Faculty of Enigeering

Cairo University

Analog Electronics Project Documentation

Analog Function Generator

Presented for ELC 3010 Cadence Project

Presented to:

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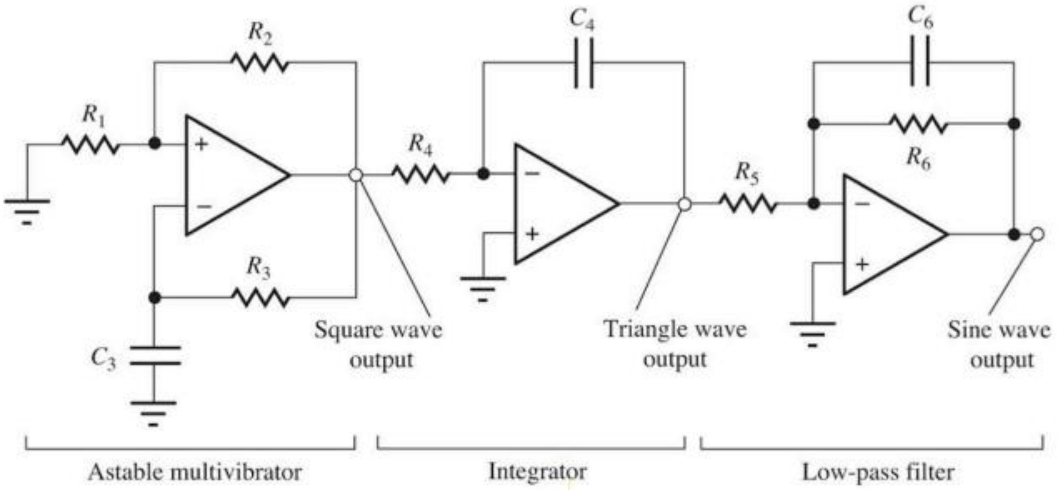
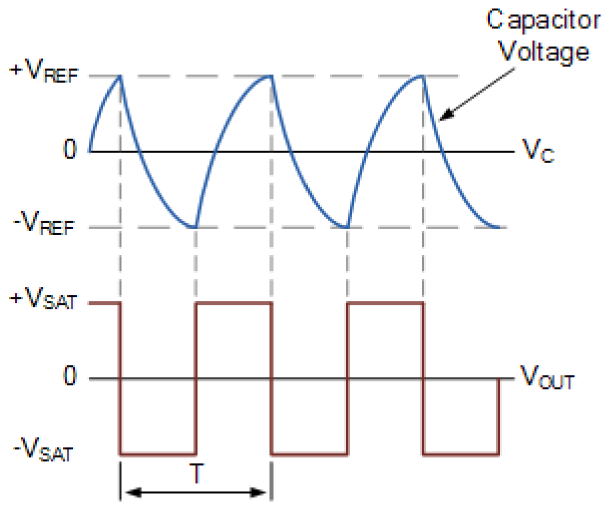
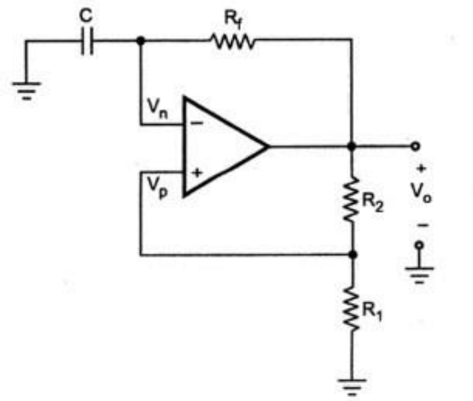


Task 1

Hand Analysis

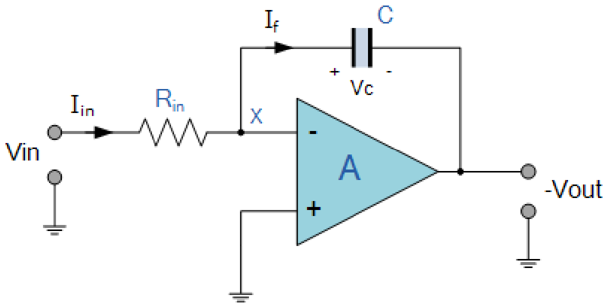
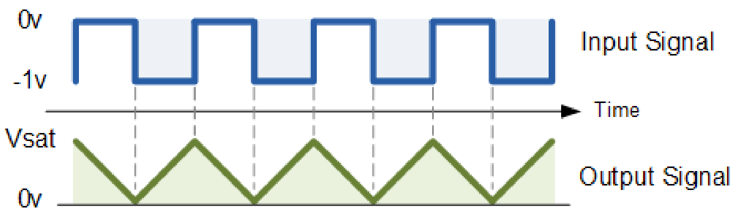
Astable Multivibrator

Square Wave Stage

Circuit Analysis	Assume $+ve$ Feedback and V_{out} Start from $-V_{cc} = -10\ V$. And C_3 initially have 7.5 V, Let $R_1 = R_2 = 1\ k\Omega \rightarrow \boldsymbol{\beta} = \frac{\boldsymbol{R_1}}{\boldsymbol{R_1+R_2}} = \frac{\mathbf{1}}{\mathbf{2}}$ And $V^+ = -\beta V_{cc} = -5\ V$. Capacitor ($C_3$) will discharge until V^+ become greater than V^- (When $V_{cap} = -\beta V_{cc} = -V_{ref}$) then V_{out} become V_{cc}. So, $V^+ = \beta V_{cc} = 5\ V$. and C_3 will charge until $V_{cap} = \beta V_{cc} = V_{ref}$ Then $V_{out} = -V_{cc}$ As shown in the figure below. 
Timing Analysis	C_3 Charging and discharging equation: $V_c = V_f - (V_f - V_i).e^{-\frac{t}{\tau}}$, $\tau = R_3C_3$ $\rightarrow \boldsymbol{T_H}$: $V_i = -\beta V_{cc}$,$V_f = V_{cc}$,$V_c = \beta V_{cc}$,$\boldsymbol{T_H = \tau\ ln\left(\frac{1+\beta}{1-\beta}\right)}$ $\rightarrow \boldsymbol{T_L}$: $V_i = \beta V_{cc}$,$V_f = -V_{cc}$,$V_c = -\beta V_{cc}$,$\boldsymbol{T_L = \tau\ ln\left(\frac{1+\beta}{1-\beta}\right)}$ $\therefore$ **Frequency:** $\boldsymbol{f = \frac{1}{T_H + T_L} = \frac{1}{2\,\tau\,ln\left(\frac{1+\beta}{1-\beta}\right)}}$, $\therefore \boldsymbol{\sigma_{duty} = 50\ \%}$
Parameters	$\boldsymbol{\rightarrow R_1 = R_2 = 1\ k\Omega}$. $\boldsymbol{\rightarrow f = 10\ kHz \ \rightarrow C_3 = 1\ nF \ \rightarrow R_3 = 45.5\ k\Omega}$. $\boldsymbol{\rightarrow f = 1\ MHz \ \rightarrow C_3 = 1\ nF \ \rightarrow R_3 = 0.455\ k\Omega}$.

Lossless Integrator

TRIANGLE WAVE STAGE

Circuit Analysis	Assume $-ve$ ideal feedback $(V^+ = V^- = 0\ V)$, V_{in} Square Wave $\because I_{in} = I_f \rightarrow I_f = -C_4 \frac{dV_{out}}{dt} = \frac{V_{in}}{R_4}$ $\therefore \boldsymbol{V_{out} = -\frac{1}{R_4 C_4} \int V_{in}\, dt + k_4 \rightarrow C_4}$ **initial condition** $\boldsymbol{k_4 = 13\ V}$. 
Timing Analysis	$\because$ Slope $= \frac{V_{pp}}{T_H} \rightarrow T_H = T_L = \frac{1}{2\ f}$ where $f = 10\ kHz\ \&\ 1\ MHz$ $\therefore V_{pp}$ must be less than $2V_{cc} \rightarrow -C_4 \frac{dV_{out}}{dt} = C_4 \frac{V_{pp}}{T_H} = \frac{V_{cc}}{R_4} \rightarrow V_{pp} = \frac{V_{cc}\, T_H}{R_4\, C_4}$ $\boldsymbol{\rightarrow \frac{V_{cc}\, T_H}{R_4\, C_4} < 2V_{cc} \rightarrow\ \ R_4 > \frac{1}{4\, C_4\, f}}$ $\rightarrow$ **Assume** $\boldsymbol{C_4 = 1\ nF \rightarrow R_4 > 25\ k\Omega}$. 
Parameters	$\boldsymbol{\rightarrow f = 10\ kHz \rightarrow C_4 = 1\ nF. \rightarrow R_4 = 25\ k\Omega}$ $\boldsymbol{\rightarrow f = 1\ MHz\ \rightarrow C_4 = 1\ nF. \rightarrow R_4 = 0.25\ k\Omega}$

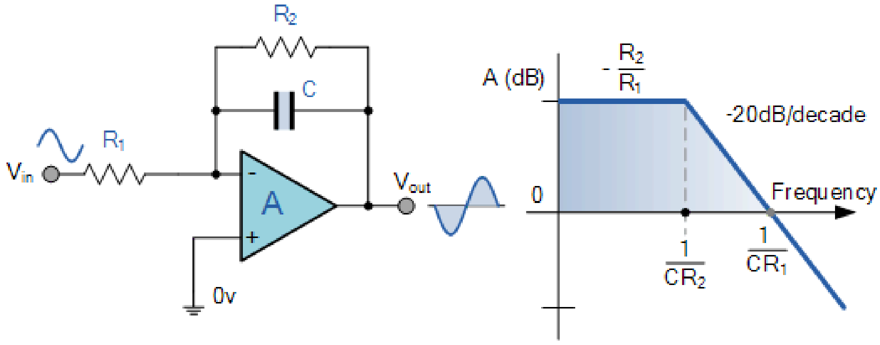
Op amp Model

OP AMP PARAMETERS

Capacitor	$\boldsymbol{C_{BW} = 10\ pF}$.
Resistor	$\boldsymbol{R_{BW} = 10\ k\Omega}$.
Gain	**gain** $\boldsymbol{= 10\ k}$

Low Pass Filter

Sine Wave Stage

Circuit Analysis	Assume $-ve$ ideal feedback $(V^{+} = V^{-} = 0\ V)$, V_{in} Triangle Wave $H(S) = \frac{V_{out}}{V_{in}} = -\frac{Z_f}{R_5} = \frac{R_6}{R_5} . \frac{1}{1+R_6\, C_6\, S}$ → with cap initial condition $k_6 = 0\ V$ **The Frequency Should be lower than cutoff frequency** $\boldsymbol{\omega_c = \frac{1}{R_6\, C_6}}$ 
Parameters	$\rightarrow \boldsymbol{f = 10\ kHz} \ \rightarrow \boldsymbol{C_6 = 1\ nF} \rightarrow \boldsymbol{R_5 = 10\ k\Omega} \ \rightarrow \boldsymbol{R_6 = 10\ k\Omega}.$ $\rightarrow \boldsymbol{f = 1\ MHz} \ \rightarrow \boldsymbol{C_6 = 2\ nF} \rightarrow \boldsymbol{R_5 = 0.1\ k\Omega} \ \rightarrow \boldsymbol{R_6 = 0.1\ k\Omega}.$

THD: **It is a Measurement that indicates how much distortion due to Harmonics in the Signal.**

$$\boldsymbol{THD = \frac{V_{RMS}\ (Without\ Fundamental)}{V_{RMS}\ (With\ Fundamental)} = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n_{RMS}}^{2}}}{V_{fundamental_{RMS}}}}$$

Where:

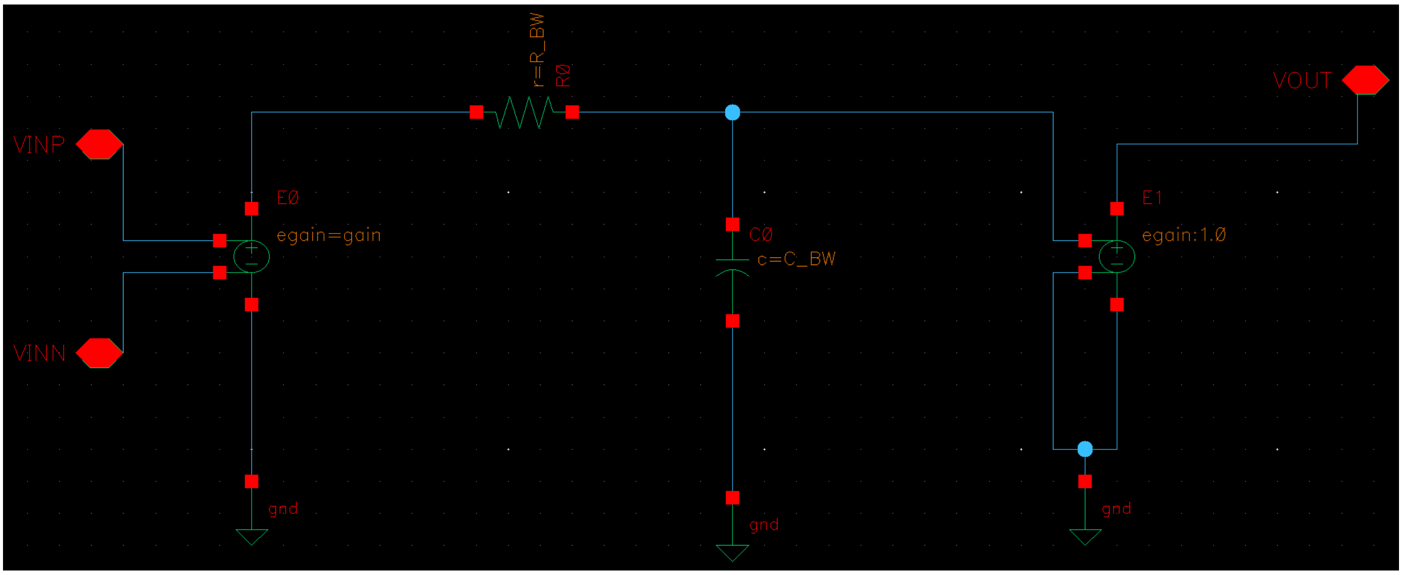
- $V_{n_{RMS}}$ is the RMS Voltage of the n^{th} Harmonics.
- $V_{fundamental_{RMS}}$ is the RMS Voltage of the Fundamental Frequency.

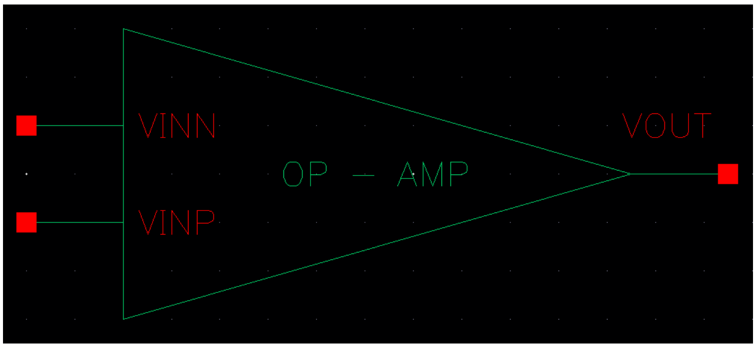
Note: **Caps initial Conditions and Resistors values are tuned to optimize the waveforms and the required operating frequency.**

Task 2

Circuit Schematic

OP - AMP MODEL





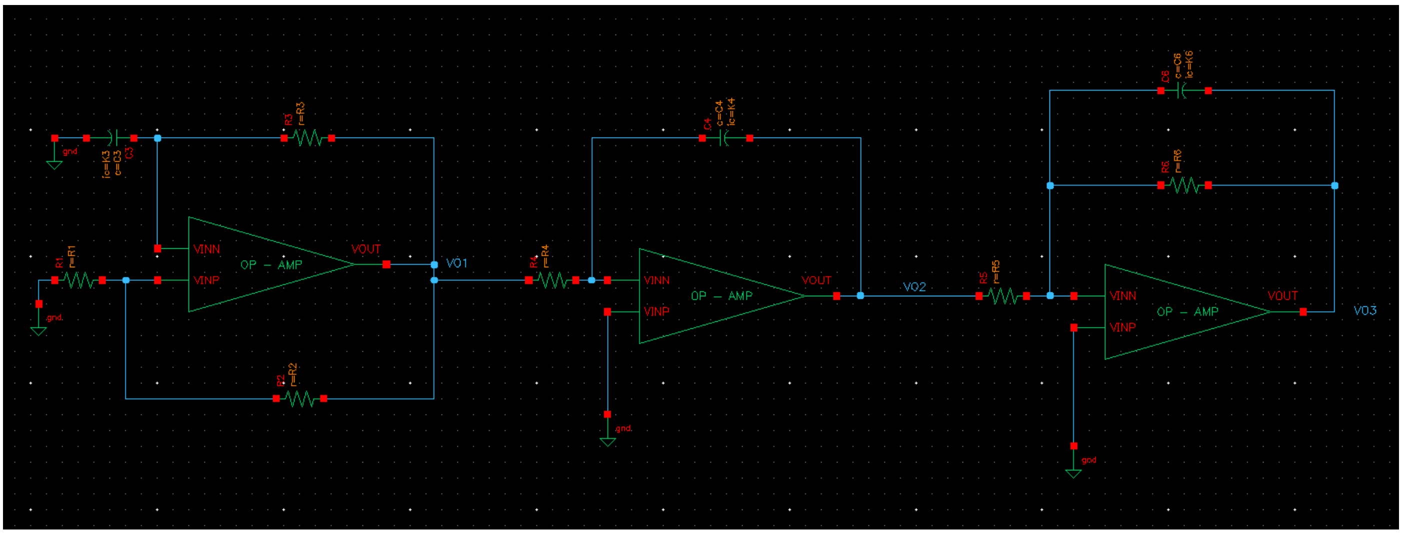
Op Amp Model

1- VCVS for Differential inputs
→ That Achieves $R_{in} = \infty$

2- RC to get the BW required.

3- Another VCVS to prevent loading effect for the following circuits (act as a buffer).

FUNCTION GENERATOR



Task 3

WAVEFORMS

Frequency = 10 kHz

Note: V_{o_1} → Square Wave Output , V_{o_2} → Triangle Wave Output , V_{o_3} → Sine Wave Output.

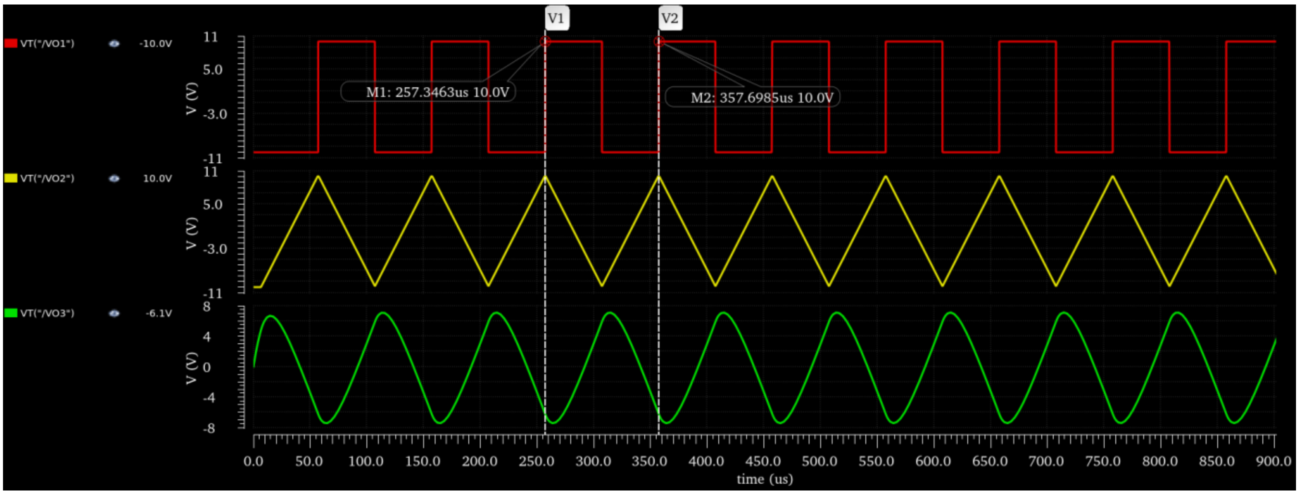
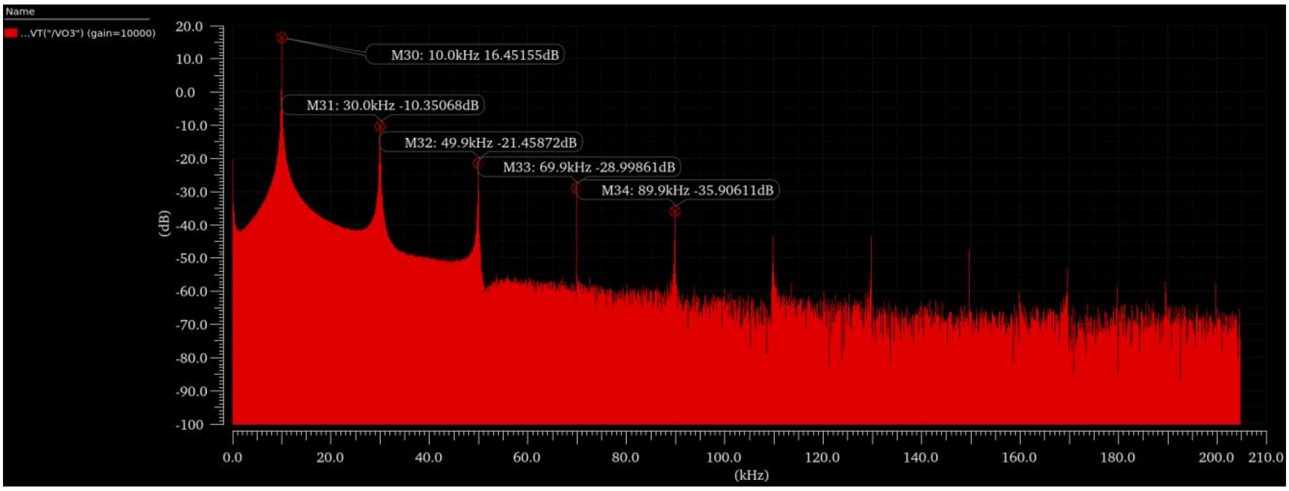


Figure 1: Gain = 10 k, BW = 10 MHz



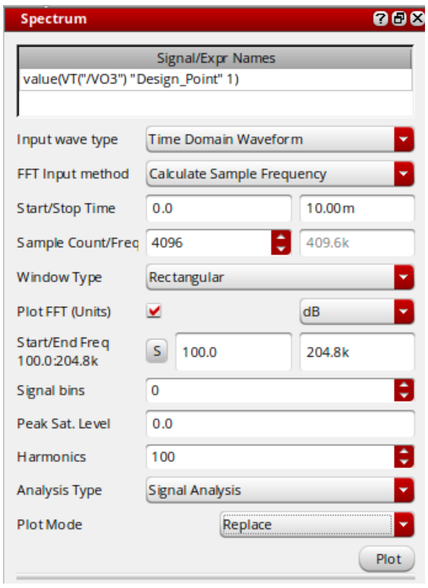


Figure 2: DFT - Gain = 10 k, BW = 10 MHz

THD	7.2670664 (%)
THD	-22.772817 (dB)

Op amp Gain Sweep

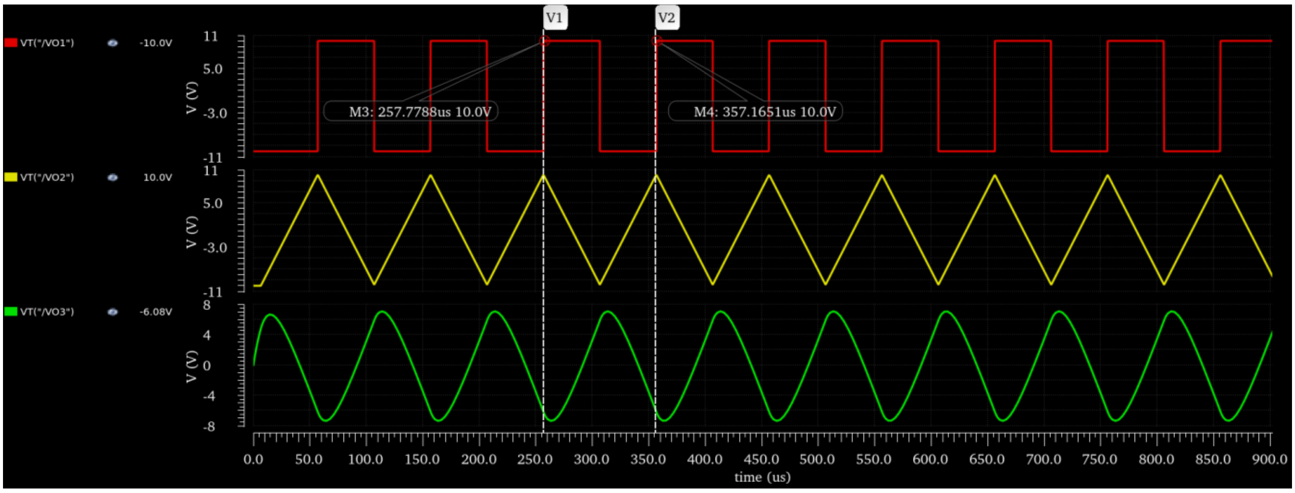


Figure 3: Gain = 1 k, BW = 10 MHz

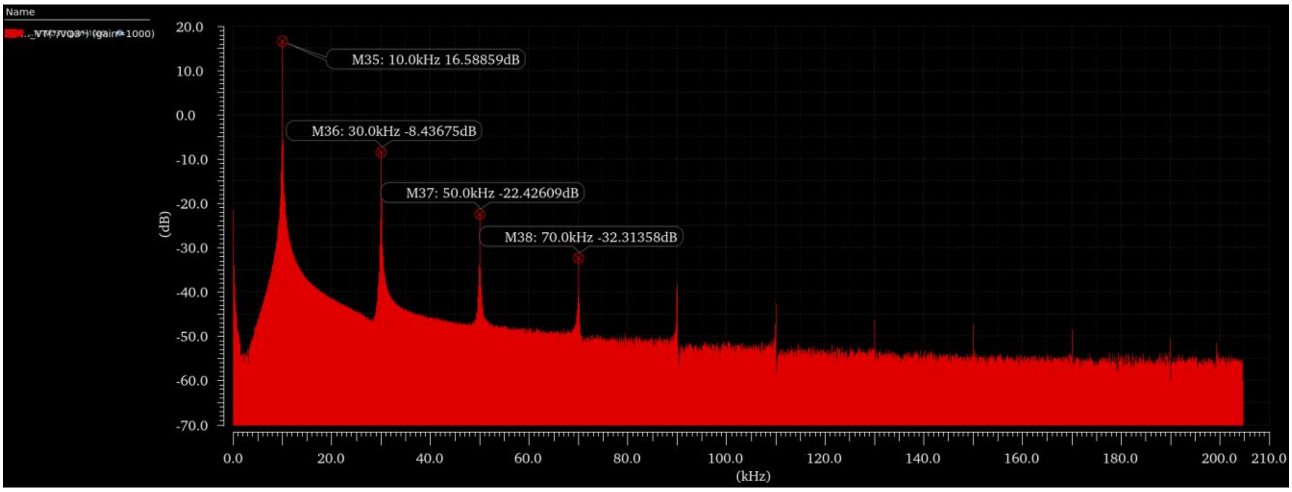


Figure 4: DFT - Gain = 1 k, BW = 10 MHz

THD	6.4524127 (%)
THD	-23.805557 (dB)

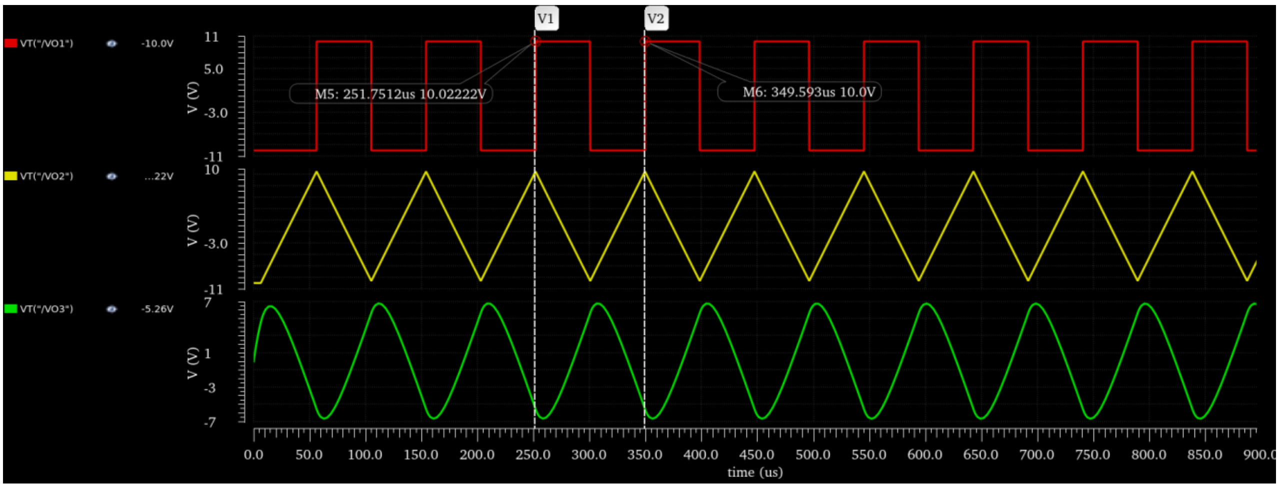


Figure 5: Gain = 100, BW = 10 MHz

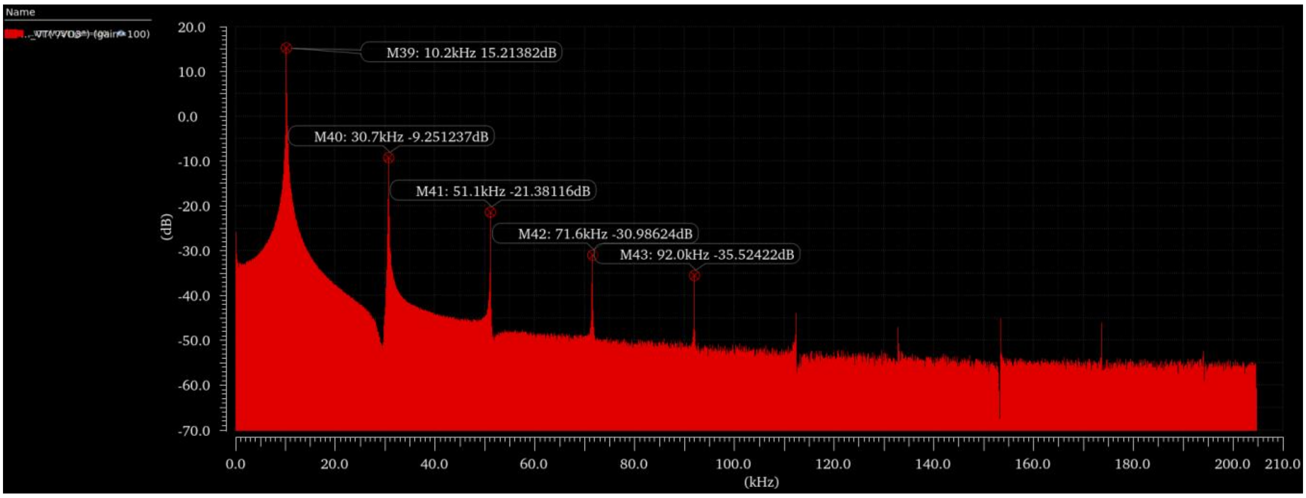


Figure 6: DFT - Gain = 100, BW = 10 MHz

THD	3.3419478 (%)
THD	-29.520007 (dB)

Op amp BW Sweep

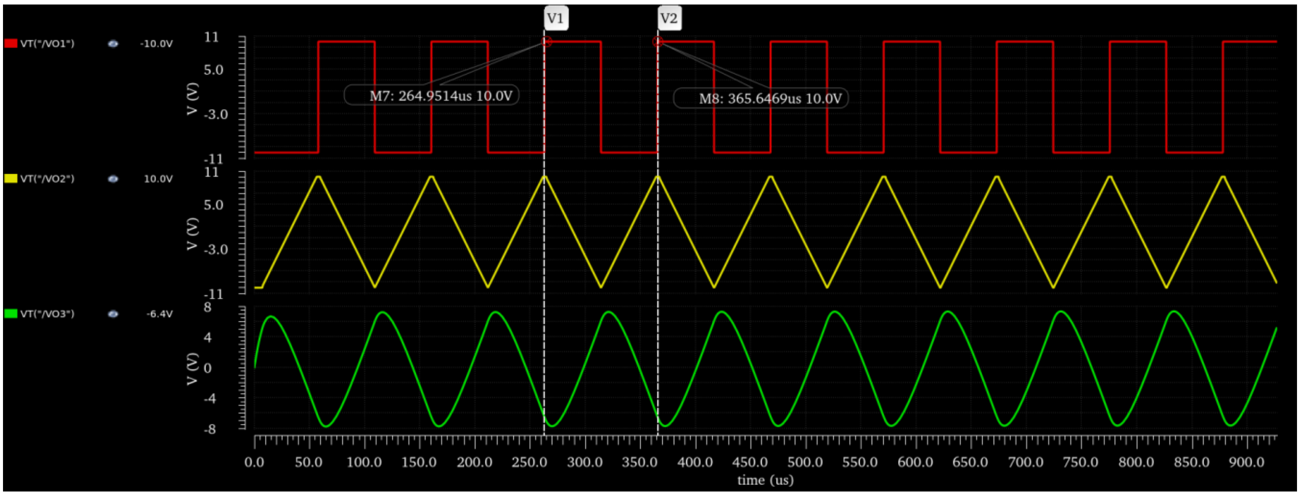


Figure 7: Gain = 10 k, BW = 1 MHz

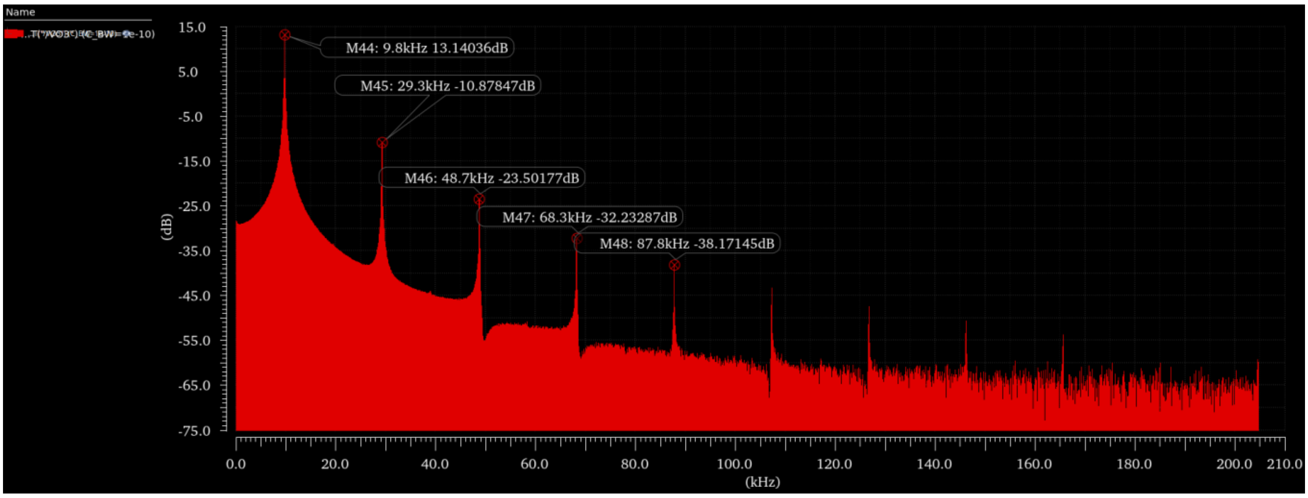


Figure 8: DFT - Gain = 10 k, BW = 1 MHz

THD	4.8309869 (%)
THD	-26.319283 (dB)

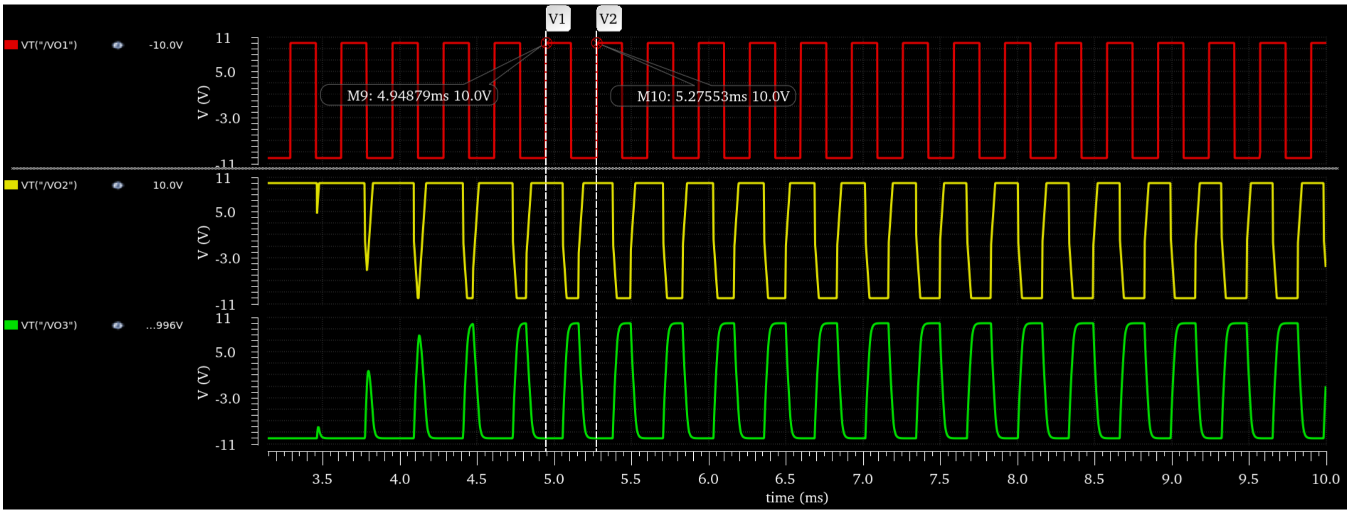


Figure 9: Gain = 10 k, BW = 1 kHz

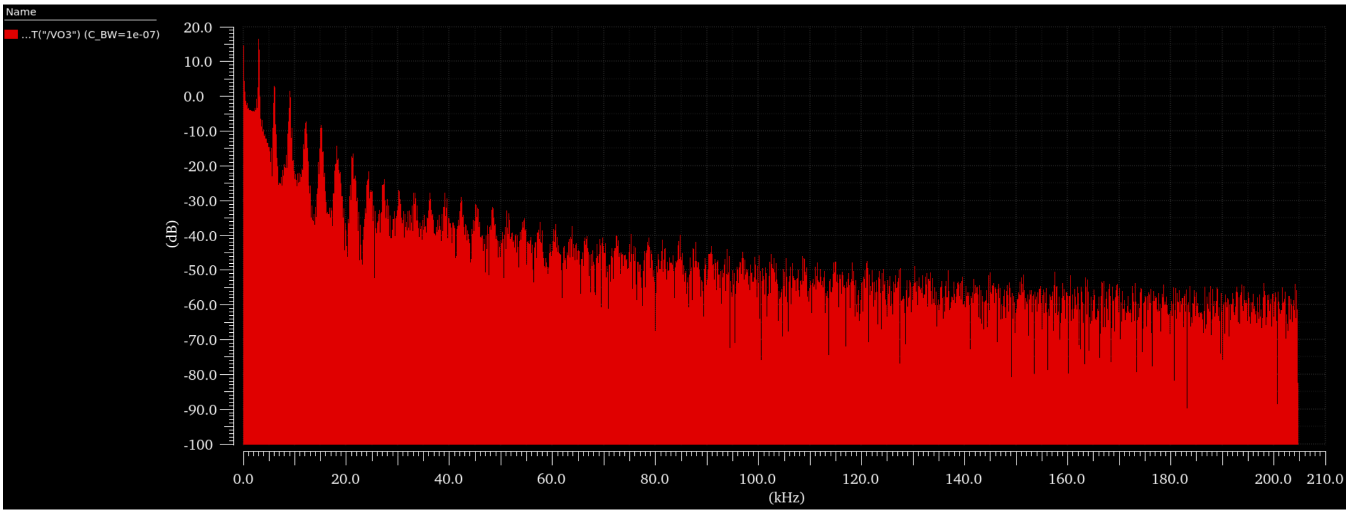


Figure 10: DFT - Gain = 10 k, BW = 1 kHz

THD 28.593711 (%)
THD -10.87459 (dB)

Frequency = 1 MHz

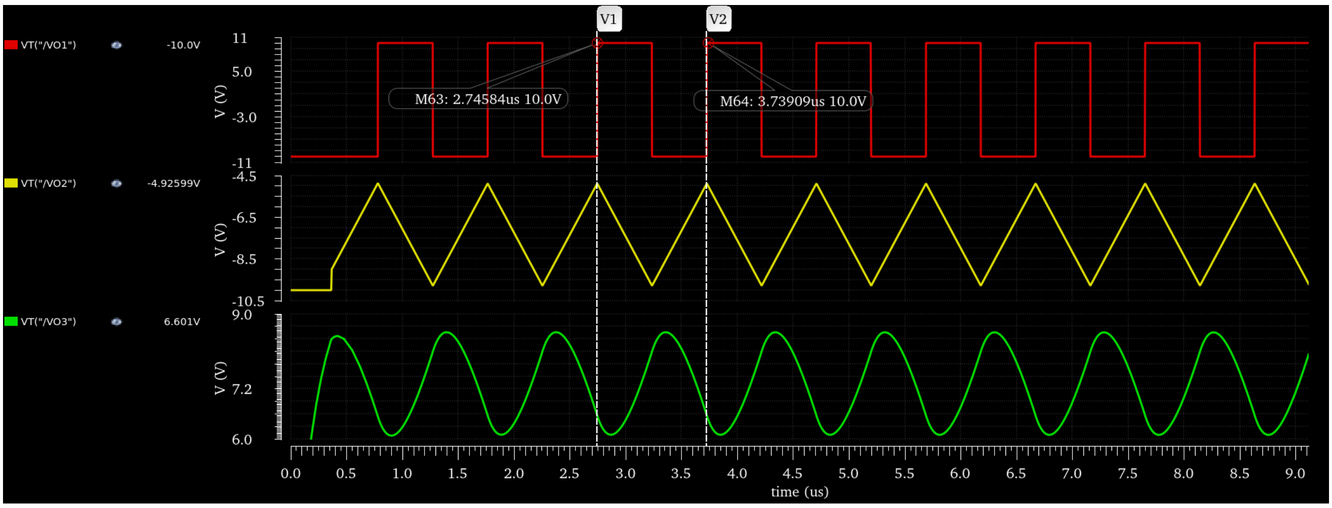


Figure 11: Gain = 10 k, BW = 10 MHz

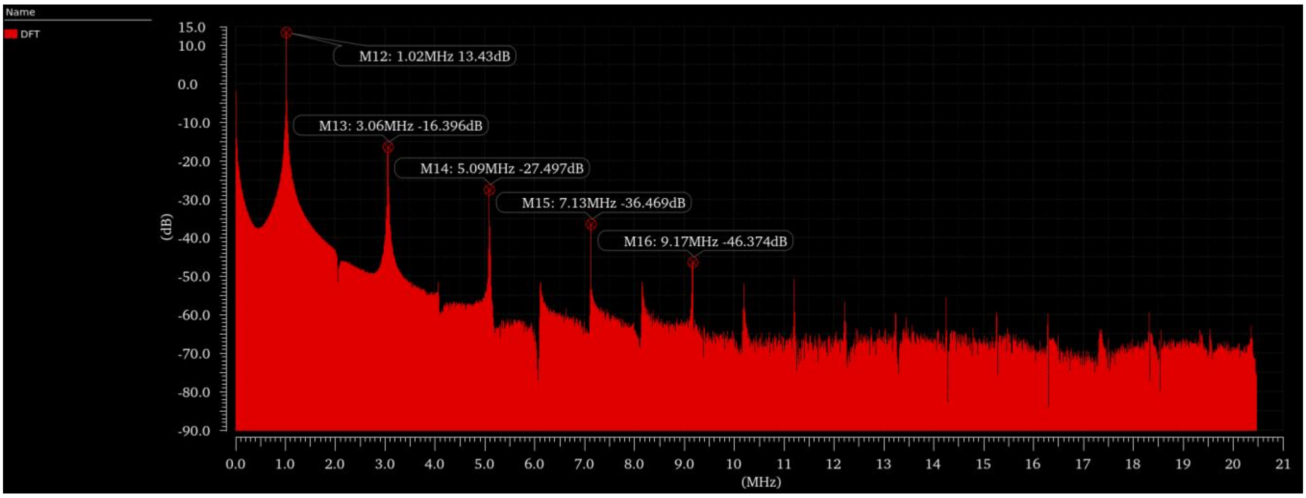


Figure 12: DFT - Gain = 10 k, BW = 10 MHz

THD	3.6802455 (%)
THD	-28.682464 (dB)

Op amp Gain Sweep

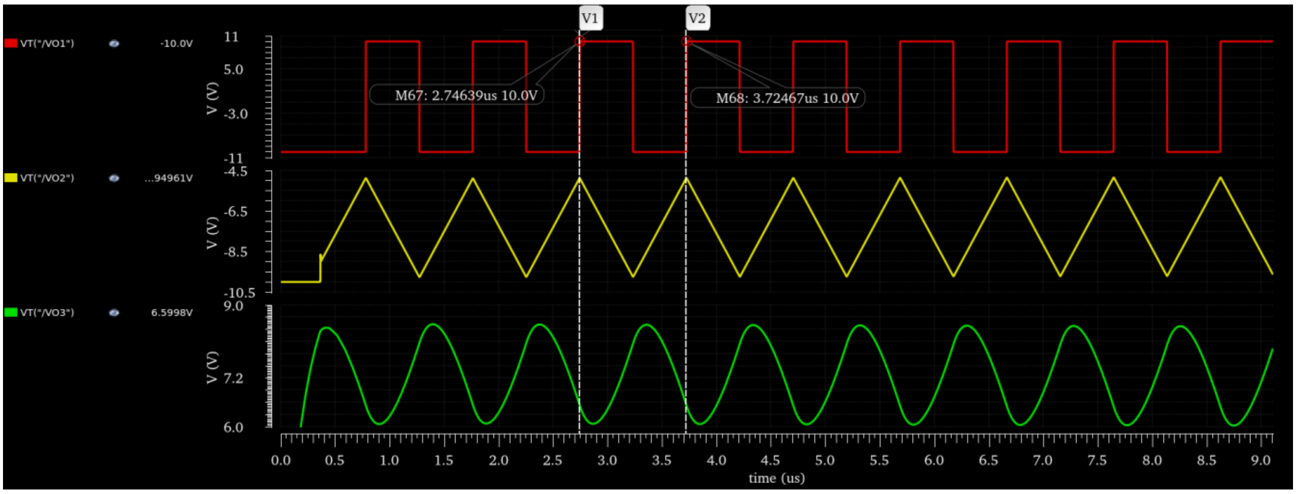


Figure 13: Gain = 1 k, BW = 10 MHz

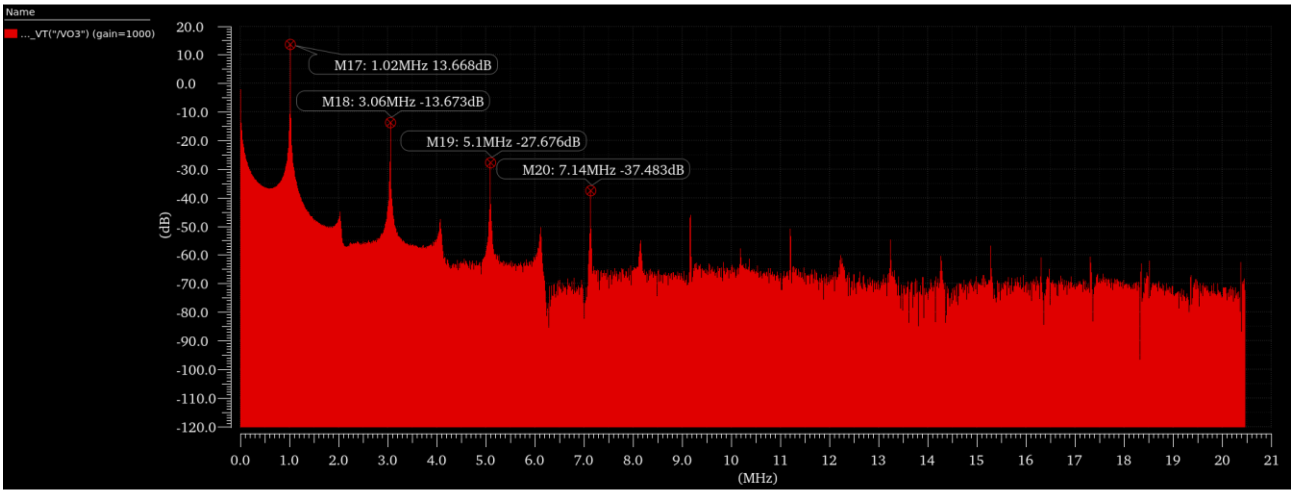


Figure 14: DFT - Gain = 1 k, BW = 10 MHz

THD	4.5288412 (%)
THD	-26.880258 (dB)

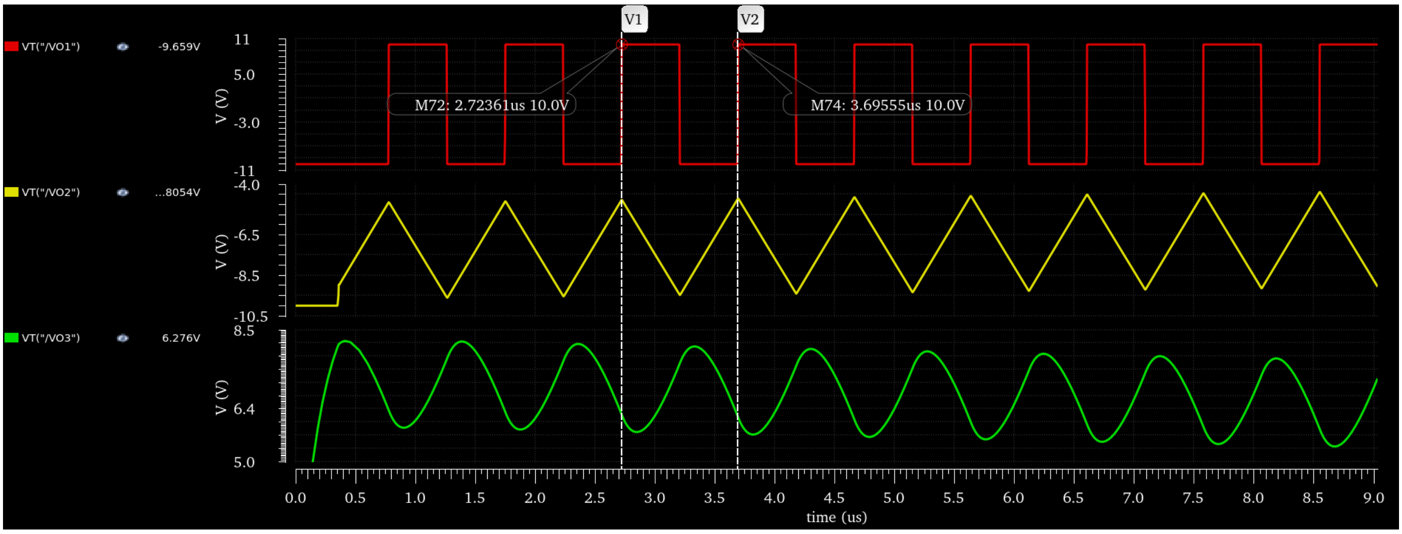


Figure 15: Gain = 100, BW = 10 MHz

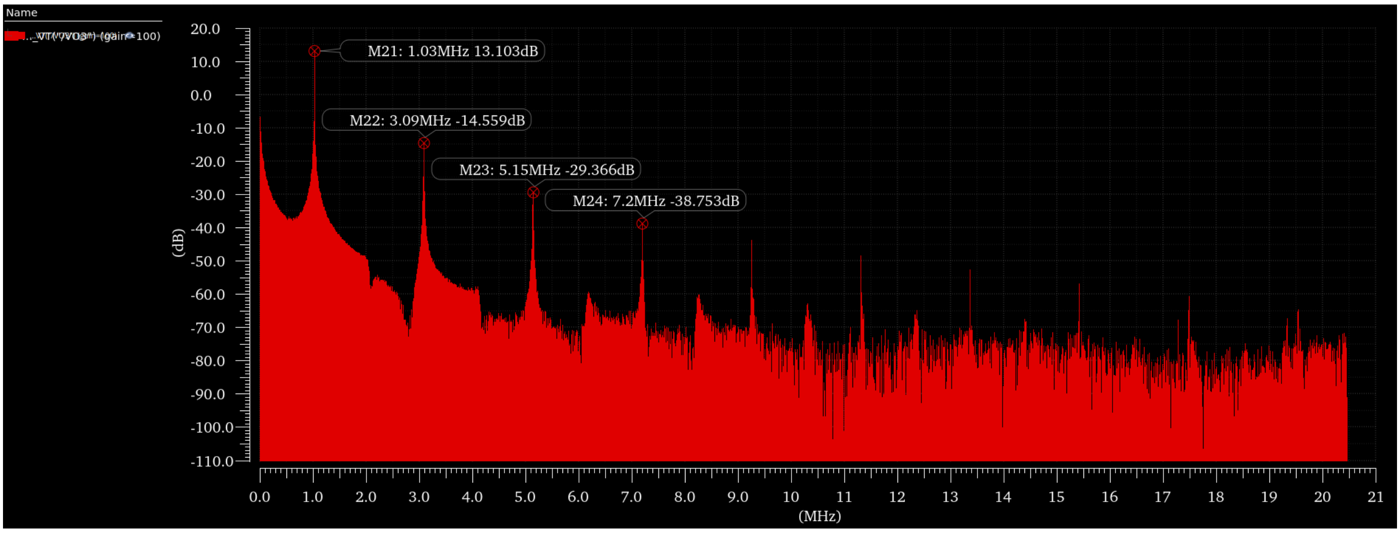


Figure 16: DFT - Gain = 100, BW = 10 MHz

THD	4.3194286 (%)
THD	-27.291474 (dB)

Op amp BW Sweep

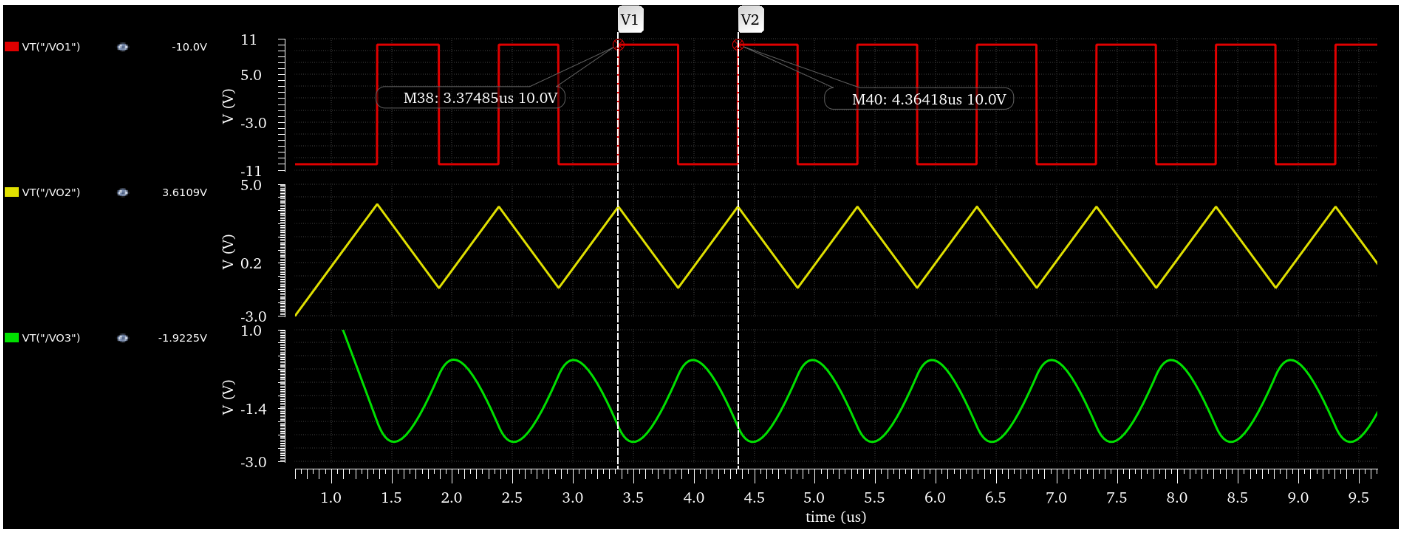


Figure 17: Gain = 10 k, BW = 1 MHz

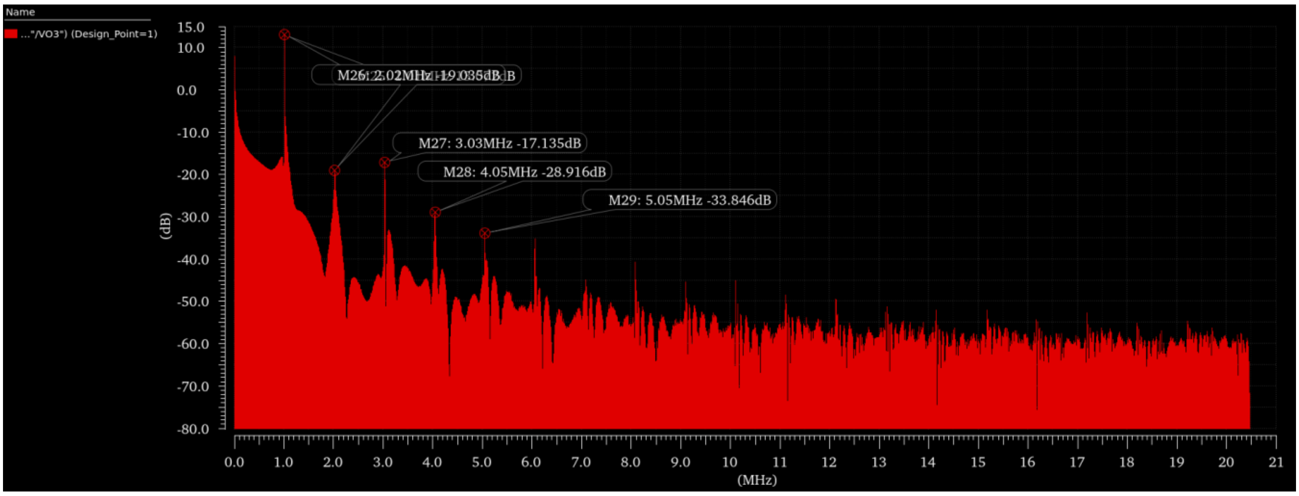


Figure 18: DFT - Gain = 10 k, BW = 1 MHz

THD 10.306389 (%)
THD -19.737869 (dB)

Note: Having the Op amp with a 1 kHz BW will cause the 1MHz generator wave to be clipped, the highest frequency that could be detected is 0.3 MHz

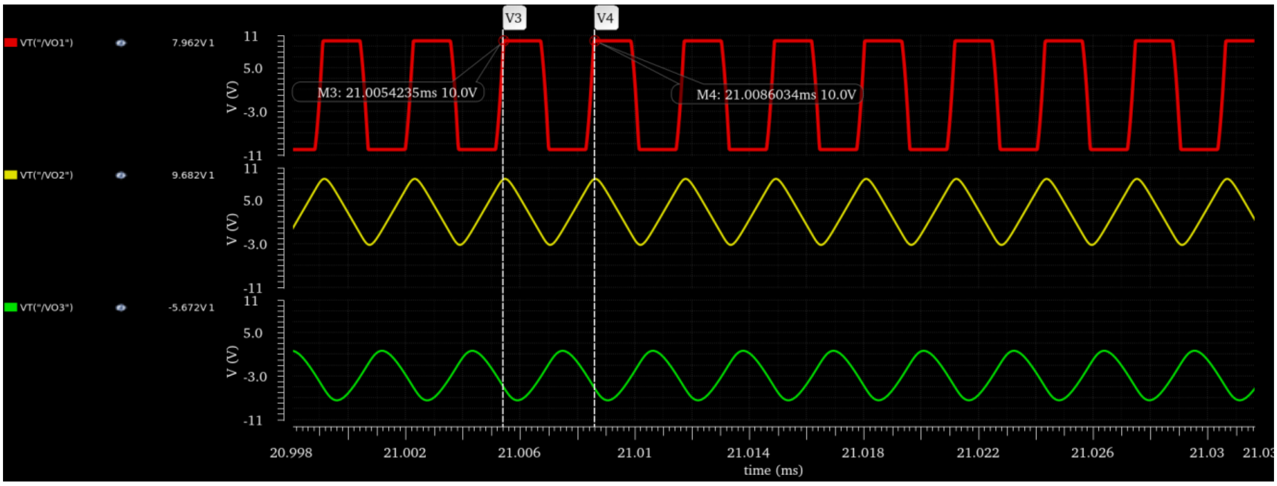


Figure 19: Gain = 10 k, BW = 1 kHz, f = 0.3 MHz

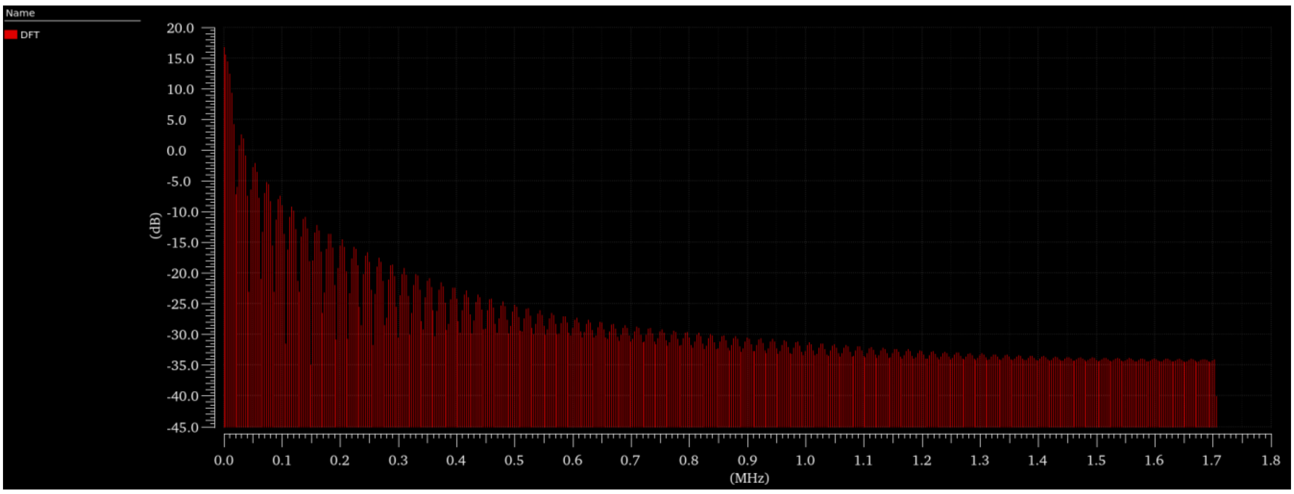


Figure 20: DFT - Gain = 10 k, BW = 1 kHz, f = 0.3 MHz

Task 4

Discussion

Initially, we developed the Building Block of our project, referred to as "the operational amplifier" or "op-amp," with designated parameters of "gain = 10,000 & BW=10 MHz." Subsequently, in order to fulfill the requirement of a "frequency range from 10 kHz to 1 MHz," we established Initial capacitance values within the nF range and proceeded to compute the corresponding resistance values.

THD

We noticed that as the gain decreases from 10k to 100, THD changes **slightly**, but if the gain is very low, THD will be much higher because OP-AMP does not reach ideality. Then we changed the BW of the op-amp, we noticed that as the BW decreases, THD changes slightly for the 1kHz signal, and **THD increases for 1MHz signal**, because OP-AMP becomes **band-limited**. As the BW increases, the higher frequencies pass the op-amp. We've observed that when we decreased the BW to 1 kHz, the 1 MHz harmonic got clipped at the output of Stage 2 & 3 as expected with highest frequency that could be detected is 0.3 MHz.

Astable Multivibrator

Square Wave Stage

We determined the range of R3 by setting the values of R1, R2, and C3 to cover the frequency range of "10 kHz up to 1 MHz." Consequently, we were able to regulate the frequency of this stage by manipulating R3.

Lossless Integrator

Triangle Wave Stage

We assumed the value C4 to get the range of R4 based on the frequency range "10 kHz up to 1 MHz".

Low Pass Filter

Sine Wave Stage

We assumed the value of C6 and assumed R5 = R6 to get the range of R6 and R5 based on the frequency range "10 kHz up to 1 MHz".

The END Thank You