design ideas

Edited by Bill Travis

Slow diodes or handy timing devices?

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Most designers consider slowness in diodes to be an imperfection or a limitation. Why not take a more positive view of the situation? After all, a zener or an avalanche diode is no more than a diode with a limited breakdown voltage, and you can view a varactor as a diode with a large and nonlinear parasitic capacitance. Similarly, could you view the slowness of a diode as a property or even a feature? For example, consider a PIN diode. Few people are aware that the key property of a PIN diode is indeed its slowness; without it, it would generate large amounts of distortion and require a larger control current to function properly. You can put this ability of slow diodes to store large amounts of electrical charge to good use in a variety of other circuits. **Figure 1** shows how to generate dead time using such diodes. A PWM sandcastle (stepped) waveform feeds a half-bridge.

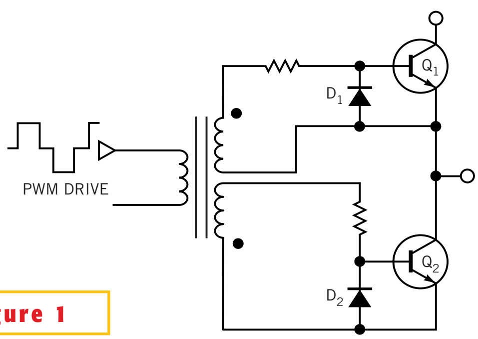

Figure 1

You can use slow diodes to generate dead time in a half-bridge configuration.

In a classical implementation, you must insert dead time in the control circuitry to avoid the simultaneous conduction of the two transistors when the duty cycle approaches 100%. This dead time is a standard feature of PWM-control ICs. If you use slow diodes for D_1 and D_2, you need no dead time. If, for example, Q_1 receives a positive base, or gate, drive and is therefore conducting, D_2 becomes forward-biased. When the control signal reverses its polarity, a negative bias appears immediately on Q_1, but D_2 cannot instantly cease conducting and short-circuits the base drive to Q_2 during all of its reverse recovery time. The advantage of generating a dead time in this way lies in the fact that you need include only a small safety margin: The phenomena governing the recovery time of a diode are similar to those resulting in storage times in power devices. In particular, they both display a strong positive-temperature coefficient, for which this scheme compensates. The ability to operate at duty cycles close to 100% allows a better usage of the power components, translating into savings and higher performance: A universal-input supply, for instance, can operate at lower supply voltages.

Figure 2 shows another example. This standard clamping circuit protects the switching transistor of a flyback converter against the voltage spike generated by the imperfect coupling between the primary and the secondary windings of the transformer. In an equivalent schematic, this scenario translates into a leakage inductance, L_F, in series with the primary winding. The circuit works in the following way: Each time the transistor turns off, the current in the leakage inductance continues to flow, but D_1 intercepts it and "redirects" it to C_1. C_1 has a large enough capacitance that cycle-to-cycle variations do not influence it. The average voltage on C_1 results from a balance between the charging input from the leakage inductance and the current that bleeds from R_1. Usually, D_1 is a fast diode, but, if you substitute it with a slow one, interesting things happen: Instead of switching off when the voltage on C_1 reaches its peak, D_1 continues to conduct, thus transferring back charge and energy from C_1 to the transformer and ultimately to the load. The overall efficiency is therefore better, and R_1 can have higher resistance and can be smaller. Added to the lower cost of a standard diode versus a fast one, the method provides non-negligible benefits.

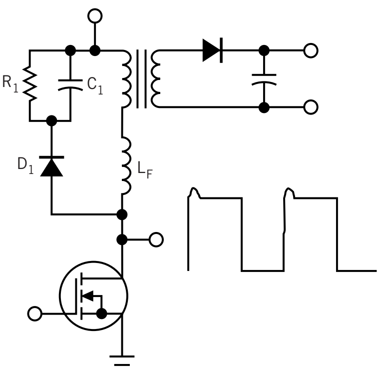

Figure 2

In this circuit, a slow diode protects the switching transistor from destructive voltage transients.

It is preferable to select a diode with a recovery time as long as possible. Popular types, such as the 1N400X series, have recovery times of approximately 2.5 μsec, but some models reach more than 5 μsec. Ideally, C_1 and L_F should resonate at a period equal to twice the diode's recovery

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time. When the component values are nearly optimum, R_1 can have a large value, its only role being to provide a "seed" current to prime the circuit. You pay a small penalty for these advantages: The peak clamping voltage increases by several volts, because you must add the positive cycle of the resonance to the average clamping voltage and because slow diodes often exhibit a slightly poorer forward-recovery characteristic than do their fast counterparts. This characteristic results in a step of several volts at the beginning of the conduction.

Normally, these small snags should pose no problem; you can substitute the new components in a design without any other change. The circuits in **figures 1** and **2** are only two examples, but you can apply the same useful principles to a variety of other circuits.□

Diode compensates distortion in amplifier stage

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THE VOLTAGE AMPLIFIER in **Figure 1** exhibits smaller nonlinear distortion than does the conventional amplifier in **Figure 2**. Diode D_1 compensates for the distortion inherent in the npn transistor. The voltage gain of a common-emitter amplifier depends on the transconductance of the transistor. The transconductance of the bipolar transistor is as follows:

$$S=\frac{eI}{k(273+T°C)}=nI,$$

where e is the charge of an electron, k is Boltzmann's constant (approximately 1.38×10^{-23}J/°K), T°C is temperature in degrees Celsius, I is the emitter current, and n=e/[k(273+T°C)]. So, the transconductance is proportional to the emitter current. Consequently, the instantaneous voltage-gain coefficient of the conventional common-emitter amplifier is proportional to the instantaneous emitter current. As a result, the negative half-cycle of the output signal gets more amplification than does the positive half-cycle (**Figure 3**).

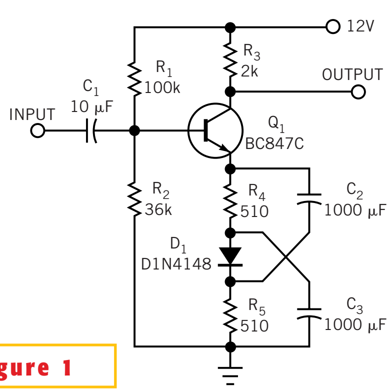

Figure 1 The addition of a simple diode in the emitter circuit yields the symmetric waveform of Figure 4.

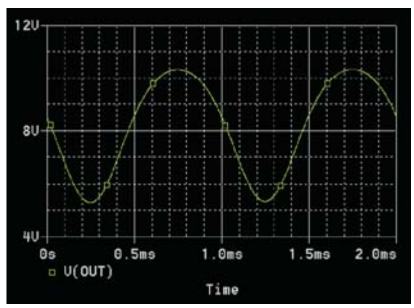

Figure 3 Nonlinearity of the transconductance of Q_1 results in this distorted waveform.

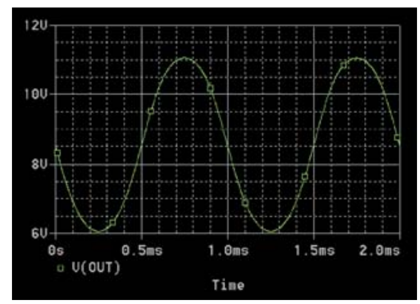

Figure 4 The diode in the circuit of Figure 1 produces varying, beneficial, negative feedback.

The dynamic resistance of diode D_1 in **Figure 1** is inversely proportional to the instantaneous current. That dynamic resistance forms part of the negative-feedback circuit of the amplifier. The average current of diode D_1 is equal to the average emitter current of transistor Q_1. However, the instantaneous current of D_1 becomes smaller, and the instantaneous dynamic resistance of D_1 becomes larger when the instantaneous emitter current of Q_1 becomes larger, and vice versa. Therefore, the negative feedback becomes stronger during the negative half-cycle of the output signal. As a result, the output signal of the amplifier becomes more symmetric (**Figure 4**). The circuits in **figures 1** and **2** have the same average collector current and the same load resistance. **Figures 3** and **4** show the results of their PSpice simulation. The amplitude of the output signal is 5V p-p in both cases with a 1-kHz sinusoidal signal applied to the input. You can see that the linearized amplifier yields a more symmetrical output signal. **Figure 5** gives the quantitative results of the simulations. The improvement in harmonic distortion accrues because of the suppression of the even harmonics in the output of the linearized amplifier.□

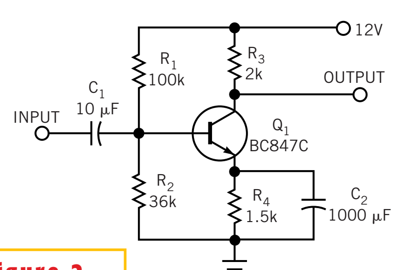

Figure 2 This amplifier circuit produces the distorted waveform of Figure 3.

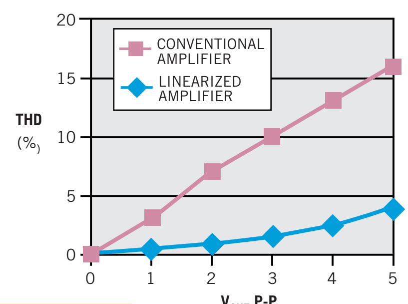

Figure 5 The linearized amplifier produces less than one-third the harmonic distortion of the conventional amplifier.

Transistors offer overload delay

Christophe Basso, On Semiconductor, Toulouse, France

Although an SMPS (switch-mode power supply) can protect itself against permanent short circuits, it sometimes has problems when dealing with transient overloads. Transient overloads are not short circuits but can push the power supply above its nominal load value. This scenario occurs with typical loads such as printer heads and small motors. When facing such a load profile, the power supply can easily trigger its protection circuit, especially if the open-loop gain is high. You will see any decrease in the output voltage on the primary side as a loss of feedback current, because the controller cannot keep the voltage constant.

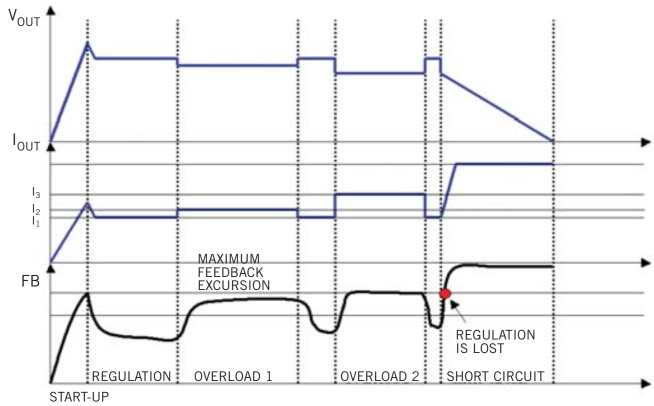

Figure 1 Overloads and short circuits can be similar in this typical power profile for a printer.

Figure 1 shows a typical power profile for a printer. You can clearly see the power variations and the corresponding feedback-voltage swings that occur. The start-up sequence is a short circuit because, with V_{OUT} far from its target, the feedback current is not yet established. The nominal output current, I_1, corresponds to the regulation zone, in which the load is constant. When a first overload occurs (I_2 in **Figure 1**), the feedback pin pushes the primary-current setpoint (in a current-mode controller), but the waveform's excursion starts to diminish, because it is approaching its maximum level. In I_3, the power supply has difficulty remaining in regulation and, in short-circuit condition, V_{OUT} collapses to ground. If the primary PWM controller has a simple short-circuit-protection scheme, the protection mechanism can trigger in the overload zones 1 and 2, whereas it should trigger only in the final one. **Figure 2** portrays an approach based on the NCP1200 from On Semiconductor (www.onsemi.com).

This circuit permanently monitors the feedback line (Pin 2) to detect whether a short circuit is present on the secondary side. If so, Pin 2 jumps to its internal pullup voltage and triggers a protective burst mode. Note that this protection acts independently of any badly coupled auxiliary level, because the high-voltage source (Pin 8) directly powers the controller. In the presence of overloads 1 and 2, Pin 2 would jump to the maximum of its capability and would trigger the protection. This circuit does not delay the rise of the feedback voltage but momentarily increases the output-power level by a given percentage. When I_{OUT} is within regulation, Pin 2 is below 3V and D_1 is not biased. As a result, Q_2 is blocked and Q_1 pulls R_3's lower terminal to ground. The current-sense pin therefore sees a current image, which the voltage-divider ratio of R_2 and R_3 affects.

In this example, $V_{PIN4} = V_{SENSE} \times R_3/(R_3+R_2) = 0.82 \times V_{SENSE}$, where V_{SENSE} is the voltage across R_{SENSE}. If the NCP1200 imposes a maximum-current setpoint of 1V, the IC authorizes 1.2V over R_{SENSE} as long as Q_1 is biased (instead of 1V in a regular configuration). As soon as Pin 2 jumps to a higher value, such as 4V, indicating a loss of regulation or a severe overload, D_1

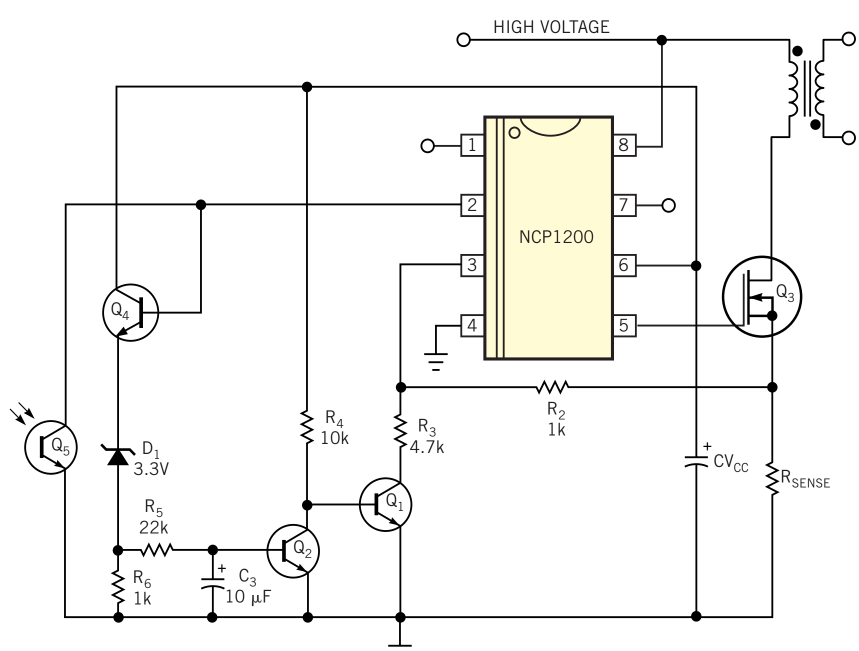

Figure 2 A transistor network increases the peak current for a moment until the power supply gives up by reducing the peak setpoint.

starts to conduct via Q_4. This transistor buffers the feedback-pin impedance: C_3 starts to charge up via R_5, and, when it reaches approximately 0.7V at 25°C, Q_1 opens. The divider goes away, the power supply no longer ensures a large peak current, and V_{OUT} goes down, thereby properly triggering the protection. As result, by dimensioning the R_5 and C_3 elements, you can insert a delay to enable the supply to cope with transient loads.□

Inertial-navigation system uses silicon sensors

Tom Niemi, Rockwell Collins, Cedar Rapids, IA

A STRAP-DOWN inertial-navigation system uses silicon sensors to measure displacement without entailing the bulk and expense of moving parts or GPS receivers. For example, a three-axis accelerometer and three angular-rate sensors can determine the position and velocity of a vehicle such as a robot or radio-controlled aircraft. This hardware configuration requires that you read and integrate the sensor outputs and then combine and process them to obtain stabilized location values. **Figure 1** shows one such complete system. An inexpensive 8-bit microcontroller can handle the sensor reading and integration tasks, and perform simple lowpass filtering of the accelerometer's output to remove conversion noise. The microcontroller can even run a basic position and velocity algorithm; alternatively, you can pass the preprocessed data to a DSP system. The NEC (www.necelam.com) μPD78-F9418A microcontroller has seven ADC inputs, so it can handle the six inputs from the sensors.

Because a Crossbow (www.crossbow.com) CXL04M3 accelerometer delivers 0.5V/g (9.8m/sec²), it can directly feed three of the microcontroller's ADC inputs. Each NEC/Tokin CG-16D angular-rate sensor generates only 1.1 mV/°/sec, so it requires the aid of an instrumentation amplifier. The Burr-Brown (www.ti.com) INA118 fills the bill. The microcontroller has enough I/O lines to drive three Varitronix (www.varitronix.com) VIM-503 41/2-digit LCDs that display the x, y, and z location relative to the starting point. One of the fundamental tasks in this application is to initialize the sensors and A/D converters to minimize bias error. **Listing 1** at the Web version of this Design Idea at www.edn.com shows the code to calibrate the accelerometer. The routine calculates the average value of the accelerometer's outputs over 1000 samples and uses this information to calculate bias-error adjustments for each axis. You apply each bias value by adding it to the readings for that axis. Using the x axis as an example, you determine the vehicle's movement from its starting point by integrating: Multiply the x-axis reading by the time squared, halve that quantity, and then add the result and the bias value to the previous x position. You find velocity by multiplying the bias-corrected x-axis reading by the time and then adding it to the previous x velocity. You can download the microcontroller code from the Web version of this Design Idea at www.edn.com.□

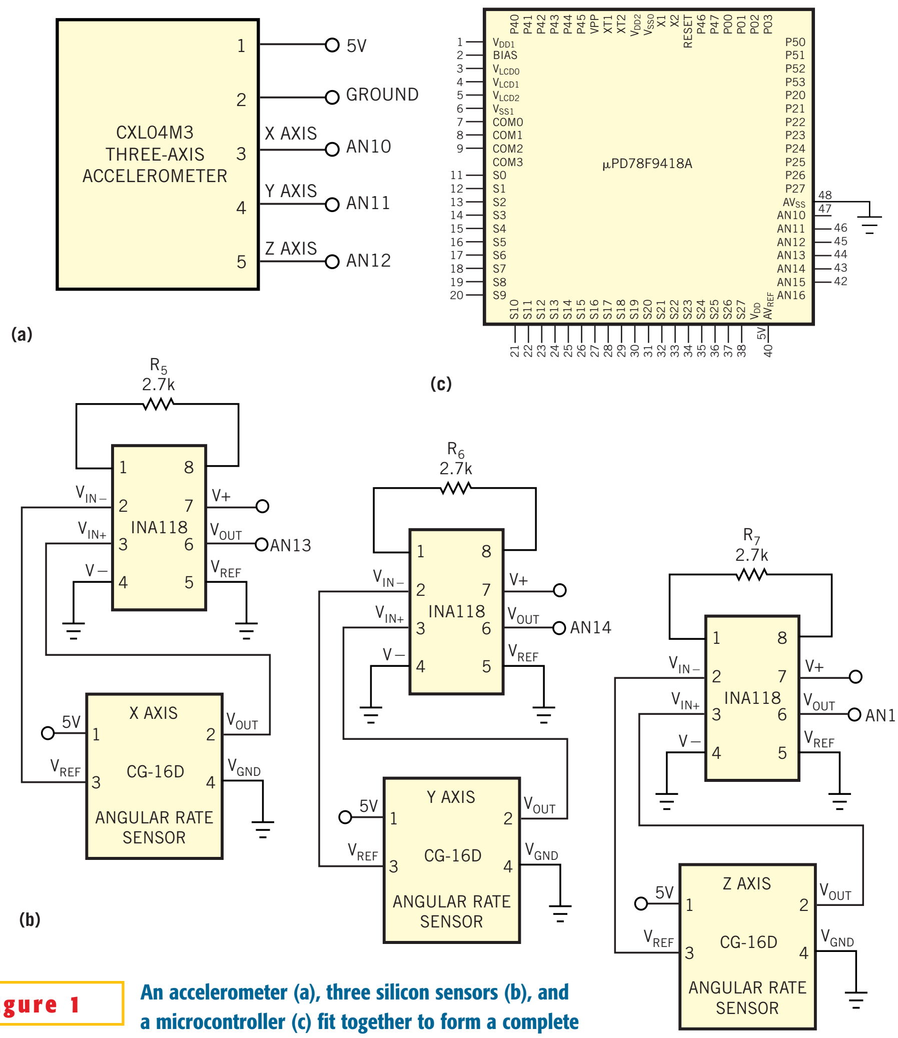

Figure 1 An accelerometer (a), three silicon sensors (b), and a microcontroller (c) fit together to form a complete inertial-navigation system.

LED driver provides oscillator for microcontroller

Wallace Ly, National Semiconductor, Santa Clara, CA

The major building blocks for a white-LED driver are an oscillator, a charge pump, and a regulated current source. National Semiconductor (www.national.com) produces a device that contains all these building blocks in the highly integrated LM2791/2 IC. You usually use white-LED drivers in tandem with cellular baseband controllers or microcontrollers. You can easily adapt the LM2791/2 to provide a clock source. You can realize a simple yet useful circuit by accounting for the fact that a pseudo square wave is present across the flying capacitor's (C_1) pins. You can take this pseudo square wave from these pins and clean it up.

To accomplish this task, you inject the signal, via a 330Ω resistor, R_1, into a simple inverter gate, such as a DM7404 hex inverter (**Figure 1**). The net signal is a clean, 2-MHz clock source. The oscilloscope graph depicts the pseudo square wave and the resultant square wave at the output of the inverters (**Figure 2**). You can use this signal as a simple clock source for a baseband controller or microcontroller to perform simple tasks such as keypad decoding or battery-identification detection.□

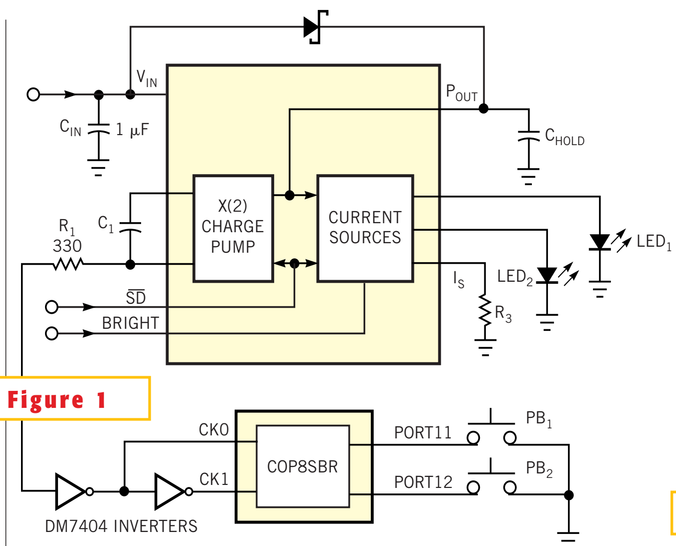

Figure 1

A white-LED driver doubles as a clocking source for a microcontroller.

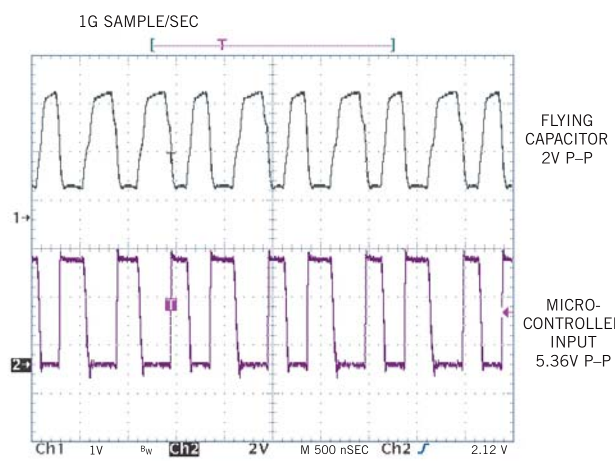

Figure 2

A logic inverter cleans up the pseudo square wave (top) from the flying capacitor; the result (bottom) is a stable clock source for the microcontroller.

Use op-amp injection for Bode analysis

Martin Galinski, Micrel Semiconductor, San Jose, CA

Bode analysis is an excellent way to measure small-signal stability and loop response in power-supply designs. Bode analysis monitors gain and phase of a control loop. It performs this monitoring by breaking the feedback loop and injecting a signal into the feedback node and then comparing the injected signal with the output signal of the control loop. The method requires a network analyzer to sweep the frequency and compare the injected signal with the output signal. The most common method of injection is the use of transformer. **Figure 1** demonstrates how a transformer injects a signal into the feedback network. A 50Ω resistor affords impedance matching to the network-analyzer source. This method allows the dc loop to maintain regulation and allows the network analyzer to insert an ac signal on the dc voltage. The network analyzer then sweeps the source while monitoring A (voltage channel) and R (reference channel) for an A/R-ratio measurement. Although this method is

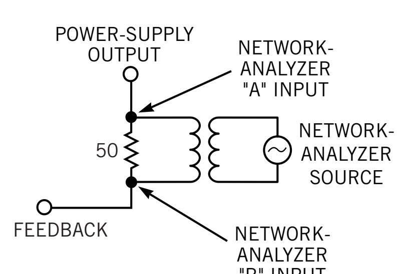

Figure 1

Bode analysis using transformer injection yields gain and phase information in a control loop.

the most common for measuring the gain and phase of a power supply, it has significant limitations. First, to measure low-frequency gain and phase, the transformer needs high inductance. Frequencies lower than 100 Hz, therefore, require a large and expensive transformer.

Also, the transformer must be able to inject high frequencies. Transformers with these wide frequency ranges generally are custom-made and usually cost several hundred dollars. By using an op amp, you can avoid the cost and frequency limitations of an injection transformer. **Figure 2** demonstrates the use of an op amp in a summing- amplifier configuration for signal injection. R_1 and R_2 reduce the dc voltage from the output to the noninverting input by half. The network analyzer is generally a 50Ω source. R_1 and R_2 also divide the ac signal from the network analyzer by half. These two signals "sum" together at half their original input. The output then gains up by a factor of two by R_3 and R_4 and goes to the feedback output. (The 50Ω resistor balances the network analyzer's source impedance.) This action essentially breaks the loop and injects the ac signal on top of the dc output voltage and sends it to the feedback terminal. By monitoring the feedback terminal (R) and output terminal (A), the analyzer measures gain and phase. This method has no minimum frequency. Make sure that the bandwidth of the op amp is much greater than the expected bandwidth of the power supply's control loop. An op amp with at least 100-MHz bandwidth is more than adequate for most linear and switching power supplies.□

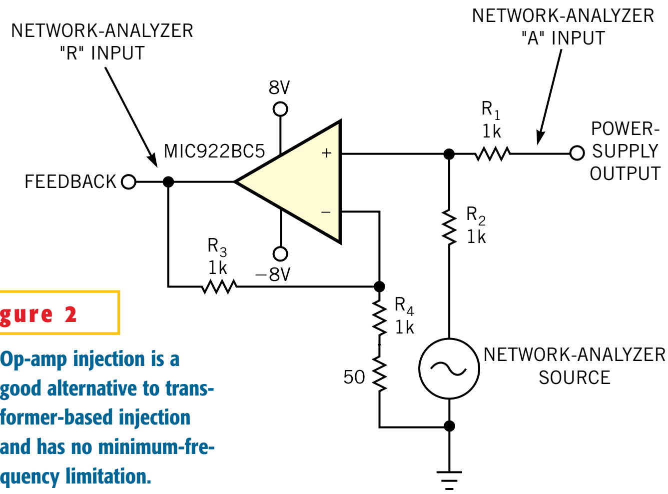

Figure 2

Op-amp injection is a good alternative to transformer-based injection and has no minimum-frequency limitation.