DEVELOPMENT AND COMPARATIVE STUDY OF AUDIO POWER AMPLIFIER CIRCUITS

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ABSTRACT

Every audio system uses audio power amplifier to amplify weak voice signals that are suitable to drive the speakers properly. Therefore, the audio power amplifier is considered an integral part of audio systems in the field of electronics (low power applications). In this research work, we have developed two audio power amplifiers using ICs CTC810 & LM386N-1 to compare their performance in terms of low voltage amplification, gain versus frequency response, bandwidth, and bass boost. The IC CTC810 is a 6 W audio power amplifier made of input amplifier unit, driver amplifier unit and the output amplifier unit. While the IC LM386N-1 is a low voltage (0.5 W) audio power amplifier, which consists of gain stage & output stage. The measured results exhibit the good performance (having output waveform with negligible distortion) of both audio power amplifier circuits using CTC810/LM386N-1 for low power applications. The output results show a very good operating performance for both the audio power amplifier circuits.

Keywords: Audio Amplifier, Frequency Response, Low Voltage Amplification, Bass Boost, CTC810, LM386N-1.

I. INTRODUCTION

The first audio amplifier was developed in 1909 by Lee De Forest when he invented the triode vacuum tube. An amplifier that provides constant gain over audible range (20 Hz-20 kHz) is referred as an audio power amplifier. In other words, an audio power amplifier is an electronic circuit that amplifies low power audio signals having frequency between 20 Hz-20 kHz to a level suitable for driving the speakers and is the final stage in a typical audio system. In the recent times, the electronic systems such as MP4 players, TV, mobile phones, audio equipment, laptops, etc. that could make voice are using the audio power amplifier. The characteristics of an audio amplifier are: (i) all the frequencies within the audio bandwidth must be equally amplified, i.e., the frequency response must be flat over the audible range, (ii) the phase of all the frequency components in the output must be same as that in the input, otherwise distortion results in the shape of the output waveform [1- 6].

Theoretically, every audio amplifier produces some amount of power amplification, but in practical scenario every audio amplifier cannot be called a power amplifier. It is the amount of power amplification that makes an amplifier power amplifier or not. A power amplifier must produce a considerable amount of power amplification so as to drive a speaker (load). A simple RC coupled pre-amplifier makes considerable amount of voltage gain but it cannot be considered as a power amplifier as its current gain is very low. A practical audio power amplifier must have dedicated circuits for producing voltage gain and current gain. Different power amplifier stages are shown in the block diagram of figure (1).

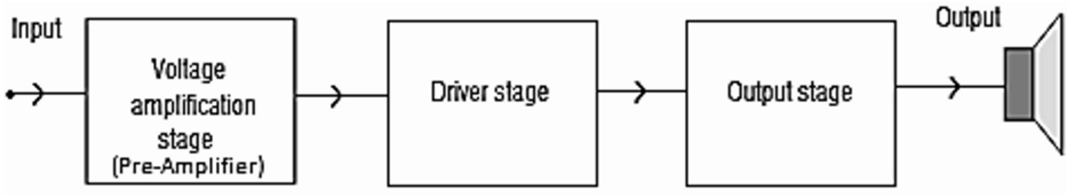

Fig. (1) Block Diagram of an Audio Power Amplifier

The input signal to the amplifier from the source will be generally in the millivolt range and it is very weak to drive the succeeding stages. Therefore, a pre-amplifier (voltage amplification stage) is required to amplify the signal for further processing, control or any other use. The elements used in pre-amplifier stage must have very low noise because the SNR of the whole system is affected by the noise introduced by this pre-amplifier unit. Other than this, the frequency band of pre-amplifier must also be wide enough, so that amplification without distortion can be ensured. The driver stage is between the voltage amplification stage and the output stage and the purpose of the driver stage is to produce enough current gain in order to drive the output stage. Since there is sufficient current gain, this stage produces considerable amount of power gain too. The output stage is the stage that is connected to the speaker which gives further improvement to the power gain and transfers this power to the speaker with minimum loss. When the load R_L is constant, a good power amplifier should have high output power, low distortion/noise, and wide bandwidth. Ideally, the only difference between the input signal and the output signal is the strength of the signal. Due to low cost, stability, low distortion, and small size etc., integrated power amplifiers are widely used [7- 9].

In this research work, audio power amplifier circuits using ICs CTC810 & LM386N-1 have been developed for low power applications (in the field of electronics) to drive the load (speaker) directly. These circuits may be employed as small room microphone and speaker system and may also be used in applications such as portable audio players, TV sound systems, intercoms, etc. Being low cost and low power operated, the performance of both circuits is excellent in their respective frequency range of the operation.

II. PERFORMANCE MEASURING METRICS

The performance measuring metrics for audio power amplifiers can be explained as follow:

2.1 FREQUENCY RESPONSE

The frequency response of an audio amplifier is the ability of an amplifier to amplify audio range of frequencies (20 Hz to 20 kHz). In other words, frequency response is used to describe the range of tones that a stereo system can reproduce [10]. There are two requirements for frequency response: (i) 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 20 Hz to 20 kHz, which is the approximate range of human hearing, (ii) the frequency response should be as flat as possible. A typical frequency curve for an audio amplifier is shown in figure (2). It can be seen that the gain is constant only for a limited band of frequencies. This range of frequency is called the mid-frequency region and the gain called mid-band gain (A_M). On both the sides of the mid- frequency region, the gain decreases. The coupling and bypass capacitors are responsible for fall of gain in the low frequency region. While in high frequency region, current gain of the transistor (β), inter-electrode and wiring capacitances reduces the gain. The bandwidth of the amplifier is represented by the flat portion of the frequency response curve, or it is defined as the difference between the frequencies f_1& f_2 (BW = f_2-f_1), where the gain of the amplifier is 70.7% of the maximum gain (i.e., $A_M/\sqrt{2}$). Thus, the wide bandwidth of an audio amplifier represents the better quality of the sound reproduction.

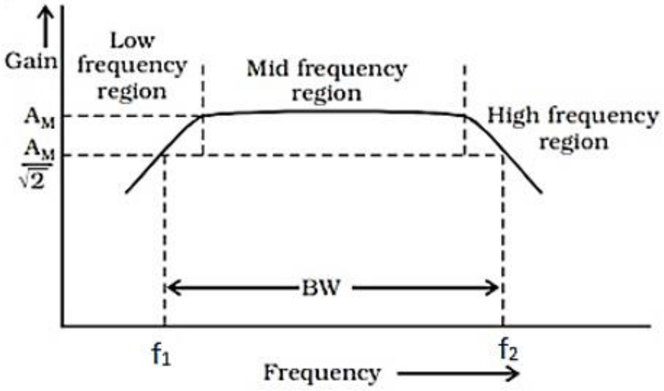

Fig. (2) Frequency Response of an Audio Power Amplifier

2.2 OUTPUT POWER

The output power of an amplifier is defined as the maximum rms (root mean square) power output within a specified distortion limit at a particular load (R_L), which can be calculated by the following relation:

$$P_o = \frac{V_o^2}{R_L} \qquad (1)$$

where, V_o is the highest rms voltage within specified distortion limit across R_L.
Generally, the speakers for an audio power amplifier have resistance from 4 Ω to 8 Ω.

2.3 SIGNAL TO NOISE RATIO

Signal to noise ratio is the ratio of signal to noise power across the output load. The higher the signal to noise ratio, the better will be the performance of an amplifier. It can be expressed as equation (2):

$$SNR = \frac{P_{signal}}{P_{noise}} \qquad (2)$$

$$\Rightarrow \quad SNR_{dB} = 10 \log_{10}\left(\frac{P_{signal}}{P_{noise}}\right) \qquad (3)$$

SNR can also be obtained by calculating the square of the amplitude ratio as:

$$SNR_{dB} = 10\log_{10}\left(\frac{A_{signal}}{A_{noise}}\right)^2$$

$$\Rightarrow \quad SNR_{dB} = 20 \log_{10}\left(\frac{A_{signal}}{A_{noise}}\right) \qquad (4)$$

where, A is the rms value of the voltage [11].

2.4 DISTORTION/ NOISE

Generally, distortion refers to any kind of deformation of an output waveform compared to its input, usually clipping, harmonic distortion, or intermodulation distortion (mixing phenomena) caused by non-linear behaviour of electronic components and power supply limitations and noise refers to any kind of unwanted signal. In audio systems, it is the low-level hiss or buzz that intrudes on quiet passage of sound [12].

III. DESRIPTION OF AUDIO POWER AMPLIFIER ICs

3.1 IC CTC810 [13]

The audio power amplifier circuit mainly depends on IC CTC810. It is monolithic IC in a 12-lead quad in-line plastic package, intended for use as a low frequency class B amplifier as shown in figure (3). The IC CTC810 has been specially developed for the audio section of TV receivers. It is capable of developing 7 W output power into an 8 Ω load (speaker). Each and every pin of IC CTC810 has some function as mentioned below:

- Pin 1 receives the main (external) power supply (4-20 V)

- Pins 2, 3, & 11 have no connection (NC)
- Pin 4 receives power supply from pin1 through a resistor and also acts as bootstrap terminal
- Pin 5 is the frequency compensation terminal
- Pin 6 receives a negative feedback from output terminal (pin 12) through an internal resistance and controls the gain of the amplifier
- Pin 7 is the ripple rejection terminal
- Pin 8 is input terminal
- Pins 9 & 10 are the ground terminals
- Pin 12 is the output terminal
- TAB act as heat sink

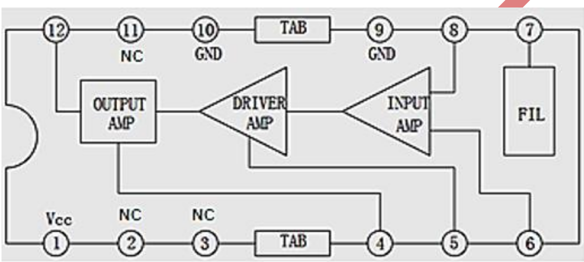

Fig. (3) Pin Diagram of IC CTC810

3.2 IC LM386N-1 [14]

The LM386N-1 is a low power audio frequency amplifier, which uses low level power supply for biasing. It is designed as 8 pin mini DIP package as shown in figure (4) and it provides voltage amplification of 20. To make the LM386N-1 a more versatile amplifier, two pins (1 and 8) are provided for gain control. With pins 1 and 8 open, the 1.35 kΩ resistor sets the gain at 20 (26 dB). If a capacitor is connected from pin 1 to 8, bypassing the 1.35 kΩ resistor, the gain will go up to 200 (46 dB). If a resistor is placed in series with the capacitor, the gain can be set to any value from 20 to 200.Each and every pin of this IC has its own function as mentioned below:

- Pins 1 and 8 denote the gain control of the amplifier where gain can be adjusted by placing R-C/C components in between these two terminals
- Pins 2 and 3 are the input pins for sound signal
- Pin 4 is the GND terminal
- Pin5 is the output terminal of the amplifier
- Pin6 is the terminal which receives the positive dc voltage
- Pin7 is the bypass terminal which is usually grounded or connected to the ground through a capacitor

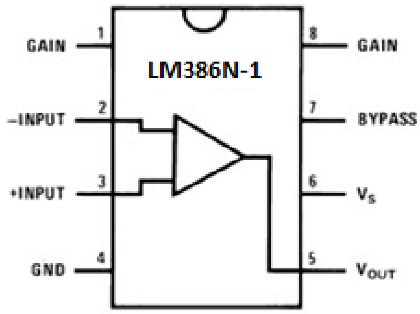

Fig. (4) Pin Diagram of IC LM386N-1

IV. DEVELOPMENT OF AUDIO POWER AMPLIFIER CIRCUITS

4.1 AUDIO POWER AMPLIFIER CIRCUIT USING IC CTC810

The external components (resistor and capacitor) values are chosen such that the output of the audio power amplifier circuit is optimum (i.e., stable and maximum output without much distortion). To bias the audio power amplifier circuit, a supply Vcc (+9 V) is connected to pin 1 of the IC which is the main supply of the circuit and a biasing voltage is also applied to pin 4 through a resistor of 100 Ω from pin 1as shown in figure (5). Now, input voice signal in electrical form is applied to the input pin 8 through a capacitor of value 10 µF and a potentiometer circuit (68 kΩ & 100 kΩ resistors). This signal is amplified by the various stages of the audio power amplifier and the output signal is available at the output pin 12 which is fed to the speaker through a capacitor of value 470 µF. To control the gain, some negative feedback has been applied from the output pin 12 to pin 6 through an internal resistance which is taken across the resistance of 82 Ω. The capacitor of 250 µF connected between pin 6 and 82 Ω blocks the dc component of the feedback signal. A capacitance of 250 µF connected between pin 7 and ground rejects the ripples. A feedback voltage through a combination of two capacitors (0.001 µF and 0.01 µF) is applied at pin 5 for the frequency compensation. One more feedback signal through the capacitor of 250 µF is also applied at pin 4 for bootstrapping and this also increases the input impedance of the amplifier circuit. A series combination of resistor 1 Ω and capacitor 0.1 µF is connected in parallel with the speaker to remove very high frequency spikes from the output signal. This circuit is designed such that it provides a maximum output power of about 7 watts across the load (speaker). A thermal limiting circuit has also been incorporated in the IC which provides protection against excessive temperature. If the temperature of IC increases beyond a certain limit then this circuit cuts off all supplies and thus protects the IC. A metallic bent down strip (TAB) has been provided in the IC for heat dissipation and is connected to the ground side of the printed circuit board (PCB).

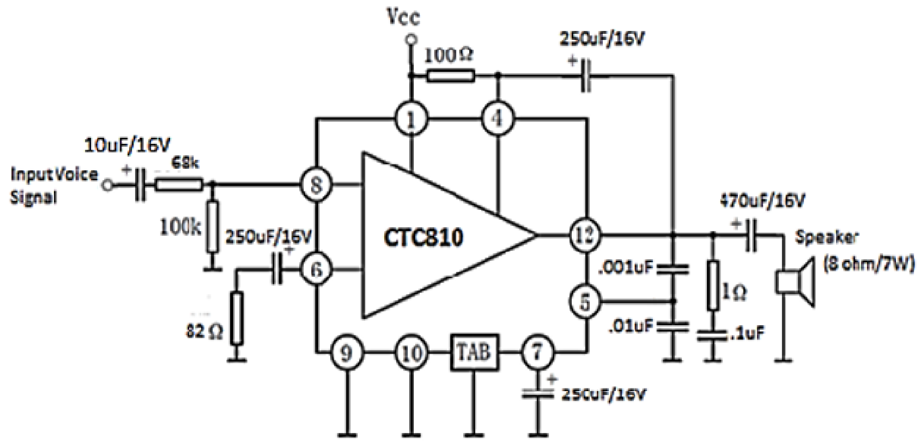

Fig. (5) Circuit diagram of an Audio Power Amplifier using IC CTC810

4.2 AUDIO POWER AMPLIFIER CIRCUIT USING IC LM386N-1

The external components (resistors and capacitors) values are chosen such that the output of the audio power amplifier circuit is optimum (i.e., stable and maximum output without much distortion). To develop an audio power amplifier, an IC LM386N-1 and some external components are used, most of them are decoupling capacitors. It is well suited to low power applications and can work with voltage supply from 4-12 volts. The complete circuit diagram of an audio power amplifier using IC LM386N-1 is shown in figure (6). To bias the IC, we apply a power supply +Vcc (4-12 V) at pin 6 and pin 4 is grounded. The input audio signal is applied between pins 3 and 2, i.e., the positive input is connected to pin 3 through a capacitor (1 µF) and a potentiometer (10 kΩ). The capacitor of 1 µF has also been used along with potentiometer to block the dc component, passes ac components of input signal and the potentiometer acts simply as volume control knob. To control the gain of the amplifier, we connect a capacitor between pin 1 and 8. Internally the gain is set to 20 (minimum value) but it can be adjusted to any value between 20 (when no capacitor is used) to 200 (when 10 µF capacitor is used). The amplified input signal is available at output terminal (pin 5). The output signal may have both ac and dc components, the undesirable dc component should not be fed to the speaker. Thus, to remove dc component, a capacitor of 560 µF has been used. Along with this capacitor, a filter circuit known as "Zobel Network" (a series combination of a capacitor of 0.047 µF and a resistor of 10 Ω in parallel with the speaker) has been used at the output pin 5 to remove the sudden high frequency oscillations/spikes or noise. With the circuit set at the maximum gain of 200, it becomes essential to use pin 7 as a bypass terminal that is connected to the ground through a capacitor of 0.47 µF for keeping the audio amplifier circuit stable and avoiding unnecessary oscillations or clipping.

Both audio power amplifier circuits as shown in figures (5 & 6) permit a user to amplify and record any sound signal. In order to record a sound signal, a 3.5 mm audio plug and a computer with sound recording software are required. Here, we can connect 3.5 mm jack of a computer in place of speaker using 3.5 mm audio plug so that any sound signal can be easily recorded into a computer like a professional microphone.

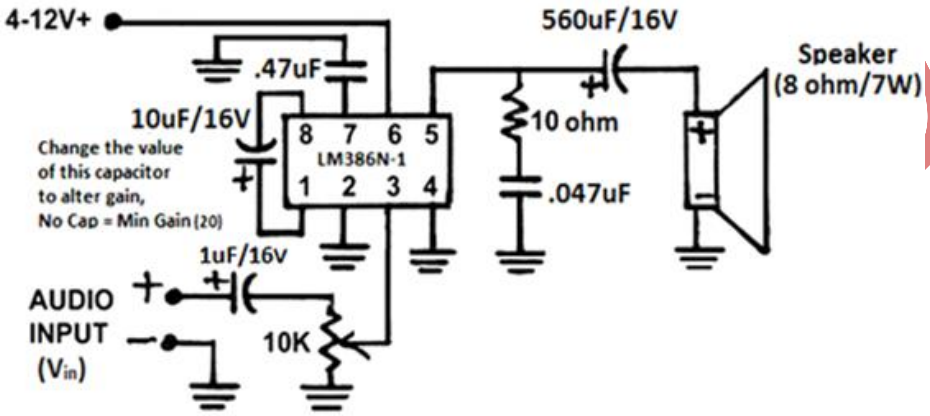

Fig. (6) Circuit diagram of an Audio Power Amplifier using LM386N-1

V. RESULTS AND DISCUSSION

Initially, a sinusoidal signal is generated using signal generator. By setting its amplitude at 100 mV peak to peak, its frequency is varied in and around the audio range (20 Hz to 20 kHz) as shown in table (1). The output is measured at the output terminal of both audio power amplifier circuits and the gain is calculated in dB using equation (4).

When a sinusoidal input signal is applied to the input terminals of the audio power amplifier circuits of figures (5 & 6), a clear amplified single tone of the set frequency is heard and the same outputs are displayed on the oscilloscope. The output waveforms of the circuit using LM386N-1 show very small distortion/noise as compared to the circuit using CTC810. Thus, low voltage sound signals can be appropriately amplified using the audio power amplifier circuit based on IC LM386N-1.

A comparative study based on data given in the table (1) and the same displayed in the figure (7) shows that the gain is higher and flat (constant) for a larger frequency range in case of LM386N-1 as compared to CTC810. The larger bandwidth of the developed circuit shown in figure (6) allows it to be used as a stereo sound amplifier in dual channel amplifier circuit. The LM386N-1 is a more versatile amplifier as two pins (1 and 8) may be used for gain control but this facility of gain control is not present in CTC810. A bass boost arrangement can be provided by inserting a resistor/capacitor network across pin 1 and 5 of the circuit in figure (6) but this facility is not available in the amplifier circuit using CTC810 of figure (5). By adding a 10 kΩ resistor in series with a capacitor of 0.033 µf between pins 1 and 5, bass frequency can be increased. Anyway, the results are more than satisfactory, and the developed audio power amplifier circuits can be used in the portable devices since both the circuits can be fabricated in an IC form.

Table-(1). Frequency Response of Audio Amplifier Circuits

(Set Vcc= +9 V and Sinusoidal Input, V_{in}= 100 mV)

S.No.	Input Frequency (Hz)	Audio Power Amplifier Circuit using IC CTC810		Audio Power Amplifier Circuit using IC LM386N-1	
		V_{out} (V)	Gain (dB)	V_{out} (V)	Gain (dB)
1.	5	-	-	1.60	24.08
2.	10	1.89	25.53	2.70	28.63
3.	20	2.53	28.06	3.07	29.74
4.	30	2.59	28.27	3.20	30.10
5.	50	2.61	28.33	3.24	30.21
6.	80	2.63	28.40	3.27	30.29
7.	100	2.66	28.50	3.29	30.34
8.	200	2.68	28.56	3.33	30.44
9.	300	2.70	28.63	3.33	30.44
10.	500	2.70	28.63	3.32	30.42
11.	800	2.70	28.63	3.32	30.42
12.	1 k	2.70	28.63	3.32	30.42
13.	2 k	2.65	28.46	3.32	30.42
14.	3 k	2.64	28.43	3.32	30.42
15.	5 k	2.55	28.13	3.32	30.42
16.	8 k	2.45	27.78	3.32	30.42
17.	10 k	2.32	27.31	3.33	30.44
18.	30 k	1.16	21.29	3.33	30.44
19.	50 k	0.64	16.12	3.35	30.50
20.	80 k	-	-	3.42	30.68
21.	100 k	-	-	3.42	30.68
22.	200 k	-	-	3.22	30.16
23.	300 k	-	-	2.64	28.43
24.	500 k	-	-	1.33	22.48

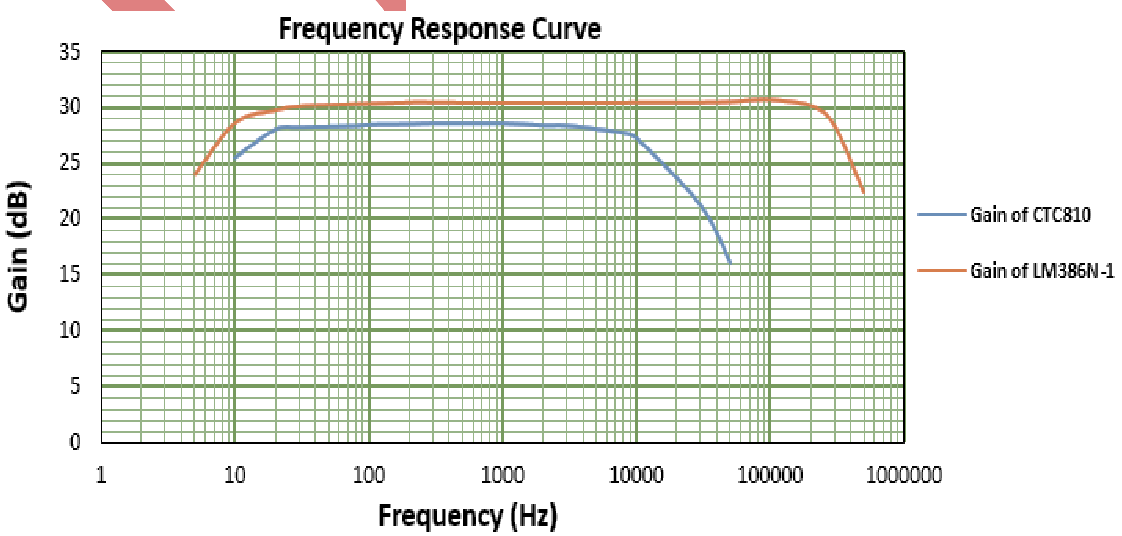

Fig. (7) Gain versus Frequency Curves for Audio Power Amplifier Circuits using CTC810/ LM386N-1

Table-(2). Comparison between Audio Power Amplifier Circuits using CTC810 and LM386N-1

S. No.	Parameter	Audio Power Amplifier Circuit using CTC810	Audio Power Amplifier Circuit using LM386N-1
1.	Bandwidth	14.8 kHz	290 kHz
2.	Low Voltage Amplification	Small Noise/Distortion	Very Small Noise/Distortion
3.	Facility of Bass Boost	No	Yes
4.	Gain versus Frequency	Flat for Small Frequency Range	Flat for Large Frequency Range
5.	Area of Application	Electronics Field (Low Power Applications)	Electronics Field (Low Power Applications)

VI. CONCLUSION

The audio power amplifier circuits developed using two well-known and widely used ICs CTC810 and LM386N-1 are working more than satisfactorily in their respective range of the frequency. From the tables (1 & 2) and figure (7), we did comparative study of both the circuits and concluded the following points:

- Both audio power amplifier circuits work as voltage/power amplifier depending upon whether they are required to produce high voltage/power gains.
- The operating conditions of the audio power amplifier circuits have to be adjusted such that to give distortion free output.
- The gain is higher and flat (constant) for larger frequency range for the audio power amplifier circuit using LM386N-1 as compared to the circuit using CTC810.
- The bandwidth of the audio power amplifier circuits is represented by the flat portion of the frequency response curve. The larger the bandwidth of an audio power amplifier circuit, the better is the quality of the sound reproduction. The large bandwidth of the audio power amplifier circuit using IC LM386N-1 allows it to be used as a stereo sound amplifier in dual channel amplifier circuit.
- The distortion/noise level in case of the audio power amplifier circuit using IC LM386N-1 is low as compared to the circuit using IC CTC810. Thus, very low voltage sound signals can be properly amplified with the audio power amplifier circuit using LM386N-1.
- The audio power amplifier circuit based onLM386N-1 provides the facility of gain control that is not available in the circuit using CTC810.
- The facility of bass boost is available in the amplifier circuit based on LM386N-1.

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