SIMPLIFYING CONVERTER DESIGN WITH A NEW INTEGRATED REGULATING PULSE WIDTH MODULATOR

Abstract

A new monolithic integrated circuit is described which contains all the control circuitry for a regulating power supply converter or switching regulator. Included in this 16-pin dual-in-line package is the voltage reference, error amplifier, oscillator, pulse width modulator, pulse steering flip-flop, dual alternating output switches, and current limiting and shutdown circuitry. This device can be used for switching regulators of either polarity, transformer coupled DC to DC converters, transformer-less voltage doublers and polarity converters, as well as other power control applications.

Introduction

Implementing a switching power supply has just become significantly easier with the introduction of the SG1524 series of Regulating Pulse Width Modulator integrated circuits. Long recognized as offering greatly improved efficiencies, the development of switching supplies has been hampered by the complexity of the low-level circuitry required to provide the proper signals for adequate control of the switching transistors. As a result, these supplies have tended to be more costly, larger in size, and with proper reliability than could be justified by their improved efficiency. Even when threats of higher energy costs and potential brown-outs have made switching supplies mandatory, their complexity has made the engineering design task a formidable undertaking.

With the introduction of the SG1524, a major portion of the complex low-level control circuit has been integrated into a single LSI linear integrated circuit. This monolithic chip, packaged in a 16-pin dual-in-line outline, implements the entire block diagram shown in Figure 1.

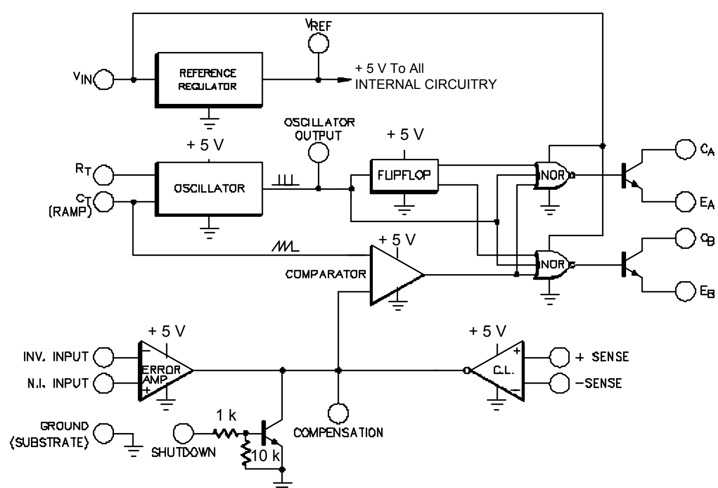

Figure 1. SG1524 Block Diagram

It is the integration of all these different functions into a single IC that qualifies the SG1524 as one of the best examples to date of large scale integration as applied to analog circuits. The remainder of this paper will describe each of the individual blocks in the following diagram in considerable detail and then offer a few basic application suggestions.

Voltage Reference

The reference circuit of the SG1524 is shown in Figure 2. This is a complete linear regulator designed to provide a constant 5 V output with input voltage variations of 8 V to 40 V. It is internally compensated and short circuit protected. It is used both to generate a reference voltage and as the regulated source for all the internal timing and controlling circuitry. This regulator may be bypassed for operation from a fixed 5 V source by connecting pins 15 and 16 together to the input voltage.

In this configuration, the maximum input voltage is 6 V. While discussing input power, it should be mentioned that the entire SG1524 IC draws less than 10 mA of current, regardless of input voltage.

This reference may be used as a 5 V source for other circuitry. It will provide up to 20 mA of output current itself and can easily be expanded to higher currents with an external PNP transistor as shown in Figure 3.

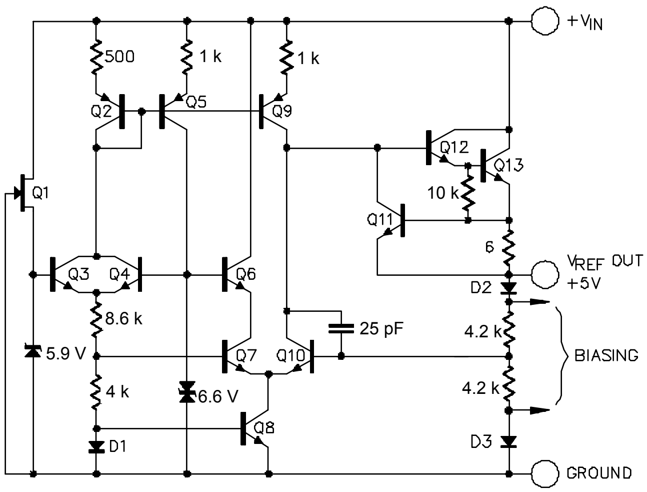

Figure 2. SG1524 Reference Circuit

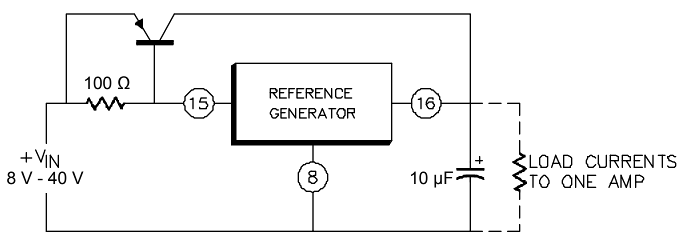

Figure 3. SG1524 Expanded Current Source

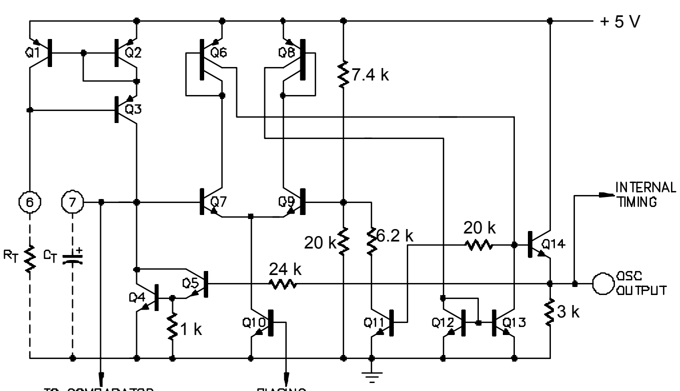

Figure 4. SG1524 Oscillator Circuit

Oscillator

The oscillator in the SG1524 uses an external resistor (R_T) to establish a constant charging current into an external capacitor(C_T). This constant-current charging gives a linear ramp voltage which provides an overall linear relationship between error voltage and output pulse width. The SG1524 oscillator circuit is shown in Figure 4.

A second output from the oscillator is a narrow clock pulse which occurs each time C_T is discharged. This output pulse is used for several functions as outlined below:

1. As a blanking pulse to both outputs to insure that there is no possibility of having both outputs on simultaneously during transitions. The width of this blanking pulse can be controlled to some extent by the value selected for C_T.
2. As a trigger for an internal flip-flop which directs the PWM signal to alternate between the two outputs. Note that for single-ended applications, the two outputs can be connected in parallel and the frequency of the output is the frequency of the oscillator. For push-pull applications, the outputs are separated and the action of the flip-flop provides an output frequency ½ that of the oscillator.
3. As a convenient place to synchronize an oscilloscope for system debugging and maintenance.
4. As a bi-directional port for external timing synchronization. The output pulse from this oscillator which is stable to within 2% over variations in both input voltage and temperature - can be used as a master clock for other circuitry, including other SG1524's. It thus follows that a positive pulse applied to this terminal can synchronize the SG1524 to an external clock signal.

The waveforms of the two outputs from the oscillator are shown in Figure 5.

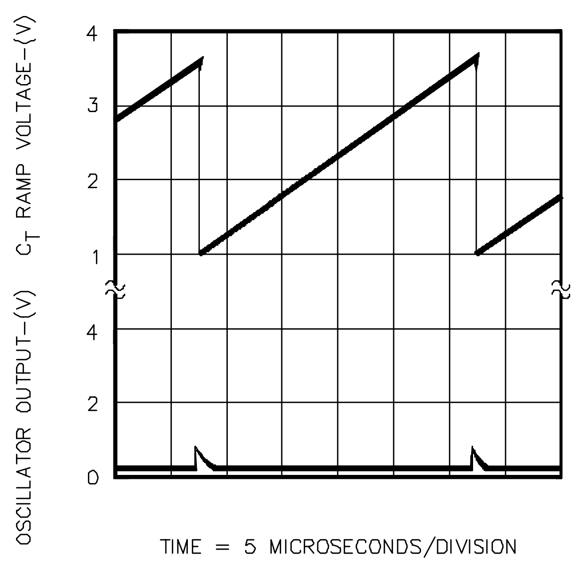

Figure 5. SG1524 Oscillator Waveforms

Error Amplifier

The error amplifier circuit, shown in Figure 6, is a simple differential input, transconductance amplifier. Both inputs and the output are available for maximum versatility. The gain of the amplifier is nominally 10,000 (80 dB) but can be easily reduced by either feedback or by shunting the output to ground with an external resistor. The overall frequency response of this amplifier which, by the way, is not internally compensated but yet is stable with unity gain feedback, is plotted with various values of external load resistance in Figure 7.

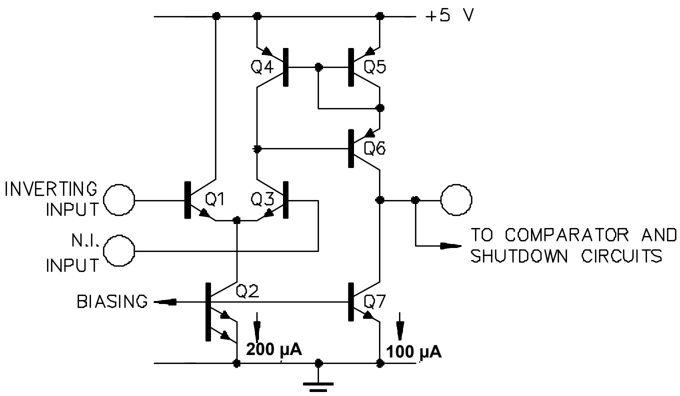

Figure 6. SG1524 Error Amplifier Schematic

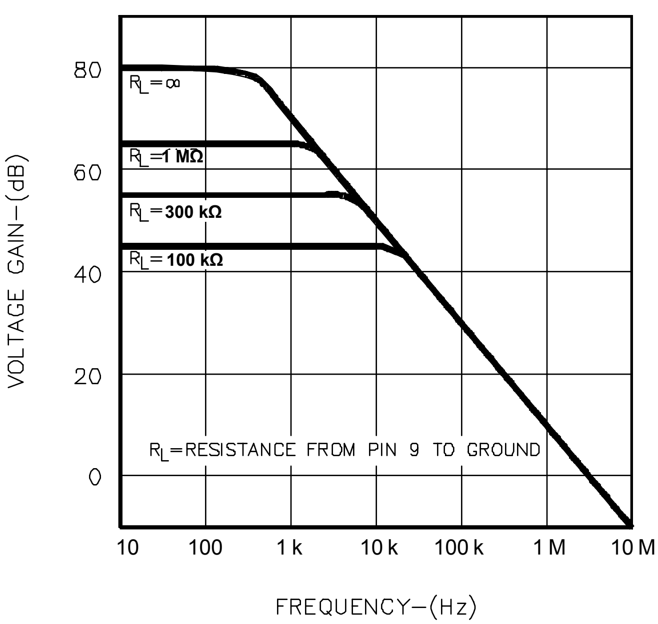

Figure 7. SG1524 Error Amp Frequency Response

Phase shifting to compensate for an output filter pole may readily be accomplished with an external series R-C combination at the output terminal of the amplifier.

Since the error amplifier is powered by the 5 V reference voltage, the acceptable common-mode input voltage range is restricted to 1.8 V to 3.4 V. This means the reference must be divided down to be compatible with the amplifier input, but yet provides the advantage of being able to be used to regulate negative output voltages. Required input dividers are shown in Figure 8.

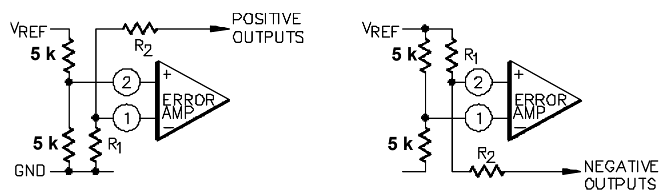

Figure 8. Error Amplifier Connections

Since this amplifier is a transconductance design, the output is a very high impedance (approximately 5 MΩ) and can source or sink only 100 µA. This makes the output terminal (Pin 9) a very convenient place to insert any programming signal which is to override the error amplifier. Internal shutdown and current limit circuits are connected here, but any other circuit which can sink 100 µA can pull this point to ground, thereby shutting off both outputs.

For example, the soft start circuit of Figure 9 can be used to hold Pin 9 to ground - and thus both outputs off - when power is first applied. As the capacitor charges, the output pulse slowly increases from zero to the point where the feedback loop takes control. The diode then isolates this turn-on circuit from whatever frequency stabilizing network might also be connected to Pin 9.

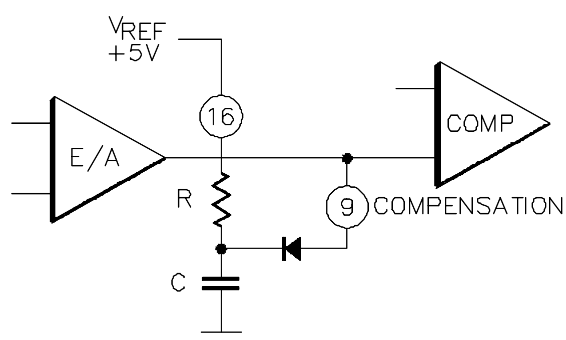

Figure 9. SG1524 Soft Start Circuitry

Current Limiting

The current limiting circuit, while shown in the block diagram as op-amp, is really only a single transistor amplifier as shown in Figure 10. It is frequency compensated and has a second transistor to provide temperature compensation and a reduction of input threshold to 200 mV. When this threshold is exceeded, the amplifying transistor turns on and, by pulling the output of the error amplifier toward ground, linearly decreases the output pulse width.

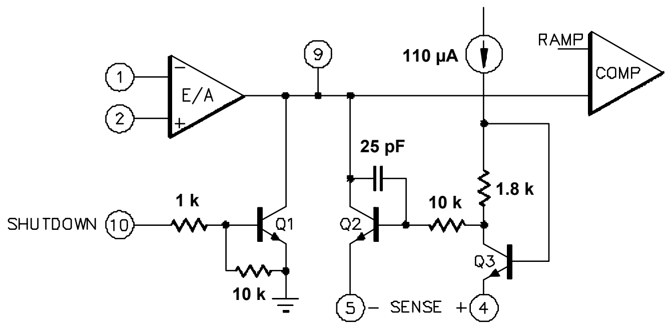

Figure 10. SG1524 Current Limiting

One consideration in using this circuit is that the sense terminals have a ± 0.3 V common mode range which requires sensing in the ground line. However, since differential inputs are available, foldback current limiting can be implemented as shown in Figure 11.

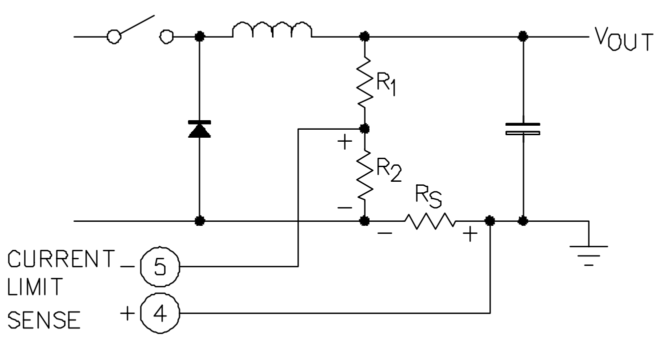

Figure 11. Foldback Current Limiting

While on the subject of protection circuitry, although overvoltage protection is not built into the SG1524, it is relatively easy to add by using the internal shutdown circuit in conjunction with a few external components as shown in Figure 12.

This circuit will provide a low level sensing and latching function and while it won't protect against a shorted output transistor, it will remove the drive signals with no power dissipation.

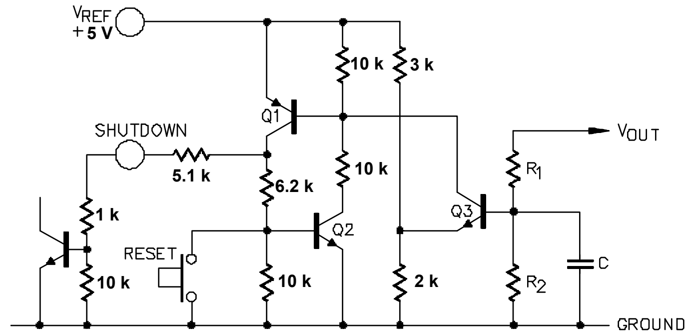

Figure 12. SG1524 Over Voltage Protection

Output Stages

The outputs of the SG1524 are two identical NPN transistors with both collectors and emitters uncommitted. These circuits are as shown in Figure 13 and include an anti-saturation network for fast response and current limiting set for an output current of approximately 100 mA.

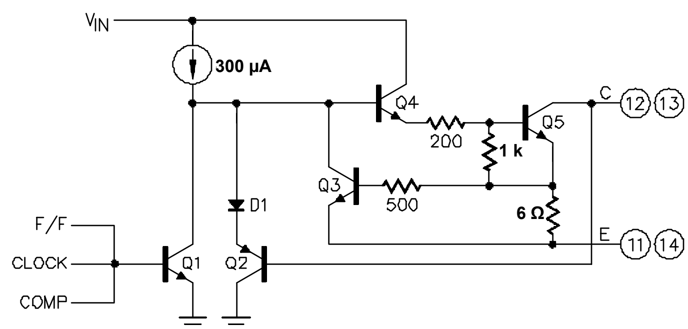

Figure 13. SG1524 Output Stage

The availability of both collectors and emitters allows a maximum versatility to enable driving either NPN or PNP external transistors; however, it must be remembered that this is only a switch which closes and opens. Power transistor turn-off drive must be developed externally. Some suggestions for output drive circuits are shown in Figure 14.

Applications

In considering applications for the SG1524, it appears that there are three general classifications of switching power supply systems. Included in the first are the transformerless voltage multiplier circuits shown in Figure 15. These circuits are primarily used for low level applications but can step up, step down, or change the polarity of an input voltage. The switches shown can be either the output stages of the SG1524 or external transistors. Note that one extra diode is required to protect the emitter-base junction of switch S_A during the times when both switches are open.

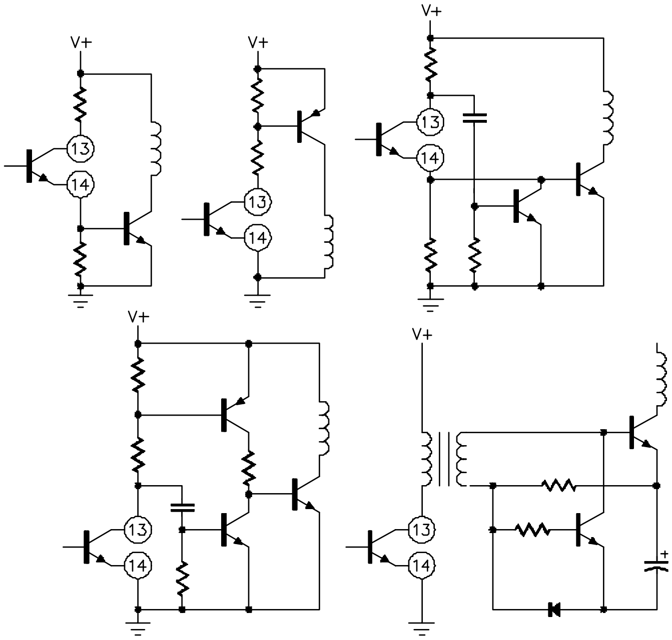

Figure 14. Driving External Transistors

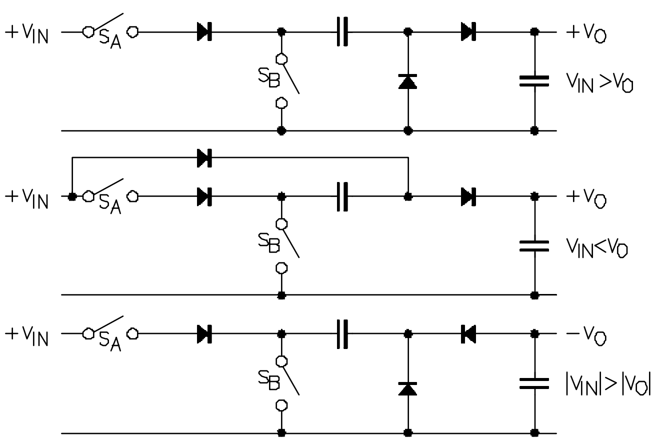

Figure 15. Capacitor/Diode Output Circuits

For higher current applications, the single-ended inductor circuits of Figure 16 represent another classification. Here, the two outputs of the SG1524 are connected in parallel, but note that this does not give twice the current as the switches are alternating internally. This does not affect external performance, however, and the SG1524 can be used to provide 0-90% duty cycle modulation in any of the configurations shown.

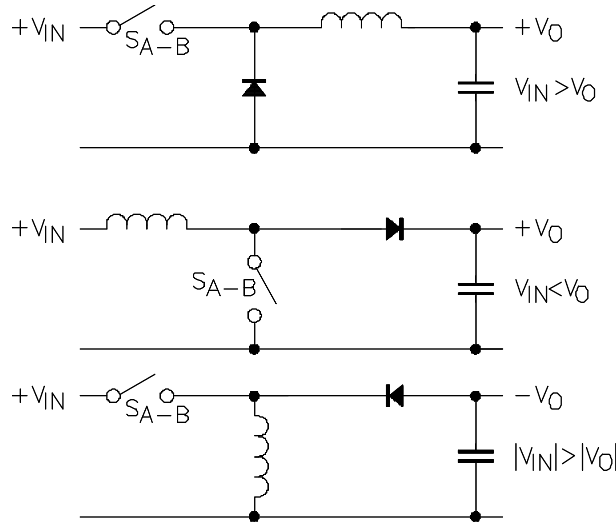

Figure 16. Single-Ended Inductor Circuits

The third general classification of power supply systems are transformer coupled, two types of which are shown in Figure 17.

The push-pull circuit represents the conventional DC to DC converter with each switch being controlled for 0-45% duty cycle modulation. The second transformer circuit is a single-ended flyback converter, useful at light loads without a separate output inductor.

To illustrate the use of the SG1524 in each of the above general classifications, the following simple, but practical, circuits are presented:

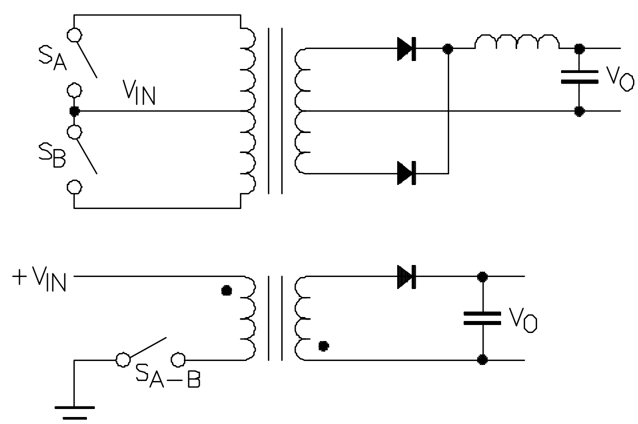

Figure 17. Transformer Coupled Circuits

Figure 18 shows the use of the SG1524 as a low current polarity converter providing a regulated -5 V output at currents up to 20 mA from a single positive input voltage. The external components required include the divider resistors to interface the reference and output voltages with the error amplifier, a resistor/capacitor to set the operating frequency, and the output diodes and capacitors. The combination of the built-in current limiting of the SG1524 output stages and the capacitor coupling of the output signal provide full protection against short circuits and the current limit amplifier is more than enough to stabilize the regulating loop and no additional compensation is required.

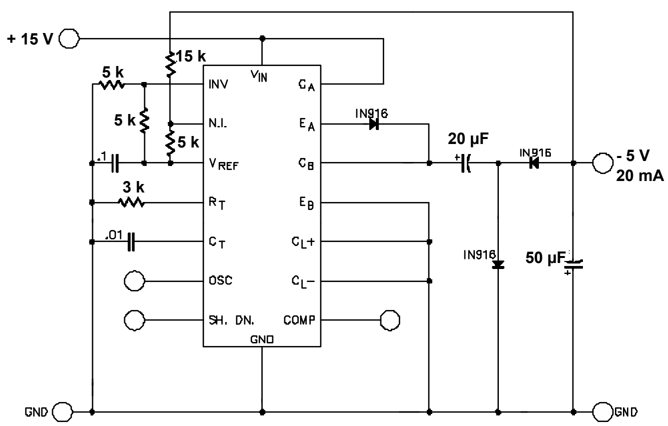

Figure 18. Low Current Polarity Converter

Another low-level circuit is the flyback converter shown in Figure 19.

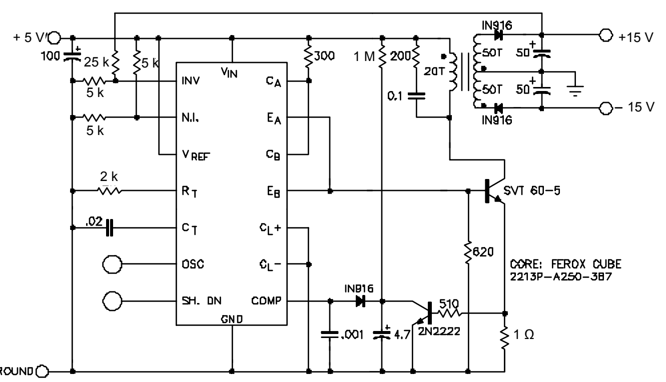

Figure 19. +5 V to ±15 V, Flyback Converter

The circuit is designed to develop a regulated ±15 V supply from a single +5 V source. Note that the reference terminal is tied to the input, disabling the internal regulator. The error amplifier resistors are also tied to the input line so that the output regulation can be no better than the input; however, an external reference could just as easily have been used.

In this application, the two output stages are connected in parallel and used as emitter followers to drive a single external transistor. Since the currents in the secondary of a flyback transformer are out of phase with the primary current, current limiting is very difficult to achieve. In this circuit, protection was provided through the use of a soft-start circuit. If either output is shorted, the transformer will saturate, providing more current through the drive transistor. This current is sensed and used to turn on the 2N2222 which resets the soft-start circuit and turn off the drive signal. If the short remains, the regulator will repetitively try to start up and reset with a time constant set by the soft-start circuit. Removing the short will then allow the regulating loop to re-establish control.

For higher current applications, the single-ended conventional switching regulator of Figure 20 is shown.

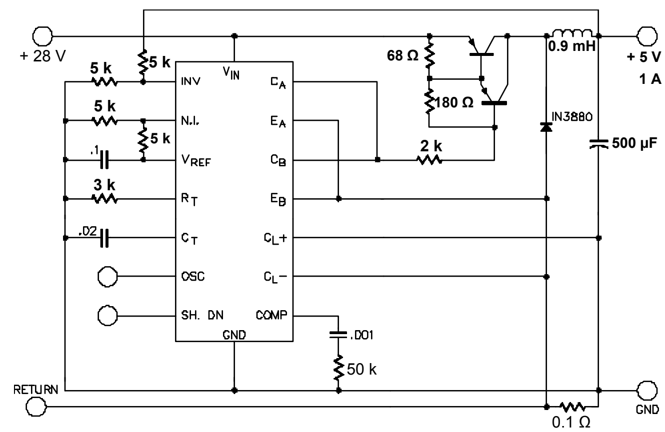

Figure 20. 1 A, Single-Ended Switching Regulator

In this case, an external PNP Darlington is used to provide a 1 A current switch. The SG1524 has the two outputs in parallel, connected as a grounded emitter amplifier. The current sense resistor is inserted in the ground line and the voltage across it used for constant current limiting. Note that in addition to the divider resistors and frequency setting $R_T C_T$, a phase compensation resistor and capacitor is used to stabilize the loop now that an inductor has been added.

A fourth application would have to be a push-pull, DC to DC regulating converter as shown in Figure 21.

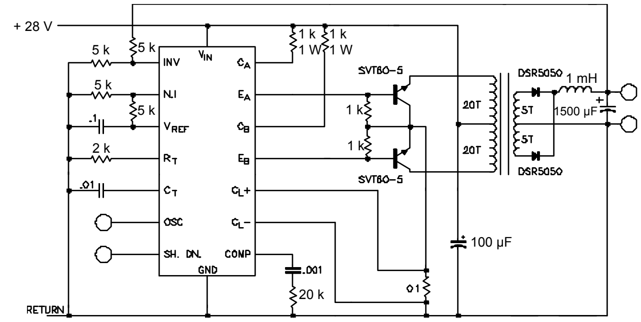

Figure 21. 5 V, 25 W, DC to DC Converter

Here the outputs of the SG1524 are connected as separate emitter followers driving external transistors. Current limiting in this application is done in the primary for several reasons: First, it's easier to live within the ±0.3 V common mode limits of the current limit amplifier; second, since this is a step-down application, the current - and therefore the power in the sense resistor - is lower; and third, if the output drive were to become non-symmetrical causing the transformer to approach saturation, the resultant current spikes will shorten the pulse width on a pulse-by-pulse basis, providing a first order correction. Note that the oscillator is set to run at 40 kHz to obtain a 20 kHz signal at the transformer.

The application as shown does not provide input-output isolation and, of course, that feature is difficult to achieve within a single IC. There are a couple of ways the SG1524 can be used with isolated power supply systems, however. The first is shown in Figure 22 where the SG1524 is direct coupled on the secondary side of the output transformer. The outputs from the IC are transformer-coupled back to the primary side to drive the switching transistors. Of course, a separate start-up power source is needed for the SG1524 but that shouldn't present much of a problem remembering that the IC draws less than 10 mA of supply current.

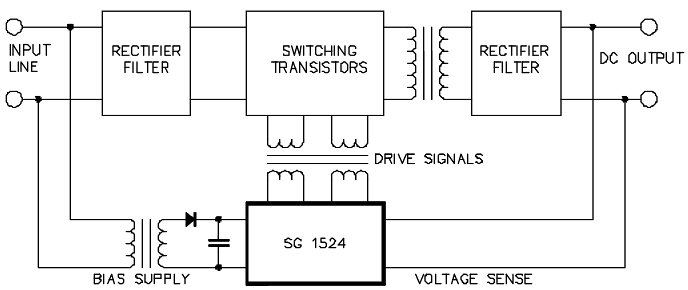

Figure 22. Input/Output Isolation

A different method of providing isolation is shown in Figure 23 where the IC is direct coupled on the primary side. Here a separate reference error amplifier (most easily implemented with a SG1532 regulator IC) is connected on the secondary and then optically coupled back to the primary side.

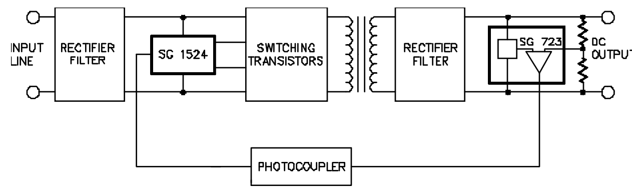

Figure 23. Input/Output Isolation

As should be evident from the above, the SG1524 was designed as the first of what will undoubtedly become a larger family of regulator IC's specifically designed for switching power supplies. As such, versatility was the primary design goal of this device and hopefully this goal has been achieved to the degree that will allow the SG1524 to find application to a wide range of power control systems.

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