UNIVERSITY OF GÄVLE

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT

Audio Power Amplifier Design

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June 2011

Bachelor's Thesis in Electronics

Acknowledgement

The authors would like to offer special thanks of gratitude to supervisor Efrain Zenteno for his professional guidance, support and encouragement from the beginning to the end. Besides, the authors would like to thank Niklas Rothpfeffer for his help to solve the problems of power amplifier part. Last but not least, the authors offer regards and blessings to all of those whose articles are cited in this paper, which are the source of knowledge.

Abstract

The audio power amplifier is used to amplify low-power audio signals to a level that can be suitable for driving the loudspeakers. Thus the audio power amplifier becomes a kind of essential part in the electronics that could make sounds.

In this thesis, a good performance audio power amplifier with tonality control is designed. It consists of three parts: pre-amplifier unit, the tonality control unit and the power amplifier unit. In the pre-amplifier unit, a TL071CP operational amplifier is applied, to amplify the low signal to be suitable for the tonality control unit. For the tonality control unit, a filter is used to achieve bass and treble control, resulting in different frequency response. In the last part, the low voltage power amplifier LM386N-1 is used.

The results of simulation in Multisim show a good output waveform and different frequency response with the tonality control. Also the pure sound can be heard by ear clearly. The good simulation result offers the encouragement to build the circuit on the board and do the measurement. The measured results show a good output waveform, the output power 256mW, THD 4.7%, the maximum voltage gain 40 etc. Meanwhile, sound can be heard by ear clearly with the tonality control. Judging from the results, the audio power amplifier is designed successfully.

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1 Introduction

1.1 Background

The audio power amplifier, which is also known as the audio amplifier, is a kind of electronic amplifiers that amplify low-power audio signals (the frequencies of the low-power signals are always between 20Hz to 20KHz,which is the range of human hearing) to a level that can be suitable for driving the loudspeakers. Nowadays all types of electronics that could make sounds are widely using the audio power amplifier, such as mobile phones, MP4 players, laptops (See Figure 1), television, audio equipment, etc. The audio power amplifier plays a quite important role in the sound reinforcement, and the speakers cannot play a good role in amplification without the audio power amplifiers.
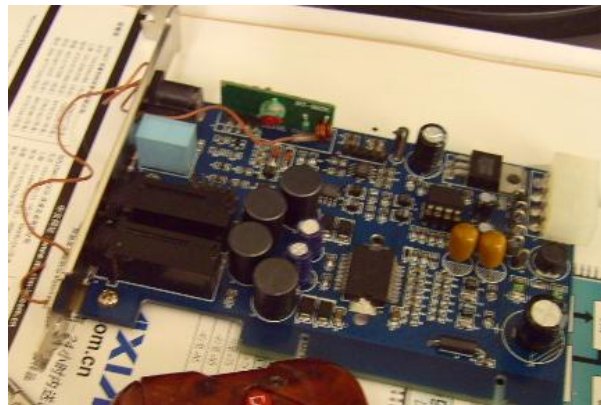

Figure 1 Audio power amplifiers in laptops [1]

Since the transistor was invented in 1940s, many kinds of different power amplifiers were developed. Up to 1970s, the transistor amplification technology became quite mature, and a variety of new circuits were developed. Examples of this are the circuit combination of Class A amplifier and Class B amplifier, current amplification circuits with large output power and small distortion. So the transistor amplifiers became the mainstream in the audio technology field.

In the early 1960s, Jack Kilby developed a new member in audio technology, i.e. integrated circuits. Up to early 1970s, the integrated circuits became recognized by the audio industry for its cheap price, small size and more functions. So far, thick film audio integrated circuits, operational amplifier integrated circuits are widely used in audio circuits [2].

1.2 Aim

By the analysis of the composition of audio power amplifier and the performance indices of amplifiers, the working principle of the audio power amplifier is better understood.

Under this condition, using the common electronic circuits, an audio power amplifier is aimed to be built successfully with the function of tone and volume control. Besides, the tonality can be changed 12dB up and down (compared with gain value at f_0=1 kHz) in the frequency range of 100Hz to 10 kHz. Good performance such as low distortion, low voltage, and low noise are preferred.

2 Theory

2.1 The composition of audio power amplifier

Audio power amplifier is a key part in stereo system. It mainly consists of three units: pre-amplifier unit, tonality control unit and power amplifier unit. The simple block diagram is shown in Figure 2. Every part will be explained in detail.
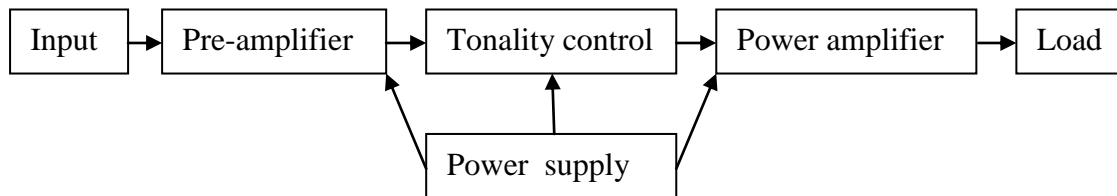
| Input | → | Pre-amplifier | → | Tonality control | → | Power amplifier | → | Load |

Power supply

Figure 2 The simple block diagram of audio power amplifier

2.1.1 Pre-amplifier unit

A pre-amplifier is required to amplify a signal, when the source level is too low and has to be pre-amplified in order to be able for further processing, control or any other use [3].

The function of audio power amplifier is to amplify the input signal from the audio source, and then drive it to the speaker. The audio sources are various: for example, microphone, record player, CD player etc. More importantly, different voltage is provided for different audio source, from some millivolt to hundreds of millivolt, but the input sensitivity of the power amplifier is constant. If different kinds of audio source input directly into the power amplifier, problems will arise. For the low input signal, the output power is low, and the power amplifier cannot use full capacity. For the high input signal, the output signal of the power amplifier will suffer overload and distortion seriously, so the power amplifier will lose the function of clean audio amplification. Therefore, a qualified and functional audio power amplifier must contain a pre-amplifier, which makes the input signal adequate to be sent to the power amplifier.

In addition to this, for the low input signal, the noise of the pre-amplifier input stage has a vital influence on signal-to-noise ratio of the whole system. As a result, the pre-amplifier unit must use low noise elements. If an integrated operational amplifier is put into use, low noise and low drift must be considered.

Last but not least, another requirement of pre-amplifier is that its frequency band must be wide enough, so that amplification without distortion can be ensured.

In the pre-amplifier design process, the non-inverting amplifier equation (1) is needed, see Figure 3.
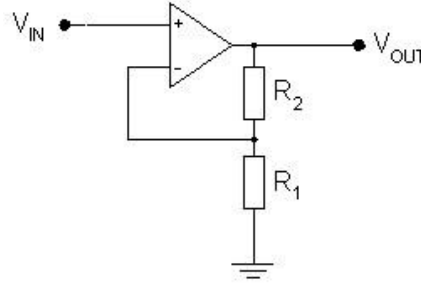

Figure 3 Non-inverting amplifier

$$V_{out} = (1 + \frac{R_2}{R_1}) \cdot V_{in} \tag{1}$$

From equation (1), the voltage gain can be calculated.

2.1.2 Tonality control unit

Tone controls allow the frequency response of the audio system to be adjusted to compensate for the response of speakers and their enclosures or the listening room, or to simply provide a more pleasing sound [4].

The most common of all modern tone control circuits was named after P.J. Baxandall who came up with the idea in 1950s [5]. It contains bass control and treble control, see Figure 4. In this type of control, the op-amp is often added to act as a buffer.
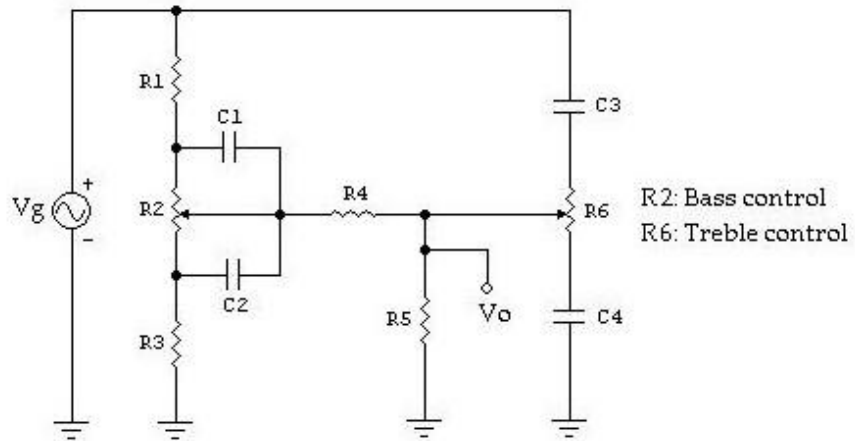

Figure 4 The James/Baxandall tone control network [6]

This tone control network can be analyzed separately, see Figure 5 and Figure 6.
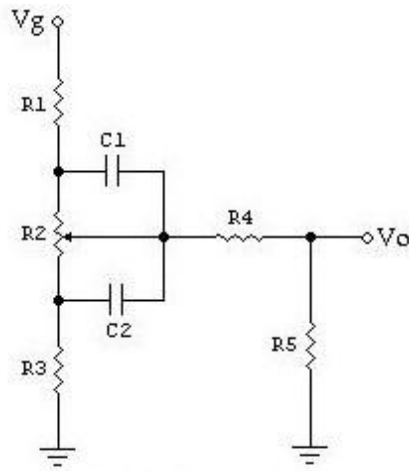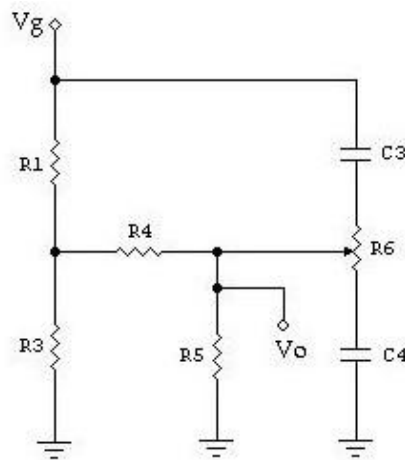
Figure 5 Bass control circuit [6]

Figure 6 Treble control circuit [6]

2.1.3 Power amplifier unit

The power amplifiers are those amplifiers which are designed to take a signal from a source device and make it suitable for driving a loudspeaker. (In a Disc Jockey system the signal typically comes from a preamplifier or signal processor). Ideally, the ONLY thing different between the input signal and the output signal is the strength of the signal [7].

The main performance qualities of a power amplifier are distortion, frequency response, signal-to-noise ratio, power etc. When the load R_L is constant, a good power amplifier should be designed for high output power, low distortion and noise, and bandwidth.

At present, integrated power amplifiers are widely used due to low cost, stability, low distortion, small size etc.

2.2 The performance indices for amplifiers

2.2.1 Output power

Strictly speaking, the output power for amplifiers is usually regarded as maximum RMS-power output per channel, at a specified distortion level at a particular load, which is considered as the most meaningful measure of power [8].

The power can be calculated by the equation:

$$P_O = \frac{U_O^2}{R_L} \tag{2}$$

Where R_L is the impedance of the load and U_O is the highest RMS voltage at a specified distortion level across R_L.

In general, a power amplifier for loudspeakers will typically be measured at 4 and 8 ohms [8].

2.2.2 Frequency response

Frequency response is the term used to describe the range of tones that a stereo system can reproduce [9].

There are two requirements for frequency response:

One requirement is that the range of frequency response should be wide enough. The lower frequency should be as low as possible, and the upper frequency as high as possible. Typically, the specified frequency range for audio components is 20Hz to 20 KHz, which is the approximate range of human hearing.

The other requirement is that the frequency response should be flat. It means being linear. A well-designed amplifier is linear across the whole operating range, and its frequency response just varies a little between 20Hz to 20 KHz.

2.2.3 Signal to noise ratio

Signal-to-noise ratio is the ratio of signal power to noise power. There is no doubt that the higher signal-to-noise ratio, the better performance of the amplifier.

It can be expressed as equation (3):

$$SNR = \frac{P_{signal}}{P_{noise}} \tag{3}$$

Also, the SNR can be expressed as equation (4):

$$SNR_{dB} = 10\log_{10}(\frac{P_{signal}}{P_{noise}}) \tag{4}$$

SNR can also be obtained by calculating the square of the amplitude ratio as equation (5):

$$\text{SNR}_{\text{dB}} = 10\log_{10}(\frac{A_{\text{signal}}}{A_{\text{noise}}})^2 = 20\log_{10}(\frac{A_{\text{signal}}}{A_{\text{noise}}}) \tag{5}$$

Where, A is the RMS voltage value.

2.2.4 Total harmonic distortion

Harmonic distortion is caused by device non-linearity. When a non-linear device is stimulated by a signal at frequency f_1, spurious output signals can be generated at the harmonic frequencies $2f_1$, $3f_1$, and $4f1\ldots nf_1$[10].

Total Harmonic Distortion of a signal is the ratio of the sum of the powers of all harmonic components above the fundamental frequency to the power of the fundamental frequency as expressed in equation (6) [11].

$$\text{THD} = \frac{P_2 + P_3 + P_4 + \cdots + P_\infty}{P_1} = \frac{\sum_{n=2}^{\infty} P_n}{P_1} \tag{6}$$

In other words, total harmonic distortion is mainly used to compare the output signal of the amplifier with the input signal, and to measure the difference of harmonic frequencies between the two.

The value of THD is expressed in percentage or in dB, and the lower the better. Generally speaking, the minimum value of THD is at 1 KHz, so the THD values of many products are measured at 1 KHz. For hi-fi application, it is usually expected to be less than 1%, which is inaudible to the human ear. Only THD larger than 10% can be perceived [12].

With use of negative feedback, low distortion is relatively easy to achieve in amplifiers [6].

3 Method

To build a complete circuit for the audio power amplifier, three units are needed to be designed: pre-amplifier unit, tonality control unit and power amplifier unit.

The circuit designed in this work is simulated by Multisim Software first, and then is built on the circuit board to do the measurements.

3.1 Pre-amplifier unit design
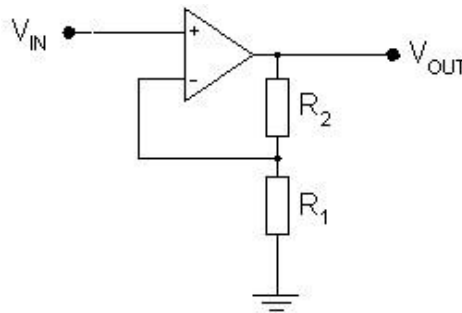
This part is designed as Figure 3.

Figure 3 Pre-amplifier unit

After studying the working principle of the operational amplifier, the actual values of the resistors R_1 and R_2 is determined. $R_1=10k\Omega$ and $R_2=30k\Omega$.

From equation (1), the voltage gain for the pre-amplifier is calculated: $(1+R_2/R_1)=4$.

3.2 Tonality control unit design

A conventional tone control is show in Figure 7, and its characteristics can be seen in Figure 8.
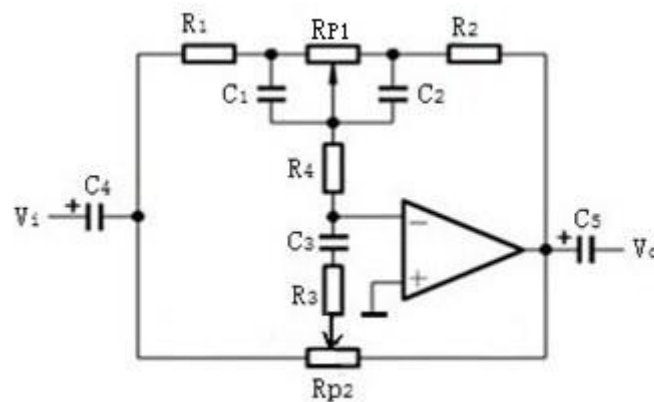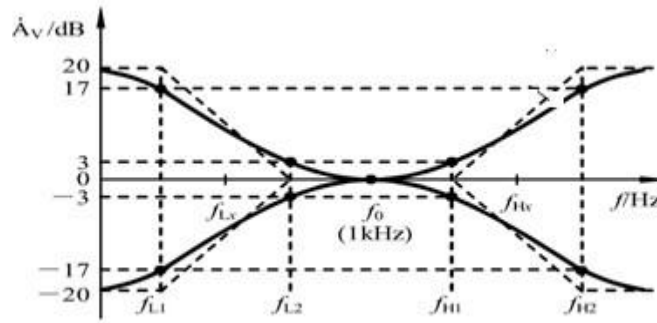

Figure 7 Tonality control circuit [6]

Figure 8 Ideal tonality control curve [13]

Because the tonality is needed to change 12dB up and down in the frequency range of 100Hz to 10 kHz (which means that F_{Lx}=100Hz, F_{Hx}=10 kHz, x=12dB);

To get the value of the alto corner frequency in the bass frequency range and treble frequency range, the equation (7) and (8) are used:

$$f_{L2}=\frac{2xf_{Lx}}{6} \tag{7}$$

$$f_{H1}=\frac{f_{Lx}/2x}{6} \tag{8}$$

So the values calculated are as follows:

f_{L2}= 400Hz;

f_{H1}=2.5 kHz;

f_{L2}=10 f_{L1}, f_{L1}=40Hz;

f_{H2}= 10f_{H1}=25 kHz;

f_0=1 kHz

When in the range of low frequency, C_3 can be seen open.

If f is smaller than f_0 and the sliding arm of the potentiometer is on the left side, this condition is the maximum low-frequency boost. See Figure 9.
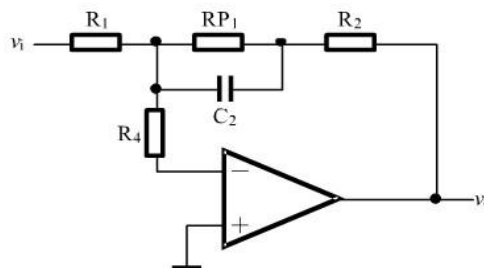

Figure 9 The maximum low-frequency boost circuit

And when the sliding arm of the potentiometer is on the right side, this condition is the maximum low-frequency attenuation. See Figure 10.
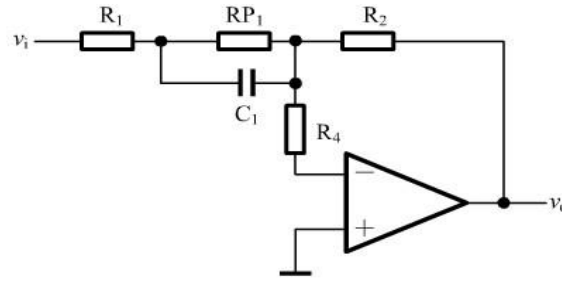
Figure 10 The maximum low-frequency attenuation circuit

In this condition, $A(j\omega) = \dfrac{V_o}{V_i} = -\dfrac{Rp1+R2}{R1} * \dfrac{1+(j\omega)/\omega 2}{1+(j\omega)/\omega 1}$

$f_{L1} = 1/(2\pi RP_1 C_2)$

$f_{L2} = (RP_1+R_2)/(2\pi * RP_1 R_2 C_2)$

For $f_{L2} = 10 f_{L1}$,

So $RP_1 = 9R_2$.

Let $R_1 = R_2 = R_4$; then $R_1 = R_2 = R_4 = (1/9)RP_1$

When in the range of high frequency, C_1 and C_2 can be seemed to be shortcut. Then the circuit can be shown in Figure 11.
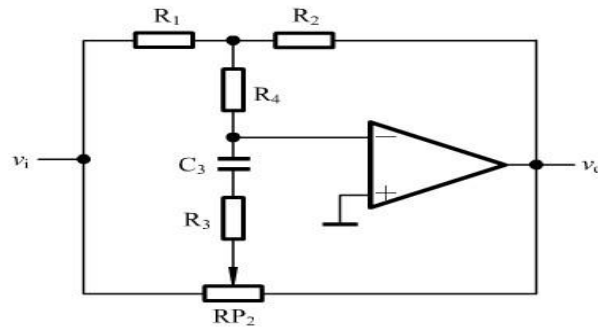

Figure 11 High frequency tone control circuit

In this circuit, R_1, R_2 and R_4 compose a Y-connection. So the circuit can be transferred to Figure 12.
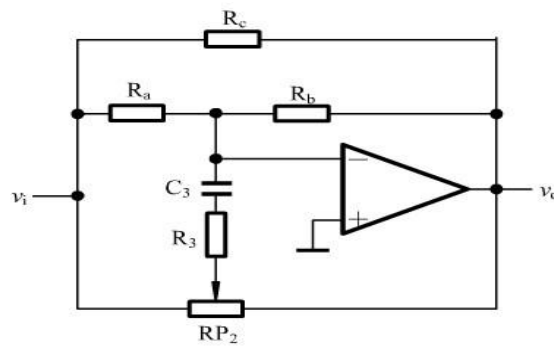

Figure 12 High frequency tone control circuit

$R_a = R_1 + R_4 + (R_1 R_4 / R_2)$

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$R_b = R_4 + R_2 + (R_2 R_4 / R_1)$

$R_c = R_1 + R_2 + (R_1 R_2 / R_4)$

For $R_1 = R_2 = R_4$;

$R_a = R_b = R_c = 3R_1 = 3R_2 = 3R_4$

If the sliding arm of the potentiometer is on the left side, this condition is the maximum high-frequency boost as Figure 13.
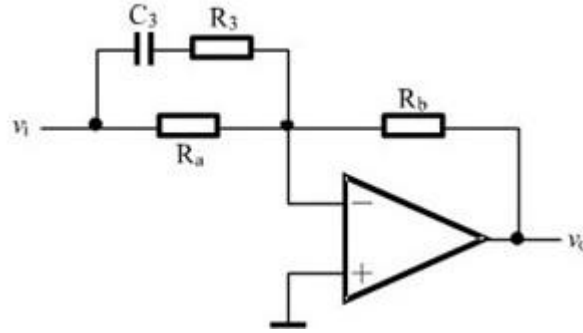

Figure 13 The maximum high-frequency boost circuit

If the sliding arm of the potentiometer is on the right side, this condition is the maximum high-frequency attenuation. See Figure 14.
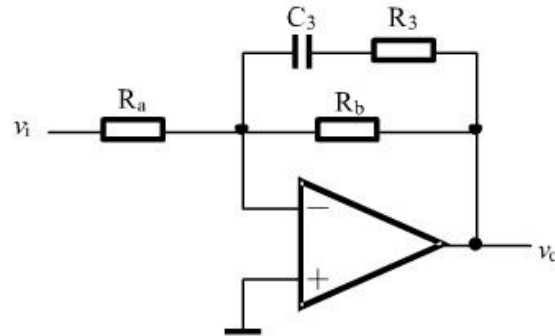

Figure 14 The maximum high-frequency attenuation circuit

In this condition, $A(j\omega) = \dfrac{V_o}{V_i} = -\dfrac{R_b}{R_a} * \dfrac{1+(j\omega)/\omega 3}{1+(j\omega)/\omega 4}$

$f_{H1} = 1/ [2\pi (R_a + R_3) C_3]$

$f_{H2} = 1/ (2\pi R_3 C_3)$

For $f_{H2} = 10 f_{H1}$;

$R_a = 9R_3$

For $R_a = R_b = R_c = 3R_1 = 3R_2 = 3R_4$;

$R_1 = R_2 = R_4 = 3R_3$

Consider about the actual condition,

$RP_1 = RP_2 = 10k\Omega$

$R_1 = R_2 = R_4 = 1.11\ k\Omega \approx 1.2k\Omega$

$R_3 = 370\ \Omega \approx 390\Omega$

$C_3 = 17nF \approx 22nF$

$C_1 = C_2 = 398nF \approx 470nF$

With the analysis above, the total tonality control circuit is built as Figure 15.Here a TL071CP integrated op-amplifier is connected to act as a buffer.
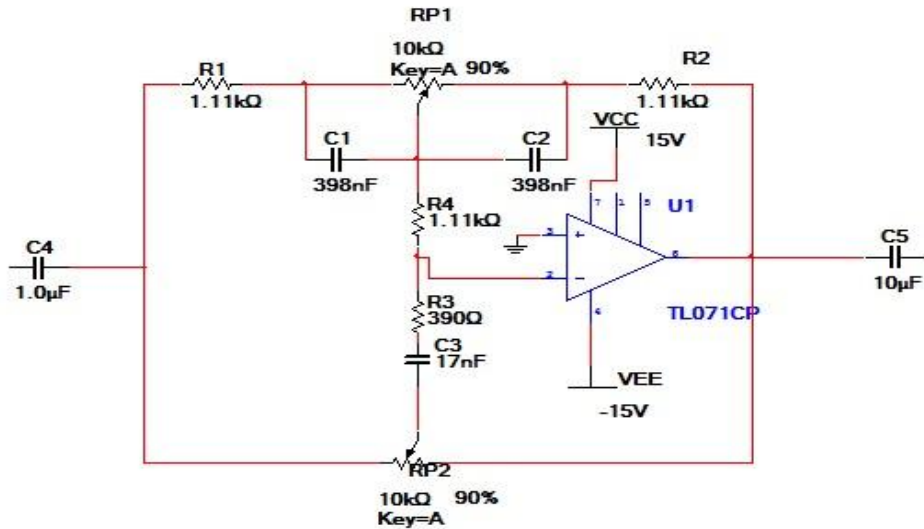
Figure 15 The designed tonality control circuit

3.3 Power amplifier design

LM386n-1 is a power amplifier that can be used in low voltage circuits. The voltage gain of it can change from 20 to 200, and its low distortion feature can make the total audio power amplifier better. In this part design, one of the typical applications on its datasheet is chosen, and its voltage gain is 20, see Appendix A. The circuit is shown in Figure 16.

Figure 16 The designed power amplifier circuit

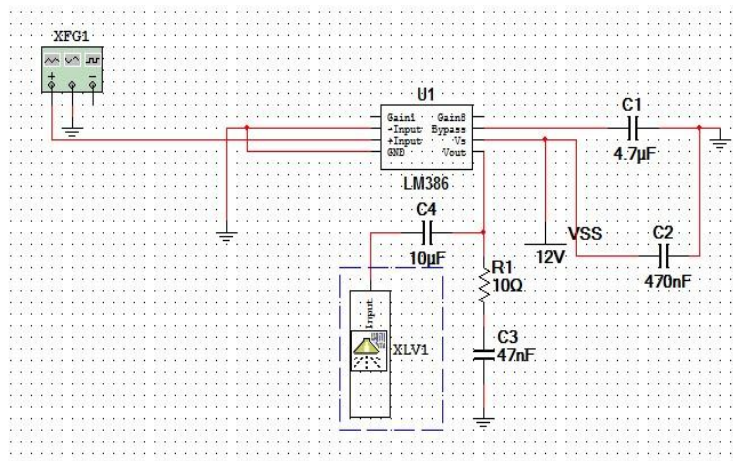## 3.4 The complete audio amplifier with tonality control

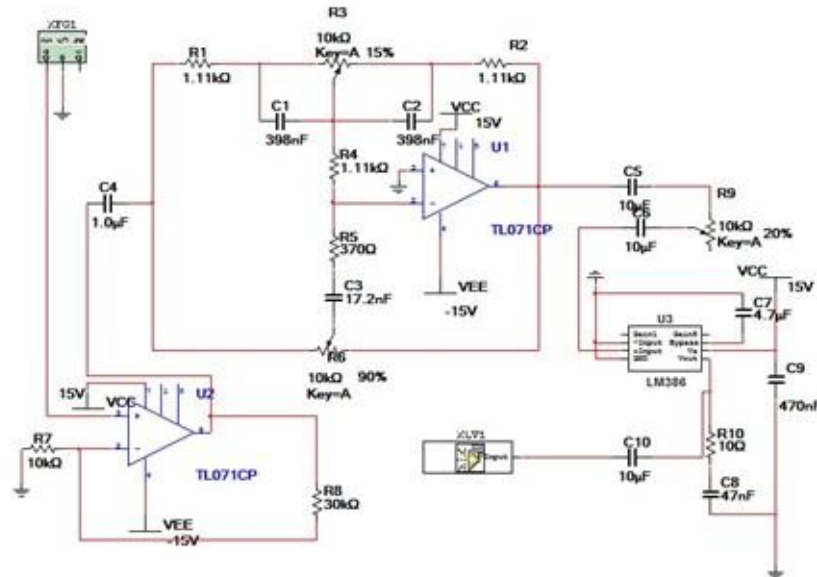Build the three parts together in the end, and the whole circuit is obtained. See Figure 17.

Figure 17 The designed whole circuit

4 Results

This section describes the results from two parts.

One part is obtained through simulation with Multisim. By analyzing the figures of output waveform and frequency response got from the simulation, the designed audio power amplifier performance may be known.

The other part is to build the circuit on the board with the electronic elements needed, and measure the output waveform, gain, power and distortion etc. Also, connect the circuit with a true speaker at the same time, to check if the tonality control can work normally and the sound heard by ear is pure.

4.1 Simulation

Connect the function generator and the oscilloscope to the whole circuit, and set a sine-wave with 50mV$_p$, 1 KHz input. The output waveform can be drawn. See Figure 18 and Figure 19.
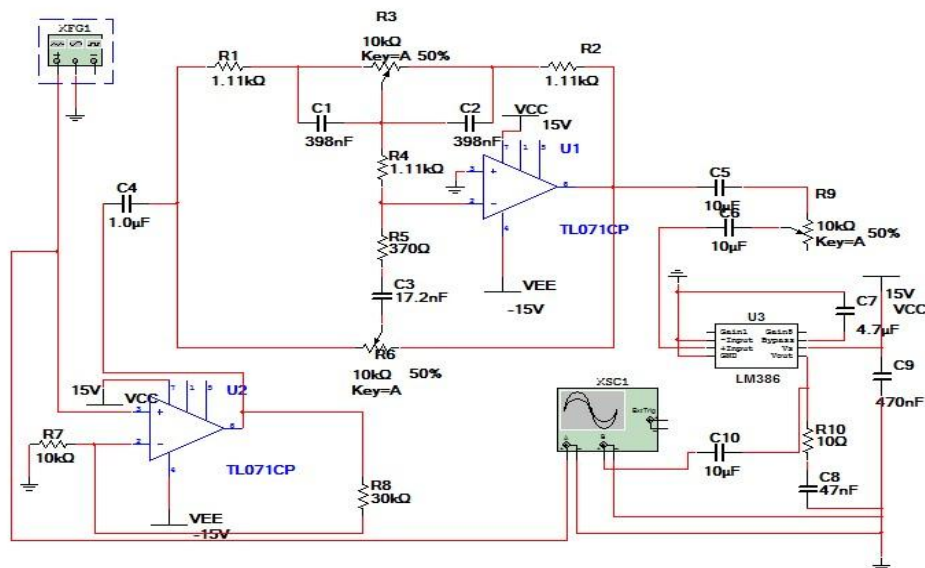
Figure 18 The whole circuit is connected to an oscilloscope.
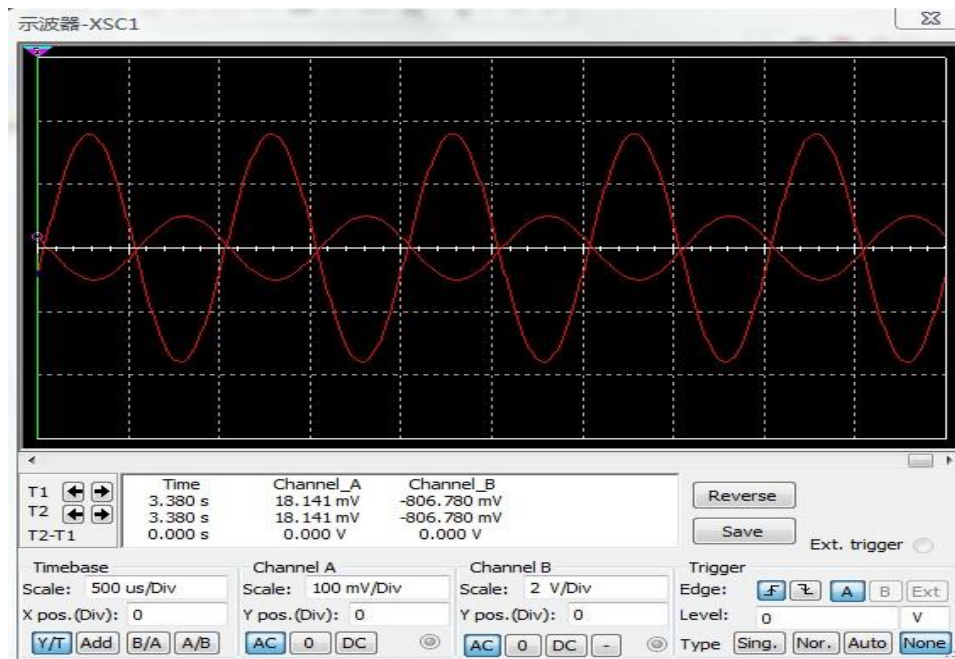
Figure 19 The output waveform

On condition that the arms of potentiometers are set to the position 50%, change the value of R_9, and the volume increases. See Figure 20. The output amplitude changes from 3.247V to 3.921V.
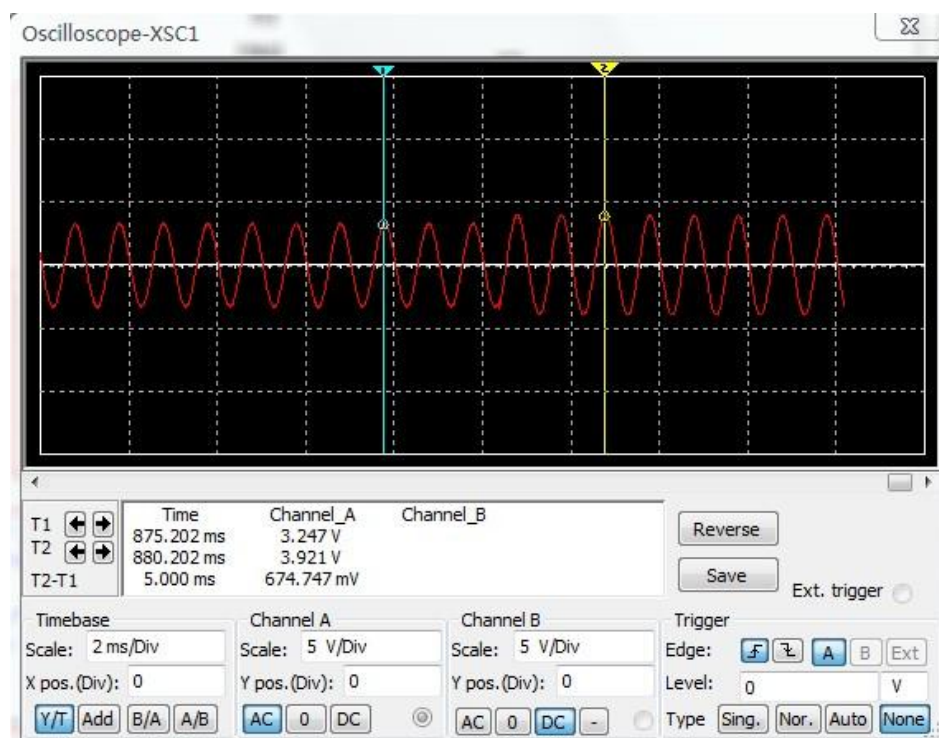
Figure 20 Volume increases with the value of R_9 changing.

R_3 is the bass control. Change the input frequency in the range lower than 1 KHz and tune R_3 at the same time. The distortion happens with frequency lower than 100Hz when R_3 is in the

range 80% to 100%, and THD value measured is 1.649% at the position of 80%, see Figure 21. On the range 0% to 80%, there is no distortion.
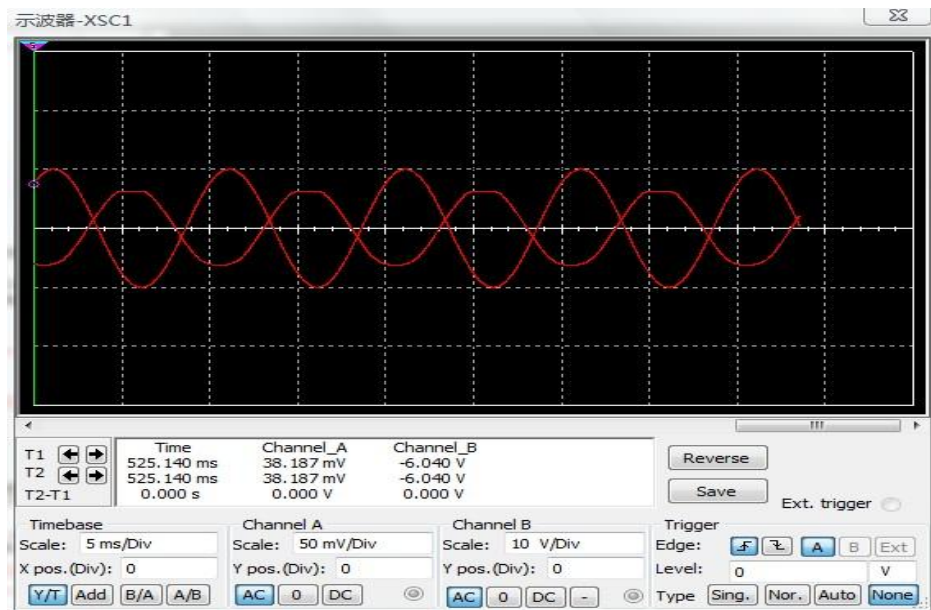
Figure 21 Distortion happens with the bass control

R_6 is the treble control. Change the input frequency in the range higher than 1 KHz and tune R_6 at the same time. The distortion happens with frequency higher than 10 KHz when R_6 is in the range 0% to 20%, and THD value measured is 2.378% at 20% position, see Figure 22. On the range 20% to 100%, there is no distortion.
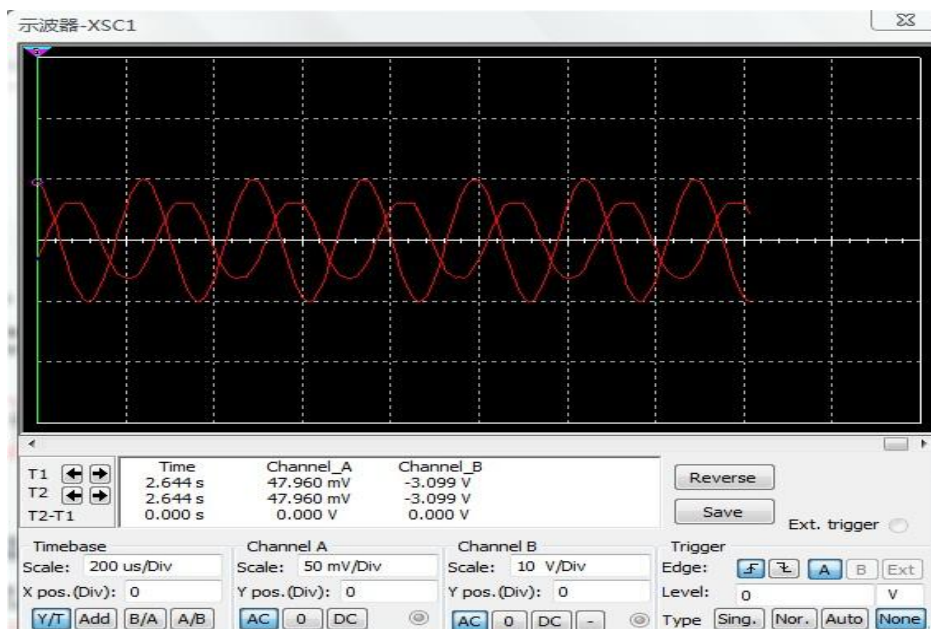
Figure 22 Distortion happens with the treble control

Then, change the oscilloscope to a bode plotter, see Figure 23. The frequency response changes with the bass and treble control, and it is always in the range of $f_L <$20Hz and $f_H >$ 20KHz.
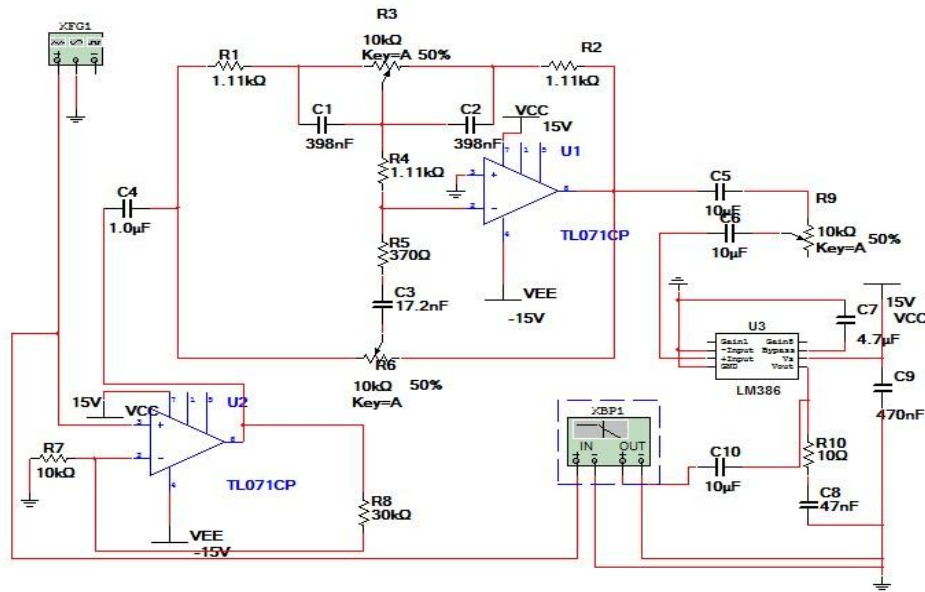
Figure 23 The whole circuit is connected to a bode plotter.

Set R_6 at 50%, and the frequency response changes with different R_3. See from Figure 24, Figure 25 and Figure 26.
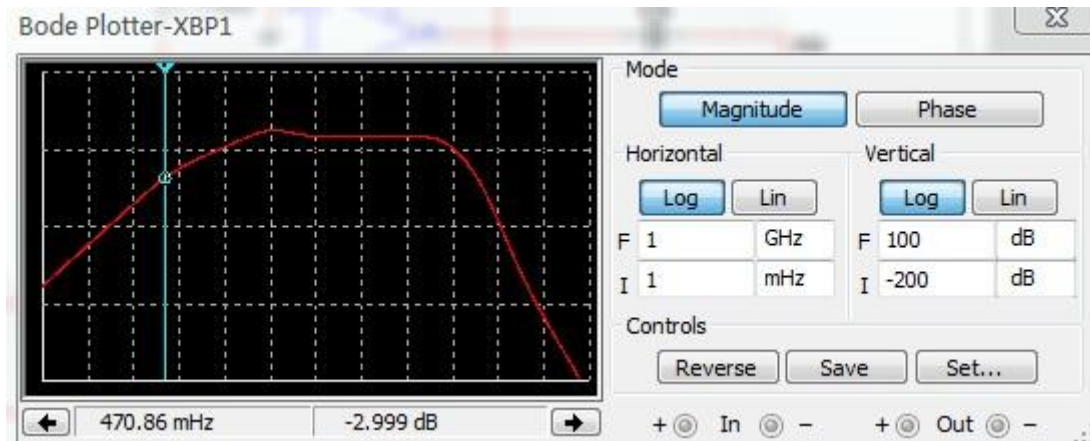
Figure 24 Frequency response with value of f_L when R_3 is at position 100%
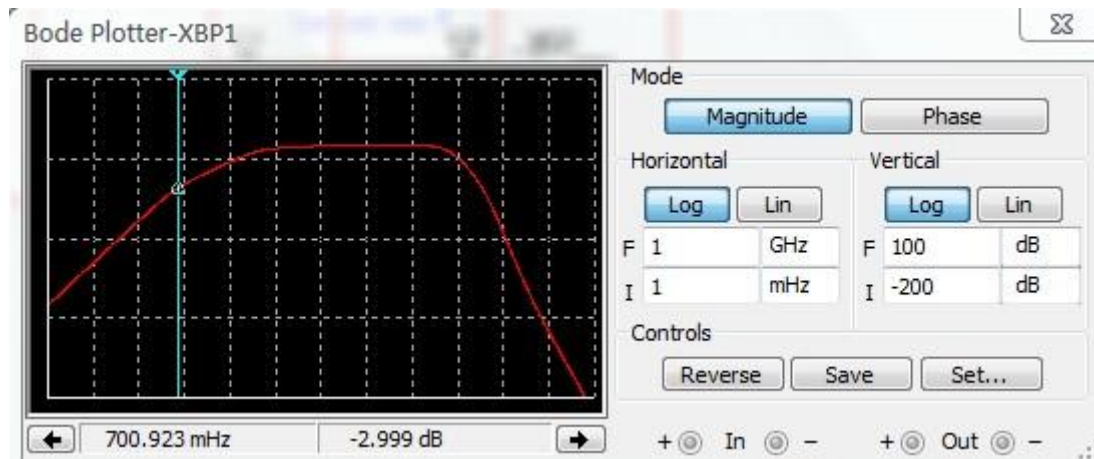
Figure 25 Frequency response with value of f_L when R_3 is at position 50%
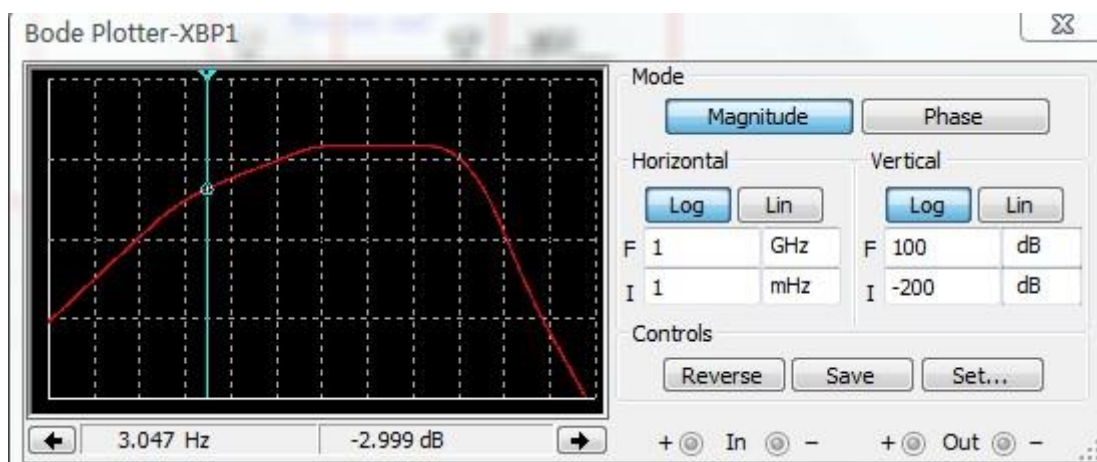
Figure 26 Frequency response with value of f_L when R_3 is at position 0%

Set R_3 at 50%, and the frequency response changes with different R_6. See Figure 27, Figure 28 and Figure 29.
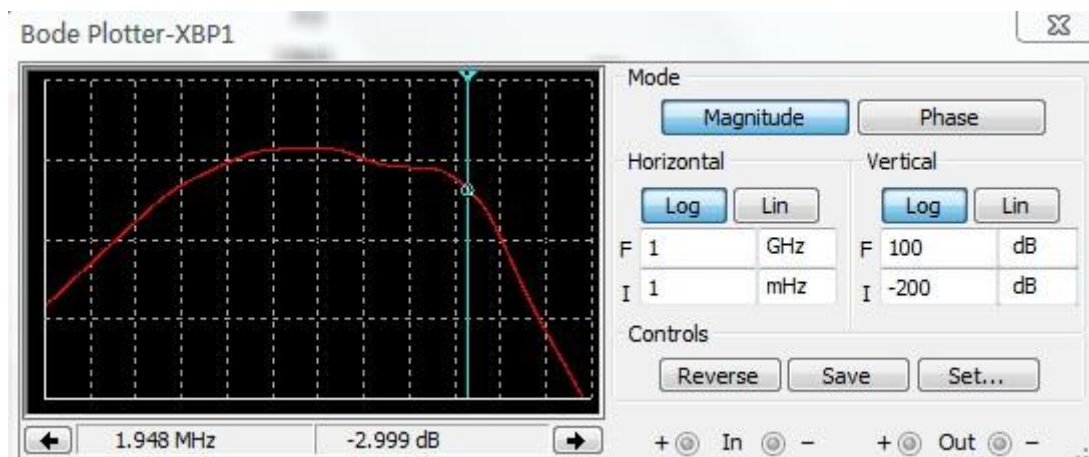
Figure 27 Frequency response with value of f_H when R_6 is at position 100%
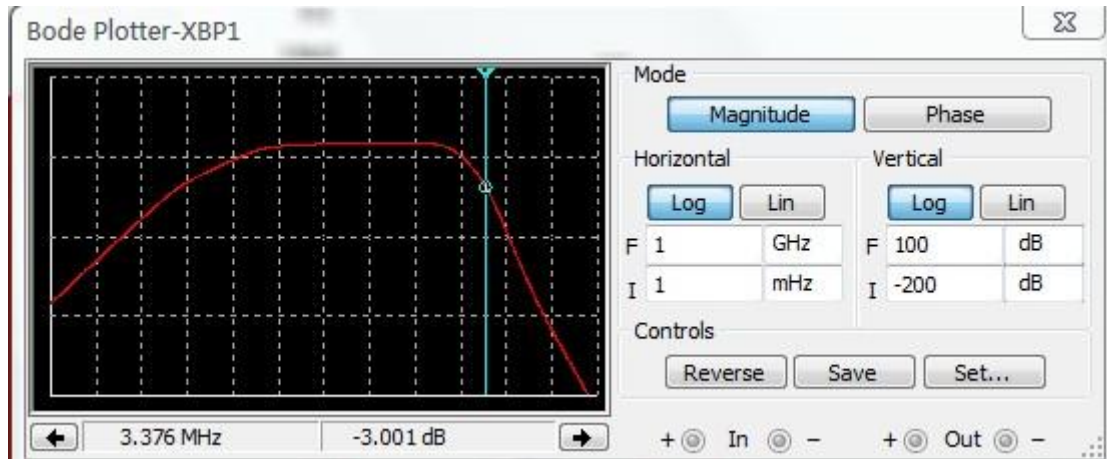
Figure 28 Frequency response with value of f_H when R_6 is at position 50%
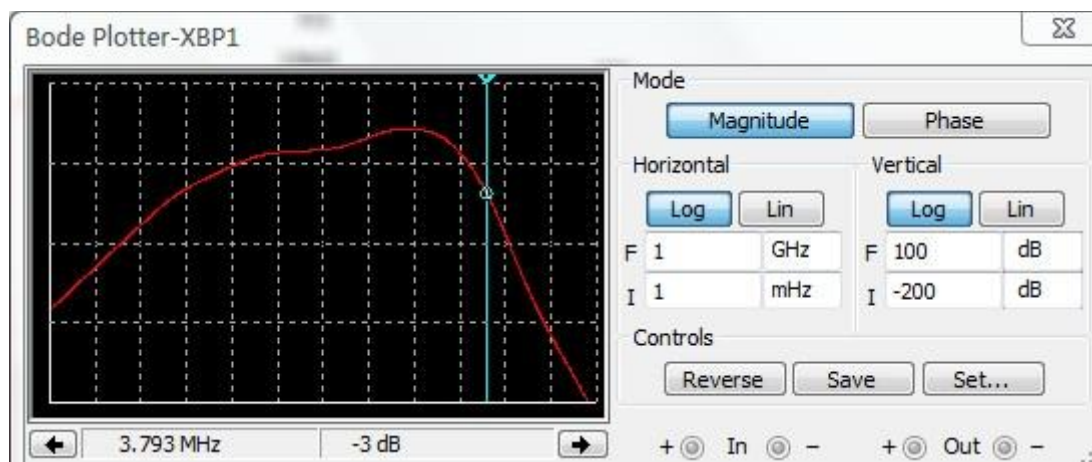
Figure 29 Frequency response with value of f_H when R_6 is at position 0%

Seen from the figures above, f_L decreases with bass boost and increases with bass attenuation; f_H decreases with treble attenuation and increases with treble boost. With the tonality control, the bandwidth of frequency response is changing relatively, which gives the information that the tonality control is designed successfully.

Everything seems OK. Then to change the bode plotter for a speaker, see Figure 30. A clear sound can be heard by ear with the bass control, treble control and volume control.
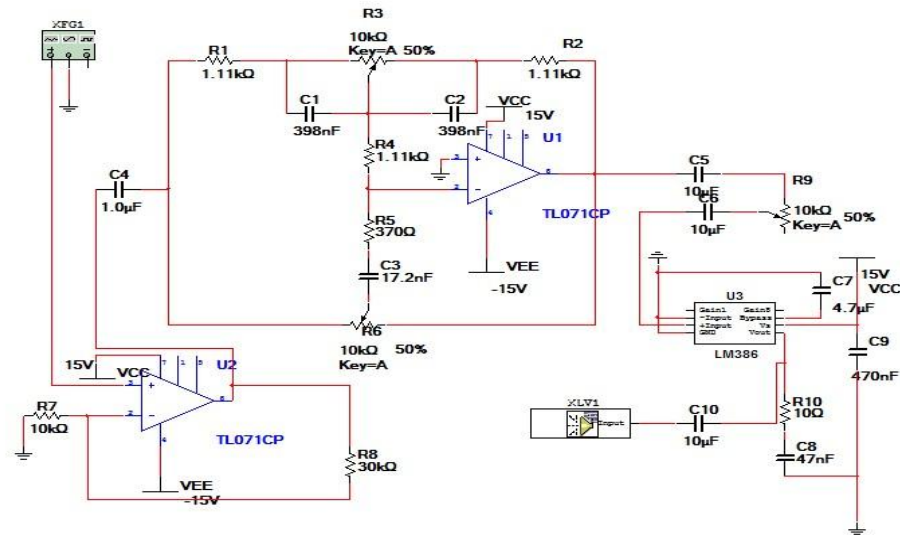
Figure 30 The whole circuit is connected to a speaker.

4.2 Measured results

Build the circuit on the board and connect the oscilloscope to the output. Use the function generator to supply a sine-wave input with $100mV_{pp}$. Besides, use the power supply to supply the TL071CP with $\pm 15V$(see Appendix B) and LM386N-1 with 6V. See Figure 31 and Figure 32.
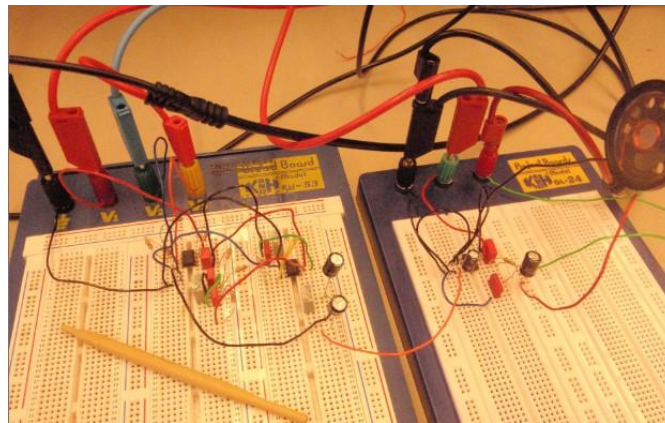
Figure 31 Build the circuit on the board
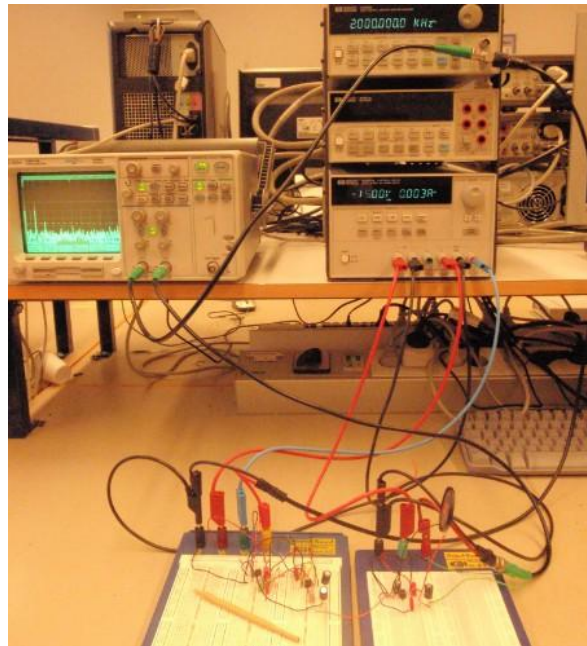
Figure 32 Build the circuit on the board with power supply, function generator and oscilloscope connected

With the input $100mV_{pp}$ (RMS: 35.72mV on the oscilloscope), change the input frequency and tune R_3, R_6 and R_9. Meanwhile, write down the maximum RMS value of output voltages without distortion. See Table 1.

Table 1 The maximum output voltages without distortion of different input frequencies (6V).

Frequency(KHz)	The maximum output voltage without distortion(V)
0.5	0.396
1	0.680
2	1.082
3	1.234
4	1.280
5	1.359
6	1.381
7	1.400
8	1.413
9	1.426
10	1.433
11	1.428

With a 8Ω speaker connected, the output frequency can be calculated by using equation (2).

$P_0 = U_0^2/R_L = 1.430^2/8 = 256mW$

The maximum gain $A_v = U_{out}/U_{in} = 1.43V/35.72mV = 40$

Meanwhile, when the frequency is in the range of f＜300Hz and f＞15KHz, ears almost cannot hear the sound.

Then try to increase the supply voltage of LM386N-1 to 12V, the output voltages increase. See Table 2.

Table 2 The maximum output voltages without distortion of different input frequencies (12V).

Frequency(KHz)	The maximum output voltage without distortion(V)
0.5	0.850
1	1.677
2	2.743
3	2.868
4	3.013
5	3.076
6	3.150
7	3.200
8	3.224
9	3.226
10	3.234
11	3.228

Table 1 and Table 2 lead to the conclusion that the output power is relative to the supplied voltage.

Next, turn off the transient waveform and push "Math" button to make FFT window appear. Push the "cursors" button to put x_1 at the operating frequency 1 KHz, and put x_2 at the second harmonic 2 KHz. Also, move Y_1 to the peak of the operating frequency and move Y_2 to the peak of the second harmonic. See Figure 33. Record the absolute value of △Y in dB and do the measurement for 5 harmonics. See Table 3.
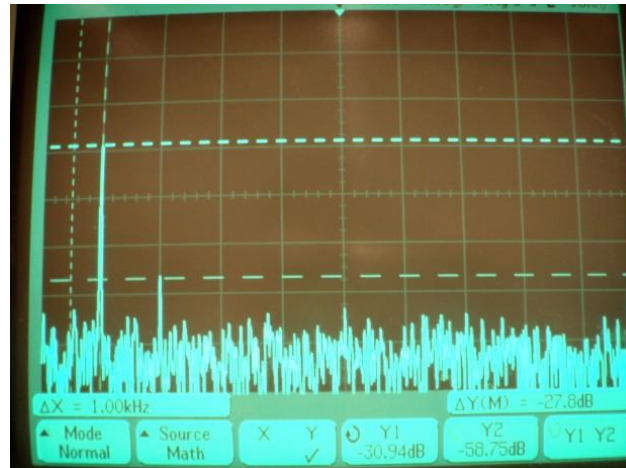
Figure 33 Using cursors on FFT to measure THD

Table 3 The absolute value of ΔY in dB of nth harmonic

nth harmonic	the absolute value of $\triangle$Y in dB
2	27.1
3	36.5
4	40.3
5	41.2

THD=$\sqrt{HD2^2 + HD3^2 + HD4^2 + HD5^2 \ldots}$

HDn=$10^{-\triangle Yn/20}$, where n=2, 3, 4, $\cdots$

HD2=0.044

HD3=0.014

HD4=0.009

HD5=0.008

THD=0.047=4.7%

The total harmonic distortion is calculated as 4.7%.

According to equation (3), the peak value of fundamental frequency is 3.85 times of the peak value of noise, see Figure 4.16.So the value of SNR is 3.85.

The value of total harmonic distortion is larger than the simulated result. In the process of measurement, the THD value and SNR value are very sensitive to long cable on the board, and all the connections. So in some ways, the measured results have more distortion and noise than that of simulation.

During the measurement process, different tone and volume can be heard by ear clearly with the tonality control and volume control. But it sounds impurely with a large volume.

5 Discussion

5.1 Methods discussion

The method in this thesis work has the following advantages.

In the pre-amplifier unit design, the operational amplifier is easy to be understood and build.

For the tonality control unit, a filter is designed. No matter in the range of low or high frequency, the audio attenuation and boost can be achieved by changing the value of the potentiometer, which can be dealt with easily.

In the power amplifier unit, LM386N-1 has the advantages of low distortion, battery operation and wide range of voltage gain, which makes it a good choice.

Totally speaking, the method we choose seems good, offering a satisfactory result.

5.2 Results analysis

The results part consists of two sections. One is the simulation results, and the other one is the measured results.

For the simulation part, a good output wave is obtained. With the change of volume control R_9, the satisfying change of output wave can be seen from Fig 20. Also, with the bass control R_3 and treble control R_6, the frequency response changes relatively, showing the good characteristics of the tonality control unit. In this part, the distortion can be seen with the tonality control, but this does not matter for the overall good performance. When a speaker is connected to the whole circuit, the characteristics of bass boost, bass attenuation, treble boost and treble attenuation can be heard by ear clearly. A satisfying simulation offers the encouragement to build the circuit on the board.

For the measured results part, a good output waveform is achieved with oscilloscope, and the change of the waveform can be seen with the bass control R_3, treble control R_6 and volume control R_9. Meanwhile, the characteristics of bass boost, bass attenuation, treble boost and treble attenuation can be heard by ear clearly. But one weakness is that it sounds impurely with a large volume, and the distortion can be seen on oscilloscope. By measuring the maximum output voltage without distortion, the output power is calculated as 256mW with 6V supply voltage, and the maximum gain is 40. In addition, the THD is calculated as 4.7% and SNR is 3.85 with the FFT measurement, and it is better if a lower THD and a higher SNR

are achieved. Anyway, the results are satisfactory, and the designed audio power amplifier can be used in the portable devices.

6 Conclusions

The audio power amplifier is designed with three parts: pre-amplifier unit, tonality control unit and power amplifier unit. For the pre-amplifier unit, Tl071CP integrated operational amplifier is used to achieve the gain of 4; for the tonality control unit, a filter is designed to achieve different tone; for the power amplifier unit, LM386N-1 integrated low voltage power amplifier is applied.

The thesis work is finished satisfactorily with simulation and measured results. With tonality control, different sound can be heard by ear clearly. In addition, the measured results show the output power is 256mW, THD is 4.7%, SNR is 3.85 and gain is 40 with 6V supply voltage. One weakness is that it sounds impurely with a large volume, and the distortion can be seen on oscilloscope. Anyway, it is better if this shortage can be improved in the future. Judging from all kinds of results, this designed audio power amplifier can meet the aim of the thesis topic.

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Appendix A

◉ National Semiconductor

LM386
Low Voltage Audio Power Amplifier

General Description

The LM386 is a power amplifier designed for use in low voltage consumer applications. The gain is internally set to 20 to keep external part count low, but the addition of an external resistor and capacitor between pins 1 and 8 will increase the gain to any value up to 200.

The inputs are ground referenced while the output is automatically biased to one half the supply voltage. The quiescent power drain is only 24 milliwatts when operating from a 6 volt supply, making the LM386 ideal for battery operation.

Features

■ Battery operation
■ Minimum external parts
■ Wide supply voltage range: 4V–12V or 5V–18V
■ Low quiescent current drain: 4 mA
■ Voltage gains from 20 to 200
■ Ground referenced input
■ Self-centering output quiescent voltage
■ Low distortion
■ Available in 8 pin MSOP package

Applications

■ AM-FM radio amplifiers
■ Portable tape player amplifiers
■ Intercoms
■ TV sound systems
■ Line drivers
■ Ultrasonic drivers
■ Small servo drivers
■ Power converters

Equivalent Schematic and Connection Diagrams
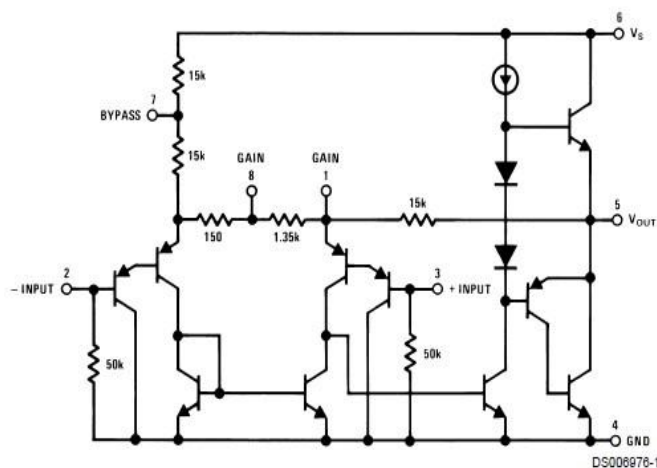
Small Outline,
Molded Mini Small Outline,
and Dual-In-Line Packages

Top View
Order Number LM386M-1,
LM386MM-1, LM386N-1,
LM386N-3 or LM386N-4
See NS Package Number
M08A, MUA08A or N08E

Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

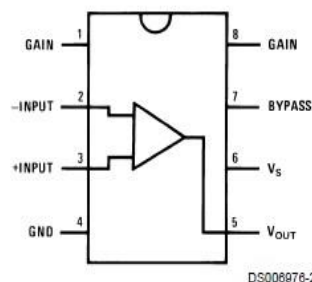|	
Supply Voltage	
(LM386N-1, -3, LM386M-1)	15V
Supply Voltage (LM386N-4)	22V
Package Dissipation (Note 3)	
(LM386N)	1.25W
(LM386M)	0.73W
(LM386MM-1)	0.595W
Input Voltage	±0.4V
Storage Temperature	−65°C to +150°C
Operating Temperature	0°C to +70°C
Junction Temperature	+150°C
Soldering Information	

Dual-In-Line Package	
Soldering (10 sec)	+260°C
Small Outline Package	
(SOIC and MSOP)	
Vapor Phase (60 sec)	+215°C
Infrared (15 sec)	+220°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

Thermal Resistance	
θ_{JC} (DIP)	37°C/W
θ_{JA} (DIP)	107°C/W
θ_{JC} (SO Package)	35°C/W
θ_{JA} (SO Package)	172°C/W
θ_{JA} (MSOP)	210°C/W
θ_{JC} (MSOP)	56°C/W

Electrical Characteristics (Notes 1, 2)

T_A = 25°C

| Parameter	Conditions	Min	Typ	Max	Units
Operating Supply Voltage (V_S)					
LM386N-1, -3, LM386M-1, LM386MM-1		4		12	V
LM386N-4		5		18	V
Quiescent Current (I_Q)	V_S = 6V, V_{IN} = 0		4	8	mA
Output Power (P_{OUT})					
LM386N-1, LM386M-1, LM386MM-1	V_S = 6V, R_L = 8Ω, THD = 10%	250	325		mW
LM386N-3	V_S = 9V, R_L = 8Ω, THD = 10%	500	700		mW
LM386N-4	V_S = 16V, R_L = 32Ω, THD = 10%	700	1000		mW
Voltage Gain (A_V)	V_S = 6V, f = 1 kHz		26		dB
	10 µF from Pin 1 to 8		46		dB
Bandwidth (BW)	V_S = 6V, Pins 1 and 8 Open		300		kHz
Total Harmonic Distortion (THD)	V_S = 6V, R_L = 8Ω, P_{OUT} = 125 mW		0.2		%
	f = 1 kHz, Pins 1 and 8 Open				
Power Supply Rejection Ratio (PSRR)	V_S = 6V, f = 1 kHz, C_{BYPASS} = 10 µF		50		dB
	Pins 1 and 8 Open, Referred to Output				
Input Resistance (R_{IN})			50		kΩ
Input Bias Current (I_{BIAS})	V_S = 6V, Pins 2 and 3 Open		250		nA

Note 1: All voltages are measured with respect to the ground pin, unless otherwise specified.

Note 2: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. Electrical Characteristics state DC and AC electrical specifications under particular test conditions which guarantee specific performance limits. This assumes that the device is within the Operating Ratings. Specifications are not guaranteed for parameters where no limit is given, however, the typical value is a good indication of device performance.

Note 3: For operation in ambient temperatures above 25°C, the device must be derated based on a 150°C maximum junction temperature and 1) a thermal resistance of 107°C/W junction to ambient for the dual-in-line package and 2) a thermal resistance of 170°C/W for the small outline package.

Typical Applications

Amplifier with Gain = 20
Minimum Parts

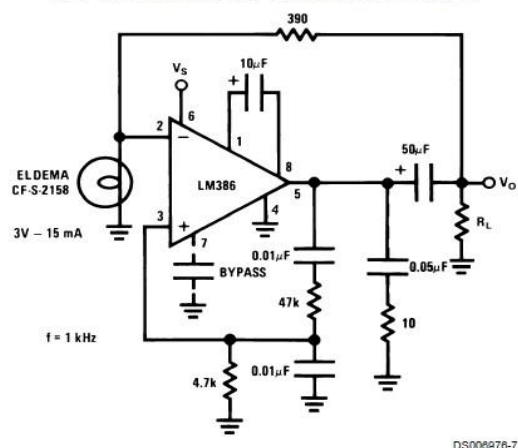DS006976-3
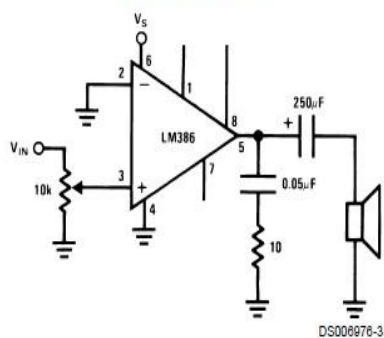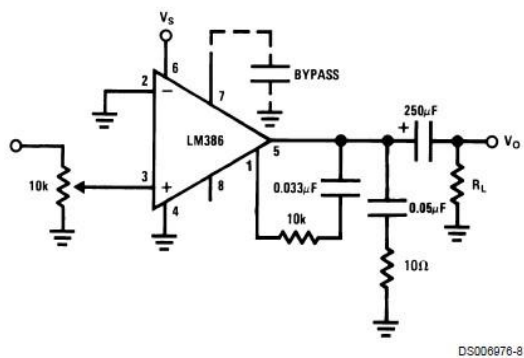
Amplifier with Gain = 200

DS006976-4
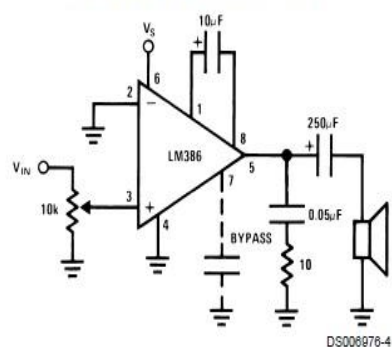
Amplifier with Gain = 50

DS006976-6
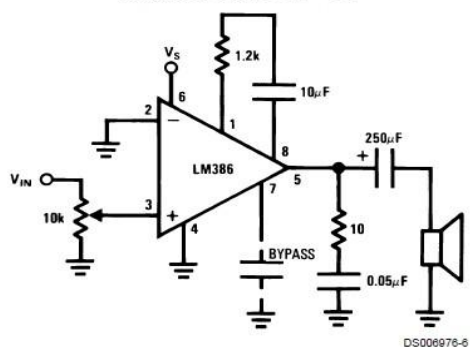
Low Distortion Power Wienbridge Oscillator

DS006976-7

Amplifier with Bass Boost

DS006976-8
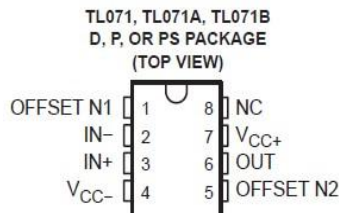
Square Wave Oscillator

DS006976-9
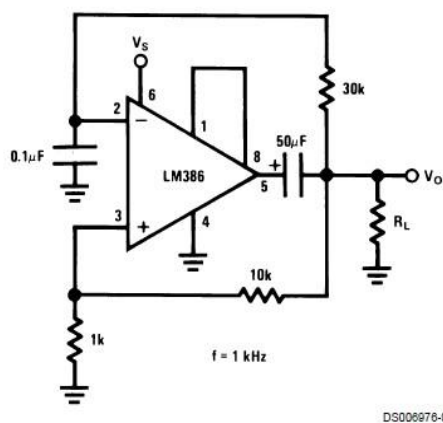
Appendix B

TL071, TL071A, TL071B, TL072
TL072A, TL072B, TL074, TL074A, TL074B
LOW-NOISE JFET-INPUT OPERATIONAL AMPLIFIERS
SLOS080J – SEPTEMBER 1978 – REVISED MARCH 2005

- Low Power Consumption
- Wide Common-Mode and Differential Voltage Ranges
- Low Input Bias and Offset Currents
- Output Short-Circuit Protection
- Low Total Harmonic Distortion . . . 0.003% Typ

- Low Noise
  V_n = 18 nV/$\sqrt{Hz}$ Typ at f = 1 kHz
- High Input Impedance . . . JFET Input Stage
- Internal Frequency Compensation
- Latch-Up-Free Operation
- High Slew Rate . . . 13 V/μs Typ
- Common-Mode Input Voltage Range Includes V_{CC+}

TL071, TL071A, TL071B
D, P, OR PS PACKAGE
(TOP VIEW)

```
OFFSET N1 [ 1    8 ] NC
      IN− [ 2    7 ] V_CC+
      IN+ [ 3    6 ] OUT
     V_CC− [ 4    5 ] OFFSET N2
```

electrical characteristics, $V_{CC\pm}$ = ±15 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†	T_A‡	TL071M TL072M			TL074M			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO}	Input offset voltage	V_O = 0, R_S = 50 Ω	25°C		3	6		3	9	mV
			Full range			9			15	
αV_{IO}	Temperature coefficient of input offset voltage	V_O = 0, R_S = 50 Ω	Full range		18			18		μV/°C
I_{IO}	Input offset current	V_O = 0	25°C		5	100		5	100	pA
			Full range			20			20	nA
I_{IB}	Input bias current‡	V_O = 0	25°C		65	200		65	200	pA
						50			50	nA
V_{ICR}	Common-mode input voltage range		25°C	±11	−12 to 15		±11	−12 to 15		V
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ	25°C	±12	±13.5		±12	±13.5		V
		R_L ≥ 10 kΩ	Full range	±12			±12			
		R_L ≥ 2 kΩ		±10			±10			
A_{VD}	Large-signal differential voltage amplification	V_O = ±10 V, R_L ≥ 2 kΩ	25°C	35	200		35	200		V/mV
				15			15			
B_1	Unity-gain bandwidth	T_A = 25°C			3			3		MHz
r_i	Input resistance	T_A = 25°C			10^{12}			10^{12}		Ω
CMRR	Common-mode rejection ratio	V_{IC} = V_{ICR}min, V_O = 0, R_S = 50 Ω	25°C	80	86		80	86		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	V_{CC} = ±9 V to ±15 V, V_O = 0, R_S = 50 Ω	25°C	80	86		80	86		dB
I_{CC}	Supply current (each amplifier)	V_O = 0, No load	25°C		1.4	2.5		1.4	2.5	mA
V_{O1}/V_{O2}	Crosstalk attenuation	A_{VD} = 100	25°C		120			120		dB

† Input bias currents of an FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive, as shown in Figure 4. Pulse techniques must be used that will maintain the junction temperature as close to the ambient temperature as possible.
‡ All characteristics are measured under open-loop conditions with zero common-mode voltage, unless otherwise specified. Full range is T_A = −55°C to 125°C.

TL071, TL071A, TL071B, TL072
TL072A, TL072B, TL074, TL074A, TL074B
LOW-NOISE JFET-INPUT OPERATIONAL AMPLIFIERS
SLOS080J – SEPTEMBER 1978 – REVISED MARCH 2005

operating characteristics, $V_{CC\pm} = \pm15$ V, $T_A = 25°C$

PARAMETER		TEST CONDITIONS		TL07xM			ALL OTHERS			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
SR	Slew rate at unity gain	$V_I = 10$ V, $C_L = 100$ pF,	$R_L = 2$ kΩ, See Figure 1	5	13		8	13		V/µs
t_r	Rise-time overshoot factor	$V_I = 20$ mV, $C_L = 100$ pF,	$R_L = 2$ kΩ, See Figure 1		0.1			0.1		µs
					20%			20%		
V_n	Equivalent input noise voltage	$R_S = 20$ Ω	$f = 1$ kHz		18			18		nV/$\sqrt{Hz}$
			$f = 10$ Hz to 10 kHz		4			4		µV
I_n	Equivalent input noise current	$R_S = 20$ Ω,	$f = 1$ kHz		0.01			0.01		pA/$\sqrt{Hz}$
THD	Total harmonic distortion	$V_I$rms = 6 V, $R_L \geq 2$ kΩ, $f = 1$ kHz	$A_{VD} = 1$, $R_S \leq 1$ kΩ,		0.003 %			0.003%		