MULTIPLIERS - SOME BASICS

In its simplest conceptual form, an analog multiplier is a three-terminal (plus common) device that will perform the mathematical operations of multiplication and division, by appropriate terminal connections. Figure 1 shows the conceptual block representing a multiplier.

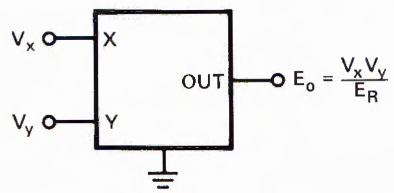


Figure 1. Conceptual multiplier. E_R is a dimensional scale constant, usually 10V

For given values of the inputs, V_x and V_y, the output will be $V_x V_y / E_R$, where E_R is a dimensional constant, usually equal to 10 volts. Since squaring is simply a multiplication of an input by itself, it follows that tying X and Y together will yield a squared term at the output, i.e., if $V_x = V_y = V_{in}$, the output will be V_{in}^2 / E_R.

Division and square-rooting, being inverses of the above operations, can be implemented by placing the multiplier in the feedback path of an operational amplifier, as Figure 2 shows. Since most multipliers use an operational amplifier as the output circuit, a set of simple external jumper connections permit the same (complete) device to perform in any of the four modes.

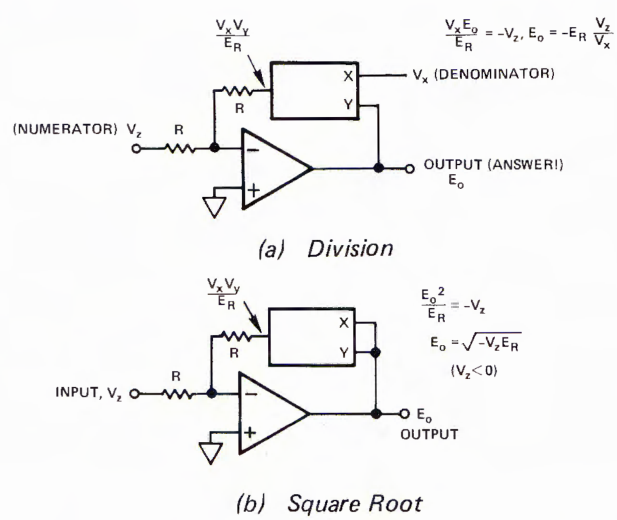


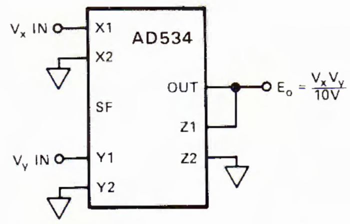
Figure 2. Feedback connection of conceptual multiplier for division and square-rooting

Of what use is such a device? Multipliers serve well in a number of areas including analog computing (e.g., ratio determination, functions, rms conversion), signal processing (amplitude modulation, frequency multiplication, servomechanisms), measurement (wattmeters and phase-sensitive detectors), and in a miscellany of useful functions (linearization of transducers, percentage computing, bridge linearizing). The Table of Contents gives a reasonably full list at a glance.

The designer, be he battle-scarred veteran, or astute neophyte, well-alerted to the difficulties of applying theoretical models to Real Solutions, will wonder what circuit contortions are required to transform the black boxes on the diagrams into Real Multipliers. Happily, very little. High performance multipliers, such as the AD532 and AD534, are completely self-contained IC's, laser-trimmed at the factory, whose actual implementation schematic is joyfully close to the theoretical. In fact, in some ways even better. The AD535 is very similar to the AD534, only it is trimmed, tested and specified in the divide mode.

MULTIPLICATION

Practical use of an AD534 in the multiply mode is shown in Figure 3. No trims, capacitors, or other appendages are required. In addition, the AD534 is even more versatile than the theoretical version introduced in Figure 1, since all the inputs are differential (including the feedback circuit). This allows such multipliers to be used in systems having grounds of less than impeccable character and permits direct subtraction, where needed, as well as permitting other terms (additive constants or variables) to be included in the transfer function.



BASIC RELATIONSHIP: $(X_1 - X_2)(Y_1 - Y_2) = 10V(Z_1 - Z_2)$

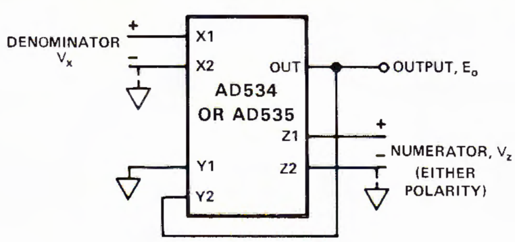
$V_xV_y = 10V\ E_o$

Figure 3. Signal connections of an actual multiplier

Many of the other multipliers in our catalog do require a set of external trims, for scale factor and/or output/input offsets, but offer compensating advantages, such as extra-low cost, wide bandwidth, an active division terminal (for YZ/X functions), or the like. Even pre-trimmed units can be externally trimmed where the application calls for optimization "to a gnat's eyelash."

DIVISION AND ROOTING

Division with the AD534 or AD535 is configured with equal ease (Figure 4). In division circuits, where the multiplying operation comprises the feedback path, only one polarity of denominator is permitted, since reversal of the denominator reverses the sense of the feedback loop. In addition, the closed-loop gain is inversely proportional to the denominator voltage (approaching "infinity" at zero input). This – in general – causes increased noise, error, and output lag, for small values of denominator, in inverse proportion to V_Z.



$V_x(-E_o) = 10V\ V_z \qquad E_o = -10\frac{V_z}{V_x}$

Figure 4. Connection of the AD534/AD535 for division

The AD534/AD535 square-roots easily, but requires a diode – connected as shown in Figure 5 – to prevent latchup, which can occur in such configurations if the input were to change polarity, even momentarily. As shown in Figure 5, the device is set up for the positive square root. The output may be made negative by reversing the diode polarity and interchanging the X input leads. Since the signal input is differential, all combinations of input and output polarities can be realized.

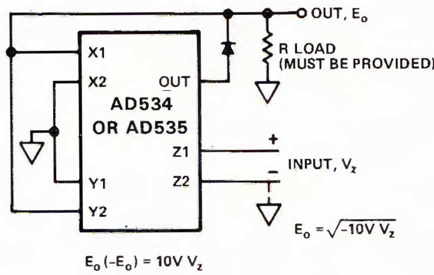


Figure 5. Connection of the AD534/AD535 for square rooting

If the output circuit does not provide a resistive load to ground, one should be connected (about 10kΩ) to maintain diode conduction. For critical applications, the Z offset can be adjusted for greater accuracy below 1V.

POLARITY

The AD534 is a 4-quadrant multiplier. This means that, for its two inputs, there are four possible permutations of polarity, and the output product will always be of the correct polarity. The inputs can be mapped on the four quadrants of an X-Y plane, as shown in Figure 6 (hence the term "4-quadrant"). Some multipliers will operate in only one or two quadrants. A two-quadrant multiplier will accept a ± signal at one input and a unipolar signal at the other; in the single-quadrant case, the inputs are restricted to a single polarity for each input.

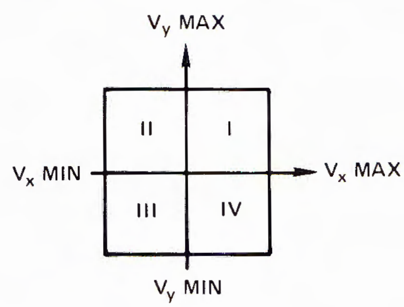


Figure 6. Input plane showing multiplication quadrants

Dividers are either two-quadrant or one-quadrant devices, because, as noted earlier, the denominator may have only one polarity. However, in the case of devices having the extra degrees of freedom provided by differential inputs, the X input may be of either polarity, as long as it is connected to X_1 and X_2 in the proper sense.

SPECIAL MULTIPLICATION-DIVISION FUNCTIONS

The 436 is an example of a specialized, dedicated, high-performance, two-quadrant divider only. The 433 and 434 are examples of three-input single-quadrant high-accuracy multiplier dividers (YZ/X); the 433 has the further distinction that the exponent of the ratio (Z/X) can be adjusted from 1/5 to 5 i.e., $Y(Z/X)^m$. In the AD531 IC, the internal reference current may be manipulated externally, permitting a form of three-variable multiplier-divider, in which the scale constant can be varied.

SCALING

As mentioned earlier, multipliers are almost always designed (but not necessarily *constrained*) to have a dimensional scale constant, E_R, of 10V. This permits either input to have any value in the 10V full-scale range, without causing the output to exceed 10V. For applications in which the maximum range of the inputs is substantially less than 10V, or if the multiplier is used for division and the numerator can exceed the denominator, it is helpful to use a smaller value of E_R. This can be done with the AD534, the AD531, the 433, and the 434.

BRIEF DEFINITIONS[2]

The most obvious specification of importance is *accuracy*, which may be defined in terms of the *total error* of the multiplier at room temperature and constant nominal supply voltage. Such errors include input and output dc imperfections, plus nonlinearity, plus feedthrough. *Temperature dependence* and *supply variation* effects are specified separately.

Scale Factor The scale-factor error is the difference between the average scale factor and the ideal scale factor of $(10V)^{-1}$. It is expressed in % of the output signal and can be trimmed for critical applications. *Temperature dependence* is specified.

Output Offset refers to the offset voltage at the output-amplifier stage. This is usually minimized at manufacture and can be trimmed where high accuracy is desired. Remember that the output offset will drift with temperature.

Linearity error, or *nonlinearity*, is the maximum difference between actual and theoretical output, for all pairs of input values, expressed as a percentage of full scale, with all other dc errors nulled, i.e., the irreducible minimum error. It is usually expressed in terms of X and Y nonlinearity, with the named input swinging over its full-scale range, and the other input at 10V. If the user recognizes that linearity errors are usually largest at large input values, improvement in predicted linearity can be gained, for small inputs, using the approximate nonlinearity equation: $f(X,Y) = |V_x|\epsilon_x + |V_y|\epsilon_y$, where ϵ_x and ϵ_y are the specified linearity errors, and V_x and V_y are the maximum respective input signal ranges.

X or Y *Feedthrough* is the signal at the output for any value of X or Y input when the other input is zero. It has two components, a linear one corresponding to an *offset* at the zero input, which may be trimmed out (but can drift), and a nonlinear one which is irreducible. Feedthrough is usually specified at one frequency (50Hz) for a 20V p-p sinewave input and increases with frequency.

Dynamic parameters include *small-signal bandwidth*, *full-power response*, *slew(ing) rate*, *small-signal amplitude error*, and *settling time*. These terms should be familiar to all but the most dc-minded op-amp users. *Small-signal bandwidth* is the frequency at which the output is down 3dB from its low-frequency value (i.e., by about 30%), for a nominal output amplitude of 10% of full scale. *Full-power response* is the maximum frequency at which the multiplier can produce full-scale voltage into its rated output load without noticeable distortion. *Slew(ing) rate* is the maximum rate of change of output voltage for a large input-signal step change. *Small-signal amplitude error* is defined in relation to the frequency at which the amplitude response, or scale factor, is in error by 1%, measured with a small (10% of full scale) signal. *Settling time* (for a ±10V step, multiplied by 10V), is the total length of time the output takes to respond to an input change and stay within some specified error band of its final value. Settling time cannot be accurately predicted from any other dynamic specifications; it is specified in terms of a prescribed measurement. *Vector error* is the most-sensitive measure of dynamic error. It is usually specified in terms of the frequency at which a phase error of 0.01 radian (0.57°) occurs.

In variable-transconductance multipliers, the most-significant lags occur in the output stage, with considerably smaller differential lags between the inputs. Thus, they are well-suited to such applications as power measurement, where input phase may be important, but the output is usually filtered.

[2]Complete definitions and tests can be found in the NONLINEAR CIRCUITS HANDBOOK.