Lecture 12B – Revision

Identify essential material and problems.

Lecture 7A - essential

- MOSFET operation (qualitative)
- Basic amplifier circuit
- DC analysis using output characteristic (Q-point)

You should be able to determine the Q-point of a MOSFET from either the output characteristic or transfer characteristic, given nay biasing circuit.

Lecture 7B - essential

- Transformer model (including magnetizing branch)
- Measurement of transformer parameters (SC and OC test)
- Current and Voltage Excitation

You should be able to calculate transformer model parameters using the short circuit and open circuit tests. You should be able to apply the concepts of current and voltage excitation to any magnetic system.

Lecture 8A - essential

- Small signal equivalent circuit of the MOSFET (at low frequencies)
- Design of the common source amplifier
- Analysis of the source follower

You should be able to design a common source amplifier, using a variety of techniques, e.g. the output characteristic and load line, or the transfer characteristic. You should be able to apply the small signal equivalent circuit of a MOSFET to any circuit.

Lecture 8B - essential

- The force equation for magnetic and electric systems.

You should be able to apply the force equation to any linear magnetic or electric system with moveable parts.

Lecture 9A - essential

- BJT operation (qualitative)
- Design of a biasing circuit using a single power supply
- Small signal equivalent circuit of a BJT
- Common emitter amplifier
- The emitter follower

You should be able to design the bias circuit for an *npn* BJT using a single power supply. You should be able to analyze (determine input impedance, gain, output impedance) any BJT amplifier circuit, by using the small signal equivalent circuit. You should be able to obtain the frequency response of the gain for any amplifier circuit.

Lecture 9B - essential

- Generator principle
- Motor principle
- The moving coil meter

You should be able to determine the deflection angle of a moving coil meter for any type of current.

Lecture 10A - essential

- Voltage amplifier equivalent circuit
- Current amplifier equivalent circuit
- The decibel
- Frequency response

You should be able to obtain the equivalent circuit of any amplifier in terms of the above models. You should be able to preform an analysis of the frequency response of any amplifier.

Lecture 10B - essential

- General bridge equations
- Average and RMS values of periodic waveforms

You should be able to derive the balance conditions for any bridge. You should be able to calculate the average and RMS values of any simple periodic waveform.

Lecture 11A - general knowledge

Know that an operational amplifier simply amplifies the voltage difference between its two input terminals.

Lecture 11B - essential

- The moving iron meter

You should be able to determine the deflection angle of a moving iron meter for any type of current. Be aware of other meter movements and construction.

Lecture 12A - essential

- The inverting amplifier
- The noninverting amplifier
- The voltage follower
- The adder circuit
- The integrator
- The precision HWR

You should be able to derive the gain for any linear op-amp circuit. You should be able to analyze an op-amp circuit that contains diodes, and describe the circuit's function.

General

All problems should have been completed, except those that have an asterisk.

All examples in the notes should be read and understood.

Permanent magnets, having been left out of the mid, may be in the final.

Quote

Dorf, R.: *Modern Control Systems*, Addison-Wesley Publishing Co., Sydney, 1980

The most important and productive approach to learning is for the student *to rediscover and recreate anew the answers and methods of the past. Thus, the ideal is to present the student with a series of problems and questions and point to some of the answers that have been obtained over the past decades. The traditional method of confronting the student not with the problem but with the finished solution means depriving him or her of all excitement, to shut off the creative impulse, to reduce the adventure of humankind to a dusty heap of theorems. The issue, then, is to present some of the unanswered and important problems which we continue to confront. For it may be asserted that what we have truly learned and understood we discovered ourselves.*

Example – Precision Peak Detector

Consider the following circuit:

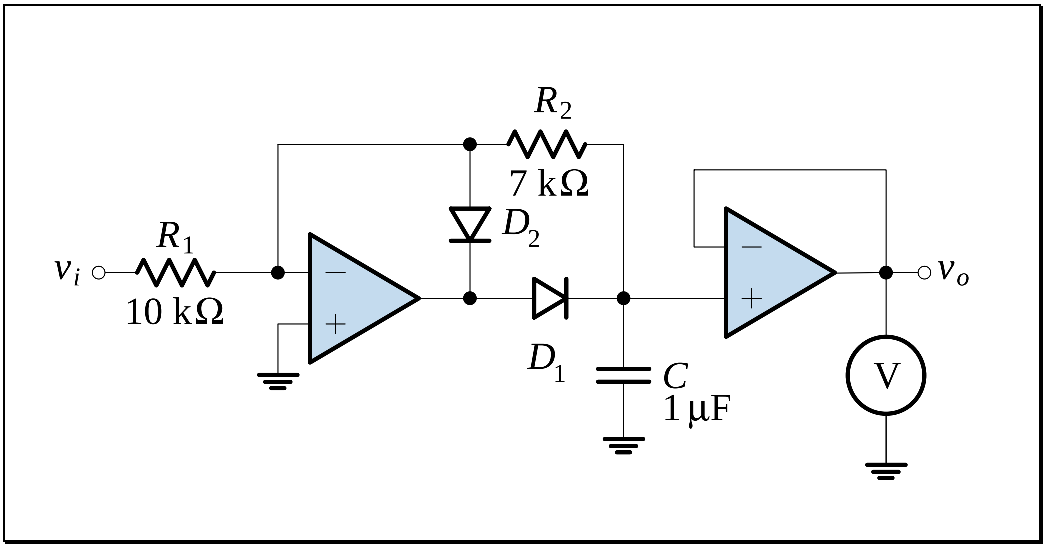


Figure 12B.1

The meter is a DC moving coil voltmeter that responds to the *average* of v_o.

The input is $v_i = \cos(2000\pi t)\,\mathrm{V}$.

We want to sketch v_i and v_o, explain how the circuit works, and determine the meter reading.

12B.6

The second op-amp circuit is just a buffer that prevents the voltmeter from loading the first circuit. Therefore an analysis of the capacitor voltage will give us v_o directly.

First, consider the input sinusoid in a positive half-cycle, with the capacitor initially uncharged:

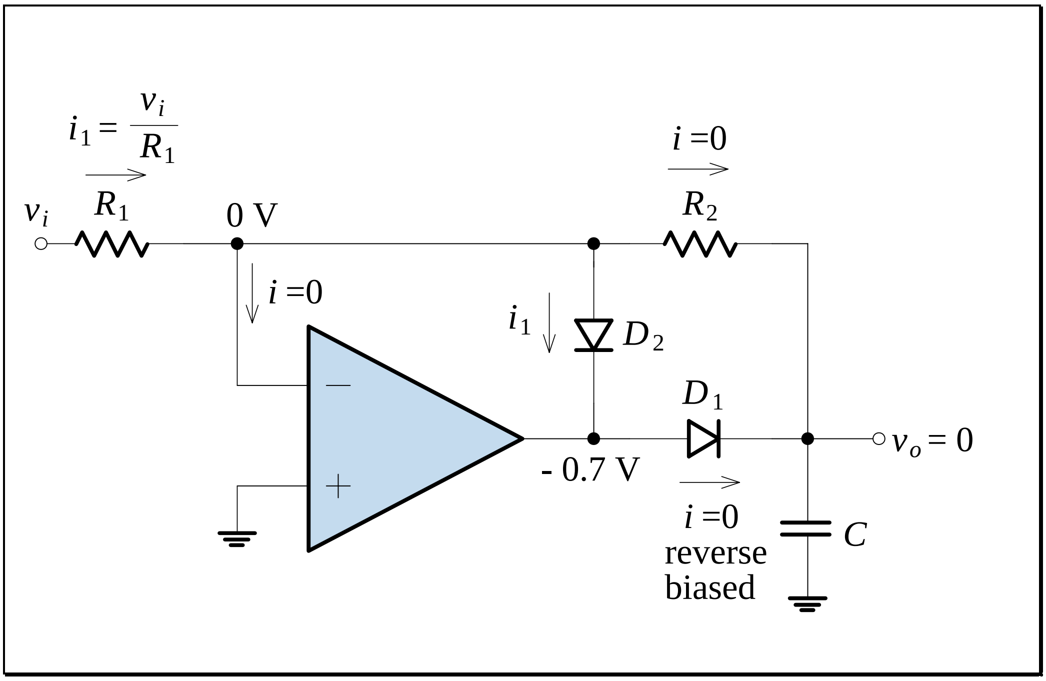


Figure 12B.2

The output is 0 V.

Next consider the first half of a negative half-cycle (up until the input's negative peak):

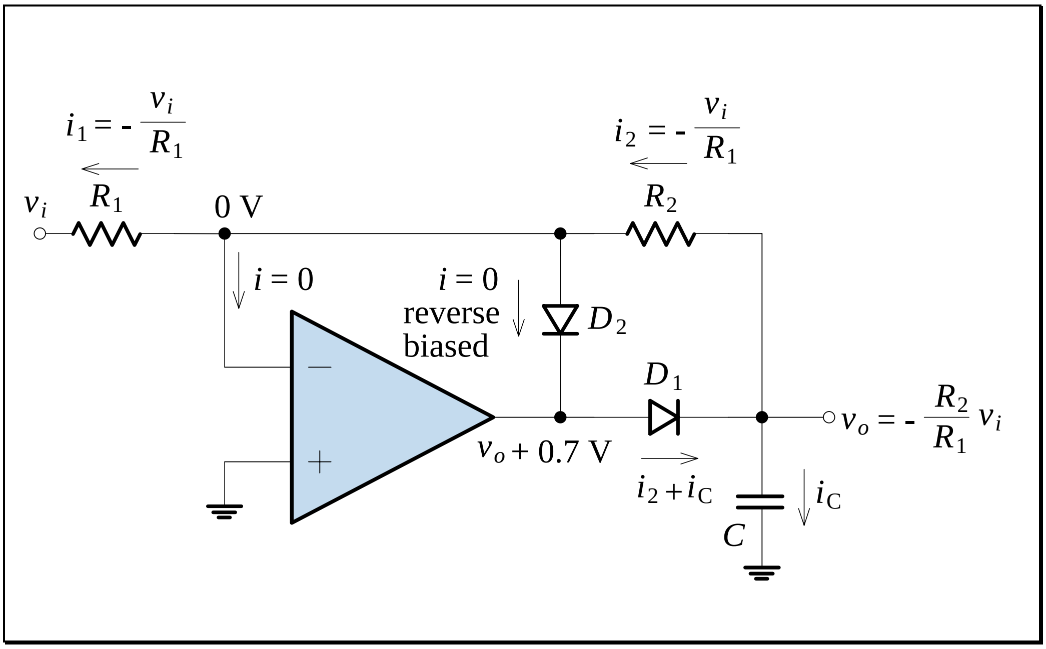


Figure 12B.3

The output is therefore $v_o = -0.7 v_i$, which is a positive sinusoid, with a peak of 0.7 V. After the input has just passed it's negative peak, the output voltage should follow according to $v_o = -0.7 v_i$. But the output voltage is across a capacitor, and for the capacitor voltage to decrease, we must remove charge from it. This means current in the upwards direction in Figure 12B.3. This current cannot go through diode D_1, so the capacitor must discharge through R_2, which will limit the rate of discharge.

We now have a conflicting requirement at the output – the capacitor must discharge according to the usual natural transient response of a charged capacitor in series with a resistor, but the op-amp would like to maintain the output voltage as a sinusoid.

The op-amp circuit must therefore change state!

12B.8

Let's assume that diode D_1 turns off, and diode D_2 turns on (and therefore the op-amp will have a negative feedback path which will maintain a virtual short-circuit at the op-amp input). Then since the left side of R_2 is at 0 V, then we know from the usual transient analysis that the capacitor voltage is a decaying exponential given by:

$$\begin{aligned} v_o &= v_o(0)e^{-t/R_2C} \\ &= 0.7e^{-143t} \\ &\approx 0.7(1-143t) \end{aligned} \tag{12B.1}$$

where the last approximation can be made because the time constant $\tau = R_2C$ is much larger than the period of the input signal, and we have assumed $t = 0$ is the instant when the capacitor starts discharging.

The currents under this discharging condition are shown below:

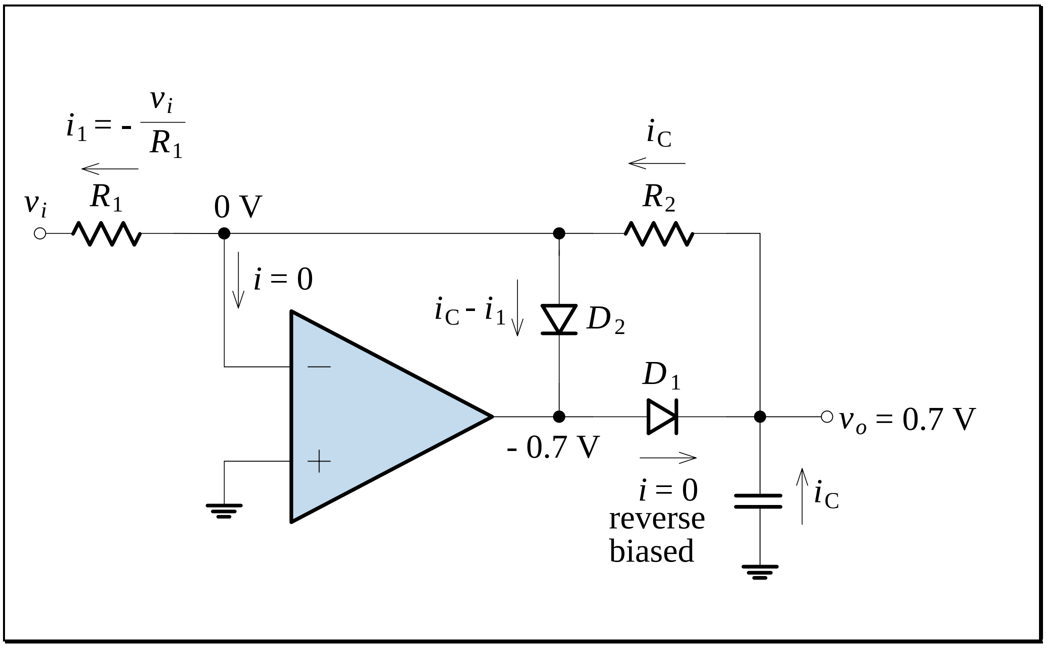


Figure 12B.4

The output voltage remains at approximately 0.7 V because the discharge rate is very slow. Since the current $i_C \approx 0.7/R_2 = 0.1\,\text{mA}$ is greater than $i_1 = -v_i/R_1$, the excess current must pass through diode D_2 and into the op-amp. The op-amp's output terminal is therefore at approximately -0.7 V, and so D_1 is indeed reverse-biased.

This state of the circuit must exist until the input once again makes $v_o = -0.7v_i$ greater than the capacitor voltage (which will occur near the next negative peak of the input waveform). Then the circuit will charge the capacitor back up to the 0.7 times the input peak.

Note that in the above analysis, it was always assumed that there was a negative feedback path around the op-amp, and that a virtual short-circuit existed between the op-amp's input terminals.

The input and output waveforms are shown below (the decay of v_o has been exaggerated for clarity):

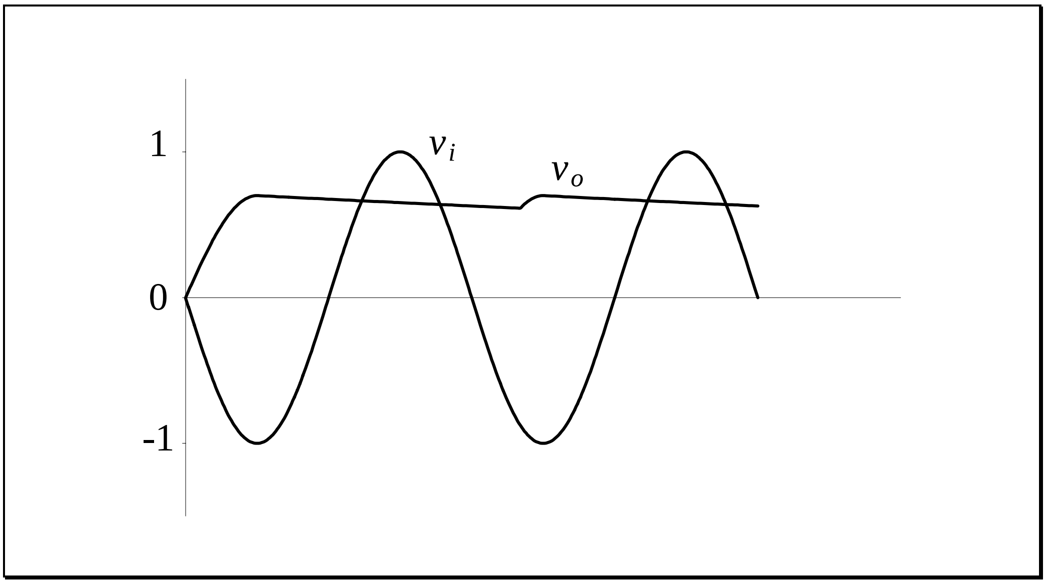


Figure 12B.5

The DC moving coil meter will respond to the average of the output voltage, and therefore read approximately 0.7 V (which is roughly equal to the RMS value of the input sinusoid).

Example – Amplifiers, Integrator

The op-amps in the circuits below have very high gain and input resistance. We want to determine the output voltage and input resistance of each circuit, if $v_i = \cos(2000\pi t)\,\mathrm{V}$.

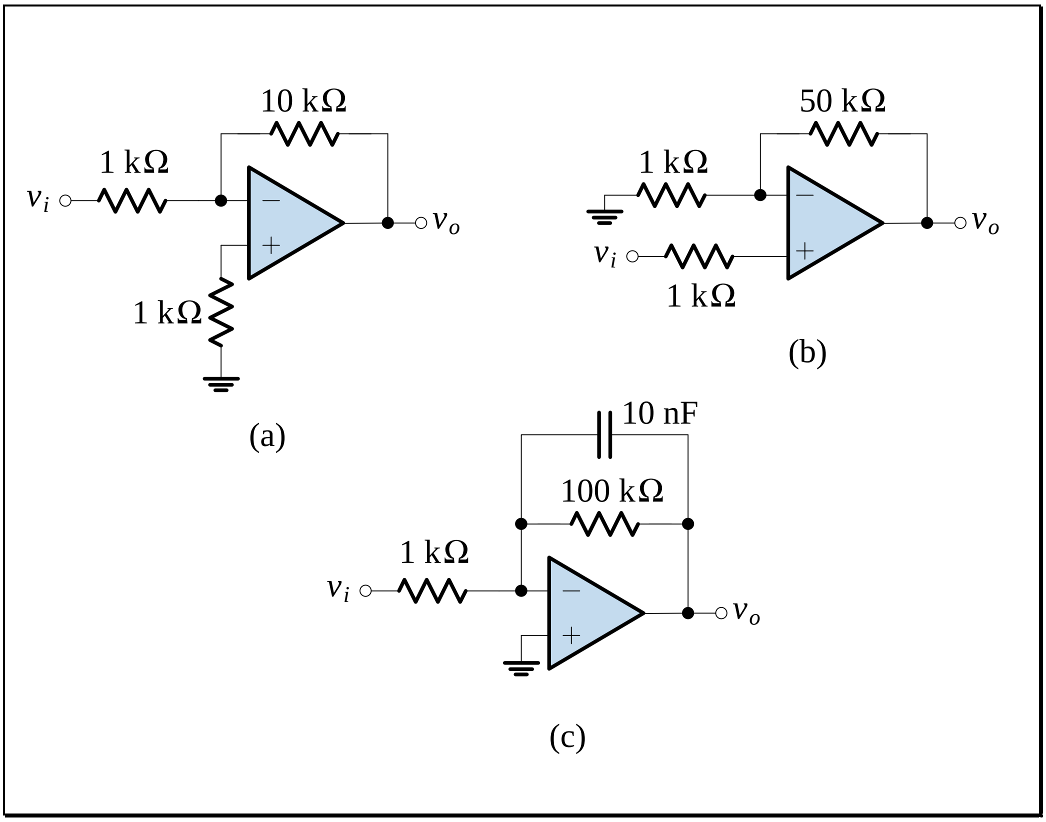


Figure 12B.6

(a) The resistor connected to the non-inverting terminal has no effect on the operation of the circuit, since the input resistance of the op-amp is very high and there is therefore no current. It would normally be put into a real circuit to counter the effects of bias currents. The circuit is therefore just an inverting amplifier, with a gain of –10. The output is then $v_o = -10\cos(2000\pi t)$. The input resistance, by definition, is the input voltage divided by the input current. Since the right-hand side of the $1\,\mathrm{k}\Omega$ is at a virtual common, the input current is $v_i/1\,\mathrm{k}$. The input resistance is therefore $1\,\mathrm{k}\Omega$.

(b) Again, the resistor attached to the non-inverting terminal has no current in it, thanks to the op-amps very high input resistance. The circuit is then just a non-inverting amplifier, with a gain of $1+50/1=51$. The output is then $v_o = 51\cos(2000\pi t)$. The input resistance is ideally infinite.

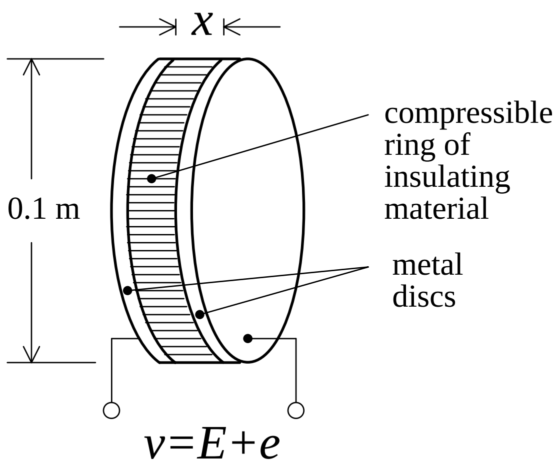
(c) The circuit is an integrator. The reactance of the capacitor at the input's frequency is $X = 1/2\pi fC = 15915\,\Omega$. Combining this with the resistor in parallel with it, we get an overall feedback impedance of $\mathbf{Z}_2 = 2470 - j15522 = 15717\angle -81°$. Then we use the generalized form for the output of an inverting amplifier, $\mathbf{V}_o = -\mathbf{Z}_2/\mathbf{Z}_1\mathbf{V}_i$. The input phasor is just $\mathbf{V}_i = 1\angle 0°$, so we get $\mathbf{V}_o = -\dfrac{15717\angle -81°}{1000}1\angle 0° = 15.72\angle 99°$ for the output phasor. Converting this to the time-domain, the output is $v_o = 15.72\cos(2000\pi t + 99°)$.

Note: You could perform an approximate analysis in the time-domain by ignoring the feedback resistor – in which case you get $v_o = -15.92\sin(2000\pi t)$, which is close to the exact answer.

Problems

1. [Voltage excited electrostatic transducer – loudspeaker]

The construction of an electrostatic transducer is shown below:



The applied voltage v produces a force on the metal discs which alters the spacing x and acoustic waves result.

For an electrostatic transducer $F \propto v^2$. However, for good sound reproduction $x \propto \text{audio signal}$ is desirable. Therefore an applied voltage $v = E + e$ is used, where E is a constant and $E >> e$ so that $v^2 = E^2 + 2Ee + e^2 \approx E(E + 2e)$.

(a) If the relative permittivity of the insulating ring is $\varepsilon_r = 1$, the DC voltage is $E = 1\,\text{kV}$, and the spacing between plates is $x \approx 0.5\,\text{mm}$, show that:

$$F \approx 0.139 + 2.78 \times 10^{-4} e \text{ N}$$

(b) The insulating ring has spring constant $K_r = 300\,\text{Nm}^{-1}$ and $e = 100 \sin(\omega t)$. Determine the peak to peak oscillation in x.

2.

A toroidal, iron-cored ($\mu_r = 2000$) coil has 1000 uniformly distributed turns. The core has a mean length of 200 mm and an airgap of length 10 mm. The coil carries an AC current $i = 2\sin(100\pi t)$.

(a) Determine the peak values of the magnetic flux density and magnetic field intensity in the gap.

(b) A second coil with 2000 turns is wound over the first coil and its terminals connected to a $100\,\Omega$ resistor. The flux density in the core equals the value calculated in (a). Determine the supply current and voltage if the peak value of the load current is 2 A.

(c) What is the mutual inductance of the system?

Ignore fringing and leakage flux, and assume perfect magnetic coupling between the coils.