UNIVERSITATEA TEHNICĂ DIN CLUJ-NAPOCA

Facultatea de Electronică, Telecomunicaţii şi Tehnologia Informaţiei

Systems with Analog integrated Circuits
Analog Interface Design and Simulation

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Year/Series/Group : 3rd-EA-2031/3

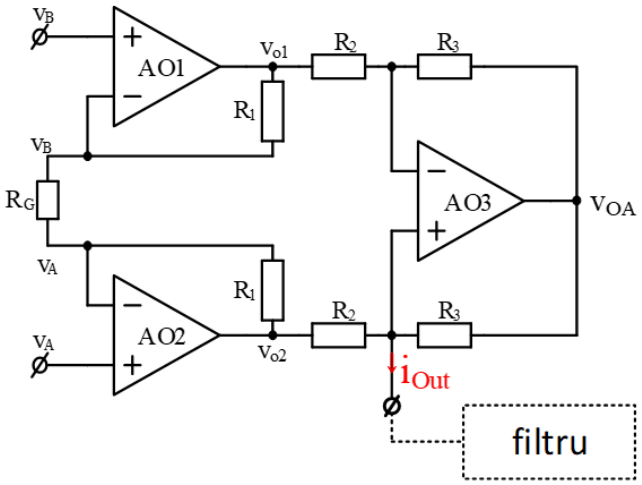
Professors: Onet Raul Ciprian, Vladu Gheorghe Eduard

Contents

1. Project Thematic

1.1 Specifications

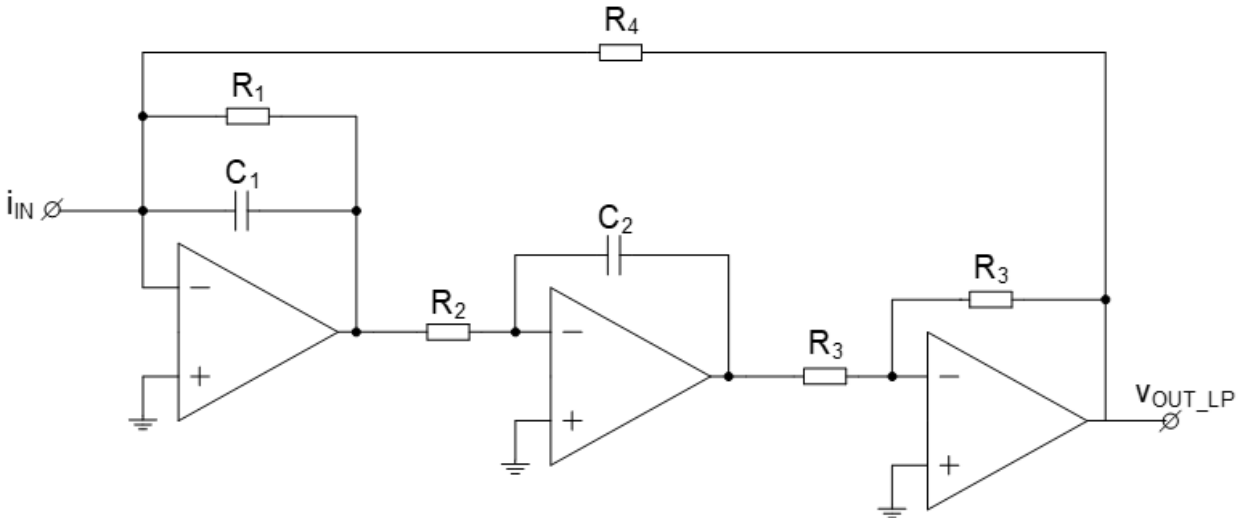
First stage



Characteristics:

Sursa semnal	amplitudine minima (pt castig maxim PGA)	amplitudine maxima (pt castig minim PGA)	unitate masura	Tip Etaj 1	|Castig| etaj 1 (liniar)
2	7.05E-02	1.41E-01	V (differential)	8	0.002

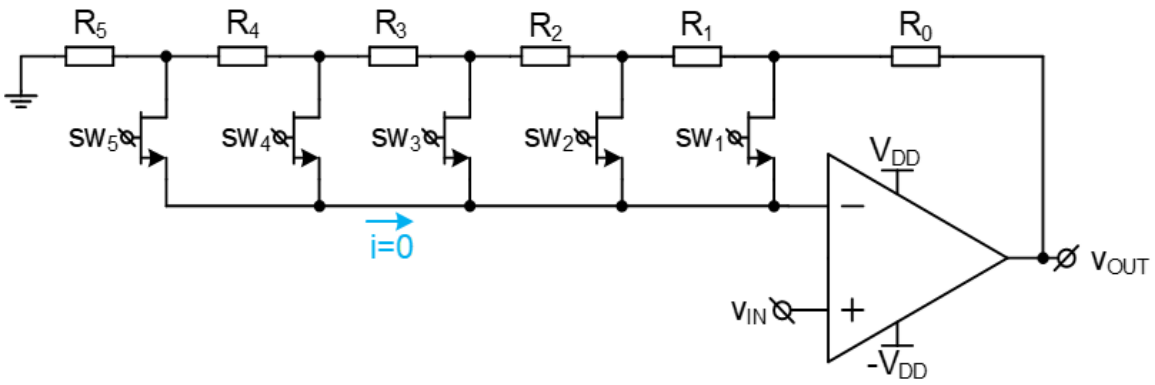
Second stage



Characteristics

tip Etaj 2	|H0| castig liniar in banda de trecere	Rintrare minim	Banda	Q
6	5000	-	3.00E+03	1.41

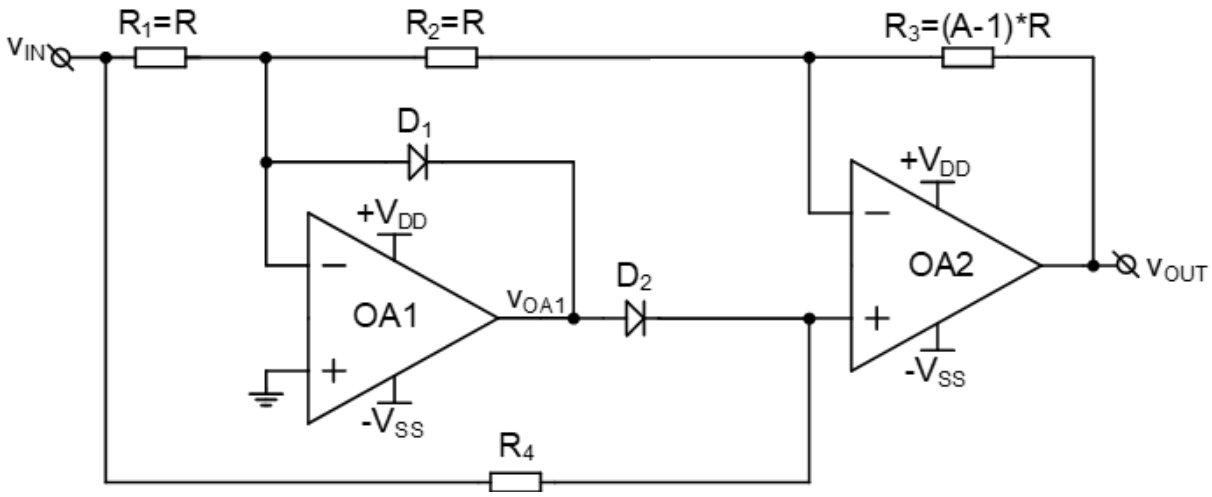
Third stage



Characteristics

tip Etaj 3	castig minim [dB]	rezolutie (pas minim) [dB]	nr pasi	castig maxim [dB]	Rintrare minim
6	5	2	4	11	

Fourth stage

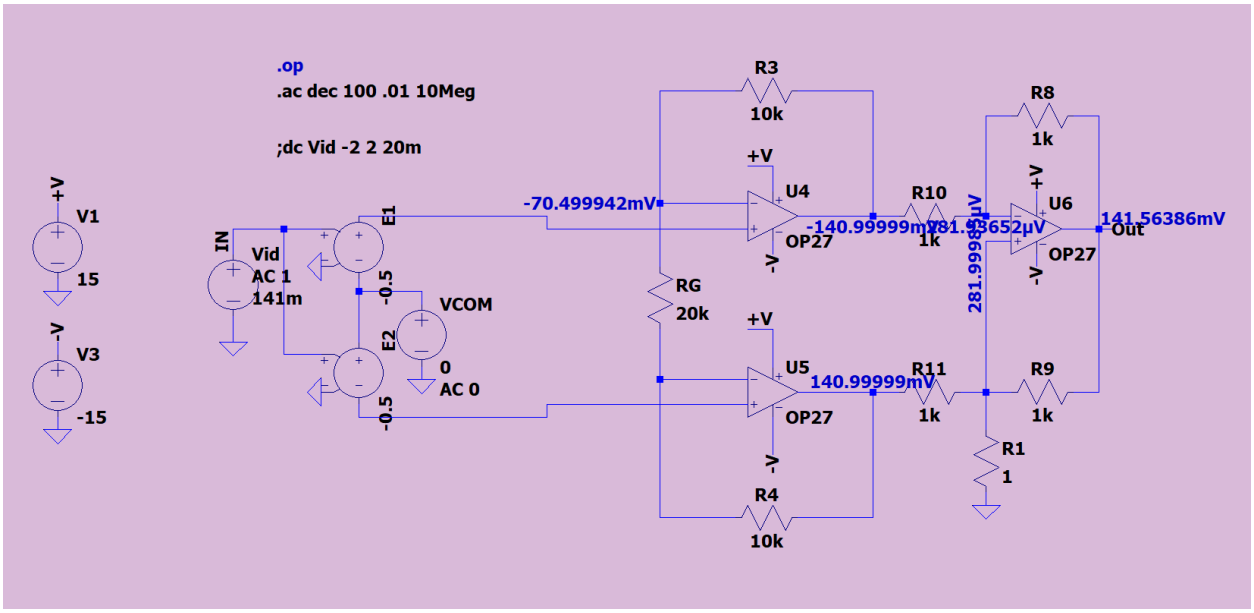


Characteristics

tip Etaj 4	|Castig| etaj 4 (liniar)	Tip AO
3	2	9

2. Components sizing

First stage

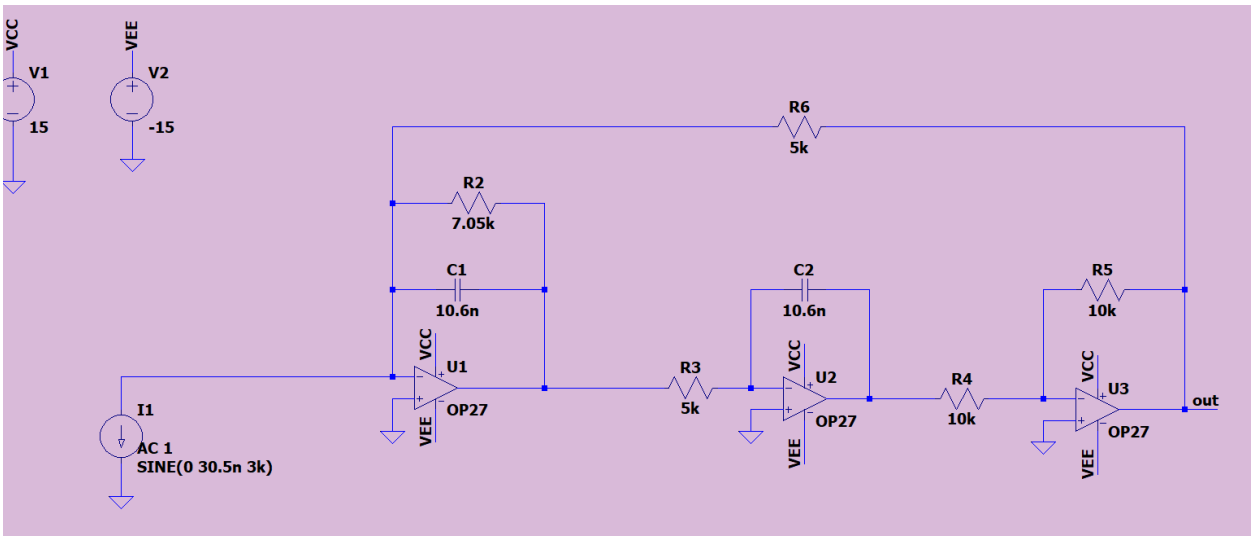


The circuit is designed to take a small differential input voltage (Vid) and amplify it while rejecting common-mode noise

The total gain is $A_{total} = (1 + \frac{R3+R4}{RG})$

⇨ R3=R4=19kΩ
R10=R11=1kΩ
R8=R9=1kΩ
R1=1Ω

Second stage



w0 [rad/sec]	Q	f0 [Hz]	H0 [linear]
1.88E+04	1.41E+00	3.00E+03	5.00E+03

C1=C2 [F]	R1 [Ohm]	R2 [Ohm]	R3 [Ohm]	R4 [Ohm] = H0
1.06E-08	7.05E+03	5.00E+03	1.00E+04	5.00E+03

LPF transfer function parameters

$H_0 = R_4;\ \omega_0 = \frac{1}{\sqrt{R_2 R_4 C_1 C_2}}$ $\quad Q = R_1\sqrt{\frac{C_1}{C_2}\cdot\frac{1}{R_2 R_4}};$

Sizing strategy:

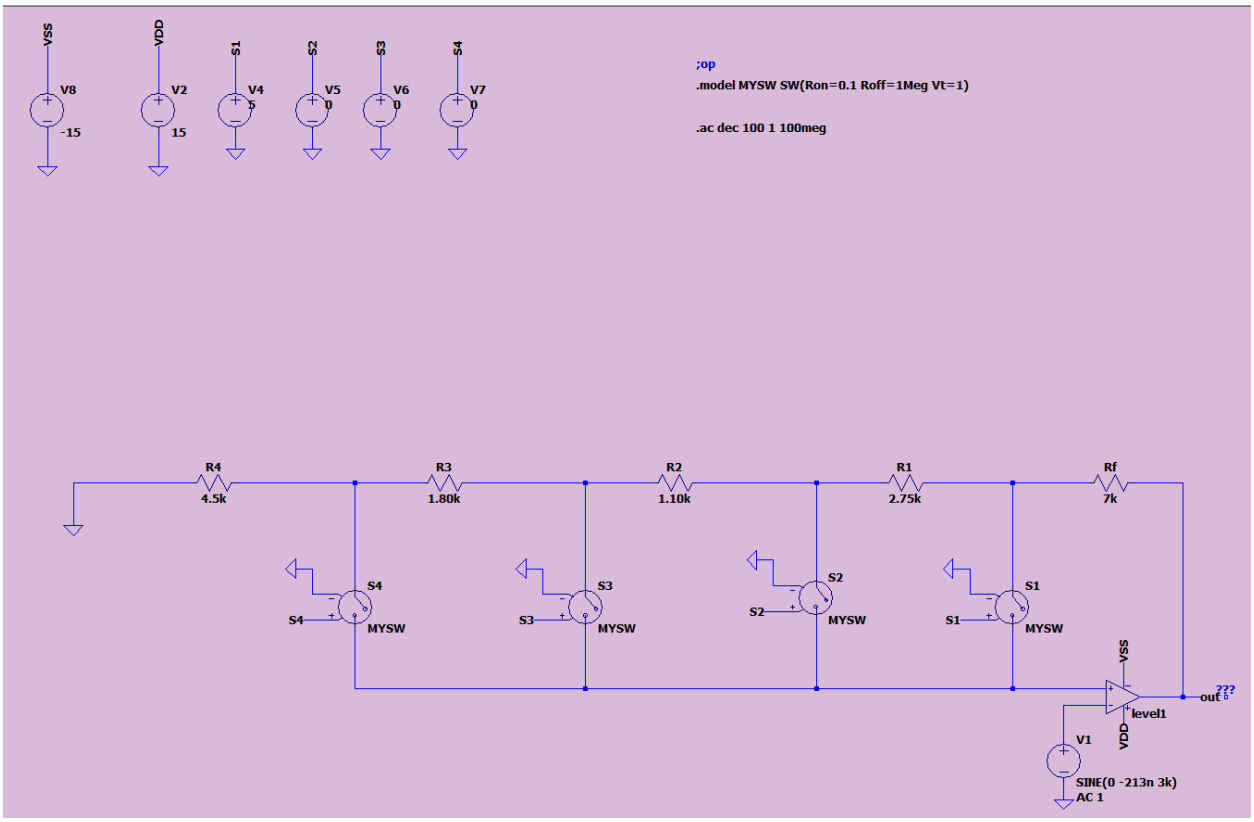
$H_0 = R_4;$

set $R_2 = R_4$; choose the value of R_3

$$C_1 = C_2 = \frac{1}{\omega_0 \cdot R_2}$$

$R_1 = Q \cdot R_2.$

Third stage

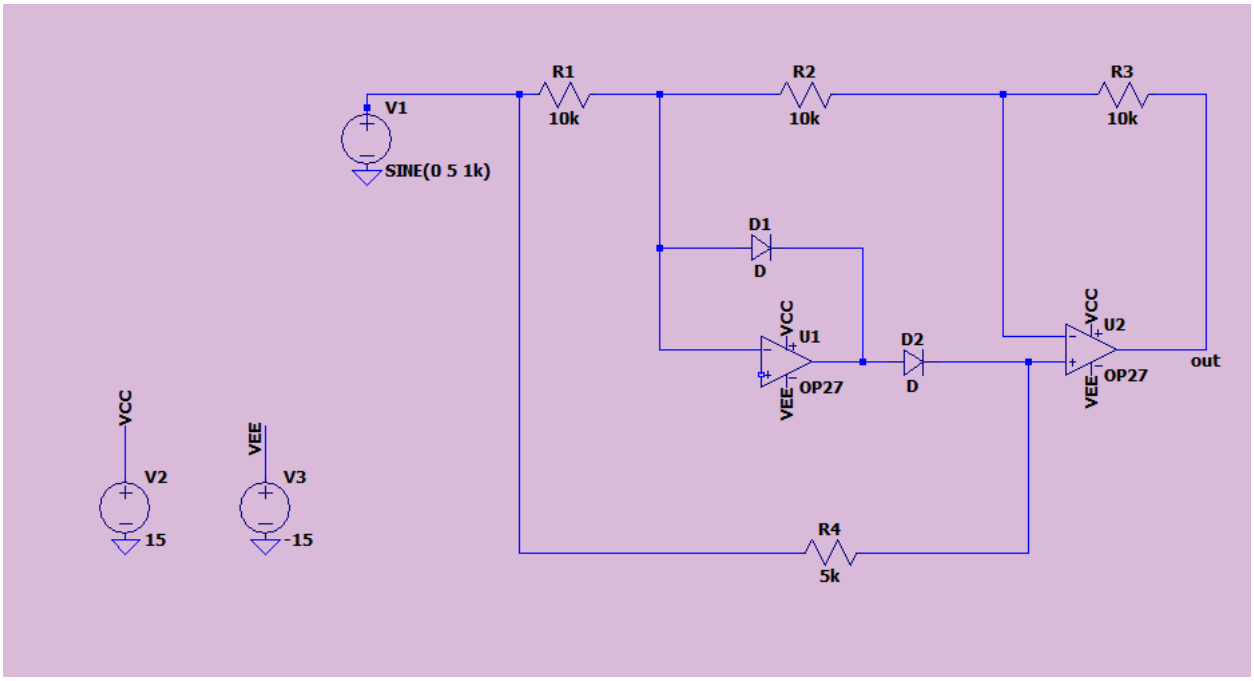


$$A_v = 1 + \frac{Rf}{Rg} \qquad R_g = -\frac{Rf}{Av - 1}$$

Choose Rf=7kΩ

- **11dB (Av=3.55k):** $S4$ is ON. $R4$=4.5 kΩ.
- **9dB (Av=2.82l):** $S3$ is ON. $R3$=1.80kΩ
- **7dB (2.24k):** $S2$ is ON. $R2$=1.10 kΩ.
- **5dB (1.78k):** S1 is ON. $R1$=2.75kΩ

Fourth stage



$V_{out} = -V_{in}(\frac{R3}{R4})$

R3/R4=2 => R3=10k, R4=5k

3. Analysis and Characterization

First stage

OP Analysis

C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj1\AI_VI_Howland

--- Operating Point ---

V(-v):	-15	voltage
V(out):	0.0707819	voltage
V(n003):	0.000140968	voltage
V(n002):	-0.0705	voltage
V(n007):	0.03525	voltage
V(n004):	-0.03525	voltage
V(n009):	0.03525	voltage
V(+v):	15	voltage
V(in):	0.0705	voltage
V(n005):	0.000141	voltage
V(n008):	0.0705	voltage
V(n001):	-0.03525	voltage
V(n006):	0	voltage
I(V1):	-0.00897508	device_current
I(Vid):	0	device_current
I(R9):	7.06409e-05	device_current
I(R10):	7.0641e-05	device_current
I(RG):	-3.525e-06	device_current
I(VCOM):	4.91277e-19	device_current
I(E2):	5.88014e-12	device_current
I(R1):	0.000141	device_current
I(R8):	7.0641e-05	device_current
I(R11):	-7.0359e-05	device_current
I(R3):	-3.525e-06	device_current
I(R4):	3.525e-06	device_current
I(E1):	5.88014e-12	device_current
I(V3):	0.00883408	device_current

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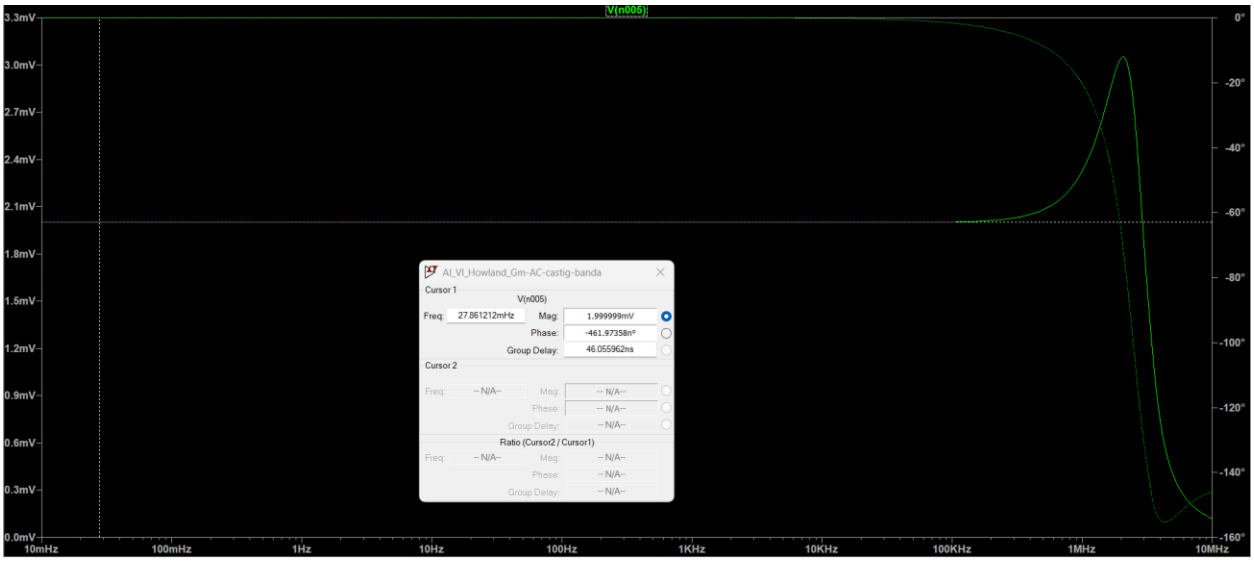
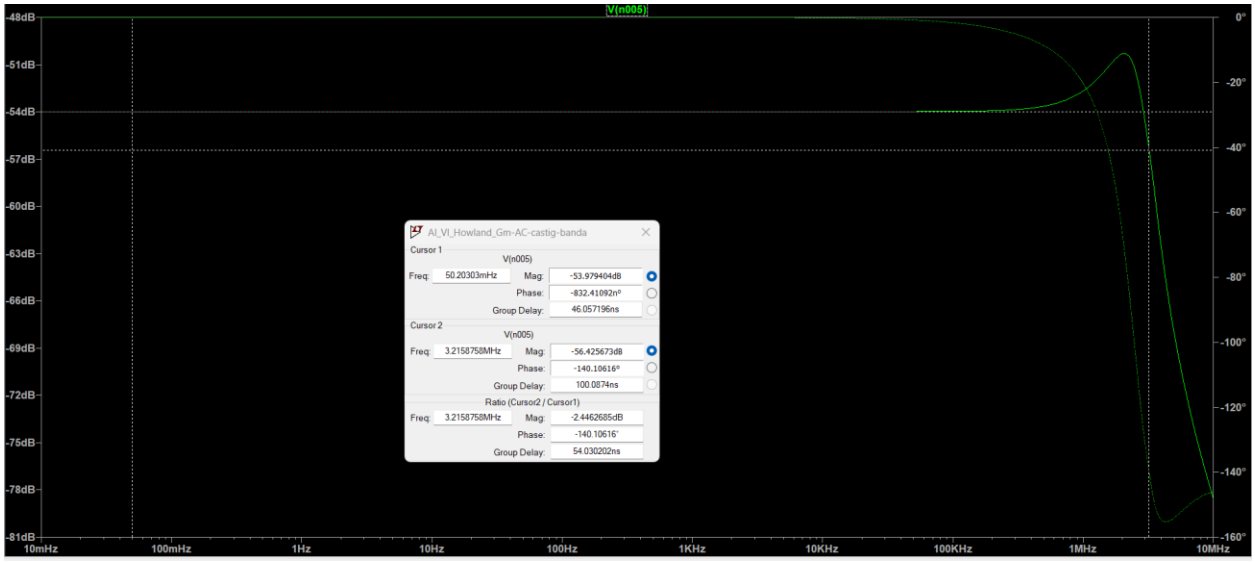
--- Operating Point ---

V(-v):	-15	voltage
V(out):	0.141564	voltage
V(n003):	0.000281937	voltage
V(n002):	-0.141	voltage
V(n007):	0.0704999	voltage
V(n004):	-0.0705	voltage
V(n009):	0.0705	voltage
V(+v):	15	voltage
V(in):	0.141	voltage
V(n005):	0.000282	voltage
V(n008):	0.141	voltage
V(n001):	-0.0704999	voltage
V(n006):	0	voltage
I(V1):	-0.00905156	device_current
I(Vid):	0	device_current
I(R9):	0.000141282	device_current
I(R10):	0.000141282	device_current
I(RG):	-7.04999e-06	device_current
I(VCOM):	9.8227e-19	device_current
I(E2):	1.17603e-11	device_current
I(R1):	0.000282	device_current
I(R8):	0.000141282	device_current
I(R11):	-0.000140718	device_current
I(R3):	-7.05001e-06	device_current
I(R4):	7.05001e-06	device_current
I(E1):	1.17603e-11	device_current
I(V3):	0.00876956	device_current

Low frequency gain

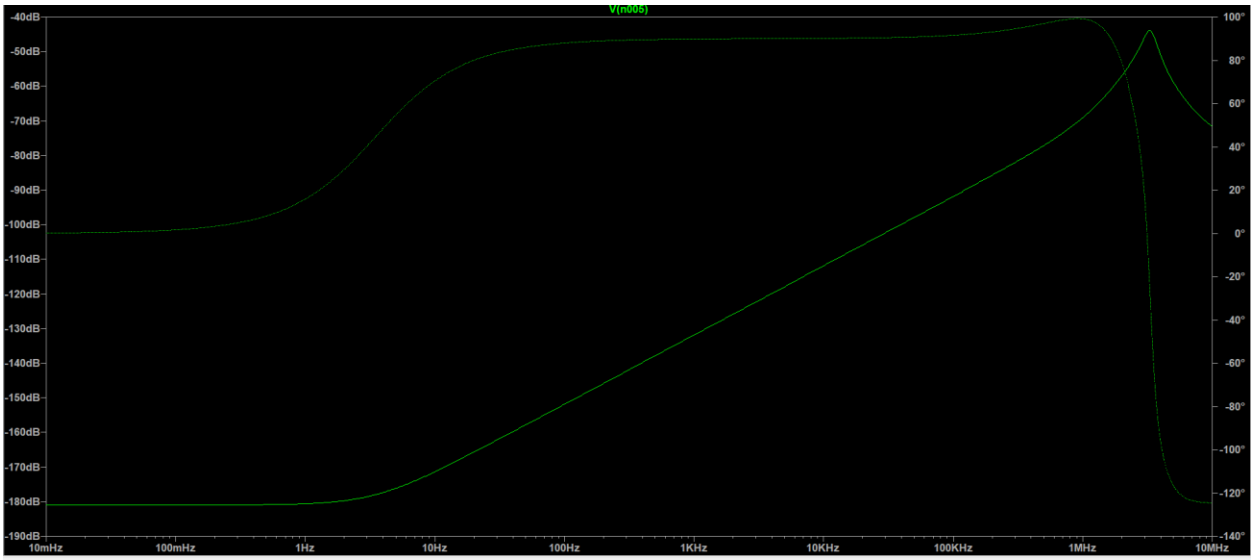


Bandwidth>Bw filter



The frequency response of the amplifier stage was analyzed to ensure the bandwidth exceeds the requirements of the subsequent filtering stages. Simulation results confirm a stable mid-band gain of **0.002 (-53.42 dB)** from DC. Using the -3 dB criterion, the amplifier bandwidth was measured at **3.215MHz**. The filter bandwidth is 3kHz (3.215MHz > 3kHz)

CMRR

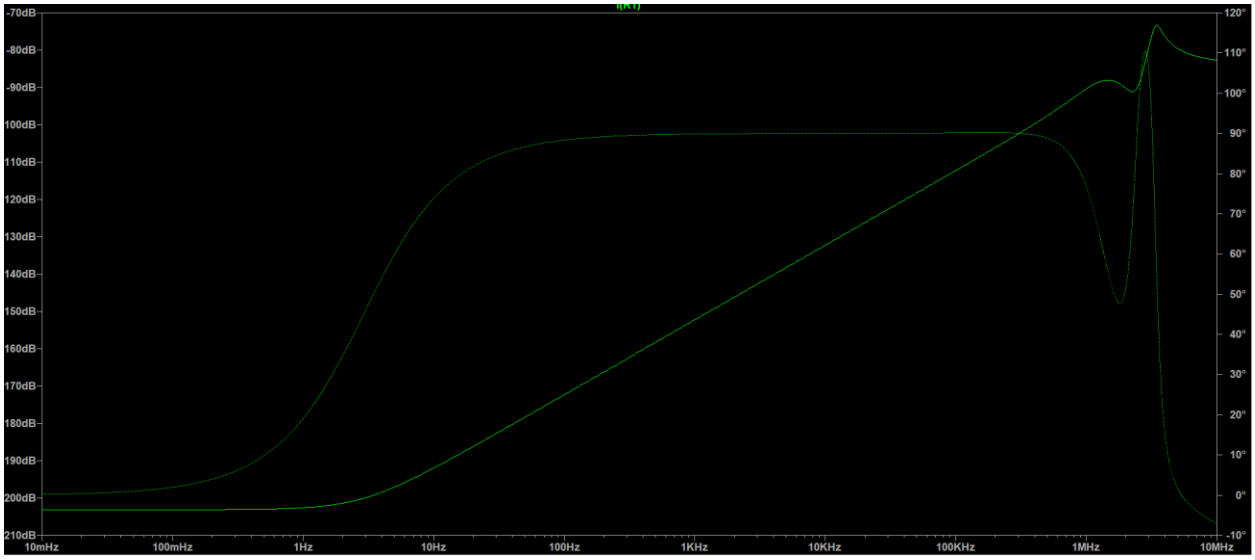


The common-mode rejection ratio (CMRR) is defined as the ratio between the differential gain (AD) and the common-mode gain (ACM).

$$CMRRdB = Av[dB] - ACM[dB]$$

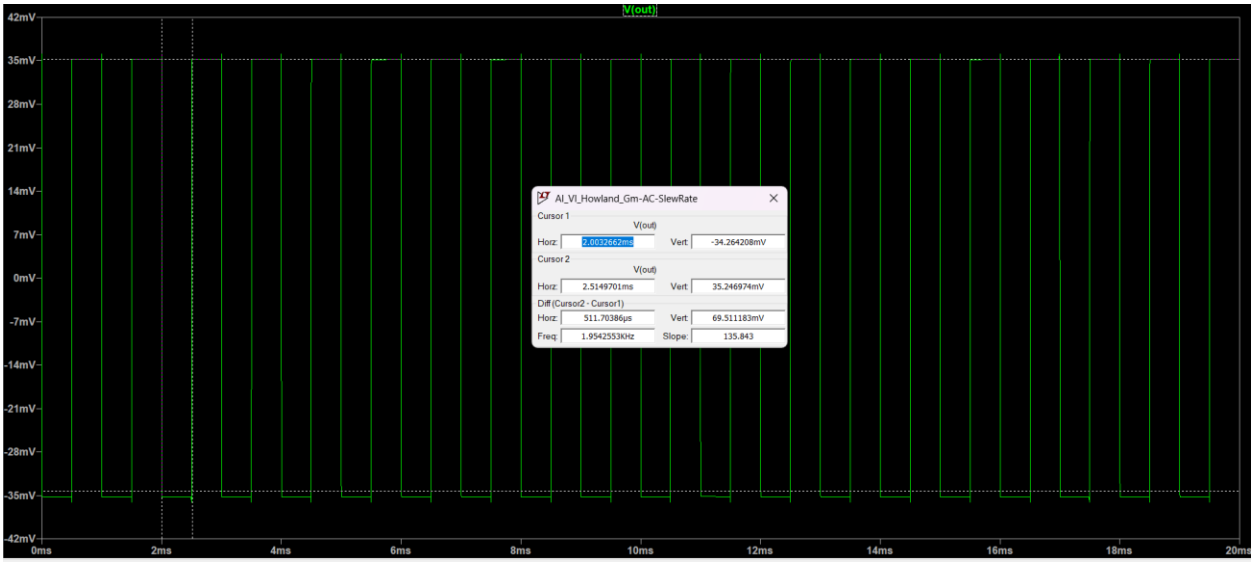
From the simulation the CMRR at low frequencies is around -180 dB(Acm) and the differential gain is -53.42 dB (Av). This gives a final value of aprox. 126 dB which confirms excellent CMRR for the instrument amplifier.

PSRR

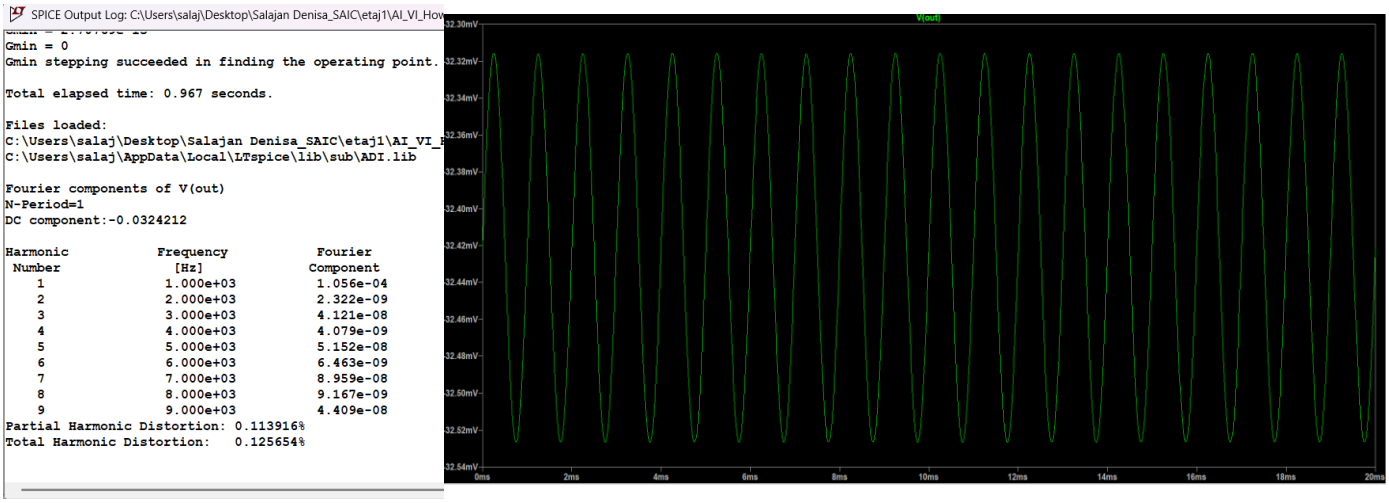


The **PSRR (Power Supply Rejection Ratio)** simulation confirms high circuit stability against power supply fluctuations. At critical ripple frequencies (**50–100 Hz**), the rejection is approximately **-105dB**, ensuring an extremely stable output current that remains immune to noise originating from the voltage regulators.

Slew Rate = $\Delta V/\Delta T$ = slope



THD<1%



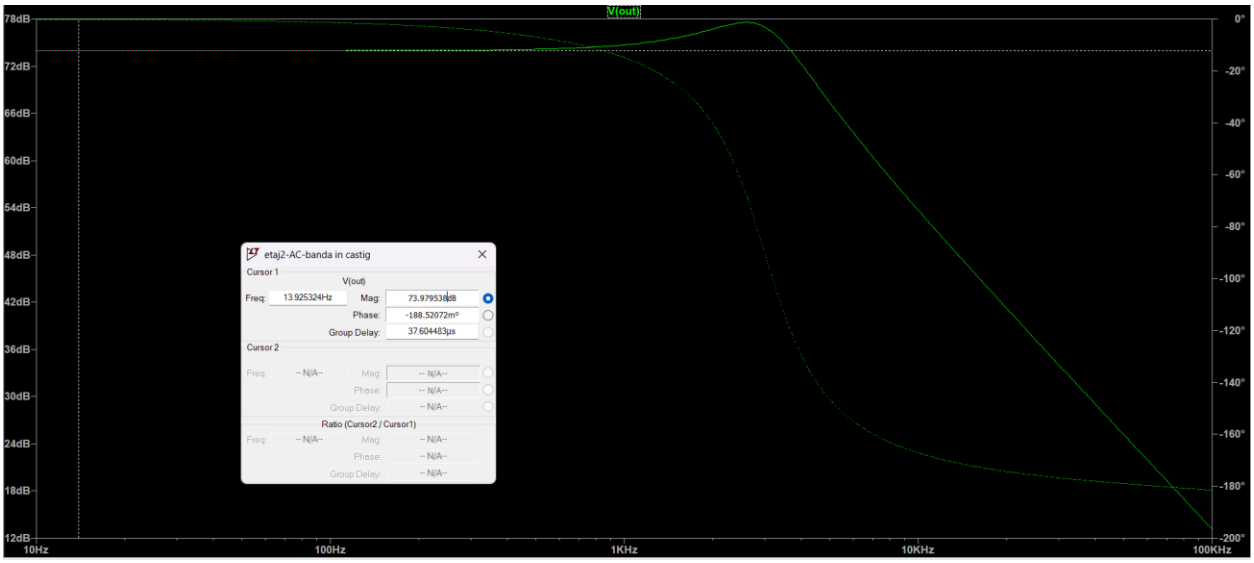
Second stage

DCOP

C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj2\etaj2-AC-band

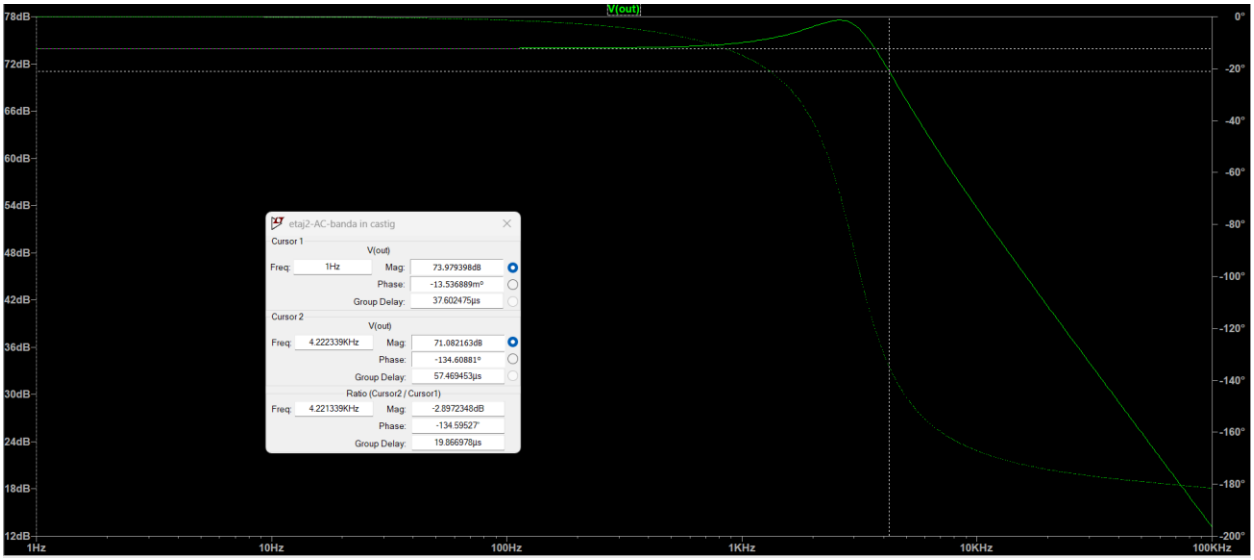
```
      --- Operating Point ---

V(vee):         -15             voltage
V(n001):        0               voltage
V(n003):        0               voltage
V(n004):        0               voltage
V(vcc):         15              voltage
V(n002):        0               voltage
V(n005):        0               voltage
V(out):         0               voltage
I(V1):          -0.00890259     device_current
I(R2):          0               device_current
I(R4):          0               device_current
I(R5):          0               device_current
I(C2):          0               device_current
I(R3):          0               device_current
I(R6):          0               device_current
I(I1):          0               device_current
I(V2):          0.00890259      device_current
I(C1):          0               device_current
Ix(u2:1):       0               subckt_current
Ix(u2:2):       0               subckt_current
Ix(u2:3):       0.00296753      subckt_current
Ix(u2:4):       -0.00296753     subckt_current
Ix(u2:5):       0               subckt_current
Ix(u1:1):       0               subckt_current
Ix(u1:2):       0               subckt_current
Ix(u1:3):       0.00296753      subckt_current
Ix(u1:4):       -0.00296753     subckt_current
```

AC Analysis(castig in banda de trecere)



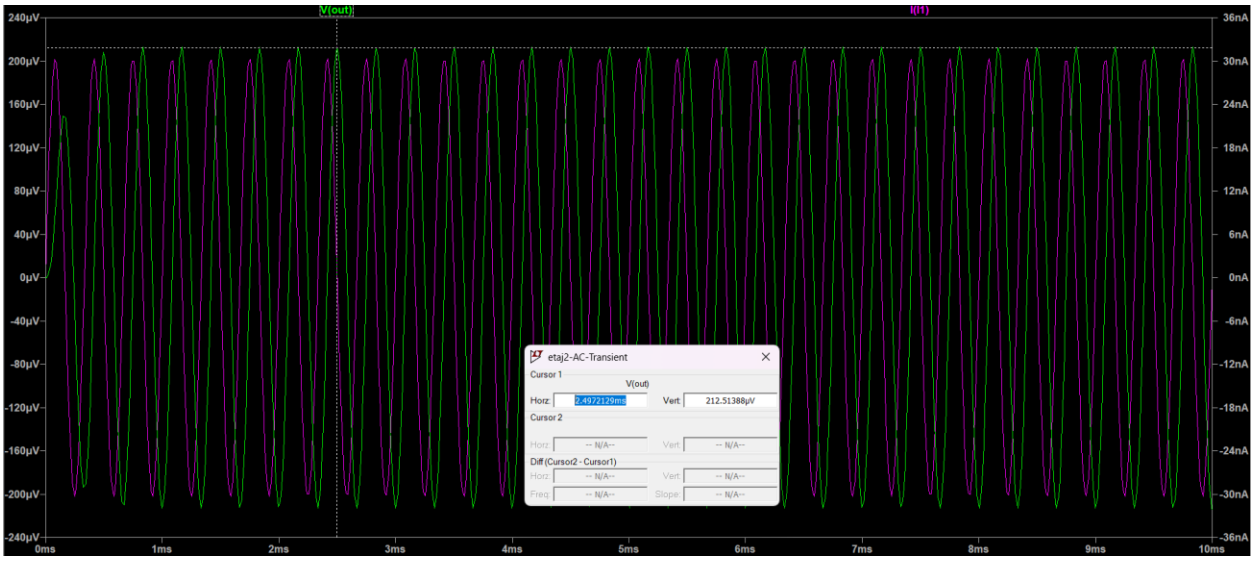
74db = H0= 5000

Bandwidth



The simulation result is at 4.22kHz which represents a deviation from the specification of 3kHz, confirming the accuracy of the integration constants (R and C)

THD<1%



SPICE Output Log: C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj2\etaj2-AC-Transient.log

```
Gmin = 0
Gmin stepping succeeded in finding the operating point.

Total elapsed time: 0.659 seconds.

Files loaded:
C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj2\etaj2-AC-Transient.net
C:\Users\salaj\AppData\Local\LTspice\lib\sub\ADI.lib

Fourier components of V(out)
N-Period=1
DC component:-9.27909e-08

Harmonic            Frequency            Fourier            Normalized          Phas
 Number               [Hz]              Component            Component         [degr
    1               3.000e+03            2.115e-04          1.000e+00          -179
    2               6.000e+03            1.353e-07          6.397e-04          -179
    3               9.000e+03            4.753e-07          2.247e-03           -64
    4               1.200e+04            1.500e-07          7.092e-04           167
    5               1.500e+04            1.803e-07          8.526e-04            46
    6               1.800e+04            7.014e-08          3.316e-04           166
    7               2.100e+04            1.458e-07          6.893e-04            62
    8               2.400e+04            8.554e-08          4.044e-04           132
    9               2.700e+04            2.394e-07          1.132e-03            94
Partial Harmonic Distortion: 0.295274%
Total Harmonic Distortion:   0.582156%
```

Third stage

DCOP (min and max)

C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj3\tb_PGA_serie_A

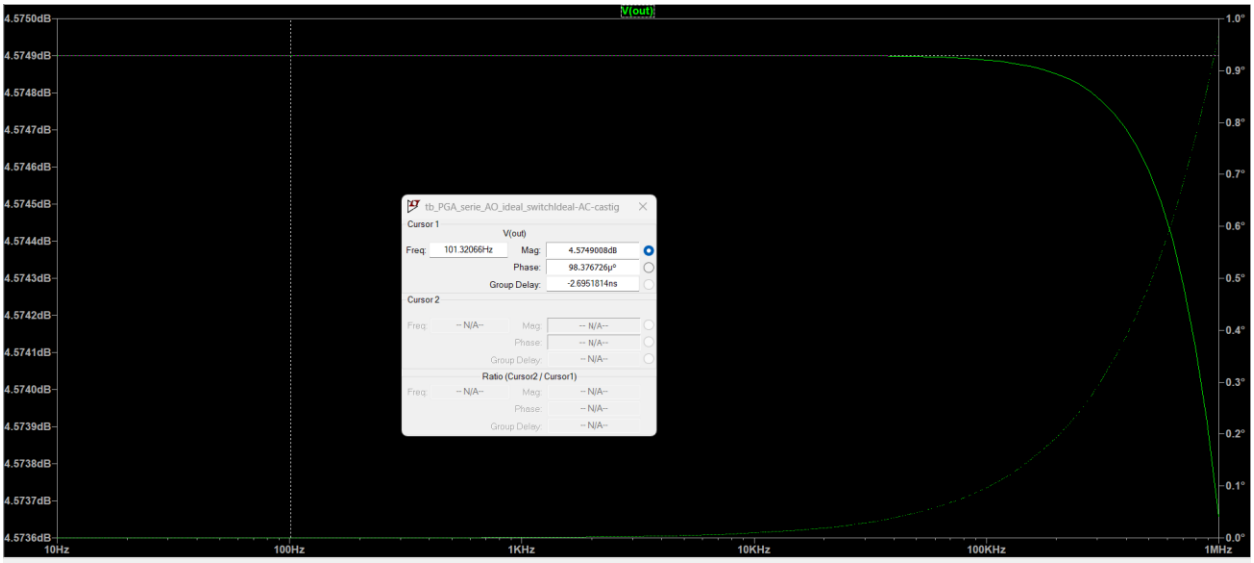
```
      --- Operating Point ---

V(n006):        1               voltage
V(n004):        1               voltage
V(s1):          5               voltage
V(s3):          0               voltage
V(n001):        0.445711        voltage
V(n005):        1               voltage
V(vss):         -15             voltage
V(vdd):         15              voltage
V(n003):        0.730924        voltage
V(s2):          0               voltage
V(s4):          0               voltage
V(out):         1.69334         voltage
V(n002):        0.622997        voltage
I(V5):          0               device_current
I(Rf):          9.90488e-05     device_current
I(R4):          -9.90468e-05    device_current
I(S3):          3.77005e-07     device_current
I(V2):          -2.8e-08        device_current
I(R1):          -9.78464e-05    device_current
I(V6):          0               device_current
I(S2):          2.69078e-07     device_current
I(V8):          3.2e-08         device_current
I(V1):          -2e-09          device_current
I(V7):          0               device_current
I(R3):          -9.84925e-05    device_current
I(R2):          -9.81155e-05    device_current
I(S1):          -1.20237e-06    device_current
```

C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj3\tb_PGA_serie_

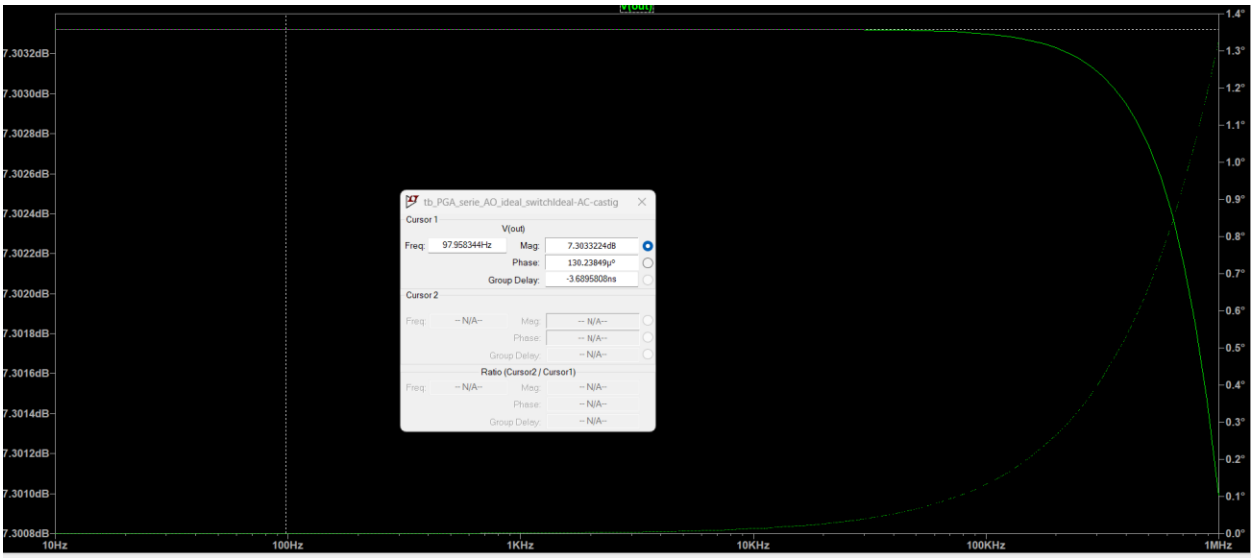
```
      --- Operating Point ---

V(n006):        1               voltage
V(n004):        2.24597         voltage
V(s1):          0               voltage
V(s3):          0               voltage
V(n001):        1               voltage
V(n005):        1               voltage
V(vss):         -15             voltage
V(vdd):         15              voltage
V(n003):        1.63828         voltage
V(s2):          0               voltage
V(s4):          5               voltage
V(out):         3.80155         voltage
V(n002):        1.3959          voltage
I(V5):          0               device_current
I(Rf):          0.000222225     device_current
I(R4):          -0.000222223    device_current
I(S3):          -3.95901e-07    device_current
I(V2):          -2.8e-08        device_current
I(R1):          -0.000220979    device_current
I(V6):          0               device_current
I(S2):          -6.38276e-07    device_current
I(V8):          3.2e-08         device_current
I(V1):          -2e-09          device_current
I(V7):          0               device_current
I(R3):          -0.000219945    device_current
I(R2):          -0.000220341    device_current
I(S1):          -1.24597e-06    device_current
```

20*log10(1.69)= 4.57 dB
20*log10(3.80) =11.6 dB

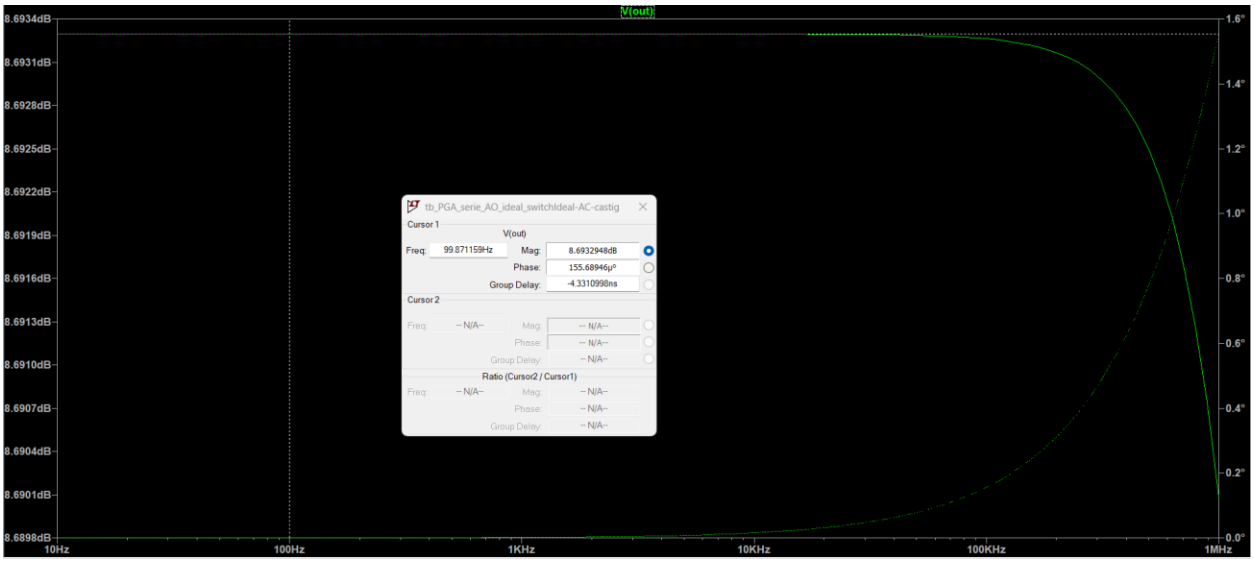
AC Analysis(toate treptele de castig)



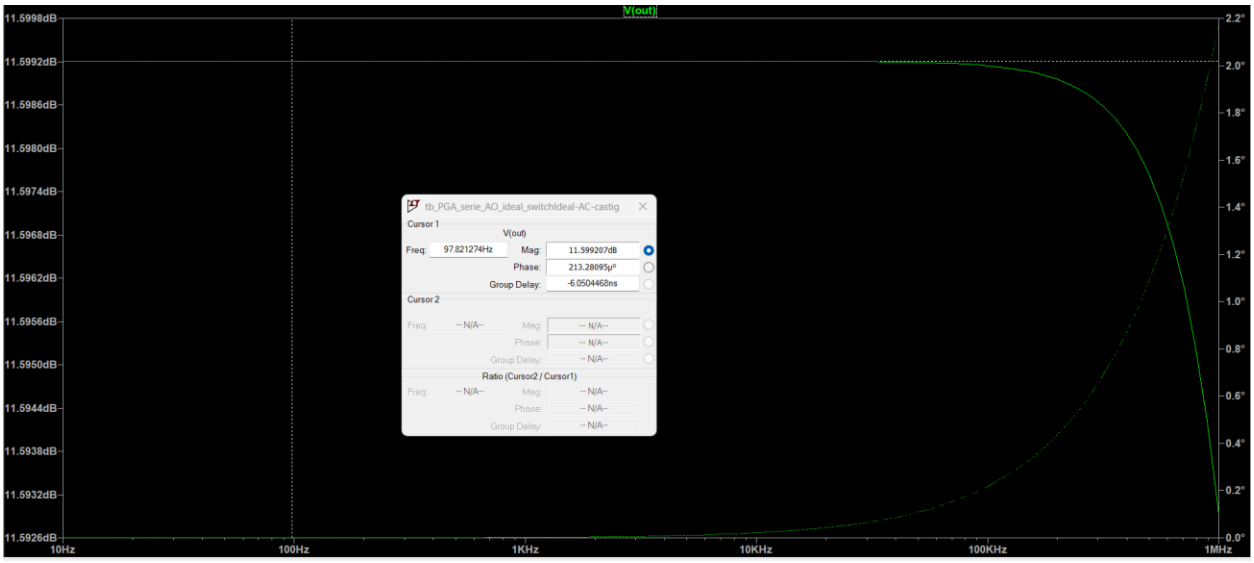
Gain=4.57db through S1



Gain=7.30db through S2

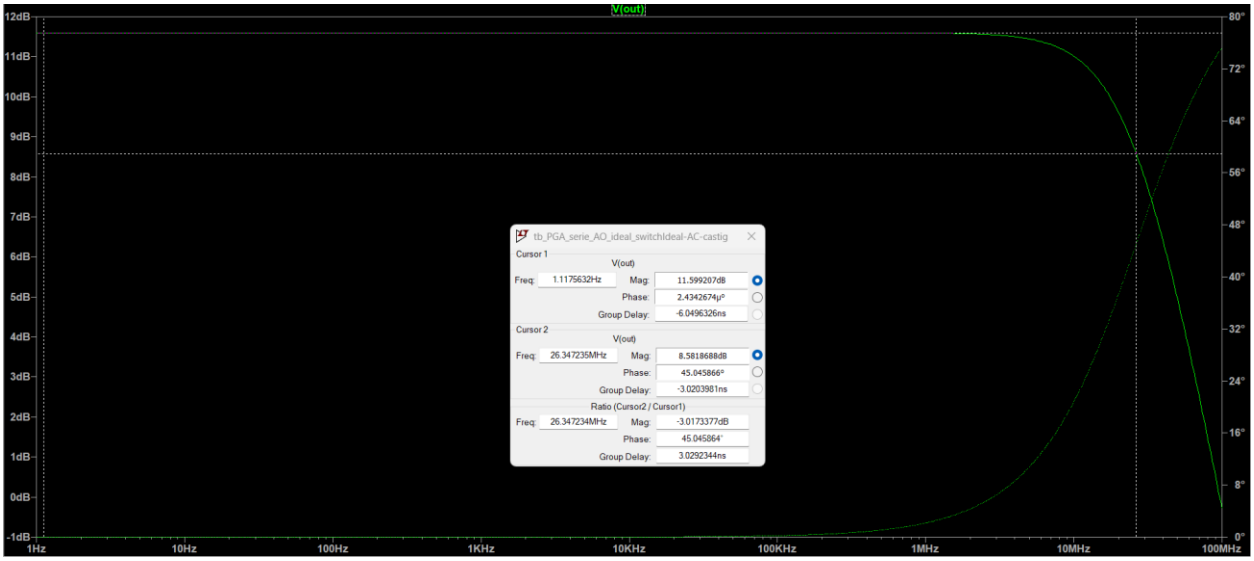


Gain=8.69dB through S3

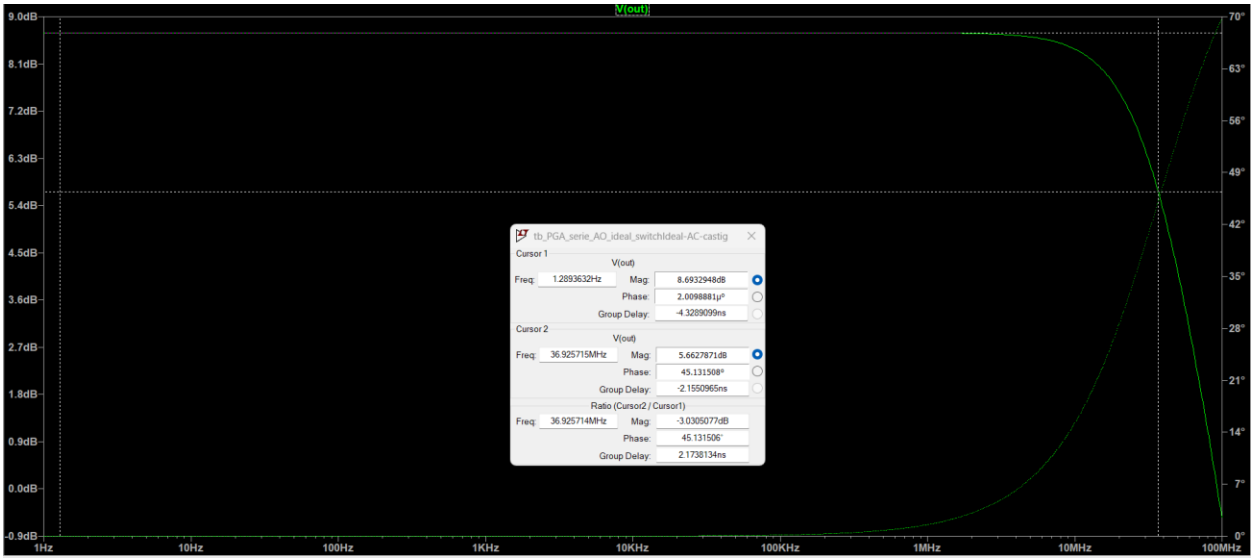


Gain=11.59dB through S4

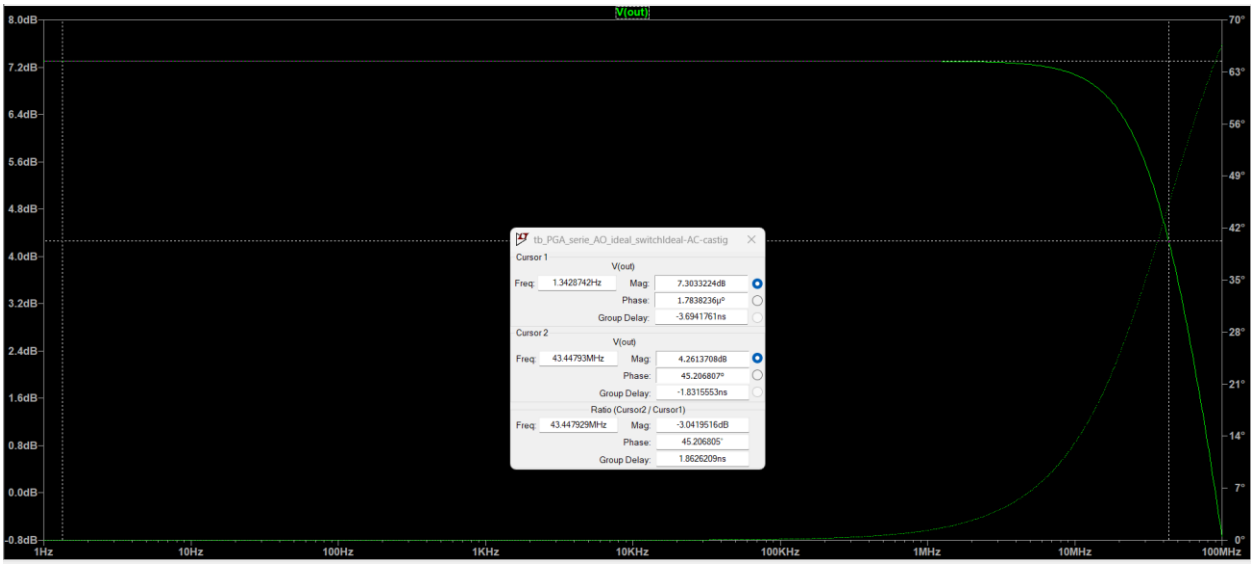
Banda PGA>Banda filtru



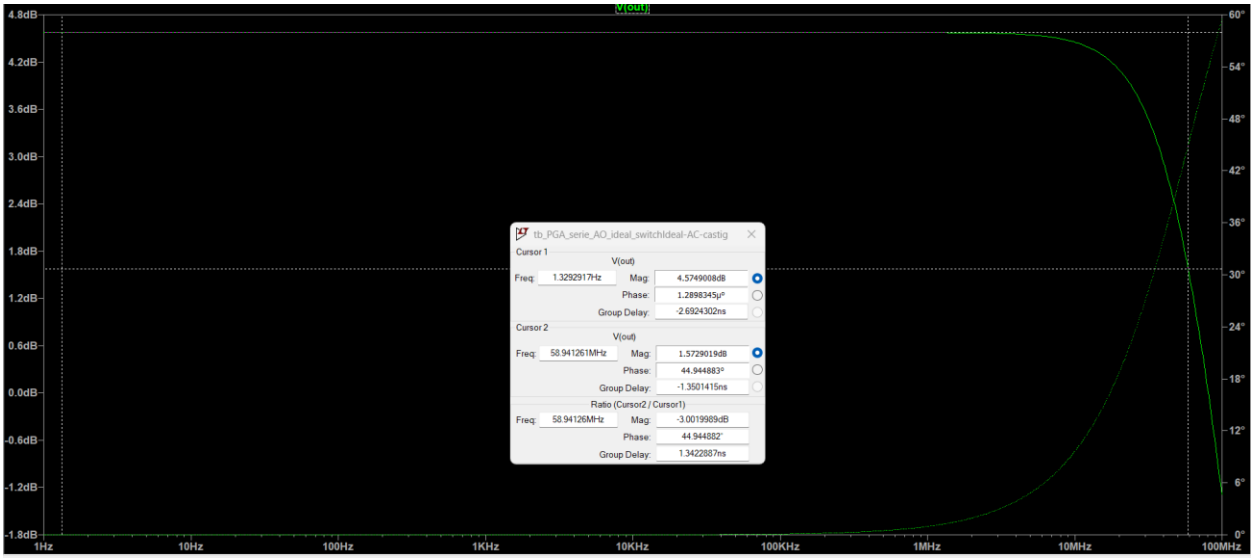
freq 26.34MHz>3kHZ



freq 36.92MHz>3kHz

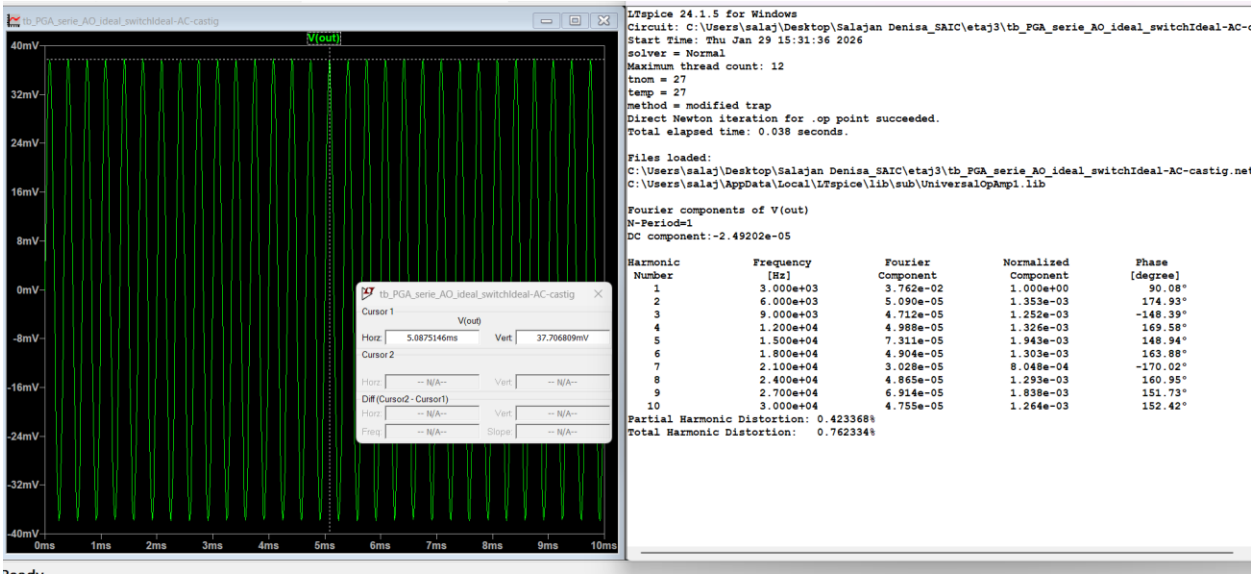


freq 43.44MHz>3kHz

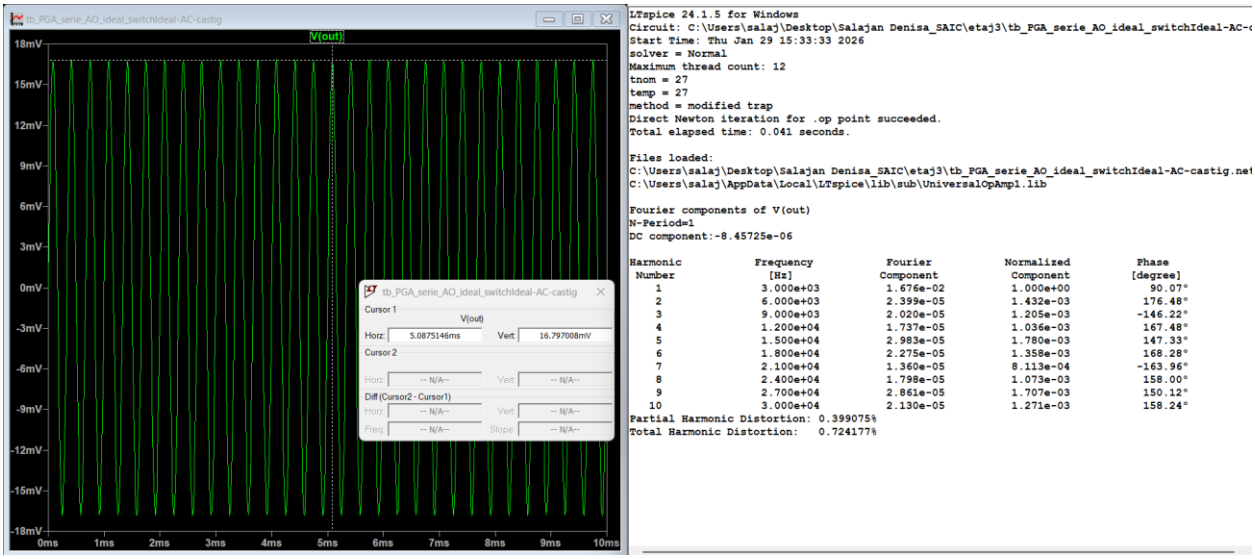


freq 58.91MHz>3kHz

THD pt castig min cu amplitudine max



THD pt castig max cu amplitudine min



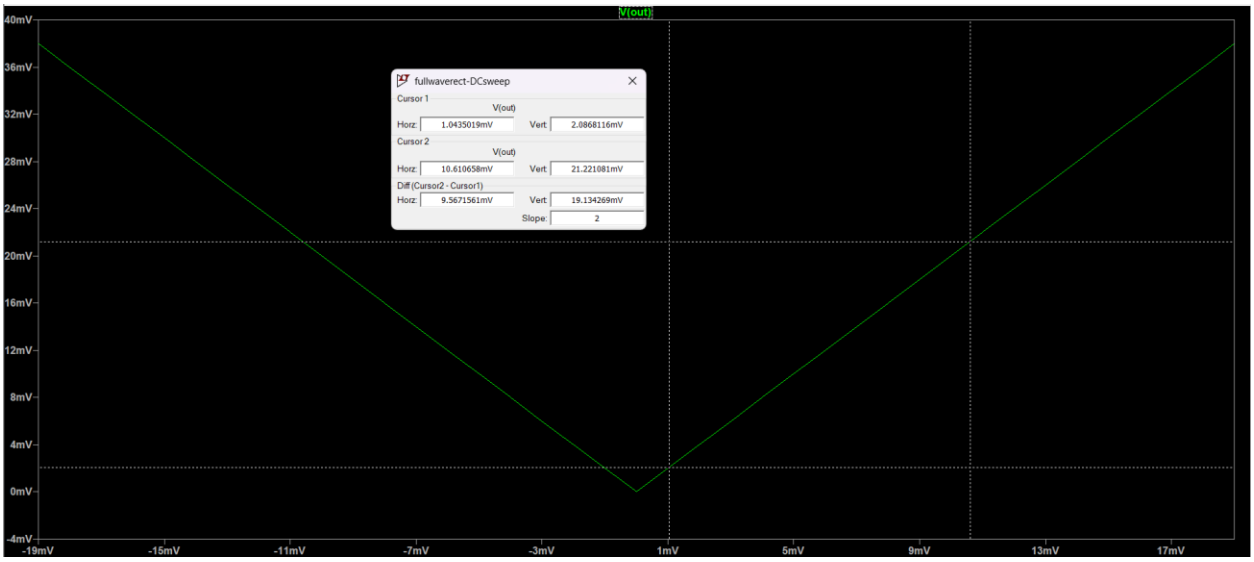
Fourth stage

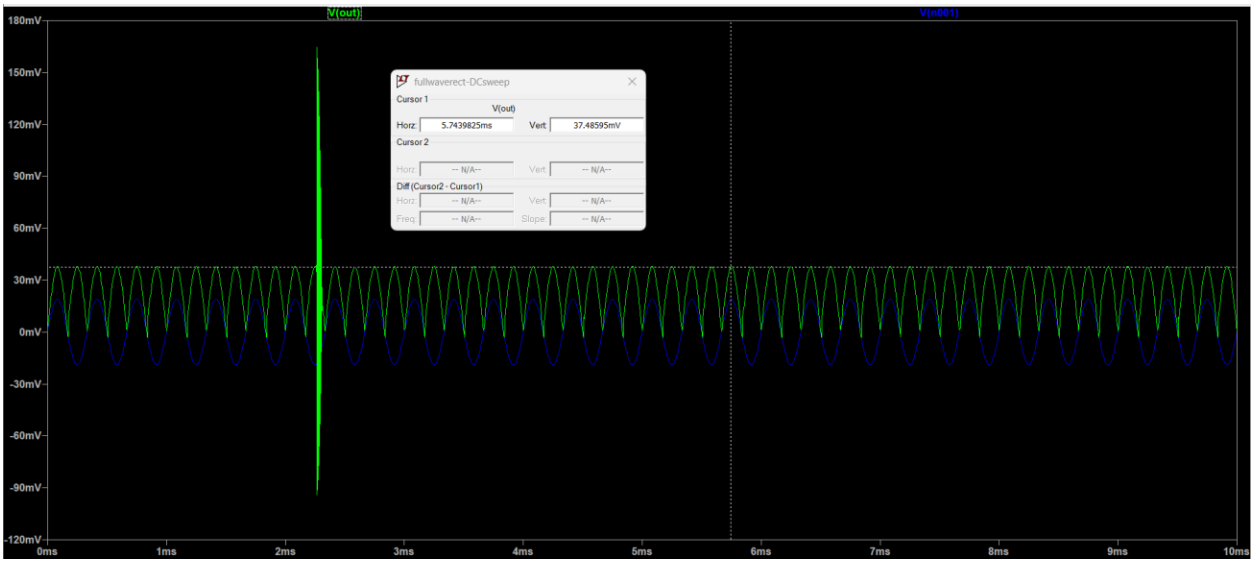
DCOP

C:\Users\salaj\Desktop\Salajan Denisa_SAIC\etaj4\fullwaverect-D

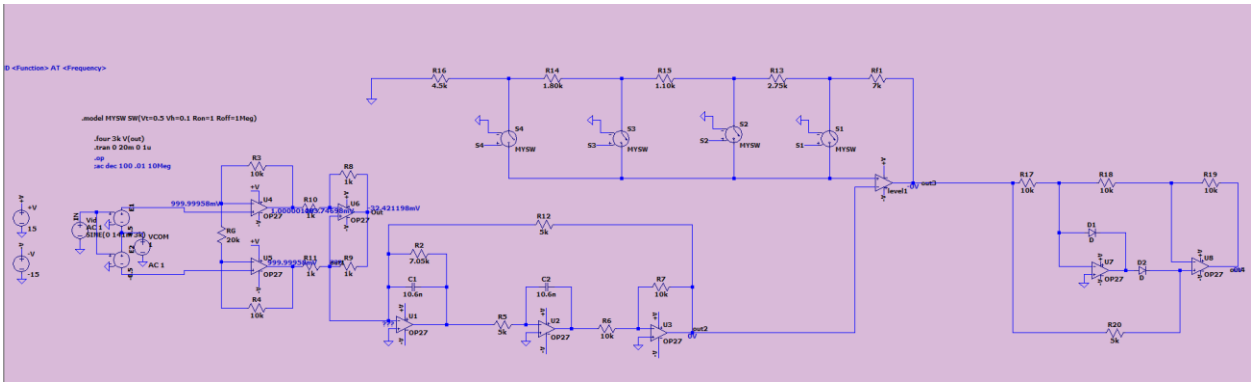
```
        --- Operating Point ---

V(n004):        -0.61349        voltage
V(vcc):         15              voltage
V(vee):         -15             voltage
V(out):         2               voltage
V(n002):        2.63842e-07     voltage
V(n005):        0.999999        voltage
V(n003):        0.999998        voltage
V(n001):        1               voltage
I(R4):          -1.68432e-10    device_current
I(D1):          0.0002          device_current
I(R1):          -0.0001         device_current
I(V2):          -0.00589403     device_current
I(V3):          0.00599403      device_current
I(R2):          9.99998e-05     device_current
I(R3):          0.0001          device_current
I(V1):          -0.0001         device_current
I(D2):          -1.62349e-12    device_current
Ix(u2:1):       1.66809e-10     subckt_current
Ix(u2:2):       1.66524e-10     subckt_current
Ix(u2:3):       0.00302263      subckt_current
Ix(u2:4):       -0.00292263     subckt_current
Ix(u2:5):       -0.0001         subckt_current
Ix(u1:1):       -4.39736e-14    subckt_current
Ix(u1:2):       4.40176e-14     subckt_current
Ix(u1:3):       0.0028714       subckt_current
Ix(u1:4):       -0.0030714      subckt_current
Ix(u1:5):       0.0002          subckt_current
```

DC Sweep +Transient





4. The Final Schematic and Functionality



5. Conclusion

Parameters:	Expected Value	Simulated Value
First stage		
Gain	0.002V/V	1.99mV
Bandwidth Freq.	>3kHz	3.215MHz
THD	<1%	0.12
Second stage		
Bandwidth	3k	4.22kHz
Castig in banda(H0)	5000	74dB=5000
THD	<1%	0.58%
Third stage		
Castig maxim	11dB	11.6dB
Castig minim	5dB	4.57dB
Banda castig minim	>3kHz	58.91MHz
Banda castig maxim	>3kHz	26.34MHz
THD castig min	<1%	0.72%
THD castig max	<1%	0.76%
Fourth stage		
Castig	2	2.06mV