Over-current protection in audio amplifiers

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Introduction
Once an engineer has designed the audio circuit of an amplifier, it would be nice to think that most of their task is complete. However, from a system perspective, that is far from true. At the very least, they must give consideration to power supply design and physical packaging (including thermal management) and, in most cases, protection.

What is meant by "protection"? Simply, it is something that prevents the amplifier from coming to harm, be it from delivering excess current or from components getting too hot. In this article we shall look at a simple and effective drop-in over-current protection circuit that the designer can add to their toolbox for a wide variety of designs.

Over current protection vs. Short-circuit protection
There is an important distinction to be made with terminology between "over-current protection" and "short circuit protection". In the case of an amplifier that has no input signal, the output terminals should be at the same potential, other than the amplifiers noise level and a possible small DC offset in both cases only a few mV at most for a well designed amplifier. In that case, what happens when the output is shorted? The answer is very little no significant potential is applied and so no significant current flows. Increasing the amplifier's input with the output shorted will result in larger and larger currents flowing. However, if these currents are within the current drive capability of the amplifier then they do not pose a risk to the amplifier.

It is also worth considering the short-circuit itself. A true short-circuit at the amplifier's output terminals will result in the amplifier seeing its own output impedance as the load likely a few tens of milliohms. However, if the "short" is at the end of the speaker wires, then the resistance could be several times larger perhaps a couple of hundred milliohms including contact resistances. In essence, the question that has to be asked is "How short is a short circuit?"

With these things in mind, it is necessary to take a pragmatic approach, and accept that it may not be possible to detect all "short circuit" situations. However, it is certainly possible to detect them when they become a risk to the amplifier, causing levels of current to flow that are beyond the specification of the amplifier. This is most accurately described as over-current protection.

Perhaps the simplest form of over-current protection is fuses. Some amplifiers have fuses not only on their power rails, but also in series with the output. Of course, fuses have many downsides: They are not convenient to reset and they may not act fast enough to prevent damage occurring, without even touching on the audible impact fuses may bring.
So how can a better over-current protection scheme be achieved?

The Circuit

![Current monitor circuit for over-current protection.](image)

**Figure 1**: Current monitor circuit for over-current protection.

The above circuit diagram shows how to use current monitors to provide an effective, easy to implement over-current protection scheme. It comprises of two separate detection circuits (U1, D1, Q1, R1-R3 comprise the positive rail detection circuit, while U2, R4-R6 comprise the negative rail detection circuit) along with a buffering and latching circuit (U3, D2-D4, R7, C1). For a single rail system, the negative rail circuit is unnecessary.

**Current monitors**

The current monitor devices used here are transconductance amplifiers. The output of the device is a current proportional to the voltage observed between the inputs, where the constant of proportionality is known as the transconductance, $G_T$.

The output current can then be put through a resistor in order to give a scalable output voltage.

**Circuit operation**

*Circuit operation*

As the currents flowing in the power rails - through R1 and R4 - increase, then so will the observed voltage across these resistors. This in turn increases the current flowing out of the current monitor devices U1 and U2, according to their gain. The resistors through which the current flows to ground, R2 and R6, determine the voltage output of the circuits.

When either of these rail monitor signals rise above a threshold voltage, the Schmitt trigger U3 will give a high output, and latch in that state through the diode D4 that loops back to its input. The voltage required is the positive-going threshold voltage ($V_{T+}$) of the buffer plus the forward voltage ($V_F$) of the series diode (D2 or D3) from the current monitors. The three diodes allow the circuit to be enabled by either current monitor or the loop independently.

The Zener diode D1 and transistor Q1 are used to provide a much higher voltage range than the current monitor U1 could support on its own, extending operation to a wide range of practical power.
Supply voltages

Setting up the circuit to a specific application
Now that the circuit is available, how is the trip current \( I_{\text{TRIP}} \) determined and then how is the circuit set to trip at that current?

First of all, it should be understood what is meant by \( I_{\text{TRIP}} \). This is the absolute current level that will cause the protection system to operate. In order to avoid false tripping, it must be set above the peak output current " not the RMS or average current.

In order to easily understand this, it is instructive to look at what you would see on an oscilloscope probing the rail monitor signals under different operating conditions of the amplifier. Note that the shown waveforms are those of a bridged amplifier:

![Figure 2: Examples of rail monitor outputs.](image)

The waveforms in figure 2 give a representation of the power supply rail current. The clipped signal case (into the rated load) will determine what the maximum expected peak current is which then allows the trip current to be set:

![Figure 3: Average, Peak and Trigger currents superimposed on current waveform.](image)

Figure 3 shows an ideal trigger current above the peak current of a clipped signal. Simply determine the peak current for the clipping power level of the amplifier (e.g., an amplifier capable of delivering 250W RMS into 4Ω suggests a peak voltage of 44.7V, and so gives a peak current of 11.1A into the rated load) and then add some margin to avoid false tripping. It is important that this margin must not exceed the capabilities of the output devices of the amplifier. For this example a reasonable target is 15A.
Now that I\textsubscript{TRIP} is known, the voltage across the sense resistor (V\textsubscript{SENSE}) can be determined. Given the 10mΩ sense resistors and 15A I\textsubscript{TRIP} then V\textsubscript{SENSE} is clearly 0.15V, and is the same on both power rails. The next step is to determine how much voltage gain is required. In this case 3V (2.3V V\textsubscript{T+} + 0.7V V\textsubscript{F}) seems a reasonable output voltage, so a voltage gain of 20 is required.

The gains of the two circuits are different, and depend on the previously discussed transconductance gain of the current monitor devices. Starting with the simpler case of the positive rail monitor, the transconductance gain of the ZXCT1009 is quoted as 10000µA/V, or 0.01A/V:

\[ G_T = 0.01 = \frac{I_{OUT}}{V_{SENSE}} \]

The output voltage of the circuit is determined by ohm's law:

\[ V_{OUT} = I_{OUT} \times R2 \]

And so the overall voltage gain is simply determined by the output resistor multiplied by the transconductance gain:

\[ \frac{V_{OUT}}{V_{SENSE}} = R2 \times 0.01 \]

Rearranging and applying this for the positive rail circuit using the ZXCT1009, the value of R2 required for the known gain required is:

\[ \frac{20}{0.01} = 2000\Omega \]

For the negative rail circuit with the ZXCT1050, there is a slight difference in that the transconductance gain of the ZXCT1050 can be adjusted through an external resistor, giving two ways to adjust the output voltage gain. In practice, the resistors are simply set according to the formula:

\[ \frac{V_{OUT}}{V_{SENSE}} = 20 \times \left(\frac{R6}{R5}\right) \]

Since the target voltage gain is 20, then R6 and R5 need to be equal in this case. The ZXCT1050 has maximum recommended values of 40kΩ for R6, and 10kΩ for R5. For best efficiency, higher values should be used, and following the recommendations in the datasheet they should be set to 7k5Ω.

The ZXCT1050 logic supply should be +5V relative to the negative rail (ie to the GND pin of the device), and this should also supply the Schmitt buffer U3. The output of the circuit will be given as a logic 1 relative to the negative rail, which is easily level shifted to other potentials if necessary, but is also appropriate for disabling gate drive devices in switching amplifiers (as the gate drive device will usually have logic inputs relative to the lowest voltage rail in the system).

\textbf{Circuit Benefits}

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There are several significant benefits in using this circuit:

1. The high transconductance gain of the current monitors allows the use of 10mΩ sense resistors. In many similar circuits values of 25mΩ to 100mΩ are not uncommon. The smaller value sense resistors allow for lower power dissipation, with consequent component cost and board space savings as well as efficiency improvements. The sense resistance is comparable to the resistance of a 6.3A fuse (which might take up to 2 seconds to burn through at 15A, providing poor protection).

2. As demonstrated, the trip current can be changed very simply through cost effective standard resistors, whilst maintaining the same low sense resistor value, allowing the same circuit block to be dropped into a wide variety of applications with minimal change.

3. The circuit allows for high rail voltages, up to ±50V, making it suitable for high power amplifiers.

Practical considerations
The circuit should be placed between the system's main reservoir capacitors and the output stage. If the sense circuit were to be placed between the power rail source (e.g., rectifier) and the main reservoir capacitors, the capacitors would not only result in slow operation of the circuit, but might also allow rather more energy to be discharged under a fault condition.

In the case of a switching amplifier, high momentary switching currents could cause false detection of an over-current condition. In practice, most switching amplifiers have moderate levels of local decoupling capacitance at the output stage and main system reservoir capacitance at the power supply. As long as the circuit is between the two, the local decoupling in the output stage should make false detection unlikely.

The circuit as suggested produces a latched output once an over-current situation is detected. Since the cause of high currents on the output is most likely due to failure of an external component such as a loudspeaker drive unit, or user error in creating a short circuit across the terminals then it will not fix itself without user intervention. As that will take a long time relative to the speed with which the circuit could reset itself it is safest to latch the protection mode and require the user to power cycle the amplifier once the short circuit condition is resolved. A simple LED indicating the over-current condition might help in this case, and can typically be driven by the Schmitt buffer's output.

Multi-channel applications bring a new challenge. The power supply may be capable of delivering levels of current that are well above those that would cause damage to a single channel's output stage, since the current is expected to be shared across multiple channels. In that situation it is preferable to have individual over-current protection systems per channel. The low power dissipation and small footprint of the suggested circuit here makes this a practical solution.

The circuit as given here is a detection and latching scheme. The system designer should determine what to do with the output of the circuit. The simple logic output allows it to be easily used to mute an input, disable a gate driver or amplifier chip, disconnect an output relay or report the information to a system microcontroller. The appropriate action will vary depending on the specific system.

Conclusion
An over-current detection scheme is easy to implement in audio amplifiers, offering cost-effective protection against external failures, which could otherwise result in damage to the amplifier. It is
simple, compact and scalable, and easily applicable to single and split rail designs. Once in the designer's toolbox it can be applied simply and effectively to a wide variety of designs with minimal change.

**References and further reading:**
Zetex ZXCT1009 datasheet  
Zetex ZXCT1050 datasheet  
Zetex Application note AN39  
Zetex Application note AN45

**About the author:**
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