Internally Trimmed Integrated Circuit Divider

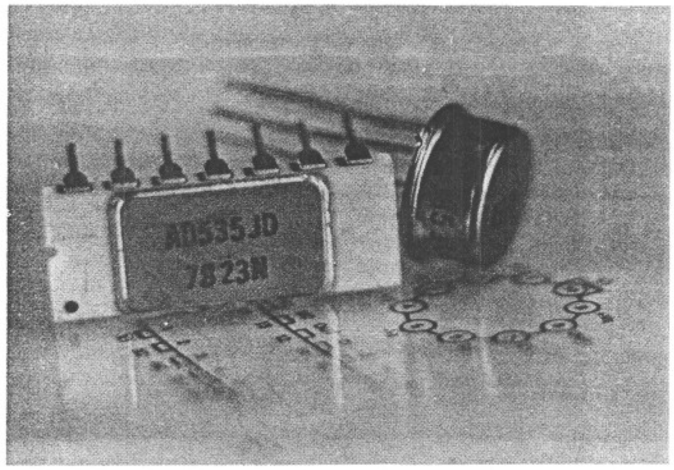
AD535

FEATURES

Pretrimmed to ±0.5% max Error, 10:1 Denominator Range (AD535K)
±2.0% max Error, 50:1 Denominator Range (AD535K
All Inputs (X, Y and Z) Differential
Low Cost, Monolithic Construction

APPLICATIONS

General Analog Signal Processing
Differential Ratio and Percentage Computations
Precision AGC Loops
Square-Rooting



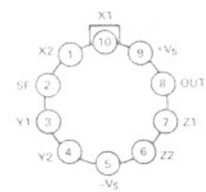
PRODUCT DESCRIPTION

The AD535 is a monolithic laser trimmed two-quadrant divider having performance specifications previously found only in expensive hybrid or modular products. A maximum divider error of ±0.5% is guaranteed for the AD535K without any external trimming over a denominator range of 10:1, ±2.0% max error over a range of 50:1. A maximum error of ±1% over the 50:1 denominator range is guaranteed with the addition of two external trims. The AD535 is the first divider to offer fully differential, high impedance operation on all inputs, including the z-input, a feature which greatly increases its flexibility and ease of use. The scale factor is pretrimmed to the standard value of 10.00; by means of an external resistor, this can be reduced by any amount down to 3.

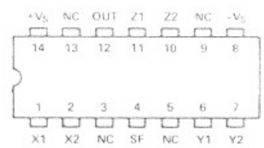
The extraordinary versatility and performance of the AD535 recommend it as the first choice in many divider and computational applications. Typical uses include square-rooting, ratio computation "pin-cushion" correction and AGC loops as illustrated in the applications section of the data sheet. The device is packaged in a hermetically sealed, 10-pin TO-100 can or 14-pin TO-116 DIP and made available in a ±1% max error version (J) and a ±0.5% max error version (K). Both versions are specified for operation over the 0 to +70°C temperature range.

PRODUCT HIGHLIGHTS

1. Laser trimming at the wafer stage enables the AD535 to provide high accuracies without the addition of external trims (±0.5% max error over a 10:1 denominator range for the AD535K).
2. Improved accuracies over a wider denominator range are possible with only two external trims (±0.5% max error over a 20:1 denominator range for the AD535K).
3. Differential inputs on the X, Y and Z input terminals enhance the AD535's versatility as a generalized analog computational circuit.
4. Monolithic construction permits low cost and, at the same time, increased reliability.



TO-100
(TOP VIEW)



TO-116
(TOP VIEW)

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Tel: 617/329-4700 TWX: 710/394-6577
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SPECIFICATIONS ($V_S = \pm15V$, $R_L \geq 2k\Omega$, $T_A = +25°C$ unless otherwise stated)

PARAMETER	CONDITIONS	AD535J	AD535K
TRANSFER FUNCTION	Figure 2	$10\frac{(Z_2 - Z_1)}{(X_1 - X_2)} + Y_1$	*
TOTAL ERROR[1]	No External Trims, Figure 2		
	$1V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	1.0% max	0.5% max
	$0.2V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	5.0% max	2.0% max
	With External Trims, Figure 5		
	$0.5V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	1.0% max	0.5% max
	$0.2V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	2.0% max	1.0% max
TEMPERATURE COEFFICIENT	$1V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	0.01%/°C typ	*
	$0.5V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	0.02%/°C typ	*
	$0.2V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	0.05%/°C typ	*
SUPPLY RELATED	$1V \leq X \leq 10V$	0.1%/V typ	*
Error	$0.5V \leq X \leq 10V$	0.2%/V typ	*
$V_S = \pm14V$ to $\pm16V$	$0.2V \leq X \leq 10V$	0.5%/V typ	*
SQUARE ROOTER	No External Trims, Figure 11		
TOTAL ERROR[1]	$1V \leq Z \leq 10V$	0.4% typ	*
	$0.2V \leq Z \leq 10V$	0.7% typ	*
NOISE[2]	X = 0.2V, f = 10Hz to 10kHz	4.5mV rms typ	*
BANDWIDTH	X = 0.2V	20kHz typ	*
INPUT AMPLIFIERS[3]			
CMRR	f = 50Hz, 20V p-p	60dB min	*
Bias Current		2.0μA max	*
Offset Current		0.1μA typ	*
Differential Resistance		10MΩ typ	*
OUTPUT AMPLIFIER[3]			
Open-Loop Gain	f = 50Hz	70dB typ	*
Small Signal Gain-Bandwidth	$V_{OUT} = 0.1V$ rms	1MHz typ	*
1% Amplitude Error	$C_{LOAD} = 1000pF$	50kHz typ	*
Output Voltage Swing	T_{min} to T_{max}	±11V min	*
Slew Rate	$V_{OUT} = 20V$ p-p	20V/μs typ	*
Settling Time	$V_{OUT} = 20V \pm1\%$	2μs typ	*
Output Impedance	Unity Gain, $f \leq 1kHz$	0.1Ω typ	*
Wide-band Noise	f = 10Hz to 5MHz	1mV rms typ	*
	f = 10Hz to 10kHz	90μV rms typ	*
OUTPUT CURRENT	T_{min} to T_{max}, $R_1 = 0$	30mA max	*
POWER SUPPLIES			
Rated Performance		±15V	*
Operating		±8V min, ±18V max	*
Supply Current	Quiescent	6mA max	*

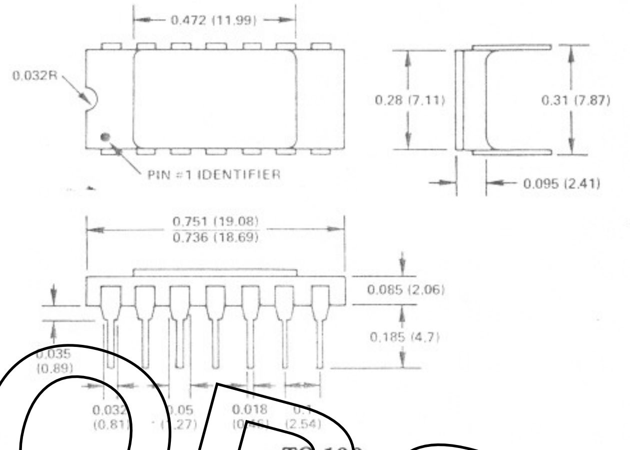
NOTES:
*Specifications same as AD535J.
[1] Figures are given as a percent of full scale (i.e. 1.0% = 100mV).
[2] Noise may be reduced as shown in Figure 14.
[3] See Figure 1 for definition of section.

Specifications subject to change without notice.

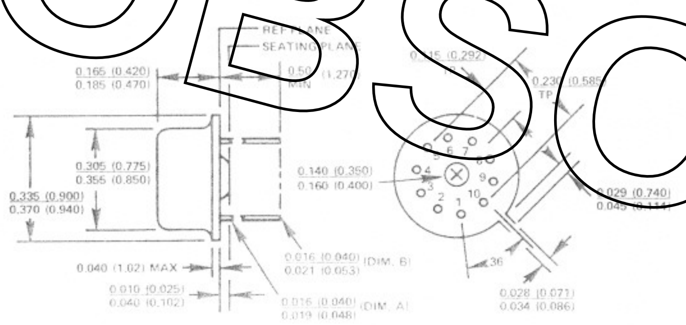
PHYSICAL DIMENSIONS

Dimensions shown in inches and (mm).

TO-116



TO-100



ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±18V
Internal Power Dissipation	500mW
Output Short-Circuit to Ground	Indefinite
Input Voltages, X_1, X_2, Y_1, Y_2, Z_1, Z_2	$\pm V_S$
Rated Operating Temp Range	0 to +70°C
Storage Temp Range	–65°C to +150°C
Lead Temp, 60s soldering	+300°C

PRICING

	1–24	25–99	100–999
AD535JH	\$26.00	\$21.00	\$16.00
AD535JD	\$30.00	\$25.00	\$20.00
AD535KH	\$36.00	\$30.00	\$24.00
AD535KD	\$41.00	\$35.00	\$29.00

FUNCTIONAL DESCRIPTION

Figure 1 is a functional block diagram of the AD535. Inputs are converted to differential currents by three identical voltage to current converters, each trimmed for zero offset. The product of the X and Y currents is generated by a multiplier cell using Gilbert's translinear technique with an internal scaling voltage.

The difference between XY/SF and Z is applied to the high gain output amplifier. The transfer function can then be expressed...

$$V_{OUT} = A\left[\frac{(X_1 - X_2)(Y_1 - V_{OUT})}{SF} - (Z_1 - Z_2)\right]$$

where A = open loop gain of output amplifier, typically 70dB at dc

X, Y, Z = input voltages

SF = scale factor, pretrimmed to 10.00V but adjustable by the user down to 3V.

In most cases the open loop gain can be regarded as infinite and SF will be 10V. Dividing both sides of the equation by A and solving the V_{OUT}, we get...

$$V_{OUT} = 10V\frac{(Z_2 - Z_1)}{(X_1 - X_2)} + Y_1$$

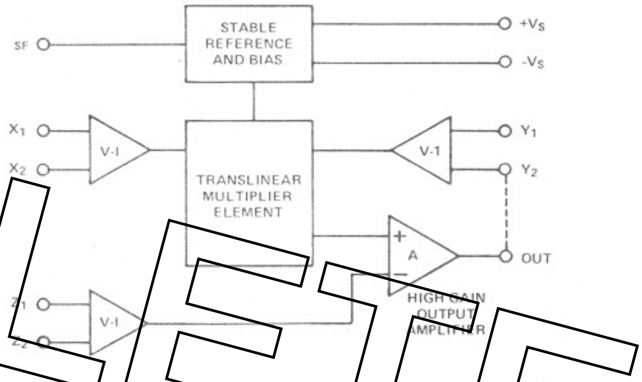


Figure 1. AD535 Functional Block Diagram

SOURCES OF ERROR

Divider error is specified as a percent of full scale (i.e. 10.00V) and consists primarily of the effects of X, Y and Z offsets and scale factor (which are trimmable) as shown in the generalized equation....

$$V_{OUT} = (SF + \Delta SF)\left[\frac{(Z_2 - Z_1) + Z_{OS}}{(X_1 - X_2) + X_{OS}}\right] + Y_1 + Y_{OS}$$

Note especially that divider error is inversely proportional to X, that is, the error increases rapidly with decreasing denominator values. Hence, the AD535 divider error is specified over several denominator ranges on page 2. (See also Figure 12, AD535 Total Error as a function of denominator values.)

Overall accuracy of the AD535 can be significantly improved by nulling out X and Z offset as described in the applications sections. Figure 13 illustrates a factor of 2 improvement in accuracy with the addition of these external trims. The remaining errors stem primarily from scale factor error and Y offsets which can be trimmed out as shown in Figure 6.

Figure 14 illustrates the bandwidth and noise relationships versus denominator voltage. Whereas noise increases with decreasing denominator, bandwidth decreases, the net result given by the expression...

$$En_{OUT}\text{ (wideband)} = \frac{1.26}{\sqrt{\left(\frac{X}{10}\right)}}\ \text{mV rms}$$

External filtering can be added to limit output voltage noise even further. In this case...

$$En_{OUT}\ (\text{B.W. externally limited}) = \frac{0.9\sqrt{f}}{\left(\frac{X}{10}\right)}\ \text{mV rms}$$

where f = bandwidth in MHz of an external filter whose bandwidth is less than the noise bandwidth of the AD535. Table 1 provides calculated values of the typical output voltage noise, both filtered and unfiltered for several denominator values.

X	Noise 10Hz to 5MHz	Noise Limited by External Filtering 10Hz to 10kHz
0.2V	8.9mV rms	4.5mV rms
0.5V	5.6mV rms	1.8mV rms
1V	4.0mV rms	0.9mV rms
10V	1.3mV rms	0.09mV rms

Table 1. AD535 Calculated Voltage Noise

APPLICATIONS

Figure 2 shows the standard divider connection without external trims. The denominator X, is restricted to positive values in this configuration. X, Y and Z inputs are differential with high (80dB typical) CMRR permitting the application of differential signals on X and Z (see Figure 3).

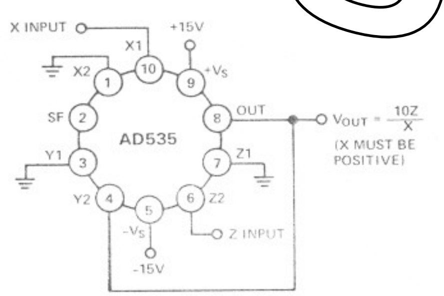


Figure 2. Divider Without External Trims

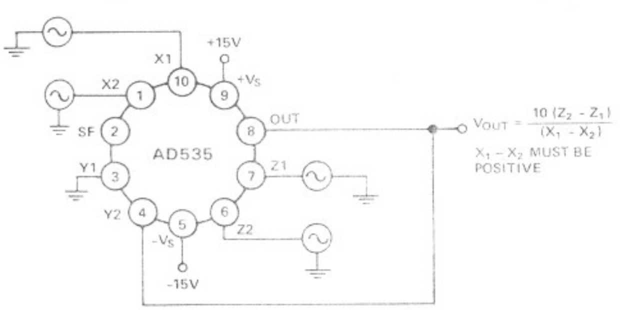


Figure 3. Differential Divider Connection

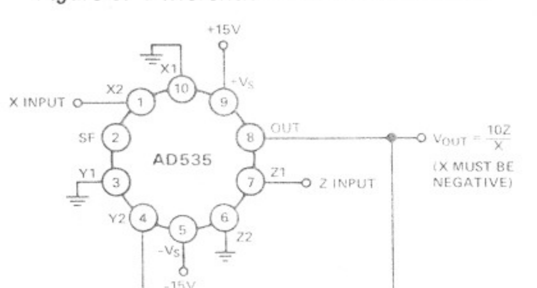


Figure 4. Divider Connection for Negative X Inputs

Negative denominator inputs are handled as shown in Figure 4. Note that in either configuration, operation is limited to two quadrants (i.e. Z is bipolar, X is unipolar).

A factor of two improvements in accuracy is possible by trimming the X and Z offsets as illustrated in Figure 5. To trim, set X to the smallest denominator value for which accurate computation is required (i.e., X = 0.2V). With Z = 0, adjust the Z_O trim for $V_{OUT} = 0$. Next, adjust the X_O trim for the best compromise when Z = +X (V_{OUT} = +10V) and Z = –X (V_{OUT} = –10V). Finally, readjust Z_O for the best compromise at Z = +X, Z = –X and Z = O. The remaining error (Figure 13) consists primarily of scale factor error, output offset and an irreducible nonlinearity component.

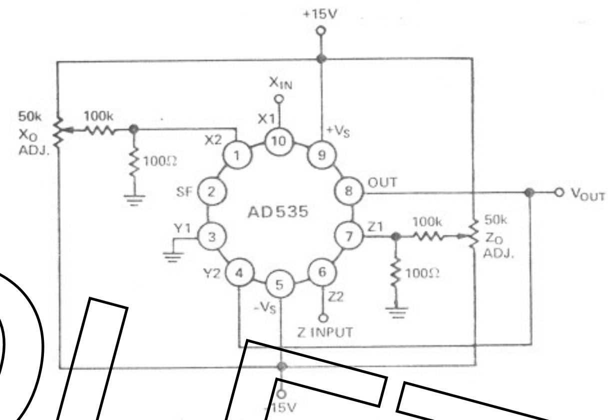


Figure 5. Precision Divider Using Two Trims

In certain applications, the user may elect to adjust SF for values between 10.00 and 3 by connecting an external resistor in series with a potentiometer between SF and $-V_S$. The approximate value of the total resistance for a given value of SF is given by the relationship:

$$R_{SF} = 5.4K\,\frac{SF}{10 - SF}$$

Due to device tolerances, allowance should be made to vary R_{SF} ±25% using the potentiometer. Note that the peak signal is always limited to 1.25 SF (i.e. ±5V for SF = 4).

The scale factor may also be adjusted using a feedback attenuator between V_{OUT} and Y2 as indicated in Figure 6. The input signal range is unaffected using this scheme.

Scale factor and output offset error can be minimized utilizing the four trim circuit of Figure 6. Adjustment is as follows:

1. Apply X = +0.2V (or the smallest required denominator value), Z = 0 and adjust Z_O for $V_{OUT} = 0$.
2. Apply X = 0.2V. Then adjust the X_O trim for the best compromise when Z = +X (V_{OUT} = +10V) and Z = –X (V_{OUT} = –10V.)
3. Apply X = +10V, Z = 0 and adjust Y_O for $V_{OUT} = 0$.
4. Apply X = +10V. Then adjust the scale factor (SF) trim for the best compromise when Z = +X (V_{OUT} = +10V) and Z = –X (V_{OUT} = –10V).
5. Repeat steps 1 and 2.
6. Apply X = 0.2V. Then adjust the Z trim for the best compromise when Z = X (V_{OUT} = +10V), Z = 0 (V_{OUT} = 0) and Z = –X (V_{OUT} = –10V).

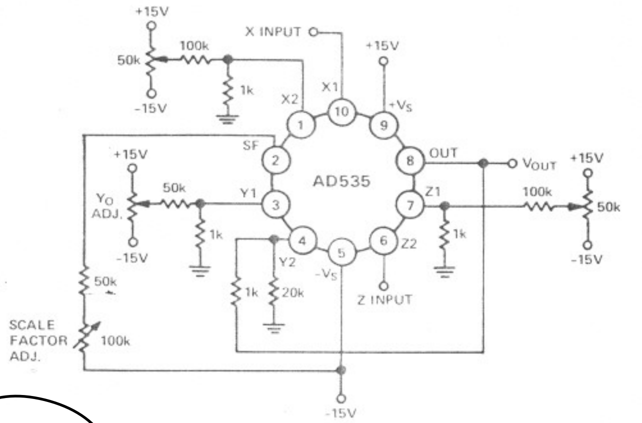


Figure 6. Precision Divider with Four External Adjustments

These trim adjustments can be made either by using two calibrated voltage sources and a DVM, or by using a differential scope, a low frequency generator, a voltage source and a precision attenuator. As shown in Figure 7, the differential scope subtracts the expected ideal output and thus displays only errors. Set the attenuation to $\frac{X}{10}$.

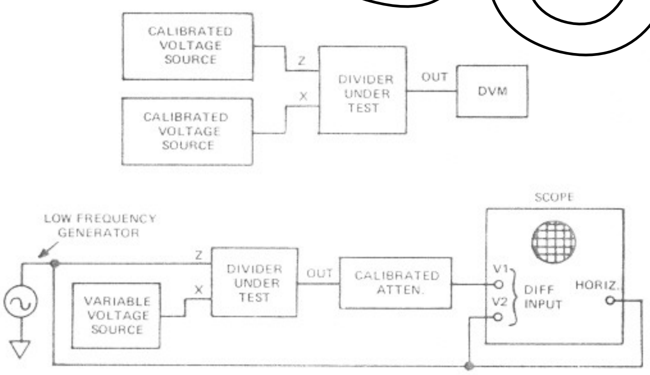


Figure 7. Alternate Trim Adjustment Set-Up

PIN-CUSHION CORRECTION

A pin-cushion corrector eliminates the distortion caused by flat screen CRT tubes. The correction equations are:

$$V_{OH} = \frac{V_{IH}}{\sqrt{V_{IH}^2 + V_{IV}^2 + L^2}}$$

$$\text{and} \quad V_{OV} = \frac{V_{IV}}{\sqrt{V_{IH}^2 + V_{IV}^2 + L^2}}$$

where: V_{OH} and V_{OV} are the horizontal and vertical output signals, respectively.

V_{IH} and V_{IV} are the horizontal and vertical input signals, respectively.

L is the length of the CRT tube.

In typical applications L (expressed in voltage) is roughly equal to full scale V_{IH} or V_{IV}. The result is that the expression, $\sqrt{(V_{IH}^2 + V_{IV}^2 + L^2)}$, varies less than 2:1 over the full range of values of V_{IH} and V_{IV}.

Major sources of divider error associated with small denominator values can thereby the minimized.

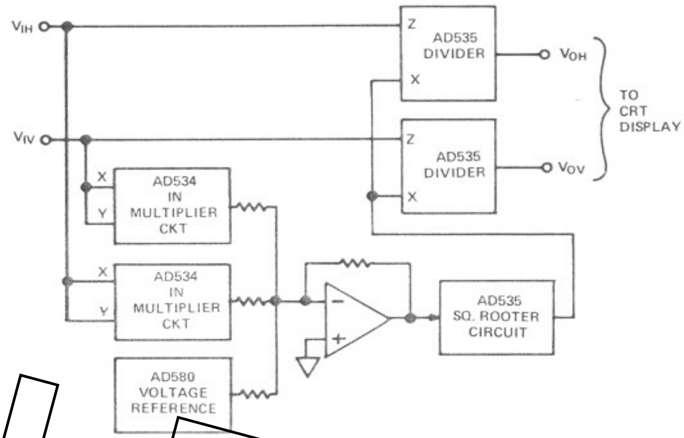


Figure 8. Pin-Cushion Corrector

Figure 9 shows an AGC loop using an AD535 divider. The AD535 lends itself naturally in this application since it is configured to provide gain rather than loss. Overall gain varies from 1 to ∞ as the denominator is servoed to maintain V_{OUT} at a constant level.

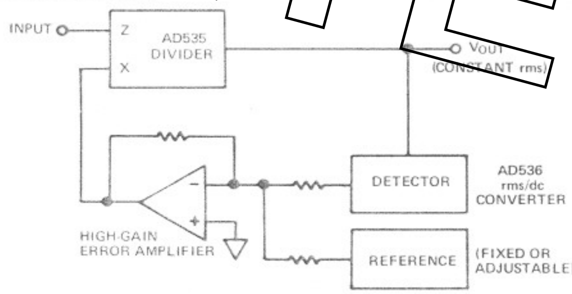


Figure 9. AGC Loop Using the AD536 rms/dc Converter as a Detector

Figure 10 shows a method for obtaining the time average as defined by:

$$\overline{X} = \frac{1}{T}\int_0^T X\,dt$$

where T is the time interval over which the average is to be taken. Conventional techniques typically provide only a crude approximation to the true time average, and furthermore, require a fixed time interval before the average can be taken. In Figure 10, the AD535 is used to divide the integrator output by the ramp generator output. Since the ramp is proportional to time, the integrator is divided by the time interval, thus allowing continuous, true time processing of signals over intervals varying by as much as 50:1.

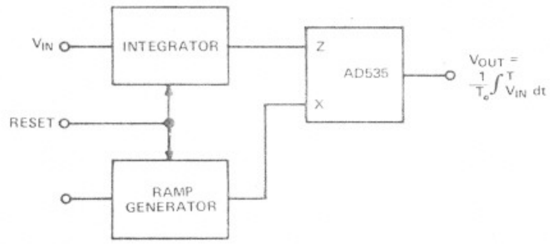


Figure 10. Time Average Computation Circuit

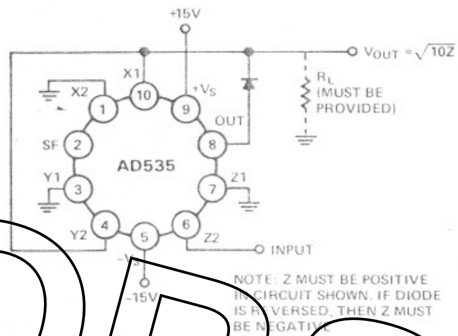


Figure 11. Square Rooter

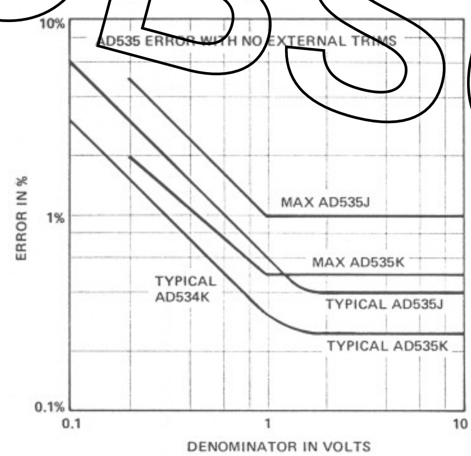


Figure 12. AD535 Error with No External Trims

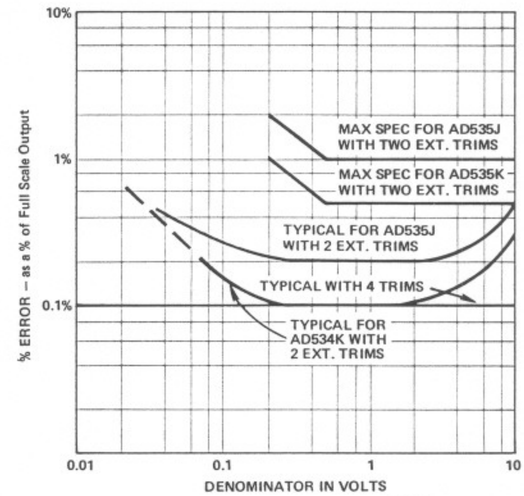


Figure 13. Errors with External Trims at 25°C

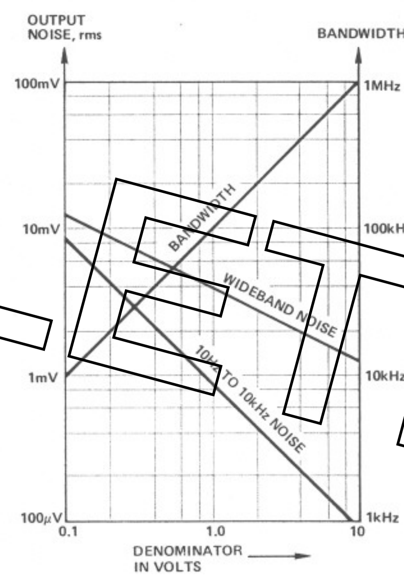


Figure 14. –3dB Bandwidth and Noise vs. Denominator

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