Ain Shams University	**ECE 334**
Faculty of Engineering	**Optical Fiber Communications**
Electronics & Comm. Eng. Dept.	**Fall 2022**

Major Task

Erbium Doped Fiber Amplifier Modelling

Optical fiber amplifiers are dominating the loss compensation in fiber-optic communication systems, especially the erbium-doped types for communication spectrum based on silica fibers. It’s required to develop a comprehensive Matlab model for erbium doped fiber amplifiers (EDFAs) operating under **static condition**.

System components:

A. Input signal streams:

- Signal streams in EDFA simulator are not defined during the simulation; the EDFA simulator assumes the average signal power.
- The system operates in C-band that has wavelength window 1525−1565 nm and uses 100 GHz optical frequency spacing between light wave carriers.

B. Pump power:

- Assume forward pumping.

C. EDF:

- Er-doped fiber can be modeled as a two-level gain medium if a homogenous broadening system is assumed, the rate equations of the upper population (N2) and lower population (N1) for k optical light beams, **including the pump and signals wavelengths**, are given by the following:

$$\frac{dN_2(z,t)}{dt} = \sum_k \frac{\lambda_k \Gamma_k \sigma_a(\lambda_k)}{A_c hc} P_k(z,t) N_1(z,t) - \sum_k \frac{\lambda_k \Gamma_k \sigma_e(\lambda_k)}{A_c hc} P_k(z,t) N_2(z,t) - \frac{1}{\tau} N_2(z,t)$$

$$N_1(z,t) + N_2(z,t) = N_T \qquad (1)$$

Where λ_k is the wavelength of kth-light, and P_k is the power of the kth-light. The absorption and emission cross-sections of the kth-light are $\sigma_a(\lambda_k)$ and $\sigma_e(\lambda_k)$, respectively. N_t is the total doping concentration of the Er^{+3}-ions. Γ_k is the confinement factor of the kth-light, and A_c is the core (doping) area.

- In CW operation, the forward propagation equation for the kth-light along the Er^{+3}-doped fiber at steady state is given as:

$$\frac{dP_k(z)}{dz} = \Gamma_k\big(\sigma_e(\lambda_k)N_2(z) - \sigma_a(\lambda_k)N_1(z)\big)P_k(z) + \Gamma_k \sigma_e(\lambda_k) N_2(z) \frac{2hc^2 \Delta\lambda_n}{{\lambda_k}^3} \qquad (2)$$

where $\Delta\lambda_n$ is the noise bandwidth, in which its value is given as 0.1 nm and the last term on the right-hand side represents ASE noise.

- It’s required to calculate $N_2(z)$ at steady state condition from (1) (put $\frac{dN_2(z,t)}{dt} = 0$) then use it to calculate power evolution across z by solving the differential equaton (2).
- The gain characteristic depends on the absorption and emission factors at different wavelengths. Absorption and emission characteristics cross sections should be extracted at each wavelength from the curves in literature or in the course slides using **WebPlotDigitizer.**

Input parameters:

Parameter	Symbol	Value
Core radius of EDF	r	$5\mu m\ at\ 1550nm$
Pump Overlap factor	Γ_p	0.4
Signal Overlap factor	Γ_s	0.8
Ion density of EDF	N	$1 * 10^{19}\ cm^{-3}$
Fiber length	L	$1 \rightarrow 50\ m$ (you will calculate optimum)
Emission and absorption cross sections	$\sigma_{em}, \sigma_{abs}$	$Extracted\ from\ curves$
Input pump power	P_P	$0.5\ W \rightarrow while\ sweeping(0.1{:}\ 1)\ W$
Input pump wavelength	λ_p	$1480\ nm$
Input signal power	P_{sin}	$0\ dBm \rightarrow while\ sweeping(-40{:}\ 10)\ dBm$
Input signal wavelength	λ_s	$C\ band{:}\ 1525 \rightarrow 1565\ nm$
Spontaneous emission life time	r	$10\ ms$
Noise bandwidth	$\Delta\lambda_n$	0.1nm

Useful Matlab functions:

- ODE45

Deliverables:

1. A pdf document containing your Matlab model in details and the flowing (7) plots extracted from simulation with comments:
   a) The absorption and emission cross section as extracted from slides using plot digitizer.
   b) $P_p\ and\ P_{sout}\ vs\ position\ in\ the\ fiber\ (z)$ at certain wavelength: 1550nm.
   c) $Gain\ vs\ fiber\ length$ at different pump powers: calculate the optimum length at 0.5W pump power.
   d) $P_{sout}\ vs\ P_{sin}$ on a log scale figure at the optimum fiber length, compare the saturation input power to theoretical.
   e) $Gain\ vs\ P_{sin}$ on a log scale figure at the optimum fiber length, compare the saturation input power to theoretical.
   f) $Gain\ vs\ \lambda$ at certain pump power and input power at all wavelengths.
   g) P_{sout} with ASE noise vs wavelength on a log scale figure with input power at 1550nm.
   Hint: When calculating ASE noise and plotting across wavelength use the noise bandwidth (0.1nm) as your increment step in wavelength vector.
2. The simulation file (.m) zipped with the report.
3. Include a cover page with the group full names.

Delivery rules:

- It's a group project, each group should be **(3)** students.
- Deadline date is on **30/12/2022.**
- The report should be delivered as a soft copy to The LMS.
- No Late reports after deadline are accepted.
- A reasonable load of the project marks will be on the neatness and clearness of the graphs.
- Copied or similar reports will receive ZERO marks!

Additional notes

- After solving Equation (1) at steady state you would obtain the following equation:

$$N_2(z) = \frac{\sum_k \frac{\lambda_k}{hc} \Gamma_k \sigma_a(\lambda_k) P_k(z)}{\sum_k \frac{\lambda_k}{hc} \Gamma_k [\sigma_a(\lambda_k) + \sigma_e(\lambda_k)] P_k(z) + \frac{A_c}{\tau}} * N_T$$

  You should input that equation with summation of all input wavelengths (pump and all signals if you have multiple wavelengths at the input) in your MATLAB equation.

- And when you write the differential equation (2), you will order MATLAB to solve it at each wavelength separately:

  Solve at pump wavelength using:

$$\frac{dP_p(z)}{dz} = \Gamma_p \left(\sigma_e(\lambda_p) N_2(z) - \sigma_a(\lambda_p) N_1(z)\right) P_p(z)$$

  Then apply for loop on all signal wavelengths using:

$$\frac{dP_{s,k}(z)}{dz} = \Gamma_{s,k} \left(\sigma_e(\lambda_{s,k}) N_2(z) - \sigma_a(\lambda_{s,k}) N_1(z)\right) P_{s,k}(z) + \Gamma_{s,k} \sigma_e(\lambda_{s,k}) N_2(z) \frac{2hc^2 \Delta\lambda_n}{{\lambda_{s,k}}^3}$$

- To help you the absorption and emission cross section file would be uploaded with the projectfile with a step (0.1nm) instead of extracting them by yourselves.