Serial 10 Gbit/s Transceiver Link Performance Analysis

Piers Dawe
Hewlett Packard Company
Fibre-Optic Communications Division
White House Road
Ipswich, England IP1 5PB
+ 44 (0)1473 465654
email : piers_dawe@hp.com

Is 10 G difficult with today's technology ?

- Mostly theoretical analysis
- Restricted to 1300nm, single mode, direct modulation
- Some comparisons with OC-48, OC-192, GbE
- Analysis by signal/noise ratio and jitter
- Predicts possible viable link specification scenarios
- Points to critical aspects of technology

Likely issues to worry about

- **Speed of electronics**
- **Speed of optoelectronics**
- **Dispersion**
- **Noise in electronics**
- **Noise in laser**
- **Interference**

Maximum launch power set by safety limits

Thermal, packaging, supply voltage issues not covered here

Comparison of SONET and Ethernet			
	SONET	GbE	
	STM-16 interoffice ~OC-48	1000BASE-LX single mode	
Payload data rate	2.378	1.000	Gbit/s
Line rate expansion	90/86	10/8	
Line rate	2.488	1.250	Gbit/s
Line clock tolerance	+/-4.6	+/-100	ppm
Tx clock jitter	no direct spec, up to 0.1UI?pk jitter can be inherited		UI total pk-pk
Laser wavelength	1266-1360	1270-1355	nm
Spectral width	4	4	rms nm
Tx min. mean power	-10	-11	dBm
Extinction ratio	8.2	9	dBo
RIN	?	-120	dB/Hz
Risetime		0.325	UI
Tx mask eye width	0.2 *	0.25 *	UI
Tx mask eye height	25-75% *	20-80% *	of DC 0, 1
Tx mask width at 50%	0.2 *	0.56 *	UI
Tx jitter generation	0.01		UI rms
Tx jitter generation	0.1 peak	0.341 total pk-pk	UI
Fibre & connector loss	7	4.57	dBo
Fibre cable loss	Not specified	0.5	dB/km
Fibre dispersion minimum	1300-1324 (G.652)	1300-1324	nm
Reach	2	5	km
Total dispersion	12	(~27)	ps/nm
Reflections, return loss	-27, -24	-12	dBo
Rx sensitivity	-18	-19	dBm
Jitter tolerance	0.15		UI pk-pk
At jitter frequencies	>1	>0.637	MHz
Jitter at Rx input	not specified	0.51	UI total pk-pk
Jitter at Rx output	not specified	0.749	UI total pk-pk
Note	* After standard Bessel filter 0.75.B		

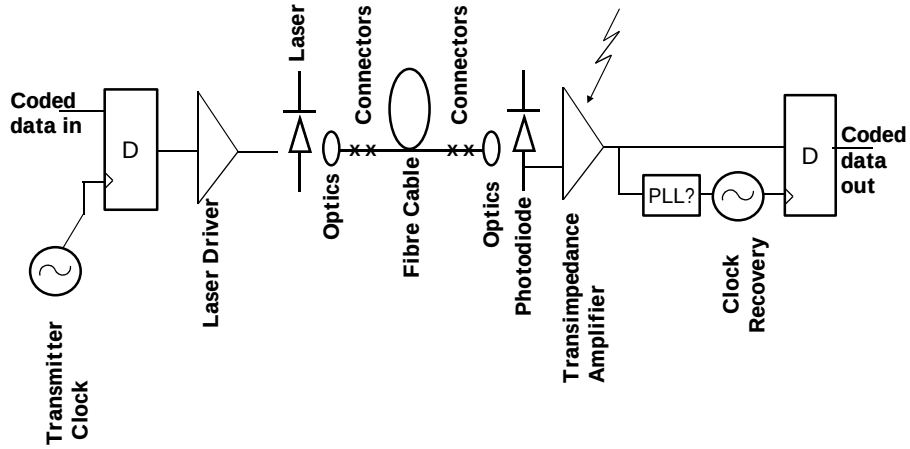
Methodology

- Follow signal quality from transmitter clock through driver, laser, optics, fibre, pin diode, preamp and clock recovery.
- Use “Q”, similar to signal/noise ratio, as measure of quality.
- If Q>7, bit-error rate $<10^{-12}$.
- My definition of Q :

$$\frac{\text{worst eye opening after “deterministic” effects}}{\text{1 standard deviation of noise.}}$$

- Deterministic effects include voltage offsets, limited bandwidth, intersymbol interference, timing offsets.
- Noise effects could be thermal noise, RIN, Jitter, mode partition noise.

Elements of link considered

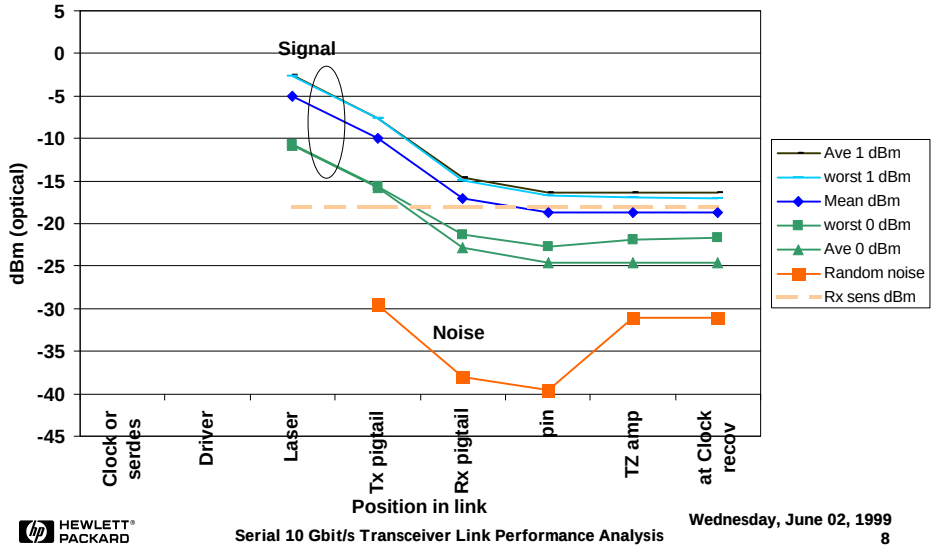


Examples of Impairments

	"Voltage" or "Current"	Timing
Deterministic	**Extinction Ratio**	**Tx duty cycle**
Most add or multiply linearly	**Bandwidth/rise times** Driver Laser Fibre dispersion Photodiode TZ amp **Coupling losses** **Connector losses** **Fibre attenuation**	**Distortion affecting timing (e.g. poor group delay)** **Clock recovery phase offset** **Deterministic jitter**
Random : **Sum of squares**	**Laser RIN** **Mode partition noise** **Shot noise** **Rx Thermal noise**	**Transmitter clock jitter** **Laser jitter** **Receive clock jitter**

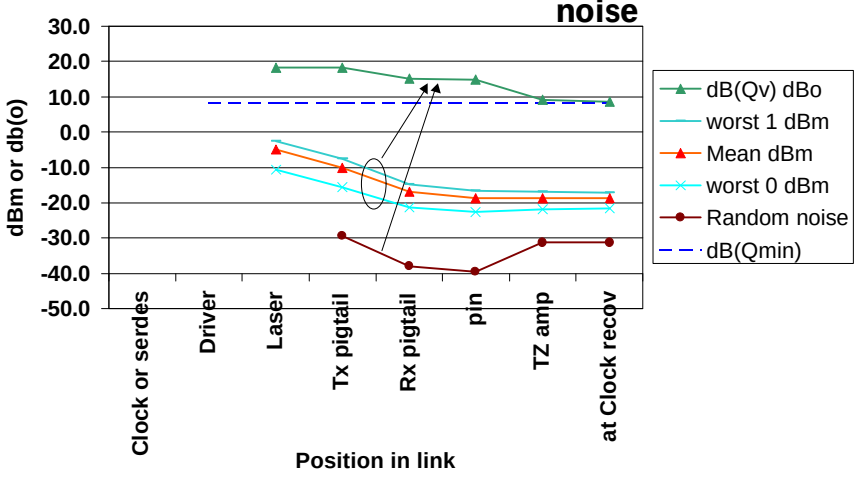
Example: Evolution of optical power from Tx to Rx

This example is an approximation to STM-16 (OC-48) Intra-Office spec

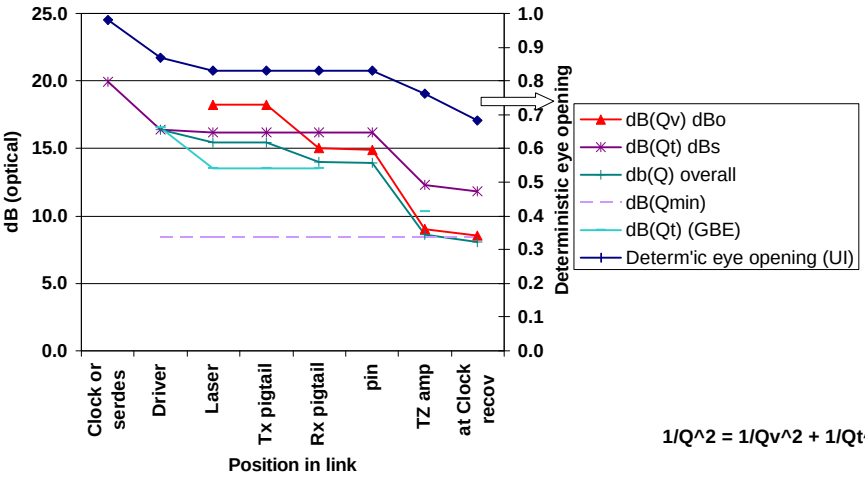


Signal/noise -> Q

$$Q = \frac{\text{worst 1 - worst 0}}{\text{noise}}$$

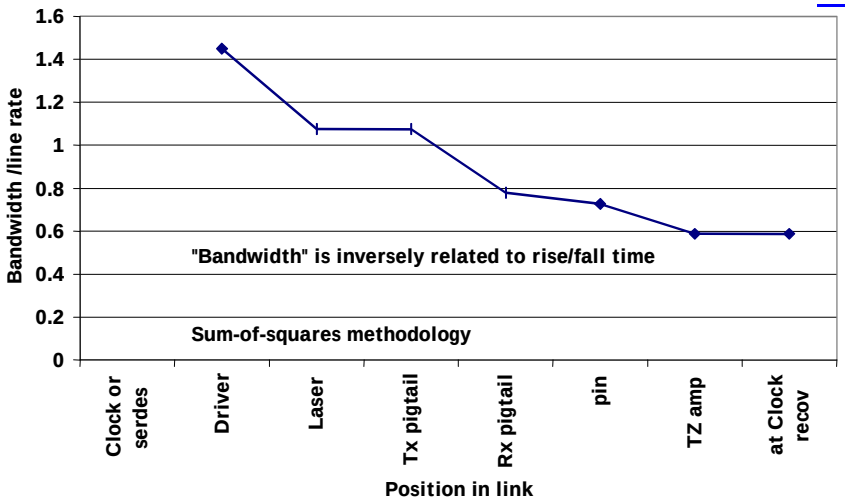


Similarly,
. . .Evolution of timing from Tx to Rx



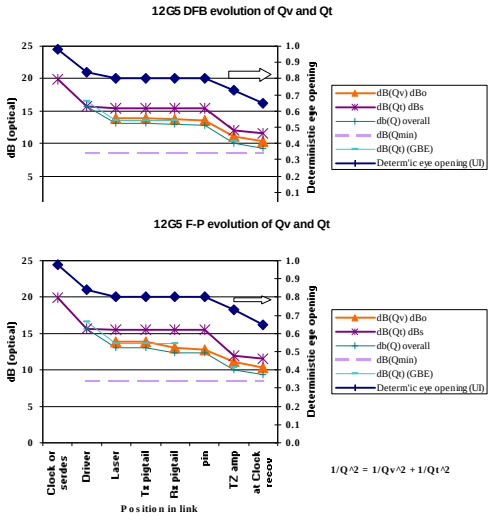
1/Q^2 = 1/Qv^2 + 1/Qt

Cumulative bandwidth deteriorates from Tx to Rx



Can we achieve the right signal quality?

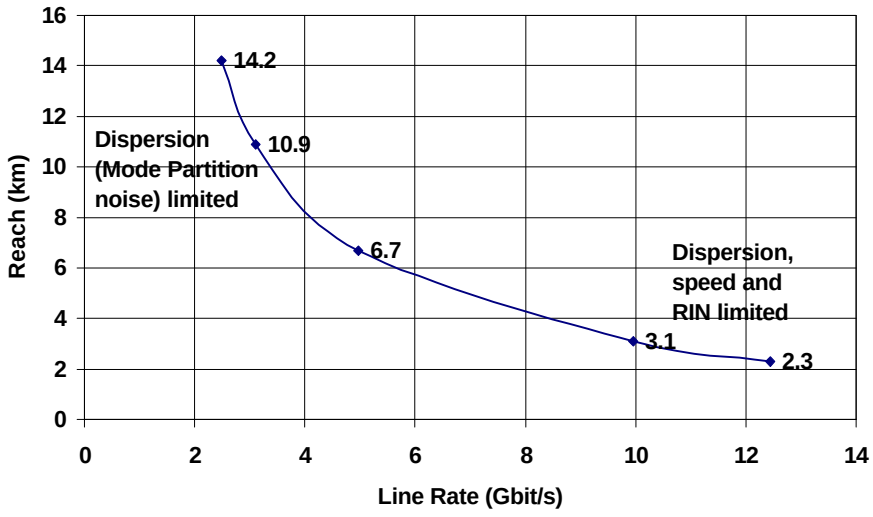
List of assumptions			
	Fabry-Perot	DFB	
Line rate	12.442	12.442	Gbit/s
Payload data rate	9.953		Gbit/s
Tx clock jitter	0.090		UI total pk-pk
Wavelength	1290		nm
Spectral half-widt	1.25	0.5	rms nm
RIN	-140	-140	dB/Hz
Extinction ratio	5		dBo
Tx mean power	-3		dBm
Risetime	32		ps 20-80%
Fibre loss	0.4		dB/km
Reach	2.3	4.9	km
Rx sensitivity	-12.8		dBm



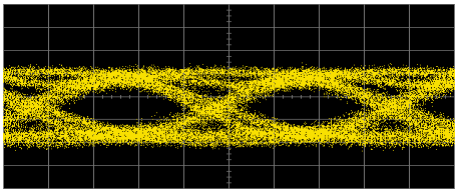
Impact of bit rate

Line rate	2.488	3.110	4.977	9.953	12.442	Gbit/s
Payload data rate	1.991	2.488	4.755	9.511	9.953	Gbit/s
Driver bandwidth	3.7	4.0	6.0	9.3	9.3	GHz
Laser bandwidth	4.0	4.5	6.0	10.6	10.6	GHz
Extinction ratio	8	7	6	5	5	dBo
RIN	-140	-140	-140	-140	-140	dB/Hz
Wavelength	1290	1290	1290	1290	1290	nm
Spectral half-width	1.25	1.25	1.25	1.25	1.25	rms nm
Tx mean power	-3	-3	-3	-3	-3	dBm
Fibre loss	0.4	0.4	0.4	0.4	0.4	dB/km
Rx sensitivity	-20.7	-18.8	-16.8	-13.6	-12.8	dBm
Reach	14.2	10.9	6.7	3.1	2.3	km

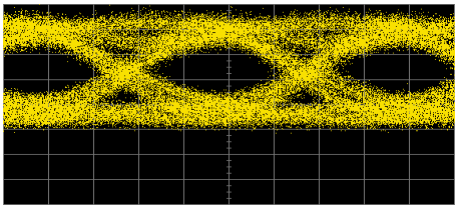
Reach vs line rate (Fabry-Perot laser)



Example laser eye diagrams to make a change from theory!



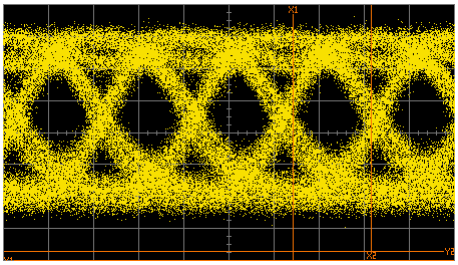
10 Gbit/s



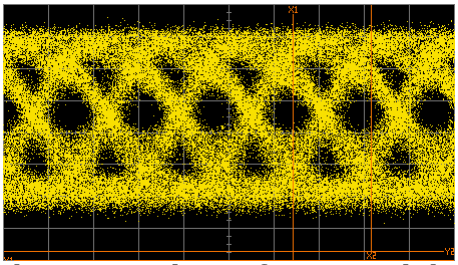
12.5 Gbit/s

Fabry-Perot laser from our labs

Even more fun eye diagrams After 6 km fibre



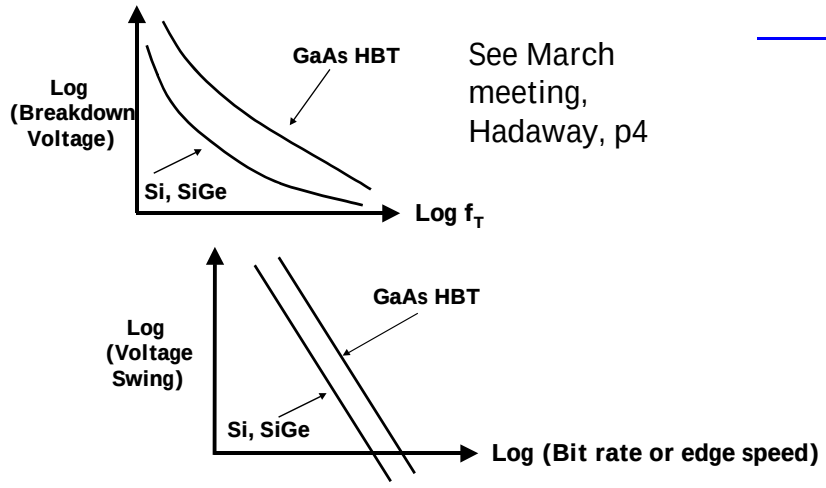
10 Gbit/s



12.5 Gbit/s

Fabry-Perot laser from our labs

Faster ICs break down at lower voltage



See March meeting, Hadaway, p4

Two effects in lower curve : (1) Technology (graph above)
(2) Circuitry issues e.g. **Miller capacitance.**

Conclusions

- **Task is evidently possible, at some cost.**
  OC-192 has been in service since 1995.

  Timing/jitter margins look acceptable
  Directly modulated lasers could be viable
  Bandwidth of the medium (fibre) is an issue

- **Can we relax the OC-192 specifications somewhat ?**
- **Transmitter speed looks very difficult (1) Driver IC**
  (2) Laser
- **Receiver sensitivity may be OK, but may be interference limited.**
- **Extending from 10 G to 12.5 G rate has significant specification implications.**

  Shortest reach ------> F-P
  Next longer reach ------> DFB
  Longer reach ------> WWDM