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Guidelines for the Speaker in a Line-Powered Speakerphone

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INTRODUCTION

In the design of a speakerphone, the selection, and mounting, of a speaker plays a major role in the resulting quality of sound which the user hears in using the end product. The purpose of this application note is to provide some guidelines in selecting the optimum speaker impedance, drive configuration, and the mounting within the speakerphone enclosure. Among the key items to be discussed here are the choice of speaker impedance, and the drive configuration to the speaker.

BASICS

First some basics – the power provided to a speaker is defined by Ohm's laws:

– $P = Vrms^2/R$
– $P = R \times Irms^2$

where R is the impedance of the speaker, Vrms is the rms voltage across the speaker terminals, and Irms is the rms current through the speaker. While this is very basic information, it is included as a reminder that when a speakerphone is designed to be powered off the telephone line, the available power out of the speaker is limited (on long loops) by the loop current, rather than by the electronics. In other words, on a long loop, where the loop current is 20 to 30 mA, there is only so much power that can be had at the speaker. Changing the speaker amplifier to a more powerful one won't help. Today's more efficient speakerphone ICs consume less current internally, thereby making more of the incoming loop current available for the speaker. But even with the most efficient circuits available, the speaker power is still limited by the loop current.

For your reference, the graphs of Figures 3 through 6 indicate the current and voltage required to produce different power levels in speakers of various impedances.

SINGLE–ENDED OR DIFFERENTIAL DRIVE?

Figure 1 depicts a typical single–ended drive to the speaker, and Figure 2 depicts a differential drive.

Figure 1. Single–Ended Speaker Drive

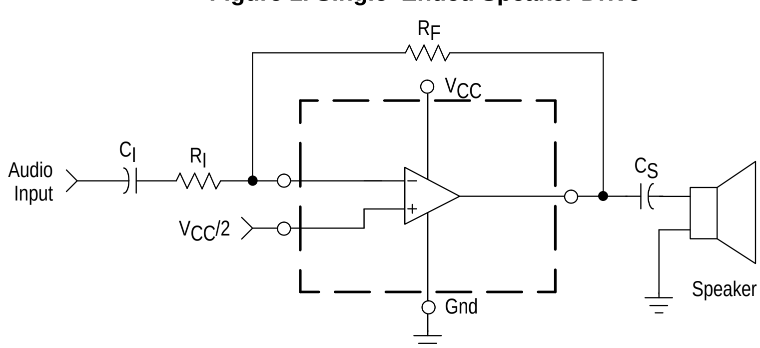
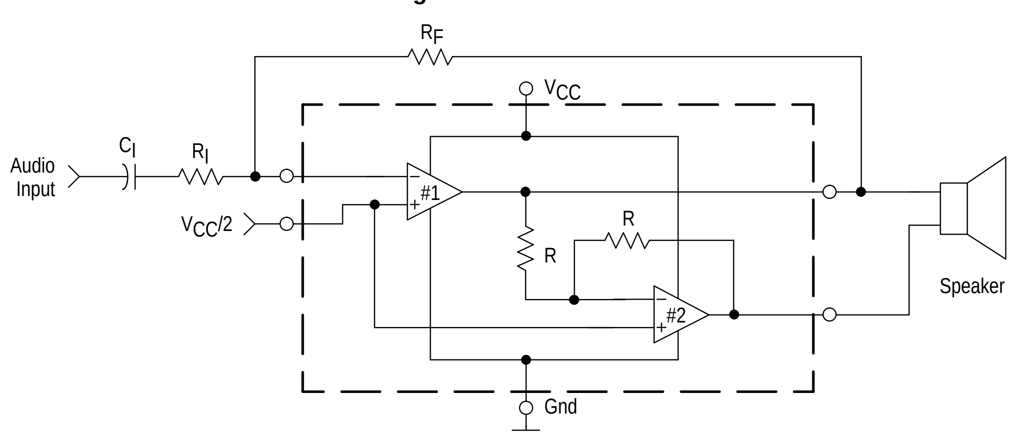


Figure 2. Differential Drive



The audio gain to the speaker in Figure 1 is R_F/R_I, and in Figure 2 it is 2 x R_F/R_I. Capacitor C_I is mainly for dc separation of the bias voltage at the speaker amplifier from the audio source, but it can also be used for low frequency roll–off.

Which configuration should be used? It would seem the differential circuit is preferable since the large capacitor (C_S, typically 47 µF) is not needed, and since twice as much voltage (and therefore four times the power) can be applied across the speaker for a given value of V_{CC}. However, the single–ended configuration has a huge advantage for phone–line powered speakerphones: It can deliver twice the power to the speaker for a given amount of available current. Since the operation of a line powered speakerphone is limited mostly by the available current, and less by voltage constraints, this feature of a single–ended driver can be a dominant consideration.

Data taken to support this concept (Table 1) was taken using the MC34119 speaker amplifier wired single–ended and differentially to a 25 Ω speaker, and monitoring the supply current required for different speaker power levels. The Supply Current indicated is that required for the speaker. The internal bias current required by the MC34119 was subtracted when taking this data.

Table 1. Current Requirements for Single–Ended and Differential Mode Speaker Amplifiers with 25 Ω Speaker

Speaker			Supply Current	
Power	Voltage	Current	Single–Ended Mode	Differential Mode
20 mW	0.707 Vrms	28 mArms	13 mA	25 mA
30 mW	0.866 Vrms	35 mArms	16 mA	31 mA
50 mW	1.11 Vrms	45 mArms	20 mA	40 mA
70 mW	1.32 Vrms	53 mArms	24 mA	48 mA
90 mW	1.50 Vrms	60 mArms	27 mA	54 mA
110 mW	1.66 Vrms	66 mArms	30 mA	60 mA
130 mW	1.80 Vrms	72 mArms	33 mA	65 mA
150 mW	1.94 Vrms	78 mArms	35 mA	70 mA

The Supply Current is essentially an average of the speaker rms current. For the single–ended mode, it is:

$$I_{sup} = \frac{(Irms \ x \ 1.414)}{\pi}$$

and for the differential mode, it is twice that. Proofs of this are contained in Appendices A and B.

HOW MUCH SPEAKER POWER IS AVAILABLE IN A SPEAKERPHONE?

In a speakerphone powered by the phone line, there is not unlimited current available – in fact it is defined by the phone line to which the speakerphone is connected. Keeping in mind that each phone line is, in effect, a current source, and that its current **must** be accepted by the telephone circuitry, then whatever current is supplied by a phone line is what is available for the speaker – minus whatever current is needed to power the internal circuitry.

Since the available current is defined by the telephone line, and since $P = I^2R$, it would seem logical to select the highest impedance speaker available. But higher impedance means higher voltage requirements, and there are two voltage limitations in this kind of application:

– Those imposed by the telephone companies, and

– Those imposed by the telephone's internal circuitry.

The most difficult situation for a line powered speakerphone is, of course, at the lowest loop current. The telephone companies guarantee (and have for decades) that the minimum loop current on any phone line is 20 mA. Although less current than that can flow in an individual telephone if parallel phones are off–hook, 20 mA will be used as the minimum in this discussion. At this current value, the telephone companies would like the voltage across the phone line to not exceed 6.0 V[1]. Since every electronic telephone has a diode bridge at the phone line connection, that leaves a maximum of 4.6 V for the internal electronics. In an ideal situation, where all 20 mA could be delivered to the speaker, there would theoretically be 92 mW available for the speaker power (4.6 V x 20 mA).

But circuits are not ideal, and allowances must be made for powering of the various ICs within a phone, as well as other realities. Typically (in 1997), dialers consume 1.0 to 2.0 mA, speech network/speakerphone circuits consume 1.0 to 5.0 mA, and speaker amplifiers use another 1.0 to 3.0 mA. A best case scenario would leave 17 mA for the speaker, and a worst case scenario would leave about 10 mA. Additionally, the speaker amplifier generally cannot be powered from the same internal point as the speech network (4.6 V in this example), but must be powered by some kind of regulator which will have a voltage drop of 0.5 to 1.5 V.

Using the best case scenario of the above numbers, the 17 mA of current to the speaker amplifier would translate to 37.8 mArms at the speaker (in a single–ended configuration). If the speaker amplifier has a true rail–to–rail output (4.1 Vpp swing), that calculates to 55 mW at the speaker. This assumes a 38 Ω speaker is used, since that is what would be required to make the above numbers be true.

The above calculations do not include voltage drops for the hookswitch, protection devices, and any other circuitry between the phone line and the speaker amplifier, as well as the fact that even rail–to–rail amplifiers need some head–room. Since these items lower the available peak–to–peak voltage to the speaker, the best speaker impedance ends up something less than 38 Ω.

At higher loop currents, the situation improves in that more power is available for the speaker, but only up to a point. For example, if the loop current is 60 mA, and assuming the internal dc voltages are a bit higher than in the above example, the current consumed by the ICs will be assumed to be 4.0 mA instead of 3.0 mA. That leaves 56 mA for the speaker, which translates to 124 mArms. Using the same 38 Ω speaker as above, the maximum voltage swing would be 13.3 V, requiring the ICs to operate at 14 to 15 V. But most telephone ICs have a maximum rating of 10 to 12 V, which provides an upper limit for the voltage swing at the speaker. But even if the 38 Ω speaker could make full use of the 124 mArms current, that represents 584 mW, which is substantially more than what any common speakerphone needs.

SELECTING THE SPEAKER IMPEDANCE

In a circuit which has a power supply powered by the 110 Vac (or 220 Vac) commercial power source, the choice of speaker impedance is usually easy. Since there is, for all practical purposes, unlimited power available, the choice of an 8.0 Ω speaker makes good sense for two reasons:

- They are usually the least expensive, and
- The low impedance value means a high voltage is not needed to obtain significant power.

However, as described in the section above, in a speakerphone powered by the phone line, the situation is different. There is not unlimited current available – it is defined by the phone line to which the speakerphone is connected. Selecting the right speaker impedance involves making best use of the available current, while staying within the voltage limitations of the system.

As described above, a speaker impedance less than 38 Ω is best. Since it can be shown that, at a loop current of 20 mA, a best case scenario would produce only 11 mW of power with an 8.0 Ω speaker, it is obvious something between 8.0 Ω and 38 Ω is needed.

To determine the optimum speaker impedance, data was taken using the MC33215[2] Speech network/speakerphone IC which contains integral speaker amplifier.

The MC33215 provides the phone line interface (except for the diode bridge), the speech network, speakerphone, and speaker amplifier, and therefore contains the majority of a basic telephone's circuitry. The only additional circuit required for a POTS phone is a dialer, which typically consumes ≈ 1.0 mA. The MC33215's dc characteristics was optimized for speakerphone operation while staying within the industry's guidelines[1], and the circuit's block diagram is shown in Figure 7. The maximum speaker power, for different values of loop current, was determined by increasing the 1.0 kHz R_X signal until the speaker amplifier's peak limiter circuit prevented any further increase in the output to the speaker. Figure 8 indicates the results for various standard speaker impedance values. Figure 9 indicates the dc voltage at the VLN pin, which is at the output of the diode bridge.

The MC34018 speakerphone IC was also tested with similar results. Since the MC34018 does not contain the speech network (but does contain a speaker amplifier with peak limiting), it offers more flexibility as far as system configuration is concerned. This makes a direct comparison with the MC33215 difficult to do in a fair manner. The MC33215 was studied in detail for this document since it was designed, and optimized, specifically for a line–powered speakerphone, and to be used with a 25 Ω speaker.

Figure 8 indicates that the highest impedance speakers do best at the low currents, while the lowest impedance speakers do best at the highest currents. The best compromise, however, for both long and short lines, is a 25 Ω speaker. The second best choice would be a 16 Ω speaker, which provides more power at high loop currents, but slightly less power at 20 mA.

MORE POWER?

A common goal among many designers of speakerphones, and speakerphone–like products, is for louder sound from the speaker. This is particularly understandable if the end product is to be used in a somewhat noisy environment (noisy office area, apartment lobby intercom, elevator emergency phone, etc.). The discussion above shows how, in a telephone line powered product, the available power to the speaker, in milliwatts, is limited by the phone line. But the sound level coming from the speaker, in dBspl, is not limited only by the number of milliwatts. The mounting of the speaker – or in other words, the acoustics of the cabinetry, has a significant impact on the sound level, and has the same level of importance as the electronics for the performance of the end product.

Four line powered speakerphones were tested for sound level using a sound level meter. The results showed a difference of as much as 15 dBspl. Three units incorporated the MC34018 speakerphone IC, and one unit used the MC33215. All four had 25 Ω speakers, and were connected to the same telephone line. The main difference among the four was the design of the enclosure, which significantly affected the sound level.

While this author does not imply to be an expert at acoustics, it has become obvious after working with many speakerphone designers for several years, and after investigating many speakerphone designs, that the cabinetry design is a significant factor which **should be considered from the very beginning of the product design.** Leaving the cabinet design to the end usually results in poor acoustic performance. Generally, speaker manufacturers can be consulted for assistance in the design of the unit's cabinet.

A word of caution here – While it is possible to obtain a higher sound level from the speaker with proper electrical and acoustic design, keep in mind that acoustic coupling from the speaker to the microphone is one of the more significant factors, and potential problem areas, in the design of a voice activated speakerphone. If the speaker's sound level is raised too high, the circuit will either oscillate, or have a poor switching response. Therefore, the acoustic coupling must also be considered in the design of the cabinetry from the very beginning.

CONCLUSION

An 8.0 Ω speaker, while usually the least expensive, is not the best choice for a line powered speakerphone. A 25 Ω speaker is the best compromise. A survey of well designed speakerphones on the market today will find most of them use a 25 Ω speaker.

REFERENCES

1. EIA–470–A, Electronic Industries Association, July 1987
2. MC33215 Data Sheet, Advanced Information, April 1997, Revision 0
3. MC34018 Data Sheet, Specifications and Applications Information
4. 1988 Bell System Technical Journal, Volume XXXIX, March 1960, No. 2

Figure 3. Speaker Voltage Requirements

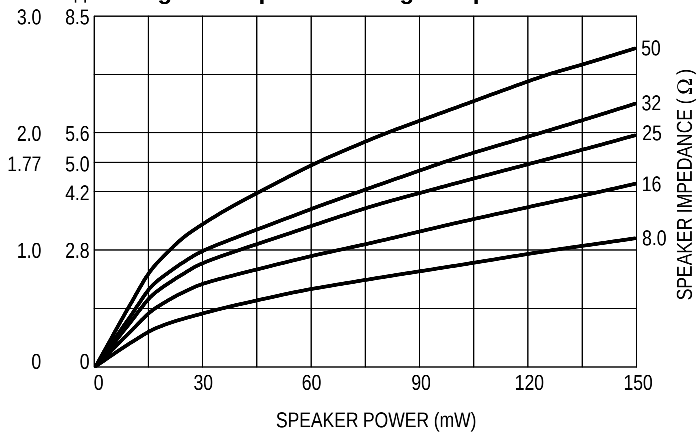


Figure 4. Speaker Current Requirements

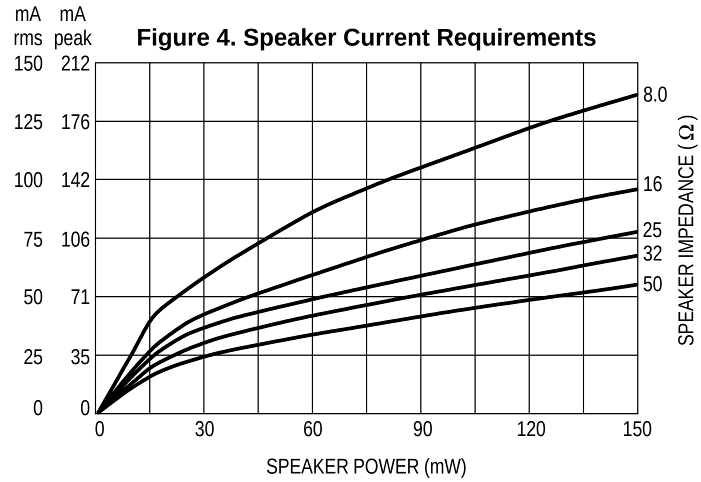


Figure 5. Speaker Voltage Requirements

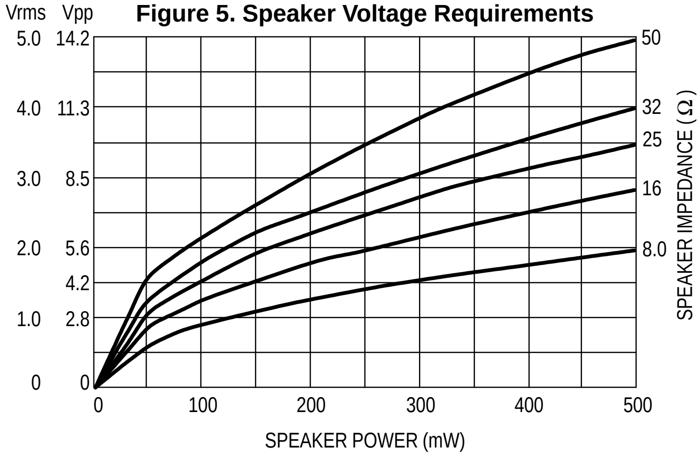


Figure 6. Speaker Current Requirements

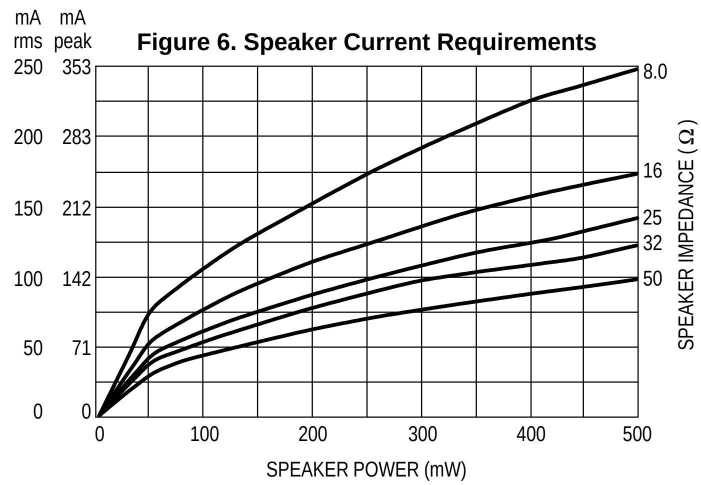


Figure 7. MC33215 Test Circuit

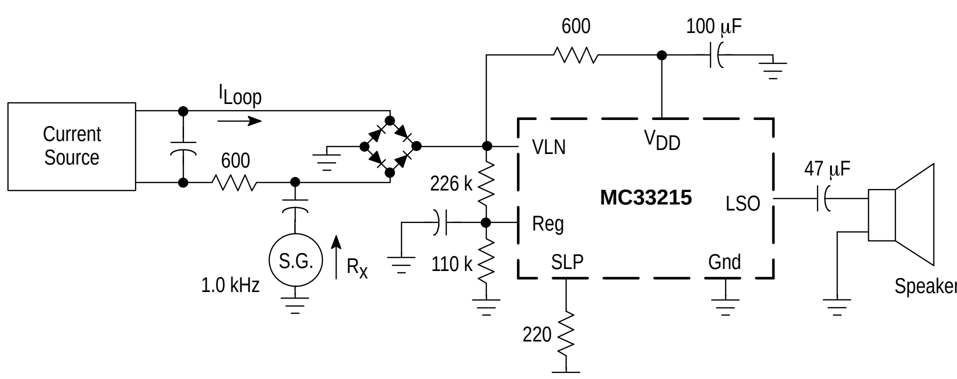


Figure 8. MC33215 Maximum Speaker Power versus Speaker Impedance

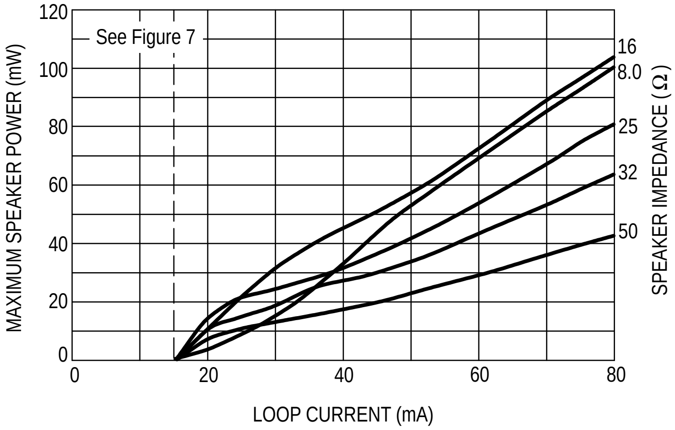
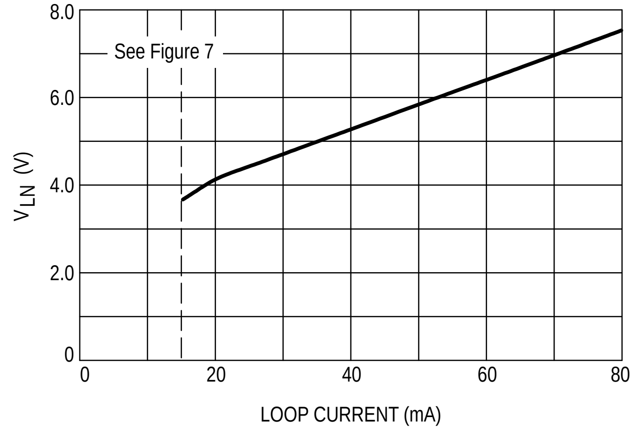


Figure 9. MC33215 DC Voltage at VLN versus Loop Current

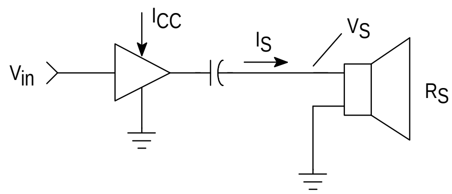


APPENDIX A

The following analysis explains why a single–ended speaker configuration uses half the current of a differential configuration for the same amount of power delivered to the speaker.

A) First the single–ended configuration will be described:

Figure 10. Single–Ended Drive

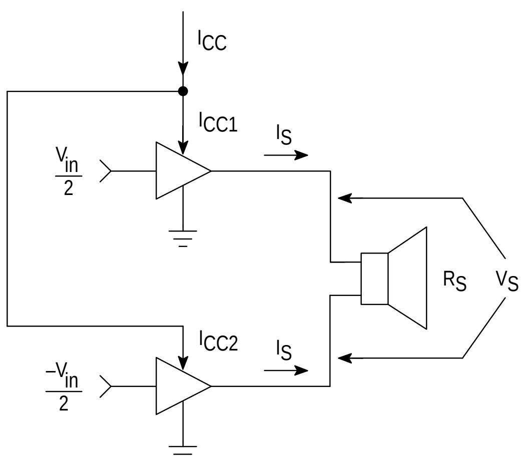


For a given power level in the speaker (P_S), the rms current in the speaker (I_S) is ($\sqrt{P_S/R_S}$), which is equal to V_S/R_S. The dc supply current to the amplifier is I_{CC}, and is proportional to I_S (neglecting the bias current required by the amplifier).

$$I_{CC} \equiv I_S = \frac{V_S}{R_S} \qquad \text{Equation 1}$$

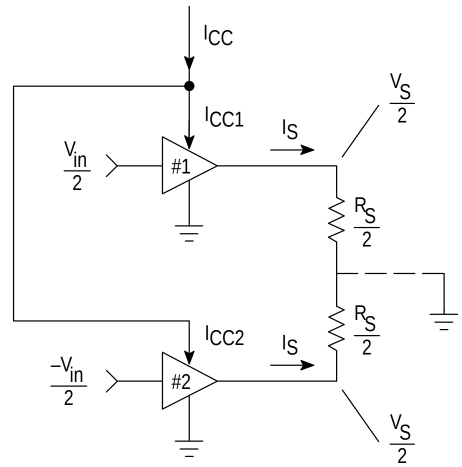
B) Now consider the differential output configuration:

Figure 11. Differential Drive



The rms voltage across the speaker (V_S) is the same as in example A above, providing the same power. In this case, it is provided by two amplifiers which are providing equal, but oppositely phased signals to the speaker. (The amplitude at each output is $V_S/2$). Because of this arrangement, the speaker impedance can be considered as two impedances in series, each $R_S/2$, with their midpoint being a virtual ground.

Figure 12. Differential Drive Detail



Since the voltage swing at each amplifier's output is $V_S/2$, then the current from each amplifier is:

$$I_S = \frac{V_S/2}{R_S/2} \text{ or } \frac{V_S}{R_S} \qquad \text{Equation 2}$$

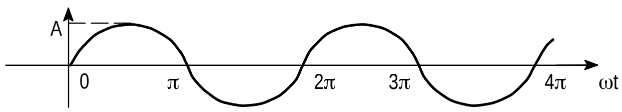
The current out of each amplifier is the same as in example A, which is logical since the speaker's current should be the same for a given power level. Since the supply current for each amplifier is proportional to its speaker current, the total current (I_{CC}) is equal to:

$$I_{CC} = (I_{CC1} + I_{CC2}) \equiv 2 \times I_S = 2 \times \frac{V_S}{R_S} \qquad \text{Equation 3}$$

If the supply voltage is the same in both examples, then twice the power is being dissipated in example B as in example A. If the power in the speaker is the same in both cases, where does the extra power go to? The answer is that it is dissipated in the output stage of amplifiers #1 and #2. Since their output voltage swing is only half that in example A, there is more voltage difference between the outputs and the supply rails. Since the speaker current has to go through that voltage difference, the extra power is dissipated there.

APPENDIX B

When supplying a sine wave signal to a speaker via an amplifier, the average current for each half cycle is calculated as follows:



$$I = A \sin \omega t$$

$$\text{Average} = \frac{\int I \, d\omega t \Big]_0^{\pi}}{\pi} = \frac{-(A \cos \omega t)\Big]_0^{\pi}}{\pi} = \frac{A + A}{\pi} = \frac{2A}{\pi}$$

$$\text{Average} = \frac{A}{1.57}$$

In a single–ended configuration, such as in Figure 10, the amplifier output will source current to the speaker as its voltage is increasing, such as from 3π/2 to 5π/2 in the above waveform. This current is supplied from the external power supply as I_{CC}. During this time the coupling capacitor to the speaker is being charged.

When the amplifier's output voltage is decreasing (from 5π/2 to 7π/2), the amplifier is sinking current from the charge stored in the capacitor to ground. During this time, the external power supply is not supplying any current to the amplifier.

The overall average power supply current for this configuration is therefore equal to one half of the sine wave's average value, or

$$I_{CC} = \frac{A}{\pi} \quad \text{(Single–Ended Mode)}$$

In a differential configuration, (Figure 11), when amplifier #1's output is greater than that of amplifier #2, it is sourcing current to the speaker, and amplifier #2's output is sinking that current to ground. The average supply current to amplifier #1 during this half cycle is 2A/π, and zero to amplifier #2. During the next half cycle, amplifier #2 is sourcing current to the speaker, and amplifier #1 is sinking that current to ground. The average supply current during this half cycle is also 2A/π (to amplifier #2). Therefore, the overall average power supply current for this configuration is:

$$I_{CC} = \frac{2A}{\pi} \quad \text{(Differential Mode)}$$

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