UNIVERSITY OF PISA
DIPARTIMENTO ING. DELL'INFORMAZIONE

SOFT-REC: a GPS/EGNOS Software Receiver

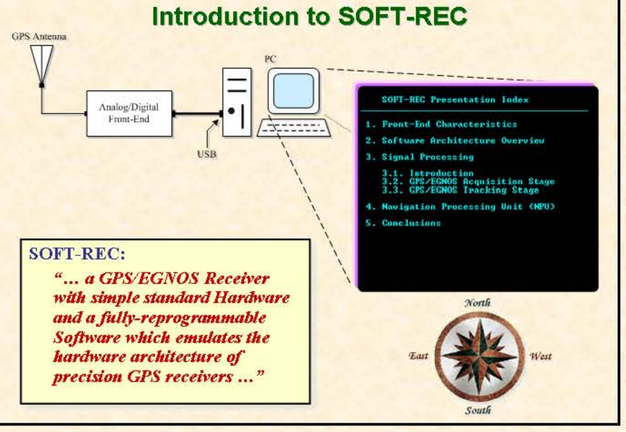
F. Principe(°), G. Bacci(*), C. Terzi(°°), M. Luise(°), and M. Casucci(°°)

(*)Dipartimento Ingegneria dell'Informazione
University of Pisa
Via G. Caruso, 56126 Pisa (Italy)
e-mail: fabio.principe@iet.unipi.it, giacomo.bacci@iet.unipi.it, marco.luise@iet.unipi.it

(**)INTECS s.p.a.
Via U. Forti, 5 Loc. Ospedaletto
56121 Pisa (Italy)
e-mail: casucci@pisa.intecs.it, terzi@pisa.intecs.it

Dresden, 19-23 June 2005

Introduction to SOFT-REC



SOFT-REC:

"... a GPS/EGNOS Receiver with simple standard Hardware and a fully-reprogrammable Software which emulates the hardware architecture of precision GPS receivers ..."

Front-End Characteristics

RF filter selects L_1 and cuts off L_2

Signals	f_{RF} (MHz)
L_1 (GPS&EGNOS)	1575.42
L_2 (GPS)	1227.6

RF/IF Down-Conversion from L_1 to 15.42 MHz (f_{IF})

$$f_{LO} = f_{RF} - f_{IF} = 1560 \text{ MHz}$$

IF Filter characteristics

f_{IF} (MHz)	B_{IF} (MHz)
15.42	2

... a programmable ADC performs a signal sampling. It is possible to select the sampling frequency and number of bits/sample ...

from Band-Pass Sampling Theorem

$$\begin{cases} k \cdot f_S \geq 2 \cdot f_{IF} + B_{IF} \\ (k-1) \cdot f_S < 2 \cdot f_{IF} - B_{IF} \end{cases}$$

k	Min f_S (MHz)	Max f_S (MHz)
1	32.84	∞
2	16.42	28.84
3	10.947	14.42
4	8.21	9.6133
5	6.568	7.21
6	5.4733	5.768
7	4.6914	4.8067
8	4.105	4.12

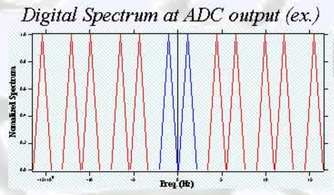
We can choose (ex.):
- $k = 6$ & $f_S = 5.5$ MHz
- or
- $k = 7$ & $f_S = 4.736$ MHz

with f_s = 5.5 MHz ... $\frac{f_S}{R_c} \approx 5.38$

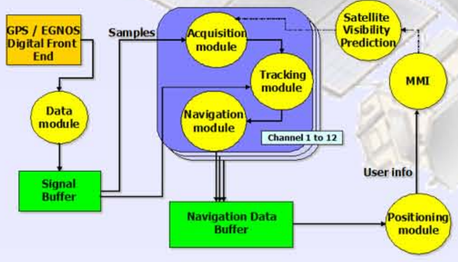
... no aliasing and more than 2 samples per chip!!!

COTS Solution: Signal Tap by ACCORD

Digital Spectrum at ADC output (ex.)



Software Architecture Overview

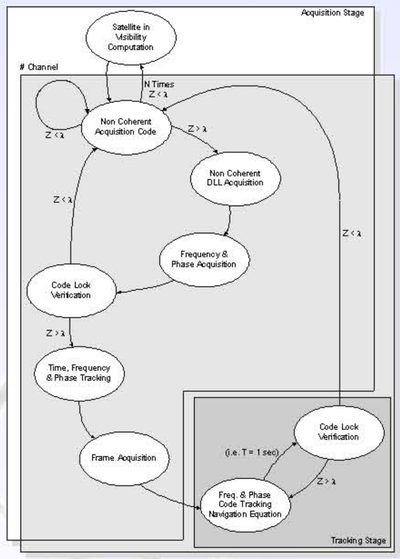


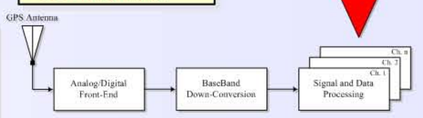
Real-Time Linux ...

"... a multithreaded and concurrent execution of the channel signal processing algorithms along with the other software modules ..."

SOFT-REC Architecture encompasses *Parallel Channel*

Number of Channels:
- 12 GPS chan.
- 2 EGNOS chan.





Main Software Stages
(for each channel)

- *Prediction of Satellite in Visibility*
- *Coarse Code Acquisition*
- *Fine Estimation of Code Timing, Carrier Phase & Doppler Shift*
- *Tracking Stage & GPS/EGNOS Frame Acquisition*
- *Navigation and Positioning Stage*

Signal Processing – Introduction

GPS/EGNOS signals:

$$GPS: \begin{cases} s_{L_1}^{GPS}(t) = A_{GPS} P(t) D(t) \cdot \cos\left(2\pi f_{L_1} t + \phi_{01}\right) + \sqrt{2} A_{GPS} C(t) D(t) \cdot \sin\left(2\pi f_{L_1} t + \phi_{01}\right) \\ s_{L_2}^{GPS}(t) = \frac{A_{GPS}}{\sqrt{2}} P(t) D(t) \cdot \cos\left(2\pi f_{L_2} t + \phi_{02}\right) \end{cases}$$

$$EGNOS: \; s_{L_1}^{EGNOS}(t) = A_{EGNOS} C(t) D(t) \cdot \sin\left(2\pi f_{L_1} t + \phi_{03}\right)$$

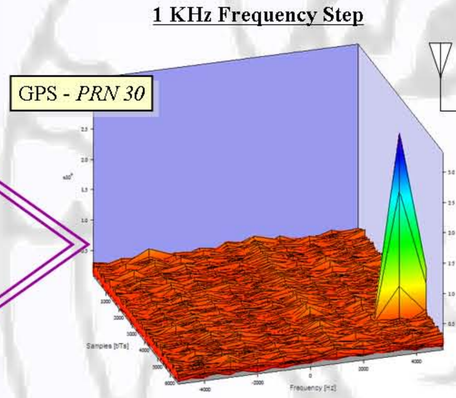
... where:
- $C(t) = \pm 1$ is GPS/EGNOS C/A code;
- $P(t) = \pm 1$ is GPS P code (PRN from 1 to 32);
- $D(t) = \pm 1$ is message data bit sequence;
- f_{L1} & f_{L2} are L_1 and L_2 carrier frequencies;
- φ_{01} & φ_{02} are GPS initial carrier phases;
- φ_{03} is EGNOS initial carrier phase;
- A_{GPS} is GPS signal amplitude;
- A_{EGNOS} is EGNOS signal amplitude.

	GPS Signal		EGNOS Signal
Signal Parameters	*C/A Channel*	*P Channel*	*C/A Channel*
Code Rate – R_c	1.023 Mchip/sec	10.23 Mchip/sec	1.023 Mchip/sec
Code Length – L_c	1023 chips (1 ms)	≈ 6 Trillion chips (1 week)	1023 chips (1 ms)
Data Rate – R_d	50 bit/sec	50 bit/sec	250 bit/sec (*uncoded data*)
			500 bit/sec (*coded data*)
Transmission Frequency	L_1 = 1575.42 MHz = 1540 R_c	L_1 = 1575.42 MHz = 154 R_c	L_1 = 1575.42 MHz = 1540 R_c
		L_2 = 1227.6 MHz = 120 R_c	

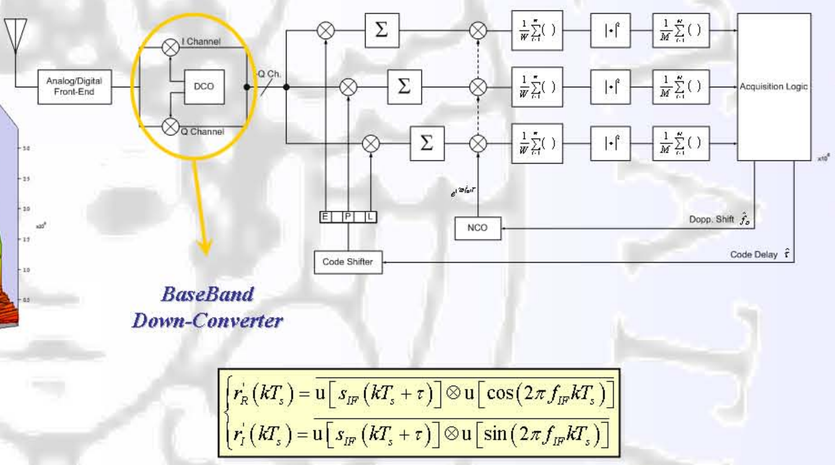
Signal Processing – GPS/EGNOS Acquisition Stage

1 KHz Frequency Step

GPS - *PRN 30*



Doppler Shift: from 5 KHz to 500 Hz

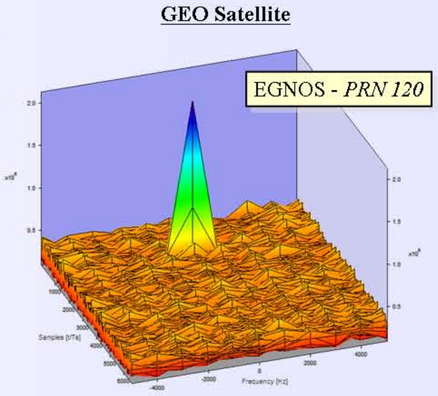


BaseBand Down-Converter

$$\begin{cases} r_R^i(kT_s) = \mathrm{u}\left[\overline{s_{IF}(kT_s + \tau)}\right] \otimes \mathrm{u}\left[\cos\left(2\pi f_{IF} kT_s\right)\right] \\ r_I^i(kT_s) = \mathrm{u}\left[\overline{s_{IF}(kT_s + \tau)}\right] \otimes \mathrm{u}\left[\sin\left(2\pi f_{IF} kT_s\right)\right] \end{cases}$$

GEO Satellite

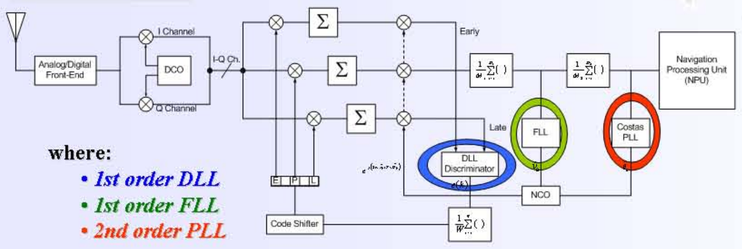
EGNOS - *PRN 120*



Coarse Doppler Shift = 0 Hz

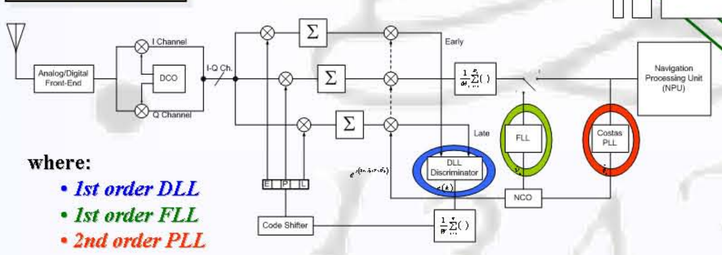
Signal Processing - GPS/EGNOS Tracking Stage

GPS Tracking Stage...



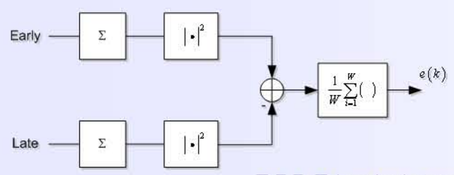
where:
- *1st order DLL*
- *1st order FLL*
- *2nd order PLL*

EGNOS Tracking Stage...



where:
- *1st order DLL*
- *1st order FLL*
- *2nd order PLL*

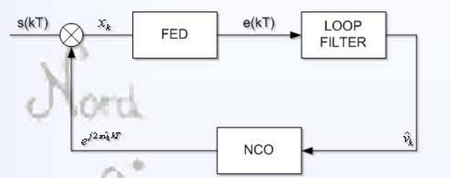
to Navigation



DLL Discriminator

S curve...

$$S(\varepsilon_k) = E\left\{e_k \,|\, \varepsilon_k = \varepsilon_0\right\}$$

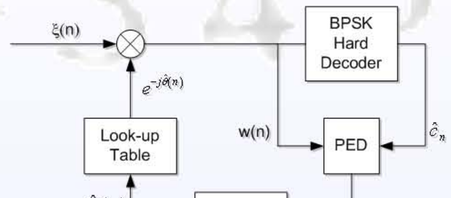


Frequency Locked Loop

S curve...

$$e(k) = \mathrm{Im}\left\{x_k^* \cdot x_{k-1}\right\}$$

$$S(\nu_k) = E\left\{e_k \,|\, \nu_k = \nu_0\right\}$$



Phase Locked Loop

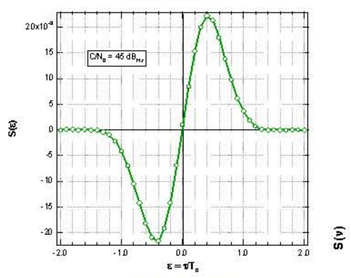
S curve...

$$e(n) = w_I(n) \cdot \mathrm{sgn}\left[w_Q(n)\right]$$

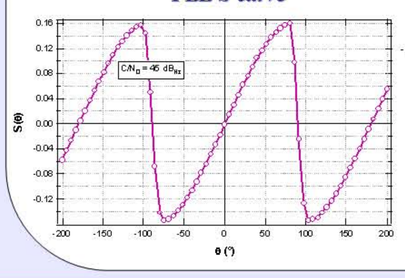
$$S(\theta_k) = E\left\{e_k \,|\, \theta_k = \theta_0\right\}$$

S curve examples

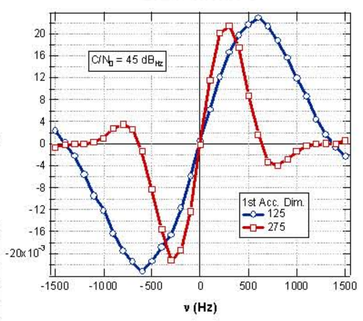
DLL S curve



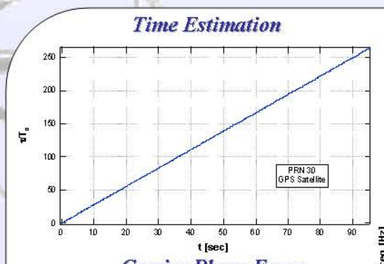
PLL S curve



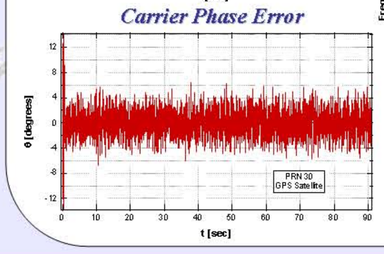
FLL S curve



Time Estimation

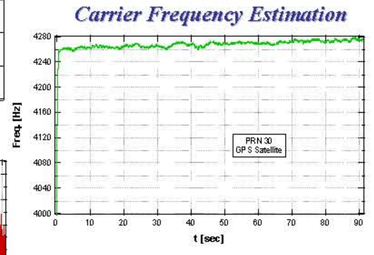


Carrier Phase Error



GPS Signal – *PRN 30*

Carrier Frequency Estimation



Navigation Processing Unit

$$R_{measured,i} = c \cdot \left(t_{received} - t_{transmitted,i}\right)$$

Conclusions

- Truly Full-SW GPS Receiver Demonstrated
- Signal Processing and Navigation Library Tested
- Off-Line Functioning Tested
- *Real-Time Software Tested*
- *Position Accuracy Evaluation in Progress*