White Paper

Unlocking the potential of LDPC,

New Flexible LDPC Option from

Datum Systems

for

PSM-500, 500L & 500LT Series Modems

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Introduction

Today, a new class of FEC is available from Datum Systems that leverages the Flexible LDPC (F-LDPC) technology from TrellisWare Technologies, Inc. F-LDPC provides a single powerful FEC code solution for any satellite link. Datum System's chose TrellisWare's F-LDPC for its LDPC implementation because it offers outstanding performance and flexibility in both block sizes and code rates.

Until recently, advances in forward error correction (FEC) design, such as Viterbi, Sequential, Trellis Code Modulation (TCM), Concatenated Viterbi/Reed-Solomon, Turbo Product Codes (TPC) or Low Density Parity Check codes (LDPC) have not been able to provide a complete solution to the requirements of a modern satellite communication channel. Typically, there are many tradeoffs between bandwidth, power, processing delay and coding gains that in the past have required the use of several different classes of FEC. Datum Systems has solved this dilemma using the F-LDPC core.

Years of field experience and simulation have shown that the performance of the modern iterative codes in widespread use today for satellite communications (TPC and LDPC) offer outstanding coding gain improvements over the legacy Intelsat coding methods of Sequential, Viterbi/Reed-Solomon and TCM. The disadvantages of the modern codes were usually (1) the large block sizes required for maximum coding gain result in large processing delays at low data rates, and (2) the cost of the hardware required for the iterative decoding and large block sizes can be prohibitive for high data rates. Datum's implementation of F-LDPC provides an exceptional range of code rates and block sizes that deliver excellent performance. In addition, advances in FPGA technology and decoder design provide high data rate throughput with low associated hardware cost.

Overview of Turbo Codes

Turbo codes have their origins in a landmark 1993 paper by Claude Berrou and Alain Glavieux, who introduced the technique of iterative, or parallel decoding, which they termed "Turbo codes". The Turbo name has been retained in the literature and industry as a name for certain types of iterative codes. TPCs and LDPCs are all considered Turbo codes. Berrou and Glavieux's iterative technique was soon applied to many types of FECs, and the TPC was developed and introduced to the market over a decade ago. LDPCs, on the other hand, have been around for much longer, having been invented by Robert Gallagher in his Ph.D. thesis in 1960. The idea sat nearly dormant for over 30 years, then was revived in the mid 1990's as hardware technology became available that made implementation practical. LDPCs have become popular in certain segments of the satellite industry, primarily the broadcast segment, as LDPCs are a part of the DVB-S2 standard. The term "traditional LDPC" will be used here to denote LDPC codes that are based on the optimization of parity check matrices. F-LDPC is a new breakthrough in FEC design that is a structured LDPC. This allows for the easy construction of parity-check matrices, and other advantages that are explained below.

Advantage of a flexible-LDPC codec design over TPCs and traditional LDPCs

In order to optimize a given satellite link, it is advantageous for any FEC to have many different FEC rates and block sizes. TPCs, traditional LDPCs, and F-LDPC are all types of block codes, that is, the decoding process works on the fixed number of data bits. Flexibility in FEC rate addresses the issue of power vs. bandwidth tradeoffs. Flexibility in block size allows processing delay vs. power to be addressed for a target Bit Error Rate (BER). Additionally, many of the constituent codes for TPC have inferior BER performance. Traditional LDPCs can be easily punctured, which permits code rate flexibility, but the block size is determined by the discovery and optimization of well-performing parity check matrices that are quite difficult to calculate. Datum's implementation of F-LDPC has a unique design that incorporates a large number of constituent codes and permits puncturing of parity bits. This combination provides great flexibility in both selectable FEC rates (7 code rates of 1/2, 2/3, 3/4, 14/17, 7/8, 10/11 & 16/17) AND block sizes (7 block sizes of 256, 512, 1k, 2k, 4k, 8k & 16 k). This flexibility allows the satellite link to be fine-tuned to an unprecedented scale.

Turbo codes, including TPCs, traditional LDPCs, and F-LDPC require multiple iteration passes through the decoder before the maximum number of errors can be corrected. The maximum decoding data rate is determined by the decoder complexity and the number of iteration passes required to correct most (or all) of the channel errors. TPC codes generally require a small number of iterations, and the decoding process is of medium complexity, therefore decoding can occur at reasonably high bit rates utilizing moderate to somewhat expensive hardware implementations. Traditional-LDPCs require a much larger number of iterations, and the decoding process is highly complex. Thus, in general, for a given data rate, the traditional LDPC decoding requires more expensive hardware to implement. F-LDPC provides the best of both worlds. The decoding process requires a smaller number of iterations, and the decoding architecture is of fairly low complexity, which provides for both high throughput and low decoder implementation cost.

Comparison of TPC, traditional LDPC and Datum System's flexible LDPC Performance

For any noisy communication channel there exists a theoretical maximum information rate for the channel for any particular noise level. This limit is called the Shannon limit of the channel, and the equations describing this maximum information rate were first presented by Claude Shannon in 1948. Shannon's equations describe an upper limit for FEC efficiency vs. BER and noise level. Classes of FEC codes and differing code rates and block sizes are often evaluated for performance by how close they approach the Shannon limit. Although there is much in the literature describing TPCs and traditional LDPCs that approach the Shannon limit, these are typically only at optimized code rates and block sizes. For example, TPCs perform best at high code rates (0.95) and large block sizes (i.e. 16kbit), but this is not a practical code for a low data rate, power limited satellite link. The fact is that TPC, traditional LDPC and Datum's LDPC all perform very close to the Shannon limit under certain conditions. A more practical way to compare competing FEC types is to stack up their performance in real-world satellite channel situations.

Are flexible-LDPCs better than TPCs? The answer is YES! As shown in *Figure - 1*, performance graphs for Datum Systems' LDPC Rate 3/4 vs. Industry Standard TPC Rate 3/4 for 8PSK and QPSK show a clear advantage for F-LDPC. For the 8psk case, the F-LDPC 1k block has the same BER performance as Compatible TPC, but with almost half the end to end delay. The Flexible LDPC 2k block offered by Datum has roughly the same delay as the Industry Standard TPC, but with 0.5 dB better performance at 1E-7 BER. The same results hold for QPSK.

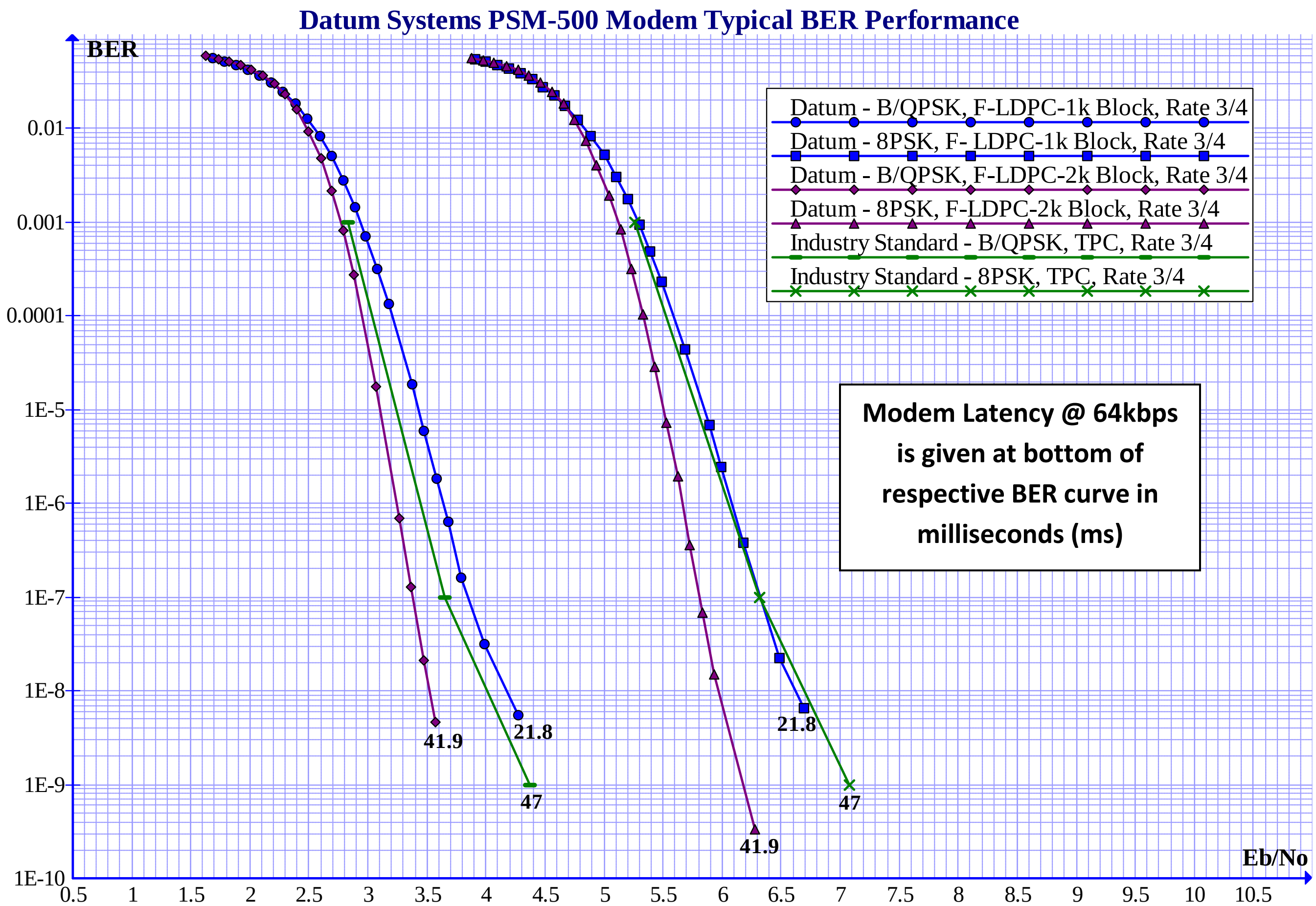


Figure - 1

The advantage of flexible LDPC over TPC is more dramatic in *Figure 2*, which shows performance graphs for Datum LDPC Rate 1/2 vs. Industry Standard TPC rate 21/44 (which is not as bandwidth efficient as Rate 1/2). In *Figure - 2*, LDPC Rate 1/2 1k block not only has less than 1/3 of the delay as Compatible TPC, but the performance is over 0.7 dB better at 1E-7.

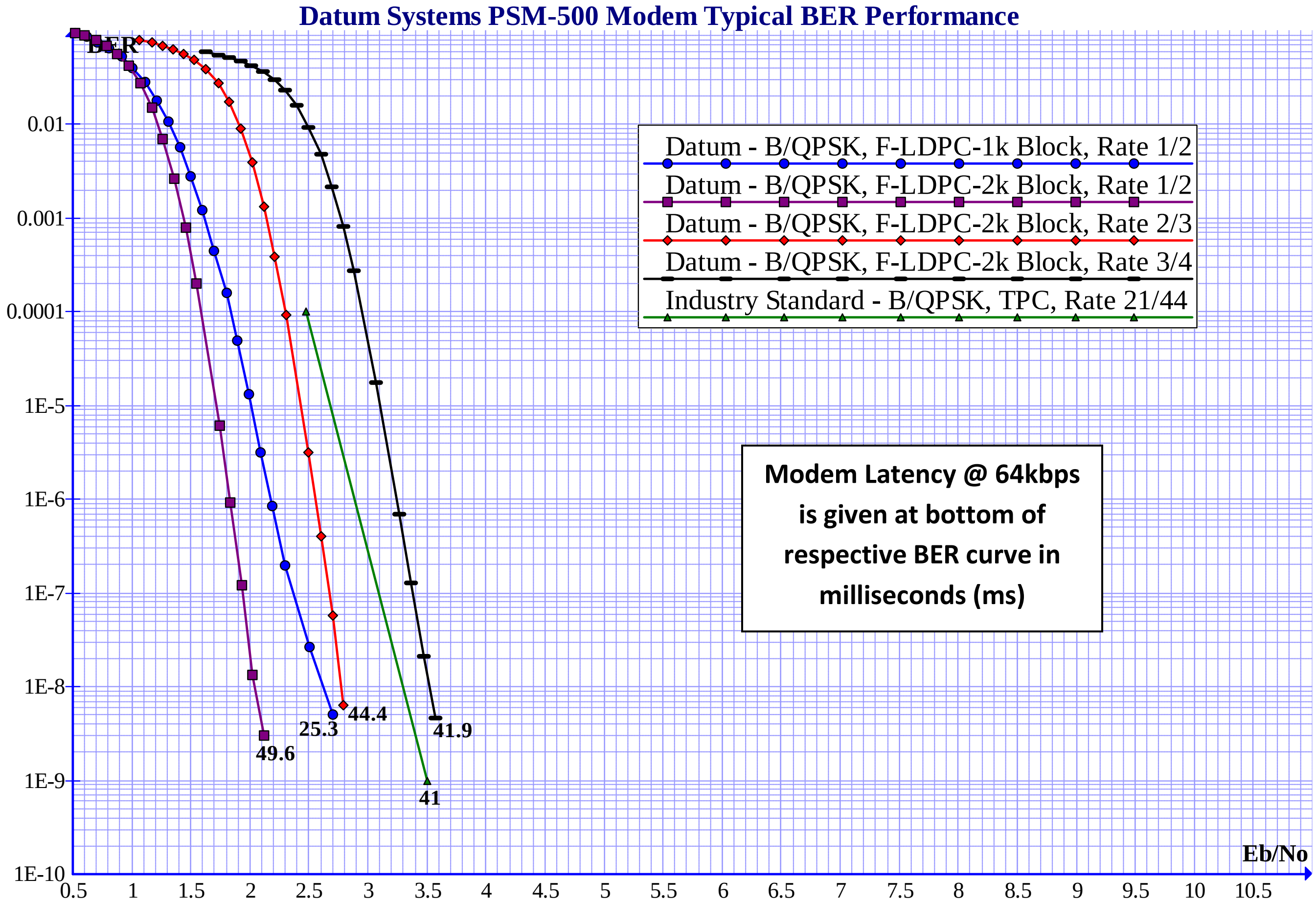


Figure - 2

Is Datum's flexible-LDPC option better than traditional LDPCs? The answer again is YES! As shown in *Figure – 3*, the performance graphs for Datum LDPC Rate 3/4 vs. Traditional LDPC Rate 3/4 for 16QAM show a clear advantage for Datum LDPC. As shown in the Figure, the Datum LDPC Rate 3/4 2k Block has the same performance as Traditional LDPC Rate 3/4, but at less than 1/9 the delay! The Datum LDPC Rate 3/4 4k Block has about 0.5 dB better BER performance, but at less than 1/4 the delay!

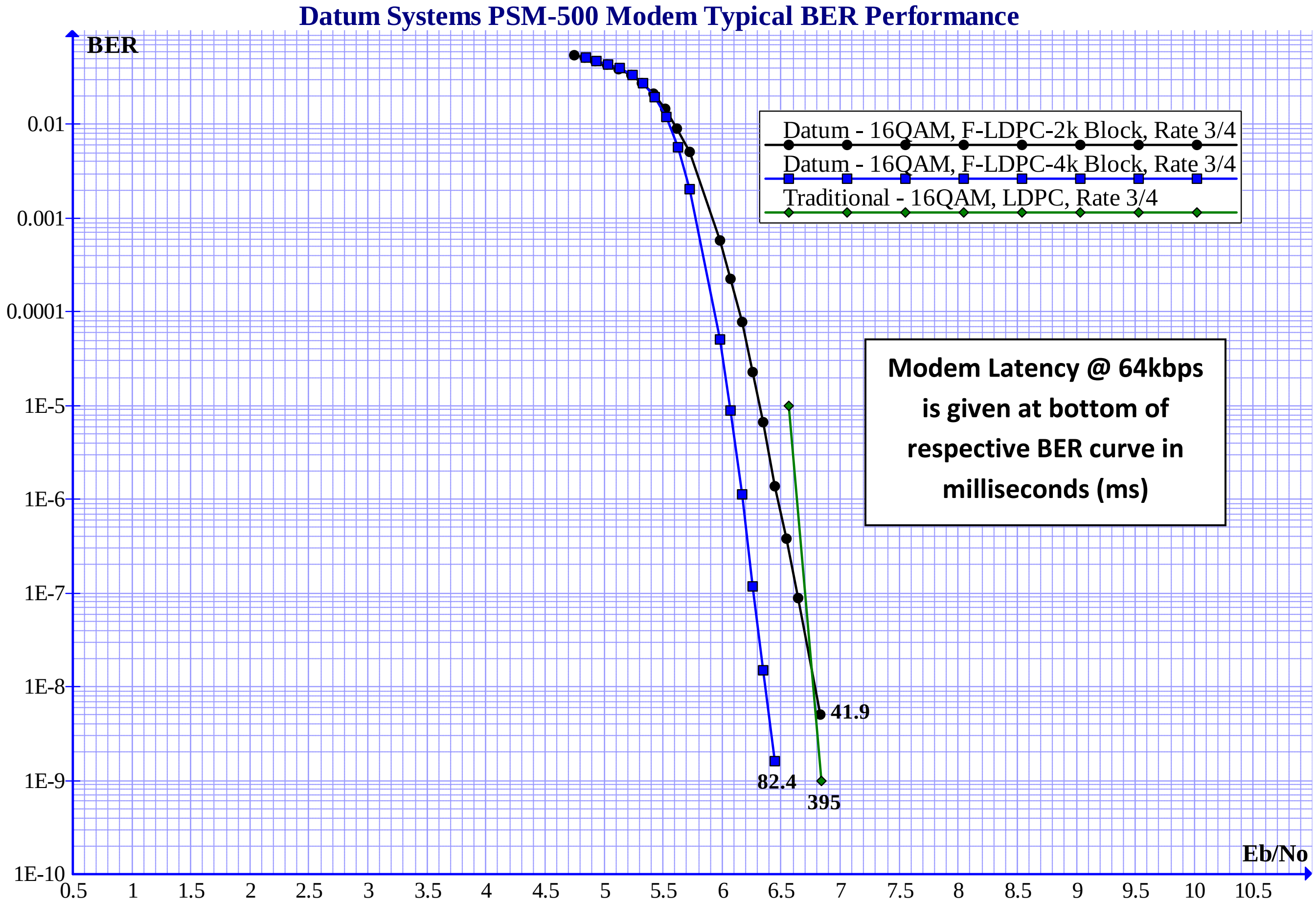


Figure -3

Conclusion and Datum LDPC Highlights

Datum Systems has integrated a highly Scalable and Flexible LDPC option into its PSM-500 Series satellite modems. This quantum leap in LDPC capability removes the barriers that forced users of traditional LDPC's to decide between high performance and low latency. Datum Systems' LDPC can give you both. In addition, this new low cost implementation makes it very cost competitive to current Turbo Product Codes, with significantly better performance and lower latency.

Additional Datum LDPC Highlights Include:

- No longer need both TPC and LDPC to maximize modem performance
- Datum LDPC performs across all available data rates, code rates, block sizes and modulation types
- 7 well distributed code rates and 7 selectable block sizes for unprecedented link design flexibility
- Flexible LDPC block sizes now offer many low latency alternatives to traditional LDPC or TPC
- Datum LDPC outperforms TPC across the board; BER vs. EB/N0 vs. Latency
- The flexible LDPC Encoder comes standard with all PSM-500 Modem models
- Complete Datum LDPC Decoder card is field –upgradable
- Software Key Enabled upgrade to LDPC-Limited (2k and below) option available for PSM-500 Series
- Datum's fast and reliable acquisition fully supports all flexible LDPC modes

PSM-500 Series Modem Processing Delay Table

	64 kbps	128 kbps	256 kbps	512 kbps
Viterbi, Rate 1/2	2.8 ms	1.4 ms	0.7 ms	0.3 ms
Viterbi, Rate 1/2 + Reed Solomon	61.5 ms	30.8 ms	15.4 ms	7.7 ms
TCM, Rate 2/3	7.5 ms	3.8 ms	1.9 ms	0.9 ms
TCM, Rate 2/3 + Reed Solomon	110.6 ms	55.3 ms	27.7 ms	13.8 ms
TPC Advanced, Rate 1/2-4k	42.7 ms	21.4 ms	10.8 ms	5.5 ms
TPC Advanced, Rate 3/4-4k	46.1 ms	23.2 ms	11.7 ms	6.0 ms
TPC Advanced, Rate 7/8-4k	58.9 ms	29.6 ms	14.9 ms	7.6 ms
TPC Advanced, Rate 0.950-4k	64.9 ms	32.6 ms	16.4 ms	8.3 ms
LDPC, Rate 1/2 & 256 Block	7.2 ms	3.7 ms	1.9 ms	1.0 ms
LDPC, Rate 1/2 & 512 Block	13.4 ms	6.8 ms	3.5 ms	1.8 ms
LDPC, Rate 1/2 & 1k Block	25.3 ms	12.8 ms	6.6 ms	3.4 ms
LDPC, Rate 1/2 & 2k Block	49.6 ms	25.1 ms	12.8 ms	6.7 ms
LDPC, Rate 1/2 & 4k Block	98.0 ms	49.5 ms	25.2 ms	13.1 ms
LDPC, Rate 1/2 & 8k Block	195.0 ms	98.5 ms	50.2 ms	26.1 ms
LDPC, Rate 1/2 & 16k Block	388.6 ms	196.2 ms	100.0 ms	51.9 ms
LDPC, Rate 2/3 & 256 Block	6.7 ms	3.4 ms	1.8 ms	1.0 ms
LDPC, Rate 2/3 & 512 Block	12.2 ms	6.2 ms	3.2 ms	1.7 ms
LDPC, Rate 2/3 & 1k Block	22.8 ms	11.6 ms	5.9 ms	3.1 ms
LDPC, Rate 2/3 & 2k Block	44.4 ms	22.5 ms	11.5 ms	6.0 ms
LDPC, Rate 2/3 & 4k Block	87.5 ms	44.3 ms	22.6 ms	11.8 ms
LDPC, Rate 2/3 & 8k Block	173.7 ms	87.8 ms	44.9 ms	23.4 ms
LDPC, Rate 2/3 & 16k Block	346.1 ms	175.0 ms	89.4 ms	46.5 ms
LDPC, Rate 3/4 & 256 Block	6.7 ms	3.4 ms	1.8 ms	1.0 ms
LDPC, Rate 3/4 & 512 Block	11.5 ms	5.9 ms	3.0 ms	1.6 ms
LDPC, Rate 3/4 & 1k Block	21.8 ms	11.0 ms	5.7 ms	3.0 ms
LDPC, Rate 3/4 & 2k Block	41.9 ms	21.2 ms	10.9 ms	5.7 ms
LDPC, Rate 3/4 & 4k Block	82.4 ms	41.7 ms	21.4 ms	11.2 ms
LDPC, Rate 3/4 & 8k Block	163.1 ms	82.5 ms	42.2 ms	22.1 ms
LDPC, Rate 3/4 & 16k Block	325.0 ms	164.4 ms	84.1 ms	43.9 ms
LDPC, Rate 14/17 & 256 Block	6.3 ms	3.3 ms	1.7 ms	0.9 ms
LDPC, Rate 14/17 & 512 Block	11.1 ms	5.7 ms	2.9 ms	1.6 ms
LDPC, Rate 14/17 & 1k Block	20.6 ms	10.5 ms	5.4 ms	2.8 ms
LDPC, Rate 14/17 & 2k Block	39.6 ms	20.1 ms	10.3 ms	5.4 ms
LDPC, Rate 14/17 & 4k Block	77.6 ms	39.3 ms	20.2 ms	10.6 ms
LDPC, Rate 14/17 & 8k Block	153.9 ms	77.9 ms	39.9 ms	20.9 ms
LDPC, Rate 14/17 & 16k Block	306.3 ms	155.0 ms	79.4 ms	41.6 ms
LDPC, Rate 7/8 & 256 Block	6.5 ms	3.3 ms	1.7 ms	0.9 ms
LDPC, Rate 7/8 & 512 Block	10.8 ms	5.5 ms	2.9 ms	1.5 ms
LDPC, Rate 7/8 & 1k Block	20.0 ms	10.2 ms	5.2 ms	2.8 ms
LDPC, Rate 7/8 & 2k Block	38.1 ms	19.3 ms	9.9 ms	5.2 ms
LDPC, Rate 7/8 & 4k Block	74.6 ms	37.8 ms	19.4 ms	10.2 ms
LDPC, Rate 7/8 & 8k Block	147.3 ms	74.7 ms	38.3 ms	20.1 ms
LDPC, Rate 7/8 & 16k Block	293.6 ms	148.7 ms	76.3 ms	40.0 ms
LDPC, Rate 10/11 & 256 Block	6.1 ms	3.2 ms	1.7 ms	0.9 ms
LDPC, Rate 10/11 & 512 Block	10.6 ms	5.4 ms	2.8 ms	1.5 ms
LDPC, Rate 10/11 & 1k Block	19.3 ms	9.9 ms	5.1 ms	2.7 ms
LDPC, Rate 10/11 & 2k Block	37.0 ms	18.8 ms	9.7 ms	5.1 ms
LDPC, Rate 10/11 & 4k Block	72.3 ms	36.6 ms	18.8 ms	9.9 ms
LDPC, Rate 10/11 & 8k Block	143.0 ms	72.5 ms	37.2 ms	19.6 ms
LDPC, Rate 10/11 & 16k Block	284.5 ms	144.1 ms	74.0 ms	38.9 ms
LDPC, Rate 16/17 & 256 Block	6.1 ms	3.1 ms	1.6 ms	0.9 ms
LDPC, Rate 16/17 & 512 Block	10.2 ms	5.2 ms	2.7 ms	1.4 ms
LDPC, Rate 16/17 & 1k Block	18.9 ms	9.6 ms	5.0 ms	2.6 ms
LDPC, Rate 16/17 & 2k Block	35.8 ms	18.2 ms	9.4 ms	5.0 ms
LDPC, Rate 16/17 & 4k Block	70.2 ms	35.6 ms	18.3 ms	9.7 ms
LDPC, Rate 16/17 & 8k Block	138.7 ms	70.3 ms	36.1 ms	19.0 ms
LDPC, Rate 16/17 & 16k Block	276.1 ms	139.9 ms	71.8 ms	37.8 ms

Datum LDPC Code Rate Selections

Datum Systems' sought to provide our users a fairly even distribution of BER curves. First, common code rates were chosen because of their popularity to satellite equipment operators. Secondly, additional code rates were chosen to fill in the holes and to provide smooth and even BER vs. EB/N0 distribution curves. The curves shown in *Figure – 4* permit the user the flexibility to fine tune their link budget calculations.

Example of Flexible LDPC Code Rate Distribution

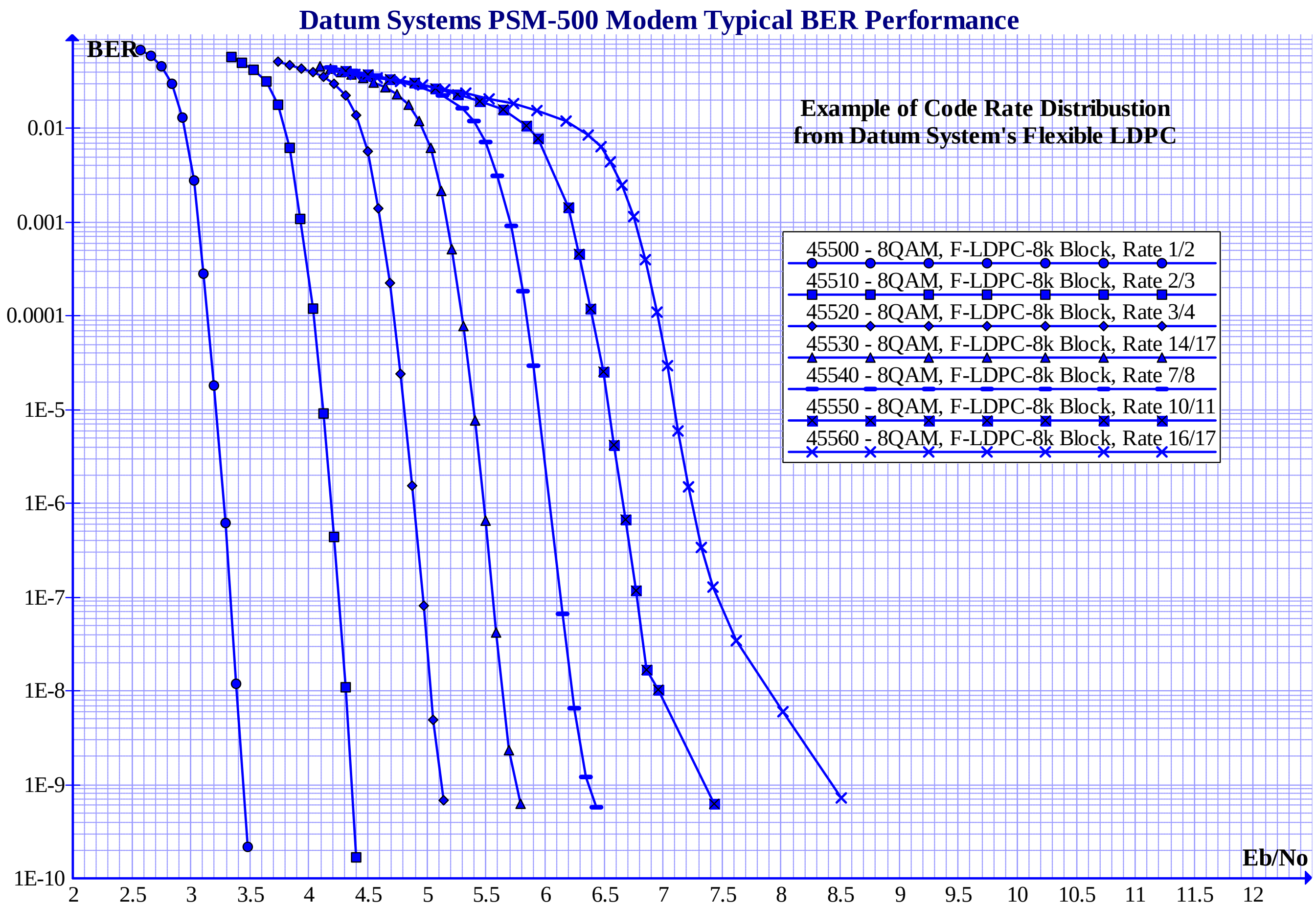


Figure - 4

Maximizing your throughput at Higher Data Rates

Is there a way to maximize higher data rate throughput? Yes! Datum Systems' LDPC permits users the flexibility of selecting higher code rates together with larger block sizes. As shown in *Figure – 5* below, a code rate of 16/17 with a block size of 16k provides excellent performance with virtually no overhead. Only 1 overhead bit is used for every 16 bits of real data. This will extensively increase your data throughput on both point-to-point and point-to multipoint configurations.

As an example, in many point-to-multipoint satellite network configurations, the outbound carriers, or sometimes referred to as forward channels, have high data rate requirements because they feed many remote locations through a single high data rate out-bound carrier. The use of higher codes rates increases the available bandwidth to the customer without the additional costs.

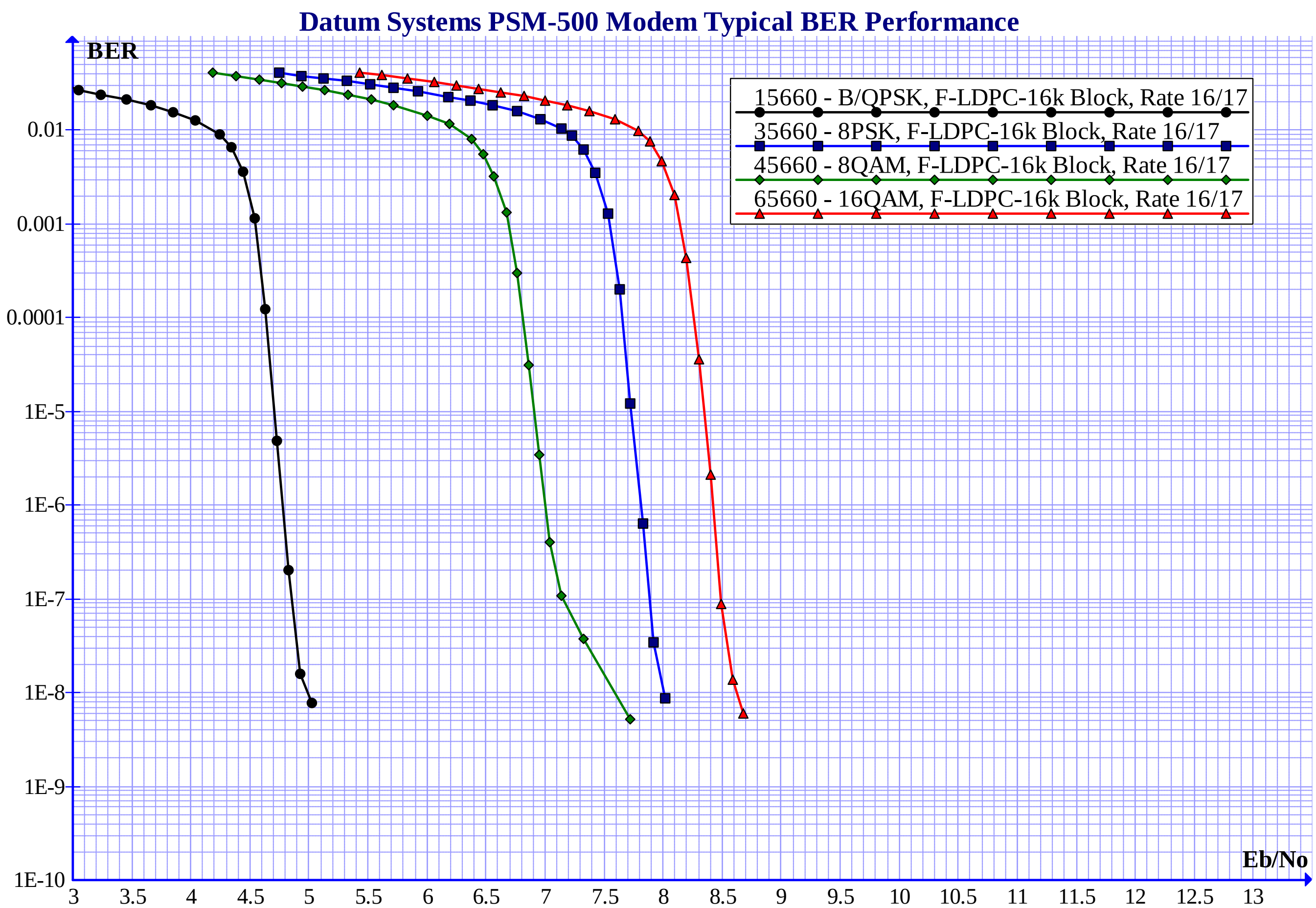
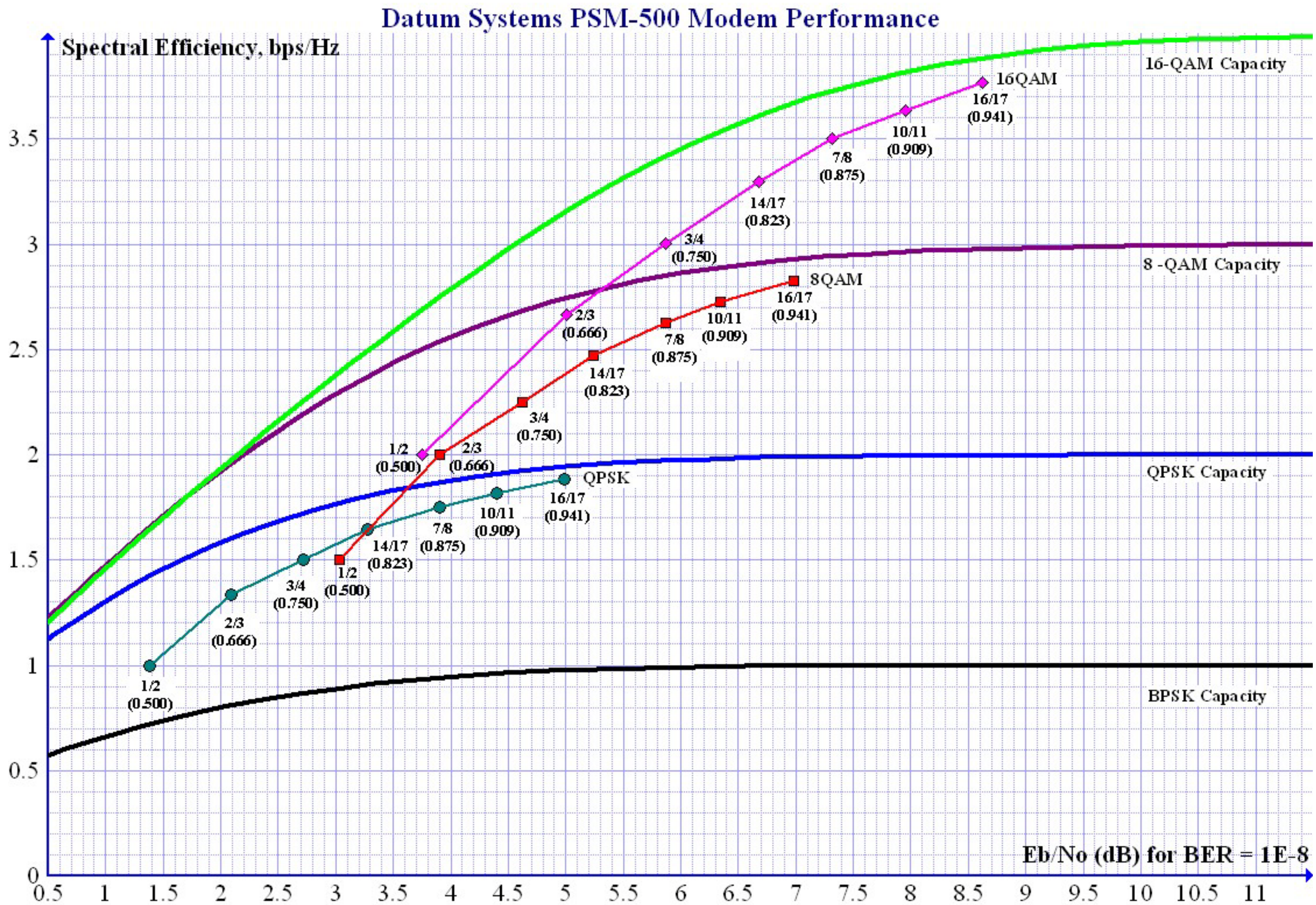
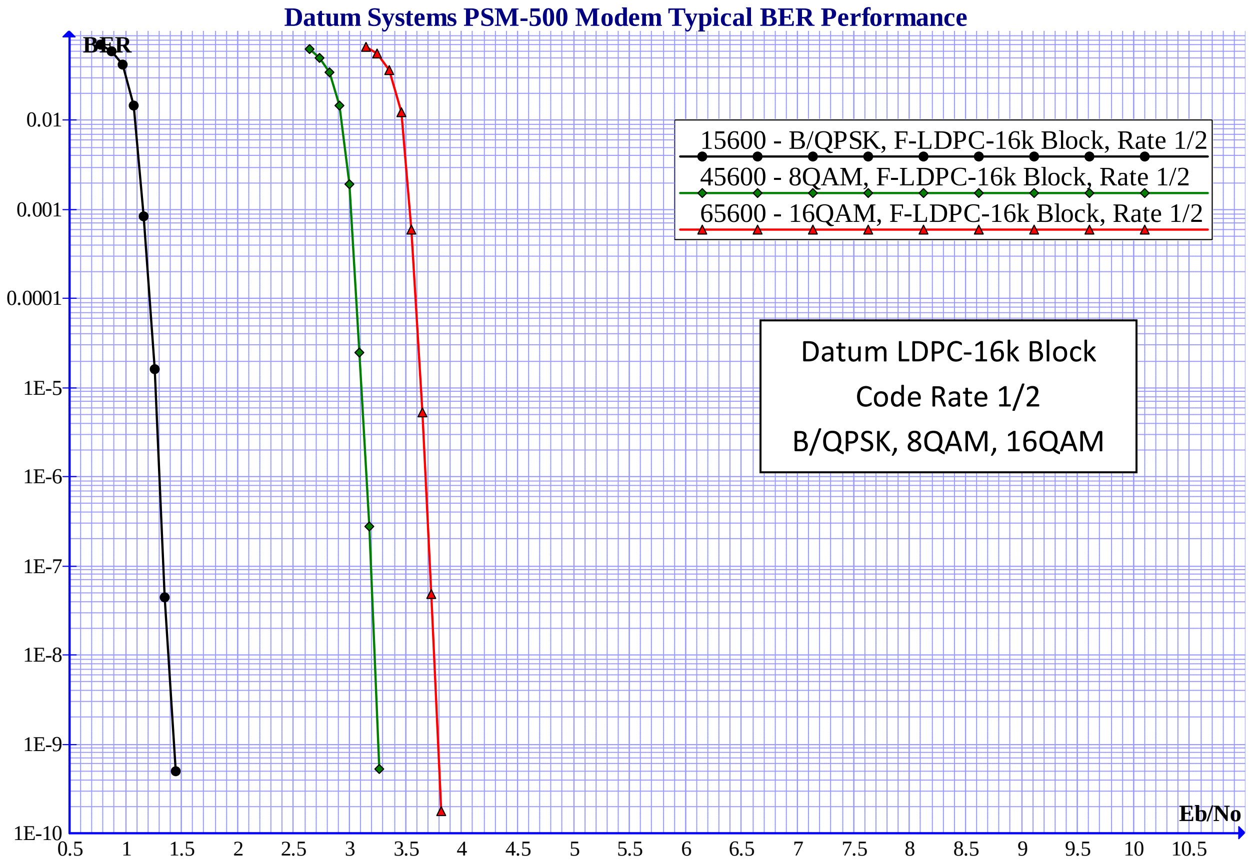


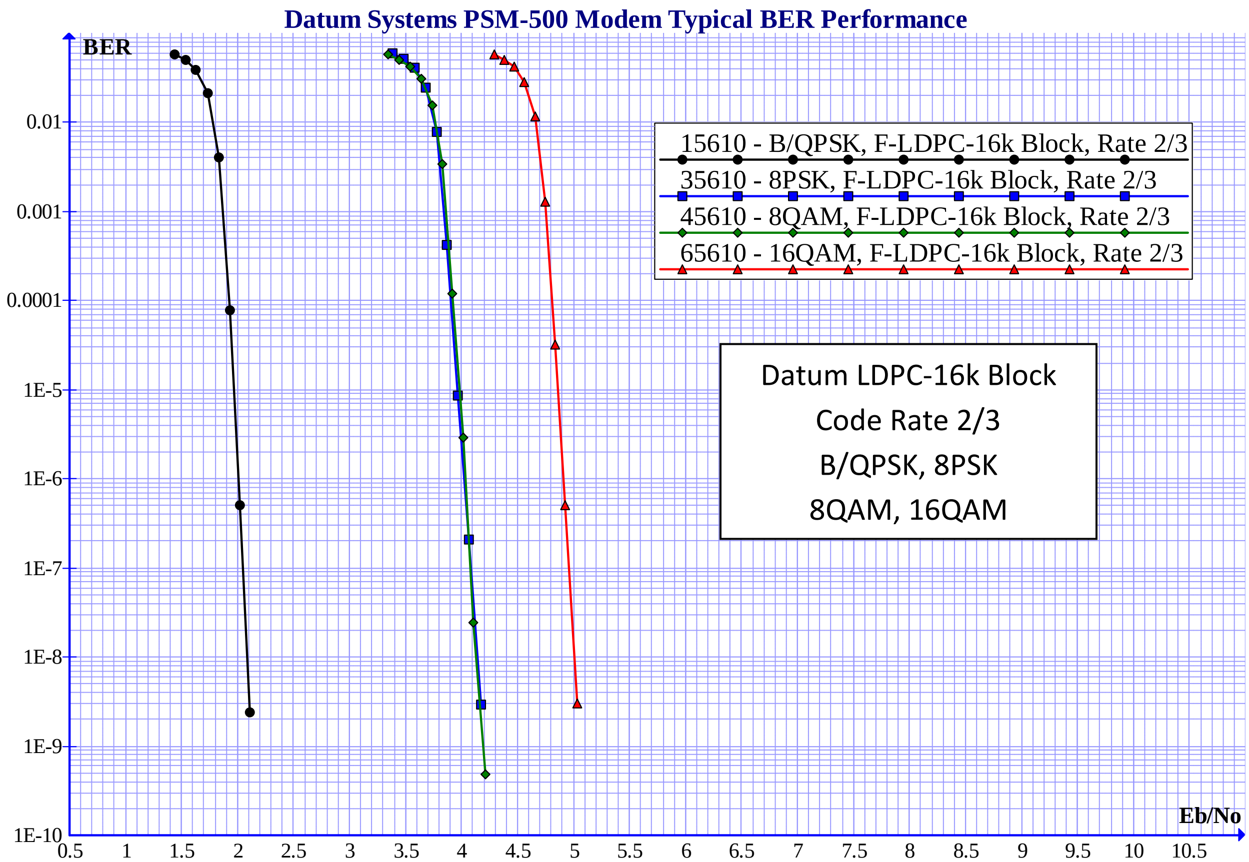
Figure - 5

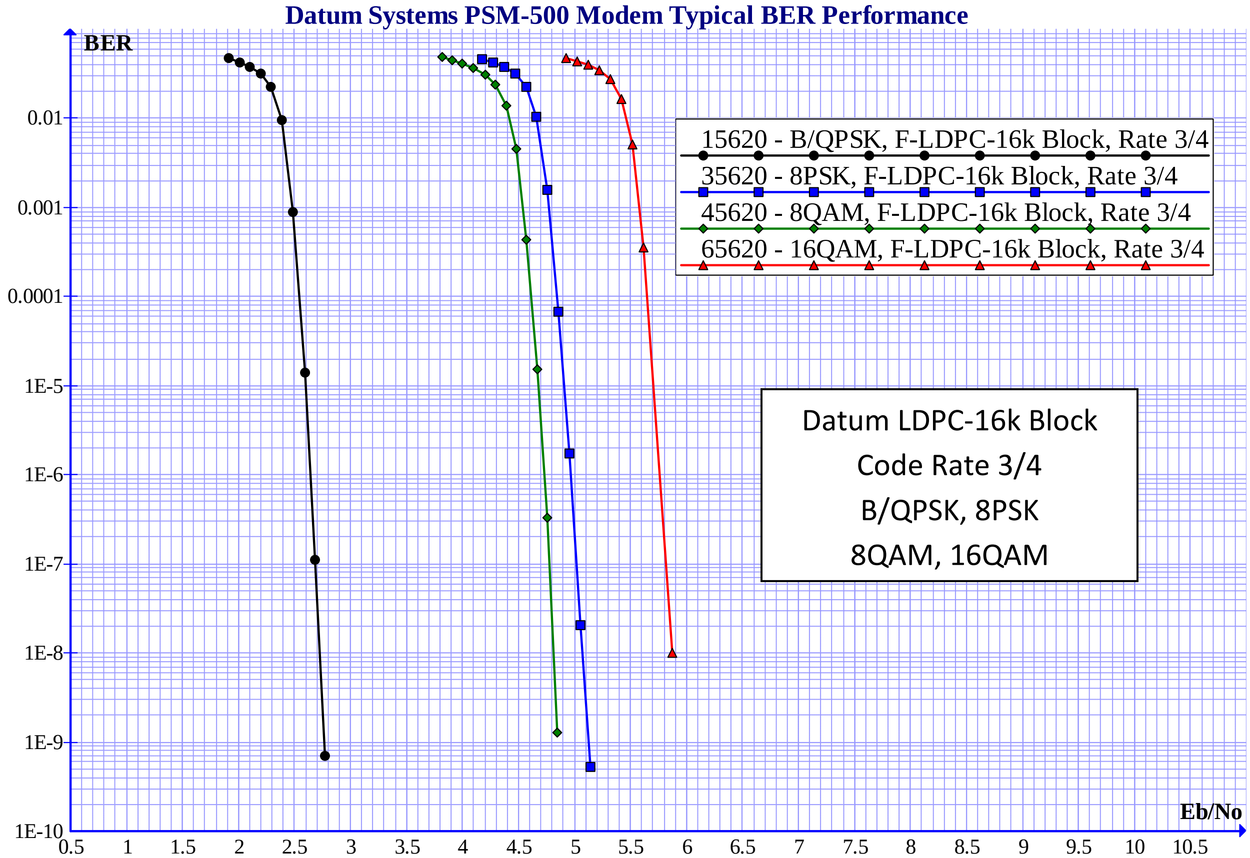
Spectral Efficiency vs. EB/N0 for Datum LDPC-16k

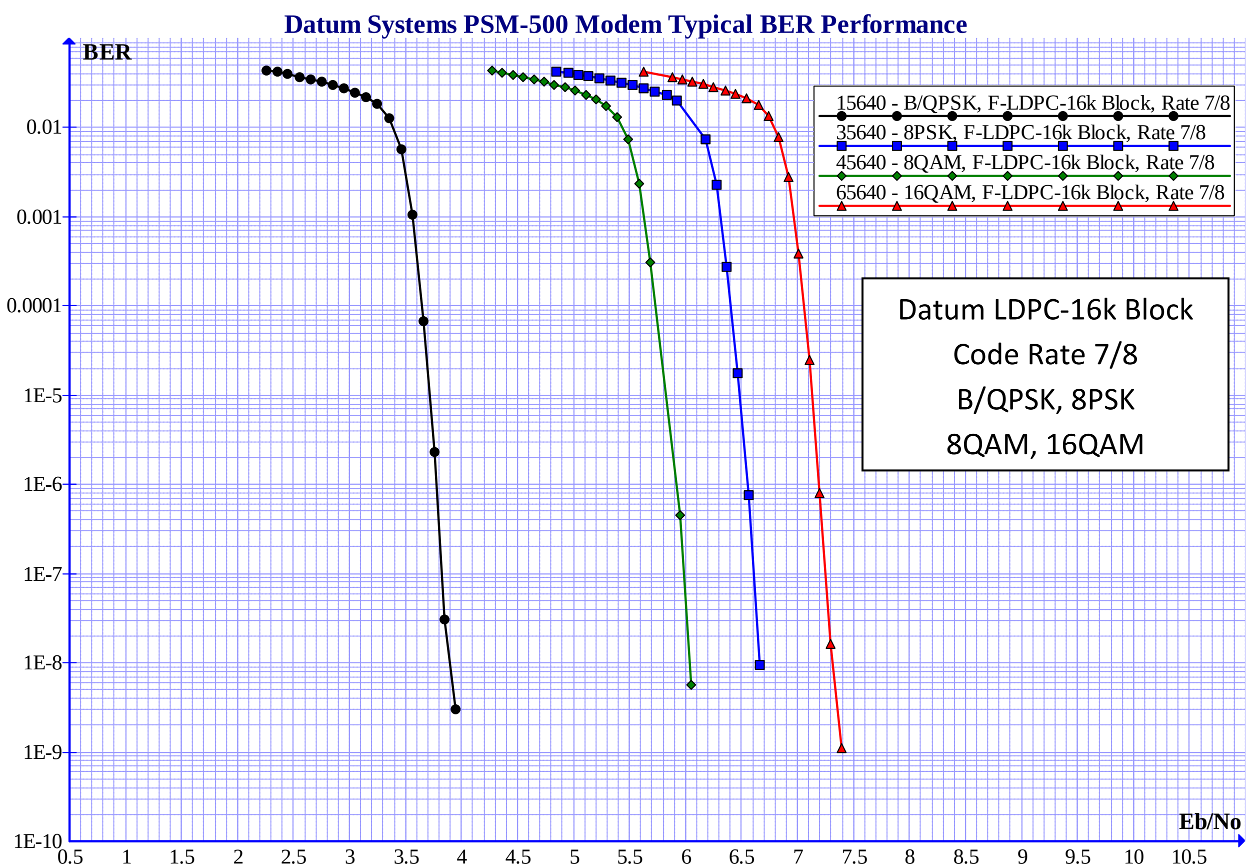


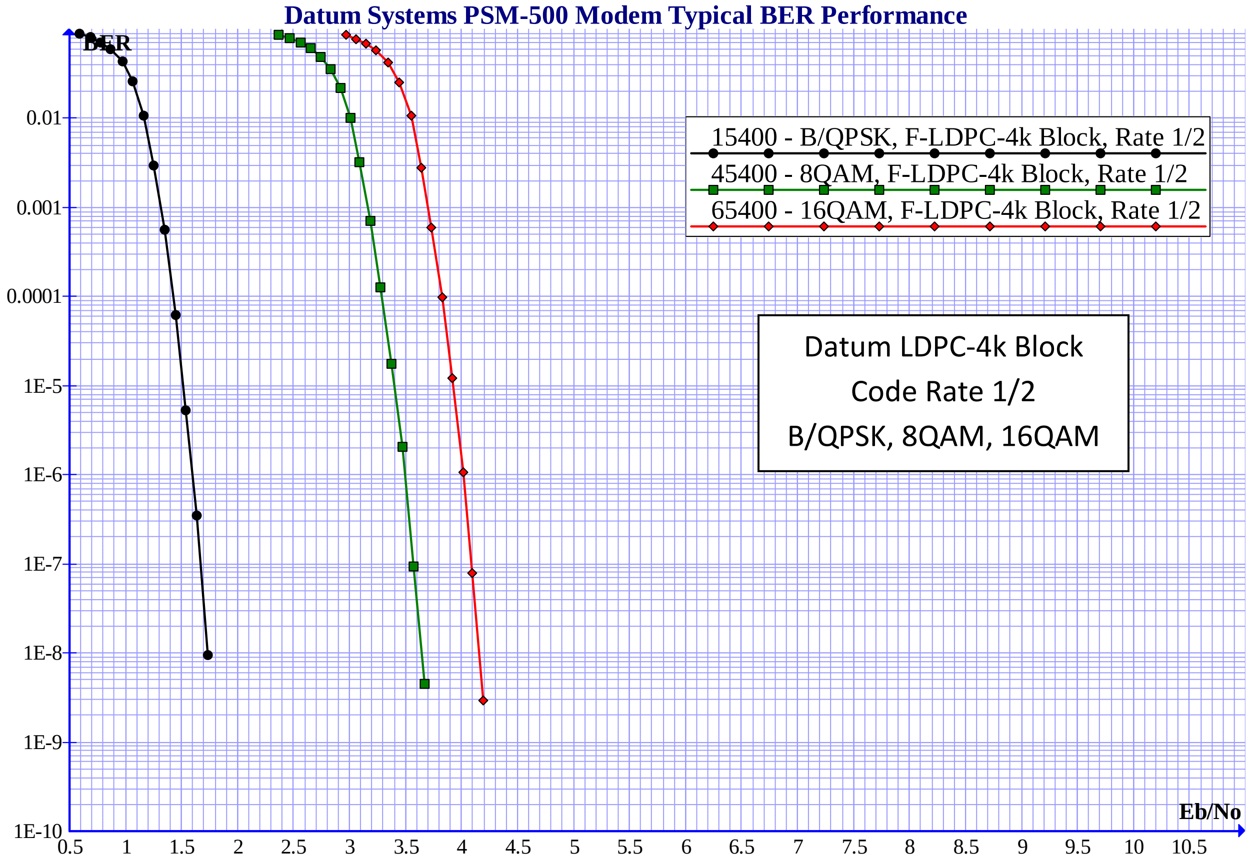
Typical Performance Curves for Selected LDPC Block Sizes and Code Rates

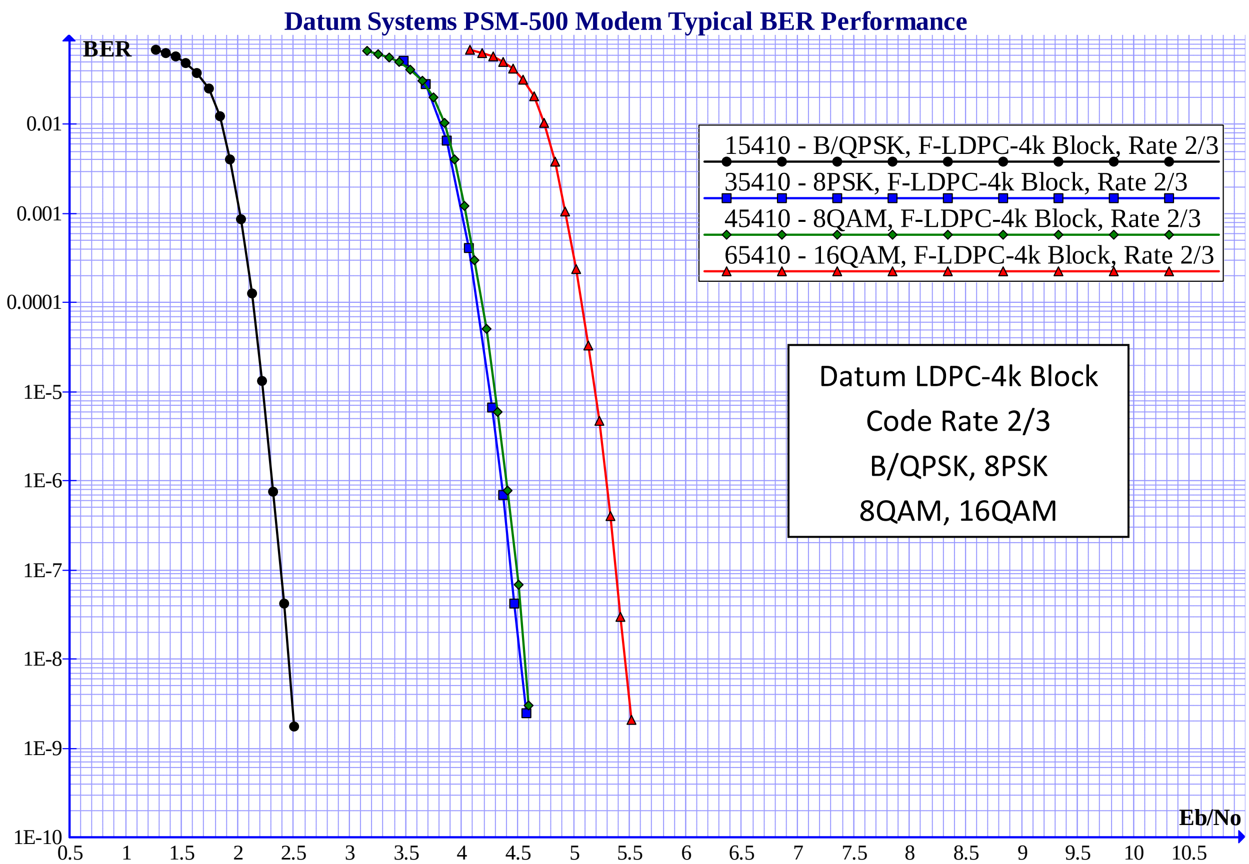




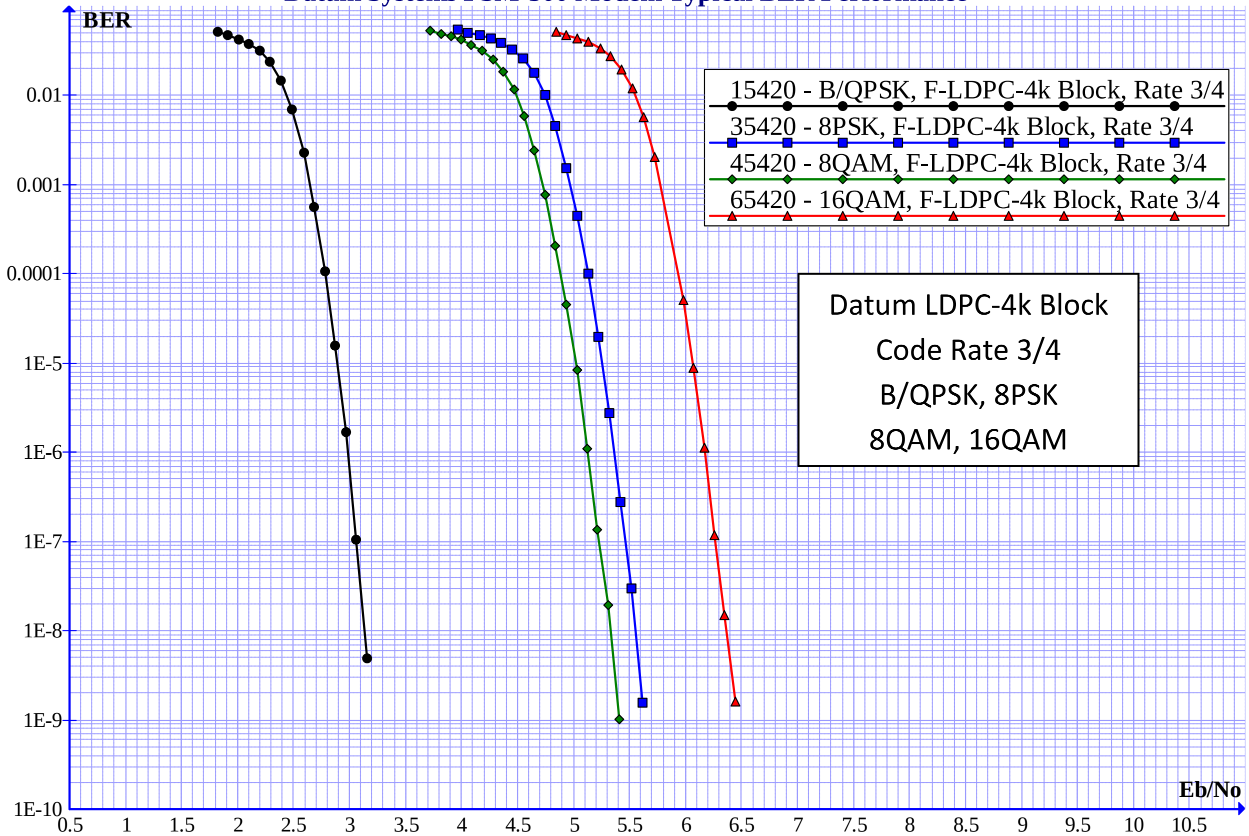

Datum Systems PSM-500 Modem Typical BER Performance
BER
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
Eb/No
15620 - B/QPSK, F-LDPC-16k Block, Rate 3/4
35620 - 8PSK, F-LDPC-16k Block, Rate 3/4
45620 - 8QAM, F-LDPC-16k Block, Rate 3/4
65620 - 16QAM, F-LDPC-16k Block, Rate 3/4
Datum LDPC-16k Block
Code Rate 3/4
B/QPSK, 8PSK
8QAM, 16QAM


Datum Systems PSM-500 Modem Typical BER Performance
BER
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
Eb/No
15640 - B/QPSK, F-LDPC-16k Block, Rate 7/8
35640 - 8PSK, F-LDPC-16k Block, Rate 7/8
45640 - 8QAM, F-LDPC-16k Block, Rate 7/8
65640 - 16QAM, F-LDPC-16k Block, Rate 7/8
Datum LDPC-16k Block
Code Rate 7/8
B/QPSK, 8PSK
8QAM, 16QAM

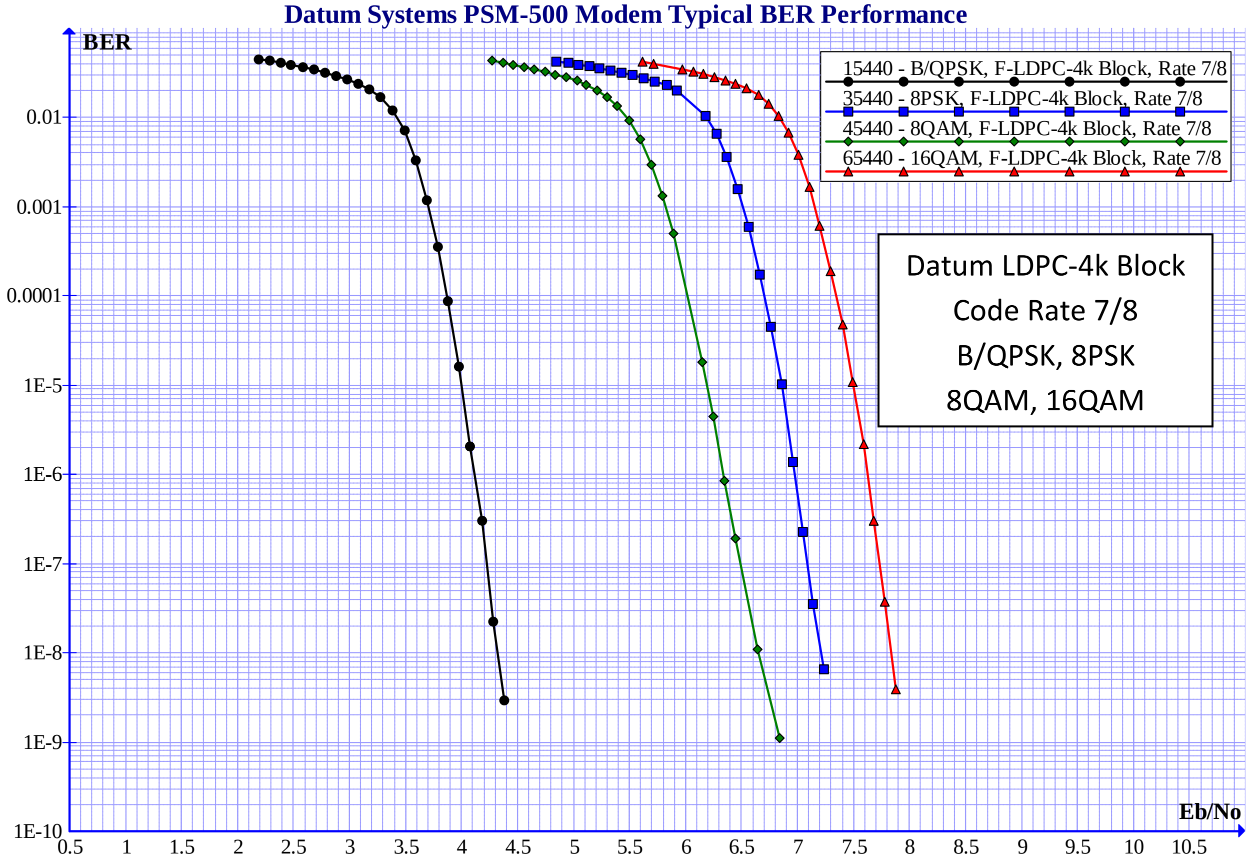

Datum Systems PSM-500 Modem Typical BER Performance
BER
15400 - B/QPSK, F-LDPC-4k Block, Rate 1/2
45400 - 8QAM, F-LDPC-4k Block, Rate 1/2
65400 - 16QAM, F-LDPC-4k Block, Rate 1/2
Datum LDPC-4k Block
Code Rate 1/2
B/QPSK, 8QAM, 16QAM
Eb/No
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5

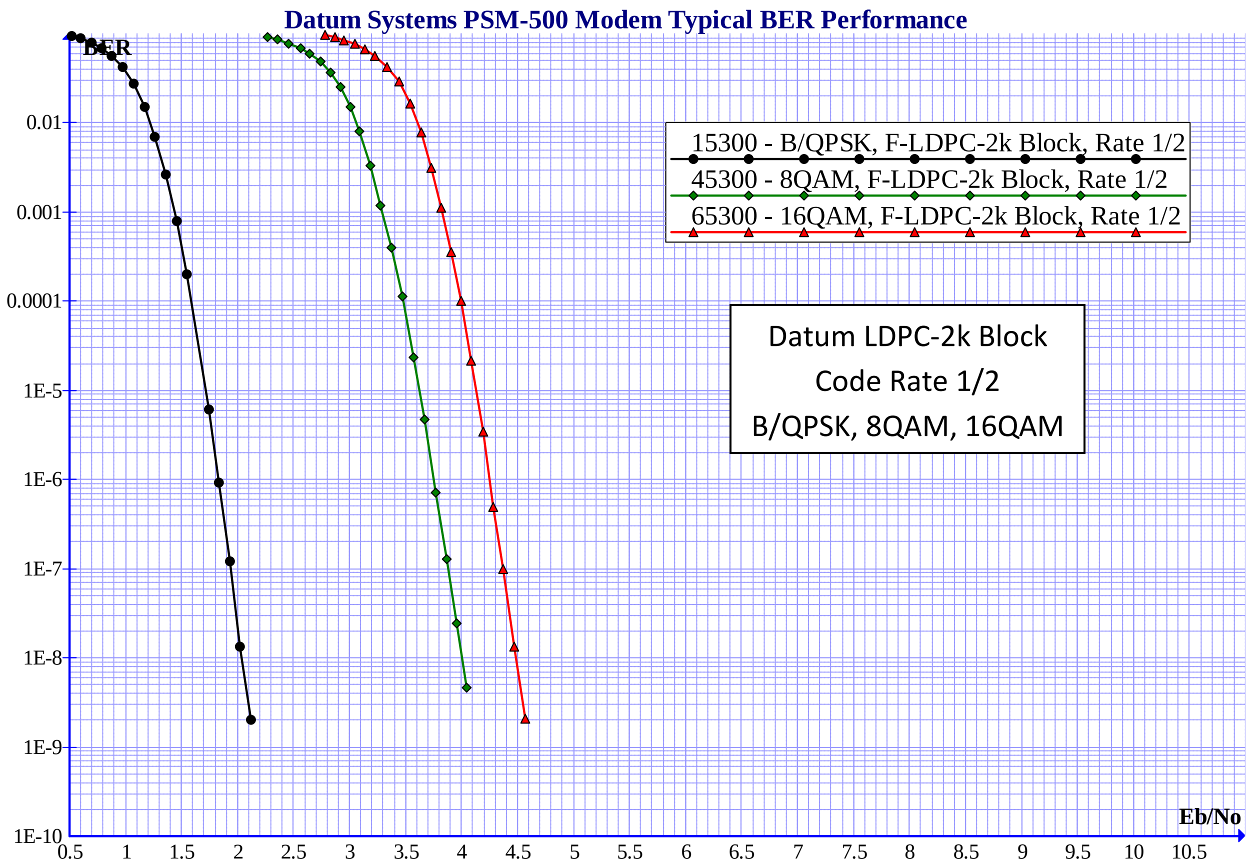

Datum Systems PSM-500 Modem Typical BER Performance
BER
15410 - B/QPSK, F-LDPC-4k Block, Rate 2/3
35410 - 8PSK, F-LDPC-4k Block, Rate 2/3
45410 - 8QAM, F-LDPC-4k Block, Rate 2/3
65410 - 16QAM, F-LDPC-4k Block, Rate 2/3
Datum LDPC-4k Block
Code Rate 2/3
B/QPSK, 8PSK
8QAM, 16QAM
Eb/No
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10 10.5

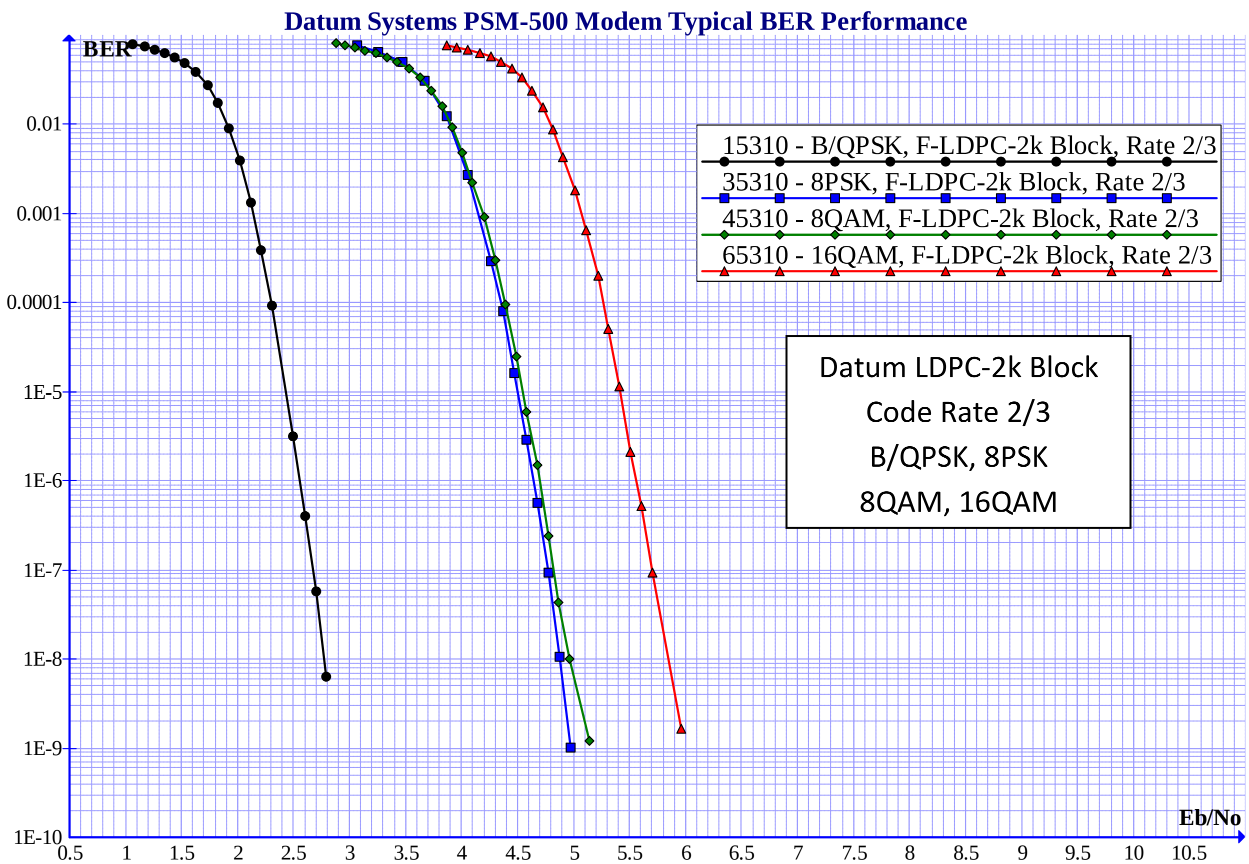
Datum Systems PSM-500 Modem Typical BER Performance

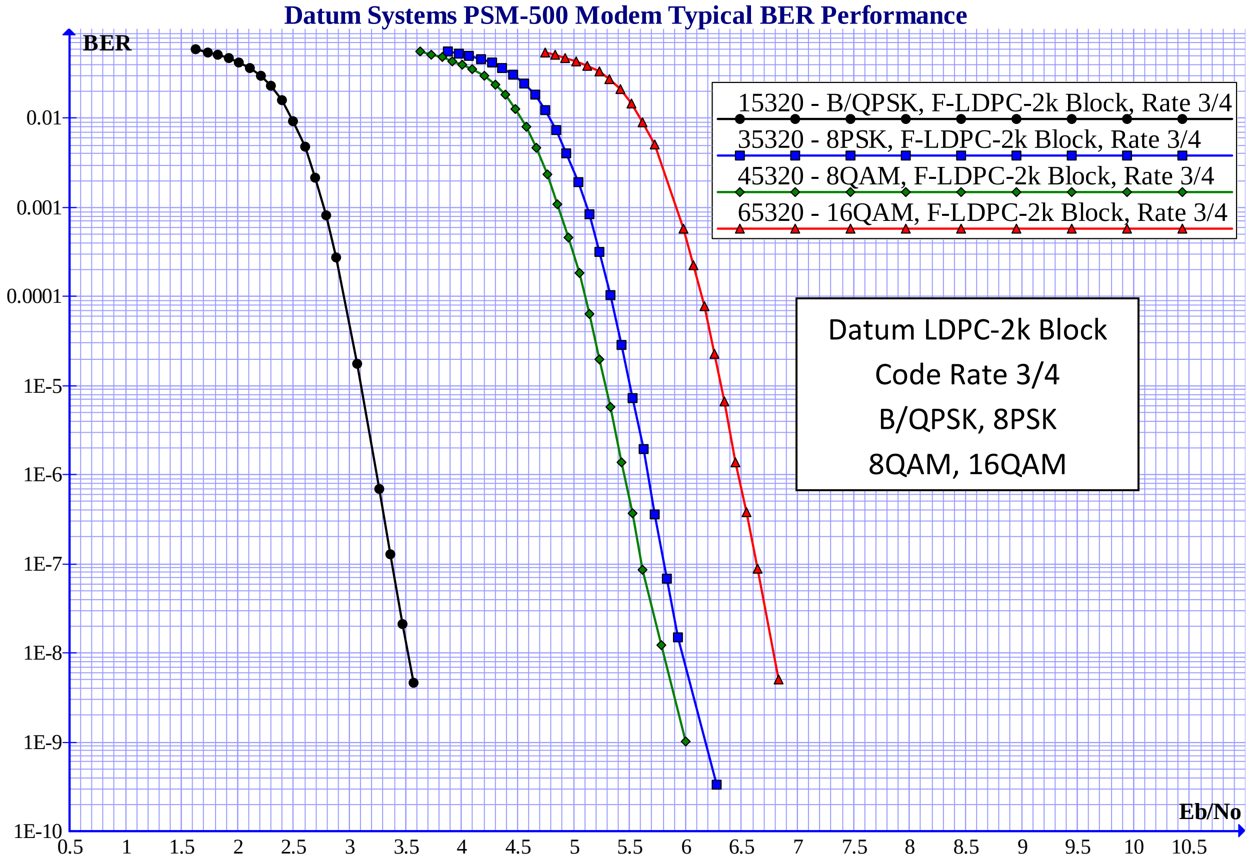


Datum Systems PSM-500 Modem Typical BER Performance

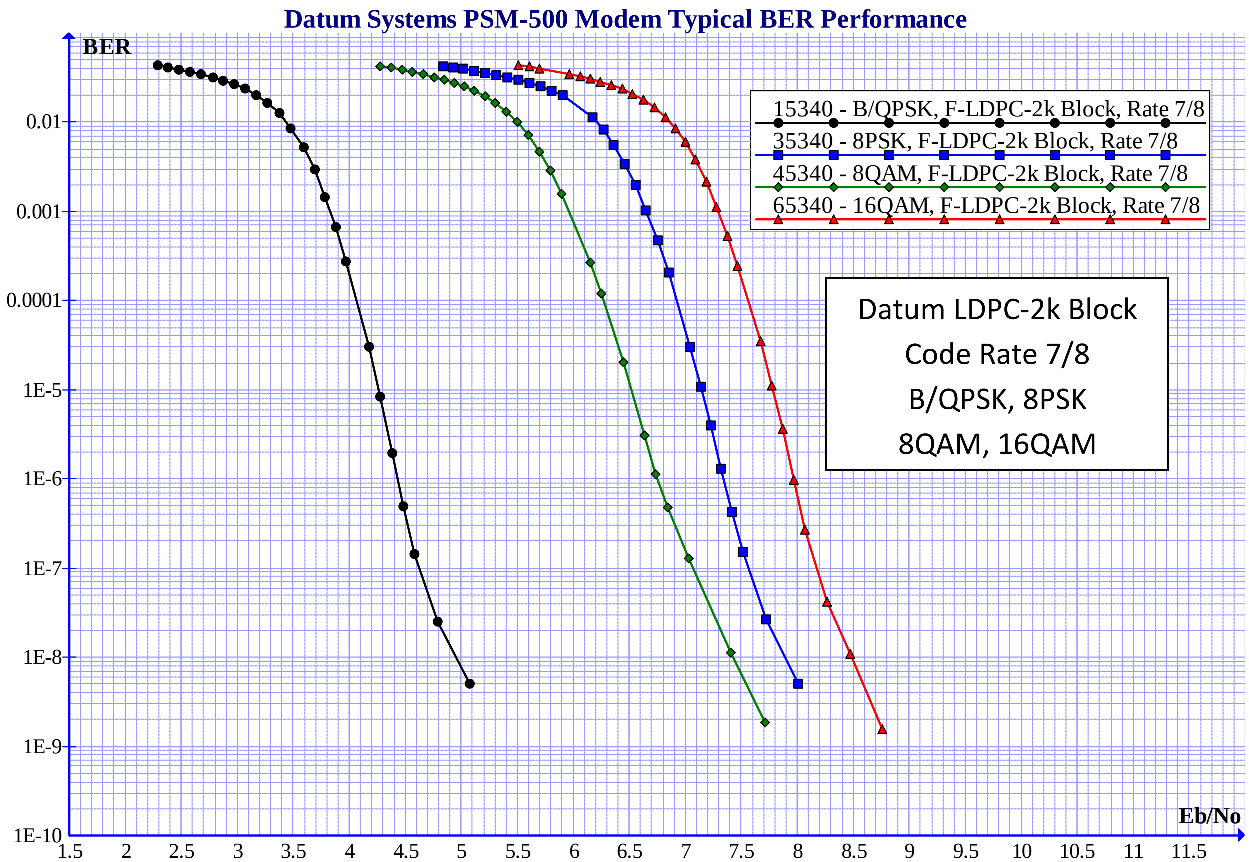



Datum Systems PSM-500 Modem Typical BER Performance
BER
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
Eb/No
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
15300 - B/QPSK, F-LDPC-2k Block, Rate 1/2
45300 - 8QAM, F-LDPC-2k Block, Rate 1/2
65300 - 16QAM, F-LDPC-2k Block, Rate 1/2
Datum LDPC-2k Block
Code Rate 1/2
B/QPSK, 8QAM, 16QAM


Datum Systems PSM-500 Modem Typical BER Performance
BER
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
Eb/No
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
15310 - B/QPSK, F-LDPC-2k Block, Rate 2/3
35310 - 8PSK, F-LDPC-2k Block, Rate 2/3
45310 - 8QAM, F-LDPC-2k Block, Rate 2/3
65310 - 16QAM, F-LDPC-2k Block, Rate 2/3
Datum LDPC-2k Block
Code Rate 2/3
B/QPSK, 8PSK
8QAM, 16QAM



Datum Systems PSM-500 Modem Typical BER Performance
BER
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
Eb/No
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
15320 - B/QPSK, F-LDPC-2k Block, Rate 3/4
35320 - 8PSK, F-LDPC-2k Block, Rate 3/4
45320 - 8QAM, F-LDPC-2k Block, Rate 3/4
65320 - 16QAM, F-LDPC-2k Block, Rate 3/4
Datum LDPC-2k Block
Code Rate 3/4
B/QPSK, 8PSK
8QAM, 16QAM



Datum Systems PSM-500 Modem Typical BER Performance
BER
0.01
0.001
0.0001
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
Eb/No
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
15340 - B/QPSK, F-LDPC-2k Block, Rate 7/8
35340 - 8PSK, F-LDPC-2k Block, Rate 7/8
45340 - 8QAM, F-LDPC-2k Block, Rate 7/8
65340 - 16QAM, F-LDPC-2k Block, Rate 7/8
Datum LDPC-2k Block
Code Rate 7/8
B/QPSK, 8PSK
8QAM, 16QAM