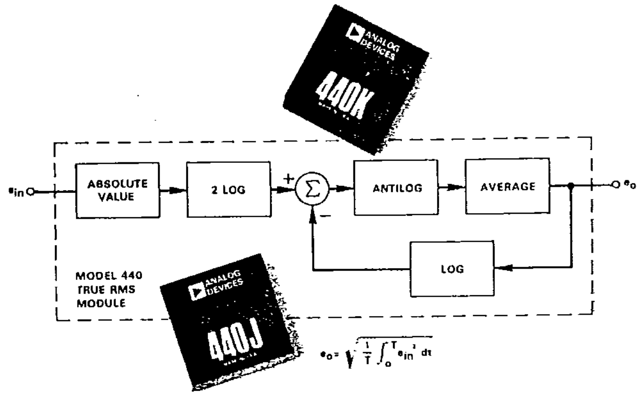
ANALOG DEVICES

Low Cost, General Purpose True RMS-to-DC Converter

MODEL 440

FEATURES
- True RMS-to-DC Measurement
- High Accuracy: 0.1% for C.F. ⩽5
- DC to 100kHz Response (1% Error)
- All Hermetically Sealed Semiconductors
- Low Cost

APPLICATIONS
- OEM RMS Instrumentation
- Complex Waveform Measurements
- SCR Controller & Power Line Measurements
- Audio, Accoustic and Vibration Measurements
- Mean Square Measurements
- Random Thermal Noise Measurements



$e_o = \sqrt{\frac{1}{T}\int_0^T e_{in}^2\,dt}$

GENERAL DESCRIPTION

Model 440 is a compact economy RMS to DC converter module featuring performance usually found in higher priced units. In addition to measuring AC signals, model 440 can also measure directly the RMS value of a waveform containing both AC and DC. No external adjustments or components are required to achieve rated performance. For measurements below 100Hz, a single external capacitor may be added to achieve 0.1% accuracy without affecting the bandwidth for high frequency measurements.

Model 440 is available in two accuracy grades: model 440K features total error of ±5mV ±0.1%, while model 440J has total error of ±15mV ±0.2%. Optional external scale factor and offset voltage trimming will significantly reduce error for both models.

WHERE TO USE MODEL 440

OEM Instrument Designers will find the small size, low cost and high accuracy of model 440 makes it an excellent choice wherever RMS measurements must be made independent of waveform. This design offers significant accuracy improvements over the common rectifier-averaging type of meter. For example, the rectifier-averaging instrument has an error of 64% of reading on a 10% duty cycle pulse train, while the model 440 will provide less than 1% error by comparison. For industrial measurements, such as SCR motor controllers, as well as line voltage measurements, with high harmonic distortion, model 440 features high crest factor capability resulting in measurement errors less than ±1%.

The RMS value of any stationary zero-mean random signal is equal to the standard deviation (σ) of that signal. Accurate measurements of random signals, including acoustical noise, mechanical vibration and electrical noise are easily accomplished.

Model 440 may also be connected (see Figure 3) to measure the Mean Square of a signal ($e_o = \overline{e_{in}^2}/V_R$). The Mean Square of a random signal is equal to the variance (σ^2).

TOTAL ACCURACY

Total output error is specified as the sum of two components; a fixed term plus a percentage of peak output signal. Model 440K, for example, has a rated accuracy of ±5mV ±0.1%, which for a one volt RMS sinewave, results in a ±6mV maximum error (±5mV fixed error plus ±1mV reading error). The fixed error component is composed of output offset and input offset errors. The % of reading error is attributed to nonlinearity and scale factor errors. Scale factor error may be reduced by external adjustment of an optional 5kΩ potentiometer (see Figure 2). Offset voltage can also be trimmed to zero by external adjustment of an optional 20kΩ pot.

Accuracy is also dependent on the input signal frequency, amplitude and crest factor which are discussed in detail below.

HIGH FREQUENCY PERFORMANCE VERSUS SIGNAL LEVEL

Shown in Figure 4 is a plot of reading error versus frequency with input signal amplitude as a parameter. This error arises because of internal limitations in slew rate capability for large signal levels. At small signal levels, slew rate limiting is not predominant. Therefore, to achieve best accuracy in wideband applications with model 440, the designer should consider scaling down the input signal to optimize performance as shown in Figure 4.

(continued on page 3)

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SPECIFICATIONS (typical @ +25°C and V_S = ±15VDC, unless otherwise noted)

MODEL	440J	440K
TRANSFER EQUATION	$e_o = \sqrt{\text{avg } (e_{in})^2}$	*
ACCURACY		
Total Error[1]		
No External Adjustment	±10mV ±0.2%, Max	±5mV ±0.1%, Max
External Adjustment[2]	±2mV ±0.1%, Max	±2mV ±0.05%, Max
vs. Temperature (0 to +70°C)	±(0.2mV ±0.02%)/°C, Max	*
vs. Supply Voltage	±0.2mV/V	*
CREST FACTOR		
Rated Accuracy	5 Min	*
±1% Reading Error	10	*
FREQUENCY RESPONSE, Sinewave		
Rated Accuracy		
Input Range, 0.1 to $7V_{rms}$	10kHz, Min	*
±1% Reading Error		
Input, $7V_{rms}$	50kHz, Min	*
Input, $0.7V_{rms}$	50kHz, Min	*
Bandwidth, -3dB		
Input Range, 0.7 to $7V_{rms}$	500kHz	*
Internal Filter Time Constant	10ms	*
External Filter Time Constant[3]	50ms/μF	*
Total Averaging Time Constant	10ms + 50ms/μF	*
OUTPUT SPECIFICATIONS		
Rated Output[4]		
Voltage	+10.0V, Min	*
Current	+10.0mA, Min	*
Resistance	0.1Ω	*
Offset Voltage		
Internally Trimmed[5]	±5mV, Max	±2mV, Max
External Trim	Adjustable to Zero	*
INPUT SPECIFICATIONS		
Voltage		
Signal Range	±10V, Peak	*
Safe Input	$\pm V_S$, Max	*
dB Range, Referred to 1V	-40dB to 17dB	*
dBm Range, referred to 0.775V (1mW in 600Ω)	-38dBm to 19dBm	*
Impedance	8.3kΩ ±2%	*
Offset Voltage	±1mV, Max	*
vs. Temperature (0 to +70°C)	±10μV/°C	*
POWER SUPPLY[6]		
Voltage, Rated Performance	±15VDC	*
Voltage, Operating	±(6 to 18)VDC	*
Current, Quiescent	±10mA	*
TEMPERATURE RANGE		
Rated Performance	0 to +70°C	*
Operating	−25°C to +85°C	*
Storage	−55°C to +125°C	*
MECHANICAL		
Case Size	1.5" x 1.5" x 0.4"	*
Mating Socket	AC1016	*
Weight	40g	*

*Specifications same as Model 440J.

[1] Error is specified as the sum of two components: a fixed term plus a percentage of output signal. The fixed error component is composed of output offset error, and input offset error. The percentage of output signal (reading error) may be reduced by external adjustment of a scale factor potentiometer.

[2] See Figure 2 for connection of optional external scale factor adjustment pot.

[3] Connect optional filter capacitor between pin 1 and pin 2 (see Figure 2). Pin 1 is protected for shorts to ground and the positive supply voltage. Pin 1 is not protected for negative voltages greater than 1 volt.

[4] Protected for short circuit to ground and/or supply voltage.

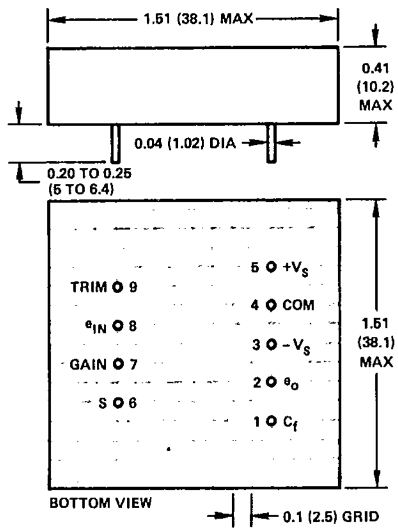
[5] Output offset voltage may be adjusted to zero. See Figure 2 and Figure 3 for connection diagram of optional 20kΩ pot. Adjustment range; ±20mV.

[6] Recommended power supply: Analog Devices' Model 915.

Specifications subject to change without notice.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



MATING SOCKET AC1016

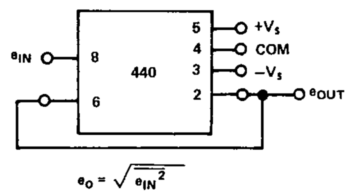
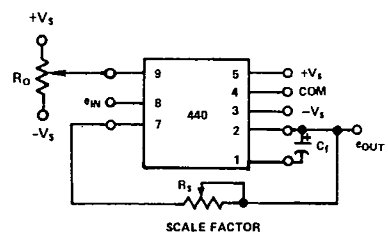


Figure 1. Wiring Connections for RMS Measurements (No External Trim)



R_s = 5kΩ
R_o = 20kΩ
Select C_f for increased averaging time constant.
(τ(ms) = 10 + 50 C_f (μF))

Figure 2. Optional External Adjustment for RMS Measurements

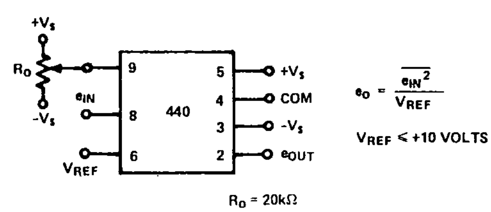


Figure 3. Wiring Connections for Mean Square Measurements with Adjustable Scale Factor (V_{REF})

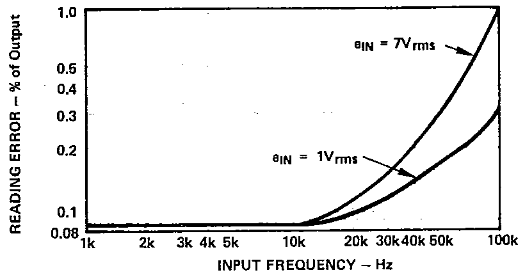


Figure 4. Error vs. Frequency, Sinewave Input

LOW FREQUENCY PERFORMANCE VERSUS FILTER TIME CONSTANT

Shown in Figure 5 is a plot of reading error versus frequency with the external filter capacitor (C_f) as a parameter. This capacitor is selected to increase the filter time constant to reduce output ripple for low frequency measurements. Accuracy at high frequencies is not affected by C_f.

In selecting the external filter capacitor, the lowest frequency component of the input signal should be determined. An averaging time constant (τ) of approximately 10 times the period of this frequency should then be selected. The averaging time constant of model 440 is determined from the following relation:

$$\tau\ (\text{ms}) = 10 + 50\ C_f\ (\mu\text{F})$$

Low leakage capacitors, such as tantalum electrolytic are recommended. Figure 5 shows curves for C_f values of 0, 1, 10 and 33μF and may be used to bracket the reading errors when other values are selected.

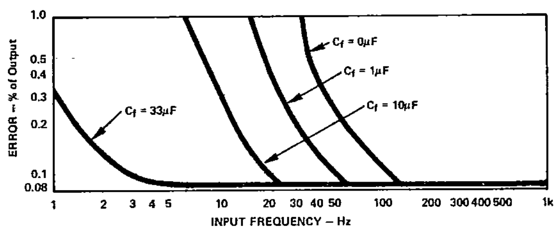


Figure 5. Error vs. Frequency, Sinewave Input

SETTLING TIME RESPONSE VERSUS FILTER TIME CONSTANT

Although there is no upper limit on how large a capacitor may be used to reduce ripple at low frequencies, there is a practical limitation due to increased settling time for step changes in RMS level occurring at the input. Figure 6 shows curves of settling time to 1% accuracy for increasing and decreasing one volt RMS input step changes. Increasing step changes (10mV to 1V_{rms}) settle to approximately three time constants (τ (ms) = 10 + 50C_f); decreasing step changes (1V_{rms} to 10mV) settle to approximately 5 time constants. The designer must consider optimizing settling time and low frequency error in selecting the external filter capacitor.

RMS MEASUREMENT ACCURACY AND CREST FACTOR

Crest factor is frequently understated in importance for RMS measurements, yet it is key to determining the accuracy of a true RMS measurement on a specific waveform. Crest factor is defined as the ratio of the peak signal amplitude to the RMS value (C.F. = V_p/V_{rms}). Figure 7 shows crest factor and RMS values for most frequently encountered waveforms. The examples shown illustrate that most common waveforms have relatively low crest factors (<2). Waveforms such as low duty cycle pulse trains have high crest factors (e.g. for a 1% duty cycle pulse train, crest factor is 10).

The peak signal input for model 440 is rated at ±10V. Crest factor, peak input voltage and RMS level are related by the crest factor definition; C.F. = V_p/V_{rms}. Therefore, for a particular waveform the max RMS input range may be determined from the signal crest factor. For example, for a sinewave, crest factor is 1.41. Therefore V_{rms} (max input) = 10V/1.41 = 7V_{rms}.

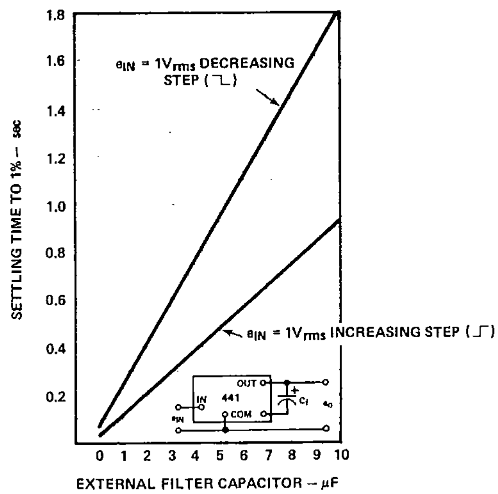


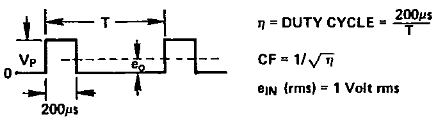
Figure 6. Settling Time vs. Filter Capacitor (C_f)

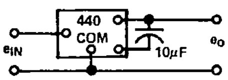
INPUT WAVEFORM	CREST FACTOR (= V_p/V_{rms})	RMS OUTPUT	RMS OUTPUT FOR V_p = 10 VOLTS
SINE WAVE	$\sqrt{2}$ (= 1.414)	$\frac{V_p}{\sqrt{2}}$	7V_{rms}
SYMMETRICAL SQUARE WAVE (OR DC)	1	V_p	10V_{rms}
TRIANGULAR WAVE	$\sqrt{3}$ (= 1.732)	$\frac{V_p}{\sqrt{3}}$	5.77V_{rms}
GAUSSIAN NOISE 2V_p CREST FACTOR 1 2 3 4 5 10^{-6} 10^{-3} 10^0 PROBABILITY OF GREATER CREST FACTORS EXAMPLE: C.F.>4 HAS A PROBABILITY OF <0.01%		RMS	C.F. / V_{rms} 1 / 10 2 / 5 3 / 3.3 4 / 2.5 5 / 2
PULSE TRAIN T, ηT	$\frac{1}{\sqrt{\eta}}$ η / C.F. 1 / 1 1/4 / 2 1/16 / 4 1/64 / 8 1/100 / 10	$V_p\sqrt{\eta}$ V_p 0.5 V_p 0.25 V_p 0.125 V_p 0.1 V_p	$10\sqrt{\eta}$ V_{rms} 10 V_{rms} 5 V_{rms} 2.5 V_{rms} 1.25 V_{rms} 1 V_{rms}
SINE-SQUARED	$\sqrt{8/3}$ (= 1.633)	$\frac{V_p}{1.63}$	6.13V_{rms}
SCR OUTPUT φ = 110°	1.68	$\frac{V_p}{1.68}$	5.95V_{rms}
SAWTOOTH PULSE 0 η 1	$\sqrt{\frac{3}{\eta}}$	$V_p\sqrt{\frac{\eta}{3}}$	$10\sqrt{\frac{\eta}{3}}$

Figure 7. Crest Factor and RMS Values for a Wide Class of Waveforms

ACCURACY AND SIGNAL CREST FACTOR

Shown in Figure 8 is a curve of reading error for model 440 with a one volt rms pulse train with variable duty cycle and peak amplitude. In this curve, pulse width (200µs) and RMS level (1 Volt) are held constant. The pulse train was selected because of its ability to generate a wide range of crest factors by varying the duty cycle (C.F. = $1/\sqrt{\eta}$). At a crest factor of 10, the peak input amplitude is 10 Volts (V_p = (C.F.) (V_{rms}). Therefore a one volt RMS level was selected to provide reading errors for crest factors from 1 to 10 (V_p from 1 to 10 Volts). Figure 8 may be used to estimate the reading error of the general class of waveform shown in Figure 7.





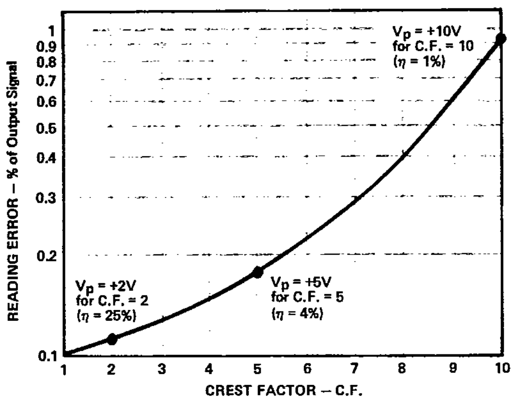


Figure 8. Error vs. Crest Factor

ACCURACY AND PULSE WIDTH

To relate error versus pulse width response, Figure 9 has been developed wherein crest factor and rms level are presented as parameters. Because of the extremely high frequency harmonic content in narrow pulse widths, the curves of Figure 9 present a worst case indication of error performance with frequency for the class of waveform shown in Figure 7. Model 440 may be used for pulse widths as small as 50µs with negligible additional error.

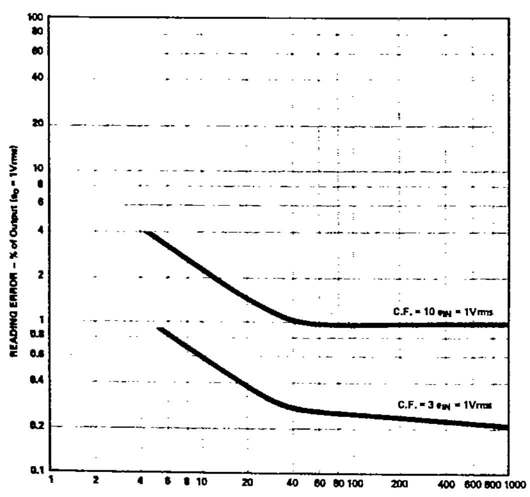


Figure 9. Error vs. Pulse Width and Crest Factor for Pulse Train

OPTIONAL EXTERNAL ADJUSTMENT PROCEDURE

Optional external trimming consists of two adjustments: output offset and scale factor. By the use of these two trims, overall accuracy may be improved significantly. To adjust output offset voltage, connect a 20k trim pot as shown in Figure 2 and short the input to common. Adjust for zero output voltage. To trim scale factor, connect a 5k trim pot as shown in Figure 2 and apply a positive DC input signal at the desired full scale RMS level (e.g., +1.000V). Adjust the scale factor pot until the output is equal to the input. Reverse the input polarity and measure the error in output level. Readjust the scale factor pot for lowest error for both polarity inputs.

When model 440 is used to perform mean square measurements, the output offset voltage may be adjusted to zero by means of a 20kΩ potentiometer connected as shown in Figure 3. To trim the output to zero, apply a +10V reference voltage to pin 6, and connect the input to signal common. Adjust the offset potentiometer for zero output.

TRUE RMS DIGITAL PANEL METER APPLICATION

Model 440 may be used to provide an economical, true RMS measurement capability for modular digital panel meters (DPM). Figure 10 illustrates an application of model 440 with a popular 3½ digit line powered DPM (Analog Devices' model AD2006). The low power requirements of model 440 allow the use of the DPM's external power outputs (±15V @ 10mA), eliminating the need for a separate power supply for model 440. The input resistor (R_1) provides the capability to easily set the nominal full scale input voltage to the DPM at 1 Volt for the peak input signal to be measured (E_{in}). For example, to measure 115VAC line voltage, R_1 would be selected for a 100:1 attenuation ratio (R_1 = 100 (R_{in}) = 830k. The external filter capacitor is selected to achieve desired accuracy for the input frequency range; a 1µF would give rated accuracy for 50-60Hz line frequencies (see Figure 5). For best accuracy, the scale factor potentiometer (R_2) would be adjusted with a precision reference voltage input; a 100VDC signal may be used with the 830kΩ.

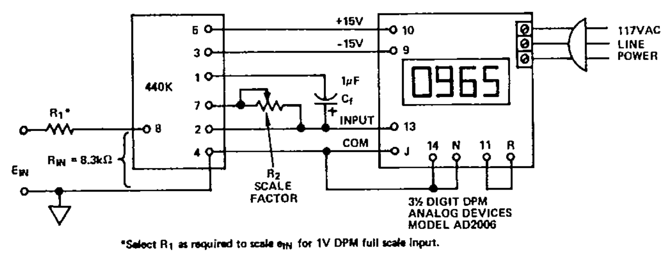


Figure 10. True RMS DPM Application Using AD2006 DPM Internal Power to Operate Model 440K