ECEN 4634 MICROWAVE AND TRANSMISSION LAB 4/28/99

Final Exam (Written Section)

Open Notes.
Show (i. e., *explain*) all work.

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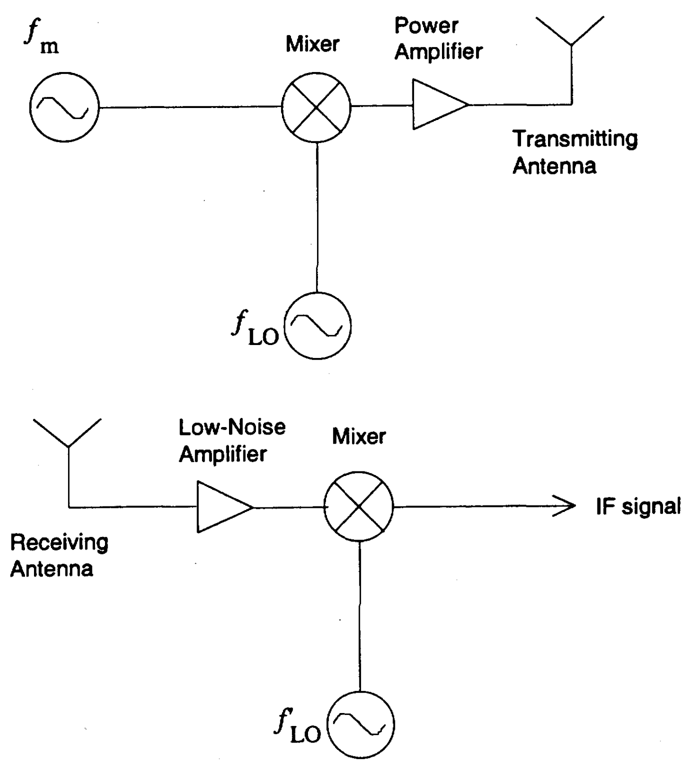
(20) 1. Consider the microwave link shown in the figure. The transmitting and receiving antennas are separated by a distance of 100 m.



The modulating frequency sent to the transmitter's mixer is $f_m = 10$ kHz, the local oscillator frequency of the transmitter is $f_{LO} = 10$ GHz, and the local oscillator frequency of the receiver is $f'_{LO} = 10.020$ GHz. The output from the transmitter's mixer is 6 dBm, and the gain of the power amplifier is 15 dB. The transmitting antenna's gain is 12 dB, the receiving antenna's effective area is 0.005 m^2, the low-noise amplifier's gain is 9 dB, and the receiver mixer's conversion loss is 5 dB. All components are impedance-matched to their respective transmission lines and sources.

(a) What frequency components appear in the IF signal at the right end of the receiver?

(b) How many watts of power appear at the output of the receiver in the IF signal? What is this value in dBm?

(20) 2. A Schottky diode is connected in shunt across a lossless transmission line of characteristic impedance $Z_0 = 50\ \Omega$ at $z = 0$. An RF voltage wave of RMS amplitude $V_+ = 1$ volt is incident from $z < 0$ towards the diode. The DC bias current on the diode is zero. The diode's parameters (in accordance with eqns. (3.6) ff. of the course notes) are: $I_S = 25\ \mu$A, $\alpha = 50\ \text{V}^{-1}$.

(a) Assume that modeling the diode as a linear RF conductance G_d is sufficiently accurate for determining the small-signal RF voltage and current. Find the reflection coefficient ρ and transmission coefficient τ on the transmission line due to this diode.

(b) Determine the DC component of the diode current I_{DC} which results from the incident voltage wave.

(20) 3. A Gunn diode is modeled by the nonlinear conductance

$$G_D = G_d + \frac{G''_d}{8} V_1^2$$

where V_1 is the RF voltage, $G_d = -2$ mS and $G''_d = 3\ \text{mS/V}^2$. The Gunn diode is connected to a resonant load whose admittance is

$$Y_L = \frac{1}{R_L} + j\omega C + \frac{1}{j\omega L}$$

where $C = 10$ pF, $R_L = 2\ \text{k}\Omega$, and $L = 30\ \mu$H. Find the frequency f at which this circuit oscillates, and the RF voltage V_1 of the oscillation.

1) (a) Inputs to transmit mixer are:

$f_m, f_{LO} \Rightarrow$ its output is $f_m, f_{LO}, f_{LO} \pm f_m, 2f_m, 2f_{LO}$, and others at higher order.

Only $f_{LO}, f_{LO} \pm f_m, 2f_{LO}$ survive to receive antenna, these input to 2nd mixer to give, with f'_{LO},

$$f'_{LO} \pm f_{LO},\ f'_{LO} \pm f_{LO} \pm f_m,\ 2f_{LO} \pm f'_{LO},\ 2f'_{LO},$$
$$2f_{LO},\ 2(f_{LO} \pm f_m),\ 4f_{LO}$$

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{10^{10}} = .03\,m$$

(b) $P_{tr} = 6\,dBm \Rightarrow 4\,mW$

$$P_r = P_{tr}\, G_{tr}\, G_r \left(\frac{\lambda}{4\pi r}\right)^2 \qquad \text{(absolute)}$$

or

$$= P_{tr,dBm} + G_{tr,dB} + G_{r,dB} + 20\log_{10}\left(\frac{\lambda}{4\pi r}\right) \qquad (dB)$$

Also

$$P_r = P_{tr}\, G_{tr}\, A_r \frac{1}{4\pi r^2}$$

or

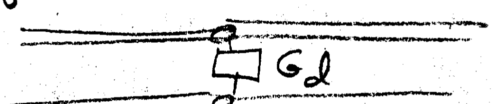
$$= P_{tr,dBm} + G_{tr,dB} + 10\log_{10}\left(\frac{A_r}{4\pi r^2}\right)$$

so

$$P_r = 6\,dBm + 12\,dB + \underbrace{10\log_{10}\left(\frac{.005}{4\pi(100)^2}\right)}_{\simeq -74\,dB} + 15\,dB$$
$$= -41\,dBm$$

Amp output is $-32\,dBm$. Conversion loss at mixer gives IF of $\underline{-37\,dBm}$ or $\underline{0.2\,\mu W}$.

2) (a)



$G_d = \alpha I_s = 0.00125\ S$

or $R_j = 800\,\Omega$

$$R_j \parallel Z_0 = \frac{50(800)}{850} = 47.059\,\Omega$$

$$\rho = \frac{47.059 - 50}{47.059 + 50} = \underline{-0.03}$$

$\tau = 1 + \rho = \underline{0.97}$

$V_d = V_1^+ \tau = 0.97\,v$ (RMS)

$$\Rightarrow v = \frac{0.97}{\sqrt{2}} \cos\omega t \Rightarrow v_{av}^2 = (0.97)^2$$

$$I_{DC} = \frac{v_{av}^2}{2} G'_d = \frac{(0.97)^2}{2} \alpha G_d = \underline{29.38\ mA}$$

3) f:

$$\frac{1}{j\omega L} + j\omega C = 0 \Rightarrow \omega = \frac{1}{\sqrt{LC}} \Rightarrow f = \frac{1}{2\pi\sqrt{LC}}$$

$$= \underline{9.189 \text{ MHz}}$$

$$G_D + \frac{1}{R_L} = 0 \Rightarrow G_d + \frac{G_d''}{8}V_1^2 + \frac{1}{R_L} = 0$$

$$V_1^2 = -\left(G_d + \frac{1}{R_L}\right)\frac{8}{G_d''} = 4 \Rightarrow \underline{\underline{V_1 = 2V}}$$

Final Exam

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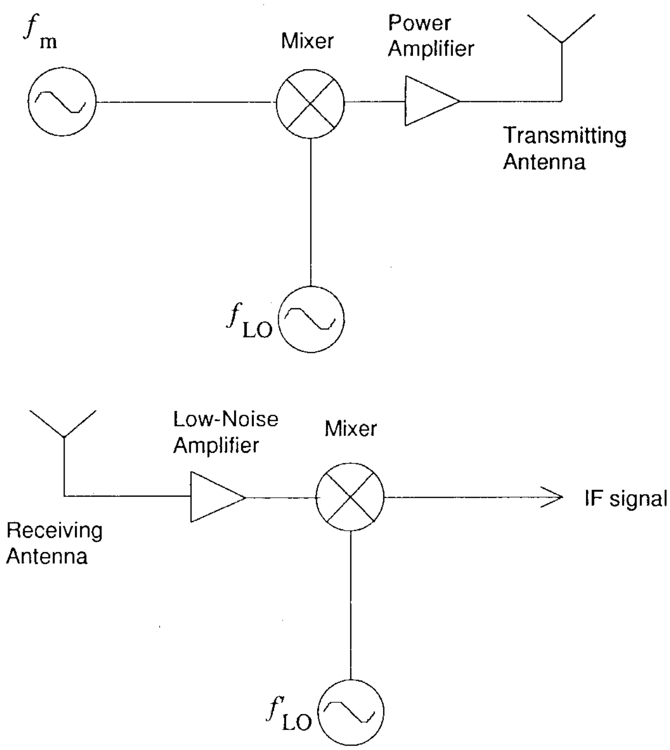
1. Consider the microwave link shown in the figure. The transmitting and receiving antennas are separated by a distance r.



The modulation sent to the transmitter's mixer is a 100 kHz sine wave. The local oscillator frequency of the transmitter is $f_{LO} = 2$ GHz, and the local oscillator frequency of the receiver is $f'_{LO} = 2.050$ GHz. Each mixer has a conversion loss of 3.5 dB, the gain of the power amplifier is 12 dB and the low-noise amplifier's gain is 9 dB. The transmitting antenna's gain is 18 dB and the receiving antenna's gain is 6 dB. All components are impedance-matched to their respective transmission lines and sources, except for the antennas, each of which has a reflection coefficient of $|\rho| = 0.5$ when connected to the transmission lines.

(a) What frequency components appear in the IF signal at the right end of the receiver? Assume the mixers are square-law (I is a quadratic function of V) diodes.

(b) The modulation signal has a power of 1 mW. If the IF output signal from the receive end has a power of -40 dBm, what is the distance r between the transmitting and receiving antennas?

2. A Schottky diode's parameters (in accordance with eqns. (4.6)-(4.9) of the course notes) are: $I_S = 60\ \mu$A, $\alpha = 100$ V^{-1}. The diode is connected in series with a 100 Ω resistor at the end ($z = 0$) of a lossless transmission line whose characteristic impedance is $Z_0 = 50$ Ω. An RF voltage wave of RMS amplitude V_+ is incident from $z < 0$ towards the diode. The DC bias current on the diode is zero.

   (a) Assume that modelling the diode as a linear RF conductance G_d is sufficiently accurate for determining the small-signal RF voltage and current. Find the reflection coefficient ρ on the transmission line due to this diode.

   (b) A DC component of the diode current $I_{\rm DC} = 25\ \mu$A is measured through the diode. Find the rms amplitude of the incident voltage wave.

3. A Gunn diode is modelled by the nonlinear conductance

$$G_D = G_d + \frac{G_d''}{8} V_1^2$$

   where V_1 is the RF voltage. If the DC bias voltage is 7 volts, $G_d = -3$ mS and $G_d'' = 12$ mS/V^2. If the bias voltage is 5 volts, $G_d = -1$ mS, while G_d'' remains the same. The Gunn diode is connected to a resonant load whose admittance is

$$Y_L = \frac{1}{R_L} + j\omega C + \frac{1}{j\omega L}$$

   Find a value for R_L for which the circuit will oscillate when the bias voltage is 7 volts, but not when it is 5 volts.

4. A 5 cm length of 50 Ω coaxial cable is short circuited at both ends. If this is to be used as a resonator for a Gunn diode oscillator, at what frequencies might the oscillator produce power? Should the diode be connected to the midpoint of this cable or not, and why?