Satellite Navigation
Principle and performance of GPS receivers


GPS Block IIF satellite – Boeing North America

AE4E08

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Course 2010 – 2011, lecture 3

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Today's topics

- Introduction – basic idea
- Link budget
- Signal de-modulation
- Receiver architecture
- Measurement precision

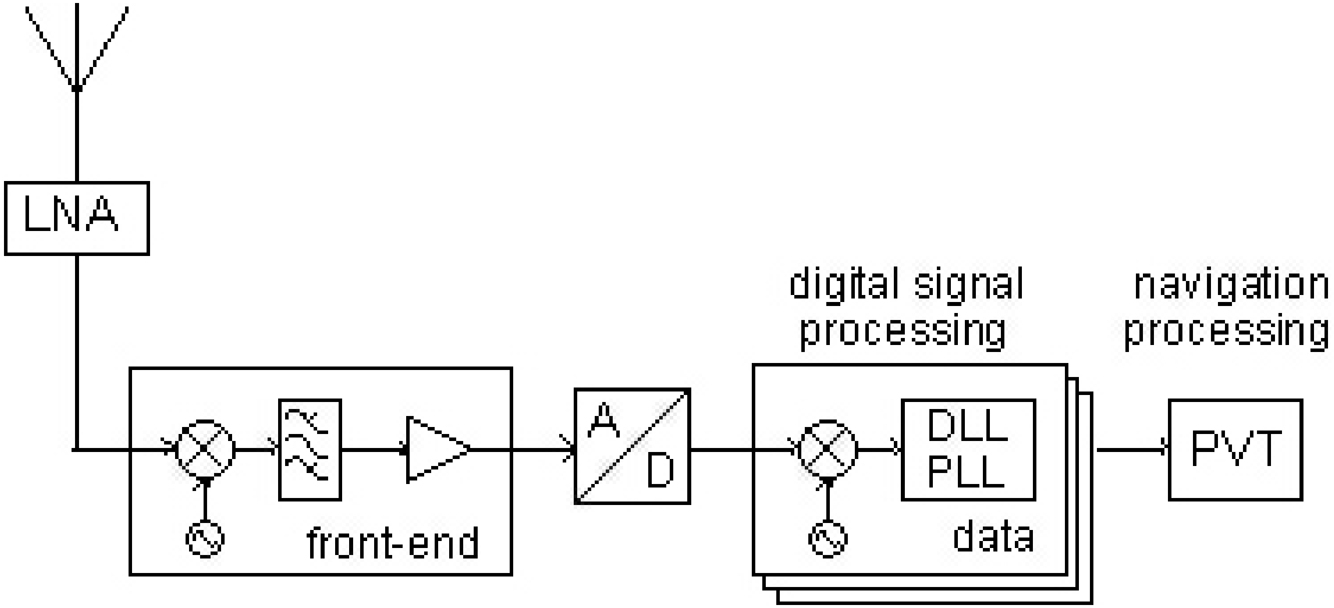
topics in part III and IV of Misra&Enge book, instead ...:

GPS Receiver Architectures and Measurements

by Michael S. Braasch and A.J. van Dierendonck
Proceedings of the IEEE, Vol. 87, No. 1, January 1999
pp. 48-64

concise exposition of subject

Receiver architecture



overview of a GNSS receiver – main building blocks

its purpose? output: - pseudorange code measurement
- carrier phase measurement
- Doppler measurement
- C/N0 measurement (signal strength)

GPS receiver architecture - functionality

basic idea

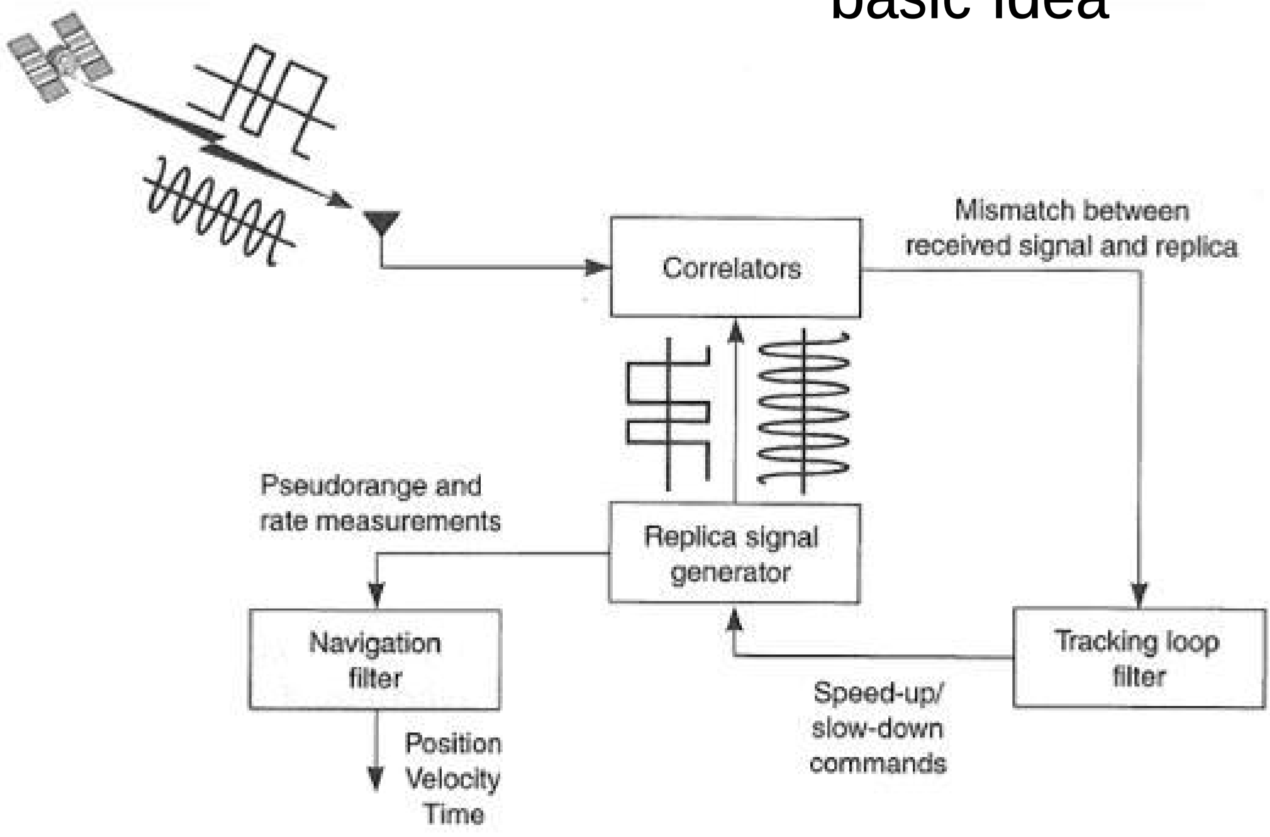
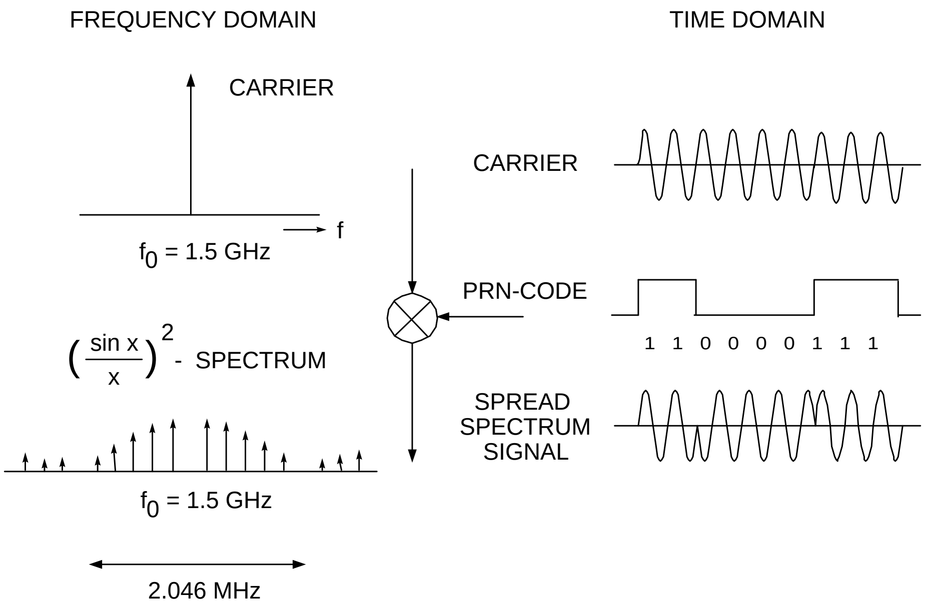


Figure 2.7 A conceptual view of a GPS receiver.

from: Misra and Enge

The GPS Signal - recap

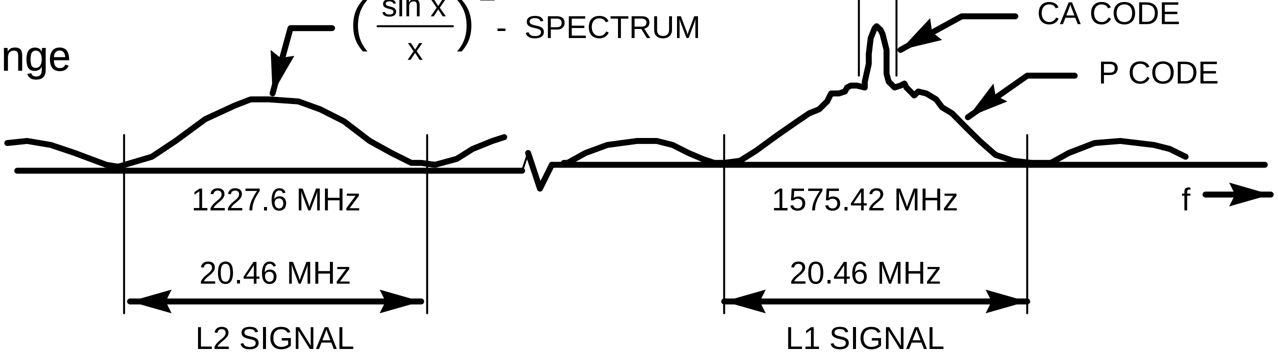


Binary Phase Shift Keying (BPSK) modulation (spread spectrum (SS) modulation)

with Pseudo Random Noise (PRN) code sequences:

- C/A code on L1 - 1.023 Mbits/sec
- P(Y) code on L1 and L2 - 10.23 Mbits/sec

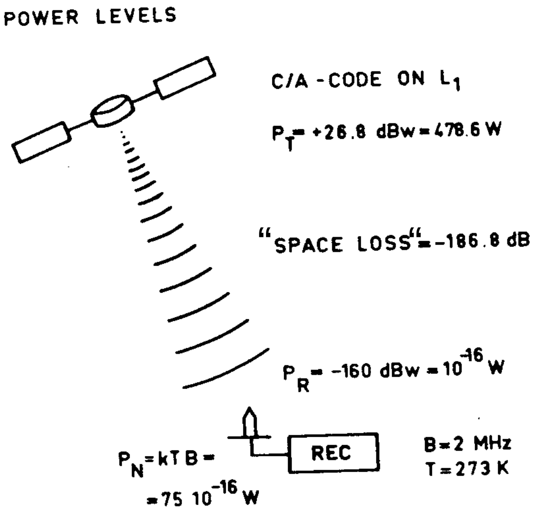
see also Figure 2.5 in Misra&Enge

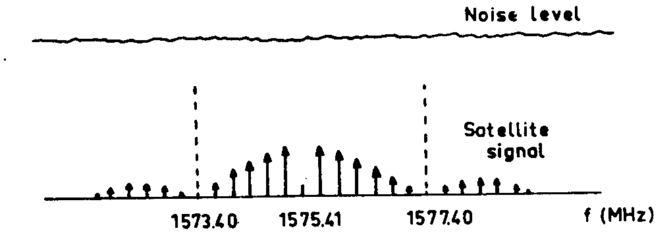


The GPS Signal at the Receiver Antenna

- Signal delayed due to the travel time
  - speed of light in vacuum
  - atmospheric delays
- Signal has undergone a Doppler shift (freq)
- Signal is very weak (amplitude)
  - ordinary spherical weakening (~158 dB)
  - atmospheric absorption (small, 1-2 dB)

typical signal-to-noise ratio (SNR) for the C/A code signal is ~1/80 (-19dB)
→ well below noise level





dB? see § 2.3.3 Misra&Enge

Link budget - 1

Table 1 from IEEE-article

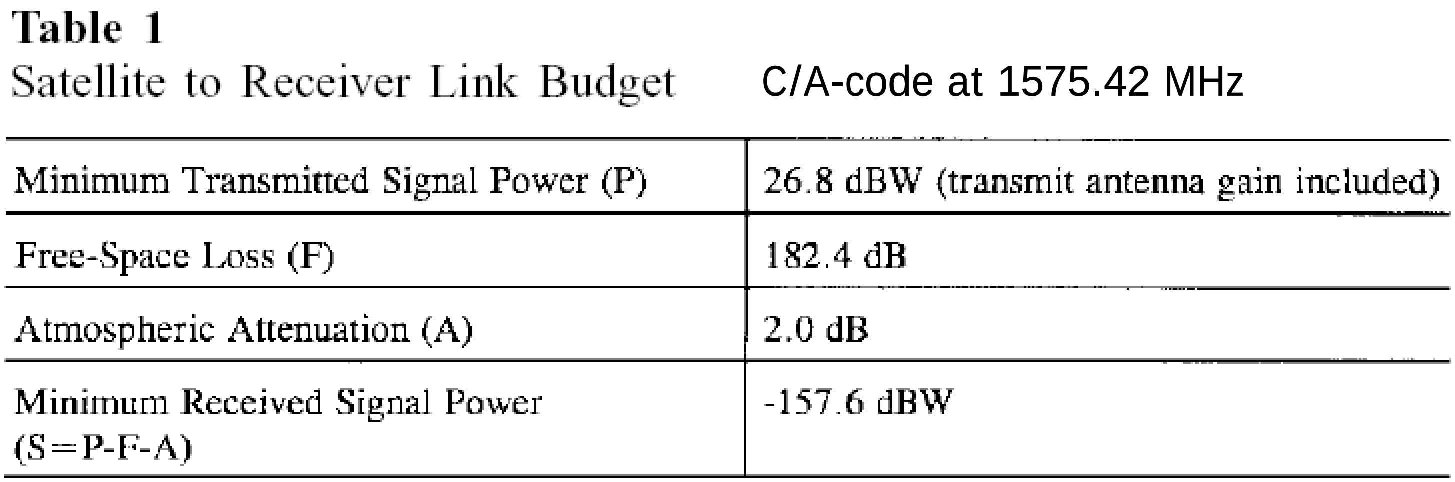


Table 1

Satellite to Receiver Link Budget

C/A-code at 1575.42 MHz

Minimum Transmitted Signal Power (P)	26.8 dBW (transmit antenna gain included)
Free-Space Loss (F)	182.4 dB
Atmospheric Attenuation (A)	2.0 dB
Minimum Received Signal Power (S=P-F-A)	-157.6 dBW

satellite antenna: directs signal in beam (not omni-directional)

EIRP: 478.63 W (or 26.8 dBW) $26.8\text{ dBW} = 10 \log_{10} 478.63\text{ W}$

$$\text{free}-\text{space loss factor} = \left(\frac{\lambda}{4\pi R}\right)^2$$

spherical spreading

factor $= 5.73 * 10^{-19}$

$-182.4\text{ dB} = 10 \log_{10} 5.73\text{e-}19$

includes effective area of (omni-directional) receiver antenna - see § 10.2 Misra&Enge

$A_E = \lambda^2/4\pi$

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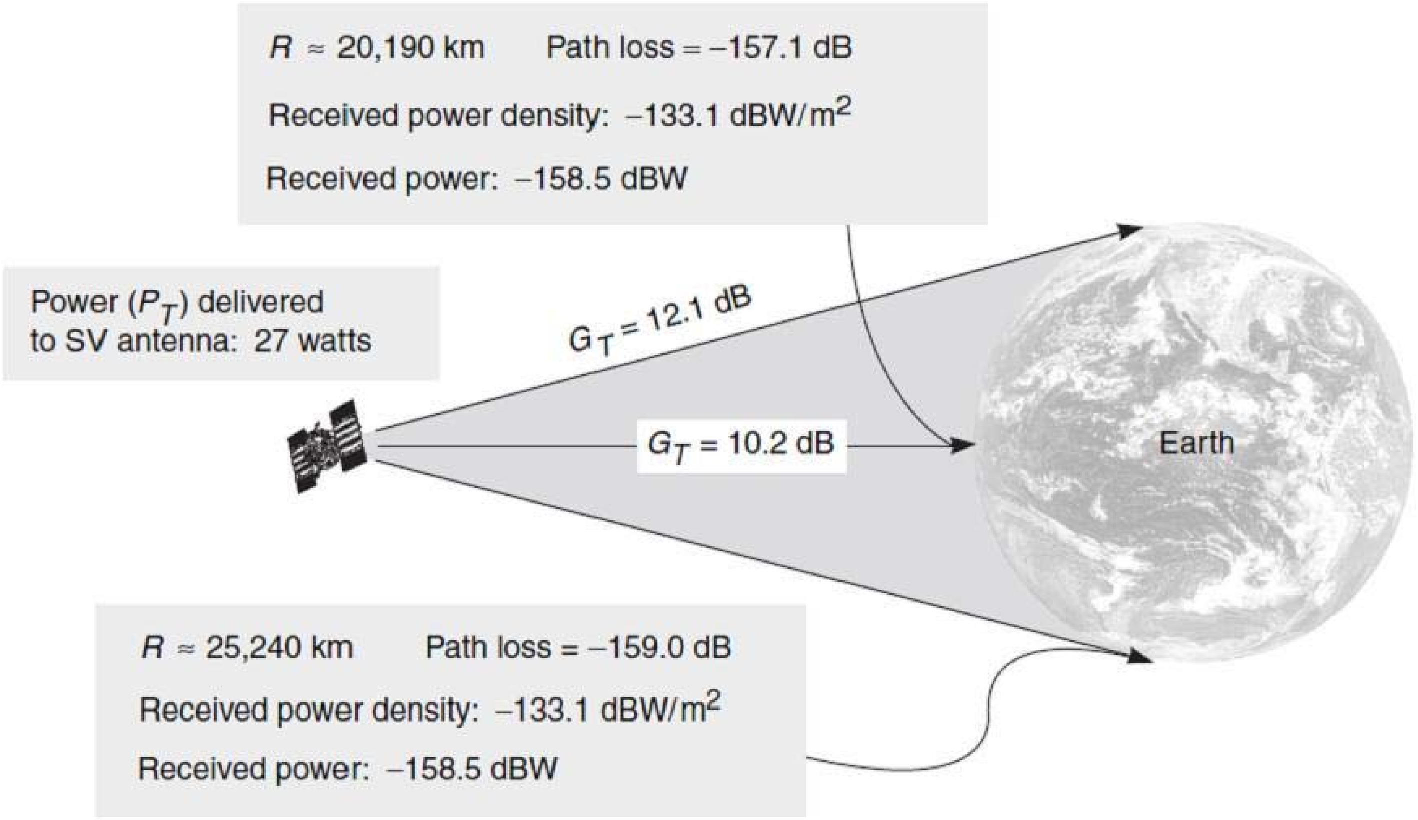
Power density of received GNSS signal



$R \approx 20{,}190$ km Path loss = −157.1 dB

Received power density: −133.1 dBW/m^2

Received power: −158.5 dBW

Power (P_T) delivered to SV antenna: 27 watts

$R \approx 25{,}240$ km Path loss = −159.0 dB

Received power density: −133.1 dBW/m^2

Received power: −158.5 dBW

Figure 10.4 Summary of power density of received GPS signal. The actual values are typically higher.

from: Misra and Enge

Link budget - 2

atmospheric loss: -2 dB

$-2\ \text{dB} = 10 \log_{10} 0.63$ (hence factor of 0.63)

$$\begin{array}{lrcl}
\Rightarrow \text{received signal power:} & 26.8\ \text{dBW} & & 478.63\ \text{W} \\
 & -182.4\ \text{dB} & & \text{x}\ \ 5.73 * 10^{-19} \\
 & -2.0\ \text{dB} & + & \text{x}\ \ 0.63 \\
\hline
 & -157.6\ \text{dBW} & & 1.738 * 10^{-16}\ \text{W}
\end{array}$$

---

noise power at receiver: $1.413*10^{-14}$ W (or –138.5 dBW) in 2 MHz bandwidth

$-138.5\ \text{dBW} = 10 \log_{10} 1.413\text{e-}14\ \text{W}$

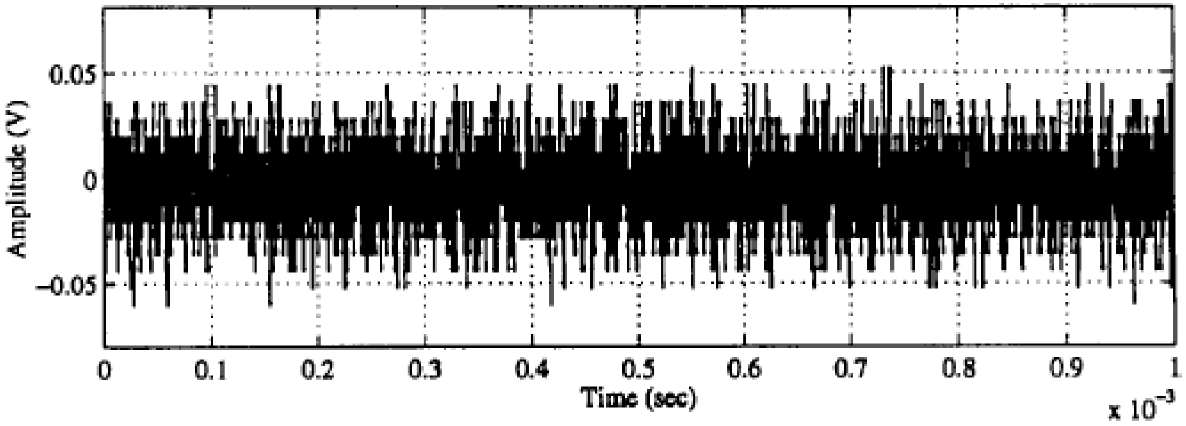
Link budget - 3

Signal-to-Noise ratio (SNR)

$$\text{SNR} = \frac{\textbf{signal power [W]}}{\textbf{noise power [W]}}$$

	signal power:	-157.6 dBW	$1.738 * 10^{-16}$ W
	noise power:	-138.5 dBW -	/ $1.413 * 10^{-14}$ W
at receiver on Earth	SNR:	-19.1 dB	0.0123

Fig. 6 (a) from IEEE-article



1 millisecond of received signal - sampled at 5 MHz (amplified & filtered)

raw GPS signal?
‘nothing’ to see !

⇒ signal indeed far
below noise-floor

Signal de-modulation

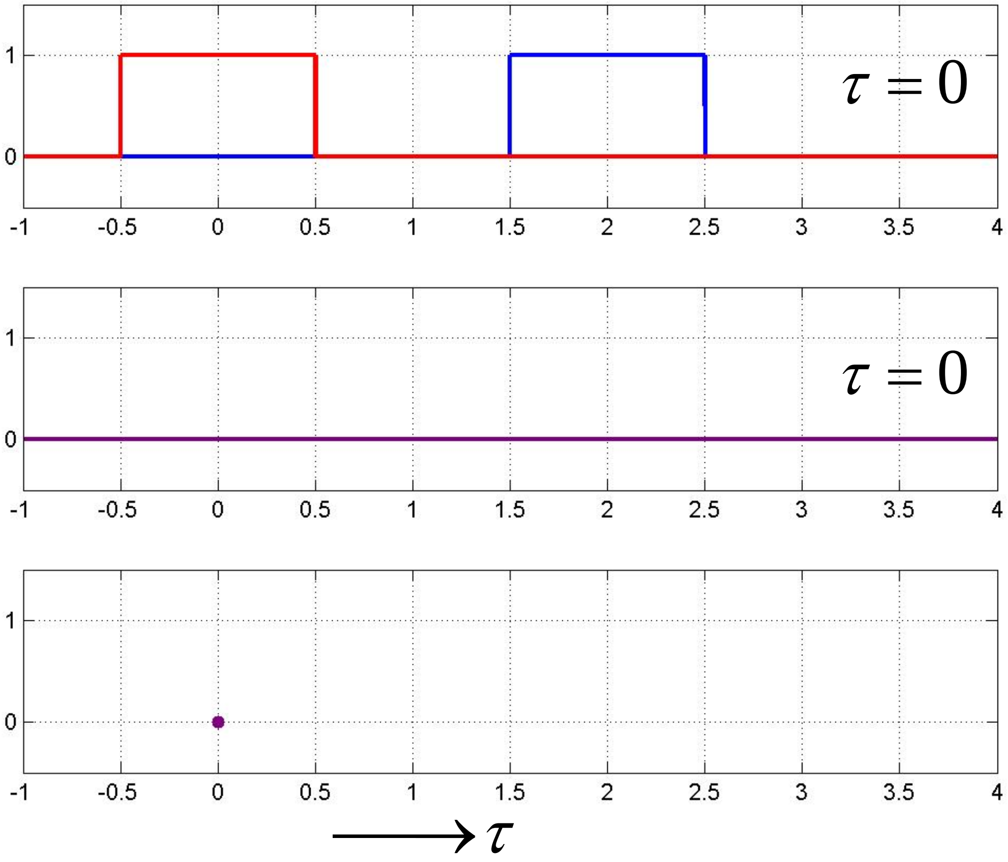
- tracking
- work-out on the blackboard ...

Correlation

Demo is on blackboard.

Correlation

- $s_1(t)$
- $s_2(t-\tau)$
- $s_1(t).s_2(t-\tau)$
- $\int s_1(t).s_2(t-\tau)$



- **shift**
- **multiply**
- **integrate**

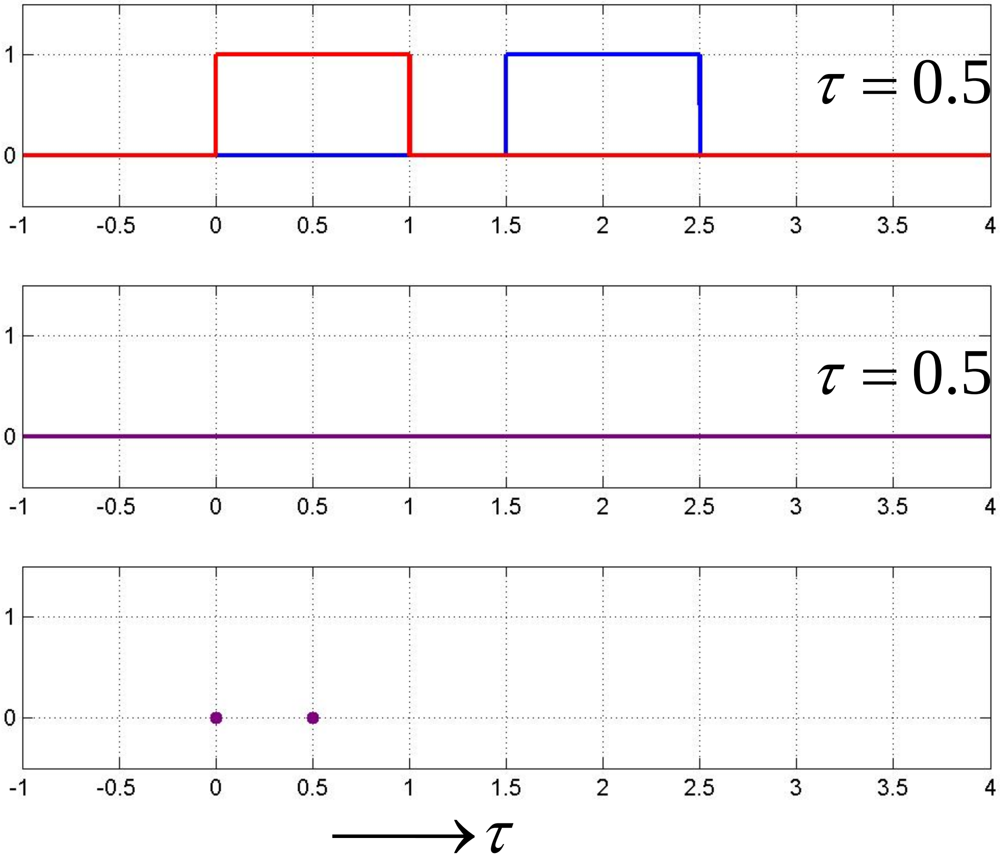
Correlation

$s_1(t)$

$s_2(t-\tau)$

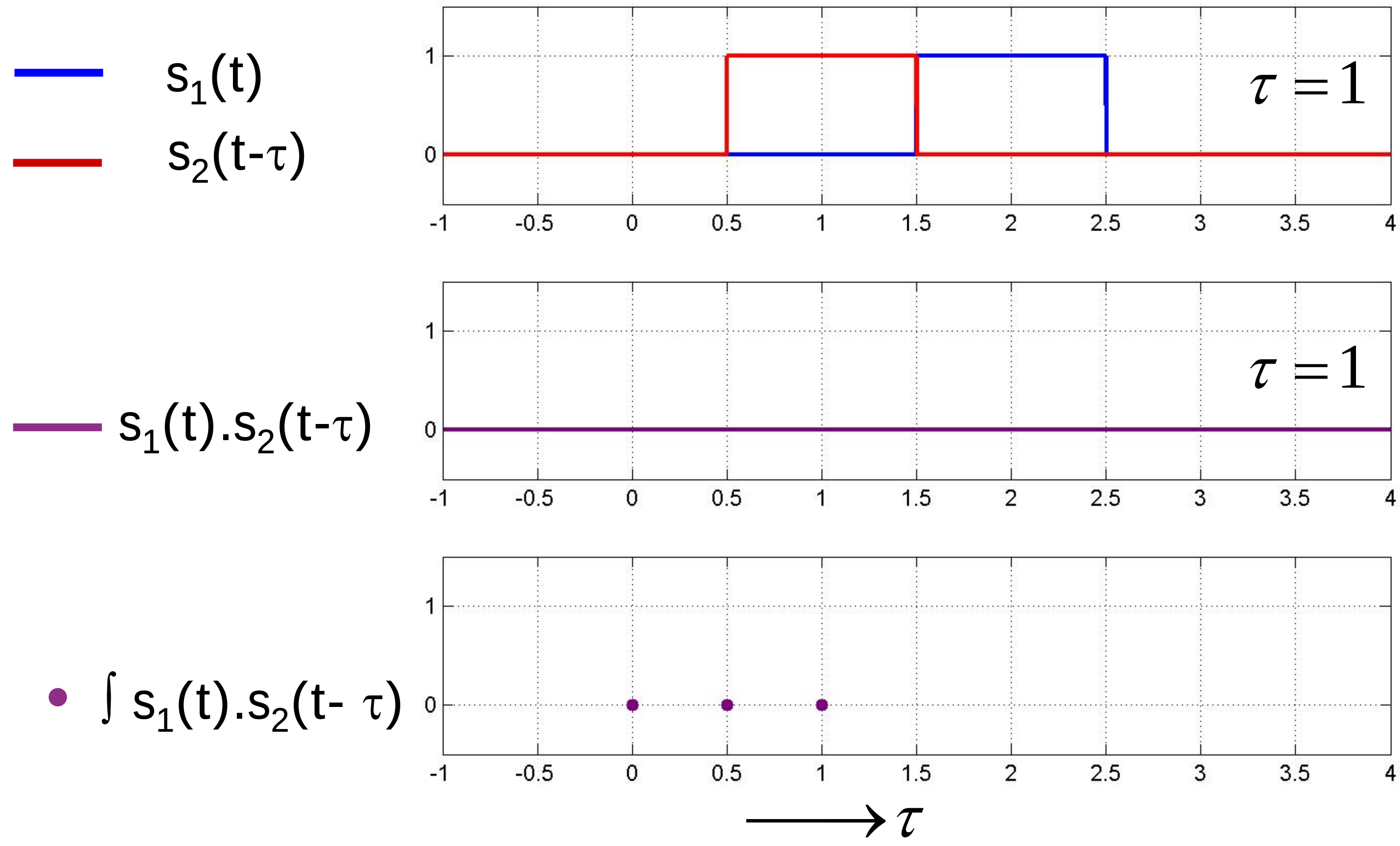
$s_1(t).s_2(t-\tau)$

- $\int s_1(t).s_2(t-\tau)$



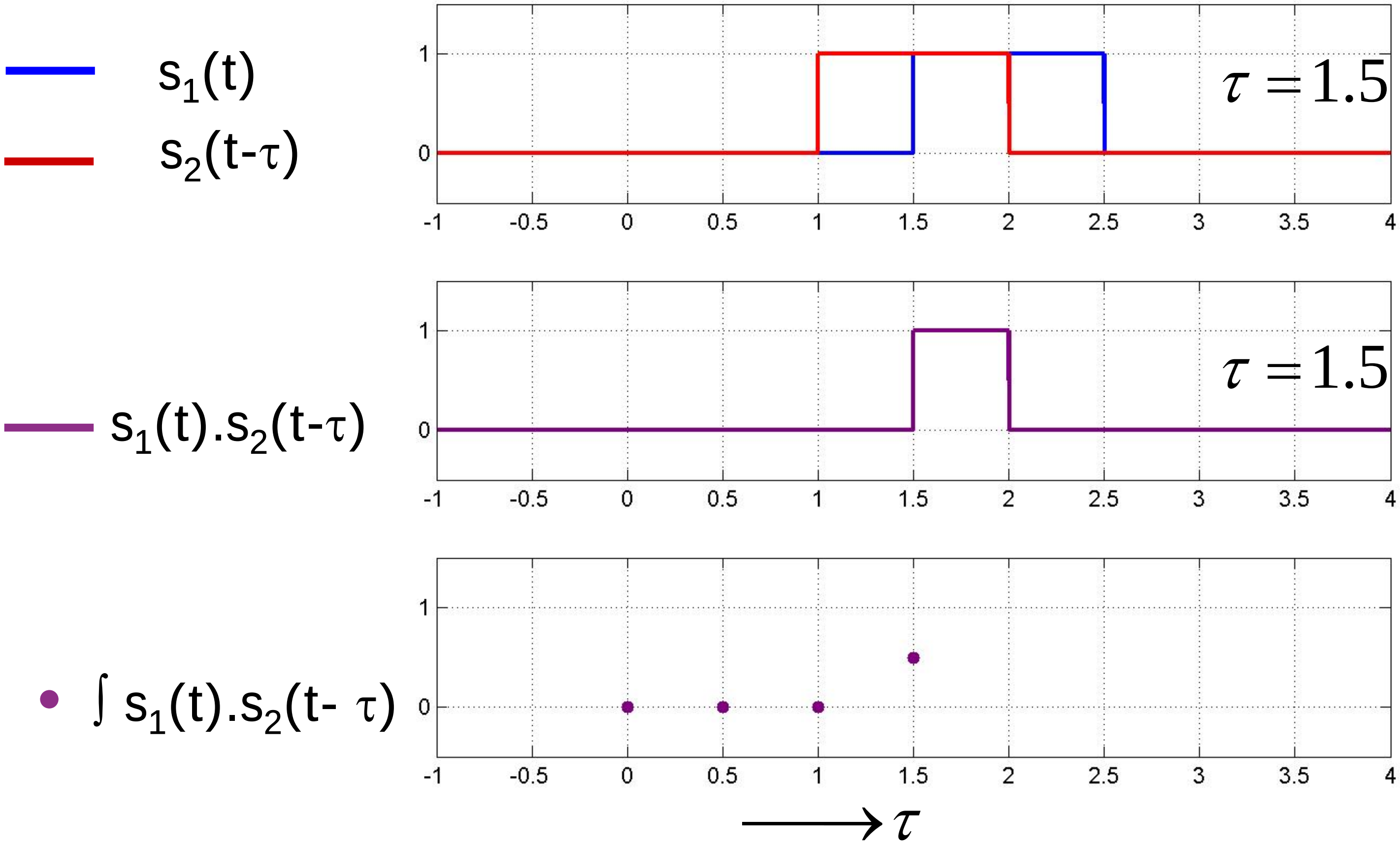
- **shift**
- **multiply**
- **integrate**

Correlation



- **shift**
- **multiply**
- **integrate**

Correlation



- **shift**
- **multiply**
- **integrate**

Correlation

— $s_1(t)$

— $s_2(t-\tau)$

— $s_1(t).s_2(t-\tau)$

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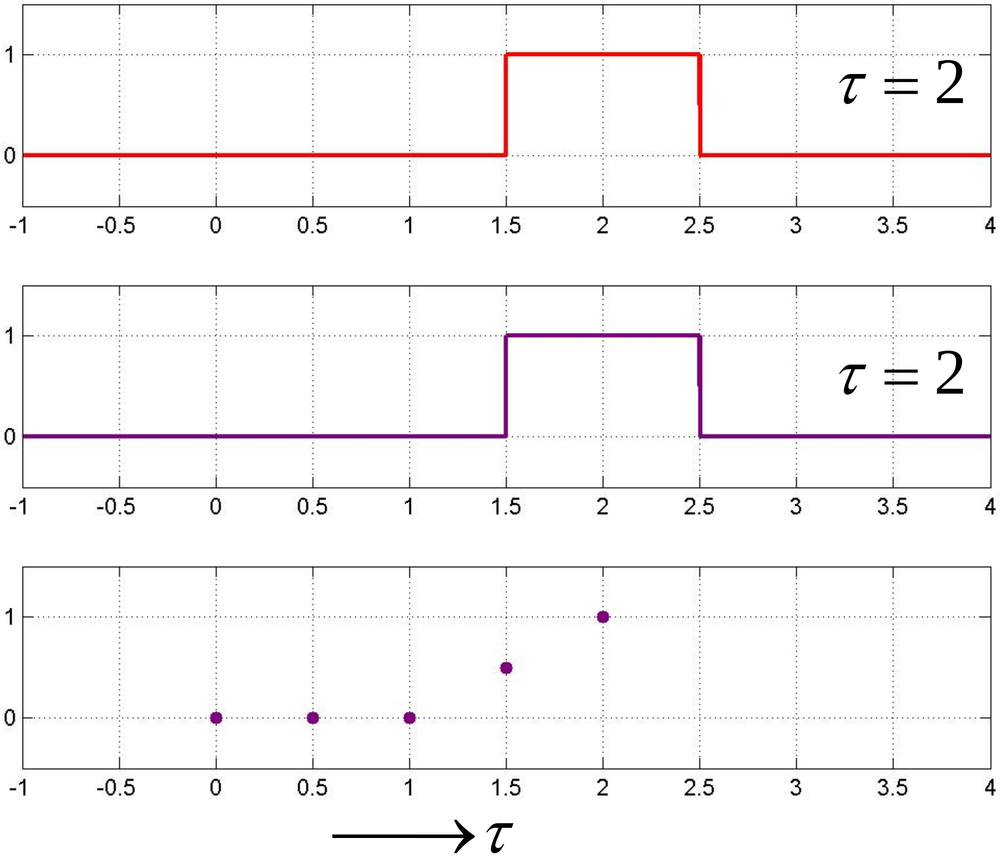

- **shift**
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- **integrate**

Correlation

— $s_1(t)$

— $s_2(t-\tau)$

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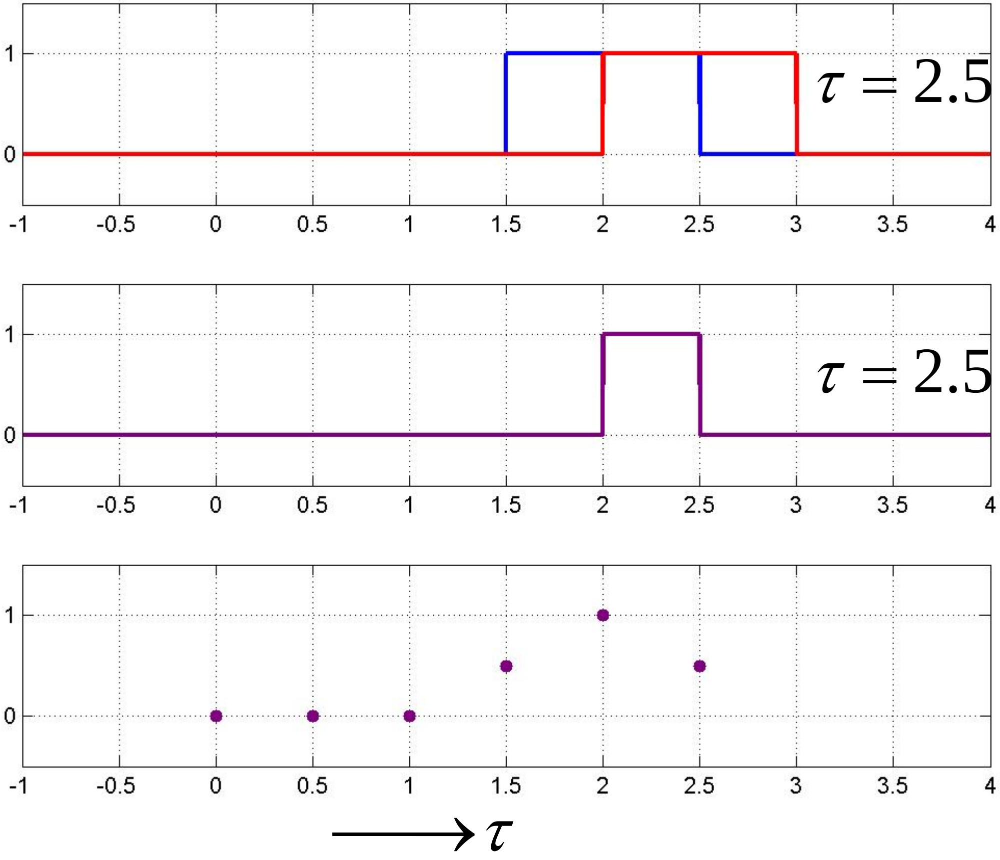


- **shift**
- **multiply**
- **integrate**

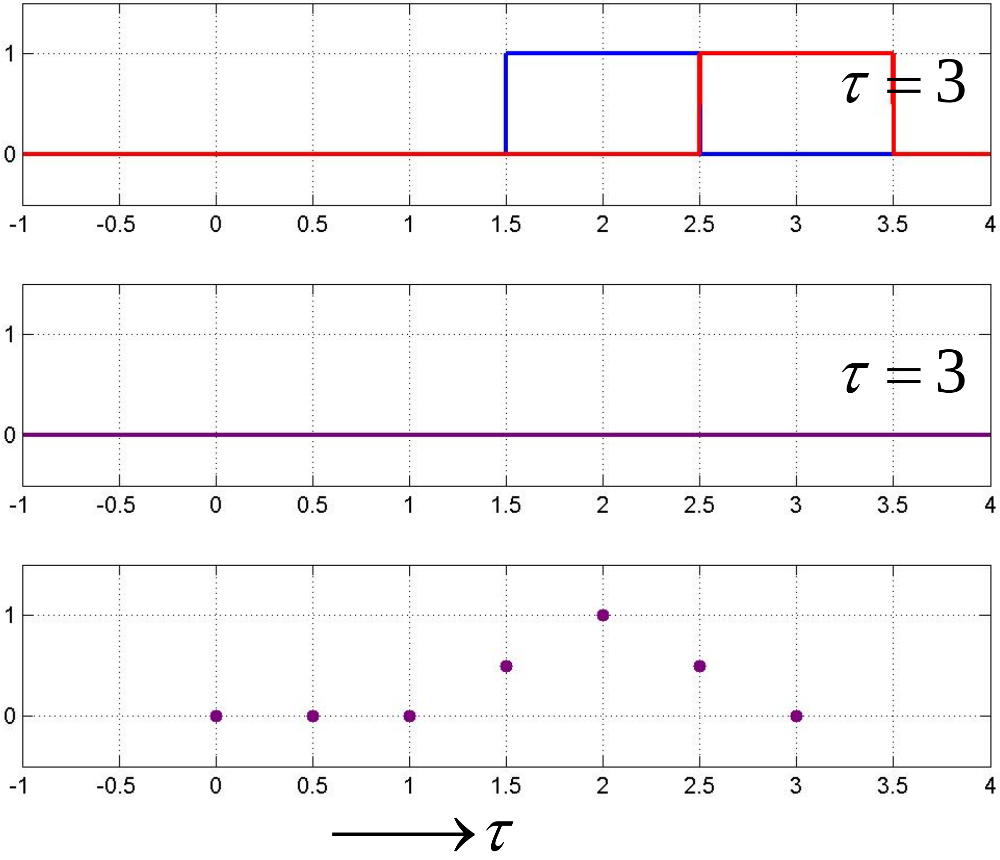
Correlation

$s_1(t)$

$s_2(t-\tau)$

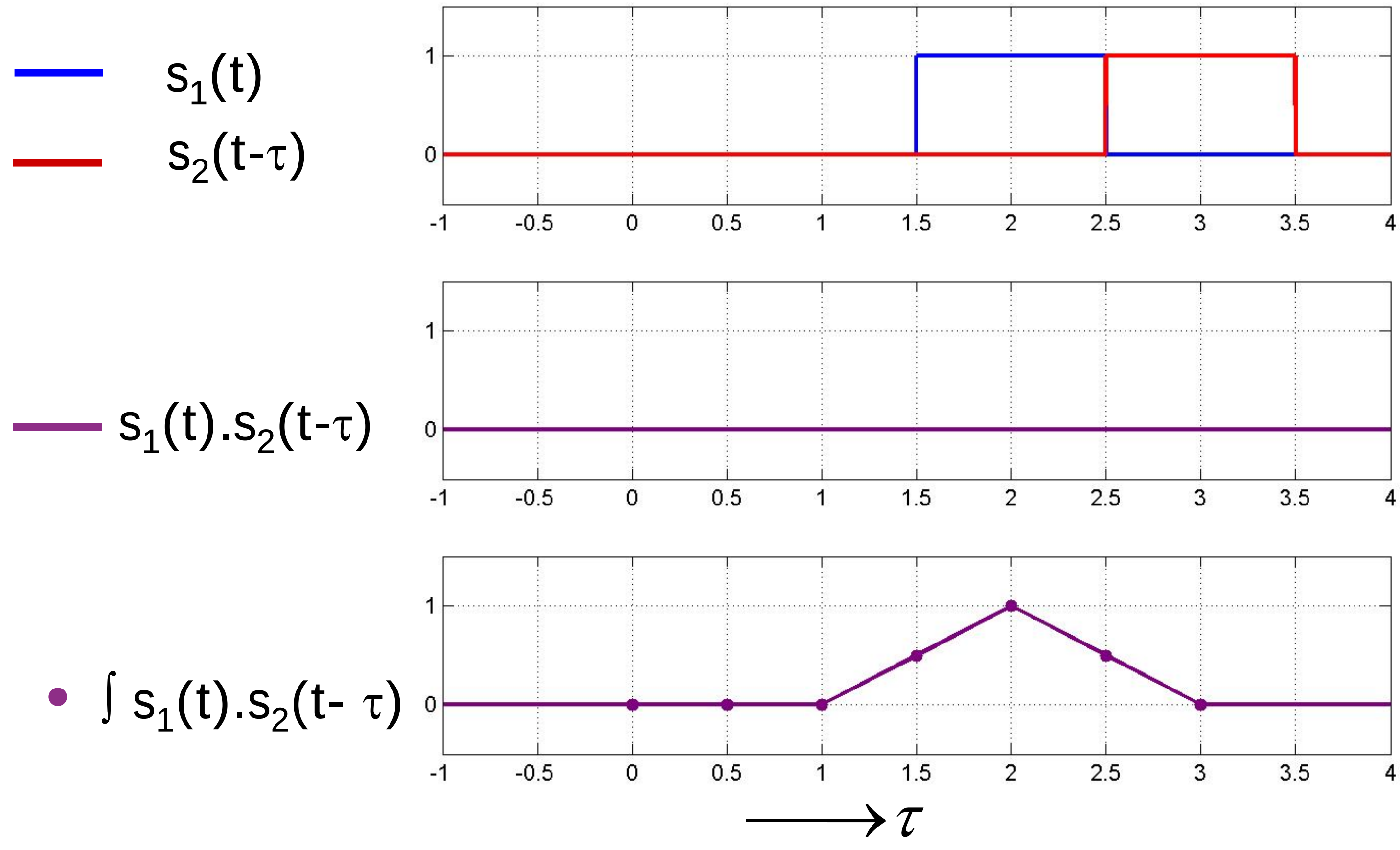
$s_1(t).s_2(t-\tau)$

- $\int s_1(t).s_2(t-\tau)$



- **shift**
- **multiply**
- **integrate**

Correlation



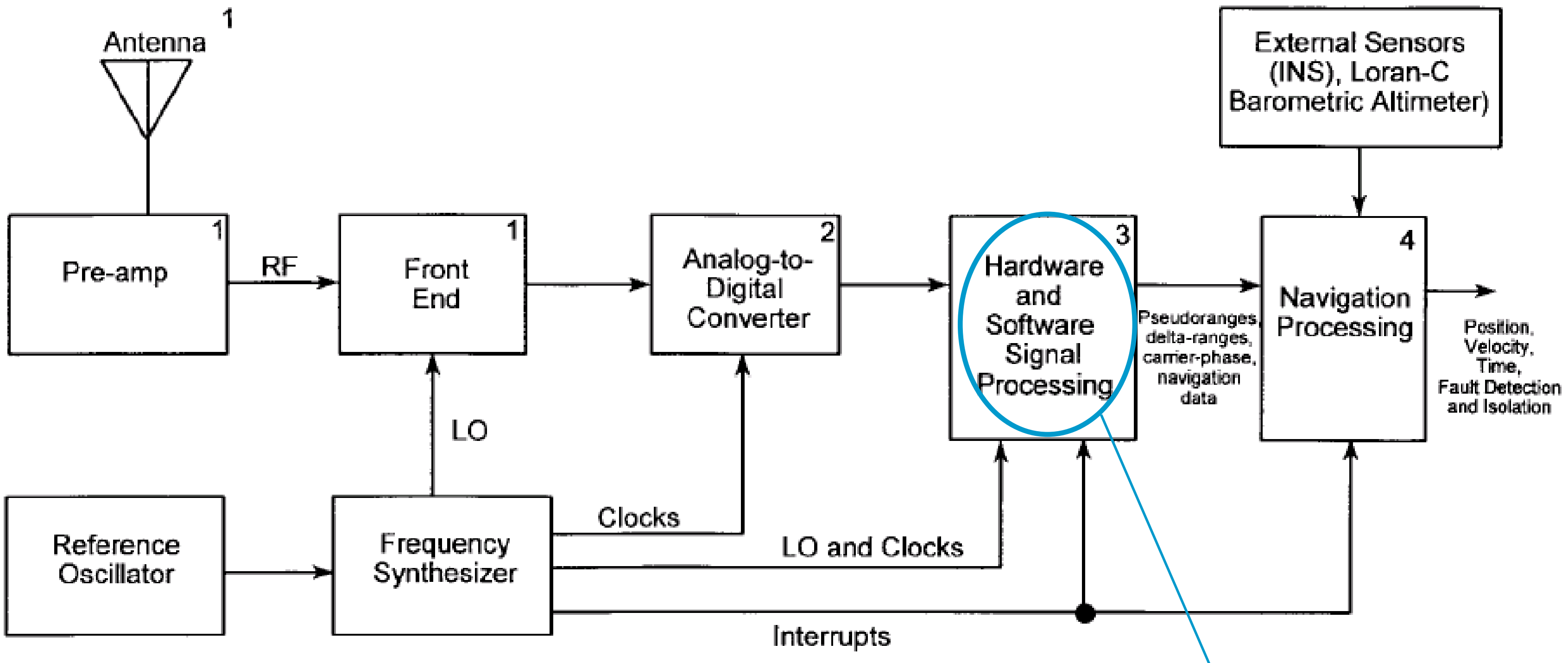
- **shift**
- **multiply**
- **integrate**

Two stages of receiver operation

- acquisition (searching)
- tracking (following) – providing measurements

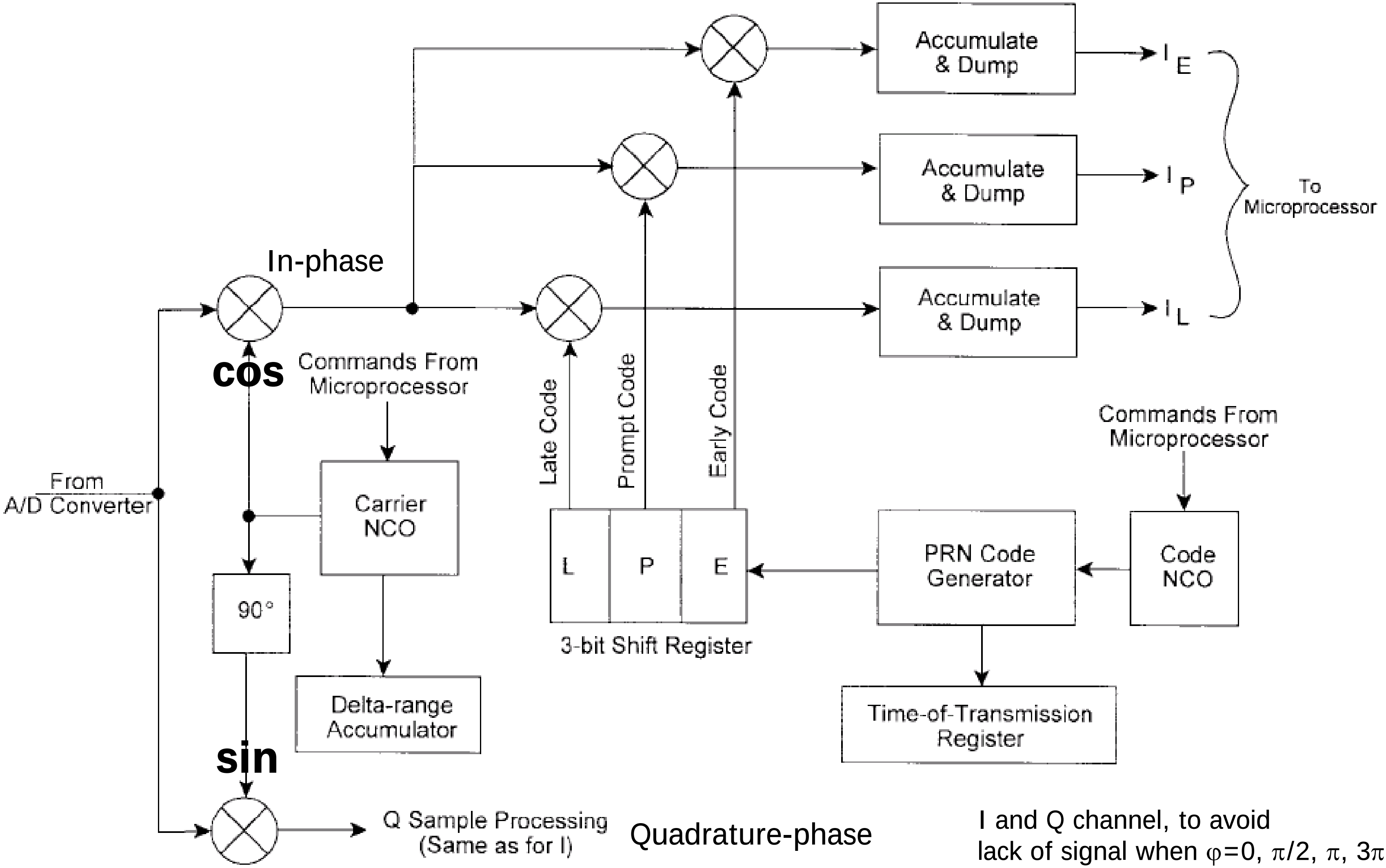
Receiver block diagram

Fig. 5 from IEEE-article



next slide ...

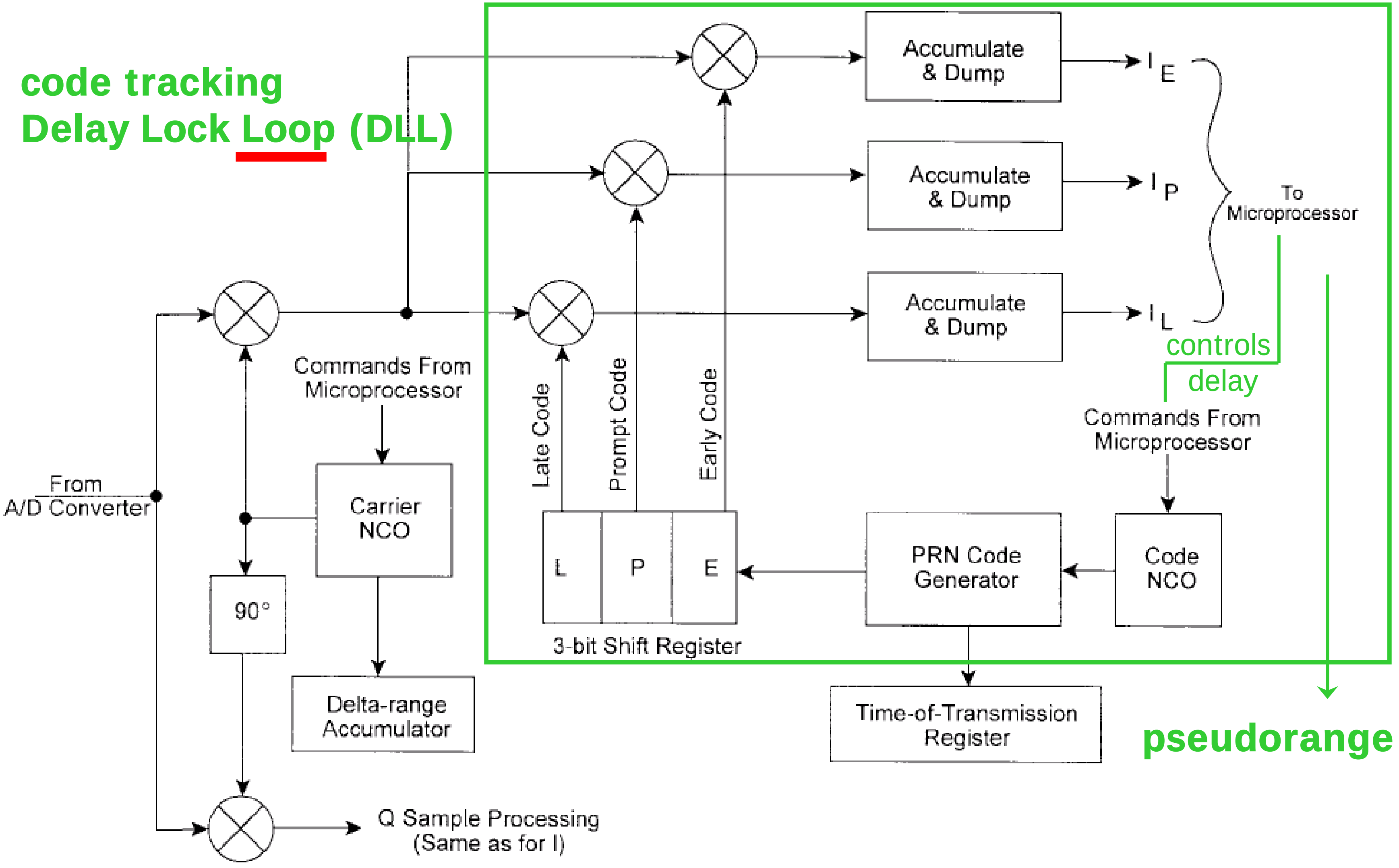
Fig. 7 from IEEE-article



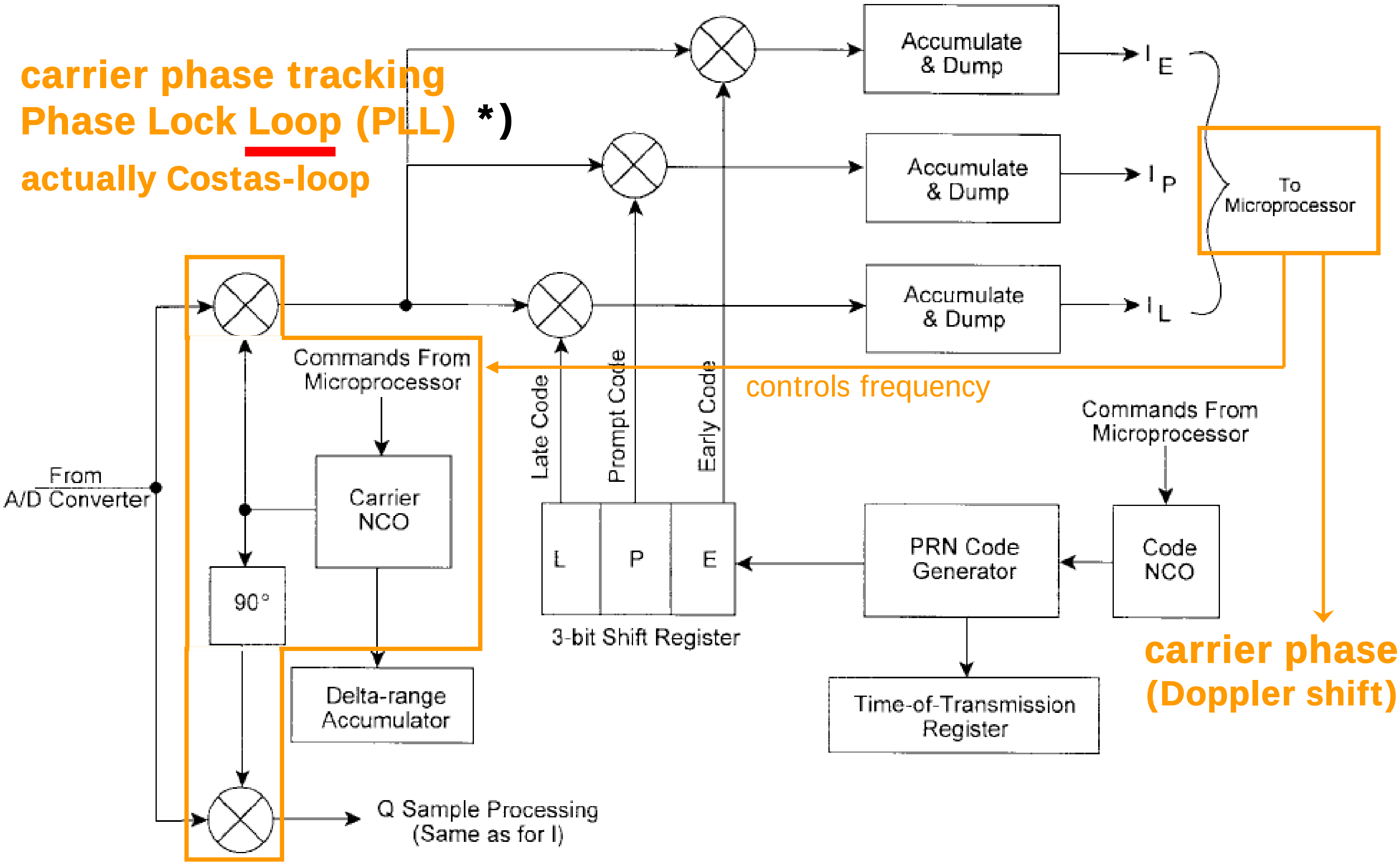
I and Q channel, to avoid
lack of signal when φ=0, $\pi/2$, π, $3\pi/2$

baseband signal processing block diagram = block 3 in Fig. 5.

code tracking
Delay Lock Loop (DLL)



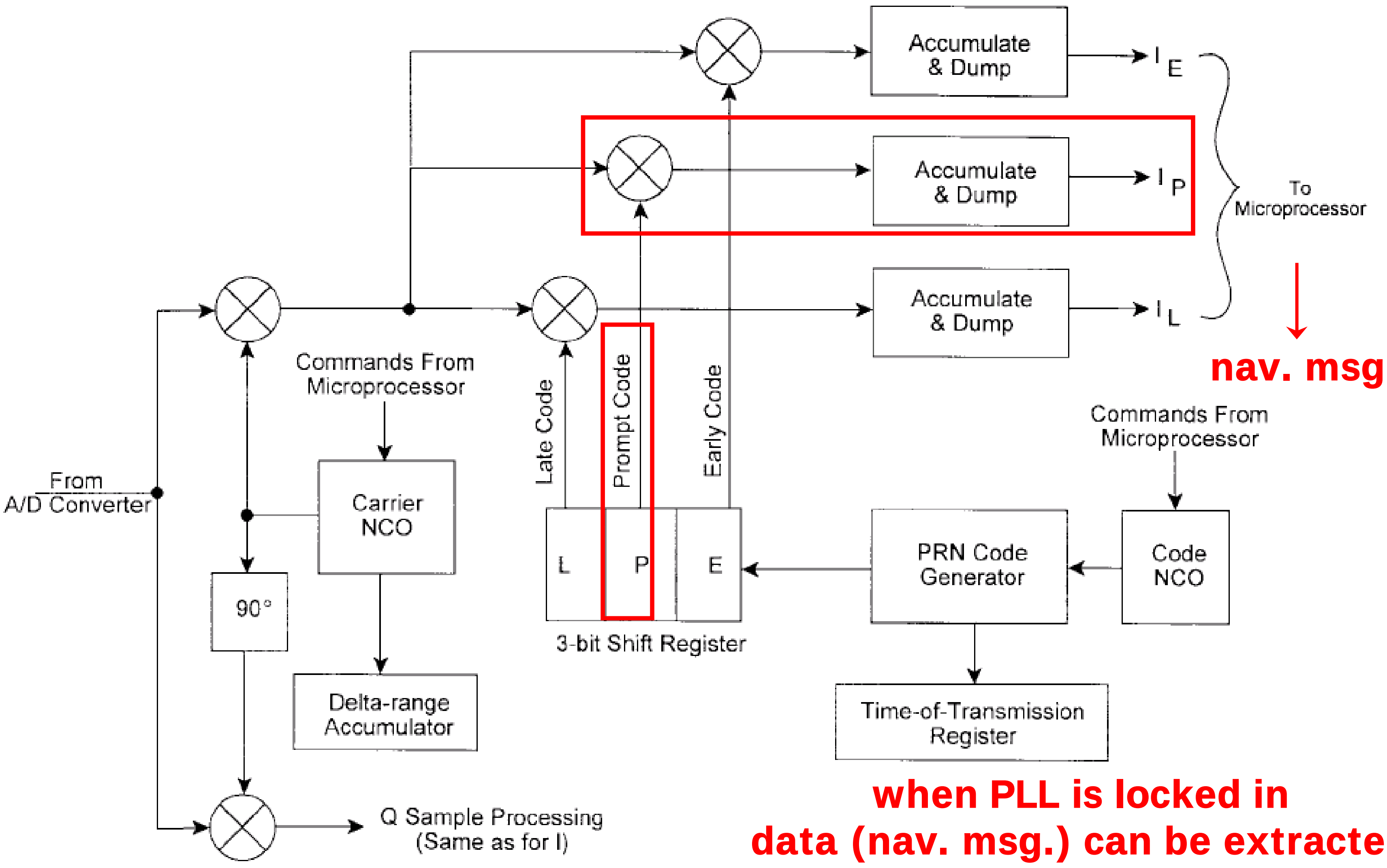
carrier phase tracking
Phase Lock Loop (PLL) *)
actually Costas-loop



controls frequency

carrier phase (Doppler shift)

*) sometimes also Carrier Tracking Loop (CTL)



nav. msg.

when PLL is locked in data (nav. msg.) can be extracted

GNSS receiver

DLL + PLL per signal, per satellite

today’s high-end GPS receiver has typically between 24 and 48 channels:

multi-constellation GNSS receiver:
much more!

- CA-code signal on L1
- P(Y)-code signal on L1
- P(Y)-code signal on L2

to track up to 12-16 GPS satellites simultaneously

generally each satellite is tracked independently
(each GPS satellite has its own unique PRN ranging code (pulse sequence))

Link budget – de-spreading

signal power at receiver: 1.738×10^{-16} W (or –157.6 dBW)

What if we could confine ourselves to a much smaller bandwidth …?

noise power at receiver: 3.54×10^{-19} W (or –184.5 dBW) in 50 Hz bandwidth

$-184.5 \text{ dBW} = 10 \log_{10} 3.54\text{e-}19 \text{ W}$

	signal power:	-157.6 dBW	1.738×10^{-16} W
	noise power:	-184.5 dBW	/ 3.54×10^{-19} W
		-	
at receiver on Earth	SNR:	+26.9 dB	490

then, GPS signal has been raised well above noise floor !!

⇒ read data when tracking

Signal to Noise Ratio (SNR)

Signal-to-Noise ratio (SNR)

$$\mathrm{SNR} = \frac{\textbf{signal power [W]}}{\textbf{noise power [W]}}$$

in the same band

(of course total noise power depends on bandwidth considered)

normalize SNR to 1 Hz bandwidth:

carrier to noise <u>density</u> ratio

$$c/n_o = \mathrm{SNR} * B$$

logarithmic scale [dB-Hz]

$$C/N_o = 10 \log_{10} c/n_o$$

see example in eq. (16) **IEEE-article**

to present signal strength independent of spreading / de-spreading stage

Performance

signal key-parameters

- power: C/N_o (code and phase)
- (PRN-code) chip-rate (code)
- (carrier) wavelength (phase)
- signal bandwidth (code) but transmitted bandwidth not infinite

next to receiver parameters as:
e.g. antenna gain, and
(code and carrier) tracking loop bandwidths

Measurement precision: code

$$\sigma_c \approx \sqrt{\frac{B_L}{2c/n_o}}\lambda_c$$ standard deviation in [m]

with

B_L	code tracking loop bandwidth (0.1 - 5 Hz)
c/n_o	carrier-to-noise density ratio
λ_c	PRN code ‘wavelength’ [m] (1 chip = 293 m for CA-code)

measurement noise due to thermal noise, coherent DLL,
for standard 1-chip Early-Late spacing (and assuming infinite signal bandwidth)

Measurement precision: phase

$$\sigma_P \approx \sqrt{\frac{B_P}{c/n_o}}\,\frac{\lambda}{2\pi}$$ standard deviation in [m]

with

B_P	carrier tracking loop bandwidth (5 - 15 Hz)
c/n_o	carrier-to-noise density ratio
λ	wavelength [m] (~0.20 m)

→ to accommodate
vehicle / platform dynamics
(and local oscillator noise)

measurement noise due to thermal noise
(and neglecting squaring loss)

Summary and outlook

Study:

- IEEE-paper by Braasch&VanDierendonck (Blackboard)

Next: GPS measurements and error sources

Assignment 1 **Future GNSS** (deadline 2 December)