

RESEARCH MIGRATION PROJECT

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TITLE - FOUR QUADRANT ANALOG MULTIPLIER

1) THEORY :

The proposed four-quadrant analog multiplier circuit is shown below. The OP-AMPS A1 and A2 are assumed to be well matched such that the quiescent current and the bias current of the OP-AMPS are equal. The MOSFETs M1 and M2 are also assumed to be matched and biased to operate in triode region. Expression for current in triode is :

$$I_d = K \frac{W}{L} \left[(V_{gs} - V_t) V_{ds} - \frac{V_{ds}^2}{2} \right] \quad (1)$$

where K is trans-conductance; W and L are the channel width and length of the MOSFET respectively. The other terms are of their usual meaning.

Since the source terminals of the MOSFETs M₁ and M₂ are virtually ground, thus using equation (1), the current I₁ and I₂ can be expressed as:

$$I_1 = K \frac{W}{L} \left[(V_G + v_2 - V_t) v_1 - \frac{v_1^2}{2} \right] \quad (2)$$

$$I_2 = K \frac{W}{L} \left[(V_G - V_t) v_1 - \frac{v_1^2}{2} \right] \quad (3)$$

If we assume R₁ = R₂ = R, then the output voltage of the OP-AMPS A₁ and A₂ i.e. v_{O1} and v_{O2} can be expressed as:

$$v_{O1} = -R K \frac{W}{L} \left[(V_G + v_2 - V_t) v_1 - \frac{v_1^2}{2} \right] \quad (4)$$

$$v_{O2} = -R K \frac{W}{L} \left[(V_G - V_t) v_1 - \frac{v_1^2}{2} \right] \quad (5)$$

The OP-AMP A₃ along with resistors R₃–R₆ form a differential amplifier, where R₃ = R₅ = R_i and R₄ = R₆ = R_f. The routine circuit analysis shows that the output voltage of the proposed circuit can be expressed as:

$$v_O = K \frac{W}{L} \left(\frac{R R_f}{R_i} \right) (v_1 v_2) = K_m (v_1 v_2) \quad (6)$$

where K_m = K $\frac{W}{L} \left(\frac{R R_f}{R_i} \right)$, is the multiplication gain. From equation (6), it is seen that the proposed topology can be used as a four- quadrant analog multiplier.

The main points to be noted - 1) both mosfet should be triode region.

2) ratio of the resistors should be maintained as mentioned.

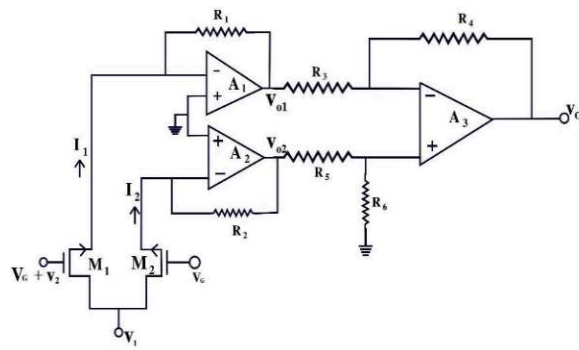
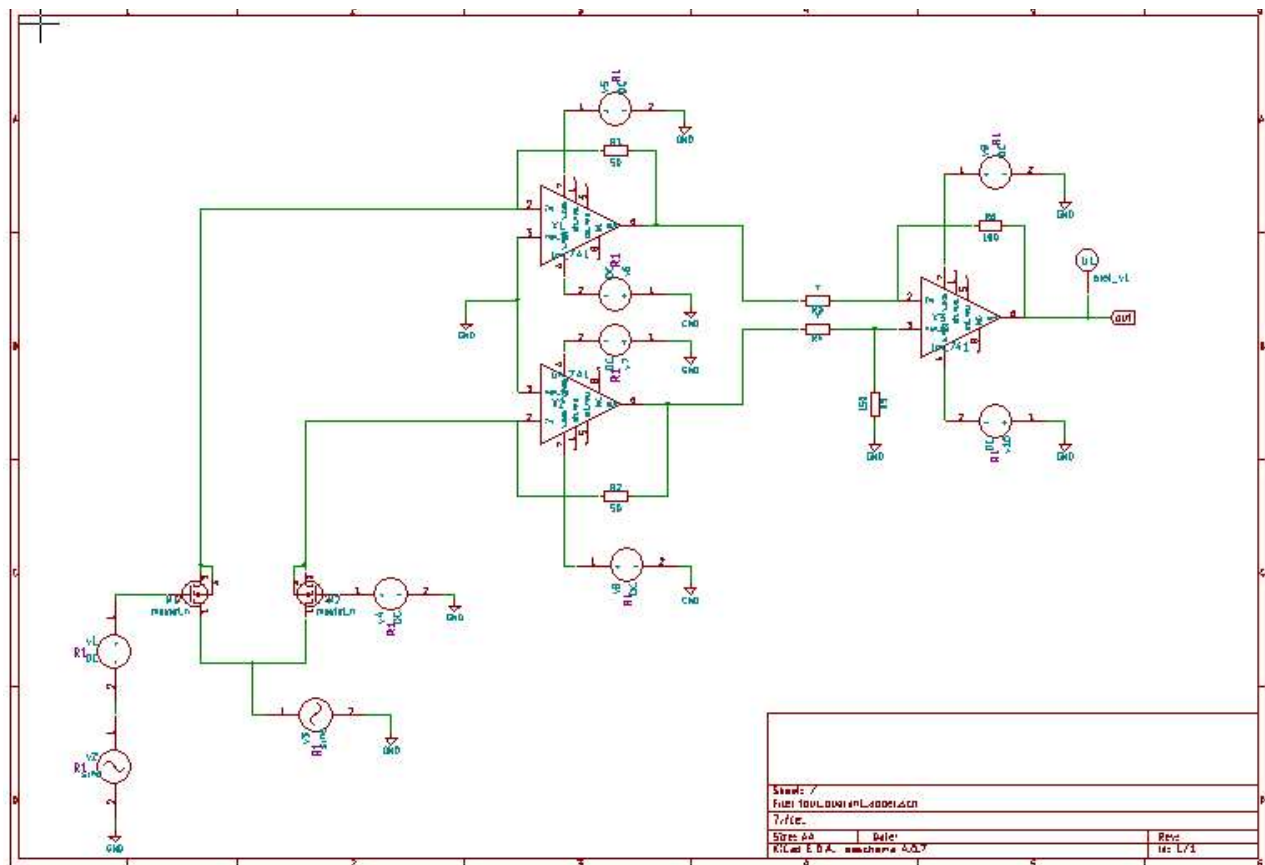


Diagram of the proposed multiplier

2) SCHEMATIC DESIGNED:

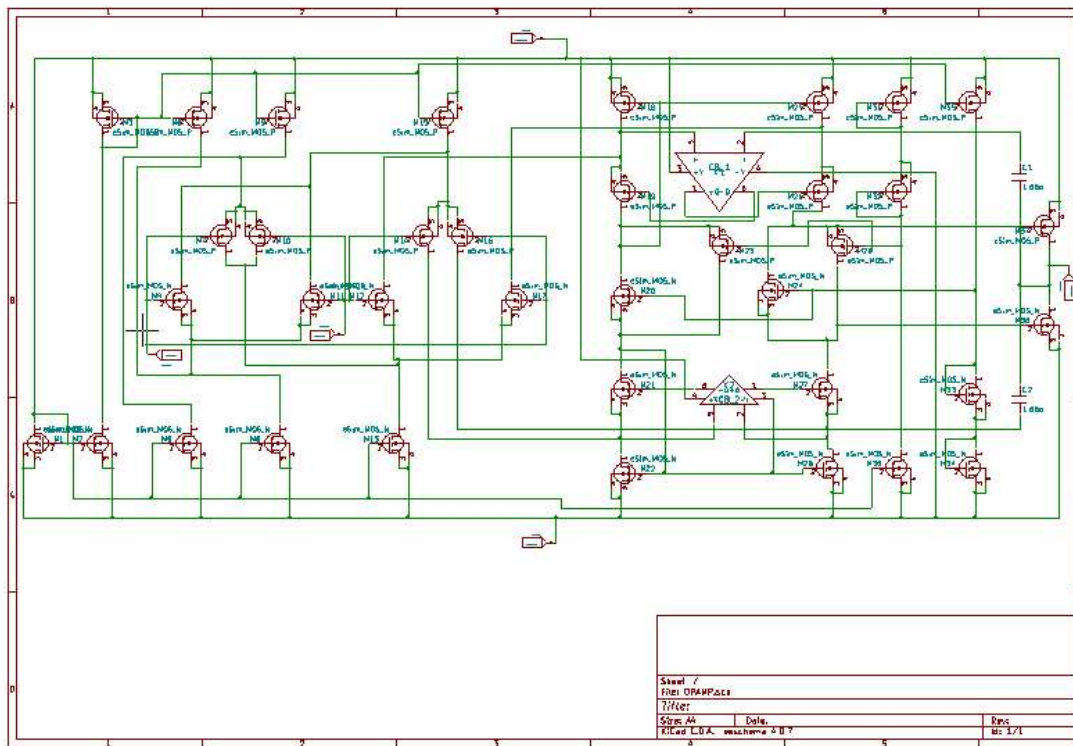
a) Four quadrant analog multiplier



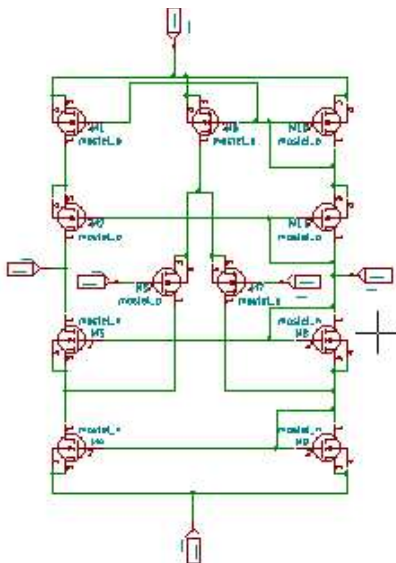
2) OPAMPS DESIGNED IN THE PAPERS - [1] [2]

The OpAmps needed for the proposed circuit should be rail to rail low voltage .I designed these OPAMPS under subcircuit using TSMC 0.35 μm CMOS model parameters . But these opamps were unable to provide the desired output .So I used

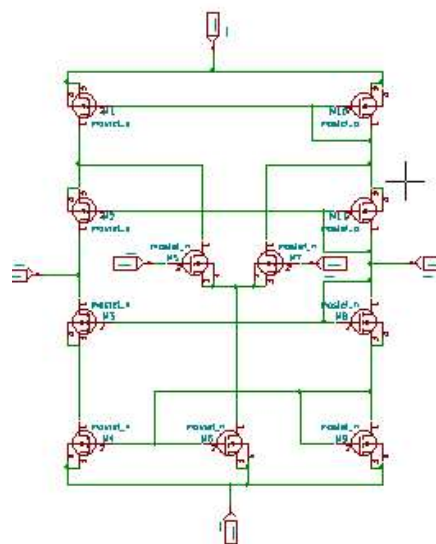
lm741 opamp and modified it according to need of circuit .After adjusting the values of the registers used in the circuit ,desired output was obtained.



rail to rail opamp designed in [1]

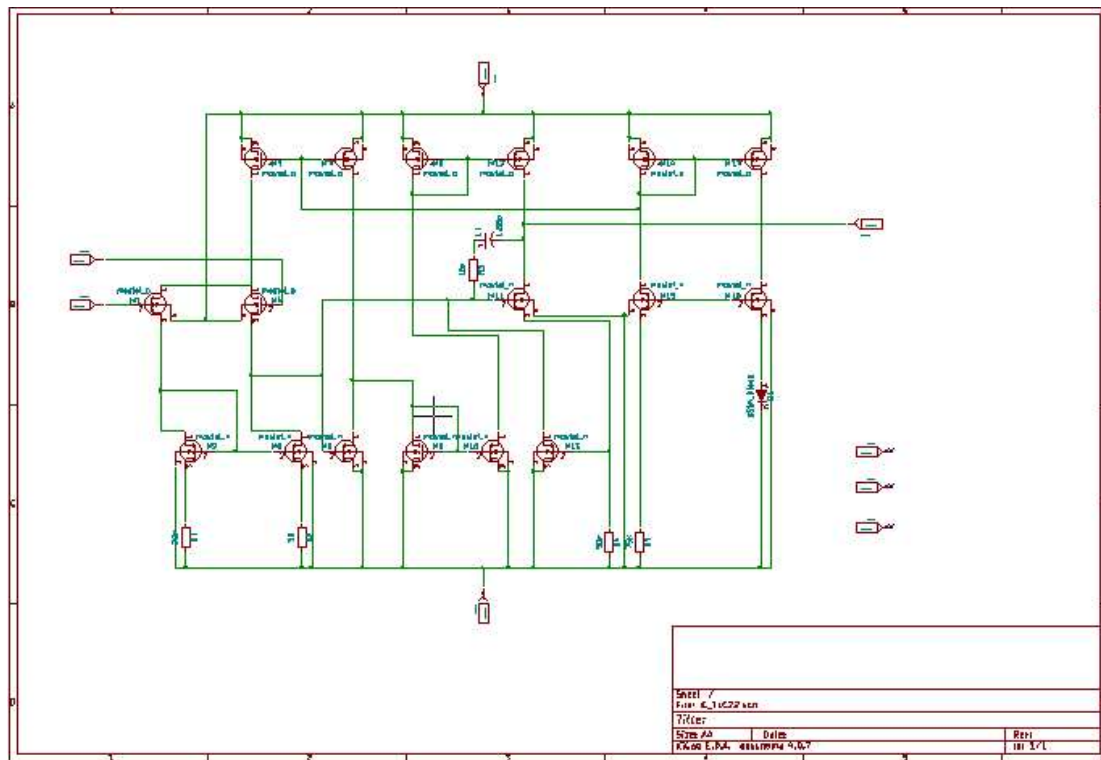


*gain booster 2 circuit used in designing the above
above opamp [1]*



*gain booster 1 circuit used in designing the above
above opamp [1]*

The above opamp is the one used in designing four quadrant analog multiplier in[3].The author used Pspice to simulate it .But when these circuits was designed in ESIM(using TSMC 0.35 μm CMOS model parameters) ,there were some error in converting ngspice model. So ,I switched to TLC2272 taking the reference of paper[2].This opamp was providing output but not as required .



TLC2272 CIRCUIT (opamp designed in[2])

3) INPUTS:

- 1) All the opamps are provided with ± 12 Volt.
- 2) Biasing voltage for the mosfet is set to 1.2 Volt.
- 3) $V_1 = \pm 0.3$ volt : $V_2 = \pm 0.5$ volt (both the inputs are sinusoidal).
- 4) TSMC 0.35 μ m CMOS model parameter

Parameters

```

NMOS .MODEL MbreakN NMOS (LEVEL=3 TOX=7.9E-9 NSUB=1E17
+ GAMMA=0.5827871 PHI=0.7 VTO=0.5445549 DELTA=0
+ UO=436.256147 ETA=0 THETA=0.1749684 KP=2.055786E-4
+ VMAX=8.309444E4 KAPPA=0.2574081 RSH=0.0559398
+ NFS=1E12 TPG=1 XJ=3E-7 LD=3.162278E-11 WD=7.046724E-8
+ CGDO=2.82E-10 CGSO=2.82E-10 CGBO=1E-10 CJ=1E-3
+ PB=0.9758533 MJ=0.3448504 CJSW=3.777852E-10
+ MJSW=0.3508721)
PMOS .MODEL MbreakP PMOS (LEVEL=3 TOX=7.9E-9 NSUB=1E17
+ GAMMA=0.4083894 PHI=0.7 VTO=-0.7140674 DELTA=0
+ UO=212.2319801 ETA=9.999762E-4 THETA=0.2020774
+ KP=6.733755E-5 VMAX=1.181551E5 KAPPA=1.5
+ RSH=30.0712458 NFS=1E12 TPG=-1 XJ=2E-7 LD=5.000001E-13

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NOTE - provided below inputs are the one used every where except dc analysis.

Analysis Source Details Ngspice Model Device Modeling Subcircuits

Select Analysis Type

☐ AC ☐ DC ☒ TRANSIENT

Transient Analysis

Start Time 0 sec

Step Time 10 ms

Stop Time 100 ms

Analysis Source Details Ngspice Model Device Modeling Subcircuits

Add library for MOSFET m1 : mosfet_n

C:\FOSSEE\Sim\library\deviceModelLibrary\MOS\NMOS-180nm.lib Add

Enter width of MOSFET m1(default=100u): 0.28u

Enter length of MOSFET m1(default=100u): 0.35u

Enter multiplicative factor of MOSFET m1(default=1): 1

Add library for MOSFET m2 : mosfet_n

C:\FOSSEE\Sim\library\deviceModelLibrary\MOS\NMOS-180nm.lib Add

Enter width of MOSFET m2(default=100u): 0.28u

Enter length of MOSFET m2(default=100u): 0.35u

Enter multiplicative factor of MOSFET m2(default=1): 1

Analysis Source Details Ngspice Model Device Modeling Subcircuits

Add subcircuit for lm_741

C:\FOSSEE\Sim\library\SubcircuitLibrary\lm_741 Add

Add subcircuit for lm_741

C:\FOSSEE\Sim\library\SubcircuitLibrary\lm_741 Add

Add subcircuit for lm_741

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4) RESULTS :

a) DC ANALYSIS -

only for dc analysis purpose ,these are the used input., the input voltage v2 is swept from -1V to + 1 V while v3 is varied from - 400 mV to + 400 mV in steps of 100 mV.

Analysis Source Details Ngspice Model Device Modeling Subcircuits

Select Analysis Type

☐ AC ☒ DC ☐ TRANSIENT

DC Analysis

Enter Source 1 v2

Start -1 Volts or Amperes

Increment 0.05 Volts or Amperes

Stop +1 Volts or Amperes

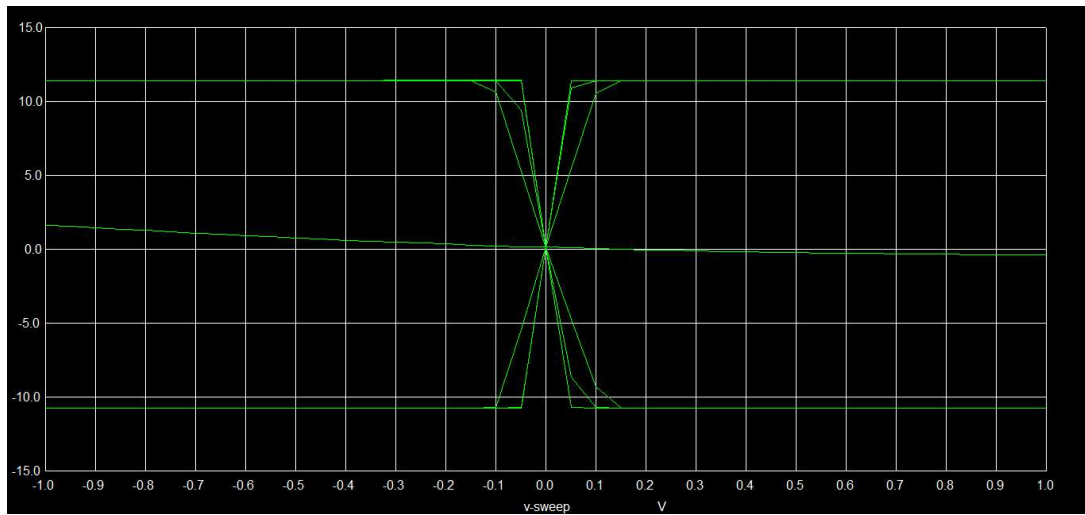
Enter Source 2 v3

Start -0.4 Volts or Amperes

Increment 0.1 Volts or Amperes

Stop +0.4 Volts or Amperes

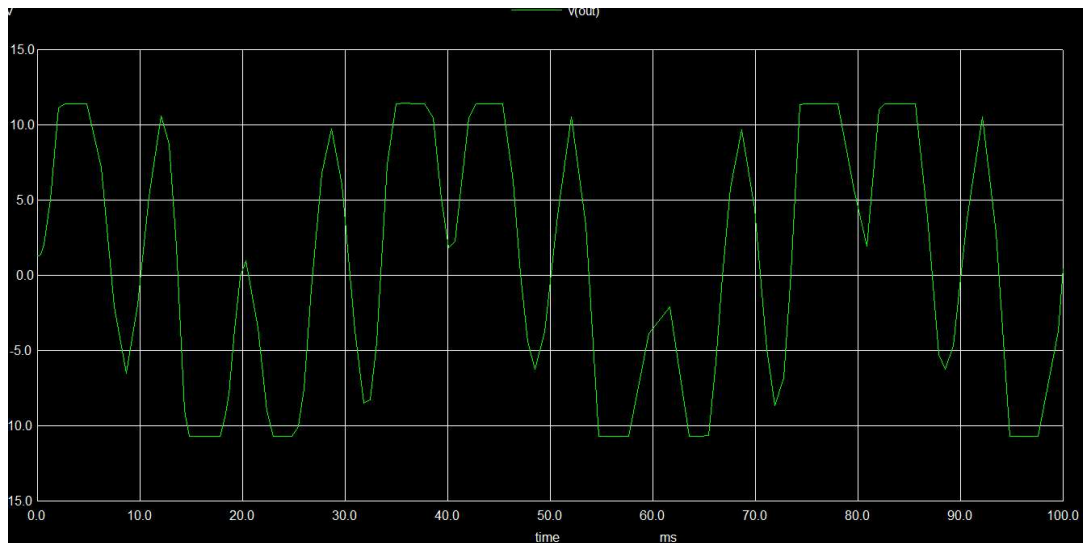
Analysis	Source Details	Ngspice Model	Device Modeling	Subcircuits
Add parameters for DC source v10				
Enter value (Volts/Amps):				12
Add parameters for DC source v1				
Enter value (Volts/Amps):				1.5
Add parameters for DC source v4				
Enter value (Volts/Amps):				1.5
Add parameters for pwl source v2				
Enter in pwl format without bracket		i.e t1 v1 t2 v2....		200mV 7ms 300mV 8ms 400mV
Add parameters for pwl source v3				
Enter in pwl format without bracket		i.e t1 v1 t2 v2....		0ms -1V 5ms 0V 10ms 1V



output for dc analysis using Piecewise Linear (PWL) Voltage Source

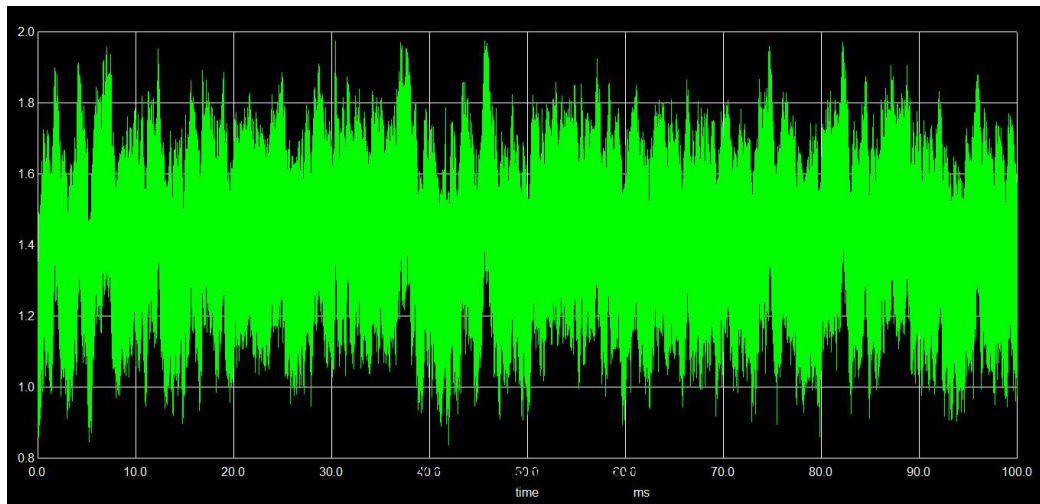
b) TRANSIENT ANALYSIS

i) Low Frequency: 50 Hz to 100 Hz.



Particularly in this case V1 has 50 Hz and V2 has 75 Hz

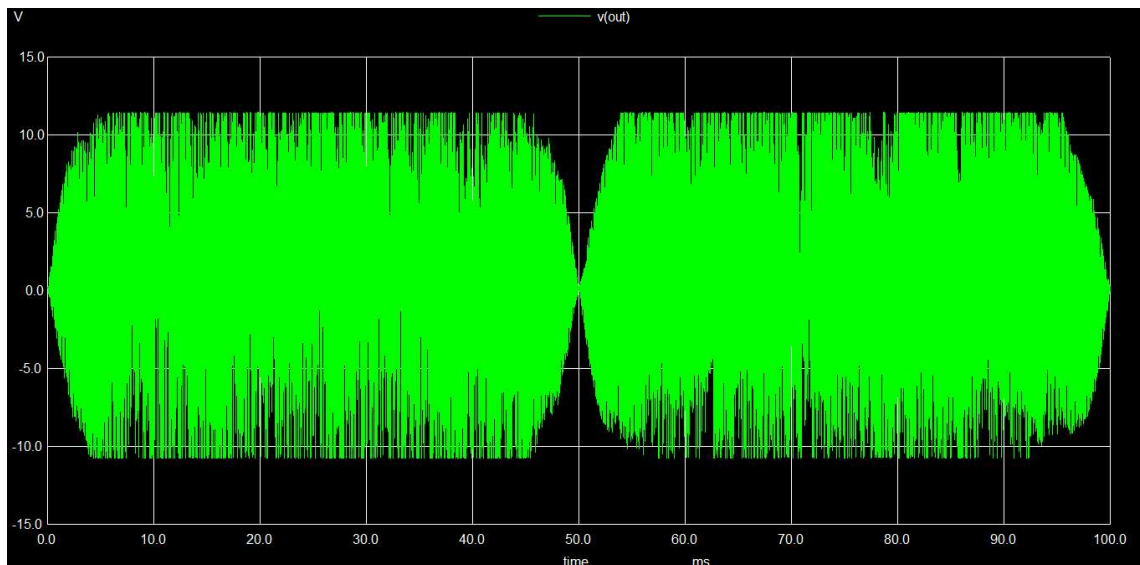
ii) High Frequency : 50k Hz to 100k Hz.



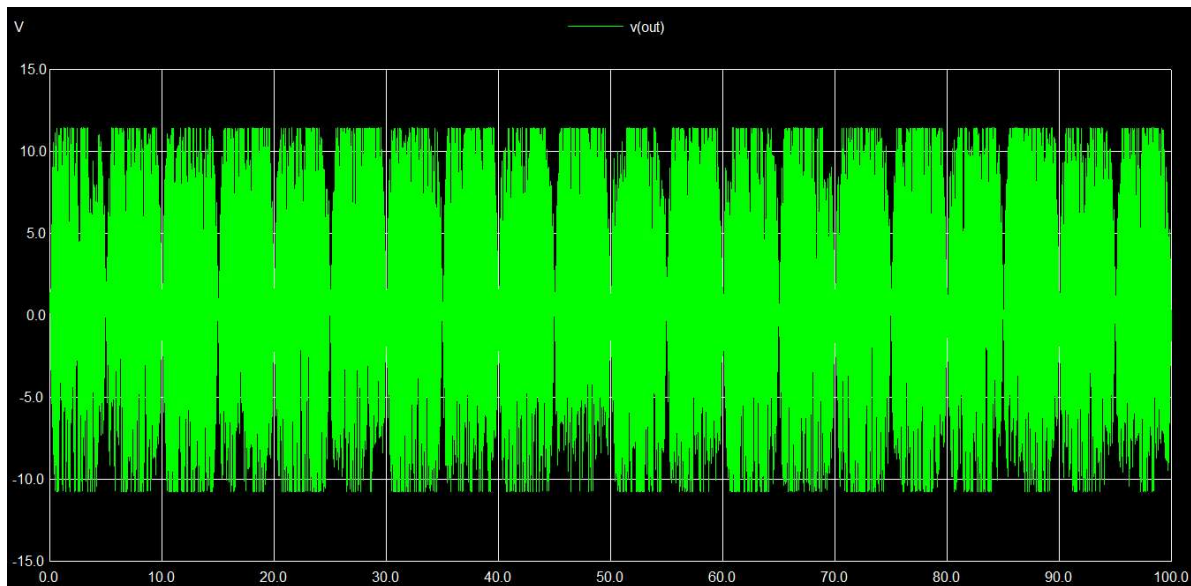
Particularly in this case V1 has 50k Hz and V2 has 75k Hz

c) APPLICATION (as amplitude modulator)

The proposed multiplier circuit, being four-quadrant multiplier, can be used as an amplitude modulator (AM). The amplitude of the carrier signal is varied in proportion to the amplitude of the message signal. This process creates upper and lower sidebands, which are the sum and difference of the frequencies of the carrier and message signals. Hence by simply multiplying message and carrier signal, AM modulated signal can be achieved. To verify the operation of the proposed configuration as a modulator, a 10 Hz signal with 300 mV amplitude is multiplied by 500 mV, 10 kHz signal. Below confirms about the modulation function-



then tested the circuit for higher frequency ranges multiplying message signal of 1k Hz to 100k Hz of carrier frequency. The circuit was still responding well and the output signal appeared as an amplitude modulated signal.



NOTE - The gain of the circuit can be easily adjusted by simply varying the values of resistors (1-6) by using the relation
$$V_o = \{(kRR_f)V_1V_2\}/R_i$$

5) CONCLUSION :

FOUR QUADRANT ANALOG MULTIPLIER was designed and simulated using ESIEM. The designed circuit was tested under various condition of amplitude and frequency of input signals, yet the circuit provided the desired output. The circuit was used as an amplitude modulator where first signal is much greater the other. The designed circuit behaved as an amplitude modulator and provided modulated output.

6) REFERENCE :

[1] S.Maiti and R.R.Pal, Low voltage high performance CMOS operational amplifier with rail-to-rail input/output stage, Journal of Electron Devices, 10(2011) 483- 488.

[b] TLC227x, TLC227xA: Advanced LinCMOS Rail-to-Rail Operational Amplifiers

[c]

🌐 (PDF) A New Method of Realization of Four-Quadrant Analog Multiplier using Operational Amplifiers ...