2. TECHNICAL REQUIREMENTS

2.1 Beacon Functional Elements

This section defines requirements for the functional elements of spread-spectrum 406 MHz distress beacons.

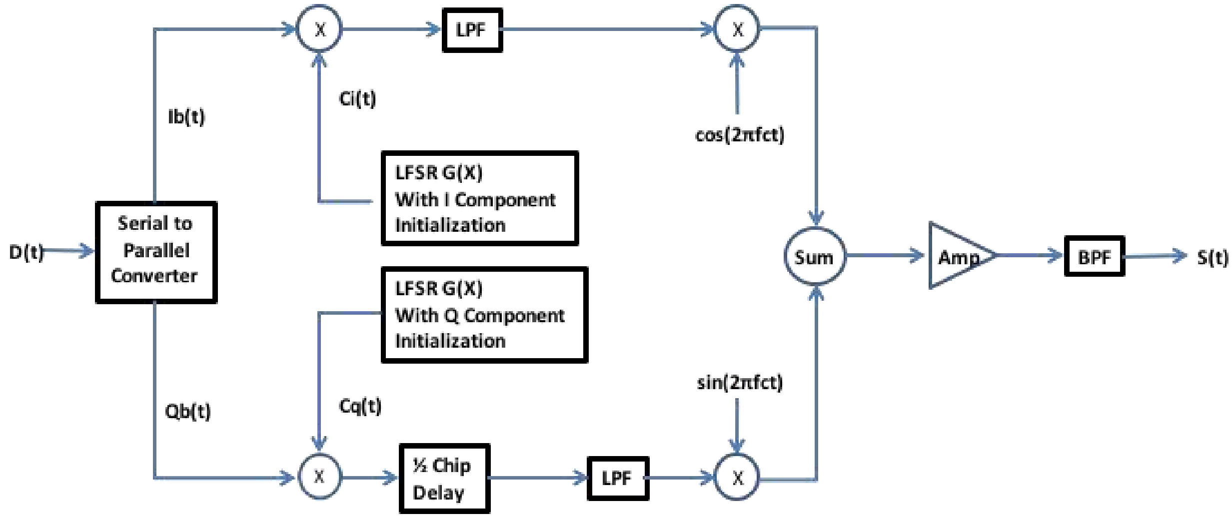
2.1.1 Transmitter Notional Functional Block Diagram

This section contains a notional functional diagram which describes the features which are described in greater detail by later sections of this document.

Figure 2-1 illustrates a notional Direct Sequence Spread Spectrum - Offset QPSK (DSSS-OQPSK) high level transmitter functional block diagram which may be used to better understand one possible implementation of the beacon signal design. In this figure:

- D(t) is the linear bit stream for each beacon burst running at 300 bits/second.
- D(t) is split into parallel bit streams Ib(t) and Qb(t) made up of odd and even bits from D(t) running at 150 bps each
- A Linear Feedback Shift Register (LFSR) function produces the two different chipping segments Ci(t) and Cq(t) using the common generator polynomial G(X). Each chipping segment runs at 38,400 chips/second. Each of Ci(t) and Cq(t) is produced by the LFSR function using the specified unique I or Q channel LFSR initialization, and is reproduced identically for each beacon burst for a given beacon mode of operation.
- Ib(t) and Qb(t) are separately mixed with their respective different chipping segments. The resultant on each channel can change state every chip period.
- The resultant of the mixing on the Q component is then delayed by ½ chip period.
- Both I and Q channels may then be low pass filtered (if necessary) and modulated onto cosine and sine sinusoids.
- The two modulated sinusoids are then summed.
- The summation resultant is amplified, band pass filtered (if necessary), and then transmitted as the outgoing beacon burst signal S(t).

Because the I and Q resultants are offset by ½ chip period from each other, when summed, the resulting signal S(t) is bounded to a maximum phase shift of 90 degrees to help minimize amplitude envelope variation.



D(t) = digital message bit stream (300 bps)
Ib(t) = I component (odd) bit stream (150 bps)
Qb(t) = Q component (even) bit stream(150 bps)
LFSR = Linear Feedback Shift Register Function
G(x) = generator polynomial
Ci(t) = I component chipping stream generated by LFSR using I channel initialization (38,400 cps)
Cq(t) = Q component chipping stream generated by LFSR using Q channel initialization (38,400 cps)
fc = carrier frequency
LPF = low pass filter (if needed)
BPF = band pass filter (if needed)
S(t) = transmitted signal

Figure 2-1: Notional DSSS-OQPKS Transmitter Functional Block Diagram

2.2 Digital Message Generator

The digital message generator will key the modulator and transmitter so that the message defined in section 3 is transmitted. This section describes the structure of the proposed signal.

2.2.1 Burst Transmission Interval

From beacon activation a total of 6 initial transmissions shall be made separated by fixed[*] 5s +0 /-0.2s intervals. The first transmission shall commence within 5 seconds of beacon activation[†], except for EPIRBs, where it shall commence within 8 seconds of beacon activation.

The beacon shall then transmit 59 bursts at nominally 30 second intervals. The time between the start of two successive transmissions (T_R) shall be randomized with uniform (flat) distribution around the stated nominal value, so that intervals between the start of two successive transmissions are randomly distributed over ± 5 seconds. The standard deviation over the 59 successive bursts of T_R shall be greater than 2.5 seconds. The minimum value of T_R observed over the 59 successive bursts shall be

[*] In this context, "fixed" refers to a repetition period which may vary within the tolerances allocated, and that no deliberate randomization within this range is required.

[†] Beacon activation is defined as the point in time at which the initiation of the activation event of the beacon occurs. E.g., the activation events include pressing of the "ON" button, water sensor immersion, the start of a shock, or deformation.

between 25.0 and 25.2 seconds, the maximum value of T_R observed over the 59 successive bursts shall be between 34.8 and 35.0 seconds.

Transmissions shall then occur at nominally 120 second intervals. The time between the start of two successive transmissions (T_R) shall be randomized with uniform (flat) distribution around the stated nominal value, so that intervals between the start of two successive transmissions are randomly distributed over ± 5 seconds. The standard deviation over the first 50 successive bursts of T_R shall be greater than 2.5 seconds. The minimum value of T_R observed over the 50 successive bursts shall be between 115.0 and 115.2 seconds, the maximum value of T_R observed over the 50 successive bursts shall be between 124.8 and 125.0 seconds.

For ELT DT transmission the first transmission shall commence within 5 seconds of beacon activation. From beacon activation a total of 24 initial transmissions shall be made separated by fixed* 5 seconds + 0.0 / - 0.2 intervals. These transmissions shall be followed by 18 transmissions separated by fixed 10 seconds + 0.0 / - 0.2. After the first 42 transmissions, ELT (DT) transmissions shall continue at nominal intervals of 28.5 seconds until the end of the ELT (DT) operating lifetime. The time between the start of two successive transmissions (T_R) shall be randomized with uniform (flat) distribution around the stated nominal value, so that intervals between the start of two successive transmissions are randomly distributed over ± 1.5 seconds. The standard deviation over the first 73 successive bursts of T_R shall be greater than 0.8 seconds. The minimum value of T_R observed over the 73 successive bursts shall be between 27.0 and 27.2 seconds, the maximum value of T_R observed over the 73 successive bursts shall be between 29.8 and 30.0 seconds.

For RLS Type 3 two-way communication (TWC) (message) capable beacons, from beacon activation a total of 6 initial transmissions shall be made separated by fixed 5s +0 /-0.2s intervals. The first transmission shall commence within 5 seconds of beacon activation, except for EPIRBs, where it shall commence within 8 seconds of beacon activation.

The beacons with RLS Type 3 TWC functionality shall then transmit 119 bursts at nominally 30 second intervals. The time between the start of two successive transmissions shall be randomized with uniform distribution around the stated nominal value, so that intervals between the start of two successive transmissions are randomly distributed over ± 5 seconds.

Transmissions shall then occur at nominally 120 second intervals. The time between the start of two successive transmissions (T_R) shall be randomized with uniform (flat) distribution around the stated nominal value, so that intervals between the start of two successive transmissions are randomly distributed over ± 5 seconds.

The transmission schedule is summarized in Table 2.1.

* In this context, "fixed" refers to a repetition period which may vary within the tolerances allocated, and that no deliberate randomization within this range is required.

Table 2.1: Transmission Schedule

IAMSAR Stage	Nominal Time from Activation	Transmission Nominal Repetition Interval	Randomization
Initial	0 to 30* Seconds	5 Seconds	0
Action / Planning	30* Seconds to 30 minutes	30 Seconds	± 5 Seconds
	30 minutes +	120 Seconds	± 5 Seconds
ELT (DT)	0 to 120 Seconds	5 Seconds	0
	120 to 300 Seconds	10 Seconds	0
	300 Seconds +	28.5 Seconds	± 1.5 Seconds
RLS Type 3 Two-Way Communication (Message) service	0 to 30* Seconds	5 Seconds	0
	30* Seconds to 60 minutes	30 Seconds	± 5 Seconds
	60 minutes +	120 Seconds	± 5 Seconds

2.2.2 Total Transmission Time

The total transmission time of each burst, measured at the 90 percent power points, shall be 1000 ms ±1 ms.

2.2.3 Direct Sequence Spread Spectrum

The digital message shall be spread using two truncated segments of a common PRN (Pseudo-Random Noise) maximum length sequence (m-sequence) producing symbols known as "chips". These sequence segments shall be deterministic and must be known by the receiver.

The two truncated spreading PRN segments shall:

a) be applied separately to the full duration of each beacon burst transmission with one segment applied to the in-phase (I) component and the other applied to the quadrature (Q) component of the signal;

b) be transmitted as separate odd and even bits, starting with 1 as the first bit. Odd bits are transmitted through the I channel and even bits the Q channel. For each bit, 256 chips are taken from the PRN sequence such that a 0 bit is represented by the non-inverted sequence and a 1 by the inverted sequence, equivalent to an exclusive-OR operation (XOR). The I and Q signal components are spread separately, each by a factor of 256 (with half-chip offset as shown in section 2.3.3). Then when the I and Q channels are combined the overall spreading factor is 128 chips/bit.

c) be generated by a method equivalent to a Linear Feedback Shift Register (LFSR) using the same generator polynomial G(x) = X23 + X18 +1 (see Figure 2-2);

d) be generated in matched pairs for the I and Q components defined in Table 2.2 for each beacon mode;

* For EPIRBs this value is 33 seconds.

e) be truncated to the first 38,400 chips of the m-sequence generated using the prescribed initialization values for each of the I and Q components with a 1/2 chip period delay imposed on the Q component relative to the I component (refer to section 2.3.3);

f) be applied to both I and Q components for the full one second duration of each beacon burst transmission including preamble, information bits, and error correction bits, to give a chipping rate of 38,400 chips/second for each component (see 2.3.1.2 for further details); and

g) be identical for each beacon burst transmission for any given burst mode.

Note that this spreading scheme method in fact allows for multiple possible non-overlapping matched I and Q component chipping segment pairs, with each segment in each pair truncated to 38,400 chips. The number of possible segments, 218, is determined by dividing the full m-sequence length for the generator polynomial, by the truncated segment length, $((2^{23})-1)/38{,}400 = 218$ segments. Non-overlapping pairs of segments can be selected from this set of 218 segments.

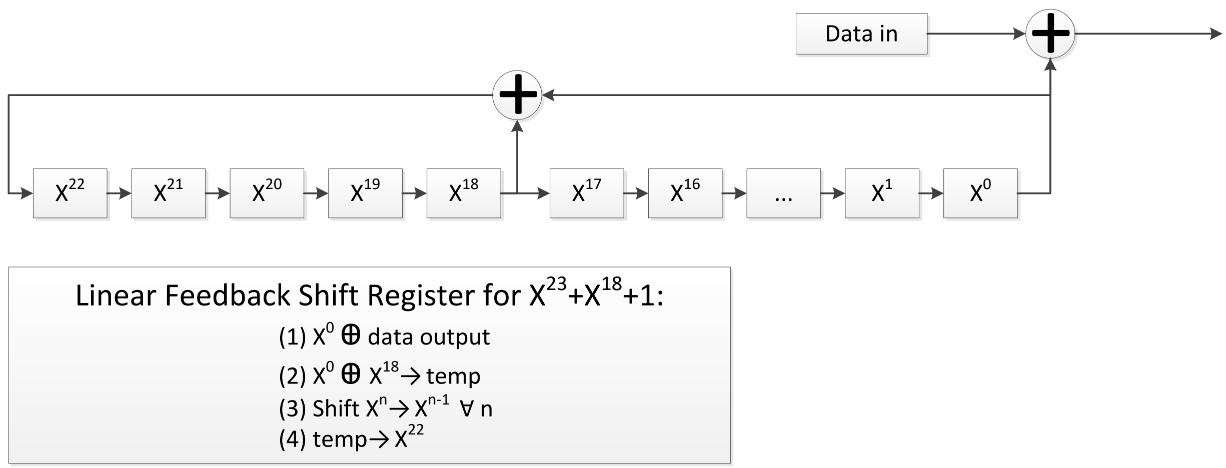


Figure 2-2: Linear Feedback Shift Register

The beacon shall be able to generate multiple PRN sequences segments, such as normal mode and self-test mode, according to Table 2.2. In order to generate these PRN sequences segments, the beacon may use a LFSR with multiple initialization values for PRN sequence segment generation. Table 2.2 provides the generator polynomial initialization LFSR values for I and Q components for beacon normal mode operation and for beacon self-test mode operation. In this table, registers are labelled from 0 to 22. The registers shift from left to right the output from register 0. For clarity, the feedback taps to be XOR'd are indicated in the table and match with the characteristic polynomial. The output chip is taken from register 0. The table also provides the first 64 chips in the order of generation from the LFSR. The 64 chip binary sequence has been displayed in hexadecimal format as demonstrated in the example below the table with the leftmost chip in sequence being the first output. The LFSR implementation (with associated initialization) leads to the correct generation of the whole 38 400 chips sequence, which can be verified to a high degree of confidence by confirming a perfect match of the first 64 chips given in Table 2.2.

Table 2.2: PRN Sequence Initialization Values

Register	*22*	*21*	*20*	*19*	*18*	*17*	*16*	*15*	*14*	*13*	*12*	*11*	*10*	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*	*0*					
XOR					1																		1		**Output *chip* sequence**			
	Register Initial Setting																								*1st*			*64th*
Normal I	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	→	8000	0108	4212	84A1
Normal Q	0	0	1	1	0	1	0	1	1	0	0	0	0	0	1	1	1	1	1	1	1	0	0	→	3F83	58BA	D030	F231
Self Test I	1	0	1	0	0	1	0	1	1	0	0	1	0	0	1	1	1	1	1	0	0	0	0	→	0F93	4A4D	4CF3	028D
Self Test Q	0	1	1	1	1	0	0	1	1	1	0	1	0	0	1	0	0	1	0	1	0	0	0	→	1497	3DC7	16CD	E124

An example of the generation of the 64 first chips of the normal I-component is given in Appendix D.

The correspondence between the logic level of the chips used to modulate the signal and the signal level is given in Table 2.3:

Table 2.3: Logic to Signal Level Assignment

Logic Level	Signal Level
1	-1.0
0	+1.0

2.2.4 Preamble

The initial 166.7 ms of the transmitted signal shall consist of the combination of the first 6400 chips of the two PRN code segments (each segment 38,400 chips long for the entire burst) used to spread the I and Q message components as illustrated in Figure 2-3. There will be no useful information encoded on either the I or Q components during the preamble. I and Q component information bits shall all be set to '0' during the preamble.

2.2.5 Digital Message

The remaining 833.3 ms of the transmitted signal shall contain a 250-bit message and will be at a nominal bit rate of 300 bps.

2.2.6 Message Content

The content of the 250 bit message is defined in section 3.

The 250 bit message is composed of two parts:

a) the useful message: 202 bits containing the information transmitted by the beacon.

b) the error correction bits: 48 bits BCH(250,202) containing bits used for error correction at reception.

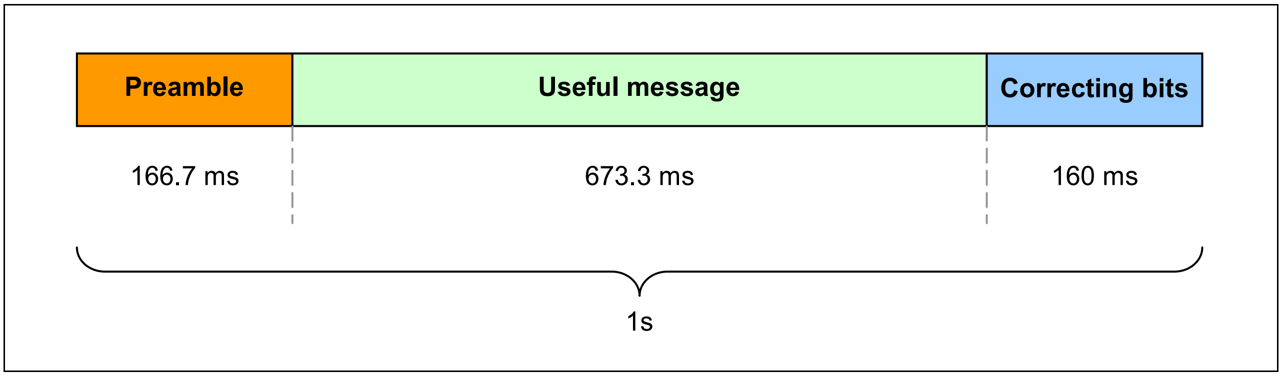


Figure 2-3: Burst general structure

2.2.7 In-Phase (I) and Quadrature-Phase (Q) Components

The odd bits of the 250-bit message are used to generate the in-phase (I) component of the message, while the even bits are used to generate the quadrature-phase (Q) component of the message. The bit rate for each channel will nominally be 150 bits/sec.

Each component starts with a 6400 chip preamble described in section 2.2.4 and is spread with the PRN code segment described in section 2.2.3 as shown in Figure 2-4.

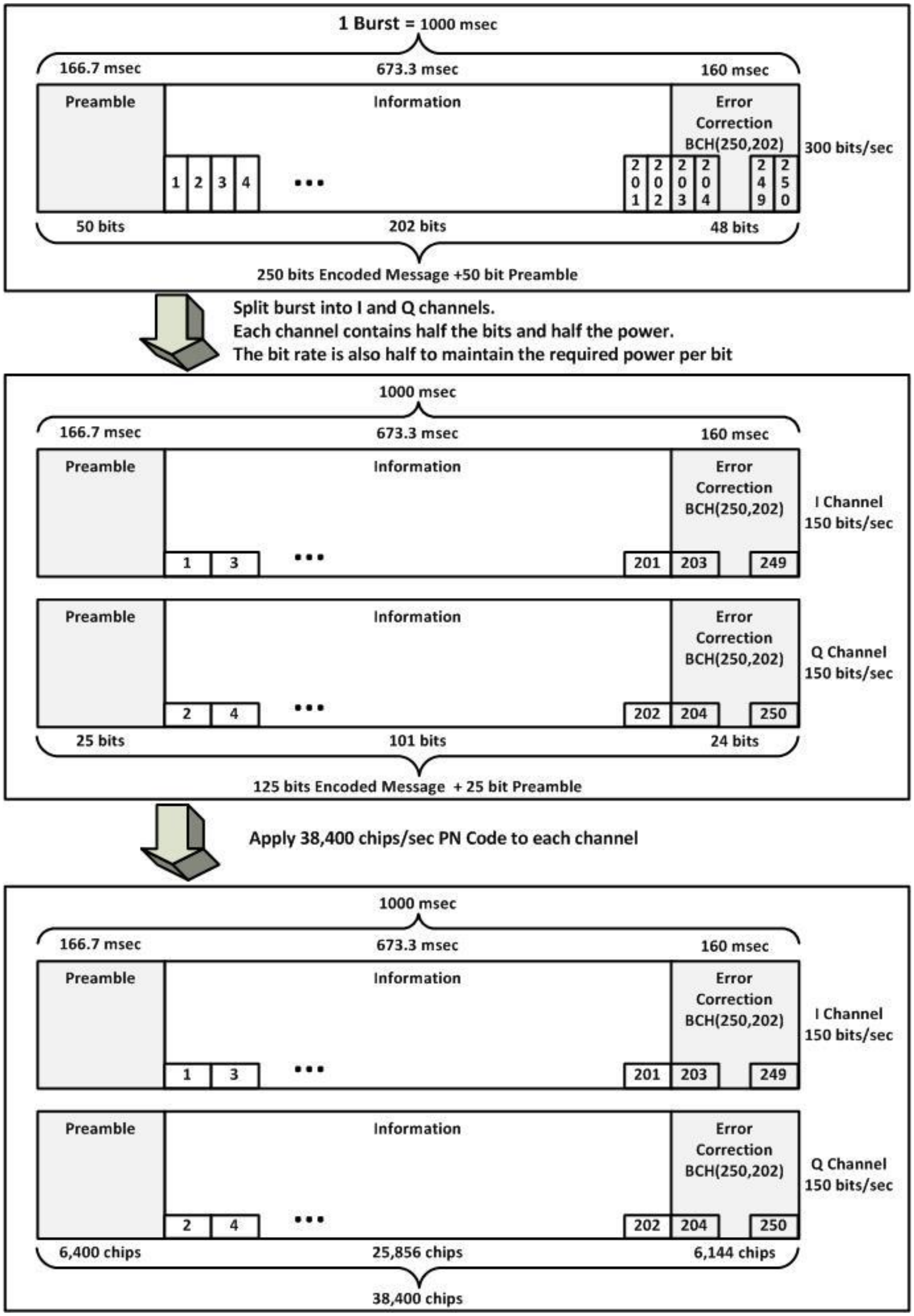


**Figure 2-4: I and Q Component Message Structure*

* The 50 bits included in the preamble contain no data and are set to "0"

The preamble and any bits allocated as ‘0’ are represented by the PRN sequence, and bits allocated as ‘1’ are sent as the PRN sequence inverted for the duration of the bit as shown in Table 2.4. This is the method of modulating data onto the PRN sequence.

Table 2.4: Bit to PRN Sequence Assignment

Bit	PRN Sequence
1	Inverted
0	Normal

2.3 Modulator and 406 MHz Transmitter

2.3.1 Transmitted Frequency

The following sections define the frequency stability requirements for the Carrier Frequency and the Chip Rate. The specifications for the carrier frequency and the chip rate may be decoupled by using separate oscillators.

2.3.1.1 Carrier Frequency Offset/Drift over aging, thermal, shock and vibration

a) Long Term Stability Requirement

The carrier frequency tolerance shall be 406.05 MHz ±1200 Hz over 5 years or the manufacturers’ declared beacon maintenance period*, whichever is greater; and

b) Short Term Stability Requirement

This requirement applies throughout the operating temperature range and during situations of temperature shock.

The maximum allowable carrier frequency variation shall be 7.4 ppb when measured over 166.7 msec within the burst.

2.3.1.2 Chip Rate Accuracy and Variation

The average chip rate shall be 38 400 ± 0.6 chips/s.

The variation of the chip rate shall be ± 0.6 chips/s^2.

These values shall be met both when measuring over the preamble and on the entire burst.

* The beacon maintenance should include validation of the frequency stability of the beacon.

2.3.2 Spurious Emissions

The in-band spurious emissions shall not exceed the levels specified by the signal mask in Figure 2-5, when measured in a 100 Hz resolution bandwidth.

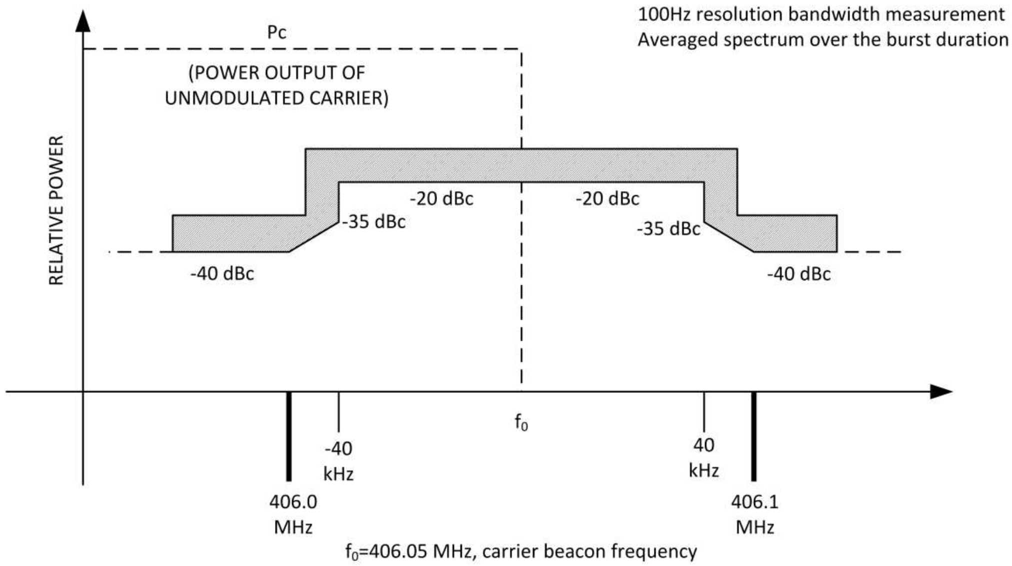


Figure 2-5: Spurious emission mask

Furthermore, out of band emissions must be limited to less than 1% of the total transmitted power*.

2.3.3 Modulation and Waveform

The RF modulation is Offset Quadrature Phase Shift Keying (OQPSK). The PRN sequences for the in-phase (I) and quadrature (Q) components of the signal are defined in section 2.2.3. The chips of the I and Q components shall have an average offset of half a chip period ± 1% of the chip period over the entire burst with I leading Q by one-half a chip period. In the constellation diagram shown below, it can be seen that this will limit the phase-change to no more than 90° at a time. The peak to peak amplitude of the I and Q components shall be on average within 15% of each other over the entire burst. The Error Vector Magnitude (EVM) of the constellation points away from ideal, measured at symbol level, shall be less than 2.5 % when measured over the entire burst.

Acceptable types of filters that may be used to produce an output waveform include half-sine (i.e., IEEE 802.15.4, Section 12.2.6), or root-raised cosine ([0.8 +/- TBD] roll-off factor may be used). If other output filters are being considered for use, the Cospas-Sarsat Secretariat must be consulted in advance so that they can consult with the Parties regarding the filter's acceptability.

The figure below illustrates the OQPSK modulation mid-burst including the one-half chip delay on the Q channel. In this figure, T represents the chip period.

* The 1% out of band emission is extracted from the recommendation ITU-R SM.1541-4, article 1.153

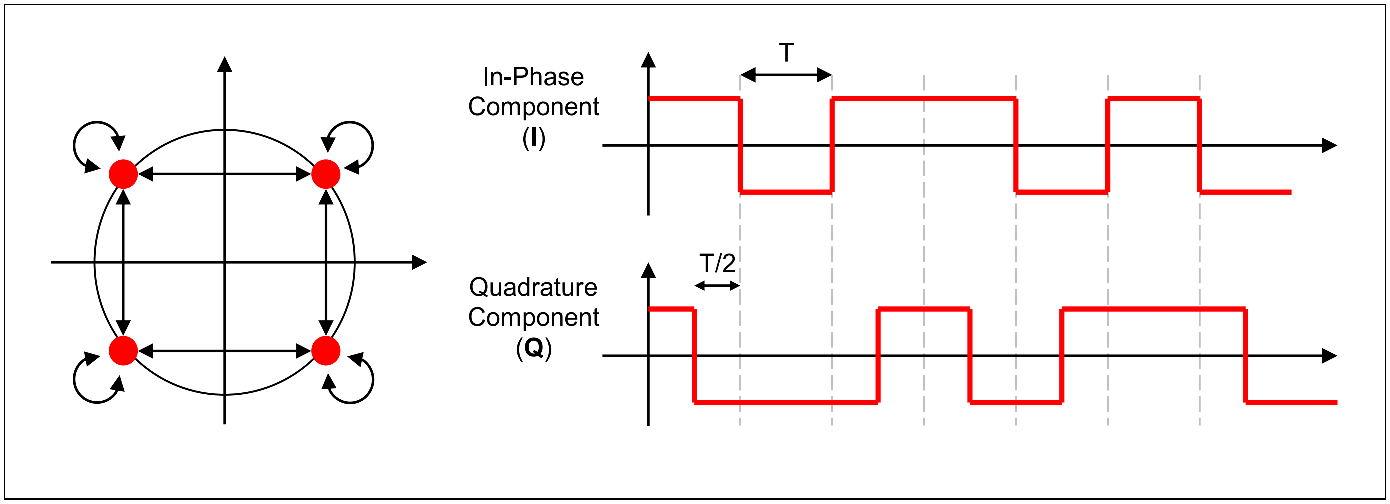


Figure 2-6: OQPSK modulation illustration

2.3.4 Voltage Standing-Wave Ratio

The modulator and 406 MHz transmitter shall be able to meet all requirements within this standard at any VSWR between 1:1 and 3:1, and shall not be damaged by any load from open circuit to short circuit.

2.3.5 Maximum Continuous Transmission

The distress beacon shall be designed to limit any inadvertent continuous 406 MHz transmission to a maximum of 45 seconds.

2.4 Transmitter Power Output

2.4.1 Transmitter Rise Time

The transmitter RF output power shall not exceed -10 dBm prior to 25 ms before the commencement of, or 25 ms after the end of, any 406 MHz burst. Power output rise time shall be less than 0.5 ms measured between the 10% and 90% power points. Preamble content shall be transmitted during the power rise time. Power output fall time shall be less than 0.5 ms between the 90% and the 10% power points.

Between 25 ms after the end of any 406 MHz burst until 25 ms before the commencement of the next 406 MHz burst the power level in the 406.0 to 406.1 MHz frequency band shall not exceed -10 dBm.

2.4.2 Effective Isotropic Radiated Power (EIRP)

Power output is defined in terms of EIRP, not power into a 50-ohm load. Required EIRP varies with elevation angle according to the table below. Greater than 65% of measured EIRP values shall meet the limits shown. In addition, 90% of the measured EIRP values shall meet the limits shown at elevation angles below 55 degrees, except for ELT(DT)s, or ELTs used in combination with automatic deployable flight recorders.

Table 2.5: Required EIRP

Elevation (°)	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
Max dBm	45	45	45	45	45	45	45	45	45	44	44	44	44	44	44	44
Min dBm	34	34	34	34	34	34	34	34	34	34	34	33	33	33	33	33

The horizontal (azimuth) antenna pattern should be substantially omnidirectional and shall remain within the minimum and maximum values of EIRP provided in the above table.

Power output shall be maintained within the above limits throughout the minimum operating lifetime of the beacon at any temperature throughout the operating temperature range. Changes in beacon output power due to for example temperature and operation over the beacons minimum lifetime when operating into a 50-ohm test load shall be taken into account during determination of compliance with the minimum and maximum EIRP limits.

2.4.3 Antenna Characteristics

Antenna polarization shall be either circular (RHCP) or linear. Antenna pattern should be hemispherical and should include coverage at high elevation angles, subject to the EIRP limits given in section 2.4.2 (effective isotropic radiated power). An ideal antenna pattern is shown below for illustration purposes.

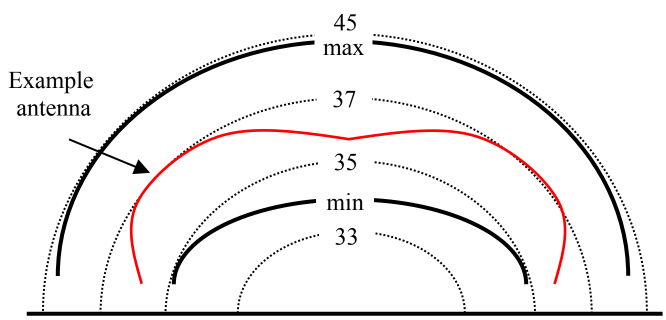


Figure 2-7: Ideal Antenna Pattern

Remote antennas or detachable antennas shall always be approved with a beacon.

The following different types of antenna may be specified for use with a 406 MHz beacon:

<u>External Antenna</u>
An antenna that is external to the casing of the beacon and that is permanently attached to the beacon and that cannot be removed by the user.

<u>Detachable Antenna</u>
An antenna that is external to the casing of the beacon and that is attached directly to the beacon by such means as an RF connector without any intermediate cable which can be removed and replaced by the user.

Detachable antennas when measured directly at the antenna feed point shall achieve a VSWR not greater than 1.5:1 referred to 50Ω.

<u>Internal Antenna</u>
An antenna that is contained within the case of the beacon where the user has no access to the antenna.

<u>Remote Antenna</u>
An antenna that is external to the casing of the beacon and which is remote from the beacon, being attached to it by means of an RF cable. The antenna and the RF cable may be permanently attached to the beacon (in this case the type and length of the antenna cable is fixed and is as supplied by the beacon manufacturer) or one or both parts (antenna or cable) may be varied by the user or the installer (in this case the type and length of the antenna cable may vary).

In either case, remote antennas, when measured directly at the antenna feed point, shall achieve a VSWR not greater than 1.5:1 referred to 50Ω.

<u>Remote Antenna without an Integrated Cable</u>

In this configuration (e.g., an ELT installed in an aircraft) there may be more than one type of approved antenna and the length and type of cable between the antenna and beacon may vary.

The characteristic impedance and minimum and maximum loss of the antenna feed cable shall be specified by the beacon manufacturer. The combined beacon, antenna and cable shall meet the EIRP requirements in section 2.4.2 (effective isotropic radiated power) when operating with the minimum and maximum stated cable loss between the antenna and the beacon.

<u>Remote Antenna with an Integrated Cable</u>

In this configuration (e.g., a military PLB with a body worn antenna) the antenna and cable combination is fixed and supplied by the beacon manufacturer (although there maybe more than one approved combination for different applications) and the length and type of cable between the antenna and beacon cannot be changed.

This combination utilising a specific manufacturer supplied integrated antenna cable shall be tested with that cable.

All antennas and cabling arrangements to be approved with a beacon shall be specified by the manufacturer and shall meet all the requirements of section 2.4.

2.5 406 MHz Homing Transmitter

The distress beacon may transmit a 406 MHz Homing signal as defined in this section*. However ELT (DT)s are not required to provide a 406-MHz homing signal.

- END OF SECTION 2 -

* A CW unmodulated 406-MHz homing and on-scene locating signal is under development with details to be provided in a future update to T.018 and will be centered at 406.050 MHz, ± 2 kHz, at a power level, repetition rate, and pulse width to be determined.