CCDF – A Better Way to Quantify the Peak-to-Average Ratio of Waveforms

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Presentation Overview

- Presentation Overview
- Power CCDF
- Single-Carrier Waveform Examples
- Conclusions

Power CCDF

- Power CCDF
  - Characterizing Digitally Modulated Signals with CCDF Curves
    - Agilent Technologies Application Note
    - 1/1/2000
    - Found on Page 9 of Application Notes web page
    - Available @ www.agilent.com

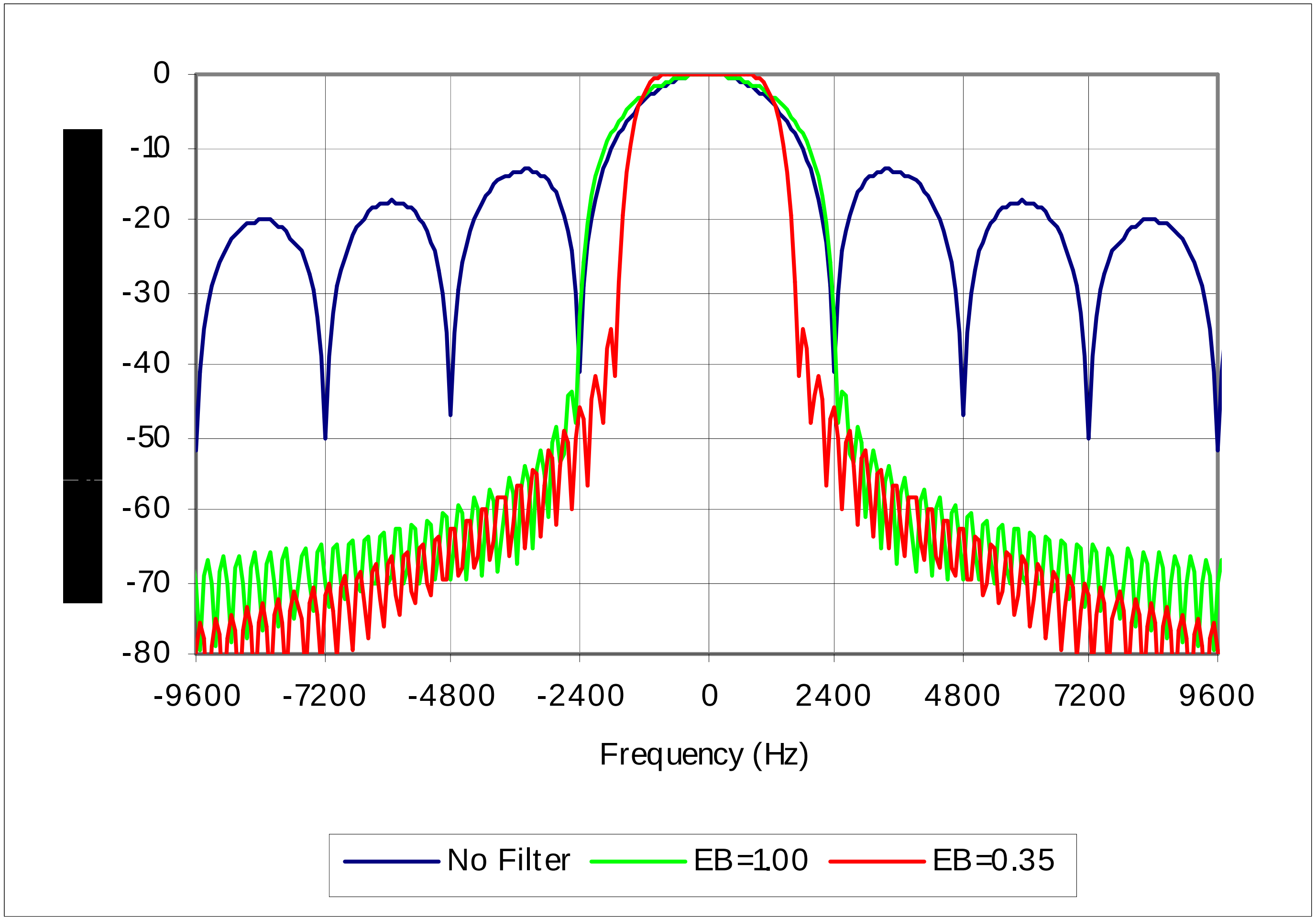
- Power CCDF
  - Power Complementary Cumulative Distribution Function
    - Compute the Probability Density Function (PDF) of the instantaneous power of a waveform (normalized by average power of waveform and converted to dB)
    - Compute Cumulative Density Function (CDF)
    - Take Complement (i.e. CCDF = 1-CDF)
  - A CCDF curve shows how much time a signal spends at or above a given power level (relative to the average power of waveform)
  - Standard Peak-to-Average (PAR) of a waveform is the largest value CCDF function will attain

Single-Carrier Waveform Examples

- Legacy Waveforms
  - MFSK, Unfiltered MPSK
    - Abrupt frequency or phase transitions
    - Constant amplitude
    - Fairly wide bandwidths
- New digital waveforms
  - Shaped Data Pulses
  - Higher data rates
  - Higher spectral efficiency
  - Challenging transmission media

- Filtered MPSK
  - Loses constant-amplitude property
- Most common family of filter shapes is Square-Root Raised Cosine (SRRC)
  - Zero Inter-Symbol Interference (ISI) during detection on AWGN channel
  - Excess Bandwidth (EB) parameter controls bandwidth
    - EB = 0.0 bandwidth approximately equal to symbol rate
    - EB = 1.0 bandwidth approximately equal to twice the symbol rate
  - PAR increases as bandwidth is decreased

MPSK Spectral Properties



SRRC PAR and Bandwidth for MPSK
(129-tap filter, 16 samples per symbol)

EB	PAR (dB)	99% Power Bandwidth	99.9% Power Bandwidth
0.10	7.0	1.031250	1.093750
0.20	5.5	1.078125	1.179688
0.35	3.9	1.156250	1.281250
0.50	3.3	1.265625	1.398438
1.00	3.6	1.637500	1.828125

Single-Carrier Waveform Examples

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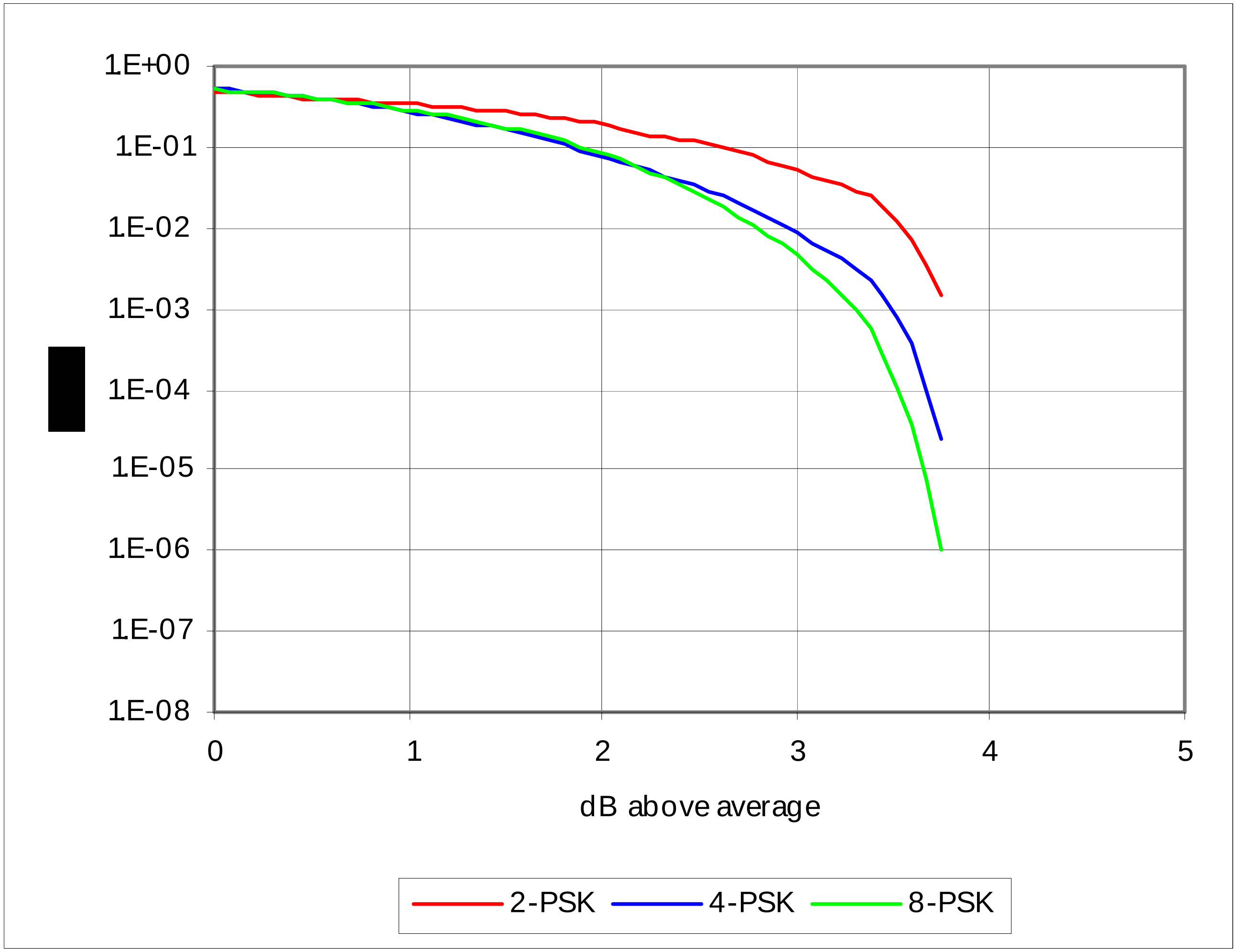
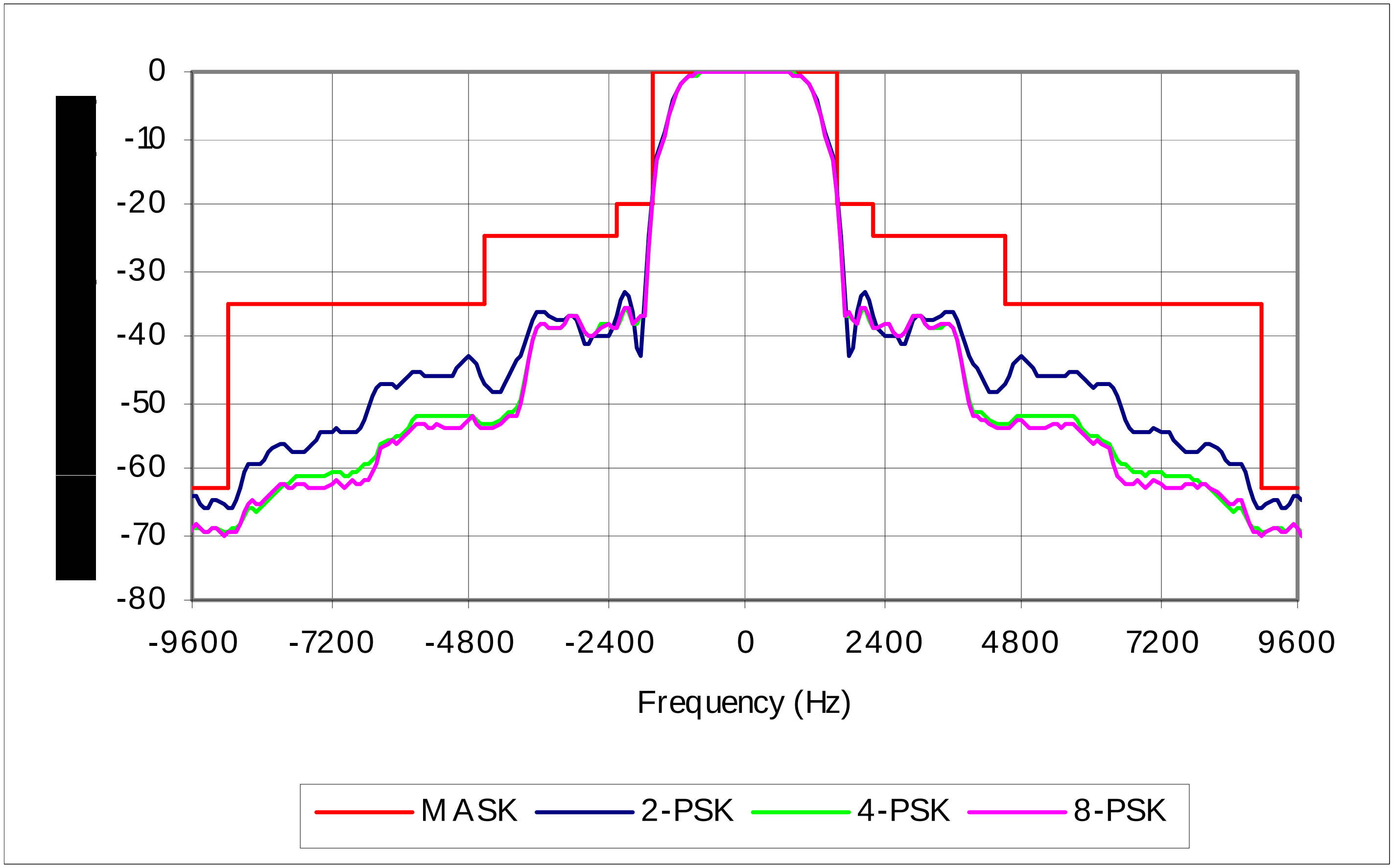
CCDF of Single-Carrier MPSK Waveforms

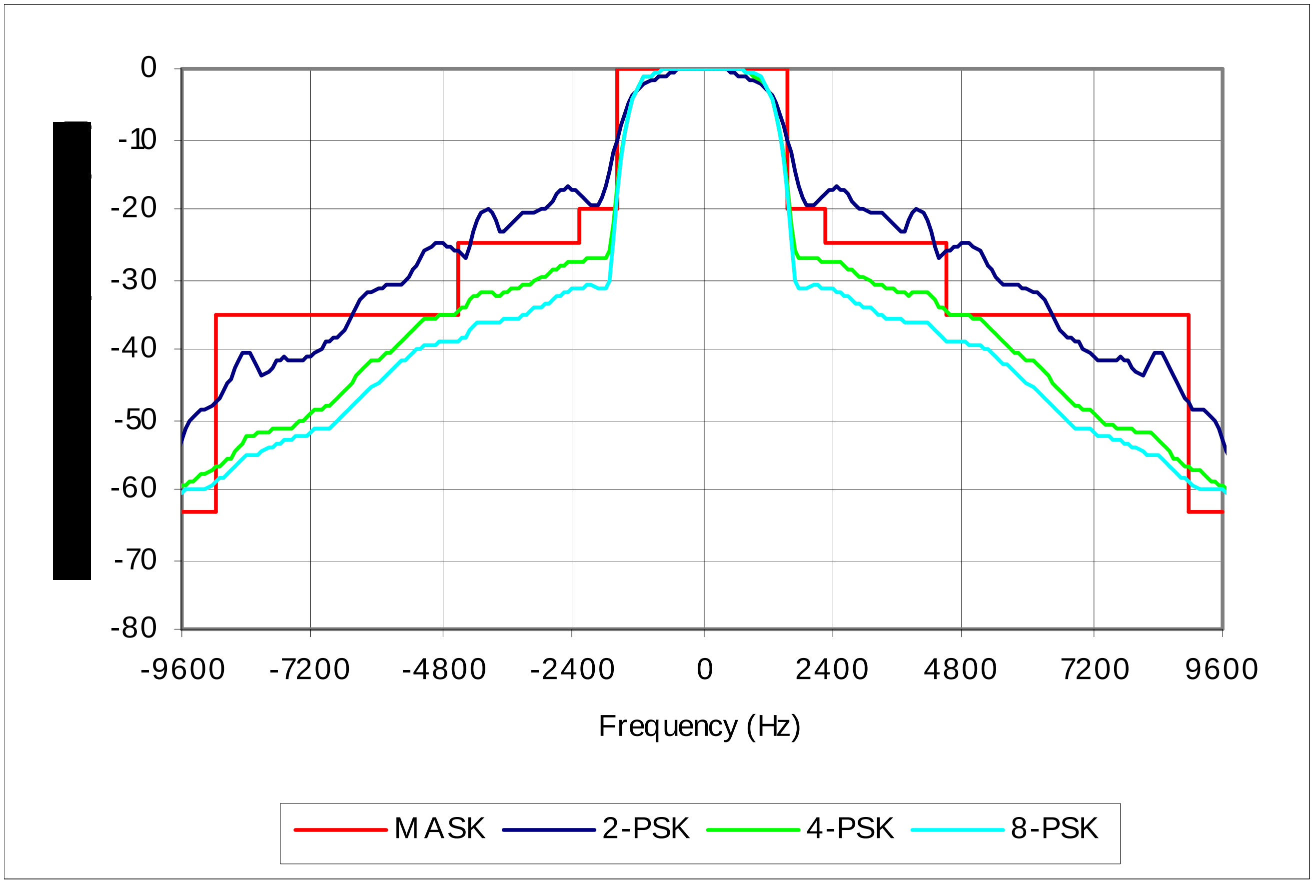


- US MIL-STD-188-110B main body waveforms always use 8-PSK modulation over-the-air independent of data rate (i.e. symbol scrambling)
- Previous figure shows an advantage to using higher-order MPSK modulations (from a peak-power perspective)
  - Is this real ???
- This can be verified by inserting a device sensitive to PAR and measuring effects of PAR
  - A power amplifier is a common device used in HF applications which can be sensitive to PAR

Transmit Spectra for PA 1 Model (Back Off 3 dB)



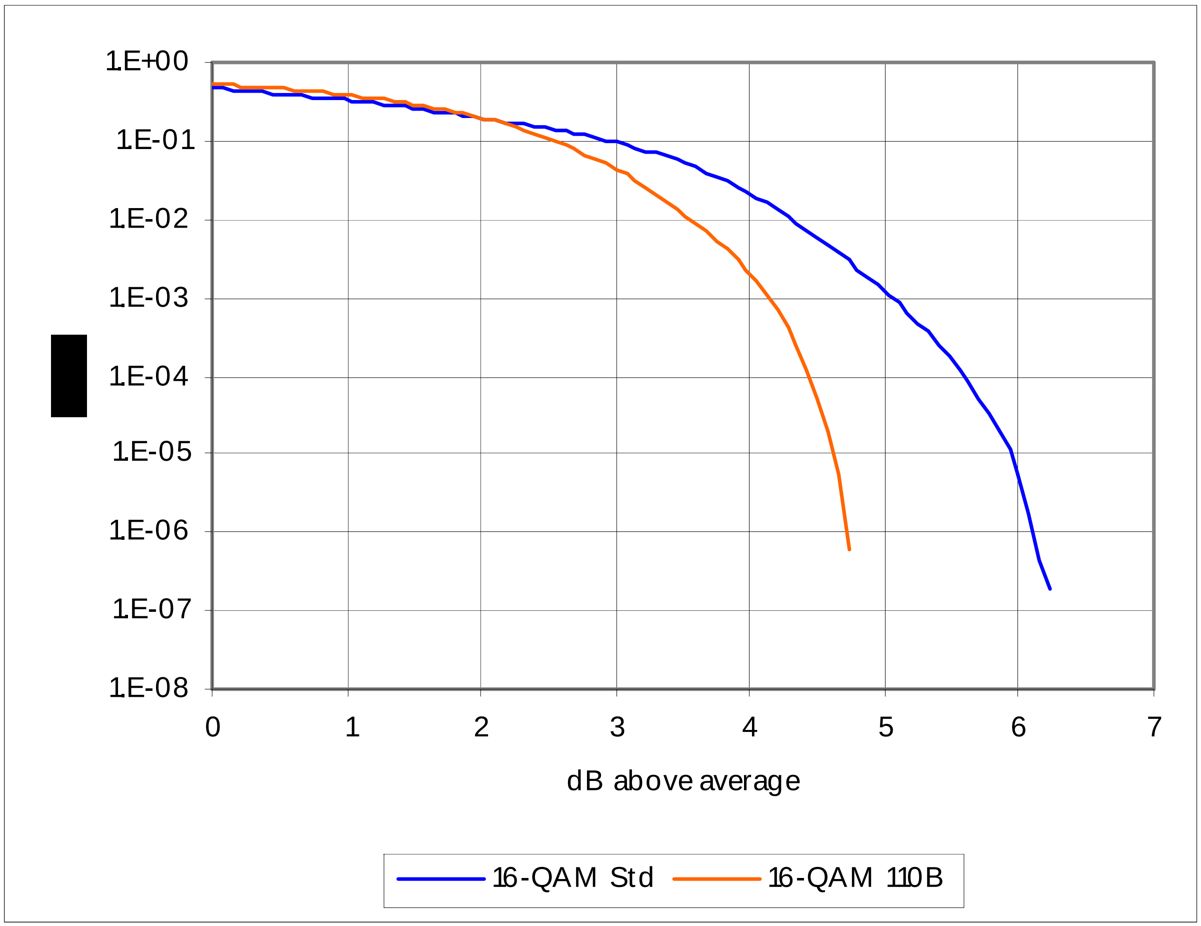
Transmit Spectra for a PA 1 Model (Back Off 2 dB)



Received SNR for MPSK Single-Carrier Waveforms

Modulation	BO (dB)	PA 2 SNR (dB)	PA 1 SNR (dB)
2-PSK	10	36.0	35.8
	6	34.8	35.1
	4	32.0	34.8
	2	28.4	17.5
4-PSK	10	36.0	35.8
	6	35.3	35.3
	4	33.4	34.8
	2	30.0	26.5
8-PSK	10	36.0	35.9
	6	35.4	35.4
	4	33.5	34.7
	2	30.1	30.1

CCDF of 16-QAM Single-Carrier Waveforms



Received SNR for MQAM Single-Carrier Waveforms

Modulation	BO (dB)	PA 2 SNR (dB)	PA 1 SNR (dB)
16-QAM	10	35.8	35.0
	6	32.1	32.6
	4	27.7	28.6
	2	23.4	0.6
16-QAM (110B)	10	36.0	35.6
	6	34.5	34.2
	4	31.3	33.4
	2	27.1	12.8

Conclusions

- CCDF is an extremely useful tool for characterizing the amplitude/power distribution of digital waveforms