



# **SWITCHING REGULATOR**

# **DATA BOOK**

*First in Quality...First in Service • Custom, Semi-custom and Standard IC's*



**EXAR Corporation**  
**750 Palomar Avenue**  
**P.O. Box 3575**  
**Sunnyvale, CA 94088-3575**  
**(408) 732-7970 TWX 910-339-9233**

Copyright©1985 by EXAR Corporation

First Printing - January 1985

EXAR reserves the right to make changes in the products contained in this book in order to improve design or performance and to supply the best possible products. EXAR also assumes no responsibility for the use of any circuits described herein, conveys no license under any patent or other right, and makes no representations that the circuits are free from patent infringement. Applications for any integrated circuits contained in this publication are for illustration purposes only and EXAR makes no representation or warranty that such applications will be suitable for the use specified without further testing or modification. Reproduction of any portion hereof without the prior written consent of EXAR is prohibited.

---

---

---

<b>FUNDAMENTALS OF SWITCHING REGULATORS</b>	3
Introduction	3
Classes of IC Regulators	3
Series-Pass Regulators	3
Switching Regulators	4
<b>PRINCIPLES OF SWITCHING REGULATORS</b>	6
<b>METHODS OF DUTY CYCLE CONTROL</b>	9
<b>MODES OF OPERATION WITH INDUCTIVE OUTPUT CIRCUITS</b>	10
Step-Down Operation	10
Step-Up Operation	11
Polarity-Inverting Operation	11
Efficiency Considerations	12
<b>STABILITY CONSIDERATIONS</b>	14
<b>SELECTION OF EXTERNAL COMPONENTS</b>	15
Selection of Switching Components	16
Selection of Filter Capacitors	16
<b>TABLE I – EXAR PARTS FEATURES AND CAPABILITIES</b>	17
<b>EXAR SWITCHING REGULATOR PRODUCTS</b>	
XR-494 Pulse-Width Modulating Regulator	20
XR-495 Pulse-Width Modulating Regulator	24
XR-1468/1568 Dual-Polarity Tracking Voltage Regulator	29
XR-1524/2524/3524 Pulse-Width Modulating Regulators	31
XR-1525A/2525A/3525A Pulse-Width Modulating Regulators	39
XR-1527A/2527A/3527A Pulse-Width Modulating Regulators	39
XR-1543/2543/3543 Power Supply Output Supervisory Circuit	47
XR-2230 Pulse-Width Modulator Control System	55
XR-4194 Dual-Polarity Tracking Regulator	63
XR-4915 $\pm 15V$ Dual Tracking Voltage Regulator	66
<b>EXAR DISTRIBUTORS</b>	68
<b>EXAR SALES REPRESENTATIVES</b>	71
<b>EXAR INTERNATIONAL SALES REPRESENTATIVES &amp; DISTRIBUTORS</b>	72
<b>QUALITY ASSURANCE STANDARDS</b>	73
<b>EXAR TECHNICAL LITERATURE REQUEST</b>	75

# Introduction

This Data Book contains a complete summary of technical information covering EXAR's entire line of switching regulator IC products. In addition, several design and application articles are also included, along with a review of fundamentals of pulse-width modulated regulator circuits.

## EXPERIENCE AND PRODUCTS

EXAR's innovativeness, product quality and responsiveness to customer needs have been the key to its success. EXAR today offers a broad line of linear and interface circuits. In the field of standard linear IC products, EXAR has extended its circuit technological leadership into the areas of communications and control circuits. Today, EXAR has one of the most complete lines of IC oscillators, timing circuits and phase-locked loops in the industry. EXAR also manufactures a large family of telecommunication circuits such as tone decoders, compandors, modulators, PCM repeaters and FSK modem circuits. In the field of industrial control circuits, EXAR manufactures a broad line of quad and dual operational amplifiers, voltage regulators, radio-control and servo driver IC's, and power control circuits.

EXAR's experience and expertise in the area of bipolar IC technology extends both into custom and standard IC products. In the area of custom IC's, EXAR has designed, developed, and manufactured, a wide range of full custom monolithic circuits, particularly for applications in the areas of telecommunications, consumer electronics, and industrial controls.

In addition to the full custom capability, EXAR also offers a unique semi-custom IC development capability for low to medium volume custom circuits. This semi-custom program is intended for those customers seeking cost-effective solutions to reduce component count and board size in order to compete more effectively in a changing marketplace. The program allows a customized monolithic IC to be developed with a turnaround time of several weeks at a small fraction of the cost of a full custom development program.

## EXCELLENCE IN ENGINEERING

EXAR quality starts in Engineering where highly qualified people are backed up with the advanced instruments and facilities needed for design and manufacture of custom, semi-custom and standard integrated circuits. EXAR's engineering and facilities are geared to handle all three classes of IC design: (1) semi-custom design programs using EXAR's bipolar, CMOS, and I<sup>2</sup>L Master-Chips; (2) full custom IC design, and (3) development and high-volume production of standard products.

Some of the challenging and complex development programs successfully completed by EXAR include analog compandors and PCM repeaters for telecommunication, electronic fuel-injection, anti-skid braking systems and voltage regulators for automotive electronics, digital voltmeter circuits, 40 MHz frequency synthesizers, high-current and high-voltage display and relay driver IC's, and many others.

## NEW TECHNOLOGIES

Through company sponsored research and development activities, EXAR constantly stays abreast of all technology areas related to changing customer needs and requirements. EXAR has a complete selection of mainstream IC technologies at its disposal. These cover linear and digital bipolar technologies, metal-gate and silicon-gate CMOS and bipolar-compatible integrated injection logic (I<sup>2</sup>L) technologies. EXAR has in-house product and process engineering groups which stay abreast of technological developments in all of these process and fabrication technologies.

## FIRST IN QUALITY/FIRST IN SERVICE

From incoming inspection of critical materials to the final test of the finished goods, EXAR performs sample testing of each lot to ensure that every product meets EXAR's high quality standards. EXAR's manufacturing process is inspected in accordance with its own stringent Quality Assurance Program, which is in compliance with MIL-I-45208. Additional special screening and testing can be negotiated to meet individual customer requirements.

Throughout the wafer fab and assembly process, the latest scientific instruments are used for inspection and modern automated equipment is used for wafer probe, ac, dc, and functional testing. Burn-in testing of finished products is also done in-house. For special environmental or high reliability burn-in tests, outside testing laboratories are used to complement EXAR's own in-house facilities.

EXAR has the ability and flexibility to serve the customer in a variety of ways, from wafer fabrication to full parametric selection of assembled units for individual customer requirements. Special marking, special packaging and military screening are only a few of the service options available from EXAR. We are certain that EXAR's service is flexible enough to satisfy 99% of your needs. The company has a large staff of Application Engineers to assist the customer in the use of the product and to handle any request, large or small.



# Fundamentals of Switching Regulators

In the design of modern electronic equipment and systems, supply voltage regulation is one of the critical circuit functions required for optimum system performance. The function of a voltage regulator is to provide a constant output voltage, under changing line or load conditions.

The advent of monolithic IC regulators has greatly simplified power supply design by reducing design complexity, improving reliability and ease of maintenance. Until recently, the field of IC regulators was dominated by linear or "series-pass" type regulators which are easy to use and require a minimum number of external components. However, under changing load and line voltage conditions, series regulators have relatively poor efficiency in power handling: a significant amount of the input power is dissipated, or wasted, in the regulator, particularly under large line input variations.

In many regulator applications, or in power supply designs, the limitations of series regulators can be overcome by using "switching regulator" systems for voltage and power flow control. Although switching regulators require somewhat more complex circuitry external to the chip, they can provide significant improvement in efficiency and versatility over conventional series regulators. Within recent years, power supplies using switching regulators have proliferated greatly, because of improvements in circuit components specifically made for them. Some of these are the inexpensive high-speed switching power transistors, low-loss ferrite cores for inductors and the complex LSI circuits which contain all the critical control circuitry. As a result, the cost and complexity of switching regulator systems have been reduced greatly, making them economically feasible for a wide range of applications.

This data book is intended as a design and applications aid for the circuit designer involved in voltage regulator or power supply design. It covers the basic principles of operation of switching regulator systems, and the monolithic LSI circuits which can be used in designing them.

## CLASSES OF IC REGULATORS

The function of a voltage regulator is to provide a well-specified and constant output voltage level from a poorly specified and sometimes fluctuating input voltage. The output of the voltage regulator would then be used as a supply voltage for the other circuits in the system. In this

manner, the fluctuations and random variations of a supply voltage under changing load conditions are essentially eliminated.

Since the regulation and control of supply voltage is one of the most fundamental and critical requirements of any electronic system design, the monolithic voltage regulator or power control circuits have become one of the essential building blocks of any analog or digital system. As a result, the monolithic voltage regulators, similar to the case of monolithic op amps, have gained wide acceptance and have greatly simplified the tedious task of designing power supply circuits.

Today, there are two very distinctly different types of IC voltage regulators which have gained wide acceptance and popularity. There are the so-called "series regulators" and "switching regulators". The series regulators control the output voltage by controlling the voltage drop across a power transistor which is connected in series with the load. The power transistor is operated in its linear region and conducts current continuously. The switching regulators, on the other hand, control the flow of power to the load by turning on-and-off one or more of the power switches connected in parallel or series with the load, and make use of inductive and capacitive energy storage elements to convert the switched current pulses into a continuous and regulated load current.

## SERIES-PASS REGULATORS

The series or series-pass type voltage regulator is connected in series between the load and unregulated supply line. It is a feedback circuit comprised of three main sections, shown in Figure 1. These are the reference voltage element, the error amplifier and the series-pass element. In most cases, a fourth section, called "overload protection circuitry", is also included in the system to prevent against burn-out under accidental overload conditions.

With reference to the simplified block diagram of Figure 1, the principle of operation of a series regulator can be briefly described as follows: The internal voltage reference generator generates a reference voltage level,  $V_R$ , which is independent of the unregulated supply voltage or the temperature changes. The error amplifier compares  $V_R$  with the sampled and scaled output voltage,  $V_S$ , and generates a corrective error signal to regulate the voltage drop across the pass element such that the  $V_R = V_S$  condition is fulfilled. The scaled voltage,  $V_S$ , is derived from the actual

output voltage by means of the so-called sampling resistors,  $R_1$  and  $R_2$ . If the error amplifier gain is very high, one can show by a simple feedback system analysis that the output voltage is, to a first order, proportional to the reference voltage  $V_R$  and independent of the input voltage:

$$V_{out} = V_R \left( \frac{R_1 + R_2}{R_2} \right) \quad (2.1)$$

The pass element is normally a high-current transistor, or a Darlington connection of two transistors. Depending on the current and power handling requirements, the pass transistor may be left external to the monolithic IC chip. For proper operation of the pass transistor, it must be biased in its linear region. Therefore, the total voltage drop,  $V_{in} - V_{out}$ , across the pass element must not exceed the breakdown voltage of the pass transistor, and must be greater than a minimum amount, called the drop-out voltage, necessary to keep the pass transistor in its linear or active region.

## SWITCHING REGULATORS

The switching regulators, which are also called switch-mode regulators, find a wide range of applications in power supply design where high-power and high-efficiency are important. The principle of operation of a switching regulator differs significantly from that of a conventional series regulator circuit. In the case of series regulators, the pass transistor is operated in its linear region to provide a controlled voltage drop across it with a steady dc current flow. In the case of switching regulators, the pass transistor is used in a controlled switch and is operated at either the **cut-off** or the **saturated** state. In this manner, the power is transmitted across the pass device in discrete current pulses, rather than a steady current flow.

The most important advantage of switching regulators over the conventional series regulators is greater efficiency, since the pass device is operated as a low impedance switch. When the pass device is at cut-off, there is no current through it, thus, it dissipates no power. When the pass device is in saturation, it is nearly a short circuit with negligible voltage drop across it; thus, it dissipates only a small amount of average power provided that it can handle the peak current loads. In either case, very little power is wasted in the regulator and pass devices, and almost all the power is transferred to the load. In this manner, a very high degree of regulator efficiency is achieved, typically in the range of 70% to 90%, relatively independent of the input/output voltage differentials. The efficiency of switching regulators is particularly apparent when there is a large input/output voltage difference across the regulator. For example, if one considers the case of a regulator operating with a 28-volt input and delivering a 5-volt output at 1A current, a conventional series regulator would require a drop of 23 volts across the series pass transistor. Thus, a total of 23 watts of power is wasted in the regulator, resulting in an overall regulator efficiency of approximately 18%. As will be described in later sections, a switching regulator can be readily designed to perform the same function with greater than 75% efficiency under similar operating conditions.

Another important advantage of the switching regulator circuits is their versatility; they can provide output voltages which can be less than, greater than, or of opposite polarity to the input voltage, as determined by the mode of operation of the circuit. In this manner, one can step-up, step-down, or invert the polarity of an input voltage to generate any arbitrary set of dc voltages within the power distribution system.

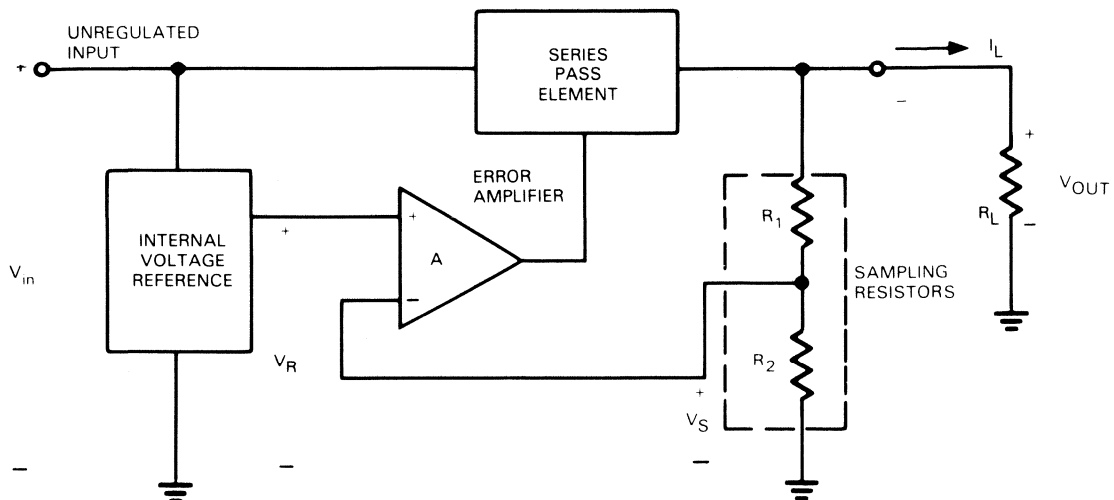


Figure 1. Simplified Block Diagram of a Series Regulator

Switching regulators also have some drawbacks. They are more complex, and require external components such as inductors or transformers. They generate more noise and output ripple than conventional series regulators, and are slower responding to transient load changes. One area of caution, when using switching regulators, is the generation of electromagnetic and radio frequency interference (RFI). This interference problem is usually solved by the use of feedthrough low-pass filters isolating the power lines into the regulator, and by using ground-shields around the regulator to suppress the interference. However, even with these precautions, switching regulator circuits are not recommended for powering very low level signal processing circuitry, where noise characteristics are very critical.

Figure 2 shows the simplified block diagram of a switching regulator power supply system, which comprises several basic blocks. With reference to the figure, the principle of operation of the switching regulator system can be described as follows: The control element is essentially a power switch, which is either "on" (i.e., a virtual short circuit) or "off" (i.e., an open circuit). The duty cycle of the control element is determined by the control logic circuitry, which is driven by an internal oscillator, and puts out periodic control pulses which activate the control pulses (i.e., the on and off duration of the switch over a given period of time is controlled by the output of the error amplifier).

The control element, or switch, delivers pulses of energy into the load circuit which is normally made up of inductive and capacitive components, and diodes. The function of the load circuit is to convert these power pulses to a

steady stream of current flow into an external load resistor,  $R_L$ . The voltage level across  $R_L$  is sensed by means of a sampling resistor network, and is connected to the input of the error amplifier. The error amplifier compares the sampled output level with that of a reference voltage, and causes the pulse width of the control logic section to vary in such a manner to keep the output voltage level across  $R_L$  constant.

The power switch which forms the control element portion of the switching regulator is normally a power transistor which is switched between cutoff and saturation. One advantage of the switching regulator over the conventional linear regulator is greater efficiency, since the cutoff and saturation modes are the two most efficient modes of operation. In the cutoff mode, there is a large voltage across the transistor but little current through it; in the saturation mode, the transistor has little voltage across it but a large amount of current. In either case, little power is wasted, and most of the input power is transferred to the output; therefore, the efficiency is high. Regulation is achieved by varying the duty cycle that controls the average current transferred to the load. As long as this average current is equal to the current required by the load, regulation is maintained.

In addition to high efficiency operation, one added advantage of the switching regulator is the flexibility of the choice of output voltages available. Depending on the particular load circuit configuration used, the output can be greater than or less than the input voltage, or be of opposite polarity to the input. These features will be explained further in the following sections.

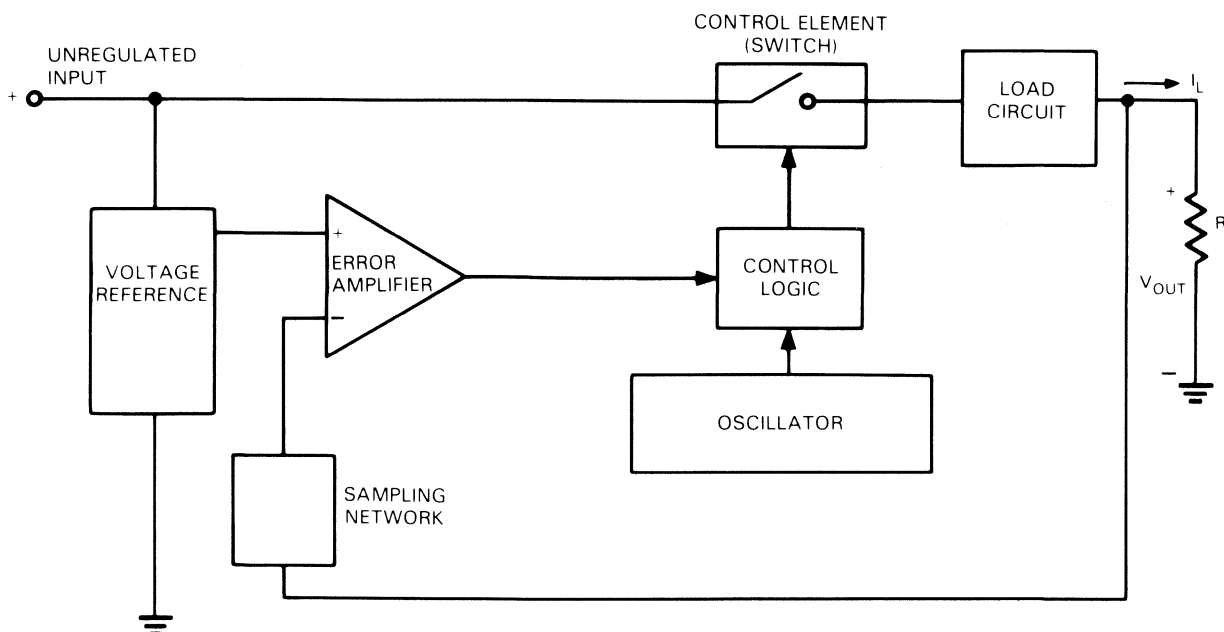


Figure 2. Simplified Block Diagram of a Switching Regulator System

# Principles of Switching Regulators

The functional block diagram of a switching regulator circuit is shown in Figure 2. The basic principle of operation of the entire regulator system was qualitatively described in the previous section. Although the switching regulator system contains a large number of subsystems, it can be divided into two major sections:

- a) Control Circuitry
- b) Output Load Circuitry

Control circuitry is comprised of the voltage reference, sampling network, error amplifier, oscillator and the control logic sections shown in Figure 2. The purpose of this circuitry is to control the rate of power flow to the load circuit, and ultimately into the output load,  $R_L$ . The control of power flow is achieved by generating control pulses which determine the on/off period of the control element. The control circuitry normally operates at very low power levels.

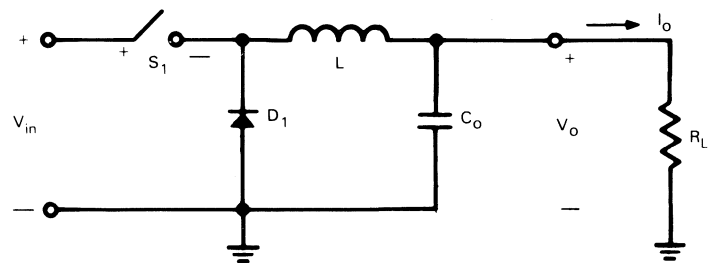
The output load circuitry is made up of the control element and the load circuit. The control element functions as a power switch, and delivers discrete packets of power, in the form of current pulses into the load current. The load circuit converts these into a steady current flow through the external load.

Depending on the type of output load circuitry used, switching regulator power supplies can be classified into three categories. These are:

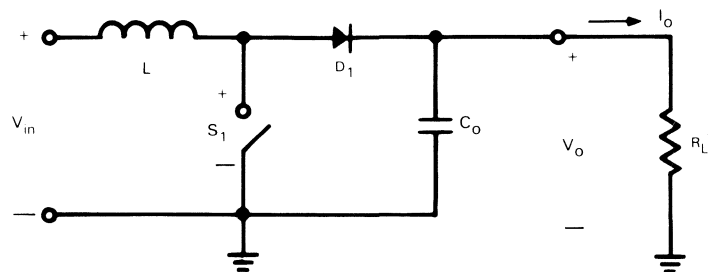
1. Single-ended inductor circuits.
2. Diode/Capacitor circuits.
3. Transformer coupled circuits.

Figure 3 shows the three basic configurations for the output circuitry of single-ended inductor type switching regulators. These are among the most frequently used output circuit configurations since they are by far the easiest to design and control for medium and high-current applications.

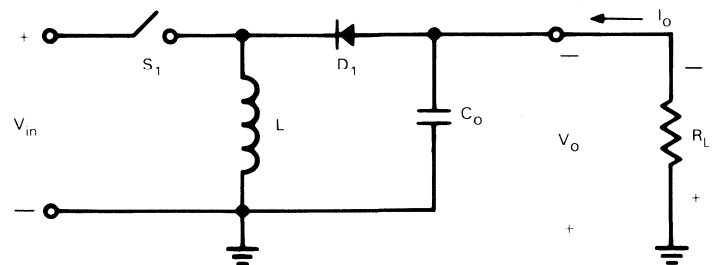
Figure 4 shows the switching regulator configurations using diode/capacitor circuits. These circuits are typically used for very low current applications, and primarily as voltage multipliers, to increase the voltage level available from a low voltage battery. Examples of such applications are the generation of voltage drive for LCD displays in watch circuits from a 1.5-volt or 3-volt battery, and in low voltage hearing aid amplifiers.



(a) STEP-DOWN CONFIGURATION ( $V_{in} > V_o$ )



(b) STEP-UP CONFIGURATION ( $V_o > V_{in}$ )



(c) INVERTING CONFIGURATION

Figure 3. Single-Ended Inductive Load Circuits

Figure 5 shows the two basic configurations of transformer coupled output circuits. The circuit of Figure 5(a) is the so-called push-pull circuit used in conventional dc-to-dc converters, with each switch controlled for 0 to 45% duty cycle modulation. The configuration of Figure 5(b) is the so-called single-ended flyback converter, which is useful at low-to-medium current loads.

The design of power supply systems using discrete circuits and the various types of output circuitry shown in Figures 3 through 5 are well covered in the literature. In the following discussions, we will primarily focus on switching regulator circuits using the single-ended inductor type output circuit shown in Figure 3, since these represent by far the most common category of application.

The control circuitry section of a switching regulator system, which controls the on/off duty cycle of the switch transistors, can be readily integrated in a monolithic IC form. In many cases, the switching transistors up to 1A current rating can also be incorporated into the monolithic chip. If higher power levels are required, the switch transistor on the chip is used as a drive for an external high current switch.

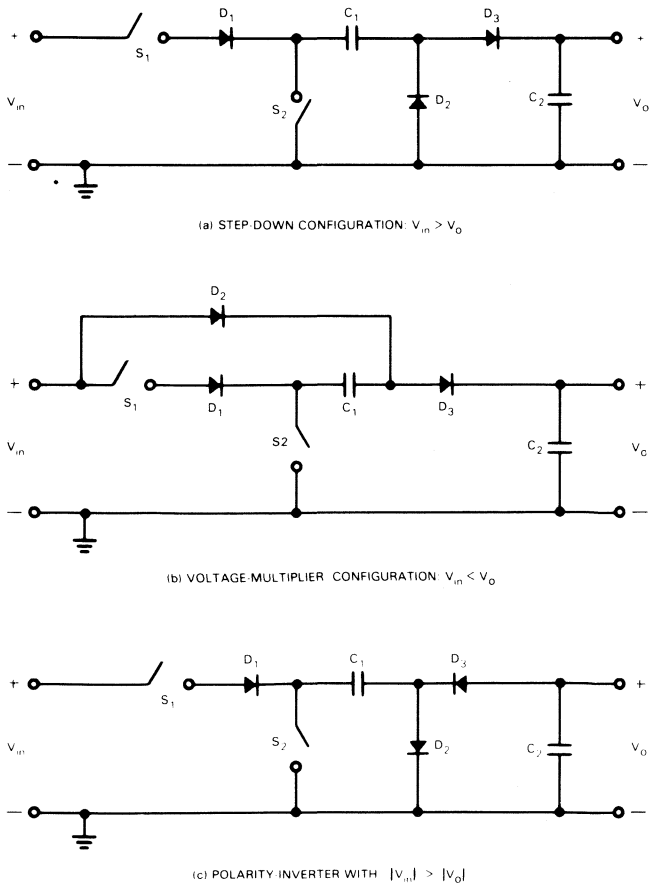


Figure 4. Diode/Capacitor Type Load Circuits

Figure 6 shows a simplified block diagram of a typical switching regulator IC used in conjunction with the single-ended inductor configuration of Figure 3(a). The circuit generates a stream of pulses which turn switch  $S_1$  "on" and "off". The output dc level is sensed through the sampling resistors,  $R_1$  and  $R_2$ , and compared against an internal voltage reference,  $V_{ref}$ , with the on/off time on the duty cycle of the switch,  $S_1$ , varied accordingly to keep the output voltage constant under changing load conditions.

Neglecting the current in the sampling resistors, the average or dc value of the output current,  $I_o$ , delivered to the load is proportional to the duty cycle of the power switch,  $S_1$ , as illustrated in Figure 7. If the sampled output voltage is lower than  $V_{ref}$ , the polarity of the comparator output signal causes the control logic to increase the duty cycle of  $S_1$  and, thus, causes the output voltage level to increase until the equilibrium is reached such that the output voltage, scaled down by the sampling resistors, is equal to the internal reference voltage. Similarly, if the output load current,  $I_o$ , is decreased, this would cause the output voltage to increase which in turn would be sensed by the control circuitry and would reduce the duty cycle of the switch accordingly.

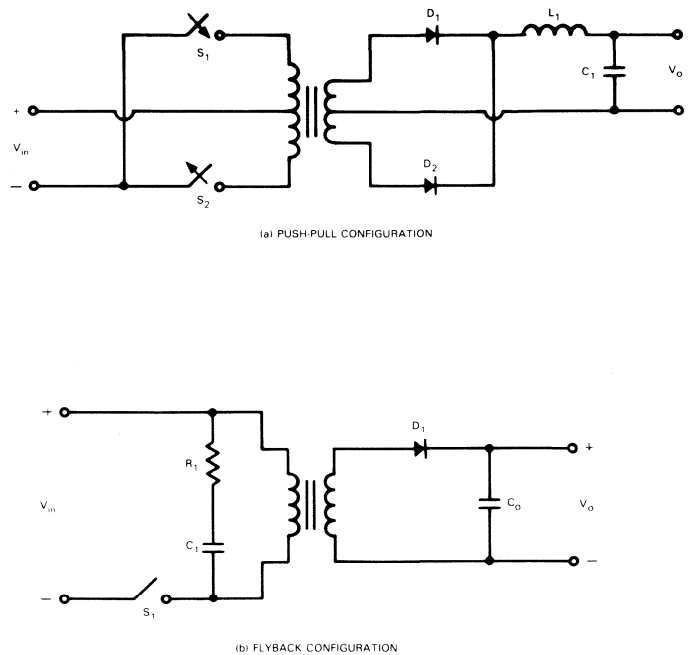


Figure 5. Transformer Coupled Load Circuits

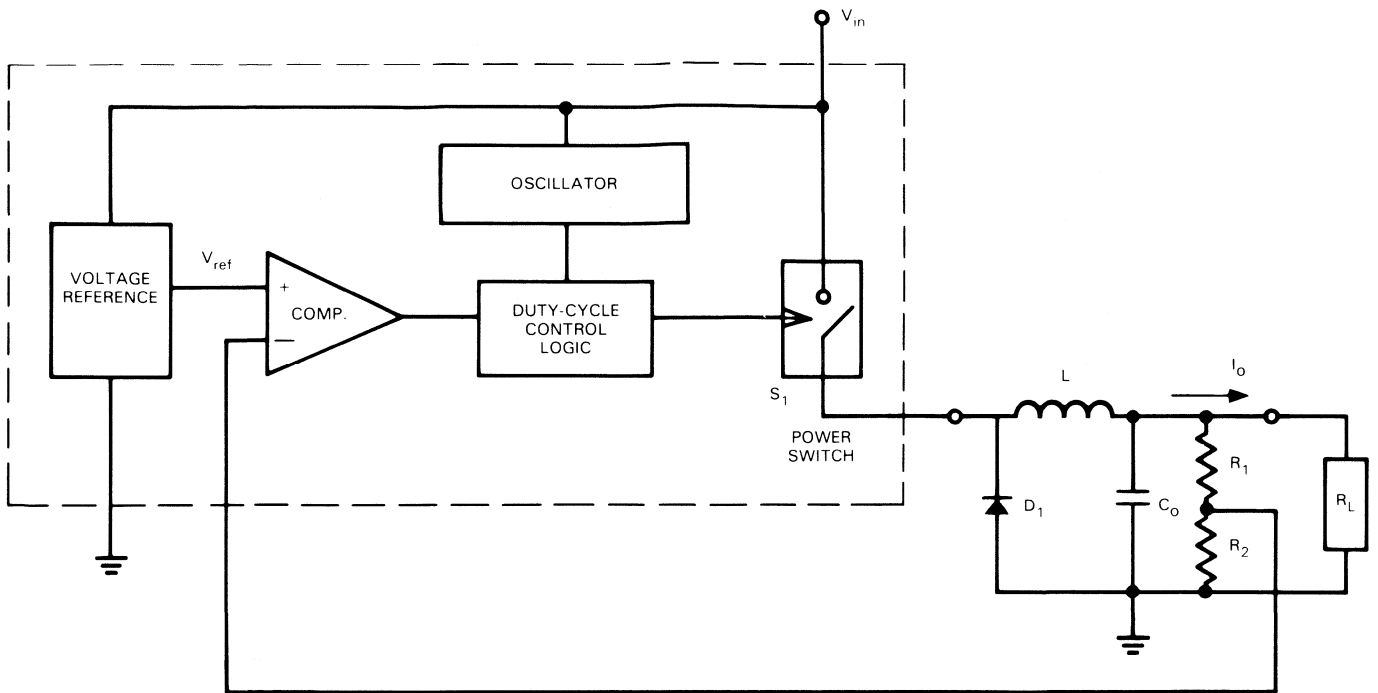


Figure 6. Simplified Block Diagram of a Switching Regulator IC in "Step-Down" Configuration

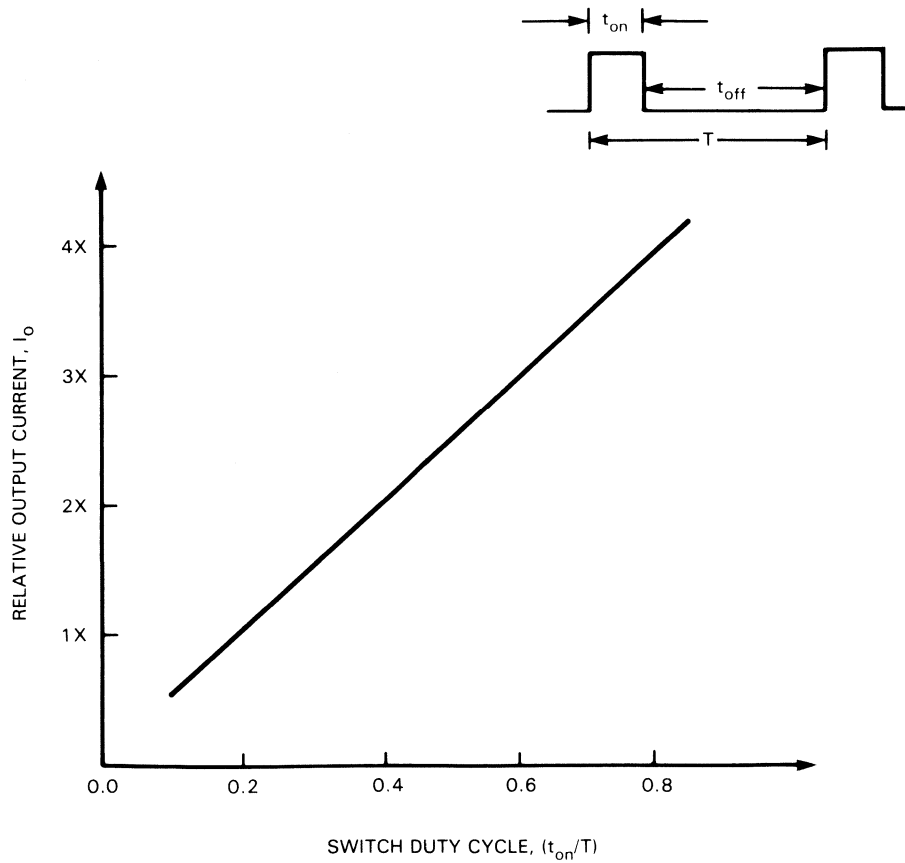


Figure 7. Output Load Current,  $I_o$ , as a Function of Switch Duty Cycle

# Methods of Duty Cycle Control

The switch duty cycle, ( $t_{ON}/T$ ), can be controlled by pulse width modulation at a fixed frequency, or by fixing the "on" or "off" time, and varying the frequency. The relative merits and disadvantages of these techniques are briefly examined below.

(a) Fixed Frequency, Variable Duty Cycle Operation:

In this type of a switching regulator, the operating frequency is fixed and the duty cycle of the pulse train is varied to change the average power. This method is often referred to as pulse width modulation (PWM). The fixed frequency concept is particularly advantageous for systems employing transformer coupled output stages. The fixed frequency aspect enables the efficient design of the associated magnetics. In addition, filtering or shielding the surroundings from the radio frequency or electromagnetic interference generated by the regulator is somewhat simplified because of the fixed frequency of switching. Because of these features, the majority of the switching regulator control IC's utilize a fixed frequency, variable duty cycle control method.

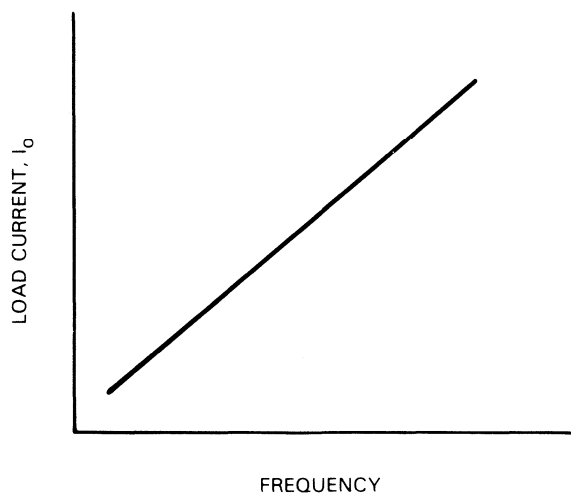
(b) Fixed On-Time, Variable Frequency:

In this method, the switch has a fixed or predetermined "on" time, and the duty cycle is varied by varying the frequency or repetition rate of the control pulses. This method provides ease of design in voltage conversion applications using the single-ended

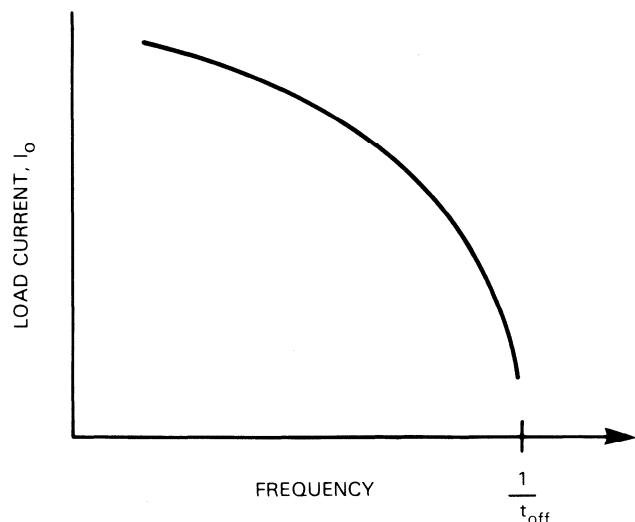
inductive output circuit configurations of Figure 3, and simplifies design calculations for the inductor value. The fixed on-time method is also advantageous for inductive output circuitry, since a consistent amount of charge is developed in the inductor during the fixed on-time. This eases the design or the selection of the inductor by defining the operating area to which the inductor is subjected under transient load conditions. Figure 8(a) shows the typical frequency vs. load current characteristics of a fixed on-time, variable frequency regulator, where the frequency increases linearly with increasing load.

(c) Fixed Off-Time, Variable Frequency:

In this type of a voltage regulator, the dc voltage at the output is varied by changing the on-time,  $t_{ON}$ , of the switch, while maintaining a fixed off-time,  $t_{OFF}$ . As shown in Figure 8(b), the fixed off-time switching regulator behaves in an opposite manner to the fixed on-time system; as the load current increases, the on-time becomes longer, thus decreasing the frequency. This approach is advantageous for the design of a switching regulator which will operate at a well-defined minimum frequency and low ripple current under full load conditions. One basic drawback of the fixed off-time system is that the maximum current in the inductor, under transient load conditions, is not well-defined. Thus, additional care is required to ensure that the saturation characteristics of the inductor are not exceeded.



(a) FIXED ON-TIME



(b) FIXED OFF-TIME

Figure 8. Typical Load Current vs Frequency Characteristics of (a) Fixed On-Time and (b) Fixed Off-Time Variable Frequency Switching Regulators

# Modes of Operation with Inductive Output Circuits

Two of the most important advantages of switched regulators are their high efficiency and their ability to step-up, step-down, or change polarity of an input voltage. These basic features can be best understood by examining the voltage and current waveforms at the output of the regulator. In this section, some of the waveforms and key design equations associated with the inductive output circuits of Figure 3 will be examined for various modes of operation under steady-state load conditions. For the sake of brevity, rigorous derivations will be omitted and only their conclusions will be presented.

## STEP-DOWN OPERATION

In the step-down operation, the switching regulator produces an output dc voltage,  $V_O$ , which is lower than the input voltage,  $V_{in}$ . Figure 9 shows the basic voltage and current waveforms associated with the circuit under steady-state operation. The switch,  $S_1$ , is assumed to have a voltage drop of  $V_{sat}$  in its "on" condition, and the diode,  $D_1$ , has a forward drop of  $V_D$  when it is conducting.

When  $S_1$  is closed, or on,  $D_1$  is off, and the current in the inductor,  $I_L$ , rises linearly from zero to its peak value,  $I_{pk}$ , with the slope:

$$\frac{dI_L}{dt} = \frac{V_L}{L} = \frac{V_{in} - V_{sat} - V_O}{L} \quad (4.1)$$

At the end of the switch on-time,  $t_{on}$ , this current reaches its maximum value,  $I_{pk}$ . When  $S_1$  is off, the inductor generates the necessary voltage to forward bias  $D_1$ , and keep  $I_L$  from changing instantaneously. During this portion of the cycle,  $I_L$  linearly decays to zero at the end of the off-time  $t_{off}$ .

At steady-state, average or dc current through  $C_O$  is zero, therefore, the output dc current,  $I_O$ , is equal to the average value of  $I_L$ , or:

$$I_O = (I_L)_{avg} = \frac{I_{pk}}{2} \quad (4.2)$$

From the waveforms shown in Figure 9, the switch "on" and "off" times can be related to the voltage levels at the input and output of the circuit, as:

$$\frac{t_{on}}{T_{off}} = \frac{V_O + V_D}{V_{in} - V_{sat} - V_O} \quad (4.3)$$

or,  $V_O$ , can be to the rest of the voltages as:

$$V_O = \left(\frac{t_{on}}{T}\right) (V_{in} - V_{sat}) - \left(\frac{t_{off}}{T}\right) V_D \quad (4.4)$$

assuming an ideal case where both the saturation and diode voltages are zero or negligible, this reduces to:

$$(V_O)_{ideal} = \left(\frac{t_{on}}{T}\right) V_{in} \quad (4.5)$$

Equation (4.5) implies that, ideally, the switching regulator in its step-down mode provides a down scaling of the input voltage by a scale factor equal to the duty cycle of the switch transistor.

Another important parameter of the step-down regulator is the peak-to-peak output ripple voltage,  $(\Delta V_O)_{pp}$ . Assuming that  $C_O$  is sufficiently large so that the ripple voltage is much lower than the average or dc value of the output,  $(\Delta V_O)_{pp}$  can be expressed as:

$$(\Delta V_O)_{pp} = \frac{I_{pk}}{8C_O} (t_{on} + t_{off}) = \frac{I_{pk}}{8C_O f} \quad (4.6)$$

where  $f = 1/T$  is the frequency or the repetition rate at which the switch opens and closes.

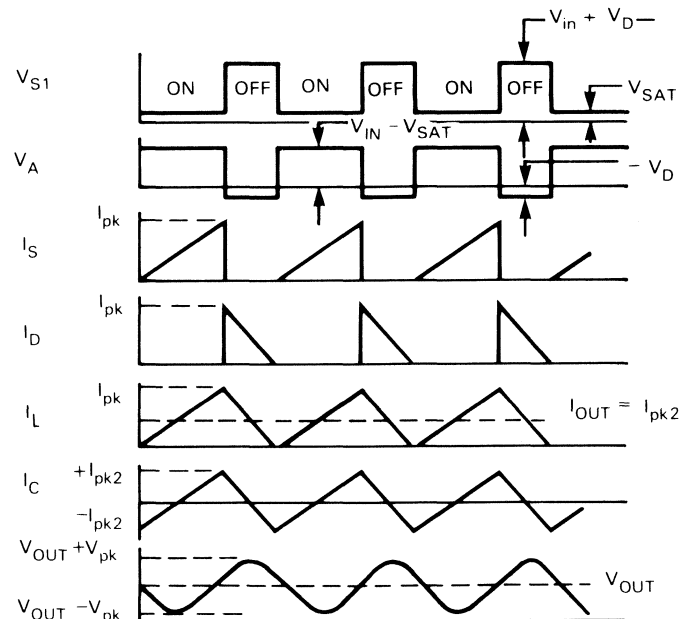
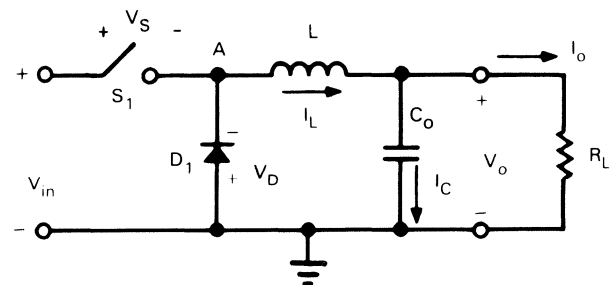


Figure 9. Switching Regulator Voltage and Current Waveforms in Step-Down Mode



## STEP-UP OPERATION

In the step-up mode the switching regulator produces an output dc voltage  $V_O$ , which is higher than  $V_{IN}$ . The circuit configuration for this mode of operation, along with the associated voltage and current waveforms, is shown in Figure 10 under steady-state operation.

With reference to Figure 10, the operation of the circuit can be summarized as follows: Assuming that  $S_1$  is open and closes at the moment  $I_L = 0$ , the current in the inductor rises linearly from zero to a peak value,  $I_{PK}$ , during  $t_{ON}$ . At the end of on-time,  $S_1$  is opened. Since  $I_L$  cannot change instantaneously, the inductor generates the necessary voltage at node A to forward-bias  $D_1$ , and keep the current continuous. During the off-time,  $I_L$  decays linearly, and reaches zero at  $t_{OFF}$ . Then,  $S_1$  closes again, and the cycle repeats itself. While  $D_1$  is conducting, it supplies current to both the hold and the loading capacitor,  $C_O$ ; when  $D_1$  is nonconducting, the output current is drawn from  $C_O$ . Note that at steady-state, the average or dc current through  $D_1$  is equal to the output or load current,  $I_L$ , and the net charge supplied to  $C_O$ , per cycle of operation, is zero.

The peak current,  $I_{PK}$ , is related to the steady-state output current as:

$$I_{PK} = 2 I_O \left( \frac{V_D + V_O - V_{SAT}}{V_{IN} - V_{SAT}} \right) \quad (4.7)$$

and the on/off times of the switch, necessary for  $I_L$  to ramp from zero to  $I_{PK}$  and back to zero, are related as:

$$\frac{t_{ON}}{T_{OFF}} = \frac{V_D + V_O - V_{SAT}}{V_{IN} - V_{SAT}} \quad (4.8)$$

Solving Eq. (4.8) for  $V_O$ , one obtains:

$$V_O = V_{IN} \left( \frac{T}{t_{OFF}} \right) - V_{SAT} \left( \frac{t_{ON}}{t_{OFF}} \right) - V_D \quad (4.9)$$

where  $T (= t_{ON} + T_{OFF})$  is the period of one full cycle of operation. In the idealized case, where the diode drop and  $V_{SAT}$  of the switch are negligible, Eq. (4.9) reduces to:

$$(V_O)_{IDEAL} = V_{IN} \left( \frac{T}{t_{OFF}} \right) \quad (4.10)$$

or, in other words, the step-up mode of operation results in up-scaling the input voltage by the ratio  $(T/t_{OFF})$ .

The peak-to-peak output ripple voltage can be expressed as:

$$(\Delta V_O)_{PP} = \frac{(I_{PK} - I_O)^2}{2 I_{PK}} (t_{OFF} / C_O) \quad (4.11)$$

with the assumption that  $(\Delta V_O) \ll V_O$ .

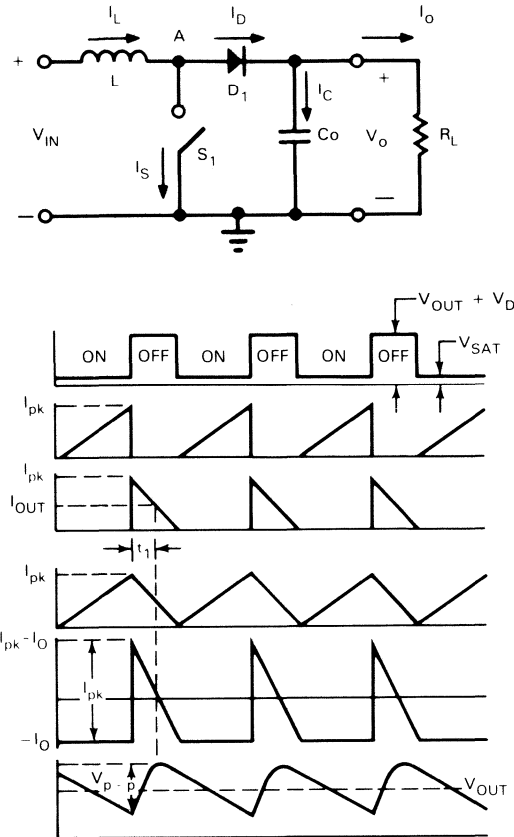


Figure 10. Voltage and Current Waveforms in Step-Up Mode

## POLARITY-INVERTING OPERATION

In the polarity-inverting mode of operation, the switching regulator produces an output voltage across the load which is the opposite polarity to the input. Figure 11 shows the basic circuit configuration for this mode of operation. The polarity inversion is achieved by making the inductor force a current in the opposite direction through the load.

The operation of the circuit can be briefly described as follows: The current,  $I_L$ , through the inductor ramps up from zero to  $I_{PK}$  during  $t_{ON}$ , and ramps down to zero during  $t_{OFF}$ , similar to the other two modes of operation described earlier. During  $t_{OFF}$ , with  $S_1$  open, the inductor generates a negative voltage at node A to forward bias  $D_1$  and keep  $I_L$  continuous. As in the case of step-up circuits, the average value of the diode current,  $I_D$ , is the steady state load current  $I_O$ , since  $C_O$  cannot pass any dc current. Thus, from the waveforms and timing relations of Figure 11, one can express the peak current,  $I_{PK}$ , as:

$$I_{PK} = 2 I_O \left( \frac{V_{IN} + V_D - V_O - V_{SAT}}{V_{IN} - V_{SAT}} \right) \quad (4.12)$$

and the on/off times of the switch, necessary for  $I_L$  to ramp up from zero to  $I_{pk}$  and back to zero, are:

$$\begin{aligned} t_{on} &= \left( \frac{V_D - V_O}{V_{in} - V_{sat}} \right) & (4.13) \\ t_{off} & \end{aligned}$$

Solving the above equation for  $V_O$ , one gets:

$$V_O = - [ (t_{on}/t_{off}) (V_{in} - V_{sat}) - V_D ] \quad (4.14)$$

In the idealized case, where  $V_D$  and  $V_{sat}$  are neglected, Eq. (4.14) will reduce to:

$$(V_O)_{ideal} = - \left( \frac{t_{on}}{t_{off}} \right) V_{in} \quad (4.15)$$

or in other words, the polarity-inverting mode of operation results in the reversal of polarity of the output voltage as well as its being scaled by the  $(t_{on}/t_{off})$  ratio.

The peak-to-peak output ripple,  $(\Delta V_O)_{pp}$ , associated with the inverting operation can be expressed as:

$$(\Delta V_O)_{pp} = \frac{(I_{pk} - I_O)^2}{2 I_{pk}} \left( \frac{t_{off}}{C_O} \right) \quad (4.16)$$

which is identical to the case of step-up operation (see Eq. 4.16).

One word of caution is in order when using the polarity inverting configuration: Since the output polarity is reversed, the feedback polarity from the sampling resistors to the voltage comparator in the control circuitry (see Figure 6) must be reversed. Normally, this is done by reversing the reference and feedback inputs into the voltage comparator.

### EFFICIENCY CONSIDERATIONS

The efficiency of a voltage regulator is defined as the ratio of the output power to the input power, i.e.:

$$\text{Regulator Efficiency} = \eta = \frac{P_O}{P_{in}} \quad (5.1)$$

where  $P_O$  is the power delivered to the load, and  $P_{in}$  is the power drawn from the power lines.

The efficiency advantage of switching regulator circuits can be illustrated best by comparing their efficiency with that of a series-pass type regulator.

#### Efficiency of a Series Regulator

In calculating the efficiency of a series regulator, similar to that shown in Figure 1, one can use a simple equivalent model of power dissipation within the regulator, as shown in Figure 12.

In this model, the current source,  $I_B$ , represents the total bias and operating current consumed in the regulator circuitry, and  $V_B$  represents the voltage drop across the pass transistor. For proper operation of the circuit,  $V_B$  is restricted to be greater than the drop-out voltage.

From the simple model of Figure 12, the input and output power levels can be written as:

$$P_{in} = V_{in} (I_B + I_L) \quad (5.2)$$

and

$$P_O = V_O I_L \quad (5.3)$$

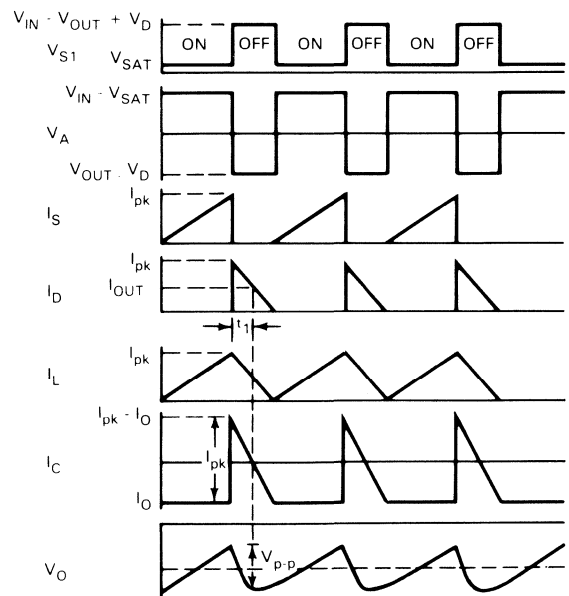
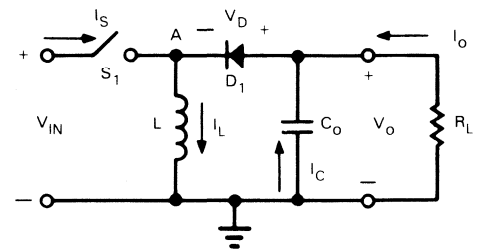


Figure 11. Voltage and Current Waveforms in Polarity-Inverting Mode

Then, the efficiency,  $\eta$ , can be expressed as:

$$\eta = \frac{P_o}{P_{in}} = \frac{1}{(1 + V_B/V_o)(1 + I_B/I_L)} \quad (5.4)$$

As given by Eq. (5.3), regulator efficiency depends directly on the ratio of load voltage and load current to the bias voltage and bias current. Since the bias current,  $I_B$ , is more or less fixed by the regulator design, the maximum rated efficiency,  $\eta$ , is obtained when the regulator is delivering its maximum rated current with the minimum input/output voltage differential. If the input contains large ac components, or large minimum/maximum fluctuations, the maximum efficiency is reduced since the average level of the input voltage would have to be increased to ensure that the instantaneous value of  $V_B$  is greater than the drop-out voltage.

### Efficiency of Switching Regulators

Starting with the basic definition of efficiency given in Eq. (5.1), one can obtain the expressions for switching regulator efficiency under various operating modes.

For the case of the step-down regulator circuit, one can derive, from Eq. (4.2) through (4.4), an expression for efficiency as:

$$(\eta)_{\text{step-down}} = \left( \frac{V_o}{V_o + V_D} \right) \left( \frac{V_{in} + V_D - V_{sat}}{V_{in}} \right) \quad (5.5)$$

In a similar manner, the efficiency expression for step-up operation can be derived from Eq. (4.7) through (4.9) as:

$$(\eta)_{\text{step up}} = \left( \frac{V_o}{V_o + V_D - V_{sat}} \right) \left( \frac{V_{in} - V_{sat}}{V_{in}} \right) \quad (5.6)$$

The efficiency expression for inverted polarity operation can be derived from Eq. (4.12) through (4.14) as:

$$(\eta)_{\text{inverter}} = \left( \frac{I_{VoI}}{V_D + I_{VoI}} \right) \left( \frac{V_{in} - V_{sat}}{V_{in}} \right) \quad (5.7)$$

The efficiency expressions given above do not take into account the quiescent power dissipation in the control circuitry, which can cause the efficiency to decrease at very low current levels, when the average input current is of the same order of magnitude as the quiescent current. The switching transient losses in the switch transistor and diode, as well as the parasitic resistances associated with the inductor, are also not included in the above expressions. In practical regulator systems, these latter losses will cause small but finite reduction in the observed efficiency as compared to the theoretical results given in Eq. (5.5) through (5.7). The exact nature of this reduction in efficiency depends on the specific transistor, diode and inductor characteristics used, as well as on the selection of operating frequency.

There are two additional observations which can be made regarding the efficiency expressions:

1. In the ideal case, where both  $V_{sat}$  and  $V_D$  go to zero, all three regulator configurations provide an ideal efficiency of 100%.
2. The efficiency expressions of Eq. (5.5) through (5.7) are not sensitive to input/output voltage differential across the regulator. This is very different than the case of a conventional series regulator where efficiency varies inversely with the input/output voltage differential (see Eq. 5.4).

As an illustration, it is worthwhile comparing the efficiency of a power supply system with a 20-volt input and a 5-volt output with a conventional series regulator, to that with a step-down switching regulator. For simplicity, quiescent power dissipation associated with the control circuitry will be neglected.

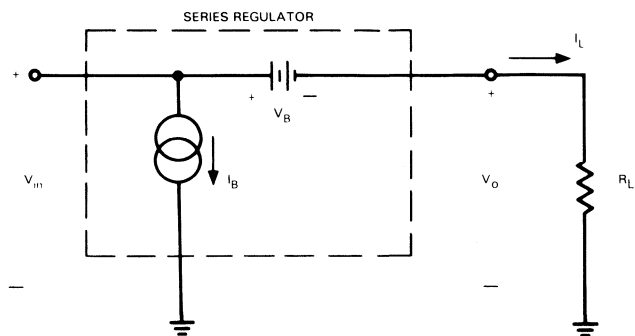
In the case of a conventional series regulator, the efficiency is:

$$(\eta)_{\text{series}} \approx \frac{5}{20} = 25\% \quad (5.8)$$

For the case of a step-down regulator, assuming typical values of  $V_D = 1$  volt, and  $V_{sat} = 1.5$  volts, one gets from Eq. (5.5):

$$(\eta)_{\text{switching}} = (5/6) \left( \frac{19.5}{20} \right) = 81.25\% \quad (5.9)$$

which illustrates one of the most important features of switching regulators namely efficient transfer of power.



**Figure 12. A Simplified Model for Calculating Efficiency of a Series Regulator**

# Stability Considerations in Switching Regulators

Similar to the case of conventional regulators, switched-mode power supplies are operated as closed-loop feedback systems; the output voltage level is constantly sensed, and a corrective signal is generated via a negative feedback path to keep it very nearly constant under varying load conditions. Since the overall regulator is a feedback system, it must be designed to meet certain stability criteria in order to assure its proper operation.

As in all feedback systems, the switching regulator circuits must also meet the so-called "Nyquist Criteria" for stability; namely the total phase shift around the regulator feedback loop must be less than  $-180$  degrees when the total loop gain is unity (i.e., 0 dB). Stated in another way, this criteria also states that the loop gain must be less than zero dB when the phase shift reaches  $-180$  degrees.

A convenient parameter to measure the margin of stability in a switching regulator is the so-called phase margin, which is defined as the amount of margin left in degrees before the phase reaches  $-180$  degrees, at the frequency where the gain is equal to zero dB. For example, if the total phase shift around the feedback-loop is  $-130$  degrees when the gain reaches unity, this corresponds to a phase margin of 50 degrees.

The higher the phase margin, the higher is the margin of stability. However, if the phase margin is too high, the system response tends to be too slow and sluggish. As a general rule, a phase margin of approximately 45 degrees is desirable for maximum stability.

In order to investigate the stability in a switching regulator, it is usually necessary to examine the gain and phase shift characteristics of each of the functional blocks that

make up the system. Then a gain and phase vs. frequency plot is constructed for each block and combined to generate a composite frequency response of the total system. The gain of each block can be added algebraically (in dB) to obtain the overall loop gain. Then, the combined gain and phase characteristics can be examined to calculate the overall phase margin. If the overall phase margin is less than 45 degrees, it is usually necessary to modify the system to enhance its stability.

The functional blocks which contribute most of the loop gain and phase shift are the error amplifier and the output LC filter. However, the sampling network and pulse width modulator must also be considered.

Gain and phase shift of the LC network is of most importance since it contributes most of the phase shift in the loop. Figure 13 shows a plot of phase shift vs. frequency for an LC filter. Note that with high values of  $(R/\sqrt{LC})$ , the phase shift approaches  $-180$  degrees. Figure 14 shows a plot of gain vs. frequency for the same filter. For high values of  $(R/\sqrt{LC})$ , the resonant peak becomes dominant.

Gain and phase plot of the error amplifier are usually provided in the manufacturer's data sheet. By tailoring the feedback network around the amplifier, it is possible to alter the closed loop frequency response for improved stability. There are various compensation and feedback techniques, such as lead, lag, and integrating networks, that will produce different gain and phase responses.

The sampling network in most switched mode power supplies is usually a resistive network to level shift the output voltage to a suitable range for the error amplifier. This contributes some voltage attenuation but no phase shift.

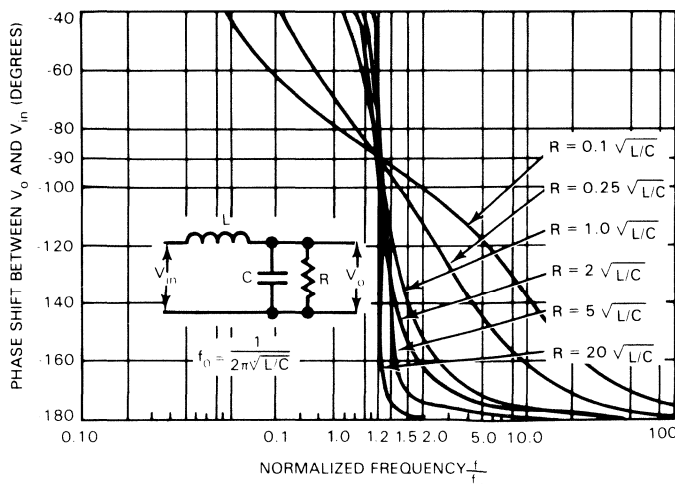


Figure 13. Phase Shift vs Frequency for Switching Regulator LC Filter

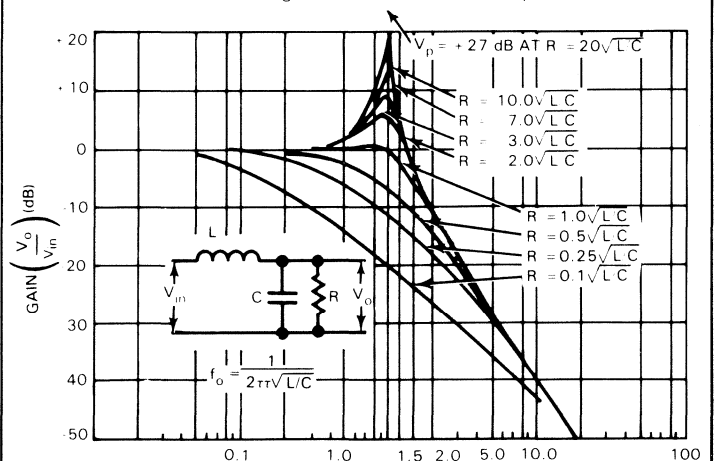


Figure 14. Gain vs Frequency for Switching Regulator LC Filter

# Selection of External Components

Switching regulator systems require the use of external inductors, capacitors, switching transistors, and diodes, in addition to the basic controller IC chip. In this section, some of the requirements of design and selection criteria for these external components shall be reviewed.

## Selecting the Inductors

In the selection of the inductor, one important criteria is the choice of the core material. The core must provide the desired inductance without saturating magnetically at the maximum peak current. In this respect, each core has a specific energy storage capability,  $LI^2_{sat}$ , where  $I_{sat}$  is the magnetic saturation current of the inductor.

The window area for the core winding must permit the number of turns necessary to obtain the required inductance with a wire size that has acceptable dc losses in the winding at maximum peak current. Each core has a specific dissipation capability,  $LI^2$ , that will result in a specific power loss or temperature rise. This temperature rise, plus the ambient temperature, must not exceed the Curie temperature of the core.

The value of the inductance,  $L$ , can be related to the basic core parameters and the total number of turns,  $N$ , in the wound core as:

$$L = N^2 \times 0.4 \pi \mu A_e l_e \times 10^{-5} \quad (7.1)$$

where:

- $\mu$  = effective permeability of core
- $l_e$  = effective magnetic path length (cm)
- $A_e$  = effective magnetic cross section (cm<sup>2</sup>)

Another useful inductor parameter is the inductor index,  $A_L$ , which is defined as:

$$A_L = 0.4 \pi \mu A_e l_e \times 10 \text{ (mH/1000 turns)} \quad (7.2)$$

From these equations, the magnetic energy, ( $LI^2$ ), stored in the core at a given current level can be written as:

$$LI^2 = (NI)^2 (A_L \times 10^{-6}) \text{ (millijoules)} \quad (7.3)$$

The maximum ampere turn capability,  $(NI)$ , of a given inductor is limited by the magnetic saturation of the core material. If the inductor index,  $A_L$ , and the saturation current,  $I_{sat}$ , are given for a particular inductance value, the maximum ampere turns can be calculated from Eq. (7.3).

If the saturation flux density,  $B_{sat}$ , is given, then the maximum energy which can be stored in the inductor can be expressed as:

$$LI^2 = \frac{(BSAT)^2 (A_e^2 \times 10^{-4})}{A_L} \text{ (millijoules)} \quad (7.4)$$

The core selected for an application must have an  $LI^2_{sat}$  value greater than calculated, to insure that the core does not saturate under maximum peak current conditions.

In switching regulator applications, power dissipation in the inductor is almost entirely due to dc losses in the winding. The dc resistance of the winding,  $R_W$ , can be calculated as:

$$R_W = P(I_W/A_W) N \quad (7.5)$$

where:

- $P$  = resistivity of wire ( $\Omega/\text{cm}$ )
- $w$  = length of turn (cm)
- $A_W$  = effective area of wire (cm<sup>2</sup>)

Core geometry provides a certain window area,  $A_C$ , for the winding. The effective area,  $A'_C$ , is  $0.5 A_C$  for toroids and  $0.65 A_C$  for pot cores. Equation (7.6) relates the number of turns, area of wire, and effective window area of a fully wound core:

$$A_W = A'_C/N \text{ (cm}^2\text{)} \quad (7.6)$$

From Eq. (7.5) and (7.6), the power dissipation,  $P_W$ , in the inductor winding can be calculated as:

$$P_W = I^2 R_W = I^2 P \frac{l_w}{A'_C} N^2 \quad (7.7)$$

Substituting for  $N$  and rearranging:

$$LI^2 = P_W \frac{A_L A_C}{P l_w} \times 10^{-6} \text{ (millijoules)} \quad (7.8)$$

Equation (7.8) shows that the  $LI^2$  capability is directly related to and limited by the maximum permissible power dissipation. One procedure for designing the inductor is as follows:

1. Calculate the inductance,  $L$ , and the peak current,  $I_{PK}$ , for the application. The required energy storage capability of the inductor,  $LI^2_{PK}$ , can now be defined (7.4) or (7.8),
2. Next, from Eq. (7.4) or (7.8), calculate the maximum  $LI^2_{sat}$  capability of the selected core, where:

$$LI^2_{sat} > LI^2_{PK}$$

3. From Eq. (7.1), calculate the number of turns,  $N$ , required for the specified inductance,  $L$ , and finally, from Eq. (7.5), the power dissipation,  $P_W$ .  $P_W$  should be less than the maximum permissible power dissipation of the core.
4. If the power losses are unacceptable, a larger core or one with a higher permeability is required, and steps 1 through 3 will have to be repeated.

Several design cycles are usually required to optimize the inductor design. With a little experience, educated guesses as to core material and size come close to requirements.

### Selection of Switching Components

The designer should be fully aware of the capabilities and limitations of power transistors used in switching applications. Transistors in linear applications operate around a quiescent point, whereas in switching applications, operation is fully on or fully off. Transistors must be selected and tested to withstand the unique stress caused by this mode of operation. Parameters such as current and voltage ratings, secondary breakdown ratings, power dissipation, saturation voltage and switching times, critically affect transistor performance in switching applications. Similar parameters are important in diode selection, including voltage, current, and power limitations, as well as forward voltage drop and switching speed.

Initial selection can begin with the voltage and current requirements. Voltage ratings of the switching transistor and diode must be greater than the maximum input voltage including any transient voltages that may appear at the input of the switching regulator. Transistor saturation voltage,  $V_{CE(sat)}$ , and diode forward voltage,  $V_D$ , at full load output current should be as low as possible to maintain high operating efficiency. The transistor and diode should be selected to handle the required maximum peak current and power dissipation.

Good efficiency requires fast switching diodes and transistors. Transistor switching losses become significant when the combined rise,  $t_r$ , plus fall time,  $t_f$ , exceeds:

$$0.05 (t_{on} + t_{off})$$

For 20 kHz operation,  $t_r + t_f$  should be less than 2.5  $\mu s$  for maximum efficiency. While transistor delay and storage times do not affect efficiency, delays in turn-on and turn-off can result in increased output voltage ripple. For optimal operation, combined delay time,  $t_d$ , plus storage time,  $t_s$ , should be less than:

$$0.05 (t_{on} + t_{off})$$

### Selection of Filter Capacitors

In general, output capacitors used in switching regulators are large ( $> 100 \mu F$ ), must operate at high-frequencies ( $> 20$  kHz), and require low ESR and ESL. An excellent trade-off between cost and performance is the solid tantalum capacitor, constructed of sintered tantalum power particles packed around a tantalum anode, which makes a rigid assembly or slug. Compared to aluminum electrolytic capacitors, solid tantalum capacitors have higher CV product-per-unit volume, are more stable, and have hermetic seals to eliminate the effects of humidity.

### Reducing Electromagnetic Interference (EMI)

Due to the wiring inductance in a circuit, rapid changes in current generate voltage transients. These voltage spikes are proportional to both the wiring inductance and the rate at which the current changes:

$$V = -L \frac{di}{dt}$$

The energy of the voltage spike is proportional to the wiring inductance and the square of the current:

$$E = 1/2 LI^2$$

Interference and voltage spiking are easier to filter, if the energy in the spikes is low and the components predominantly high-frequency.

To minimize the EMI problem, the following precautions are recommended:

- Keep loop inductance to a minimum by utilizing appropriate layout and interconnect geometry.
- Keep loop area and lead lengths as small as possible and, in step-down mode, return the input capacitor directly to the diode to reduce EMI and ground-loop noise.
- Select an external diode that can hold peak recovery current as low as possible. This reduces the energy content of the voltage spikes.

Table I

FEATURES / CAPABILITIES	XR-494	XR-495	XR-1524	XR-1525A	XR-1527A	XR-1543	XR-2230	XR-4194	XR-4195
Pulse Width Modulating	X	X	X	X	X		X		
Maximum Frequency (Guaranteed)				400kHz	400 kHz		100kHz		
Maximum Frequency (Typical)	300 kHz	300kHz	300kHz						
Linear Ramp Oscillator	X	X	X	X	X		X		
Capacitor Charge Oscillator									
Deadtime Adjustment (Freq. Dependent)	X	X	X	X	X		X		
Independent Deadtime Adjustment									
Maximum Input Voltage	40V	40V	40V	35V	35V	40V	±15V	±45	±30
Minimum Input Voltage	7V	7V	8V (4.5V)	8V	8V	4.5V	±10V	Vo+2V	Vo+2V
Output Current Capability	200mA	200mA	100mA	200mA	200mA		30mA	150mA	100mA
Single Ended Output								X	X
Double Ended Output	X	X	X	X	X		X	X	X
Totem Pole Output				X	X				
Internal Soft Start				X	X				
External Soft Start Capability	X	X	X				X		
Internal Current Sense Amplifier	X	X	X			X	X		
Internal Reference Voltage	5.0V	5.0V	5.0V	5.1V	5.1V	2.5V		X	X
Internal Precision Reference				X	X	X			
Error Amp	X	X	X	X	X		X	X	X
Under-Voltage Sense/Lockout				X	X	X			
Over-Voltage Sense						X			
External Shutdown Control			X	X	X	X			
SCR Trigger Capability						X			
Double Pulse Protection	X	X		X	X		X		





# **EXAR Switching Regulator Products**

# Pulse-Width Modulating Regulator

## GENERAL DESCRIPTION

All functions required to construct a pulse-width modulating regulator are incorporated on a single monolithic chip in the XR-494. The device is primarily designed for power supply control and contains an on-chip 5-volt regulator, two error amplifiers, an adjustable oscillator, dead-time control comparator, a pulse-steering flip-flop, and output control circuits. Either common emitter or emitter follower output capability is provided by the uncommitted output transistors. Single-ended or push-pull output operation may be selected through the output control function. The XR-494 architecture prohibits the possibility of either output being pulsed twice during push-pull operation. The internal amplifier's circuitry allows for a common-mode input voltage range of  $-0.3$  volts to  $V_{CC} - 2$  volts. The dead-time control comparator provides approximately 5% dead-time unless the dead-time control is externally driven.

## FEATURES

- Complete PWM Power Control Circuitry
- Uncommitted Outputs
  - for 200-mA Sink or Source
- Output Control Selects Single-Ended or Push-Pull Operation
- Internal Circuitry Prohibits Double Pulse at Either Output
- Variable Dead-time
- Circuit Architecture
  - Provides Easy Synchronization
- Current Limiting Capability

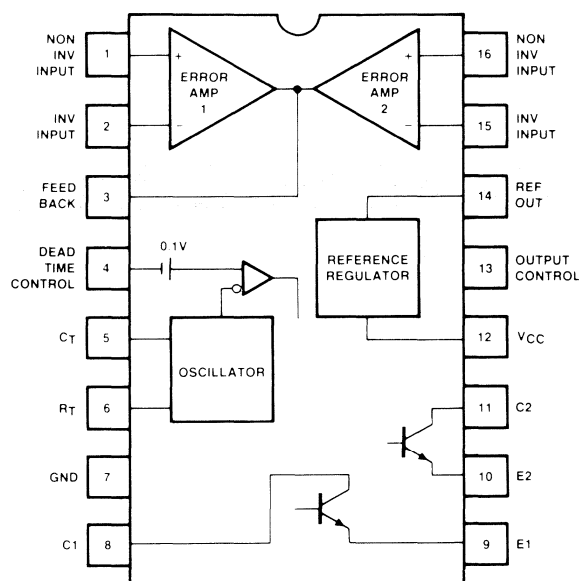
## APPLICATIONS

- Power Control Systems
- Switching Regulators

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage, $V_{CC}$	41V
Collector Output Voltage	41V
Amplifier Input Voltage	$V_{CC} + 0.3V$
Collector Output Current	250 mA/each
Power Dissipation 25°C	
Ceramic Package	1000 mW
Derate Above +25°C	8 mW/°C
Plastic Package	625 mW
Derate Above +25°C	5.0 mW/°C
Operating Junction Temperature, $T_j$	150°C
Storage Temperature	-65°C to +150°C

## FUNCTIONAL BLOCK DIAGRAM



## ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-494M	Ceramic	-55°C to +125°C
XR-494CN	Ceramic	0°C to +70°C
XR-494CP	Plastic	0°C to +70°C

## SYSTEM DESCRIPTION

The XR-494 Pulse-width Modulator contains all the necessary control functions for a high-performance switching regulator. The XR-494 can be used in step-down, step-up, and inverting configuration, as well as transformer-coupled flyback and push-pull modes with a minimum number of components. Current limiting is possible by using either error amplifier provided on the XR-494. Soft-start function can be achieved by connecting an RC network between the  $V_{ref}$  and the dead-time control pins. The dead-time pin can also be used for over-voltage protection by using a shunt regulator. The output control input must be grounded for single-ended output operation (both inputs tied in parallel). For push-pull configuration, this pin must be tied to the internal 5V reference. Multiple units can be easily synchronized to an external source by providing a sawtooth waveform to the  $C_T$  terminals, and by terminating the  $R_T$  pin to the reference output.

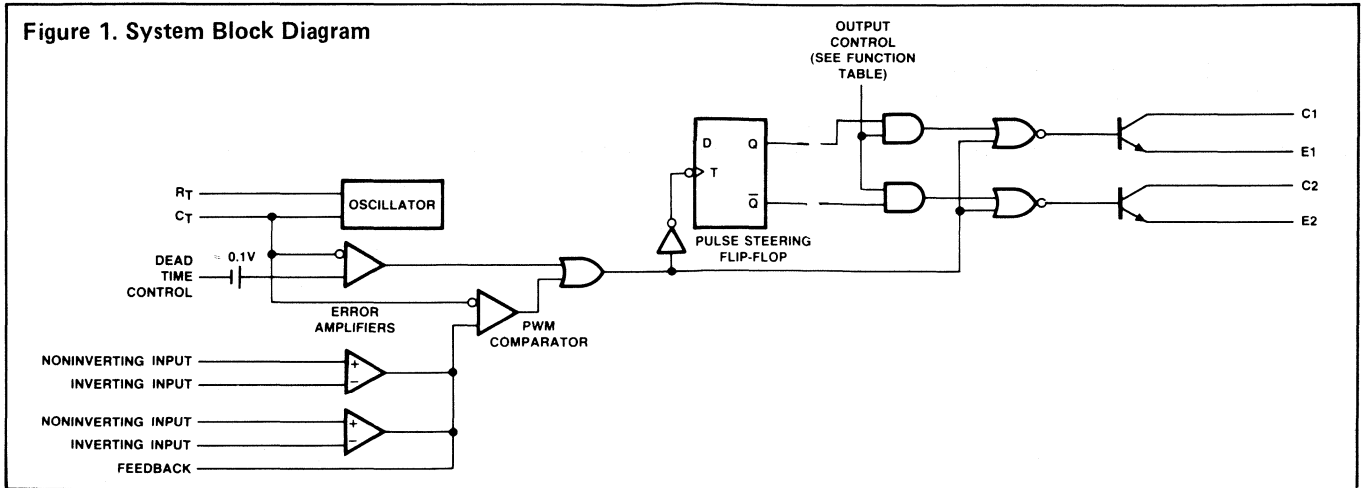
**ELECTRICAL CHARACTERISTICS**
**Test Conditions:**  $V_{CC} = 15V$ ,  $T_A$  = over recommended operating temperature range, unless otherwise specified.

SYMBOL	PARAMETERS	MIN.	TYP.	MAX.	UNIT	CONDITIONS
REFERENCE SECTION						
	Output Voltage ( $V_{ref}$ )	4.75	5.0	5.25	V	$I_O = 1\text{ mA}$
	Input Regulation		2.0	25.0	mV	$V_{CC} = 7V\text{ to }40V$
	Output Regulation		1	15	mV	$I_O = 1\text{ to }10\text{ mA}$
	Output Voltage Change with Temperature		0.2	1	%	$\Delta T_A = \text{Min. to Max.}$
	Short Circuit Output Current	10	35	50	mA	$V_{ref} = 0$ (Note 1) XR-494M only
		—	35	—	mA	$V_{ref} = 0$ (Note 1) XR-494CP and CN
OSCILLATOR SECTION						
	Frequency		10		kHz	$C_T = 0.01\ \mu F$ , $R_T = 12\text{ k}\Omega$
	Standard Deviation of Frequency		10		%	All values of $V_{CC}$ , $C_T$ , $R_T$ . $T_A = \text{constant}$ (see Note 2)
	Frequency Change with Voltage		0.1		%	$V_{CC} = 7V\text{ to }40V$ , $T_A = 25^\circ C$
	Frequency Change with Temperature			2	%	$C_T = 0.01\ \mu F$ , $R_T = 12\text{ k}\Omega$ $\Delta T_A = \text{Min. to Max.}$
DEADTIME CONTROL SECTION						
	Input Bias Current (Pin 4)		-2	-10	$\mu A$	$V_I = 0V\text{ to }5.25V$
	Maximum Duty Cycle (each output)	45			%	$V_I = 0$ (Pin 4)
	Input Threshold Voltage (Pin 4)	0	3	3.3	V	Maximum Duty Cycle Zero Duty Cycle
ERROR AMPLIFIER SECTIONS						
	Input Offset Voltage		2	10	mV	$V_O$ (Pin 3) = 2.5V
	Input Offset Current		25	250	nA	$V_O$ (Pin 3) = 2.5V
	Input Bias Current		0.2	1	$\mu A$	$V_O$ (Pin 3) = 2.5V
	Common-Mode Input Voltage Range	-0.3 to $V_{CC}-2$			V	$V_{CC} = 7V\text{ to }40V$
	Open-Loop Voltage Amplification	70	95		dB	$\Delta V_O = 3V$ , $V_O = 0.5V\text{ to }3.5V$
	Unity Gain Bandwidth		800		kHz	
	Common-Mode Rejection Ratio	65	80		dB	$V_{CC} = 40V$ , $T_A = 25^\circ C$
	Output Sink Current (Pin 3)	0.3	0.7		mA	$V_{ID} = -15\text{ mV to }-5V$ , $V$ (Pin 3) = 0.7V
	Output Source Current (Pin 3)	-2			mA	$V_{ID} = 15\text{ mV to }5V$ , $V$ (Pin 3) = 3.5V
OUTPUT SECTION						
	Collector Off-State Current		2	100	$\mu A$	$V_{CE} = 40V$ , $V_{CC} = 40V$
	Emitter Off-State Current			-100	$\mu A$	$V_{CC} - V_C = 40V$ , $V_E = 0$ XR-494M Max. = $-150\ \mu A$
	Collector-Emitter Saturation Voltage (Common Emitter)		1.1	1.3	V	$V_E = 0$ , $I_C = 200\text{ mA}$
	(Emitter-Follower)		1.5	2.5	V	XR-494M Max. = 1.5V
	Output Control Input Current			3.5	mA	$V_C = 15V$ , $I_E = -200\text{ mA}$ $V_I = V_{ref}$
PWM COMPARATOR SECTION						
	Input Threshold Voltage (Pin 3)		4	4.5	V	Zero Duty Cycle
	Input Sink Current (Pin 3)	0.3	0.7		mA	$V$ (Pin 3) = 0.7V
TOTAL DEVICE						
	Standby Supply Current		6	10	mA	$V_{CC} = 15V$ Pin 6 at $V_{ref}$
			9	15	mA	$V_{CC} = 40V$ All Other Inputs and Outputs Open.
	Average Supply Current		7.5		mA	$V = 2V$ (Pin 4)

Note 1: Duration of the short circuit should not exceed one second.

 Note 2: Standard deviation is a measure of the statistical distribution about the mean as derived from the formula  $\sigma =$  .

Figure 1. System Block Diagram



## RECOMMENDED OPERATING CONDITIONS

PARAMETERS	XR-494M		XR-494CN XR-494CP		UNITS
	MIN	MAX	MIN	MAX	
Supply Voltage, $V_{CC}$	7	40	7	40	V
Amplifier Input Voltage, $V_I$	-0.3	$V_{CC}-2$	-0.3	$V_{CC}-2$	V
Collector Output Voltage, $V_O$		40		40	V
Collector Output Current (each transistor)		200		200	mA
Current Into Feedback Terminal		0.3		0.3	mA
Timing Capacitor, $C_T$	0.47	10,000	0.47	10,000	nF
Timing Resistor, $R_T$	1.8	500	1.8	500	$k\Omega$
Oscillator Frequency	1	300	1	300	kHz
Operating Free-air Temperature, $T_A$	-55	125	0	75	$^{\circ}C$

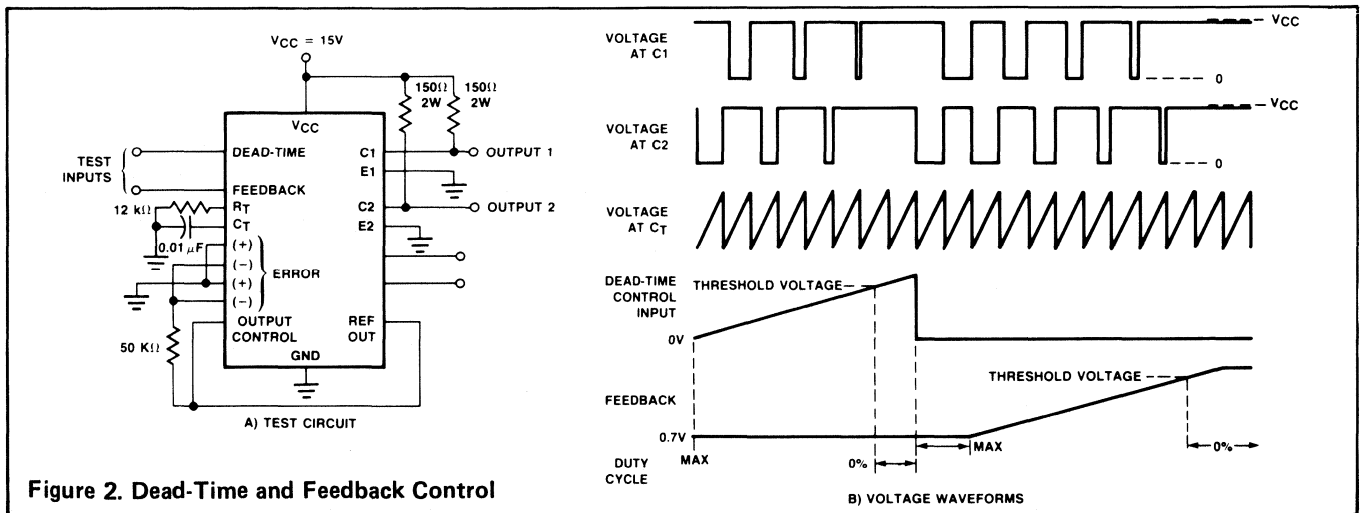


Figure 2. Dead-Time and Feedback Control

SWITCHING CHARACTERISTICS:  $T_A = 25^{\circ}C$ ,  $V_{CC} = 15V$ .

PARAMETER	MIN	TYP	MAX	UNIT	TEST CONDITIONS
Output Voltage Rise Time	—	100	200	ns	Common-Emitter Configuration (See Figure 4)
Output Voltage Fall Time	—	25	100	ns	
Output Voltage Rise Time	—	100	200	ns	Emitter-Follower Configuration (See Figure 5)
Output Voltage Fall Time	—	40	100	ns	

### FUNCTION TABLE

INPUTS	OUTPUT FUNCTION
OUTPUT CONTROL	
Grounded	Single-ended or parallel output Normal push-pull operation PWM Output at Q1 PWM Output at Q2
At $V_{ref}$	
At $V_{ref}$	
At $V_{ref}$	

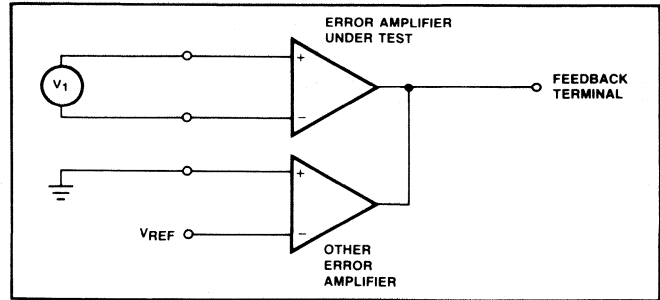


Figure 3. Error-Amplifier Characteristics

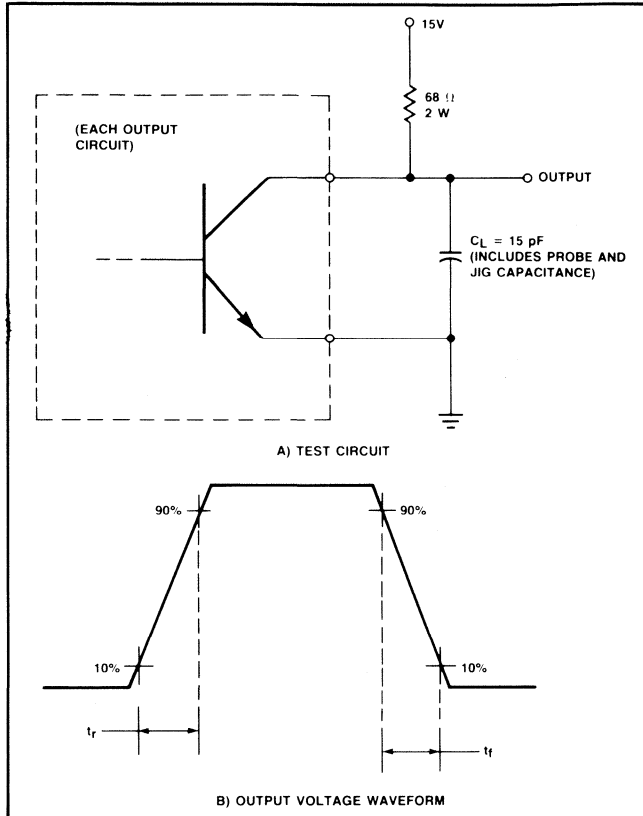


Figure 4. Common Emitter Configuration

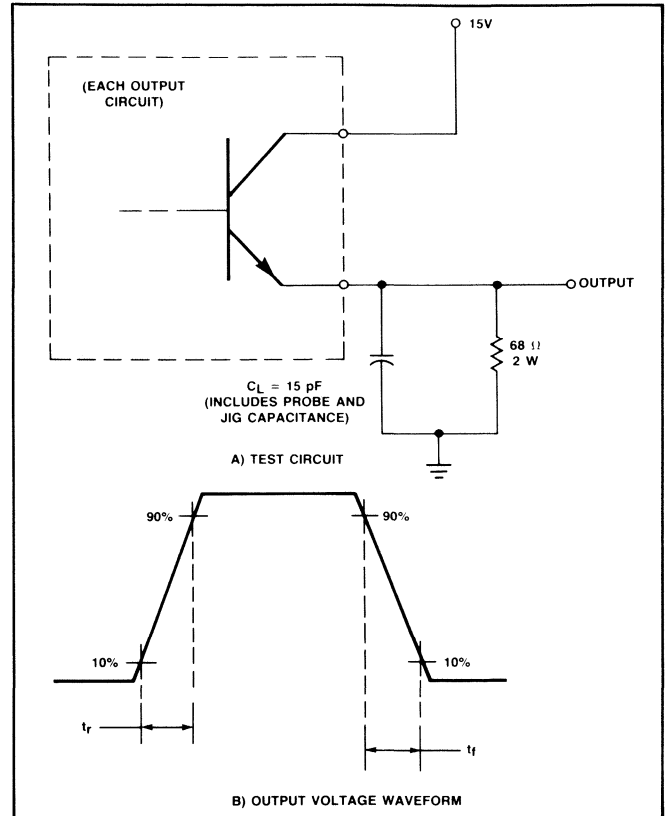


Figure 5. Emitter Follower Configuration

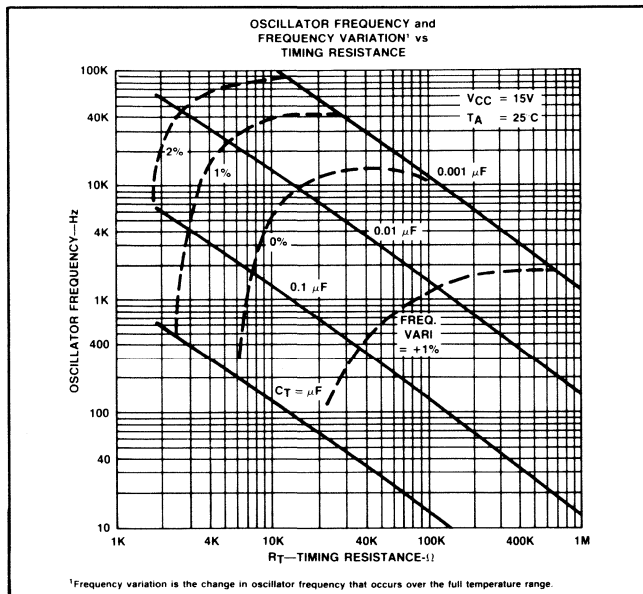


Figure 6. Oscillator Frequency

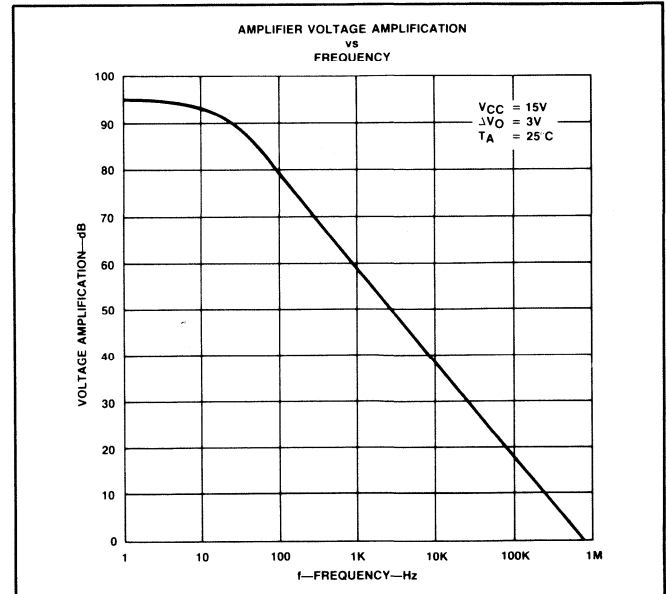


Figure 7. Amplifier Voltage Amplification

# Pulse-Width Modulating Regulator

## GENERAL DESCRIPTION

All functions required to construct a pulse-width modulating regulator are incorporated on a single monolithic chip. The device is primarily designed for power supply control and contains an on-chip 5-volt regulator, two error amplifiers, an adjustable oscillator, a dead-time control comparator, a pulse-steering flip-flop, and output control circuits. Either common emitter or emitter follower output capability is provided by the uncommitted output transistors. Single-ended or push-pull output operation may be selected through the output control function.

The XR-495 also contains an on-chip 39-volt Zener diode for high-voltage applications, where  $V_{CC}$  is greater than 40 volts, and an output steering control that overrides the internal control of the pulse-steering flip-flop.

## FEATURES

- Complete PWM Power Control Circuitry
- Uncommitted Outputs
  - for 200-mA Sink or Source
- Single-ended or Push-pull Operation
- Internal Circuitry Prohibits Double Pulse
  - at Either Output
- Variable Dead-time
- Current Limiting

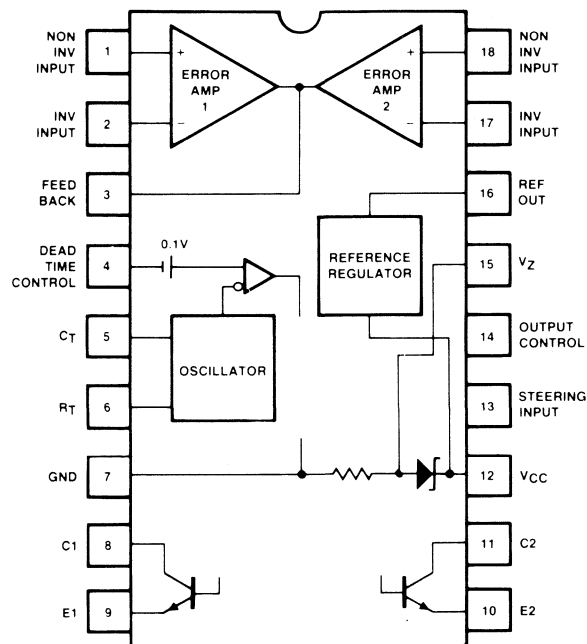
## APPLICATIONS

- Power Control Systems
- Switching Regulators

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage, $V_{CC}$	41V
Collector Output Voltage	41V
Amplifier Input Voltage	$V_{CC} + 0.3V$
Collector Output Current	250 mA/each
Power Dissipation 25°C	
Ceramic Package	1000 mW
Derate Above +25°C	8 mW/°C
Plastic Package	625 mW
Derate Above +25°C	5.0 mW/°C
Operating Junction Temperature, $T_J$	150°C
Storage Temperature	-65°C to +150°C

## FUNCTIONAL BLOCK DIAGRAM



## ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-495M	Ceramic	-55°C to +125°C
XR-495CN	Ceramic	0°C to +70°C
XR-495CP	Plastic	0°C to +70°C

## SYSTEM DESCRIPTION

The XR-495 pulse-width modulator contains all the necessary control functions for a high-performance switching regulator. The XR-495 can be used in step-down, step-up, and inverting configuration, as well as transformer-coupled flyback and push-pull modes with a minimum number of components. Current limiting is possible by using either error amplifier provided on the XR-495. Soft-start function can be achieved by connecting an RC network between the  $V_{ref}$  and the dead-time control pins. The dead-time pin can also be used for over-voltage protection by using a shunt regulator. The output control input must be grounded for single-ended output operation (both inputs tied in parallel). For push-pull configuration, this pin must be tied to the internal 5V reference. Multiple units can be easily synchronized to an external source by providing a sawtooth waveform to the  $C_T$  terminals, and by terminating the  $R_T$  pin to the reference output.

**ELECTRICAL CHARACTERISTICS**
**Test Conditions:**  $V_{CC} = 15V$ ,  $T_A =$  over recommended operating temperature range, unless otherwise specified.

SYMBOL	PARAMETERS	MIN	TYP	MAX	UNIT	CONDITIONS
REFERENCE SECTION						
	Output Voltage ( $V_{ref}$ )	4.75	5.0	5.25	V	$I_O = 1\text{ mA}$
	Input Regulation		2.0	25.0	mV	$V_{CC} = 7V\text{ to }40V$
	Output Regulation		1	15	mV	$I_O = 1\text{ to }10\text{ mA}$
	Output Voltage Change with Temperature		0.2	1	%	$\Delta T_A = \text{Min. to Max.}$
	Short Circuit Output Current	10	35	50	mA	$V_{ref} = 0$ (Note 1) XR-495M only
		–	35	–	mA	$V_{ref} = 0$ (Note 1) XR-495CP and CN
OSCILLATOR SECTION						
	Frequency		10		kHz	$C_T = 0.01\ \mu F$ , $R_T = 12\text{ k}\Omega$
	Standard Deviation of Frequency		10		%	All values of $V_{CC}$ , $C_T$ , $R_T$ . $T_A = \text{constant}$ (see Note 2)
	Frequency Change with Voltage		0.1		%	$V_{CC} = 7V\text{ to }40V$ , $T_A = 25^\circ C$
	Frequency Change with Temperature			2	%	$C_T = 0.01\ \mu F$ , $R_T = 12\text{ k}\Omega$ $\Delta T_A = \text{Min. to Max.}$
DEADTIME CONTROL SECTION						
	Input Bias Current (Pin 4)		-2	-10	$\mu A$	$V_I = 0V\text{ to }5.25V$
	Maximum Duty Cycle (each output)	45			%	$V_I = 0$ (Pin 4)
	Input Threshold Voltage (Pin 4)	0	3	3.3	V	Maximum Duty Cycle Minimum Duty Cycle
ERROR AMPLIFIER SECTIONS						
	Input Offset Voltage		2	10	mV	$V_O$ (Pin 3) = 2.5V
	Input Offset Current		25	250	nA	$V_O$ (Pin 3) = 2.5V
	Input Bias Current		0.2	1	$\mu A$	$V_O$ (Pin 3) = 2.5V
	Common-Mode Input Voltage Range	-0.3 to $V_{CC}-2$			V	$V_{CC} = 7V\text{ to }40V$
	Open-Loop Voltage Amplification	70	95		dB	$\Delta V_O = 3V$ , $V_O = 0.5V\text{ to }3.5V$
	Unity Gain Bandwidth		800		kHz	
	Common-Mode Rejection Ratio	65	80		dB	$V_{CC} = 40V$ , $T_A = 25^\circ C$
	Output Sink Current (Pin 3)	0.3	0.7		mA	$V_{ID} = -15\text{ mV to }-5V$ , $V$ (Pin 3) = 0.7V
	Output Source Current (Pin 3)	-2			mA	$V_{ID} = 15\text{ mV to }5V$ , $V$ (Pin 3) = 3.5V
OUTPUT SECTION						
	Collector Off-State Current		2	100	$\mu A$	$V_{CE} = 40V$ , $V_{CC} = 40V$
	Emitter Off-State Current			-100	$\mu A$	$V_{CC} = V_C = 40V$ , $V_E = 0$ XR-495M Max. = -150 $\mu A$
	Collector-Emitter Saturation Voltage (Common Emitter)		1.1	1.3	V	$V_E = 0$ , $I_C = 200\text{ mA}$ XR-495M Max. = 1.5V
	(Emitter-Follower)		1.5	2.5	V	$V_C = 15V$ , $I_E = -200\text{ mA}$
	Output Control Input Current			3.5	mA	$V_I = V_{ref}$
PWM COMPARATOR SECTION						
	Input Threshold Voltage (Pin 3)		4	4.5	V	Zero Duty Cycle
	Input Sink Current (Pin 3)	0.3	0.7		mA	$V$ (Pin 3) = 0.7V
TOTAL DEVICE						
	Standby Supply Current		6	10	mA	$V_{CC} = 15V$ Pin 6 at $V_{ref}$
			9	15	mA	$V_{CC} = 40V$ All Other Inputs and Outputs Open.
	Average Supply Current		7.5		mA	$V = 2V$ (Pin 4)

## ELECTRICAL CHARACTERISTICS (Continued)

SYMBOL	PARAMETERS	MIN	TYP	MAX	UNIT	CONDITIONS
STEERING CONTROL SECTION						
	Input Current			-200 200	=A =A	$V_I = 0.4V$ $V_I = 2.4V$
ZENER DIODE SECTION						
	Breakdown Voltage		39		V	$V_{CC} = 41V, I_Z = 2\text{ mA}$
	Sink Current		0.3		mA	$V_I (\text{Pin } 15) = 1V$

Note 1: Duration of the short circuit should not exceed one second.

Note 2: Standard deviation is a measure of the statistical distribution about the mean as derived from the formula,  $\sigma =$  .

## SWITCHING CHARACTERISTICS: $T_A = 25^\circ C, V_{CC} = 15V.$

PARAMETER	MIN	TYP	MAX	UNIT	TEST CONDITIONS
Output Voltage Rise Time	—	100	200	ns	Common-Emitter Configuration (See Figure 4)
Output Voltage Fall Time	—	25	100	ns	
Output Voltage Rise Time	—	100	200	ns	Emitter-Follower Configuration (See Figure 5)
Output Voltage Fall Time	—	40	100	ns	

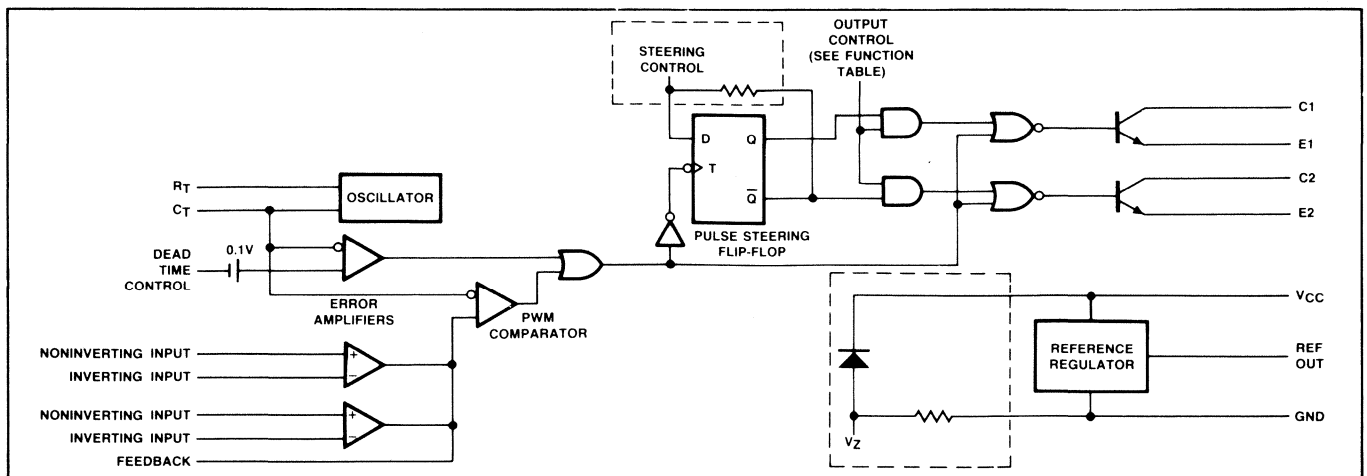


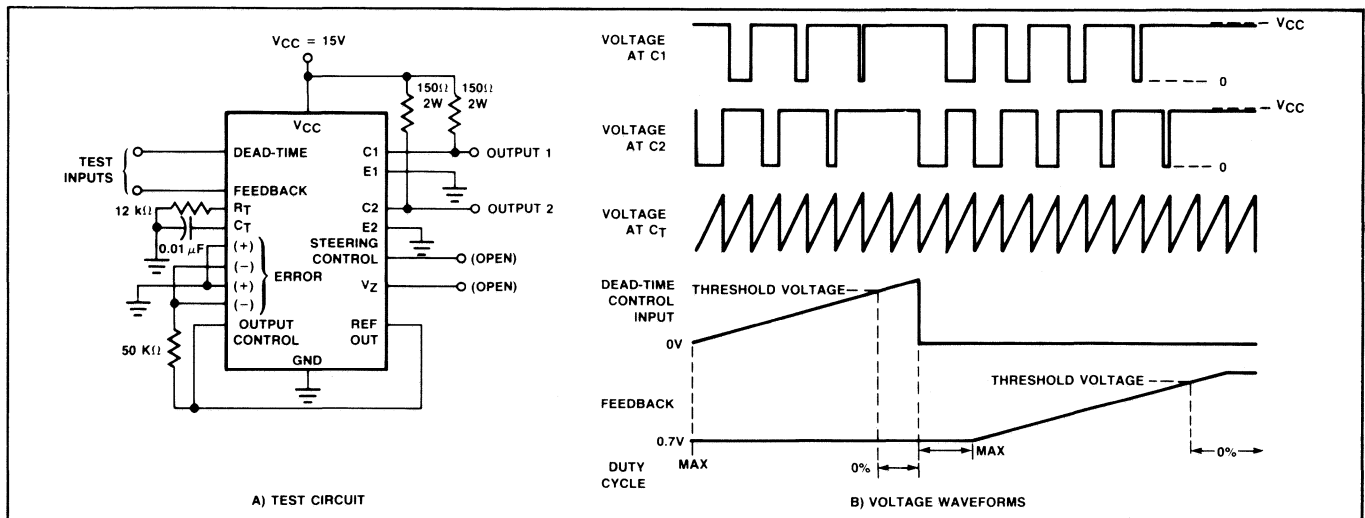
Figure 1. System Block Diagram

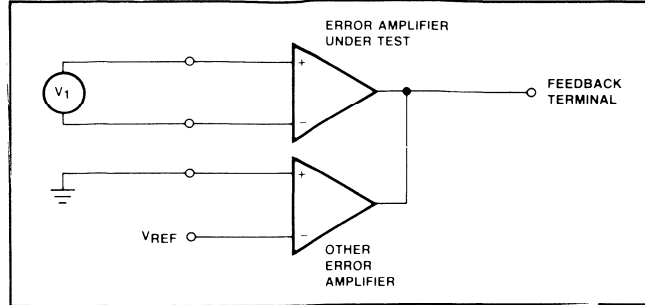


INPUTS		
OUTPUT CONTROL (Pin 14)	STEERING INPUT (Pin 13)	OUTPUT FUNCTION
Grounded	Open	Single-ended or Parallel Output
$V_{ref}$	Open	Normal Push-pull Output
$V_{ref}$	$V_I < 0.4V$	PWM Output at Q <sub>1</sub>
$V_{ref}$	$V_I > 2.4V$	PWM Output at Q <sub>2</sub>

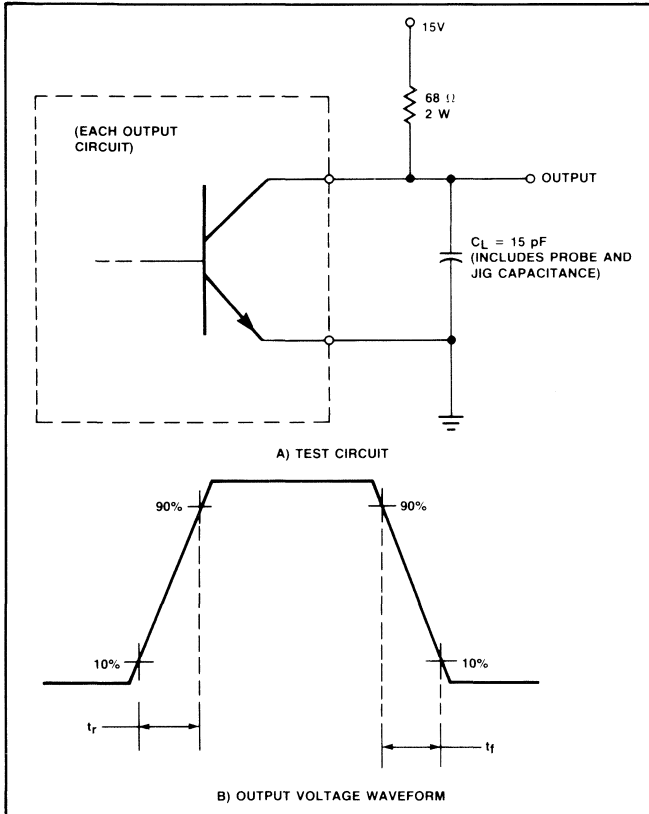
**Table 1: Function Table for Output Control.**
**RECOMMENDED OPERATING CONDITIONS**

PARAMETERS	XR-495M		XR-495CN XR-495CP		UNIT
	MIN	MAX	MIN	MAX	
Supply Voltage, $V_{CC}$	7	40	7	40	V
Amplifier Input Voltages, $V_I$	-0.3	$V_{CC} - 2$	-0.3	$V_{CC} - 2$	V
Collector Output Voltage, $V_O$		40		40	V
Collector Output Current (each transistor)		200		200	mA
Current into Feedback Terminal		0.3		0.3	mA
Timing Capacitor, $C_T$	0.47	10,000	0.47	10,000	nF
Timing Resistor, $R_T$	1.8	500	1.8	500	k $\Omega$
Oscillator Frequency	1	300	1	300	kHz
Operating Free-air Temperature, $T_A$	-55	125	0	75	$^{\circ}C$

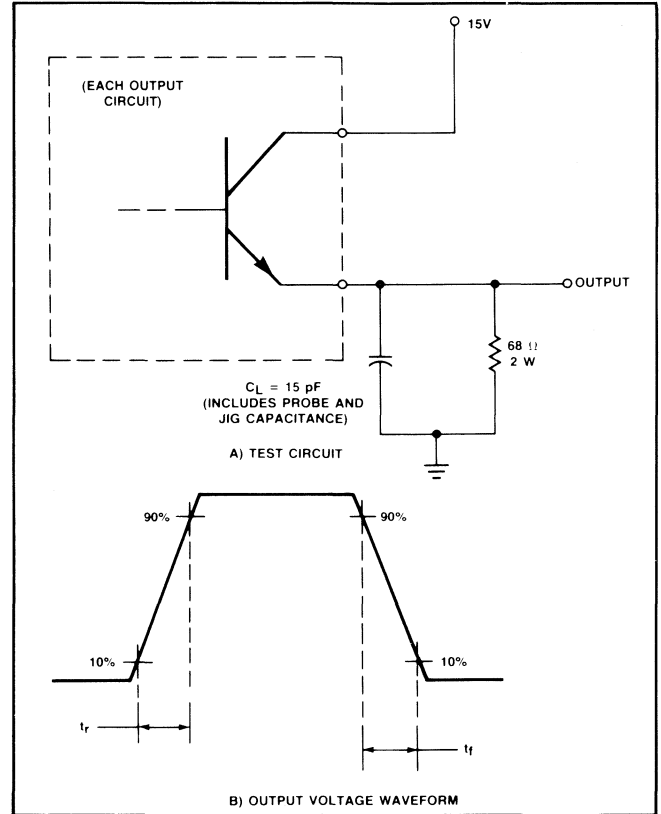

**Figure 2: Dead-time and Feedback Control**



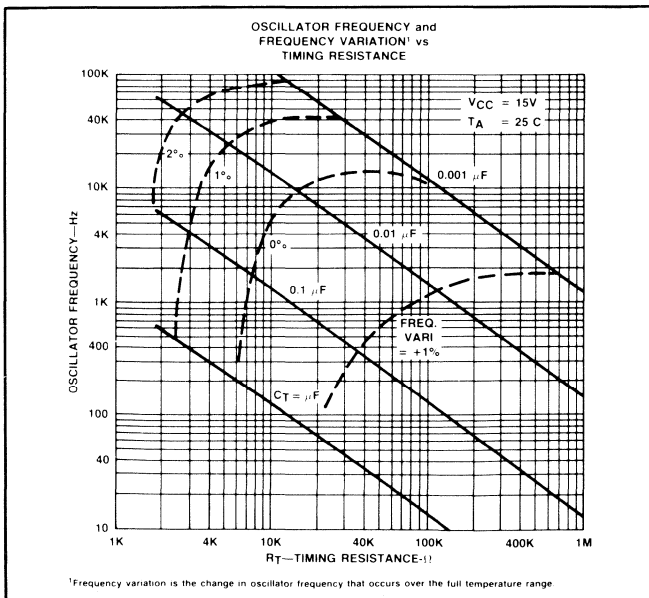
**Figure 3: Error Amplifier Characteristics**



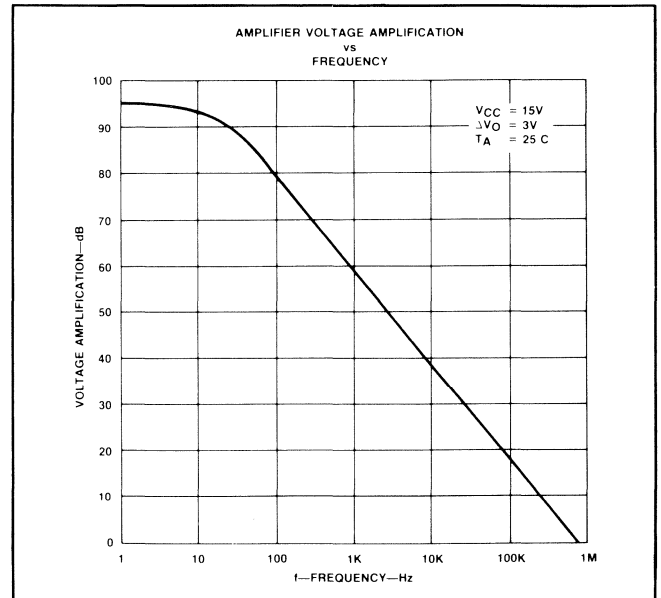
**Figure 4. Common-emitter Configuration**



**Figure 5: Emitter-follower Configuration**



**Figure 6: Oscillator Frequency and Frequency Variation vs. Timing Resistance.**



**Figure 7. Amplifier Voltage Amplification vs. Frequency.**

## Dual-Polarity Tracking Voltage Regulator

### GENERAL DESCRIPTION

The XR-1468/1568 is a dual-polarity tracking voltage regulator, internally trimmed for symmetrical positive and negative 15V outputs. Current output capability is 100 mA, and may be increased by adding external pass transistors. The device is intended for local "on-card" regulation, which eliminates the distribution problems associated with single point regulation.

The XR-1468CN and XR-1568N are guaranteed over the 0°C to 70°C commercial temperature range. The XR-1568M is rated over the full military temperature range of -55°C to +125°C.

### FEATURES

- Internally Set for  $\pm 15\text{V}$  Outputs
- $\pm 100\text{ mA}$  Peak Output Current
- Output Voltages Balanced Within 1% (XR-1568)
- 0.06% Line and Load Regulation
- Low-Standby Current
- Output Externally Adjustable from  $\pm 14.5$  to  $\pm 20$  Volts
- Externally Adjustable Current Limiting
- Remote Sensing

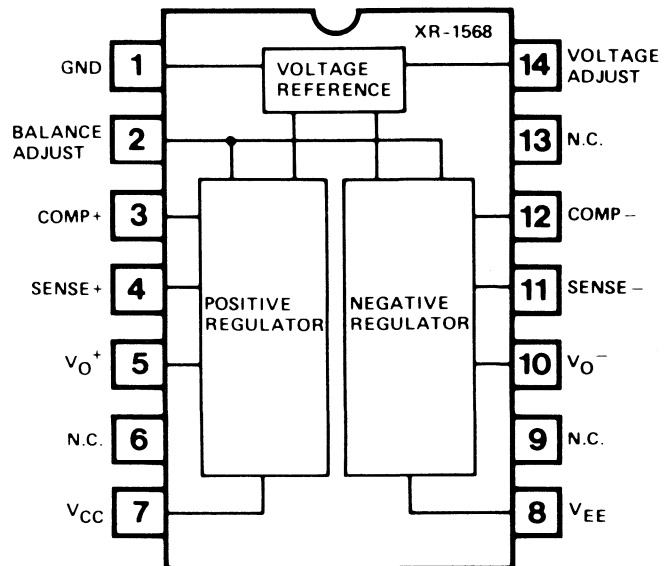
### APPLICATIONS

- Main Regulation in Small Instruments
- On-Card Regulation in Analog and Digital Systems
- Point-of-Load Precision Regulation

### ABSOLUTE MAXIMUM RATINGS

Power Supply	$\pm 30$ Volts
Minimum Short-Circuit Resistance	4.0 Ohms
Load Current, Peak	$\pm 100\text{ mA}$
Power Dissipation	
Ceramic (N) Package	1.0 Watt
Derate Above +25°C	6.7 mW/°C
Operating Temperature	
XR-1568M	-55°C to +125°C
XR-1468C/1568	0°C to +70°C
Storage Temperature	-65°C to +150°C

### FUNCTIONAL BLOCK DIAGRAM



### ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-1568M	Ceramic	-55°C to +125°C
XR-1568N	Ceramic	0°C to +70°C
XR-1468CN	Ceramic	0°C to +70°C

### SYSTEM DESCRIPTION

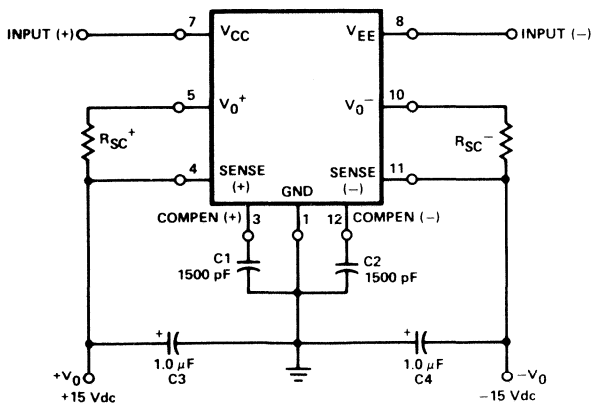
The XR-1468/1568 is a dual polarity tracking voltage regulator combining two separate regulators with a common reference element in a single monolithic circuit, thus providing a very close balance between the positive and negative output voltages. Outputs are internally set to  $\pm 15$  volts but can be externally adjusted between  $\pm 8.0$  to  $\pm 20$  volts with a single control. The circuit features  $\pm 100\text{ mA}$  output current, with externally adjustable current limiting, and provision for remote voltage sensing.

## ELECTRICAL CHARACTERISTICS

**Test Conditions:**  $V_{CC} = +20V$ ,  $V_{EE} = -20V$ ,  $C1 = C2 = 1500\text{ pF}$ ,  $C3 = C4 = 1.0\text{ }\mu\text{F}$ ,  $R_{SC+} = R_{SC-} = 4.0\text{ }\Omega$ .  
 $I_{L+} = I_{L-} = 0$ ,  $T_C = +25^\circ\text{C}$  unless otherwise noted. See Figure 1.

PARAMETER	XR-1468C			XR-1568			UNIT	CONDITIONS
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.		
Output Voltage	14.5	15	15.5	14.8	15	15.2	Vdc	
Input Voltage			30			30	Vdc	
Input-Output Voltage Differential	2.0			2.0			Vdc	
Output Voltage Balance		$\pm 50$	$\pm 300$		$\pm 50$	$\pm 150$	mV	
Line Regulation Voltage			10 20			10 20	mV	$V_{in} = 18V$ to $30V$ $T_L$ to $T_H$
Load Regulation Voltage			10 30			10 30	mV	$I_L = 0$ to $50\text{ mA}$ , $T_J = \text{constant}$ $T_A = T_L$ to $T_H$
Output Voltage Range	8.0		20	8.0		20	Vdc	See Figure 1
Ripple Rejection		75			75		dB	$f = 120\text{ Hz}$
Output Voltage Temperature Stability		0.3	1.0		0.3	1.0	%	$T_L$ to $T_H$
Short-Circuit Current Limit		60			60		mA	$R_{SC} = 10\text{ ohms}$
Output Noise Voltage		100			100		$\mu\text{Vrms}$	$BW = 10\text{ Hz} - 10\text{ kHz}$
Positive Standby Current		2.4	4.0		2.4	4.0	mA	$V_{in} = +30V$
Negative Standby Current		1.0	3.0		1.0	3.0	mA	$V_{in} = -30V$
Long-Term Stability		0.2			0.2		%/kHr	

$\dagger T_L = 0^\circ\text{C}$  for XR-1468C/1568     $\dagger\dagger T_H = +75^\circ\text{C}$  for XR-1468C/1568     $T_J = \text{Junction Temp.}$   
 $= -55^\circ\text{C}$  for XR-1568M                     $= +125^\circ\text{C}$  for XR-1568M                     $T_C = \text{Case Temp.}$



C1 and C2 should be located as close to the device as possible. A  $0.1\text{ }\mu\text{F}$  ceramic capacitor may be required on the input lines if the device is located an appreciable distance from the rectifier filter capacitors.  
 C3 and C4 may be increased to improve load transient response and to reduce the output noise voltage. At low temperature operation, it may be necessary to bypass C4 with a  $0.1\text{ }\mu\text{F}$  ceramic disc capacitor.

Figure 1. Basic 50 mA Regulator

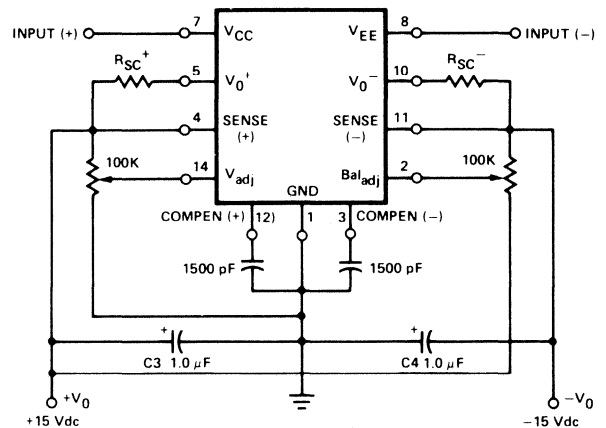


Figure 2. Voltage Adjust and Balance Adjust Circuit

## Pulse-Width Modulating Regulator

### GENERAL DESCRIPTION

The XR-1524 family of monolithic integrated circuits contain all the control circuitry for a switching regulator power supply. Included in a 16-Pin dual-in-line package is the voltage reference, an error amplifier, an oscillator, a pulse-width modulator, a 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  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ , while the XR-2524/3524 are designed for commercial applications of  $0^{\circ}\text{C}$  to  $+70^{\circ}\text{C}$ .

### 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

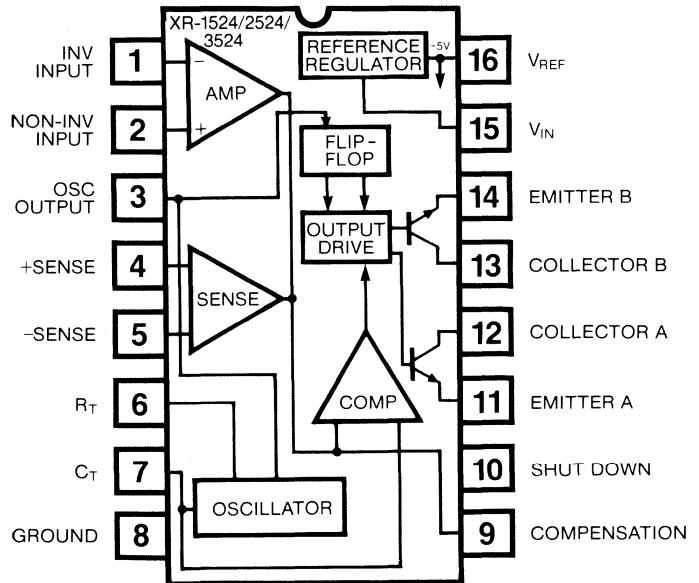
### APPLICATIONS

- 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 $+25^{\circ}\text{C}$	8 mW/ $^{\circ}\text{C}$
Plastic Package	625 mW
Derate Above $+25^{\circ}\text{C}$	5.0 mW/ $^{\circ}\text{C}$
Operating Temperature	
XR-1524	$-55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$
XR-2524/3524	$0^{\circ}\text{C}$ to $+70^{\circ}\text{C}$
Storage Temperature	$-65^{\circ}\text{C}$ to $+150^{\circ}\text{C}$

### FUNCTIONAL BLOCK DIAGRAM



### ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-1524M	Ceramic	$-55^{\circ}\text{C}$ to $+125^{\circ}\text{C}$
XR-2524N	Ceramic	$0^{\circ}\text{C}$ to $+70^{\circ}\text{C}$
XR-2524P	Plastic	$0^{\circ}\text{C}$ to $+70^{\circ}\text{C}$
XR-3524N	Ceramic	$0^{\circ}\text{C}$ to $+70^{\circ}\text{C}$
XR-3524P	Plastic	$0^{\circ}\text{C}$ to $+70^{\circ}\text{C}$

### SYSTEM DESCRIPTION

The XR-1524 series of pulse-width modulating control circuits can be used in step-up, step-down, and inverting types of switching regulators. It is capable of maintaining an output from input voltages between 8 and 40 volts. By connecting Pin 15 and Pin 16 together, it can be operated from a fixed 5-volt supply. The output drivers can handle over 50 mA of current, and can be used in a push-pull configuration or a single-ended mode. A simple soft-start circuit, which is made up of a diode and an RC network, keeps the output drivers off when power is first applied to the device. As the capacitor charges up, the duty cycle is slowly increased, causing the output drivers to slowly turn on.

## ELECTRICAL CHARACTERISTICS

**Test Conditions:**  $T_A = -55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  for the XR-1524, and  $0^{\circ}\text{C}$  to  $+70^{\circ}\text{C}$  for the XR-2524/3524,  
 $V_{IN} = 20\text{V}$ , and  $f = 20\text{ kHz}$ , unless otherwise specified.

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

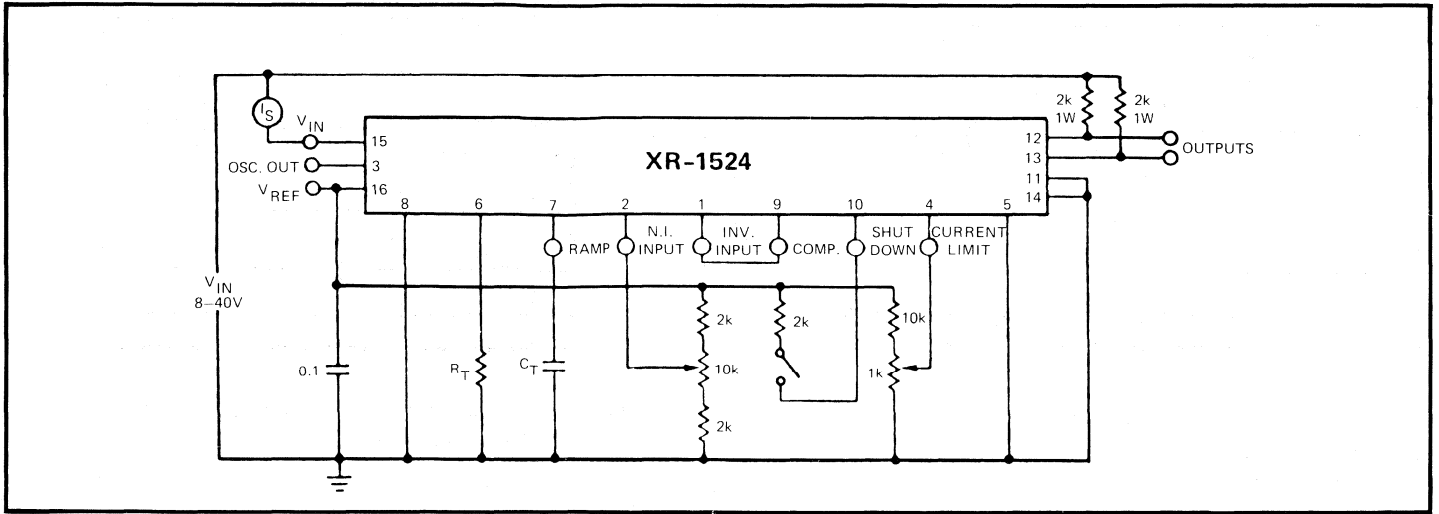


Figure 1: Open Loop Test Circuit.

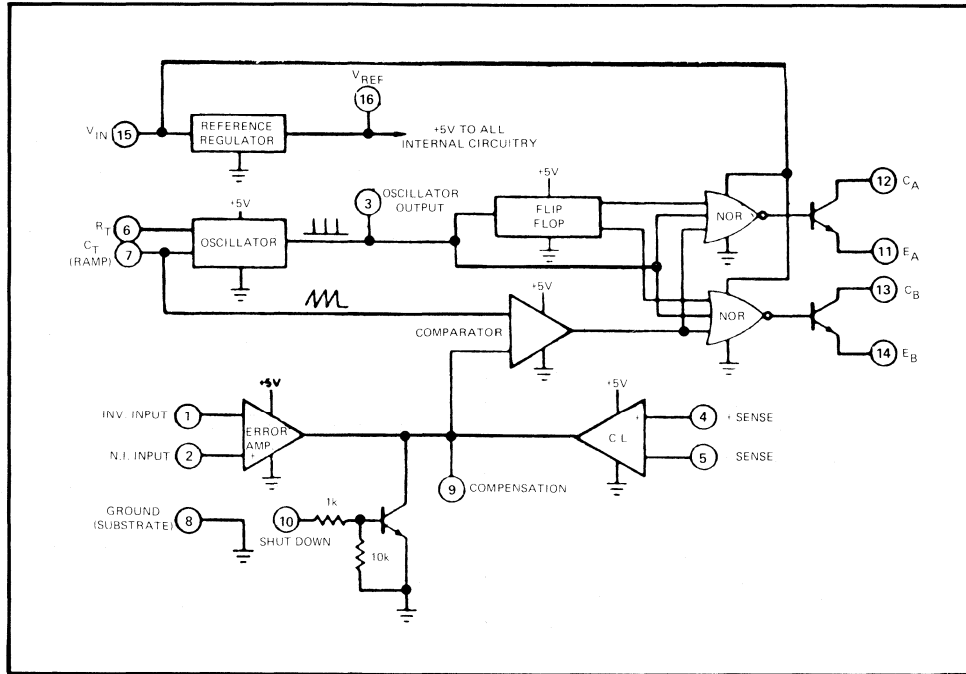


Figure 2: Detailed System Block Diagram of XR-1524.

## PRINCIPLES OF OPERATION

### Voltage Reference Section

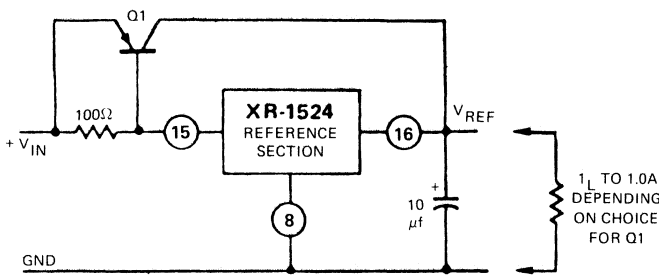
The internal voltage reference and regulator section provides a 5-volt reference output at Pin 16. This voltage also serves as a regulated voltage source for the internal timing and control circuitry. This regulator may be bypassed for operation from a fixed 5 volt supply by connecting Pins 15 and 16 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 3.

### 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  $30 \mu A$  to 2 mA, i.e.,  $1.8K < R_T < 100K$ .

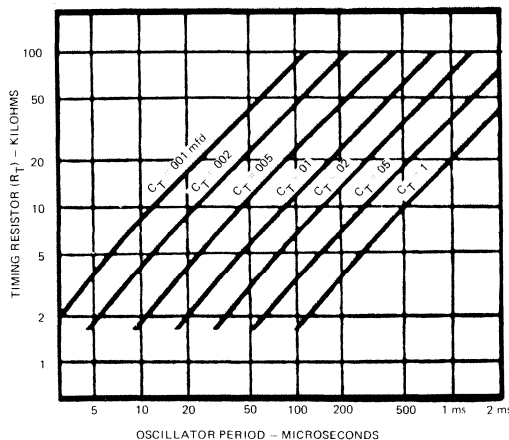
The oscillator period is approximately  $T = R_T C_T$ , where T is in microseconds when  $R_T = \text{ohms}$ , and  $C_T = \text{microfarads}$ .



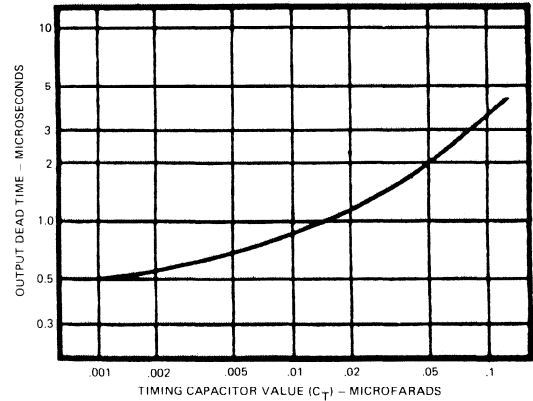
**Figure 3: Using the Internal Regulator as 5V Power Supply for External Circuitry.**

The use of Figure 4 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.

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 5. 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  $\mu$ F.



**Figure 4: Oscillator Period as a Function of  $R_T$  and  $C_T$ .**



**Figure 5: Output State 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 2 k $\Omega$ .

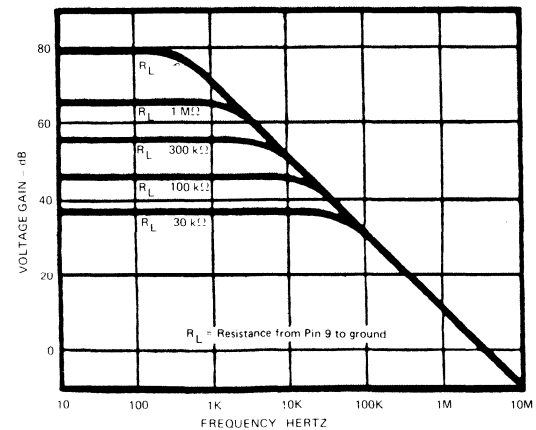
If two or more XR-1524 circuits must be synchronized together, one must be designated as master with its  $R_T C_T$  set for the correct period. The slaves should each have an  $R_T C_T$ , set for approximately 10% longer period than the master; with the added requirement that  $C_T$  (slave) = 1/2  $C_T$  (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 ( $R_L \approx 5$  m $\Omega$ ).

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 6.



**Figure 6: Error Amplifier Frequency Response as a Function of External Resistor,  $R_L$ , at Pin 9.**

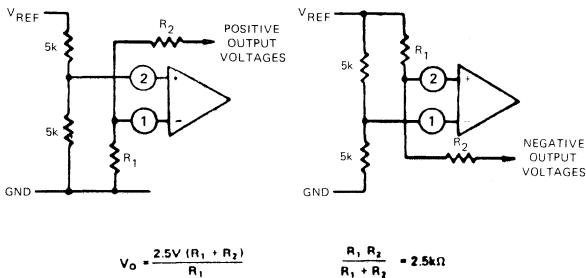


In addition to dc gain control, the compensation terminal is also the place for ac phase compensation. The frequency response curves of Figure 6 show the uncompensated amplifier with a single pole at approximately 200 Hz, and a unity gain cross-over at 5 MHz.

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 RC 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.

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 7. 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.



**Figure 7: Error Amplifier Biasing Circuits.**  
(Note: Change in Input Connections for Opposite Polarity Outputs.)

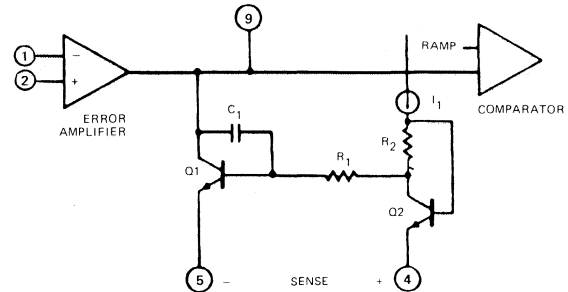
### Current Limiting Controls

The current limiting circuitry of the XR-1524 is shown in Figure 8.

By matching the base-emitter voltages of Q<sub>1</sub> and Q<sub>2</sub>, and assuming negligible voltage drop across R<sub>1</sub>,

$$\text{Threshold} = V_{BE}(Q_1) + I_1 R_2 - V_{BE}(Q_2) = I_1 R_2 \approx 200 \text{ mV}$$

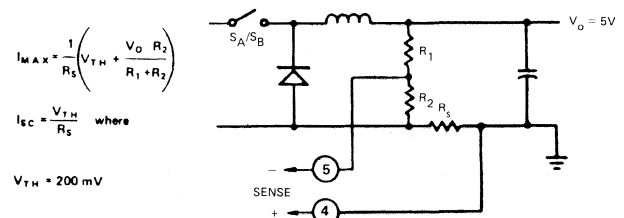
Although this circuit provides a relatively small threshold with a negligible temperature coefficient, there are some limitations to its use. The most important of which is the ± 1 volt common-mode range which requires sensing in the ground line. Another factor to consider is that the frequency compensation provided by R<sub>1</sub>C<sub>1</sub> and Q<sub>1</sub> provides a rolloff pole at approximately 300 Hz.



**Figure 8: Current Limiting Circuitry of the XR-1524.**

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.

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 16.) 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 9. This circuit can reduce the short-circuit current (I<sub>SC</sub>) to approximately 1/3 the maximum available output current (I<sub>MAX</sub>).



**Figure 9: Foldback Current Limiting Used to Reduce Power Dissipation Under Shorted Output Conditions.**

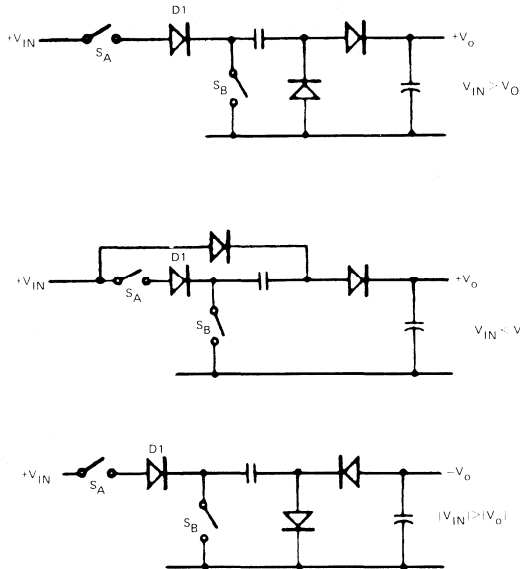
### Output Circuits

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.

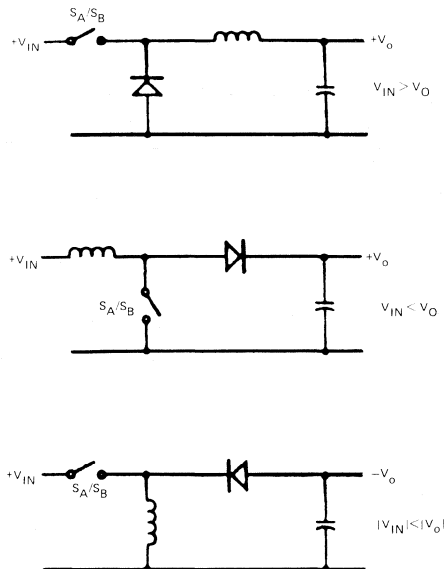
In considering the application of the XR-1524 for voltage regulator circuitry, there are a multitude of output configurations possible. In general, however, they fall into three basic classifications:

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

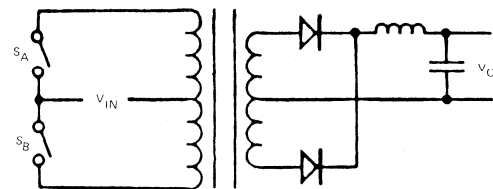
Examples of each category are shown in Figure 10, 11, and 12. In each case, the switches indicated can be either the output transistors in the XR-1524 or added external transistors according to the load current requirements.



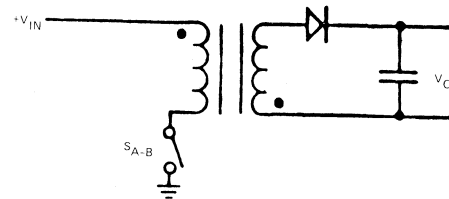
**Figure 10: Capacitor-Diode Coupled Voltage Multiplier Output Stages. (Note: Diode  $D_1$  is necessary to Prevent Reverse Emitter-Base Breakdown of Transistor Switch,  $S_A$ .)**



**Figure 11: Single-ended Inductor Circuits Where the Two Outputs of the XR-1524 are Connected in Parallel.**



**(a) Push-Pull**



**(b) Flyback**

**Figure 12: 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 5. Of course, since  $C_T$  also helps determine the operating frequency, the range of control is somewhat limited.

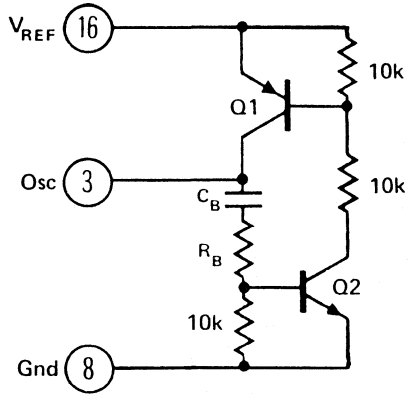
Method 2: For 0.5 to 5.0 microseconds, the blanking pulse may be extended by adding a small capacitor from Pin 3 to ground. The value of the capacitor must be less than 1000 pF or triggering will become unreliable.

Method 3: For longer and more well-controlled blanking pulses, a simple one-shot latch similar to the circuit shown in Figure 13 should be used.

When this circuit is triggered by the oscillator output pulse, it will latch for a period determined by  $C_{BR}R_B$  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  $C_T$ .



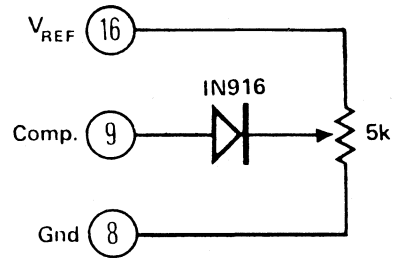
Q1 and Q2 = Small Signal General Purpose Transistors

**Figure 13: Recommended External Circuitry for Long Duration Blanking Pulse Generation, (Method 3 of Deadband Control. Note: For 5  $\mu$ sec blanking, choose  $C_B = 200$  pF,  $R_B = 10$   $\pi$ M.)**

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 14.

This circuit will limit the error amplifiers voltage range, since its current source output will only supply 200  $\mu$ A. Additionally, this circuit will not affect the operating frequency.

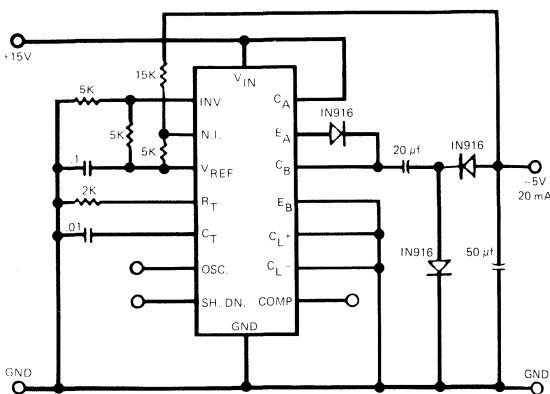
AP



**Figure 14: Using a Clamp Diode to Control Deadband (Method 4 of Deadband Control).**

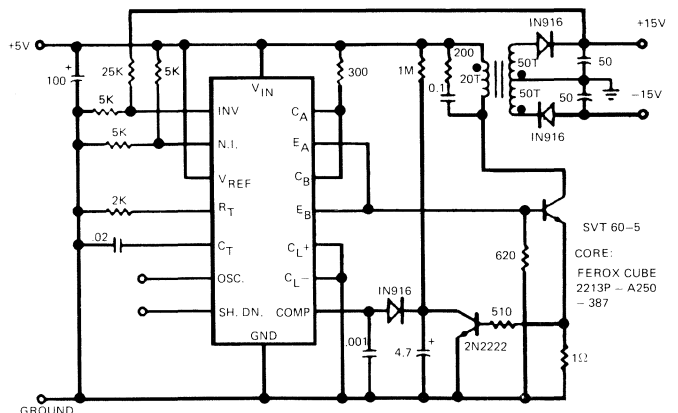
**APPLICATIONS INFORMATION**

**Polarity Converting Regulator:** The XR-1524 pulse-width modulating regulator can be interconnected as shown in Figure 15. 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.



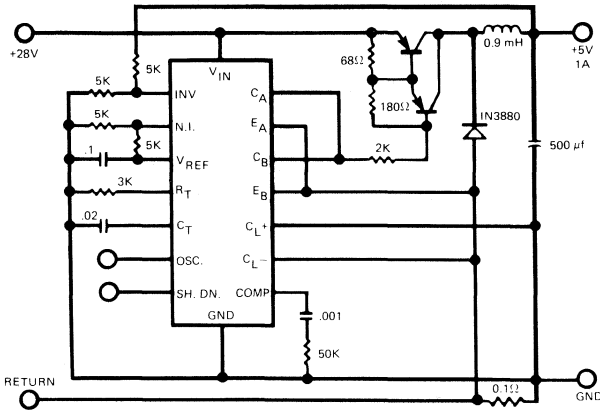
**Figure 15: Circuit Connection for Polarity Converting Regulator ( $V_{in} = +15V$ ,  $V_{out} = -5V$ ).**

**Flyback Converter:** Figure 16 shows the application of XR-1524 in a low current dc-dc converter, using the flyback converter principle (see Figure 12b). The particular values given in the figure are chosen to generate  $\pm 15$  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.



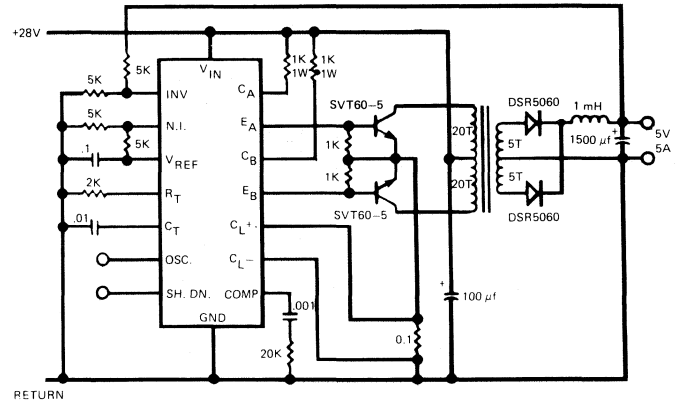
**Figure 16: A Low-Current dc-dc Converter Using Flyback Principle. ( $V_{out} = \pm 15V$ ,  $V_{in} = +5V$ ,  $I_L \times 20$  mA).**

**Single-ended Regulator:** The XR-1524 operates as an efficient single-ended pulse-width modulating regulator, using the circuit connection shown in Figure 17. In this configuration, the two output transistors of the circuit are connected in parallel by shorting Pins (12,13) and (11,14) together, to provide for effective 0 - 90% duty cycle modulation. The use of an output inductance requires an RC phase compensation on Pin 9, as shown in the figure.



**Figure 17: Conventional Single-ended Regulator Connection.**  
 $(V_{in} = +28V, V_O = +5V, I_{out} \leq 1 \text{ Amp})$

**Push-pull Converter:** The circuit of Figure 18 shows the use of the XR-1524 in a transformer-coupled dc-dc converter with push-pull outputs (see Figure 12a). 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 PWM 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 18: A High-Current dc-dc Converter with Push-pull Outputs.**  
 $(V_{in} = +28V, V_O = +5V, I_o \leq 5A)$

# Pulse-Width Modulating Regulators

## GENERAL DESCRIPTION

The XR-1525A/1527A is a series of monolithic integrated circuits that contain all of the control circuitry necessary for a pulse-width modulating regulator. Included in the 16-Pin dual-in-line package is a voltage reference, an error amplifier, a pulse-width modulator, an oscillator, under-voltage lockout, soft-start circuitry, and output drivers.

The XR-1525A/2525A/3525A series features NOR logic, giving a LOW output for an OFF state. The XR-1527A/2527A/3527A series features OR logic, giving a HIGH output for an OFF state.

## FEATURES

- 8V to 35V Operation
- 5.1V Reference Trimmed to  $\pm 1\%$
- 100 Hz to 500 kHz Oscillator Range
- Separate Oscillator Sync Terminal
- Adjustable Deadtime Control
- Internal Soft-Start
- Input Under-voltage Lockout
- Latching PWM to Prevent Double Pulsing
- Dual Source/Sink Output Drivers
  - Capable of Over 200 mA
- Power-FET Drive Capability

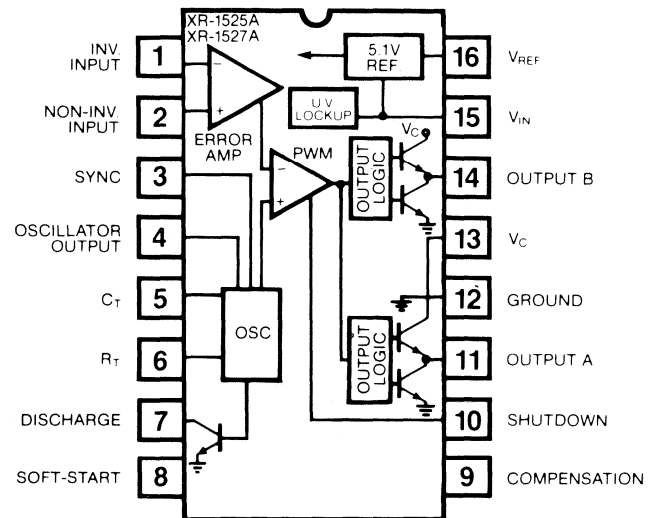
## APPLICATIONS

- Power Control Systems
- Switching Regulators
- Industrial Controls

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage (+ $V_{IN}$ )	+ 40V
Collector Supply Voltage ( $V_C$ )	+ 40V
Logic Inputs	-0.3V to 5.5V
Analog Inputs	-0.3V to + $V_{IN}$
Output Current, Source or Sink	500 mA
Reference Output Current	50 mA
Oscillator Charging Current	5 mA
Power Dissipation	
Ceramic Package	1000 mW
Derate above $T_A = +25^\circ\text{C}$	8.0 mW/ $^\circ\text{C}$
Plastic Package	625 mW
Derate above $T_A = +25^\circ\text{C}$	5.0 mW/ $^\circ\text{C}$
Operating Junction Temperature ( $T_J$ )	+ 150 $^\circ\text{C}$
Storage Temperature Range	-65 $^\circ\text{C}$ to +150 $^\circ\text{C}$

## FUNCTIONAL BLOCK DIAGRAM



## ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-1525A/27AN	Ceramic	-55 $^\circ\text{C}$ to +125 $^\circ\text{C}$
XR-2525A/27AN	Ceramic	-25 $^\circ\text{C}$ to +85 $^\circ\text{C}$
XR-2525A/27AP	Plastic	-25 $^\circ\text{C}$ to +85 $^\circ\text{C}$
XR-3525A/27AN	Ceramic	0 $^\circ\text{C}$ to +70 $^\circ\text{C}$
XR-3525A/27AP	Plastic	0 $^\circ\text{C}$ to +70 $^\circ\text{C}$

## SYSTEM DESCRIPTION

The on-chip 5.1-volt reference is trimmed to  $\pm 1\%$  initial accuracy, and the common-mode input range of the error amplifier is extended to include the reference voltage. Deadtime is adjustable with a single external resistor. A sync input to the oscillator allows multiple units to be slaved together, or a single unit to be synchronized to an external clock. A positive-going signal applied to the shutdown pin provides instantaneous turnoff of the outputs. The under-voltage lockout circuitry keeps the output drivers off, and the soft-start capacitor discharged, for an input voltage below the required value. The latch on the PWM comparator insures the outputs to be active only once per oscillator period, thereby eliminating any double pulsing. The latch is reset with each clock pulse.

The output drivers are totem-pole designs capable of sinking and sourcing over 200 mA.

**ELECTRICAL CHARACTERISTICS**
**Test Conditions:**  $V_{IN} = +20V$ ,  $T_J =$  Full operating temperature range, unless otherwise specified.

PARAMETER	XR-1525A/2525A XR-1527A/2527A			XR-3525A XR-3527A			UNIT	CONDITIONS
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.		
<b>VOLTAGE REFERENCE SECTION</b>								
Output Voltage	5.05	5.10	5.15	5.00	5.10	5.20	V	$T_J = 25^\circ C$
Line Regulation		10	20		10	20	mV	$V_{IN} = 8V$ to 35V
Load Regulation		20	50		20	50	mV	$I_L = 0$ to 20 mA
Temperature Stability (2)		20	50		20	50	mV	$T_J =$ Full Operating Range
Total Output Variation (2)	5.00		5.20	4.95		5.25	V	Line, Load & Temperature
Output Short Circuit Current		80	100		80	100	mA	$T_J = 25^\circ C$ , $V_{ref} = 0V$
Output Noise Voltage (2)		40	200		40	200	$\mu V$ rms	$T_J = 25^\circ C$ , $10 Hz \leq f \leq 10 kHz$
Long Term Stability (2)		20	50		20	50	mV/KHR	$T_J = 125^\circ C$
<b>OSCILLATOR SECTION (Note 3)</b>								
Initial Accuracy (2,3)		$\pm 2$	$\pm 6$		$\pm 2$	$\pm 6$	%	$T_J = 25^\circ C$ , $f = 40 kHz$
Temperature Stability (2)		$\pm 3$	$\pm 6$		$\pm 3$	$\pm 6$	%	$T_J =$ Full Operating Range
Input Voltage Stability (2,3)		$\pm 0.3$	$\pm 1$		$\pm 1$	$\pm 2$	%	$V_{IN} = 8V$ to 35V
Minimum Frequency			100			100	Hz	$R_T = 150 k\Omega$ , $C_T = 0.1 \mu F$
Maximum Frequency	400			400			kHz	$R_T = 2 k\Omega$ , $C_T = 1 nF$
Current Mirror	1.7	2.0	2.2	1.7	2.0	2.2	mA	$I_{RT} = 2 mA$
Clock Amplitude (2,3)	3.0	3.5		3.0	3.5		V	
Clock Pulse Width (2,3)	0.3	0.5	1.0	0.3	0.5	1.0	$\mu sec$	$T_J = 25^\circ C$ , $R_D = 0\Omega$
Sync Threshold	1.2	2.0	2.8	1.2	2.0	2.8	V	
Sync Input Current		1.0	2.5		1.0	2.5	mA	Sync Voltage = 3.5V
<b>ERROR AMPLIFIER SECTION (<math>V_{CM} = 5.1V</math>)</b>								
Input Offset Voltage		0.5	5.0		2	10	mV	$R_L \geq 10 M\Omega$ $T_J = 25^\circ C$
Input Bias Current		1	10		1	10	$\mu A$	
Input Offset Current			1			1	$\mu A$	
DC Open-Loop Gain	60	75		60	75		dB	
Gain Bandwidth Product (2)	1	2		1	2		MHz	$V_{CM} = 1.5V$ to 5.2V
Output Low Voltage		0.2	0.5		0.2	0.5	V	
Output High Voltage	3.8	5.6		3.8	5.6		V	$V_{IN} = 8V$ to 35V
Common-Mode Rejection Ratio	60	75		60	75		dB	
Supply Voltage Rejection Ratio	50	60		50	60		dB	
<b>PULSE-WIDTH MODULATING COMPARATOR</b>								
Minimum Duty Cycle			0			0	%	Zero Duty Cycle Maximum Duty Cycle
Maximum Duty Cycle	45	49		45	49		%	
Input Threshold (3)	0.6	0.9		0.6	0.9		V	
Input Threshold (3)		3.3	3.6		3.3	3.6	V	
Input Bias Current (2)		0.05	1.0		0.05	1.0	$\mu A$	
<b>SOFT-START SECTION</b>								
Soft-Start Current	25	50	80	25	50	80	$\mu A$	$V_{shutdown} = 0V$ $V_{shutdown} = 2V$ $V_{shutdown} = 2.5V$
Soft-Start Voltage		0.4	0.6		0.4	0.6	V	
Shutdown Input Current		0.4	1.0		0.4	1.0	mA	
<b>OUTPUT DRIVERS (Each Output) <math>V_C = 20V</math></b>								
Output Low Voltage		0.2	0.4		0.2	0.4	V	$I_{sink} = 20 mA$ $I_{sink} = 100 mA$ $I_{source} = 20 mA$ $I_{source} = 100 mA$ $V_{comp}$ and $V_{SS} =$ High $V_C = 35V$ $T_J = 25^\circ C$ , $C_L = 1 nF$ $T_J = 25^\circ C$ , $C_L = 1 nF$ $V_{SD} = 3V$ , $C_S = 0$ , $T_J = 25^\circ C$
Output Low Voltage		1.0	2.0		1.0	2.0	V	
Output High Voltage	18	19		18	19		V	
Output High Voltage	17	18		17	18		V	
Under-voltage Lockout	6	7	8	6	7	8	V	
Collector Leakage (4)			200			200	$\mu A$	
Rise Time (2)		100	600		100	600	nsec	
Fall Time (2)		50	300		50	300	nsec	
Shutdown Delay (2)		0.2	0.5		0.2	0.5	$\mu sec$	
<b>TOTAL STANDBY CURRENT</b>								
Supply Current		14	20		14	20	mA	$V_{IN} = 35V$

**Note 2:** These parameters, although guaranteed over the recommended operating conditions, are not 100% tested in production.

**Note 3:** Tested at  $f = 40 kHz$  ( $R_T = 3.6 k\Omega$ ,  $C_T = 0.01 \mu F$ ,  $R_D = 0\Omega$ ).

**Note 4:** Applies to XR-1525A/2525A/3525A only, due to polarity of output pulses.

## PRINCIPLES OF OPERATION

The different control blocks within the XR-1525A/1527A function as follows:

### Voltage Reference Section

The internal voltage reference circuit of the XR-1525A/1527A is based on the well-known "band-gap" reference, with a nominal output voltage of 5.1 volts, internally trimmed to  $\pm 1\%$  accuracy. It is short circuit protected and is capable of providing up to 20 mA of reference current. A simplified circuit schematic is shown in Figure 7.

### Oscillator Section

The sawtooth oscillator derives its frequency from an external timing resistor/capacitor pair. The timing resistor,  $R_T$ , determines the charging current into the timing capacitor,  $C_T$ . The magnitude of this current is approximately given by:

$$\frac{V_{ref} - 2V_{BE}}{R_T} \approx \frac{3.7V}{R_T}$$

where  $R_T$  may range from 2 k $\Omega$  to 150 k $\Omega$ . In general, temperature stability is maximized with lower values of  $R_T$ . The current source charging  $C_T$  creates a linear ramp voltage which is compared to fixed thresholds within. When the capacitor voltage reaches +3.3 volts, the oscillator output (Pin 4) goes high, turning ON the discharge transistor. The capacitor is discharged through the deadtime resistor,  $R_D$ . When the voltage on  $C_T$  falls to +1.0 volt, the oscillator output goes low, the discharge transistor is turned OFF, and the capacitor is charged through the constant current source as another cycle starts. With large values of  $R_D$  (500 $\Omega$ , maximum), deadtime is increased. The actual operating frequency is thus a function of the charge and discharge times. Figure 2 shows how charge time is related to  $R_T$  and  $C_T$ , with  $R_D = 0\Omega$ . Deadtime is a function of  $R_D$  and  $C_T$ , and can vary between 0.5 to 7  $\mu$ sec, with  $R_D = 0\Omega$ , as shown in Figure 3. The equivalent circuit schematic of the oscillator section is shown in Figure 8.

A unit can be synchronized to an external source by selecting its free-running oscillator period to be 10% longer than the period of the external source. A positive-going pulse of at least 300 nsec wide should be applied to the sync terminal for reliable triggering; however, it should not exceed the free-running pulse width by more than 200 nsec. The amplifier of the pulse should be kept between 2 and 5 volts. Multiple units can be synchronized to each other by connecting all  $C_T$  pins, and oscillator output pins together;  $R_T$  pins and discharge pins on slave oscillators must be left open.

### Error Amplifier

The error amplifier of the XR-1525A/1527A is a differential input transconductance amplifier. Its common-mode range covers the reference voltage. Its open-loop gain, typically 75 dB, can be reduced by a load resistor on Pin 9. To ensure proper operation, the output load should be limited to 50 k $\Omega$  or greater. An equivalent circuit schematic of the error amplifier is shown in Figure 9.

### Soft-Start Circuitry

The soft-start function is provided to achieve controlled turn-on of the pulse-width modulator. When power is applied to the device, the external capacitor,  $C_{soft-start}$ , on Pin 8 is charged by a 50  $\mu$ A constant current source. The ramp voltage appearing on this capacitor is fed into the pulse-width modulator, which gradually increases its output duty cycle from zero to the prescribed value. When the shutdown terminal is raised to a positive value, an internal transistor turns ON, and discharges the capacitor,  $C_S$ , causing the PWM to turn OFF. When the shutdown terminal is open or pulled low, the transistor turns OFF, and  $C_S$  begins charging as before. The turn-on time (time required to charge  $C_S$  to +2.7 volts) can be approximated as:

$$T_C \text{ (msec)} = 54 C_S$$

where  $C_S$  is in  $\mu$ F.

### Output Section

The output drivers of the XR-1525A/1527A are totem-pole designs capable of sinking and sourcing 200 mA. The low source impedance in the high or low states provides ideal interfacing with bipolar as well as FET power transistors. Either push-pull or single-ended output configurations are possible with separate collector supply terminals. The equivalent schematic of the output drivers is shown in Figure 10.

## RECOMMENDED OPERATING CONDITIONS

Note 1: Range over which the device is functional and parameter limits are guaranteed.

Collector Supply Voltage ( $V_C$ )	+4.5V to +35V
Sink/Source Load Current	
(Steady State)	0 to 100 mA
Sink/Source Load Current (Peak)	0 to 400 mA
Reference Load Current	0 to 20 mA
Oscillator Frequency Range	100 Hz to 400 kHz
Oscillator Timing Resistor	2 k $\Omega$ to 150 k $\Omega$
Oscillator Timing Capacitor	0.001 $\mu$ F to 0.1 $\mu$ F
Deadtime Resistor Range	0 to 500 $\Omega$

## EQUIVALENT SCHEMATIC DIAGRAM

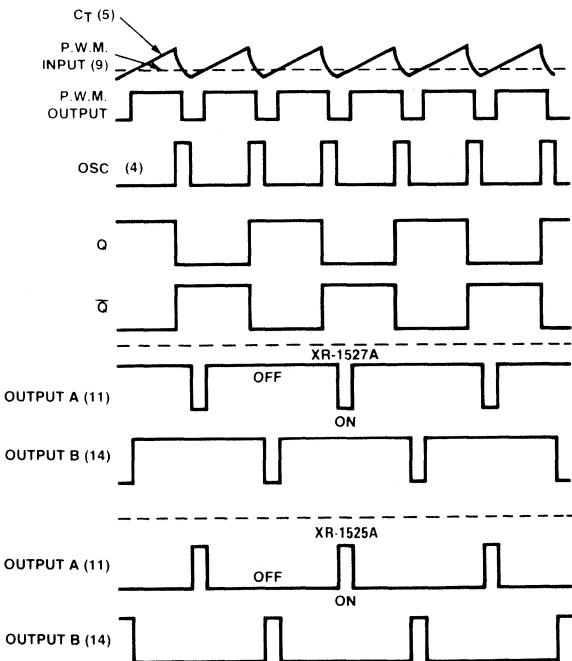
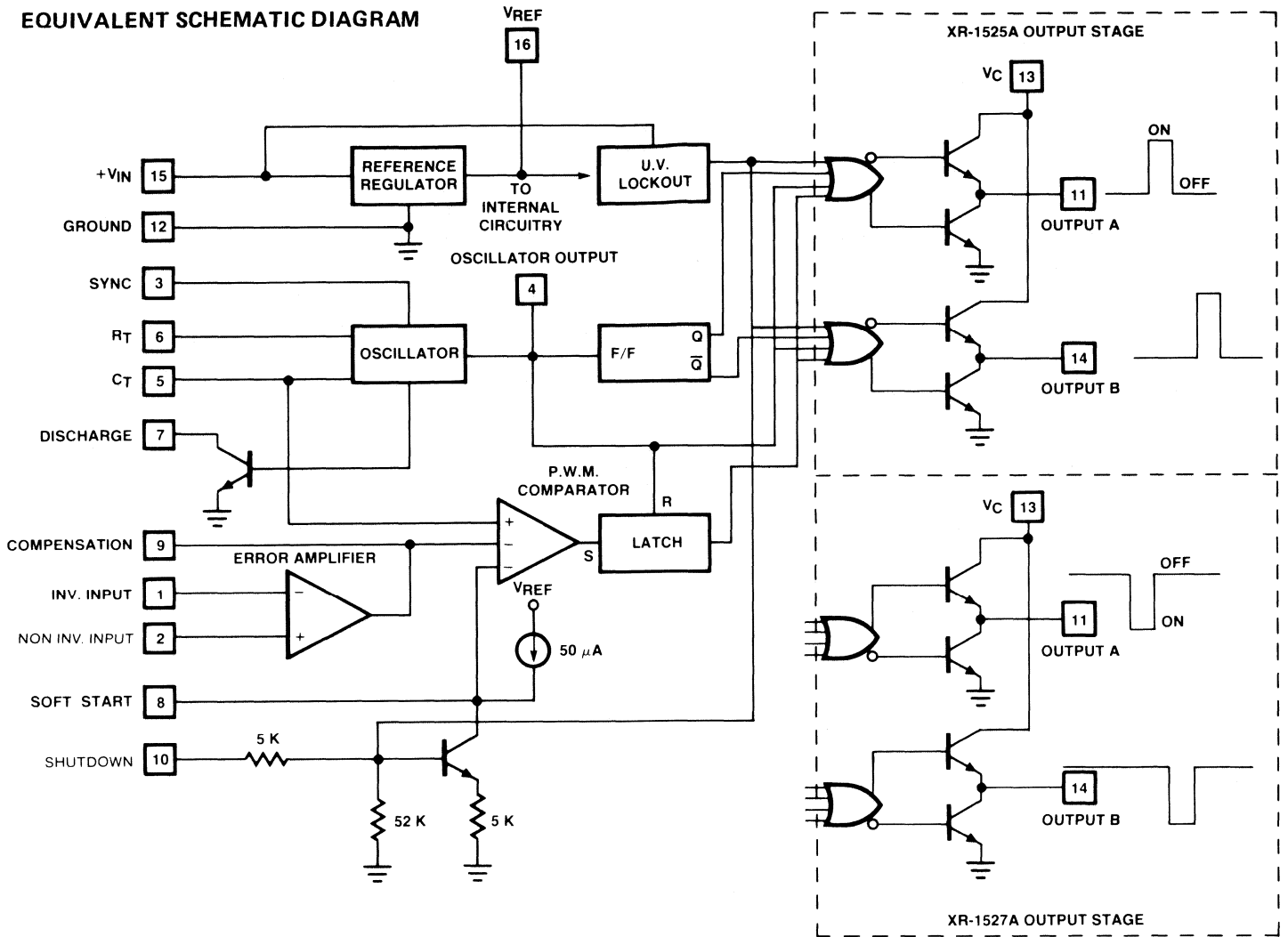


Figure 1: Typical Waveforms – XR-1525A/1527A.

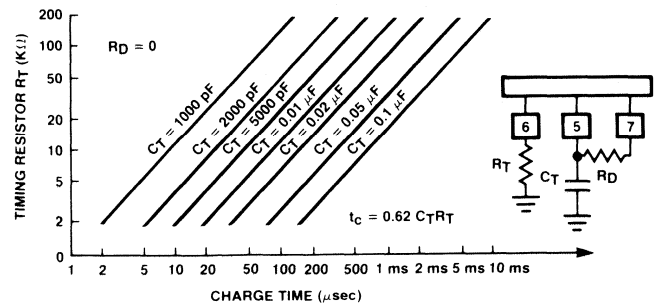


Figure 2: Oscillator Charge Time vs.  $R_T$  and  $C_T$ .



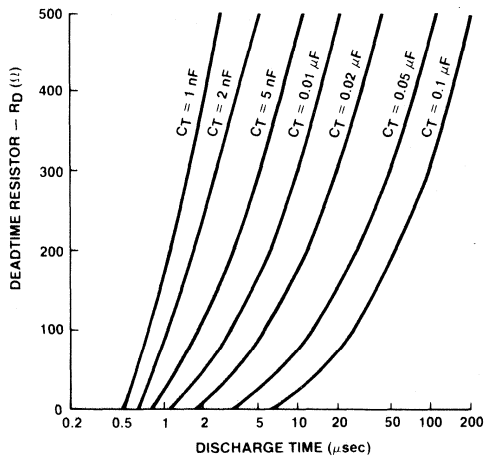


Figure 3: Oscillator Discharge Time vs  $R_D$  and  $C_T$ .

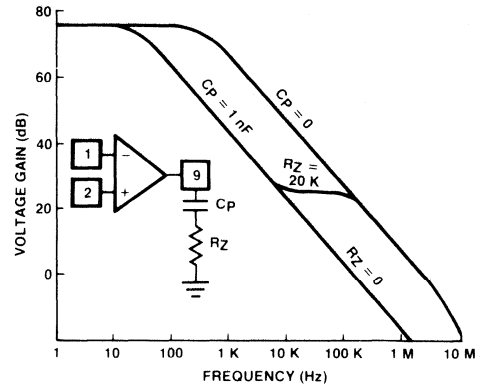


Figure 4: Error Amplifier Open-Loop Frequency Response.

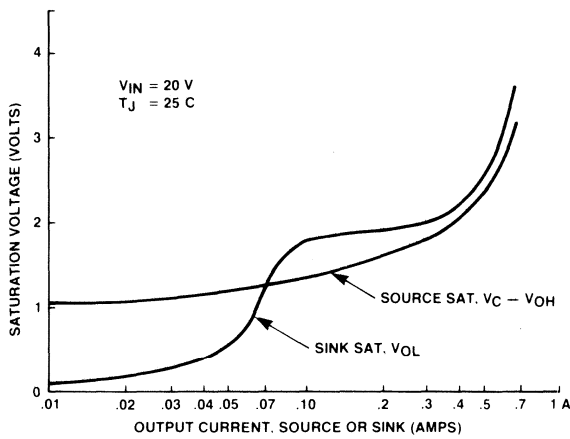


Figure 5: Output Saturation Characteristics.

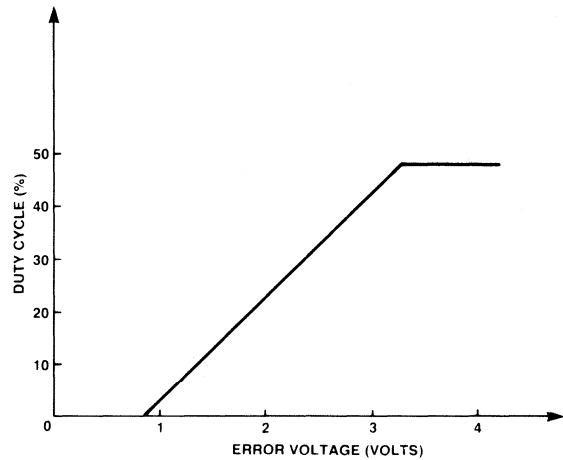


Figure 6: Output Duty Cycle vs. Error Voltage.

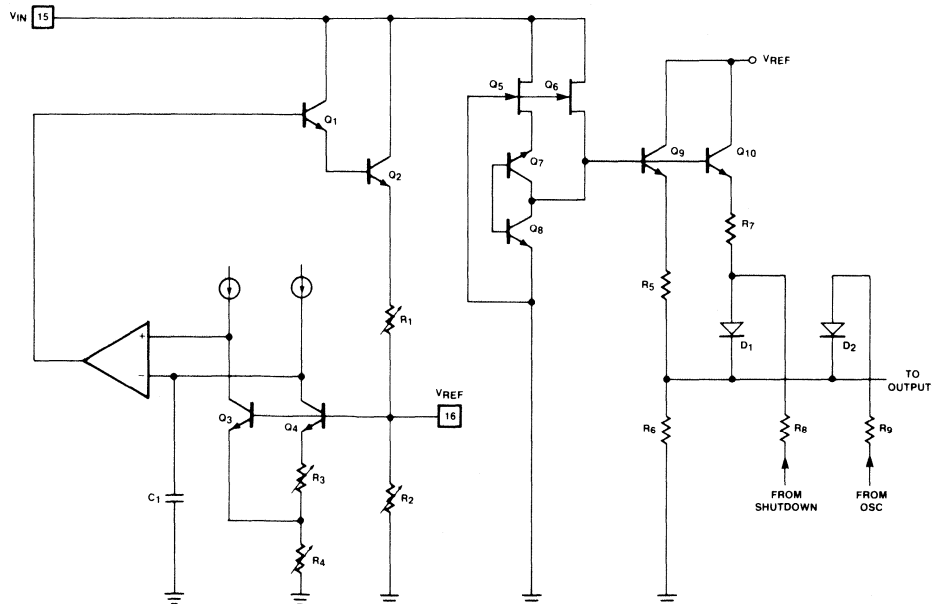
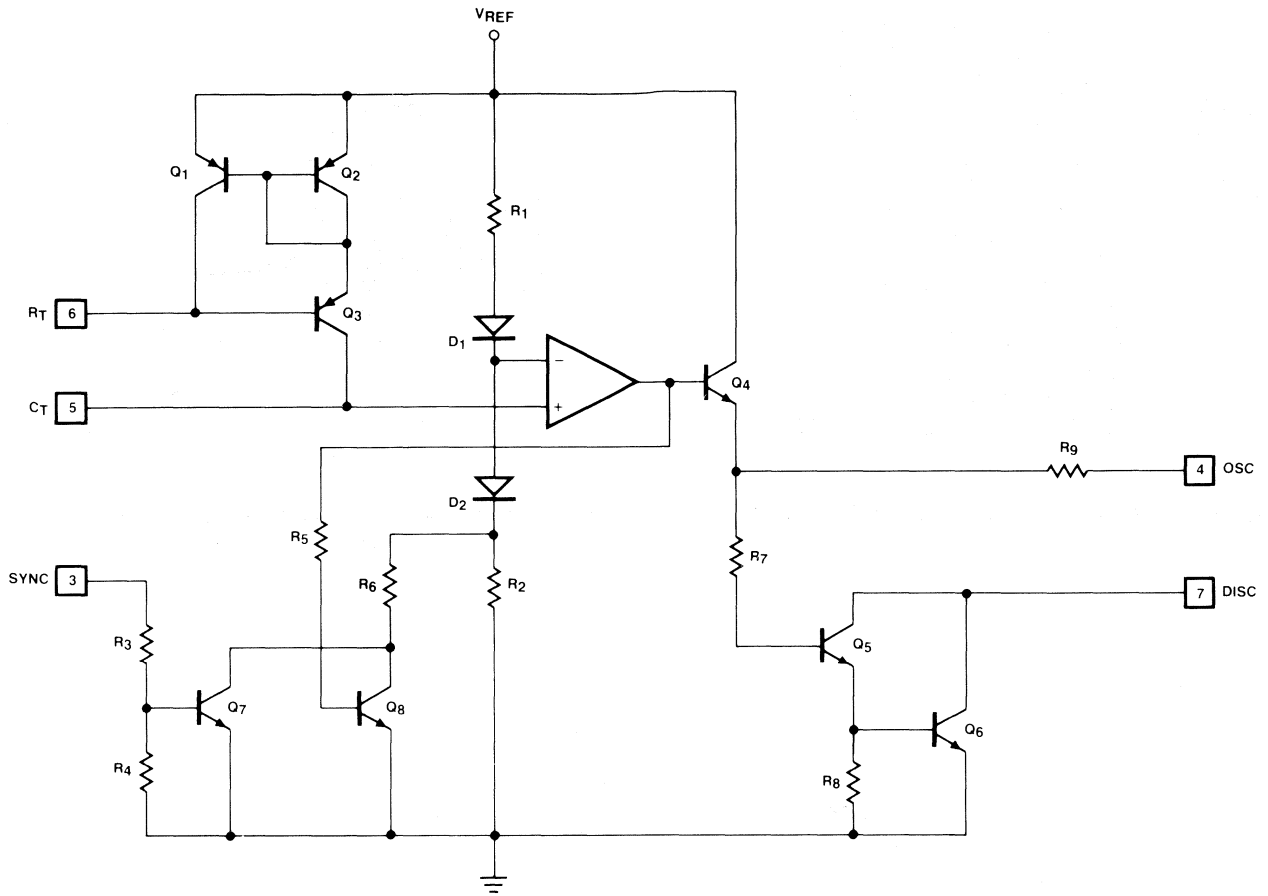
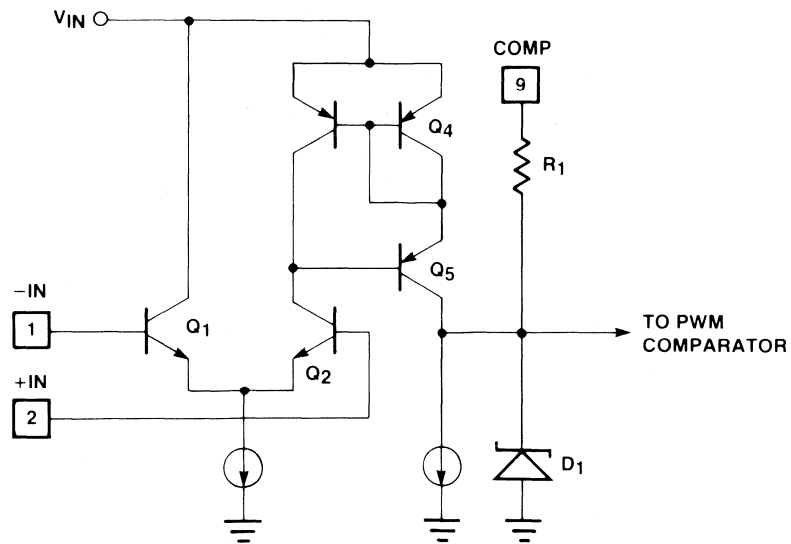


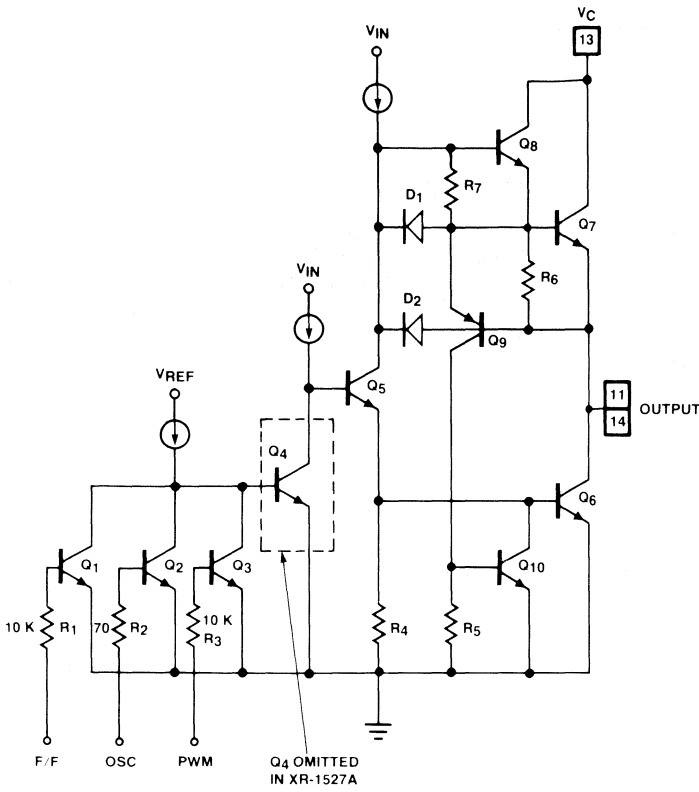
Figure 7: Equivalent Schematic of Voltage Reference Section.



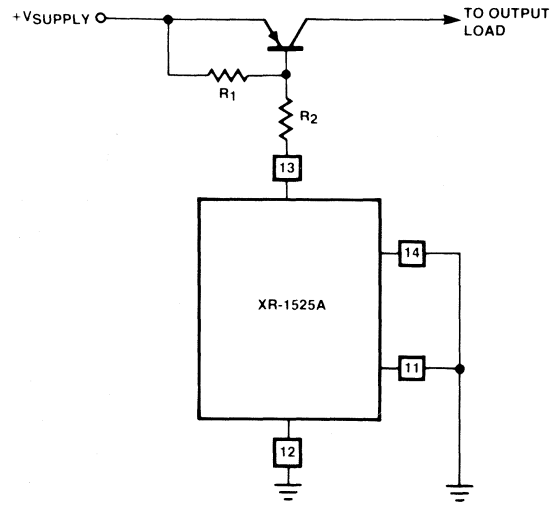
**Figure 8: Equivalent Schematic of the Oscillator Section.**



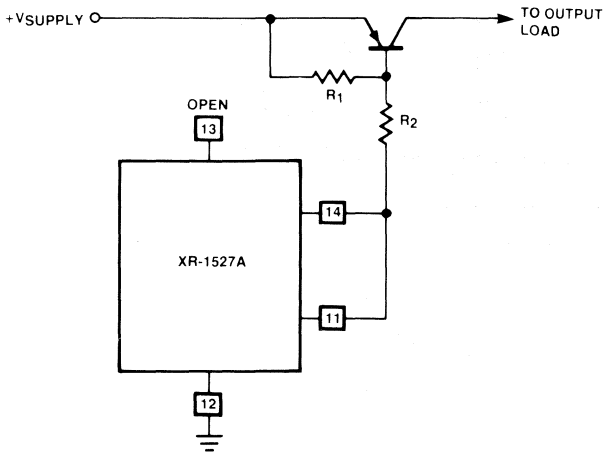
**Figure 9: Equivalent Schematic of Error Amplifier Section.**



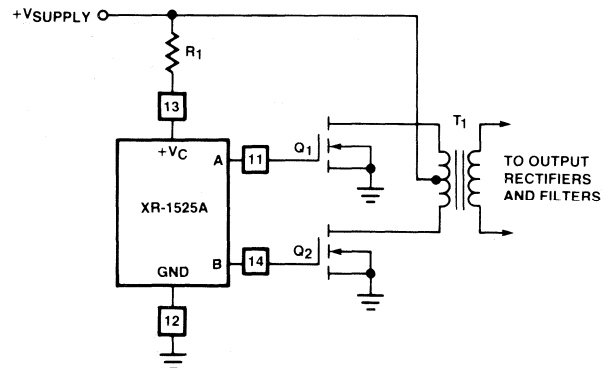
**Figure 10: Equivalent Schematic of Output Drivers.**



**Figure 11: Single-Ended Output for XR-1525A.**



**Figure 12: Single-Ended Output for XR-1527A.**



**Figure 13: Push-Pull Outputs with XR-1525A.**

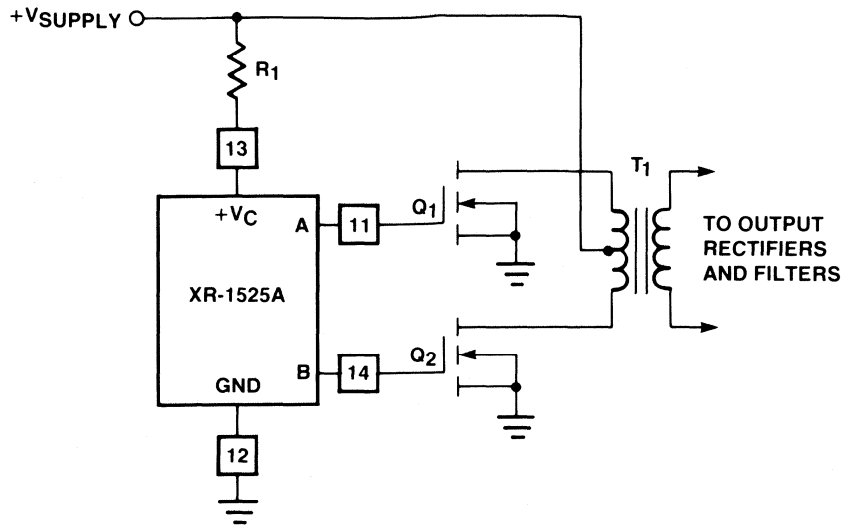


Figure 14: Power FET Push-Pull Outputs with XR-1525A.

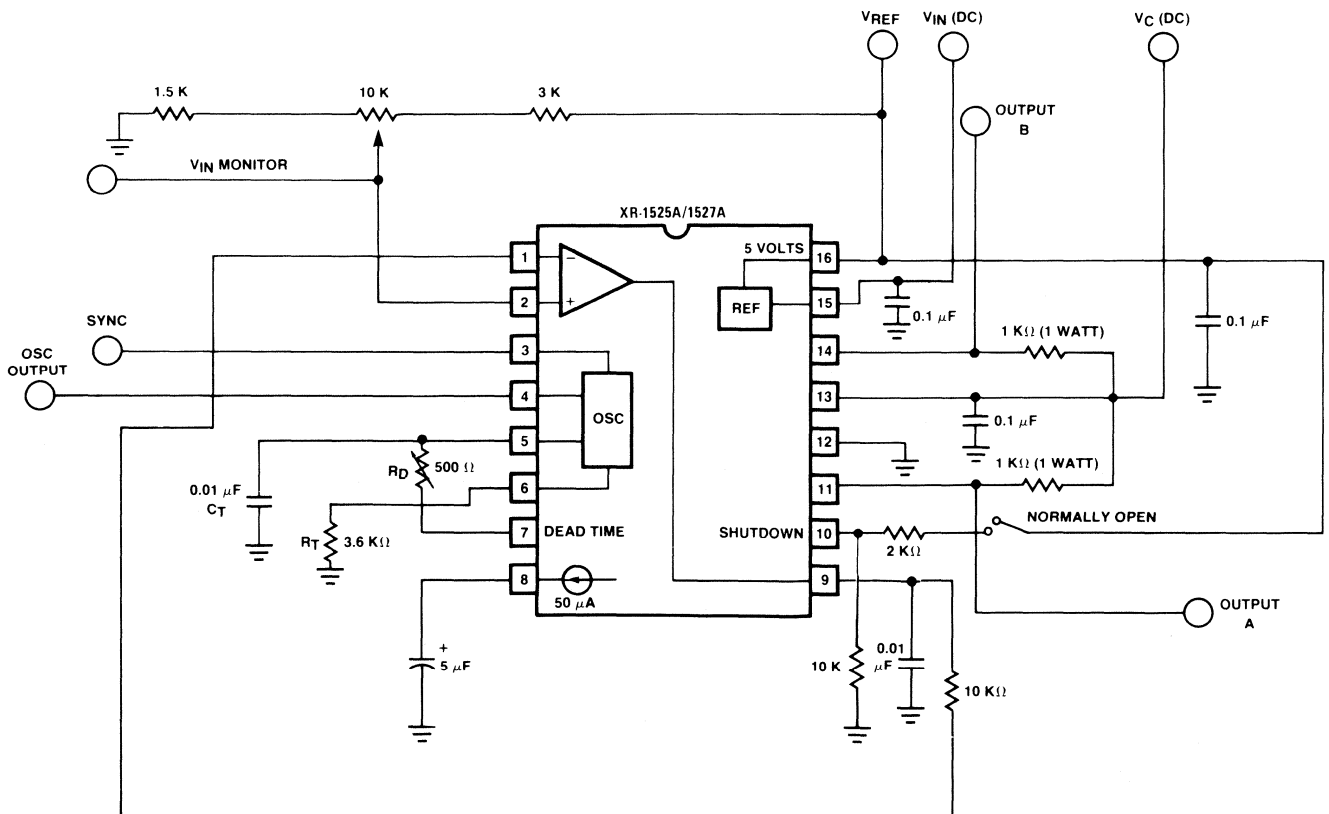


Figure 15: Generalized Test Circuit.

## Power Supply Output Supervisory Circuit

### GENERAL DESCRIPTION

The XR-1543/2543/3543 are monolithic integrated circuits that contain all the functions necessary to monitor and control the output of a power supply system. Included in the 16-Pin dual-in-line package is a voltage reference, an operational amplifier, voltage comparators, and a high-current SCR trigger circuit. The functions performed by this device include over-voltage sensing, under-voltage sensing and current limiting, with provisions for triggering an external SCR "crowbar."

The internal voltage reference on the XR-1543 is guaranteed for an accuracy of  $\pm 1\%$  to eliminate the need for external potentiometers. The entire circuit may be powered from either the output that is being monitored or from a separate bias voltage.

### FEATURES

Over-Voltage Sensing Capability	
Under-Voltage Sensing Capability	
Current Limiting Capability	
Reference Voltage Trimmed	$\pm 1\%$
SCR "Crowbar" Drive	300 mA
Programmable Time Delays	
Open Collector Outputs	
and Remote Activation Capability	
Total Standby Current	Less than 10 mA

### APPLICATIONS

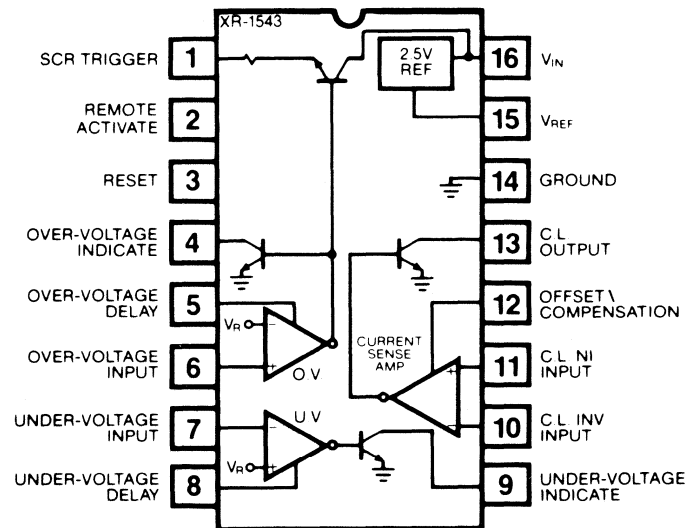
DC/DC Converters	Power Line Monitors
Switch Mode Power Supplies	Linear Power Supplies

### ABSOLUTE MAXIMUM RATINGS

Input Supply Voltage, $V_{IN}$	40V
Sense Inputs	$V_{IN}$
SCR Trigger Current (Note 1)	300 mA
Indicator Output Voltage	40V
Indicator Output Sink Current	50 mA
Power Dissipation (Ceramic)	1000 mW
Derate Above $T_A = +25^\circ\text{C}$	8.0 mW/ $^\circ\text{C}$
Power Dissipation (Plastic)	625 mW
Derate Above $T_A = 25^\circ\text{C}$	5.0 mW/ $^\circ\text{C}$
Operating Junction Temperature ( $T_J$ )	+150 $^\circ\text{C}$
Storage Temperature Range	-65 $^\circ\text{C}$ to +150 $^\circ\text{C}$

Note 1: At higher input voltages, a dissipation limiting resistor,  $R_G$ , is required.

### FUNCTIONAL BLOCK DIAGRAM



### ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-1543M	Ceramic	-55 $^\circ\text{C}$ to +125 $^\circ\text{C}$
XR-2543N	Ceramic	-25 $^\circ\text{C}$ to +85 $^\circ\text{C}$
XR-3543N	Ceramic	0 $^\circ\text{C}$ to +70 $^\circ\text{C}$
XR-3543P	Plastic	0 $^\circ\text{C}$ to +70 $^\circ\text{C}$

### SYSTEM DESCRIPTION

An output supervisory circuit, such as the XR-1543, is used to control and monitor the performance of a power supply. In many systems, it is crucial that the supply voltage is always within some minimum and maximum level, to guarantee proper performance, and to prevent damage to the system. If the supply voltage is out of tolerance, it is often desirable to shut down the system or to have some form of indication to the operator or system controller. As well as protecting the system, the power supply sometimes needs to be protected under short circuit and current overload situations. By providing an SCR "crowbar" on the output of a power supply, it can be shut off under certain fault conditions as well.

The over-voltage sensing circuit (O.V.) can be used to monitor the output of a power supply and provide triggering of an SCR, when the output goes above the prescribed voltage level. The under-voltage sensing circuit (U.V.) can be used to monitor either the output of a power supply or the input line voltage.

## ELECTRICAL CHARACTERISTICS

**Test Conditions:**  $V_{IN} = 10V$ ,  $T_J$  = full operating temperature range, unless otherwise specified.  
Refer to Figure 9 for component designation.

PARAMETER	XR-1543/2543			XR-3543			UNIT	CONDITIONS	
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.			
Input Voltage Range	4.5		40	4.5		40	V	$T_J = 25^\circ\text{C}$ to max $T_J = \text{min to max}$ $T_J = 25^\circ\text{C}$ , $V_{IN} = 40V$	
Input Voltage Range	4.7		40	4.7		40	V		
Supply Current		7	10		7	10	mA		
REFERENCE VOLTAGE SECTION (Pins 15 and 16)									
Output Voltage	2.48	2.50	2.52	2.45	2.50	2.55	V	$T_J = 25^\circ\text{C}$ $T_J = \text{min to max}$ $V_{IN} = 5$ to $30V$ $I_{ref} = 0$ to $10\text{ mA}$ $V_{ref} = 0V$	
Output Voltage	2.45		2.55	2.40		2.60	V		
Line Regulation		1	5		1	5	mV		
Load Regulation		1	10		1	10	mV		
Short Circuit Current	12	15	25	12	15	25	mA		
Temperature Stability		50			50		ppm/ $^\circ\text{C}$		
SCR TRIGGER SECTION (Pins 1, 2, and 3)									
Peak Output Current	100	200	400	100	200	400	mA	$V_{IN} = 5V$ , $R_G = 0\Omega$ , $V_O = 0$ $V_{IN} = 15V$ , $I_O = 100\text{ mA}$ $V_{IN} = 40V$ Pin 2 = GND Pin 2 = Open Pin 2 = GND, Pin 3 = GND Pin 2 = GND, Pin 3 = Open $T_J = 25^\circ\text{C}$ , $R_L = 50\Omega$ , $C_D = 0$ $T_J = 25^\circ\text{C}$ , $R_L = 50\Omega$ , $C_D = 0$ , Pin 2 = $0.4V$ $T_J = 25^\circ\text{C}$ , $R_L = 50\Omega$ , $C_D = 0$ , Pin 6 = $2.7V$	
Peak Output Voltage	12	13		12	13		V		
Output OFF Voltage		0	0.1		0	0.1	V		
Remote Activate Current		0.4	0.8		0.4	0.8	mA		
Remote Activate Voltage		2	6		2	6	V		
Reset Current		0.4	0.8		0.4	0.8	mA		
Reset Voltage		2	6		2	6	V		
Output Current Slew Rate		400			400		mA/ $\mu\text{s}$		
Propagation Delay Time (From Pin 2)		300			300		nsec		
Propagation Delay Time (From Pin 6)		500			500		nsec		
COMPARATOR SECTIONS (Pins 4, 5, 6, 7, 8, and 9)									
Input Threshold (Input Voltage Rising on Pin 6 & Falling on Pin 7)	2.45	2.50	2.55	2.40	2.50	2.60	V		$T_J = 25^\circ\text{C}$ $T_J = \text{min to max}$ Sense input = $0V$ $V_D = 0V$ $I_L = 10\text{ mA}$ $V_{out} = 40V$ $C_D = 0$ } Pin 6 = $2.7V$ Pin 7 = $2.3V$ $T_J = 25^\circ\text{C}$
Input Hysteresis		25			25		mV		
Input Bias Current		0.3	1.0		0.3	1.0	$\mu\text{A}$		
Delay Saturation		0.2	0.5		0.2	0.5	V		
Delay High Level		6	7		6	7	V		
Delay Charging Current	200	250	300	200	250	300	$\mu\text{A}$		
Indicate Saturation Voltage		0.2	0.5		0.2	0.5	V		
Indiate Leakage Current		0.01	1.0		0.01	1.0	$\mu\text{A}$		
Propagation Delay Time		400			400		nsec		
Propagation Delay Time		10			10		msec		
CURRENT LIMIT AMPLIFIER SECTION (Pins 10, 11, 12, and 13)									
Input Voltage Range	0		$V_{IN}-3V$	0		$V_{IN}-3V$	V	Pin 12 = Open, $V_{CM} = 0V$ Pin 12 = Open, $V_{CM} = 0V$ Pin 12 = $10\text{ k}\Omega$ to GND $V_{IN} = 15V$ , $0 \leq V_{CM} \leq 12V$ $V_{CM} = 0V$ , Pin 12 = Open $I_L = 10\text{ mA}$ $V_{out} = 40V$ $T_J = 25^\circ\text{C}$ , $A_v = 0\text{ dB}$ $T_J = 25^\circ\text{C}$ , $V_{overdrive} = 100\text{ mV}$	
Input Bias Current		0.3	1.0		0.3	1.0	$\mu\text{A}$		
Input Offset Voltage		0	10		0	15	mV		
Input Offset Voltage Common Mode	80	100	120	70	100	130	mV		
Rejection Ratio	60	70		60	70		dB		
Open Loop Gain	72	80		72	80		dB		
Output Saturation Voltage		0.2	0.5		0.2	0.5	V		
Output Leakage Current		0.01	1.0		0.01	1.0	$\mu\text{A}$		
Small Signal Bandwidth		5			5		MHz		
Propagation Delay Time		200			200		nsec		

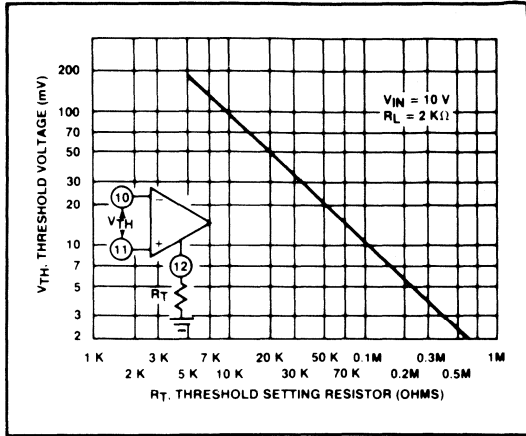


Figure 1: Current Limiting Threshold ( $V_{TH}$ ) vs. Threshold Setting Resistor ( $R_T$ ).

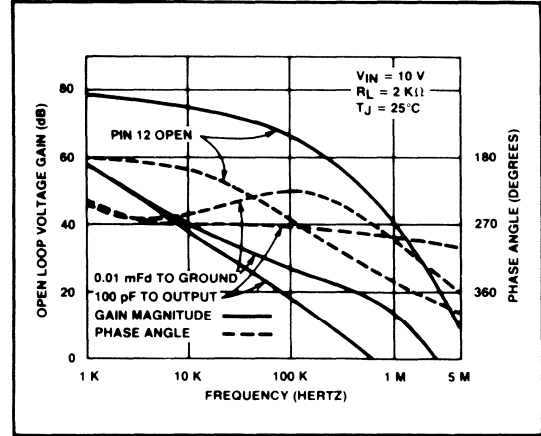


Figure 2: Current Limiting Amplifier – Frequency Response.

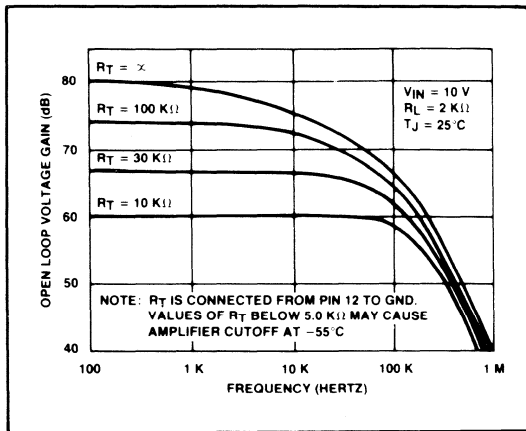


Figure 3: Current Limiting Amplifier Gain vs. Threshold Setting Resistor ( $R_T$ ).

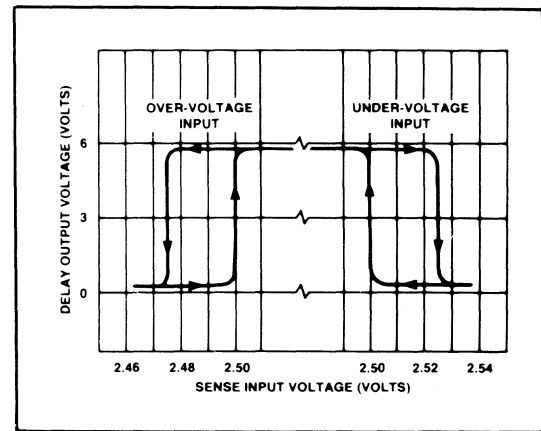


Figure 4: Over-Voltage and Under-Voltage Comparator Hysteresis.

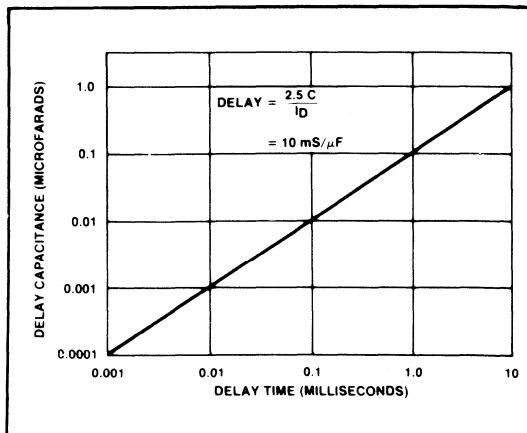


Figure 5: Comparator Activation Delay vs. Capacitor Value.

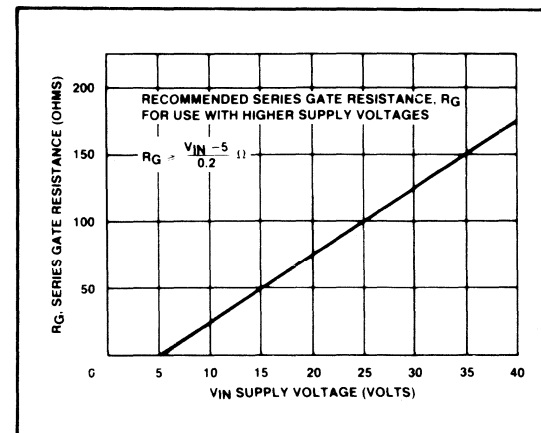


Figure 6: SCR Trigger -- Series Gate Resistance ( $R_G$ ) vs. Input Voltage.

## PRINCIPLES OF OPERATION

The internal control blocks of the XR-1543 operate as follows:

### Voltage Reference Section

The internal voltage reference circuit of the XR-1543 is based on the well-known "band-gap reference" with a nominal output voltage of 2.50 volts, internally trimmed to give an accuracy of  $\pm 1\%$  at  $25^{\circ}\text{C}$ . It is capable of providing a stable output voltage over a wide input voltage range. Furthermore, its performance is guaranteed for changes in line and load conditions. The accuracy of the output voltage is guaranteed to  $\pm 2\%$  maximum for the XR-1543/2543, and  $\pm 4\%$  maximum for the XR-3543, over the entire operating temperature range.

The output of the reference circuit is capable of providing up to 10 mA of current for use as a reference for external circuitry. The primary function of this circuit is to provide a very accurate and stable reference input for the under-voltage and over-voltage comparators, thereby enabling very precise monitoring of line and output voltages without potentiometers.

### Comparator Section

The under-voltage and over-voltage sensing comparators of the XR-1543 are identical except for the input polarities. Each section is made up of two comparators in series whose inputs are referenced to 2.50 volts. The delay terminal between the comparators requires an external capacitor to ground for programmable time delays on the output.

When an out-of-tolerance situation occurs, the first comparator activates a current source which then charges the external capacitor at a constant rate. This ramp voltage is then compared to the reference voltage by the second comparator which activates the output indicating circuit. With no external capacitor, the overall time delay from sense input to output is approximately  $0.5 \mu\text{sec}$ . The charging current for the capacitor,  $C_D$ , is approximately  $250 \mu\text{A}$  which results in the following relationship:

$$\text{Time delay} = 10 C_D \text{ (msec)}$$

where  $C_D$  is in  $\mu\text{F}$ .

The output npn transistors are capable of sinking 10 mA with saturation voltage of less than 0.4 volts. The outputs can be "wired OR'd" to provide a single output indicator.

### Current Sensing Amplifier

The operational amplifier used in the XR-1543 is a high-gain, externally compensated amplifier with open collector

outputs. The npn input stage provides for a wide input common mode range extending from ground to approximately 3 volts below the positive supply. With a  $2 \text{ k}\Omega$  pull-up resistor, the open-loop voltage gain is 72 dB minimum with a unity gain bandwidth beyond 5 MHz. The operational amplifier may be used as a comparator or, if linear amplification is required, external compensation may be added for stable performance over a wide frequency range.

The input offset voltage of this amplifier is specified for 10 mV maximum; however, it may be programmed externally for thresholds up to 200 mV. By connecting a resistor,  $R_T$ , from Pin 12 to ground, the input threshold voltage can be varied. For most current sensing applications, the required threshold polarity calls for a positive voltage on the inverting input. Reducing the impedance on Pin 12 also lowers the overall voltage gain of the amplifier, which makes this pin a convenient point to apply frequency compensation. This can be accomplished by either connecting  $C_1$  to the output, or  $C_2$  to ground as shown in Figure 8. The diode,  $D_1$ , and the resistor,  $R_C$ , are used only if it is necessary to increase the frequency response by operating the output at a higher current and/or isolating the load from  $R_C$  and  $C_1$ , when the amplifier is off.

### SCR Trigger Section

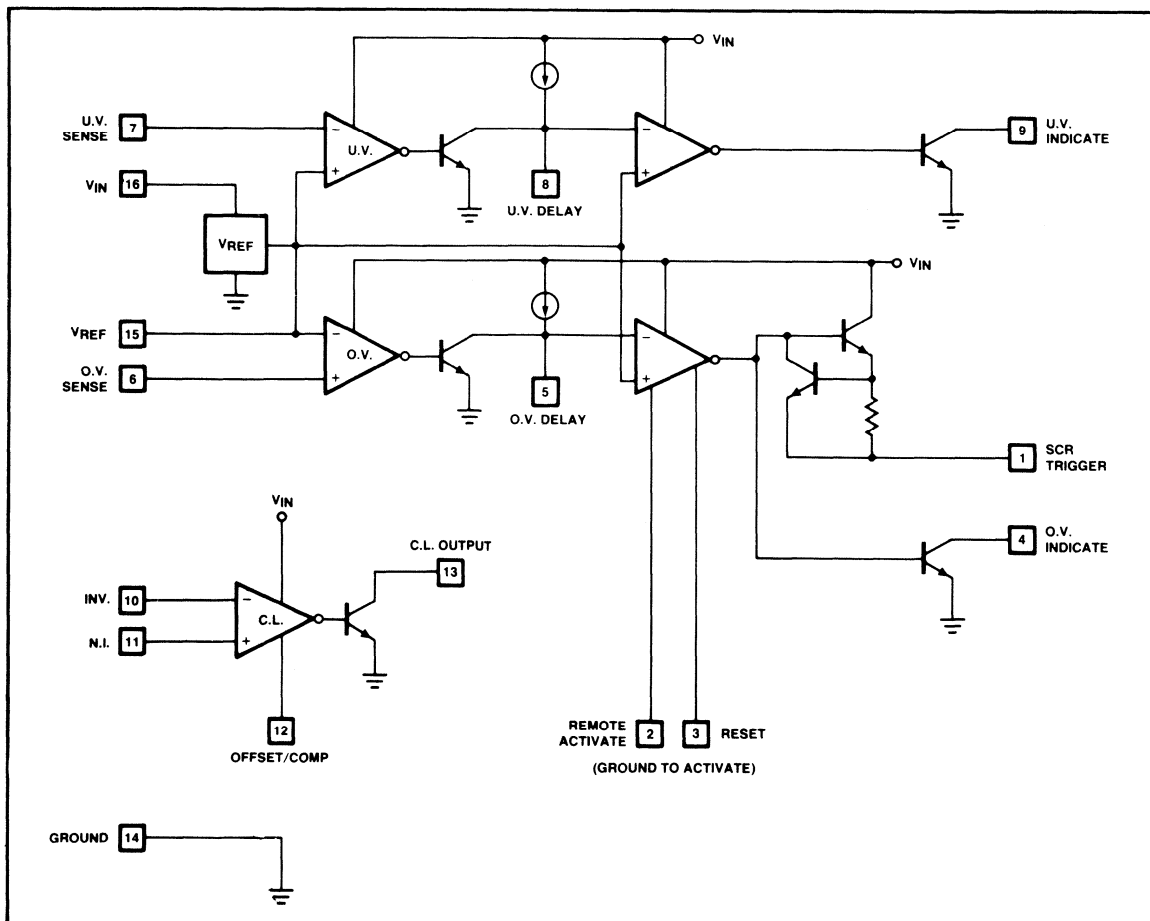
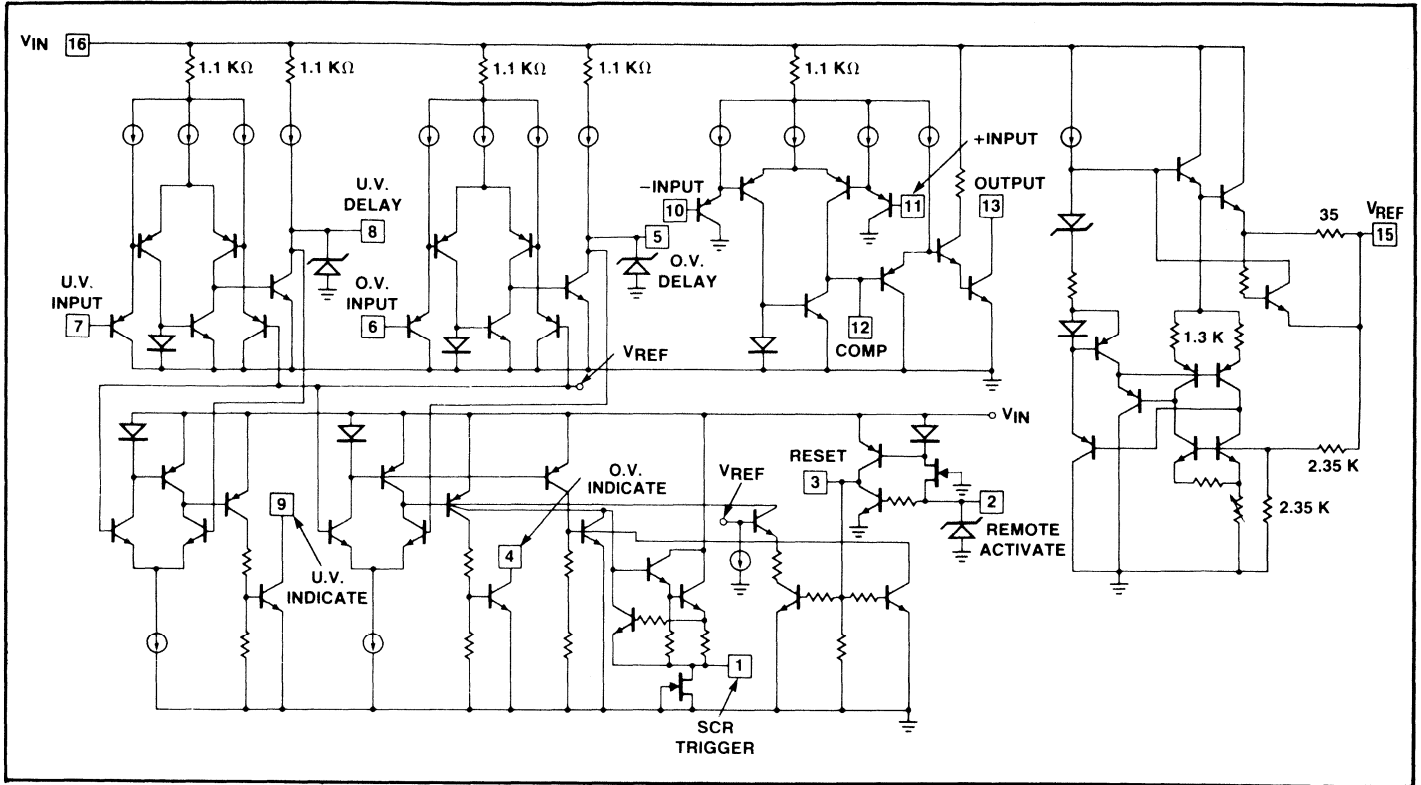
The SCR trigger section of the XR-1543 is connected to the output of the over-voltage comparator and is capable of handling 300 mA. The circuit also provides for remote activation of the output as well as a reset terminal. When an over-voltage situation occurs, the output of the sensing comparator goes low, turning "on" the over-voltage indicate transistor. At the same time, the comparator drives an npn Darlington pair which provides 300 mA to activate an external SCR crowbar.

A remote activation circuit is included to allow the user to activate the SCR crowbar in other than an over-voltage situation. When this terminal, Pin 2, is grounded, it forces the output of the comparator low which activates the output circuitry in the same manner as the over-voltage comparator does.

Another function of this circuit is to provide the capability to latch the O.V. indicate and SCR trigger outputs "on", after a fault is sensed. This is done by connecting the remote activate terminal (Pin 2) to the O.V. indicating terminal (Pin 4). When an O.V. condition occurs, Pin 2 is pulled low, which in turn holds the outputs in the "on" condition until the reset terminal is externally grounded, removing the latch and turning "off" the outputs. If the external connection is not made, the high current output will be activated only as long as a fault condition exists. When the fault condition disappears, the outputs will be disabled. The thresholds for both remote activation and reset terminals are approximately 1.2 volts.



**EQUIVALENT SCHEMATIC DIAGRAM**



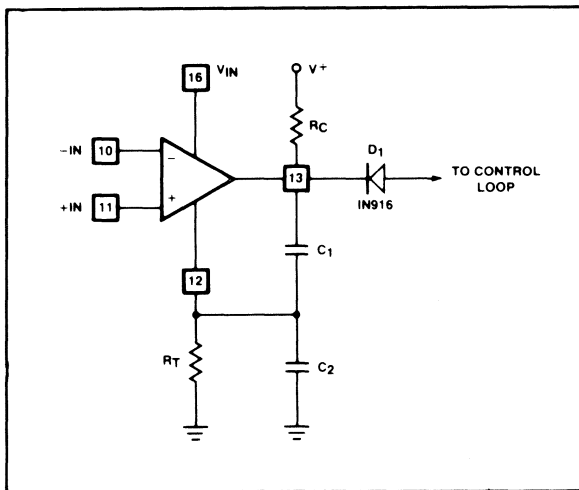
**Figure 7: XR-1543 Block Diagram.**

## APPLICATIONS INFORMATION

A typical application of the XR-1543 is to monitor a single power supply output voltage as shown in Figure 9. In this circuit, both over- and under-voltage sensing and current-limiting functions are performed. The circuit shown is powered from an external bias capable of supplying 10 mA in addition to the activation current for the SCR trigger. With Pin 2 tied to Pin 4, a latch has been provided such that when an over-voltage situation occurs, the o.v. indicator and SCR trigger are activated and held until the reset terminal is externally grounded.

In powering an SCR from supply voltages greater than 5 volts, an external resistor,  $R_G$ , is required on Pin 1 to limit the power dissipation for the XR-1543. Although the XR-1543 is capable of handling 300 mA of current, its power dissipation must be kept below the absolute maximum ratings.

In this circuit, current-limiting is performed by sensing the voltage drop across the resistor,  $R_{SC}$ , in the positive supply line. The threshold for the amplifier is externally set by the resistor,  $R_T$ .



**Figure 8: Current Limiting Amplifier Connections for Threshold Control and Frequency Compensation.**

The values of the external components used in Figure 9 are calculated as follows:

1. Current limiting threshold,  $V_{TH} \approx \frac{1000}{R_T}$

2.  $C_1$  is determined by the loop dynamics.

3. Peak current to load,

$$I_P \approx \frac{V_{TH}}{R_{SC}} + \frac{V_O}{R_{SC}} \left( \frac{R_2}{R_2 + R_3} \right)$$

4. Short circuit current,

$$I_{SC} = \frac{V_{TH}}{R_{SC}}$$

5. Low output voltage limit,

$$V_O (\text{low}) = \frac{2.5(R_4 + R_5 + R_6)}{R_5 + R_6}$$

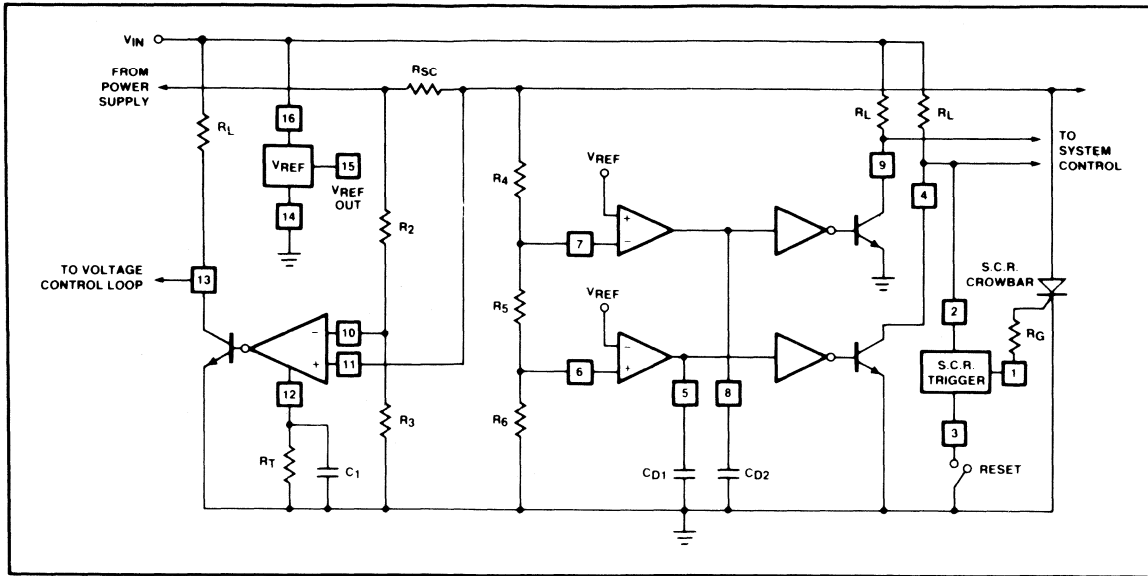
6. High output voltage limit,

$$V_O (\text{high}) = \frac{2.5(R_4 + R_5 + R_6)}{R_6}$$

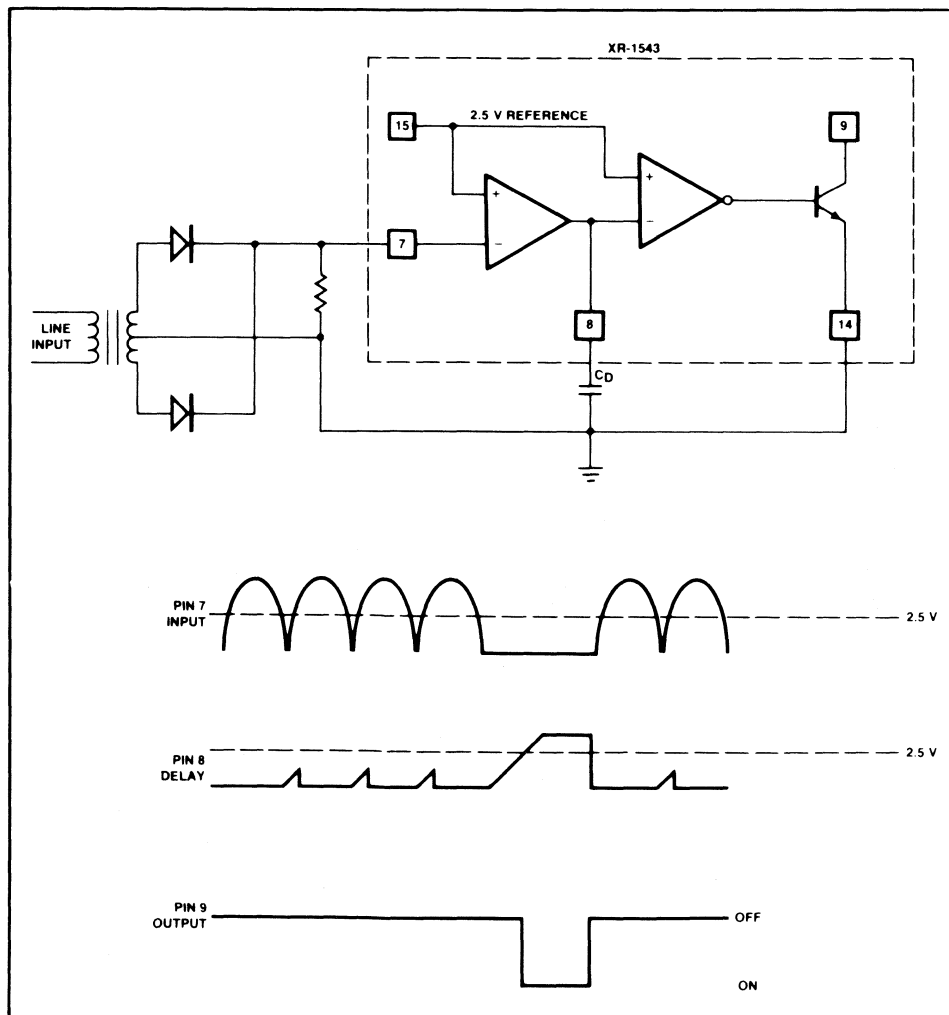
7. Voltage sensing delay,  $T_D = 10,000 C_D$

8. SCR trigger power limiting resistor,

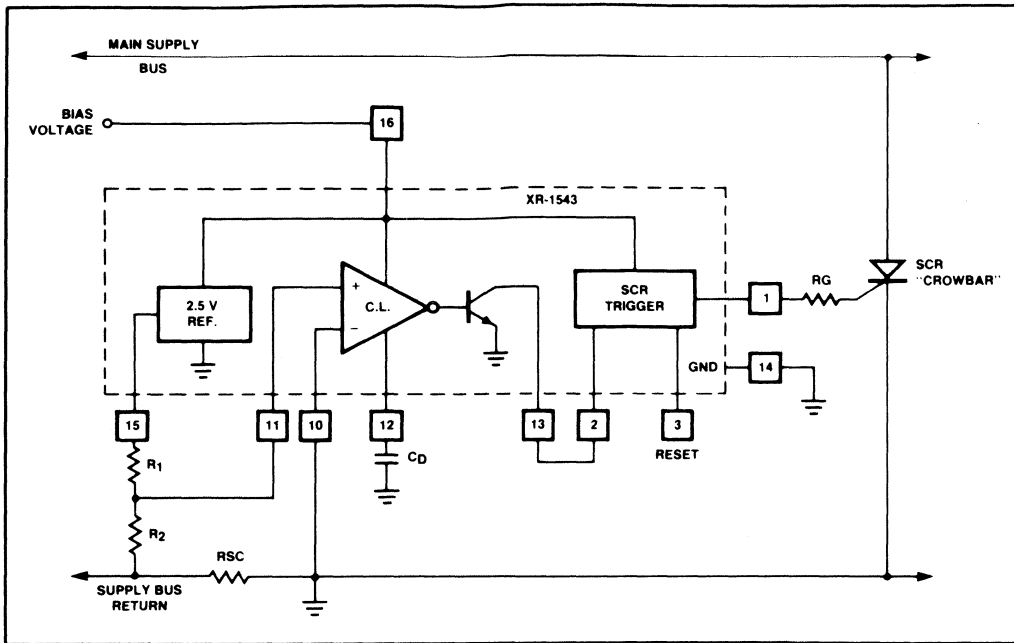
$$R_G > \frac{V_{IN} - 5}{0.2}$$



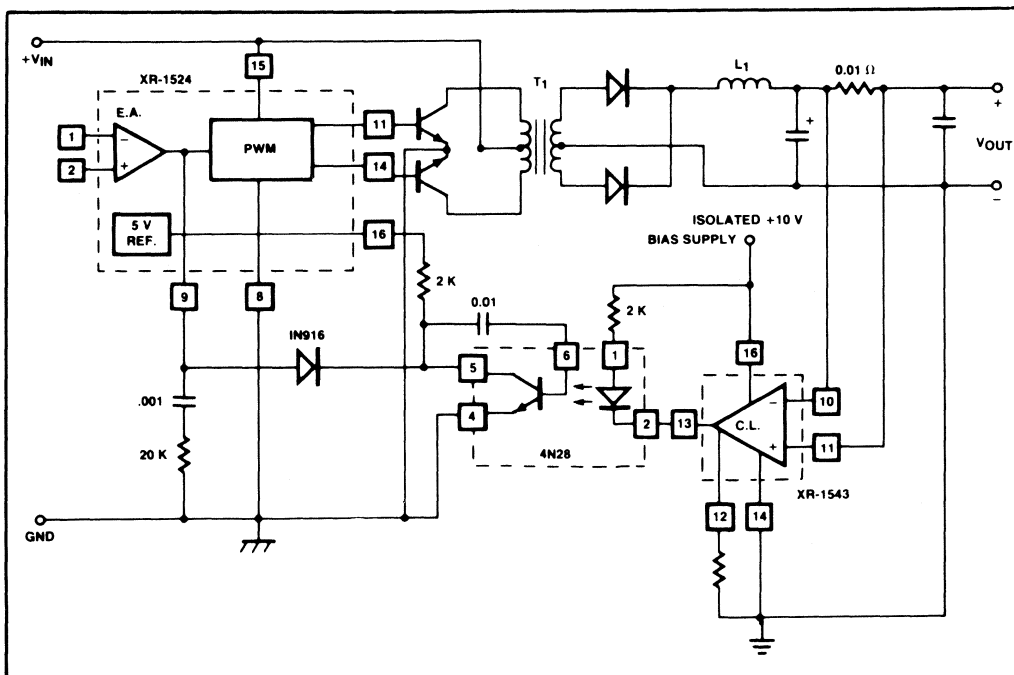
**Figure 9: Typical Connection for Linear Foldback Current Limiting as well as Over-Voltage and Under-Voltage Protection.**



**Figure 10: XR-1543 – Input Line Monitor Circuit.**



**Figure 11: XR-1543 – Over Current Shutdown Circuitry.**



**Figure 12: XR-1543 – DC Converter with Isolated Current Limiting.**

# Pulse-Width Modulator Control System

## GENERAL DESCRIPTION

The XR-2230 is a high-performance monolithic pulse-width modulator control system. It contains all the necessary control blocks for designing switch mode power supplies, and other power control systems. Included in the 18-Pin dual-in-line package are two error amplifiers, a sawtooth generator, and the necessary control logic to drive two open-collector power transistors. Also included are protective features, such as adjustable dead-time control, thermal shutdown, soft-start control, and double-pulse protection circuitry.

The device provides two open-collector output transistors which are driven 180° out-of-phase, and are capable of sinking 30 mA. These outputs can be used to implement single-ended or push-pull switching regulation of either polarity in transformerless or transformer-coupled converters.

## FEATURES

- Thermal Shutdown
- Adjustable Dead-time
- Dual Open-Collector
  - 30 mA Output Transistors
- Double-Pulse Protection Circuit
- Soft-Start Control
- High-Speed Remote Shut-Down Input
- Two High-Performance Error Amplifiers
  - with  $\pm 5V$  Input Common-Mode Range

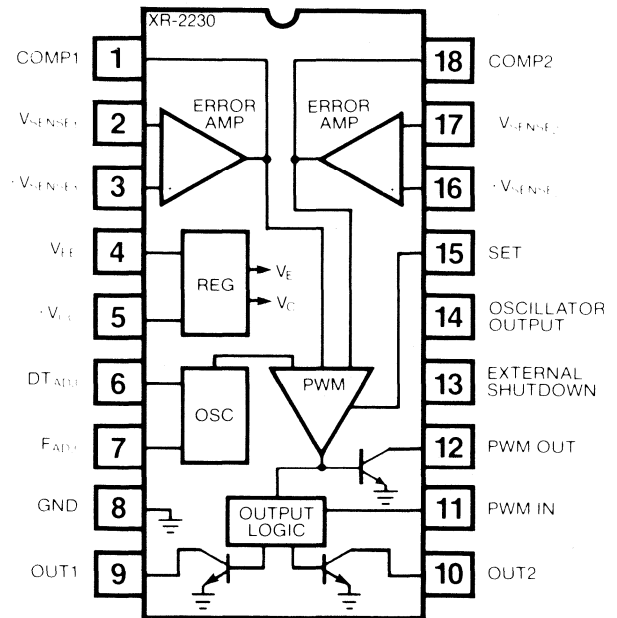
## APPLICATIONS

- Switching Regulators
- Motor-Speed Controllers
- Pulse-Width Modulated Control Systems

## ABSOLUTE MAXIMUM RATINGS

Positive Supply Voltage	-0.5 to +18V
Negative Supply Voltage	+0.5 to -18V
Input Voltage	-18 to +18V
Output Voltage	-0.5 to +18V
Power Dissipation ( $T_A \leq 25^\circ C$ )	400 mW
Operating Temperature	-10°C to +85°C
Storage Temperature	-55°C to +125°C

## FUNCTIONAL BLOCK DIAGRAM



## ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-2230CP	Plastic	0°C to +70°C

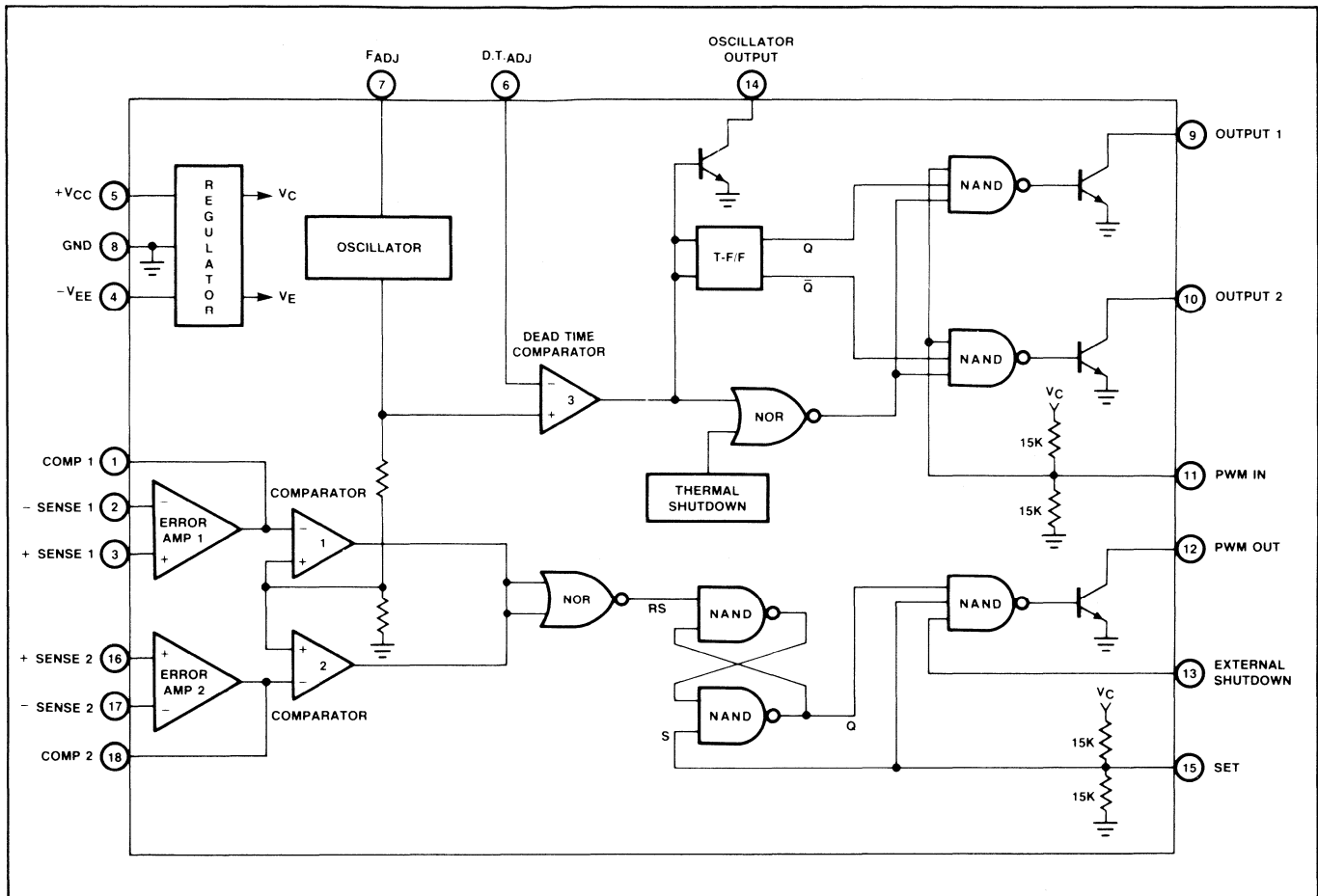
## SYSTEM DESCRIPTION

The XR-2230 PWM circuit contains two high-performance error amplifiers with wide input common-mode range, and large voltage gains. Typically, one amplifier (Pins 16, 17, 18) is used for current sensing and the other (Pins 1, 2, 3) is used as an error amplifier to sense the output voltage. The XR-2230 requires a split supply between  $\pm 8$  volts and  $\pm 15$  volts, however, it can be operated from a single supply with proper external biasing on the ground pin and input pins of the error amplifiers. The output drivers capable of sinking 30 mA at a saturation voltage of about 0.3V can be used in a push-pull configuration, or can be paralleled for a single-ended configuration with a duty cycle between 0% to over 90%.

The XR-2230 features a self-protecting thermal-shutdown circuitry which turns off the output drivers when the junction temperature exceeds 130°C. The on-board regulator stabilizes the oscillator frequency to 0.1%/V for reliable performance.

**ELECTRICAL CHARACTERISTICS**
**Test Conditions:**  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = +12\text{V}$ ,  $V_{EE} = -12\text{V}$ ,  $f_{OSC} = 20\text{ kHz}$ , unless otherwise specified.

SYMBOL	PARAMETERS	MIN.	TYP.	MAX.	UNIT	CONDITIONS
<b>SUPPLY SECTION</b>						
$V_{CC}$	Positive Supply Voltage	+10			V	
$V_{EE}$	Negative Supply Voltage			-10	V	
$I_{CC}$	Positive Supply Current	7.0	11.0	15.0	mA	
$I_{EE}$	Negative Supply Current	-2.0	-6.0	-2.0	mA	
<b>OSCILLATOR SECTION</b>						
$f_{OSC}$	Frequency Range	10		100	kHz	$R_T = 30\text{ k}\Omega$ , $C_T = 4700\text{ pF}$ $V_{CC} = +10\text{V} \approx +15\text{V}$ $V_{CC} = +18\text{V}$ , $V_{EE} = -8\text{V}$
	Initial Accuracy		0.1	15	%	
	Supply Voltage Stability				%/V	
	Low Supply Voltage	-20		+20	%	
$V_{OSC}$	Temperature Stability		0.01		%/ $^\circ\text{C}$	$f_{OSC} = 20\text{ kHz}$
$\delta$	Sawtooth Peak Voltage	3.0	3.5	4.0	V	
	Duty Cycle Range	10		90	%	
<b>VOLTAGE ERROR AMPLIFIER</b>						
$V_{OS}$	Input Offset Voltage		2	10	mV	$AV_{CL} = 40\text{ dB}$
$I_{BIAS}$	Input Bias Current		-.5	-30	$\mu\text{A}$	
$A_{VO}$	Open-Loop Gain	60	90		dB	
$f_{-3dB}$	Closed-Loop Bandwidth		25		kHz	
$CMRR$	Common-Mode Rejection Ratio	60	90		dB	$V_{ICM} = \pm 4.5\text{V}$ $R_L = 10\text{ k}\Omega$ $V_{CC} = +8\text{V}$ , $V_{EE} = -8\text{V}$ $AV_{CL} = 14\text{ dB}$ , $R_F = 10\text{ k}\Omega$
$V_{OM}$	Output Voltage Swing	$\pm 5$			V	
$SR$	Slew Rate	2	4		V/ $\mu\text{s}$	
	Input Voltage Range		$\pm 5$		V	
<b>CURRENT ERROR AMPLIFIER</b>						
$V_{OS}$	Input Offset Voltage		4	20	mV	$AV_{CL} = 40\text{ dB}$
$I_{BIAS}$	Input Bias Current		-1.0	-60	$\mu\text{A}$	
$A_{VO}$	Open-Loop Gain	60	90		dB	
$f_{-3dB}$	Closed-Loop Bandwidth		25		kHz	
$CMRR$	Common-Mode Rejection Ratio	60	90		dB	$V_{ICM} = \pm 4.5\text{V}$ $R_L = 10\text{ k}\Omega$ $V_{CC} = +8\text{V}$ , $V_{EE} = -8\text{V}$ $AV_{CL} = 14\text{ dB}$ , $R_F = 10\text{ k}\Omega$
$V_{OM}$	Output Voltage Swing	$\pm 5$			V	
$SR$	Slew Rate	4	8		V/ $\mu\text{s}$	
	Input Voltage Range		$\pm 5$		V	
<b>MODULATOR SECTION</b>						
$t_d$	Set Input Open Voltage (Pin 15)	3.1	3.6	4.1	V	$V_{CC} = +8\text{V}$ , $V_{EE} = -8\text{V}$
	Modin Input Open Voltage (Pin 11)	2.8	3.3	4.3	V	
	Inhibit Input Current (Pin 13)	3.1	3.6	4.1	V	$V_{CC} = +8\text{V}$ , $V_{EE} = -8\text{V}$
	Inhibit Propagation Delay	2.8	3.3	4.3	V	
$t_f$	Out1, Out 2, Output Voltage (Pins 9 & 10)	-50	-10		$\mu\text{A}$	$I_O = 30\text{ mA}$ , $T_A = 25^\circ\text{C}$ $T_A = -10 \approx +85^\circ\text{C}$
	Low Supply Voltage		60		ns	
	Out1, Out2 Fall Time			0.3	V	$I_O = 27\text{ mA}$ , $T_A = 25^\circ\text{C}$
	Modout Output Voltage (Pin 12)			0.4	V	
	Under Low Supply Voltage			0.3	V	$I_O = 16\text{ mA}$ , $T_A = 25^\circ\text{C}$ $T_A = -10 \approx +85^\circ\text{C}$
	Oscillator Output Voltage (Pin 14)			0.3	V	
	Thermal Shutdown Temp.			0.4	V	$I_O = 14\text{ mA}$ , $T_A = 25^\circ\text{C}$ $I_O = 3\text{ mA}$ , $T_A = 25^\circ\text{C}$ $T_A = -10 \approx +85^\circ\text{C}$
				0.6	V	
			130		$^\circ\text{C}$	



**Figure 1. Equivalent Schematic Diagram**

## PRINCIPLES OF OPERATION

The heart of the XR-2230 is the sawtooth generator. As seen in Figure 1, this sawtooth drives one input of each of the three system comparators. Comparators one and two have their other inputs tied to the outputs of the error amplifiers. These comparators will now produce, at their outputs, square waves which will have a duty cycle proportional to the voltage at the inputs to the error amplifiers, or pulse width information. The pulse width information is fed into the NOR gate and used to provide the reset information to the pulse-width modulation flip-flop (PWM). The PWM flip-flop information is fed into the NAND gate with the external shutdown and PWM flip-flop set input. The information from the NAND gate drives an open-collector transistor to provide the pulse-width modulation output, Pin 12. The PWM output will be a square wave with a frequency set by the sawtooth generator, and a duty cycle equal to either comparator, one or two, whichever is shorter. If the external shutdown, Pin 13, is driven low, the

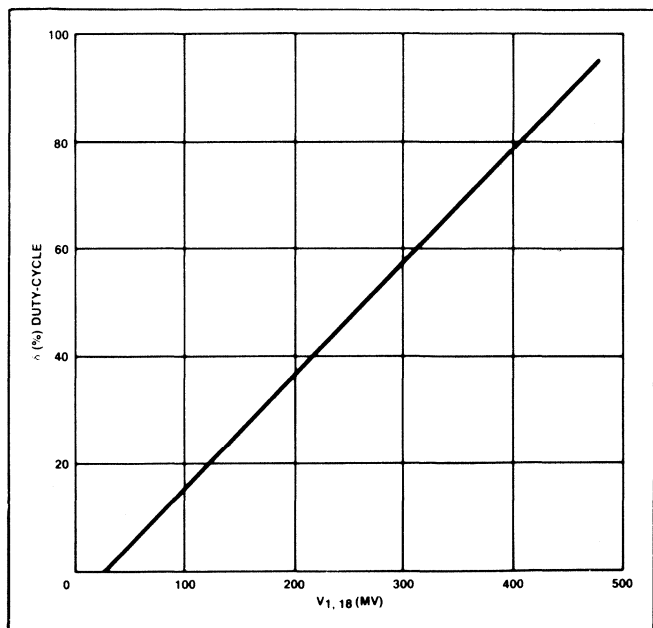
PWM output will remain low or go to zero duty cycle. The set input of the PWM flip-flop, Pin 15, is normally connected to the buffered sawtooth generator output, Pin 14, so that a reset pulse is provided every cycle. Each output transistor is driven by a three input NAND gate. These inputs consist of:

1. Pulse width information from the PWM input, Pin 11, which is used to control the off time of the output transistors. The PWM input is normally tied to the PWM output so that the output transistor's off time is a function of the error amplifier's input voltage.
2. Pulse-steering information from flip-flop two, which will determine which output transistor receives the PWM input signal. Flip-flop two will toggle once every cycle of the sawtooth generator's output, which will make the output transistor's toggle frequency one-half that of the sawtooth generator's.

- Information from dead-time and thermal shutdown circuitry. The dead-time is an externally adjustable time between one output transistor turning off and the other turning on. This is used to protect external circuitry. This dead-time is controlled by an external voltage applied to Pin 6, which is internally compared with the sawtooth waveform. The thermal shutdown circuitry will drive the input to the NAND gate low, if the junction temperature exceeds 130°C. This will make both outputs low.

The circuit control blocks and functions operate as follows:

**Error Amplifiers** — These are high-gain op amps which are used to sense output conditions, voltage and current, and provide a dc voltage to comparators one and two. This will in turn adjust the PWM output duty cycle and ultimately that of the output transistors to correct for errors in the output voltage or overcurrent conditions. The amplifier's outputs are provided for tailoring the closed-loop gain or frequency response of the system. Figure 2 shows the relationship between output duty cycle, Pins 11 and 12 connected, and the voltage at Pins 1 or 18. Amplifier two is approximately twice as fast as Amplifier one, and should, therefore, be used to sense output current.



**Figure 2. Modulation Duty Cycle vs Error Voltage**

**External Shutdown, Pin 13** — A low level signal applied to this pin will turn both outputs on. If not used, this input should be left open-circuited. The impedance at this node is approximately 1 MΩ.

**Oscillator Output, Pin 14** — This is an open-collector output which will be a square wave with a frequency set by the sawtooth generator. The duty cycle of this output will vary from 10 to 90%, and is a function of the dead-time setting. This pin is normally connected to Pin 15, set to provide reset pulses for the PWM flip-flop.

**Set, Pin 15** — This is the set input for the PWM flip-flop. A low-going signal at this pin will cause the flip-flop to be reset. The impedance at this pin is approximately 7.5 kΩ. This pin is normally connected to the oscillator output, Pin 14.

**PWM Out, Pin 12** — This is an open-collector output which provides a square wave with a duty cycle determined by the error amplifiers. This output is normally connected to PWM IN, Pin 11.

**PWM In, Pin 11** — This is the input which controls the duty cycle of the output transistors. A low level on this pin will drive both output transistors on. The impedance into this pin is approximately 7.5 kΩ.

**Output Transistors, Pins 9 and 10** — These pins provide the open-collector output transistors which are capable of sinking 30 mA, typically. They are alternately turned off, 180° out-of-phase, at a rate equal to one-half the frequency of the oscillator.

**F<sub>ADJ</sub>, Pin 7** — A resistor, R<sub>ext</sub> to +V<sub>CC</sub>, and a capacitor, C<sub>ext</sub>, to ground from this pin, set the frequency of the sawtooth and oscillator output, by the relationship:

$$f_{OSC} = \frac{2.68}{R_{ext} \times C_{ext}}$$



The sawtooth waveform, a signal varying from zero volts to +5V, will be present at Pin 7. Normal values of  $R_{EXT}$  will range from 1 k $\Omega$  to 100 k $\Omega$ . Figure 3 shows the oscillator period as a function of various  $R_{EXT}$  and  $C_{EXT}$  values.

The dead-time (minimum time from one output turning on to the other turning off) is controlled by the voltage applied to Pin 6.

**Dead-time Control, Pin 6** — Figure 4 shows output dead-time as a function of  $V_{PIN 6}$ . The maximum duty cycle of each output is also controlled by the dead-time, and may be determined by the following expression:

$$\text{Duty Cycle Max (\%)} = \left(1 - \frac{.35}{V_{PIN 6}}\right) \times 50\%$$

$$V_{PIN 6} < 3.5V$$

The impedance into this pin is approximately 10 k $\Omega$ .

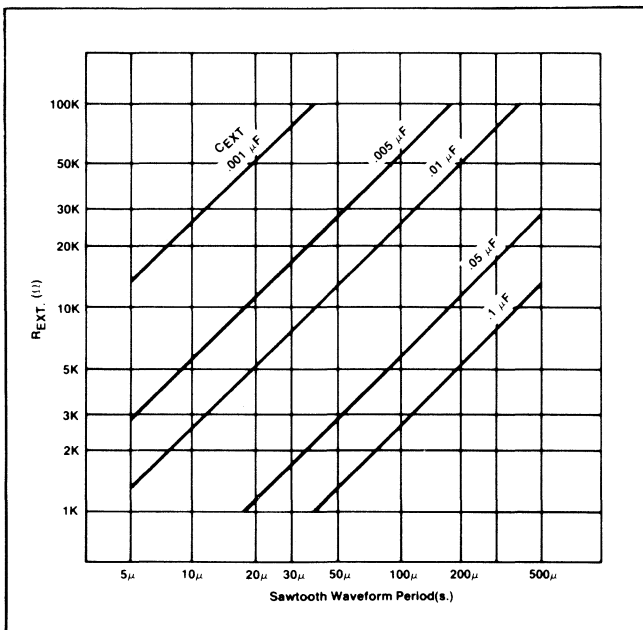


Figure 3. Oscillation Period vs  $R_{EXT}$  and  $C_{EXT}$

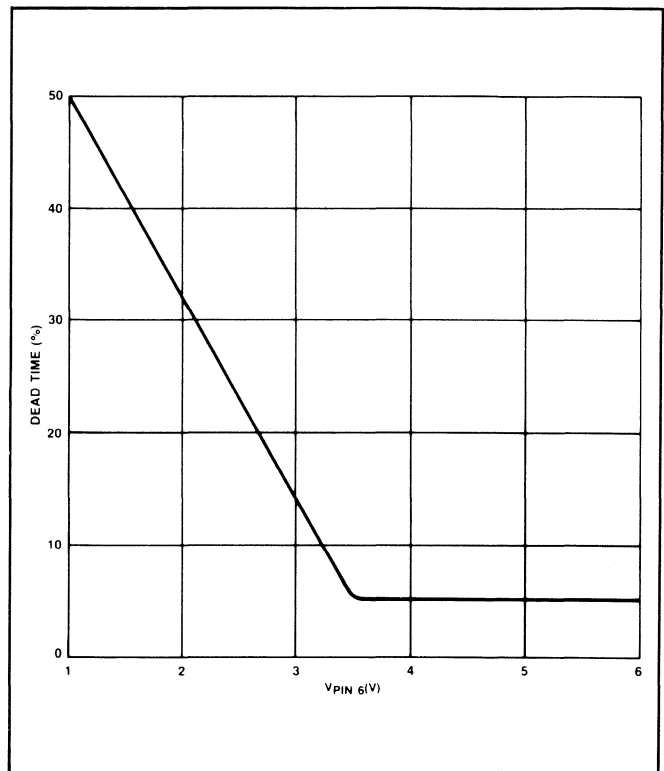
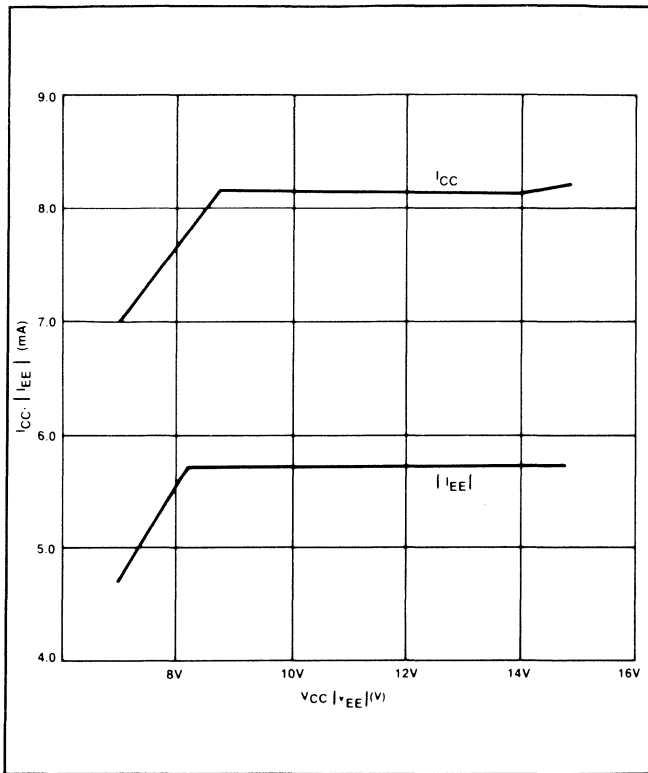


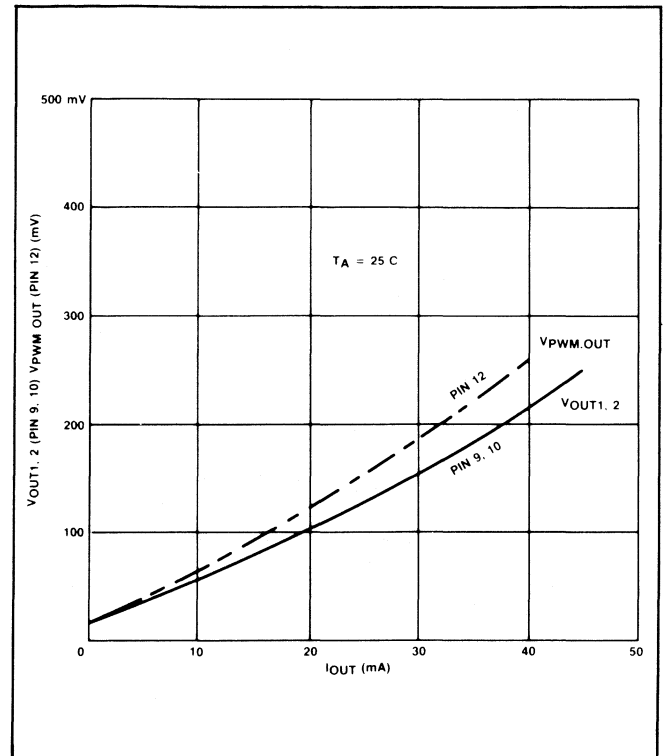
Figure 4. Dead Time vs Dead Time Adjustment Voltage

## RECOMMENDED OPERATING CONDITIONS

SYMBOL	PARAMETER	CONDITION	UNIT
$V_{CC}$	Positive Supply Voltage	+10 $\approx$ +15	V
$V_{EE}$	Negative Supply Voltage	-10 $\approx$ -15	V
$R_R$	Minimum Feedback Resistance	10	k $\Omega$
$A_V$	Minimum Voltage Gain	14 5	dB V/V



**Figure 5. Supply Current vs Supply Voltage**



**Figure 6. Output Saturation Voltage vs Load Current**

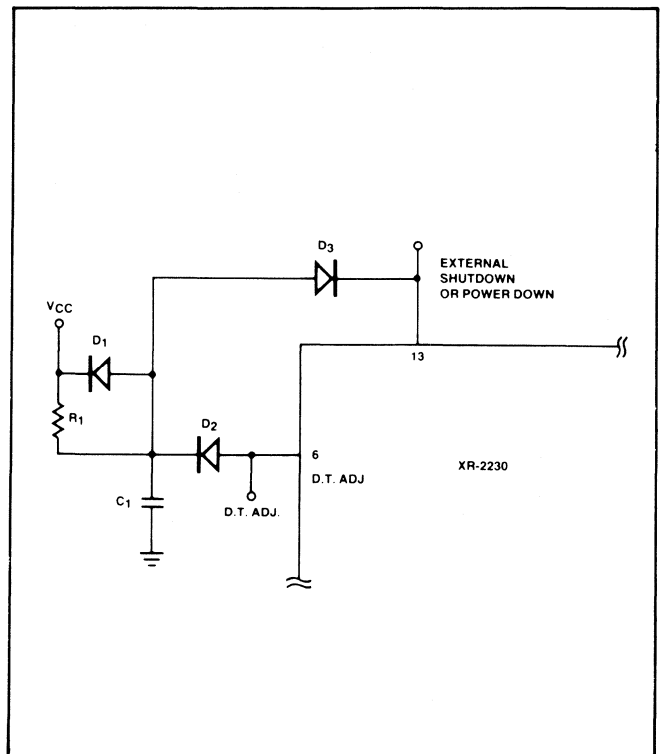
**APPLICATIONS INFORMATION**

The soft-start function may be implemented as shown in Figure 7. This configuration will reduce the output duty cycle to zero, and gradually increase to its normal operating point, whenever power is applied to the circuit, or after an external shutdown command has been given. This is used to keep the magnetics in the circuit from saturating.

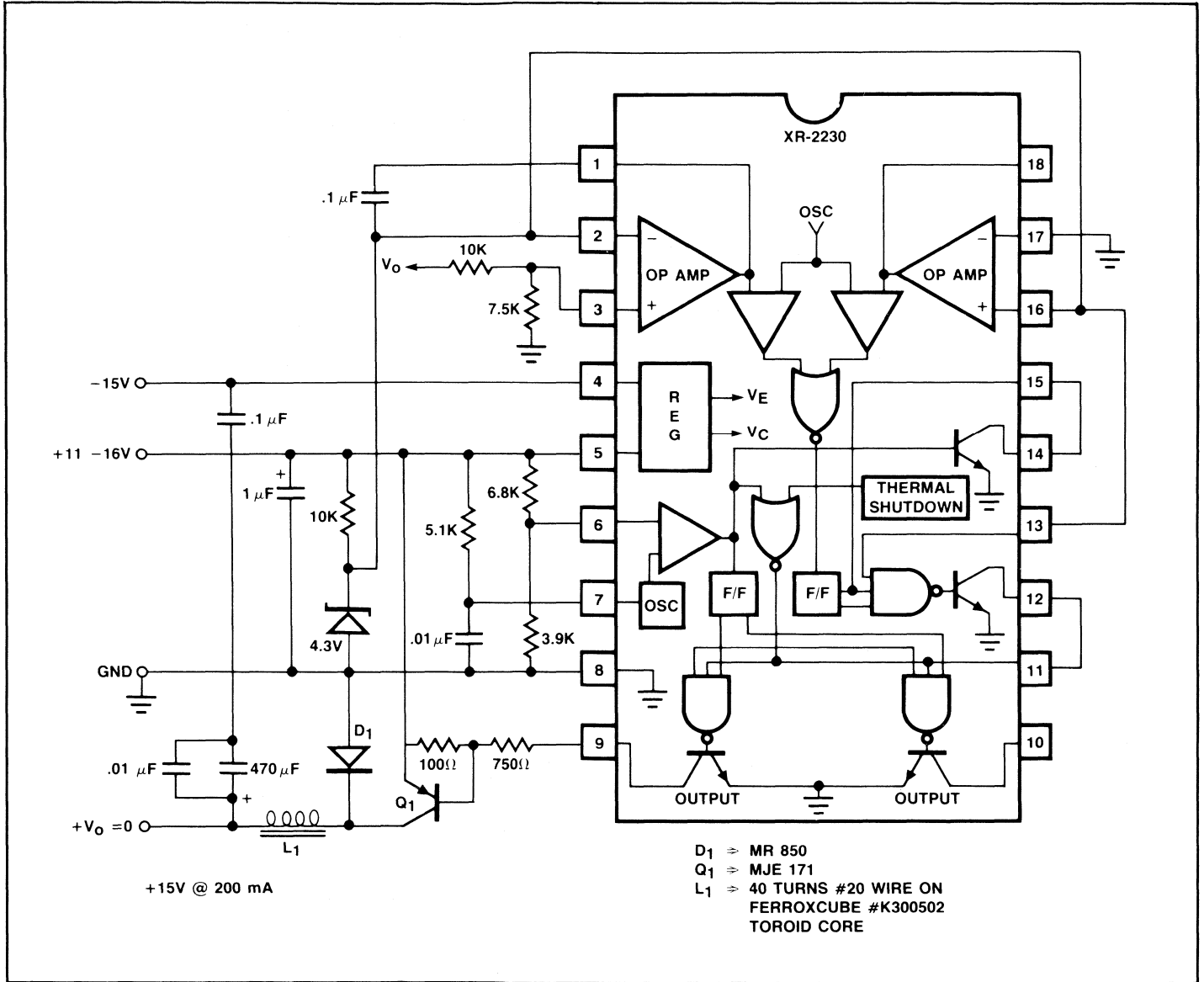
The time for the duty cycle to start will be approximately equal to  $R_1 \times C_1$ .

A typical step-down switching regulator configuration is shown in Figure 8. Only one output transistor is used, so that the maximum duty cycle will be limited to 45%. If a larger duty cycle range is needed, the two outputs may be externally NOR'd as shown in Figure 9. This configuration will allow up to 90% duty cycles.

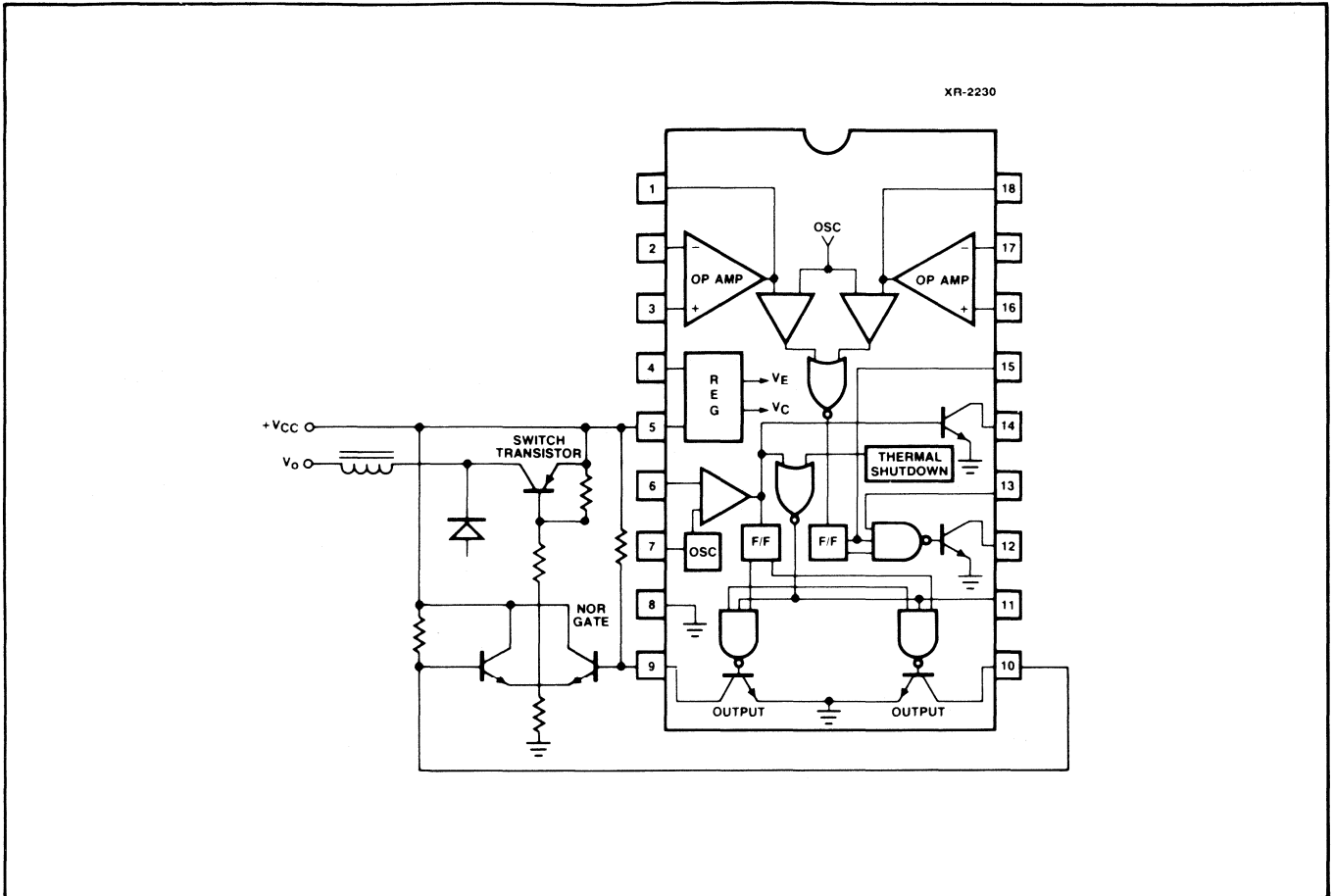
Figure 10 shows a detailed timing diagram of circuit operation.



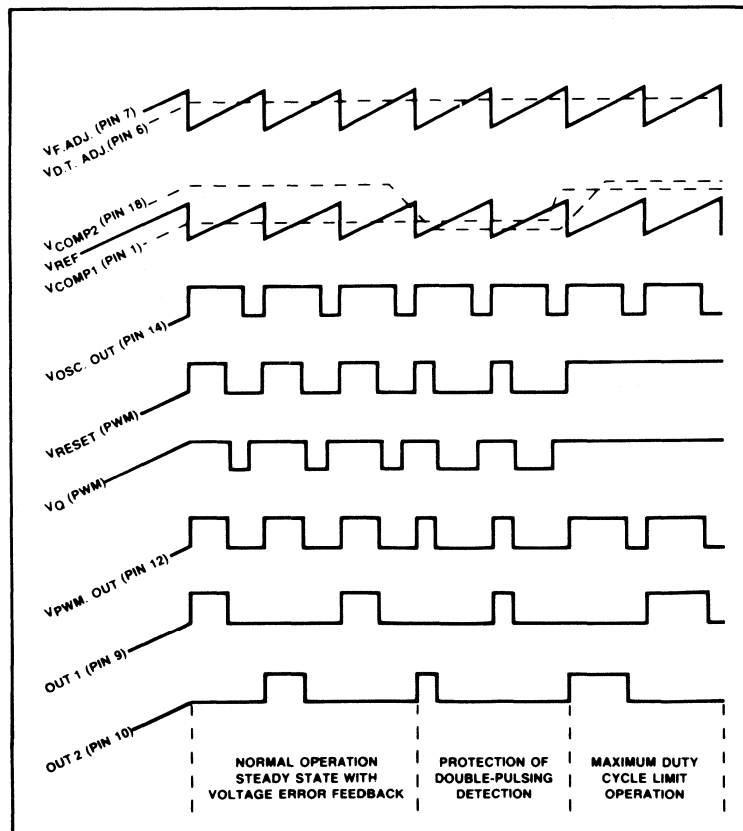
**Figure 7. Soft Start Connection**



**Figure 8: +10V Step-Down Regulator**



**Figure 9. Outputs Nor'd for up to 90% Duty Cycle's**



**Figure 10. Timing Waveform Diagram**

## Dual Tracking Voltage Regulators

### GENERAL DESCRIPTION

The XR-4194 is a dual polarity tracking regulator designed to provide balanced or unbalanced positive and negative output voltages at currents of up to 200 mA. A single resistor can be used to adjust both outputs between the limits of  $\pm 50$  mV and  $\pm 42$  V. The device is ideal for local on-card regulation, which eliminates the distribution problems associated with single-point regulation. The XR-4194 is available in a 14-pin ceramic dual-in-line package, which has a 900 mW rating.

### FEATURES

- Direct Replacement for RM/RC-4194
- Both Outputs Adjust with Single Resistor
- Load Current to  $\pm 200$  mA with 0.2% Load Regulation
- Low External Parts Count
- Internal Thermal Shutdown at  $T_J = 175^\circ\text{C}$
- External Adjustment for  $\pm V_O$  Unbalancing

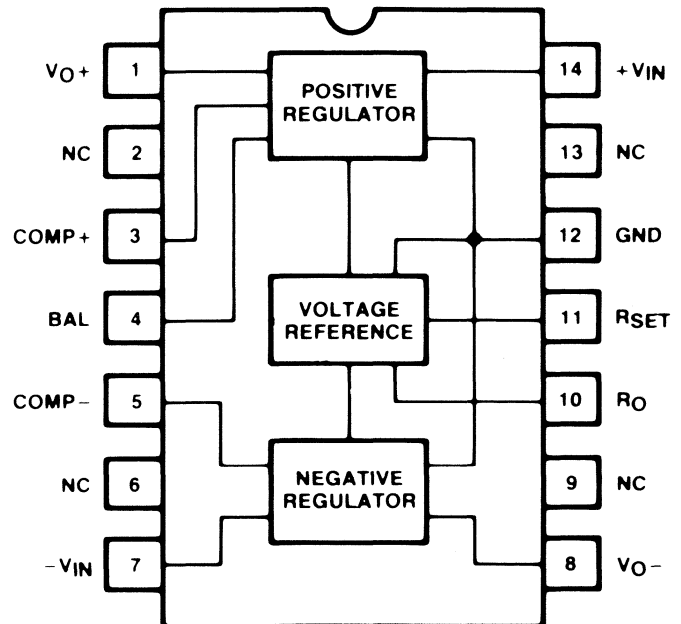
### APPLICATIONS

- On-Card Regulation in Analog and Digital Systems
- Main Regulation in Small Instruments
- Point-of-Load Precision Regulation

### ABSOLUTE MAXIMUM RATINGS

Input Voltage $\pm V$ to Ground	
XR-4194M	$\pm 45$ V
XR-4194CN	$\pm 35$ V
Input/Output Voltage Differential	$\pm 45$ V
Power Dissipation at $T_A = 25^\circ\text{C}$	900 mW
Load Current	150 mA
Operating Temperature Range	
XR-4194M	$-55^\circ\text{C}$ to $+150^\circ\text{C}$
XR-4194CN	$0^\circ\text{C}$ to $+125^\circ\text{C}$
Storage Temperature Range	$-65^\circ\text{C}$ to $+150^\circ\text{C}$

### FUNCTIONAL BLOCK DIAGRAM



### ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-4194M	Ceramic	$-55^\circ\text{C}$ to $+125^\circ\text{C}$
XR-4194CN	Ceramic	$0^\circ\text{C}$ to $+70^\circ\text{C}$

### SYSTEM DESCRIPTION

The XR-4194 is a dual polarity tracking voltage regulator. An on board reference, set by a single resistor, determines both output voltages. Tracking accuracy is better than 1%. Non-symmetrical output voltages are obtained by connecting a resistor to the balance adjust (Pin 4). Internal protection circuits include thermal shutdown and active current limiting.

## ELECTRICAL CHARACTERISTICS

Test Conditions:  $\pm 5 \leq V_{OUT} \leq V_{MAX}$ : XR-4194M  $-55^{\circ}\text{C} \leq T_J \leq +125^{\circ}\text{C}$ : XR-4194CN  $0^{\circ}\text{C} \leq T_J \leq +70^{\circ}\text{C}$

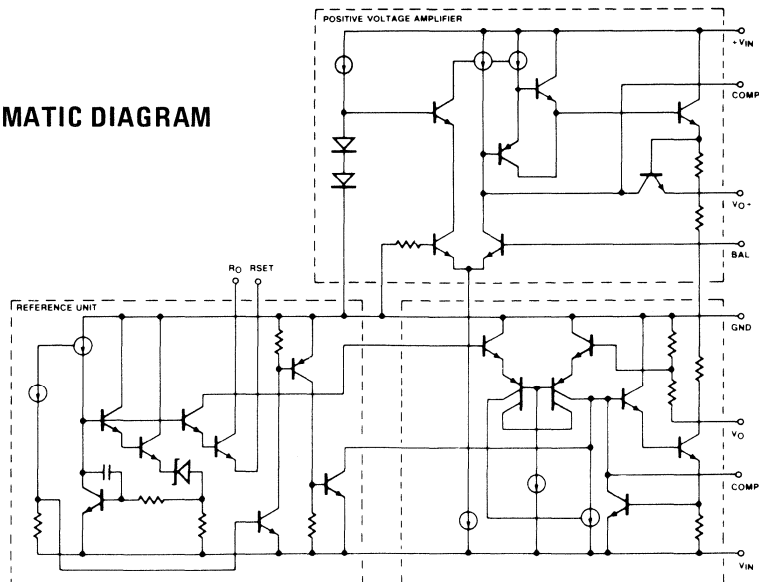
PARAMETERS	XR-4194M			XR-4194CN			UNIT	CONDITIONS
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.		
Line Regulation		0.02	0.1		0.02	0.1	% $V_{OUT}$	$\geq V_{IN} = 0.1 V_{IN}$ XR-4194CN, M: $I_L = 5$ to $100$ mA
Load Regulation		0.001	0.0025		0.001	0.004	% $V_O/mA$	
TC of Output Voltage		0.002	0.020		0.003	0.015	%/ $^{\circ}\text{C}$	$V_{IN} = V_{MAX}, V_O = 0V$
*Stand-by Current Drain from		+0.3	+1.0		+0.3	+1.5	mA	
to		-1.2	-2.0		-1.2	-2.0		$V_{IN} = V_{MAX}, V_O = 0V$
Input Voltage Range	$\pm 9.5$		$\pm 45$	$\pm 9.5$		$\pm 35$	V	$R_{SET} = 71.5$ K $T_J = 25^{\circ}\text{C}$ $R_{SET} = 71.5$ K
Output Voltage Scale Factor	2.45	2.5	2.55	2.38	2.5	2.62	K $\Omega/V$	
Output Voltage Range	0.05		+42	0.05		$\pm 35$	V	f - $120$ Hz, $T_J = 25^{\circ}\text{C}$
Output Voltage Tracking			1.0			2.0	%	
Ripple Rejection		70			70		dB	$I_L = 50$ mA $C_L = 4.7$ $\mu\text{F}$ , $V_O = \pm 15$ V f = $10$ Hz to $100$ kHz
Input-Output Voltage Diff.	3.0			3.0			V	
Output Noise Voltage		250			250		$\mu\text{V RMS}$	
Internal Thermal Shutdown		175			175		$^{\circ}\text{C}$	
Internal Thermal								

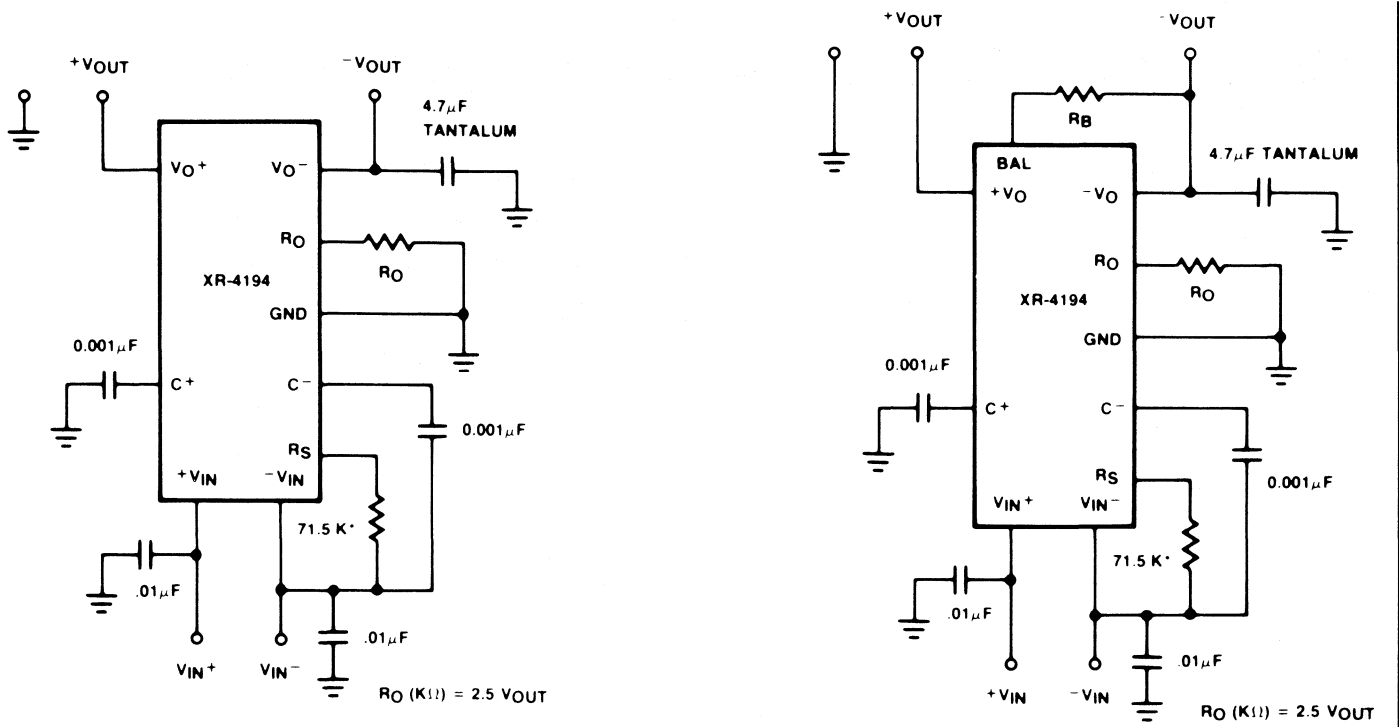
\* $\pm I_{Quiescent}$  will increase by  $50 \mu\text{A}/V_{OUT}$  on positive side and  $100 \mu\text{A}/V_{OUT}$  on negative side.

## THERMAL CHARACTERISTICS

PARAMETERS	XR-4194M			XR-4194CN			CONDITIONS
	MIN	TYP	MAX	MIN	TYP	MAX	
Power Dissipation			900 mW			900 mW	$T_A = 25^{\circ}\text{C}$
Thermal Resistance			2.2 W			2.2 W	
Junction to Ambient		128 $^{\circ}\text{C/W}$			128 $^{\circ}\text{C/W}$		
Junction to Case		55 $^{\circ}\text{C/W}$			55 $^{\circ}\text{C/W}$		

## EQUIVALENT SCHEMATIC DIAGRAM





\* For Best Tracking Temperature Coefficient of  $R_O$  Should Be Same As For  $R_S$

Adjust  $R_O$  for  $V_S = 6\text{ V}$  (15 K!) then  
Adjust  $R_B$  for  $V_S = 12\text{ V}$  (20 K!)

**Figure 1. Typical Applications**

# ±15V Dual-Tracking Voltage Regulator

## GENERAL DESCRIPTION

The XR-4195 is a dual-polarity tracking regulator designed to provide balanced positive and negative 15V output voltages at currents of up to 100 mA.

The device is ideal for local "on-card" regulation, which eliminates the distribution problems associated with single-point regulation. Intended for ease of application, the XR-4195 requires only two external components for operation.

## FEATURES

- Direct Replacement for RM/RC-4195
- ± 15V Operational Amplifier Power
- Thermal Shutdown at  $T_J = 175^{\circ}\text{C}$
- Output Currents to 100 mA
- Available in 8-Pin Plastic Mini-DIP
- Low External Parts Count

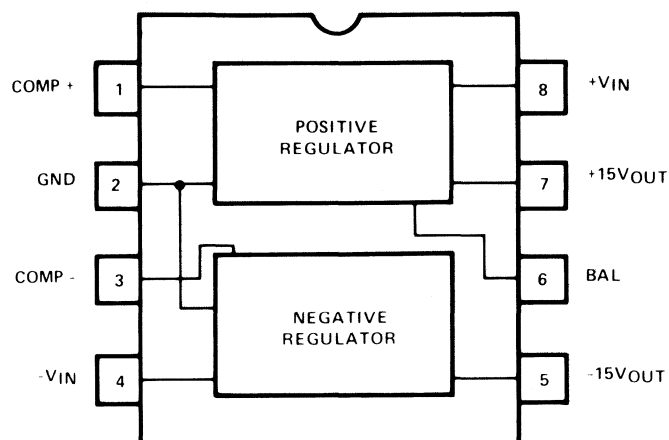
## APPLICATIONS

- Operational Amplifier Supply
- On-Card Regulation
- Regulating High Voltage

## ABSOLUTE MAXIMUM RATINGS

Input Voltage $\pm V$ to Ground	±30V
Power Dissipation at $T_A = 25^{\circ}\text{C}$	600 mW
Load Current	100 mA
Operating Temperature Range	0°C to +125°C
Storage Temperature Range	-65°C to +150°C

## FUNCTIONAL BLOCK DIAGRAM



## ORDERING INFORMATION

Part Number	Package	Operating Temperature
XR-4195CP	Plastic	0°C to +70°C

## SYSTEM DESCRIPTION

The XR-4195 is a dual polarity tracking voltage regulator, internally trimmed to ±15V. Only output capacitors are required for operation. Internal protection circuits include thermal shutdown and active current limiting. The device may be configured as a signal output high voltage regulator by adding a voltage divider between an output pin, the device ground (Pin 2) and system ground.



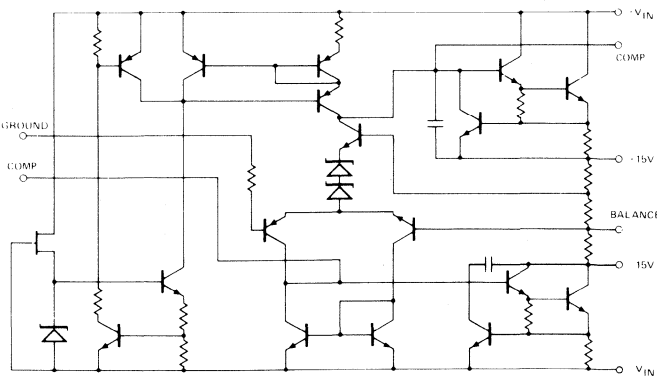
## ELECTRICAL CHARACTERISTICS

Test Conditions:  $I_L = 1 \text{ mA}$ ,  $V_{CC} = \pm 20\text{V}$ ,  $C_L = 10 \mu\text{F}$  unless otherwise specified.

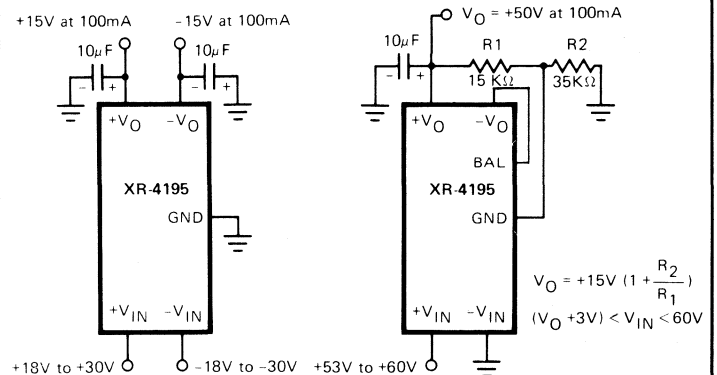
PARAMETERS	MIN	TYP	MAX	UNIT	CONDITIONS
Line Regulation		2	20	mV	$V_{IN} = \pm 18 \text{ to } \pm 30\text{V}$
Load Regulation		5	30	mV	$I_L = 1 \text{ to } 100 \text{ mA}$
Output Voltage Temperature Stability		0.005	0.015	$\%/^{\circ}\text{C}$	
Standby Current Drain		$\pm 1.5$	$\pm 3.0$	mA	$V_{IN} = \pm 30\text{V}$ , $I_L = 0\text{mA}$
Input Voltage Range	18		30	V	
Output Voltage	14.5	15	15.5	V	$T_i = +25^{\circ}\text{C}$
Output Voltage Tracking		$\pm 50$	$\pm 300$	mA	
Ripple Rejection		75			$f = 120 \text{ Hz}$ , $T_i = +25^{\circ}\text{C}$
Input-Output Voltage Differential	3			V	$I_L = 50 \text{ mA}$
Short-Circuit Current		220		mA	$T_i = +25^{\circ}\text{C}$
Output Noise Voltage		60		$\mu\text{V RMS}$	$T_i = +25^{\circ}\text{C}$
Internal Thermal Shutdown		175		$^{\circ}\text{C}$	$f = 100 \text{ Hz to } 100 \text{ kHz}$

## THERMAL CHARACTERISTICS

PARAMETERS	XR-4195CP			CONDITIONS
	MIN.	TYP.	MAX.	
Power Dissipation			0.6W	$T_A = 25^{\circ}\text{C}$
Thermal Resistance		$210^{\circ}\text{C/W}$		$T_C = 25^{\circ}\text{C}$ $\theta_{J-C}$ $\theta_{J-A}$



EQUIVALENT SCHEMATIC DIAGRAM



Balanced Output

Positive Single Supply

TYPICAL APPLICATIONS

**ALABAMA**

Marshall Electronics  
3313 Office Center, Ste. 106  
Huntsville, AL 35801  
205 881-9235

Pioneer  
1207 Putnam Drive  
Huntsville, AL 35805  
205 837-9300

Resisticap  
11547-B So. Memorial Pkwy.  
Huntsville, AL 35815-0889  
205 883-4270

RM Electronics  
4702 Governors Drive  
Huntsville, AL 35805  
205 883-4270

**ARIZONA**

Bell Industries  
1705 W. 4th Street  
Tempe, AZ 85281  
602 966-7800  
TWX: 910-950-0133

Marshall Electronics  
835 West 22nd Street  
Tempe, AZ 85282  
602 968-6181

Sterling Electric  
3501 E. Broadway Road  
Phoenix, AZ 85040  
602 268-2121  
TLX: 667317 "STERLING PHX"

Western Micro  
7740 East Redfield Drive  
Scottsdale, AZ 85260  
602 948-4240

**ARKANSAS**

Carlton-Bates  
3600 West 69th Street  
Little Rock, AR 72219  
501 562-9100

**CALIFORNIA**

A.V.E.D.  
1582 Parkway Loop, Unit G  
Tustin, CA 92680  
213 770-0871

Bell Industries  
1-830 Vernon St., Bldg. 1  
Roseville, CA 95678  
916 969-3100

Bell Industries  
1161 N. Fair Oaks Avenue  
Sunnyvale, CA 94086  
408 734-8570  
TWX: 910-339-9378

Bell Industries  
7450 Ronson Road  
San Diego, CA 92111  
619 268-1277

Diplomat  
20151 Bahama Street  
Chatworth, CA 91311  
213 341-4411

Diplomat  
7140 McCormick  
Costa Mesa, CA 92626  
714 549-8401

Diplomat  
9787 Aero Drive, Ste. E  
San Diego, CA 92123  
619 292-5693

Diplomat  
1283 "F" Mtn. View/Alviso Rd.  
Sunnyvale, CA 94086  
408 734-1900  
TWX: 910-379-0006

IEC/JACO  
20600 Plummer Road  
Chatsworth, CA 91311  
213 998-2200  
TWX: 910-494-1923

IEC/JACO  
17062 Murphy  
Irvine, CA 92714  
714 660-1055

Marshall Electronics  
8015 Deering Avenue  
Canoga Park, CA 91304  
818 999-5001

Marshall Electronics  
9674 Telstar Avenue  
El Monte, CA 91731-3004  
818 442-7204

Marshall Electronics  
17321 Murphy Avenue  
Irvine, CA 92714  
714 556-6400

Marshall Electronics  
10105 Carroll Canyon Rd.  
San Diego, CA 92131  
619 478-9600

Marshall Electronics  
788 Palomar Avenue  
Sunnyvale, CA 94086  
408 732-1100

Western Microtechnology  
10040 Bubb Road  
Cupertino, CA 95104  
408 725-1664

Zeus Components, Inc.  
1130 Hawk Circle  
Anaheim, CA 92807  
714 632-6880

**COLORADO**

A.C.T.  
4016 Youngfield Street  
Wheatridge, CO 80033  
303 422-9229

Bell Industries  
8155 West 48th Avenue  
Wheatridge, CO 80033  
303 424-1985  
TWX: 910-938-0393

Diplomat Electronics  
96 Inverness Drive, East  
Suite R  
Englewood, CO 80112  
303 740-8300

Marshall Electronics  
7000 North Broadway  
Denver, CO 80221  
303 427-1818

**CONNECTICUT**

Diplomat Electronics  
52 Federal Road  
Danbury, CT 06810  
203 797-9674

J.V. Electronics  
690 Main Street  
East Haven, CT 06512  
203 469-2321

Marshall Electronics  
Barnes Industrial Park  
20 Sterling Drive  
P.O. Box 200  
Wallingford, CT 06492  
203 265-3822

**DELAWARE**

(See Pennsylvania)

**FLORIDA**

Diplomat Electronics  
2120 Calumet Street  
Clearwater, FL 33515  
813 443-4514

Diplomat Electronics  
1300 N.W. 65th Place  
Fort Lauderdale, FL 33309  
305 974-8700

Future Electronics  
2073 Range Road  
Clearwater, FL 33575  
813 596-8295

Hammond Electronics  
6600 N.W. 21st Avenue  
Fort Lauderdale, FL 33309  
305 973-7103

Hammond Electronics  
1230 W. Central Boulevard  
Orlando, FL 32805  
305 849-6060

Marshall Electronics  
1101 N.W. 62nd Street  
Suite 306D  
Fort Lauderdale, FL 33309  
305 928-0661

Marshall Electronics  
4205 34th Street, S.W.  
305 841-1878

**GEORGIA**

Diplomat Electronics  
6659 Peachtree, Suite B  
Norcross, GA 30092  
404 449-4133

Marshall Electronics  
4350 J International Blvd.  
Norcross, GA 30093  
404 923-5750

Pan American  
889 Buford Road  
Comming, GA 30130  
404 577-2144

**IDAHO**

(See Washington)

**ILLINOIS**

Diplomat Electronics  
1071 Judson Street  
Bensenville, IL 60160  
312 595-1000

GBL-Gould  
610 Bonnie Lane  
Elk Grove Village, IL 60007  
312 490-0155

Marshall Electronics  
1261 Wiley Road, Unit F  
Schaumburg, IL 60195  
312 490-0155

Intercomp  
2200 Stongton Ave., Suite 21  
Hoffman Estates, IL 60695  
312 843-2040

Repron  
721 W. Algonquin Road  
Arlington Heights, IL 60005  
312 593-7070

RM Electronics  
180 Crossen  
Elk Grove Village, IL 60007  
312 932-5150  
TWX: 910-651-3245

**INDIANA**

Altex  
12774 N. Meridian  
Carmel, IN 46032  
317 848-1323  
TWX: 810-341-3481

Graham Electronics  
133 S. Pennsylvania Street  
Indianapolis, IN 46204  
317 634-8202  
TWX: 810-341-3481

Graham Electronics  
3606 E. Maunee Avenue  
Fort Wayne, IN 46803  
219 423-3422

RM Electronics  
7031 Corporate Circle Dr.  
Indianapolis, IN 46278  
317 291-7110

**IOWA**

Bell Industries  
1221 Park Place, N.E.  
Cedar Rapids, IA 52412  
319 395-0730

Deeco, Inc.  
2500 16th Avenue, S.W.  
Cedar Rapids, IA 52406  
319 365-7551  
TWX: 910-525-1331

**KANSAS**

(See Missouri)

**KENTUCKY**

(See Indiana)

**LOUISIANA**

(See Texas)

**MAINE**

(See Massachusetts)

**MARYLAND**

Diplomat Electronics  
9150 Rumsey Rd., Ste. A-6  
Columbia, MD 20877  
301 995-1226

Marshall Electronics  
8445 Helgerman Court  
Gaithersburg, MD 20877  
301 840-9450

Pioneer  
9100 Gaither Road  
Gaithersburg, MD 20760  
301 948-0710  
TWX: 710-828-0545

**MASSACHUSETTS**  
Almo Electronics  
60 Shawmut Avenue  
Canton, MA 02021  
617 329-8810

Diplomat Electronics  
28 Comming Park  
Woburn, MA 01801  
617 329-8810

Gerber  
128 Carnegie Row  
Norwood, MA 02062  
617 329-2400  
TWX: 710-336-1987

Marshall Electronics  
One Wilshire Road  
Burlington, MA 01803  
617 272-8200

RC Components  
222 Andover Street  
Wilmington, MA 01887  
617 657-4310  
TWX: 710-347-1743

**MICHIGAN**  
Ambur Electronics  
1344 So. Commerce  
Walled Lake, MI 48088  
313 669-3710

Marshall Electronics  
13760 Merriman Road  
Livonia, MI 48150  
313 525-5850

RM Electronics  
4310 R.B. Chaffee Memorial Drive  
Grand Rapids, MI 49508  
616 531-9300  
TWX: 810-273-8779

Reptron Electronics  
34404 Glendale Road  
Livonia, MI 48150  
313 525-2700

**MINNESOTA**  
Marshall Electronics  
13810 24th Ave., NS No. 460  
Plymouth, MN 55441  
612 559-2211

Merit Electronics  
2525 Nevada Avenue  
Warehouse Suite 210  
Minneapolis, MN 55427  
612 546-5383

**MISSISSIPPI**  
(See Alabama)

**MISSOURI**  
Olive Electronics  
9910 Page Boulevard  
St. Louis, MO 63132  
314 426-4500  
TWX: 910-763-0720

**MONTANA**  
(Call EXAR Direct)

**NEBRASKA**  
(See Missouri)

**NEVADA**  
(See California)

**NEW HAMPSHIRE**  
(See Massachusetts)

**NEW JERSEY**  
Diplomat Electronics  
490 S. River View Drive  
Totowa, NJ 07512  
201 785-1830

GCI  
Route 73  
Berlin, NJ 08009  
609 768-6767

Marshall Electronics  
101 Fairfield Road  
Fairfield, NJ 07006  
201 882-0320

Marshall Electronics  
102 Gaither Drive  
Mt. Laurel, NJ 08054  
609 234-9100 (NJ)  
215 627-1920 (PA)

**NEW MEXICO**  
Bell Industries  
11728 Linn N.E.  
Albuquerque, NM 87123  
505 292-2700  
TWX: 910-989-0625

Betatron  
2825 B Broadbent Pkwy., N.E.  
Albuquerque, NM 87123  
505 344-2318

**NEW YORK**  
Diplomat Electronics  
4610 Wetzell Road  
Liverpool, NY 13088  
315 652-5000

Diplomat Electronics  
110 Marcus Drive  
Melville, NY 11747  
516 454-6400

JACO  
145 Oser Avenue  
Hauppauge, NY 11787  
516 273-5500  
TWX: 510-227-6232

Marshall Electronics  
10 Hooper Road  
Endwell, NY 13760  
607 754-1570

Marshall Electronics  
275 Oser Avenue  
Hauppauge, LI, NY 11788  
516 273-2424

Marshall Electronics  
1280 Scottsville Road  
Rochester, NY 14624  
716 235-7620

S.A.I.  
564 Smith Street  
Farmingdale, NY 11735  
516 293-2710

Zeus Components Inc.  
100 Midland Avenue  
Poartchester, NY 10573  
914 937-7400  
TWX: 710-567-1248

**NORTH CAROLINA**  
Hammond  
2923 Pacific Avenue  
Greensboro, NC 27406  
919 275-6391

**NORTH DAKOTA**  
(Call EXAR Direct)

**OHIO**  
Graham  
239 Northland Boulevard  
Cincinnati, OH 45246  
513 772-1661  
TWX: 810-461-2896

Marshall Electronics  
6212 Executive Boulevard  
Dayton, OH 45424  
513 236-8088

Marshall Electronics  
5905B Harper Road  
Solon, OH 44139  
216 248-1788

Reptron Electronics  
830 Busch Court  
Columbus, OH 43229  
614 436-6675

**OKLAHOMA**  
Quality Components  
9934 E. 21st Street, S.  
Tulsa, OK 74128  
918 664-8812

Radio, Inc.  
1000 S. Main Street  
Tulsa, OK 74119  
918 587-9123

**OREGON**  
Bell Industries  
6024 S.W. Jean Road  
Lake Oswego, OR 97034  
503 241-4115  
TWX: 910-455-8177

Marshall Electronics  
8230 S.W. Nimbus Avenue  
Beaverton, OR 97005  
503 644-5050

Radar Electric Co., Inc.  
704 S.E. Washington  
Portland, OR 97214  
503 232-3404  
TWX: 910-464-2386

Western Microtechnology  
13770 S.W. 24th Street  
Beaverton, OR 97005  
503 641-9312

**PENNSYLVANIA**  
Advacom  
5620 West Road  
McKean, PA 16426  
814 476-7774

Almo Electronics  
9815 G Roosevelt Boulevard  
Philadelphia, PA 19114  
215 698-4000

Pioneer  
261 Gilbralter Road  
Horsham, PA 19044  
215 674-4000  
TWX: 510-665-6778

**RHODE ISLAND**  
(See Massachusetts)

**SOUTH CAROLINA**  
Hammond Electronics  
1035 Lowndes Hill Road  
Greenville, SC 29607  
803 233-4121

**SOUTH DAKOTA**  
(Call EXAR Direct)

**TENNESSEE**  
(See Alabama)

**TEXAS**  
ERA  
1147-B Larry Mahan  
El Paso, TX 79925  
915 592-4126

International Electronics  
10937 Pellicano Drive  
El Paso, TX 79935  
915 598-3406

Marshall Electronics  
8705 Shoal Creek Blvd.  
Suite 202  
Austin, TX 78758  
512 458-5654

Marshall Electronics  
14205 Proton Road  
Dallas, TX 75234  
214 233-5200

Marshall Electronics  
3698 Westchase Drive  
Houston, TX 77042  
713 789-6600

Quality Components  
4257 Kellway Circle  
Addison, TX 75001  
214 387-4949  
TWX: 910-860-5459

Quality Components  
1005 Industrial Blvd.  
Sugarland, TX 77478  
713 491-2255  
TWX: 910-880-4893

**UTAH**  
Bell Industries  
3639 W. 2150 South  
Salt Lake City, UT 84120  
801 972-6969  
TWX: 910-925-5686

Diplomat  
3007 S.W. Temple  
Salt Lake City, UT 84115  
801 486-4134

**VERMONT**  
(See Massachusetts)

**VIRGINIA**  
(See Maryland)

**WASHINGTON**  
Bell Industries  
1900 132nd Avenue, N.E.  
Bellevue, WA 98005  
206 747-1515

IEC/JACO  
1750 124th Avenue, Ste. J  
Bellevue, WA 98005

Marshall Electronics  
14102 N.E. 21st Street  
Bellevue, WA 98007  
206 747-9100

Radar Electric Co., Inc.  
168 Western Avenue, W.  
Seattle, WA 98119  
206 282-2511  
TWX: 910-444-2052

Western Microtechnology  
14778 N.E. 95th Avenue  
Redmond, WA 98052  
206 881-6737

### WISCONSIN

Bell Industries  
W 227 N 913 W. Mound Avenue  
Waukesha, WI 53186  
414 547-8879

RM Electronics, Inc.  
2626 S. 162nd Street  
Berlin, WI 53151  
414 784-4420

Taylor Electric Co.  
1000 W. Donges Bay Road  
Mequon, WI 53092  
414 241-4321  
TWX: 910-262-3414

### WYOMING

(See Colorado)

### CANADA

Cam Guard Supply Ltd.  
1777 Ellice Avenue  
Winnipeg, Manitoba R3H 0W5  
504 786-8401

Cam Guard Supply Ltd.  
2055 Boundary Road  
Vancouver, British Columbia V5M 3L2  
604 291-1441

Cam Guard Supply Ltd.  
162 - 36 116th Avenue  
Edmonton, Alberta T5M 3V4  
403 453-6693

Cam Guard Supply Ltd.  
1501 Ontario Avenue  
Sashotton, Saskatchewan S7K 1S7

Cam Guard Supply Ltd.  
500 Norfinch Drive  
Downsview, Ontario M34 1V4  
416 736-1744

Future Electronics  
237 Humus Boulevard  
Pt. Claire, Montreal  
Quebec H9R 5C7  
514 694-7710

Intek Electronics Ltd.  
10-8385 St. George Street  
Vancouver, British Columbia V5X 4P3  
604 324-6831  
TWX: 610-922-5032

Intek Electronics Ltd.  
4616 99th Street  
Edmonton, Alberta T6E 5H5  
403 437-2755

L.A. Varah  
504 A Iroquois Shore Drive  
Oakville, Ontario L6H 3K4  
416 842-8484  
TWX: 06-982397

R.A.E. Industrial Electronics  
3455 Gardner Court  
Burnaby, British Columbia V5G 4J7  
604 291-8866  
TWX: 610-929-3065

**ALABAMA**

Rep Incorporated  
11535 Gilleland Rd./PO Box 4889  
Huntsville, AL 35803/35815  
(205) 881-9270  
TWX 810-726-2102

**ALASKA**

(Call EXAR Direct)

**ARIZONA**

Summit Sales  
7825 E. Redfield Road  
Scottsdale, AZ 85260  
(602) 998-4850  
TWX 920-950-1283

**ARKANSAS**

(See Oklahoma)

**CALIFORNIA (No.)**

Criterion  
3350 Scott Blvd., Bldg. 44  
Santa Clara, CA 95051  
(408) 988-6300  
TWX 910-338-7352

**CALIFORNIA (So.)**

Harvey King, Inc.  
8124 Miramar Road  
San Diego, CA 92126  
(619) 556-5252

Landa/Minyard, Inc.  
1618 Cotner Avenue  
Los Angeles, CA 90025  
(213) 879-0770  
TWX 910-342-6343

Landa/Minyard, Inc.  
1616 East 4th Street, Ste. 280  
Santa Ana, CA 92701  
(714) 543-7805

**COLORADO**

Candal Inc.  
1536 Cole Blvd., Ste. 145  
Golden, CO 80401  
(303) 233-0155  
TLX 703771 CANDAL UD

**CONNECTICUT**

Phoenix Sales  
386 Main Street  
Ridgefield, CT 06877  
(203) 438-9644  
TWX 710-467-0662

**DELAWARE**

(See Maryland)

**FLORIDA**

Donato & Assoc., Inc.  
5401 Kirkman Rd., Ste. 785  
Orlando, FL 32819  
(305) 352-0727  
TWX 810-850-0244

Donato & Assoc., Inc.  
535 Hollow Ridge Rd./PO Box 1560  
Palm Harbor, FL 33563  
(813) 785-3327

**GEORGIA**

Rep Incorporated  
1044 Cooleedge Road  
Tucker, GA 30084  
(404) 938-4358  
TWX 810-766-0822

**HAWAII**

(Call EXAR Direct)

**ILLINOIS (No.)**

Janus, Inc.  
3166 Des Plaines Ave., Ste. 14  
Des Plaines, IL 60018  
(312) 298-9330  
TWX 910-692-4024

**ILLINOIS (So.)**

(See Missouri)

**INDIANA**

(See Ohio)

**IOWA**

(Call EXAR Direct)

**KANSAS**

(See Missouri)

**KENTUCKY**

(See Ohio)

**LOUISIANA**

(See Texas)

**MAINE**

(See Massachusetts)

**MARYLAND**

Component Sales  
106 Old Court Rd., Ste 204  
Baltimore, MD 21208  
(301) 484-3647  
TWX 710-862-0852

**MASSACHUSETTS**

Mass Tech Sales  
54 Hartford St., Ste. 102  
Westwood, MA 02090  
(617) 329-8820  
TWX 710-321-9335

**MICHIGAN (Detroit Area)**

J.L. Montgomery Assoc., Inc.  
27200 Lahser Rd./PO Box 244  
Southfield, MI 48037  
(313) 358-2616  
TWX 810-224-4981

**(Western Michigan Area)**

J.L. Montgomery Assoc., Inc.  
2214 Oak Industrial Dr., NE  
Grand Rapids, MI 49505  
(616) 774-9308

**MINNESOTA**

Dan'l Engineering  
1631 East 79th St., Ste. S145  
Minneapolis, MN 55420  
(612) 854-7550  
TLX 291008 DANL ENG BLTN

**MISSISSIPPI**

(See Alabama)

**MISSOURI**

KKB and Company  
1610 S. Big Band Blvd.  
St. Louis, MO 63117  
(314) 647-2400  
TWX 910-761-1040

KKG and Company  
104 North 12th  
Blue Springs, MO 64015  
(816) 229-0001  
TWX 910-997-0718

**MONTANA**

(See Colorado)

**NEBRASKA**

(See Missouri)

**NEVADA**

(See California No.)

**NEW HAMPSHIRE**

(See Massachusetts)

**NEW JERSEY (No.)**

(See New York City)

**NEW JERSEY (So.)**

Vantage Sales Co.  
6981 North Park Dr., Ste. 110  
Pennsauken, NJ 08109  
(609) 663-6660  
TWX 710-892-0107

**NEW MEXICO**

Syn Tech  
8016 A Zuni Rd., SE  
Albuquerque, NM 87108  
(505) 266-7951

**NEW YORK (Upstate)**

Quality Components  
3343 Harlem Road  
Buffalo, NY 14225  
(716) 837-5430  
TWX 910-997-1313

Quality Components  
116 E. Fayette Street  
Manlius, NY 13104  
(315) 682-8885

**NEW YORK (City)**

Trionic Assoc., Inc.  
320 Northern Blvd.  
Great Neck, NY 11021  
(516) 466-2300  
TWX 510-223-0834

**NORTH CAROLINA**

Zucker Assoc., Inc.  
PO Box 19868  
Raleigh, NC 27619  
(919) 782-8433  
TWX 510-928-0513

**NORTH DAKOTA**

(See Minnesota)

**OHIO**

McFadden Sales  
1093 Fishinger Road  
Columbus, OH 43221  
(614) 459-1280  
TWX 810-482-1623

**OKLAHOMA**

(See Texas)

**OREGON**

Components West, Inc.  
15255 SW & 2nd Ave., Ste. A  
Tigard, OR 97223  
(503) 684-1671  
TWX 910-467-8740

**PENNSYLVANIA (West)**

(See Ohio)

**PENNSYLVANIA (East)**

(See New Jersey So.)

**RHODE ISLAND**

(See Massachusetts)

**SOUTH CAROLINA**

(See North Carolina)

**SOUTH DAKOTA**

(See Minnesota)

**TENNESSEE (West)**

Rep Incorporated  
113 S. Branner Avenue  
Jefferson City, TN 37760  
(615) 475-4105  
TWX 810-570-4203

**TENNESSEE (East)**

(See North Carolina)

**TEXAS**

Technical Marketing  
9027 Northgate Blvd., Ste. 140  
Austin, TX 78758  
(512) 835-0064

Technical Marketing  
3320 Wiley Post Road  
Carrollton, TX 75006  
(214) 387-8601  
TWX 910-860-5158

Technical Marketing  
2901 Wilcrest Drive  
Houston, TX 77042  
(713) 783-4497

**UTAH**

(See Colorado)

**VERMONT**

(See Massachusetts)

**VIRGINIA**

(See Maryland)

**WASHINGTON**

Components West Inc.  
311-1 Shoreline Drive  
Liberty Lake, WA 99019  
(509) 255-6224

Components West Inc.  
8275 166th NE  
Redmond, WA 98052  
(206) 885-5880

**WASHINGTON D.C.**

(See Maryland)

**WEST VIRGINIA**

(See Ohio)

**WISCONSIN (So. East)**

Janus, Inc.  
11430 Bluemound Road  
Milwaukee, WI 53026  
(414) 476-9104

**WISCONSIN (West)**

(See Minnesota)

**WYOMING**

(See Colorado)

**CANADA**

Clark-Hurman Associates  
148 Colonnade Rd., Ste. 205  
Nepean, Ontario K2E 7J5  
(613) 727-5626, 727-5627

Clark-Hurman Associates  
37 George St. N, Ste. 404  
Brampton, Ontario L6X 1R5  
(416) 453-1118

## ARGENTINA

Rayo Electronics SRL  
Belgrando 990  
Pisos 6Y2  
Buenos Aires  
Phone: 37 98 90  
TLX: (390) 122153 (RAYOX AR)

## AUSTRALIA

Total Electronics  
9 Harker Street  
P.M.B. No 250  
Burwood, 3125  
Phone: 288 4044  
TLX: (790) 31261 (TOTELEC AA)

Tronic Bits  
P.O. Box 371  
Mentone  
Victoria, 3194  
Phone: 587-2257  
TLX: (790) 151479 (TRON AA)

## BELGIUM

(See Germany)

## BRAZIL

Intectra Do Brazil  
AV Paulista 807-S/415  
Sao Paulo, Brazil  
Phone: 285-6305  
TLX: 01139872 (BRCO BR)

ROHM Do Brazil Industria  
Electronica Ltda.  
Al. Reo Negro, 1356 - Alphaville  
Cep 06400 - Barueri, Sp  
Phone: (011) 421-4577  
TLX: (391) 1135275 (UIEL BR)

## DENMARK

Mer-el A/S  
Ved Klaedebo 18  
DK-2970 Horsholm  
Phone: 571000  
TLX: (855) 37360 (MEREL DK)

## FINLAND

Yleiselektronikka/oy  
Luomannotko 6  
02200 Espoo 20  
Phone: 90-452-1255  
TLX: 123212 (YLEOYF)

## FRANCE

Tekelec/Airtonic  
Rue Carle Vernet No. 2  
Cite des Bruyeres  
F-92310 Sevres  
Phone: (1) 534 75 35  
TLX: (842) 204552 (TKLEC A)

## GERMANY (West)

Rohm Electronics GmbH  
D-4051 Korschenbroich  
Muehlenstrasse 70  
Phone: (02161) 6101-0  
TLX: (841) 852330 (ROHM D)

## GREECE

General Electronics Ltd.  
209 Thivon Street  
Nikea, Piraeus 7  
VNUJVUY  
Phone: 49 13595  
TLX: (863) 212949 (GELT GR)

## HONG KONG

Rohm Electronics (H.K.) Co., Ltd.  
Flat 13, 3/F Newport Centre  
116, Mataukok Road, Tokwawan  
Kowloon  
Phone: 3-343481  
TLX: (780) 37503 (REHCL HX)

## INDIA

Zenith Electronics  
106, Mittal Chambers  
Nariman Point, Bombay 400021  
Phone: 2024464, 2027887  
TLX: (953) 11 3153 (ZINTH IN)

Fegu  
2584 Wyandotte Street  
Mountain View, CA 94043 USA  
Phone: (415) 961-2380  
TLX: 345-599 (FEGU ELEC PLA)

## ISRAEL

MLRN EElectronics  
15 Kineret St. Bney-Brak  
P.O. Box 10205  
Tel-Aviv 61 101  
Phone: 03 796 927 or 03 708 174-5  
TLX: 342107 (RNIS)

## ITALY

Eledra 3S S.P.A.  
Viale Elvezia, 18  
20154 Milano  
Phone: 34 93 041  
TLX: (843) 332332 (ELEDRA I)

## JAPAN

Tokyo Electron Ltd.  
Panetron Division  
38 FL Shinjuku Nomura Bldg.  
1-26-2, Nishi-Shinjuku  
Shinjuku-ku, Tokyo 160  
Phone: 03-343-4411  
TLX: (781) 2322240 (LABTEL J)

## KOREA

(Call EXAR Direct)

## LATIN AMERICA

Intechtra  
2629 Terminal Blvd.  
Mtn. View, CA 94043 USA  
Phone: (415) 967-8818  
TLX: 345 545 (INTRECTRA MNTV)

## LIECHTENSTEIN

(See Switzerland)

## LUXEMBOURG

(See Germany)

## NETHERLANDS

Nijerk Elektronika B.V.  
Drentestraat 7 1083HK  
Amsterdam, Holland  
Phone: 020 462221  
TLX: 11625 (NESCO NL)

## NEW ZEALAND

Professional Electronics Ltd.  
P.O. Box 31143  
22A Milford Road  
Milford, Auckland 9  
Phone: 46 94 50  
TLX: (791) 21084 (PROTON)

## NORWAY

Hefro Teknisk A/S  
P.O. Box 6596  
Rodezokken 80, Trondheimsuir  
Oslo 5  
Phone: 30 02 86  
TLX: (791) 21084 (PROTON)

## SINGAPORE

Rohm Electronics Co. Pte., Ltd.  
Unit A, 3rd Floor  
No. 12 Arumug AM Road No. 04.01  
Singapore 1440  
Phone: 745 9342  
TLX: (786) 26648 (ROHMS)

## SOUTH AFRICA

South Continental Devices (Pty.) Ltd.  
Suite 516, 5th Floor, Randover House  
Cor Hendrik Verwoerd, Dover Road  
Randburg, Transvaal  
Phone: 48 05 15  
TLX: (960) 4-24849 (SA)

Alpha Centary  
P.O. Box 783095  
Sandton 2146  
Phone: (011) 787-4680  
TLX: (960) 4-25077 SA

## SPAIN

Unitronics, S.A.  
Princesa, 1  
Madrid 8  
Phone: 242-52-04  
TLX: (831) 46786 (UTRON E)

## SWEDEN

Lagercrantz Electronix AB  
Kanalvagen 5  
S-194 01 Upplands Vasby  
Phone: (0760) 86 120  
TLX: (854) 11275 (LAGER S)

## SWITZERLAND

Stolz AG  
Taefernstr .15  
CH-5405  
Baden-Daettwill  
Phone: 056-840151  
TLX: 54070 (STLZ CH)

## TAIWAN

Sea Union  
P.O. Box 45-95 Tai Pei  
Room 303, Hua-Nan Bldg.  
No. 162, Chang An East Rd, 2nd Sec.  
Taipei, Taiwan, Rep. of China  
Phone: 751-2063 or 751-6856  
TLX: 24209 (SEAUNION TAIPEI)

## TURKEY

Testas  
Karanfil Sokak No. 41  
Bakanliklar, Ankara

## UNITED KINGDOM

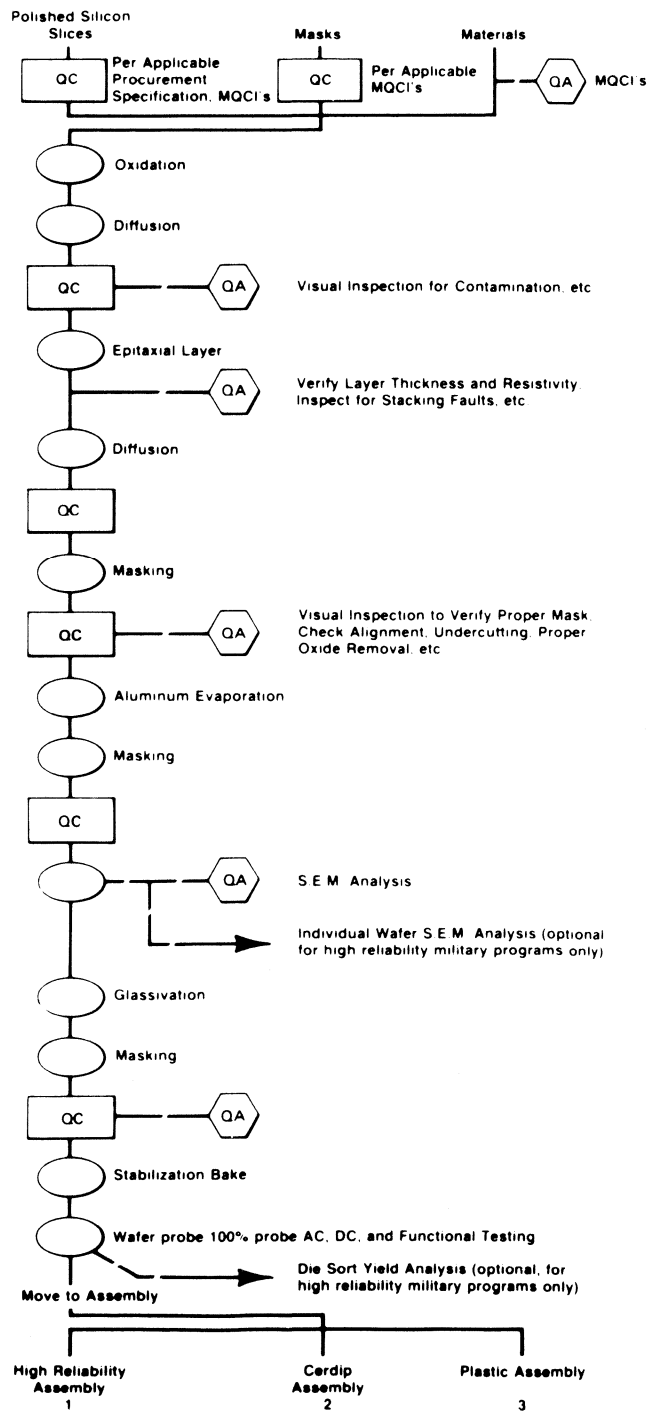
Thame Components  
Thame Park Road  
Thame, Oxon OX9 3RS  
Phone: (084) 421 3146  
TLX: (851) 837917 (MEMEC G)

## ALL OTHER COUNTRIES

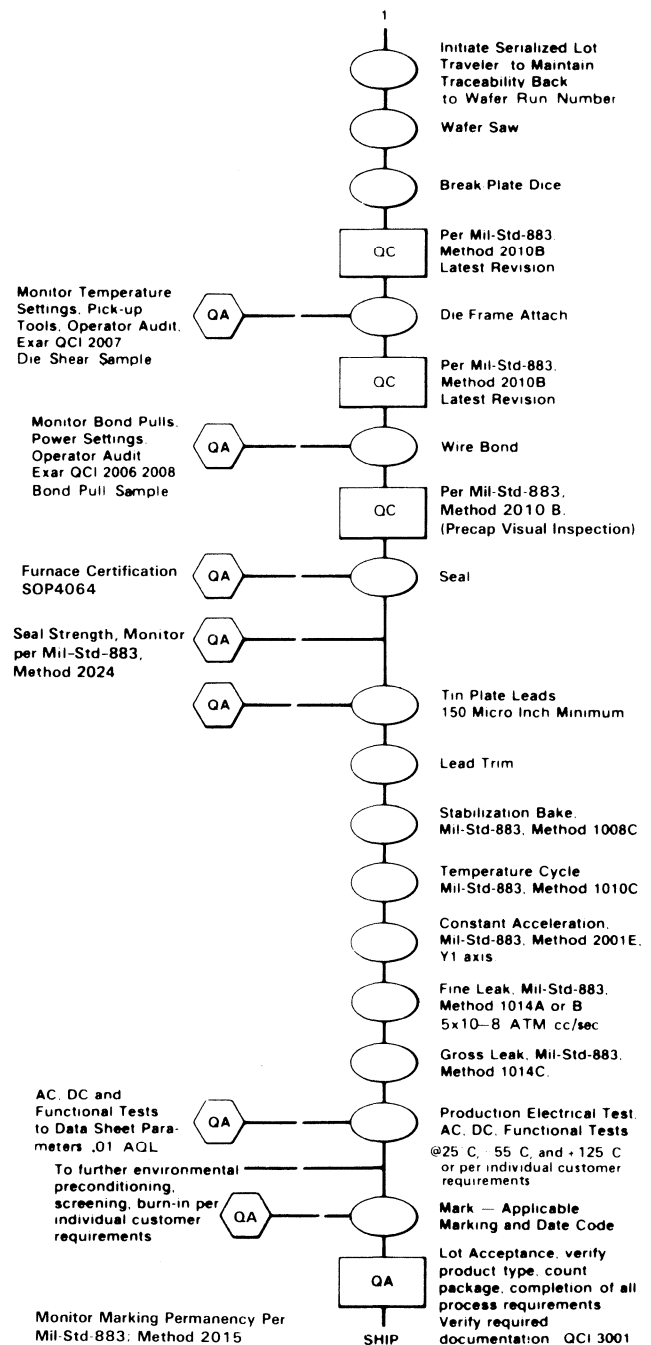
(Call EXAR Direct)

The quality assurance program at EXAR Corporation defines and establishes standards and controls on manufacturing, and audits product quality at critical points during manufacturing. The accompanying Manufacturing/QA process flow charts illustrate where quality assurance audits the manufacturing process, by inspection or test. The insertion of these quality assurance points is designed to insure that the highest quality standards are maintained on EXAR products during manufacturing. Realizing that these standard Manufacturing/QA process flows do not meet the needs of every customer requirement, EXAR Quality Assurance will negotiate any additional screening needs to meet any individual customer's specific requirement.

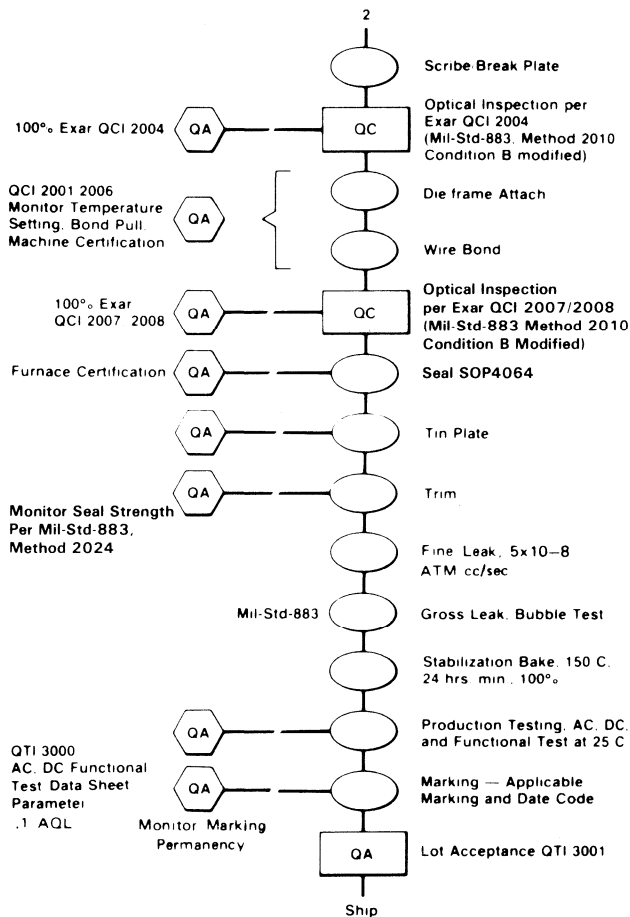
### Wafer Fabrication/QA Flow



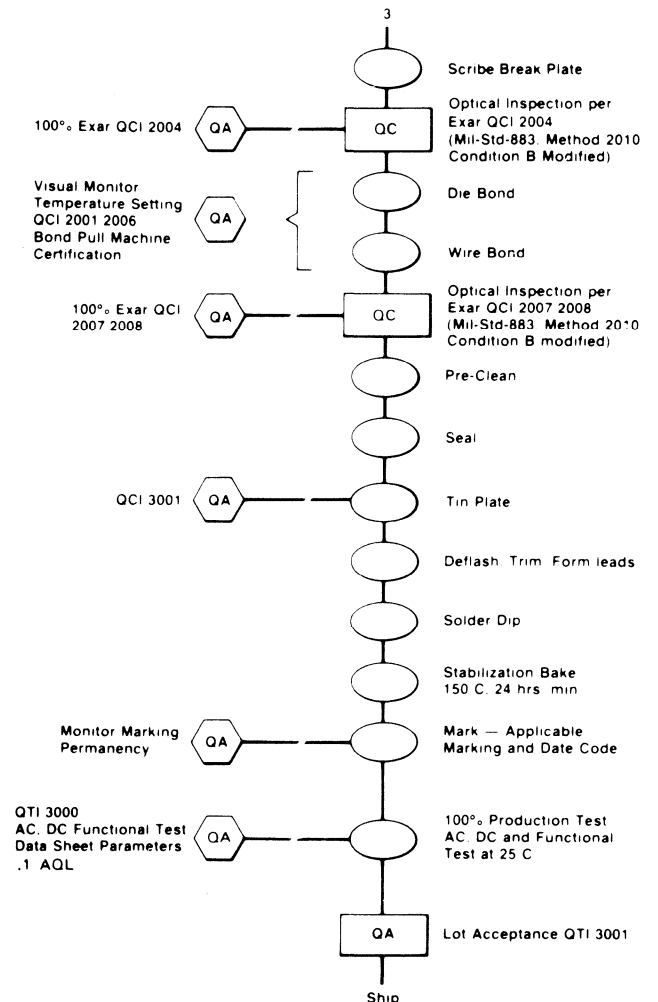
### High Reliability Assembly/QA Flow



### Cerdip Assembly Q/A Flow



### Plastic Assembly Q/A Flow



## PRODUCT ORDERING INFORMATION

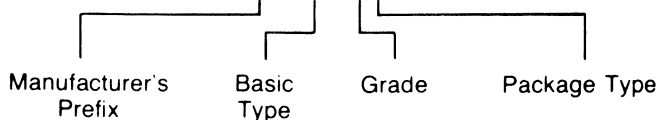
### Part Identification

**XR**  
 Manufacturer's Prefix  
**Grade**  
 M = Hi-Rel  
 N = Prime  
 Electrical  
 P = Prime  
 Electrical  
 C = Commercial  
 K = Kit

**XXXXX**  
 Basic Type  
**Package Type**  
 N = Ceramic Dual-in-line  
 P = Plastic Dual-in-line  
 MD = Small Outline

Example:

**XR-2120 CN**



### Definition of Symbols:

- M** = Hi-Rel Grade Part, Ceramic Package Only, and are guaranteed to operate over the temperature range of -55° to +125 °C.
- N** = Prime Grade Part, Ceramic Package.
- P** = Prime Grade Part, Plastic Package.
- CN** = Commercial Grade Part, Ceramic Package.
- CP** = Commercial Grade Part, Plastic Package.
- MD** = Commercial Grade Part, Plastic Small Outline Package (Marking does not include MD letters)

N, P, CN and CP parts are electrically identical and guaranteed to operate over 0°C to +70 °C range unless otherwise stated. In addition, N and P parts generally have operating parameters more tightly controlled than the CN or CP parts.

For details, consult Exar Sales Headquarters or Sales /Technical Representatives.

### Legend:

- Operation
- Surveillance
- 100% inspection
- QC** = Quality Control
- QA** = Quality Assurance



## EXAR DATA BOOK

This single volume data book combines all of EXAR's catalogs (see below) into one easy-to-use, comprehensive publication. The book contains a complete summary of technical information covering EXAR's full line of standard, custom and semi-custom IC products.

## STANDARD PRODUCT GUIDE

A complete short-form catalog of all of EXAR's standard products, quality assurance programs and technical capabilities. Key features and applications of each of EXAR's products are given, along with their functional block diagrams, package types, and operating temperature ranges. Products are grouped according to their applications, and a complete industry-wide cross reference chart is provided.

## CUSTOM AND SEMI-CUSTOM PRODUCT GUIDE

This book contains a complete outline and summary of EXAR's unique custom and semi-custom IC design, development, and production capabilities. Full custom and semi-custom programs which offer unique and effective methods of manufacturing an almost unlimited variety of custom linear or digital monolithic ICs is included as well as packaging information and Quality Assurance Program information.

## MODEM DESIGN HANDBOOK

This publication includes all EXAR data sheets and application notes relating to Modem products as well as a section on Modem fundamentals. Subjects covered in this fundamentals section include: Modulation and Demodulation techniques for both FSK and PSK systems, filter considerations, line interface, and test modes. The scope of this manual allows even the beginning modem designer to implement EXAR's available integrated circuits into complete working modems.

## SWITCHING REGULATOR DATA BOOK

EXAR's entire line of switching regulator IC products are specified in this technical data book. In addition, several design and application articles are included, along with a review of the fundamentals of pulse-wide modulated regulator circuits.

## PHASE-LOCKED LOOP DATA BOOK

The fundamentals of design and application of monolithic phase-locked loop (PLL) circuits are included in this data book. A long list of PLL applications are illustrated covering FM demodulation, frequency synthesis, FSK, and tone detection. Particular emphasis is given to the application of PLL circuits in data interface and communication systems such as FSK Modems. This book also contains the data sheets and electrical specifications for all of EXAR's PLL products.

## OPERATIONAL AMPLIFIER DATA BOOK

A collection of technical articles on the fundamentals of monolithic IC op amps is contained in this technical publication. Some of the basic op amp circuits are given, and the application of IC op amps in active filter design is discussed. A complete set of electrical specifications on EXAR's bipolar and BIFET op amp products is included.

## TIMER DATA BOOK

Provided in this publication is a collection of technical articles and application information on monolithic timer IC products. Also included are the data sheets and detailed electrical specifications for all of EXAR's timer circuits, including the programmable timer/counter, micropower, and long-delay timers.

## FUNCTION GENERATOR DATA BOOK

This comprehensive data book contains a number of technical articles and application notes on monolithic voltage-controlled oscillators (VCO), and function generator IC products. In addition, the data sheets and technical specifications for EXAR's monolithic VCO's and function generators are included.

## APPLICATIONS DATA BOOK

This practical applications guide contains a complete and up-to-date set of application notes prepared by EXAR's technical staff. These application notes cover a wide range of subjects, such as FSK Modems, active filters, telecommunication circuits, electronic music synthesis and many more. In each case, specific design examples are given to demonstrate the applications discussed.

## SURFACE MOUNT IC BROCHURE

---

## TECHNICAL LITERATURE REQUEST

To obtain the technical literature of interest to you, contact the EXAR Sales Representative nearest you, or write **EXAR Corporation, P.O. Box 3575, Sunnyvale, CA 94088-3575**, on your company letterhead.

Data Books can be ordered directly from EXAR, at a nominal charge, by completing and sending this request card to EXAR with an appropriate check or money order (include \$4.00 for postage and handling). Make checks payable to EXAR Corporation.

- PLEASE SEND:
- |  |  |
|--|--|
| <input type="checkbox"/> EXAR Complete Binder Set of Data Books - \$15.95      | <input type="checkbox"/> EXAR Phase-Locked Loop Data Book - \$3.95     |
| <input type="checkbox"/> EXAR Standard Product Guide - No Charge               | <input type="checkbox"/> EXAR Operational Amplifier Data Book - \$3.95 |
| <input type="checkbox"/> EXAR Custom and Semi-Custom Product Guide - No Charge | <input type="checkbox"/> EXAR Timer Data Book - \$3.95                 |
| <input type="checkbox"/> EXAR Modem Design Handbook - \$4.95                   | <input type="checkbox"/> EXAR Function Generator Data Book - \$3.95    |
| <input type="checkbox"/> EXAR Switching Regulator Data Book - \$3.95           | <input type="checkbox"/> EXAR Applications Data Book - \$3.95          |
|  | <input type="checkbox"/> EXAR Data Book - \$15.95                      |
|  | <input type="checkbox"/> EXAR Surface Mount IC Brochure - No Charge    |

NAME \_\_\_\_\_ TITLE \_\_\_\_\_  
COMPANY \_\_\_\_\_  
ADDRESS \_\_\_\_\_  
CITY/STATE/ZIP \_\_\_\_\_  
PHONE (\_\_\_\_) \_\_\_\_\_ MY COMPANY MANUFACTURES \_\_\_\_\_



EXAR Corporation, 750 Palomar Avenue, Sunnyvale, CA 94086