EE 232 Lightwave Devices **HW#7 Solutions**
Prof. Ming C. Wu **Fall 2006**

Constant Values:

$h\_bar := 1.05459 \cdot 10^{-34}$ (J-sec) $q := 1.6 \cdot 10^{-19}$ (Coul) $mW := 10^{-3}$

$m0 := 9.11 \cdot 10^{-31}$ (kg) $c := 3 \cdot 10^{8}$ (m/sec) $mA := 10^{-3}$

$nm := 10^{-9}$ (m) $\varepsilon 0 := 8.854 \cdot 10^{-12}$ (F/m)

$\mu m := 10^{-6}$ (m) $eV := 1.6 \cdot 10^{-19}$ (Joul) $kT := 0.026 \cdot eV$

$nr := 3.5$ $\varepsilon r := nr^2$ $\varepsilon r = 12.25$

1. $dgdN := 2 \cdot 10^{-16} \cdot 10^{-4}$ $Ntr := 10^{18} \cdot 10^{6}$ $\varepsilon := 10^{-16} \cdot 10^{-6}$ $GHz := 10^{9}$

$\alpha i := 10 \cdot 100$ $w := 1 \cdot \mu m$ $L := 200 \cdot \mu m$ $t := 0.1 \cdot \mu m$ $A := w \cdot L$

$R := 30\%$ $nr := 3$ $\tau := 10^{-9}$ $\lambda := 1.24 \cdot \mu m$ $\eta i := 100\%$

$\Gamma := 50\%$ $vg := \dfrac{c}{nr}$ $vg = 1 \times 10^{8}$

(a) $\alpha m := \dfrac{1}{2 \cdot L} \cdot \ln\left(\dfrac{1}{R \cdot R}\right)$ $\alpha m = 6.02 \times 10^{3}$

$gth := \dfrac{1}{\Gamma} \cdot (\alpha m + \alpha i)$ $gth = 1.404 \times 10^{4}$ [m-1]

$\tau p := \dfrac{1}{\Gamma \cdot vg \cdot gth}$ $\tau p = 1.425 \times 10^{-12}$ [sec]

(b) $P := 1 \cdot mW$ $P = 1 \times 10^{-3}$

$S(P) := \dfrac{P}{\dfrac{1.24}{\frac{\lambda}{\mu m}} \cdot q \cdot \dfrac{w \cdot L \cdot t}{\Gamma} \cdot \alpha m \cdot vg}$ $S(1 \cdot mW) = 2.596 \times 10^{20}$ [photons/m^3]

(c) $\omega r(S) := \sqrt{\dfrac{vg \cdot dgdN \cdot S}{\tau p}}$ $fr(S) := \dfrac{1}{2 \cdot \pi} \cdot \omega r(S)$ $fr(S(1 \cdot mW)) = 3.038 \times 10^{9}$ [Hz]

(d) $\tau p = 1.425 \times 10^{-12}$

$\dfrac{\varepsilon}{vg \cdot dgdN} = 5 \times 10^{-11}$ Nonlinear effect dominates

$K := 4 \cdot \pi^2 \cdot \left(\tau p + \dfrac{\varepsilon}{vg \cdot dgdN}\right)$ $K = 2.03 \times 10^{-9}$ seccond

(e)

$\gamma(P) := K\cdot fr(S(P))^2 + \frac{1}{\tau}$ $\qquad\qquad$ $\gamma(1\cdot mW) = 1.974\times 10^{10}$

$$H(P,\omega) := \frac{\omega r(S(P))^2}{\omega r(S(P))^2 - \omega^2 - i\cdot\omega\cdot\gamma(P)}$$

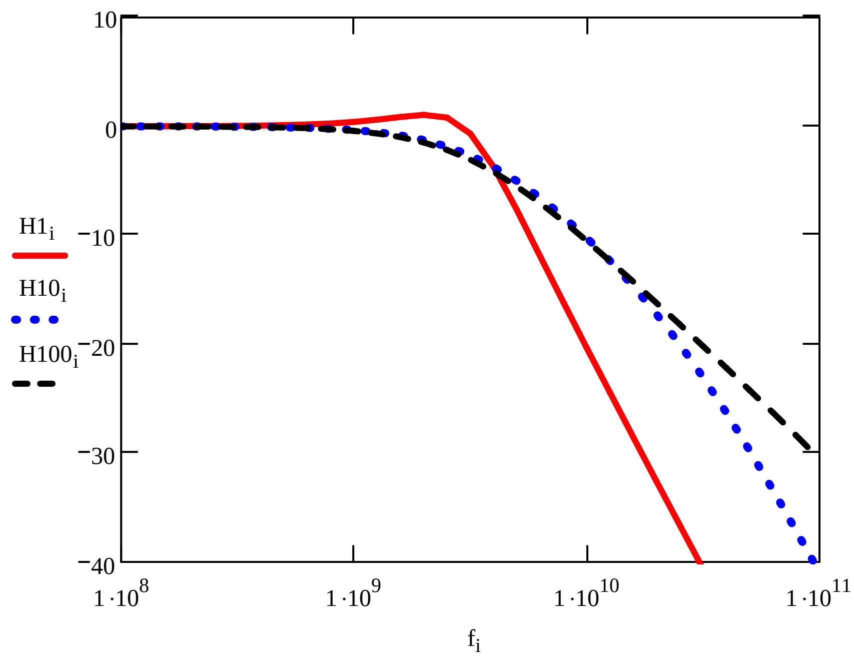
$i := 0 .. 30$

$f_i := 10^{\frac{i-10}{10}}\cdot GHz$

$H1_i := 10\cdot\log\left[\left(\left|H\left(1\cdot mW, 2\cdot\pi\cdot f_i\right)\right|\right)^2\right]$

$H10_i := 10\cdot\log\left[\left(\left|H\left(10\cdot mW, 2\cdot\pi\cdot f_i\right)\right|\right)^2\right]$

$H100_i := 10\cdot\log\left[\left(\left|H\left(100\cdot mW, 2\cdot\pi\cdot f_i\right)\right|\right)^2\right]$



2. $\alpha := 10^4 \cdot 10^2$ (absorption coefficient) $ve := 10^7 \cdot 10^{-2}$ $vh := 2 \cdot 10^6 \cdot 10^{-2}$

$\eta i := 90\%$ $R := 50$ (load resistance)

$A := 100\mu m \cdot 100 \cdot \mu m$ $A = 1 \times 10^{-8}$

(a) $\tau\_t(W) := \frac{1}{2.8} \cdot \frac{W}{vh}$

$\tau\_RC(W) := \varepsilon r \cdot \varepsilon 0 \cdot \frac{A}{W}$

(b) $\tau(W) := \tau\_t(W) + \tau\_RC(W)$

$f\_3dB(W) := \frac{1}{2 \cdot \pi} \cdot \frac{1}{\tau(W)}$

(c) $\tau\_min := 2 \cdot \sqrt{\left(\frac{1}{2.8} \cdot \frac{W}{vh}\right) \cdot \left(\varepsilon r \cdot \varepsilon 0 \cdot \frac{A}{W}\right)}$ $\tau\_min = 8.802 \times 10^{-12}$ [sec]

$f\_3dB\_max := \frac{1}{2 \cdot \pi} \cdot \frac{1}{\tau\_min}$ $f\_3dB\_max = 1.808 \times 10^{10}$ [Hz]

Obtained when

$W := 1\mu m$ (initial value)

Given $\tau\_t(W) = \tau\_RC(W)$

$W\_opt := \text{Find}(W)$ $W\_opt = 1 \times 10^{-6}$ [m]

(d)

$\eta(W) := \eta i \cdot (1 - \exp(-\alpha \cdot W))$

$\eta(W\_opt) = 0.569$

3. $d := 2 \cdot \mu m$ $W := 0.5 \cdot \mu m$ $\alpha := 10^4 \cdot 10^2$ $\alpha e := 5 \cdot 10^4 \cdot 10^2$ $\beta p := 5 \cdot 10^3 \cdot 10^2$ $R := 50$

(a) $\eta i := 100\%$

$\eta ext := \eta i \cdot (1 - \exp(-\alpha \cdot d))$ $\eta ext = 0.865$

$k := \frac{\beta p}{\alpha e}$ $k = 0.1$

$Mn := \frac{1 - k}{\exp[-(1 - k) \cdot \alpha e \cdot W] - k}$ $Mn = 166.691$

Responsivity R0 (A/W) $R0 := \eta ext \cdot \frac{q}{\frac{1.24}{1.55} \cdot q} \cdot Mn$ $R0 = 180.164$ (A/W)

(b) Consider transit time and multiplication time only, assume the APD has sufficiently small area such that RC time is much smaller.

$ve := 10^5$ $vh := 2 \cdot 10^4$

$\tau d := \frac{d}{vh}$ $\tau d = 1 \times 10^{-10}$

$\tau m := \frac{Mn \cdot k \cdot W}{ve} + \frac{W}{vh}$ $\tau m = 1.083 \times 10^{-10}$

$f\_3dB := \frac{1}{2 \cdot \pi} \cdot \frac{1}{\tau d + \tau m}$ $f\_3dB = 7.639 \times 10^8$ [Hz]

(c) $F := k \cdot Mn + (1 - k) \cdot \left(2 - \frac{1}{Mn}\right)$ $F = 18.464$

$10 \cdot \log(F) = 12.663$ (dB)

(d) $\Delta f := 10^9$

$is2(ip) := 2 \cdot q \cdot ip \cdot Mn^2 \cdot F \cdot \Delta f$

$it2 := \frac{4 \cdot kT}{R} \cdot \Delta f$

$SNR(ip) := \frac{ip^2 \cdot Mn^2}{is2(ip) + it2}$

$ip := 0.1 \cdot mA$ (initial guess value)

Given $SNR(ip) = 1000$

$ip0 := Find(ip)$ $ip0 = 5.91 \times 10^{-6}$ Minimum photocurrent to achieve SNR = 1000

$P := \frac{ip0}{\eta ext \cdot \frac{1.55}{1.24}}$ $P = 5.468 \times 10^{-6}$ W

$P\_dBm := 10 \cdot \log\left(\frac{P}{mW}\right)$ $P\_dBm = -22.621$