1.14 Differentiators

Look at the circuit in Figure 1.34. The voltage across C is $V_{in} - V$, so

$$I = C\frac{d}{dt}(V_{in} - V) = \frac{V}{R}$$

If we choose R and C small enough so that $dV/dt \ll dV_{in}/dt$, then

$$C\frac{dV_{in}}{dt} \approx \frac{V}{R}$$

or

$$V(t) = RC\frac{d}{dt}V_{in}(t)$$

That is, we get an output proportional to the rate of change of the input waveform.

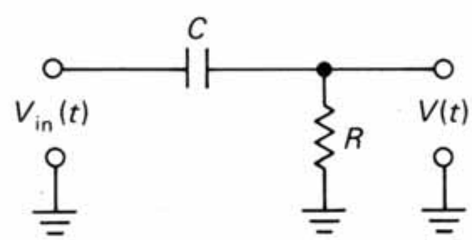

Figure 1.34

To keep $dV/dt \ll dV_{in}/dt$, we make the product RC small, taking care not to "load" the input by making R too small (at the transition the change in voltage across the

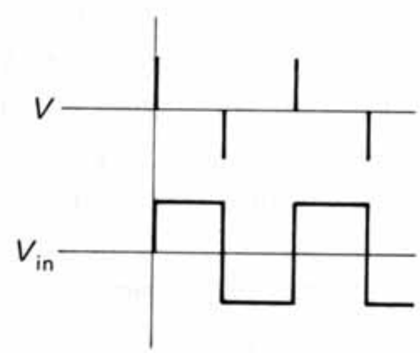

Figure 1.35

The Art of Electronics
by Horowitz and Hill pp. 22-23.

capacitor is zero, so *R* is the load seen by the input). We will have a better criterion for this when we look at things in the frequency domain. If you drive this circuit with a square wave, the output will be as shown in Figure 1.35.

Differentiators are handy for detecting *leading edges* and *trailing edges* in pulse signals, and in digital circuitry you sometimes see things like those depicted in Figure 1.36. The *RC* differentiator generates spikes

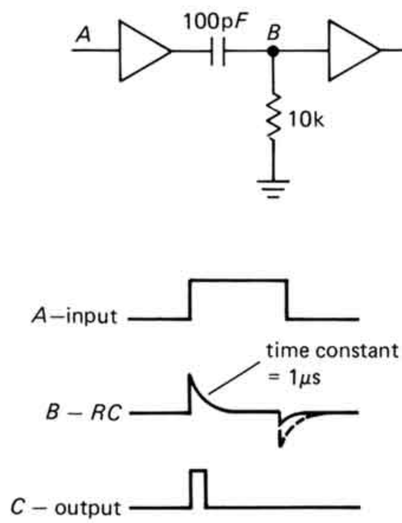

Figure 1.36

at the transitions of the input signal, and the output buffer converts the spikes to short square-topped pulses. In practice, the negative spike will be small because of a diode (a handy device discussed in Section 1.25) built into the buffer.

Unintentional capacitive coupling

Differentiators sometimes crop up unexpectedly, in situations where they're not welcome. You may see signals like those shown in Figure 1.37. The first case is caused by a square wave somewhere in the circuit coupling capacitively to the signal line you're looking at; that might indicate a miss-

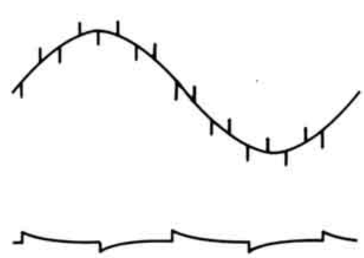

Figure 1.37

ing resistor termination on your signal line. If not, you must either reduce the source resistance of the signal line or find a way to reduce capacitive coupling from the offending square wave. The second case is typical of what you might see when you look at a square wave, but have a broken connection somewhere, usually at the scope probe. The very small capacitance of the broken connection combines with the scope input resistance to form a differentiator. *Knowing that you've got a differentiated "something" can help you find the trouble and eliminate it.*

1.15 Integrators

Take a look at the circuit in Figure 1.38. The voltage across R is $V_{in} - V$, so

$$I = C\frac{dV}{dt} = \frac{V_{in} - V}{R}$$

If we manage to keep $V \ll V_{in}$, by keeping the product RC large, then

$$C\frac{dV}{dt} \approx \frac{V_{in}}{R}$$

or

$$V(t) = \frac{1}{RC}\int^{t} V_{in}(t)\,dt + \text{constant}$$

We have a circuit that performs the integral over time of an input signal! You can see how the approximation works for a square-wave input: $V(t)$ is then the exponential

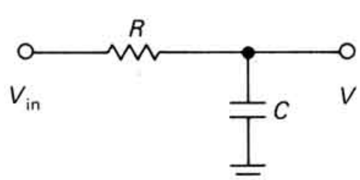

Figure 1.38

charging curve we saw earlier (Fig. 1.39). The first part of the exponential is a ramp, the integral of a constant; as we increase the time constant RC, we pick off a smaller part of the exponential, i.e., a better approximation to a perfect ramp.

Note that the condition $V \ll V_{in}$ is just the same as saying that I is proportional to V_{in}. If we had as input a *current* $I(t)$, rather than a

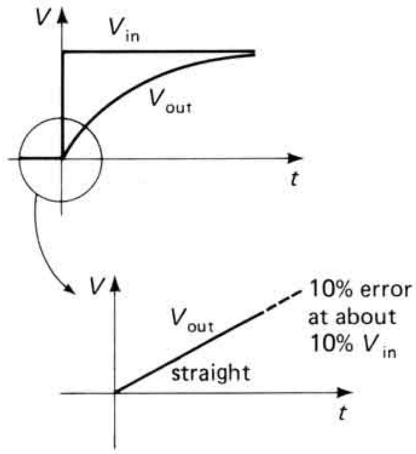

Figure 1.39

voltage, we would have an exact integrator. A large voltage across a large resistance approximates a current source and, in fact, is frequently used as one.

Later, when we get to operational amplifiers and feedback, we will be able to build integrators without the restriction $V_{out} \ll V_{in}$. They will work over large frequency and voltage ranges with negligible error.

The integrator is used extensively in analog computation. It is a useful subcircuit that finds application in control systems, feedback, analog/digital conversion, and waveform generation.

Ramp generators

At this point it is easy to understand how a ramp generator works. This nice circuit is extremely useful, for example in timing circuits, waveform and function generators, oscilloscope sweep circuits, and analog/digital conversion circuitry. The circuit is shown in Figure 1.40. From the capacitor equation

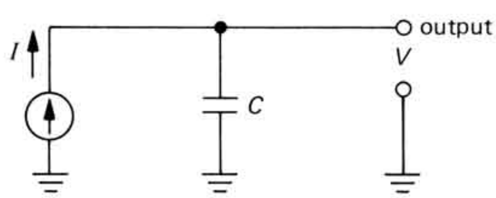

Figure 1.40

$I = C(dV/dt)$, you get $V(t) = (I/C)t$. The output waveform is as shown in Figure 1.41. The ramp stops when the current source "runs out of voltage," i.e., reaches the limit of its compliance. The curve for a simple RC, with the resistor tied to a voltage source equal to the compliance of the current source, and with R chosen so that