

SG2524, SG3524 REGULATING PULSE-WIDTH MODULATORS

SLVS077B – APRIL 1977 – REVISED JULY 1999

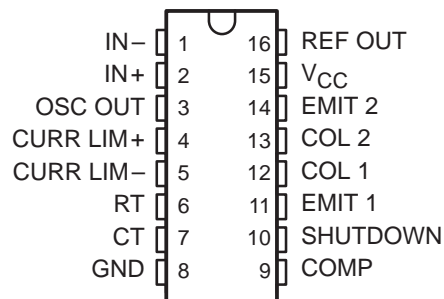
- Complete PWM Power Control Circuitry
- Uncommitted Outputs for Single-Ended or Push-Pull Applications
- Low Standby Current . . . 8 mA Typ
- Interchangeable With Silicon General SG2524 and SG3524

description

The SG2524 and SG3524 incorporate all the functions required in the construction of a regulating power supply, inverter, or switching regulator on a single chip. They also can be used as the control element for high-power-output applications. The SG2524 and SG3524 were designed for switching regulators of either polarity, transformer-coupled dc-to-dc converters, transformerless voltage doublers, and polarity converter applications employing fixed-frequency, pulse-width-modulation (PWM) techniques. The complementary output allows either single-ended or push-pull application. Each device includes an on-chip regulator, error amplifier, programmable oscillator, pulse-steering flip-flop, two uncommitted pass transistors, a high-gain comparator, and current-limiting and shut-down circuitry.

The SG2524 is characterized for operation from -25°C to 85°C , and the SG3524 is characterized for operation from 0°C to 70°C .

D OR N PACKAGE
(TOP VIEW)



AVAILABLE OPTIONS

T _A	INPUT REGULATION MAX (MV)	PACKAGED DEVICES		CHIP FORM (Y)
		SMALL OUTLINE (D)	PLASTIC DIP (N)	
0°C to 70°C	30	SG3524D	SG3524N	SG3524Y
-25°C to 85°C	20	SG2524D	SG2524N	—

The D package is available taped and reeled. Add the suffix R to the device type (e.g., SG3524DR). Chip forms are tested at 25°C.



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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

 **TEXAS
INSTRUMENTS**

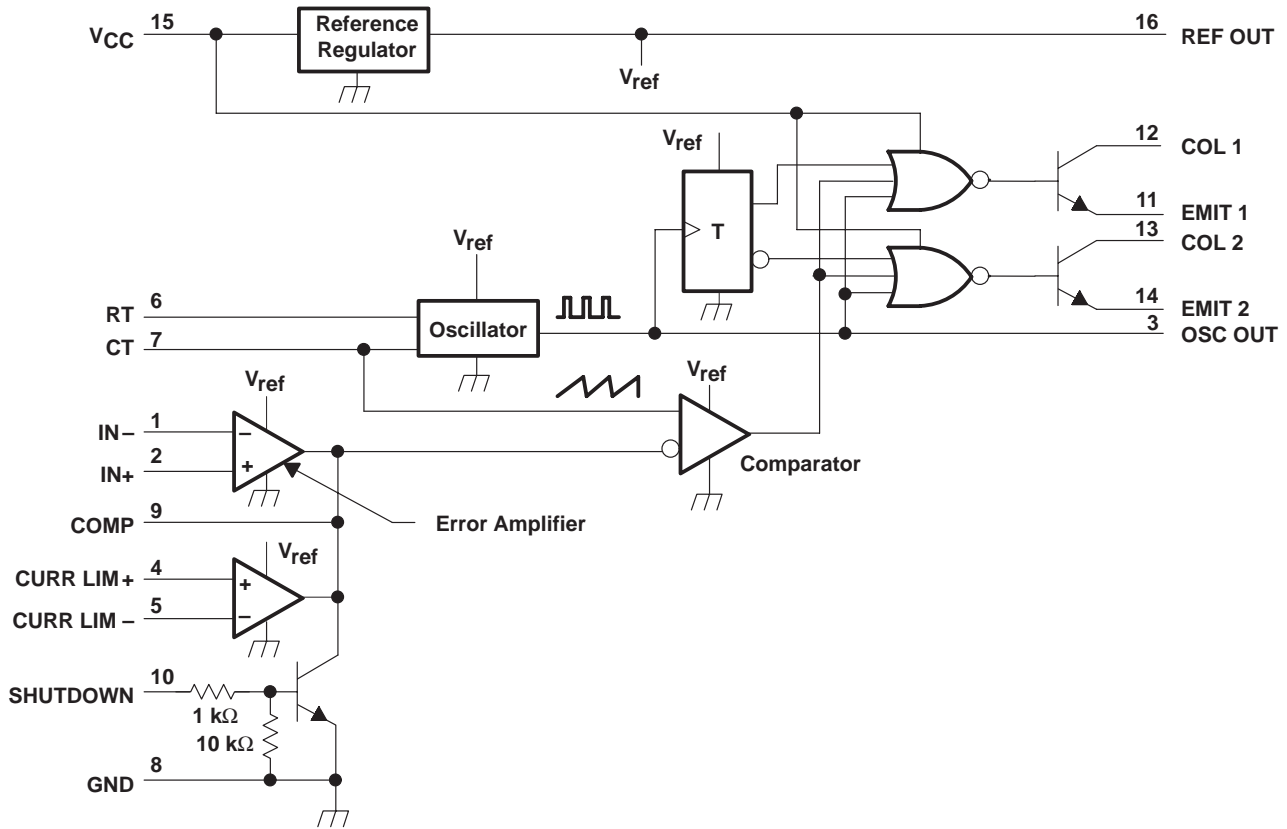
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functional block diagram



NOTE A: Resistor values shown are nominal.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{CC} (see Notes 1 and 2)	40 V
Collector output current, I_{CC}	100 mA
Reference output current, $I_{O(ref)}$	50 mA
Current through CT terminal	-5 mA
Package thermal impedance, θ_{JA} (see Notes 3 and 4): D package	112°C/W
N package	88°C/W
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	260°C
Storage temperature range, T_{stg}	-65°C to 150°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

- NOTES:
- All voltage values are with respect to network ground terminal.
 - The reference regulator may be bypassed for operation from a fixed 5-V supply by connecting the V_{CC} and reference output pin both to the supply voltage. In this configuration, the maximum supply voltage is 6 V.
 - Maximum power dissipation is a function of $T_{J(max)}$, θ_{JA} , and T_A . The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_{J(max)} - T_A)/\theta_{JA}$. Operation at the absolute maximum T_J of 150°C can impact reliability.
 - The package thermal impedance is calculated in accordance with JESD 51, except for through-hole packages which use a trace length of zero.

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recommended operating conditions

	SG2524		SG3524		UNIT
	MIN	MAX	MIN	MAX	
Supply voltage, V_{CC}	8	40	8	40	V
Reference output current	0	50	0	50	mA
Current through CT terminal	-0.03	-2	-0.03	-2	mA
Timing resistor, R_T	1.8	100	1.8	100	k Ω
Timing capacitor, C_T	0.001	0.1	0.001	0.1	μ F
Operating free-air temperature	-25	85	0	70	$^{\circ}$ C

electrical characteristics over recommended operating free-air temperature range, $V_{CC} = 20$ V, $f = 20$ kHz (unless otherwise noted)

reference section

PARAMETER	TEST CONDITION [†]	SG2524			SG3524			SG3524Y			UNIT
		MIN	TYP [‡]	MAX	MIN	TYP [‡]	MAX	MIN	TYP [‡]	MAX	
Output voltage		4.8	5	5.2	4.6	5	5.4	5			V
Input regulation	$V_{CC} = 8$ V to 40 V		10	20		10	30		10		mV
Ripple rejection	$f = 120$ Hz		66			66			66		dB
Output regulation	$I_O = 0$ mA to 20 mA		20	50		20	50		20		mV
Output voltage change with temperature	$T_A = \text{MIN to MAX}$		0.3%	1%		0.3%	1%				
Short-circuit output current [§]	$V_{ref} = 0$		100			100			100		mA

[†] For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

[‡] All typical values, except for temperature coefficients, are at $T_A = 25^{\circ}$ C

[§] Standard deviation is a measure of the statistical distribution about the mean as derived from the formula:

$$\sigma = \sqrt{\frac{\sum_{n=1}^N (x_n - \bar{X})^2}{N - 1}}$$

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electrical characteristics over recommended operating free-air temperature range, $V_{CC} = 20\text{ V}$, $f = 20\text{ kHz}$ (unless otherwise noted)

oscillator section

PARAMETER		TEST CONDITIONS†	SG2524, SG3524			SG3524Y			UNIT
			MIN	TYP‡	MAX	MIN	TYP‡	MAX	
f_{OSC}	Oscillator frequency	$C_T = 0.001\ \mu\text{F}$, $R_T = 2\ \text{k}\Omega$	450			450			kHz
Standard deviation of frequency§		All values of voltage, temperature, resistance, and capacitance constant	5%			5%			
Δf_{OSC}	Frequency change with voltage	$V_{CC} = 8\text{ V to }40\text{ V}$, $T_A = 25^\circ\text{C}$	1%			1%			
	Frequency change with temperature	$T_A = \text{MIN to MAX}$	2%						
Output amplitude at OSC OUT		$T_A = 25^\circ\text{C}$	3.5			3.5			V
t_w	Output pulse duration (width) at OSC OUT	$C_T = 0.01\ \mu\text{F}$, $T_A = 25^\circ\text{C}$	0.5			0.5			μs

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

‡ All typical values, except for temperature coefficients, are at $T_A = 25^\circ\text{C}$

§ Standard deviation is a measure of the statistical distribution about the mean as derived from the formula:

$$\sigma = \sqrt{\frac{\sum_{n=1}^N (x_n - \bar{X})^2}{N - 1}}$$

error amplifier section

PARAMETER		TEST CONDITIONS†	SG2524			SG3524			SG3524Y			UNIT
			MIN	TYP‡	MAX	MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_{IO}	Input offset voltage	$V_{IC} = 2.5\text{ V}$	0.5	5		2	10		2		mV	
I_{IB}	Input bias current	$V_{IC} = 2.5\text{ V}$		2	10		2	10		2	μA	
Open-loop voltage amplification			72	80		60	80		80		dB	
V_{ICR}	Common-mode input voltage range	$T_A = 25^\circ\text{C}$	1.8 to 3.4			1.8 to 3.4					V	
CMMR	Common-mode rejection ratio			70			70			70	dB	
B_1	Unity-gain bandwidth			3			3			3	MHz	
Output swing		$T_A = 25^\circ\text{C}$	0.5		3.8	0.5		3.8	0.5		3.8	V

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

‡ All typical values, except for temperature coefficients, are at $T_A = 25^\circ\text{C}$



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electrical characteristics over recommended operating free-air temperature range, $V_{CC} = 20\text{ V}$, $f = 20\text{ kHz}$ (unless otherwise noted)

output section

PARAMETER	TEST CONDITIONS†	SG2534, SG3524			SG3524Y			UNIT
		MIN	TYP‡	MAX	MIN	TYP‡	MAX	
$V_{(BR)CE}$	Collector-emitter breakdown voltage	40						V
	Collector off-state current	$V_{CE} = 40\text{ V}$			0.01 50			μA
V_{sat}	Collector-emitter saturation voltage	$I_C = 50\text{ mA}$			1 2			V
V_O	Emitter output voltage	$V_C = 20\text{ V}, I_E = -250\text{ }\mu\text{A}$			17 18			V
t_r	Turn-off voltage rise time	$R_C = 2\text{ k}\Omega$			0.2			μs
t_f	Turn-on voltage fall time	$R_C = 2\text{ k}\Omega$			0.1			μs

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

‡ All typical values, except for temperature coefficients, are at $T_A = 25^\circ\text{C}$.

comparator section

PARAMETER	TEST CONDITIONS†	SG2534, SG3524			SG3524Y			UNIT
		MIN	TYP‡	MAX	MIN	TYP‡	MAX	
	Maximum duty cycle, each output	45%						
V_{IT}	Input threshold voltage at COMP	Zero duty cycle			1			V
		Maximum duty cycle			3.5			
I_{IB}	Input bias current				-1			μA

† For conditions shown as MIN or MAX, use the appropriate value specified under recommended operating conditions.

‡ All typical values, except for temperature coefficients, are at $T_A = 25^\circ\text{C}$.

current limiting section

PARAMETER	TEST CONDITIONS	SG2524			SG3524			SG3524Y			UNIT
		MIN	TYP‡	MAX	MIN	TYP‡	MAX	MIN	TYP‡	MAX	
V_I	Input voltage range (either input)	-1 to 1			-1 to 1						V
$V_{(SENSE)}$	Sense voltage at $T_A = 25^\circ\text{C}$	175	200	225	175	200	225	175	200	225	mV
	Temperature coefficient of sense voltage	0.2			0.2			0.2			$\text{mV}/^\circ\text{C}$

‡ All typical values, except for temperature coefficients, are at $T_A = 25^\circ\text{C}$.

total device

PARAMETER	TEST CONDITIONS	SG2524, SG3524			SG3524Y			UNIT
		MIN	TYP‡	MAX	MIN	TYP‡	MAX	
I_{st}	Standby current	$V_{CC} = 40\text{ V}, I_{N-}, \text{CURR LIM+}, C_T, \text{GND}, \text{COMP}, \text{EMIT 1}, \text{EMIT 2 grounded}, I_{N+}$ at 2 V, All other inputs and outputs open			8 10			mA

‡ All typical values, except for temperature coefficients, are at $T_A = 25^\circ\text{C}$.



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PARAMETER MEASUREMENT INFORMATION

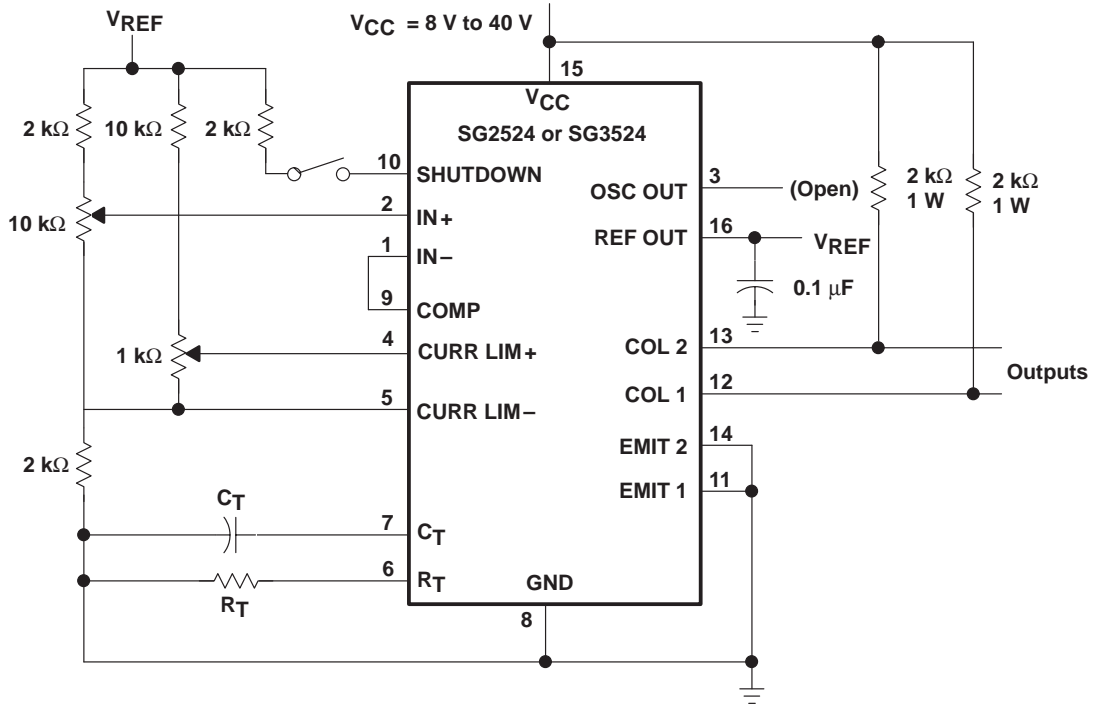


Figure 1. General Test Circuit

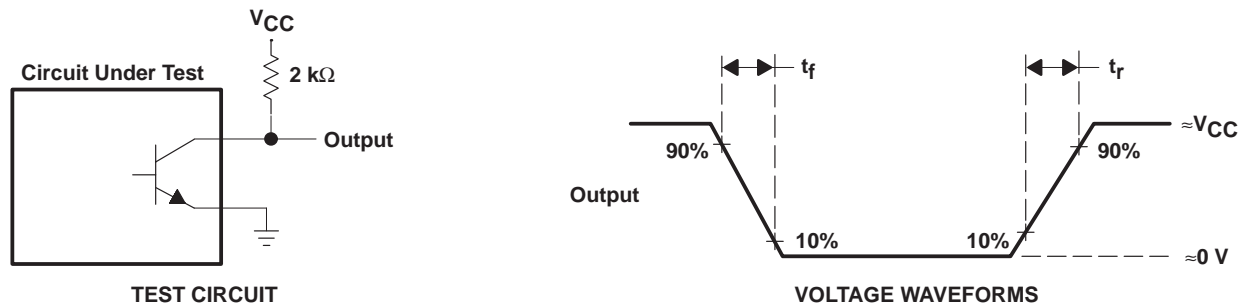
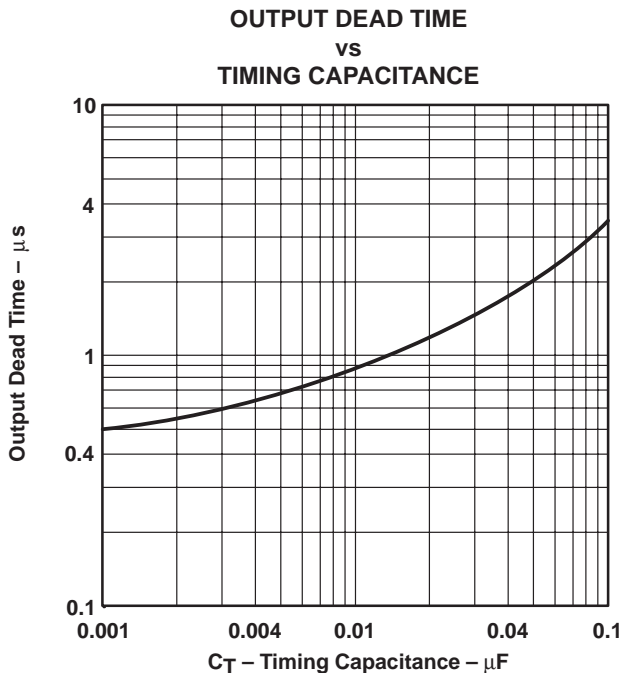
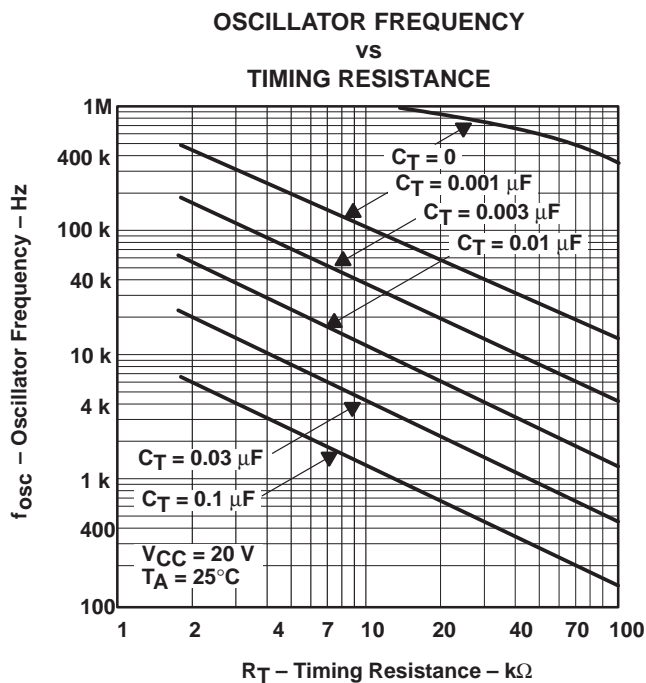
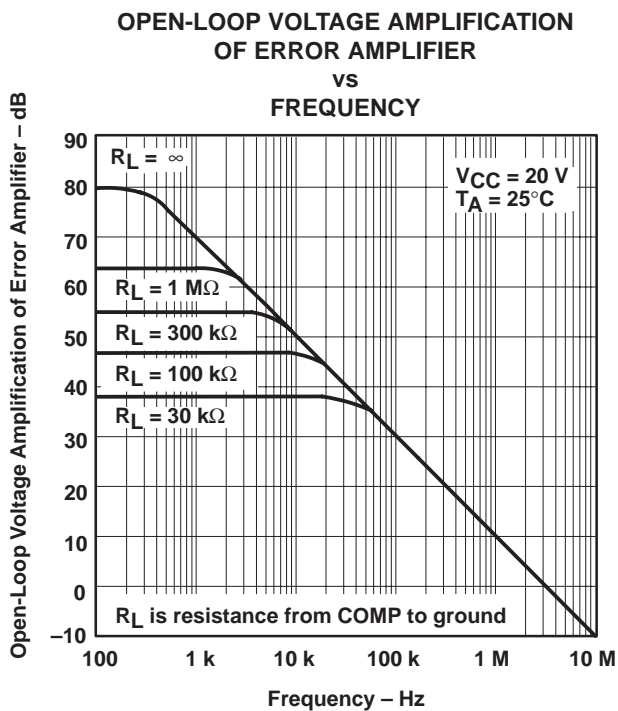


Figure 2. Switching Times

TYPICAL CHARACTERISTICS



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PRINCIPLES OF OPERATION†

The SG2524 is a fixed-frequency pulse-width-modulation voltage-regulator control circuit. The regulator operates at a fixed frequency that is programmed by one timing resistor, R_T , and one timing capacitor, C_T . R_T establishes a constant charging current for C_T . This results in a linear voltage ramp at C_T , which is fed to the comparator providing linear control of the output pulse duration (width) by the error amplifier. The SG2524 contains an onboard 5-V regulator that serves as a reference, as well as supplying the SG2524 internal regulator control circuitry. The internal reference voltage is divided externally by a resistor ladder network to provide a reference within the common-mode range of the error amplifier as shown in Figure 6, or an external reference can be used. The output is sensed by a second resistor divider network and the error signal is amplified. This voltage is then compared to the linear voltage ramp at C_T . The resulting modulated pulse out of the high-gain comparator is then steered to the appropriate output pass transistor (Q1 or Q2) by the pulse-steering flip-flop, which is synchronously toggled by the oscillator output. The oscillator output pulse also serves as a blanking pulse to ensure both outputs are never on simultaneously during the transition times. The duration of the blanking pulse is controlled by the value of C_T . The outputs may be applied in a push-pull configuration in which their frequency is half that of the base oscillator, or paralleled for single-ended applications in which the frequency is equal to that of the oscillator. The output of the error amplifier shares a common input to the comparator with the current-limiting and shut-down circuitry and can be overridden by signals from either of these inputs. This common point also is available externally and can be employed to control the gain of, to compensate the error amplifier, or to provide additional control to the regulator.

APPLICATION INFORMATION†

oscillator

The oscillator controls the frequency of the SG2524 and is programmed by R_T and C_T as shown in Figure 4.

$$f \approx \frac{1.30}{R_T C_T}$$

where: R_T is in $k\Omega$
 C_T is in μF
 f is in kHz

Practical values of C_T fall between 0.001 and 0.1 μF . Practical values of R_T fall between 1.8 and 100 $k\Omega$. This results in a frequency range typically from 130 Hz to 722 kHz.

blanking

The output pulse of the oscillator is used as a blanking pulse at the output. This pulse duration is controlled by the value of C_T as shown in Figure 5. If small values of C_T are required, the oscillator output pulse duration can still be maintained by applying a shunt capacitance from OSC OUT to ground.

synchronous operation

When an external clock is desired, a clock pulse of approximately 3 V can be applied directly to the oscillator output terminal. The impedance to ground at this point is approximately 2 $k\Omega$. In this configuration, $R_T C_T$ must be selected for a clock period slightly greater than that of the external clock.

† Throughout these discussions, references to the SG2524 apply also to the SG3524.

APPLICATION INFORMATION†

synchronous operation (continued)

If two or more SG2524 regulators are operated synchronously, all oscillator output terminals must be tied together. The oscillator programmed for the minimum clock period is the master from which all the other SG2524s operate. In this application, the $C_T R_T$ values of the slaved regulators must be set for a period approximately 10% longer than that of the master regulator. In addition, C_T (master) = 2 C_T (slave) to ensure that the master output pulse, which occurs first, has a longer pulse duration and subsequently resets the slave regulators.

voltage reference

The 5-V internal reference can be employed by use of an external resistor divider network to establish a reference common-mode voltage range (1.8 V to 3.4 V) within the error amplifiers as shown in Figure 6, or an external reference can be applied directly to the error amplifier. For operation from a fixed 5-V supply, the internal reference can be bypassed by applying the input voltage to both the V_{CC} and V_{REF} terminals. In this configuration, however, the input voltage is limited to a maximum of 6 V.

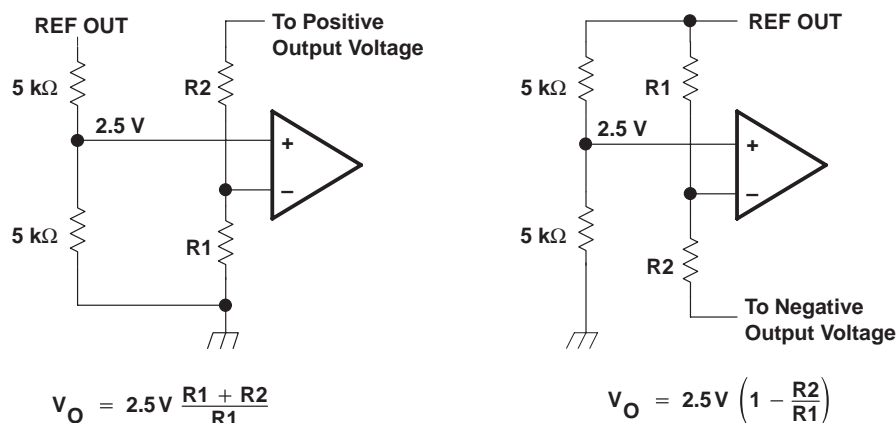


Figure 6. Error-Amplifier Bias Circuits

error amplifier

The error amplifier is a differential-input transconductance amplifier. The output is available for dc gain control or ac phase compensation. The compensation node (COMP) is a high-impedance node ($R_L = 5 \text{ M}\Omega$). The gain of the amplifier is $A_V = (0.002 \text{ }\Omega^{-1})R_L$ and can easily be reduced from a nominal 10,000 by an external shunt resistance from COMP to ground. Refer to Figure 3 for data.

compensation

COMP, as discussed above, is made available for compensation. Since most output filters introduce one or more additional poles at frequencies below 200 Hz, which is the pole of the uncompensated amplifier, introduction of a zero to cancel one of the output filter poles is desirable. This can best be accomplished with a series RC circuit from COMP to ground in the range of 50 k Ω and 0.001 μF . Other frequencies can be canceled by use of the formula $f \approx 1/RC$.

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APPLICATION INFORMATION†

shut-down circuitry

COMP can also be employed to introduce external control of the SG2524. Any circuit that can sink 200 μA can pull the compensation terminal to ground and thus disable the SG2524.

In addition to constant-current limiting, CURR LIM+ and CURR LIM– may also be used in transformer-coupled circuits to sense primary current and shorten an output pulse should transformer saturation occur. CURR LIM– may also be grounded to convert CURR LIM+ into an additional shut-down terminal.

current limiting

A current-limiting sense amplifier is provided in the SG2524. The current-limiting sense amplifier exhibits a threshold of 200 mV ±25 mV and must be applied in the ground line since the voltage range of the inputs is limited to 1 V to –1 V. Caution should be taken to ensure the –1 V limit is not exceeded by either input, otherwise damage to the device may result.

Foldback current limiting can be provided with the network shown in Figure 7. The current-limit schematic is shown in Figure 8.

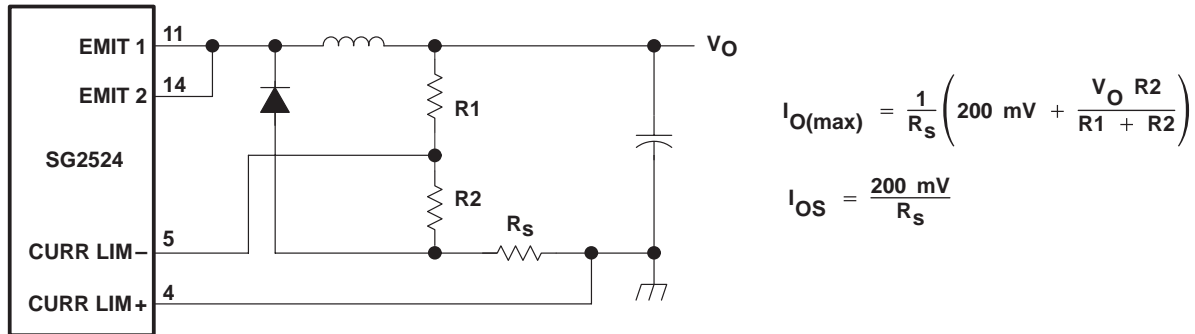


Figure 7. Foldback Current Limiting for Shorted Output Conditions

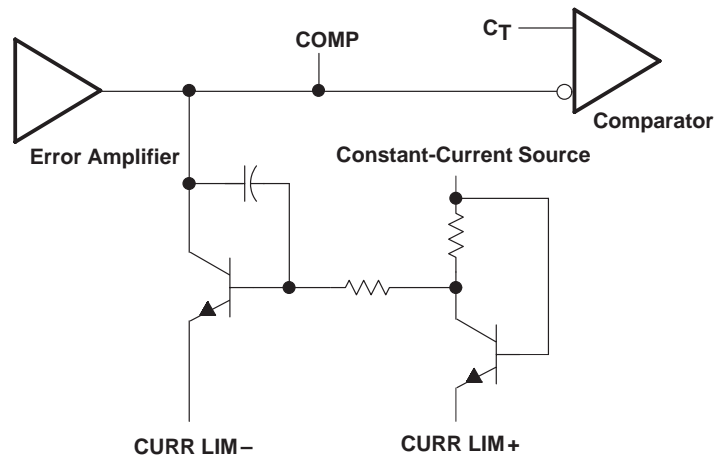


Figure 8. Current-Limit Schematic

† Throughout these discussions, references to the SG2524 apply also to the SG3524.

APPLICATION INFORMATION†

output circuitry

The SG2524 contains two identical npn transistors, the collectors and emitters of which are uncommitted. Each transistor has antisaturation circuitry that limits the current through that transistor to a maximum of 100 mA for fast response.

general

There are a wide variety of output configurations possible when considering the application of the SG2524 as a voltage regulator control circuit. They can be segregated into three basic categories:

1. Capacitor-diode-coupled voltage multipliers
2. Inductor-capacitor-implemented single-ended circuits
3. Transformer-coupled circuits

Examples of these categories are shown in Figures 9, 10 and 11 respectively. Detailed diagrams of specific applications are shown in Figures 12 through 15.

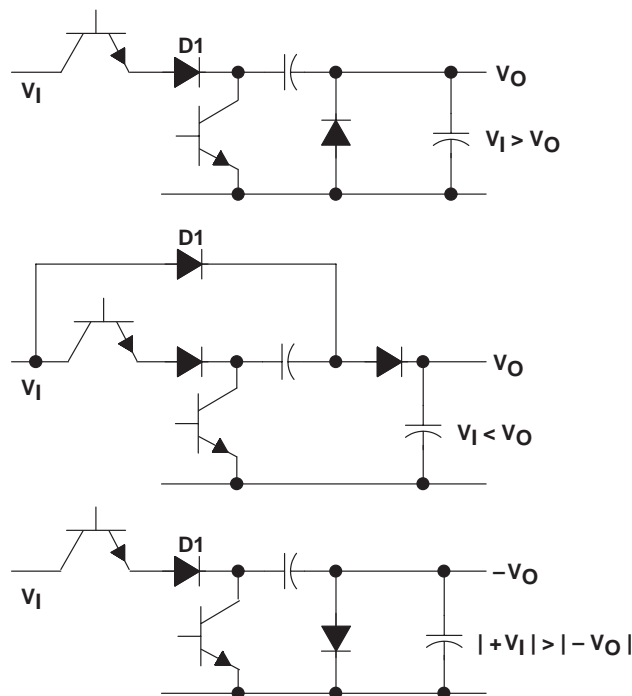


Figure 9. Capacitor-Diode-Coupled Voltage-Multiplier Output Stages

† Throughout these discussions, references to the SG2524 apply also to the SG3524.

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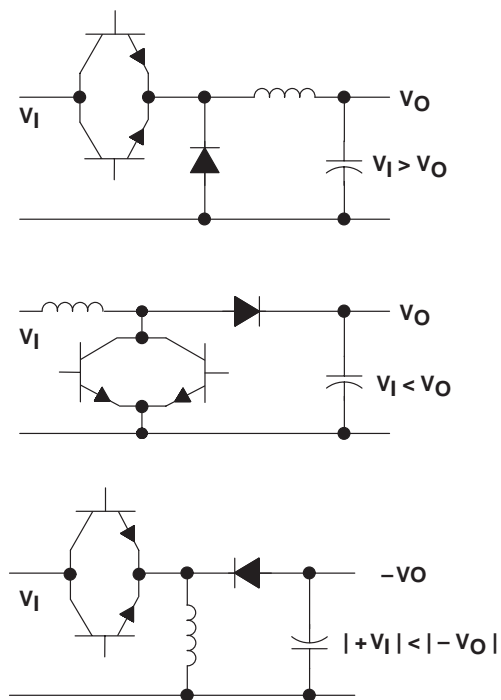


Figure 10. Single-Ended Inductor Circuit

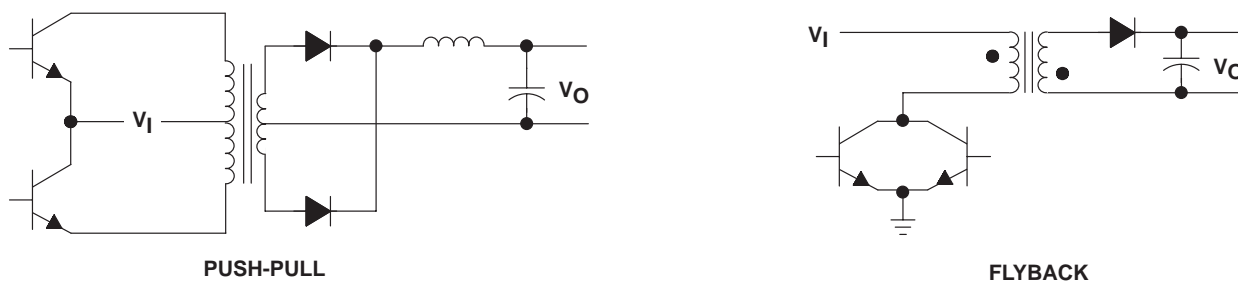


Figure 11. Transformer-Coupled Outputs

† Throughout these discussions, references to the SG2524 apply also to the SG3524.

APPLICATION INFORMATION†

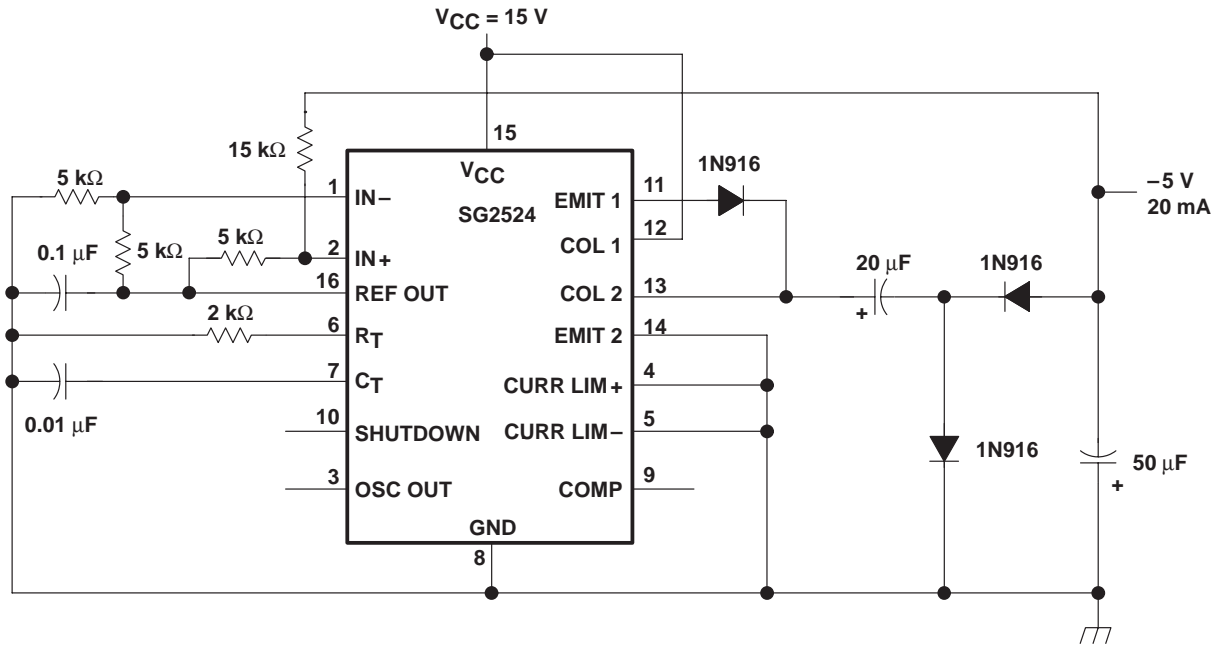


Figure 11. Capacitor-Diode Output Circuit

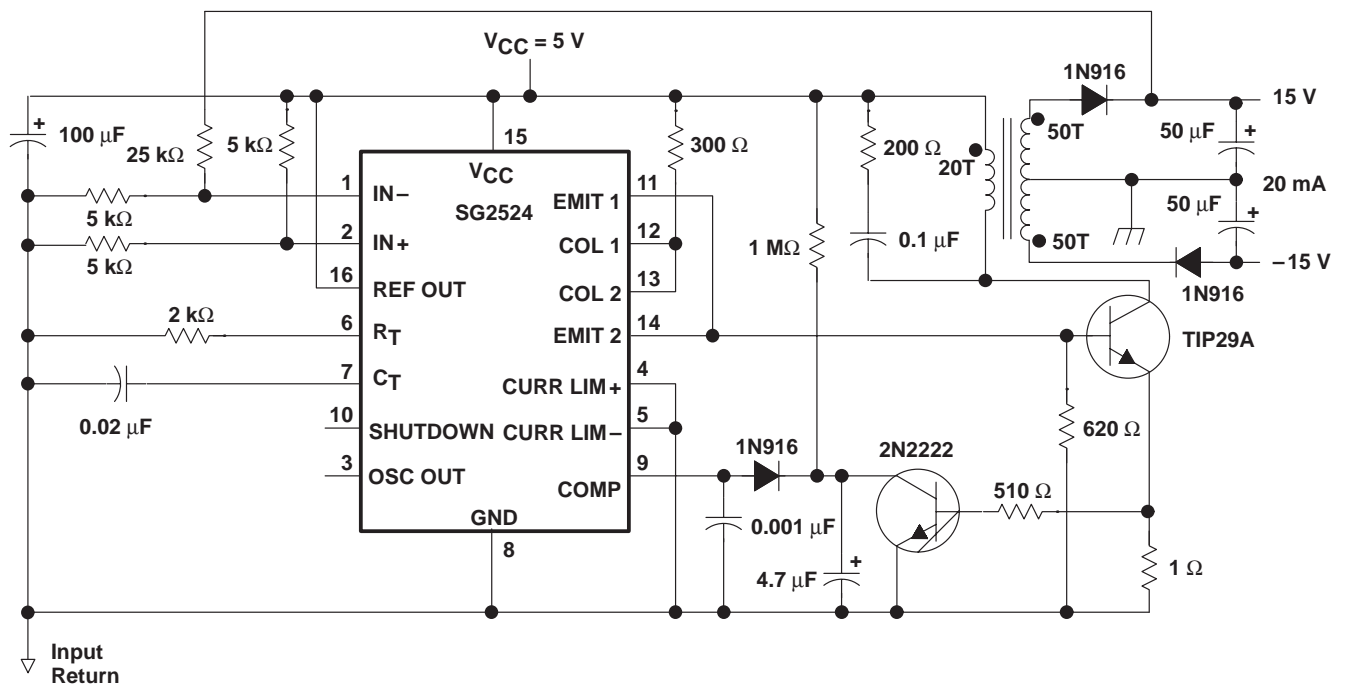


Figure 12. Flyback Converter Circuit

† Throughout these discussions, references to the SG2524 apply also to the SG3524.

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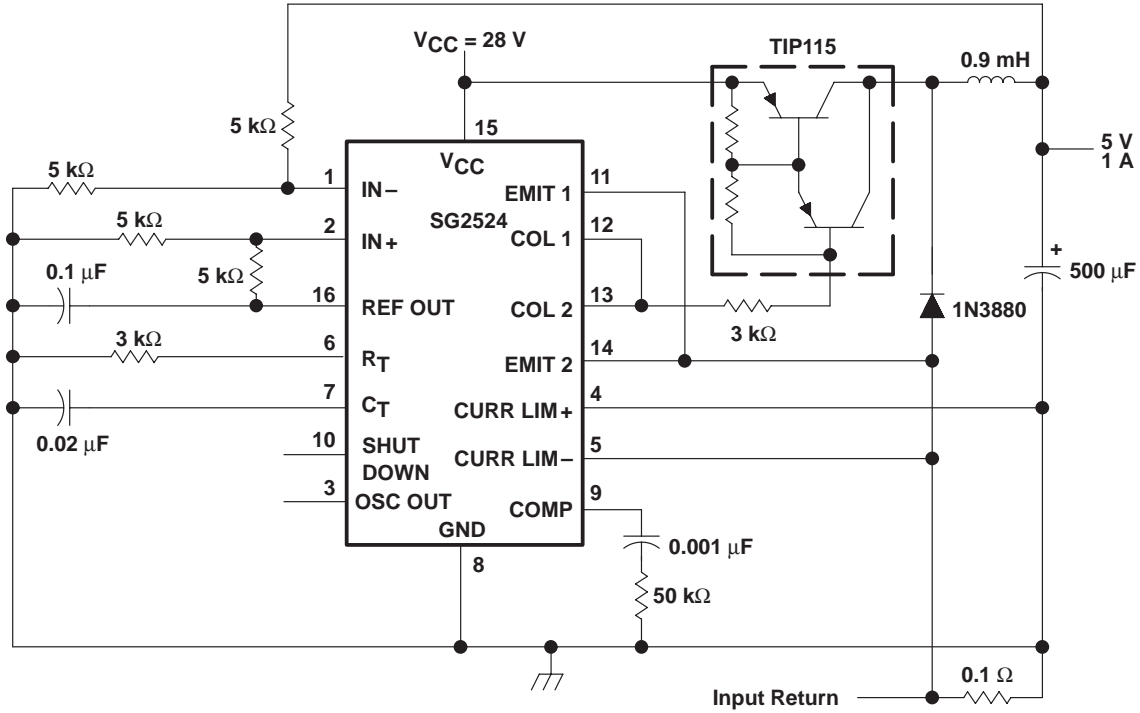


Figure 13. Single-Ended LC Circuit

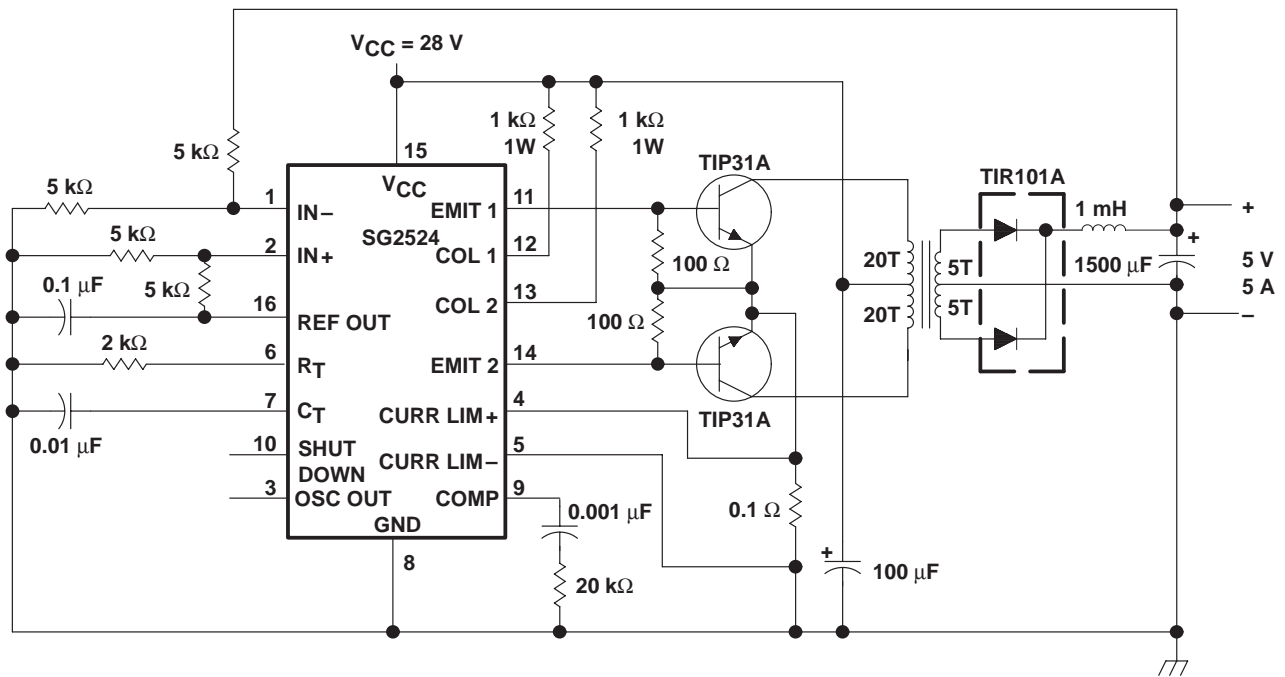


Figure 14. Push-Pull Transformer-Coupled Circuit

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