50 GHz *p-i-n* Photodiode

GaAs-Air interface as Top Reflector

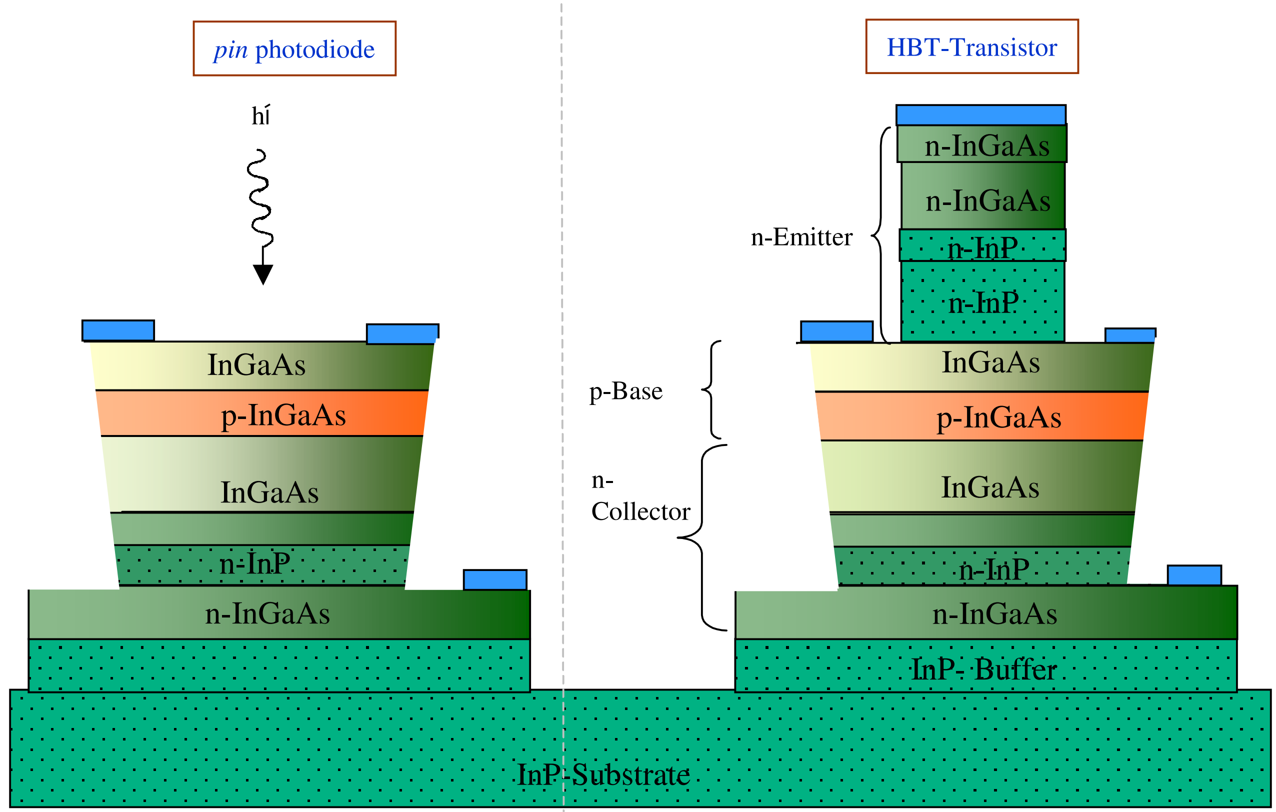
Doping Level	Layer	Thickness (nm)
2x10^8 / cm^3	p-GaAs	20
2x10^8 / cm^3	p-$Al_{0.2}Ga_{0.8}As$	200
undoped	$Al_{0.2}Ga_{0.8}As$◊ GaAs	38
undoped	GaAs	470
undoped	GaAs◊ $Al_{0.2}Ga_{0.8}As$	38
2x10^8 / cm^3	n-$Al_{0.2}Ga_{0.8}As$	390
undoped	$Al_{0.2}Ga_{0.8}As$	180
	n-AlAs/ $Al_{0.2}Ga_{0.8}As$ – 24 pairs as Bottom DBR	
	n-GaAs-Substrate	

1. http://www.fen.bilkent.edu.tr/~ozbay/Papers/34-99apl-ozbaypin.pdf
2. Electronics Letters, Oct, 1994, pp 1796

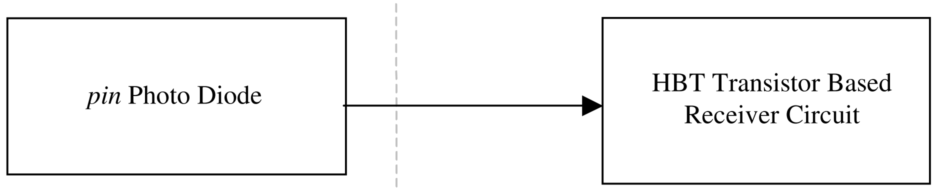
Ashok Rangawamy
(Directed by: Dr. V. K. Jain)

InP–InGaAs Single HBT Technology for Photoreceiver OEIC's at 40 Gb/s

Doping Level
Sn-3x10[19] / cm[3]
Sn-2x10[19] / cm[3]
Si-1x10[19] / cm[3]
Si-4x10[17] / cm[3]
undoped
Zn-3.5x10[19] / cm[3]
undoped
Sn-1x10[19] / cm[3]
Si-1x10[19] / cm[3]
Sn-3.5x10[19] / cm[3]
undoped
undoped



Thickness (nm)
75
225
50
250
5
50
400
50
30
340
100
375x10[3]

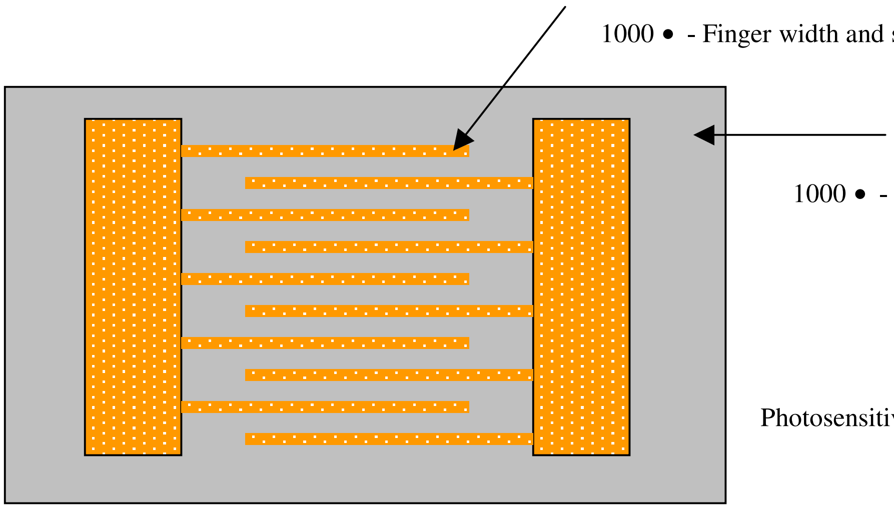


HBT – Heterojunction Bipolar Transistor

1. Huber, IEEE Journal. Light Wave Tech. Vol 18, July 2000, 992
2. Razavi, Design of Integrated Circuits for optical communications

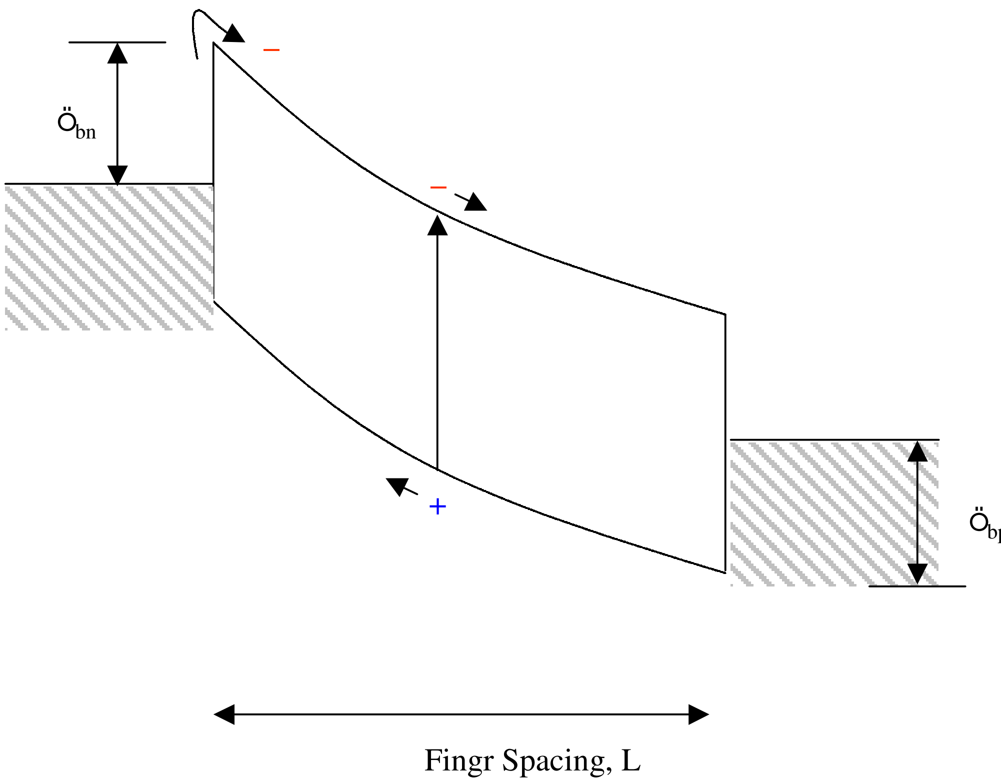
Metal-Semiconductor-Metal (MSM) Photo detector

- Formation of two schottky contacts on a undoped semiconductor layer, either single or interdigitated

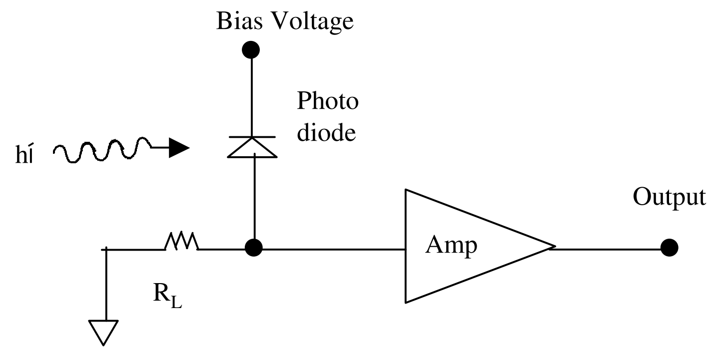


Energy Band Diagram of MSM detector under Bias

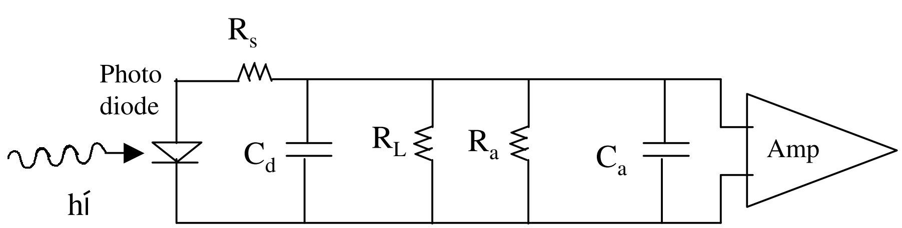
- Adjacent metal/ semiconductor/ metal interfaces are schottky barriers, which serve as two back to back diodes
- When Bias is applied across fingers, one junction becomes FB and other RB
- Photo generated electron-hole pairs in the bulk are swept away by the electric field



Bandwidth Calculation



Equivalent Circuit



C_d = Junction + Packaging Capacitance

R_L = Bias Resistor

R_s = Series Resistance of photodiode(small and can be neglected)

R_a = Amplifier Input Resistance

C_a = Amplifier Input Capacitance

Bandwidth Calculation

$$C_T = \text{Total Capacitance} = C_D \parallel C_a$$

$$R_T = \text{Total Resistance} = R_D \parallel R_a$$

$$\text{Bandwidth} = \frac{1}{2\pi R_T C_T}$$

Example

$C_D = 3\text{pf}$ $\quad C_a = 4\text{pf}$

$R_L = 1\text{K}\Omega$ $\quad R_a = 1\text{M}\Omega$

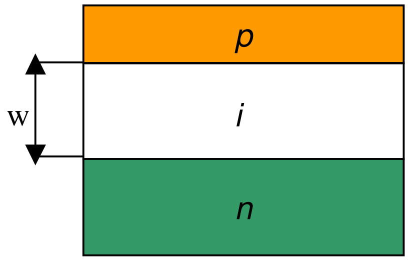
$R_T = R_L \parallel R_a \approx 1\text{K}\Omega$

$C_T = C_D \parallel C_a = 7\text{pf}$

$$\text{Bandwidth} = \frac{1}{2\pi \times 1 \times 10^3 \times 7 \times 10^{-12}} = 23\text{MHz}$$

Gerd Keiser, Optical fiber communications, p. 253

Bandwidth



Bandwidth,

$$BW = \frac{0.44}{\tau_r}$$

Where τ_r is the transit time

$$\tau_r = \frac{w}{\nu_d}$$

ν_d is the saturated carrier drift velocity

Example[1]

Let

$$\nu_d = 8 \times 10^6 \, cm/s$$

$$w = 20 \times 10^{-4} \, cm$$

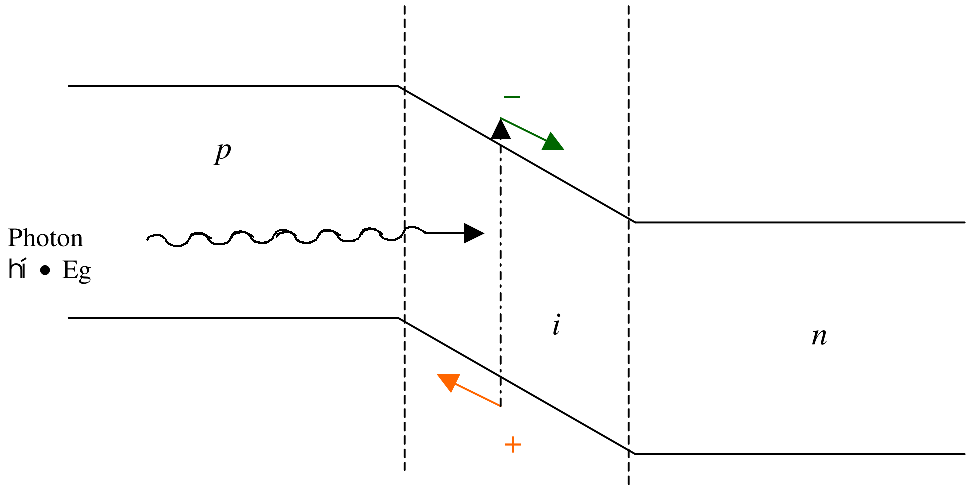
$$\tau_r = \frac{w}{\nu_d} = \frac{20 \times 10^{-4}}{8 \times 10^6} = 0.25 ns$$

Bandwidth,

$$BW = \frac{0.44}{0.25 \times 10^{-9}} = 1.76 GHz$$

Gerd Keiser, Optical fiber communications, pp 236

Working Principle of pin diode



Simple Energy Band diagram for a pin diode

- Photons with an energy greater than or equal to the bandgap energy Eg, generates e-h pairs which act as photocurrent carriers
- Wavelength corresponding to Eg is the cut off wavelength which is upper limit of wavelength range

Cutoff Wavelength,

$$\lambda_c = \frac{hc}{E_g} = \frac{1240}{E_g(eV)} \text{ in nm}$$

Example

Bandgap of GaAs at 300K is 1.43 eV

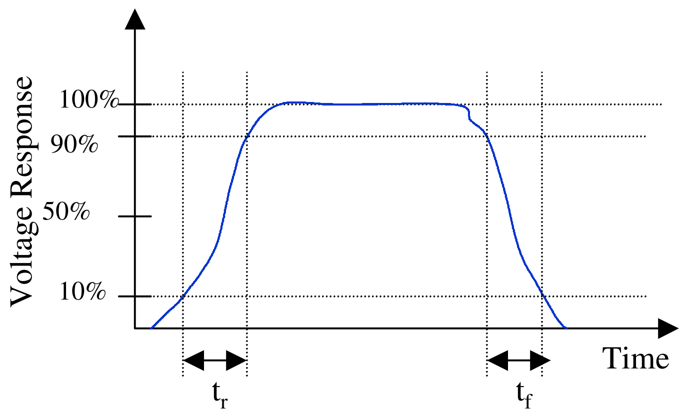
Cutoff Wavelength,

$$\lambda_c = \frac{hc}{E_g} = \frac{1240}{1.43} = 867 \text{ nm}$$

Hence GaAs photodiode will not operate for photons of wavelength greater than 867 nm

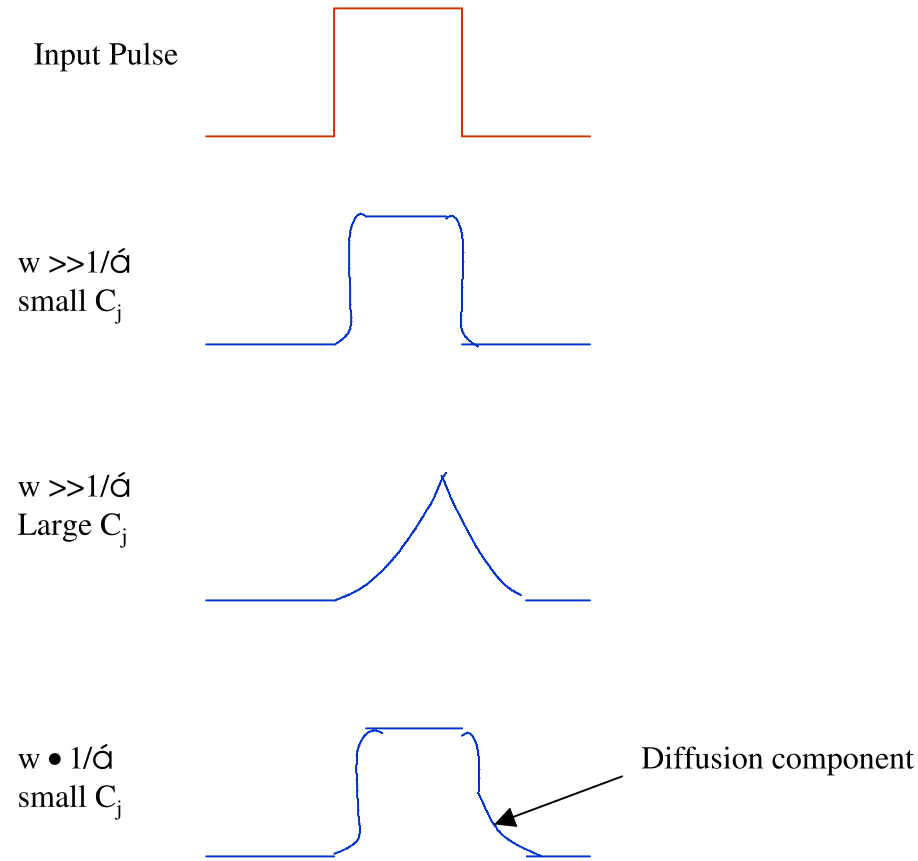
Gerd Keiser, Optical fiber communications, pp 236

Photodiode Pulse Response

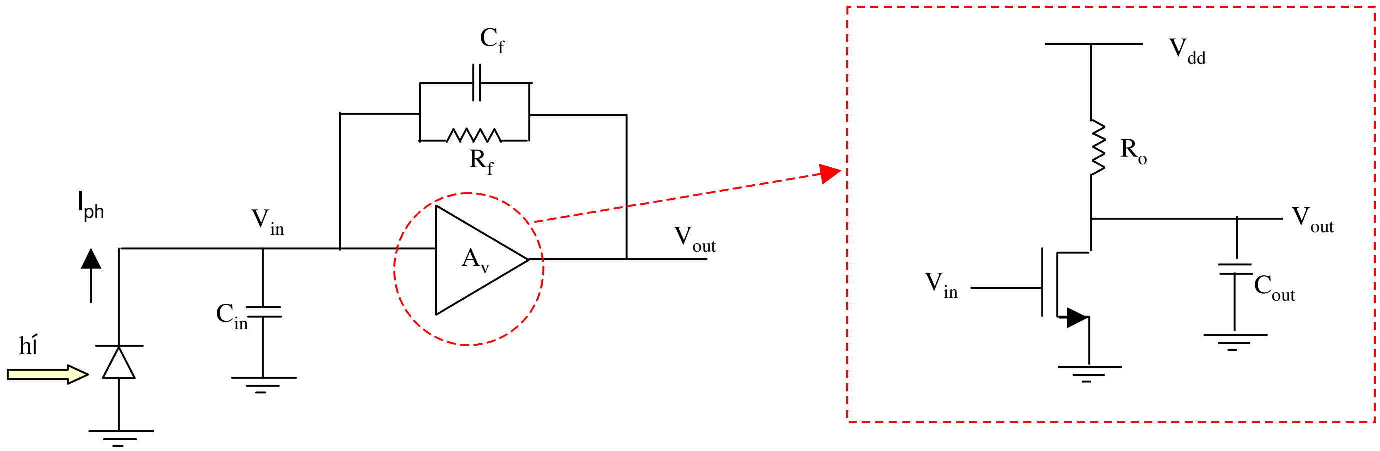


t_r-Rise Time
t_f-Fall Time

Both depends on carrier drift velocity, intrinsic region width w and junction capacitance Cj



Simple Receiver Circuit



Transimpedance Amplifier with CS Voltage Amplifier

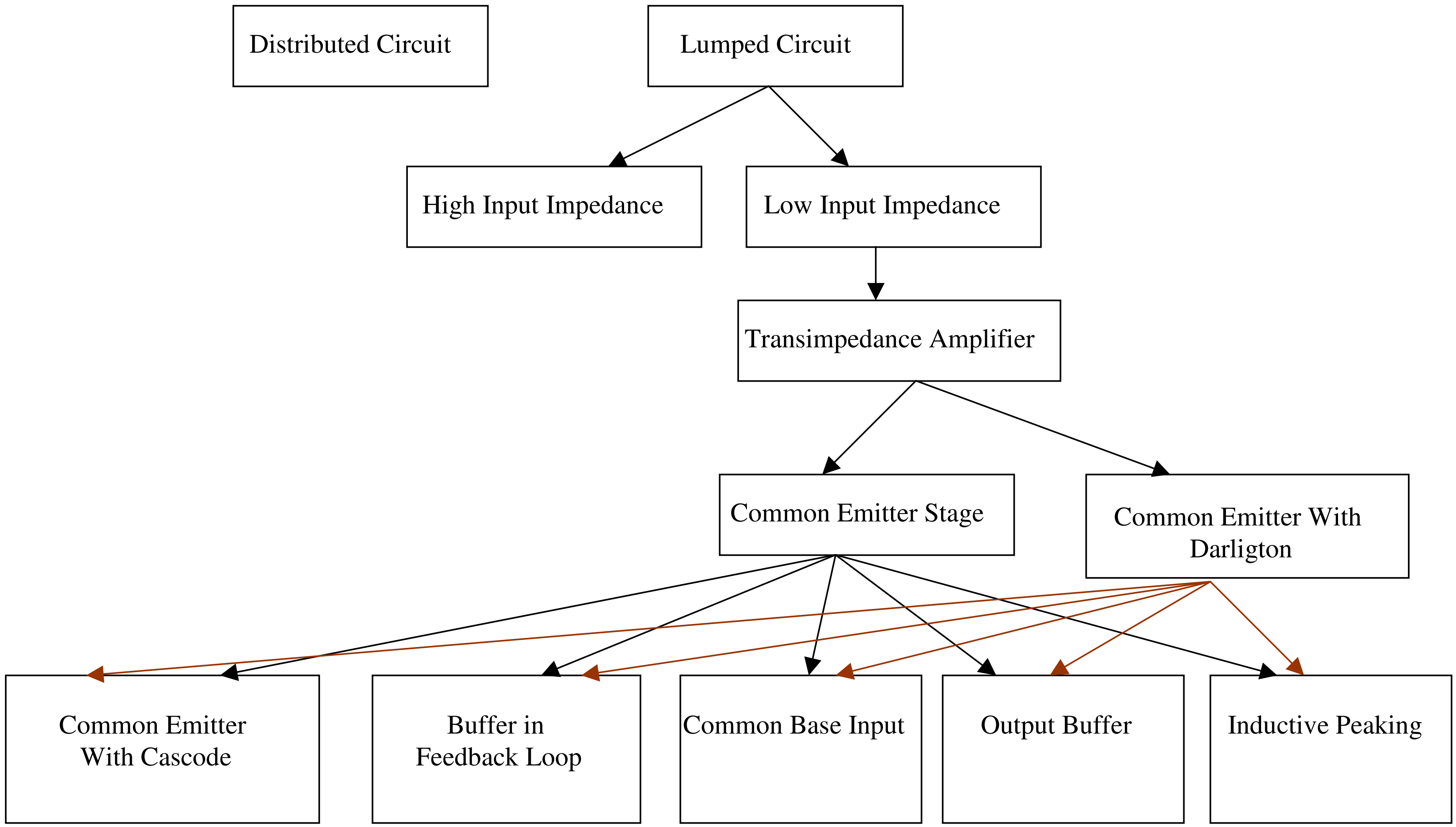
Transimpedance function of the receiver circuit

$$H_r(f) = \frac{v_{out}}{i_{in}} = \frac{R_f\left(\frac{A_v}{1-A_v}\right)}{1 + j2\pi f\left(C_f + \frac{C_{in}}{1-A_v}\right)}$$

Voltage gain of CS stage with feedback loading

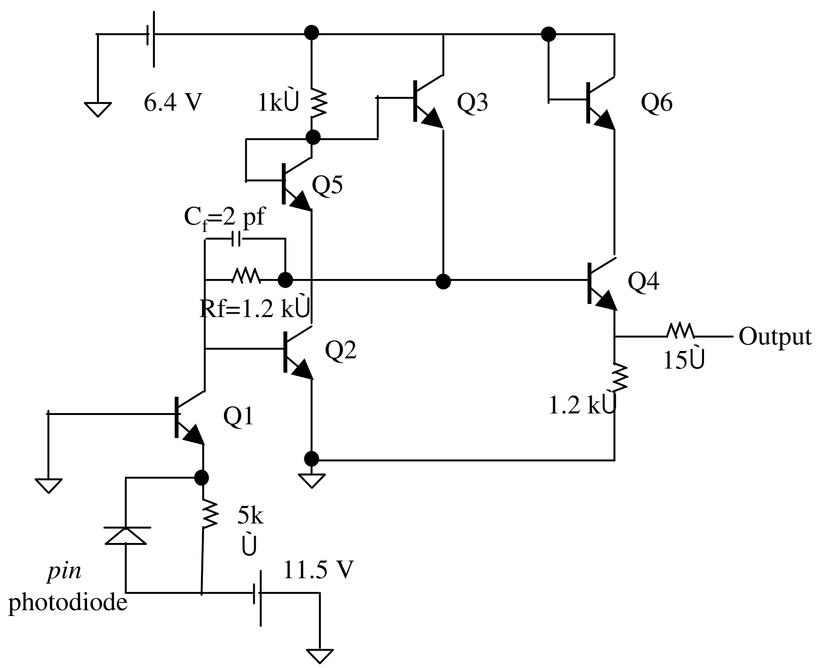
$$A_v = \frac{-g_m + \frac{1}{R_f} + j2\pi f C_f}{\frac{1}{R_o} + \frac{1}{R_f} + j2\pi f\left(C_{out} + C_f\right)}$$

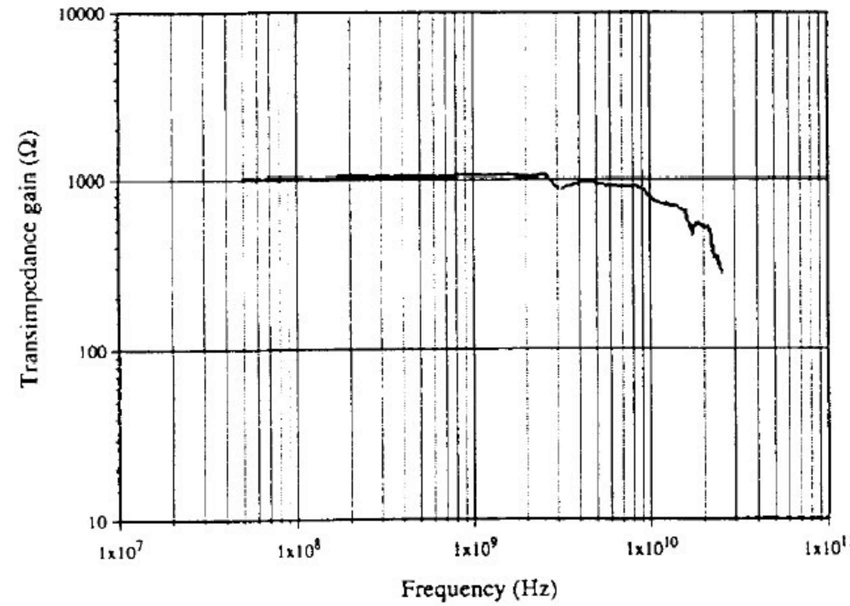
Wide Bandwidth Preamplifier Circuits



Huber, Dieter
InP/InGaAs single hetero-junction bipolar transistors for integrated photoreceivers operating at 40 Gb/s and beyond

Common Base HBT Based Preamplifier Circuit

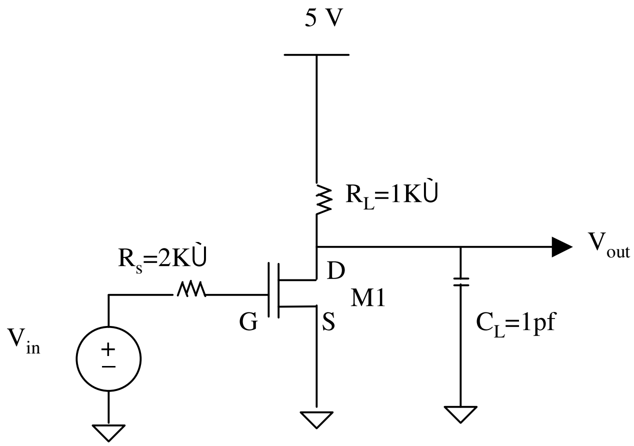


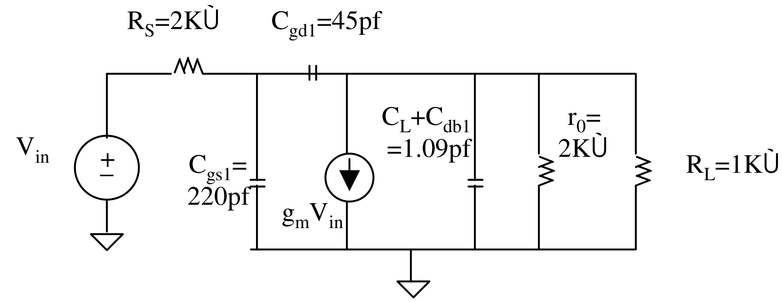


Measured Frequency Response

Tognod Vanisri, IEEE J. Solid State Circuits, Vol 30, June 1995, pp-677

First pass Amplifier (CS)





Small Signal Equivalent Circuit at High Frequencies

Example[1]

$$\tau_{gs1} = C_{gs1} r_{gs1} = C_{gs1} R_S = 220 \times 10^{-15} \times 2000 = 0.44 \text{ ns}$$

$$\tau_{gd1} = C_{gd1} r_{gd1} = C_{gd1} (R_S + R_L + g_m . \frac{1}{1 + g_m R_E} . R_S . R_L) = 45 \times 10^{-15} \times \left(2000 + 1000 + \frac{12 \times 10^{-3} \times 2000 \times 1000}{1 + 0} \right) = 1.215 \text{ ns}$$

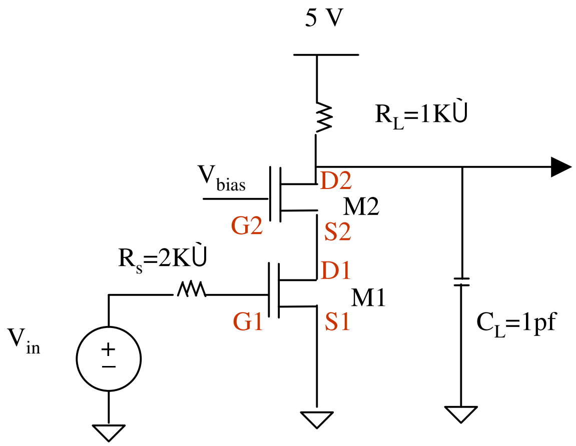
$$\tau_{gb1} = C_{gb1} r_{gb1} = C_{gb1} (R_L \parallel r_o) = 0.09 \times 10^{-12} \times (1000 \parallel 2000) = 0.06 \text{ns}$$

$$\tau_L = C_L (R_L \parallel r_o) = 1 \times 10^{-12} \times (1000 \parallel 2000) = 0.67 \text{ns}$$

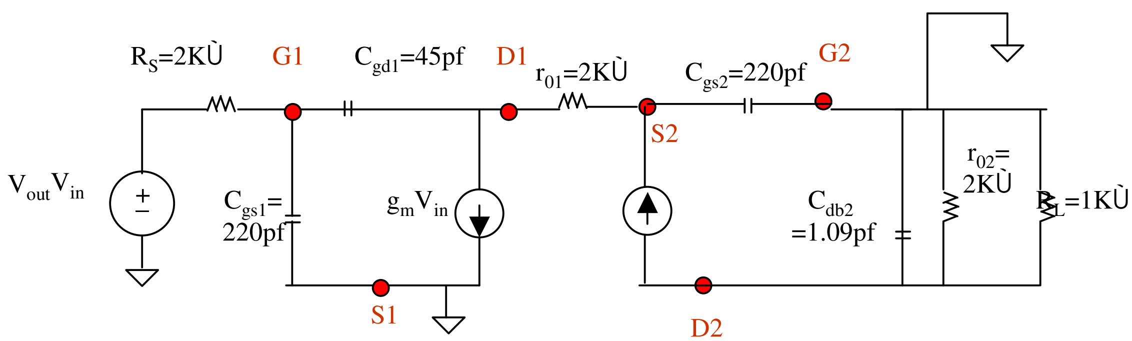
$$\text{Bandwidth} = \frac{1}{\tau_{gs1} + \tau_{gd1} + \tau_{gb1} + \tau_L} = \frac{10^9}{0.44 + 1.215 + 0.06 + 0.67} = 419.28 \text{ MHz}$$

1. Lee, Design of CMOS RF ICs, pp 155

Second pass Cascode Amplifier (CS)

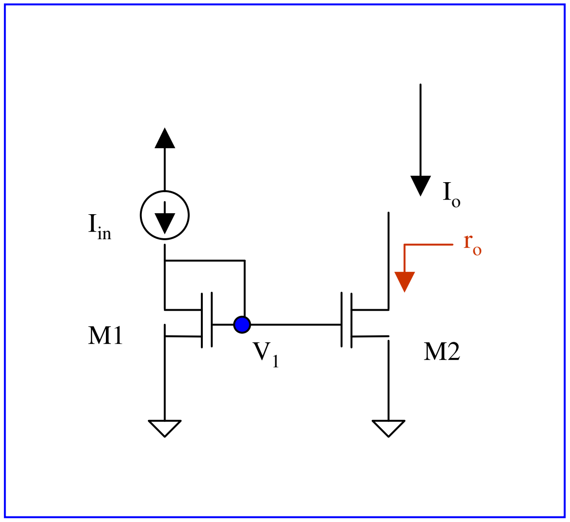


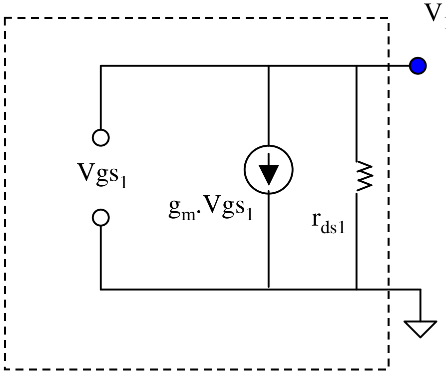
Small Signal Equivalent Circuit at High Frequencies

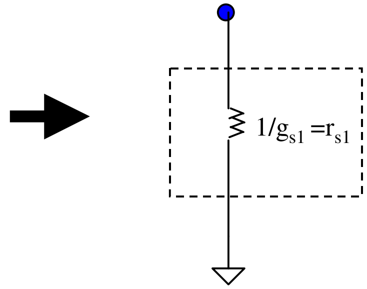


1. Lee, Design of CMOS RF ICs, pp 155

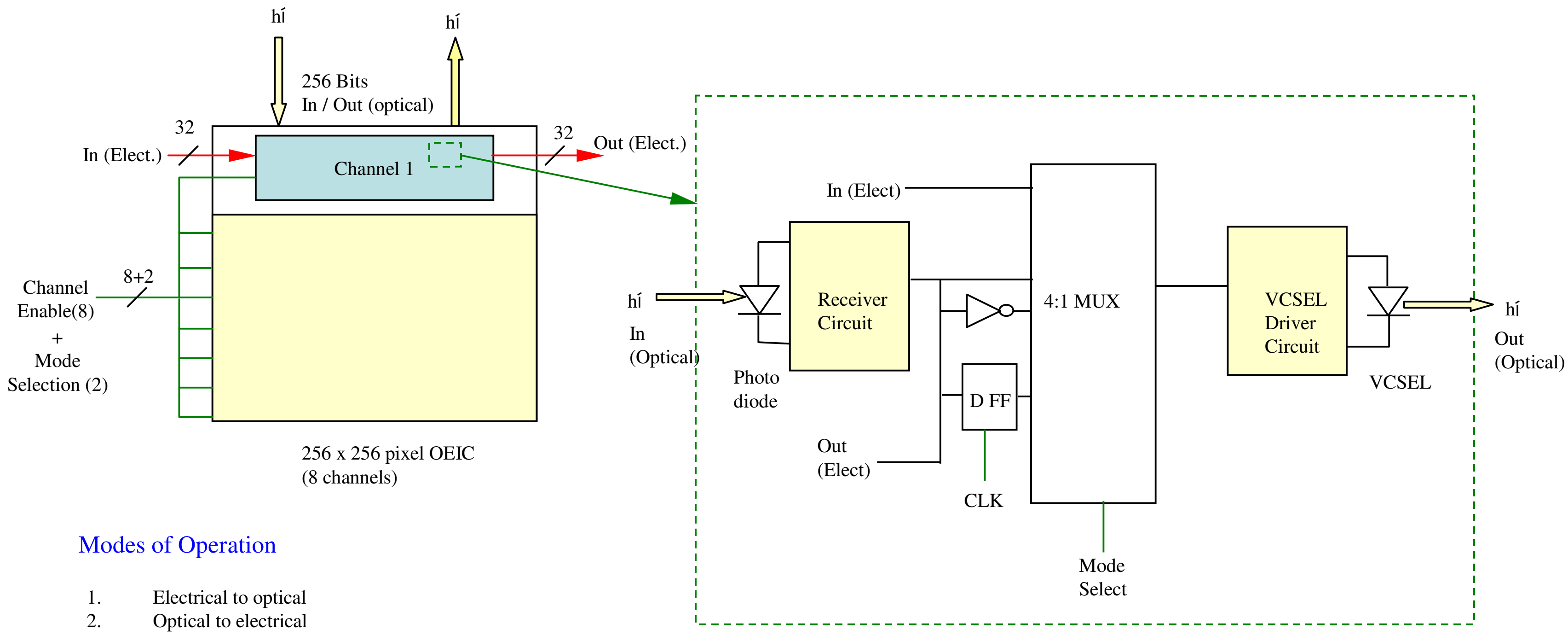
Current Mirror







32 bit 8 Channel Bidirectional OEIC[1]



Single Pixel

Modes of Operation

1. Electrical to optical
2. Optical to electrical
3. Optical to electrical to Optical
4. Optical to electrical to Optical with synchronization using D FFs

1. D.V. Plant, "256-Channel Bidirectional optical interconnect using VCSELs and Photodiodes on CMOS, IEEE J. Lightwave Technologies, Vol.19, No. 8, August 2001