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Department of Electrical, Electronic and Computer Engineering

Analogue Electronics

ENE 310

Practical Report: Multistage Amplifiers and Power Amplifiers

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FORM A

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Table of contents

Experiment description 5
Problem analysis 5
Problem definition 5
Problem approach and solution 5
Design context 6
Social 6
Culture 6
Environment 6
Ethical and legal 6
Safety 6
Economic 7
Design objectives 7
Design concept 7
Single chip solution 7
Transistor solution 7
Combination 8
Design optimisation 8
Input stage 8
Gain stage 8
Current gain stage 9
Power stage 9
Complete Amplifier 13
Frequency response 13
Design detail 14
Input stage 14
Gain stage 15
Current gain stage 16
Power stage 17
Total amplifier 17
Frequency Response 20
Benefits 21
Instruction manual (mains version) 22
Set up for use 22
Warnings 22
Specification 22
Price and marketing 23
Pricing 23
Marketing strategy 23
Resources 24
Text References (Harvard Style) 24
Suppliers details and addresses 24
Personal Highlights 25
Ntokozo Mazibuko: 25
Francois Botha 25

Table of Figures

Figure 1 Two port model for input stage_____8
Figure 2 Two port model of the main gain stage_____8
Figure 3 Two port model of current gain stage_____9
Figure 4 Two port model of current gain stage_____9
Figure 5 Class AB power stage_____10
Figure 6 Class A power stage_____10
Figure 7 Class B power stage_____12
Figure 8 Crossover distortion_____12
Figure 9 Total amplifier two port model_____13
Figure 11 Actual input stage output_____15
Figure 15 Final Output of actual circuit_____17
Figure 16 Entire circuit except power phase_____18
Figure 17 Entire circuit and bias points parameters_____19
Figure 18 Simulated final output_____20
Figure 19 Simulated frequency response plot_____21

Table of Tables

Table 1 Estimated market price_____23

Experiment description

The primary objective of the practical assignment was to design and build a multiphase audio amplifier with a suitable output power phase. Complementary objectives included; testing the current and voltage characteristics of transistors in forward active mode, optimising biasing networks to achieve maximum swing, determining optimal number and type of phases necessary to achieve maximum symmetrical gain, considering a suitable feedback network to improve linearity, limit gain and control gain. The objective of gaining hands on experience and understanding of transistor amplifiers was an additional objective.

Problem analysis

Problem definition

A crucial element in communication is being able to hear precisely what the other party is saying and thus can be able to respond accordingly. If I cannot hear what you are saying, there is a barrier blocking us from communicating. For the music to communicate to you; you must be able to hear it and this is where amplifiers come into the picture. People are looking for greater amplification and less distortion in their music or other audio. If you are using a hearing aid, the amplifier quality determines the quality of life that you live as communication is vital to us humans. To further communication (all sorts), the design of effective and inexpensive amplifiers is vital.

The signal from an input transducer is often a very small signal in terms of power and is often not able to drive any significant electronic devises without amplification. In the case of this practical the transducer could be a microphone or an input from a portable device, which is usually battery powered and thus limited in power.

Professional audio amplifiers are costly and often expensive. These devices can often also be complicated to operate and include many features unnecessary for the simple purpose of amplifying your mp3 player. These devises are often also large and designed for large high powered speakers.

Professional devises are often designed to produce signals of recording quality which is much higher than required for portable music players to sound good. This adds unnecessary cost.

Problem approach and solution

The approach followed to serve as a solution was to design a transistor based amplifier. The input would be a portable mp3 music player. Care was taken to ensure that the gain design was linear, distortion less and symmetrical.

It would be designed to produce sufficient quality for the user to enjoy his music but not professional quality. Simplicity is also a factor and thus the only adjustment to be included would be gain control, or in lay terms, volume control. The device would also be designed to be pocket sized.

Design context

The context of the design consists of much aspect and can be described in terms of social, cultural, environment, ethical and legal, safety and economic context.

Social

The first aspect to consider here is the appeal of the product to the customer. One has to consider what types of physical appearance would appeal to the person. What are the modern trends that would make the product fashionable? One should also consider the way in which the product would influence social interaction. For instance it could be use in the organising of a spontaneous party by provide music, or as a voice amplifier at an informal outdoor meeting. The manufacture of the product can provide jobs. Extra consideration can be given to enhance this by for instance recruiting artists to produce limited edition artistic casing for the product.

Culture

Portable music players and speaker systems have become an integral part of modern culture. Thus the product would be well received by customers looking for a simple and cheaper alternative.

Environment

The world is moving more and more towards green energy and energy efficiency has become big consideration when purchasing an electric device. The product design should ideally optimise to use energy sparingly and reduce the number of components used in it. Consideration should be given to using recyclable materials such as an aluminium casing versus a plastic one. Alternate power supply such as solar power was also considered to reduce the environmental impact of the device while at the same time improving portability.

Ethical and legal

Firstly one has to ensure that all the regulation stipulated by the local authorities are adhered to, for instance limiting electromagnetic noise to acceptable levels and ensuring that the device can operate in the electrically noisy environment of the modern world. Customers would require long product life and durability. The device would have to be stable, thus requiring considerations such as cooling methods to ensure that the device does not fail under continues and prolonged operation. A suitable casing would also aid longevity. Ensuring that the product is of good quality, and ensuring that suitable replacement and guarantee policies are in place, would ensure customer satisfaction and avoid legal action.

Safety

Safety considerations would call for parts to be eclectically insulated by a suitable casing and that parts that become hot are protected from direct contact to prevent personal injury to users as well as fire hazards. Cooling implemented in the form of a heat sink must also ensure the surface area is large enough to avoid excessive heating, thus causing a fire hazard or risk of burn injuries. The replacement of poisonous substances with safe ones is also a consideration, for instance lead free solder. Adhering to safety standards such as SABS standards are essential.

Economic

Here one has to consider the cost of producing the device and weather it will be economically viable and competitive. A further consideration is the economic situation of the targeted customer and his ability to pay for such a device. The work force required in manufacturing and marketing the device will contribute to job creation and economic uplift.

Design objectives

The design was done to be affordable and simple in build, enabling easy access to a music amplifier to be used with portable equipment. The device was designed have a gain as large as possible while still maintaining an appropriate level of linearity. An objective was set to achieve a gain of at least 50 V/V and a power gain sufficient to drive a 10 W speaker an impedance of 8 Ω. A further objective is to ensure that the frequency pass band of the amplifier passes all the frequencies in the normally accepted band for music (100 Hz to 20 kHz) without distortion.

At the same time the device was stabilised against high frequency noise that would cause the device to become unstable. The design takes care to optimise energy efficiency especially in the power phase that consumes the most energy. Here the design with the highest power transfer and efficiency will prove to save the most energy. Cooling was implemented in the form of heat sinks to protect the device from thermal breakdown, and to meat the safety and longevity requirements. The design is intended to be used with an external power supply produced by a third party and to run off mans supply. An alternative design will incorporate a battery pack and solar panel to recharge it. This would be aimed at the green market.

Design concept

Three alternative solutions were considered for the problem namely; a single chip solution, a transistor solution and a combination.

Single chip solution

TDA7052A/AT

This is a device that can operate safely on a supply between 4.5V and 18V to power a 1W load. It has a minimum output of 0.5 W

TBA820M

This is a device that can operate safely on a supply between 3V and 16V to power a 1.2W load. It has a minimum output of 0.95 W

Transistor solution

The biggest consideration with a transistor system is how to combine the stages and which stages are necessary to achieve the desired result. One could include a differential pair input stage to eliminate noise or if noise is not a consideration it can be left out. Darlington pair devises could give sufficient voltage and current gain in a single stage such that only a power stage needs to be added. Current buffer stages such as emitter follower stages could be considered to improve inter stage loading. Supply voltage is another consideration as a larger supply can produce a larger power output.

Combination

A single chip solution might be combined with a power phase to deliver a larger power output.

Design optimisation

This section gives an overview of the amplifier design in terms of basic amplifier theory and two port models. These models are based on the detailed designs in the next section. It also justifies the configurations chosen and looks at alternatives considered.

Input stage

The design contained four amplifier phases. The first phase was chosen to be a differential pair BJT amplifier to eliminate noise and achieve an initial gain. A differential stage also gave the benefit of higher input impedance thus reducing input loading. A two port model of this stage is given bellow:

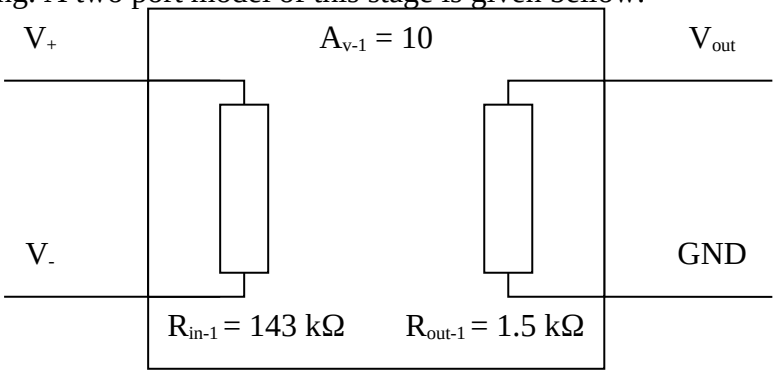


Figure 1 Two port model for input stage

Alternatives to this input stage could be the use of A MOSFET differential pair to improve the input impedance to a level where there is virtually no input loading. This has the disadvantage of reduced input stage gain.

Gain stage

For the main gain stage a common emitter stage was used. A two port model of the main gain stage is given bellow.

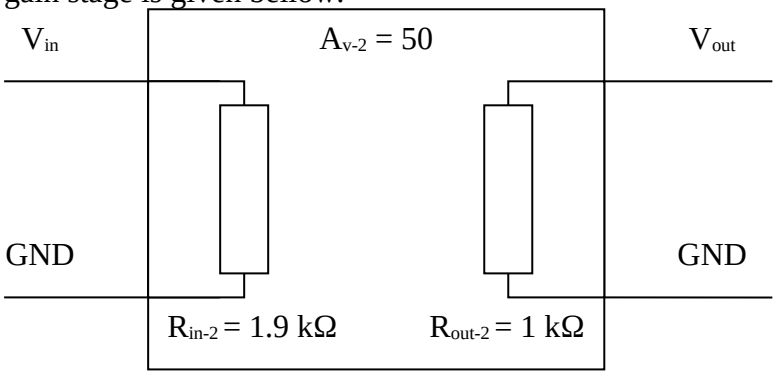


Figure 2 Two port model of the main gain stage

Current gain stage

An emitter follower, or common collector, configuration was used for the main current gain to buffer the signal before the power stage that has a very low input resistance. It is necessary to include this stage before the power stage to prevent inter-stage loading from consuming all the gain achieved in the previous stages.

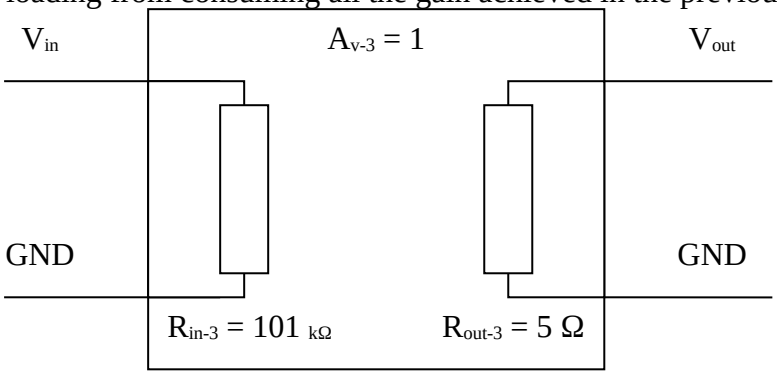


Figure 3 Two port model of current gain stage

Power stage

Implemented stage - Class AB

An AB class Power stage was designed to achieve the final current gain and to significantly increase the signal power. The advantage of an AB class Power amplifier is that it eliminates cross over distortion. It is also significantly more power efficient than an A class stage since most of the current that flows through the transistors in this stage is delivered to the load. If an AB class power stage is used transistors with a significantly smaller current rating can be used as compared to when an A class power stage is used. This reduces the cost of the transistors used, and improves safety and stability but reducing the amount of heat generated. The two port model for the power stage is:

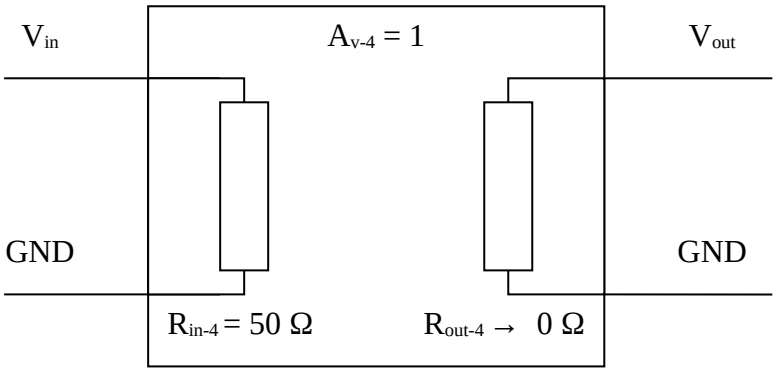


Figure 4 Two port model of current gain stage

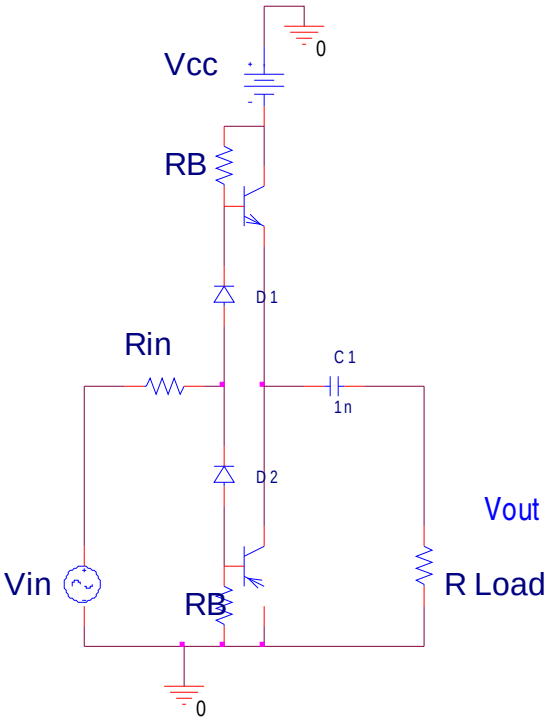


Figure 5 Class AB power stage

Alternative 1 – Class A

A typical example of an A class power stage would be an emitter follower circuit as the one shown below.

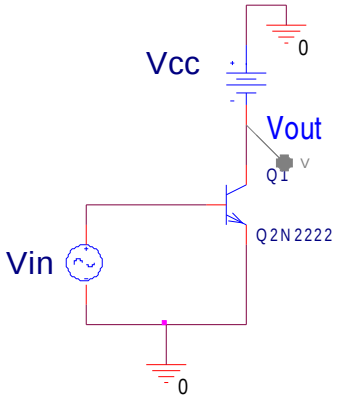


Figure 6 Class A power stage

The power that a class A power stage supplies to the load at the output is given by:

$$P_{out} = v_o i_L$$

Where vo is the voltage at the output and iL is the current through the resistor RL. However we know that:

$$v_0 = V_0 \sin(\omega t) + \frac{Vcc}{2}$$

$$i_L = \frac{v_0}{R_L}$$

Therefore the output power is given by:

$$P_{out} = (Vcc)^2 \frac{1}{4R_L} + \frac{V_0^{\ 2}}{2R_L}$$

However the Vcc term is a useless Dc term, which means that the effective output power of the system is:

$$P_{eff} = \frac{V_0^{\ 2}}{2R_L}$$

The power consumed by the transistor is given by:

$$P_Q = i_C v_{CE}$$

Where it is assumed iC = vCE is much larger than iBvBE.
For now we will assume that the transistor is biased for maximum swing as this biasing gives the maximum power output.

$$v_{CE} = \frac{Vcc}{2} - V_0 \sin(\omega t)$$

$$i_c \approx i_L = \frac{v_o}{R_L}$$

Therefore we have that the average supplied power is given by:

$$P_Q = \frac{(Vcc)^2}{4R_L} - \frac{V_0^{\ 2}}{2R_L}$$

The effective power supplied by the power supply is given by:

$$P_S = (Vcc) i_c$$

$$= \frac{(Vcc)^2}{2R_L}$$

And the useful signal power is given by:

$$P_{use} = \frac{V_0^{\ 2}}{2R_L}$$

Maximum swing V0 = Vcc/2.
The power efficiency is given by:

$$\eta = \frac{P_{use}}{P_S} * 100\%$$

$$= \frac{(Vcc)^2}{8R_L} / \frac{(Vcc)^2}{2R_L} * 100\%$$

$$= 25\%$$

Therefore it can be seen that even though this power amplifier is linear, it has a power efficiency of 25%, which compared to other classes, is not good. It is wasteful of energy and requires larger, more expensive components.

Alternative 2 – Class B

A class AB power stage is constructed as show below.

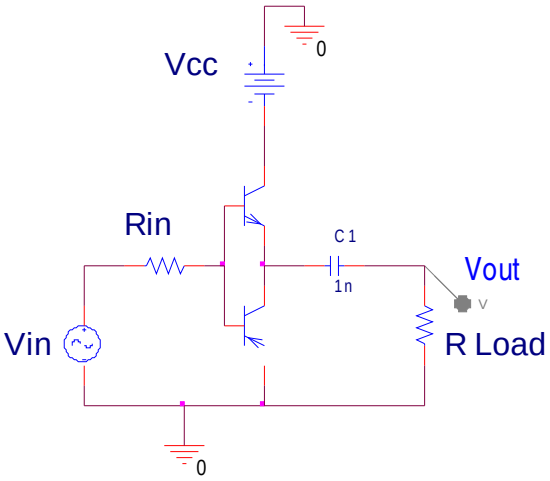


Figure 7 Class B power stage

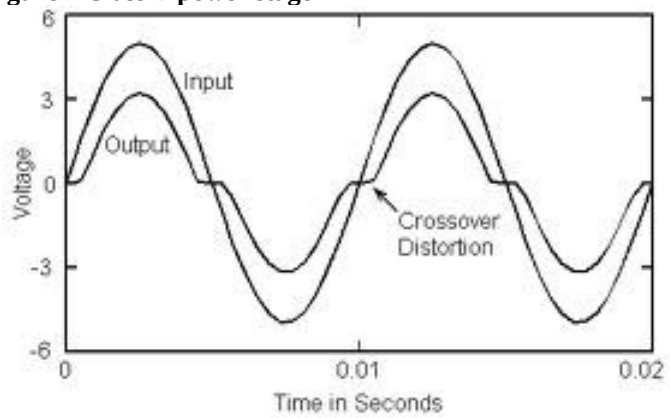


Figure 8 Crossover distortion
Source: [Online]. Available: http://users.ece.gatech.edu/mleach/lowtim/output.html

One of the main disadvantages of a class B power stage is that is causes cross over distortion. This is because there is a dead zone between when the signal drops below the typical 0.7 V turn on voltage of the NPN transistor until it reaches the typical tur-on of the PNP transistor 0f -0.7 V. This causes a dead band and the distortion shown above

The voltage at the output resistor is given by:

$$v_0 = V_0 \sin(\omega t)$$

$$i_L = \frac{v_0}{R_L}$$

The power to the load is given by:

$$P_{out} = v_o i_L$$

$$P_{out} = \frac{V_0^{\ 2}}{2R_L}$$

The power supplied by the source is given by:

$$P_S = (Vcc) i_c$$

$$= \frac{(Vcc)V_0}{\pi R_L}$$

To obtain maximum power efficiency in a Class B amplifier set V0 = Vcc.
The reason why this is possible without distortion is due to the fact that each transistor only amplifies for the positive or negative parts of the input signal and not both.

$$P_{out} = \frac{(Vcc)^2}{2R_L}$$

And the power efficiency is given by:

$$\eta = \frac{P_{use}}{P_S} * 100\%$$

$$= \frac{(Vcc)^2}{2R_L} / \frac{(Vcc)^2}{\pi R_L} * 100\%$$

$$= 78.4\%$$

Alternative 3 – Class AB

A class AB power stage combines the best of both the Class A and the class B type power stages by introducing a slight bias to improve linearity together with the two transistor complement to maintain good power efficiency. The simplest way to achieve this bias is by using a diode to introduce a slight voltage offset. However due to power dissipation in the two RB resistors and power dissipation in the current buffer transistor the power efficiency of the class AB amplifier is between 25% and 78.4 %.

Complete Amplifier

When all the stages are combined and the loading factors considered the two port model for the entire amplifier is:

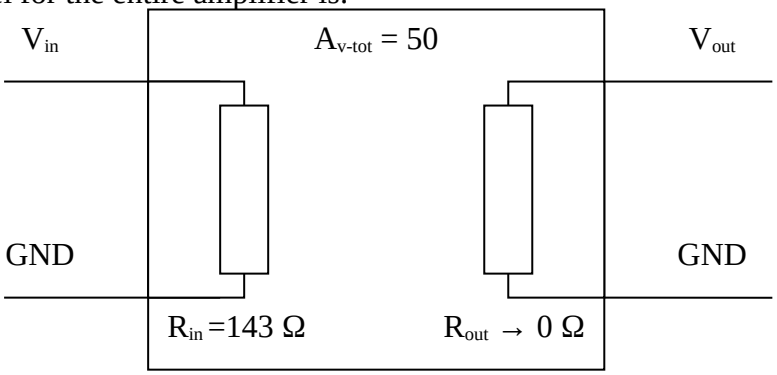


Figure 9 Total amplifier two port model

Frequency response

The right values for the coupling capacitors and bypass capacitors have to be chosen to ensure that the low frequency response is low enough to allow a 100 Hz signal to pass. Failure to limit the high frequency response could lead to susceptibility to noise and instability that could cause the amplifier to malfunction. The method of using Miller's theorem to limit the high response was used. The alternative is to use a load capacitor in parallel to the lad to limit the high frequency response.

Design detail

This section shows the actual designs used for the device. With the exception of the power stage all transistors used in the lab experiment where NPN type Q2N2222A BJT transistors. The input was kept at a constant 200mVp-p

Input stage

This stage is responsible for eliminating noise and was designed to have a high input impedance to limit input loading and compensate for variable input resistance. The design is shown in the diagram below and the parameters are as follows:

Chosen I_C = %5 mA

V_f = 0.7

B = 100

V_T = -14.3

$I_T = 2*I_C$ = 10 mA

$R_T = V_T/I_T$ = 1.43 kΩ ≈ 1.5 kΩ

gm = 40* I_C = 40*5m = 200 mA/V

Choose Rc = 1.5 kΩ

$|A_{v-1}| = 0.5*gm*R_C$ = 150V/V

R_{out-1} = Rc = 1.5 kΩ

$R_{in-1} = (B + 1) R_T$ = 143 kΩ

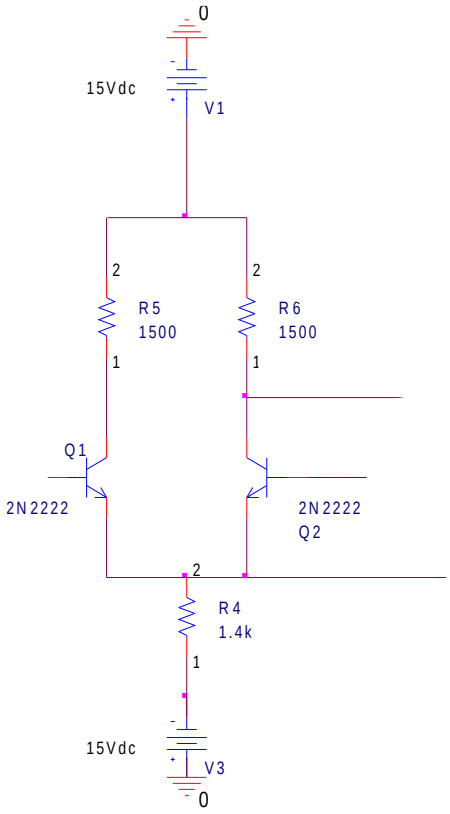


Figure 10 Circuit – input stage

Due to the mismatch of the discrete components the open loop gain on the real circuit was only 10 V/V and when this stage was connected to the whole circuit it measured a gain as shown on the scope to be 290/200mVp-p which is 1.45V/V

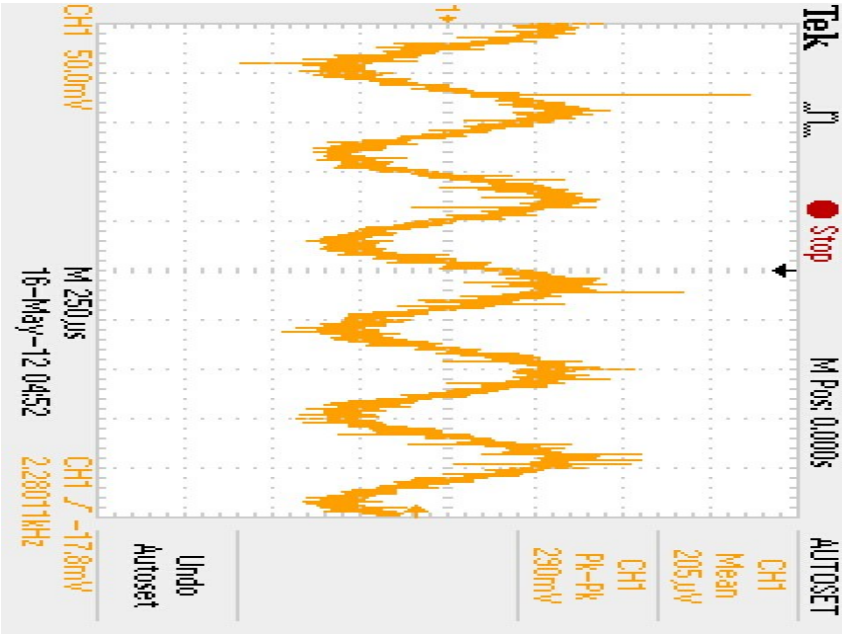


Figure 11 Actual input stage output

Gain stage

This stage is responsible for the bulk of the gain of the amplifier. The circuit is shown below and its design parameters are:

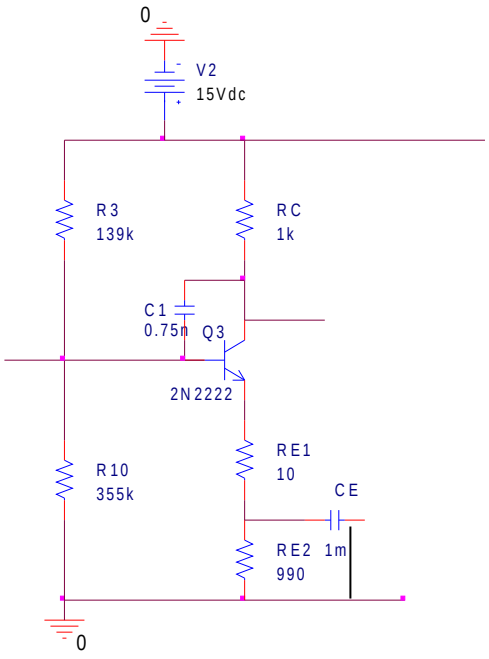


Figure 12 Circuit - Gain stage

Choose $I_C = 5mA$

B= 100

$V_f = 0.7$ V

Choose $V_{CE} = 5$ V

Choose $V_E = 5$ V

$R_E = R_C = 5V/5mA = 1k\Omega$

$I_C = (V_{BB} - I_C)/((B+1)* R_E + R_{BB})$

Choose $R_{BB} = 100\ k\Omega$

$V_{BB} = 10.75$ V

R1 = 355 kΩ

R2 = 139 kΩ

R_E is spilt into R_{E1} and R_{E2} , a bypass capacitor is connected between them thus:

$|A_{v-2}| = R_C / R_{E1} = 50V/V$ $\qquad R_{in-2} = R1 \| R2 \| (R_\pi + (B+1)* R_E) = 1.9k\Omega$

$R_{out-2} = R_C = 1\ k\Omega$

his stage showed an open loop gain of about 50 V/V and the same result with the rest of the circuit connected. The result is exactly the same as the output at the final stage shown in Figure 15.

Current gain stage

This stage is responsible for buffering the signal from the gain stage and improving internal loading factors to improve the overall gain. The circuit diagram is shown bellow and the design parameters are:

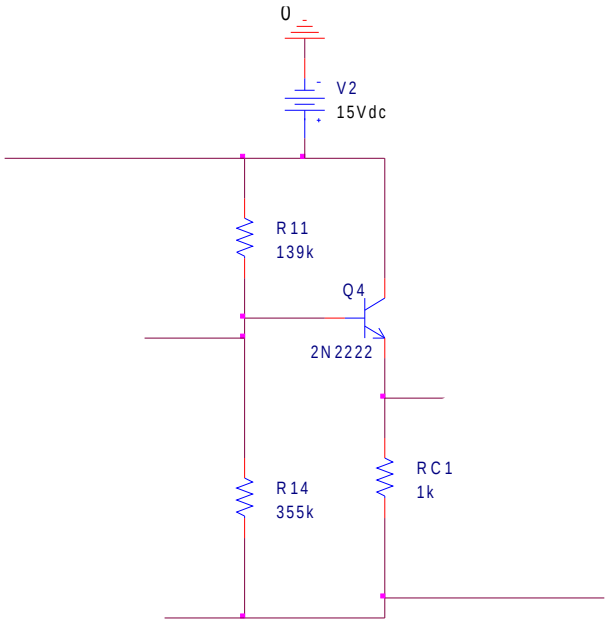


Figure 13 Circuit - Current gain stage

Choose $I_C = 5mA$

B= 100

$V_f = 0.7$ V

Choose $V_{CE} = 10$ V

Choose $V_E = 5$ V

$R_E = 5V/5mA = 1k\Omega$

$I_C = (V_{BB} - I_C)/((B+1)* R_E + R_{BB})$

Choose $R_{BB} = 100\ k\Omega$

$V_{BB} = 10.75$ V

R1 = 355 kΩ

R2 = 139 kΩ

$\left| A_{v\text{-}3} \right| = 1$

$R_{in\text{-}3} = R1 \| R2 \| (R_\pi + (B+1)* R_E) = 101\ k\Omega$

$R_{out\text{-}3} = 1/gm = 5\ \Omega$

The resulting output is exactly the same as the output at the final stage shown in Figure 15.

Power stage

A Class AB Power stage was designed with the following design equations:

$P_L = 10W$ $R_L = 8\ \Omega$ $B_f = 50$ $Vcc = 15$ V

$V_0 = \sqrt{(2 * R_L * P_L)} = 12.65$

$i_{L=} V_0 / R_L = 1.581$ A

$i_L = i_E = i_C$

$i_B = i_C / B_f = 31.62$ mA

$V_B = V_L + V_f = 13.35$

$R_B = (Vcc - V_B) / i_B = 50\ \Omega$

$R_{out} = 1/gm \rightarrow 0\ \Omega$, $gm \rightarrow \infty$

$R_{in\text{-}4} = R_\pi = 50\ \Omega$

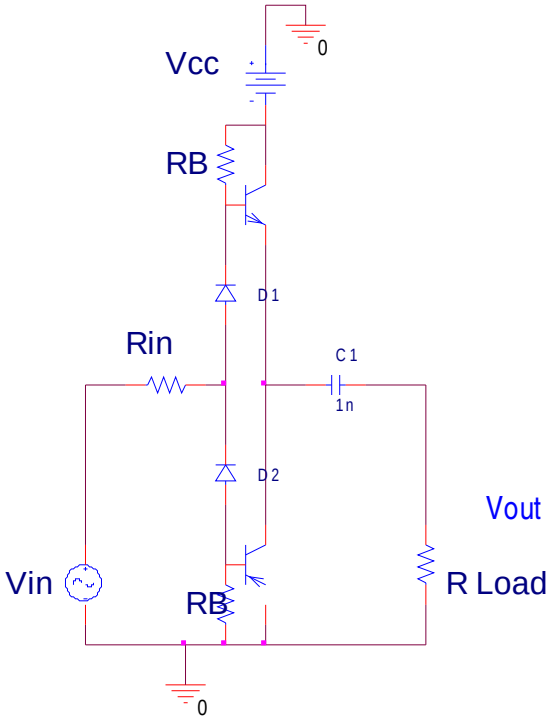


Figure 14 Circuit- Power Stage

The scope picture below (Figure 3##) shows the final output of the amplifier after all the stages to be 12.1/.2 = 60.5. There is a slight distortion on the Waveform but this is still before the feedback network is connected.

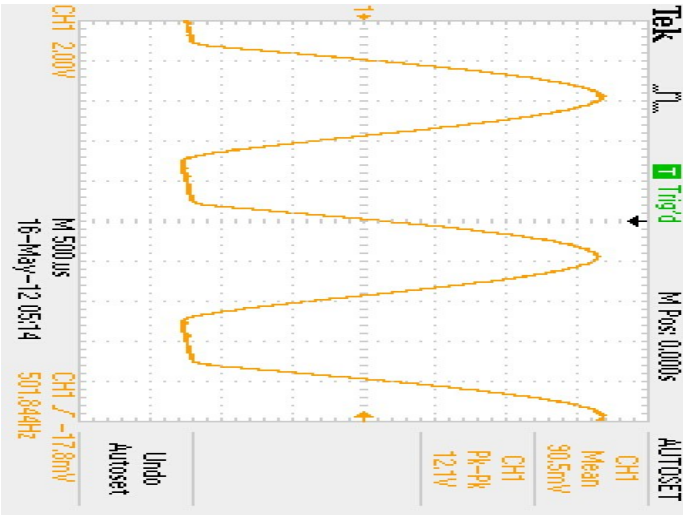


Figure 15 Final Output of actual circuit

Total amplifier

The spice diagram below shows the completed spice diagram excluding the power phase. The spice bias point parameters shown where indeed very close to the actual bias point parameters.

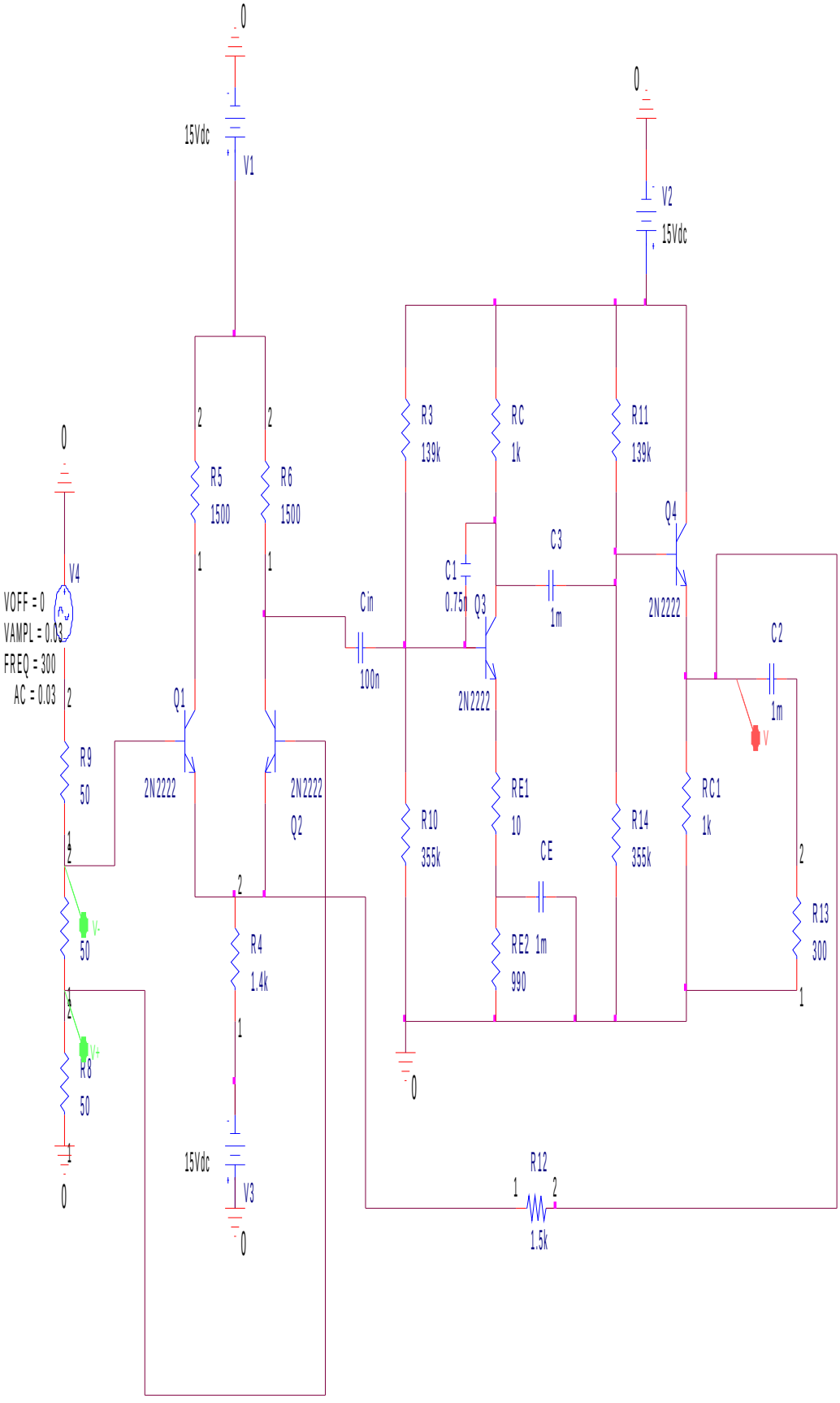


Figure 16 Entire circuit except power phase

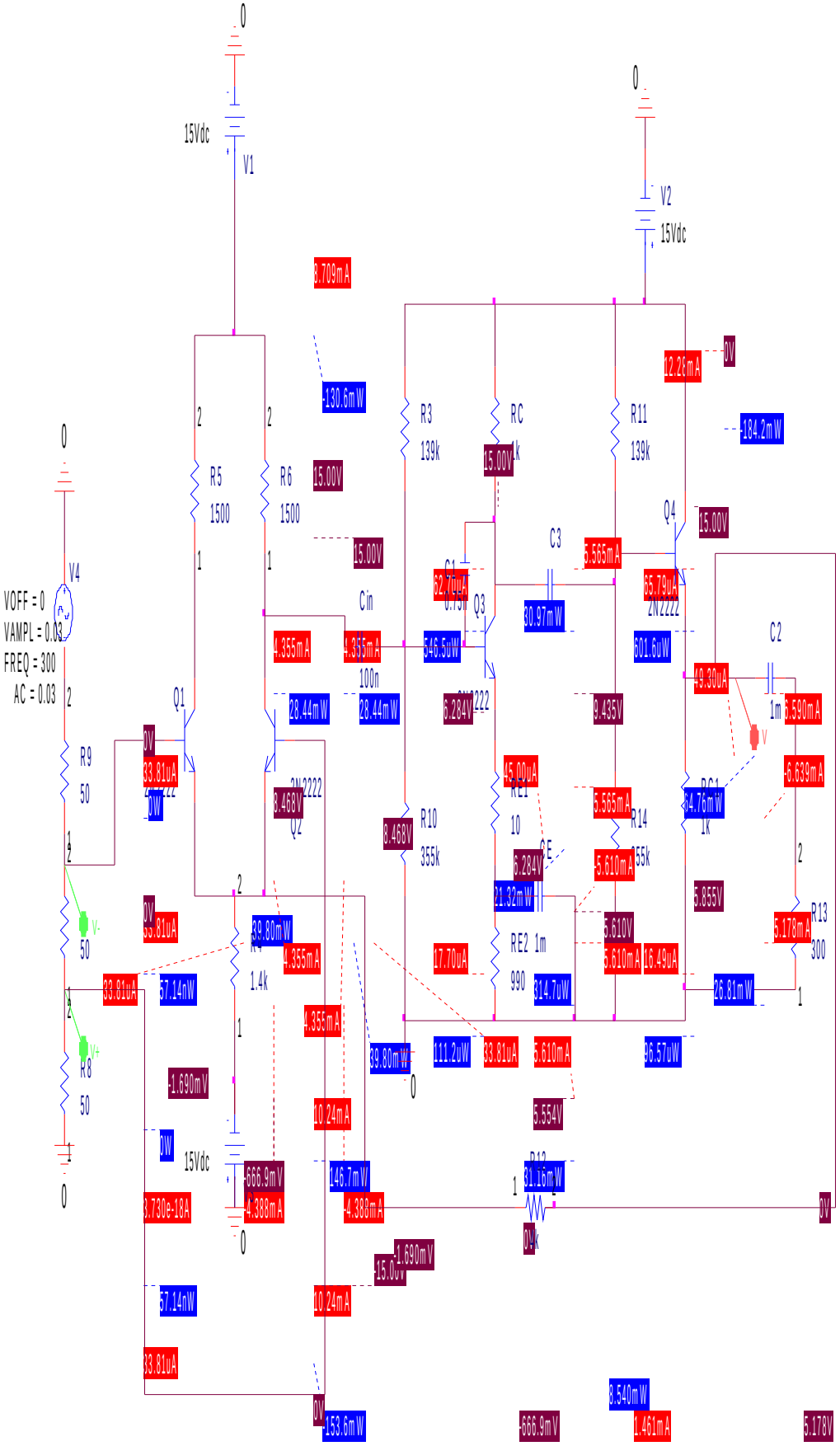


Figure 17 Entire circuit and bias points parameters

A shunt series feed back topology was applied to the circuit in the form of R_f. The output of the simulation with the feed back adjusted in such a way as to achieve maximum gain while maintaining linearity is shown below. That is R_f = 1.5 kΩ and a gain of 300 V/V on the 10 mV input to 3V output. Applying a feedback of about Rf = 1.5 kΩ. A similar result that produced linear output was observed in the actual circuit for a much larger feedback resistance.

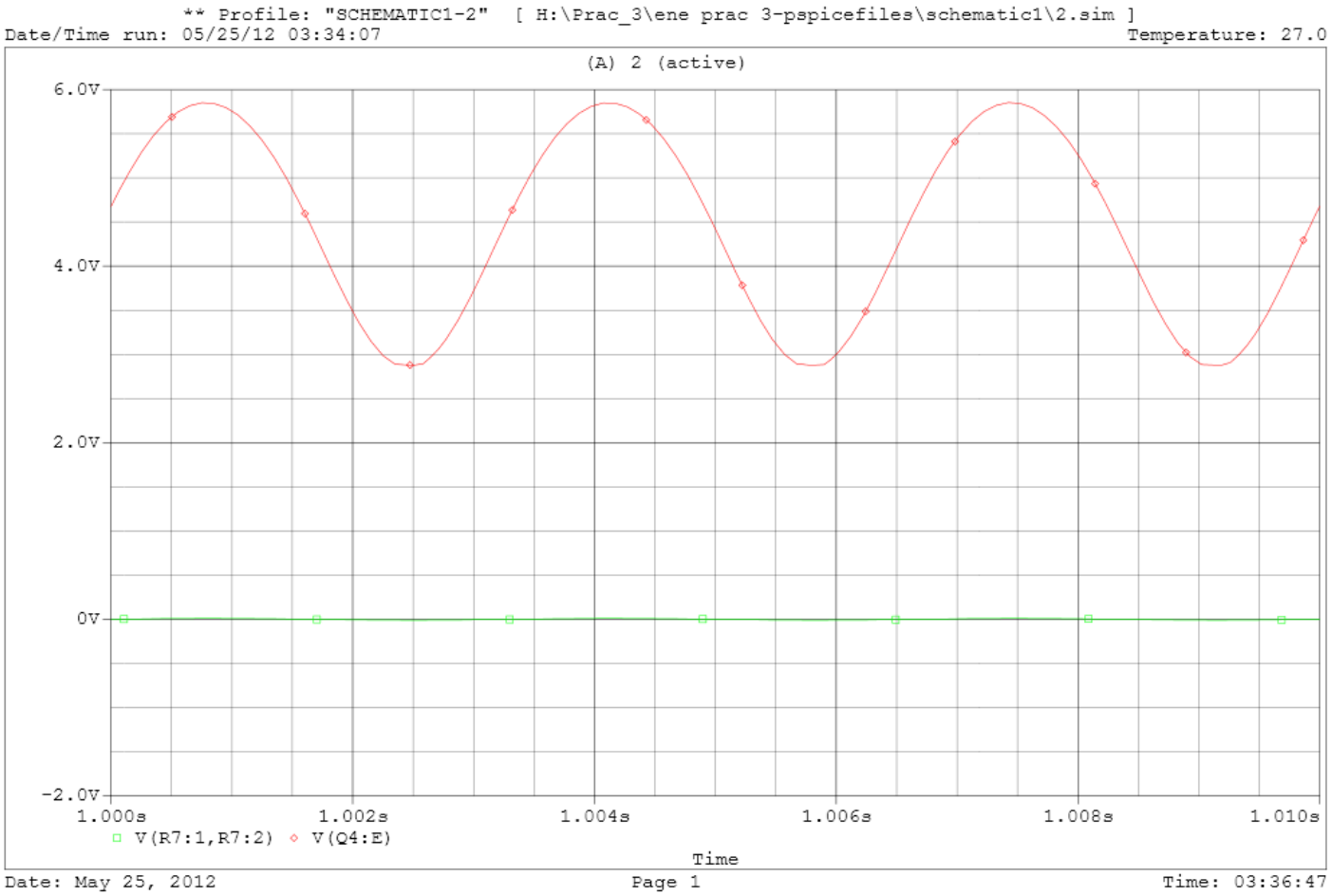


Figure 18 Simulated final output

Frequency Response

All the coupling capacitors with the exception of the capacitor coupling the input stage to the gain stage where chosen to be very large (C = 1mf), thus they would not contribute significantly to the low frequency cut-off. Thus the capacitor between the input and gain stage is responsible foot the low frequency cut of point. It was calculated that if this was to be 100Hz it would need to be 10nf. Simulation results had a result of 100 nf, While actual results required it to be larger than 1 uf such that a cut off of 75 Hz was observed with a 10uF capacitor. This cut off is still high enough to suppress supply hum at 50 Hz.

The high frequency cut off was achieved by using Miller's theorem. The value calculated to achieve the high cut-of 20 kHz was 1.6 nf almost half of that 0.75 nf achieved the cut-off in simulation and the calculated value of 1.6 did it or the actual circuit. The simulate frequency response is shown below.

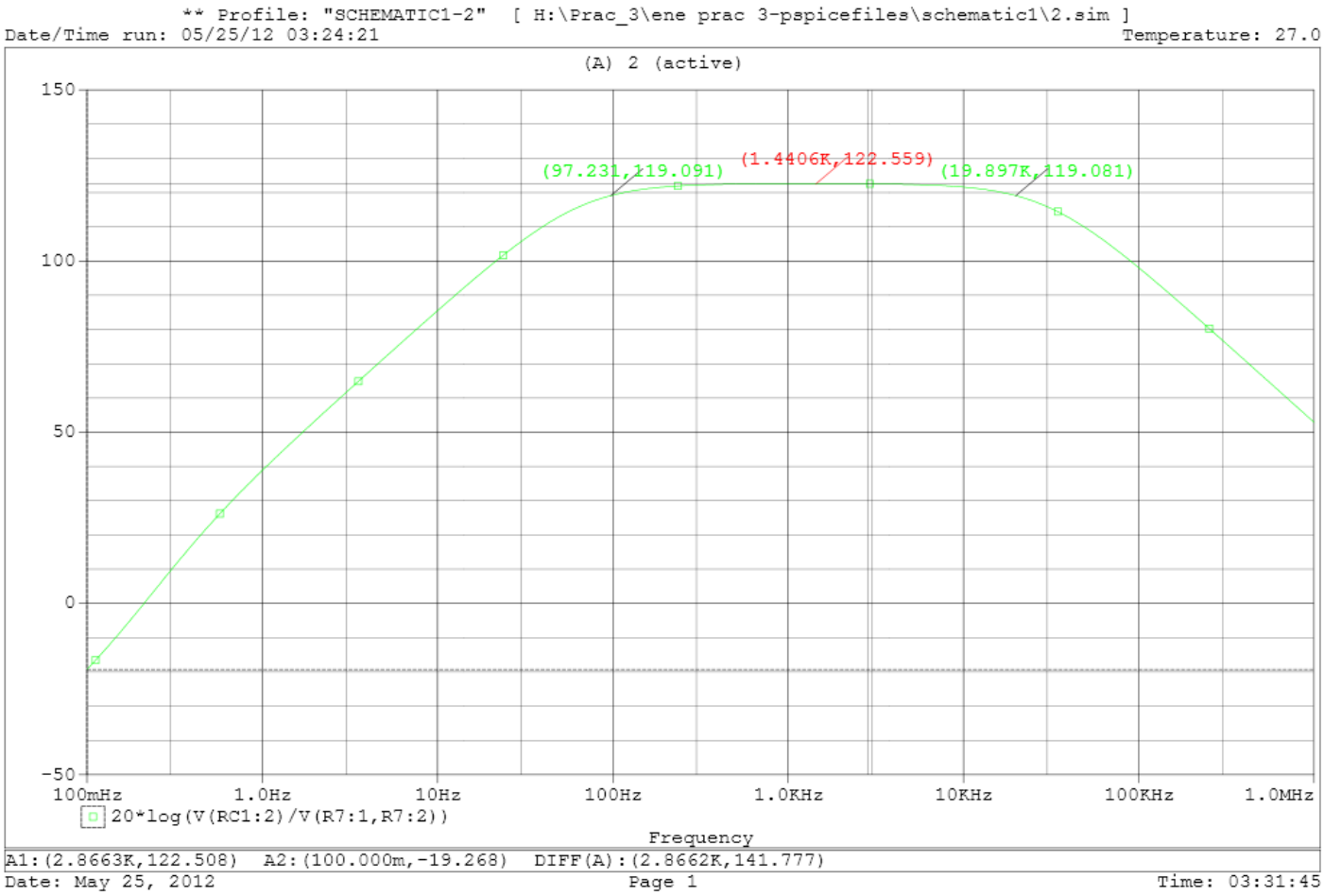


Figure 19 Simulated frequency response plot

Benefits

The product will benefit the customers in its affordability. It will also be more fit for the purpose of use with portable devises than professional equipment. It simplicity would make it easy to use and set up.

Instruction manual (mains version)

This instruction manual will aid the user of this device to use the device safely, and to avoid damage. This is damage to the device itself or devises connected to it. It is recommended that the user takes note of the safety precautions to avoid personal harm or property damage.

Set up for use

1. Connect the speaker to the terminals. Ensure that the power is turned off and that the supply is disconnected from mains.
2. Plug the power supply into the socket on the device.
3. Plug supply into mains and ensure the switch in the socket is turned on only afterwards.
4. Connect to music player or microphone.
5. Turn devise on with the switch on the device.
6. Adjust gain control (volume) knob.

Warnings

7. Only connect/disconnect speaker when power is turned off and disconnected from mains.
8. Do not exceed the maximum input voltage of 0.5 Volts
9. Do not use speaker rated less than 10 W nominal (not peak).
10. Do not cover. Always allow device to cool in free air. To not block air vents.
11. Do not use in wet conditions. Device not water resistant.
12. Live electricity inside cover, do not open. Risk of shock exists even when mains are disconnected.
13. Do not attempt repairs yourself. Only have device serviced by qualified persons.

Specification

- Frequency response 20Hz to 20 kHz
- Supply voltage: + - 15 V DC
- Max gain: 60 V/V
- Nominal power: 10W
- Input range: 10mV - 500Mv

Price and marketing

Pricing

Estimated market price	Unit price	Total
4 x 2N2222A Transistors	R 12	R 48
1 x TIP41 Power transistor	R20	R20
1 x TIP42 Power transistor	R20	R20
2 x Heat sink	R25	R25
13 x 0.5 W resistors	R0.1	R1.3
2 x 6W resistors	R0.50	R1
5 x Capacitors	R3	R15
1 x Metal casing	R50	R50
1 x Circuit bard printing and drilling	R40	R40
1 x Control Pot	R10	R10
1 x Power Supply	R80	R80
1 x Switch	R10	R10
Other hardware and consumables	R20	R20
Connectors	R30	R30
Printed manual	R10	R10
Assembly labour 30 min at R20 an hour	R20	R10
Total cost price		R 390.3
Selling price at + 25% profit		R 487.88
V.A.T included		R 556.18

Table 1 Estimated market price

Marketing strategy

The marketing strategy is aimed at the youth who enjoy music on the move. They would be able to use the devices with their cell phones and mp3 players. Bothe online sales and bulk sales to chain stores are being considered with 5% discount for chain stores. Value packs with the speaker included would also be very suitable for chain stores.

Resources

Text References (Harvard Style)

Neamen, D. 2007. *Microelectronics: Circuit Analysis and Design*.3rd ed. New York: McGraw-Hill

Schlater, N.1999. *Electronics Technology Handbook* [online]. Available from http://0-www.accessengineeringlibrary.com.innopac.up.ac.za/. McGraw-Hill. [Downloaded 14/05/2011]

Sinha, S. 2008. *Analogue Amplifiers-Analysis & Design: Through Objectives Type Questions*. 1st ed. Pretoria: University of Pretoria

Sinha, S. 2011. *Study Manual Analogue Electronics: ENE 310*. Pretoria: University of Pretoria

[Online]. Available: http://users.ece.gatech.edu/mleach/lowtim/output.html

Suppliers details and addresses

Electronics123
Shop 1 Moulton Centre
Cnr. Codonia and Moulton Road
Waverley
Pretoria
Gauteng
0186
South Africa
Tel: 012 3322356
Fax: 012 3320487
www.electronics123.co.za

Mantech Electronics
32 Laub Street
New Centre
Johannesburg
South Africa
Tel: 011 493 9307
Fax: 011 493 9319
www.mantech.co.za

Personal Highlights

Ntokozo Mazibuko:

This is by far one of the most enjoyable, time consuming and stressful practical that I've had to do in my academic career. It was enjoyable in the sense that you get a certain satisfaction when you hear that sound being amplified and playing through the speaker. With the other practicals they want us to design filters and the results aren't so gratifying, and as young people music is what we know. This practical is the reason why some of wanted to become engineers, to design things that matter to us. It was stressful and time consuming in the sense that you spend endless hours in the labs trying to get the desired output. Having resistors smoking when you thought that your design was perfect and thus you have to re-design. I really enjoyed this practical though and am very thankful to Prof. Sinha for the passion he has for his module, because it rubs off on us somehow.

Francois Botha

I fount the practical rather difficult, but approached it as a challenge. I was rather disappointed when the nature of analogue electronics once again caused me to get different results in the demo than the day before. It is always hard to work with something that is so sensitive to variables in the environment. I have come to understand that is why it is so important to try and minimise these effect by good designs and elements like feedback that stabilise the circuits. I have found that a good understanding of the practical work always spill over into my theory work, giving me a much deeper and intuitive understanding. I really enjoyed prof. Sinha enthusiasm end the good attitudes of the teaching assistants. I would like to thank all of you for your hard work and for always being available to help.