Circuit Theory and Electronics Fundamentals

Álvaro Dias Patrício, 95768

Inês de Sousa Afonso, 95797

José Severino Medeiro, 95811

Integrated Master in Aerospace Engineering, Técnico, University of Lisbon

Laboratory 4 Report

Group 8

May 23, 2021

Contents

1 Introduction **3**

2 Simulation Analysis **5**
2.1 Audio Amplifier converter graphs 5

3 Theoretical Analysis **8**
3.1 Step 1: DC and AC analysis for the Gain Stage 8
3.2 Step 2: DC and AC analysis for the Output Stage 8
3.3 Step 3: AC analysis for the Audio Amplifier 9

4 Conclusion **12**

1 Introduction

The aim of this laboratory assignment was to create an audio amplifier circuit and analyze it both theoretically and by simulation using Ngspice, designing the gain and output stages . It receives an audio input of 10mV as is connected to an 8 Ohm speaker. The source has an 100 Ohm impedance and the circuit is supplied with 12V by a DC source (Vcc).

In order to have a good voltage amplifier, a high gain A_v, a hight input impedance Z_i and a low output impedance are required, so that the input and output voltages do not get degraded. There are two stages in the audio amplifier circuit: the gain and output stages.

Firstly, in the gain stage a common emitter amplifier with degeneration was used as it leads to a high Z_i as well as a high gain A_v. However, it also has high Z_o, that degrades the output signal. The next stages then, solves this problem. For this stage a NPN transistor was used.

Secondly, in the output stage a common collector amplifier was used because it not only keeps the hight gain A_v from the first stage but also has a low Z_o. This happens because of its high input impedance which connects to the lower output impedance (but still high) from the previous stage and the gain in this section is approximately 1. For this stage a PNP transistor was used.

The quality of the audio amplifier, comparing to others, is determined by a merit classification system. It takes into account the cost of the components used, the voltage gain, the cut off frequency and the bandwidth. The merit is calculated according the following equation:

$$MERIT = \frac{VoltageGain * Bandwidth}{Cost * LowerCutOffFrequency} \tag{1}$$

And the cost of the components is: resistors = 1 monetary unit (MU) per kOhm; capacitors = 1 MU/uF; transistors = 0.1 MU per diode.

Figure 1 shows the layout of the implemented circuit and its actual architecture implemented for each stage will sooner be analyzed in detail.

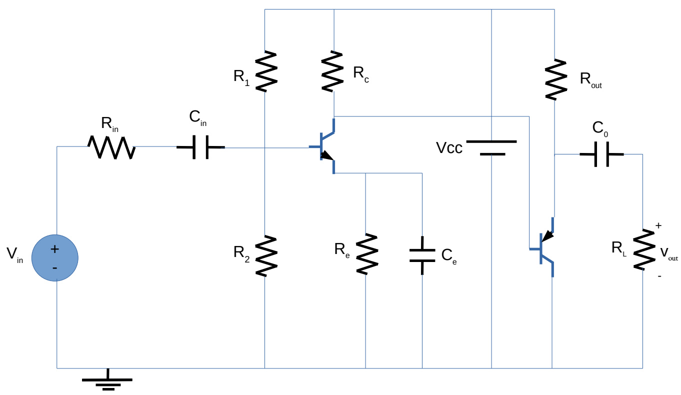

Figure 1: Circuit analysed.

Table 1 shows the resistors, capacitors and number of transistors, as well as the total cost of the circuit.

Name	**Value**
BJT	2
#R_S	1.000000e+02
#R_L	8.000000e+00
#R_1	4.184307e+04
#R_2	3.632612e+03
#R_E1	1.407179e-01
#R_C2	2.053763e+01
#R_OUT	7.463904e+00
&C_I	8.494862e-04
&C_B	2.010353e-04
&C_O	9.654473e-05
£Cost	1.192770e+03

Table 1: Variables preceded by # is of type *resistance* and expressed in Ohm; variables preceded by & is of type *capacitance* and expressed in Farad; A variable preceded by £ is of type *cost* and expressed in Unit of Cost; the numbers of $BJTs$ are in units.

In Section 2, the circuit is analyzed by simulation in Ngspice, using the Philips BJT'S model BC557A (PNP) and BC547A (NPN) for the transistors. The simulation allowed to compute the input and output frequencies (where the difference between both corresponds to the bandwidth), as well as the gain.

Then, in Section 3, a theoretical analysis of the circuit in presented, using a suitable OP, making sure the transistors are in the Forward Active Region) and incremental theoretical models studied in order to predict the gain and the input and output impedances for each stage.

In the conclusion, Section 4 the theoretical and the simulation results were compared.

2 Simulation Analysis

2.1 Audio Amplifier converter graphs

In this section we evaluated the Audio Amplifier proposed. In order to analise the circuit after the transiant period, we have chosen $t \in [1ms; 20ms[$.

The graphs for NGSpice are displayed here, alongside the table with the required elements:

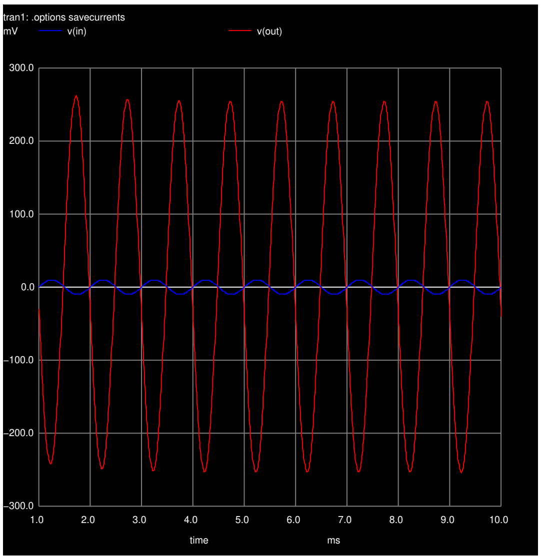

Figure 2: v_{in} and v_{out}.

It is worth noting that the output is not distorted, making this amplifier a viable option for usage.

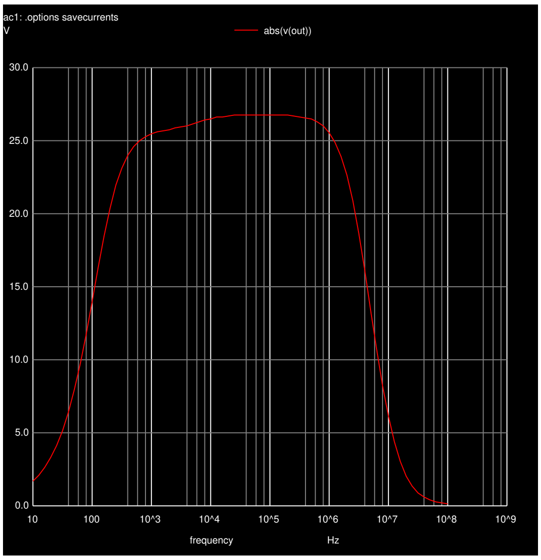

Figure 3: $|v_{out}/v_{in}|$.

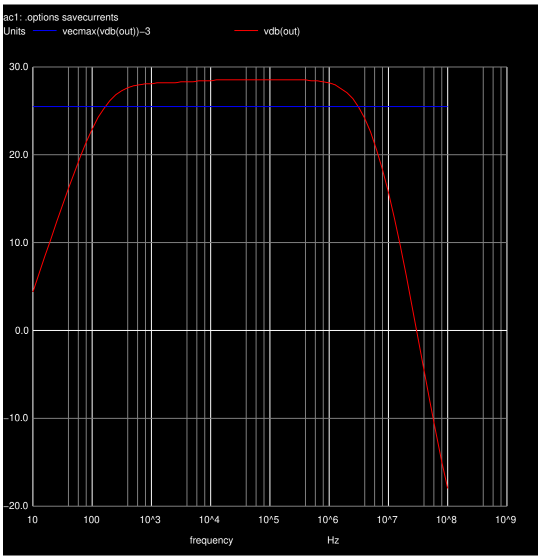

Figure 4: $db(v_{out})$ and $max(db(v_{out})) - 3$.

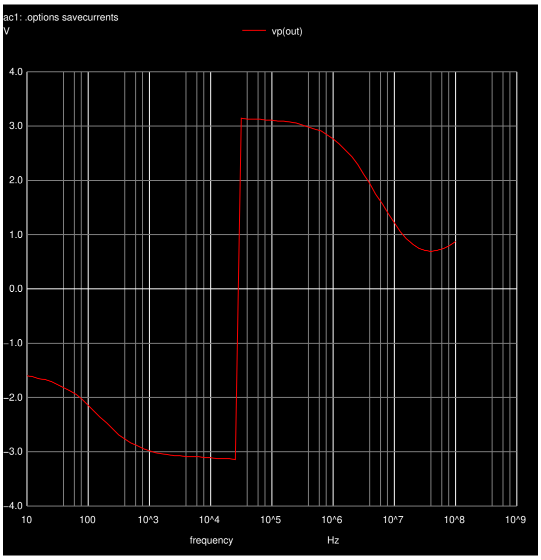

Figure 5: Phasor of v_{out}, rad

Table 2 shows the simulated operating point results for the circuit under analysis. From here we can see that the transistors stay in the FAR region.

Name	Value
v(coll)-v(base)	9.013326e+00
v(coll)	9.734626e+00

Table 2: Variables are of type *voltage* and expressed in Volt.

Table 3 shows the simulated frequency response results for the circuit.

Name	Value
amplitude	1.609672e+01
f2 - f1	3.069301e+06
merit	2.558219e+02

Table 3: Merit is in *per voltage per cost* and expressed in Volt^{-1}UC^{-1}; $f1 - f2$ is of the type *frequency* and expressed in Hz; other variables are adimentional.

Table 4 and table 5 show the input and output impedances, respectivly.

Name	Value
zin	4.108189e+02 + j*-3.13945e+01

Table 4: Variables are of type *impedance* and expressed in Ohm.

Name	Value [A or V]
zout	3.443039e+01 + j*6.020237e-01

Table 5: Variables are of type *impedance* and expressed in Ohm.

3 Theoretical Analysis

In this section, a theoretical analysis of the previously shown circuit was conducted. An audio amplifier is always divided into two separate stages, as said before. The first stage has the main function of increasing the amplitude of the voltage signal so that it can be used in the second stage. The high impedance helps to prevent signal corruption even in the first stage. Moreover, this high impedance at the output is a problem because it becomes difficult to connect the speaker without degradation of the output signal. The second stage, on the other hand, will have a low impedance so that it allows you to connect the speakers without the least possible loss of information or degradation of the signal.

The human ear perceives frequencies in a range of frequencies between 20 Hz to 20 kHz so we should choose coupling capacitors that behave like short circuits for these frequencies, as the coupling capacitors affect the lower cutoff frequency and thus the bandwidth.

3.1 Step 1: DC and AC analysis for the Gain Stage

The Gain Stage under analysis is the following:

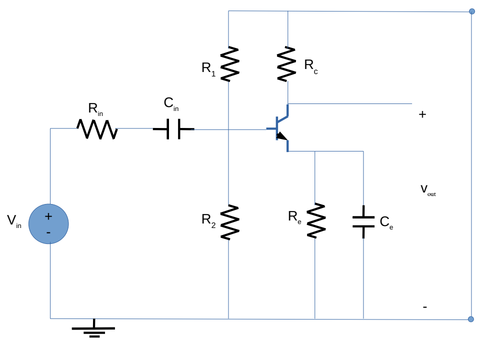

Figure 6: Gain Stage circuit.

The capacitor bypass has the main function of preventing a loss of gain in the resistors and the main function of the resistors is to make the temperature effect stable. In the AC circuit the gain is more important and in the DC circuit the temperature effect is more important. In addition, the capacitors work as open circuits at low frequency and the current also stabilizes in the resistors thanks to the effect of temperature. At high frequencies we have the capacitors in equivalent short circuit and a bypass is used in the resistors to avoid loss of gain.

The values for the DC analysis, from where we garantee that the first BJT is on the FAR region, are in table 6, and the AC results are distribuited in the input and output impedance from the gain stage (1) (table 7) and the gain from this stage (table **??**). Both of the previous analysis were done by using the Octave script given, and as such are covered in the lectures 16 and 17.

3.2 Step 2: DC and AC analysis for the Output Stage

The Output Stage under analysis is the following:

The values for the DC analysis, from where we garantee that the first BJT is on the FAR region, are in table 6, and the AC results are distribuited in the input and output impedance from the gain stage (1) (table 7) and the gain from this stage (table **??**). Both of the previous

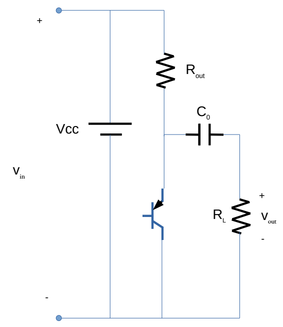

Figure 7: Gain Stage circuit.

analysis were done by using the Octave script given, and as such are covered in the lectures 16 and 17.

3.3 Step 3: AC analysis for the Audio Amplifier

To make a more correct analysis, we have chosen to calculate the various variables using the full circuit. The DC analysis is the same as before, therefore we did not repeat it; the AC analysis was done using the following circuit:

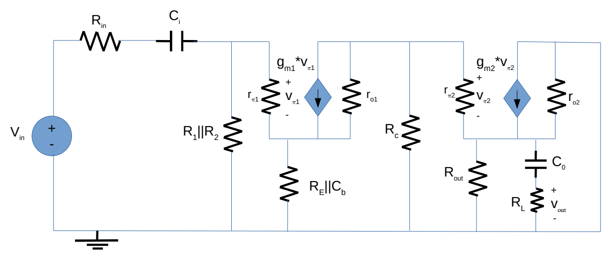

Figure 8: Audio Amplifier AC circuit.

The important results from all this analysis are in the next tables:

Name	Value
$V_{coll} - V_{base}$	1.171628e+01
$V_{coll} - V_0$	1.171822e+01

Table 6: The variables are of type *voltage* and expressed in Volt.

Here we can assure that the BJT's are in the FAR region, since both diferences in voltages are positive, hence ensuring the wanted behaviour.

From this table we can see that the imput impedance of audio amplifier is almost the same as the gain stage and that the output impedance of the amplifier differs significantly from the output stage of the output stage. We can also see that the racio between the input impedance

Name	Value
#$Z_{in-emitter}$	2.967127e+02
#$Z_{out-emitter}$	-4.741967e-01
#$Z_{in-collector}$	2.967127e+02
#$Z_{out-collector}$	-4.741967e-01
$Z_{in-collector}/Z_{out-emitter}$	-6.257165e+02
#Z_{in}	2.967133e+02
#Z_{out}	-3.742502e-01

Table 7: The variables of type *impedance* and expressed in Ohm.

of the output stage and output impedance of the gain stage is big, allowing us to connect the two together. We can also observe that the output impedance of the gain stage is far larger than that of the output stage; this is the primary reason we use the output stage. We only print the real part of the input and output impedances in order to be coerent with the previous results.

Name	Value
$Gain1 \times Gain2$	8.884388e+00
$Gain$	9.244711e+00

Table 8: Variables are adimentional.

Here we can see that the gain from the full circuit is smaller than that of both parts combined, which means that the output stage is influencing the gain stage and vice versa.

The following figures show the plot obtained in the theoretical analysis for the gain and phase:

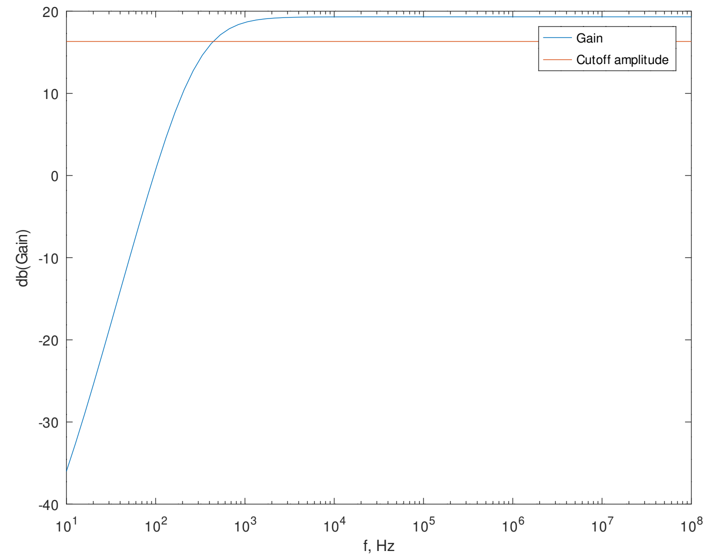

Figure 9: $db(v_{out})$ and $max(db(v_{out})) - 3$.

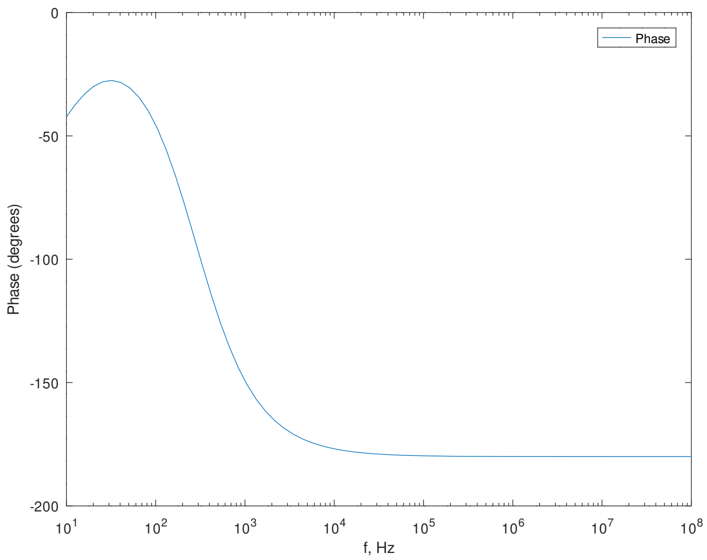

Figure 10: Phasor of v_{out}, degrees.

4 Conclusion

All things considered, an audio amplifier with the smallest number of components that allows a greater gain in voltage was the main objective of this laboratory. A theoretically and simulated model was created to analyze this amplifier and see how it works.

Using Octave as the theoretical analysis and Ngspice for the simulation, a very discrepant results were observed between the two. The main cause of this problem is due of the transistor models used in Ngspice that is more complex than Octave models. Transistors in Ngspice makes it impossible to get the same results because of non-linearity components.

It is possible to say that the theoretical model had a good result even with its low complexity, but only for low frequencies, as shown in figures 12, 14, 11, 13. This is possibly due to the rise of second and higher order derivatives of the function that describe the circuit and in the theoretical analysis are not considered. The phasor calculation are, however, diferent in all frequencies. But it shows that Ngspice has results more like reality due to more accurate models and components.

The tables with the results are the following:

Name	Value
$V_{coll} - V_{base}$	1.171628e+01
$V_{coll} - V_0$	1.171822e+01

Name	Value
v(coll)-v(base)	9.013326e+00
v(coll)	9.734626e+00

Table 9: Results in Octave and NGSpice, respectivily. The variables are of type *voltage* and expressed in Volt (As shown in Tables 6 and 2).

Name	Value
$\#Z_{in-emitter}$	2.967127e+02
$\#Z_{out-emitter}$	-4.741967e-01
$\#Z_{in-collector}$	2.967127e+02
$\#Z_{out-collector}$	-4.741967e-01
$Z_{in-collector}/Z_{out-emitter}$	-6.257165e+02
$\#Z_{in}$	2.967133e+02
$\#Z_{out}$	-3.742502e-01

Name	Value
zin	4.108189e+02 + j*-3.13945e+01

Name	Value [A or V]
zout	3.443039e+01 + j*6.020237e-01

Table 10: Results in Octave and NGSpice, respectivily. NGSpice values are of of type *impedance* and expressed in Ohm; variables preceded by # are of type *impedance* and expressed in Ohm; other variables are adimentional. (As shown in Tables 7, 4 and 5)

Name	Value
$Gain1 \times Gain2$	8.884388e+00
$Gain$	9.244711e+00

Name	Value
amplitude	1.609672e+01
f2 - f1	3.069301e+06
merit	2.558219e+02

Table 11: Results in Octave and NGSpice, respectivily. Merit is in *per voltage per cost* and expressed in Volt^{-1}UC^{-1}; $f1 - f2$ is of the type *frequency* and expressed in Hz; other variables are adimentional. (As shown in Tables 8 and 3)

The Merit result was 260.6748 $V^{-1}uc^{-1}$ by Ngspice. It was agreed by the members of the group that the main goal of task was completed.

The obtained plot with NGSpice and Octave are the following:

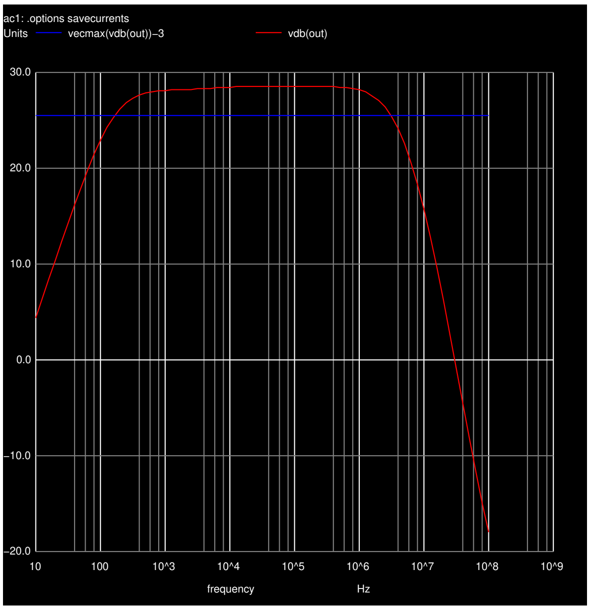

Figure 11: NGSpice plot:$db(v_{out})$ and $max(db(v_{out})) - 3$.

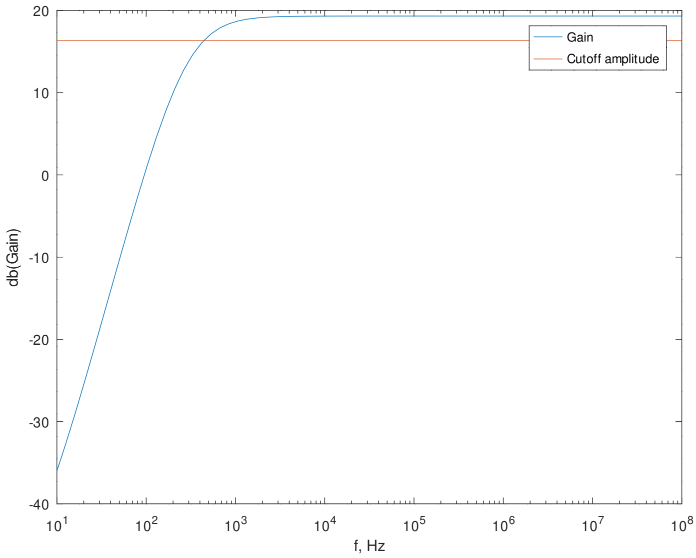

Figure 12: Octave plot:$db(v_{out})$ and $max(db(v_{out})) - 3$.

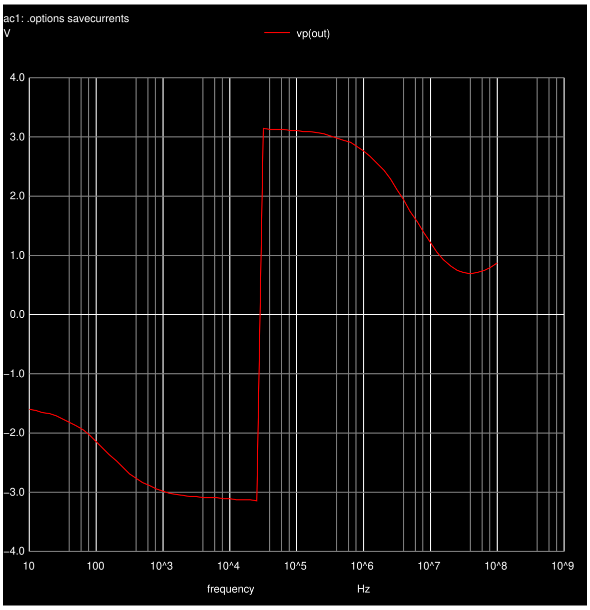

Figure 13: NGSpice plot: Phasor of v_{out}, rad

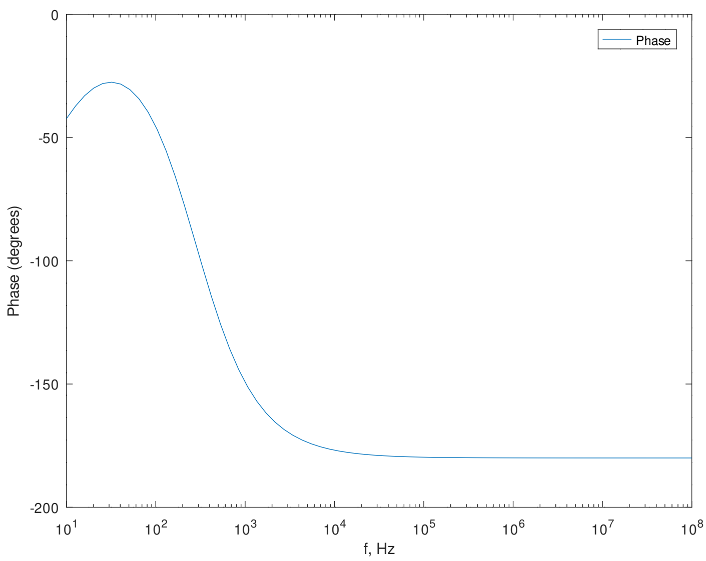

Figure 14: Octave plot: Phasor of v_{out}, rad

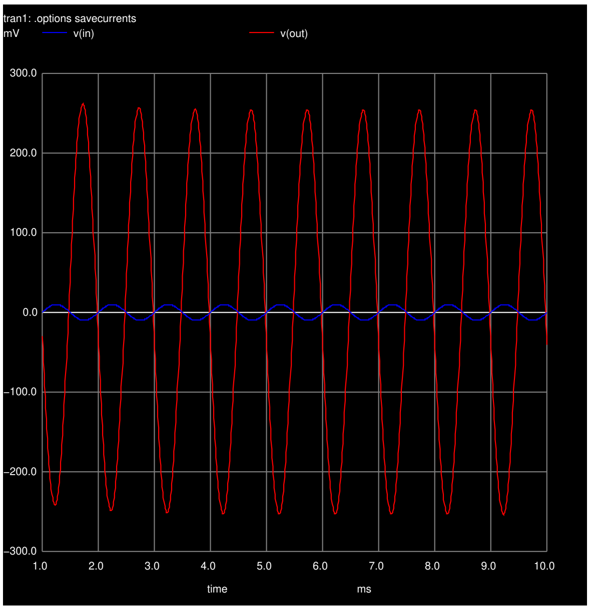

Figure 15: NGSpice plot: v_{in} and v_{out}.

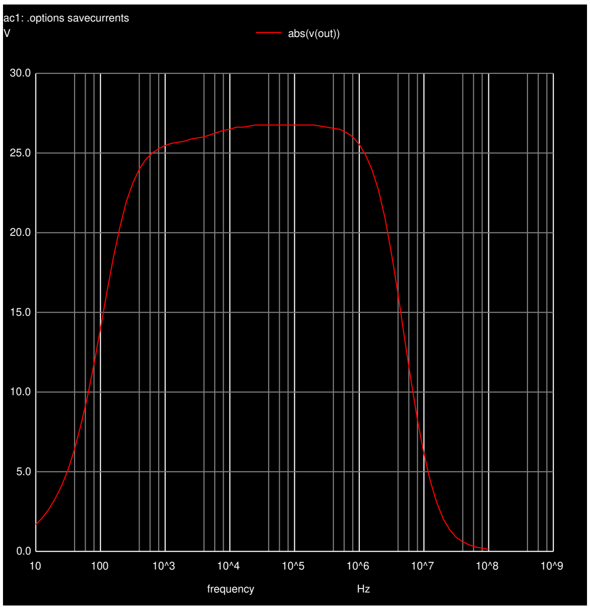

Figure 16: $|v_{out}/v_{in}|$.