## EXAR <br> OPERATONAL AMPLIFIER DATA B00K

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

FUTURE ELECTRONICS INC.
4800 Dufferin Street
Downsview, Ontario
M3H 5S8
Tel.: (416) 663-5563

## Introduction

This Data Book contains a complete summary of technical information covering Exar's entire line of monolithic IC operational amplifier products. In addition, several design and applications articles are also included, along with a review of fundamentals of IC op-amps. To help the designer to choose the right op-amp for his application, a number of convenient cross-reference charts are also included which show the key features of each of the products discussed, in terms of different classes of applications.

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Exar reserves the right to make changes at any time in order to improve design and to supply the best product possible.

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## Fundamentals of Operational Amplifiers

The "ideal" operational amplifier can be defined as a voltagecontrolled voltage amplifier circuit which offers infinite voltage gains with an infinite input impedance, zero output impedance, and infinite bandwidth. The advantage of such an idealized block of gain is that one can perform a large number of mathematical "operations", or generate a number of circuit functions by applying passive feedback around the amplifier.
The key features of operational amplifier application can be illustrated using the simple feedback circuit of Figure 1, and assuming that the operational amplifier has infinite gain and infinite input impedance. Then, the following two conditions have to be satisfied:
a) Since the voltage gain is infinite, the net voltage across the input terminals of the operational amplifier must be zero, if the operational amplifier output voltage is to be finite. In the circuit of Figure 1, this causes the inverting input terminal of the operational amplifier to behave as a "virtual ground".
b) Since the input impedance of the ideal operational amplifier is infinite, no input current is drawn by the operational amplifier, the total current going into the circuit node connected to the inverting input of the operational amplifier (node Q in Figure 1) must be equal to the total current coming out, i.e.:

$$
\begin{equation*}
I_{S}=-I_{F} \text { and } \frac{V_{I N}}{R_{S}}=-\frac{\mathrm{V}_{\mathrm{O}}}{R_{\mathrm{F}}} \tag{1}
\end{equation*}
$$

Solving for the overall voltage gain, one obtains:

$$
\begin{equation*}
A_{V}=\frac{V_{\mathrm{OUT}}}{\mathrm{~V}_{\mathrm{IN}}}=-\frac{\mathrm{R}_{\mathrm{F}}}{\mathrm{R}_{\mathrm{S}}} \tag{2}
\end{equation*}
$$

Because of this property, the noninverting input of an operational amplifier is often referred to as its "summing input".


Figure 1. The "Ideal" Operational Amplifier as a Feedback Amplifier.

In the case of actual operational amplifiers, both the voltage gain and the input impedance are quite high, but still finite. Figure 2 shows the same basic feedback circuit assuming that the amplifier now has a finite input resistance, $\mathrm{R}_{\mathbb{N}}$, and a finite voltage gain A. For simplicity, the output impedance
of the operational amplifier is assumed to be negligible. The overall voltage gain of the circuit can now be expressed as: $A_{V}=V_{\text {OUT }} / V_{I N}=-\frac{R_{F}}{R_{S}}\left[\frac{1}{1+\frac{1}{A}\left(1+R_{F} / R_{S}+R_{F} / R_{I N}\right)}\right]$


Figure 2. Basic Feedback Configuration Using an Operational Amplifier With Finite Input Impedance and Gain.

It should be noted that, for large values of $\mathrm{R}_{\mathrm{IN}}$, as the voltage gain increases (i.e. A $\rightarrow \infty$ ), this expression rapidly converges to that given in equation 2 ; and the circuit performance becomes solely determined by the external components.

In addition to having finite gain and input impedance, an actual operational amplifier circuit also has finite input bias currents as well as input offset voltage and currents. A more complete model of a practical operational amplifier is shown in Figure 3 where $I_{B}$ indicates the finite input bias currents; $\mathrm{V}_{\mathrm{io}}$ and $\mathrm{I}_{\mathrm{io}}$ represent the voltage and current offsets associated with the circuit and $\mathrm{R}_{\mathrm{O}}$ is the output resistance. Due to non-zero values of $\mathrm{V}_{\mathrm{io}}$ and $\mathrm{I}_{\mathrm{i}}$ in a practical operational amplifier circuit, $\mathrm{V}_{\text {OUT }} \neq 0$ for $\mathrm{V}_{\mathrm{IN}}=0$.


Figure 3. Equivalent Circuit of a Practical Operational Amplifier Showing the Effects of Finite Input Impedance, Current and Voltage Offsets.

## Definitions of Operational Amplifier Terms

Since the operational amplifier has become a universal building block for circuit and system design, a number of widely accepted design terms have evolved which describe the comparative merits of various operational amplifiers. Some of these terms are defined below:

Input Offset Voltage: The input voltage which must be applied across the input terminals to obtain zero output voltage.

Input Offset Current: The difference of the currents into the two input terminals with the output at zero volts.

Input Bias Current: The average of the two input currents.
Input Common-Mode Range: Maximum range of input voltage that can be simultaneously applied to both inputs without causing cutoff or saturation of amplifier gain stages.

Common-Mode Rejection Ratio: Ratio of the differential open-loop gain to the common-mode open-loop gain.

Supply Voltage Rejection Ratio: Input offset voltage change per volt of supply voltage change.

Input Resistance: The ratio of the change in input voltage to the change in input current on either input with the other grounded.

Supply Current: The current required from the power supply to operate the amplifier with no load and the output at zero.

Output Voltage Swing: The peak output voltage swing, referred to zero, that can be obtained without clipping.

Large-Signal Voltage Gain: The ratio of the output voltage swing to the change in input voltage required to drive the output from zero to this voltage.

Full-Power Bandwidth: Maximum frequency over which the full output voltage swing can be obtained.

Unity-Gain Bandwidth: Frequency at which the open loop voltage gain is equal to unity.

Slew Rate: The maximum time rate of change of the output voltage, for a voltage step applied to the input. It is normally measured at the zero crossing point of the output voltage swing with the amplifier frequency compensated for unity gain.

Overload Recovery Time: Time required for the output stage to return to active region, when driven into hard saturation.

Gain Margin: The amount by which the voltage gain is below the unity ( 0 dB ) level, at the frequency where the excess phase shift across the amplifier is exactly $180^{\circ}$. It is measured in decibels, and must be positive for unconditional stability.

Phase Margin: $180^{\circ}$ minus the excess phase shift at the frequency where the magnitude of the open loop voltage gain is equal to unity. It is measured in degrees and must be positive for unconditional stability.

# Basic Applications of Operational Amplifiers 

The general usefulness of the operational amplifier stems from the fact that when used in a feedback loop, its overall performance and transfer characteristics are determined almost totally by the choice of feedback components. To be universally useful in such an application, the "ideal" operational amplifier should exhibit infinite gain, infinite input impedance and infinite bandwidth. Although these are all idealized characteristics, the practical monolithic operational amplifiers closely approximate these features, particularly for low frequency applications.

The availability and the low-cost of the integrated operational amplifier makes it an extremely versatile building block for analog system or equipment design. Therefore, it is mandatory that the circuit designer be familiar with the fundamental applications of operational amplifiers. This section of Exar's Operational Amplifier Data Book is intended to familiarize the designer with some of the simple but fundamental circuit configurations using IC operational amplifiers. The discussion is slanted toward the practical applications of operational amplifiers, as controlled by the external feedback circuitry. The particular operational amplifier parameters will be discussed as they effect the circuit performance and accuracy.

The integrated operational amplifiers shown in the figures are for the most part internally compensated, so frequency stabilization components are not shown; nowever, other amplifiers using external compensation may be utilized to achieve greater operating speed in many circuits.

## The Inverting Amplifier

The basic operational amplifier circuit is shown in Figure 1. This circuit gives closed-loop gain of $\mathrm{R}_{2} / \mathrm{R}_{1}$ when this ratio is small compared with the amplifier open-loop gain and, as the name implies, is an inverting circuit. The input impedance is equal to $R_{1}$. The closed-loop bandwidth is equal to the unity-gain frequency divided by one plus the closed-loop gain.

The only cautions to be observed are that $R_{3}$ should be chosen to be equal to the parallel combination of $R_{1}$ and $R_{2}$ to minimize the offset voltage error due to bias current; and that there will be a DC offset voltage at the amplifier output' equal to closed-loop gain times the offset voltage at the amplifier input.

Offset voltage at the input of an operational amplifier is comprised of two components, these components are identified in specifying the amplifier as input offset voltage and input bias current. The input offset voltage is fixed for a particular amplifier; however, the contribution due to input bias current is dependent on the circuit configuration used. For minimum offset voltage at the amplifier input without sircuit adjustment, the source resistance for both inputs
should be equal. In this case, the maximum offset voltage would be the algebraic sum of amplifier offset voltage and the voltage drop across the source resistance due to offset current. Amplifier offset voltage is the predominant error term for low source resistances, and offset current causes the main error for high source resistances.


Figure 1. Inverting Amplifier

In high source resistance applications, offset voltage at the amplifier output may be adjusted by adjusting the value of $\mathrm{R}_{3}$ and using the variation in voltage drop across it as an input offset voltage trim.

Offset voltage at the amplifier output is not as important in AC coupled applications. Here the only consideration is that any offset voltage at the output reduces the peak-to-peak linear output swing of the amplifier.

The gain-frequency characteristic of the amplifier and its feedback network must be such that oscillation does not occur. To meet this condition, the phase shift through amplifier and feedback network must never exceed $180^{\circ}$ for any frequency where the combined gain of the amplifier and its feedback network is greater than unity. In practical applications, the phase shift should not approach $180^{\circ}$ since this is the situation of conditional stability. Obviously, the most critical case occurs when the attenuation of the feedback network is zero.

Amplifiers which are not internally compensated may be used to achieve increased performance in circuits where feedback network attenuation is high, i.e., the amount of feedback around the amplifier is low. The compensation trade-off for a particular connection is stability versus bandwidth. Larger values of compensation capacitor yield greater stability and lower bandwidth and vice versa.

## The Non-Inverting Amplifier

Figure 2 shows a high input impedance non-inverting circuit. This circuit gives a closed-loop gain equal to the ratio of ( $R_{1}+R_{2}$ ) to $R_{1}$. Its closed-loop 3-dB bandwidth is equal to the amplifier unity-gain frequency divided by the closed-loop gain.


Figure 2. Non-Inverting Amplifier

The primary differences between this connection and the inverting circuit are that the output is not inverted and that the input impedance is very high and is equal to the differential input impedance multiplied by loop gain (open-loop gain/closed-loop gain). In DC coupled applications, input impedance is not as important as input current and its voltage drop across the source resistance. To minimize the output error due to the input bias current of the operational amplifier, $\left(R_{1}+R_{2}\right)$ should be chosen equal to the source impedance of the input signal. Applications cautions are the same for this amplifier as for the inverting amplifier with one exception: the amplifier output will go into saturation if the input is allowed to float. This may be important if the amplifier must be switched from source to source. The compensation trade off discussed for the inverting amplifier is also valid for this connection.

## The Unity-Gain Buffer

The unity-gain buffer is shown in Figure 3. The circuit gives the highest input impedance of any operational amplifier circuit. Input impedance is equal to the differential input impedance multiplied by the open-loop gain, in parallel with common mode input impedance. The gain error of this circuit is equal to the reciprocal of the amplifier open-loop gain or to the common-mode rejection, whichever is less. Input impedance is a misleading concept in a DC coupled unity-gain buffer. Bias current for the amplifier will be
supplied by the source resistance and will cause an error at the amplifier input due to its voltage drop across the source resistance.

The cautions to be observed in applying this circuit are as follows: the amplifier must be compensated for unity-gain operation, and the output swing of the amplifier may be limited by the amplifier common-mode range. The input signal swing should not exceed the input common-mode range, since this may cause a latch-up condition.


Figure 3. Unity-Gain Buffer

## Summing Amplifier

The summing amplifier, a special case of the inverting amplifier, is shown in Figure 4. The circuit gives an inverted output which is equal to the weighted algebraic sum of all three inputs. The gain of any input of this circuit is equal to the inverse ratio of the appropriate input resistor to the feedback resistor, $\mathrm{R}_{4}$. Amplifier bandwidth may be calculated as in the inverting amplifier shown in Figure 1 by assuming the input resistor to be the parallel combination of $\mathrm{R}_{1}, \mathrm{R}_{2}$, and $\mathrm{R}_{3}$. Application cautions are the same as those for the inverting amplifier. If an uncompensated amplifier is used, compensation is calculated on the basis of this bandwidth as is discussed in the section describing the simple inverting amplifier.


Figure 4. Summing Amplifier

The advantage of this circuit is that there is no interaction between inputs, therefore, operations such as summing and weighted-averaging are implemented very easily.

## The Difference Amplifier

The difference amplifier is the complement of the summing amplifier and allows the subtraction of two voltages or, as a special case, the cancellation of a signal common to the two inputs. This circuit is shown in Figure 5 and is useful as a computational amplifier, in making a differential to singleended conversion, or in rejecting an unwanted common-mode signal.


Figure 5. Difference Amplifier

Circuit bandwidth may be calculated in the same manner as for the inverting amplifier, but input impedance is somewhat more complicated. Input impedance for the two inputs is not necessarily equal: inverting input impedance is the same as for the inverting amplifier of Figure 1 and the noninverting input impedance is the sum of $\mathrm{R}_{3}$ and $\mathrm{R}_{4}$. Gain for either input is the ratio of $R_{1}$ to $R_{2}$ for the special case of a differential input single-ended output where $R_{1}=R_{3}$ and $R_{2}=R_{4}$. The general expression for gain is given in the figure. Compensation should be chosen on the basis of amplifier bandwidth.

Care must be exercised in applying this circuit since input impedances are not equal for minimum bias current error.

## Differentiator Circuit

The basic principle of a differentiator circuit is shown in the simplified connection diagram of Figure 6. However, although mathematically accurate, this particular connection is not directly useful in practice because it is extremely susceptible to high frequency noise since AC gain increases at the rate of 6 dB per octave. In addition, the feedback network of the differentiator made up of the resistor $\mathrm{R}_{3}$ and the capacitor
$\mathrm{C}_{3}$ is an RC low pass filter which contributes $90^{\circ}$ phase shift to the loop and may cause stability problems even with an amplifier which is compensated for unity-gain.

A practical differentiator which corrects the high frequency noise problem is shown in Figure 7. Here both the stability and noise problems are corrected by addition of two additional components, $R_{1}$ and $C_{2} . R_{2}$ and $C_{2}$ form a 6 dB per


Figure 6. Basic Differentiator Connection


Figure 7. Practical Differentiator Circuit
octave high frequency roll-off in the feedback network, and $\mathrm{R}_{1} \mathrm{C}_{1}$ form a 6 dB per octave roll-off network in the input network for a total high frequency roll-off of 12 dB per octave, to reduce the effect of high frequency input and amplifier noise. In addition $\mathrm{R}_{1} \mathrm{C}_{1}$ and $\mathrm{R}_{2} \mathrm{C}_{2}$ form lead networks in the feedback loop which, if placed below the amplifier unity-gain frequency, provide $90^{\circ}$ phase lead to compensate the $90^{\circ}$ phase lag of $\mathrm{R}_{2} \mathrm{C}_{1}$ and prevent loop instability.

## Integrator Circuit

Figure 8 shows the basic circuit connection for performing the mathematical operation of integration. This circuit is essentially a low-pass filter with a constant frequency roll-off of -6 dB per octave.

The circuit must be provided with an external method of establishing initial conditions. This is shown in the figure as the double-pole, single-throw switch $S_{1}$. When $S_{1}$ is in position 1, the amplifier is connected in unity-gain configuration, and capacitor $C_{1}$ is discharged, setting an initial condition of zero volts. When $S_{1}$ is in position 2, the amplifier is connected as an integrator, and its output will be the time-integral of the input voltage.


Figure 8. The Integrator Circuit

The cautions to be observed with this circuit are two: the amplifier used should generally be stabilized for unity-gain operation and $R_{2}$ must equal $R_{1}$ for minimum error due to bias current.

## Simple Low-Pass Filter

The simple low-pass filter is shown in Figure 9. This circuit has a 6 dB per octave roll-off after a closed-loop 3-dB point defined by ${ }_{\mathrm{f}}^{\mathrm{C}}$. Gain below this corner frequency is defined by the ratio of $R_{3}$ to $R_{1}$. The circuit may be considered as an AC integrator at frequencies well above $\mathrm{f}_{\mathrm{C}}$; however, the time domain response is that of a single RC rather than an integral.

A gain vs. frequency plot of circuit response is shown in Figure 10 to illustrate the difference between this circuit and the true integrator. Note that the frequency response is flat for frequencies below $\mathrm{f}_{\mathrm{C}}$

$$
\text { where } f_{C}=\frac{1}{2 \pi R_{3} C_{1}}
$$



Figure 9. A Simple Low-Pass Filter Circuit


Figure 10. Frequency Response of the Simple Low-Pass Filter.

## Current-to-Voltage Converter

Current may be measured in two ways with an operational amplifier: the current may be converted into a voltage with a resistor and then amplified or it may be injected directly into a summing node. Converting into voltage is undesirable for two reasons: first, an impedance is inserted into the measuring line causing an error; second, amplifier offset voltage is also amplified with a subsequent loss of accuracy. The use of a current-to-voltage converter avoids both of these problems.

The current-to-voltage converter is shown in Figure 11. The input current is fed directly into the summing note, and the amplifier output voltage changes to extract the same current from the summing node through $R_{1}$. The scale factor of this circuit is $R_{1}$ volts per ampere of current. The only conversion error in this circuit is the bias current of the operational amplifier input which is summed algebraically with the input current, $\mathrm{I}_{\text {IN }}$. The main design constraints are that scale factors must be chosen to minimize errors due to bias current and since voltage gain and source impedance are often indeterminate (as with photocells) the amplifier must be compensated for unity-gain operation.


Figure 11. Operational Amplifier as a Current-to-Voltage Converter.

## Voltage Controlled Current-Source

Figures 12, 13, and 14 show three simple circuit configurations for voltage-controlled constant-current stages. The circuit of Figure 12 is a basic current-sink circuit which uses a pair of Darlington connected NPN transistors external to the operational amplifier. Assuming that the base current of $T_{1}$ is negligible compared to the controlled current $I_{0}$, the current of the output transistors is equal to $\mathrm{V}_{\text {IN }} / \mathrm{R}_{1}$.


Figure 12. Voltage-Controlled Current-Sink Circuit

Figure 13 shows a current-source circuit which uses a composite connection of external PNP and NPN transistors and produces a constant output current which is proportional to the net voltage drop across the sensing resistor, $\mathrm{R}_{1}$.


Figure 13. Voltage-Controlled Current-Source Circuit

Figure 14 shows an alternate approach to obtaining a voltagecontrolled current source which does not require additional active devices. The circuit provides an output current proportional to the input voltage $\mathrm{V}_{\mathbf{I N}}$. If the resistors $\mathrm{R}_{1}$ through $R_{4}$ are chosen to be equal and much larger than $R_{5}$, then the output current is:

$$
\mathrm{I}_{\text {OUT }}=\mathrm{V}_{\text {IN }} / \mathrm{R}_{5}
$$

The above expression assumes that the current through $\mathrm{R}_{3}$ is much smaller than $\mathrm{I}_{0}$.


Figure 14. A Voltage-Controlled Current Source Circuit Which Does Not Require External Active Devices.

This circuit can supply an output current of either polarity, up to the maximum positive or negative output current available from the operational amplifier. The maximum voltage compliance of the output is limited by the output swing of the operational amplifier minus the voltage drop across the sensing resistor, $\mathrm{R}_{5}$.

## Triangle Wave Oscillator

A constant amplitude triangular wave generator is shown in Figure 15. This circuit provides a variable frequency triangular wave whose amplitude is independent of frequency. This entire circuit can be built inexpensively, using a dual operational amplifier IC, such as the XR-4558.


Figure 15. A Simple Triangle Wave Oscillator.

The generator embodies an integrator as a ramp generator and a threshold detector with hysterisis as a reset circuit. The integrator has been described in a previous section and requires no further explanation. The threshold detector is similar to a Schmitt trigger in that it is a latch circuit with a large dead zone. This function is implemented by using positive feedback around an operational amplifier. When the amplifier output is in either the positive or negative saturated state, the positive feedback network provides a voltage at the non-inverting input which is determined by the attenuation of the feedback loop and the saturation voltage of the amplifier. To cause the amplifier to change states, the voltage at the input of the amplifier must be caused to change polarity by an amount in excess of the amplifier input offset voltage.

When this is done, the amplifier saturates in the opposite direction and remains in that state until the voltage at its input again reverses. The complete circuit operation may be understood by examining the operation with the output of the threshold detector in the positive state. The detector positive saturation voltage is applied to the integrator summing junction through the combination $\mathrm{R}_{3}$ and $\mathrm{R}_{4}$ causing the current $\mathrm{I}_{\mathrm{A}}$ to flow.

The integrator then generates a negative-going ramp with a rate of $\mathrm{I}_{\mathrm{A}} / \mathrm{C}_{1}$ volts per second until its output equals the negative trip point of the threshold detector. The threshold detector then changes to the negative output state, and supplies a negative current, $\mathrm{I}_{\mathrm{B}}$, at the integrator summing point. The integrator now generates a positive-going ramp with a rate of $I_{B} / C_{1}$ volts per second until its output equals the positive trip point of the threshold detector, where the deiector again changes output state and the cycle repeats.

Triangular wave frequency is determined by $R_{3}, R_{4}$ and $C_{1}$ and the positive and negative saturation voltages of the amplifier $A_{1}$. Amplitude is determined by the ratio of $R_{5}$ to the combination of $R_{1}$ and $R_{2}$ and the threshold detector saturation voltages. Positive and negative ramp rates are equal and positive and negative peaks are equal if the detector has equal positive and negative saturation voltages. The output waveform may be offset with respect to ground if the inverting input of the threshold detector, $\mathrm{A}_{1}$, is offset with respect to ground.

The generator may be made independent of temperature and supply voltage if the detector is clamped with matched zener diodes.

The integrator section should be compensated for unity-gain. The detector section may require compensation if power supply impedance causes oscillation during its transition time. The current into the integrator should be large with respect to the input bias current for maximum symmetry; and offset voltage should be small with respect to peak output voltage swing.

# Active Filter Design with IC Op-Amps 

## INTRODUCTION

Frequency selective networks for use in the frequency range below 100 kHz have always been a problem. In this area of operation the inductors and capacitors required are large, both in value and physical size. Also, at these frequencies inductors and capacitors become quite lossy and the circuit Q's begin to suffer.

The answer to this problem is to exchange the large inductor and capacitor for a large block of gain, and use well known feedback principles to achieve selectivity with R-C active filters. Previously, to achieve a high degree of accuracy and circuit stability, a large number of active components was required in a fairly sophisticated circuit. Consequently, the design time and number of active components required made the use of active filters quite expensive.

The solution to this problem came with the advent of integrated circuits which allowed transistors to be "less expensive" than resistors. Now, excellent gain blocks can be fabricated at fairly reasonable costs. And as technology improves, the performance will continue to improve and the costs will continue to decline, making the use of active filters very economical.

The availability of low cost dual or quad operational amplifier IC's have made the operational amplifier based active filter techniques cost effective over conventional passive filters. The recent availibility of programmable quad operational amplifiers such as the XR-4202 or the XR-346 have provided the active filter designer with the flexibility to externally program gain-bandwidth product, supply current, input bias current, input offset current, input noise and the slew rate. The user, therefore, can trade off bandwidth for supply current or optimize the noise figure. Likewise, other amplifier characteristics can be programmed for a specific need.
Since the operational amplifier plays such a key role in the active filter, its characteristics are of prime importance. By using operational amplifiers as the basic gain stage of the active filter, problems previously encountered due to low input impedance, high output impedance and low gain are virtually eliminated. Operational amplifiers provide the required response for various filter types. Some of the more popular filters are multiple feedback, state variable, bi-quad and Sallen Key which can be used to obtain high pass, band pass and low pass filter functions (and which are capable of giving the designer all of the standard filter responses, i.e., Butterworth, Chebychev, Bessel, etc.)

This application article is intended to assist the designer in selecting the optimum filter for his application. It begins with a table of transfer functions and network defining equations for the high pass, low pass, band pass and the band reject filters. A guide to the three types of filter responses will be presented, also several filter realizations are illustrated with their respective merits and limitations. Finally, the entire contents are brought together to provide the designer
a complete working schematic of an active filter in a modem configuration utilizing the XR-4202 Quad Programmable Operational Amplifier along with the XR-2206 Waveform Generator and the XR-2211 Precision Tone Decoder.

## TRANSFER FUNCTIONS AND EQUATIONS

Table 1 is intended to give the designer a brief review of the basic transfer functions, and network defining equations. It is noted that a family of curves exists for all cases except first order low pass and high pass. This is due to the presence of $\alpha$, the damping coefficient. This point will be expanded upon in the next section of filter responses.

## FILTER RESPONSES

Once the transfer function has been determined, the next step in filter design is to decide upon the desired response. As previously mentioned the damping of the filter determines it's characteristics near cut off. There are three basic types of responses which are depicted in Table 2 along with their characteristics. In the case of the Butterworth and Bessel, the response has been fixed. However, for the Chebychev the $\alpha$ is chosen for the particular response desired. This is done by using a nomograph such as the one shown in Figure 1. To use a nomograph the information required is: $\mathrm{A}_{\max }$ (maximum ripple in the passband), $\mathrm{A}_{\min }$ (minimum attenuation in the stop band), and $\Omega_{\mathrm{s}}$ (ratio of the $\mathrm{A}_{\min }$ bandwidth to the $\mathrm{A}_{\max }$ bandwidth). These terms are illustrated in Figure 2. Once these terms are known the nomograph is used by locating $A_{\max }$ and drawing a straight line through $A_{\min }$ to the left hand side of the graph. From this point a horizontal line is drawn to the intersection of $\Omega_{\mathrm{S}}$. The minimum order of the transfer function will be the number of the curve passing above this point. Once this is done the $\alpha$ and wo for each stage is found by consulting the Chebychev network parameter tables for the desired passband ripple, and the number of poles. Such tables can be found in standard filter handbooks.

## FILTER REALIZATIONS

There are numerous ways of realizing the transfer functions discussed. Each of these methods have their own relative merits. The configuration selected depends primarily on the specific application and the desired sensitivity parameters. Sensitivity parameters are a means of relating the resultant change in the transfer function due to an element change. Although these parameters are only directly applicable to an infinitesimal change they are easily used to evaluate performance for $1 \%$ changes, and many times are used for element changes up to $10 \%$. Examples will be given later in this section that will help clarify this parameter.

The filter realizations presented here are to be used as a basic guide to help the designer to become more adept at designing filters. State-variable and multiple-feedback filters will be discussed and the relative merits of each will be given. It will also be shown that many of the commonly used filters are actually specific cases for the filters mentioned.

TABLE 1


TABLE 2

| Filter Type | $\alpha$ | Basic Features | Amp. Response |
| :--- | :---: | :--- | :--- |
| Bessel | $\sqrt{3}$ | Best time delay <br> Smoothest phase response |  |
| Butterworth | $\sqrt{2}$ | Maximally flat amplitude <br> response |  |
| Chebychev | Can <br> Vary | Passband ripple <br> Fast cutoff slope |  |



FIGURE 1


FIGURE 2
Figure 3 illustrates a typical multiple-feedback connection with the non-inverting input grounded. To minimize offset this point should be returned to ground via a resistor whose value is equal to the impedance at the inverting input. The transfer function for this circuit is given by E-1. Each element represents a single resistor or capacitor. To realize the transfer function each admittance parameter is replaced by $1 / R$ for a resistor and sC for a capacitor. An example will help to clarify this point. If the desired response is a high pass, the


FIGURE 3

E-1

$$
\frac{E_{0}}{E_{1}}(s)=\frac{-Y_{1} Y_{3}}{Y_{5}\left(Y_{1}+Y_{2}+Y_{3}+Y_{4}\right)+Y_{3} Y_{4}}
$$

form of the characteristic equation is given in Table 1. To transform $\mathrm{E}-1$ into the high-pass characteristic, then $\mathrm{Y}_{1}$, $Y_{3}$, and $Y_{4}$ become capacitors and $Y_{2}$ and $Y_{5}$ resistors. (It should be obvious that a low-pass function could have been fabricated by letting $Y_{2}$ and $Y_{5}$ be capacitors, and similarly a bandpass function could have been realized by making $Y_{3}$ and $Y_{4}$ capacitors.) The terms of the network function of the high-pass filter shown in Figure 4 are given in Table 3 along with their sensitivity parameters. The transfer function for Figure 4 is given by $\mathrm{E}-2$.


FIGURE 4

## E-2

$$
\frac{E_{0}}{E_{1}}(s)=\frac{-\left(C_{1} / C_{4}\right) s^{2}}{s^{2}+s\left(1 / R_{5}\right)\left(C_{1} / C_{3} C_{4}+1 / C_{4}+1 / C_{3}\right)+1 / R_{2} R_{5} C_{3} C_{4}}
$$

As can be seen from the sensitivity parameters, there is a high degree of circuit sensitivity due to the component tolerances. Due to the interaction of components the tuning of this circuit may be rather involved. However, with tight component tolerances, these circuits give the designer very predictable results. Due to the high input impedance and low output impedance, several of these stages may easily be cascaded to achieve a higher order function. What is desired is to have a lower sensitivity to component tolerances. The most commonly used filter for this purpose is the state-variable.

The state-variable synthesis approach is used in most present day Universal Active Filters (U.A.F.). With this method the actual $n^{\text {th }}$ order polynomial of the transfer function is simulated as it would be with an analog computer. When using the state-variable approach all three outputs (high-pass, low-pass and band-pass) are all available simultaneously. The sensitivities with respect to component tolerances are typically less than or equal to one, and the sensitivity of Q

TABLE 3

| Parameter | Defining Equation | Sensitivity |
| :---: | :---: | :---: |
| $\mathrm{H}_{0}$ | $=\frac{\mathrm{C}_{1}}{\mathrm{C}_{4}}$ | $\mathrm{S}_{\mathrm{C}_{1}} \mathrm{H}_{0}=-\mathrm{S}_{\mathrm{C}_{4}} \mathrm{H}_{0}=1$ |
| $\alpha$ | $=\sqrt{\frac{R_{2}}{R_{5}}}\left(\frac{C_{1}}{\sqrt{C_{3} C_{4}}}+\sqrt{\frac{\mathrm{C}_{3}}{\mathrm{C}_{4}}}+\sqrt{\frac{\mathrm{C}_{4}}{\mathrm{C}_{3}}}\right)$ | $\begin{aligned} & \mathrm{S}_{\mathrm{C}_{3}}^{\alpha}=\frac{1}{2}-\frac{1}{\alpha \omega_{0} \mathrm{R}_{5} \mathrm{C}_{3}}\left(\frac{\mathrm{C}_{1}}{\mathrm{C}_{3}}+1\right) \\ & \mathrm{S}_{\mathrm{C}_{4}}^{\alpha}=\frac{1}{2}-\frac{1}{\alpha \omega_{0} \mathrm{R}_{5} \mathrm{C}_{4}}\left(\frac{\mathrm{C}_{1}}{\mathrm{C}_{3}}+1\right) \\ & \mathrm{S}_{\mathrm{C}_{1}}^{\alpha}=\frac{1}{\alpha \omega_{0} \mathrm{R}_{5}} \frac{\mathrm{C}_{1}}{\mathrm{C}_{3} \mathrm{C}_{4}} \\ & \mathrm{~S}_{\mathrm{R}_{2}}^{\alpha}=-\mathrm{S}_{\mathrm{R}_{5}}^{\alpha}=\frac{1}{2} \end{aligned}$ |
| $\omega_{0}$ | $=\left(\frac{1}{\mathrm{R}_{2} \mathrm{R}_{5} \mathrm{C}_{3} \mathrm{C}_{4}}\right)^{1 / 2}$ | $\mathrm{S}_{\mathrm{R}_{2}} \omega_{0}=\mathrm{S}_{\mathrm{R}_{5}} \omega_{0}=\mathrm{S}_{\mathrm{C}_{3}} \omega_{0}=\mathrm{S}_{\mathrm{C}_{4}} \omega_{0}=-\frac{1}{2}$ |

Note: The sensitivity of $\mathrm{H}_{O}$ with This implies that if $\mathrm{C}_{1}$ changes by $1 \%$ $\mathrm{H}_{O}$ will also change by $1 \%$. The defining equation for a sensitivity parameter is

$$
S_{X} Y=\frac{x d Y}{Y d x}
$$

with respect to amplifier gain is nearly zero, if the amplifier gain is high. Because of the high amplifier gain requirement these filters tend to be limited to audio range. The cost of reducing the circuit element sensitivities is the need to use ( $n+2$ ) operational amplifiers to synthesize an $n$th order transfer function. For this reason, this type of configuration may not be cost effective in the synthesis of low Q high-pass and low-pass filters.
Figure 5 shows a typical state-variable configuration whose characteristic equations are given by $\mathrm{E}-3, \mathrm{E}-4$, and $\mathrm{E}-5$. It is noted that these equations all have the same denominators; and the numerator is determined by the point at which the output is taken. This form may also be used to simulate a band-reject function by summing the high-pass and lowpass outputs. The defining equations and sensitivity parameters are given in Table 4. It is noted here that the bi-quad is actually a slight variation of a second order state-variable.


FIGURE 5

$$
E-3 \quad \frac{E_{L P}}{E_{1}}=\frac{\left(\frac{1}{R_{5} R_{6} C_{1} C_{2}}\right)\left(\frac{1+R_{4} / R_{3}}{1+R_{1} / R_{2}}\right)}{s^{2}+s\left(\frac{1}{R_{5} C_{1}}\right)\left(\frac{1+R_{4} / R_{3}}{1+R_{2} / R_{1}}\right)+\frac{R_{4}}{R_{3}}\left(\frac{1}{R_{5} R_{6} C_{1} C_{2}}\right)}
$$

$$
\begin{aligned}
& \frac{\mathrm{E}-4}{\mathrm{E}_{\mathrm{HP}}} \mathrm{E}_{1}=\frac{s^{2}\left(\frac{1+\mathrm{R}_{4} / R_{3}}{1+\mathrm{R}_{1} / \mathrm{R}_{2}}\right)}{s^{2}+s\left(\frac{1}{R_{5} C_{1}}\right)\left(\frac{1+\mathrm{R}_{4} / R_{3}}{1+\mathrm{R}_{2} / R_{1}}\right)+\frac{R_{4}}{R_{3}}\left(\frac{1}{R_{5} R_{6} C_{1} C_{2}}\right)} \\
& \mathrm{E}-5 \\
& \frac{E_{B P}}{E_{1}}=\frac{-s\left(\frac{1}{R_{5} C_{1}}\right)\left(\frac{1+R_{4} / R_{3}}{1+R_{1} / R_{2}}\right)}{s^{2}+s\left(\frac{1}{R_{5} C_{1}}\right)\left(\frac{1+R_{4} / R_{3}}{1+R_{2} / R_{1}}\right)+\frac{R_{4}}{R_{3}}\left(\frac{1}{R_{5} R_{6} C_{1} C_{2}}\right)}
\end{aligned}
$$

## MODEM FILTER

A typical application for an active filter is the input stage of a frequency demodulator. Any noise or spurious signals at this point would affect the overall quality of the output. A more specific example can be cited by considering the F.S.K. system shown in Figure 6. (Frequency shift keying is a means of transmitting digital information, primarily through telecommunications links.) This type of system is thoroughly covered in Exar Application Note, AN-01 and will only be briefly discussed here.

In this system, the digital data to be transmitted is used to key the XR-2206. The frequency shift keyed output of the XR-2206 is then sent through the hybrid and out on to the line. (The hybrid is used to obtain isolation between data transmitted and data received, and also may be used to amplify the received signal.) In full duplex operation this system must be able to receive and transmit simultaneously. Due to line losses, the received signal may range from -12 dBm to -48 dBm . The output level of the transmitter is typically -6 dBm (allowing for a 6 dB loss in the hybrid), due to line mismatch, the hybrid may only provide 10 dB of isolation to the filter. (Therefore, the levels at the input of the filter, assuming a gain of 6 dB from the line through the hybrid is -6 and

TABLE 4

| Output | Parameters | Defining Equation | Sensitivity |
| :---: | :---: | :---: | :---: |
| $\begin{aligned} & \text { Low } \\ & \text { Pass } \\ & \text { E-3 } \end{aligned}$ | $\mathrm{H}_{0}$ | $\frac{1+R_{3} / R_{4}}{1+R_{1} / R_{2}}$ | $\begin{aligned} & \mathrm{S}_{\mathrm{R}_{1}} \cdot \mathrm{H}_{0}=-\mathrm{S}_{\mathrm{R}_{2}}{ }^{\mathrm{H}_{0}}=-1 /\left(1+\mathrm{R}_{2} / \mathrm{R}_{1}\right) \\ & \mathrm{S}_{\mathrm{R}_{3}}{ }^{\mathrm{H}_{0}}=-\mathrm{S}_{\mathrm{R}_{4}}{ }^{\mathrm{H}_{0}}=\frac{1}{\mathrm{H}_{0}}\left(\frac{\mathrm{R}_{3} / \mathrm{R}_{4}}{1+\mathrm{R}_{1} / \mathrm{R}_{2}}\right) \end{aligned}$ |
|  | $\omega_{0}$ | $\left[\frac{R_{4}}{R_{3} R_{5} R_{6} C_{1} C_{2}}\right]^{1 / 2}$ | $\mathrm{S}_{\mathrm{R}_{3}} \omega_{0}=\mathrm{S}_{\mathrm{R}_{5}} \omega_{0}=\mathrm{S}_{\mathrm{R}_{6}} \omega_{0}=\mathrm{S}_{\mathrm{C}_{1}} \omega_{0}=\mathrm{S}_{\mathrm{C}_{2}} \omega_{0}=-\mathrm{S}_{\mathrm{R}_{4}} \omega_{0}=-\frac{1}{2}$ |
|  | $\alpha$ | $\frac{1+\mathrm{R}_{4} / \mathrm{R}_{3}}{1+\mathrm{R}_{2} / \mathrm{R}_{1}}\left(\frac{\mathrm{R}_{3} \mathrm{R}_{6} \mathrm{C}_{2}}{\mathrm{R}_{4} \mathrm{R}_{5} \mathrm{C}_{1}}\right)^{1 / 2}$ | $\begin{aligned} & \mathrm{S}_{\mathrm{R}_{4}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{R}_{3}}{ }^{\alpha}=-\frac{1}{2}+\frac{\mathrm{R}_{4} / \mathrm{R}_{3}}{\mathrm{R}_{5} \mathrm{C}_{1} \alpha \omega_{0}\left(1+\mathrm{R}_{2} / \mathrm{R}_{1}\right)} \\ & \mathrm{S}_{\mathrm{R}_{1}} \alpha=-\mathrm{S}_{\mathrm{R}_{2}}{ }^{\alpha}=\frac{1}{1+\mathrm{R}_{1} / \mathrm{R}_{2}} \\ & \mathrm{~S}_{\mathrm{R}_{6}}{ }^{\alpha}=\mathrm{S}_{\mathrm{C}_{2}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{R}_{5}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{C}_{1}} \alpha=\frac{1}{2} \end{aligned}$ |
| High <br> Pass <br> E-4 | $\mathrm{H}_{0}$ | $\frac{1+\mathrm{R}_{4} / \mathrm{R}_{3}}{1+\mathrm{R}_{1} / \mathrm{R}_{2}}$ | $\begin{aligned} & \mathrm{S}_{\mathrm{R}_{1}} \mathrm{H}_{0}=-\mathrm{S}_{\mathrm{R}_{2}} \mathrm{H}_{0}=-1 /\left(1+\mathrm{R}_{2} / \mathrm{R}_{1}\right) \\ & \mathrm{S}_{\mathrm{R}_{3}}{ }^{\mathrm{H}_{0}}=-\mathrm{S}_{\mathrm{R}_{4}}{ }^{\mathrm{H}_{0}}=\frac{1}{\mathrm{H}_{0}}\left(\frac{\mathrm{R}_{4} / \mathrm{R}_{3}}{1+\mathrm{R}_{1} / \mathrm{R}_{2}}\right) \end{aligned}$ |
|  | $\omega_{0}$ | SAME AS LOW PASS |  |
|  | $\alpha$ | $\left(\frac{1+\mathrm{R}_{4} / \mathrm{R}_{3}}{1+\mathrm{R}_{2} / \mathrm{R}_{1}}\right)\left(\frac{\mathrm{R}_{3} \mathrm{R}_{6} \mathrm{C}_{2}}{\mathrm{R}_{4} \mathrm{R}_{5} \mathrm{C}_{1}}\right)^{1 / 2}$ | $\begin{aligned} & \mathrm{S}_{\mathrm{R}_{4}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{R}_{3}}{ }^{\alpha}=-\frac{1}{2}+\frac{\mathrm{R}_{4} / \mathrm{R}_{3}}{\mathrm{R}_{5} \mathrm{C}_{1} \alpha \omega_{0}\left(1+\mathrm{R}_{2} / \mathrm{R}_{1}\right)} \\ & \mathrm{S}_{\mathrm{R}_{1}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{R}_{2}}{ }^{\alpha}=\frac{1}{1+\mathrm{R}_{1} / \mathrm{R}_{2}} \\ & \mathrm{~S}_{\mathrm{R}_{6}}{ }^{\alpha}=\mathrm{S}_{\mathrm{C}_{2}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{R}_{5}}{ }^{\alpha}=-\mathrm{S}_{\mathrm{C}_{1}}{ }^{\alpha}=1 / 2 . \end{aligned}$ |
| Band <br> Pass <br> E-5 | $\mathrm{H}_{0}$ | $\frac{\mathrm{R}_{2}}{\mathrm{R}_{1}}$ | $\mathrm{S}_{\mathrm{R}_{1}} \mathrm{H}_{0}=-\mathrm{S}_{\mathrm{R}_{2}}{ }^{\mathrm{H}_{0}}=-1$ |
|  | $\omega_{0}$ | SAME AS LOW PASS |  |
|  | $\mathrm{Q}=1 / \alpha$ | $\left(\frac{1+\mathrm{R}_{2} / \mathrm{R}_{1}}{1+\mathrm{R}_{4} / \mathrm{R}_{3}}\right)\left(\frac{\mathrm{R}_{4} \mathrm{R}_{5} \mathrm{C}_{1}}{\mathrm{R}_{3} \mathrm{R}_{6} \mathrm{C}_{2}}\right)^{1 / 2}$ | $\begin{aligned} & S_{R_{5}} Q^{2}=S_{C_{1}} Q=-S_{R_{6}}{ }^{Q}=-S_{C_{2}} Q^{2}=\frac{1}{2} \\ & S_{R_{4}} Q^{Q}=S_{R_{3}} Q^{2}=\frac{1}{2}-\frac{R_{4} / R_{3}}{R_{5} C_{1} \alpha \omega_{0}\left(1+R_{2} / R_{1}\right)} \\ & S_{R_{2}} Q=-S_{R_{1}} Q=\frac{1}{1+R_{1} / R_{2}} \end{aligned}$ |



FIGURE 6
-42 dBm for the desired signal and -16 dBm from the local oscillator.) This means that in a worst case situation, the input level of the received signal is -42 dBm with the level of the local oscillator 26 dB above this. For the XR-2211 to operate with a low bit error rate, the input should be 6 dB higher than the interfering signal. This implies that the stopband $\mathrm{A}_{\text {min }}$ from Figure 2 is 32 dB . The XR-2211 has an internal preamplifier with a dynamic range of greater than 60 dB , and requires a minimum input level of -38 dBm to cause limiting. If we choose a filter to have a passband ripple of 1 dB and an overall gain of 5 dB , the input conditions of the XR- 2211 will be satisfied. The filters introduce a phase shift that is only linear for approximately $1 / 2$ to $1 / 3$ of the passband, therefore, a bandwidth of 400 Hz is used for the filter. The general shape of the filter is shown in Figure 7.


FIGURE 7

Note: The values used in this filter are based on a modem using an XR-2206 as the modulator and XR-2211 as the demodulator. If digital techniques are used, the filter parameters may be different due to the harmonics generated by digital synthesis of a sine wave and higher signal to noise requirements of the demodulator.

To find the minimum number of poles required for this response the nomograph in Figure 1 is used. The point falls between a 2 and 3 pole filter. The values of $\omega_{0}+\alpha$ are determined from the tables for a 3rd order chebychev response with 1 dB ripple.

From tables

$$
\left.\begin{array}{r}
\omega_{0}=.997098 \\
\omega_{0}=.495609 \\
\omega_{0}=.494171
\end{array}\right\} \quad \begin{aligned}
& \text { complex pole } \\
& \text { - real pole } .
\end{aligned}
$$

The geometric center is $\omega_{0}=\sqrt{\omega_{3} \omega_{2}}$ or $\sqrt{f_{3} f_{2}}=f_{0}$

The filter $Q_{0}=Q_{0}=\frac{f_{0}}{f_{3}-f_{2}}=\frac{\sqrt{(1925)(2325)}}{2325-1925}=5.28892$

The Q of each section of the filter is determined by Equation 6.

$$
\mathrm{QA}=\frac{\left(\frac{\omega_{1}}{\mathrm{Q}_{0}}\right)^{2}+4+\sqrt{\left[\left(\frac{\omega_{1}}{Q_{0}}\right)^{2}+4\right]^{2}-4\left(\frac{\alpha_{1} \omega_{1}}{\mathrm{Q}_{0}}\right)^{2}}}{2\left(\frac{\alpha_{1} \omega_{1}}{\mathrm{Q}_{0}}\right)^{2}}
$$

$\mathrm{Q}_{1}=21.49=\mathrm{Q}_{2}$ Section 2 is a reflection of section one about $\mathrm{f}_{\mathrm{O}}$. The center frequencies are found by $\mathrm{E}-7$.

E-7 $\quad M=\frac{\alpha \omega_{1} Q_{1}}{2 Q_{0}}+\sqrt{\left(\frac{\alpha \omega_{1} Q_{1}}{2 Q_{0}}\right)^{2}-1}$

Where
$M=\frac{\omega_{1}}{\omega_{0}}=\frac{\omega_{0}}{\omega_{2}}=\frac{f_{1}}{f_{0}}=\frac{f_{0}}{f_{2}}$
$\mathrm{M}=1.0955$
$\mathrm{f}_{1}=2317.6$
$\mathrm{f}_{2}=1931.1$
for Section 3 the real pole is transformed into a complex pole pair.

$$
\mathrm{Q}_{3}=\frac{2 \mathrm{Q}_{0}}{\alpha \omega_{\mathrm{B}}}=10.7
$$

and $f_{3}=f_{0}$.

The 3 filter stages are now defined:

$$
\begin{array}{ll}
\mathrm{f}_{1}=2317.6 & \mathrm{Q}_{1}=21.49 \\
\mathrm{f}_{2}=1931.1 & \mathrm{Q}_{2}=21.49 \\
\mathrm{f}_{3}=2115.56 & \mathrm{Q}_{3}=10.7
\end{array}
$$

In this example the multiple-feedback approach is used since 3 pole pairs can be generated with 3 op-amps, 6 capacitors and 9 resistors; an equivalent filter could have been designed with the state-variable techniques, but this would have required 9 op-amps to realize. The actual filter is shown in Figure 8. All capacitor values are chosen to be $.01 \mu \mathrm{f}, 5 \%$ and all resistors are $1 \%$. The values for this filter and a low band filter are shown in Table 5.

TABLE 5

|  |  | $\mathbf{f}_{0}$ | $\omega_{0}$ | $\mathbf{Q}_{0}$ | $\mathbf{R}_{1}$ | $\mathbf{R}_{2}$ | $\mathbf{R}_{3}$ | $\mathbf{C}_{1}$ | $\mathbf{C}_{2}$ | $\mathbf{H}_{0}$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Originate | $\mathbf{A}$ | 1931.1 | 12.1335 K | 21.49 | 88.6 K | 192 | 354 K | .01 | .01 | 2 |
|  | $\mathbf{B}$ | 2317.6 | 14.562 K | 21.49 | 74 K | 160 | 295 K | .01 | .01 | 2 |
|  | $\mathbf{C}$ | 2115.6 | 13.293 K | 10.7 | 40 K | 355 | 161 K | .01 | .01 | 2 |
| Answer | $\mathbf{1}$ |  |  |  |  |  |  |  |  |  |
|  | $\mathbf{A}$ | 1362.26 | 10.115 K | 11.827 | 58.5 K | 421 | 234 K | .01 | .01 | 2 |
|  | $\mathbf{B}$ | 975.51 | 6129.3 | 11.827 | 96.5 K | 695 | 386 K | .01 | .01 | 2 |
|  | $\mathbf{C}$ | 1152.78 | 7.243 K | 5.832 | 40.3 K | 1219.5 | 161 K | .01 | .01 | 2 |



FIGURE 8

# Choosing the Right Op Amp 

Because of its versatility and ease of application, the op-amp is often the easiest active component to design into the circuit. However, once the initial "paper design" is accomplished, the user is faced with the key question: which op-amp is the best choice for the particular application? The availability of a very wide choice of IC op-amps of varying part numbers, types and features does not make the answer to this question an easy one. If the op-amp characteristics are not carefully considered, the total system performance may be degraded: similarly if each op-amp is overspecified with an excessive amount of "overkill" for the particular application, then the system cost will increase unnecessarily. The key selection criteria is finding the lowest cost operational amplifier which will be sufficient to meet the system performance requirements. This section provides a brief summary of various classes of IC op-amps, their features and key applications, to assist the user in choosing the most cost-effective operational amplifier for his application.

## General Purpose Op-Amps

A wide variety of op-amp applications such as low-frequency amplifiers, active filters, voltage-to-current converters and voltage regulators are most economically accomplished using the low-cost general purpose IC op-amps. These op-amps are almost all variations of the basic 741-type op-amp, and offer significant cost savings over any special-purpose op-amps. They are commercially available in single, dual or quad versions. The dual and quad op-amps are particularly cost-effective for applications such as active filters which require a multiplicity of op-amps. The cost per op-amp is usually lower if one can use multiple op-amp IC's rather than single op-amps.

The single and dual general purpose op-amps are available in both internally compensated and uncompensated versions. The quad op-amps are almost invariably internally compensated, to reduce the IC package pin count. Most general purpose IC op-amps have comparable electrical characteristics, namely open loop gain of $\geqslant 20 \mathrm{mV} / \mathrm{V}$, small-signal unity gain bandwidth of 1 to 2 MHz and a slew rate of $\approx 1 \mathrm{~V} / \mu \mathrm{sec}$.

Exar manufactures a wide choice of dual or quad general purpose op-amps. All of these op-amps are internally compensated to make them cost-effective and reduce the external parts count. Exar's general purpose op-amps recommended for most applications are XR-1458 and XR-4558 for duals, and XR-4136, XR-4212 and XR-4741 for quad op-amps.

## Ground Sensing Op-Amps

These types of op-amps have an input stage common-mode range which extends all the way to the negative supply rail. This is obtained by using Darlington-connected PNP transistors at the input stage of the op-amp. The key advantage of this class of op-amps is that they can be operated with a single positive supply, and still be able to detect or sense small signals near ground potential. The particular circuit recommended for this application is Exar's XR-3403 quad operational amplifier.

## Programmable Op-Amps

Programmable op-amps allow the user to "program" or set the operating current levels within the IC op-amp by means of an external setting resistor, and thus be able to trade-off power dissipation for slew-rate or signal bandwidth. These circuits are normally available in quad form, where the power levels of all or some of the op-amps in the package can be programmed by one or two external setting resistors. The key areas of applications for programmable op-amps are active filters and telecommunication channel filters where the user is normally concerned with power dissipation. These op-amps can also be programmed to operate at micro-power levels, by the choice of external setting resistors.

The programmable quad operational amplifiers are available with either one or two separate setting controls. Those with a single setting control have all four of the operational amplifiers programmed from same current setting control. Those with two setting controls have the four op-amps on the chip programmed either in groups of two, or in groups of one and three op-amps. The advantage of partitioned programming is that some of the op-amps in the IC package can be operated at a different power or bandwidth level than the rest of the opamps in the same chip. For example, in an active filter application, the three op-amps performing the filtering can be operated at a low-power level, yet the fourth op-amp which may be serving as an output buffer can be operated at a higher power level to provide load-drive capability.

Exar offers the broadest product line of programmable op-amps in the industry: The XR-4202, XR-146 and the XR-346-2 families of op-amps are all-bipolar programmable quad op-amp circuits. The XR-4202 offers a single current-setting control for all of the four op-amps on the chip; the XR-146 and the XR-346-2 offer partitioned programming of the four op amps. The XR-094 and XR-095 families are programmable FETinput quad op-amps which have the same pin configuration as the XR-146 and the XR-346-2 families, respectively. These programmable FET-input quad op-amps are fabricated using Exar's ion-implanted bipolar/FET or BIFET process technology which combines matched junction FETs and high-performance bipolar transistors on the same chip.

## FET-Input Op-Amps

Finite input impedance or input bias currents associated with conventional bipolar op-amps can be a problem in specific applications such as sample-hold circuits or signal sensing applications from high-impedance signal sources such as transducer systems. For such applications, op-amps with junctionFET input stages offer significant performance advantages since they offer input resistances of the order of $10^{12}$ ohms, and input bias currents in the low pico-ampere range. Another unique feature of FET-input op-amps is their high slew-rate and wide bandwidth. For example, most FET-input op-amps offer slew-rates in excess of $10 \mathrm{~V} / \mu \mathrm{sec}$ and unity gain bandwidth of 3 MHz .

The FET-input op-amps offer somewhat higher offset voltages and input noise than all-bipolar op-amps; however some specially designed FET input op-amps, such as Exar's XR-072 and XR-074 series have input noise voltages comparable to conventional bipolar op-amps.

Exar offers a wide selection of FET-input dual and quad opamps which are manufactured using Exar's ion-implanted BIFET process. The XR-082/XR-083 and the XR-072 are dual op-amps; the XR-074 and the XR-084 are quad FET-input op-amps. The XR-094 and the XR-095 are programmable quad FET-input op-amps. Because of their low power capability, the programmable BIFET op-amps are particularly suitable for low-power active filter designs.

## Low Noise Op-Amps

These op-amps are particularly suited for audio amplifier and mixer applications, where low noise is of prime importance. The noise characteristics of an op-amp are determined by the noise generated at the input stage, since the noise generated at this point is amplified by the full open-loop gain of the amplifier. In most cases, input noise voltages of $10 \mathrm{nV} / \sqrt{\mathrm{Hz}}$ or less is required to be suitable for high quality or professional audio signal processing applications. Such low noise characteristics are normally obtained by careful device design and manufacturing processing of the IC chips. In general, all-bipolar operational amplifiers tend to have better low noise characteristics than the FET-input op-amps.

Exar manufactures a number of low noise op-amp circuits uniquely suited to audio applications. Among Exar's family of low noise op-amps, the XR-5534 operational amplifier, and its dual versions, the XR-5532 and the XR-5533 offer the best noise performance.

## Low Distortion Op-Amps

In addition to low noise characteristics, another key performance requirement for audio applications is low distortion. The distortion characteristics of op-amps are normally determined by the design of the output stage as well as the amplifier bandwidth characteristics. The total harmonic distortion (THD) is made up of three components: (a) intermodulation distortion; (b) cross-over distortion which depends on output stage design, and (c) slew-induced distortion which occurs when the output of the op-amp is forced to slew faster than its slew-rate.

The cross-over distortion can be avoided by using op-amps which have class-AB, rather than class-B type output stages. All of Exar's op-amps fall into this category.

To avoid slew-induced distortion, one should ensure that the slew rate of the amplifier is never exceeded during the excursions of the input signal. The high-speed operational amplifiers such as Exar's XR-5533 or XR-5534 op-amps which have slew rates in excess of $10 \mathrm{~V} / \mu \mathrm{sec}$ with a power bandwidth of 200 kHz can easily cover the entire audio frequency range without introducing slew-induced distortion.


## Overview of Exar's Op Amp Products

Exar offers one of the widest selections of multiple op amps in the IC industry. These op amps vary from the general purpose 741-type quad and dual op amps to FET-input, low noise or programmable operational amplifier IC's, optimized for specific
applications or performance features. Table 1 shows an overview of the wide selection of op amp products available from Exar. A summary of the key features of these op amps are given in Table 2.

TABLE 1
An Overview of Exar's Op-Amp Products


TABLE 2
Key Features of Exar's Op-Amp Products

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  | $\checkmark$ | $\checkmark$ | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |  |
| Singe op-Amp |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | $\checkmark$ |
| Dual 0 P-Amp | $\checkmark$ |  |  | $\checkmark$ |  |  |  |  |  |  | $\checkmark$ |  |  |  |  |  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  |  |
| Otatad P-Amp |  |  | $\checkmark$ |  |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ |  |  |  |  |
|  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Progammable |  |  |  |  |  |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ |  |  |  |  | $\checkmark$ |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  | $\checkmark$ |  |  |  |  | $\checkmark$ | $\checkmark$ |  |  |  |  |  |  |
|  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |  |  |  |  |  |  |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ |
|  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |  |  |  |  |  |  |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ |
|  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Low Nose | $\checkmark$ |  | $\checkmark$ |  |  |  |  |  |  |  |  |  |  |  |  |  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ | $\checkmark$ |
|  |  |  |  |  |  |  |  |  |  |  |  | $\checkmark$ |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ |
|  | $\checkmark$ |  | $\checkmark$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | $\checkmark$ |  | $\checkmark$ |
|  | $\checkmark$ |  | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ | $\checkmark$ |  | $\checkmark$ | $\checkmark$ | $\checkmark$ | $\checkmark$ | $\checkmark$ |  |  |  |

## Industry-Wide Op-Amp Cross Reference

| MANUFACTURER | PART NUMBER | EXAR DIRECT REPLACEMENT | MANUFACTURER | PART NUMBER | EXAR DIRECT REPLACEMENT |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Advanced Micro Devices | AM1458PC | XR-4558P | RCA | CA1458E | XR-4558CP |
| Fairchild | $\mu \mathrm{A} 1458 \mathrm{TC}$ <br> 3043DC <br> 3043PC <br> 3503DM <br> 4136DM <br> 4136DC <br> 4136PC <br> 4558TC | XR-4558CP <br> XR-3403CN <br> XR-3403CP <br> XR-3403M <br> XR-4136M <br> XR-4136CN <br> XR-4136CP <br> XR-4558CP | Signetics | MC1458V <br> NE5558V <br> NE5534N <br> NE5534AN <br> NE5533N <br> NE5533AN <br> NE5532FE <br> NE5532AFE | XR-4558CP <br> XR-4558CP <br> XR-5534CP <br> XR-5534P <br> XR-5533CP <br> XR-5533P <br> XR-5532CP <br> XR-5532P |
| Harris | HA4741-2 HA4741-5 | $\begin{aligned} & \text { XR-4741M } \\ & \text { XR-4741CP } \end{aligned}$ | Texas Instruments | $\begin{aligned} & \text { RM4136J } \\ & \text { RC4136J } \end{aligned}$ | $\begin{aligned} & \text { XR-4136M } \\ & \text { XR-4136CN } \end{aligned}$ |
| Motorola | MC1402L <br> MC1402P <br> MC1458P <br> MC3403L <br> MC3403P <br> MC3503L | XR-4202N <br> XR-4202P <br> XR-4558CP <br> XR-3403CN <br> XR-3403CP <br> XR-3503M | $\frac{y}{4-8}$ | RC4136N RC4558P SN72558P TL072CP TL072CJG TL072IP TL072IJG | XR-4136CP <br> XR-4558CP <br> XR-4558CP <br> XR-072CP <br> XR-072CN <br> XR-072P <br> XR-072N |
| National Semiconductor | LM1458N <br> LM146 <br> LM146-2 <br> LM246 <br> LM246-2 <br> LM346 <br> LM346-2 | XR-4558CP <br> XR-146M <br> XR-146-2M <br> XR-246 <br> XR-246-2 <br> XR-346CP <br> XR-346-2CP |  | TL072MJG TL082CP TL082CJG TL082IP TL082IJG TL082MJG TL083CN TL083CJ | XR-072M <br> XR-082CP <br> XR-082CN <br> XR-082P <br> XR-082N <br> XR-082M <br> XR-083CP <br> XR-083CN |
| Precision Monolithics | SSS1458 | XR-4558CP |  | $\begin{aligned} & \text { TL083IN } \\ & \text { TL083IJ } \end{aligned}$ | $\begin{aligned} & \text { XR-083P } \\ & \text { XR-083N } \end{aligned}$ |
| Raytheon | RC1458NB <br> RC3403ADC <br> RC3403ADB <br> RC3503ADC <br> RM4136DC <br> RC4136DC <br> RC4136DB <br> RC4558NB <br> RC4739DC <br> RC4739DB <br> HA4741-2 <br> HA4741-5 | XR-4558CP <br> XR-3403CN <br> XR-3403CP <br> XR-3503M <br> XR-4136M <br> XR-4136CN <br> XR-4136CP <br> XR-4558CP <br> XR-4739CN <br> XR-4739CP <br> XR-471M <br> XR-4741CP |  | TL083MJ <br> TL074CJ <br> TL074IN <br> TL074IJ <br> TL074MJ <br> TL084CN <br> TL084CJ <br> TL084IN <br> TL084IJ <br> TL084MJ | XR-083M <br> XR-074CN <br> XR-074P <br> XR-074N <br> XR-074M <br> XR-084CP <br> XR-084CN <br> XR-084P <br> XR-084N <br> XR-084M |

## Quality Assurance Standards

The quality assurance program at Exar Integrated Systems defines and establishes standards and controls on manufacturing, and audits product quality at critical points during manufacturing. The accompanying Manufacturing/QA process flows illustrate where quality assurance audits, by inspection or test, the manufacturing process. The insertion of these quality assurance points is designed to insure the highest quality standards are maintained on Exar product during its manufacture.

Realizing that these standard Manufacturing/QA process flows do not meet the needs of every customer's specific requirements, Exar quality assurance can negotiate and will screen product to meet any individual customer's specific requirement.

All products ending with the suffix M are fully screened to the requirements of MIL-STD-883, Method 5004, Condition C.

HIGH RELIABILITY ASSEMBLY/QA FLOW


# Low-Noise Dual BIFET Operational Amplifier 

## GENERAL DESCRIPTION

The XR-072 low-noise junction FET input dual operational amplifier is designed to offer higher performance than conventional bipolar dual op-amps. Each of the two op-amps on the chip is closely matched in performance characteristics, and each amplifier features high slew-rate, low input bias and offset currents, and low offset voltage drift with temperature. The XR-072 FET-input dual op-amp is fabricated using ion implanted bipolar/FET or "BIFET" technology which combines well-matched junction FETs and high-performance bipolar transistors on the same monolithic integrated circuit. Its low noise characteristics make it particularly well-suited to low level signal processing, audio preamplification and active filter design.

## FEATURES

Direct Replacement for Texas Instruments TL072
High-Impedance Junction FET Input Stage
Internal Frequency Compensation
Low Power Consumption
Wide Common-Mode and Differential Voltage Ranges
Low Input Bias and Offset Currents
Output Short-Circuit Protection
Latch-Up-Free Operation
High Slew-Rate . . . $13 \mathrm{~V} / \mu \mathrm{s}$, Typical
Low Noise $\ldots 18 \mathrm{nV} / \sqrt{\mathrm{Hz}}$, Typical

## APPLICATIONS

Active Filter Design
Sample/Hold and Servo Systems
Audio Signal Processing
Analog Control Systems

## EQUIVALENT SCHEMATIC



ABSOLUTE MAXIMUM RATINGS
Supply Voltage
$\pm 18 \mathrm{~V}$
Differential Input Voltage
$\pm 30 \mathrm{~V}$
Input Voltage Range (Note 1)
$\pm 15 \mathrm{~V}$
Output Short-Circuit Duration (Note 2) Indefinite
Package Power Dissipation:
Plastic Package
Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Ceramic Package
Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$ $5.0 \mathrm{mV} /{ }^{\circ} \mathrm{C}$ 750 mW $6.0 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$
Storage Temperature Range
$-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$
Note 1: For Supply Voltage less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.
Note 2: The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

## AVAILABLE TYPES

| Part Number | Package |
| :--- | :--- |
| XR-072M | Ceramic |
| XR-072N | Ceramic |
| XR-072P | Plastic |
| XR-072CN | Ceramic |
| XR-072CP | Plastic |

## Operating Temperature

$-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$
$-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$
$-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$
FUNCTIONAL BLOCK DIAGRAM

## ELECTRICAL CHARACTERISTICS

$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}= \pm 15 \mathrm{~V}$, unless otherwise specified.

| CHARACTERISTICS | XR-072M |  |  | XR-072 |  |  | XR-072C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 3 | 6 9 |  | 3 | 6 9 |  | 3 | $\begin{aligned} & 10 \\ & 13 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\mathrm{V}_{\mathrm{OS}}$ <br> $\mathrm{V}_{\mathrm{OS}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Offset Voltage Temp. Coef. |  | 10 |  |  | 10 |  |  | 10 |  | $\mu \mathrm{V} /{ }^{\circ} \mathrm{C}$ | $\Delta \mathrm{V}_{\mathrm{OS}} / \Delta \mathrm{T}$ | $\mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=$ Full Range |
| Input Bias Current |  | 30 | $\begin{array}{r} 200 \\ 50 \end{array}$ |  | 30 | $\begin{array}{r} 200 \\ 20 \end{array}$ |  | 30 | $\begin{array}{r} 200 \\ 7 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  | 5 | $\begin{aligned} & 50 \\ & 20 \end{aligned}$ |  | 5 | $\begin{aligned} & 50 \\ & 10 \end{aligned}$ |  | 5 | $\begin{array}{r} 50 \\ 2 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | IOS | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current (per amplifier) |  | 1.4 | 2.5 |  | 1.4 | 2.5 |  | 1.4 | 2.5 | mA | $\mathrm{I}_{\mathrm{CC}}$ | No Load, No Input Signal |
| Input Common Mode Range | $\pm 12$ |  |  | $\pm 12$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Voltage Gain | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | 50 25 | 200 |  | $\begin{aligned} & 25 \\ & 15 \end{aligned}$ | 200 |  | $\mathrm{V} / \mathrm{mV}$ | $\mathrm{A}_{\text {VOL }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega, \mathrm{~V}_{0}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Max. Output Swing (peak-to-peak) | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | V | V OPP | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Resistance |  | $10^{12}$ |  |  | $10^{12}$ |  |  | $10^{12}$ |  | $\Omega$ | $\mathrm{R}_{\text {in }}$ | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$. |
| Unity-Gain Bandwidth |  | 3 |  |  | 3 |  |  | 3 |  | MHz | BW | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Common-Mode Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{~K} \Omega$ |
| Supply-Voltage Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | PSRR |  |
| Channel Separation |  | 120 |  |  | 120 |  |  | 120 |  | dB |  | $A_{V}=100$, Freq. $=1 \mathrm{kHz}$ |
| Slew Rate |  | 13 |  |  | 13 |  |  | 13 |  | $\mathrm{V} / \mu \mathrm{S}$ | $\mathrm{dV}_{\text {OUT }} / \mathrm{dt}$ | $\begin{aligned} & A_{V}=1, R_{L}=2 \mathrm{~K} \Omega \\ & C_{L}=100 \mathrm{pF}, \mathrm{~V}_{1}=10 \mathrm{~V} \end{aligned}$ |
| Rise Time Overshoot |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  | $\begin{aligned} & \mu \mathrm{sec} \\ & \% \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{0} \end{aligned}$ | $\begin{aligned} & A_{V}=1, R_{L}=2 \mathrm{~K} \Omega \\ & C_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=20 \mathrm{mV} \end{aligned}$ |
| Equivalent Input Noise Voltage |  | 18 |  |  | 18 |  |  | 18 |  | $\mathrm{nV} / \sqrt{\mathrm{Hz}}$ | $\mathrm{e}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega, \mathrm{f}=1 \mathrm{kHz} \\ & \mathrm{f}=10 \mathrm{~Hz} \text { to } 10 \mathrm{kHz} \end{aligned}$ |
| Equivalent Input <br> Noise Current |  | 0.01 |  |  | 0.01 |  |  | 0.01 |  | $\mathrm{pA} / \sqrt{\mathrm{Hz}}$ | $\mathrm{i}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega \\ & \mathrm{f}=1 \mathrm{kHz} \end{aligned}$ |
| Total Harmonic Distortion |  | 0.01 |  |  | 0.01 |  |  | 0.01 |  | \% | THD | $\begin{aligned} & \mathrm{V}_{0}=10 \mathrm{~V}, \mathrm{rms} \\ & \mathrm{f}=10 \mathrm{kHz}, \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega \\ & \mathrm{R}_{\mathrm{S}} \leqslant 1 \mathrm{~K} \Omega \end{aligned}$ |

# Low-Noise Quad BIFET Operational Amplifier 

## GENERAL DESCRIPTION

The XR-074 low-noise junction FET input quad operational amplifier is designed to offer higher performance than conventional bipolar quad op-amps. Each of the four op-amps on the chip is closely matched in performance characteristics, and each amplifier features high slew-rate, low input bias and offset currents, and low offset voltage drift with temperature. The XR-074 FET input quad op-amp is fabricated using ion implanted bipolar/FET or "BIFET" technology which combines well-matched junction FETs and high-performance bipolar transistors on the same monolithic integrated circuit. Its low noise characteristics make it particularly well-suited to low level signal processing, audio preamplification and active filter design.

## FEATURES

Direct Replacement for Texas Instruments TL074
Same Pin Configuration as XR-3403
High-Impedance Junction FET Input Stage
Internal Frequency Compensation
Low Power Consumption
Wide Common-Mode and Differential Voltage Ranges
Low Input Bias and Offset Currents
Output Short-Circuit Protection
Latch-Up-Free Operation
High Slew-Rate $\ldots 13 \mathrm{~V} / \mu$ s, Typical
Low Noise . . . $18 \mathrm{nV} / \sqrt{\mathrm{Hz}}$, Typical

## APPLICATIONS

Active Filter Design
Sample/Hold and Servo Systems
Audio Signal Processing
Analog Control Systems

## EQUIVALENT SCHEMATIC



## ABSOLUTE MAXIMUM RATINGS

Supply Voltage $\pm 18 \mathrm{~V}$
Differential Input Voltage $\pm 30 \mathrm{~V}$
Input Voltage Range(Note 1) $\pm 15 \mathrm{~V}$
Output Short-Circuit Duration (Note 2) Indefinite
Package Power Dissipation:
Plastic Package
Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Ceramic Package
Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Storage Temperature Range
625 mW
$5.0 \mathrm{mV} /{ }^{\circ} \mathrm{C}$
750 mW
$6.0 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$
Note 1: For Supply Voltage less than +15 V , the absolute maximum input voltage is equal to the supply voltage.
Note 2: The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.
AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | ---: |
| XR-074M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-074N | Ceramic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-074P | Plastic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-074CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-074CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS
$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}= \pm 15 \mathrm{~V}$, unless otherwise specified.

| CHARACTERISTICS | XR-074M |  |  | XR-074 |  |  | XR-074C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 3 | 6 9 |  | 3 | 6 9 |  | 3 | $\begin{aligned} & 10 \\ & 13 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\mathrm{V}_{\mathrm{OS}}$ $V_{\text {OS }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Offset Voltage Temp. Coef. |  | 10 |  |  | 10 |  |  | 10 |  | $\mu \mathrm{V} /{ }^{\circ} \mathrm{C}$ | $\Delta \mathrm{V}_{\mathrm{OS}} / \Delta \mathrm{T}$ | $\mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=$ Full Range |
| Input Bias Current |  | 30 | $\begin{array}{r} 200 \\ 50 \end{array}$ |  | 30 | $\begin{array}{r} 200 \\ 20 \end{array}$ |  | 30 | $\begin{array}{r} 200 \\ 7 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  | 5 | 50 20 |  | 5 | $\begin{aligned} & 50 \\ & 10 \end{aligned}$ |  | 5 | $\begin{array}{r} 50 \\ 2 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | IOS | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current (per amplifier) |  | 1.4 | 2.5 |  | 1.4 | 2.5 |  | 1.4 | 2.5 | mA | $\mathrm{I}_{\mathrm{CC}}$ | No Load, No Input Signal |
| Input Common Mode Range | $\pm 12$ |  |  | $\pm 12$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Voltage Gain | 50 25 | 200 |  | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | 25 15 | 200 |  | $\mathrm{V} / \mathrm{mV}$ | $\mathrm{A}_{\text {VOL }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega, \mathrm{~V}_{0}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Max. Output Swing (peak-to-peak) | 24 24 | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | V | $\mathrm{V}_{\text {OPP }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Resistance |  | $10^{12}$ |  |  | $10^{12}$ |  |  | $10^{12}$ |  | $\Omega$ | $\mathrm{R}_{\text {in }}$ | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Unity-Gain Bandwidth |  | 3 |  |  | 3 |  |  | 3 |  | MHz | BW | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Common-Mode Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{~K} \Omega$ |
| Supply-Voltage Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | PSRR |  |
| Channel Separation |  | 120 |  |  | 120 |  |  | 120 |  | dB |  | $\mathrm{A}_{\mathrm{V}}=100$, Freq. $=1 \mathrm{kHz}$ |
| Slew Rate |  | 13 |  |  | 13 |  |  | 13 |  | $\mathrm{V} / \mu \mathrm{S}$ | dV ${ }_{\text {OUT } / \mathrm{dt}}$ | $\begin{aligned} & A_{V}=1, \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=10 \mathrm{~V} \end{aligned}$ |
| Rise Time Overshoot |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  |  | 0.1 10 |  |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  | $\begin{aligned} & \mu \mathrm{sec} \\ & \% \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{o}} \end{aligned}$ | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=20 \mathrm{mV} \end{aligned}$ |
| Equivalent Input Noise Voltage |  | 18 |  |  | 18 |  |  | 18 |  | $\mathrm{nV} / \sqrt{\mathrm{Hz}}$ | $\mathrm{e}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega, \mathrm{f}=1 \mathrm{kHz} \\ & \mathrm{f}=10 \mathrm{~Hz} \text { to } 10 \mathrm{kHz} \end{aligned}$ |
| Equivalent Input Noise Current |  | 0.01 |  |  | 0.01 |  |  | 0.01 |  | $\mathrm{pA} / \sqrt{\mathrm{Hz}}$ | $i_{n}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega \\ & \mathrm{f}=1 \mathrm{kHz} \end{aligned}$ |
| Total Harmonic Distortion |  | 0.01 |  |  | 0.01 |  |  | 0.01 |  | \% | THD | $\begin{aligned} & \mathrm{V}_{0}=10 \mathrm{~V}, \mathrm{rms} \\ & \mathrm{f}=10 \mathrm{kHz}, \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega \\ & \mathrm{R}_{\mathrm{S}} \leqslant 1 \mathrm{~K} \Omega \end{aligned}$ |

## XR-082/083

# Dual BIFET Operational Amplifiers 

## GENERAL DESCRIPTION

The XR-082/XR-083 family of junction FET input dual operational amplifiers are designed to offer higher performance than conventional bipolar op-amps. Each amplifier features high slew-rate, low input bias and offset currents, and low offset voltage drift with temperature. These operational amplifier circuits are fabricated using ion-implantation technology which combines well-matched junction FETs and high-performance bipolar transistors on the same monolithic chip. This technology, known as the bipolar/FET or "BIFET" process, results in greatly improved performance compared to conventional op-amps fabricated using only bipolar transistors.
The XR-082 family of dual BIFET op-amps are packaged in 8-pin dual-in-line packages. The XR-083 family of op-amps offer independent offset adjustment for each of the individual op-amps on the same chip, and are available in 14 -pin dual-in-line packages.

## FEATURES

Direct Replacement for Texas Instruments TL082 and TL083
Low Power Consumption LM324
Wide Common-Mode and Differential Voltage Ranges
Low Input Bias and Offset Currents
Output Short-Circuit Protection
High Input Impedance . . . FET Input Stage
Internal Frequency Compensation
Latch-Up-Free Operation
High Slew-Rate ... $13 \mathrm{~V} / \mu$ s, Typical

## APPLICATIONS

Active Filter Design
Sample/Hold and Servo Systems
Audio Signal Processing
Analog Control Systems

## EQUIVALENT SCHEMATIC



| ABSOLUTE MAXIMUM RATINGS |  |
| :--- | ---: |
| Supply Voltage | $\pm 18 \mathrm{~V}$ |
| Differential Input Voltage | $\pm 30 \mathrm{~V}$ |
| Input Voltage Range (Note 1) | $\pm 15 \mathrm{~V}$ |
| Output Short-Circuit Duration (Note 2) | Indefinite |
| Package Power Dissipation: | 625 mW |
| $\quad$ Plastic Package | $5.0 \mathrm{mV} /{ }^{\circ} \mathrm{C}$ |
| $\quad$ Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$ | 750 mW |
| $\quad$ Ceramic Package | $6.0 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$ |
| Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$ | $-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$ |

Note 1: For Supply Voltage less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.
Note 2: The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

## AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-082M/XR-083M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-082N/XR-083N | Ceramic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-082P/XR-083P | Plastic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-082CN/XR-083CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-082CP/XR-083CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS
$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}= \pm 15 \mathrm{~V}$, unless otherwise specified.

| CHARACTERISTICS | XR-082M/XR-083M |  |  | XR-082/XR-083 |  |  | XR-082C/XR-083C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 3 | 6 9 |  | 3 | 6 9 |  | 5 | $\begin{aligned} & 15 \\ & 20 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\begin{array}{\|l\|l} \mathrm{v}_{\mathrm{OS}} \\ \mathrm{v}_{\mathrm{OS}} \end{array}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Offset Voltage Temp. Coef. |  | 10 |  |  | 10 |  |  | 10 |  | $\mu \mathrm{V} /{ }^{\circ} \mathrm{C}$ | $\Delta \mathrm{V}_{\mathrm{OS}} / \Delta \mathrm{T}$ | $\mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=$ Full Range |
| Input Bias Current |  | 30 | $\begin{array}{r} 200 \\ 50 \end{array}$ |  | 30 | $\begin{array}{r} 200 \\ 20 \end{array}$ |  | 30 | $\begin{array}{r} 400 \\ 20 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  | 5 | 100 20 |  | 5 | $\begin{array}{r} 100 \\ 10 \end{array}$ |  | 5 | $\begin{array}{r} 200 \\ 5 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{OS}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current (per amplifier) |  | 1.4 | 2.8 |  | 1.4 | 2.8 |  | 1.4 | 2.8 | mA | $\mathrm{I}_{\mathrm{CC}}$ | No Load, No Input Signal |
| Input Common Mode Range | $\pm 12$ |  |  | $\pm 12$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Voltage Gain | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | 25 | 200 |  | $\mathrm{V} / \mathrm{mV}$ | Avol | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega, \mathrm{~V}_{0}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Max. Output Swing (peak-to-peak) | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | V | $\mathrm{V}_{\text {OPP }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Resistance |  | $10^{12}$ |  |  | $10^{12}$ |  |  | $10^{12}$ |  | $\Omega$ | $\mathrm{R}_{\text {in }}$ | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Unity-Gain Bandwidth |  | 3 |  |  | 3 |  |  | 3 |  | MHz | BW | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Common-Mode Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{~K} \Omega$ |
| Supply-Voltage Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | PSRR |  |
| Channel Separation |  | 120 |  |  | 120 |  |  | 120 |  | dB |  | $\mathrm{A}_{\mathrm{V}}=100$, Freq. $=1 \mathrm{kHz}$ |
| Slew Rate |  | 13 |  |  | 13 |  |  | 13 |  | $\mathrm{V} / \mu \mathrm{S}$ | dV $\mathrm{out}_{\text {out }}$ dt | $\begin{aligned} & A_{V}=1, R_{L}=2 \mathrm{~K} \Omega \\ & C_{L}=100 \mathrm{pF}, \mathrm{~V}_{1}=10 \mathrm{~V} \end{aligned}$ |
| Rise Time Overshoot |  | $\begin{gathered} 0.1 \\ 10 \end{gathered}$ |  |  | $\begin{gathered} 0.1 \\ 10 \end{gathered}$ |  |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  | $\begin{aligned} & \mu \mathrm{sec} \\ & \% \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{O}} \end{aligned}$ | $\begin{aligned} & A_{V}=1, \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=20 \mathrm{mV} \end{aligned}$ |
| Equivalent Input Noise Voltage |  | 47 |  |  | 47 |  |  | 47 |  | $\mathrm{nV} / \sqrt{\mathrm{Hz}}$ | $\mathrm{e}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega \\ & \mathrm{f}=1 \mathrm{kHz} \end{aligned}$ |

## XR-084

## Quad BIFET Operational Amplifier

## GENERAL DESCRIPTION

The XR-084 junction FET input quad operational amplifier is designed to offer higher performance than conventional bipolar quad op-amps. Each of the four op-amps on the chip is closely matched in performance characteristics, and each amplifier features high slew-rate, low input bias and offset currents, and low offset voltage drift with temperature. The XR-084 FET input quad op-amp is fabricated using ion implanted bipolar/FET or "BIFET" technology which combines well-matched junction FETs and high-performance bipolar transistors on the same monolithic integrated circuit.

## FEATURES

Direct Replacement for Texas Instruments TL084
Same Pin Configuration as XR-3403 LM324
High-Impedance Junction FET Input Stage
Internal Frequency Compensation
Low Power Consumption
Wide Common-Mode and Differential Voltage Ranges
Low Input Bias and Offset Currents
Output Short-Circuit Protection
Latch-Up-Free Operation
High Slew-Rate . . $13 \mathrm{~V} / \mu \mathrm{s}$, Typical

## APPLICATIONS

Active Filter Design
Sample/Hold and Servo Systems
Audio Signal Processing
Analog Control Systems

## EQUIVALENT SCHEMATIC



## ABSOLUTE MAXIMUM RATINGS

Supply Voltage $\pm 18 \mathrm{~V}$
Differential Input Voltage $\pm 30 \mathrm{~V}$
Input Voltage Range (Note 1)
Output Short-Circuit Duration (Note 2)
Package Power Dissipation:
Plastic Package
Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Ceramic Package
Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Storage Temperature Range
$-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$
Note 1: For Supply Voltage less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.
Note 2: The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

## AVAILABLE TYPES

Part Number
XR-084M
XR-084N
XR-084P
XR-084CN
XR-084CP

## Package

Ceramic
Ceramic Plastic Ceramic Plastic

## Operating Temperature

$-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$
$-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$
$-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$

## FUNCTIONAL BLOCK DIAGRAM



## ELECTRICAL CHARACTERISTICS

$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}= \pm 15 \mathrm{~V}$, unless otherwise specified.

| CHARACTERISTICS | XR-084M |  |  | XR-084 |  |  | XR-084C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 3 | 6 9 |  | 3 | 6 9 |  | 5 | $\begin{aligned} & 15 \\ & 20 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\begin{aligned} & \mathrm{v}_{\mathrm{OS}} \\ & \mathrm{v}_{\mathrm{OS}} \end{aligned}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Offset Voltage Temp. Coef. |  | 10 |  |  | 10 |  |  | 10 |  | $\mu \mathrm{V} /{ }^{\circ} \mathrm{C}$ | $\Delta \mathrm{V}_{\mathrm{OS}} / \Delta \mathrm{T}$ | $\mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=$ Full Range |
| Input Bias Current |  | 30 | 200 50 |  | 30 | $\begin{array}{r} 200 \\ 20 \end{array}$ |  | 30 | $\begin{array}{r} 400 \\ 20 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  | 5 | 100 20 |  | 5 | $\begin{array}{r} 100 \\ 10 \end{array}$ |  | 5 | $\begin{array}{r} 200 \\ 5 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | IOS | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current (per amplifier) |  | 1.4 | 2.8 |  | 1.4 | 2.8 |  | 1.4 | 2.8 | mA | $\mathrm{I}_{\mathrm{CC}}$ | No Load, No Input Signal |
| Input Common Mode Range | $\pm 12$ |  |  | $\pm 12$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Voltage Gain | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | $\begin{aligned} & 25 \\ & 15 \end{aligned}$ | 200 |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega, \mathrm{~V}_{0}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Max. Output Swing (peak-to-peak) | 24 24 | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | V | $\mathrm{V}_{\text {OPP }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Resistance |  | $10^{12}$ |  |  | $10^{12}$ |  |  | $10^{12}$ |  | $\Omega$ | $\mathrm{R}_{\text {in }}$ | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Unity-Gain Bandwidth |  | 3 |  |  | 3 |  |  | 3 |  | MHz | BW | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Common-Mode Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{~K} \Omega$ |
| Supply-Voltage Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | PSRR |  |
| Channel Separation |  | 120 |  |  | 120 |  |  | 120 |  | dB |  | $A_{V}=100$, Freq. $=1 \mathrm{kHz}$ |
| Slew Rate |  | 13 |  |  | 13 |  |  | 13 |  | $\mathrm{V} / \mu \mathrm{S}$ | dV $\mathrm{out}^{\text {/ }} \mathrm{dt}$ | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=10 \mathrm{~V} \end{aligned}$ |
| Rise Time Overshoot |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  |  | $\begin{gathered} 0.1 \\ 10 \end{gathered}$ |  | $\begin{aligned} & \mu \mathrm{sec} \\ & \% \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{o}} \end{aligned}$ | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=20 \mathrm{mV} \end{aligned}$ |
| Equivalent Input Noise Voltage |  | 47 |  |  | 47 |  |  | 47 |  | $\mathrm{nV} / \sqrt{\mathrm{H} z}$ | $e_{n}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega \\ & \mathrm{f}=1 \mathrm{kHz} \end{aligned}$ |

# Programmable Quad BIFET Operational Amplifier 

## GENERAL DESCRIPTION

The XR-094 and XR-095 junction FET input quad programmable operational amplifiers consist of four independent, high gain, internally compensated amplifiers. Two external resistors ( $\mathrm{R}_{\mathrm{SET}}$ ) allow the user to program supply current slew-rate input noise without the usual sacrifice of gain bandwidth product. For example, the user can trade-off slew-rate for supply current or optimize the noise figure for a given source impedance. Except for the two programming pins at the end of the package, the XR-094 and XR-095 pin-out is the same as the popular $324,3403,124,148$ and 4741 operational amplifiers.
As shown in the individual functional block diagrams, the XR-094 will find great application in active filter designs where only the output amplifier would require a high slew-rate. The XR-095 allows the user to program for two specific frequencies where dual op-amps are employed to perform this function.

## FEATURES

Same Pin Configuration as LM-346
High-Impedance Junction FET Input Stage
Internal Frequency Compensation
Low Power Consumption
Wide Common-Mode and Differential Voltage Ranges
Low Input Bias and Offset Currents
Output Short-Circuit Protection Latch-Up-Free Operation
High Slew-Rate . . $13 \mathrm{~V} / \mu$ s, Typical
Programmable Electrical Characteristics

## APPLICATIONS INFORMATION

Total Supply Current $=5.6 \mathrm{~mA}\left(\mathrm{I}_{\mathrm{SET}} / 320 \mu \mathrm{~A}\right)$
Slew-Rate $=13 \mathrm{~V} / \mu \mathrm{S}\left(\mathrm{I}_{\text {SET }} / 320 \mu \mathrm{~A}\right)$
$\mathrm{I}_{\mathrm{SET}}=$ Current into pin 8, pin 9 (see schematic)
$\mathrm{I}_{\mathrm{SET}}=\frac{+\mathrm{V}_{\mathrm{CC}}--\mathrm{V}_{\mathrm{EE}}-0.6 \mathrm{~V}}{\mathrm{R}_{\mathrm{SET}}}$

EQUIVALENT SCHEMATIC


## ABSOLUTE MAXIMUM RATINGS

Supply Voltage $\pm 18 \mathrm{~V}$
Differential Input Voltage $\pm 30 \mathrm{~V}$
Input Voltage Range (Note 1) $\pm 15 \mathrm{~V}$
Output Short-Circuit Duration (Note 2) Indefinite
Package Power Disspation:
Plastic Package $\quad 625 \mathrm{~mW}$ Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C} \quad 5.0 \mathrm{mV} /{ }^{\circ} \mathrm{C}$
Ceramic Package Derate Above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C} \quad 6.0 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$
Storage Temperature Range $-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$
Note 1: For Supply Voltage less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.
Note 2: The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

## AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-094/XR-095M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-094/XR-095N | Ceramic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-094/XR-095P | Plastic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-094/XR-095CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-094/XR-095CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

## FUNCTIONAL BLOCK DIAGRAMS



## ELECTRICAL CHARACTERISTICS

$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}= \pm 15 \mathrm{~V}$, unless otherwise specified.
$\mathrm{I}_{\mathrm{SET}}=320 \mu \mathrm{~A}$.

| CHARACTERISTICS | XR-094/095M |  |  | XR-094/095 |  |  | XR-094/095C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 3 | 6 9 |  | 3 | 6 9 |  | 5 | $\begin{aligned} & 15 \\ & 20 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\mathrm{V}_{\mathrm{OS}}$ <br> $\mathrm{V}_{\mathrm{OS}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Offset Voltage Temp. Coef. |  | 10 |  |  | 10 |  |  | 10 |  | $\mu \mathrm{V} /{ }^{\circ} \mathrm{C}$ | $\Delta \mathrm{V}_{\mathrm{OS}} / \Delta \mathrm{T}$ | $\mathrm{R}_{\mathrm{S}}=50 \Omega, \mathrm{~T}_{\mathrm{A}}=$ Full Range |
| Input Bias Current |  | 30 | 200 50 |  | 30 | $\begin{array}{r} 200 \\ 20 \end{array}$ |  | 30 | $\begin{array}{r} 400 \\ 20 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  |  | 100 20 |  | 5 | $\begin{array}{r} 100 \\ 10 \end{array}$ |  | 5 | $\begin{array}{r} 200 \\ 5 \end{array}$ | $\begin{aligned} & \mathrm{pA} \\ & \mathrm{nA} \end{aligned}$ | IOS | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current (per amplifier) |  | 1.4 | 2.8 |  | 1.4 | 2.8 |  | 1.4 | 2.8 | mA | $\mathrm{I}_{\mathrm{CC}}$ | No Load, No Input Signal |
| Input Common Mode Range | $\pm 12$ |  |  | $\pm 12$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Voltage Gain | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 200 |  | $\begin{aligned} & 25 \\ & 15 \end{aligned}$ | 200 |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{~K} \Omega, \mathrm{~V}_{0}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Max. Output Swing (peak-to-peak) | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | $\begin{aligned} & 24 \\ & 24 \end{aligned}$ | 27 |  | 24 24 | 27 |  | V | V ${ }_{\text {OPP }}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Resistance |  | $10^{12}$ |  |  | $10^{12}$ |  |  | $10^{12}$ |  | $\Omega$ | $\mathrm{R}_{\text {in }}$ | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Unity-Gain Bandwidth |  | 3 |  |  | 3 |  |  | 3 |  | MHz | BW | $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$ |
| Common-Mode Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{~K} \Omega$ |
| Supply-Voltage Rejection | 80 | 86 |  | 80 | 86 |  | 70 | 76 |  | dB | PSRR |  |
| Channel Separation |  | 120 |  |  | 120 |  |  | 120 |  | dB |  | $A_{V}=100$, Freq. $=1 \mathrm{kHz}$ |
| Slew Rate |  | 13 |  |  | 13 |  |  | 13 |  | $\mathrm{V} / \mu \mathrm{S}$ | $d V_{\text {out }} / \mathrm{dt}$ | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}, \mathrm{~V}_{1}=10 \mathrm{~V} \end{aligned}$ |
| Rise Time Overshoot |  | $\begin{array}{r} 0.1 \\ 10 \end{array}$ |  |  | 0.1 10 |  |  | 0.1 10 |  | $\begin{aligned} & \mu \mathrm{sec} \\ & \% \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{o}} \end{aligned}$ | $\begin{aligned} & A_{V}=1, R_{L}=2 \mathrm{~K} \Omega \\ & C_{L}=100 \mathrm{pF}, \mathrm{~V}_{1}=20 \mathrm{mV} \end{aligned}$ |
| Equivalent Input Noise Voltage |  | 47 |  |  | 47 |  |  | 47 |  | $\mathrm{nV} / \sqrt{\mathrm{H} z}$ | $\mathrm{e}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=100 \Omega \\ & \mathrm{f}=1 \mathrm{kHz} \end{aligned}$ |

## XR-146/246/346

## Programmable Quad Operational Amplifier

The XR-146 family of quad operational amplifiers contain four independent high-gain, low-power, programmable op-amps on a monolithic chip. The use of external bias setting resistors permit the user to program gain-bandwidth product, supply current, input bias current, input offset current, input noise and the slew rate.

The basic XR-146 family of circuits offer partitioned programming of the internal op-amps where one setting resistor is used to set the bias levels in the three op-amps, and a second bias setting is used for the remaining op-amp. Its modified version, the XR-$346-2$ provides a separate bias setting resistor for each of the two op-amp pairs.

## FEATURES

## Programmable

Micropower operation
Low noise
Wide power supply range
Class AB output
Ideal pin out for biquad active filters
Overload protection for input and output
Internal frequency compensation

## APPLICATIONS INFORMATION

Total Supply Current $=1.4 \mathrm{~mA}\left(\mathrm{I}_{\mathrm{SET}} / 10 \mu \mathrm{~A}\right)$
Gain Bandwidth Product $=1 \mathrm{MHz}\left(\mathrm{I}_{\mathrm{SET}} / 10 \mu \mathrm{~A}\right)$
Slew Rate $=0.4 \mathrm{~V} / \mu \mathrm{s}\left(\mathrm{I}_{\mathrm{SET}} / 10 \mu \mathrm{~A}\right)$
Input Bias Current $\cong 50 \mathrm{nA}\left(\mathrm{I}_{\mathrm{SET}} / 10 \mu \mathrm{~A}\right)$
$\mathrm{I}_{\mathrm{SET}}=$ Current into pin 8 , pin 9 (see schematic)
$\mathrm{I}_{\mathrm{SET}}=\frac{\mathrm{V}^{+}-\mathrm{V}^{-}-0.6 \mathrm{~V}}{\mathrm{R}_{\mathrm{SET}}}$

## EQUIVALENT SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS
Supply Voltage
XR-146 $\pm 22 \mathrm{~V}$

XR-246/346 $\pm 18 \mathrm{~V}$
Differential Input Voltage (Note 1) $\pm 30 \mathrm{~V}, ~$
XR-146/246/346
Common Mode Input Voltage (Note 1)
XR-146/246/346 15 V
Power Dissipation (Note 2)
XR-146
900 mW
XR-246/346
500 mW
Output Short Circuit Duration (Note 3)
XR-146/246/346
Indefinite
Maximum Junction Temperature
XR-146
$150^{\circ} \mathrm{C}$
XR-246
XR-346
Storage Temperature Range
XR-146/246/346
$-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$

## AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-146M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-246N | Ceramic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-246P | Plastic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-346/346-2CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+70^{\circ} \mathrm{C}$ |
| XR-346/346-2CP | Plastic | $0^{\circ} \mathrm{C}$ to $+70^{\circ} \mathrm{C}$ |

FUNCTIONAL BLOCK DIAGRAMS


ELECTRICAL CHARACTERISTICS $\left(\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}, \mathrm{I}_{\text {SET }}=10 \mu \mathrm{~A}\right)$

| PARAMETER | XR-146 |  |  | XR-246/346 |  |  | UNITS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |
| Input Offset Voltage |  | 0.5 | 5 |  | 0.5 | 6 | mV | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}, \mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| Input Offset Current |  | 2 | 20 |  | 2 | 100 | nA | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}$ |
| Input Bias Current |  | 50 | 100 |  | 50 | 250 | nA | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}$ |
| Supply Current (4 Op-Amps) | 8 | 1.4 | 2.0 |  | 1.4 | 2.5 | mA |  |
| Large Signal Voltage Gain | 100 | 1000 |  | 50 | 1000 |  | $\mathrm{V} / \mathrm{mV}$ | $\mathrm{R}_{\mathrm{L}}=10 \mathrm{k} \Omega, \Delta \mathrm{V}_{\text {OUT }}= \pm 10 \mathrm{~V}$ |
| Input CM Range | $\pm 13.5$ | $\pm 14$ |  | $\pm 13.5$ | $\pm 14$ |  | V |  |
| CM Rejection Ratio | 80 | 100 |  | 70 | 100 |  | dB | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{k} \Omega$ |
| Power Supply Rejection Ratio | 80 | 100 |  | 74 | 100 |  | dB | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{k} \Omega$ |
| Output Voltage Swing | $\pm 12$ | $\pm 14$ |  | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{k} \Omega$ |
| Short-Circuit Current | 5 | 20 | 30 | 5 | 20 | 30 | mA |  |
| Gain Bandwidth Product | 0.8 | 1.2 |  | 0.5 | 1.2 |  | MHz |  |
| Phase Margin |  | 60 |  |  | 60 |  | Deg |  |
| Slew Rate |  | 0.4 |  |  | 0.4 |  | V/ $\mu \mathrm{s}$ |  |
| Input Noise Voltage |  | 28 |  |  | 28 |  | $\mathrm{nV} / \sqrt{\mathrm{Hz}}$ | $\mathrm{f}=1 \mathrm{kHz}$ |
| Channel Separation |  | 120 |  |  | 120 |  | dB | $\begin{aligned} & \mathrm{R}_{\mathrm{L}}=10 \mathrm{k} \Omega, \Delta \mathrm{~V}_{\text {OUT }}=0 \mathrm{~V} \text { to } \\ & \pm 12 \mathrm{~V} \end{aligned}$ |
| Input Resistance |  | 1.0 |  |  | 1.0 |  | $\mathrm{M} \Omega$ |  |
| Input Capacitance |  | 2.0 |  |  | 2.0 |  | pF |  |

The following specifications apply over the Maximum Operating Temperature Range.

| Input Offset Voltage |  | 0.5 | 6 |  | 0.5 | 7.5 | mV | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}, \mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :--- |
| Input Offset Current |  | 2 | 25 |  | 2 | 100 | nA | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}$ |
| Input Bias Current |  | 50 | 100 |  | 50 | 250 | nA | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}$ |
| Supply Current (4 Op-Amps) |  | 1.5 | 2.0 |  | 1.5 | 2.5 | mA |  |
| Large Signal Voltage Gain | 50 | 1000 |  |  | 25 | 1000 | $\mathrm{~V} / \mathrm{mV}$ | $\mathrm{R}_{\mathrm{L}}=10 \mathrm{k} \Omega, \Delta \mathrm{V}_{\mathrm{OUT}}= \pm 10 \mathrm{~V}$ |
| Input CM Range | $\pm 13.5$ | $\pm 14$ |  | $\pm 13.5$ | $\pm 14$ |  | V |  |
| CM Rejection Ratio | 70 | 100 |  | 70 | 100 |  | dB | $\mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| Power Supply Rejection Ratio | 76 | 100 |  | 74 | 100 |  | dB | $\mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| Output Voltage Swing | $\pm 12$ | $\pm 14$ |  | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{k} \Omega$ |

ELECTRICAL CHARACTERISTICS $\left(\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}, \mathrm{I}_{\text {SET }}=1 \mu \mathrm{~A}\right)$

| Input Offset Voltage |  | 0.5 | 5 |  | 0.5 | 6 | $m V$ | $V_{C M}=0 \mathrm{~V}, \mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :--- |
| Input Bias Current |  | 7.5 | 20 |  | 7.5 | 100 | nA | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}$ |
| Supply Current (4 Op-Amps) |  | 140 | 250 |  | 140 | 300 | $\mu \mathrm{~A}$ |  |
| Gain Bandwidth Product | 80 | 100 |  | 50 | 100 |  | kHz |  |

ELECTRICAL CHARACTERISTICS $\left(\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 1.5 \mathrm{~V}, \mathrm{I}_{\mathrm{SET}}=10 \mu \mathrm{~A}\right)$

| Input Offset Voltage |  | 0.5 | 5 |  | 0.5 | 7 | mV | $\mathrm{V}_{\mathrm{CM}}=0 \mathrm{~V}, \mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :--- |
| Input CM Range | $\pm 0.7$ |  |  | $\pm 0.7$ |  |  | V |  |
| CM Rejection Ratio |  | 80 |  |  | 80 |  | dB | $\mathrm{R}_{\mathrm{S}} \leqslant 50 \Omega$ |
| Output Voltage Swing | $\pm 0.6$ |  |  | $\pm 0.6$ |  |  | V | $\mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{k} \Omega$ |

TYPICAL PERFORMANCE CHARACTERISTICS


TYPICAL PERFORMANCE CHARACTERISTICS (Continued)


Note 1: For supply voltages less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.
Note 2: The maximum power dissipation for these devices must be derated at elevated temperatures and is dictated by $\mathrm{T}_{\mathrm{j} M A X}$, $\theta \mathrm{jA}$, and the ambient temperature, $\mathrm{T}_{\mathrm{A}}$. The maximum available power dissipation at any temperature is $\mathrm{P}_{\mathrm{d}}=\left(\mathrm{T}_{\mathrm{j} M A X}-\mathrm{T}_{\mathrm{A}}\right) / \theta \mathrm{jA}$ or the $25^{\circ} \mathrm{C} \mathrm{P}_{\mathrm{dMAX}}$, whichever is less.
Note 3: Any of the amplifier outputs can be shorted to ground indefinitely; however, more than one should be simultaneously shorted as the maximum junction temperature will be exceeded.

# Quad Operational Amplifier 

## GENERAL DESCRIPTION

The XR-3403 is an array of four independent operational amplifiers, each with true differential inputs. The device has electrical characteristics similar to the popular 741. However, the XR-3403 has several distinct advantages over standard operational amplifier types in single supply applications. The XR-3403 can operate at supply voltages as low as 3.0 volts or as high as 36 volts with quiescent currents about one-fifth of those associated with the 741 (on a per amplifier basis). The common mode input range includes the negative supply, thereby eliminating the necessity for external biasing components in many applications. The output voltage range also includes the negative power supply voltage. The XR-3503 is the military-grade version of the XR-3403.

## FEATURES

Short Circuit Protected Outputs
Class AB Output Stage for Minimal Crossover Distortion
True Differential Input Stage
Single Supply Operation: 3.0 to 36 Volts
Split Supply Operation: $\pm 1.5$ to $\pm 18$ Volts
Low Input Bias Currents: 500 nA Max
Four Amplifiers per Package
Internally Compensated
Similar Performance to Popular 741
Direct Pin-for-Pin Replacement for MC3403/3503, LM324 and RC4137

| ABSOLUTE MAXIMUM RATINGS |  |
| :--- | ---: |
| Power Supply Voltages |  |
| $\quad$ Single Supply |  |
| Split Supplies | $\pm 6 \mathrm{~V}$ |
| Input Differential Voltage Range with |  |
| Split Power Supply | $\pm 30 \mathrm{~V}$ |
| Input Common Mode Voltage Range* | $\pm 15 \mathrm{~V}$ |
| Package Power Dissipation: | 625 mW |
| Plastic Package | $5.0 \mathrm{mV} /{ }^{\circ} \mathrm{C}$ |
| Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$ | 750 mW |
| Ceramic Package | $6.0 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$ |
| Derate above TA $=+25^{\circ} \mathrm{C}$ | $-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$ |

*For Supply Voltage less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.

## AVAILABLE TYPES

XR-3503M
XR-3403CN
XR-3403CP

Package
Ceramic
Ceramic
Plastic

Operating Temperature
$-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$

EQUIVALENT SCHEMATIC DIAGRAM


FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS
$\left(\mathrm{V}_{\mathrm{CC}}=+15 \mathrm{~V}, \mathrm{~V}_{\mathrm{EE}}=15 \mathrm{~V}, \mathrm{~T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}\right.$ unless otherwise noted.)

| CHARACTERISTICS | XR-3503M |  |  | XR-3403C |  |  | UNITS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |
| Input Offset Voltage |  | 2.0 | 5.0 6.0 |  | 2.0 | $\begin{aligned} & \hline 10 \\ & 12 \end{aligned}$ | mV | $\mathrm{T}_{\mathrm{A}}=\mathrm{T}_{\text {high }}$ to $\mathrm{T}_{\text {low }} 1$ |
| Input Offset Current |  | 30 | 50 200 |  | 30 | $\begin{array}{r} 50 \\ 200 \end{array}$ | nA | TA $=\mathrm{T}_{\text {high }}$ to $\mathrm{T}_{\text {low }}$ |
| Large Signal Open-Loop Voltage Gain | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | $\begin{aligned} & 200 \\ & 300 \\ & \hline \end{aligned}$ |  | $\begin{aligned} & 20 \\ & 15 \end{aligned}$ | 200 |  | V/mV | $\begin{aligned} & \mathrm{V}_{\mathrm{O}}= \pm 10 \mathrm{~V} \\ & \mathrm{R}_{\mathrm{L}}=2.0 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=\mathrm{T}_{\text {high }} \text { to } \mathrm{T}_{\text {low }} \\ & \hline \end{aligned}$ |
| Input Bias Current |  | $\begin{aligned} & -200 \\ & -300 \end{aligned}$ | $\begin{array}{r} -500 \\ -1500 \end{array}$ |  | -200 | $\begin{aligned} & -500 \\ & -800 \end{aligned}$ | nA | $\mathrm{T}_{\mathrm{A}}=\mathrm{T}_{\text {high }}$ to $\mathrm{T}_{\text {low }}$ |
| Output Impedance |  | 75 |  |  | 75 |  | $\Omega$ | $\mathrm{f}=20 \mathrm{~Hz}$ |
| Input Impedance | 0.3 | 1.0 |  | 0.3 | 1.0 |  | $\mathrm{M} \Omega$ | $\mathrm{f}=20 \mathrm{~Hz}$ |
| Output Voltage Swing | $\begin{aligned} & \pm 12 \\ & \pm 10 \\ & \pm 10 \end{aligned}$ | $\begin{array}{r}  \pm 13.5 \\ \pm 13 \end{array}$ |  | $\begin{aligned} & \pm 12 \\ & \pm 10 \\ & \pm 10 \end{aligned}$ | $\begin{array}{r}  \pm 13.5 \\ \pm 13 \end{array}$ |  | V | $\begin{aligned} & \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & \mathrm{R}_{\mathrm{L}}=2.0 \mathrm{~K} \Omega \\ & \mathrm{R}_{\mathrm{L}}=2.0 \mathrm{~K} \Omega \\ & \mathrm{~T}_{\mathrm{A}}=\mathrm{T}_{\text {high }} \text { to } \mathrm{T}_{\text {low }} \\ & \hline \end{aligned}$ |
| Input Common Mode Voltage Range | $+13 \mathrm{~V}-\mathrm{V}_{\text {EE }}$ | $+13.5 \mathrm{~V}-\mathrm{V}_{\mathrm{EE}}$ |  | $+13 \mathrm{~V}-\mathrm{V}_{\text {EE }}$ | $+13.5 \mathrm{~V}-\mathrm{V}_{\mathrm{EE}}$ |  | V |  |
| Common Mode Rejection Ratio | 70 | 90 |  | 70 | 90 |  | dB | $\mathrm{R}_{\mathrm{S}}<10 \mathrm{~K} \Omega$ |
| Power Supply Current ( $\mathrm{V}_{\mathrm{O}}=0$ ) |  | 2.8 | 4.0 |  | 2.8 | 7.0 | mA | $\mathrm{R}_{\mathrm{L}}=\infty$ |
| Individual Output Short-Circuit Current ${ }^{2}$ | $\pm 20$ | $\pm 30$ | $\pm 45$ | $\pm 10$ | $\pm 20$ | $\pm 45$ | mA |  |
| Positive Power Supply Rejection Ratio |  | 30 | 150 |  | 30 | 150 | $\mu \mathrm{V} / \mathrm{V}$ |  |
| Negative Power Supply Rejection Ratio |  | 30 | 150 |  | 30 | 150 | $\mu \mathrm{V} / \mathrm{V}$ |  |
| Average Temperature Coefficient of Input Offset Current |  | 50 |  |  | 50 |  | $\mathrm{pA} /{ }^{\circ} \mathrm{C}$ | $\mathrm{T}_{\mathrm{A}}=\mathrm{T}_{\text {high }}$ to $\mathrm{T}_{\text {low }}$ |
| Average Temperature Coefficient of Input Offset Voltage |  | 10 |  |  | 10 |  | $\mu \mathrm{V} /{ }^{\circ} \mathrm{C}$ | $\mathrm{T}_{\mathrm{A}}=\mathrm{T}_{\text {high }}$ to $\mathrm{T}_{\text {low }}$ |
| Power Bandwidth |  | 9.0 |  |  | 9.0 |  | kHz | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=2.0 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{O}}=20 \mathrm{~V}(\mathrm{p}-\mathrm{p}) \\ & \mathrm{THD}=5 \% \end{aligned}$ |
| Small Signal Bandwidth |  | 1.0 |  |  | 1.0 |  | MHz | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{O}}=50 \mathrm{mV} \end{aligned}$ |
| Slew Rate |  | 0.6 |  |  | 0.6 |  | $\mathrm{V} / \mu_{\mathrm{s}}$ | $\begin{aligned} & \mathrm{AV}=1, \mathrm{~V}_{\mathrm{i}}=-10 \mathrm{~V} \\ & \text { to }+10 \mathrm{~V} \end{aligned}$ |
| Rise Time |  | 0.6 |  |  | 0.6 |  | $\mu \mathrm{s}$ | $\begin{aligned} & \mathrm{Av}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{O}}=50 \mathrm{mV} \end{aligned}$ |
| Fall Time |  | 0.6 |  |  | 0.6 |  | $\mu \mathrm{s}$ | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{O}}=50 \mathrm{MV} \end{aligned}$ |
| Overshoot |  | 20 |  |  | 20 |  | \% | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{O}}=50 \mathrm{mV} \end{aligned}$ |
| Phase Margin |  | 60 |  |  | 60 |  | Degrees | $\begin{aligned} & \mathrm{A}_{\mathrm{V}}=1, \mathrm{R}_{\mathrm{L}}=2.0 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}}=200 \mathrm{pF} \end{aligned}$ |
| Crossover Distortion |  | 1.0 |  |  | 1.0 |  | \% | $\begin{aligned} & \left(\mathbf{V}_{\text {in }}=30 \mathrm{mV} \mathrm{p}-\mathrm{p}\right. \\ & \mathbf{V}_{\text {out }}=2.0 \mathrm{~V} \mathrm{p}-\mathrm{p} \\ & \mathbf{F}=10 \mathrm{kHz}) \end{aligned}$ |

${ }^{1} \mathrm{~T}_{\text {high }}=+125^{\circ} \mathrm{C}$ for XR-3503M, $+70^{\circ} \mathrm{C}$ for XR-3403C
$\mathrm{T}_{\text {low }}=-55^{\circ} \mathrm{C}$ for XR-3503M, $0^{\circ} \mathrm{C}$ for XR-3403C
${ }^{2}$ Not to exceed maximum package power dissipation.
${ }^{3}$ Output will swing to ground.

## ELECTRICAL CHARACTERISTICS $\quad\left(\mathrm{V}_{\mathrm{CC}}=5.0 \mathrm{v}, \mathrm{V}_{\mathrm{EE}}=\mathrm{Gnd}, \mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}\right.$ unless otherwise noted.)

| CHARACTERISTICS | XR-3503M |  |  | XR-3403C |  |  | UNITS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |
| Input Offset Voltage |  | 2.0 | 5.0 |  | 2.0 | 10 | mV |  |
| Input Offset Current |  | 30 | 50 |  | 30 | 50 | nA |  |
| Input Bias Current |  | -200 | -500 |  | -200 | -500 | nA |  |
| Large Signal Open Loop Voltage Gain | 20 | 200 |  | 20 | 200 |  | $\mathrm{V} / \mathrm{mV}$ | $\mathrm{R}_{\mathrm{L}}=2.0 \mathrm{~K} \Omega$ |
| Power Supply Rejection Ratio |  |  | 150 |  |  | 150 | $\mu \mathrm{V} / \mathrm{V}$ |  |
| Output Voltage Range ${ }^{3}$ | $\begin{gathered} 3.5 \\ \mathrm{v}_{\mathrm{CC}}-1.5 \mathrm{~V} \end{gathered}$ |  |  | $\begin{gathered} 3.5 \\ \mathrm{v}_{\mathrm{CC}}-1.5 \mathrm{~V} \end{gathered}$ |  |  | Vp-p | $\begin{aligned} & \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{CC}}=5.0 \mathrm{~V} \\ & \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega \\ & 5.0 \mathrm{~V} \leqslant \mathrm{~V}_{\mathrm{CC}} \leqslant 30 \mathrm{~V} \end{aligned}$ |
| Power Supply Current |  | 2.5 | 4.0 |  | 2.5 | 7.0 | mA |  |
| Channel Separation |  | -120 |  |  | -120 |  | dB | $\begin{gathered} \mathrm{f}=1.0 \mathrm{kHz} \text { to } 20 \mathrm{kHz} \\ \text { (Input Referenced) } \end{gathered}$ |

## Quad Operational Amplifier

## GENERAL DESCRIPTION

The XR-4136 is an array of four independent internally-compensated operational amplifiers on a single silicon chip, each similar to the popular 741, but with a power consumption less than one 741 . Good thermal tracking and matched gain-bandwidth products make these quad op-amps useful for active filter applications.

## FEATURES

Direct Pin-for-Pin Replacement for RC4136 and RM4136 Low Power Consumption - 50 mW typ. and 120 mW max. Short-Circuit Protection
Internal Frequency Compensation
No Latch-Up
Wide Common-Mode and Differential Voltage Ranges Matched Gain-Bandwidth

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage
XR-4136M $\pm 22 \mathrm{~V}$
XR-4136C $\pm 18 \mathrm{~V}$
Common Mode
Voltage Range
Differential Input Voltage
$\pm 30 \mathrm{~V}$
Internal Power Dissipation
Ceramic Package:
Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Plastic Package:
Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Storage Temperature Range:
750 mW $6 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$
625 mW
$5 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$
$-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$

## AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-4136M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-4136CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-4136CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

## EQUIVALENT SCHEMATIC



FUNCTIONAL BLOCK DIAGRAM


## ELECTRICAL CHARACTERISTICS $\quad T_{A}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ unless otherwise specified

| CHARACTERISTICS | XR4136M |  |  | XR4136C |  |  | UNITS | SYMBOLS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 1 | 5.0 |  | 1 | 6.0 | mV | $\left\|\mathrm{V}_{\text {io }}\right\|$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  | 10 | 200 |  | 10 | 200 | nA | ${ }^{1} \mathrm{I}_{\text {io }}{ }^{\text {l }}$ |  |
| Input Bias Current |  | 80 | 500 |  | 80 | 500 | nA | $\mathrm{I}_{\mathrm{b}}{ }^{\text {l }}$ |  |
| Input Resistance | 0.3 | 1.8 |  | 0.3 | 1.8 |  | $\mathrm{M} \Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Large Signal Voltage Gain | 50 | 60 |  | 20 | 40 |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 12$ | $\pm 14$ |  | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 10 \mathrm{~K} \Omega$ |
|  | $\pm 10$ | $\pm 12$ |  | $\pm 10$ | $\pm 12$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Input Voltage Range | $\pm 12$ | $\pm 13.5$ |  | $\pm 12$ | $\pm 13.5$ |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Common Mode Rejection Ratio | 70 | 105 |  | 70 | 105 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Supply Voltage Rejection Ratio |  | 10 | 150 |  | 10 | 150 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Power Consumption |  | 50 | 120 |  | 50 | 120 | mW | $\mathrm{P}_{\mathrm{i}}$ |  |
| Transient Response (unity gain) <br> Risetime <br> Overshoot |  | $\begin{array}{r} 0.07 \\ 20 \end{array}$ |  |  | $\begin{array}{r} 0.07 \\ 20 \\ \hline \end{array}$ |  | $\begin{aligned} & \mu \mathrm{s} \\ & \% \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{o}} \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{in}}=20 \mathrm{mV} \\ & \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}} \leq 100 \mathrm{pF} \end{aligned}$ |
| Unity Gain Bandwidth | 2.0 | 3.0 |  |  | 3.0 |  | MHz | BW |  |
| Slew Rate (unity gain) |  | 1.6 |  |  | 1.6 |  | $\mathrm{V} / \mathrm{\mu s}$ | $\mathrm{dV}_{\text {out }} / \mathrm{dt}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Channel Separation (open loop) |  | 120 |  |  | 120 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{~K} \Omega \\ & \hline \end{aligned}$ |
| (Gain of 100) |  | 105 |  |  | 105 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{~K} \Omega \end{aligned}$ |

The following specifications apply for $-55^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq+125^{\circ} \mathrm{C}$ for XR- 4136 M : $0^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq+70^{\circ} \mathrm{C}$ for XR-4136C

| Input Offset Voltage |  |  | 6.0 |  |  | 7.5 | mV | $\mathrm{V}_{\text {io }}$ \| | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Input Offset Current |  |  | 500 |  |  | 300 | nA | ${ }^{1} \mathrm{I}_{\text {io }} \mid$ |  |
| Input Bias Current |  |  | 1500 |  |  | 800 | nA | $\mathrm{I}_{\mathrm{b}}$ |  |
| Large-Signal Voltage Gain | 25 |  |  | 15 |  |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 10$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Power Consumption |  |  | $\begin{aligned} & 150 \\ & 200 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 150 \\ & 200 \end{aligned}$ | $\begin{aligned} & \mathrm{mW} \\ & \mathrm{~mW} \end{aligned}$ | $\begin{aligned} & \mathrm{P}_{\mathrm{i}} \\ & \mathrm{P}_{\mathrm{i}} \end{aligned}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=\text { High } \\ & \mathrm{T}_{\mathrm{A}}=\text { Low } \end{aligned}$ |
| Output Short-Circuit Current | 5 | 17 | 35 | 5 | 17 | 35 | mA | $\mathrm{I}_{\text {SC }}$ |  |

## TYPICAL PARAMETER MATCHING:

$\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ unless otherwise noted

|  | XR4136M |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: |
| CHARACTERISTICS | TYP. | XR4136C <br> TYP. | UNITS | SYMBOLS | CONDITIONS |
| Input Offset Voltage | $\pm 1.0$ | $\pm 2.0$ | mV | $1 \mathrm{~V}_{\mathrm{io}} /$ |  |
| Input Offset Current | $\pm 7.5$ | $\pm 7.5$ | nA | $\mathrm{I}_{\mathrm{io}} /$ |  |
| Input Bias Current | $\pm 15$ | $\pm 15$ | nA | $\mathrm{I}_{\mathrm{b}}$ |  |
| Voltage Gain | $\pm 0.5$ | $\pm 1.0$ | dB |  |  |

## XR-4202

# Programmable Quad Operational Amplifier 

## GENERAL DESCRIPTION

The XR-4202 is an array of four independent operational amplifiers on a single silicon chip. The operating current of the array is externally controlled by a single resistor or current source, allowing the user to trade-off power dissipation for bandwidth.

## FEATURES

## Programmable

Micropower Operation
Wide Input Voltage and Common Mode Range
Internal Frequency Compensation
No Latch-Up
Matched Parameters
Short-Circuit Protection

## APPLICATION INFORMATION

The following approximate relations are useful for design:

| Gain-Bandwidth Product | $\approx 50$ ISET | $(\mathrm{KHz})$ |
| :--- | :--- | :--- | :--- |
| Power Supply Current | $\approx 30$ ISET | $(\mu \mathrm{A})$ |
| Slew Rate | $\approx 20$ ISET | $(\mathrm{V} / \mathrm{ms})$ |

Where: ISET is in $\mu \mathrm{A}$
$I_{S E T}=\frac{\mathrm{V}_{\mathrm{EE}}-\mathrm{V}_{\mathrm{BE}}}{\mathrm{R}_{\mathrm{SET}}}$ WHERE $\mathrm{V}_{\mathrm{BE}}$ DIODE VOLTAGE $\approx 0.65 \mathrm{~V}$

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage $\pm 18 \mathrm{~V}$
Differential Input Voltage $\pm 30 \mathrm{~V}$
Power Dissipation
Ceramic Package:
Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Plastic Package:
Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Common Mode Range
Short Circuit Duration
Storage Temperature
AVAILABLE TYPES
Part Number
Package
XR-4202M
XR-4202N
XR-4202P

Operating Temperature

$$
\begin{aligned}
& -55^{\circ} \mathrm{C} \text { to }+125^{\circ} \mathrm{C} \\
& -40^{\circ} \mathrm{C} \text { to }+85^{\circ} \mathrm{C} \\
& -40^{\circ} \mathrm{C} \text { to }+85^{\circ} \mathrm{C}
\end{aligned}
$$

## EQUIVALENT SCHEMATIC DIAGRAM



FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS HIGH POWER MODE ( $\mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$, ISET $=75 \mu \mathrm{~A}$ and $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$ unless otherwise specified)

| CHARACTERISTICS | MIN | TYP | MAX | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Short Circuit Current | 5 | 17 | 30 | mA | ISC | $0^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq 75^{\circ} \mathrm{C}$ |
| Supply Current | 0.8 | 1.7 | 6.0 | mA | $\mathrm{I}_{\text {S }}$ | Note 3 |
| Input Offset Voltage |  | 0.8 | 5.0 | mV | $\mathrm{V}_{\text {io }}$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Bias Current |  | 80 | 500 | nA | $\mathrm{I}_{\mathrm{b}}$ |  |
| Input Off-set Current |  | 10 | 200 | nA | $\mathrm{I}_{\mathrm{io}}$ |  |
| Input Resistance | 0.1 | 0.6 |  | $\mathrm{M} \Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Input Common Mode Voltage Range | 12 | $\pm 14$ |  | $\pm$ V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Common Mode Rejection Ratio | 70 | 110 |  | dB | CMRR |  |
| Voltage Supply Rejection Ratio |  | 15 | 150 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR |  |
| Large Signal Voltage Gain | 74 | 88 |  | dB | AVOL | $\mathrm{R}_{\mathrm{L}}=3 \mathrm{~K} \Omega ; \Delta \mathrm{V}_{\mathrm{O}}= \pm 10 \mathrm{~V}$ |
| Output Voltage Swing | $\pm 10$ | $\pm 13.6$ |  | $\pm$ V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}}=3 \mathrm{~K} \Omega$ |
| Gain-Bandwidth Product |  | 3.5 |  | MHz | $\mathrm{f}_{1}$ |  |
| Phase Margin |  | 45 |  | Deg. |  |  |
| Rise Time |  | 70 |  | ns | ${ }_{\text {t }}$ | $\Delta \mathrm{V}_{\mathrm{O}}= \pm 20 \mathrm{mV}$ |
| Overshoot |  | 20 |  | \% | $\mathrm{t}_{0}$ | $\Delta V_{0}= \pm 20 \mathrm{mV}$ |
| Channel Separation |  | $\begin{aligned} & 120 \\ & 105 \end{aligned}$ |  | $\begin{aligned} & \hline \mathrm{dB} \\ & \mathrm{~dB} \end{aligned}$ |  | Any amp. pair: freq. $=1 \mathrm{~Hz}, \mathrm{R}_{\mathrm{L}}=3 \mathrm{~K} \Omega$ <br> Any amp. pair: freq. $=10 \mathrm{KHz}, \mathrm{R}_{\mathrm{L}}=3 \mathrm{~K} \Omega$ |
| Slew Rate |  | 1.5 |  | V/ $\mu \mathrm{s}$ | $\mathrm{dV}_{\text {out }} / \mathrm{dt}$ |  |
| Input Voltage Noise |  | 25 |  | $\mathrm{nV} / \sqrt{\mathrm{Hz}}$ | $\mathrm{e}_{\mathrm{n}}$ | Bandwidth 100 Hz to 10 KHz |

Note: Short circuit may be taken to either supply line or ground on only one amplifier at a time.
ELECTRICAL CHARACTERISTICS HIGH POWER MODE ( $\mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}, \mathrm{I}_{\text {SET }}=75 \mu \mathrm{~A}$ and $\mathrm{T}_{\mathrm{A}}=-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ )

| CHARACTERISTICS | MIN | TYP | MAX | UNITS | SYMBOL | CONDITIONS |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: |
| Input Offset Voltage |  | 0.8 | 10 | mV | $\mathrm{V}_{\text {io }}$ | $\mathrm{R}_{\mathrm{s}} \leqslant 10 \mathrm{~K} \Omega$ |
| Input Bias Current |  | 80 | 1500 | nA | $\mathrm{I}_{\mathrm{b}}$ |  |
| Input Offset Current |  | 10 | 200 | nA | $\mathrm{I}_{\mathrm{io}}$ |  |
| Large Signal Voltage Gain | 68 | 88 |  | dB | $\mathrm{~A}_{\text {vol }}$ | $\mathrm{R}_{\mathrm{L}}=3 \mathrm{~K} \Omega$ <br> $\Delta \mathrm{~V}_{\mathrm{o}}= \pm 10 \mathrm{~V}$ |

## ELECTRICAL CHARACTERISTICS MICROPOWER MODE (ISET $=1 \mu \mathrm{~A}, \mathrm{~V}_{\mathrm{S}}= \pm 1.5 \mathrm{~V}$ )

| CHARACTERISTICS | MIN | TYP | MAX | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Supply Current |  |  | 100 | $\mu \mathrm{A}$ | $\mathrm{I}_{\text {S }}$ | Note 3 |
| Input Bias Current |  |  | 200 | nA | $\mathrm{I}_{\mathrm{B}}$ |  |
| Input Offset Current |  |  | 20 | nA | IOS |  |
| Input Offset Voltage |  | 0.5 | 5 | mV | $\mathrm{V}_{\text {os }}$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Resistance | 0.5 |  |  | $\mathrm{M} \Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Input Common Mode Voltage Range | 0.3 | $\pm 0.8$ |  | $\pm$ V | $\mathrm{V}_{\mathrm{i}} \mathrm{CM}$ |  |
| Common Mode Rejection Ratio | 60 | 100 |  | dB | CMRR |  |
| Voltage Supply Rejection Ratio |  | 20 | 200 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR |  |
| Large Signal Voltage Gain | 66 | 80 |  | dB | $\mathrm{A}_{\text {vol }}$ | $\mathrm{R}_{\mathrm{L}} \geq 100 \mathrm{~K} \Omega$ |
| Gain-Bandwidth Product |  | 50 |  | KHz | $\mathrm{f}_{1}$ |  |
| Phase Margin |  | 75 |  | Deg. |  |  |
| Slew-Rate |  | 20 |  | V/ms | dV $\mathrm{orut} / \mathrm{dt}$ |  |
| Rise Time |  | 7 |  | $\mu \mathrm{s}$ | ${ }^{\text {t }}$ R | $\Delta \mathrm{V}_{\mathrm{O}}= \pm 20 \mathrm{mV}$ |
| Overshoot |  | 0 |  | \% | $\mathrm{t}_{0}$ | $\Delta \mathrm{V}_{\mathrm{O}}= \pm 20 \mathrm{mV}$ |
| Channel Separation |  | $\begin{aligned} & 120 \\ & 120 \\ & \hline \end{aligned}$ |  | $\begin{aligned} & \hline \mathrm{dB} \\ & \mathrm{~dB} \end{aligned}$ |  | $\begin{aligned} & \text { Freq. }=\mathrm{Hz}: \mathrm{R}_{\mathrm{L}}=20 \mathrm{~K} \Omega, \Delta \mathrm{~V}_{\mathrm{O}}= \pm 0.5 \mathrm{~V} \\ & \text { Freq. }=1 \mathrm{KHz}: \mathrm{R}_{\mathrm{L}}=10 \mathrm{~K} \Omega, \Delta \mathrm{~V}_{\mathrm{O}}= \pm 0.5 \mathrm{~V} \end{aligned}$ |
| Equivalent Input Voltage Noise |  | 200 |  | $\mathrm{nV} / \sqrt{\mathrm{Hz}}$ | $\mathrm{e}_{\mathrm{n}}$ | Bandwidth $=100 \mathrm{~Hz}$ to 10 KHz |

PARAMETER MATCHING (ISET $=75 \mu \mathrm{~A}^{(2)}$ )

| CHARACTERISTICS | MIN | TYP | MAX | UNITS | SYMBOL |  |
| :--- | ---: | ---: | ---: | :---: | :---: | :---: |
| Input Offset Voltage |  | 1 |  | $\pm \mathrm{mV}$ | $\mathrm{V}_{\mathrm{OS}}$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Bias Current |  | 10 |  | $\pm \mathrm{nA}$ | $\mathrm{I}_{\mathrm{B}}$ |  |
| Input Offset Current |  | 2 |  | $\pm \mathrm{nA}$ | $\mathrm{I}_{\mathrm{OS}}$ |  |
| Gain-Bandwidth Product |  | 100 |  | $\pm \mathrm{KHz}$ | $\mathrm{f}_{1}$ |  |
| Slew Rate |  | 0.2 |  | $\pm \mathrm{V} / \mu \mathrm{s}$ | $\mathrm{dV}_{\mathrm{o} / \mathrm{dt}}$ |  |

NOTES: 1. All tests refer to a single Op. amp unless otherwise specified.
2. Tests apply for parameter matching between any Op. amp pair.
3. Tests apply to four Op. amps and bias network.

## XR-4212

## Quad Operational Amplifier

## GENERAL DESCRIPTION

The XR-4212 is an array of four independent internally compensated operational amplifiers on a single silicon chip, each similar to the popular 741, but with a power consumption less than one 741 . Good thermal tracking and matched gainbandwidth products make these Quad Op-amps useful for active filter applications.

## FEATURES

Same Pinout as MC3403 and LM324
Low Power Consumption - 50 mW typ. and 120 mW max.
Short-Circuit Protection
Internal Frequency Compensation
No Latch-Up
Wide Common-Mode and Differential Voltage Ranges
Matched Gain-Bandwidth

ABSOLUTE MAXIMUM RATINGS

| Supply Voltage |  |
| :--- | ---: |
| XR-4212M | $\pm 22 \mathrm{~V}$ |
| XR-4212C | $\pm 18 \mathrm{~V}$ |
| Common Mode |  |
| Voltage | VEE to VCC |
| Output Short-Circuit Duration | Indefinite |
| Differential Input Voltage | $\pm 30 \mathrm{~V}$ |
| Internal Power Dissipation |  |
| Ceramic Package: | 650 mW |
| Derate above TA $=+25^{\circ} \mathrm{C}$ | 625 mWW |
| Plastic Package: | $5 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$ |
| Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$ | $-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$ |
| Storage Temperature Range: |  |

## AVAILABLE TYPES

Part Number
XR-4212M
XR-4212CN
XR-4212CP

Package
Ceramic
Ceramic
Plastic

Operating Temperature
$-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$

EQUIVALENT SCHEMATIC


FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ unless otherwise specified

| CHARACTERISTICS | XR-4212M |  |  | XR-4212C |  |  | UNITS | SYMBOLS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 1 | 5.0 |  | 1 | 6.0 | mV | $\left\|V_{i o}\right\|$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  | 10 | 50 |  | 10 | 50 | nA | ${ }^{1} \mathrm{iol}$ |  |
| Input Bias Current |  | 80 | 500 |  | 80 | 500 | nA | $\mid \mathrm{Ib}_{\mathrm{b}}$ \| |  |
| Input Resistance | 0.3 | 1.8 |  | 0.3 | 1.8 |  | $\mathrm{M} \Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Large Signal Voltage Gain | 20 | 60 |  | 5 | 40 |  | V/mV | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \\ & \hline \end{aligned}$ |
| Output Voltage Swing | $\pm 12$ | $\pm 14$ |  | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 10 \mathrm{~K} \Omega$ |
|  | $\pm 10$ | $\pm 12$ |  | $\pm 10$ | $\pm 12$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Input Voltage Range | $\pm 12$ | $\pm 13.5$ |  | $\pm 12$ | $\pm 13.5$ |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Common Mode Rejection Ratio | 70 | 105 |  | 70 | 105 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Supply Voltage Rejection Ratio |  | 10 | 150 |  | 10 | 150 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR | $\mathrm{R}_{\mathrm{s}} \leq 10 \mathrm{~K} \Omega$ |
| Power Consumption |  | 50 | 120 |  | 50 | 120 | mW | $\mathrm{P}_{\mathrm{i}}$ |  |
| Transient Response (unity gain) <br> Risetime <br> Overshoot |  | $\begin{array}{r} 0.07 \\ 20 \end{array}$ |  |  | $\begin{array}{r} 0.07 \\ 20 \\ \hline \end{array}$ |  | $\begin{aligned} & \mu \mathrm{s} \\ & \% \\ & \hline \end{aligned}$ | $\begin{array}{r} \mathrm{t}_{\mathrm{r}} \\ \mathrm{t}_{0} \\ \hline \end{array}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{in}}=20 \mathrm{mV} \\ & \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}} \leq 100 \mathrm{pF} \end{aligned}$ |
| Unity Gain Bandwidth | 2.0 | 3.0 |  |  | 3.0 |  | MHz | BW |  |
| Slew Rate (unity gain) |  | 1.6 |  |  | 1.6 |  | $\mathrm{V} / \mu \mathrm{s}$ | $\mathrm{dV}_{\text {out }} / \mathrm{dt}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Channel Separation (open loop) <br> (Gain of 100 ) |  | 120 |  |  | 120 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{~K} \Omega \end{aligned}$ |
|  |  | 105 |  |  | 105 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{~K} \Omega \end{aligned}$ |
| The following specifications apply for $-55^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq+125^{\circ} \mathrm{C}$ for XR-4212M: $0^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq+70^{\circ} \mathrm{C}$ for XR-4212C |  |  |  |  |  |  |  |  |  |
| Input Offset Voltage |  |  | 6.0 |  |  | 7.5 | mV | $\mathrm{V}_{\mathrm{io}} \mathrm{l}$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  |  | 200 |  |  | 200 | nA | $\mathrm{I}_{\text {io }} \mathrm{l}$ |  |
| Input Bias Current |  |  | 1500 |  |  | 800 | nA | $\mathrm{I}_{\mathrm{b}}$ |  |
| Large-Signal Voltage Gain | 20 |  |  | 5 |  |  | V/mV | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \\ & \hline \end{aligned}$ |
| Output Voltage Swing | $\pm 10$ |  |  | $\pm 10$ |  |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Power Consumption |  |  | $\begin{aligned} & 150 \\ & 200 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 150 \\ & 200 \end{aligned}$ | $\begin{aligned} & \mathrm{mW} \\ & \mathrm{~mW} \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{P}_{\mathrm{i}} \\ & \mathrm{P}_{\mathrm{i}} \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=\text { High } \\ & \mathrm{T}_{\mathrm{A}}=\text { Low } \end{aligned}$ |
| Output Short-Circuit Current | 5 | 17 | 35 | 5 | 17 | 35 | mA | ISC |  |

## TYPICAL PARAMETER MATCHING:

$\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ unless otherwise noted

| CHARACTERISTICS | XR-4212M <br> TYP. | XR-4212C <br> TYP. | UNITS | SYMBOLS | CONDITIONS |
| :--- | :---: | :---: | :---: | :---: | :---: |
| Input Offset Voltage | $\pm 1.0$ | $\pm 2.0$ | mV | $\mid \mathrm{V}_{\mathrm{iol}}$ | $\mathrm{R}_{\mathrm{s}} \geq 10 \mathrm{~K} \Omega$ |
| Input Offset Current | $\pm 7.5$ | $\pm 7.5$ | nA | I iol |  |
| Input Bias Current | $\pm 15$ | $\pm 15$ | nA | $\mathrm{I}_{\mathrm{b}}$ |  |
| Voltage Gain | $\pm 0.5$ | $\pm 1.0$ | dB | AVOL | $\mathrm{R}_{\mathrm{s}} \geq 2 \mathrm{~K} \Omega$ |

# Quad Operational Amplifier 

## GENERAL DESCRIPTION

The XR-4741 is an array of four independent internally-compensated operational amplifiers on a single silicon chip, each similar to the popular 741 . Each amplifier offers performance equal to or better than the 741 type in all respects. It has high slew rate, superior bandwidth, and low noise, which makes it excellent for audio amplifiers or active filter applications.

## FEATURES

Short-Circuit Protection
Internal Frequency Compensation
No Latch-Up
Wide Common-Mode and Differential Voltage Ranges
Matched Gain-Bandwidth
High Slew Rate
Unity Gain-Bandwidth
Low Noise Voltage
Input Offset Current
Input Offset Voltage
Supply Range

$$
\begin{array}{r}
1.6 \mathrm{~V} / \mu \mathrm{S}(\mathrm{Typ}) \\
3.5 \mathrm{MHz}(\mathrm{Typ}) \\
9 \mathrm{NV} \sqrt{\mathrm{~Hz}} \\
60 \mathrm{nA}(\mathrm{Typ}) \\
.5 \mathrm{mV}(\mathrm{Typ}) \\
\pm 2 \mathrm{~V} \text { to } \pm 20 \mathrm{~V}
\end{array}
$$

## ABSOLUTE MAXIMUM RATINGS

Supply Voltage
XR-4741

Common Mode
Voltage
Output Short-Circuit Duration
Differential Input Voltage
Internal Power Dissipation
Ceramic Package:
Derate above TA $=+25^{\circ} \mathrm{C}$
Plastic Package:
Derate above $\mathrm{T}_{\mathrm{A}}=+25^{\circ} \mathrm{C}$
Storage Temperature Range:
$\mathrm{V}_{\text {EE }}$ to $\mathrm{V}_{\mathrm{CC}}$ Indefinite
$\pm 30 \mathrm{~V}$
880 mW
$5.8 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$
625 mW
$5 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$

AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-4741M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-4741CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-4741CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

## EQUIVALENT SCHEMATIC



FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS $T_{A}=+25^{\circ} \mathrm{C}, \mathrm{v}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ unless otherwise specified

| CHARACTERISTICS | XR-4741M |  |  | XR-4741C |  |  | UNITS | SYMBOLS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 0.5 | 3.0 |  | 1.0 | 5.0 | mV | $\left\|\mathrm{V}_{\text {io }}\right\|$ | $\mathrm{R}_{\mathrm{s}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  | 10 | 30 |  | 10 | 50 | nA | $\left\|\mathbf{I}_{\mathbf{i o}}\right\|$ |  |
| Input Bias Current |  | 60 | 200 |  | 60 | 300 | nA | $\left\|\mathrm{I}_{\mathrm{b}}\right\|$ |  |
| Differential Input Resistance |  | 5 |  |  | 5 |  | $\mathrm{M} \Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Input Noise Voltage ( $\mathrm{f}=1 \mathrm{kHz}$ ) |  | 9 |  |  | 9 |  |  |  |  |
| Large Signal Voltage Gain | 50 | 100 |  | 25 | 50 |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\begin{aligned} & \pm_{12} \\ & \pm_{10} \end{aligned}$ | $\begin{aligned} & \pm 13.7 \\ & \pm 12.5 \end{aligned}$ |  | $\begin{aligned} & \pm 12 \\ & \pm 10 \end{aligned}$ | $\begin{aligned} & \pm 13.7 \\ & \pm 12.5 \end{aligned}$ |  | $\mathrm{V}$ | $\mathrm{V}_{\text {out }}$ <br> Vout | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 10 \mathrm{~K} \Omega \\ & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \end{aligned}$ |
| Full Power Bandwidth |  | 25 |  |  | 25 |  | kHz |  |  |
| Output Resistance |  | 300 |  |  | 300 |  | $\Omega$ |  |  |
| Input Voltage Range | $\pm 12$ | $\pm 13.5$ |  | $\pm 12$ | $\pm 13.5$ |  | V | $\mathrm{V}_{\text {iCM }}$ |  |
| Common Mode Rejection Ratio | 80 | 100 |  | 80 | 100 |  | dB | CMRR | $\mathrm{R}_{\mathrm{s}} \leq 10 \mathrm{~K} \Omega$ |
| Supply Voltage Rejection Ratio |  | 10 | 100 |  | 10 | 100 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR | $\mathrm{R}_{\mathrm{s}} \leq 10 \mathrm{~K} \Omega$ |
| Power Consumption |  |  | 150 |  |  | 210 | mW | $\mathrm{P}_{\mathrm{i}}$ |  |
| Transient Response (unity gain) <br> Risetime <br> Overshoot |  | $\begin{array}{r} .07 \\ 20 \end{array}$ |  |  | $\begin{array}{r} .07 \\ 20 \end{array}$ |  | $\begin{aligned} & \mu \mathrm{s} \\ & \% \end{aligned}$ | $\begin{aligned} & t_{r} \\ & t_{0} \end{aligned}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{in}}=20 \mathrm{mV} \\ & \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}} \leq 100 \mathrm{pF} \end{aligned}$ |
| Unit Gain Bandwidth |  | 3.5 |  |  | 3.5 |  | MHz | BW |  |
| Slew Rate (unity gain) |  | 1.6 |  |  | 1.6 |  | $\mathrm{V} / \mu \mathrm{s}$ | $\mathrm{dV}_{\text {out }} / \mathrm{dt}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Channel Separation (open loop) <br> (Gain of 100 ) |  | 120 |  |  | 120 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{s}}=1 \mathrm{~K} \Omega \end{aligned}$ |
|  |  | 105 |  |  | 105 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{s}}=1 \mathrm{~K} \Omega \end{aligned}$ |
| The following specifications apply for $-55^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq+125^{\circ} \mathrm{C}$ for XR-4741M: $0^{\circ} \mathrm{C} \leq \mathrm{T}_{\mathrm{A}} \leq+70^{\circ} \mathrm{C}$ for XR-4741C |  |  |  |  |  |  |  |  |  |
| Input Offset Voltage |  | 4.0 | 5.0 |  | 5.0 | 6.5 | mV | $\left\|V_{i o}\right\|$ | $\mathrm{R}_{\mathrm{s}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  |  | 75 |  |  | 100 | nA | $\left\|\mathrm{I}_{\text {io }}\right\|$ |  |
| Input Bias Current Input Voltage Range | $\pm 12$ |  | 325 | $\pm 12$ |  | 400 | $\begin{gathered} \mathrm{nA} \\ \mathrm{~V} \end{gathered}$ | $\mathrm{I}_{\mathrm{b}}$ |  |
| Common Mode Rejection Ratio | 74 |  |  | 74 |  |  | db |  |  |
| Large-Signal Voltage Gain | 25 |  |  | 15 |  |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 10$ | $\pm 12.5$ |  | $\pm 10$ | $\pm 12.5$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega$ |
| Power Consumption <br> Supply Voltage Rejection Ratio | $\pm 12.0$ | $\pm 13.7$ <br> 100 | $\begin{array}{r} 150 \\ 200 \\ \mu \mathrm{~V} / \mathrm{V} \end{array}$ | $\pm 12$ | $\pm 13.7$ <br> 100 | $\begin{array}{r} 150 \\ 200 \\ \mu \mathrm{~V} / \mathrm{V} \end{array}$ | $\begin{aligned} & \mathrm{mW} \\ & \mathrm{~mW} \end{aligned}$ | $\begin{aligned} & P_{i} \\ & P_{i} \end{aligned}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 10 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\mathrm{S}}= \pm 15 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=\text { High } \\ & \mathrm{T}_{\mathrm{A}}=\text { Low } \end{aligned}$ |
| Output Short-Circuit Current | $\pm 5$ | $\pm 15$ |  | $\pm 5$ | $\pm 15$ |  | mA | ${ }^{\text {ISC }}$ |  |

## XR-1458/4558

## Dual Operational Amplifier

## GENERAL DESCRIPTION

The XR-1458/4558 is a pair of independent internally compensated operational amplifiers on a single silicon chip, each similar to the popular 741 , but with a power consumption less than one 741 . Good thermal tracking and matched gain-bandwidth products make these Dual Op-amps useful for active filter applications.

## FEATURES

Direct Pin-for-Pin Replacement for MC1458, RC4558, N5558 Low Power Consumption -50 mW typ. and 120 mW max. Short-Circuit Protection
Internal Frequency Compensation
No Latch-Up
Wide Common-Mode and Differential Voltage Ranges Matched Gain-Bandwidth

ABSOLUTE MAXIMUM RATINGS
Supply Voltage
XR-4558CP $\pm 18 \mathrm{~V}$
Input Voltage (Note 1) $\pm 15 \mathrm{~V}$
Common Mode
Voltage Range
Output Short-Circuit Duration (Note 2)
Differential Input Voltage
Internal Power Dissipation (Note 3)
Plastic Package:
Storage Temperature Range:
Operating Temperature Range:
$\mathrm{V}_{\mathrm{EE}}$ to $\mathrm{V}_{\mathrm{CC}}$
Indefinite
$\pm 30 \mathrm{~V}$
500 mW
$-65^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+70^{\circ} \mathrm{C}$

## AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-1458CP | Plastic | $0^{\circ} \mathrm{C}$ to $+70^{\circ} \mathrm{C}$ |
| XR-4558CP | Plastic | $0^{\circ} \mathrm{C}$ to $+70^{\circ} \mathrm{C}$ |

Note 1: For supply voltages less than $\pm 15 \mathrm{~V}$, the absolute maximum input voltage is equal to the supply voltage.
Note 2: Short circuit may be to ground or either supply. Rating applies to $+125^{\circ} \mathrm{C}$ case temperature or $+75^{\circ} \mathrm{C}$ ambient temperature for XR1458/4558.
Note 3: Rating applies for case temperatures to $125^{\circ} \mathrm{C}$; derate linearly at $6.5 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$ for ambient temperatures above $+75^{\circ} \mathrm{C}$ for XR1458/4558.

EQUIVALENT SCHEMATIC DIAGRAM


## FUNCTIONAL BLOCK DIAGRAM



ELECTRICAL CHARACTERISTICS $\quad T_{A}=+25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ unless otherwise specified

| CHARACTERISTICS | XR1458/4558CP |  |  | UNITS | SYMBOLS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 0.5 | 6.0 | mV | $\left\|\mathrm{V}_{\text {iol }}\right\|$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  | 5 | 200 | nA | $\left\|\mathrm{I}_{\text {iol }}\right\|$ |  |
| Input Bias Current |  | 40 | 500 | nA | $\mid \mathrm{I}_{\mathrm{b}}$ \| |  |
| Input Resistance | 0.3 | 5 |  | $\mathrm{M} \Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Large Signal Voltage Gain | 20 | 300 |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 10 \mathrm{~K} \Omega$ |
|  | $\pm 10$ | $\pm 13$ |  | V | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Input Voltage Range | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{V}_{\text {iCM }}$ |  |
| Common Mode Rejection Ratio | 70 | 90 |  | dB | CMRR | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Supply Voltage Rejection Ratio |  | 30 | 150 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Power Consumption |  | 50 | 170 | mW | $\mathrm{P}_{\mathrm{i}}$ |  |
| Transient Response (unity gain) Risetime Overshoot |  | $\begin{array}{r} 0.13 \\ 5 \end{array}$ |  | $\begin{gathered} \mu \mathrm{s} \\ \% \end{gathered}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{O}} \end{aligned}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{in}}=20 \mathrm{mV} \\ & \mathrm{R}_{\mathrm{L}}=2 \mathrm{~K} \Omega \\ & \mathrm{C}_{\mathrm{L}} \leq 100 \mathrm{pF} \end{aligned}$ |
| Unity Gain Bandwidth |  | 3.0 |  | MHz | BW |  |
| Slew Rate (unity gain) |  | 1.0 |  | $\mathrm{V} / \mu \mathrm{s}$ | dV ${ }_{\text {out/dt }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Channel Separation (open loop) |  | 120 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{kHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{~K} \Omega \end{aligned}$ |
|  |  | 105 |  | dB |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{kHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{~K} \Omega \end{aligned}$ |
| The following specifications apply for $0^{\circ} \mathrm{C} \leqslant \mathrm{T}_{\mathrm{A}} \leqslant+70^{\circ} \mathrm{C}$ for XR4558CP |  |  |  |  |  |  |
| Input Offset Voltage |  |  | 7.5 | MV | $\left\|V_{\text {io }}\right\|$ | $\mathrm{R}_{\mathrm{S}} \leq 10 \mathrm{~K} \Omega$ |
| Input Offset Current |  |  | 300 | nA | $\left\|\mathrm{I}_{\text {iol }}\right\|$ |  |
| Input Bias Current |  |  | 800 | nA | $\mathrm{Ib}^{\text {b }}$ |  |
| Large-Signal Voltage Gain | 15 |  |  | $\mathrm{V} / \mathrm{mV}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{s}} \geq 2 \mathrm{~K} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 10$ |  |  | mV | $\mathrm{V}_{\text {out }}$ | $\mathrm{R}_{\mathrm{L}} \geq 2 \mathrm{~K} \Omega$ |
| Power Consumption |  | $\begin{array}{r} 90 \\ 120 \end{array}$ | $\begin{aligned} & 150 \\ & 200 \end{aligned}$ | $\begin{aligned} & \mathrm{mW} \\ & \mathrm{~mW} \end{aligned}$ | $\begin{aligned} & \mathrm{P}_{\mathrm{i}} \\ & \mathrm{P}_{\mathrm{i}} \end{aligned}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=\text { High } \\ & \mathrm{T}_{\mathrm{A}}=\text { Low } \end{aligned}$ |

# Dual Low-Noise Operational Amplifier 

## GENERAL DESCRIPTION

The XR-4739 dual low-noise operational amplifier is fabricated on a single silicon chip using the planar epitaxial process. It was designed primarily for preamplifiers in consumer and industrial signal processing equipment. The device is pin compatible with the $\mu \mathrm{A} 739$ and MC1303, however, compensation is internal. This permits a lowered external parts count and similified application.
The XR-4739 is available in molded dual in-line 14 -pin package, and operates over the commercial temperature range from $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$.

## FEATURES

Internally Compensated Replacement for $\mu \mathrm{A} 739$ and MC1303
Signal-to-Noise Ratio 76 dB (RIAA 10 mV ref.)
Channel Separation 125 dB
Unity Gain Bandwidth 3 MHz
Output Short-circuit Protected
$0.1 \%$ Distortion at 8.5 V RMS Output into $2 \mathrm{~K} \Omega$ Load

ABSOLUTE MAXIMUM RATINGS
Supply Voltage
Internal Power Dissipation (Note 1)
Differential Input Voltage
500 mW
Input Voltage (Note 2)
$\pm 30 \mathrm{~V}$
Storage Temperature Range
Lead Temperature (Soldering, 60 sec .)
Output Short-Circuit Duration (Note 3)

## AVAILABLE TYPES

Part Number
XR-4739CN
XR-4739CP

Package Types
Ceramic
Plastic

Operating Temperature
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$
$0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$

SCHEMATIC DIAGRAM


FUNCTIONAL BLOCK DIAGRAM


ELECTRICAL CHARACTERISTICS $\left(\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{v}_{\mathrm{CC}}= \pm 15 \mathrm{~V}\right.$ unless otherwise specified)

| PARAMETER | MIN | TYP | MAX | UNITS | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Input Offset Voltage |  | 2.0 | 6.0 | mV | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{k} \Omega$ |
| Input Offset Current |  | 5.0 | 200 | nA |  |
| Input Bias Current |  | 40 | 500 | nA |  |
| Input Resistance | 0.3 | 5.0 |  | $\mathrm{M} \Omega$ |  |
| Large-Signal Voltage Gain | 20 | 60 |  | K | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{k} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 12$ | $\pm 14$ |  | V | $\mathrm{R}_{\mathrm{L}} \geqslant 10 \mathrm{k} \Omega$ |
|  | $\pm 10$ | $\pm 13$ |  | V | $\mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{k} \Omega$ |
| Input Voltage Range | $\pm 12$ | $\pm 14$ |  | V |  |
| Common Mode Rejection Ratio | 70 | 100 |  | dB | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{k} \Omega$ |
| Supply Voltage Rejection Ratio |  | 10 | 150 | $\mu \mathrm{V} / \mathrm{V}$ | $\mathrm{R}_{\mathrm{S}} \leqslant 10 \mathrm{k} \Omega$ |
| Power Consumption |  | 40 | 120 | mW |  |
| Transient Response (unity gain) Risetime |  | 0.15 |  | $\mu \mathrm{s}$ | $\begin{aligned} & \mathrm{V}_{\mathrm{in}}=20 \mathrm{mV} \\ & \mathrm{R}_{\mathrm{L}}=20 \mathrm{k} \Omega \\ & \mathrm{C}_{\mathrm{L}} \leqslant 100 \mathrm{pF} \end{aligned}$ |
| Transient Response (unity gain) Overshoot |  | 10 |  | \% | $\begin{aligned} & \mathrm{V}_{\text {in }}=20 \mathrm{mV} \\ & \mathrm{R}_{\mathrm{L}}=2 \mathrm{k} \Omega \\ & \mathrm{C}_{\mathrm{L}} \leqslant 100 \mathrm{pF} \end{aligned}$ |
| Slew Rate (unity gain) |  | 1.0 |  | V/ $\mu \mathrm{s}$ | $\mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{k} \Omega$ |
| Broadband Noise Voltage |  | 2.5 |  | $\mu \mathrm{V}_{\text {RMS }}$ | $\begin{aligned} & \mathrm{B}_{\mathrm{W}}=10 \mathrm{~Hz}-30 \mathrm{KHz} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{k} \Omega \end{aligned}$ |
| Channel Separation |  | 125 |  | dB | $\begin{aligned} & \mathrm{f}=1.0 \mathrm{kHz} \\ & \mathrm{AV}=40 \mathrm{~dB} \\ & \mathrm{R}_{\mathrm{S}}=1 \mathrm{k} \Omega \end{aligned}$ |
| The following specifications apply for $0^{\circ} \mathrm{C} \leqslant \mathrm{T}_{\mathrm{A}} \leqslant 75^{\circ} \mathrm{C}$ unless otherwise specified |  |  |  |  |  |
| Input Offset Voltage |  | 3.0 | 7.5 | mV | RS $\leqslant 10 \mathrm{k} \Omega$ |
| Input Offset Current |  | 7.0 | 300 | nA |  |
| Input Bias Current |  | 50 | 800 | nA |  |
| Large-Signal Voltage Gain | 15,000 | 200,000 |  |  | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{k} \Omega \\ & \mathrm{~V}_{\text {out }}= \pm 10 \mathrm{~V} \end{aligned}$ |
| Output Voltage Swing | $\pm 10$ | $\pm 13$ |  | V | $\mathrm{R}_{\mathrm{L}} \geqslant 2 \mathrm{k} \Omega$ |
| Power Consumption |  |  |  |  | $\mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}$ |
|  |  | 100 | 150 | mW | $\mathrm{T}_{\mathrm{A}}=70^{\circ} \mathrm{C}$ |
|  |  | 110 | 200 | mW | $\mathrm{T}_{\mathrm{A}}=0^{\circ} \mathrm{C}$ |

## Notes:

1. Rating applies for ambient temperatures below $+75^{\circ} \mathrm{C}$
2. For supply voltages less than 15 V , the absolute maximum input voltage is equal to the supply voltage.
3. Short-circuit may be to ground, ty pically 45 mA . Rating applies to $+125^{\circ} \mathrm{C}$ ambient temperature.

## XR-5532/5533

## Dual Low-Noise Operational Amplifiers

## GENERAL DESCRIPTION

The XR-5532/XR-5533 family of dual low-noise operational amplifiers are especially designed for application in high quality professional audio equipment. Their low-noise, wide bandwidth and output drive capability make them ideally suited for instrumentation and control circuits as well as active filter design.

The XR-5532 is internally compensated and is available in 8-pin dual-in-line package. The XR-5533, available in 14-pin package, has separate balance and compensation terminals for each of the amplifier sections.

## FEATURES

Direct Replacement for Signetics NE 5532/5533
Wide Small-Signal Bandwidth: 10 MHz
High-Current Drive Capability
( 10 V rms into $600 \Omega$ at $\mathrm{V}_{\mathrm{s}}= \pm 18 \mathrm{~V}$ )
High Slew Rate: $13 \mathrm{~V} / \mu \mathrm{s}$
Wide Power-Bandwidth: 200 kHz
Very Low Input Noise: $4 \mathrm{nV} / \sqrt{\mathrm{Hz}}$

## APPLICATIONS

High Quality Audio Amplification
Telephone Channel Amplifier
Servo Control Systems
Low-Level Signal Detection
Active Filter Design

EQUIVALENT SCHEMATIC


## ABSOLUTE MAXIMUM RATINGS

| Power Supply | $\pm 22 \mathrm{~V}$ |
| :--- | ---: |
| Input Common-Mode Range | $-\mathrm{V}_{\mathrm{EE}}$ to $+\mathrm{V}_{\mathrm{CC}}$ |
| Differential Input Voltage (Note 1) | $\pm 0.5 \mathrm{~V}$ |
| Short Circuit Duration (Note 2) | Indefinite |
| Power Dissipation (Package Limitation) |  |
| Ceramic Package 14-Pin | 750 mW |
| Ceramic Package 8-Pin | 600 mW |
| Derate Above T ${ }_{\mathrm{A}}=25^{\circ} \mathrm{C}$ | $5 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$ |
| Storage Temperature | $-60^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$ |

Note 1: Diodes protect the inputs against over-voltage. Therefore, unless current-limiting resistors are used, large currents will flow if the differential input voltage exceeds 0.6 V . Maximum current should be limited to $\pm 10 \mathrm{~mA}$.
Note 2: Output may be shorted to ground at $\mathrm{V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=15 \mathrm{~V}$, $\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$. Temperature and/or supply voltages must be limited to ensure dissipation rating is not exceeded.

## AVAILABLE TYPES

| Part Number | Package | Temperature |
| :--- | :--- | :---: |
| XR-5532N/XR-5533N | Ceramic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-5532P/XR-5533P | Plastic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-5532CN/XR-5533CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-5532CP/XR-5533CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

FUNCTIONAL BLOCK DIAGRAM


## ELECTRICAL CHARACTERISTICS

$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=15 \mathrm{~V}$ unless otherwise specified.

| CHARACTERISTICS | XR-5532/XR-5533 |  |  | XR-5532C/XR-5533C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| DC CHARACTERISTICS |  |  |  |  |  |  |  |  |  |
| Input Offset Voltage |  | 0.5 | 4 5 |  | 0.5 | $\begin{aligned} & 4 \\ & 5 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\mathrm{V}_{\mathrm{OS}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  | 20 | $\begin{array}{r} 300 \\ 400 \\ \hline \end{array}$ |  | 20 | $\begin{aligned} & 300 \\ & 400 \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{nA} \\ & \mathrm{nA} \\ & \hline \end{aligned}$ | $\mathrm{I}_{\mathrm{OS}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Bias Current |  | 500 | $\begin{array}{r} 1500 \\ 2000 \\ \hline \end{array}$ |  | 500 | $\begin{aligned} & 1500 \\ & 2000 \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{nA} \\ & \mathrm{nA} \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Large Signal Voltage Gain | $\begin{aligned} & 25 \\ & 15 \\ & \hline \end{aligned}$ | 100 |  | $\begin{aligned} & 25 \\ & 15 \\ & \hline \end{aligned}$ | 100 |  | $\begin{aligned} & \mathrm{V} / \mathrm{mV} \\ & \mathrm{~V} / \mathrm{mV} \end{aligned}$ | $\mathrm{A}_{\mathrm{VOL}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 600 \Omega, \mathrm{~V}_{\mathrm{O}}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current (Each Amplifier) |  | 4 | 8 |  | 4 | 8 | mA | $\mathrm{I}_{\mathrm{CC}}$ | $\mathrm{R}_{\mathrm{L}}=$ Open |
| Output Swing | $\begin{array}{r}  \pm 12 \\ \pm 15 \\ \hline \end{array}$ | $\begin{aligned} & \pm 13 \\ & \pm 16 \\ & \hline \end{aligned}$ |  | $\pm 12$ | $\pm 13$ |  | $\begin{aligned} & \mathrm{V} \\ & \mathrm{~V} \end{aligned}$ | V OUT | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 600 \Omega \\ & \mathrm{~V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=15 \mathrm{~V} \\ & \mathrm{~V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=18 \mathrm{~V} \end{aligned}$ |
| Output Short Circuit Current |  | 38 |  |  | 38 |  | mA | $\mathrm{I}_{\text {SC }}$ | (Note 2) |
| Input Resistance | 30 | 100 |  | 30 | 100 |  | $\mathrm{k} \Omega$ | $\mathrm{R}_{\mathrm{IN}}$ |  |
| Common-Mode Range | $\pm 12$ | $\pm 13$ |  | $\pm 12$ | $\pm 13$ |  | V | $\mathrm{V}_{\mathrm{iCM}}$ |  |
| Common-Mode Rejection | 70 | 100 |  | 70 | 100 |  | dB | CMRR |  |
| Power Supply Rejection |  | 10 | 100 |  | 10 | 100 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR |  |
| Channel Separation |  | 120 |  |  | 120 |  |  | dB |  |
| AC CHARACTERISTICS (XR-5533 and XR-5533C only. See Note A for XR-5532.) |  |  |  |  |  |  |  |  |  |
| Transient Response Rise Time Overshoot |  | $\begin{aligned} & 20 \\ & 20 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 20 \\ & 20 \\ & \hline \end{aligned}$ |  | $\begin{aligned} & \text { nsec } \\ & \% \end{aligned}$ | $\begin{aligned} & \mathrm{t}_{\mathrm{r}} \\ & \mathrm{t}_{\mathrm{O}} \\ & \hline \end{aligned}$ | Voltage Follower $\begin{aligned} & \mathrm{R}_{\mathrm{L}}=600 \Omega, \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF} \\ & \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF} \\ & \hline \end{aligned}$ |
| AC Gain |  | $\begin{array}{r} 6 \\ 2.2 \\ \hline \end{array}$ |  |  | $\begin{array}{r} 6 \\ 2.2 \\ \hline \end{array}$ |  | $\begin{aligned} & \mathrm{V} / \mathrm{mV} \\ & \mathrm{~V} / \mathrm{mV} \end{aligned}$ |  | $\begin{aligned} & \mathrm{f}=10 \mathrm{kHz} \\ & \mathrm{C}_{\mathrm{C}}=0 \\ & \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF} \\ & \hline \end{aligned}$ |
| Unity-Gain Bandwidth |  | 10 |  |  | 10 |  | MHz | BW | $\mathrm{C}_{\mathrm{C}}=22 \mathrm{pF}, \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}$ |
| Slew Rate |  | $\begin{array}{r} 13 \\ 6 \\ \hline \end{array}$ |  |  | $\begin{array}{r} 13 \\ 6 \\ \hline \end{array}$ |  | V/ $\mu \mathrm{sec}$ <br> V/ $\mu \mathrm{sec}$ |  | $\begin{aligned} & \mathrm{C}_{\mathrm{C}}=0 \\ & \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF} \\ & \hline \end{aligned}$ |
| Power Bandwidth |  | 95 |  |  | 95 |  | KHz | $\mathrm{fp}_{\mathrm{p}}$ | $\mathrm{V}_{\text {OUT }}= \pm 10 \mathrm{~V}, \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF}$ |
| NOISE CHARACTERISTICS |  |  |  |  |  |  |  |  |  |
| Input Noise Voltage |  | $\begin{aligned} & 5.5 \\ & 3.5 \end{aligned}$ | $\begin{array}{r} 7 \\ 4.5 \end{array}$ |  | 7 4 |  | $\begin{aligned} & \mathrm{nV} / \sqrt{\mathrm{Hz}} \\ & \mathrm{nV} / \sqrt{\mathrm{Hz}} \end{aligned}$ | $\mathrm{e}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{f}_{\mathrm{O}}=30 \mathrm{~Hz} \\ & \mathrm{f}_{\mathrm{O}}=1 \mathrm{kHz} \end{aligned}$ |
| Input Noise Current |  | $\begin{aligned} & 1.5 \\ & 0.4 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 2.5 \\ & 0.6 \\ & \hline \end{aligned}$ |  | $\begin{aligned} & \mathrm{pA} / \sqrt{\mathrm{Hz}} \\ & \mathrm{pA} / \sqrt{\mathrm{Hz}} \end{aligned}$ | $\mathrm{i}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{f}_{\mathrm{O}}=30 \mathrm{~Hz} \\ & \mathrm{f}_{\mathrm{O}}=1 \mathrm{kHz} \end{aligned}$ |
| Broadband Noise Figure |  | 0.9 |  |  | 0.9 |  | dB | $\mathrm{F}_{\mathrm{N}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=5 \mathrm{k} \Omega \\ & \mathrm{f}=10 \mathrm{~Hz} \text { to } 20 \mathrm{kHz} \end{aligned}$ |

Note A: XR-5532 and XR-5532C are internally compensated, with internal $\mathrm{C}_{\mathrm{C}}=22 \mathrm{pF}$. Thus, their AC Characteristics correspond to those listed above for $\mathrm{C}_{\mathrm{C}}=22 \mathrm{pF}$.


Typical Frequency Compensation and Offset Adjustment Circuit.


Typical Test Circuit for Closed Loop Frequency Response.

# Low-Noise Operational Amplifier 

## GENERAL DESCRIPTION

The XR-5534 is a high-performance low-noise operational amplifier especially designed for application in high quality and professional audio equipment. It offers significantly better noise performance, output drive capability and power bandwidth than the conventional 741-type operational amplifiers.
The low noise characteristics of the XR-5534 also makes it ideally suited for instrumentation and control circuits and telephone channel amplifiers. The op-amp is internally compensated for gain equal to, or higher than, three. The frequency response can be optimized with an external compensation capacitor for various applications such as operating in unity-gain mode or driving capacitive loads.

## FEATURES

Direct Replacement for Signetics NE 5532/5533
Wide Small-Signal Bandwidth: 10 MHz
High-Current Drive Capability
$\left(10 \mathrm{~V}\right.$ rms into $600 \Omega$ at $\left.\mathrm{V}_{\mathrm{s}}= \pm 18 \mathrm{~V}\right)$
High Slew Rate: $13 \mathrm{~V} / \mu \mathrm{s}$
Wide Power-Bandwidth: 200 kHz
Very Low Input Noise: $4 \mathrm{nV} / \sqrt{\mathrm{Hz}}$

## APPLICATIONS

High Quality Audio Amplification
Telephone Channel Amplifiers
Servo Control Systems
Low-Level Signal Detection
Active Filter Design

## EQUIVALENT SCHEMATIC



ABSOLUTE MAXIMUM RATINGS

| Power Supply | $\pm 22 \mathrm{~V}$ |
| :--- | ---: |
| Input Common-Mode Voltage | $+\mathrm{V}_{\mathrm{CC}}$ to $-\mathrm{V}_{\mathrm{EE}}$ |
| Differential Input Voltage (Note 1) | $\pm 0.5 \mathrm{~V}$ |
| Power Dissipation (Package Limitation) |  |
| $\quad$ Ceramic package | 385 mW |
| Plastic Package | 300 mW |
| Derate Above $+25^{\circ} \mathrm{C}$ | $2.5 \mathrm{~mW} /{ }^{\circ} \mathrm{C}$ |
| Short Circuit Duration (Note 2) | Indefinite |
| Storage Temperature | $-60^{\circ} \mathrm{C}$ to $+150^{\circ} \mathrm{C}$ |

Note 1: Diodes protect the inputs against over-voltage. Therefore, unless current-limiting resistors are used, large currents will flow if the differential input voltage exceeds 0.6 V . Maximum current should be limited to $\pm 10 \mathrm{~mA}$.
Note 2: Output may be shorted to ground at $\mathrm{V}_{\mathrm{S}}= \pm 15 \mathrm{~V}, \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C}$. Temperature and/or supply voltages must be limited to ensure dissipation rating is not exceeded.

## AVAILABLE TYPES

| Part Number | Package | Operating Temperature |
| :--- | :--- | :---: |
| XR-5534M | Ceramic | $-55^{\circ} \mathrm{C}$ to $+125^{\circ} \mathrm{C}$ |
| XR-5534N | Ceramic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-5534P | Plastic | $-25^{\circ} \mathrm{C}$ to $+85^{\circ} \mathrm{C}$ |
| XR-5534CN | Ceramic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |
| XR-5534CP | Plastic | $0^{\circ} \mathrm{C}$ to $+75^{\circ} \mathrm{C}$ |

## FUNCTIONAL BLOCK DIAGRAM



## ELECTRICAL CHARACTERISTICS

$\mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C}, \mathrm{V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=15 \mathrm{~V}$, unless otherwise specified.

| DC CHARACTERISTICS | XR-5534M |  |  | XR-5534 |  |  | XR-5534C |  |  | UNITS | SYMBOL | CONDITIONS |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. |  |  |  |
| Input Offset Voltage |  | 0.5 | 2 |  | 0.5 | $\begin{aligned} & 4 \\ & 5 \end{aligned}$ |  | 0.5 | $\begin{aligned} & 4 \\ & 5 \end{aligned}$ | $\begin{aligned} & \mathrm{mV} \\ & \mathrm{mV} \end{aligned}$ | $\mathrm{V}_{\text {OS }}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Offset Current |  | 10 | $\begin{array}{r} 200 \\ 500 \\ \hline \end{array}$ |  | 20 | $\begin{array}{r} 300 \\ 400 \\ \hline \end{array}$ |  | 20 | $\begin{array}{r} 300 \\ 400 \\ \hline \end{array}$ | $\begin{aligned} & \mathrm{nA} \\ & \mathrm{nA} \\ & \hline \end{aligned}$ | $\mathrm{I}_{\mathrm{OS}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Input Bias Current |  | 400 | $\begin{array}{r} 800 \\ 1500 \\ \hline \end{array}$ |  | 500 | $\begin{aligned} & 1500 \\ & 2000 \\ & \hline \end{aligned}$ |  | 500 | $\begin{aligned} & 1500 \\ & 2000 \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{nA} \\ & \mathrm{nA} \\ & \hline \end{aligned}$ | $\mathrm{I}_{\mathrm{B}}$ | $\begin{aligned} & \mathrm{T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Large Signal Voltage Gain | $\begin{aligned} & 50 \\ & 25 \end{aligned}$ | 100 |  | $\begin{aligned} & 25 \\ & 15 \\ & \hline \end{aligned}$ | 100 |  | $\begin{aligned} & 25 \\ & 15 \\ & \hline \end{aligned}$ | 100 |  | $\begin{aligned} & \mathrm{V} / \mathrm{mV} \\ & \mathrm{~V} / \mathrm{mV} \end{aligned}$ | AVOL | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 600 \Omega, \mathrm{~V}_{0}= \pm 10 \mathrm{~V} \\ & \mathrm{~T}_{\mathrm{A}}=25^{\circ} \mathrm{C} \\ & \mathrm{~T}_{\mathrm{A}}=\text { Full Range } \end{aligned}$ |
| Supply Current |  | 4 | 6.5 |  | 4 | 8 |  | 4 | 8 | mA | $\mathrm{I}_{\mathrm{CC}}$ | $\mathrm{R}_{\mathrm{L}}=$ Open |
| Output Swing | $\begin{array}{r}  \pm 12 \\ \pm 15 \\ \hline \end{array}$ | $\begin{array}{r}  \pm 13 \\ \pm 16 \\ \hline \end{array}$ |  | $\begin{array}{r}  \pm 12 \\ \pm 15 \\ \hline \end{array}$ | $\begin{array}{r}  \pm 13 \\ \pm 16 \\ \hline \end{array}$ |  | $\pm 12$ | $\pm 13$ |  | $\begin{aligned} & \mathrm{V} \\ & \mathrm{~V} \end{aligned}$ | VOUT | $\begin{aligned} & \mathrm{R}_{\mathrm{L}} \geqslant 600 \Omega \\ & \mathrm{~V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=15 \mathrm{~V} \\ & \mathrm{~V}_{\mathrm{CC}}=\mathrm{V}_{\mathrm{EE}}=18 \mathrm{~V} \end{aligned}$ |
| Output Short Circuit Current |  | 38 |  |  | 38 |  |  | 38 |  | mA | ISC | (Note 2) |
| Input Resistance | 50 | 100 |  | 30 | 100 |  | 30 | 100 |  | K $\Omega$ | $\mathrm{R}_{\text {in }}$ |  |
| Common-Mode Range | $\pm 12$ | $\pm 13$ |  | $\pm 12$ | $\pm 13$ |  | $\pm 12$ | $\pm 13$ |  | V | $\mathrm{V}_{\mathrm{i}} \mathrm{CM}$ |  |
| Common-Mode Rejection | 80 | 100 |  | 70 | 100 |  | 70 | 100 |  | dB | CMRR |  |
| Power Supply Rejection |  | 10 | 50 |  | 10 | 100 |  | 10 | 100 | $\mu \mathrm{V} / \mathrm{V}$ | PSRR |  |
| AC CHARACTERISTICS |  |  |  |  |  |  |  |  |  |  |  |  |
| Transient Response Rise Time Overshoot |  | $\begin{aligned} & 20 \\ & 20 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 20 \\ & 20 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 20 \\ & 20 \\ & \hline \end{aligned}$ |  | $\begin{aligned} & \mathrm{nSec} \\ & \% \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathbf{t}_{\mathrm{r}} \\ & \mathbf{t}_{\mathrm{O}} \\ & \hline \end{aligned}$ | Voltage Follower $\begin{aligned} \mathrm{R}_{\mathrm{L}}=600 \Omega, \mathrm{C}_{\mathrm{C}} & =22 \mathrm{pF} \\ \mathrm{C}_{\mathrm{L}} & =100 \mathrm{pF} \end{aligned}$ |
| AC Gain |  | $\begin{array}{r} 6 \\ 2.2 \\ \hline \end{array}$ |  |  | $\begin{array}{r} 6 \\ 2.2 \\ \hline \end{array}$ |  |  | $\begin{array}{r} 6 \\ 2.2 \\ \hline \end{array}$ |  | $\begin{aligned} & 6 \\ & 2.2 \end{aligned}$ | $\begin{aligned} & \mathrm{V} / \mathrm{mV} \\ & \mathrm{~V} / \mathrm{mV} \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{f}=10 \mathrm{kHz} \\ & \mathrm{C}_{\mathrm{C}}=0 \\ & \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF} \end{aligned}$ |
| Unity-Gain Bandwidth |  | 10 |  |  | 10 |  |  | 10 |  | MHz | BW | $\mathrm{C}_{\mathrm{C}}=22 \mathrm{pF}, \mathrm{C}_{\mathrm{L}}=100 \mathrm{pF}$ |
| Slew Rate |  | 13 6 |  |  | 13 6 |  |  | 13 6 |  | V/usec <br> $\mathrm{V} / \mu \mathrm{sec}$ |  | $\begin{aligned} & \mathrm{C}_{\mathrm{C}}=0 \\ & \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF} \end{aligned}$ |
| Power Bandwidth |  | 9 |  |  | 95 |  |  | 95 |  | KHz | ${ }^{\text {f }}$ | $\mathrm{V}_{\text {OUT }}= \pm 10 \mathrm{~V}, \mathrm{C}_{\mathrm{C}}=22 \mathrm{pF}$ |
| NOISE CHARACTERISTICS |  |  |  |  |  |  |  |  |  |  |  |  |
| Input Noise Voltage |  | $\begin{aligned} & 5.5 \\ & 3.5 \\ & \hline \end{aligned}$ | $\begin{array}{r} 7 \\ 4.5 \\ \hline \end{array}$ |  | $\begin{aligned} & 5.5 \\ & 3.5 \\ & \hline \end{aligned}$ | $\begin{array}{r} 7 \\ 4.5 \\ \hline \end{array}$ |  | 7 4 |  | $\begin{aligned} & \mathrm{nV} / \sqrt{\mathrm{Hz}} \\ & \mathrm{nV} / \sqrt{\mathrm{Hz}} \end{aligned}$ | $\mathrm{e}_{\mathrm{n}}$ | $\begin{aligned} \mathrm{f}_{0} & =30 \mathrm{~Hz} \\ \mathrm{f}_{0} & =1 \mathrm{kHz} \end{aligned}$ |
| Input Noise Current |  | $\begin{aligned} & 1.5 \\ & 0.4 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 1.5 \\ & 0.4 \\ & \hline \end{aligned}$ |  |  | $\begin{aligned} & 2.5 \\ & 0.6 \end{aligned}$ |  | $\begin{aligned} & \mathrm{pA} / \sqrt{\mathrm{Hz}} \\ & \mathrm{pA} / \sqrt{\mathrm{Hz}} \end{aligned}$ | $\mathrm{i}_{\mathrm{n}}$ | $\begin{aligned} & \mathrm{f}_{0}=30 \mathrm{~Hz} \\ & \mathrm{f}_{0} 1 \mathrm{kHz} \end{aligned}$ |
| Broadband Noise Figure |  | 0.9 |  |  | 0.9 |  |  | 0.9 |  | dB | $\mathrm{F}_{\mathrm{N}}$ | $\begin{aligned} & \mathrm{R}_{\mathrm{S}}=5 \mathrm{~K} \Omega \\ & \mathrm{f}=10 \mathrm{~Hz} \text { to } 20 \mathrm{kHz} \end{aligned}$ |



Typical Frequency Compensation and Offset Adjustment Circuit.


Typical Test Circuit for Closed Loop Frequency Response.

# Additional Technical Literature 

## Other Data Books

As a companion set to this Operational Amplifier Data Book, Exar's technical staff and applications engineers have prepared a series of additional Data Books which cover some of the key features and applications of Exar's other IC products. These Data Books also present a number of tutorial articles on the fundamentals of such important IC products as timers, phaselocked loops, and voltage-controlled oscillators. These books are available directly from your Exar sales or technical representative.
A brief description of each of these data books is given below:

## TIMER DATA BOOK:

This data book provides a collection of technical articles and application information on monolithic timer IC products. Also included are the data sheets and the detailed electrical specifications of all of Exar's timer circuits, including the programmable timer/counters, micropower and long-delay timers. (48 pages)

## PHASE-LOCKED LOOP DATA BOOK:

This data book covers the fundamentals of design and applications of monolithic phase-locked loop (PLL) circuits. A
long list of PLL applications are illustrated covering FM demodulation, frequency synthesis, FSK and tone detection. Particular emphasis is given to application of PLL circuits in data interface and communication systems such as FSK modems. This book also contains the data sheets and electrical specifications of all of Exar's PLL products. (72 pages)

## FUNCTION GENERATOR DATA BOOK:

This comprehensive data book contains a number of technical articles and application notes on monolithic voltagecontrolled oscillator (VCO) and function generator IC products. In addition, the data sheets and technical specifications of Exar's monolithic VCOs and function generators are given. (50 pages)

## APPLICATIONS DATA BOOK:

This book 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. (70 pages)

## Application Notes

Exar's Applications Engineering Department has prepared a comprehensive set of application notes and information in Exar's products and technologies. A list of these application notes, along with a brief description of their contents, is given below:

## AN-01: Stable FSK Modems Featuring the XR-2206, XR-2207

 and XR-2211Design of stable full-duplex FSK modems is described using the XR-2206 or the XR-2207 as the modulator, and the XR-2211 as the demodulator with carrier-detection capability. Complete design examples are given for FSK modems covering mark/space frequencies from a few Hertz to 100 kHz .

## AN-02: XR-C240 Monolithic PCM Repeater

The principle of operation of the XR-C240 monolithic regenerative repeater IC is described. Design examples and external connections of the circuit are discussed for applications in T-1 type 1.544 Megabit PCM telephone lines.

## AN-03: Active Filter Design with IC Op-Amps

Fundamentals of active filters are discussed, transfer functions
and design equations for various classes of high-, low- and bandpass filters are given. Particular design examples are provided for FSK modem filters, using the XR-4202 programmable quad op-amp.

## AN-04: XR-C277 Low-Voltage PCM Repeater IC

The design principles and the applications of the XR-C277 low-voltage ( 6.3 volt) regenerative PCM repeater are described. The monolithic IC contains all the basic functional blocks of a conventional PCM repeater, including the automatic line builtout section. Circuit connection diagrams and application examples are given for operation in 1.544 Megabit T-1 type PCM telephone systems.

AN-05: Tri-State FSK Modem Design Using XR-2206/XR-2211 Design of FSK modems with carrier detection and control capability are discussed. Such a "tri-state" modem uses a third carrier frequency for control functions, in addition to the normal "mark" and "space" frequencies used in conventional "bi-state" FSK systems. This carrier control feature allows each transmitter in a modem system to be automatically interrogated, one at a time, by a control processor, without interference from other modem transmitters within the system.

AN-06: Precision PLL System Using XR-2207/XR-2208
A two-chip versatile phase-locked loop system is described, using the XR-2207 oscillator as the VCO, and the XR-2208 multiplier as the phase detector. The resulting PLL system features $20 \mathrm{ppm} /{ }^{\circ} \mathrm{C}$ temperature stability. Design equations are given to tailor the circuit parameters to specific applications.

AN-07: Single-Chip Frequency Synthesizer Employing the XR-2240
The operation of the XR-2240 programmable/counter IC as a frequency synthesizer is described. The circuit can simultaneously multiply an input frequency by an integer modulus M , and divide it by a different modulus $\mathrm{N}+1$. Thus, a wide range of non-integer output frequencies can be produced from a single input reference frequency.

AN-08: Dual-Tone Decoding with XR-567 and XR-2567 Application examples are given for simultaneous or sequential decoding of dual-tone control signals using either two XR-567 PLL tone decoders, or a single XR-2567 dual tone decoder. The examples include high-speed, narrow-band tone detection and Touch-Tone ${ }^{\circledR}$ decoding.

AN-09: Sinusoidal Output from XR-215 Monolithic PLL Circuit
A simple circuit technique is described to convert the VCO output of the XR-215 into a low-distortion sinewave. The external sinewave-shaping circuit is obtained using the XR-C101 monolithic NPN transistor array.

## AN-10: XR-C262 High-Performance PCM Repeater

The design principle and the electrical characteristics of the XR-C262 high-performance PCM repeater IC are described. The circuit contains all the active components necessary for a regenerative PCM repeater system and operates with a single 6.8 volt power supply. Circuit connection and application examples are given for its use in 1.5 Megabit or 2 Megabit PCM systems.

AN-11: A Universal Sinewave Converter Using the XR-2208 and XR-2211
A circuit technique is described which can convert any periodic waveform into a low-distortion sinewave. The circuit operation is completely independent of input waveform amplitude and frequency as long as the input signal is periodic, and can operate over a frequency range of 1 Hz to over 100 kHz .

AN-12: A Wide Tracking Range Precision PLL System Using the XR-2212 and XR-4151
A two-chip PLL system is described which offers extremely wide tracking range without harmonic locking. The system uses the XR-2212 precision PLL along with the XR-4151 voltage/frequency converter, and is ideally suited for motorspeed or tape-drive control applications.

AN-13: Frequency Selective AM Detection Using Monolithic Phase-Locked Loops
Design of frequency selective coherent AM and $\mathrm{AM} / \mathrm{FM}$ demodulator systems is described using the XR-2228 Multiplier/ Detector and the XR-215 or the XR-2212 PLL ICs.

AN-14: A Complete Function Generator System Using the XR-2206
A laboratory quality self-contained function generator system is described, using the XR-2206 waveform generator IC. Complete circuit connection diagram, parts list and assembly instructions are given for a DC to 100 kHz self-contained function generator system with AM/FM capability and triangle, sine and square wave output.

AN-15: An Electronic Music Synthesizer Using the XR-2207 and the XR-2240
Design of a simple, low-cost "music synthesizer" system is described. The electronic music synthesizer is comprised of the XR-2207 voltage-controlled oscillator IC which is driven by the pseudo-random binary pulse pattern generated by the XR-2240 counter/timer circuit.

## AN-16: Semi-Custom LSI Design with I ${ }^{2}$ L Gate Arrays

A unique design approach to developing complex LSI systems is described using XR-300 and XR-500 I 2 L gate arrays. This technique greatly reduces the design and tooling cost and the prototype fabrication cycle associated with the conventional full-custom IC development cycle; and thus makes custom ICs economically feasible even at low production volumes.

## AN-17: XR-C409 Monolithic I2L Test Circuit

A monolithic test circuit has been developed for evaluation of speed and performance capabilities of Exar's Integrated Injection Logic ( $\mathrm{I}^{2} \mathrm{~L}$ ) technology. This test circuit, designated the XR-C409, is intended to familiarize the I ${ }^{2} \mathrm{~L}$ user and the system designer with some of the performance features of $I^{2} \mathrm{~L}$ such as its frequency capability and power-speed tradeoffs.

# Monolithic Chips for Hybrid Assemblies 

The major performance characteristics of Exar products are also available in chip form. All chips are 100\% electrically tested for guaranteed DC parameters at $25^{\circ} \mathrm{C}$; and $100 \%$ visually inspected at 30 x to 100 x magnification using Exar's standard visual inspection criteria or MIL-STD-883, Method 201, depending on the individual customer requirements. Each chip is protected with an inert glass passivation layer over the metal interconnections. The chips are packaged in waffle-pack carriers with an anti-static shield and cushioning strip plated over the active surface to assure protection during shipment. All chips are produced on the same well-proven production lines that produce Exar's standard encapsulated devices. The Quality Assurance testing of dice is provided by normal production testing of packaged devices.


Typical Bipolar Chip Cross Section

## FEATURES

DC Parameters Guaranteed at $25^{\circ} \mathrm{C}$
$100 \%$ Visual Inspection
Care in Packaging
100\% Stabilization Bake (Wafer Form)
$10 \%$ LTPD on DC Electrical Parameters

## CHIPS IN WAFER FORM

Probed and inked wafers are also available from Exar. The hybrid microcircuit designer can specify either scribed or unscribed wafers and receive a fully tested silicon wafer. Rejected die are clearly marked with an ink dot for easy identification in wafer form.

## ELECTRICAL PARAMETERS

Probing the IC chips in die form limits the electrical testing to low level DC parameters at $25^{\circ} \mathrm{C}$. These DC parameters are characteristic of those parameters contained on the individual device data sheet and are guaranteed to an LTPD of $10 \%$.

The AC parameters, which are similar to those in the standard Exar device data sheets, have been correlated to selected DC probe parameters and are guaranteed to an LTPD of $20 \%$.

## HANDLING PRECAUTIONS AND PACKAGING OPTIONS

Extreme care must be used in the handling of unencapsulated semiconductor chips or dice to avoid damage to the chip surface. Exar offers the following three handling or packaging options for monolithic chips supplied to the customer:

Cavity or Waffle Pack: The dice are placed in individual compartments of the waffle pack (see figure). The plastic snap clips permit inspection and resealing.

Vial Pack: The vial is filled with inert freon TF and a plastic cap seals the vial. The freon acts as a motion retarder and cleansing agent.

Wafer Pack: The entire wafer is sandwiched between two pieces of mylar and vacuum sealed in a plastic envelope.


Typical Cavity Pack (Waffle Pack)

