

CCSDS RECOMMENDATIONS FOR RADIO FREQUENCY AND MODULATION SYSTEMS

Earth Stations and Spacecraft

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;
- c) [that the SFCG has approved a Recommendation¹ specifying a spectrum mask for Category-A Space-to-Earth links operating in certain bands²;](#)
- b)d) [that Category-A Space-to-Earth links using bi-phase-L, to comply to the SFCG Recommendation¹, requires a strict filtering that can degrade the link performance;](#)
- e)e) that Category-A Space-to-Earth links are usually designed to permit simultaneous ranging operations;
- f)f) that convolutionally encoded data have sufficient data transitions to ensure coded symbol clock recovery in accordance with the CCSDS recommended standards;
- e)g) 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;
- f)h) that NRZ waveforms without a subcarrier have a non-zero spectral density at the RF carrier;
- g)i) 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;
- h)j) that the ambiguity which is peculiar to NRZ-L and bi-phase-L waveforms can be removed by adequate steps;
- i)k) that use of NRZ-M and NRZ-S waveforms results in errors occurring in pairs;
- j)l) 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);
- k)m) 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;

¹ See [SFCG recommendation 21-2R4 or latest version.](#)

² [Category A bands are: 2200-2290 MHz, 8450-8500 MHz, and 25-27.0 GHz.](#)

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- (2) that in cases where a subcarrier is employed, NRZ-L should be used;
- (3) that for direct modulation schemes having a residual carrier, only bi-phase-L waveforms should be used;
- (4) that, to comply with the SFCG Recommendation¹, direct modulation schemes at previous point uses using a bi-phase-L waveform shall have modulation index not higher than 1.25 rad and be filtered with a Butterworth filter of 3rd order, with a cut-off frequency equal to 3.5-4.5 times² the coded symbol rate; that, in case of simultaneous ranging operations, for not impacting their performance, the Butterworth filtering shall be performed only on the bi-phase-L signal, prior to the combination with the ranging signal⁴;
- (5) that Category-A Space-to-Earth links shall not use direct modulation schemes with bi-phase-L when the coded symbol rate is larger than 300 kbps;
- (6) that ambiguity resolution should be provided.

Commented [AM1]: Is it fine that we give a range of Butterworth filtering cut-off?

Commented [AM2]: proposal to forbid to Category A missions the use of SP-L/PM, for >= 300 kbps.

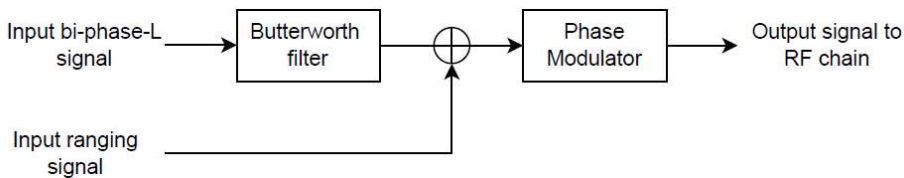


Figure 1: example of bi-phase-L filtering scheme with simultaneous ranging operations.

~~Insert figure of Option A block diagram. Andrea to provide new figure.~~

~~Recommend range of mod indices for use with bi-phase-L.~~

³ The Butterworth filter cut-off frequency shall be selected as trade-off between spectral compliance to the SFCG mask, signal distortions, and the adopted modulation index. Namely, a low cut-off frequency ensure compliance with margin to the spectral mask, while increases distortions. Similarly, higher modulation indexes, provides higher carrier suppression, but requires stricter Butterworth filtering.

⁴ See recommendations 401.0 (3.4.1) or latest version. [Figure 1](#) shows an example of simultaneous transmission of a bi-phase-L and ranging signal, as sum of the two signals before phase modulation. For not impacting ranging operations, the Butterworth filtering shall be performed before the combination with the ranging signal.

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