



# AD536A—SPECIFICATIONS (@ +25°C, and ±15 V dc unless otherwise noted)

Model	AD536AJ			AD536AK			AD536AS			Units
	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
<b>TRANSFER FUNCTION</b>										
<b>CONVERSION ACCURACY</b>										
Total Error, Internal Trim <sup>1</sup> (Figure 1)	$V_{OUT} = \sqrt{\text{avg.}(V_{IN})^2}$			$V_{OUT} = \sqrt{\text{avg.}(V_{IN})^2}$			$V_{OUT} = \sqrt{\text{avg.}(V_{IN})^2}$			mV ± % of Reading
vs. Temperature, T <sub>MIN</sub> to +70°C	<b>±5 ±0.5</b>			<b>±2 ±0.2</b>			<b>±5 ±0.5</b>			mV ± % of Reading/°C
+70°C to +125°C	<b>±0.1 ±0.01</b>			<b>±0.05 ±0.005</b>			<b>±0.1 ±0.005</b>			mV ± % of Reading/°C
vs. Supply Voltage	±0.1 ±0.01			±0.1 ±0.01			±0.1 ±0.01			mV ± % of Reading/V
dc Reversal Error	±0.2			±0.1			±0.2			± % of Reading
Total Error, External Trim <sup>1</sup> (Figure 2)	±3 ±0.3			±2 ±0.1			±3 ±0.3			mV ± % of Reading
<b>ERROR VS. CREST FACTOR<sup>2</sup></b>										
Crest Factor 1 to 2	Specified Accuracy			Specified Accuracy			Specified Accuracy			% of Reading
Crest Factor = 3	-0.1			-0.1			-0.1			% of Reading
Crest Factor = 7	-1.0			-1.0			-1.0			% of Reading
<b>FREQUENCY RESPONSE<sup>3</sup></b>										
Bandwidth for 1% Additional Error (0.09 dB)										
V <sub>IN</sub> = 10 mV	5			5			5			kHz
V <sub>IN</sub> = 100 mV	45			45			45			kHz
V <sub>IN</sub> = 1 V	120			120			120			kHz
±3 dB Bandwidth										
V <sub>IN</sub> = 10 mV	90			90			90			kHz
V <sub>IN</sub> = 100 mV	450			450			450			kHz
V <sub>IN</sub> = 1 V	2.3			2.3			2.3			MHz
<b>AVERAGING TIME CONSTANT (Figure 5)</b>										
	25			25			25			ms/μF CAV
<b>INPUT CHARACTERISTICS</b>										
Signal Range, ±15 V Supplies	0 to 7			0 to 7			0 to 7			V rms
Continuous rms Level										V rms
Peak Transient Input	±20			±20			±20			V peak
Continuous rms Level, ±5 V Supplies	0 to 2			0 to 2			0 to 2			V rms
Peak Transient Input, ±5 V Supplies	±7			±7			±7			V peak
Maximum Continuous Nondestructive Input Level (All Supply Voltages)	±25			±25			±25			V peak
Input Resistance	13.33	16.67	20	13.33	16.67	20	13.33	16.67	20	kΩ
Input Offset Voltage	0.8 ±2			0.5 ±1			0.8 ±2			mV
<b>OUTPUT CHARACTERISTICS</b>										
Offset Voltage, V <sub>IN</sub> = COM (Figure 1)	±1			±0.5			±2			mV
vs. Temperature	±0.1			±0.1			±0.2			mV/°C
vs. Supply Voltage	±0.1			±0.1			±0.2			mV/V
Voltage Swing, ±15 V Supplies	0 to +11			0 to +11			0 to +11			V
±5 V Supply	0 to +2			0 to +2			0 to +2			V
<b>dB OUTPUT (Figure 13)</b>										
Error, V <sub>IN</sub> 7 mV to 7 V rms, 0 dB = 1 V rms	±0.4			±0.2			±0.5			dB
Scale Factor	-3			-3			-3			mV/dB
Scale Factor TC (Uncompensated, see Figure 1 for Temperature Compensation)	-0.033			-0.033			-0.033			dB/°C
I <sub>REF</sub> for 0 dB = 1 V rms	5	20	<b>80</b>	5	20	<b>80</b>	5	20	<b>80</b>	μA
I <sub>REF</sub> Range	1			1			1			μA
<b>I<sub>OUT</sub> TERMINAL</b>										
I <sub>OUT</sub> Scale Factor	40			40			40			μA/V rms
I <sub>OUT</sub> Scale Factor Tolerance	±10			±10			±10			%
Output Resistance	20	25	30	20	25	30	20	25	30	kΩ
Voltage Compliance	-V <sub>S</sub> to (+V <sub>S</sub> -2.5 V)			-V <sub>S</sub> to (+V <sub>S</sub> -2.5 V)			-V <sub>S</sub> to (+V <sub>S</sub> -2.5 V)			V
<b>BUFFER AMPLIFIER</b>										
Input and Output Voltage Range	-V <sub>S</sub> to (+V <sub>S</sub> -2.5 V)			-V <sub>S</sub> to (+V <sub>S</sub> -2.5 V)			-V <sub>S</sub> to (+V <sub>S</sub> -2.5 V)			V
Input Offset Voltage, R <sub>S</sub> = 25 k	±0.5			±0.5			±0.5			mV
Input Bias Current	20			20			20			nA
Input Resistance	10 <sup>8</sup>			10 <sup>8</sup>			10 <sup>8</sup>			Ω
Output Current	(+5 mA, -130 μA)			(+5 mA, -130 μA)			(+5 mA, -130 μA)			μA
Short Circuit Current	20			20			20			mA
Output Resistance	1			1			1			Ω
Small Signal Bandwidth	1			1			1			MHz
Slew Rate <sup>4</sup>	5			5			5			V/μs
<b>POWER SUPPLY</b>										
Voltage Rated Performance	±15			±15			±15			V
Dual Supply	±3.0		±18	±3.0		±18	±3.0		±18	V
Single Supply	+5		+36	+5		+36	+5		+36	V
Quiescent Current	1.2			1.2			1.2			mA
Total V <sub>S</sub> , 5 V to 36 V, T <sub>MIN</sub> to T <sub>MAX</sub>	2			2			2			mA
<b>TEMPERATURE RANGE</b>										
Rated Performance	0			0			-55			°C
Storage	-55			-55			-55			°C
<b>NUMBER OF TRANSISTORS</b>										
	65			65			65			

## NOTES

<sup>1</sup>Accuracy is specified for 0 V to 7 V rms, dc, or 1 kHz sine wave input with the AD536A connected as in the figure referenced.

<sup>2</sup>Error vs. crest factor is specified as an additional error for 1 V rms rectangular pulse input, pulsewidth = 200 μs.

<sup>3</sup>Input voltages are expressed in volts rms, and error is percent of reading.

<sup>4</sup>With 2k external pull-down resistor.

Specifications subject to change without notice.

Specifications shown in **boldface** are tested on all production units at final electrical test. Results from those tests are used to calculate outgoing quality levels. All min and max specifications are guaranteed, although only those shown in boldface are tested on all production units.

## ABSOLUTE MAXIMUM RATINGS<sup>1</sup>

### Supply Voltage

Dual Supply	±18 V
Single Supply	+36 V
Internal Power Dissipation <sup>2</sup>	500 mW
Maximum Input Voltage	±25 V Peak
Buffer Maximum Input Voltage	±V <sub>S</sub>
Maximum Input Voltage	±25 V Peak
Storage Temperature Range	-55°C to +150°C
Operating Temperature Range	
AD536AJ/K	0°C to +70°C
AD536AS	-55°C to +125°C
Lead Temperature Range	
(Soldering 60 sec)	+300°C
ESD Rating	1000 V

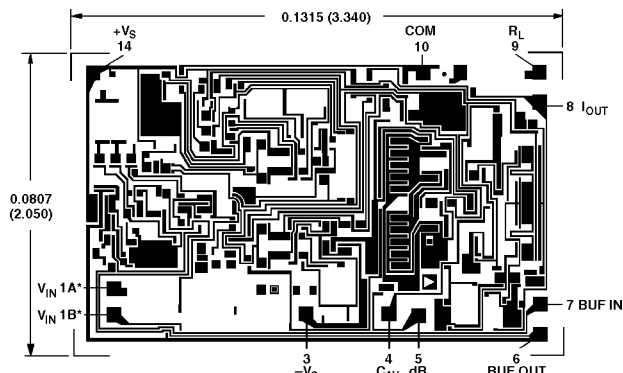
### NOTES

<sup>1</sup>Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

<sup>2</sup>10-Pin Header:  $\theta_{JA} = 150^{\circ}\text{C}/\text{W}$ ; 20-Leadless LCC:  $\theta_{JA} = 95^{\circ}\text{C}/\text{W}$ ; 14-Lead Size Brazed Ceramic DIP:  $\theta_{JA} = 95^{\circ}\text{C}/\text{W}$ .

## CHIP DIMENSIONS AND PAD LAYOUT

Dimensions shown in inches and (mm).



PAD NUMBERS CORRESPOND TO PIN NUMBERS FOR THE TO-166 14-LEAD CERAMIC DIP PACKAGE.

### NOTE

\*BOTH PADS SHOWN MUST BE CONNECTED TO V<sub>IN</sub>.  
THE AD536A IS AVAILABLE IN LASER TRIMMED CHIP FORM.  
SUBSTRATE CONNECTED TO -V<sub>S</sub>.

## ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
AD536AJD	0°C to +70°C	Side Brazed Ceramic DIP	D-14
AD536AKD	0°C to +70°C	Side Brazed Ceramic DIP	D-14
AD536AJH	0°C to +70°C	Header	H-10A
AD536AKH	0°C to +70°C	Header	H-10A
AD536AJQ	0°C to +70°C	Cerdip	Q-14
AD536AKQ	0°C to +70°C	Cerdip	Q-14
AD536ASD	-55°C to +125°C	Side Brazed Ceramic DIP	D-14
AD536ASD/883B	-55°C to +125°C	Side Brazed Ceramic DIP	D-14
AD536ASE/883B	-55°C to +125°C	LCC	E-20A
AD536ASH	-55°C to +125°C	Header	H-10A
AD536ASH/883B	-55°C to +125°C	Header	H-10A
AD536AJCHIPS	0°C to +70°C	Die	
AD536AKH/+	0°C to +70°C	Header	H-10A
AD536ASCHIPS	-55°C to +125°C	Die	
5962-89805012A	-55°C to +125°C	LCC	E-20A
5962-8980501CA	-55°C to +125°C	Side Brazed Ceramic DIP	D-14
5962-8980501IA	-55°C to +125°C	Header	H-10A

## STANDARD CONNECTION

The AD536A is simple to connect for the majority of high accuracy rms measurements, requiring only an external capacitor to set the averaging time constant. The standard connection is shown in Figure 1. In this configuration, the AD536A will measure the rms of the ac and dc level present at the input, but will show an error for low frequency inputs as a function of the filter capacitor, C<sub>AV</sub>, as shown in Figure 5. Thus, if a 4 μF capacitor is used, the additional average error at 10 Hz will be 0.1%, at 3 Hz it will be 1%. The accuracy at higher frequencies will be according to specification. If it is desired to reject the dc input, a capacitor is added in series with the input, as shown in Figure 3, the capacitor must be nonpolar. If the AD536A is driven with power supplies with a considerable amount of high frequency ripple, it is advisable to bypass both supplies to ground with 0.1 μF ceramic discs as near the device as possible.

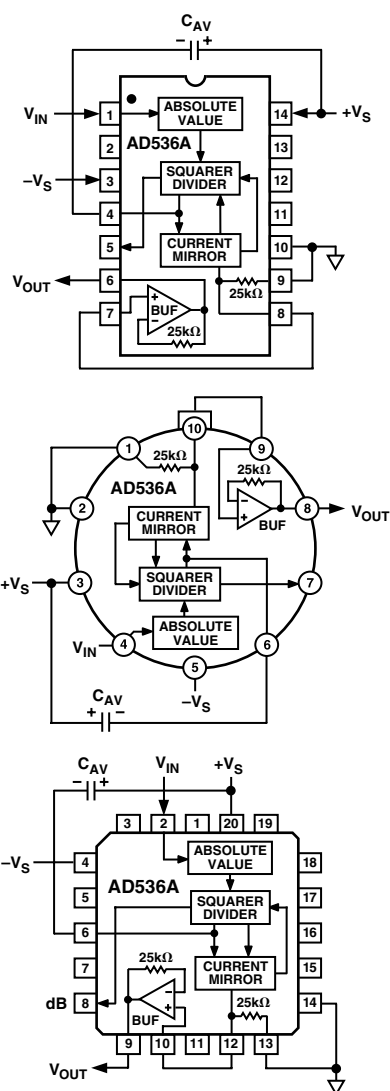


Figure 1. Standard RMS Connection

# AD536A

The input and output signal ranges are a function of the supply voltages; these ranges are shown in Figure 14. The AD536A can also be used in an unbuffered voltage output mode by disconnecting the input to the buffer. The output then appears unbuffered across the 25 kΩ resistor. The buffer amplifier can then be used for other purposes. Further the AD536A can be used in a current output mode by disconnecting the 25 kΩ resistor from ground. The output current is available at Pin 8 (Pin 10 on the "H" package) with a nominal scale of 40 μA per volt rms input positive out.

## OPTIONAL EXTERNAL TRIMS FOR HIGH ACCURACY

If it is desired to improve the accuracy of the AD536A, the external trims shown in Figure 2 can be added. R4 is used to trim the offset. Note that the offset trim circuit adds 365 Ω in series with the internal 25 kΩ resistor. This will cause a 1.5% increase in scale factor, which is trimmed out by using R1 as shown. Range of scale factor adjustment is ±1.5%.

The trimming procedure is as follows:

1. Ground the input signal,  $V_{IN}$ , and adjust R4 to give zero volts output from Pin 6. Alternatively, R4 can be adjusted to give the correct output with the lowest expected value of  $V_{IN}$ .
2. Connect the desired full scale input level to  $V_{IN}$ , either dc or a calibrated ac signal (1 kHz is the optimum frequency); then trim R1, to give the correct output from Pin 6, i.e., 1000 V dc input should give 1.000 V dc output. Of course, a ±1.000 V peak-to-peak sine wave should give a 0.707 V dc output. The remaining errors, as given in the specifications are due to the nonlinearity.

The major advantage of external trimming is to optimize device performance for a reduced signal range; the AD536A is internally trimmed for a 7 V rms full-scale range.

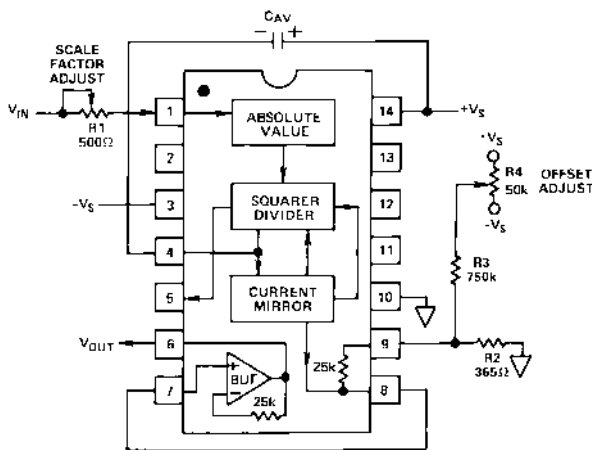


Figure 2. Optional External Gain and Output Offset Trims

## SINGLE SUPPLY CONNECTION

The applications in Figures 1 and 2 require the use of approximately symmetrical dual supplies. The AD536A can also be used with only a single positive supply down to +5 volts, as shown in Figure 3. The major limitation of this connection is that only ac signals can be measured since the differential input stage must be biased off ground for proper operation. This biasing is done at Pin 10; thus it is critical that no extraneous signals be coupled into this point. Biasing can be accomplished

by using a resistive divider between  $+V_S$  and ground. The values of the resistors can be increased in the interest of lowered power consumption, since only 5 mA of current flows into Pin 10 (Pin 2 on the "H" package). AC input coupling requires only capacitor C2 as shown; a dc return is not necessary as it is provided internally. C2 is selected for the proper low frequency break point with the input resistance of 16.7 kΩ; for a cutoff at 10 Hz, C2 should be 1 μF. The signal ranges in this connection are slightly more restricted than in the dual supply connection. The input and output signal ranges are shown in Figure 14. The load resistor,  $R_L$ , is necessary to provide output sink current.

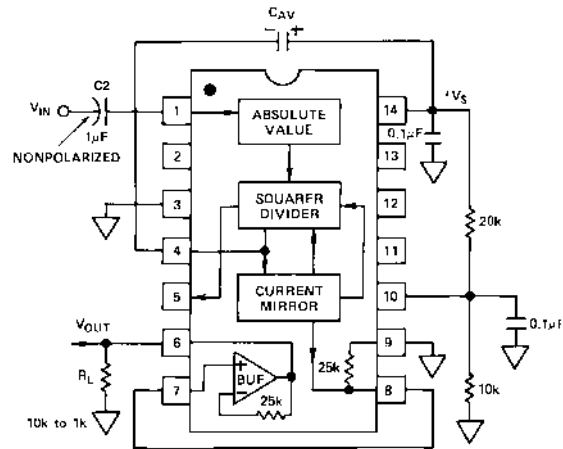


Figure 3. Single Supply Connection

## CHOOSING THE AVERAGING TIME CONSTANT

The AD536A will compute the rms of both ac and dc signals. If the input is a slowly-varying dc signal, the output of the AD536A will track the input exactly. At higher frequencies, the average output of the AD536A will approach the rms value of the input signal. The actual output of the AD536A will differ from the ideal output by a dc (or average) error and some amount of ripple, as demonstrated in Figure 4.

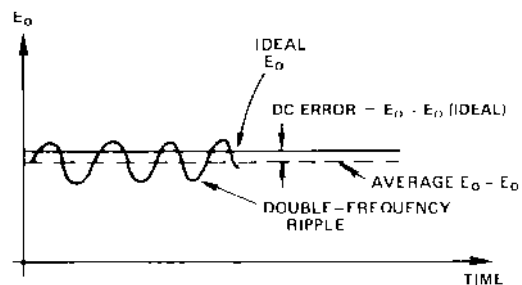


Figure 4. Typical Output Waveform for Sinusoidal Input

The dc error is dependent on the input signal frequency and the value of  $C_{AV}$ . Figure 5 can be used to determine the minimum value of  $C_{AV}$  which will yield a given percent dc error above a given frequency using the standard rms connection.

The ac component of the output signal is the ripple. There are two ways to reduce the ripple. The first method involves using a large value of  $C_{AV}$ . Since the ripple is inversely proportional to  $C_{AV}$ , a tenfold increase in this capacitance will affect a tenfold reduction in ripple. When measuring waveforms with high crest

factors, (such as low duty cycle pulse trains), the averaging time constant should be at least ten times the signal period. For example, a 100 Hz pulse rate requires a 100 ms time constant, which corresponds to a 4  $\mu\text{F}$  capacitor (time constant = 25 ms per  $\mu\text{F}$ ).

The primary disadvantage in using a large  $C_{AV}$  to remove ripple is that the settling time for a step change in input level is increased proportionately. Figure 5 shows that the relationship between  $C_{AV}$  and 1% settling time is 115 milliseconds for each microfarad of  $C_{AV}$ . The settling time is twice as great for decreasing signals as for increasing signals (the values in Figure 5 are for decreasing signals). Settling time also increases for low signal levels, as shown in Figure 6.

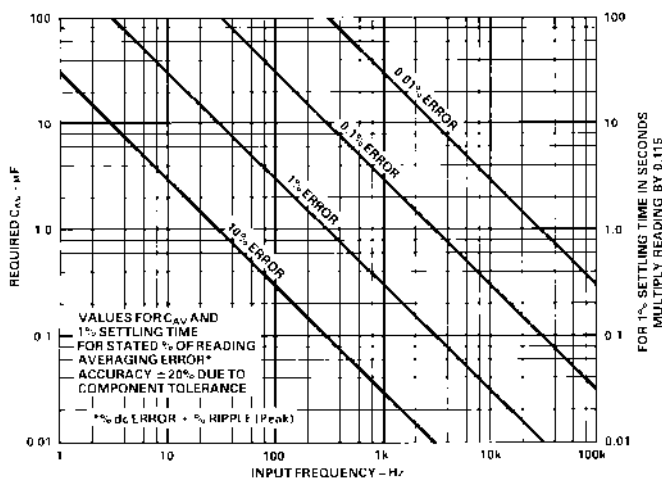


Figure 5. Error/Settling Time Graph for Use with the Standard rms Connection in Figure 1

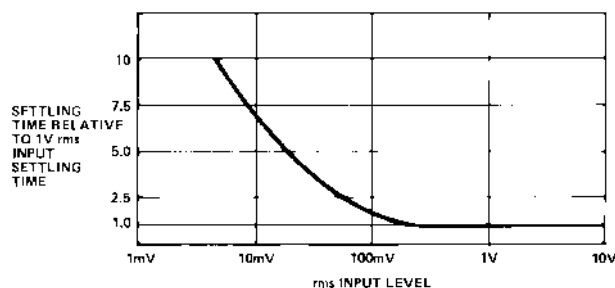


Figure 6. Settling Time vs. Input Level

A better method for reducing output ripple is the use of a "post-filter." Figure 7 shows a suggested circuit. If a single-pole filter is used ( $C_3$  removed,  $R_x$  shorted), and  $C_2$  is approximately twice the value of  $C_{AV}$ , the ripple is reduced as shown in Figure 8 and settling time is increased. For example, with  $C_{AV} = 1 \mu\text{F}$  and  $C_2 = 2.2 \mu\text{F}$ , the ripple for a 60 Hz input is reduced from 10% of reading to approximately 0.3% of reading. The settling time, however, is increased by approximately a factor of 3. The values of  $C_{AV}$  and  $C_2$  can, therefore, be reduced to permit faster settling times while still providing substantial ripple reduction.

The two-pole post-filter uses an active filter stage to provide even greater ripple reduction without substantially increasing the settling times over a circuit with a one-pole filter. The values of  $C_{AV}$ ,  $C_2$ , and  $C_3$  can then be reduced to allow extremely fast settling times for a constant amount of ripple. Caution should be exercised in choosing the value of  $C_{AV}$ , since the dc error is dependent upon this value and is independent of the post filter.

For a more detailed explanation of these topics refer to the *RMS to DC Conversion Application Guide 2nd Edition*, available from Analog Devices.

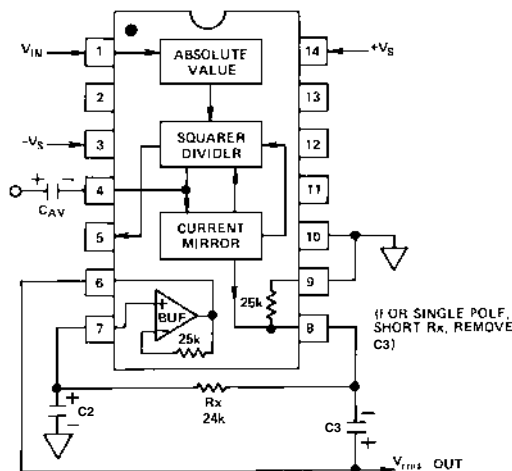


Figure 7. 2-Pole "Post" Filter

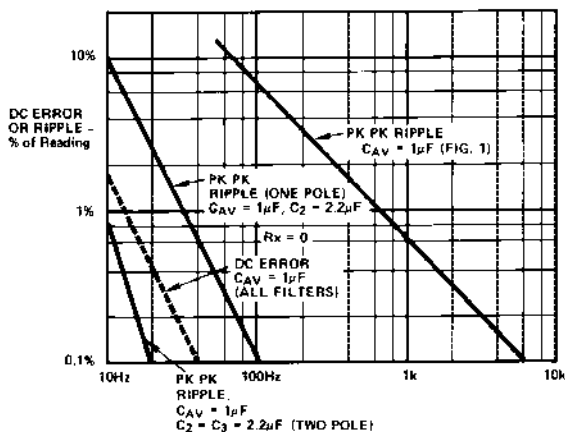


Figure 8. Performance Features of Various Filter Types

## AD536A PRINCIPLE OF OPERATION

The AD536A embodies an implicit solution of the rms equation that overcomes the dynamic range as well as other limitations inherent in a straightforward computation of rms. The actual computation performed by the AD536A follows the equation:

$$V_{rms} = Avg. \left[ \frac{V_{IN}^2}{V_{rms}} \right]$$

# AD536A

Figure 9 is a simplified schematic of the AD536A; it is subdivided into four major sections: absolute value circuit (active rectifier), squarer/divider, current mirror, and buffer amplifier. The input voltage,  $V_{IN}$ , which can be ac or dc, is converted to a unipolar current  $I_1$ , by the active rectifier  $A_1, A_2$ .  $I_1$  drives one input of the squarer/divider, which has the transfer function:

$$I_4 = I_1^2 / I_3$$

The output current,  $I_4$ , of the squarer/divider drives the current mirror through a low-pass filter formed by  $R_1$  and the externally connected capacitor,  $C_{AV}$ . If the  $R_1, C_{AV}$  time constant is much greater than the longest period of the input signal, then  $I_4$  is effectively averaged. The current mirror returns a current  $I_3$ , which equals  $Avg. [I_4]$ , back to the squarer/divider to complete the implicit rms computation. Thus:

$$I_4 = Avg. [I_1^2 / I_4] = I_1 \text{ rms}$$

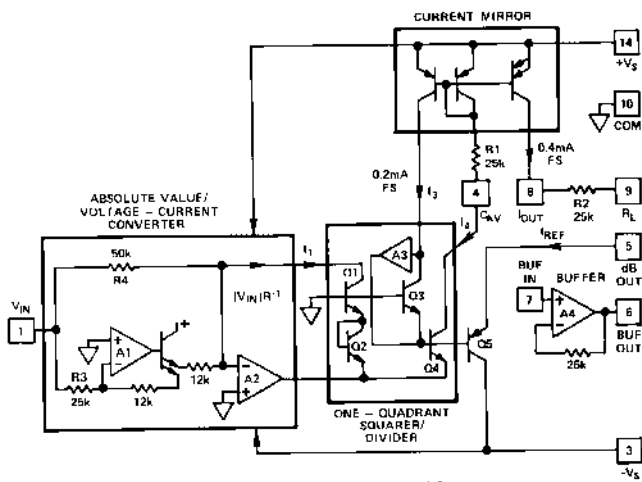


Figure 9. Simplified Schematic

The current mirror also produces the output current,  $I_{OUT}$ , which equals  $2I_4$ .  $I_{OUT}$  can be used directly or converted to a voltage with  $R_2$  and buffered by  $A_4$  to provide a low impedance voltage output. The transfer function of the AD536A thus results:

$$V_{OUT} = 2R_2 I \text{ rms} = V_{IN} \text{ rms}$$

The dB output is derived from the emitter of  $Q_3$ , since the voltage at this point is proportional to  $-\log V_{IN}$ . Emitter follower,  $Q_5$ , buffers and level shifts this voltage, so that the dB output voltage is zero when the externally supplied emitter current ( $I_{REF}$ ) to  $Q_5$  approximates  $I_3$ .

## CONNECTIONS FOR dB OPERATION

A powerful feature added to the AD536A is the logarithmic or decibel output. The internal circuit computing dB works accurately over a 60 dB range. The connections for dB measurements are shown in Figure 10. The user selects the 0 dB level by adjusting  $R_1$ , for the proper 0 dB reference current (which is set to exactly cancel the log output current from the squarer/divider at the desired 0 dB point). The external op amp is used to provide a more convenient scale and to allow compensation of the  $+0.33\%/^{\circ}\text{C}$  scale factor drift of the dB output pin. The special T.C. resistor,  $R_2$ , is available from Tel Labs in Londonderry, N.H. (model Q-81) or from Precision Resistor Inc., Hillside, N.J. (model PT146). The averaged temperature coefficients of resistors  $R_2$  and  $R_3$  develop the  $+3300$  ppm needed to reverse compensate the dB output. The linear rms output is available at Pin 8 on DIP or Pin 10 on header device with an output impedance of  $25 \text{ k}\Omega$ ; thus some applications may require an additional buffer amplifier if this output is desired.

dB Calibration:

1. Set  $V_{IN} = 1.00 \text{ V dc}$  or  $1.00 \text{ V rms}$
2. Adjust  $R_1$  for dB out =  $0.00 \text{ V}$
3. Set  $V_{IN} = +0.1 \text{ V dc}$  or  $0.10 \text{ V rms}$
4. Adjust  $R_5$  for dB out =  $-2.00 \text{ V}$

Any other desired 0 dB reference level can be used by setting  $V_{IN}$  and adjusting  $R_1$ , accordingly. Note that adjusting  $R_5$  for the proper gain automatically gives the correct temperature compensation.

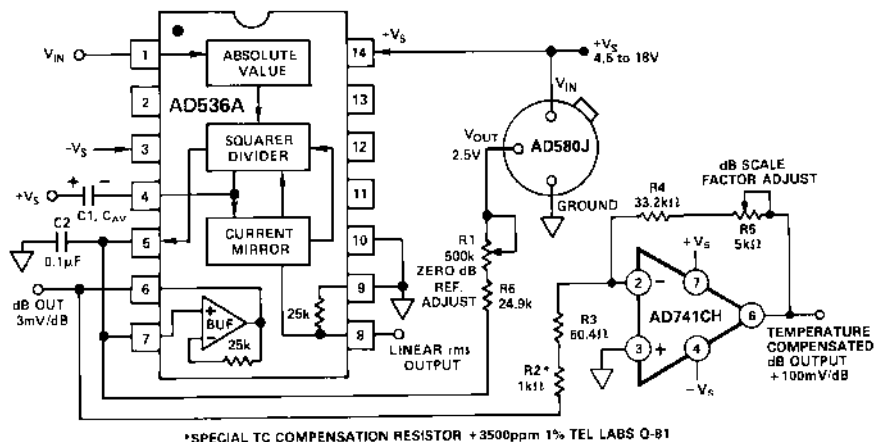


Figure 10. dB Connection

## FREQUENCY RESPONSE

The AD536A utilizes a logarithmic circuit in performing the implicit rms computation. As with any log circuit, bandwidth is proportional to signal level. The solid lines in the graph below represent the frequency response of the AD536A at input levels from 10 millivolts to 7 volts rms. The dashed lines indicate the upper frequency limits for 1%, 10%, and 3 dB of reading additional error. For example, note that a 1 volt rms signal will produce less than 1% of reading additional error up to 120 kHz. A 10 millivolt signal can be measured with 1% of reading additional error (100  $\mu$ V) up to only 5 kHz.

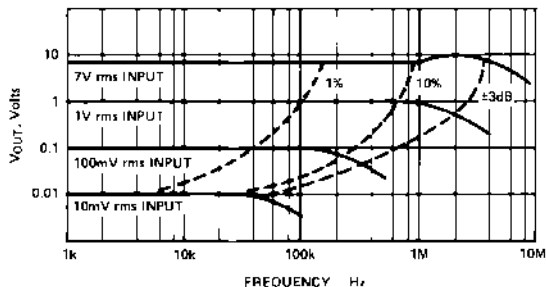


Figure 11. High Frequency Response

## AC MEASUREMENT ACCURACY AND CREST FACTOR

Crest factor is often overlooked in determining the accuracy of an ac measurement. Crest factor is defined as the ratio of the peak signal amplitude to the rms value of the signal ( $CF = V_p / V_{rms}$ ). Most common waveforms, such as sine and triangle waves, have relatively low crest factors ( $<2$ ). Waveforms which resemble low duty cycle pulse trains, such as those occurring in switching power supplies and SCR circuits, have high crest factors. For example, a rectangular pulse train with a 1% duty cycle has a crest factor of 10 ( $CF = 1/\sqrt{\eta}$ ).

Figure 12 is a curve of reading error for the AD536A for a 1 volt rms input signal with crest factors from 1 to 11. A rectangular pulse train (pulsewidth 100  $\mu$ s) was used for this test since it is the worst-case waveform for rms measurement (all the energy is contained in the peaks). The duty cycle and peak amplitude were varied to produce crest factors from 1 to 11 while maintaining a constant 1 volt rms input amplitude.

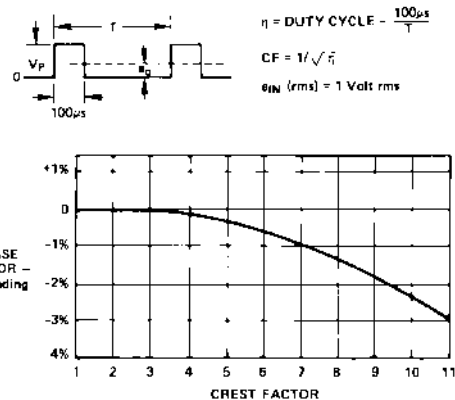


Figure 12. Error vs. Crest Factor

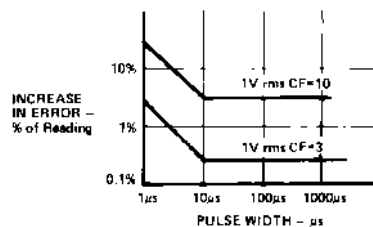


Figure 13. AD536A Error vs. Pulsewidth Rectangular Pulse

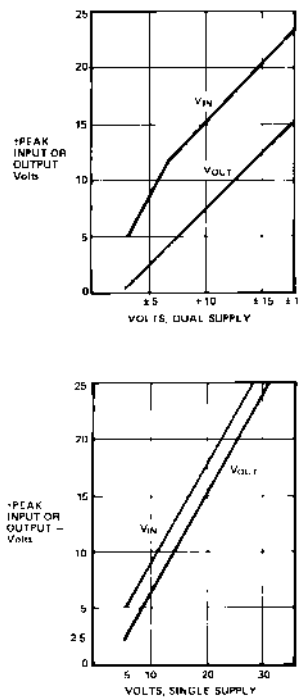
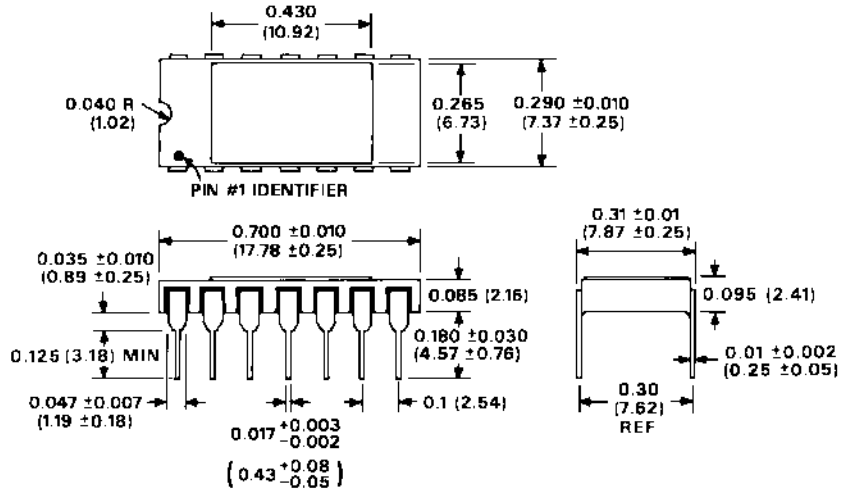


Figure 14. AD536A Input and Output Voltage Ranges vs. Supply

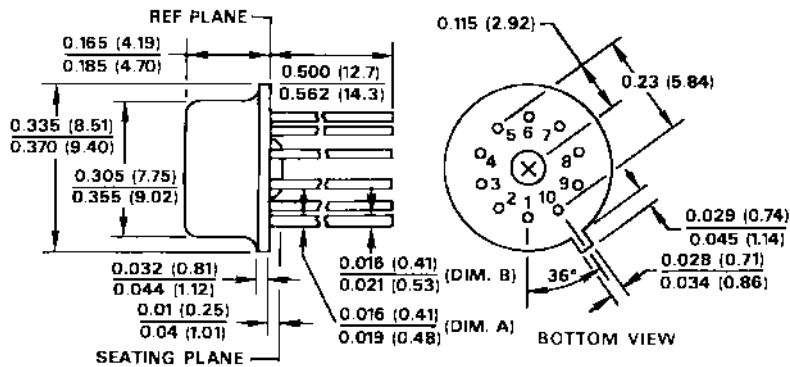
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

D-14 Package  
TO-116



H-10A Package  
TO-100



E-20A Package  
LCC

