Optical Fiber Transmitters

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The laser diode has advantages over other sources. These are:

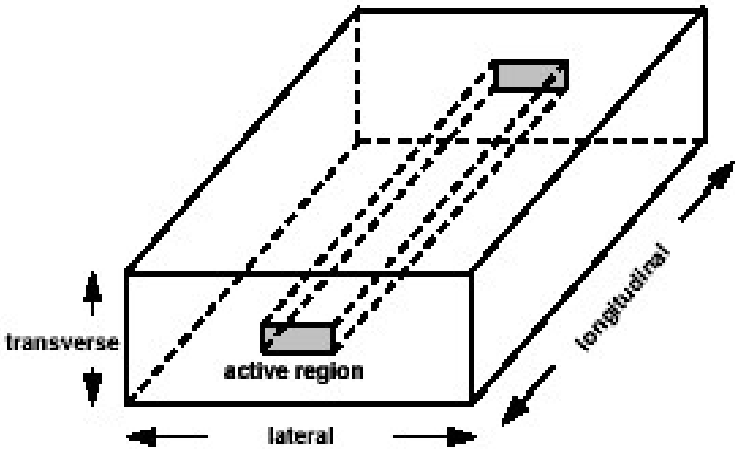
1. High radiance:
2. Narrow linewidth of the order of 1nm ($1A^o$) or less .
3. Modulation capabilities which at present extend up into the gigahertz range.
4. Relative temporal coherence: which is considered essentially to a low hetrodyne (coherent) detection in high capacity system, but at present is primary of use in single-mode systems.
5. Good spatial coherence

These advantages, together with the compatibility of the injection laser with optical fibers (e.g. size) led to the early development of the device in the 1960s.

- **Laser Modes**

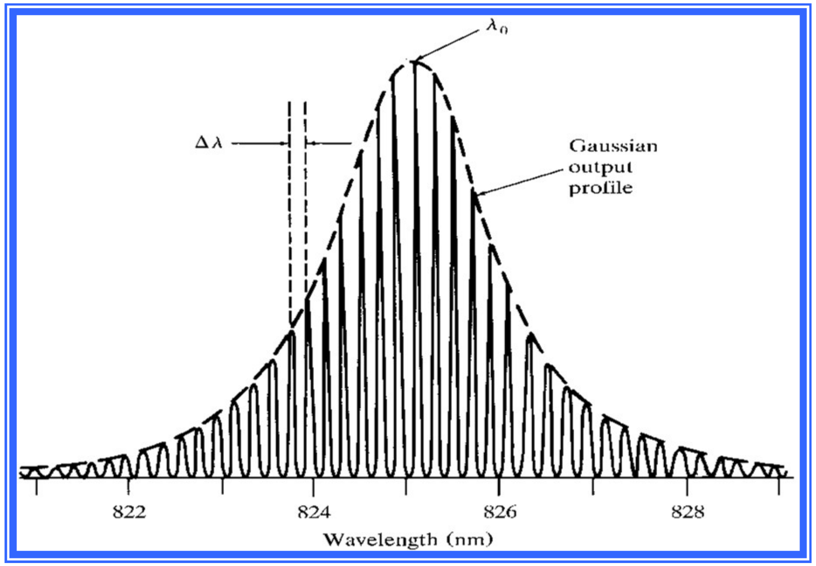
The optical radiation within the resonant cavity sets up a pattern of electric and magnetic field line called the **modes** of the cavity.

Each set of modes can be described in terms of the longitudinal, lateral, and transverse



- the longitudinal modes are

1. related to the length L of the cavity
2. Determine the principal structure of the frequency spectrum of the emited optical radiation.
3. Many longitudinal modes can exist.



The condition for longitudinal resonance is

$$m\lambda_m = 2nL$$

Where m is the longitudinal mode number, l_m the free space wavelength of the k^{th} mode, n is the refractive index of the semiconductor material at this wavelength and L the length of the laser cavity

Thus the frequency separation between adjacent modes is

$\Delta f = f_m - f_{m-1} = C / 2nL$

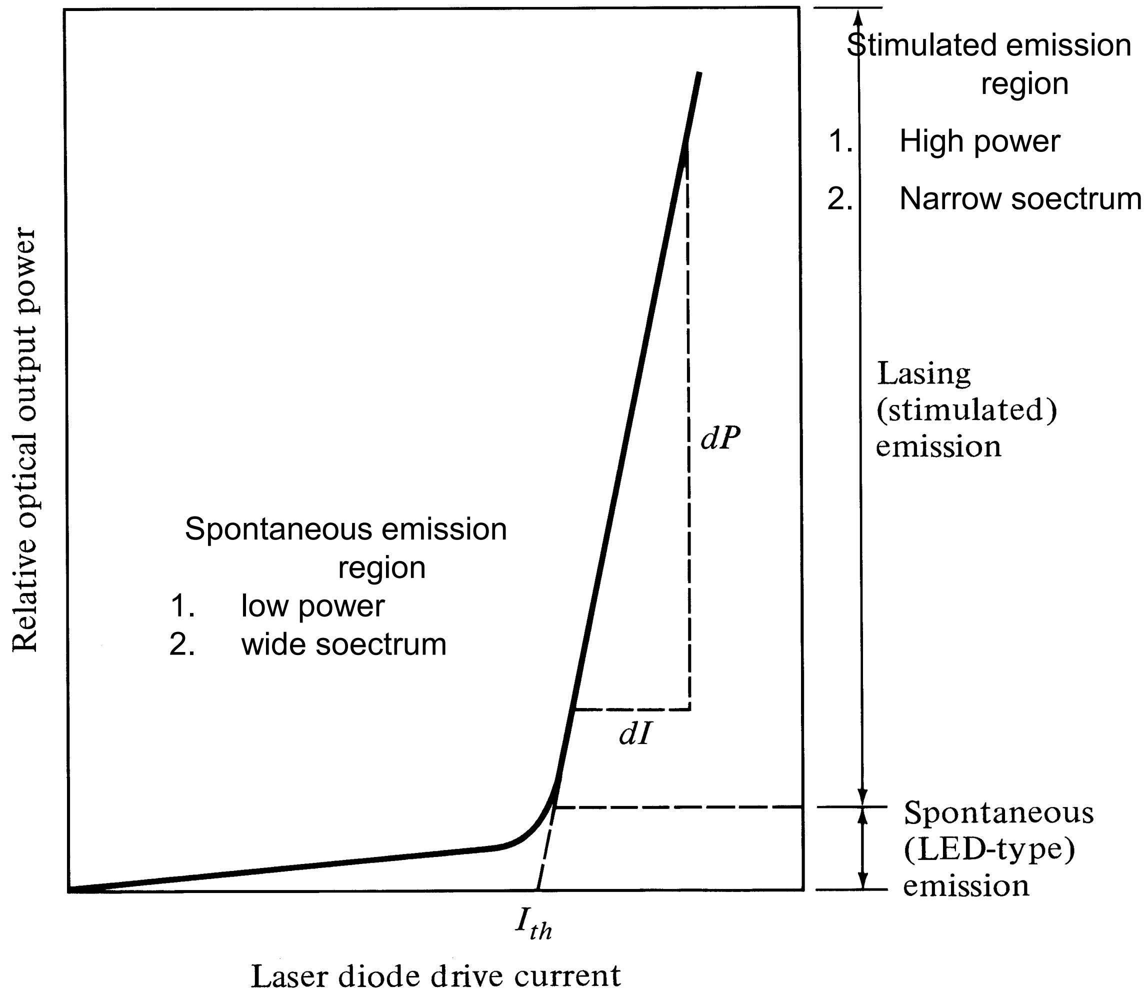
In terms of free-space wavelength assuming $\Delta f \ll f_m$, $\Delta\lambda = \lambda_m \Delta f / f_m$

- The transverse modes

They associated with the electromagnetic field and beam profile in the direction perpendicular to the plane of the PN junction.

They largely determine such laser characteristics as the radiation pattern (angular distribution of the optical output power) and the threshold current density.

Light output against current characteristics for a laser diode



External quantum efficiency η_{ext}

- Experimentally, η_{ext} is calculated from the straight line portion of the curve for the emitted optical power P versus drive current I, which gives

$$\eta_{ext} = \frac{q\,dP}{E_g\,dI} = 0.8065\,\lambda(\mu m)\frac{dP(mW)}{dI(mA)}$$

Where E_g is the band gap energy in electron volts.

- for standard semiconductor lasers, η_{ext} of 15 – 20 % per facet.

  High quality devices have η_{ext} of 30 – 40.

Threshold current temperature dependence

- The temperature dependence of the threshold current density (j_{th}) (as shown in the figure) being approximately exponential for most common structures. It is given by the following equation

$$J_{th} \propto \exp(T/T_o)$$

and

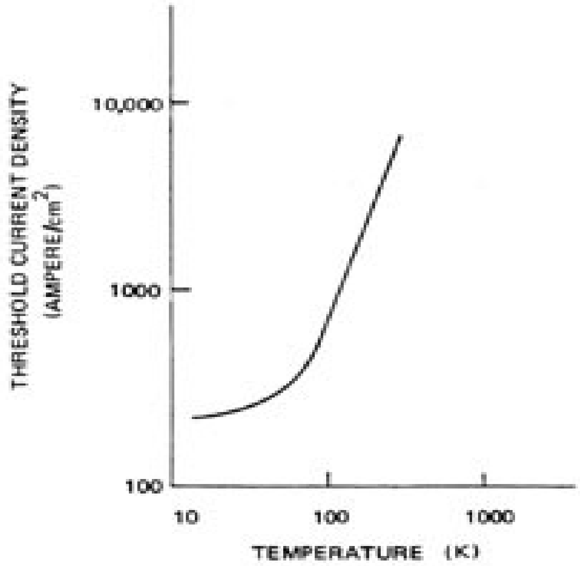
$$I_{th}(T) = I_o \exp(T/T_o)$$

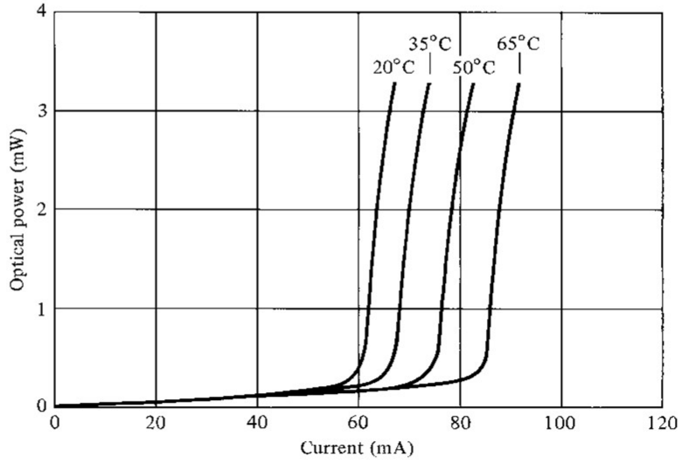
where T is the device temperature.

T_o is the threshold temperature coefficient which is a charecteristics temperature describing the quality of the material

I_o is a current established at a reference temperature and $I_{th}(T)$ is the threshold current at T temperature.

- For AlGaAs T_o is usually between 120 and 190 K°, whereas for InGaAsP devices it is between 40 and 75 K°.

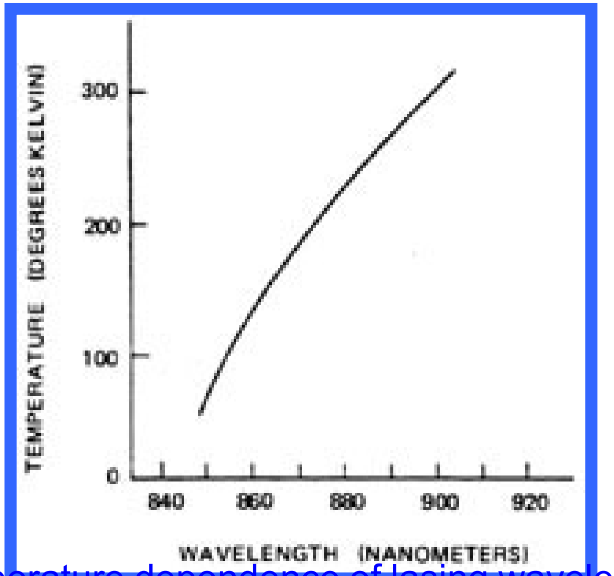




Temperature dependence of threshold current

Spectral properties

- One important property of the laser diode is the dependence of its wavelength on the temperature (about 0.25nm/k)
- and on the injection current (about 0.05nm/mA).



Temperature dependence of lasing wavelength

Dynamic response

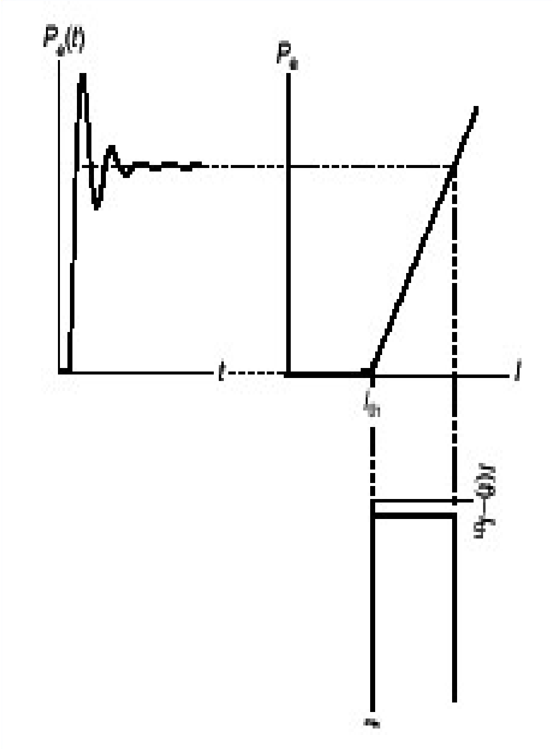
- ➢ switch on _delay
- ➢ relaxation oscillation (RO).
- ➢ The RO damping has been observed and is believed to be due to several mechanisms including:

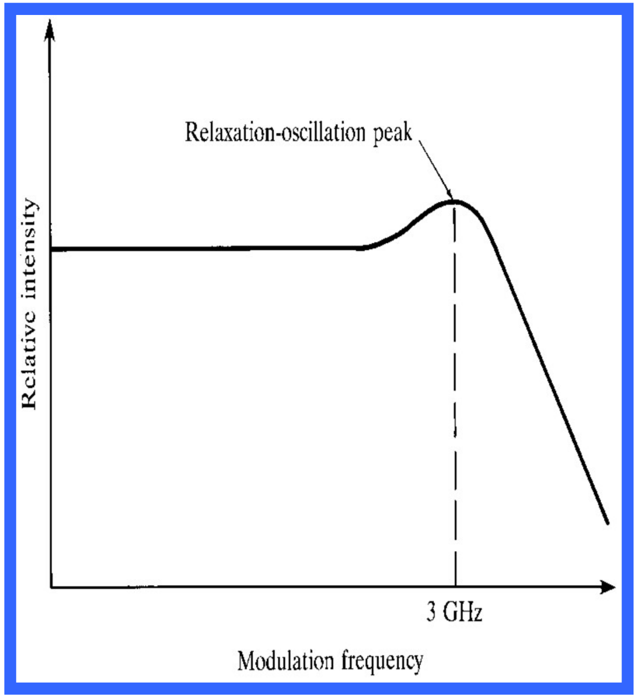
1. The feeding of the spontaneous emission into the lasing mode.
2. Gain nonlinearities.

- ➢ It may be reduced by biasing the laser near threshold (prebiasing).

Turn on Delay (lasers)

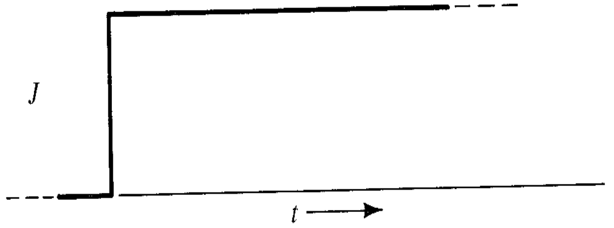
- **When the driving current suddenly jumps from low ($I_1 < I_{th}$) to high ($I_2 > I_{th}$) , (step input), there is a finite time before the laser will turn on**
- **This delay limits bit rate in *digital systems***





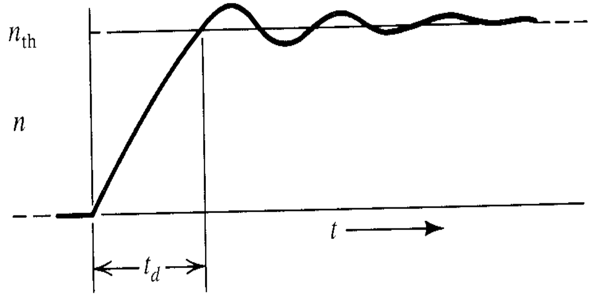
$$t_d = \tau \ln \frac{I_p}{I_p + (I_B - I_{th})}$$

- **Input current**
  - **Assume step input**



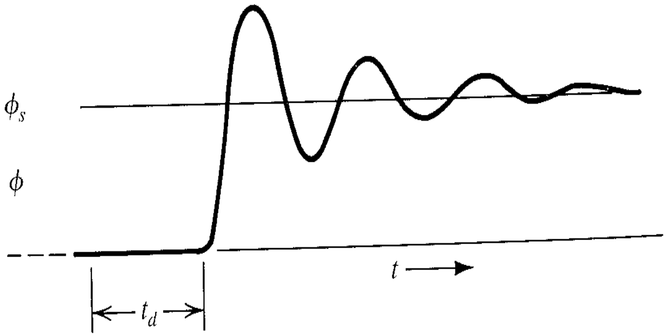
(a)

- **Electron density**
  - **steadily increases until threshold value is reached**



(b)

- **Output optical power**
  - **Starts to increase only after the electrons reach the threshold**



(c)

Frequency chirp

- The direct modulation of a single longitudinal mode semiconductor laser can cause a dynamic shift of the peak wavelength emitted from the device. This phenomena is referred to as frequency chirping and results in dynamic linewidth broadening under the direct modulation of the injection current.
- Frequency chirping is a nonlinear effect.

For **example**, theoretical prediction of the wavelength shift that may occur with an InGaAsP laser under modulation of a few gigabit / s are around 0.05 nm (6.4 GHz frequency shift).

- There are two effects contributing to the chirp

1. The change in temperature that follow sthe change in the drive current
2. The change in carrier concentration.

In laser diode, the refractive index varies with carrier density.

Modulation $\rightarrow$ vary current $\rightarrow$ vary carrier density
$\rightarrow$ vary refractive index $\rightarrow$ index varies with time
$\rightarrow$ phase delay varies with time $\rightarrow$ induces new frequency

frequency varies with time : chirp

- chirp results in broadening of a laser linewidth
- chirp magnitude is ~ 100MHz - GHz/mA,
  ~ 0.001% of center frequency

Frequency chirp

- A number of techniques are employed to reduce the frequency chirp:

1. biase the laser sufficiently above threshold so that the modulation current does not drive the device below the threshold where the rate of change of optical output power varies rapidly with time.
2. Damping of the relaxation oscillations that can occur at turn-on and turn-off which result in large power fluctuations [this is achieved by shaping the electrical drive pulses].

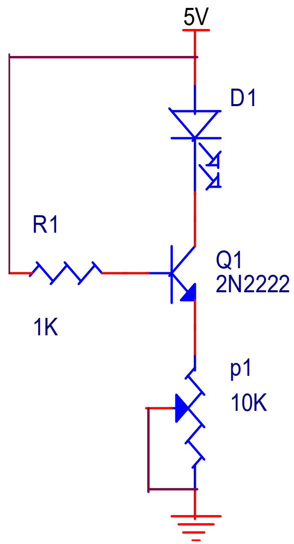
Noise sources

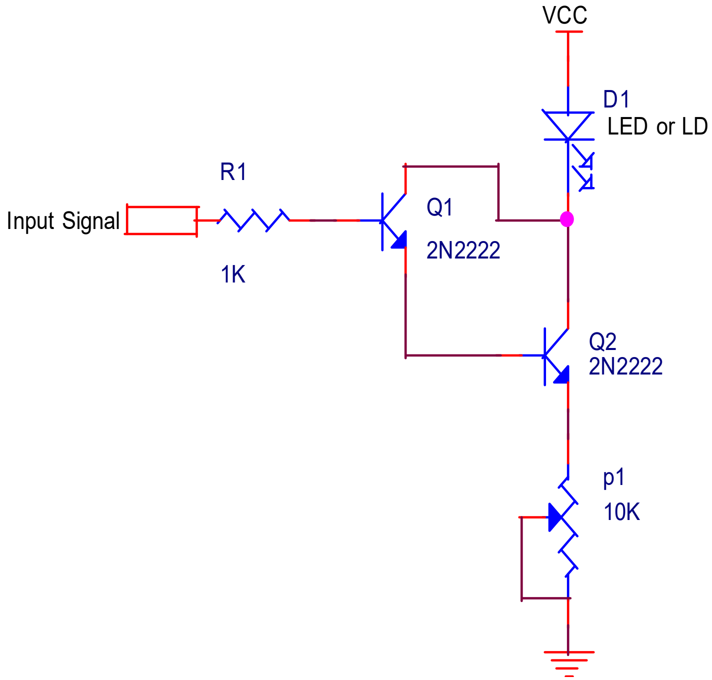
The sources of noise in the laser diode are:-

1- phase or frequency noise.
2- instabilities in operation such as kinks in the light output against current characteristics and self pulsation.
3- Reflection of light back into the device .
4- mode partition noise.

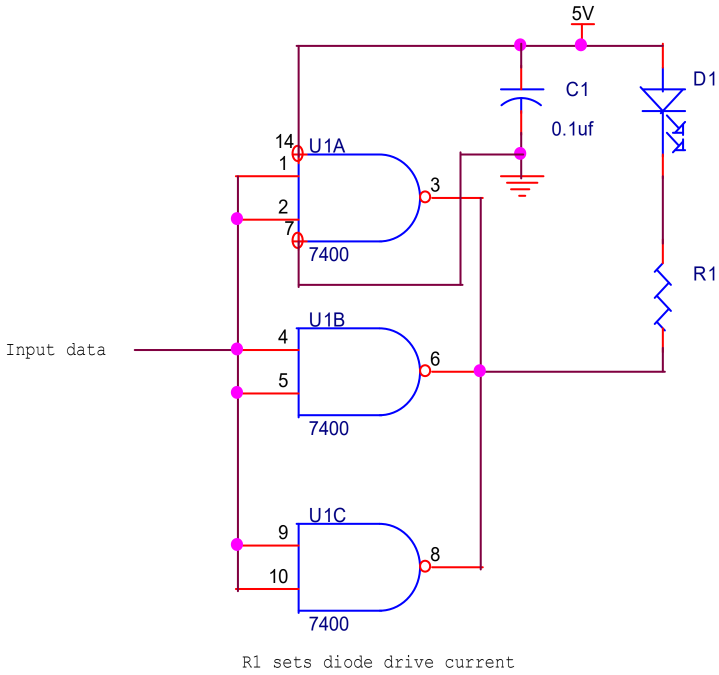
Parameter	**LED**	**Laser diodes**
output Power	Linearly proportion to drive current	Proportional to current above threshold
Current	50-100 mA Peak	I_{th} 5-40mA
Coupled power	Moderate	high
Bandwidth	Moderate	high
Wavelengths Available	0.66-1.55µm	0.78-1.55µm
Emission spectrum	40-190 nm FWHM	0.1-10nm FWHM
Cost	5-300$	5-3000$

Some optical source drivers

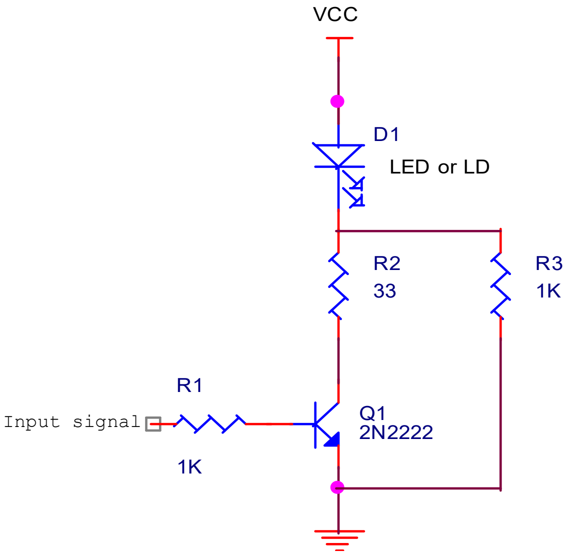




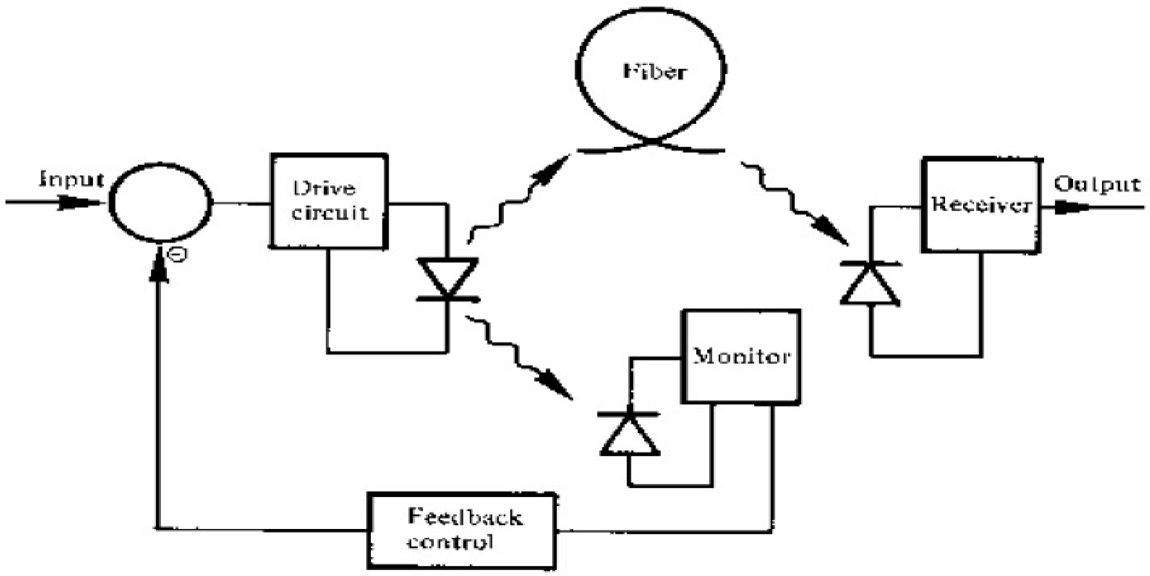
Analog driver circuit with Darlington transistor pair



Digital driver circuit using logic gates



Digital driver circuit using prebiasing technique



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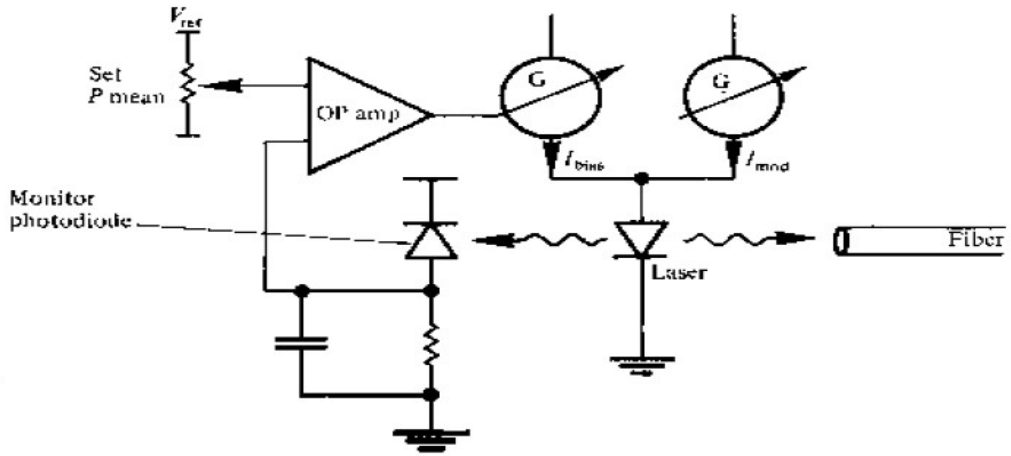

Fig. 10.12 Mean power feedback circuit for control of the laser bias current.