W. J. Prudhomme WB5DEP
1405 Richland Avenue
Metairie LA 70001

The Unzapper

A keep-alive circuit for yourself.

Whenever you use an electric power tool or any electrical device for that matter, you expose yourself to the possibility of a fatal electric shock by coming in contact with faulty wiring and providing a path through your body to any surrounding grounded surface. Most wiring in homes now makes use of grounded three wire outlets to insure the extra conductor to protect against a drill or other electrical equipment from becoming shorted by tripping the circuit breaker. However, this is no 100% guarantee of safety since the return ground conductor could become faulty without your knowledge (bad connections, etc.). For this reason, the new National Electric Code is requiring Ground Fault Interrupter circuits to be installed on all outdoor circuits and bathroom circuits in new homes. This new requirement is doubly important for outlets near swimming pools or outlets used for lawn tools and power tools.

A Ground Fault Interrupter (GFI) is a device which continuously monitors the current balance in an ungrounded conductor with the current in a neutral conductor in order to protect the user from ground faults. If the current in the neutral conductor is equal to that of the hot conductor, a ground fault condition does not exist since this is the normal operation of a load connected to the circuit.

However, if the current in the neutral wire becomes less than the current in the hot wire, then a ground fault exists, because a portion of the current is finding a return by an unintended path such as a leaky electrical appliance or tragically, through an

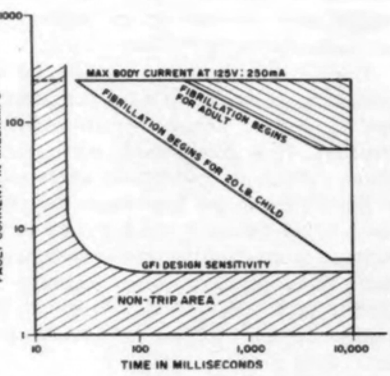


Fig. 1. For an adult, as little as 60 mA of current can cause fatal fibrillation of the heart. The GFI described in this article has a sensitivity of 4 mA. (Graph courtesy Pass & Seymour, Inc.)

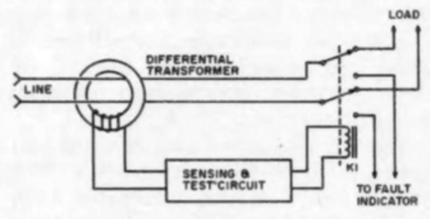
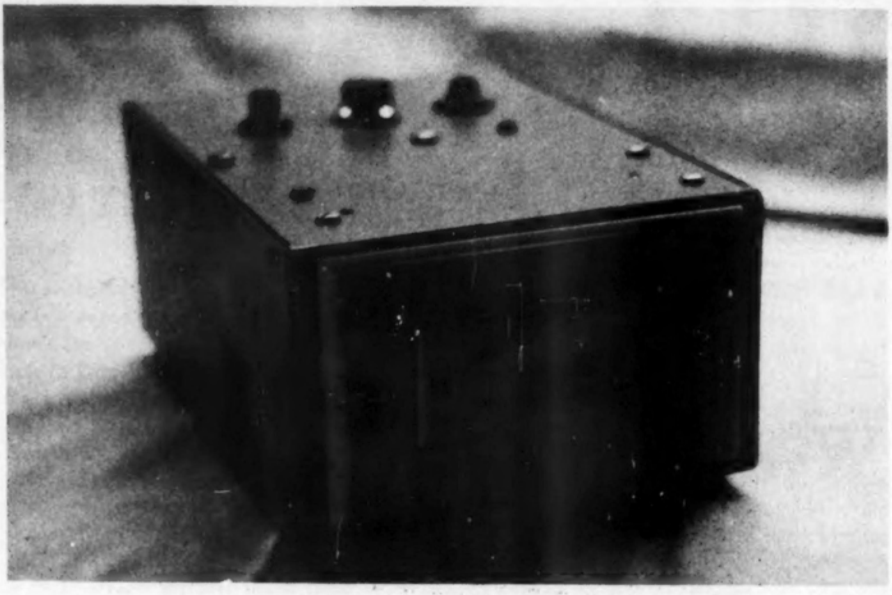


Fig. 2. Current leakage to ground on the load side causes an imbalance in the circuit. The resultant induced voltage in the toroid is amplified and used to actuate relay K1. The GFI does not depend on a third wire ground and incorporates a built-in test circuit for periodic checking.



Front view of the GFI.

individual. The GFI device will detect this situation and operate a relay which disconnects the power going to that particular load fast enough to protect the individual.

To understand the nature of a fatal electric shock, we refer to the graph shown in Fig. 1. This graph indicates that the maximum body current that an individual can withstand at 125 volts is 250 milliamps. It also indicates that muscle control leading to a fatal condition occurs at approximately 8 milliamps for a small child and up to approximately 60 milliamps for an adult. From the graph, it's also possible to see that the GFI device described in this article has a sensitivity of 4 milliamps and will operate within 30 milliseconds to prevent the current from ever appearing in the hazardous portion of the curve.

Fig. 2 is a simplified diagram of the basic operation of a GFI system. It consists basically of a sensing differential transformer, the sensing and test circuit, and a relay to de-energize the main circuit. Current leakage to ground on the load side causes an imbalance in the transformer circuit. The resultant induced voltage in the toroid is amplified and used to actuate an SCR which controls relay K1. From the basic diagram, it is possible to see that the GFI device does not depend on a third wire ground system. It also incorporates a built-in test circuit for periodic checking. There are two basic commercially available models of GFI devices, one that installs directly into an outdoor outlet. There are also commercial models available as portable units that may be plugged into standard circuits without the necessity of rewiring the house circuit.

This article describes a method for the amateur to construct a GFI device which is portable and can be used in many different situations. It is exceptionally applicable to amateur electronic installations where many of the devices in use have metal enclosures which could present a shock hazard to the amateur. It may also be used in conjunction with transformerless power supplies to prevent fatal shock conditions should the amateur come in contact with various portions of the circuit.

Circuit Description

Referring to Fig. 3, one of the main elements of the circuit is a toroid transformer, T1, which consists of a two-wire primary circuit and a secondary circuit used to sense the unbalanced condition. The actual details of the winding of this transformer are contained in a later section of this article. Resistor R1 is connected in such a way as to provide a 4 milliamp imbalance in the primary circuit used to simulate actual ground fault conditions for testing the circuit.

Resistor R2 and C1 form a filter circuit to help suppress spikes which may appear on the secondary side of the transformer from turning load equipment on and off. This eliminates tripping of the relay under these conditions, while having a negligible effect on normal operation of the circuit.

The integrated circuit, IC1, is an operational amplifier type 741 which is used to amplify the small voltage generated in the secondary winding of transformer T1. The gain of this operational amplifier is determined by the ratio of R5 and R6 expressed as follows:

$$\text{GAIN} = \frac{R5}{R6}$$

In this particular circuit, with R5 set at one megohm and R6 @ 2.7k, the gain is well over 300. However, the actual gain is limited by the input gain control, R3. A gain of 300 should be sufficient to fire the SCR, since it requires approximately 0.8 volts to trigger its control gate. With an imbalance of 4 milliamps on the primary of T1, approximately 3 millivolts appear across the secondary winding connected to the input of IC1. Since the gain of the op amp is set at 300, about 0.9 volts appear on the gate of the SCR which is sufficient to trigger it and cause relay K1 to operate. Once the SCR triggers, the circuit must be broken manually for it to reset. The reason for this is that we are supplying power through the relay coil to the SCR from a dc source and due to the nature of the SCR, this dc path must be broken before the SCR will turn off and restore the circuit to normal operation. Since the 120 V ac output is supplied through double-pole double-throw relay contacts, when the relay operates, the 120 volts ac is transferred from the output of the unit to a neon indicator light making it possible to see that the unit has operated and the power has been turned off.

Diodes D1 and D2 also work in conjunction with the RC filter circuit to reduce transients that would cause false triggering of the unit. These diodes should be fast acting switching diodes such as the 1N914 type.

A parts list and PC circuit board details are contained in Figs. 4 and 5 respectively.

The basic components such as the integrated circuit, SCR, and other small components are located on a circuit board as shown in Fig. 6. The toroid transformer,

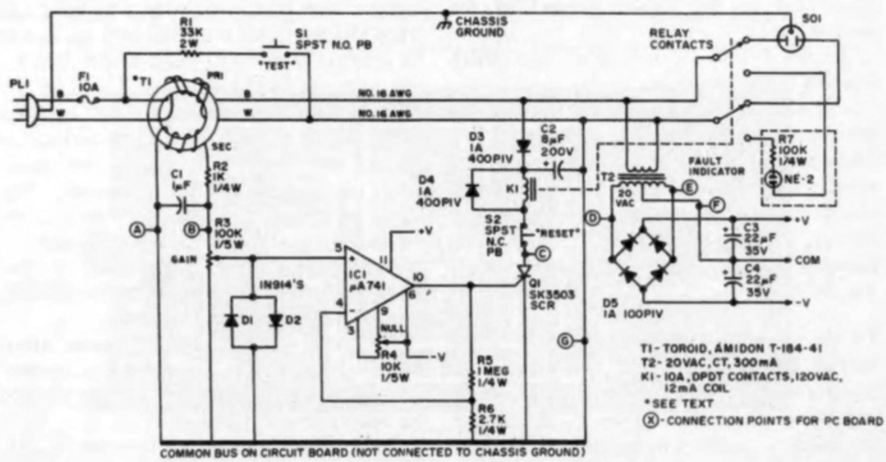
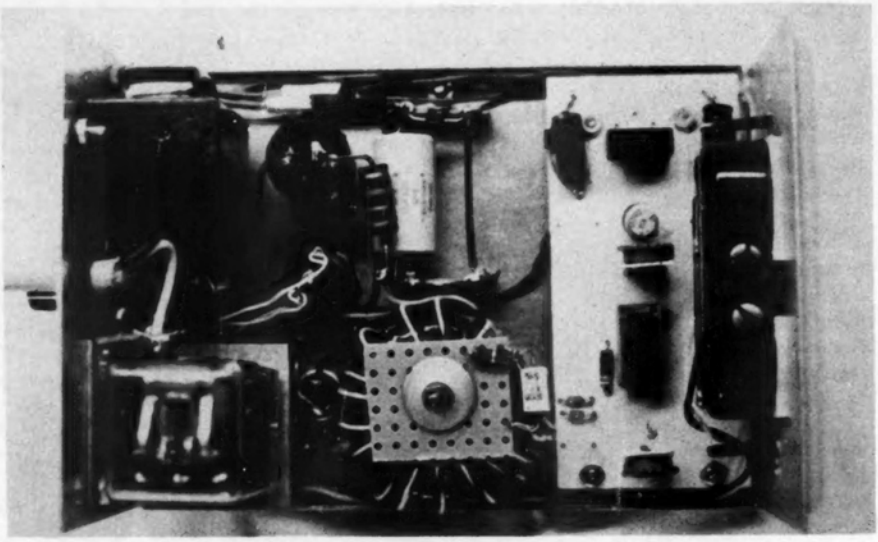


Fig. 3. Schematic diagram.



Top view.

relay and power supplies are located externally to the circuit board and connected by suitable wiring as shown in the diagram. It is important to note that the ground conductor from the ac supply should be connected directly to the metal chassis of the enclosure. However, since we are using a transformerless power supply to operate relay K1, it should also be noted that the common bus on the electronic circuit is not connected to the chassis ground of the enclosure.

I used a 3" x 7" x 5" enclosure which allowed ample room for the location of the power supply, relay and circuit board along with toroidal transformer. The relay used was a plug-in type, available at several of the surplus suppliers advertising in 73. The relay should have a 120 volt ac coil with contact ratings of approximately 10 Amps. The physical location of the parts is shown in Fig. 7.

Toroid Transformer Details

The heart of the unit is the toroidal transformer T1 which is used to sense an imbalance in one of the main conductors of the primary circuit. The toroid which I used is an Amidon Associates type T-184-41 iron toroid core. This toroid core has an inside diameter of 1.84 inches and is light green in color.

The secondary winding of the transformer consists of approximately 600 turns of #30 enamel wire covering the entire circuit of the transformer. While this appears at first to be a very tedious operation to wind this many turns on the toroid, there is a method of winding it in a very short period of time. In my particular case, I used the enamel wire obtained from a peaking coil from the television set. This wire appears to be approximately #30 gauge and is ideal for winding the secondary of T1. The TV peaking coil has a certain amount of adhesive to keep its windings in place and acts as an excellent bobbin for running the secondary turns through the transformer. The actual winding time for the secondary on my particular transformer was approximately ½ hour. If you should lose count of the number of turns, the secondary should have a dc resistance of about 30 Ohms.

After the secondary of the transformer has been wound, wrap the entire transformer with black vinyl electrical tape to protect the small diameter conductor.

The primary consists of 12 turns of #16 solid conductor twisted pair wire. I used one black and one white wire conductor to

Parts List

C1 – 1 uF, non-polarized
C2 – 8 uF, 200 V
C3, C4 – 22 uF, 35 V
D1, D2 – 1N914 or equiv.
D3, D4 – 1 Amp, 400 piv rectifiers
D5 – 1 Amp, 100 piv bridge
IC1 – uA741 operational Amp
K1 – 10 Amp, DPDT contacts, 120 V ac, 12 mA coil
Q1 – SK3503 SCR or equiv.
R1 – 33k, 2 W
R2 – 1k, ¼ W
R3 – 100k, 1/5 W trim pot
R4 – 10k, 1/5 W trim pot
R5 – 1 meg, ¼ W
R6 – 2.7k, ¼ W
R7 – 100k, ¼ W
S1 – SPST, N.O. push-button switch
S2 – SPST, N.C. push-button switch
T1 – Toroid, Amidon T-184-41 (see text)
T2 – 20 V ac, CT, 300 mA
Miscellaneous – three prong ac plug and line-cord, socket, enclosure, fuse and fuse holder

Fig. 4.

conform to the color coding of the National Electric Code and to help to keep the polarity of the entire system in accordance with the wiring throughout the house. The 12 turn twisted pair primary winding is spread out over the entire transformer to get maximum flux linkage to the secondary. By winding the transformer in this manner, it is possible to see that the current in both conductors of the primary winding should be equal under normal circumstances and since they are twisted together, should cancel out completely within the toroidal transformer. Also, if an imbalance exists between the conductors, this imbalance will be sensed by the secondary winding and produce an ac signal which can be amplified to trigger the SCR. The secondary winding produces an output of approximately 3 to 4 millivolts when there is a 4 milliamp imbalance on the primary. This voltage output is sufficient to operate the SCR when amplified by the integrated circuit amplifier.

To mount the transformer, use 2 small squares of perf board with a hole drilled in the center for mounting onto the enclosure. Once the toroid is sandwiched between the 2 pieces of perf board, it is possible to install the mounting bolt and tighten the boards down for permanent installation. Then the small secondary wire can be fed through a couple of the holes on the top portion of the insulator, and soldered to terminals installed at this point. The RC filter consisting of R2 and C1 can also be mounted on the perf board and the output from this filter brought down to the input of the amplifier with regular hook-up wire.

By using a circuit board mounted to the transformer as a connection point for the secondary, it is possible to avoid any problems with breaking the very small enamel wire which has been used for the secondary to transformer.

Conclusion And Results

Once the GFI has been constructed and

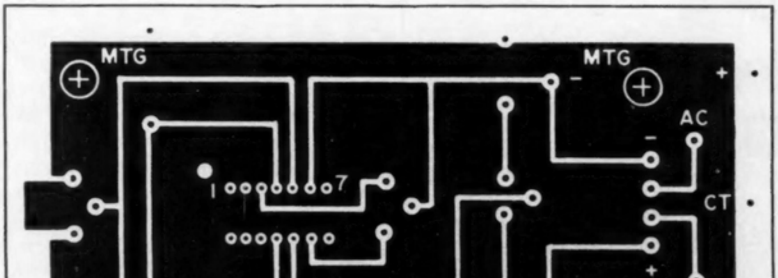


Fig. 5. Printed Circuit Board Layout (full size).

operating, there are only two minor adjustments which have to be made. First of all, the null adjustment, R4, should be adjusted so that there is zero voltage between the output terminal and the common bus during idle conditions. This is necessary to prevent false triggering of the SCR.

The next step is to adjust the input gain of the unit for proper operation. By depressing the test button, it is possible to introduce simulated fault condition. While holding the test button down, advance the gain control R3 until the relay operates. You may want to advance the gain somewhat further to provide even more sensitivity on the unit. Since most commercial units operate with a 5 milliamp sensitivity, any sensitivity greater than this provides that much more protection for the user. However, if the gain is set too high, it may result in nuisance tripping by spikes, and transients that are not controlled by the filter circuits.

In actual operation, it is best to test the circuit before each use to make sure that the circuitry is operating and will protect the user from ground fault conditions. This is done by depressing the test button and seeing if the unit operates to remove the ac from the outlet. Then by pressing the reset button, the circuit to the SCR is broken and the relay returns to its normal position.

It should be obvious from the circuit and discussion that this unit protects the user only from "ground fault" conditions. It will not protect an individual if he gets directly across the power line.

The circuit is also designed for a 3 wire system, but will operate satisfactorily on 2 wire systems since it detects any type ground leakage whether it be through the ground conductor operating the unit, a ground path through a water pipe, or any other metal conductor that travels back to the grounded conductor of the power system.

I am sure that there may be some improvements to the circuit that I have not incorporated at this time. Perhaps, it may be possible to tune the toroid to 60 Hertz and thereby greatly increase the sensitivity of the T1 transformer. However, I have not investigated this possibility at this time, and would be interested to hear from anyone who has

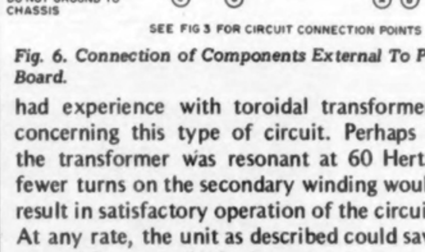


Fig. 6. Connection of Components External To PC Board.

had experience with toroidal transformers concerning this type of circuit. Perhaps if the transformer was resonant at 60 Hertz, fewer turns on the secondary winding would result in satisfactory operation of the circuit. At any rate, the unit as described could save your life, and that's its most important feature.

References

National Electrical Code – 1975 Edition, pg. 31, paragraph 210-8.

Pass & Seymour, Inc. – Syracuse, New York 13209, brochure #3375.

... WB5DEP