The Consultative Committee for Space Data Systems

Draft Recommendations for
Space Data System Standards

RADIO FREQUENCY AND MODULATION SYSTEMS— PART 1: EARTH STATIONS AND SPACECRAFT

DRAFT RECOMMENDED STANDARD

CCSDS 401.0-P-26.1

PINK SHEETS
March 2017

The Consultative Committee for Space Data Systems

Draft Recommendations for Space Data System Standards

RADIO FREQUENCY AND MODULATION SYSTEMS—PART 1: EARTH STATIONS AND SPACECRAFT

DRAFT RECOMMENDED STANDARD

CCSDS 401.0-P-26.1

PINK SHEETS

March 2017

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 401.0-P-26.1	Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft, Draft Recommended Standard, Issue 26.1	March 2017	Current draft: – updates recommendations 2.4.18 and 2.5.6B.

NOTE – Only pages containing changes to the existing recommendations are included.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH

The CCSDS,

considering

(a) that efficient use of RF spectrum resources is becoming increasingly important with the increasing congestion of the frequency bands;

(b) that the 8025-8400 MHz band is heavily used and interference conflicts may become increasingly frequent in this band;

(c) that the SFCG has approved a Recommendation[1] ~~–~~which specifies a spectrum mask for emissions with symbol rates below and above 2 Ms/s;

(d) that the SFCG has approved a Recommendation[2] on the use of the 8025-8400 MHz band recommending that bandwidth- and power-efficient modulation and coding techniques be used;

(e) that CCSDS 131.0-B-2, CCSDS 131.2-B-1, and CCSDS 131.3-B-1 foresee a number of coding schemes, some of which may be incompatible with the bandwidth-efficient use of the 8025-8400 MHz band;

(f) that contiguous to 8400 MHz, a particularly sensitive allocation to Space Research, deep space, requires adequate protection from unwanted emissions generated by EES;[3]

(g) that only filtered suppressed carrier systems can meet the bandwidth efficiency of SFCG spectrum mask Recommendation for symbol rates in excess of 2 Ms/s and limit unwanted emissions into the neighboring bands;[1]

(h) that Square Root Raised Cosine (SRRC) filtered 4-Dimensional 8~~–~~PSK Trellis Coded Modulation (SRRC-4D 8PSK TCM),[4] ~~Square Root Raised Cosine filtered~~SRRC-QPSK, SRRC-OQPSK, SRRC-8PSK~~ bit interleaved coded modulation (8PSK BiCM),[5] GMSK,~~ SRRC-16APSK, SRRC-32APSK, and SRRC-64APSK,[6] and some filtered OQPSK[7] modulations spectra can meet the SFCG emission mask for symbol rates in excess of 2 Ms/s with acceptable end-to-end losses;

---

[1] See SFCG Recommendation 21-2R~~2~~4 or latest version.

[2] See SFCG Recommendation 14-3R~~7~~10 or latest version.

[3] See SFCG Recommendation 14-1R1 or latest version.

[4] Square Root Raised Cosine ($\alpha = 0.35$ and $\alpha = 0.5$) 4D 8PSK Trellis Coded Modulation. See Annex 1.

~~[5] See CCSDS 131.2-B-1 and 131.3-B-1 or latest version.~~

[6] ~~Gaussian Minimum Shift Keying (BTS = 0.25), with precoding as in figure 2.4.18-1 (see CCSDS 413.0-G-2). B refers to the one-sided 3-dB bandwidth of the filter~~Square Root Raised Cosine with α = 0.2, 0.25, 0.3, and 0.35 (see Annex 2).

[7] Filtered (Square Root Raised Cosine $\alpha = 0.5$) Offset QPSK; Butterworth 6 poles, $BT_S = 0.5$; agencies may also utilize filtered OQPSK modulation with other types of bandpass filters provided that the equivalent baseband BT_S is not greater than 0.5 and they ensure compliance with SFCG Recommendation 21-2R~~2~~4 (or latest version) and interoperability with the cross-supporting networks. B refers to the one-sided 3-dB bandwidth of the filter.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

~~(i) that since GMSK modulation is inherently differential in nature, the use of GMSK with precoding is necessary to optimize bit error rate performance;~~

~~(j) that SRRC 4D 8PSK TCM and SRRC 8PSK BiCM offer better link performance than uncoded GMSK and filtered Offset QPSK for the same or better bandwidth efficiency;~~

~~(k) that current technology allows implementing and processing of SRRC 4D 8PSK TCM and SRRC 8PSK BiCM modulations at the rates required in the band;~~

~~(l) that baseband filtered OQPSK receivers are readily available in most space agencies' ground networks;~~

~~(m) that baseband filtered 8PSK receivers (suitable for both SRRC 4D 8PSK TCM and SRRC 8PSK BiCM) are readily available through a number of vendors;~~
(j) that baseband filtered QPSK, OQPSK, and 8PSK receivers are readily available in most space agencies' ground networks;

(j) that baseband filtered higher-order-modulations receivers are readily becoming available through a number of vendors;

(k) that a phase imbalance of less than 3 degrees and an amplitude imbalance of less than 0.5 dB should result in acceptable performance degradations;

l) that a channel with in-band ripple up to 0.1 dB, out-of-band rejection of at least 30 dB, and in-band (within channel symbol rate) group-delay variations up to 10 percent of the signal duration[8] should result in acceptable performance degradations even in case no equalization is used at the receiver;

noting

(1) that ~~GMSK or~~ filtered OQPSK signals can also be demodulated by unfiltered OQPSK receivers with some mismatching losses;[9]

(2) that many missions are currently operating in this band with a signaling efficiency[10] over 1.75 source bits/channel symbol;

~~(3) that the constellation bit mappings for SRRC 4D 8PSK TCM[10] and SRRC 8PSK BiCM[11] are different;~~
(3) that recommended maximum values of phase noise and HPA linearity are needed to ensure small end-to-end losses;

(4) that linearization techniques (pre-distortion) or compensation (equalization, centroid tuning) or both can reduce the channel losses, especially for APSK modulations;

[8] 1 ns at 100 Ms/s (channel symbol rate).
[9] See annex B.4 of CCSDS 413.0-G-2 for ~~GMSK,~~ SRRC~~,~~ and Butterworth filtered OQPSK mismatching losses.
[10] Ratio of source data rate to channel symbol rate.
~~[10] Available options are 2.0 b/s/Hz, 2.25 b/s/Hz, 2.5 b/s/Hz and 2.75 b/s/Hz; Square Root Raised Cosine filter with $\alpha = 0.35$ or $\alpha = 0.5$. See Annex 1.~~
~~[11] See CCSDS 131.2-B-1 and 131.3-B-1 or latest version.~~

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

(5) that the use of a frame header and of pilot symbols can improve the acquisition time as well as tracking performance;

(6) that the constellation bit mapping for SRRC-4D 8PSK TCM[11] is natural, while constellation bit mappings for SRRC-8PSK, SRRC-16APSK, SRRC-32APSK, and SRRC-64APSK are Gray coded and are different in CCSDS 131.2-B-1 and CCSDS 131.3-B-1;

recommends

(1) that a mission planning to operate in the 8025-8400 MHz band shall use SRRC-4D 8PSK TCM[11] or ~~SRRC 8PSK BiCM[12] or GMSK~~SRRC-QPSK, SRRC-OQPSK, SRRC-8PSK, SRRC-16APSK, SRRC-32APSK, and SRRC-64APSK[13] or filtered OQPSK;~~[14,]~~[15]

(2) that a mission planning to use this band should select the most bandwidth-efficient channel coding scheme from CCSDS 131.0-B-2 or 131.2-B-1 or 131.3-B-1 compatible with the mission constraints;

~~(3) that the phase noise for all the oscillators of the SRRC-4D 8PSK TCM[16] and SRRC 8PSK BiCM[17] communication chain shall be limited according to the mask given in figure 2.4.18-13 for channel symbol rates from 1 Ms/s up to 100 Ms/s.~~

(3) that Variable Coding and Modulation (VCM) or Adaptive Coding and Modulation (ACM) techniques should be used where practicable;[16]

(4) that linearization techniques (pre-distortion) at the transmitter or compensation (such as equalization or centroid tuning) at the receiver should be used to minimize the end-to-end losses at least for 16APSK and higher order modulations, and in any case if the channel is worse than in considering (k);

---

[11] Available options are 2.0 b/s/Hz, 2.25 b/s/Hz, 2.5 b/s/Hz and 2.75 b/s/Hz; Square Root Raised Cosine filter with $\alpha = 0.35$ or $\alpha = 0.5$ (see Annex 1).

~~[12] See CCSDS 131.2-B-1 and 131.3-B-1 or latest version.~~

[13] ~~Gaussian Minimum Shift Keying ($BT_S = 0.25$), with precoding as in figure 2.4.18-1 (see CCSDS 413.0-G-2). B refers to the one-sided 3-dB bandwidth of the filter~~Square Root Raised Cosine filter with $\alpha = 0.2, 0.25, 0.3,$ and 0.35 (see Annex 2).

~~[14]Filtered (Square Root Raised Cosine $\alpha = 0.5$) Offset QPSK; baseband Butterworth 6 poles, $BT_S = 0.5$; agencies may also utilize filtered OQPSK modulation with other types of bandpass filters provided that the equivalent baseband BT_S is not greater than 0.5 and they ensure compliance with SFCG Recommendation 21-2R2 (or latest version) and interoperability with the cross-supporting networks. B refers to the one-sided 3-dB bandwidth of the filter.~~

[15] ~~CCSDS 131.2-B-1 and 131.3-B-1 allow in addition a number of higher order modulations. It is expected that a future revision of this recommendation will also include such schemes~~Filtered (Square Root Raised Cosine $\alpha = 0.5$) Offset QPSK; baseband Butterworth 6 poles, BTS = 0.5; agencies may also utilize filtered OQPSK modulation with other types of bandpass filters provided that the equivalent baseband BTS is not greater than 0.5 and they ensure compliance with SFCG Recommendation 21-2R4 (or latest version) and interoperability with the cross-supporting networks. B refers to the one-sided 3-dB bandwidth of the filter.

~~[16] Available options are 2.0 b/s/Hz, 2.25 b/s/Hz, 2.5 b/s/Hz and 2.75 b/s/Hz; Square Root Raised Cosine filter with $\alpha = 0.35$ or $\alpha = 0.5$. See Annex 1.~~

~~[17] See CCSDS 131.2-B-1 and 131.3-B-1 or latest version.~~

[16] Relative Recommended Practices (Magenta Books) are under preparation.

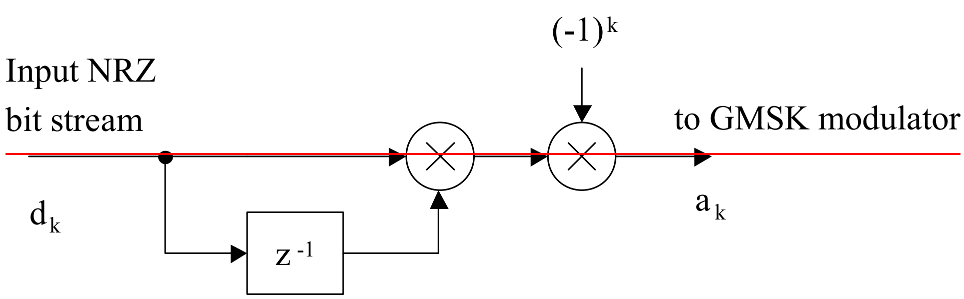
2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

(5) that a frame header (see A2.5) and pilot symbols[17] should be used to improve the acquisition and tracking performance especially for modulations with order higher than 8PSK;

(6) that the phase noise of the communication chain should be limited according to the mask given Annex 1 or Annex 2 depending on the selected scheme;[18]

(7) that the modulator's phase imbalance shall not exceed 5 degrees for SRRC-QPSK, SRRC-OQPSK, SRRC-4D 8PSK TCM, SRRC-8PSK, and SRRC-16APSK and 3 degrees for SRRC-32APSK and SRRC-64APSK, and the amplitude imbalance shall not exceed 0.5 dB between the constellation points;

(8) that the AM/PM slope for the non-linear amplifier shall be less than 5°/dB unless appropriate equalization at the receiver is performed.



~~**Figure 2.4.18-1: GMSK Precoder**~~

[17] For systems compliant with CCSDS 131.2-B-1 and CCSDS 131.3-B-1, the relevant standard should be consulted. For systems compliant with CCSDS 131.0-B-2 further work is needed.
[18] For filtered OQPSK,[14] Annex 2 applies.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 1

4-Dimensional 8-PSK Trellis Coded Modulation Definition

(Normative)

A1.1 GENERAL

The 4D-8PSK trellis-coded modulator consists of a serial-to-parallel converter, a differential coder, a trellis encoder (convolutional coder), a constellation mapper, and an 8PSK modulator (see figure 2.4.18-1). Note that in this figure, 'wi' (with index i = 1, … , m) represent the uncoded bits and 'xj' (with index j = 0, … , m) are the coded bits. The trellis encoder is based on a 64-state systematic convolutional coder and can be considered as the inner code if an outer block code is introduced. Carrier phase ambiguity is resolved by the use of a differential coder located prior to the trellis encoder. Spectral efficiencies of 2, 2.25, 2.5, and 2.75 bits/channel-symbol are achieved with four possible architectures of the constellation mapper. The output switch addresses successively one of the four symbols ($Z^{(0)} – Z^{(3)}$) from the constellation mapper to the 8PSK modulator.

The present standard is based on the following parameters:

- size of the constellation: M=8 phase states (8PSK);
- number of signal set constituents: L=4 (shown as $Z^{(0)}$ … $Z^{(3)}$ in figure 2.4.18-1);
- number of states for the trellis encoder: 64;
- rate of the convolutional coder used for the construction of the trellis: R=3/4;
- rate of the modulation: R_m=m/(m+1) selectable to 8/9, 9/10, 10/11, or 11/12;
- efficiency of the modulation:
  - R_{eff}=2 bits per channel-symbol (for R_m=8/9);
  - R_{eff}=2.25 bits per channel-symbol (for R_m=9/10);
  - R_{eff}=2.5 bits per channel-symbol (for R_m=10/11);
  - R_{eff}=2.75 bits per channel-symbol (for R_m=11/12).

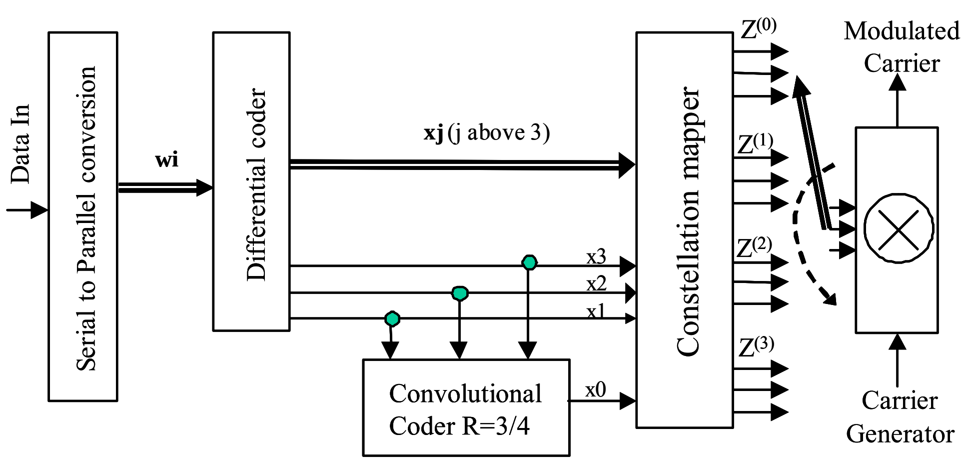


Figure 2.4.18-1: Structure of the 4D 8PSK-TCM Coder/Mapper

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 1 (Continued)

A1.3 CONVOLUTIONAL CODER

The convolutional coder used to implement the trellis is depicted in figure 2.4.18-3. The shift registers of the encoder are clocked at the rate of $R_{ChS}/4$.

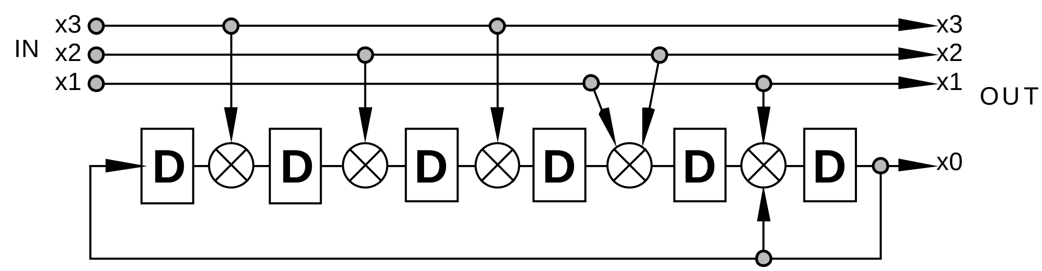
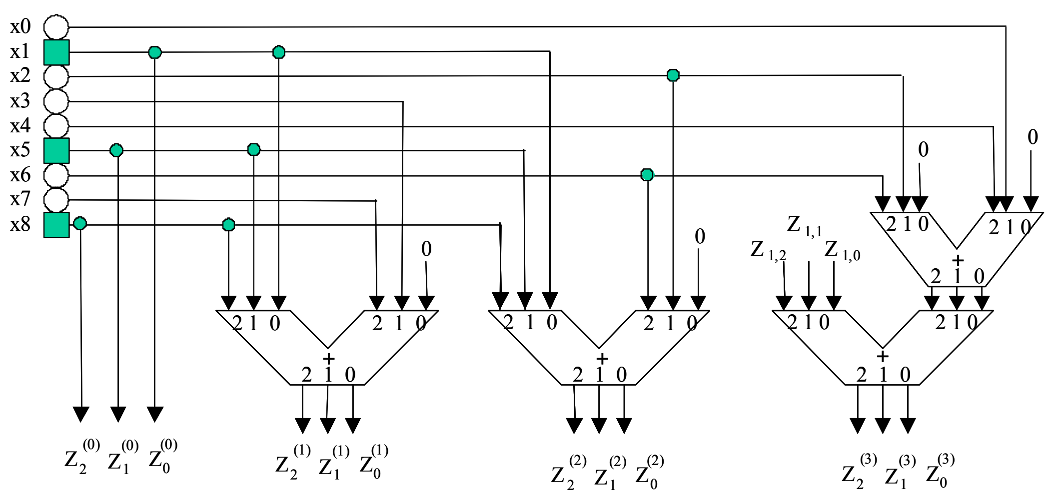


Figure 2.4.18-3: Convolutional Coder Recommended for High Data Rates

A1.4 CONSTELLATION MAPPER FOR 4D-8PSK-TCM

The constellation mapper principles are given in figures 2.4.18-4 to 2.4.18-7 for the four possible efficiencies of this modulation (i.e., 2 bits/channel-symbol, 2.25 bits/channel-symbol, 2.5 bits/channel-symbol, and 2.75 bits/channel-symbol). These mappers implement the straightforward logical mapping described in the ~~equations~~figures below. The correspondence between the signals $Z^{(i)}$ at the input of the modular and the 8PSK phase states of the constellations follows a natural mapping (i.e., 0, 1, 2 …, 7 anticlockwise).



■ = line connected to differential coder

○ = line connected to serial-to-parallel converter or convolutional coder

Figure 2.4.18-4: Constellation Mapper for 2 Bits/Channel-Symbol

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 1 (Continued)

A1.6 SRRC CHANNEL FILTERING

The normalized transfer function of the SRRC filter shall be:[19,20]

$$H(f) = 1 \qquad \text{if } |f| < f_N(1-\alpha)$$

$$H(f) = \sqrt{\frac{1}{2} + \frac{1}{2}\sin\left\{\frac{\pi}{2 f_N}\left(\frac{f_N - |f|}{\alpha}\right)\right\}} \qquad \text{if } f_N(1-\alpha) \le |f| \le f_N(1+\alpha)$$

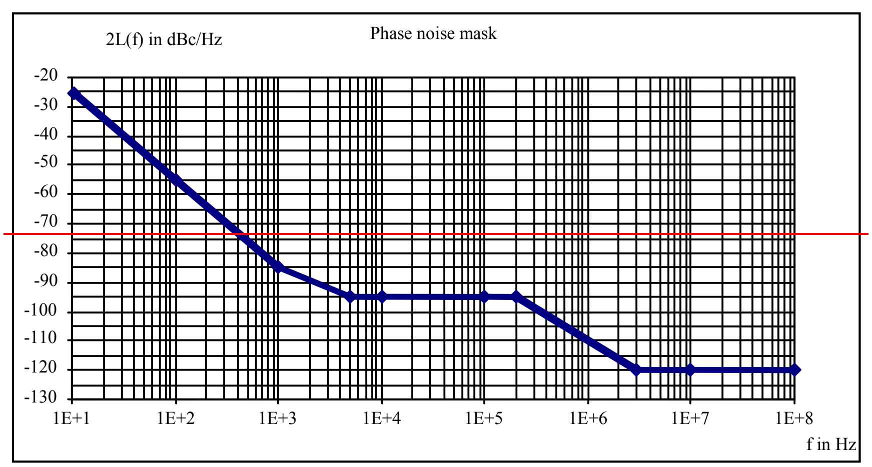
$$H(f) = 0 \qquad \text{if } |f| > f_N(1+\alpha)$$

where $f_N = 1/(2\,T_{chs}) = R_{chs}/2$ is the Nyquist frequency and α -is the roll-off factor;
The non-normalized value of H(f) can be obtained multiplying its normalized value by $\sqrt{T_{chs}}$.
The specified values for the roll-off factor are α = 0.35 and 0.5.

A1.7 PHASE NOISE

It is recommended that theThe phase noise for all the oscillators of the 8PSK communication chain shall be limited according to the mask given in figure 2.4.18-12 for channel symbol rates fromabove 1 Ms/s up to 100 Ms/s.

NOTE – The figure shows the double sided phase noise mask 2L(f) in dBc/Hz versus frequency in Hz.



[19] SRRC filtering can be practically implemented either with baseband filters or with RF post-amplifier filters each able to fulfill SFCG Recommendation 21-2R24 (see CCSDS 413.0-G-1).
[20] This formulation yields an impulse response function with dimensions of Hz (or 1/s). Sometimes in literature, the transfer function is shown with a multiplication factor $\sqrt{T_{chs}}$ in front.

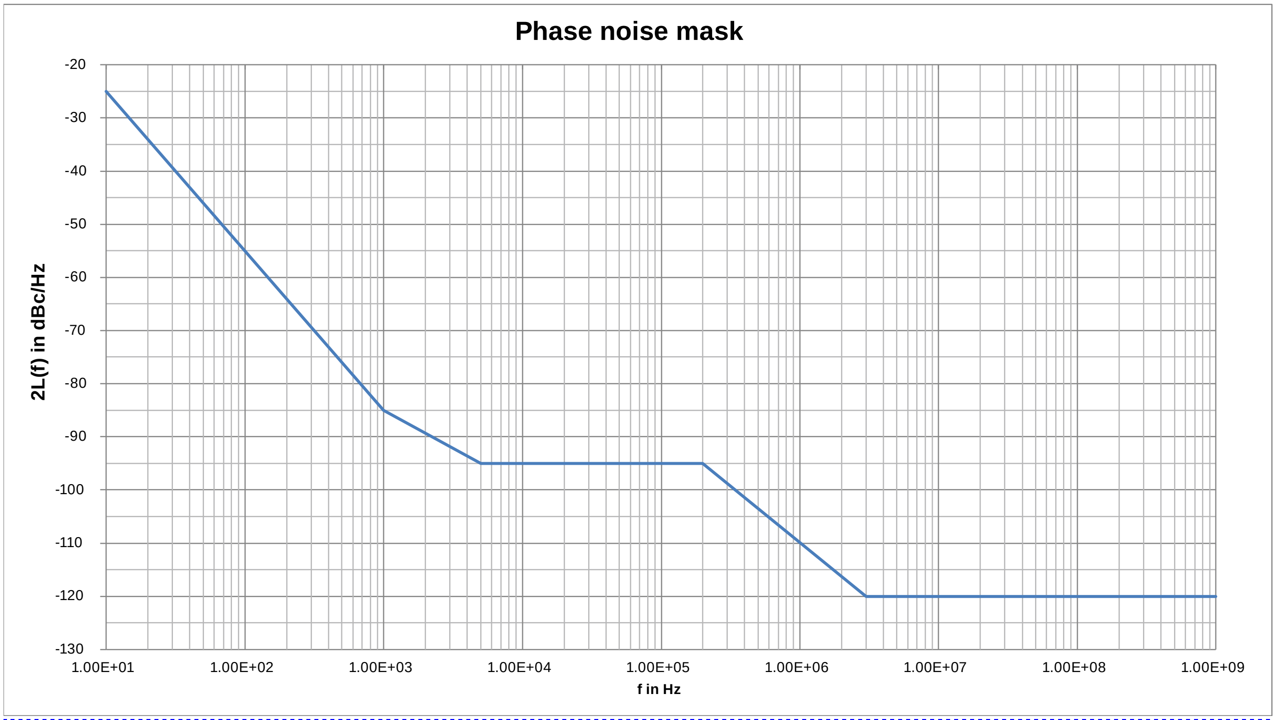


Figure 2.4.18-12: 8PSK Phase Noise Mask Recommendation

A1.8 BIT MAPPING TO CONSTELLATION

The following convention is used to identify each bit in an *N*-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0', the following bit is defined to be 'Bit 1', and so on up to 'Bit *N*−1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 2.4.18-13).

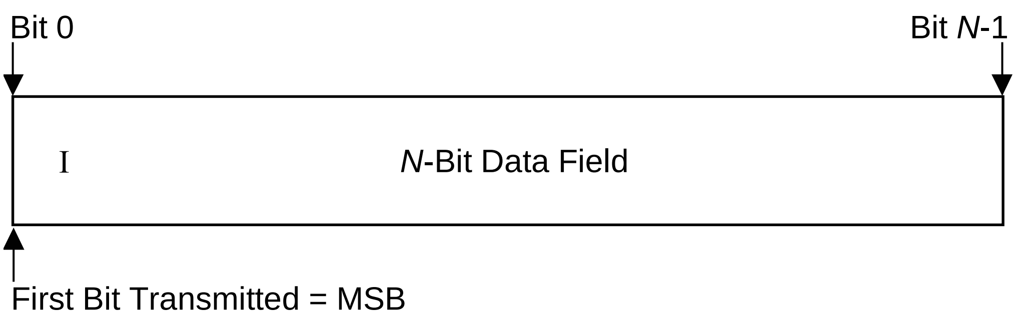
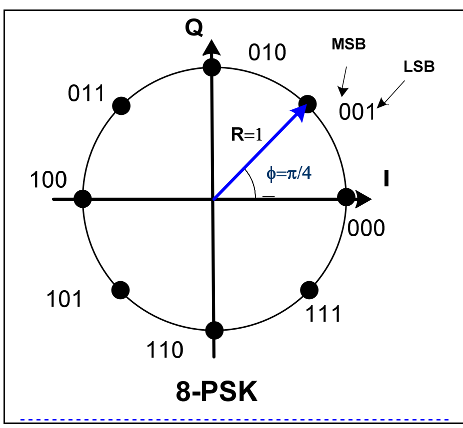


Figure 2.4.18-13: Bit Numbering Convention

For instance, bits 3i, 3i+1, 3i+2 of the modulator input determine the i[th] 8PSK symbol where i = 0, 1, 2,… (*N*/3)−1 and *N* is the block size to be transmitted.

The modulation shall employ a natural mapping constellation (i.e., 0, 1, 2 …, 7 anticlockwise) as in figure 2.4.18-14 with associated bit numbering convention as in figure 2.4.18-13.

$Z^{(i)}$ represents the signals (three lines) at the input of the modulator with $Z^{(0)}$ being the signal set of the first constellation and $Z^{(3)}$ being the signal set of the fourth constellation.



Phase state	Phase angle (°)	$Z^{(i)}$
A	0	000
B	45	001
C	90	010
D	135	011
E	180	100
F	225	101
G	270	110
H	315	111

Figure 2.4.18-14: 4D-8PSK-TCM Symbol Mapping into Constellation

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 - INFORMATIVE

Comparison of 8PSK Constellations

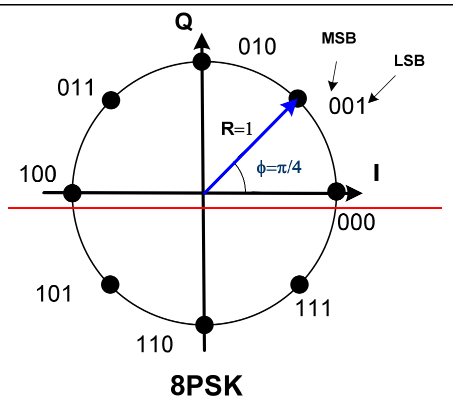
A2.1 GENERAL

The 8PSK constellation used with 4D-8PSK-TCM differs from the ones used with 8PSK BiCM: in particular, while the former is based on natural mapping (needed to allow proper set partitioning), the latter employs Gray mapping, taking advantage of better performance (in a BiCM scheme).

A2.2 4D-8PSK-TCM

The constellation mapper principles are given in figures 2.4.18-5 to 2.4.18-8 for the four possible efficiencies of this modulation (i.e., 2 bits/channel-symbol, 2.25 bits/channel-symbol, 2.5 bits/channel-symbol and 2.75 bits/channel-symbol). These mappers implement the straightforward logical mapping described in the equations below. The correspondence between the signals $Z^{(i)}$ at the input of the modular and the 8PSK phase states of the constellations follows a natural mapping (i.e., 0, 1, 2 …, 7 anticlockwise as specified in A1.4) resulting in figure 2.4.18-14.

$Z^{(i)}$ represents the signals (three lines) at the input of the modulator with $Z^{(0)}$ being the signal set of the first constellation and $Z^{(3)}$ being the signal set of the fourth constellation.



Phase state	Phase angle (°)	$Z^{(i)}$
A	0	000
B	45	001
C	90	010
D	135	011
E	180	100
F	225	101
G	270	110
H	315	111

Figure 2.4.18-14: 4D-8PSK-TCM Symbol Mapping into Constellation

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.3 8PSK BICM

A2.3.1 CASE 1

Modulations in accordance with CCSDS 131.2-B-1 employ a conventional Gray-coded constellation with absolute mapping (no differential coding) as in figure 2.4.18-15 with associated bit numbering convention as in figure 2.4.18-16.

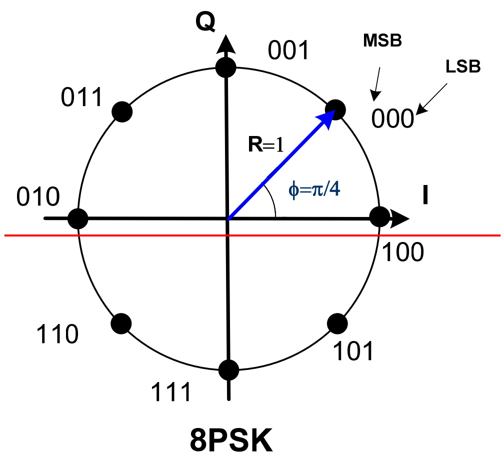


Figure 2.4.18-15: 8PSK BiCM Symbol Mapping into Constellation (Case 1)

The following convention is used to identify each bit in an *N*-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0', the following bit is defined to be 'Bit 1', and so on up to 'Bit *N*-1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 2.4.18-16).

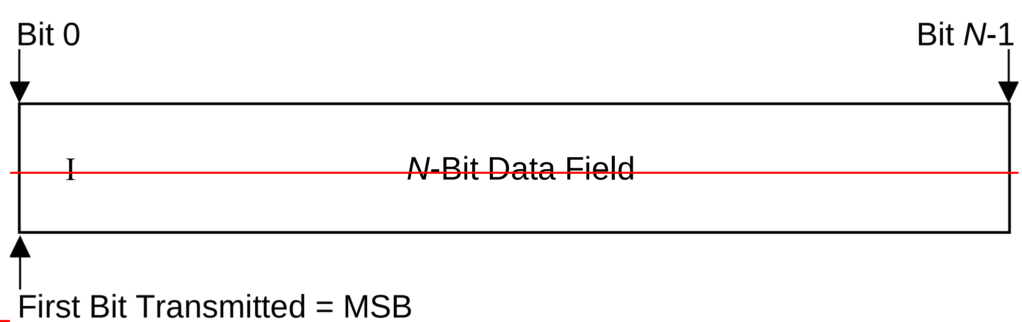


Figure 2.4.18-16: Bit Numbering Convention

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

Bits 3i, 3i+1, 3i+2 of the modulator input determine the ith 8PSK symbol where i = 0, 1, 2,… (*N*/3)-1 and *N* is the block size to be transmitted.

A2.3.2 CASE 2

Modulations in accordance with CCSDS 131.3-B-1 employ a conventional Gray-coded constellation with absolute mapping (no differential coding) with bit mapping into 8PSK constellation[20] that differs from A2.3.1 resulting in figure 2.4.18-17 with same bit numbering convention as in figure 2.4.18-16.

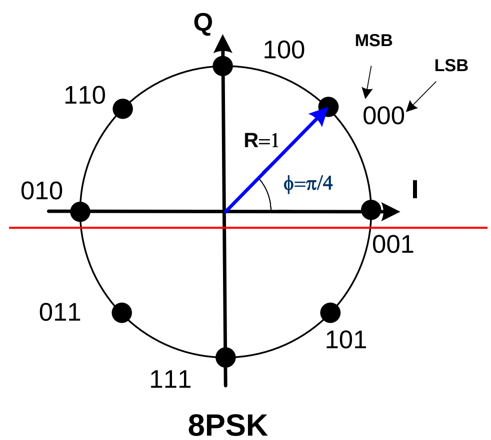


Figure 2.4.18-17: 8PSK BiCM Symbol Mapping into Constellation (Case 2)

Bits 3i, 3i+1, 3i+2 of the modulator input determine the ith 8PSK symbol where i = 0, 1, 2,… (*N*/3)-1 and *N* is the block size to be transmitted.

[20] See Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Services, News Gathering and other Broadband Satellite Applications. ETSI EN 302 307 V1.2.1 (2009-08). Sophia-Antipolis: ETSI, 2009.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2

QPSK/OQPSK/8PSK/16APSK/32APSK/64APSK Modulation Definition

(Normative)

A2.1 GENERAL

The modulation formats here specified shall follow the template provided in table 2.4.18-2, with the relevant parameters that define each constellation. For multi-circle constellations, and in particular for 16- and 32-APSK, different values are provided for the ratio of outer to inner circle radius, optimized based on the code rate used in CCSDS 131.2-B-1 and CCSDS 131.3-B-1.

Table 2.4.18-2: Modulation Definition

Item	QPSK and OQPSK	8PSK	16APSK	32APSK	64APSK
Number of constellation concentric circumferences	1	1	2	3	4
Number of uniformly spaced points per circumference	$N_1=4$	$N_1=8$	$N_1=4$, $N_2=12$	$N_1=4$, $N_2=12$, $N_3=16$	$N_1=4$, $N_2=12$, $N_3=20$, $N_4=28$
Ratio of outer circle to inner circle radius	N.A.	N.A.	$\gamma_1=R_2/R_1$ as per CCSDS 131.2-B-1 and CCSDS 131.3-B-1 (See also [21])	$\gamma_1=R_2/R_1$ and $\gamma_2=R_3/R_1$ as per CCSDS 131.2-B-1 and CCSDS 131.3-B-1 (See also [22])	$\gamma_1=R_2/R_1=2.73$, $\gamma_2=R_3/R_1=4.52$, $\gamma_3=R_4/R_1=6.31$
Radii relation for unit average symbol level (average symbol energy =1)	N.A.	N.A.	$[R_1]^2+3[R_2]^2=4$	$[R_1]^2+3[R_2]^2+4[R_3]^2=8$	$[R_1]^2+3[R_2]^2+5[R_3]^2+7[R_4]^2=16$
Bit-to-symbol mapping	Bits 2i (MSB) and 2i+1 (LSB) determine the i-th QPSK symbol	Bits 3i (MSB), 3i+1 and 3i+2 (LSB) determine the i-th 8PSK symbol	Bits 4i (MSB), 4i+1, 4i+2 and 4i+3 (LSB) determine the i-th 16APSK symbol	Bits 5i (MSB), 5i+1, 5i+2, 5i+3 and 5i+4 (LSB) determine the i-th 32APSK symbol	Bits 6i (MSB), 6i+1, 6i+2, 6i+3, 6i+4 and 6i+5 (LSB) determine the i-th 64APSK symbol
Constellation proper	(See figure 2.4.18-17)	(See figures 2.4.18-18 and 2.4.18-19)	(See figure 2.4.18-20)	(See figure 2.4.18-21)	(See figure 2.4.18-22)

[21] For a multistandard system, the range to be covered for γ_1 varies from 2.57 to 3.15.

[22] For a multistandard system, the range to be covered for γ_1 varies from 2.53 to 2.84 and the range for γ_2 varies from 4.30 to 5.27.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.2 SRRC CHANNEL FILTERING

The transfer function of the SRRC filter shall be:[23,24]

$$H(f)=1 \qquad \text{if } |f| < f_N(1-\alpha)$$

$$H(f)=\sqrt{\frac{1}{2}+\frac{1}{2}\sin\left\{\frac{\pi}{2f_N}\left(\frac{f_N-|f|}{\alpha}\right)\right\}} \qquad \text{if } f_N(1-\alpha)\le|f|\le f_N(1+\alpha)$$

$$H(f)=0 \qquad \text{if } |f| > f_N(1+\alpha)$$

where $f_N = 1/(2\,T_{chs}) = R_{chs}/2$ is the Nyquist frequency and α is the roll-off factor. The specified values for the roll-off factor are α = 0.2, 0.25, 0.3 and 0.35.

A2.3 PHASE NOISE

The phase noise for all the oscillators of the communication chain shall be limited according to the mask given in figure 2.4.18-15 for channel symbol rates above 1 Ms/s.

NOTE – The figure shows the double-sided phase noise mask 2L(f) in dBc/Hz versus frequency in Hz.

[23] SRRC filtering can be practically implemented with baseband filters able to fulfill SFCG Recommendation 21-2R4 (see CCSDS 413.0-G-2).

[24] This formulation yields an impulse response function with dimensions of Hz (or 1/s). Sometimes in literature, the transfer function is shown with a multiplication factor $\sqrt{T_{chs}}$ in front.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

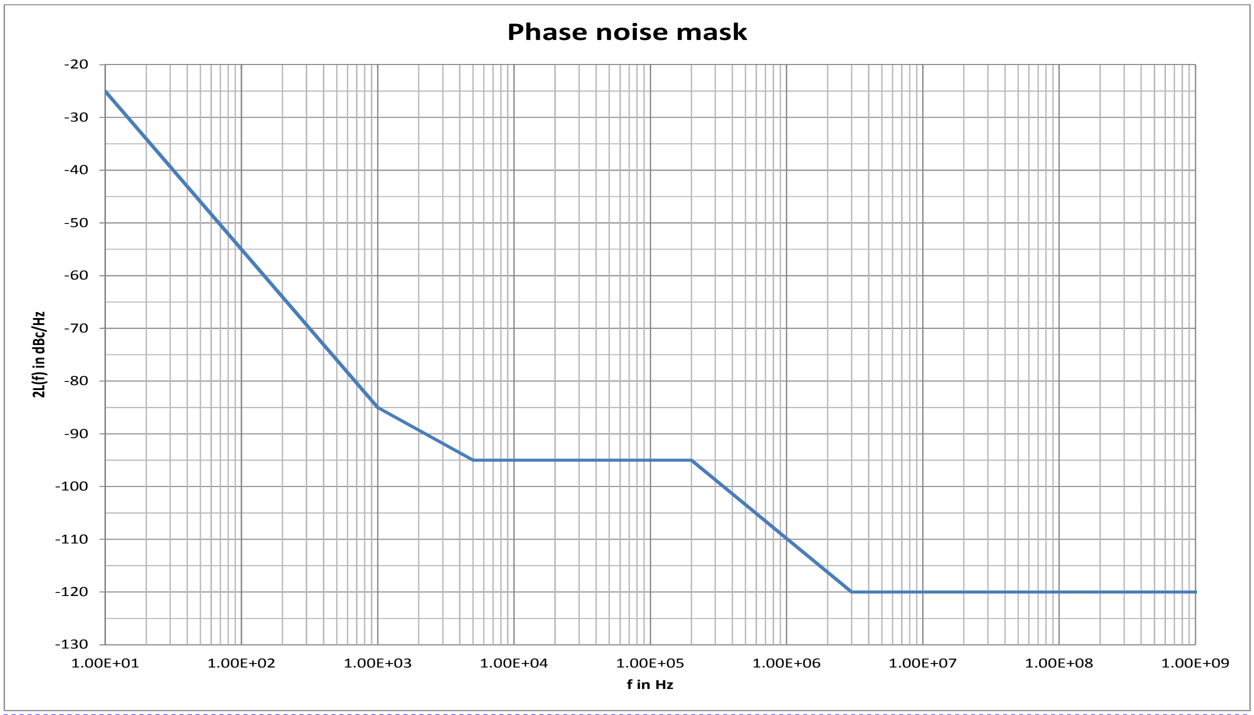


Figure 2.4.18-15: Phase Noise Mask Recommendation

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.4 BIT MAPPING TO CONSTELLATION

The following convention is used to identify each bit in an *N*-bit field. The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be 'Bit 0', the following bit is defined to be 'Bit 1', and so on up to 'Bit *N*−1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0' (see figure 2.4.18-16).

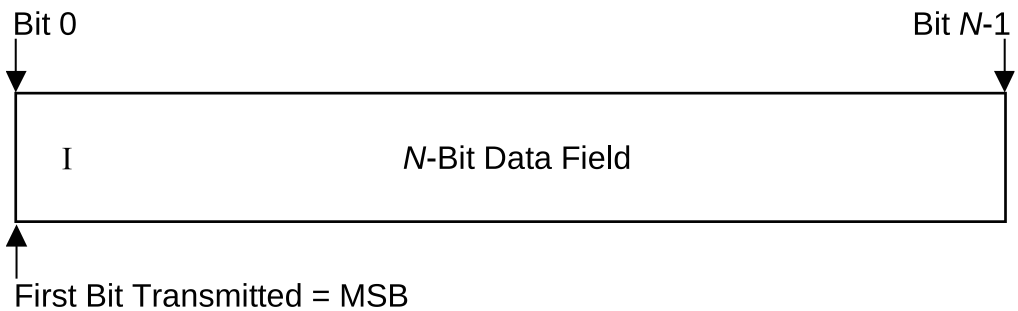


Figure 2.4.18-16: Bit Numbering Convention

For instance, bits 3i, 3i+1, 3i+2 of the modulator input determine the ith 8PSK symbol where i = 0, 1, 2,… (N/3)−1 and N is the block size to be transmitted.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.4.1 QPSK and OQPSK

Modulations with coding in accordance with CCSDS 131.0-B-2, 131.2-B-1, or CCSDS 131.3-B-1 shall employ a conventional Gray-coded constellation[25] with absolute mapping (no differential coding) as in figure 2.4.18-17 with associated bit numbering convention as in figure 2.4.18-16.

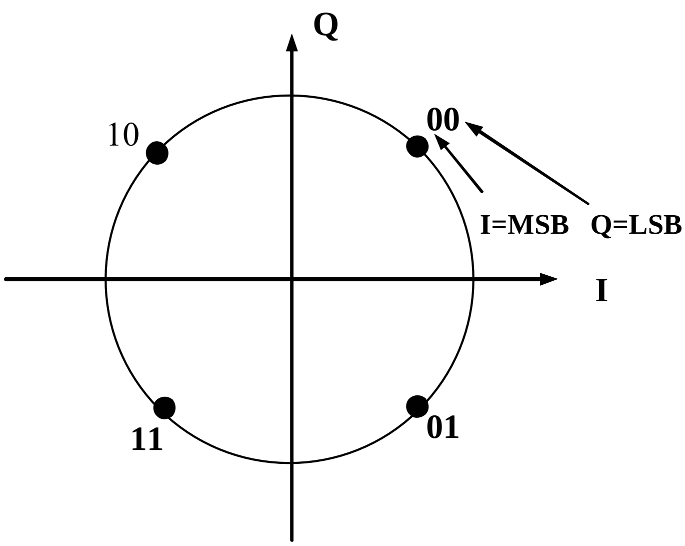


Figure 2.4.18-17: QPSK and OQPSK Symbol Mapping into Constellation

[25] The mapping is the same as in recommendation 2.4.10.

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.4.2 8PSK

Modulations with coding in accordance with CCSDS 131.0-B-2,131.2-B-1, or CCSDS 131.3-B-1 shall employ a conventional Gray-coded constellation with absolute mapping (no differential coding) as respectively in figures 2.4.18-18 and 2.4.18-19 with associated bit numbering convention as in figure 2.4.18-16.

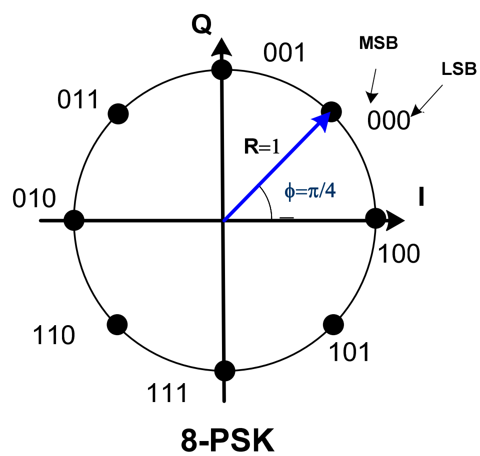


Figure 2.4.18-18: 8PSK Symbol Mapping into Constellation (CCSDS 131.0-B-2 and 131.2-B-1)

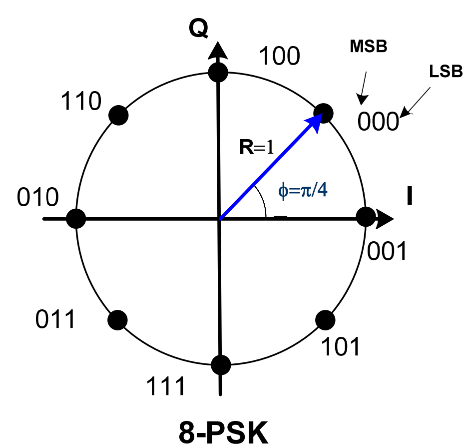


Figure 2.4.18-19: 8PSK Symbol Mapping into Constellation (CCSDS 131.3-B-1)

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.4.3 16APSK

Modulations with coding in accordance with CCSDS 131.0-B-2 or 131.2-B-1, and CCSDS 131.3-B-1 shall employ a conventional Gray-coded constellation with absolute mapping (no differential coding) as in figure 2.4.18-20 and with associated bit numbering convention as in figure 2.4.18-16.

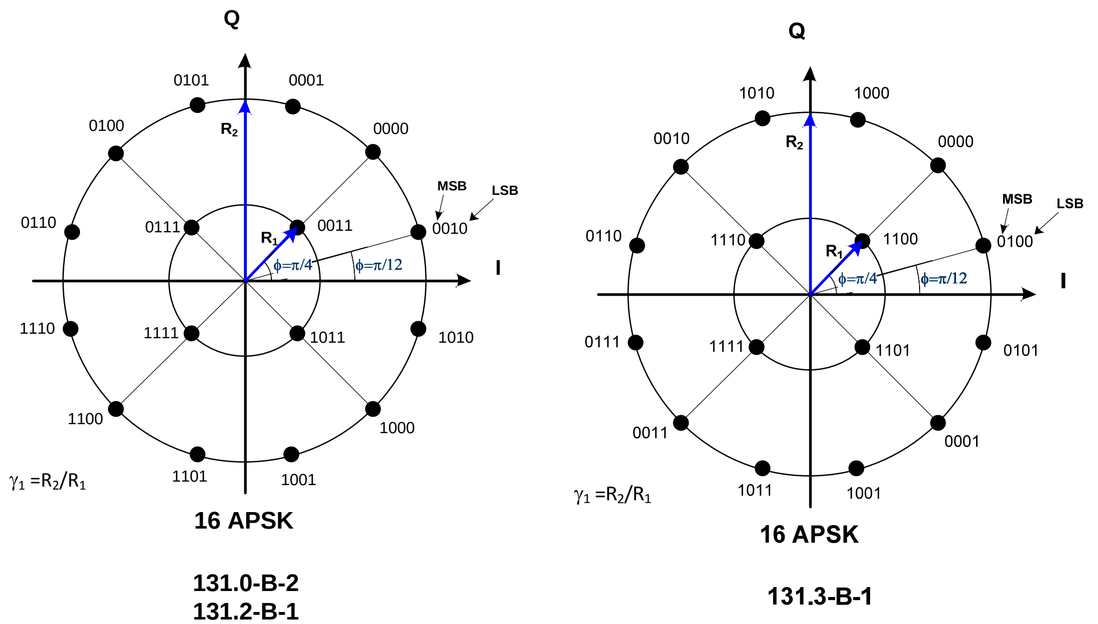


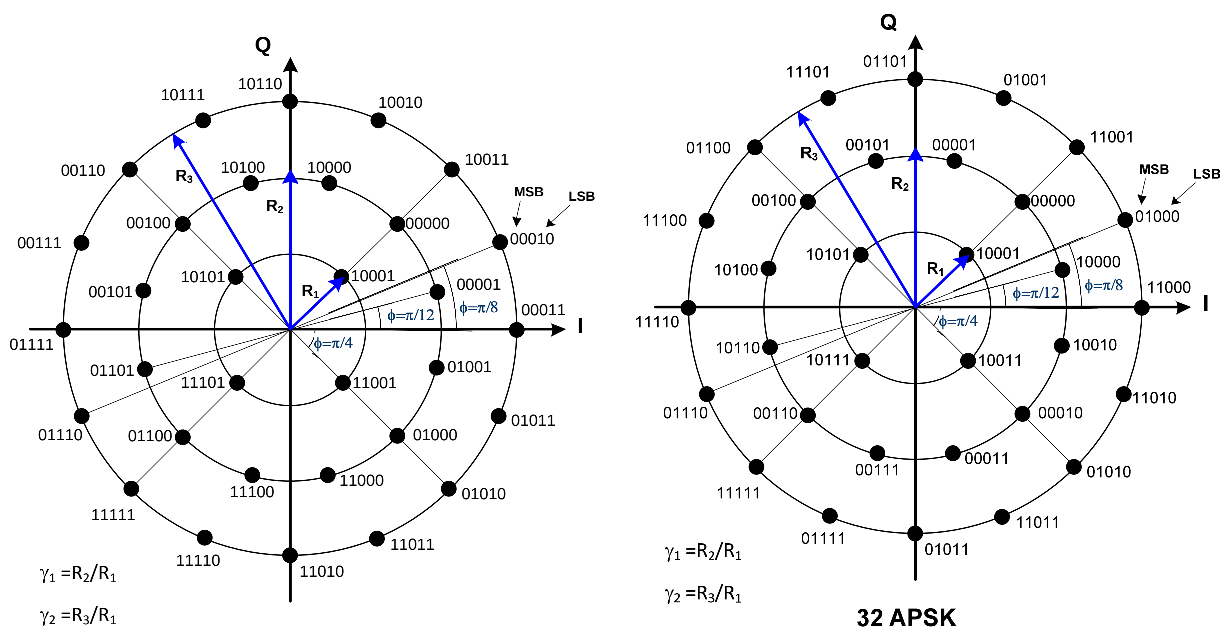
Figure 2.4.18-20: 16APSK Symbol Mapping into Constellation

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.4.4 32APSK

Modulations with coding in accordance with CCSDS 131.0-B-2 or 131.2-B-1, and CCSDS 131.3-B-1 shall employ a conventional Gray-coded constellation with absolute mapping (no differential coding) as in figure 2.4.18-21 and with associated bit numbering convention as in figure 2.4.18-16.



32 APSK

131.0-B-2
131.2-B-1

32 APSK

131.3-B-1

Figure 2.4.18-21: 32APSK Symbol Mapping into Constellation

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.4.5 64APSK

Modulations with coding in accordance with CCSDS 131.0-B-2 or 131.2-B-1 shall employ a conventional Gray-coded constellation with absolute mapping (no differential coding) as in figure 2.4.18-22 and with associated bit numbering convention as in figure 2.4.18-16.

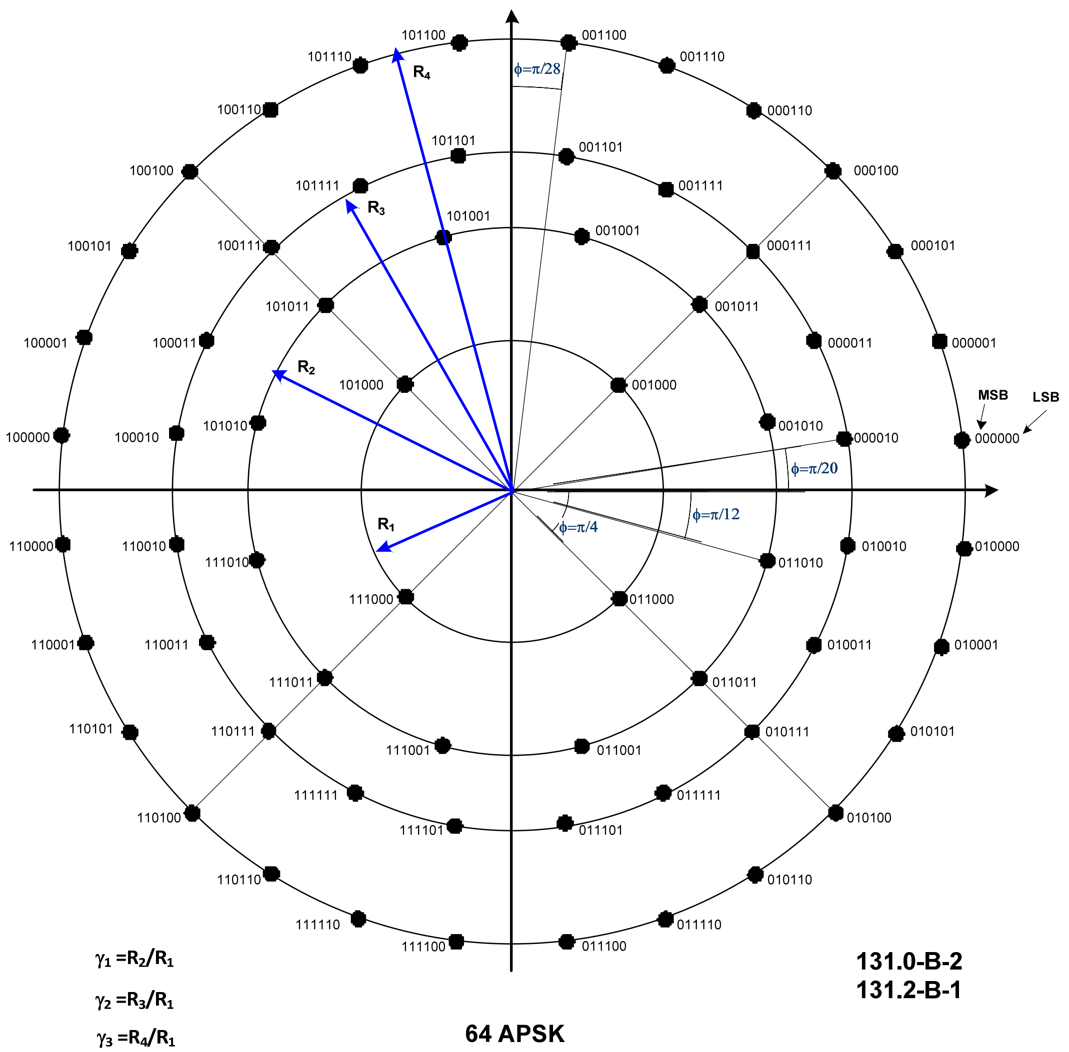


Figure 2.4.18-22: 64APSK Symbol Mapping into Constellation

2.4.18 MODULATION METHODS AT HIGH SYMBOL RATE TRANSMISSIONS, EARTH EXPLORATION SATELLITES (EES) 8 GHZ BAND, SPACE-TO-EARTH (Continued)

ANNEX 2 (Continued)

A2.5 FRAME HEADER MODULATION

The frame header shall consist of π/2-BPSK modulated symbols as defined below.

Assuming that the frame header binary sequence of length *N* is denoted as:

$$(x_1, x_2, \ldots, x_N)$$

then the in-phase (I) and the quadrature (Q) components of the *N* π/2-BPSK modulated symbols shall be determined according to the following rule:

$$I_{2i-1} = Q_{2i-1} = \frac{1}{\sqrt{2}}\left(1 - 2x_{2i-1}\right)$$

for $i = 1, 2, \ldots, N/2$

$$I_{2i} = -Q_{2i} = -\frac{1}{\sqrt{2}}\left(1 - 2x_{2i}\right)$$

2.5.6B DIFFERENTIAL ONE-WAY RANGING FOR SPACE-TO-EARTH LINKS IN ANGULAR SPACECRAFT POSITION DETERMINATION, CATEGORY B (Continued)

(p) that the *Space Research service* frequency allocation for Category B missions is 10 MHz in the 2 GHz band, 50 MHz in the 8 GHz band, 400 MHz in the 32 GHz band, and 1 GHz in the 37 GHz band;

(q) that quasar flux is reduced and system noise temperature is higher at 32 and 37 GHz as compared to 8 GHz;

(r) that DOR tones are used by many interplanetary missions and that the frequency bands used for DOR tones are shared with other satellite and terrestrial users;

(s) that missions with limited downlink tracking capability will benefit from a lower frequency DOR tone to aid with integer cycle ambiguity resolution;

recommends

(1) that DOR tones shall be sine-waves;

(2) that either direct tone detection or carrier-aided tone detection shall be used;

(3) that DOR tones shall be coherent with the downlink RF carrier frequency if carrier-aided detection is used;

(4) that one DOR tone shall be used in the 2 GHz band, two DOR tones shall be used in the 8 GHz band, and three DOR tones shall be used in the 32 and 37 GHz bands;

(5) that the approximate DOR tone fundamental harmonics frequencies used in each band shall be those in table 2.5.6B-1;

Table 2.5.6B-1: Recommended DOR Tones

Space-to-Earth Frequency Band	Number of DOR Tones	Approximate DOR Tone Fundamental Harmonics Frequencies	Notes
2 GHz	1	±4 MHz	
8 GHz	2	±41 MHz and ±20 MHz	1, 2
32 & 37 GHz	3	±41 MHz, ±20 MHz, and ±76 MHz	1, 2

NOTES

1 The lower frequency DOR tone may be chosen as 4 MHz rather than 1 MHz for missions that will have sufficient navigation data to maintain an accurate ephemeris. The delay ambiguity that must be resolved for a 4 MHz tone is 0.25 μsec. This is easily accomplished for missions with long tracking passes.

2 A telemetry signal, such as a subcarrier in the 250 kHz to 1 MHz range, can be used in place of a 1 MHz DOR tone for ambiguity resolution.