

Experiment 1

Continuous-Time Signals:

Audio Generation, Multiplication, Squaring and Square-Rooting

Systems and Signals Laboratory

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Electronic components required for this experiment

- AD633 analog multiplier
- 0.1μF (ceramic disk, 20%) capacitor (2)

For the bonus square-rooting circuit you will need the following additional components:

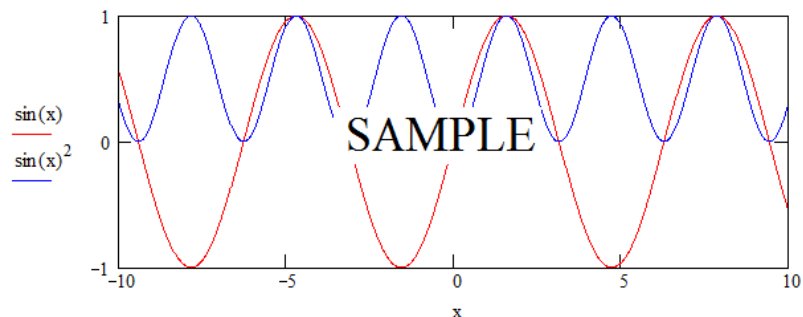
- LM741 operational amplifier
- 1N4148 (fast switching) diode
- 10kΩ (1/4 Watt, 5%) resistor (2)
- 10kΩ breadboard compatible potentiometer (mini pot)

1. Pre-lab

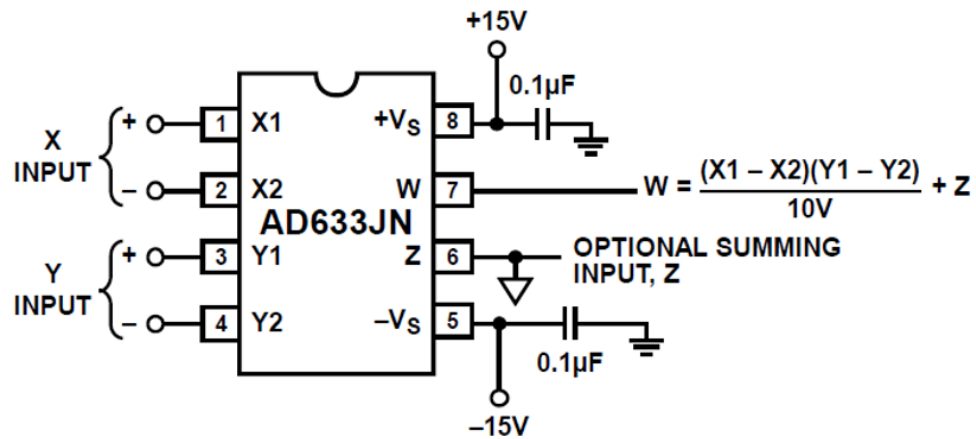
- a. Squaring a sinusoid leads to frequency doubling (and DC bias) according to the trigonometric identity

$$\sin^2 x = \frac{1}{2}(1 - \cos 2x)$$

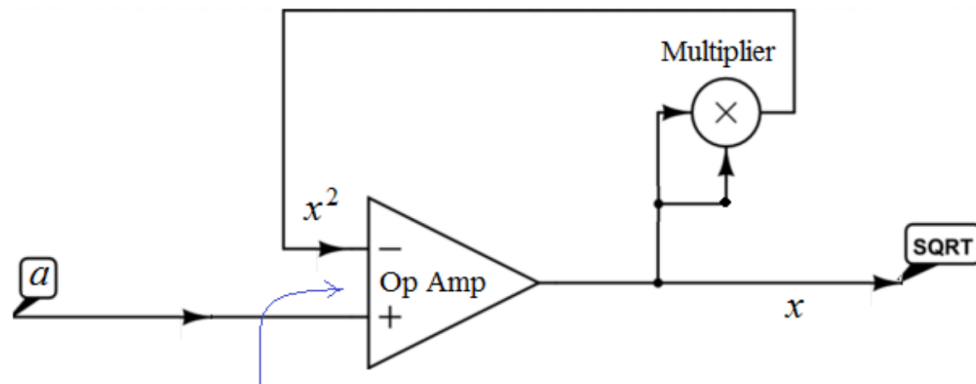
Verify the above identity by plotting. Also, generate a single plot that displays $\sin(x)$ and $\sin^2 x$. Your plot should look similar to the plot in the following figure.



- b. Familiarize yourself with the AD633 analog multiplier chip by reading its data sheet.

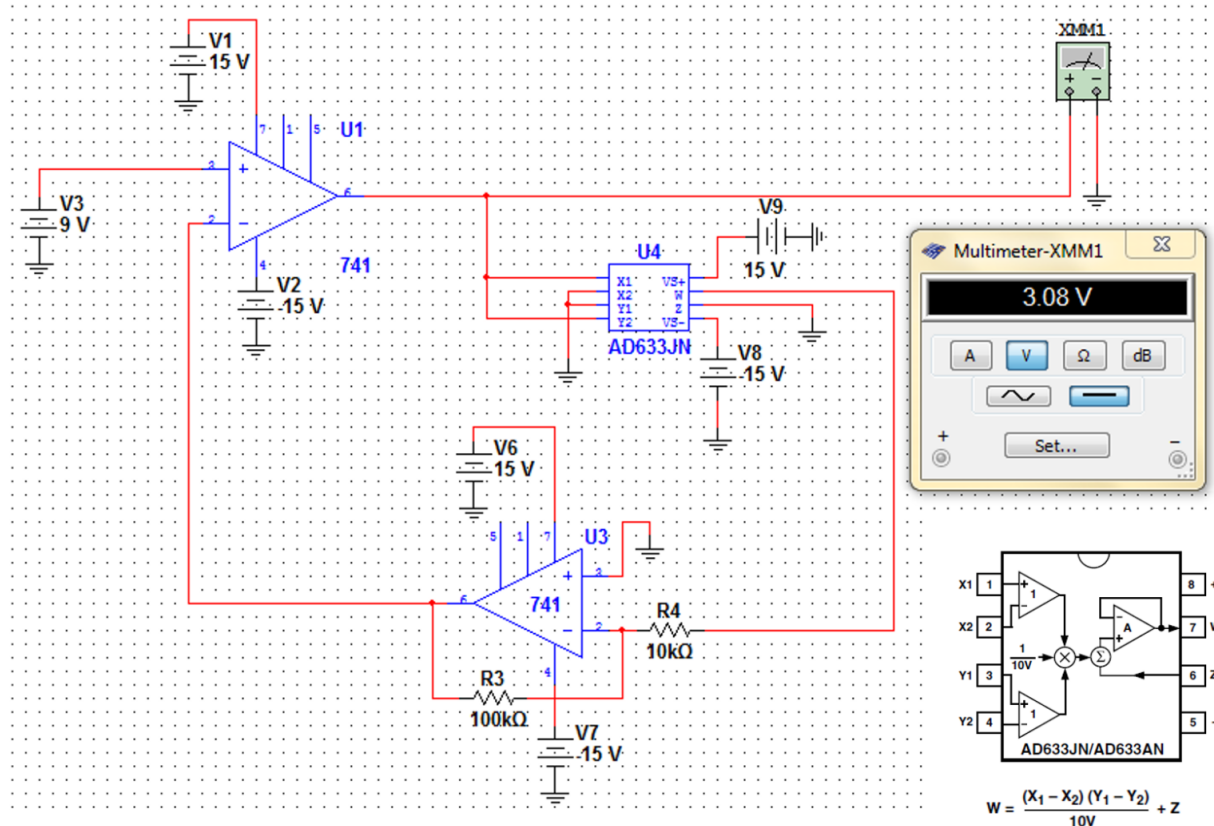


- c. The following circuit generates the square root of its input.



Op Amp forces its input voltage to zero; i.e., $x^2 = a$.

Simulate the above circuit using Multisim employing the AD633 multiplier and the 741 op amp. Since the multiplier divides by 10, an additional amplifier with gain +10 is required in the circuit. An inverting amplifier of gain -10 can be used. In this case, the extra -ve sign can be taken care of by using pins 1 (X1) and 4 (Y2) of the multiplier to generate $-x^2$. The simulated circuit is shown below. Determine the output of your simulation for the input voltages: 10, 9 and 4.



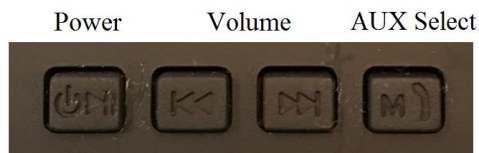
- d. Throughout this laboratory course you will be making use of a circuit breadboard to build and power your circuits. Read about how to properly use a [circuit breadboard](#).
- e. Read the following lab activity. This is the experiment that you will be performing in the upcoming lab session.

2. Lab activity

In this experiment you will employ a speaker to listen to the sound of a pure sinusoid and determine the range of frequencies that the human ear is capable of hearing. Then, you will attempt to predict whether a signal is sinusoidal, triangular or square by listening to it on a speaker. You will also build an AD633 analog multiplier circuit and use it to perform signal multiplication and squaring.

Warning: In the following procedures that involve the speaker make sure that the speaker volume is set so that it is loud enough to hear the signal, but in a way that is comfortable and safe to your ears.

- a. Use the waveform generator to generate a sine wave (1Vpp, 100Hz) frequency) on CH 1. Connect CH1 to the speaker using the BNC-to-3.5mm-plug (shown in the following figure).



Switch the speaker on and set its volume so that you can comfortably hear the signal. Describe the sound of the signal as you vary the frequency between 10Hz and 400Hz (by increments of 10Hz). Use the large waveform generator knob to vary the frequency. Use your smart phone to record the audio signal as you vary the frequency from 100Hz to 400Hz (you are asked to submit this recording along with your lab report). As you increase the frequency, you will have to lower the speaker's volume so that the audio generated is always comfortable to your ears. Determine the lowest audible frequency.

Remember to always make note of your measurements and write down your observations in your lab journal.

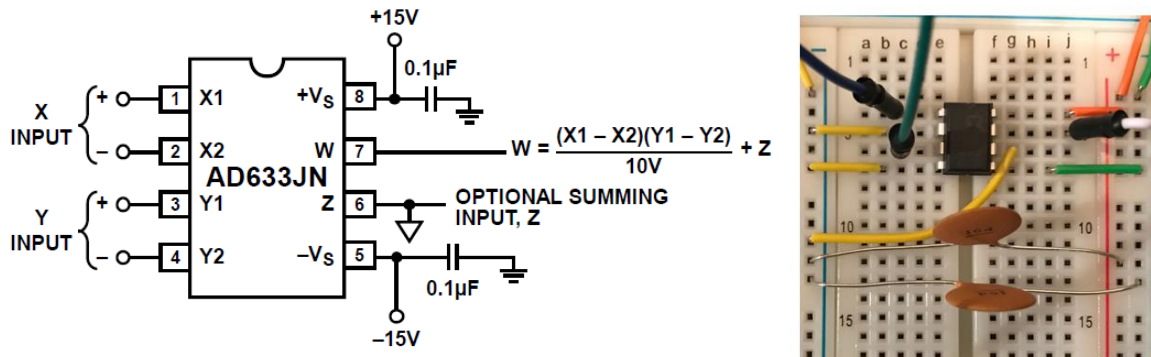
- b. Repeat Part a for frequencies between 1kHz and 15kHz (by increments of 1kHz). Use the large waveform generator knob to vary the frequency. You need to adjust the speaker's volume, as needed, so that the audio is always comfortable to your ears. What is the value of the highest audible frequency?
- c. How does a 1kHz (1Vpp) sine wave sound? How does a 1kHz (1Vpp) triangular wave sound? How does a 1kHz (1Vpp) square wave sound. Record the audio generated by each of these signals. Next, try to predict the waveform from its sound as your lab partner sets the waveform generator to output a sine, triangular and square signals (in a random order, while you are not looking). Rank the waveforms from highest pitch to lowest pitch. What property of a periodic waveform (with a fixed frequency) increases the waveform pitch? Explain in your report.

Switch off the speaker and disconnect it from the waveform generator.

It is lab policy that you (under the supervision of your lab instructor) store back all instruments, devices and cables that you use in the designated lab cabinet. You must do that now, before you proceed to the next step.

- d. Use the breadboard supplied to you by your instructor to install the AD633 analog multiplier chip (obtained from your lab instructor along with the breadboard wiring kit). *Please be careful not to bend or break the chip pins. Your lab instructor must verify the circuit connections before you apply power to the chip. Try to be as neat as possible when you breadboard your circuit.*

The following is a sample built circuit. Use your cellphone camera to take a picture of your completed circuit for inclusion in your lab report.



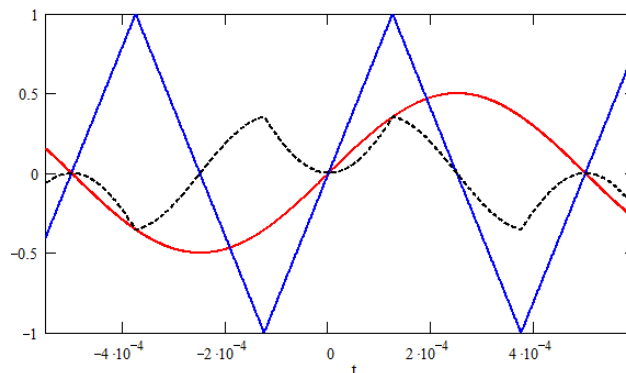
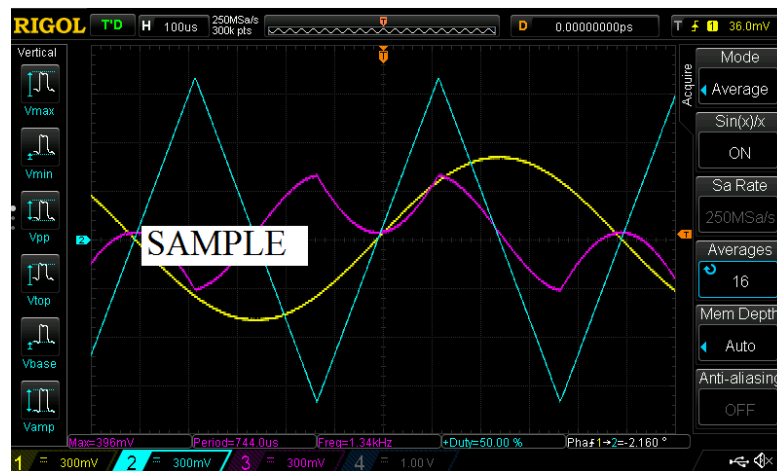
Ask your lab instructor to provide you with three BNC-to-hook-clip cables. Use two cables to connect two signals generated by the waveform generator on CH1 and CH2, respectively. The other cable is to be used to connect the output of the AD633 multiplier to CH1 of the scope. You will also need three banana-to-alligator-clip cables to power the chip (refer to the following figure to identify the cables) and two 0.1μF capacitors. The capacitors are used to suppress any sudden fluctuations in the supply voltage.

Make sure to always separate the alligator clips from each other so that you do not short the DC supply. If needed, ask your instructor for electric tape to isolate the clips from each other.

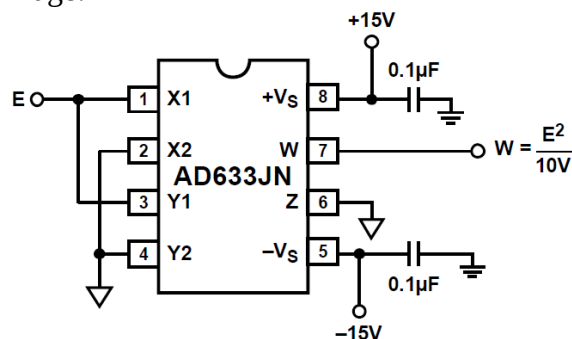


- e. Employ the circuit (from Part d) to multiply a 1kHz (1Vpp) sine wave and a 2kHz (2Vpp) triangular wave. Both signals are to have zero offset and be phase aligned. Recall that you have used the scope's "Math" utility in Experiment 0 to generate such waveform product.

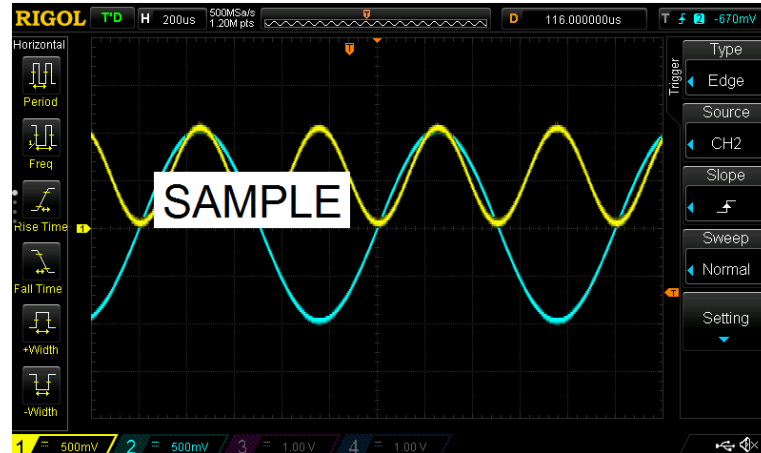
By grounding pins 2, 4 and 6 the chip will generate (on pin 7) the normalized product $W = X1 * Y1 / 10$. Display the sine, triangular and product waves on the scope's CH1, CH2 and CH3 respectively. In order to undo the division by 10 present in the output W , set the scope's CH3 probe to 10X. Also, set all channels to 300mV/div and 100 μ s/div. Save the scope's display on your memory stick. The following sample scope display employs the "averaging mode" that can be accessed from the "Acquire" Menu. Also shown below is the Mathcad generated signal product.



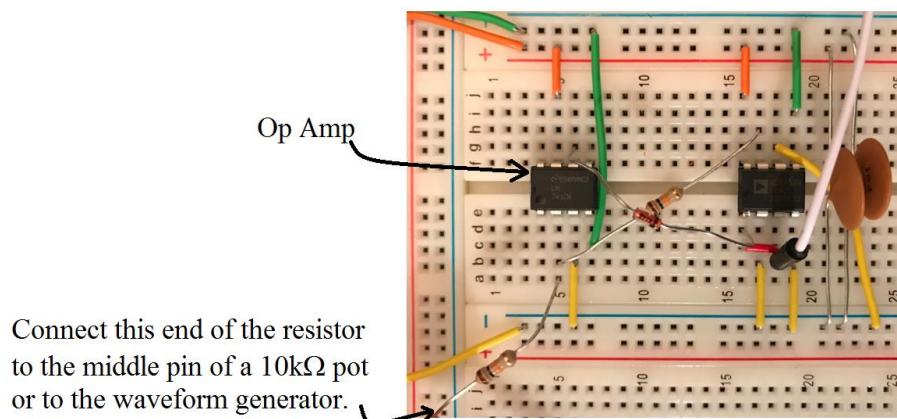
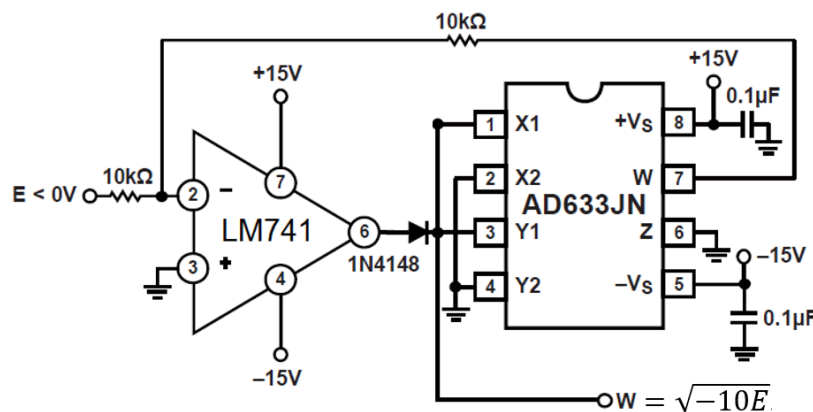
- f. Modify the multiplier circuit (according to the following figure) in order to perform the squaring of a (2Vpp, 1kHz) sine wave. Connect the output signal W to the scope CH1 (set to 10X probe). Connect the input signal to CH2 (set to 1X probe). If the traces are not stable, try to set the triggering source (access it from the trigger menu button) to CH2. Save the scope's trace image.



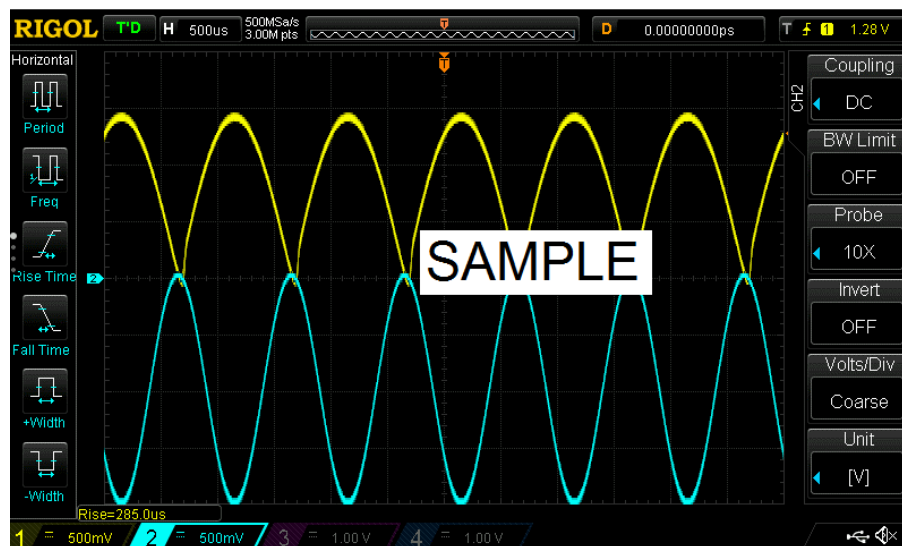
A sample scope display is shown below.



- g. **(Bonus: Square-rooter circuit.** Arrange with your lab instructor to complete this bonus at a convenient time) Add the operational amplifier (use an LM741) to the above squaring circuit, as shown below. The 1N4148 diode is required to prevent latch up, which can occur in such applications if the input were to change polarity. The output voltage at pin 1 (or 3) of the AD633 is given by $W = \sqrt{-10E}$, where E is set to a negative value. So, if we want this analog square-rooter circuit to compute $\sqrt{9}$, we would have to set the input E to $-\frac{9}{10} = -0.9$.



- Use a voltmeter to measure W for $E = -0.9\text{V}$. Repeat for $E = -0.3\text{V}$ and -1.6V . In your report, you are to compute the relative error in percent for each case. Employ a $10\text{k}\Omega$ pot with pins 1, 2 (middle pin) and 3 connected to -15V , E and ground, respectively. Use a small screw driver to set the voltage E .
- Determine, experimentally, the largest value $|10E|$ for which the circuit can compute the square root. What determines this upper limit on $|10E|$?
- Next, generate and save the scope's display for the output signal W if the input signal is $E = -0.1 + 0.1\sin(2000\pi t)$. Note: E is a DC-offset 0.2Vpp sine wave of frequency 1kHz . Apply the input signal to the scope's CH2 and the square-root signal to CH1. Set the probes for CH1 and CH2 to 1X and 10X , respectively. Set CH1 and CH2 to 500mV/div and $500\mu\text{s/div}$. A sample scope display is shown below.



Restore the probe setting of all channels of the scope back to 1X before you leave the lab. Disassemble your circuit and sort the wires and components back in the storage bins, under your instructor's supervision. Be very careful while removing the AD633 chip (and the LM741) from the breadboard in order not to bend its pins.

3. Post-lab

Write your lab report according to the required format. Analyze and discuss, in details, all results obtained from your pre-lab and your lab activity in your report. Explain the limitations of the circuits that you have built. Also, report the absolute relative errors (in percent) for all experimental measurement whenever the true value is known.

Appendix 1

AD633 Analog Multiplier Data Sheet



Low Cost
Analog Multiplier
AD633

Data Sheet

FEATURES

4-quadrant multiplication
Low cost, 8-lead SOIC and PDIP packages
Complete—no external components required
Laser-trimmed accuracy and stability
Total error within 2% of full scale
Differential high impedance X and Y inputs
High impedance unity-gain summing input
Laser-trimmed 10 V scaling reference

APPLICATIONS

Multiplication, division, squaring
Modulation/demodulation, phase detection
Voltage-controlled amplifiers/attenuators/filters

GENERAL DESCRIPTION

The AD633 is a functionally complete, four-quadrant, analog multiplier. It includes high impedance, differential X and Y inputs, and a high impedance summing input (Z). The low impedance output voltage is a nominal 10 V full scale provided by a buried Zener. The AD633 is the first product to offer these features in modestly priced 8-lead PDIP and SOIC packages.

The AD633 is laser calibrated to a guaranteed total accuracy of 2% of full scale. Nonlinearity for the Y input is typically less than 0.1% and noise referred to the output is typically less than 100 μ V rms in a 10 Hz to 10 kHz bandwidth. A 1 MHz bandwidth, 20 V/ μ s slew rate, and the ability to drive capacitive loads make the AD633 useful in a wide variety of applications where simplicity and cost are key concerns.

The versatility of the AD633 is not compromised by its simplicity. The Z input provides access to the output buffer amplifier, enabling the user to sum the outputs of two or more multipliers, increase the multiplier gain, convert the output voltage to a current, and configure a variety of applications. For further information, see the [Multiplier Application Guide](#).

FUNCTIONAL BLOCK DIAGRAM

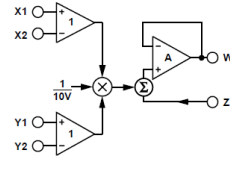


Figure 1.

The AD633 is available in 8-lead PDIP and SOIC packages. It is specified to operate over the 0°C to 70°C commercial temperature range (J Grade) or the -40°C to +85°C industrial temperature range (A Grade).

PRODUCT HIGHLIGHTS

1. The AD633 is a complete four-quadrant multiplier offered in low cost 8-lead SOIC and PDIP packages. The result is a product that is cost effective and easy to apply.
2. No external components or expensive user calibration are required to apply the AD633.
3. Monolithic construction and laser calibration make the device stable and reliable.
4. High (10 M Ω) input resistances make signal source loading negligible.
5. Power supply voltages can range from ± 8 V to ± 18 V. The internal scaling voltage is generated by a stable Zener diode; multiplier accuracy is essentially supply insensitive.

PIN CONFIGURATIONS AND FUNCTION DESCRIPTIONS

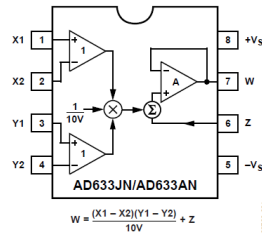


Figure 2. 8-Lead PDIP

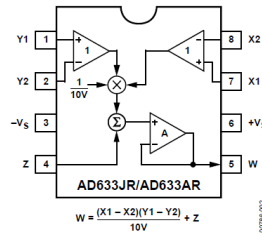


Figure 3. 8-Lead SOIC

Table 4. 8-Lead PDIP Pin Function Descriptions

Pin No.	Mnemonic	Description
1	X1	X Multiplicand Noninverting Input
2	X2	X Multiplicand Inverting Input
3	Y1	Y Multiplicand Noninverting Input
4	Y2	Y Multiplicand Inverting Input
5	-Vs	Negative Supply Rail
6	Z	Summing Input
7	W	Product Output
8	+Vs	Positive Supply Rail

Table 5. 8-Lead SOIC Pin Function Descriptions

Pin No.	Mnemonic	Description
1	Y1	Y Multiplicand Noninverting Input
2	Y2	Y Multiplicand Inverting Input
3	-Vs	Negative Supply Rail
4	Z	Summing Input
5	W	Product Output
6	+Vs	Positive Supply Rail
7	X1	X Multiplicand Noninverting Input
8	X2	X Multiplicand Inverting Input

Appendix 2

LM741 Operational Amplifier Data Sheet



LM741

SNOSC25D – MAY 1998 – REVISED OCTOBER 2015

LM741 Operational Amplifier

1 Features

- Overload Protection on the Input and Output
- No Latch-Up When the Common-Mode Range is Exceeded

2 Applications

- Comparators
- Multivibrators
- DC Amplifiers
- Summing Amplifiers
- Integrator or Differentiators
- Active Filters

3 Description

The LM741 series are general-purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439, and 748 in most applications.

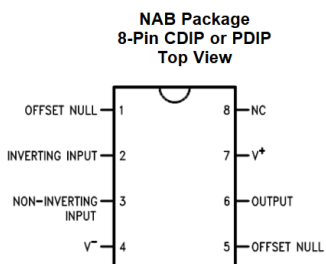
The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common-mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741 and LM741A except that the LM741C has their performance ensured over a 0°C to +70°C temperature range, instead of –55°C to +125°C.

Device Information⁽¹⁾

PART NUMBER	PACKAGE	BODY SIZE (NOM)
LM741	TO-99 (8)	9.08 mm × 9.08 mm
	CDIP (8)	10.16 mm × 6.502 mm
	PDIP (8)	9.81 mm × 6.35 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.



Pin Functions

PIN		I/O	DESCRIPTION
NAME	NO.		
INVERTING INPUT	2	I	Inverting signal input
NC	8	N/A	No Connect, should be left floating
NONINVERTING INPUT	3	I	Noninverting signal input
OFFSET NULL	1, 5	I	Offset null pin used to eliminate the offset voltage and balance the input voltages.
OFFSET NULL			
OUTPUT	6	O	Amplified signal output
V+	7	I	Positive supply voltage
V–	4	I	Negative supply voltage