Analog multiplier

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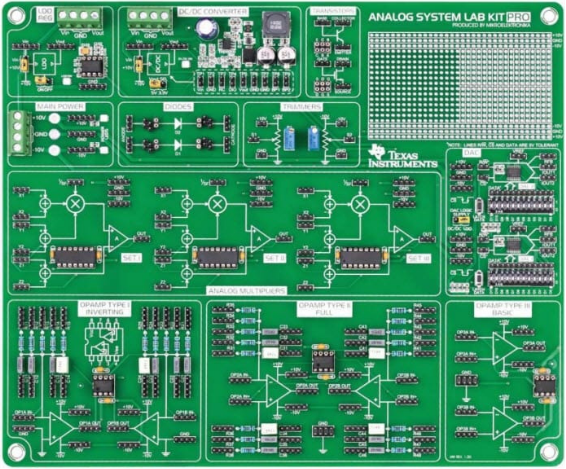
About the experiment

We are going to perform this experiment using Analog System Design TI ASLKpro Starter Kit donated by Texas Instruments(India).
The user manual of the kit can be found at `http://www.mikroe.com/downloads/get/1741/analog_system_lab_pro_manual.pdf`



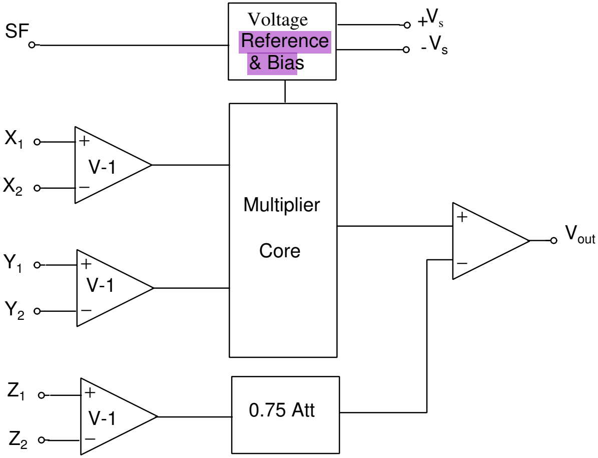
MPY634: Four Quadrant Analog Multiplier

The MPY634 has three differential inputs and a general purpose opamp at the multiplier output so that it can be easily configured for different scale factors or for inverse operations. Note that the default scale factor is 10.

In this experiment we shall use the IC for following applications/configurations.

- Four quadrant analog multiplier-basic testing, multiplication of two time varying signals, Analog divider
- Squarer and square rooter, use in True RMS measurement
- Amplitude modulation and demodulation
- Phase detection

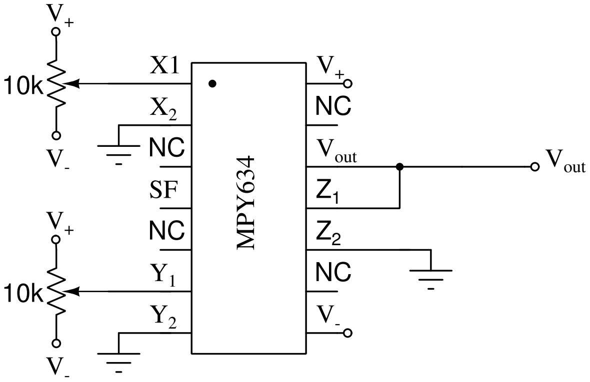
MPY 634: Analog Multiplier



$$V_{out} = A\left[\frac{(X_1 - X_2)(Y_1 - Y_2)}{SF} - (Z_1 - Z_2)\right]$$

Analog Multiplier: 1.Four Quadrant multiplication

The circuit diagram for this part of the experiment has been shown below.

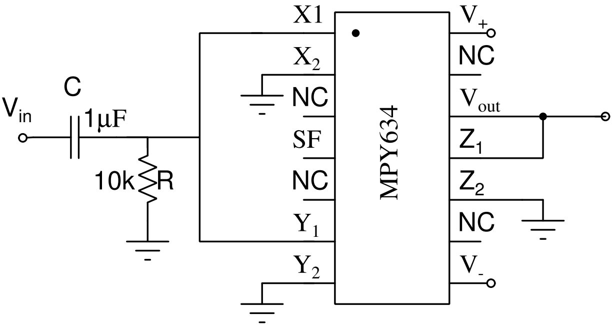


Four quadrant multiplication

Verify four quadrant multiplication operation by applying all four combinations of DC inputs polarities and measuring V_{out}.

1. For X_1 = 4 V and Y_1= 8 V.
2. For X_1 = 4V and Y_1= -8 V.
3. For X_1 = -4 V and Y_1= 8 V.
4. For X_1 = -4 V and Y_1= -8 V.

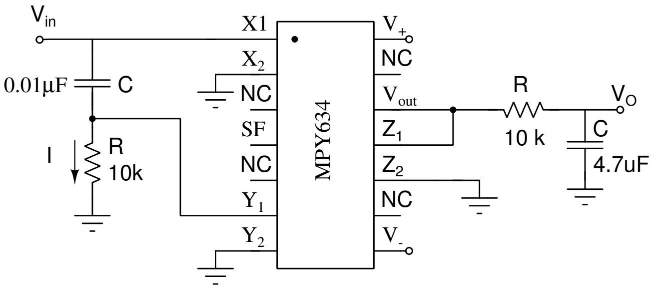
Squarer circuit-1



- The circuit behaves as a squarer circuit.
- The *RC* network ensures that the input signal does not have any DC component.
- Apply V_{in} of 10 V_{PP}, 1 kHz sinusoidal signal and observe V_{out} and V_{in} on oscilloscope in DC mode.

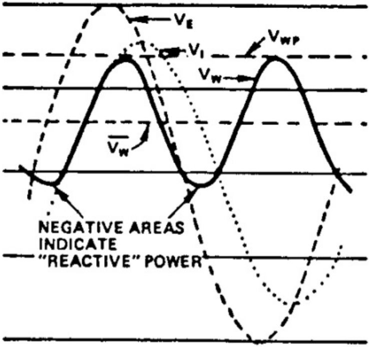
Squarer circuit-2

- $V_{out} = \dfrac{V_{in}^2}{10} = \dfrac{[5sin(2\pi 1000t)]^2}{10}$
- This is essentially the power dissipated in 10k resistor at the input in mW. (The scale factor is 10 and the resistor is 10K)
- The power will vary sinusoidally at twice the frequency of the input and will always be positive. Note the phase relations as well.
- Why does V_{out} have a DC offset? Use another RC circuit in the output circuit to eliminate the DC component in V_{out}.



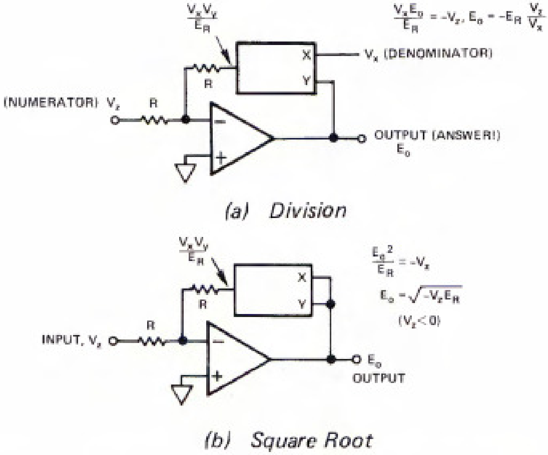
- Set V_{in} =5 Sin$2\pi 1000t$. Then $I = I_m Sin(2\pi 1000t - \phi)$.
- Note that Y_1= IR. Observe the voltage at Y_1 on DSO.
- Measure its amplitude and phase difference between X_1 and Y_1.
- Write the expression for the output of the multiplier V_{out}.
- The AC component of the output voltage can be measured at V_{out} on DSO in AC mode.
- Measure DC component of the multiplication at V_o on DSO at the output of RC network connected as LPF.

- Verify the values of the DC component V_o, amplitude and frequency of the AC component of the output voltage V_{out} and phase relation between the two inputs with their calculated values.
- Observe that, the V_{out} is the power in the input RC circuit (how?). Note that for part of the cycle, the power is negative, that is due to reactive power component introduced by the capacitor as shown in the figure below.



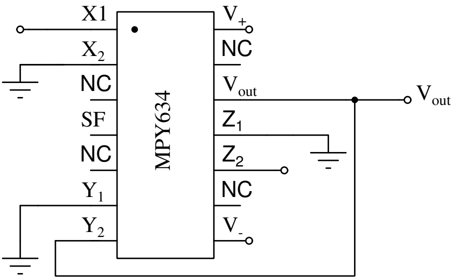
Conceptual divider and square rooter

1. Division and square rooting are inverse functions of the multiplication and squaring.
2. These can be implemented by placing the multiplier in the feedback as shown in figure below.



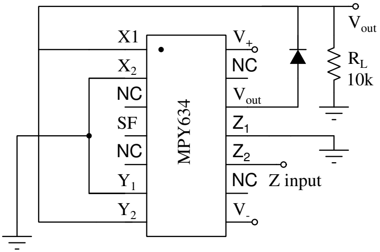
MPY 634 as Divider

- The MPY634 can be configured as a two-quadrant divider by connecting the multiplier in the feedback loop (applied to the Y_2 input) and using the Z_2 terminal as a signal input (numerator) and X_1 input is denominator, as shown in the figure below.
- Note that only one polarity of denominator is permitted, since reversal of the denominator reverses the sense of the feed-back loop.
- To ensure negative feedback, apply X input such that **0.1V** $\leqslant$ **X** $\leqslant$ **10V** while Z input can be bipolar time varying signal with swing $\pm$10V.
- Note, division by zero is not permitted.



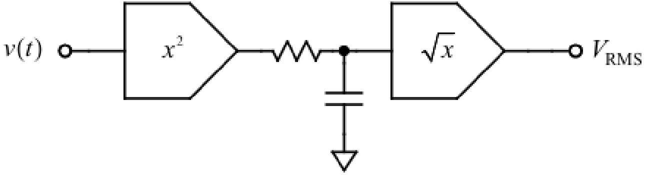
MPY 634 as Squarerooter

- Square rooter is one quadrant circuit that can compute square root of the input of either polarity such that $V_{out} = \sqrt{SF * Z_2}$.
- The feedback is incorporated by feeding output to X_1 and Y_2 inputs.
- Since real square roots occur only for positive arguments, it is necessary to constrain either input, or output or both, if the input changes the polarity to prevent "latch up".The diode and resistor ensure that the multiplier inputs never go negative, avoiding latch-up.
- Apply Z input in the range 2 to 9 V DC in steps of 1V and observe the output voltage.
- Do not dismantle the circuit. We will need it for the next part.



MPY 634 for "true RMS" measurement

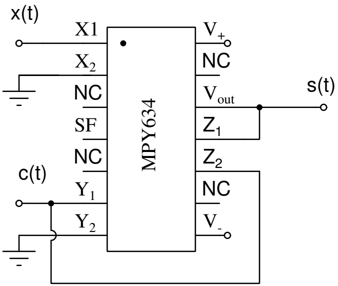
- RMS value of a time-varying signal is obtained by measuring the square root of average of its squared amplitude (squarer circuit), where the average is over a time interval usually much longer than the period of the lowest frequency AC component in the signal.
- We can realize the average using a low-pass filter with the cutoff frequency well below the lowest frequency of any AC signal component.



True RMS Measurement

- Configure the circuit shown above by choosing appropriate values of R and C. Use R = 15k and C = 4.7μF.
- Apply input signal with following specifications to measure and verify the output voltage:
  - Sinusoidal, triangular with amplitude 2, 4, 6, 8, and 10 V_{p-p} at frequency 1kHz.
  - The above signals with DC offset of 1V, 2V.
  - Connect a half wave rectifier using a diode and a resistor. Now apply the half wave rectifier output to the RMS measurement circuit. Apply the input voltage of 5 Sin$2\pi 1000t$ to the rectifier. What is the RMS value of half wave rectified signal? Measure and verify.
- Tabulate your results.

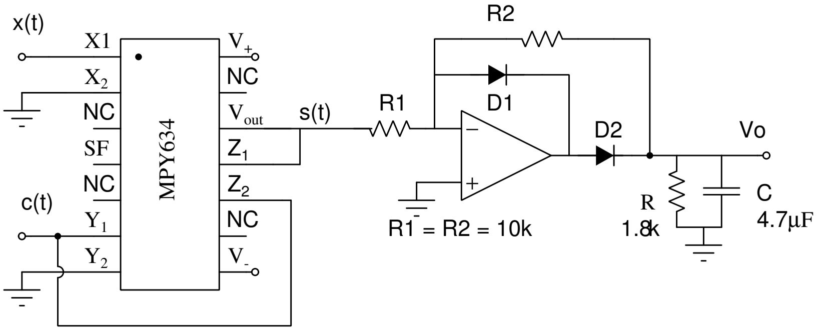
1. In amplitude modulation (AM), the amplitude of the carrier wave, a high frequency periodic signal, c(t) $= C sin(2\pi f_c t)$, is varied with the amplitude of the message signal x(t)=M$sin(2\pi f_m t)$ typically a lower frequency signal, to obtain modulated signal s(t). The resulting shape of the carrier as a result of modulation is called the envelope.
2. Figure shows how MPY634 can be used as a simple amplitude modulator. The continuous carrier signal is provided by summing the carrier at the Z_2 input which is connected to Y_1 input where the carrier signal is applied, and the modulating signal is applied to the X input.



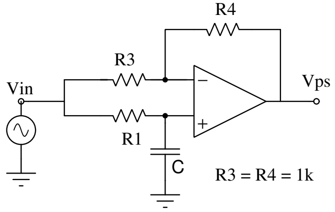
- Make the connections for the amplitude modulation circuit.
- Apply modulating signal x(t)=$2sin(2\pi 100t)$, and the carrier signal of c(t)=$2sin(2\pi 1000t)$.
- Observe the modulated voltage.
- Vary the amplitude and frequency of the carrier (for frequencies from 1KHz to 10kHz) and modulating signal (for frequencies from 100Hz-1kHz) and note the corresponding waveforms.
- This signal is transmitted by the AM transmitters.

Amplitude demodulation

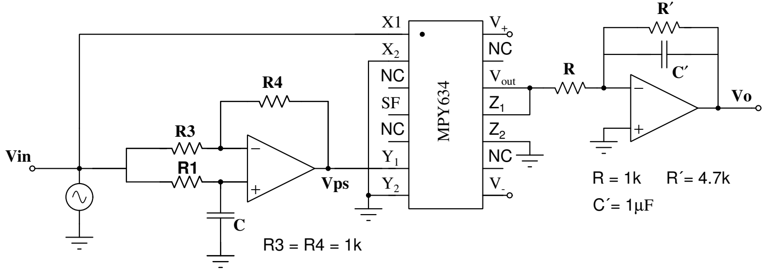
- Demodulation is the process in which the message signal is extracted from the modulated signal received by the receiver.
- Figure shows the precision rectifier with a capacitor filter used for this purpose.
- Connect the demodulator part to the modulator.
- Set =c(t)=$1.2sin(2\pi 10000t)$, x(t)=$2.5sin(2\pi 100t)$. Observe the amplitude modulated envelope and corresponding demodulated output.



- Multiplier can also be used to detect phase angle between the two phase shifted input signals.
- The circuit below shows an all pass filter which is used to introduce a phase shift.
- Derive the transfer function and explain how it can be use to generate the two phase shifted signals. What is the range of the phase angle that can be varied?
- Refer the schematic diagram of the board and use one of the "OPAMP TYPE II FULL" to implement the following circuit.
- Apply 8Vp-p, 1kHz input signal and observe the phase angle between V_{in} and V_{ps}. and verify the phase angle for following R1 =1k and C=1μF (Use onboard resistors and capacitors.)

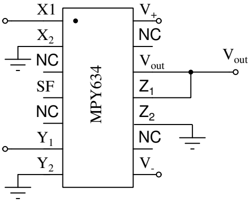


- Now connect the circuit shown below.
- Vary the resistor R1 from 1k, 2.2 k and 10k (onboard) for C $= 0.1\ \mu$F (C35 marked on the board) and observe the phase angle ϕ and V_o.
- Repeat the above step by connecting another capacitor (C36) in parallel with C35 to make effective capacitance C$=0.2\mu$F.
- Repeat for C $= 1\mu$F(C34) as well.
- Tabulate all t e observations and verify the observed output voltage with the calculated values for each phase angle.



Phase detector-3

- Disconnect the all pass filter from the multiplier.
- Apply $2V_{PP}$, 1 kHz signal at X input and the TTL output from function generator to Y input.
- Set the phase shift of 0^0, 90^0, and 180^0 between the signal and TTL output using phase menu of the AWG and observe the output voltage waveform for V_{out} and V_o in each case.
- Explain your observations. We shall revisit this concept in the next experiment!!



Squarer Circuit

Let input voltage be

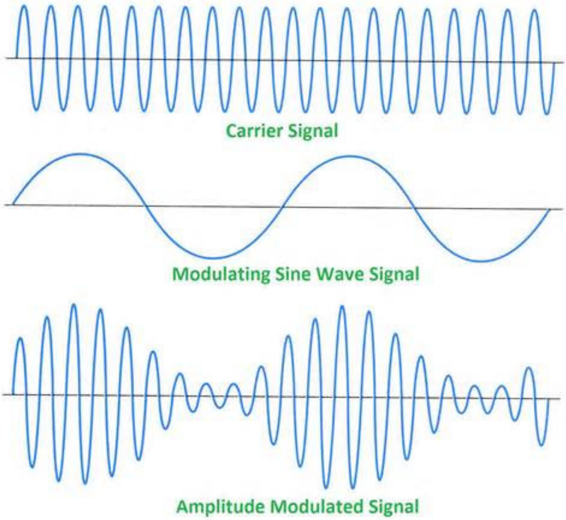
$$
\begin{aligned}
V_{in} &= V_m Sin\omega t \\
V_{out} &= \frac{(V_m Sin\omega t)^2}{SF} = \frac{V_m^2}{2SF}(1 - cos2\omega t) \\
&= \frac{V_m^2}{2SF} \text{ - } \frac{V_m^2}{2SF}(cos2\omega t)
\end{aligned}
$$

The first term is DC component and the second term is cosine wave with frequency 2ω.

Multiplication of two phase shifted sinusoidal signals

$$
\begin{aligned}
V_{in} &= V_m sin\omega t && \text{.......... X input}\\
Y_1 &= V_y sin(\omega t + \phi) && \text{..........Y input}\\
V_{out} &= (V_m sin\omega t)\ (V_y sin(\omega t + \phi))\\
&= \frac{V_m V_y}{2SF}(sin\omega t)(sin(\omega t + \phi))\\
&= \frac{V_m V_y}{2SF}[(cos\phi) - (cos(2\omega t + \phi)]
\end{aligned}
$$

Amplitude modulation waveforms



Amplitude demodulation waveform