No Class Next Week - Thu Nov 8

- The OpEL will close at 4:30PM on Thursday Nov 8.
- Week 9 is due next Wed (Nov 7) as usual.

- The make-up lab (photoflash) is due Wed Nov 14.
LM/TLC 555 Timer

As an Astable Multivibrator
The TLC555C Chip (in your kit)

RESET can override TRIG, which can override THRES.
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.

[Image of the 555 Timer circuit diagram]

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.
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 \((Vcc)\) when \(V_C < \frac{1}{3}V_{CC}\), and low \((0\ V)\) when \(V_C > \frac{1}{3}V_{CC}\)

\(\frac{1}{3}V_{CC}\) = 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 \((Vcc)\) when \(V_C > \frac{2}{3}V_{CC}\)

\(\frac{2}{3}V_{CC}\) = the voltage across the two lower resistors in the internal voltage divider.

http://www.williamson-labs.com/480_555.htm
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 an 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 \(V_{\overline{Q}} \approx V_{CC}\).

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 \(R_b\).
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, $Q\bar{b}$ 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 ($\approx 0 \text{ V}$), 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.
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 $R_a = 0 \, \Omega$, 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 $\frac{2}{3}V_{CC}$
  - $T_H = (R_a + R_b) \times C \times [-\ln(\frac{1}{2})]$ (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 $\frac{1}{3}V_{CC}$
  - $T_{Low} = R_b \times C \times [-\ln(\frac{1}{2})]$ (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 = \( \frac{T_{\text{high}}}{(T_{\text{high}} + T_{\text{low}})} = \frac{(R_a + R_b)}{(R_a + 2R_b)} > 50\% \) 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)
Metronomes

- Emits regular sounds, usually a single frequency tone, beat, or click, which instrument players and singers use to count the meter or tempo of a piece of music.
- The repetition rate of the sound from a metronome can be adjusted by the musician.
  - The typical range is from 40 to 200 beats per minute (bpm), which translates to a frequency of 0.667 to 3.33Hz.
The value of C must be changed
If you have a kit from 2010 with no speaker, see an OpEL GTA to obtain one.

Note new value
Time constants of two different resistor-capacitor networks determine the length of time the timer output, $t_1$ and $t_2$, is at 5V and 0V, respectively.

\[ t_1 = 0.693(R_a + R_b)C \]

\[ t_2 = 0.693(R_b)C \]
Types of Capacitors

- Fixed Capacitors
  - Nonpolarized
    - May be connected into circuit with either terminal of capacitor connected to the high voltage side of the circuit.
    - Insulator: Paper, Mica, Ceramic, Polymer
  - Electrolytic
    - The negative terminal must always be at a lower voltage than the positive terminal
    - Plates or Electrodes: Aluminum, Tantalum
Nonpolarized

- It’s difficult to make nonpolarized capacitors that store a large amount of charge or operate at high voltages.
  - Tolerance on capacitance values is very large
    - +50%/-25% is not unusual

<http://www.marvac.com/fun/ceramic_capacitor_codes.aspx>
Electrolytic

Pspice Symbols

Fabrication

Electrolytic Capacitors

- The negative electrode must always be at a lower voltage than the positive electrode.
  - So in your circuit, the negative electrode must be grounded.
**Frequency and Duty Cycle**

\[ f = \frac{1}{t_1 + t_2} = \frac{1.44}{(R_a + 2R_b)C} \]

\[ D = \frac{t_2}{t_1 + t_2} = \frac{R_b}{R_a + 2R_b} \]

When the output of the 555 timer changes from 5V to 0V, a pulse current will flow through the speaker, causing the speaker to create a click sound. You will change the frequency of the pulses to the speaker by changing the value of \( R_a \). Since \( R_a \) is usually much larger than \( R_b \), the frequency of the pulses are linearly proportional to the value of \( R_a \) and the duty cycle of the pulse waveform will be very short.
Why is there a resistor in series with the speaker?

- A portion of the LM555 timer datasheet is shown below

(NOTE: the MOSFET switch is more efficient than the BJT switch, and [TCL555 data sheet](#) is different! The TLC555’s $I_{\text{SINK}}$ is much higher than the LM555’s $I_{\text{SINK}}$.)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Limits</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LM555C</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>Min</td>
<td>Typ</td>
</tr>
<tr>
<td>Output Voltage Drop (Low)</td>
<td>$V_{\text{CC}} = 15\text{V}$</td>
<td>0.1</td>
<td>0.25</td>
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<tr>
<td></td>
<td>$I_{\text{SINK}} = 10\text{mA}$</td>
<td>0.4</td>
<td>0.75</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>$I_{\text{SINK}} = 200\text{mA}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_{\text{CC}} = 5\text{V}$</td>
<td>0.25</td>
<td>0.35</td>
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<tr>
<td></td>
<td>$I_{\text{SINK}} = 8\text{mA}$</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>$I_{\text{SINK}} = 5\text{mA}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Voltage Drop (High)</td>
<td>$I_{\text{SOURCE}} = 200\text{mA}$, $V_{\text{CC}} = 15\text{V}$</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$I_{\text{SOURCE}} = 100\text{mA}$, $V_{\text{CC}} = 15\text{V}$</td>
<td>12.75</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>$V_{\text{CC}} = 5\text{V}$</td>
<td>2.75</td>
<td>3.3</td>
</tr>
<tr>
<td>Rise Time of Output</td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Fall Time of Output</td>
<td></td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>
Sink versus Source

- When a component sinks current at its output, current is defined as positive when entering the component from the external circuitry.
- When a component sources current at its output, current is defined as positive when it leaves the component and flows into the external circuitry.
  - In a 555 timer, the output voltage is limited to 0 V & Vcc, which is +5 V in the circuit for our experiment.
  - In the metronome circuit, current only flows when the output voltage is less than Vcc, which forces current to flow into the 555 timer at the output terminal.
    - The 555 timer will sink current.
    - The 200 Ω resistor acts as a current limiting resistor to insure that the current sinking into the 555 timer will not exceed the maximum current allowed according to the datasheet.
Why won’t the sound be loud?

- Electromagnet generates a magnetic field that causes the diagram to change position based upon the magnitude of the current through the voice coil.
  - We hear sound when the diaphragm moves, which only occurs when the current through the voice coil changes.

- 0.5W speaker with 8 Ω equivalent impedance.
  - $5 \text{V} / 8 \Omega = 0.625 \text{A}$ to produce full power (vs. the $I_{\text{SINK}}$ available!)

http://en.wikipedia.org/wiki/Loudspeaker
Measurement of Capacitance

- Is requested in the laboratory procedure. However, the value of the capacitor used in this experiment is beyond the capability of the DMM.
  - Ignore this step.
The ground for the arbitrary function generator and both channels of the Velleman oscilloscope are connected and are tied to earth ground.

- To determine the voltage across the speaker and the current flowing through it will require some thought.

- [The Digilent Analog Discovery uses differential scope inputs, which are isolated from the ground.]
If you place the red probe where the current marker is in this schematic and the black probe at the output of the 555 timer (pin 3), you will force the output voltage of the 555 to be 0 V.

- You will not see a square wave output from the 555 timer.

Similarly, you can not put the red probe between the 200 Ω resistor and the 555 and the black probe between the 200 Ω resistor and the speaker because you will then force the node voltage between the 200 Ω resistor and the speaker to be equal to 0 V.

- The square wave output from the LM 555 timer will only be dropped across the 200 Ω resistor and the speaker will have a constant 5 V across it.
Math Functions on the Velleman Scope

- If you place the red probe between the 200 Ω resistor and the speaker and connect the black probe to the ANDY board ground, then the measurement displayed on the scope will be the output voltage from the LM 555 timer plus the voltage across the 200 Ω resistor.
  - Alternatively, you can look at this measurement as Vcc minus the voltage dropped across the speaker.

- If you measure the voltage at the output of the 555 timer, you can use the Math functions to obtain only the voltage across the 200 Ω resistor. Then, divide the result by the resistance to find the current.
  - A similar technique can be used to determine the voltage across the speaker.
Math Functions on the Digilent Scope

Note:
The Digilent Analog Discovery uses differential scope inputs, which are isolated from the ground.