

ENGR3499-2: Real World Microcontrollers

Assignment: Your first PCB

In this class, you have one assignment and one project. This is the handout for the assignment. Its learning goals are to give you many of the skills needed to complete your project, most importantly how to draw schematics and how to layout printed circuit boards using KiCad.

You have about 3 weeks to complete this assignment. Feel free to finish it faster if you want more time for your project. The grading will be done once you have completed all steps, however be prepared to discuss your progress each week during our Zoom sessions.

In this assignment, you will design your first printed circuit board. Below you will find a simple schematic of a circuit that goes Beep Beep Beep when you press it's button. Your job is to recreate that schematic in KiCad, then layout a PCB for it.

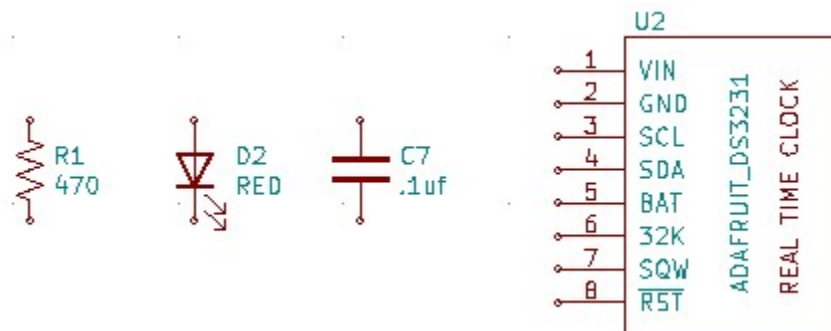
The step below detail what you are to do for this assignment, but talk less about how to do it. For instruction using KiCad you will watch a series of seven videos that take you through a similar project. And always, please feel free to ask questions if anything in the videos is unclear.

- The first video talks about what KiCad is and how to install it.

Watch: *Getting To Blinky 5.0 – Introduction* (6 min)

- https://www.youtube.com/watch?v=BVhWh3AsXQs&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJcN&index=2&t=0s

- Install KiCad on your computer. Installing KiCad is pretty easy. If you would like more information, the previous video talked about how to do it. Download it here: <https://kicad-pcb.org/download/>
- Symbols like these:

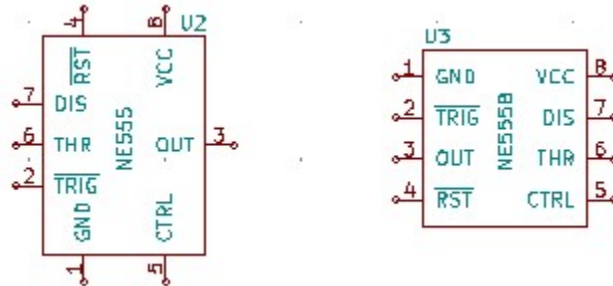


are used to represent each component in your circuit. The KiCad library has many to choose from, but you will still need to draw some yourself (such as the Adafruit module above).

Watch: *Getting To Blinky 5.0 - Schematic Symbol Creation* (15 min)

- https://www.youtube.com/watch?v=LaUd8WfFooU&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJCn&index=3&t=0s

- In the steps that follow you will be using KiCad to redraw the schematic that I have attached below. Start by running KiCad, then create a New Project, call it *RealWorldBeepy*.
- Before drawing your schematic, make sure you have all the symbols that your circuit uses. As mentioned, some symbols you need to create yourself. The first step in doing that is to make a *symbol library* to put your custom symbols in. Using the *Library Editor*, create a new library called *RealWorldBeepyLib*, when asked to choose between *Global* and *Project*, pick *Project*.
- Create a schematic symbol for the NE555 chip. I've included the datasheet for the NE555 below. Arrange the order of the pins in a way that makes drawing the schematic intuitive (as was done in the video). For example, when drawing this circuit, the symbol on the left is better than the one on the right.




Note: When defining the pins in KiCad for the NE555 symbol, you can set the *Electrical Type* to a value that best fits that pin, or simply set all the pins to *bidirectional*.

- Now that you have all the custom symbols ready to go, figuring out how to draw the schematic is next.

Watch: *Getting To Blinky 5.0 - Making The Schematic* (14 min)

- https://www.youtube.com/watch?v=01OYONrYtNQ&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJCn&index=4&t=0s

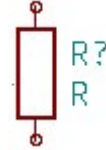
- It time to draw your schematic. Start by opening your project's schematic in KiCad, it should be empty, just a border and title block. Setup your schematic by

clicking  (found on the top toolbar). Now set the page size to 8.5 x 11 and *Title Block* values:

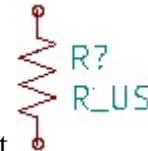
- Issue date = today's date
- Revision = Rev 1.0
- Title = Real World Beepy
- Company = You can pick your own name (I use *Stan Reifel & Co.*)

- Redraw the Beepy schematic by copying my version found below. Be sure to include the NE555 symbol that you created earlier. Here are a few notes as you draw your schematic:



- When looking up resistors in the *Choose Symbol* dialog box, you can type




in *R* (to select the symbol that looks like this one commonly used



in Europe and Asia), or you can type in *R_US* (to select). Either one is OK.

- Note that in my example schematic *C1* and *C3* are non-polarized capacitors, so search for the symbol *C*. *C2* and *C4* are polarized, use symbol *CP1* for these.
- Also notice that I did not draw the wires connecting all the 9 volt pins and all the ground pins. Instead I used power and ground symbols. This is done to reduce clutter on the schematic, making it easier to read. Find these symbols by selecting  from the toolbar on the right.
- Note that my schematic does not include a battery, instead I added a 2 pin power connector. On your schematic, I suggest using the generic connector symbol *Conn_01x02*. Note the *01x02* indicates a connector having pins in 1 row with 2 columns.
- After you have placed all the symbols and wired them up, be sure to run the *Annotate Schematic Symbols* command by clicking on . This will assign each component in your schematic a part reference number (i.e. R1, C3, J4...).
- An important subject not covered in the videos is creating the BOM, or *Bill of Materials*. When done correctly, the schematic can automatically generate a parts list for your project, complete with quantities and order numbers. I've included the BOM that KiCad made for my example schematic.

For each component in your design, KiCad already knows its reference number (i.e. R1, C3, J4...) and its value (i.e. 47K, 0.1uf). What needs to be added now are the part numbers used to buy them. For my example schematic, I purchased all the components from Digikey, so to my BOM I added the Digikey part numbers.

- Now add the Digikey part numbers to your schematic. Start by clicking on  found on the top toolbar. Press the *Add Field* button to create a new column, label it *Digikey*. For each component in the list, copy the order numbers from my

BOM into your *Digikey* fields. Later when designing your circuit board, knowing the exact part numbers will help you choose the right PCB footprint.

- Your schematic is almost done. Before you can start laying out your circuit board, you need to assign the PCB footprints that match each physical component in your design.

Watch: *Getting To Blinky 5.0 - Associating Symbol and Footprint* (11 min)

- https://www.youtube.com/watch?v=IIPKGoW0VBY&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJCn&index=5&t=0s

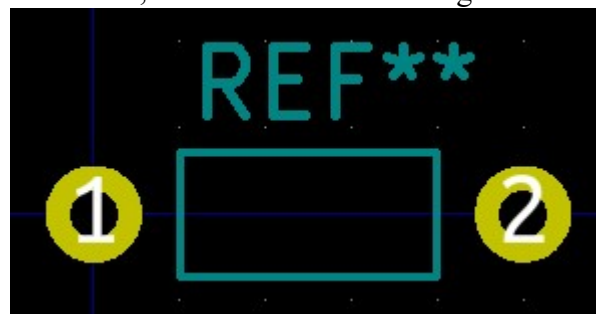
- For many of the components in your circuit, you will find a PCB footprint in the KiCad library that works nicely. However, there are times when you need to design your own.

Watch: *Getting To Blinky 5.0 - Creating A Custom Footprint* (15 min)

- https://www.youtube.com/watch?v=-7yFlz6wdUA&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJCn&index=6&t=0s

- For this project, you will need to create two custom PCB footprints.
 - Before making your custom footprints, you need to make a library to put them in. The video above talks about how to do that.
 - Your circuit uses resistors that are through-hole (as opposed to surface mount) and are rated at 1/8 watt. The KiCad library does not have a good footprint for these. Draw your own with two round pads (56mils in diameter having 29mil holes). Space the pads 250mils apart. Between the pads draw the part outline as a rectangle on the front silkscreen layer (F.Silks).

When you are done, it should look something like this:





Note: It is completely optional if you would like to make footprints that use the *F.CrtYd* or *F.Fab* layers. You only need to place the pads and draw part outlines on the *F.Silks* layer.

- Your project includes a tiny speaker that's soldered directly to your board. KiCad does not have a speaker footprint in its library so you will need to

create it. Start by looking at the speaker's datasheet to determine it's dimensions. Here's how to find the datasheet:

1. Earlier you entered the speaker's Digikey part number into your *Bill of Materials*. Find it now by hovering the mouse of the speaker's symbol in your schematic, then press *E*. Copy the part number from the *Digikey* field.
(Fun fact: All Digikey part numbers end in "-ND").
2. Go to www.digikey.com then paste the speaker's part number in the search box.
3. Look on this page for "Datasheets", then click the link.

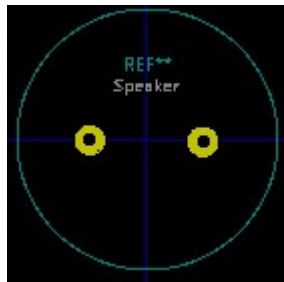
Note all dimensions in this datasheet are in millimeters. KiCad is equally happy to work in units of inches or millimeters. Switch between them by clicking on  or  found in the toolbar along the left.

On the datasheet, notice the speaker's pins have a diameter of 0.8 +/- 0.05 mm. To be safe, let's call it 0.85mm. When choosing the pad's hole size, you want to make it bigger than the pin. In most cases making it bigger by about 8mils or 0.2mm should be enough.

The diameter of the pad obviously needs to be bigger than the hole. I suggest making it at least two times bigger.

Now it's time to draw the footprint. Start by placing two round pads. Be sure to set the pad's diameter and hole size. Also draw the component's outline on the front silkscreen layer (F.SilkS), make it about the same size as the speaker.

Mine looks like this:

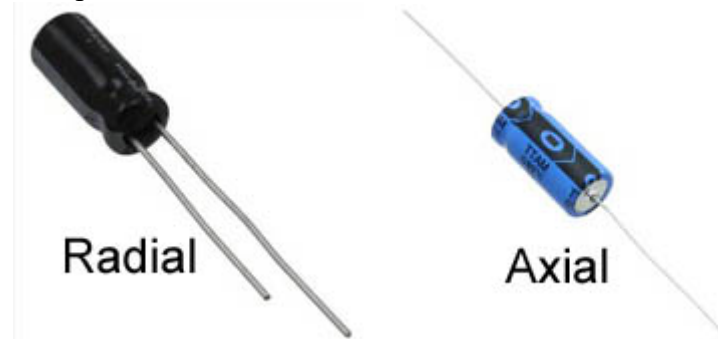


- Now assign each symbol in your schematic its PCB footprint as was done in the video. For the resistors and speaker, use the custom footprints that you just made. For all the other parts, find the matching footprint from the KiCad library.


Note: An important difference between the videos and your project is that they used surface mount components, whereas you will populate your board with through-hole parts.

Here are some tips for choosing the right footprints when assigning them to the symbols in your schematic:


- For C1 & C3, start by selecting *Capacitor_THT* (the THT is for through-hole) in the library. These capacitors are non-polarized so choose a footprint that begins with *C_*, not *CP_*. I suggest picking one that begins with *C_Rect*. The most important thing to get right is the pin spacing, or pitch. The Digikey website is a great resource for this. Lookup the part number, then scroll down to the *Product Attributes* section to find the *Lead Spacing*, *Package*, and *Size*. These caps have a spacing of 2.5mm, so choose a footprint that ends in *_P2.50mm*. Lastly, pick the footprint that is close to the length *L* and width *W* of your part.
- For C2 & C4, also start with *Capacitor_THT*. These are polarized so use *CP_*. Next pick between *radial* and *axial*.



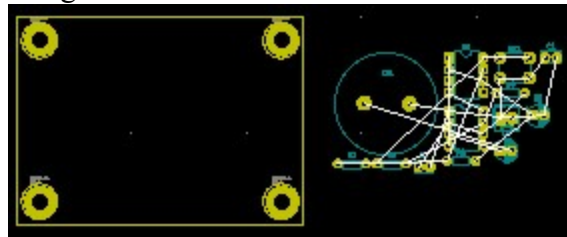
Again, look up the part number on Digikey to find the component's *Lead spacing* and *Size*. Now choose the footprint with the right diameter (D) and lead spacing (P).

- My favorite connectors for PCBs are *Molex KK* connectors with 0.1" pin spacing. For J1, start looking up its footprint using *Connector_Molex*. Note that all the dimensions in the KiCad libraries are in millimeters, so 0.1" is represented as 254 (2.54mm). J1 has 2 pins, organized in 1 row with 2 columns. So find the footprint that includes in it's name:
Molex, KK, 254, 1x02, Vertical
 - Use these same techniques to choose the footprints for SW1 and U1.
- Your schematic is now done, congratulations! The next step is to learn about PCB design.
- Watch: Getting To Blinky 5.0 - Finishing The Layout (25 min)
- https://www.youtube.com/watch?v=D_7Y33AoagY&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJCn&index=7&t=0s
- Before designing your PCB, be sure you have generated the schematic's netlist by clicking on .

- Now start the layout of your PCB. Follow the instructions in the video *Getting To Blinky 5.0 - Creating A Custom Footprint*. They talk about the first steps at the 12:40 point.
- For your board, define the *Board Outline* as a rectangular, 2.5" x 1.8". This is easier if you first set the grid (using the top toolbar) to 100.00 mils. It's also helpful to keep an eye on the status bar's dx & dy as you draw the lines.
- Add 4 mounting holes to your board, one in each corner. They don't do this in the video, so here's how:

- From the right toolbar select , then click in the workspace.
- In the listbox, expand *MountingHole*.
- Choose a mounting hole with a *_Pad*. Here are some useful sizes:
 - For 4-40 screws *MountingHole_3.2mm_M3_Pad*
 - For 6-32 screws *MountingHole_3.7mm_Pad*
- Double click on the pad of your choice, then click to place it on the PCB.
- Clean up the mounting hole's display by hover over it, then press *E*. Uncheck all the *Show* checkboxes.

- If you followed the steps in the video, along with a few here, your board should now look something like this:



- Perhaps the most important step in laying out a PCB is positioning each component. I spend a great deal of time on this step, about an hour for a board with 30 parts.

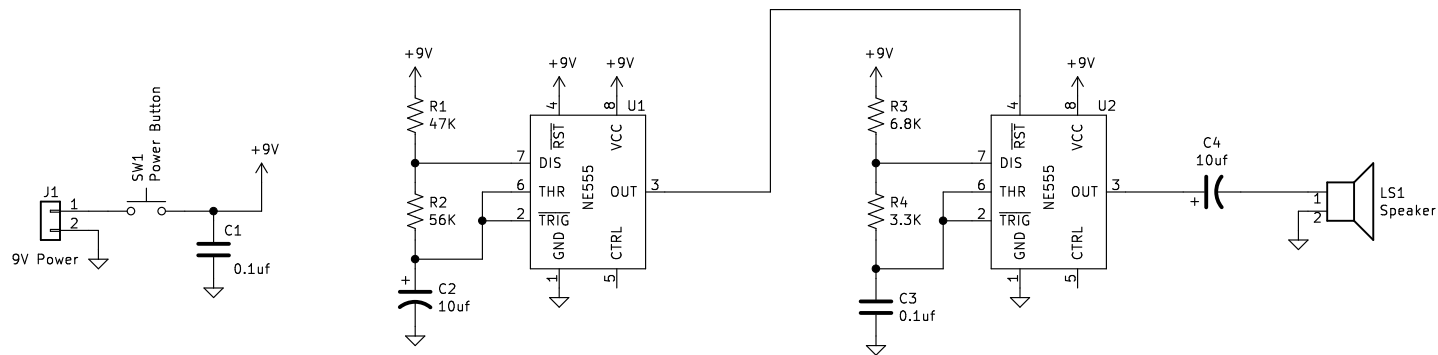
First I place all the parts that I want in specific locations (perhaps all the connectors along one side of the board, push buttons that need to line up with holes in the board's enclosure...).

Then I think about organizing the layout so the parts wired to each other are also close to each other. Often rotating a part by 90° or 180° can be a big help. Basically, you are trying to minimize the trace lengths.

Place the footprints on your board in a way that will make routing the traces easiest.

- Now that you have positioned each component, the fun part begins! Using the techniques in the last video, route the traces on your board to wire everything up.
- Watch: *Getting To Blinky 5.0 - Output Files For Manufacturing* (20 min)

- https://www.youtube.com/watch?v=3oL6ZdCUZvA&list=PLy2022BX6EspFAKBCgRuEuzapuz_4aJCn&index=8&t=0s
- When the board is “electrically” finished, I always add additional text on the front silkscreen layer. I suggest adding these:
 - The name of your board: “REAL WORLD BEEPY”
 - The version number: “V1.0”
 - Label the power connector with “9V” and mark the pins with a “+” & “-“
 - Be sure to add your name. I often copyright my designs by adding:
(c) 2020 - STANLEY REIFEL & CO.
- Now make the files needed to manufacture your PCB. First create a folder inside your project named *Gerbers*, then generate the files for these layers, saving them in the *Gerbers* folder.
 - F.Cu
 - B.Cu
 - F.Silk
 - B.Silk
 - F.Mask
 - B.Mask
 - Edge.Cuts
 - The Drill file
- How will they turn them in to me?
- Will they have the boards made? Sent to me or them directly?
- Attachments:
 - Schematic
 - BOM
 - 555 data sheet



S. Reifel & Co.

Sheet: /

File: Beepy.sch

Title: Real World Beepy

Size: A Date: 2020-08-22

KiCad E.D.A. kicad (5.1.6)-1

Rev: Rev 1.0

Id: 1/1

Beepy Bill Of Materials

Item	Qty	Reference(s)	Value	Digikey
1	2	C1, C3	0.1uf	BC1084CT-ND
2	2	C2, C4	10uf	493-14344-1-ND
3	1	J1	9V Power	900-0022232021-ND
4	1	LS1	Speaker	2104-SM231508-1-ND
5	1	R1	47K	CF18JT47K0CT-ND
6	1	R2	56K	CF18JT56K0CT-ND
7	1	R3	6.8K	CF18JT6K80CT-ND
8	1	R4	3.3K	CF18JT3K30CT-ND
9	1	SW1	Power Button	450-1647-ND
10	2	U1, U2	NE555	296-NE555P-ND

LM555 Single Timer

Features

- High-Current Drive Capability: 200 mA
- Adjustable Duty Cycle
- Temperature Stability of 0.005%/°C
- Timing From μ s to Hours
- Turn off Time Less Than 2 μ s

Applications

- Precision Timing
- Pulse Generation
- Delay Generation
- Sequential Timing

Description

The LM555 is a highly stable controller capable of producing accurate timing pulses. With a monostable operation, the delay is controlled by one external resistor and one capacitor. With astable operation, the frequency and duty cycle are accurately controlled by two external resistors and one capacitor.

8-DIP



8-SOIC



Ordering Information

Part Number	Operating Temperature Range	Top Mark	Package	Packing Method
LM555CN	0 ~ +70°C	LM555CN	DIP 8L	Rail
LM555CM		LM555CM	SOIC 8L	Rail
LM555CMX		LM555CM	SOIC 8L	Tape & Reel

Block Diagram

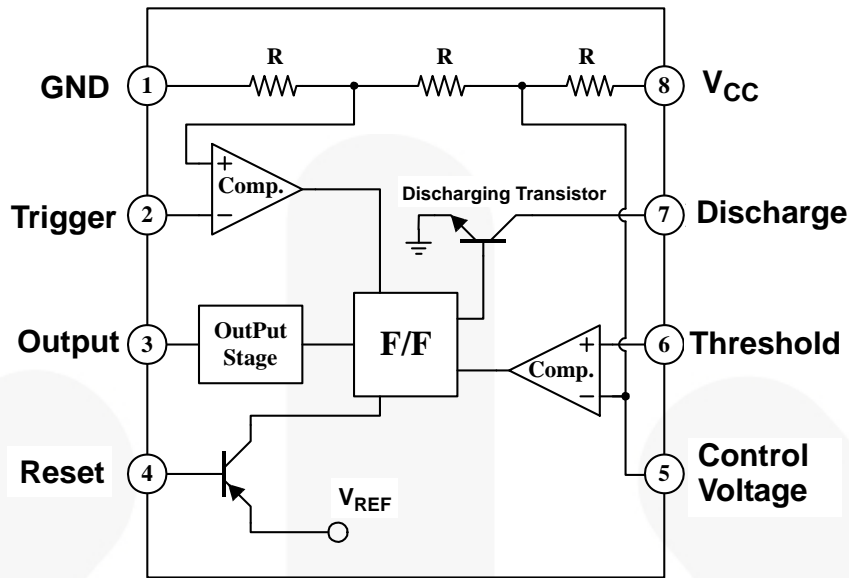


Figure 1. Block Diagram

Absolute Maximum Ratings

Stresses exceeding the absolute maximum ratings may damage the device. The device may not function or be operable above the recommended operating conditions and stressing the parts to these levels is not recommended. In addition, extended exposure to stresses above the recommended operating conditions may affect device reliability. The absolute maximum ratings are stress ratings only. Values are at $T_A = 25^\circ\text{C}$ unless otherwise noted.

Symbol	Parameter	Value	Unit
V_{CC}	Supply Voltage	16	V
T_{LEAD}	Lead Temperature (Soldering 10s)	300	$^\circ\text{C}$
P_D	Power Dissipation	600	mW
T_{OPR}	Operating Temperature Range	0 ~ +70	$^\circ\text{C}$
T_{STG}	Storage Temperature Range	-65 ~ +150	$^\circ\text{C}$

Electrical Characteristics

Values are at $T_A = 25^\circ\text{C}$, $V_{CC} = 5 \sim 15\text{ V}$ unless otherwise specified.

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Supply Voltage	V_{CC}		4.5		16.0	V
Supply Current (Low Stable) ⁽¹⁾	I_{CC}	$V_{CC} = 5\text{ V}, R_L = \infty$		3	6	mA
		$V_{CC} = 15\text{ V}, R_L = \infty$		7.5	15.0	mA
Timing Error (Monostable) Initial Accuracy ⁽²⁾	ACCUR	$R_A = 1\text{ k}\Omega$ to $100\text{ k}\Omega$ $C = 0.1\text{ }\mu\text{F}$		1.0	3.0	%
Drift with Temperature ⁽³⁾	$\Delta t / \Delta T$			50		ppm / $^\circ\text{C}$
Drift with Supply Voltage ⁽³⁾	$\Delta t / \Delta V_{CC}$			0.1	0.5	% / V
Timing Error (Astable) Initial Accuracy ⁽²⁾	ACCUR	$R_A = 1\text{ k}\Omega$ to $100\text{ k}\Omega$ $C = 0.1\text{ }\mu\text{F}$		2.25		%
Drift with Temperature ⁽³⁾	$\Delta t / \Delta T$			150		ppm / $^\circ\text{C}$
Drift with Supply Voltage ⁽³⁾	$\Delta t / \Delta V_{CC}$			0.3		% / V
Control Voltage	V_C	$V_{CC} = 15\text{ V}$	9.0	10.0	11.0	V
		$V_{CC} = 5\text{ V}$	2.60	3.33	4.00	V
Threshold Voltage	V_{TH}	$V_{CC} = 15\text{ V}$		10.0		V
		$V_{CC} = 5\text{ V}$		3.33		V
Threshold Current ⁽⁴⁾	I_{TH}			0.10	0.25	μA
Trigger Voltage	V_{TR}	$V_{CC} = 5\text{ V}$	1.10	1.67	2.20	V
		$V_{CC} = 15\text{ V}$	4.5	5.0	5.6	V
Trigger Current	I_{TR}	$V_{TR} = 0\text{ V}$		0.01	2.00	μA
Reset Voltage	V_{RST}		0.4	0.7	1.0	V
Reset Current	I_{RST}			0.1	0.4	mA
Low Output Voltage	V_{OL}	$V_{CC} = 15\text{ V}$, $I_{SINK} = 10\text{ mA}$		0.06	0.25	V
		$V_{CC} = 15\text{ V}$, $I_{SINK} = 50\text{ mA}$		0.30	0.75	V
		$V_{CC} = 5\text{ V}$, $I_{SINK} = 5\text{ mA}$		0.05	0.35	V
High Output Voltage	V_{OH}	$V_{CC} = 15\text{ V}$, $I_{SOURCE} = 200\text{ mA}$		12.5		V
		$V_{CC} = 15\text{ V}$, $I_{SOURCE} = 100\text{ mA}$	12.75	13.30		V
		$V_{CC} = 5\text{ V}$, $I_{SOURCE} = 100\text{ mA}$	2.75	3.30		V
Rise Time of Output ⁽³⁾	t_R			100		ns
Fall Time of Output ⁽³⁾	t_F			100		ns
Discharge Leakage Current	I_{LKG}			20	100	nA

Notes:

1. When the output is high, the supply current is typically 1 mA less than at $V_{CC} = 5\text{ V}$.
2. Tested at $V_{CC} = 5.0\text{ V}$ and $V_{CC} = 15\text{ V}$.
3. These parameters, although guaranteed, are not 100% tested in production.
4. This determines the maximum value of $R_A + R_B$ for 15 V operation, the maximum total $R = 20\text{ M}\Omega$, and for 5 V operation, the maximum total $R = 6.7\text{ M}\Omega$.

Application Information

Table 1 below is the basic operating table of 555 timer.

Table 1. Basic Operating Table

Reset (PIN 4)	V_{TR} (PIN 2)	V_{TH} (PIN 6)	Output (PIN 3)	Discharging Transistor (PIN 7)
Low	X	X	Low	ON
High	$< 1/3 V_{CC}$	X	High	OFF
High	$> 1/3 V_{CC}$	$> 2/3 V_{CC}$	Low	ON
High	$> 1/3 V_{CC}$	$< 2/3 V_{CC}$	Previous State	

When the low signal input is applied to the reset terminal, the timer output remains low regardless of the threshold voltage or the trigger voltage. Only when the high signal is applied to the reset terminal, the timer's output changes according to threshold voltage and trigger voltage.

When the threshold voltage exceeds $2/3$ of the supply voltage while the timer output is high, the timer's internal discharge transistor turns on, lowering the threshold voltage to below $1/3$ of the supply voltage. During this time, the timer output is maintained low. Later, if a low signal is applied to the trigger voltage so that it becomes $1/3$ of the supply voltage, the timer's internal discharge transistor turns off, increasing the threshold voltage and driving the timer output again at high.

1. Monostable Operation

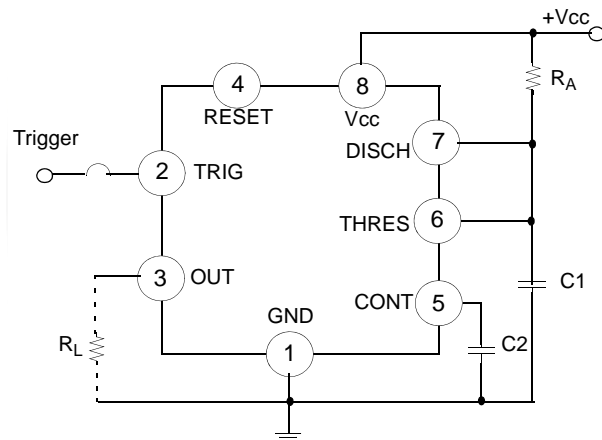


Figure2. Monostable Circuit

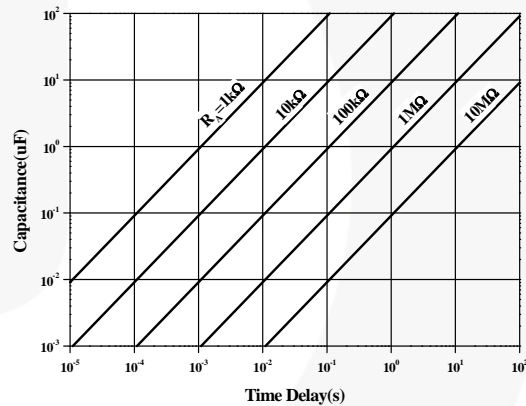


Figure 3. Resistance and Capacitance vs. Time Delay (t_D)

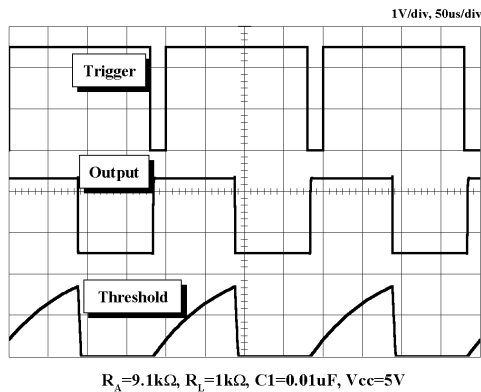


Figure 4. Waveforms of Monostable Operation

1. Monostable Operation

Figure 2 illustrates a monostable circuit. In this mode, the timer generates a fixed pulse whenever the trigger voltage falls below $V_{CC}/3$. When the trigger pulse voltage applied to the #2 pin falls below $V_{CC}/3$ while the timer output is low, the timer's internal flip-flop turns the discharging transistor off and causes the timer output to become high by charging the external capacitor C1 and setting the flip-flop output at the same time.

The voltage across the external capacitor C1, V_{C1} increases exponentially with the time constant $t = R_A * C$ and reaches $2 V_{CC}/3$ at $t_D = 1.1 R_A * C$. Hence, capacitor C1 is charged through resistor R_A . The greater the time constant $R_A C$, the longer it takes for the V_{C1} to reach $2 V_{CC}/3$. In other words, the time constant $R_A C$ controls the output pulse width.

When the applied voltage to the capacitor C1 reaches $2 V_{CC}/3$, the comparator on the trigger terminal resets the flip-flop, turning the discharging transistor on. At this time, C1 begins to discharge and the timer output converts to low. In this way, the timer operating in the monostable repeats the above process. Figure 3 shows the time constant relationship based on R_A and C. Figure 4 shows the general waveforms during the monostable operation.

It must be noted that, for a normal operation, the trigger pulse voltage needs to maintain a minimum of $V_{CC}/3$ before the timer output turns low. That is, although the output remains unaffected even if a different trigger pulse is applied while the output is high, it may be affected and the waveform does not operate properly if the trigger pulse voltage at the end of the output pulse remains at below $V_{CC}/3$. Figure 5 shows such a timer output abnormality.

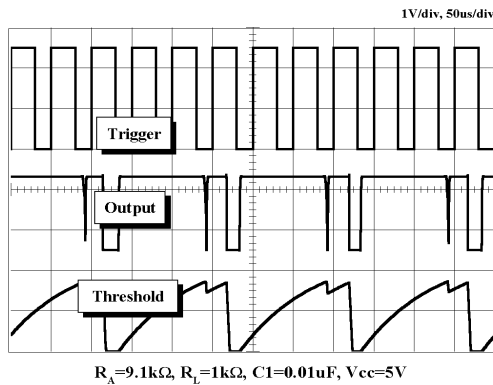


Figure 5. Waveforms of Monostable Operation (abnormal)

2. Astable Operation

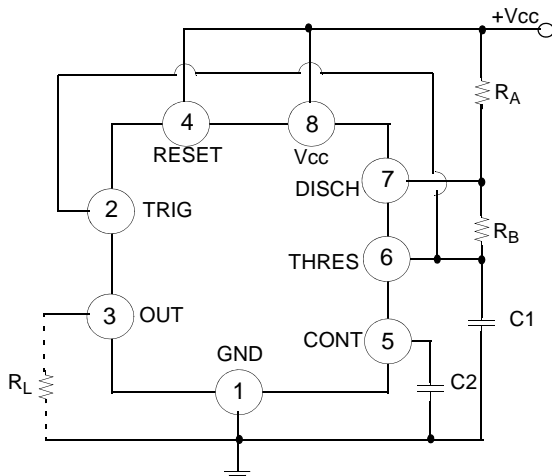


Figure 6. A Stable Circuit

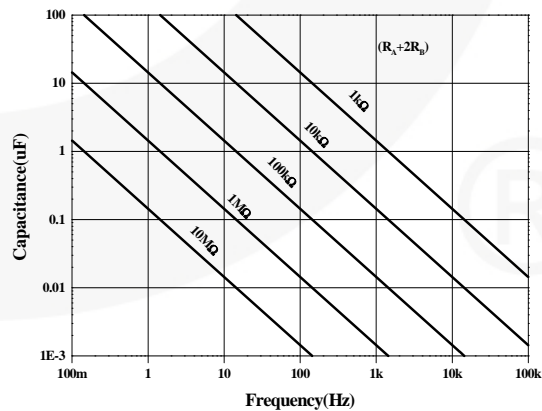
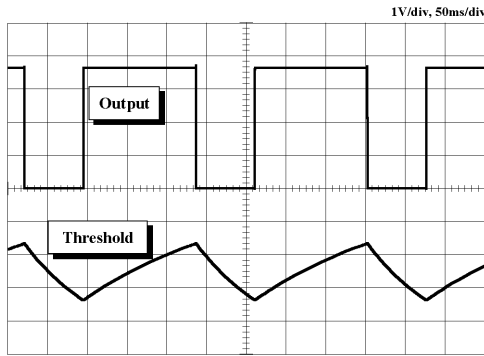


Figure 7. Capacitance and Resistance vs. Frequency



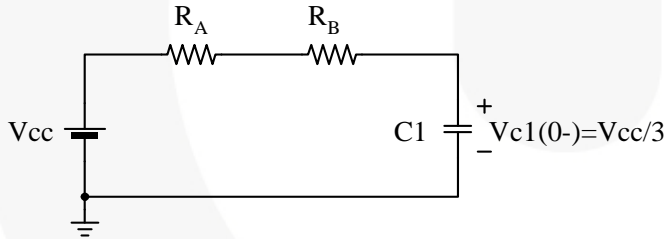
$R_A = 1k\Omega$, $R_B = 1k\Omega$, $R_L = 1kW$, $C_1 = 1\mu F$, $V_{CC} = 5V$

Figure 8. Waveforms of Astable Operation

An astable timer operation is achieved by adding resistor R_B to Figure 2 and configuring as shown on Figure 6. In the astable operation, the trigger terminal and the threshold terminal are connected so that a self-trigger is formed, operating as a multi-vibrator. When the timer output is high, its internal discharging transistor turns off and the V_{C1} increases by exponential function with the time constant $(R_A + R_B) \cdot C$.

When the V_{C1} , or the threshold voltage, reaches $2 V_{CC}/3$; the comparator output on the trigger terminal becomes high, resetting the F/F and causing the timer output to become low. This turns on the discharging transistor and the C_1 discharges through the discharging channel formed by R_B and the discharging transistor. When the V_{C1} falls below $V_{CC}/3$, the comparator output on the trigger terminal becomes high and the timer output becomes high again. The discharging transistor turns off and the V_{C1} rises again.

In the above process, the section where the timer output is high is the time it takes for the V_{C1} to rise from $V_{CC}/3$ to $2 V_{CC}/3$, and the section where the timer output is low is the time it takes for the V_{C1} to drop from $2 V_{CC}/3$ to $V_{CC}/3$. When timer output is high, the equivalent circuit for charging capacitor C_1 is as follows:



$$C_1 \frac{dv_{c1}}{dt} = \frac{V_{CC} - V(0-)}{R_A + R_B} \quad (1)$$

$$V_{C1}(0+) = V_{CC}/3 \quad (2)$$

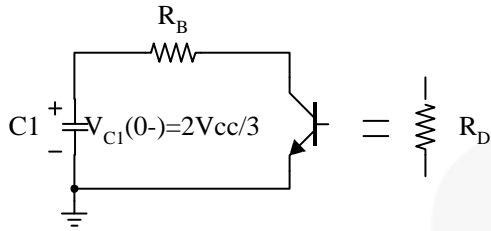
$$V_{C1}(t) = V_{CC} \left(1 - \frac{2}{3} e^{-\left(\frac{t}{(R_A + R_B)C_1} \right)} \right) \quad (3)$$

Since the duration of the timer output high state (t_H) is the amount of time it takes for the $V_{C1}(t)$ to reach $2 V_{CC}/3$,

$$V_{C1}(t) = \frac{2}{3} V_{CC} = V_{CC} \left(1 - \frac{2}{3} e^{-\left(\frac{t_H}{(R_A + R_B)C_1} \right)} \right) \quad (4)$$

$$t_H = C_1(R_A + R_B) \ln 2 = 0.693(R_A + R_B)C_1 \quad (5)$$

The equivalent circuit for discharging capacitor C1, when timer output is low is, as follows:



$$C_1 \frac{dv_{C1}}{dt} + \frac{1}{R_A + R_B} v_{C1} = 0 \quad (6)$$

$$v_{C1}(t) = \frac{2}{3} V_{CC} e^{-\frac{t}{(R_A + R_D)C_1}} \quad (7)$$

Since the duration of the timer output low state (t_L) is the amount of time it takes for the $v_{C1}(t)$ to reach $V_{CC}/3$,

$$\frac{1}{3} V_{CC} = \frac{2}{3} V_{CC} e^{-\frac{t_L}{(R_A + R_D)C_1}} \quad (8)$$

$$t_L = C_1(R_B + R_D) \ln 2 = 0.693(R_B + R_D)C_1 \quad (9)$$

Since R_D is normally $R_B \gg R_D$ although related to the size of discharging transistor,

$$t_L = 0.693 R_B C_1 \quad (10)$$

Consequently, if the timer operates in astable, the period is the same with ' $t = t_H + t_L = 0.693(R_A + R_B)C_1 + 0.693 R_B C_1 = 0.693(R_A + 2R_B)C_1$ '

because the period is the sum of the charge time and discharge time. Since frequency is the reciprocal of the period, the following applies:

$$\text{frequency, } f = \frac{1}{t} = \frac{1.44}{(R_A + 2R_B)C_1} \quad (11)$$

3. Frequency Divider

By adjusting the length of the timing cycle, the basic circuit of Figure 1 can be made to operate as a frequency divider. Figure 9 illustrates a divide-by-three circuit that makes use of the fact that retriggering cannot occur during the timing cycle.

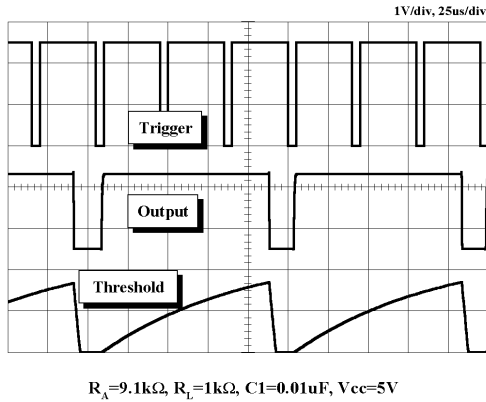


Figure 9. Waveforms of Frequency Divider Operation

4. Pulse Width Modulation

The timer output waveform may be changed by modulating the control voltage applied to the timer's pin 5 and changing the reference of the timer's internal comparators. Figure 10 illustrates the pulse width modulation circuit.

When the continuous trigger pulse train is applied in the monostable mode, the timer output width is modulated according to the signal applied to the control terminal. Sine wave, as well as other waveforms, may be applied as a signal to the control terminal. Figure 11 shows the example of pulse width modulation waveform.

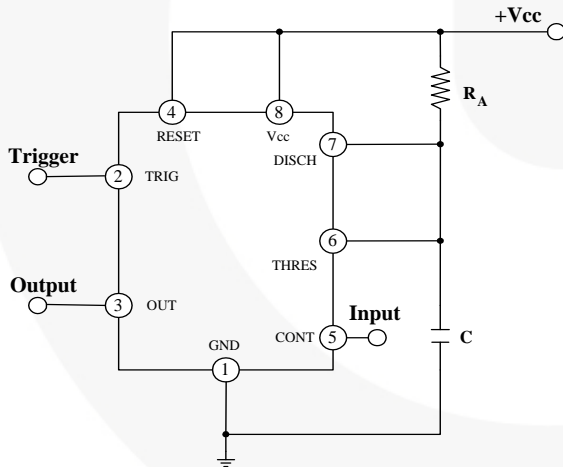


Figure 10. Circuit for Pulse Width Modulation

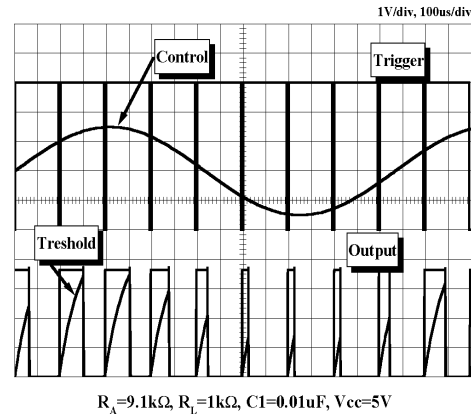


Figure 11. Waveforms of Pulse Width Modulation

5. Pulse Position Modulation

If the modulating signal is applied to the control terminal while the timer is connected for the astable operation, as in Figure 12, the timer becomes a pulse position modulator.

In the pulse position modulator, the reference of the timer's internal comparators is modulated, which modulates the timer output according to the modulation signal applied to the control terminal.

Figure 13 illustrates a sine wave for modulation signal and the resulting output pulse position modulation; however, any wave shape can be used.

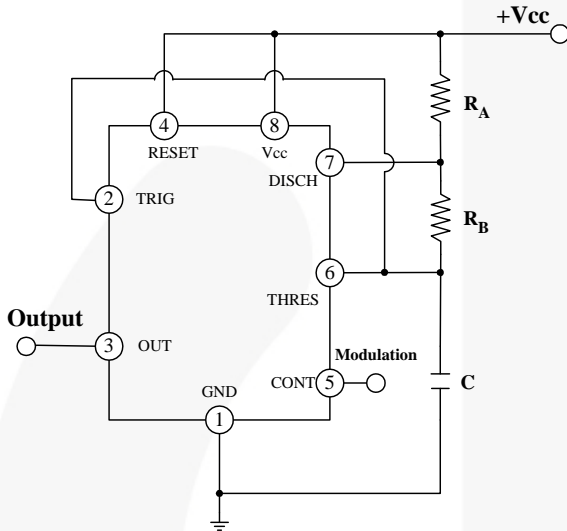


Figure 12. Circuit for Pulse Position Modulation

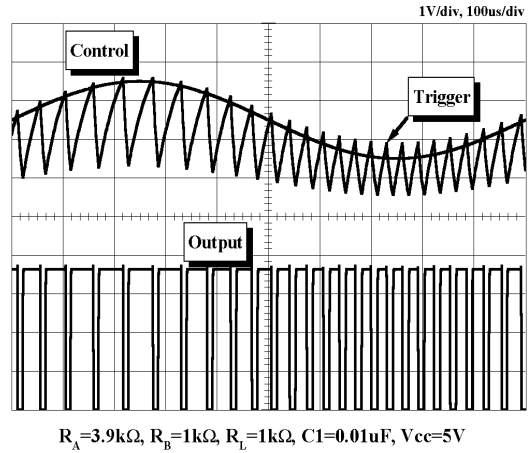


Figure 13. Waveforms of pulse position modulation

6. Linear Ramp

When the pull-up resistor R_A in the monostable circuit shown in Figure 2 is replaced with constant current source, the V_{C1} increases linearly, generating a linear ramp. Figure 14 shows the linear ramp generating circuit and Figure 15 illustrates the generated linear ramp waveforms.

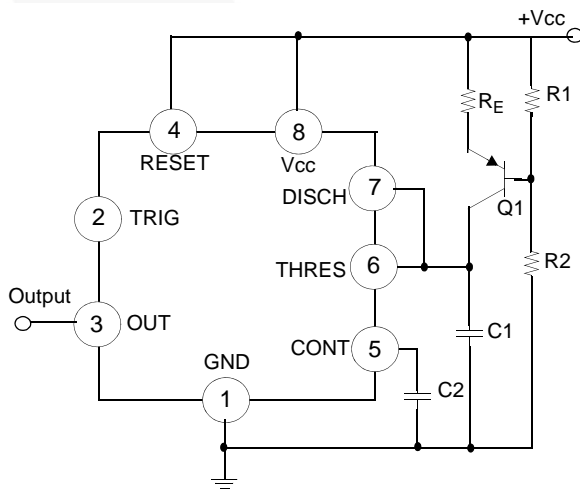


Figure 14. Circuit for Linear Ramp

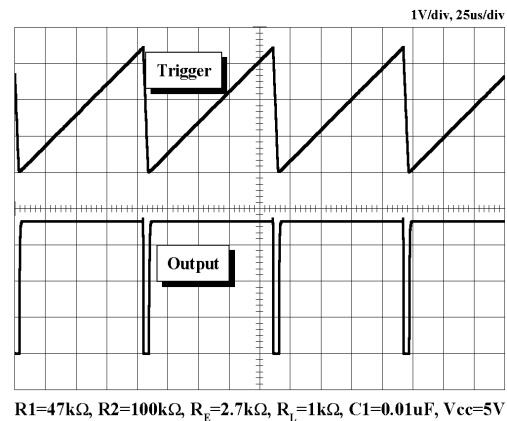


Figure 15. Waveforms of Linear Ramp

In Figure 14, current source is created by PNP transistor Q1 and resistor R1, R2, and R_E.

$$I_C = \frac{V_{CC} - V_E}{R_E} \quad (12)$$

Here, V_E is

$$V_E = V_{BE} + \frac{R_2}{R_1 + R_2} V_{CC} \quad (13)$$

For example, if V_{CC} = 15 V, R_E = 20 kΩ, R₁ = 5 kΩ, R₂ = 10 kΩ, and V_{BE} = 0.7 V,
V_E = 0.7 V + 10 V = 10.7 V, and
I_C = (15 - 10.7) / 20 k = 0.215 mA.

When the trigger starts in a timer configured as shown in Figure 14, the current flowing through capacitor C1 becomes a constant current generated by PNP transistor and resistors.

Hence, the V_C is a linear ramp function as shown in Figure 15. The gradient S of the linear ramp function is defined as follows:

$$S = \frac{V_{p-p}}{t} \quad (14)$$

Here the V_{p-p} is the peak-to-peak voltage.

If the electric charge amount accumulated in the capacitor is divided by the capacitance, the V_C comes out as follows:

$$V = Q/C \quad (15)$$

The above equation divided on both sides by t gives:

$$\frac{V}{t} = \frac{Q}{C} \quad (16)$$

and may be simplified into the following equation:

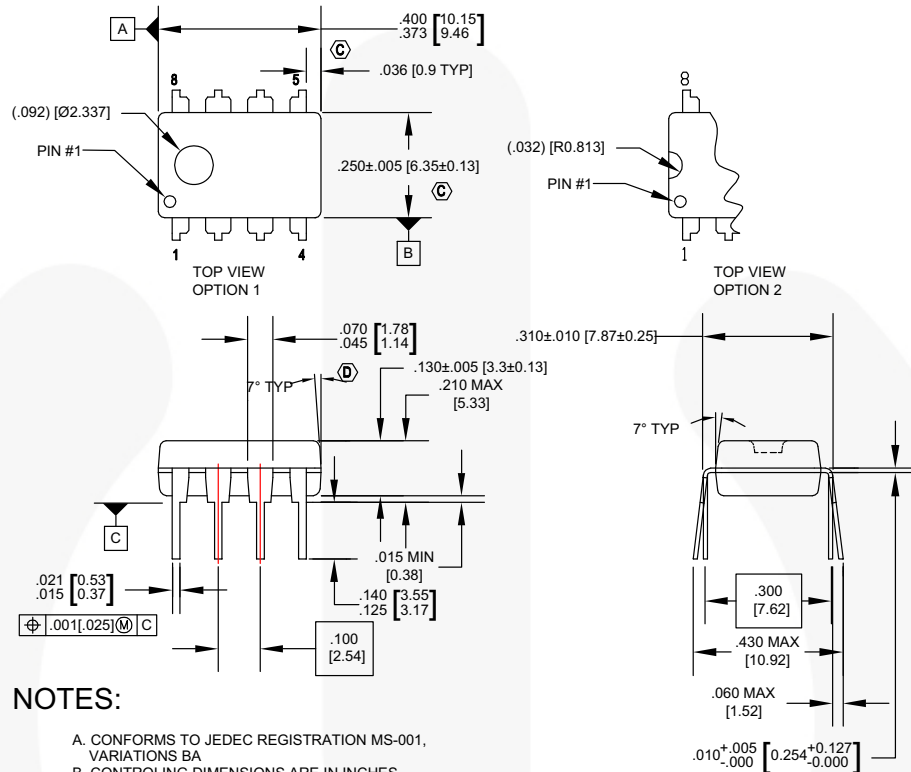
$$S = I/C \quad (17)$$

In other words, the gradient of the linear ramp function appearing across the capacitor can be obtained by using the constant current flowing through the capacitor.

If the constant current flow through the capacitor is 0.215 mA and the capacitance is 0.02 μF, the gradient of the ramp function at both ends of the capacitor is S = 0.215 m / 0.022 μ = 9.77 V/ms.

Physical Dimensions

8-DIP



N08EREVG

Figure 16. 8-Lead, DIP, JEDEC MS-001, 300" WIDE

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Physical Dimensions (continued)

8-SOIC

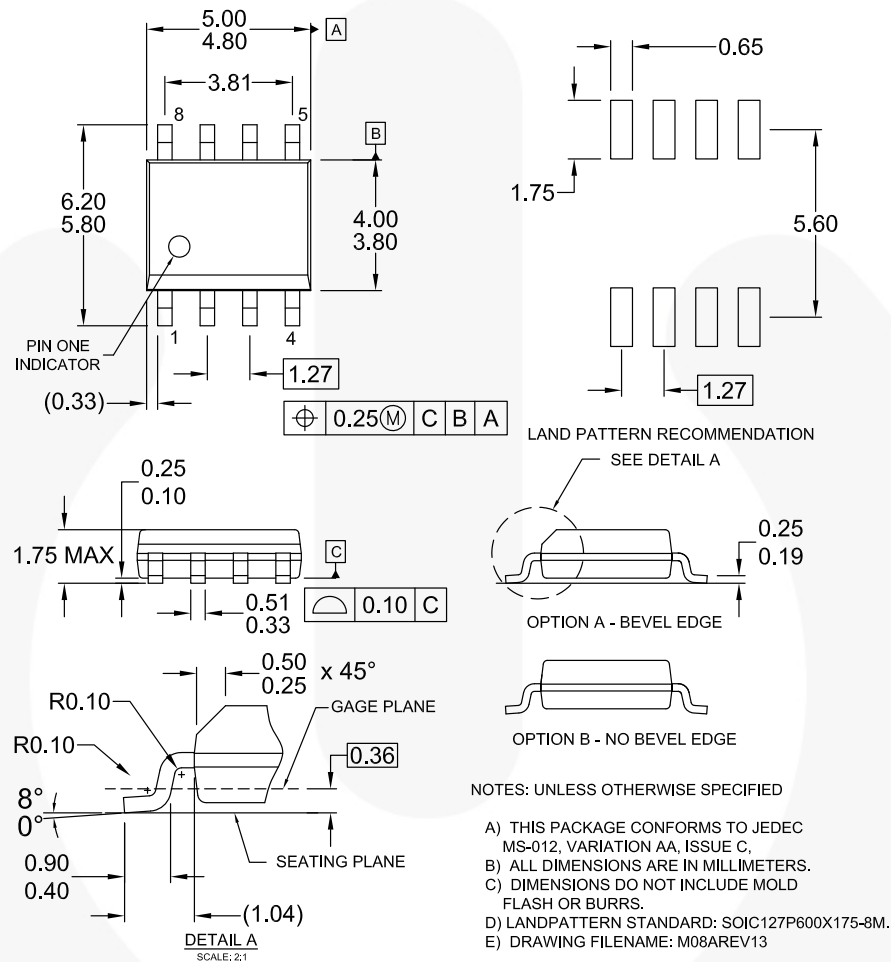


Figure 17. 8-Lead, SOIC, JEDEC MS-012, 150" NARROW BODY

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