

Assignment 3

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- 1 - The EDFA design is split into 2 stages, the first stage of the amplifier is the pre-amplifier like a setup for the second stage. The second stage is a power booster amplifier that configuration used to boost launch power. In the second stage it uses a mirror so that the signals make a double-pass through the stage to increase efficiency and gain.

The conditions on ~~light~~ length for the design is that different for the stages. L_1 could / should be relatively short since it only needs a small amount of gain. L_2 would be longer b/c it needs more gain but the mirror with double pass configuration helps limit the needed length. The total noise figure of the amplifier is mostly in the first stage. To get a low noise figure we use 980 nm pump in the stage. As for the second stage we want high power conversion efficiency so we need 1480 nm of pumping.

2-a) $\lambda = 650 \text{ nm}$ $N_{in} = 4 \times 10^{16} \text{ photon/s}$ $N_e = 6 \times 10^{16} \text{ electron/s}$

$$E_{ph} = \frac{hc}{\lambda} = 3,058 \times 10^{-19} \text{ eV}$$

$$\frac{P}{E_{ph}} = N_{in} \Rightarrow P = E_{ph} N_{in} = (3,058 \times 10^{-19} \text{ eV}) (4 \times 10^{16} \text{ photon/s})$$

$$P_{in} = 12,23 \text{ mW}$$

b) $N_e = \frac{I_p}{q} \Rightarrow I_p = N_e q = (6 \times 10^{16} \text{ elect/s}) (1,602 \times 10^{-19} \text{ C/electron})$

$$I_p = 9,612 \text{ mA}$$

c) $\eta = \frac{\text{electron generated}}{\text{photon incident}} = \frac{I h \nu}{P q}$

$$\eta = \frac{6 \times 10^{16} \text{ elect/s}}{4 \times 10^{16} \text{ photon/s}} \Rightarrow \eta = 1,5$$

d) $R_d = \frac{\eta \lambda}{1,24} \text{ or } I_p = R_d P_{in} \Rightarrow$

$$R_d = 0,786$$

- e) There is photocurrent gain because $\eta > 1$ meaning that there was added current between the input and output.

$$f = \frac{c}{\lambda} \quad \lambda = \frac{c}{f}$$

3-a) $v = 2.25 \times 10^8 \text{ m/s}$ $\eta = 1.0$ $E_g = 1.43 \text{ eV}$

λ_{cutoff}

$$h\nu < E_g \Rightarrow \frac{hc}{\lambda} < E_g$$

$$\frac{hc}{E_g} < \lambda_{\text{cutoff}}$$

$$\frac{(4.1357 \times 10^{-15} \text{ eV/s}) (3 \times 10^8 \text{ m/s})}{1.43 \text{ eV}} < \lambda_{\text{cutoff}}$$

$$\boxed{\lambda_c > 867 \text{ nm}}$$

b) $\eta = \frac{P_{\text{abs}}}{P_{\text{in}}} = 1 - e^{-\alpha W} = 1 - e^{-(10^4 \text{ cm}^{-1}) \left(\frac{100 \text{ nm}}{1 \text{ m}} \right) (2 \times 10^{-6} \text{ m})}$

$$\boxed{\eta = 0.865}$$

$$\tau_{tr} = \frac{W}{v} = \frac{2 \times 10^{-6} \text{ m}}{2.25 \times 10^8 \text{ m/s}} = \boxed{8.89 \text{ ps}}$$

RC Time: $\tau_{rc} = (R_L + R_S) C_p$

$$C_p = \frac{\epsilon_r \epsilon_0 A}{d} = \frac{(3.5) (8.85 \times 10^{-12} \text{ F/m}) (400 \times 10^{-6} \text{ m})^2}{2 \times 10^{-6}} = 2.29 \times 10^{-14} \text{ F}$$

$$\tau_{rc} = (1000 \Omega + 0) 2.29 \times 10^{-14} \text{ F} = 22.9 \text{ ps}$$

$$BW = \frac{1}{2\pi(\tau_{tr} + \tau_{rc})} = \frac{1}{2\pi(22.9 \text{ ps} + 8.89 \text{ ps})}$$

$$\boxed{BW = 5.0064 \times 10^9 \text{ Hz} = 5.0064 \text{ GHz}}$$

4-a) Please refer to the attached Matlab code and graph to see the plot.

In the plot of exact vs. approximate. We can see that approximately $10 < M < 60$ we are within 10% of the exact and approx. This is clear in the second graph which displays the % diff. between both curves

$$b) \quad SNR = \frac{(MRP_{in})^2}{2qM^2M^x(RP_{in} + I_d)\Delta f + 4(k_B T / R_L)F_n \Delta f}$$

$$SNR = \frac{(MRP_{in})^2}{BM^x + \sigma_T}$$

$$\text{where } B = 2q(RP_{in} + I_d)\Delta f$$

$$\sigma_T = 4(k_B T / R_L)F_n \Delta f$$

$$\frac{d SNR}{dx} = 0 = - \frac{(RP_{in})^2 (BM^x + \frac{\sigma_T}{M^2})}{(BM^x + \sigma_T / M^2)^2}$$

$$\Rightarrow \frac{dq}{dx} = -\frac{q'}{q^2}$$

$$\frac{d}{dx} (BM^x + \frac{\sigma_T}{M^2}) = 0$$

$$\Rightarrow M = \left(\frac{2\sigma_T}{Bx} \right)^{\frac{1}{x+2}}$$

$$M = \left(\frac{8(k_B T / R_L)F_n \Delta f}{2q(RP_{in} + I_d)\Delta f x} \right)^{\frac{1}{x+2}}$$

We find $M = 18.15$ for SNR_{max} with the given values. We find SNR is 23.73 dB which according to the graph is a very good approx. of the F_n expression. Since the max is at 217.

Question 4 - part a

```
syms F_A(M) F_A_apx(M) f_diff(M)

% set the given constants
k_A = 0.45;
x = 0.79;

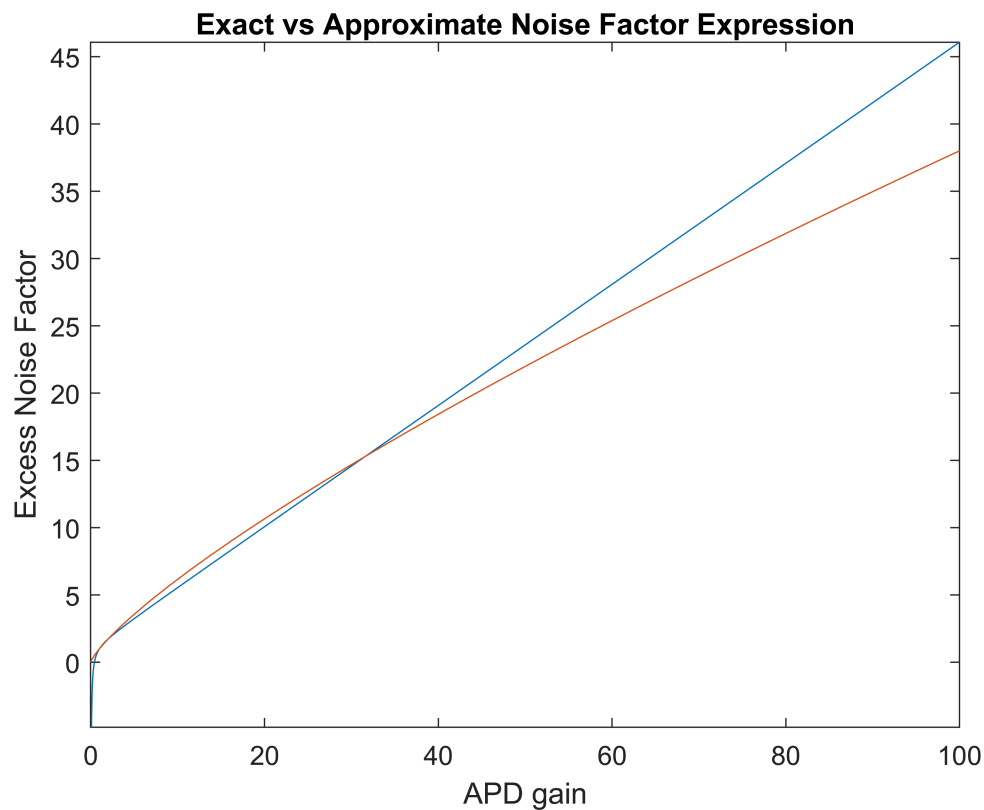
% create the approx and exact functions
F_A(M) = k_A*M + (1 - k_A) * (2 - 1/M);
F_A_apx(M) = M^x;

% plots
fplot(F_A, [0, 100]);

hold on

fplot(F_A_apx,[0, 100]);
title('Exact vs Approximate Noise Factor Expression')
ylabel('Excess Noise Factor')
xlabel('APD gain')

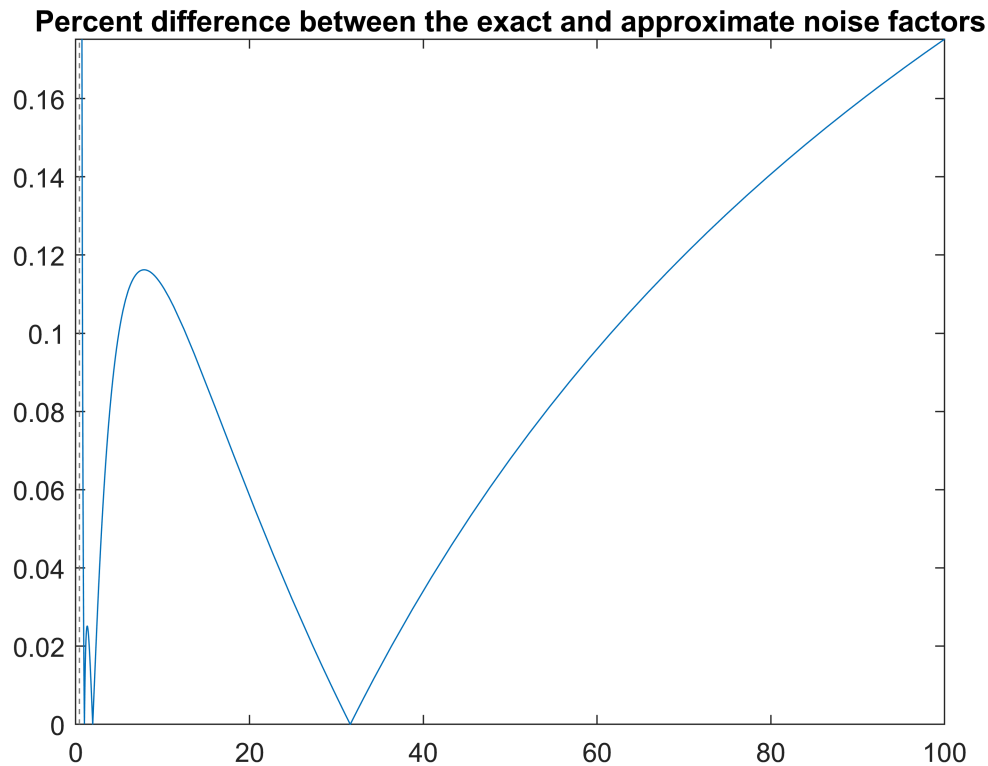
hold off
```



```
% plot of the % difference between the functions
f_diff(M) = abs(F_A(M) - F_A_apx(M)) / F_A(M);

fplot(f_diff(M), [0,100])
```

```
title('Percent difference between the exact and approximate noise factors')
```



part B

```
syms M_g(x) SNR(M) F_A
```

```
% set the constants
```

```
R = 1; % A/W
```

```
I_d = 10e-9; % A
```

```
F_n = 2.5;
```

```
T = 300; % K
```

```
R_L = 50; % ohms
```

```
delta_f = 2e9; % Hz
```

```
P_in = 2e-6; % W
```

```
k_B = 1.38e-23;
```

```
q = 1.602e-19; % C
```

```
% create the M function derived in the notes to find max SNR
```

```
M_g(x) = ((8 * F_n * delta_f * (k_B * T / R_L)) / (2 * q * x * delta_f * (R * P_in + I_d)))^(1/x)
```

```
% M-value for max SNR
```

```
APD_gain = vpa(M_g(0.79))
```

```
APD_gain = 18.154177880867923023991642885102
```

```
% SNR function
```

```
SNR(M) = 10 * log10((M * R * P_in)^2 / ((2 * q * M^2 * (k_A*M + (1 - k_A) * (2 - 1/M)) * delta_f * I_d)))
```

```
% SNR max value based on M-value
```

```
SNR_M = vpa(SNR(APD_gain))
```

```
SNR_M = 23.735395344992784343534522900102
```

```
% plot of SNR
```

```
fplot(SNR(M), [0,100])
```

```
title('SNR vs ADP gain')
```

```
ylabel('SNR')
```

```
xlabel('APD gain')
```

