Metropolitan Beacon System (MBS) ICD

Version G1.0

(An Implementation of a Terrestrial Beacon System)

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1 Introduction

This document describes the air interface of the Metropolitan Beacon System (MBS) system, an instantiation of Terrestrial Beacon Systems. Generally, Terrestrial Beacon Systems (TBS) consist of a network of ground-based beacons broadcasting signals for positioning purposes. As a subset of TBS, MBS is designed to facilitate three dimensional UE positioning in areas where in-orbit satellite based systems are most challenged, such as indoors, or in dense urban environments and extends UE positioning capabilities in these environments.

2 MBS System Features

MBS provides a high precision, reliable, consistent positioning system indoors and in urban canyons, where GNSS solutions are degraded or denied.

In addition to the high 2-D accuracy, the MBS system architecture also provides for high resolution and accuracy in the vertical dimension, with the aid of embedded sensors.

MBS technology provides a very fast time to first fix (TTFF), on the order of ~6 seconds under cold start conditions.

Similar to GNSS, MBS technology allows computation of the location on the device without any network dependence thus enabling a wide variety of standalone applications.

3 High Level Architecture

The high level system architecture is shown in Figure 1.

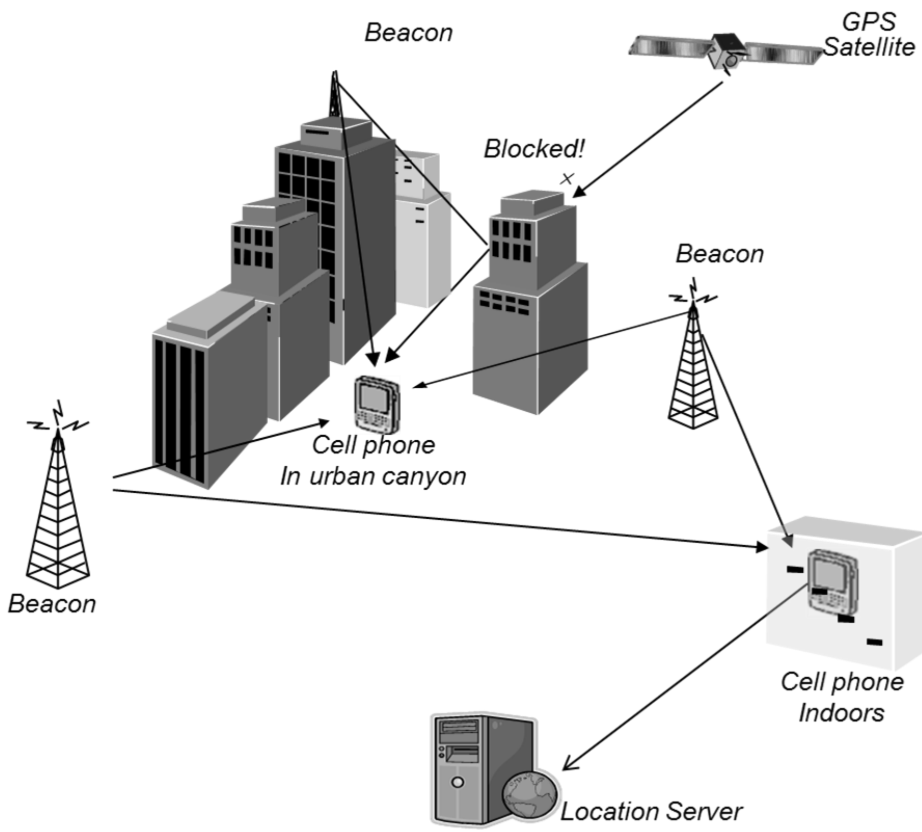


Figure 1: MBS System Architecture

MBS beacons are an overlay network used to cover a metropolitan area. Various components in Figure 1 are described below:

Beacon: The beacons in this figure denote the MBS beacons broadcasting the MBS signal. The beacons may be housed on roof tops or towers (typically pre-existing cell/broadcast sites), or in any other location deemed appropriate by the operator of the MBS network.

Cell Phone: An example device that needs location information is shown as a cell phone under GNSS-challenged conditions such as urban canyons and indoors where GNSS signals from satellites may not be received reliably or may provide poor performance. The cell phones shown in the figure would be capable of receiving and processing MBS signals. Note that any device equipped to process MBS signals would work under these scenarios. A data or a voice connection is NOT required for a device to compute its location using the MBS technology.

Location Server: In certain applications, it may be useful for a centralized server to compute the location with information it receives from the mobile because of the additional information that may be available to the server device at the time of location determination.

GPS Satellite: Shown for illustrative purposes that it is blocked by buildings in an urban canyon.

4 MBS Signal Structure

4.1 MBS Signal Generation

The MBS signal shall be generated from a PN sequence and BPSK spreading. The chipping rate shall be $1.023\ m/2$ Mchips/sec, where *m* is an integer greater than or equal to 2, and the length of the PN sequence shall be $1024\ n - 1$, where *n* is an integer greater than or equal to 1.

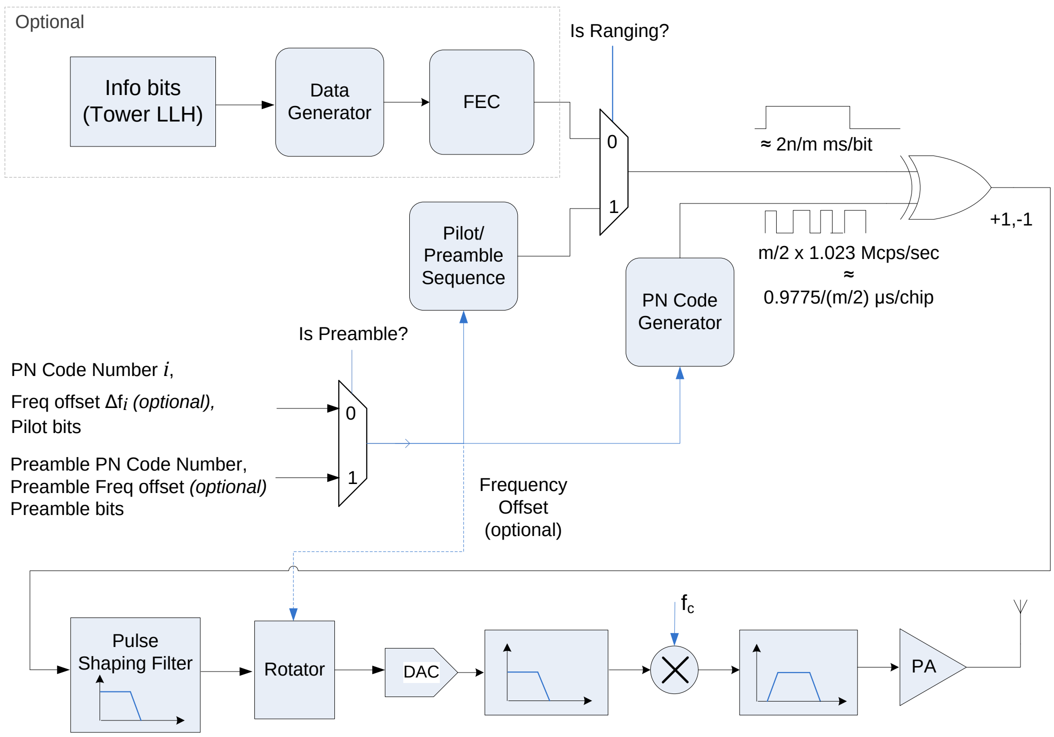


Figure 2: MBS Signal Generation

The various blocks in the Signal Generator are described below:

1 **PN Code Generator:** Generates binary waveforms of length $1024\ n - 1$. The PN code generator generates chips at the rate of $1.023\ m/2$ Mchips/sec (period of each chip is $1/1.023/(m/2)$ µs).

2 **Data Generator (Optional):** Collects information from sensors and other information such as tower Latitude, Longitude, Height (LLH) and other information and formats them into frames and sub-frames.

3 **FEC:** Adds forward error correction. See Figure 10 for optional block diagram.

4 **Pilot/(Optional)Preamble Sequence:** During some periods MBS beacons transmit a known sequence of bits. During ranging periods, they transmit pilot bits, which enable long coherent integration to improve ranging performance. During the optional preamble, they transmit the preamble bits, which help with acquisition.

A timing view of the bitstream that is being sent at the output of the XOR gate in Figure 2 is shown below:

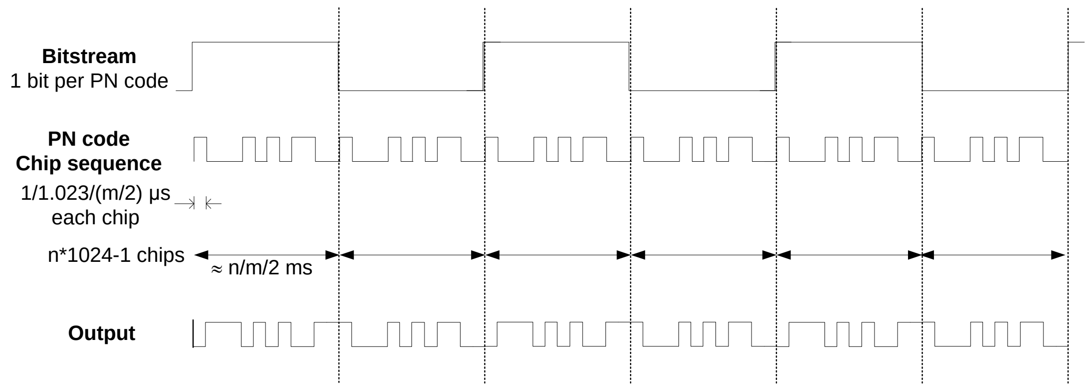


Figure 3: Timing View of XOR'd bitstream

4.2 MBS Signal Spectral Characteristics

The transmit spectrum shall have the following characteristics:

Parameter	**Value**
Tx transmission type	Spread spectrum transmission using BPSK spreading
RF BW (null-to-null)	$1.023\ m$ MHz, where m = 2,3,4,…

The MBS signal transmission may be in any of the bands described in Section 7.

4.3 MBS Signal Temporal Characteristics

The MBS architecture shall use an access scheme where each beacon transmits its bitstream for a specified duration within each transmission period.

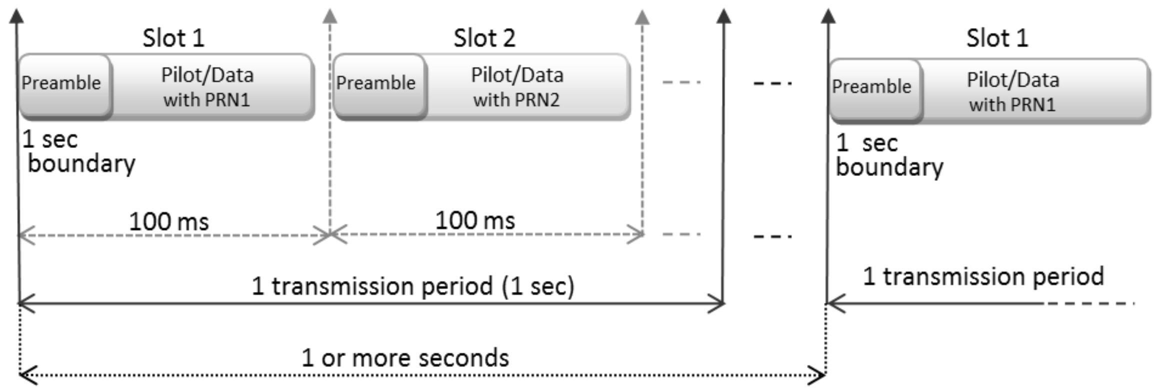


Figure 4: Optional Slotted MBS Mode

System parameters:

- Each transmission period shall be 1sec long
  - Transmission periods shall be Δ_T seconds apart, where Δ_T shall be an integer greater than or equal to 1
- There shall be ten 100ms slots in each transmission period
- The MBS signal shall be generated from a PRN sequence and BPSK spreading
- Each transmitter shall be assigned
  - One of the ten slots as its primary slot
  - One PRN code
- Additional optional transmitter parameters include
  - A primary slot pattern
    - This is a sequence of slot indexes (each one in the range 1 to 10), that determine which slot the transmitter will transmit in successive seconds of transmission.
    - The sequence may be as basic as a simple repetition of the primary slot, or may be any sequence of slot indexes, with each transmitter potentially having a different periodicity in their slot pattern.
  - Secondary slot patterns
    - Each beacon may have up to nine secondary slot patterns.
    - These may have the same or different PRN as the primary slot pattern of that transmitter, and will have a transmit power that should be between 0dB to 50dB lower than the transmit power of the primary slot pattern.

  - Frequency offset
    - Each beacon may be assigned a frequency offset relative to the carrier frequency, to be applied to the pilot and data sections of each transmission period.
- The chipping rate shall be $1.023\ m/2$ Mcps, where m is an integer greater than or equal to 2
- Each PN code shall have $1024\ n - 1$ chips and shall last $\frac{n+(n-1)/1023}{m/2}$ ms
  - Every 100ms slot includes $\frac{100\ m/2}{n+(n-1)/1023}$ PN code symbols
  - One PN code symbol must be used as a guard time between slots; therefore there are $\frac{100\ m/2}{n+(n-1)/1023} - 1$ PN code symbols available for ranging and data transmission in each 100ms.
  - For example, when m=2 and n=1, the system can fit 100 PN code symbols in 100ms, out of which 99 are available for ranging and data transmission.
- Each beacon optionally transmits a preamble using a PN code reserved only for preambles.
  - Optional ranging slots (described in the next section) have a preamble of length p_R PN codes (leaving $\frac{100\ m/2}{n+(n-1)/1023} - 1 - p_R$ PN codes for pilot symbols)
  - Optional hybrid slots (described in the next section) have a preamble of length p_H PN codes (leaving $\frac{100\ m/2}{n+(n-1)/1023} - 1 - p_H$ PN codes for pilot and data symbols)
  - If frequency offsets are utilized in a given MBS deployment, the preamble will have a fixed frequency offset across transmitters (it may or may not equal zero), and this will be independent of the frequency offset that the transmitters are assigned and apply to their pilot and data sections.
- A list of possible PN Codes used by MBS is shown in the Appendix.

5 Databurst Format

MBS may use the concept of databursts in order to be able to transmit all the data required for trilateration (such as latitude, longitude, etc.) in a short amount of time, and also be able to perform long coherent integrations to enable high ranging accuracy. An optional implementation would be to divide the time available to a transmitter into ranging portions and data portions. During the ranging part, transmitters transmit pilot symbols that enable long coherent integration, and during the data part, transmitters transmit data symbols at a physical-layer rate of 1 bit per PN code period. An optional slot structure, implementing the above methodology, is presented below.

5.1 Slot Structure

1. Separate slots for ranging and data
    - One slot uses BPSK pilot symbols for ranging
    - This may be followed by one or more slots that are hybrid (ranging & data slots)
2. Use error-correcting codes & CRC for the data portions

In general, an MBS deployment may have zero or more hybrid slots for each ranging slot. In scenarios where there are zero hybrid slots, receivers must obtain assistance data via another channel in order to perform trilateration.

In terms of alignment of above slot structure to GPS time, MBS physical slot 1 of the ranging frame starts at 'GPS time in seconds' modulo $(1 + N_{hybrid\_slots})$ = 0, plus 'GPS time offset' (where N_{hybrid_slots} is the number of hybrid slots for each ranging slot, and 'GPS time offset' is the offset of MBS system time relative to GPS time. GPS time offset is either transmitted over the air during the hybrid slots, or is available from assistance via another channel.)

One possible implementation, for the optional scenario of m=2,n=1, which results in 99 PN code symbols per 100ms being available for ranging and data transmission, uses the following settings:

- Slot structure consists of one ranging slot followed by two hybrid slots
    - This structure is referred to as RH1H2 and is depicted in Figure 5
- Ranging slots:
    - 7 PN codes for preamble
    - 92 PN codes for pilot symbols
- Hybrid ranging & data slots:
    - 4 PN codes for preamble
    - 14 PN codes for pilot symbols
    - 81 PN codes for data transmission using BPSK at 1 PN code/symbol

Figure 5: Optional slot structure for a given transmitter. The blocks above are 1 or more sec apart and represent 1 slot (100ms). The lengths of the preamble, pilot, and data portions in the above diagram correspond to the optional scenario where m=2,n=1 and where there are two hybrid slots for each ranging slot.

5.2 Error-correcting code and CRC check

MBS shall use error-correcting codes to ensure operation at low SNRs and uses CRC to ensure that the decoded bits are valid. The error-correcting codes and CRC polynomials chosen for MBS may vary from implementation to implementation. For an optional implementation, see the one described in Section 9.

Using the RH1H2 slot structure and optional implementation described in Section 9, MBS is able to support 102 information bits in one data packet. These information bits are used for transmitting information required for trilateration (such as Tx lat/long/altitude).

5.3 Modulation

In ranging slots, after the optional preamble, MBS shall use BPSK modulation to transmit $\frac{100\, m/2}{n+(n-1)/1023} - 1 - p_R$ pilot bits over the same number of PN code periods. These are the pilot bits that enable the long coherent integration times. The pilot bit sequence during ranging slots is described below.

In hybrid slots, after the optional preamble, there are $\frac{100\, m/2}{n+(n-1)/1023} - 1 - p_H$ PN code periods left in the slot. MBS uses BPSK modulation to transmit pilot bits over a subset of these code periods, and then uses DBPSK (differential BPSK) modulation to transmit data bits over the remaining PN code periods. The transmitter uses the last pilot bit as the first DBPSK data bit so that it can maximize the number of data bits it can transmit, even though it is using DBPSK. The pilot bit sequence is different for H1 and H2 slots.

The pilot bit sequences for ranging and hybrid slots depend on the MBS network configuration.

6 Packet Types – MAC Layer

MBS supports various packet types, such as one that carries trilateration information and one that carries GPS time information. For each packet type, MBS could support encryption of the payload, and MBS service providers may choose to encrypt or may choose not to encrypt the various packets.

6.1 Periodicity of Packet Type Transmission

The periodicity and the associated time offset of the transmission for various packet types is MBS service provider specific. The packet transmissions of a particular type may be staggered relative to other beacons.

As an example, in the beacon with Tx ID 1 occupying slot 1, one type of packet may be transmitted once in 30 seconds starting at GPS TOW second (modulo 30)=0 and a second type of packet may be transmitted at all other times. Whereas, in the beacon with Tx ID 2 occupying slot 2, the first type of packet may be transmitted once in 30 seconds starting at GPS TOW second (modulo 30)=3 and the second type of packet may be transmitted at all other times.

7 Frequency Bands of Operation

Frequency bands that currently support MBS are listed in Table 1.

Table 1: Frequency bands of operation of MBS

Region/Country	Name	Band	Comments
USA	M-LMS	919.75-927.25MHz	See FCC Part 90 sub-part M regulations [2]

The Tx center frequency may be in any supported band. The range of values of the Tx center frequency for a particular MBS deployment depends on the size of the available frequency band and the bandwidth of that particular MBS implementation. That is, if a frequency band spans from B_{min} to B_{max} MHz, and if the bandwidth of a particular MBS implementation is W MHz, then the Tx center frequency may be anywhere in the range $B_{min}+W/2$ to $B_{max}-W/2$, with 1 KHz resolution.

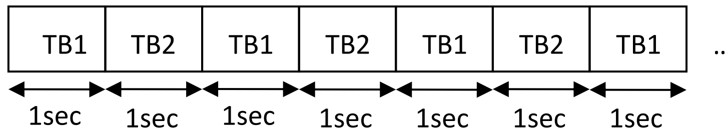
8 Optional Implementations

Based on the description of MBS in the preceding sections, an MBS service provider may choose their own specific implementation, based on the bandwidth, chip rate, PN code length, slot structure, and packet structure they would like to their system to have.

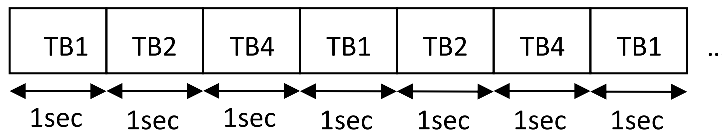
Four optional implementations are described in Sections 9 to 12, and are referred to as TB1, TB2, TB3, and TB4, respectively. These do not constitute an exhaustive list of possible MBS implementations, and are a small subset of possible implementations.

8.1 Combinations of MBS configurations

In addition, an MBS service provider may interleave different configurations. As described in Section 4.3, transmission periods shall be Δ_T seconds apart, where Δ_T shall be an integer greater than or equal to 1. For example, it is possible to interleave TB1 with a Δ_T equal to 2, with TB2 with a Δ_T equal to 2, so that TB1 is transmitted during the odd seconds and TB2 is transmitted during the even seconds. Another example can be the interleaving of TB1, TB2, and TB4, each with a Δ_T equal to 3. This can be visualized in Figure 6.



a) Example of interleaving of MBS configurations



b) Alternative example of interleaving of MBS configurations

Figure 6: Optional interleavings of MBS configurations

It should be noted that each interleaved configuration may have a different Tx center frequency. For example, in the first optional case in Figure 6, it is possible that TB1 has a different Tx center frequency than TB2.

Another possibility for an MBS service provider is to frequency-multiplex different configurations, that is, transmit them in different frequency bands. For example, it is possible to interleave TB1 with a Δ_T equal to 1, with TB2 with a Δ_T equal to 1, so that TB1 is transmitted on one center frequency and TB2 is transmitted on another center frequency, in such a way that they don't overlap. This can be visualized in Figure 7.

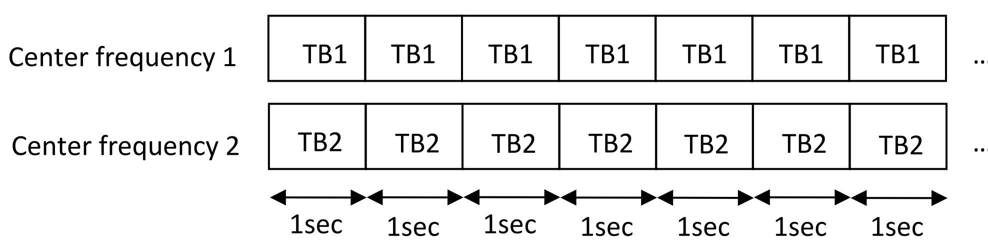


Figure 7: Optional frequency multiplexing of MBS configurations

In MBS implementations that use a frequency offset, the frequency offset used by a beacon in each interleaved or frequency-multiplexed configuration may be tied together by a fixed mapping. For example, in the first optional case in Figure 6, it is possible that the frequency offset that a beacon uses in TB1 is directly mapped to the frequency offset it uses in TB2. That is, if the set of frequency offsets available in TB1 is denoted by $\Delta f_{TB1,k1}$ where k_1=1,2,3,…, and the set of frequency offsets available in TB2 is denoted by $\Delta f_{TB2,k2}$ where k_2=1,2,3,…, then an MBS implementation may choose to set each beacon's TB2 offset using a fixed mapping $\Delta f_{TB2} = g(\Delta f_{TB1})$, where one example of the mapping is $k_2 = k_1$.

8.2 MBS Profiles

A given MBS deployment will be described by which MBS configurations are used (e.g. TB1 and TB2), whether they are interleaved, whether they are frequency multiplexed, which PRN codes are used, whether frequency offset is used, etc. The set of the parameters that describe a given MBS deployment can be captured under the concept of profiles.

A few such combinations are defined in Table 2.

Table 2: MBS Profiles

Profile Index	Frequency band	Transmission mode pattern	MBS configu rations	Center frequency (MHz)	Δ_T[1] (sec)	Frequency Offset Max[2] (Hz)	Set of PRN codes
0	M-LMS	TB1 + TB2 (simultaneous)	TB1	920.773	1	0	Codes from Table 12: 1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20
			TB2	924.442	1	0	Codes from Table 13: 1,2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20
1	M-LMS	TB1,TB2 (interleaved)	TB1	925.977	2	0	Codes from Table 12: 1,2,8,23,25,28,30,37,38,39,40, 41,64,73,74,79,83,87,93,97,98, 99,101,103,104,108,110,114, 116,123
			TB2	924.442	2	0	Codes from Table 13: 3,26,29,30,35,38,41,43,45,55, 57,64,65,68,70,71,72,74,76,78, 81,88,90,91,96,99,107,112, 118, 119

[1] Time between transmission periods, as defined in Section 4.3
[2] Determines set of frequency offsets used, as defined in Section 9.2

9 Optional Implementation: TB1

This section describes the specific MBS implementation referred to as TB1.

Table 3: TB1 Configuration

Configuration	Bandwidth (MHz)	Chip rate (Mcps)	PN code length (chips)	Slot Structure
m = 2, n = 1	2.046	1.023	1023	RH1H2 (ranging followed by two hybrid slots)

9.1 Spectral characteristics

The frequency response of the transmit filter for TB1 is shown in Figure 8. Refer to Section 7 for bands of operation supported.

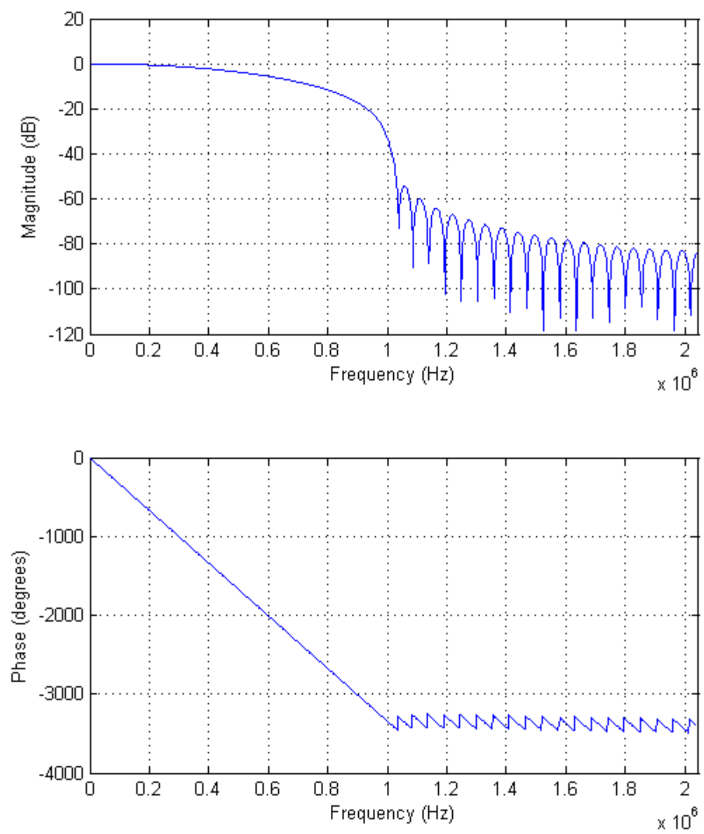


Figure 8: Frequency response of the transmit filter for TB1

9.2 Temporal Characteristics

In addition to the temporal characteristics described in Section 4.3, TB1 has the following system parameters:

- The chipping rate shall be 1.023 Mcps
- Each PN code shall have 1023 chips and shall last 1ms
  - Every 100ms slot includes 100 PN code symbols
  - One PN code symbol shall be used as a guard time between slots; therefore there are 99 PN code symbols available for ranging and data transmission in each 100ms.
- Each beacon transmits a preamble using a PN code reserved only for preambles.
  - The preamble is transmitted using GPS PRN 7. GPS PRN 7 uses a delay of 139 chips for the G2 code or, alternately, the G2 code has an initial state of 0646 in octal format (the least-significant-digit is the right-most digit) with the last stage state specified first. Note that the G2 delay and G2 code initial state are specified in the exact same way as in the GPS interface specification IS-GPS-200 Revision E.
  - Ranging slots have a preamble of length 7 PN codes (leaving 92 PN codes for pilot symbols). The preamble pattern is 1, 1, 1, -1, -1, -1, 1.
  - Hybrid slots have a preamble of length 4 PN codes (leaving 95 PN codes for pilot and data symbols). The preamble pattern is 1, 1, 1, -1.
- Each beacon may be assigned a frequency offset of the form Round(k*FrequencyOffsetMax/3)
  - k is an integer in the range -3 to 3.
  - FrequencyOffsetMax is in units of Hz and is implementation dependent, determined according to the established profile. The range of FrequencyOffsetMax across all profiles is 0KHz to 10KHz.
- A list of possible PN Codes used by TB1 is shown in Appendix B.

9.3 Slot Structure

The slot structure of TB1, given the temporal characteristics describe above is as follows:

- Slot structure consists of one ranging slot followed by two hybrid slots
  - This structure is referred to as RH1H2 and is depicted in Figure 9
- Ranging slots:
  - 7 PN codes for preamble
  - 92 PN codes for pilot symbols
- Hybrid ranging & data slots:
  - 4 PN codes for preamble
  - 14 PN codes for pilot symbols
  - 81 PN codes for data transmission using BPSK at 1 PN code/symbol

Figure 9: Slot structure for TB1, for a given transmitter. The blocks above are 1 or more sec apart and represent 1 slot (100ms).

Using the RH1H2 slot structure and optional implementation from above, TB1 is able to support 102 information bits in one data packet. These information bits are used for transmitting information required for trilateration (such as Tx lat/long/altitude).

In terms of alignment of above slot structure to GPS time, MBS physical slot 1 of the R frame (see Figure 9) starts at 'GPS time in seconds' modulo 3 = 0, plus 'GPS time offset' (from MBS packet type 2, described in Section 9.6.3.1.5)

9.4 Error-correcting code and CRC check

TB1 uses a convolutional code with constraint length 7 and a 16-bit CRC polynomial. A block diagram of the encoding process is shown in Figure 10.

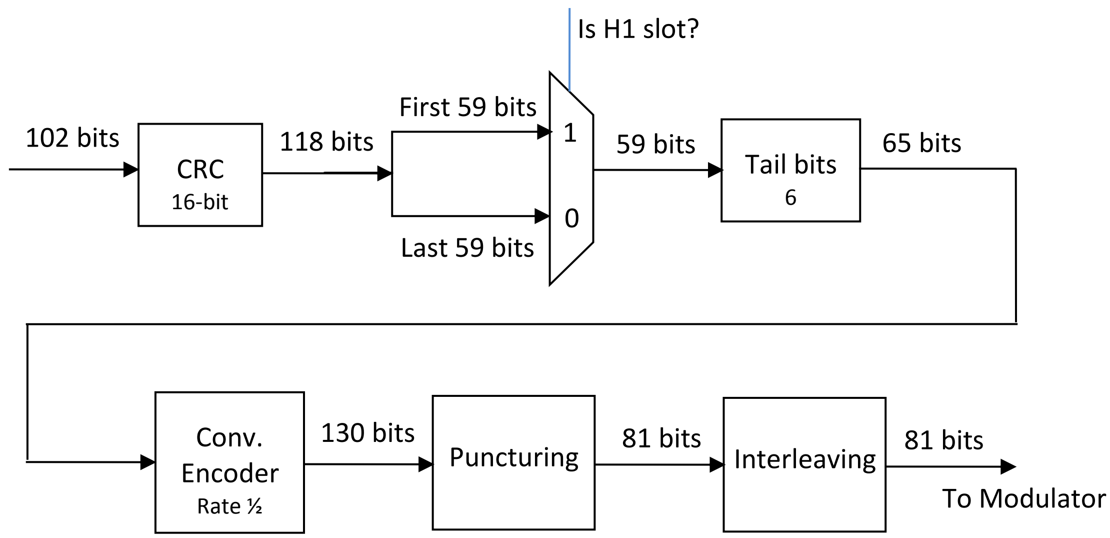


Figure 10: Encoding process for TB1

The CRC check is accomplished using a length-N_{crc} CRC code. The value of N_{crc} is 16, and the CRC polynomial used is x^16 + x^15 + x^12 + x^7 + x^6 + x^4 + x^3 + 1.

Each of the two hybrid slots is encoded and decoded separately, though the CRC is common to both slots. That is, the transmitter takes the 102 information bits, calculates the 16 bits of CRC, resulting in 118 bits. It then divides these 118 bits into two parts of length 59 bits, and it is these 59 bits which are encoded and transmitted using the 81 available PN code symbols in each hybrid slot.

The error-correcting code used is a convolutional code. The code has constraint-length 7 and is a rate-1/2 code that is punctured to ensure that the encoded bits fit within the 81 available PN code symbols in each hybrid slot. The transmitter adds 6 all-zero tail bits to the information bits before encoding, due to the nature of convolutional coding and decoding.

The encoding process shown in Figure 10 and described above can also be visualized in Figure 11

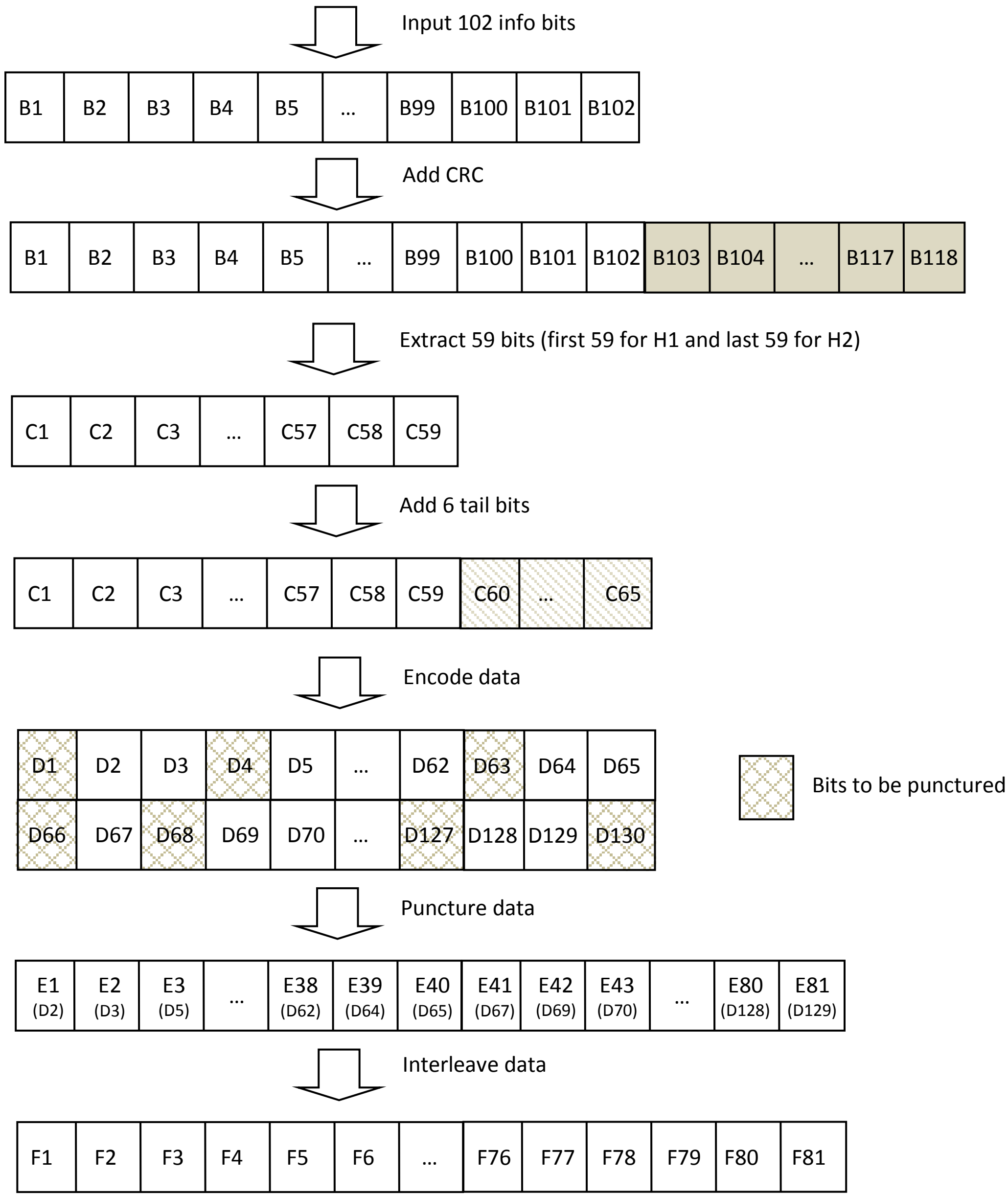


Figure 11: Encoding process visualization

The encoding process for this optional scenario can be summarized as:

1. Take 102 info bits as inputs
2. Add 16 CRC bits, to end up with 118 bits
3. Split into two groups of 59 bits (first 59 for H1 slot last 59 for H2)
4. For each group of 59 bits

a. Add 6 tail bits, to end up with 65 bits
b. Encode using the rate ½ encoder, to end up with 130 bits
c. Puncture the output of the encoder, to end up with 81 bits
d. Interleave the above bits, and send the result to the modulator, to be transmitted over-the-air to the receiver.

Encoder information

- Convolutional encoder of rate: ½
- Constraint-length: 7
- Encoder polynomials: [171 133] (in octal)
- Puncturing pattern: Of the 130 encoder output bits, select 81, according to

1. $b_{punct}[k] = b_{enc}[idx\_pass[k]]$, k = 0 to 80
2. where

```
idx_pass[] = {
1,2,4,6,7,9,10,12,14,15,17,18,20,21,23,25,26,28,29,31,33,34,36,37,3
9,41,42,44,45,47,49,50,52,53,55,57,58,60,61,63,64,66,68,69,71,72,74
,76,77,79,80,82,84,85,87,88,90,92,93,95,96,98,100,101,103,104,106,1
07,109,111,112,114,115,117,119,120,122,123,125,127,128 };
```

- Interleaving pattern: From the input bit sequence $b_{punct}[k]$ where k = 0 to 80, calculate the output bit sequence $b_{out}[k]$ according to

3. $b_{out}[k] = b_{punct}[idx\_permute[k]]$, k = 0 to 80
4. where idx_permute is the following length-81 array:

```
5. idx_permute[] = {
6. 4,21,80,65,39,35,6,32,8,47,45,25,23,76,41,16,30,7,46,11,9,51,2,43,7
   1,79,69,74,50,70,78,10,62,17,60,15,13,5,68,36,27,72,75,40,38,54,24,
   52,64,58,55,20,63,59,26,67,31,49,0,56,42,61,53,66,3,18,48,22,34,57,
   12,33,19,37,73,28,1,29,77,44,14 };
```

(The receiver demodulates the signal in each slot, de-interleaves the resulting soft bits and passes them through the decoder. The receiver concatenates the output of the decoder from the two hybrid slots H1 and H2 and does a CRC check to ensure that the block of data was sent successfully)

9.5 Modulation

In ranging slots, after the preamble, TB1 shall use BPSK modulation to transmit 92 pilot bits over the same number of PN code periods. The pilot bit sequence during ranging slots is described below.

In hybrid slots, after the preamble, there are 95 PN code periods left in the slot. TB1 uses BPSK modulation to transmit pilot bits over 14 PN code periods, and then uses DBPSK (differential BPSK) modulation to transmit data bits over the remaining 81 PN code periods. The transmitter uses the last pilot bit as the first DBPSK data bit so that it can maximize the number of data bits it can transmit, even though it is using DBPSK. The pilot bit sequence is different for H1 and H2 slots.

The pilot bit sequences for ranging and hybrid slots depend on the network configuration and may be in one of two modes:

- Pilot Sequence Mode 1:
  - Ranging (R) slot:
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
    0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0
  - H1 pilot sequence: 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0
  - H2 pilot sequence: 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1

- Pilot Sequence Mode 2:
  - R slot:
    1,1,1,1,1,0,1,0,1,1,0,1,0,0,0,1,1,0,1,1,0,0,1,1,1,0,0,0,0,1,0,
    1,1,0,1,1,0,1,0,1,1,1,0,0,1,0,0,1,1,1,0,0,1,1,0,0,0,1,1,0,1,1,
    0,0,1,0,1,1,0,0,0,1,0,0,1,1,0,1,0,0,0,0,0,1,0,1,1,1,1,1,0,1
  - H1 pilot sequence: 0, 1, 0, 0, 1, 1, 1, 0, 1, 0, 1, 1, 1, 0
  - H2 pilot sequence: 0, 0, 1, 0, 0, 1, 0, 1, 1, 1, 0, 0, 1, 0

In all sequences above, a ‘0’ is mapped to ‘-1’, and a ‘1’ is mapped to ‘1’ during modulation.

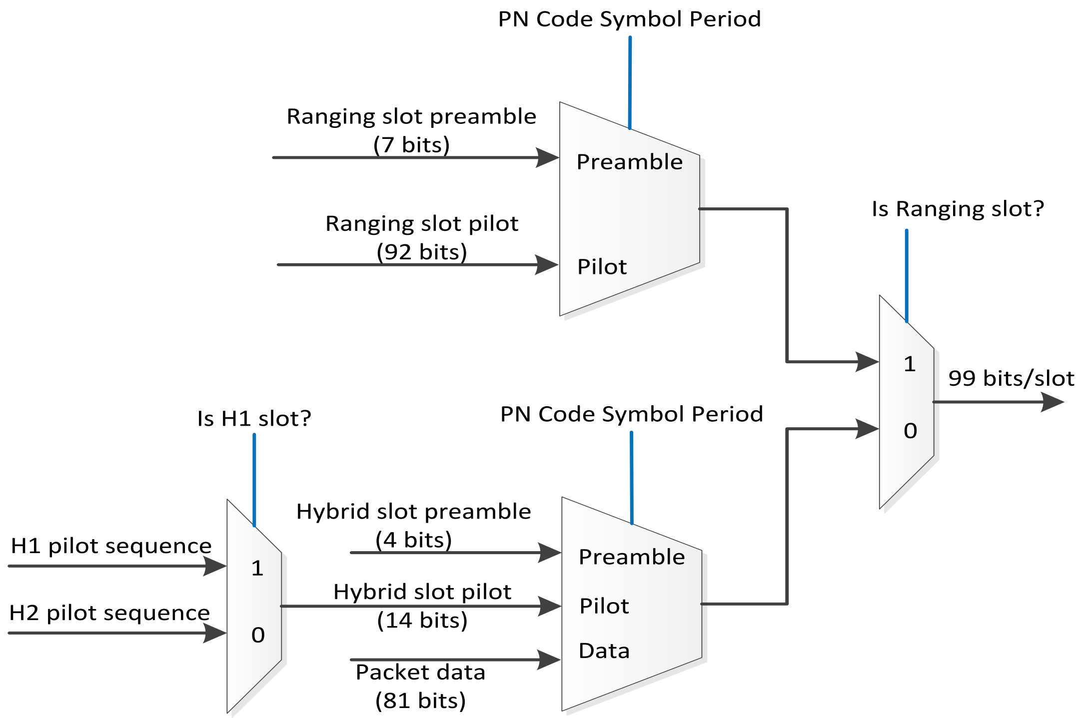


Figure 12: Modulation process for TB1, which uses the RH1H2 slot structure

9.6 Packet Types – MAC Layer

TB1 is able to carry 102 information bits per data packet, and the resulting packet types that are supported are listed in Table 4.

Table 4: Packet types for TB1

Type	Payload	Number of payload bits	Number of slots
0	Reserved	TBD	TBD
1	Latitude, longitude, altitude, Tx correction, Tx quality, pressure, temperature, weather info, weather data quality.	99	2
2	TxID, Tx correction, pressure, temperature, weather info, weather data quality, GPS time – Week number, GPS time – TOW, GPS time offset, Slot Index, UTC time offset.	96	2
3-6	Reserved	TBD	any
7	Extended packet type identifier. For future use.	TBD	any

This section specifies how many bits are required to be transmitted for each field of each packet type listed above.

9.6.1 Overall Packet Structure

Since there is more than one data packet type, there is a need for an indicator to denote which one the Rx is seeing at any given time.

Three bits are allocated to describe the packet type. Extension packet types may be supported by using '111' as the base packet type (to denote 'more packet type information to come'), and then have a few bits after that to denote more packet types.

The total payload of the RH1H2 scheme is 102 information bits per RH1H2 triplet of slots. Out of those 102 bits, 3 are for packet type index, leaving 99 bits for the data payload and any other framing overhead.

If some data to be transmitted is more than can be carried in one RH1H2 packet, the Tx sends the data over more than one packet. In that case, there is a need for a scheme to identify how the bits from the current data packet fit into the overall set of data bits that are to be transmitted. In order to have unambiguous understanding by the receiver on what is being transmitted in each data packet the following scheme is used:

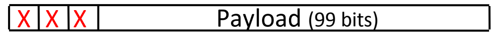
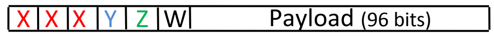


Figure 13: Packet structure for packet types 0 and 1



XXX : Packet type
Y : Reserved bit
Z : Start bit
W : Stop bit

Figure 14: Packet structure for packet types other than 0 and 1

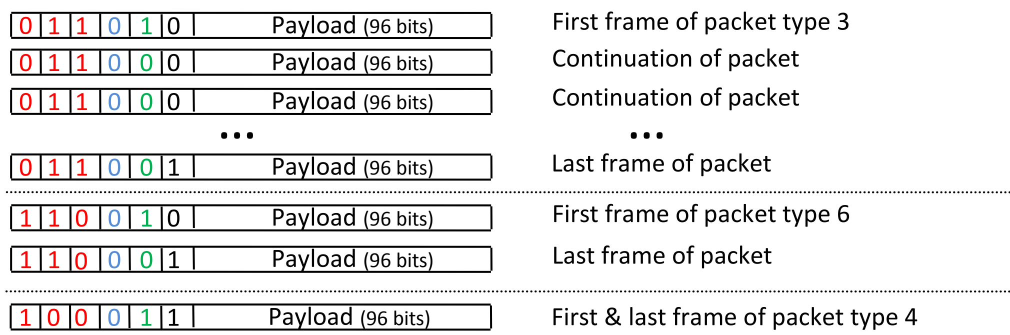


Figure 15: Packet structure examples

- In every packet of 102 bits, the first three bits are the packet type
- For packet types 0 and 1:
    - The next 99 bits contain the main packet payload
- For packet types other than 0 and 1:
    - The fourth bit is a reserved bit.
    - The fifth bit is the start bit, and denotes whether this frame begins a new packet (1) or the continuation of a previous packet (0).
    - The sixth bit is the stop bit, and denotes whether this is the last frame of a packet (1) or a continuation frame of a packet (0).
    - The next 96 bits contain the packet payload

Summary: 3 bits of framing overhead for packet types 0 and 1, and 6 bits of framing overhead for packet types other than 0 and 1.

9.6.2 Packet Structure for Packet Type 1 (Full Trilateration Information)

Table 5: Packet Info for Packet Type 1

Field	bit_index	num_bits
Packet type	1 – 3	3
Payload	4 – 102	99

Table 6: Payload for Packet Type 1

Field	field_id	bit_index	num_txbits	step_size	min_value	max_value	units
Latitude	1	1 – 26	26	4/2^20	-90	90	degrees
Longitude	2	27 – 53	27	4/2^20	-180	180	degrees
Altitude	3	54 – 68	15	29/100	-500	9002.43	m (WGS84 [3])
Tx correction	4	69 – 73	5	1	0	25	ns
Tx quality	5	74 – 77	4	1	0	15	N/A
Pressure	6	78 – 87	10	12	94,500	106,776	Pa
Temperature	7	88 – 94	7	0.8	228	329.6	K
Weather info	8	95 – 97	3	2	0	14	N/A
Weather data quality	9	98 – 99	2	2	0	6	N/A

9.6.2.1 Descriptions of the fields of packet type 1

Individual MBS service providers should map the raw values of the bits for each field to a range and resolution they feel best meets their requirements. Below are descriptions and optional ranges for each field based on the information in Table 6.

Note that to obtain the numerical value for a given field from the bits in the payload, the equation is

$$numerical\ value = min\_value\ +\ step\_size\ \times bit\_value$$

where *min_value* and *step_size* are the corresponding values from Table 6 and *bit_value* is the conversion of the binary number represented by the corresponding bits in the payload to decimal.

9.6.2.1.1 Latitude

Latitude of the Tx antenna. Range: [-90, 90] degrees.

9.6.2.1.2 Longitude

Longitude of the Tx antenna. Range: [-180, 180] degrees.

9.6.2.1.3 Altitude

Altitude of the Tx antenna. Range: [-500, 9002.43] meters.

9.6.2.1.4 Tx Correction

Tx correction is the residual timing error left over after the Tx adjusts its transmission to account for the various delays in the system, such as cable delays. The receiver needs to take the Tx correction into account to fine-tune the pseudorange estimate from each transmitter (the Tx correction value for a given beacon needs to be subtracted from the receiver time stamp of the time-of-arrival estimate for that beacon).

Range: [0,25] ns.

Note: A bit sequence of all ones for the Tx Correction bit field denotes an invalid Tx Correction value, i.e. the transmitter has not been able to determine the Tx Correction value.

9.6.2.1.5 Tx Quality

Each beacon transmits some bits that denote to the receiver some relative quality metric about that particular beacon.

Range: [0, 15].

9.6.2.1.6 Pressure

The transmitter shall transmit atmospheric pressure information to the receiver and should transmit a transformation of the pressure measured at the beacon, e.g. an estimated pressure at a reference altitude level. TB1 uses a reference altitude of 0m HAE according to the WGS84 model [3].

Range: [94500, 106776] Pa.

9.6.2.1.7 Temperature

The temperature measured at the beacon, which represents ambient atmospheric temperature.

Range: [228, 329.6] Kelvin.

9.6.2.1.8 Weather Info

Each transmitter may transmit some bits that denote to the receiver some extra information about the weather and/or weather equipment, to enable improved altitude calculation.

Range: [0,14]

9.6.2.1.9 Weather Data Quality

Each transmitter may transmit some bits that denote to the receiver some relative quality metric about the weather data (pressure, temperature). The mapping between Weather Data Quality value and what it means is as follows

- 0 : The weather data from this Tx is unreliable. Do not use it.
- 6 : The weather data from this Tx is as good as possible.
- Other values : Reserved.

Range: [0,6]

9.6.3 Packet Structure for Packet Type 2 (Tx ID and GPS time along with Partial Trilateration Info)

Table 7: Packet Info for Packet Type 2

Field	bit_index	num_bits
Packet type	1 – 3	3
Reserved bit	4	1
Start bit	5	1
Stop bit	6	1
Payload	7 – 102	96

Table 8: Payload for Packet Type 2

Field	field_id	bit_index	num_txbits	step_size	min_value	max_value	units
Tx ID	1	1 – 15	15	1	0	2^15-1	N/A
Tx correction	2	16 – 20	5	1	0	25	Ns
Pressure	3	21 – 31	11	6	94,500	106,776	Pa
Temperature	4	32 – 39	8	0.4	228	329.6	K
Weather info	5	40 – 43	4	1	0	14	N/A
Weather Data Quality	6	44 – 46	3	1	0	6	N/A
GPS time – Week Number	7	47 – 56	10	1	0	2^10-1	weeks
GPS time – TOW in seconds	8	57 – 76	20	1	0	2^20-1	s
Time offset relative to GPS	9	77 – 86	10	1	0	1000	ns
Slot Index	10	87 – 90	4	1	0	9	N/A
UTC time offset from GPS	11	91 – 96	6	1	0	63	s

9.6.3.1 Descriptions of the fields of packet type 2

Individual MBS service providers should map the raw values of the bits for each field to a range and resolution they feel best meets their requirements. Below are descriptions and optional ranges for each field based on the information in Table 8.

Note that to obtain the numerical value for a given field from the bits in the payload, the equation is

$$numerical\ value = min\_value\ +\ step\_size\ \times bit\_value$$

where *min_value* and *step_size* are the corresponding values from Table 8 and *bit_value* is the conversion of the binary number represented by the corresponding bits in the payload to decimal.

9.6.3.1.1 Transmitter ID

The Tx ID field must be a unique ID that identifies each transmitter within one major deployment area, such as within North America. With 15 bits, up to 32,768 unique transmitters can be identified. The Tx ID should be used, along with an almanac on the receiver, to extract the lat/long/height of each transmitter, as well as the Tx quality information for each transmitter.

Range: [0, 2^15-1]

9.6.3.1.2 Tx correction

Tx correction is as described in Section 9.6.2.1.

Range: [0,25] ns

9.6.3.1.3 Pressure, Temperature, and Weather Data Quality

Pressure, Temperature, and Weather Data Quality are as described in Section 9.6.2.1.

Pressure	Range: [94500, 106776] Pa
Temperature	Range: [228, 329.6] Kelvin
Weather Data Quality	Range: [0,6]

9.6.3.1.4 GPS time – Week number & TOW

This represents the GPS time of the R frame immediately preceding the H1/H2 frames in which this packet was carried. GPS time is represented as time of week (TOW) and GPS week number.

TOW is the number of seconds since the beginning of the GPS week, which runs from zero to 604799 at the end of week. The TOW second count returns to zero coincident with the resetting of the GPS PRN codes.

The GPS week number represents the GPS weeks (modulo 1024) since week 0 which started at 00:00:00 Sunday 6th January, 1980.

Week number Range: [0,2^10-1] weeks, with 1 week resolution
TOW seconds Range: [0, 604799] sec, with 1 sec resolution

9.6.3.1.5 MBS time offset relative to GPS

This is the offset of MBS system time relative to GPS time. Note that MBS system time is always delayed relative to GPS time by the number of nanoseconds specified in this field and is expected to be a constant.

Range: [0,1000] ns, with 1ns resolution.

9.6.3.1.6 Slot Index

This is the physical time slot in which a transmitter is transmitting.

Range: [0,9].

9.6.3.1.7 UTC time offset from GPS

This is the UTC time offset from GPS time. The UTC offset field can accommodate 63 leap seconds (six bits).

Range: [0,63] sec, with 1 sec resolution.

9.6.4 Additional Packet Types

Additional packets using packet type greater than 2 may be defined as required for the TB1 configuration.

9.6.5 Periodicity of Packet Type Transmission

The periodicity and the associated time offset of the transmission for various packet types is MBS service provider specific. The packet transmissions of a particular type may be staggered relative to other beacons.

As an example, in the beacon with Tx ID 1 occupying slot 1, the packet with type 2 may be transmitted once in 30 seconds starting at GPS TOW second (modulo 30)=0 and packet type 0 may be transmitted at all other times. Whereas, in the beacon with Tx ID 2 occupying slot 2, packet type 2 may be transmitted once in 30 seconds starting at GPS TOW second (modulo 30)=3 and packet type 0 may be transmitted at all other times.

10 Optional Implementation: TB2

This section describes the specific MBS implementation referred to as TB2.

Table 9: TB2 Configuration

Configuration	Bandwidth (MHz)	Chip rate (Mcps)	PN code length (chips)	Slot Structure
m = 5, n = 2	5.115	2.5575	2047	R (ranging only)

10.1 Spectral characteristics

The frequency response of the transmit filter for TB2 is shown in Figure 16. Refer to Section 7 for bands of operation supported.

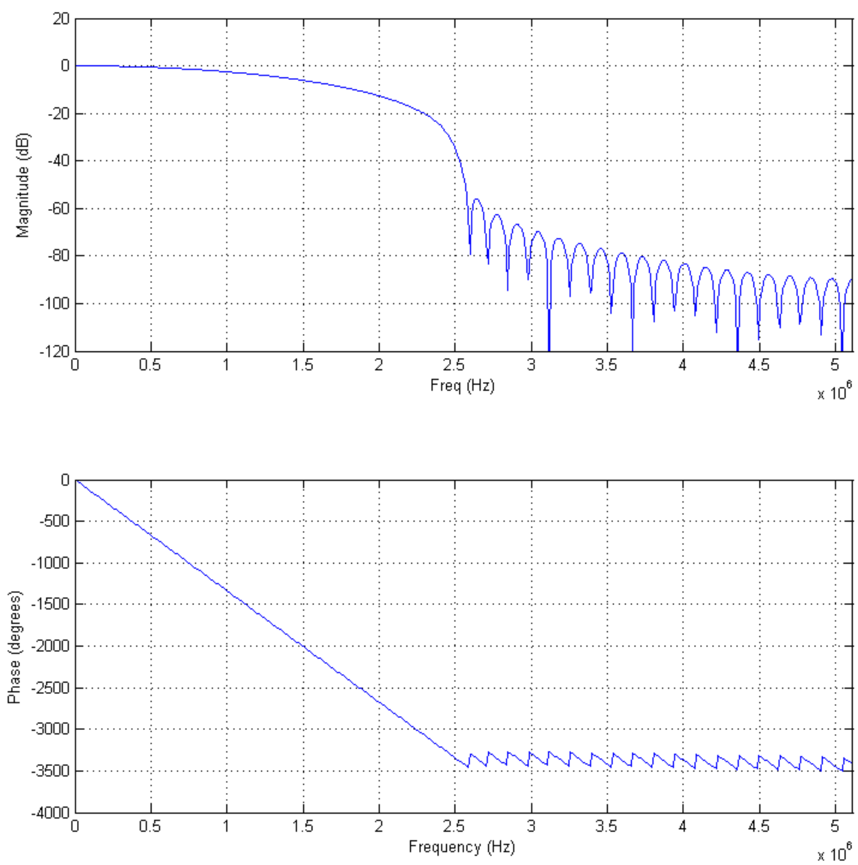


Figure 16: Frequency response of the transmit filter for TB2

10.2 Temporal Characteristics

In addition to the temporal characteristics described in Section 4.3, TB2 has the following system parameters:

- The chipping rate shall be 2.5575 Mcps
- Each PN code shall have 2047 chips and shall last 2.047/2.5575 ms (roughly 0.8ms)
  - Every 100ms slot includes 124.94 PN code symbols
  - Roughly 1.55ms shall be used as a guard time between slots; therefore there are 123 PN code symbols available for ranging in each 100ms.
- Each beacon transmits a preamble using a PN code reserved only for preambles.
  - The polynomial that is used for the spreading sequence during the preamble is represented in octal as 4161, where the least-significant-digit is the right-most digit. It is generated using the method described in Figure 19.
  - The preamble is of length 11 PN codes. The preamble pattern is 1, 1, 1, -1, -1, -1, 1, -1, -1, 1, -1.
  - This leaves 112 PN codes for pilot symbols
- Each beacon may be assigned a frequency offset of the form Round(k*FrequencyOffsetMax/3)
  - k is an integer in the range -3 to 3.
  - FrequencyOffsetMax is in units of Hz and is implementation dependent, determined according to the established profile. The range of FrequencyOffsetMax across all profiles is 0KHz to 10KHz.
- A list of possible PN Codes used by TB2 is shown in Appendix C.

10.3 Slot Structure

TB2 uses only ranging slots. That is, it has no hybrid slots and transmits no data. Any information required by the receiver for trilateration must come from assistance data via other channels.

10.4 Error-correcting code and CRC check

Since TB2 transmits no data, no error-correcting codes or CRC are used.

10.5 Modulation

In all slots, after the preamble, TB2 shall use BPSK modulation to transmit 112 pilot bits over the same number of PN code periods. The pilot bit sequence depends on the network configuration and may be in one of two modes:

- Pilot Sequence Mode 1:
  0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
  0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
  0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

- Pilot Sequence Mode 2:
  1,1,1,1,1,1,0,1,1,0,0,0,1,0,0,1,0,1,0,1,0,0,1,1,1,1,0,1,0,0,1,1,1,1,0,1,1,1,1,1,1,0,0,0,1,0,
  1,1,0,1,1,0,0,0,0,0,1,1,1,0,0,1,1,1,1,1,0,0,1,1,0,0,1,1,0,1,0,1,0,1,0,0,1,0,1,0,1,1,1,1,0,1,
  1,0,0,0,0,0,0,1,1,1,1,1,1,0,1,1,0,0,0

In all sequences above, a ‘0’ is mapped to ‘-1’, and a ‘1’ is mapped to ‘1’ during modulation.

10.6 Packet Types – MAC Layer

Since TB2 transmits no data, it supports no packets.

11 Optional Implementation: TB3

This section describes the specific MBS implementation referred to as TB3.

Table 10: TB3 Configuration

Configuration	Bandwidth (MHz)	Chip rate (Mcps)	PN code length (chips)	Slot Structure
m = 10, n = 4	10.23	5.115	8191	R (ranging only)

11.1 Spectral characteristics

The frequency response of the transmit filter for TB3 is shown in Figure 17. Refer to Section 7 for bands of operation supported.

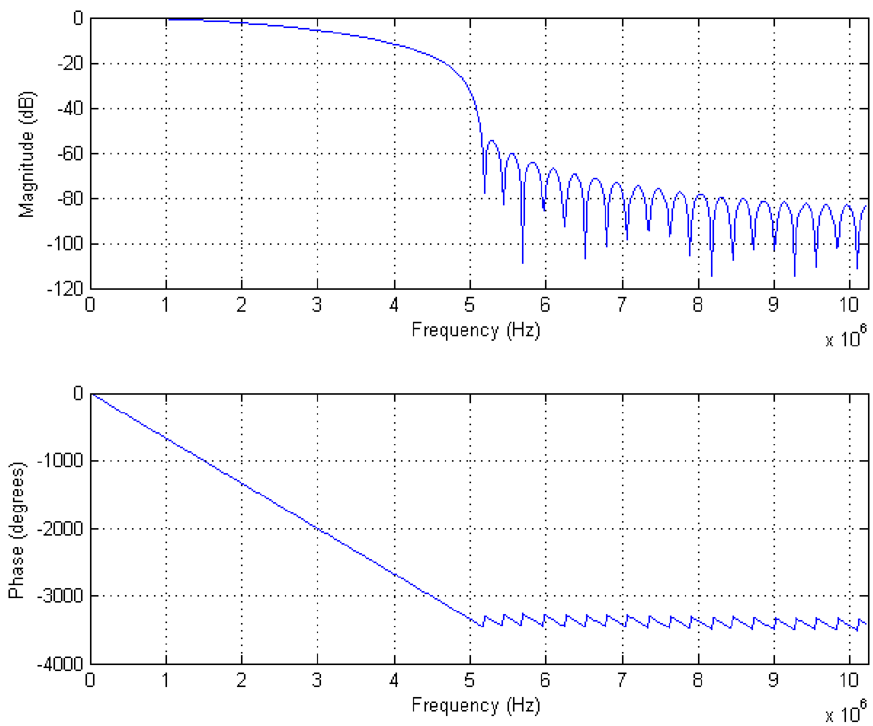


Figure 17: Frequency response of the transmit filter for TB3

11.2 Temporal Characteristics

In addition to the temporal characteristics described in Section 4.3, TB3 has the following system parameters:

- The chipping rate shall be 5.115 Mcps
- Each PN code shall have 8191 chips and shall last 8.191/5.115 ms (roughly 1.6ms)
  - Every 100ms slot includes 62.45 PN code symbols
  - Roughly 1.45ms shall be used as a guard time between slots; therefore there are 61 PN code symbols available for ranging in each 100ms.
- Each beacon transmits a preamble using a PN code reserved only for preambles.
  - The polynomial that is used for the spreading sequence during the preamble is represented in octal as 22202, where the least-significant-digit is the right-most digit. It is generated using the method described in Figure 19.
  - The preamble is of length 5 PN codes. The preamble pattern is 1, 1, 1, -1, 1.
  - This leaves 56 PN codes for pilot symbols
- Each beacon may be assigned a frequency offset of the form Round(k*FrequencyOffsetMax/3)
  - k is an integer in the range -3 to 3.
  - FrequencyOffsetMax is in units of Hz and is implementation dependent, determined according to the established profile. The range of FrequencyOffsetMax across all profiles is 0KHz to 10KHz.
- A list of possible PN Codes used by TB3 is shown in Appendix D.

11.3 Slot Structure

TB3 uses only ranging slots. That is, it has no hybrid slots and transmits no data. Any information required by the receiver for trilateration must come from assistance data via other channels.

11.4 Error-correcting code and CRC check

Since TB3 transmits no data, no error-correcting codes or CRC are used.

11.5 Modulation

In all slots, after the preamble, TB3 shall use BPSK modulation to transmit 56 pilot bits over the same number of PN code periods. The pilot bit sequence depends on the network configuration and may be in one of two modes:

- Pilot Sequence Mode 1:
  0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
  0,0,0,0,0,0,0,0,0

- Pilot Sequence Mode 2:
  1,0,0,1,0,1,0,1,1,0,1,0,0,1,1,0,1,0,1,1,1,0,1,1,0,0,0,1,1,0,1,1,0,0,1,0,1,0,1,1,0,1,1,0,1,1,0,
  1,1,1,1,1,1,0,0,1

In all sequences above, a ‘0’ is mapped to ‘-1’, and a ‘1’ is mapped to ‘1’ during modulation.

11.6 Packet Types – MAC Layer

Since TB2 transmits no data, it supports no packets.

12 Optional Implementation: TB4

This section describes the specific MBS implementation referred to as TB4.

Table 11: TB4 Configuration

Configuration	Bandwidth (MHz)	Chip rate (Mcps)	PN code length (chips)	Slot Structure
m = 20, n = 8	20.46	10.23	8191	R (ranging only)

12.1 Spectral characteristics

The frequency response of the transmit filter for TB4 is shown in Figure 18. Refer to Section 7 for bands of operation supported.

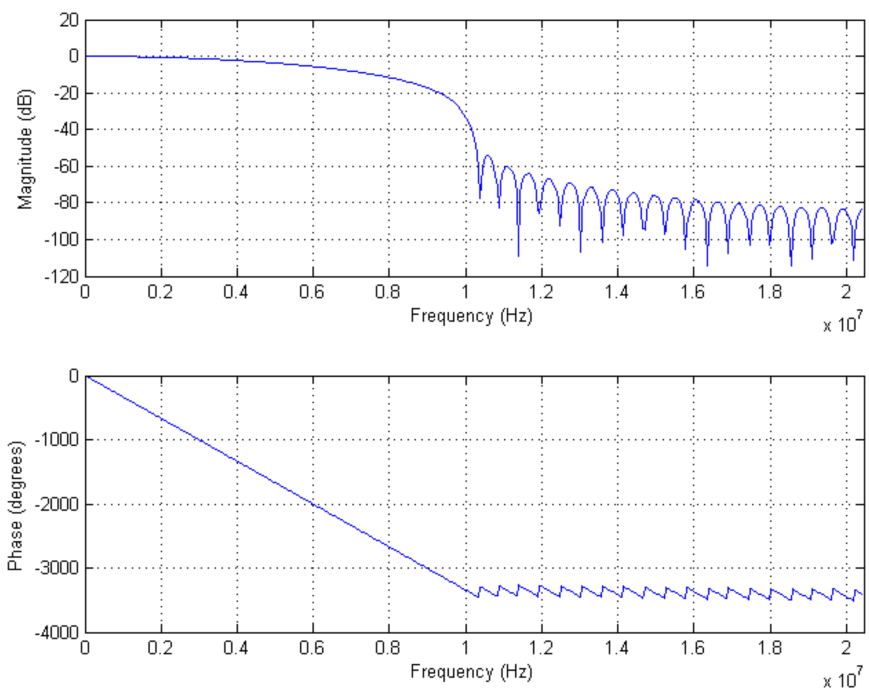


Figure 18: Frequency response of the transmit filter for TB4

12.2 Temporal Characteristics

In addition to the temporal characteristics described in Section 4.3, TB4 has the following system parameters:

- The chipping rate shall be 10.23 Mcps
- Each PN code shall have 8191 chips and shall last 8.191/10.23 ms (roughly 0.8ms)
  - Every 100ms slot includes 124.89 PN code symbols
  - Roughly 1.51ms shall be used as a guard time between slots; therefore there are 123 PN code symbols available for ranging in each 100ms.
- Each beacon transmits a preamble using a PN code reserved only for preambles.
  - The polynomial that is used for the spreading sequence during the preamble is represented in octal as 22202, where the least-significant-digit is the right-most digit. It is generated using the method described in Figure 19.
  - The preamble is of length 11 PN codes. The preamble pattern is 1, 1, 1, -1, -1, -1, 1, -1, -1, 1, -1.
  - This leaves 112 PN codes for pilot symbols
- Each beacon may be assigned a frequency offset of the form Round(k*FrequencyOffsetMax/3)
  - k is an integer in the range -3 to 3.
  - FrequencyOffsetMax is in units of Hz and is implementation dependent, determined according to the established profile. The range of FrequencyOffsetMax across all profiles is 0KHz to 10KHz.
- A list of possible PN Codes used by TB4 is shown in Appendix D.

12.3 Slot Structure

TB4 uses only ranging slots. That is, it has no hybrid slots and transmits no data. Any information required by the receiver for trilateration must come from assistance data via other channels.

12.4 Error-correcting code and CRC check

Since TB4 transmits no data, no error-correcting codes or CRC are used.

12.5 Modulation

In all slots, after the preamble, TB4 shall use BPSK modulation to transmit 112 pilot bits over the same number of PN code periods. The pilot bit sequence depends on the network configuration and may be in one of two modes:

- Pilot Sequence Mode 1:

0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,
0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0

- Pilot Sequence Mode 2:
  1,1,1,1,1,1,0,1,1,0,0,0,1,0,0,1,0,1,0,1,0,0,1,1,1,1,0,1,0,0,1,1,1,1,0,1,1,1,1,1,1,0,0,0,1,0,
  1,1,0,1,1,0,0,0,0,0,1,1,1,0,0,1,1,1,1,1,0,0,1,1,0,0,1,1,0,1,0,1,0,1,0,0,1,0,1,0,1,1,1,1,0,1,
  1,0,0,0,0,0,0,1,1,1,1,1,1,1,0,1,1,0,0,0

In all sequences above, a ‘0’ is mapped to ‘-1’, and a ‘1’ is mapped to ‘1’ during modulation.

12.6 Packet Types – MAC Layer

Since TB4 transmits no data, it supports no packets.

Appendix A: Transmit Filter Taps (at 4 samples per chip)

Idx	Filter Tap	Idx	Filter Tap	Idx	Filter Tap
1	-0.000000176795813	27	-0.005032525589647	53	0.003688476821592
2	-0.000105400894759	28	0.000578496047144	54	0.000225006980155
3	-0.000506510439665	29	0.007274083361462	55	-0.002820151710350
4	0.000017926535619	30	-0.001071930604566	56	-0.000154303305525
5	0.000622069897515	31	-0.011446509363444	57	0.002225666433076
6	-0.000020943705042	32	0.002346672474270	58	0.000110028727138
7	-0.000702490451183	33	0.020665533546919	59	-0.001801760932846
8	0.000025153457115	34	-0.006945246406238	60	-0.000081556225106
9	0.000799260255750	35	-0.048569967588775	61	0.001488005612170
10	-0.000030877723955	36	0.046724283110992	62	0.000061814962858
11	-0.000917876978677	37	0.379367282666764	63	-0.001250042945255
12	0.000038128166689	38	0.802942566327759	64	-0.000048246760490
13	0.001064594329818	39	1.000000000000000	65	0.001064594329818
14	-0.000048246760490	40	0.802942566327759	66	0.000038128166689
15	-0.001250042945255	41	0.379367282666764	67	-0.000917876978677
16	0.000061814962858	42	0.046724283110992	68	-0.000030877723955
17	0.001488005612170	43	-0.048569967588775	69	0.000799260255750
18	-0.000081556225106	44	-0.006945246406238	70	0.000025153457115
19	-0.001801760932846	45	0.020665533546919	71	-0.000702490451183
20	0.000110028727138	46	0.002346672474270	72	-0.000020943705042
21	0.002225666433076	47	-0.011446509363444	73	0.000622069897515
22	-0.000154303305525	48	-0.001071930604566	74	0.000017926535619
23	-0.002820151710350	49	0.007274083361462	75	-0.000506510439665
24	0.000225006980155	50	0.000578496047144	76	-0.000105400894759
25	0.003688476821592	51	-0.005032525589647	77	-0.000000176795813
26	-0.000347859335185	52	-0.000347859335185		

Appendix B: PN Codes that may be used by MBS, for PN code length 1023

In general, any family of PN codes may be used for MBS. For example, the GPS family of Gold Codes may be used, as shown in Table 12 below. Note that the G2 delay and G2 code initial state in Table 12 below are specified in the same way as in the GPS interface specification IS-GPS-200 Revision E.

Table 12: Optional PN Codes used by MBS, based on GPS family of Gold Codes

Index	G2 Delay	G2 Initial State (Octal)	Index	G2 Delay	G2 Initial State (Octal)	Index	G2 Delay	G2 Initial State (Octal)
1	12	201	27	150	1362	53	407	1054
2	15	1220	28	157	1505	54	422	263
3	16	1510	29	211	1560	55	438	277
4	21	232	30	225	103	56	445	471
5	22	1115	31	230	1702	57	446	1234
6	29	1174	32	235	1076	58	456	1653
7	30	476	33	237	1617	59	461	435
8	34	1523	34	238	1707	60	462	216
9	37	1552	35	248	735	61	463	107
10	48	1563	36	289	1641	62	465	421
11	52	267	37	291	1750	63	467	1104
12	56	213	38	292	764	64	476	1003
13	68	1007	39	298	667	65	482	610
14	72	1740	40	326	1010	66	484	142
15	76	376	41	327	404	67	499	1411
16	79	1637	42	333	1004	68	500	604
17	83	171	43	357	1070	69	503	1460
18	85	1436	44	358	434	70	525	72
19	87	307	45	359	1216	71	530	641
20	122	1016	46	365	1572	72	536	746
21	126	140	47	373	663	73	537	1363
22	127	1060	48	386	450	74	539	1674
23	130	706	49	389	1445	75	540	736
24	135	1156	50	395	1654	76	556	1330
25	144	215	51	399	272	77	567	327

Index	G2 Delay	G2 Initial State (Octal)	Index	G2 Delay	G2 Initial State (Octal)	Index	G2 Delay	G2 Initial State (Octal)
26	145	1106	52	405	262	78	568	1153
79	580	632	101	816	332	123	959	1562
80	586	606	102	818	66	124	960	1671
81	595	740	103	819	1033	125	1012	551
82	602	1663	104	836	1277	126	1015	1455
83	603	1731	105	837	537	127	1018	1745
84	607	375	106	846	242	128	1021	1774
85	657	717	107	849	1024			
86	663	727	108	851	205			
87	711	1747	109	853	1041			
88	712	1763	110	870	1310			
89	714	374	111	877	455			
90	732	25	112	879	1113			
91	740	1230	113	883	1644			
92	761	521	114	885	1751			
93	762	1250	115	886	1764			
94	771	45	116	891	1737			
95	780	1160	117	894	573			
96	792	256	118	900	1045			
97	797	305	119	911	436			
98	798	1142	120	926	1323			
99	814	1550	121	953	206			
100	815	664	122	955	1441			

The ‘G2 delay’ referred to in the table above is the delay of the G2 code used in the standard GPS PN Code generation of length 1023. In pseudocode:

```
 y1 = standard_gps_m_sequence1_G1;
 y2 = standard_gps_m_sequence2_G2;
PN_code = xor(y1, circular_shift(y2,delay));
```

Appendix C: Alternate PN Codes that may be used by MBS, for PN code length 2047

An alternate list of PN codes for MBS is shown in Table 13, and consists of maximal length sequences. The table contains the LFSR (Linear Feedback Shift Register) polynomial taps required for code generation. For all polynomials shown in octal in Table 13, the least-significant-digit is the right-most digit.

The initial state is the same for all PRNs, and in octal form is 3777. Generation of these codes is done using an LFSR as shown in Figure 19, with N=11.

Table 13: Alternate optional PN Codes used by MBS, based on maximal length sequences of length 2047

Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)
1	4005	44	5253	87	6501
2	4027	45	5263	88	6507
3	4053	46	5265	89	6557
4	4055	47	5337	90	6561
5	4107	48	5357	91	6637
6	4143	49	5403	92	6673
7	4145	50	5411	93	6675
8	4173	51	5421	94	6727
9	4215	52	5463	95	6733
10	4237	53	5477	96	6741
11	4251	54	5501	97	6747
12	4261	55	5513	98	6765
13	4317	56	5531	99	7005
14	4341	57	5545	100	7035
15	4347	58	5557	101	7041
16	4353	59	5575	102	7047
17	4415	60	5607	103	7053
18	4451	61	5613	104	7071
19	4473	62	5623	105	7107
20	4475	63	5625	106	7113
21	4505	64	5657	107	7125
22	4511	65	5675	108	7161
23	4521	66	5733	109	7175
24	4563	67	5735	110	7201

Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)
25	4565	68	5747	111	7223
26	4577	69	5755	112	7243
27	4603	70	6013	113	7273
28	4617	71	6015	114	7335
29	4653	72	6037	115	7431
30	4671	73	6127	116	7461
31	4707	74	6141	117	7467
32	4731	75	6153	118	7555
33	4767	76	6205	119	7565
34	5001	77	6211	120	7603
35	5007	78	6263	121	7621
36	5025	79	6277	122	7627
37	5051	80	6315	123	7633
38	5141	81	6323	124	7647
39	5155	82	6325	125	7655
40	5177	83	6351	126	7665
41	5205	84	6367	127	7715
42	5221	85	6447	128	7751
43	5247	86	6455		

Code polynomial taps are provided as an (N+1)-bit string:
$P_N P_{(N-1)} P_{(N-2)} \ldots P_1 P_0$ where P_N and P_0 are always 1

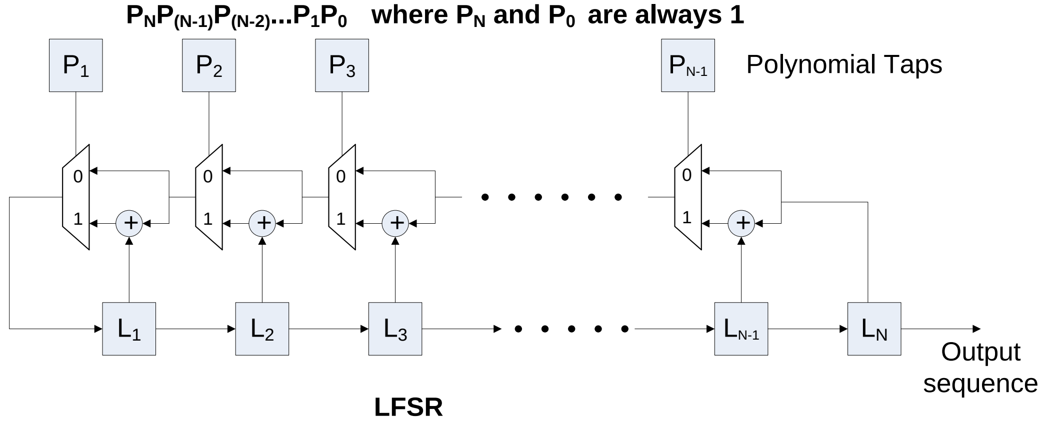


Figure 19: LFSR for code generation of maximal length sequences in Table 13

Appendix D: Alternate PN Codes that may be used by MBS, for PN code length 8191

An alternate list of PN codes for MBS is shown in Table 14, and consists of maximal length sequences. The table contains the LFSR (Linear Feedback Shift Register) polynomial taps required for code generation. For all polynomials shown in octal in Table 14, the least-significant-digit is the right-most digit.

The initial state is the same for all PRNs, and in octal form is 17777. Generation of these codes is done using an LFSR as shown in Figure 19, with N=13.

Table 14: Alternate optional PN Codes used by MBS, based on maximal length sequences of length 8191

Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)
1	20033	44	24417	87	32275
2	20157	45	24477	88	32333
3	20273	46	24567	89	32371
4	20451	47	24765	90	32461
5	20553	48	25161	91	32467
6	20627	49	25173	92	32517
7	21045	50	25245	93	32535
8	21171	51	25353	94	32563
9	21263	52	25363	95	32671
10	21367	53	26041	96	33133
11	21447	54	26215	97	33235
12	21615	55	26225	98	33325
13	21771	56	26327	99	33433
14	22051	57	26341	100	33471
15	22075	58	26431	101	33523
16	22141	59	26457	102	33631
17	22155	60	26617	103	34047
18	22235	61	26761	104	34261
19	22301	62	26775	105	34311
20	22411	63	27051	106	34341
21	22631	64	27227	107	34371
22	22657	65	27337	108	34713
23	22675	66	27427	109	35057
24	22717	67	27515	110	35141

Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)	Index	PN Code Polynomial (octal)
25	23021	68	27531	111	35163
26	23077	69	27625	112	35323
27	23113	70	27645	113	35325
28	23131	71	27657	114	35421
29	23173	72	27777	115	35453
30	23231	73	30117	116	35455
31	23261	74	30177	117	35477
32	23365	75	30301	118	35545
33	23473	76	30323	119	35557
34	23563	77	30417	120	35631
35	23571	78	30515	121	35645
36	23641	79	30733	122	35651
37	23713	80	31035	123	35777
38	24043	81	31145	124	36025
39	24061	82	31273	125	36703
40	24165	83	31303	126	37005
41	24325	84	31701	127	37445
42	24343	85	32033	128	37475
43	24411	86	32231		

References

[1] IS-GPS-200, Revision D, Navstar GPS Space Segment/Navigation User Interfaces, 7 March, 2006.
[2] FCC Code of Federal Regulations, Title 47, Part 90 Subpart M, 1 October 2010.
[3] WGS84, “Department of Defense World Geodetic System 1984”, Third Edition, 4 July 1997.