



True RMS-to-DC IC Converter

General Description

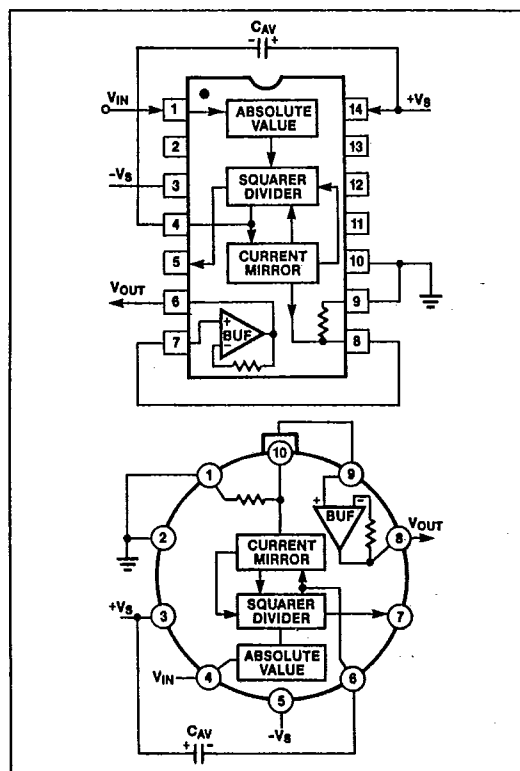
The AD536A and AD636 are true RMS-to-DC converters. They feature low power and are designed to accept low level input signals from 0 to $7V_{rms}$ for the AD536A and 0 to $200mV_{rms}$ for the AD636. Both devices accept complex input waveforms containing AC and DC components. They can be operated from either a single supply or dual supplies. Both devices draw less than 1mA of quiescent supply current making them ideal for battery powered applications.

Input and output offset, positive and negative waveform symmetry (DC reversal), and full-scale accuracy are laser trimmed, so that no external trims are required to achieve full rated accuracy.

Applications

Digital Multimeters
Battery Powered Instruments
Panel Meters
Process Control

Typical Operating Circuit



T-73-27 Features

- ◆ True RMS-to-DC Conversion
- ◆ Computes RMS of AC and DC Signals
- ◆ Wide Response:
 - 2MHz Bandwidth for $V_{rms} > 1V$ (AD536A)
 - 1MHz Bandwidth for $V_{rms} > 100mV$ (AD636)
- ◆ Auxiliary dB Output: 60dB range for AD536A
50dB range for AD636
- ◆ Single or Dual Supply Operation
- ◆ Low Power: 1.2mA typ for AD536A
800μA typ for AD636

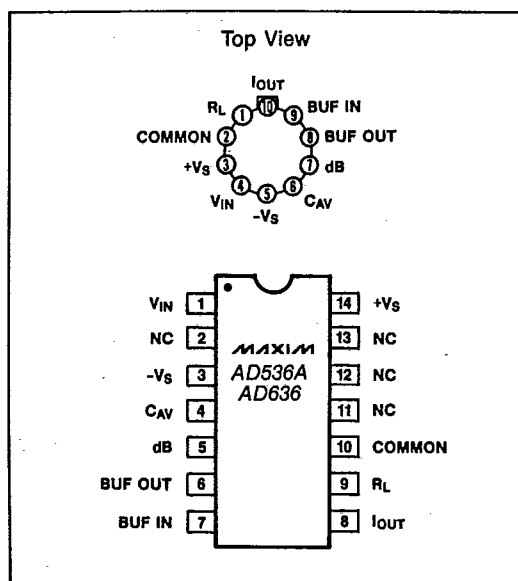
Ordering Information

PART	TEMP. RANGE	PACKAGE*
AD536AJC/D	0°C to +70°C	Dice
AD536AJCWE	0°C to +70°C	16 Lead Wide S.O.
AD536AJD	0°C to +70°C	14 Lead Ceramic
AD536AJH	0°C to +70°C	10 Lead TO-100
AD536AJN	0°C to +70°C	14 Lead Plastic
AD536AJQ*	0°C to +70°C	14 Lead Cerdip
AD536AKCWE	0°C to +70°C	16 Lead Wide S.O.
AD536AKD	0°C to +70°C	14 Lead Ceramic
AD536AKH	0°C to +70°C	10 Lead TO-100

Ordering Information continued on last page.

* Maxim reserves the right to ship Ceramic Packages in lieu of Cerdip Packages

Pin Configuration



AD536A/AD636

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True RMS-to-DC IC Converter**ABSOLUTE MAXIMUM RATINGS**

Supply Voltage: Dual Supplies (AD536A)	±18V	Power Dissipation (Package) (continued):	
(AD636)	±12V	Ceramic (Derate 10mW/°C above +75°C)	500mW
Single Supply (AD536A)	+36V	TO-100 metal can (Derate 7mW/°C above +75°C) ..	450mW
(AD636)	+24V	Output Short Circuit Duration	Indefinite
Input Voltage (AD536A)	±25V	Operating Temperature Range:	
(AD636)	±12V	Commercial (J,K)	0°C to +70°C
Power Dissipation (Package)		Military (S)	-55°C to +125°C
Plastic DIP (Derate 12mW/°C above +75°C)	450mW	Storage Temperature Range	-65°C to +150°C
Small Outline (Derate 10mW/°C above +75°C) ...	400mW	Lead Temperature (Soldering, 10 sec)	300°C

Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions above those indicated in the operational sections of the specification is not implied. Exposure to absolute maximum ratings conditions for extended periods may affect the device reliability.

ELECTRICAL CHARACTERISTICS—AD536A ($T_A = 25^\circ\text{C}$, $+V_S = +15\text{V}$, $-V_S = -15\text{V}$, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
TRANSFER EQUATION			$V_{OUT} = [\text{avg.}(V_{IN})^2]^{1/2}$			
CONVERSION ACCURACY						
Total Error, Internal Trim (Note 1)		AD536AJ,AS AD536AK		$\pm 5 \pm 0.5$ $\pm 2 \pm 0.2$		mV $\pm\%$ of Reading
Total Error vs. Temperature	T_{MIN} to +70°C	AD536AJ AD536AK AD536AS		$\pm 0.1 \pm 0.01$ $\pm 0.05 \pm 0.005$ $\pm 0.1 \pm 0.005$		mV $\pm\%$ of Reading/°C
	+70°C to +125°C	AD536AS		$\pm 0.03 \pm 0.005$		
Total Error vs. Supply				$\pm 0.1 \pm 0.01$		mV $\pm\%$ of Reading
Total Error vs. DC Reversal		AD536AJ,AS AD536AK		± 0.2 ± 0.1		% of Reading
Total Error, External Trim (Note 1)		AD536AJ,AS AD536AK		$\pm 3 \pm 0.3$ $\pm 2 \pm 0.1$		mV $\pm\%$ of Reading
ERROR vs. CREST FACTOR (Note 2)						
Additional Error	Crest Factor 1 to 2 Crest Factor = 3 Crest Factor = 7		Specified Accuracy -0.1 -1.0			% of Reading
FREQUENCY RESPONSE (Note 3)						
Bandwidth for 1% Additional Error (0.09dB)	$V_{IN} = 10\text{mV}$ $V_{IN} = 100\text{mV}$ $V_{IN} = 1\text{V}$		5 45 120			kHz
$\pm 3\text{dB}$ Bandwidth	$V_{IN} = 10\text{mV}$ $V_{IN} = 100\text{mV}$		90 450			kHz
	$V_{IN} = 1\text{V}$		2.3			MHz
AVERAGING TIME CONSTANT (Fig. 3)			25			ms/ μF C_{AV}
INPUT CHARACTERISTICS						
Input Signal Range	$\pm 15\text{V}$ Supplies Continuous rms Peak Transient		0 to 7			V_{rms}
			± 20			V_{PK-PK}
	$\pm 5\text{V}$ Supplies Continuous rms Peak Transient		0 to 2			V_{rms}
			± 7			V_{PK-PK}
Safe Input	All Supplies		± 25			V
Input Resistance			13.33	16.7	20.00	k Ω
Input Offset Voltage		AD536AJ,AS AD536AK	± 0.8 ± 0.5	± 2 ± 1		mV

True RMS-to-DC IC Converter**ELECTRICAL CHARACTERISTICS—AD536A (Continued)**(T_A = 25°C, +V_S = +15V, -V_S = -15V, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
OUTPUT CHARACTERISTICS					
Offset Voltage	T _A = +25°C	AD536AJ AD536AK AD536AS	±1 ±0.5	±2 ±1 ±2	mV
	T _{MIN} to T _{MAX}	AD536AJ,AK AD536AS	±0.1	±0.2	mV/°C
	Supply Voltage	AD536AJ,AK AD536AS	±0.1 ±0.2		mV/V
Output Voltage Swing	±15V Supplies ±5V Supplies	0 to +11 0 to +2	+12.5		V
Output Current	Source Sink	+5 -130			mA μA
Short Circuit Current			20		mA
Output Resistance				0.5	Ω
dB OUTPUT					
Error	V _{IN} = 7mV to 7V _{rms} 0dB = 1V _{rms}	AD536AJ AD536AK AD536AS	±0.4 ±0.2 ±0.5	±0.6 ±0.3 ±0.6	dB
Scale Factor			-3		mV/dB
Scale Factor TC (Uncompensated)			+0.33		% of Reading
I _{REF}	0dB = 1V _{rms}		5	20	80 μA
I _{REF} Range			1		100 μA
I_{OUT} TERMINAL					
I _{OUT} Scale Factor			40		μA/V _{rms}
I _{OUT} Scale Factor Tolerance			±10	±20	%
Output Resistance		20	25	30	kΩ
Voltage Compliance			-V _S to (+V _S - 2.5V)		V
BUFFER AMPLIFIER					
Input and Output Voltage Range			-V _S to (+V _S - 2.5V)	V	
Input Offset Voltage	R _S = 25kΩ		±0.5	±4	mV
Input Bias Current			20	60	nA
Input Resistance			10 ⁸		Ω
Output Current	Source Sink	+5 -130			mA μA
Short Circuit Current			20		mA
Small Signal Bandwidth			1		MHz
Slew Rate (Note 5)			5		V/μs

Note 1: Accuracy is specified for 0 to 7V_{rms}, DC to 1kHz sinewave input with the AD536A.**Note 2:** Error vs. crest factor is specified as an additional error for 1V_{rms} rectangular pulse stream, pulse width = 200μs.**Note 3:** Input voltages are expressed in volts rms, and error as % of reading.**Note 4:** With 4kΩ external pulldown resistor.**Note 5:** Accuracy is specified for 0 to 200mV, DC to 1kHz sinewave input. Accuracy is degraded at higher rms signal levels.

AD536A/AD636

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True RMS-to-DC IC Converter**ELECTRICAL CHARACTERISTICS—AD536A (Continued)**(T_A = 25°C, +V_S = +15V, -V_S = -15V, unless otherwise noted.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
POWER SUPPLY					
Dual Supplies	Rated Performance	±3.0		±18	V
Single Supply	Rated Performance	+5		+36	V
Quiescent Current	Total V _S , 5V to 36V T _{MIN} to T _{MAX}		1.2	2	mA

Note 1: Accuracy is specified for 0 to 7V_{rms}, DC to 1kHz sinewave input with the AD536A.Note 2: Error vs. crest factor is specified as an additional error for 1V_{rms} rectangular pulse stream, pulse width = 200μs.

Note 3: Input voltages are expressed in volts rms, and error as % of reading.

Note 4: With 4kΩ external pulldown resistor.

ELECTRICAL CHARACTERISTICS—AD636 (T_A = 25°C, +V_S = +3V, -V_S = -5V, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
TRANSFER EQUATION			$V_{OUT} = [\text{avg.}(V_{IN})^2]^{1/2}$			
CONVERSION ACCURACY						
Total Error, Internal Trim (Notes 5,6)		AD636J AD636K			$\pm 0.5 \pm 0.6$ $\pm 0.2 \pm 0.3$	mV $\pm$ % of Reading
Total Error vs. Temperature (0°C to +70°C)		AD636J AD636K			$\pm 0.1 \pm 0.01$ $\pm 0.1 \pm 0.005$	mV $\pm$ % of Reading/°C
Total Error vs. Supply				$\pm 0.1 \pm 0.01$		mV $\pm$ % of Reading
Total Error vs. DC Reversal	$V_{IN} = 200\text{mV}$	AD636J AD636K		± 0.2 ± 0.1		% of Reading
Total Error, External Trim (Note 5)		AD636J AD636K		$\pm 0.3 \pm 0.3$ $\pm 0.1 \pm 0.1$		mV $\pm$ % of Reading
ERROR vs. CREST FACTOR (Note 3)						
	Crest Factor 1 to 2 Crest Factor = 3 Crest Factor = 6		Specified Accuracy -0.2 -0.5			% of Reading
FREQUENCY RESPONSE (Notes 6,8)						
Bandwidth for 1% Additional Error (0.09dB)	$V_{IN} = 10\text{mV}$ $V_{IN} = 100\text{mV}$ $V_{IN} = 200\text{mV}$		14 90 130			kHz
$\pm 3\text{dB}$ Bandwidth	$V_{IN} = 10\text{mV}$ $V_{IN} = 100\text{mV}$		100 900			kHz
	$V_{IN} = 200\text{mV}$		1.5			MHz
			25			ms/ μF C_{AV}
AVERAGING TIME CONSTANT (Fig. 3)						
INPUT CHARACTERISTICS						
Input Signal Range	Continuous rms, All Supplies		0 to 200			mV _{rms}
	Peak Transient +3V, -5V Supplies $\pm 2.5\text{V}$ Supplies $\pm 5\text{V}$ Supplies		± 2.8 ± 2 ± 5			V_{PK-PK}
	Safe Input		± 12			V
	Input Resistance		5.33	6.7	8.00	k Ω
Input Offset Voltage		AD636J AD636K			± 0.5 ± 0.2	mV

True RMS-to-DC IC Converter**AD536A/AD636****4****ELECTRICAL CHARACTERISTICS—AD636 (Continued)**(T_A = 25°C, +V_S = +3V, -V_S = -5V, unless otherwise noted.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
OUTPUT CHARACTERISTICS (Note 5)						
Offset Voltage	T _A = +25°C	AD636J AD636K			±0.5 ±0.2	mV
	T _{MIN} to T _{MAX}			±10		mV/°C
	With Supply Voltage			±0.1		mV/V
Output Voltage Swing	±3 -5V Supplies		0 to 1			V
	±5V to ±16.5V Supplies		0 to 1			
Output Resistance			8	10	12	kΩ
dB OUTPUT						
Error	7mV ≤ V _{IN} ≤ 300mV	AD636J AD636K		±0.3 ±0.1	±0.5 ±0.2	dB
Scale Factor				-3		mV/dB
Scale Factor Tempco				+0.33 -0.033		%/°C dB/°C
I _{REF}	0dB = 1V _{rms}		2	4	8	μA
I _{REF} Range			1		50	μA
I _{OUT} TERMINAL						
I _{OUT} Scale Factor				100		μA/V _{rms}
I _{OUT} Scale Factor Tolerance			-20	±10	+20	%
Output Resistance			8	10	12	kΩ
Voltage Compliance				-V _S to (+V _S - 2.0V)		V
BUFFER AMPLIFIER						
Input and Output Voltage Range			-V _S to (+V _S - 2V)		V	
Input Offset Voltage	R _S = 10kΩ	AD636J AD636K		±0.8 ±0.5	±2 ±1	mV
Input Current				20	60	nA
Input Resistance				10 ⁸		Ω
Output Current	Source Sink		+5 -130			mA μA
Short Circuit Current				20		mA
Small Signal Bandwidth				1		MHz
Slew Rate (Note 9)				5		V/μs
POWER SUPPLY						
Rated Performance Dual Supplies Single Supply			+2/-2.5 +5	+3/-5	±16.5 +24	V
Quiescent Current (Note 10)				0.8	1	mA

Note 5: Accuracy is specified for 0 to 200mV, DC to 1kHz sinewave input. Accuracy is degraded at higher rms signal levels.**Note 6:** Measured at pin 8 of DIP and S.O. (I_{OUT}), with pin 9 tied to COMMON.**Note 7:** Error vs. crest factor is specified as an additional error for 200mV_{rms} rectangular pulse input, pulse width = 200μs.**Note 8:** Input voltages are expressed in volts rms.**Note 9:** With 10kΩ external pulldown resistor from pin 6 (BUF OUT) to -V_S.**Note 10:** With BUF input tied to -V_S.**MAXIM**

True RMS-to-DC IC Converter

Detailed Description

The AD536A/636 uses an implicit method of RMS computation that overcomes the dynamic range as well as other limitations inherent in a straightforward computation of the RMS. The actual computation performed by the AD536A/636 follows the equation:

$$V_{rms} = \text{Avg.} [V_{IN}^2 / V_{rms}]$$

The input voltage, V_{IN} , applied to the AD536A/636 is processed by an absolute value/voltage to current converter that produces a unipolar current I_1 (see Figure 1). This current drives one input of a squarer/divider that produces a current I_4 that has a transfer function:

$$I_4 = \frac{I_1^2}{I_3}$$

The current I_4 drives the internal current mirror through a low pass filter formed by R_4 and an external capacitor, C_{AV} . As long as the time constant of this filter is greater than the longest period of the input signal, I_4 is averaged. The current mirror returns a current, I_3 , to the square/divider to complete the circuit. The current I_4 is then a function of the average of (I_1^2/I_4) which is equal to I_{rms} .

The current mirror also produces a $2I_4$ output current, I_{OUT} , that can be used directly or converted to a voltage using resistor R_2 and the internal buffer to provide a low impedance voltage output. The transfer function for the AD536A/636 is:

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

The dB output is obtained by the voltage at the emitter of Q3 which is proportional to the $-\log V_{IN}$. The emitter follower Q5 buffers and level shifts this voltage so that the dB output is zero when the externally set emitter current for Q5 approximates I_3 .

Standard Connection

(Figure 2)

The standard rms connection requires only one external component, C_{AV} . In this configuration the AD536A/636 measures the rms of the AC and DC levels present at the input, but shows an error for low frequency inputs as a function of the C_{AV} filter capacitor. Figure 3 gives practical values of C_{AV} for various values of averaging error over frequency for the standard rms connections (no post filtering). If a $4\mu F$ capacitor is chosen, the additional error at 10Hz will be 0.1%. If the DC error can be rejected, a capacitor should be connected in series with the input, as would typically be the case in single supply operation.

The input and output signal ranges are a function of the supply voltages. Refer to the electrical characteristics for guaranteed performance. The buffer amplifier can be used either for lowering the output impedance of the circuit, or for other applications such as buffering high impedance input signals. The AD536A/636 can be used in current output mode by disconnecting the internal load resistor R_L from ground. The current output is available at pin 8 (pin 10 on the "H" package) with a nominal scale of $40\mu A/\text{Volt rms}$ input for the AD536A and $100\mu A/\text{Volt rms}$ input for the AD636. The output is positive.

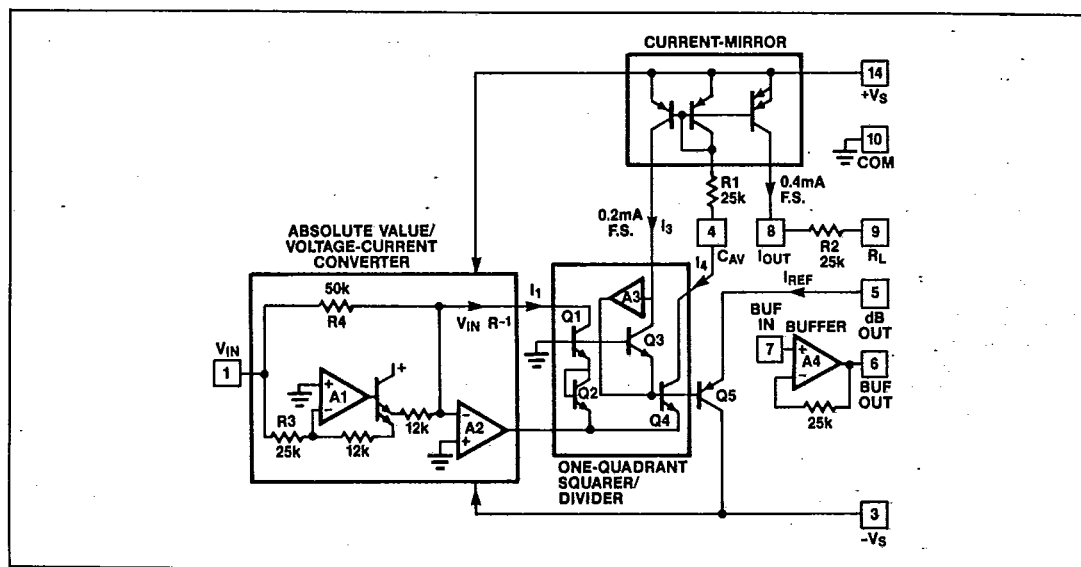


Figure 1. Simplified Schematic

True RMS-to-DC IC Converter

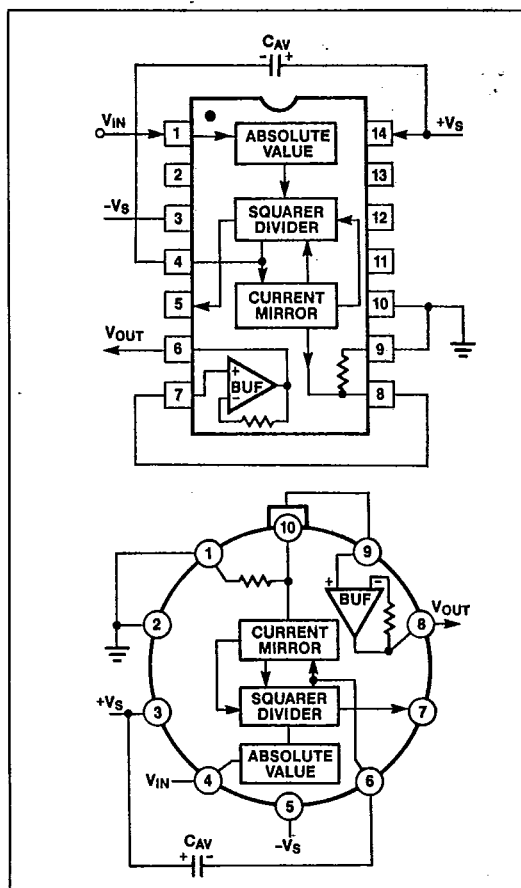


Figure 2. AD536A/AD636 Standard rms Connection

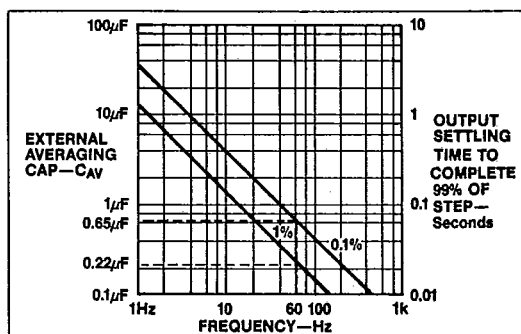


Figure 3. Lower Frequency for Stated % of Reading Error and Settling Time for Circuit Shown in Figure 2

High Accuracy Adjustments

The accuracy of the AD536A/636 can be improved by the addition of external trims as shown in Figure 4. R4 trims the offset. The input should be grounded and R4 adjusted to give zero volts output from pin 6. R1 is trimmed to give the correct value for either a calibrated DC input or a calibrated AC signal. For example: 200mV DC input should give 200mV DC output, a $\pm 200\text{mV}$ peak to peak sinewave should give 141mV DC output.

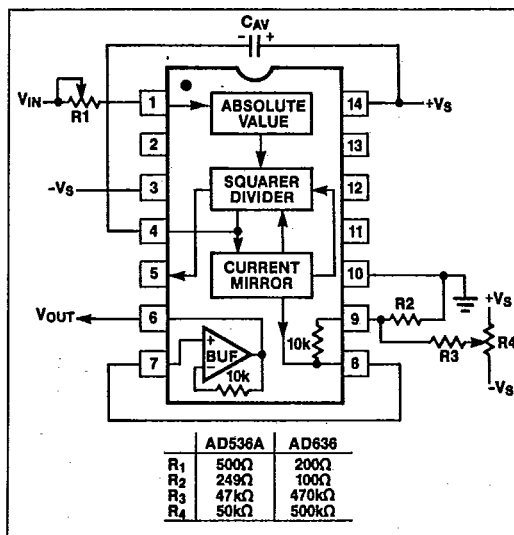


Figure 4. Optional External Gain and Output Offset Trims

Single Supply Operation

Both the AD536A and AD636 can be used with single supplies down to +5V. See Figure 5. 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. The load resistor is necessary to provide output sink current. The input signal is coupled through C2 and the value chosen so that the desired low frequency break point is obtained with the input resistance of 16.7k ohms for the AD536A and 6.7k ohms for the AD636.

Figure 5 shows how to bias pin 10 within the range of the supply voltage (pin 2 on "H" packages). It is critical that no extraneous signals are coupled into this pin. A capacitor connected between pin 10 and ground is recommended. The common pin requires less than 5μA of input current, and if the current flowing through the resistors R1 and R2 is chosen to be approximately 10 times the common pin current, or 50μA, the resistor values can easily be calculated.

AD536A/AD636

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True RMS-to-DC IC Converter

AD536A/AD636

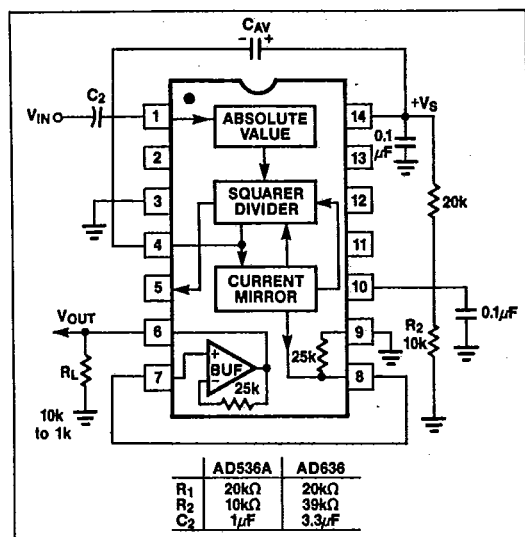


Figure 5. Single Supply Operation

Choosing the Averaging Time Constant

Both the AD536A and AD636 compute the rms value of AC and DC signals. At low frequencies and DC, the output tracks the input exactly; at higher frequencies, the average output approaches the rms value of the input signal. The actual output differs from the ideal by an average (or DC) error plus some amount of ripple.

The DC error term is a function of the value of C_{AV} and the input signal frequency. Figure 3 allows C_{AV} to be selected for either 0.1% or 1% error. The output ripple is inversely proportional to the value of C_{AV} . Waveforms with high crest factors, such as a pulse train with low duty cycle, should have an average time constant chosen to be at least ten times the signal period.

Using a large value of C_{AV} to remove the output ripple increases the settling time for a step change in the input signal level. Figure 3 shows the relationship between C_{AV} and settling time, where 100ms settling equals 1μF of C_{AV} . The settling time, or time for the rms converter to settle to within a given percent of the change in rms level, is set by the averaging time constant, which varies approximately 2:1 between increasing and decreasing input signals. For example, increasing input signals require 2.3 time constants to settle to within 1% and 4.6 time constants for decreasing signals levels.

In addition, the settling time also varies with input signal levels, increasing as the input signal is reduced, and decreasing as the input is increased as shown in figures 6(a) and 6(b).

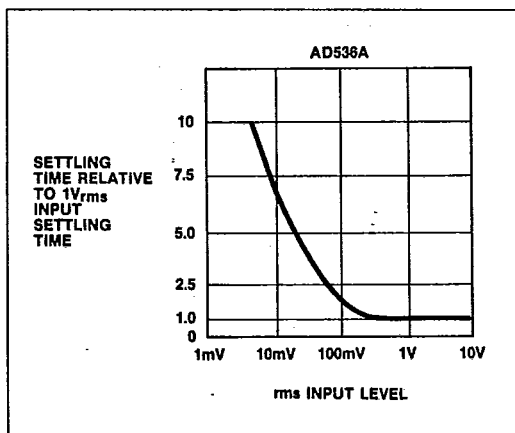


Figure 6A. AD536A Settling Time vs. Input Level

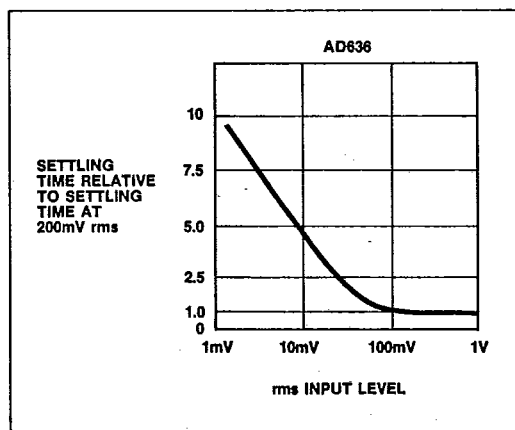


Figure 6B. AD636 Settling Time vs. Input Level

True RMS-to-DC IC Converter

Using Post Filters

A post filter allows a smaller value of C_{AV} , and reduces ripple and improves the overall settling time. The value of C_{AV} should be just large enough to give the maximum DC error at the lowest frequency of interest. The post filter is used to remove excess output ripple. Figures 7, 8 and 9 give recommended filter connections and values for both the AD536A and AD636. Table 1 lists the number of time constants required for the rms section to settle to within different percentages of the final value for a step change in the input signal.

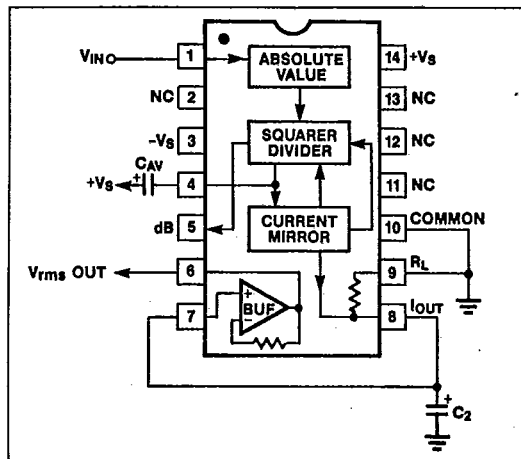


Figure 7. AD536A/AD636 with a 1 Pole Output Filter

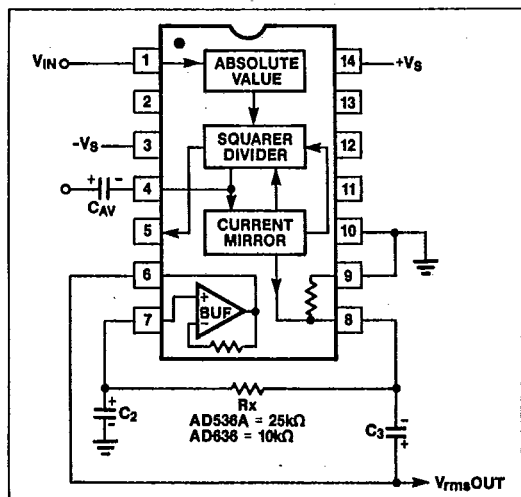


Figure 8. AD536A/AD636 with a 2 Pole Output Filter

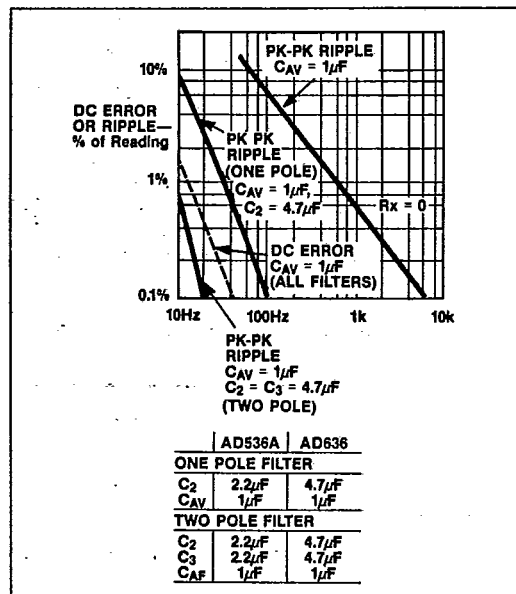


Figure 9. Performance Features of Various Filter Types for AD536A/AD636

Table 1. Number of RC Time Constants (τ) Required for AD536A, AD636, rms Converters to Settle to Within Stated % of Final Value

	For Increasing Amplitudes	For Decreasing Amplitudes
Basic Formulas	$\Delta V \sqrt{1-e^{-T/RC}}$	$\Delta V \sqrt{e^{-T/RC}}$
Settling Time to Within Stated % of New rms Level		
1%	2.0 τ (4.6 τ)	4.6 τ (4.6 τ)
0.1%	3.1 τ (6.9 τ)	6.9 τ (6.9 τ)
0.01%	4.2 τ (9.2 τ)	9.2 τ (9.2 τ)
(τ) Settling Times for Linear RC Filter		

AD536A/AD636



Frequency Response

The AD536A/636 utilizes a logarithmic circuit in performing the rms computation of the input signal. The bandwidth of the rms converters are proportional to signal level. Figures 11 and 12 represent the frequency response of the converters from 10mV to 1V rms for the AD536A and 1mV to 1V for the AD636 respectively. The dashed lines indicate the upper frequency limits for 1%, 10%, and ± 3 dB of reading additional error. Caution must be used when designing rms measuring systems so that overload does not occur. The input clipping level for the AD636 is ± 12 V, and for the AD536A it is ± 20 V. A 7V rms signal with a crest factor of 3 has a peak input of 21 volts!



True RMS-to-DC IC Converter**— Ordering Information (continued)**

PART	TEMP. RANGE	PACKAGE*
AD536AKQ*	0°C to +70°C	14 Lead CERDIP
AD536ASD	-55°C to +125°C	14 Lead Ceramic
AD536ASH	-55°C to +125°C	10 Lead TO-100
AD536ASQ*	-55°C to +125°C	14 Lead CERDIP
AD636JC/D	0°C to +70°C	Dice
AD636JCWE	0°C to +70°C	16 Lead Wide S.O.
AD636JD	0°C to +70°C	14 Lead Ceramic
AD636JH	0°C to +70°C	10 Lead TO-100
AD636JN	0°C to +70°C	14 Lead Plastic
AD636JQ*	0°C to +70°C	14 Lead CERDIP
AD636KCWE	0°C to +70°C	16 Lead Wide S.O.
AD636KD	0°C to +70°C	14 Lead Ceramic
AD636KH	0°C to +70°C	10 Lead TO-100
AD636KN	0°C to +70°C	14 Lead Plastic
AD636KQ*	0°C to +70°C	14 Lead CERDIP

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