Resistor-Capacitor Circuit

Structure

This circuit consists of a capacitor and resistor in series with a DC voltage source, such as a battery, and a switch:

When the switch is up, it connects the battery to the resistor and capacitor in a series loop. When the switch is down, it connects the capacitor and resistor in a series loop.

Function

The circuit demonstrates how the RC time constant works. When the capacitor is charging, it should reach 63.7% of its final value at a time of $R*C$. When it is discharging, it should reach 63.7% of its final value at a time of $R*C$. These points are marked in red in the graph below:

Now this particular circuit has a battery voltage of 5, so the capacitor would be at 5 volts if fully charged (i.e., around 50 ms on the graph). The circuit has a 3300 ohm resistor and a 0.003 mF capacitor, so its RC constant is $3300 \times 0.003 = 9.9$ ms. Thus, the RC time when the capacitor is charging is at about 10 ms, and the RC time when it is discharging is about 60 ms.
The units matter. When the resistance and capacitance are measured in ohms and Farads, then the time constant is in seconds. Thus, one way to solve RC problems is to convert all resistor and capacitor values to ohms and Farads. However, there is a handy shortcut. Because most capacitors are small and their values are given in pico-Farads (10^-9), micro-Farads (10^-6) or milli-Farads (10^-3), the RC constant is

- in pico-seconds when the capacitor’s value is in pF (pico-Farads),
- in micro-seconds when the capacitor’s value is in uF (micro-Farads),
- in milli-seconds when the capacitor’s value is in mF (milli-Farads).

In the example above, because the capacitor’s value is in mF, the RC constant (9.9) is in msec. This only works if the resistor’s value is in ohms, and not Kohms (10^3) or Mohms (10^6).

**Behavior**

Both an ideal battery and an ideal capacitor have no resistance, so the only resistance in this circuit comes from the resistor. The capacitor acts like a battery in that it has a voltage drop across it, but unlike a battery, that voltage drop changes. When the capacitor is discharged, there is no voltage across it. When the capacitor in this circuit is fully charged, it has the same voltage drop across it as the battery, but the polarities are reversed. That is, if the battery’s polarities want the current to circulate counterclockwise, as in the circuit above, then the capacitor’s polarities want the current to circulate clockwise. The net effect is that no current circulates. It is hard to remember which way the polarities go, so just keep in mind that the capacitor’s polarities oppose the current that was used to charge it.

When the capacitor is discharged and the switch goes up, the voltage across the resistor equals the battery’s voltage (because the capacitor has no voltage drop yet, and it offers no resistance). Thus the initial current is given by Ohm’s law as V/R where V is the battery voltage and R is the resistance of the resistor. This current starts to charge the capacitor. For every amp of current, the voltage on the capacitor rises by 1/C volts where C is the capacitance of the capacitor. As the voltage on the capacitor rises, it opposes the battery’s voltage, so the voltage drop across the resistor gets less and less. Hence the current gets less and less, and the charging of the capacitor slows down.

When the capacitor is fully charged and the switch goes down, then the voltage across the resistor equals the voltage of the fully-charged capacitor. Ohm’s law determines the current through the resistor. As the current leaves the capacitor, the voltage decreases by 1/C volt for every amp of current that leaves. As the voltage on the capacitor decreases, so does the voltage drop across the resistor, and hence the current through the resistor decreases. Thus, the discharging of the capacitor slows down.