



Spread Spectrum in the SLM-5650B/C: Features, Performance, and Applications

*A description of the Spread Spectrum option in the SLM-5650B & SLM-5650C Satellite Modems,
including available options, performance and potential applications*

December 2019



Abstract

Direct sequence spread spectrum (DSSS) is an option in the SLM-5650B and SLM-5650C Satellite Modems. This white paper describes the operation of DSSS within the SLM-5650B/C modems, as well as performance and some potential applications.

DSSS Overview

When spreading by a factor of “N” using the DSSS technique, a given transmitted symbol is replaced by a random sequence of N sub-symbols, or “chips.” In the frequency domain, the net effect of spreading on the transmitted waveform is to widen the spectrum by a factor of N, while simultaneously lowering the power spectral density (PSD) by this same factor. This is illustrated below in Figure 1.

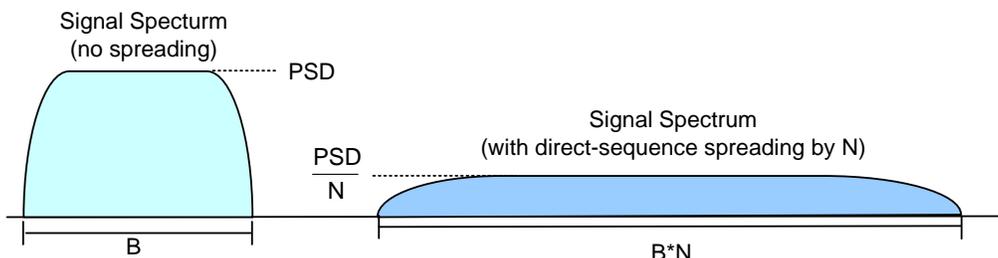


Figure 1: Effect of Spreading by N on Transmitted Spectrum

As shown in Figure 1, when the total transmitted power is kept constant, the PSD is reduced by a factor of N. Since the bandwidth is increased by a factor of N, when additive noise is added on a satellite link, the signal-to-noise ratio (SNR) of the received signal is also reduced by this same factor of N. At the receiver, de-spreading the signal adds back a “processing gain” factor of N. Hence absent any implementation loss, the net effect of spreading and de-spreading a signal on the overall satellite link budget is zero (i.e. the decrease in signal-to-noise ratio is offset by the processing gain).

The above conclusion is true for any DSSS implementation. It is important to keep this in mind when evaluating competing claims from various vendors. At times, competing vendors have been known to apply the DSSS processing gain without also properly considering the increase in noise bandwidth of the signal, thereby improperly concluding or implying that DSSS can be used to improve a satellite link budget. This is never the case. For a fixed amount of transmitted power (or satellite power equivalent bandwidth (PEB)) and at a fixed information data rate, the only difference in the link budget performance between a DSSS and non-DSSS link lies in potential differences in implementation loss between the spread and non-spread modes.

Even though DSSS does not have a positive effect on a satellite link budget, there are several potential applications where it can be a very beneficial feature. These are discussed in the Potential DSSS Applications section below.

DSSS in the SLM-5650B/C Satellite Modems

In the SLM-5650B/C, DSSS is supported in BPSK modulation modes combined with Low Density Parity Check (LDPC) forward error correction (FEC). Note that use of BPSK modulation vs. QPSK modulation has the identical effect as spreading. That is, for a given FEC code type and code rate, the selection of BPSK vs. QPSK doubles the bandwidth and decreases the power spectral density of the transmitted signal by a factor of two. With the same transmitted power and implementation loss, there is no change in the link budget. Hence, a selection of BPSK modulation is analogous to using QPSK with a spreading factor of 2. Since BPSK is generally more robust with a somewhat lower implementation loss than QPSK, supporting spreading for only BPSK modulation does not in any way limit the use or functionality of the DSSS feature (one can think of using BPSK as the first spreading stage).

Likewise, LDPC FEC is the highest performing FEC available, and since for DSSS modes there are no interoperability issues with legacy products, supporting only LDPC FEC in conjunction with DSSS does

not in any way limit overall performance or functionality. Table 1 shows the SLM-5650B/C FEC modes that support DSSS.

Mod / FEC	Code Rate	Eb/No Guaranteed (Typical)				Data Rate Range [kbps]
		10 ⁻⁵	10 ⁻⁶	10 ⁻⁷	10 ⁻⁸	
LPDC Modes						
High Performance						
BPSK HP	1/3	1.8 (1.6)	1.9 (1.7)	2.0 (1.8)	2.1 (1.9)	32 - 15,000
BPSK HP	1/2	2.0 (1.7)	2.1 (1.8)	2.2 (1.9)	2.3 (2.0)	32 - 15,000
Low Latency						
BPSK LL	0.378	1.9 (1.6)	2.0 (1.7)	2.1 (1.8)	2.2 (1.9)	32 - 5,000
BPSK LL	0.451	2.1 (1.8)	2.2 (1.8)	2.3 (2.0)	2.4 (2.1)	32 - 5,000
BPSK LL	0.541	2.2 (1.9)	2.3 (2.0)	2.4 (2.1)	2.5 (2.2)	32 - 5,000
Ultra Low Latency						
BPSK ULL	1/2	3.1 (2.8)	3.4 (3.1)	3.7 (3.4)	3.8 (3.5)	32 - 2,000

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

Integer spreading factors of 2, 3, 4, 5, . . . 510, 511, 512 are supported in the SLM-5650B/C Satellite Modems. Since data rates associated with spreading applications are sometimes reasonably small, the low latency and ultra low latency variants of the LDPCs can be important operational modes. One should also note from Table 1 that the Eb/No performance of the Low Latency LDPC modes are within a few tenths of a dB from the high-performance mode (i.e. there is only a small performance advantage for the HP mode).

Given an Eb/No value from Table 1, the required SNR (or equivalently Ec/No, where “Ec” is the energy in a chip-time), and bandwidth efficiency BW_{eff} in information bits/symbol can be calculated as:

$$\frac{E_c}{N_o} [\text{dB}] = \frac{E_b}{N_o} [\text{dB}] + 10 \log_{10} \left[\frac{R_c M_o}{N} \right] + L_I [\text{dB}] \quad [1]$$

$$BW_{\text{eff}} = \frac{R_c M_o}{N} \quad [2]$$

Where

R_c = Code Rate of the FEC (2nd column of Table 1)

M_o = Modulation Order in bits/sym (BPSK = 1, QPSK = 2, 8PSK = 3, etc)

Note that M_o = 1 for all DSSS applications.

N = Spreading Factor

L_I = Additional DSSS Implementation Loss, beyond implementation loss included in non-spread Eb/No as shown in Table 1.

L_I = 0.1 dB in the SLM-5650B/C implementation

Figure 2 plots the typical performance of the DSSS modes using Equations [1] and [2] for the Low Latency LDPC FEC modes given in Table 1. Note that the three available code rates, combined with the various available spreading factors define operating points spaced roughly 1 dB apart over a signal-to-noise operating range of roughly 0 to -27dB. The operating points parallel and maintain close proximity to the Shannon Limit over the entire range. This enables selection of a near-optimal operating point matching the requirements of a wide range of potential applications.

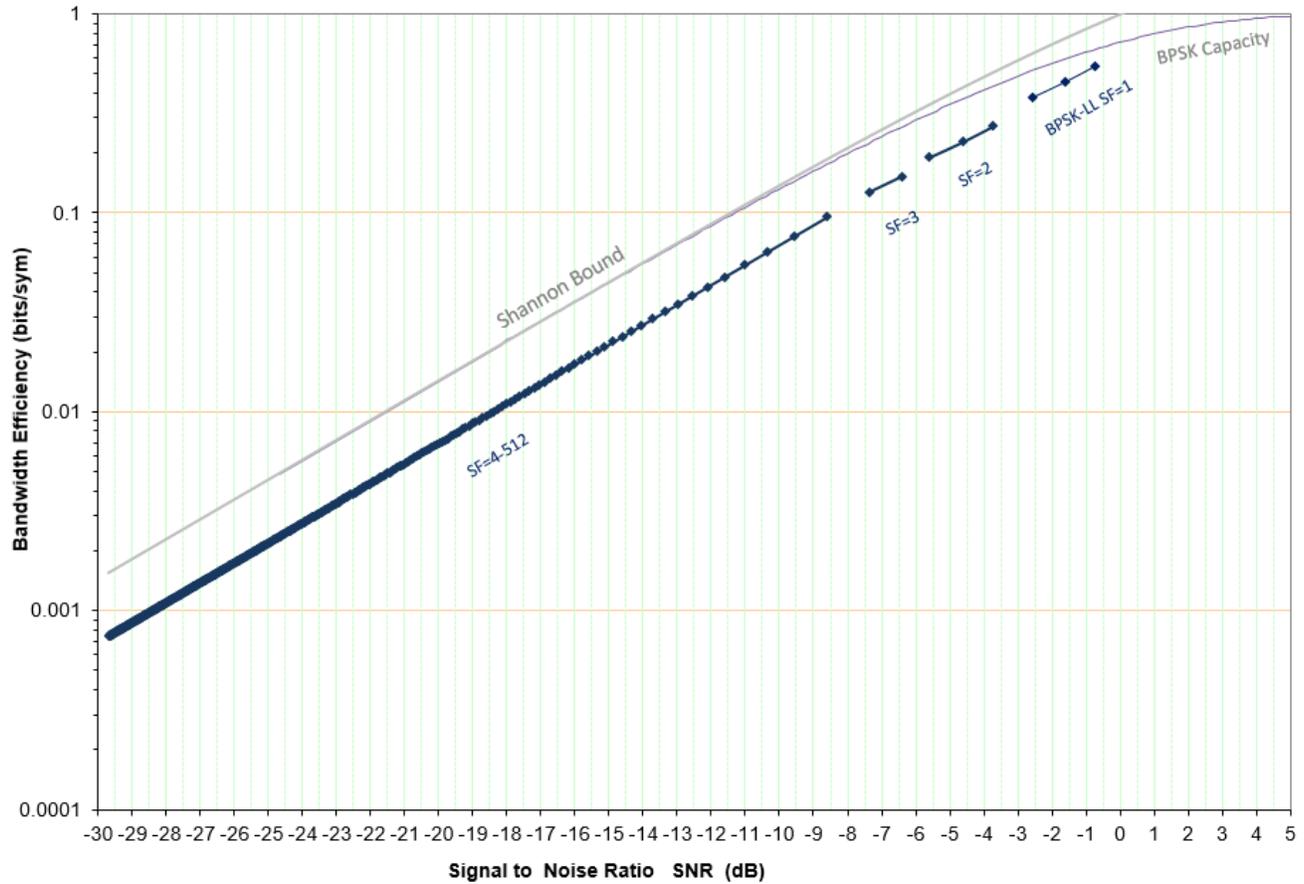


Figure 2: Performance of Low Latency DSSS Modes Compared to the Shannon Limit

Potential DSSS Applications

DSSS can be used in support of several important satellite communication applications. Some key applications include:

Small Antennas: 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 3.

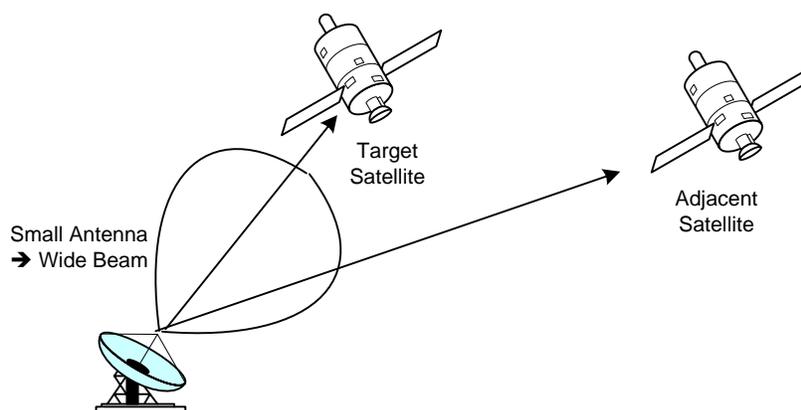


Figure 3: Small Antenna Illuminates Adjacent Satellite

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.

Multiple Access or stacked carriers: The spreading sequences assigned within a set of different modems can be configured to be orthogonal to each other. Such a configuration enables the modems to share a common frequency band without significant interference between the signals of different terminals. This Code Division Multiple Access (CDMA) mechanism is analogous to Frequency Division Multiple Access (FDMA), where the CDMA signals are orthogonal in the “code space” as opposed to the frequency dimension for FDMA. Figure 4 illustrates the composite spectrum of a set of signals using FDMA, where the spectra are separated in frequency, and also the composite spectrum of a set of signals using CDMA, where the signals share the same frequency band, but are separated by orthogonal spreading sequences.

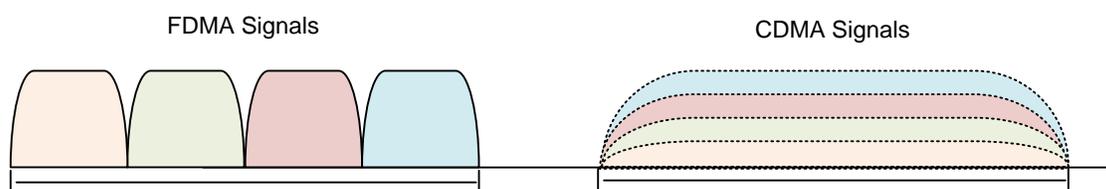


Figure 4: FDMA and CDMA

Absent any differences in implementation losses, FDMA and CDMA have the same network bandwidth efficiencies and capacity. However, CDMA can have an advantage in multiple access networks in the areas of network management and configuration control. In order to share a given bandwidth, FDMA users would need to be assigned center frequencies and bandwidths so as not to interfere or overlap with each other. If users are dynamically entering and leaving the system, this requires constant operator configuration of the modems, or some automated control mechanism (such as our Vipersat Management System product). In the CDMA approach, a set of modems, once configured, can enter and leave the network without the need for any manual operator control of other modems or any central control mechanism. This “hubless” form of multiple access can have important practical and cost advantages for some networks.

Anti-Jamming: DSSS can be utilized to overcome jamming (either intentional or inadvertent). Figure 5 illustrates an example jamming situation. In the case where an interfering signal is transmitted in the same channel as a primary signal of interest, spreading can be enabled in order to maintain a connection. If the same bandwidth is maintained on the satellite, the information bit rate is reduced as the key trade-off. The signal-to-interference plus noise-ratio (SINR) that can be tolerated is roughly the same as the signal to noise ratio (E_c/N_0) calculated in Equation [1] and plotted in Figure 2 for the low latency LDPC FEC.

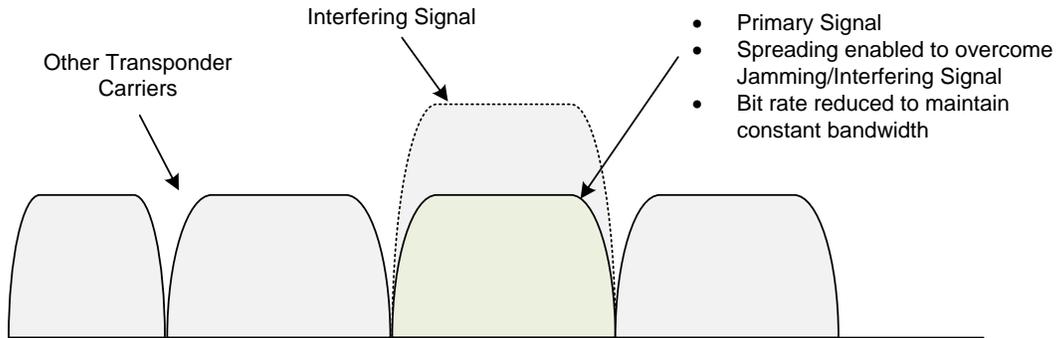


Figure 5: DSSS Used to Overcome Jamming

The SLM-5650B/C has automatic configuration options that enable a user to maintain a constant bandwidth while adjusting the spreading and FEC modes to a point necessary to overcome jamming in the SINR range from 0 to -27 dB.

Low Power Spectral Density (L-PSD) Carrier under carrier(s): DSSS can be used to enable the transmission of a low data rate signal underneath a stronger signal. With sufficient spreading, the presence of the L-PSD signal does not impact the stronger signal. Figure 6 illustrates the L-PSD situation. Table 2 calculates example examples of the impact of the L-PSD carrier on the stronger carrier

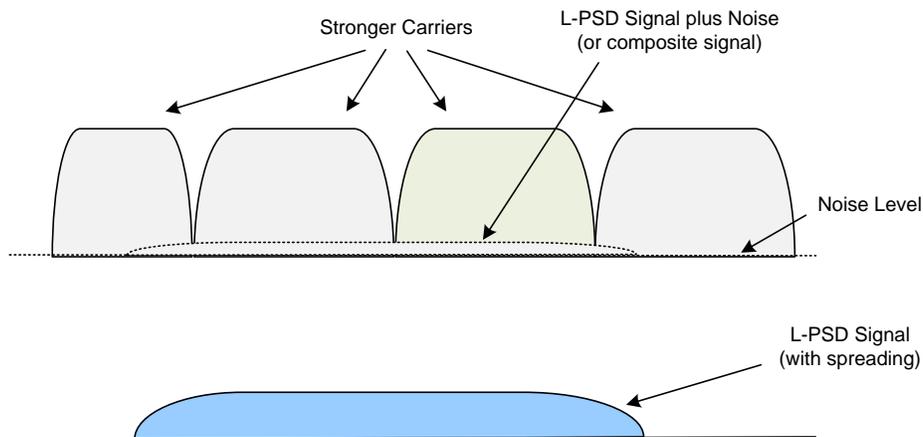


Figure 6: DSSS Used for L-PSD Carrier under carrier

BPSK 0.378 Spread Factor	SNR [dB]	Composite Signal Level Increase [dB]
1	-2.6	1.91
2	-5.6	1.06
4	-8.6	0.56
8	-11.6	0.29
16	-14.6	0.15
32	-17.6	0.07
64	-20.6	0.04
128	-23.7	0.02

} Essentially no impact on stronger carriers

Table 2: Composite Signal Level Increase (L-PSD)

Conclusion

A flexible and high-performance DSSS implementation is provided as an option in the SLM-5650B/C Satellite Modems. Available spreading factors (2-512, all integers) in conjunction with BPSK modulation and LDPC FEC modes support operation in an SNR range 0 to -27 dB with approximately 1.0 dB of granularity across the entire range. The modem is optimized to approximate Shannon Limit performance while simultaneously minimizing latency.

The DSSS option in the SLM-5650B/C can be used to enable multiple important applications, including (1) the use of ultra small antennas, (2) providing a hub-less, low-cost multi-access network, (3) supporting Anti-Jamming applications, and (4) L-PSD carrier under carrier applications.

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