Introduction to Global Navigation Satellite System (GNSS) Signal Structure

Dinesh Manandhar

Center for Spatial Information Science

The University of Tokyo

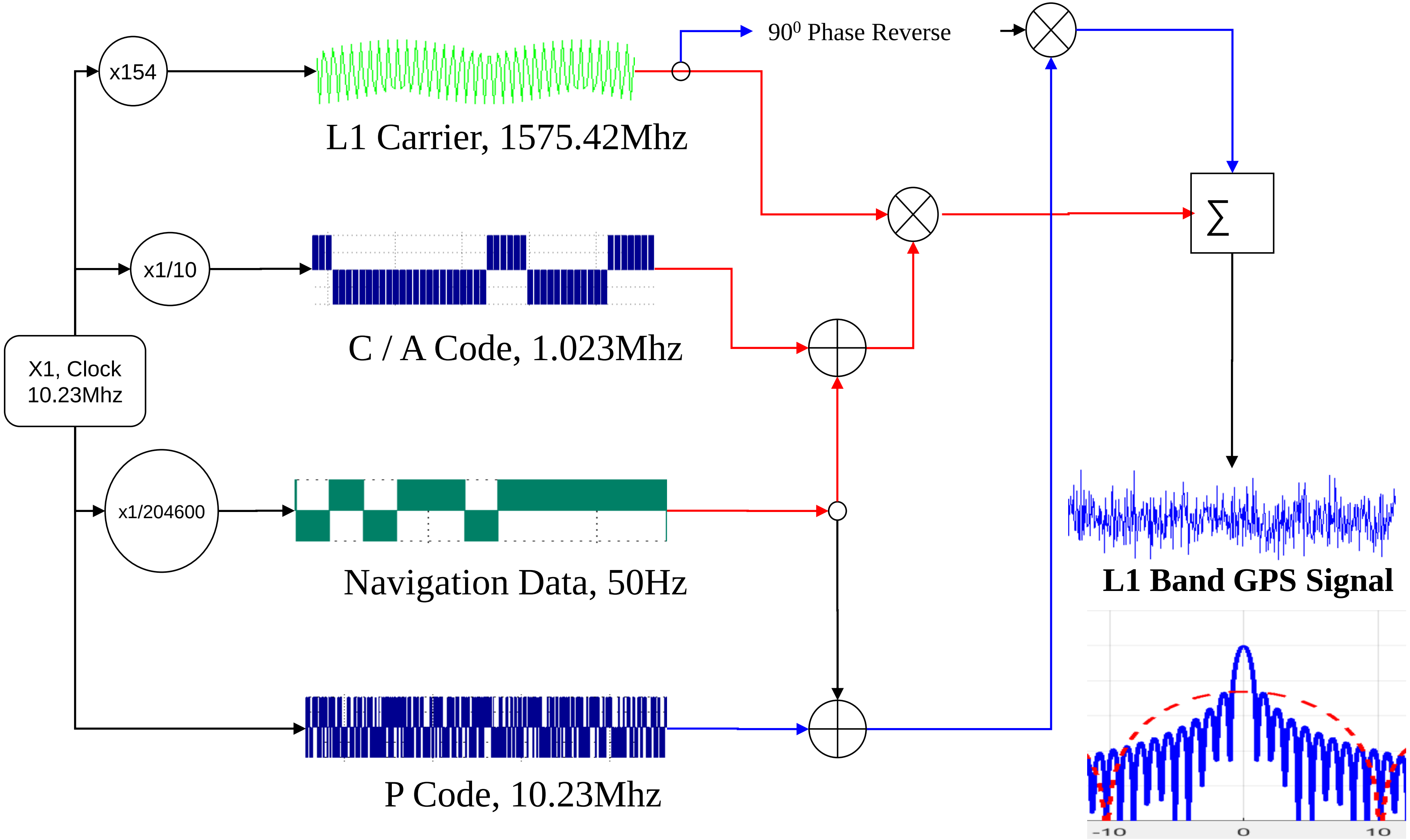
Contact Information: dinesh@iis.u-Tokyo.ac.jp

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

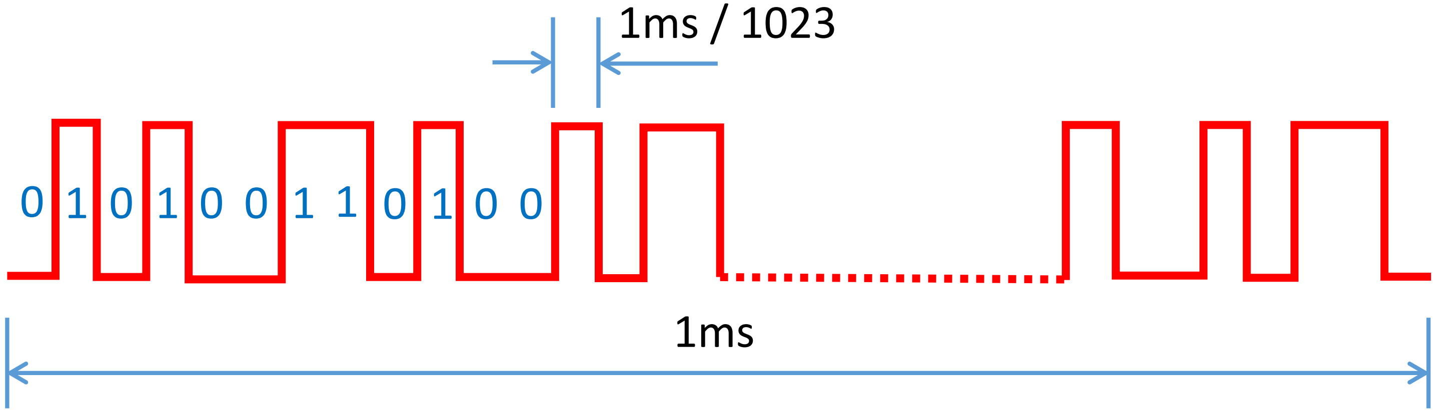
CDMA: Code Division Multiple Access
FDMA: Frequency Division Multiple Access
BPSK : Binary Phase Shift Keying
BOC: Binary Offset Carrier

GPS Signal Structure

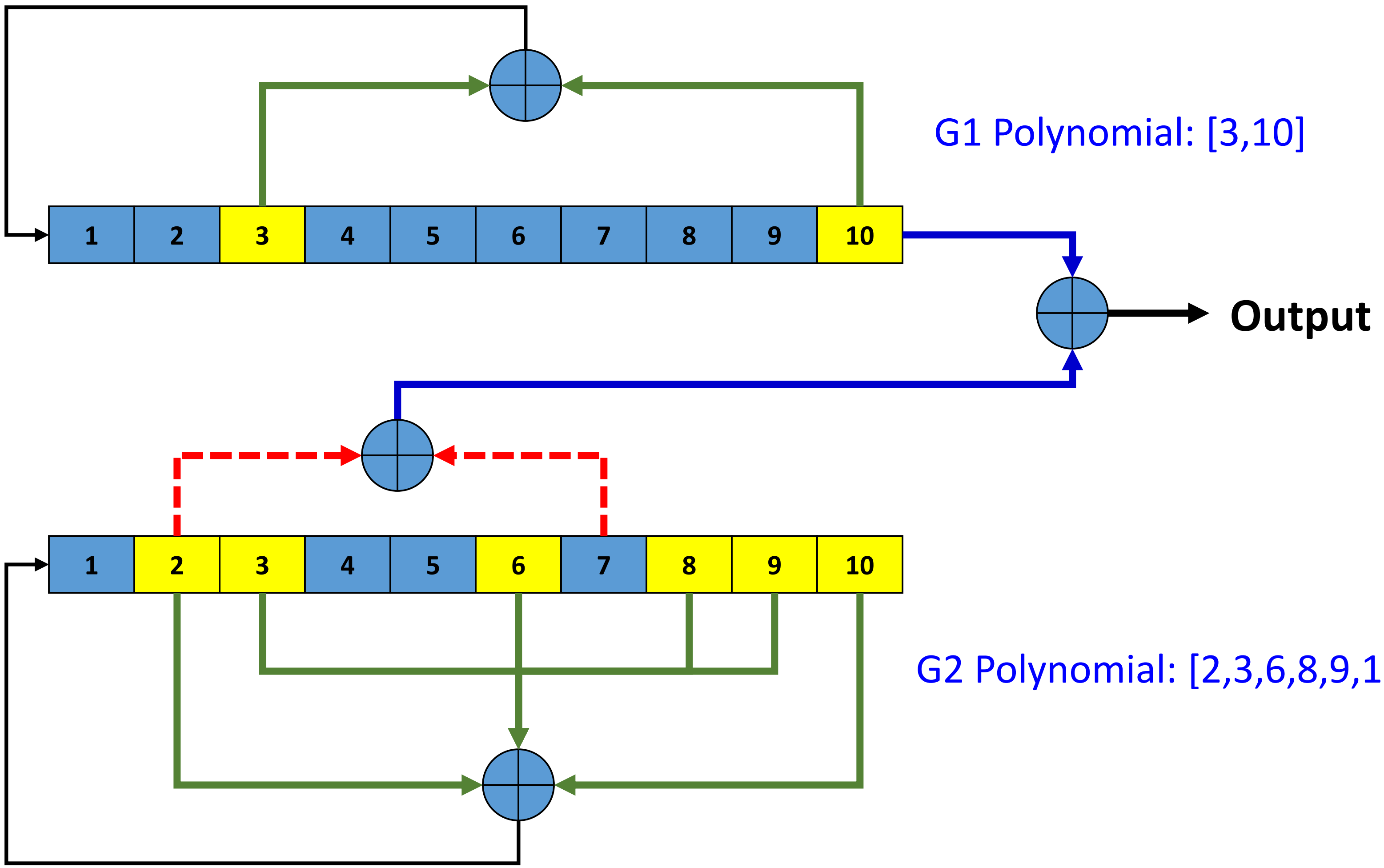


PRN (Pseudo Random Noise) Code

- 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.



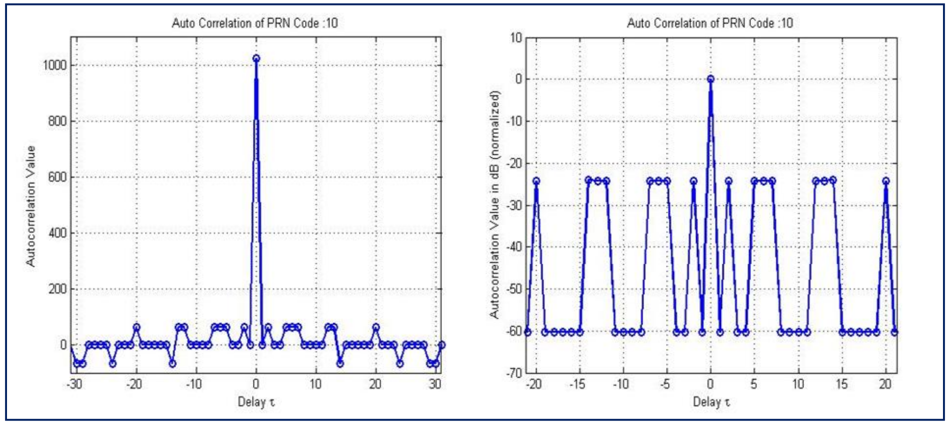
GPS L1C/A PRN Code Generator

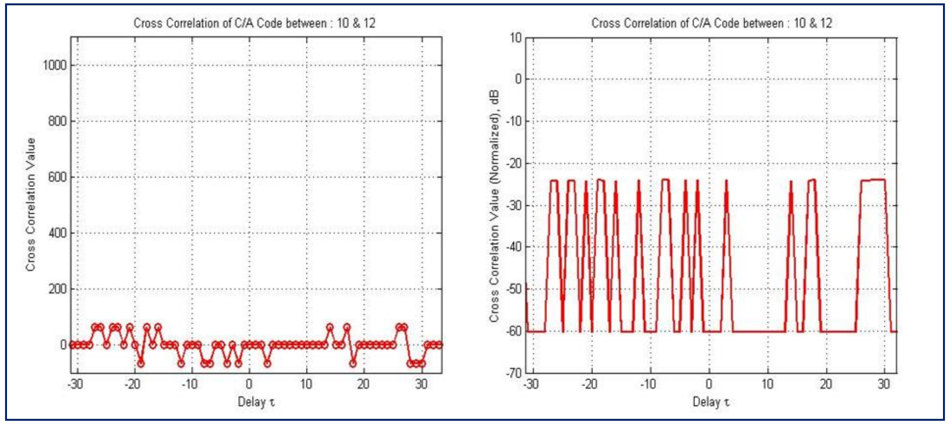


G1 Polynomial: [3,10]

G2 Polynomial: [2,3,6,8,9,10]

Characteristics of PRN Code





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

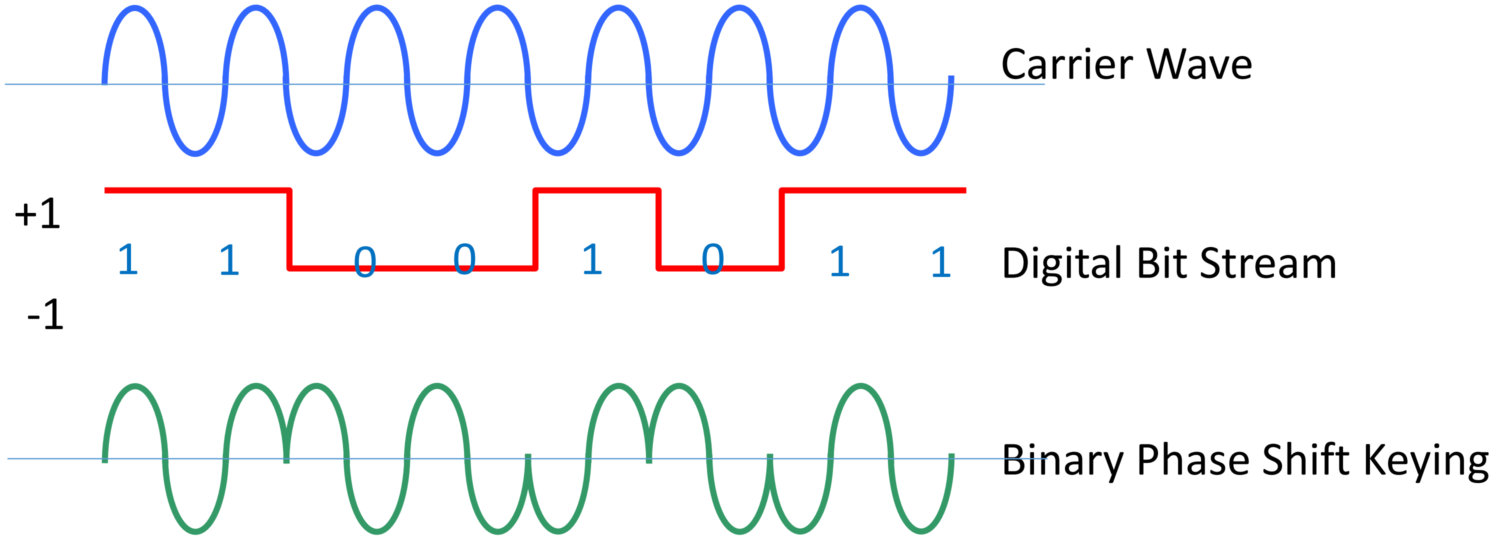
Cross-correlation: Only three values:
1, 63 or 65 (Ideal Case)

- 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

BPSK (Binary Phase Shift Keying)

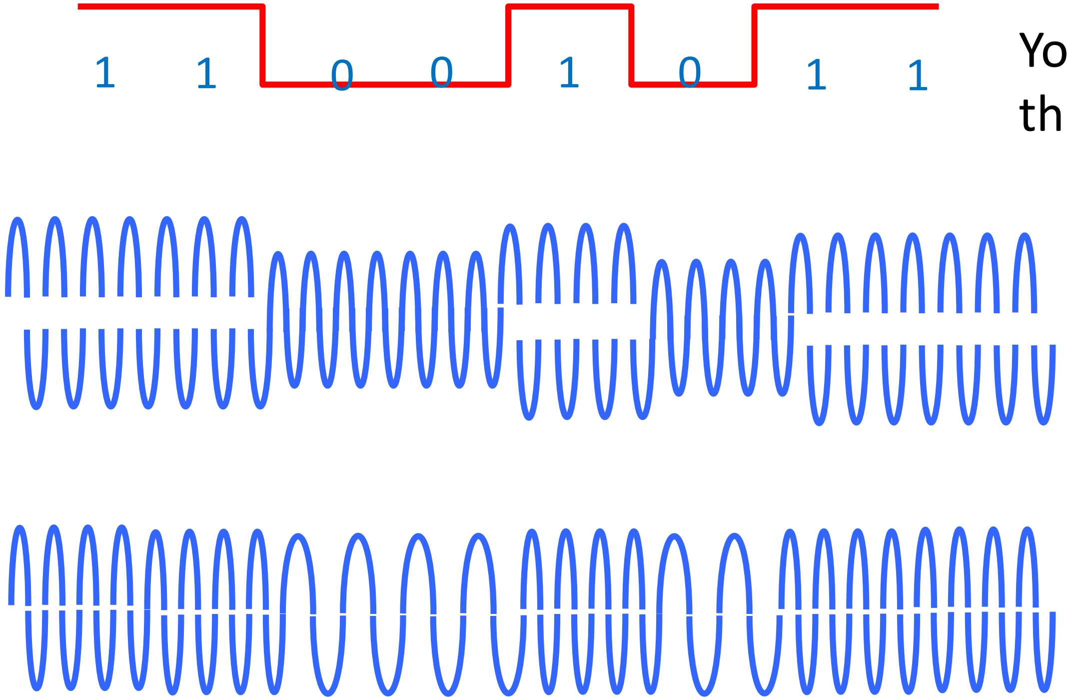
Phase shift keying is a digital modulation scheme that conveys data by changing, or modulating, the phase of the carrier wave. BPSK uses two phases which are separated by a half cycle.



Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@iis.u-tokyo.ac.jp

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.



You want to transmit this binary code

Amplitude Shift Keying

Frequency Shift Keying

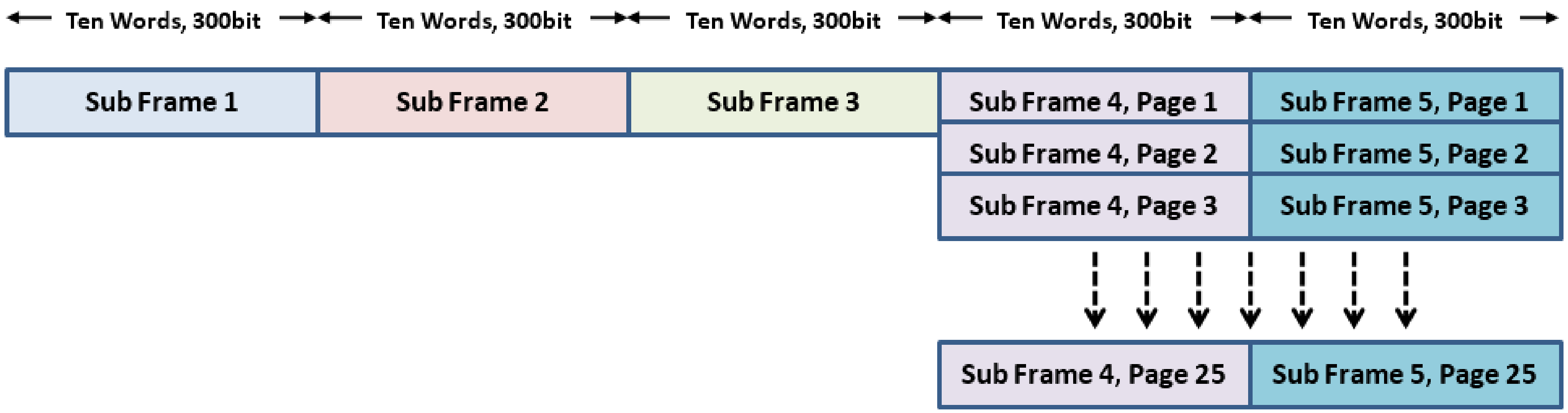
CDMA vs. FDMA

	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

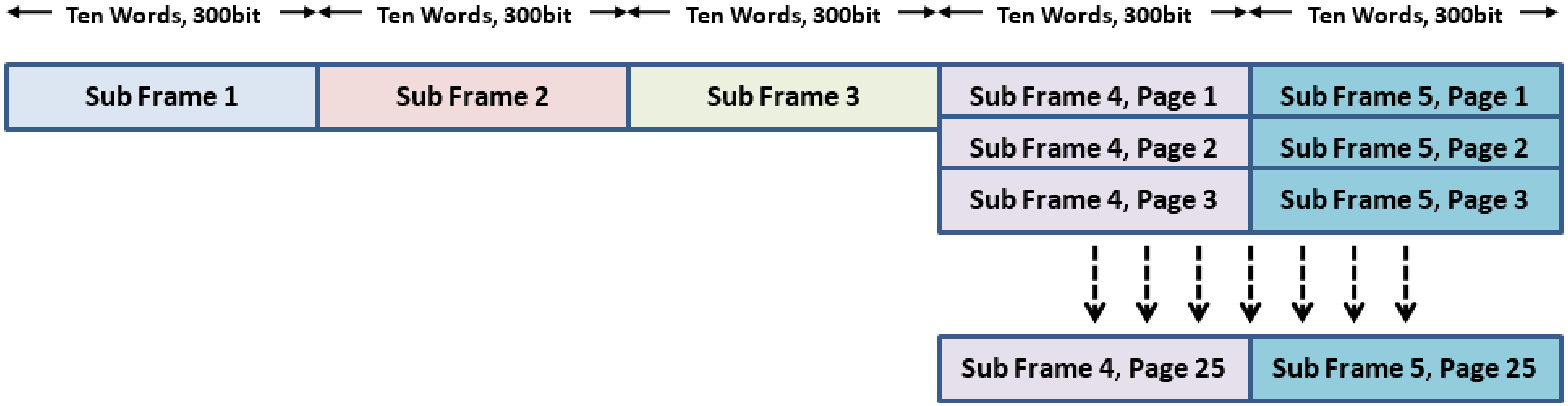
Navigation Data

- 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



GPS L1C/A Signal NAV MSG



Ten Words, 300bit | Ten Words, 300bit | Ten Words, 300bit | Ten Words, 300bit | Ten Words, 300bit

Sub Frame 1 | Sub Frame 2 | Sub Frame 3 | Sub Frame 4, Page 1 | Sub Frame 5, Page 1

Sub Frame 4, Page 2 | Sub Frame 5, Page 2

Sub Frame 4, Page 3 | Sub Frame 5, Page 3

Sub Frame 4, Page 25 | Sub Frame 5, Page 25

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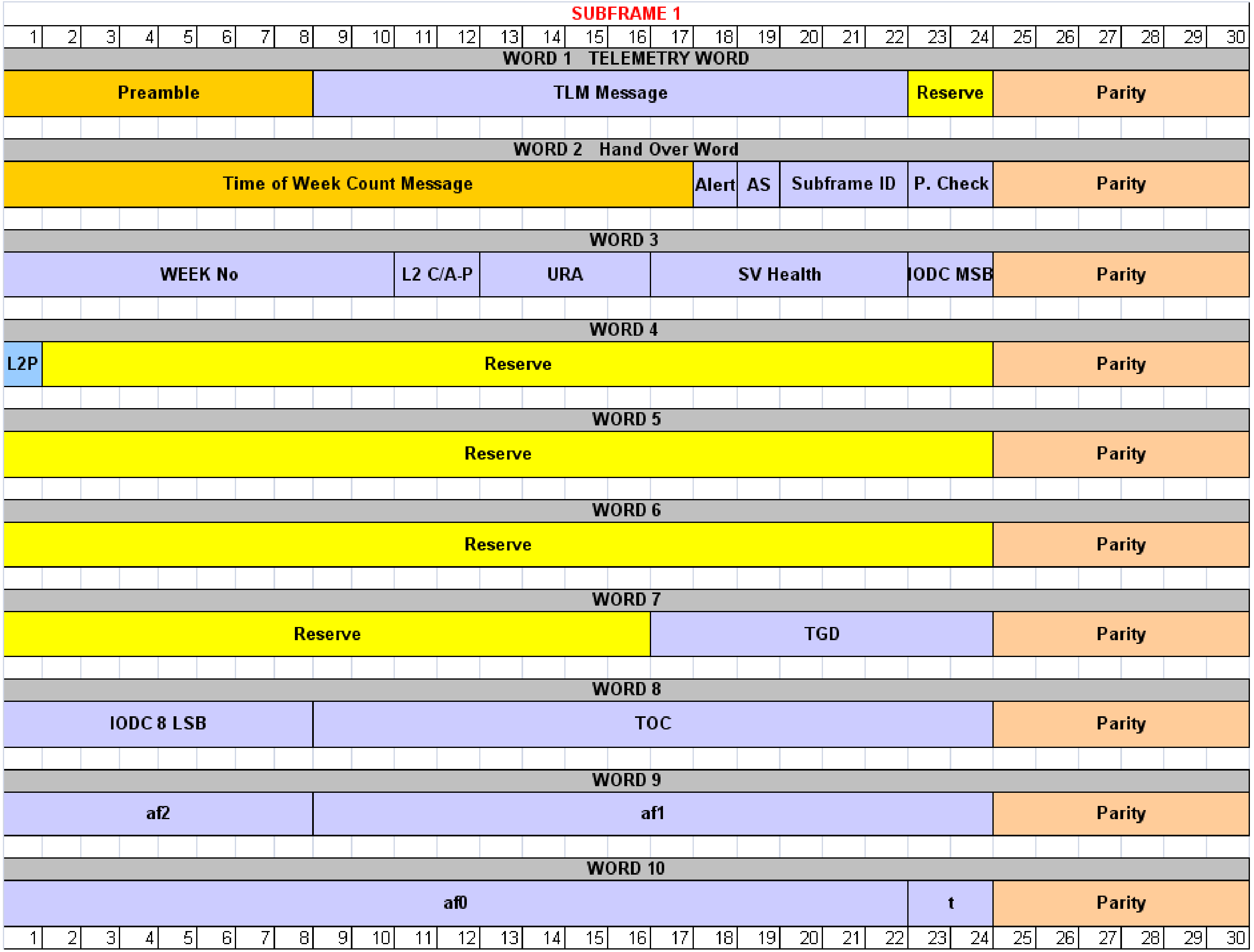
Navigation Message, Sub-frame 1



SUBFRAME 1

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Preamble								TLM Message														Reserve		Parity					
WORD 2 Hand Over Word																													
Time of Week Count Message																	Alert	AS	Subframe ID			P. Check		Parity					
WORD 3																													
WEEK No										L2 C/A-P		URA				SV Health						IODC MSB		Parity					
WORD 4																													
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WORD 5																													
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IODC 8 LSB								TOC																Parity					
WORD 9																													
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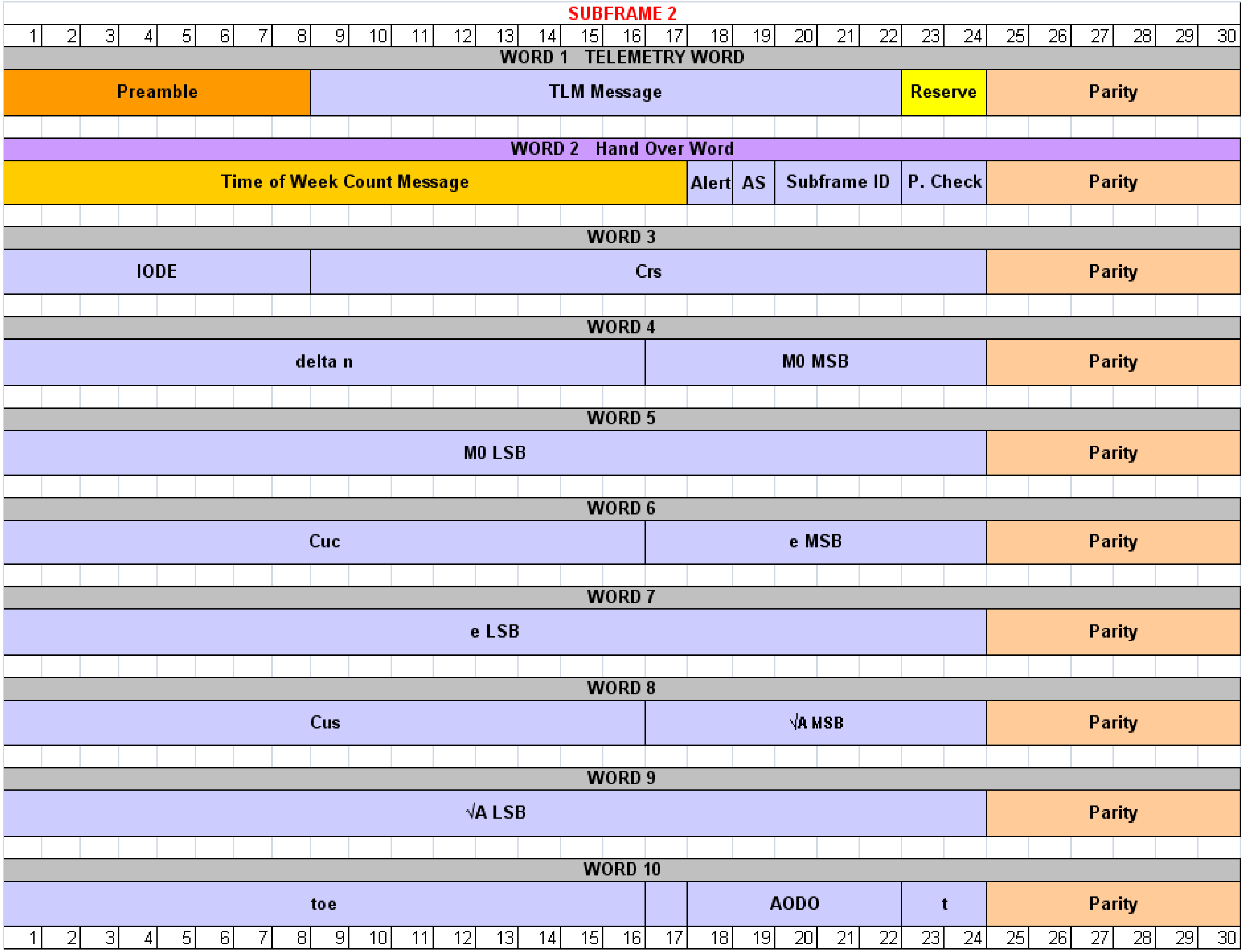
GPS L1C/A Signal NAV MSG, Sub-frame 2



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<tr><td colspan="30">WORD 1 TELEMETRY WORD</td></tr>
<tr><td colspan="8">Preamble</td><td colspan="14">TLM Message</td><td colspan="2">Reserve</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 2 Hand Over Word</td></tr>
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<tr><td colspan="30">WORD 3</td></tr>
<tr><td colspan="8">IODE</td><td colspan="16">Crs</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 4</td></tr>
<tr><td colspan="16">delta n</td><td colspan="8">M0 MSB</td><td colspan="6">Parity</td></tr>
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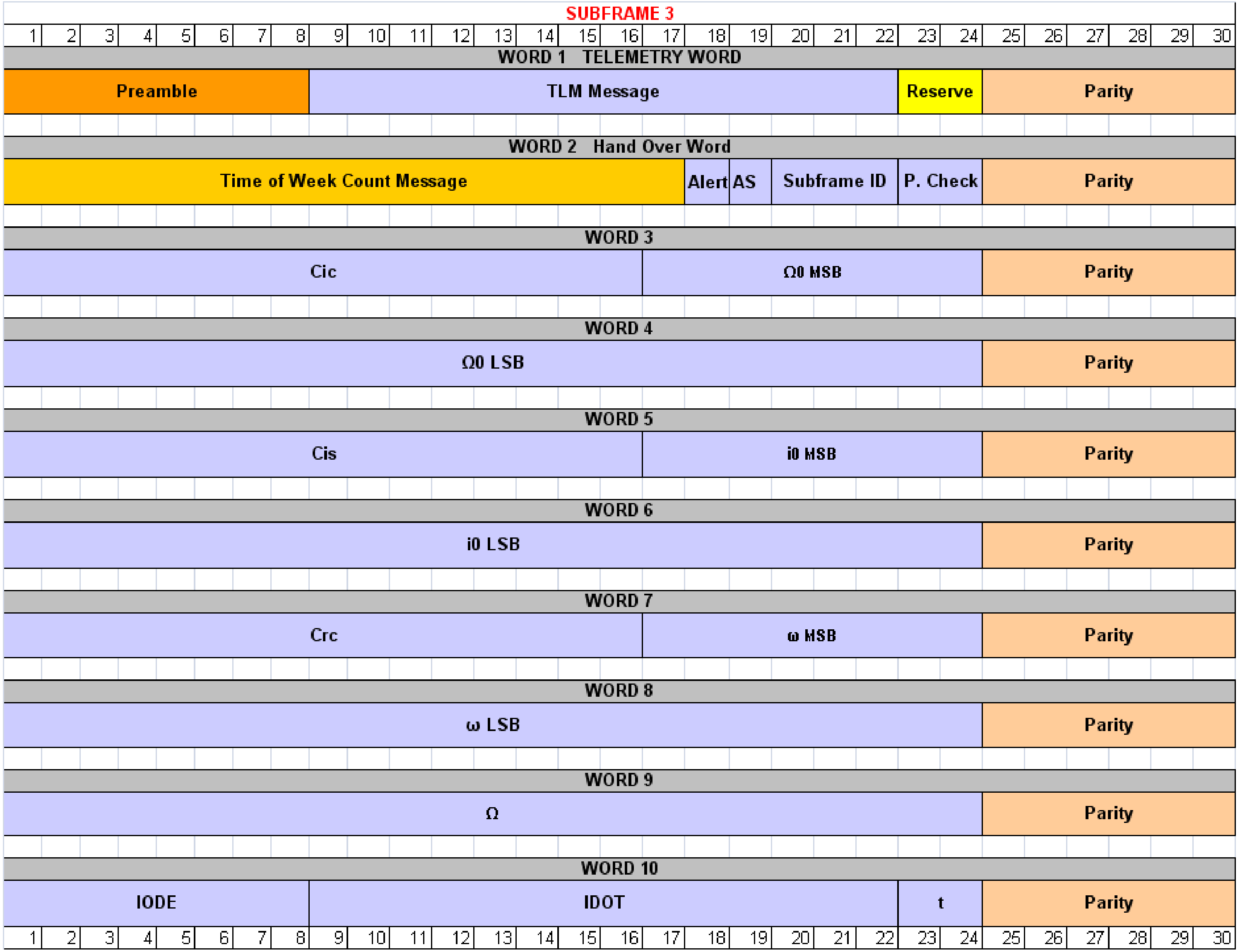
GPS L1C/A Signal NAV MSG, Sub-frame 3



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<tr><td colspan="30">WORD 1 TELEMETRY WORD</td></tr>
<tr><td colspan="8">Preamble</td><td colspan="14">TLM Message</td><td colspan="2">Reserve</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 2 Hand Over Word</td></tr>
<tr><td colspan="17">Time of Week Count Message</td><td>Alert</td><td>AS</td><td colspan="3">Subframe ID</td><td colspan="2">P. Check</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 3</td></tr>
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<tr><td colspan="24">Ω</td><td colspan="6">Parity</td></tr>
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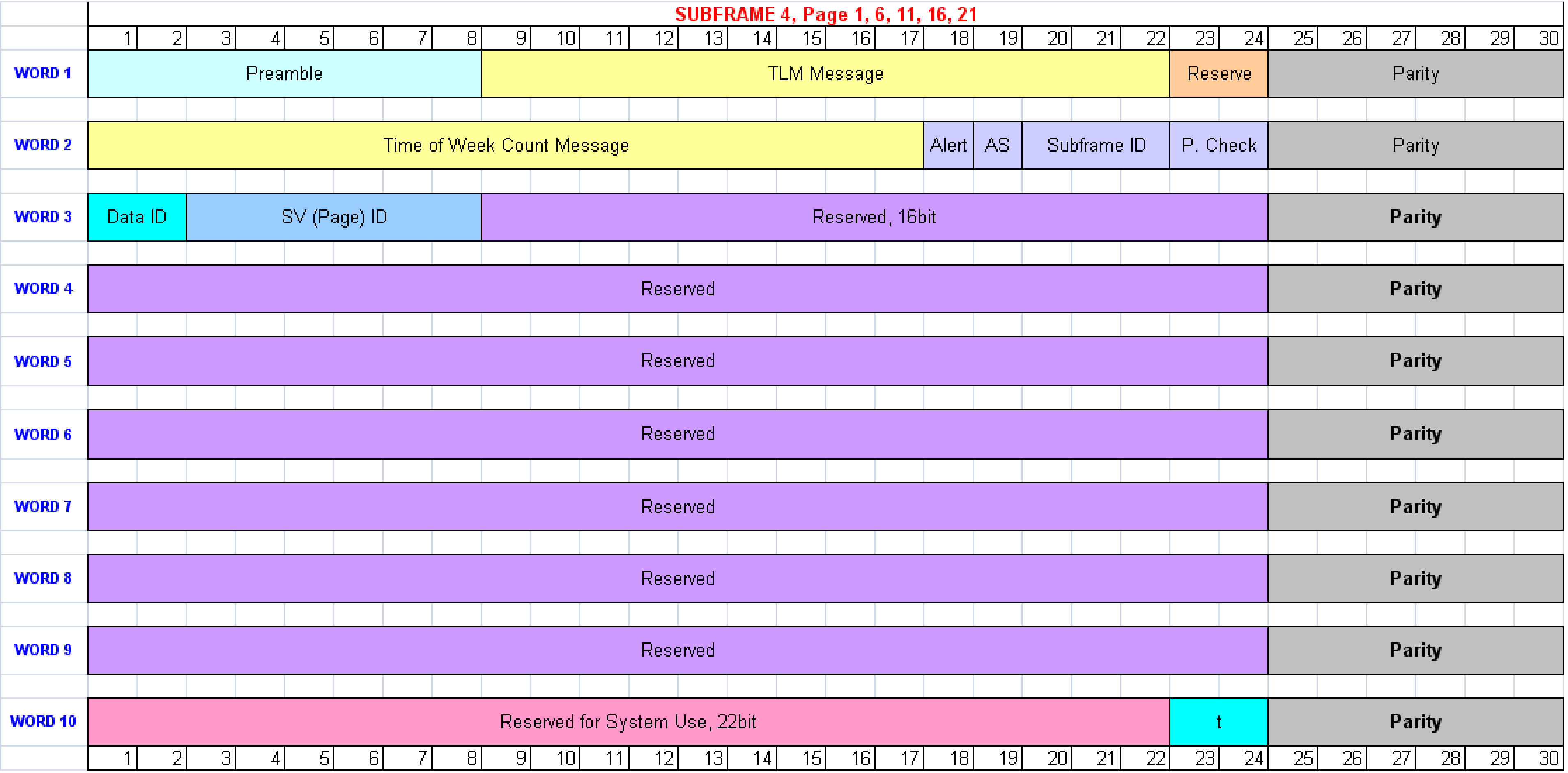
GPS L1C/A Signal NAV MSG, Sub-frame 4 Page 1,6,11,16,21



SUBFRAME 4, Page 1, 6, 11, 16, 21

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WORD 9	Reserved																								**Parity**					
WORD 10	Reserved for System Use, 22bit																						t		**Parity**					
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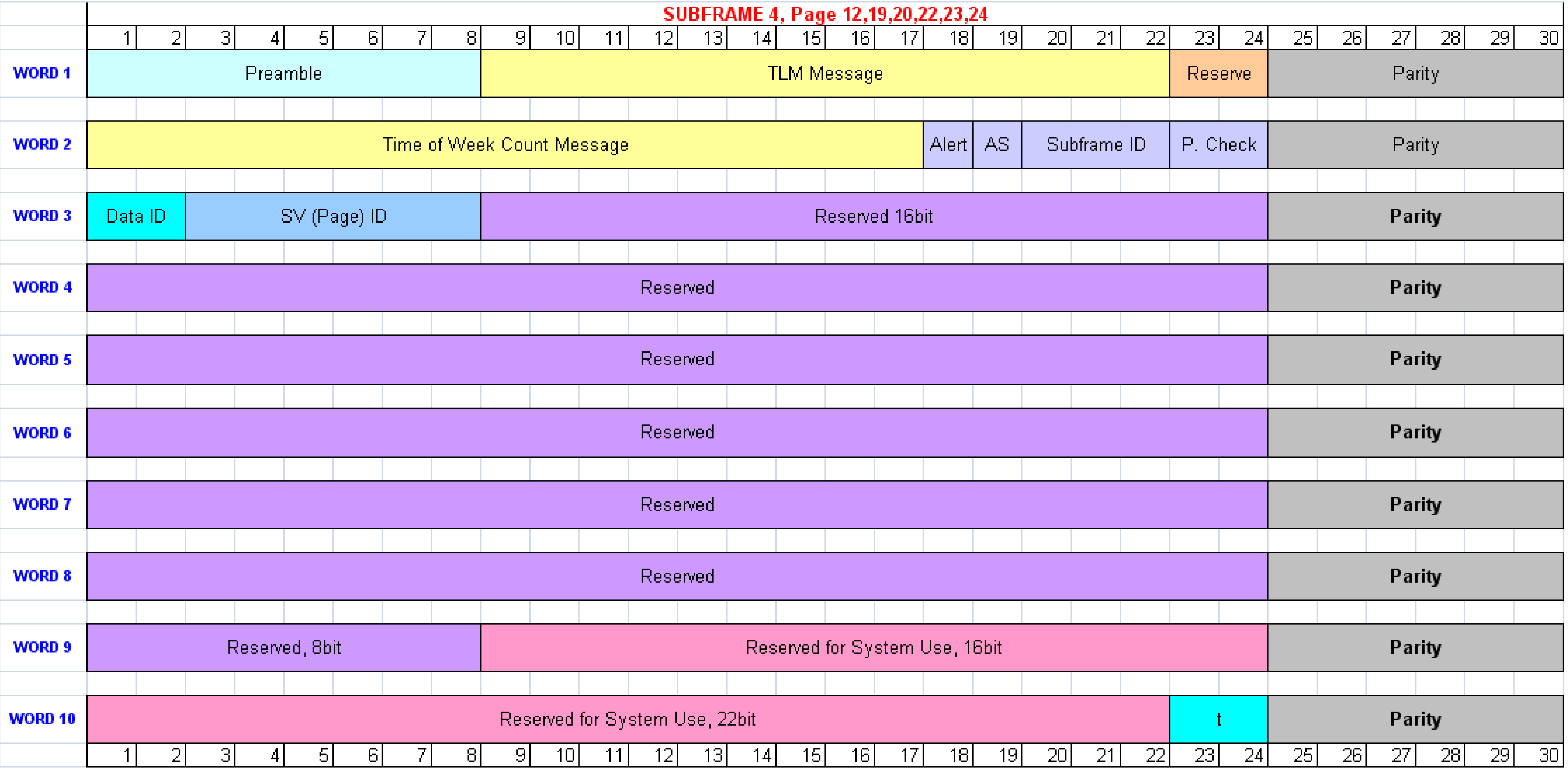
GPS L1C/A Signal NAV MSG, Sub-frame 4 Page 12,19,20,22,23,24



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WORD 1	Preamble								TLM Message														Reserve		Parity					
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WORD 7	Reserved																								**Parity**					
WORD 8	Reserved																								**Parity**					
WORD 9	Reserved, 8bit								Reserved for System Use, 16bit																**Parity**					
WORD 10	Reserved for System Use, 22bit																						t		**Parity**					
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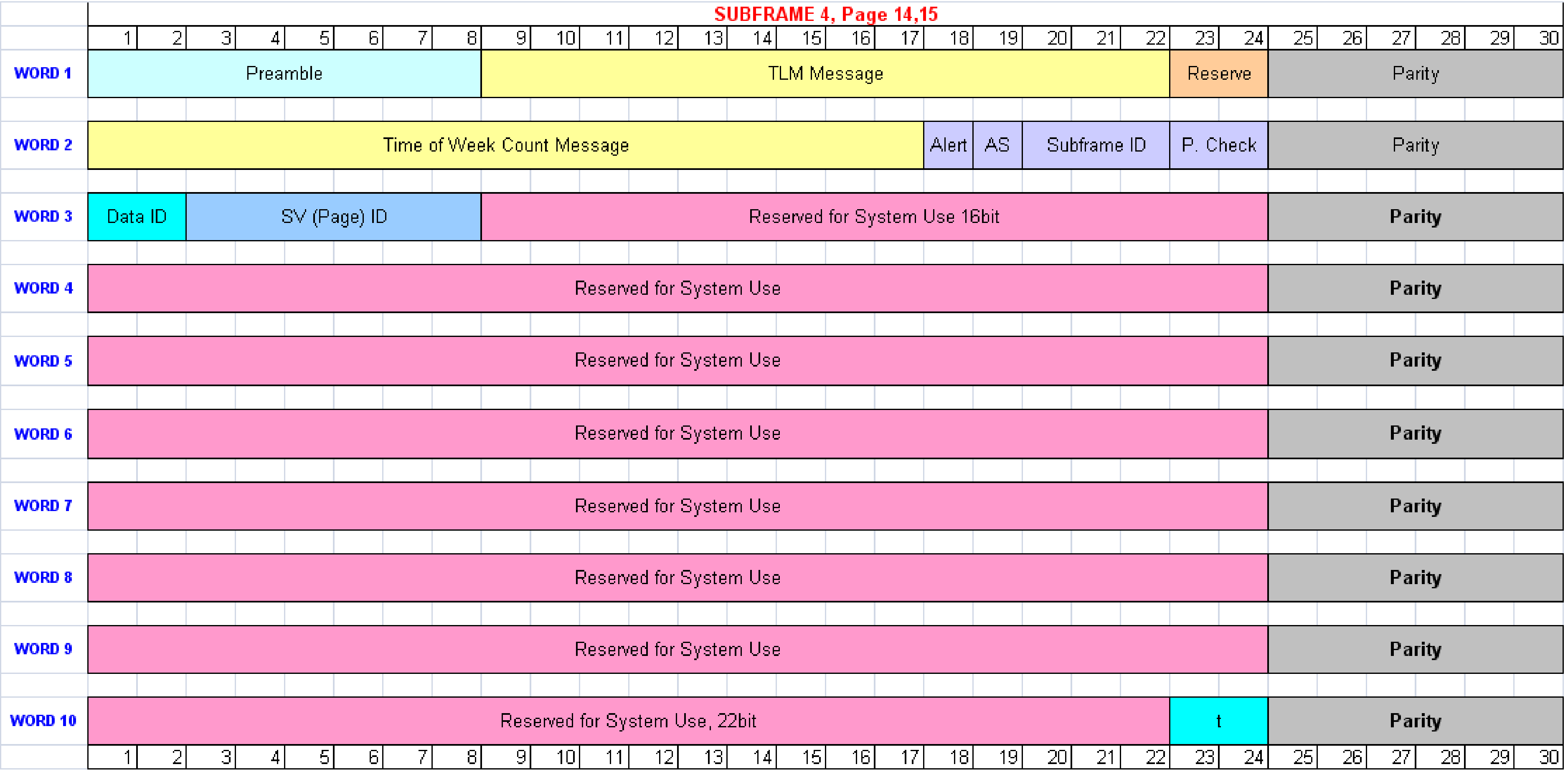
GPS L1C/A Signal NAV MSG, Sub-frame 4, Page 14, 15



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WORD 1	Preamble								TLM Message														Reserve		Parity					
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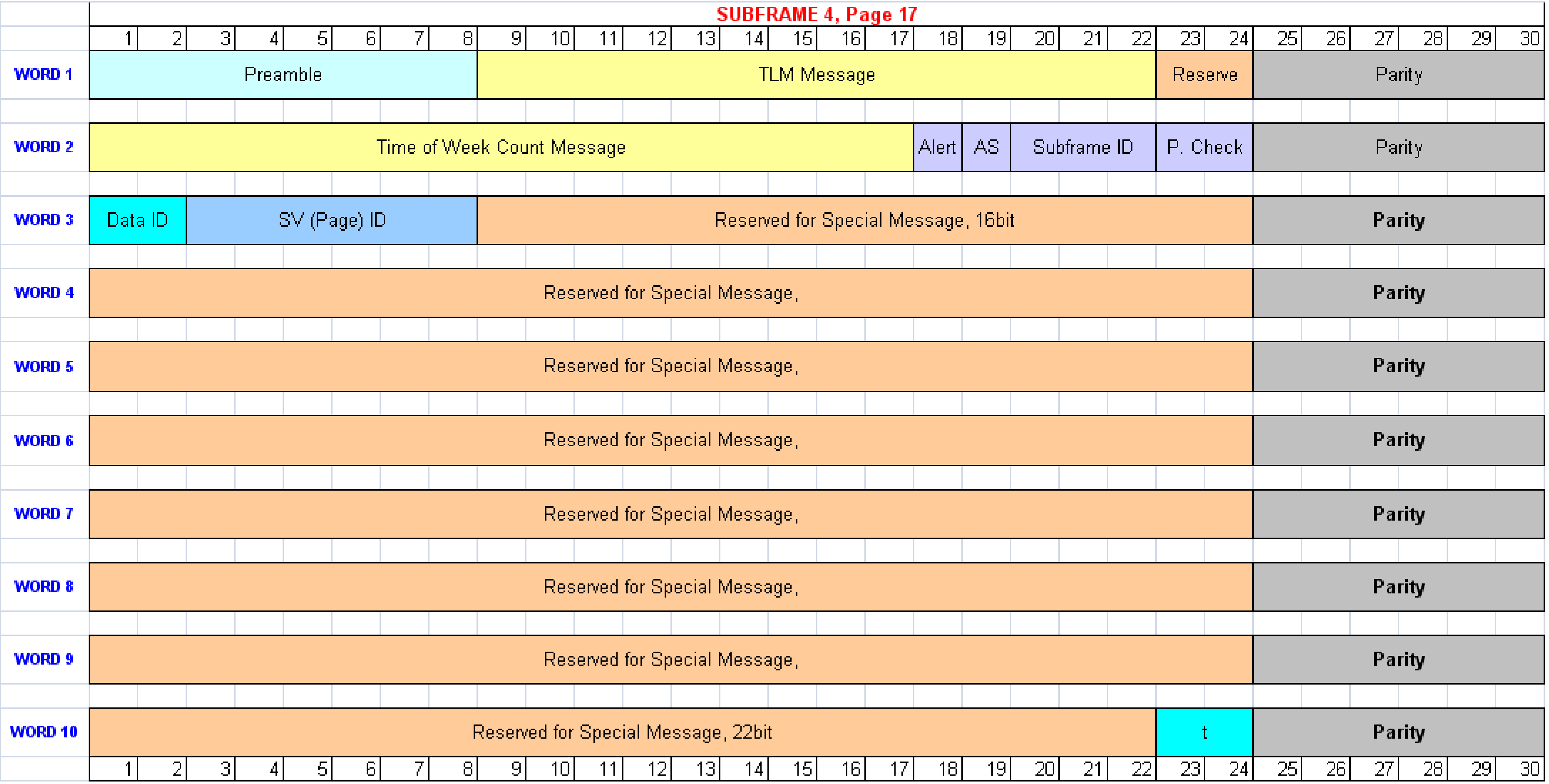
GPS L1C/A Signal NAV MSG, Sub-frame 4, Page 17



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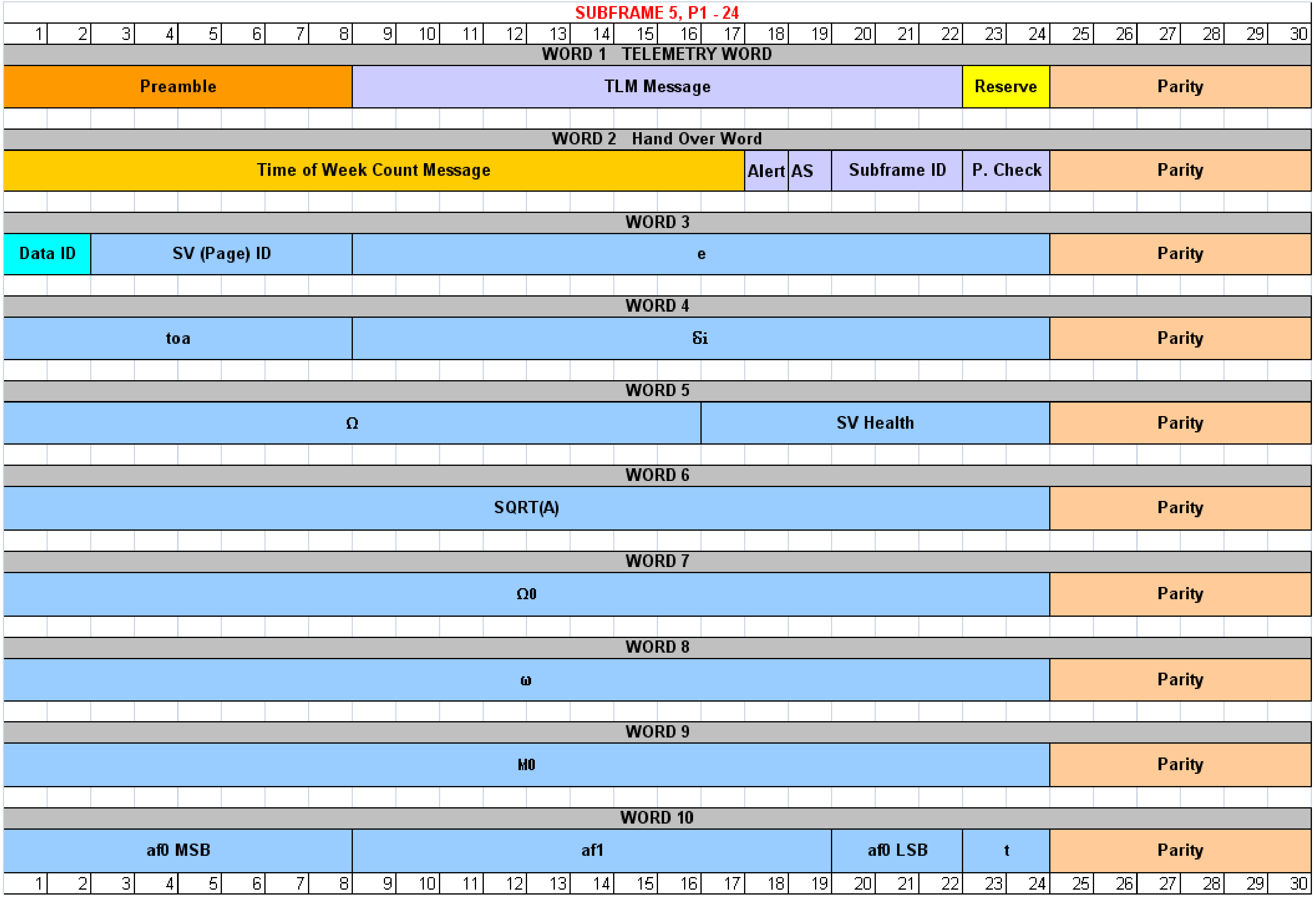
GPS L1C/A Signal NAV MSG, Sub-frame 5



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<tr><td colspan="30">WORD 2 Hand Over Word</td></tr>
<tr><td colspan="17">Time of Week Count Message</td><td>Alert</td><td>AS</td><td colspan="3">Subframe ID</td><td colspan="2">P. Check</td><td colspan="6">Parity</td></tr>
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<tr><td colspan="8">toa</td><td colspan="16">δi</td><td colspan="6">Parity</td></tr>
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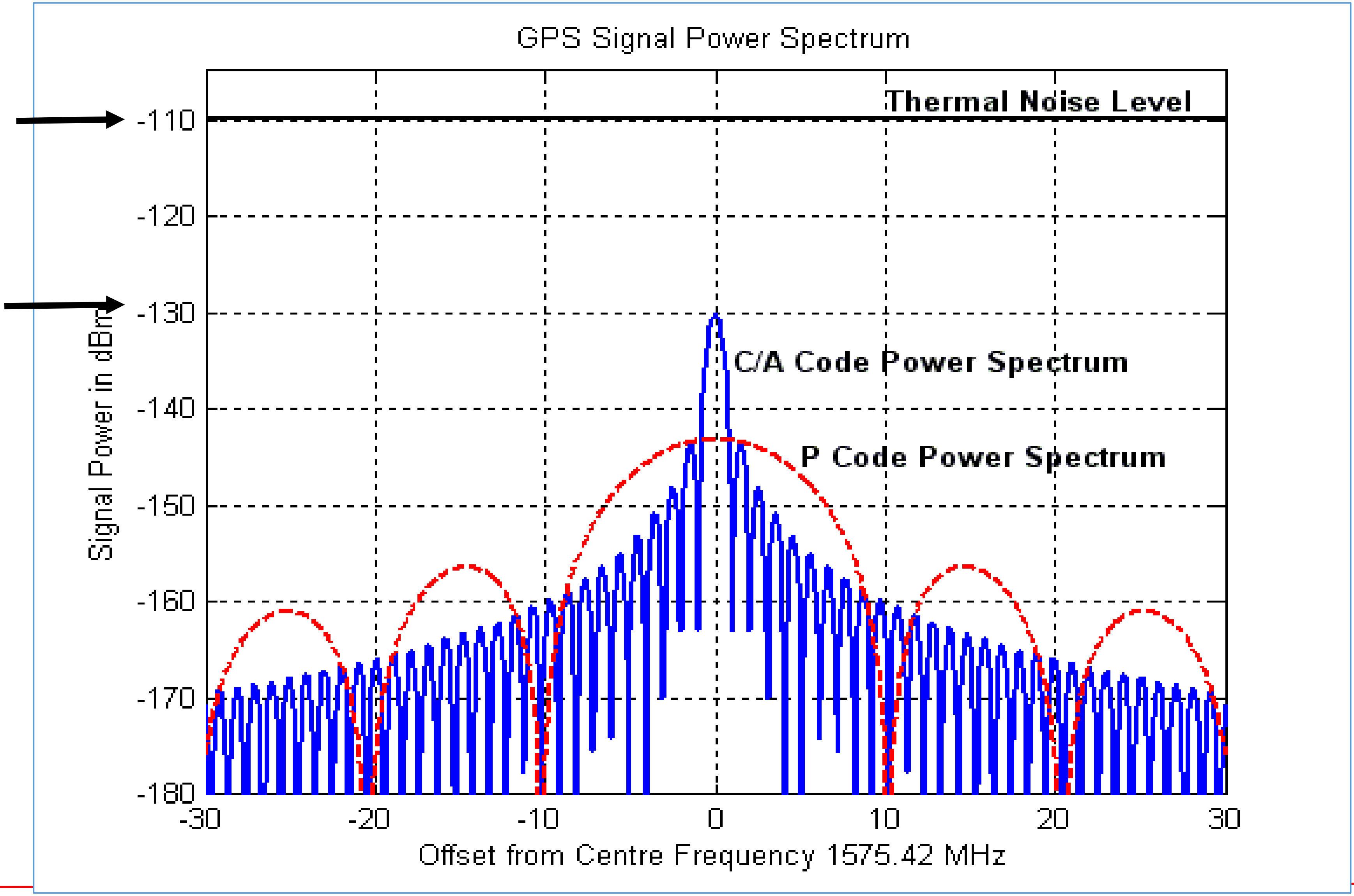
<tr><td colspan="24">M0</td><td colspan="6">Parity</td></tr>
<tr><td colspan="30">WORD 10</td></tr>
<tr><td colspan="8">af0 MSB</td><td colspan="11">af1</td><td colspan="3">af0 LSB</td><td colspan="2">t</td><td colspan="6">Parity</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td></tr>
</table>

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

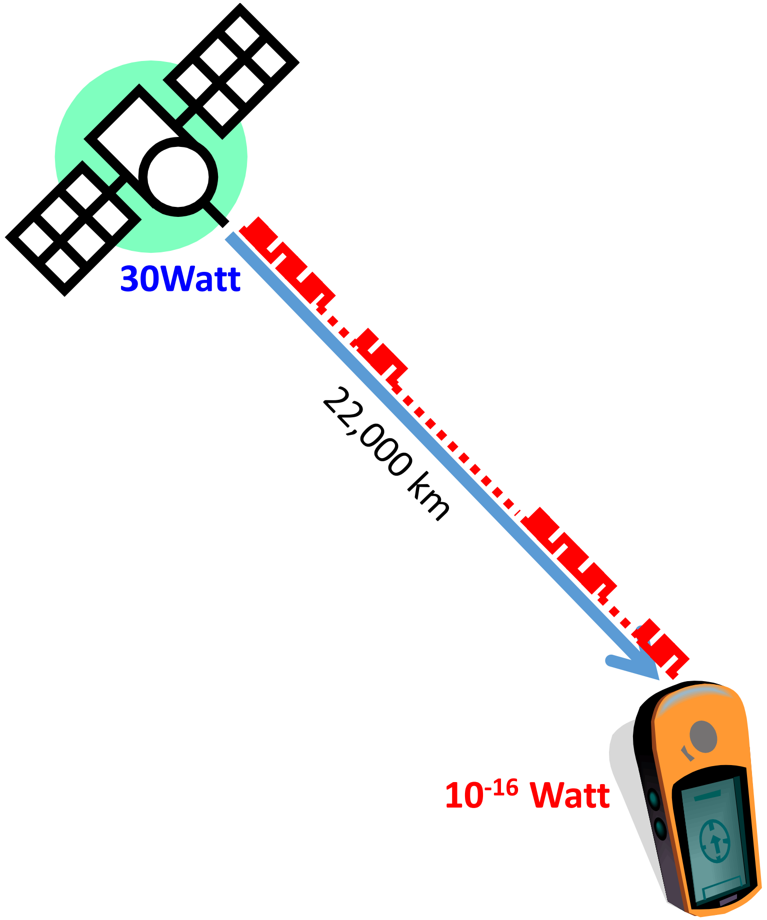
Mobile phone, WiFi, BT etc have power level above -110dBm, much higher than GPS Signal Power



Dinesh Manandhar, CSIS, The University of Tokyo, dinesh@iis.u-tokyo.ac.jp

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

Power of GPS Signal vs. Other Signals

Signal Type	Power (based on calculations, not measured)		
	Watt	dBW	dBm
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**
GPS**	**1e-16W**	**-160dBW**	**-130dBm**

Above Noise

Below Noise

- *   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