



Performance of Variable Coded Modulations over a Nonlinear Channel for VCM Protocol Red Book

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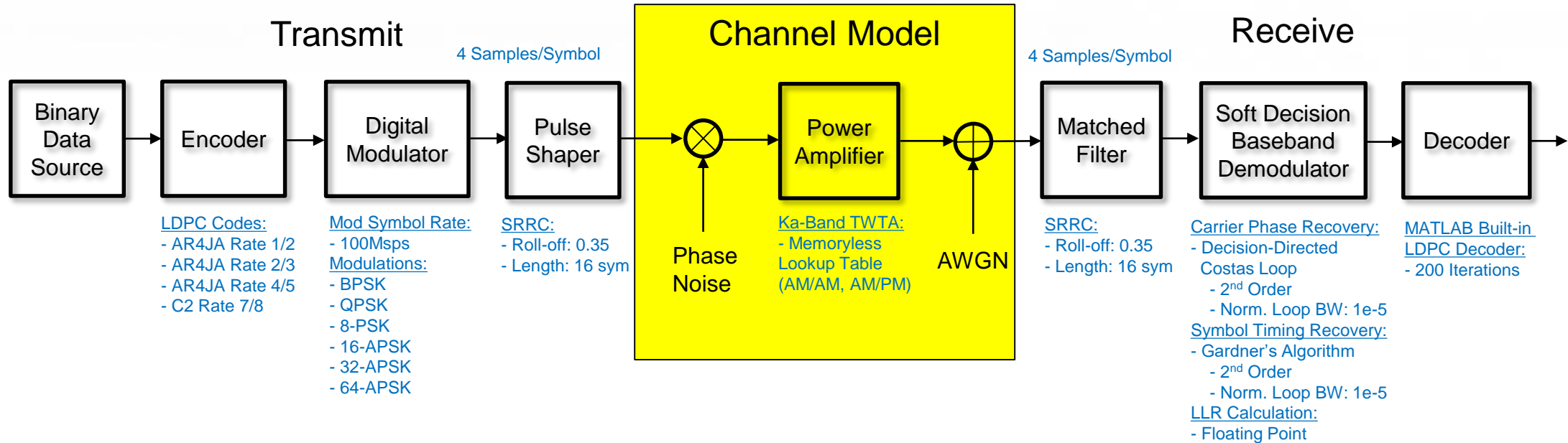
Electrical Engineering Division



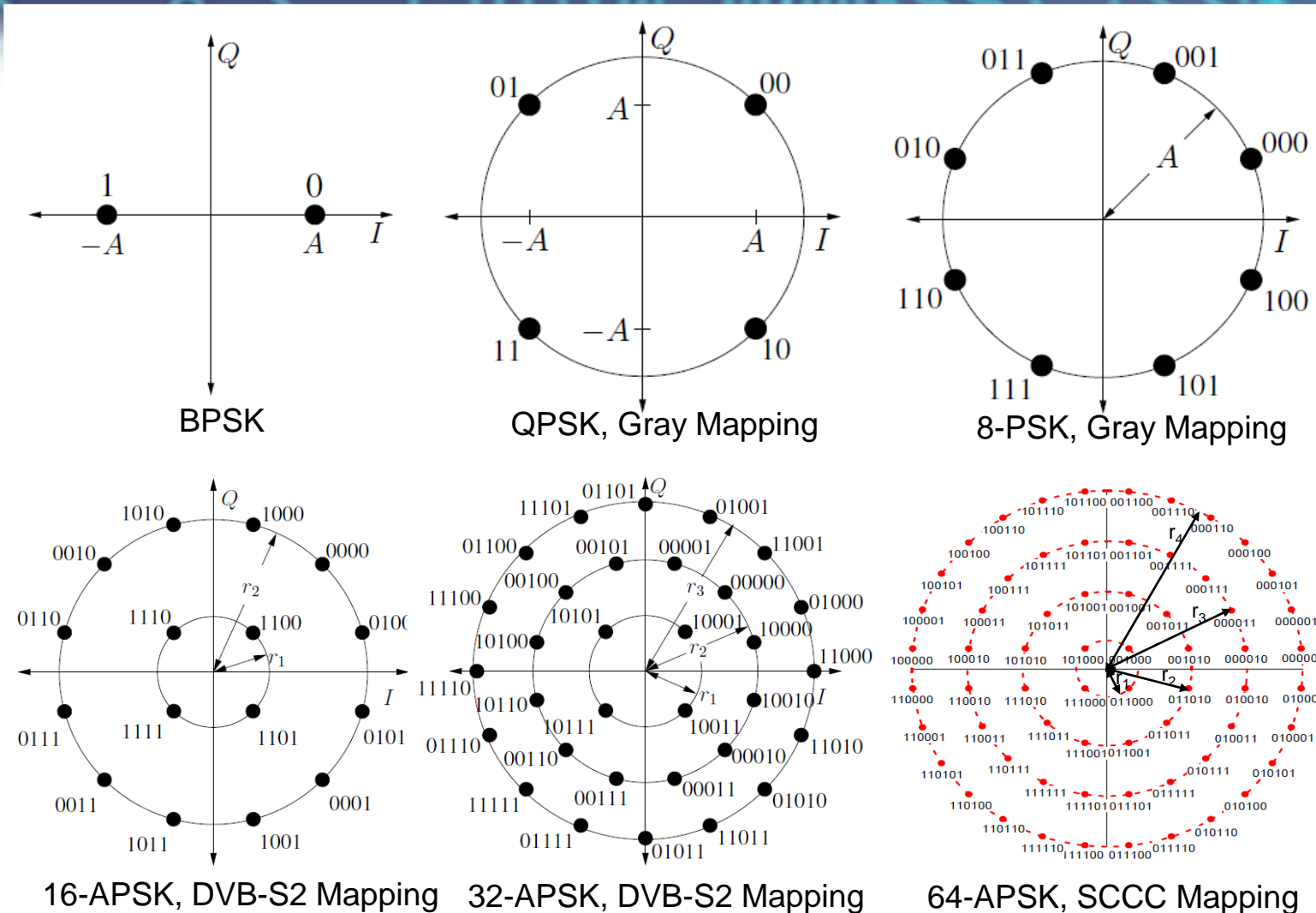
Background

- Goal
 - Evaluate the performance of the Recommended Standard's codes and modulations specified in the “Variable Coded Modulation Protocol” Red Book (CCSDS 431.1-R-0.1), over a nonlinear channel.
- Objectives:
 - Perform simulations that identifies the operating Eb/No required to achieve a CWER of $1e-4$ over a nonlinear channel for a subset of the following MODCOD combinations:
 - Channel Codes:
 - AR4JA (Rate 1/2, 2/3, 4/5) LDPC codes (K=16384), C2 LDPC codes
 - Modulations:
 - BPSK, QPSK, 8-PSK, 16-APSK, 32-APSK, 64-APSK
 - Compare against performance over an ideal AWGN channel with simulation results presented in input paper, SLS-CS_18-09.

End-to-End Simulation



Signal Constellations

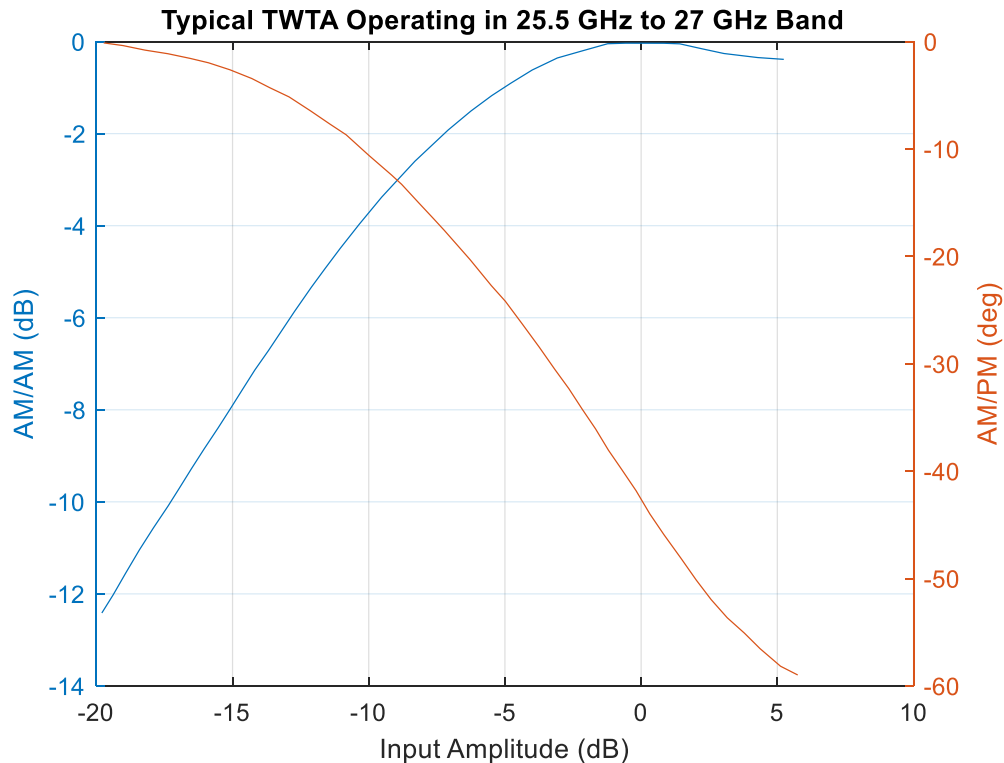


Modulation	Code Rate	Constellation Ratio Specification
16-APSK	1/2	$r_2/r_1 = 3.15$
	2/3	$r_2/r_1 = 3.15$
	4/5	$r_2/r_1 = 2.75$
	7/8	$r_2/r_1 = 2.63$
32-APSK	1/2	$r_2/r_1 = 4.00$ $r_3/r_1 = 8.00$
	2/3	$r_2/r_1 = 3.15$ $r_3/r_1 = 6.25$
	4/5	$r_2/r_1 = 2.72$ $r_3/r_1 = 4.87$
	7/8	$r_2/r_1 = 2.57$ $r_3/r_1 = 4.41$
64-APSK	1/2	$r_2/r_1 = 2.73$ $r_3/r_1 = 4.52$ $r_4/r_1 = 6.31$
	2/3	$r_2/r_1 = 2.73$ $r_3/r_1 = 4.52$ $r_4/r_1 = 6.31$
	4/5	$r_2/r_1 = 2.73$ $r_3/r_1 = 4.52$ $r_4/r_1 = 6.31$
	7/8	$r_2/r_1 = 2.73$ $r_3/r_1 = 4.52$ $r_4/r_1 = 6.31$

Details of Channel Model

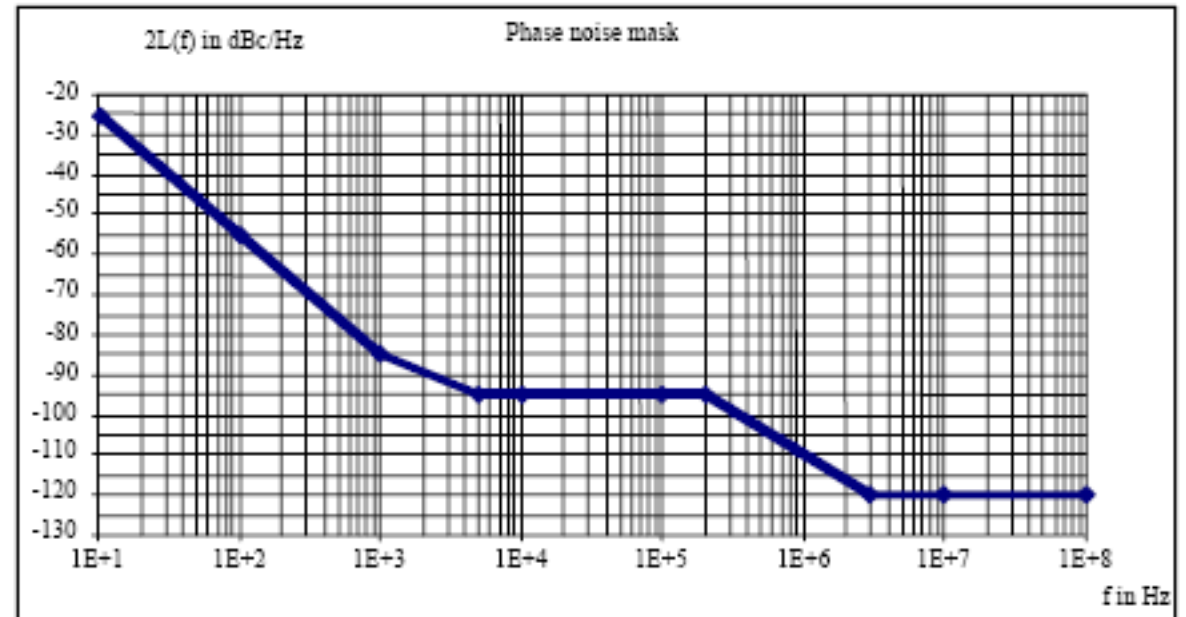
- Power Amplifier

- TWTA model from SCCC Green Book CCSDS 130.11-G-0 is used.
- AM/AM and AM/PM nonlinear distortions are modeled and applied as memoryless lookup tables.



- Phase Noise

- Phase noise profile from input paper SLS-RFM_09-09 “ESA advanced coding and modulation performance under realistic channel conditions” is used.



Analysis Approach

- Adopted analysis approach applied in the SCCC Green Book CCSDS 130.11-G-0 using figure-of-merit (FOM) known as “Total Degradation” (TD).

$\frac{E_b}{N_0}$ required on a nonlinear channel to achieve CWER of 1e-4

$\frac{E_b}{N_0}$ required on ideal AWGN channel to achieve CWER of 1e-4

Amplifier output back-off that represents measured reduction in available power in the link

$$TD = \left[\left(\frac{E_b}{N_0} \right)_{NL} - \left(\frac{E_b}{N_0} \right)_{AWGN} \right] + OBO \quad (\text{dB})$$

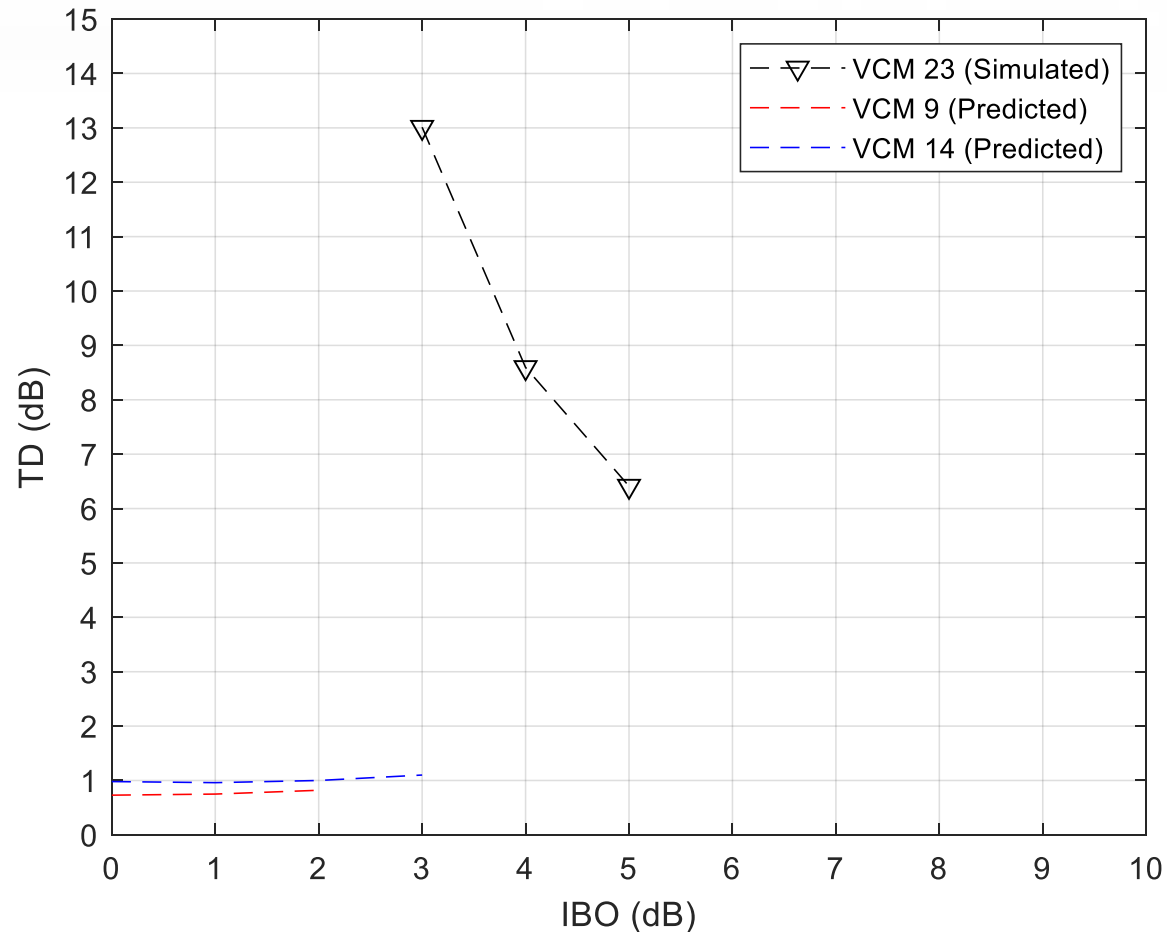
“Demodulation Loss” – Ratio between power needed at receiver to achieve CWER of 1e-4 over the non-linear channel and the linear AWGN channel.

Analysis Approach (Cont.)

- For each VCM mode:
 1. Perform IBO/OBO optimization by means of total degradation (TD).
 2. Report Eb/No required to achieve a CWER of $1e-4$ over the specified nonlinear channel.
 3. Apply distortion mitigation to decrease TD and repeat steps 1-2.
- Mitigation techniques considered:
 1. Centroidal pre-distortion (Refer to “DVB-S2 modem algorithms design and performance over typical satellite channels” by Casini)
 2. Ideal sample-by-sample phase post-distortion de-rotation *
 3. Receiver mean phase de-rotation *

* We are currently analyzing these mitigation techniques, results are pending.

TD Optimization without Distortion Mitigation - Preliminary Simulation Results



VCM 9: QPSK, Rate 2/3 AR4JA LDPC
VCM 14: 8PSK, Rate 4/5 AR4JA LDPC
VCM 23: 32APSK, Rate 7/8 C2 LDPC

Optimum TD Simulation Results without Distortion Mitigation

VCM Mode	Code	K	N	Modulation	Ideal Required $(E_b/N_o)_{AWGN}$ [dB] @ CWER=1e-4	Required $(E_b/N_o)_{NL}$ [dB] @ CWER=1e-4	IBO [dB]	OBO [dB]	TD [dB]
4	AR4JA (16K,1/2)	16384	32768	BPSK	0.93				
5	AR4JA (16K,2/3)	16384	24576	BPSK	1.75				
6	AR4JA (16K,4/5)	16384	20480	BPSK	2.71				
7	C2	7136	8160	BPSK	3.84				
8	AR4JA (16K,1/2)	16384	32768	QPSK	0.93				
9	AR4JA (16K,2/3)	16384	24576	QPSK	1.75	2.04	0	0.35	0.64
10	AR4JA (16K,4/5)	16384	20480	QPSK	2.71				
11	C2	7136	8160	QPSK	3.84				
12	AR4JA (16K,1/2)	16384	32768	8-PSK	2.28				
13	AR4JA (16K,2/3)	16384	24576	8-PSK	3.7				
14	AR4JA (16K,4/5)	16384	20480	8-PSK	5.14	5.81	0	0.31	0.98
15	C2	7136	8160	8-PSK	6.6				
16	AR4JA (16K,1/2)	16384	32768	16-APSK	3.3				
17	AR4JA (16K,2/3)	16384	24576	16-APSK	4.72				
18	AR4JA (16K,4/5)	16384	20480	16-APSK	6.14				
19	C2	7136	8160	16-APSK	7.5				
20	AR4JA (16K,1/2)	16384	32768	32-APSK	4.93				
21	AR4JA (16K,2/3)	16384	24576	32-APSK	6.4				
22	AR4JA (16K,4/5)	16384	20480	32-APSK	7.88				
23	C2	7136	8160	32-APSK	9.32	12.1	10	4.23	7.01
24	AR4JA (16K,1/2)	16384	32768	64-APSK	6.1				
25	AR4JA (16K,2/3)	16384	24576	64-APSK	8.05				
26	AR4JA (16K,4/5)	16384	20480	64-APSK	9.8				
27	C2	7136	8160	64-APSK	11.4				

With Phase Noise
1 Frame Error

With Phase Noise
5 Frame Errors

No Phase Noise
30 Frame Errors

Summary

- We have verified that the LDPC VCM modes operate with non-linear distortions.
- The TD FOM is a useful measure to study the total end-to-end losses for non-linear channels but may not be relevant to an actual system.
- We are researching other methods of mitigation and will report when studies are completed.

Acronym List

- VCM – Variable Coded Modulation
- LDPC – Low Density Parity Check
- CWER – Codeword Error Rate
- IBO – Input Back-off
- OBO – Output Back-off
- TD – Total Degradation
- AWGN – Additive White Gaussian Noise
- SCCC – Serially Concatenated Convolutional Code
- TWTA – Traveling Wave Tube Amplifier
- E_b/N_0 – Bit-Energy-to-Noise-Power-Density Ratio
- SRRC – Square Root Raised Cosine
- FOM – Figure of Merit

