intech ADVANCED ANALOG

MODEL 551 MULTIPLIER

DESCRIPTION

The Model 551 is an accurate analog multiplier that can be used for multiplying, dividing, or square-rooting. *Total error* over all four quadrants with any combination of X and Y inputs between ±10V is less than ±0.25%. That's right, the total error is less than ±25mV! Although the 551 multiplier circuit uses the transconductance effect, a new error-nulling technique was developed by FMI to significantly improve accuracy. The *performance* of the 551 is comparable to expensive pulse-height-pulse-width types, but the *cost* is comparable to transconductance-type multipliers. And you don't have to add expensive external trim pots to have ±0.25% accuracy. . .we ship the multiplier to you with the accuracy built into the unit *and* fully tested. Also, the accuracy is very stable over the full temperature range. And the package size of 1.5" x 1.5" x 0.4" is unusually small for a high-accuracy multiplier. So the Model 551 Multiplier offers an unprecedented combination of good *accuracy* and *stability, small size,* and *low cost.*

APPLICATIONS

The Model 551 Multiplier computes the product of two input voltages. But by varying external connections, the 551 can also be used for dividing and square-rooting. Pin connections for these other modes of operation are shown on page 4.

Multipliers are also used in general instrumentation for. . .

- Measuring Power
- Measuring RMS Levels
- Linearizing Signals
- Controlling System Gain

And in sophisticated communications and display systems for. . .

- Frequency Doubling
- Modulating
- Demodulating
- Voltage-Tuning of Active Filters and Oscillators
- Linearizing CRT Displays
- Coordinate Rotation

FILTERING OF NOISE

The accuracy of the Model 551 Multiplier is so good that semiconductor noise becomes a limiting factor on accuracy. With the 551, you can easily add a low-pass filter to trade off bandwidth for reduced noise. Simply add a capacitor C_O between the pins "SJ" and "OUT". This will provide a 6dB/octave roll-off with a time constant of 140kΩ x C_O seconds. Pin "SJ" is the summing junction of the output amplifier, so this low-pass filter acts only on the output stage. See Figure 1 for a simplified diagram.

FEATURES. . . . .

Accuracy of ± 0.25% without external trimming!

Low Drift . . . . . .±0.015%/°C

Low Noise 1.5mVrms

Low Price. . . . . . .

Output: $E_O = \frac{XY}{10}$

Time Constant: $R_O C_O$, where $R_O \sim 140k\Omega$

Optional User-Added Capacitor

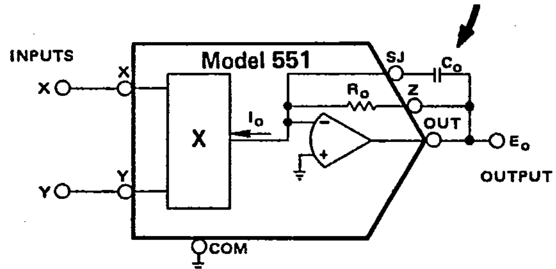


Figure 1. Low-Pass Filtering of the 551 Multiplier Output

ELECTRICAL SPECIFICATIONS—MULTIPLY MODE

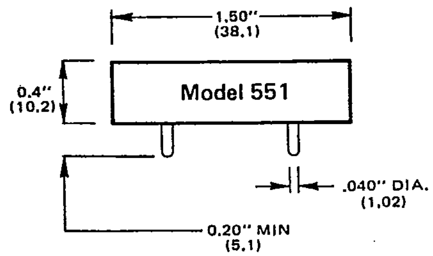
(Typical at 25 °C and ±15Vdc unless otherwise specified.)

MODEL	551
ACCURACY	
Total Error (1)	±0.25% max
Avg. Error vs. Temperature (2)	±0.015%/°C max
Avg. Error vs. Supply	±0.05%/%
Output Noise up to 10kHz	1.5mVrms
Nonlinear Component of Error	±0.1% max
Warm—Up Time	1 minute
INPUTS (Both X and Y)	
Input Voltage Range	
for Rated Accuracy	±10V
for Safe Operation	±16V
Input Impedance	50kΩ
Input Bias Current	100nA max
OUTPUT	
Output—Voltage	±10V
—Current	±5mA
Output Impedance	1Ω
FREQUENCY RESPONSE	
-3dB Small Signal	200kHz
Small-Signal Amplitude Error	±1% at 10kHz min
Small-Signal Vector Error	±1% at 1kHz
Full-Power Response	10kHz
Slew Rate	0.6V/μsec
Settling-Time for 20V Step	50μsec to 0.1%
TEMPERATURE RANGE	
Rated Specifications	-25°C to +85°C
Storage	-55°C to +100°C
POWER SUPPLY	±14Vdc to ±16Vdc
Supply Drain at Quiescent	±18mA

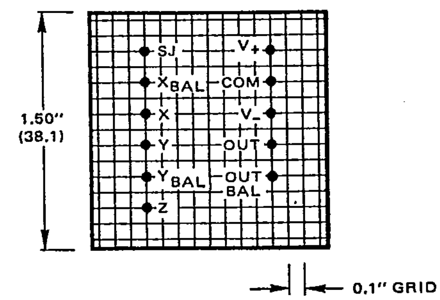
(1) Percent of full-scale, so the maximum error is ±25mV. Includes all error terms (offsets, gain and nonlinearity) for any combination of X and Y. The output offset (X=0, Y=0) component of error is less than ±10mV at 25°C, and is typically ±5mV.

(2) Over 0 °C to +70 °C; double for the -25 °C to +85 °C range. This drift spec includes all error components (offsets, gain, and nonlinearity) for any combination of inputs X and Y. It is given as a percent of full-scale, so the maximum drift is 1.5mV/ °C. Of this, the output offset drift (X=0, Y=0 condition) is guaranteed to be less than ±0.2mV/°C over +25°C to +70°C, and ±0.4mV/°C over -25°C to +85°C.

OUTLINE DIMENSIONS

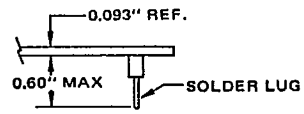


Dimensions in millimeters are shown in parentheses.



Case: Black Epoxy
Pins: Gold-flashed over silver plated, ½ hard brass
Weight: 1.5 oz.
Mating Socket: MS10. Unit price (1-99)

MS10 is made of glass-epoxy board with swaged-in terminals. It has 11 terminals that mate with the pins of the 551 multiplier.



TYPICAL ON FMI SOCKETS

PIN CONNECTIONS

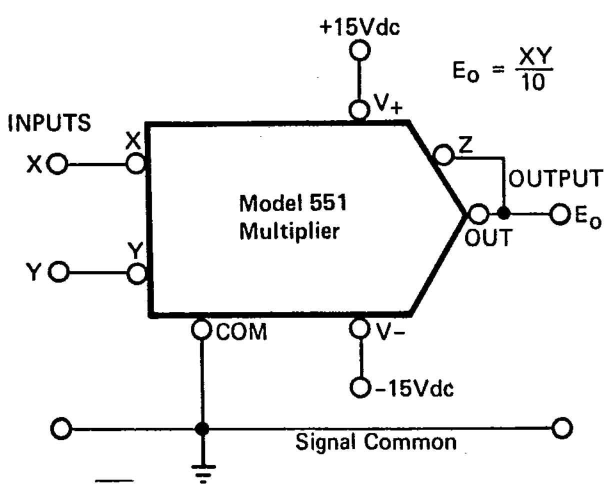


Figure 2. Pin Connections in Multiply—Mode

PERFORMANCE

Accuracy

An ideal multiplier would have an output of XY/10 volts, where X and Y are two input voltages ranging between ±10Vdc. Since the Model 551 has a full-scale output of ±10Vdc and a specified accuracy at 25°C of ±0.25%, the output must be within ±25mV of the ideal XY/10 volt output for any combination of X and Y. This total error limit of ±25mV includes output offset, input offsets, gain, and nonlinearity. For critical applications, the output offset, input offsets, and gain can be externally trimmed. The nonlinearity is a maximum of ±0.1% with X of ±10V and sweeping Y through ±10V, or with Y of ±10V and sweeping X through its range of ±10V. Also, the nonlinearity with X=0 or Y=0 is less than ±0.1% of full-scale. Since the linear error terms may be trimmed externally, the ±0.1% nonlinearity is the final limit on accuracy. The initial, untrimmed output offset will be less than ±10mV. The total error is given by.

$$\text{Error} = \underbrace{E_{os}}_{\text{OUTPUT OFFSET}} + \underbrace{\epsilon_x Y + \epsilon_y X}_{\text{INPUT OFFSET}} + \underbrace{K\frac{XY}{10}}_{\text{GAIN ERROR}} + \underbrace{f(X,Y)}_{\text{NON-LINEARITY}}$$

With the 551 multiplier, trimming E_{os}, ϵ_x, and ϵ_y to zero will generally reduce the error to ±0.1%.

Drift

Each of the error components (output offset, input offsets, and nonlinearity) change with temperature. Total error drift for the 551 is a maximum of ±0.015%/°C (or ±1.5mV/°C) from 0°C to +70°C. Of this drift, the gain component is typically ±0.002%/°C. Output offset drift is less than ±0.2mV/°C from +25°C to +70°C, and is less than ±0.4mV/°C from -25°C to +85°C. In conventional transconductance multipliers, the nonlinearity drift is usually very large. A new circuit technique was developed by FMI to compensate for drift in nonlinearity. The result is a remarkably low total drift that is typically better than ±0.01%/°C, and is guaranteed to be less than ±0.015%/°C.

Frequency Response

The accuracy is better than ±0.25% at low frequency but degrades with increasing signal frequency. The "small-signal frequency response" is measured with DC on either the X or Y input and with a small AC signal on the other input. The -3dB small-signal response is 3dB—down in amplitude from its ideal value. Small-signal amplitude error is a more meaningful spec—this is the frequency at which the amplitude error exceeds ±1%. A curve of amplitude error-versus-frequency is shown in Figure 3. Vector error is found by directly subtracting the output from the input, so it is very dependent on phase-shift from input to output. An input-to-output phase shift of only 0.57° will cause a vector error of 1%.

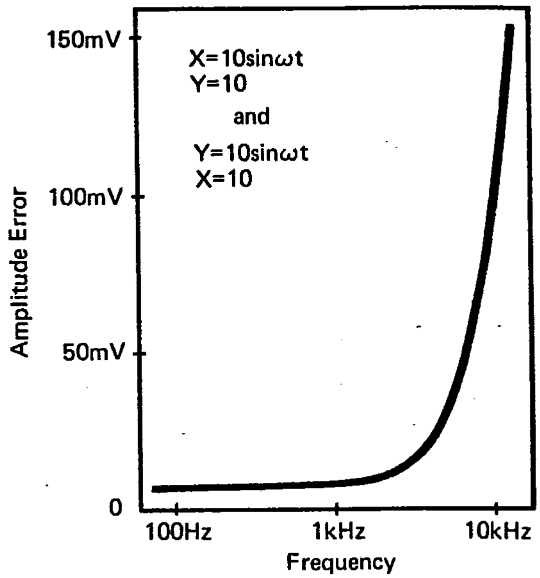


Figure 3. Amplitude Error vs. Frequency

AC null suppression is a critical factor in modulator applications. This is also referred to as "feedthrough". It is measured with zero on one input and a full-scale AC signal of 20V peak-to-peak on the other input. The output should be zero, but a small amount of the AC input will show up at the output. AC feedthrough depends on the input offsets, the nonlinearity around zero, and input-signal frequency. The input offset may be externally trimmed to minimize AC feedthrough, but at low frequencies it will always be less than 20mV peak-to-peak for the Model 551. Typical curves of AC feedthrough are shown below.

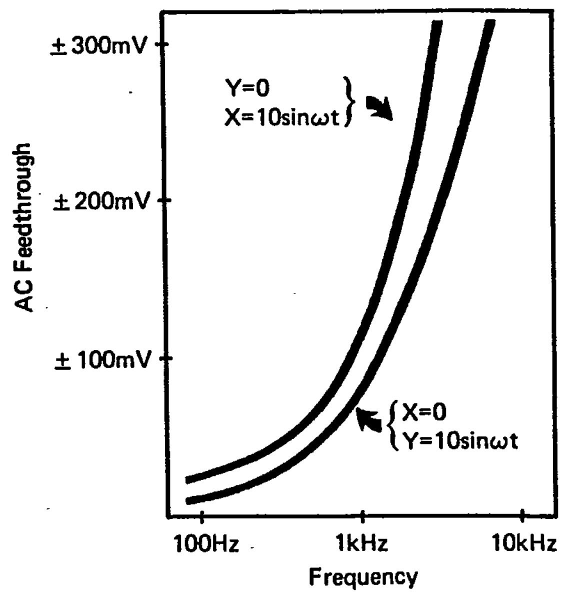


Figure 4. AC Feedthrough vs. Frequency

OPERATION

Multiply Mode

For multiplication, connect pin Z to OUT, as shown on page 2, and apply the inputs to pins X and Y. External trimming is usually not needed, but the unit has provisions for trimming all linear components of error if desired.

Output Offset: To adjust the output offset, make both X and Y zero. Then connect a 50kΩ potentiometer between ±15V, connect the wiper to pin OUT_{BAL}, and adjust for zero at pin OUT. Adjustment range is ±40mV.

Input Offset: To minimize AC feed-through with X=0 and Y=10sinωt; connect a 50kΩ potentiometer between ±15V, connect the wiper to pin X_{BAL}, and adjust for minimum output at pin OUT. Reverse the input connections to adjust Y_{BAL}. Range of adjustment is about ±30mV.

Gain Adjustment: First add a 2MΩ resistor between pins SJ and Z to lower the gain, then add a 20kΩ potentiometer between pins Z and OUT as shown below.

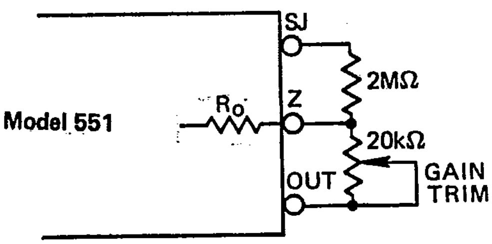


Figure 5. Optional Gain Trimming

This provides a ±6% range of adjustment.

Divide Mode

For use as a divider, the 551 is connected as shown in Figure 6. The internal op amp will make Z/R_O equal to $XE_O/10R_O$, so the output E_O will be 10Z/X. There are two restrictions. . .

- The ratio of Z/X must be less than unity.
- The denominator X must be a negative voltage. Therefore, the output will be negative when the numerator Z is positive.

Error in divide-mode becomes greater as the denominator becomes smaller. With a multiplier error of ϵ_m, the error in divide-mode is:

$$E_o = \frac{10Z}{X} - \frac{10}{X}\epsilon_m \quad \text{Error in Divide-Mode}$$

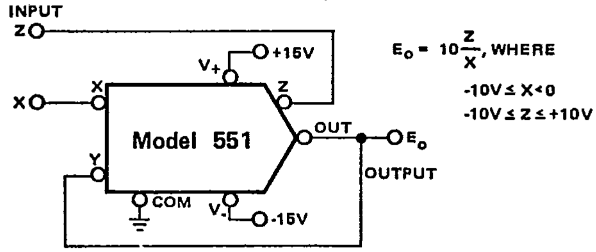


Figure 6. Connections for Divide-Mode

So the error in divide-mode is ±0.25% of full-scale (±25mV) when the denominator is at -10V, but becomes larger as X becomes smaller. Also, the bandwidth is reduced as the denominator becomes smaller. The -3dB bandwidth is approximately 120kHz with X of -10V, and 40kHz with X of -5V.

To externally trim error, first connect the unit in multiply-mode and trim the unit as a multiplier, then connect to divide. If gain is trimmed, the 20kΩ gain trim pot should be in series with the Z-input.

Square-Root Mode

Square-rooting is accomplished by putting the multiplier into a feedback loop as shown in Figure 7.

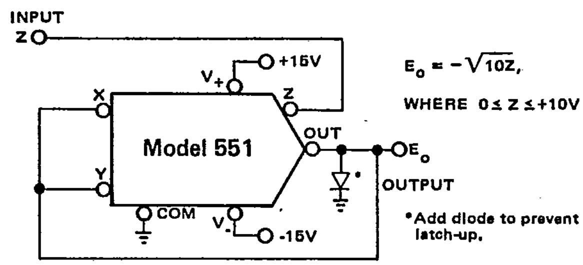


Figure 7. Connections for Square-Root Mode

The input signal must be positive, and as a practical matter must be limited in dynamic range. The error in square-root mode becomes greater as the input signal becomes smaller. With a multiplier error of ϵ_m, the output will be:

$$E_O = \sqrt{10Z - 10\epsilon_m} \quad \text{Error Term}$$

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