

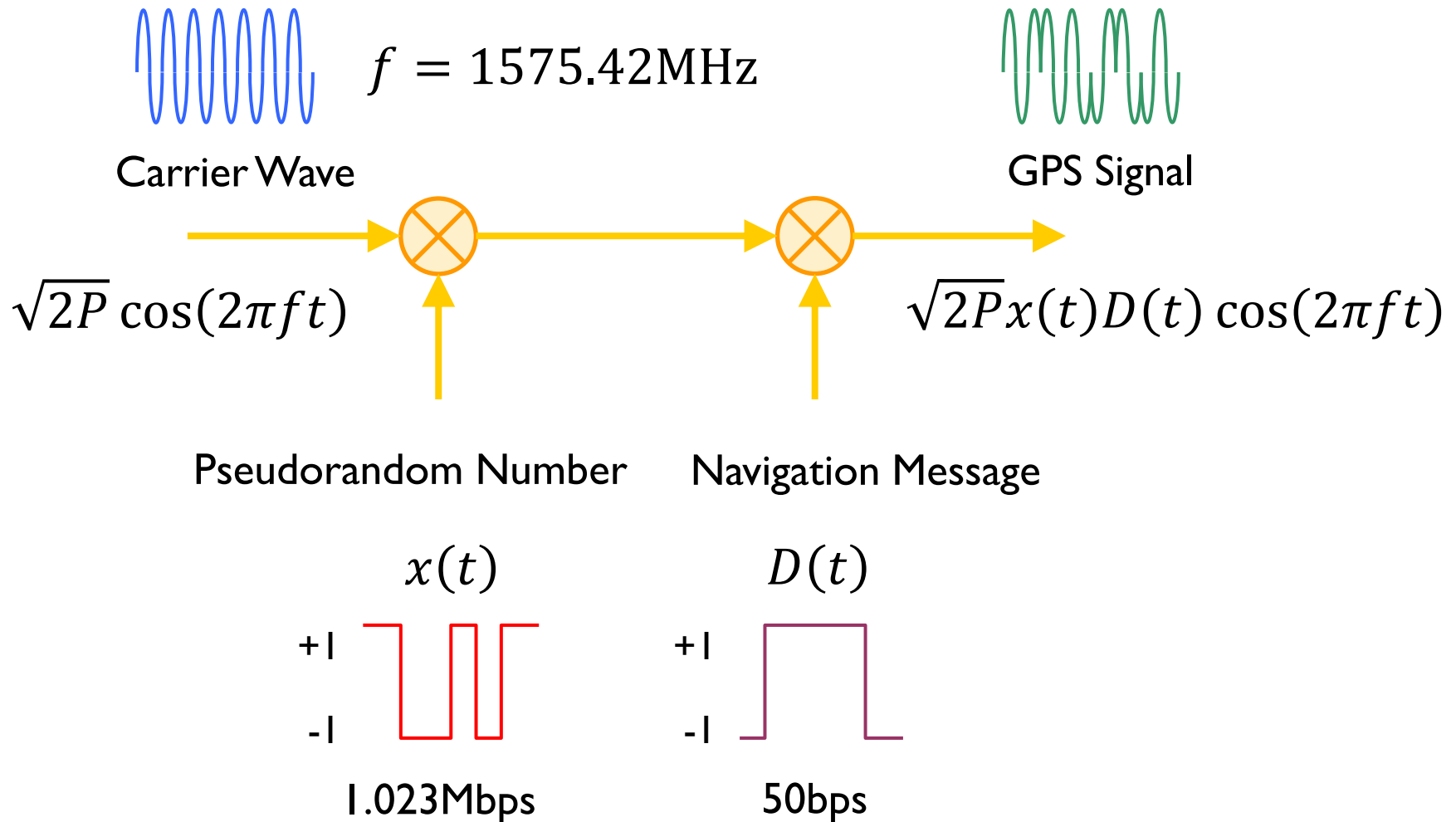
09: Navigation Message

Taro Suzuki

Navigation Message

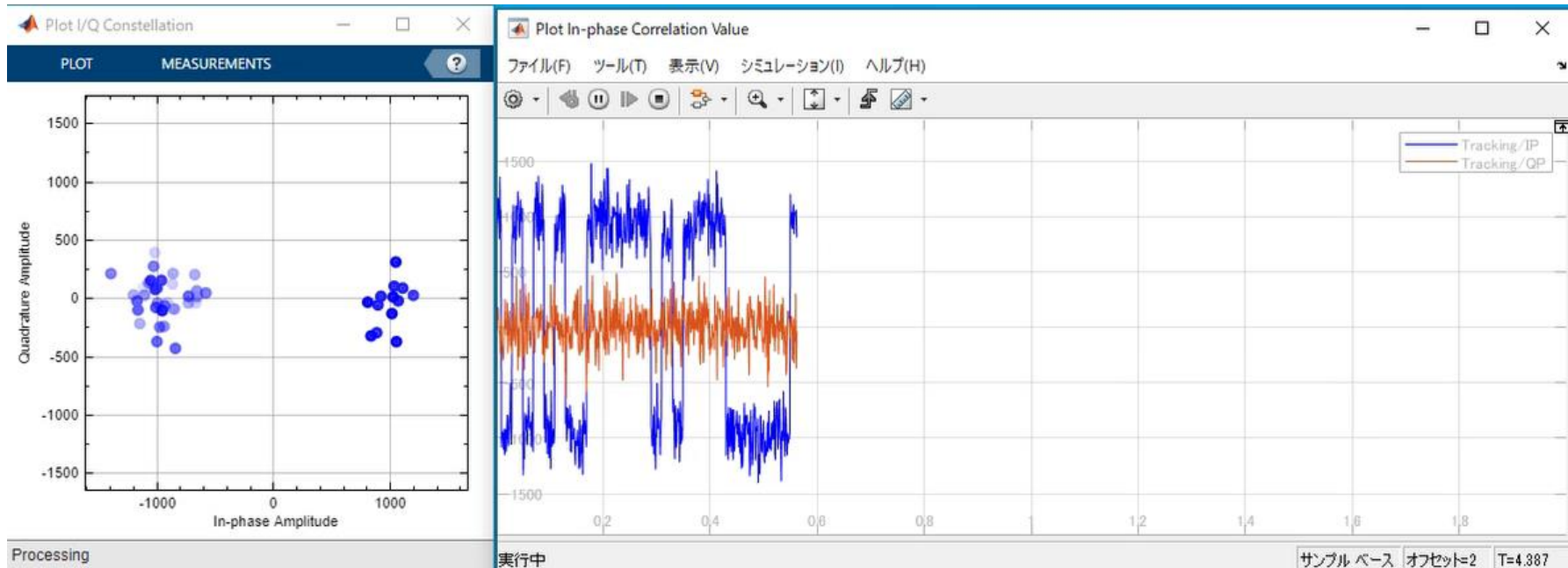
- ▶ Positioning signals contain navigation data and are continuously received to obtain the following information
 - ▶ Ephemeris (satellite orbit parameters)
 - ▶ Almanac (rough satellite orbit parameters)
 - ▶ Time correction parameters (for correction of GPS satellite time)
 - ▶ Ionospheric delay estimation parameters
 - ▶ Satellite health information

GPS Signal Architecture



Tracking output

- ▶ In-phase correlation output is navigation message bit



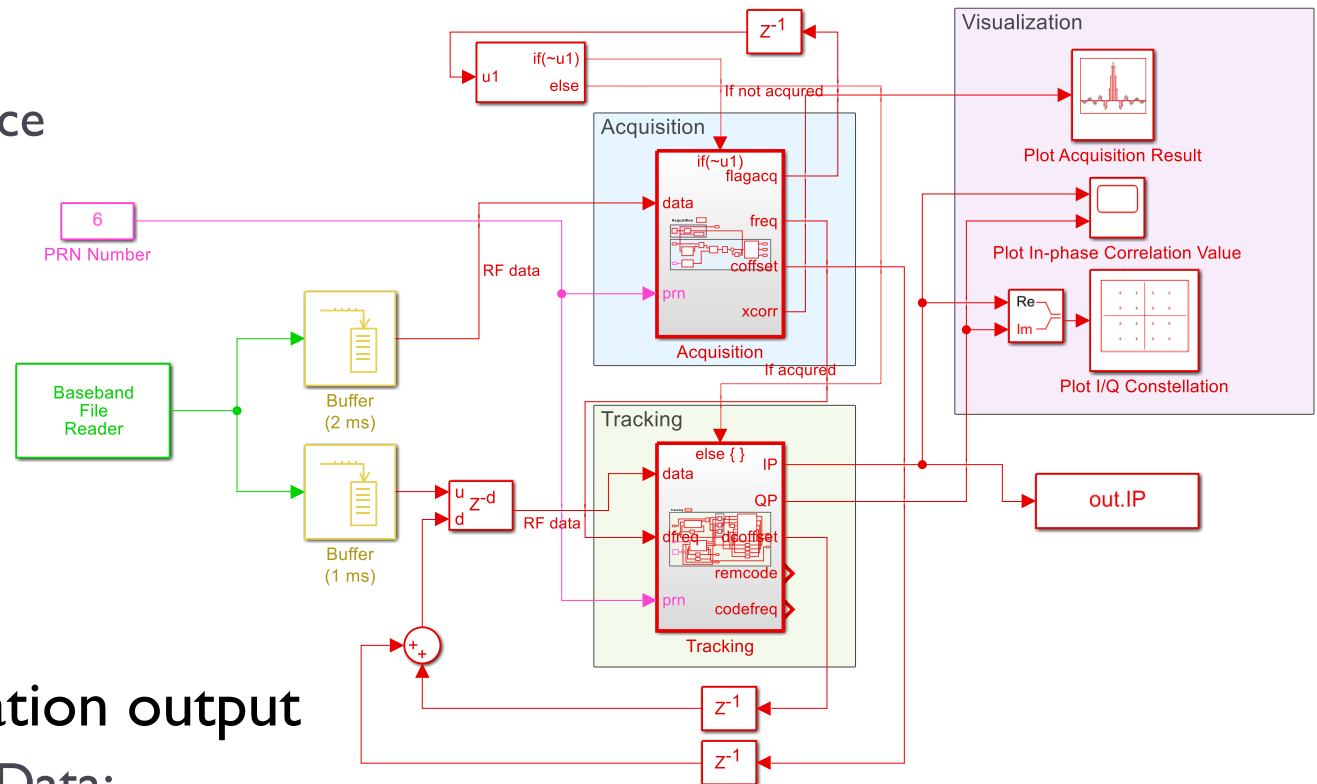
Exercise 1: Log Correlation Outputs

► Simulink

► /09_Navigation_Message/simulink/**Ex I/tracking_I ch.slx**

► Blocks

► To Workspace



► Save correlation output

► IP = out.IP.Data;

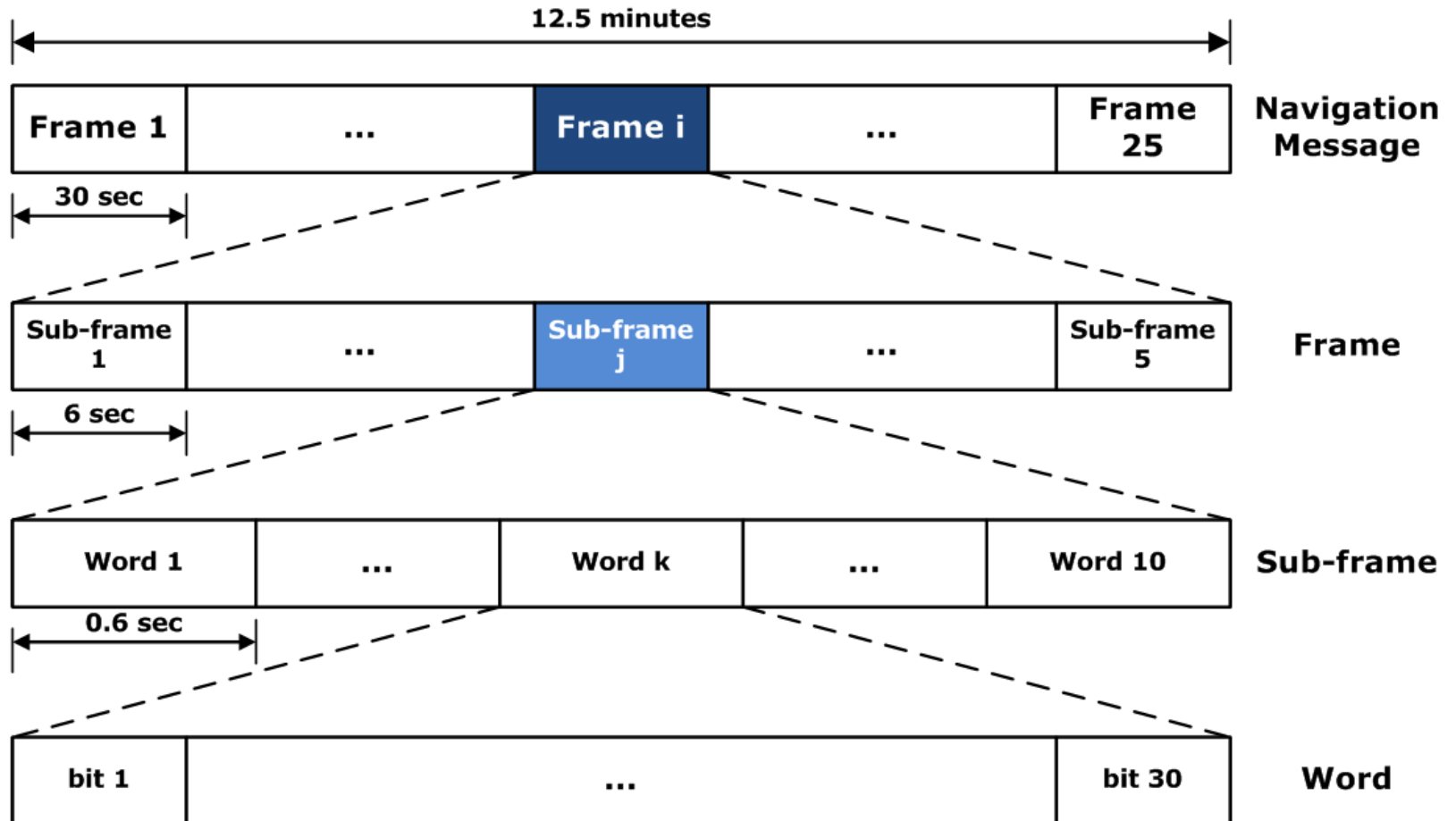
► save IP IP

Navigation Message

Band	System	Signal	Nav. Type	Rate	Error Detection / Correction	Preamble bits	Secondary Code
L1	GPS/QZS	L1C-A	LNAV	50 bps, 300 bits, 6 sec.	Hamming Code	8bit	-
		L1C-B	CNAV-2	100 bps, 1800 bits, 18 sec.	BCH+LDPC+Interleaving	None	1800 bits
	GALILEO	E1	I/NAV	125 bps, 250 bits, 2 sec.	½Convolution+Interleaving+CRC	10bit	25 bits (E1C)
	GLONASS	G1	NAV	50 bps, 100 bits, 2 sec.	Hamming Code	30bit	-
	BeiDou (MEO)	B1I	D1 NAV	50 bps, 300 bits, 6 sec.	BCH+Interleaving	11 bit	NH20
	BeiDou (GEO)	B1I	D2 NAV	500 bps, 300 bits, 0.6 sec.	BCH+Interleaving	11 bit	-
	SBAS	L1	SBAS	250 bps, 250 bits, 1 sec.	½Convolution	(8x3) bit Encoded	-
L2	GPS/QZS	L2C	CNAV	25 bps, 300 bits, 12 sec.	½Convolution	8bit	-
	GLONASS	G2	NAV	50 bps, 100 bits, 2 sec.	Hamming Code	30bit	-
L5	GPS/QZS	L5	CNAV	50 bps, 300 bits, 6 sec.	½Convolution	8bit	NH10 (L5I), NH20 (L5Q)
	GALILEO	E5a	F/NAV	25 bps, 250 bits, 10 sec.	½Convolution+Interleaving+CRC	10bit	20 bits (E5aI) 100 bits (E5aQ)
	GALILEO	E5b	I/NAV	125 bps, 250 bits, 2 sec.	½Convolution+Interleaving+CRC	10bit	4 bits (E5bI) 100 bits (E5aQ)
	BeiDou (MEO)	B1I	D1 NAV	50 bps, 300 bits, 6 sec.	BCH+Interleaving	11 bit	NH20
	BeiDou (GEO)	B1I	D2 NAV	500 bps, 300 bits, 0.6 sec.	BCH+Interleaving	11 bit	-

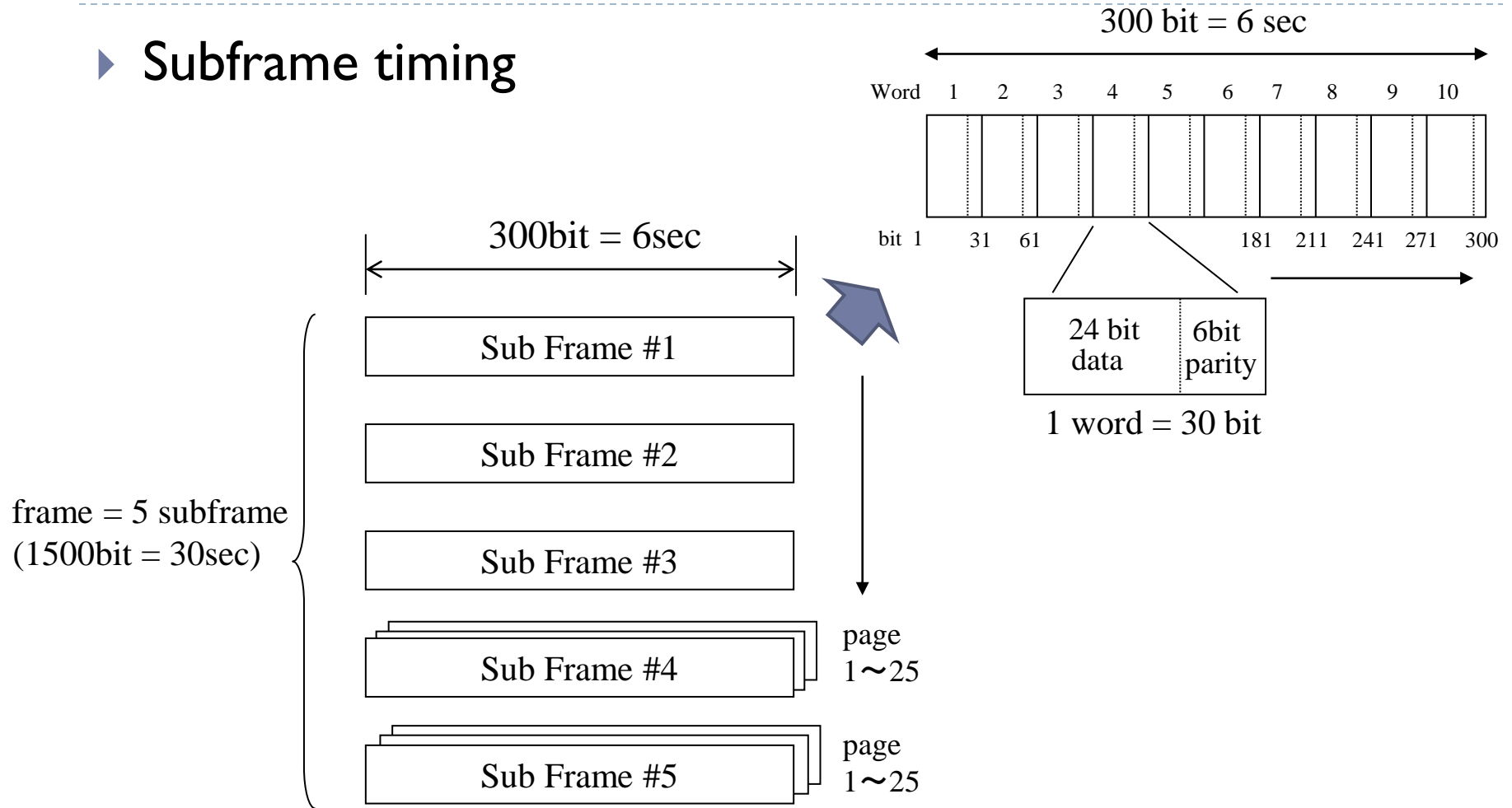
GPS L1 Navigation Message (1)

► LNAV structure



GPS L1 Navigation Message (2)

► Subframe timing

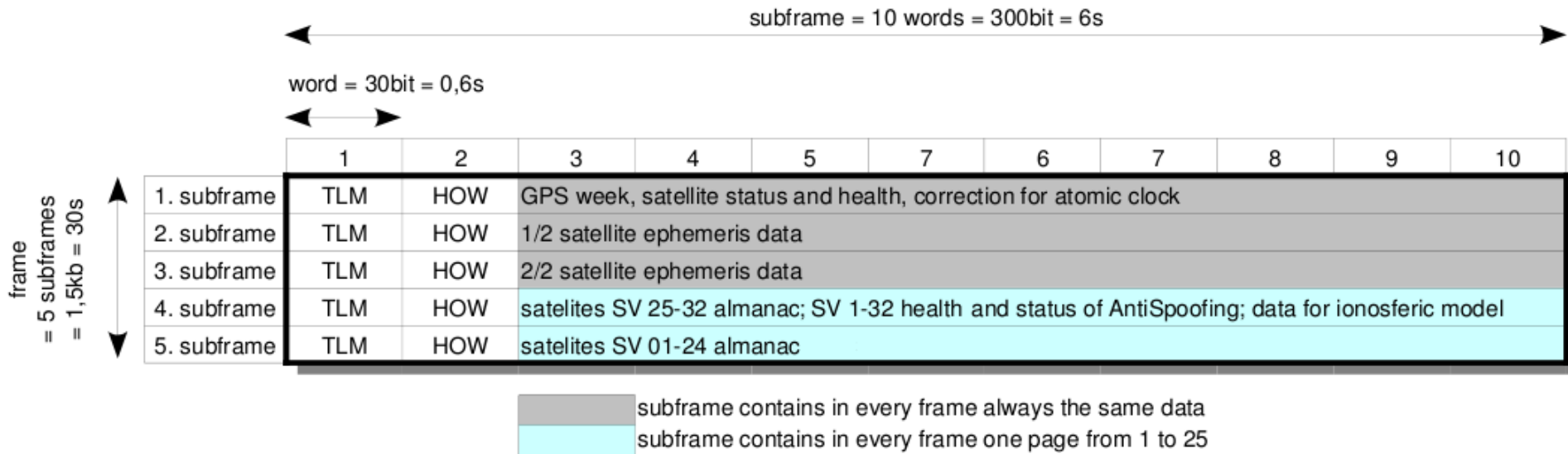


GPS L1 Navigation Message (3)

► LNAV structure

Navigation message

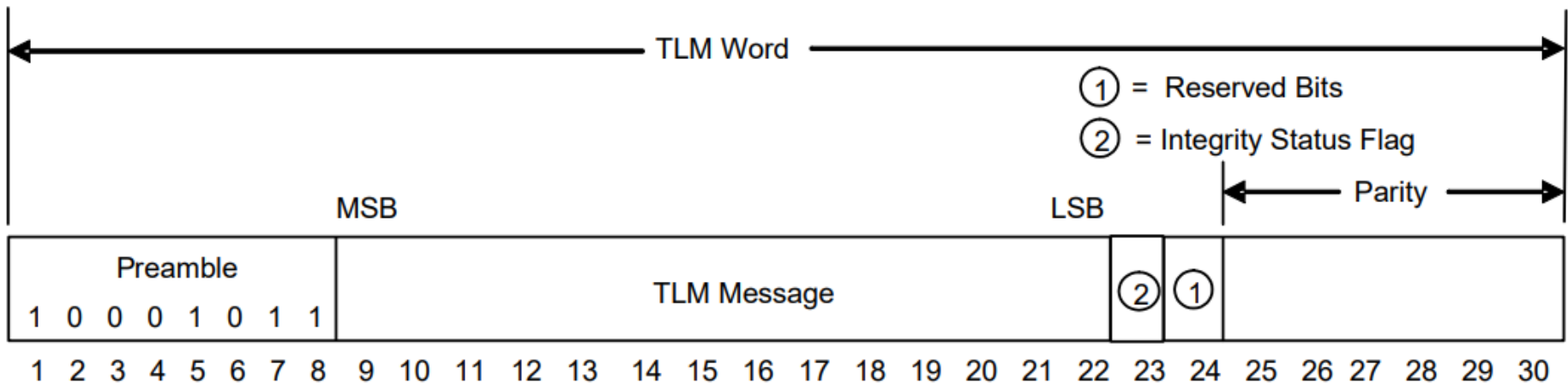
Navigation message = 25 frames = 125 subframes = 1250 words = 37,5kb = 12,5min



TLM

▶ TLM: Telemetry Word

- ▶ 30 bits (8 bit **preamble**, 16 bit **data**, 6bit **parity**)

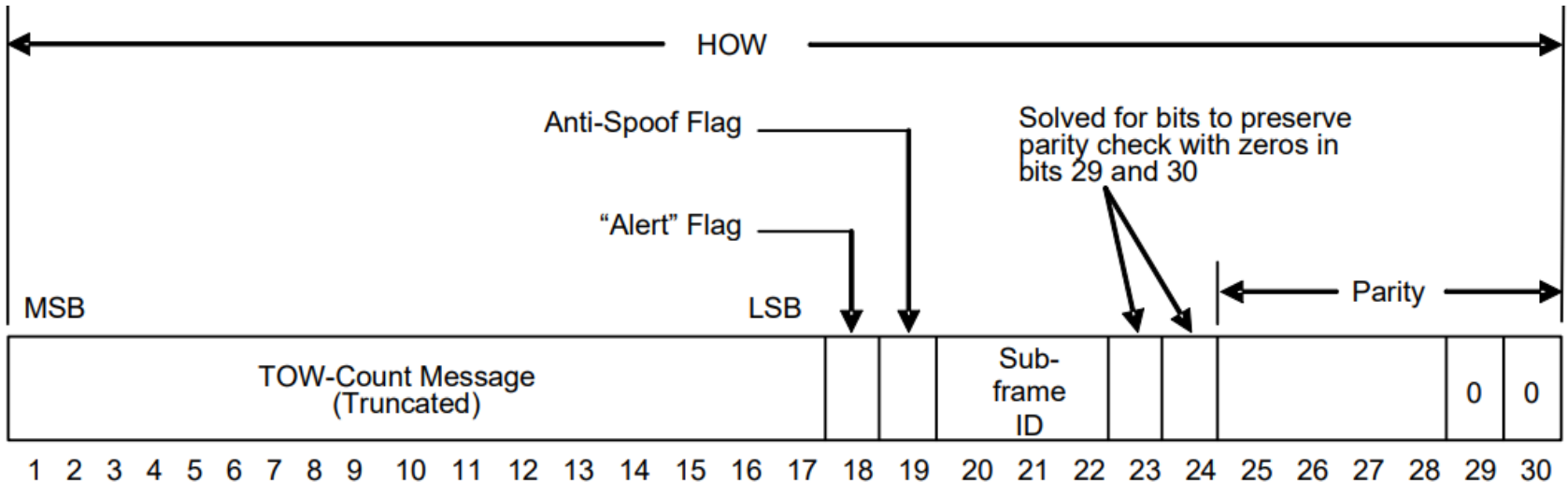


- ▶ Preamble is used to find the beginning of a subframe and to synchronize the navigation bits

HOW

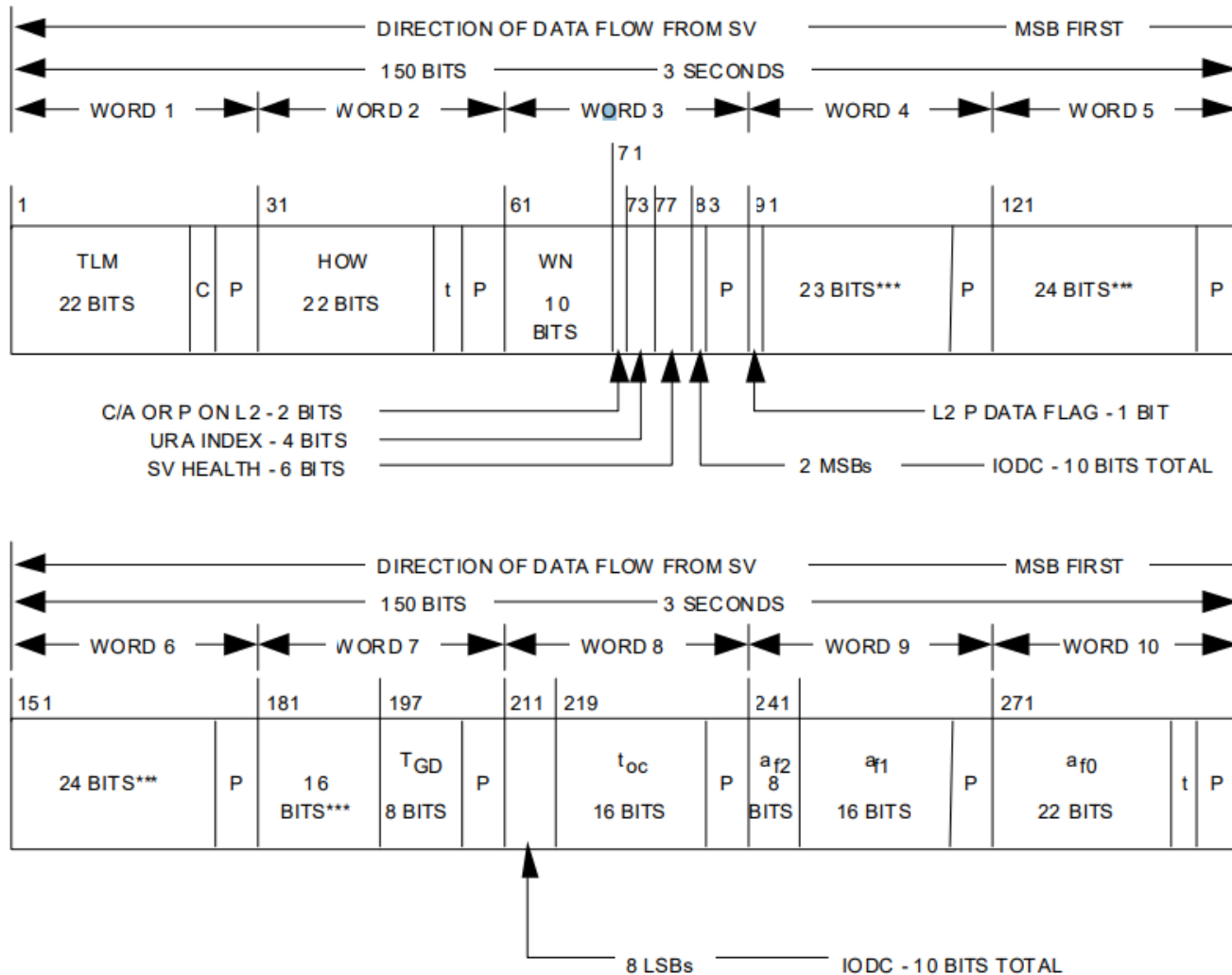
▶ HOW: Hand Over Word

- ▶ 30 bits (17 bit **time of week**, 7 bit data, 6bit **parity**)

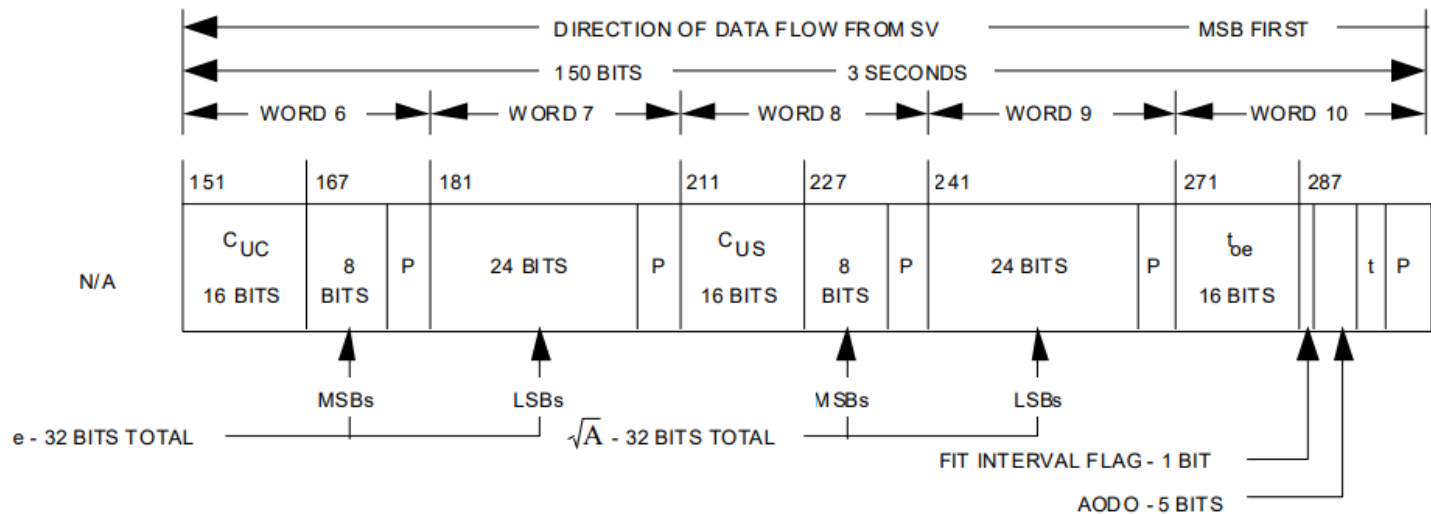
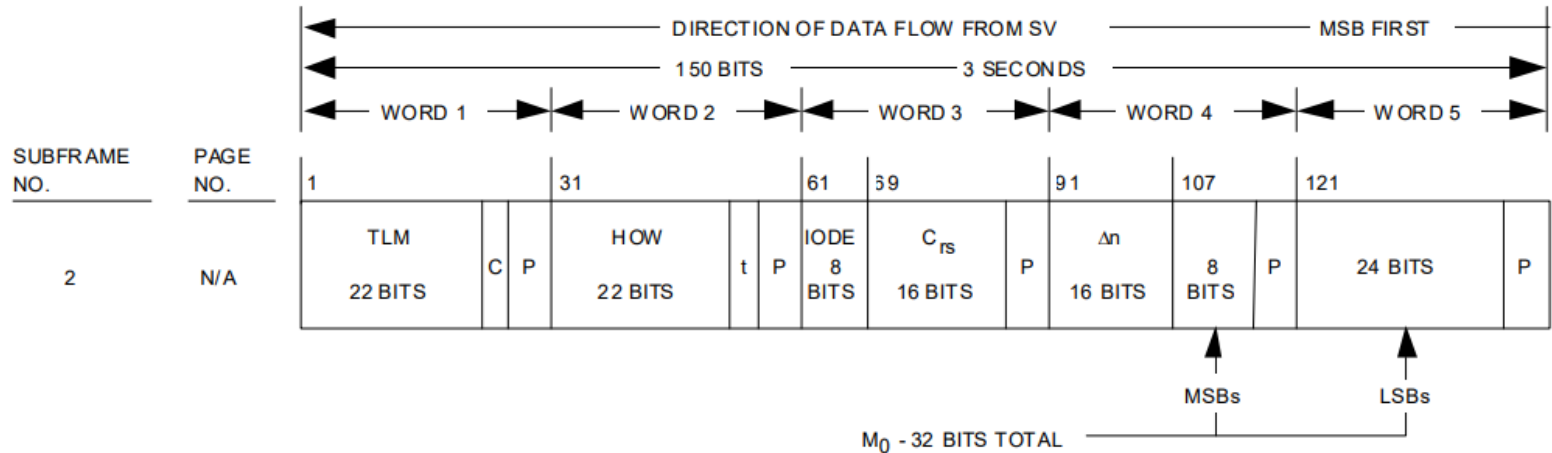


- ▶ TOW-count is time information
- ▶ Sub-frame id is used to check following subframe number

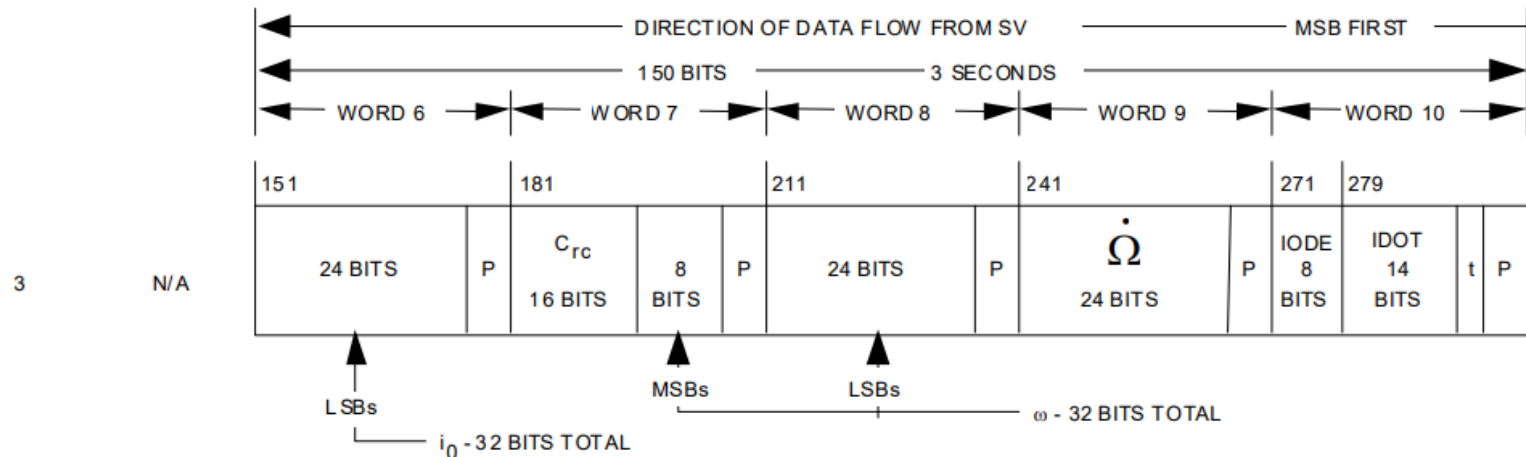
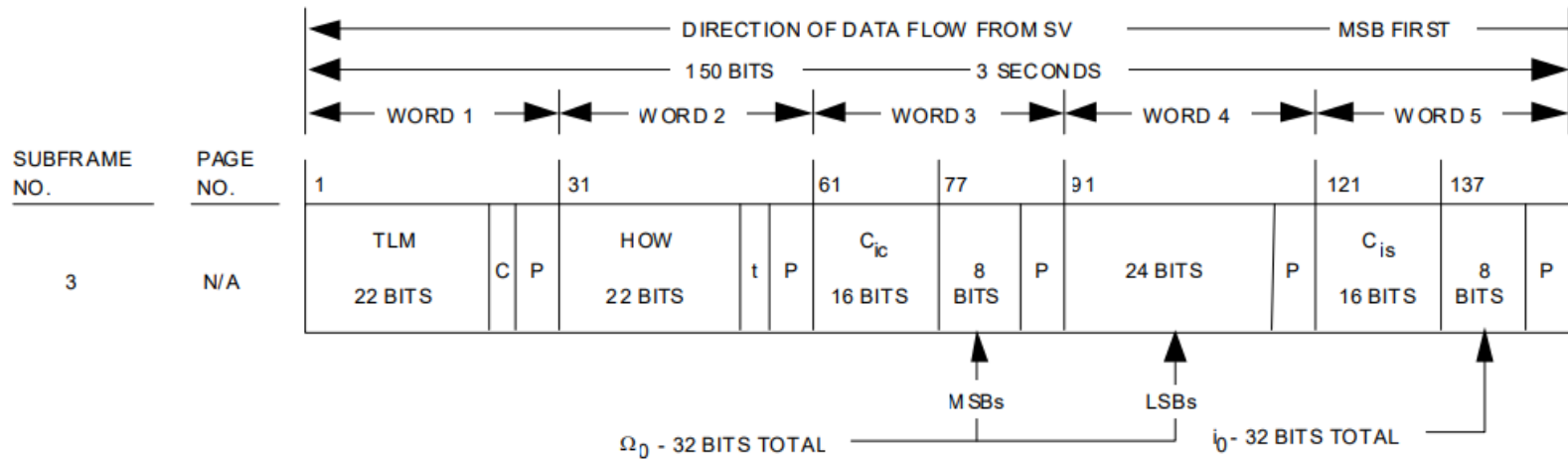
Subframe 1



Subframe 2



Subframe 3



Flow of Decoding Navigation Message

- ▶ Input: In-phase correlation outputs
- ▶ Find preambles
- ▶ Determine 20ms navigation bits
- ▶ Decoding TOW counts and Subframe ID from HOW
 - ▶ Parity check
- ▶ Determine subframe bits (300 bits / 6 second)
 - ▶ Decoding and parity check in each word
- ▶ If subframe 1 to 3 can be decoded, decoding of the navigation messages required for positioning is complete

Preamble Detection

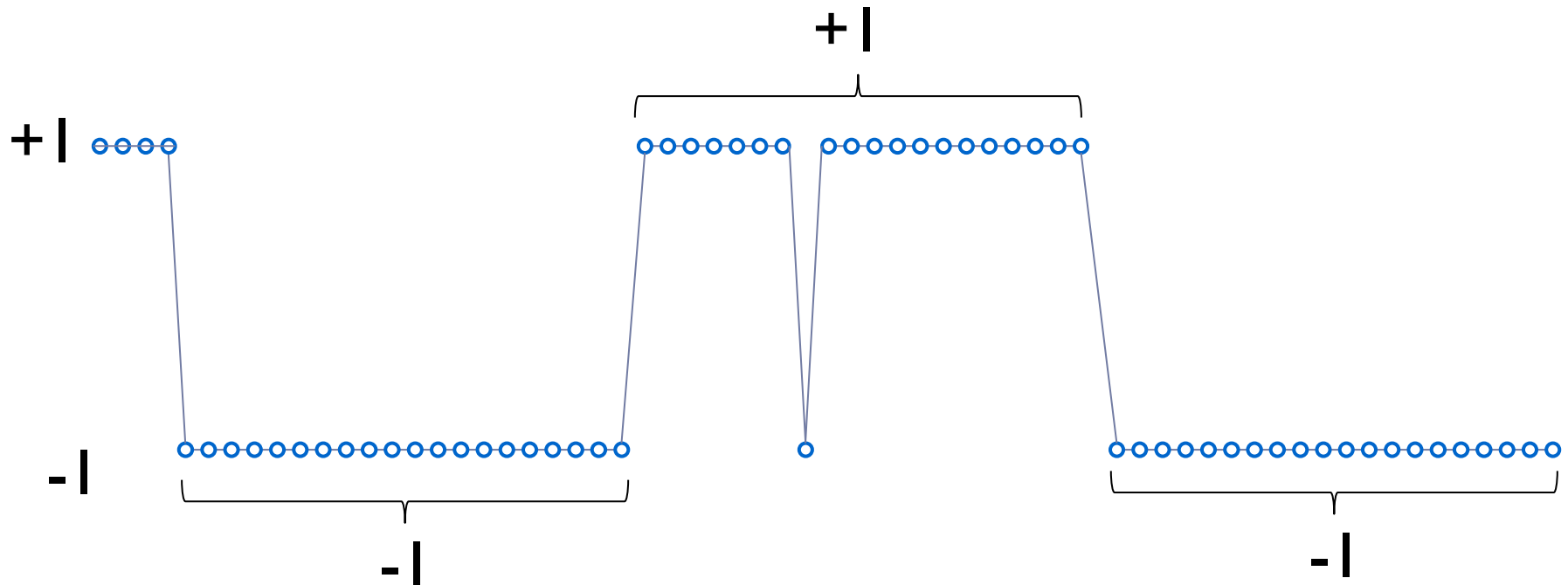
- ▶ At first, In-phase correlation output is 1 ms
- ▶ Navigation bit is 20 ms
- ▶ Upsampling the preamble to 1 ms and compute cross-correlation to find the beginning of the subframe



- ▶ From multiple candidate subframe headings, determine the correct subframe head based on the spacing of the correlation points (a peak should appear every 300 bits per subframe)

Navigation Bits Determination

- ▶ Navigation bits determined by majority vote of 20 (20ms) In-phase correlation values

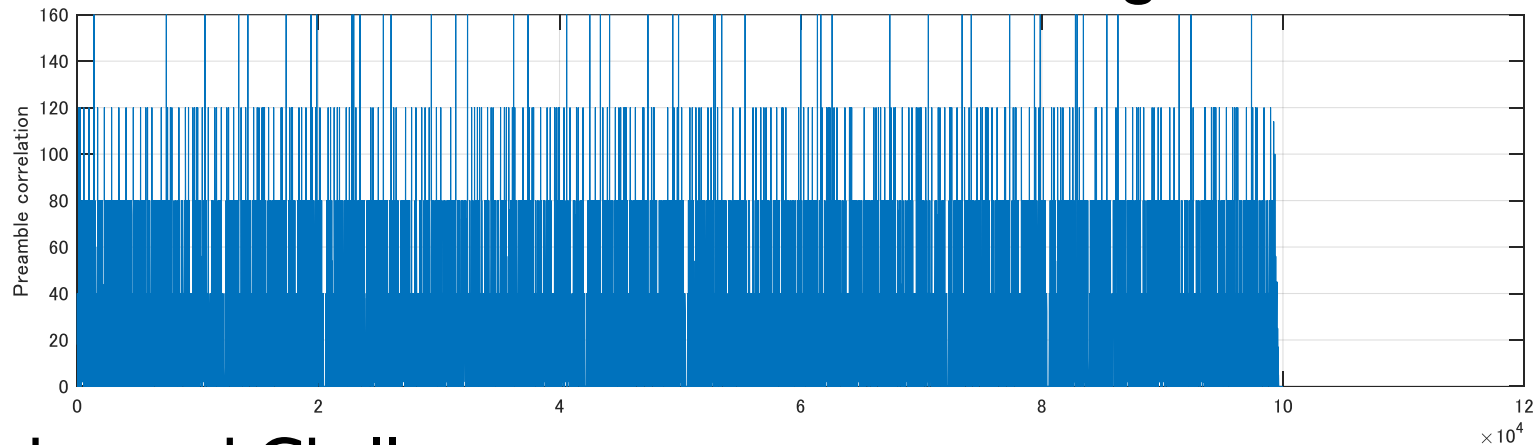


Exercise 2: Navigation Bits Determination

► MATLAB

- `/09_Navigation_Message/matlab/Ex2_run_navigationbits_determination1.m`

- Find the preamble from the output of the in-phase correlation values and determination navigation bits

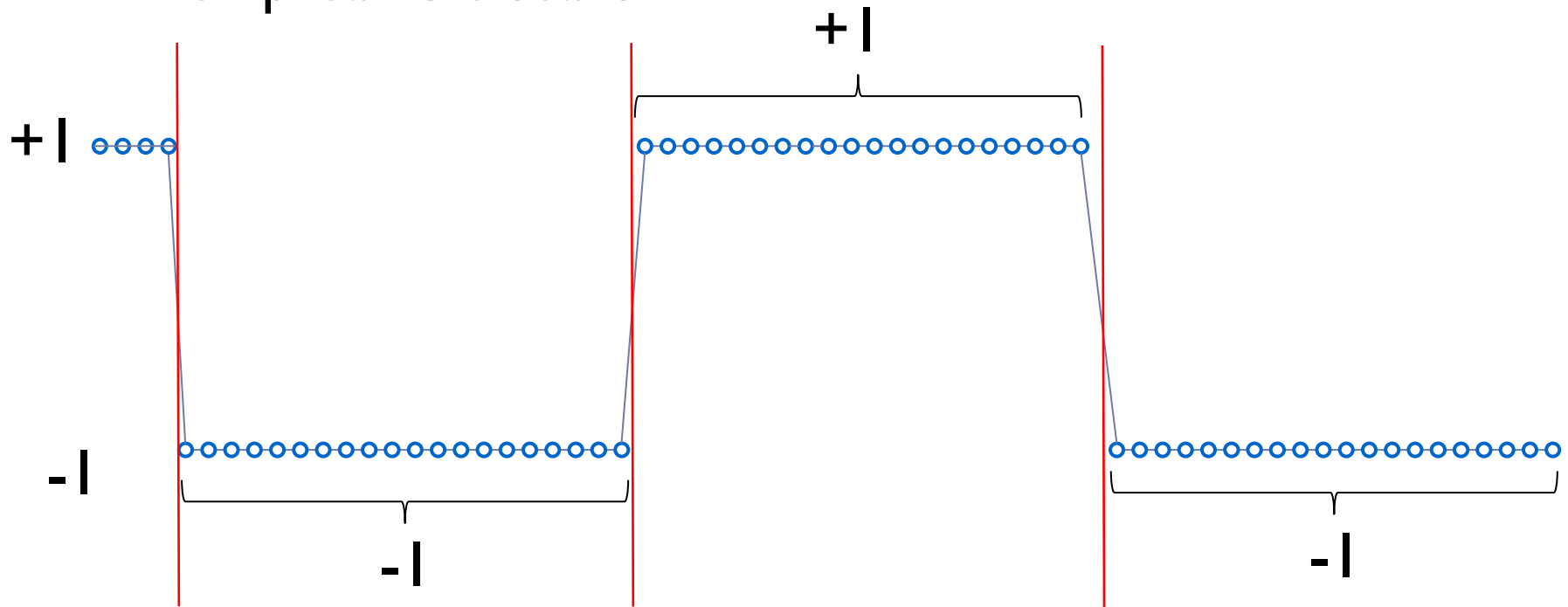


► Advanced Challenge:

- Find the index of the first preamble automatically

Bit synchronization + Preamble Detection

- ▶ First determine the 20 ms navigation bits from the timing of bit switching
- ▶ Then preamble search

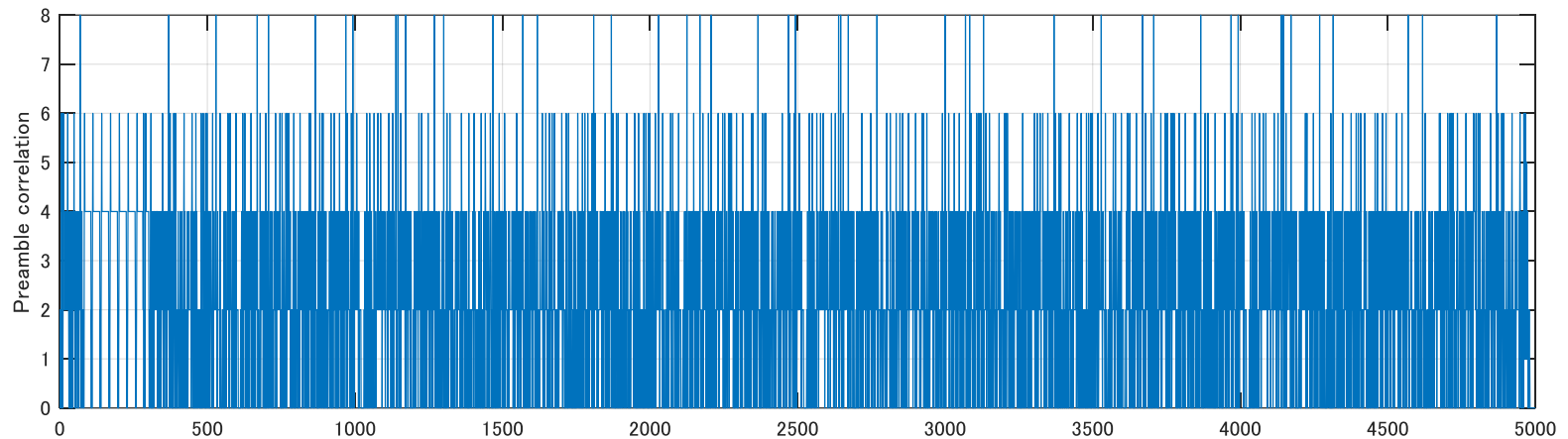


Exercise 3: Navigation Bits Determination

► MATLAB

► /09_Navigation_Message/matlab/**Ex3_run_navigationbits_determination2.m**

► Bit synchronization then Preamble Detection



Parity Check

► Hamming code

- (32,26) Hamming Code
- Error correction capability is available, but is used for error detection

$$\begin{aligned}
 D1 &= d1 \oplus D_{30}^* \\
 D2 &= d2 \oplus D_{30}^* \\
 D3 &= d3 \oplus D_{30}^* \\
 &\vdots \\
 &\vdots \\
 &\vdots \\
 D24 &= d24 \oplus D_{30}^*
 \end{aligned}$$

Last 2 bits of one previous word

Parity bits

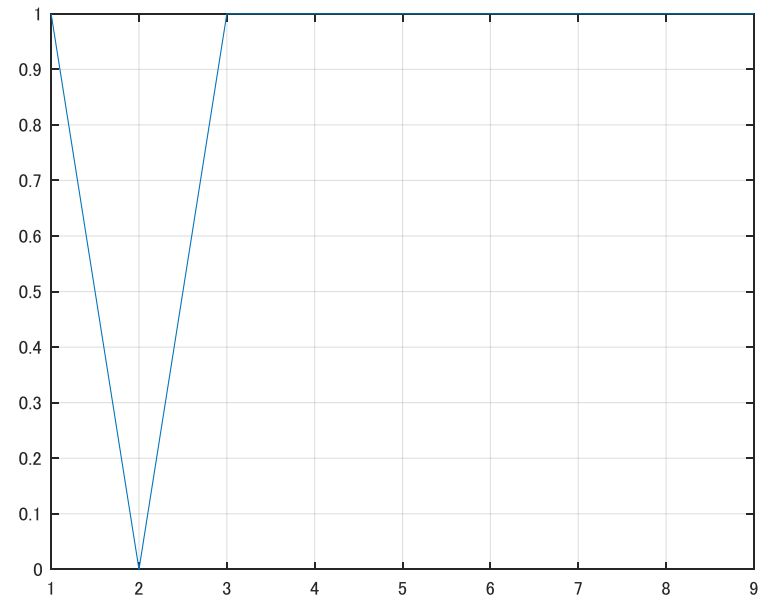
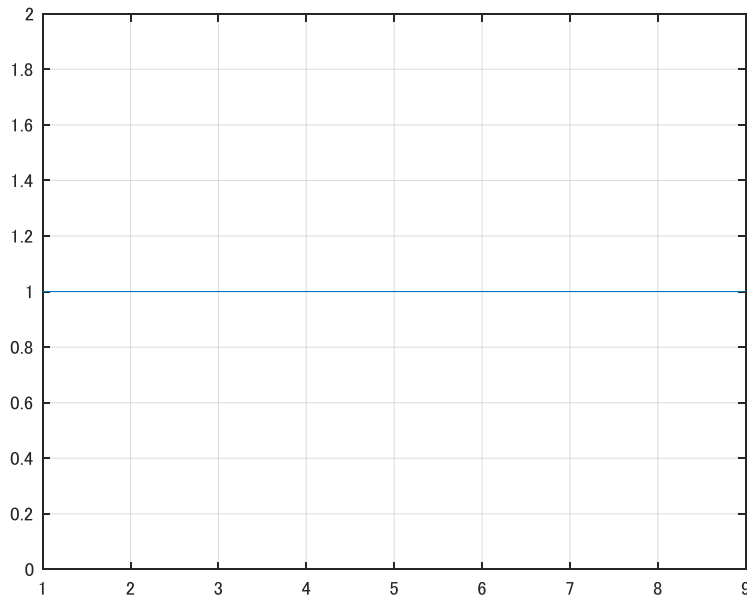
$$\begin{aligned}
 D25 &= D_{29}^* \oplus d1 \oplus d2 \oplus d3 \oplus d5 \oplus d6 \oplus d10 \oplus d11 \oplus d12 \oplus d13 \oplus d14 \oplus d17 \oplus d18 \oplus d20 \oplus d23 \\
 D26 &= D_{30}^* \oplus d2 \oplus d3 \oplus d4 \oplus d6 \oplus d7 \oplus d11 \oplus d12 \oplus d13 \oplus d14 \oplus d15 \oplus d18 \oplus d19 \oplus d21 \oplus d24 \\
 D27 &= D_{29}^* \oplus d1 \oplus d3 \oplus d4 \oplus d5 \oplus d7 \oplus d8 \oplus d12 \oplus d13 \oplus d14 \oplus d15 \oplus d16 \oplus d19 \oplus d20 \oplus d22 \\
 D28 &= D_{30}^* \oplus d2 \oplus d4 \oplus d5 \oplus d6 \oplus d8 \oplus d9 \oplus d13 \oplus d14 \oplus d15 \oplus d16 \oplus d17 \oplus d20 \oplus d21 \oplus d23 \\
 D29 &= D_{30}^* \oplus d1 \oplus d3 \oplus d5 \oplus d6 \oplus d7 \oplus d9 \oplus d10 \oplus d14 \oplus d15 \oplus d16 \oplus d17 \oplus d18 \oplus d21 \oplus d22 \oplus d24 \\
 D30 &= D_{29}^* \oplus d3 \oplus d5 \oplus d6 \oplus d8 \oplus d9 \oplus d10 \oplus d11 \oplus d13 \oplus d15 \oplus d19 \oplus d22 \oplus d23 \oplus d24
 \end{aligned}$$

Exercise 4: Parity Check

► MATLAB

► /09_Navigation_Message/matlab/**Ex4_run_check_parity.m**

► Check parity in the words

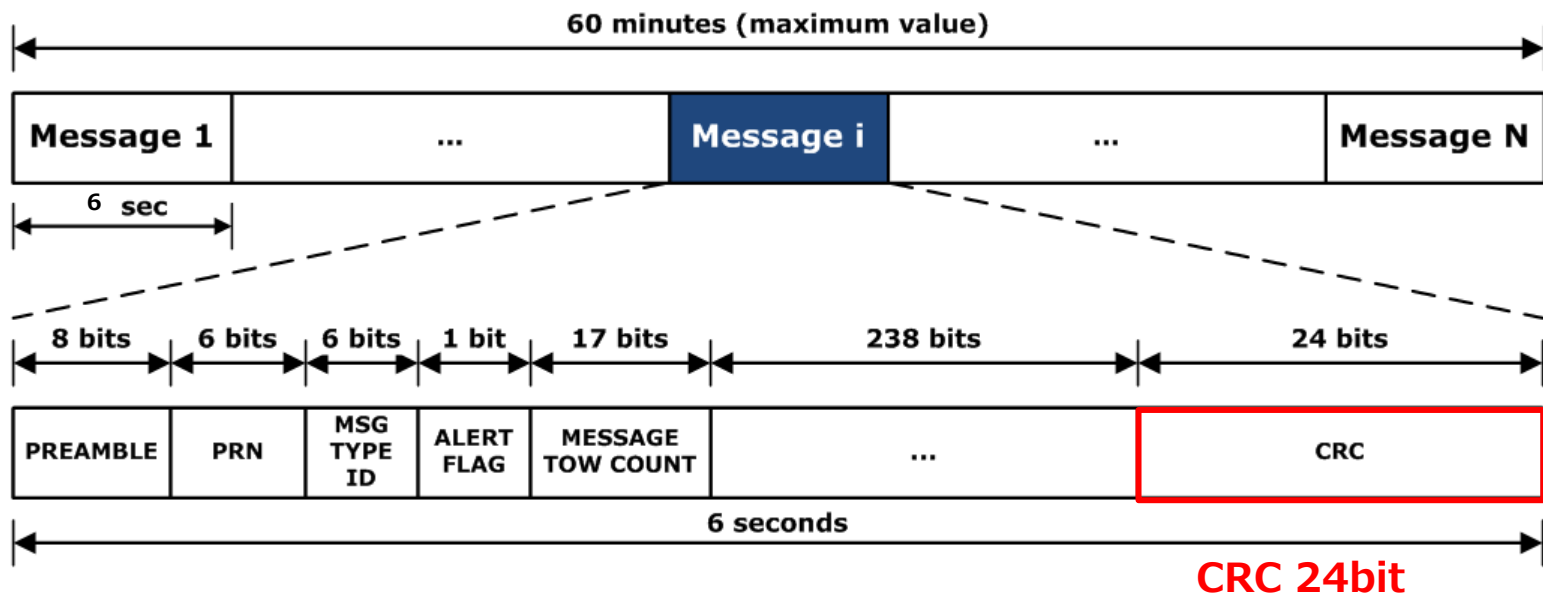


Forward Error Correction

- ▶ New signals add more advanced navigation message error correction techniques
 - ▶ GPS L2C/L5: **CNAV**
 - ▶ $\frac{1}{2}$ Convolutional code
 - ▶ Galileo L1/L5: **INAV, FNAV**
 - ▶ $\frac{1}{2}$ Convolution+Interleaving+CRC
 - ▶ GPS L1C: **CNAV2**
 - ▶ BCH+**LDPC**+Interleaving
- ▶ Improved availability of positioning in urban and forest environments

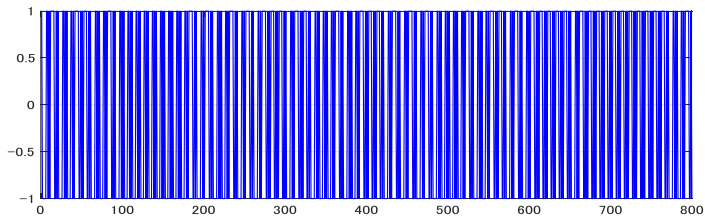
L5 (CNAV)

- ▶ Ephemeris
 - ▶ Message (10,11,30-37)
- ▶ 1 Message = 6 second
- ▶ 1/2 Convolution code
 - ▶ Viterbi decoder
- ▶ Error detection
 - ▶ CRC in a message

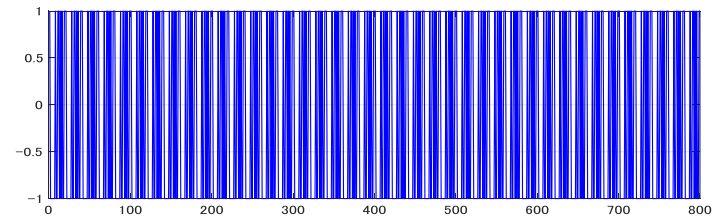


L5 (CNAV)

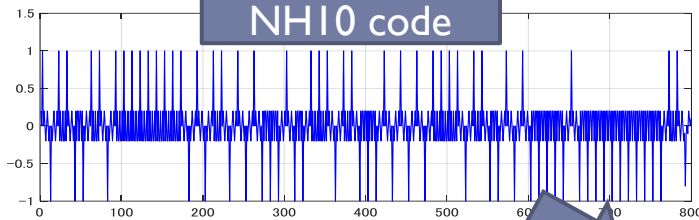
L5I



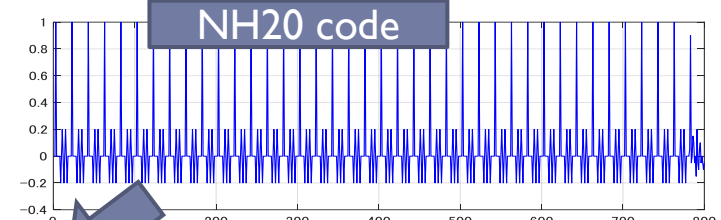
L5Q



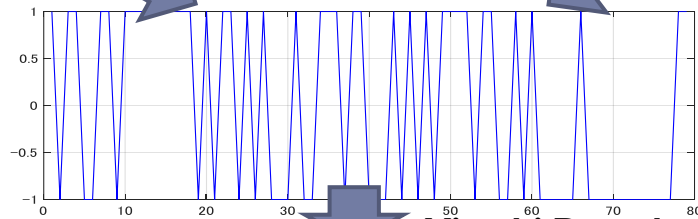
NH10 code



NH20 code

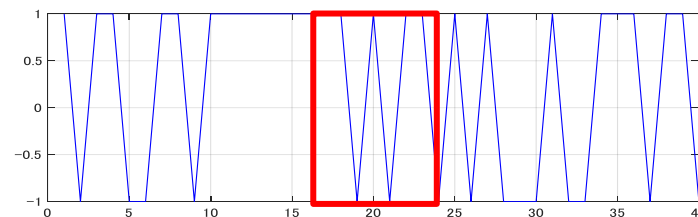


Navigation bits
100 bps



Viterbi Decoder

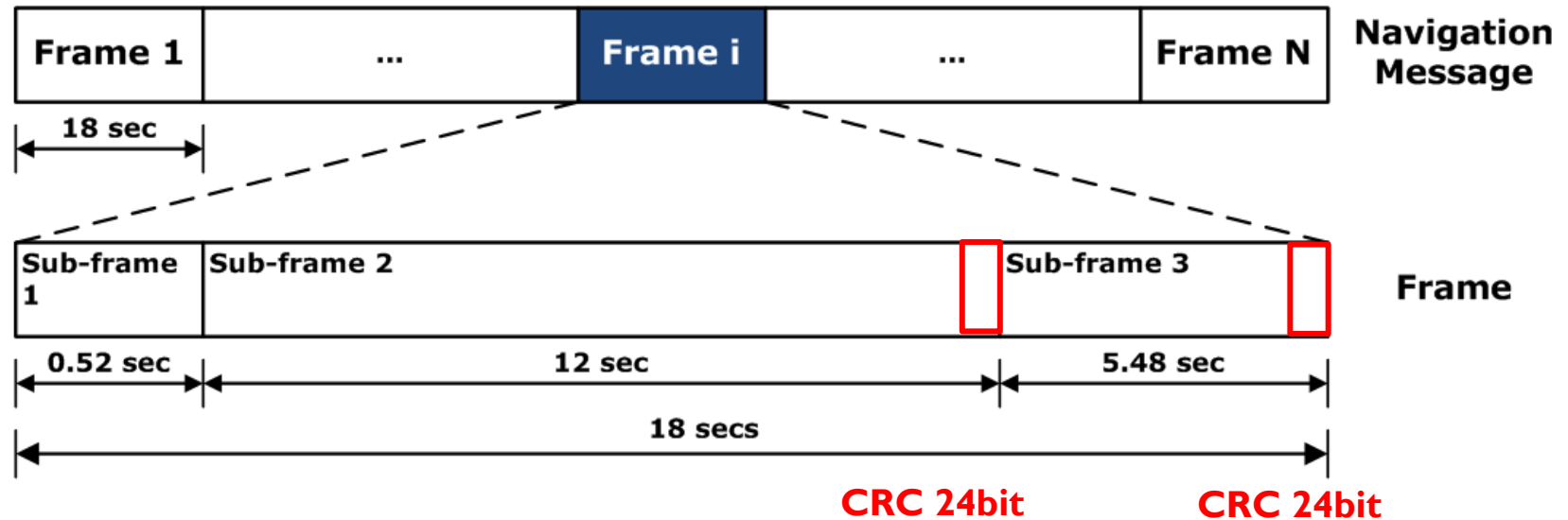
Navigation bits
50bps



Preamble search

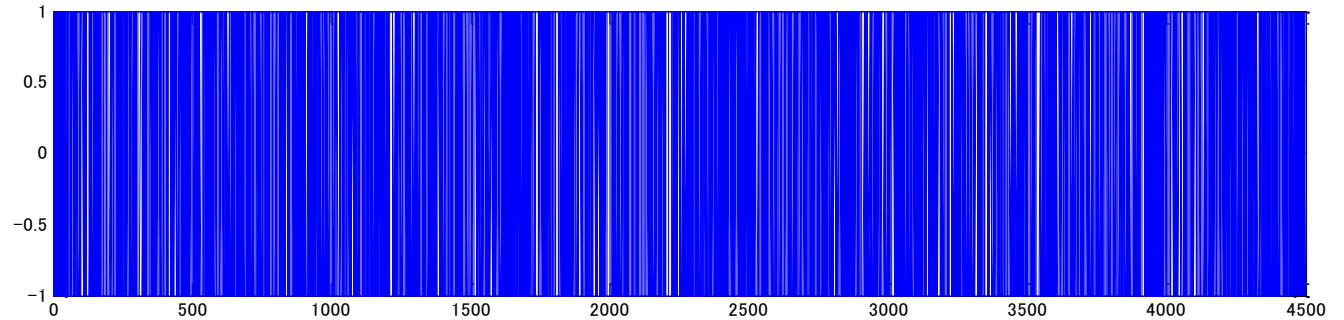
L1C (CNAV2)

- ▶ 10 ms code
- ▶ Ephemeris
 - ▶ Frame (1,2,3)
- ▶ 1 Frame = 18 second
- ▶ LDPC + interleave
 - ▶ LDPC decoding
- ▶ Subframe contains CRC

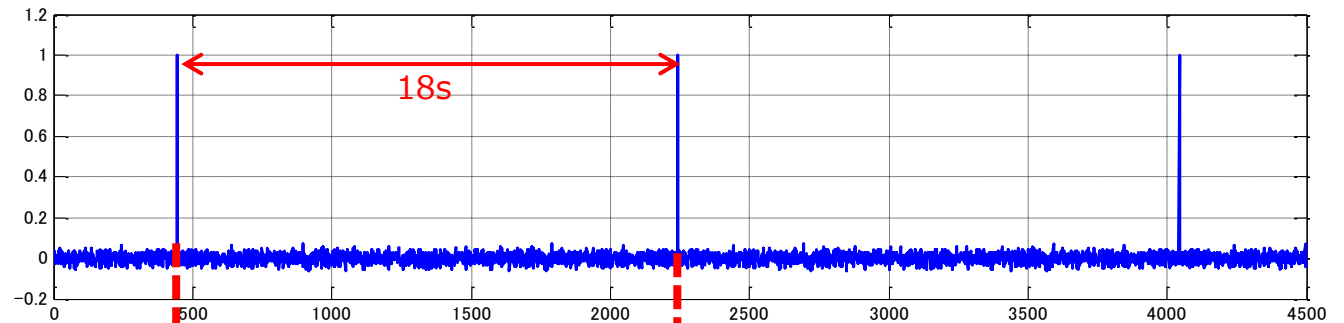


L1C (CNAV2)

LICP



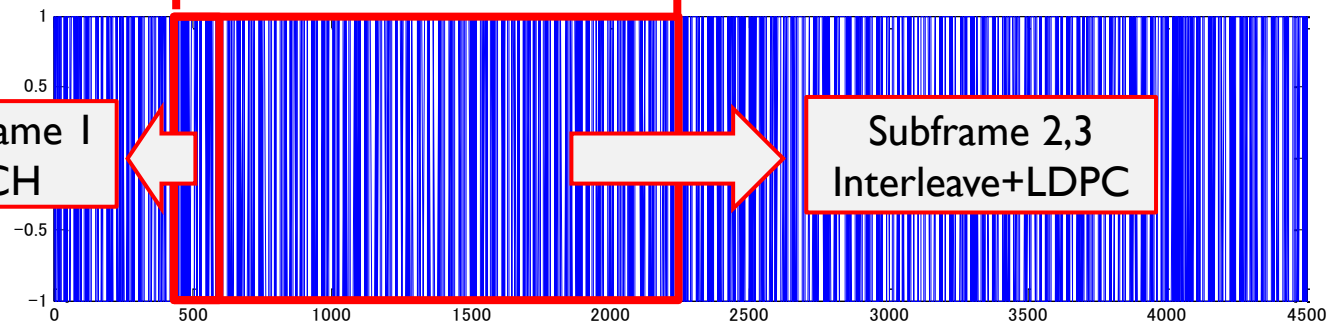
Correlation
between LICP
and LICO



LICD

Subframe 1
BCH

Subframe 2,3
Interleave+LDPC



Exercise 5: Decode TOW

► MATLAB

- /09_Navigation_Message/matlab/**Ex5_run_decode_tow.m**
- Confirmation by comparison with RF data acquisition time

epoch =

13	57	54
13	58	0
13	58	6
13	58	12
13	58	18
13	58	24
13	58	30
13	58	36
13	58	42
13	58	48
13	58	54
13	59	0
13	59	6
13	59	12
13	59	18
13	59	24

Exercise 6: Decode Navigation Data

► MATLAB

► /09_Navigation_Message/matlab/ **Ex6_run_decode_nav.m**

```
function eph = ephstruct()
```

```
eph.update = 0;  
eph.counter = 0;
```

```
%% SF1
```

```
eph.week = 0;  
eph.code = 0;  
eph.sva = 0;  
eph.svh = 0;  
eph.iodc = 0;  
eph.flag = 0;  
eph.tgd = [0 0 0 0];  
eph.f2 = 0;  
eph.f1 = 0;  
eph.f0 = 0;
```

```
eph.ttr = [0 0 0 0 0 0];  
eph.toc = [0 0 0 0 0 0];  
eph.toe = [0 0 0 0 0 0];
```

```
%% SF2
```

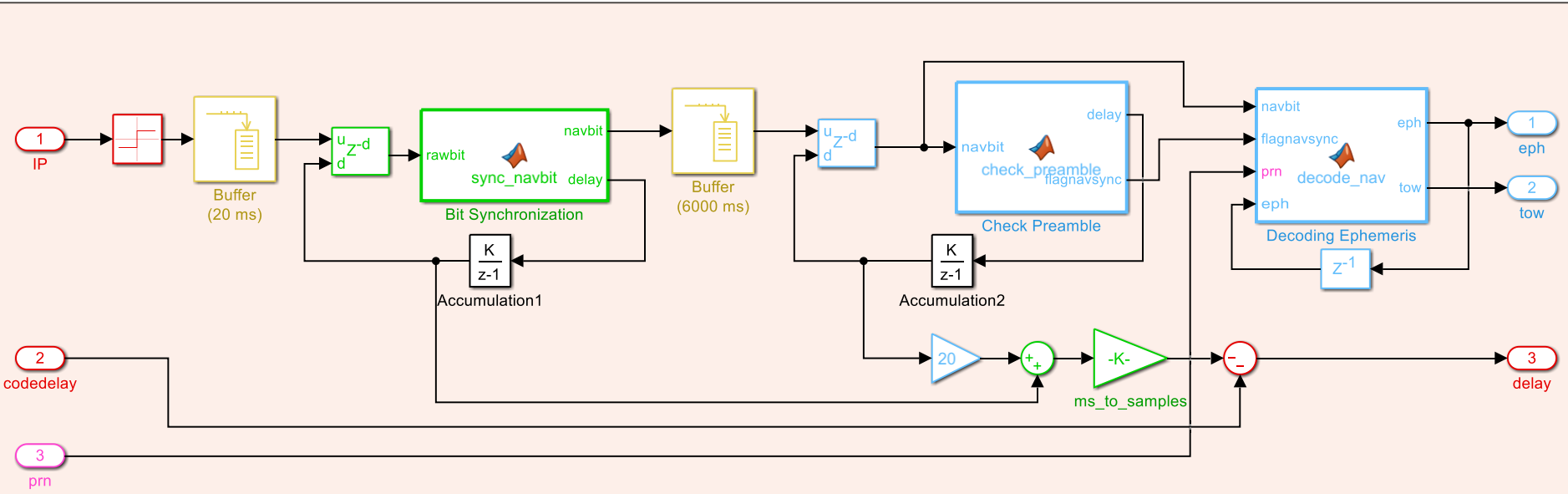
```
eph.iode = 0;  
eph.crs = 0;  
eph.deln = 0;  
eph.M0 = 0;  
eph.cuc = 0;  
eph.e = 0;  
eph.cus = 0;  
eph.A = 0;  
eph.toes = 0;  
eph.fit = 0;
```

```
%% SF3
```

```
eph.cic = 0;  
eph.OMG0 = 0;  
eph.cis = 0;  
eph.i0 = 0;  
eph.crc = 0;  
eph.omg = 0;  
eph.OMGd = 0;  
eph.iode = 0;  
eph.idot = 0;
```

▶ Decode Navigation Messages

Decoding



Exercise 7: Decode Navigation Data

► Simulink

► /09_Navigation_Message/simulink/Ex7/navigation_1ch.slx

