

Understanding Relationships between Voltage – Current – Impedance

Foreword

This paper addresses general sound reinforcement system design issues and offers application solutions provided by Lab.gruppen C Series power amplifiers. We'll review these products' capabilities, provide guidelines for amplifier sizing based on speaker load and, describe the important relationship between voltage & current.

Let's begin by identifying 3 core functions of an amplifier:

- 1) Provide clean, undistorted audio power to the speakers
- 2) Protect the speakers from excessive signals and abuse
- 3) Protect the amplifier itself under all conditions

System Design

The purpose of a quality engineered sound reinforcement system design is to deliver the program at the required **Sound Pressure Level** or **SPL** to a listener's position. We begin by selecting a speaker system, placing it at some distance 'd' from the listener and delivering ' P_{SPKR} ' watts of power from an Amplifier as shown in figure 1.

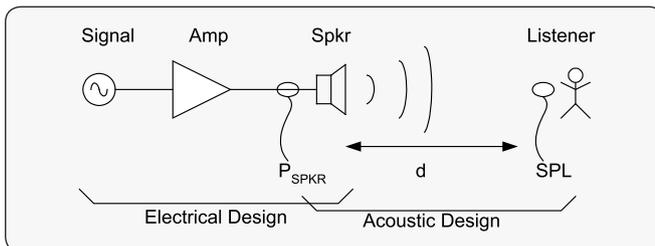


Figure 1

Acoustic Design

In the Acoustic Design, the ' P_{NOM} ' which is the nominal power and, ' P_{MAX} ' which is the maximum power, dictate the size amplifier we need given the target **SPL**. Both power levels must be identified to properly match the amplifier for the speaker's characteristic impedance or ' R_{LOAD} ' (8ohm, 4ohm, 2ohm, etc.) Let's look at a few factors concerning the Acoustic Design while referring to figure 2.

Sound decreases in level 6dB for every doubling of distance 'd' from the speaker; e.g. 60 feet is -6dB compared to 30 feet and 120 feet is -6dB compared to 60 feet. The speaker's specified sensitivity is its output SPL, measured typically at 1 Meter on axis when driven with 1 Watt. Most manufacturers will specify this as the ' $dB_{SPL}/W/M$ ' sensitivity value for their product along with the maximum power handling capability or ' P_{MAX} '.

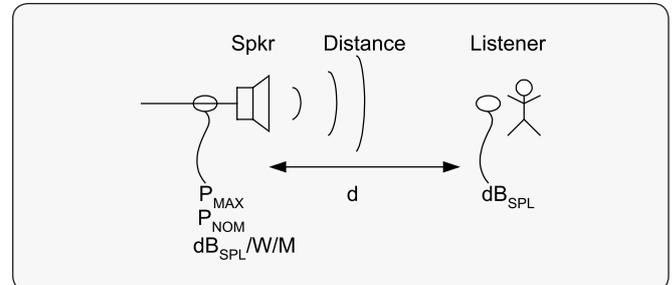


Figure 2

Knowing the speaker sensitivity and the target ' dB_{SPL} ' at the listener position, we can calculate for the nominal power required at the speaker or ' P_{NOM} '. The ' P_{NOM} ' should not exceed ' P_{MAX} ' else the speaker may be overdriven.¹

When the speaker is selected and the nominal power P_{NOM} requirements have been determined for the target **SPL** at the listener we can then specify the correct type and size of amplifier.

Electrical Design

In the Electrical Design, we'll choose an amplifier with a maximum power output ' P_{AMP} ' at the load impedance ' R_{LOAD} ' that is greater than or equal to ' P_{MAX} '. You must also factor for additional power or "headroom" to ensure the amplifier does not clip or distort when delivering its' maximum power or P_{MAX} . Headroom is the difference in dB between the nominal operating level you expect from the system and the maximum output or clip level. The goal is to design a system with a properly sized amplifier that is gain matched for the nominal input signal levels from the console and provides sufficient headroom (in the range of +6dB to +20dB) so that the peak power

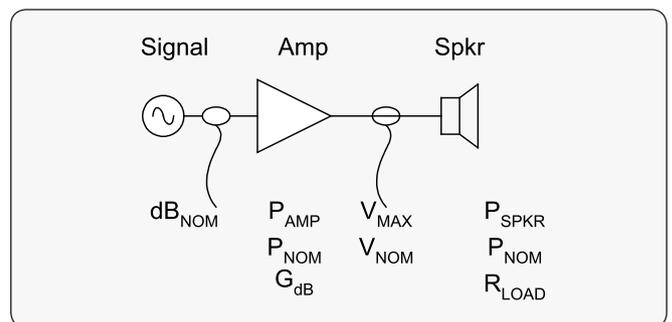


Figure 3

levels are delivered without clipping.

At this point the electro-acoustic system should provide the target sound levels. If we add signal processing capabilities to ensure reliable, maintainable and consistent performance we'll achieve a high quality sound experience.

What amplifier performance features should you look for and how will they effect the configuration of the entire system? Let's first look at the system's electrical design.

A power amplifier applies an audio voltage to a speaker and for a given load impedance a certain power will be drawn. If our amplifier can limit the speaker voltage to ' V_{MAX} ', which would deliver ' P_{MAX} ' to the speaker, we can protect the speaker from damage caused by excessive power. We may also choose to limit output voltage to ' V_{NOM} ' to maintain the nominal power ' P_{NOM} ' to the speaker. At all times our goal is to deliver the correct power to produce the desired level ' dB_{SPL} ' at the listener position.

Another system consideration is the required input signal level to the amplifier ' dB_{NOM} ' to produce the power ' P_{NOM} ' at the speaker and the desired ' dB_{SPL} ' at the listening position. As a matter of convention, designers will choose 0 dBu or +4 dBu as the nominal input signal to drive a system to nominal SPL levels. Using the amplifier's gain control you can adjust for 'VNOM' at the output for a given 'dBNOM' input level.

Electrical Types

There are two amplifier configurations used to drive commercial speaker systems; they are high impedance or low impedance. Each has distinct performance advantages and both may be appropriate for use in the same venue. Both deliver amplifier power to the speakers but the difference is in the way they drive the connected loads including speaker(s) and the interconnecting cable(s).

Large scale, low impedance systems deliver high current and are intended for high quality, high **SPL** applications. Stage productions and concert performances will always use high current, low impedance speaker systems that are configured to service a few speakers and to deliver the maximum power. Longer speaker cables will dissipate more amplifier output current so the available power at the speaker will decrease proportionally. Low impedance systems use large gauge speaker cables that are as short as possible to efficiently deliver maximum amplifier power.

High impedance systems, also known as constant voltage systems, deliver high peak voltages, typically 70v or 100v and are generally used for low to moderate SPL applications. These systems use large

quantities of installed speakers as typically found in airports, hotels and convention centers and they may have hundreds of feet of speaker cable connecting them to the amplifier. The resistance of these long speaker lines combined with the characteristic reactive load produced by many attached speakers requires high constant voltage to drive the line, compensating for cable loss while delivering the maximum power.

Mixed use of low and high impedance systems can be found in venues such as cinemas or theme parks. The low impedance speakers are used for sound reinforcement in the presentation spaces and separate high impedance systems are used for the speakers that deliver voice paging and background music in lobbies, rest rooms or other non-presentation spaces. Amplifiers such as the Lab.gruppen C Series are a great choice for these permanent installations because they service both low and high impedance speaker systems from a common 2 rack-space unit with 4 separate channels.

Power, Signals and Ohms

The two system types, high impedance and low impedance, each have different electrical requirements. A proper system design for either type necessitates calculating for voltage, power and dB values. To solve for these we use Ohm's law. Ohm's law and the power definition describe the current through and the voltage across a speaker relating the power in the load to current, voltage, and load

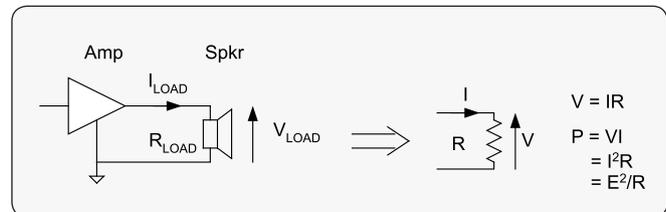


Figure 4

resistance. Figure 4 shows the currents and voltages and provides expressions for power.

In most speaker specification sheets you will see different types of rating voltages listed. The voltage across the speaker can be described as peak or **RMS** values, where 'peak' refers to the maximum value and '**RMS**' can be thought of as a time average measure of the power producing effect of the signal voltage. Figure

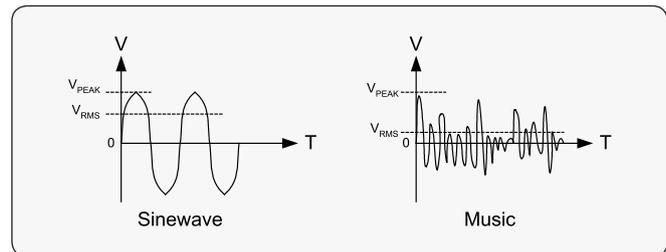


Figure 5

5 shows the differences between peak and **RMS** values for a single note (sine wave) and for typical musical program signals.³

Speaker Impedance

Let's look at voltages and currents for various speaker impedances and powers. Figure 6 shows an 8 ohm load driven with 100 watts of power.⁴

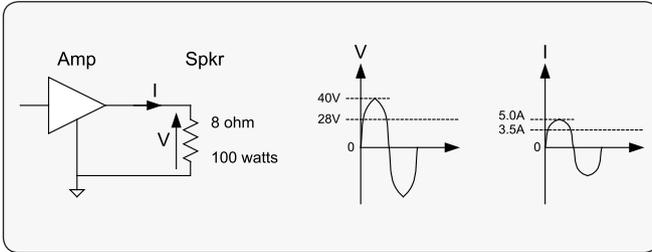


Figure 6

Low Impedance speakers are typically in the range of 2 ohms to 16 ohms. The ratio of voltage to current (V/I) remains constant for the same load. As the speaker load decreases for a given amplifier power the voltage (V_{RMS}) decreases and the current (I_{RMS}) increases. This may appear to be a simple concept but in reality it is something that many commercial grade amplifiers do not adequately address. That's because delivering high voltage for high impedance systems and high current for low impedance systems, with 4 separate channels, all within the same compact 2U chassis, presents some real performance challenges for the amplifier designer. It necessitates added protection features and demands the highest quality components. It begins with the power supply which is the heart of an amplifier and C-Series are designed to continuously produce full output without "sag" or diminished output during demanding high current operation with low impedance speakers and, with the change of the rear panel DIP switches, the same channel swings the voltage for high impedance output that remains constant ensuring peak performance in distributed systems.

To give you an idea of how important it is to specify an amplifier that can deliver the power under all conditions let's look at the differences in voltage and current for a low impedance system using two different power levels, 100W & 1000W with 2, 4 & 8 ohm impedances. Note the differences in the voltage V_{RMS} and Current I_{RMS} requirements to deliver the same power. In the first reference it requires 3.5 amps at 28 volts to deliver 100W into an 8 ohm load.

Amplifier Power	Load Impedance	Voltage V_{RMS}	Current I_{RMS}
100 W	8 ohm	28 V	3.5 A
100 W	4 ohm	20 V	5.0 A
100 W	2 ohm	14 V	7.0 A
1000 W	8 ohm	90 V	11.1 A
1000 W	4 ohm	63 V	16.0 A
1000 W	2 ohm	45 V	22.0 A

Decrease the speaker load to 2 ohms, which is the minimum safe operating level and it requires 7 amps at 14 volts to deliver the same 100 watts. Nothing else has changed, only the load impedance. Now let's look at the requirements for a Constant Voltage system using the 70.7 and 100 V_{RMS} outputs with different load impedances. Here the output voltage remains constant and the output current (which is much lower than with low impedance systems) varies by load for a given power:

Amplifier Power	Load Impedance	Voltage V_{RMS}	Current I_{RMS}
10 W	500 ohm	70.7 V	0.14 A
25 W	200 ohm	70.7 V	0.35 A
50 W	100 ohm	70.7 V	0.71 A
100 W	50 ohm	70.7 V	1.4 A
1000 W	5 ohm	70.7 V	14.14 A
10 W	1000 ohm	100 V	0.1 A
25 W	400 ohm	100 V	0.25 A
50 W	200 ohm	100 V	0.5 A
100 W	100 ohm	100 V	1.0 A
1000 W	10 ohm	100 V	10.0 A

As these numbers show there are significant differences in the amount of current and voltage required to deliver the target power in low and high impedance systems. A quality amplifier design is therefore required to provide an assortment of comprehensive protection features for consistent operation with the best sound quality, day after day. Let's examine some of these features and apply what we have learned.

VPL Voltage Peak Limiter

VPL greatly enhances the C Series amplifier's utility for individual channels used in mixed systems that require both low and high impedance amplification in a single unit. Selecting the appropriate peak voltage limit for the load ensures the amplifier operates at the highest levels yet within its limits. **VPL** is an effective protection feature that when properly configured reduces the triggering of either the high temperature or **CPL** current peak limiter protection circuits that mute individual channels when active.

The Lab.gruppen C Series amplifier's peak output voltage limits may be set to values of $1.414 \times V_{RMS}$ to limit power output. To set the limits all we need to know is the required power and the load impedance.

To match the amplifier to speaker load, **VPL** is configured with DIP switches on the rear panel in 8 steps from 30% to 100% of maximum output voltage. **VPL** may be set to hard or soft clip limit and enables safe operation with low or high impedance loads. There are 3 green front panel LEDs that indicate -4dB, -10dB, -40dB input signal levels that's useful for selecting the appropriate input gain for driving the attached load and to achieve the target **SPL**.

Front panel red LED's will illuminate when **VPL** is active. There's also a second red SIG | HI-IMP LED that, when illuminated along with the **VPL** LED, indicates a shorted load has been detected which requires remedial action.

High impedance 70Volt amplifier outputs are configured for a

maximum of $70.7 V_{RMS}$ (with headroom that's $100 V_{PEAK}$) and the matching high impedance speakers are designed to reach their rated power at 70.7V. Connect the speakers (as many as required to cover area) to the amplifier so long as the total load is kept below the total power capability of the amplifier.

For high impedance loads we set amplifier peak voltage to $100 V_{PEAK}$ so the $70.7 V_{RMS}$ voltage is not exceeded.

CPL Current Peak Limiter

Another Lab.gruppen amplifier configuration and protection feature is offered with **CPL** or the Current Peak Limiter. **CPL** is an indicator for maximum amplifier output current. The trigger is based on the output transistors which have limits on the amount of current they can safely source and the **CPL** limiter will flash the front panel LED when the maximum current draw is approaching. The LED will change to a steady orange and the channel will mute when high output current & voltage in excess of the output limit is sensed. will hold the channel muted until the load and/or input gain is reduced and peak current is below the protection threshold. In situations where the load impedance is not known **CPL** is a useful indicator (producing a steady orange LED) for sensing when the amplifier is near the maximum load or is experiencing extremely low load impedance. The **CPL** circuit cycles every 6 seconds and if the load returns to a state that's within predetermined limits, the amplifier channel will automatically resume operation. **CPL** does not affect program signals when driving a properly matched load.

Amplifier Setup

If system gain is properly configured and sufficient headroom (the difference in dB between operating level and maximum output or clip level) has been factored into the design, then the maximum peaks in the program material will be reproduced without clipping.

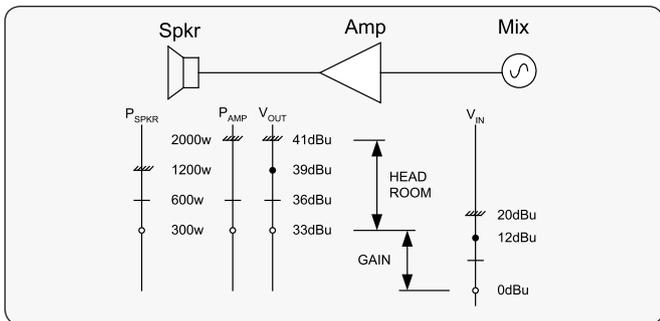


Figure 7

This is important because all audio devices in the signal chain contribute to the system's ultimate sound quality and, clipping anywhere in the signal chain cannot be corrected elsewhere in the chain.

Lab.gruppen C Series amplifiers can be configured to limit the output voltage with a variety of gain settings to match a nominal input level.

This enables the system designer to optimize the amplifier Gain Structure, allowing for the desired operating headroom.

Figure 7 shows this design approach. Our 4-ohm speaker is rated at 600w maximum average power and 1200w maximum peak power. If we select the Lab.gruppen C 68:4 amplifier we can expect 1700w with headroom. High level dynamic music program's V_{PEAK} can reach levels of 3 to 10 times V_{RMS} corresponding to +10 to +20 dB of required headroom to avoid amplifier clipping and prior to reaching the speaker's maximum power handling. The powers and voltages in dBu for this gain structure are shown.

Example: if we want our mixer output signal at 0dBu to provide our nominal operating power of 450w we will set the amplifier gain to +35dB. The amplifier then has 6 dB of headroom before it clips and we set the **VPL** switch to 141V corresponding to 1700W at 4-ohms. The mixer has 20dB of headroom before it clips.

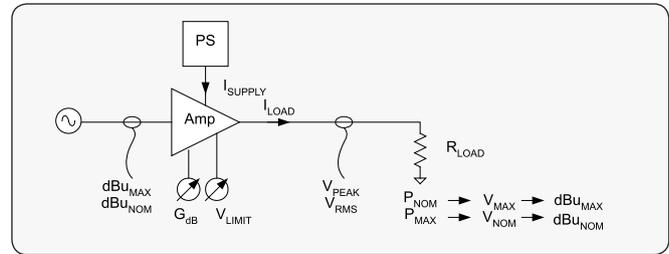


Figure 8

Lab.gruppen C Series amplifiers have input gain settings in 3dB steps from +23dB to +44dB. This broad range of gain settings provides great flexibility in configuring the amplifier to ensure you can match the nominal input level for maximum headroom.⁵

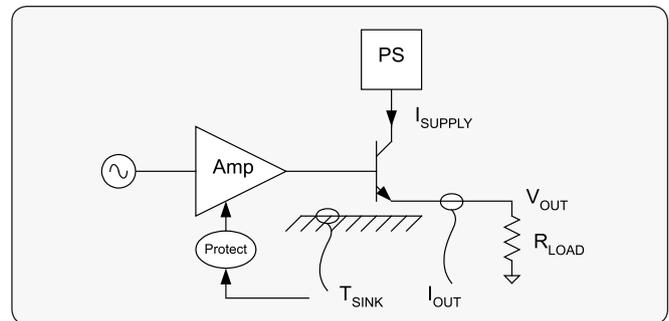


Figure 9

Amplifier Protection

First and foremost, the Lab.gruppen is founded on the design and manufacture of exceptionally reliable amplifiers that deliver the highest quality sound. Whether permanently installed or on the road touring they are great and consistent performers.

The primary protection circuits monitor for excesses in voltage, current and temperature as shown in figure 9. Let's review these features.

High Temperature Protection

Amplifiers convert power supply energy to load energy using the output transistors, which are modulated by the input signal. Output transistors generate heat that's dissipated by the heat sink. Lab.gruppen amplifiers use a variable speed fan to exhaust the heat through the chassis rear panel. That's why it is imperative that the air inlets on the front panel are kept clear of restrictions and the filter screens are maintained.

At all times the heat sink temperature is monitored and the thermal protection circuit will engage whenever the amplifier exceeds limits that would otherwise damage the output transistors. The yellow TEMP LED on the front panel will flash when the amplifier is approaching the limit and once a thermal limit is exceeded the LED will illuminate (steady) and the amplifier channel will mute. When a safe operating temperature is reached the amplifier channel will un-mute and return to service; the front panel TEMP LED will turn off. Amplifier thermal protection is influenced by the selection of the input gain and VPL. Input level should be reduced as soon as the TEMP LED begins flashing. If the level reduction results in program levels that are too low check the **VPL** DIP switches to ensure the output is optimized for the load. If the **VPL** is set correctly and the thermal protection circuit continues to engage you will need to re-evaluate the load. This may necessitate a decrease in the number of speakers connected thus changing the load impedance or it may require an increase in the amplifier size.

There's also a separate thermal limit sensor for the power supply and when triggered all channels will mute; they will remain muted until the power supply returns to a safe operating temperature whereupon the mute is released.

PAL Power Average Limiter

The C Series amplifier's power supply is monitored for current draw that's averaged. If a sustained high current situation occurs that's close to the trip point for the mains breaker, the PAL circuit will engage to limit the draw and power output. The front panel PAL LED will illuminate when active and the circuit does not affect short duration, high current demands in the power supply that's present with dynamic program. A common reason for the PAL to engage with a properly sized load is the presence of a short.

VHF Very High Frequency protection

Whenever the amplifier is operating at near maximum power levels, any very high frequencies that are caused by oscillations in the signal chain will damage the speaker and/or the amplifier. Sustained very high frequencies above 10kHz are not typical in transient program material and when sensed the channel will mute and the front panel LED will illuminate. The circuit will automatically cycle every 6 seconds. Transient program materials with frequencies up to 20kHz will pass without causing the circuit to engage.

Monitoring & Control

The NomadLink Network is a standard feature and enables remote monitoring of the amplifier configuration and condition. This is a very useful tool when the amplifiers are located in remote equipment rooms that are away from the control position. A PC editor application displays all front panel indicators along with the positions of the DIP switches on the amplifier rear panel. Additional remote control of amplifier functions includes individual channel mute or un-mute, solo and sequential power on-off. Up to 16 subnet of 60 amplifiers each (Total = 3840 ch.'s) can be monitored and controlled in a NomadLink network.

Conclusion

When laying out a sound system there are several design "Best Practices" that should be observed to ensure the installed system has the kind of performance and reliability you intended. A cornerstone of these practices is a thorough understanding of Ohm's Laws and how it relates to equipment selections that properly match the application - amplifiers and their loads.

Once you have determined the correct size amplifiers for your system look at the various protection and monitoring features that are available to you that enhance the sonic performance and reliability of the system under all operation conditions. Lab.gruppen C Series amplifiers drive both low & high impedance systems and offer the greatest utility for any permanent installation requiring exceptional sound quality and performance.

Unique protection features such as **VPL & CPL** combined with a broad assortment of input gain selections enable more options for the designer to configure the headroom with maximum output. Lab.gruppen's power density, which is the measure of power available in the smallest amount of rack space with 4 discreet channels per C Series chassis means you'll always have low & high impedance configuration flexibility, the most available power, best sonic performance and most comprehensive speaker protection. This adds up to the best overall value for any sound system amplifier.

Terms & Abbreviations

dB: The dB symbol represents the decibel, a unit of measurement that expresses levels for audio electronics, RF signals and communications. The dB is a logarithmic unit for a ratio that can be used for power, sound pressure level, voltages or intensity.

d: The distance between a speaker and a listener position or target audience location. Sound decreases in level 6dB for every doubling of distance or 'd' from the speaker.

E: The symbol E represents the voltage or electrical pressure of the electrons in a circuit and its unit of measure is the volt. The symbol V is used interchangeably.

I: The symbol I represents the current or rate of flow of electrons in a circuit and the unit of measure is the ampere that's also abbreviated as amp.

Ohms: The resistance of an electrical circuit measured with voltage and current present where the ratio of voltage to current (V/I) is always the same for the same resistive R material. The ratio is called resistance, measured in ohms and expressed as $R = V / I$ or algebraically $E = IR$ and $I = E/R$.

P_{AMP}: The output power of an amplifier.

P_{NOM}: The nominal amplifier power. When matched with a load this power level provides sufficient SPL for operational requirements.

P_{MAX}: The maximum power produced. This level should provide the speaker with the maximum power within the unit's safe operating area limit.

P_{SPKR}: Amplifier power expressed in watts that's delivered to the speaker.

Power: Power is based on Joule's & Ohm's Laws, expressed in watts: $P = I^2R$; $P = IE$; $P = E^2/R$

R_{LOAD}: The total resistance or impedance of the load including all intermediary connections between the amplifier output and speaker.

R or Resistance: R represents the Resistance of a circuit and its unit of measure is the ohm.

RMS: Root Mean Squared can be thought of as a time average measure of magnitude of the power producing effect of the signal voltage.

SPL: Sound Pressure Level is an acoustic measurement usually expressed in dB. It is commonly defined using a reference which is the approximate intensity at 1000 Hz, barely audible at the threshold of hearing or which is zero phons.

V: The symbol V represents the Voltage or electrical pressure exerted by the electrons.

V_{MAX}: The maximum voltage at the amplifier output.

V_{NOM}: The nominal voltage at the amplifier output.

Watt: The power produced by current flowing to a voltage potential: 1 amp flowing through a potential of 1 volt produces 1 watt.

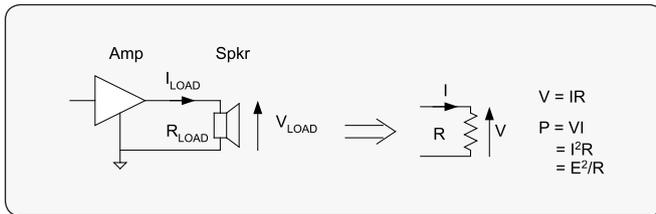
Appendix

1: To find the maximum speaker power use the equation:
 $DB_{SPL} = dB_{SPL}/W/M + 10\log(P_{NOM} / 1W) - 20\log(d_{METERS} / 1M)$

To find the required nominal speaker power PNOM use the equation:
 $P_{dB-NOM} = DB_{SPL} + 20\log(d_{METERS} / 1M) - dB_{SPL}/W/M. P_{NOM} = 10^{(P_{dB-NOM} / 10)}$

2: Ohm's law is a definition based on observations made by German physicist Georg Ohm in the early 1800s. He measured current flow (I) through various conductors as different voltages V, were applied. Ohm found that the ratio of voltage to current (V/I) was always the same for the same material. Today we call that ratio resistance, measured in ohms and expressed as $R = V / I$. With a little algebra we can rewrite the equation as $V = I R$ or $I = V / R$. A second definition concerns the power dissipated in a resistance. Power in watts is defined as $P = V I$, the product of voltage times current. We can use the Ohm's law forms of $V = I R$ or $I = V / R$ to substitute into the power definition for alternate power expressions $P = I^2 R$ and $P = E^2 / R$, or rearranging, $I = \text{SQRT}(P / R)$ or $E = \text{SQRT}(P R)$

3: For a sine wave, $V_{PEAK} = 1.414 V_{RMS}$. For music, V_{PEAK} is typically 3

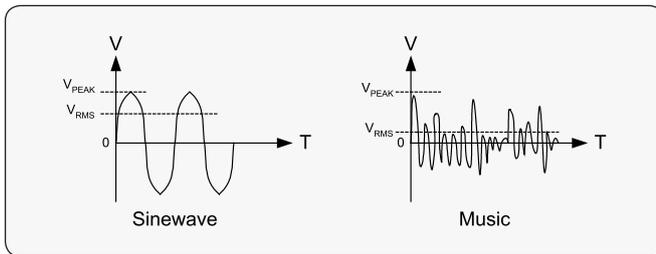


to 10 times V_{RMS} corresponding to +10 to +20 dB of headroom.

Voltage ratios and Gain ratios are often described in decibels. Most often the voltage ratio, **dBu**, is given by the following definition:

$$dBu = 20\log(V_{RMS} / 0.775v).$$

Gain ratios are usually expressed as: $dB = 20\log(V_{OUT} / V_{IN})$



4: We use $I = \text{SQRT}(P / R)$ or $E = \text{SQRT}(P R)$ to calculate RMS voltage and current. Peak values are (1.414 x RMS).

5: If you want to limit the power to the speaker or ' P_{MAX} ' use the equation:

$V_{RMS} = \text{SQRT}(P_{MAX} R_{LOAD})$ to set the amplifier output VPL voltage protection limiter control or V_{LIMIT} to V_{RMS} (or $VPK = 1.414 V_{RMS}$) to protect the speakers.

The output voltage V_{RMS} value corresponds to a **dBu** value of $dBu_{OUT} = 20\log(V_{RMS} / 0.775)$. Set the amplifier Gain control to produce this level for 10dBu input as given by $GdB = dBu_{OUT} - dBu_{IN}$. Alternately, we can map 0dbu input to V_{NOM} to exchange V_{NOM} for V_{RMS} , now using the voltage limiter to control nominal output instead of maximum output.

