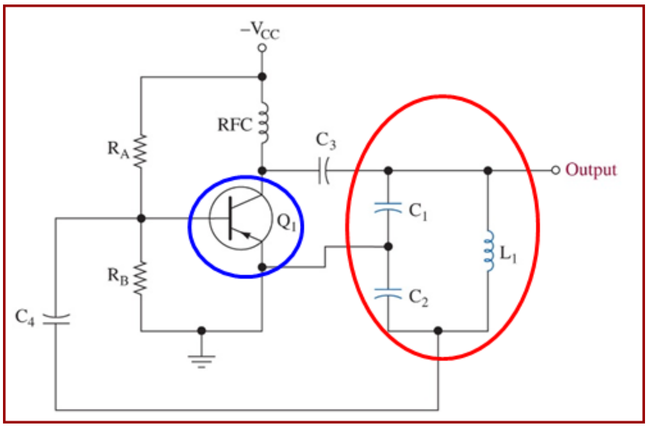
Q1

a) The sketch of a Colpitts oscillator is shown below – the key point is to remember how the transistor is used for the amplifier block and the two series capacitors C1-C2 and inductor L1 are the feedback network. The other components are Ra and Rb to bias the BJT, RFC is an inductor that blocks the AC signal but let the DC signal pass to bias the amplifier. C4 blocks the DC but let the AC signal from the feedback pass over to the BJT.



b) The main 3 parameters are the gain of the feedback network β, the effective input impedance of the feedback network, and the resonant frequency of the loop.
Barkhausen criteria are mentioned in the relevant slides, two conditions (one on gain and one on phase shift) of the overall loop to ensure oscillations are maintained.

c) Simple application of the resonant frequency formula for this oscillator, see slides.

d) Heterodyne receivers are described in the slides in the last week of lectures, with block diagram given. In minimal terms an RF branch with a BPF, an LO, and an IF branch with amplifier and/or BPF, all three (RF, LO, IF) connected to a mixer. However, the Colpitts oscillator above does not allow to tune the oscillator, which is the main point of heterodyne receivers, hence the question is asking to suggest how to make the Colpitts into a variable oscillator, for which we have seen two approaches…variable components or varactors.

Q2

a) This question can be solved by simply applying knowledge of mixers, i.e. the output of the mixer contains the sum and difference components of the inputs. In this case LO has a minimum and max frequency and IF is fixed, so you end up having 4 possible frequencies at the output of the mixer.

b) Straightforward application of definition of Q

c) Convert the input power in dB (10*log10…) and follow the attenuation/gain chain at the IF branch…

d) To find the SNR you need to calculate the noise power at the output of the LNA. You need the input noise power given the bandwidth of BPF1 and the operating temperature, then calculate how that input noise power is processed by the chain BPF1+LNA. The SNR is finally the ratio (or in dB the difference) between signal and noise power levels

e) To solve this you need to remember Friis equation on the best way to cascade two amplifier to minimise the overall noise figure of the system…

f) You need a non-linear component, diode, BJT or FET…with pros and cons discussed in the slides.

Q3 $I_t = I_C\sqrt{1+\frac{m^2}{2}}$

$$13A = 12A\sqrt{1+\frac{m^2}{2}}$$

$$1+\frac{m^2}{2} = \frac{13^2}{12^2} = \frac{169}{144}$$

$$m^2 = 2(1.1736-1) = 0.3472$$

$$m = 0.59$$

$$\%m = 0.59 \times 100 = 59\%$$

(a) When the input to an ideal non-linear device is a carrier and its sidebands, the output contains the following frequencies:

i) The carrier frequency
ii) The upper sideband
iii) The lower sideband
iv) A DC component
v) A frequency equal to the carrier minus the lower sideband and the upper sideband minus the carrier, which is the original signal frequency

(b) Advantages:

i) They can handle relatively high-power signal
ii) Distortion levels are acceptable for most AM applications
iii) They are highly efficient.
iv) They develop a readily usable dc voltage for the automatic gain control circuits

Disadvantages:

i) Power is absorbed from the tuned circuit by the diode circuit. This reduces the Q and selectivity of the tuned input circuit
ii) No amplification occurs in a diode detector circuit

(c)

$$Q = \frac{f_c\left(log^{-1}\frac{db}{20}\right)^{\frac{1}{2}}}{4\Delta f} = \frac{100KHz\left(log^{-1}\frac{80}{20}\right)^{\frac{1}{2}}}{4\times 200Hz} = \frac{10^7}{8\times 10^2} = 12{,}500$$

(d) Received power at the antenna is given by: $P = \frac{V^2}{R} = \frac{(10\mu V)^2}{40\Omega} = 2.5\times 10^{-12}W$

Received power in dBm= $10\log_{10}\frac{P}{1mW} = 10\log_{10}\frac{2.5\times10^{-12}W}{1mW} = -86\ dBm$

Received power in dBW is given by, $10\log_{10}\frac{P}{1W} = 10\log_{10}\frac{2.5\times10^{-12}W}{1W} = -116\ dBW$

Now, adding the gains at various stages, the output power can be calculated as

$$P_{out(dBm)} = -86dBm + 10\ dB + 4\ dB + 22\ dB + 25\ dB + 25\ dB - 3\ dB + 30\ dB = 27\ dBm$$

Now, $27\ dBm = 10\times\log_{10}\frac{P_{out}}{1mW}$

i.e., $2.7 = \log_{10}\frac{P_{out}}{1\ mW}$

i.e., $501 = \frac{P_{out}}{1\ mW}$,

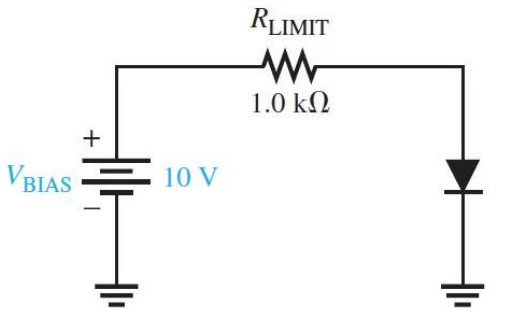
i.e., $P_{out} = 0.5\ W$

Q4

(a) How is the electric field across the *pn* junction created. [5]

The electric field across the *pn* junction of a diode is created by donor atoms in the n region losing free electrons to acceptor atoms in the p region. This creates positive ions in the n region near the junction and negative ions in the p region near the junction. A field is then established between the ions.

(b) Using the complete diode model, determine the forward voltage and forward current of the diode in Fig. 1(b) below with $r'_d = 10\ \Omega$. . Also find the voltage across the limiting resistor. [3+3+3=9]

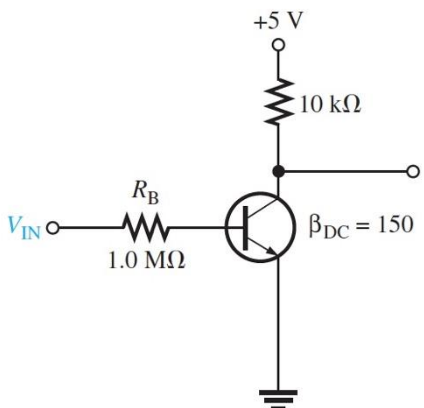


$$I_F = \frac{V_{BIAS} - 0.7}{R_{LIMIT} + r'_d} = \frac{10\ V - 0.7V}{1.0k\Omega + 10\Omega} = \mathbf{9.21\ mA}$$

$$V_F = 0.7\ V + I_F r'_d = 0.7\ V + (9.21mA)(10\ \Omega) = 7\mathbf{92\ mV}$$

$$V_{R_{LIMIT}} = I_F R_{LIMIT} = (9.21\ mA)(1.0\ k\Omega) = \mathbf{9.21\ V}$$

(c) Determine $I_{C(sat)}$ for the transistor in Fig. 1(c). What is the value of I_B necessary to produce saturation? What minimum value of V_{IN} is necessary for saturation? Assume $V_{CE(sat)} = 0$ V. [3+3+5=11]



	$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{5V}{10k\Omega} = \mathbf{500\ \mu A}$ $I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{500\ \mu A}{150} = \mathbf{3.33\ \mu A}$ $I_{B(min)} = \frac{V_{IN(min)} - 0.7\ V}{R_B}$ $R_B I_{B(min)} = V_{IN(min)} - 0.7\ V$ $V_{IN(min)} = R_B I_{B(min)} + 0.7\ V = (3.33\ \mu A)(1.0\ M\Omega) + 0.7\ V = \mathbf{4.03\ V}$