A Cost-effective Lab Device for Studying Thyristors

by

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Abstract: The ubiquitous thyristor (e.g., SCR, triac) is used in a wide variety of applications to control AC power. It is one of several topics covered in our Consumer Power Electronics course, and is supported by a lab exercise. We have modified a previous design to create a low-cost device used for safely exploring thyristor operation in a lab setting.

This paper begins with background information on the (thyristor-related) educational goals for the course and its associated lab. Next, we describe how the project got started and how it became a student project. It turned out to be quite fortuitous that this particular student took over the project, because he proposed several very sensible safety and usability enhancements, which are explained and illustrated.

The lab device's technical description is provided in detail for the benefit of those who may want to use it in their labs. This includes a full circuit schematic, the enclosure layout, a complete parts list (with suppliers), and photographs. Finally, we discuss how the device is used in the lab to fulfill the associated learning objectives.

Keywords: Thyristors, educational technology, education, laboratories.

I. Introduction

Among the devices introduced in our Consumer Power Electronics course are thyristors, including diacs, SCRs (silicon controlled rectifiers), and triacs. Topics covered include the basic characteristics and operation of each device, snubbing circuits to prevent overvoltage and over-current conditions, triggering circuits, time-proportioned zero-crossing power control, and phase-angle-fired power control. These lecture topics are reinforced with a lab that investigates the performance of a triac using three types of control circuitry: simple on/off control, time-proportioned zero-crossing, and phase-angle firing. Since the triac is used to control 120-V_{rms} line voltage, a fixture is used to contain the circuitry for improved safety.

The main campus had a lab device they used to support the lab activity (see Figure 1), but we (at a satellite campus) did not. Our lab is essentially the same as the lab at the main campus, which was developed by J. Michael Jacob and is documented in his text [1] (used with permission). Our initial plan was to duplicate the fixture used at the main campus. The professor found an interested student and set up a directed project to find the parts, build a prototype, and construct several copies for use in the lab.

Figure 1: Main campus thyristor lab fixture

The student proposed several enhancements to improve the safety and usability of the fixture. These included changes to the case itself, the method for making electrical connections, and how main power was switched. After evaluating several different enclosures, we decided to use a standard plastic junction box available at many home improvement centers. This eliminated the sharp corners of the metal box, as well as the need for grounding it.

Electrical connections to the old fixture were made by attaching standard clip leads to wires that had the last ½" or so of insulation removed. The wires protruded through a rectangular hole in the top of the box, covered by a piece of Plexiglas to protect the user from inadvertently touching one of the bare wires. Although effective, making the connection was a bit tricky. The new design uses banana jacks attached to the lid of the box, as shown in Figure 2.

Figure 2: New thyristor fixture design, top-right view

The old fixture used a toggle switch soldered directly to the circuit board for switching power to the circuit. The handle for the switch barely protruded through the top of the box and, since it was also covered by the Plexiglas, had to be switched using a screwdriver, pencil, etc. (The Plexiglas cover was mounted less than ½" from the metal cover so that students could not fit their fingers under it and get shocked). For the updated fixture, a standard wall switch is used, connected to the circuit board with several inches of stranded 18-gauge wire (see Figure 3), and the lid was milled out to allow the switch handle to protrude through the case while the body of the switch remains inside.

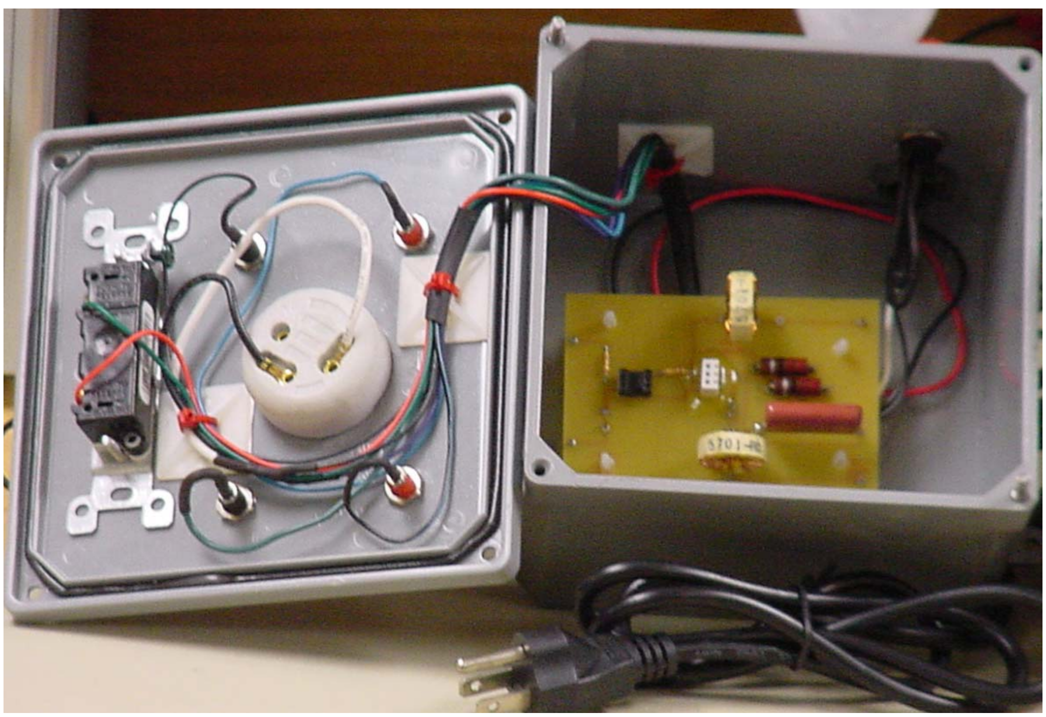

Figure 3: Inside of lab fixture

Finally, a fuse was added at the first junction from the power cord, to cut power in case of an over-current condition. Because of the different topology of the new fixture--having circuit components mounted to the removable cover--adhesive-backed wire ties were attached to the inside of the case and the underside of the cover. This prevents the circuit connections from being stressed when the lid is removed.

II. Electrical Description

There are four basic parts of the electronics: the power circuit, trigger circuit, snubbing circuitry, and user interface. A schematic of the entire circuit is shown in Figure 4. This section briefly discusses the electrical design parameters and the calculations to verify the circuit will operate within the limits of the thyristor and its optically-coupled trigger.

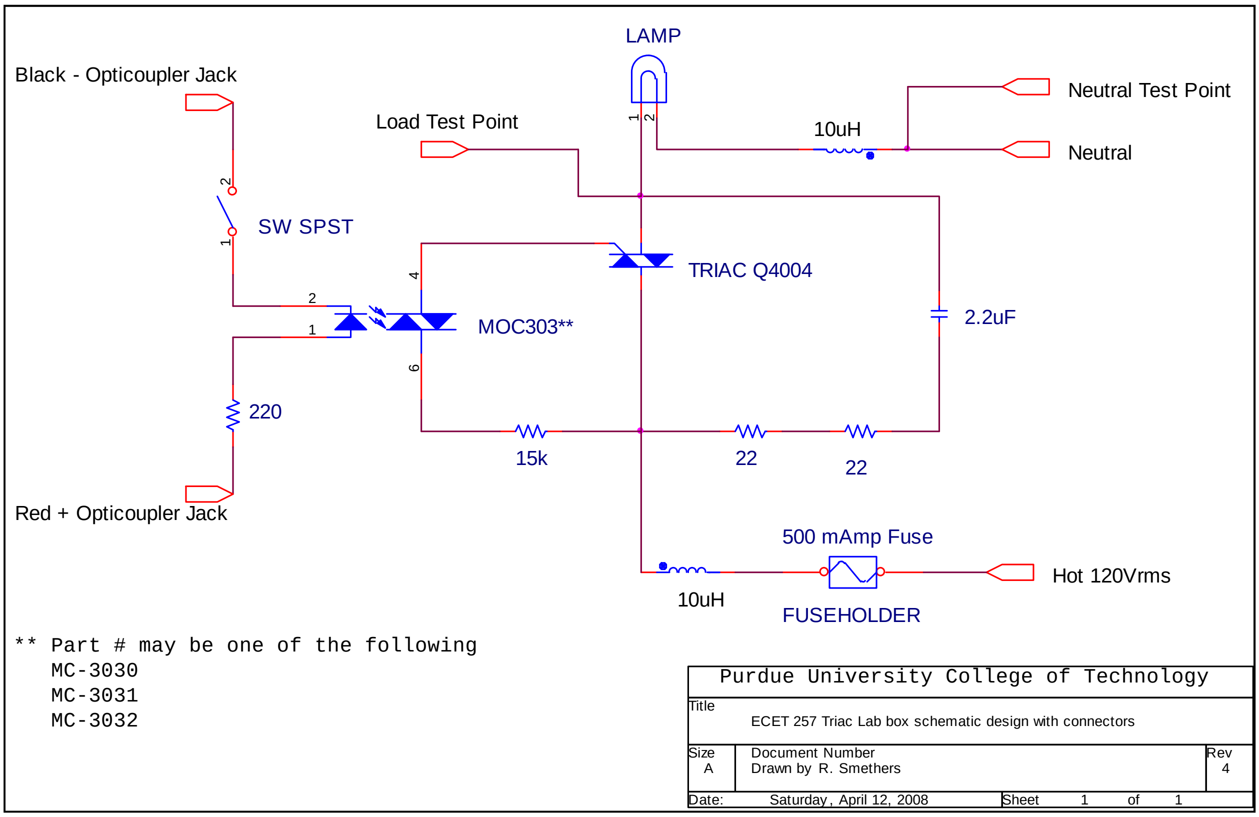

Figure 4: Circuit schematic

The power circuit consists of a power cord, fuse, the triac, and a load. The power cord is a standard 120-V three-prong cord designed for use with desktop computers, scavenged from a bunch of extras that our IT (information technology) guy had on hand. We cut off the end that normally plugs into a computer's power supply, and connected the individual wires to the circuitry. The normal load is a 60-W ceiling fan light bulb, which is both compact and designed to handle a bit of vibration (i.e., handling during lab). The fuse protects the circuit from excessive current. Although the original design called for a 500-mA fuse, that value is right at the limit of normal operation, so a 750-mA or 1-A fuse is probably a better choice. The triac, when triggered, delivers power to the load.

The triac is fired by an optically-coupled triac trigger (opto-isolator), such as the MOC3011 (non-zero crossing) or the MOC3032 (zero crossing). A 220-Ω resistor limits the input-side current. The MOC3011 has a typical forward voltage of 1.15 V [2] and the primary side of the trigger circuit is designed to be run by a 5-V TTL signal. This limits the current to less than 20 mA, which is well below the 60-mA spec [2] as shown in Equation 1. The switch on the top panel of the box (see Figure 2) connects power from the external TTL source to the input side of the optoisolator.

$$i_{primary} = \frac{5V - 1.15V}{220\Omega} = 17.5\ mA \qquad (1)$$

The output side of the opto-isolator has a maximum repetitive surge current of 1 A and a minimum holding current of 100 µA. [2] Since line voltage (120 V_{rms}) is applied to this side of the IC, the 15-kΩ resistor limits its current to about 11.3 mA_p, as shown in Equation 2.

$$i_{output} = \frac{170V_p}{15k\Omega} = 11.3\ mA_p \qquad (2)$$

This is enough current to trigger the Teccor Q4004L triac we use for the lab. [3]

The thyristor needs snubbing circuitry to protect it by limiting the rate of rise of current and voltage [1, pp. 396-402]. The two 10-µH series inductors limit the current rise to 8.5 A/µs, as shown in Equation 3. This is well below the critical rate of rise of current, 50 A/µs [3]. Likewise, the parallel RC circuit limits the critical rate of rise of voltage to 0.64 V/µs, as shown in Equation 4. This is well below the critical rate of rise of voltage, 2 V/µs [3].

$$\frac{di}{dt} = \frac{v_p}{L} = \frac{170\ V_p}{20\ \mu H} = 8.5\ A/\mu s \qquad (3)$$

$$\left.\frac{dv}{dt}\right|_{worst} = \frac{V_{DRM}}{(R_{load} + R_{snub})C_{snub}} = \frac{400V_p}{(240\Omega + 44\Omega)(2.2\mu F)} = 0.64\ V/\mu s \qquad (4)$$

The final part of the electrical circuitry is the user interface. The following components are located on the front panel, as shown in Figure 2.

- Banana jacks are used for connecting to the opto-isolator chip and for providing test points for measuring the waveforms across both it and the load.
- A standard SPST switch is used to make and break the connection to the opto-isolator.
- A light bulb socket provides for easy change-out of standard household bulbs.

Inside the case, mounted directly to the PCB, are sockets for the opto-isolator (black socket on the left) and the triac (white socket in the center), as shown in Figure 3.

III. Physical Description

Parts were acquired from several sources, partially because of availability and partially to save money. The plastic case is a standard junction box with a removable lid, purchased from a local

Home Depot. The holes in the lid for the banana jacks, light socket, and light switch were drilled with a standard hand drill and/or milled out using a Dremel tool (see Figure 5 and Figure 6). Line drawings of the top panel, including layout dimensions, are shown in Figure 5 and Figure 6.

As mentioned in the previous section, the power cords were scavenged from extras that were available from our IT guy.

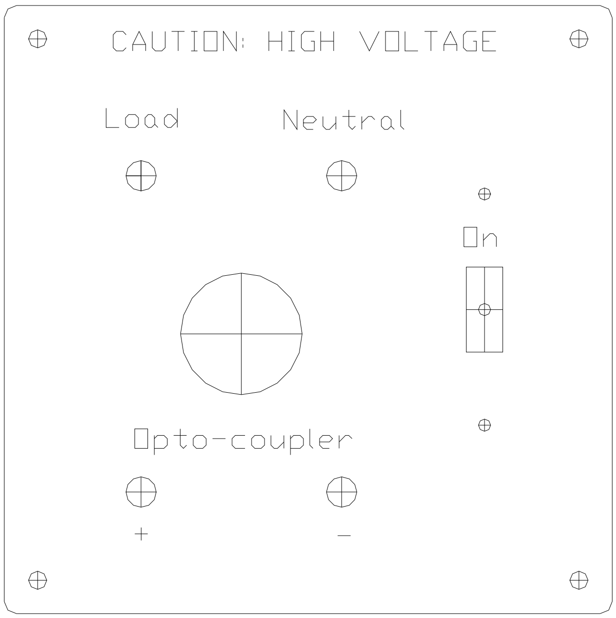

Figure 5: Top panel layout of thyristor lab fixture

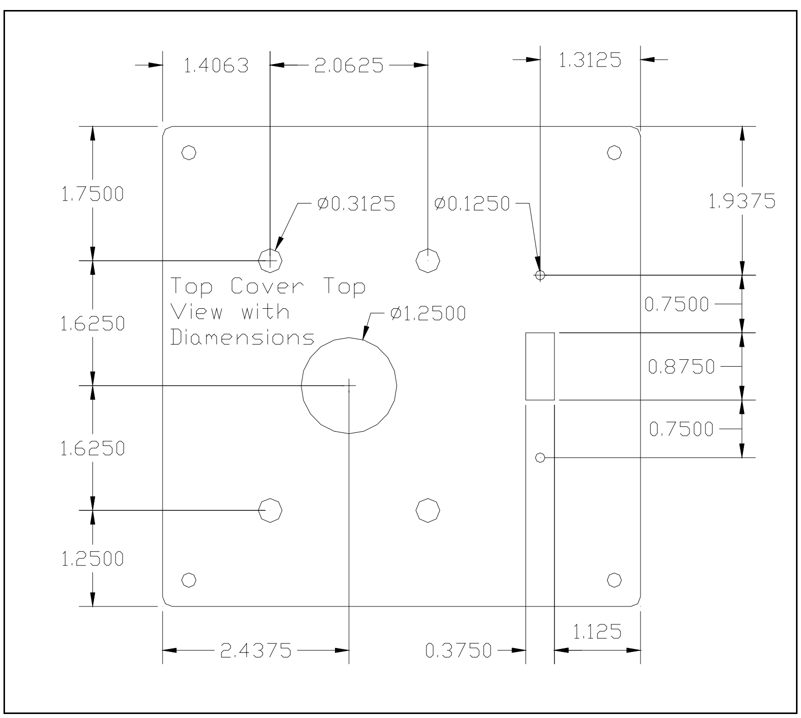

Figure 6: Top panel dimensions of thyristor lab fixture

Other parts sourced from Home Depot include the light bulb socket and bulb, switch, epoxy glue for securing each triac socket to its PCB (to decrease stress on the solder joints), clamp connector to secure the power cord to the junction box, and studs and wing nuts to make the lid easily removable. The complete parts list, except for the printed circuit board, is shown in the attachment, Table 1.

The PCBs were laid out by one of the faculty and ordered from ExpressPCB [4].

The banana jacks, IC socket, fuse, and fuse holder came from Jameco Electronics [5]. One pair of banana jacks is used for the load test points: red for the hot side, labeled “Load;” and black for the neutral side, labeled “Neutral.” These test points enable measuring the waveform to the load (i.e., light bulb). A second pair of banana jacks is used for the control signals to the opto-coupler, red for the positive side and black for the negative side. The opto-coupler output triggers the triac to power the load. The IC socket for the opto-coupler chip is soldered to the printed circuit board (PCB). A small hole was drilled in the side of the box for the fuse holder and fuse.

Most of the electronic parts, including the resistors, inductors, capacitor, and transistor socket are from Digi-key Corporation [6]. All were soldered directly to the PCB. The TO-220 transistor socket is for the triac.

Other parts included adhesive supports to mount the PCB so the components do not make contact with the case, from Richco, Inc. [7]; 18-gauge stranded wire to connect components not soldered to the PCB, from Newark [8]; and adhesive rubber “feet” for the junction box, some zip tie straps, and shrink tubing (donated personally).

IV. Lab Overview

Our thyristor lab is titled “Power Control with the Triac” and is designed to run about 2 ½ hours. Students observe the performance of the triac first using simple on/off control, then time-proportioned zero-crossing control, and finally phase-angle-fired control. There is an additional half hour or so of pre-lab work focused on obtaining the datasheet and identifying characteristics of the triac, then performing a few basic calculations relating to its operation.

The first procedure consists of connecting a voltage supply (through a current-limiting resistor) directly to the optically coupled triac trigger and verifying on/off operation of the triac/light. In the second procedure students control the trigger with a variable-duty-cycle pulse, and observe the effect of several different duty cycles. The third procedure involves phase-angle-firing control. The students use a 555-timer circuit and a variable DC control voltage to vary the duty cycle to a standard (i.e., not zero-crossing) optically coupled triac trigger. Additionally, they use a transformer, rectifier, and zener regulator to power the 555 timer. A step-by-step description of the lab is given in [1], pp. 437-443.

V. Conclusion

Thyristors are used in a wide variety of AC electronics. As such, they are an important and practical part of the electrical engineering (EE) and electrical engineering technology (EET) curricula. This paper briefly described our course learning objectives, followed by a detailed depiction of a low-cost lab device that we use to support those objectives. Our goal is to help interested instructors easily replicate the appliance for use in their EE or EET programs. Toward that end, the device is described thoroughly, including the parts needed and where they were acquired, the physical layout of the front panel, construction of the device, and its electrical design including schematic. We have used them safely and effectively in our labs for two years.

References

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[8] http://www.newark.com. Last accessed 29 December 2009.

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Table 1: Part requirements per unit*

Jameco Electronics

Description	Manufacturer #	Jameco #	Quantity
Binding Post, Breadboard, set of two containing one black, one red ONE RED	GIP001-R	77691PS	2
06C DIPLOMATE SOK 15AUPHBZ 6 pin ic socket	2-641296-4	837951	1
Fuse Holders, Panel Mount, 1/4X1-1/4 inch	zb3220-r	102825	1
Fuse .5Amp Fast Blow	gfs5250-r	102041	1

Digi-key

Description	Manufacturer #	Digi-key #	Quantity
RESISTOR 22 OHM 1W CARB COMP	OA220KE	OA220KE-ND	2
TRANSISTOR SOCKET TO-220 .100	10-18-2031	WM2551-ND	1
CHOKE RF HI CURRENT 10UH 15% RAD	5701-RC	M8709-ND	2
2.2UFD/250VDC METAL POLY CAP	ECQ-E2225KS	E2225-ND	1
RES 15K OHM 1/4W 5% CARBON FILM	CFR-25JB-15K	15KQBK-ND	1
RES 220 OHM 1/4W 5% CARBON FILM	CFR-25JB-220R	220QBK-ND	1

Richco

Description	Manufacturer #		Quantity
5/8" PCB support adhesive base standoff (donated)	LCBSBM-10-01A-RT		4

Home Depot

Description	Home Depot #		Quantity
Junction box	499-979		1
Porcelain fixture socket	615-441		1
SPST standard white wall light switch			1
Loktite 2 part epoxy glue **	677-156		1
3/8 clamp conn 5 per bag	839-647		1
60 watt ceiling fan bulbs 2 per pack	206-767		1
Hanger bolts #8-32x1" bag #80181	254-827		2
Wing nut # 8 bag #18981	254-827		2

Newark

Description	Newark #		Qty
Hook-Up Wire	52F2186		1
Hook-Up Wire	99B2433		1
Hook-Up Wire	03F4411		1

all wire is 100ft roles in Blue, Violet, and Black

Additional supplies needed			Qty
Adhesive wire base	Donated		3
Zip tie strips	Donated		3
Assorted sizes of shrink tubing	Donated		as needed
PCB from South Bend stock room			1

* List does not include printed circuit board

** Used to secure the TO-220 socket in all units