

## **SLS-RFM\_24-12: Proposed Updates to Rec. 2.4.7 and Rec. 2.2.7 with PCM/PM/NRZ-L**

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NASA/GSFC Code 567

### Background:

- During Fall CCSDS 2023 meeting, NASA presented RFM 23-11: Gaps between CCSDS 401.0 and the LunaNet Interoperability Specification (LNIS) V5 and Gateway specs.
- One of the gaps identified was the S-band Proximity forward and return medium rate links and the X-band up and down medium rate links up to 1 Msps.
- Lunar missions have identified PCM/PM/NRZ-L as a potential modulation to fill gap.
- Action was given to ESA to see if they have any fundamental objection to PCM/PM/NRZ-L.
- In Spring 2024 CCSDS meeting, NASA/GSFC presented a way forward to study the filtering for the return links. Given a WG consensus to go ahead with the study, NASA/GSFC accepted the action to define the filtering and simulate the performance.
- In July 2024 CCSDS telecom meeting, NASA/GSFC presented performance results to define filtering for PCM/PM/NRZ-L to close Spring 2024 action.
- What is missing the forward medium rate links recommendation 2.2.7.
- We present update to Rec. 2.4.7 to include PCM/PM/NRZ-L filtering specifications and the update to Rec. 2.2.7 to fill the forward link gap.

## 2.4.7 CHOICE OF PCM WAVEFORMS IN RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

- a) that NRZ waveforms rely entirely on data transitions for coded symbol clock recovery, and this recovery becomes problematical unless an adequate transition density can be guaranteed;
- b) that due to the presence of the mid-bit transitions, bi-phase-L waveforms provide better properties for bridging extended periods of identical coded symbols after initial acquisition though NRZ-L waveforms with randomization provides similar but slightly less performance;
- c) that the SFCG has approved a Recommendation<sup>1</sup> specifying a spectrum emissions mask for Category A space-to-Earth links operating in certain frequency bands<sup>2</sup>;
- d) that the SFCG emissions mask is relaxed for bi-phase-L modulations with coded symbol rates up to 150 ksps, where the bi-phase-L channel symbol rate in the SFCG Recommendation<sup>1</sup> is defined as twice the coded symbol rate;
- e) that Category A space-to-Earth links using bi-phase-L with coded symbol rates greater than 150 ksps, to comply with the SFCG Recommendation<sup>1</sup>, requires a strict filtering that can highly degrade the link performance;
- f) that Category A space-to-Earth links can be designed to permit simultaneous ranging operations;
- g) that convolutionally encoded data have sufficient data transitions to ensure coded symbol clock recovery in accordance with the CCSDS recommended standards, in practice, it could be beneficial to randomize the data;
- h) that with coherent PSK subcarrier modulation, it is possible by adequate hardware implementation to bridge extended periods of identical coded symbols even when NRZ waveforms are used;
- i) that NRZ waveforms modulated directly on the carrier (i.e., without a subcarrier) have a non-zero spectral density at the RF carrier;
- j) that coherent PSK subcarrier modulated by NRZ data and using an integer subcarrier frequency to coded symbol rate ratio, as well as bi-phase-L waveforms, have zero spectral density at the RF carrier;
- k) that residual carrier modulation with NRZ-L data using phase locked loops for carrier recovery are susceptible to degradation from a data imbalance of greater than 10% can be mitigated using convolutional codes and/or randomization;
- l) that residual carrier modulation with NRZ-L data can alternatively be phase locked with Costas loops to mitigate data imbalance degradation but then includes squaring losses;
- m) that the ambiguity which is peculiar to NRZ-L and bi-phase-L waveforms can be removed by adequate steps;
- n) that use of NRZ-M and NRZ-S waveforms results in errors occurring in pairs;
- o) that it is desirable to prevent unnecessary decoder node switching by frame synchronization prior to convolutional decoding (particularly true for concatenated convolutional Reed-Solomon coding);

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<sup>1</sup> See SFCG recommendation 21-2R5 or latest version.

<sup>2</sup> 2200-2290 MHz, 8450-8500 MHz, and 25.5-27.0 GHz

- p) that to promote standardization, it is undesirable to increase the number of options unnecessarily, and that for any proposed scheme, those already implemented by space agencies should be considered first;

#### recommends

- (1) that for modulation schemes which use a subcarrier, the subcarrier to coded symbol rate ratio should be an integer;
- (2) that in cases where a subcarrier is employed, NRZ-L should be used;
- (3) that for direct modulation schemes<sup>3</sup> having a residual carrier, bi-phase-L and NRZ-L waveforms should be used;
- (4) that, to comply with the SFCG Recommendation<sup>1</sup> for coded symbol rate up to 150 kbps, direct modulation schemes using a bi-phase-L waveform shall use a modulation index not higher than 1.25 rad and be filtered with a Butterworth filter of 3<sup>rd</sup> order, with a cut-off frequency equal to 3.3 times the coded symbol rate (BTs = 3.3);
- (5) that, to comply with the SFCG Recommendation<sup>1</sup> for coded symbol rates up to 1 Mbps, direct modulation schemes using NRZ-L shall use a modulation index not higher than 1.26 rad and be filtered with a Butterworth filter of 2<sup>nd</sup> order with a cut-off frequency equal to 1.3 times the coded symbol rate;
- (6) that, in case of simultaneous ranging operations, the filtering shall be performed only on the bi-phase-L or NRZ-L signal, prior to the combination with the ranging signal<sup>4</sup> in order to not impact link performance;
- (7) that CCSDS agencies use a data randomizer as specified in the CCSDS telemetry synchronization and channel coding blue book, CCSDS 131.0-B-5 (or latest edition);
- (8) that ambiguity resolution should be provided.

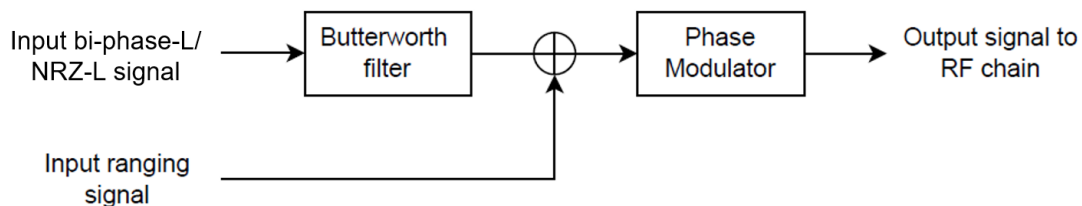


Figure 2.4.7-1: Example of Bi-Phase-L/NRZ-L Filtering Scheme with Simultaneous Ranging Operations.

<sup>3</sup> For purposes of this Recommendation, direct modulation schemes are defined as modulations where the data is modulated directly on the carrier without use of a subcarrier (e.g., PCM/PM/NRZ and PCM/PM/Bi-phase)

<sup>4</sup> See recommendations 401.0 (3.4.1) or latest version. Figure 2.4.7-1 shows an example of simultaneous transmission of a bi-phase-L/NRZ-L and ranging signal, as sum of the two signals before phase modulation.

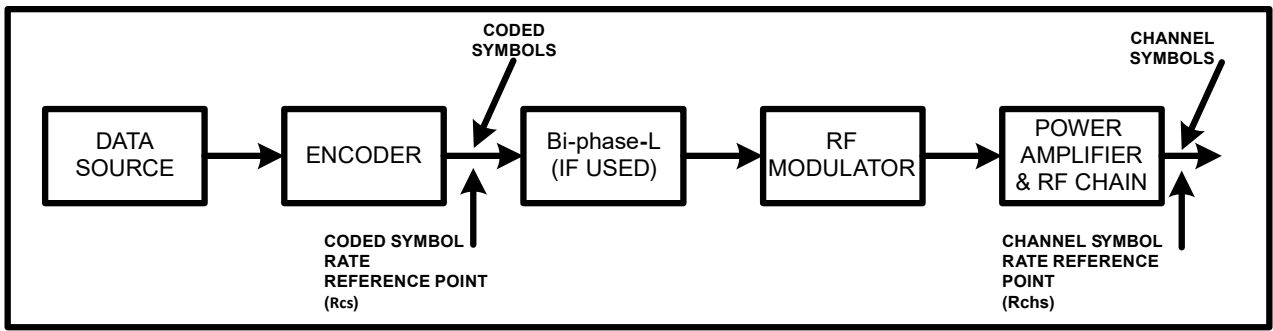


Figure 2.2.7-1: Telemetry Rates Definition

## 2.2.7 MEDIUM-RATE TELECOMMAND SYSTEMS

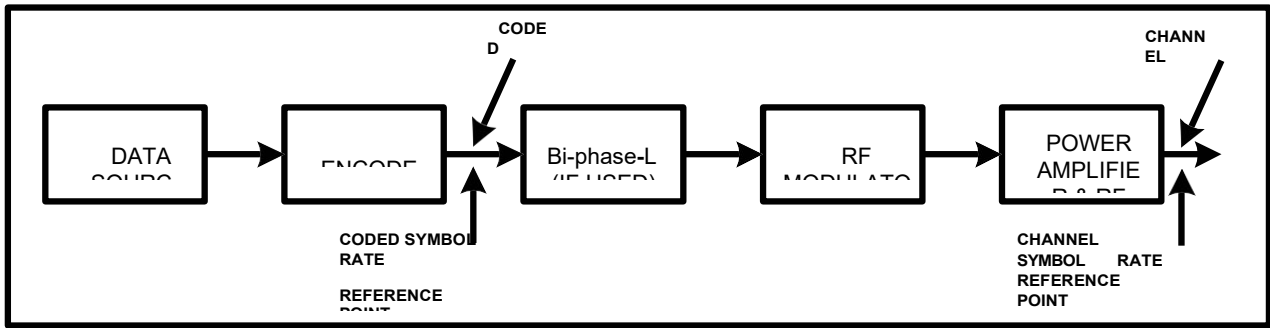
### The CCSDS,

#### considering

- (a) that most space agencies presently utilize either 8 kHz or 16 kHz subcarriers for telecommand transmissions where coded symbol rates are less than or equal to 4 coded ksymbol/s;
- (b) that missions in the near future may require higher rates telecommanding capabilities, in the range 8 coded ksymbol/s to 256 coded ksymbol/s;
- (c) that the possibility of simultaneous ranging, telecommand transmission and telemetry reception can result in optimal utilization of the Earth station coverage time;
- (d) that ranging requires that a distinct carrier component be present in the up- and down-link signals;
- (e) that subcarrier modulation techniques require substantially more spectrum compared to other modulation techniques;
- (f) that the use of PCM/PM/bi-phase-L and PCM/PM/NRZ-L modulations is justified when a distinct carrier component is required and only for coded symbol rates below 2 coded Msymbol/s;
- (g) that residual carrier modulation with NRZ-L data using phase locked loops for carrier recovery are susceptible to degradation from a data imbalance of greater than 10% can be mitigated using convolutional codes and/or randomization;
- (h) that residual carrier modulation with NRZ-L data can alternatively be phase locked with Costas loops to mitigate data imbalance degradation but then includes squaring losses;

#### recommends

- (1) that CCSDS agencies use PCM/PM/bi-phase-L direct on the carrier for medium rate telecommand data transmission in the range<sup>1</sup>  $R = 4000 \cdot 2^n$  coded symbol/s where  $n=1 \dots 6$ .
- (2) that CCSDS agencies use PCM/PM/NRZ-L direct on the carrier for medium rate telecommand data transmission in the range<sup>1</sup>  $R = 256 \text{ Ksymbol/s to } 1 \text{ Msymbol/s}$ .



**Figure 2.2.7-1: Telecommand Rates Definition**

<sup>1</sup> For the purpose of this recommendation, the coded symbol rates are defined prior to bi-phase-L encoding.