

Chapter 6

Creating a Printed Circuit Board Schematic

In this chapter, we will learn the following to World Class standards:

- **Studying the Electrical Design**
- **Selecting the Integrated Circuit to Flash the LEDs**
- **Selecting the Integrated Circuit for Timing**
- **Selecting the Light Emitting Diodes (LEDs)**
- **Selecting a Small Power Switch**
- **Selecting the RJ-45 Connector**
- **Drawing the Printed Circuit Board Schematic**

Studying the Electrical Design

As in every project a mechanical or electrical designer starts, they need to have a complete understanding of what needs to be accomplished. In this chapter, that means we want to be able to create a printed circuit board that can test a standard computer network patch cable. Now, although most designers have assignments given to them and they have never before completed a similar task, so begins the path to discovery. For the majority of designers in the world, although they have drawn floor plans, created part details and purchased components from catalogs, they have not designed a printed circuit board. We will tell any designer that like most disciplinary tasks, there is a process, the electrical and mechanical parts are very much smaller and once we construct our first design; we will want to continue learning about printed circuit boards.



Figure 6.1 – Network Cable

The first item on our list to invention is to examine a network cable. In the computer network industry there are multiple ways of connecting a computer to a network such a company's Local Area Network (LAN) or our computer to a high-speed modem at a residential setting to connect to the Internet. A popular method is to use a wireless network card in our computer and to connect through radio waves to a wireless router. Another method is to connect to the corporate server through a fiber optic cable. The design we will work on in this chapter is where there is a network card in the computer and we use a Category 5e or 6 patch cable to connect to a switch. A category 5e cable supports 100 Megabits per second (Mbps) communication speed and the Category 6 cable is for 1000 Mbps or one Gigabit per second. Both cables use the same wiring scheme and therefore we can utilize our cable testing circuit board for both types of cable assemblies.

A network patch cable (also known as a straight through cable) meets the Electronic Industry Standard TIA/EIA 568-B wiring standard. The cable assembly is comprised of two RJ-45 cable connectors and a cable that is a minimum of 1 meter long and does not exceed 100 meters in length. If we have a straight run that exceeds the 100 meter (328 feet) distance, we can use a network switch in the middle and add another patch cable to make the balance of the distance.

Network Patch Cable Bill of Material		
Item No.	Description	Qty
1	RJ-45 connector	2
2	Category 5e cable	10 ft.

The RJ45 connector has small spikes that spear through the wire's insulation to create an electrical path when we crimp the connector to the end of the cable. The Category 5e and 6 cable has eight 26 AWG conductors, where each pair is twisted, so there are four twisted pairs. We can purchase the cable without shielding for applications that do not involve Electromagnetic Interference (EMI) or we can use the cable with shielding for environments where we anticipate EMI problems.

In order to make a network patch cable, we need tools to do the work. This includes a wire cutter, cable strippers, RJ- 45 cable crimpers, a pair of scissors.

Category 5e or 6 cable typically comes in 1000 foot boxes. When we receive the box of cable, we want to inspect the cable for damage that may have occurred during shipping. Another concern technicians have is that the individual conductor insulation is not properly color coded which means we will have a difficult time determining the order of the wires when aligning them before crimping.

Before cutting the cable, we should have done a site inspection to determine the length that we require. We need to add another 10% to 50% to the cable length, so we can move computers or other network devices around in the room without having to make another cable. Extra cable can be coiled and tied up with a plastic cable ties, so we do not have a trip hazard in the office. Now that we have determined the cable length, use the wire cutter to slice the cable.

The next step is to employ a wire stripper to remove approximately 2 inches of the exterior insulation surrounding the four twisted pairs of wires. Now we would like to separate all four pairs of wires into a star pattern with the white orange - orange pair in the north, the white blue - blue pair in the east, the white brown - brown pair in the south and the white green - green pair in the west.

At this moment, we need to untwist each pair and straighten the individual conductors between our thumb and index finger.

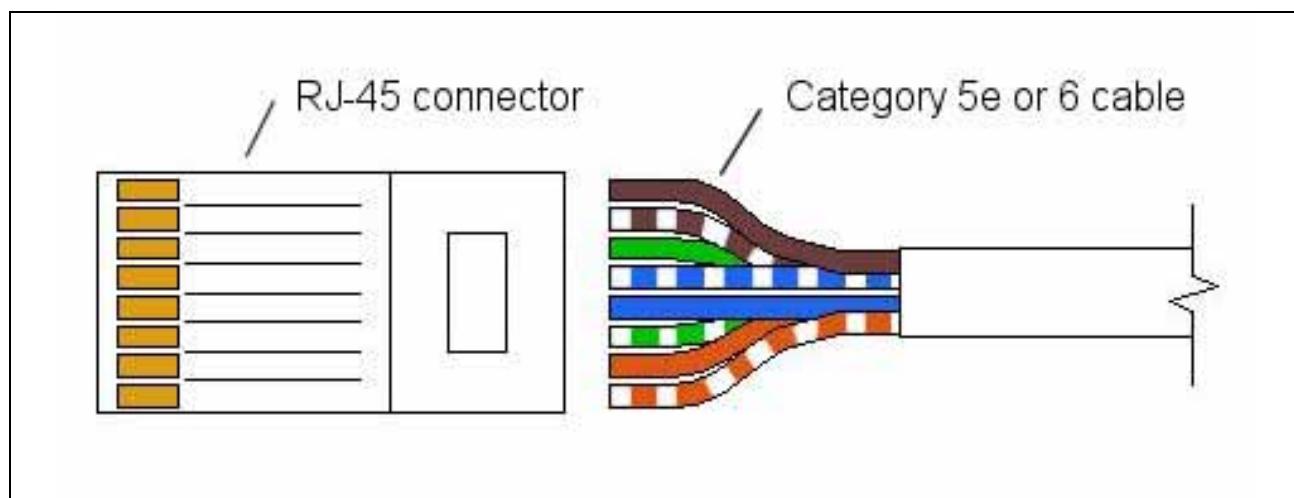


Figure 6.2 – 568-B Wiring

Align the wires from left to right as shown in figure 6.2. The 2 inch long wires will appear as a flat ribbon. Use a sharp wire cutter on the RJ-45 wire crimper to cut the ribbon down to just over a

half an inch from the end of the outer insulation. With the tab on the RJ-45 facing away, insert the flat ribbon into the connector as shown in figure 6.2. We can see the copper wire when looking into the clear end of the connector and by checking each side. A crooked cut of the ribbon will cause the wire to be engaged on one side of the connector and not on the opposite side. Also, the exterior cable insulation will be under the stress relief bar on the connector. Cutting the ribbon too long and there will not be a stress relief in the cable assembly and the constant wiggling during the cable's lifetime will cause an early failure. Insert the RJ-45 connector and cable into the crimping head and squeeze tightly. Some cable crimpers have a ratchet mechanism that will not release the connector until the prescribed squeeze has been achieved.

Repeat the process on the other side of the cable and our assembly is complete. Now, we need to test the cable with a RJ-45 cable tester, which is our project in this chapter.

The cable tester should have an indicator showing that the conductors are in the correct position. We can accomplish this act by using Light Emitting Diodes (LEDs) that do not require much power, that will not burn out for the life of the product and can easily run on battery power. To control the LEDs, we want an Integrated Circuit (IC) that is designed as a flash sequencer, so the battery only lights one LED at a time. When we look at our assembly, the cable tester will flash eight lights in a row showing that the cable is assembled properly. The advantage of having eight lamps versus four is that we can use the same tester for different communication cable types such as crossover cables. Our tester needs an on – off switch and can have another LED showing the switch is in the on position. On the outside of the case that holds the printed circuit board, we will want artwork showing the name of the product and diagrams showing the correct test pattern for patch and crossover cables.

Selecting the Integrated Circuit to Flash the LEDs

The main component on the printed circuit board will be the CD4017B integrated circuit that is manufactured by companies such as National Semiconductor and Texas Instrument. The ten outputs are turned on, one at a time in response to a clock timer such as the 555 timer. Figures 6.3, the logic diagram, Figure 6.4, the connection diagram and figure 6.5 the physical dimensions are from the National Semiconductor CD4017B datasheet.¹

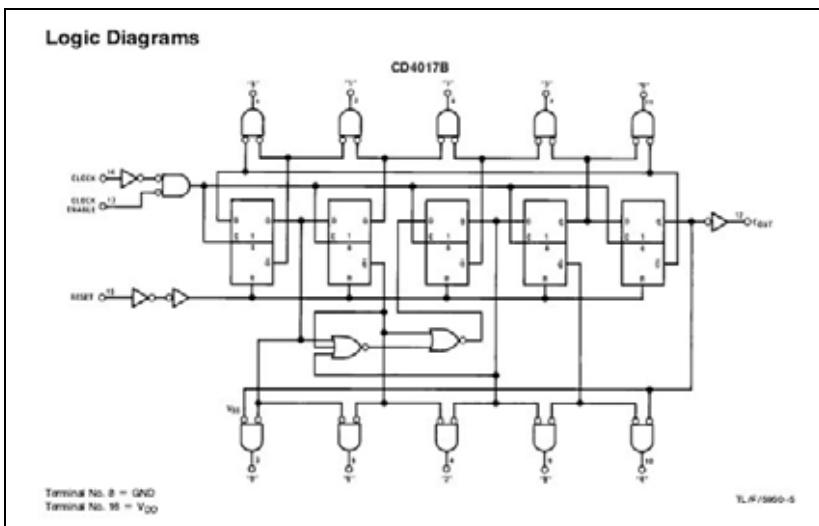


Figure 6.3 – National Semiconductor CD4017 Diagram

¹ CD4017BM/CD4017BC Decade Counter/Divider with Ten Decoded Outputs, 1995, National Semiconductor Corporation, April 30, 2009, <<http://www.national.com/ds/CD/CD4017BC.pdf#page=1>>

The CD4017B package has 16 connections which ten are outputs for devices like LEDs, one is for the clock enable, the clock input, the V_{DD} (positive supply voltage), the V_{SS} (negative supply voltage or ground), and the reset which will start the cycle again at output “0”. An LED can reside also on the carry out signal if we desire. For the sequence flasher to operate, the reset input needs to be low, the clock input needs to be high and the clock enable needs to be low. So when we design our circuit, we need to have these electrical settings in these positions for the LEDs to flash in order. Notice we choose an IC with a pin through package for our project. If we proceed to production, we will change to an above board IC package.

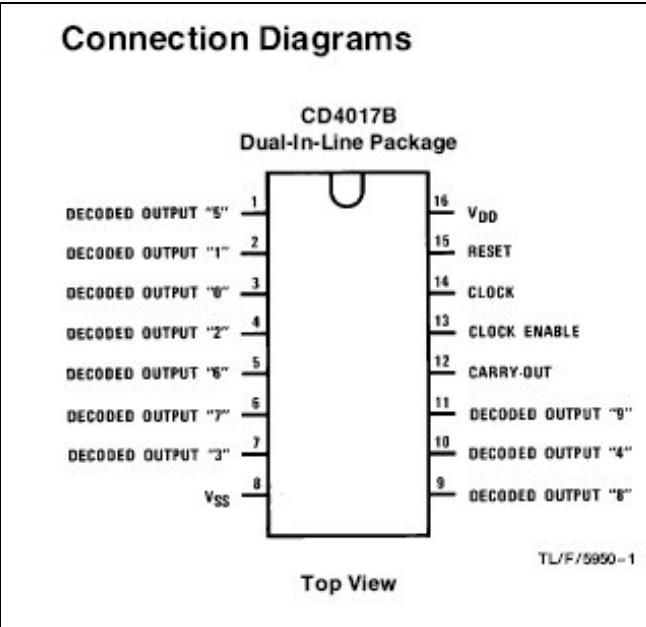


Figure 6.4 – CD4017B Connection Diagram

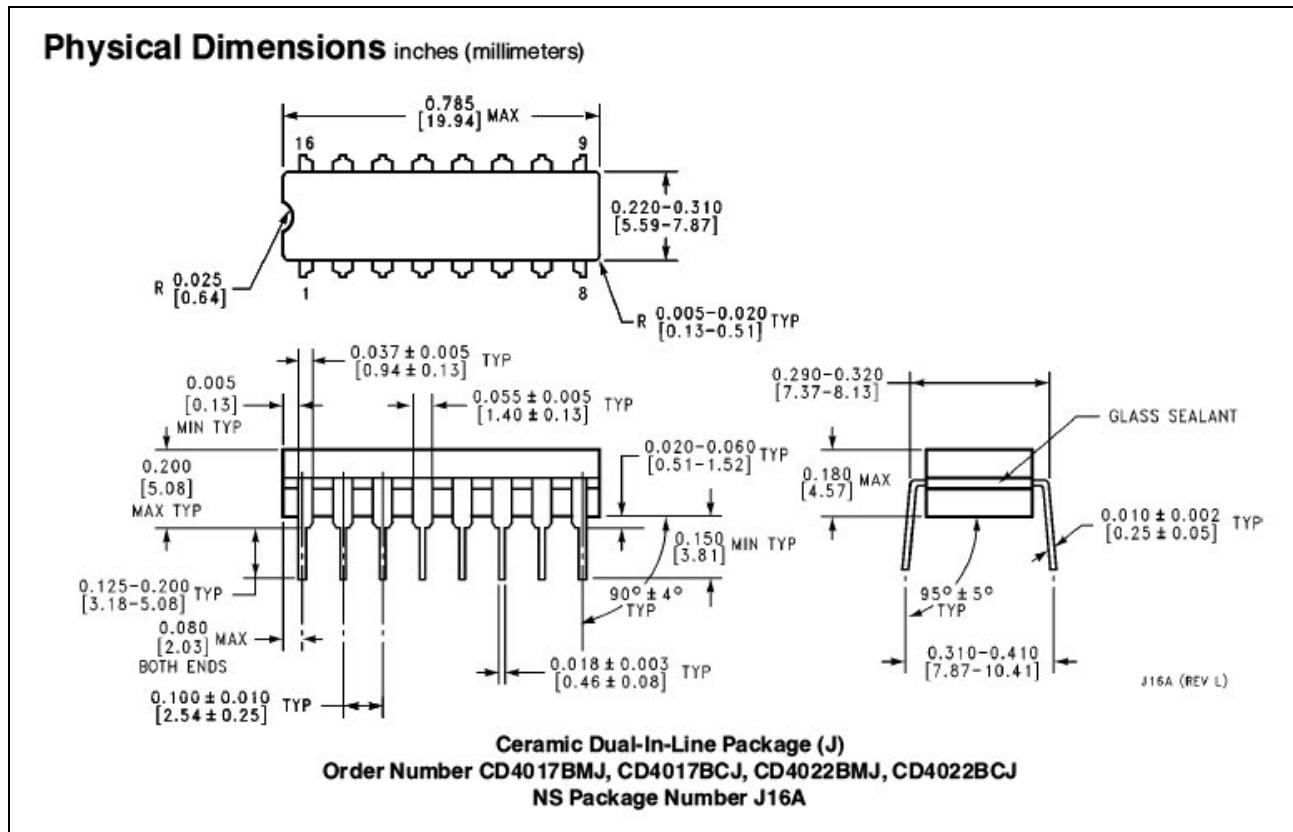


Figure 6.5 – National Semiconductor’s CD4017B Physical Dimensions

Selecting the Integrated Circuit for Timing

We can use an oscillating circuit to control the flash rate of the CD4017 integrated circuit or we can add the National Semiconductor LM555 timer chip. The 555 timer was introduced in 1972 and billions of these integrated circuits are used annually. The images in figure 6.6, schematic diagram, figure 6.7, connection diagram, figure 6.8, astable diagram (modified), figure 6.9, timing formulas and figure 6.10, physical dimensions are from the National Semiconductor LM555 datasheet.²

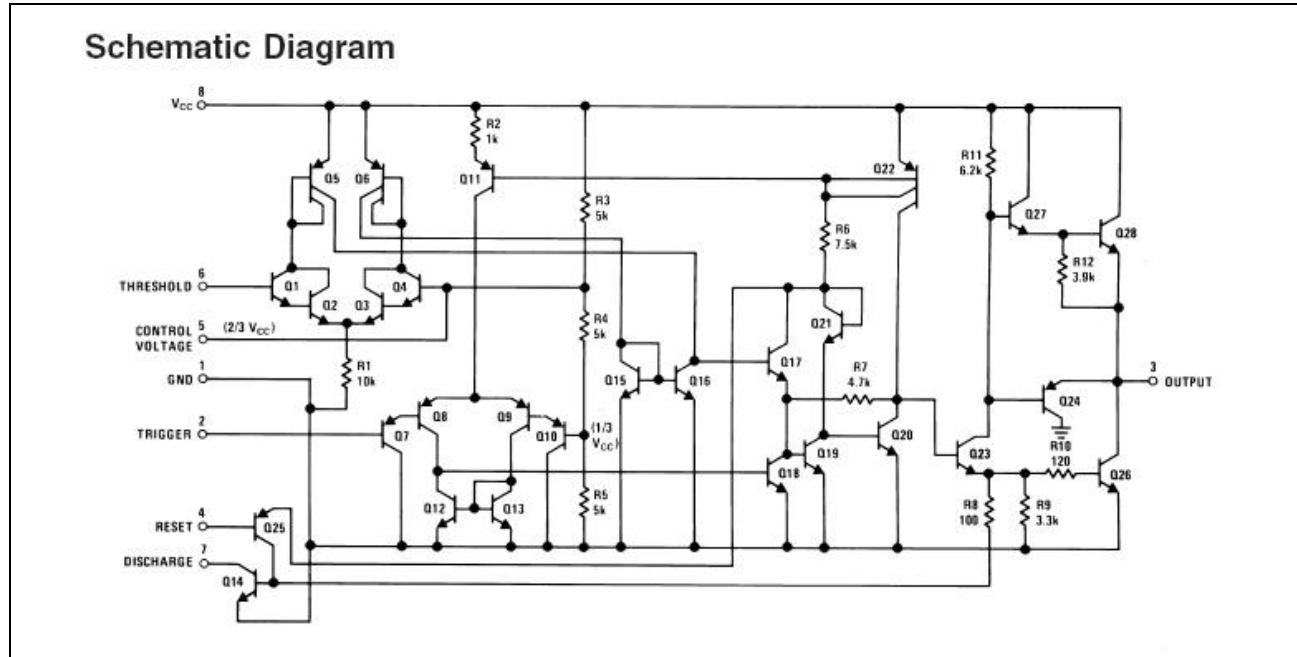


Figure 6.6 – National Semiconductor’s LM555 Schematic Diagram

We will connect the Vcc pin 8 to the positive side of the 9-volt battery and connect the GND pin 1 to the negative post. The output pin 3 goes directly to the clock pin on the CD4017 integrated circuit. The trigger, discharge, threshold and reset pins will be set up in astable mode, which means the pulse rate will beat regularly. The astable mode is shown in the National Semiconductor’s datasheet and in figure 6.8.

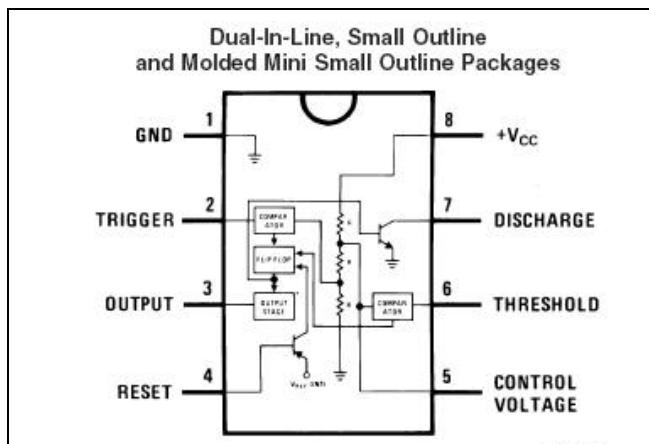


Figure 6.7 –LM555 Connection Diagram

² LM555 Timer, July 2006, National Semiconductor Corporation, April 30, 2009,
<http://www.national.com/ds/LM/LM555.pdf>

We need to compute the size of the resistor A and B shown in figure 6.8 and the magnitude of the capacitor. The formula for capacitor charge time is:

$$t_1 = 0.693 (R_A + R_B) C$$

And the formula for capacitor discharge time is:

$$t_2 = 0.693 (R_B) C$$

So the total period is:

$$T = t_1 + t_2 = 0.693 (R_A + 2R_B) C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B) C}$$

ASTABLE OPERATION

If the circuit is connected as shown in *Figure 4* (pins 2 and 6 connected) it will trigger itself and free run as a multivibrator. The external capacitor charges through $R_A + R_B$ and discharges through R_B . Thus the duty cycle may be precisely set by the ratio of these two resistors.

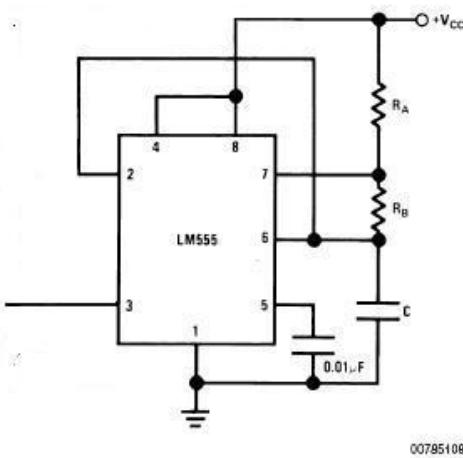


FIGURE 4. Astable

In this mode of operation, the capacitor charges and discharges between $1/3 V_{cc}$ and $2/3 V_{cc}$. As in the triggered mode, the charge and discharge times, and therefore the frequency are independent of the supply voltage.

FIGURE 5. Astable Waveforms

The charge time (output high) is given by:

$$t_1 = 0.693 (R_A + R_B) C$$

And the discharge time (output low) by:

$$t_2 = 0.693 (R_B) C$$

Thus the total period is:

$$T = t_1 + t_2 = 0.693 (R_A + 2R_B) C$$

The frequency of oscillation is:

$$f = \frac{1}{T} = \frac{1.44}{(R_A + 2R_B) C}$$

Figure 6 may be used for quick determination of these RC values.

The duty cycle is:

$$D = \frac{R_B}{R_A + 2R_B}$$

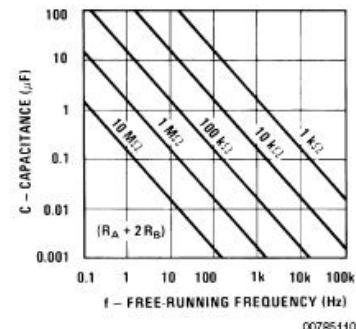


Figure 6.8 – Wired for Astable Operation

We are going to estimate the time for each LED to light at $1/3$ second, so $f = 3$ oscillations per second. If the capacitor is 1.0 microfarad or (0.000001 farads), the total resistance is 480952 ohms as shown in the computation.

Figure 6.9 – Formula for Timing

$$R = \frac{T}{0.693 C} = \frac{0.3333}{0.693(0.000001)} = 480952 \text{ ohms}$$

Therefore, we will select resistor R_B to be 240k ohms and R_A to be 1k ohms.

The last piece of information we extracted from the National Semiconductor datasheet shows the physical dimensions of the chip. Again, if we proceed to production with our design, we will change to an above board IC package.

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

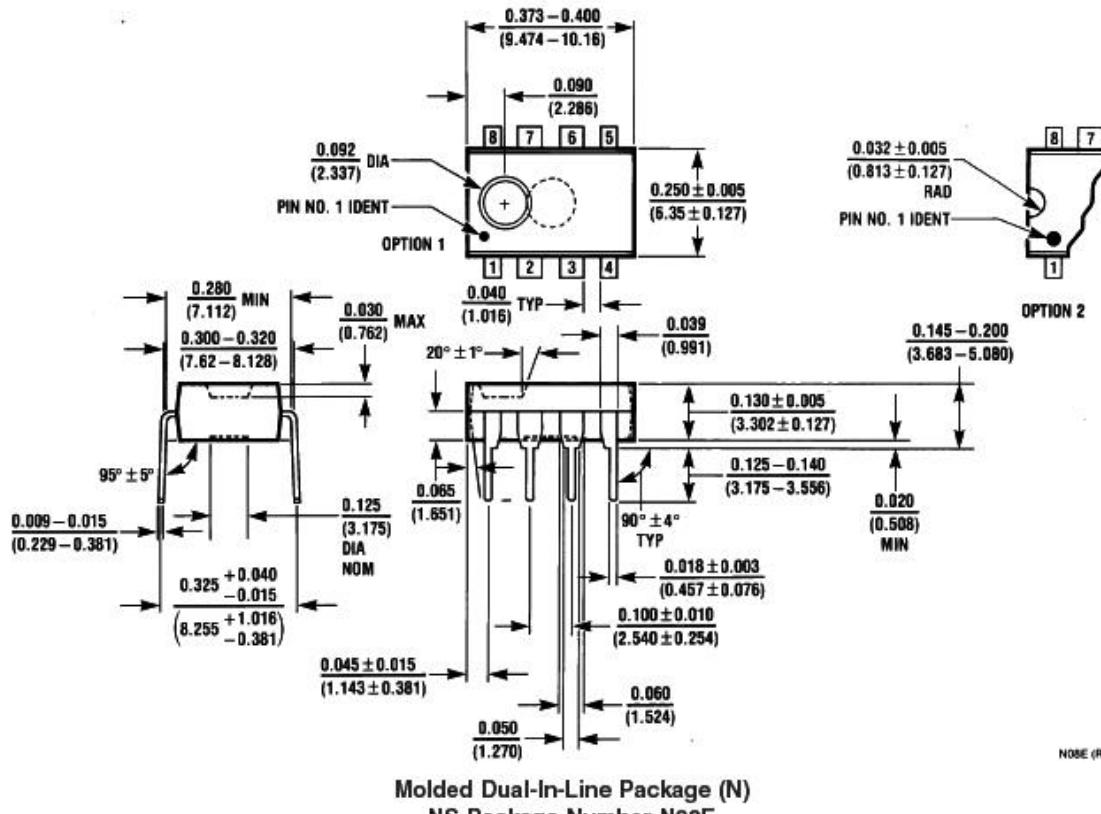


Figure 6.10 – National Semiconductor’s LM555 Physical Dimensions

Selecting the Light Emitting Diodes (LEDs)

Light Emitting Diodes (LEDs) are more versatile than the previously utilized incandescent lamps, which we had to replace frequently and the LEDs work well in direct current circuits such as the one we are describing. Where incandescent lamps can have 2,000 to 10,000 hours of life, the green LED we select can run up to 75,000 hours.

A LED must be placed on the printed circuit board in the correct orientation. The longer lead is the anode or positive side and thus the shorter lead is the cathode for the negative return. Another common feature that we see in LED applications is placing a resistor in front of the anode to protect the Led from an over current failure. We can examine the electrical characteristics from the LED manufacturer, Lumex by viewing the information from their datasheet shown in figures 6.11 and 6.12.³

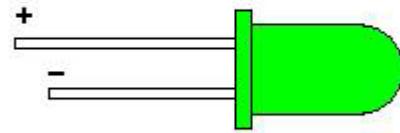


Figure 6.10 – Standard LED

ELECTRO-OPTICAL CHARACTERISTICS $T_A=25^\circ\text{C}$					$I_f=20\text{mA}$
PARAMETER	MIN	TYP	MAX	UNITS	TEST COND
PEAK WAVELENGTH		565		nm	
FORWARD VOLTAGE		2.2	2.6	V _f	
REVERSE VOLTAGE	5.0			V _r	$I_r=100\mu\text{A}$
AXIAL INTENSITY		50		med	$I_f=20\text{mA}$
VIEWING ANGLE		30		2x theta	
EMITTED COLOR:	GREEN				
EPOXY LENS FINISH:	GREEN TRANSPARENT				

LIMITS OF SAFE OPERATION AT 25°C

PARAMETER	MAX	UNITS
PEAK FORWARD CURRENT*	150	mA
STEADY CURRENT	25	mA
POWER DISSIPATION	105	mW
DERATE FROM 25°C	-1.2	mW/ $^\circ\text{C}$
OPERATING, STORAGE TEMP.	-40 TO +85	$^\circ\text{C}$
SOLDERING TEMP.	+260	$^\circ\text{C}$
2.0mm FROM BODY		3 SEC. MAX

* $t < 10\mu\text{s}$

Figure 6.11 – Standard Green LED from Lumex

We will compute the resistor size using the formula, $R = (V_s - V_L) / I$, where V_s is the supply

³ T-5mm 565nm Green LED Datasheet SSL-LX5093GT-11, October 19, 2006, Lumex Inc., May 3, 2009,
<http://www.lumex.com/pdf/SSL-LX5093GT-11.pdf>

voltage and V_L is the LED voltage. The supply voltage is 9V and the LED voltage is 2.2 V. The current of the LED is 25 millamps (mA). Now, we can calculate the resistance and get an answer of 272 ohms as shown in the computation.

$$R = (9V - 2.2V) / 0.025A = 272 \text{ ohms}$$

Many circuit boards use a 1000 (1k) ohm resistor in front of LEDs when the supply voltage is 12V_{DC} or less. We will use resistors with a value of 300 ohms.

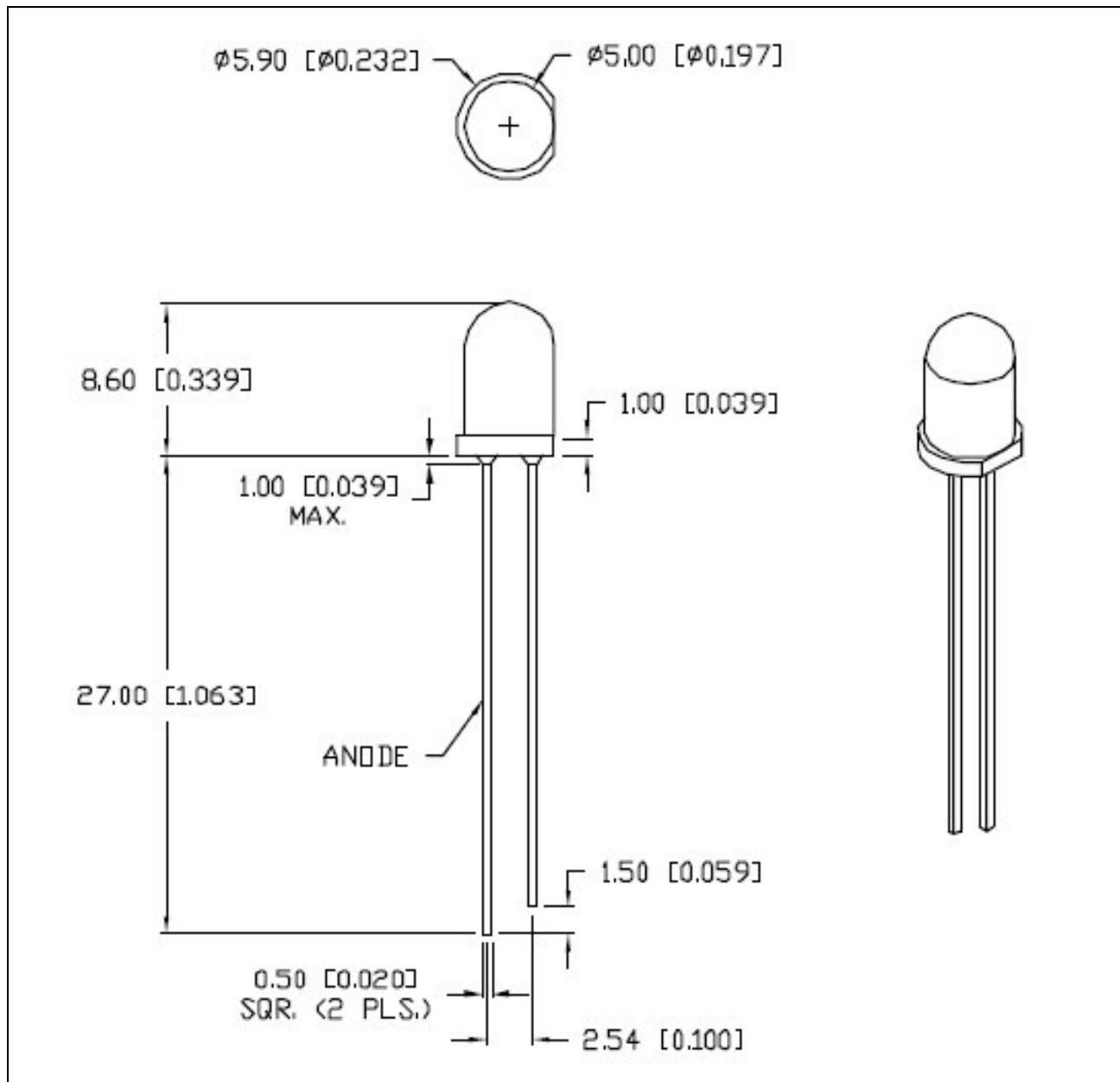


Figure 6.12 – Standard Green LED Physical Properties

The next component we will select is the power switch to turn the cable tester on or off.

Selecting a Small Power Switch

One of the last components we will select in the design of the cable tester is the on – off switch. We will select the C and K components 1101-M1-S3-Z3-QE Miniature Slide Switch. The C and K components datasheets are shown in figure 6.13, the electrical characteristics, figure 6.14, the slide switch function, figure 6.15, the panel-mount physical dimensions, figure 6.16, the slide switch actuator, figure 6.17, the slides switch contact material.⁴

Our switch is to be panel mounted on the exterior of the cable tester enclosure. The switch is a basic on- off type with maintain action. The switch's silver contacts are rated to handle 6 amps at 28 V_{DC}.

The electrical life of the switch is 40,000 make and break cycles with the silver electrical contacts. The operating temperature of the switch is from -30°C to 65°C, which is in the range of the temperatures that a technician would use the cable tester. The switch housing is not waterproof, but our design does not require this functionality.

1000 Series Miniature Slide Switches

<p>Features/Benefits</p> <ul style="list-style-type: none">• Variety of actuators and terminations• Panel mount tabs available• Epoxy terminal seal—compatible with bottom-wash cleaning• RoHS compliant <p> Models Available</p>	<p>Typical Applications</p> <ul style="list-style-type: none">• Test & measurement equipment• Telecommunications• Computer & peripherals 
<hr/> <p>Specifications</p> <p>CONTACT RATING: B contact material: 0.4 VA max. @ 20 V AC or DC max. Q contact material: 6 AMPS @ 120 V AC or 28 V DC, 3 AMPS @ 250 V AC. See page J-15 for additional ratings.</p> <p>ELECTRICAL LIFE: 100,000 make-and-break cycles at full load on models with B, K or P contact material; 40,000 cycles on models with G, Q, L, M, S or R contact material.</p> <p>CONTACT RESISTANCE: Below 10 m Ω typ. initial @ 2-4 V DC, 100 mA, for both silver and gold plated contacts.</p> <p>INSULATION RESISTANCE: 10⁹ Ω min.</p> <p>DIELECTRIC STRENGTH: 1,000 Vrms min. @ sea level.</p> <p>OPERATING TEMPERATURE: -30°C to 65°C</p> <p>SOLDERABILITY: Per MIL-STD-202F method 208D, or EIA RS-186E method 9 (1 hour steam aging).</p> <p>Materials</p> <p>CASE: dialyl phthalate (DAP), (UL 94V-0).</p> <p>ACTUATOR: Nylon, black, standard.</p> <p>HOUSING: Stainless steel.</p> <p>SWITCH SUPPORT: Brass or steel, matte-tin plated.</p> <p>END CONTACTS: B contact material: Copper alloy, with gold plate over nickel plate. Q contact material: Coin silver, silver plated. See page I-16 for additional contact materials.</p> <p>CENTER CONTACT & ALL TERMINALS: B contact material: Copper alloy, with gold plate over nickel plate. Q contact material: Copper alloy, silver plated. See page J-16 for additional contact materials.</p> <p>TERMINAL SEAL: Epoxy. Refer to Soldering and Cleaning in Technical Data chapter</p> <p><small>NOTE: Any models supplied with Q, B, G, P, S or R contact material are RoHS compliant.</small></p> <p><small>NOTE: Specifications and materials listed above are for switches with standard options.</small></p> <p><small>For information on specific and custom switches, consult Customer Service Center.</small></p>	

Figure 6.13 – C and K Components 1000 Series Miniature Slide Switches

⁴ CK components 1000 Series Miniature Slide Switches, 2009, CoActive Technologies., May 4, 2009, <http://www.ck-components.com/14394/1000_4feb.pdf>

The 1101 switch function gives us an on-none-on functionality. We will wire the 9 volt supply to the number 2 contact and the output to the number three contact. By not wiring the number one contact, this switch is essentially an on-off switch.

1000 Series Miniature Slide Switches

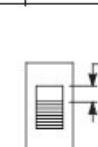
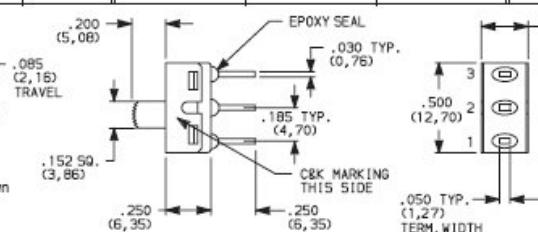
SWITCH FUNCTION												
NO. POLES	MODEL NO.	SWITCH FUNCTION			CONNECTED TERMINALS			SCHEMATIC				
		POS. 1	POS. 2	POS. 3	POS. 1	POS. 2	POS. 3					
SP	1101	ON	NONE	ON	1-2	N/A	2-3	SPDT				
	1103	ON	OFF	ON		OPEN						
	1108	MOM.	NONE	ON		N/A						
SPDT												
 <p>Actuator shown in position 1</p>  <p>EPOXY SEAL .030 TYP. (.076) CBK MARKING THIS SIDE .050 TYP. (.127) TERM. WIDTH Terminal Nos. For Reference Only</p>												
Part number shown: 1101M2S3CQE2												

Figure 6.14 – C and K Components 1000 Series Miniature Slide Switch Function

Figure 6.15 shows the panel mounting plate with tabs. We will use two 4-40 screws to hold the switch in position on the exterior case.

In figure 6.16, we will choose the S3 (0.2 inch high) actuator, which will make the assembly easy to turn on. Any higher switch actuator is not necessary.

And as we previously stated, we will use the silver contacts (Q rating).

As we see in this switch, building a purchase part number can be a rather lengthily process. Most switch catalogs require several steps in identifying the exact switch we desire.

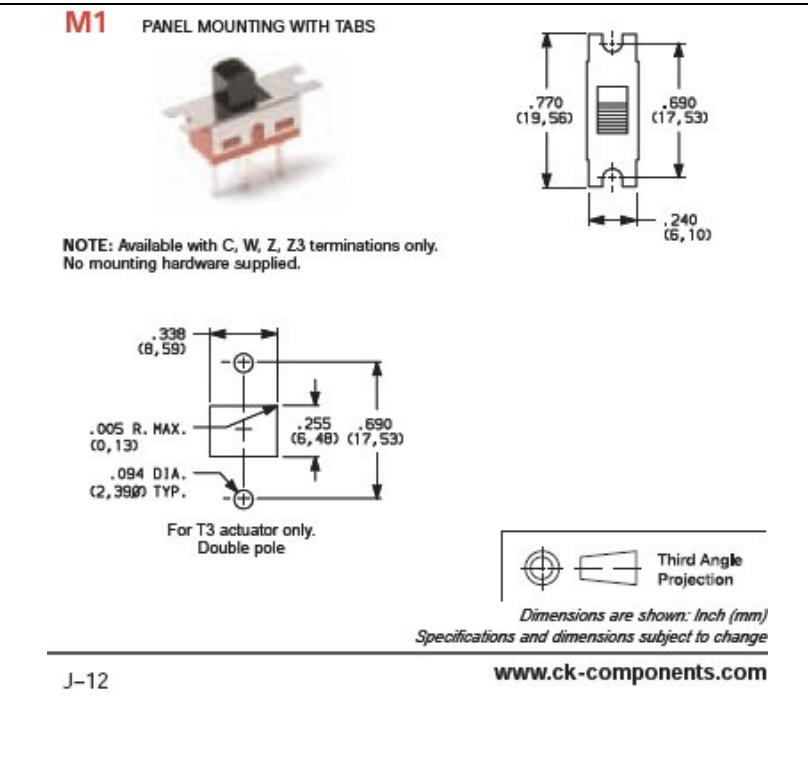


Figure 6.15 – C and K Components Panel Mounting

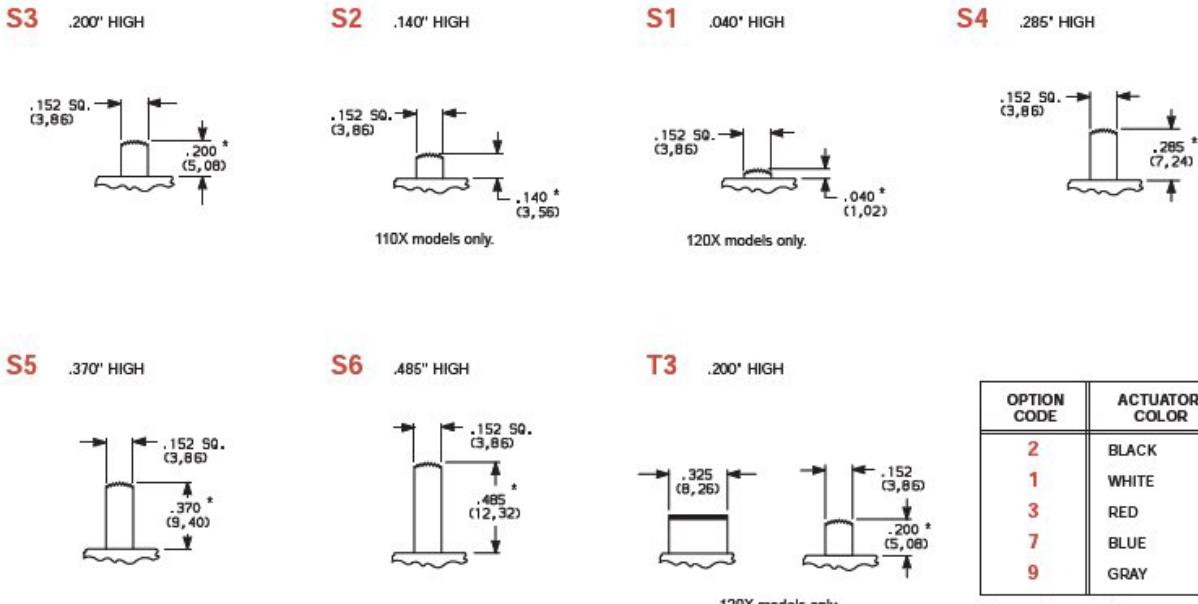


Figure 6.16 – C and K Components 1000 Series Miniature Slide Switch Actuator

1000 Series Miniature Slide Switches

CONTACT MATERIAL

OPTION CODE	CONTACT MATERIAL	TERMINAL PLATING	RATINGS	
B	GOLD ¹	GOLD ³	LOW LEVEL/DRY CIRCUIT	0.4 VA MAX. @ 20 V AC OR DC MAX.
P		MATTE-TIN ⁶		
Q	SILVER ^{4,5}	GOLD ³	POWER	6 AMPS @ 120 V AC OR 28 V DC; 3 AMPS @ 250 V AC.
S		MATTE-TIN ⁶		
G	GOLD OVER SILVER ^{2,3}	GOLD ³	LOW LEVEL/DRY CIRCUIT OR POWER	0.4 VA MAX @ 20 V AC OR DC MAX OR 6 AMPS @ 120 V AC OR 0.4 MAX. 28 V DC; 3 AMPS @ 250 V AC.
R		MATTE-TIN ⁶		

Figure 6.17 – C and K Components 1000 Series Miniature Slide Switch Contact Material

Selecting the contact material can affect the price of the switch. Some plating materials such as gold or silver will increase the overall cost of the electrical component.

Selecting the RJ-45 Receptacle

We need to decide whether the RJ-45 connector on the printed circuit board will exit perpendicular to the board or will be mounted with the opening for the jack straight up. We will select a connector with the solder pins 90° to the PCB as shown in figure 6.18.

The RJ-45 connector we will utilize is the Stewart Connector number SS-7188-NF. An image of the datasheet is shown in figure 6.18.⁵

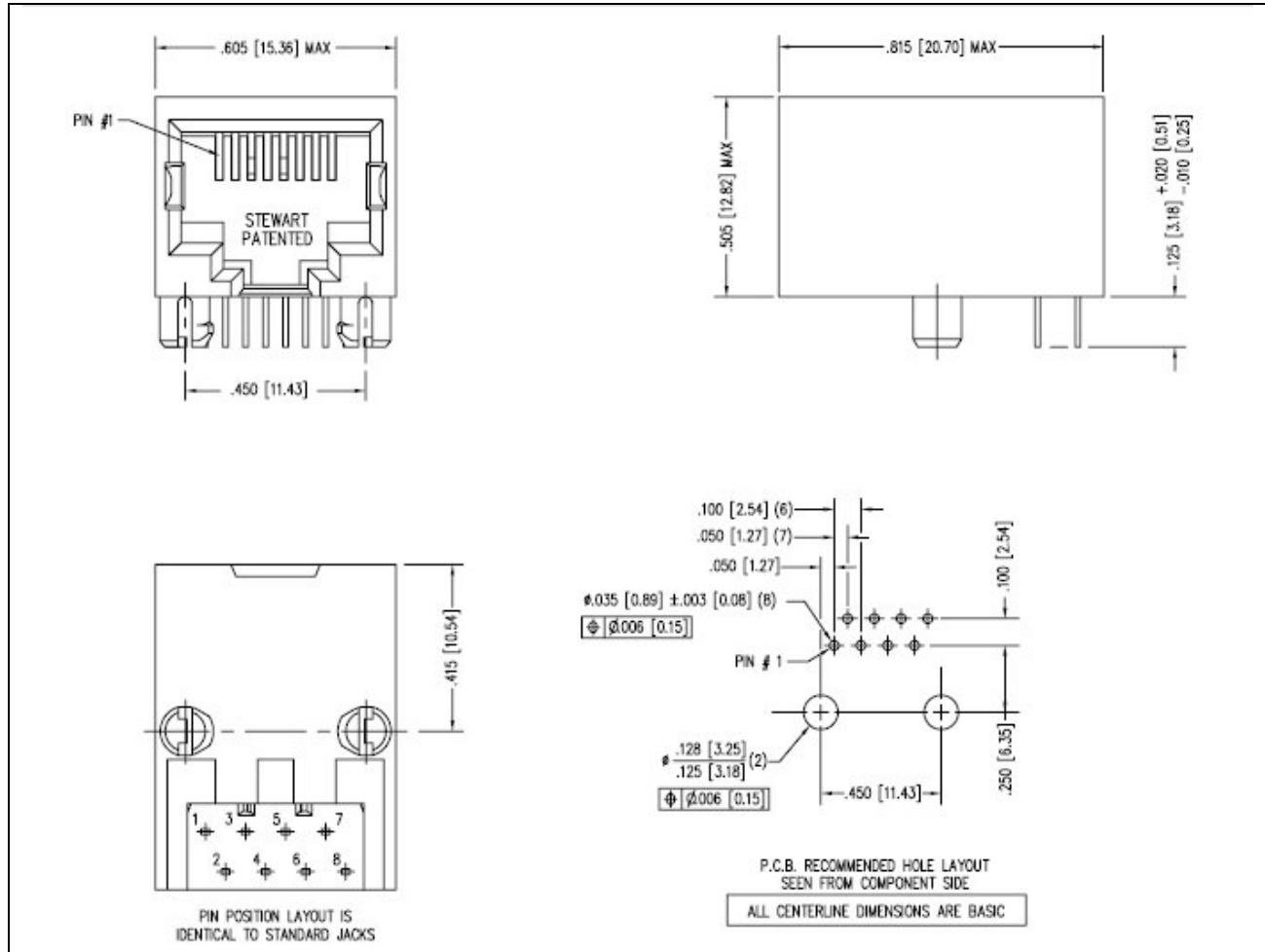


Figure 6.18 – The RJ-45 Jack from Stewart Connector

Besides the 8 pins going into the printed circuit board, there are two posts to provide stress relief to the assembly from the constant plugging and unplugging by technicians testing cables.

Drawing the Printed Circuit Board Schematic

Use the drawing blocks in the Electrical Symbols Library on the worldclasscad.com website to draw the Cable Tester Transmitter Printed Circuit Board (PCB) as shown in figure 6.19 and the Cable Tester Receiver PCB as shown in figure 6.21. We will draw the schematic using a grid set at 0.25 and the snap set at 0.0.3125, so that the electronic symbols in the library will connect

⁵ Stewart Connector SS-7188-NF, July 9, 2007, Bel Fuse., May 5, 2009,
<http://www.belfuse.com/Data/Datasheets/CT710006.pdf>

easily with the lines representing tracks on the printed circuit board.

The hidden linetype represents the boundary of the printed circuit board with the power on off switch shown connected to the printed circuit board through terminals E1 and E2 and the Power LED connected to the PCB through terminals E3 and E4. Some manufacturers just have holes in the printed circuit board at positions E1 through E4, and wires are soldered there to connect to exterior components.

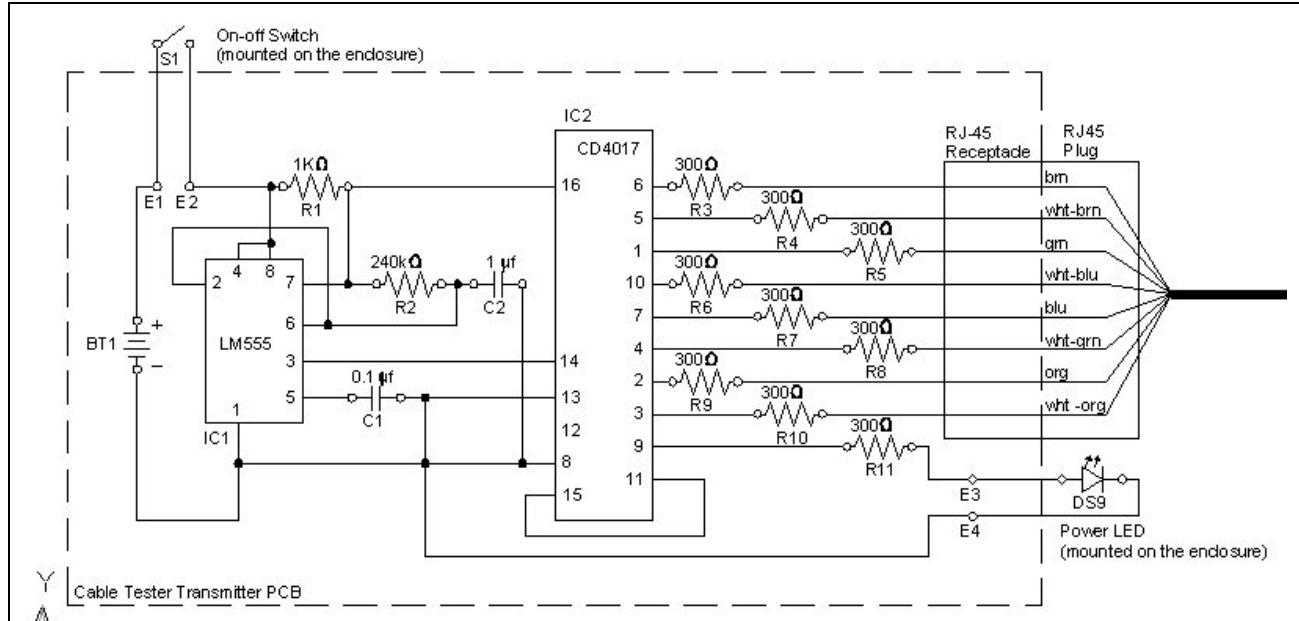


Figure 6.19 – Transmitter Printed Circuit Board

We create the material list early in the project, so we can purchase the parts for our prototype board. When we are building the Bill of Material for a printed circuit board, we do not use the item numbering techniques previously used in mechanical assemblies that progress from item 1 and move numerically upward. We use the same identifiers as we see on any board, such as C1 for the $0.1\mu F$ capacitor and R1 for the $1k\Omega$ resistor. The letter matches the industry's standard identifier for each electrical component and the number is the counter of the item on the board.

Cable Tester Transmitter PCB Bill of Material		
Item No.	Description	Qty
PCB1	Bare Board, Transmitter	1
BT1	Battery, 9Vdc	1
C1	Capacitor, $0.1\mu F$, 16 Vdc	1
C2	Capacitor, $1.0\mu F$, 16 Vdc	1
DS9	LED, Green, 5mm	1
E1-4	Terminal	4
IC1	LM555 Clock Timer	1
IC2	CD4017 Counter / Divider	1
R1	Resistor, $1k\Omega$	1
R2	Resistor, $240k\Omega$	1
R3-R11	Resistor, 300Ω	9
RJ45-1	Jack, RJ-45	1
S1	Switch, On-Off, 28Vdc	1
W1	Wire, 24 AWG, white	12 in.

Figure 6.20 – Transmitter Assembly Bill of Material

We initially label the Bill of Material as we can see in figure 6.20, but we will most likely change the components item number when the printed circuit board is laid out. At that time, the electrical components are numbered from top left to right, so whatever resistor is in the far top left corner will be labeled R1 and we will proceed with the identifying all resistors from that point.

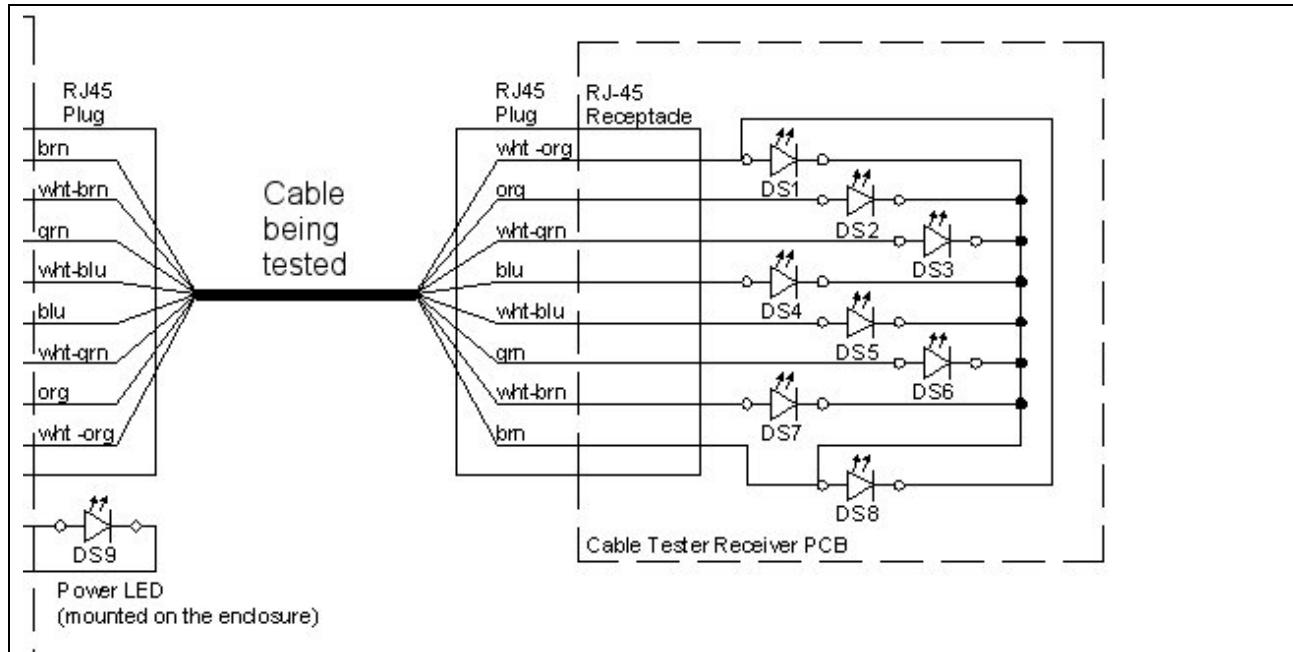


Figure 6.21 – Receiver Printed Circuit Board

We suggest that the quantities for electrical components, which we see in the three Bill of Materials in this chapter, should be tripled, so there are spare parts during the prototyping phase of the project.

Cable Tester Receiver PCB Bill of Material		
Item No.	Description	Qty
PCB2	Bare Board, Receiver	1
DS1-8	LED, Green, 5mm	8
RJ45-1	Jack, RJ-45	1

Figure 6.21 – Receiver Assembly Bill of Material

In the next chapter, we will create the printed circuits boards.

* World Class CAD Challenge 9-6 * - The project engineer wants to you to draw a printed circuit board schematic of the cable tester in your CAD program using the electrical symbols library on the worldclasscad.com website in the next 30 minutes. Place the electrical diagram in a border along with notes and completed title block.

Continue this drill four times using some other ideas, such as four flashing LEDs, each time completing the drawing under 30 minutes to maintain your World Class ranking.