Pulse-Width Modulating Regulator

GENERAL DESCRIPTION

The XR-1524 family of monolithic integrated circuits contain all the control circuitry for a regulating power supply inverter or switching regulator. Included in a 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 shut-down circuitry. This device can be used for switching regulators of either polarity, transformer coupled DC to DC converters, transformerless voltage doublers and polarity converters, as well as other power control applications. The XR-1524 is specified for operation over the full military temperature range of −55°C to +125°C, while the XR-2524 and XR-3524 are designed for commercial applications of 0°C to +70°C.

FEATURES

Direct Replacement for SG-1524/2524/3524
Complete PWM power control circuitry
Single ended or push-pull outputs
Line and load regulation of 0.2%
1% maximum temperature variation
Total supply current less than 10 mA
Operation beyond 100 kHz

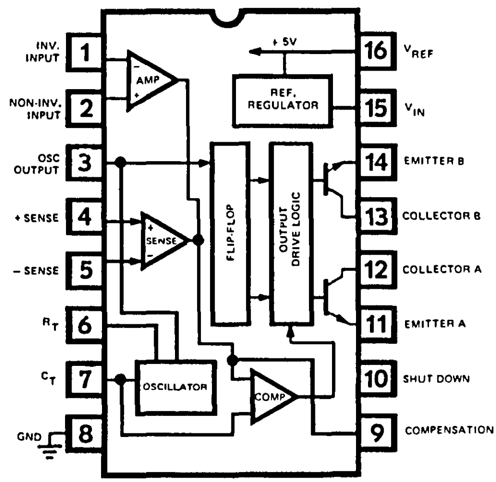
APPLICATIONS

Switching Regulators
Pulse-width Modulated Power Control Systems

ABSOLUTE MAXIMUM RATINGS

Input Voltage	40V
Output Current (each output)	100 mA
Reference Output Current	50 mA
Oscillator Charging Current	5 mA
Power Dissipation	
Ceramic Package	1000 mW
Derate above +25°C	8 mW/°C
Plastic Package	625 mW/°C
Derate above +25°C	5 mW/°C
Operating Temperature Range	
XR-1524	−55°C to +125°C
XR-2524/XR-3524	0°C to +70°C
Storage Temperature Range	−65°C to +150°C

FUNCTIONAL BLOCK DIAGRAM



ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-1524M	Ceramic	−55°C to +125°C
XR-2524N	Ceramic	0°C to +70°C
XR-2524P	Plastic	0°C to +70°C
XR-3524N	Ceramic	0°C to +70°C
XR-3524P	Plastic	0°C to +70°C

SYSTEM DESCRIPTION

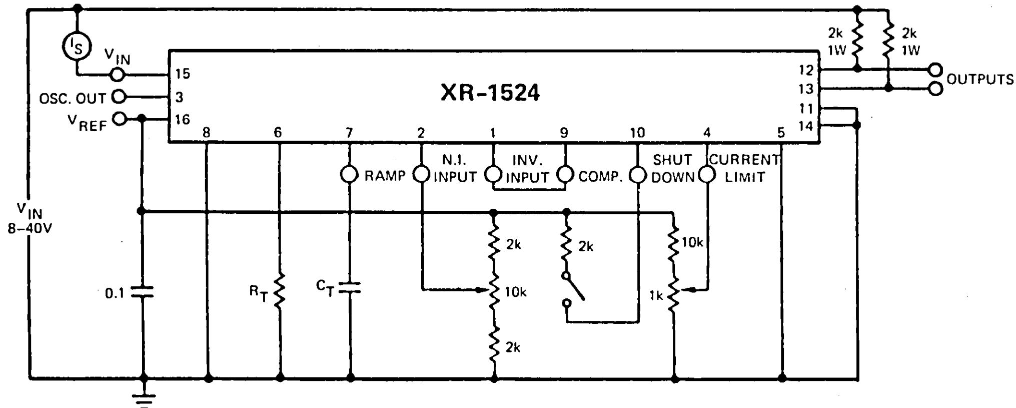
The XR-1524/2524/3524 pulse width modulating regulator is a complete monolithic switching regulator. An internal 5V reference, capable of supplying up to 50 mA to external loads, provides an on board operating standard. The oscillator frequency and duty cycle are adjusted by an external RC network. Regulation is controlled by an error amplifier which, combined with the sense amplifier, also allows current limiting and remote shutdown functions. The outputs of the XR-1524/2524/3524 are two identical NPN transistors with both emitters and collectors uncommitted. Each output transistor has antisaturation circuitry for fast response and local current limiting set at 100 mA.

ELECTRICAL SPECIFICATIONS

Test Conditions: T_A = −55°C to +125°C for the XR-1524 and 0°C to +70°C for the XR-2524 and XR-3524, V_{IN} = 20V, and f = 20 kHz, unless specified otherwise.

PARAMETERS	XR-1524/ XR-2524			XR-3524			UNITS	CONDITIONS
	MIN	TYP	MAX	MIN	TYP	MAX		
REFERENCE SECTION								
Output Voltage	4.8	5.0	5.2	4.6	5.0	5.4	V	
Line Regulation		10	20		10	30	mV	V_{IN} = 8 to 40 Volts
Load Regulation		20	50		20	50	mV	I_L = 0 to 20 mA
Ripple Rejection		66			66		dB	f = 120 Hz, T_A = 25°C
Short Circuit Current Limit		100			100		mA	V_{REF} = 0, T_A = 25°C
Temperature Stability		0.3	1		0.3	1	%	Over Operating Temperature Range
Long Term Stability		20			20		mV/khr	T_A = 25°C
OSCILLATOR SECTION								
Maximum Frequency		300			300		kHz	C_T = .001 μF, R_T = 2 KΩ
Initial Accuracy		5			5		%	R_T and C_T constant
Voltage Stability			1			1	%	V_{IN} = 8 to 40 Volts, T_A = 25°C
Temperature Stability			2			2	%	Over Operating Temperature Range
Output Amplitude		3.5			3.5		V	Pin3, T_A = 25°C
Output Pulse Width		0.5			0.5		μS	C_T = .01 mfd, T_A = 25°C
ERROR AMPLIFIED SECTION								
Input Offset Current			2		2		μA	
Input Offset Voltage		0.5	5		2	10	mV	V_{CM} – 2.5 Volts
Input Bias Current		2	10		2	10	μA	V_{CM} = 2.5 Volts
Open Loop Voltage Gain	72	80		60	80		dB	
Common Mode Voltage	1.8		3.4	1.8		3.4	V	T_A = 25°C
Common Mode Rejection Ratio		70			70		dB	T_A = 25°C
Small Signal Bandwidth		3			3		MHz	A_V – 0 dB, T_A = 25°C
Output Voltage	0.5		3.8	0.5		3.8	V	T_A = 25°C
COMPARATOR SECTION								
Duty Cycle	0		45	0		45	%	% Each Output On
Input Threshold		1			1		V	Zero Duty Cycle
Input Threshold		3.5			3.5		V	Max. Duty Cycle
Input Bias Current		1			1		μA	
CURRENT LIMITING SECTION								Pin 9 = 2V with Error Amplifier
Sense Voltage	190	200	210	180	200	220	mV	Set for Max. Out, T_A = 25°C
Sense Voltage Temp. Coef.		0.2			0.2		mV/°C	
Common Mode Voltage	−1		+1	−1		+1	V	
OUTPUT SECTION (Each Output)								
Max. Collector-Emitter Voltage	40			40			V	
Collector Leakage Current		0.1	50		0.1	50	μA	V_{CE} = 40V
Saturation Voltage		1	2		1	2	V	I_C = 50 mA
Emitter Output Voltage	17	18		17	18		V	V_{IN} = 20V
Rise Time		0.2			0.2		μS	R_C = 2 KΩ, T_A = 25°C
Fall Time		0.1			0.1		μS	R_C = 2 KΩ, T_A = 25°C
TOTAL STANDBY CURRENT (Excluding oscillator charging current, error and current limit dividers, and with outputs open)		8	10		8	10	mA	V_{IN} = 40V

OPEN LOOP TEST CIRCUIT



DESCRIPTION OF CIRCUIT OPERATION

VOLTAGE REFERENCE SECTION

The internal voltage reference and regulator section provides a 5-volt reference output at pin 16. This voltage also serves as a regulated voltage source for the internal timing and control circuitry. This regulator may be bypassed for operation from a fixed 5-volt supply by connecting pins 15 and 16 together to the input voltage. In this configuration, the maximum input voltage is 6.0 volts.

This reference regulator may be used as a 5-volt source for other circuitry. It will provide up to 50 mA of current itself and can easily be expanded to higher currents with an external PNP as shown in Figure 2.

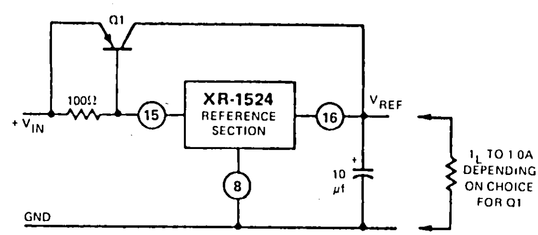


Figure 2. Using the Internal Regulator as 5V Power Supply for External Circuitry

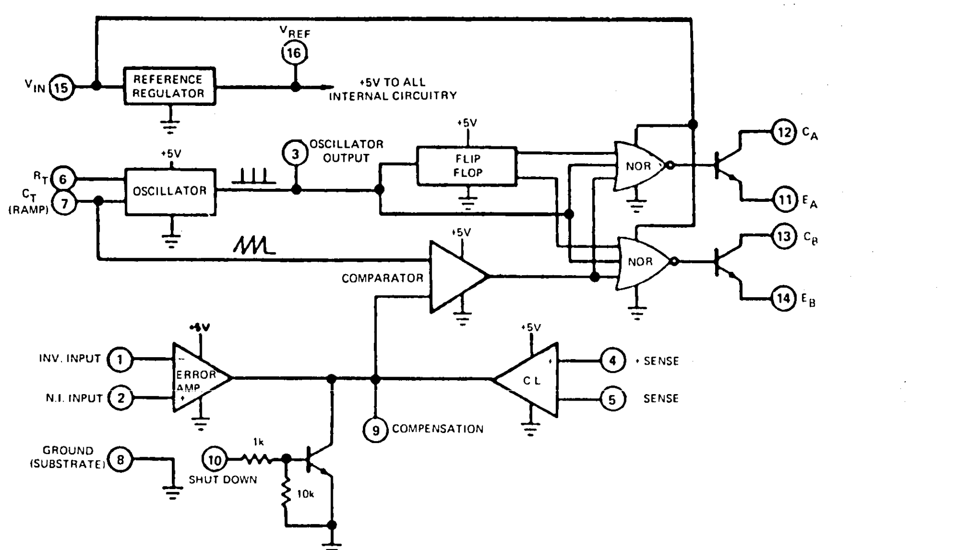


Figure 1. Detailed System Block Diagram of XR-1524

OSCILLATOR SECTION

The oscillator section in the XR-1524 uses an external resistor (R_T) to establish a constant charging current into an external capacitor (C_T). While this uses more current than a series connected RC, it provides a linear ramp voltage on the capacitor which is also used as a reference for the comparator. The charging current is equal to 3.6V $\div$ R_T and should be kept within the range of approximately 30 μA to 2 mA, i.e., 1.8K $< R_T <$ 100K.

The oscillator period is approximately $T = R_T C_T$ where *T is in microseconds when R_T = ohms and C_T =* microfarads.

The use of Figure 3 allows the selection of R_T and C_T for a wide range of operating frequencies. Note that for series regulator applications, the two outputs can be connected in parallel for an effective 0 – 90% duty cycle and the frequency of the oscillator is the frequency of the output. For push-pull applications, the outputs are separated and the flip-flop divides the frequency such that each output's duty cycle is 0 – 45% and the overall frequency is 1/2 that of the oscillator.

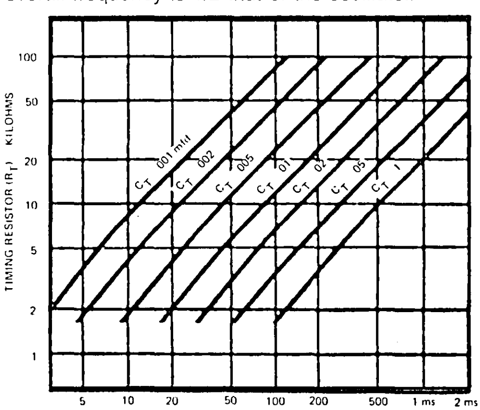


Figure 3. Oscillator Period as a Function of R_T and C_T

The range of values for C_T also has limits as the discharge time of C_T determines the pulse width of the oscillator output pulse. This pulse is used (among other things) as a blanking pulse to both outputs to insure that there is no possibility of having both outputs on simultaneously during transitions. This output dead time relationship is shown in Figure 4. A pulse width below approximately 0.5 microseconds may allow false triggering of one output by removing the blanking pulse prior to the flip-flop's reaching a stable state. If small values of C_T must be used, the pulse width may still be expanded by adding a shunt capacitance ($\approx$ 100 pF) to ground at the oscillator output. (Note: Although the oscillator output is a convenient oscilloscope sync input, the cable and input capacitance may increase the blanking pulse width slightly.) Obviously, the upper limit to the pulse width is determined by the maximum duty cycle acceptable. Practical values of C_T fall between .001 and 0.1 μF.

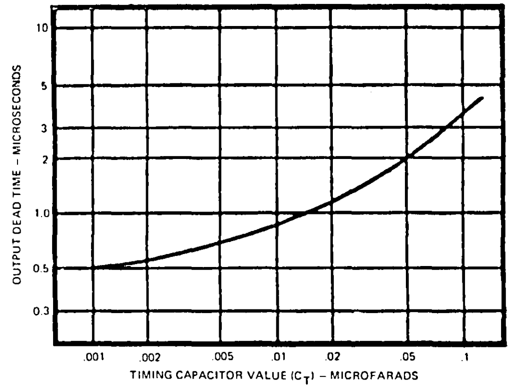


Figure 4. Output Stage Dead Time as a Function of the Timing Capacitor Value

If it is desired to synchronize the XR-1524 to an external clock, a pulse of $\approx$ +3 volts may be applied to the oscillator output terminal with $R_T C_T$ set slightly greater than the clock period. The same considerations of pulse width apply. The impedance to ground at this point is approximately 2K ohms.

If two or more XR-1524 circuits must be synchronized together, one must be designated as master with its $R_T C_T$ set for the correct period. The slaves should each have an $R_T C_T$ set for approximately 10% longer period than the master with the added requirement that C_T (slave) = 1/2 C_T (master). Then connecting pin 3 on all units together will insure that the master output pulse – which occurs first and has a wider pulse width – will reset the slave units.

ERROR AMPLIFIER SECTION

The error amplifier is a simple differential-input, transconductance amplifier. The output is the compensation terminal, pin 9, which is a high-impedance node ($R_L \approx$ 5 MΩ). The gain is

$$A_V = g_m R_L = \frac{8 I_C R_L}{2kT} \approx .002 R_L$$

and can easily be reduced from a nominal of 10,000 by an external shunt resistance from pin 9 to ground, as shown in Figure 5.

In addition to DC gain control, the compensation terminal is also the place for AC phase compensation. The frequency response curves of Figure 5 show the uncompensated amplifier with a single pole at approximately 200 Hz and a unity gain cross-over at 5 MHz.

Typically, most output filter designs will introduce one or more additional poles at a significantly lower frequency. Therefore, the best stabilizing network is a series R-C combination between pin 9 and ground which introduces a zero to cancel one of the output filter poles. A good starting point is 50 KΩ plus .001 μF.

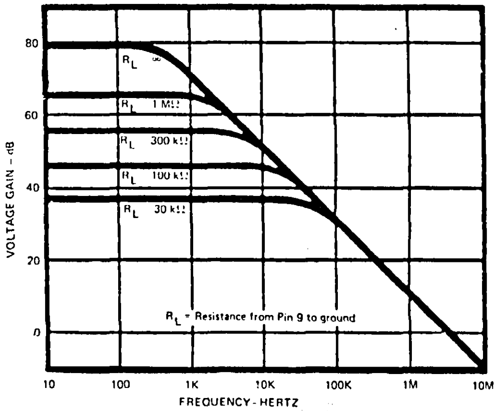


Figure 5. Error Amplifier Frequency Response as a Function of External Resistor, R_L, at Pin 9

One final point on the compensation terminal is that this is also a 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 200 μA can pull this point to ground, thus shutting off both outputs.

While feedback is normally applied around the entire regulator, the error amplifier can be used with conventional operational amplifier feedback and is stable in either the inverting or non-inverting mode. Regardless of the connections, however, input common-mode limits must be observed or output signal inversions may result. For conventional regulator applications, the 5-volt reference voltage must be divided down as shown in Figure 6. The error amplifier may also be used in fixed duty cycle applications by using the unit gain configuration shown in the open loop test circuit.

CURRENT LIMITING CONTROLS

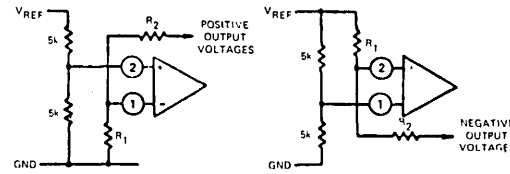
The current limiting circuitry of the XR-1524 is shown in Figure 7.

By matching the base-emitter voltages of Q1 and Q2, and assuming negligible voltage drop across R_1,

$$\text{Threshold} = V_{BE}\,(Q1) + I_1 R_2 - V_{BE}\,(Q2) = I_1 R_2 \simeq 200 \text{ mV}$$

Although this circuit provides a relatively small threshold with a negligible temperature coefficient, there are some limitations to its use, the most important of which is the ± 1 volt common mode range which requires sensing in the ground line. Another factor to consider is that the frequency compensation provided by R_1C_1 and Q1 provides a roll-off pole at approximately 300 Hertz.

Since the gain of this circuit is relatively low, there is a transition region as the current limit amplifier takes over pulse width control from the error amplifier. For testing purposes, threshold is defined as the input voltage to get 25% duty cycle with the error amplifier signaling maximum duty cycle.



$$V_O = \frac{2.5V\,(R_1 + R_2)}{R_1} \qquad \frac{R_1 R_2}{R_1 + R_2} = 2.5k\Omega$$

Figure 6. Error Amplifier Biasing Circuits. *(Note: Change in Input Connections for Opposite Polarity Outputs)*

In addition to constant current limiting, pins 4 and 5 may also be used in transformer-coupled circuits to sense primary current and shorten an output pulse, should transformer saturation occur. (Refer to Figure 15.) Another application is to ground pin 5 and use pin 4 as an additional shutdown terminal, i.e., the output will be off with pin 4 open and on when it is grounded. Finally, foldback current limiting can be provided with the network of Figure 8. This circuit can reduce the short-circuit current (I_{SC}) to approximately one-third the maximum available output current (I_{MAX}).

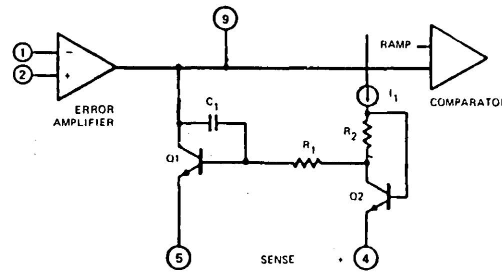


Figure 7. Current Limiting Circuitry of the XR-1524

OUTPUT CIRCUITS

The outputs of the XR-1524 are two identical NPN transistors with both collectors and emitters uncommitted. Each output transistor has antisaturation circuitry for fast response, and current limiting set for a maximum output current of approximately 100 mA. The availability of both collectors and emitters allows maximum versatility to enable driving either NPN or PNP external transistors.

$$I_{MAX} = \frac{1}{R_S}\left(V_{TH} + \frac{V_O\,R_2}{R_1 + R_2}\right)$$

$$I_{SC} = \frac{V_{TH}}{R_S} \quad \text{where}$$

$$V_{TH} = 200 \text{ mV}$$

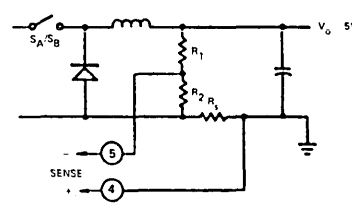


Figure 8. Foldback Current Limiting Can Be Used to Reduce Power Dissipation Under Shorted Output Conditions

In considering the application of the XR-1524 to voltage regulator circuitry, there are a multitude of output configurations possible. In general, however, they fall into three basic classifications:

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

Examples of each category are shown in Figures 9, 10 and 11. In each case, the switches indicated can be either the output transistors in the XR-1524 or added external transistors according to the load current requirements.

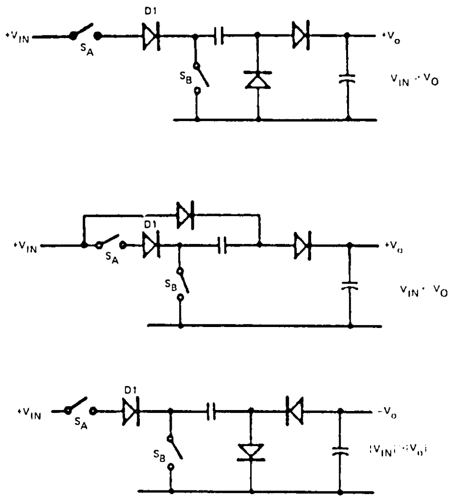


Figure 9. Capacitor-Diode Coupled Voltage Multiplier Output Stages. *(Note: Diode D1 is Necessary to Prevent Reverse Emitter-Base Breakdown of Transistor Switch S_A)*

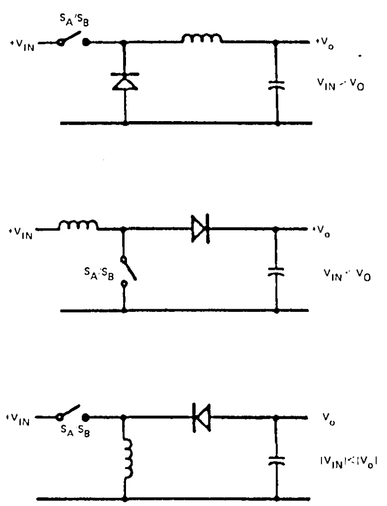


Figure 10. Single-ended Inductor Circuits Where the Two Outputs of the XR-1524 are Connected in Parallel

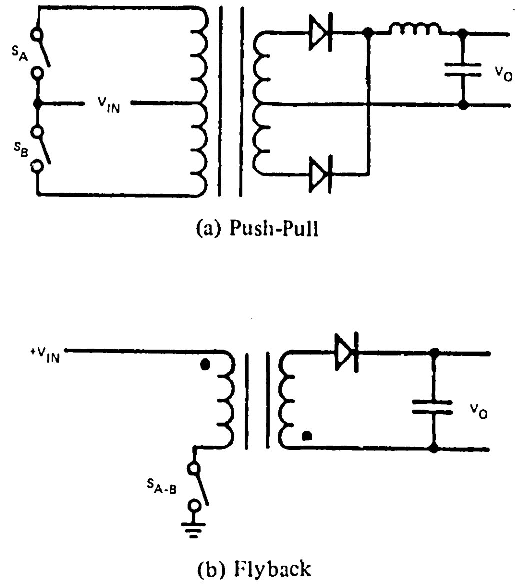


Figure 11. Push-Pull and Flyback Connections for Transformer-Coupled Outputs

DEADBAND CONTROL

The XR-1524 pulse width modulating regulator provides two outputs which alternate in turning on for push-pull inverter applications. The internal oscillator sends a momentary blanking pulse to both outputs at the end of each period to provide a deadband so that there cannot be a condition when both outputs are on at the same time. The amount of deadband is determined by the width of the blanking pulse appearing on pin 3 and can be controlled by any one of the four techniques described below:

Method 1: For 0.2 to 2.0 microseconds, the deadband is controlled by the timing capacitor, C_T, on pin 7. The relationship between C_T and deadband is shown in Figure 4. Of course, since C_T also helps determine the operating frequency, the range of control is somewhat limited.

Method 2: For 0.5 to 5.0 microseconds, the blanking pulse may be extended by adding a small capacitor from pin 3 to ground. The value of the capacitor must be less than 1000 pF or triggering will become unreliable.

Method 3: For longer and more well-controlled blanking pulses, a simple one-shot latch similar to the circuit shown in Figure 12 should be used.

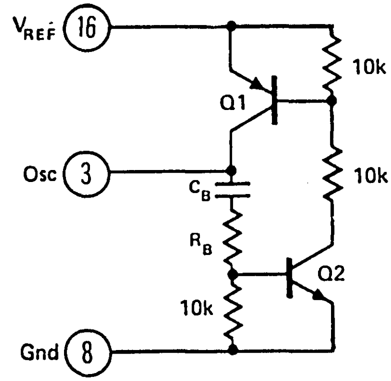


Figure 12. Recommended External Circuitry for Long Duration Blanking Pulse Generation (Method 3 of Deadband Control. *Note: For 5 μsec blanking, choose C_B = 200 pF, R_B = 10 KΩ)*

When this circuit is triggered by the oscillator output pulse, it will latch for a period determined by $C_B R_B$ providing a well-defined deadband.

Another use for this circuit is as a buffer when several other circuits are to be synchronized to one master oscillator. This one-shot latch will provide an adequate signal to insure that all the slave circuits are completely reset before allowing the next timing period to begin.

Note that with this circuit, the blanking pulse holds off the oscillator so its width must be subtracted from the overall period when selecting R_T and C_T

Method 4: Another way of providing greater deadband is just to limit the maximum pulse width. This can be done by using a clamp to limit the output voltage from the error amplifier. A simple way of achieving this clamp is with the circuit shown in Figure 13.

This circuit will limit the error amplifier's voltage range since its current source output will only supply 200 μA. Additionally, this circuit will not affect the operating frequency.

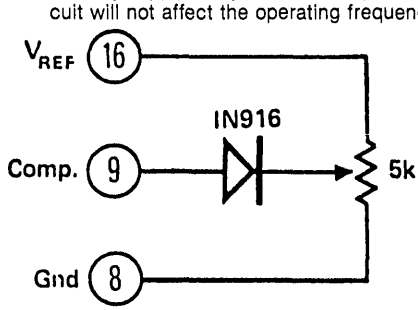


Figure 13. Using a Clamp Diode to Control Deadband (Method 4 of Deadband Control)

APPLICATIONS INFORMATION

POLARITY CONVERTING REGULATOR

The XR-1524 pulse width modulating regulator can be interconnected as shown in Figure 14. The component values shown in the figure are chosen to generate a -5 volt regulated supply voltage from a +15 volt input. This circuit is useful for an output current of up to 20 mA with no additional boost transistors required. Since the output transistors are current limited, no additional protection is necessary. Also, the lack of an inductor allows the circuit to be stabilized with only the output capacitor.

FLYBACK CONVERTER

Figure 15 shows the application of XR-1524 in a low-current DC-DC converter, using the flyback converter principle (see Figure 11b). The particular values given in the figure are chosen to generate ±15 volts at 20 mA from a +5 volt regulated line. The reference generator in the XR-1524 is unused. The reference is provided by the input voltage. Current limiting in a flyback converter is difficult and is accomplished here by sensing current in the primary line and resetting a soft-start circuit.

SINGLE ENDED REGULATOR

The XR-1524 operates as an efficient single-ended pulse width modulating regulator, using the circuit connection shown in Figure 16. In this configuration, the two output transistors of the circuit are connected in parallel by shorting pins (12, 13) and (11, 14) together, respectively, to provide for effective 0 – 90% duty-cycle modulation. The use of an output inductance requires an R-C phase compensation on pin 9, as shown in the figure.

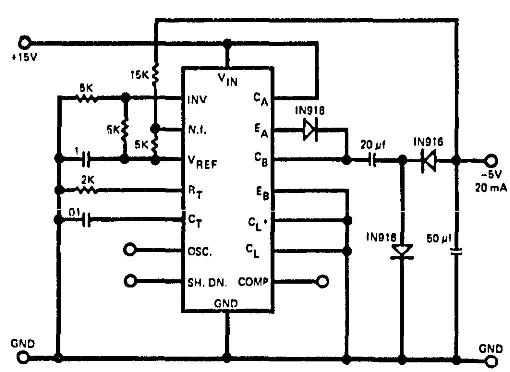


Figure 14. Circuit Connection for Polarity Converting Regulator (V_{in} = +15V, V_{out} = −5V)

PUSH-PULL CONVERTER

The circuit of Figure 17 shows the use of XR-1524 in a transformer-coupled DC-DC converter with push-pull outputs (see Figure 11a). Note that the oscillator must be set at twice the desired output frequency as the XR-1524's internal flip-flop divides the frequency by 2 as it switches the P.W.M. signal from one output to the other. Current limiting is done in the primary. This causes the pulse/width to be reduced automatically if the transformer saturation occurs.

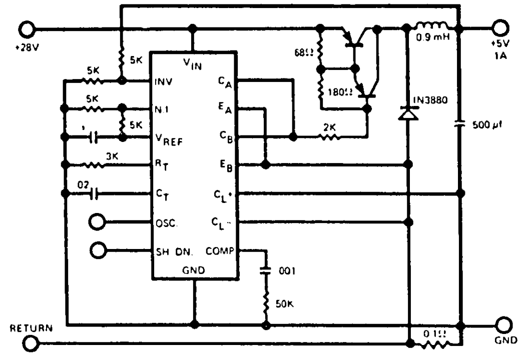


Figure 16. Conventional Single-Ended Regulator Connection (V_{in} = +28V, V_0 = +5V, I_{out} ≤ 1 Amp)

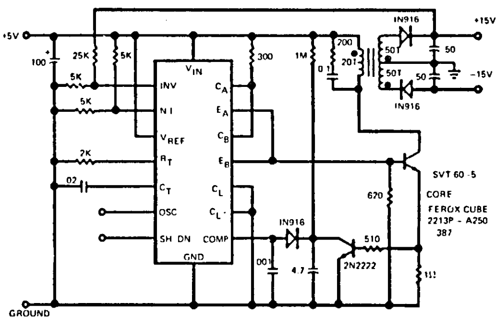


Figure 15. A Low-Current DC-DC Converter Using Flyback Principle (V_{out} = ±15V, V_{in} = +5V, I_L ≤ 20 mA)

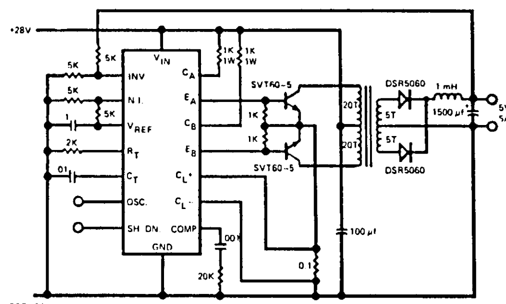


Figure 17. A High-Current DC-DC Converter with Push-Pull Outputs (V_{in} = +28V, V_0 = +5V, I_0 ≤ 5A)