Introduction to Global Navigation Satellite System (GNSS) How It Works?

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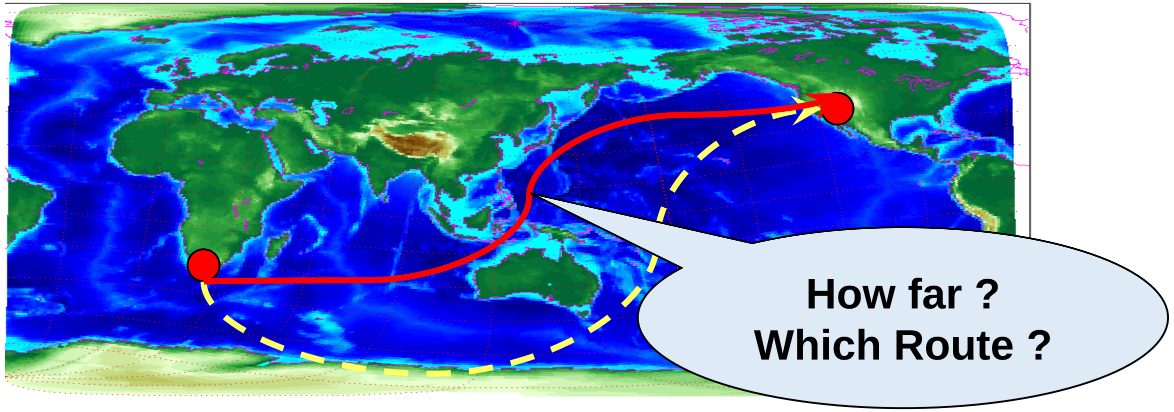
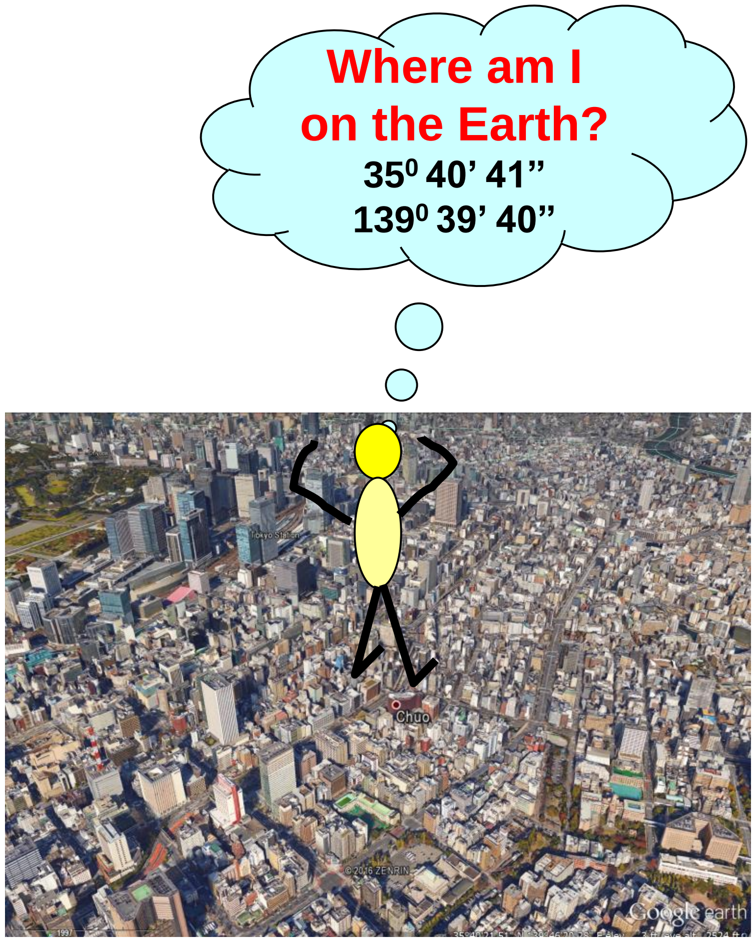
Fundamental Problem

- How to know my location precisely ?
  - In any condition
  - At any time
  - Everywhere on earth (at least outdoors!)
- How to navigate to the destination? ?
  - Guidance or Navigation





Navigation Types

- Landmark-based Navigation
  - Stones, Trees, Monuments
    - Limited Local use
- Celestial-based Navigation
  - Stars, Moon
    - Complicated, Works only at Clear Night
- Sensors-based Navigation
  - Dead Reckoning
    - Gyroscope, Accelerometer, Compass, Odometer
    - Complicated, Errors accumulate quickly
- Radio-based Navigation
  - LORAN, OMEGA
    - Subject to Radio Interference, Jamming, Limited Coverage
- Satellite-based Navigation or GNSS
  - TRANSIT, GPS, GLONASS, GALILEO, QZSS, BEIDOU (COMPASS), IRNSS
    - Global, Difficult to Interfere or Jam, High Accuracy & Reliability

What is GNSS?

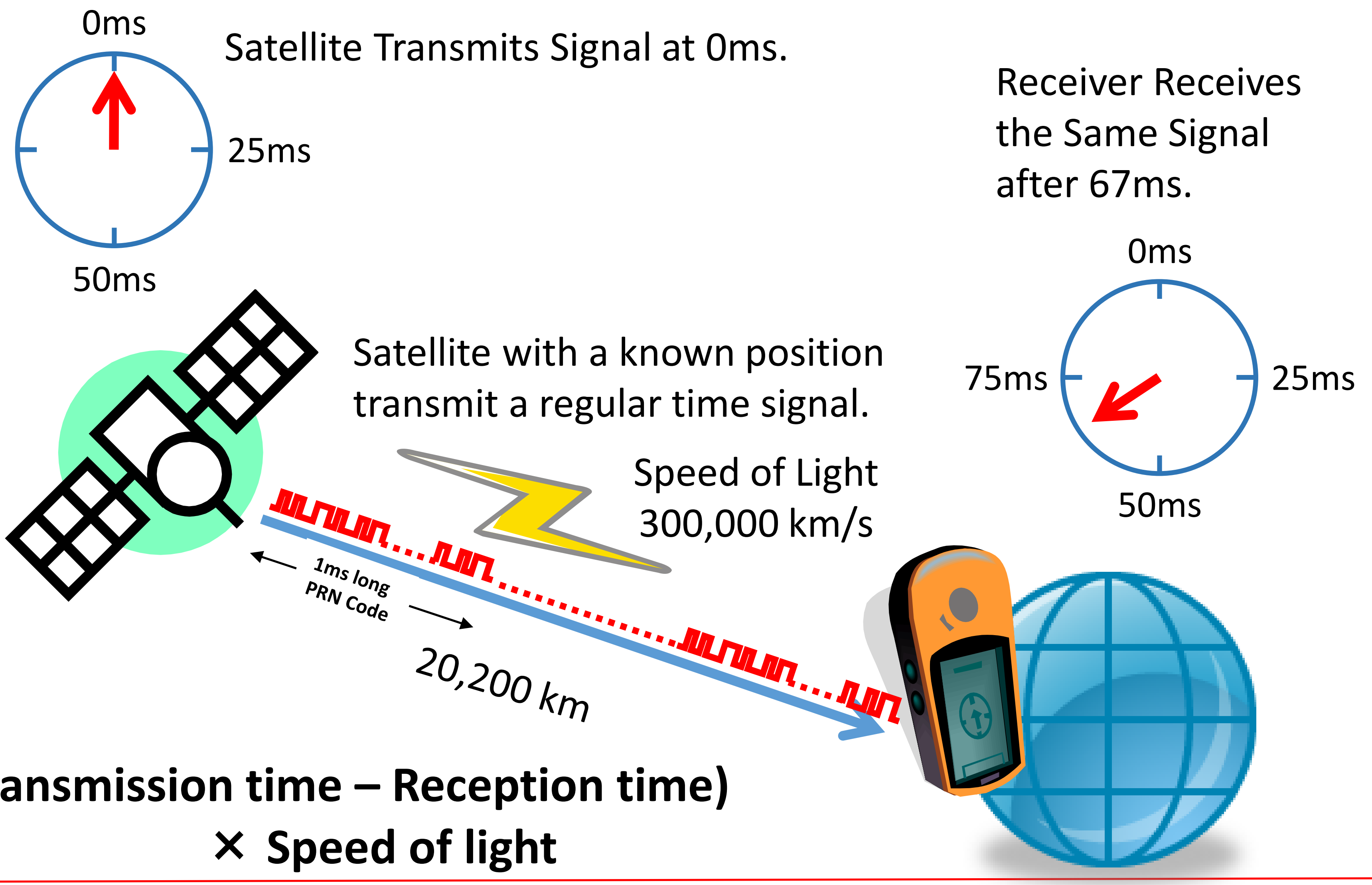
Global Navigation Satellite System (GNSS) is the standard generic term for all navigation satellites systems like GPS, GLONASS, GALILEO, BeiDou, QZSS, NAVIC.

- Global Constellation
  - GPS USA
  - GLONASS, Russia
  - Galileo, Europe
  - BeiDou (COMPASS), China
- Regional Constellation
  - QZSS, Japan
  - NAVIC (IRNSS), India

Satellite Based Augmentation System (SBAS)

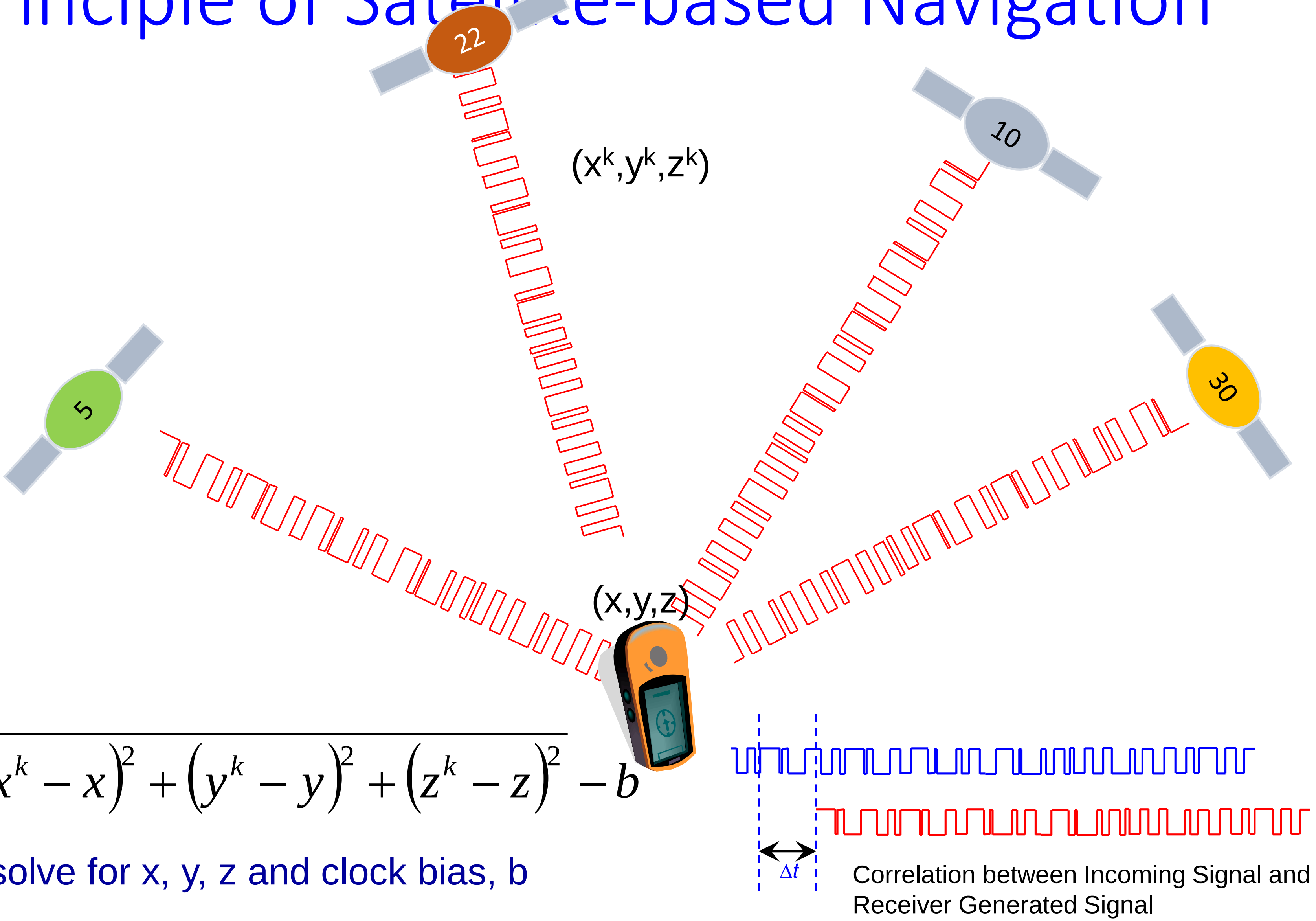
- Satellite Based Augmentation System (SBAS) are used to augment GNSS Data
  - Provide Higher Accuracy, Integrity, Continuity and Availability
  - Some correction data like satellite orbit, satellite clock and atmospheric data are broadcasted from communication satellites
  - Used by ICAO for Aviation
- Different Types of SBAS
  - WAAS, USA
  - MSAS, Japan
  - EGNOS, Europe
  - GAGAN, India
  - SDCM, Russia

Determine the Distance using Radio Wave



Distance = (Transmission time – Reception time)
× Speed of light

Principle of Satellite-based Navigation



$$\rho^k = \sqrt{(x^k - x)^2 + (y^k - y)^2 + (z^k - z)^2} - b$$

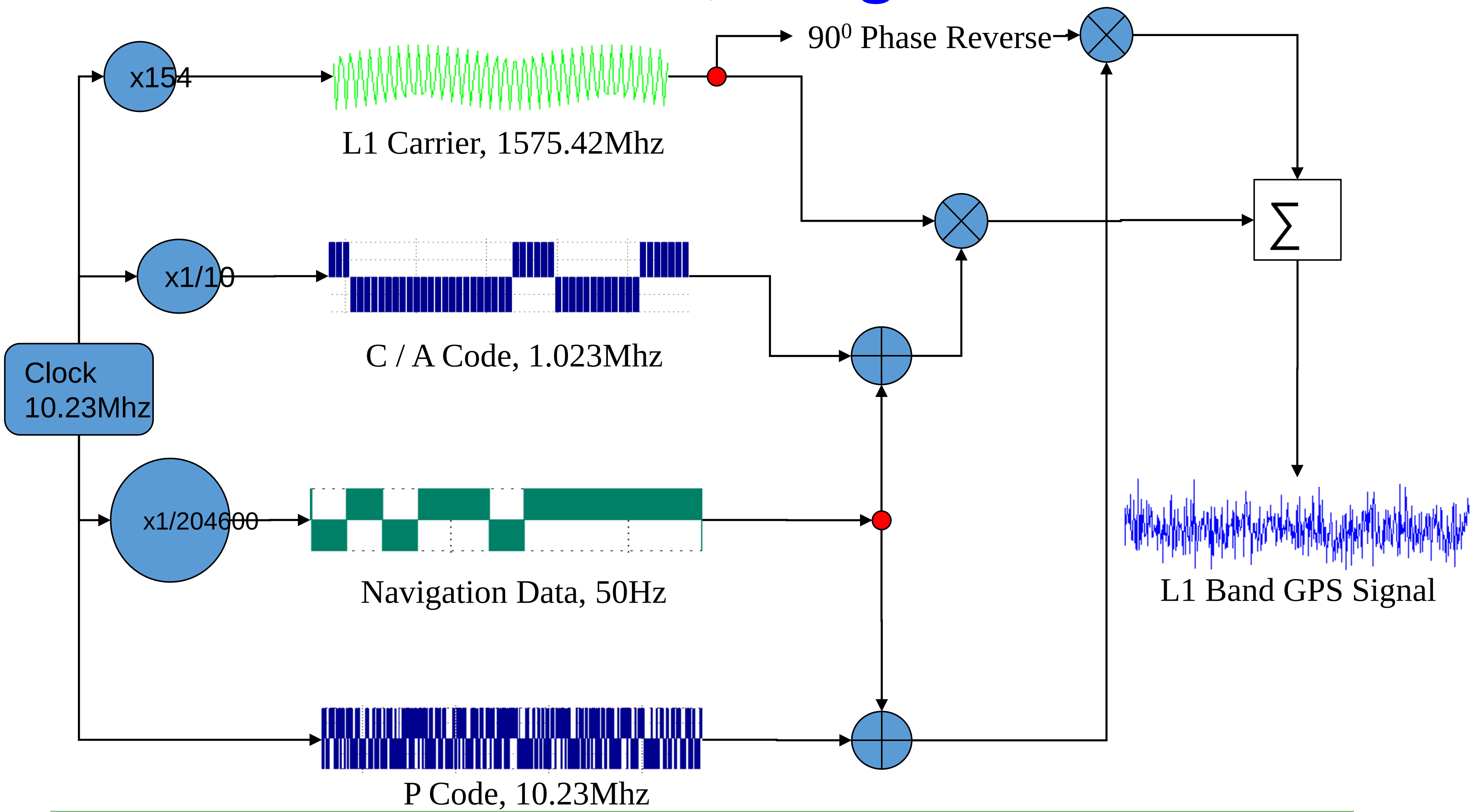
If $k \geq 4$, solve for x, y, z and clock bias, b

Characteristics of GNSS Signals

- GNSS Signals have basically three types of signals
  - Carrier Signal
  - PRN Code (C/A Code)
  - Navigation Data
- All GNSS Signals except GLONASS are based on CDMA
  - Only GLONASS use FDMA
  - Future Signals of GLONASS will also use CDMA
- The modulation scheme of GNSS signals are BPSK and various versions of BOC

CDMA: Code Division Multiple Access
FDMA: Frequency Division Multiple Access
BPSK : Binary Phase Shift Keying
BOC: Binary Offset Carrier

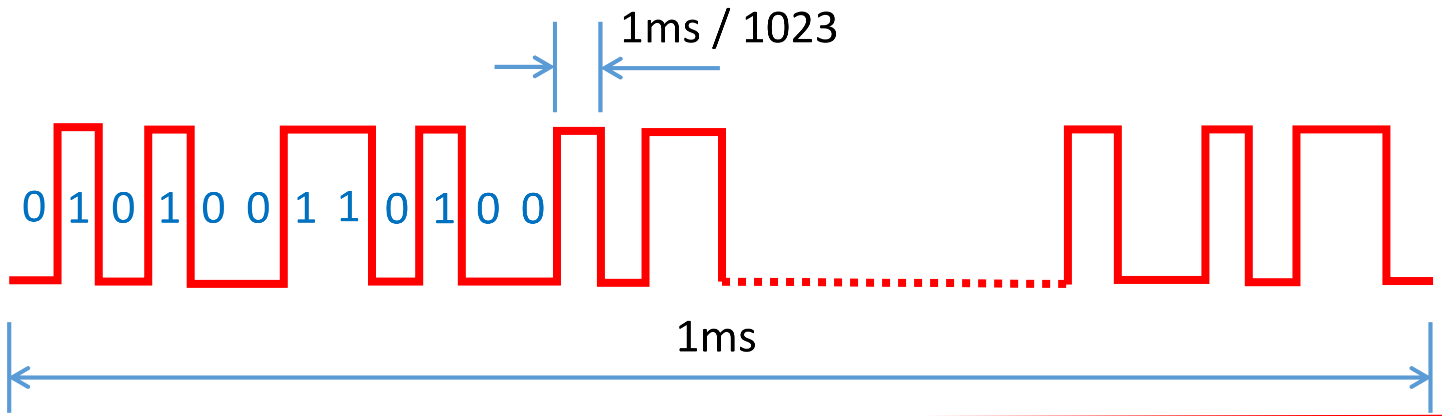
Method of GPS L1C/A Signal Generation



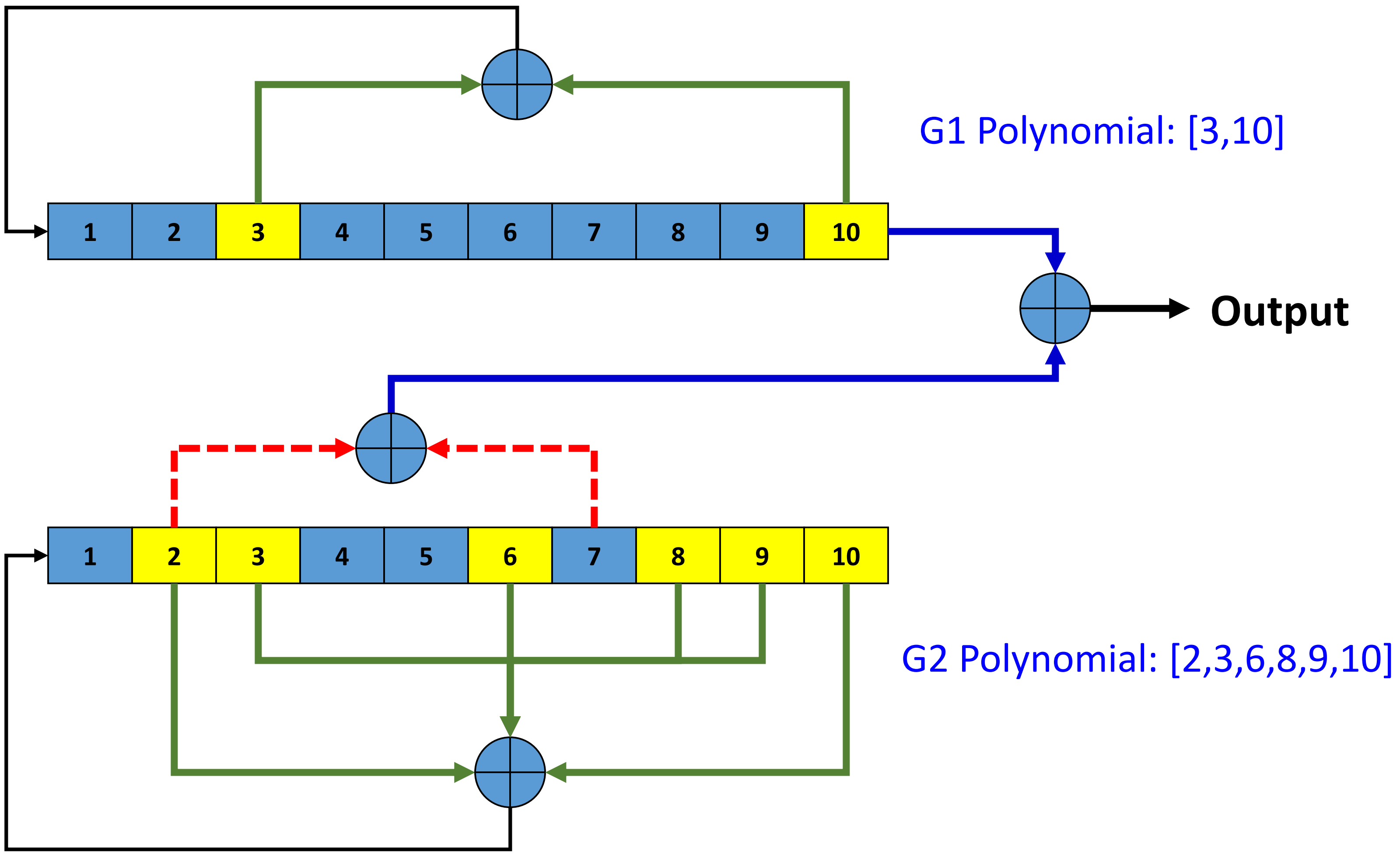
$$s_i(t) = \sqrt{2P_i(t)} \cdot CA\left(t - \tau_i(t)\right) \cdot D\left(t - \tau_i(t)\right) \cdot \cos\left(2\pi\left(f_L + \delta f_{L,i}(t)\right)t + \phi_i(t)\right) + n_i(t)$$

PRN (Pseudo Random Noise) Code

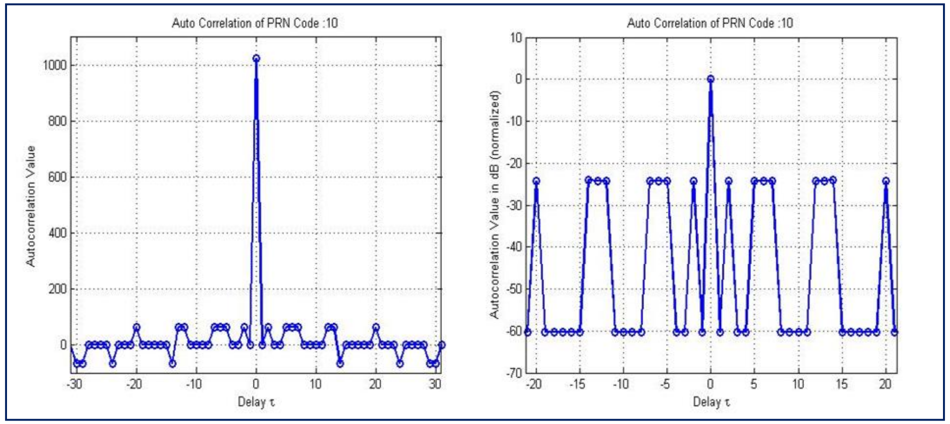
- PRN Code is a sequence of randomly distributed zeros and ones that is one millisecond long.
    - This random distribution follows a specific code generation pattern called Gold Code.
    - There are 1023 zeros or ones in one millisecond.
- Each GPS satellite transmits a unique PRN Code.
    - GPS receiver identifies satellites by its unique PRN code or ID.
- It is continually repeated every millisecond and serves for signal transit time measurement.
    - The receiver can measure where the PRN code terminated or repeated.

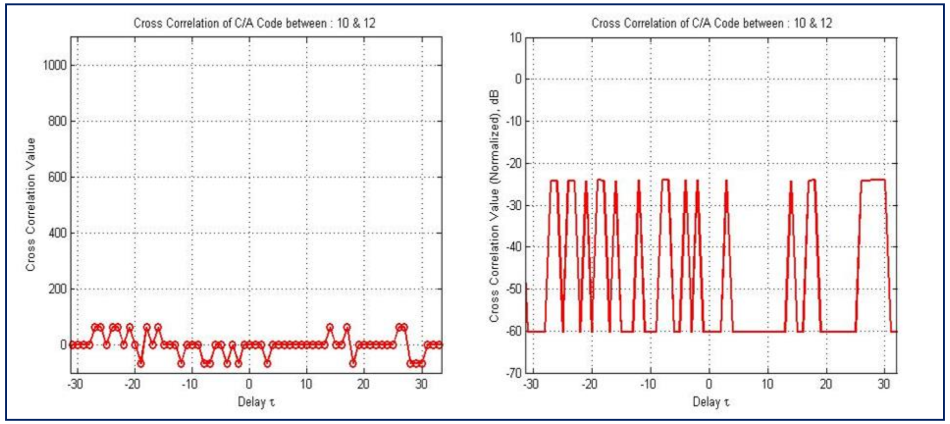


GPS L1C/A PRN Code Generator



Characteristics of PRN Code





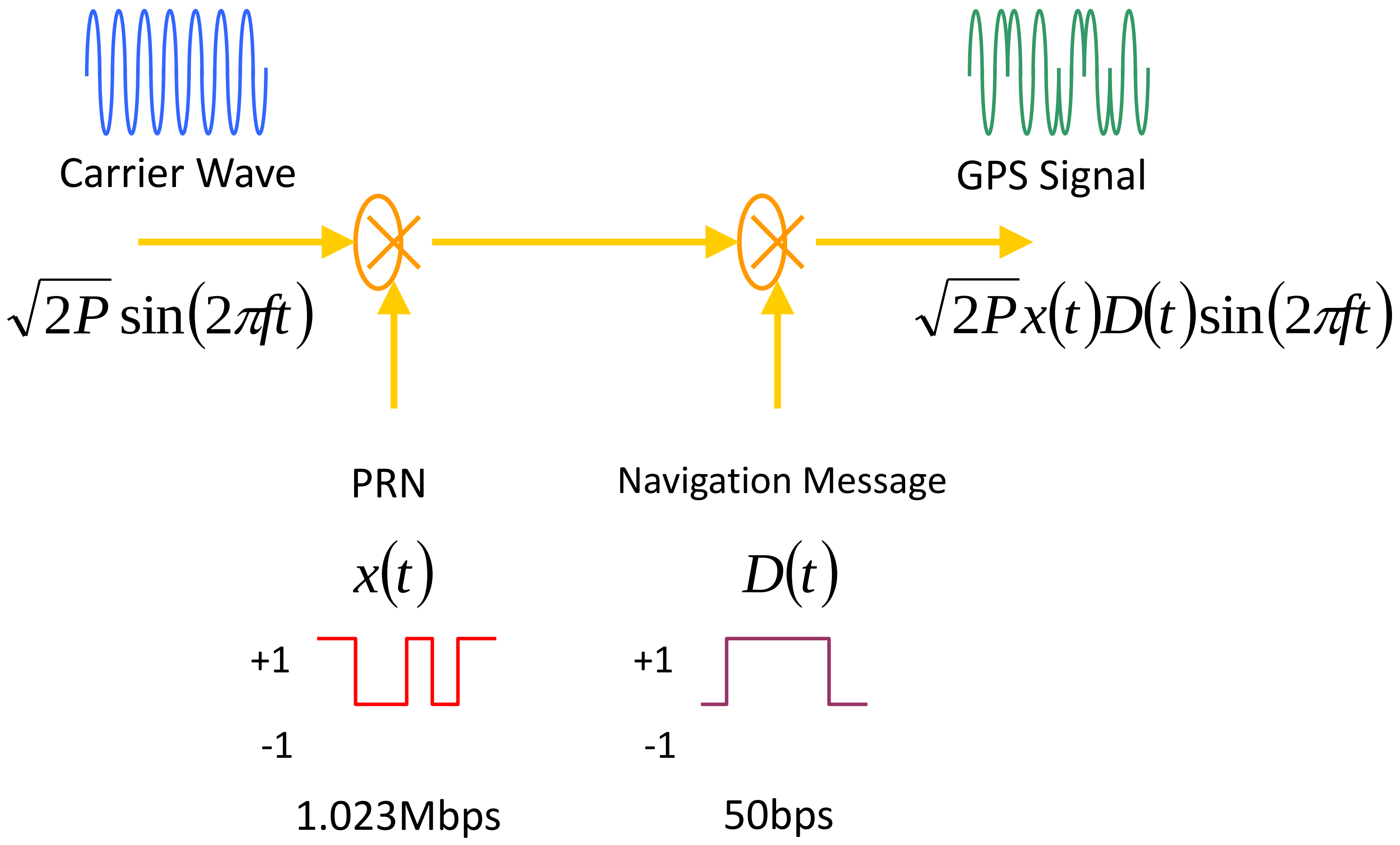
Auto-correlation: Only four values:
1023, 1, 63 or 65 (Ideal case)

Cross-correlation: Only three values:
1, 63 or 65 (Ideal Case)

- PRN codes are very uniquely designed.
- GPS and other GNSS use CDMA
  - One PRN code is assigned to one satellite.
  - In case of GPS, PRN code is 1023 bits long.
  - GLONASS is different. It uses FDMA. The same code for all satellites but different frequencies.
  - Some new signals of GLONASS also uses CDMA signals

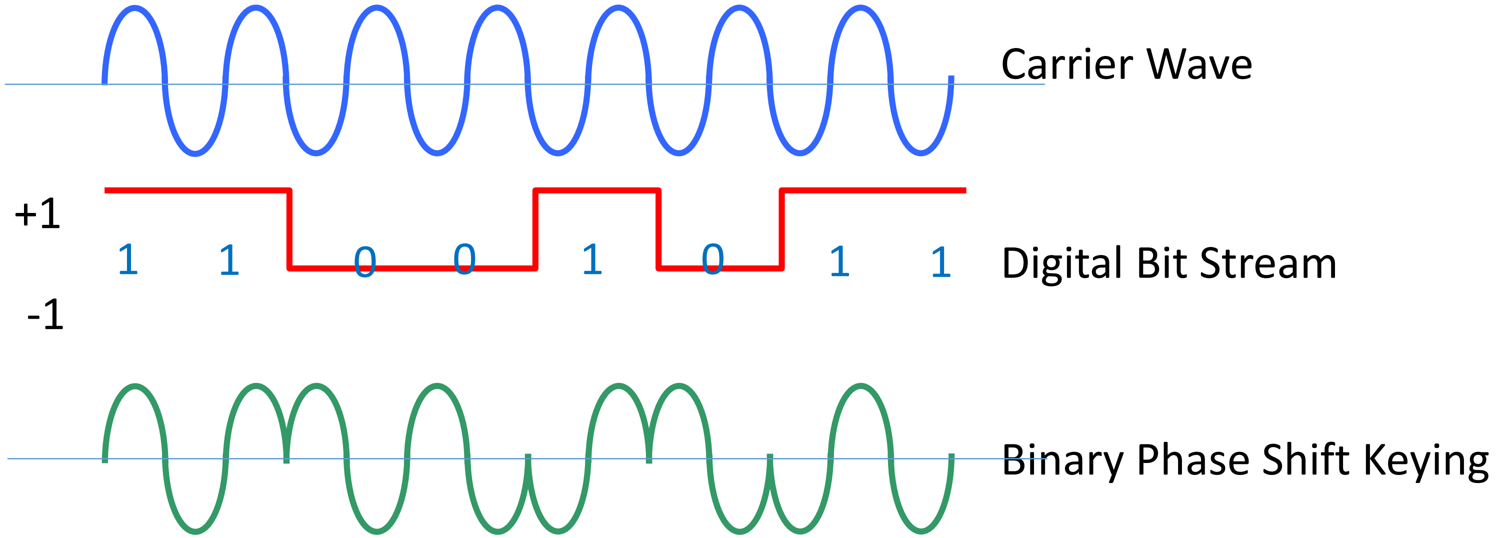
- Maximum Cross-correlation Value is -23dB.
- If any signal above this power enters a GPS receiver, it will totally block all GPS signals.
- If longer PRN code is used, receiver becomes more resistive to Jamming signal
  - But, signal processing is more complex

GPS signal structure



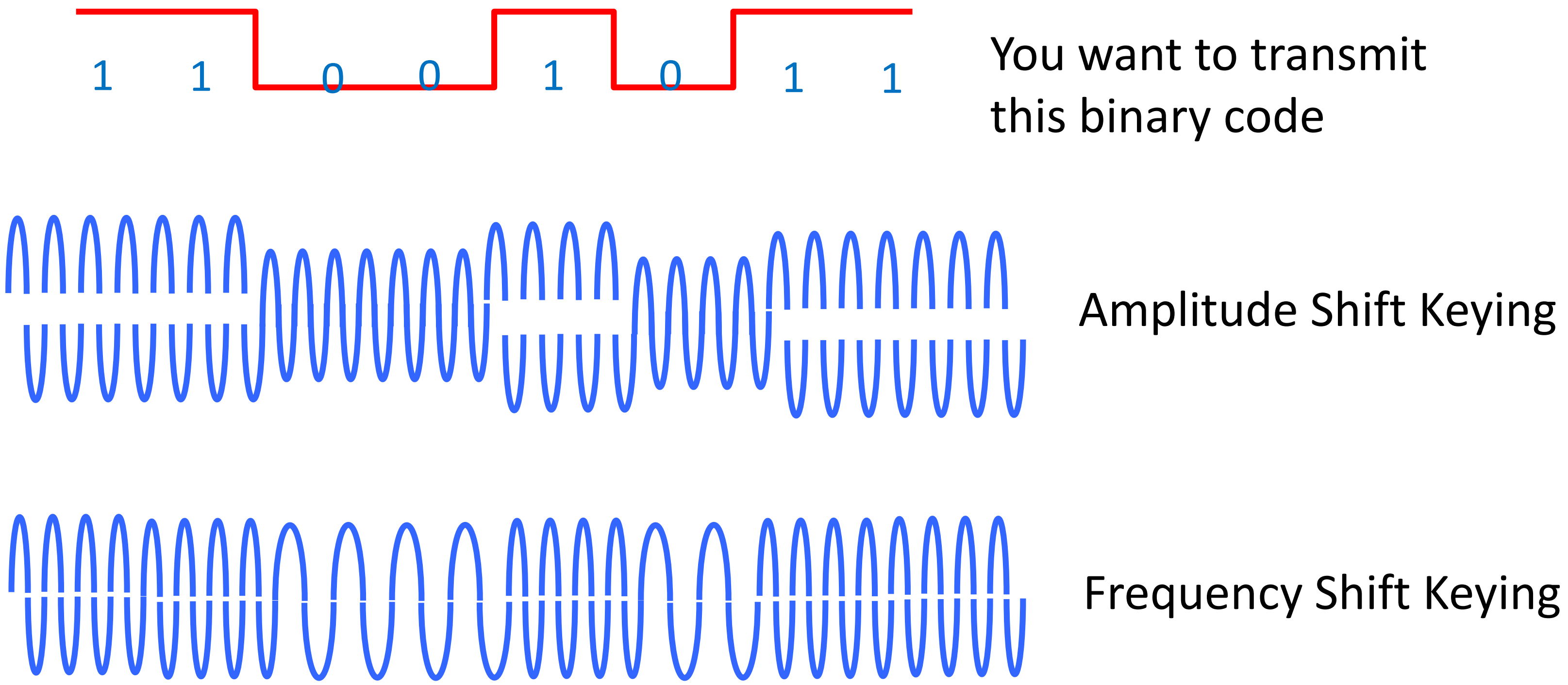
BPSK (Binary Phase Shift Keying)

Phase shift keying is a digital modulation scheme that conveys data by changing, or modulating, the phase of the carrier wave. BPSK uses two phases which are separated by a half cycle.



Modulation

Modulation is the process of conveying a message signal, for example a digital bit stream, into a radio frequency signal that can be physically transmitted.



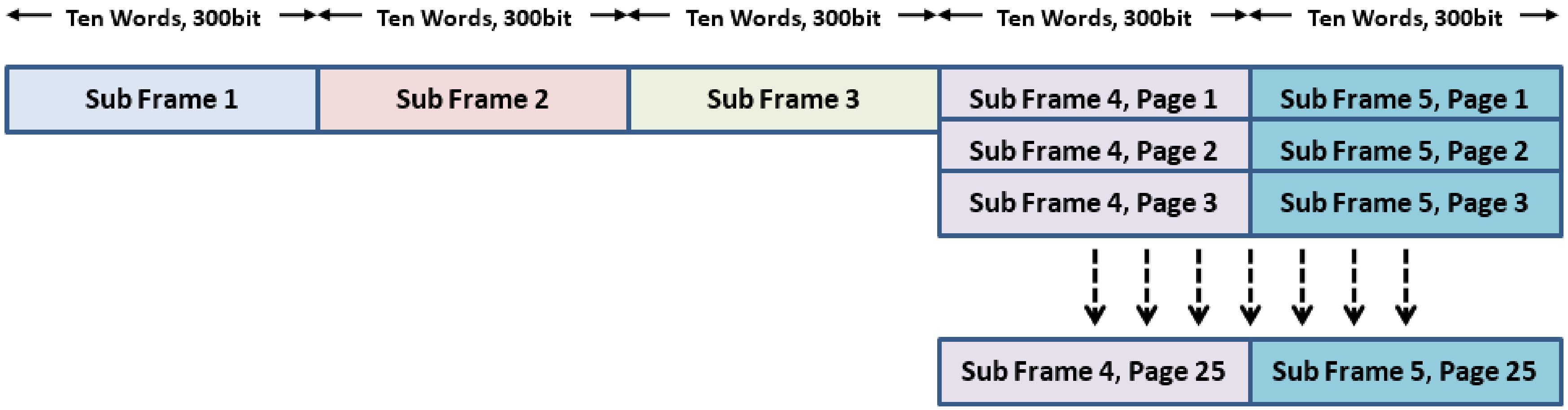
CDMA vs. FDMA

	CDMA [GPS, QZSS, Galileo, BeiDou, IRNSS, Future GLONASS Satellites]	FDMA [GLONASS]
PRN Code	Different PRN Code for each satellite Satellites are identified by PRN Code	One PRN Code for all satellites Satellites are identified by center frequency
Frequency	One Frequency for all satellites	Different frequency for each satellite
Merits & Demerits	Receiver design is simpler No Inter-Channel Bias More susceptible to Jamming	Receiver design is complex Inter-channel bias problem Less susceptible to Jamming

Navigation Data

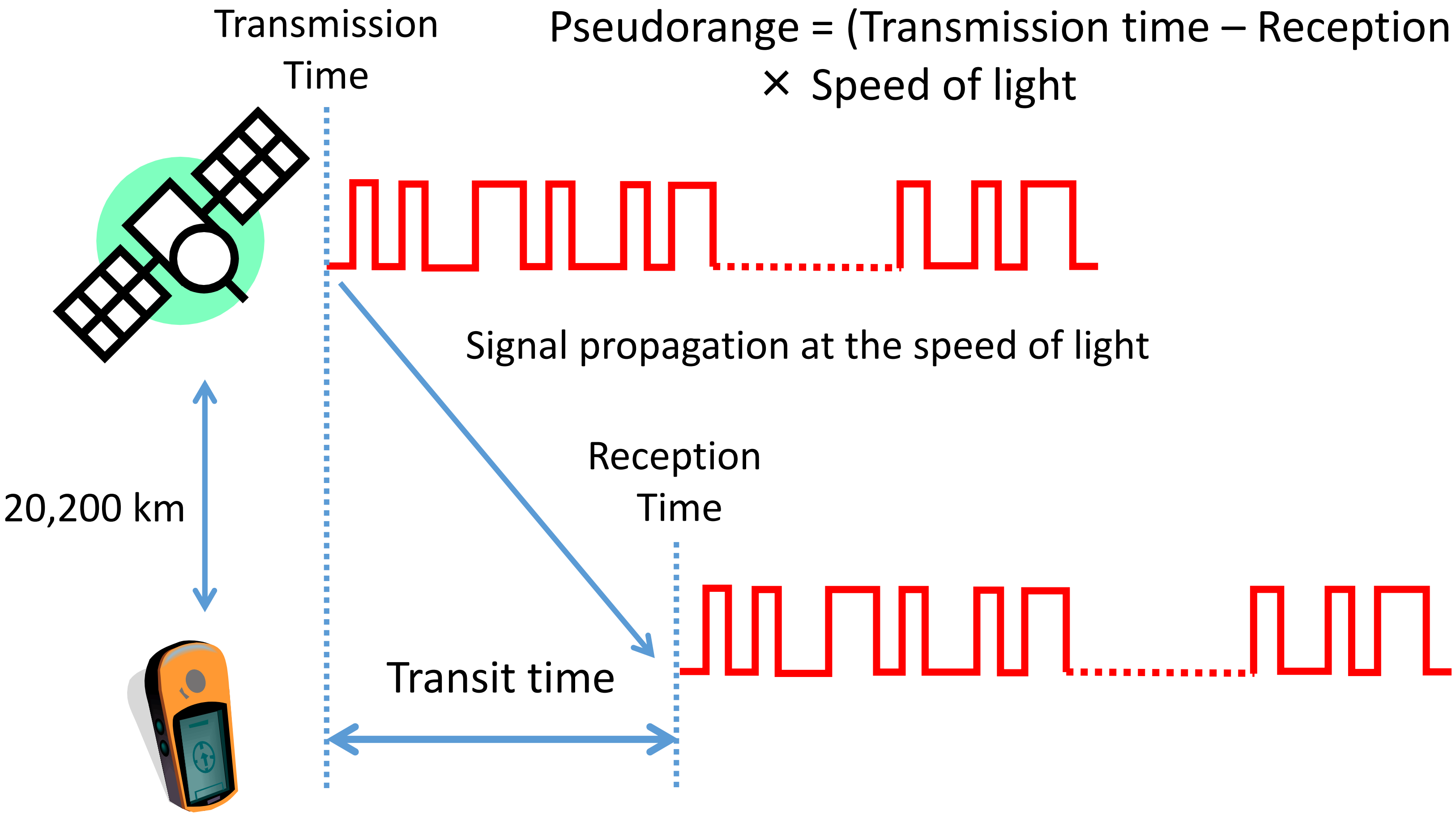
- Navigation Data or Message is a continuous stream of digital data transmitted at 50 bit per second. Each satellite broadcasts the following information to users.
  - Its own highly accurate orbit and clock correction (**ephemeris**)
  - Approximate orbital correction for all other satellites (**almanac**)
  - System health, etc.

GPS L1C/A Signal NAV MSG



Pseudorange (1/2)

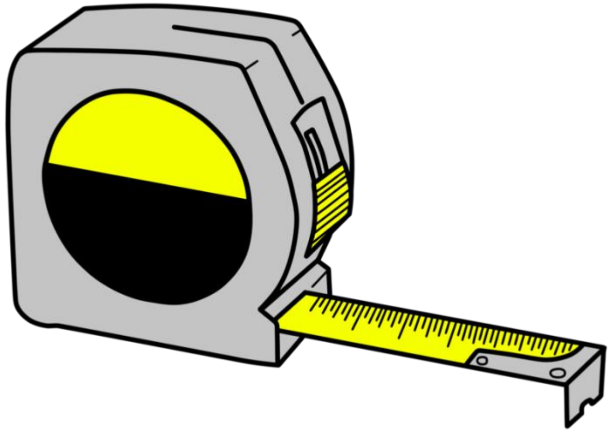
Pseudorange = (Transmission time – Reception time) × Speed of light



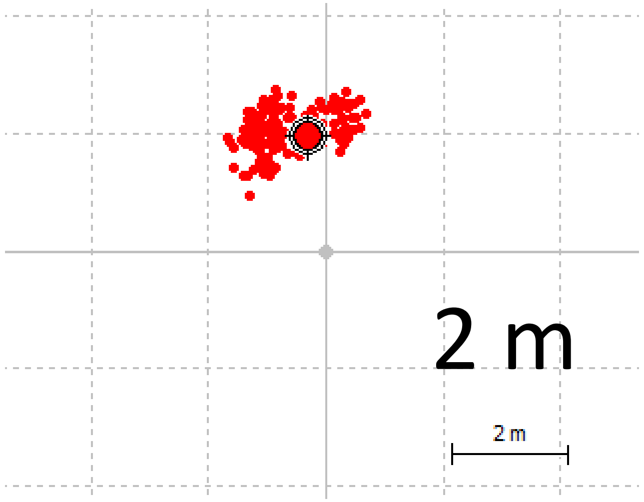
A GPS receiver measures the signal transmission time from the code phase at signal reception time.

Pseudorange (2/2)

- Essential GNSS observable
- ***Full*** distance between the satellite and the receiver
- Provides a position accuracy of approximately a few meters

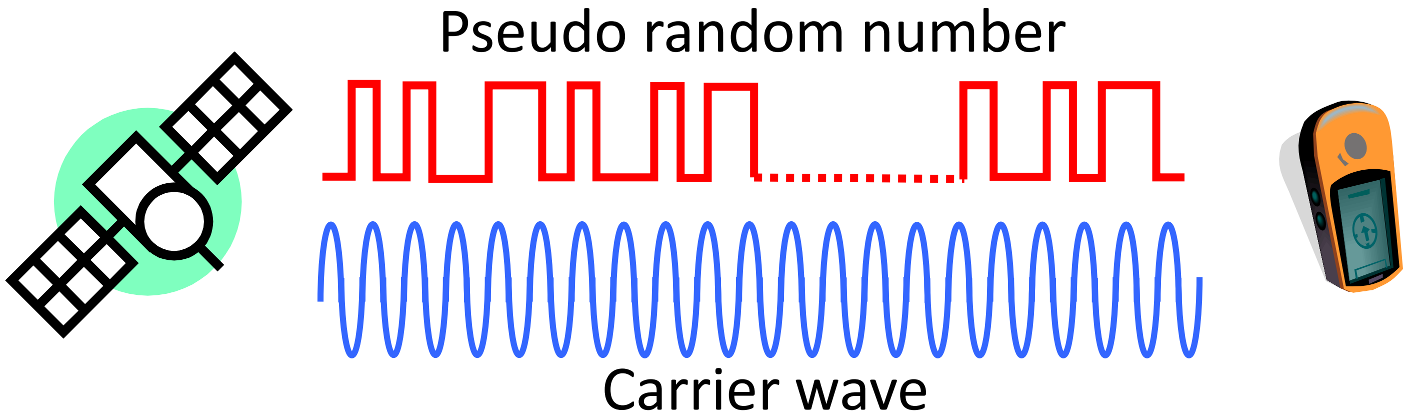


20,200 km



Carrier phase (1/2)

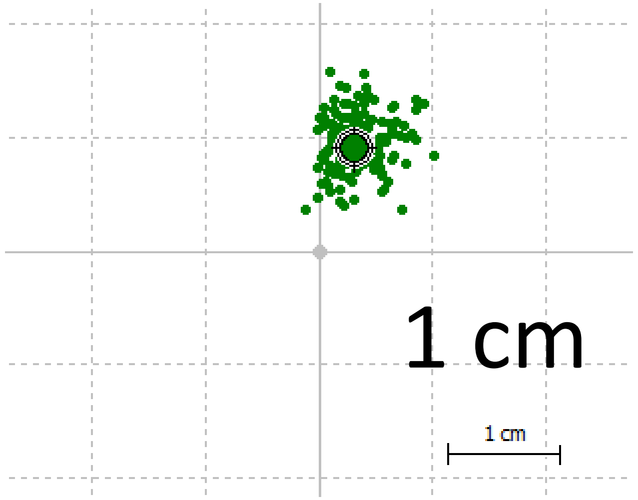
- PRN repeats every 1ms, which corresponds 300 km in distance at the speed of light, but pseudorange accuracy is about 1 m.
- Carrier phase provides millimeter range accuracy, but repeats every cycle, which correspond 19 cm in distance at a GPS signal carrier frequency of 1575.42 MHz.



Carrier phase (2/2)

- ***Fractional*** carrier phase of the received signal
- Therefore there is an unknown integer number of full carrier cycles between the satellite and the receiver
- Provide "survey-grade" accuracy of 1-2 cm once the unknown number of full carrier cycles are resolved

19 cm



1 cm

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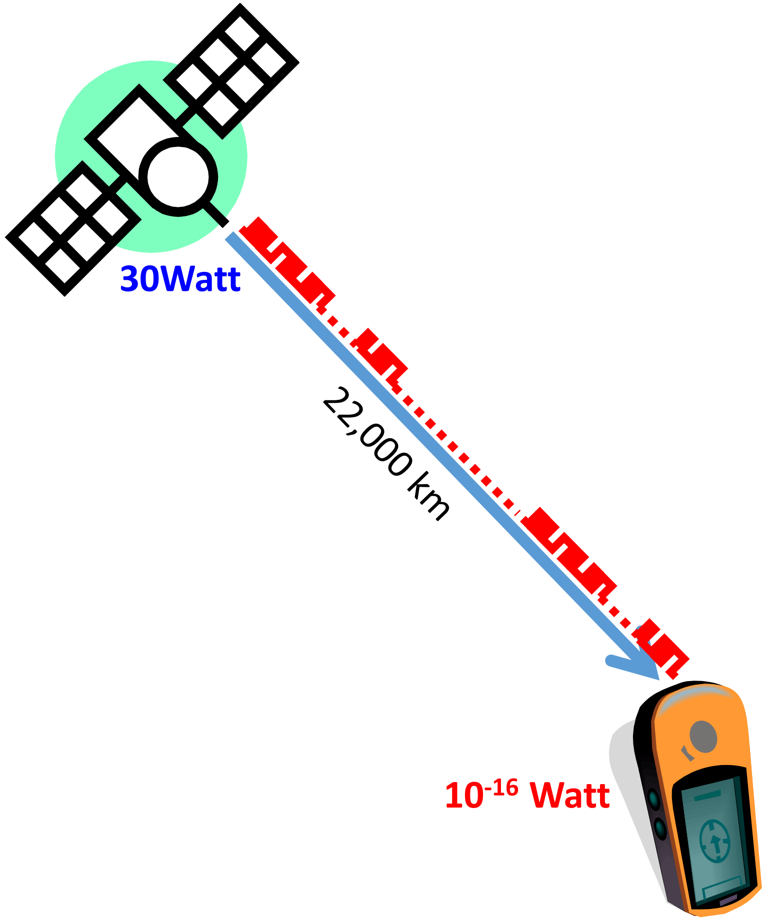
GPS Signal Power: How Strong or How Weak?

- GPS satellites are about 22,000km away
- Transmit power is about 30W
- This power when received at the receiver is reduced by 10^{16} times.
  - The power reduces by 1/distance^2
  - This is similar to seeing a 30W bulb 22,000Km far
- GPS signals in the receiver is about 10^{-16} Watt, which is below the thermal noise



GPS Signal Power: How Strong or How Weak?

- GPS Signal Power at Receiver
  - -130dBm or -160dBW
- Thermal Noise Power
  - Defined by $kT_{eff}B$, where
    - $K = 1.380658e\text{-}23JK^{-1}$, Boltzman Constant
    - $T_{eff} = 362.95$, for Room temperature in Kelvin at 290
      - Teff is effective Temperature based on Frii's formula
    - $B = 2.046MHz$, Signal bandwidth
  - Thermal Noise Power = -110dBm for 2MHz bandwidth
  - If Bandwidth is narrow, 50Hz
    - Noise Power = -156dBm

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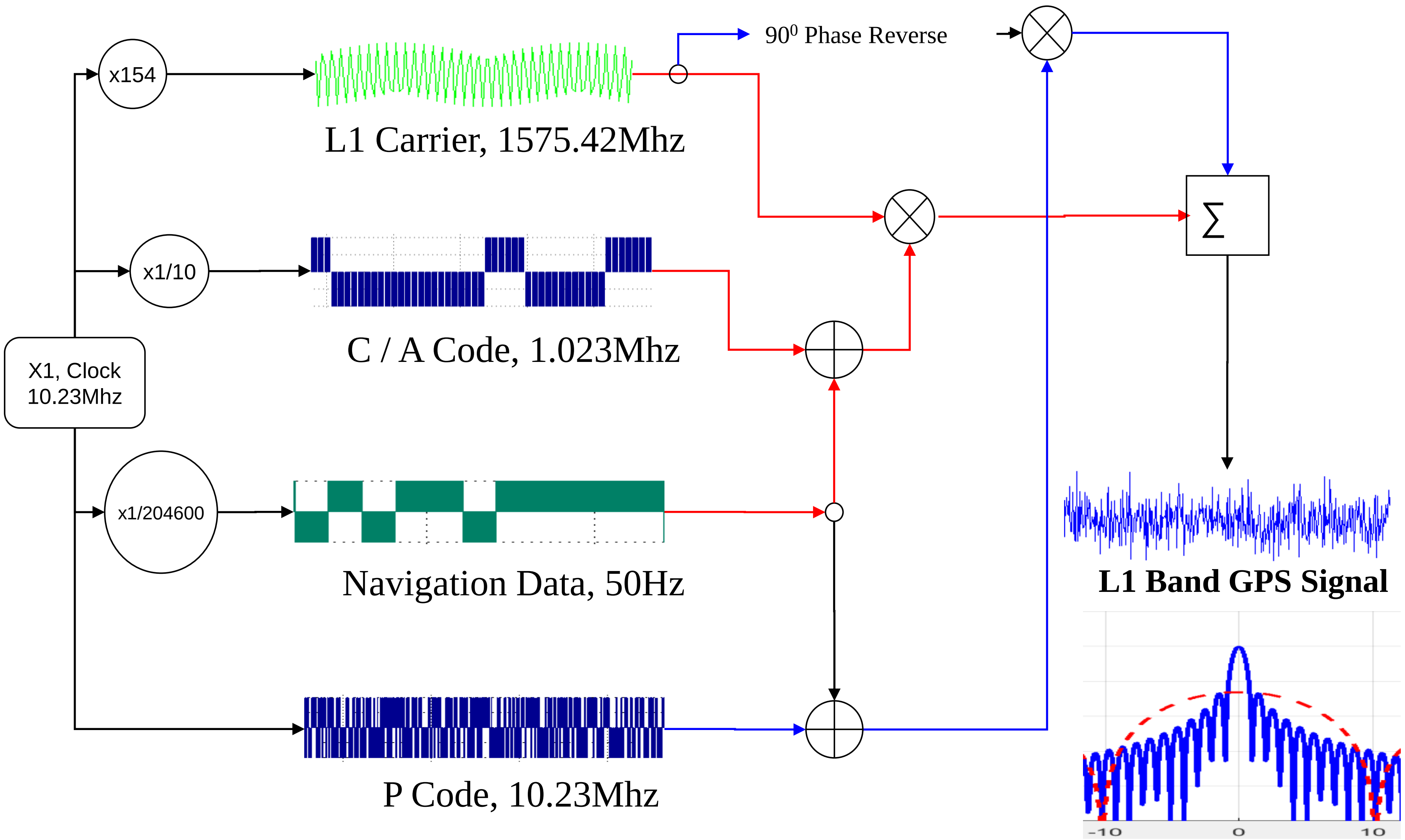
GPS Signal Structure

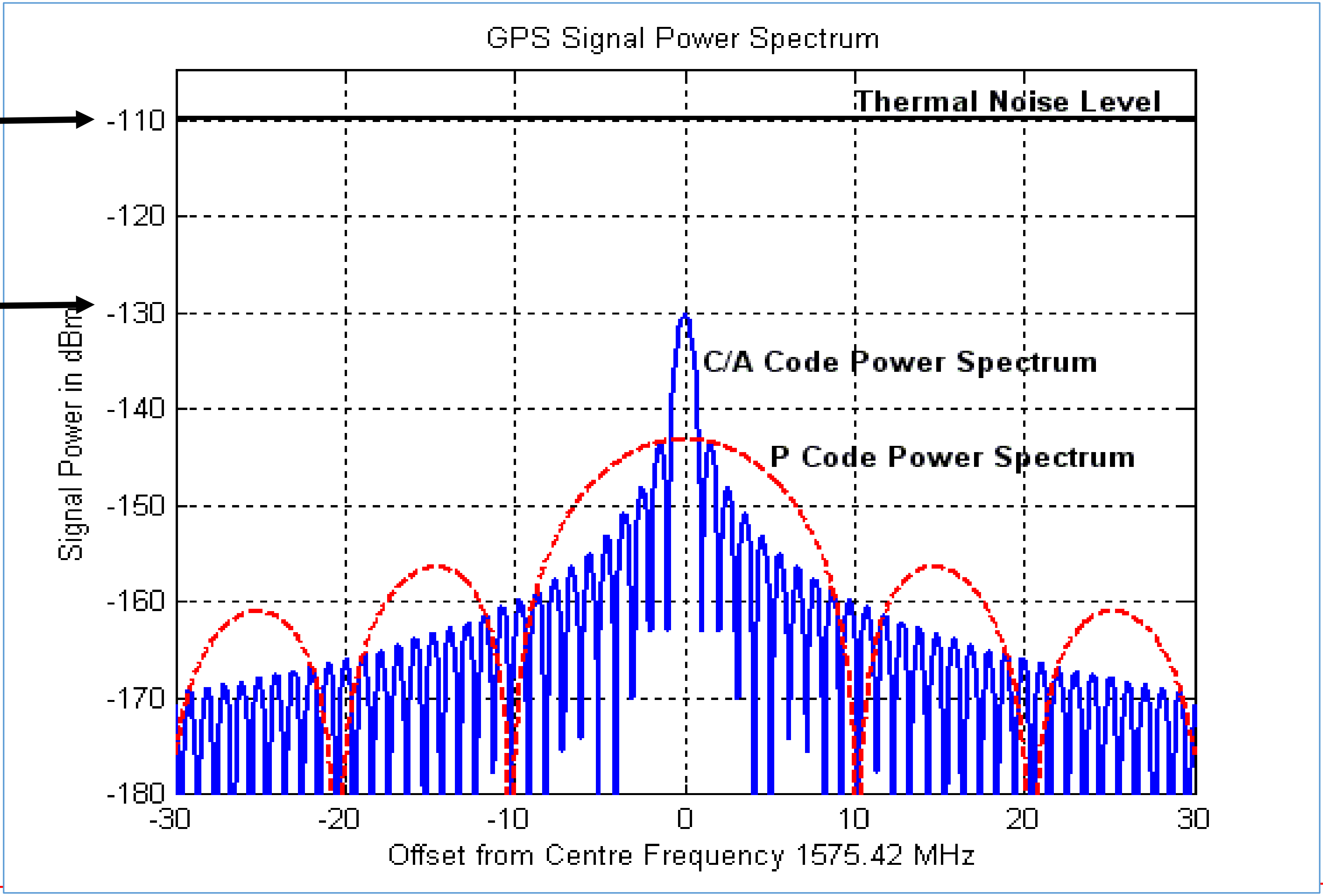


GPS Signal Power

Noise Power
Any Signal below this noise level can't be measured in a Spectrum Analyzer

GPS Signal Power at Antenna, -130dBm

Mobile phone, WiFi, BT etc have power level above -110dBm, much higher than GPS Signal Power



Power of GPS Signal vs. Other Signals

	Signal Type	Power (based on calculations, not measured)		
		Watt	dBW	dBm
Above Noise	Mobile Phone Handset TX Power *	1W	0dBW	30dBm
	RX Power at Mobile Phone Handset*	100e-6W	-40dBW	-70dBm
	ZigBee	316e-16W	-115dBW	-85dBm
	VHF	200e-16W	-137dBW	-107dBm
	Thermal Noise	**79e-16W**	**-141dBW**	**-111dBm**
Below Noise	GPS**	**1e-16W**	**-160dBW**	**-130dBm**

- * Actual power values will differ. These are just for comparison purpose
- ** GPS Signals are hidden under the noise. Thus, it can't be measured directly e.g. using a Spectrum Analyzer

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