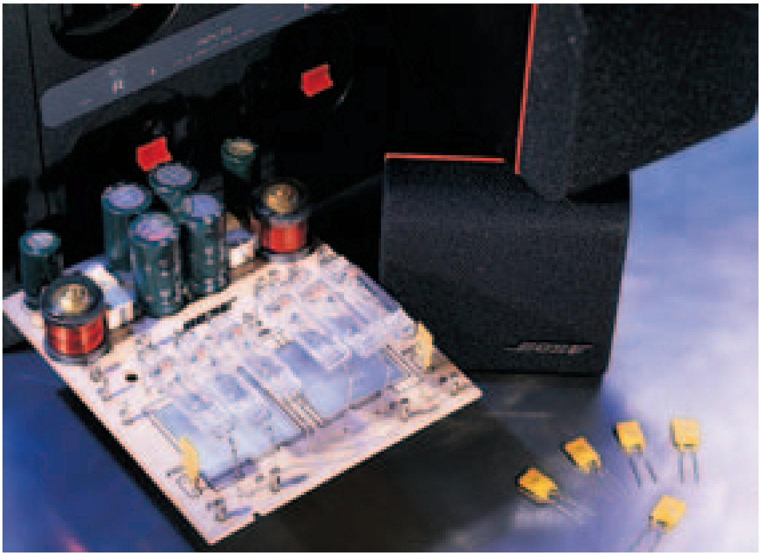
Loudspeakers
Application Note

Many loudspeaker systems incorporate PolySwitch devices for overcurrent protection. By tripping during high-current conditions and resetting when no longer needed, PolySwitch devices provide reliable protection without the nuisance and replacement costs associated with fuses.



The Problem

Today's speakers are generally designed and sold independently of amplifiers. Thus, mismatches may occur, which can lead to damage. Also, the advent of digital recordings and compact discs places extra burdens on sound systems. Speaker damage can result from a number of factors, including the following situations:

- High-power amplifiers used with low-power speakers may simply overdrive the speaker coils with excessive power during sustained high volume.
- Low-power amplifiers may be overdriven so that clipping occurs. This causes an upward frequency shift of power that can overload the tweeter. This problem is especially common with the wide dynamic ranges found on compact discs.
- Digital recordings, including compact discs, with their ability to reproduce high-frequency material, place extra strain on tweeters.

The protection choices for loudspeaker systems are fairly limited. Fuses will protect the speaker, but a blown fuse will be a source of frustration for the user and may result in field returns for the manufacturer. Also, the addition of a fuse holder and wire so that the fuse is accessible will increase material costs. Because the fuse must be accessible, it can be defeated or replaced with the wrong fuse. Circuit breakers are an alternative method. However, they can arc as they start to open and cause disturbing noise until they are fully open. PolySwitch resettable devices are typically used to solve these problems.

The Solution

PolySwitch resettable devices provide soft switching into a high-resistance tripped state, and automatically reset to a low-resistance state when power is removed. At normal operating temperatures, these devices have very low resistances (from 30mΩ to 800mΩ for the RXE devices typically used in speakers). Therefore, their insertion loss is usually less than 0.1dB. They have essentially no capacitive or inductive reactance and cause no measurable distortion over the audio range of frequencies.

When excessive currents are flowing, the temperature of the PolySwitch device increases and the crystalline structure of the polymer begins to change to an amorphous state and expand. Conductive paths within the polymer mass separate, causing a dramatic increase in the device's resistance. This increased resistance reduces the amount of current that can flow to a minimal level. The time it takes for a particular device to trip depends on the amount of current flowing.

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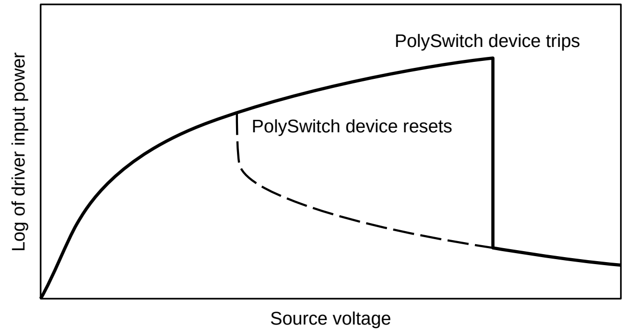
Figure 1. Effect on Load Power



The resistance of the PolySwitch device in the tripped state (R_{PS}) is typically three to four decades higher than the untripped resistance. Tripped state resistance is determined from the square of the PolySwitch devices voltage (V_{PS}) and the power dissipation of the device (P_D). P_D is essentially constant for a particular PolySwitch device in the tripped state. It can be affected by heat transfer conditions, such as the way the part is mounted or connected, air currents, and other factors. The formula for Rps when the device is in the tripped state is as follows:

$$Rps = \frac{V_{PS}^{2}}{P_D}$$

$$Rps \cong \frac{V^2}{P_D}$$

(V is the drive voltage and V_{PS} is the voltage across the PolySwitch device. They can be assumed to be approximately equal for this equation.) As long as the drive voltage is sufficient, the PolySwitch device will stay in the tripped state and protect the system. Figure 1 shows how the load power is reduced by 20 to 30dB after the device trips. The formula for dB power attenuation in the tripped state is:

$$\text{Atten.} = 20 \log \frac{V - V_{PS}}{V}$$

where:

$$V_{PS} = \frac{V + \sqrt{V^2 - 4R_L P_D}}{2}$$

When the drive voltage is increased, the PolySwitch device resistance increases, causing the power output to decrease. When the drive voltage is reduced, the power increases along the dotted line in Figure 1. When the drive voltage is reduced so that the PolySwitch device can no longer draw sufficient power to keep itself in the tripped state, the device resets. Since PolySwitch devices reset themselves, they do not have to be accessible or replaceable by the user. The drive voltage at which the PolySwitch device will reset is approximately:

$$V \leq 2\sqrt{R_L P_D}$$

where R_L is the load resistance.

Applications

Figure 2 shows the most simple installation, which consists of a PolySwitch device in series with the driver. The PolySwitch device should be sized so that its time-to-trip at any particular current is less than the time required to damage the driver at that current. The circuit in Figure 2 will have the power characteristics shown in Figure 1.

PolySwitch device with shunting resistor

Some designers would like to reduce the drive power by a smaller fixed amount in case of a fault, rather than the large amount.

Figure 2. Typical Circuit

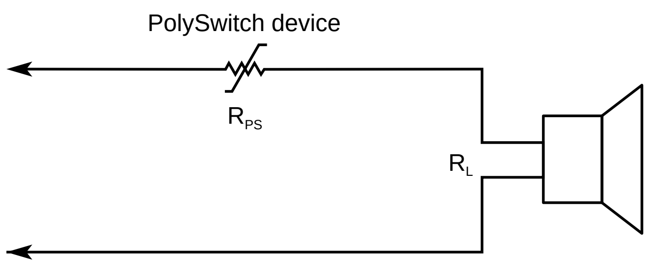


Figure 3. Shunt Resistor Circuit

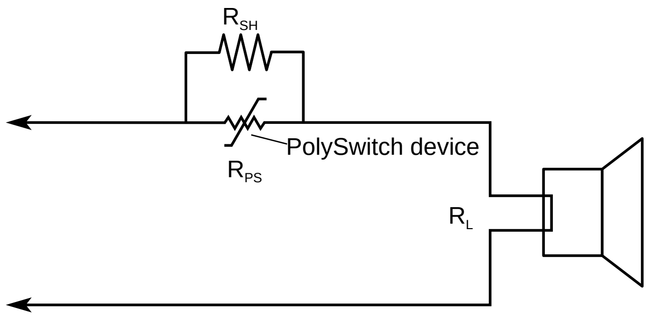


Figure 4. Effect on Load Power—Shunt Resistor

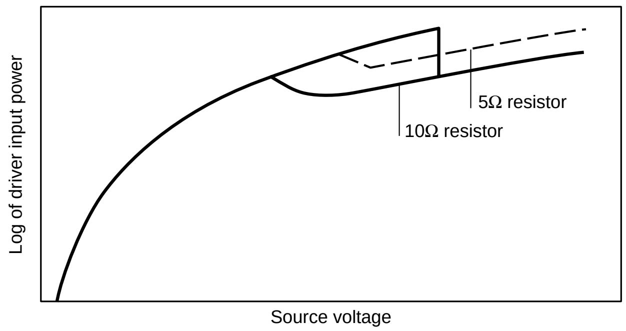


Figure 5. Shunt Lightbulb Circuit

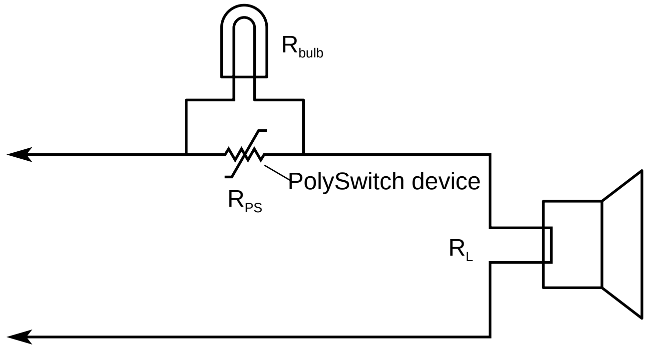


Figure 3 shows a sample circuit with a shunt resistor in parallel with the PolySwitch device. Figure 4 shows the load power characteristics for a 5Ω and 10Ω shunt resistor.

Now, the dB power attenuation when the PolySwitch device trips is approximately:

$$\text{Atten.} \cong 20 \log \frac{R_L}{R_L + R_{SH}}$$

where R_{SH} is the value of shunt resistance. The approximate source voltage at which the PolySwitch device resets in this case is:

$$V \le 2R_L \sqrt{P_D \left\langle \frac{1}{R_L} + \frac{1}{R_{SH}} \right\rangle}$$

PolySwitch Device with Shunting Lightbulb

A third method is to use a shunting lightbulb in parallel with the PolySwitch device as shown in Figure 5. Figure 6 shows the load power characteristics for a 0.5Ω and 1.5Ω lightbulb.

As with the shunting resistor, the PolySwitch device normally carries most of the current. When the PolySwitch device trips, most of the current now passes through the lightbulb. As the bulb filament lights and heats it exhibits a PTC effect (about 1 decade of resistance increase). As with the fixed-shunt resistor, increases in drive voltage will increase load power. However, the PTC effect of the lightbulb causes this increase to be much flatter than the increase seen with the fixed-shunt resistor. The result is less of an increase in speaker power as the volume is increased as shown in Figure 1.

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The same equations for dB attenuation and reset drive voltage for the fixed-shunt resistor apply for the shunt lightbulb. The value for shunt resistance now depends on a complex balance between the PolySwitch device resistance and lightbulb resistance.

The lightbulb is typically used only for its PTC effect, but it can also be used as an overload indication to the user. An LED in series with a resistor can also be used as an overload indication, but it does not have any PTC effect.

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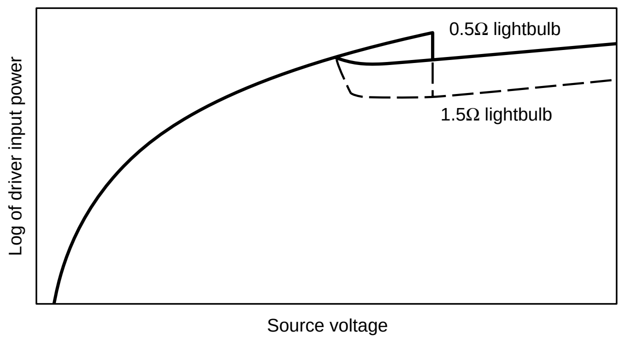
The choice between a shunt resistor and a lightbulb resistor, or the choice to use nothing at all in parallel with the PolySwitch device, depends on the protection philosophy of the speaker designer. Components can be chosen so that the user immediately hears the attenuation when the PolySwitch device trips. Alternatively, components can be chosen so that the user never hears an attenuation, just a reduced volume increase as he or she turns up the volume control after the PolySwitch device has tripped.

Device Selection

Deciding which part to use must be based on a knowledge of the specific protection needs of the driver. An analysis of the time it takes to cause damage for various drive currents would be very useful.

For effective protection, the PolySwitch device's time-to-trip curve at the lowest expected ambient temperature should lie below the driver's time-to-damage curve. If a complete time-to-damage curve for the driver is not available, the designer can choose a PolySwitch device with a trip

Figure 6. Effect on Load Power—Shunt Lightbulb



current just below the maximum safe steady-state current for the driver. In either case, the designer should conduct an empirical investigation to verify performance.

The RXE series of PolySwitch devices is rated from 60-72V.

The SPK series may also be used where connectors are needed rather than mounting to a PCB. For more information on this product line contact your local Raychem Circuit Protection representative.