Basics of Satellite Navigation – an Elementary Introduction

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SATELLITE SIGNAL

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Satellite signal

- 5.1 Introduction
  - 5.1.1 Objectives
    - How does the signal structure look like?
    - How is the satellite message modulated onto the signal?
    - How are the observables deduced from the transmitted signal?

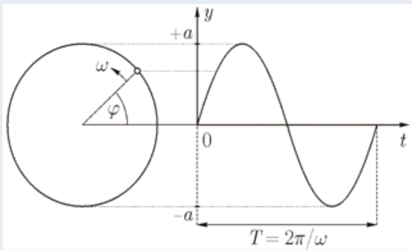
Satellite signal - Introduction

- Frequency and phase
  - Definition

$$f = \frac{d\varphi}{dt} \rightarrow \varphi = \int_{t_0}^{t} f \, dt$$

  - Phase equation

$$\varphi^s = f\,(t - t_\rho) = f\,(t - \frac{\rho}{c})$$



This is the phase of a signal emitted with constant frequency at the satellite at epoch $t_0 = 0$ as observed at epoch t and at a receiver in a distance ρ from the satellite.

Satellite signal - Introduction

- Beat phase

$$\varphi_R^S = \varphi_R - \varphi^S = f\frac{\rho}{c} = \frac{\rho}{\lambda}$$

  The beat phase is the difference between the phase of a reference signal generated in the receiver and the phase of the received satellite signal.
- Measureable is the fractional phase only. Thus, phases are ambiguous by an integer number of cycles.
- Example:

  The beat phase of a signal emitted with frequency f = 1.5 GHz in a distance ρ = 20 000 km is exactly 10^8 cycles. The observable fractional phase within one cycle, thus, is zero.

Satellite signal

- 5.2 Signal structure
  - 5.2.1 Oscillators
    - Electromagnetic signals are generated by means of oscillators or frequency standards (atomic clocks).
      - Atomic clocks with frequency stabilities of 10^{-13} - 10^{-15} over one hour are on board of the satellites.
        - » cesium
        - » rubidium
        - » hydrogen maser
      - Receivers are equipped with less expensive quartz oscillators with frequency stabilities of 10^{-11} over one hour.

Satellite signal - Signal structure

- 5.2.2 Signal components
  - The oscillators on board of the satellites generate a fundamental frequency.

    f_0 = 10.23 MHz

  - Two carrier signals in the L-band , denoted L1 and L2, are generated by integer multiplications of f_0.

    L1 = 154 f_0 = 1575.42 MHz → λ = 19.0 cm

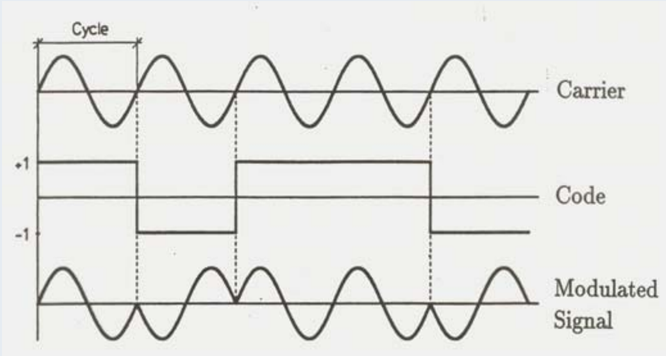
    L2 = 120 f_0 = 1227.60 MHz → λ = 24.4 cm

Satellite signal - Signal structure

- Onto the carriers, codes are modulated to provide satellite clock readings at the receiver (PRN codes) and to transmit information such as the orbital parameters (data code).
  - Distinction
    - » C/A-code (coarse/acquisition code)
    - » P-code (precision code)
    - » Y-code (classified code which results from a combination of the P-code with an encrypting W-code)

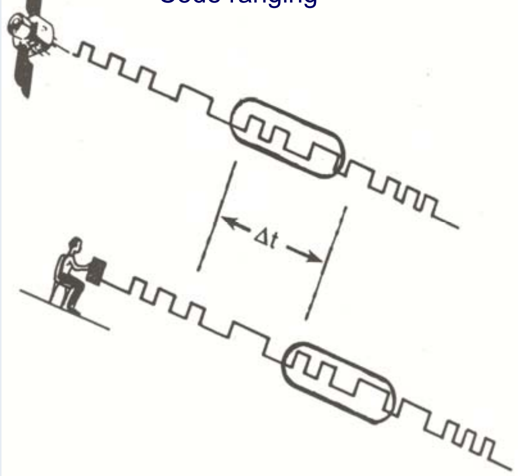
Satellite signal - Signal structure

Biphase modulation



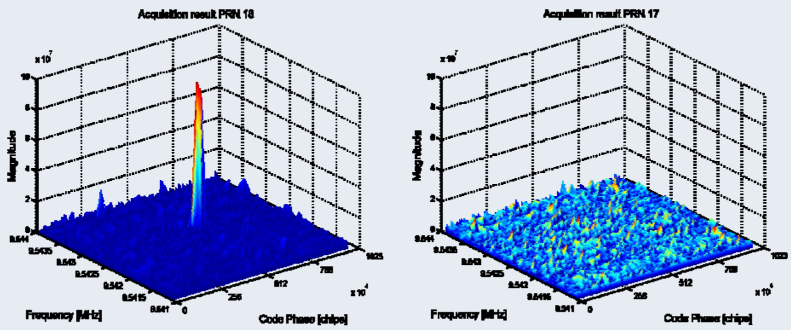
Satellite signal - Signal structure

Code ranging



Satellite signal - Signal structure

Example: C/A-code correlation



Satellite signal - Signal structure

– Characteristics

	C/A-code	P-code
Chipping rate	$f_0/10$	f_0
Chiplength	300 m	30 m
Repetition rate	1 millisecond	266 days (= 38 weeks)
Numbers	37 x unique	37 x one-week segments
Properties	free access	encrypted when A-S is on
	easy to acquire	more accurate

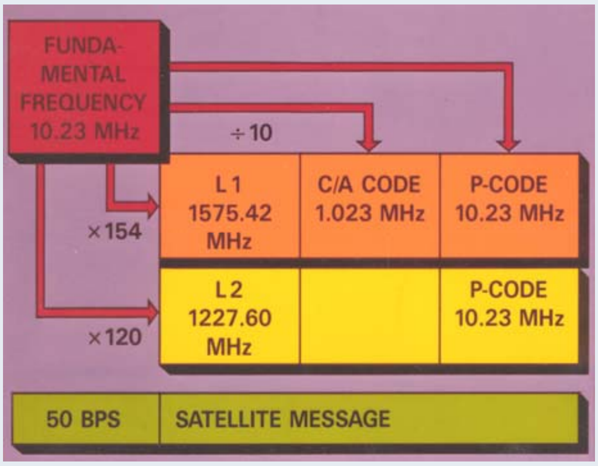
Satellite signal - Signal structure

Summary of GPS frequencies and chipping rates

Component	Frequency	(MHz)
Fundamental frequency	f_0	= 10.23
Carrier L1	$f_0 \cdot 154$	= 1 575.42 (λ_{L1} = 19.0 cm)
Carrier L2	$f_0 \cdot 120$	= 1 227.60 (λ_{L2} = 24.4 cm)
P-code	f_0	= 10.23
C/A-code	$f_0/10$	= 1.023
W-code	$f_0/20$	= 0.5115
Navigation message	$f_0/204\ 600$	= $50 \cdot 10^{-6}$

Satellite signal - Signal strength

Emitted signal (at present)



Satellite Signal

- 5.3 Signal processing
  - 5.3.1 Principles
    - The signal emitted from the satellite contains three components; symbolically:
      - Carrier L1 + C/A-code + navigation message
      - Carrier L1 + Y-code + navigation message
      - Carrier L2 + Y-code + navigation message

      Note that the C/A-code signal on L1 is twice as powerful as the P-code signal on L1. The same ratio exists between the P-code signals on L1 and L2.

Satellite signal - Processing

- The goal of signal processing is the recovery of the signal components:
  - Carrier wave → phase measurement
  - PRN-code → run-time measurement
  - Navigation message → satellite positioning

  Note that phase measurements provide pseudoranges which are much more accurate than code pseudoranges.

Satellite signal - Processing

- 5.3.3 Observables
  - Coderange
    - Coderanges are pseudoranges because of the synchronization error
    - Noise amounts to 10-300 cm depending on PRN-code and the correlation technique.
    - Narrow correlation technique (“super tracker”) makes C/A-code receivers as accurate as P-code receivers.
    - Coderanges are (practically) unambiguous.

Satellite signal - Processing

- Phaserange
  - Phaseranges are pseudoranges because of the synchronization error.
  - Noise amounts to 0.2-2 mm depending on several facts like the bandwidth in the phase tracking loop.
  - Phaseranges are ambiguous.
- Range rate (Doppler frequency)
  - Ranges are appropriate for positioning whereas range rates are more suited for velocity determination.
  - Range rates are affected by bias rates only.
  - Noise amounts to 0.3 ms^{-1} if the measurement was performed in the C/A-code tracking loop.

Satellite signal - Processing

- 5.3.4 Biases
  - Signal transmission
    - Satellite clock bias
    - Orbital errors
  - Signal propagation
    - Ionospheric refraction
    - Tropospheric refraction
  - Signal reception
    - Receiver clock bias (solved as an additional unknown)
    - Variations of antenna phase center
    - Multipath propagation

Observables - Data acquisition

Multipath propagation