SPEAKER PROTECTOR

This simple circuit will protect your stereo speakers in the event of amplifier failure.

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IF YOU'VE HAD FIRST-HAND EXPERIENCE with damaged speakers due to a faulty amplifier, or if you value your speakers enough to want to prevent such damage in the first place, then the circuit described in this article is for you. The circuit will protect speakers against an amplifier that may have a shorted output stage and thus deliver excessive DC voltages that will easily ruin a speaker coil. If your amplifier has a sound-processing delay after the power has been turned on, a functionally similar circuit is already built in. This article will give you a basic idea of the delay's function and how it works to protect the speakers. The circuit is designed for solid-state amplifiers and is not necessary for tube-type amplifiers that have output transformers. (An output transformer blocks any DC from the speaker terminals.)

The circuit is very versatile and can be customized for many different applications. Plans for home stereo, automotive, and commercial PA/guitar amplifier applications are included.

The most common cause of speaker failure is catastrophic amplifier failure. That's in contrast to the conception that the speaker has been overdriven by an amp that's operating normally. Most often the speaker power level has been chosen to match the driving amplifier. Semiconductors designed to handle high current, such as bipolar power transistors and MOSFET's, usually short when they blow out. Often these devices are connected directly to an amplifier's DC power-supply rails or through a small amount of resistance that can't effectively limit the current when the short occurs.

The DC level of an amplifier's power supply is designed to accommodate the peak power levels that occur when the amp is driving the speaker at full power. A 100-watt amplifier has power-supply rails of at least 40 volts. Under normal operating conditions, that level would never be applied to the speaker coil for more than a few seconds. However, if an output device in the amp shorts, the DC is applied to the speaker continuously. In the case of a 100-watt amplifier, that causes a power dissipation of:

$$P_D = (40V/\text{speaker resistance})40V$$

Speaker resistance is usually one to two ohms less than the AC impedance. If a blown amplifier is connected to a 100-watt speaker with a 7-ohm DC resistance, the power being dissipated is:

$$P_D = (40V/7\Omega)40V = 228 \text{ watts}$$

The speaker will be able to dissipate that power for only a couple of seconds before the coil is damaged due to excessive heat.

When the protector circuit senses a DC voltage on the speaker line, it activates a relay whose contacts are in series with the speaker; after two seconds the relay disconnects the speaker until the DC is removed. A fuse is inadequate for this application because the value needed to protect the speaker against DC will blow out at peak power levels during normal operation. Conversely, a fuse value chosen to allow peak power operating levels will not protect the speaker against a DC voltage. The protector circuit allows peaks to occur in the power level and also protects the speaker against DC. It should be used in conjunction with a fuse value calculated from peak power levels. The fuse should be placed as close to the amplifier as possible, if not in the same chassis, and is therefore not shown in the protector circuit's schematic.

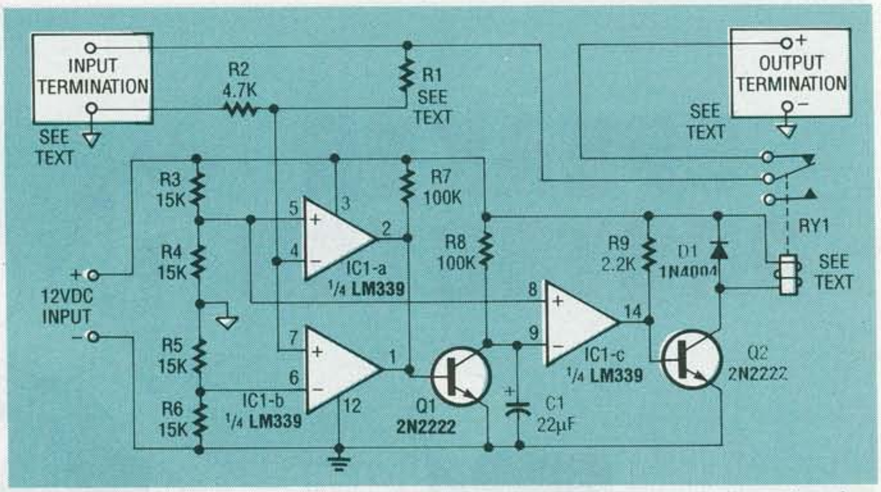


FIG. 1—IF AN AMPLIFIER OUTPUT SHORTS, this circuit will protect your speakers from the harmful DC voltage that will be present at the amplifier's speaker outputs.

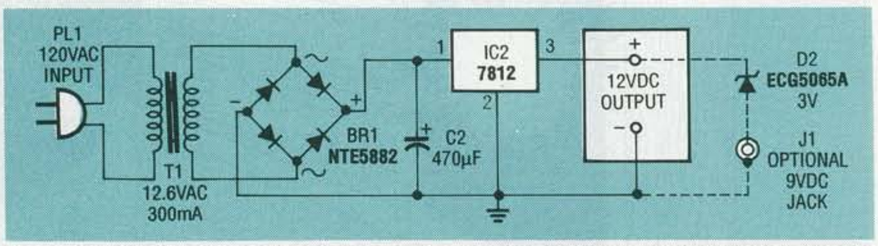


FIG. 2—THE POWER SUPPLY can be used for up to four individual protector circuits. The optional 9-volt DC output jack can be used to power an electric-guitar footpedal or fuzzbox.

Circuitry

The protector circuit's. schematic is shown in Fig. 1 and the power supply is shown in Fig. 2. Up to four individual protector circuits can be powered from one supply, although most applications will require only one or two circuits per chassis. The optional 9-volt DC output jack can be used to power a footpedal or fuzzbox, eliminating the need for a DC wall transformer when the circuit is used to protect guitar-amplifier speakers. The power supply can be modified for different applications, and we'll talk about them later.

Referring to Fig. 1, the voltage-divider resistors R3–R6 are used to bias the positive and negative inputs of the window comparator formed by IC1-a and IC1-b. The inputs are biased at plus and minus 3 volts. The voltage divider also provides a 9-volt reference for the negative input of comparator IC1-c.

Resistors R1 and R2 form an input voltage divider fed from the speaker terminals of an audio amplifier. The input divider is referenced to analog ground, and the output of the divider is connected to the negative and positive inputs of the window comparator (IC1-a and IC1-b). The outputs of IC1-a and IC1-b are open-collector stages, wired together, and pulled high through R7. That forms a wired OR function and completes the window comparator. When the output of the R1-R2 voltage divider exceeds the reference levels set by R4 and R5, the output of the window comparator goes low and removes the bias from Q1. The input voltage at which that happens is determined by the value of R1. The formulas for calculating R1 are presented later in this article. Transistor Q1 is turned off while the output of the window comparator is low, thus allowing timing-capacitor C1 to begin charging through R8.

Under normal input conditions (an AC audio signal), the output of the window comparator will return to a high level when the input returns to the plus and minus 3-volt range. That biases Q1 into conduction and immediately discharges C1. If a DC signal large enough to trigger the window comparator is present on the input, then Q1 will remain in its off state and C1 will charge until it reaches 9 volts with reference to the power-supply ground. When C1 reaches 9 volts it triggers comparator IC1-c causing its output to go high and bias Q2 into conduction via R9. When turned on, Q2 grounds one end of relay RY1 thereby activating it and disconnecting the audio passing through its contacts from the speaker. The relay contacts will remain open until the DC input is removed from the protector circuit. Diode D1 protects Q2 against reverse-bias spikes generated by the relay coil.

The circuit has two separate grounds: a speaker ground and a power-supply ground. Under no circumstances should these two grounds be connected together. If two circuits are used together, then three entirely separate grounds will exist: a power-supply ground and a speaker ground for each circuit (see Fig. 3-*a*).

Some stereo amplifiers, especially those used in car-radio amplifiers, have differential or floating-ground outputs for each channel and cannot be connected together. Figures 3-*a*, -*b*, and -*c* are AC model diagrams showing the equivalent connection paths between two circuits

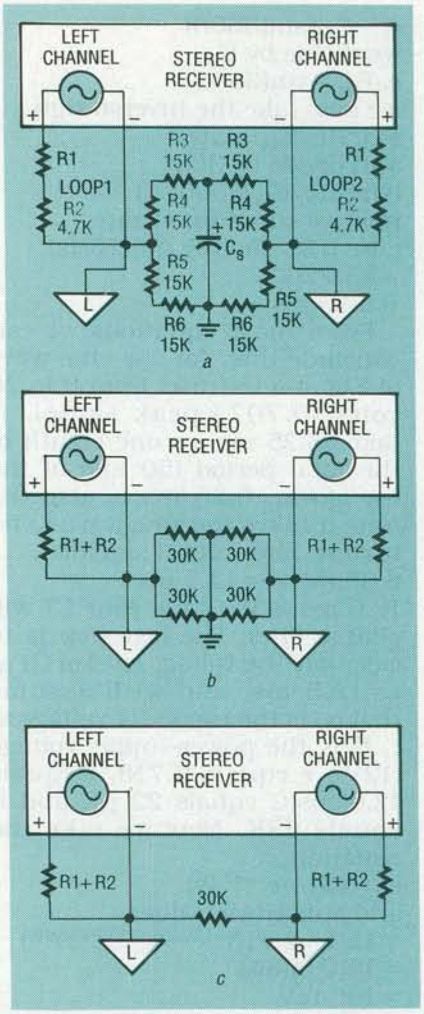


FIG. 3—THE CIRCUIT HAS A SPEAKER GROUND and a power-supply ground that should never be connected together; *a* shows that the current flowing in either loop is not a function of the other; *b* shows the power-supply capacitor from *a* (C_S) replaced by a wire; and, in *c*, the equivalent resistance between the two speaker grounds is shown as 30K.

TABLE 1

POWER OUTPUT OF AMP (W)	4-OHM LEAD				8-OHM LEAD			
	RMS VOLT-AGE	PEAK VOLT-AGE	R1 VALUE IN OHMS	FUSE VALUE IN AMPS	RMS VOLT-AGE	PEAK VOLT-AGE	R1 VALUE IN OHMS	FUSE VALUE IN AMPS
10W	6.3V	8.9V	5.2K	2.2A	8.9V	12.7V	9.2K	1.6A
20W	8.9V	12.7V	9.2K	3.2A	12.7V	17.9V	15.2K	2.2A
30W	11.0V	15.5V	12.5K	3.9A	15.5V	21.9V	19.6K	2.7A
35W	11.8V	16.7V	13.8K	4.2A	16.7V	23.7V	21.5K	3.0A
40W	12.7V	17.9V	15.2K	4.5A	17.9V	25.3V	23.3K	3.2A
50W	14.1V	20.0V	17.4K	5.0A	20.0V	28.3V	26.6K	3.5A
60W	15.5V	21.9V	19.6K	5.5A	21.9V	31.0V	29.6K	3.9A
75W	17.3V	24.5V	22.4K	6.1A	24.5V	34.7V	33.7K	4.3A
85W	18.4V	26.0V	24.1K	6.5A	26.0V	36.9V	36.0K	4.6A
100W	20.0V	28.3V	26.6K	7.0A	28.3V	40.0V	39.6K	5.0A
120W	21.9V	31.0V	29.6K	7.8A	31.0V	43.8V	43.9K	5.5A
140W	23.7V	33.5V	32.4K	8.4A	33.5V	47.3V	47.8K	5.9A
150W	24.5V	34.7V	33.7K	8.7A	34.7V	49.0V	49.7K	6.1A
175W	26.5V	37.4V	36.8K	9.4A	37.4V	52.9V	53.9K	6.6A
200W	28.3V	40.0V	39.6K	10.0A	40.0V	56.6V	58.0K	7.0A
250W	31.6V	44.7V	44.8K	11.2A	44.7V	63.3V	65.3K	7.9A
300W	34.7V	49.0V	49.7K	12.3A	49.0V	69.3V	72.0K	8.7A

operating from a single power supply. Figure 3-*a* clearly shows that the current flowing in either Loop 1 or Loop 2 is not a function of the other. The speaker grounds return to the common power supply rails through the voltage-divider resistors R3–R6. Figure 3-*b* shows the power-supply capacitor from 3-*a*, which is seen as a short to AC, replaced by a wire. Finally, in Fig. 3-*c*, the equivalent resistance between the two speaker grounds is shown as 30K. DO NOT short the two grounds together under any circumstance.

If the amplifier speaker grounds are connected inside the amplifier, they should NOT be connected at the speaker protection circuit's chassis. High current is assumed to be flowing in each speaker ground lead and connection of separate ground leads anywhere except inside the amplifier will degrade performance.

Calculations

To calculate the value for R1, which determines the time it takes C1 to reach nine volts, the following example analysis is presented. The first step is to calculate the RMS (average) voltage applied to the speaker terminals to obtain the rated amount of power. We'll arbitrarily use 100 watts and a speaker load of 8 ohms. From the equation:

$P = (I^2)R$

we can substitute values

$100W = (I^2)8$

divide by 8

$12.5 = I^2$

take the square root of both sides

$I = 3.53$ amps

From the equation:

$V = IR$

we can substitute values

$V = 8(3.53A)$

$= 28.28$ volts RMS

As a final check use the formula

$P = IV$

we can substitute values

$P = 3.53A(28.28V)$

$= 99.82$ watts

To calculate the value for R1 we use the equation:

$((V_{IN}(R2))/V_{OUT}) - R2 = R1$

and substitute values

$= ((28.28V(4.7K))/3V) - 4.7K$

$= 39.60K$

To calculate the fuse value for amplifier short-circuit protection, use the equation:

$V_P = V_{RMS}/0.707$

and substitute values

$28.28V/0.707 = 40$ volts

From the equation:

$I = V_P/R$

we can substitute values

$40V/8$ ohms

$= 5$ amps

If you would rather avoid making all of the calculations, Table 1 shows the correct resistance values to be used for R1 for 10- to 300-watt applications. Appropriate fuse values are also provided in Table 1.

The next step is to calculate the maximum time that C1 will charge, and the voltage level it will reach before it is discharged, under normal operating conditions. This is a necessary analysis in order to prove that the circuit will not trigger falsely when peak audio power levels are reached. The lowest frequency normally associated with audio is 20 Hz. It has the longest time period (50 milliseconds) in the audio spectrum so we'll use it for analysis of the speaker protector circuit. (An actual audio signal is quite complex, but the complexity of the waveforms only decreases the time that C1 will charge, so we'll therefore use 20 Hz.)

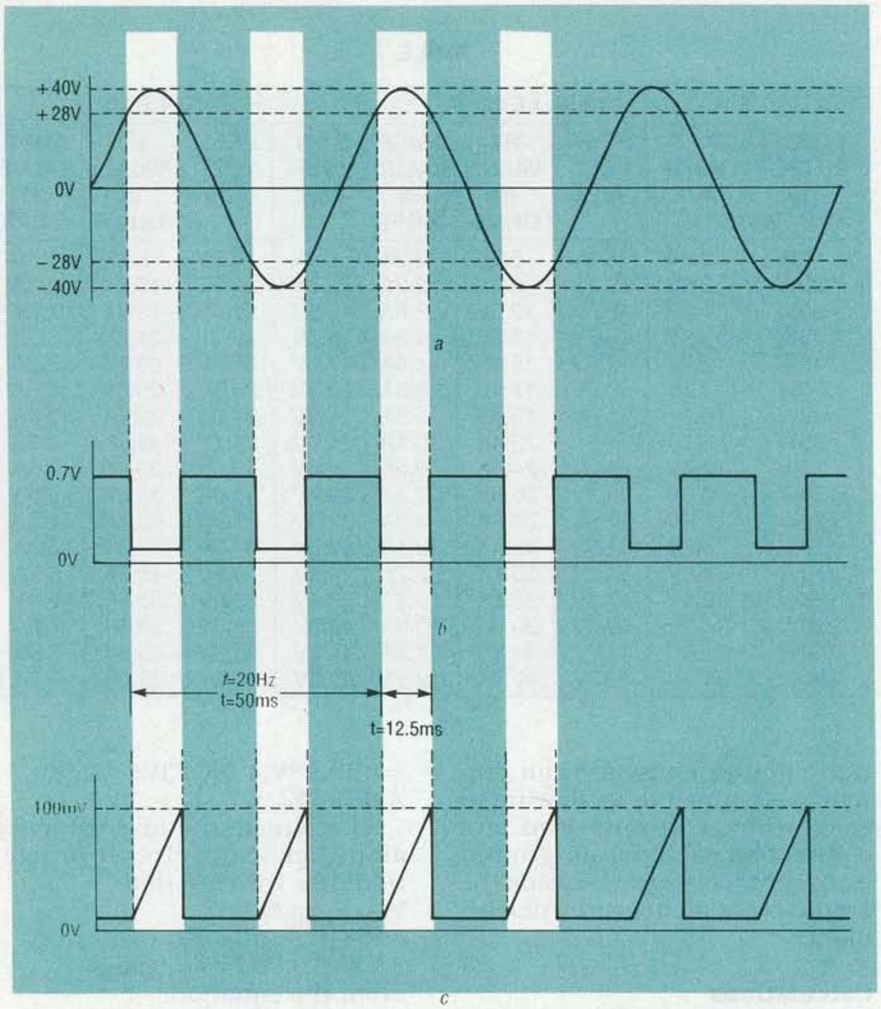
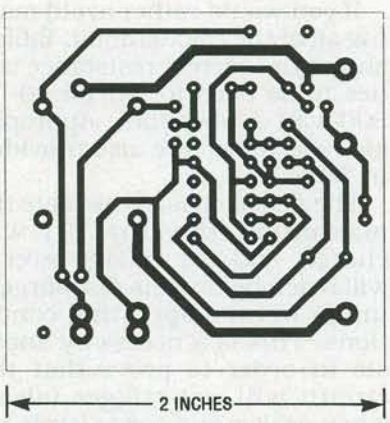
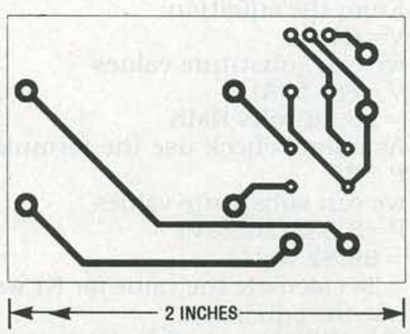


FIG. 4—SHOWN IS THE INPUT TEST SIGNAL (*a*), the Q1 base voltage (*b*), and the Q1 collector voltage (*c*).



MAIN FOIL PATTERN shown actual size.

Capacitor C1 will charge whenever the input voltage exceeds the RMS voltage level necessary to produce 100 watts if R1 is equal to 39.6K. Figure 4 shows the analysis waveforms for the circuit; shown is the input test signal (*a*), the Q1 base voltage (*b*), and the Q1 collector voltage (*c*). Referring to Fig. 4-*a*, to calculate the time that the input waveform is between 28 and 40 volts, we'll first assume that e_I is the instantaneous voltage level (28.28 VRMS), E_M is the maximum or peak voltage level ($40.00V_P$), the frequency is *f* (20 Hz), pi (π) is equal to 3.14, t is the time for sine wave to reach 28.28 V_{RMS}, and that 2π radians equals 360 degrees (and we'll stick to degrees from this point on). That out of the way, from the equation:



POWER SUPPLY FOIL PATTERN shown actual size.

$e_I = E_M(\sin(360ft))$
we divide by E_M
$e_I/E_M = \sin(360ft)$
we now take the inverse sign
$\sin^{-1}(e_I/E_M) = 360ft$
and divide by 360f
$(\sin^{-1}(e_I/E_M))/360f = t$
now we substitute values
$(\sin^{-1}(28.28/40))/360(20Hz)$
$= 45/7200$
$= 6.25$ ms

From those equations we can conclude that, for the sine wave of Fig. 4-*a* to travel from 0 to 28 volts (0.707 × peak value), it takes 6.25 ms, or one eighth of the total period (50 ms) of the waveform. 6.25 ms is also the time it takes the sine wave to return to zero volts. Therefore:
6.25 ms(2) = 12.5 ms
12.5 ms is the total time C1 will charge (4-*c*). The last step is to calculate the voltage level of C1 at t = 12.5 ms, and we'll assume that e_C is the capacitor voltage at t, E is the power-supply voltage (12V), e equals 2.718, t equals 12.5 ms, C equals 22 µF, and R equals 68K. Now we take the equation:
$e_C = E(1 - e^{-t/(CR)})$
and substitute values
$= 12(1 - 2.718^{-12.5ms/(22\mu F)68K})$
$= 12(0.0084)$
$= 100$ mV

The speaker protector circuit will disconnect the amplifier from the speaker after a 2-second interval using the values shown for R8 and C1. That amount of time will protect the speaker under most circumstances. Charging time for C1 to reach 9 volts can be calculated by rearranging that equation and assuming that e equals 2.718, ln is the natural log (the inverse of e^X), E is the power-supply voltage (12V), e_C is the capacitor voltage (9V), t is the time for C to charge to 9V, C equals 22 µF, and R equals 68K. The rearranged equation is:
$t = CR(\ln(E/E - e_C))$
now we substitute values
$t = (22\ \mu F(68K))(\ln(12/(12 - 9)))$
$= 1.49(1.39)$
$= 2.0$ seconds

To change the time delay for the speaker protector circuit to disconnect the speaker from a DC voltage use the equation $R8 = t/1.39C$ to recalculate the value of R8.

Construction

Construction of the protector

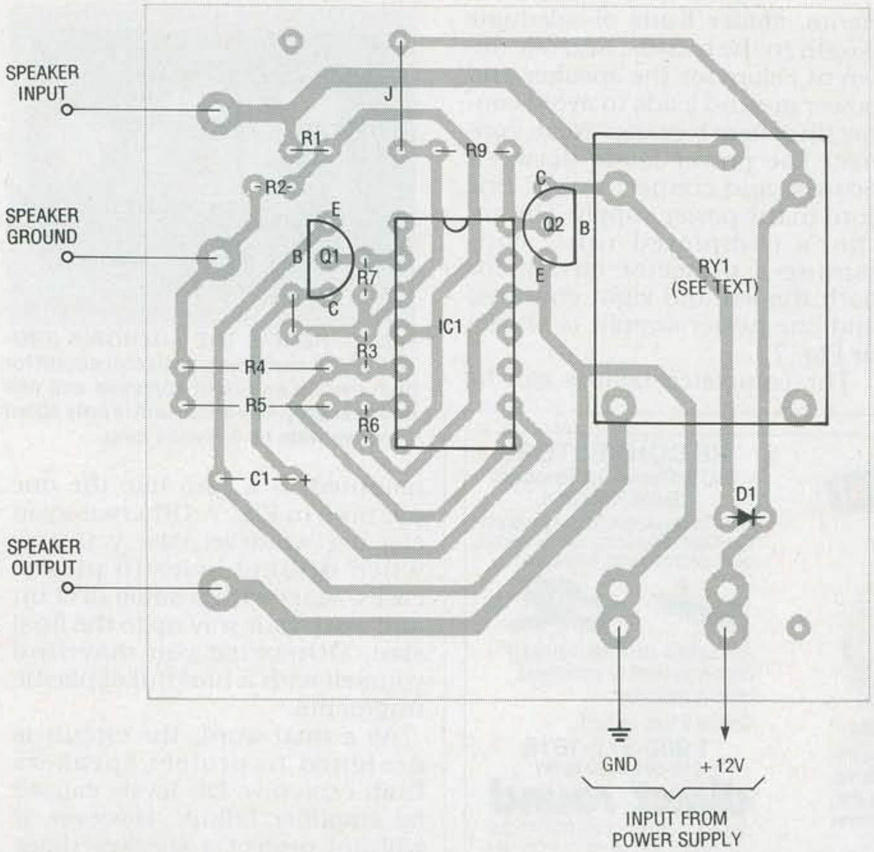


FIG. 5—PARTS-PLACEMENT DIAGRAM for the protector circuit. The 5-amp relay will mount right on the board, while the 15-amp relay must be mounted on the edge of the board using double-sided tape.

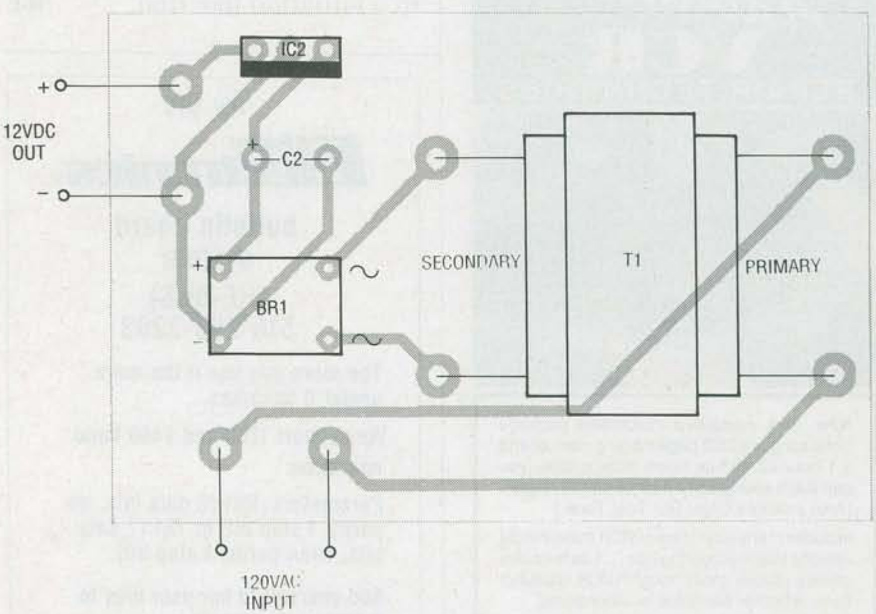


FIG. 6—PARTS-PLACEMENT DIAGRAM for the power-supply board.

PARTS LIST

All resistors are ¼-watt, 10%.
R1—value depends on your setup (see text and Table 1)
R2—4700 ohms
R3–R6—15,000 ohms
R7, R8—100,000 ohms
R9—2200 ohms

Capacitors
C1—22 µF, 35 volts, radial electrolytic
C2—470 µF, 35 volts, radial electrolytic

Semiconductors
IC1—LM339N quad open-collector voltage comparator
IC2—7812 12-volt regulator
D1—1N4004 diode
D2—ECG 5065A 3-volt Zener diode (required for optional 9-VDC output, see text)
Q1, Q2—2N2222 NPN transistor
BR1—ECG 5882 1-amp bridge rectifier

Other components
T1—120/12-VAC 300-mA transformer
RY1—5- or 15-amp relay (see text)
J1—optional 9-VDC jack (whatever type best suits your needs)

Miscellaneous: PC boards, AC plug and line cord, 18-gauge stranded hookup wire, cabinet(s), speaker-input and -output jacks (RCA jacks, spring-terminal board, etc.), solder, etc.

Note: The following items are available from Applitron Electronics, 2721 Creswell Road, Bel-Air, MD 21014: Kit of parts for the speaker protector circuit including an etched and drilled PC board and all parts that mount on it for $14.95. Please specify the value of R1 you desire (standard 10% values only) and P.A./guitar, home stereo, or automotive version. Add an additional $3.50 for the optional high-current (15 amp) relay. A kit of parts for the 12-volt supply is also available that includes an etched and drilled PC board and all parts that mount on it for $14.95. Include $1.95 postage and handling for each kit ordered and allow 3–4 weeks for delivery. Maryland State residents must add 5% sales tax.

circuit depends on the intended use. Once you have a clear idea of the application, then you can customize the circuit to meet your needs. To use the circuit to protect car-stereo speakers, replace R4 and R5 with 3-volt Zener diodes. That will ensure that the window-comparator reference voltages, with respect to analog ground, will be independent of the DC supply voltage. For power levels below 100 watts, you can use the 5-amp relay shown in the parts list; above 100 watts, you must use a 15-amp relay.

The parts-placement diagram for the protector circuit is shown in Fig. 5. The PC board is configured for on-board mounting of the 5-amp relay that the author used.

A compatible relay with a different pinout can be used. However, it may have to be mounted on the edge of the board using double-sided tape; it will then have to be hardwired to the board. The parts-placement diagram for the power-supply board is shown in Fig. 6.

After mounting all components, solder leads of adequate length to the boards, and use different colors for the speaker and power ground leads to avoid connecting them together. Next, connect the power leads between boards, and connect an AC line cord to the power supply. The author's completed unit, containing a protector circuit for both the left and right channels and one power supply, is shown in Fig. 7.

The completed boards can be mounted in a case like the one pictured in Fig. 7. Otherwise you can use whatever case you like. When drilling holes in plastic cases, start with a small drill bit and work your way up to the final size. Otherwise you may find yourself with a handful of plastic fragments.

As a final word, the circuit is designed to protect speakers from excessive DC levels caused by amplifier failure. However, it will not protect a speaker that's rated at power levels much less than the driving amplifier can supply—only your own common sense in keeping the volume down will protect your speakers in a situation like that. **R-E**

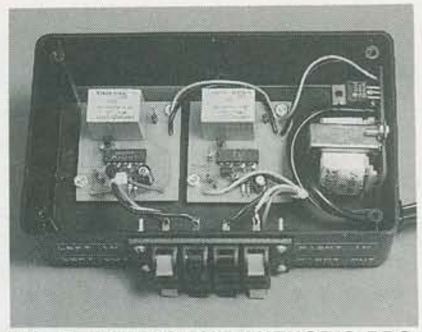


FIG. 7—HERE'S THE AUTHOR'S PROTOTYPE. It contains a protector circuit for both the left and right channels and one power supply. The entire unit is only about 4 inches wide by 6 inches long.