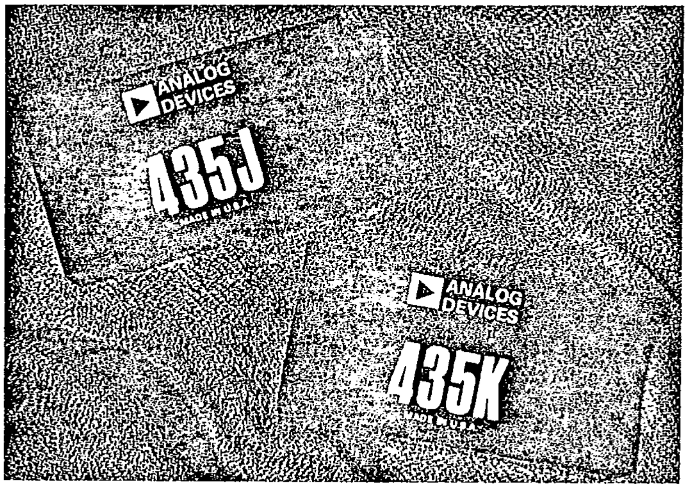
ANALOG DEVICES

Precision, 1/4%, 1/10% Multiplier, Divider, Square Rooter

MODEL 435

FEATURES
- High Accuracy Without Trimming: 0.1% max (435K); 0.25% max (435J)
- Low Accuracy Drift: 0.01%/°C max (435K)
- Low Output Offset Drift: 0.2mV/°C max (435K)
- Scale Factor Adjustment: Single Trim Pot
- Low Nonlinearity: 0.05% max (435K)
- Low Noise: 1mV rms (10Hz to 1MHz)

APPLICATIONS
- Phase Detection
- Power Measurement
- Automatic Gain Control
- Modulation and Demodulation



GENERAL DESCRIPTION

Model 435K is a precision transconductance multiplier that combines factory trimmed accuracy to within 0.1% max with output offset drift of only 0.002%/°C max, and nonlinearity of 0.05% max. Corresponding specifications for model 435J are 0.25% max accuracy, 0.003%/°C max offset drift and nonlinearity of 0.1% max. All specifications apply for any X or Y input signal within ±10 volts over all four quadrants. Optional trimming may be used to further improve accuracy, typically by a factor of two. In addition, the model 435 features excellent noise performance of 1mV, rms in a bandwidth of 10Hz to 1MHz. Bandwidth is 250kHz (-3dB) and feedthrough for model 435J is 20mV p-p, max and 10mV p-p, max for model 435K. Model 435 may also be used as a precision divider, squarer or square rooter.

ACCURACY

Multiplication accuracy is specified as a percentage of full scale output and is guaranteed without external trimming. Full scale output for model 435 is ±10 volts; the maximum error for model 435K is ±0.1%, or ±10mV. This error includes all room temperature error terms (scale factor, output offset, feedthrough and nonlinearity) for any input (X or Y) combination of ±10 volts. For improved accuracy, the output offset, scale factor and feedthrough may be trimmed using external trim potentiometers connected to the power supply. When external trimming is used to improve accuracy, nonlinearity becomes the limiting error term. Model 435 features very low nonlinearity (±0.05% max, 435K) to enable the user to perform very accurate operations using model 435. Output noise, typically 250µV, rms (10Hz to 10kHz) is significantly reduced over previous multiplier designs to permit improved signal resolution.

SCALE FACTOR ADJUSTMENT

Model 435 features a unique scale factor (gain) adjustment control which permits the user to easily compensate for system errors. The external scale factor (gain) pot will provide an adjustment range of at least ±1% and may be located away from the 435 module for operator convenience.

FREQUENCY RELATED SPECIFICATIONS

Feedthrough, linearity, gain and phase shift, which are components of overall multiplier accuracy, are frequency dependent parameters. On model 435, feedthrough is constant for both X and Y inputs up to 1kHz. Between 1kHz and 9kHz, it rises at about 6dB/octave. Above 9kHz, the X input feedthrough remains constant. Y input feedthrough continues to rise at 6dB/octave up to 60kHz and then levels off above that frequency. A plot of feedthrough vs. frequency is shown in Figure 1.

Nonlinearity for both the X and Y inputs also increases with frequency at a 6dB/octave rate above the break frequency of 1.5kHz. Figure 1 shows a typical plot of nonlinearity vs. frequency for the 435. Gain and input to output phase shift for the model 435 are shown in Figure 2; the data was recorded with Y input = +10V and X input = 2V p-p. All multipliers have a reduced gain at frequencies approaching the small signal bandwidth. For model 435 a 1% amplitude error occurs at 30kHz and a 1% "vector" error in output phase shift occurs at 2kHz.

(continued on page 3)

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SPECIFICATIONS (typical @ +25°C and ±15V unless otherwise noted)

MODEL	435J	435K
TRANSFER FUNCTIONS		
Multiply Mode	$e_o = XY/10$	•
Divide Mode	$e_o = 10Z/X$	•
Square Root Mode	$e_o = -\sqrt{10Z}$	•
Squaring Mode	$e_o = X^2/10$	•
ACCURACY (MULTIPLICATION MODE)[1]		
Total Output Error at +25°C		
Internal Trim	±0.25% max	±0.1% max
External Trim	±0.08%	±0.05%
vs. Temperature 0 to +70°C	±0.01%/°C	±0.01%/°C max
vs. Supply Voltage	±0.02%/%	•
Warm Up Time, to Rated Performance	5 minutes	•
NONLINEARITY		
X Input (Y = ±10V; X = 20V p-p, 10Hz)	±0.1% max	±0.05% max
Y Input (X = ±10V; Y = 20V p-p, 10Hz)	±0.1% max	±0.05% max
OUTPUT OFFSET		
Initial, @ +25°C	±10mV max	±5mV max
vs. Temperature, 0 to +70°C	±0.3mV/°C max	±0.2mV/°C max
vs. Supply Voltage	±1mV/%	•
SCALE FACTOR		
Initial Error, @ +25°C	±0.1%	±0.05%
vs. Temperature, 0 to +70°C	±0.01%/°C	•
FEEDTHROUGH		
X = 0, Y = 20V p-p, 10Hz	20mV p-p max	10mV p-p max
With External Trim	5mV p-p	•
Y = 0, X = 20V p-p, 10Hz	20mV p-p max	10mV p-p max
With External Trim	5mV p-p	•
FREQUENCY RESPONSE		
-3dB, Small Signal	250kHz	•
Full Power Response	25kHz	•
Slew Rate	2V/μs	•
1% Amplitude Error	30kHz	•
1% Vector Error (0.57°)	2kHz	•
Overload Recovery Time	5μs	•
Settling Time, ±1%, 20V Step	10μs	•
Settling Time, ±0.1%, 20V Step	20μs	•
RATED OUTPUT[2]		
Voltage, 2kΩ Load	±10V min	•
Current	±5mA min	•
Impedance	0.1Ω	•
Load Capacitance	0.01μF min	•
OUTPUT NOISE		
Voltage, 10Hz to 10kHz	250μV rms	•
Voltage, 10Hz to 1MHz	1mV rms	•
INPUT RESISTANCE		
X Input Terminal	100kΩ	•
Y Input Terminal	100kΩ	•
Z Input Terminal	70kΩ	•
INPUT BIAS CURRENT		
X Input Terminal	50nA	•
vs. Temperature, 0 to +70°C	50pA/°C	•
Y Input Terminal	100nA	•
vs. Temperature, 0 to +70°C	100pA/°C	•
Z Input Terminal	70μA	•
vs. Temperature, 0 to +70°C	5nA/°C	•
MAXIMUM INPUT VOLTAGE		
For Rated Accuracy, X, Y, Z Terminals	±10V	•
Safe Input Level	$\pm V_S$	•
POWER SUPPLY[3]		
Voltage, Rated Performance	±15V	•
Voltage, Operating	±(12 to 18)V	•
Current, Quiescent	±8mA	•
TEMPERATURE RANGE		
Rated Performance	0 to +70°C	•
Operating	-25°C to +85°C	•
Storage	-55°C to +125°C	•
MECHANICAL		
Case Size	1.65" x 3.07" x 0.65"	•
Weight, grams	85	•
Mating Socket	AC1023	•

*Specifications same as model 435J.

[1] Accuracy is guaranteed with no external trim adjustments when connected in the multiplication mode. All accuracy is % of full scale output where full scale output is ±10V (±0.1% = ±10mV error).

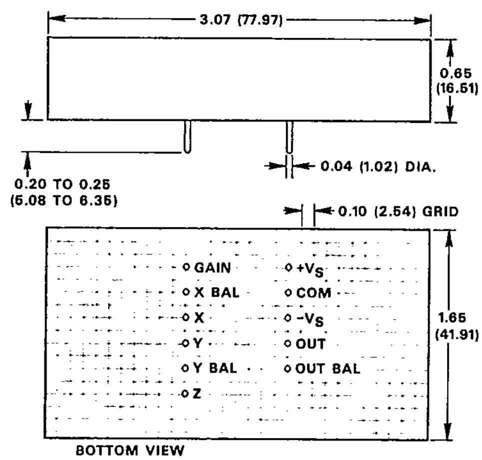
[2] Short circuit protected to ground.

[3] Recommended power supply; ADI model 904, ±15V @ 50mA output.

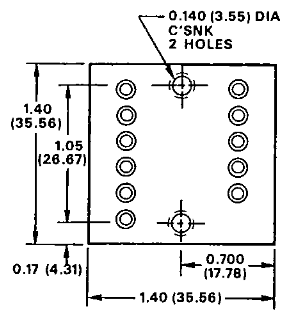
Specifications subject to change without notice.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

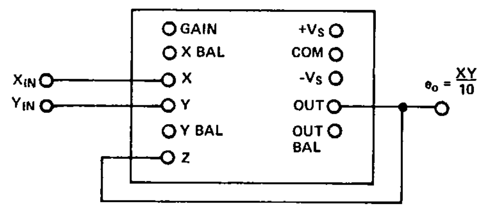


MATING SOCKET AC1023



MULTIPLIER CONNECTIONS

Bottom View



ADDITIONAL MULTIPLIERS/DIVIDERS

Analog Devices manufactures a wide array of modules to fill almost any multiplier/divider design need. A list of some of these models with their salient operating features is given below. One of these devices will surely provide the optimum solution to your engineering problem.

429 - High Speed, fp = 2MHz – 1%, ½% Accuracy
426 - Best Buy – 1% – Low Nonlinearity and Feedthrough
436 - High Accuracy 2-Quadrant Divider
434 - High Accuracy 1-Quadrant Divider, Square Rooter

NONLINEAR CIRCUITS HANDBOOK

The Nonlinear Circuits Handbook, available from Analog Devices, is an invaluable source of information on principles, circuitry, performance specifications, testing and application of the class of devices designed for use in nonlinear applications. This text provides you with all the fundamentals and guidelines necessary for the proper selection and use of function modules.

Applying the Multiplier, Divider, Square Rooter

(continued from page 1)

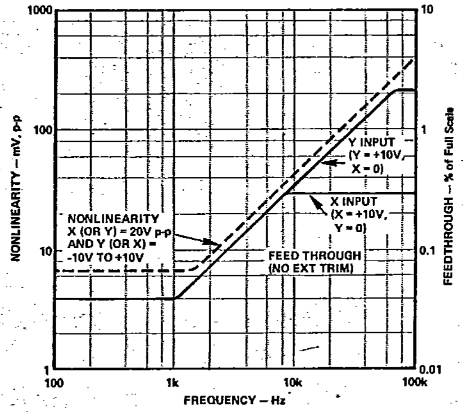


Figure 1. Feedthrough and Nonlinearity vs. Frequency.

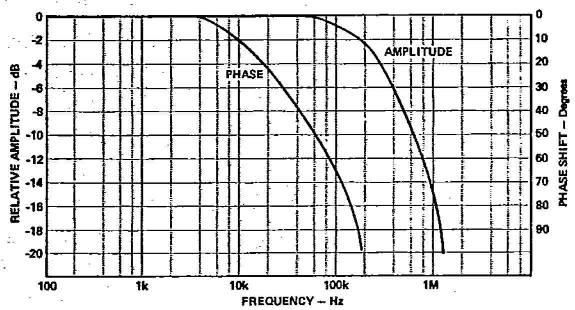


Figure 2. Amplitude and Phase vs. Frequency

OPTIONAL TRIM – MULTIPLY MODE

As shipped, the multiplier meets its listed specifications without the use of any external trim potentiometers. Terminals are provided for optional feedthrough and offset adjustments. Using these adjustments overall static multiplication error may be reduced to only 0.08% (435J). The 20kΩ trim potentiometers should be connected as shown in Figure 3.

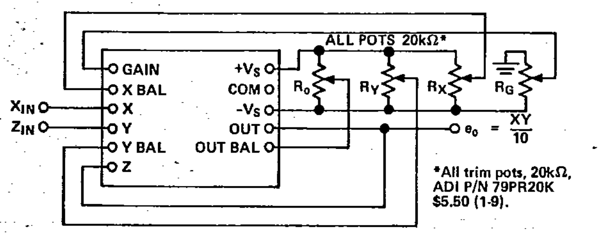


Figure 3. Multiplier Connections

NOTE: Allow unit to warm up for 5 minutes before making adjustments.

ADJUSTMENT PROCEDURE FOR OFFSET

1. Jumper X input and Y input to ground.
2. Adjust R_0 for an output of zero volts.
3. Remove jumper from X and Y inputs.

ADJUSTMENT PROCEDURE FOR FEEDTHROUGH

1. Jumper Y input to ground and apply 20 VPP at 1kHz to X input.
2. Adjust R_Y for minimum output voltage.
3. Remove jumper from Y input.
4. Jumper X input to ground and apply 20 VPP at 1kHz to Y input.
5. Adjust R_X for minimum output voltage.
6. Remove jumper from X terminal.

ADJUSTMENT PROCEDURE FOR GAIN

1. Set X and Y inputs to +10.000V dc (tie X and Y inputs together).
2. Adjust gain pot for desired output level (10.00V dc ±1%).

DIVISION

Model 435 has a wide bandwidth and excellent linearity which allows it to achieve very high performance in divider applications in the dc to 250kHz region. Restrictions and limitations imposed on divider operation and the contribution of error terms are illustrated in the discussion below.

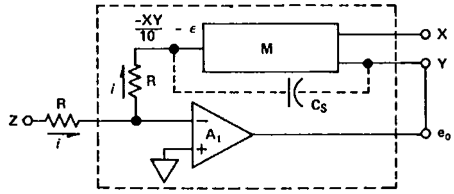


Figure 4. Divider Model

The expression for divider operation can be written:

$$e_o = \underbrace{\frac{10Z}{X}}_{\text{Ideal Division}} - \underbrace{\frac{10E}{X}}_{\text{Error Term}}$$

where E represents the errors associated with the divider.

Breaking E into its component parts, e_o can be expressed as follows:

$$e_o = \underbrace{\frac{10Z}{X}}_{\text{ideal divider}} - \underbrace{\frac{10E_{NV}}{X}}_{\text{noise error}} - \underbrace{\frac{10E_{OS}}{X}}_{\text{offset error}} - \underbrace{\frac{10E_{OS}/^\circ C}{X}}_{\text{offset drift error}} - \underbrace{\frac{10E_{NLX}}{X}}_{\text{X nonlinearity error}} - \underbrace{\frac{10E_{NLY}}{X}}_{\text{Y nonlinearity error}}$$

All of these errors, both static errors and signal dependent errors, are inversely proportional to the denominator signal level. Figure 5 shows the inverse relationship of output voltage noise vs. denominators for the 435 in the divider mode.

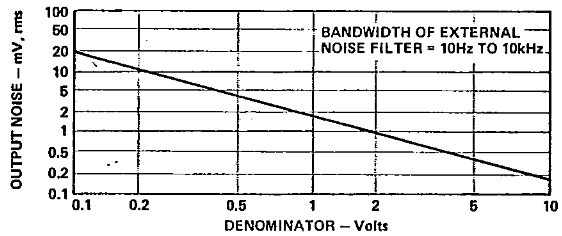


Figure 5. Output Voltage Noise vs. Denominator-Divide Mode

Signal dependent errors are the X and Y nonlinearities. It is important to use the terminal with the largest nonlinearity for the denominator. Since E_{NLX} and E_{NLY} can be expressed as a percentage of the input signal, it can be seen, in the error terms

$$\frac{-10E_{NLX}}{X} \text{ and } \frac{-10E_{NLY}}{X}$$

that the effect of X nonlinearities are practically independent of signal and may be trimmed out.

Bandwidth is also degraded with a decrease in denominator level, due to the increase in system gain;

i.e.) for X = Z = 1V, e_0 = 10V

$$\text{and } \frac{e_0}{Z} = \frac{10}{1} = 10$$

Since the gain bandwidth product is constant, a bandwidth 1/10 of that obtained for full scale denominator levels will be obtained for division at 1V levels.

For other denominator levels, bandwidth is determined by:

$$\text{B.W.} = \frac{\text{Denominator Level}}{\text{Full Scale Denominator}} \times (\text{Multiplier B.W.})$$

Before selecting a multiplier/divider for divide applications, errors resulting from the lowest anticipated denominator signal should be considered. After such considerations have been made one can further appreciate the importance of starting with an accurate, high speed multiplier such as model 435K. It is also highly recommended that the optional trim procedure for division be performed.

OPTIONAL TRIMMING – DIVIDE MODE

Connections are made as shown in Figure 6.

NOTE: Allow unit to warm up for 5 minutes before making adjustments.

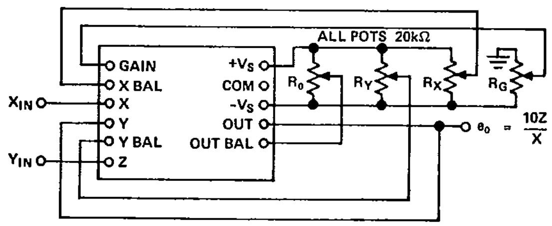


Figure 6. Divider Connections

The suggested trim procedure is (starting with centered adjustments):

*1. With Z = 0, trim R_0 to hold output constant, as X is varied from −10V toward −1.0V.
2. With Z = 0, trim R_Y for zero at X = −10V.
3. With Z = X and/or Z = −X, trim R_X for minimum worst-case variation as X is varied from −10V to −1.0V.
4. Repeat 1 and 2 if step 3 required large initial adjustment.
5. With Z = X = 1.00V (tie Z and X inputs together) adjust R_g for desired output (10.0V ±1%).

*For best accuracy X should be allowed to vary from −10V to lowest expected denominator.

SQUARE ROOTING

When connected as shown in Figure 7, the model 435 will provide the square root of Z_{IN}.

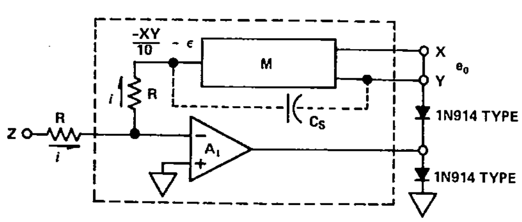


Figure 7. Square Root Model

By summing currents at the op amp's summing junction

$$\frac{Z}{R} = \frac{XY}{10R} + \frac{\epsilon}{R} = \frac{Y^2}{10R} + \frac{\epsilon}{R}$$

where ϵ represents all errors associated with the multiplier. Solving for the output voltage, Y,

$$e_0 = \pm\sqrt{10\,(Z - \epsilon)}$$

There are two values of e_0 for every value of Z. However, only negative values of e_0 will provide the negative feedback necessary for circuit stability. To restrict the output from going positive, diodes are connected as shown in Figure 7. The output is then:

$$e_0 = -\sqrt{10\,(Z - \epsilon)}$$

Errors, ϵ, associated with the multiplier, are inside the square root and consequently their effect, for large values of Z, is reduced. The reason for the improved performance can be seen by inspecting the circuit. The output is fed back to both the X and Y terminals, resulting in twice the feedback.

OPTIONAL ADJUSTMENT PROCEDURE – SQUARE ROOT

1. Apply a voltage to the Z terminal equal to the lowest anticipated input voltage.
2. Adjust R_0 such that $e_0 = -\sqrt{10Z_{IN}}$ where Z_{IN} is the voltage applied in step 1.

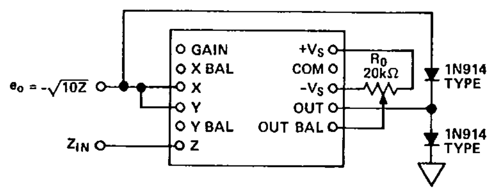


Figure 8. Square Root Connections

DIVISION SPECIFICATIONS (TYPICAL, TRIMMED)

OUTPUT FUNCTION	10(Z)/X
Numerator Range	±10V
Denominator Range, 0.1% Accuracy	-1V to -10V
Denominator Range, 1% Accuracy	-0.1V to -10V
Bandwidth Formula, (-3dB)	(X/10) 300kHz

SQUARE ROOTING SPECIFICATIONS (TYPICAL, TRIMMED)

OUTPUT FUNCTION	$-\sqrt{10(Z)}$
Dynamic Range	1000 to 1 (+0.010V ⩽Z⩽+10V)
Accuracy (% of Full Scale)	0.1%
Bandwidth Formula, (-3dB)	(300kHz) $\sqrt{\lvert X\rvert/10}$

Table 1. Division & Square Rooting Specifications

C225a–10–8/80

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