

ANALOG MULTIPLIER

■ GENERAL DESCRIPTION

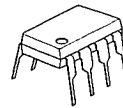
The NJM4200 is the industry's first integrated circuit multiplier to have complete compensation for nonlinearity, the primary source of error and distortion. This is also the first IC multiplier to have three on-board operational amplifiers designed specifically for use in multiplier logging circuits. These specially-designed amplifiers are frequency compensated for optimum AC response in a logging circuit; the heart of a multiplier, and can therefore provide superior AC response in comparison to other analog multipliers.

Versatility is unprecedented; this is the first IC multiplier that can be used in a wide variety of applications without sacrificing accuracy. Four-quadrant multiplication, one-quadrant division or square-rooting, and RMS-to-DC conversion can all be easily implemented with predictable accuracy. The nonlinearity compensation is not just trimmed at a single temperature, it is designed to provide compensation over the full temperature range. This nonlinearity compensation combined with the low gain and offset drift inherent in a well-designed monolithic chip provides a very low tempo on accuracy.

The excellent linearity and versatility were achieved through circuit design rather than special grading or trimming therefore unit cost is very low. Analog multipliers can now be used in application where price was previously an inhibiting factor.

The NJM4200 is ideal for use in low-distortion audio modulation circuits, voltage-controlled active filters, and precision oscillators.

■ PACKAGE OUTLINE



NJM4200D

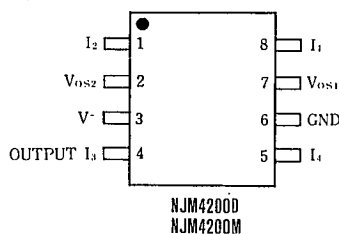


NJM4200M

■ FEATURES

- High accuracy
  - Non-linearity (0.3% max.)
  - Temperature coefficient (0.005%/°C typ.)
- Multiple functions
  - Multiply, divide, square, square root, RMS-to-DC conversion, AGC, and modulate/demodulate
- Wide bandwidth (4MHz typ.)
- Package Outline DIP8, DMP8
- Bipolar Technology

■ CONNECTION DIAGRAM



## ■ ABSOLUTE MAXIMUM RATINGS

(Ta=25°C)

PARAMETER	SYMBOL	RATINGS	UNIT
Supply Voltage	V <sup>-</sup>	-22	V
Power Dissipation	P <sub>D</sub>	(DIP8) 500	mW
		(DMP8) 300	mW
Input Current	I <sub>IN</sub>	-5	mA
Operating Temperature Range	T <sub>opr</sub>	-40~+85	°C
Storage Temperature Range	T <sub>stg</sub>	-40~+125	°C

## ■ ELECTRICAL CHARACTERISTICS

(Ta=25°C, V<sup>-</sup>=-15V)

PARAMETER	SYMBOL	TEST CONDITION	NJM4200			UNIT	
			MIN.	TYP.	MAX.		
Input range(I <sub>1</sub> , I <sub>2</sub> and I <sub>4</sub> )	I <sub>IN</sub>		1.0	—	1000	μA	
Total error as multiplier	—	Operational Temperature Range	—	—	±3.0	%	
							Untrimmed
							With external trim
							Versus temperature
Versus Supply	—	V <sup>-</sup> = -9V ~ -18V	—	±0.005	—	%/°C	
Nonlinearity	—	50μA < I < 250μA	—	—	±0.3	%	
Input offset voltage	V <sub>IO</sub>	I <sub>1</sub> =I <sub>2</sub> =I <sub>4</sub> =150μA	—	—	±10	mV	
Input bias current	I <sub>B</sub>	I <sub>1</sub> =I <sub>2</sub> =I <sub>4</sub> =150μA	—	—	500	nA	
Average temperature coefficient of input offset voltage	—	I <sub>1</sub> =I <sub>2</sub> =I <sub>4</sub> =150μA	—	—	±100	μV/°C	
Output current range(I <sub>3</sub> )	I <sub>O</sub>	(Note 1)	1.0	—	1000	μA	
Frequency response, -3 dB	f <sub>R</sub>		—	4	—	MHz	
Operating voltage	V <sup>-</sup>		-9	-15	-18	V	
Operating Current	I <sub>CC</sub>	I <sub>1</sub> =I <sub>2</sub> =I <sub>4</sub> =150μA, Ta=25°C	—	—	4	mA	

Note 1: These specifications apply with output (I<sub>3</sub>) connected to an op amp summing junction. If desired, the output (I<sub>3</sub>) at pin (4) can be used to drive a resistive load directly. The resistive load should be less than 700 ohms and must be pulled up to a positive supply such that the voltage on pin (3) stays within a range of 0 to +5V.

## FUNCTION DESCRIPTION

The NJM4200 multiplier is designed to multiply two input currents ( $I_1$  and  $I_2$ ) and to divide by a third input current ( $I_3$ ). The output is also in the form of a current ( $I_4$ ). A simplified circuit diagram is shown in Figure 1. The nominal relationship between the three inputs and the output is:

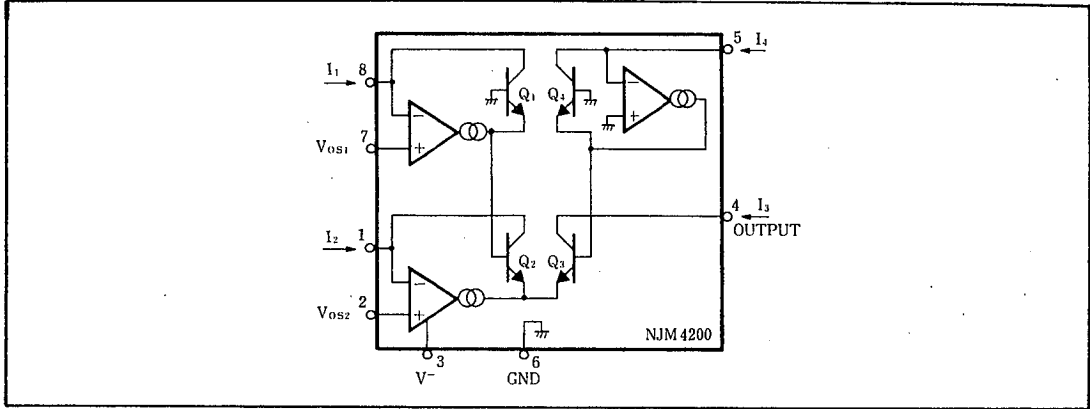


Figure 1. 4200 Multiplier Functional Diagram

$$I_3 = \frac{I_1 I_2}{I_4} \quad (1)$$

All four currents must be positive and restricted to a range of  $1\mu\text{A}$  to  $1\text{mA}$ . The three input currents go into the multiplier chip at op-amp summing junctions which are nominally at zero volts. Therefore, an input voltage can be easily converted to an input current by a series resistor. Any number of currents may be summed at the inputs. Depending on the application, the output current can be converted to a voltage by an external op-amp or used directly. This capability of combining input currents and voltages in various combinations provides great versatility in application.

Inside the multiplier chip, the three op-amps make the collector currents of transistors  $Q_1$ ,  $Q_2$ , and  $Q_4$  equal to their respective input currents ( $I_1$ ,  $I_2$ , and  $I_4$ ). These op-amps are designed with current-source outputs and are phase-compensated for optimum frequency response as a multiplier. Power drain of the op-amps was minimized to prevent the introduction of undesired thermal gradients on the chip. The three op-amps operate on a single-supply voltage (nominally  $-15\text{V}$ ) and total quiescent current drain is less than  $4\text{mA}$ . These special op-amps provide significantly improved performance in comparison to 741-type op-amps.

The actual multiplication is done within the log-antilog configuration of the  $Q_1$ - $Q_4$  transistor array. These four transistors, with associated proprietary circuitry, were specially designed to precisely implement the relationship.

$$V_{\text{BEN}} = \frac{kT}{q} \ln \frac{I_{\text{CN}}}{I_{\text{SN}}} \quad (2)$$

Previous multiplier designs have suffered from an additional undesired linear term in the above equation; the collector current times the emitter resistance. This  $I_{\text{C}}r_{\text{E}}$  term can cause significant linearity error. In four-quadrant multiplier circuits, this added  $I_{\text{C}}r_{\text{E}}$  term introduces a parabolic nonlinearity even with matched transistors. New JRC has developed a unique and proprietary means of inherently compensating for this undesired  $I_{\text{C}}r_{\text{E}}$  term. Furthermore, this New JRC-developed circuit technique compensates linearity error over temperature changes. The nonlinearity-versus-temperature is significantly improved over earlier designs.

From equation (2) and by assuming equal transistor junction temperatures, summing base-to-emitter voltage drops around the transistor array yields:

$$\frac{kT}{q} [\ln \frac{I_1}{I_{\text{S1}}} + \ln \frac{I_2}{I_{\text{S2}}} - \ln \frac{I_3}{I_{\text{S3}}} - \ln \frac{I_4}{I_{\text{S4}}}] = 0 \quad (3)$$

The equation reduces to:

$$\frac{I_1 I_2}{I_3 I_4} = \frac{I_{\text{S1}} I_{\text{S2}}}{I_{\text{S3}} I_{\text{S4}}} \quad (4)$$

The ratio of reverse saturation currents,  $I_{\text{S1}}I_{\text{S2}}/I_{\text{S3}}I_{\text{S4}}$  depends on the transistor matching. In a monolithic multiplier this matching is easily achieved and the ratio is very close to unity, typically  $1.0 \pm 1\%$ . The final result is the desired relationship:

$$I_3 = \frac{I_1 I_2}{I_4} \quad (5)$$

The inherent linearity and gain stability combined with low cost and versatility makes this new circuit ideal for a wide range of nonlinear functions.

Applications

Four-Quadrant, General-Purpose Multiplier

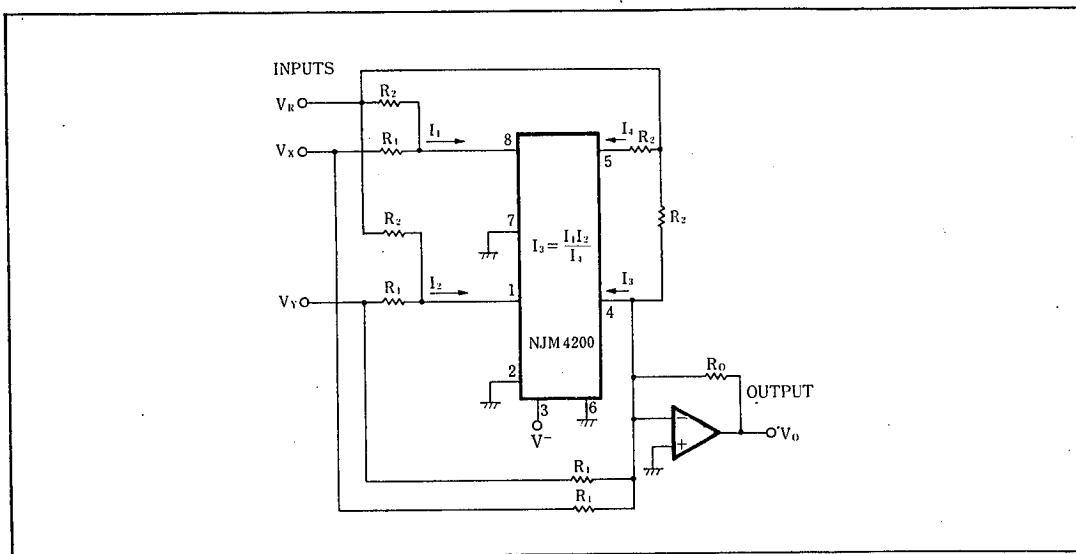


Figure 2. Four-Quadrant General Purpose Multiplier Using the NJM4200

The general schematic for a four-quadrant multiplier using the NJM4200 IC is shown in Figure 2. A positive reference voltage,  $V_R$ , is used to offset the multiplier chip. To stay within the most linear operating range, it is necessary that  $V_R/R_2$  plus  $V_X/R_1$  be limited to a range of  $50\mu A$  to  $250\mu A$ . Within the operating range, input and output currents are given by the following equations:

$$I_1 = \frac{V_X + V_R}{R_1 + R_2} \quad I_2 = \frac{V_Y + V_R}{R_1 + R_2} \quad I_3 = \frac{V_X + V_Y + V_R + V_0}{R_1 + R_1 + R_2 + R_0} \quad I_4 = \frac{V_R}{R_2}$$

Combining these relationships through the equation  $I_3 = I_1 I_2 / I_4$  yields:

$$V_0 = \frac{R_0 R_2}{R_1^2} \frac{V_X V_Y}{V_R}$$

The reference voltage  $V_R$  must be positive, but  $V_X$  and  $V_Y$  can be AC voltages. The positive supply voltage can be used as the reference in many applications where a well-regulated +15V is available. Some typical values for a multiplier scaled at  $V_X V_Y / 10$  are calculated below:

- Given:**  $V_X$  and  $V_Y$  have range of  $-10V$  to  $+10V$   
 Desired scaling is  $V_0 = V_X V_Y / 10$   
 Reference voltage  $V_R$  is  $+15V$

**Calculation:**

(1) Choose  $R_1 = 100k\Omega$

(2) Calculate  $R_0$  from  $\frac{R_0 R_2}{R_1^2} \frac{1}{V_R} = \frac{1}{10}$

From requirement of  $+50\mu A$  minimum

$$\frac{-10V + 15V}{100K + R_2} = 50\mu A$$

$$R_0 = \frac{R_1^2 V_R}{R_2^2 \cdot 10}$$

$$R_0 = (100k\Omega) \cdot 15 / 10$$

**Results:**

$$R_0 = 150k\Omega$$

$$V_0 = \frac{V_X V_Y}{10} \text{ with } V_R = +15V$$

$$R_1, R_2 = 100k\Omega$$

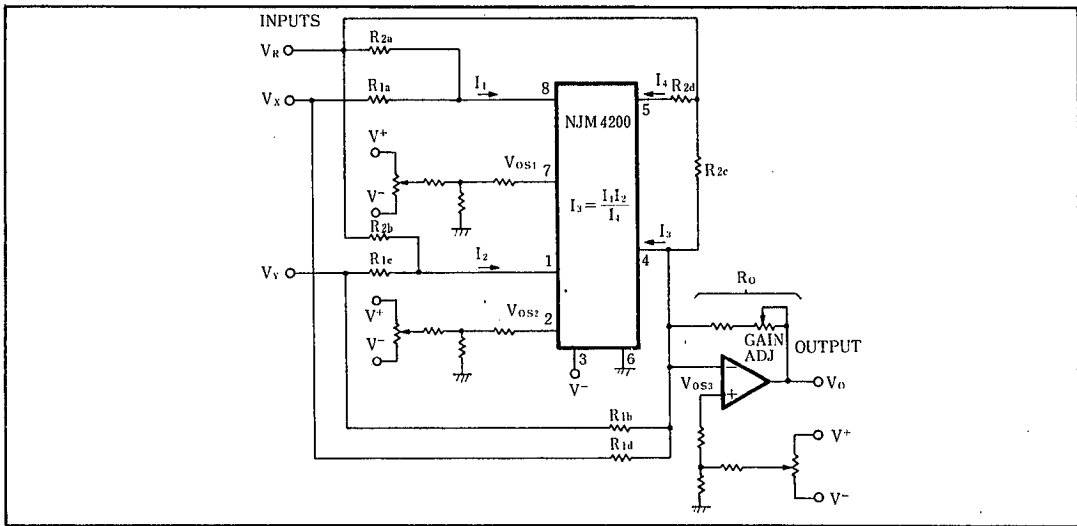
$$R_0 = 150k\Omega$$

These values cause a range on  $I_1$  and  $I_2$  of  $50\mu A$  to  $250\mu A$  for  $V_X$  and  $V_Y$  of  $-10V$  to  $+10V$ .

While the choice of values for  $R_1, R_2$  and  $R_0$  are arbitrary, best results are obtained by operating  $I_1$  and  $I_2$  over a range of approximately  $50\mu A$  to  $250\mu A$ .

Accuracy of the four-quadrant multiplier is dependent upon both the NJM4200 chip and the external components. AC feedthrough, which is the undesired output when multiplying one AC input by zero on the other input, is dependent on op amp offsets and on the matching of the  $R_1$  and  $R_2$  resistor sets. Gain accuracy depends on the external reference voltage  $V_R$ , the resistor ratio  $R_0 R_2 / R_1^2$ , and the multiplier chip. Linearity depends almost entirely upon the multiplier IC. The linear error terms can all be nulled externally by trimming resistor ratios or offsets. A four-quadrant multiplier with provision for external trimming of linear error components is shown in Figure 3. The optimum mix of component tolerances, trimming range, and cost is very application dependent. With moderate-cost components and no external trimming, the NJM4200 is more accurate than many of the complete IC multipliers. With precision components and external trimming as shown in Figure 3, the NJM4200 is capable of performance comparable to the best hybrid or modular multipliers.

The error analysis is most easily done by separately considering resistor match, offsets, and gain; then superimposing the results.



**Figure 3. Four-Quadrant, General-Purpose Multiplier with Offset Adjustments**

## Resistor Matching

Assuming no op amp offsets and no error due to the multiplier chip, then the output would be the sum of the items given below:

$$\text{Desired Output} = \frac{R_0 R_{2d}}{R_{1a} R_{1c}} \frac{V_X V_Y}{V_R}$$

$$V_Y \text{ Feedthrough} = \frac{R_0}{R_{1c}} \left( \frac{R_{2d}}{R_{2a}} - \frac{R_{1c}}{R_{1b}} \right) V_Y$$

$$V_X \text{ Feedthrough} = \frac{R_0}{R_{1a}} \left( \frac{R_{2d}}{R_{2b}} - \frac{R_{1a}}{R_{1d}} \right) V_X$$

$$\text{Output Offset} = \frac{R_0}{R_{2a}} \left( \frac{R_{2d}}{R_{2b}} - \frac{R_{2a}}{R_{2c}} \right) V_R^2$$

The AC feedthrough is directly proportional to the matching of the  $R_2$  resistor set and the  $R_1$  resistor set. AC feedthrough on the X or Y input is related to resistor tolerance as:

$$\text{AC Feedthrough} \sim R_0 / R_1 \times 2 \times \text{Res. Tol.} \times V_{IN}$$

For example, if  $R_0 / R_1$  were 1.5 as in the example given previously and the resistors were matched to within 1%, then the maximum AC feedthrough due to resistor mismatch would be 3% of the  $V_X$  or  $V_Y$  input voltage. This AC feedthrough can be nulled directly by trimming the resistor sets or indirectly by trimming offsets.

## Effect of Op Amp Offsets

In a multiplier, the offsets are cross multiplied and can thus cause AC feedthrough. When one input is zero and the other is a large AC signal, then the output will be the offset of the "zero" input times the AC signal. To quantify this effect, consider the circuit as shown in Figure 3. The offsets of each amplifier are due to both input offset voltage for the op amp and the input offset current times the source resistance.

These offsets can be lumped together into a single  $V_{OS}$  term. For this analysis, assume that the external resistors are perfectly matched ( $R_1$ 's and  $R_2$ 's all matched). The set of equations below must be combined to see their interaction:

$$\begin{aligned}
 I_1 &= \frac{V_X - V_{OS1}}{R_1} + \frac{V_R - V_{OS1}}{R_2} & \text{Desired Output} &= \frac{R_0 R_2}{R_1^2} \frac{V_X V_Y}{V_R} \\
 I_2 &= \frac{V_Y - V_{OS2}}{R_1} + \frac{V_R - V_{OS2}}{R_2} & V_Y \text{ Feedthrough} &= \frac{R_0}{R_1} \frac{1}{V_R} \left[ V_{OS4} - \left( \frac{R_2}{R_1} + 1 \right) V_{OS1} \right] V_Y \\
 I_3 &= \frac{V_X - V_{OS3}}{R_1} + \frac{V_Y - V_{OS3}}{R_1} + \frac{V_R - V_{OS3}}{R_2} + \frac{V_O - V_{OS3}}{R_0} & V_X \text{ Feedthrough} &= \frac{R_0}{R_1} \frac{1}{V_R} \left[ V_{OS4} - \left( \frac{R_2}{R_1} + 1 \right) V_{OS2} \right] V_X \\
 I_3 &= \frac{V_R - V_{OS4}}{R_2} & I_3 &= \frac{I_1 I_2}{I_4} & \text{Output Offset} &= \left( \frac{2R_0}{R_1} + \frac{R_0}{R_2} + 1 \right) V_{OS3} - \left( \frac{R_0}{R_1} + \frac{R_0}{R_2} \right) (V_{OS1} + V_{OS2})
 \end{aligned}$$

For simplicity,  $V_{OS}^2$  terms and gain-error factors on error terms can be dropped. The output voltage would then be the sum of the terms given above:

To estimate magnitudes, consider the previous example where  $R_0 = 150k\Omega$ ,  $R_1$  and  $R_2$  were  $100k\Omega$ , and  $V_R = 15V$ . Then,

$$V_Y \text{ Feedthrough} = 1/10(V_{OS4} - 2V_{OS1})V_Y$$

$$V_X \text{ Feedthrough} = 1/10(V_{OS4} - 2V_{OS2})V_X$$

$$\text{Output Offset} = 5.5V_{OS3} - 3(V_{OS1} + V_{OS2})$$

To carry this example further, let each  $V_{OS}$  term have a maximum value of  $\pm 10mV$ . The worst-case combination would then be a feedthrough of  $0.003V_Y$  and  $0.003V_X$ . Output offset could be as high as  $115mV$ , but would generally be less.

The trimming procedure is straight-forward when done in the following recommended sequence.

1. Apply a full-scale AC voltage To  $V_Y$  and make  $V_X$  zero. Trim  $V_{OS1}$  for output null ( $V_O = 0$ ).
2. Apply the same full scale AC voltage to  $V_X$  and  $V_Y$  zero. Trim  $V_{OS2}$  for output null ( $V_O = 0$ ).
3. Apply zero to both inputs ( $V_X = 0$  and  $V_Y = 0$ ). Trim  $V_{OS3}$  for output null ( $V_O = 0$ ).
4. Adjust scale factor with  $R_0$ . Always adjust the input offsets before setting the scale factor.

In most application, the offset adjustments are used to compensate for the  $R_1$  and  $R_2$  resistor network mismatch as well as the op amp offsets. Thus, the range of offset adjustment is usually chosen to encompass both error terms. For example, the  $V_Y$  feedthrough is:

$$\left\{ \frac{R_0}{R_1} \left( \frac{R_{2a}}{R_{2b}} - \frac{R_{1a}}{R_{1b}} \right) + \frac{R_0}{R_1} \frac{1}{V_R} \left[ V_{OS4} - \left( \frac{R_2}{R_1} + 1 \right) V_{OS1} \right] \right\} V_Y$$

Varying  $V_{OS1}$  over sufficient range can compensate for both offset and resistor mismatch.

### One Quadrant Divider

Division is very easily implemented with the NJM4200 multiplier when the inputs are all positive. The circuit for one-quant division is shown in Figure 4. The inputs  $V_X$ ,  $V_Z$ , and  $V_R$  must be positive and the input currents  $I_1$ ,  $I_2$  and  $I_4$  must be restricted in range. Within the rated range,  $I_1 I_2$  will equal  $I_3 I_4$  and therefore:

$$\begin{aligned}
 \left( \frac{V_X}{R_1} \right) \times \left( \frac{V_R}{R_2} \right) &= \left( \frac{V_O}{R_0} \right) \times \left( \frac{V_Z}{R_4} \right) \\
 V_O &= \frac{R_0 R_4}{R_1 R_2} V_R \frac{V_X}{V_Z}
 \end{aligned}$$

The reference input  $V_R$  is generally fixed and the ratio of  $R_0 R_4 / R_1 R_2$  is usually chosen to make  $V_O = 10V$  at the maximum value of  $V_X / V_Z$ . For example, if  $V_R = 6.2V$  and  $V_X / V_Z$  maximum is one, then choose  $R_0 R_4 / R_1 R_2$  of  $10/6.2$  which is 1.613. The output would then be:

$$V_O = 10 \frac{V_X}{V_Z}, \text{ where } \frac{V_X}{V_Z} \leq 1$$

As with the four-quadrant multiplier circuit, op amp offsets cross-multiply with the inputs.

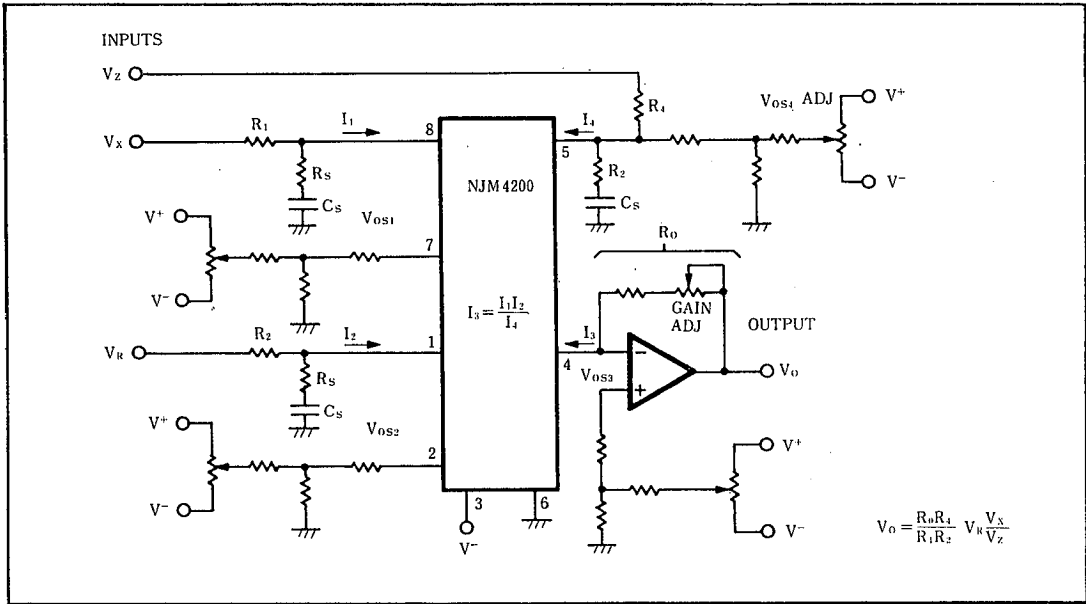


Figure 4. One-Quadrant Divider

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These offsets should be nulled to obtain best accuracy. The output voltage with offsets considered, but neglecting  $V_{OS}^2$  terms, is given by:

$$V_o = \underbrace{\frac{R_1 R_0 V_R V_X}{R_1 R_2 V_Z} + \frac{R_1 R_0}{R_1 R_2} \left[ \frac{V_R V_X}{V_Z^2} V_{OS4} - \frac{V_X}{V_Z} V_{OS2} - \frac{V_R}{V_Z} V_{OS1} \right]}_{\text{Error Terms}} + V_{OS3}$$

Because the offsets and signals are interactive, the recommended procedure for adjustment is the following:

1. Monitor the offsets at pins (8) and (1) directly and adjust  $V_{OS1}$ ,  $V_{OS2}$  to null them. This removes the  $V_{OS1}$  and  $V_{OS2}$  error terms.
2. Make  $V_X = V_Z$  and sweep over their full dynamic range. The output should be constant; vary the  $V_{OS4}$  ADJ pot for a constant output of  $R_4 R_0 V_R / R_1 R_2$  plus  $V_{OS3}$ .
3. Apply the minimum value of  $V_X / V_Z$  and adjust  $V_{OS3}$  to obtain the proper  $V_o$ .
4. Apply the maximum value of  $V_X / V_Z$  and adjust  $R_0$  for proper  $V_o$ .

The accuracy will be limited only by the nonlinearity, which for the NJM4200 is very small.

**Square-Rooting**

The circuit for implementing the square-rooting function is shown in Figure 5. An input voltage  $V_X$  multiplied by a reference voltage  $V_R$  is made equal to the square of the output voltage. The relationship  $I_1 I_2 = I_3 I_4$  becomes:

$$\frac{V_X V_R}{R_1 R_2} = \frac{V_o^2}{R_0 R_4}$$

The input voltage must be positive. Scaling is determined by the external resistor network and reference voltage  $V_R$ . The output voltage is given by:

$$V_o = \sqrt{\frac{R_0 R_4}{R_1 R_2} V_R V_X}$$

In most applications, the resistors should be comparable in value and  $V_R$  should be in the range of 5V to 15V. A scale factor of 10 is very convenient and provides an output range of 0.3V to 10V for an input range of 10mV to 10V. In equation form:

$$V_o = \sqrt{10 V_X}, \quad 10\text{mV} < V_X < 10\text{V}$$

The offsets can be externally trimmed as needed. The nonlinear nature of the square-rooting function makes the error due to offsets very small for large inputs and very large at low input levels. With offsets included, the output voltage is:

$$V_o = \left[ \frac{R_0 R_4}{R_1 R_2} V_R \left( 1 - \frac{V_{OS2}}{V_R} \right) V_X - \frac{R_0 R_4}{R_1 R_2} V_R V_{OS1} + V_o (V_{OS3} + V_{OS4}) \right]^{1/2}$$

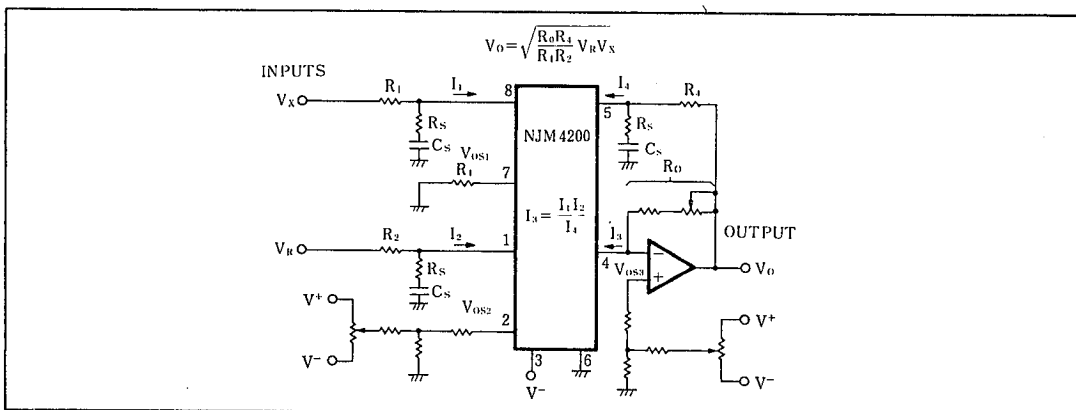


Figure 5. Square-Rooting Circuit



The term  $V_{OS2}/V_R$  affects gain only and is constant, therefore varying  $R_O$  can compensate for the  $V_{OS2}$  error term. The effect of  $V_{OS3}$  and  $V_{OS4}$  is additive and only one of these offsets are advisable to be adjusted. The  $V_{OS1}$  term should be trimmed to zero. The recommended trimming sequence is as follows:

1. Adjust  $V_{OS3}$  to zero directly by monitoring pin(4).
2. Apply minimum value of  $V_X$  and adjust  $V_{OS1}$  for correct  $V_O$ .
3. Apply maximum value of  $V_X$  and adjust  $R_O$  for correct  $V_O$ .

The square-rooting circuit can easily be designed for overall accuracy of  $\pm 0.2\%$  when using the NJM4200 IC multiplier.

### RMS-to-DC Converter

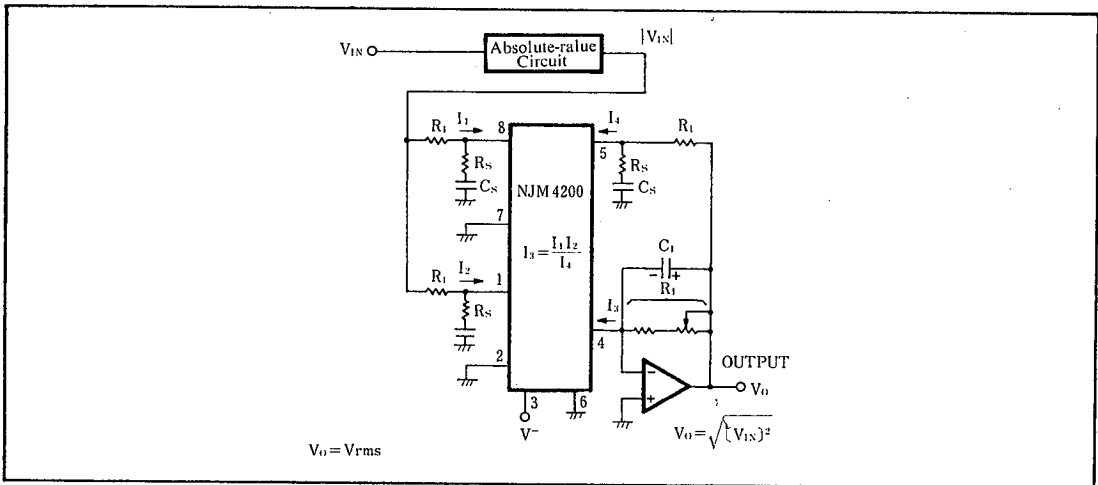
The root-mean-square value of a complex waveform can be computed directly by squaring, integrating, and then square rooting. The NJM4200 is ideally suited to this computation and the entire RMS-to-DC conversion can be implemented with a single device.

A functional diagram is shown in Figure 6. An absolute-value circuit, or precision rectifier, first converts the AC input into a rectified positive voltage. Input currents  $I_1$  and  $I_2$  are made equal and will be  $|V_{IN}|/R_1$ . The remaining input current,  $I_4$ , is made equal to  $V_O/R_O$  plus a derivative term,  $C_1 dV_O/dt$ . Combining these relationships according to  $I_1 I_2 = I_3 I_4$ ,

$$\frac{V_{IN}^2}{R_1^2} = \frac{V_O^2}{R_1^2} + C_1 \frac{dV_O}{dt} \frac{V_O}{R_1}$$

This equation is equivalent to

$$V_O^2 + \frac{R_1 C_1}{2} \frac{d}{dt} (V_O^2) = V_{IN}^2$$



**Figure 6. RMS-to-DC Converter**

The output voltage squared is the exponentially-weighted average of the input-voltage squared. Square-rooting both sides of the equation, and considering the polarity constraints inherent in this implementation, gives the desired results:

$$V_O = \sqrt{[V_{IN}(t)]^2}$$

This is the true RMS value of  $V_{IN}$  within the frequency range where the averaging time constant  $R_1 C_1 / 2$  is of sufficient magnitude for low-pass filtering. Capacitor  $C_1$  must be large enough in value to adequately average the signal at its minimum frequency.

Various practical considerations limit performance for very small input signals, so this circuit is usually designed for a specific input voltage range. As with the divide and square-root modes of operation, the NJM4200 may require a stabilizing  $R_S C_S$  at the input summing junctions (pins 8, 1, and 5).

The specific component values and external adjustments needed depends on the particular application.

**Design Considerations**

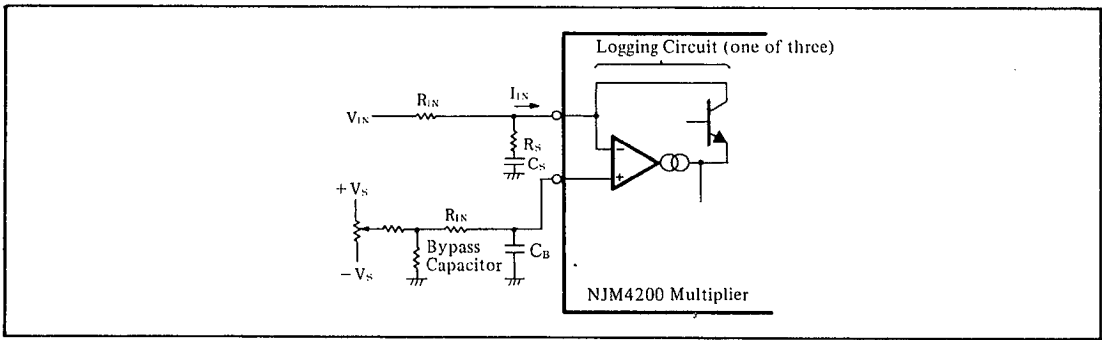
**Frequency Response and Stability**

The op amps within the NJM4200 multiplier are stabilized for optimum performance in the four-quadrant multiplier configuration. At extremes of input current, the stability becomes marginal and external phase compensation may be required. The possibility of undesired oscillations should be considered for input currents of less than  $50\mu\text{A}$  or greater than  $500\mu\text{A}$ . Dividing and square-rooting operations often require a wide dynamic range on the input currents.

Two techniques are very helpful for assuring frequency stability and minimizing noise under a wide range of conditions:

1. Connect a series  $R_S C_S$  from input summing junction to ground as shown in Figure 7. This network has the effect of attenuating the feedback at high frequencies and thereby stabilizing the op amp. Loop gain at high frequencies is sacrificed, but this is seldom of concern in dividing or square-rooting applications. Recommended values are  $10\text{k}\Omega$  for  $R_S$  and  $0.005\mu\text{F}$  for  $C_S$
2. The resistor on the noninverting input can be bypassed as shown in Figure 7. This helps to reduce noise.

The need for these frequency compensating techniques will depend on the application, particularly the input current range and input signal characteristics.



**Figure 7. Optional Frequency Stability Components  $R_S, C_S$  and  $C_B$**

**Gain Stability**

This type of multiplier is very sensitive to temperature gradients across the transistor quad ( $Q_1$  to  $Q_4$  and  $Q_2$  to  $Q_3$ ). The ambient temperature tends to affect offsets, but temperature gradients will cause a gain error. Several steps can be taken to minimize this effect:

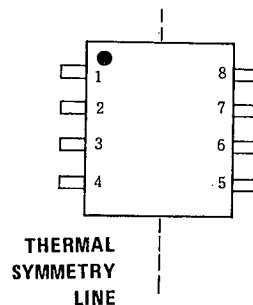
1. Keep the multiplier physically remote from power dissipating components.
  2. When using printed-circuit boards, make pad sizes and layout pattern as symmetrical as possible.
  3. Head sinking or epoxy potting can be used if necessary. This will tend to prevent rapid changes in temperature gradient.
- Power drain within the multiplier chip itself is relatively low, therefore the gain stability can be very good if the IC is not exposed to temperature gradients.

**Offset Stability**

Input offset voltage of the op amps can be easily trimmed if desired. The effects of input bias current drift can be minimized by making the impedance approximately equal on the inverting and noninverting inputs. The equivalent input offset will then depend only on the difference in bias currents rather than the absolute values.

**■ THERMAL SYMMETRY**

The scale factor is sensitive to temperature gradients across the chip in the lateral direction. Where possible, the package should be oriented such that sources generating temperature gradients are located physically on the line of thermal symmetry. This will minimize scale-factor error due to thermal gradients.



## MEMO

[CAUTION]

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