LM/TLC 555 Timer

As an Astable Multivibrator
The TLC555C Chip (in your kit)
An integrated chip that is used in a wide variety of circuits to generate square wave and triangular shaped single and periodic pulses.

- Examples in your home are
  - high efficiency LED and fluorescence light dimmers and
  - temperature control systems for electric stoves
  - tone generators for appliance “beeps”

- The Application Notes section of the datasheets for the TLC555 and LM555 timers have a number of other circuits that are in use today in various communications and control circuits.
Terms you may see in 555 circuits:

- **Astable** – a circuit that can not remain in one state.
- **Monostable** – a circuit that has one stable state. When perturbed, the circuit will return to the stable state.
- **One Shot** – Monostable circuit that produces one pulse when triggered.
- **Flip Flop** – a digital circuit that flips or toggles between two stable states (bistable). The Flip Flop inputs decide which of the two states its output will be.
- **Multivibrator** – a circuit used to implement a simple two-state system, which may be astable, monostable, or bistable.
- **CMOS** – complimentary MOSFET logic. CMOS logic dominates the digital industry because the power requirements and component density are significantly better than other technologies.
Two Types of 555 Multivibrators

- **Monostable**
  - A single pulse is outputted when an input voltage attached to the trigger pin of the 555 timer equals the voltage on the threshold pin.

- **Astable**
  - A periodic square wave is generated by the 555 timer.
    - The voltage for the trigger and threshold pins is the voltage across a capacitor that is charged and discharged through two different RC networks.

I know – who comes up with these names?
How a 555 Timer Works

- We will operate the 555 Timer as an Astable Multivibrator in the circuit for the metronome.

http://www.williamson-labs.com/480_555.htm
The components that make up a 555 timer are shown within the gray box.

Internal resistors form a voltage divider that provides $\frac{1}{3}V_{CC}$ and $\frac{2}{3}V_{CC}$ reference voltages.

Two internal voltage comparators determine the state of a D flip-flop.

The flip-flop output controls a transistor switch.

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As a reminder, an Op Amp without a feedback component is a voltage comparator.

- Output voltage changes to force the negative input voltage to equal the positive input voltage.
  - A maximum output voltage ($V_o$) is against the positive supply rail ($V+$) if the positive input voltage ($v_2$) is greater than negative input voltage ($v_1$).
  - A minimum output voltage ($V_o$) is against the negative supply rail ($V-$) if the negative input voltage ($v_1$) is greater than the positive input voltage ($v_2$).
The voltage comparators use the internal voltage divider to keep the capacitor voltage \( V_C \) between \( \frac{1}{3}V_{CC} \) and \( \frac{2}{3}V_{CC} \).

The output of the **lower voltage comparator** will be high (\( V_{cc} \)) when \( V_C < \frac{1}{3}V_{CC} \), and low (0 V) when \( V_C > \frac{1}{3}V_{CC} \) (\( \frac{1}{3}V_{CC} = \text{the voltage across the lower resistor in the internal voltage divider} \)).

The output of the **upper voltage comparator** will be low (0 V) when \( V_C < \frac{2}{3}V_{CC} \), and high (\( V_{cc} \)) when \( V_C > \frac{2}{3}V_{CC} \) (\( \frac{2}{3}V_{CC} = \text{the voltage across the two lower resistors in the internal voltage divider} \)).
The bipolar transistor (BJT) acts as a switch.

NOTE: Your kit TLC555 uses a MOSFET instead of a BJT.
As you will learn in ECE 2204, a BJT or MOSFET transistor can be connected to act like a switch.

- When a positive voltage is applied to the base or gate, the transistor acts like there is a very small resistor is between the collector and the emitter, or the drain and the source.
- When ground is applied to the base or gate, the transistor acts like there is a open circuit between the collector and the emitter, or the drain and the source.
The transistor inside the 555 switches the discharge pin (7) to ground (or very close to 0 V), when Qbar (the Q with a line over it) of the D flip-flop is high ($V_{Qbar} \approx V_{CC}$).

The transistor grounds the node between external timing resistors $R_a$ and $R_b$. The capacitor discharges through $R_b$ to ground through the transistor. *Current through $R_a$ also goes to ground through the transistor.*

When the transistor is switched off, it acts like an open circuit. $V_{CC}$ now charges the capacitor through $R_a$ and $R_b$. 

http://www.williamson-labs.com/480_555.htm
The capacitor charges through \( R_A \) and \( R_B \).

- Because \( V_C \) started 0 V, the first timing period will be longer than the periods that follow.
- The capacitor charges through $R_a$ and $R_b$ until $V_C = \frac{2}{3}V_{CC}$.

- When $V_C$ reaches $\frac{2}{3}V_{CC}$, the output of the upper voltage comparator changes and resets the D flip-flop, $Q_{bar}$ switches to high ($\approx V_{CC}$), and the transistor switches on.

- The capacitor then begins discharging through $R_b$ & the transistor to ground.
Discharging:

The capacitor discharges through $R_b$ and the transistor to ground.

Current through $R_a$ is also grounded by the transistor.

- When $V_C$ reaches $\frac{1}{3}V_{CC}$, the output of the lower voltage comparator changes and sets the D flip-flop, $Qbar$ switches to low ($\approx 0$ V), and the transistor switches off.
- The capacitor then begins charging through $R_a$ and $R_b$.

Thus, the voltage of the capacitor can be no more than $\frac{2}{3}V_{CC}$ and no less than $\frac{1}{3}V_{CC}$ if all of the components internal and external to the 555 are ideal.

http://www.williamson-labs.com/480_555.htm
The output of the 555 timer, pin 3, is Q on the D flip-flop.

- When Qbar is 5 V and the capacitor is charging, Q is 0 V.
- When Qbar is 0 V and the capacitor is discharging, Q is 5 V.

Thus, the output of a 555 timer is a continuous square wave function (0 V to 5 V) where:

- the period is dependent on the sum of the time it takes to charge the capacitor to $\frac{2}{3}V_{CC}$ and the time that it takes to discharge the capacitor to $\frac{1}{3}V_{CC}$.
- In this circuit, the only time that the duty cycle (the time that the output is at 0 V divided by the period) will be 0.5 (or 50%) is when $Ra = 0 \, \Omega$, which should not be allowed to occur as that would connect $V_{CC}$ directly to ground when the transistor switches on.

http://www.williamson-labs.com/480_555.htm
Astable Multivibrator - Waveforms

- $T_H$ is the time it takes $C$ to charge from $\frac{1}{3}V_{CC}$ to $\frac{2}{3}V_{CC}$
  - $T_H = (R_a + R_b)C[-\ln(\frac{1}{2})]$ (from solving for the charge time between voltages)

- $T_L$ is the time it takes $C$ to discharge from $\frac{2}{3}V_{CC}$ to $\frac{1}{3}V_{CC}$
  - $T_{Low} = R_bC[-\ln(\frac{1}{2})]$ (from solving for the charge time between voltages)

- The duty cycle (% of the time the output is high) depends on the resistor values.

Williamson Labs 555 astable circuit waveform animation
The duty cycle of the standard 555 timer circuit in Astable mode must be greater than 50%.

- $T_{\text{high}} = 0.693(R_a + R_b)C$  [C charges through $R_a$ and $R_a$ from $V_{CC}$]
- $T_{\text{low}} = 0.693R_bC$  [C discharges through $R_b$ into pin 7]
- $R_1$ must have a resistance value greater than zero to prevent the discharge pin from directly shorting $V_{DD}$ to ground.
- Duty cycle = $T_{\text{high}} / (T_{\text{high}} + T_{\text{low}}) = (R_a + R_b) / (R_a + 2R_b) > 50\%$ if $R_a \neq 0$

Adding a diode across $R_b$ allows the capacitor to charge directly through $R_a$.

This sets $T_{\text{high}} \approx 0.693R_aC$
$T_{\text{low}} = 0.693R_bC$  (unchanged)
Useful 555 Timer Chip Resources

- **TI Data Sheets and design info**
  - Data Sheet (pdf)
  - Design Calculator (zip)
- **Williamson Labs**  [http://www.williamson-labs.com/480_555.htm](http://www.williamson-labs.com/480_555.htm)
  - Timer tutorials with a 555 astable circuit waveform animation.
  - Philips App Note [AN170](http://www.doctronics.co.uk/pdf_files/555an.pdf) (pdf)
- **Wikipedia - 555 timer IC**
- **NE555 Tutorials**  [http://www.unitechelectronics.com/NE-555.htm](http://www.unitechelectronics.com/NE-555.htm)
- **Doctronics 555 timer tips**  [http://www.doctronics.co.uk/555.htm](http://www.doctronics.co.uk/555.htm)
- **The Electronics Club**  [http://www.kpsec.freeuk.com/555timer.htm](http://www.kpsec.freeuk.com/555timer.htm)
- **555 Timer Circuits**  [http://www.555-timer-circuits.com](http://www.555-timer-circuits.com)
- **Philips App Note AN170**  [http://www.doctronics.co.uk/pdf_files/555an.pdf](http://www.doctronics.co.uk/pdf_files/555an.pdf)