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Power Op Amp Protects Load Circuitry with Precise Current Limiting

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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. Some power amplifiers provide slightly more protection with a programmable fixed current limit, where the maximum output current is fixed at a (hopefully) safer level using an external resistor. 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

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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_{SENSE}). These input pins are typically connected across a small external current sensing resistor, R_{CS}. 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_{SENSE} 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_{SENSE} 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_{SENSE}/R_{CS} with V_{SENSE} 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:

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

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

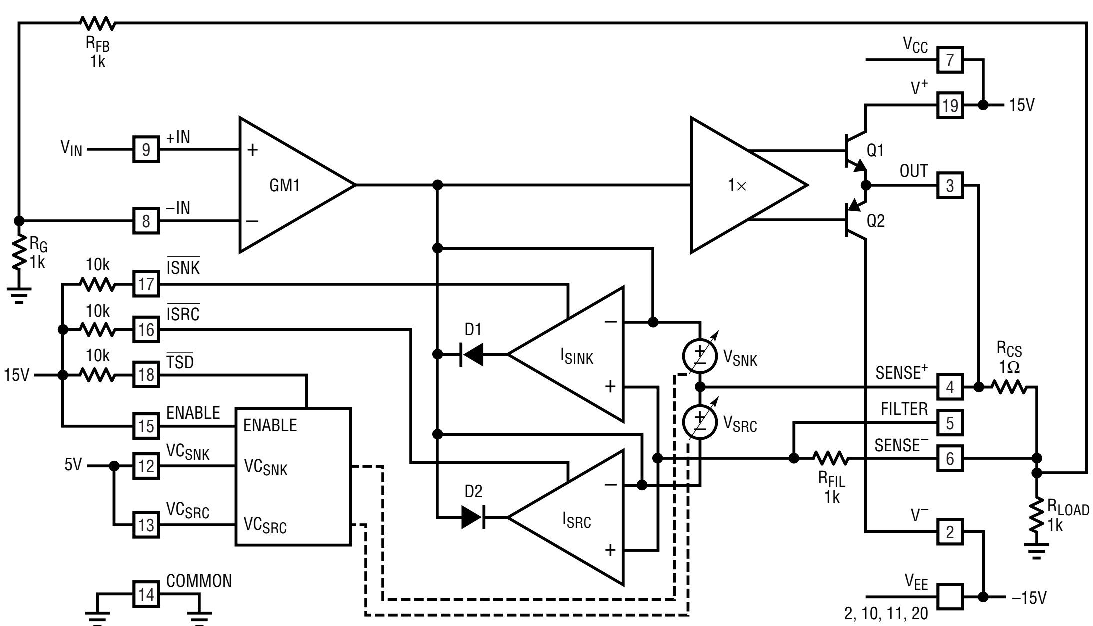

Figure 1. The LT1970 is a basic power amplifier with built-in voltage control of the output current limit.

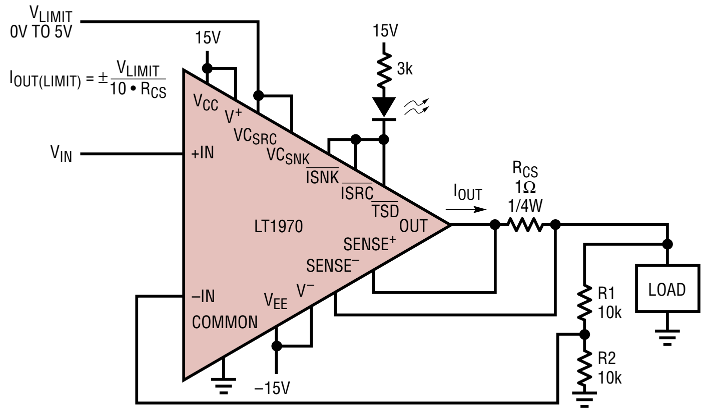

Figure 2. A typical LT1970 circuit

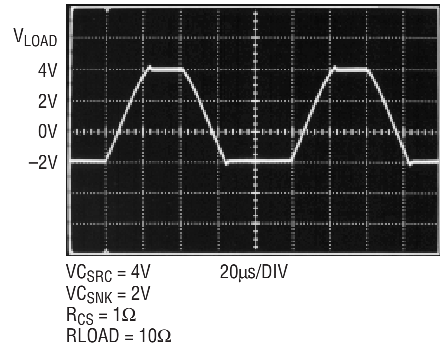

Figure 3. Current limiting clamps the output voltage of the circuit of Figure 2 at precise levels. Independent control allows different sourcing and sinking current limits.

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 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

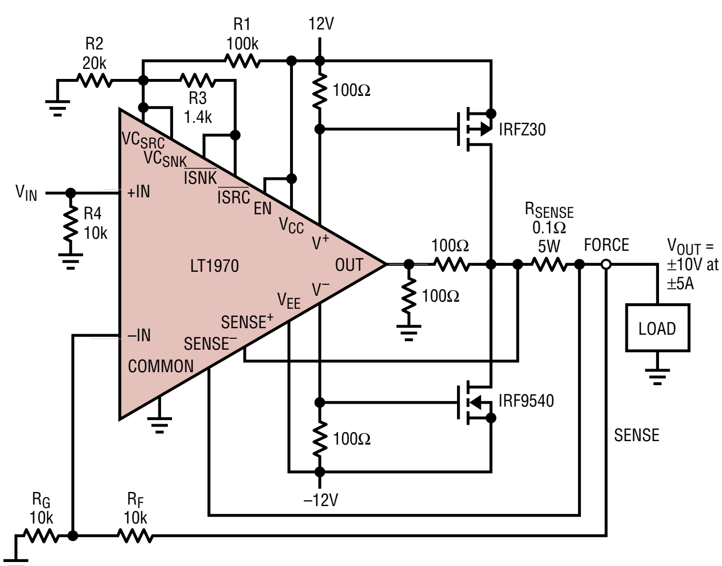

Figure 4. Boosting the output current capability to ±5A

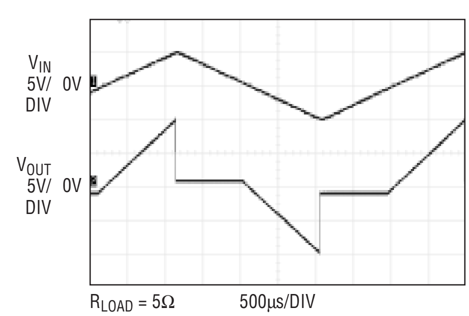

Figure 5. Snap-back current limiting provides an added measure of safety.

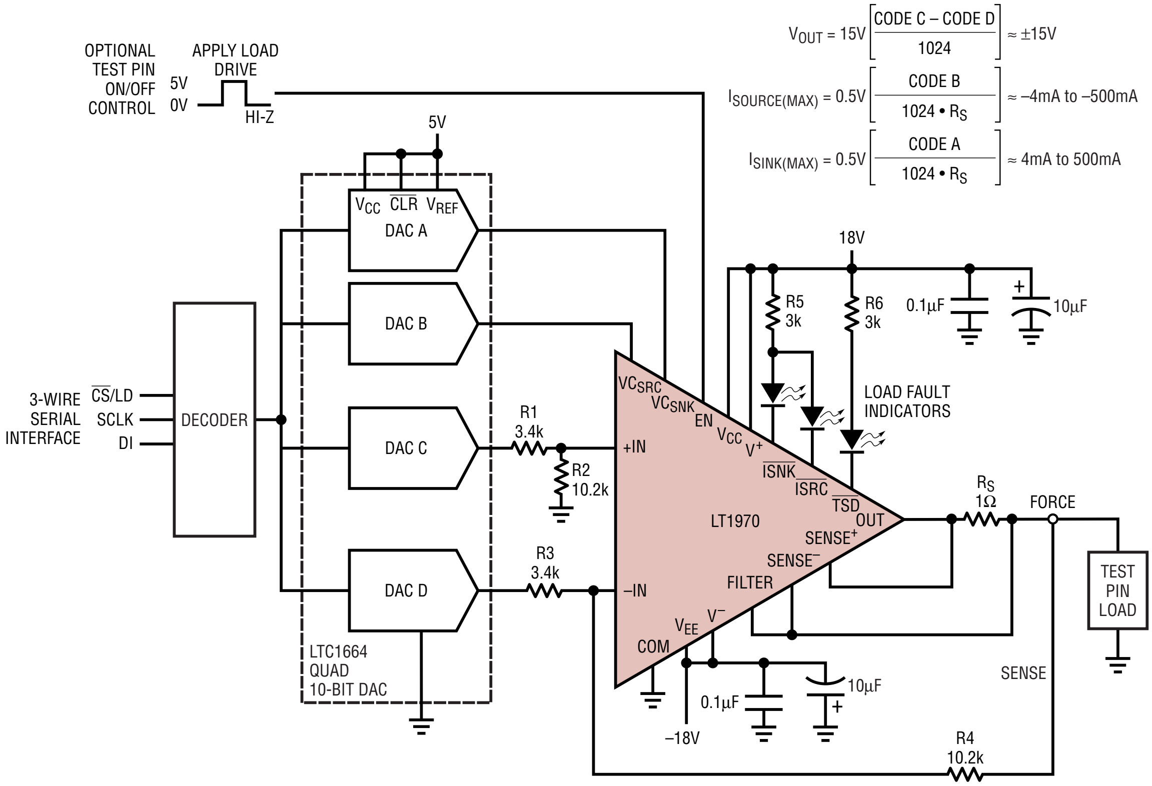

Figure 6. An analog pin driver with DAC controlled parameters

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

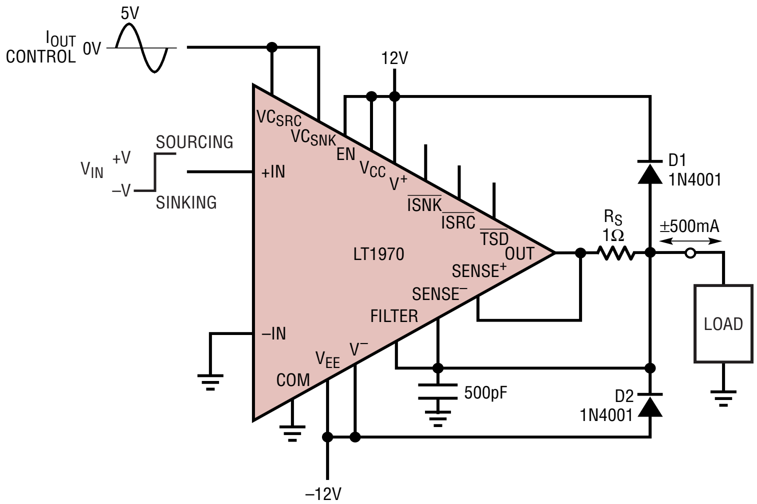

Figure 7. A power comparator steers a controlled amount of output current.

conduct the controlled current level the output voltage will go to one supply 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 requiring back to back diodes, Zeners or references to limit the output swing to a precise level. The ability to linearly vary the clamped voltage just adds more to the challenge. A symmetrical clamp circuit (Figure 8) is fairly simple to implement by using the current limit sense amplifiers of the LT1970 to monitor just the output voltage, instead of the output current. The amplifier operates normally until the V_{SENSE+} voltage exceeds the threshold controlled by the current limit control input voltages. The internal divide by 10 from the control input to the clamping threshold requires 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 threshold voltages are the same in either direction the output clamping is symmetrical. Figure 9 illustrates this clamping action.

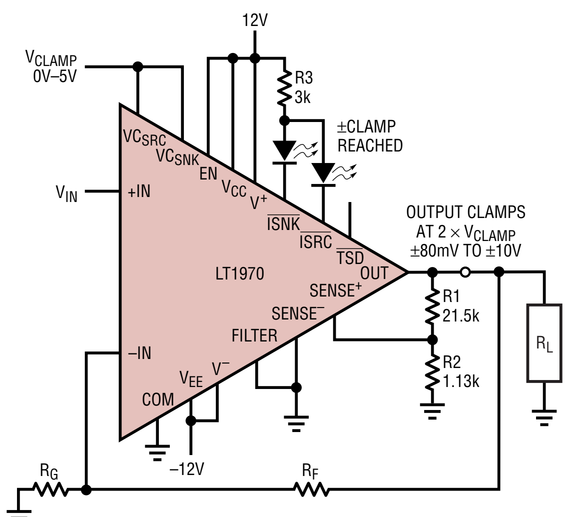

Figure 8. Symmetrical output voltage clamping is easy to implement with the LT1970.

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 possibly faulty) at each tested node. Tight control of the output current in these systems is important to prevent damage to the tested unit. The LT1970's ability to control both output voltage and current makes possible many innovative applications that otherwise would be difficult or impractical to implement.

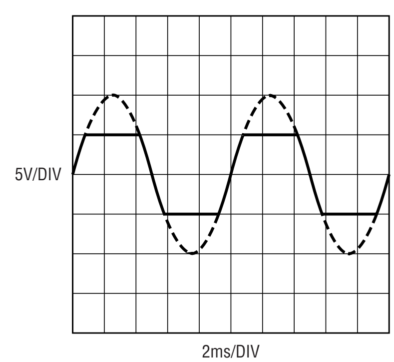

Figure 9. Voltage clamping response of the circuit of Figure 8