Code Tracking; Multipath

GPS Signals And Receiver Technology MM13

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Today's Subjects

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- Code tracking – Delay Lock Loops (DLL)
- Multipath and DLL

Code Tracking

The Delay Lock Loop (DLL)

Code Tracking Task

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- Enhance the accuracy of code phase obtained by acquisition
- Maintain exact alignment of the codes (local and received) – minimize the τ_i:
  - To maximum possible power of the received signal
  - In order to have accurate time of arrival measurements

$$I_i = \frac{\sin(\pi \Delta f_i T)}{(\pi \Delta f_i T)} \sqrt{2 \frac{S}{N_0}} \cdot T \cdot R(\tau_i) \cdot D_i \cdot \cos(\Delta \varphi_i) + n_{I_i}$$

- Provide means to measure time of arrival of received signals

Code Tracking Idea

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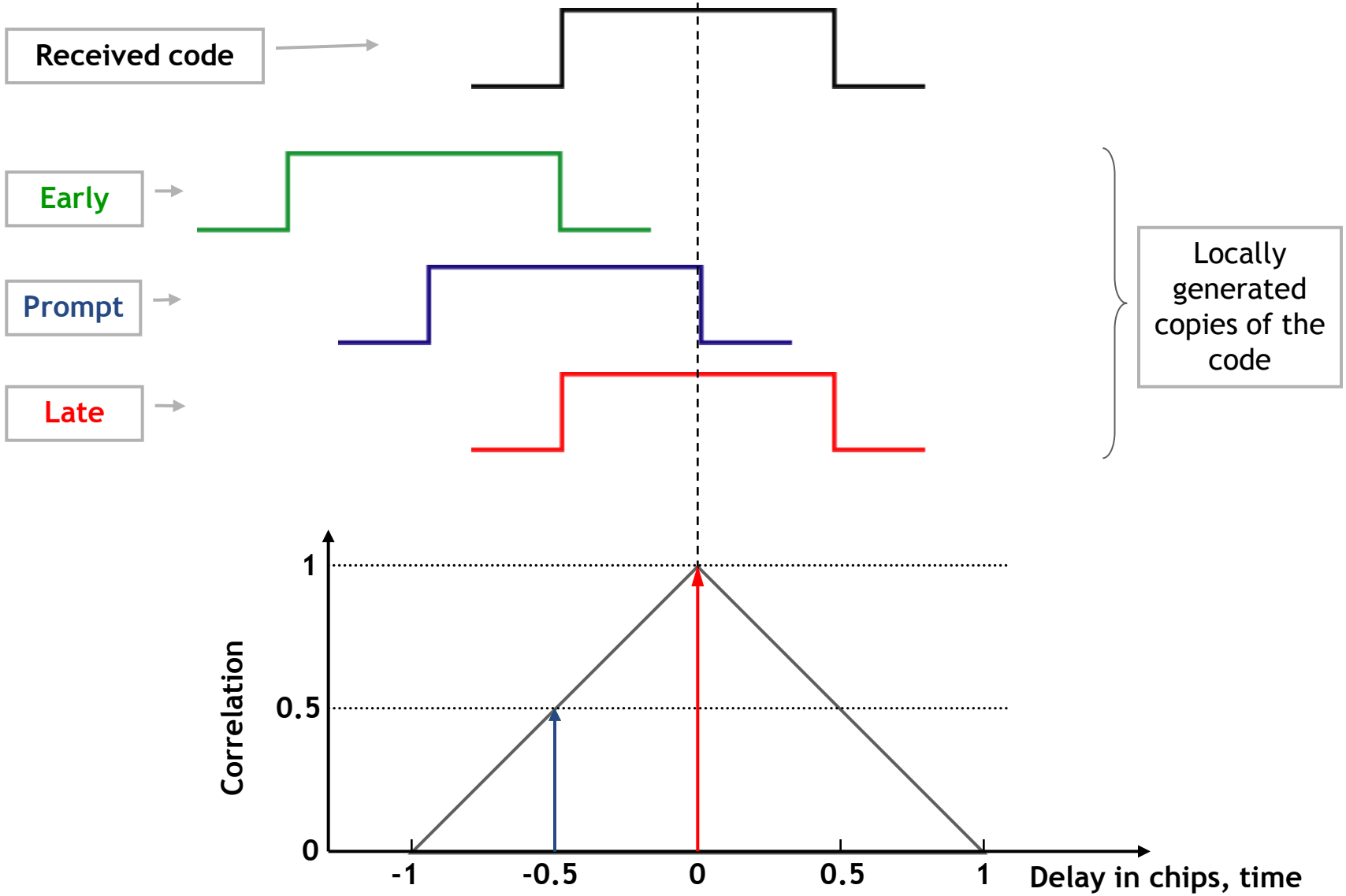
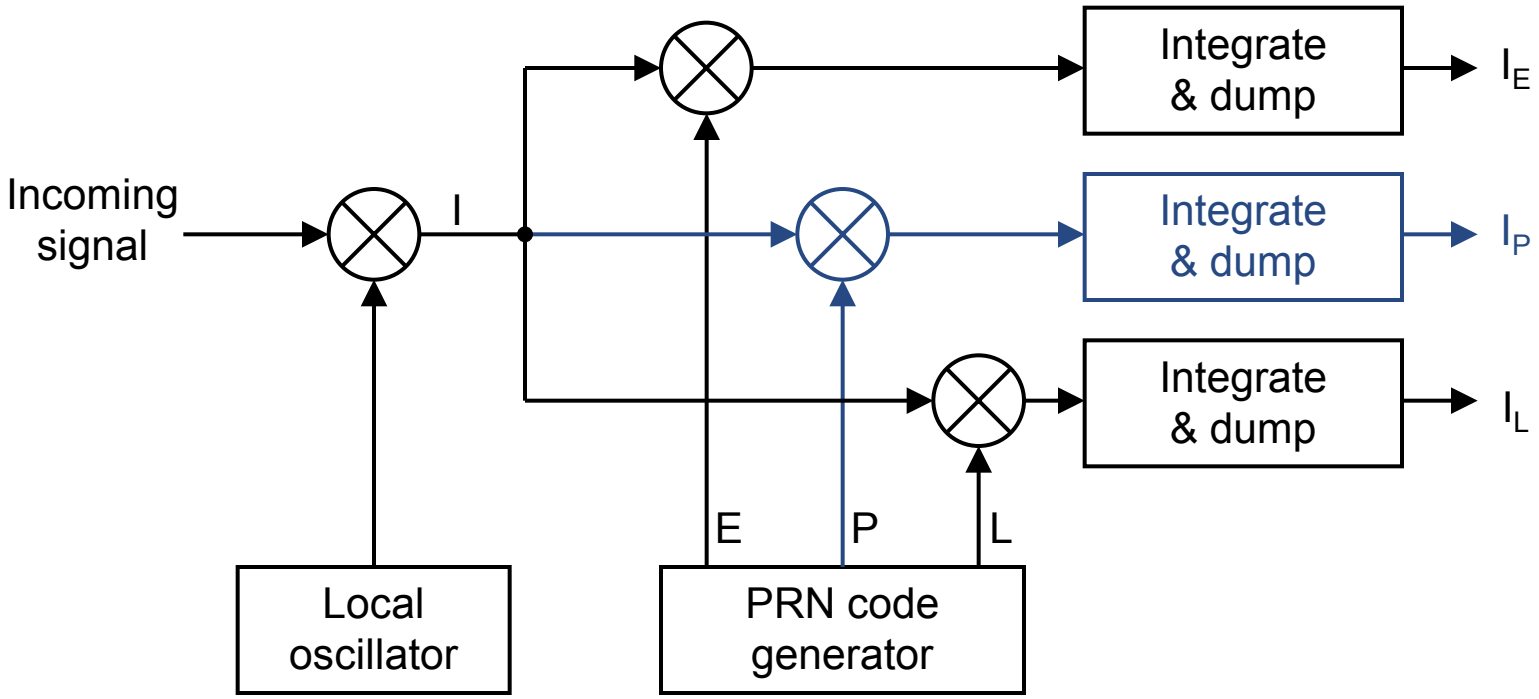
- General idea is the same as in general tracking loop: measure the tracking error, filter it, update local copy of the signal (update frequency of the generator)
- The error detector: the autocorrelation properties of the code are used to “compare” the incoming signal to an advanced and a delayed local copies of the signal

Code Tracking Idea



Code Tracking Loop Construction

- **Block diagram of the Early-Late correlators**



Code Discriminator

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- **Code discriminators:**
  - **The coherent discriminator is the simplest of all :**

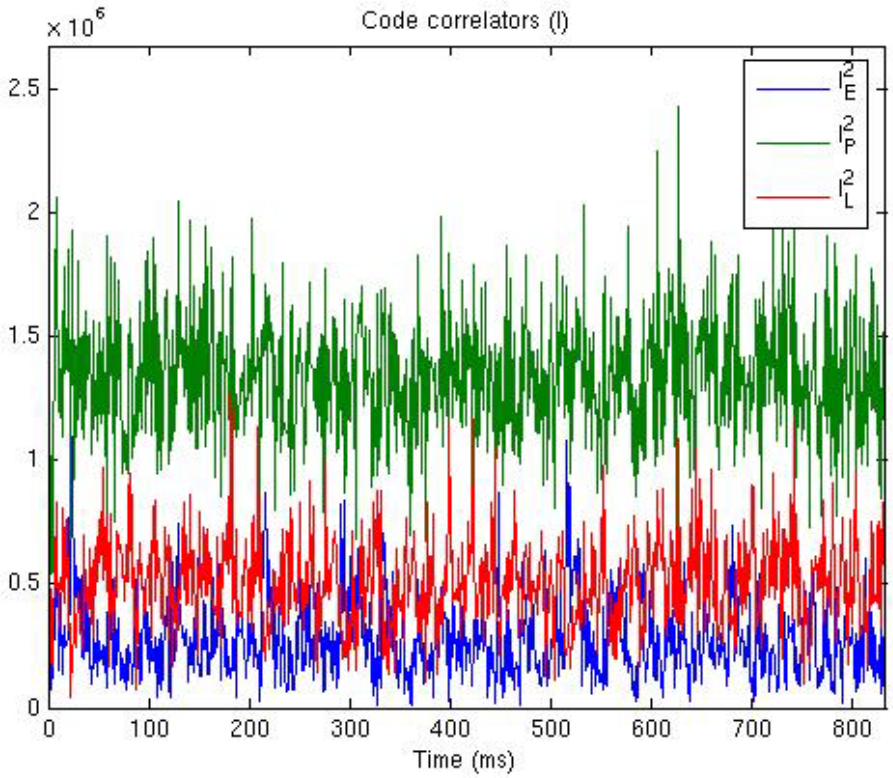
$$D = I_E - I_L$$

  - **A more complicated discriminators are signal amplitude independent e.g. normalized early minus late:**

$$D = \frac{\left(I_E^2 + Q_E^2\right) - \left(I_L^2 + Q_L^2\right)}{\left(I_E^2 + Q_E^2\right) + \left(I_L^2 + Q_L^2\right)}$$

- **Feedback the discriminator output to the PRN code generator (through a loop filter), which will adjust the code phase of the early, prompt and late codes**

Coherent DLL



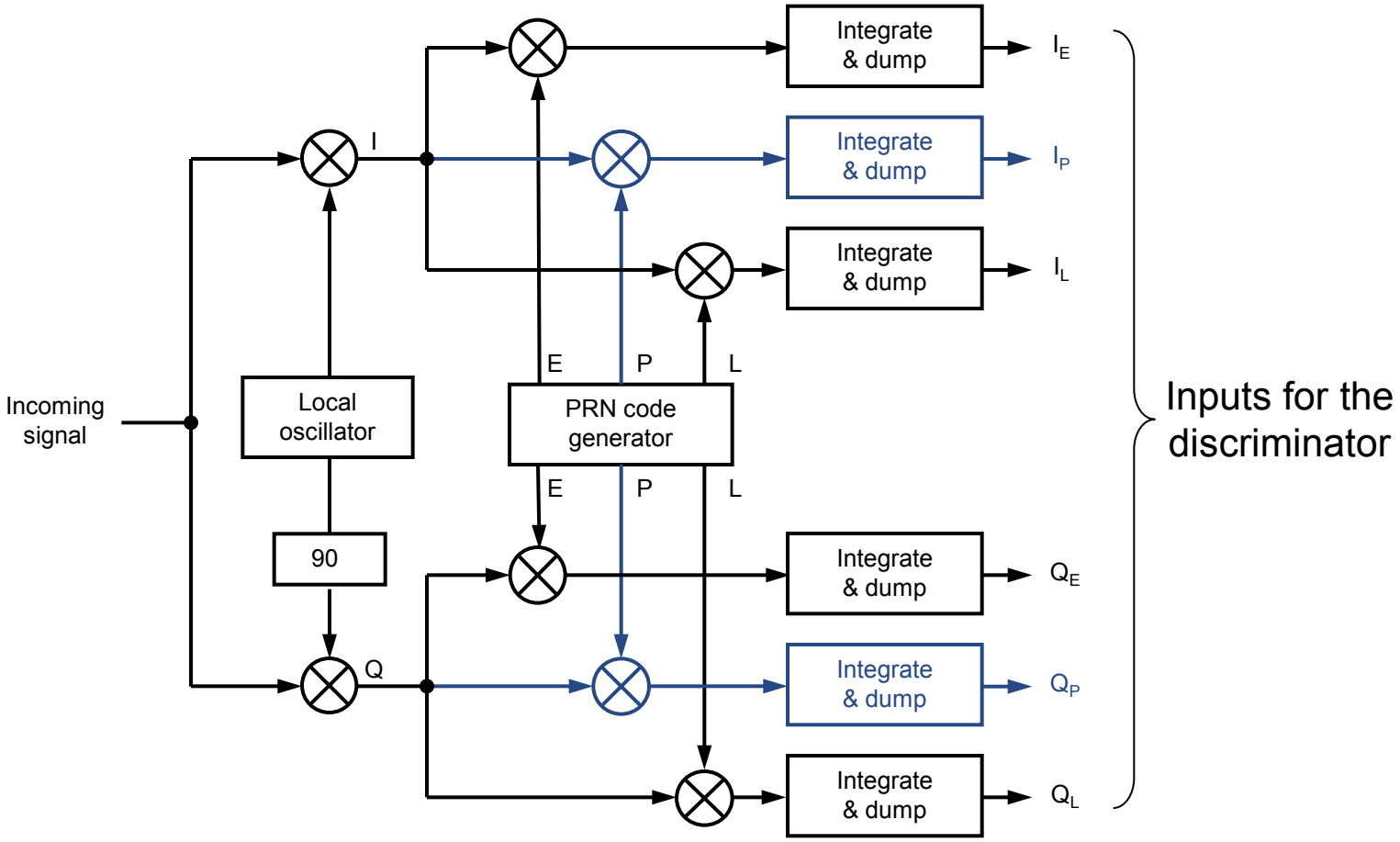
- Three outputs from the correlators are shown here (in-phase signal)
- The DLL tries to equalize power of the early and late signals by adjusting frequency of the code generator
- Second method is to move in time a pre-generated code
  - Can cause SNR loss
  - Low transmission time tracking resolution

Noncoherent DLL

- The signal power is not in the In-phase arm, if the PLL has not locked on to the carrier. In such cases it is needed to track the code phase also in the quadrature arm.
- A plot will demonstrate this situation later
- Next slide shows an improved DLL design, which is insensitive to such problem

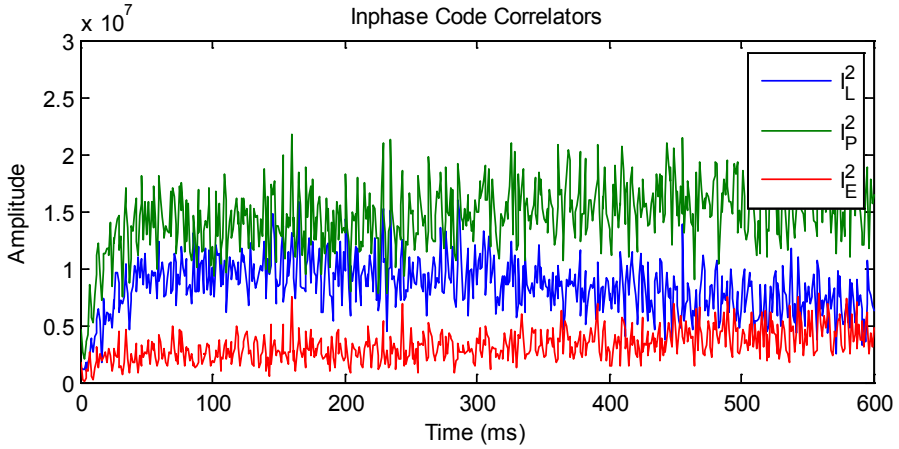
$$D = \frac{\left(I_E^2 + Q_E^2\right) - \left(I_L^2 + Q_L^2\right)}{\left(I_E^2 + Q_E^2\right) + \left(I_L^2 + Q_L^2\right)}$$

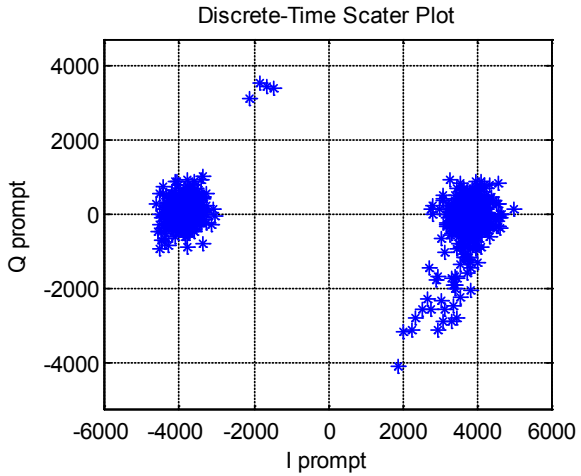
Noncoherent DLL

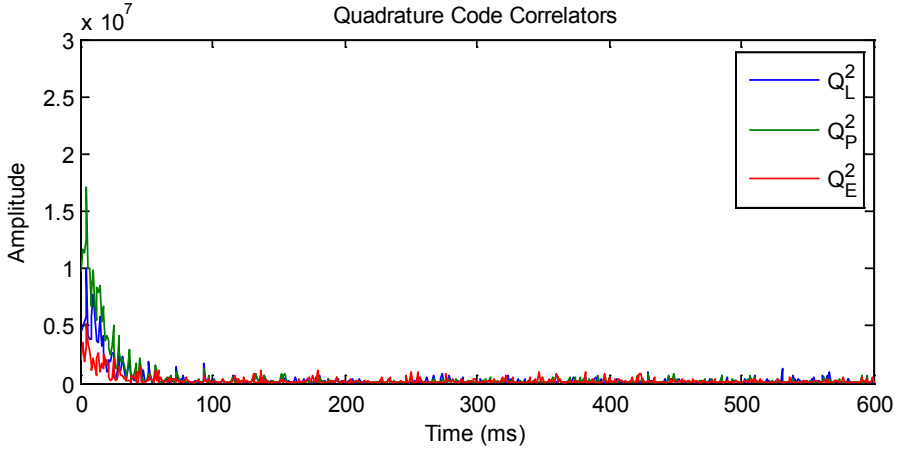


Noncoherent DLL

- **Output from the 6 correlators, when the PLL is in locked state. It is sufficient to use only inphase correlators for DLL discriminator.**

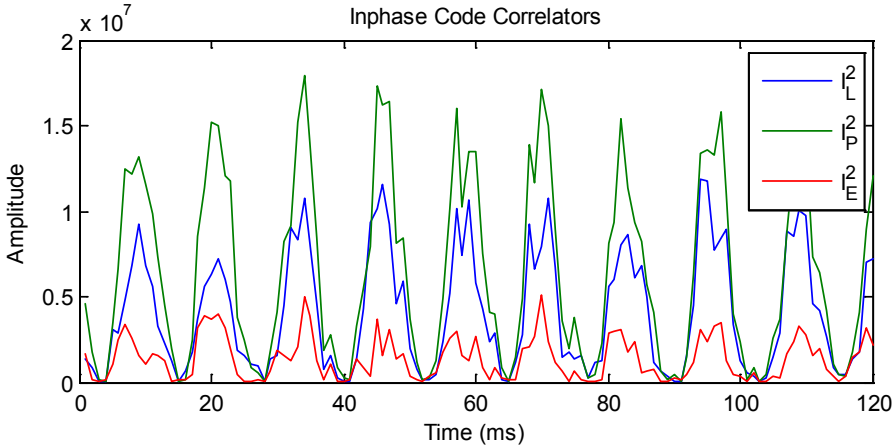


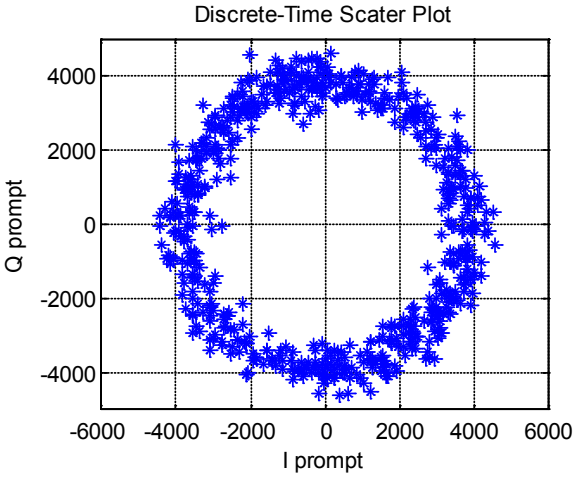


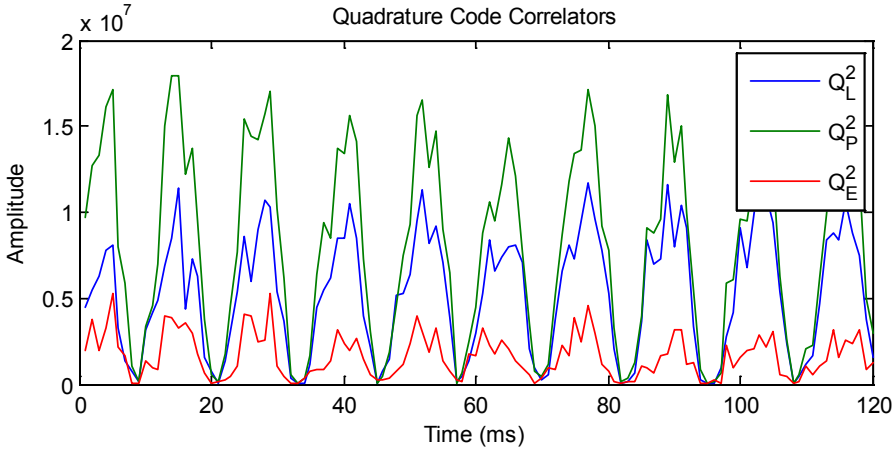


Noncoherent DLL

- Output from the correlators if the PLL is not in the lock state. The DLL must rely on outputs from all 6 correlators







Code Tracking Loop

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- The DLL error measurements are noisier than PLL
  - Therefore output form PLL is often used to aid DLL
  - The DLL noise bandwidth is reduced to minimize noise (even more in case of an aided DLL)
  - Longer integration time can be used due to low Doppler values
- The new, BOC type signals have multiple autocorolation peaks – the DLL must make shure that it tracks the main peak

Differences Between C/A And BOC Tracking

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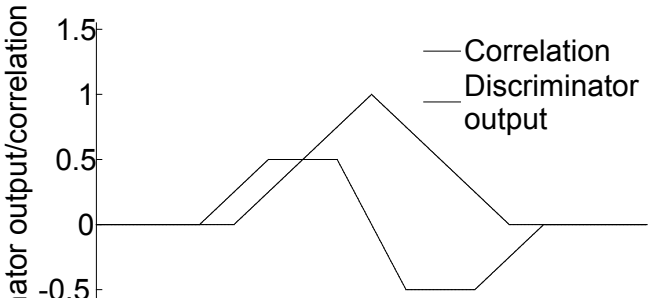
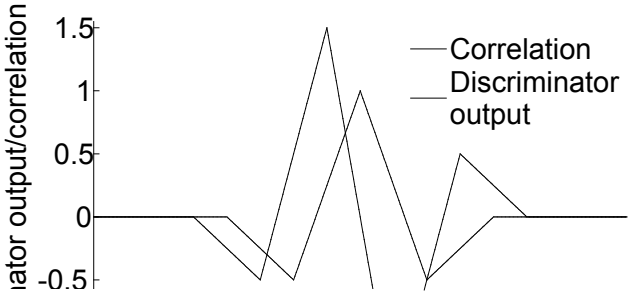
- Figures show signal autocorrelation and DLL discriminator output (E-L 0.5 chip spacing)
- BOC autocorrelation function and the discriminator have several minima and maxima. This is a problem for the traditional tracking therefore additional checks are introduced.





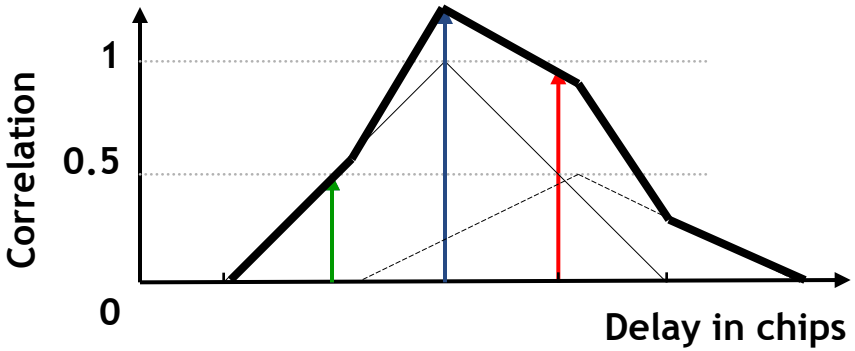
Multipath

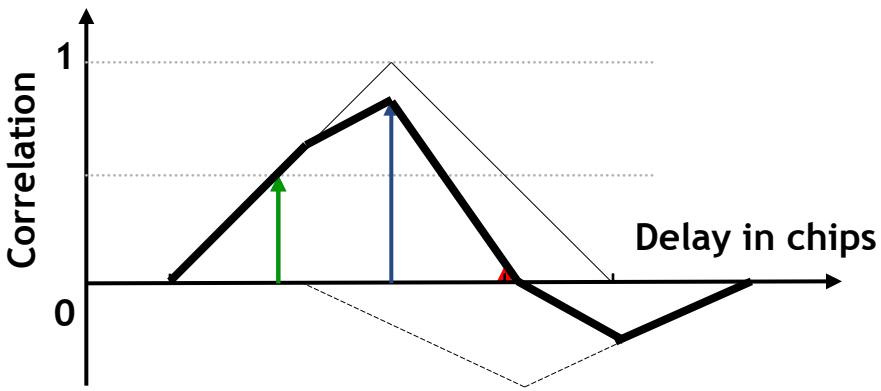
Tracking Errors Due To Multipath

- The multipath signal is a delayed and attenuated copy of the direct signal. There can be several (M) multipath signals.

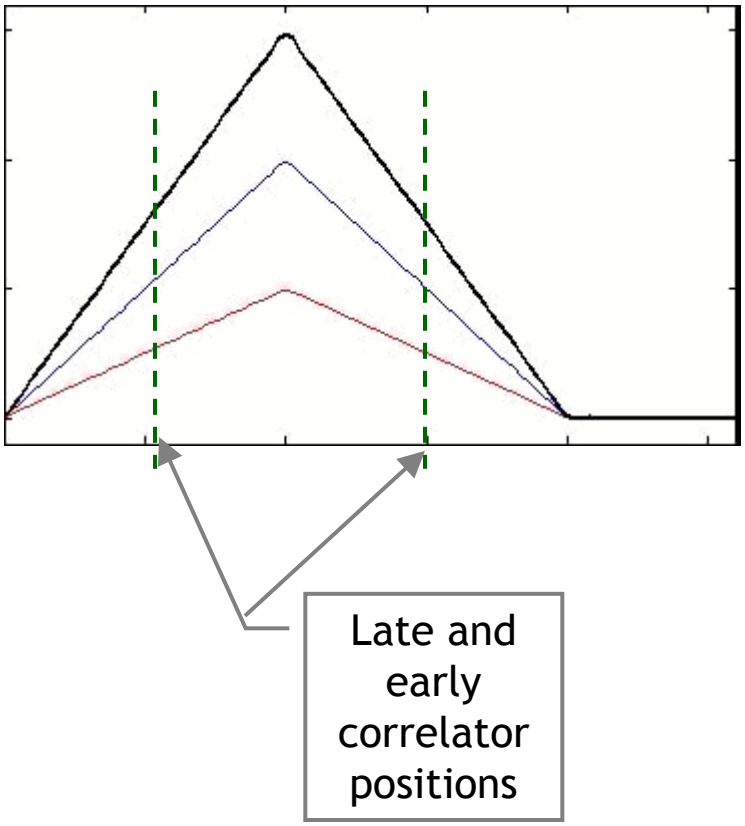
$$x(t) = \sum_{i=1}^{M} A_i(t) D(t - \tau_i(t)) C(t - \tau_i(t)) \cos(2\pi(f_0 + v_i(t)) + \varphi_i(t)) + n(t)$$

- The figures show the constructive and destructive interference of just one multipath signal





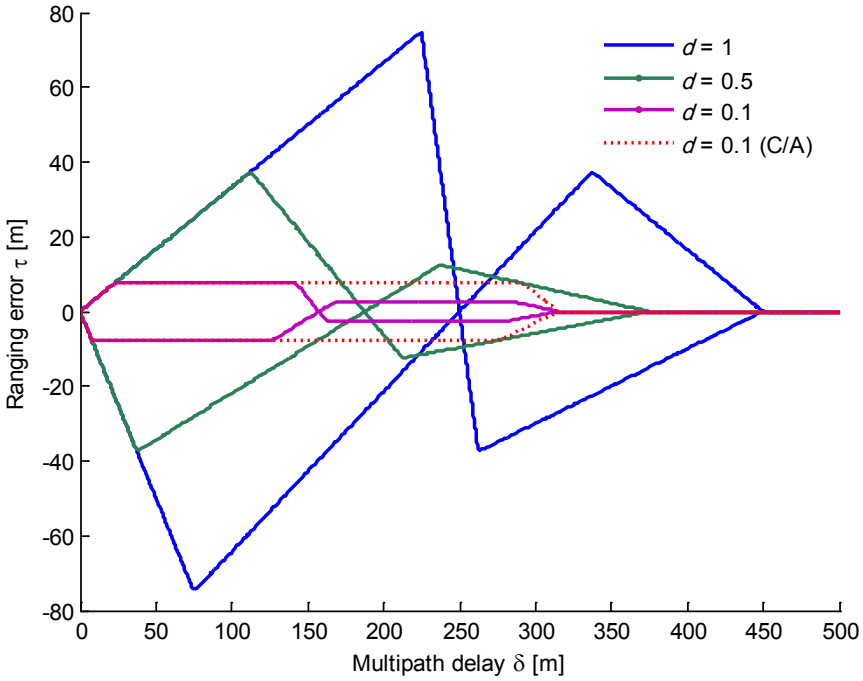
Multipath Video



- The video shows how the delay of the multipath signal affects correlation results in the receiver

- Blue line – the direct signal
- Red line – a multipath (delayed) signal
- Black line – combined result of the two signals

Multipath Envelope



- Multipath envelope shows what is the expected ranging error due to a multipath signal (50% of the direct signal power)
- The figure shows multipath envelopes for BOC(1, 1) signal using correlators with different spacing *d* and one envelope for GPS signal

Methods To Minimize Multipath Errors

- Antenna design – does not receive signals that have reflected once
- Special antenna design that blocks potential multipath signals from low elevation angles
- Special DLL, discriminator designs
- RAIM enables to detect erroneous measurements

Methods To Minimize Multipath Errors

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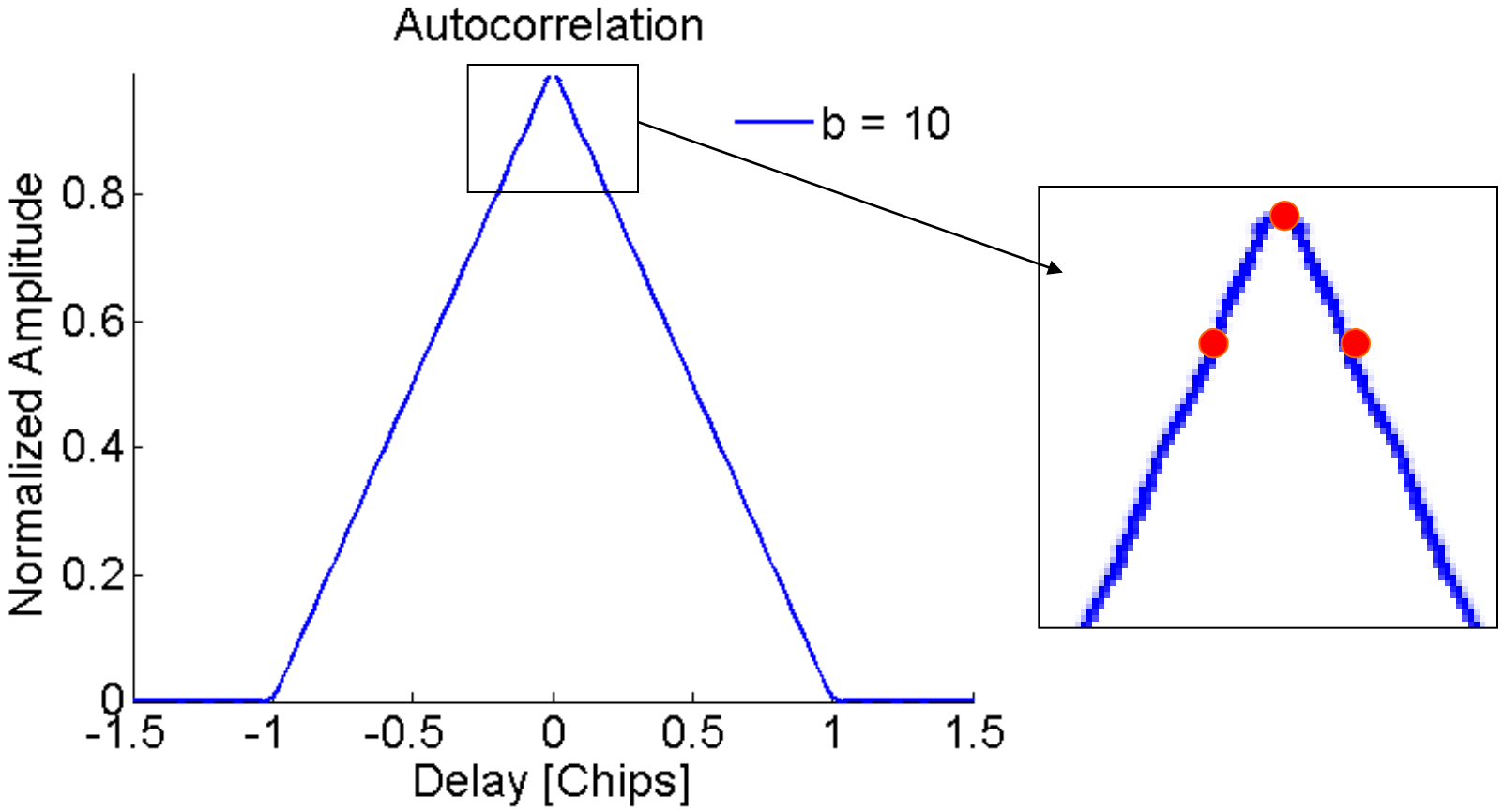
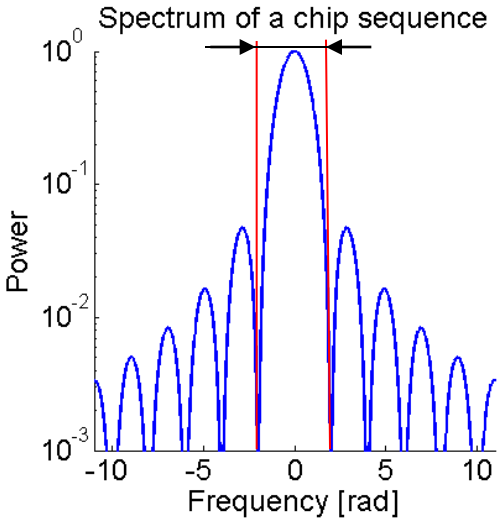
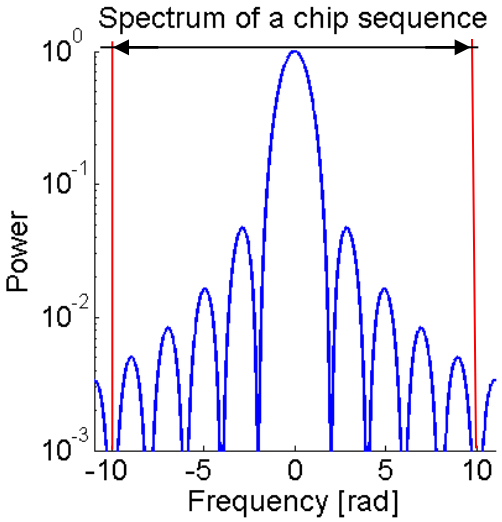
- DLL with narrow correlator spacing



Wide vs. Narrow Bandwidth





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Methods To Minimize Multipath Errors

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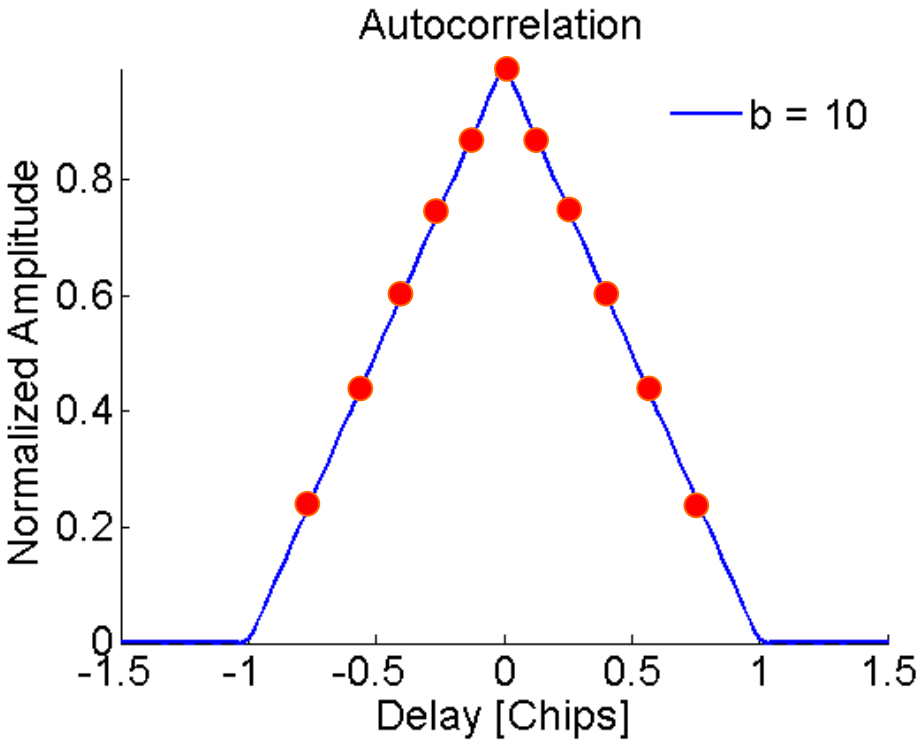
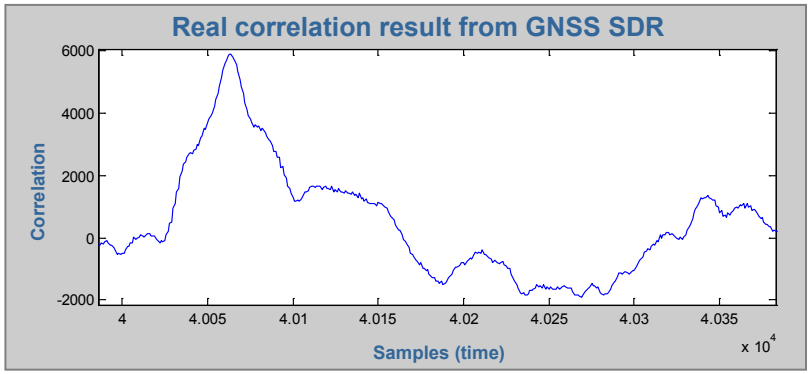
- DLL with many correlators – monitors the (auto)correlation shape





Methods To Minimize Multipath Errors

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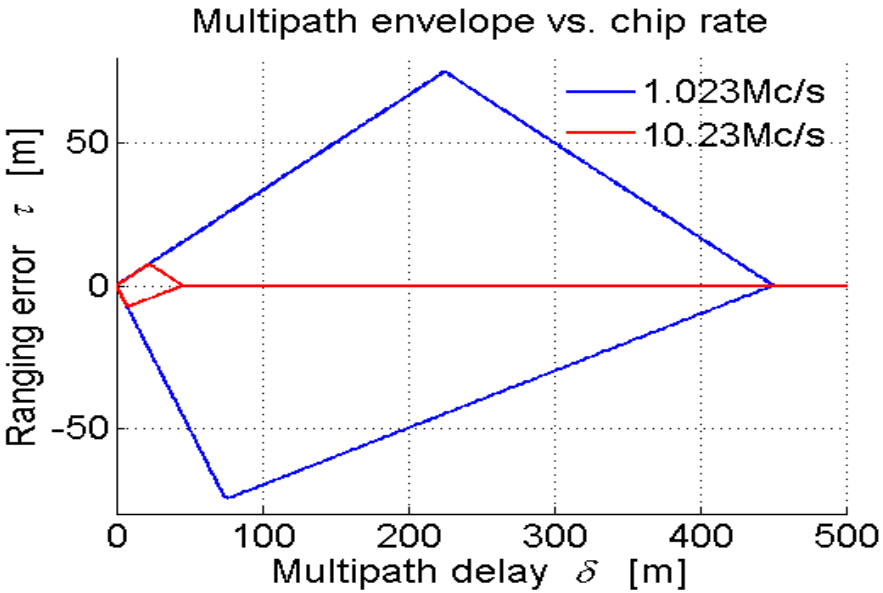
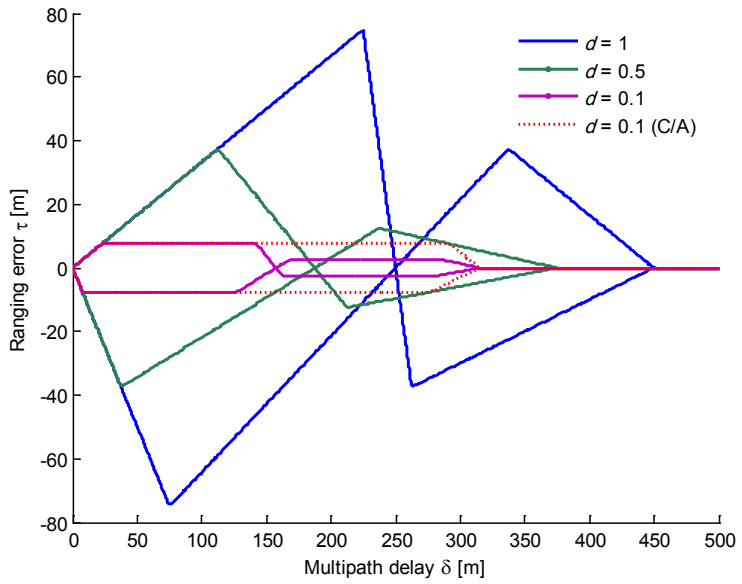
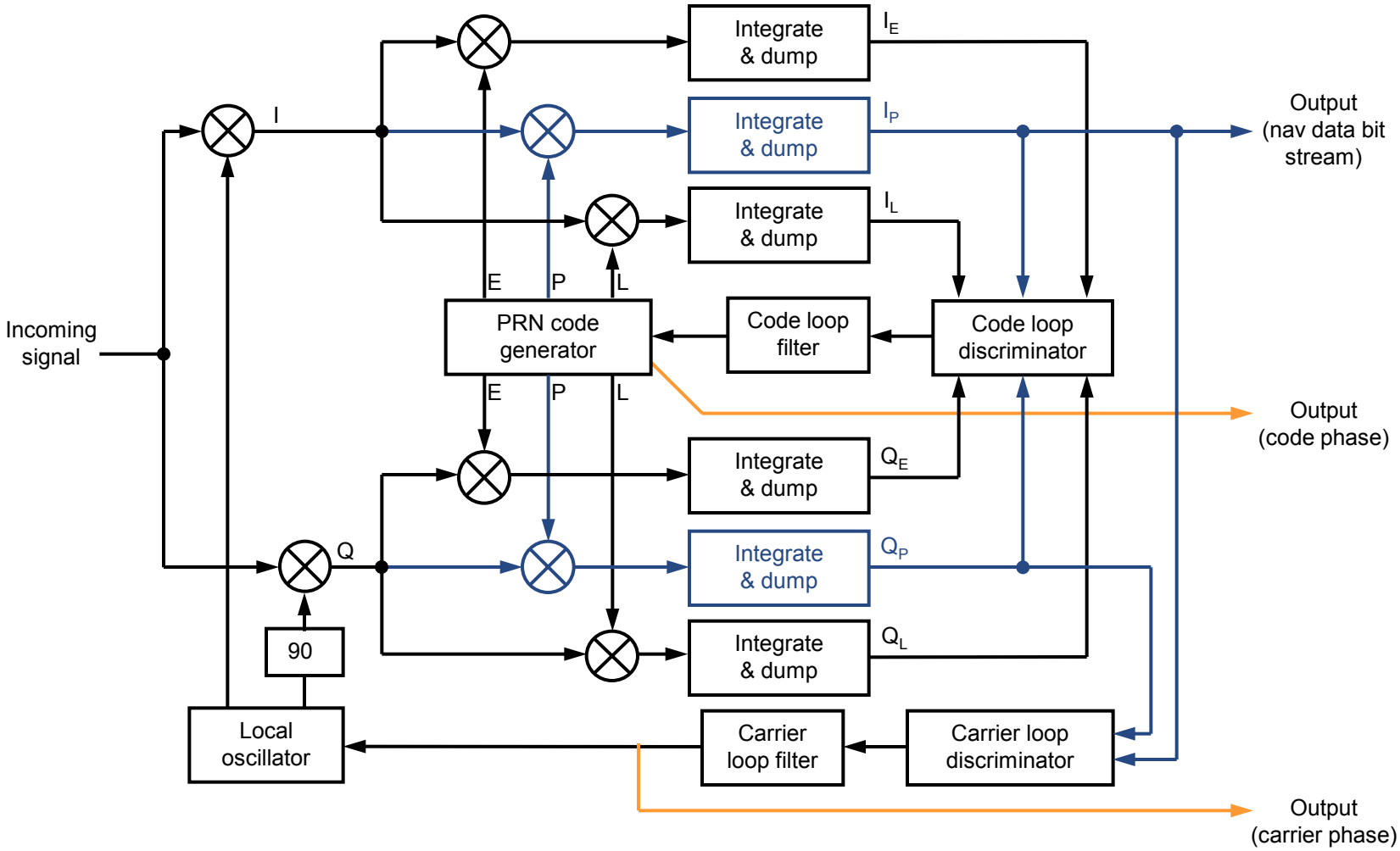
- **Signal design:**
  - **High chipping rate signals have narrow autocorrelation functions – potential for very precise tracking**
    - **High chipping rate yields high bandwidth requirements**
  - **BOC signals have narrow autocorrelation functions**





Combining Tracking Tasks

Complete Receiver Channel



GPS Signal Tracking Movie

Questions and Exercises

Exercise

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- Make a DLL tracking loop. Block process in 1ms.