

Semiconductor Current Regulators Protect Circuits

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Current regulators (non-switchable and switchable) are a new family of useful and versatile devices targeted for use in communications, networking, and power conversion circuits. Current regulators (or current sources) traditionally consist of resistors and other discrete active components, and are extensively used in the design of high performance analog and mixed signal circuits and systems. These simple-to-use, two-terminal fixed current regulators, or switchable three-terminal current regulators, allow designers to simplify their circuits. Additionally, a family of non-switchable non-polarized ac current regulators are also available for applications requiring current limiting in ac circuits.

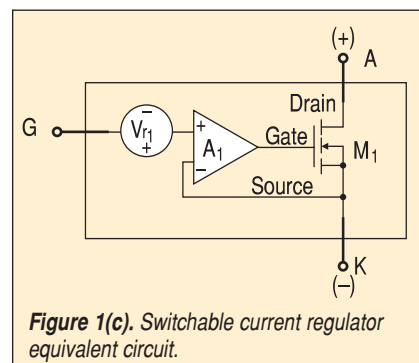
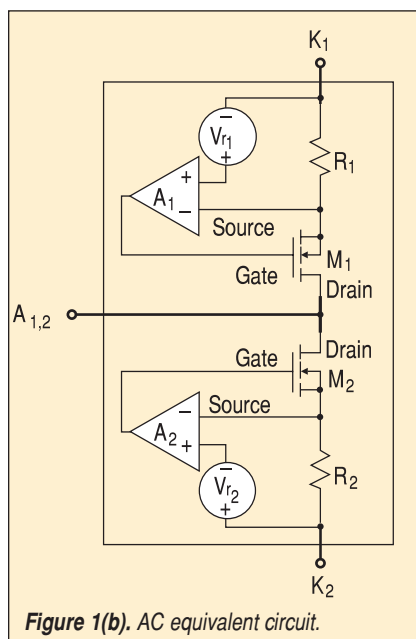
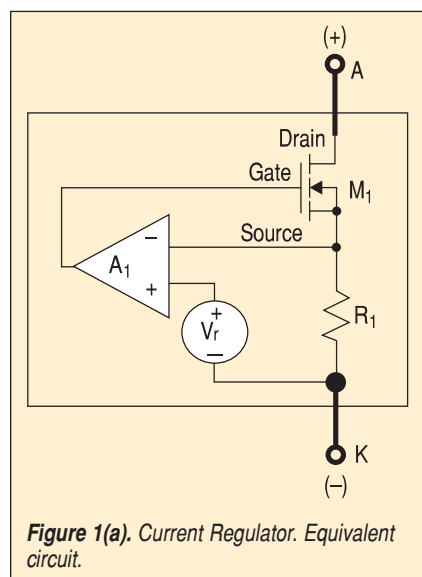
Figure 1(a) shows the equivalent circuit of a dc current regulator. M1 is a high voltage discrete MOSFET whose gate is driven by

A family of current regulators can be used to create minimum component, high performance power supplies, power supply and network protection circuits, active noise filters, and wide dynamic range Class A amplifiers.

amplifier A1, and whose inverting input is the intersection of the M1 source and the top of a current sense resistor, R1. A1's other input is the output of a reference voltage, V_r . The negative terminal of V_r connects to the lower side of R1 and becomes the cathode terminal of the current regulator.

In operation, when the M1 drain (the anode of the current regulator) is more positive than its source, the current through it is controlled so that the voltage across R1 is regulated in feedback by A1 to be V_r . V_r is designed to be

approximately 3.0V so that if R1 is chosen as 300 Ω , then the regulated current is 10mA. In the ac current regulator equivalent circuit (Figure 1b), two current regulator circuits are placed back-to-back to limit current flow in either direction. Figure 1(c) shows the equivalent circuit of the switchable current regulator in which the current sensing resistor can be selected by the user to provide regulated currents up to 100mA. A plot of plateau current, $I_{D(P)}$, vs external resistance, R_K , is in Figure 2(a). Figure 2(b) shows the circuit with an external resistance.



Current Regulators

Some current regulator applications involve voltages $>48V$, and so precautions should be taken. Also, many or all of the designs may require heat sinking, overcurrent and overtemperature protection.

Power Supply Protection

Power supply applications tend to be cost sensitive and require high reliability. The main system power supply may have built-in protection, such as

short-circuit, overcurrent, and overtemperature. Assume a system power supply (Figure 3) drives m loads and load #3 is shorted. Protection features built into this system power supply will detect the short and gracefully shut it down. Because of the short, all m loads will lose their power. In fact, the system power will be unavailable until the shorted load is removed.

Figure 4 shows the same power distribution system with current regulators in series with all m loads. Assume again that load #3 is shorted, so the voltage into load #3 will collapse to zero. The current regulator, IC_3 , allows load #3 to go to zero without pulling down or overloading the system power supply. The other $m-1$ loads will continue to receive power. In fact, one of the loads may even have redundant circuitry built into it that reports to the CPU that load #3 went down, and that it will take over whatever tasks #3 was doing. Other similar strategies may be used to implement overall system robustness and uninterrupted operation. Here, current regulators, IC_1 through IC_m , in series with the m loads provide added flexibility and system capability.

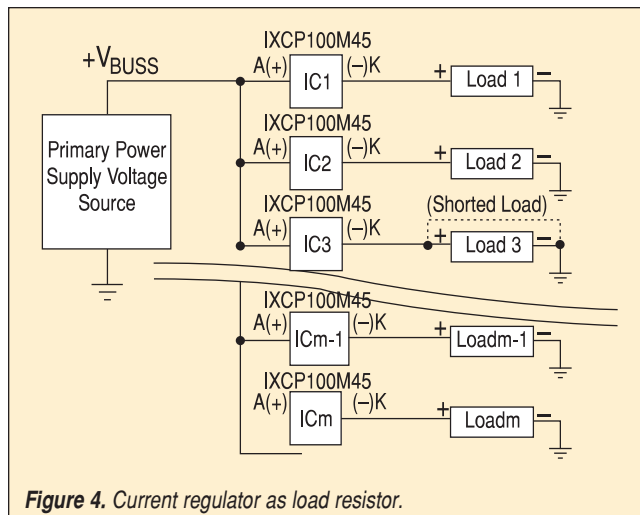
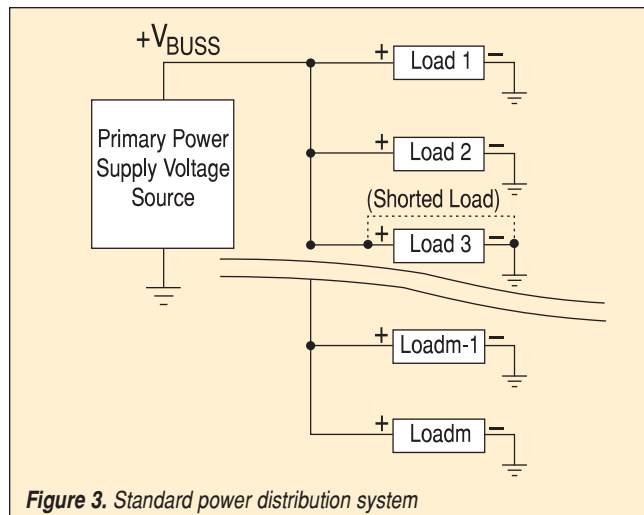
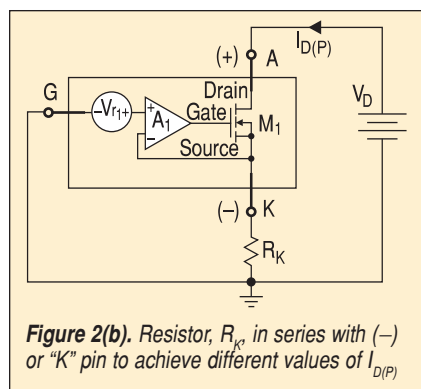
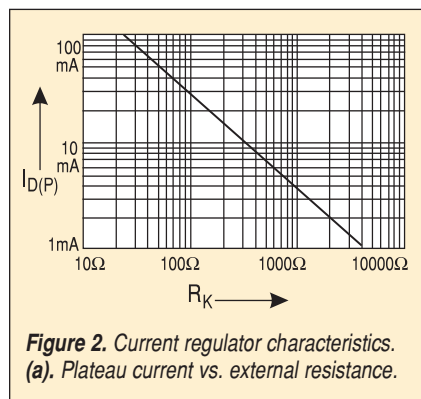
In some applications the load may be located away from the system power source. Therefore, it is essential to account for the possibility of cabling shorts not only to ground but to some other potential, such as the ac

mains, where potentials may be of opposite polarity or even greater than the voltage provided by the system power supply. Instead of a dc current regulator, (IXCP10M45 through IXCP100M45) a bidirectional ac current regulator such as the IXCP50MAC45 would be needed. If more than 100mA is required, current regulators may be paralleled.

Protecting SMPS

Switching power supplies generate high frequency noise that is difficult to reduce or eliminate. The noise may be due to: internal clocking transients, high speed turn-on and off of the output switches, momentary cross-conduction of the upper and lower switches, the snappiness of the switching free-wheeling diodes, stray inductances, and other factors. Instead of using bulky passive inductors and capacitors for filtering, current regulators can be used to emulate an infinite value inductor (analogous to a voltage source that can emulate an infinite value capacitor).

An LM317 linear regulator acts a noise filter in the SMPS of Figure 5(a). Figure 5(b) shows a current regulator with a zener diode as an SMPS noise filter. Both circuits are designed to output $\sim +29V @ 80mA$, with a $\sim 6V$ input-to-output drop. For noise rejection, the key parameter is input power supply ripple rejection; the better it is, the better the noise rejection. At



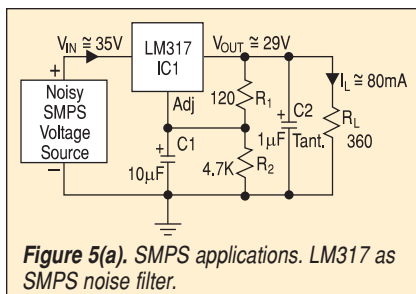


Figure 5(a). SMPS applications. LM317 as SMPS noise filter.

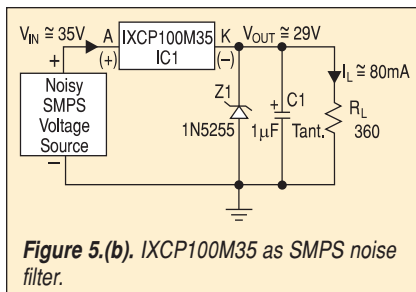


Figure 5(b). IXCP100M35 as SMPS noise filter.

first, it may appear that linear regulators would work better, especially based on its typical data sheet specification of 80 dB rejection with a minimum of 66dB at 120Hz. Noise components from a switcher, especially one running at several hundreds of kHz, has noise components beyond 10MHz. A linear regulator's 80dB ripple rejection at 120Hz is 17db at 1MHz. *Figure 6* compares the LM317's ripple rejection with that of the current regulator. The current regulator ripple rejection starts at 58dB and is still 46dB at 1MHz, 19dB better power supply rejection at 1MHz!

Simple IC solutions don't exist for a 48V power supply active noise filter. Both circuits in *Figure 7(a)* and *(b)* provide 58db of noise rejection at 1MHz with an input-to-output drop of ~6V, as before. The circuit in *Figure 7(a)* uses a resistor and filter capacitor; the one in *Figure 7(b)* uses a current regulator to do an equivalent task. The filter capacitor is a 1000μF, 63V, low ESR type (0.05Ω ESR, Panasonic ECE-A1JFS102). The physical size of this capacitor is almost two orders of magnitude larger than that of the current regulator.

Off-line Power Supplies

High voltage current regulators

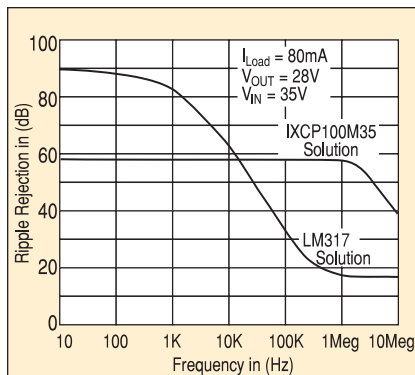


Figure 6. Ripple rejection comparison between LM317 and IXCP100M35 solutions.

simplify design of universal, off-line power supplies operating from 90Vac to 260Vac by minimizing component count and cost. The off-line power supply in *Figure 8(a)* provides a regulated +43Vdc @ 80mA. A simple, 5W, zener diode, Z1, sets the 43V output. Key points to note are the small size and value of the input and output filter capacitor, C1=22μF and C2=39μF, respectively. As a comparison, similar ripple and output current performance for a universal off-line power supply is in *Figure 8(b)*. The conventional circuit of *Figure 8(b)* uses much larger input and output capacitors: C1=100μF and C2=220μF, respectively. Due to the wide variation in currents sourced by the widely varying ac input, three 5W zener diodes, Z1, Z2, and Z3, are needed to meet the power dissipation requirements. Also, the dropping resistor value is 1kΩ, at 100W. In contrast, the current regulator, IC1, IXCP100M45 only needs to dissipate 33W.

The multiple output, off-line power supply in *Figure 9* has two zener diodes stacked to produce 15V and +5V. By inspection, the +5V output current, I_{outb} , is what is left over from the +15V output current, I_{outa} . For example, with the maximum of 20mA available from IC1, IXCP20M45, if I_{outa} consumes 5mA, then I_{outb} cannot be greater than 10mA. *Figure 10* shows that an off-line negative output supply can be created just as easily.

Current regulators in universal, off-line power supplies reduce overall

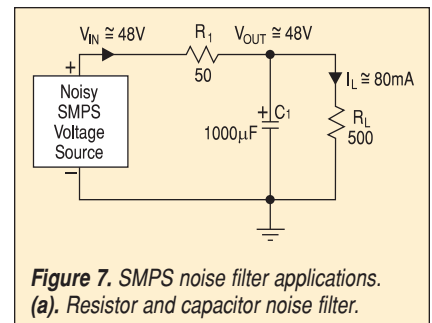


Figure 7. SMPS noise filter applications. (a). Resistor and capacitor noise filter.

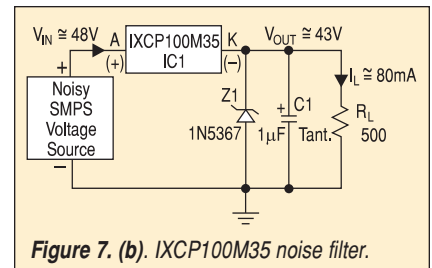


Figure 7. (b). IXCP100M35 noise filter.

cost, size and heat generation. Because no inductors are used, there are inherently no radiated emissions, as is the case with off-line switchers. As an added benefit, the low value input capacitor, C1, minimizes power factor issues. Using a dropping resistor to reduce the rectified off-line voltages is no longer necessary and is an expensive alternative. Current regulator-based off-line power supplies are an attractive alternative for output requirements less than 100mA.

Protecting Cables

Current regulators in series with network and telecommunications cables will protect sensitive, mission critical equipment from inadvertent network cable shorts to ground or to destructive ac power. Network cables can be snaked next to ac power cables as well as grounded conduit. They may even run unprotected across factory floors and can short at some point. An ac current regulator placed in series with networking equipment — one at the output of such equipment and the other at the input of a network card — can protect both systems from cable shorts to ground or to the other more dangerous (and lethal) ac mains power. It is not unusual that network cabling becomes snaked or has its insulation scraped when cross-

Current Regulators

ing an ac mains. It may even melt, which then results in a short to one of the network conductors and the ac mains. The current regulators in *Figure 11* illustrate their placement with respect to the twisted wire cabling, network hub and the remotes.

If you had a current regulator protection system as in *Figure 11*, the worst that would occur will be the network card somehow misbehaving due to noise. (The current limited ac mains into your network card will definitely be seen by your network card as unwanted noise.) You would call your network administrator — complain that your net isn't working properly. The administrator will confirm that there is something wrong with the network cabling and runs another cable to your office from the network hub. As a word of caution, check with your network administrator to be sure that the components added in series with the network shown in *Figure 11* don't affect the reliability of the network connection.

Current regulators can also act as start-up devices for universal off-line SMPS. These power supplies must contend with input power voltages as low as 90Vac and as high as 260Vac. This translates to full wave rectified voltage range of 127Vdc to 368Vdc. *Figure 12* shows a start-up circuit for a universal off-line SMPS. Depending on the application, the designer selects the current range required — from 2mA and up. Because the power dissipation across a current regulator only goes directly with the voltage across it, the circuit in *Figure 12* provides the most efficient solution without shutting off the start-up circuit during normal operation.

Figure 13 shows a start-up circuit using the switchable current regulator circuit, IXCP10M45S, which is shut down whenever the SMPS provides a Power Good (PGD) signal. This circuit improves the overall efficiency of the SMPS by turning off unneeded

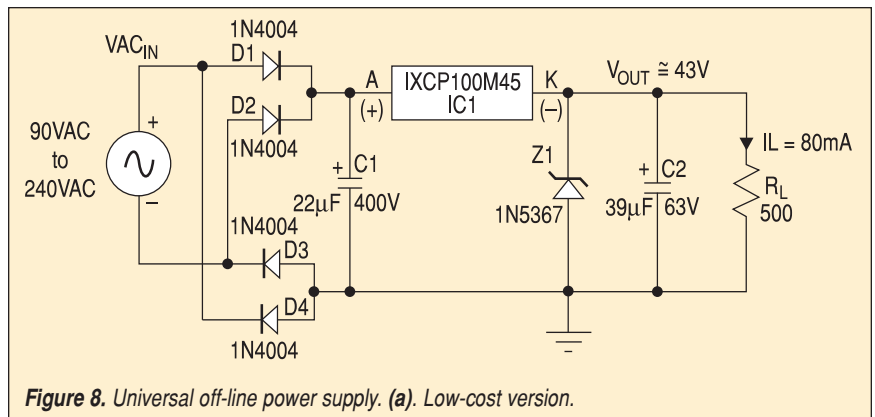


Figure 8. Universal off-line power supply. (a). Low-cost version.

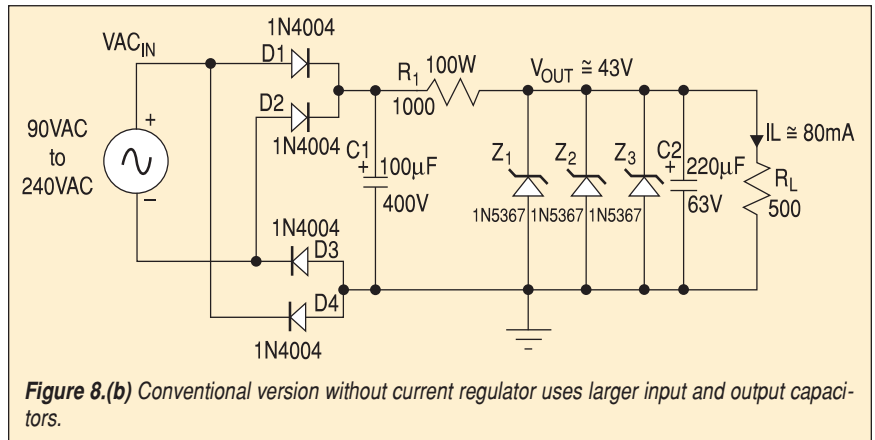


Figure 8.(b) Conventional version without current regulator uses larger input and output capacitors.

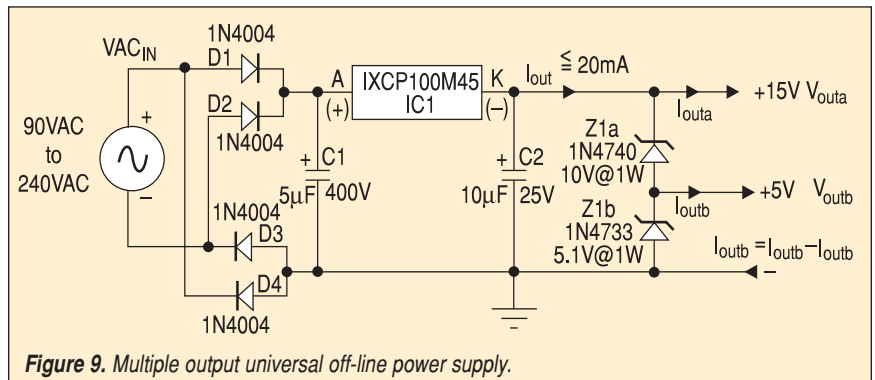


Figure 9. Multiple output universal off-line power supply.

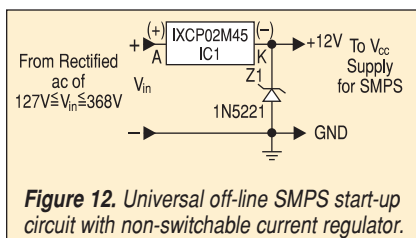
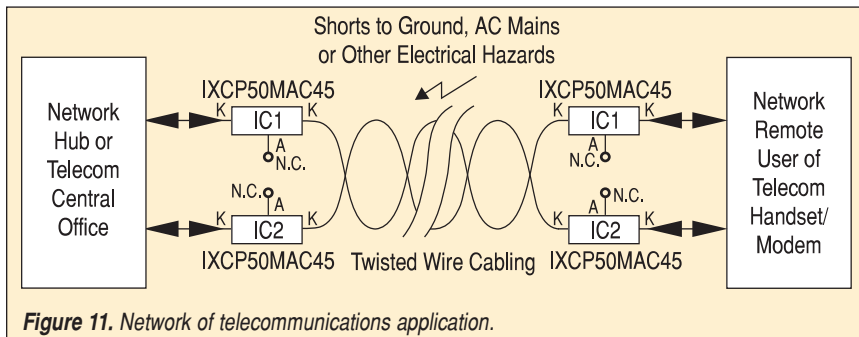
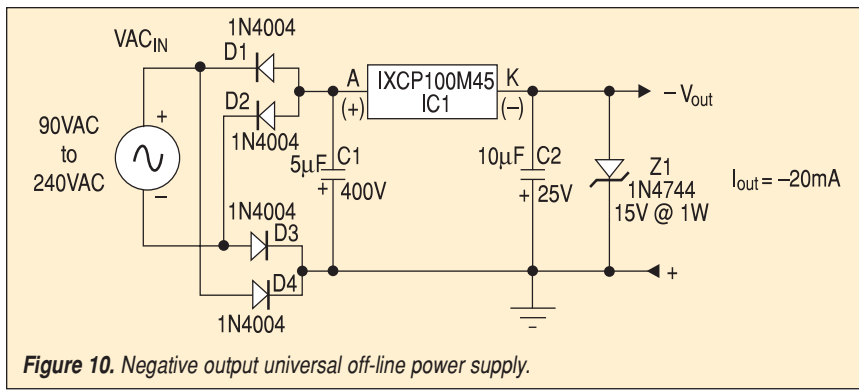
circuits during normal operation. R1 is used to adjust the IXCP10M45S device regulating current to 1mA, as shown in *Figure 2(a)*.

Floating DC Power

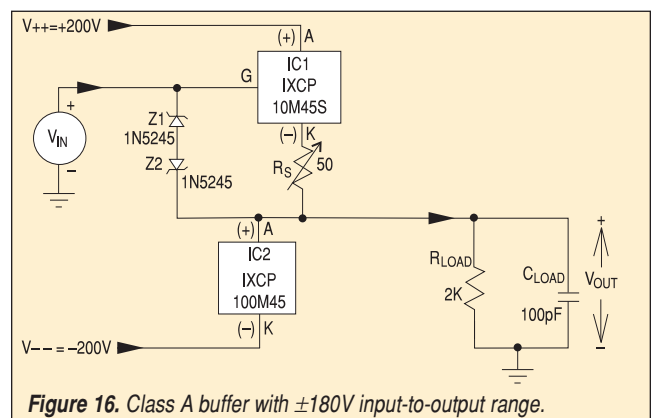
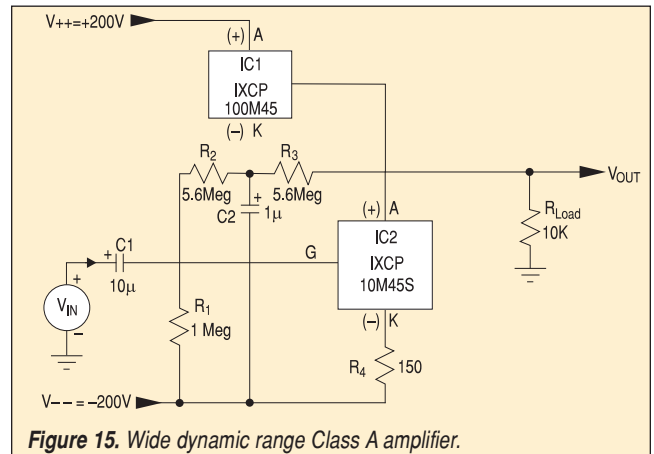
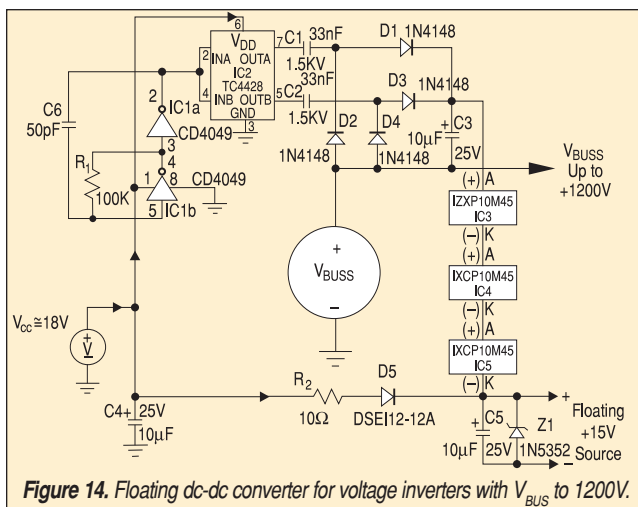
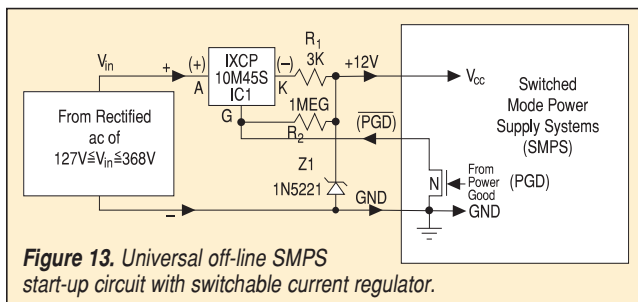
Current regulators can be used to replace isolated dc-dc converters needed to power most gate drivers and current sensors that surround today's high power IGBTs and MOSFETs. The circuit in *Figure 14* implements a floating dc voltage source to power the IC gate drivers used to drive and protect high power IGBTs and MOSFETs. This same circuit can

also be used to power other circuitry, such as current sensors, temperature sensors and others.

The 10mA current regulators, IC3 through IC5, provide the trickle current needed to keep the IC gate driver power supply storage capacitor from discharging during periods when the IGBT or MOSFET is in either the on or off state for long periods. These current regulators are stacked in series to provide the full 1200Vdc breakdown needed by the application. The bootstrap circuit with D1 and R1 supplies the greater power needed during switching. Zener diode, Z1, keeps the



floating V_{CC} power below +15V between V_{CC} and the emitter or source of the driven IGBT and MOSFET. The anode return of the current regulator is at a voltage greater than V_{BUS} by 15V to



17V. The power supply circuit for this low current supply is the simple charge pump circuit also in *Figure 14*. Here, the TSC427 is used to provide buffering to an oscillator output running at 100kHz. Capacitors C1 and C2 act as the charge pump capacitors to turn on D1 and D3 during positive going edges and D2 and D4 clamp the top plate of C1 and C2 during the negative going edges.

Advantages of the circuit provided in *Figure 14* are:

- Very low cost compared with other floating power supply solutions — such as modular dc-dc converters
- No magnetics to take up space and introduce additional EMI
- Very low capacitance to the floating node — only the reverse biased junction capacitances of the bootstrap diode and the current regulator are all that are connected to the floating V_{CC} node
- Low component count and space requirements

Current Regulators

Amplifier Circuits

Current regulators can also be employed in high voltage, wide dynamic range analog circuits. Class A circuits are still the only way to obtain uncompromising amplifier performance where absolute linearity coupled with excellent transient response are needed. *Figure 15* shows a Class A amplifier with -3db points at 10Hz and 2MHz. It provides a gain of 55, and a $\pm 180\text{V}$ peak-to-peak output. The high peak-to-peak output can provide unclipped and uncompressed dynamic range of over 160dB — equivalent to a 28-bit A/D-D/A combination. The amplifier maintains its linearity performance with source degeneration and keeping the change in drain current during operation to no more than 10% of its nominal range provided by IC1, the 100mA IXCP100M45 current regulator.

The source follower in *Figure 16* uses IC1, the switchable current regulator IXCP10M45S, as the input device followed by a pull-down current source, the IXCP100M45. Zener diodes Z1 and Z2, 1N5245 are used to protect the gate of IC1. By placing a resistor in series with the upper device, the input to output offset can be set to zero. This circuit will swing within $\pm 10\text{V}$ of the full supply voltage of $\pm 200\text{V}$.

Figure 17 uses the source followers in combination with the Class A amplifier to create a feedback amplifier with buffered input and output. The first source follower, IC1, buffers the input and drives the source of IC2. The second

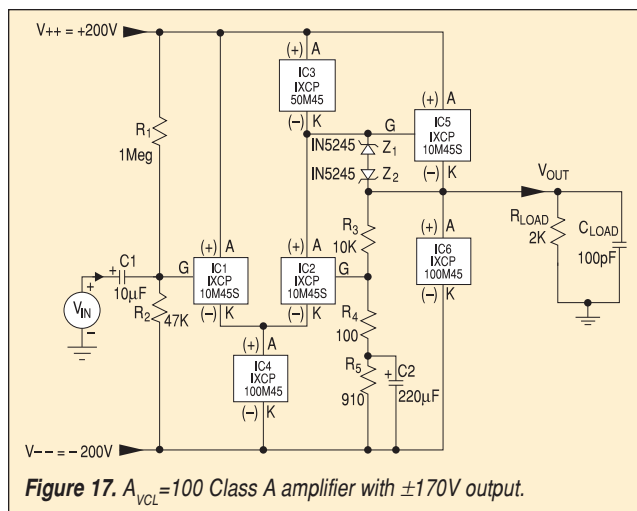


Figure 17. $A_{VCL}=100$ Class A amplifier with $\pm 170\text{V}$ output.

source follower, IC5, buffers the high impedance drain output of IC2 from the load, which is modeled as a $2\text{K}\Omega$ in parallel with 100pF. The Class A amplifier circuit in *Figure 17* is designed for a closed loop gain of 100 with its -3dB bandwidth corners fixed at 10Hz and 2MHz.

Current regulators are available in fixed current ranges from 1mA to 100mA. Also available are ac current regulators from 10mA to 50mA ranges. For additional design flexibility, switchable current regulators can be externally programmed to currents from under 1mA to above 100mA. Presently available are current regulators rated at 350V and 450V, and higher voltages are presently in development.