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-19.1

PINK SHEETS

August 2008

The Consultative Committee for Space Data Systems

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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 the CCSDS 131.0-B-1, *TM Synchronization and Channel Coding*, foresees 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 filtered 4-Dimensional 8 PSK Trellis Coded Modulation (SRRC-4D 8PSK TCM),[4] GMSK,[5] and some filtered OQPSK[6] modulations spectra can meet the SFCG emission mask for symbol rates in excess of 2 Ms/s with acceptable end-to-end losses;

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

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[1] See SFCG Recommendation 21-2R2 or latest version.
[2] See SFCG Recommendation 14-3R7 or latest version.
[3] See SFCG Recommendation 14-1 or latest version.
[4] Square Root Raised Cosine (α = 0.35 and α = 0.5) 4D 8PSK Trellis Coded Modulation. See ~~CCSDS 413.0-G-1~~Annex 1.
~~[5] Gaussian Minimum Shift Keying (BT_S = 0.25), with precoding. See CCSDS 413.0-G-1.~~
[5] Gaussian Minimum Shift Keying (BT_S = 0.25), with precoding as in figure 2.4.18-1 (see CCSDS 413.0-G-1). B refers to the one-sided 3-dB bandwidth of the filter.
~~[6] Square Root Raised Cosine (α = 0.5) Filtered Offset QPSK; Butterworth Bandpass Filtered (6 poles, BT_S = 1.0) Offset QPSK. See CCSDS 413.0-G-1.~~
[6]Filtered (Square Root Raised Cosine α = 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 21-2R2 (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)

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

(jk) that current technology allows implementing and processing of SRRC-4D 8PSK TCM modulation at the rates required in the band;

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

noting

(1) that GMSK or filtered OQPSK signals can also be demodulated by OQPSK receivers with some mismatching losses;[7]

(2) that many missions are currently operating in this band with a signaling efficiency[8] over 1.75 source bits/channel symbol;

recommends

(1) that a mission planning to operate in the 8025-8400 MHz band use SRRC-4D 8PSK TCM[9] or GMSK[10] or filtered OQPSK;[11]

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

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[7] See annex B.4 of CCSDS 413.0-G-1 for GMSK, SRRC, and Butterworth filtered OQPSK mismatching losses.
[8] Ratio of source data rate to channel symbol rate.
[9] 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 CCSDS 413.0-G-1Annex 1.
[10]Gaussian Minimum Shift Keying ($BT_S = 0.25$), with precoding. See CCSDS 413.0-G-1.
[10] Gaussian Minimum Shift Keying ($BT_S = 0.25$), with precoding as in figure 2.4.18-1 (see CCSDS 413.0-G-1). B refers to the one-sided 3-dB bandwidth of the filter.
[11] Square Root Raised Cosine ($\alpha = 0.5$) Filtered Offset QPSK; Butterworth Bandpass Filtered (6 poles, $BT_S = 1.0$) Offset QPSK. See CCSDS 413.0-G-1. Agencies may also utilize baseband-filtered OQPSK modulation with other types of Bandpass filters provided that BT_S is not greater than 1.0 and they ensure compliance with SFCG Recommendation 21-2R2 (or latest version) and interoperability with the cross-supporting networks.
[11]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.

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

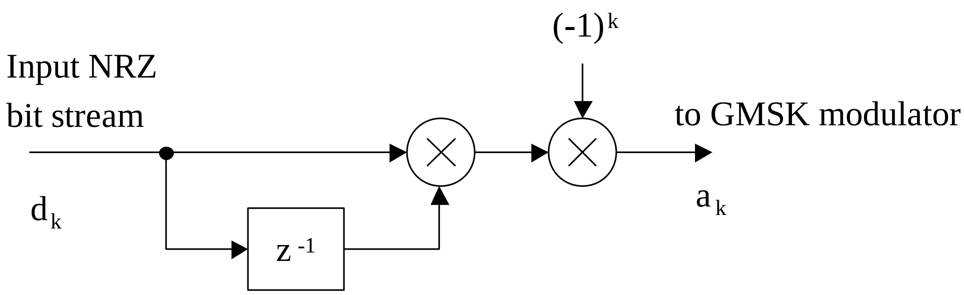


Figure 2.4.18-1: GMSK Precoder

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

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 2.4.18-2). 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 2.4.18-2);
- 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).

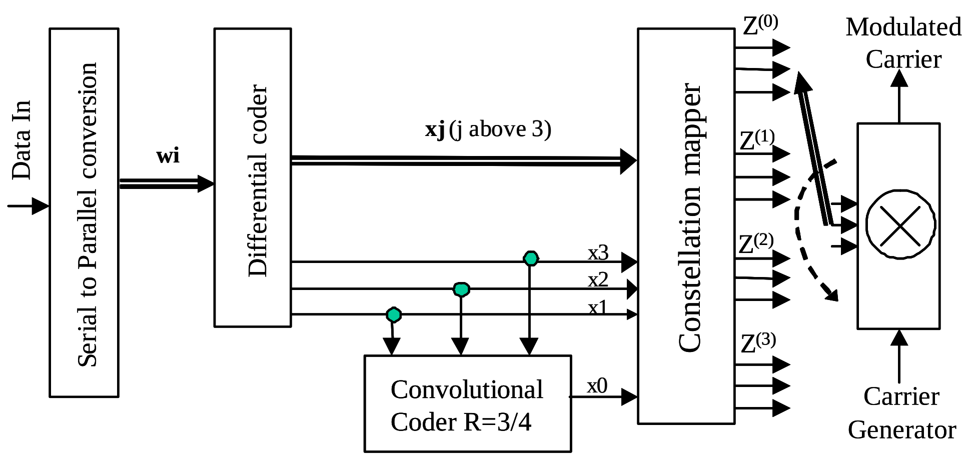


Figure 2.4.18-2: Structure of the 4D 8PSK-TCM Coder/Mapper

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

ANNEX 1 (Continued)

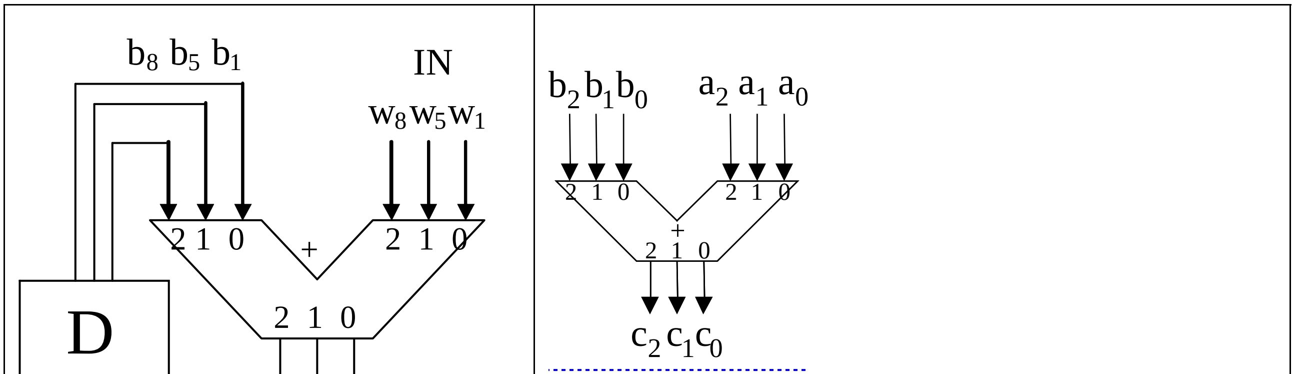
A1.2 DIFFERENTIAL CODER

The differential coder is depicted in figure 2.4.18-3. Table 2.4.18-1 gives the bit reference at input and output of the differential coder in each case.

Table 2.4.18 -1: Bit Mapping for Differential Coder with Modulo-8 Addition

Efficiencies in bits /channel-symbol							
2		2.25		2.5		2.75	
bit IN	bit OUT	bit IN	bit OUT	bit IN	bit OUT	bit IN	bit OUT
w1	x1	w2	x2	w3	x3	w4	x4
w5	x5	w6	x6	w7	x7	w8	x8
w8	x8	w9	x9	w10	x10	w11	x11

An example of differential encoder connections is given in figure 2.4.18-3 for the 2 bits/channel-symbol case. The structure of the modulo-8 adder is also shown; it is applicable to both the coder mapper and differential coder.



$c_0 = a_0 \oplus b_0$ with carry r_0

$c_1 = a_1 \oplus b_1 \oplus r_0$ with carry r_1

$c_2 = a_2 \oplus b_2 \oplus r_1$

$r_0 = a_0.b_0$

$r_1 = (a_1.b_1)+(a_1.r_0)+(b_1.r_0)$

where . corresponds to a logical AND, and + to a logical OR

Figure 2.4.18-3: Differential Coder and Modulo-8 Adder Principle

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 2.4.18-4. The shift registers of the encoder are clocked at the rate of $R_{ChS}/4$.

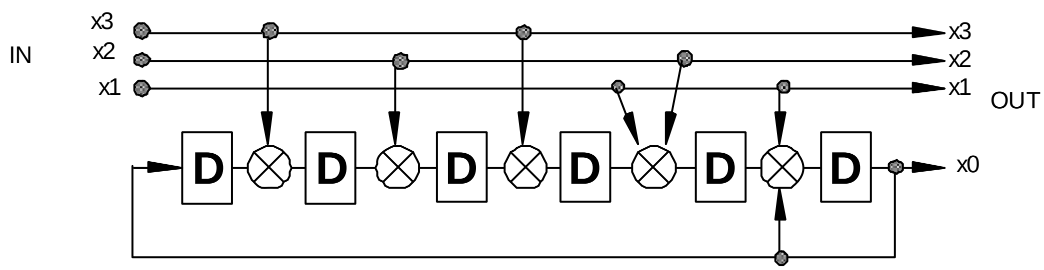
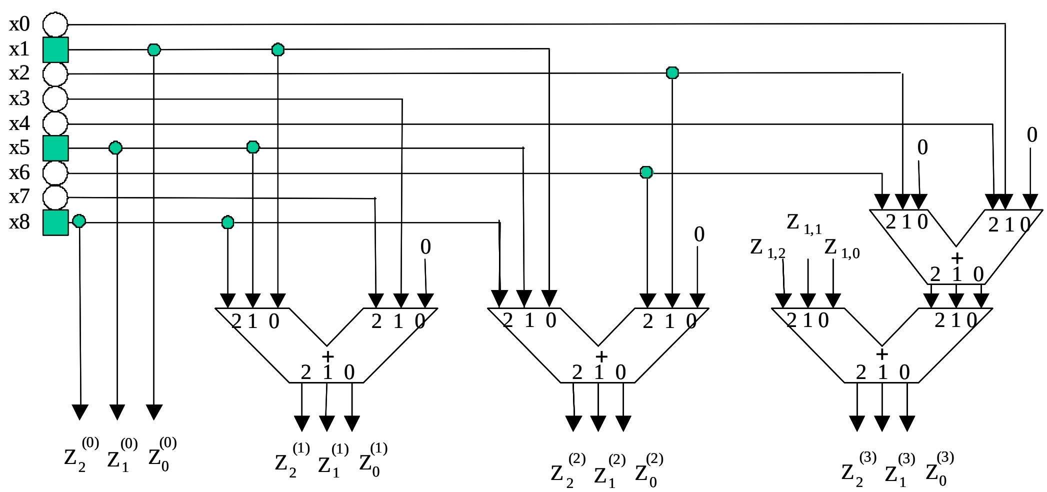


Figure 2.4.18-4: Convolutional Coder Recommended for High Data Rates

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

The constellation mapper principles are given in figures 2.4.18-5 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).



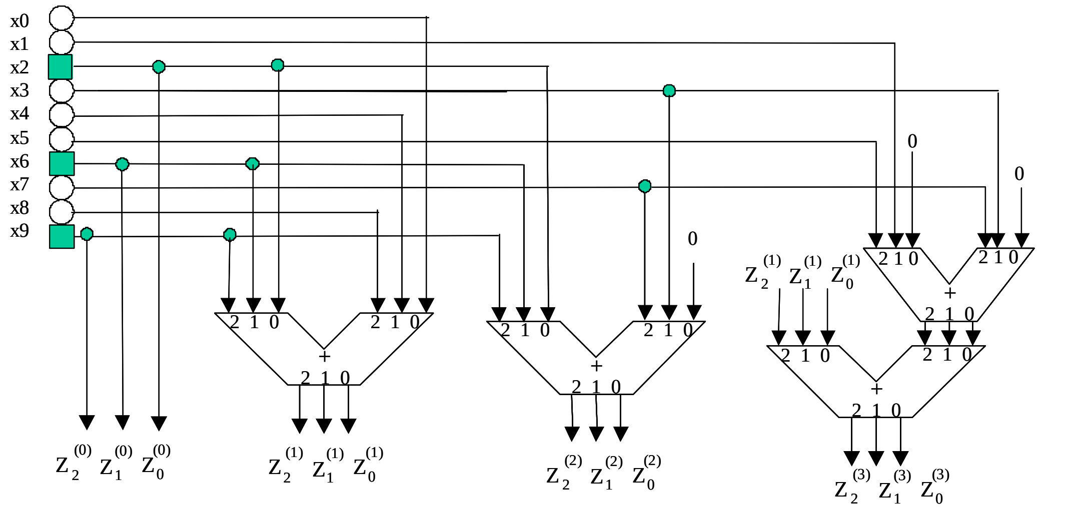
■ = line connected to differential coder

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

Figure 2.4.18-5: 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)

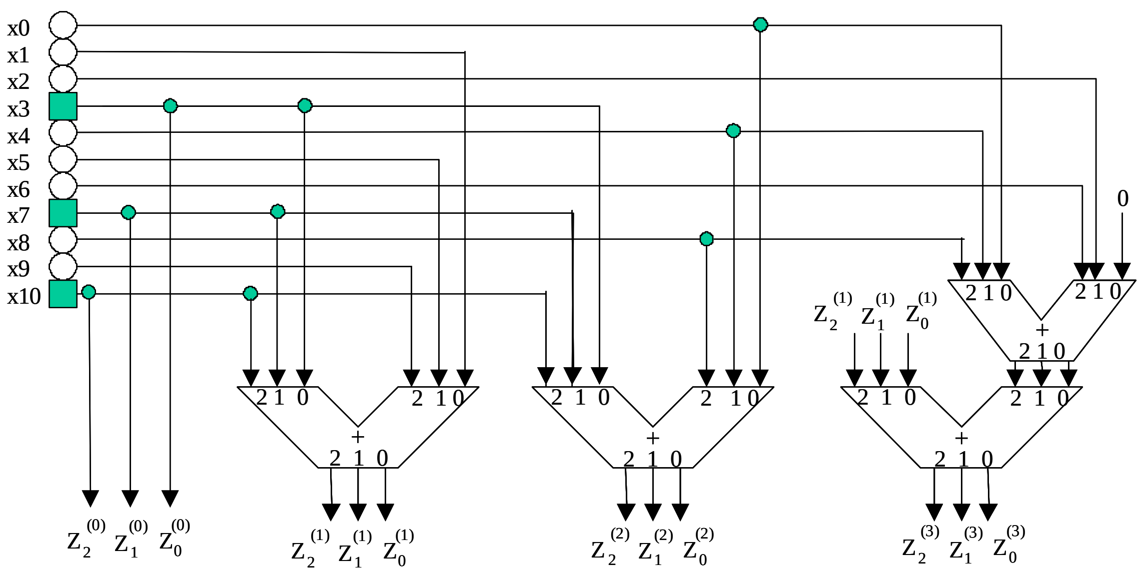
ANNEX 1 (Continued)



= line connected to differential coder

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

Figure 2.4.18-6: Constellation Mapper for 2.25 Bits/Channel-Symbol



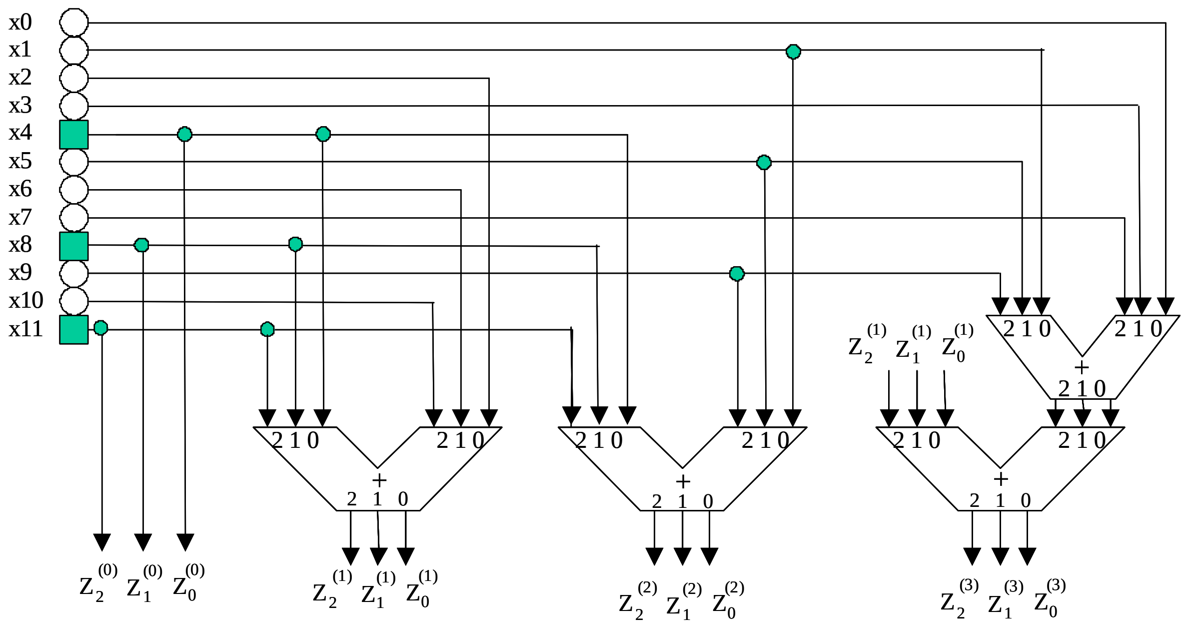
= line connected to differential coder

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

Figure 2.4.18-7: Constellation Mapper for 2.5 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)



■ = line connected to differential coder

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

Figure 2.4.18-8: Constellation Mapper for 2.75 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)

A1.5 CODER/MAPPER IMPLEMENTATION AT 2, 2.25, 2.5, AND 2.75 BITS/CHANNEL-SYMBOL EFFICIENCY

The principle of the coder-mapper for 2, 2.25, 2.5, and 2.75 bits/channel-symbol efficiency is given in figures 2.4.18-9 through 2.4.18-12.

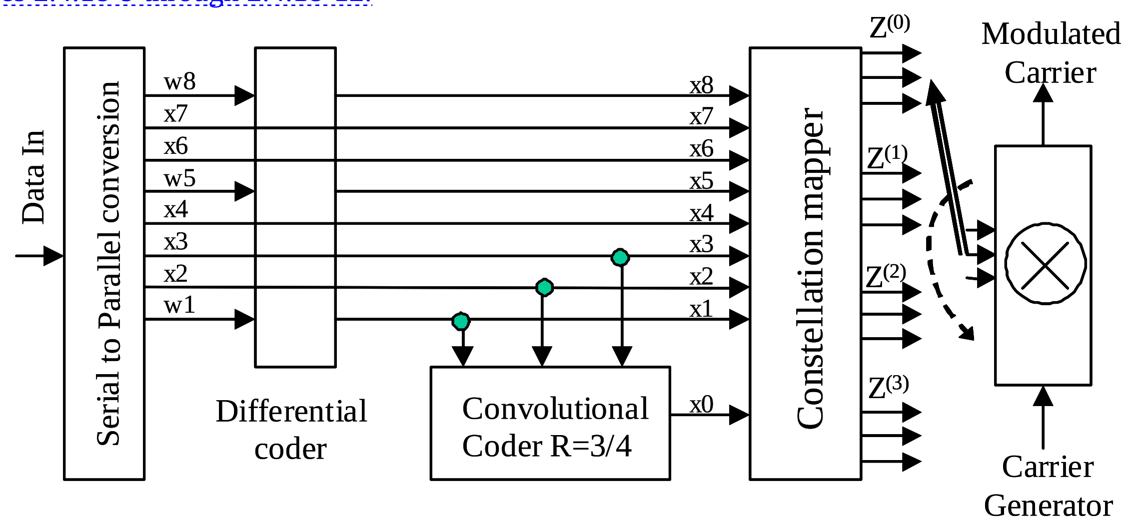


Figure 2.4.18-9: Coder and Mapper Implementation for 2 Bits/Channel-Symbol Efficiency

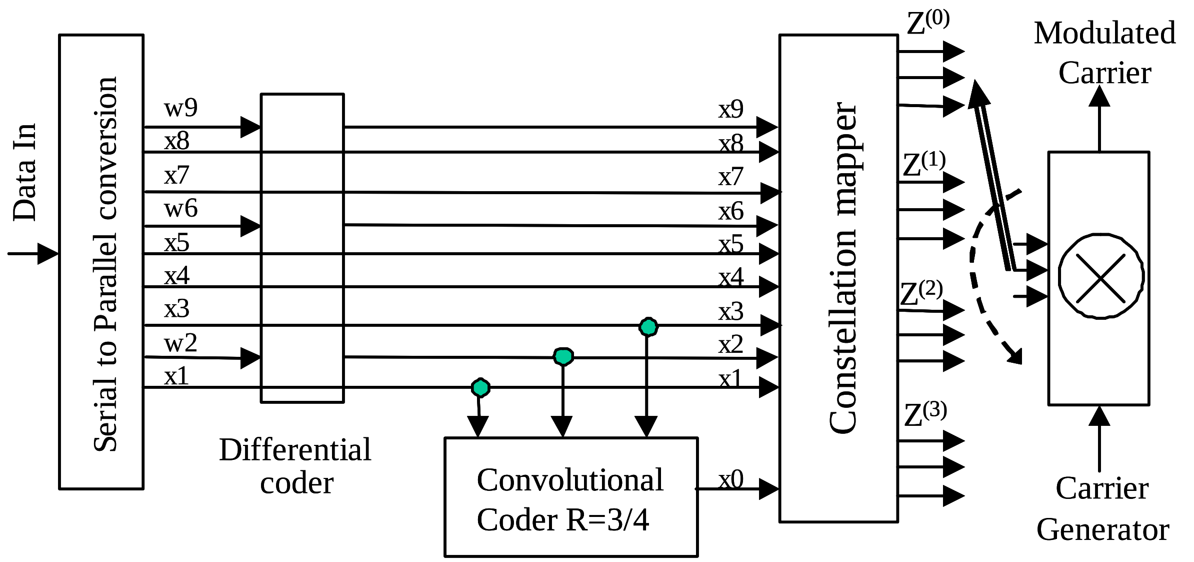


Figure 2.4.18-10: Coder and Mapper Implementation at 2.25 Bits/Channel-Symbol Efficiency

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

ANNEX 1 (Continued)

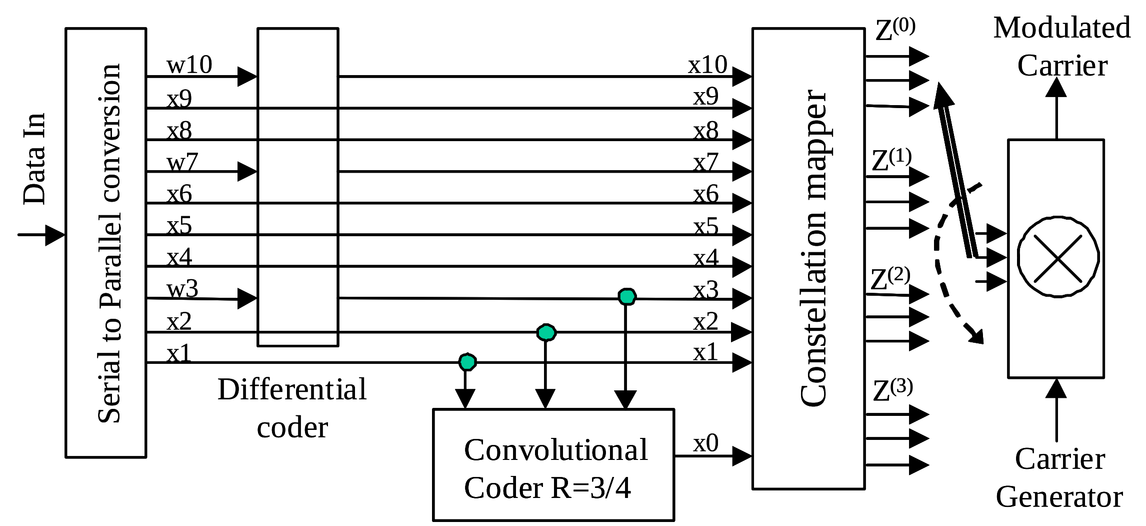


Figure 2.4.18-11: Coder and Mapper Implementation at 2.5 Bits/Channel-Symbol Efficiency

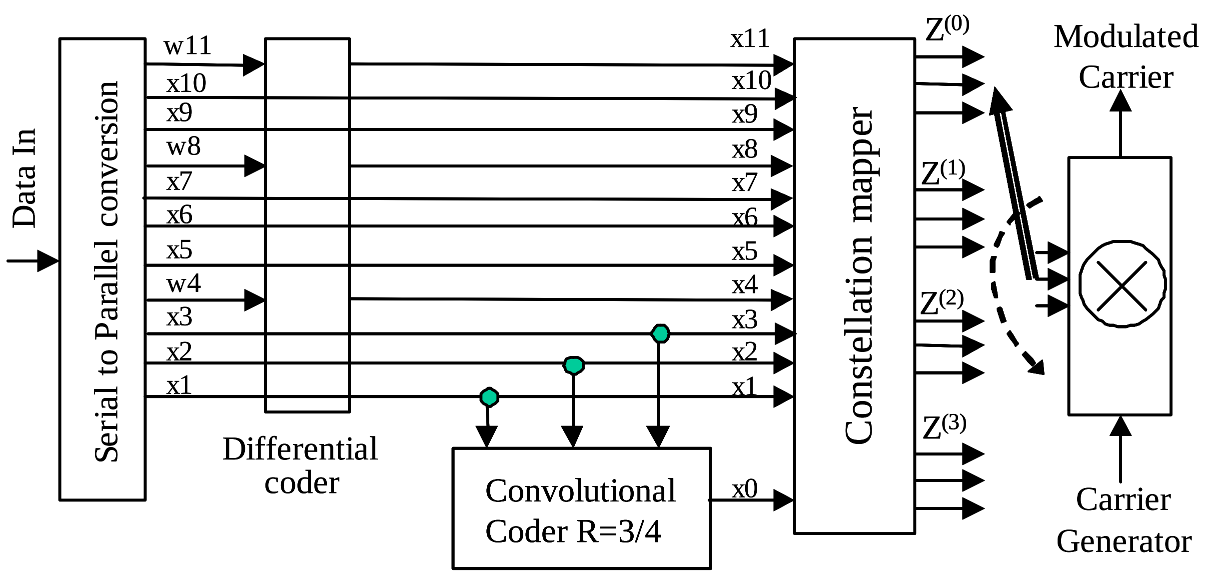


Figure 2.4.18-12: Coder and Mapper Implementation at 2.75 Bits/Channel-Symbol Efficiency

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:[12]

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

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

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

where

$f_N = 1/(2\,T_{chs}) = R_{chs}/2$ is the Nyquist frequency and α is the roll-off factor;

The non-normalized value of H(f) can be obtained multiplying its normalized value by $\sqrt{T_{chs}}$.

A1.7 PHASE NOISE

It is recommended that the phase noise for all the oscillators of the 4D-8PSK-TCM communication chain 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. The figure shows the double sided phase noise mask 2L(f) in dBc/Hz versus frequency in Hz.

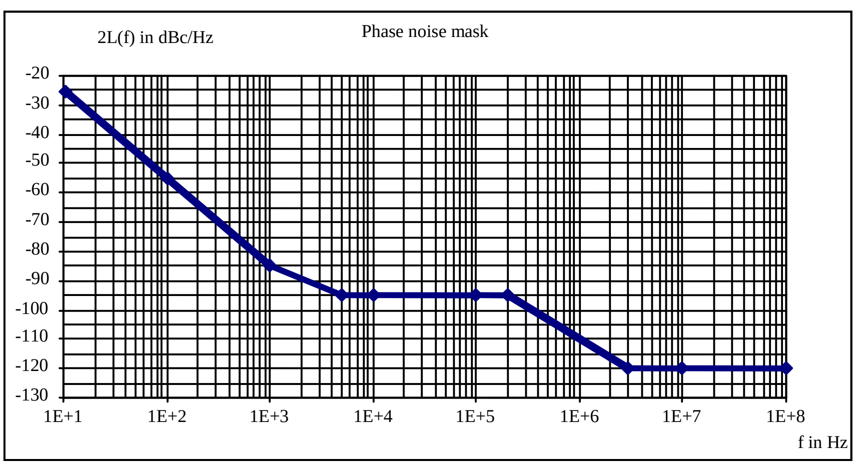


Figure 2.4.18-13: 4D-8PSK-TCM Phase Noise Mask Recommendation

[12] SRRC filtering can be practically implemented either with baseband filters or with RF post-amplifier filters each able to fulfill SFCG Recommendation 21-2R2 (see CCSDS 413.0-G-1).

3.5.1 MINIMUM SET OF SPACECRAFT - EARTH STATION TESTS REQUIRED TO ENSURE COMPATIBILITY

The CCSDS,

considering

(a) that cross support will frequently be required for Telemetry, Tracking, and/or Command operation;

(b) that it is desirable to assure compatibility of the spacecraft with the ground network before the launch of a spacecraft;

(c) that this compatibility is usually verified by compatibility tests;

(d) that all parties have a common understanding of the tests;

recommends

that, in accordance with the required cross support, all relevant tests set forth in Table 3.5.1-1 shall be performed.

3.5.1 MINIMUM SET OF SPACECRAFT - EARTH STATION TESTS REQUIRED TO ENSURE COMPATIBILITY (Continued)

TABLE 3.5.1-1

TEST TYPES[1]
SPACECRAFT RADIO FREQUENCY
Transmitter frequency and frequency stability Transmitter residual carrier phase jitter Transmitter RF spectrum measurement Receiver rest frequency determination Receiver acquisition frequency range and rate Receiver tracking frequency range and rate Receiver signal level monitoring (AGC level)
TELEMETRY
Telemetry modulation index Telemetry receiver carrier threshold Telemetry frame and/or bit error rate Telemetry spectrum False locking of carrier Telemetry degradation due to transient response of ranging channel
TELECOMMAND
S/C receiver command and carrier threshold S/C receiver telecommand tolerance to phase modulation index variation Telecommand receiver spurious carrier immunity Telecommand receiver spurious modulation immunity Telecommand receiver Doppler tracking performance
RANGING
Transponder ranging delay Ranging downlink modulation index vs. uplink modulation index Ranging downlink and uplink spectrum Ranging downlink modulation index vs. uplink signal-to-noise power
DOPPLER
Measurement of transponder turnaround ratio Doppler tracking accuracy
EARTH STATION ANTENNA TRACKING SYSTEM
Receiver carrier signal level threshold

[1] Performance measurements shall be carried out from maximum power level down to the operational threshold.