



T-73-27 Integrated Circuit True RMS-to-DC Converter

AD536A

FEATURES

True RMS-to-DC Conversion

Laser-Trimmed to High Accuracy

0.2% max Error (AD536AK)

0.5% max Error (AD536AJ)

Wide Response Capability:

Computes RMS of AC and DC Signals

450kHz Bandwidth: $V_{rms} > 100mV$

2MHz Bandwidth: $V_{rms} > 1V$

Signal Crest Factor of 7 for 1% Error

dB Output with 60dB Range

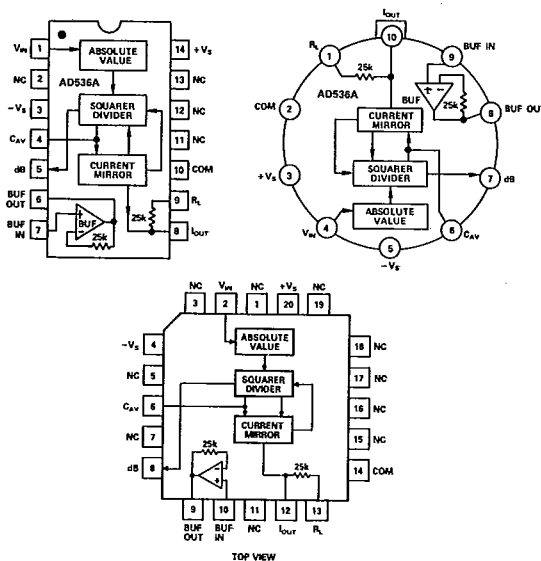
Low Power: 1.2mA Quiescent Current

Single or Dual Supply Operation

Monolithic Integrated Circuit

-55°C to +125°C Operation (AD536AS)

PIN CONFIGURATIONS AND FUNCTIONAL BLOCK DIAGRAMS



PRODUCT DESCRIPTION

The AD536A is a complete monolithic integrated circuit which performs true rms-to-dc conversion. It offers performance which is comparable or superior to that of hybrid or modular units costing much more. The AD536A directly computes the true rms value of any complex input waveform containing ac and dc components. It has a crest factor compensation scheme which allows measurements with 1% error at crest factors up to 7. The wide bandwidth of the device extends the measurement capability to 300kHz with 3dB error for signal levels above 100mV.

An important feature of the AD536A not previously available in rms converters is an auxiliary dB output. The logarithm of the rms output signal is brought out to a separate pin to allow the dB conversion, with a useful dynamic range of 60 dB. Using an externally supplied reference current, the 0dB level can be conveniently set by the user to correspond to any input level from 0.1 to 2 volts rms.

The AD536A is laser trimmed at the wafer level for input and output offset, positive and negative waveform symmetry (dc reversal error), and full-scale accuracy at 7V rms. As a result, no external trims are required to achieve the rated accuracy of the unit.

There is full protection for both inputs and outputs. The input circuitry can take overload voltages well beyond the supply levels. Loss of supply voltage with inputs connected will not cause unit failure. The output is short-circuit protected.

The AD536A is available in two accuracy grades (J, K) for commercial temperature range (0 to +70°C) applications, and one grade (S) rated for the -55°C to +125°C extended range. The AD536AK offers a maximum total error of $\pm 2mV \pm 0.2\%$ of reading, and the AD536AJ and AD536AS have maximum errors of $\pm 5mV \pm 0.5\%$ of reading. All three versions are available in either a hermetically sealed 14-pin DIP or 10-pin TO-100 metal can. The AD536AS is also available in a 20-pin hermetically sealed ceramic leadless chip carrier.

PRODUCT HIGHLIGHTS

1. The AD536A computes the true root-mean-square level of a complex ac (or ac plus dc) input signal and gives an equivalent dc output level. The true rms value of a waveform is a more useful quantity than the average rectified value since it relates directly to the power of the signal. The rms value of a statistical signal also relates to its standard deviation.
2. The crest factor of a waveform is the ratio of the peak signal swing to the rms value. The crest factor compensation scheme of the AD536A allows measurement of highly complex signals with wide dynamic range.
3. The only external component required to perform measurements to the fully specified accuracy is the capacitor which sets the averaging period. The value of this capacitor determines the low frequency ac accuracy, ripple level and settling time.
4. The AD536A will operate equally well from split supplies or a single supply with total supply levels from 5 to 36 volts. The one milliamper quiescent supply current makes the device well-suited for a wide variety of remote controllers and battery powered instruments.
5. The AD536A directly replaces the AD536 and provides improved bandwidth and temperature drift specifications.

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

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Model	AD536AJ		AD536AK		AD536AS		Units
	Min	Max	Min	Max	Min	Max	
TRANSFER FUNCTION	$V_{OUT} = \sqrt{\text{avg.}(V_{IN})^2}$		$V_{OUT} = \sqrt{\text{avg.}(V_{IN})^2}$		$V_{OUT} = \sqrt{\text{avg.}(V_{IN})^2}$		
CONVERSION ACCURACY							
Total Error, Internal Trim ¹ (Figure 1) vs. Temperature, T_{min} to +70°C +70°C to +125°C	±5 ±0.5 ±0.1 ±0.01		±2 ±0.2 ±0.05 ±0.005		±5 ±0.5 ±0.1 ±0.005 ±0.3 ±0.005		mV % of Reading mV % of Reading/°C mV % of Reading/V
vs. Supply Voltage dc Reversal Error	±0.1 ±0.01 ±0.2		±0.1 ±0.01 ±0.1		±0.1 ±0.01 ±0.2		±% of Reading mV % of Reading
Total Error, External Trim ¹ (Figure 2)	±3 ±0.3		±2 ±0.1		±3 ±0.3		
ERROR VS. CREST FACTOR ²							
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		
FREQUENCY RESPONSE ³							
Bandwidth for 1% additional error (0.09dB)							
$V_{IN} = 10\text{mV}$	5		5		5		kHz
$V_{IN} = 100\text{mV}$	45		45		45		kHz
$V_{IN} = 1\text{V}$	120		120		120		kHz
±3dB Bandwidth							
$V_{IN} = 10\text{mV}$	90		90		90		kHz
$V_{IN} = 100\text{mV}$	450		450		450		kHz
$V_{IN} = 1\text{V}$	2.3		2.3		2.3		MHz
AVERAGING TIME CONSTANT (Figure 5)	25		25		25		ms/μF CAV
INPUT CHARACTERISTICS							
Signal Range, ±15V Supplies							
Continuous rms Level	0 to 7		0 to 7		0 to 7		V rms
Peak Transient Input	±20		±20		±20		V peak
Continuous rms Level, ±5V Supplies	0 to 2		0 to 2		0 to 2		V rms
Peak Transient Input, ±5V Supplies	±7		±7		±7		V peak
Maximum Continuous Nondestructive Input Level (All Supply Voltages)	±25		±25		±25		V peak
Input Resistance	13.33		13.33		13.33		kΩ
Input Offset Voltage	16.67 0.8 ±2		16.67 0.5 ±1		16.67 0.8 ±2		mV
OUTPUT CHARACTERISTICS							
Offset Voltage, $V_{IN} = \text{COM}$ (Figure 1) vs. Temperature	±1 ±0.1		±0.5 ±0.1		±2 ±0.2		mV mV/°C
vs. Supply Voltage	±0.1		±0.1		±0.2		mV/V
Voltage Swing, ±15V Supplies ±5V Supply	0 to +11 0 to +2		0 to +11 0 to +2		0 to +11 0 to +2		V V
dB OUTPUT (Figure 13)							
Error, $V_{IN} = 7\text{V rms}$, 0dB = 1V rms	±0.4 -3		±0.2 -3		±0.5 -3		dB mV/dB
Scale Factor	-0.033 +0.33		-0.033 +0.33		-0.033 +0.33		dB/°C
Scale Factor TC (Uncompensated, see Figure 1 for Temperature Compensation)	±0.33		±0.33		±0.33		% of Reading/°C
I_{REF} for 0dB = 1V rms	5		5		5		μA
I_{REF} Range	1 80 100		1 20 80 100		1 20 80 100		μA
LOAD TERMINAL							
I_{OUT} Scale Factor	40		40		40		μA/V rms
I_{OUT} Scale Factor Tolerance	±10 ±20		±10 ±20		±10 ±20		%
Output Resistance	25 30		25 30		25 30		kΩ
Voltage Compliance	$-V_S$ to (+ V_S -2.5V)		$-V_S$ to (+ V_S -2.5)		$-V_S$ to (+ V_S -2.5V)		V
BUFFER AMPLIFIER							
Input and Output Voltage Range	$-V_S$ to (+ V_S -2.5V)		$-V_S$ to (+ V_S -2.5V)		$-V_S$ to (+ V_S -2.5V)		V
Input Offset Voltage, $R_S = 25\text{k}$	±0.5 20		±0.5 20		±0.5 20		mV
Input Bias Current	±4 60		±4 60		±4 60		nA
Input Resistance	10 ⁸		10 ⁸		10 ⁸		Ω
Output Current	(+5mA, -130μA)		(+5mA, -130μA)		(+5mA, -130μA)		
Short Circuit Current	20		20		20		mA
Output Resistance	0.5		0.5		0.5		Ω
Small Signal Bandwidth	1		1		1		MHz
Slew Rate ⁴	5		5		5		V/μs
POWER SUPPLY							
Voltage Rated Performance	±15		±15		±15		V
Dual Supply	±3.0 +5		±3.0 +5		±3.0 +5		V
Single Supply	±18 +36		±18 +36		±18 +36		V
Quiescent Current	1.2		1.2		1.2		mA
Total V_S , 5V to 36V, T_{min} to T_{max}	2		2		2		
TEMPERATURE RANGE							
Rated Performance	0 +70		0 +70		-55 +125		°C
NUMBER OF TRANSISTORS	65		65		65		

NOTES

¹Accuracy is specified for 0 to 7V rms, dc or 1kHz sinewave input with the AD536A connected as in the figure referenced.²Error vs. crest factor is specified as an additional error for 1V rms rectangular pulse input, pulse width = 200μs.³Input voltages are expressed in volts rms, and error is percent of reading.⁴With 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.

Applying the AD536A

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ABSOLUTE MAXIMUM RATINGS¹

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

NOTES

¹Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and 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.

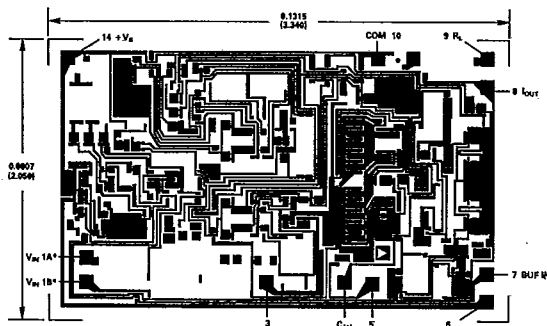
²10-Pin Header: $\theta_{JA} = 150^\circ\text{C/W}$

20-Pin LCC: $\theta_{JA} = 95^\circ\text{C/W}$

14-Pin Size Brazed Ceramic DIP: $\theta_{JA} = 95^\circ\text{C/W}$

CHIP DIMENSIONS AND PAD LAYOUT

Dimensions shown in inches and (mm).



PAD NUMBERS CORRESPOND TO PIN NUMBERS FOR THE TO-118 14-PIN CERAMIC DIP PACKAGE.

NOTE
¹NOT ALL PADS SHOWN MUST BE CONNECTED TO V_S.
 THE AD536A IS AVAILABLE IN LASER TRIMMED CHIP FORM.
 SUBSTRATE CONNECTED TO -V_S.

ORDERING GUIDE

Model ¹	Temperature Range	Package Description	Package Option ²
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	-55°C to +125°C	LCC	E-20A
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

NOTES

¹"S" grade chips are available tested at +25°C and +125°C. "J" grade chips are also available.

²For outline information see Package Information section.

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_{AV}, as shown in Figure 5. Thus, if a 4μF capacitor is used, the additional average error at 10Hz will be 0.1%; at 3Hz 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 0.1μF ceramic discs as near the device as possible.

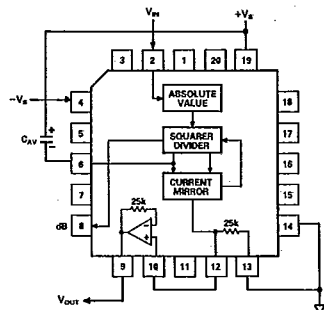
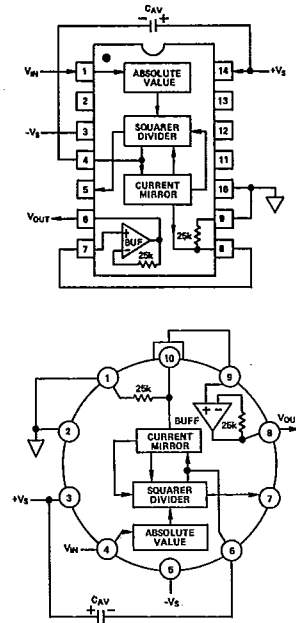


Figure 1. Standard RMS Connection

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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 25k 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 25k resistor from ground. The output current is available at Pin 8 (Pin 10 on the "H" package) with a nominal scale of 40 μ A 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. R_4 is used to trim the offset. Note that the offset trim circuit adds 365 Ω in series with the internal 25k Ω resistor. This will cause a 1.5% increase in scale factor, which is trimmed out by using R_1 as shown. Range of scale factor adjustment is $\pm 1.5\%$.

The trimming procedure is as follows:

1. Ground the input signal, V_{IN} , and adjust R_4 to give zero volts output from Pin 6. Alternatively, R_4 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 (1kHz is the optimum frequency); then trim R_1 to give the correct output from Pin 6, i.e., 1.000V dc input should give 1.000V dc output. Of course, a ± 1.000 V peak-to-peak sine wave should give a 0.707V 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 7V rms full-scale range.

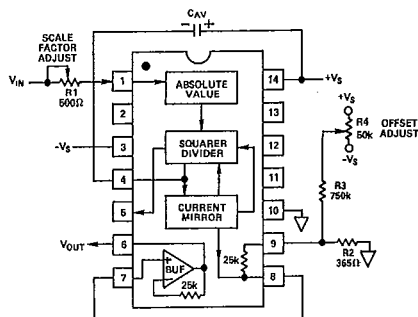


Figure 2. Optional External Gain and Output Offset Trims

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 μ A of current flows into Pin 10 (Pin 2 on the "H" package). AC input coupling requires only capacitor C_2 as shown; a dc return is not necessary as it is provided internally. C_2 is selected for the proper low frequency break point with the input resistance of 16.7k Ω ; for a cut-off at 10Hz, C_2 should be 1 μ F. 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.

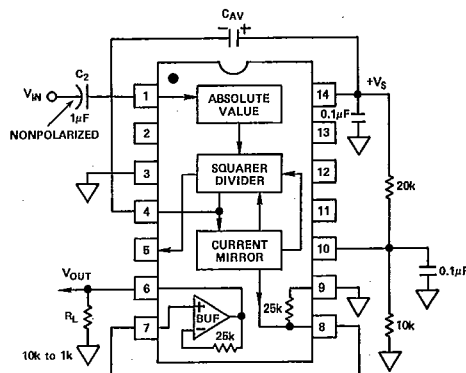


Figure 3. Single Supply Connection

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.

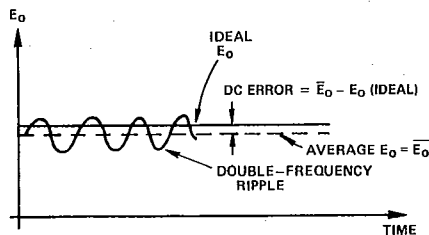


Figure 4. Typical Output Waveform for Sinusoidal Input

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 effect 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 100Hz pulse rate requires a 100ms time constant, which corresponds to a 4 μ F capacitor (time constant = 25ms per μ F).

RMS Measurements—AD536A

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.

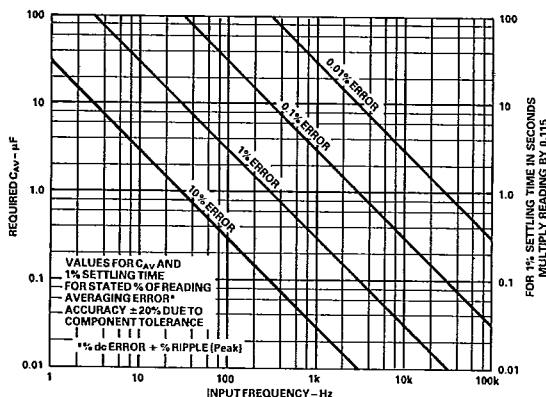


Figure 5. Error/Settling Time Graph for Use with the Standard RMS Connection in Figure 1

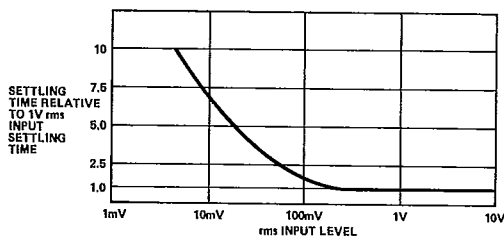


Figure 6. Settling Time vs. Input Level

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 $C_{AV} = 1\mu F$ and $C_2 = 2.2\mu F$, the ripple for a 60Hz 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.

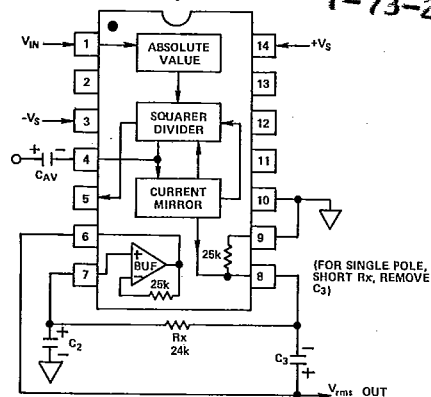


Figure 7. 2-Pole "Post" Filter

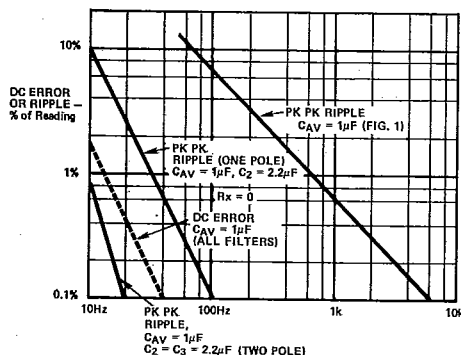


Figure 8. Performance Features of Various Filter Types

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 straight-forward computation of rms. The actual computation performed by the AD536A follows the equation:

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

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:

$$I_4 = I_1^2/I_3$$

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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:

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

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:

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

The dB output is derived from the emitter of Q3, since the voltage at this point is proportional to $-\log V_{IN}$. Emitter follower, Q5, buffers and level shifts this voltage, so that the dB output voltage is zero when the externally supplied emitter current (I_{REF}) to Q5 approximates I_3 .

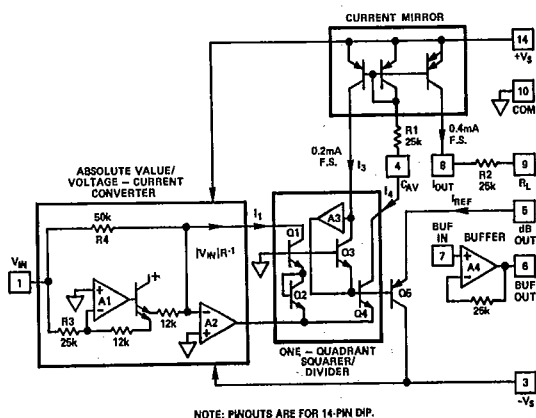


Figure 9. Simplified Schematic

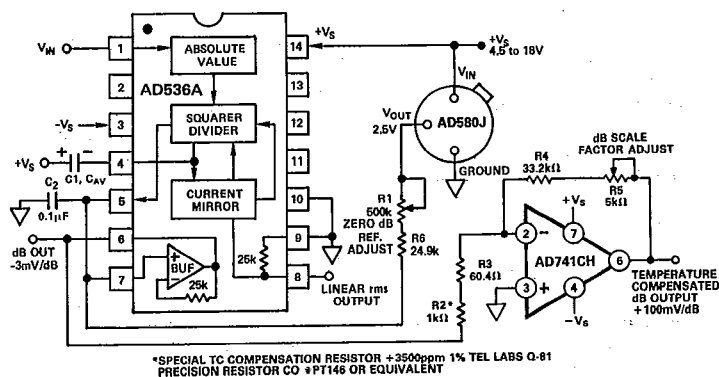


Figure 10. dB Connection

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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 60dB range. The connections for dB measurements are shown in Figure 10. The user selects the 0dB level by adjusting R_1 for the proper 0dB reference current (which is set to exactly cancel the log output current from the squarer/divider at the desired 0dB 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 $+3300\text{ppm}$ 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 $25k\Omega$; 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 1.00V rms
2. Adjust R_1 for dB out = 0.00V
3. Set $V_{IN} = +0.1\text{V}$ dc or 0.10V rms
4. Adjust R_5 for dB out = -2.00V

Any other desired 0dB 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.

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 3dB of reading additional error. For example, note that a 1 volt rms signal will produce less than 1% of reading additional error up to 120kHz. A 10 millivolt signal can be measured with 1% of reading additional error (100µV) up to only 5kHz.

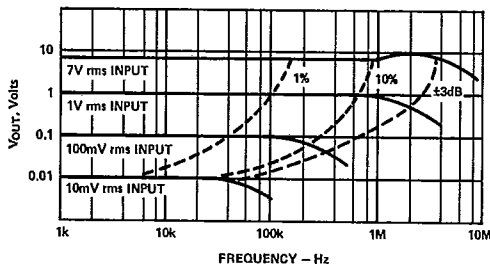


Figure 11. High Frequency Response

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 ($C.F. = V_p/V_{rms}$). 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 ($C.F. = 1/\sqrt{\eta}$).

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 (pulse width 100µs) 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.

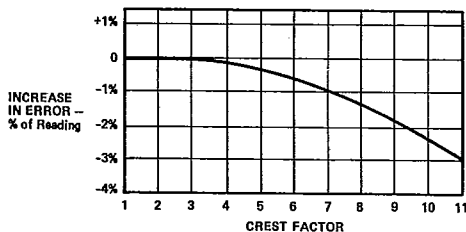
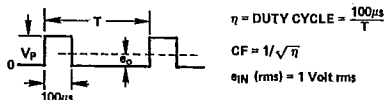


Figure 12. Error vs. Crest Factor

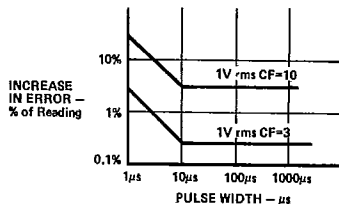


Figure 13. AD536A Error vs. Pulse Width Rectangular Pulse

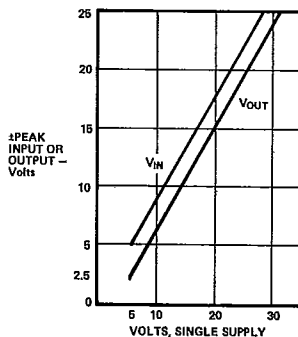
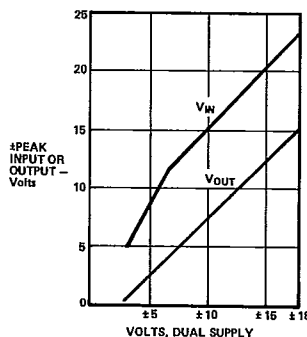


Figure 14. AD536A Input and Output Voltage Ranges vs. Supply