CARE AND FEEDING AND A LITTLE THEORY

Even the most-carefully designed multiplier is at the mercy of its circuit surroundings. Evaluate the power supply and its distribution scheme in your circuit. Choose a well-regulated, low output-impedance supply (yes, the manufacturer's spec says 0.00001Ω output impedance, but what does it look like at 350kHz?) Is the supply immune to fast transients or do they sail through to the output? If you're working from a switching supply, is the noise specification adequate for your application?

Observe good grounding techniques. There is nothing wrong with "bussed" grounds if the rules and limitations of the game are understood. Single-point grounding is required in a high-accuracy system, *especially* when high- and low-current returns exist in the circuit. Any high currents returning from a load should be grounded directly at the supply, not tied together with an input reference ground and 17 other points before returning "home".

Bypass capacitors are always in order. A high-speed device like the 429, albeit internally bypassed, seems by its nature to demand bypassing; but plenty of trouble can come from a "slower" 750kHz AD532 that has been incited to riot by poorly bypassed supply lines. Normally, well-designed multipliers are very forgiving of improperly bypassed supplies, but prudence is always in order. Aluminum electrolytics are fine, but they must be shunted with $0.01\mu F$ disc capacitors if there is to be any hope of high-frequency functioning. High-speed devices driving heavy or dynamically varying loads often require a "flywheel," especially if they are located some distance from the power supply. In these cases, solid tantalum capacitors are a good choice for the bypassing service. When using solid tantalum capacitors, the $0.01\mu F$ disc shunt may (or may not) be deleted. (This is a matter which arouses passionate debate in some circles, but if your name is going on the schematic, the disc shunt is recommended.) Offset and scaling adjustments will sometimes be desirable. Keep the wire lengths between the pots and the IC or module as short as possible. Components directly associated with the multiplier should also be mounted near it. As frequency goes up, this becomes even more important. Choose components with care. A poor grade of trim potentiometer used to set the scale factor on an AD534 externally (SF pin) can introduce more error (due to mechanical vibration, temperature, humidity, etc.) than the multiplier itself.

The dynamics of multipliers are governed by the same counsel as those of operational amplifiers. Phase shift, slewing rate, settling time, load considerations, etc., are all very real issues and must be addressed by manufacturer (we do our best!) and user alike. When putting things inside the AD534's feedback path, it's good to remember that the thing is going to oscillate if your addition has 137° of phase shift in it.

A LITTLE THEORY

Now that we have seen the many things multipliers can do . . . how do they work? We will discuss here the design technique most widely used—and characteristic of such IC types as the AD534, AD532, AD531, etc. It is variously known as the "transconductance technique," the translinear circuit, the Gilbert Cell, etc. It is described in some detail in several of the references at the end of this section.

The transconductance multiplier is conceptually simple. One input controls the gain of an active (FET, vacuum tube, transistor) device, which amplifies the other input in proportion to the control input. Almost all transconductance multipliers in production today use transistors as the active element, because of their linear, consistent relationship between collector current and transconductance, and because they are so easy to fabricate in matched thermally tracking sets on IC chips.

A four-quadrant transconductance multiplier consists of a set of matched current sources, a set of voltage-to-current converters, to convert the X, Y, (and, in the case of the AD534, Z) input voltages to linearly related currents, a 6-transistor multiplying "cell" that produces two currents whose difference is proportional to the product of the input voltages, and a differential-input amplifier that converts the difference current to a single-ended output voltage.

These elements, with the exception of the output amplifier and its feedback circuit, which are omitted for clarity, can be seen in Figure 62. The matched current sources are all labeled "I"; the X input voltage is applied at the bases of QA and QB, generating a proportional difference current in R_X; the Y input voltage is applied at the bases of QC and QD, generating a proportional difference current in R_Y; the multiplying cell consists of diode-connected transistors Q1 and Q2, plus the four transistors Q3, Q4, Q5, Q6. The output difference current is equal to the sum of $I_3 + I_5$, less the sum of $I_4 + I_6$.

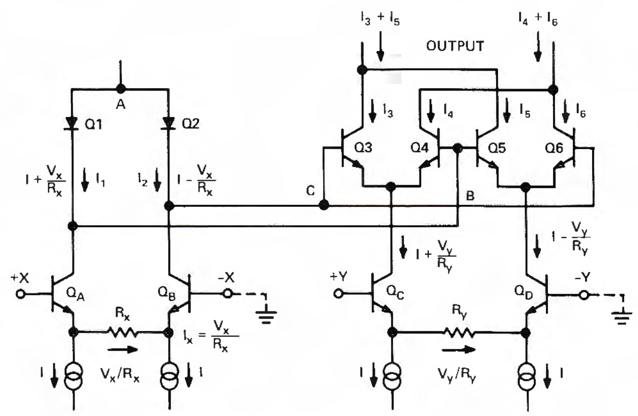

Figure 62. Basic 4-quadrant variable-transconductance multiplier circuit

In order to explain how this multiplier operates, let us first define the more-obvious relationships among the currents. By inspection of the figure,

$$I_1 = I + V_X/R_X \tag{1}$$

$$I_2 = I - V_X/R_X \tag{2}$$

$$I_3 + I_4 = I + V_y/R_y \tag{3}$$

$$I_5 + I_6 = I - V_y/R_y \tag{4}$$

The assumptions throughout will be similar geometries, infinite β, no series or shunt resistance, and isothermal operation.

Following the loop A–B–C–A via Q1, Q4, Q3, Q2,

$$V_{Q1} + V_{beQ4} = V_{beQ3} + V_{Q2} \tag{5}$$

Then, since

$$V_{beQi} \cong \frac{kT}{q} \ln \frac{I_i}{I_{ceo}} \tag{6}$$

equation (5) can be boiled down to

$$\ln I_{Q_1} + \ln I_{Q_4} = \ln I_{Q_3} + \ln I_{Q_2} \tag{7}$$

Therefore,

$$I_1 I_4 = I_3 I_2 \tag{8}$$

Similarly, for loop A–B–C–A via Q1, Q5, Q6, Q2,

$$I_1 I_5 = I_6 I_2 \tag{9}$$

As noted earlier, the output current is

$$I_o = I_3 + I_5 - (I_4 + I_6) \tag{10}$$

Substituting the relationships (8) and (9) in (10),

$$I_o = I_3 + I_6 I_2 / I_1 - I_3 I_2 / I_1 - I_6 \tag{11}$$

$$= I_3 (I_1 - I_2)/I_1 - I_6 (I_1 - I_2)/I_1$$

$$= (I_3 - I_6)(I_1 - I_2)/I_1 \tag{12}$$

Substituting (1) and (2) for I_1 and I_2 in the numerator of (12),

$$I_o = (I_3 - I_6)(2V_X/R_X)/I_1 \tag{13}$$

From (8) and (3), we can see that

$$I_4 = \frac{I_3 I_2}{I_1} = I + \frac{V_y}{R_y} - I_3 \tag{14}$$

Hence, we can solve for I_3,

$$I_3 = \frac{I_1 I + I_1 V_y / R_y}{I_1 + I_2} = \frac{I_1 I + I_1 V_y / R_y}{2I} \tag{15}$$

Similarly, from (9) and (4), we can see that

$$I_5 = \frac{I_6 I_2}{I_1} = I - \frac{V_y}{R_y} - I_6 \tag{16}$$

Solving for I_6,

$$I_6 = \frac{I_1 I - I_1 V_y / R_y}{2I} \tag{17}$$

Substituting (15) and (17) in (13) and simplifying,

$$I_o = \frac{2 I_1 V_y / R_y}{2I} \cdot \frac{2V_X / R_X}{I_1}$$

$$= 2 \frac{V_X V_y}{I R_X R_y} \tag{18}$$

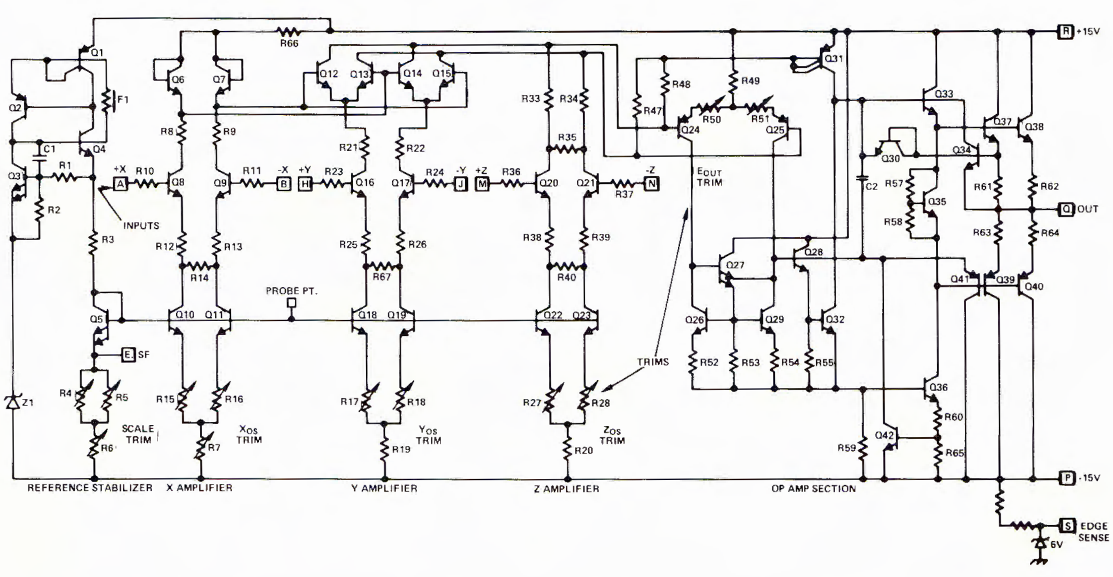

Figure 63. Schematic diagram of complete laser-trimmed multiplier (from ANALOG DIALOGUE 9-3, 1975, page 5)

Figure 63 is a complete schematic of a version of the AD534. The six-transistor multiplier cell consists of Q6, Q7, Q12, Q13, Q14, and Q15. $(R_{12} + R_{13} + R_{14})$ is analogous to R_X, $(R_{25} + R_{26} + R_{27})$ is analogous to R_Y, and $(R_{38} + R_{39} + R_{40})$ is analogous to R_Z. The difference current, $2V_Z/R_Z$, is made equal to the output current by feedback around the output amplifier. Therefore, when the "sense" feedback from E_O is to Z_1 ("+Z"), and the "reference", Z_2 ("–Z"), is at ground,

$$E_O = V_Z, \tag{19}$$

and

$$E_O = \frac{R_Z}{R_X R_Y I} V_X V_Y$$

The "trim" resistors that adjust the current sources are automatically adjusted for balanced operation – all difference currents at zero when the respective inputs are at zero – and the scale factor is automatically adjusted to $(10V)^{-1}$, by means of laser trimming at the wafer stage. A temperature-compensated buried-Zener-diode reference circuit controls the current-sources – hence the scale factor – with excellent stability against time and temperature.

A BRIEF BIBLIOGRAPHY

Note: Items are *not* available from Analog Devices unless identified by an asterisk(*).

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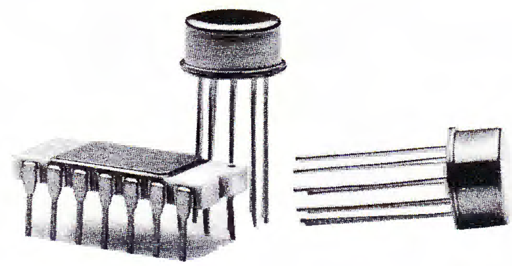
NONLINEAR CIRCUITS HANDBOOK, D. H. Sheingold, Ed., Analog Devices, Inc., 1974, 1976,* P.O. Box 796, Norwood MA 02062, $5.95

"A Precise Four-Quadrant Multiplier with Subnanosecond Response," B. Gilbert, *IEEE Journal of Solid-State Circuits*, December, 1968

TECHNICAL DATA

In this section, you will find brief descriptions and specifications of most of the multiplier/divider products mentioned in the text, extracted from the Analog Devices Short Form Guide to Electronic Products for Precision Measurement and Control. The complete Short Form Guide, containing similar information on all Analog Devices products, is available upon request. Detailed information, in the form of complete data sheets on specific products, may also be had without charge.

Computational Circuits: IC's



Analog Devices is the industry's leading supplier of Analog Computational Circuits. Utilizing the linearized transconductance technique, Analog Devices has developed a line of low cost, monolithic circuits which can multiply, divide, square and square-root analog voltage magnitudes. The most recent development is the AD535, the world's first laser-trimmed, 2-quadrant dedicated divider.

MULTIPLIER IC's

The AD531 is the first monolithic programmable multiplier/divider to provide the true transfer function $V_X \cdot V_Y/kI_Z$ without the need for an external level shifting op amp at the output. Not just a multiplier, the AD531 is truly a computation circuit that is ideally suited to such applications as automatic gain control (AGC), true rms-to-dc conversion, ratio determination and vector operations; in addition, it provides the normal mathematical functions of four-quadrant multiplication, two-quadrant division, squaring, and square rooting.

The AD532 is the first internally trimmed single chip monolithic multiplier/divider. It guarantees a maximum multiplying error of ±1.0% and a ±10V output voltage without the need for external trimming resistors or an output op amp.

The Analog Devices' AD533 is a low cost integrated circuit 4 quadrant multiplier consisting of a transconductance multiplying element, stable reference, and output amplifier on a monolithic silicon chip. Specified accuracy is achieved with feedthrough, offset, and gain trim pots.

The AD534 is the most accurate and versatile IC multiplier/divider manufactured today. Laser trimming provides accuracies up to 0.25% max error at +25°C (AD534L) and 1.0% max error from −55°C to +125°C (AD534T); and a buried Zener reference provides excellent long-term stability. In addition to the metal package, a new convenient DIP package is available.

SPECIFICATIONS (min, max @ V_S = ±15V, T_A = +25°C unless otherwise noted)

Models	AD531J(AD531K)(AD531L) (AD531S)	AD532J(AD532K) (AD532S)	AD533J(AD533K)(AD533L) (AD533S)	AD534J(AD534K)(AD534L) (AD534S)(AD534T)
Full Scale Accuracy – %	2(1)(0.5)(1)	2(1)(1)	2(1)(0.5)(1)	1(0.5)(0.25)(1)(0.5)
Divides and Square Roots	YES	YES	YES	YES
Multiplication Characteristics				
Output Function	XY/kIz	$(X_1 - X_2)(Y_1 - Y_2)/10$	XY/10	$[(X_1 - X_2)(Y_1 - Y_2)/10] + Z_2$
Accuracy vs. Temperature (±) – %/°C	0.04(0.03)(0.01)(0.02 max)	0.04(0.03)(0.04 max)	0.04(0.03)(0.01)(0.01)	0.022(0.015)(0.008) (0.02 max)(0.01 max)
Accuracy vs. Supply	0.5%/%	0.05	0.5	±0.01% ±14V to ±16V
Output Offset				
Initial	Adj. to zero	±40mV(±30mV) (±30mV)max	Adj. to zero	±30mV(±15mV)(±10mV)(±30mV) (±15mV)max
Drift – /°C	0.7(0.7)(1.0 max)(2.0 max)μV	0.7(0.7)(2.0 max)mV	0.7mV	0.2(0.1)(0.1)(0.5 max)(0.3 max)mV
Scale Factor	Dynamically Variable	Fixed	Fixed	3 to 10
Nonlinearity				
X Input (X = 20V p-p, Y = ±10V dc) – ±%	0.8(0.5)(0.3)(0.5)[1]	0.8(0.5)(0.5)	0.8(0.5)(0.5)(0.5)	0.4(0.3 max)(0.12 max)(0.4)(0.3 max)
Y Input (Y = 20V p-p, X = ±10V dc) – ±%	0.3(0.2)(0.2)(0.2)[1]	0.3(0.2)(0.2)	0.3(0.2)(0.2)(0.2)	0.01(0.1 max)(0.1 max)(0.01)(0.1 max)
Feedthrough				
X = 0, Y = 20V p-p 50Hz – mV p-p	–	150(80)(80)max	–	1(10 max)(10 max)(1)(10 max)
with External Trim – mV p-p	100(60)(30)(60)max[1]	–	150(100)(50)(100)max	–
Y = 0, X = 20V p-p 50Hz – mV p-p	–	200(100)(100)max	–	30(30 max)(12 max)(30)(30 max)
with External Trim – mV p-p	150(80)(40)(80) max[1]	–	200(100)(50)(100) max	–
Bandwidth				
-3dB Small Signal – MHz	1	1	1	1
Full Power Response - kHz	750	750	750	not spec'd
Slew Rate – V/μs	45	45	45	20
Output Characteristics				
Voltage at Rated Load (min) – V	±10	±10	±10	±11
Current (min) –mA	±5	±5	±5	±5
Input Resistance				
X/Y/Z Input – Ω	10M/6M/36k[2]	10M/10M/36k	10M/6M/36k	10M
Input Bias Current				
X/Y Input – μA	3(4 max)(2 max)(4 max)	3(4 max)(4 max)	3(7.5 max)(5 max)(7.5 max)	2 max
Power Supply (V_S)				
Rated Performance – V	±15	±15	±15	±15
Operating – V	±15 to ±18[3]	±10 to ±18[3]	±15 to ±18[3]	±8 to ±18
Quiescent Current – mA max	±6.5	±6	±6	±6
Operating Temperature Range[4]	C(C)(C)(M)	C(C)(M)	C(C)(C)(M)	C(C)(C)(M)(M)

[1] I_{REF} = full scale. [2] Sense Terminal [3] AD531S/AD532S/AD533S ±10 to ±22 [4] C: 0 to +70°C M: -55°C to +125°C [5] D: 14 Pin Ceramic Dip H: 10 Pin TO-100

RMS TO DC CONVERTER IC

A monolithic rms to dc converter, the AD536A computes the true rms value of any complex waveform without the need for external adjustment. The device utilizes a crest factor compensation scheme to achieve less than 1% error at crest factors up to 7. The AD536A is available in a new, inexpensive metal package as well as a ceramic DIP.

SPECIFICATIONS

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

Models	AD536AJ (AD536AK)(AD536AS)
Transfer Equation	$V_{OUT} = \sqrt{avg. (V_{IN})^2}$
Conversion Accuracy	
Total Error	
Input: 0 to $7V_{rms}$	±5mV ±0.5%(±2mV ±0.2%)(±2mV ±0.2%) of Rdg., max
vs. Temperature T_{min} to +70°C	±(0.1mV ±0.01% Rdg.)(0.05mV ±0.005% Rdg.)(0.1mV ±0.005% of Rdg.)/°C max
+70°C to +125°C	(–)(–) ±(0.3mV ±0.005% of Reading)/°C max
vs. Supply Voltage	±(0.1mV ±0.01% Reading)/V
Error vs. Crest Factor	
1 to 2	0
3	–0.1% of Reading
7	-1% of Reading
Frequency Response (Sinewave)	
Bandwidth for ±1% Reading	
Additional Error	
$10mV < V_{IN} \leq 100mV$	6kHz
$100mV < V_{IN} \leq 1V$	40kHz
$1V < V_{IN} \leq 7V$	100kHz
Bandwidth, -3dB	
$10mV < V_{IN} \leq 100mV$	50kHz
$100mV < V_{IN} \leq 1V$	300kHz
$1V < V_{IN} \leq 7V$	2MHz
±1% Reading Error	
Input: 0.1 to $7V_{rms}$	100kHz
Bandwidth, -3dB, $1V_{rms}$	1MHz
External Filter Time Constant	25ms/µF
Signal Output	
Rated Output	
Voltage, ±15V Supplies	0 to +10V min
Voltage, 0, +5V Supplies	0 to +2V min
Current	(+5mA, -130µA) min
Resistance	0.5Ω max
Short Circuit Current	20mA
Offset Voltage	±2mV(±1mV)(±2mV) max
vs. Temperature	±(100)(100)(200 max)µV/°C
vs. Supply	±100µV/V
Signal Input	
Signal Range ±15V Supply	±20V Peak
Signal Range 0, +5V Supply	±5V Peak (ac - coupled)
Safe Input ±15V Supply	±30V
Input Impedance	16.7kΩ ±20%
dB Output	
Scale Factor (+25°C)	-3mV/dB
Scale Factor TC	–0.3% of Reading/°C
I_{REF}, for $1.0V_{rms}$ = 0dB	20µA
Accuracy ($1.0V_{rms}$ = 0dB)	
Input: 7mV to $7V_{rms}$	±0.5(±0.2)(±0.5)dB
Power Supply	
Voltage Rated Performance	
Dual Supply	±3 to ±18V
Single Supply +5 to +36V	+5 to +36V
Quiescent Current	1mA
Temperature Range	
Operating	0 to +70°C
Storage	-55°C to +150°C
Packages	14 Pin Ceramic DIP (D) 10 Pin Metal Can (H)

DEDICATED IC DIVIDER

The AD535 is a monolithic laser-trimmed two quadrant divider with performance specifications previously available only in high cost hybrid or modular devices. A maximum divider error of ±0.5% is guaranteed with no external trim over a denominator range of 10 to 1.

SPECIFICATIONS

(V_S = ±15V, $R_L \geq 2k\Omega$, T_A = 25°C typical unless otherwise stated)

Parameter	Conditions	AD535J(K)
Transfer Function		$10 \frac{(Z_2 - Z_1)}{(X_1 - X_2)} + Y_1$
Total Error – % max	No External Trims	
	$1V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	1.0(0.5)
	With External Trim	
	$0.5V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	1.0(0.5)
Temperature Coefficient – %/°C	$1V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	0.01
	$0.2V \leq X \leq 10V$, $Z \leq \lvert X \rvert$	0.05
Total Error, Square Root – %	No External Trim	
	$1V \leq Z \leq 10V$	0.4
Bandwidth – kHz	X=0.2V	20
Input Amplifiers		
Bias Current – µA max		2.0
CMRR – dB min	dc to 50Hz, 20V p-p	60
Differential Impedance – mΩ		10
Output Amplifier		
Small Signal Gain Bandwidths – MHz	$V_{OUT} = 0.1V_{rms}$	1
Output Voltage Swing – V min	T_{min} to T_{max}	±11
Slew Rate – V/µs	V_{OUT} = 20V p-p	20
Current – mA max	T_{min} to T_{max}	30
Power Requirement		
Rated Performance – V		±15
Operating – V		±8 to ±18
Supply Current – mA max	Quiescent	6
Operating Temperature Range – °C		0 to +70
Packages	14 Pin Ceramic DIP (D) 10 Pin Metal Can (H)	

Computational Circuits: Modules

MULTIFUNCTION MODULES

Model 433 will perform multiplication, division, or exponentiation up to the 5th power or root. Offering ½% (433J) and ¼% (433B) accuracy as well as simple programmability, model 433 is ideal for generating linear and non-linear functions as well as for linearizing transducer signals in medical and industrial applications.

Model 434 is optimized for one quadrant divider applications and features external adjustment capability to eliminate all dc offset errors. Accuracy without external adjustment is ½% max (434A) and ¼% (434B) over a 100:1 denominator range. Model 434 may be connected as a precision wide dynamic range square rooter offering ½% (434B) max error over 1000:1 range.

SPECIFICATIONS

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

Model	Multifunction 433J(433B)	One Quadrant Divider 434A(434B)
Transfer Function	$e_o = \frac{10}{V_{REF}} V_y \left(\frac{V_z}{V_x}\right)^m$	$e_o = \frac{10}{V_{REF}} V_y \frac{V_z}{V_x}$ $e_o = \frac{10}{V_{REF}} V_y \frac{I_z}{I_x}$
Reference Voltage, V_{REF} (Internal Source)	+9.0V ±5% @ 1mA	+9.0 ±5% @ 1mA
Rated Output	+10.5V @ 5mA, min	+10.5V @ 5mA, min
External Adjustment m	$1/5 \leqslant m \leqslant 5$	NA
Total Output Error @ +25°C	±0.5%(±0.25%) max	±0.5%(±0.25%) max
Input Range ($V_z \leqslant V_x$)	0.01V to 10V, V_z 0.1V to 10V, V_x	$0.01 \leqslant V_z \leqslant +10V$ $[0.1 \leqslant I_z \leqslant +100\mu A]$ $0.1 \leqslant V_x \leqslant +10V$ $[1 \leqslant I_x \leqslant +100\mu A]$
Over Specified Temp. Range	±1%(±1% max)	±1% (±1% max)
Bandwidth, V_y, V_z		
Small Signal (−3dB), 10% of dc level		
$V_y = V_z = V_x = 10V$	100kHz	100kHz
$V_y = V_z = V_x = 0.01V$	400Hz	400Hz
Power Supply, Rated Performance	±15V dc @ 10mA	±15V dc @ 8mA
Temperature Range, Rates Performance	0 to +70°C (−25°C to +85°C)	−25°C to +85°C
Case Dimensions	1.5" x 1.5" x 0.62"	1.5" x 1.5" x 0.62"

MULTIPLIERS/ DIVIDERS

Model 426 is a low cost, 1% (426A,K) and ½% (426L) general purpose multiplier/divider. Model 429 offers excellent 10MHz bandwidth and 1% max (429A), ½% max (429B) accuracy. Model 435 provides precision performance of ½% (435J) and 0.1% (435K) max error with no external trimming. Model 436 is a precision two quadrant divider with max error of ½% (436A) and ¼% (436B) over a 100:1 denominator range with no external adjustment required.

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

Model[1]	General Purpose 426A(426K)(426L)	Accurate Wideband 429A(429B)	High Accuracy 435J(435K)	High Accuracy 2-Quadrant Divider 436A(436B)
Divides and Square Roots	Yes	Yes	Yes	Divide Only
Multiplication Characteristics				
Output Function	XY/10	XY/10	XY/10	10Z/X
Error, Internal Trim	1%(1%)(0.5%) max	1%(0.5%) max	0.25%(0.1%) max	0.5%(0.25%) max
Error, External Trim	0.6%(0.6%)(0.35%)	0.7%(0.3%)	0.15%(0.08%)	0.3%(0.1%) max
Accuracy vs. Temperature	0.05(0.04 max)(0.04 max) %/°C	0.05%/°C(0.04%/°C max)	0.01%/°C(0.01%/°C max)	0.04%/°C(0.2%/°C) max
Output Offset				
Initial @ +25°C	20mV	20mV(10mV) max	10mV(5mV) max	10mV, V_x = +10V
vs. Temperature	2mV/°C(1mV/°C max)(1mV/°C max)	2mV/°C(1mV/°C max)	0.3mV/°C(0.2mV/°C) max	0.5mV/°C
Nonlinearity				
X Input (X = 20V p-p; Y = ±10V dc)	0.6%(0.6%)(0.25%) max	0.5%(0.2%) max	0.1%(0.05%) max	0.1%(0.05%)
Y Input (Y = 20V p-p; X = ±10V dc)	0.3%(0.3%)(0.25% max	0.3%(0.2%) max	0.1%(0.05% max	$0.1V \leqslant V_x \leqslant 10V$
Bandwidth				
−3dB Small Signal	400kHz	10MHz	300kHz	300kHz
Full Power Response	80kHz	2MHz min	30kHz	30kHz
Slew Rate	5V/µs	120V/µs min	2V/µs	2V/µs
Output Voltage/Current	±11V min/±11mA min	±11V min/±11mA min	±10V min/±5mA min	±10V min/±5mA min
Power Supply, Rated Performance	±15V dc @ ±5mA	±15V dc @ ±12mA	±15V dc @ ±6mA	±15V dc @ ±9mA
Temperature Range, Rated Performance	−25 to +85°C(0 to +70°C)(0 to +70°C)	−25°C to +85°C	0 to +70°C	−25°C to +85°C
Case Dimensions, inches	1.5 x 1.5 x 0.6	1.5 x 1.5 x 0.6	1.65 x 3.07 x 0.65	1.5 x 1.5 x 0.62

[1] Other popular models not shown, but available (contact factory) 432J/K, 428J/K, 424J/K, 427J/K

LOGARITHMIC AMPLIFIERS

Models 759N/P are low cost, fast response dc logarithmic amplifiers offering 1% conformance to ideal log operation over four decades of current operation, 20nA to 200μA. Featuring 200kHz bandwidth @ I_{SIG} = 1μA, these new economy designs are the industries fastest log/antilog amplifiers and offer an attractive alternative to in-house designs. Voltage logging from 1mV to 10V is also provided, with 2% max conformance error over the entire range. Designed for ease of use, models 759N/P are complete and offer internal reference current (10μA) scale factors (K=2, 1, 2/3 V/decade) and log/antilog operation by simple pin selection. External components are not required for logging currents over a six decade range, from 1nA to 1mA. Model 759N computes the log of positive input signals, while model 759P computes the log of negative input signals. Applications for models 759N/P include data compression and expansion, chemical analysis of liquids and conversion of exponential transducer signals to linear form. Models 755N/P are high accuracy, complete, dc logarithmic amplifiers, offering 1/2% log conformity over a four decade range, 10nA to 100μA. A 1% log conformity is also guaranteed over a six decade range, 1nA to 1mA. For increased flexibility, three scale factors (K=2, 1, 2/3 V/decade), as well as log or antilog operation may be selected by simple pin connection. The 10μA internal reference current may also be externally adjusted. Model 755N computes the log of positive input signals; model 755P computes the log of negative input signals.

Models 757N/P are high accuracy, complete, temperature compensated, dc log ratio amplifiers, capable of either current log ratio or voltage log ratio. Models 757N/P can process signals spanning 6 decades (1nA to 1mA) at either input channel (I_{SIG}, I_{REF}), maintaining 1% log conformity. Log ratio amplifiers are suited for applications such as blood analysis, chromatography, chemical analysis and absorbance measurements.

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

Model[1]	Economy, Wideband, Log/Antilog Amplifier 759N/P	High Accuracy Log/Antilog Amplifier 755N/P	High Accuracy, Log/Antilog Ratio Amplifier 757N/P
Transfer Functions			
Current Mode	$e_o = -K \log_{10} \frac{I_{SIG}}{I_{REF}}$	$e_o = -K \log_{10} \frac{I_{SIG}}{I_{REF}}$	$e_o = -K \log_{10} \frac{I_{SIG}}{I_{REF}}$
Voltage Mode	$e_o = -K \log_{10} \frac{E_{SIG}}{E_{REF}}$	$e_o = -K \log_{10} \frac{E_{in}}{E_{REF}}$	$e_o = -K \log_{10} \left(\frac{e_1}{e_2} \times \frac{R_2}{R_1}\right)$
Antilog Mode	$e_o = E_{REF}\, 10^{-\left(\frac{E_{SIG}}{K}\right)}$	$e_o = E_{REF}\, 10^{-\left(E_{in}/K\right)}$	$e_o = E_{REF}\, 10^{-\left(\frac{E_{in}}{K}\right)}$
Log Conformity Error, Referred to Input			
I_{SIG}, I_{REF} Range			
20nA to 100μA	±1% max (I_{REF}[3] = 10μA)	–	–
10nA to 1mA	±2% max (I_{REF}[3] = 10μA)	–	–
10nA to 100μA	–	±0.5% max (I_{REF}[3] = 10μA)	±0.5% max
1nA to 1mA	±5% (I_{REF}[3] = 10μA)	±1% max (I_{REF}[3] = 10μA)	±1% max
Scale Factor (K) Selections[2,3]	2, 1, 2/3 Volt/Decade, ±1%	2, 1, 2/3 Volt/Decade, ±1%	1 Volt/Decade ±1%
Small Signal Bandwidth, −3dB			
I_{SIG} = 1μA	200kHz	10kHz	25kHz
I_{SIG} = 100μA	300kHz	40kHz	50kHz
Input Specifications			
I_{SIG} Channel; Input Range	1nA to 1mA	1nA to 1mA	1nA to 1mA
Bias Current	200pA max	10pA	10pA
Offset Voltage	±2mV max	±0.4mV	±1mV max
I_{REF} Channel, Input Range	–	–	1nA to 1mA
Bias Current	–	–	10pA
Offset Voltage	–	–	±1mV max
Rated Output Voltage/Current	±10V min @ ±5mA	±10V min @ ±5mA	±10V min @ ±5mA
Power Supply, Rated Performance	±15V dc @ ±4mA	±15V dc @ ±10mA	±15V dc @ ±8mA
Case Dimensions	1.125" x 1.125" x 0.4"	1.5" x 1.5" x 0.4"	1.5" x 1.5" x 0.4"

[1] For positive inputs, specify "N" model; for negative inputs, specify "P" model.
[2] K is positive for "N" models; negative for "P" models.
[3] Externally adjustable.

RMS-to-DC Converters: Modules

TRUE RMS-TO-DC CONVERTERS

These compact true rms-to-dc converter modules are an excellent choice for use in all types of OEM rms instrumentation. In addition to measuring ac signals, all models also measure directly the rms value of waveforms containing both ac and dc. No external adjustments or components are required to achieve rated performance.

Model 442 is a high performance true rms-to-dc converter featuring 8MHz bandwidth, low drift to ±35μV/°C ±0.01% of reading/°C maximum, and ±1% reading error to 800kHz. Accuracy is held to within ±2mV ±0.15% of reading for input signals of 0 to 2V rms. If optional adjustments are performed, this accuracy can be improved to ±0.5mV ±0.05% of reading. Model 442 is designed to be used in high performance instrumentation where response to low level, high speed signals, is of greatest importance.

Model 440 is a compact rms-to-dc converter featuring performance usually found in higher priced units. Model 440 is available in two accuracy grades; model 440K features total error of ±5mV ±0.1% of reading, while model 440J has total error of ±15mV ±0.2% of reading. Rated accuracy is achieved for signal crest factors as high as 5. Less than ±1% reading error occurs with signal crest factor as high as 10.

Model 441 is a low cost design capable of performing high accuracy measurements (0.2%, 441K) on simple ac signals, such as sinewaves, and on a wide range of complex waveforms. For measurements below 100Hz, a single external capacitor may be added to achieve 0.1% accuracy without affecting the bandwidth for higher frequency measurements. The model 441 delivers its excellent performance over a wide range of power supplies (±4 to ±18V dc) making it ideal for battery operated applications.

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

Model	**Wideband, High Accuracy 442J(442K)(442L)**	**General Purpose 440J(440K)**	**Economy 441J(441K)**
Accuracy			
No External Adjustment	±2mV ±0.15% max	±15mV ±0.2%, (±5mV ±0.1%) max	±10mV ±0.4% (±5mV ±0.2%) max
External Adjustment	±0.5mV ±0.05% max	±10mV ±0.1%, (±2mV ±0.05%) max	±2mV ±0.1%, max
vs. Temperature (0 to +70°C)	±(0.1mV ±0.01%)/°C max [442J] ±(0.05mV ±0.01%)/°C max [442K] ±(0.035mV ±0.01%)/°C max [442L	±(0.2mV ±0.02%)/°C max	±(0.2mV ±0.03%)/°C max
Crest Factor, Rated Accuracy	7	5 min	3 min
Frequency Response, Sinewave			
Rated Accuracy			
Input Range, 0.1 to $7V_{rms}$	20kHz, min	10kHz, min	10kHz, min
±1% Reading Error			
Input, $7V_{rms}$	800kHz, min	50kHz, min	20kHz, min
Input, $0.7V_{rms}$	150kHz	100kHz, min	30kHz, min
Bandwidth, -3dB			
Input Range, 0.7 to $7V_{rms}$	8MHz	500kHz	75kHz
Output Specifications			
Rated Output	+10V min/+5mA min	+10V min/+10mA min	+10V min/+5mA min
Offset Voltage (Adj. to Zero)	±2mV max	±5mV, (±2mV) max	±10mV(±5mV) max
Input Voltage Range	±10V, Peak	±10V, Peak	±10V, Peak
Power Supply			
Voltage, Rated Performance	±15V dc	±15V dc	±15V dc
Voltage, Operating	±(6 to 18)V dc	±(6 to 18)V dc	±(4 to 18)V dc
Current, Quiescent	±12mA	±10mA	±10mA
Temperature Range, Operating	0 to +70°C	0 to +70°C	0 to +70°C
Case Dimensions	1.5" x 1.5" x 0.4"	1.5" x 1.5" x 0.4"	2" x 2" x 0.4"

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