Higher-Order Modulation and Turbo Coding Options for the CDM-600 Satellite Modem

* 8-PSK Rate 3/4 Turbo
* 16-QAM Rate 3/4 Turbo
* 16-QAM Rate 3/4 Viterbi/Reed-Solomon
* 16-QAM Rate 7/8 Viterbi/Reed-Solomon

November 7, 2001

Introduction

Since the introduction of the CDM-600 Satellite modem in August 2001, some significant enhancements have been added. These include:

* 8-PSK Rate 3/4 Turbo
* 16-QAM Rate 3/4 Turbo
* 16-QAM Rate 3/4 Viterbi/Reed-Solomon
* 16-QAM Rate 7/8 Viterbi/Reed-Solomon

These new modulation and FEC options can be applied to existing CDM-600 units by uploading new firmware using Comtech's Flash Upgrade technology. No hardware modifications are necessary, the upgrade can be performed in a matter of minutes. Please note that the 16-QAM modes are a new FAST upgrade option, and customers should contact Comtech EF Data's Sales and Marketing for information on option pricing.

These new modes are primarily being offered as a bandwidth-efficient alternatives to existing schemes. With present and future generation transponders no longer being power limited, the emphasis is now on utilizing bandwidth as efficiently as possible. The table below compares the power and bandwidth performance of these new schemes. For reference, QPSK Rate 3/4 Turbo, and the popular Intelsat IESS 310 standards are shown.

Mode	Eb/No at BER = 10^{-6} Guaranteed (Typical in parentheses)	Eb/No at BER = 10^{-8} Guaranteed (Typical in parentheses)	Spectral Efficiency	Occupied Bandwidth for 1 Mbps Carrier*
QPSK Rate 3/4 Turbo	3.8 dB (3.3 dB)	4.4 dB (3.9 dB)	1.50 bits/Hz	793 kHz
8-PSK Rate 2/3 TCM and Reed-Solomon (IESS-310)	6.5 dB (6.2 dB)	6.9 dB (6.6 dB)	1.82 bits/Hz	654 kHz
8-PSK Rate 3/4 Turbo	7.7 dB (7.3 dB)	8.3 dB (7.8 dB)	2.25 bits/Hz	529 kHz
16-QAM Rate 3/4 Turbo	7.8 dB (7.4 dB)	8.6 dB (8.2 dB)	3.00 bits/Hz	396 kHz
16-QAM Rate 3/4 Viterbi/Reed-Solomon	8.1 dB (7.5 dB)	8.6 dB (8.0 dB)	2.73 bits/Hz	435 kHz
16-QAM Rate 7/8 Viterbi/Reed-Solomon	9.5 dB (9.0 dB)	10.1 dB (9.5 dB)	3.18 bits/Hz	374 kHz

*The occupied bandwidth is defined at the width of the transmitted spectrum taken at the –10 dB points on the plot of power spectral density. This equates to 1.19 x symbol rate for the CDM-600 transmit filtering.

Maximum data rate

The new 16-QAM Viterbi/Reed Solomon modes can operate up to a maximum data rate of 20 Mbps.

The new Turbo modes are at present limited to 5 Mbps. However, a second generation Turbo Codec will be available in Q1 of 2002 that will permit operation up to 20 Mbps, as well as providing additional TPC code rates.

Delay

Like the previous versions of TPC, the new Turbo modes offer signifcantly lower processing delay (latency) than the concatenated RS modes. The value of delay in the TPC modes will be approximately 30% of the delay values seen with Viterbi/Reed-Solomon.

'Soft knee' characteristic of Turbo

The traditional concatenated RS schemes exhibit a very pronounced threshold effect – a small reduction in Eb/No can result in total loss of demod and decoder synchronization. Just as in the case of the QPSK Rate 3/4 Turbo, the new modes do not suffer from this problem – the demod and decoder remain synchronized down to the point where the output error rate becomes unusable. This is considered to be a particularly advantageous characteristic in a fading environment. Typically, in both 16-QAM and 8-PSK Turbo modes the demod and decoder can remain synchronized ***2 – 3 dB below*** the Viterbi/Reed-Solomon or TCM cases.

8-PSK Turbo versus 8-PSK TCM

It can be seen that the 8-PSK Rate 2/3 TCM/Reed-Solomon case yields a BER performance approximately 1.2 dB better than the Rate 3/4 Turbo. This is due to combination of Trellis Coding and Reed-Solomon being particularly powerful, and Turbo, on its own cannot equal this. However, it should be noted that the Rate 3/4 Turbo mode is ***20% more bandwidth efficient*** than the TCM case. The customer has the option, in the same unit, to use the TCM mode where the transponder is power limited, or to switch to Turbo when bandwidth limited. The additional advantages of Turbo (lower delay, performance during fades etc) should also be considered.

The most important point to consider is that Comtech EF Data now provides an un-paralleled degree of flexibility, with a sufficiently broad of modulation and FEC options that the user can optimize power and bandwidth is a huge number of different situations.

Why not concatenate RS and Turbo?
This question has been asked often, and the short answer is that it does not provide any advantage!

This may appear a surprising result, and it is necessary to understand the characteristics of both the Viterbi and Turbo decoders for this to make sense.

Now, given operation in AWGN (additive white gaussian noise), at the output from the demodulator the errors are *uniformly* distributed. However, at the output of the primary FEC decoder, the errors are anything but uniformly distributed – they are clustered together in bursts. The Reed-Solomon decoder can only correct a small number of errors in each processing block (determined by the **n** and **k** values of the particular code chosen) and in general, if the clustered errors were to be fed directly to the RS decoder, the number of errors correctable is exceeded, and no correction takes place at all. For this reason, the data is interleaved in the modulator, and de-interleaved in the demod (after the primary FEC decoder) for the express purpose of re-distributing the clustered errors. The interleaving takes place over of a number of Reed-Solomon blocks, so the when de-interleaving takes place, a cluster of errors is spread out over a number of blocks. The RS decoder can then correct these errors, and provide useful coding gain.

However, when comparing Viterbi and Turbo (as primary FEC devices) the Turbo decoder produces error bursts that are far longer than in the Viterbi case, and so the interleaving/de-interleaving depths found in the standard designs (4 or 8 blocks) are totally inadequate to change the error distribution sufficiently for the RS decoder to correct the residual errors. Comtech EF Data has experimented with the concatenation of RS with TPC, and no benefit is gained. However, at some point in the future work may be carried out to determine if it is possible to derive an interleaving/de-interleaving and RS decoder scheme that is optimized for the Turbo error distribution, and hence provide further performance enhancements.

Why is there so little difference between 8-PSK and 16-QAM Turbo?
By inspection of the performance curves, it will be seen that there is very little difference between the performance of 8-PSK and 16-QAM (in the order of 0.2 dB). This may again seem surprising at first, but this is to be expected.

Considering the *uncoded* performance of 8-PSK and 16-QAM (assuming Gray-coded constellations) there is only 0.4 dB difference between the two cases. 16-QAM is a particularly good modulation technique, demonstrating a 2.6 dB advantage over 16-PSK (which has the same spectral efficiency). Now, given that the same Rate 3/4 TPC is being applied in both cases, with a fixed amount of coding gain (approx. 7.5 dB at 10^{-7}) the theoretical optimum performance of 8-PSK is only 0.4 dB better than 16-QAM.

In practice, the 8-PSK case suffers from a slightly higher implementation loss than 16-QAM. The need to de-rotate the constellation in increments of 45 degrees (for phase ambiguity resolution) implies more complex signal processing than the 16-QAM case, which being a square constellation only needs to be de-rotated in increments of 90 degrees. In the particular implementation of the 45 degree de-rotator in the CDM-600 some simplifications were necessary that resulted in a small loss of performance (estimated to be around about 0.1 dB).

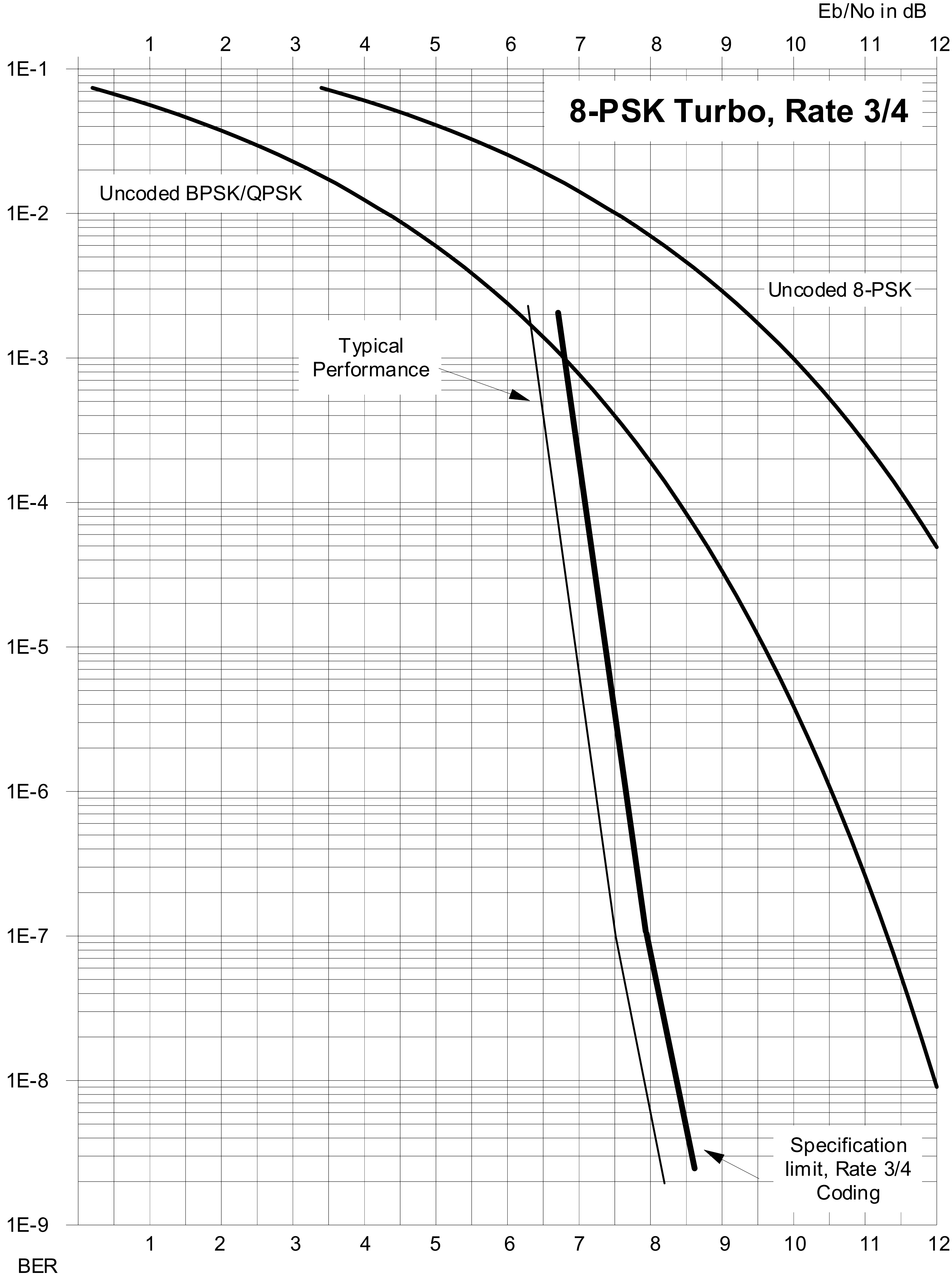
In addition, the TPC decoder (like Viterbi, Sequential, or TCM) can only provide maximum coding gain when presented with *soft* decisions from the demod. Rather than providing hard decisions, (1 or 0) the demod computes soft-decision metrics that indicate the confidence level of the 1 or zero decision. In the case of 16-QAM the computation of soft-decision metrics is straightforward (as a result of the square constellation) but the 8-PSK case requires significantly more processing, and the result, in the CDM-600, is performance slightly less than optimum (again by about 0.1 dB). The net result of these factors is 8-PSK performance that is around 0.2 dB better than the 16-QAM case, and not the 0.4 dB predicted by theory.

The need for an Adaptive Equalizer?

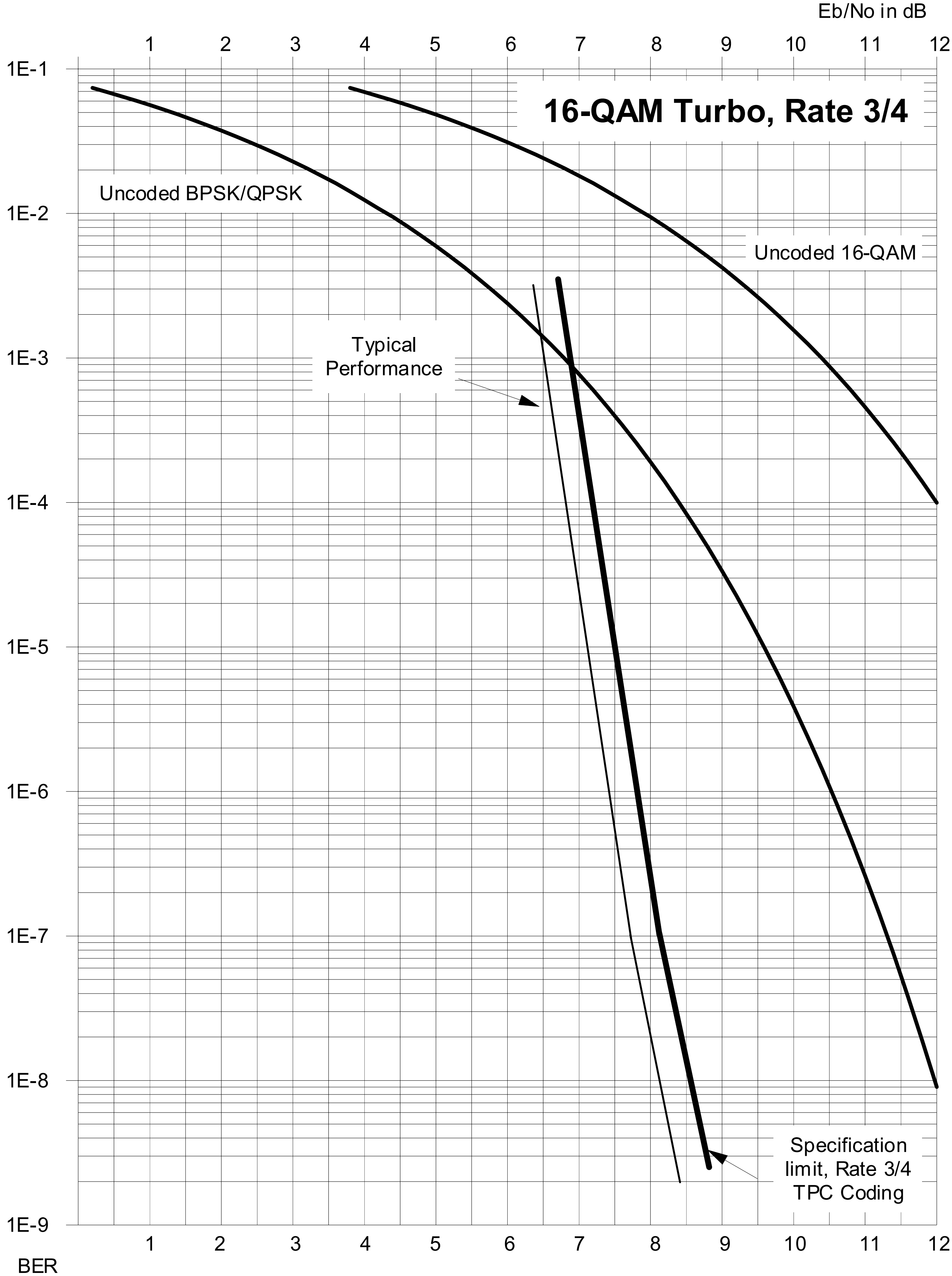
The results presented here were derived in IF loop, in an idealized environment. In practice, the 16-QAM modes are more sensitive to real-world impairments than 8-PSK. In particular, because 16-QAM exhibits more carrier envelope variation than QPSK or 8-PSK , it is sensitive to amplifier non-linearities. Also, group delay variation, amplitude slope, and phase noise affect 16-QAM more than 8-PSK.

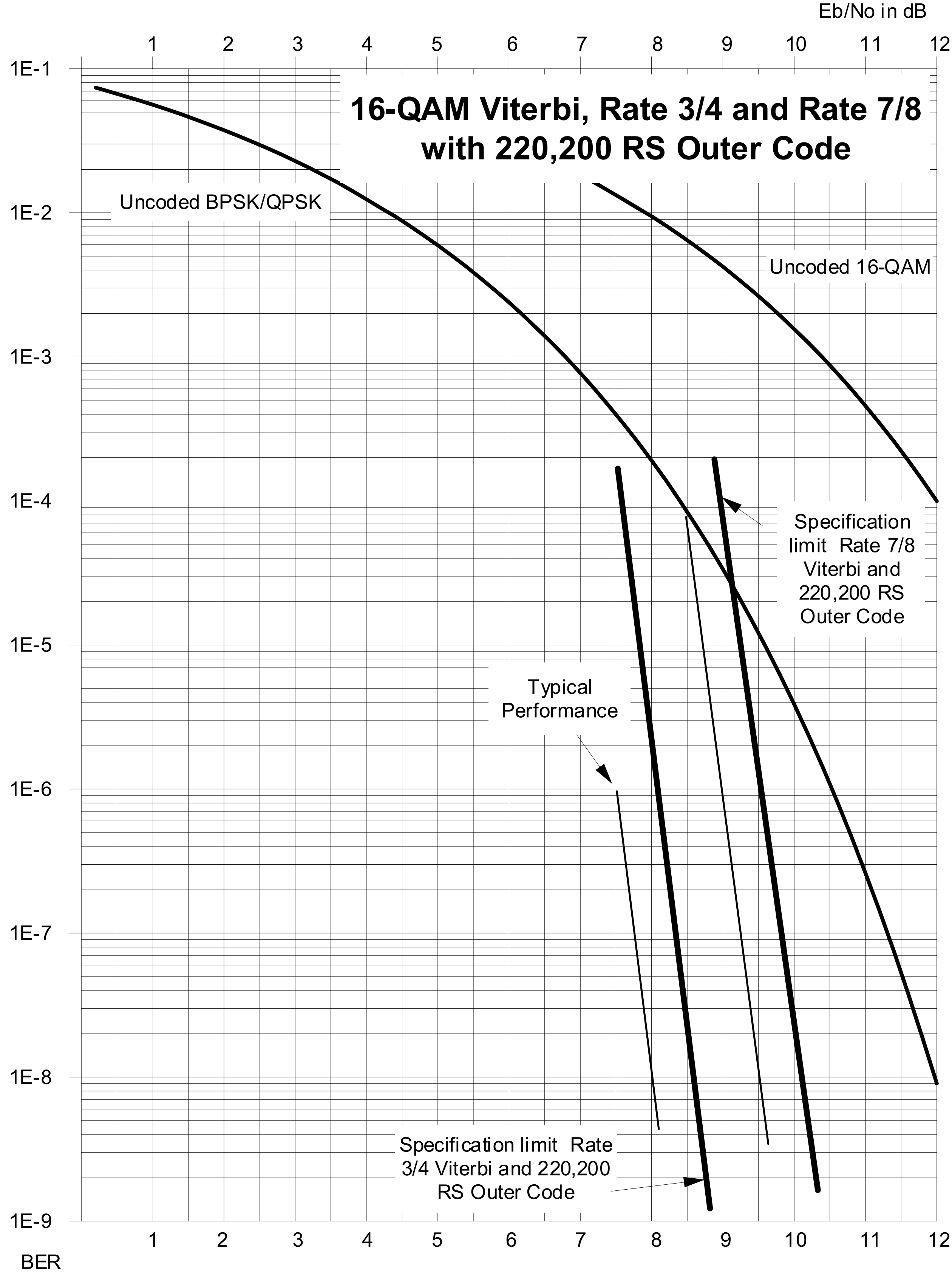
Some designs, particularly those operating at high symbol rates, include an adaptive equalizer that mitigates these impairments. This is a technology that Comtech EF Data is actively working on for its next-generation of very high speed (~155 Mbps) modems.

However, it is Comtech EF Data’s position that for data rates up to 20 Mbps (which implies symbol rates up to a maximum of 7.3 Msymbols/second) that the group delay variation and amplitude slope, over the symbol rate bandwidth, found in typical RF chains and satellite transponders should not cause significant impairments to be considered problematic. Therefore, at the present time, an equalizer is not considered necessary.



Eb/No in dB
1 2 3 4 5 6 7 8 9 10 11 12
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
8-PSK Turbo, Rate 3/4
Uncoded BPSK/QPSK
Uncoded 8-PSK
Typical Performance
Specification limit, Rate 3/4 Coding
BER


Eb/No in dB
1
2
3
4
5
6
7
8
9
10
11
12
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
16-QAM Turbo, Rate 3/4
Uncoded BPSK/QPSK
Uncoded 16-QAM
Typical Performance
Specification limit, Rate 3/4 TPC Coding
BER


16-QAM Viterbi, Rate 3/4 and Rate 7/8
with 220,200 RS Outer Code
Eb/No in dB
1
2
3
4
5
6
7
8
9
10
11
12
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
BER
Uncoded BPSK/QPSK
Uncoded 16-QAM
Specification limit Rate 7/8 Viterbi and 220,200 RS Outer Code
Typical Performance
Specification limit Rate 3/4 Viterbi and 220,200 RS Outer Code