Introduction

Snap, crackle and pop are the last sounds you ever want to hear when working with high power circuits, but such disturbing noises can be prevented by the new LT1970 op amp with variable current limiting.

Electronics designers do not often celebrate at the sound of components being overdriven to their demise. The resulting lingering scent of melted plastic and burnt metal can result in wasteful hours of discussion with curious co-workers who are interested in duplicating the explosive circuit. This cost in man-hours, added to the cost of the deceased components, can be staggering.

An important rule in working with high power circuitry is that any device that provides a significant amount of output power must provide some measure of protection of the circuitry it drives. Most power amplifiers only limit output current to the maximum current the amp can supply. This simple measure primarily protects the amplifier itself without much regard to the downstream load circuitry. Most power amplifiers only limit output current to the maximum current the amp can supply. This simple measure primarily protects the amplifier itself without much regard to the downstream load circuitry. Some power amplifiers provide slightly more protection with a programmable fixed current limit, where the maximum output current is fixed at a safely lower level. The LT1970 500mA power op amp takes load protection to the next logical step by providing an on-the-fly adjustable and precise output current limit that can continuously adapt to and protect load circuitry. The current limit, both sourcing and sinking, is adjusted through two 0V–5V voltage inputs, making it easy to create current limit control.

One obvious application of the LT1970 is in Automatic Test Equipment (ATE). In ATE, power amplifiers are used as pin drivers. These test pins force conditions at numerous points on a tested circuit board to determine both continuity and functionality. As each test point presents a unique load to the driver, the ability to tailor the voltage and maximum output current prevents damage to the board being tested. Without this flexibility, the tester itself could destroy the very unit it is testing should any test node present an unexpected load condition to the driver. ATE is only one obvious example. Myriad interesting applications are made possible...
possible by the full and immediate control of a power amplifier output voltage and current.

A Look Inside the LT1970

The LT1970 is as easy to use as any basic op amp. It is a unity gain stable voltage feedback amplifier with good performance characteristics. The input offset voltage is less than 1mV, bias current is 160nA, gain bandwidth product is 3.6MHz and it slews at 1.6V/μs. It can operate with a total supply voltage of 36V over a –40°C to 125°C temperature range. It is also a power amplifier with a maximum output current limit of 800mA, both sourcing and sinking, built in thermal shutdown protection and comes in a small 20-pin TSSOP power package. The underside of the package has an exposed metal pad to facilitate heat sinking. These are only the basic amplifier characteristics; there are other built-in features that set the LT1970 apart.

Figure 1 is a block diagram of the LT1970. A standard amplifier topology is composed of a differential-input transconductance stage, g_m1, driving a unity gain high current output stage. The inputs can handle 36 volts differentially without conducting any current. This is an important feature when the current limit amplifiers become active and take control of the output voltage.

The current limit amplifiers, labeled I_SINK and I_SRC, provide the unique output current limiting control in both the sinking and sourcing direction. These amplifiers connect to the high impedance output of the input stage and have a much higher transconductance than the g_m1 stage. The current limit amplifiers monitor the voltage between two sense input pins, SENSE+ and SENSE− (for simplicity this voltage difference will be referred to a simply V_SENS). These input pins are typically connected across a small external current sensing resistor, RCS. As shown each amplifier has an independently controlled offset voltage, V_SNK and V_SRC, which set the thresholds for the output current limit. When V_SENS is less than either offset voltage, the current limit amplifiers are disconnected from the signal path. This functionality is indicated by diodes D1 and D2.

When V_SENS exceeds either current limit offset voltage the applicable current limit amplifier becomes active and takes control of the signal path from the input stage, g_m1. Feedback control of the amplifier is now through the current limit path and the output current is regulated to a value of V_SENS/RCS with V_SENS forced to the value of the threshold voltage, V_SNK or V_SRC depending on the direction of the output current flow. Voltage control of these thresholds is the key to on-the-fly current limit adjustments.

Two current limit control inputs, V_CSNK and V_CSRC set the current limit thresholds. These pins take a 0V to 5V input to independently control the maximum sinking or sourcing current. The sinking current limit threshold, V_SNK, is equal to one tenth the voltage applied to the V_CSNK pin (likewise for the sourcing current limit). This sets the maximum output current in either direction to a voltage-controlled value of:

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I_{OUT(MAX)} = \frac{V_{CSNK} \text{ or } V_{CSRC}}{10 \cdot R_{CS}}
\]

If \( R_{CS} \) is selected to be a 1Ω resistor, a 0V to 5V control voltage adjusts the current limit over the range of 4mA to 500mA. The accuracy of the current limit at 500mA is guaranteed to be 2% maximum or within 10mA. The lower limit of 4mA, instead of 0mA, is intentional. A non-linearity with control input voltages less than 0.1V is built-in to prevent the sourcing and sinking limit amplifiers from ever being activated at the same time. This would

Figure 1. The LT1970 is a basic power amplifier with built-in voltage control of the output current limit.
result in an uncontrolled output. The bandwidth from the control inputs to the output is 2MHz, which can be useful for AC current modulation. The response time for the current limit amplifiers to take control of the output is fast, typically 4μs.

Other features include an active high enable input, three open collector error flags and separate power supply input lines. The enable input turns off the LT1970 and drops the supply current to 600μA. It also places the output stage into a high impedance, zero output current, state. The error flags, which can drive LEDs, indicate that the driver is in current limit, in either direction, or that a load condition has caused the LT1970 to enter its thermal shutdown protection. The V_{CC} and V_{EE} supply pins power all of the internal circuitry except for the high current output stage. The output stage is powered from the V^+ and V^- pins, which conduct all of the output current. Biasing the output stage from lower supply voltage levels can significantly reduce the power dissipation in the output stage in high current applications.

**Application Ideas Abound**

Having complete control over the voltage and current applied to a load in a single device leads to innumerable application possibilities. The ease of limiting or modulating the output current of the LT1970 solves many circuit problems and can protect many a load circuit. Here are a few ideas.

**Figure 2.** A typical LT1970 circuit

Figure 2 shows the basic application of the LT1970 power amplifier. This is a simple noninverting gain of two amplifier until the current limiting is activated. Figure 3 shows the separate current limiting control for sourcing and sinking. With V_{CSRC} set to 4V, a sense resistor R_{CS} of 1Ω and a 10Ω load on the amplifier, the maximum output voltage is 4V due to current limiting at 400mA. Setting V_{CSNK} to 2V sets the sinking current in this example to 200mA. The three error flags are ORed together to provide a single indication of the LT1970 reaching current or thermal limits.

**Need More than 500mA?**

The 500mA output stage of the LT1970 is adequate for many applications, but there are also some higher current applications that can benefit from the unique current limit control. Figure 4 shows how easy it is to boost the output current to ±5A using an external complementary pair of MOSFETs. The output current sense resistor is

**Figure 3.** Current limiting clamps the output voltage of the circuit of Figure 2 at precise levels. Independent control allows different sourcing and sinking current limits.

**Figure 4.** Boosting the output current capability to ±5A

Figure 5. Snap-back current limiting provides an added measure of safety.
scaled down to 0.1Ω to extend the same 0V to 5V current limit control to a range from 40mA to 5A. The gate voltage drive is developed from the V+ and V– supply pins with the current needed by the LT1970 output stage as it drives a 100Ω load. This Class B power stage is intended for DC and low frequency, <1kHz, designs as crossover distortion between sourcing and sinking current becomes evident at higher frequencies. In very high current designs, having externally connected gain-setting resistors allows for Kelvin sensing at the load. By connecting the feedback resistor right at the load, the voltage placed on the load is exactly what it should be. Any voltage drop across the current sense resistor is inside the feedback loop and thus does not create a voltage error.

“Snap-Back” Current Limiting
Figure 4 also shows a unique way to use the open-collector error flags to provide extra protection to the load circuitry. When the amplifier enters current limit in either direction, the appropriate error flag goes low. This high impedance to 0V transition can provide a large amount of hysteresis to the current limit control inputs, forcing a drastic reduction in output current. Resistors R1, R2 and R3 in this example set the current limit control at 2V max and 200mV min. Should the load current ever exceed the predetermined maximum limit, the output current snaps back to the min level. The output current remains at this lower level until the signal drops to a point where the load current is less than the minimum set value. When the signal is low enough, the flag output goes open and the current limit reverts to the maximum value. This action simulates an automatically resetting fuse. Figure 5 shows the action of this hysteresis with a maximum current limit of 2A snapping back to 200mA when exceeded in either direction.

Digitally Controlled V and I
Figure 6 shows a way to combine a D-to-A converter such as the quad 10-bit LTC1664 with an LT1970 to give complete control over output voltage and current. This circuit could be applied as an analog pin driver for ATE applications. The circuit is a difference amplifier with a gain of three to produce ±15V output from 0V to 5V DAC generated inputs. The two other DACs control the maximum output current. Again, Kelvin sensing at the load pin preserves precision voltage control across the load. The enable pin of the LT1970 can be used to strobe new voltage and current limit settings to the load after each DAC update.

Power Comparator
The simple circuit shown in Figure 7 is a different type of comparator. This comparator steers the direction of current flow through the load, which could be resistive, capacitive or inductive. The magnitude of the current is controlled by the normal current limit control input voltages and can be DC or modulated up to 2MHz. There is no voltage feedback so the input voltage drives either the top or the bottom output transistor fully on. The output will source or sink the load current depending on the polarity of the input voltage. On a cautionary note, if the load cannot
conduct the controlled current level
the output voltage will go to one sup-
ply rail or the other. Clamp diodes
from the output to the supplies are
shown together with a small frequency
compensation capacitor at the
SENSE− pin. This is for the case where
the load is highly inductive and able
to generate high voltage transients at
the moment of current reversal.

### Symmetrical Voltage Clamp

Voltage clamping amplifier circuits
are often complicated designs requir-
ing back to back diodes, Zeners or
references to limit the output swing
to a precise level. The ability to lin-
early vary the clamped voltage just
adds more to the challenge. A sym-
metrical clamp circuit (Figure 8) is
fairly simple to implement by using
the current limit sense amplifiers of
the LT1970 to monitor just the out-
put voltage, instead of the output
current. The amplifier operates nor-
manly until the VSENSE+, voltage exceeds
the threshold controlled by the cur-
rent limit control input voltages. The
internal divide by 10 from the control
input to the clamping threshold re-
quires an external divide by 20 resistor
network between the circuit output
and the SENSE+ pin. This allows a 0V
to 5V control signal to produce an
output clamp voltage over the range
of ±80mV to ±10V. Since the thresh-
old voltages are the same in either
direction the output clamping is sym-
metrical. Figure 9 illustrates this
clamping action.

### Conclusion

The LT1970 is a versatile and easy to
use power op amp with a built-in
precision adjustable current limit,
which can protect load circuitry from
damage caused by excessive power
from the amplifier. This feature is
particularly useful in ATE systems
where the load is variable (and possi-
ibly faulty) at each tested node. Tight
control of the output current in these
systems is important to prevent dam-
age to the tested unit. The LT1970’s
ability to control both output voltage
and current makes possible many
innovative applications that other-
wise would be difficult or impractic
to implement.