RC Differentiator

Here is a circuit for a RC differenetiator.

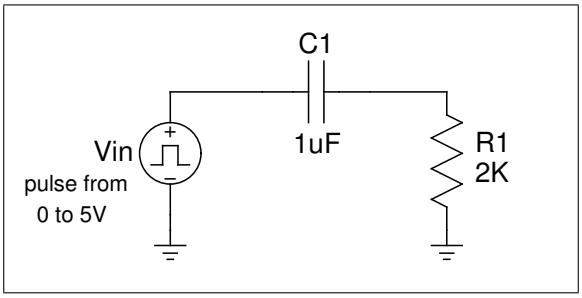

Figure 1: RC Differentiator Circuit

Analysis:

- At time zero, the capacitor is assumed to be discharged and be at zero volts.
- We know that the capacitor will not allow an instantaneous change in voltage across its terminals as this requires infinite current as: $I_c = C\frac{dv}{dt}$
- Thus, when the instantaneous change in V_{in} occurs, since the capacitor cannot allow a change in voltage across its terminals, all of V_{in}'s voltage will appear across V_R. Thus, $V_R = V_{in}$ at the moment that V_{in} transitions to 5V. This can be seen by writing a KVL loop of the circuit. Here, we see that,

$$\begin{aligned} -5 + 0 + V_R &= 0 \\ V_R &= 5 \end{aligned}$$

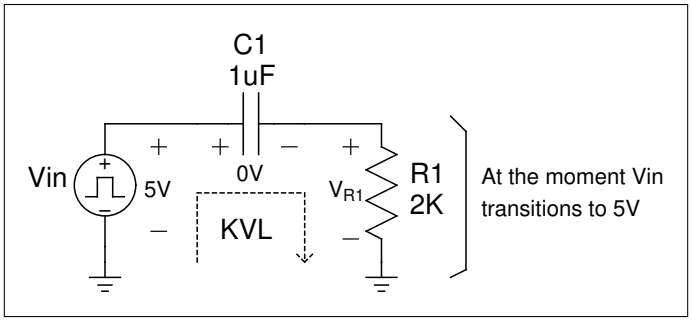

Figure 2: KVL Loop During Charging

- After a time determined by the time constant of $C1$ and $R1$, the voltage across $C1$ rises exponentially to 5 volts. As it does, V_R will decrease exponentially as writing a KVL loop for the circuit shows.

$$\begin{aligned} -Vin + V_C + V_R &= 0 \\ V_R &= V_{in} - V_c \quad ; \quad \text{as Vc grows, Vr goes down} \end{aligned}$$

- When V_{in} transitions back to zero volts again as shown in figure 3, V_{in}'s positive terminal is at zero volts, effectively connecting $C1$'s left side to ground.

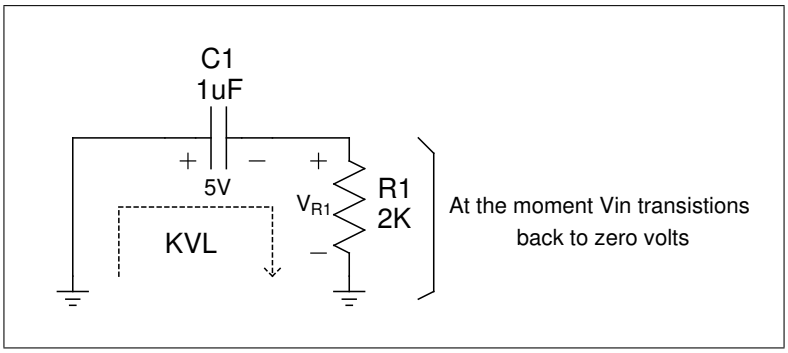

Figure 3: KVL Loop Once V_{in} Transitions back to Zero Volts

- Thus, the output is now at -5 volts as a KVL loop analysis shows:

$$+5 + V_r = 0$$
$$V_r = -5$$

- Finally, $C1$ discharges through the $R1$ again and V_r reaches zero volts again after about 10 τ. An ngspice netlist and waveform for the behavior of the circuit is shown below.

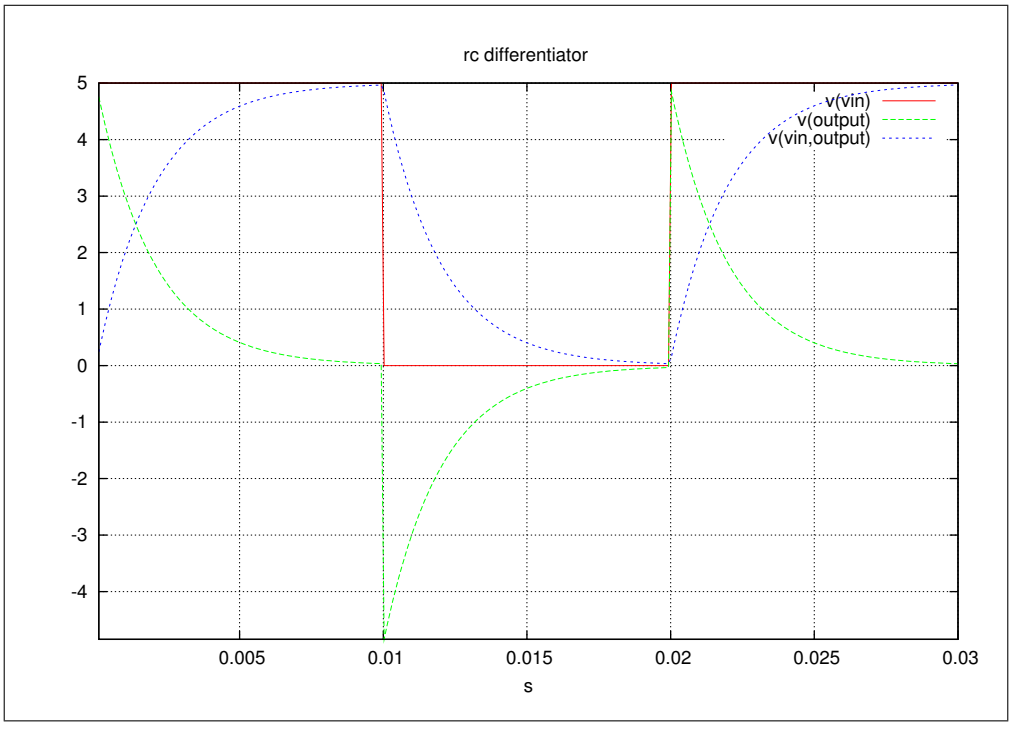

Figure 4: RC Differentiator Simulation Output

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RC differentiator
*pulse must be long relative to RC time constant
*5V input source with 1ns delay, 1nS edges, 10ms pulse width, 20ms cycle time

Vin     vin        gnd      5.0 PULSE(0 5.0 1ns 1ns 1ns 10ms 20ms)
c1      vin     output      1uf
rload   output     gnd      2k                ;1k load resistor

.control
  set hcopydevtype=postscript
  set hcopypscolor=true
  set color0 = rgb:f/f/f
  set color1 = rgb:0/0/0
  tran 0.1ms 30ms
  plot V(vin) V(output) V(vin,output) xl 0.1ms 30ms
* gnuplot rc_diff  V(vin) V(output) V(vin,output) xl 0.1ms 30ms ;make plot for latex
.endc
.end
```