

# Mode Partition Noise Handling in Spreadsheet Model

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# Problem Statement and Solution

- Mode Partition Noise (MPN) penalty calculation does not take into account inter-symbol interference (ISI)
- RIN properly treated, need to **apply the same approach** for MPN
- Need to make appropriate corrections in Pcross

# How do we calculate the penalties

- Spreadsheet uses well documented formulas to calculate individual penalties
  - Inter-symbol interference (ISI), relative intensity noise (RIN), mode partition noise (MPN)
- Interactions of penalties (non-linear addition) is handled by adding the cross penalty ( $P_{cross}$ ), correcting for the effect
- Assumes all penalties have Gaussian distribution, can use error function to calculate the bit error rate

# BER calculation

The worst case BER is given by:

$$BER = \frac{1}{2} * erfc\left(\frac{d_{\min}}{\sqrt{2}\sigma_{\text{tot}}}\right) = \frac{1}{2} * erfc\left(\frac{Q}{\sqrt{2}}\right)$$

$d_{\min}$  - minimum distance from “1” level to threshold (includes ISI)

$\sigma_{\text{tot}}$  – standard deviation of the noise, includes all contributions (receiver noise, RIN, mode partition noise, modal noise):

$$\sigma_{\text{tot}}^2 = \sigma_{\text{rx}}^2 + \sigma_{\text{rin}}^2 + \sigma_{\text{mpn}}^2 + \sigma_{\text{mn}}^2$$

In the spreadsheet model, **RIN and mode partition noise standard deviations are calculated relative to the OMA and OMA/2 respectively [1, 2]**

To find the individual penalty for the signal dependent noises (RIN, MPN),  $d_{\min}$  has to take into account the ISI **in the PENALTY formulas**

This is already done with RIN [3,4], but not with MPN, need to make appropriate changes to the spreadsheet model

# Current state for RIN column

Formula shows in the cell entry area when you click in any cell (here R18) in Prin column (R)

Formula bar:  $=10*\text{LOG10}(1/\text{SQRT}(1-18*(Q/AA18)^2))$

Case	850nm serial	newMMF	Attenuation=	3.5 dB/km	Model/Form						
Target reach	0.07 km		Fiber at	850 nm	NomSens QMA						
L_start=	0.002 km		C_att=	1.00	Receive Refl Rx						
L_inc=	0.007 km		Attenuation=	3.62 dB/km	Rec_BW= :						
Power Budget P=	5.61 dB		at	840 nm	c_rx						
DCD Connections C	1.5 dB		Disp. min. Uo=	1316 nm	T_rx(10-90)						
Pwr.Bud.-Conn.Loss	4.11 dB		Disp. So=	0.103 ps/nm^2*km	TP4 Eye						
C1=	480 ns.MHz		Disp. D1=	-108.68 ps/(nm.km)	Opening						
Reflection Noise factor	0 no units				RMS Baseline wander SD						
Effective Rate	27427 MBd		(not in use)	10							
Tb_eff=	36 ps		BWm=	4400 MHz*km	P_BLW(no ISI)						
Effective Rec Eye	0.21 UI		Eff. BWm=	4.4E+03 MHz*km	P_BLW						
Pisi	P Eye	P_DJ	P_DJ	Preflection	Pcross						
central	corners	central	corners	centra	Beta						
J=0, dB	(dB)	(dB)	(dB)	(dB)	SDmpn						
					Pmpn						
					Prin						
					central						
1E+06	2.2E+06	30	34	1.85	0.24	0.02	0.18	-1E-02	0.00	0.00	0.16
#####	#####	30	34	1.85	0.24	0.02	0.18	0	-0.01	0.00	0.31
#####	488,889	30	34	1.86	0.24	0.02	0.18	0	-0.05	0.00	0.31
#####	275,000	31	34	1.88	0.24	0.02	0.18	0	-0.09	0.00	0.31

Correction for ISI (divide by AA18)

$$18*(Q/AA18)^2$$

Prin cell clicked, R18 here

**RIN is correctly handled**

# Current state for MPN

Formula shows in the cell entry area when you click in any cell (here Q18) in Pmpn column (Q)

fx =10\*LOG10(1/SQRT(1-(Q\*P18)^2))

F	G	H	I	J	K	L	M	N	O	P	Q	R
ingham, Piers Dawe, David Dolfi Agilent Technologies								Rev. 3.2/3	This file		100	
(20-80)	20 ps	Case	850nm serial	newMMF		Attenuation=	3.5 dB/km					
(10-90)	30 ps	Target	Target reach	0.07 km		Fiber at	850 nm	NomSe				
V(OMA)	-130 dB/Hz	and	L_start=	0.002 km		C_att=	1.00	Receiv				
it MinER	-138.0 dB/Hz	graph	L_inc=	0.007 km		Attenuation=	3.62 dB/km	Re				
L_Coef=	0.70	Power Budget P=		5.61 dB		at	840 nm					
let.Jitter	4.7 ps	inc. DCD	Connections C	1.5 dB		Disp. min. Uo=	1316 nm	T_D				
CD_DJ=	2.3273 ps	TP3Pwr.	Bud.-Conn.	Loss 4.11 dB		Disp. So=	0.103 ps/nm^2*km					
act. DJ=	0.07 (UI)	ex DCD	C1=	480 ns.MHz		Disp. D1=	-108.68 ps/(nm.km)					
k(OMA)	0.3	Reflection Noise factor		0 no units		RMS Baseline wa						
e height	46.6%	Effective Rate		27427 MBd		(not in use)	10					
Refl Tx	-12 dB	Tb_eff=		36 ps		BWm=	4400 MHz*km	P_BL'				
oisePen	0.3 dB	Effective Rec Eye		0.21 UI		Eff. BWm=	4.4E+03 MHz*km					
task top	0.2 UI	Pisi PEye		P_DJ P_DJ		Preflection						
BWcd	effBWm	Te	Tc	central	corners	central	corners	centra	Beta	SDmpn	Pmpn	Prin
(MHz)	(MHz)	(ps)	(ps)	J=0, dB	(dB)	(dB)	(dB)	(dB)			(dB)	(dB)
1E+06	2.2E+06	30	34	1.85	0.24	0.02	0.18	-1E-02	0.00	0.00		
#####	#####	30	34	1.85	0.24	0.02	0.18	0	-0.01	0.00	0.00	0.61
#####	488,889	30	34	1.86	0.24	0.02	0.18	0	-0.05	0.00	0.00	0.61

Correction for ISI is missing (divide by AA18)

$$-(Q*P18)^2$$

**MPN is not handled correctly**

Prin cell clicked, Q18 here

# Proposed solution

- Apply the same modification in Q column as for RIN (divide Q value by the appropriate column AA value)

Formula bar:  $f_x = 10 * \text{LOG10}(1 / \text{SQRT}(1 - (Q / AA18 * P18)^2))$

Case	850nm serial	newMMF	Attenuation=	3.5 dB/km								
Target reach	0.07 km	Fiber at	850 nm	NomSe								
L_start=	0.002 km	C_att=	1.00	Receiv								
L_inc=	0.007 km	Attenuation=	3.62 dB/km	Re								
Power Budget P=	5.61 dB	at	840 nm									
Connections C	1.5 dB	Disp. min. Uo=	1316 nm	T_rx								
TP3Pwr.Bud.-Conn.Loss	4.11 dB	Disp. So=	0.103 ps/nm <sup>2</sup> *km									
C1=	480 ns.MHz	Disp. D1=	-108.68 ps/(nm.km)									
Reflection Noise factor	0 no units			RMS Baseline wa								
Effective Rate	27427 MBd	(not in use)	10									
Tb_eff=	36 ps	BWm=	4400 MHz*km	P_BL'								
Effective Rec Eye	0.21 UI	Eff. BWm=	4.4E+03 MHz*km									
Pisi	P_Eye	P_DJ	P_DJ	Preflection								
central corners	central corners	centra	Beta	SDmpn								
J=0, dB	(dB)	(dB)	(dB)	Pmpn								
				Prin								
1E+06	2.2E+06	30	34	1.85	0.24	0.02	0.18	-1E-02	0.00	0.00	0.61	
#####	#####	30	34	1.85	0.24	0.02	0.18	0	-0.01	0.00	0.00	0.61
#####	488,889	30	34	1.86	0.24	0.02	0.18	0	-0.05	0.00	0.00	0.61

Without change

$$-(Q * P18)^2$$



With change

$$-(Q / AA18 * P18)^2$$

# Other changes needed

- Appropriate change in Pcross needs to be made (column S):

Before:

```
=-10*LOG10(AA18*SQRT(1-Q*Q*((SD_blw^2+AK18)/AA18^2+Vmn+P18*P18)))
```



After:

```
=-10*LOG10(AA18*SQRT(1-Q*Q*((SD_blw^2+AK18+P18^2)/AA18^2+Vmn)))
```

P18 moved inside inner parenthesis, divided by AA values (ISI)



# Related and Future Work

- MPN theory is valid for SMF with MMF sources only, but mistakenly also applied to MMF [5]
- Two effects working in opposite direction:
  - MPN is time and pattern dependent, worst case is at bit edges and for high ISI bits for both SMF and MMF
  - MMF reduces MPN compared to SMF, reduction proportional to effective number of mode groups (launch conditions matter!)

# References

1. G. Agrawal et. al.: JLT, Vol.6, No.56, May 1988, pp. 620-625
2. K. Ogawa: IEEE JQE, Vol. QE-18, No.5, May 1982., pp. 849-855
3. [http://www.ieee802.org/3/ae/public/oct01/dawe\\_1\\_1001.pdf](http://www.ieee802.org/3/ae/public/oct01/dawe_1_1001.pdf), pages 14-15
4. [http://www.ieee802.org/3/ae/public/mar00/dawe\\_1\\_0300.pdf](http://www.ieee802.org/3/ae/public/mar00/dawe_1_0300.pdf), page 6  
(slides 11 and 12)
5. *P. Pepeljugoski - unpublished work*