Pin photodiode (PT10XGC)

$P_{min} = -20$ dBm @ $BER = 10^{-12}$, $B = 9$ GHz

$R = 0.8$ A/W

SMF28 optical fiber

$\alpha = 0.2$ dB/km

CQF 938/500 DFB laser

$P_t = 50$mW $=$ 17dBm

$\lambda = 1550$nm

$\Delta f = 1$MHz

Maximum distance

$$PB = 17 + 20 = 37\text{dB}$$

$$\frac{37\text{dB}}{0.2\text{dB/km}} = \boxed{185\text{ km}}$$

we will also need the thermal noise

$$49.5 = \frac{[(0.8)(10^{-5})]^2}{\sigma_{th}^2}$$

$$\sigma_{th}^2 = \frac{[(0.8)(10^{-5})]^2}{49.5}$$

$$\sigma_{th}^2 = 1.29 \times 10^{-12}$$

Use an EDFA (CPA Series from JDS Uniphase)

Flatness 1.5dB

PMD 0.5ps

NF 6.0 for $G = 23$dB

8.4 for $G = 13$dB

$$5 < G < 23\text{dB}$$

$P_{sat} = 17$dBm

Why is the noise figure gain dependent?

Gain is changed by increasing pump power, which increases the population inversion.

High gain $\rightarrow$ higher n_{sp}

Where can we place the EDFA?

At the transmitter : Power Amplifier

At the receiver : Pre-amplifier

In the middle of the link

As a power amplifier the EDFA will not do much because $P_t = P_{sat}$

What is the best case (No EDFA noise)?
EDFA adds no noise

$$P_B = 17 + 20 + 23 = 60\,dB$$

$$L = \frac{60}{.2} = 300\,Km$$

USE EDFA as a preamplifier

$$\sigma^2_{ASE} = 4R^2 G^2 P_{in}\, n_{sp}X\, hf\, \Delta f$$

We know everything except for $n_{sp}X$
The spec sheet provides noise figure NF

$$NF = \left(\frac{SNR_{in}}{SNR_{out}}\right) = \frac{SNR_{shot}}{SNR_{ase}} = \left(\frac{(RP_{in})^2}{2qRP_{in}\Delta f}\right) \frac{4R^2G^2 P_{in} n_{sp}X\, hf\Delta f}{(RGP_{in})^2}$$

$$= \left(\frac{R\cancel{P_{in}}}{2q\cancel{\Delta f}}\right) \frac{4\, n_{sp}X\, hf\, \cancel{\Delta f}}{\cancel{P_{in}}}$$

$$= R\left(\frac{hf}{q}\right) 2\, n_{sp}X$$

$$R = \eta \frac{q}{hf}$$

$$NF = \eta\left(\frac{q}{hf}\right)\left(\frac{hf}{q}\right) 2\, n_{sp}X$$

$$NF = (\eta)(2n_{sp}X)$$

We just need η

$$R = 0.8 = \eta\, \frac{(1.55)}{1.24}$$

$$\eta = 0.64$$

$$10\log_{10}(6) = (0.64)\, 2n_{sp}X$$

$$n_{sp}X = \frac{10\log_{10}(6)}{(2)(0.64)}$$

$\boxed{n_{sp}X = 6}$ for high gain

for low gain $n_{sp}X = 7.22$

Assume σ^2_{ASE} is the dominant noise term

$$SNR = \frac{(RGP_{in})^2}{4 R^2 G^2 P_{in} n_{sp} \chi \, hc \, \Delta f} \lambda$$

$$SNR = \frac{P_{in} \lambda}{4 \, n_{sp} \chi \, hc \, \Delta f}$$

$$P_{in} = (SNR)(4) \, n_{sp} \chi \left(\frac{hc}{\lambda}\right) \Delta f$$

$$P_{in} = (49.5)(4)(6) \frac{(6.6\times10^{-34})(3\times10^{8})}{1.55\times10^{-6}} (9\times10^{9})$$

$$P_{in} = 1.37 \, \mu W = -28.65 \, dBm$$

$$L = \frac{17 + 28.65}{0.2}$$

$L = 228$ Km a gain of 43 Km
substanially shorter than the ideal of
300 Km

Was the assumption valid?

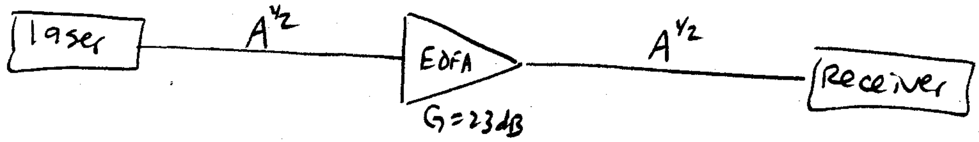
$$\sigma^2_{ASE} = 4R^2 G^2 P_{in} n_{sp} \chi \frac{hc}{\lambda} \Delta f = 9.6\times10^{-10}$$

$$\sigma_{sh}^2 = 2q R G P_{in} = 6.98\times10^{-23}$$

$$\sigma_{th}^2 = 1.29\times10^{-12}$$

so $\sigma^2_{ASE} \gg \sigma_{sh}^2$
$\sigma^2_{ASE} \gg \sigma_{th}^2$

Now place the EDFA in the middle of the link



The EDFA noise is independent of position

$$\sigma_{ASE}^2 = 4R^2G^2 P_{in}\, n_{sp} X \frac{hc}{\lambda} \Delta f$$

$$= 4R^2G^2 (P_t A)\, n_{sp} X \frac{hc}{\lambda} \Delta f$$

But the noise is attenuated by $A^{1/2}$

$$\sigma_{ASE}^2 = 4R^2G^2 (P_t A)\, n_{sp} X \frac{hc}{\lambda} \Delta f \, A^{1/2}$$

Assume σ_{ASE}^2 dominates

$$SNR = \frac{(\cancel{R} P_t A \cancel{G})^2}{4\cancel{R^2}\cancel{G^2}(P_t A)\, n_{sp} X \frac{hc}{\lambda} \Delta f \, A^{1/2}}$$

$$SNR = \frac{P_t \, A^{1/2}}{4\, n_{sp} X \frac{hc}{\lambda} \Delta f}$$

$$A^{1/2} = (SNR)\, 4\, n_{sp} X \frac{hc}{\lambda} \Delta f \left(\frac{1}{P_t}\right)$$

$$A = \left[(49.5)(4)(6)\frac{(6.6\times10^{-34})(3\times10^{8})}{1.55\times10^{-6}} \frac{(9\times10^{9})}{50\times10^{-3}}\right]^2$$

$$A = 7.46\times10^{-10} = 91.3\,dB$$

$$L = \frac{91.3}{0.2} = 456.5\ Km > 300\,Km$$ so something is wrong

check assumptions

$$\sigma_{sh}^2 = 2q\,R\,G\,P_{in} = 1.9\times10^{-27}$$

$$\sigma_{ASE}^2 = 4R^2G^2 P_{in}\, n_{sp} X \frac{hc}{\lambda} \Delta f \, A^{1/2} = 7.16\times10^{-19}$$

$$\sigma_{th}^2 = 1.29\times10^{-12}$$

so $\sigma_{th}^2 > \sigma_{ASE}^2$

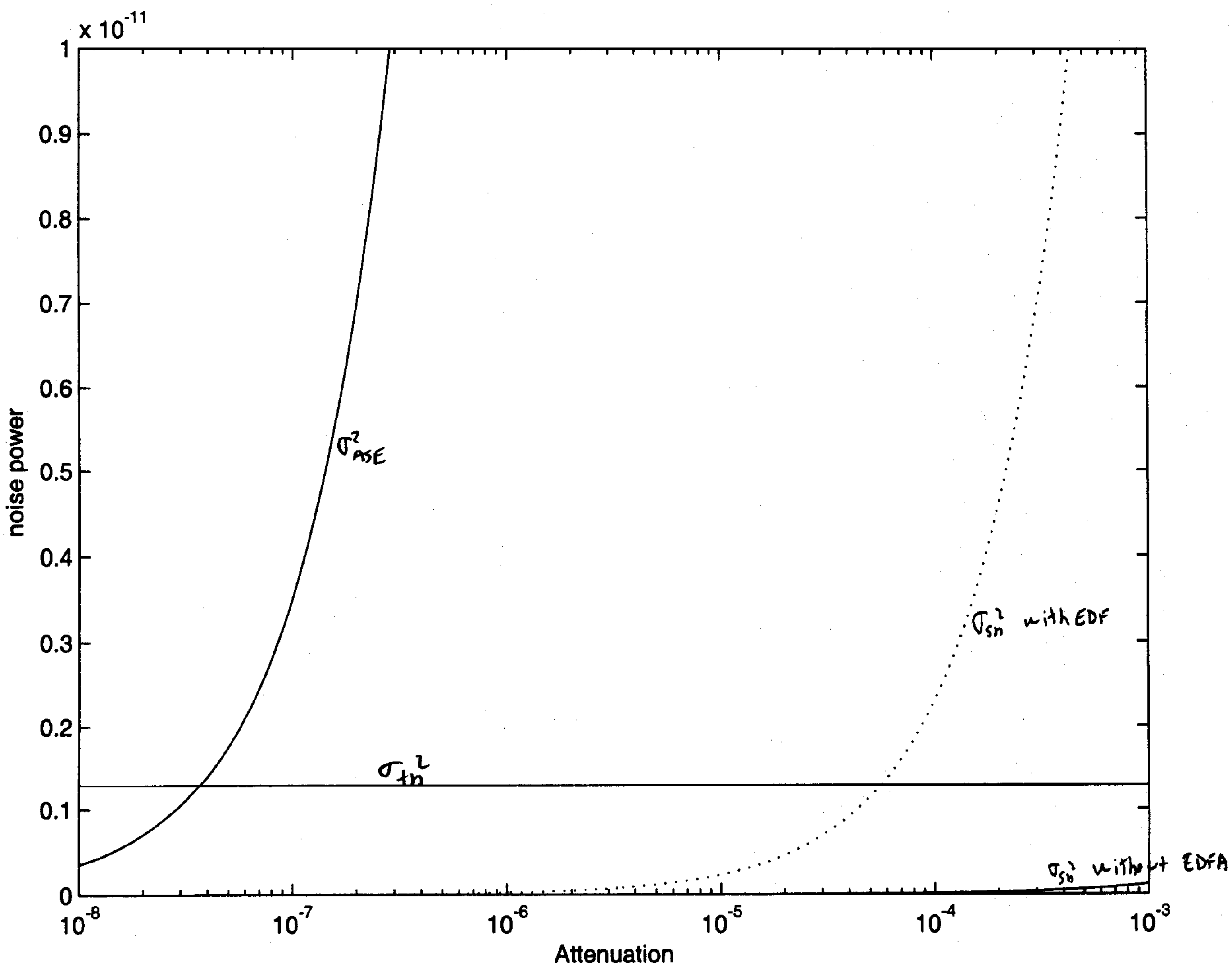
$$SNR = \frac{(R P_t A G)^2}{\sigma_{th}^2 + 4R^2G^2 (P_t A)\, n_{sp} X \frac{hc}{\lambda} \Delta f\, A^{1/2}}$$

$$(R^2 P_t^2 G^2) A^2 - SNR (4) R^2 G^2 P_t\, n_{sp} X \frac{hc}{\lambda} \Delta f\, A^{1.5} - SNR\, \sigma_{th}^2 = 0$$

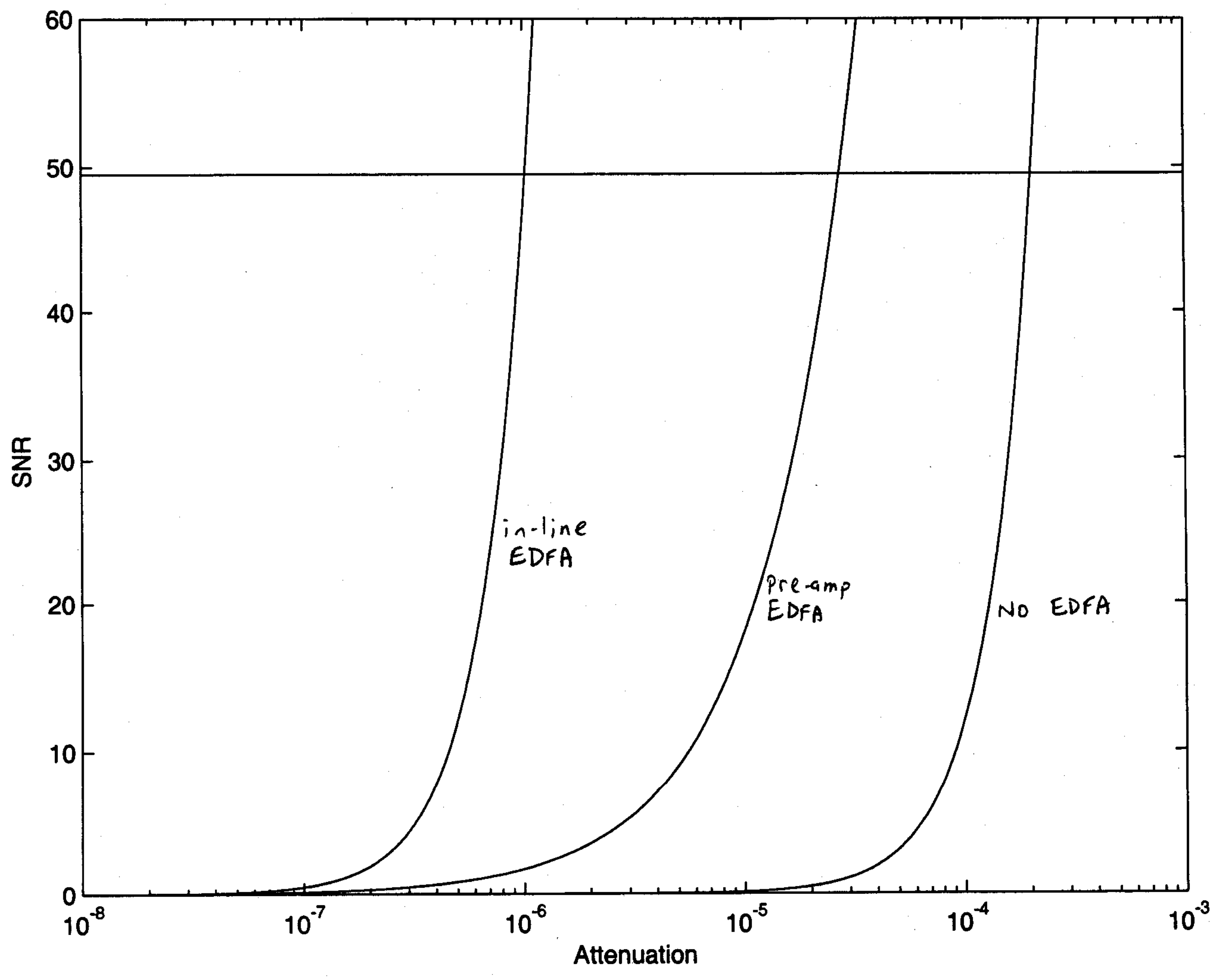
Solve for A

$A = 1.023 \times 10^{-6} = 59.9\ dB$

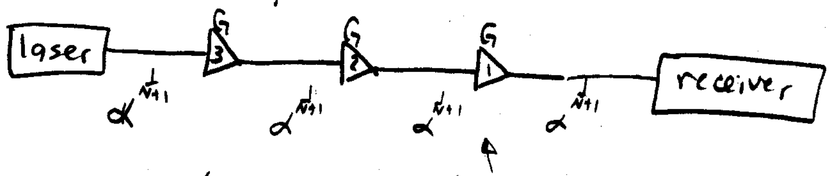
$L = \frac{59.9}{0.2} = 299.5\ Km$ very close to ideal length



x 10^-11
noise power
Attenuation
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
σ^2_{ASE}
σ_{th}^2
σ_{sn}^2 with EDF
σ_{sn}^2 without EDFA


SNR
60
50
40
30
20
10
0
10^-8
10^-7
10^-6
10^-5
10^-4
10^-3
Attenuation
in-line EDFA
pre-amp EDFA
No EDFA

If multiple amplifiers are used



$$\sigma^2_{ASE} = 4\,(R P_t \alpha G^N)\left(R\, n_{sp} \chi \frac{hc}{\lambda} \Delta f\, G\right)$$

$$\sigma^2_{ASE1} = \sigma^2_{ASE}\, \alpha^{\frac{1}{N+1}}$$

$$\sigma^2_{ASE2} = \sigma^2_{ASE} \left(\alpha^{\frac{2}{N+1}}\right) G$$

$$\sigma^2_{ASE3} = \sigma^2_{ASE}\, \alpha^{\frac{3}{N+1}} G^2$$

$$\cdots$$

$$\sigma^2_{ASE,TOT} = \frac{\sigma^2_{ASE}}{G}\left[G \alpha^{\frac{1}{N+1}} + \left(G \alpha^{\frac{1}{N+1}}\right)^2 + \left(G \alpha^{\frac{1}{N+1}}\right)^2 + \cdots \left(G \alpha^{\frac{1}{N+1}}\right)^{N-1}\right]$$

$$= \sigma^2_{ASE}\, \alpha^{\frac{1}{N+1}} \left[1 + G\alpha^{\frac{1}{N+1}} + \left(G\alpha^{\frac{1}{N+1}}\right)^2 + \cdots \left(G \alpha^{\frac{1}{N+1}}\right)^{N-1}\right]$$

let $G\, \alpha^{\frac{1}{N+1}} = r$

$$\sigma^2_{ASE,TOT} = \sigma^2_{ASE}\, r \left(1 + r + r^2 + \cdots r^{N-1}\right)$$

$$1 + r + r^2 + \cdots = \frac{1}{1-r} \quad \text{if } |r| < 1$$

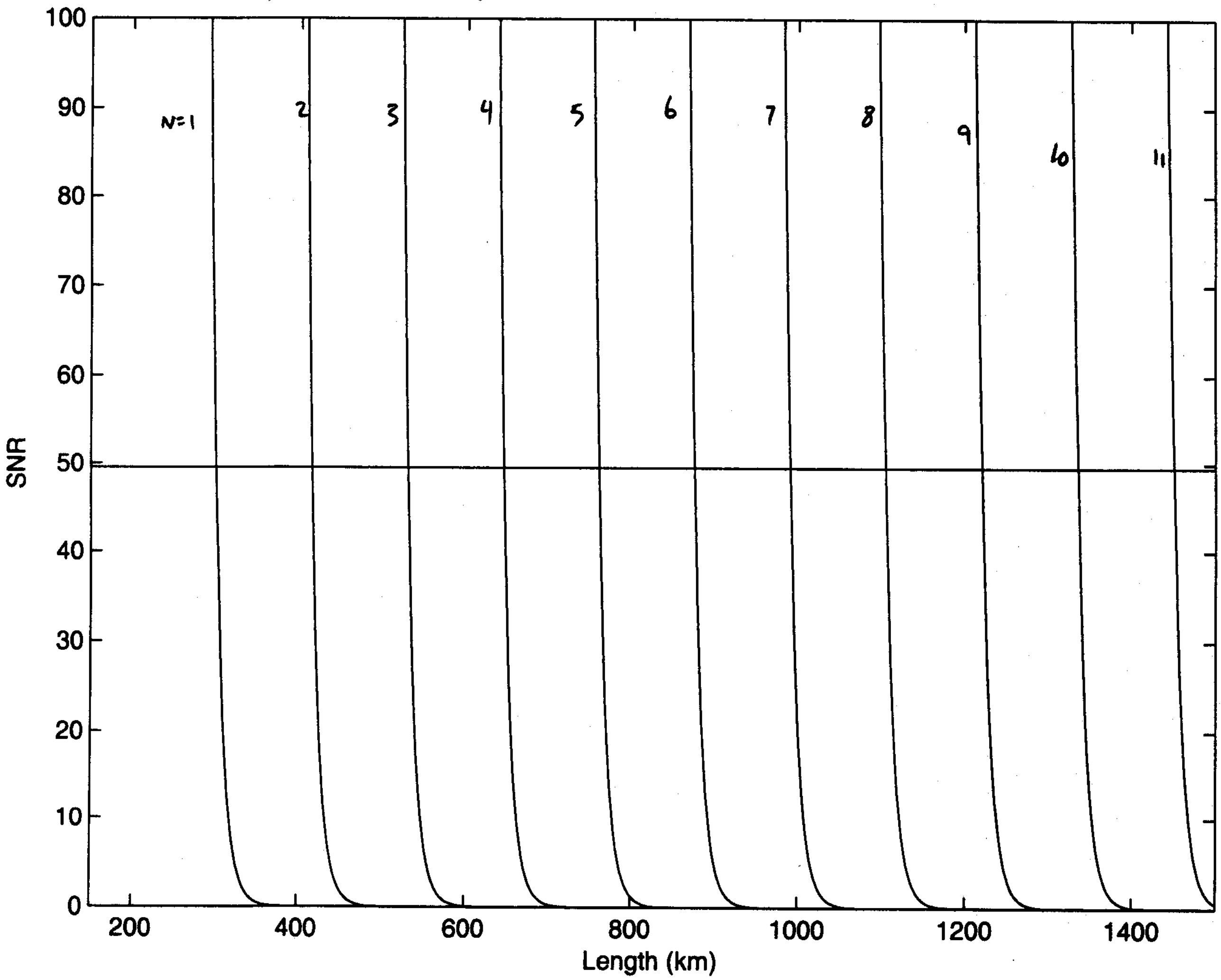
$$r^N + r^{N+1} + \cdots = r^N\left(1 + r + r^2 + \cdots\right) = r^N \frac{1}{1-r}$$

$$1 + r + r^2 + \cdots r^N = \frac{1}{1-r} - \frac{r^N}{1-r} = \frac{1-r^N}{1-r}$$

$$\sigma^2_{ASE,TOT} = 4\,(R P_t \alpha G^N)\left(R\, n_{sp} \chi \frac{hc}{\lambda} \Delta f\right)\left(G \alpha^{\frac{1}{N+1}}\right)\left(\frac{1 - G^N \alpha^{\frac{N}{N+1}}}{1 - G\, \alpha^{1/N+1}}\right)$$

$$SNR_{(n)} = \frac{(R \alpha P_t G^N)^2}{\underbrace{2qR\alpha P_t G^N \Delta f}_{\text{shot}} + \underbrace{\sigma_{th}^2}_{\text{thermal}} + \underbrace{\sigma^2_{ASE,TOT}}_{\text{ASE}}}$$

with in-line EDFAs



$\alpha = 0.2 \, dB/km$