Multipath Interference Penalty

IEEE 100GNGOPTX Study Group

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Multipath Interference Background

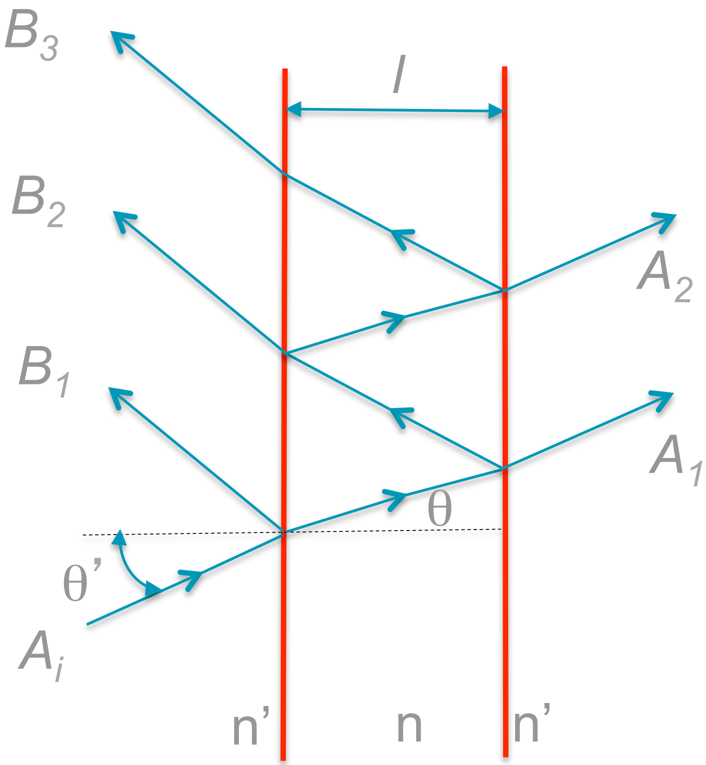
- Multipath interference penalty is as result of cascaded patch cord with connectors having finite reflection
- To investigate the worse case multipath penalty, here assumed the light is coherent and patch cords are lossless
  - Typical coherent length is expected to be in 10's m
- Each patch cord resembles a Fabry-Perot Etalon
  - Cascaded patch cords acts as an external cavity
- Cascaded patch cords each acts as an Etalon
  - Each patch cord may go through destructive or constructive interference as result of temperature, pressure, movements, polarization
  - At certain time and/or condition cascaded patch cord could go into constructive or destructive interference
  - The multipath penalty is bounded and does not cause an error floor

Basic Fabry-Perot Etalon

- Infinite reflections in an Etalon must be considered
- The number of partial waves produced by reflection at two end surfaces is given by [1]

$$\delta = \frac{4 \cdot \pi \cdot l \cdot \cos\theta}{\lambda}$$

Where l is the patch cord length, θ is the incident angle, and λ is the wavelength



Basic Fabry-Perot Etalon cont.

Given incident wave A_i the reflected and transmitted wave are given by

$$B_1 = r \cdot A_i \qquad B_2 = tt'r' \cdot A_i e^{i\delta} \qquad B_3 = tt'r'^3 \cdot A_i e^{2i\delta} \quad . \quad . \quad .$$

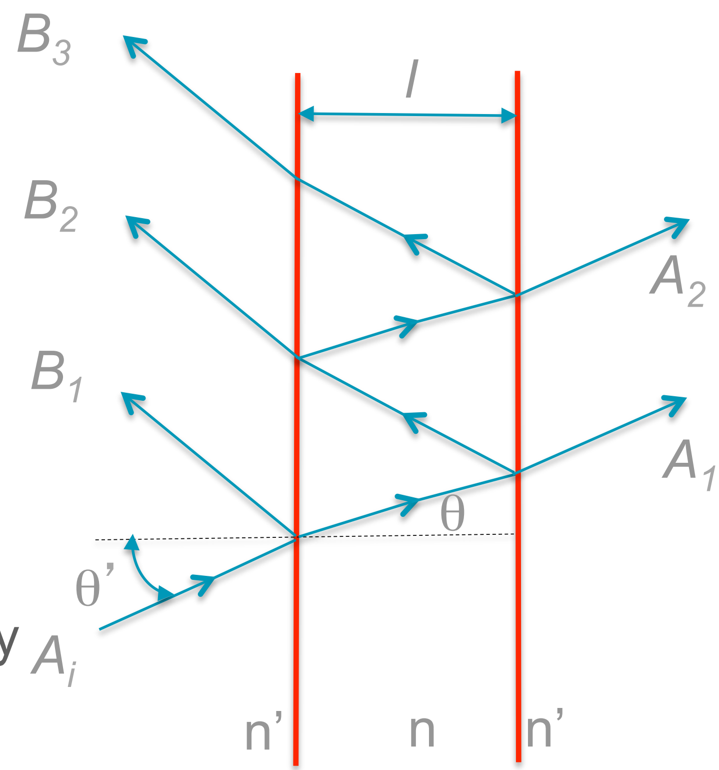
$$A_1 = tt' \cdot A_i \qquad A_2 = tt'r'^2 \cdot A_i e^{i\delta} \qquad A_3 = tt'r'^4 \cdot A_i e^{2i\delta} \quad . \quad . \quad .$$

Adding up A terms transmitted wave given by

$$A_t = tt'\left(1 + r'^2 e^{i\delta} + r'^4 e^{2i\delta} + \quad . \quad . \quad . \right)$$

Adding up B terms the reflected wave given by

$$A_r = \left\{r + tt'r'e^{i\delta} \cdot \left(1 + r'^2 e^{i\delta} + r'^4 e^{2i\delta} + \quad . \quad . \quad . \right)\right\}$$



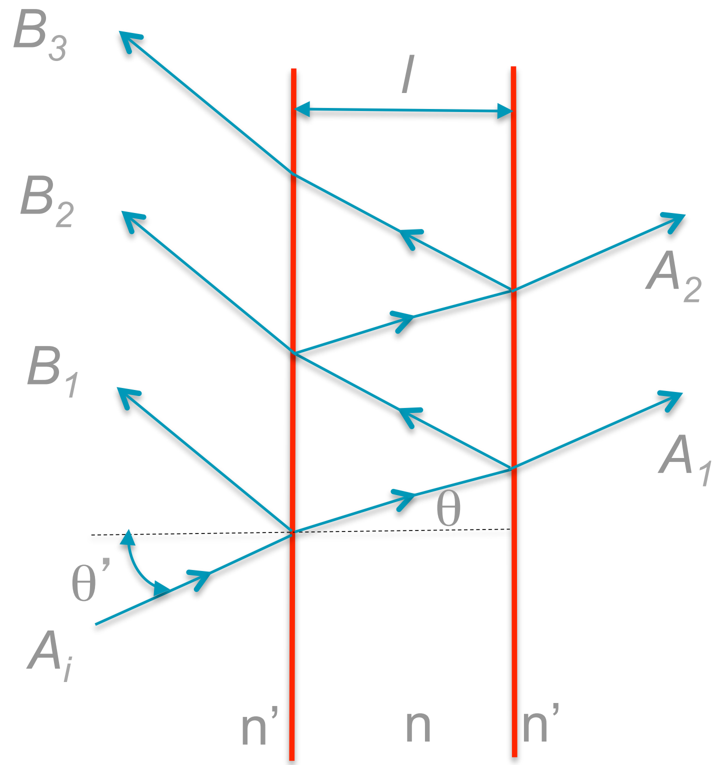
Basic Fabry-Perot Etalon cont.

Given r'=-r one gets

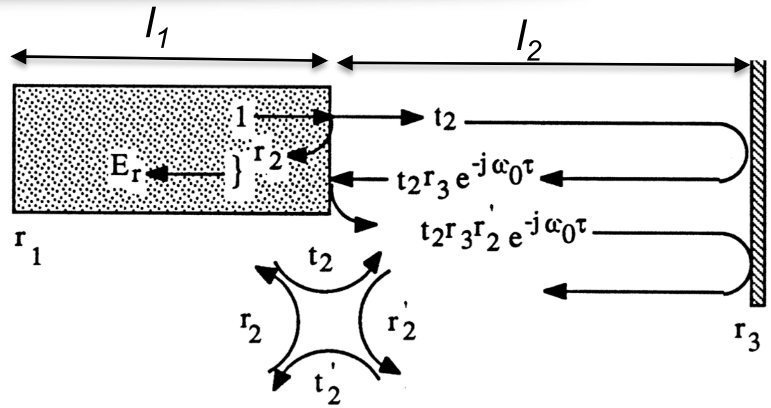
$$r^2 + tt' = 1 \qquad R \equiv r^2 = r'^2 \qquad T \equiv tt'$$

One may then drive the transmitted intensity I_t ($A_tA_t^*$) given incident incident I_t ($A_iA_i^*$)

$$\frac{I_t}{I_i} = \frac{A_t \cdot A_t^*}{A_r \cdot A_r^*} = \frac{(1-R)^2}{(1-R)^2 + 4R\sin^2\left(\delta/2\right)}$$



Using external cavity formulation for derivation of R_{eff}



Starting with basic EMF theory [2], use of τ for delay in the cavity l_2, and use derivation given in [3] for E_r and

$$E_r = r_2 + t_2 t'_2 r_3 e^{-j\omega_0\tau} \cdot U(\tau) + t_2 t'_2 r_3^2 e^{-j2\omega_0\tau} \cdot U^2(\tau) + \cdots$$

After some simplification and use of geometric series the close form solution is

$$E_r = r_2 + \frac{t_2 t'_2 r_3 e^{-j\omega_0\tau} U(\tau)}{1 - r'_2 r_3 e^{-j\omega_0\tau} U(\tau)}$$

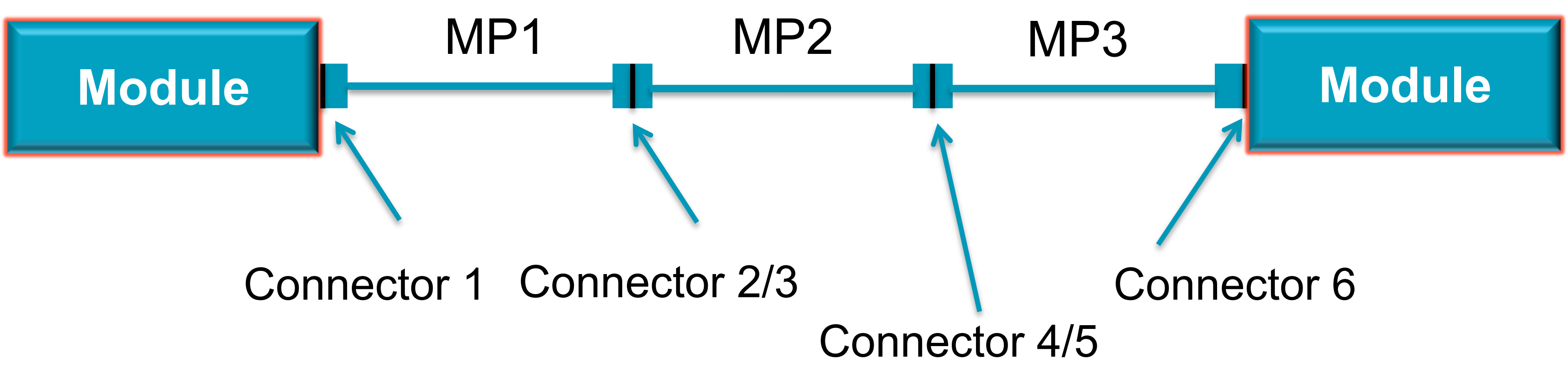
After some rearrangement and replacing r_2, r_3 with fraction of reflected intensity $\sqrt{R_2}$ and $\sqrt{R_3}$

$$R_{eff} = \frac{\left(\sqrt{R_2} + \sqrt{R_3} e^{-j\omega_0\tau} U(\tau)\right)}{\left(1 - \sqrt{R_2 R_3} e^{-j\omega_0\tau} U(\tau)\right)}$$

External cavity l_2 has effectively created wavelength dependent mirror $R(\lambda)$. $U(\tau)$ is a time operator and is unity for steady state.

Multiple Patch Cords Reference Model

- Multipath Penalty with up to 3 patch cords are analyzed
- Assumes lossless patch cords/connectors
- Beyond 3 patch cords or 4 connectors the probability of constructive interference will be unlikely and after 2 or 3 patch cords the length of the cable could be beyond the coherent length of laser
  - Where intensity addition results instead of field addition



An Approximation to Multipath Interference Penalty

- A simple approximation to calculated multipath interference is provided by D. Duff [4] where it assumes reflections between patch cords are negligible

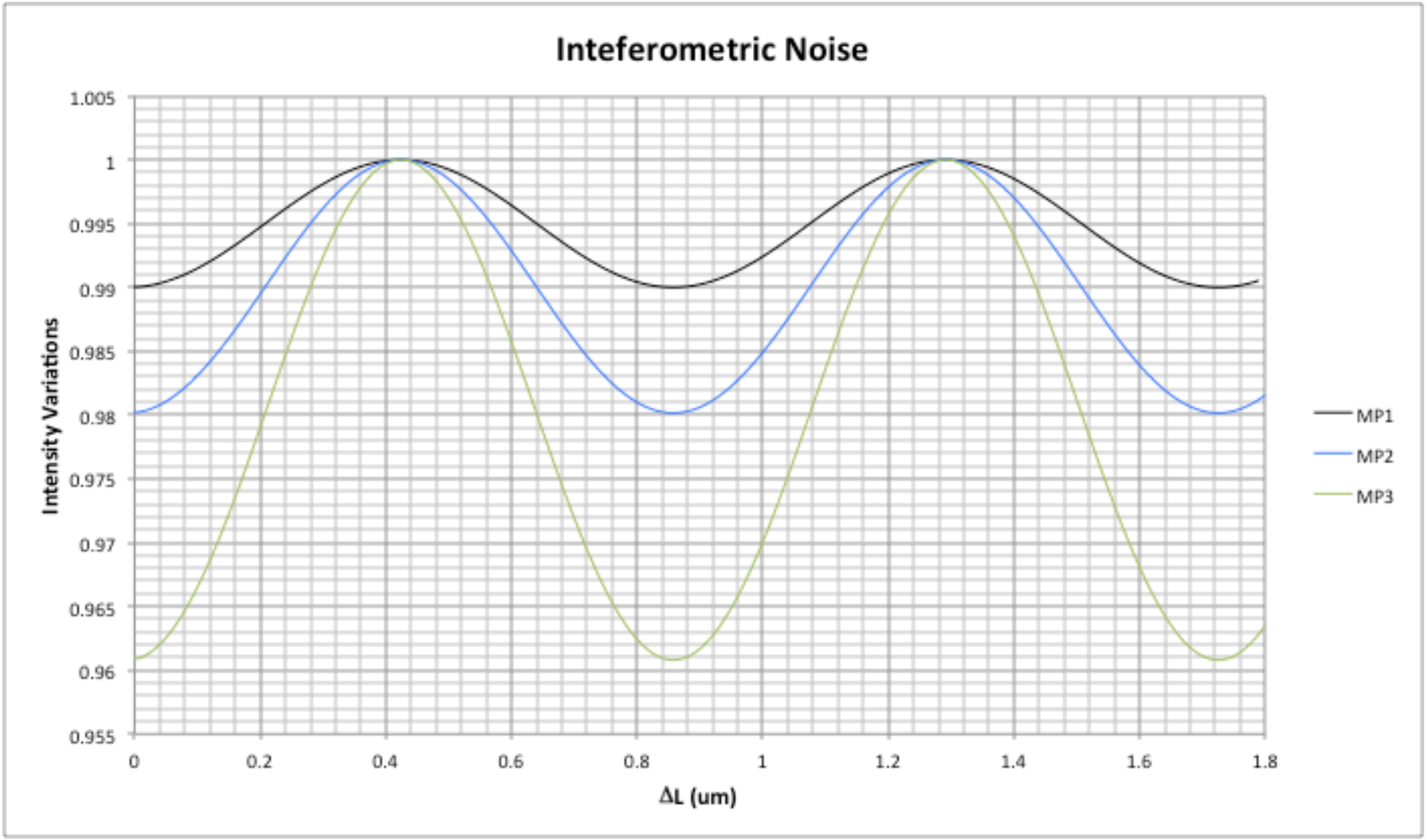
$$P_{mpi} = 10 \cdot \log_{10}\left[1 - 4N \cdot \sqrt{R_1 \cdot R_2}\right](dB)$$

Where N is the number of patch cords cascaded, R_1 and R_2 are reflection at each end of patch cord

- Duff results matches exactly with results presented here for using external cavity formulation to account for cross cavity reflections for single patch cord, then Duff formulation under estimating as number of patch cords increases.

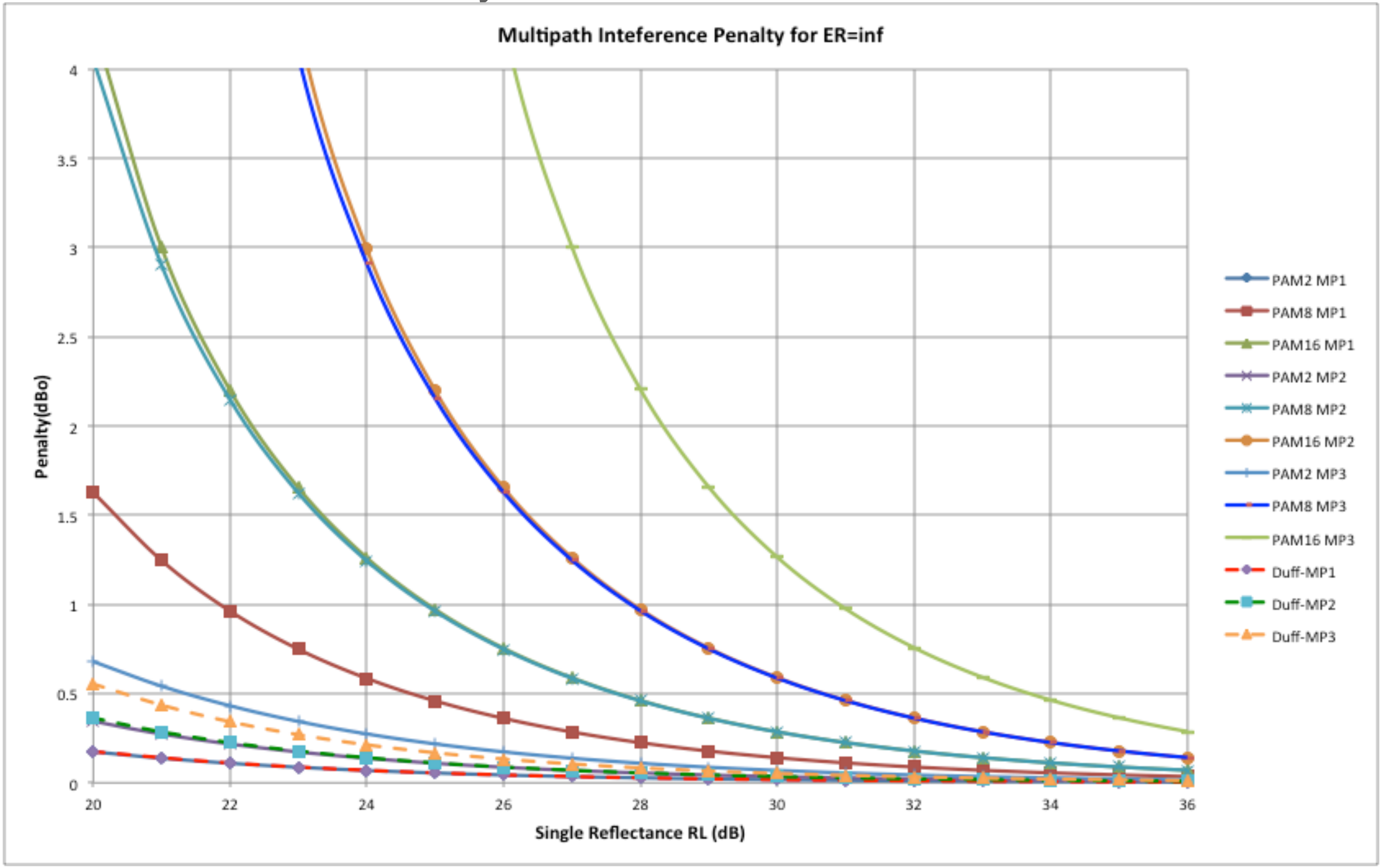
Multipath Interference Penalty

- Multipath penalty shown with up to 3 lossless patch cords
  - Each patch cord has response designated at MP1, sometimes two patch cord will walk resulting in MP2, and even less frequently MP2 can combine with MP1 to result MP3 response



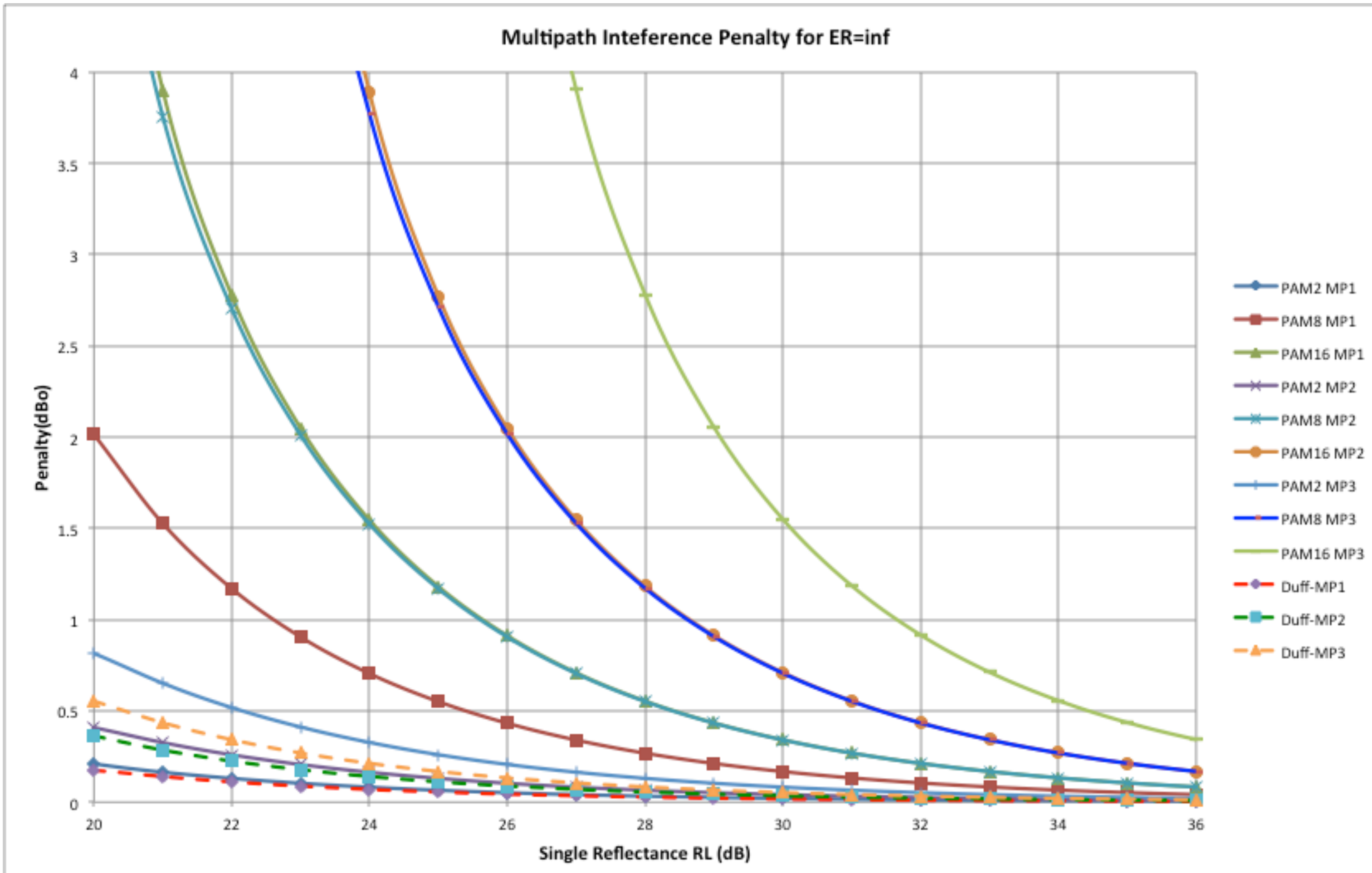
Multipath Interference Penalty

- Penalty assuming ER=∞
  - Results for MP1 exactly matches derivation given [4] which neglects some of the secondary reflections



Multipath Interference Penalty

- Penalty assuming ER=8 dB
  - With ER=8 dB there is slight deviation with results given [4] which neglects some of the secondary reflections



Summary

- Multipath Interference Penalty are real eve though sometimes difficult to observe
- The good news is that Multipath Interference Penalty are bounded and directly related the connector reflections
- Beside improving connector RL, Coherent length, and finite loss can also mitigate Multipath Interference Penalty
- Higher PAM signaling are more sensitive to Multipath Interference Penalty
- With PAM-16 budget already challenged not sure how the budget can be met without improving connector RL=26 dB
- With PAM-8 even if one assumes 3 lossless patch cord the penalty is 2 dBo where it would get mitigate as result of cable/connector loss and non-coherent addition if the cable length>20 m.

References

[1] Amnon Yariv, Optical Electronics, Yariv, New York, HRW, 1985.

[2] R. E. Collin, Foundations of Microwave Engineering, New York, McGraw-Hill, 1966.

[3] A. Ghiasi and A. Gopinath, Optical signal distribution scheme for millimeter phased array radar, RL-TR-92-104, Rome Laboratory, AFSC, Griffiss AFB, NY, 1992.

[4] D. Duff, et al., Measurements and simulations of multipath interference for 1.7 Gbit/s lightwave system utilizing single and multifrequency lasers, Proc. OFC, 1989.

Thank You