Unit 44 Differentiator circuits

- The output from a differentiator circuit is given by:

$$V_{out} = -CR_f \frac{dV_{in}}{dt}$$

When we feed a signal into a differentiator circuit, we obtain an output voltage which is the time rate of change of the input voltage signal. The basic circuit used is shown in Figure 44.1.

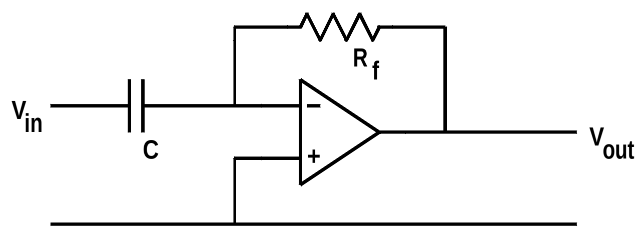

Figure 44.1: The differentiator circuit.

This circuit is analyzed by again using the two rules from Unit 39. The voltage across the capacitor gives the charge on the capacitor as:

$$Q = C \times (V_{in} - 0) = C \times V_{in}$$

The input current is the time rate of change of charge which gives:

$$I_{in} = \frac{dQ}{dt} = C\frac{dV_{in}}{dt}$$

Since no current flows into the op-amp terminals, the same current must also flow in the feedback resistor, R_f, which gives:

$$I_{in} = I_f = \frac{0 - V_{out}}{R_f} = -\frac{V_{out}}{R_f}$$

resulting in the basic equation for differentiators:

$$V_{out} = -CR_f \frac{dV_{in}}{dt}$$

44.1 Example

44.1 In the circuit in Figure 44.2 (a), the function generator, FG, is set to give an output triangular waveform of frequency 1 kHz and amplitude 10 mV as shown in Figure 44.2 (b). Calculate the output voltage waveform and sketch the waveform which would be observed on a two channel oscilloscope with channel A displaying the input signal and channel B displaying the output signal.

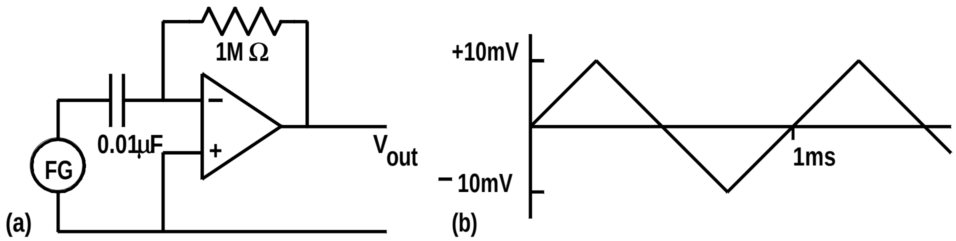

Figure 44.2: Example 44.1.

First calculate the time constant, T, in seconds:

$$T = CR = 0.01\,\mu\text{F} \times 1\,\text{M}\Omega = 10^{-2} \times 10^{-6} \times 10^{6} = 10^{-2}\,\text{s}$$

The period of the waveform is $P = \frac{1}{f} = \frac{1}{1000} = 1\,\text{ms}$

The input waveform goes from $\pm 10\,\text{mV}$ to $\mp 10\,\text{mV}$ in 0.5 ms and therefore the rate of change of the input signal is:

$$\left|\frac{dV_{in}}{dt}\right| = \frac{10\,\text{mV} - (-10\,\text{mV})}{0.5 \times 10^{-3}\,\text{s}} = \pm 40\,\text{V}\,\text{s}^{-1}$$

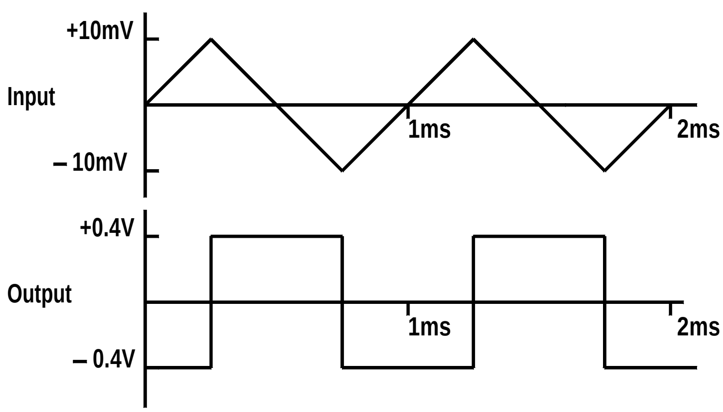

Figure 44.3: Oscilloscope trace of input and output for Example 44.1.

The output voltage is therefore:

$$V_{out} = \pm 10^{-2}\,\mathrm{s} \times 40\,\mathrm{V\,s^{-1}} = \pm 0.4\,\mathrm{V}$$

The oscilloscope display is shown in Figure 44.3. You should pay particular attention to the alignment of the two waveforms and to the sign of the output square wave signal. When the input is increasing, the output is negative due to the inverting amplifier configuration.

44.2 Problems

44.1 Calculate the output voltage waveform from the circuit in Figure 44.4 for an input triangular waveform of frequency 250 Hz and of amplitude 30 mV.

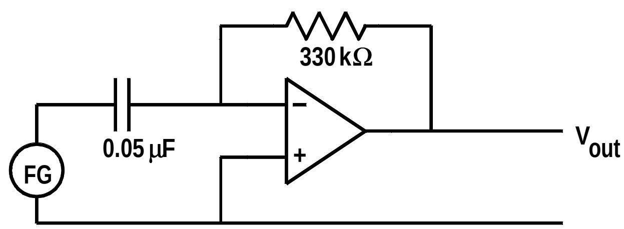

Figure 44.4: Problem 44.1.

44.2 Calculate the output voltage waveform from the circuit in Figure 44.5 when the function generator is set to give an input sinusoidal waveform of frequency 200 Hz and of amplitude 0.1 V. Sketch the traces for the input and output voltage waveforms which you would observe on a double channel oscilloscope.

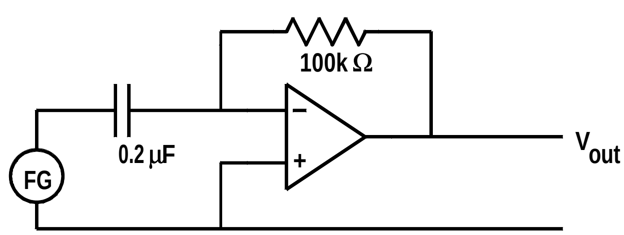

Figure 44.5: Problem 44.2.

44.3 If the signal frequency in Problem 44.2 is changed from 200 Hz to 400 Hz, what changes will occur in the output voltage waveform?