EDC Performance versus Tx Specifications
and
Its implications for TP2 testing

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Sep. 2004

IEEE 802.3aq meeting – Ottawa

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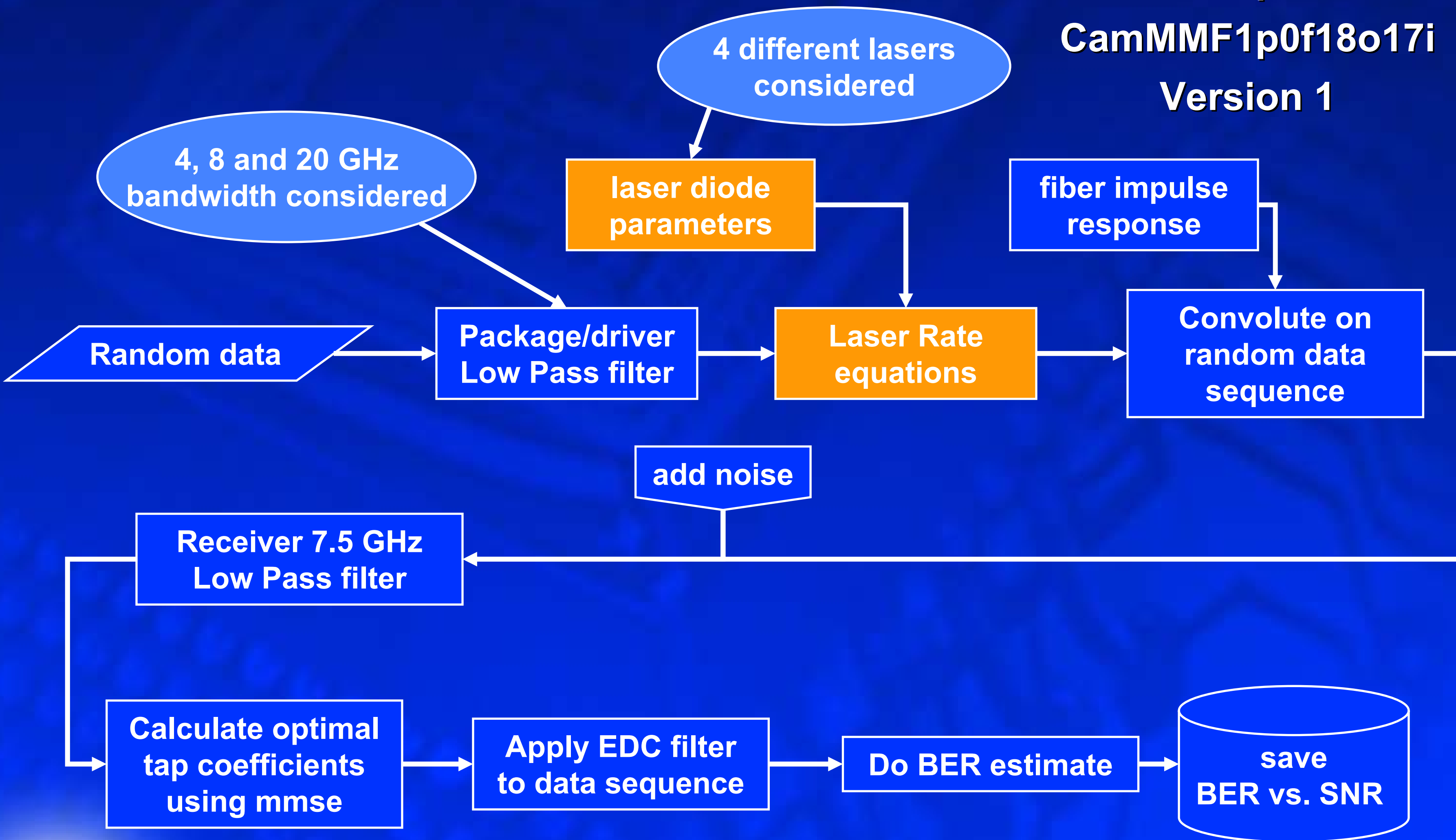
Objective of presentation

- Establish an understanding of how the characteristics of a transmitter influence the link penalty and the performance of EDC

- How do we evaluate the characteristics of the transmitter in a EDC link?
  - TP2 testing: How can EDC performances be predicted?

EDC simulation path

CamMMF1p0f42o20i *
CamMMF1p0f48o17i
CamMMF1p0f18o17i
Version 1



* For plot of impulse response see:
http://www.ieee802.org/3/aq/public/upload/channel_tp3.040914.pdf

Laser Rate equations

laser diode parameters → Laser Rate equations

- **Solve rate-equations using matlab**
- **Initial input data from Cartledge, J. Lightwave tech. vol 15, no. 5 1997 p 852**
- **laser with threshold current of 16.6 mA**
- **Parameters modified to give 4 other lasers with approx. same I_{th} and 8, 13, 17 and 32 GHz Relax. freq.**
- **I_{bias}= 70 mA; I_{mod} = 100 mApp**

$$
\begin{cases}
\dfrac{dP}{dt} = G \cdot P + Rsp - \dfrac{P}{\tau_p} \\[2ex]
\dfrac{dN}{dt} = \dfrac{I}{q} - \dfrac{N}{\tau_c} - G \cdot P \\[2ex]
G = G_N (N - N_0)(1 - \varepsilon_{NL}) \\[4ex]
\dfrac{d\phi}{dt} = \dfrac{1}{2} \beta_c \left[G_N (N - N_0) - \tau_p \right]
\end{cases}
$$

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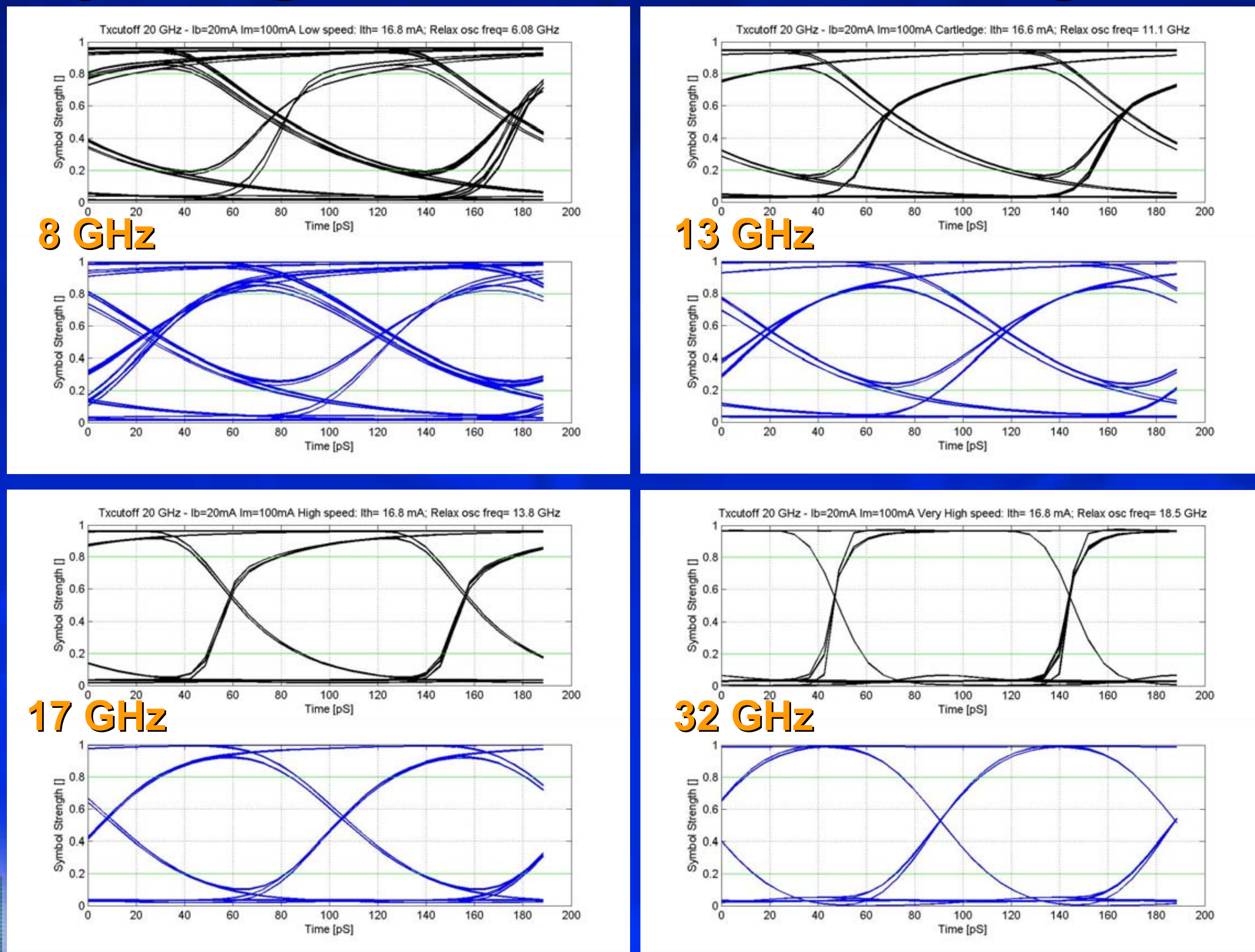
Eyediagrams – 20 GHz package - BtB



laser output

filtered output

laser output

filtered output

- Ibias= 70 mA; Imod = 100 mApp

Relative Penalty
Back to Back – no EDC

Penalty at BER=10^-9

Table 1

Laser \ Package	Bad (4 GHz BW)	Good (8 GHz BW)	Perfect (20 GHz BW)
Bad (BW 8 GHz)	7.1	3.6	3.0
Good (BW 13 GHz)	5.8	3.1	2.4
Better (BW 17 GHz)	3.1	1.2	0.9
Perfect (BW 32 GHz)	2.2	0.5	0 (reference)

all numbers in dBo

- Ibias= 70 mA; Imod = 100 mApp

Relative Penalty
Back to Back – with EDC
DFE: 5- taps FFE + 2-taps FB

Table 2

Package / Laser	Bad (4 GHz BW)	Good (8 GHz BW)	Perfect (20 GHz BW)
Bad (BW 8 GHz)	1.9	1.0	0.8
Good (BW 13 GHz)	1.7	0.8	0.6
Better (BW 17 GHz)	0.9	0.3	~0
Perfect (BW 32 GHz)	0.5	~0	< 0

Penalty at BER=10^-9 all numbers in dBo

- Ibias= 70 mA; Imod = 100 mApp

Relative Penalty after 300m fiber – with EDC DFE: 5-taps FFE + 2-taps FB

Penalty at BER=10^-9 CamMMF1p0f42020i Table 3

Laser \ Package	Bad (4 GHz BW)	Good (8 GHz BW)	Perfect (20 GHz BW)
Bad (BW 8 GHz)	4.7	3.8	3.6
Good (BW 13 GHz)	4.5	3.6	3.4
Better (BW 17 GHz)	3.7	3.0	2.9
Perfect (BW 32 GHz)	3.2	2.6 9.7 (no EDC)	2.5 8.2 (no EDC)

all numbers in dBo

•Ibias= 70 mA; Imod = 100 mApp

Conclusions from 'EDC performance vs relaxed transmitter specs'**

- A Decision-Feedback Equalizer seems to be able to compensate for both bandwidth limiting effects and non-linearities originating from the laser source and package
- A Feed-Forward Equalizer seems to be able to compensate for bandwidth limiting effects (in package)

- The penalty of the fiber and of the laser seems to add up:
  - With a DFE the penalty difference between BTB (w/EDC) and fiber (w/EDC) is approx. 2.8 dB (fiber penalty) for all package+laser combinations
  - This is not the case for a Feed-Forward Equalizer

This is not correct in the general case

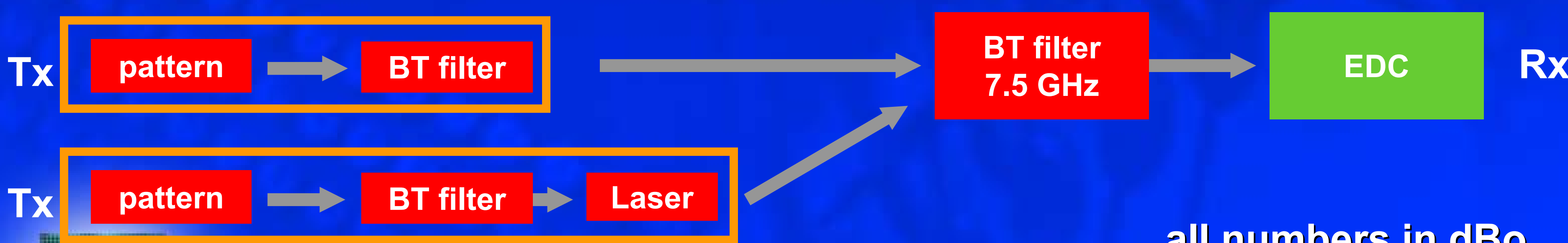
**http://www.ieee802.org/3/aq/public/upload/lobel_1_0804.pdf

In the search of The General Case

Reference Tx – Back-to-back

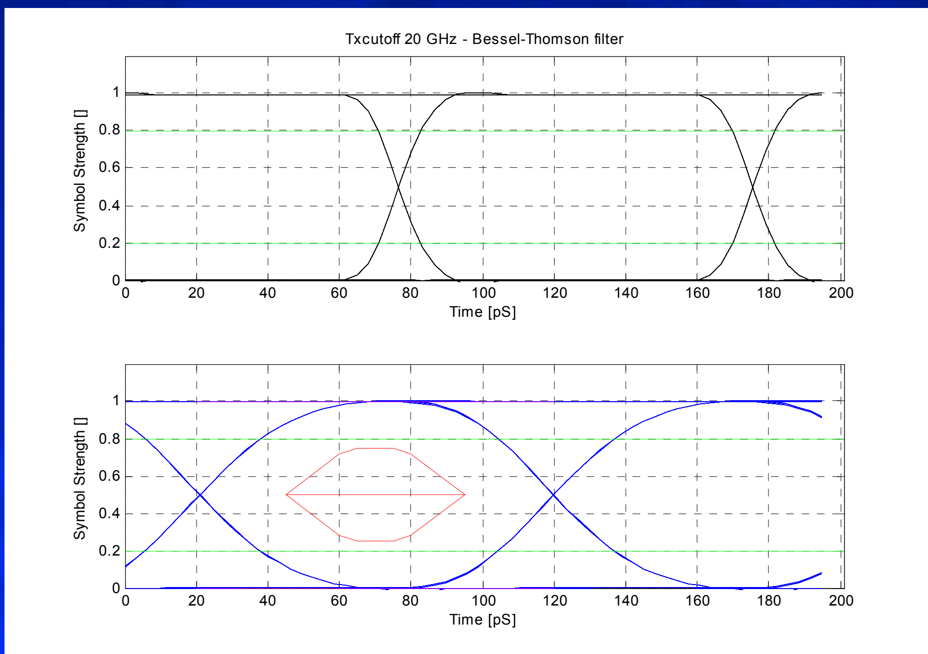
Table A — **Rx bandwidth of 7.5GHz remains fixed for all cases**

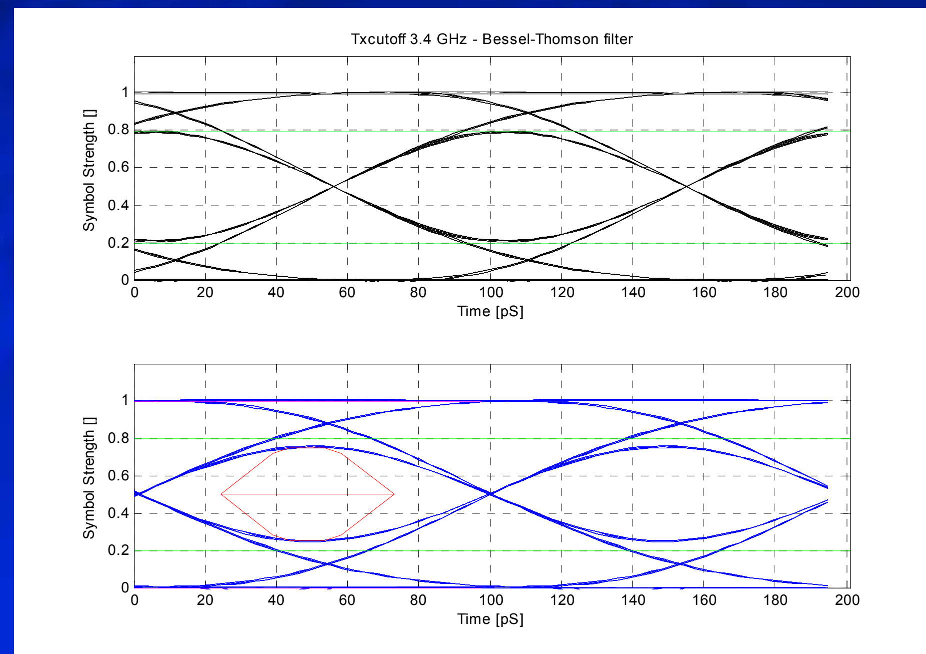
Tx \ Filter complexity	no EDC	5-taps FFE	9-taps FFE	5+2 taps DFE	9+2 taps DFE
Bessel Thomson 3.4 GHz filter	3,3	1,8	1,3	0,8	0,7
Bessel Thomson 4 GHz filter	2,2	0,9	0,6	0,4	Na
Bessel Thomson 8 GHz filter	0,4	-0,4	-0,4	-0,3	Na
Bessel Thomson 20 GHz filter	**0**	-0,6	-0,6	-0,5	-0,5
Low-speed laser w/ 4GHz filter	4,7	2,8	2,7	1,6	1,6



all numbers in dBo

4-order Bessel Thomson Tx





Reference: 20GHz

3.4 GHz

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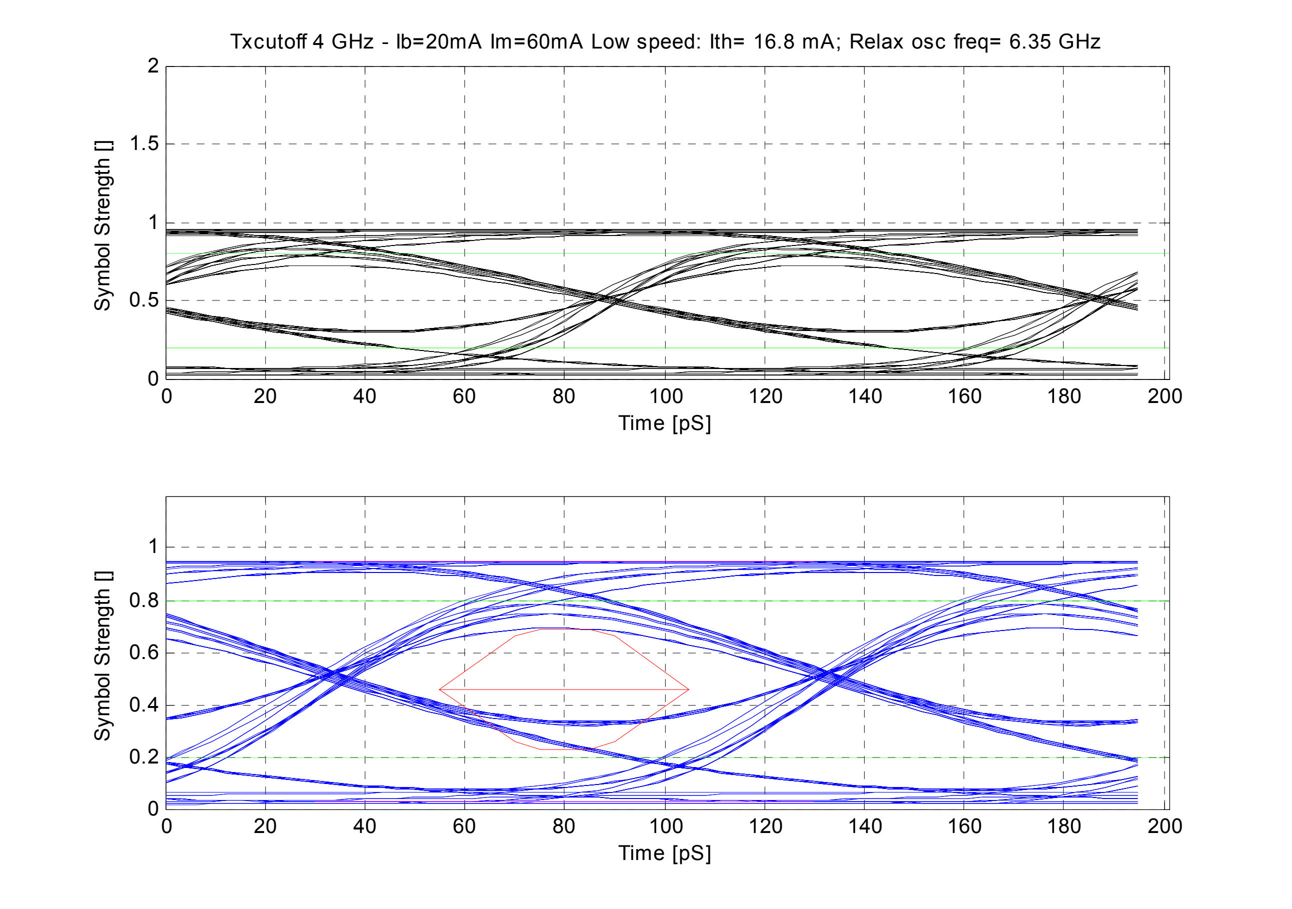
Low speed laser – Tx charateristics - BtB



The penalty is less than 3 dB (Eye mask spec) if EDC is applied

- Ibias= 50 mA; Imod = 60 mApp (4-order 4GHz BT applied before laser)

Low-speed laser = 'good' 8 GHz f_{res} (see table in back-up)

Full link – fiber penalty estimation

Table B CamMMF1p0f42o20i.txt

	No EDC	5-taps FFE	9-taps FFE	5+2-taps DFE	9+2-taps DFE
Bessel Thomson 3.4 GHz filter	-	11,9	7,7	3,7	3,2
Bessel Thomson 4 GHz filter	-	11,0	7,2	3,4	tbc
Bessel Thomson 8 GHz filter	8,7	8,5	5,3	2,7	tcb
Bessel Thomson 20 GHz filter	8,2	7,9	4,7	2,6	2,2
low speed 4 GHz BW limitation	-	-	9,8	4,7	4,2

Tx: 20 GHz BT - Estimation of penalty of fiber alone

(reference is still 'no EDC' Back-to-back)

all numbers in dBo

42o20i Cambridge file

Table C

42020i	Tx	Filter	|Fiber w/EDC| + |Tx w/o EDC| Table A+ table B		|Fiber + Tx| w/EDC Table B		|Fiber w/EDC| + |Tx w/EDC| Table A + table B
	4 GHz BT	5-taps FFE	10,1 (7.9+2.2)	<=	11,0	>	8,7 (7.9+0.9)
		9-taps FFE	7,0	<=	7,2	>	5,3
		5+2-taps DFE	4,8	>	3,4	>	3,0
	Laser Low-Speed 4GHz	9-taps FFE	9,4	<=	9,8	>	7,5
		5+2-taps DFE	7,2	>	4,7	>	4,1
		9+2-taps DFE	6,8	>	4,2	>	4,1

CamMMF1p0f42o20i.txt

all numbers in dBo

18o17i Cambridge file

Table D

	Tx	Filter	|Fiber w/EDC| + |Tx w/o EDC|		|Fiber + Tx| w/EDC		|Fiber w/EDC| + |Tx w/EDC|
18017i	4 GHz BT	5-taps FFE	5,7	>	5,2	>	4,3
		9-taps FFE	5,1	>	4,5	>	3,5
		5+2-taps DFE	5,7	>	5,1	>	3,7
	Laser Low-speed 4 GHz BT	9-taps FFE	7,6	>	6,9	>	5,6
		5+2-taps DFE	7,9	>	6,9	>	4,8
		9+2-taps DFE	7,5	>	5,3	>	4,8

CamMMF1p0f18o17i.txt

all numbers in dBo

48o17i Cambridge file

Table E

	Tx	Filter	|Fiber w/EDC| + |Tx w/o EDC|		|Fiber + Tx| w/EDC		|Fiber w/EDC| + |Tx w/EDC|
48017i	4 GHz BT	5-taps FFE	7.0	>	6.0	>	5.6
		9-taps FFE	5.9	>	5.4	>	4.3
		5+2-taps DFE	5.9	>	5.4	>	4.1
	Laser Low-speed 4 GHz BT	9-taps FFE	8.4	>	7.7	>	6.5
		5+2-taps DFE	8.3	>	5.9	>	5.3
		9+2-taps DFE	8.2	>	5.5	>	5.4

CamMMF1p0f48o17i.txt

all numbers in dBo

Observations

- The combined solution (fiber +Tx) has always higher penalty than the individual contributions.
  – In some cases using a DFE they are close to equal
- The addition of the fiber suppresses the ability of the EDC to correct for Tx impairments
  – In some cases for a FFE the fiber enhances the penalty of the Tx !

-The above observations have been confirmed using the 'good' laser with a 4GHz and 8GHz package.

- Preliminary simulations using a laser that is less damped (ringing) seems to confirm the observations also.

Summary

- FFE can correct Tx impairments in BtB configuration
  - The observed/measured FFE correction in BtB will be reduced significantly when fiber is added (amount is fiber and EDC filter dependent and may be negative)

- DFE corrects laser impairments even after fiber
  - The observed/measured DFE correction in BtB will only be slightly reduced when fiber is added (amount is fiber dependent)
  - The correction can be significantly reduced if FFE section in DFE is too small to handle the impulse response

Conclusions of relevance for TP2 testing

- The ’trace approach’ can establish a clear link between the Tx impairment and its penalty.
  – the burden falls directly on the source of the impairment
- A clear link can only be established if a ’fiber model’ is included in the math of the ’trace approach’
  – May complicate math significantly
- A clear link is highly dependent on complexity of EDC filter
  – It seems that math must use finite EDC filter complexity
  – Requirement of minimum filter complexity (# taps) will need to be specified

Closing remarks

- Relaxation of Tx specs worse than LR eye mask requires a DFE solution
  - DFE can effectively correct Tx impairment
- In the case of a DFE, the 'Trace approach' allows a closer specification of the Tx characteristics
- In the case of a FFE, the 'Trace approach' offers limited advantages over 'eye mask'

Backup

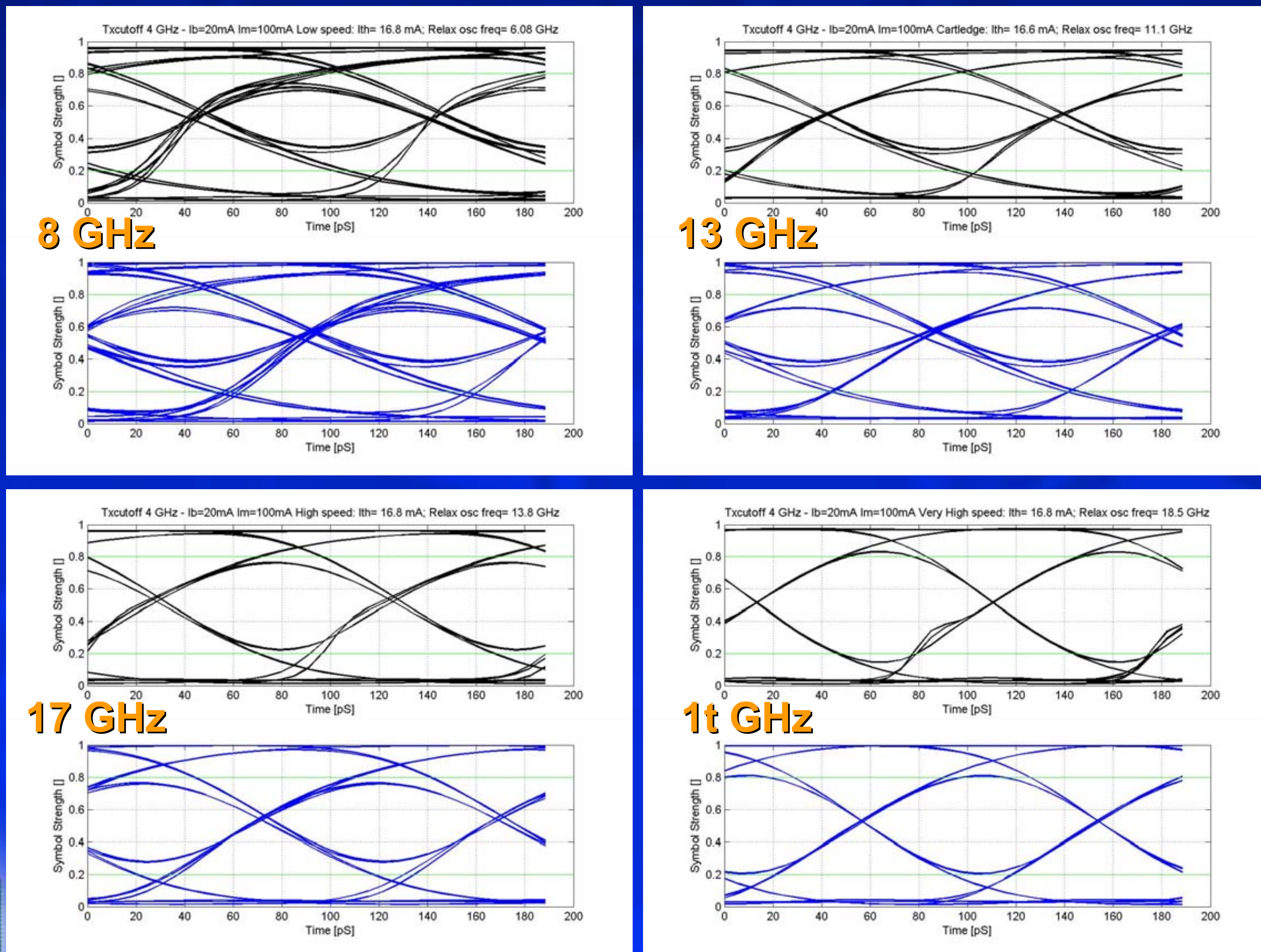
Laser parameters

Cartledge laser

parameter	8 GHz	13 GHz	17 GHz	32 GHz	
nsp		1.7			Spontanous emission factor []
L		0.025			cavity length [cm]
w	0.0002	0.0001			active layer width [cm]
d	1e-5	8e-6			active layer thickness [cm]
Gamma		0.24			Confinement factor []
g0		1.6e-6	3e-6	1e-5	gain slope constant [cm^3/s)
neff		3.4			effective refractive index []
n		4			group refractive index []
vg		7.5e+9			Group Velocity [cm/s]
sig_g		2.13e-16	4e-16	1.33e-15	Diffential gain coeffienct [cm^2]
epsilon		1.48e-17			gain compression factor [cm^3]
eps_nl	2.96e-7	7.4e-7			Gain compression coefficient []
NT		1.07e+18			Carrier density of transparancy [1/cm^3]
Anr	4e+8	1e+8	1.27e+9	3e+9	Nonradiative recombination rate [1/s]
Brr		1e-10			Radiative recombination rate [cm^3/s]
C_Auger		3e-29			Auger recombination coefficient [cm^6/s]
a_int	25	20			internal loss [cm-1]
a_mir	48	155			Mirror loss [cm-1]

values not shown are common for all lasers

Eyediagrams – 4 GHz package - BtB



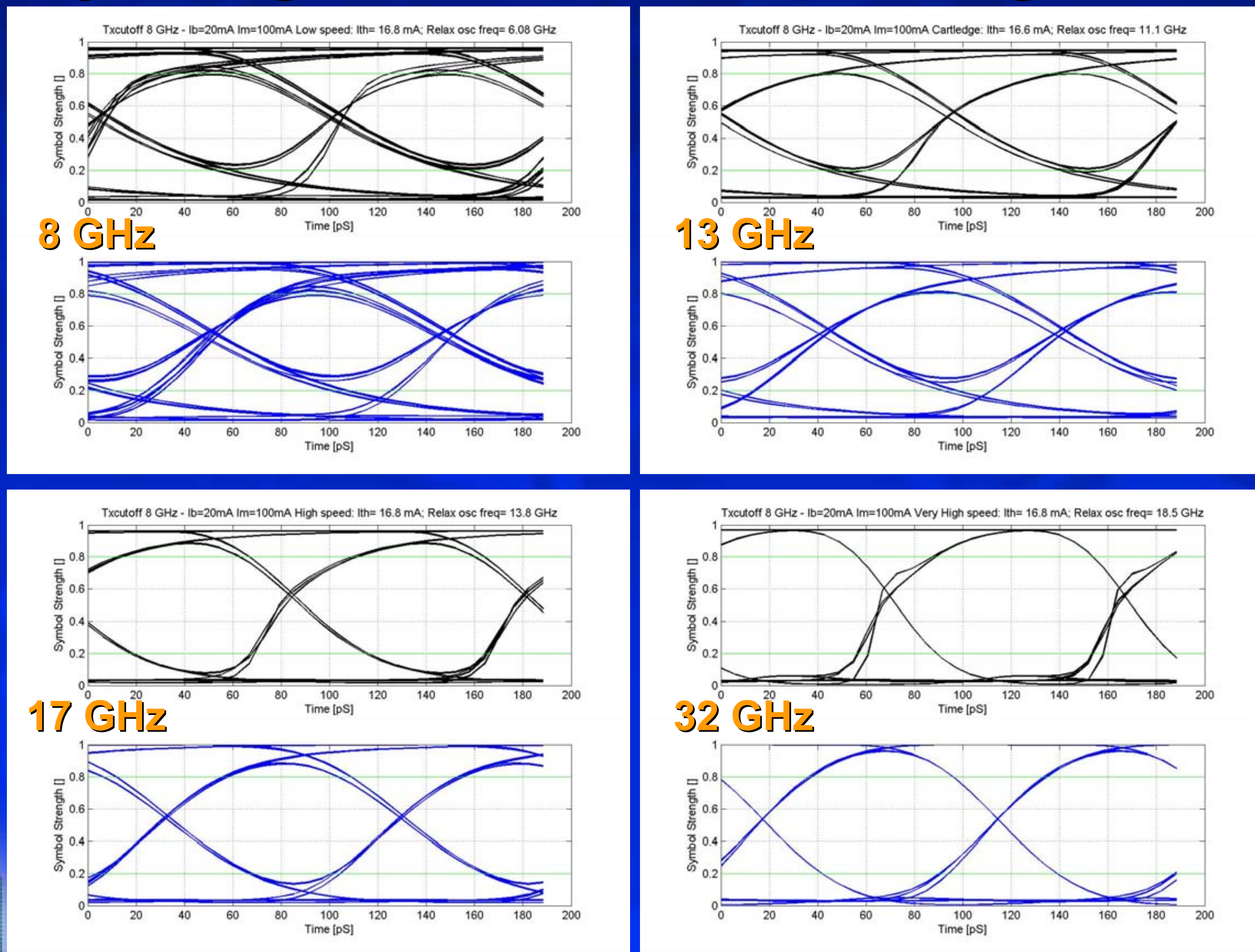
laser output

filtered output

laser output

filtered output

Eyediagrams – 8 GHz package - BtB



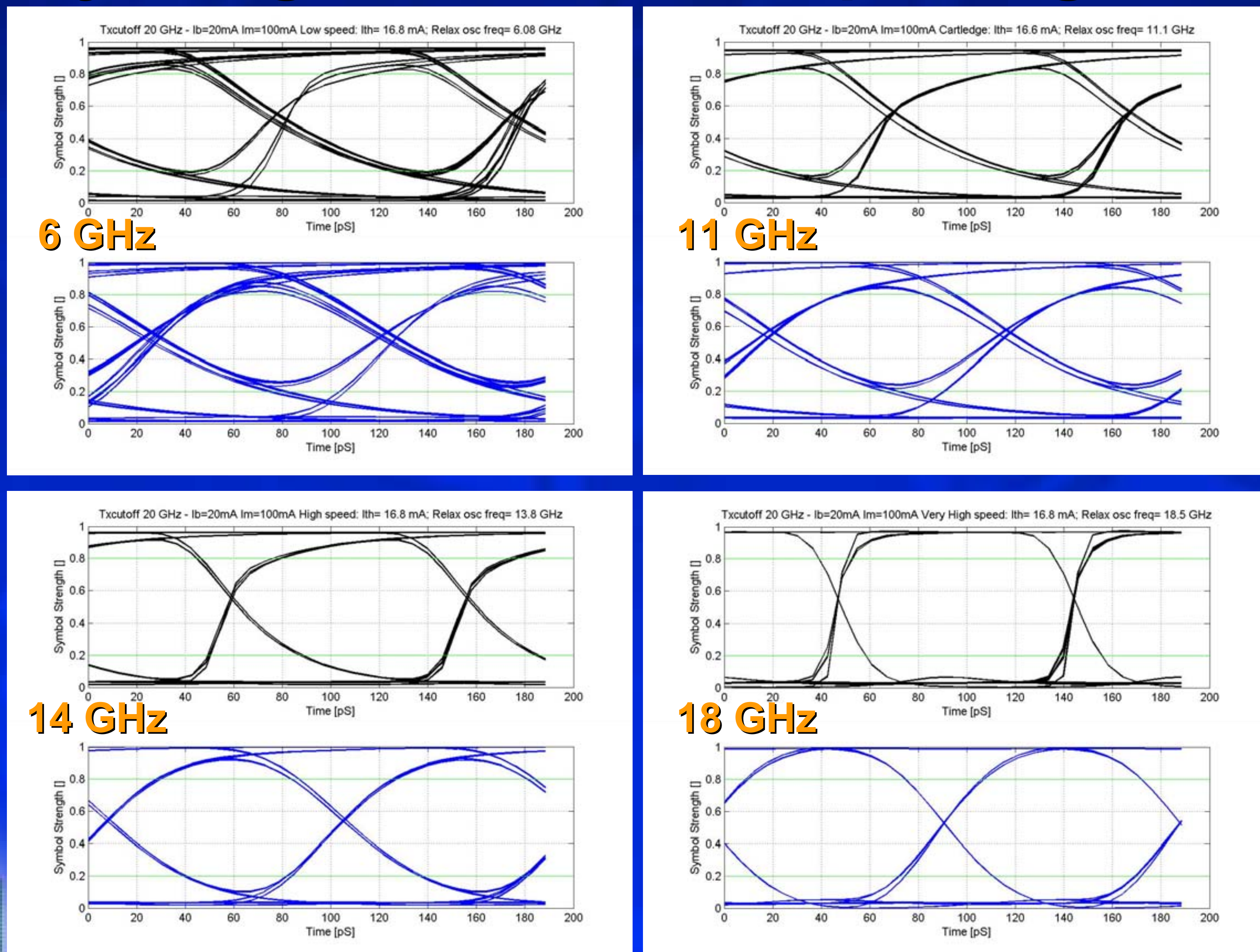
laser output

filtered output

laser output

filtered output

Eyediagrams – 20 GHz package



laser output

filtered output

laser output

filtered output