

FEATURES

True rms-to-dc conversion

200 mV full scale

Laser-trimmed to high accuracy

0.5% maximum error (AD636K)

1.0% maximum error (AD636J)

Wide response capability

Computes rms of ac and dc signals

1 MHz, -3 dB bandwidth: $V_{rms} > 100$ mV

Signal crest factor of 6 for 0.5% error

dB output with 50 dB range

Low power: 800 μ A quiescent current

Single or dual supply operation

Monolithic integrated circuit

Low cost

GENERAL DESCRIPTION

The AD636 is a low power monolithic IC that performs true rms-to-dc conversion on low level signals. It offers performance that is comparable or superior to that of hybrid and modular converters costing much more. The AD636 is specified for a signal range of 0 mV to 200 mV rms. Crest factors up to 6 can be accommodated with less than 0.5% additional error, allowing accurate measurement of complex input waveforms.

The low power supply current requirement of the AD636, typically 800 μ A, is ideal for battery-powered portable instruments. It operates from a wide range of dual and single power supplies, from ± 2.5 V to ± 16.5 V or from +5 V to +24 V. The input and output terminals are fully protected; the input signal can exceed the power supply with no damage to the device (allowing the presence of input signals in the absence of supply voltage), and the output buffer amplifier is short-circuit protected.

The AD636 includes an auxiliary dB output derived from an internal circuit point that represents the logarithm of the rms output. The 0 dB reference level is set by an externally supplied current and can be selected to correspond to any input level from 0 dBm (774.6 mV) to -20 dBm (77.46 mV). Frequency response ranges from 1.2 MHz at 0 dBm to greater than 10 kHz at -50 dBm.

The AD636 is easy to use. The device is factory-trimmed at the wafer level for input and output offset, positive and negative waveform symmetry (dc reversal error), and full-scale accuracy at 200 mV rms. Therefore, no external trims are required to achieve full-rated accuracy.

Rev. E

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FUNCTIONAL BLOCK DIAGRAM

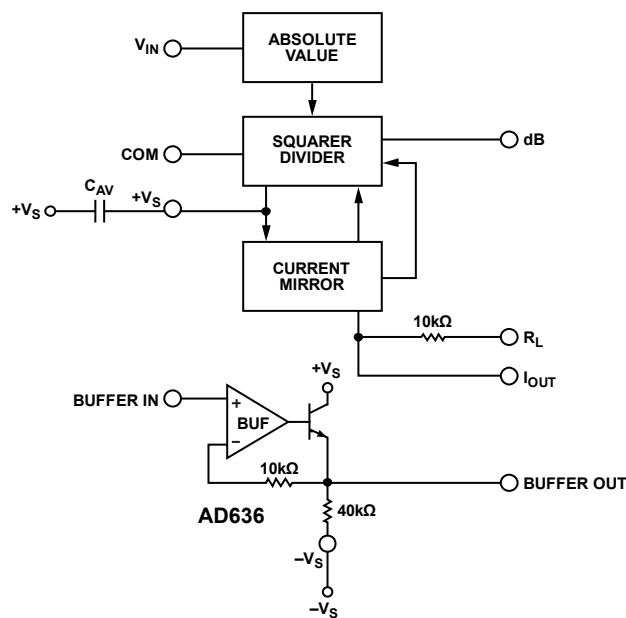


Figure 1.

The AD636 is available in two accuracy grades. The total error of the J-version is typically less than ± 0.5 mV $\pm 1.0\%$ of reading, while the total error of the AD636K is less than ± 0.2 mV to $\pm 0.5\%$ of reading. Both versions are temperature rated for operation between 0°C and 70°C and available in 14-lead SBDIP and 10-lead TO-100 metal can.

The AD636 computes the true root-mean-square 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 because it is a measure of the power in the signal. The rms value of an ac-coupled signal is also its standard deviation.

The 200 mV full-scale range of the AD636 is compatible with many popular display-oriented ADCs. The low power supply current requirement permits use in battery-powered hand-held instruments. An averaging capacitor is the only external component required to perform measurements to the fully specified accuracy is. Its value optimizes the trade-off between low frequency accuracy, ripple, and settling time.

An optional on-chip amplifier acts as a buffer for the input or the output signals. Used in the input, it provides accurate performance from standard 10 M Ω input attenuators. As an output buffer, it sources up to 5 mA.

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REVISION HISTORY

5/13—Rev. D to Rev. E

Reorganized Layout.....	Universal
Changes to Figure 1	1
Change to Table 1	4
Added Typical Performance Characteristics Section	7
Added Theory of Operation Section; Changes to Figure 7 and Figure 8	8
Changed Applying the AD636 Section to Applications Section; Changes to Figure 9, Figure 10, and Single-Supply Connection Section.....	10
Changes to Figure 11	11
Changes to Figure 13 and A Complete AC Digital Voltmeter Section.....	12
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Changes to Ordering Guide	14

11/06—Rev. C to Rev. D

Changes to General Description	1
Changes to Table 1.....	3
Changes to Ordering Guide.....	13

1/06—Rev B to Rev. C

Updated Format.....	Universal
Changes to Figure 1 and General Description	1
Deleted Metallization Photograph	3
Added Pin Configuration and Function Description Section	6
Updated Outline Dimensions.....	14
Changes to Ordering Guide	14

8/99—Rev A to Rev. B

SPECIFICATIONS

@ 25°C, +V_S = +3 V, and -V_S = -5 V, unless otherwise noted.¹

Table 1.

Model	AD636J			AD636K			Unit
	Min	Typ	Max	Min	Typ	Max	
TRANSFER FUNCTION	$V_{OUT} = \sqrt{\text{avg} \times (V_{IN})^2}$			$V_{OUT} = \sqrt{\text{avg} \times (V_{IN})^2}$			
CONVERSION ACCURACY							
Total Error, Internal Trim ^{2,3}			±0.5 ± 1.0			±0.2 ± 0.5	mV ± % of reading
vs. Temperature, 0°C to +70°C			±0.1 ± 0.01			±0.1 ± 0.005	mV ± % of reading/°C
vs. Supply Voltage		±0.1 ± 0.01			±0.1 ± 0.01		mV ± % of reading/V
DC Reversal Error at 200 mV		±0.2			±0.1		% of reading
Total Error, External Trim ²		±0.3 ± 0.3			± 0.1 ± 0.2		mV ± % of reading
ERROR VS. CREST FACTOR ⁴							
Crest Factor 1 to 2	Specified Accuracy			Specified Accuracy			
Crest Factor = 3	-0.2			-0.2			% of reading
Crest Factor = 6	-0.5			-0.5			% of reading
AVERAGING TIME CONSTANT	25			25			ms/μF of C _{AV}
INPUT CHARACTERISTICS							
Signal Range, All Supplies							
Continuous RMS Level	0 to 200			0 to 200			mV rms
Peak Transient Inputs							
+3 V, -5 V Supply	±2.8			±2.8			V p-p
±2.5 V Supply	±2.0			±2.0			V p-p
±5 V Supply	±5.0			±5.0			V p-p
Maximum Continuous Nondestructive Input Level (All Supply Voltages)	±12			±12			V p-p
Input Resistance	5.33	6.67	8	5.33	6.67	8	kΩ
Input Offset Voltage	±0.5			±0.2			mV
FREQUENCY RESPONSE ^{3,5}							
Bandwidth for 1% Additional Error (0.09 dB)							
V _{IN} = 10 mV	14			14			kHz
V _{IN} = 100 mV	90			90			kHz
V _{IN} = 200 mV	130			130			kHz
±3 dB Bandwidth							
V _{IN} = 10 mV	100			100			kHz
V _{IN} = 100 mV	900			900			kHz
V _{IN} = 200 mV	1.5			1.5			MHz
OUTPUT CHARACTERISTICS ³							
Offset Voltage, V _{IN} = COM	±0.5			±0.2			mV
vs. Temperature	±10			±10			μV/°C
vs. Supply	±0.1			±0.1			mV/V
Voltage Swing							
+3 V, -5 V Supply	0.3	0 to 1.0		0.3	0 to 1.0		V
±5 V to ±16.5 V Supply	0.3	0 to 1.0		0.3	0 to 1.0		V
Output Impedance	8	10	12	8	10	12	kΩ

Model	AD636J			AD636K			Unit
	Min	Typ	Max	Min	Typ	Max	
dB OUTPUT							
Error, $V_{IN} = 7 \text{ mV to } 300 \text{ mV rms}$		± 0.3	± 0.5		± 0.1	± 0.2	dB
Scale Factor		-3.0			-3.0		mV/dB
Scale Factor Temperature Coefficient		0.33			0.33		% of reading/ $^{\circ}\text{C}$
		-0.033			-0.033		dB/ $^{\circ}\text{C}$
I_{REF} for 0 dB = 0.1 V rms	2	4	8	2	4	8	μA
I_{REF} Range	1		50	1		50	μA
I_{OUT} TERMINAL							
I_{OUT} Scale Factor		100			100		$\mu\text{A/V rms}$
I_{OUT} Scale Factor Tolerance	-20	± 10	+20	-20	± 10	+20	%
Output Resistance	8	10	12	8	10	12	k Ω
Voltage Compliance		$-V_S$ to ($+V_S - 2 \text{ V}$)			$-V_S$ to ($+V_S - 2 \text{ V}$)		V
BUFFER AMPLIFIER							
Input and Output Voltage Range	$-V_S$ to ($+V_S - 2 \text{ V}$)			$-V_S$ to ($+V_S - 2 \text{ V}$)			V
Input Offset Voltage, $R_S = 10 \text{ k}\Omega$		± 0.8	± 2		± 0.5	± 1	mV
Input Bias Current		100	300		100	300	nA
Input Resistance		10^8			10^8		Ω
Output Current	(+5 mA, -130 μA)			(+5 mA, -130 μA)			
Short-Circuit Current		20			20		mA
Small Signal Bandwidth		1			1		MHz
Slew Rate ⁶		5			5		V/ μs
POWER SUPPLY							
Voltage, Rated Performance		+3, -5			+3, -5		V
Dual Supply	+2, -2.5		± 16.5	+2, -2.5		± 16.5	V
Single Supply	5		24	5		24	V
Quiescent Current ⁷		0.80	1.00		0.80	1.00	mA
TEMPERATURE RANGE							
Rated Performance	0		+70	0		+70	$^{\circ}\text{C}$
Storage	-55		+150	-55		+150	$^{\circ}\text{C}$
TRANSISTOR COUNT							
		62			62		

¹ All minimum and maximum specifications are guaranteed. Specifications shown in **boldface** are tested on all production units at final electrical test and are used to calculate outgoing quality levels.

² Accuracy specified for 0 mV to 200 mV rms, dc or 1 kHz sine wave input. Accuracy is degraded at higher rms signal levels.

³ Measured at Pin 8 of PDIP (I_{OUT}), with Pin 9 tied to common.

⁴ Error vs. crest factor is specified as additional error for a 200 mV rms rectangular pulse train, pulse width = 200 μs .

⁵ Input voltages are expressed in V rms.

⁶ With 10 k Ω pull-down resistor from Pin 6 (BUF OUT) to $-V_S$.

⁷ With BUF IN tied to COMMON.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Ratings
Supply Voltage	
Dual Supply	±16.5 V
Single Supply	24 V
Internal Power Dissipation ¹	500 mW
Maximum Input Voltage	±12 V _{PEAK}
Storage Temperature Range	–55°C to +150°C
Operating Temperature Range	0°C to 70°C
Lead Temperature Range (Soldering 60 sec)	300°C
ESD Rating	1000 V

¹ 10-Lead TO: $\theta_{JA} = 150^{\circ}\text{C}/\text{W}$.
 14-Lead PDIP: $\theta_{JA} = 95^{\circ}\text{C}/\text{W}$.

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.

ESD CAUTION



ESD (electrostatic discharge) sensitive device. Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

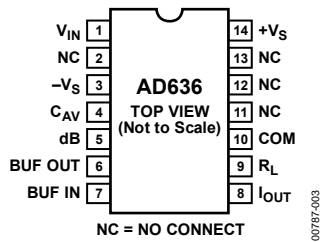


Figure 2. 14-Lead SBDIP Pin Configuration

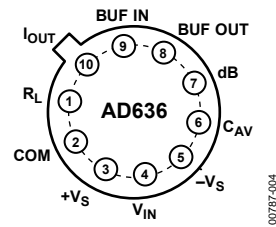


Figure 3. 10-Pin TO-100 Pin Configuration

Table 3. Pin Function Descriptions—14-Lead SBDIP

Pin No.	Mnemonic	Description
1	V_{IN}	Input Voltage.
2	NC	No Connection.
3	$-V_S$	Negative Supply Voltage.
4	C_{AV}	Averaging Capacitor.
5	dB	Log (dB) Value of the RMS Output Voltage.
6	BUF OUT	Buffer Output.
7	BUF IN	Buffer Input.
8	I_{OUT}	RMS Output Current.
9	R_L	Load Resistor.
10	COM	Common.
11, 12, 13	NC	No Connection.
14	$+V_S$	Positive Supply Voltage.

Table 4. Pin Function Descriptions—10-Pin TO-100

Pin No.	Mnemonic	Description
1	R_L	Load Resistor.
2	COM	Common.
3	$+V_S$	Positive Supply Voltage.
4	V_{IN}	Input Voltage.
5	$-V_S$	Negative Supply Voltage.
6	C_{AV}	Averaging Capacitor.
7	dB	Log (dB) Value of the RMS Output Voltage.
8	BUF OUT	Buffer Output.
9	BUF IN	Buffer Input.
10	I_{OUT}	RMS Output Current.

TYPICAL PERFORMANCE CHARACTERISTICS

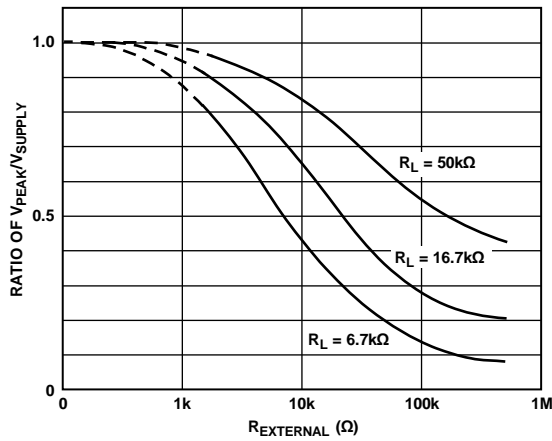


Figure 4. Ratio of Peak Negative Swing to $-V_s$ vs. $R_{EXTERNAL}$ for Several Load Resistances

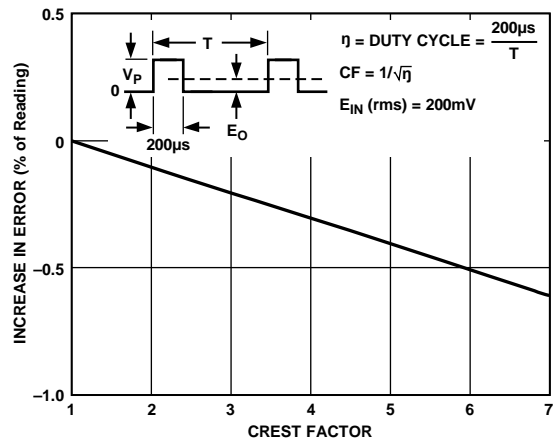


Figure 6. Error vs. Crest Factor

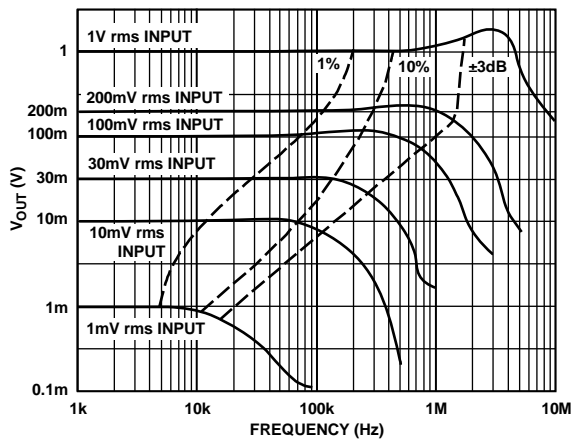


Figure 5. AD636 Frequency Response

THEORY OF OPERATION

RMS MEASUREMENTS

The AD636 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 AD636 follows the equation:

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

The AD636 is comprised of four major sections: absolute value circuit (active rectifier), squarer/divider, current mirror, and buffer amplifier (see Figure 7, for a simplified schematic). The input voltage, V_{IN} , which can be ac or dc, is converted to a unipolar current I_1 , by the active rectifier A1, A2. I_1 drives one input of the squarer/divider, which has the transfer function:

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

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. Therefore,

$$I_4 = Avg \times \left[\frac{I_1^2}{I_4} \right] = I_1_{rms}$$

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 A4 to provide a low impedance voltage output. The transfer function of the AD636 thus results

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

The dB output is derived from the emitter of Q_3 , because 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 .

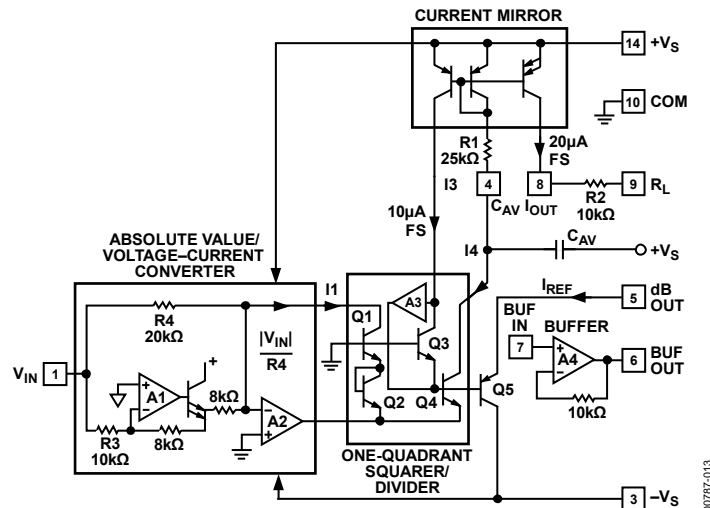


Figure 7. Simplified Schematic

THE AD636 BUFFER AMPLIFIER

The buffer amplifier included in the AD636 offers the user additional application flexibility. It is important to understand some of the characteristics of this amplifier to obtain optimum performance. Figure 8 shows a simplified schematic of the buffer.

Because the output of an rms-to-dc converter is always positive, it is not necessary to use a traditional complementary Class AB output stage. In the AD636 buffer, a Class A emitter follower is used instead. In addition to excellent positive output voltage swing, this configuration allows the output to swing fully down to ground in single-supply applications without the problems associated with most IC operational amplifiers.

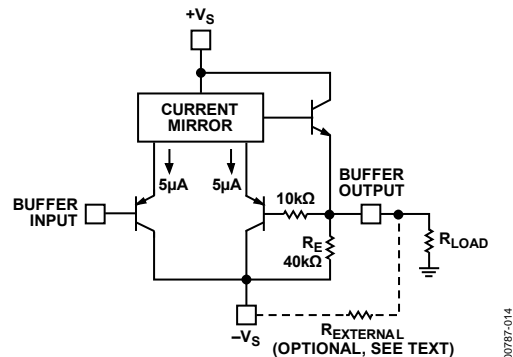


Figure 8. Buffer Amplifier Simplified Schematic

When this amplifier is used in dual-supply applications as an input buffer amplifier driving a load resistance referred to ground, steps must be taken to ensure an adequate negative voltage swing. For negative outputs, current flows from the load resistor through the 40 kΩ emitter resistor, setting up a voltage divider between $-V_s$ and ground. This reduced effective $-V_s$, limits the available negative output swing of the buffer. The addition of an external resistor in parallel with R_E alters this voltage divider such that increased negative swing is possible.

Figure 4 shows the value of R_{EXTERNAL} for a particular ratio of V_{PEAK} to $-V_S$ for several values of R_{LOAD} . The addition of R_{EXTERNAL} increases the quiescent current of the buffer amplifier by an amount equal to R_{EXT}/V_S . Nominal buffer quiescent current with no R_{EXTERNAL} is 30 μA at $-V_S = -5\text{ V}$.

FREQUENCY RESPONSE

The AD636 uses a logarithmic circuit to perform the implicit rms computation. As with any log circuit, bandwidth is proportional to signal level. The solid lines in Figure 5 represent the frequency response of the AD636 at input levels from 1 mV to 1 V rms. The dashed lines indicate the upper frequency limits for 1%, 10%, and $\pm 3\text{ dB}$ of reading additional error. For example, note that a 1 V rms signal produces less than 1% of reading additional error up to 220 kHz. A 10 mV signal can be measured with 1% of reading additional error (100 μV) up to 14 kHz.

AC MEASUREMENT ACCURACY AND CREST FACTOR (CF)

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 ($CF = V_P/V_{\text{rms}}$). Most common waveforms, such as sine and triangle waves, have relatively low crest factors (<2). Waveforms that 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 6 is a curve of reading error for the AD636 for a 200 mV rms input signal with crest factors from 1 to 7. A rectangular pulse train (pulse width 200 μs) was used for this test because 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 7 while maintaining a constant 200 mV rms input amplitude.

APPLICATIONS

The input and output signal ranges are a function of the supply voltages as detailed in the specifications. The AD636 can also be used in an unbuffered voltage output mode by disconnecting the input to the buffer. The output then appears unbuffered across the 10 k Ω resistor. The buffer amplifier can then be used for other purposes. Further, the AD636 can be used in a current output mode by disconnecting the 10 k Ω resistor from the ground. The output current is available at Pin 8 (Pin 10 on the H package) with a nominal scale of 100 μ A per volt rms input, positive out.

STANDARD CONNECTION

The AD636 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 9. In this configuration, the AD636 measures the rms of the ac and dc level present at the input but shows an error for low frequency inputs as a function of the filter capacitor, C_{AV} , as shown in Figure 13. Therefore, if a 4 μ F capacitor is used, the additional average error at 10 Hz is 0.1%, and at 3 Hz it is 1%. The accuracy at higher frequencies is 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 11; the capacitor must be nonpolar. If the AD636 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 μ F ceramic discs as near the device as possible. C_F is an optional output ripple filter.

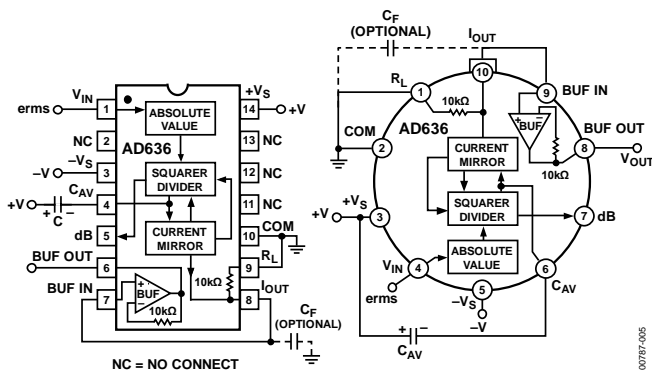


Figure 9. Standard RMS Connection

OPTIONAL TRIMS FOR HIGH ACCURACY

If it is desired to improve the accuracy of the AD636, the external trims shown in Figure 10 can be added. R4 is used to trim the offset. The scale factor is trimmed by using R1 as shown. The insertion of R2 allows R1 to either increase or decrease the scale factor by $\pm 1.5\%$.

The trimming procedure is as follows:

- Ground the input signal, V_{IN} , and adjust R4 to give 0 V output from Pin 6. Alternatively, R4 can be adjusted to give the correct output with the lowest expected value of V_{IN} .
- 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, that is, 200 mV dc input should give 200 mV dc output. Of course, a ± 200 mV peak-to-peak sine wave should give a 141.4 mV dc output. The remaining errors, as given in the specifications, are due to the nonlinearity.

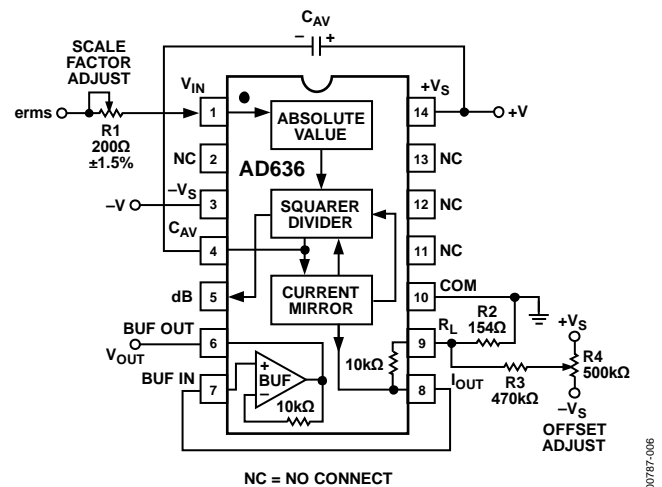


Figure 10. Optional External Gain and Output Offset Trims

SINGLE-SUPPLY CONNECTION

Although the applications illustrated in Figure 9 and Figure 10 assume the use of dual power supplies, three external bias components connected to the COM pin enable powering the AD636 with unipolar supplies as low as 5 V. The two resistors and capacitor network shown connected to Pin 10 in Figure 11 are satisfactory over the same range of voltages permissible with dual supply operation. Any external bias voltage applied to Pin 10 is internally reflected to the V_{IN} pin, rendering the same ac operation as with a dual supply. DC or ac + dc conversion is impractical, due to the resultant dc level shift at the input. The capacitor insures that no extraneous signals are coupled into the COM pin. The values of the resistors are relatively high to minimize power consumption because only 1 μ A of bias current flows into Pin 10 (Pin 2 on the H package).

Alternately, the COM pin of some CMOS ADCs provides a suitable artificial ground for the AD636. AC input coupling requires only Capacitor C2 as shown; a dc return is not necessary because it is provided internally. C2 is selected for the proper low frequency break point with the input resistance of 6.7 k Ω ; for a cut-off at 10 Hz, C2 should be 3.3 μ F. The signal ranges in this connection are

Frequency Response ± 3 dBm

Input

- 0 dBm = 5 Hz to 380 kHz
- 10 dBm = 5 Hz to 370 kHz
- 20 dBm = 5 Hz to 240 kHz
- 30 dBm = 5 Hz to 100 kHz
- 40 dBm = 5 Hz to 45 kHz
- 50 dBm = 5 Hz to 17 kHz

Calibration

First, calibrate the 0 dB reference level by applying a 1 kHz sine wave from an audio oscillator at the desired 0 dB amplitude.

This can be anywhere from 0 dBm (770 mV rms – 2.2 V p-p) to -20 dBm (77 mV rms – 220 mV p-p). Adjust the I_{REF} calibration trimmer for a zero indication on the analog meter.

Then, calibrate the meter scale factor or gain. Apply an input signal -40 dB below the set 0 dB reference and adjust the scale factor calibration trimmer for a 40 μ A reading on the analog meter.

The temperature compensation resistors for this circuit can be purchased from Micro-Ohm Corporation, 1088 Hamilton Rd., Duarte, CA 91010, Part #Type 401F, 2 k Ω , 1% + 3500 ppm/ $^{\circ}$ C.

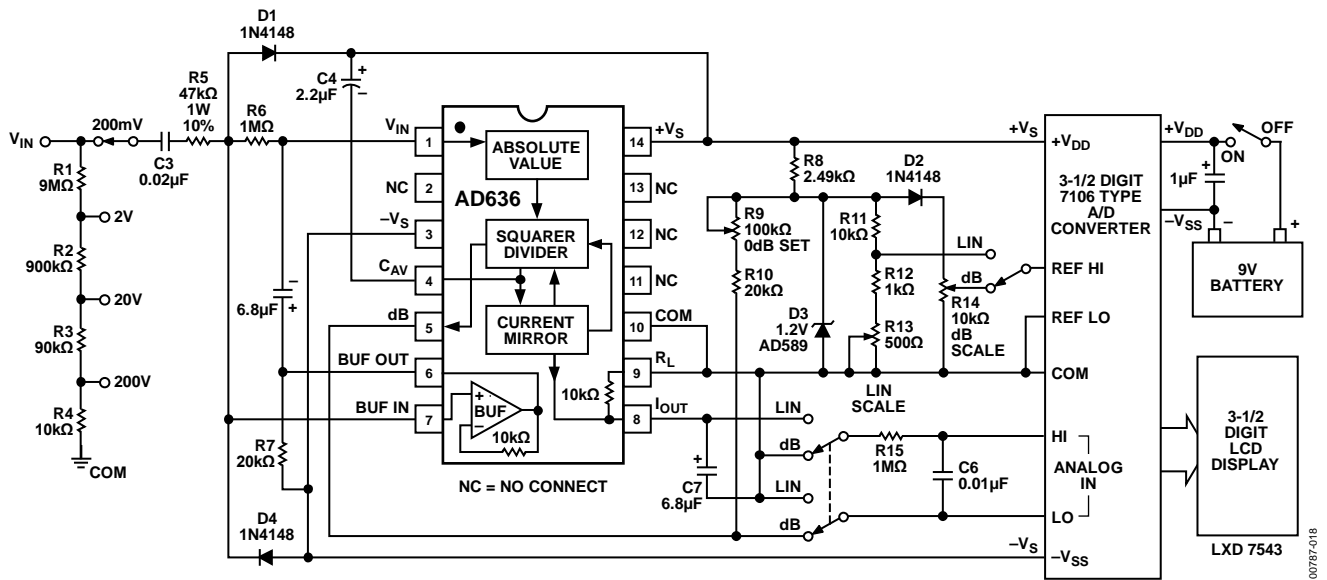
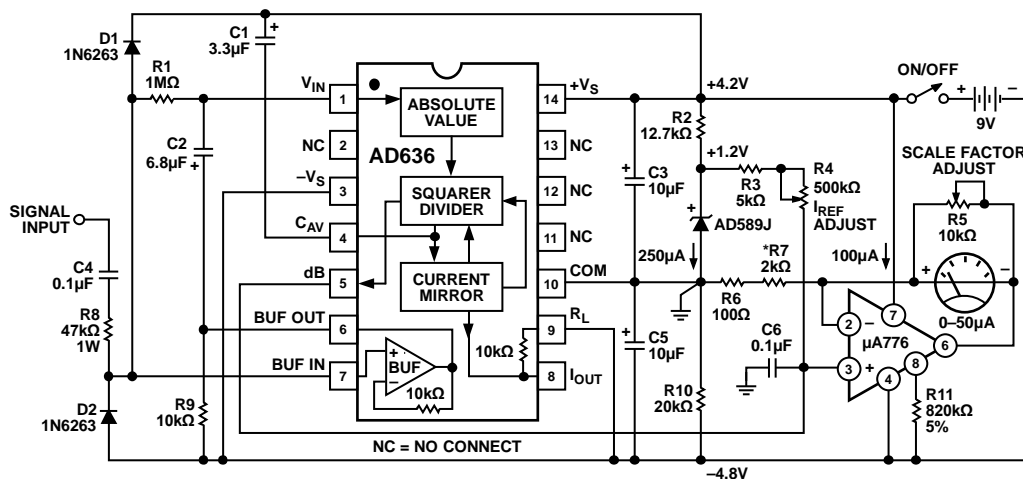


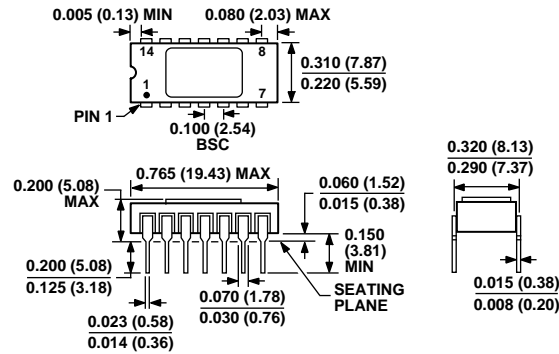
Figure 17. Portable, High-Z Input, RMS DPM and dB Meter Circuit



ALL RESISTORS 1/4W 1% METAL FILM UNLESS OTHERWISE STATED EXCEPT *WHICH IS 2k Ω +3500ppm 1% TC RESISTOR.

Figure 18. Low Power, High Input Impedance dB Meter

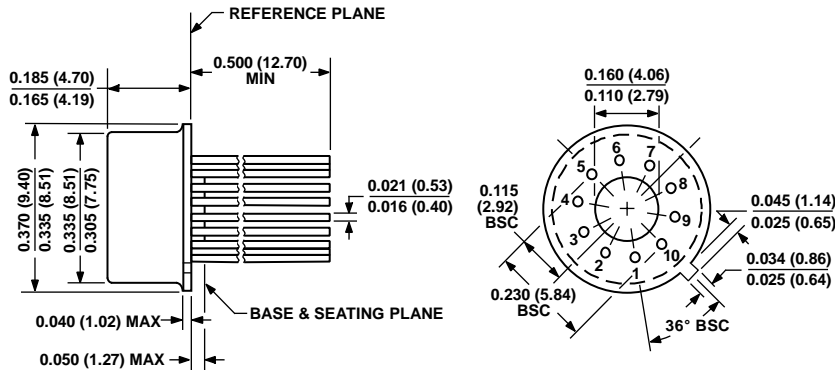
OUTLINE DIMENSIONS



CONTROLLING DIMENSIONS ARE IN INCHES; MILLIMETER DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF INCH EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

Figure 19. 14-Lead Side-Brazed Ceramic Dual In-Line Package [SBDIP] (D-14)

Dimensions shown in inches and (millimeters)



DIMENSIONS PER JEDEC STANDARDS MO-006-AF
CONTROLLING DIMENSIONS ARE IN INCHES; MILLIMETER DIMENSIONS (IN PARENTHESES) ARE ROUNDED-OFF INCH EQUIVALENTS FOR REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

Figure 20. 10-Pin Metal Header Package [TO-100] (H-10)

Dimensions shown in inches and (millimeters)

ORDERING GUIDE

Model ¹	Temperature Range	Package Description	Package Option
AD636JDZ	0°C to +70°C	14-Lead SBDIP	D-14
AD636KDZ	0°C to +70°C	14-Lead SBDIP	D-14
AD636JH	0°C to +70°C	10-Pin TO-100	H-10
AD636JHZ	0°C to +70°C	10-Pin TO-100	H-10
AD636KH	0°C to +70°C	10-Pin TO-100	H-10
AD636KHZ	0°C to +70°C	10-Pin TO-100	H-10

¹ Z = RoHS-Compliant Part.

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