Unit 27 Small signal diode circuits

- When a diode is operated in the small signal region, the dynamic resistance or change of voltage across the diode for a change of current through the diode is given by:

$$R_{dyn} = \frac{dV}{dI} = \frac{25\,\mathrm{mV}}{I}$$

We have seen in Unit 24 that the current in a diode is given by:

$$I = I_0 \exp\left(\frac{V}{25\,\mathrm{mV}}\right)$$

where V is the voltage across the diode and 25 millivolts is the calculated value of $\frac{kT}{e}$ at room temperature.

If we avoid situations where the diode current is large, then we do not need to consider the effect of the bulk resistance of the diode since it is small compared to the junction effects. This is the case when the voltage across the diode is less than the knee voltage.

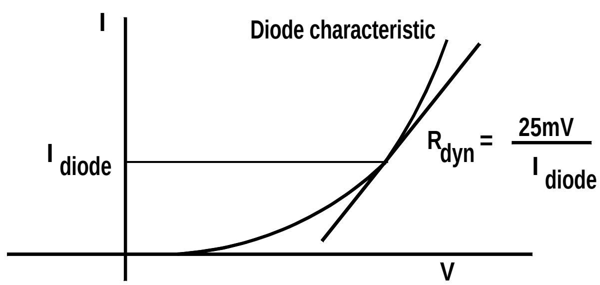

Figure 27.1: Diode characteristic and dynamic resistance.

Differentiate the diode current equation quoted above to obtain the change of current with voltage.

$$\begin{aligned}
\frac{dI}{dV} &= \frac{d}{dV}\left(I_0 \exp\left(\frac{V}{25\,\mathrm{mV}}\right)\right) \\
&= \frac{I_0}{25\,\mathrm{mV}} \exp\left(\frac{V}{25\,\mathrm{mV}}\right) \\
&= \frac{I}{25\,\mathrm{mV}}
\end{aligned}$$

The dynamic resistance is the reciprocal of this:

$$R_{dyn} = \frac{dV}{dI} = \frac{25\,\mathrm{mV}}{I}$$

which, in words, is 25 millivolts divided by the DC current through the diode. This is shown in Figure 27.1

This equation for the dynamic resistance is a key tool in the analysis of diode and transistor circuits.

27.1 Examples

27.1 Calculate the change in the voltage across the diode if the setting of the power supply voltage, V_+, in the circuit in Figure 27.2, is changed from +10 V to +11 V.

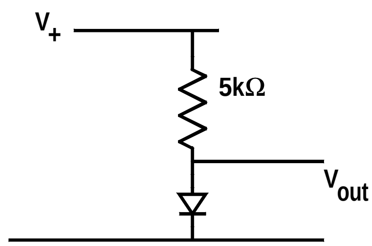

Figure 27.2: Example 27.1.

We first make the approximation that the DC voltage across the diode is 0.7 V.

This gives the basic equation as:

$$\begin{aligned} 10\,\mathrm{V} &= 0.7\,\mathrm{V} + I \times 5\,\mathrm{k\Omega} \\ \text{and therefore} \quad I_{10} &= \frac{10\,\mathrm{V} - 0.7\,\mathrm{V}}{5\,\mathrm{k\Omega}} = 1.86\,\mathrm{mA} \end{aligned}$$

For a supply voltage of 11 V we get:

$$I_{11} = \frac{11\,\mathrm{V} - 0.7\,\mathrm{V}}{5\,\mathrm{k\Omega}} = 2.06\,\mathrm{mA}$$

The average DC current is 1.96 mA ≈ 2 mA. The dynamic resistance is then:

$$\frac{25\,\mathrm{mV}}{I} = \frac{25\,\mathrm{mV}}{2\,\mathrm{mA}} = 12.5\,\Omega$$

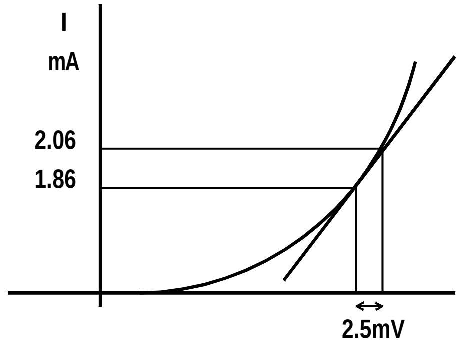

Figure 27.3: I–V characteristic for Example 27.1.

The change in current is $2.06 - 1.86 = 0.2\,\text{mA}$. So the change in voltage across the diode is given by:

$$12.5\,\Omega \times 0.2\,\text{mA} = 2.5\,\text{mV}$$

This procedure is shown diagrammatically in Figure 27.3.

The alternative exact approach involves solving equations of the form:

$$V_{supply} = 5\,\text{k}\Omega \times I_0 \exp\left(\frac{V_{diode}}{25\,\text{mV}}\right) + V_{diode}$$

for V_{diode} with supply voltages of 10 V and 11 V and then getting the difference of the two diode voltages. You should attempt to solve this exact equation if only to prove to yourself that the linearized approach used above is significantly simpler to calculate! You could also set up this circuit in the lab and obtain some experimental values.

27.2 Calculate the output voltage waveform which would be observed on an oscilloscope connected to point A in the circuit shown in Figure 27.4.

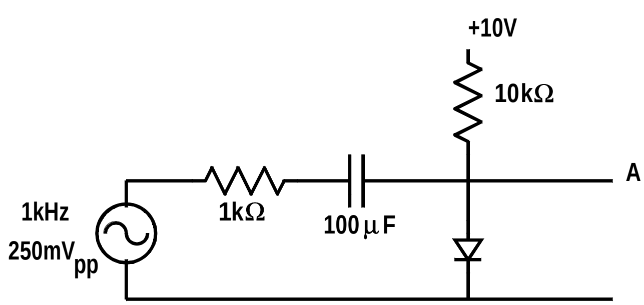

Figure 27.4: Example 27.2.

We use the principle of superposition (Unit 21) to calculate the DC component and the AC component separately and we then combine the two components at the end using the principle of superposition.

Calculate the DC component as shown in Figure 27.5 (a). We have a forward biased diode and therefore the DC voltage at the output is 0.7 V. The DC current through the diode is:

$$\frac{10\,\text{V} - 0.7\,\text{V}}{10\,\text{k}\Omega} = 0.93\,\text{mA}$$

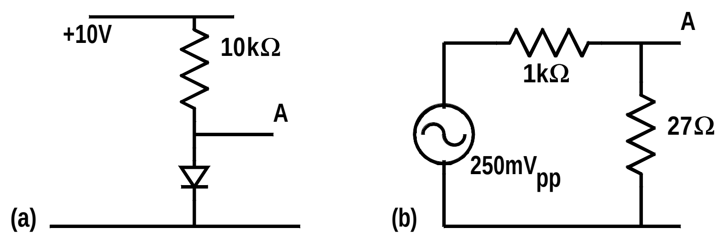

Figure 27.5: DC and AC circuits for Example 27.2.

The effective circuit for the AC component of the signal is sho wn in Figure 27.5 (b). The impedance of the 100 μF capacitor at 1 kHz is:

$$|Z_C| = \frac{1}{2\pi f C} = 1.6\,\Omega$$

(see Units 10 and 12). This value of 1.6 Ω is negligible compared to the 1 kΩ in series with the capacitor so the capacitor is effectively a short circuit for AC and can be omitted. (Note that the capacitor must remain in the circuit to block the DC component.) The dynamic resistance of the diode is:

$$R_{dyn} = \frac{25\,\text{mV}}{I_{DC}} = \frac{25\,\text{mV}}{0.93\,\text{mA}} = 27\,\Omega$$

The dynamic resistance of the diode and the 1 kΩ form a potential divider (Unit 4) and this is the effective circuit that is shown in Figure 27.5 (b). We can neglect the effect of the 10 kΩ which should be in parallel with the 27 Ω.

The AC component of the output is therefore:

$$V_{out\,AC} = \frac{27\,\Omega}{1\,\text{k}\Omega + 27\,\Omega} \times 250\,\text{mV}_{\text{pp}} = 6.5\,\text{mV}_{\text{pp}}$$

The signal which would be observed on an oscilloscope connected to the output at point A is a 0.7 V DC with a superimposed 6.5 mV_{pp}, 1 kHz AC component as is shown in Figure 27.6.

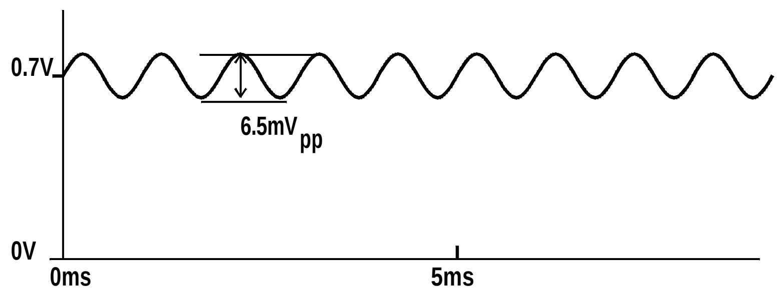

Figure 27.6: Oscilloscope output from circuit of Example 27.2.

27.2 Problems

27.1 Compare the values for the dynamic resistance calculated using the formula $R_{dyn} = \frac{25\,\text{mV}}{I}$ with the values which you estimated in Problem 24.2.

27.2 Calculate the change in the voltage at A, in Figure 27.7, resulting from a change in the voltage at B from 6 V to 7 V.

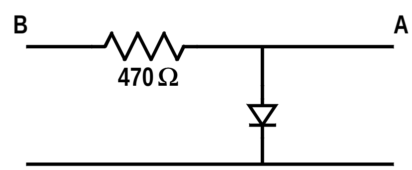

Figure 27.7: Problem 27.2.

27.3 Calculate the change in the alternating voltage at A, in Figure 27.8, when the voltage at B changes from 8 V to 12 V.

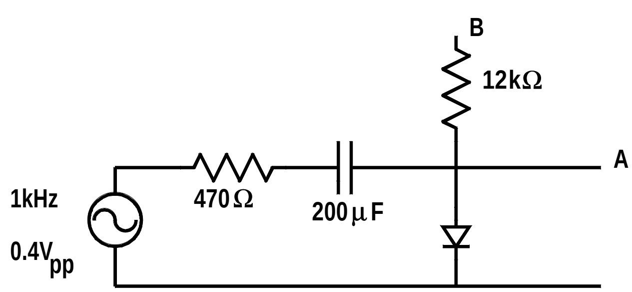

Figure 27.8: Problem 27.3.

27.4 A 20 Hz, 3 V amplitude square waveform voltage signal superimposed on a 12 V DC is applied to point B, in Figure 27.9.

A 1 V_{pp} sinusoidal signal at 1 kHz is applied as shown in the circuit.
Give a sketch of the input voltage waveform at B.
Give a sketch of the output voltage waveform at A.

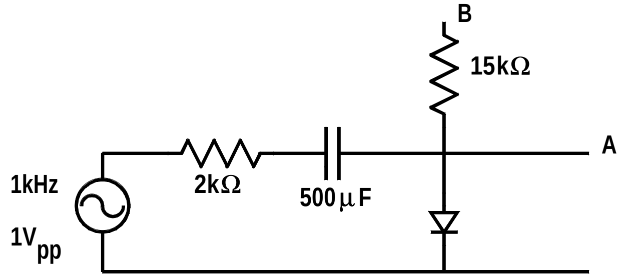

Figure 27.9: Problem 27.4.

27.5 Use the principle of superposition to calculate the voltage waveform at the output from the circuit in Figure 27.10. Sketch the waveform which you would observe on an oscilloscope with a time base set to 0.1 s per division.

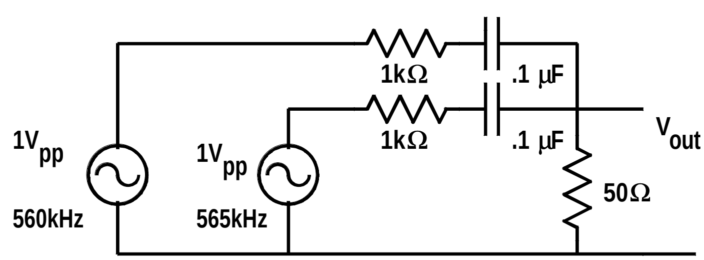

Figure 27.10: Problem 27.5.