Unit-3

Lecture -8

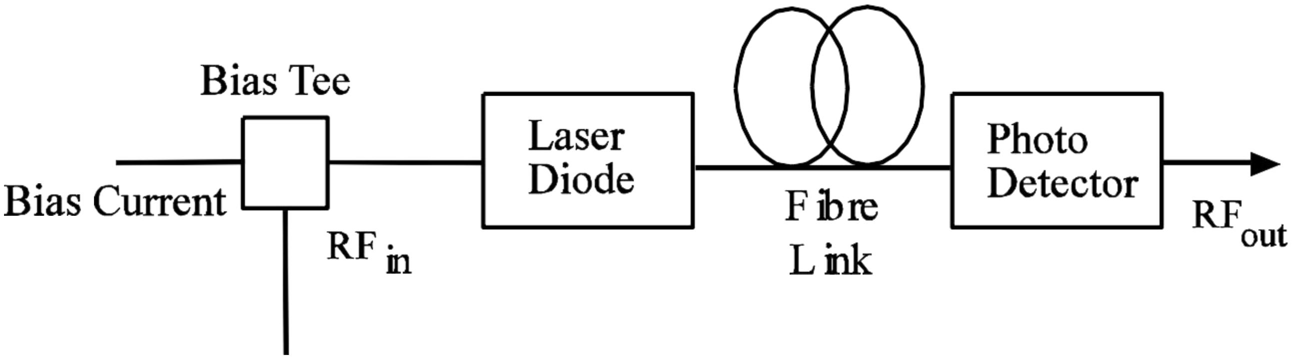
Optical Modulation, Distributed Feedback Laser

Types of Optical Modulation

- Direct modulation is done by superimposing the modulating (message) signal on the driving current
- External modulation is done after the light is *generated;* the laser is driven by a dc current and the modulation is done after that separately
- Both these schemes can be done with either *digital* or *analog* modulating signals

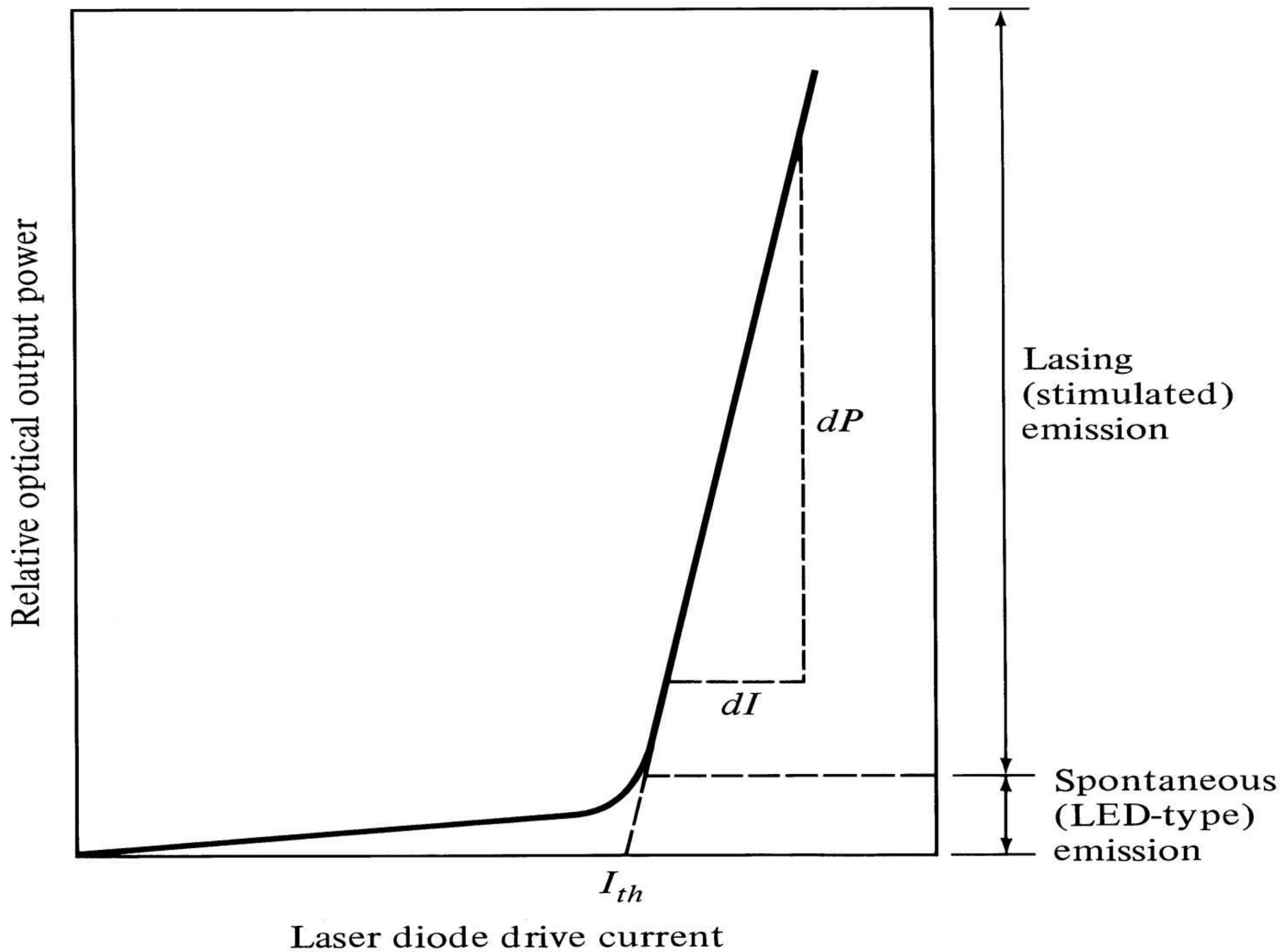
- Direct modulation of semiconductor lasers
  - --- frequency response
  - --- relaxation oscillation
  - --- chirp
- external modulators:
  - --- Electro-absorption modulators
  - --- Mach-Zehnder interferometer
- New mechanisms for laser-diode modulation
- Short-pulse techniques

Direct Modulation



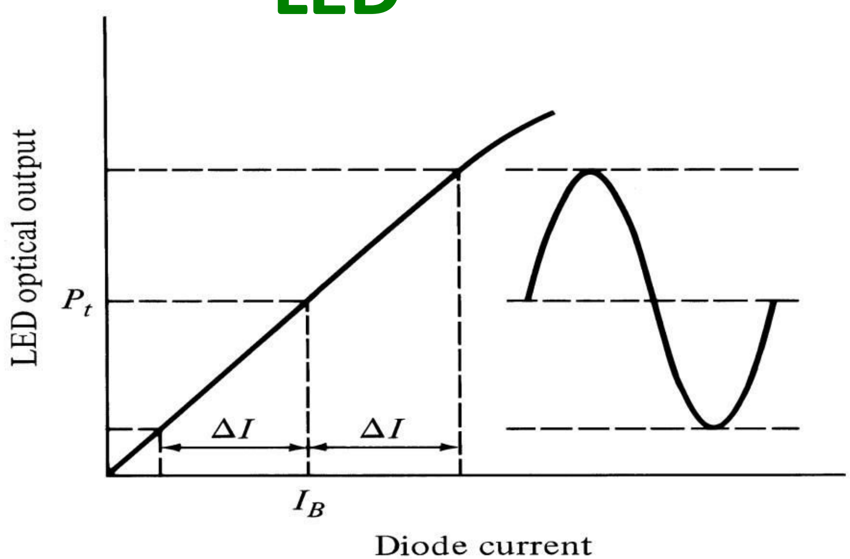
- The message signal (ac) is superimposed on the bias current (dc) which modulates the laser
- Robust and simple, hence widely used
- Issues: laser resonance frequency, chirp, turn on delay, clipping and laser nonlinearity

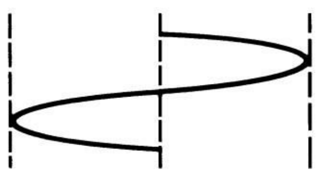
Optical Output vs. Drive Current of a Laser



Direct Analog Modulation

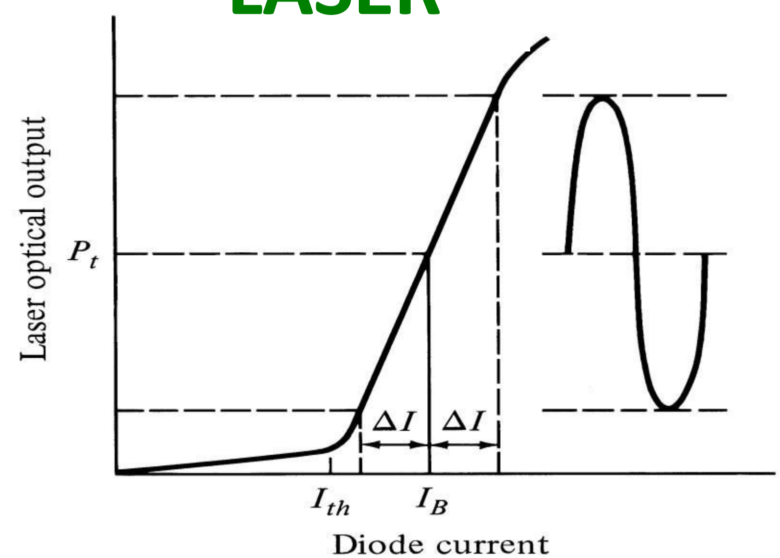
LED



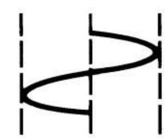


$$I_B' = I_B$$

LASER



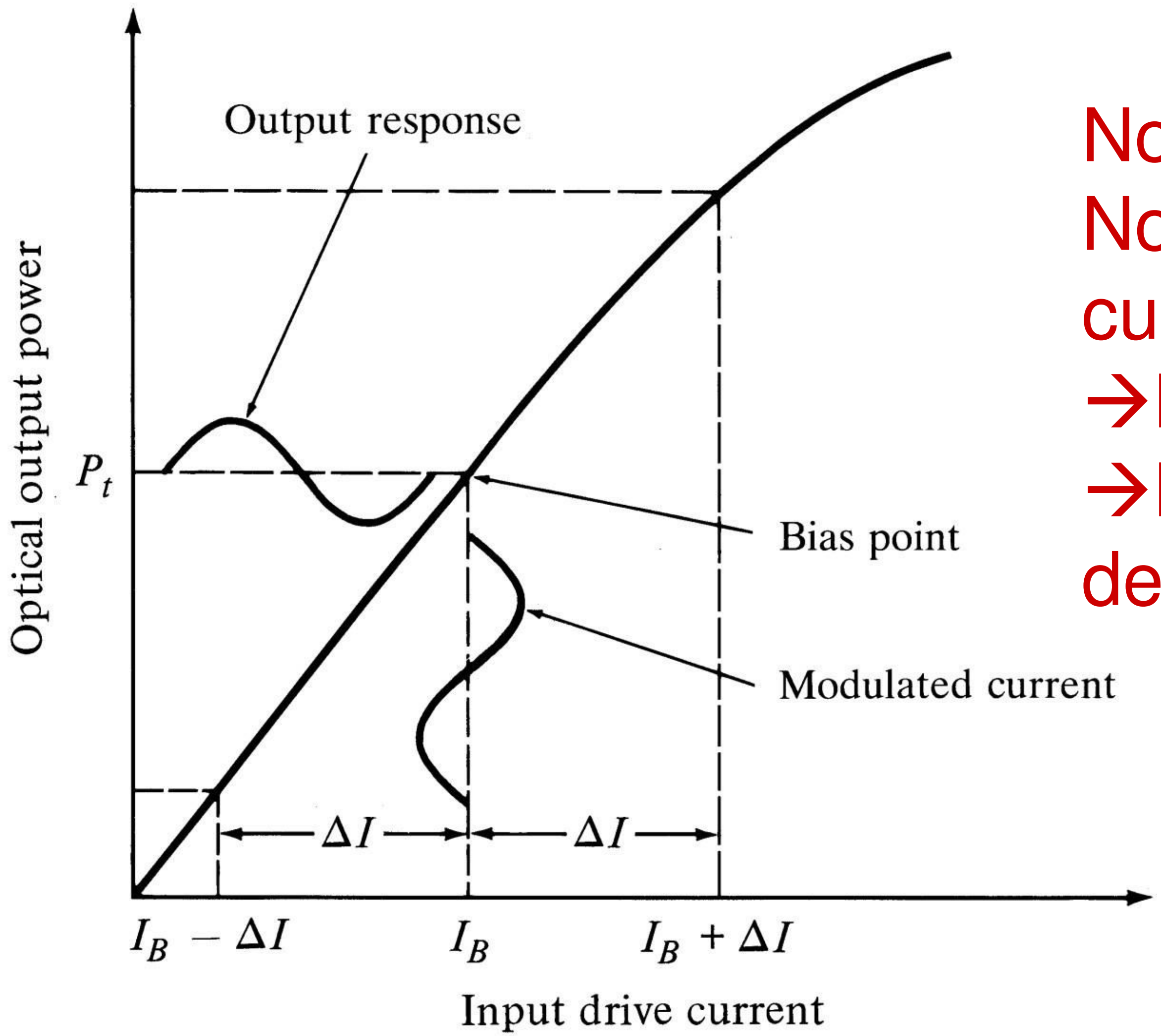
$$I_B' = I_B - I_{th}$$



Modulation index (depth)

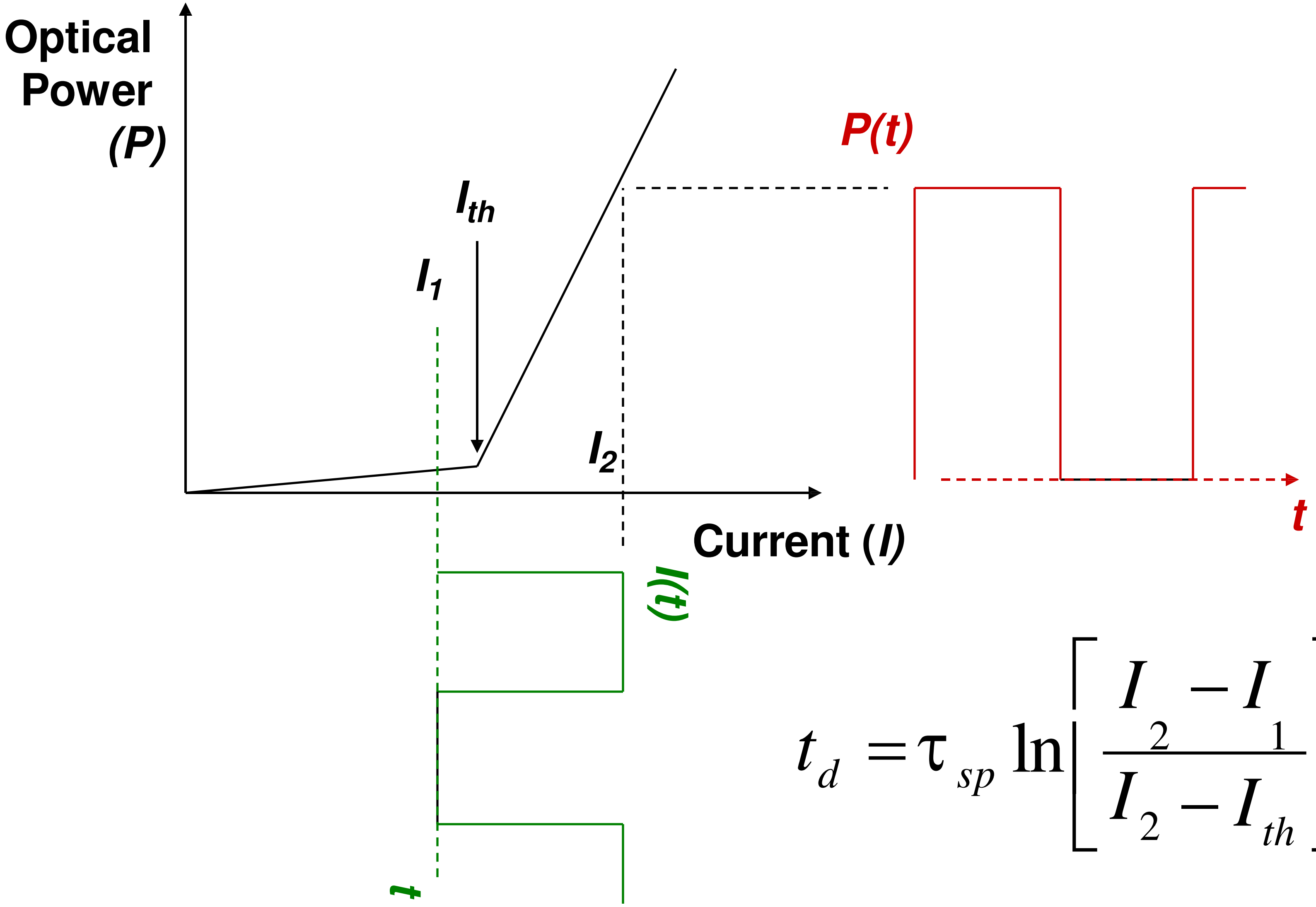
$$m = \Delta I / I_B'$$

Analog LED Modulation



Note:
No threshold current
→No clipping
→No turn on delay

Laser Digital Modulation



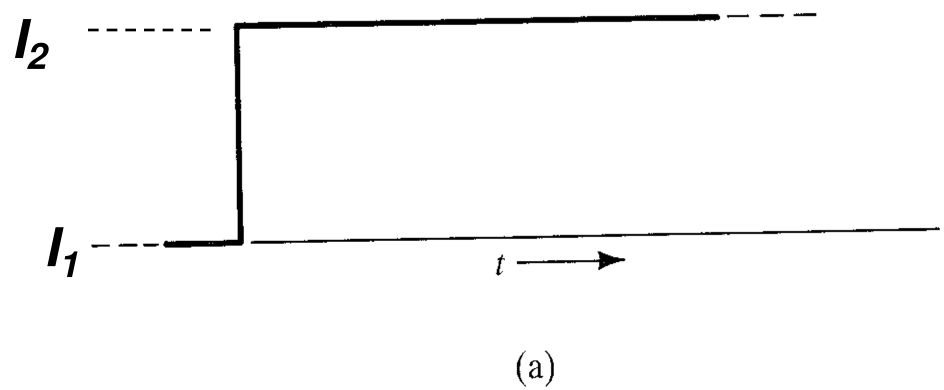
$$t_d = \tau_{sp} \ln\left[\frac{I_2 - I_1}{I_2 - I_{th}}\right]$$

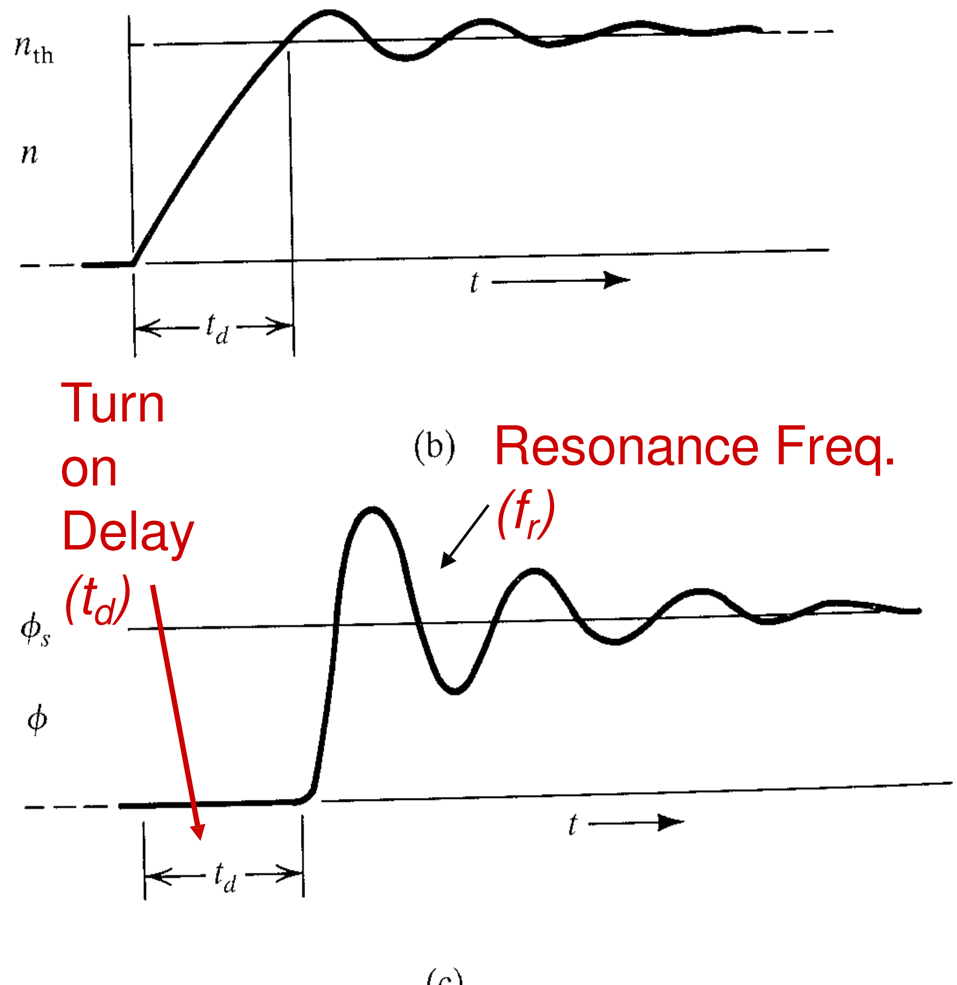
Turn on Delay (lasers)

- 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*
- Can you think of any solution?

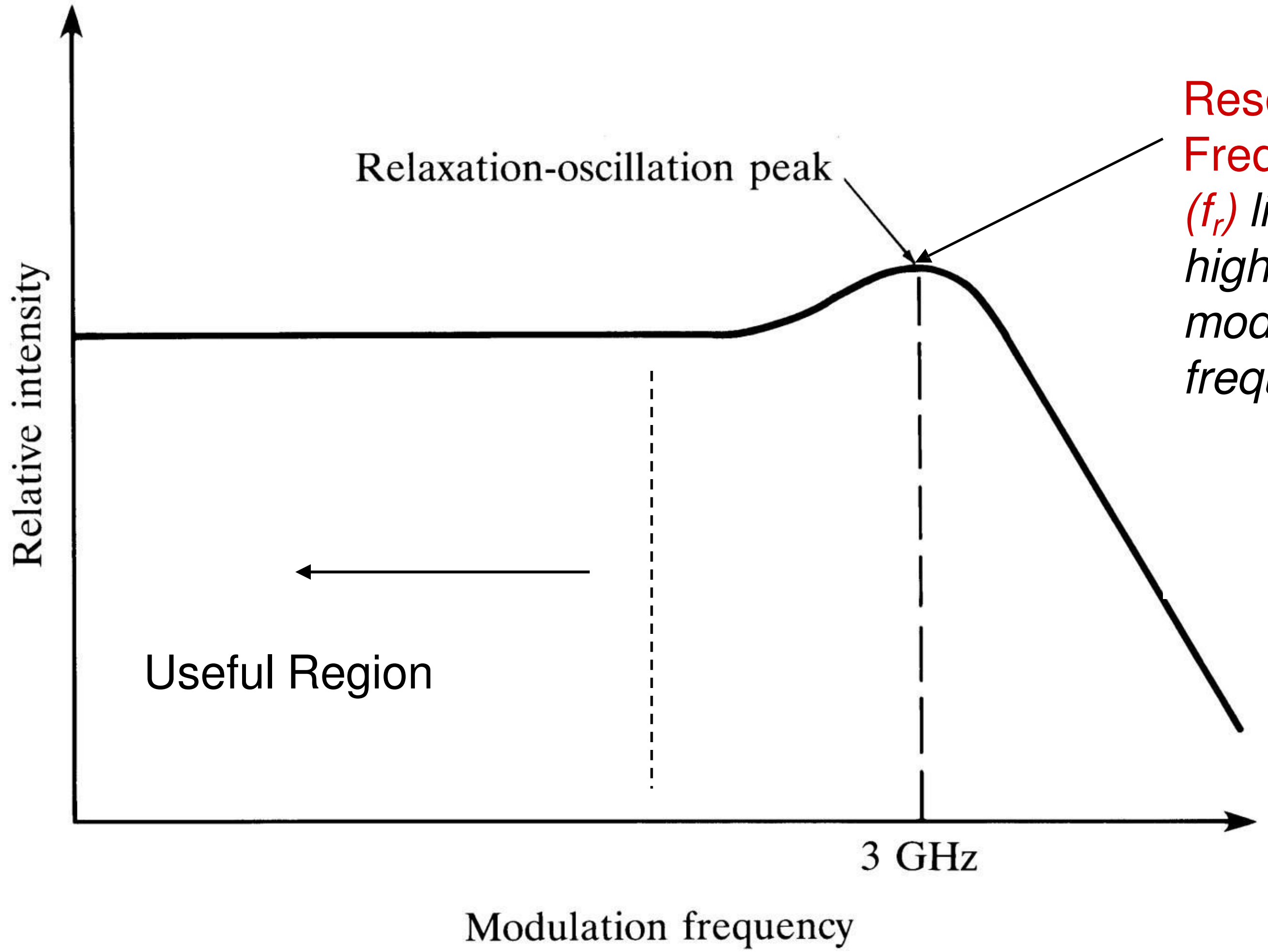
$$t_d = \tau_{sp} \ln\left[\frac{I_2 - I_1}{I_2 - I_{th}}\right]$$

- Input current
  - Assume step input
- Electron density
  - steadily increases until threshold value is reached
- Output optical power
  - Starts to increase only after the electrons reach the threshold



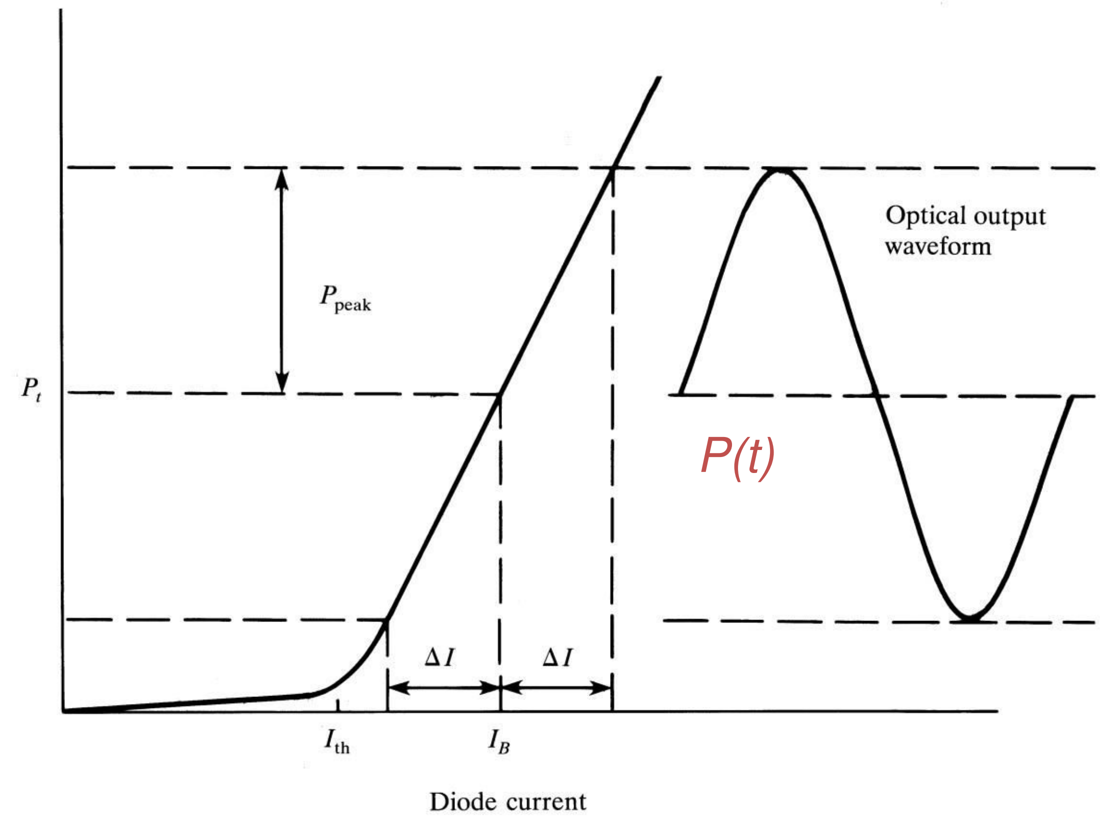


Frequency Response of a Laser

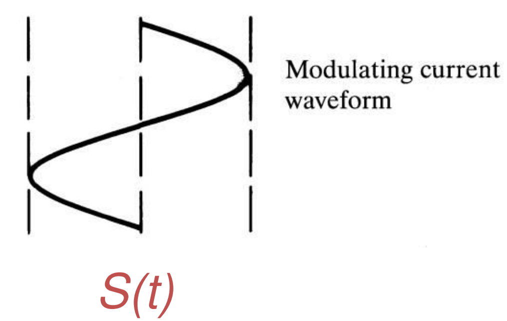


Resonance Frequency (f_r) *limits the highest possible modulation frequency*

Laser Analog Modulation



$$P(t) = P_t[1 + m\,s(t)]$$

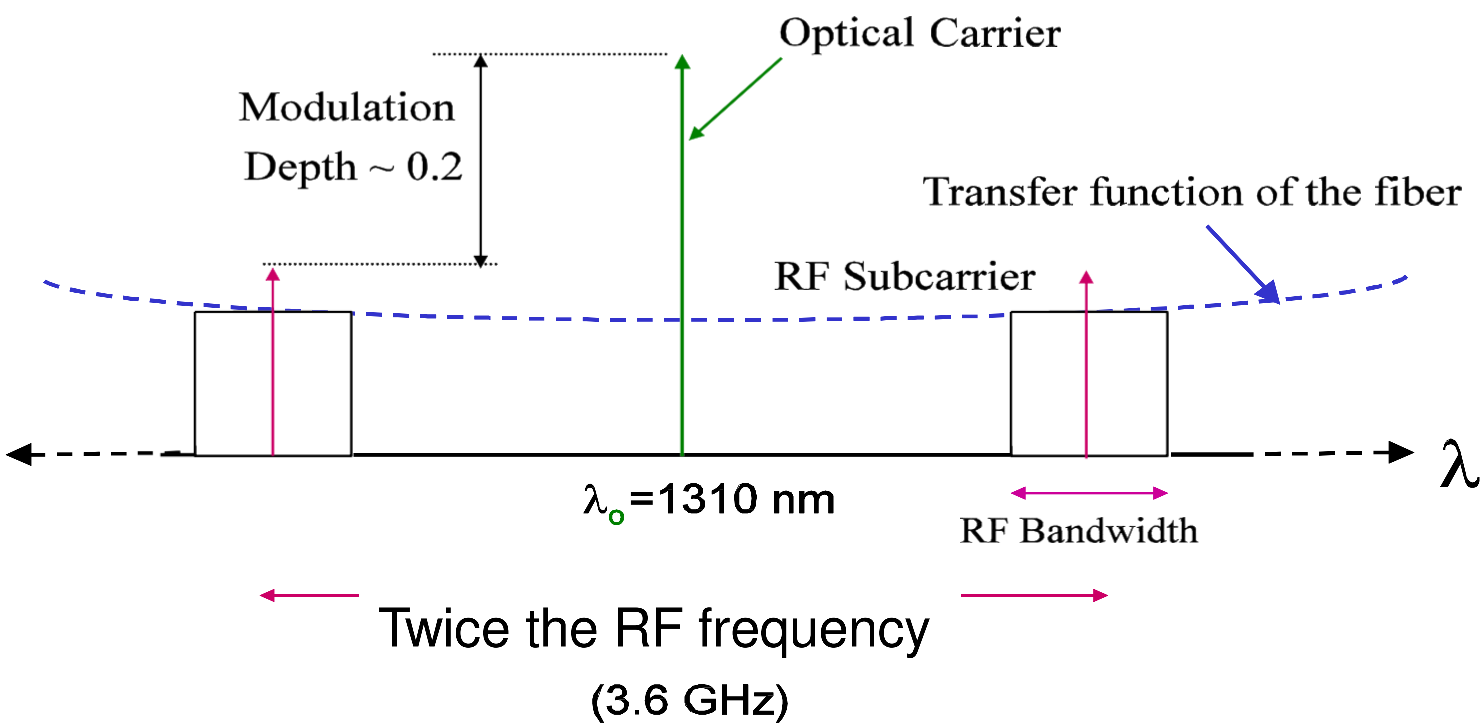


Here *s(t)* is the modulating signal,

P(t): output optical power

P_t: mean value

The modulated spectrum



Two sidebands each separated by modulating frequency

Limitations of Direct Modulation

- Turn on delay and resonance frequency are the two major factors that limit the speed of digital laser modulation
- Saturation and clipping introduces nonlinear distortion with analog modulation (especially in multi carrier systems)
- Nonlinear distortions introduce second and third order intermodulation products
- Chirp: Laser output wavelength drift with modulating current is also another issue

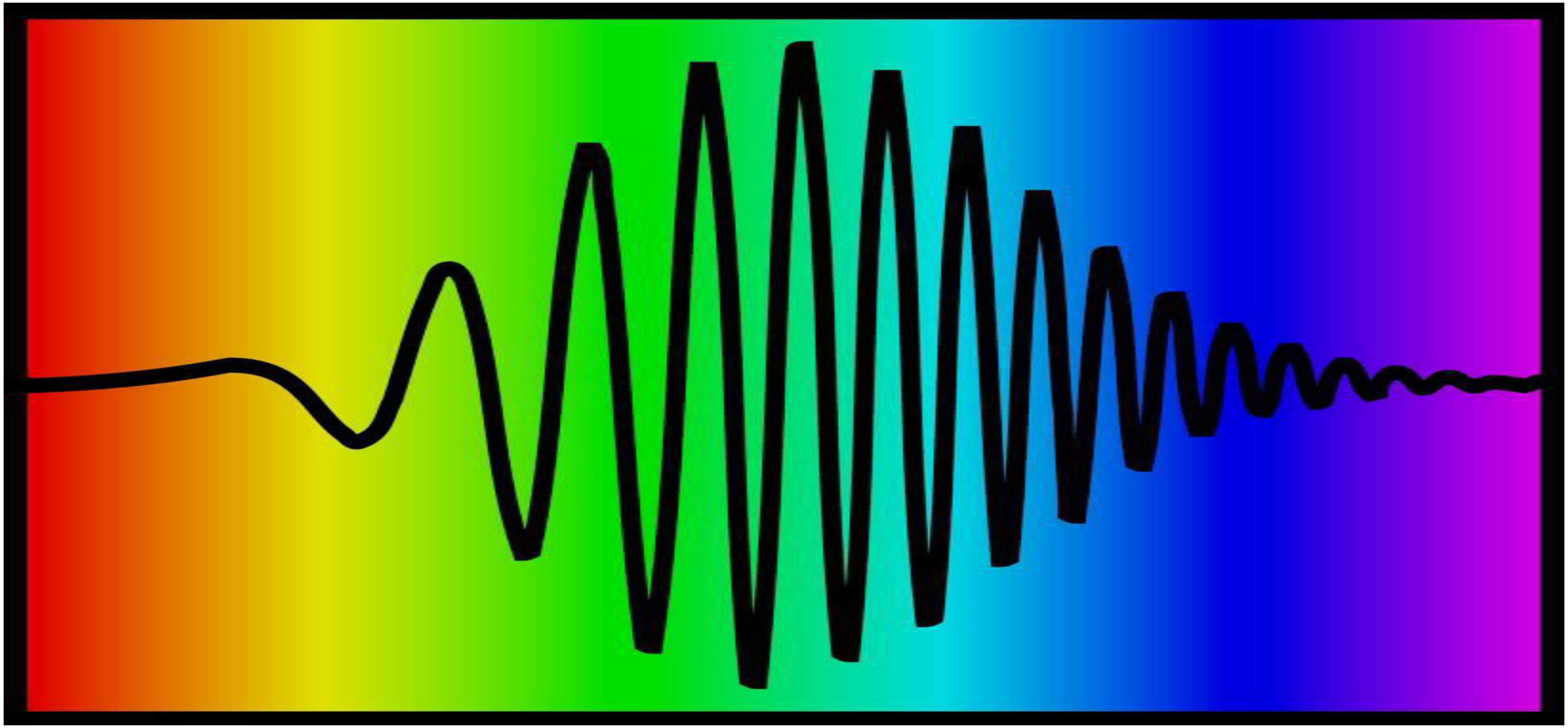
Chirp

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

Modulation → vary current → vary carrier density
→ vary refractive index → index varies with time
→ phase delay varies with time → 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

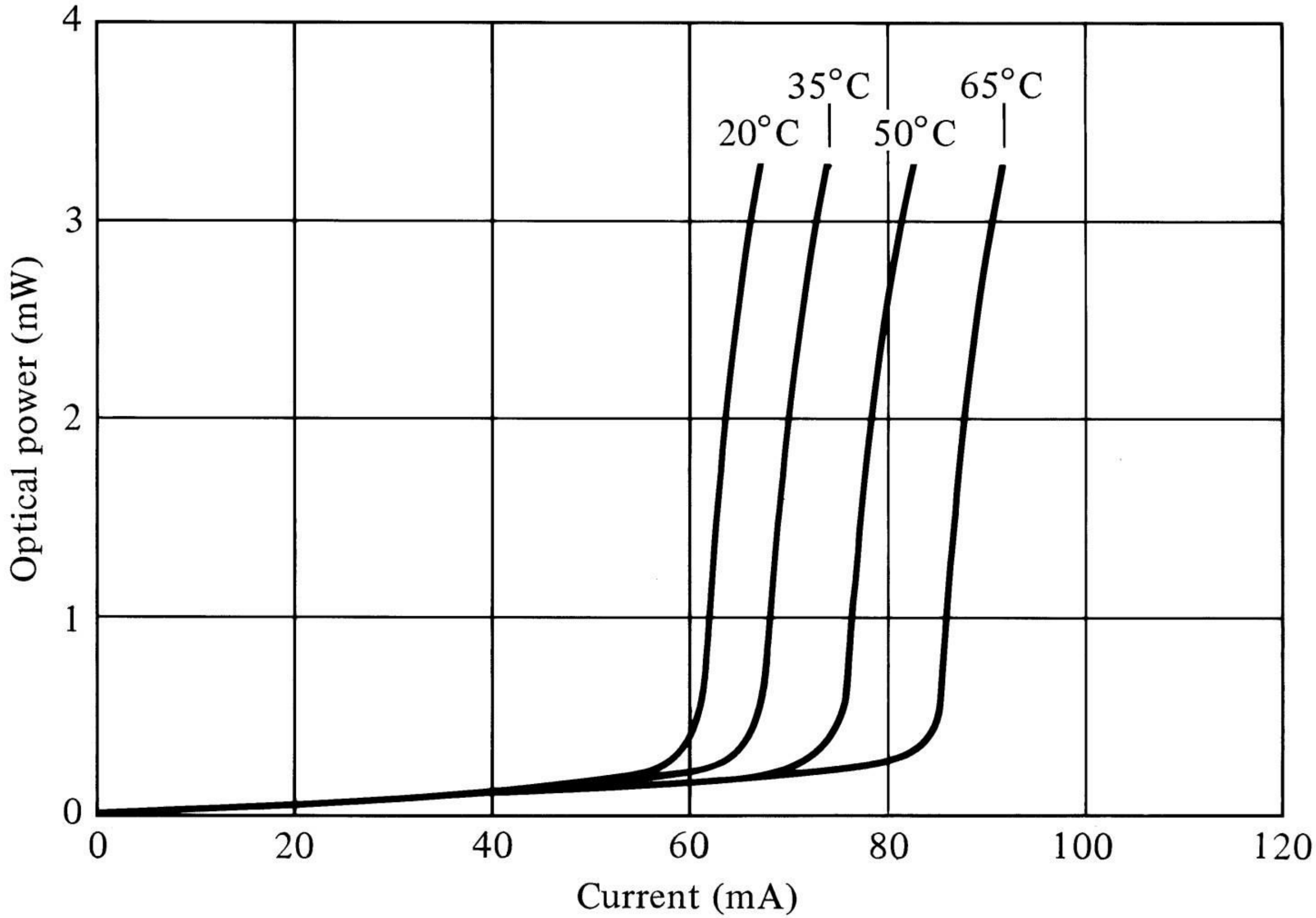


A pulse can have a frequency that varies in time.

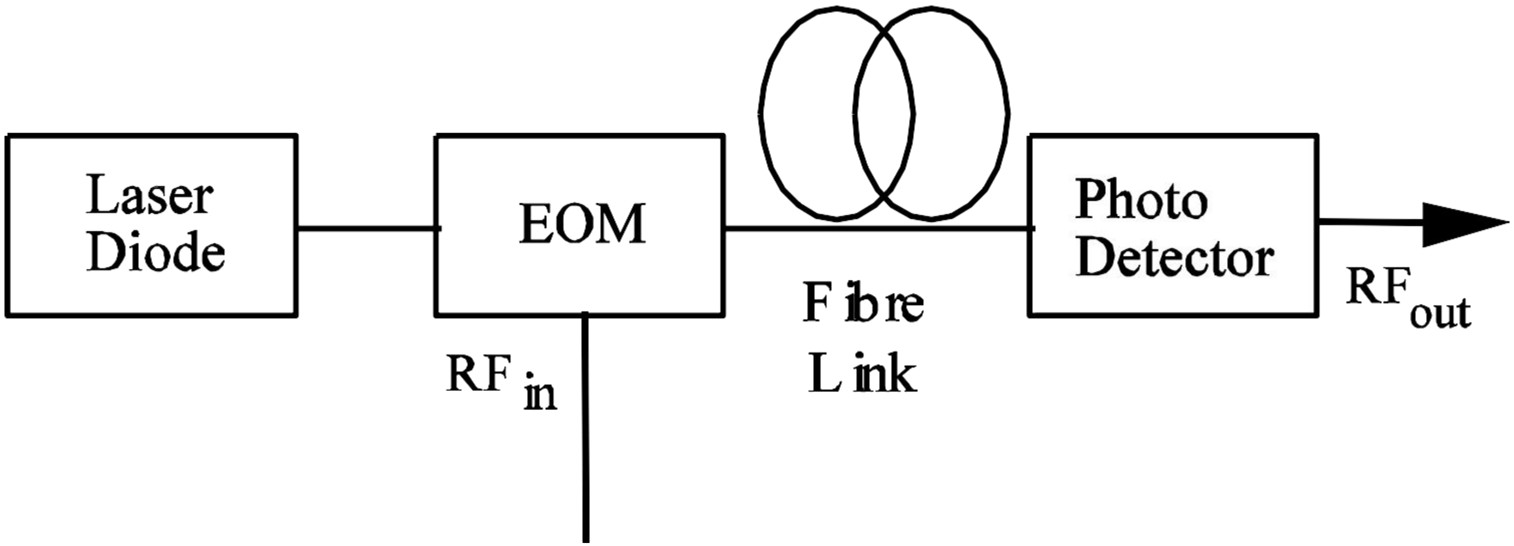
This pulse increases its frequency linearly in time (from red to blue).

In analogy to bird sounds, this pulse is called a "chirped" pulse.

Temperature dependency of the laser is another issue

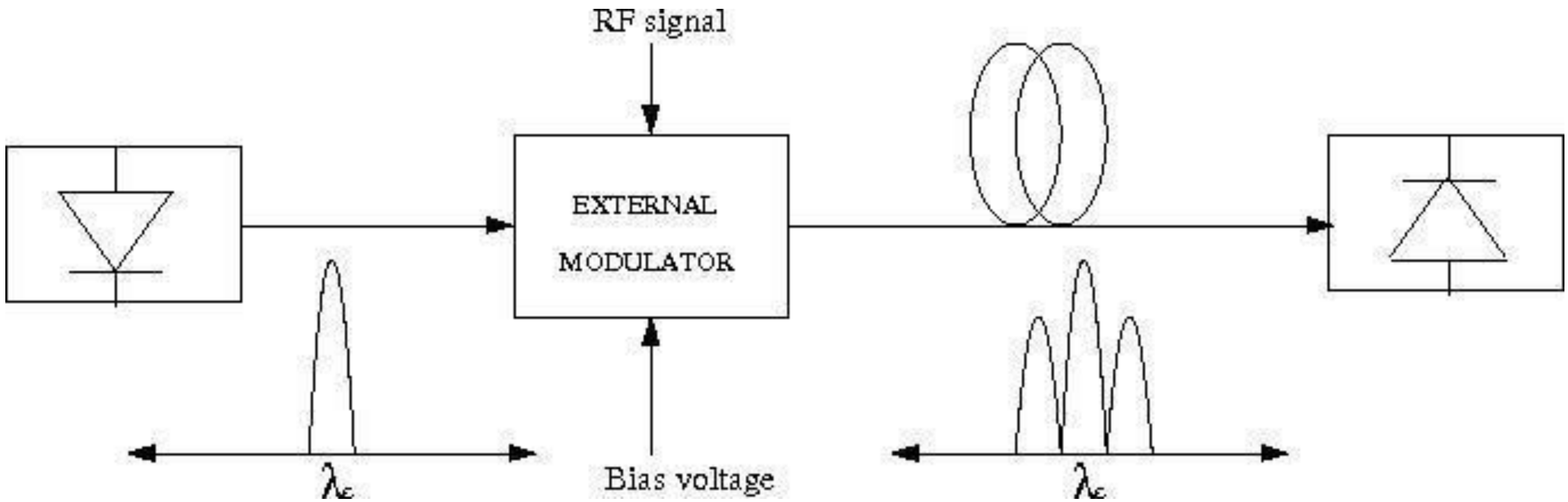


External Optical Modulation



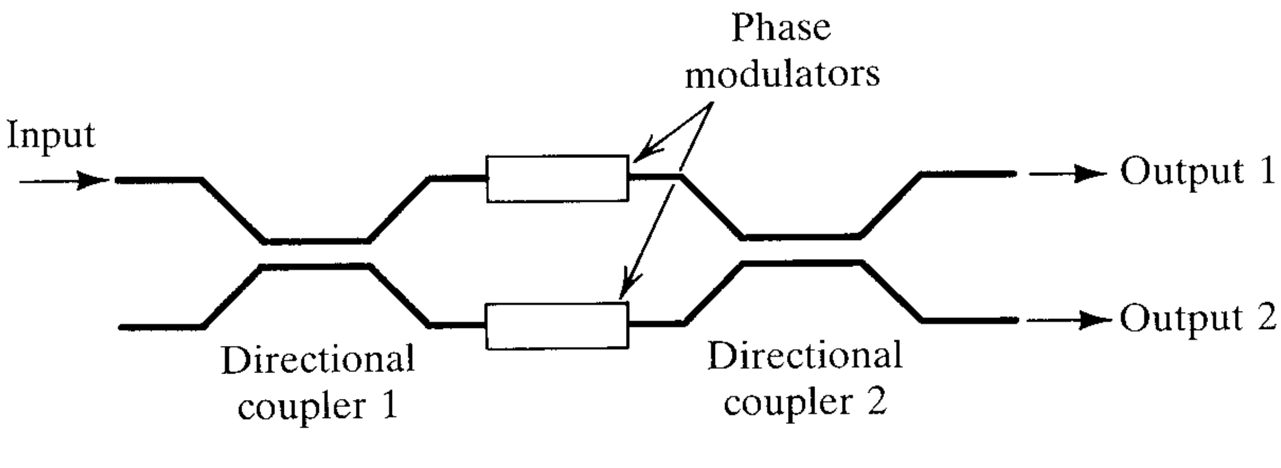
- Modulation and light generation are separated
- Offers much wider bandwidth → up to 60 GHz
- More expensive and complex
- Used in high end systems

External Modulated Spectrum

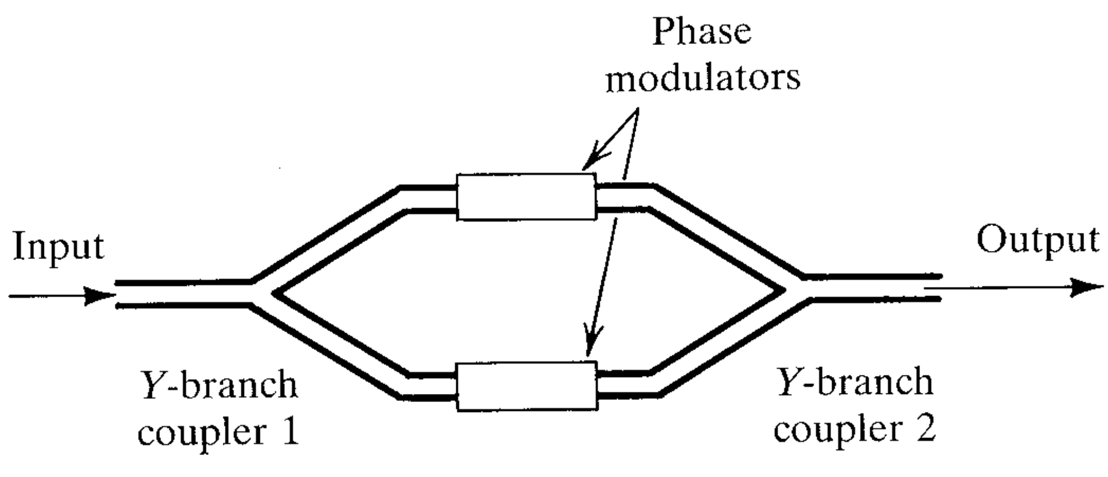


- Typical spectrum is double side band
- However, single side band is possible which is useful at extreme RF frequencies

Mach-Zehnder Interferometers



(a)

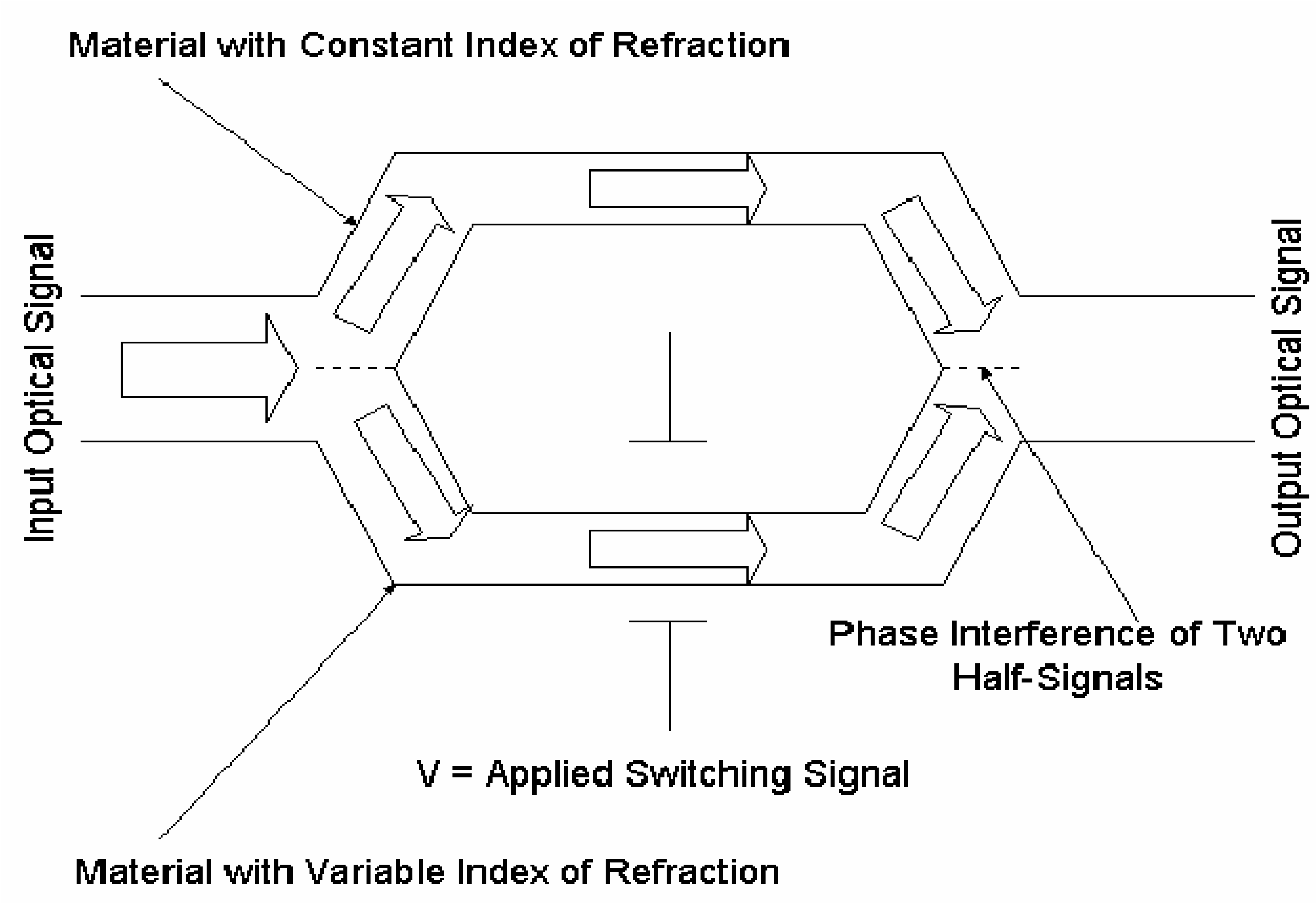


(b)

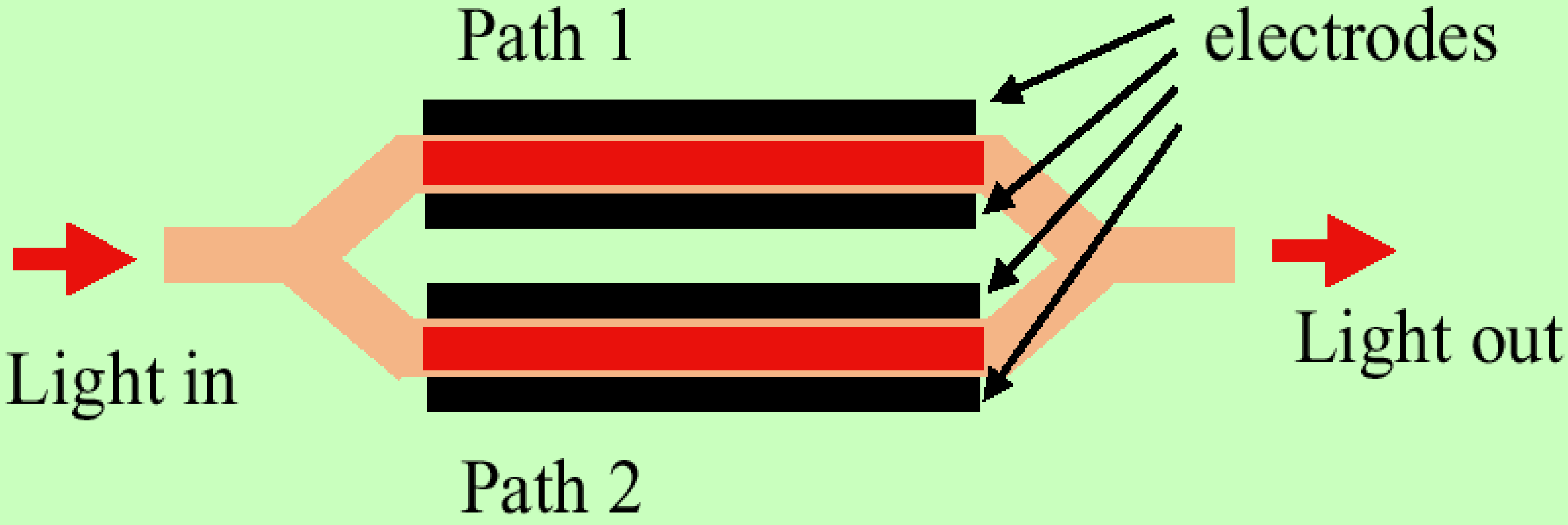
Parameters to characterize performance of optical modulation

- modulation depth
- bandwidth
- insertion loss
- degree of isolation
- power handling
- induced chirp

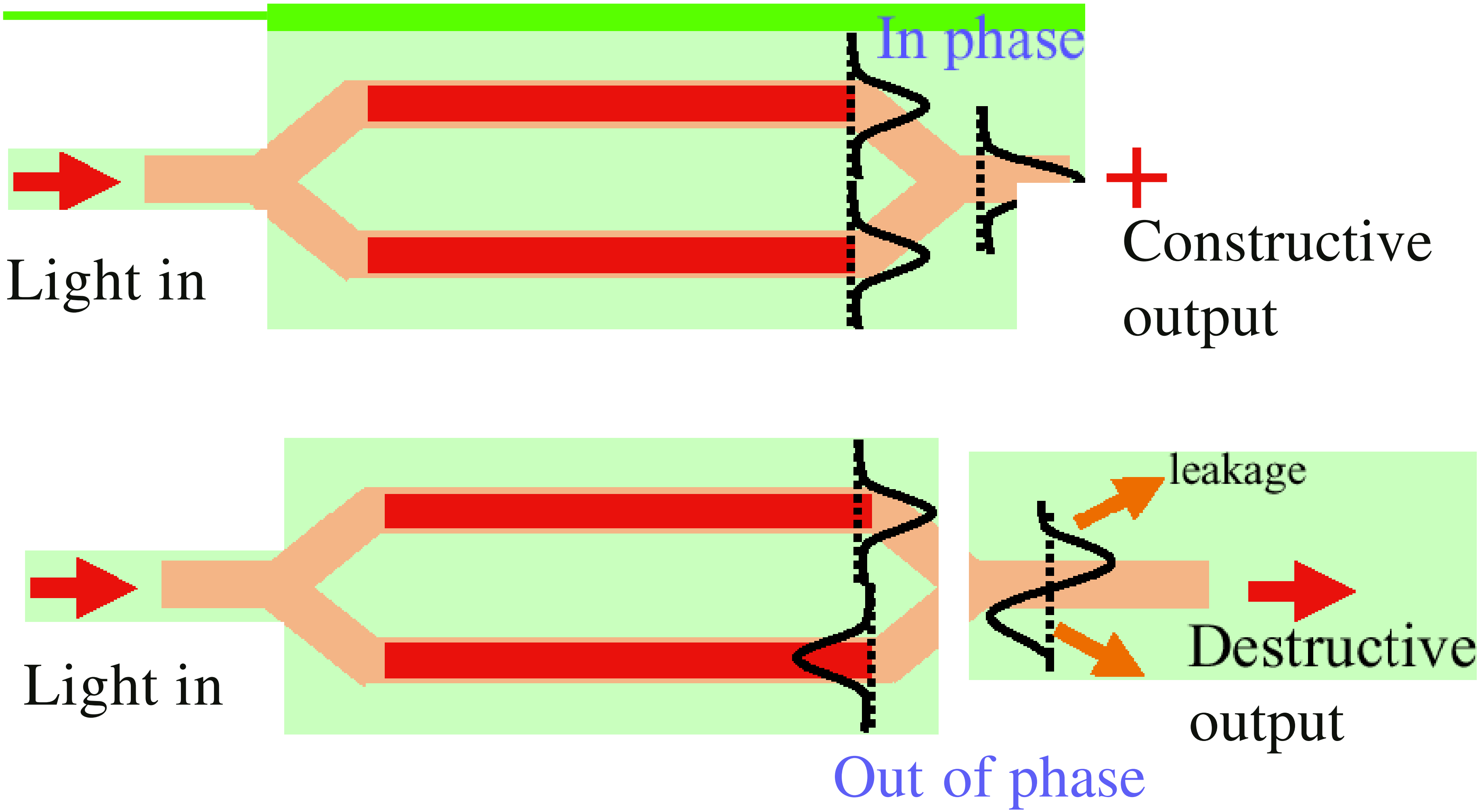
Mach- Zehnder modulator

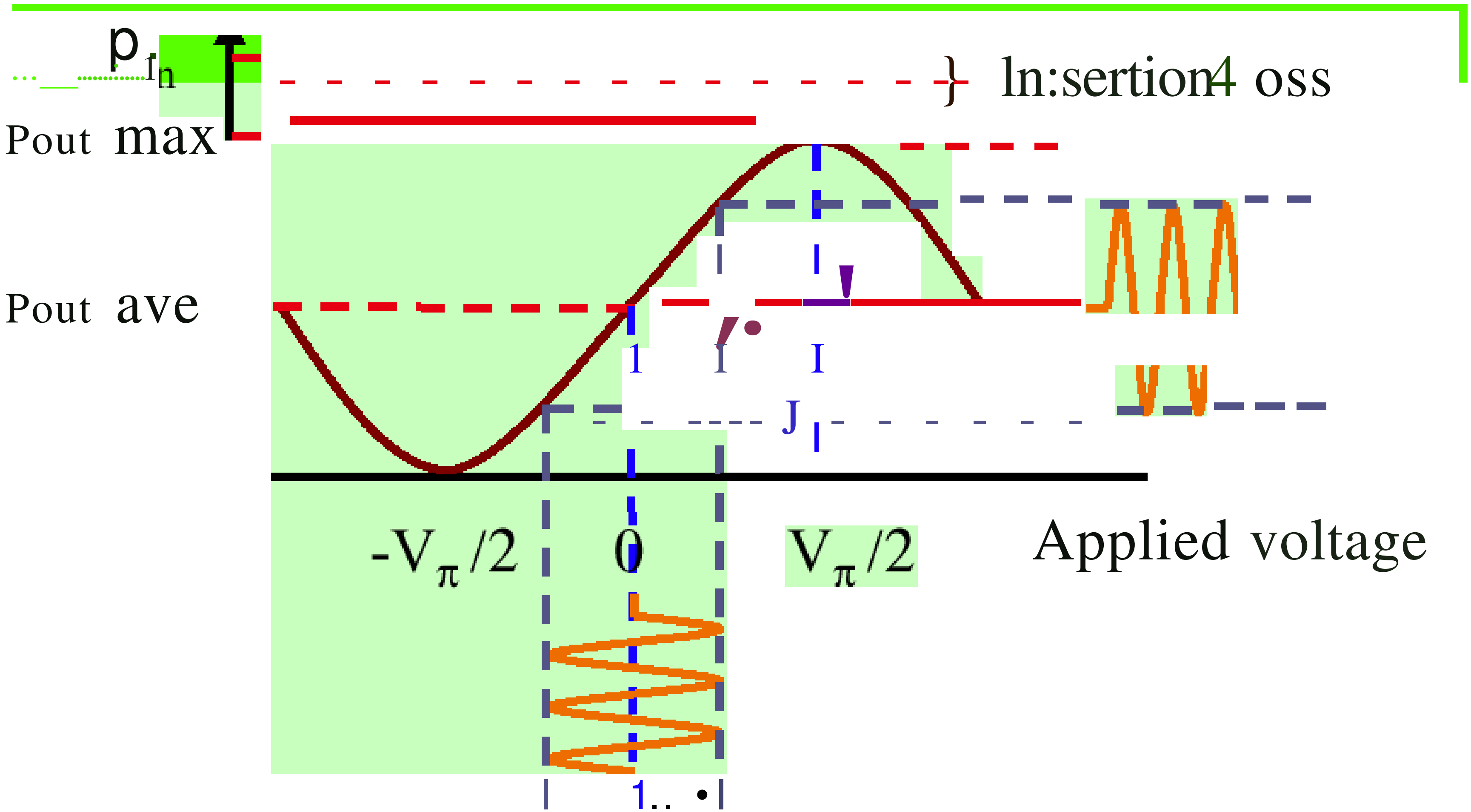


Mach- Zehnder modulator



- Applying voltages to electrodes to change the refractive indices of light paths 1 & 2.
- The optical paths of 1 & 2 vary with the applied voltage.
- In phase → strong output light; out of phase → weak output.
- Output light is then modulated by voltage signal.


In phase
Light in
Constructive output
leakage
Light in
Destructive output
Out of phase

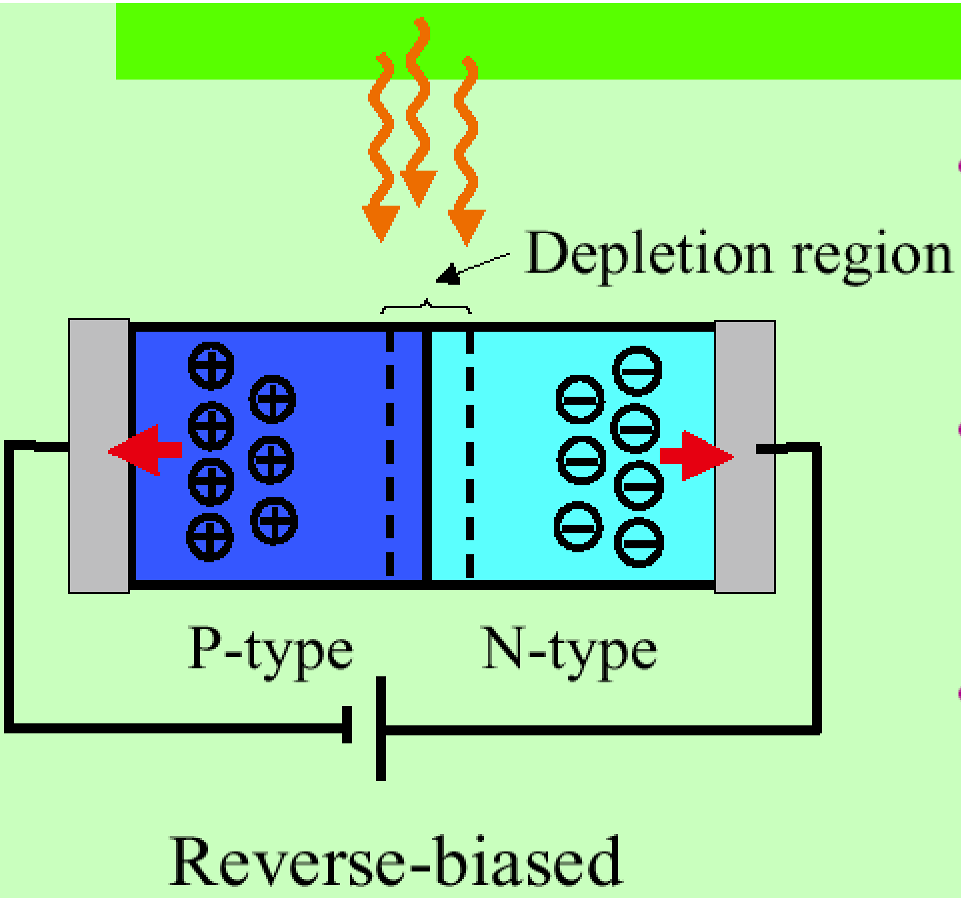


AC modulation

Characteristics of Mach- Zehnder modulator

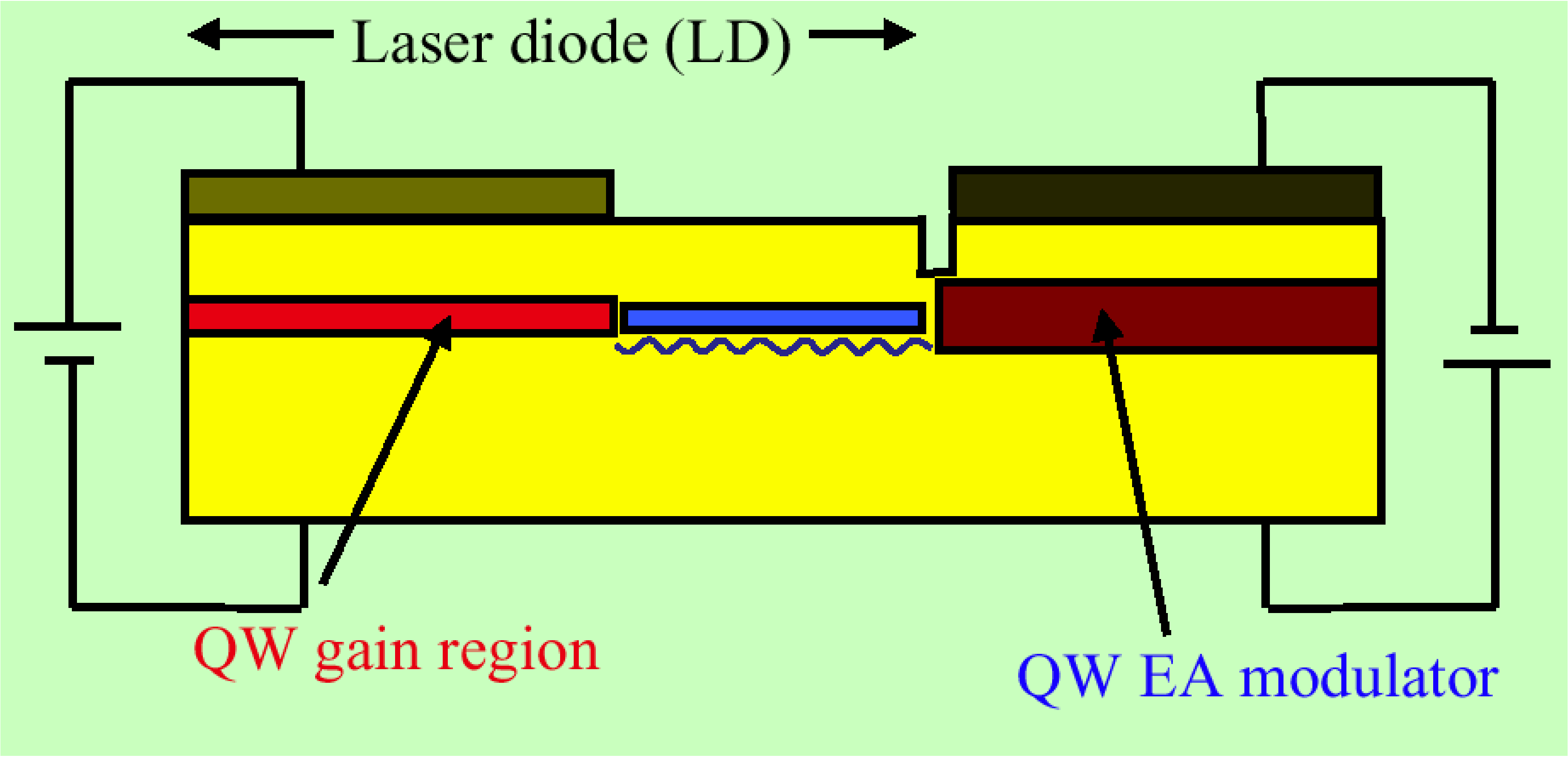
- material: $LiNbO_3$
- modulation depth: better than 20 dB
- bandwidth : could be 60 GHz
- insertion loss : ≥ 4 dB
- power handling : 200 mW
- induced chirp : negligible
- V_π: a few volts, depending on bandwidth

Electro- absorption (EA) modulator



- When the P-N structure in LED is reverse-biased, it becomes light absorption.
- At zero-bias, absorption is weak. Under strong reverse-biased, absorption is strong.
- Light intensity is then modulated by the voltage signal.

Integration of EA modulator with LD



Characteristics of EA modulator

- material: semiconductor QWs
- modulation depth: better than 10 dB
- bandwidth : could be 40 GHz
- insertion loss : almost zero
- power handling : 1 mW
- induced chirp : negligible
- operation voltage: 2 V
- integrable with LD

Mach-Zehnder Principle

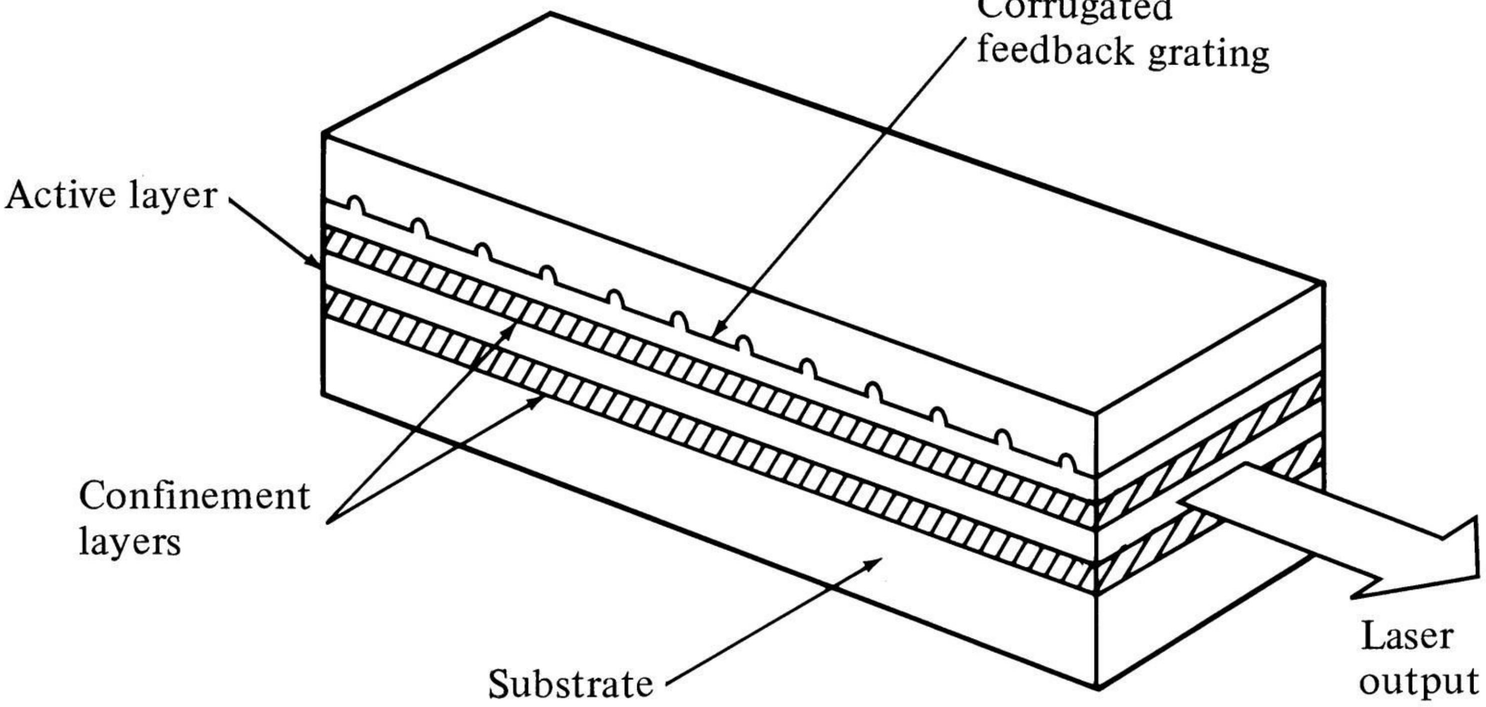
- total relative phase difference between the two interfering signals
  (1) in the upper output branch is $\beta\Delta L + \pi$
  (2) in the lower output branch is $\beta\Delta L$

- if $\beta\Delta L = m\pi$
  (1) where m is odd $\Rightarrow$ two signals add in phase (constructive interference)
  (2) where m is even $\Rightarrow$ two signals are out of phase (destructive interference)

- if only one input is active, then the ouput tranfer function (power) can be expressed as

$$\begin{pmatrix} T_{=}(f) \\ T_{\times}(f) \end{pmatrix} = \begin{pmatrix} \sin^2(\beta\Delta L/2) \\ \cos^2(\beta\Delta L/2) \end{pmatrix} \begin{matrix} \longleftarrow \text{"bar" state} \\ \longleftarrow \text{"cross" state} \end{matrix}$$

Distributed Feedback Laser (Single Mode Laser)



The optical feedback is provided by fiber Bragg Gratings
→ Only one wavelength get positive feedback