Audio Amplifier

-Computer aided design project-

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Coordinating professor

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1. Theoretical foundations

An amplifier, electronic amplifier or (informally) amp is an electronic device that can increase the power of a signal (a time-varying voltage or current). It is a two-port electronic circuit that uses electric power from a power supply to increase the amplitude of a signal applied to its input terminals, producing a proportionally greater amplitude signal at its output. The amount of amplification provided by an amplifier is measured by its gain: the ratio of output voltage, current, or power to input. An amplifier is a circuit that has a power gain greater than one. [19]

An audio power amplifier (or power amp) is an electronic amplifier that amplifies low-power electronic audio signals such as the signal from radio receiver or electric guitar pickup to a level that is high enough for driving loudspeakers or headphones. Audio power amplifiers are found in all manner of sound systems including sound reinforcement, public address and home audio systems and musical instrument amplifiers like guitar amplifiers. It is the final electronic stage in a typical audio playback chain before the signal is sent to the loudspeakers. [18]

Negative feedback is a technique used in most modern amplifiers to improve bandwidth and distortion and control gain. In a negative feedback amplifier part of the output is fed back and added to the input in opposite phase, subtracting from the input. The main effect is to reduce the overall gain of the system. However, any unwanted signals introduced by the amplifier, such as distortion are also fed back. Since they are not part of the original input, they are added to the input in opposite phase, subtracting them from the input. In this way, negative feedback also reduces nonlinearity, distortion and other errors introduced by the amplifier. [19]

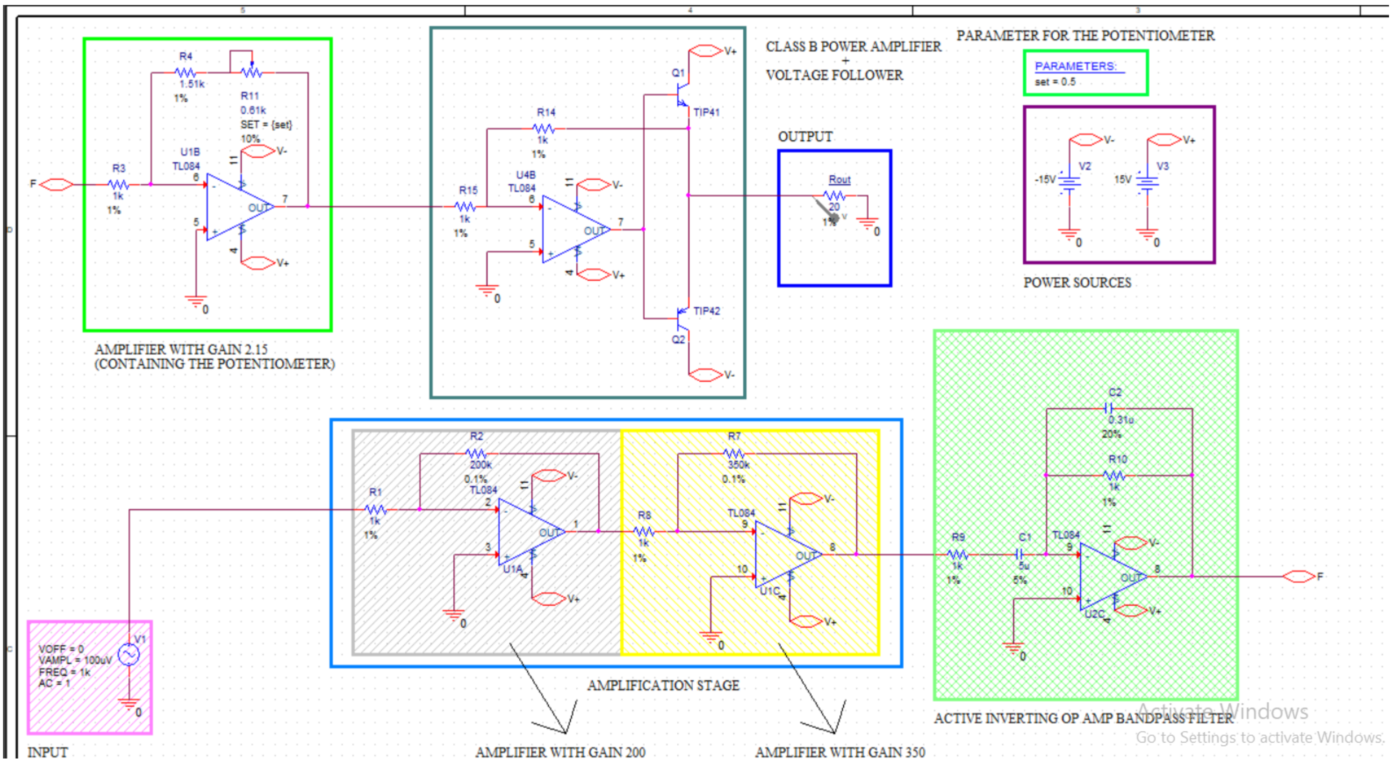
Power amplifier circuits (output stages) are classified as A, B, AB and C for analog designs—and class D and E for switching designs. The power amplifier classes are based on the proportion of each input cycle (conduction angle) during which an amplifying device passes current. The image of the conduction angle derives from amplifying a sinusoidal signal. If the device is always on, the conducting angle is 360°. If it is on for only half of each cycle, the angle is 180°. The angle of flow is closely related to the amplifier power efficiency. [19]

2. Circuit description

The aim of the project is to design and implement an audio amplifier which has the amplitude of the input signal equal to 100μV and the output will be in the (5V, 7V) interval. The output resistance (speaker) is 20Ω. As for the bandwidth, its values are in the (32Hz, 512Hz).

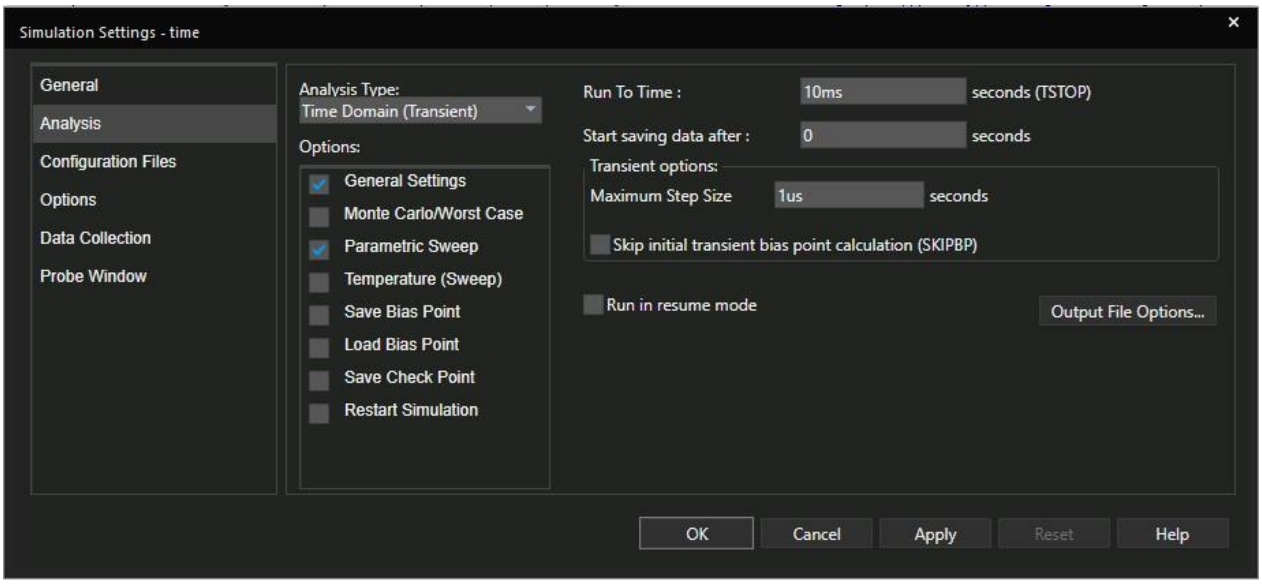
3. Circuit

3.1. Schematic

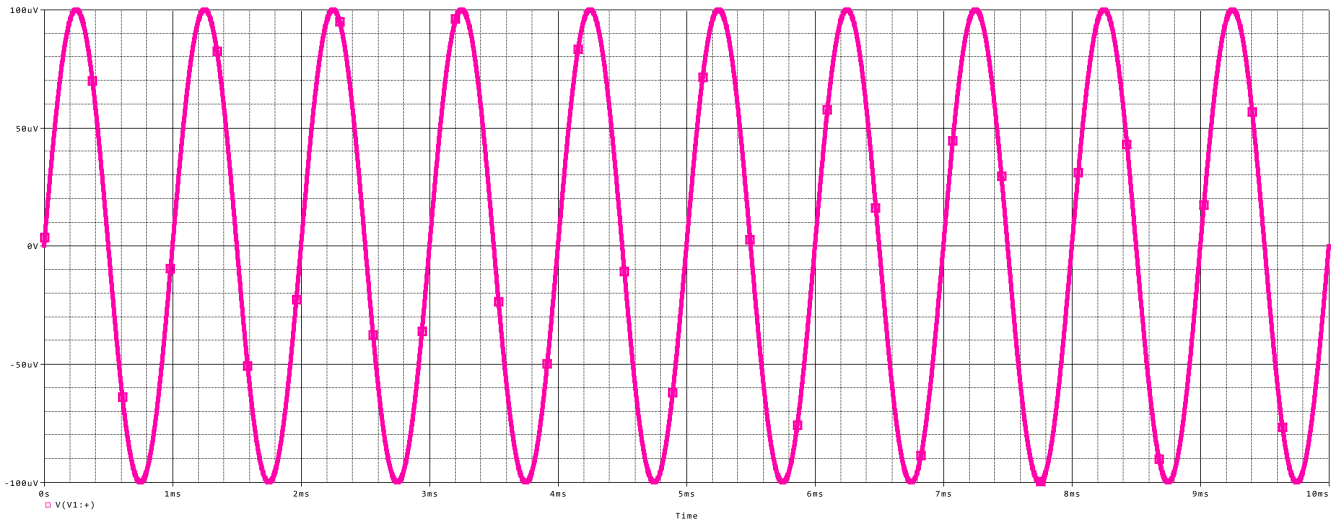


3.2. Simulation results

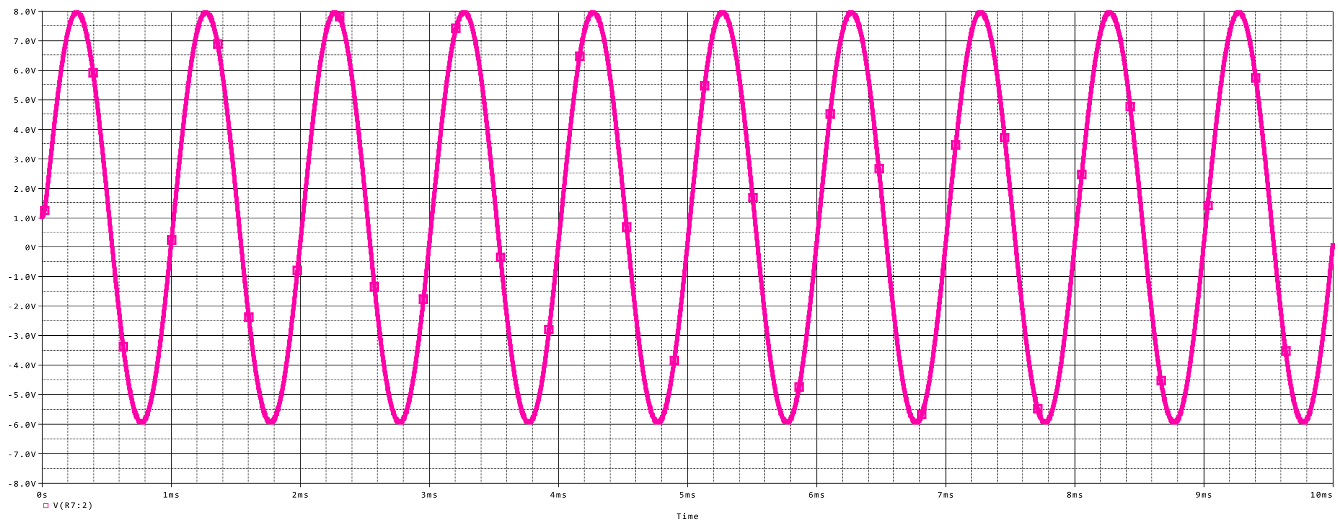
3.2.1. Time domain



The input signal (amplitude of 100µV):

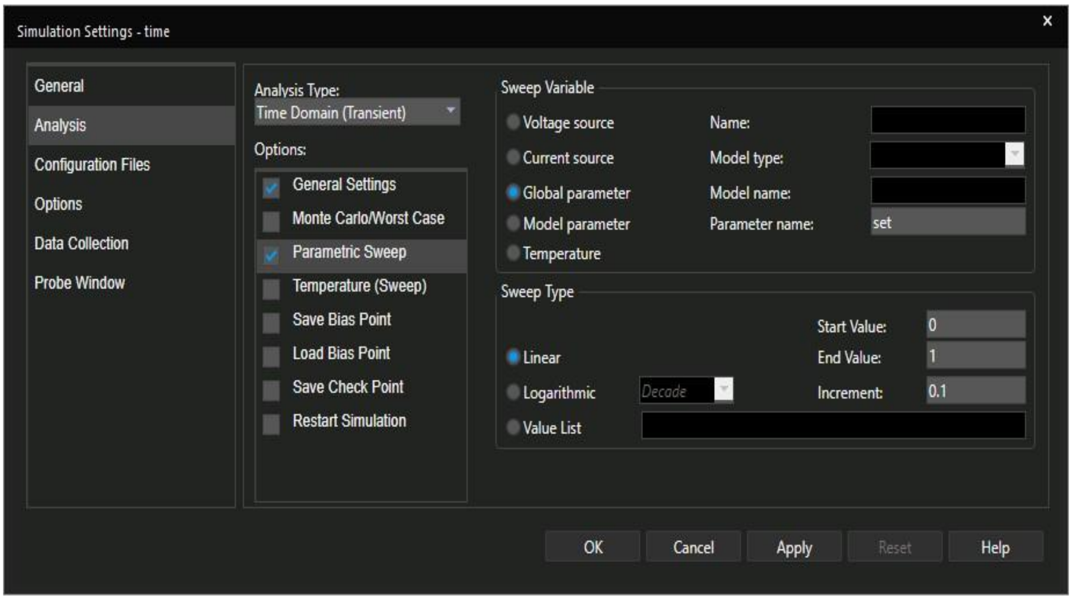


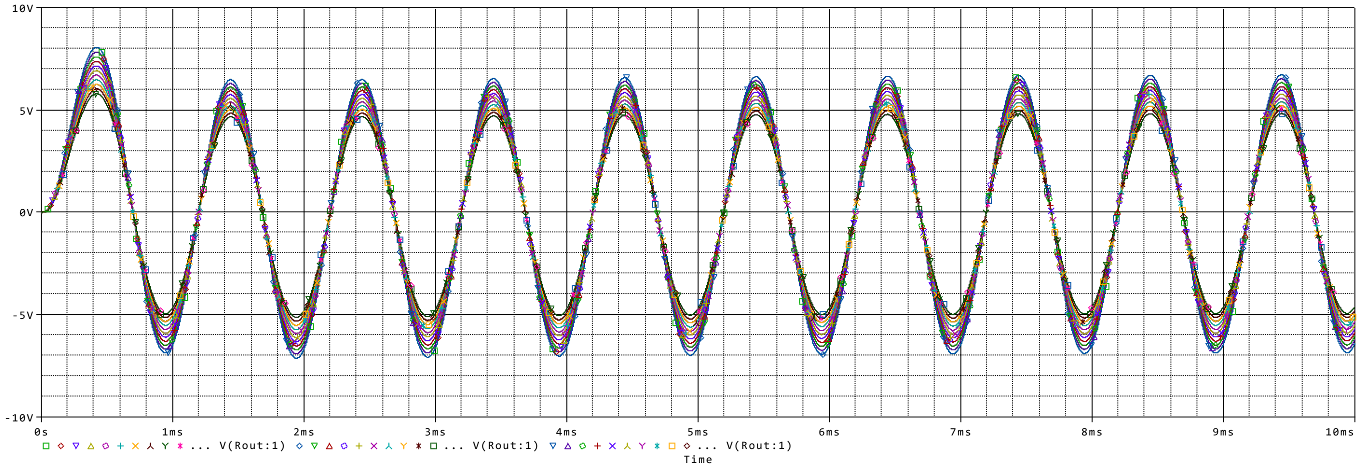
The signal after going through the first amplification stage:



We can see that it goes as high as 8V, but with an offset of 1V, thus, the amplitude is 7V.

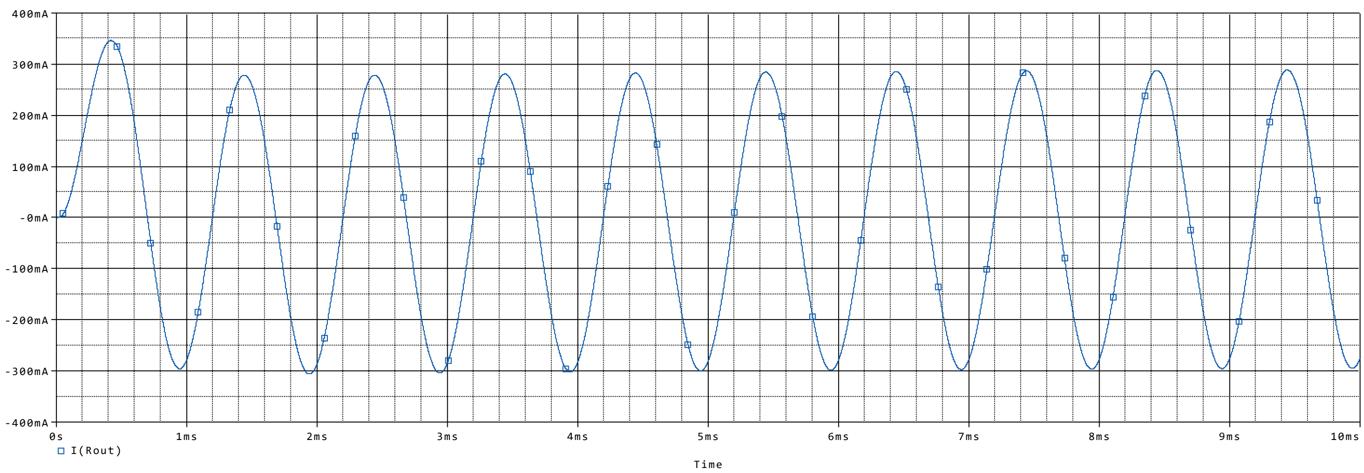
Then we add the Parametric Sweep option to visualize the output for each position of the potentiometer:



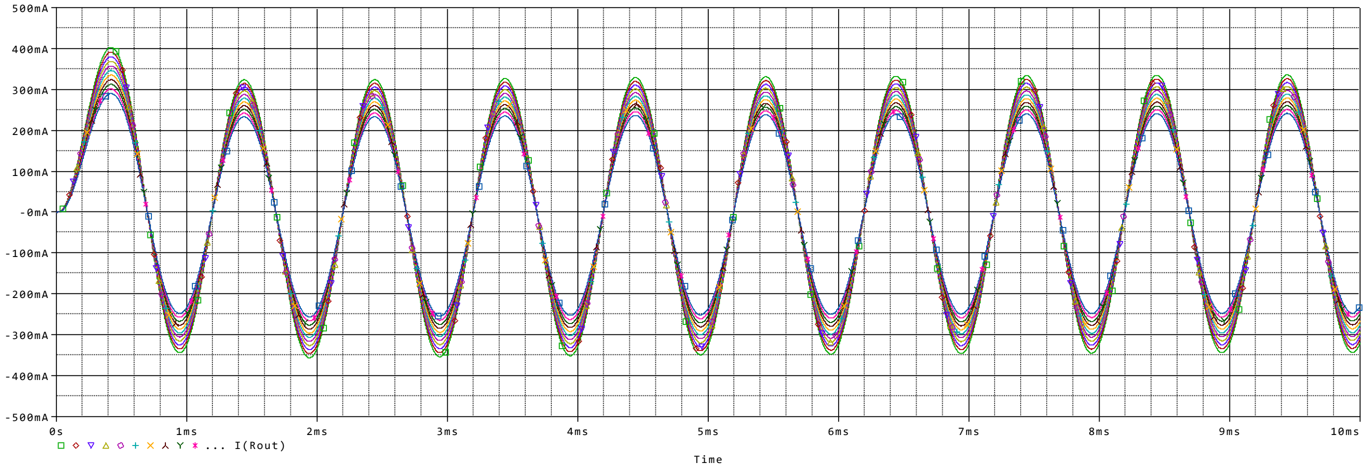


The signal can be observed to stabilize, at the output, between 5V and 7V (lowest value at 4.57, due to the tolerance and the real life standardization of components and the highest value at 6.1V).

The current on the output resistor:

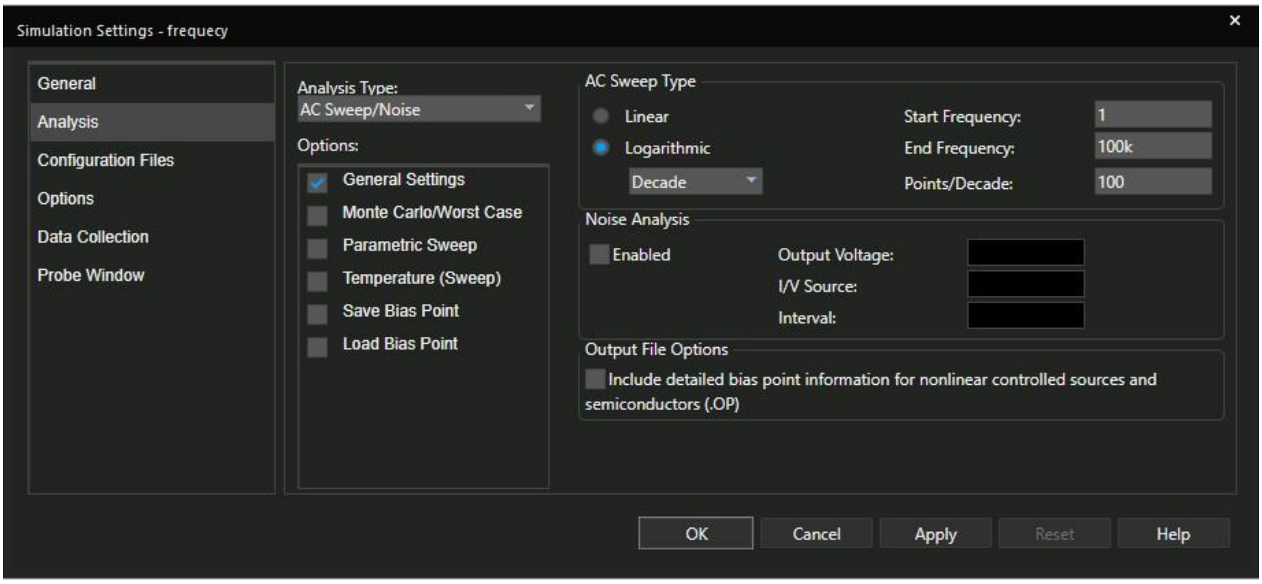


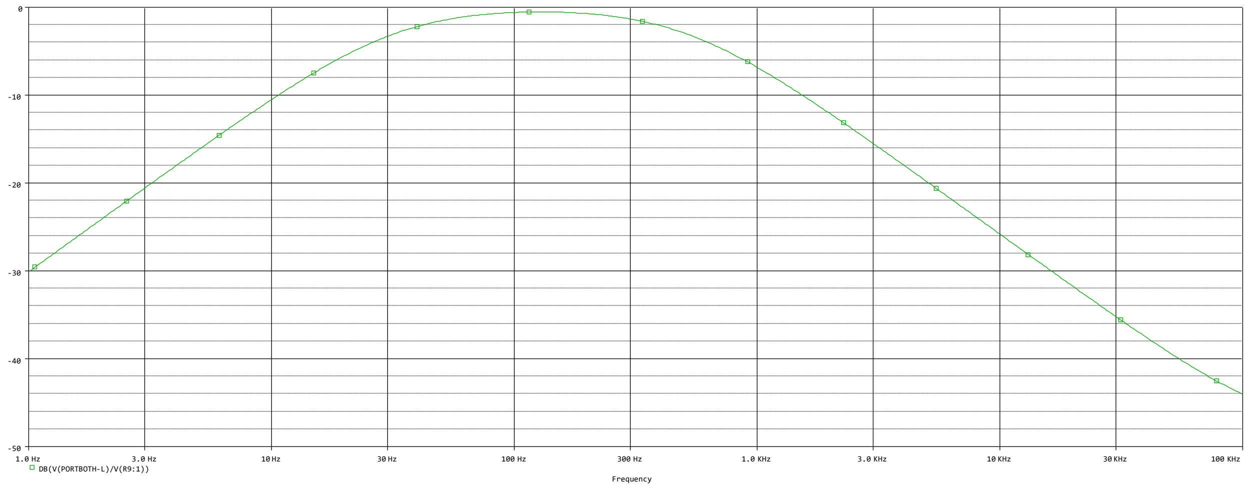
As we can see, the current stabilizes somewhere at about 310mA, which is between 350mA and 250mA (values computed at (9), (10)). Now let's see the parametric sweep for the output current:

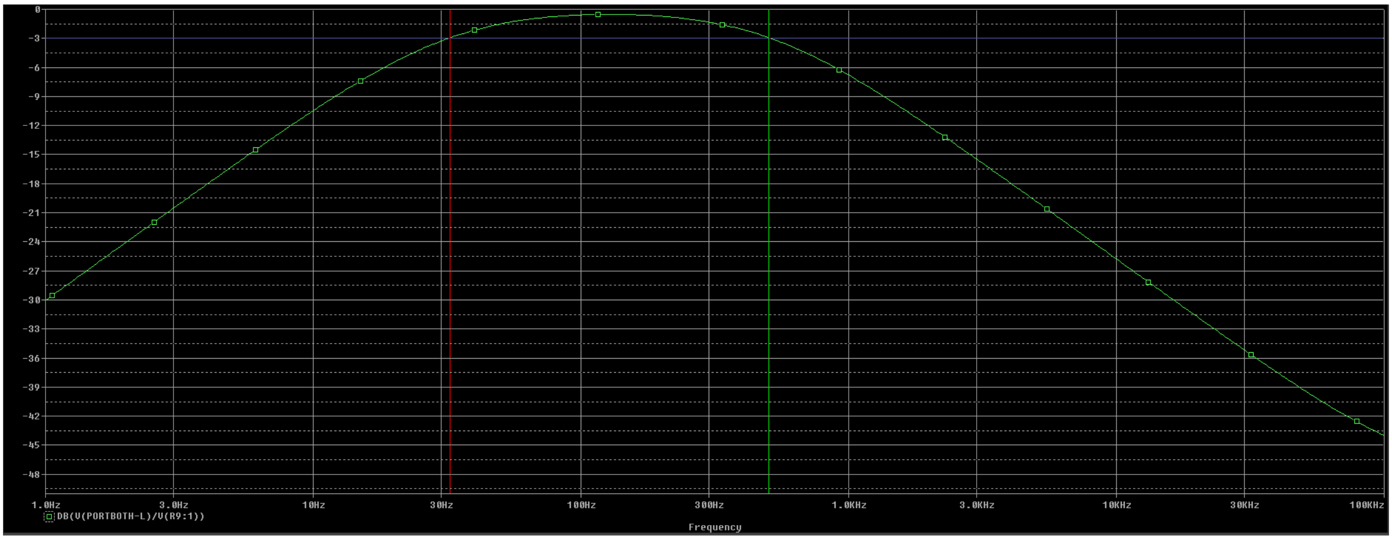


Here we can observe that the output current still stays between the values calculated at (9) and (10).

3.2.2. AC Sweep (in order to determine the band-pass, cut off frequencies)





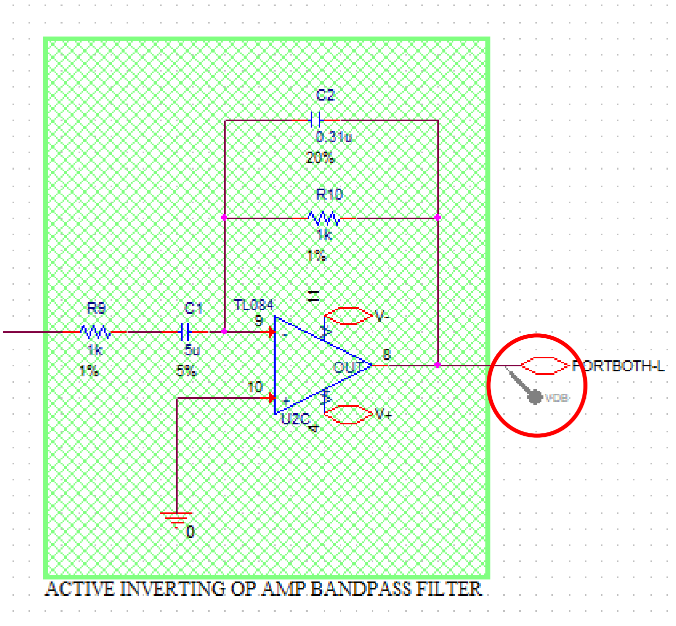


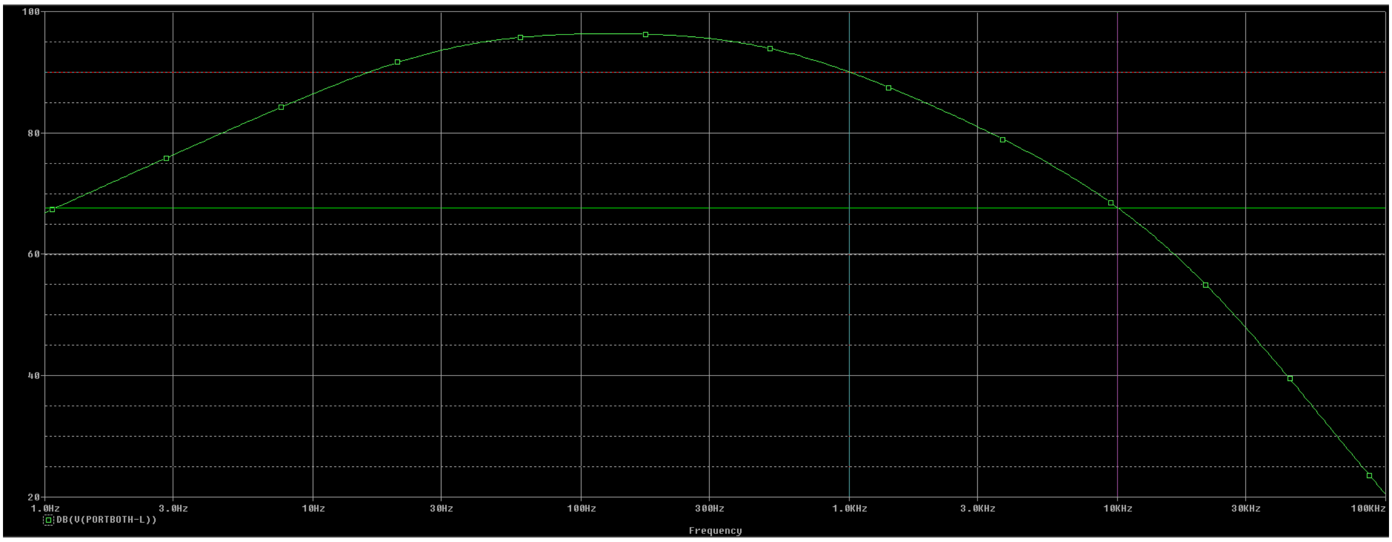
Here it can be observed that the bandwidth is indeed between 32Hz and 512Hz.

	Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		32.058m		
		X Values	32.438	509.545	-477.107		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
	CURSOR 1,2	DB(V(PORTBOTH-L)/V(R9:1))	-2.9773	-3.0094	32.058m		0.000	0.000	-2.9773	-3.0094	-2.9934

Filter order:

To find the filter order I used a dB. Magnitude of Voltage Marker, at the output of the bandpass filter [21]:

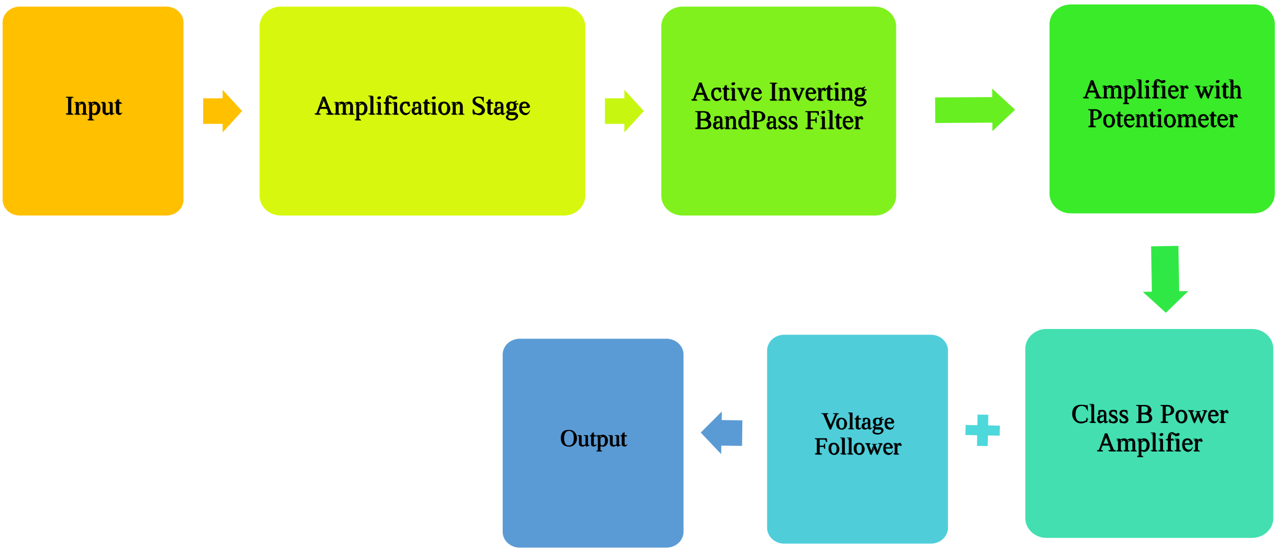




Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		22.340		
	X Values	1.0000K	10.000K	-9.0000K		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	DB(V(PORTBOTH-L))	90.028	67.688	22.340		0.000	0.000	90.028	67.688	78.858

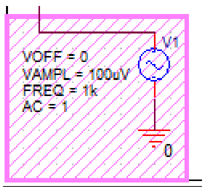
As shown above, the difference is approximately 22, so we can consider that the filter is of 1st order.

4. Block diagram



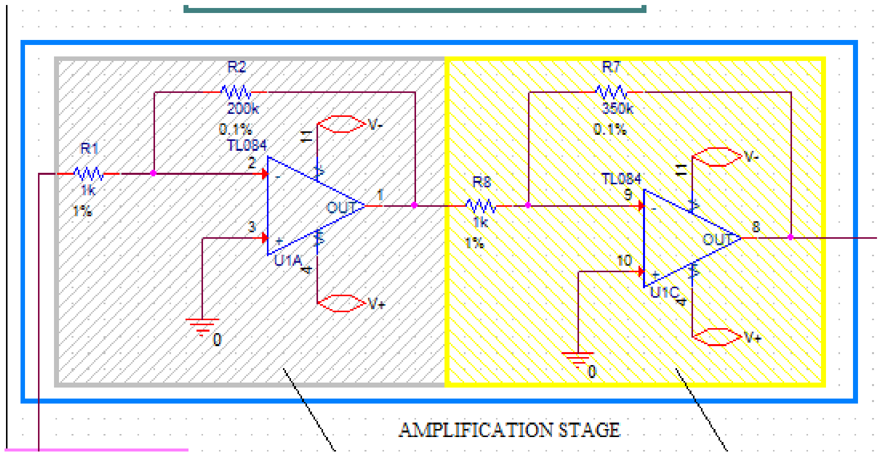
4.1. Input

Voltage input of amplitude 100 µV, with a frequency of 1kHz (so that when we view the simulation results, we can have a better perspective of the graphics), offset 0V.



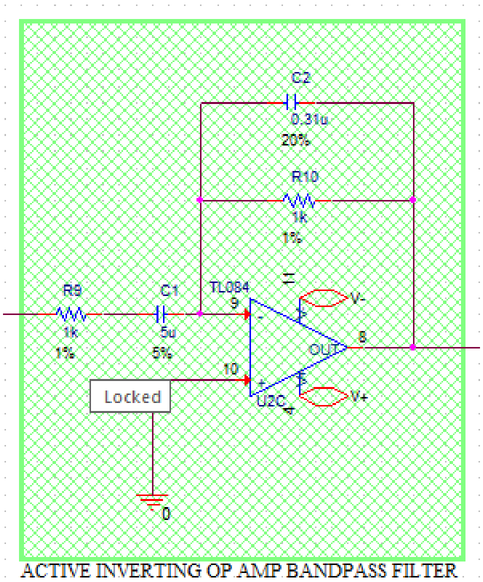
4.2. Amplification Stage (composed of two stages, each of them containing amplifiers)

Converting the input from µV to mV then to V. Divided in 2 stages, first stage having the gain of 250 and the second having the gain of 300.[1]



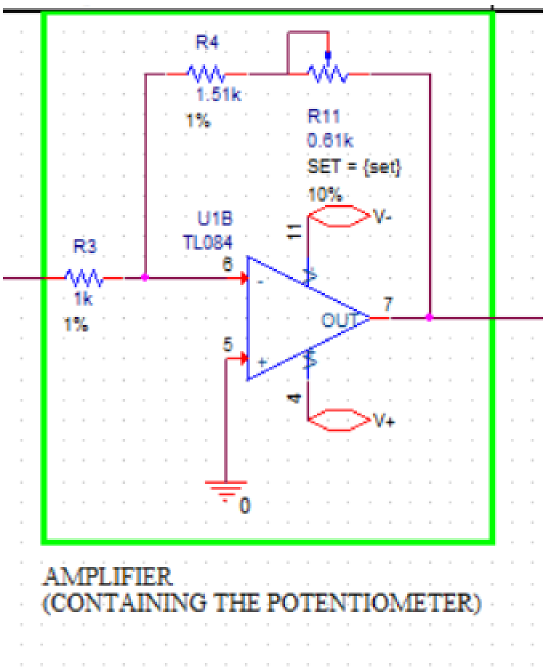
4.3. Active inverting bandpass filter (with gain of 1k)

Designed to have a much narrower band pass. The output of the filter is taken from the OpAmp's output. [4][16]



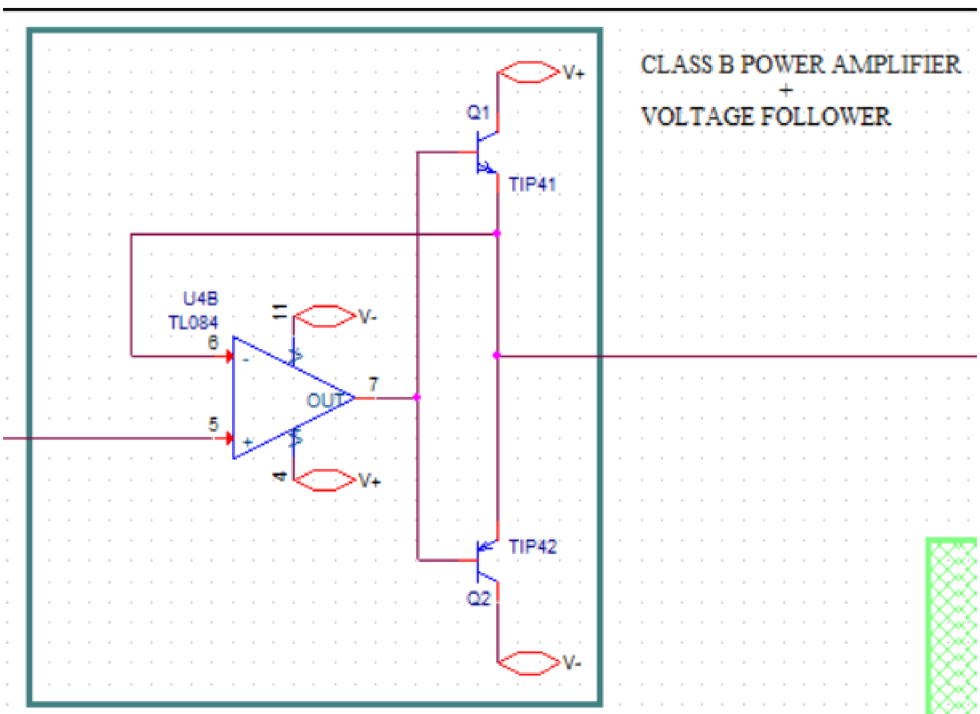
4.4. Amplifier

This stage aims to amplify the signal, after it comes out from the filter, where it suffers a damping, thus negating the damping imposed by the filter (as it will be demonstrated in the calculus section later). It contains a potentiometer that drives the signal between 5 and 7V.



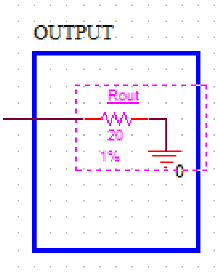
4.5. Class B power amplifier + Voltage follower

Amplifies the signal with 2 active devices, each operates over one half of the cycle (the device currents are combined so that the load current is continuous), thus efficiency is much more improved. The crossover distortion can be reduced further by using negative feedback. The voltage follower gives an efficient isolation of output from the input signal. The circuit of voltage follower is shown below. [1][2][3]

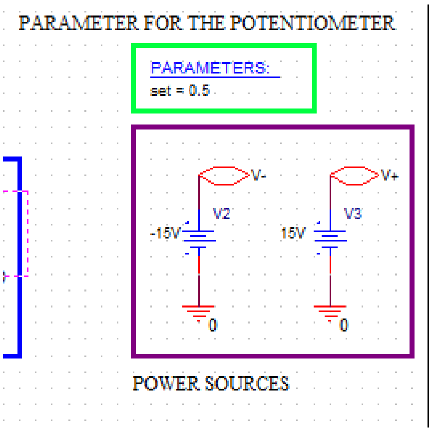


4.6. Output

We have the speaker, which is represented by R_{out}.



The circuit also contains 2 power sources for each OpAmp and the transistors. There also can be observed the PARAM part which contains the {set} variable, used for each stage of the potentiometer (0->0.1->0.2-> …->1).



5. Equations

5.1. Total gain computation:

$$A_v = \frac{V_{out}}{V_{in}} \quad [13](1)$$

$$A_v = \frac{7V}{100\mu V} = 70000$$

5.2. Individual gain computation and resistances calculus:

Since $A_v = 70000$ we can consider that the first gain, $A_{v1} = 200$ and the second gain, $A_{v2} = 350$.

The resistances for the first OpAmp:

$$A_{v1} = -\frac{R_1}{R_2} = 200 \quad [13](2)$$

Thus:

$$R_2 = 200k\Omega$$

$$R_1 = 1k\Omega$$

As for the second's amplifier resistances:

$$A_{v2} = -\frac{R_7}{R_8} = 350 \;\; [13](3)$$

Thus:

$$R_7 = 350k\Omega$$

$$R_1 = 1k\Omega$$

5.3. Bandpass calculus:

The gain needs to be 1, because there is no need for the filter to amplify.

$$A_{vb} = -\frac{R_{10}}{R_9} = 1 \;\; [13](4)$$

Thus:

$$R_{10} = 1k\Omega$$

$$R_9 = 1k\Omega$$

Low cut off frequency:

$$f_1 = 32Hz$$

High cut off frequency:

$$f_{\mathrm{h}} = 512Hz$$

Formulas used:

$$\mathrm{f_l} = \frac{1}{2\pi \mathrm{R_{10} C_2}} \quad [14](5)$$

$$\mathrm{f_h} = \frac{1}{2\pi \mathrm{R_9 C_1}} \quad [14](6)$$

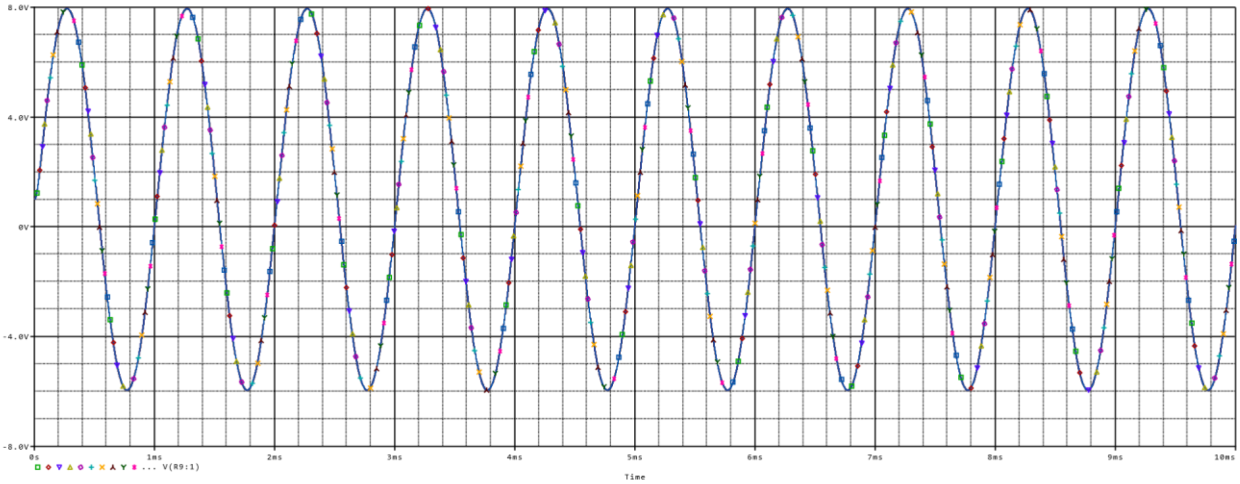
For $\mathrm{f_l}$:

$$32 = \frac{1}{6.28C_2} => 200.96C_2 = 1 => C_2 = 4976nF$$

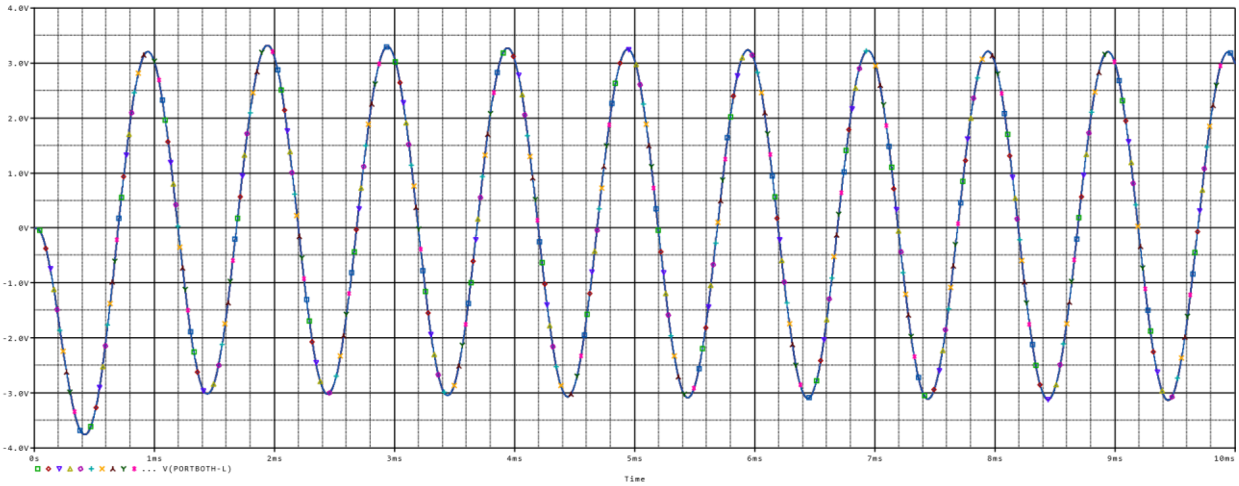
For $\mathrm{f_h}$:

$$512 = \frac{1}{6.28C_1} => 3215.36C_1 = 1 => C_1 = 311nF$$

But because the filter seemed to be damping the input signal, as exemplified below:



Signal before entering the filter



Signal after exiting the BPF

The signal that enters the last amplification stage, has an amplitude of approximately 3.3V

Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		3.2805		
	X Values	3.9430m	0.000	3.9430m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(F)	3.2804	-14.347u	3.2805		0.000	0.000	3.2804	-14.347u	1.6402
	V(F)	3.2804	-14.347u	3.2805		-479.050n	3.6226p	3.2804	-14.347u	1.6402

5.4. Last amplification stage with potentiometer:

First we will consider for $V_{out\_min,}$ potentiometer set on 0:

$$\frac{V_{out\_min}}{V_{in}} = \frac{R_4}{R_3} \quad [17] \tag{7}$$

$$\frac{R_4}{R_3} = \frac{5V}{3.3V} => \frac{R_4}{R_3} = 1.51$$

So,

$$R_4 = 1.51k\Omega$$

$$R_3 = 1k\Omega$$

Now we can consider V_{out_max}, with potentiometer set on 1:

$$\frac{V_{out\_max}}{V_{in}} = \frac{R_4 + R_{11}}{R_3} \quad [17] \tag{8}$$

$$\frac{R_4 + R_{11}}{R_3} = \frac{7V}{3.3V} => \frac{R_4 + R_{11}}{R_3} = 2.12$$

Since we have:

$$R_4 = 1.51k\Omega$$

$$R_3 = 1k\Omega$$

Then:

$$1.51k\Omega + R_{11} = 2.12k\Omega => R_{11} = 0.61k\Omega$$

5.5. Current on the speaker (R_{out})

Ohm's law:

$$V = I * R <=> I = \frac{V}{R} \; [22](9)$$

We know that:

$$R_{out} = 20\Omega$$

Since we need the output to be between 5 and 7V, we have the following currents:

$$I_{max} = \frac{V_{max}}{R_{out}} = \frac{7V}{20\Omega} = 0.35A \; (10)$$

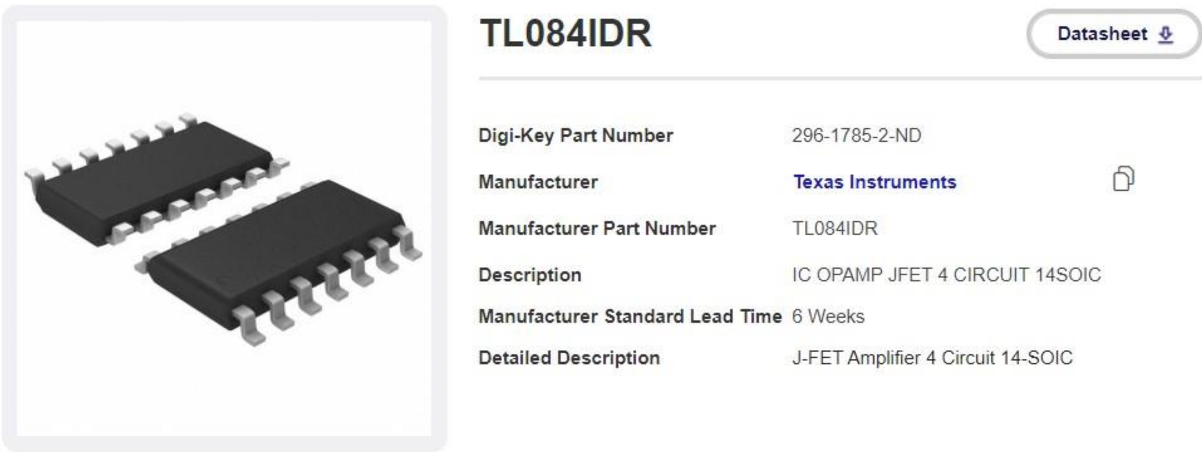
$$I_{min} = \frac{V_{min}}{R_{out}} = \frac{5V}{20\Omega} = 0.25A \; (11)$$

6. Standardization

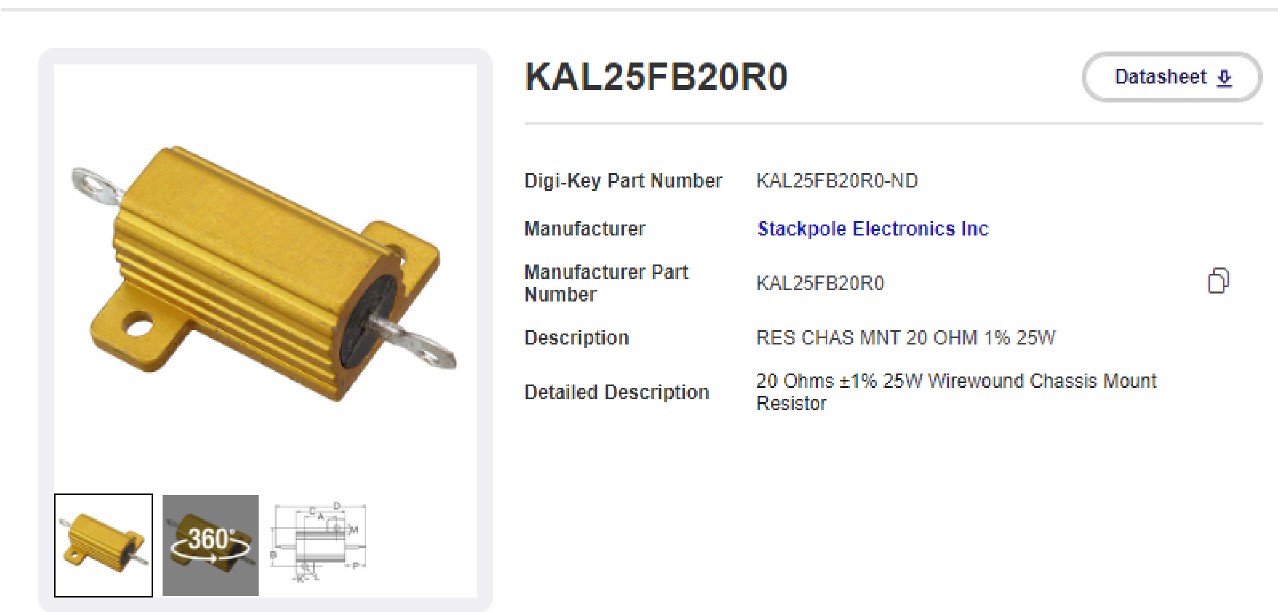
All that is left for now, is to find the real-life equivalent components, to make sure the circuit can be built and implemented. This can be realised by checking different stores and manufacturers shops.

I will present below screenshots with the components that were used:

TL084[5]



20Ω Resistor (R_{out}) [20]:



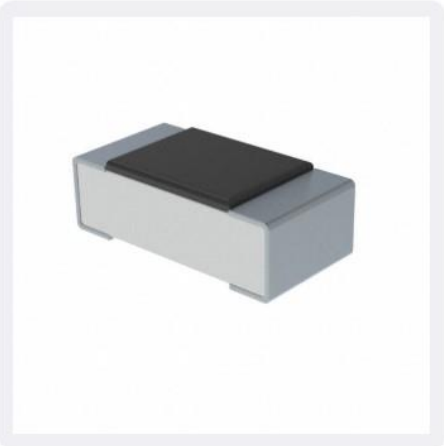
1kΩ Resistors [6]:

UAL10-1KF8

Datasheet

Digi-Key Part Number	696-1426-ND
Manufacturer	Riedon
Manufacturer Part Number	UAL10-1KF8
Description	RES CHAS MNT 1K OHM 1% 10W
Manufacturer Standard Lead Time	12 Weeks
Detailed Description	1 kOhms ±1% 10W Wirewound Chassis Mount Resistor

200kΩ Resistor [7]:



RN73R1JTTD2003B25

Datasheet

Digi-Key Part Number	2019-RN73R1JTTD2003B25TR-ND
Manufacturer	KOA Speer Electronics, Inc.
Manufacturer Part Number	RN73R1JTTD2003B25
Description	RES 200K OHM 0.1% 1/10W 0603
Manufacturer Standard Lead Time	14 Weeks
Detailed Description	200 kOhms ±0.1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thin Film

350kΩ Resistor [8]:

RN55C3503BRE6

Datasheet

Digi-Key Part Number	RN55C3503BRE6-ND
Manufacturer	Vishay Dale
Manufacturer Part Number	RN55C3503BRE6
Description	RES 350K OHM 1/8W .1% AXIAL
Manufacturer Standard Lead Time	34 Weeks
Detailed Description	350 kOhms ±0.1% 0.125W, 1/8W Through Hole Resistor Axial Flame Retardant Coating, Military, Moisture Resistant, Safety Metal Film

1.51kΩ≈1.54kΩ Resistor [9]:

RER65F1R54RC02 Datasheet

Digi-Key Part Number	RER65F1R54RC02-ND
Manufacturer	Vishay Dale
Manufacturer Part Number	RER65F1R54RC02
Description	RES CHAS MNT 1.54 OHM 1% 10W
Detailed Description	1.54 Ohms ±1% 10W Wirewound Chassis Mount Resistor

4976nF≈5μF Capacitance [10]:

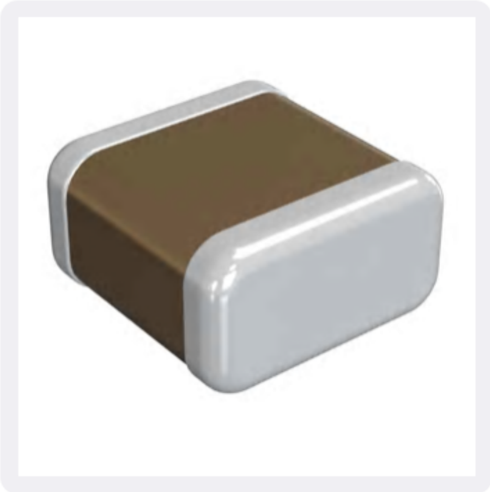
New Product NEW

ECW-FG1B505J

ECW-FG1B505J Panasonic Electronic Components | 10-ECW-FG1B505J-ND DigiKey Electronics

Digi-Key Part Number	10-ECW-FG1B505J-ND
Manufacturer	Panasonic Electronic Components
Manufacturer Part Number	ECW-FG1B505J
Description	CAP FILM 5UF 5% 1.1KVDC RADIAL
Manufacturer Standard Lead Time	13 Weeks
Detailed Description	5μF Film Capacitor 1100V (1.1kV) Polypropylene (PP), Metallized Radial

311nF≈0.33μF Capacitance [11]:

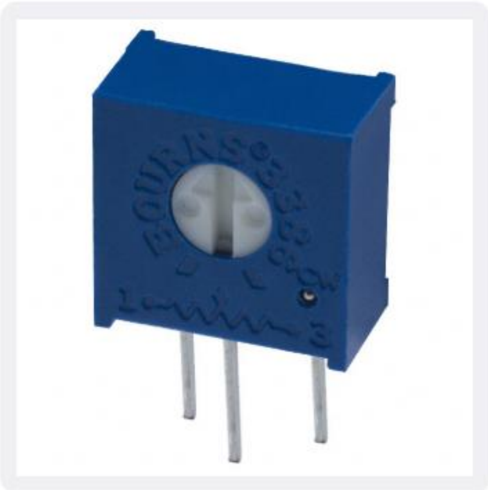


GRM033R60J334ME90D

Datasheet

Digi-Key Part Number	490-10408-2-ND
Manufacturer	Murata Electronics
Manufacturer Part Number	GRM033R60J334ME90D
Description	CAP CER 0.33UF 6.3V X5R 0201
Manufacturer Standard Lead Time	15 Weeks
Detailed Description	0.33µF ±20% 6.3V Ceramic Capacitor X5R 0201 (0603 Metric)

0.61kΩ≈600Ω Potentiometer [12]:

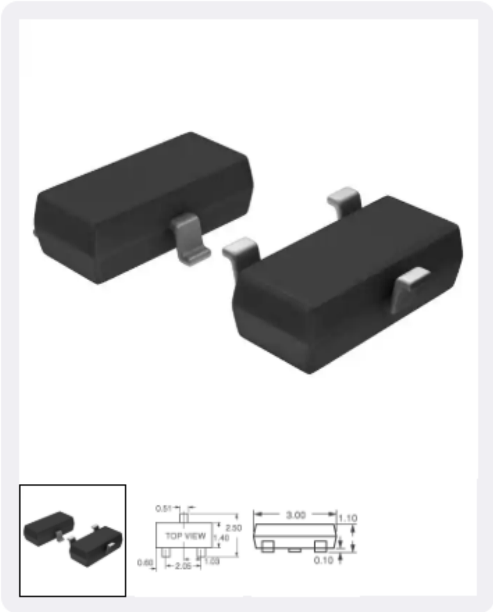


3386H-1-601LF

Datasheet

Digi-Key Part Number	3386H-1-601LF-ND
Manufacturer	Bourns Inc.
Manufacturer Part Number	3386H-1-601LF
Description	TRIMMER 600 OHM 0.5W PC PIN SIDE
Manufacturer Standard Lead Time	7 Weeks
Detailed Description	600 Ohms 0.5W, 1/2W PC Pins Through Hole Trimmer Potentiometer Cermet 1 Turn Side Adjustment

NPN Transistor [23]



MMBT3904-7-F

Datasheet

Digi-Key Part Number	MMBT3904-FDITR-ND
Manufacturer	Diodes Incorporated
Manufacturer Part Number	MMBT3904-7-F
Description	TRANS NPN 40V 0.2A SMD SOT23-3
Manufacturer Standard Lead Time	15 Weeks
Detailed Description	Bipolar (BJT) Transistor NPN 40V 200mA 300MHz 300mW Surface Mount SOT-23-3

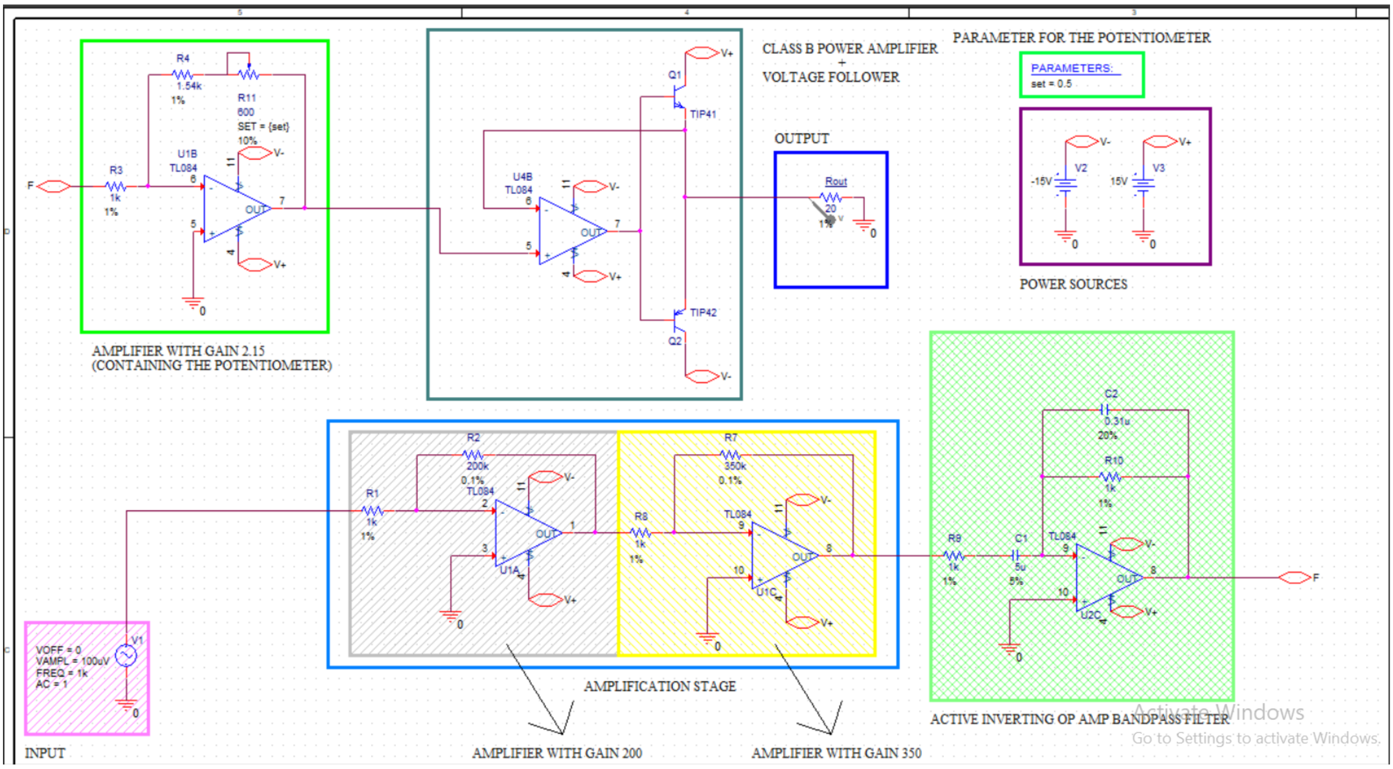
PNP Transistor [22]

FZT796ATA

Datasheet

Digi-Key Part Number	FZT796ATR-ND
Manufacturer	Diodes Incorporated
Manufacturer Part Number	FZT796ATA
Description	TRANS PNP 200V 0.5A SOT-223
Manufacturer Standard Lead Time	15 Weeks
Detailed Description	Bipolar (BJT) Transistor PNP 200V 500mA 100MHz 2W Surface Mount SOT-223

With the values and the components found in the real life, the circuit (+the tolerances displayed) now is:



7. BOM List

```
1    1    C1   5u   5%   Panasonic Electronic Components
2    1    C2   0.31u    20% Murata Electronics
3    1    Q1   TIP41        Diodes Incorporated
4    1    Q2   TIP42        Diodes Incorporated
5    1    Rout      20   1%   Stackpole Electronics Inc
6    5    R1   1k   1%   Riedon
          R3   1k   1%   Riedon
          R8   1k   1%   Riedon
          R9   1k   1%   Riedon
          R10  1k   1%   Riedon
7    1    R2   200k      0.1%     KOA Speer Electronics, Inc
8    1    R4   1.54k     1%   Vishay Dale
9    1    R7   350k      0.1%     Vishay Dale
10   1    R11  600 10% Bourns Inc.
11   3    U1   TL084        Texas Instruments
          U2   TL084        Texas Instruments
          U4   TL084        Texas Instruments
```

8. Conclusion

During this project I gained a lot of knowledge about different aspects of circuit building, simulation, editing and research. After trial and failure I managed to learn, and understand how to design a circuit properly and solve/debug different errors. And most important of all, the project forced me out of my comfort zone and pushed me to learn to adapt, improvise and improve in the fastest way possible.

As further advancements to the project, I would dare say that I could go on and try and integrate each stage of the circuit in a component, thus simplifying the current design. Although the request was not to search for cheap components as well, I tried to choose a budget friendly set of parts. Another good idea, might be to split the amplifying stage in 3 steps instead of 2, thus making it easier to find cheaper components, as well as using a class AB power amplifier instead of a class B amplifier, being considered a good compromise between amplifiers.

9. Bibliography

[1] https://www.eetimes.com/boosting-up-microvolts-for-analog-applications/#

[2] https://en.wikipedia.org/wiki/Power_amplifier_classes#Class_B

[3] https://www.electrical4u.com/voltage-follower/

[4] https://www.electronics-tutorials.ws/filter/filter_7.html

[5] https://www.digikey.ro/product-detail/en/texas-instruments/TL084IDR/2961785-2-ND/378426

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