Unit 52 Timers

- The voltage across a capacitor in a charging RC circuit is:

$$V_C = V_{sup}\left(1 - e^{\frac{-t}{RC}}\right)$$

- The voltage across the capacitor in a discharging RC circuit is:

$$V_C = V_{sup}e^{\frac{-t}{RC}}$$

- The charge-up time or discharge time between $\frac{1}{3}V_{sup}$ and $\frac{2}{3}V_{sup}$ is :

$$T = 0.7RC$$

- The time taken for a capacitor to charge from 0 V to $\frac{2}{3}V_{sup}$ is :

$$T = 1.1RC$$

- The two time intervals generated by a 555 Timer IC are given by:

$$T_1 = 0.7(R_A + R_B)C \quad \text{and} \quad T_2 = 0.7R_BC$$

The basic timing element used in integrated circuit timers such as the 555 Timer is the RC charging circuit shown in Figure 52.1 (b).

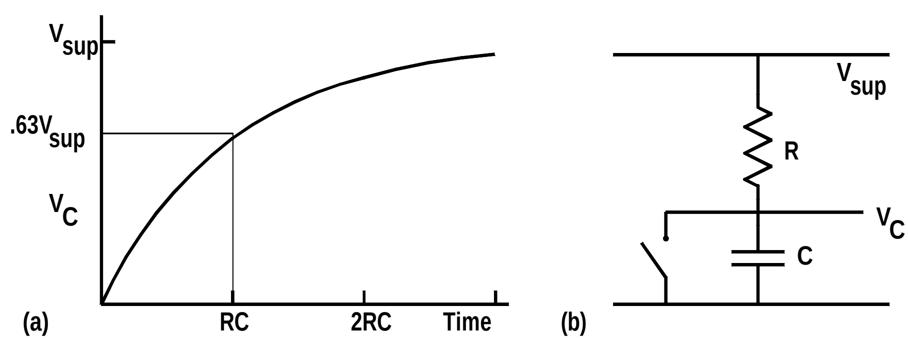

Figure 52.1: RC charging curve.

The switch shorts out the capacitor until time $t = 0$ when the switch is opened allowing the capacitor to charge up through the resistor. The voltage across the capacitor, as a function of time, is shown in Figure 52.1 (a).

The analysis proceeds as follows:

The voltage across the resistor R is $V_{sup} - V_C$.

The current is therefore $I = \frac{dQ}{dt} = \frac{V_{sup} - V_C}{R}$.

The charge on the capacitor is $Q = CV_C$ which, after differentiation, becomes $\frac{dQ}{dt} = C\frac{dV_C}{dt}$.

Equate these two expressions for the current to get:

$$RC\frac{dV_C}{dt} = V_{sup} - V_C$$

This differential equation has a solution:

$$V_C = V_{sup}\left(1 - e^{\frac{-t}{RC}}\right)$$

where RC is called the time constant. This is the graph of the voltage across the capacitor which is plotted in Figure 52.1 (a).

At the time $T = RC$, the calculated value of the V_C is $0.63V_{sup}$. This is indicated on the graph of Figure 52.1 (a). The output has made 63% of its total change at time $T = RC$.

This 63% response in one time constant has applications in other areas of measurement since many measuring instruments have a similar first order time response. A thermometer is warmed by heat transfer from the surroundings. The rate of heat transfer is proportional to the temperature difference between the thermometer and the surroundings. The more massive the thermometer (and usually the more rugged the thermometer) the larger the heat capacity or time constant. A typical industrial thermometer will have a time constant of about 30 seconds. This means that if the temperature of the flowing fluid in which the thermometer is immersed changes suddenly, it will take 30 seconds before the thermometer registers 63% of the change and 120 seconds before the reading is within 2% of the correct value.

If a slightly different circuit is used, such as that in Figure 52.2 (b), then when the switch is open the voltage across the capacitor is the supply voltage V_{sup}. If the switch is closed at time $t = 0$ then the capacitor discharges through R following the curve shown in Figure 52.2 (a). A differential equation can be set up as in the analysis of the RC charging case and the equation:

$$V_C = V_{sup}e^{\frac{-t}{RC}}$$

obtained for the voltage across the capacitor.

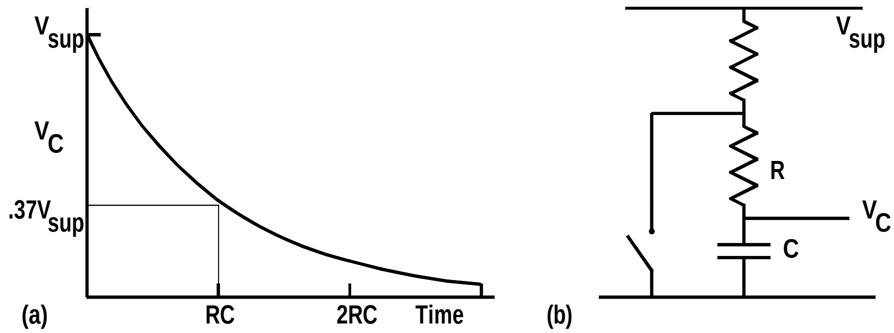

Figure 52.2: RC discharging curve.

Define T_L as the time taken for the capacitor in Figure 52.3 (b) to charge from 0 V to the lower voltage V_L.

Define T_H as the time taken for the capacitor in Figure 52.3 (b) to charge from 0 V to the higher voltage V_H.

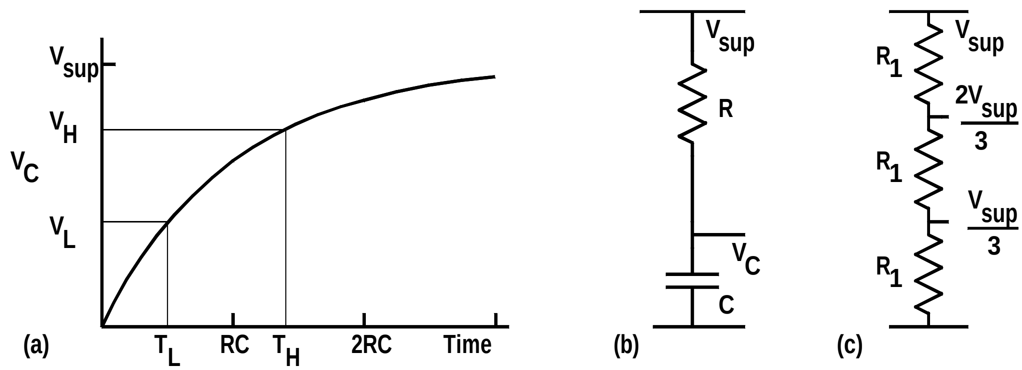

Figure 52.3: Charge-up time to the two voltages V_L and V_H.

From the solution to the charge-up equation we get:

$$V_L = V_{sup}\left(1 - e^{\frac{-T_L}{RC}}\right)$$
$$\text{and} \quad V_H = V_{sup}\left(1 - e^{\frac{-T_H}{RC}}\right)$$

Rearrange these equations and take natural logs (ln) to get:

$$\begin{aligned} -T_L &= RC\ln\left(\frac{V_{sup} - V_L}{V_{sup}}\right) \\ \text{and} \quad -T_H &= RC\ln\left(\frac{V_{sup} - V_H}{V_{sup}}\right) \end{aligned}$$

Subtract these two to get:

$$T_H - T_L = RC\left(\ln\left(\frac{V_{sup} - V_L}{V_{sup}}\right) - \ln\left(\frac{V_{sup} - V_H}{V_{sup}}\right)\right) = RC\ln\left(\frac{V_{sup} - V_L}{V_{sup} - V_H}\right)$$

Now set $V_L = \frac{1}{3}V_{sup}$ and $V_H = \frac{2}{3}V_{sup}$.

We have chosen these values because it is easy to get these two voltages by using three resistors in series connected between the power supply and ground as shown in Figure 52.3 (c).

Put these voltages into the expression for $T_H - T_L$ to get a time T such that:

$$T = RC\ln\left(\frac{V_{sup} - \frac{1}{3}V_{sup}}{V_{sup} - \frac{2}{3}V_{sup}}\right) = RC\ln 2 = 0.693RC \approx 0.7RC$$

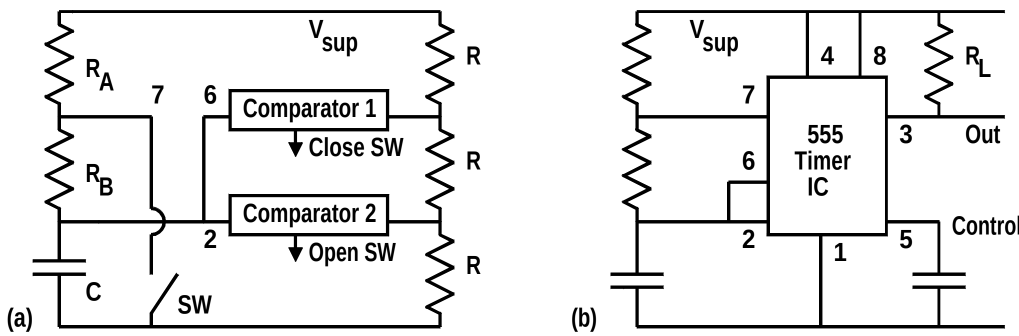

Figure 52.4: Internal circuit blocks of the 555 Timer.

Consider the circuit shown in block diagram form in Figure 52.4 (a). Three resistors in series give reference voltages of $\frac{1}{3}V_{sup}$ and $\frac{2}{3}V_{sup}$. The voltage across the capacitor is compared with these two voltages in comparators 1 and 2. The outputs of the two comparators toggle a switch SW which changes the capacitor from being charged up through R_A and R_B in series, with time constant $(R_A + R_B)C$, to being discharged through R_B, with time constant R_BC. When the voltage across the capacitor increases past $\frac{2}{3}V_{sup}$ comparator 1 toggles and closes the switch, starting a discharge cycle. When the voltage across the capacitor decreases below $\frac{1}{3}V_{sup}$, comparator 2 toggles and opens the switch to allow the capacitor to charge up again. The capacitor is therefore alternately charged up and discharged in a continuous cycle between the limits of $\frac{1}{3}V_{sup}$ and $\frac{2}{3}V_{sup}$.

In the diagram of Figure 52.4 (a), the numbers at the various points in the circuit indicate the pin numbers of the 555 Timer IC which is shown in Figure 52.4 (b). The comparators, the three resistor chain and the switch are all contained within the 555 Timer IC.

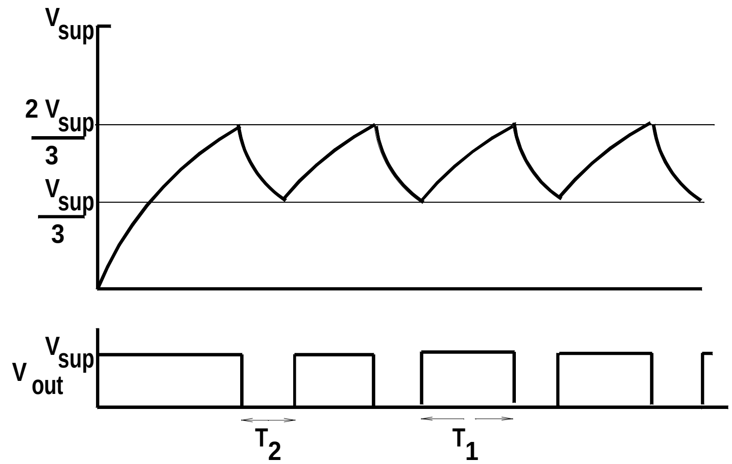

Figure 52.5: Capacitor and output voltage waveforms for the 555 Timer.

The voltage across the capacitor as a function of time is shown in Figure 52.5 which also shows the section of the charging and discharging exponential curve followed by the capacitor voltage. The 555 Timer has one extra important feature. Pin 3 gives an output signal which is an indicator of the state of the IC comparators. The output from pin 3 is at the supply voltage when the capacitor is charging up and the output from pin 3 is at 0 V when the capacitor is discharging.

The timing of the waveform is such that the time T_1 for the capacitor to charge from $\frac{1}{3}V_{sup}$ to $\frac{2}{3}V_{sup}$ is given by:

$$T_1 = 0.7(R_A + R_B)C$$

because the capacitor charges through R_A and R_B in series. The time for the capacitor to discharge from $\frac{2}{3}V_{sup}$ to $\frac{1}{3}V_{sup}$ is given by:

$$T_2 = 0.7R_BC$$

because the capacitor discharges through R_B.

One disadvantage of this timer circuit is that the output from pin 3 is an asymmetric waveform. The mark to space ratio is not 1:1, that is the waveform is not square. Greater control of the mark to space ratio can be achieved by using a circuit such as that shown in Figure 52.6.

Here the capacitor charges up through R_1 and the diode with a time constant of $T_1 = 0.7R_1C$.

The discharge path is through R_2 and the diode in series with R_2 to give a time constant $T_2 = 0.7R_2C$.

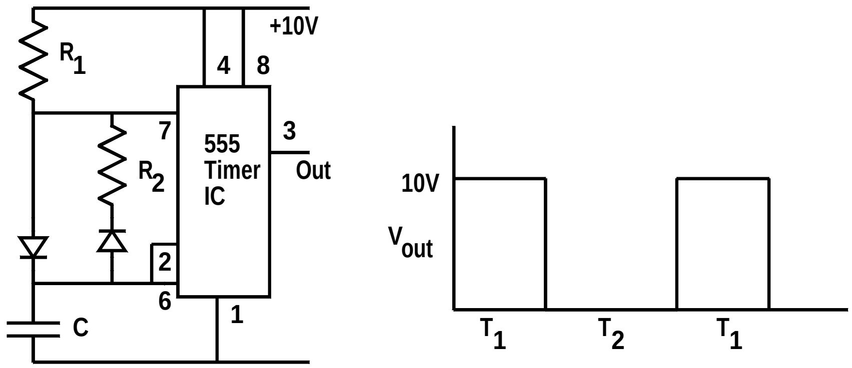

Figure 52.6: Circuit for generation of arbitrary mark to space ratio.

The time constants are now independently set because the steering diodes steer the charging and discharging currents through different resistors. Any mark to space ratio can be obtained with this circuit.

These applications of the 555 Timers have all been as astable oscillators where a continuous train of pulses is generated. In contrast, Figure 52.7 shows a circuit which gives monostable operation.

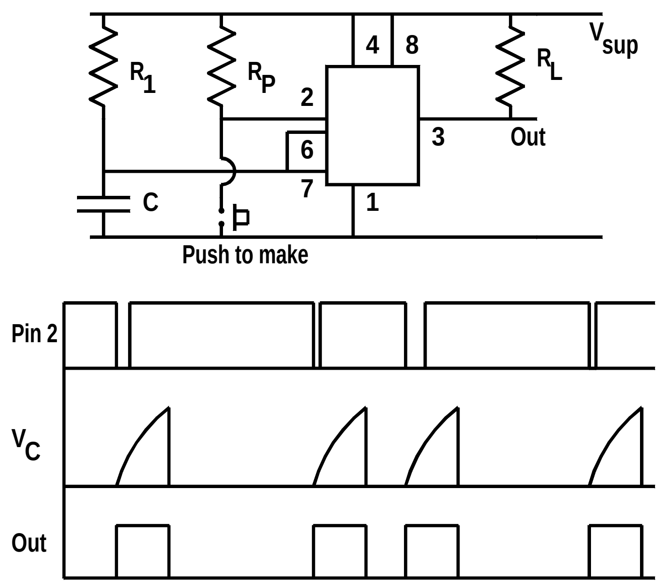

Figure 52.7: Triggered operation of the 555 Timer.

When the push to make button is pressed, the voltage on pin 2 is brought to 0 V and this triggers comparator 2 (refer to Figure 52.4 (a)) and causes the switch to open, allowing the capacitor to charge up. As soon as the voltage on the capacitor reaches $\frac{2}{3}V_{sup}$, comparator 1 operates and the switch is closed again, discharging the capacitor. The output voltage at pin 3 is normally at 0 V but rises to V_{sup} during the time the capacitor is charging up and a pulse of length $T = 1.1RC$ appears at the output each time the button is pressed. The length of this output pulse is independent of the length of time for which the button is pressed as long as it is shorter than the pulse length.

This circuit is a very convenient method of generating a fixed pulse length on demand. A typical application of this would be a controller for a photographic enlarger timer switch. Each time the button is pressed, the enlarger lamp turns on for a fixed length of time. The ON time can be adjusted by varying the time constant by using a variable resistor in place of the fixed resistor R_1.

52.1 Example

52.1 Calculate component values for a 555 Timer circuit which generates a 0 V to 10 V waveform with a 0 V for 6 ms and a 10 V for 13 ms.

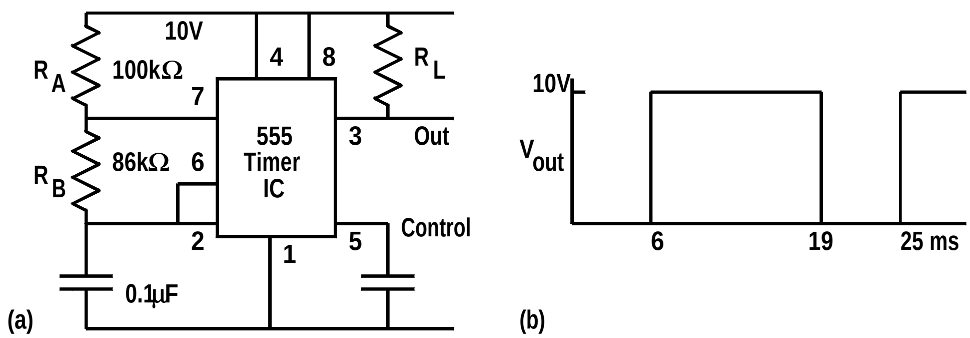

Figure 52.8: Example 52.1.

A suitable circuit is shown in Figure 52.8 (a). Choose a value for C of 0.1 μF. The discharge time is then 6×10^{-3} s which gives:

$$T_2 = 6 \times 10^{-3} = 0.7 \times 0.1 \times 10^{-6} \times R_B$$

and therefore $R_B = \frac{6\times10^{-3}}{0.7\times0.1\times10^{-6}} = 86\,\text{k}\Omega$.
We also have:

$$T_1 = 13 \times 10^{-3} = 0.7 \times 0.1 \times 10^{-6}(86\,\text{k}\Omega + R_A)$$

and therefore $86\,\text{k}\Omega + R_A = 186\,\text{k}\Omega$ which gives $R_A = 100\,\text{k}\Omega$.
The resulting waveform output from the circuit is shown in Figure 52.8 (b). The values of $100\,\text{k}\Omega$ and $86\,\text{k}\Omega$ for R_A and R_B depend on the initial choice of C. If R_A or R_B had turned out to be substantially different from these values then a different value for C might have to be selected.

52.2 Problems

52.1 Show that the time taken for a capacitor to charge from 0 V to $\frac{2}{3}V_{sup}$ through a resistor R is given by $1.1RC$.

52.2 Design a circuit using a 555 Timer IC which gives an output waveform of 12 V for 50 ms followed by 0 V for 16 ms. Sketch the expected waveform and the circuit showing component values.

52.3 Design a circuit using a 555 Timer IC which gives an output waveform of 9 V for 0.1 ms followed by 0 V for 8 ms. Sketch the expected waveform and the circuit showing component values.

52.4 Design a circuit which will give a single pulse of 3.2 s duration each time a button is pressed. Sketch the expected waveform and the circuit showing component values.

52.5 Design a circuit and calculate component values for a 555 Timer circuit which will flash a set of three high intensity light emitting diodes (leds) on and off once per second so as to operate as a compact bicycle rear light. The leds can be connected in parallel between pin 3 and the supply voltage. Discuss the relative advantages and disadvantages of putting the leds in series or in parallel.

52.6 Calculate the output, at pin 3, from the circuit shown in Figure 52.9. Sketch the voltage waveforms which would be observed with an oscilloscope when Channel A is connected to pin 3 and Channel B is connected across the capacitor.

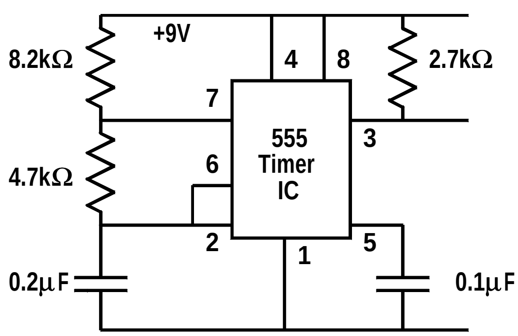

Figure 52.9: Problem 52.6.