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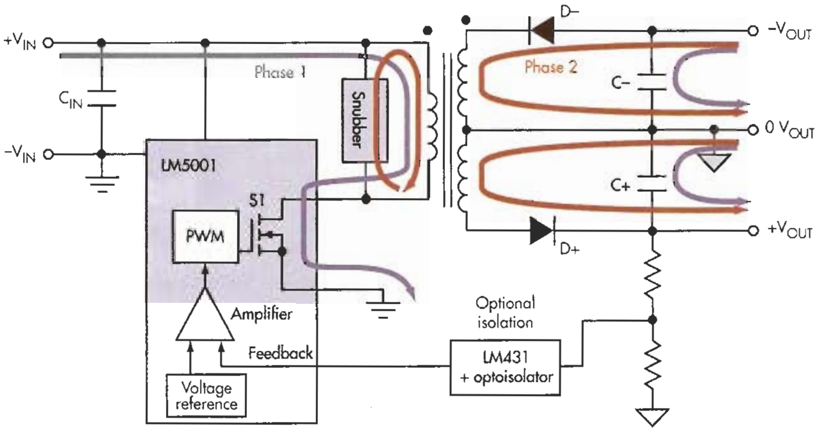
Powering The Signal Path

Using an integrated flyback IC along with post filtering will deliver a high-performance split-rail power supply.

Power delivered to sensitive analog circuitry must be treated differently than power for digital circuitry. All circuits are affected by noise delivered through the power supply, yet analog loads tend to be more sensitive. The actual type of circuitry and application will determine the tolerable noise limits. Powering digital circuitry today is a fairly straightforward task and can be handled with available power design tools, such as National Semiconductor's Webench tools *(www.national.com/webench)*.

Sensitive analog designs like those found within medical and video systems often require lower-noise power sources. System designers must pay special attention to ensure the power-supply rails don't contain noise above amplitude limits within specific areas of concern. Noise may need to be limited to specific amplitudes over frequency ranges that the system is dealing with (or harmonics of these frequencies).



1. The basic flyback architecture converts a wide input voltage into one or more output voltages.

SPLIT-RAIL POWERING OF ANALOG CIRCUITS

When biasing sensitive analog circuitry, designers often turn to split-rail power circuits to get optimal performance. Analog-system designers utilize differential power rails centered around a system ground to maintain a low-impedance analog reference. Creating an analog reference above system ground (often called a virtual ground) can result in subsequent signal distortion problems.

A virtual ground can be created with resistors or an active circuit that sets a reference voltage for analog operations (amplifiers, integrators, comparators, etc.). When employing a virtual ground, a designer must deal with the fact that it will vary with ground currents passing through this node (which will always be the case).

As ground currents vary, the virtual ground will also vary by the product of the ground current and the impedance of the node, resulting in unwanted distortion in the signal path. When a true ground is used for the analog ground, this distortion doesn't exist because the impedance of the ground itself is 0 (or close to it). Therefore, currents in/out of the node will not cause any voltage change.

Another advantage of designing with a true ground reference is the ability to drive analog signals biased above and below earth ground. This provides clear advantages when it comes to driving differential signals between different earth ground potentials, as seen when driving signals between systems on different power grids.

No matter what tolerances and differences exist between the driving circuit and receiving circuit, the receiver knows where to find the analog signal. Also, the analog signal biased around earth ground can expect lower leakage currents as compared to a signal that's always at a potential above (or below) earth ground. Leakage current can result in higher distortion and attenuation of the analog signal being carried. True analog grounds also reduce the risk of signal problems during power up or powering down a circuit. Audio designs often need to deal with clicks and pops generated during powering up or down a circuit when using a virtual ground.

Numerous approaches exist to create a split-rail power supply, all of which have tradeoffs. Design techniques include switch capacitor, buck-boost, and Cuk architectures, which are briefly explained in the online version of this article.

ISOLATED POWER

Different physical locations are often at different voltage potentials. When power and/or a signal (analog or digital) is connected to a remote location, a designer must be aware that the ground differences between locations could cause system-related problems. When grounds are connected together across cables, one may find unwanted ground currents that can result in increased noise, negatively affecting system performance.

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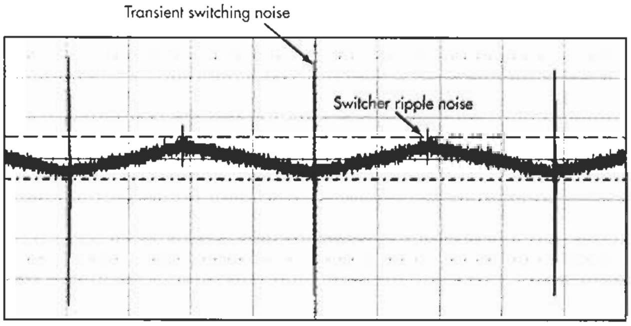


2. Transient and ripple noise in switching power supplies develops from the turn on and off of switching devices and the charge and discharge cycle of the output capacitor.

Designers often need to isolate analog signals using coupling capacitors or transformers. But for dc signals, this may require special signal coding to ensure spectral density for proper energy transfer. By isolating a power supply, one can float an entire circuit, thus eliminating potential noise issues. In addition, floating the power supply and associated circuitry can produce better noise immunity, especially when it comes to induced noise such as electrostatic discharge (ESD) or electromagnetic interference (EMI). The design discussed in this article provides the option of isolating the ground and analog rails being generated.

FLYBACK TOPOLOGY

A flyback switching topology converts a wide input voltage into one or more output voltages with the option of isolating the output(s) from the inputs *(Fig. 1)*. As discussed above, output isolation is used when the power supply delivers power to a remote location where the ground reference voltages may differ. In place of the inductor found in other switching-regulator architectures, a transformer (or coupled inductors) is used as the inductive storage element.

The regulator toggles between two phases at the switching frequency. During phase 1, the primary switch is closed, causing current flow into the transformer core (shown in blue). Also, the secondary catch diodes (D+ and D–) remain off, and energy is delivered to the output from the output capacitors (C+ and C–). During phase 2, the secondary delivers energy to the outputs and output capacitors via the forward-biased catch diodes (shown in red). The output capacitors are charged during phase 2 to ensure continuous delivery of energy during phase 1.

During transitions between the two phases, current changes paths, which causes voltage excursions that must be considered. As the regulator enters phase 2, the primary switch is opened and the primary current continues to flow as the primary field collapses. The result of this current flow will be a high voltage induced across the switch.

This transient voltage can result in two different problematic issues: the voltage may exceed the limits of the IC itself, and the high-voltage transients can produce coupled and emitted noise. Placing a circuit across the primary winding of the transformer (often called a snubber) can limit this voltage, significantly reducing both of these issues.

POWER-SUPPLY NOISE

Noise can enter an analog system from many paths, including from the power supply itself. Though a properly designed circuit will reject certain amounts of power-supply noise, the lower the power-supply noise, the lower the signal distortion caused by such noise. The move to switching power in sensitive analog systems will continue to increase as designers are forced to be more conscious of power-efficient design.

Switching-regulator noise is generated from multiple sources, with the highest contributions related to the "switching" of current flow. Switching of the current flow transfers energy between passive storage elements (inductors and capacitors) that use diodes and transistors to perform the switching. Devices charge during some cycles and discharge during others, resulting in ripple currents and ripple voltages. Switching ripple on power-supply output voltages may be intolerable when biasing analog circuitry, yet often acceptable with digital circuits *(Fig. 2)*.

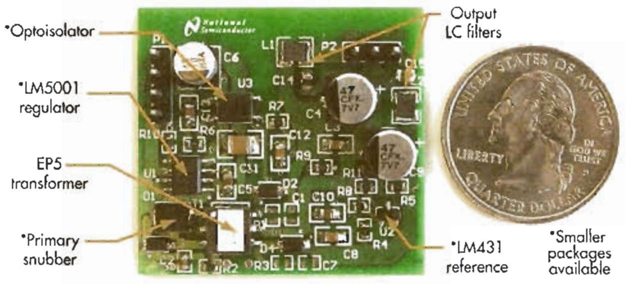
In addition, the ability to establish a fixed frequency in a switching regulator(s) lets the designer move the switching noise to a frequency that doesn't cause unwanted interference. Locking a regulator's oscillator to a fixed (or variable) frequency can provide significant performance advantages in analog systems. System designers can lock the regulator frequency to an available clock or to a software-controlled counter/timer and, as needed, employ software to dynamically move the switching frequency.

Switching power supplies all exhibit noise associated with the charge and discharge cycle of the output capacitor

Table 1: Output Regulation*

V_{IN}	I_{OUT} (A)	$+V_{OUT}$	$-V_{OUT}$	V_{OUT} (+ to –)
8.00	0.025	4.99	-4.99	9.98
8.00	0.100	4.98	-4.98	9.96
8.00	0.250	4.97	-4.97	9.94
12.00	0.025	4.99	-4.99	9.98
12.00	0.100	4.98	-4.98	9.96
12.00	0.250	4.97	-4.97	9.94
24.00	0.025	4.99	-4.99	9.98
24.00	0.100	4.98	-4.98	9.96
24.00	0.250	4.98	-4.97	9.95
30.00	0.025	4.99	-4.98	9.98
30.00	0.100	4.98	-4.98	9.96
30.00	0.250	4.98	-4.97	9.95

**load from +5 V_{OUT} to –5 V_{OUT}*



3. An entire isolated-power, switch-mode power supply delivers ±5 V at 250 mA.

(called ripple noise), as well as the transient noise caused by the turn on and turn off of the switching devices (as discussed earlier). To reduce ripple noise, boost the switching frequency and/or increase the inductance of the transformer.

Higher frequency reduces ripple noise, yet there's always a limit to the switching frequency. Frequency limit is a function of the switches being employed and the pulse-width limit of the regulator itself. At higher frequencies, the output switches will dissipate more power caused by the ac losses. This loss should be considered when selecting a switching frequency.

Since the transformer turns ratio in a flyback converter can be selected to provide an ideal input/output voltage ratio, the minimum pulse-width limit is often not a limiting factor with a flyback design, as it is with other switching topologies.
The flyback controller does have a maximum oscillator frequency that must be understood, yet often switching losses limit the frequency well before the oscillator's limit.

Adding a noise filter to the output of a switching power supply is a good way to reduce switcher noise. A simple LC low-pass filter helps lower ripple and transient noise to a level acceptable for most analog power supplies. The design discussed later adds a series inductor followed by a capacitor to ground to provide the required filtering needed.

In lieu of an LC filter, some designers may opt for an additional linear regulator after a switch-mode regulator. The idea is to use a switching regulator to regulate to just above the voltage needed for the linear regulator to operate properly (called the dropout voltage). Driving the linear regulator input just above the dropout voltage creates an accurate voltage with minimal loss across the linear regulator. Linear regulators can be used as noise filter circuits, but be aware that a linear regulator itself doesn't provide much switching noise attenuation.

These regulators usually have minimal effect on noise above just a few kilohertz, yet properly chosen input and output capacitors can provide significant low-pass filtering. For very sensitive analog circuitry, one needs to pay attention to the noise generated by the linear regulator. Low-noise linear regulators are available for biasing of such circuitry.

Table 2: Cross Regulation

V_{IN} = 15 V	$-V_{OUT}$ = 180 Ω* (27 mA)		$-V_{OUT}$ = 20 Ω* (250 mA)	
$+V_{OUT}$ I_{OUT} (A)	$+V_{OUT}$	$-V_{OUT}$	$+V_{OUT}$	$-V_{OUT}$
0.025	4.99	-4.97	4.99	-4.71
0.050	4.98	-5.03	4.98	-4.79
0.100	4.98	-5.10	4.98	-4.86
0.150	4.98	-5.14	4.98	-4.90
0.200	4.97	-5.19	4.98	-4.94
0.250	4.97	-5.23	4.97	-4.97

*load from 0 V_{OUT} to - V_{OUT}

KEY DESIGN ELEMENTS

The circuit shown in Figure 3 uses the LM5001 integrated flyback regulator, developed by National Semiconductor, with a very small surface-mount EP5 transformer. This circuit inputs 9 V to 30 V and comfortably delivers 250 mA on each output (±5 V). A system requiring higher current can use the LM5000 to deliver about twice this amount of power.

Isolation: When the need arises for input to output isolation, isolation must be added from the output(s) back to the regulator's feedback input. This is accomplished by simply adding an LM431 voltage-reference/amplifier IC to monitor the output voltage and feed back an error current through an optoisolator.

Primary and secondary ground planes should be sufficiently spaced, yet connected with a high-voltage capacitor to reduce unwanted output noise during switching. Isolation limits are set by the breakdown limits of the transformer, the optoisolator, and the capacitor across the ground planes.

Transformer: The transformer should be selected properly for ideal operation, smallest size, and lowest cost. Transformer design includes theory that's not included in this article. Popular inductor companies can use the key parameters from a design to recommend an available transformer or produce a transformer optimized for an application.

The key parameters for the transformer include physical size, inductance, and turns ratio. The physical size and type of core determines the amount of energy that can be stored (in phase 1) before saturation. A larger-sized core also provides the ability to lower the equivalent series resistance (ESR) by using lower gauge wire, resulting in lower losses. In general, the larger the transformer, the more power that can be delivered and/or the better the efficiency.

The inductance determines the transformer's rate of storage and discharge and ultimately the magnitude of its ripple currents. Higher inductance will lower ripple current and can improve operation. Yet as inductance is increased (more turns), the resistance of the winding increases, resulting in higher transformer losses. These tradeoffs should be considered as you select a transformer.

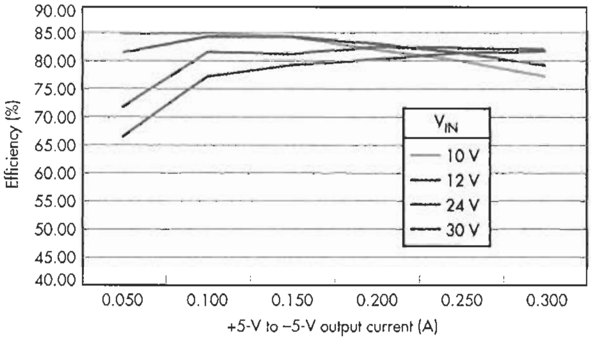
Circuit protection: Current limiting and thermal limiting are provided by the LM5001 series of regulator ICs. The current limit is fixed as per datasheet specification. Though a direct secondary current limit isn't available with basic flyback circuits, power delivered to a heavily loaded secondary will be limited by the IC primary switch-current limit. If the secondary outputs are shorted, the regulator will limit current. Still, the circuit needs to absorb additional power, which results in increased temperatures on the transformer, the catch diodes, and the regulator IC.

Most system implementations work safely without extra protection circuitry on the secondary side of the transformer. But, if the power rails might be inadvertently shorted, some designers may opt to add a fuse or other means of extra protection.

CIRCUIT PERFORMANCE MEASUREMENTS

The circuit shown in Figure 3 is a working design that produces +5-V and –5-V rails on a very small, double-sided printed-circuit board (PCB). These power rails are appropriate for use in biasing most sensitive analog circuits. The device has been successfully employed in designs where the power is delivered from a remote power source (9 V to 29 V). The outputs are fully isolated from the input so that the earth grounds at the two locations can vary without affecting noise on the circuit being powered.

This circuit provides very clean and stable rails for powering a remote analog (and/or digital) system with superior system performance. Other low-noise, split-rail power designs often require multiple regulators, resulting in higher noise, larger PCB size, and higher cost. For a more detailed explanation of the circuit operation and the full design package (PCB, BOM, etc.), go to *www.national.com/rd/RDhtml/RD-171.html.*



4. Shown is the circuit's efficiency at various input and output conditions.

Regulation of the positive rail stays well within 5% tolerance over loads from 25 mA to 250 mA *(Tables 1 and 2).* The negative rail is slightly less accurate, but also maintains 5% cross regulation with loads above 30 mA. Though the negative rail isn't directly regulated with a feedback loop to the regulator, it provides acceptable regulation via mutual coupling of the transformer.

The output noise was measured on each rail with respect to the output ground and the differential +5-V to –5-V noise. In all cases, the transient noise was below 20 mV p-p, and ripple noise is below 5 mV p-p. See the online version of this article *(www.electronicdesign.com)* for oscilloscope shots of the measured noise.

The design described here is very stable and provides over 45° of phase margin. Because the output filter is outside the feedback loop, it does not affect the stability of the control loop. Again, check out the online version of this article for a discussion on loop compensation.

Efficiency of the flyback design shown was measured to be above 80% over most of the operating range *(Fig. 4).* Power losses arise from the transformer, the catch diodes, and the IC itself (internal switch and biasing). As mentioned above, the frequency was limited to limit the ac losses, yet still provides the advantages of a small transformer core size. At low loads and high input voltages, the IC biasing dominates the losses.

At higher loads the transformer begins to saturate and ultimately starts to dominate the loss budget. The design as shown runs without any single element losing significant amounts of energy—thus no component runs at elevated temperatures when delivering full power.

In terms of power-supply noise, any power bus emits electromagnetic interference, which may result in regulatory issues during system testing. Load transients, switching ripple noise, and switching transient noise on a power bus can cause unwanted radiation. Reducing noise via the methods discussed may significantly reduce system EMI.

When measuring noise on a power bus, understand what you see. Large amounts of energy can radiate from power circuits, so a less than ideal probe without proper ground connections can cause incorrect measurements. Use one or two high-frequency probes with a small ground stub. A ground wire of any length can result in false noise measurements.

Taking the time to properly observe the power supplied to analog and high-speed devices is worth the effort. Some bench time early in the prototype debug stage can save a lot of debug time later on.

CONCLUSION

Good analog design starts with a clean analog power supply. The circuit presented provides a very clean and fully isolated +5-V and –5-V rail. The circuit easily fits on a small double-sided PCB with all components placed on one side of the board. The layout shown can shrink further in size by using components available in smaller packages. If isolation is unnecessary, size and cost reductions are possible by removing the feedback isolation circuit.

Higher voltage outputs are possible, and higher currents are attainable, by using the higher-power LM5000. Though the transformer needed for a flyback design does cost more than a single inductor, other approaches will often require more than one inductor and more than one regulator, resulting in a higher overall solution cost, and likely higher noise.

By employing an integrated flyback IC along with post filtering, one can design a high-performance split-rail power supply with superior system results.