100G-SR4 relative power and cost estimates

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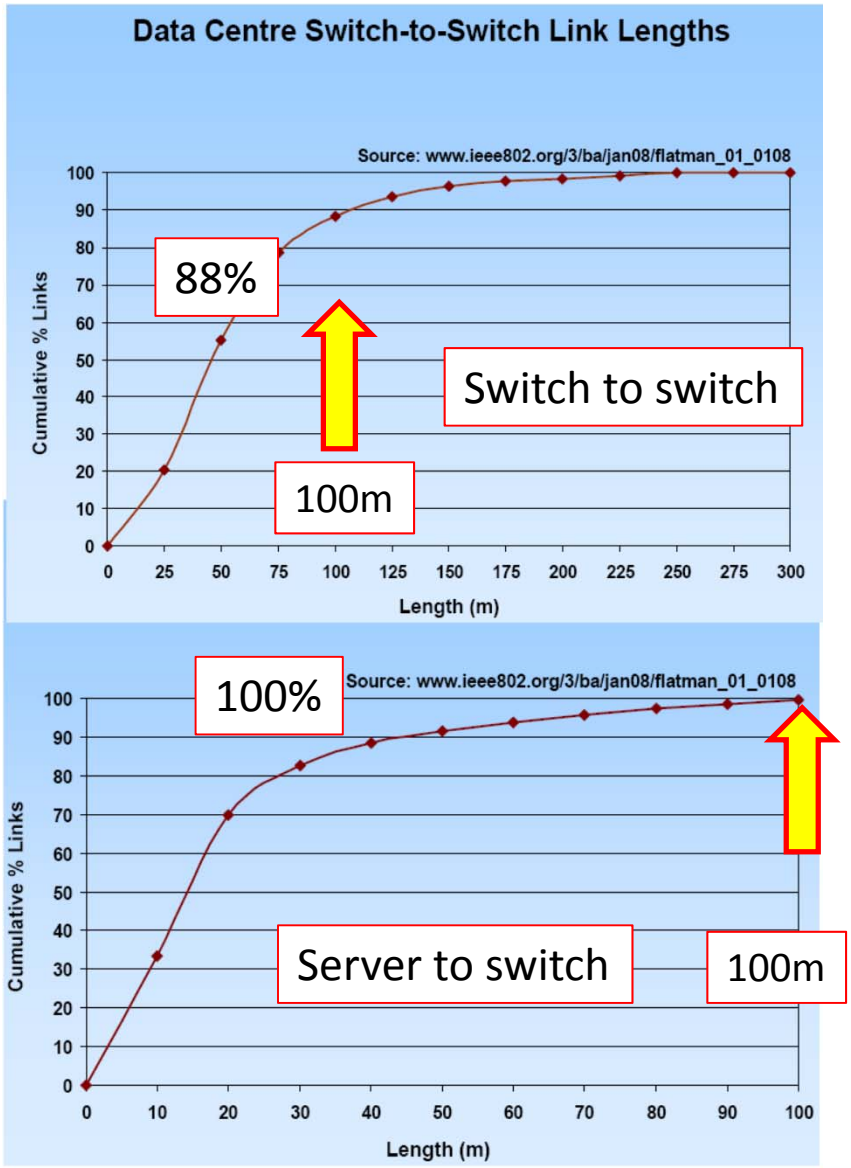
Applications - recap

- Data Center link lengths
  - 100 m covers ~90% of switch to switch links
  - 100% of server to switch links
    - ***Flatman_01_0911***
    - ***Kolesar_01_0911***: good agreement for single link length distribution
  - Andy Moorwood, Infinera: "10's of metres, weighted to low end… 100m reach on MMF may be good enough"
    - ***From "Intra and Inter Rack Connectivity Requirements", OIF Workshop January 16th 2012***
  - Mark Nowell, Cisco: "… at least 100m on latest multi-mode fibre"
    - Q&A after presentation of ***Nowell_01_0911***
- Fiber Channel objective: 100m on OM4
    - Higher rate, but single channel
- HPC/server environment: <50-75m
  - ***Pepeljugoski_01_1111***

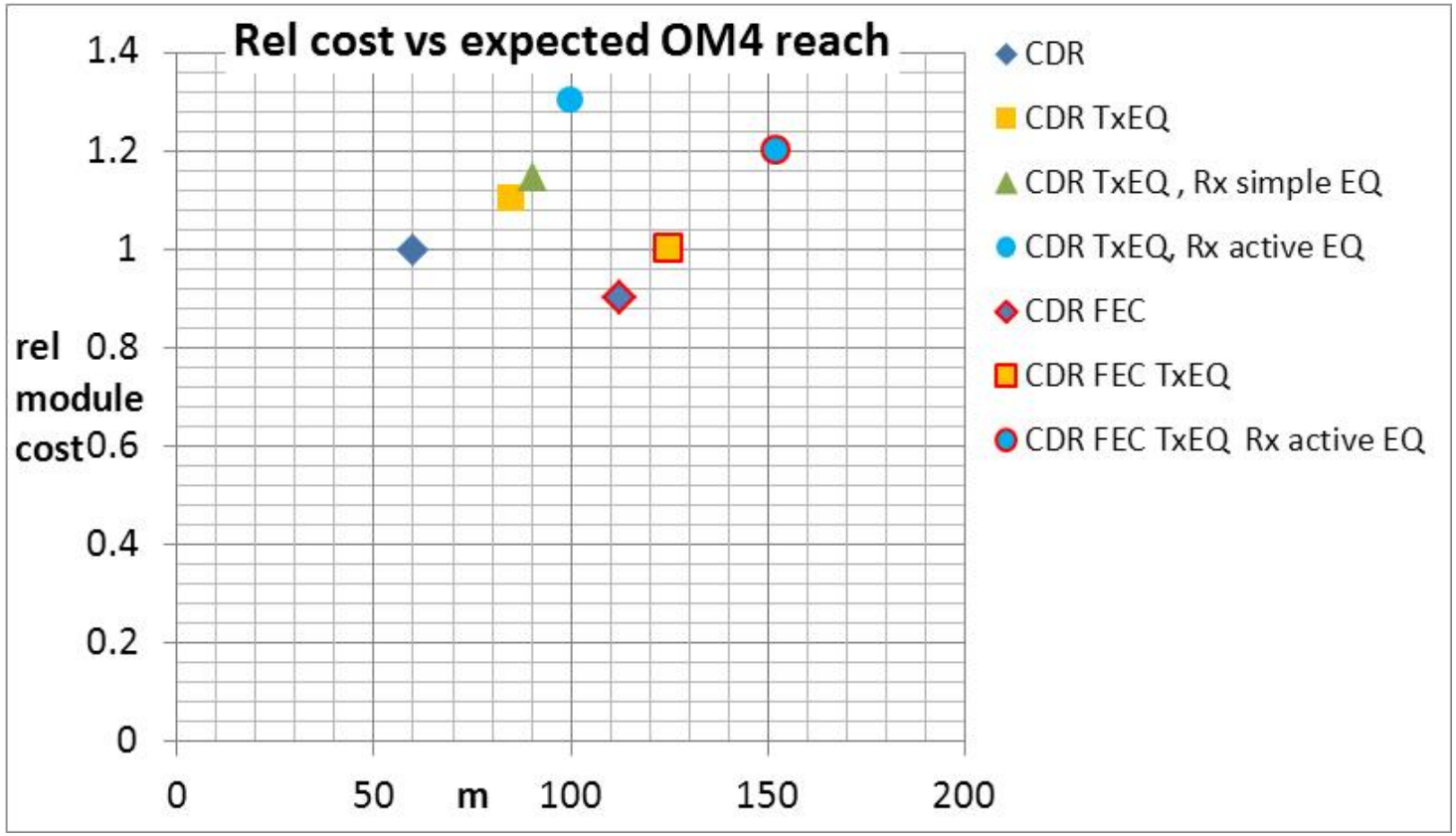


Technical feasibility - recap

- VCSEL performance
  - Performance of high volume designs is yet to be published
  - Anticipated performance for a fully retimed module
    - with FEC: 100m to 150m on OM4
    - without FEC: from 50 to 70m on OM4 for a simple retimed module
      - » Up to 70 to 100m on OM4 with simple Tx and Rx EQ, with added cost and power compared to a FEC enabled module
    - Similar reach expectations in ***King_01_1111*** and ***"100G Next Gen SR4 vis-à-vis SR10", John Petrilla***
  - If VCSEL performance ends up at worst case expectations, we have these low power (~30mW/channel) performance enhancements to fall back on inside the module:
    - Simple equalization in optical Tx chain may enable 1 to 1.5 dB lower Tx penalties
    - Simple (fixed) Rx chain 'peaking' or CTLE) may enable 1 to 1.5 dB of SRS improvement for worst case channel, depending on Tx characteristics

Relative Cost Estimates

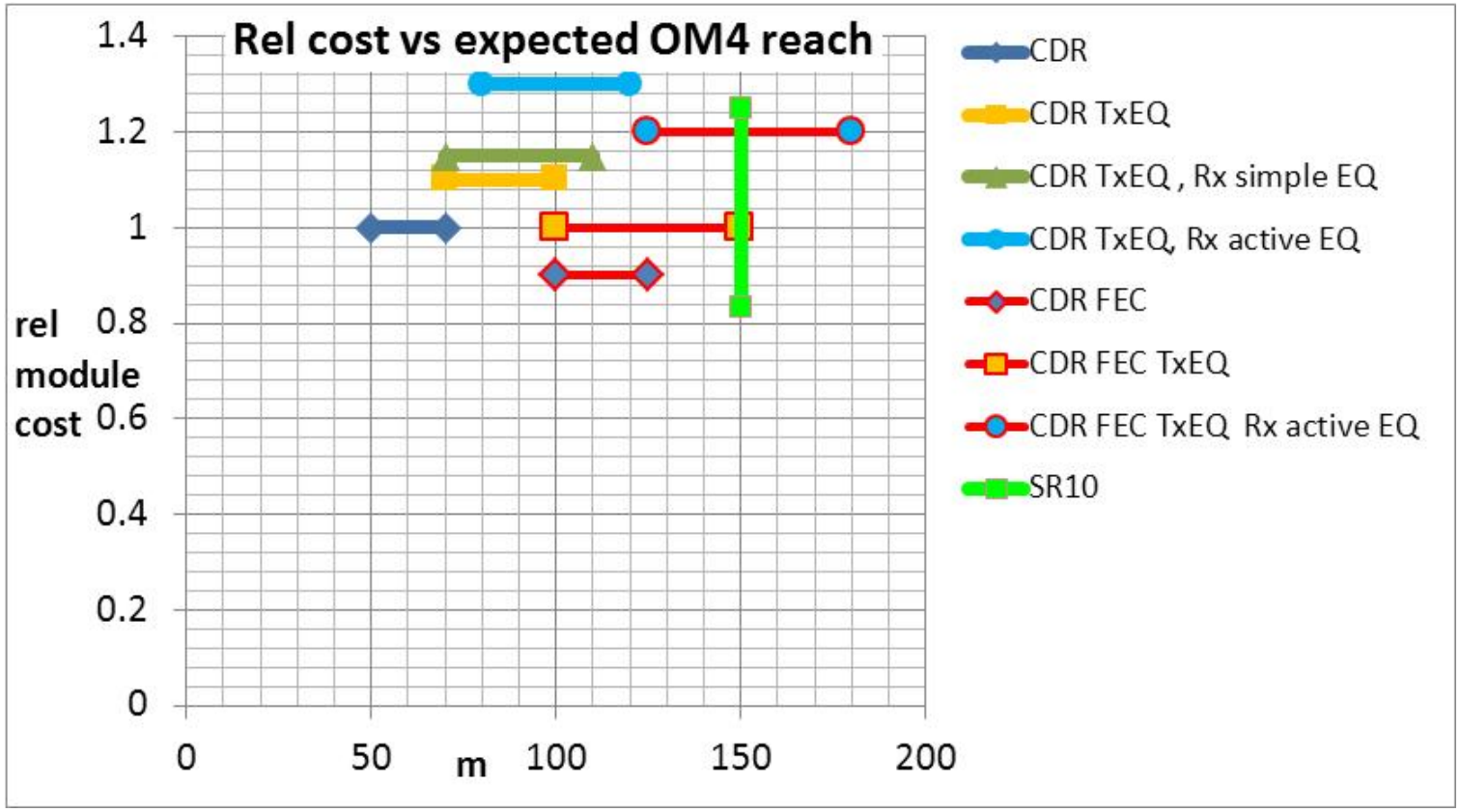
Estimated relative module cost vs reach



- Expected reach numbers based on ***King_01_1111*** , approximate cost numbers based on estimated set up and test time. Where a range of reach values were estimated (eg for slow or fast rise times) a mid point was taken.

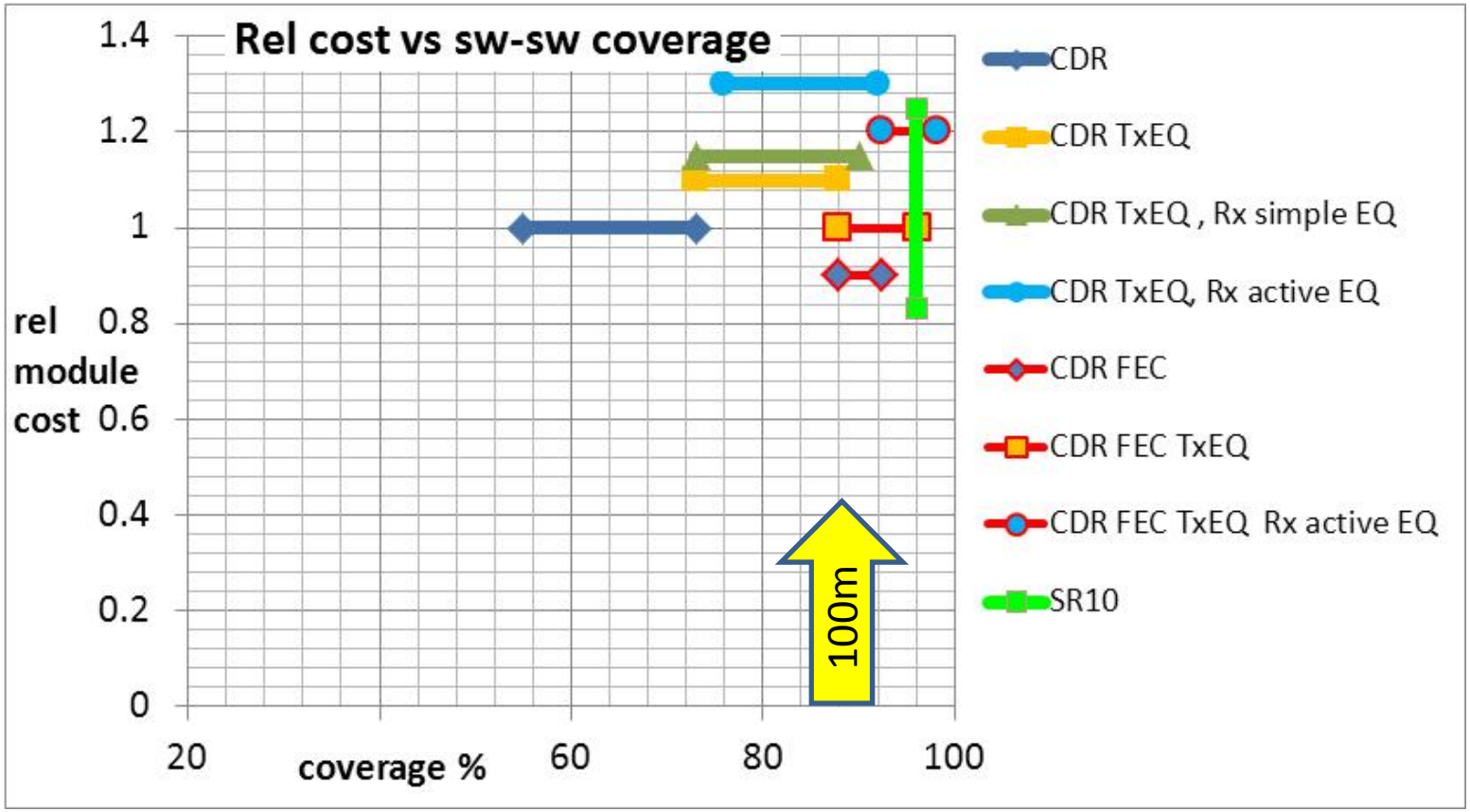
- Noted: FEC is very cost effective performance enhancer

Estimated relative module cost vs reach (ranges)



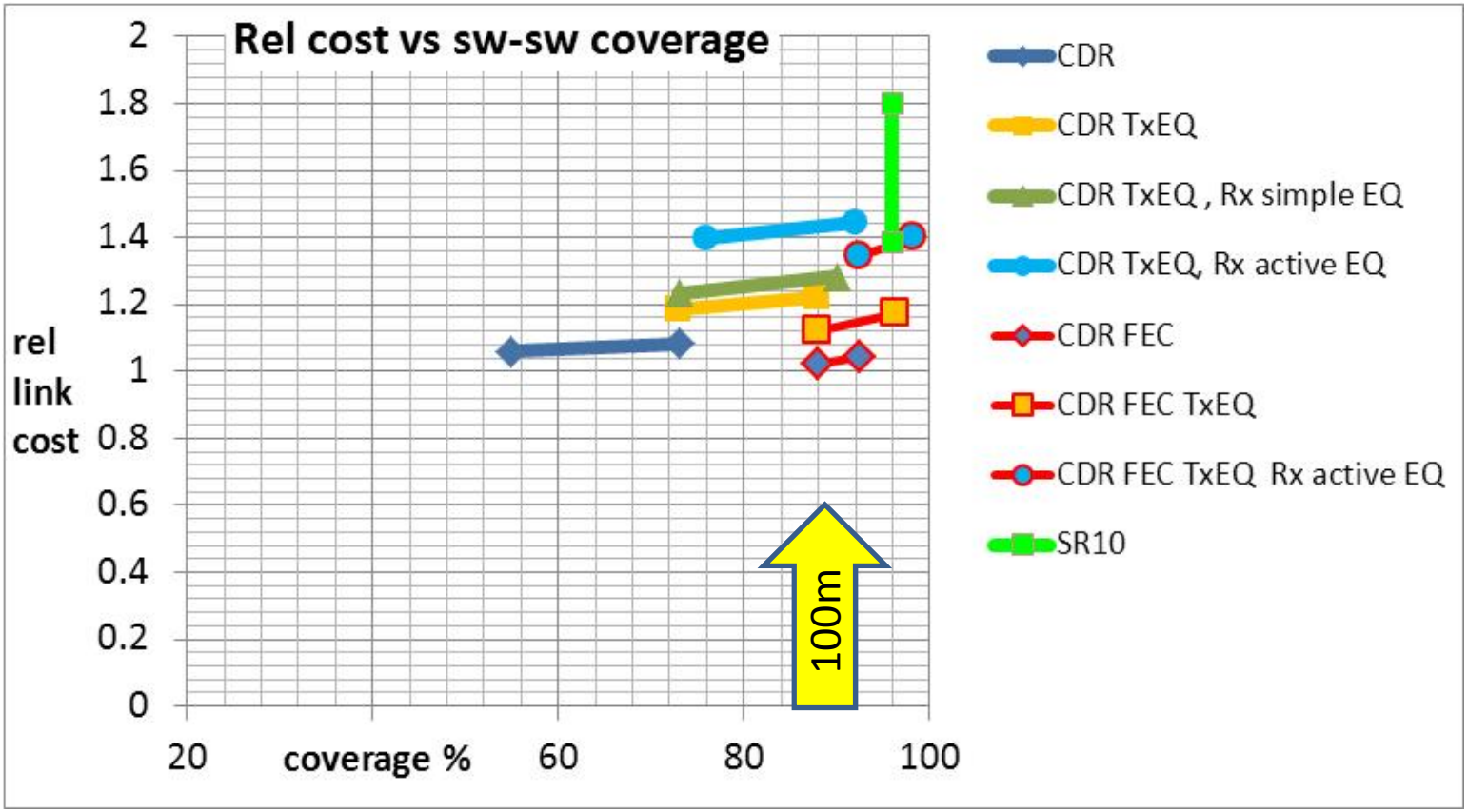
- Same reach numbers based on ***King_01_1111*** , but range of reach values plotted (for slow or fast VCSEL rise times); approximate cost numbers based on estimated set up and test time .
- Relative cost of 100G-SR10 added (high and low estimates are consistent with ***"100G Next Gen SR4 vis-à-vis SR10" by John Petrilla***, and estimated relative module cost 100G-SR10 vs 100G-SR4 included in back up slides in this presentation.

Estimated relative module cost vs coverage



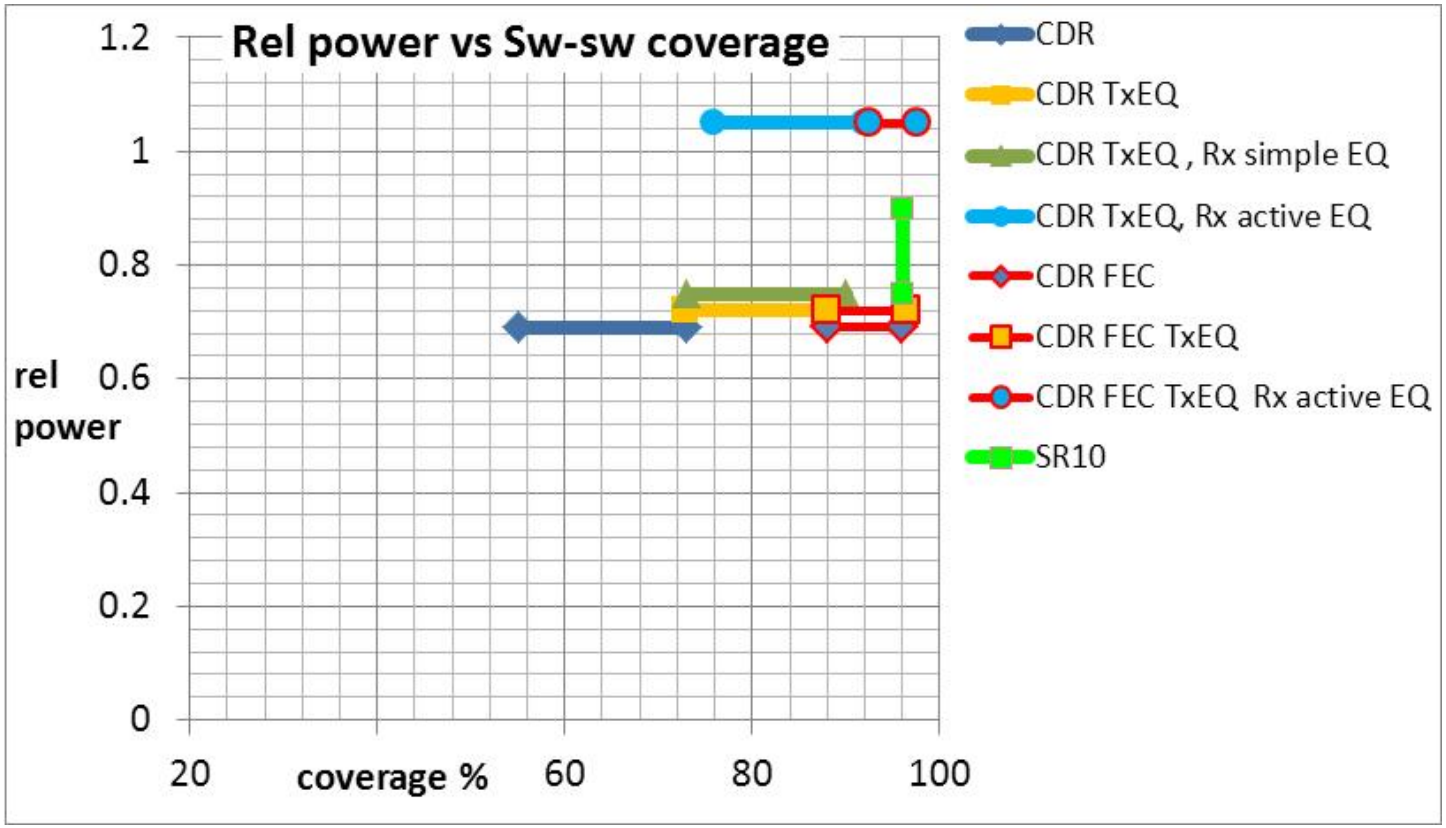
- Same examples, but plotted against % coverage of switch to switch links ***(Flatman_01_0911)***

Estimated relative module cost vs coverage



- As previous slide, but attempting to include the cost of connectivity
  - relative total link cost estimated from ***"Low Cost 100GbE Links" by Scott Kipp (Brocade), Doug Coleman and Steve Swanson (Corning)***
- Lower fibre count makes SR4 economically attractive cf SR10

Relative module power



- coverage and power similar for SR10 and FEC enabled SR4
  - Relative power of SR4 variants and SR10 consistent with ***"100G Next Gen SR4 vis-à-vis SR10" by John Petrilla***, and ***King_01_1111***

Back up

Estimated relative module cost
100G-SR10 vs 100G-SR4

100G-SR10	Rel cost	100G-SR4	Rel cost
10G VCSEL	10x	25G VCSEL	8x
10G Driver	10x	quad 25G driver	8x
10G PIN-TIA	10x	quad 25G PIN TIA	8x
10 channel electrical input EQ's & line drivers	10x	4xCDR pairs and electrical input EQ & line drivers (integrated with quad driver)	8x
10 channel testing	~10x	4 channel testing	~6x
PCBA and shell	1x	PCBA and shell	2x
Weighted relative cost	**~10x**		**~ 8x**

Cost of CDRs is a fraction of the total IC cost, and a relatively small fraction of total cost

FEC vs non FEC: 20 ps VCSEL rise time

Rate/FEC	Reach limit definition	OM4 reach	Typ. latency: 50m fiber + FEC	Max. latency: max reach + FEC	Notes
25.8 GBd, no FEC	power budget	**70 m**	250 ns	350 ns	~2.5 dB VECP
25.8 GBd, high latency FEC	power budget	155 m	550 ns	1075 ns	high ~4.5dB VECP
25.8 GBd, high latency FEC	3.6 dB VECP	**125 m**	550 ns	925 ns	1.7 dB margin for spec relaxation
25.8 GBd, high latency FEC	3.0 dB VECP	**100 m**	550 ns	800 ns	2.6 dB margin for spec relaxation
28 GBd, low latency FEC	power budget	140 m	280 ns	730 ns	high ~4.8 dB VECP !
28 GBd, low latency FEC	3.6 dB VECP	**100 m**	280 ns	530 ns	2.0 dB margin for spec relaxation

FEC vs non FEC: 16 ps VCSEL rise time

Rate/FEC	Reach limit definition	OM4 reach	Typ. latency: 50m fiber + FEC	Max. latency: max reach + FEC	Notes
25.8 GBd, no FEC	power budget	**100 m**	250 ns	500 ns	~2.2 dB VECP
25.8 GBd, high latency FEC	power budget	170 m	550 ns	1150 ns	high ~4 dB VECP !
25.8 GBd, high latency FEC	3.6 dB VECP	**155 m**	550 ns	1075 ns	1.2 dB margin for spec relaxation
25.8 GBd, high latency FEC	3.0 dB VECP	**135 m**	550 ns	975 ns	2.2 dB margin for spec relaxation
28 GBd, low latency FEC	power budget	160 m	280 ns	830 ns	high ~4.5 dB VECP !
28 GBd, low latency FEC	3.6 dB VECP	**135 m**	280 ns	705 ns	1.7 dB margin for spec relaxation

MMF developments

- Opportunity for new multimode fibres with higher bandwidth:
  - MMF with chromatic dispersion mitigation for VCSELs showing effective bandwidth up to 10,000 MHz.km
    - ECOC 2011, Tu.3.C.3: “Chromatic Dispersion Compensated Multimode Fibers for Data Communications”, Denis Molin, Marianne Astruc, Pierre Sillard; Draka Communications, France

Strawman reach objective for 100G-SR4

- “Define a FEC enabled 4-lane 100 Gb/s PHY for operation over MMF with reach up to at least 100m”
  - Meets requirements of the data center.
  - Consistent with Fiber Channel objectives.
  - Technically feasible, with several low power techniques available to achieve the distance.
  - Allows new fiber technology to be part of the solution.