Performance Analysis of EPoC FEC for Passive Coax Plants

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Introduction and Scope

- During the Victoria meeting it was agreed to specify two sets of LDPC codes (prodan_3bn_01_0513.pdf):
  - One code set for passive plants
  - One code set for active plants
- During the Geneva meeting codes were presented:
  - For active plants: prodan_3bn_01b_0713.pdf
  - For passive plants: pietsch_3bn_01_0713.pdf
- This presentation provides a more detailed performance analysis for the codes for passive plants. This includes AWGN performance and various burst noise scenarios.
- For reasons of self-containedness, this presentation contains the code description. The codes are the same as described in pietsch_3bn_01_0713.pdf.

Codes Parameters and Deployment Scenarios

CODES	Rate	Length
A	---	---
B	$R_B = 8/9$	16200
C	$R_C = 0.848$	5940
D	$R_D = 3/4$	1120
E	$R_E = 41/46$	16560
F	$R_F = 26/30$	10800
G	$R_G = 13/15$	5400
H	$R_H = 3/4$	960

DEPLOYMENT	Passive plant	Active plant
US, low band	E, F, G, H	B, C, D
DS, low band	E, F, G, H	---
US, high band	E, F, G, H	---
DS, high band	E, F, G, H	B

Code choice for passive plants:

- Typically, the code with the longest code words (E) will be preferred choice whenever possible, e.g. considering grant size, potential transmission windows, and latency requirements.
- For US transmissions, small grant sizes will entail the use of the shorter codes. Code E may be rarely used in some situations
- For DS transmissions, we will mostly see the use of code E. For TDD, shorter code words are necessary to increase efficiency for short transmission windows.

Code Description

- All LDPC codes for passive plants are quasi-cyclic and binary
- The matrix M to calculate the parity bits has nearly upper diagonal form for all codes
  - Only the first sub-diagonal of the matrix M is non-zero
  - The parity matrices H are constructed so that encoding can be realized with low complexity
- In the following slides the parity check matrices H of the LDPC codes are given
- Description
  - In all tables the top row indexes columns of the parity check matrix
  - The second row of the tables indicates information (1) and parity (0) columns
  - The third row of the tables indicates transmitted columns (1) and punctured columns (0)

Parity Matrices for Codes E and F

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	·	203	·	·	188	278	·	·	313	·	·	·	·	56	308	248	206	142	25	309	·	355	257	·	·	·	·	99	·	42	·	303	·	·	·	·	197	126	359	308	257	342	113	·	318	109
0	61	·	·	·	·	·	·	319	106	·	250	153	·	·	283	32	·	·	·	·	225	·	284	·	132	71	113	·	·	130	173	194	287	129	19	294	307	·	·	265	233	·	274	·	·	318
·	61	113	·	·	·	268	330	·	·	142	·	·	·	·	·	·	·	202	·	279	282	·	132	99	·	203	129	26	347	·	74	181	352	84	·	293	353	212	309	·	199	·	·	303	·	210
·	·	113	183	·	302	·	·	221	153	349	5	334	256	269	·	·	208	61	240	·	40	·	·	194	·	·	·	·	123	·	·	·	·	1	147	288	·	109	·	122	333	152	·	275	42	142
·	·	·	183	244	·	·	89	·	·	105	·	301	331	·	·	·	194	·	237	155	·	36	·	·	142	248	·	182	51	51	·	·	191	·	107	54	91	·	18	254	·	75	225	111	200	116
·	·	·	·	244	189	45	352	118	·	·	59	·	340	99	267	122	·	·	·	·	·	213	·	159	86	·	352	·	·	·	163	151	339	225	326	·	·	147	170	·	·	7	198	110	300	35

Figure 8: Base code information bits: 41; (max) block length: 46. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
183	90	·	·	160	295	·	·	268	240	182	127	·	187	·	·	179	288	·	167	14	327	96	·	215	359	·	·	273	344	261
183	0	·	·	·	276	291	·	·	58	308	348	286	·	4	93	·	·	171	·	·	·	207	54	190	352	309	34	223	84	62
·	0	61	·	·	·	184	160	212	235	·	·	·	256	·	39	191	236	303	324	·	·	·	292	·	83	132	189	224	251	142
·	·	61	122	351	·	344	51	·	·	·	267	122	·	284	341	94	335	·	·	256	194	270	·	240	127	351	234	·	202	228
·	·	·	122	175	104	·	206	42	·	91	·	198	329	266	·	·	·	284	269	73	192	·	93	1	·	220	197	44	·	266

Figure 4: Base code information bits: 26; (max) block length: 30. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

Parity Matrices for Codes G and H

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1
0	·	·	45	·	92	28	·	137	111	344	2	338	190	258	328	13
0	241	·	·	284	·	·	186	·	198	185	334	76	148	236	93	190
·	241	122	119	171	17	244	303	218	356	258	53	181	330	271	279	150
·	·	122	0	287	36	135	84	72	245	208	303	239	124	176	284	121

Figure 2: Base code information bits: 13; (max) block length: 15. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 360

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
0	16	·	·	21	9	·	·	33	44	·	·	15	40	4	56	47
0	1	·	·	·	·	·	12	39	42	40	2	·	54	33	32	12
·	1	32	·	·	4	46	50	·	·	44	7	43	47	23	·	48
·	·	32	3	34	·	44	58	8	·	·	54	14	4	·	43	26
·	·	·	3	27	43	41	·	·	38	56	20	20	·	13	16	10

Figure 1: Base code information bits: 12; (max) block length: 16. Lifting: ROTATION SPACE:NESTED CYCLIC:1: 60

Edge Density, Parity Checks and Lifting Size

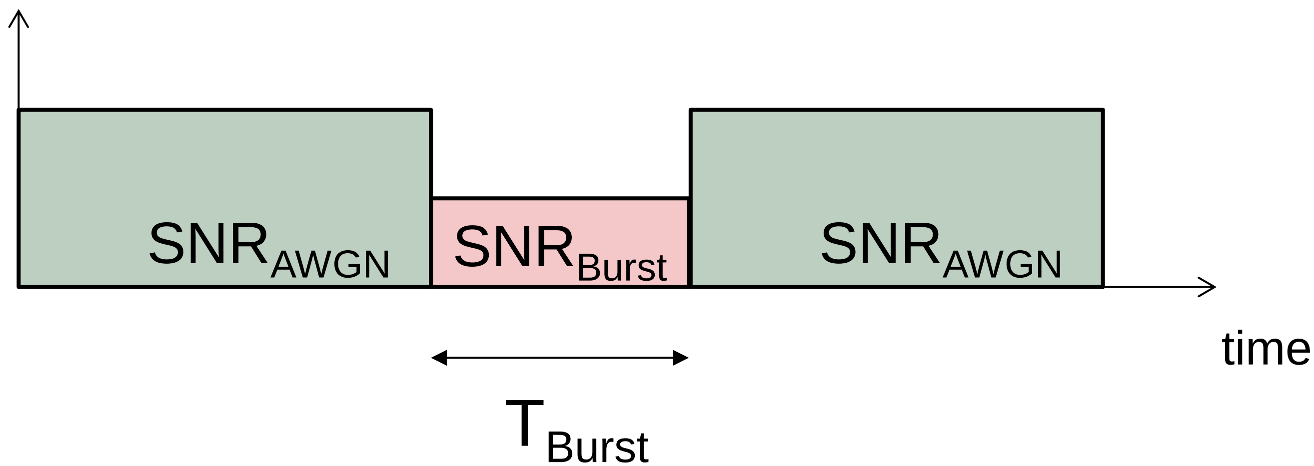
Base n	Base k	Rate	Lifting Z	Information Bits	Code word length	Parity checks	Based edges	Edge density
46	41	0.8913	**360**	14760	16560	**2160**	154	**3.348**
30	26	0.8667	**360**	9360	10800	**1800**	98	**3.267**
15	13	0.8667	**360**	4680	5400	**1080 (1440)**	54 (56)	**3.6 (3.73)**
16	12	0.75	**60**	720	960	**300**	53	**3.3125**

Performance Analysis of the LDPC Codes

- In the following slides a detailed performance analysis of the proposed LDPC codes is provided
- Simulation results are shown for
  - AWGN
  - Burst noise including required time interleaving depth
  - OFDM symbol durations of 20 μs and 40 μs
- Performance metric of interest is a bit error rate (BER) of 1e-8
  - A BER of 1e-8 corresponds roughly to a frame error rate of 1e-6

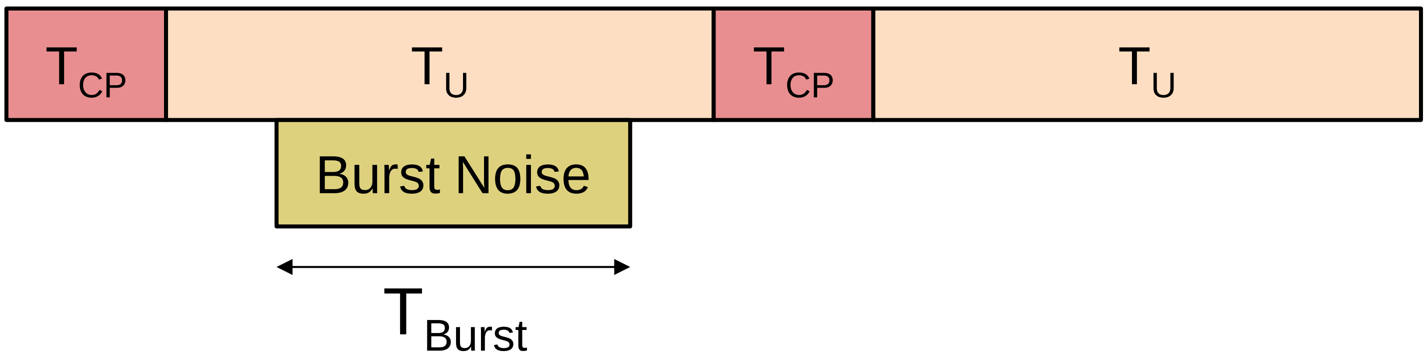
Burst Noise in OFDM

- To analyze performance in burst noise, a simple model is chosen
  - Burst noise is modeled as white Gaussian noise with a certain SNR_{Burst}
    - Burst noise is assumed to be wideband
  - Burst noise is modeled with time duration T_{burst} and burst SNR SNR_{Burst}



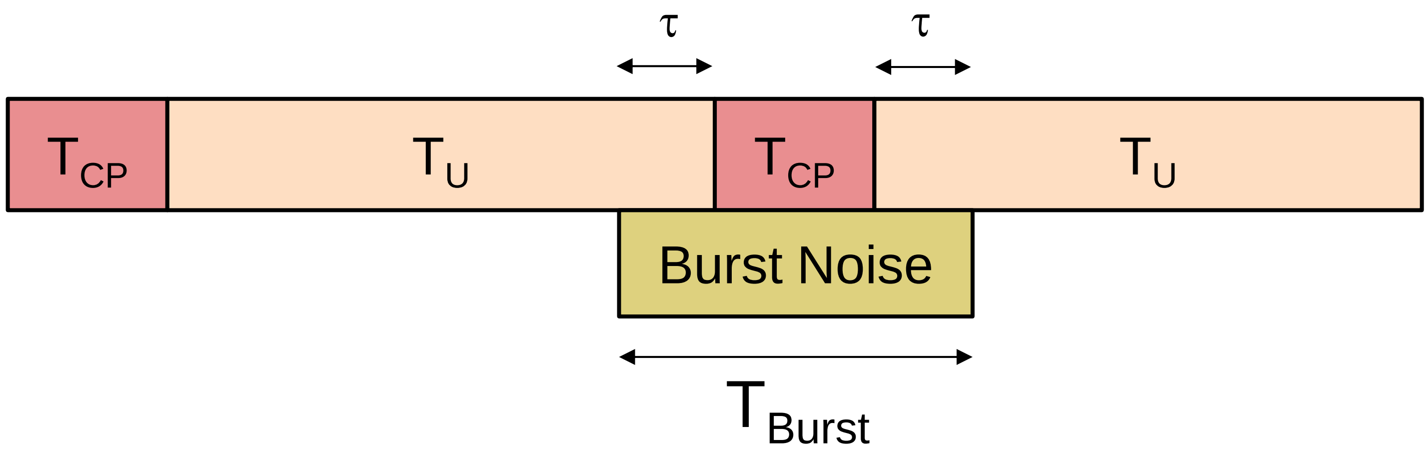
- The burst noise duration T_{Burst} is assumed to be shorter than the duration of an OFDM symbol
  - In this case, burst noise can impact one or two OFDM symbols

Burst Noise affecting One OFDM Symbol



- Effective SNR in OFDM symbols hit by burst noise
  - $SNR = -10 \cdot \log_{10}(10\text{^}(-SNR_{Burst,\ effective}/10) + 10\text{^}(-SNR_{AWGN,\ effective}/10))$
    - $SNR_{Burst,\ effective} = SNR_{Burst} – 10 \cdot \log_{10}(T_{Burst} / T_U)$
    - $SNR_{AWGN,\ effective} = SNR_{AWGN} – 10 \cdot \log_{10}(1 - T_{Burst} / T_U)$
- Effective SNR in OFDM symbols not hit by burst noise
  - $SNR = SNR_{AWGN}$

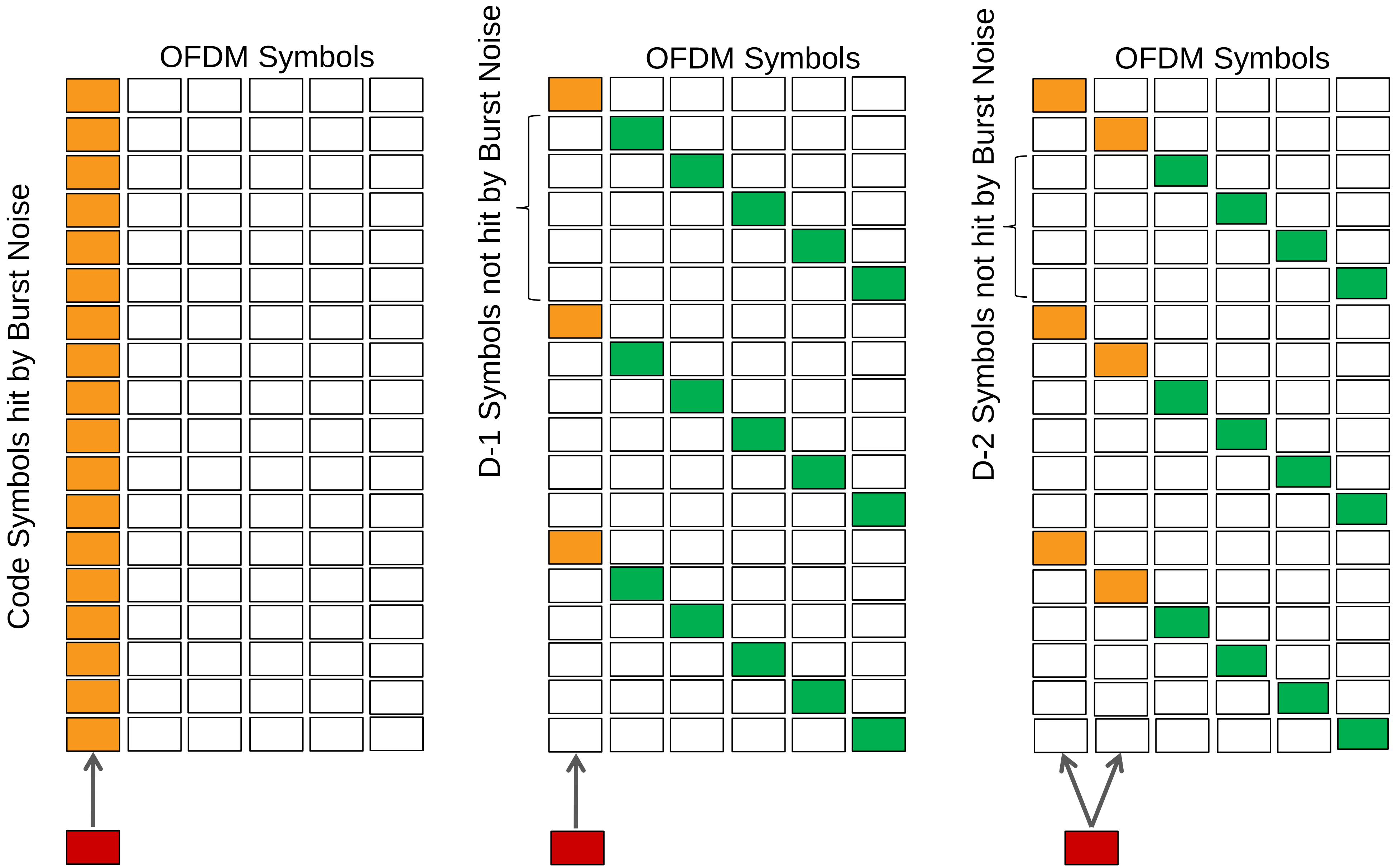
Burst Noise affecting Two OFDM Symbols



- Effective SNR in OFDM symbols hit by burst noise
  - $SNR = -10 \cdot \log_{10}(\ 10\text{^}(-SNR_{Burst,\ effective}/10) + 10\text{^}(-SNR_{AWGN,\ effective}/10)\ )$
    – $SNR_{Burst,\ effective} = SNR_{Burst} - 10 \cdot \log_{10}(0.5 \cdot (T_{Burst} - T_{CP}) / T_U)$
    – $SNR_{AWGN,\ effective} = SNR_{AWGN} - 10 \cdot \log_{10}(1 - 0.5 \cdot (T_{Burst} - T_{CP}) / T_U)$

- Effective SNR in OFDM symbols not hit by burst noise
  - $SNR = SNR_{AWGN}$

Frequency Domain View of Time Interleaving Depth D



Burst Noise
w/o Time Interleaving

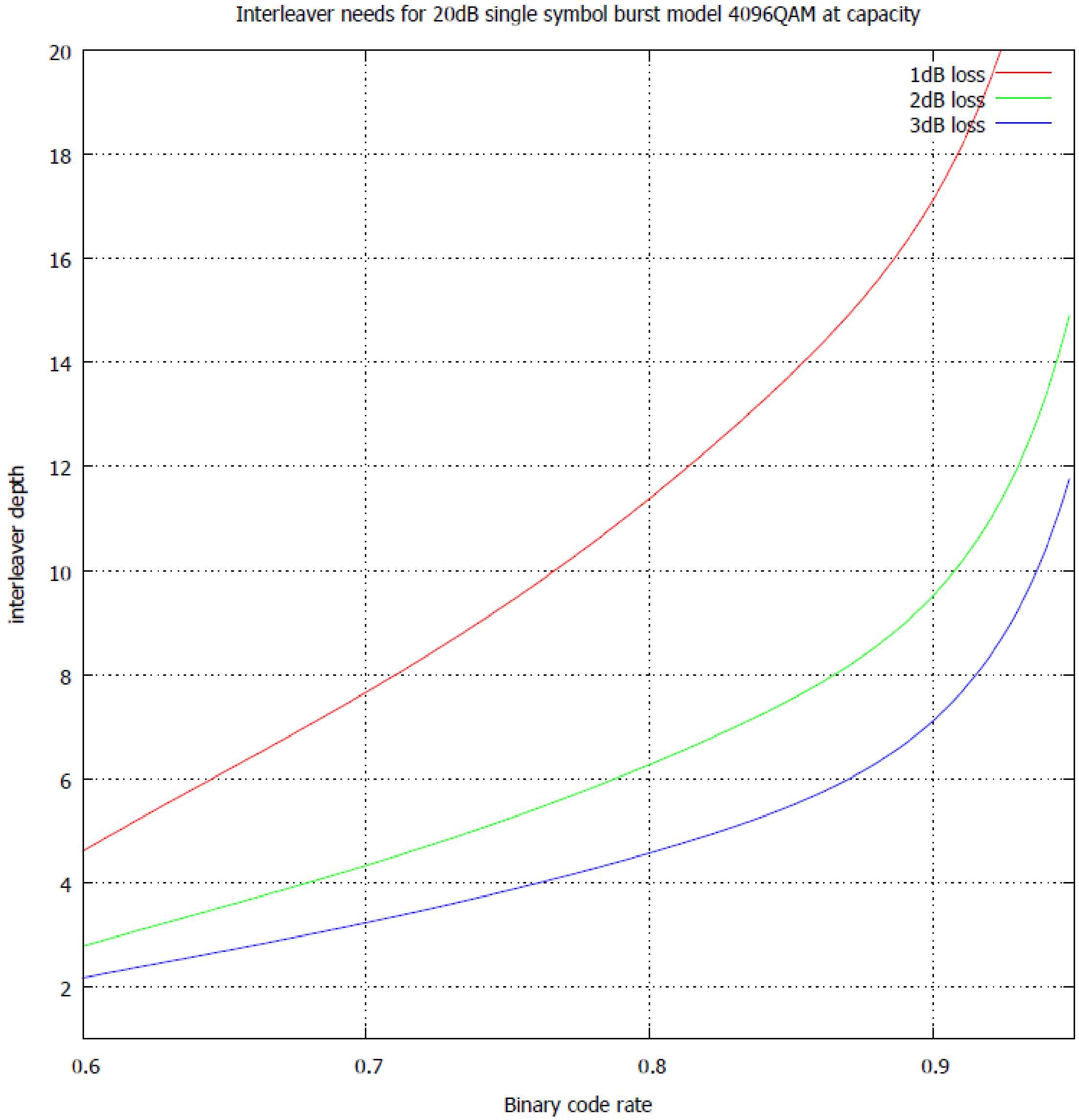
Burst noise affecting one OFDM symbol w/ Depth D = 6

Burst noise affecting two OFDM symbols w/ Depth D = 6

Consideration on Time Interleaving Depth D

- The depth D of the time domain interleaving impacts how many QAM symbols of a code word are affected by burst noise
  - For a larger interleaving depth D less symbols of a code word are impacted and performance improves
  - The drawback of a large interleaving depth D is increased PHY latency
    - However, if the depth D is too small, BER performance does not reach the BER target of 1e-8 anymore
- Hence, an important metric is the required interleaving depth D to achieve BER = 1e-8 at a fixed AWGN SNR
  - Interleaving depths are provided in the following
- Comments on required interleaving depth D
  - It can be shown that the required interleaving depth D is related to the inverse of the code rate R, i.e. $D \sim 1 / (1 - R)$

Code Rate and Interleaving Depth



- In burst noise a higher AWGN SNR is needed for the same capacity
  - This increase in SNR is called loss in the figure
  - This can be seen as required SNR margin for burst noise
- For a given margin, the figure shows the required interleaving depth as a function of code rate
- Codes with higher rate require higher interleaving depth
  - In comparisons for burst noise performance, code rates must be identical

Simulation Assumptions

- Downstream
  - 4096QAM
  - OFDM symbol durations T_U = 20 μs and T_U = 40 μs
  - Cyclic prefix length T_{CP} = 2.5 μs
  - Burst noise
    a) T_{Burst} = 16 μs, SNR_{Burst} = 20 dB equally affecting two OFDM symbols
- Upstream
  - 1024QAM
  - OFDM symbol durations T_U = 20 μs and T_U = 40 μs
  - Cyclic prefix length T_{CP} = 2.5 μs
  - Burst noise
    a) T_{Burst} = 1 μs, SNR_{Burst} = 0 dB affecting one OFDM symbol only
    b) T_{Burst} = 10 μs, SNR_{Burst} = 10 dB equally affecting two OFDM symbols

LDPC Decoder Assumptions

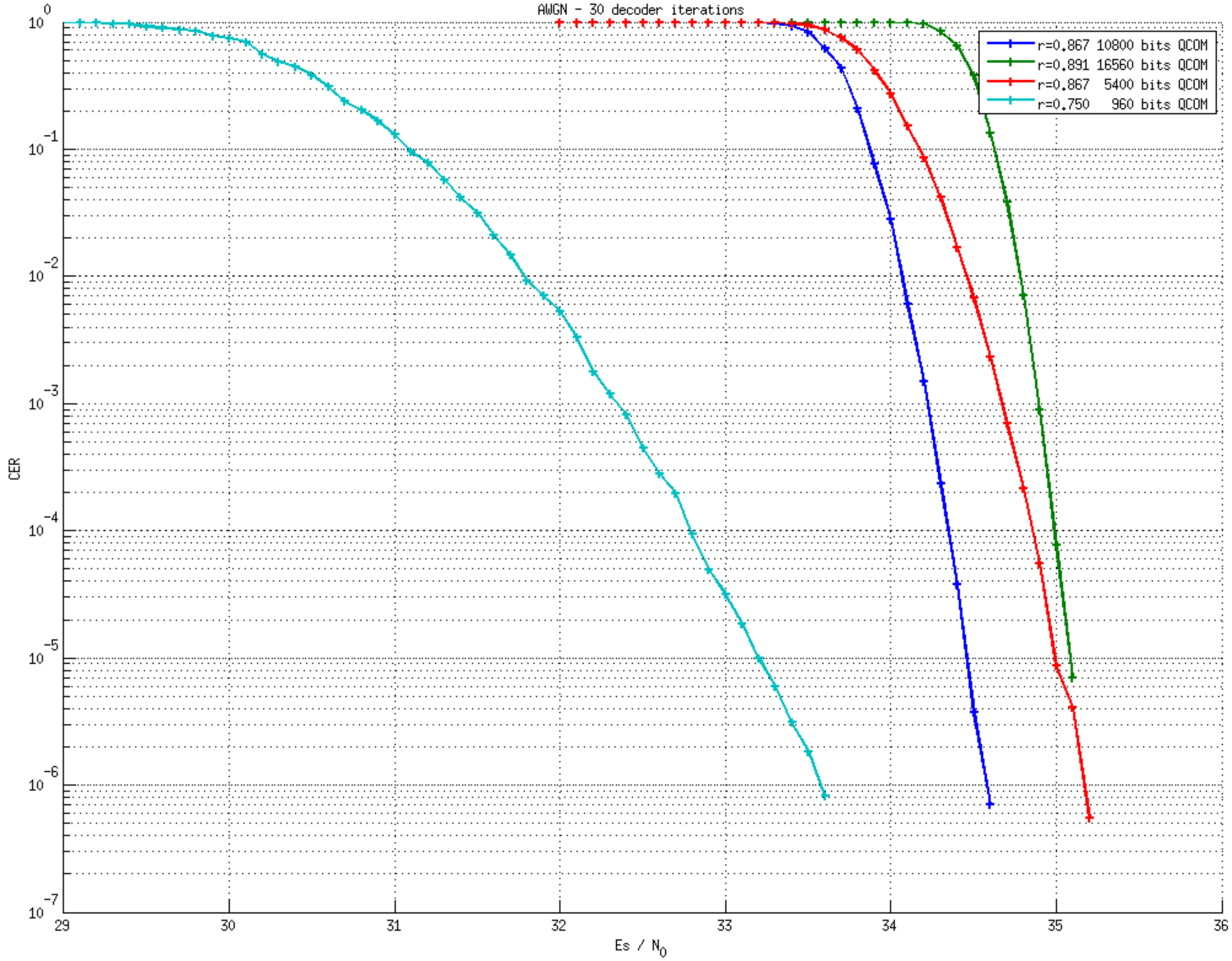
- Sum product decoder
- Flooding schedule
  - No layered iterations are applied
- The maximal number of iterations is set to 20 or 30, respectively
  - In the hardware implementation, layered iterations would be applied
    - This allows reducing the number of iterations roughly by 50%
    - Since the implementation and performance of a layered schedule is LDPC code specific, it is not used for code comparison
- Simulation methodology according to prodan_3bn_02_0313.pdf

Required Interleaving Depths for Burst Noise

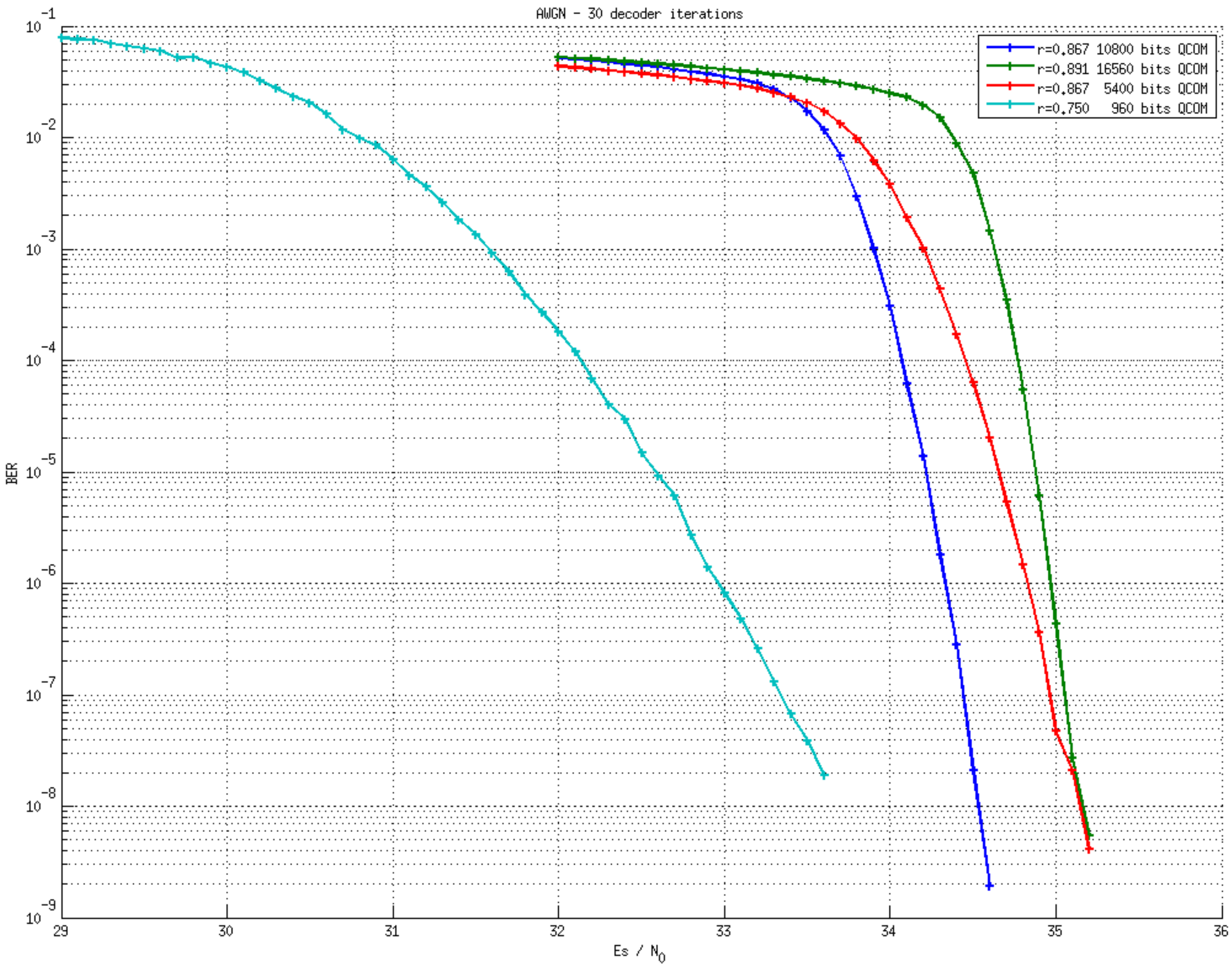
- The table shows the required time interleaving depths to achieve CER = 1e-6 and BER = 1e-8 and OFDM symbol duration 20 μs
  - The simulation results in the following slides assume these interleaving depths

Burst Model	Long Code Length = 16560	Medium Code I Length = 10800	Medium Code II Length = 5400	Short Code Length = 960
Downstream Model a)	D = 17			
Upstream Model a)		D = 17	D = 17	D = 17
Upstream Model b)		D = 17	D = 17	D = 17

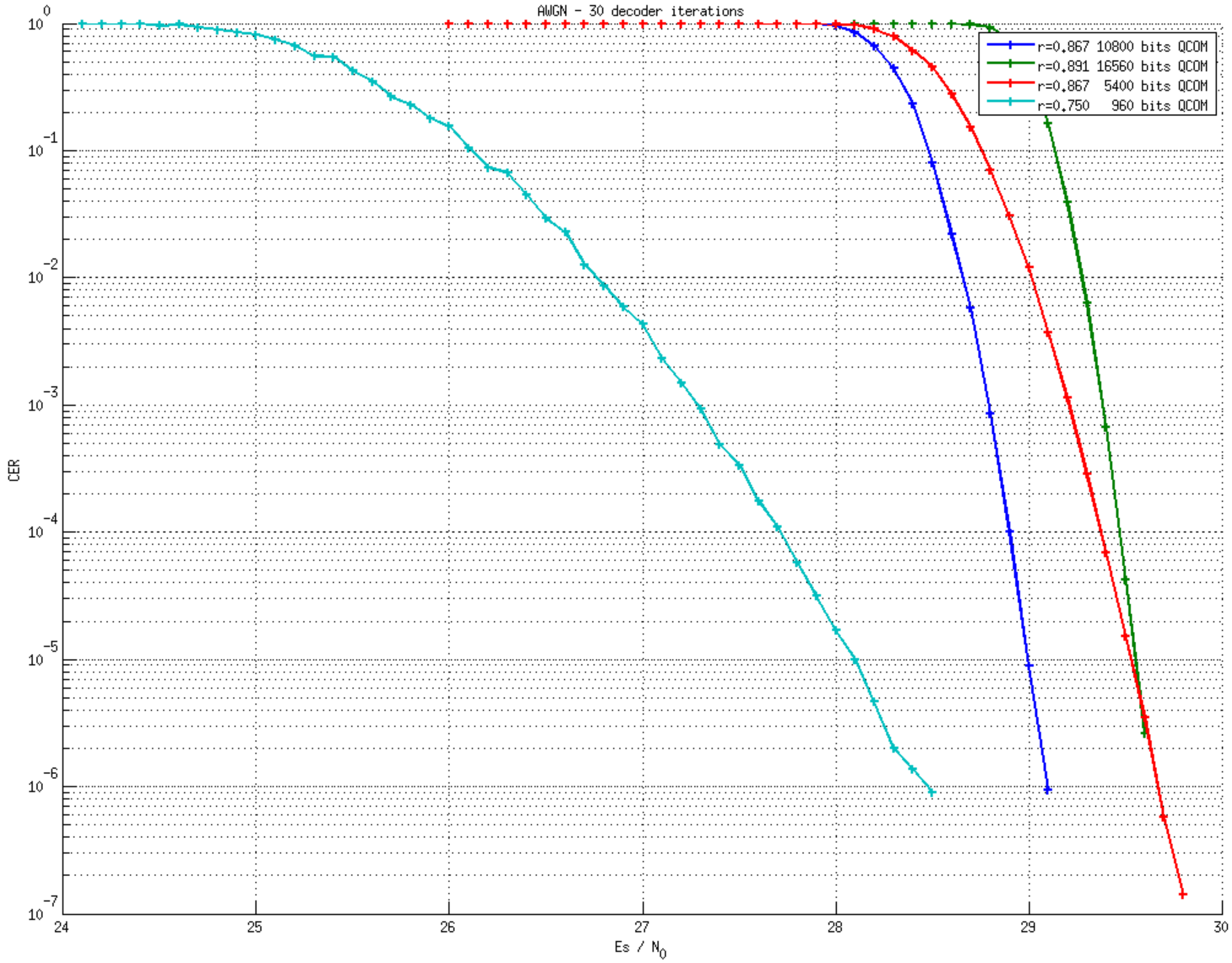
AWGN Performance for 4096QAM – CER



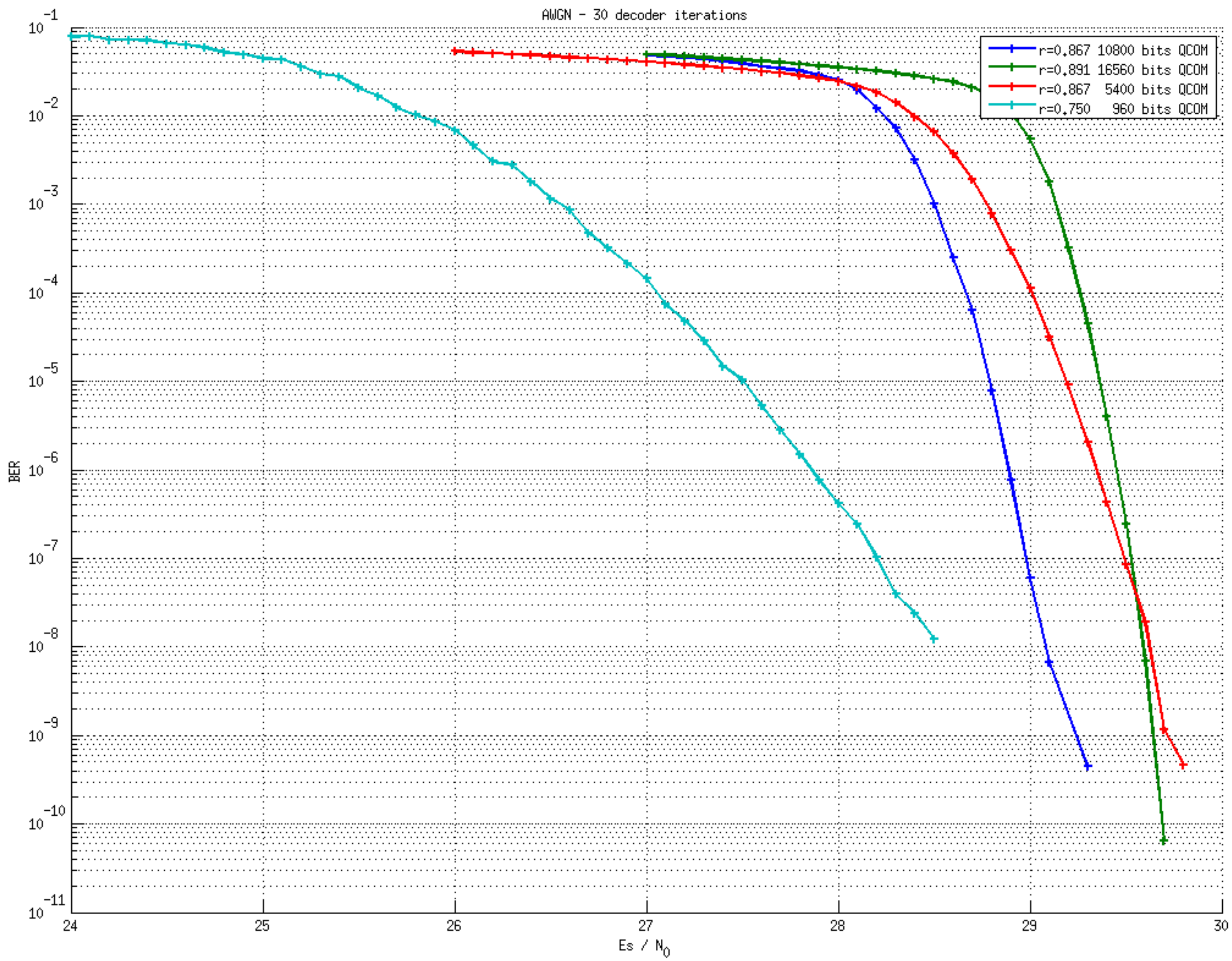
AWGN Performance for 4096QAM – BER



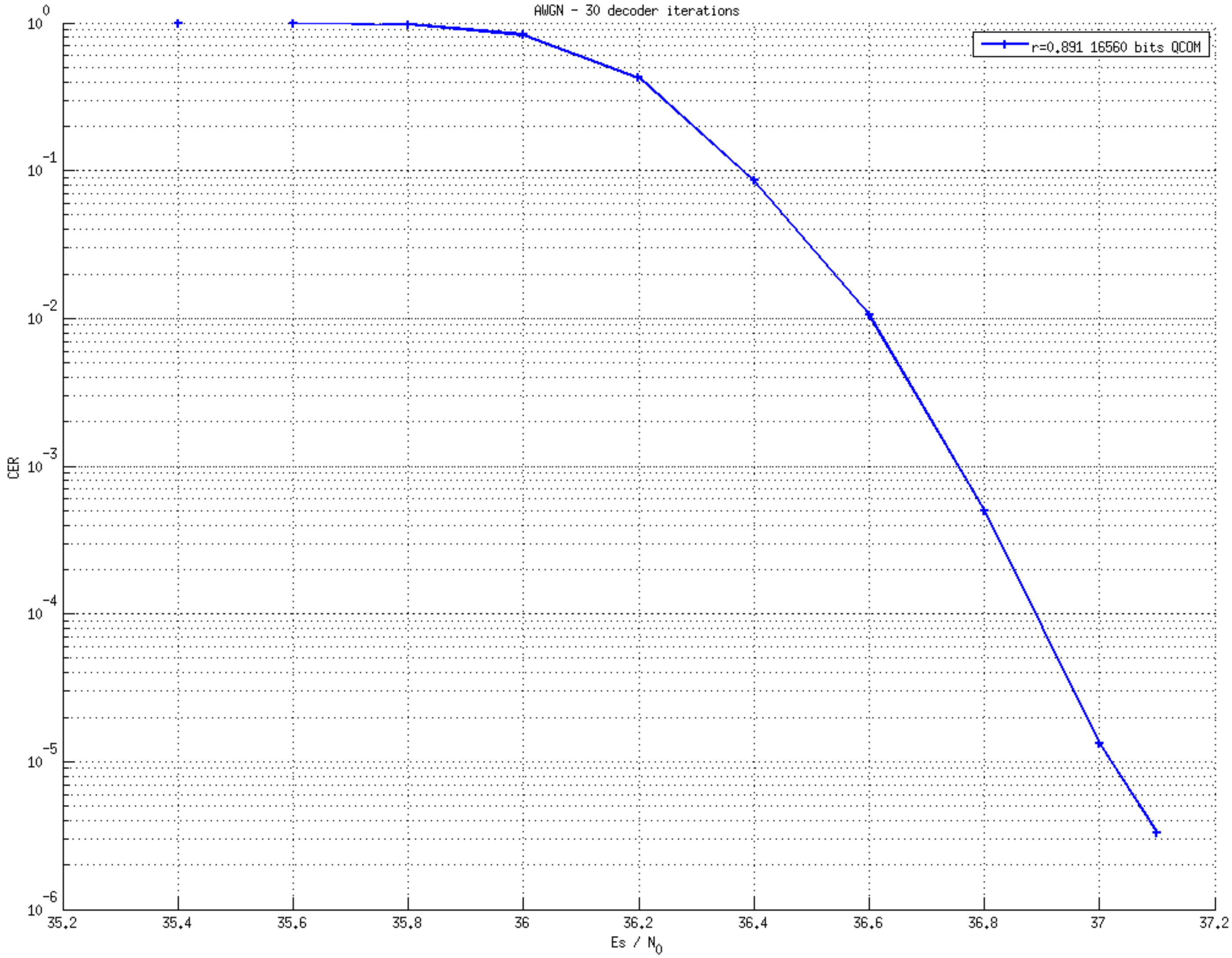
AWGN Performance for 1024QAM – CER



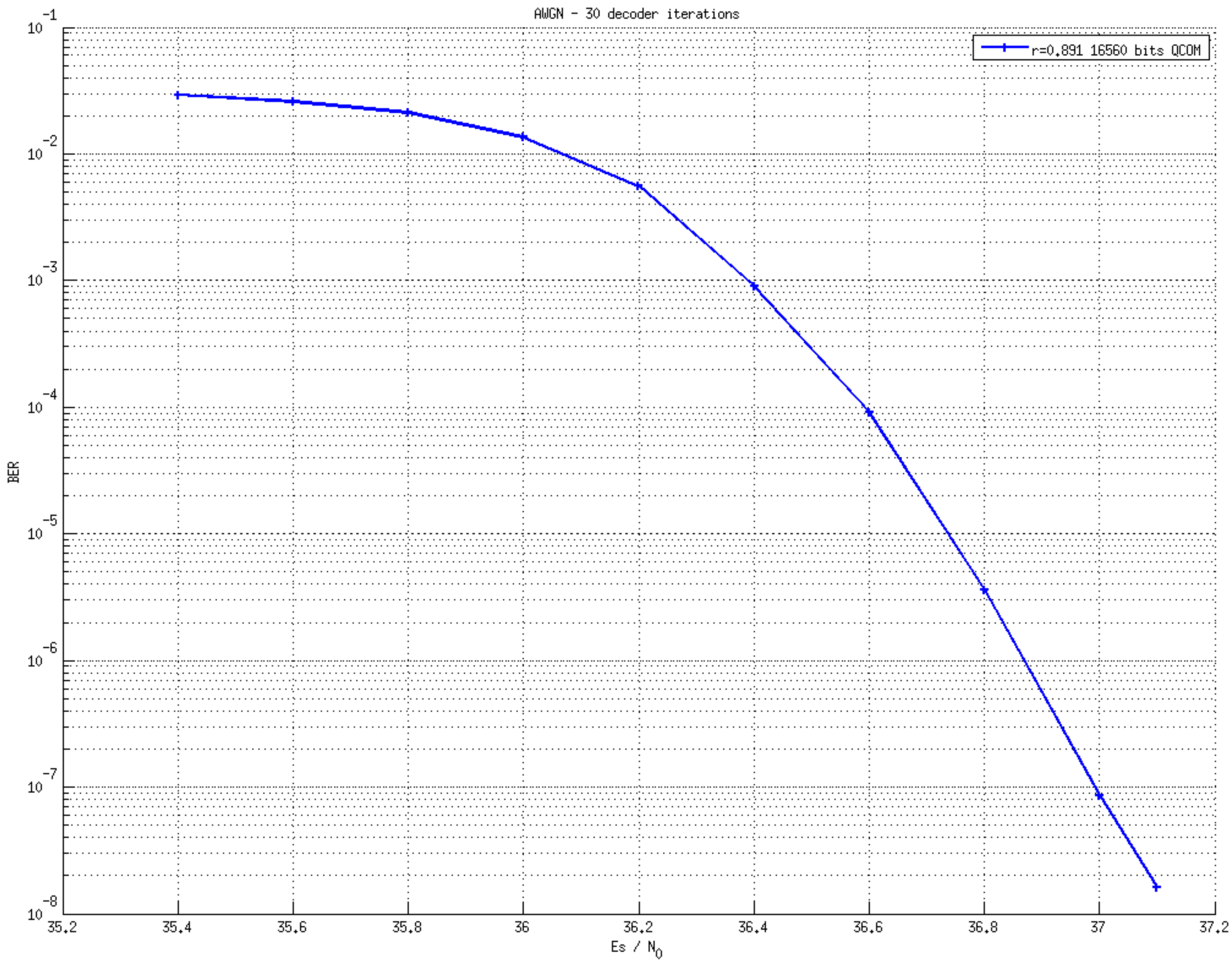
AWGN Performance for 1024QAM – BER



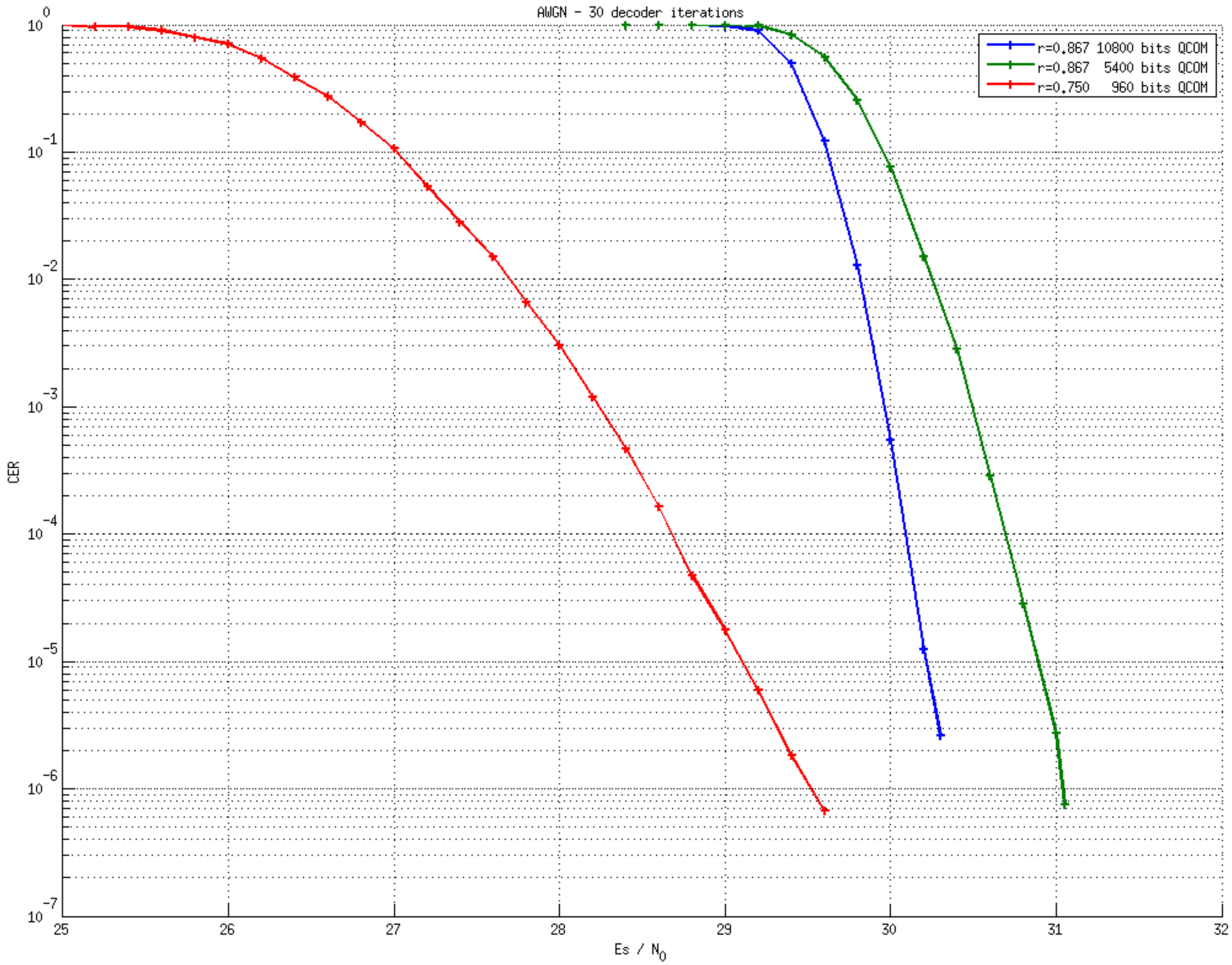
DS Burst Model a) – CER, 20 μs Symbol Duration



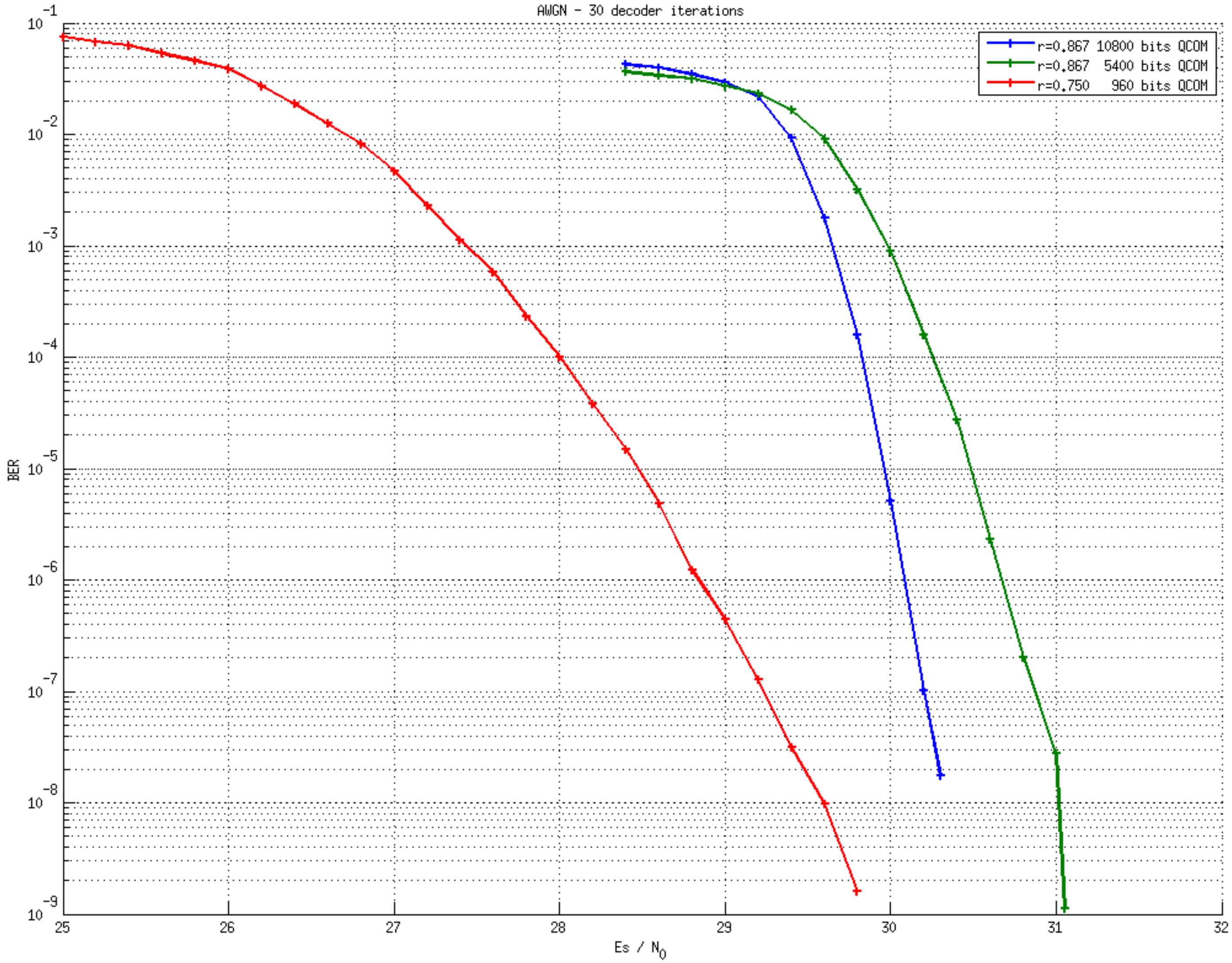
DS Burst Model a) – BER, 20 μs Symbol Duration



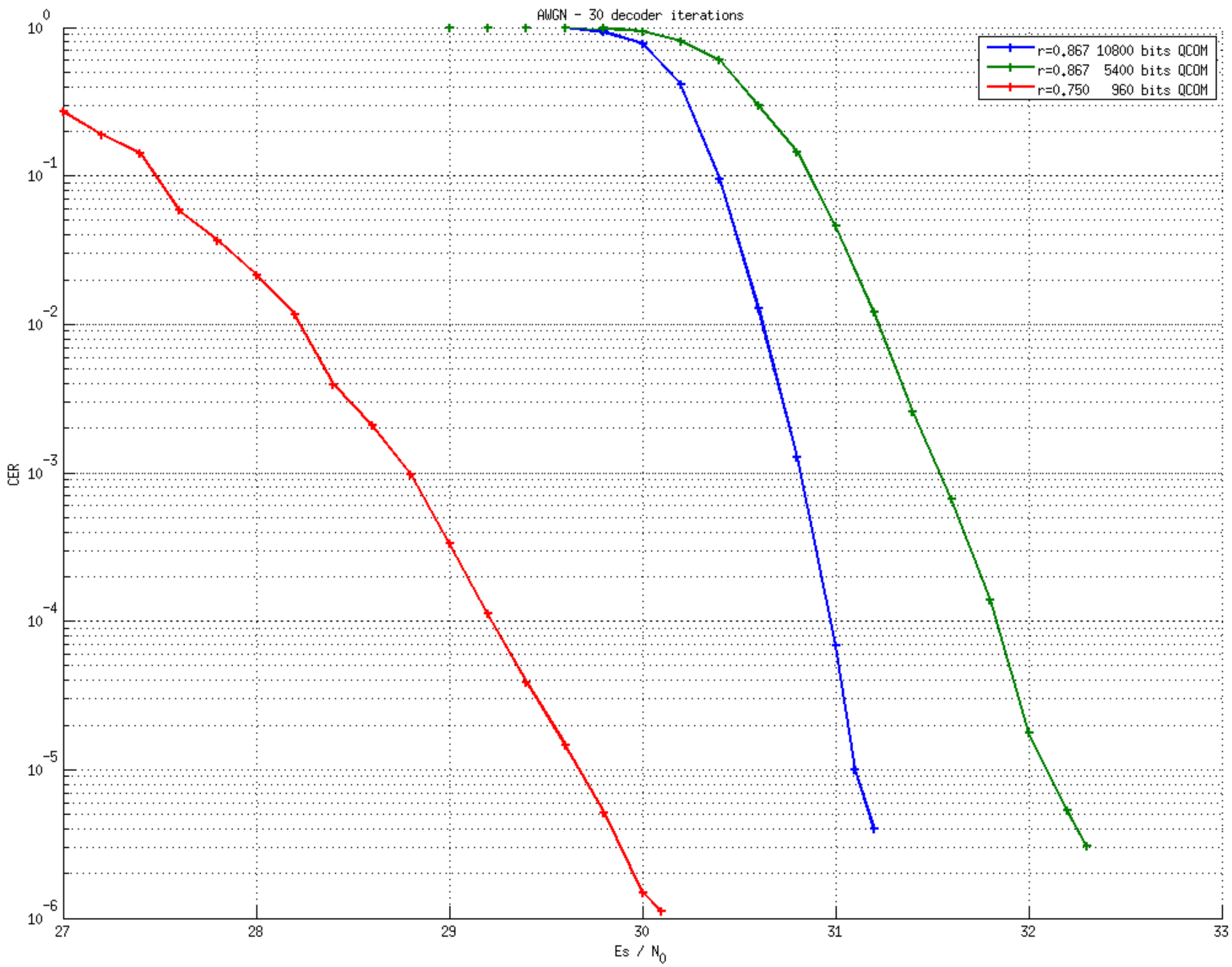
US Burst Model a) – CER, 20 μs Symbol Duration



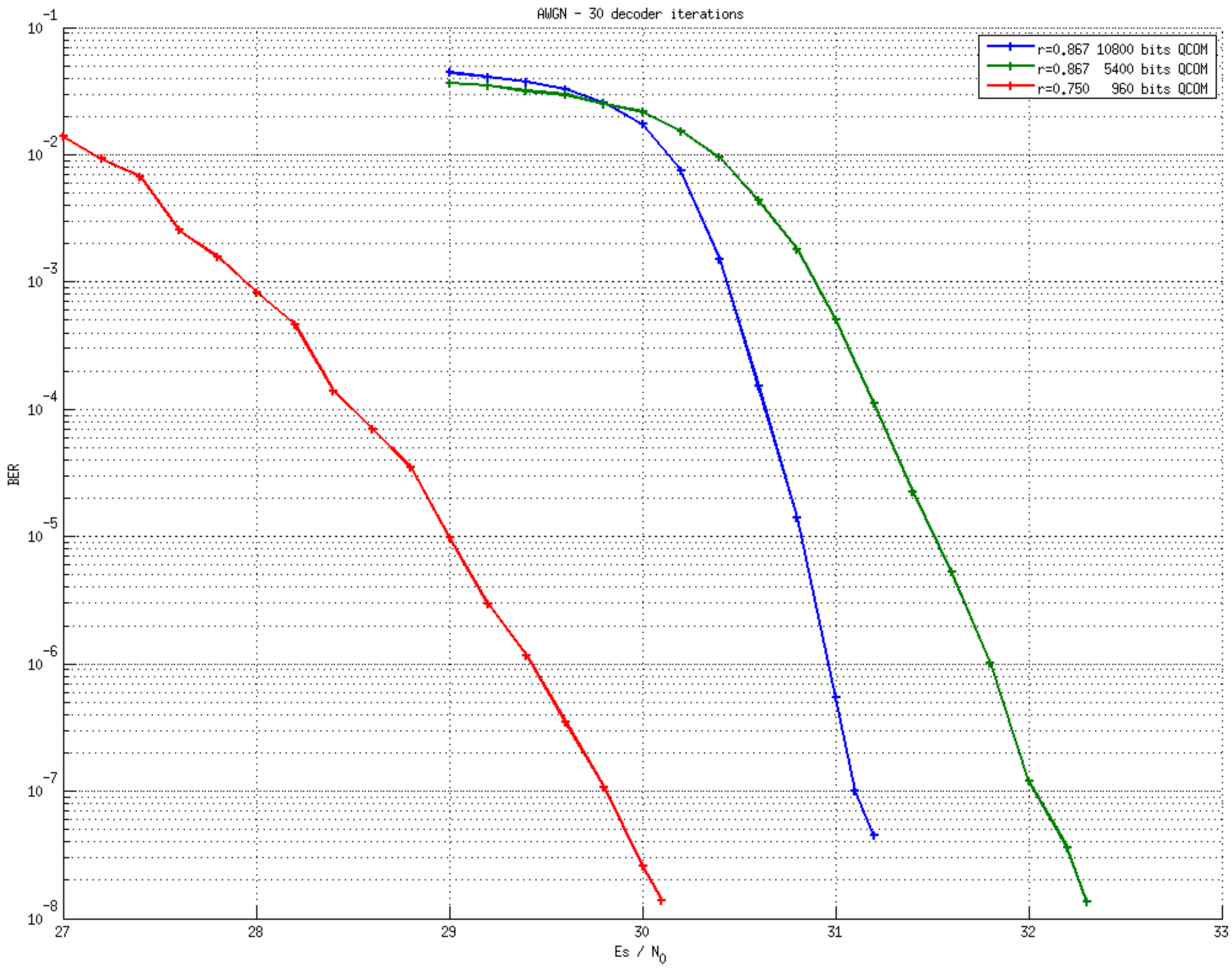
US Burst Model a) – BER, 20 μs Symbol Duration



US Burst Model b) – CER, 20 μs Symbol Duration



US Burst Model b) – BER, 20 μs Symbol Duration



Discussion and Conclusions

- Performance results were presented for AWGN and burst noise scenarios
- Agreed performance metrics are shown to be met

thank you