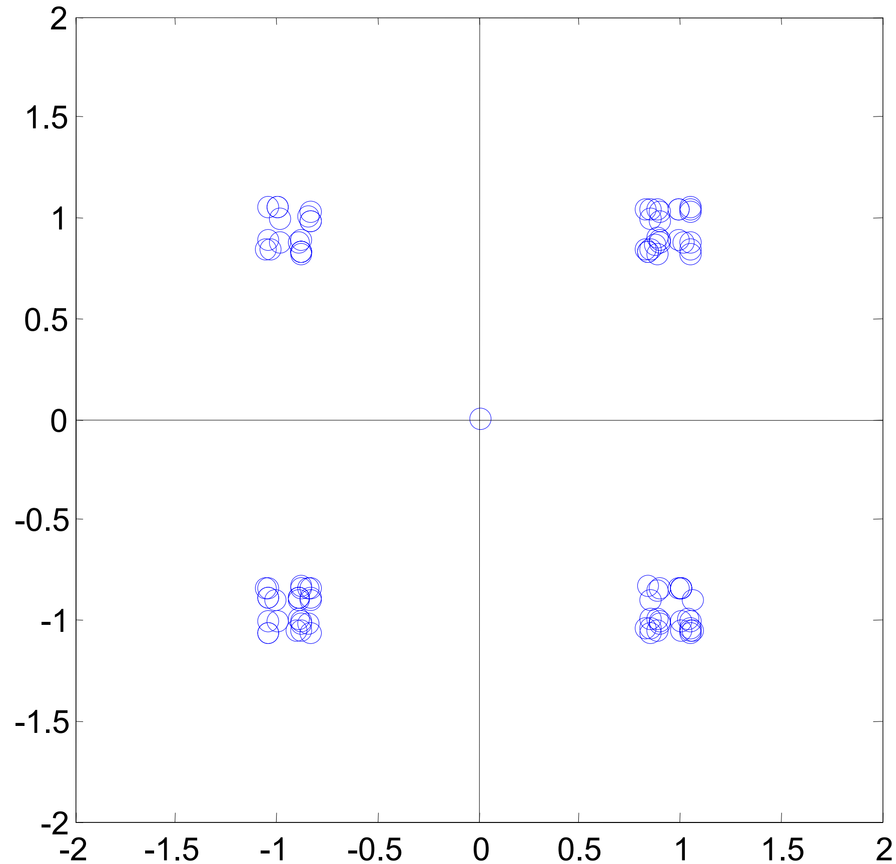



Constellation Corresponding to
I and Q channels sampled with no timing error

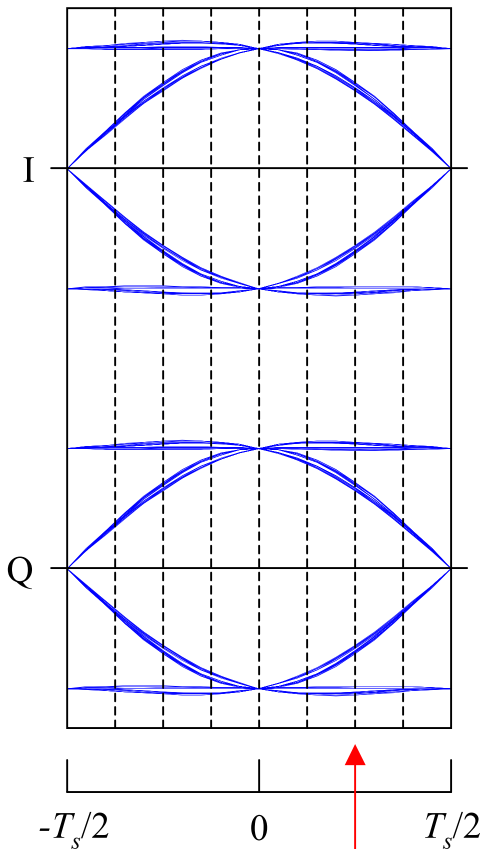
# The Eye Diagram and the Effects of Symbol Timing Offset for QPSK

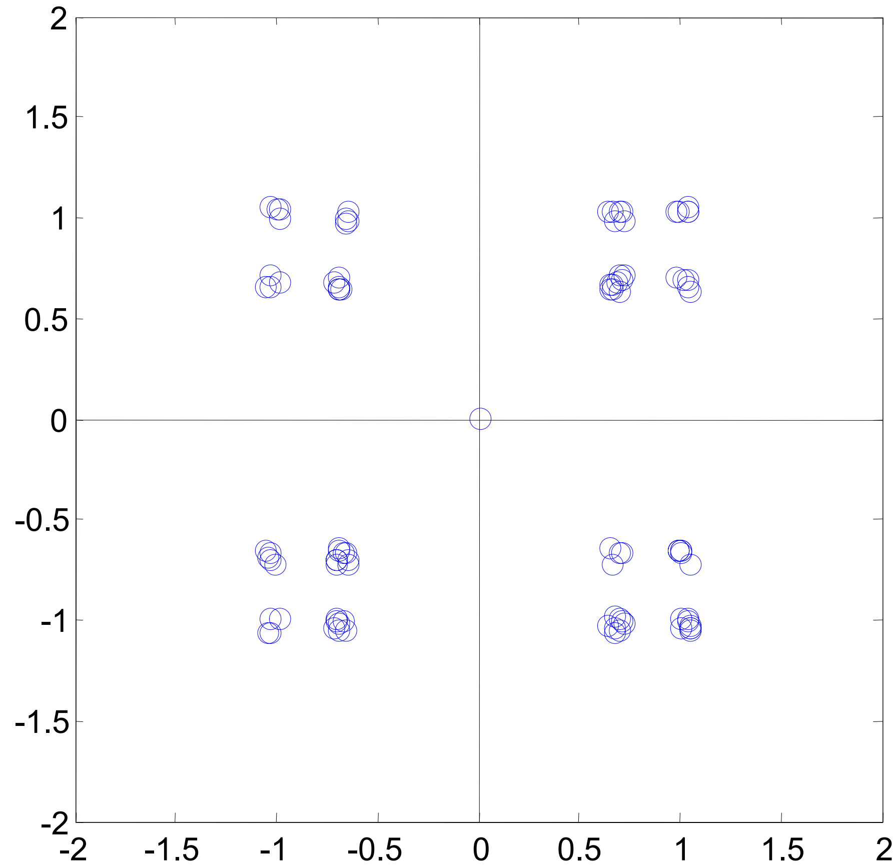



Constellation Corresponding to
I and Q channels sampled with timing error = $0.125T_s$

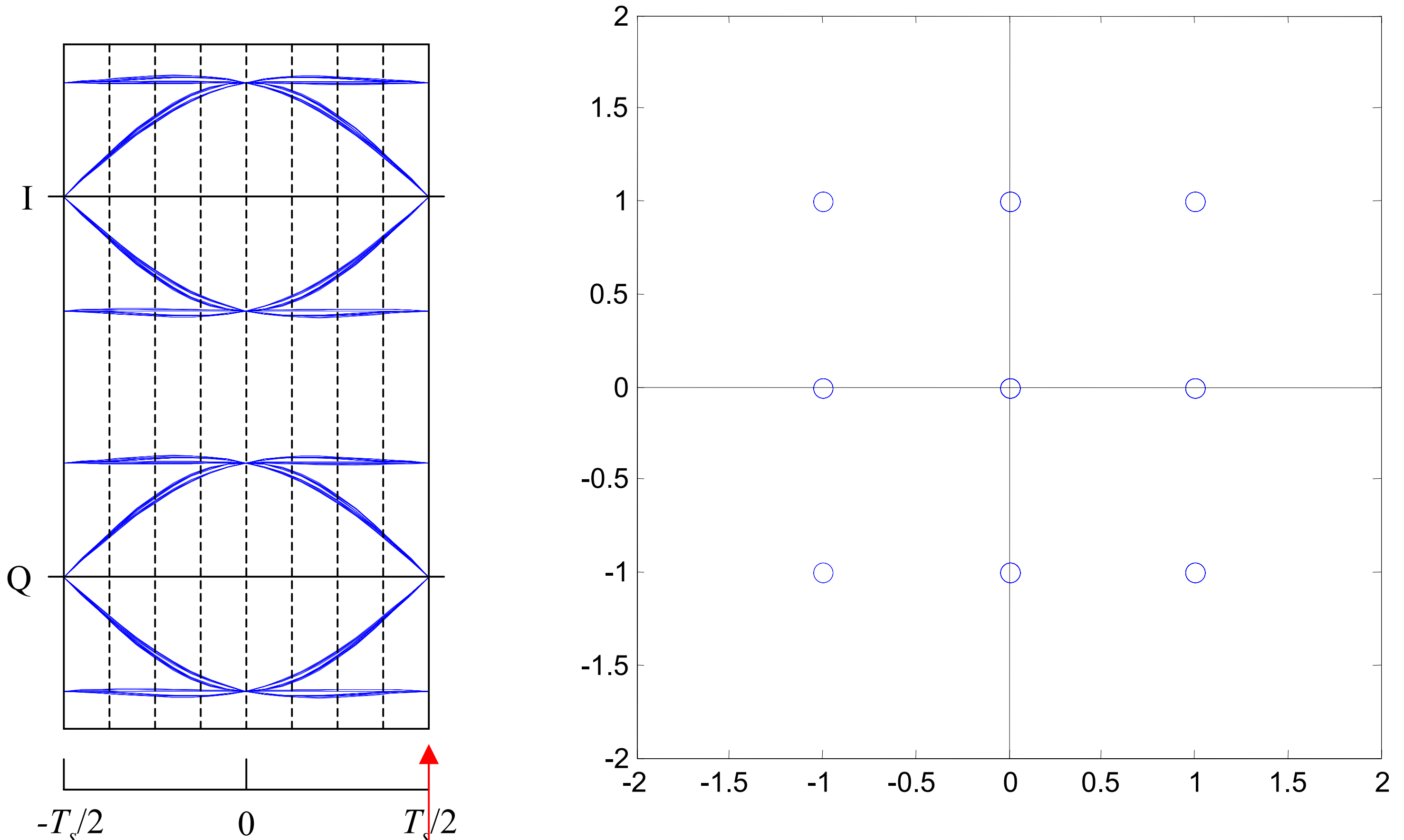
# The Eye Diagram and the Effects of Symbol Timing Offset for QPSK



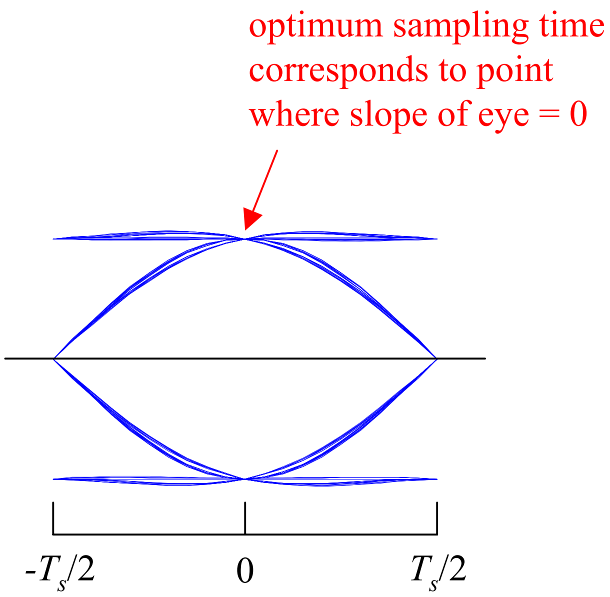

Constellation Corresponding to
I and Q channels sampled with timing error = $0.25T_s$

# The Eye Diagram and the Effects of Symbol Timing Offset for QPSK

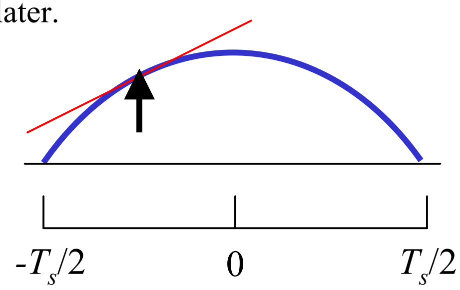



Constellation Corresponding to
I and Q channels sampled with timing error = $0.5T_s$

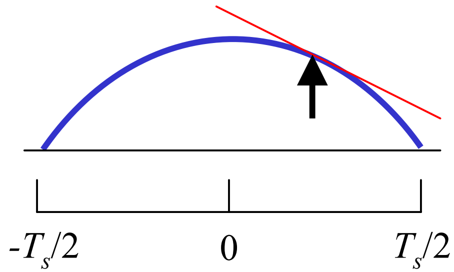
# Timing Error Detectors



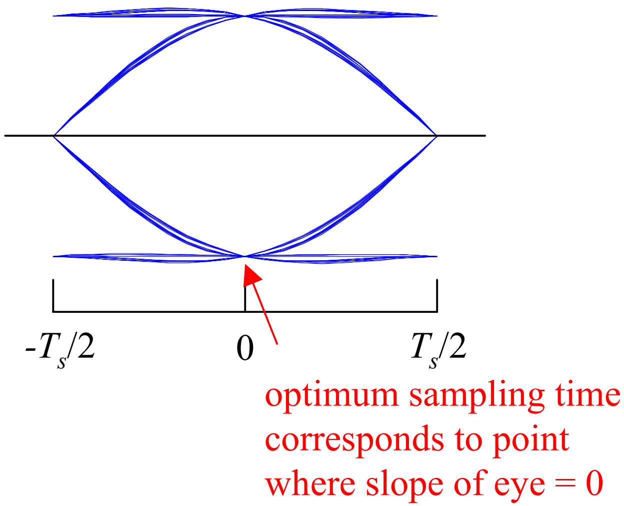

matched filter output sampled too early:
⇨the slope is positive
⇨the timing should be delayed (i.e. sample clock period increased) so that the next sample taken a little later.




matched filter output sampled too late:
⇨the slope is negative
⇨the timing should be advanced (i.e. sample clock period decreased) so that the next sample taken a little sooner.



# Timing Error Detectors

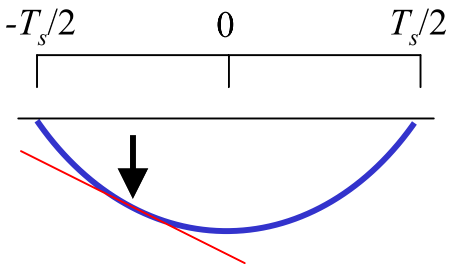



matched filter output sampled too early:

⇨the slope is negative (but should be positive)

⇨the timing should be delayed (i.e. sample clock period increased).

⇨need to qualify the slope by the sign of the matched filter output.

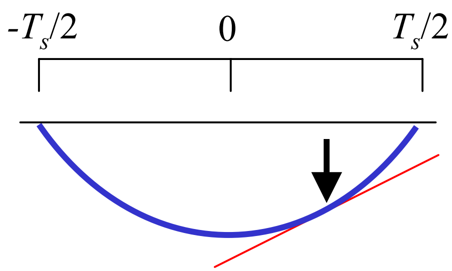



matched filter output sampled too late:

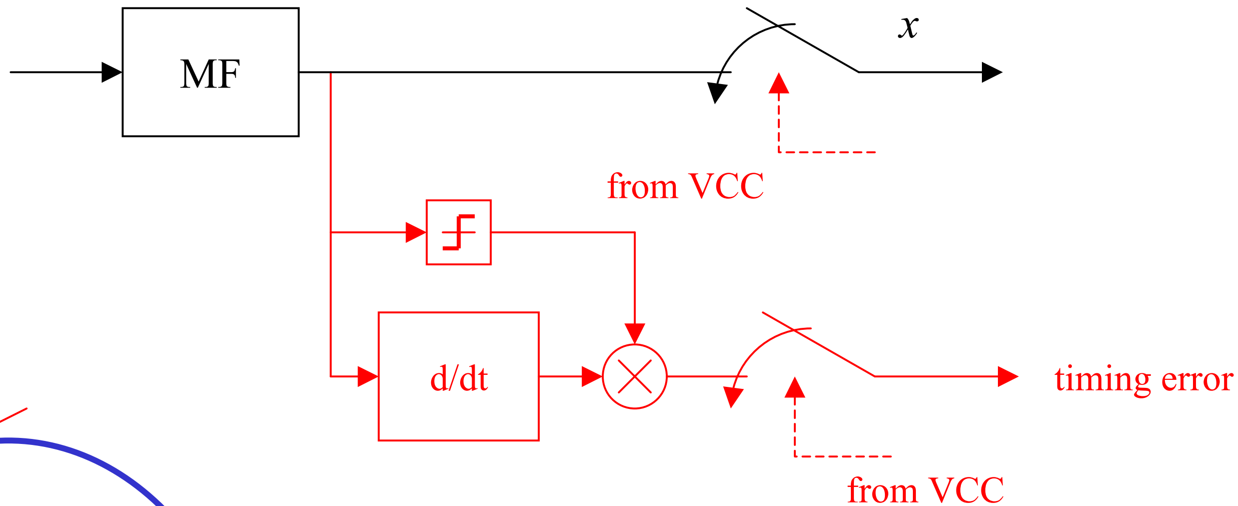
⇨the slope is positive (but should be negative)

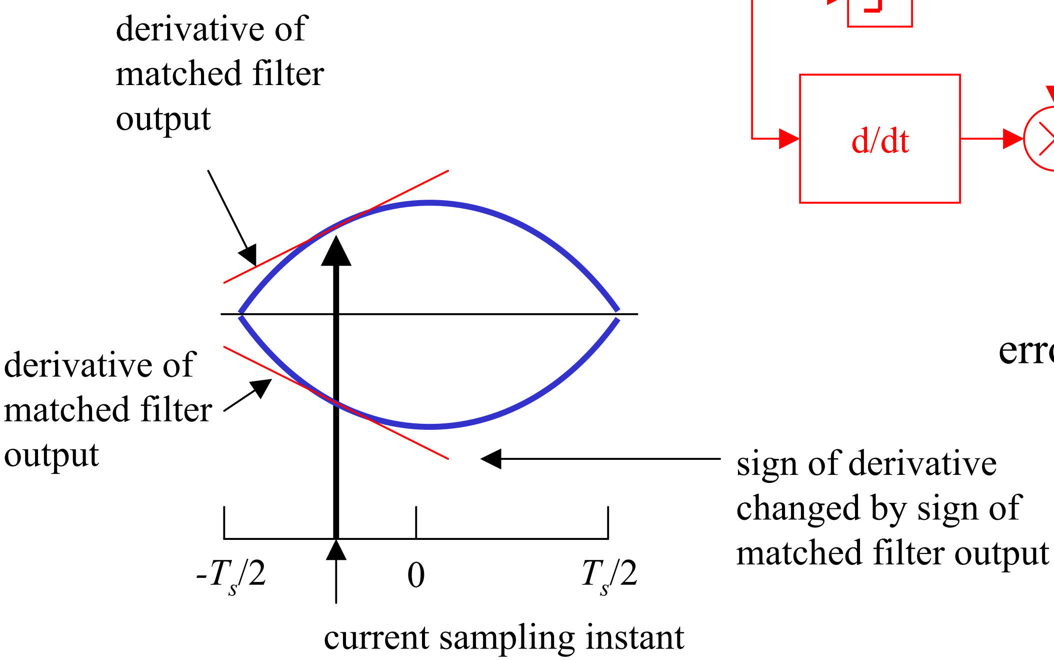
⇨the timing should be advanced (i.e. sample clock period decreased).

⇨need to qualify the slope by the sign of the matched filter output.



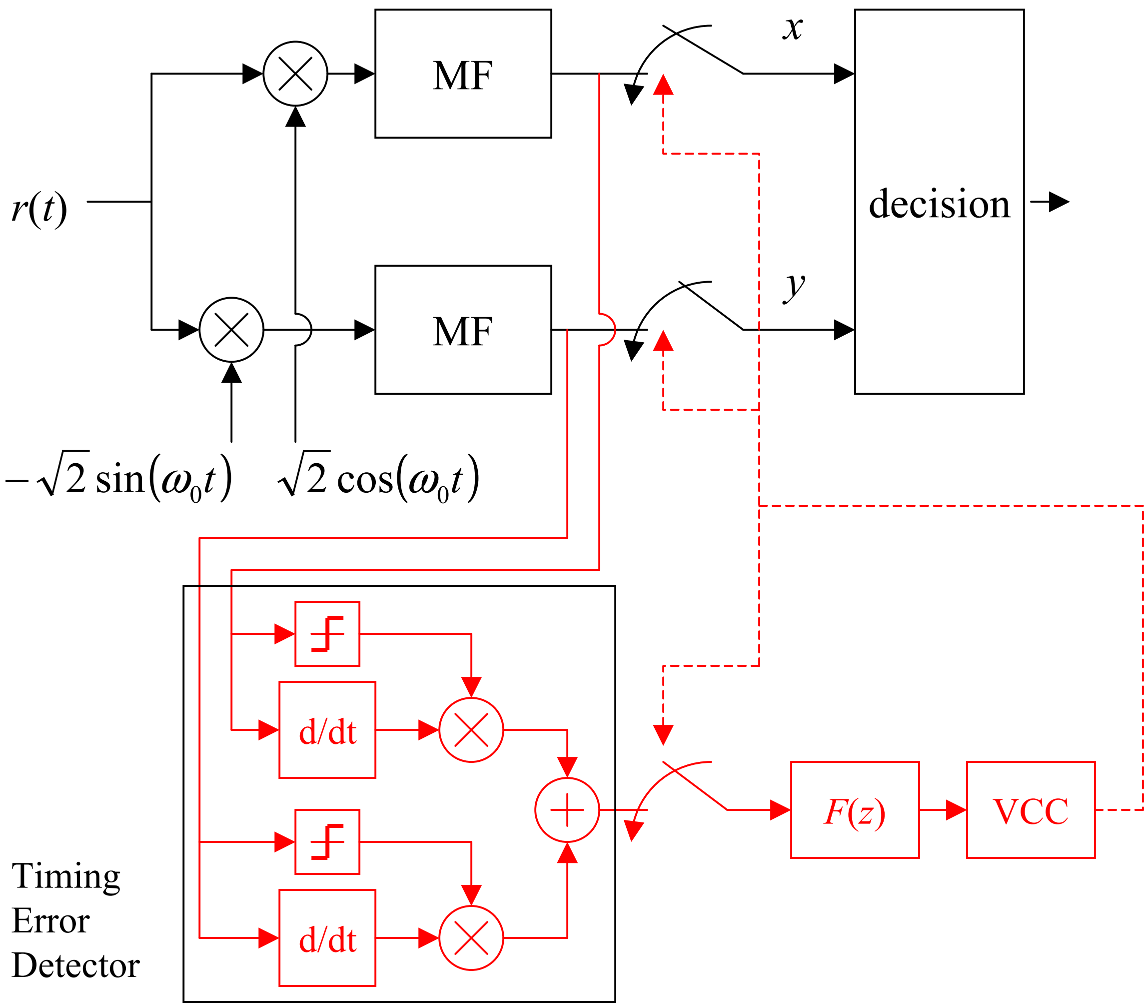
# Maximum Likelihood TED



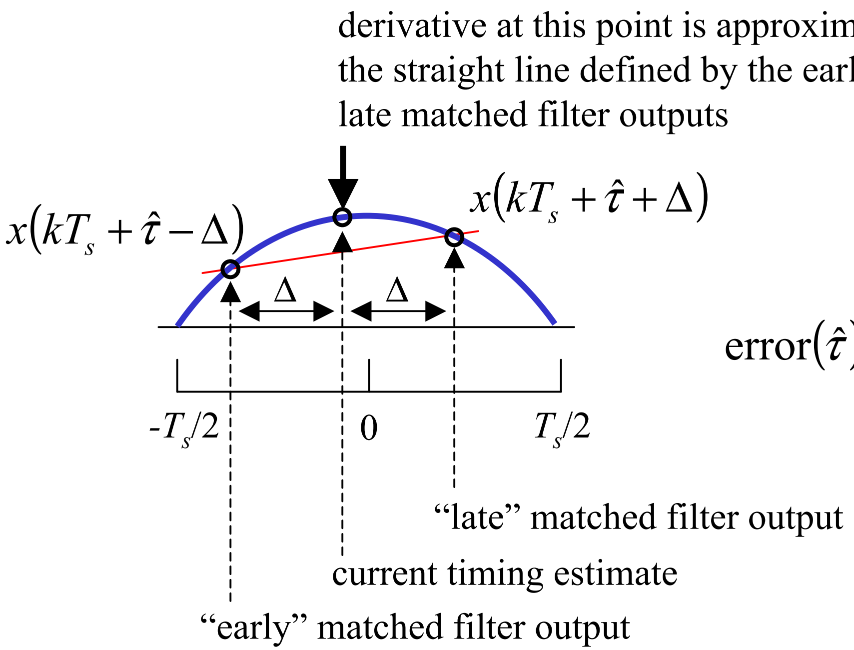




$$\text{error}(\hat{\tau}) = \left|x(kT_s + \hat{\tau})\right| \dot{x}(kT_s + \hat{\tau} - \Delta)$$

# ML Symbol Timing Synchronization



# Approximate ML Timing Error Detector: The Early-Late Gate Detector




$$\text{error}(\hat{\tau}) = \left|x(kT_s+\hat{\tau}+\Delta)\right| - \left|x(kT_s+\hat{\tau}-\Delta)\right|$$

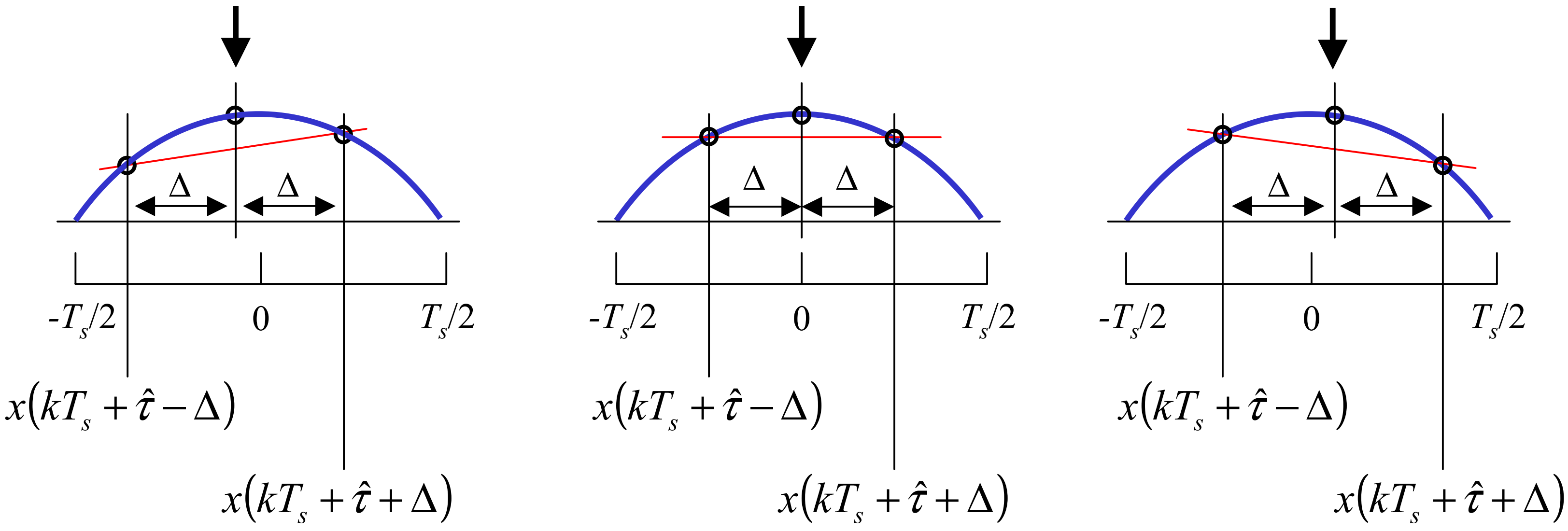
Note: abs included to qualify the sign of the slope

# How the Early-Late Gate Detector Works

matched filter output sampled too early:
⇨ the timing should be delayed
⇨ slope of line is positive
⇨ slope used to control VCC

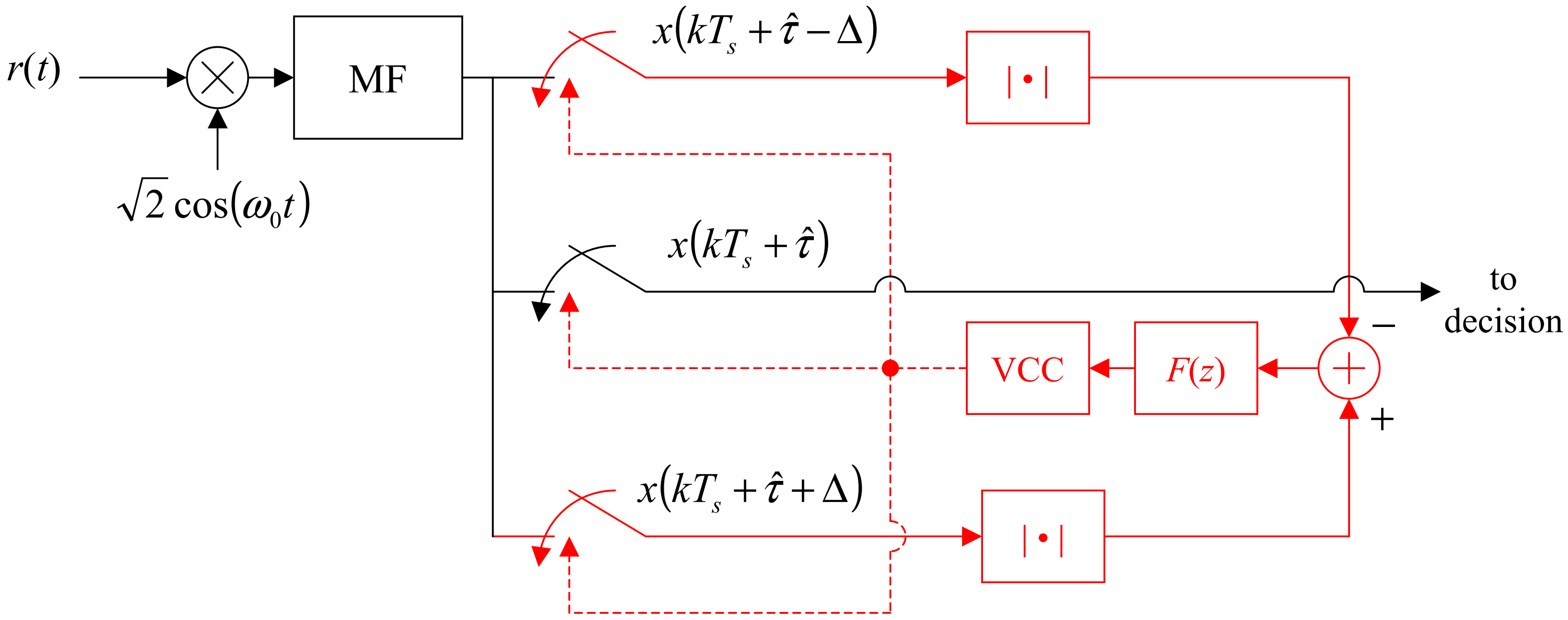
matched filter output sampled just right:
⇨ the timing should remained unchanged
⇨ slope of line is zero
⇨ slope used to control VCC

matched filter output sampled too late:
⇨ the timing should be advanced
⇨ slope of line is negative
⇨ slope used to control VCC

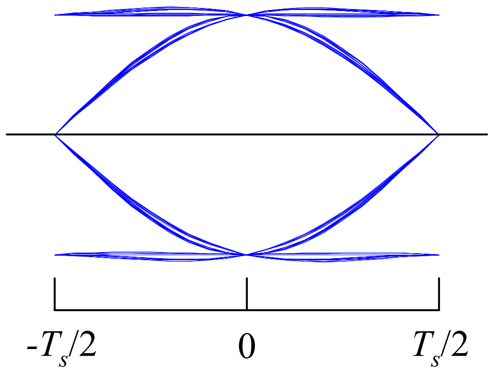


# Early-Late Gate Symbol Timing Synchronization

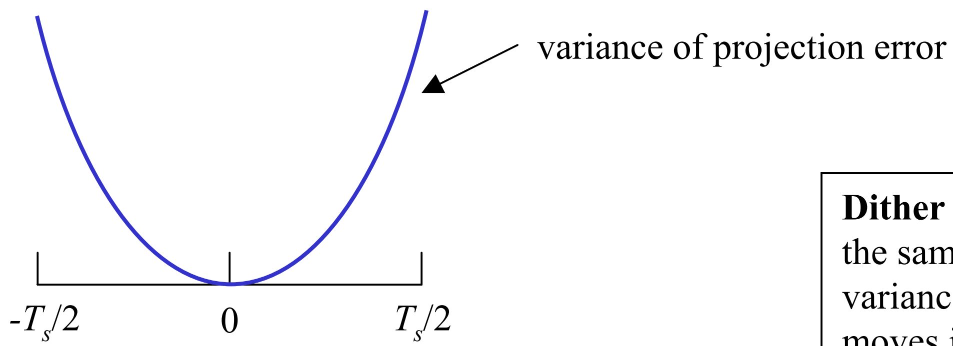
BPSK Example



# Non Derivative Based Technique

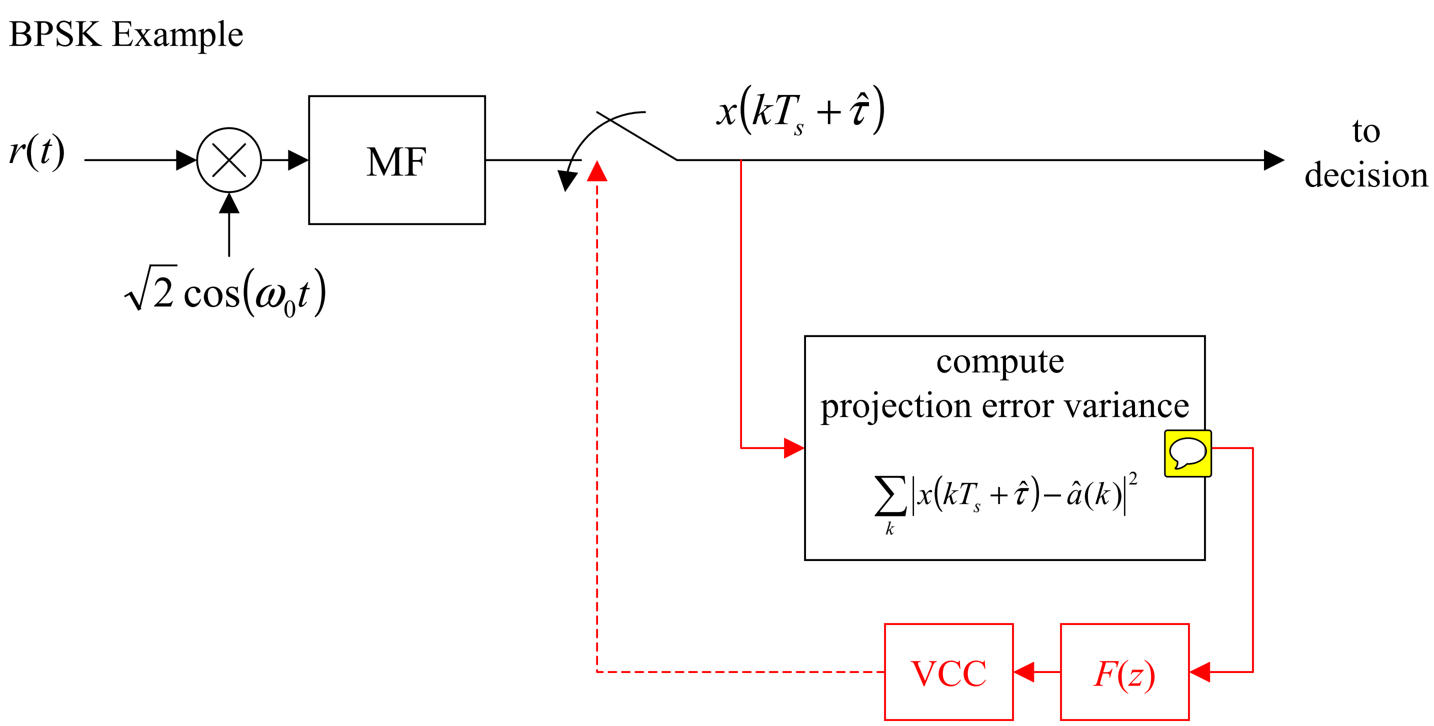



variance of projection error is minimum when sampling the eye at the optimum sampling time

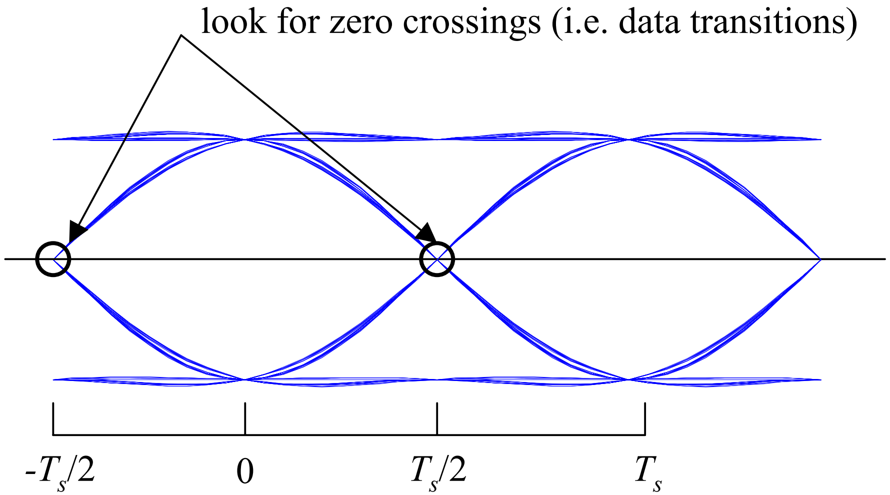


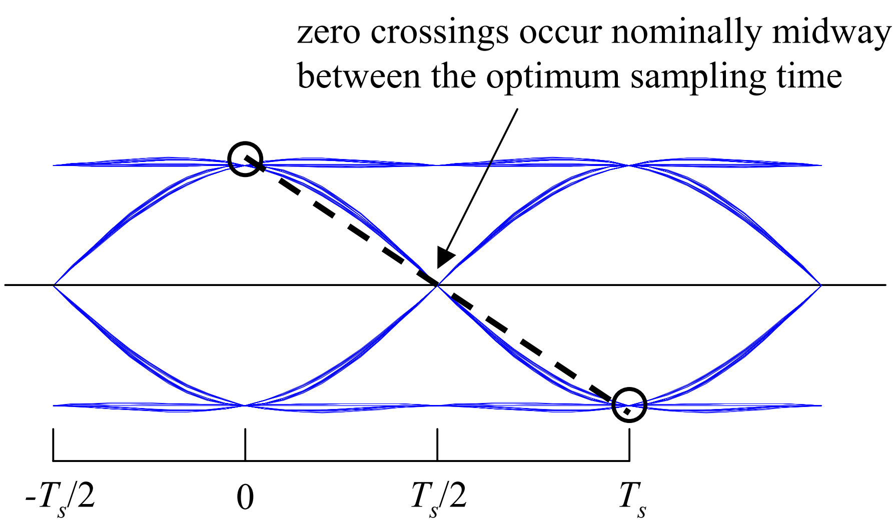

**Dither Loop**: “dithers” (i.e. changes) the sampling instant, computes the variance of the projection error, and moves in direction of smallest projection error variance.

# Dither Loop for Symbol Timing Synchronization



# Data Transition Tracking Loop (DTTL) (for BPSK or QPSK)



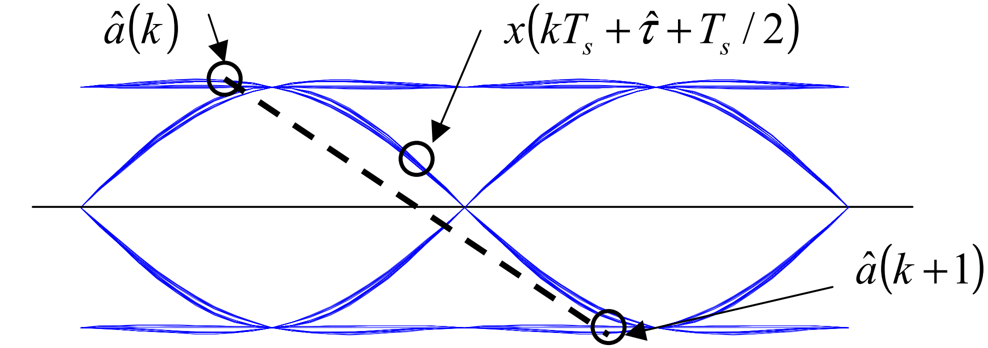




**Basic Idea**: if the loop knows where the zero crossings are, then it knows where the optimum sampling instants are!

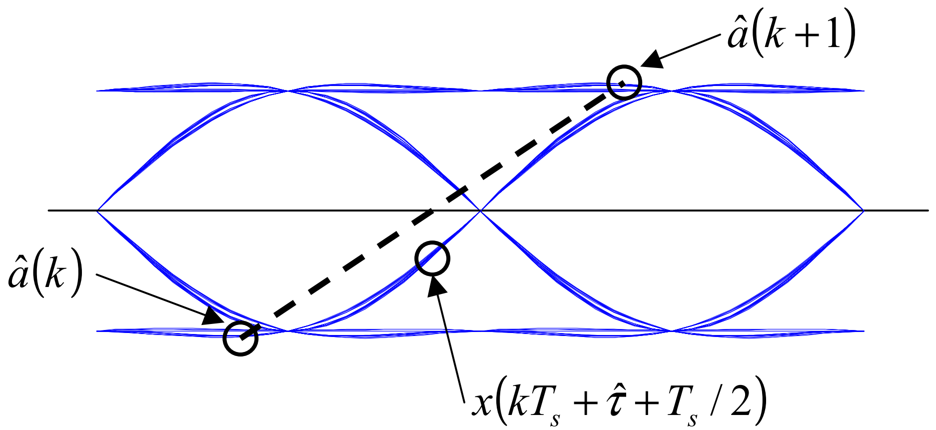
# DTTL Timing Error Detector

$$\text{error}(\hat{\tau}) = x(kT_s + \hat{\tau} + T_s/2)\left[|x(kT_s + \hat{\tau})| - |x(kT_s + \hat{\tau} + T_s)|\right]$$
$$= x(kT_s + \hat{\tau} + T_s/2)\left[\hat{a}(k) - \hat{a}(k+1)\right]$$

DTTL Detector requires the matched filter output sampled at 2 samples/symbol.



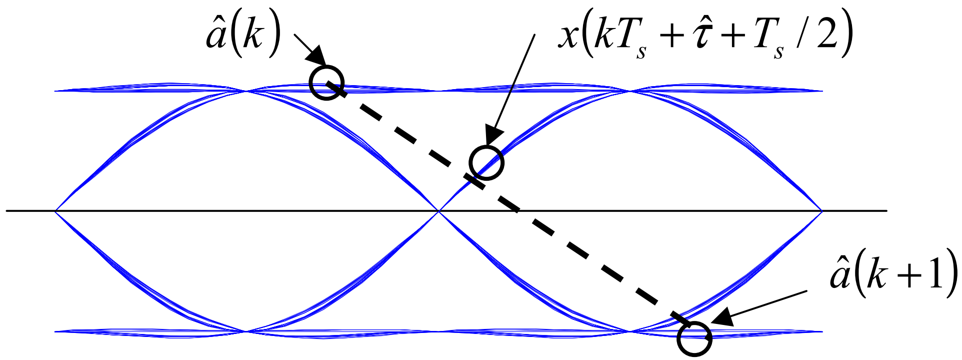

error > 0 ⇨ timing needs to be advanced



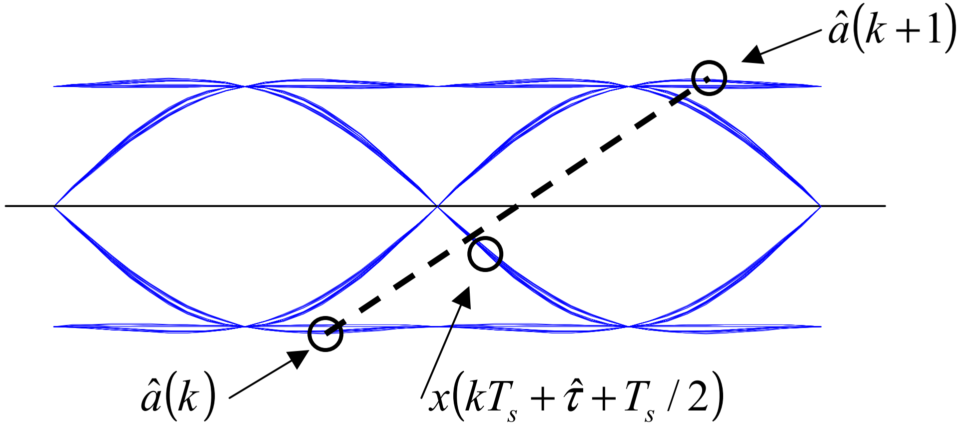

error > 0 ⇨ timing needs to be advanced

# DTTL Timing Error Detector

$$\text{error}(\hat{\tau}) = x(kT_s + \hat{\tau} + T_s/2)\left[\left|x(kT_s + \hat{\tau})\right| - \left|x(kT_s + \hat{\tau} + T_s)\right|\right]$$
$$= x(kT_s + \hat{\tau} + T_s/2)\left[\hat{a}(k) - \hat{a}(k+1)\right]$$

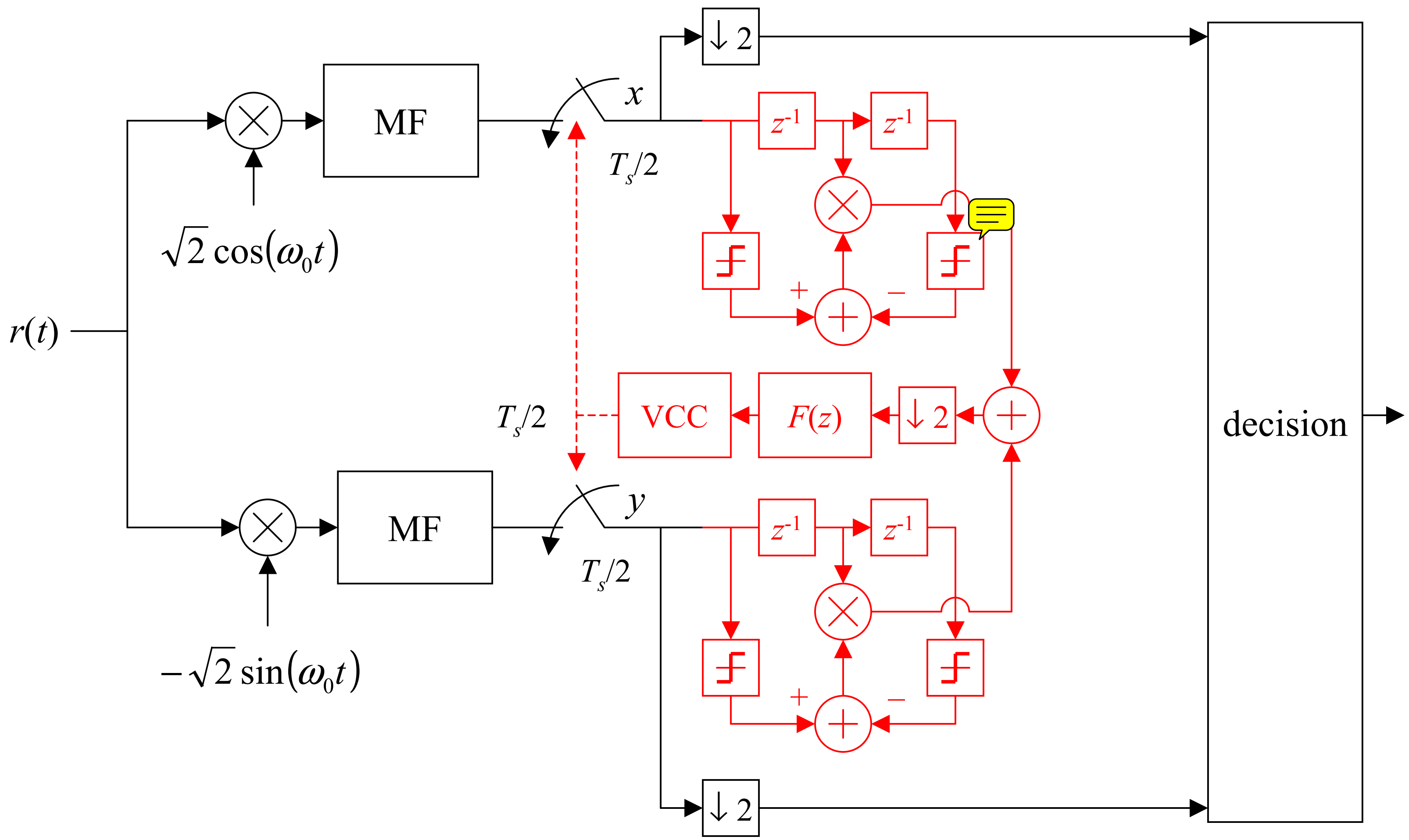



error < 0 ⇨ timing needs to be delayed

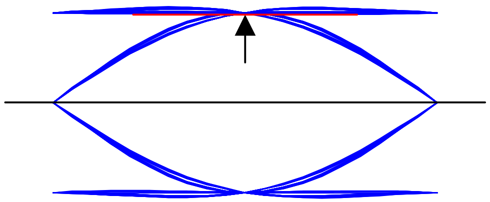



error < 0 ⇨ timing needs to be delayed

# DTTL for QPSK

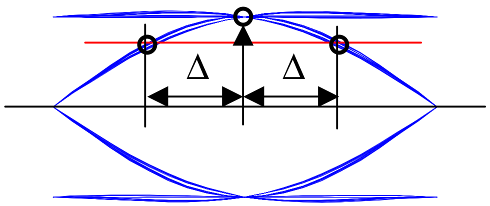


# Summary and Comparison



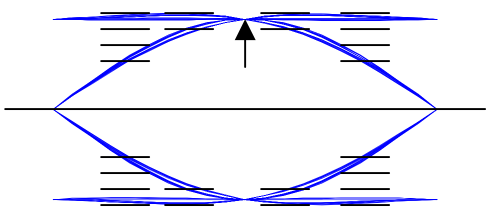
**Maximum Likelihood**: find the point where the derivative of the eye is zero.

$$\text{error}(\hat{\tau}) = |x(kT_s + \hat{\tau})|\dot{x}(kT_s + \hat{\tau} - \Delta)$$



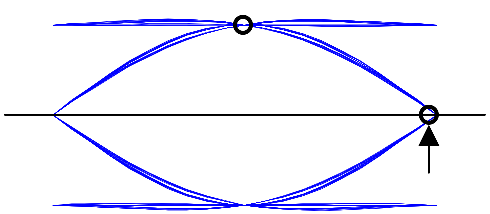

**Early-Late Gate**: approximates the ML detector by finding the point where the approximate derivative of the eye is zero.

$$\text{error}(\hat{\tau}) = |x(kT_s + \hat{\tau} + \Delta)| - |x(kT_s + \hat{\tau} - \Delta)|$$



**Dither**: find the point where the projection error variance is a minimum.

$$\text{error}(\hat{\tau}) = \sum_k |x(kT_s + \hat{\tau}) - \hat{a}(k)|^2$$



**DTTL**: find the point where the zero crossings occur. Data decisions determine the sign of the timing error. (Must operate at 2 samples/symbol.)

$$\text{error}(\hat{\tau}) = x(kT_s + \hat{\tau} + T_s / 2)[\hat{a}(k) - \hat{a}(k+1)]$$