Low Power Spectral Density (L-PSD) applications in the SLM-5650B/C:

A description of the L-PSD applications in the SLM-5650B & SLM-5650C Satellite Modems

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Abstract

Direct Sequence Spread Spectrum (DSSS) is an option in the SLM-5650B and SLM-5650C Satellite Modems. This white paper describes the options available in Comtech EF Data's DSSS to support Low Power Spectral Density (L-PSD) applications.

L-PSD Application

Some satellite communication applications require very small aperture antennas. Examples include airborne and other mobile communications systems where available antenna space is very limited. Small antennas inherently have wide antenna radiation patterns. Wide radiation patterns can in turn result in the small antenna illuminating adjacent satellites. This situation is illustrated in Figure 1.

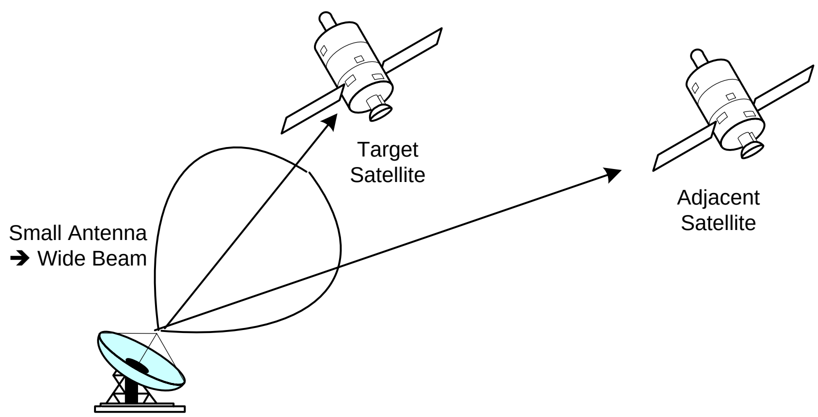

Figure 1: Small Antenna Illuminates Adjacent Satellite

In order to control adjacent satellite inference (ASI), the FCC and other bodies governing satellite communications place limits on the maximum PSD transmitted in the direction of an adjacent satellite by a ground-based satellite terminal. Since DSSS reduces the transmitted PSD, it can be used to enable a link budget to close thru the primary satellite while meeting PSD emission limits towards the adjacent satellite. In this case, use of DSSS increases the occupied bandwidth (or alternately reduces the data rate) as the key trade-off needed to enable the use of a small antenna.

DSSS waveform options

With any DSSS waveform designed for L-PSD applications, the key attributes are: 1) Very strong underlying Modulation and Forward Error Correction (FEC), 2) Flexibility in PSD control, and 3) Latency considerations. The remainder of this paper will discuss the options provided by Comtech EF Data's DSSS waveform family.

Modulation and FEC options

Comtech EF Data provides several options with our DSSS waveform to support multiple applications. The baseline modulation is either BPSK or QPSK. It should be noted that QPSK with DSSS provides no advantage in spectral efficiency or power spectral density. However, we do support this mode for other applications. This paper will focus on L-PSD applications and BPSK base modulation.

Since in L-PSD applications the entire goal is to minimize the PSD, it is critical to start with a very strong underlying Modulation and Coding (ModCod). To support this, Comtech EF Data has developed a family of Low-Density Parity Check (LDPC) FEC options. Each is designed to optimally support various applications. The family includes three members: 1) High Performance (HP) long block size (16k), 2) Low Latency (LL) medium block size (4k), and 3) Ultra-Low Latency (ULL) short block size (2k). Table 1 summarizes the BPSK options in this family.

ModCod	Spectral Efficiency	BER Performance (Es/No) Spec/(Typ)				Data Rate Range
		10^{-5}	10^{-6}	10^{-7}	10^{-8}	
HP BPSK 1/3	0.333	-3.0 (-3.2)	-2.9 (-3.1)	-2.8 (-3.0)	-2.7 (-2.9)	8k – 13.333M
HP BPSK 1/2	0.500	-1.0 (-1.3)	-0.9 (-1.2)	-0.8 (-1.1)	-0.7 (-1.0)	8k – 13.333M
LL BPSK .378	0.378	-2.3 (-2.6)	-2.2 (-2.5)	-2.1 (-2.4)	-2.0 (-2.3)	8k – 5M
LL BPSK .451	0.451	-1.4 (-1.7)	-1.3 (-1.6)	-1.2 (-1.5)	-1.1 (-1.4)	8k – 5M
LL BPSK .541	0.541	-0.5 (-0.8)	-0.4 (-0.7)	-0.3 (-0.6)	-0.2 (-0.5)	8k – 5M
ULL BPSK 1/2	0.500	0.1 (-0.2)	0.4 (0.1)	0.7 (0.4)	0.8 (0.5)	8k – 2M

Table 1: Modulation and FEC Modes Supporting DSSS in the SLM-5650B/C

Depending upon the application data rate, the user can select the appropriate sub-member (HP, LL or ULL).

DSSS options

Comtech EF Data provides a unique integer-based DSSS with spread factors from 1 (none) to 512 in integer increments (i.e. 2, 3, 4, ….510, 511, 512). In addition, our design provides selection of either a 15th order or 17th order power balanced polynomial each with 10,000 Gold Sequence Numbers (GSN). Given an Es/No value from Table 1, the required SNR (or equivalently Ec/No, where "Ec" is the energy in a chip-time) can be calculated as:

$$\frac{Ec}{No}\,[\mathrm{dB}] = \frac{Es}{No}\,[\mathrm{dB}] - 10\mathrm{Log10}[\mathrm{SF}] + L_I[\mathrm{dB}]$$

Where:

SF = Spreading Factor

L_I = Additional DSSS implementation loss, beyond implementation loss included in non-spread Es/No as shown in Table 1. L_I = 0.1 dB in the SLM-5650B implementation.

The resulting family of curves for spread factors 1 to 15 is shown below (note integer spread factors continue to 512).

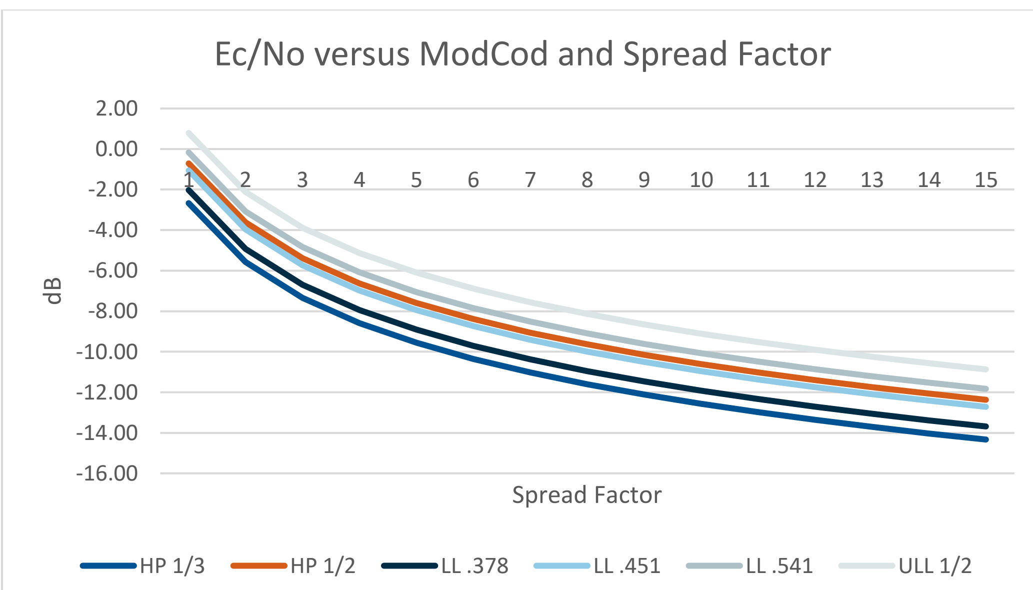

Figure 2: L-PSD Performance – Small Spread Factors

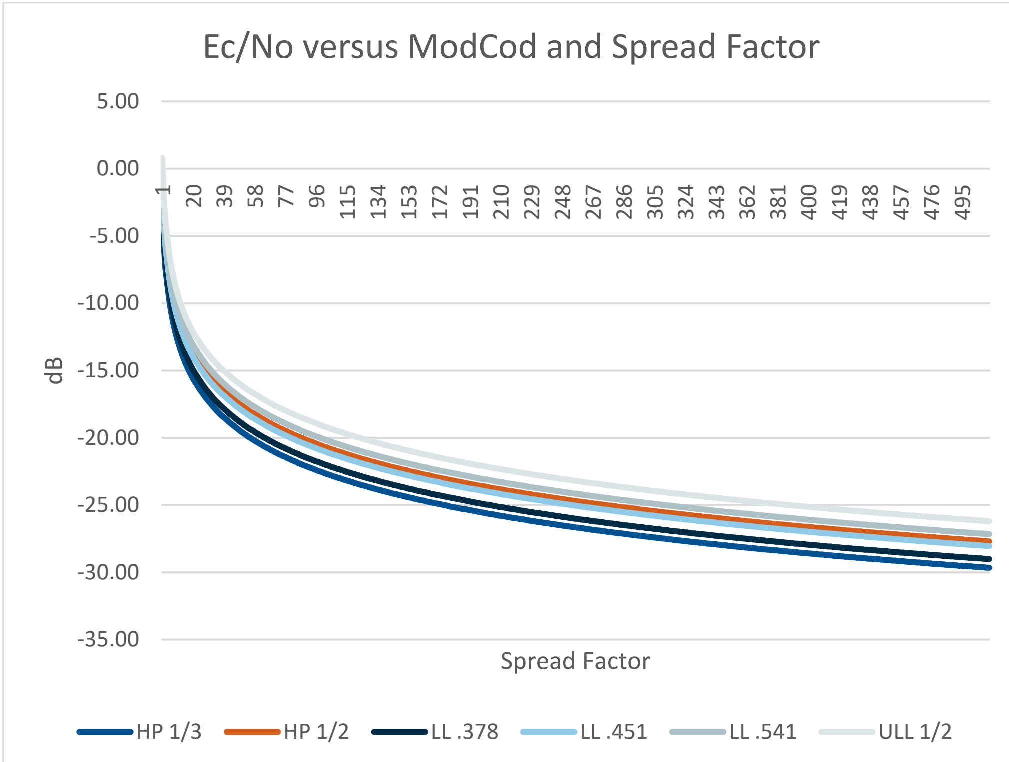

Figure 3: L-PSD Performance – Spread Factors up to 512

As can be seen, the Low Latency (LL) .378 and .451 code rates provide a great trade-off between coding/processing gain and latency. The combined family provides PSD level increments of approximately 0.5dB between 0.5dB and -6dB and then incrementally smaller increments.

Spectral Efficiency

Since we have started with the best FEC options, Comtech EF Data's solution provides unprecedented spectral efficiency for L-PSD applications.

$$BW_{eff} = \frac{RcMo}{SF}$$

Where:

R_c = Code Rate of the FEC
M_o = Modulation Order in bits/symbol (BPSK = 1, QPSK =2)
Note that M_o = 1 for all DSSS applications.
SF = Spreading Factor

Table 2 provides example equivalent chip rates for user data rates of 200 kbps, 1 Mbps and 2 Mbps with spread factors 1 through 15.

Waveform	Data Rate	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor	Spread Factor
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate	Chip Rate
HP 1/3	200,000	600,000	1,200,000	1,800,000	2,400,000	3,000,000	3,600,000	4,200,000	4,800,000	5,400,000	6,000,000	6,600,000	7,200,000	7,800,000	8,400,000	9,000,000
HP 1/2	200,000	400,000	800,000	1,200,000	1,600,000	2,000,000	2,400,000	2,800,000	3,200,000	3,600,000	4,000,000	4,400,000	4,800,000	5,200,000	5,600,000	6,000,000
LL .378	200,000	529,101	1,058,201	1,587,302	2,116,402	2,645,503	3,174,603	3,703,704	4,232,804	4,761,905	5,291,005	5,820,106	6,349,206	6,878,307	7,407,407	7,936,508
LL .451	200,000	443,459	886,918	1,330,377	1,773,836	2,217,295	2,660,754	3,104,213	3,547,672	3,991,131	4,434,590	4,878,049	5,321,508	5,764,967	6,208,426	6,651,885
LL .541	200,000	369,686	739,372	1,109,057	1,478,743	1,848,429	2,218,115	2,587,800	2,957,486	3,327,172	3,696,858	4,066,543	4,436,229	4,805,915	5,175,601	5,545,287
ULL 1/2	200,000	400,000	800,000	1,200,000	1,600,000	2,000,000	2,400,000	2,800,000	3,200,000	3,600,000	4,000,000	4,400,000	4,800,000	5,200,000	5,600,000	6,000,000
HP 1/3	1,000,000	3,000,000	6,000,000	9,000,000	12,000,000	15,000,000	18,000,000	21,000,000	24,000,000	27,000,000	30,000,000	33,000,000	36,000,000	39,000,000	42,000,000	45,000,000
HP 1/2	1,000,000	2,000,000	4,000,000	6,000,000	8,000,000	10,000,000	12,000,000	14,000,000	16,000,000	18,000,000	20,000,000	22,000,000	24,000,000	26,000,000	28,000,000	30,000,000
LL .378	1,000,000	2,645,503	5,291,005	7,936,508	10,582,011	13,227,513	15,873,016	18,518,519	21,164,021	23,809,524	26,455,026	29,100,529	31,746,032	34,391,534	37,037,037	39,682,540
LL .451	1,000,000	2,217,295	4,434,590	6,651,885	8,869,180	11,086,475	13,303,769	15,521,064	17,738,359	19,955,654	22,172,949	24,390,244	26,607,539	28,824,834	31,042,129	33,259,424
LL .541	1,000,000	1,848,429	3,696,858	5,545,287	7,393,715	9,242,144	11,090,573	12,939,002	14,787,431	16,635,860	18,484,288	20,332,717	22,181,146	24,029,575	25,878,004	27,726,433
ULL 1/2	1,000,000	2,000,000	4,000,000	6,000,000	8,000,000	10,000,000	12,000,000	14,000,000	16,000,000	18,000,000	20,000,000	22,000,000	24,000,000	26,000,000	28,000,000	30,000,000
HP 1/3	2,000,000	6,000,000	12,000,000	18,000,000	24,000,000	30,000,000	36,000,000	42,000,000	48,000,000	54,000,000	60,000,000	66,000,000	72,000,000	78,000,000	84,000,000	90,000,000
HP 1/2	2,000,000	4,000,000	8,000,000	12,000,000	16,000,000	20,000,000	24,000,000	28,000,000	32,000,000	36,000,000	40,000,000	44,000,000	48,000,000	52,000,000	56,000,000	60,000,000
LL .378	2,000,000	5,291,005	10,582,011	15,873,016	21,164,021	26,455,026	31,746,032	37,037,037	42,328,042	47,619,048	52,910,053	58,201,058	63,492,063	68,783,069	74,074,074	79,365,079
LL .451	2,000,000	4,434,590	8,869,180	13,303,769	17,738,359	22,172,949	26,607,539	31,042,129	35,476,718	39,911,308	44,345,898	48,780,488	53,215,078	57,649,667	62,084,257	66,518,847
LL .541	2,000,000	3,696,858	7,393,715	11,090,573	14,787,431	18,484,288	22,181,146	25,878,004	29,574,861	33,271,719	36,968,577	40,665,434	44,362,292	48,059,150	51,756,007	55,452,865
ULL 1/2	2,000,000	4,000,000	8,000,000	12,000,000	16,000,000	20,000,000	24,000,000	28,000,000	32,000,000	36,000,000	40,000,000	44,000,000	48,000,000	52,000,000	56,000,000	60,000,000

Table 2: Example DSSS Chip rates vs. User Data rates

Latency Considerations

Like all block codes, LDPC requires reception of a complete block before encoding or decoding can occur. The result is that additional processing latency is incurred. Without going into the details, a simple approximation of the processing latency can be defined by:

$$\text{FEC Processing Latency} \sim \frac{\text{N}*\text{Blocksize}}{\text{Symbol Rate}}$$

End-to-end IP packet latency is based on the IP packet size and the user data rate plus the FEC processing latency.

$$\text{End-to-End IP Packet Latency} \sim \frac{\text{N}*\text{Blocksize}}{\text{Symbol Rate}} + (\text{IP Packet Size (bytes)} * 8) / \text{User Data Rate}$$

Where:
N = Table 3 below:

ModCod	N (multiplier)
BPSK HP 1/3	2.3
BPSK HP 1/2	2.2
BPSK LL .378	2.5
BPSK LL .451	2.3
BPSK LL .541	2.1
BPSK ULL 1/2	2.0

Table 3: Multiplier factor per ModCod

Block Size = 16k for HP, 4k for LL and 2k for ULL

Measured latency is provided in Table 4 below:

64 Byte Packets	Measured End-to-end Latency (msec)		
	100 ksps	200 ksps	500 ksps
BPSK HP 1/3	365	182	73
BPSK HP 1/2	353	176	71
BPSK LL .378	103	51	21
BPSK LL .451	92	47	20
BPSK LL .541	84	43	18
BPSK ULL 1/2	42	22	10

1472 Byte Packets	Measured End-to-end Latency (msec)		
	100 ksps	200 ksps	500 ksps
BPSK HP 1/3	709	354	142
BPSK HP 1/2	582	291	117
BPSK LL .378	409	203	82
BPSK LL .451	347	175	71
BPSK LL .541	296	149	61
BPSK ULL 1/2	274	138	56

Table 4: Measured end-to-end latency per ModCod

Conclusion

A flexible and high-performance DSSS implementation is provided as an option in the SLM-5650B and SLM-5650C Satellite Modems. Available spreading factors (2-512, all integers) in conjunction with BPSK modulation and a very strong family of LDPC FEC modes supports operation in an SNR range of 0 to -27 dB with approximately 0.5 dB of granularity across the entire range.

For additional information, please contact us.

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