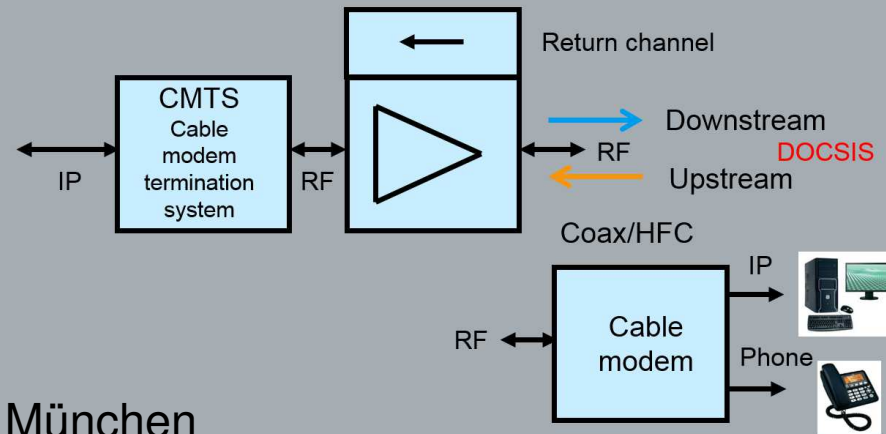
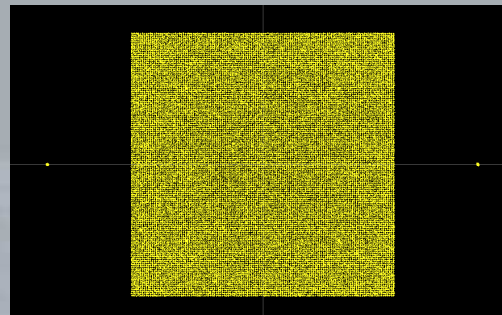
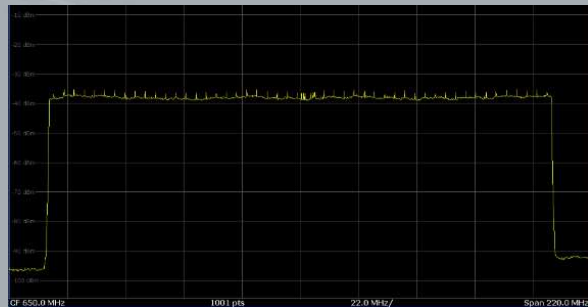


„Signalpegel-Definition bei DOCSIS3.1 ...“



Walter Fischer
Rohde&Schwarz Trainingszentrum München



März 2019

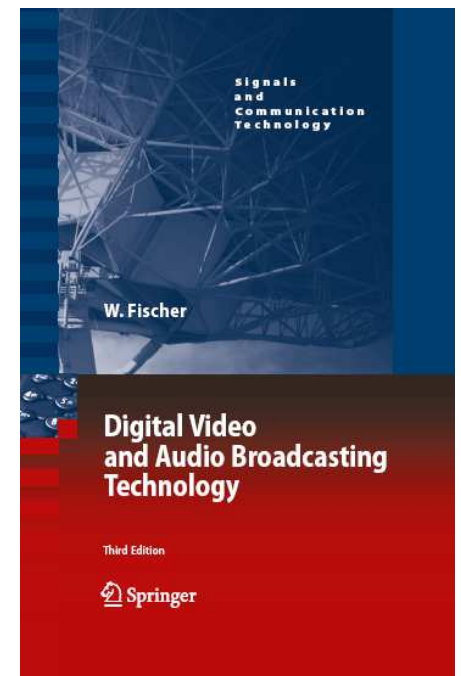
Referent

Walter Fischer

Dipl.Ing.(FH)

**Rohde&Schwarz
Training Center, Munich**

Walter.Fischer@ROHDE-SCHWARZ.COM



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

Zusammenfassung



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

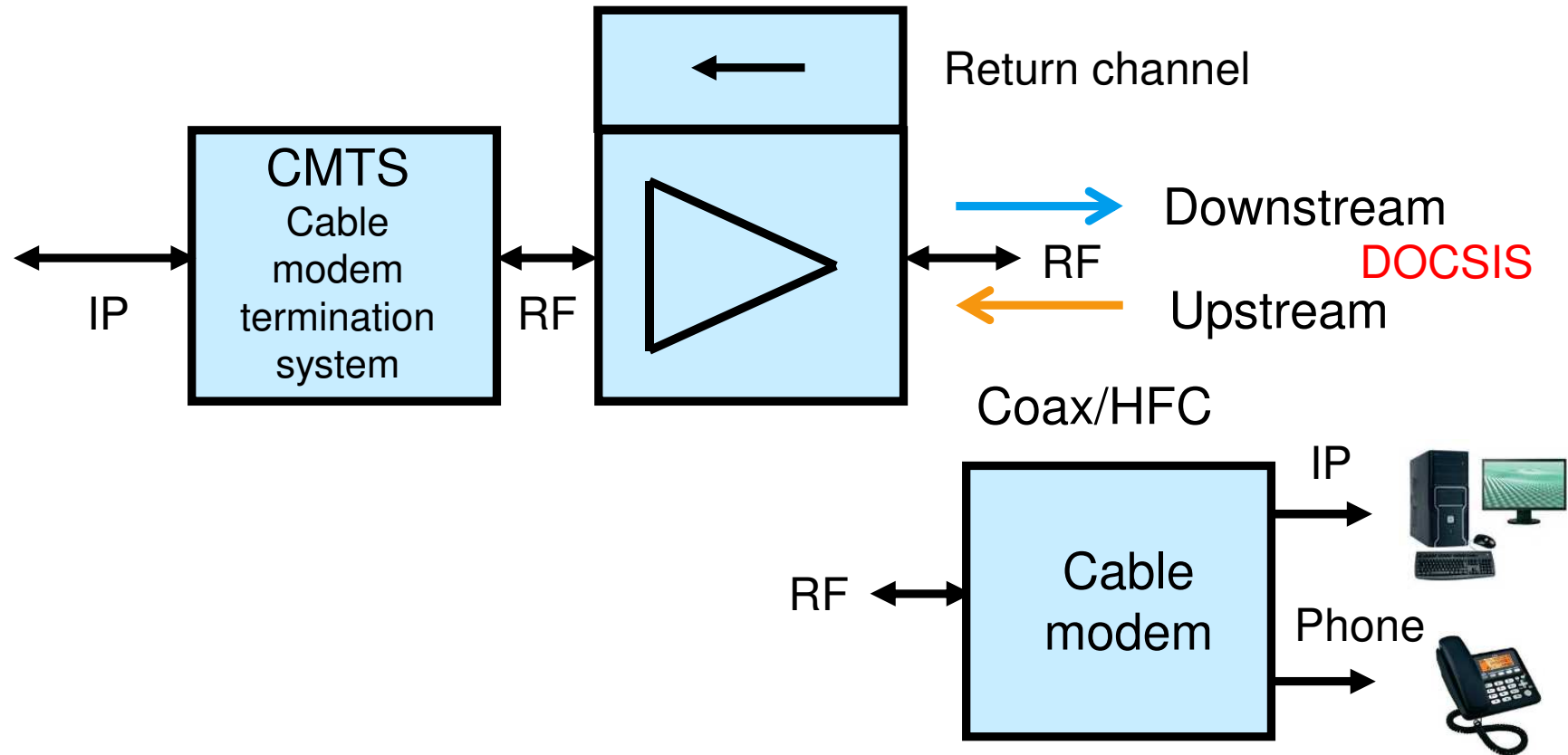
Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

Zusammenfassung



Broadband Internet & Telephone via CATV



DOCSIS – Data-over-Cable Service Interface Specification

DOCSIS – Data over Cable Service Interface Specification

DOCSIS 1.0	1997 Cable Labs, ITU-T spec. ITU-T J.112
DOCSIS 1.1	1999 QoS capabilities
DOCSIS 2.0	2001 enhanced upstream speeds ITU-T J.122
DOCSIS 3.0	2006 increase of both up and downstream speed, IPv6 ITU-T J.222
DOCSIS 3.1	2013 10Gbit/s downstream, 1Gbit/s upstream, OFDM, 4096QAM

Physical Layer Specification

CM-SP-PHYv3.1-I02-140320

DOCSIS standard =

bidirectional transmission of high-speed data over
broadband cable networks using hybrid fiber-coaxial infrastructure

all DOCSIS standards are backward compatible



DOCSIS Physical Layer

DOCSIS 1.0 ... 3.0:

Downstream =

ITU-T J83B [US] Single Carrier 64QAM/256QAM

or

ITU-T J83A (DVB-C) [EURO-DOCSIS] Single Carrier 64QAM/256QAM

Upstream = Single Carrier, QPSK ... 64QAM, TDMA, CDMA

DOCSIS 3.1:

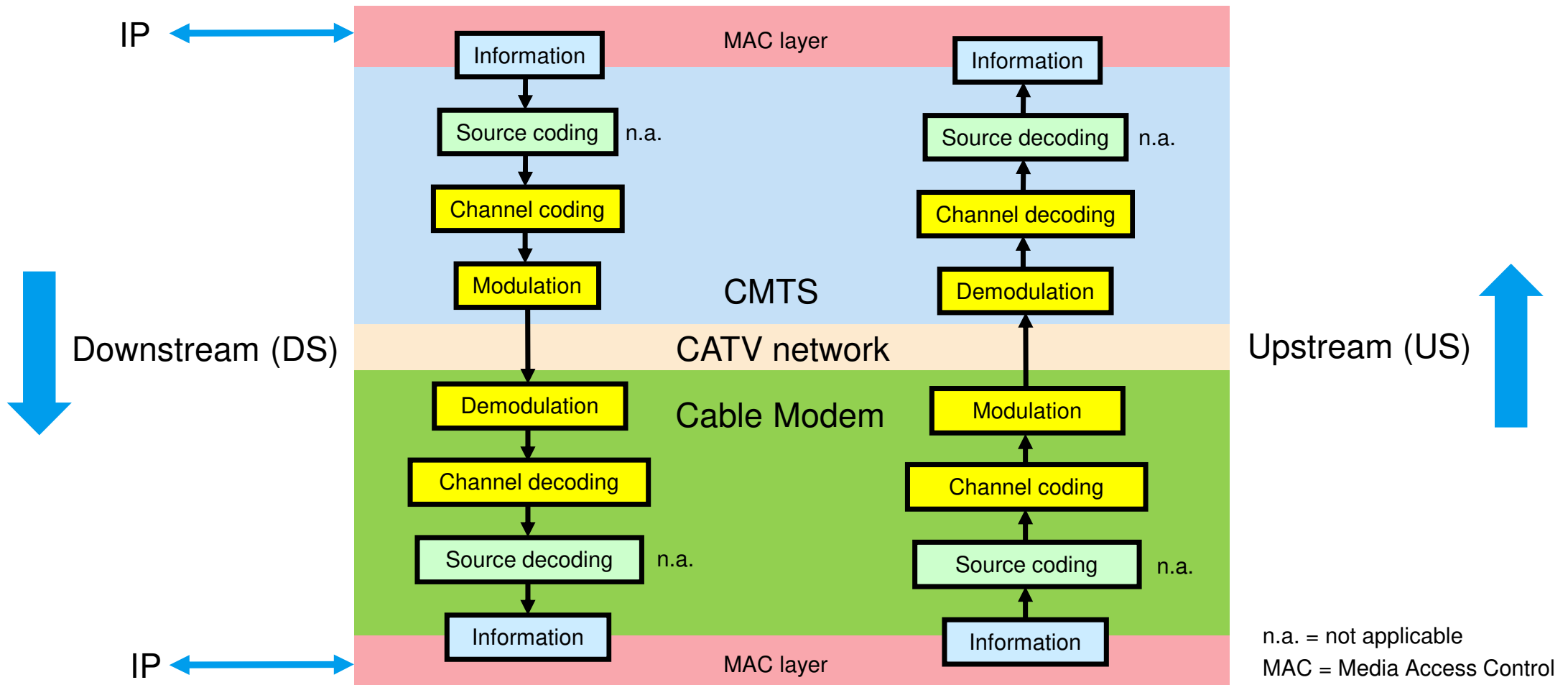
Downstream = **OFDM**, 4096 (4K) QAM and higher (16K QAM)

4K/8K OFDM, 50/25 kHz carrier distance

Upstream = **OFDM**, minislots in time and frequency domain
up to 4096 (4K) QAM, 2K/4K OFDM, 50/25 kHz carrier distance

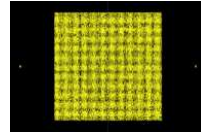


DOCSIS Downstream and Upstream



DOCSIS 3.1 Downstream

up to 16384QAM



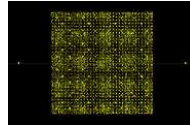
Parameter	DOCSIS 3.1	DOCSIS 3.0
Type of modulation	OFDM 4K and 8 K FFT	single carrier (J.83/B, DVB-C)
Frequency range	108 MHz to 1218 MHz (1794 MHz)	45 MHz to 1002 MHz
Block bandwidth	up to 192 MHz	6 MHz / 8 MHz
QAM constellations	up to 4096, 8k, 16k	up to 256
Cyclic prefix length	0.9375 μ s to 5 μ s	n/a
Pilots	scattered and continuous	n/a
Forward Error Correction	BCH-LDPC	Reed-Solomon
DS capacity (bps)	8 G (10 G)	300 M (1 G)

25 kHz / 50 kHz carrier spacing
7680 / 3840 carriers in 192 MHz bandwidth



DOCSIS 3.1 Upstream

up to 4096QAM

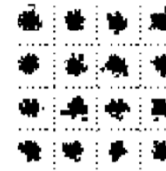


Parameter	DOCSIS 3.1	DOCSIS 3.0
Type of modulation	OFDM 2K and 4 K FFT	single carrier TDMA, S-CDMA
Frequency range	5 MHz to 204 MHz	5 MHz to 85 MHz
Block bandwidth	up to 96 MHz	up to 6.4 MHz
QAM constellations	up to 4096	QPSK to 64
Cyclic prefix length	0.9375 μ s to 6.25 μ s	n/a
Pilots	complementary and continuous	n/a
Forward Error Correction	LDPC	Reed-Solomon
US capacity (bps)	400 M (1 G to 2.5 G)	100 M (300 M)

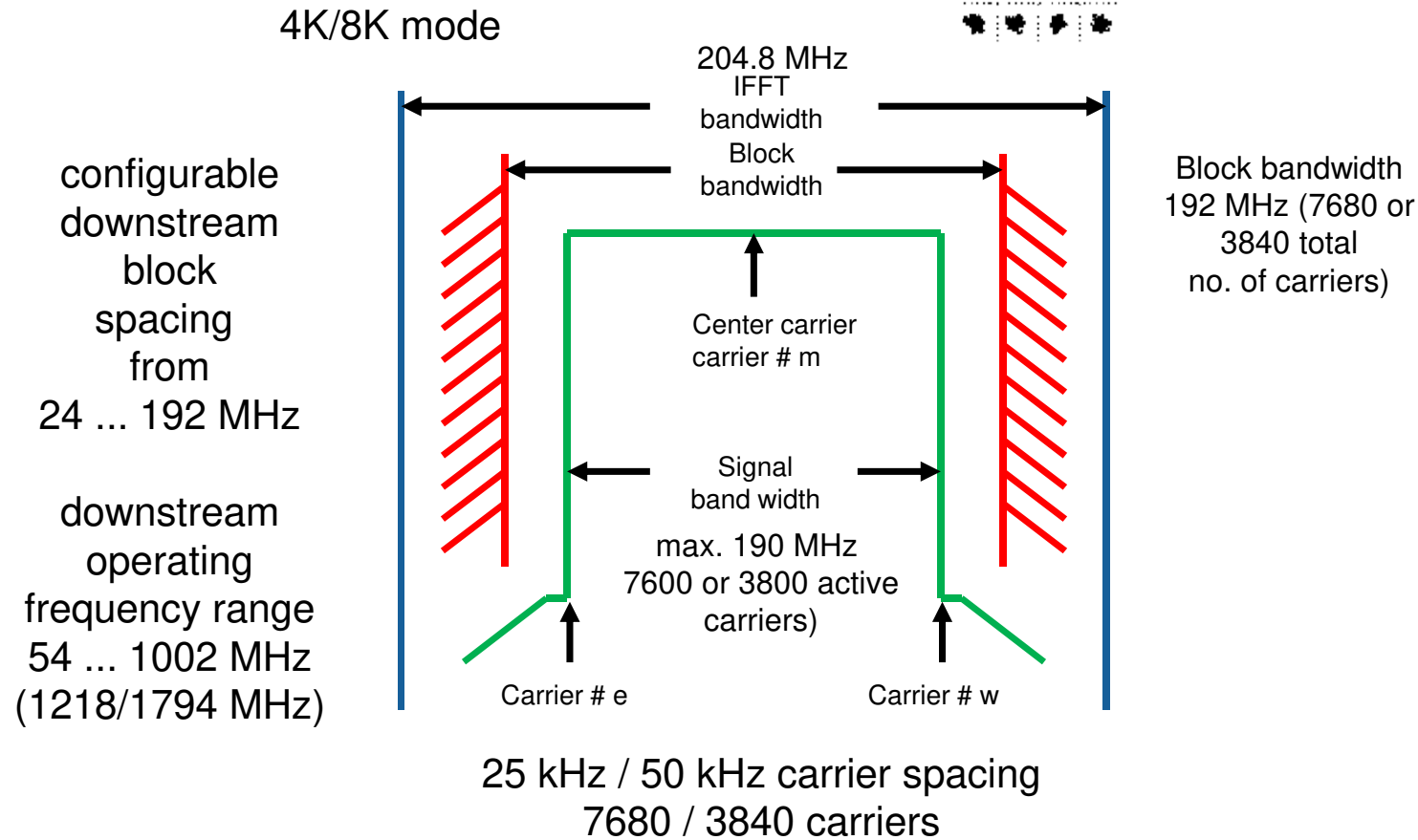
25 kHz / 50 kHz carrier spacing
3840 / 1920 carriers in 96 MHz bandwidth



DOCSIS 3.1 Downstream Spectrum



Up to 1024/4096/16384QAM



(... DOCSIS3.1 symbol duration ... 20 or 40 μ s ... OFDM, 1...5 μ s guard)

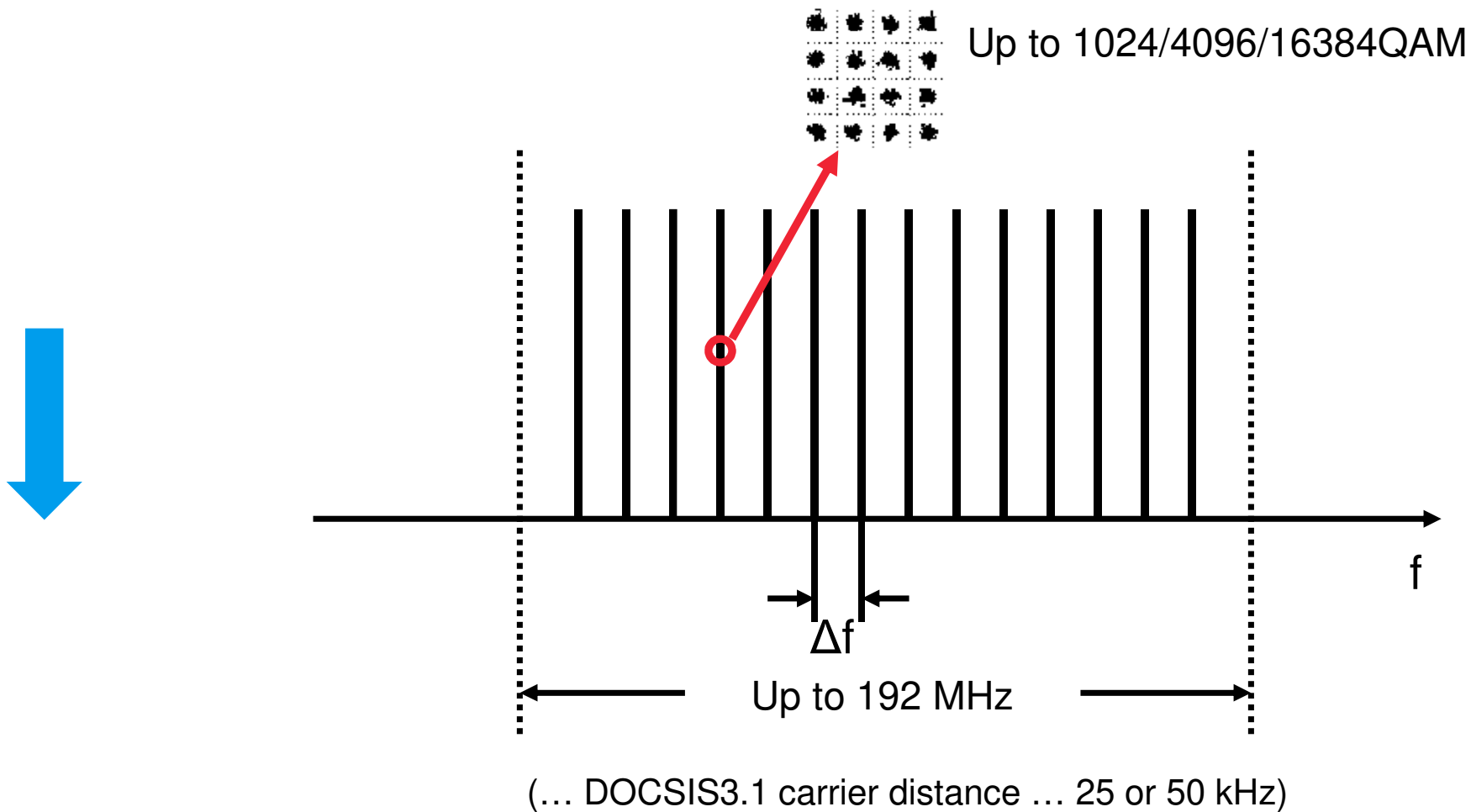


DOCSIS3.1 Downstream Block Bandwidth

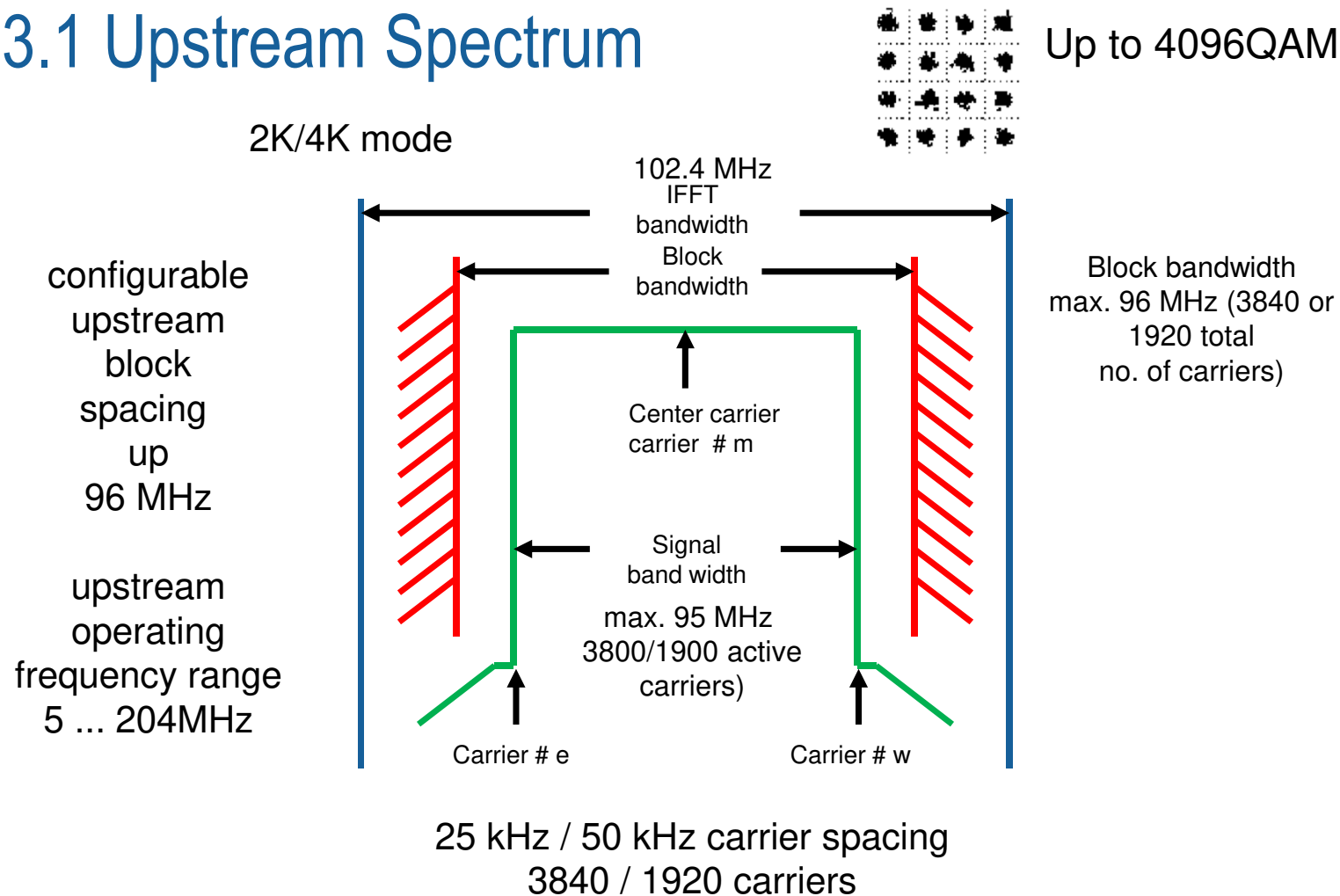


4K mode	$4096 \cdot 50 \text{ kHz} = 204.8 \text{ MHz} = \text{IFFT bandwidth}$
	$3800 \cdot 50 \text{ kHz} = 190 \text{ MHz} = \text{signal bandwidth}$
	$3840 \cdot 50 \text{ kHz} = 192 \text{ MHz} = \text{block bandwidth}$
8K mode	$8192 \cdot 25 \text{ kHz} = 204.8 \text{ MHz} = \text{IFFT bandwidth}$
	$7600 \cdot 25 \text{ kHz} = 190 \text{ MHz} = \text{signal bandwidth}$
	$7680 \cdot 25 \text{ kHz} = 192 \text{ MHz} = \text{block bandwidth}$

Downstream: OFDM Subcarriers in DOCSIS3.1



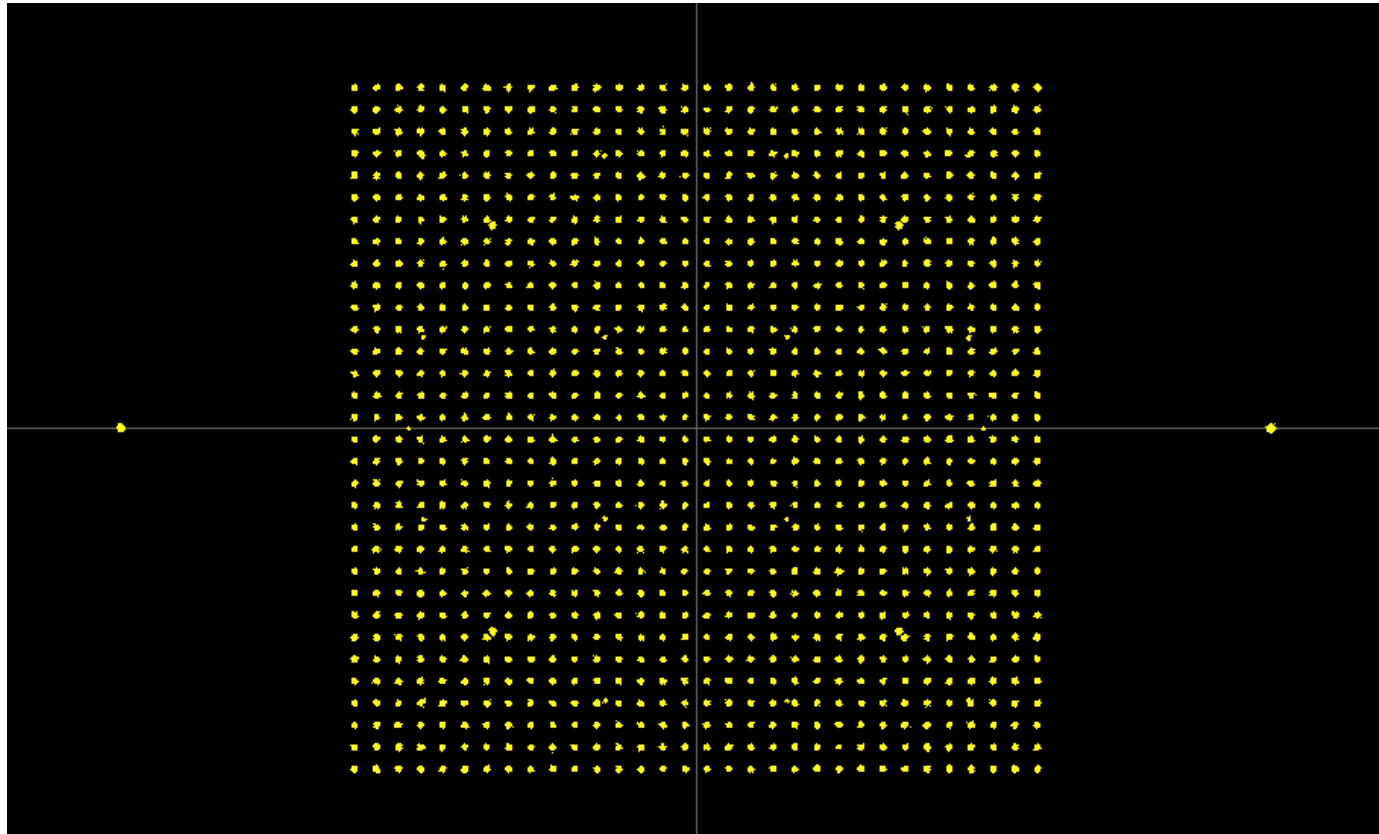
DOCSIS 3.1 Upstream Spectrum



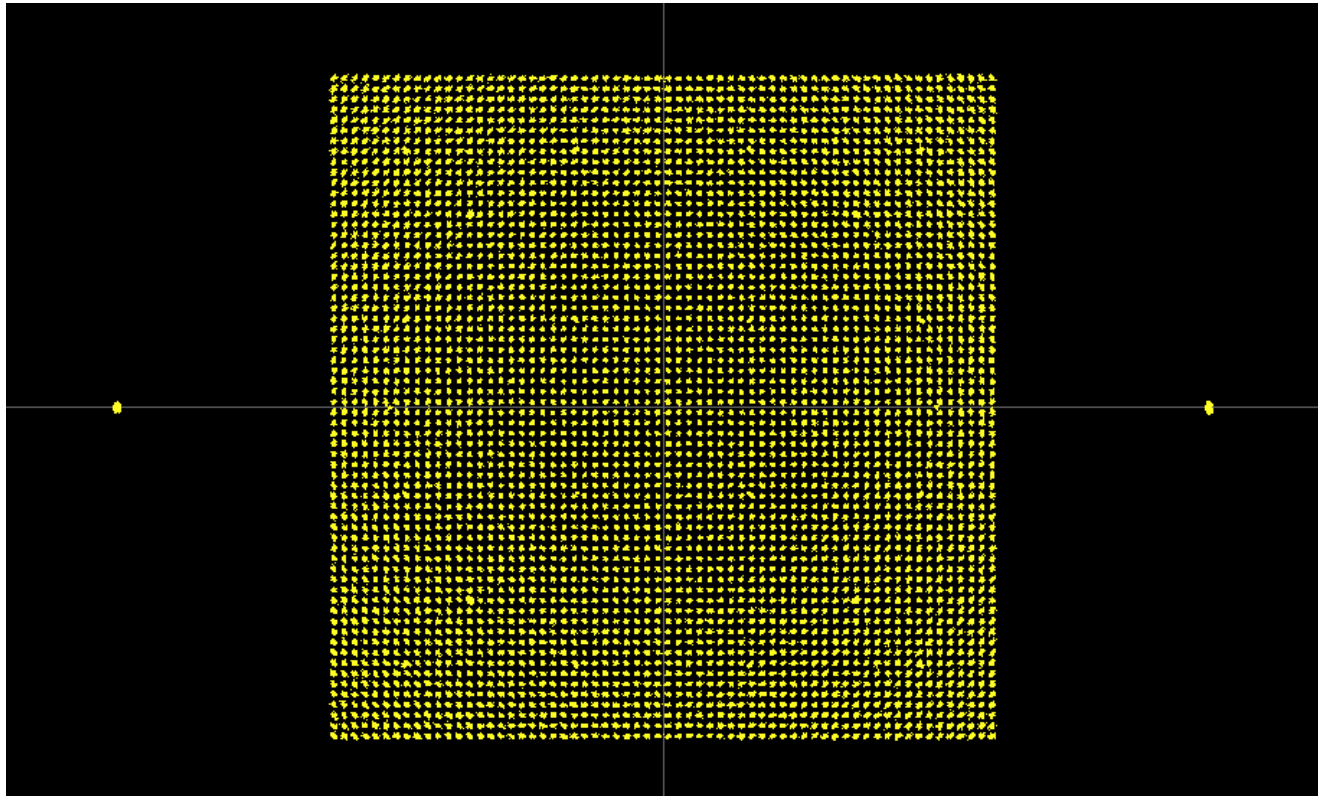
(... DOCSIS3.1 symbol duration ... 20 or 40 μ s ... OFDM, 1...5 μ s guard)



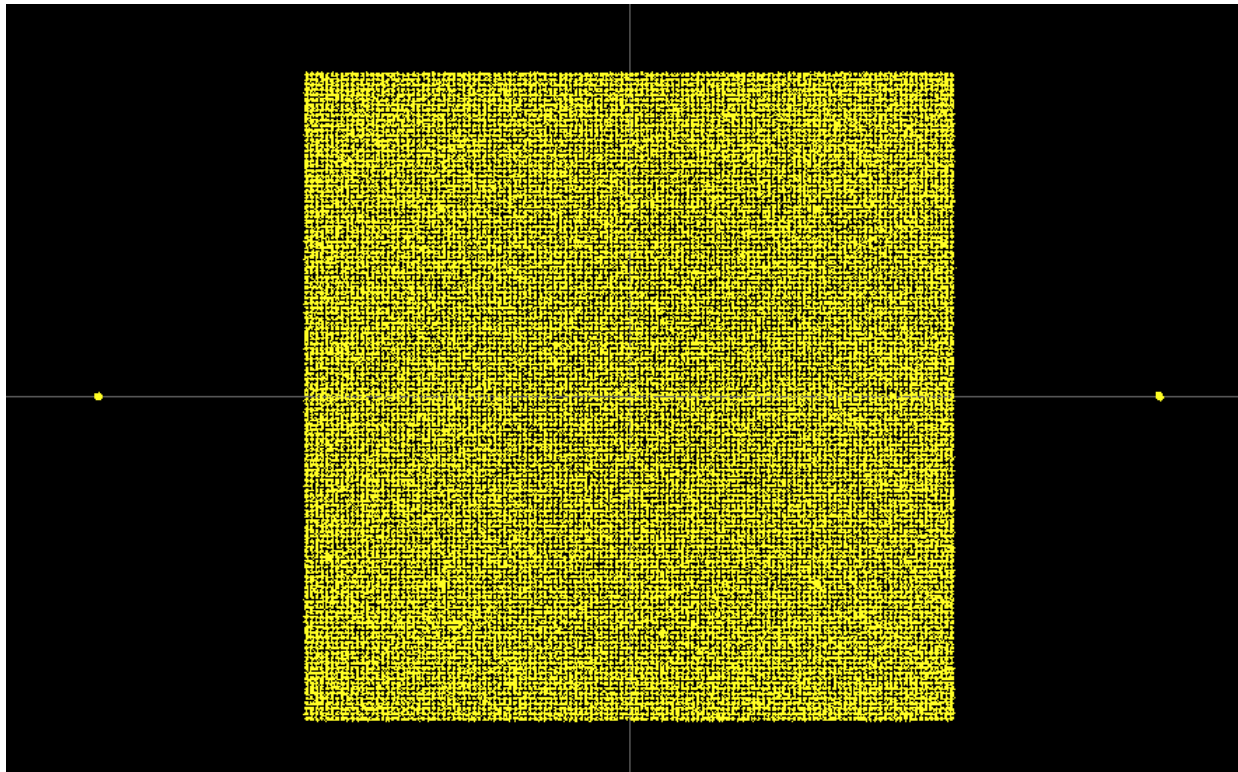
DOCSIS3.1 - 1024QAM Downstream



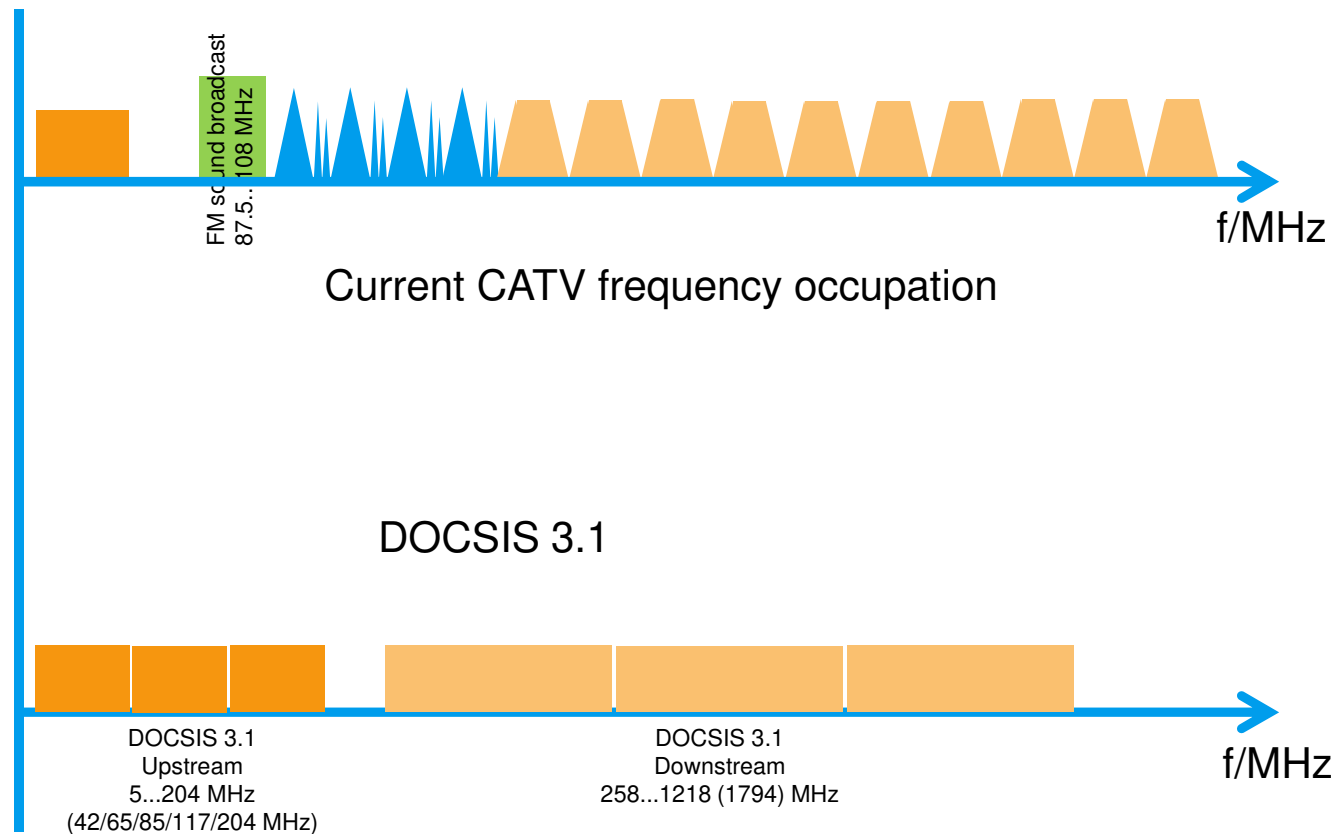
DOCSIS3.1 - 4096QAM Downstream



DOCSIS3.1 - 16384QAM Downstream



DOCSIS 3.1 Channel Occupation



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

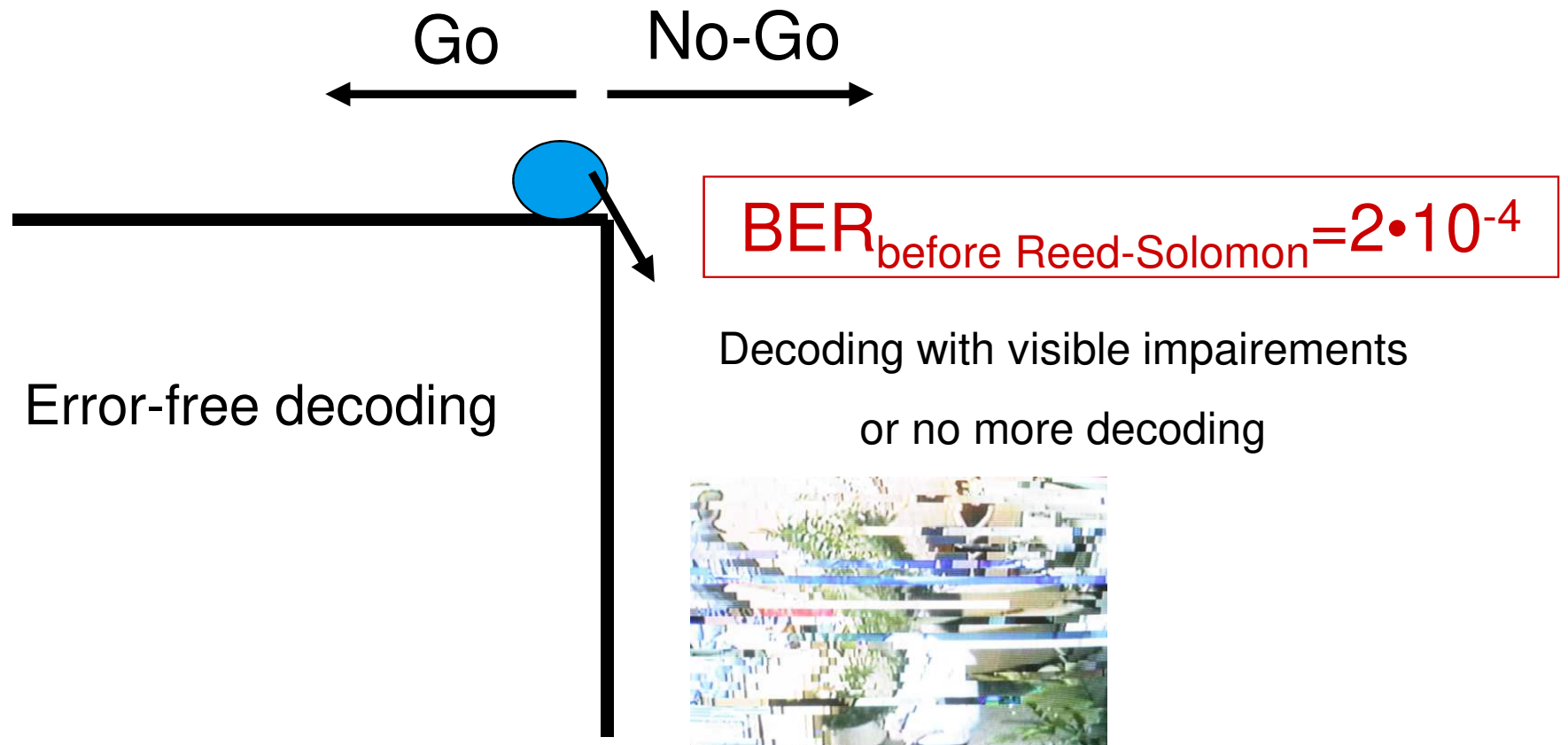
Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

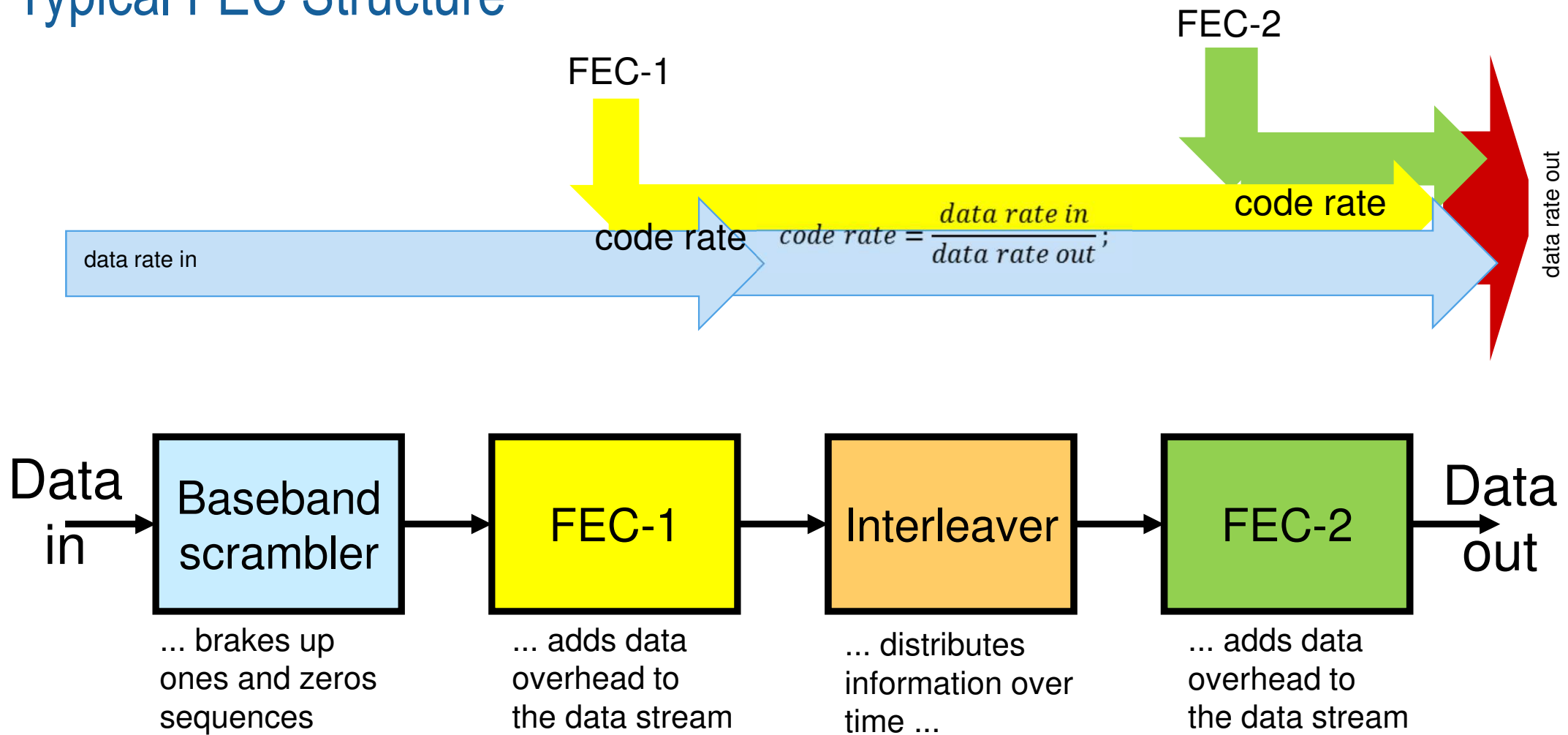
Zusammenfassung



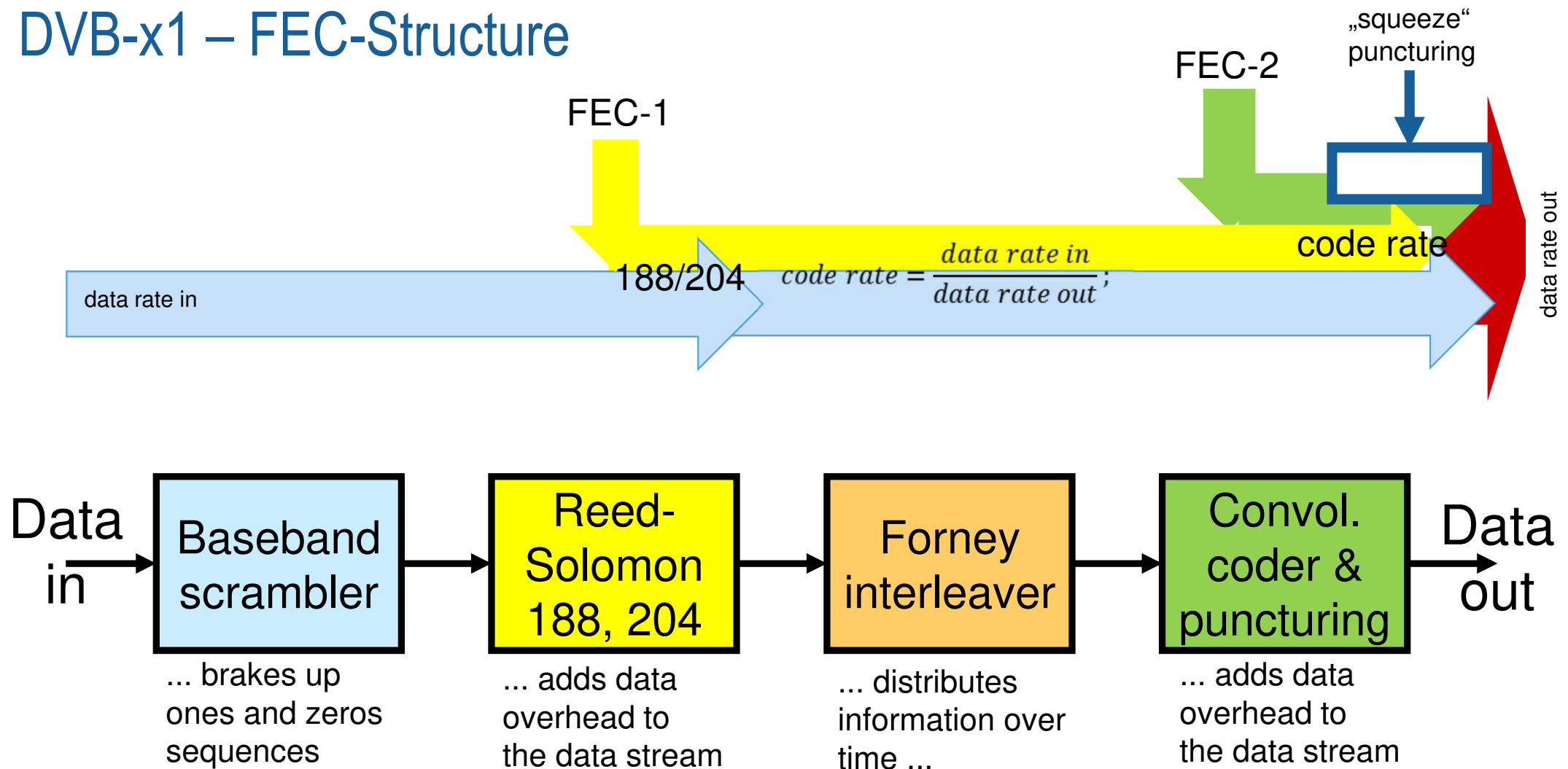
Fall-off-the-Cliff @ DVB-C/J83A



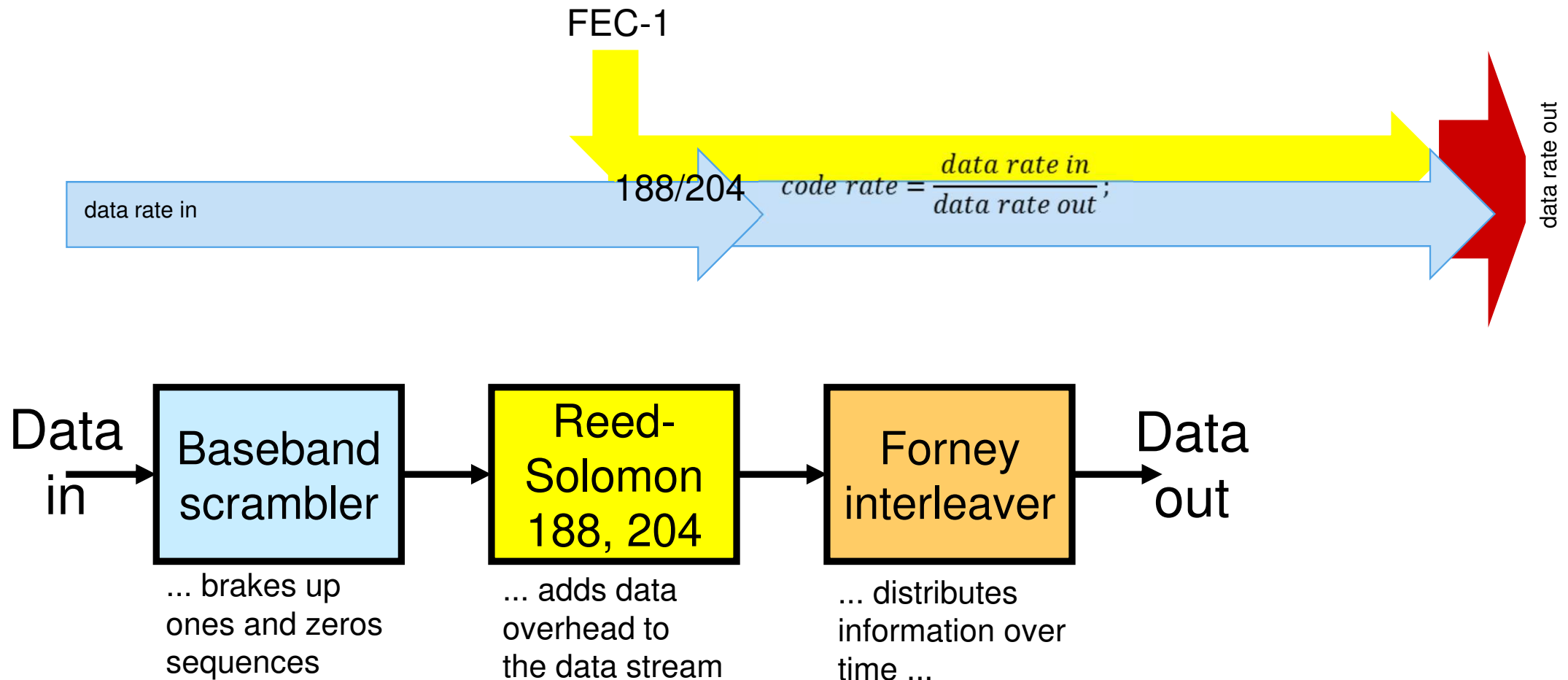
Typical FEC Structure



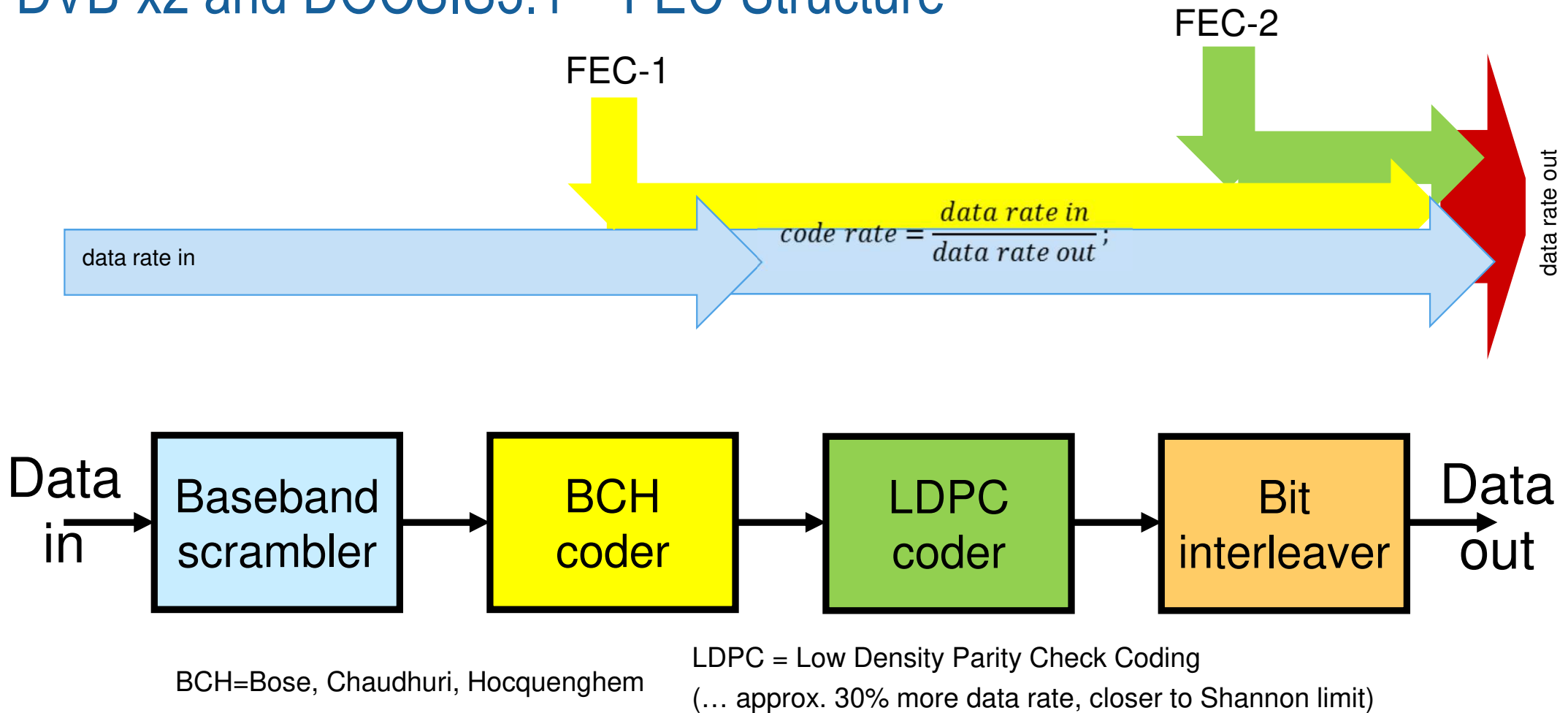
DVB-x1 – FEC-Structure



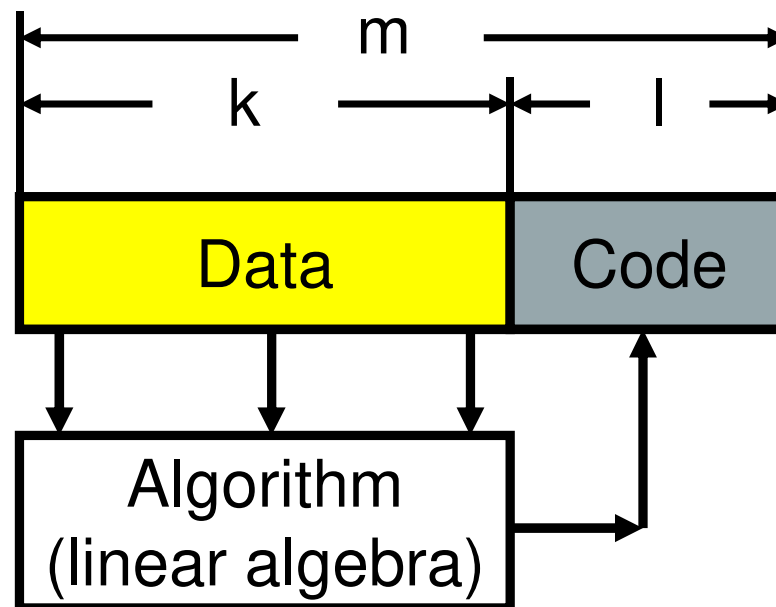
DVB-C & DOCSIS3.0 – FEC-Structure



DVB-x2 and DOCSIS3.1 – FEC-Structure



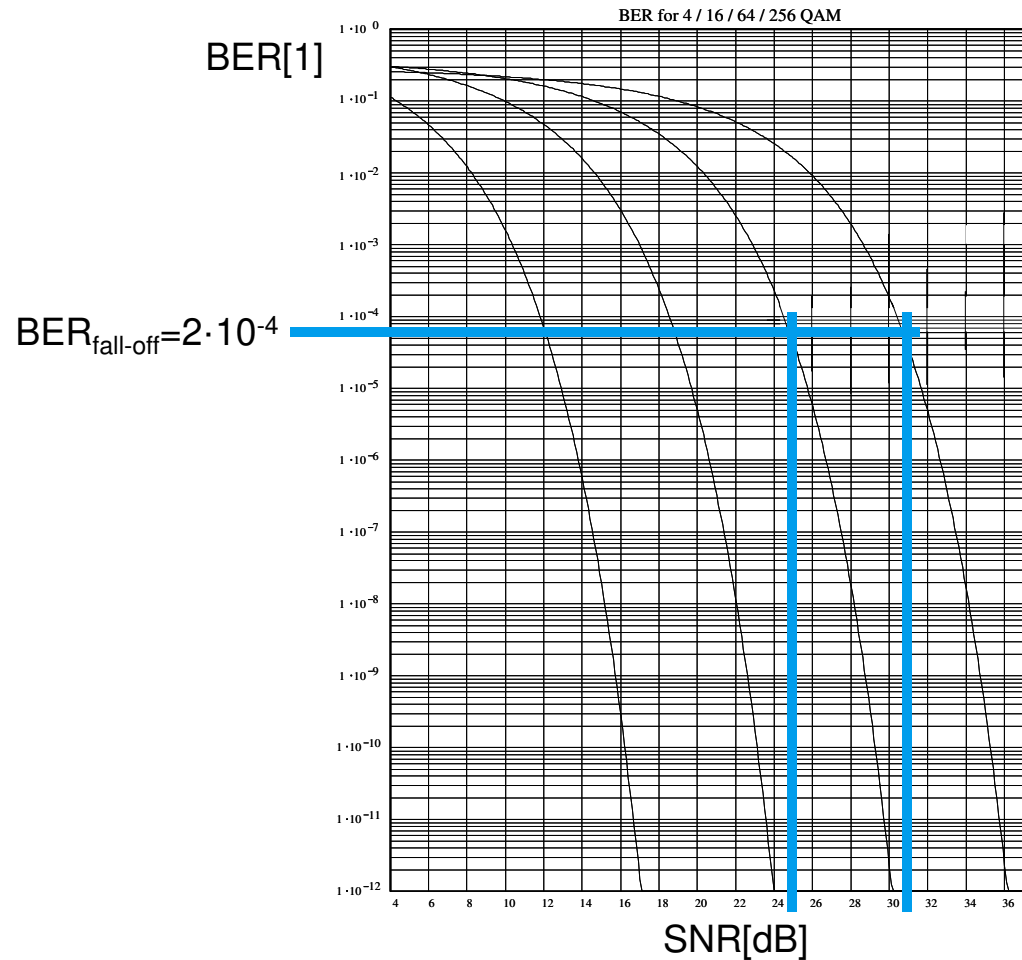
BCH and LDPC Block Code



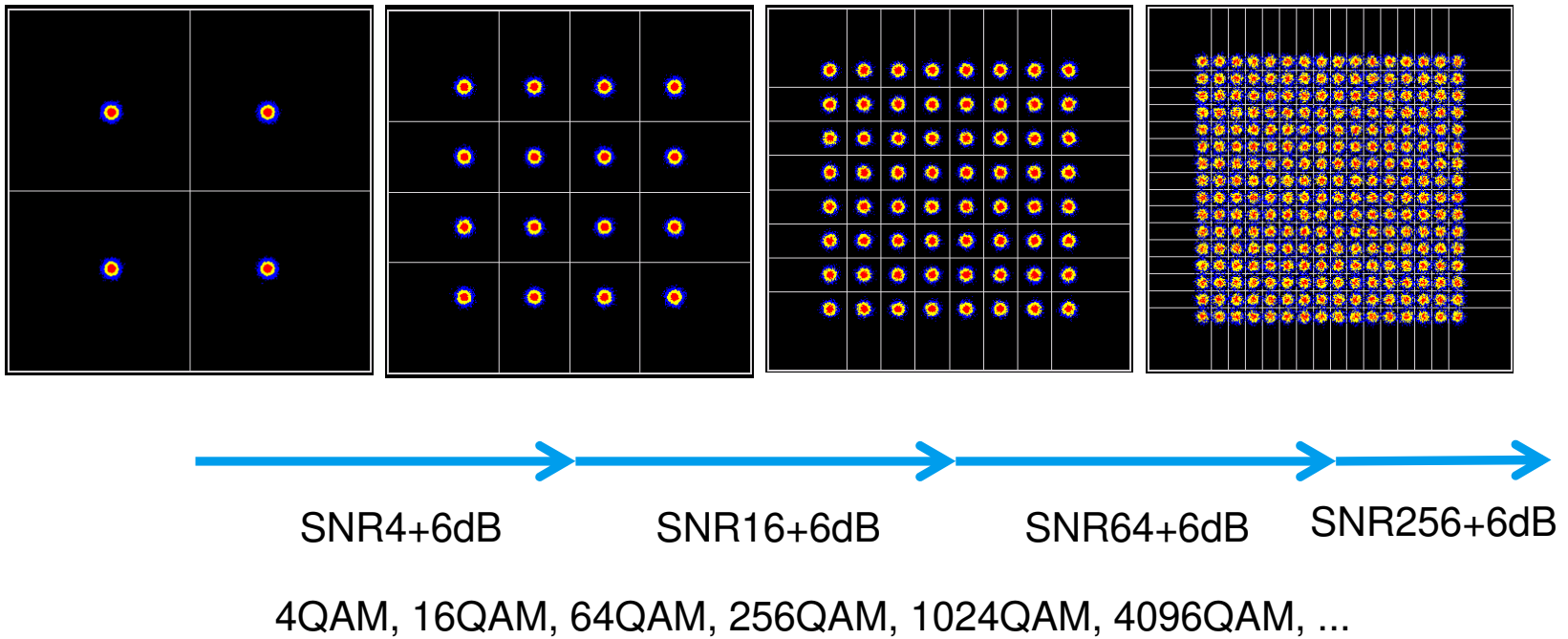
$$m = k + l$$

BCH, LDPC

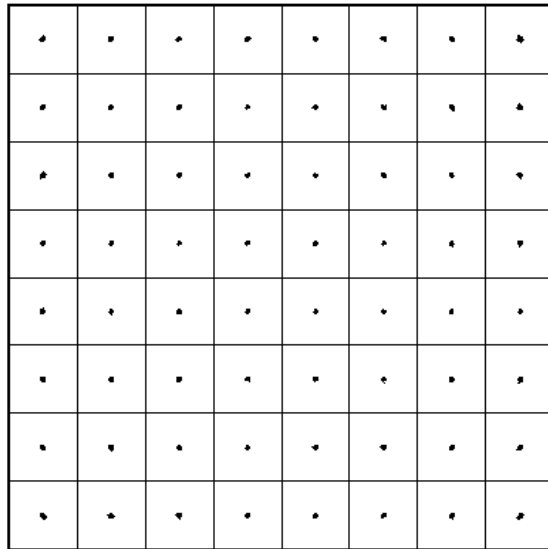
BER=f(SNR) in DVB-C/DOCSIS3.0



Required SNR(QAM Order)



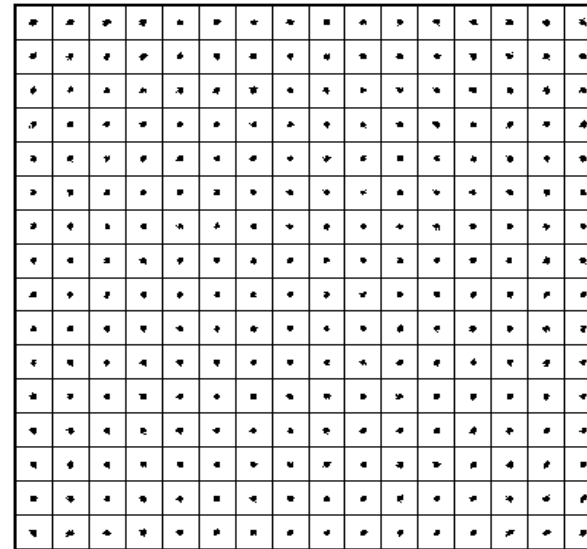
Mainly used Modulation in Cable: 64QAM, 256QAM



64QAM

$BER_{\text{fall-off}} = 2 \cdot 10^{-4}$

Fall-off-the-cliff ~ 25dB



256QAM

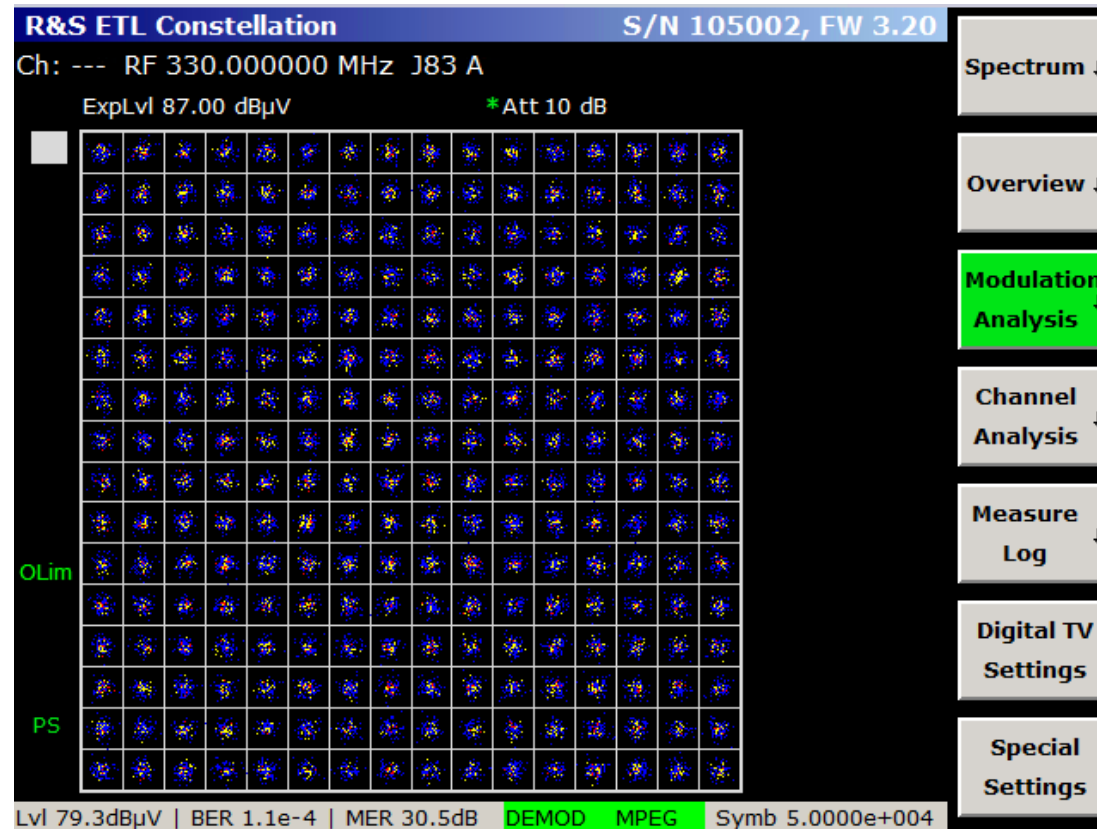
Fall-off-the-cliff ~ 31dB

$BER_{\text{fall-off}} = 2 \cdot 10^{-4}$

$SNR_{64} + 6\text{dB} = SNR_{256}$

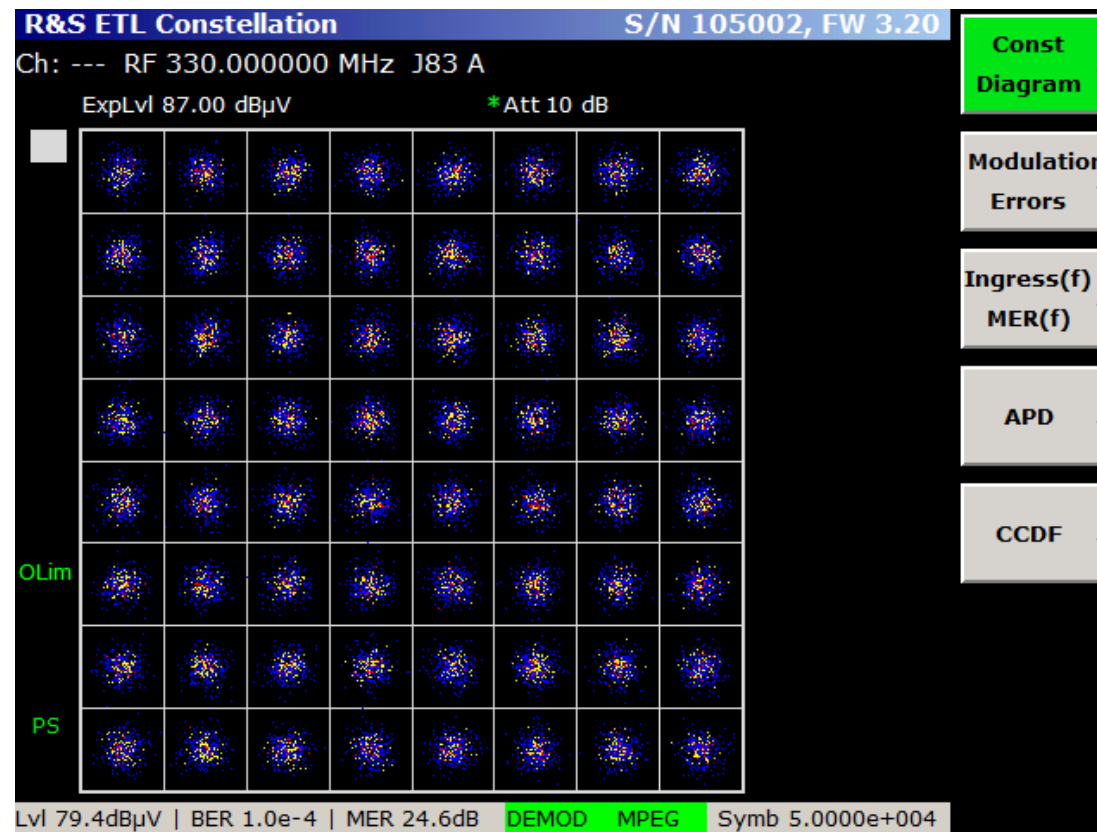
DVB-C @256QAM @Fall-off-the-Cliff

256QAM
MER=30.4dB
BER=1.1·10⁻⁴

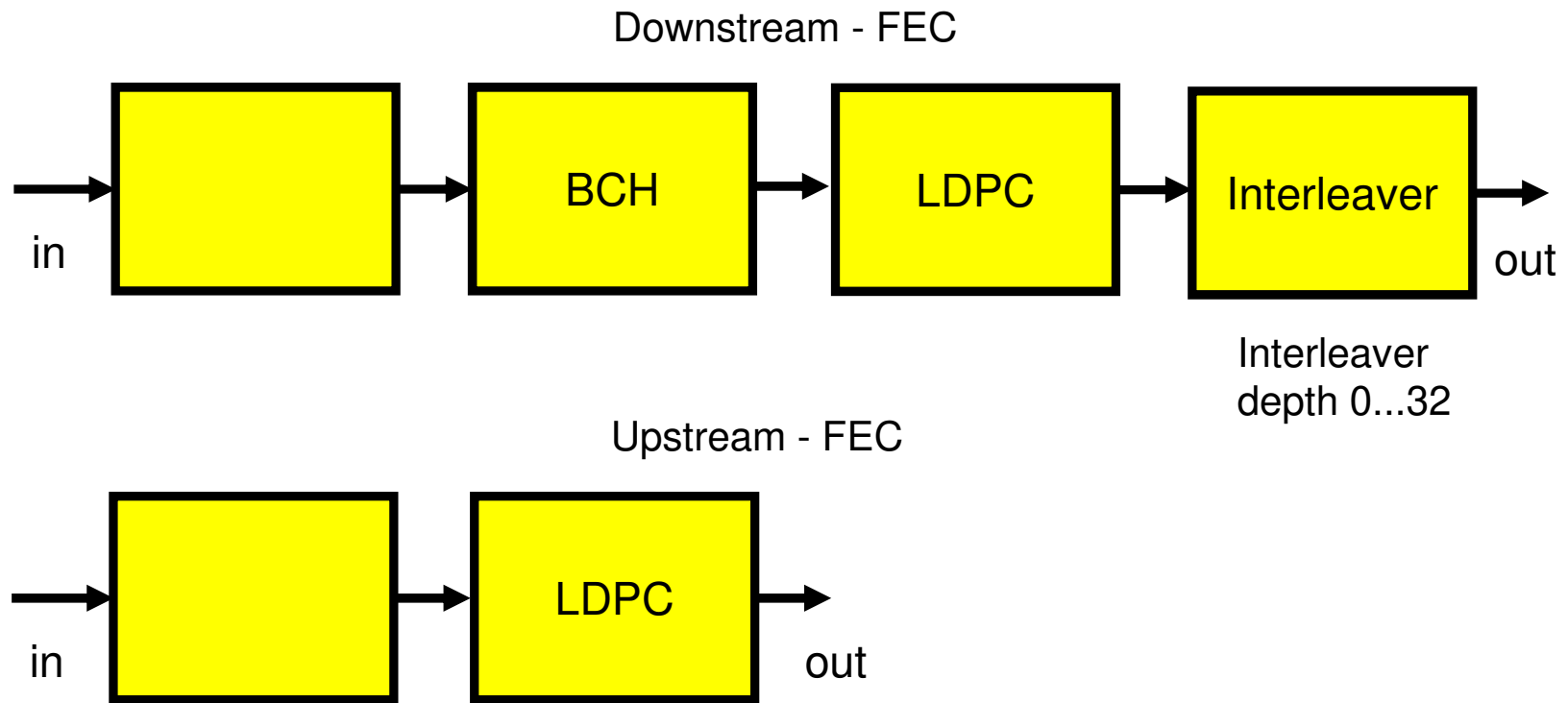


DVB-C @64QAM @Fall-off-the-Cliff

64QAM
MER=24.6dB
BER=1.1·10⁻⁴



DOCSIS 3.1 FEC – Forward Error Correction



DOCSIS 3.1 Modulation Parameter

LDPC
+
BCH
31dB@DVB-C
= - 4dB gain



Modulation mode downstream	min CNR (AWGN) (... 1GHz)	min CNR (AWGN) (...1.2GHz)
16QAM	15.0 dB	15.0 dB
64QAM	21.0 dB	21.0 dB
128QAM	24.0 dB	24.0 dB
256QAM	27.0 dB	27.0 dB
512QAM	30.5 dB	30.5 dB
1024QAM	34.0 dB	34.0 dB
2048QAM	37.0 dB	37.5 dB
4096QAM	41.0 dB	41.5 dB
8192QAM		
16384QAM		



Modulation mode upstream	min CNR (AWGN)
QPSK	11.0 dB
8QAM	14.0 dB
16QAM	17.0 dB
32QAM	20.0 dB
64QAM	23.0 dB
128QAM	26.0 dB
256QAM	29.0 dB
512QAM	32.5 dB
1024QAM	35.5 dB
2048QAM	39.0 dB
4096QAM	43.0 dB

only LDPC
no BCH



$\Delta=+2\text{dB}$ rel. DS



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

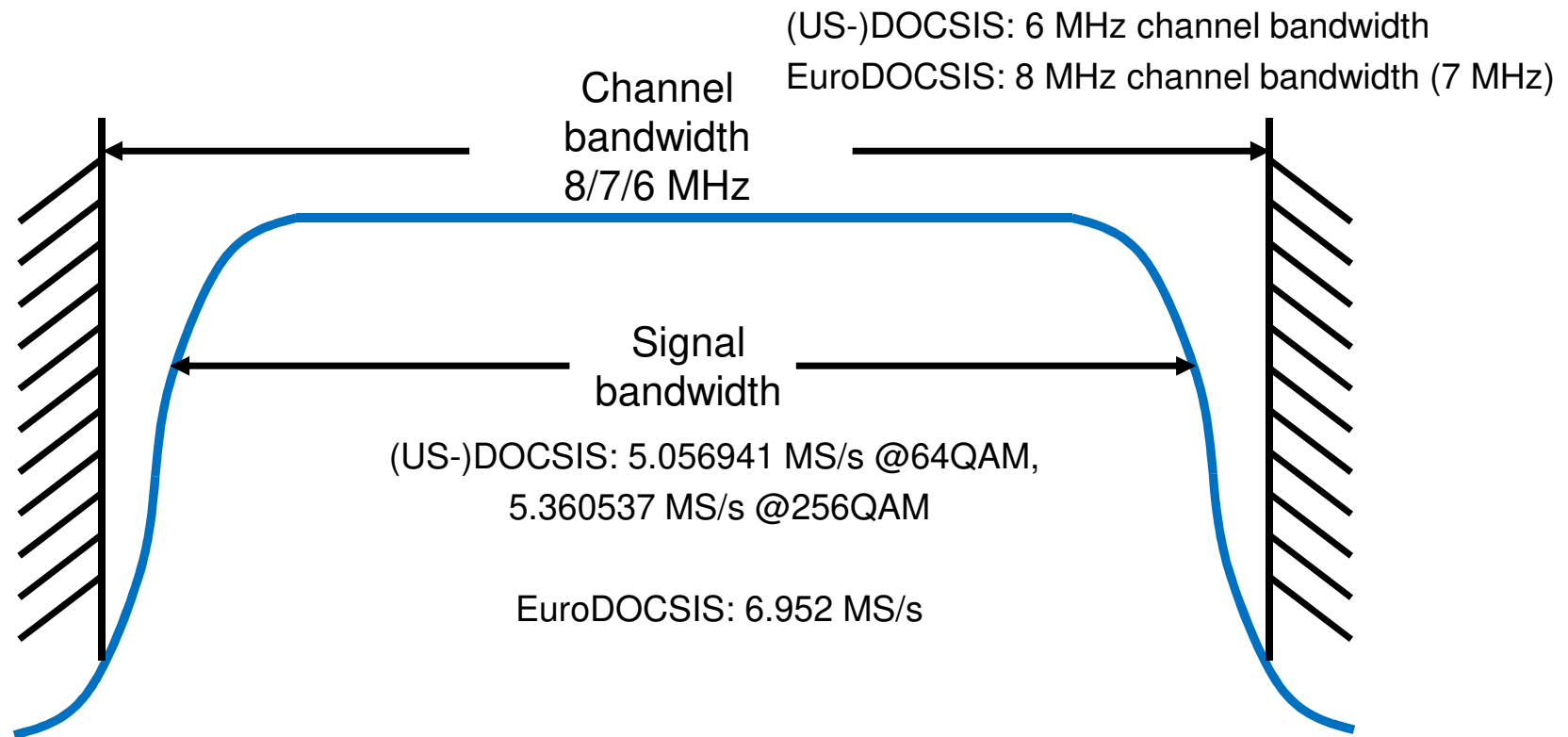
Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

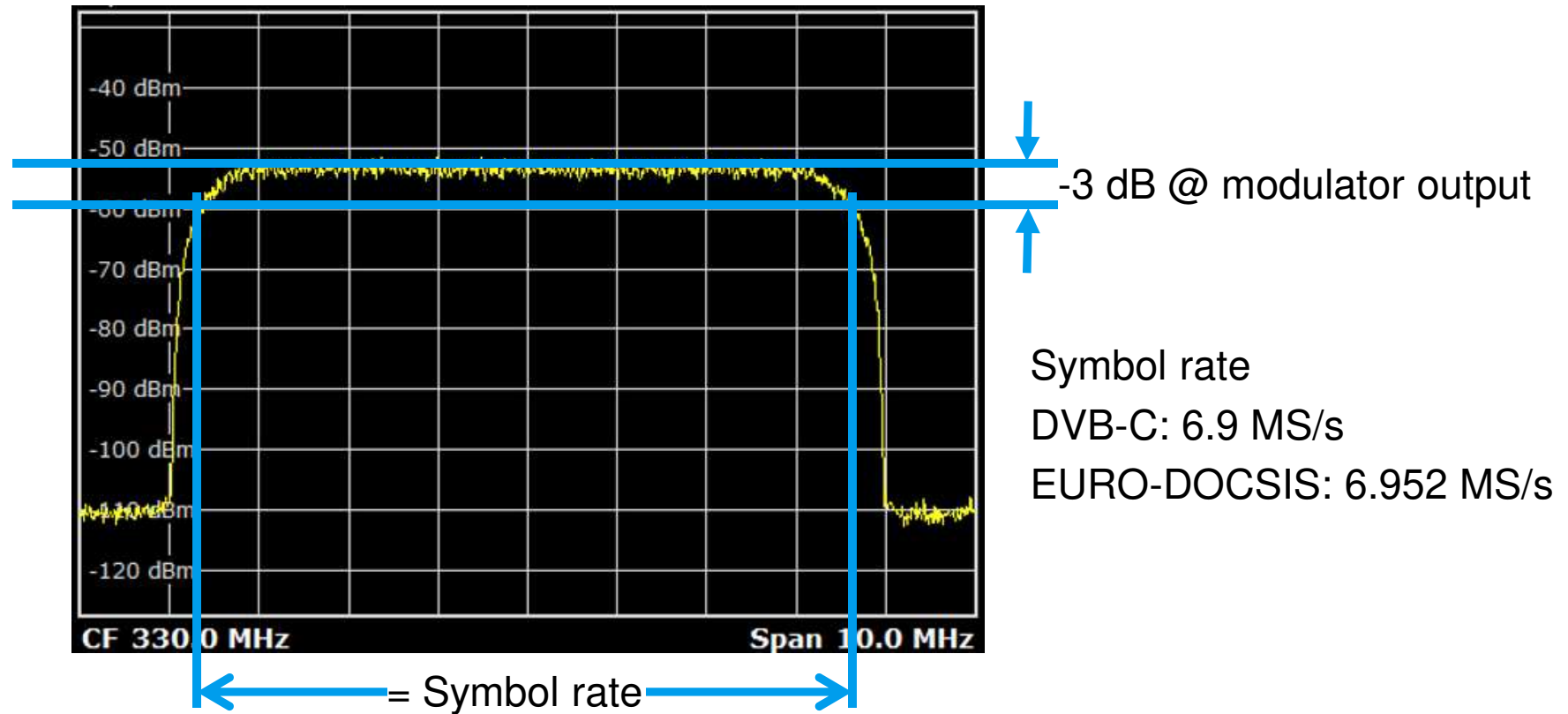
Zusammenfassung



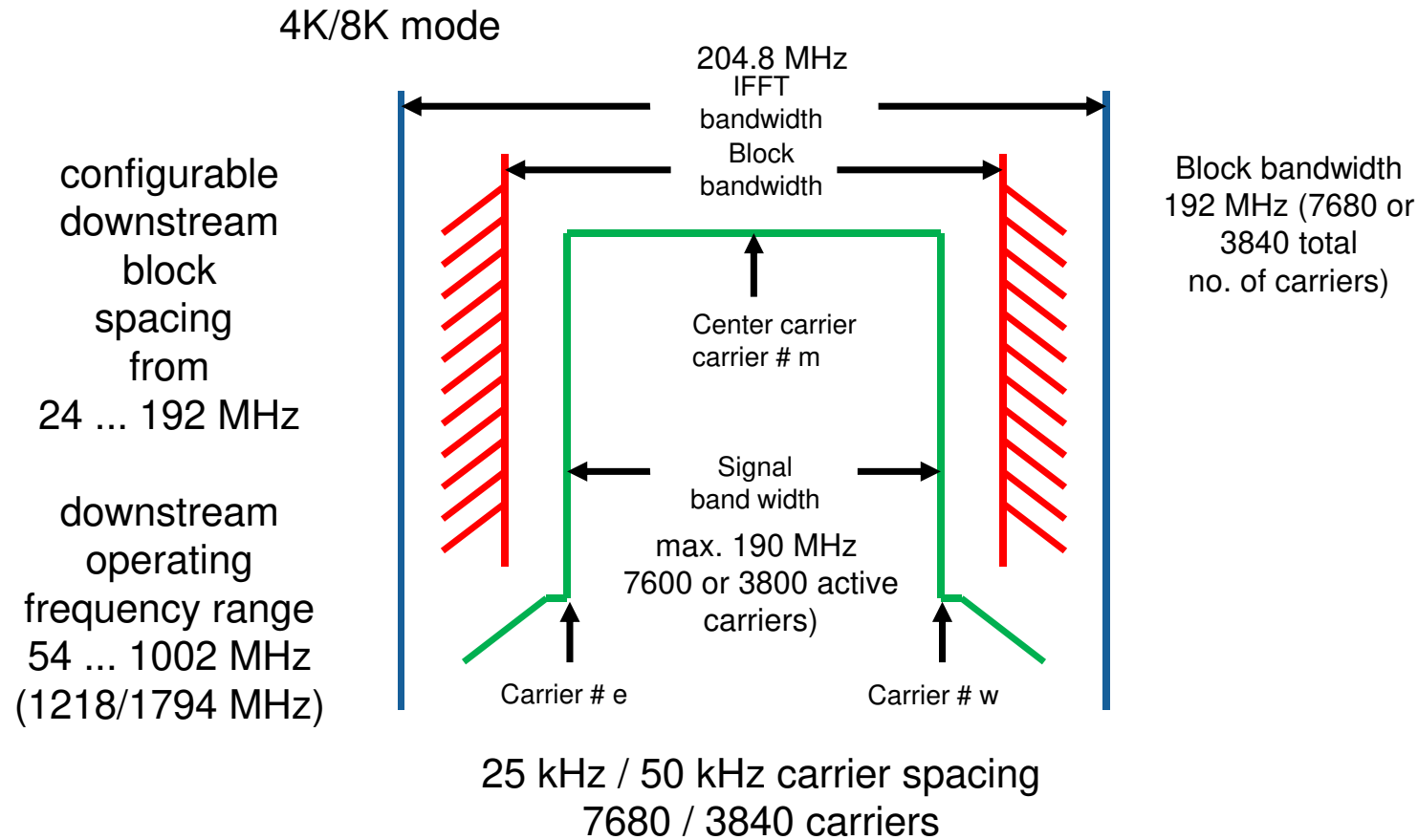
CATV Channel (DVB-C, J83A, B, C, DOCSIS-Downstream)



DVB-C-Spectrum ($r=0.15$, $SR=6.9$ MS/s)



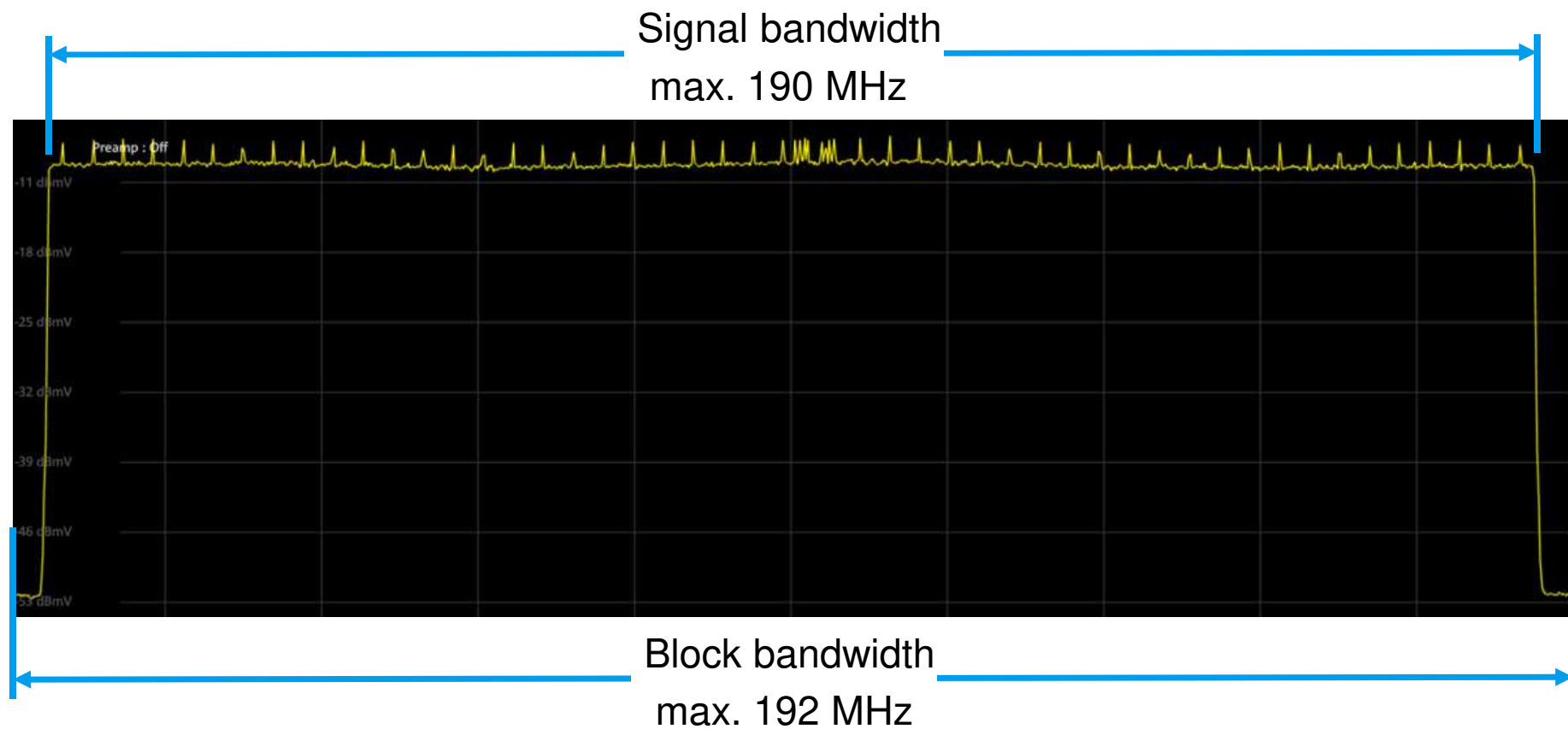
DOCSIS 3.1 Downstream Spectrum



(... DOCSIS3.1 symbol duration ... 20 or 40 μ s ... OFDM, 1...5 μ s guard)



DOCSIS3.1 Downstream Spectrum



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

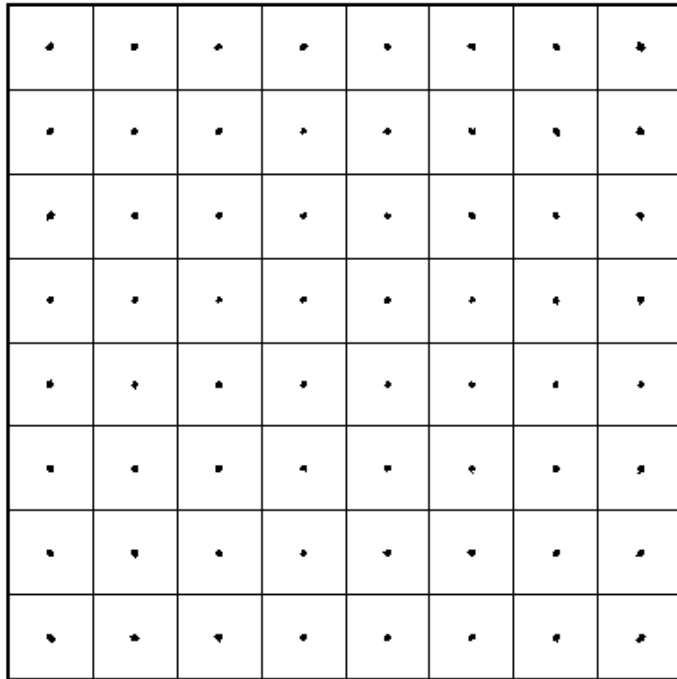
Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

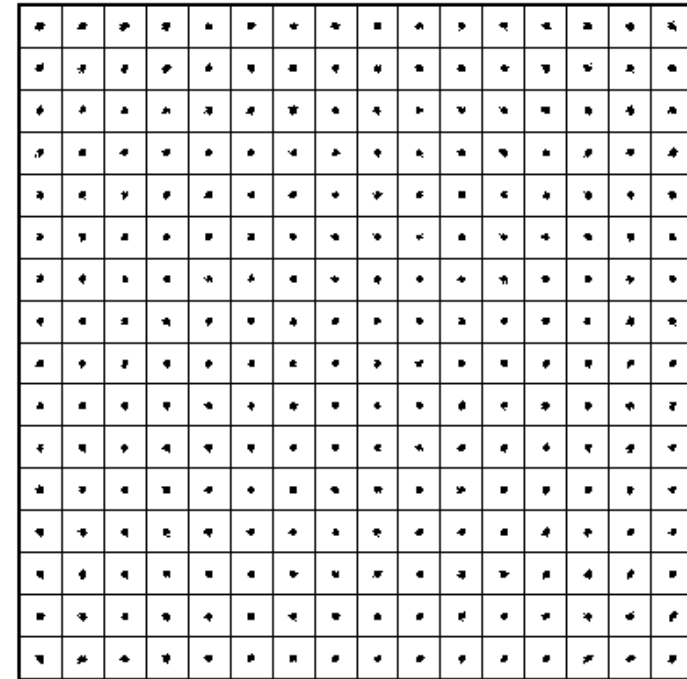
Zusammenfassung



DVB-C (J83A) Constellation Diagram (EuroDOCSIS)



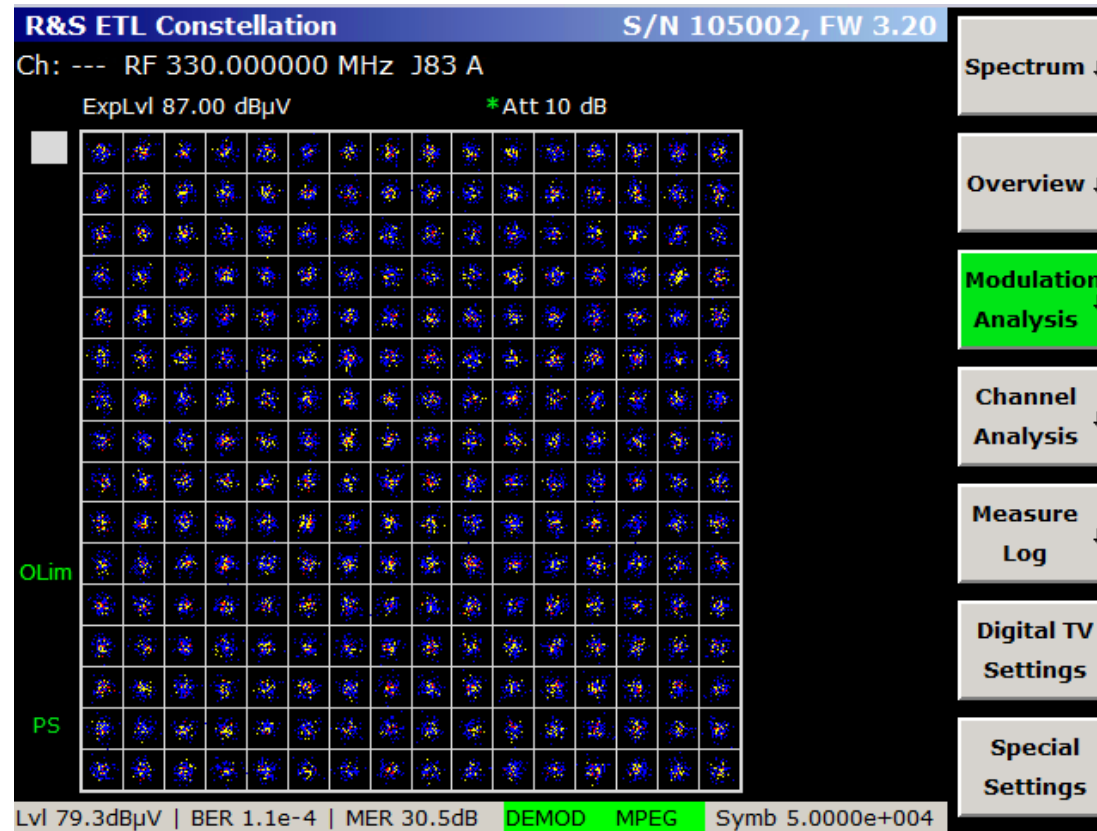
64QAM, SR = 6.952 MS/s, $r=0.15$
 Gross data rate = $6.952 \text{ MS/s} \cdot 6 \text{ bit/symbol} =$
 $41.712 \text{ Mbit/s};$
 Net data rate = $188/204 \cdot 41.712 \text{ Mbit/s} = 38.44 \text{ Mbit/s};$



256QAM, SR = 6.952 MS/s, $r = 0.15$
 Gross data rate = $6.952 \text{ MS/s} \cdot 8 \text{ bit/symbol} =$
 $55.616 \text{ Mbit/s};$
 Net data rate = $188/204 \cdot 55.616 \text{ Mbit/s} = 51.25 \text{ Mbit/s};$

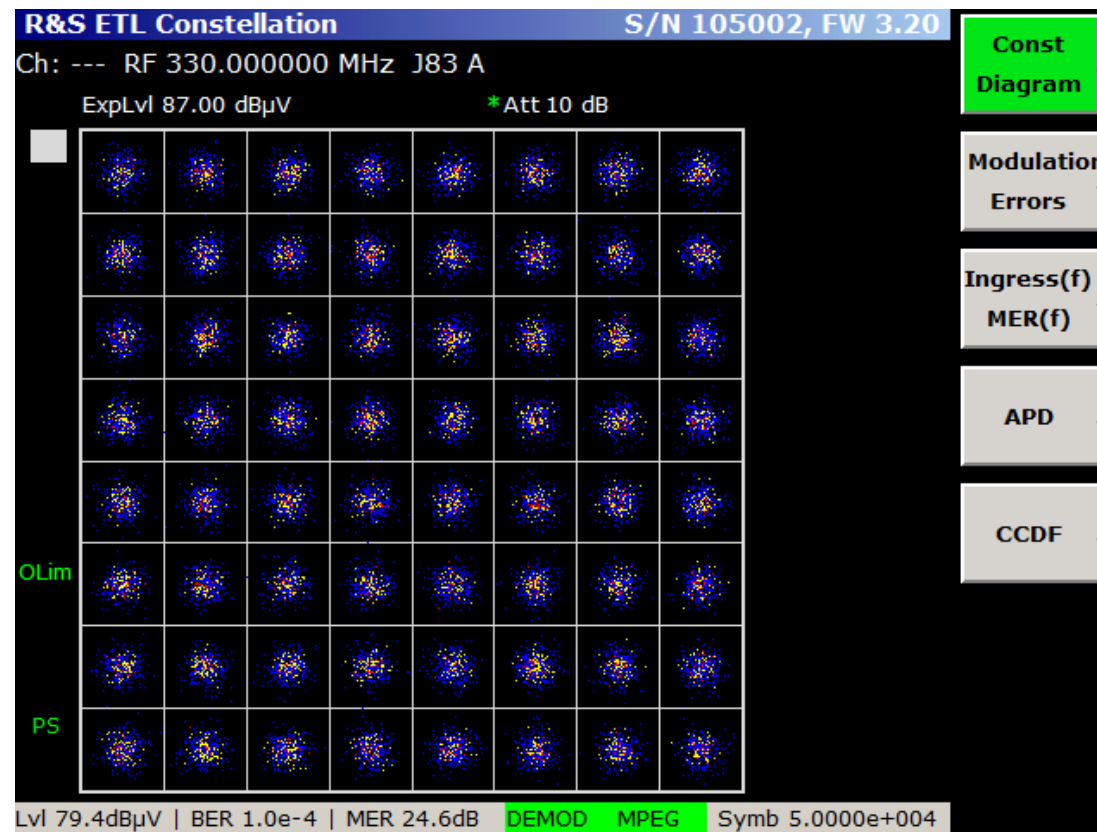
DVB-C @256QAM @Fall-off-the-Cliff

256QAM
MER=30.4dB
BER=1.1·10⁻⁴

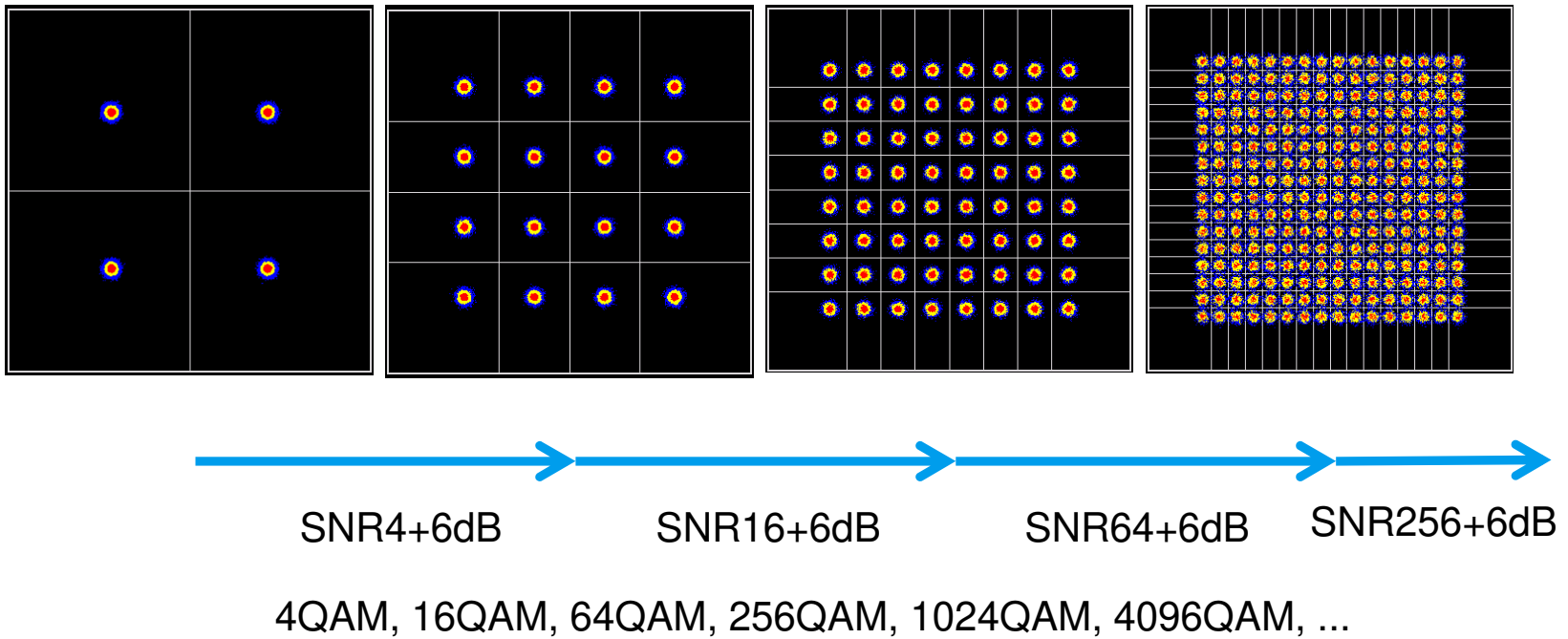


DVB-C @64QAM @Fall-off-the-Cliff

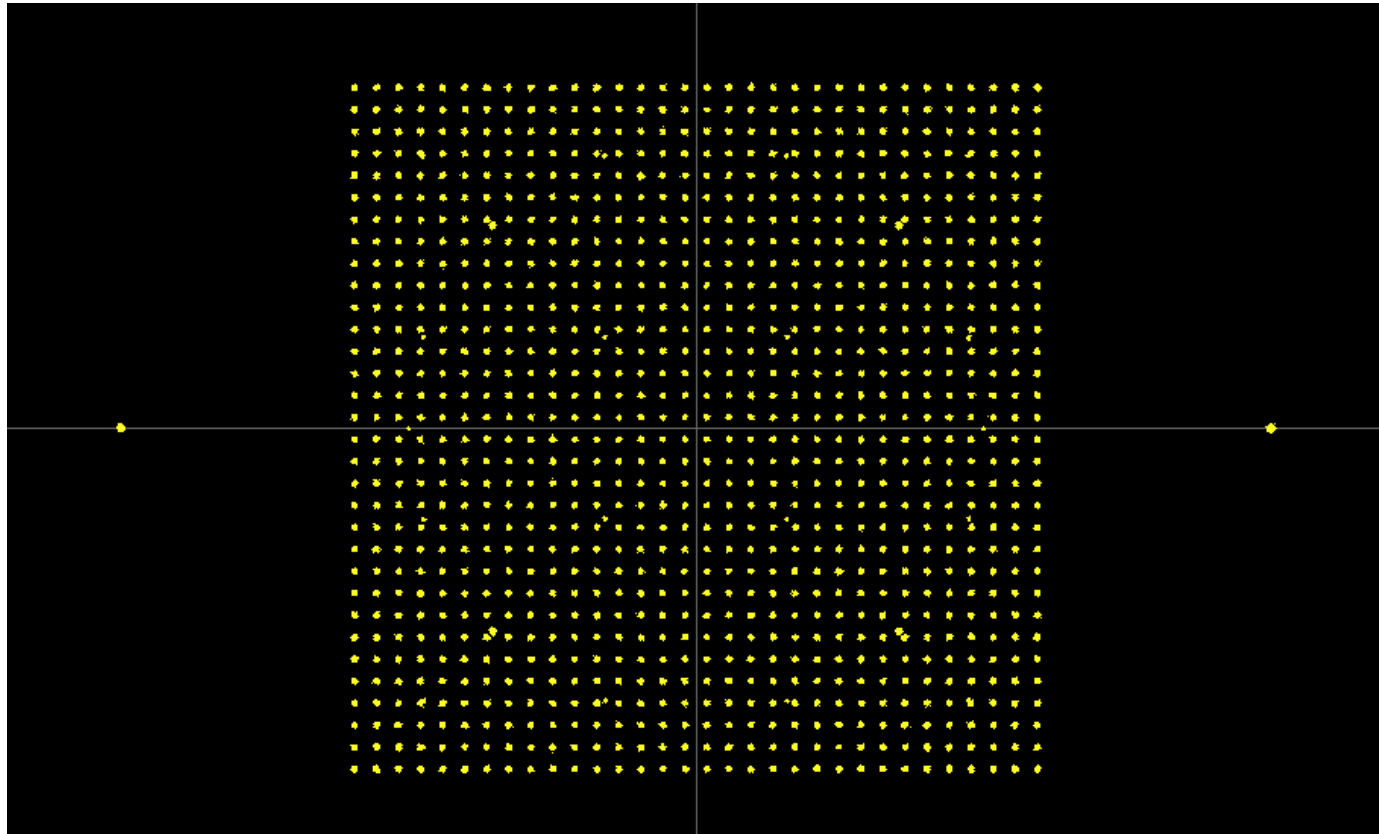
64QAM
MER=24.6dB
BER=1.1·10⁻⁴



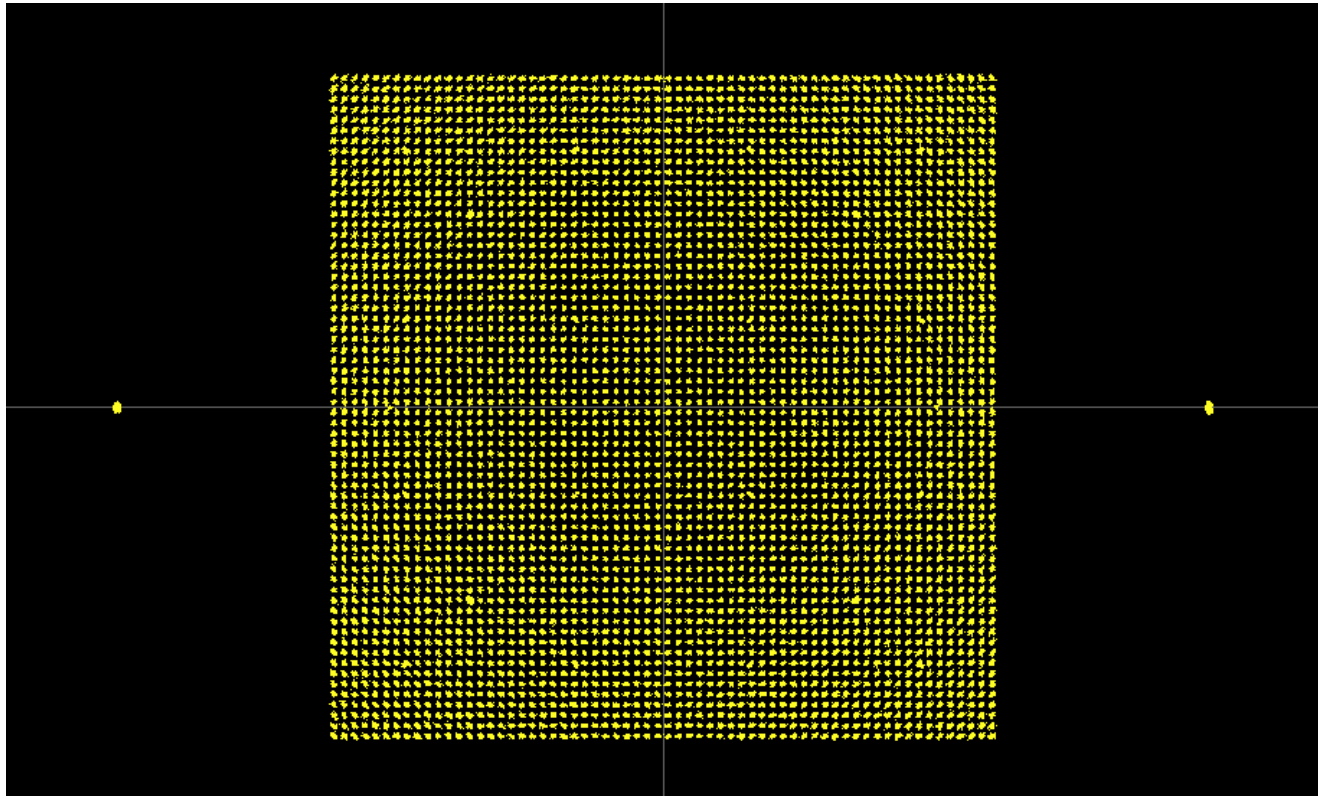
Required SNR(QAM Order)



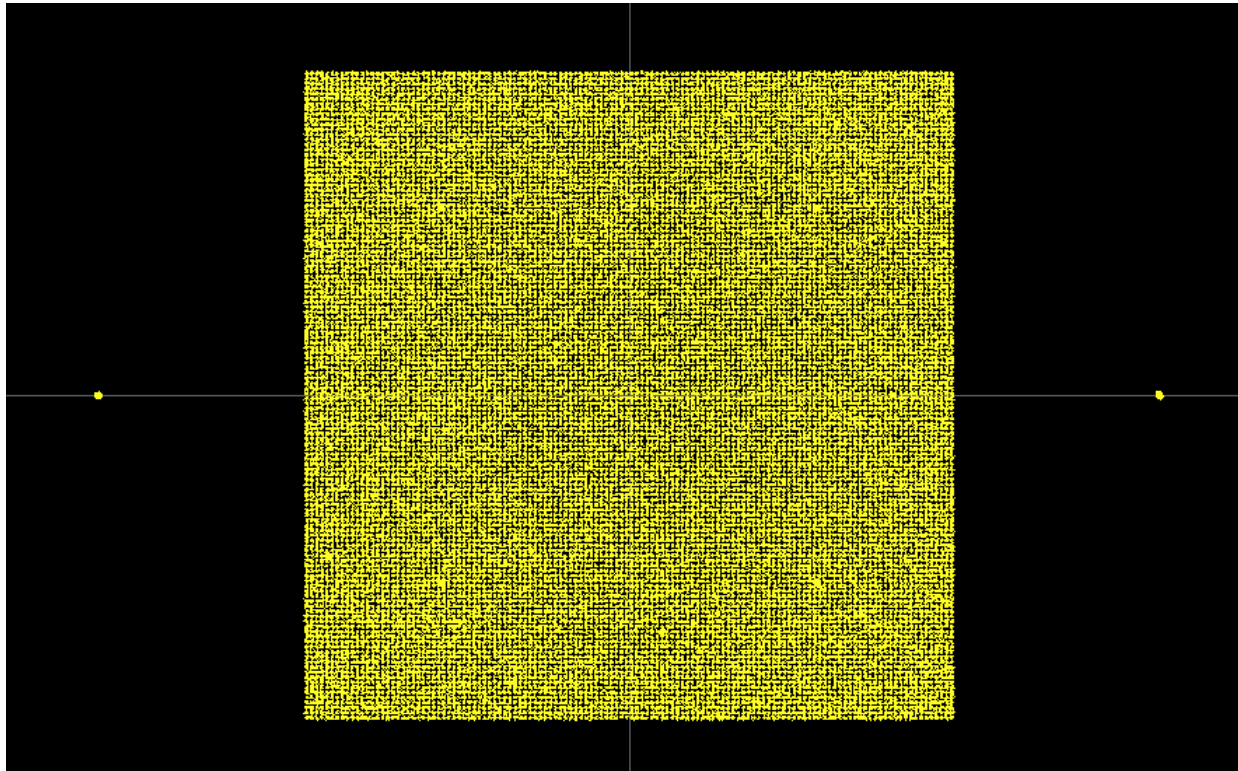
DOCSIS3.1 - 1024QAM Downstream



DOCSIS3.1 - 4096QAM Downstream



DOCSIS3.1 - 16384QAM Downstream



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

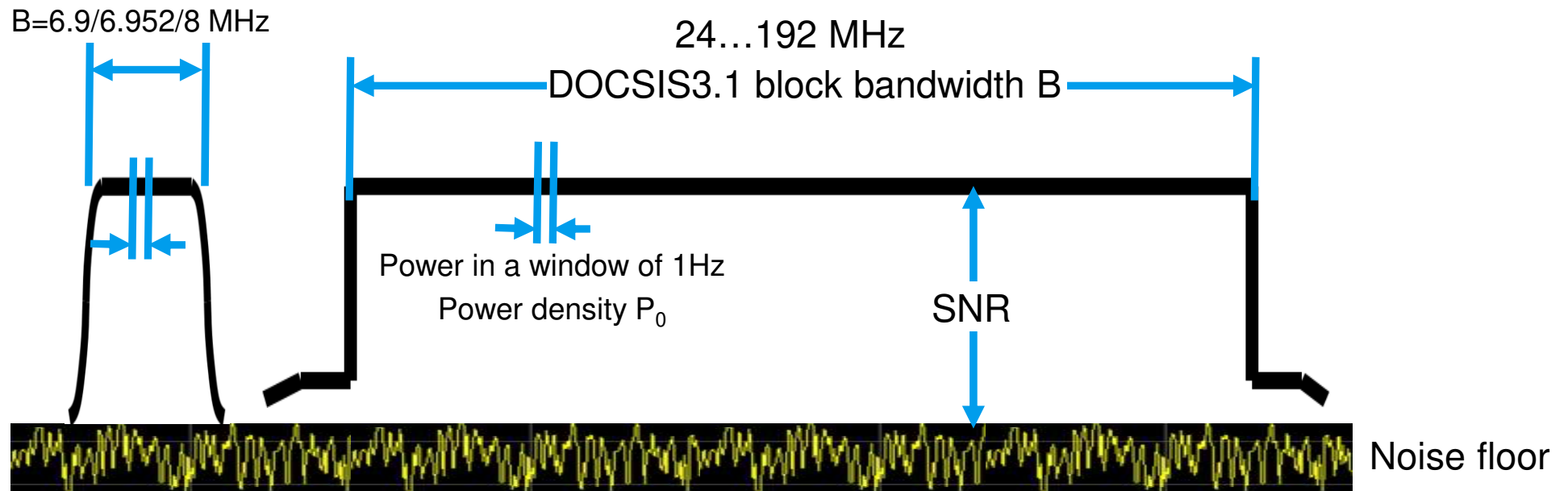
Messparameter

Zusammenfassung



Channel Power and Power Density

DOCSIS3.1 SNR gain of ~4dB in DS (BCH+LDPC)
DOCSIS3.1 SNR gain of ~2dB in US (LDPC)

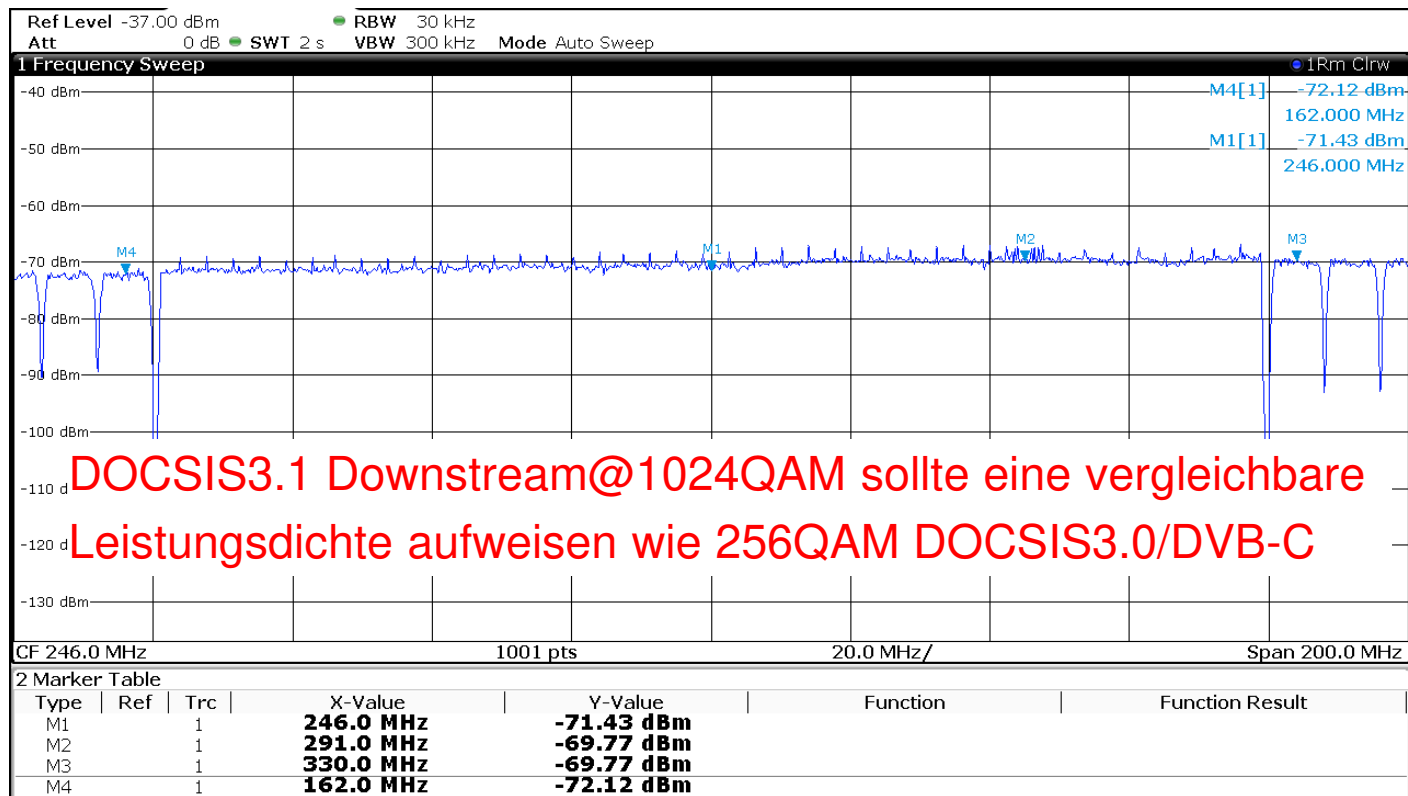


$$\text{Channel power} = P_0[\text{dBm/Hz}] + 10 \log(B[\text{Hz}]);$$

„Leistungsdichte“

Comparable physical parameters between DOCSIS3.0 and DOCSIS3.1: power density P_0

Example CATV Spectrum including DOCSIS3.1



Messung der Leistung bei DOCSIS3.1 und DOCSIS3.0

DOCSIS3.0

Messung der Leistung
in einer Bandbreite
entsprechend
der Symbolrate
(6.9 ... 6.952 MHz)

DOCSIS3.1

Messung der Leistung

- in 6 MHz Bandbreite
- in der vollen Kanalbandbreite (190 MHz)
- (in 8 MHz Bandbreite ?)
- Leistungsdichte in dBm/Hz



DOCSIS3.1 Messungen



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

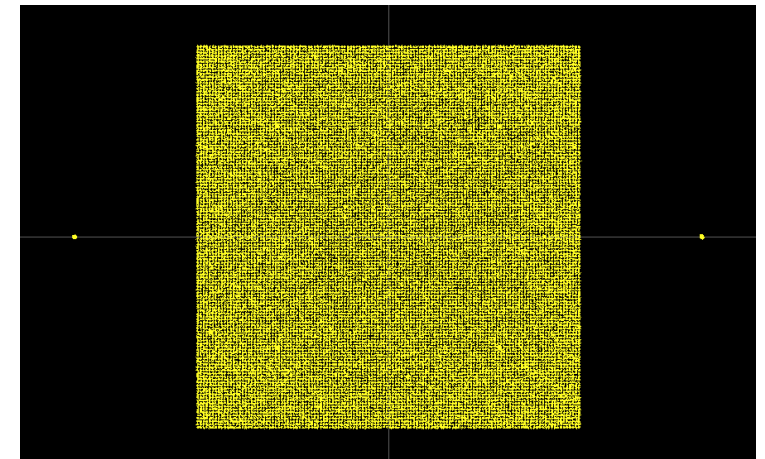
Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

Zusammenfassung



DOCSIS3.1 Measurement Technology ...



CLGD ... Simulating Multichannel CATV Load

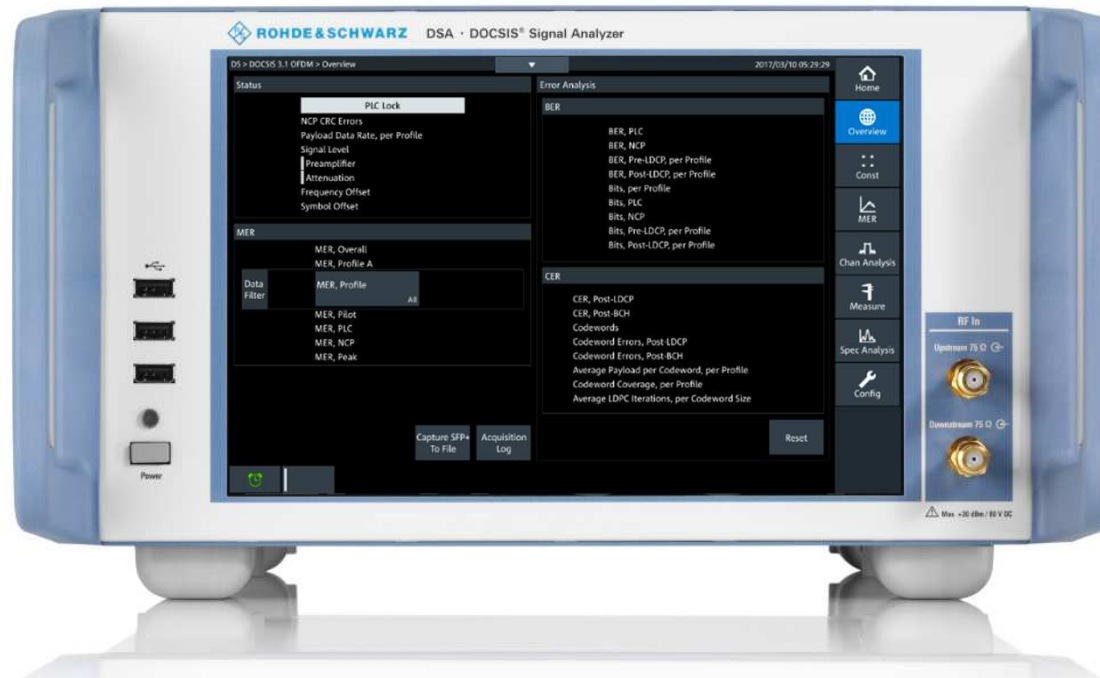
ATV
DVB-C
DOCSIS



/3.1/ARB Generator

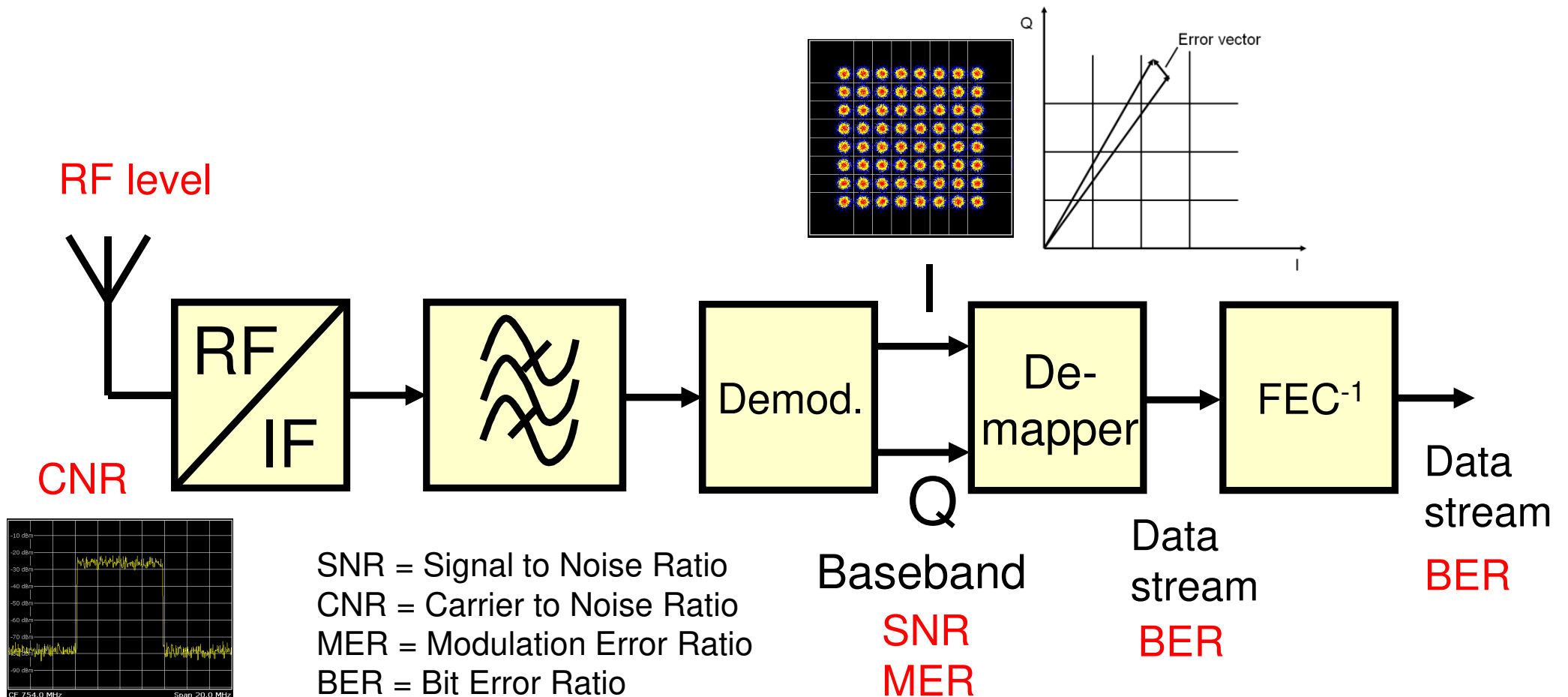


R&S DSA – DOCSIS Signal Analyzer



DVB-C
J83A, B, C
DOCSIS
EuroDOCSIS
DOCSIS3.1

DOCSIS1.0...3.0 Downstream Measurement Parameter



Terms CNR, SNR, MER, BER

The **CNR** is the carrier to noise ratio that means the relation between the wanted carrier signal („Carrier“) and the unwanted interferers (typically so-called „white noise“, AWGN = Additive White Gaussian Noise), measured in the RF channel.

That means the CNR is a measurement parameter at the receiver input (or transmitter output).

The **SNR** is the distance between the wanted demodulated LF signal (LF = Low Frequency, e.g. audio) and the unwanted noise.

That means the SNR = Signal to Noise Ratio is a measurement parameter inside the receiver.

During a data transmission bit errors will happen caused by interferers at the transmission link.

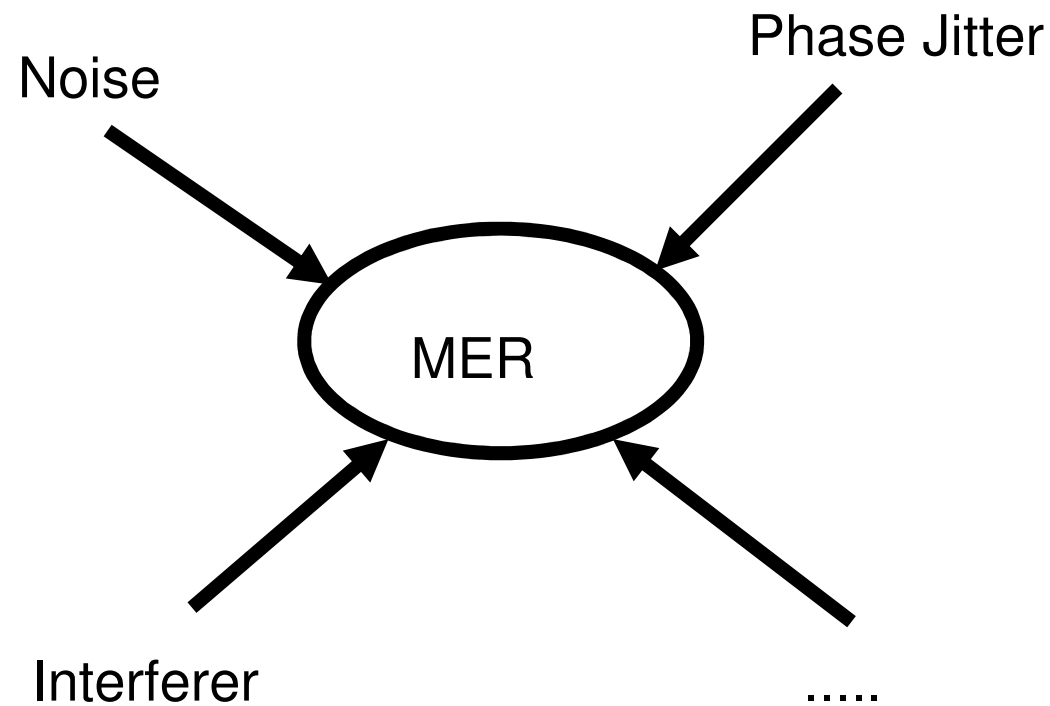
Bit errors are a function of the CNR and SNR. The bit error ratio **BER** represents the the relation between the bit errors and the transmitted bits.

In digital modulation the so-called **MER** (Modulation Error Ratio) describes the „modulation quality“ of a digital modulated carrier. In mobile communication instead of the MER the EVM = Error Vector Magnitude is in use.

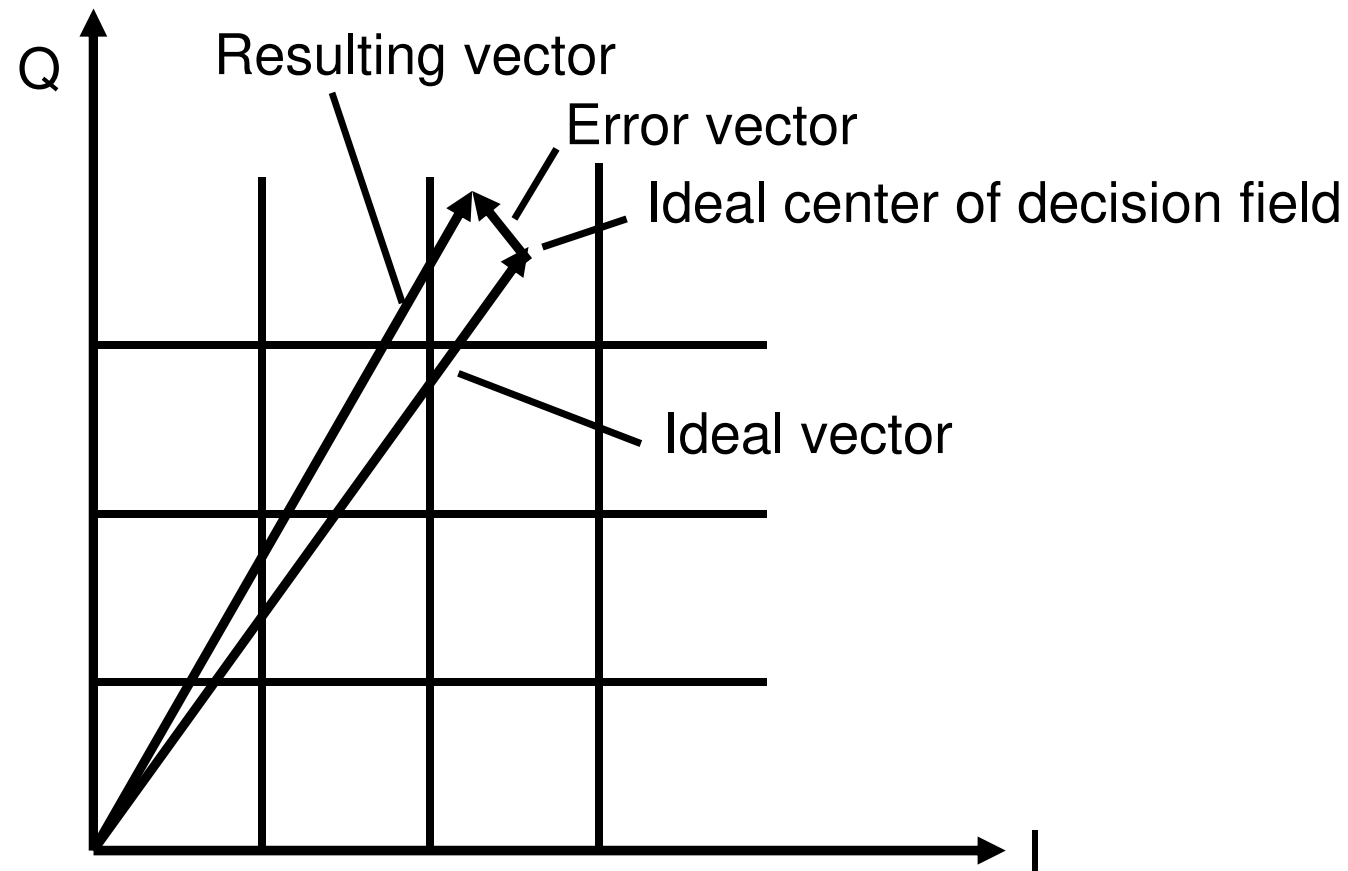


MER – Modulation Error Ratio

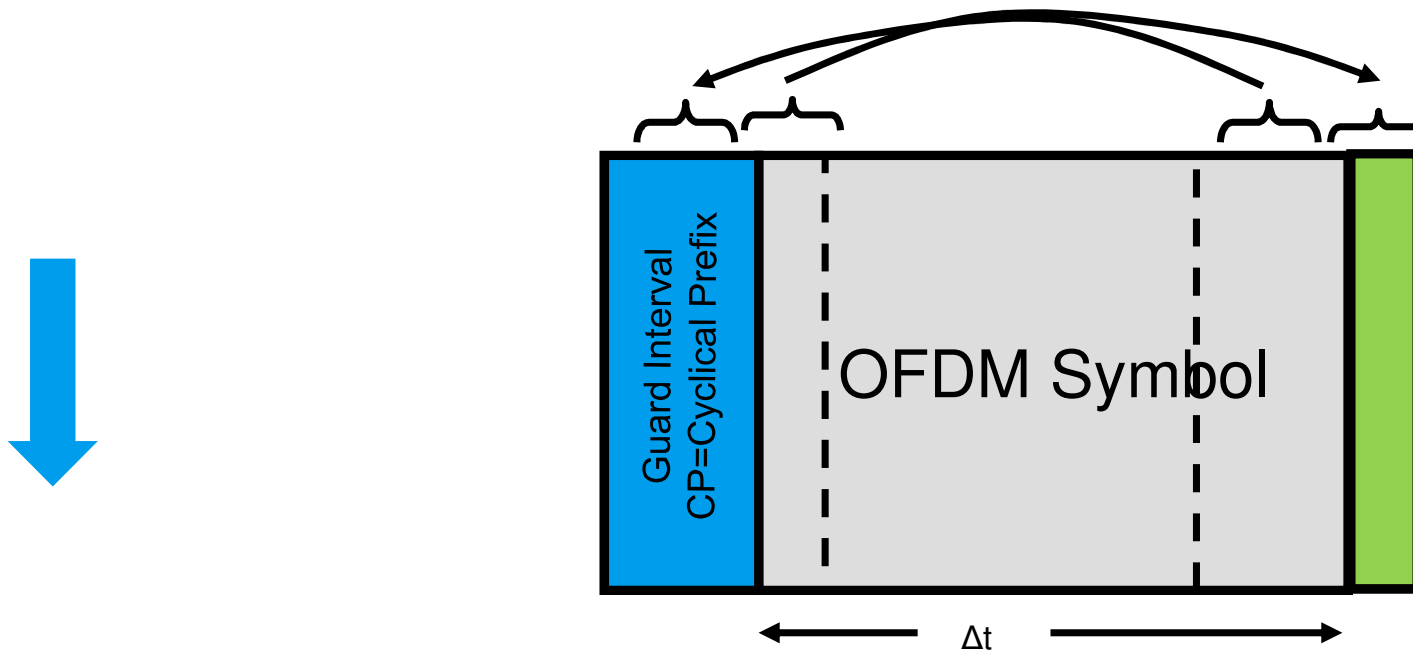
$$\text{MER[dB]} \leq \text{SNR[dB]}$$



MER – Modulation Error Ratio



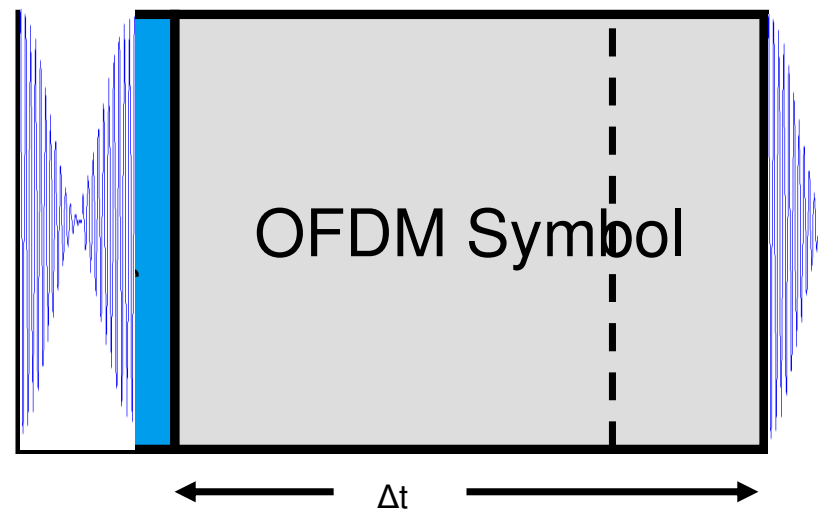
Guard Interval / CP before and behind of the Symbol



(... DOCSIS3.1 symbol duration ... 20 or 40 μ s ... OFDM, 1...5 μ s guard)

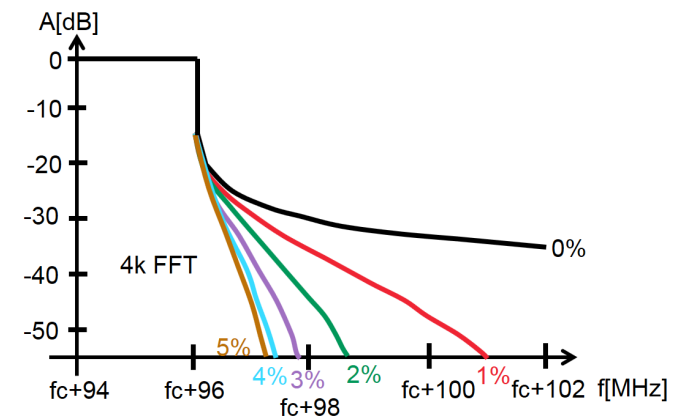
Guard Interval & Windowing

DOCSIS 3.1



Tukey-rised cosine windowing
in DOCSIS 3.1

Tukey-raised cosine windowing,
embedded in the cyclic prefix



(... DOCSIS3.1 symbol duration ... 20 or 40 μ s ... OFDM, 1...5 μ s guard)

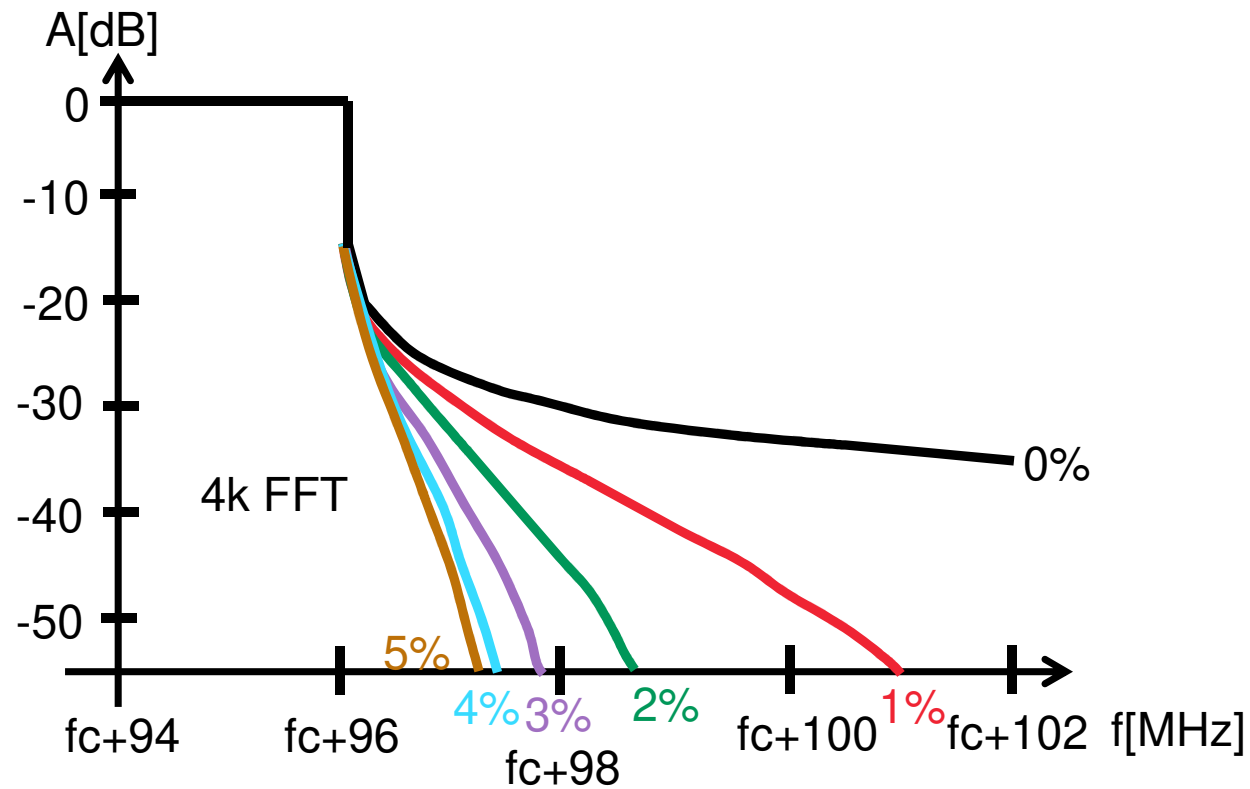
Cyclic Prefix and Windowing Roll-Off Period



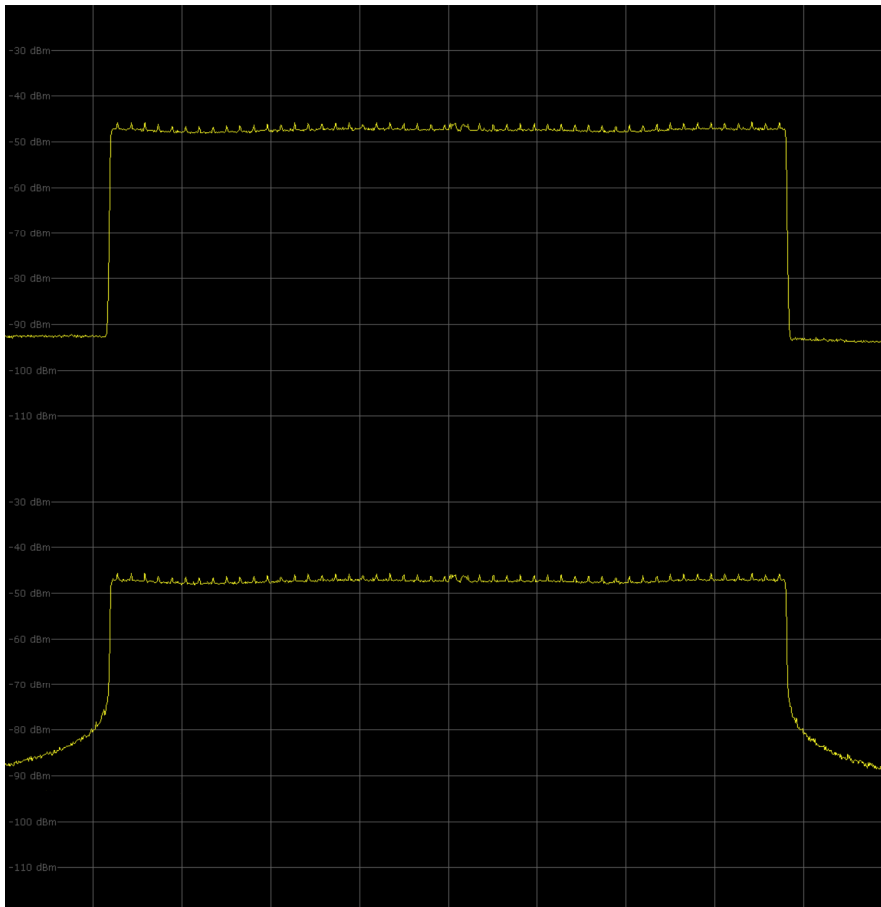
Cyclic prefix (μs)	Cyclic prefix samples
0.9375	$192 \cdot T_s$
1.25	$256 \cdot T_s$
2.5	$512 \cdot T_s$
3.75	$768 \cdot T_s$
5.0	$1024 \cdot T_s$

Roll-off periode (μs)	Roll-off periode samples
0	$0 \cdot T_s$
0.3125	$64 \cdot T_s$
0.625	$128 \cdot T_s$
0.9375	$192 \cdot T_s$
1.25	$256 \cdot T_s$

Windowing and Spectrum Shape



Windowing Function and Shoulders ...

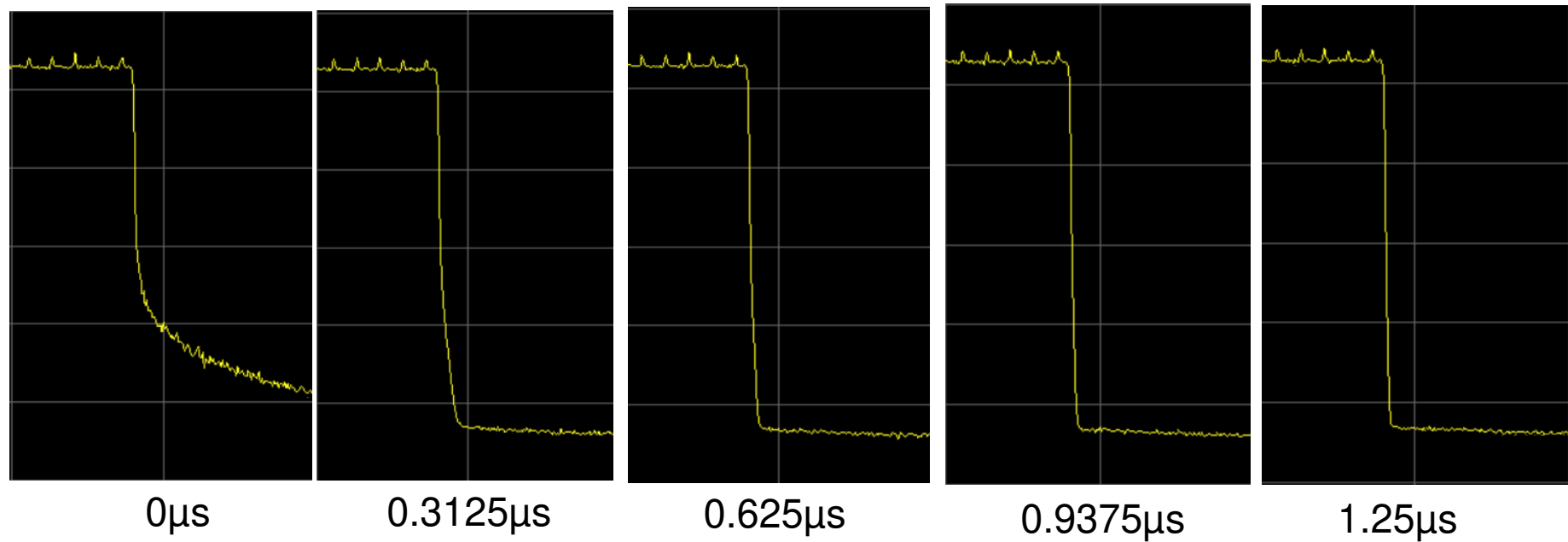


Windowing 1.25µs

Channel	Modulator State	Carrier Definition	Power (dBuV)	FFT Size	Windowing (us)	Cyclic Prefix (us)	Continuous Pilot Parameter	Interleaver Depth	Exclusion Band	
									Start Subcarrier	Width
1	ON	204MHz (CENTER) Subcarriers: 3800	90.0	4K	0	5.0	48	2	0 0 0	0 0 0
☐	PLC Location	PLC Source	PLC Source Port	NCP Order	Profile ID	Profile Constellation	Profile Port	Profile Source	Profile FEC Code Shortening	Advanced Options
	2104	TEST	1001	QPSK	A B C D	QAM4096 QAM1024 QAM1024 QAM256	NONE 10200 0 b/s NONE 10201 0 b/s NONE 10202 0 b/s NONE 10203 0 b/s	FILL FILL FILL FILL	1779 1779 1779 1779	Advanced

Windowing 0µs

Windowing Function and Shoulder



Agenda

Einleitung ... DOCSIS3.1 im Überblick

Fehlerschutz DOCSIS3.0 versus DOCSIS3.1

Spektrum DOCSIS3.0 vs DOCSIS3.1

Modulationsverfahren DOCSIS3.0 und DOCSIS3.1

Signalpegelung bei DVB-C/DOCSIS3.0 und DOCSIS3.1

Messparameter

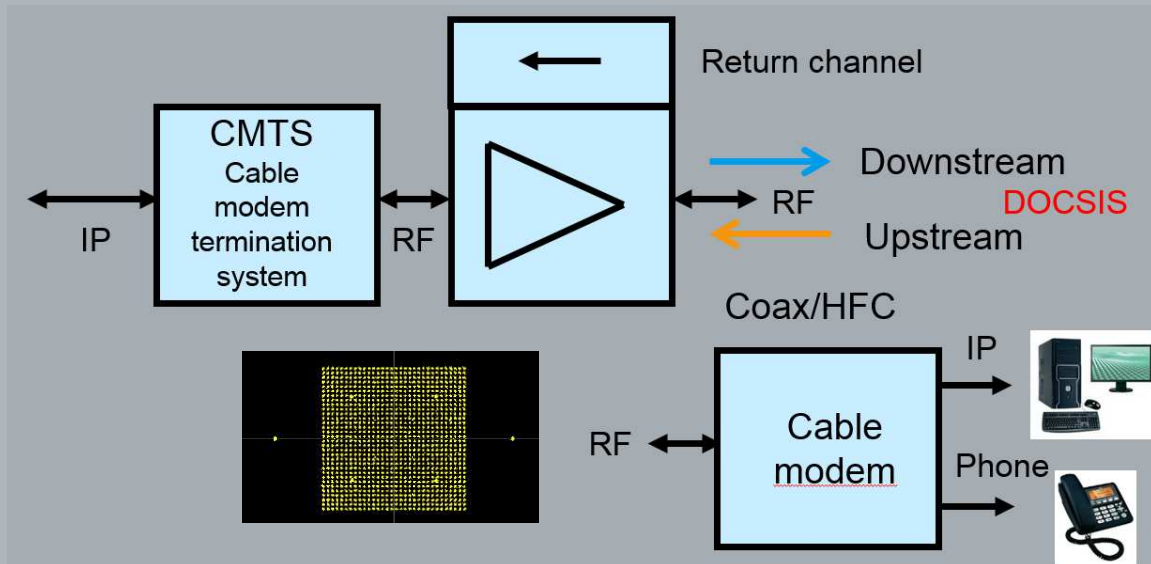
Zusammenfassung



Zusammenfassung

- DOCSIS3.1 bereits in einigen Regionen in Europa in Betrieb
- DOCSIS3.1 mit modernem Fehlerschutz (wie DVB-T2 und jetzt auch bei 5G)
- DOCSIS3.1 mit OFDM und bis zu 16364QAM
- Verbesserter DOCSIS3.1-Fehlerschutz bringt ca. 4 dB im Downstream
- Fehlerschutz im Upstream ohne BCH-Codierung, deswegen um ca. 2 dB „schlechter“ wie DS
- 190 MHz breites DOCSIS3.1-Spektrum im Vergleich zum 8 MHz breiten DVB-C/DOCSIS3.0-Kanal
- DOCSIS3.1-Pegelung nach „Leistungsdichte“ nicht nach Gesamt-Block-Pegel
oder nach äquivalent breitem 6 bzw. 8-MHz-Kanal-Pegel
- DOCSIS3.1-Messparameter grundsätzlich vergleichbar wie bei DVB-C/DOCSIS3.0
- MER-Messung auch auf OFDM-Träger-Ebene





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