

DESIGN AND DEVELOPMENT OF A PUBLIC ADDRESS AUDIO AMPLIFIER

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ABSTRACT

This research work is a design and development of a public address audio amplifier capable of driving 30watts of power into an 8-ohm speaker. The design is broken down into four units which are power supply unit, signal processor unit, voltage amplifier unit and power amplifier unit. The public address audio amplifier was designed, developed and tested and the results show that the amplifier maintains low distortion and noise. In addition, the amplifier exhibits strong linear characteristics. The input and output power was 42watts and 30.25watts while the efficiency was 78.5%, which shows that the developed amplifier worked satisfactorily.

Keywords: *active devices, amplification, linear, non linear, distortion.*

1. INTRODUCTION

The first transistor was invented in 1947, since then the pace of electronic technology has gone from the use of bulky tubes to an extensive use of micro-chip solid-state semiconductors and from miniaturization to micro-miniaturization with yet seeming limitless possibilities unexplored. All these development have resulted in an evasive electronic design technique with a cardinal priority to maximize speed, efficiency and power output at the expense of minimized space, size and cost.[1]

Electronic devices have the singular ability to control the current flowing through them by means of another current flowing through or voltage applied across their terminals; hence they are also called active devices. Whether the device in question is voltage-controlled or current-controlled, the amount of power required for the controlling signal is typically far less than the amount of power available in the controlled current. Because of this disparity between the controlling and controlled powers, active devices may be employed to govern a large amount of power. This behavior is known as amplification.[2]

The benefits of electronic amplification cannot be overemphasized as it enables the designer to detect, manipulate and control small signals which in most cases constitute the signal of interest. For example, a dynamic microphone that is picking up a loud voice or instrument may produce an electrical signal somewhere in the neighborhood of 0.1 volt. This will require some pre-amplification to a line level signal (usually about 1 volt) before further processing can be done.

An electronic amplifier is a device of increasing the power of a signal. It does by taking power from a power supply and controlling the output to match input signal shape but with larger amplitude. An idealized amplifier can be said to be “a piece wire with gain“, as the output is an exact replica of the input, but larger. Then the amplifying element he said to be linear. [3]

Real amplifiers (e.g. transistor) are not linear and the output will only approximate the input. Non-linearity is the origin of distortion within an amplifier. Any real amplifier is an imperfect realization of an ideal amplifier. One important limitation of a real amplifier is that the out output it can generate is ultimately limited by the power available from the power supply. An amplifier can saturate and clip the output if the input signal becomes too large for the amplifier to reproduce. [4]

An amplifier can be divided into three categories: small signal amplifiers, low frequency power amplifiers and radio frequency (RF) power amplifiers.

2. DESIGN CONSIDERATION

The Design of the public address audio amplifier is divided into the following stages:

- (i) Power Supply unit
- (ii) Signal Processor unit
- (iii) Voltage amplifier unit
- (iv) Power amplifier unit

2.1 Power supply unit

The ac components of the power supply Unit (PSU) are Transformers, Wire connectors, Fuse, Shock hazard insulators. The dc components include, Rectifier, Filter capacitors.

The PSU components are connected as shown in Figure 1. A commercial centre-tapped transformer rated at 30volts was used to supply power. With an input of about 210V the transformer secondary windings outputs about ±18V ac. The ac current is limited to a maximum of 3A by means of a slow blow fuse. A dc output is obtained from the sinusoidal input using a process of full wave rectification.

2.1.1 Ripple Voltage of Capacitor Filter

The filtered output of a capacitor filtered PSU generates a dc ripple voltage (V ripple) that is inversely proportional to the filter capacitor value as may be deduced from the mathematical representation in equation 1.[5]

$$V_r(\text{rms}) = V_{\text{ripple}}/2\sqrt{3} = I_{\text{dc}} \cdot V_{\text{dc}}/4 \cdot \sqrt{3fCV_m} \dots \dots \dots (1)$$

Where $V_r(\text{rms})$ is the rms value of ac component of signal

Hence the filter capacitor is chosen large enough to provide acceptably low ripple voltage,with voltage rating sufficient to handle the worst-case combination of no load and high line voltage (I.e. 10% worst-case line – voltage variation).

The preamplifier is implemented using a the C1815bipolar junction transistor in a voltage divider configuration with a degenerate emitter according to the Ebers-Moll Model [6] to obtain a combination of bias stability, linearity and large voltage gain.

Taken a preamplifier with a voltage gain of 50, quiescent collector current of 1mA and a V_{cc} of +22V, for signals from 20Hz to 20kHz. R_c is chosen to set V_c at $0.5V_{cc}$ for the largest possible symmetrical swing without clipping. with V_c at 22V and V_c at 11V, R_c is determined from

$$V_c = V_{cc} - I_c R_c \dots \dots \dots (2)$$

$$R_c = (V_{cc} - V_c) / I_c = (22 - 11) / 0.001 \Omega = 11000 \Omega = 11K$$

R_e is selected to set a voltage gain of 50 therefore,

$$A_v = -R_c / R_e \dots \dots \dots (3)$$

$$50 = 11000 / R_e$$

$$R_e = 220$$

$$R_e = R_E / (1 + \beta) \dots \dots \dots (4)$$

Where r_e is the transistor base-emitter resistance

R_{E1} is the bypass emitter resistor 1

$$\text{And } r_e = 25/I_{c,mA} = 25 \dots\dots\dots(5)$$

Thus $R_{E1} = 220 - 25 = 195\Omega$ but nearest preferred value is 220Ω

The problem with a Class A transistor amplifier is that emitter voltage varies significantly as the base emitter drop varies with temperature since the base I held at constant voltage by R1 and R2. To solve this, a bypassed emitter R_E is added to ensure temperature stability. If the value is too small the emitter voltage will be much smaller than the base emitter drop leading to the temperature instability (usually with a value about $0.1R_c$ i.e $1.1 k \Omega$ or $1.2k \Omega$).

The emitter bypass capacitor was chosen so its impedance was small compared with R_e at the lowest signal frequency of interest (650Hz for human voice)ie,

$$X_C = 1/2\pi fC < R_e \dots\dots\dots(6)$$

let C be $10\mu F$

$$X_C = 1/(2\pi \times 650 \times 10^{-6}) = 25 \Omega \text{ and this is far lesser than } 220\Omega$$

R1 and R2 is made stiff enough to set V_b on the criterion that $R1//R2$ is much less than the dc impedance looking into the base. A ratio 10:1 is ideal.

$$R2 \text{ is made to be equal to } 1/10^{th} h_{fe} R_e \dots\dots\dots(7)$$

$$\text{therefore } R2 = 1/10 \times 100 \times 220 = 2.2k$$

$$V_B = V_{cc} R2 / (R1 + R2) \dots\dots\dots(8)$$

$$V_B = V_{BE} + V_E \dots\dots\dots(9)$$

$$V_B = 0.7 + 2.2 = 2.9V$$

Therefore substituting the value of V_B , R2 and V_{CC} into equation 8

$$2.9V = 22(2.2K) / (R1 + 2.2K)$$

Solving for R1 we get $14.5K\Omega$

The nearest preferred value for R1 is $15K$.

Thus the Parallel combination of R1 and R2 i.e $(15K//2.2K)$ gives $1.92K$ which is $\ll h_{fe} R_e (22K)$ thereby fulfilling the criterion.

C1 is chosen so that all frequencies of interest are passed by the high pass filter it forms in combination with the parallel resistance of the base biasing resistors (the impedance looking into the base itself will usually be much larger because of the way the base resistors are chosen and it can be ignored); that is,

$$C1 \geq 1/2\pi f (R1//R2) \dots\dots\dots(10)$$

$$C1 \geq 1/(2\pi \times 650 \times 15K//2.2K)$$

$$C1 \geq 1/(2\pi \times 650 \times 1.92K)$$

$$C1 \geq 12.7 \approx 10 \mu F$$

The input impedance is therefore the Thevenin equivalent resistance R_{TH} of the voltage divider in parallel with the dc impedance looking into the base, which satisfies the criterion of impedance matching

$$R_{TH} = R/R2 \dots\dots\dots(11)$$

$$R_{TH} = 15K//2.2K = 1.92K$$

$$\text{the dc impedance looking into the base is } h_{fe} \times R_e \dots\dots\dots(12)$$

$$= 100 \times 220\Omega = 22K$$

$$\text{Then } Z_{IN} = 1.92K//22K = 1.766K$$

The output impedance is the collector resistance in parallel with R_e

$$Z_{OUT} = 11K//220 = 215.7\Omega$$

2.2 The Signal Processor unit

The signal processor comprises a simple Baxandall volume control/mixer realized with a passive filter into a wide bandwidth op-amp. It is implemented as shown in the circuit of figure 1 with volume control for input, as well as bass boost and treble gain control. The lower 3dB frequency is set at about 33.86Hz by C_1 ($1 \mu F$) with an upper roll off at about 20.4kHz. This is meant to ensure that at higher frequencies unity gain is achieved.

2.3 The Voltage Amplifier Unit

The voltage amplification stage is designed using the JRC4558 opamp with excellent audio qualities, high slew rate $>5\text{uv/s}$, wide bandwidth, and very linear output. Negative feedback is used to set the closed loop gain of the amplifier at 20dB. The input resistor R_2 is made high enough to limit the effects of input bias currents and offset voltage.

$$A_v = 1 + R_f/R_i \dots\dots\dots(13)$$

$$A_v = 1 + 10 = 11$$

$$A_{v(\text{dB})} = 20 \log 11 = 20.8\text{dB}$$

$$F_{OL} = 1/(2\pi R_1 C_1) \dots\dots\dots(14)$$

$$F_{OL} = 1/(2\pi \times 78 \times 10^3 \times 100 \times 10^{-9}) = 20.4\text{Hz}$$

$$F_{OH} = 1/(2\pi R_2 C_2) \dots\dots\dots(15)$$

$$F_{OH} = 1/(2\pi \times 10 \times 10^3 \times 1 \times 10^{-9}) = 15.92\text{KHz}$$

therefore Effective Bandwidth = 15.9KHz

2.4 The Power Amplifier Unit

The voltage amplifier unit is followed by a very high gain current amplifier realized by two pairs of complementary transistors connected in darlington pair configuration. The TIP 4 and TIP 41 as well as 2SC3281 and 2SA1302 were used to realize this as shown in figure 1

The voltage divider formed by the resistors at the output terminal of the opamp biases the base of the output transistors barely into conduction so that the output transistors function as a Class AB amplifier. The 220 Ω Emitter Base resistors in the output transistors is meant to improve the turn-off speed of the darlington pairs and to prevent leakage current through Q1 (sensor) from biasing Q2 (output) into conduction. The R-C Zobel network.[7] preceding the speaker output serves to bleed off currents at a time constant of 6nanoseconds after the amplifier is put-off. This is to ensure the safety of the speaker coils.

3. THE OPERATIONAL PRINCIPLE OF THE PUBLIC ADDRESS AMPLIFIER

From figure 1, the Audio signal is capacitively coupled into the input stage. This is a transistor current source with a voltage divider bias. The C1815 transistor is used and the base voltage V_B provided by a stiff voltage divider. “Stiff” in the sense that the divider impedance $R1/R2$ is much less than the dc impedance looking into the base $h_{FE}R_E$ ((1.92K Ω and 22K Ω respectively in this case). Applying V_B to the base with $V_B > 0.6V$, ensures that the emitter is always conducting. This bias is adopted to obtain a combination of bias stability, linearity and large voltage gain because it is more or less independent of transistor current gain (beta value); beta is temperature sensitive and its actual value is usually not well defined. With average gain of 50 (34dB) the output is amplified and effectively non-inverted. The output of this first stage is capacitively coupled to a signal processor. The signal processor is a standard Baxandall feedback tone control, and gives an almost dead flat frequency response with the controls in the centre position. It is pertinent to note that it is inverting, which complements the microphone preamplifier (also inverting) so the absolute signal polarity is maintained. The signal is then passed through a passive Band pass filter at the non-inverting input of the opamp A2. The -3dB cut-off frequency is set at about 20Hz and the upper roll-off frequency I 15,7kHz. This ensures a linear amplification of signals within the entire audio frequency range. A variable resistor is provided to adjust signals intensity (MASTER VOLUME) at the input of the Band pass filter. The signal is further amplified through the Voltage Amplifier Stage with a nominal closed loop gain of (20.4dB). By means of negative feedback, the overall gain is somewhat reduced and noise signal eliminated at this stage.

Finally, the signal passes through a high-current output stage, which drives the speaker load. The output stage is a trans resistance power amplifier, translating the small-signal output current from the Voltage Amplifier stage to a highly amplified voltage signal at its output node. The selected topology utilizes a darlington pair in a push-pull Class AB arrangement. The Darlington pair consists of two complementary transistors connected as shown in Figure 1. This structure doubles the beta value of the transistor, allowing low gain devices to be used for high gain applications. This is especially useful when considering the low noise transistors (TIP41/TIP42 and 2SC1302/2SA3280) that are employed in this design.

The entire unit derives the amplified power from a rectified, capacitor-filtered, unregulated power supply unit that is used to produce dual voltages of approximately +/-22 volts with low noise and minimal ripple. Safely measures are incorporated to prevent a potential lethal shock from filter capacitors during fabrication. Circuit protection is implemented at the power supply unit by means of a 3A slow-blow fuse. Additionally, circuitry such as the R-C Zobel network is provided to avoid damage to input/output devices and the speaker coils.

The power Supply Unit (PSU), the preamplifier circuit and the power amplifier were properly circuited inside the case while the output transistors were placed on a large heat sink. The circuits were implemented with the components soldered neatly on veroboards.

The following and other safety measures were observed during construction and prior to testing:

- (i) Components were soldered using a 40W soldering iron and proper soldering techniques observed
- (ii) The circuit boards were tested for continuity at various levels of the construction work
- (iii) Appropriate cables were used to connect each section into circuit and the entire circuit was grounded at a common point within the box.
- (iv) All circuit components, veroboards, transformers, potentiometers, rectifiers, input and outputs, were properly screwed to the wooden base and metal case.

5. TESTING

The supply voltage was tested as 162V from the mains and stepped-up to 210V using a commercial voltage regulator. The transformer output voltage was measured as $\pm 15.2V$ which after rectification and capacitor filtration gave an average of 22.01V. Continuity test was performed on the preamplifier, booster amplifier, and power supply unit before they were interconnected. The fuse was in place and all volume controls turned down before the unit was powered for the first time for about 5 minutes. After power was applied, all transistors and the op amp were felt with the finger tips to check for any heating component. Subsequently, the test time was increased to 10mins, 20mins, 30minutes and all components were observed to operating at ambient room temperature. With the inputs in common mode, the output voltage and current was measured using a digital multimeter to be 0 volts. The volume controls was set at a minimum then the audio signal was applied. The volume was gradually increased and the output was considerably impressive especially as the volume increased.

6. RESULTS

6.1 MAXIMUM POWER CONSIDERATION

6.1.1 INPUT POWER

The power supplied to the load by the amplifier is drawn from the power supply that provide the input or dc power. The amount of this input power can be calculated using

$$P_i(\text{dc}) = V_{cc} I_{dc} \dots \dots \dots (16)$$

Where V_{cc} is 22V and I_{dc} has an approximate value of 3A

$$P_i(\text{dc}) = 22V \times 3A = 66W$$

Where I_p is the peak value of the output current waveform

$$P_i(\text{dc}) = V_{cc} (2I_{dc} / \pi) \dots \dots \dots (17)$$

$$P_i(\text{dc}) = (22V \times 2 \times 3) / \pi = 42W$$

6.1.2 OUTPUT POWER

$$P_o(\text{ac}) = V_{cc}^2/2R_L \dots \dots \dots (18)$$

Where $V_{cc} = 22\text{V}$ and $R_L = 8\Omega$

$$P_o(\text{ac}) = 22^2/2(8) = 30.25\text{W}$$

$$P_i(\text{dc}) = 2V_{cc}^2/\pi R_L \dots \dots \dots (19)$$

$$P_i(\text{dc}) = 2 \times 22^2/\pi(8) = 38.5\text{W}$$

6.2 Efficiency

The efficiency of any amplifier can be calculated using the equation 20 and 21

$$\% \eta = P_o(\text{ac})/P_i(\text{dc}) \times 100\% \dots \dots \dots (20)$$

$$\% \eta = [V_L^2(\text{rms})/R_L]/[V_{cc}(2I_{dc}/\pi)] \times 100\% \dots \dots \dots (21)$$

$$\% \eta = \pi V_L(p)/4V_{cc} \times 100\% \dots \dots \dots (22)$$

This relation shows that the larger the peak voltage, the higher the amplifier efficiency, up to a maximum value when $V(p) = V$, this maximum then being

$$\text{Max } \eta = \pi/4 \times 100\% = 78.5\%$$

7. CONCLUSION

This work is a design and development of a public address audio amplifier. The device was tested after it was constructed and the results obtained was input power 42watts, output power 30.25watts, efficiency 78.5%. These results show that the device worked satisfactorily.

8. REFERENCES

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