CTS-Prep Workshop II
Ohm's Law, Impedance and Decibels
Italy, April 2020
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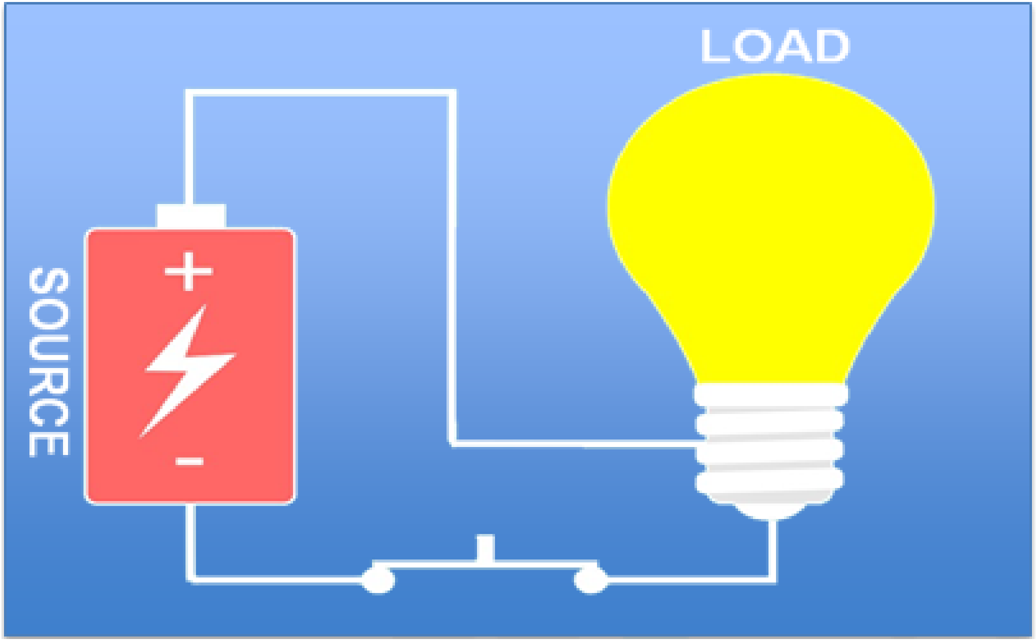
Goals

- Review Ohm's Law
  - Calculate V, I, R and P
  - Understand Bus Power in AV systems
- Calculate Speaker Systems Impedance (Z)
- Understand Impedance matching with amplifiers
- Review the concept of Decibel
- Understand Decibel calculations
- Review Speaker configurations

Circuits

Circuits have:

- Source
- Load
- Conductor

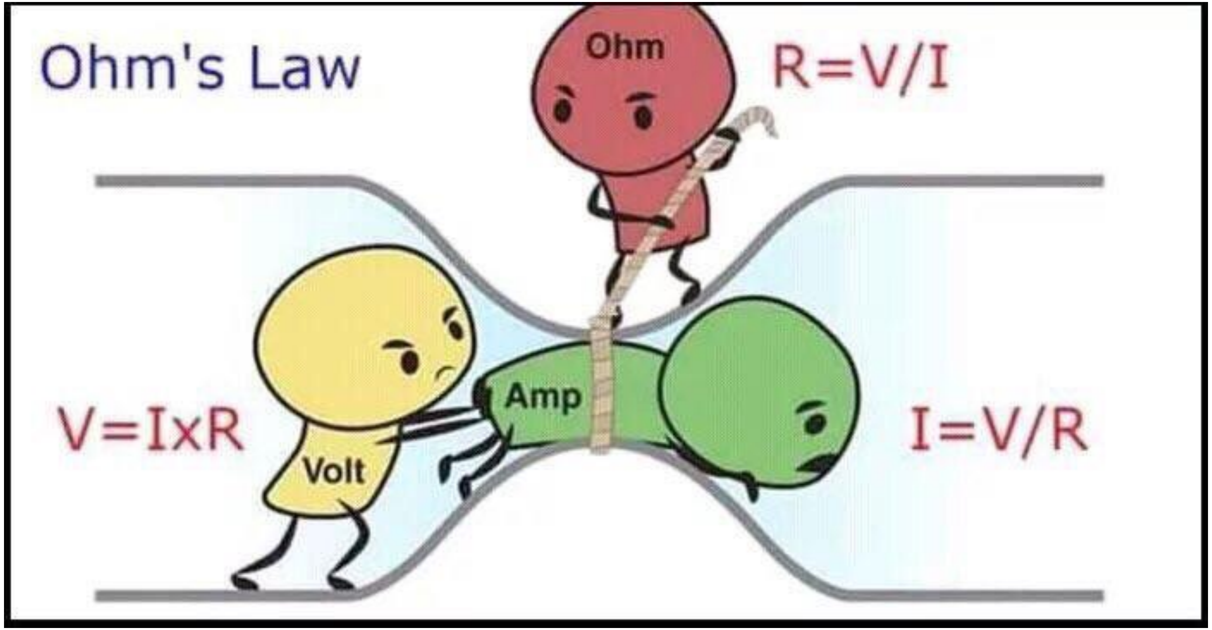


Ohm's Law $V = I * R$

V (voltage) - volts

I (current) - amperes

R (resistance) - ohms



Introduction to Ohm's Law

- Expresses the relationships between Voltage (V), Current (I) and Resistance (R) in an electrical circuit

$$V = I * R$$

- Helps calculate the Power (P) in a circuit

$$P = I * V \qquad P = V^2/R \qquad P = I^2 * R$$

- If you know any 2 values, you can find the third one.

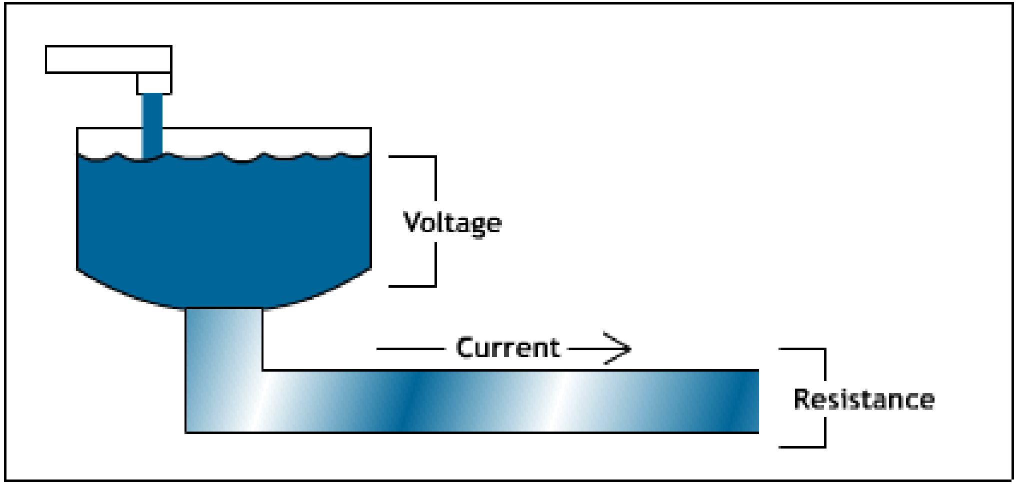
Current and Voltage

- Expressed in amps by the symbol “I”
  - The flow of electrons in a circuit
  - In a DC circuit the flow is in one direction back to source
  - In an AC circuit the flow reverses periodically.
- I = V / R

- The force that causes the electrons to flow.
  - Expressed in Volts or V (or E, Electromotive Force)
  - Mic level .002V
  - Line level 0.316V (consumer) or 1.23V(pro)
  - Loudspeaker level up to 100V
- V = I * R

Resistance

- The opposition to the flow of electrons
  - Expressed in ohms (O) and by the symbol R
  - Applies to DC (e.g. battery)
  - For AC is called Impedance (Z), to be discussed later
- R = V / I



Activity: Ohm's Law Calculations

Calculate the current in a circuit where the voltage is 2V and resistance is 8 ohms.

- I = 2 / 8
- **I = 0.25 A**

Calculate the voltage in a circuit where the current is 4 amps and resistance is 25 ohms.

- V = 4 * 25
- **I = 100 V**

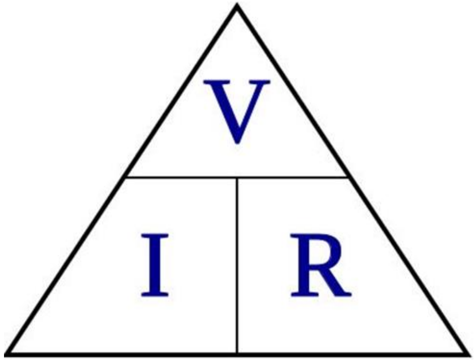
BUS Powered solutions

- An electrical connection between a host and a set of devices attached to and dependent upon the host is called a Bus
- When the connexion also carries power, we refer to it as Bus Power.
- Ohm's Law defines the relationship between V, I and R as V= I * R and it is critical to the operation of the bus

Source: https://www.quora.com/What-is-Ohms-law-2

BUS Powered solutions

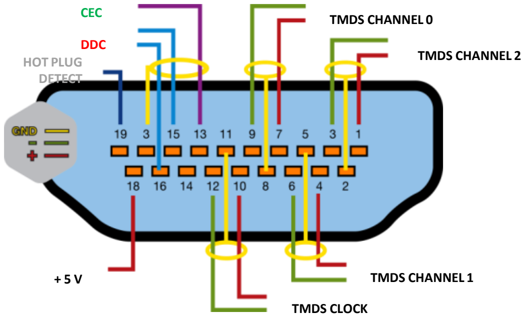
- Due to the resistance of the cable, some of the voltage is lost in the transmission
- 5 meters of AWG 28 copper wire will add 1.1 omhs of resistance, for various types of connectors this means:
  - USB 5V @ 200 mA, .22 V or 4.4%
  - Display port 3.3 V @ 300 mA, .33 V or 6.6%
  - HDMI 5V @ 50 mA, .06 V or 1.2% (for a 15 meter HDMI cable it would be 3.6%), if it supplies more current, say 150 mA, the drop becomes 4.8%.

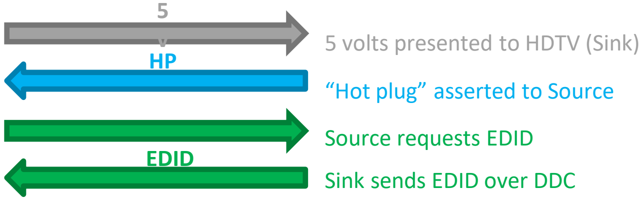


Source:
https://commons.wikimedia.org/wiki/Category:Ohm%27s_law

BUS Powered solutions

- Why does it matter?
  - Every time a source is connected to a sink, the source sends 5V to the sink and expects them back in the Hot Plug Detect Pin, to confirm that a sink has been connected.
  - This then triggers EDID and HDCP.
  - If the HPD does not happen, the signal will not be displayed





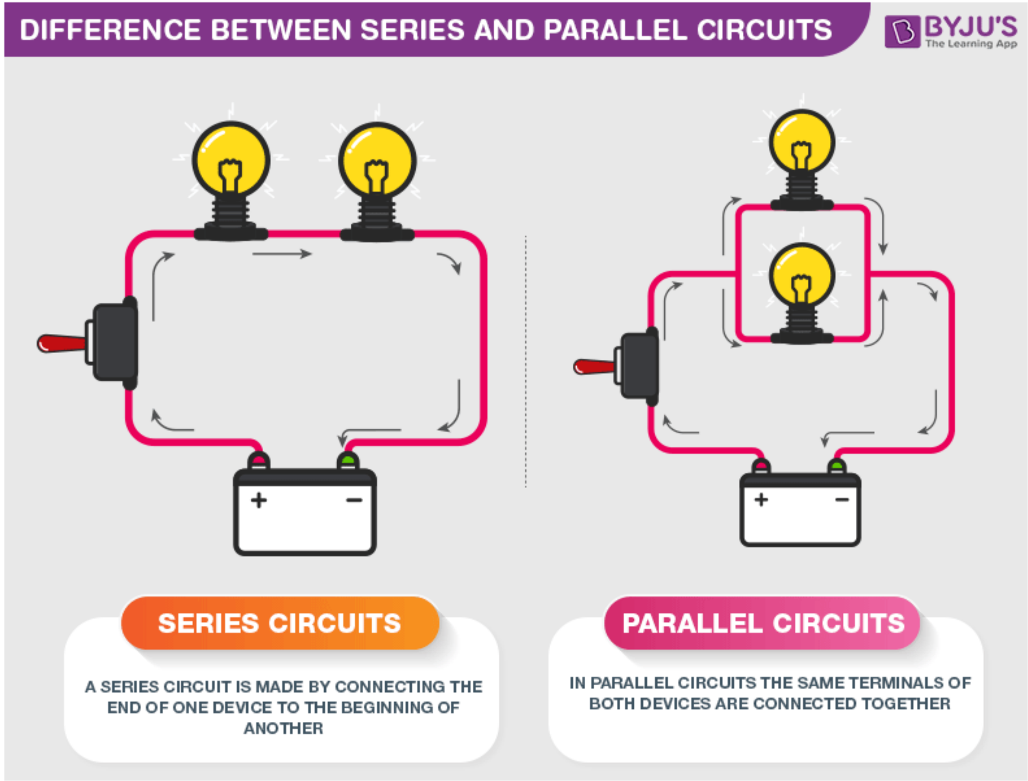
BUS Powered solutions

- With HDMI, manufacturers are asking for more power from the source for equalizer chips, media converters and downstream devices.
- The 5V/55 mA of the specification may not be enough for the system to function.
- A voltage inserter at the source, disables pin 18 and replaces the power with a transformer at 1000 mA or a USB connection at 500(USB2.0)/900 mA(USB3.0)

Impedance (AC resistance)

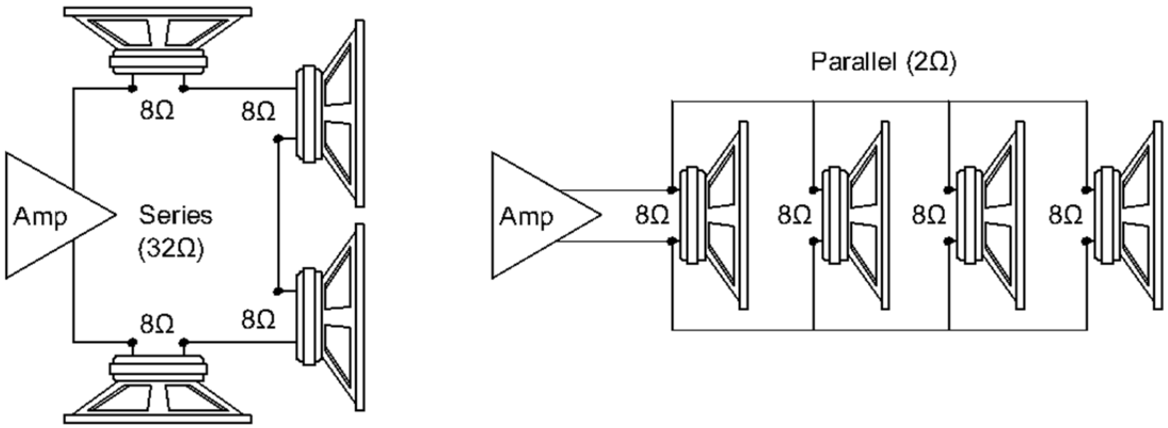
- Like Resistance, but applied to Alternating Current (AC).
- (Audio signals, radio signals, the power from the wall outlet)
- Expressed in ohms and with the symbol Z
- Important for loudspeakers and power amps

Series and Parallel Circuits



Wiring Loudspeakers

- Loudspeakers have a nominal impedance
- Impedance is the opposition to alternating current flow
- A common loudspeaker has an impedance of 4, 8 or 16 Ohms



Audio

- Impedance (Z) is Resistance (R) to AC signals
  - Series $Z_{total} = Z_1 + Z_2 + ...+ Z_i$
  - Parallel

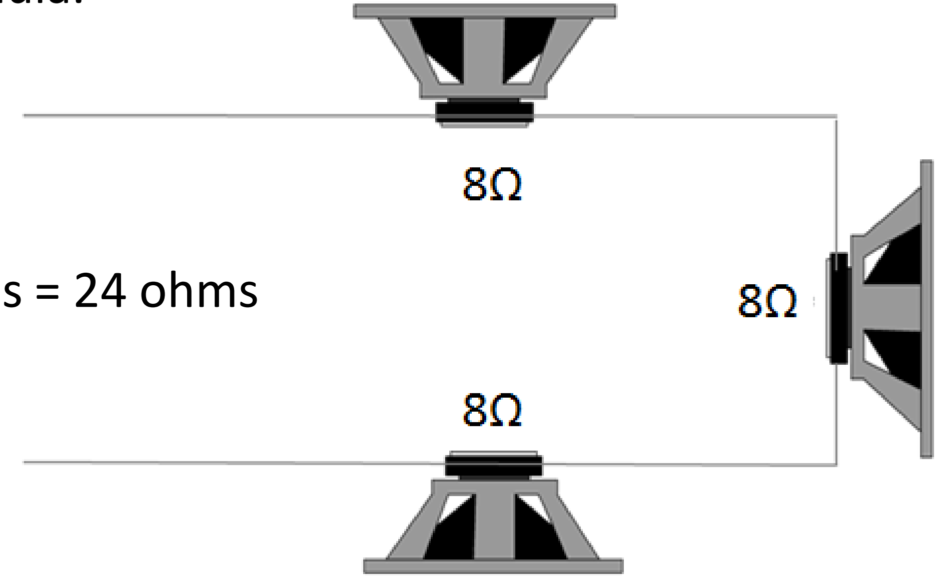
    Different Z's

$$Z_T = \frac{1}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} \cdots \frac{1}{Z_N}}$$

    Same Z all speakers $Z_{total} = Z_1 / N$

Series Impedance Example

Calculate the impedance of the following loudspeaker circuit. First, identify what type of circuit you're dealing with, then calculate the impedance from the corresponding formula.

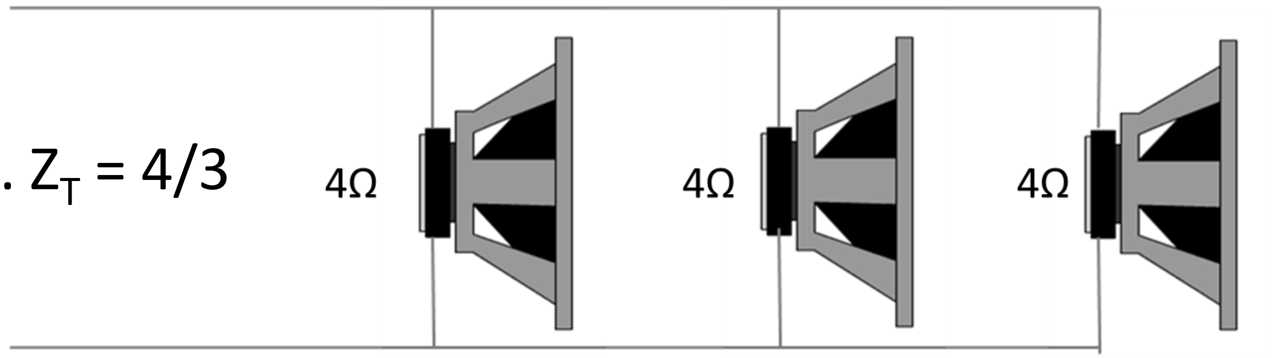


8 ohms + 8 ohm + 8 ohms = 24 ohms

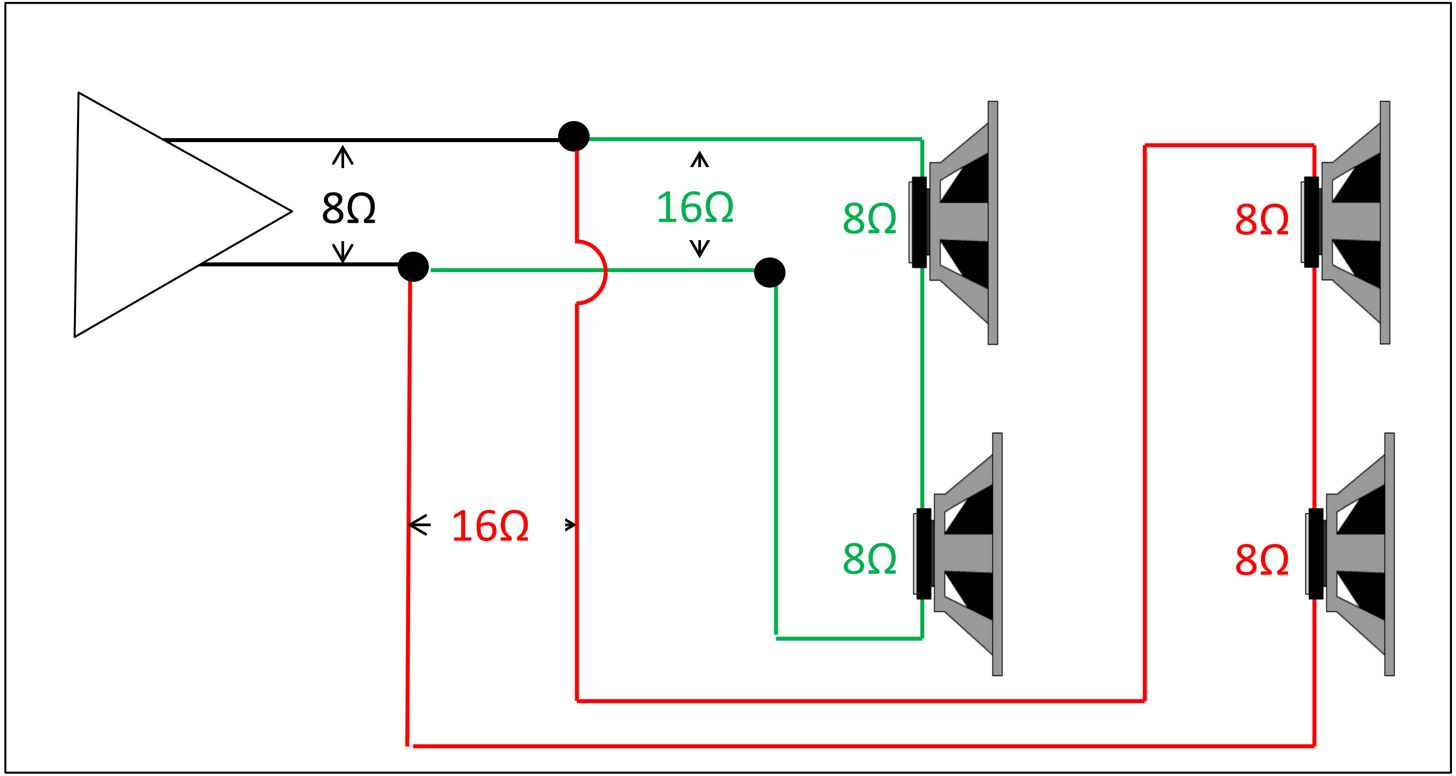
Parallel Impedance Example

Calculate the impedance of the following loudspeaker circuit. First, identify what type of circuit you're dealing with, then calculate the impedance from the corresponding formula.

1.33 ohms. $Z_T = 4/3$

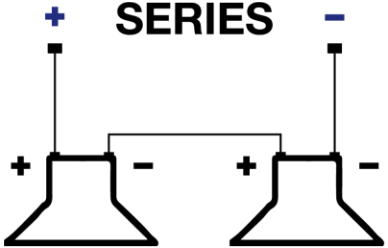


Loudspeakers Wired in a Series Parallel Circuit



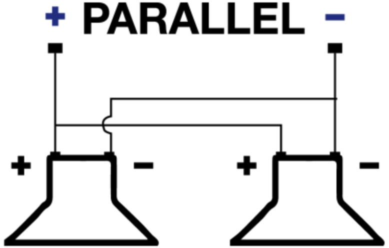
Audio

SERIES



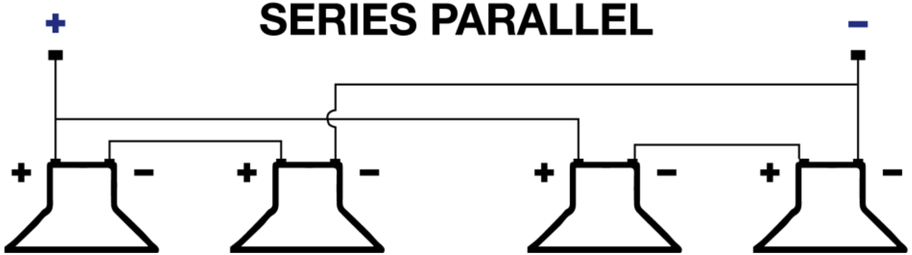
SPKRS.	LOAD
2 x 16 Ω	= 32 Ω
2 x 18 Ω	= 16 Ω
2 x 4 Ω	= 8 Ω
3 x 8 Ω	= 24 Ω

PARALLEL



SPKRS.	LOAD
3 x 8 Ω	= 2.67 Ω
2 x 4 Ω	= 2 Ω
2 x 8 Ω	= 4 Ω
2 x 16 Ω	= 8 Ω

SERIES PARALLEL



SPKRS.	LOAD
4 x 8 Ω	= 8 Ω
4 x 16 Ω	= 16 Ω

Audio

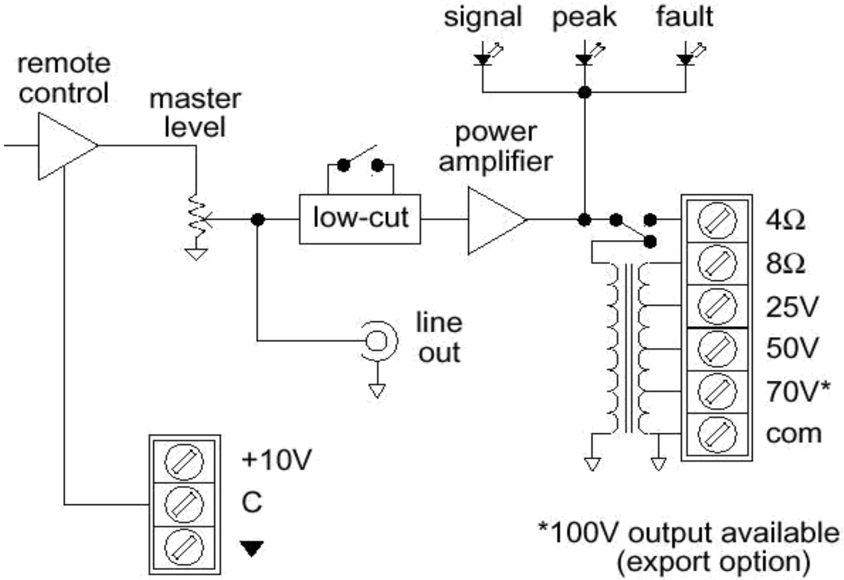
- Many Series Speakers or long cables → Very High Z

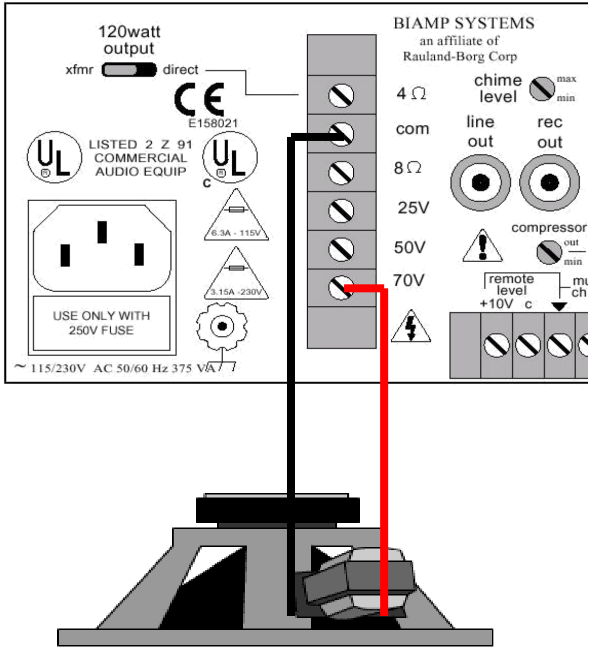
  Sound deterioration

- Many Parallel Speakers → Very Low Z

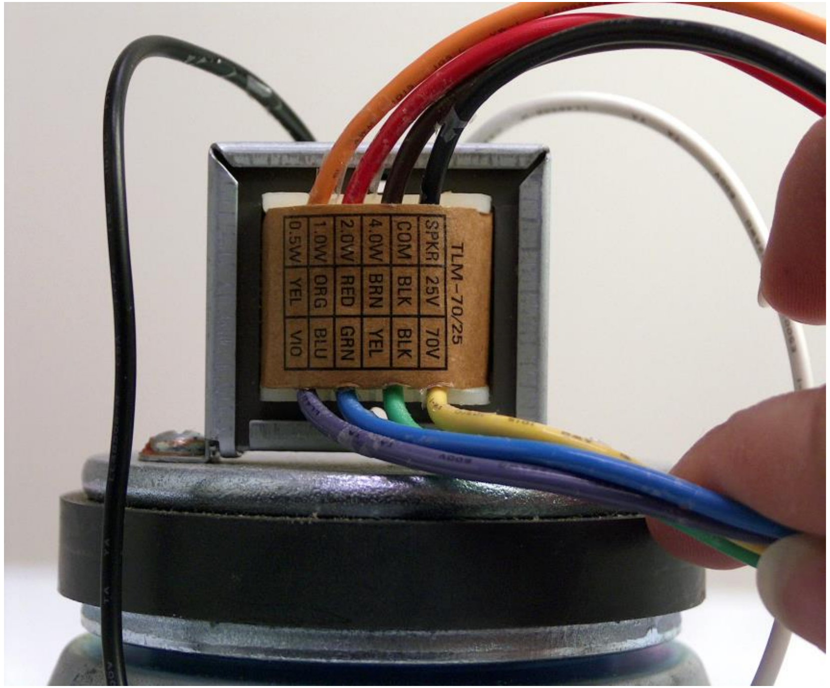
Constant Voltage

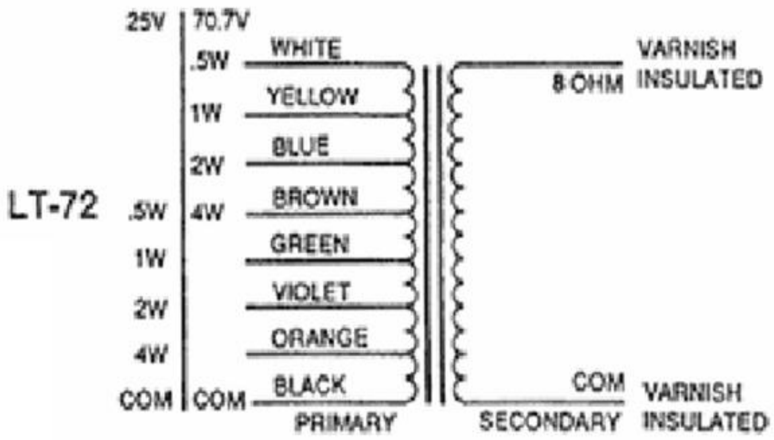
A transformer added to a loudspeaker will increase the impedance of that loudspeaker to the amp





Constant Voltage





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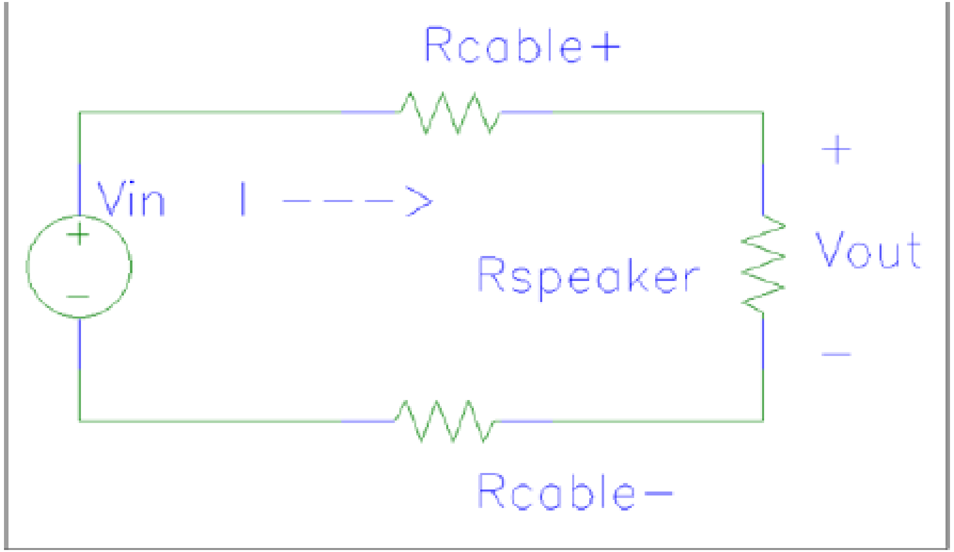
Audio



Audio

Speaker Cable Transmission Distance as a Function of Conductor Size vs. Loss															
AWG	Power Loss in Cable (% Loss & dB Loss)														
	4 Ohm Speaker					8 Ohm Speaker					70V Speaker				
	1%	5%	11%	21%	50%	1%	5%	11%	21%	50%	1%	5%	11%	21%	50%
	0.04	0.2	0.5	1	3	0.04	0.2	0.5	1	3	0.04	0.2	0.5	1	3
6	22 ft	109 ft	277 ft	571 ft	1930 ft	43 ft	218 ft	554 ft	1141 ft	3859 ft	1058 ft	5338 ft	13580 ft	27965 ft	94548 ft
8	14 ft	69 ft	174 ft	359 ft	1214 ft	27 ft	137 ft	349 ft	718 ft	2428 ft	666 ft	3359 ft	8546 ft	17598 ft	59498 ft
10	9 ft	43 ft	110 ft	226 ft	764 ft	17 ft	86 ft	219 ft	452 ft	1528 ft	419 ft	2114 ft	5377 ft	11072 ft	37434 ft
12	5 ft	27 ft	69 ft	142 ft	480 ft	11 ft	54 ft	138 ft	284 ft	959 ft	263 ft	1327 ft	3376 ft	6952 ft	23505 ft
14	3 ft	17 ft	43 ft	89 ft	302 ft	7 ft	34 ft	87 ft	179 ft	604 ft	166 ft	836 ft	2127 ft	4380 ft	14809 ft
16	2 ft	10 ft	27 ft	55 ft	185 ft	4 ft	21 ft	53 ft	110 ft	371 ft	102 ft	513 ft	1305 ft	2687 ft	9085 ft
18	1 ft	7 ft	17 ft	35 ft	117 ft	3 ft	13 ft	34 ft	69 ft	234 ft	64 ft	323 ft	823 ft	1694 ft	5726 ft
20	1 ft	4 ft	11 ft	22 ft	74 ft	2 ft	8 ft	21 ft	44 ft	147 ft	40 ft	204 ft	518 ft	1068 ft	3610 ft
22	1 ft	3 ft	7 ft	13 ft	46 ft	1 ft	5 ft	13 ft	27 ft	91 ft	25 ft	126 ft	321 ft	661 ft	2234 ft
24	0 ft	2 ft	4 ft	9 ft	29 ft	1 ft	3 ft	8 ft	17 ft	57 ft	16 ft	80 ft	202 ft	417 ft	1409 ft

Power Amplifier Ratings

Amplifiers have an output impedance they are expecting to have connected to their output terminals.

Output Power (per channel, RMS watts, both channels driven)	2 ohms, 1 kHz, 1% THD +/- 1 dB	350
	4 ohms, 1 kHz, 1% THD	270
	4 ohms, 20 Hz-20 kHz, 0.1% THD	225
	8 ohms, 1 kHz, 1% THD	170
	8 ohms, 20 Hz-20 kHz, 0.1% THD	150

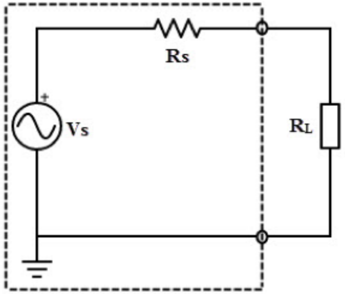
Dual mode (with both channels driven):

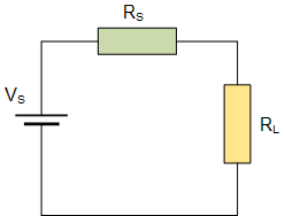
240 watts into 4 ohms.
220 watts into 8 ohms.
225 watts with 70 volt output.

Power Amplifier Ratings

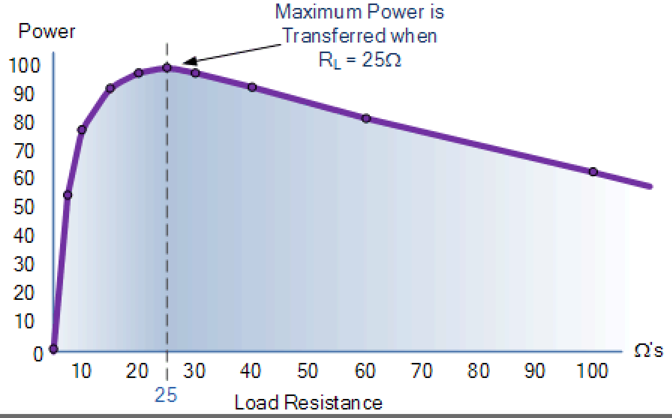
- Matching this output impedance with the loudspeaker load maximizes energy transfer from amplifier to loudspeaker to acoustic energy
- What happens if we don’t calculate the expected load and match that with the power amplifiers capabilities?

Maximum Power Theorem





Where:
$R_S = 25\Omega$
R_L is variable between 0 – 100Ω
$V_S = 100v$



The Vs and Rs are the Thevenin-equivalent voltage and resistance of the source, respectively. RL is the load resistance. Current through the load is

$$I = \frac{V_S}{R_S + R_L}$$

Power dissipated in the load is given by:

$$P_L = I^2 R_L$$

$$P_L = \left[\frac{V_S}{R_S + R_l}\right]^2 R_L$$

Since Vs and Rs are Thevenin equivalents and constant power depends on RL. To find the value of RL for which power is maximized, the above expression is differentiated with respect to RL and then equated to zero. The value obtained for R_L is:

$$R_L = Rs$$

Audio

- Example: A PA amplifier is rated at 120 W @ 100 V, therefore you could connect:
  - 20 x 5 W (100 V) ceiling speaker for a total of 100 W
  - 40 x 2.5 W (100 V) ceiling speakers for a total of 100 W
  - 10 x 5 W (100 V) ceiling speakers and 20 x 2.5 W (100 V) ceiling speakers for a total of 100 W
  - Any combination of speakers that add up to no more than 120 W, but it is recommended not to exceed 80% of the amplifier rating, thus 96 W

Audio

- Decibel
  - Use it because we hear logarithmically
  - It is always a ratio of two values
  - For acoustics, the formulas are:

    dB= 10 * log (P_2/P_1) for power

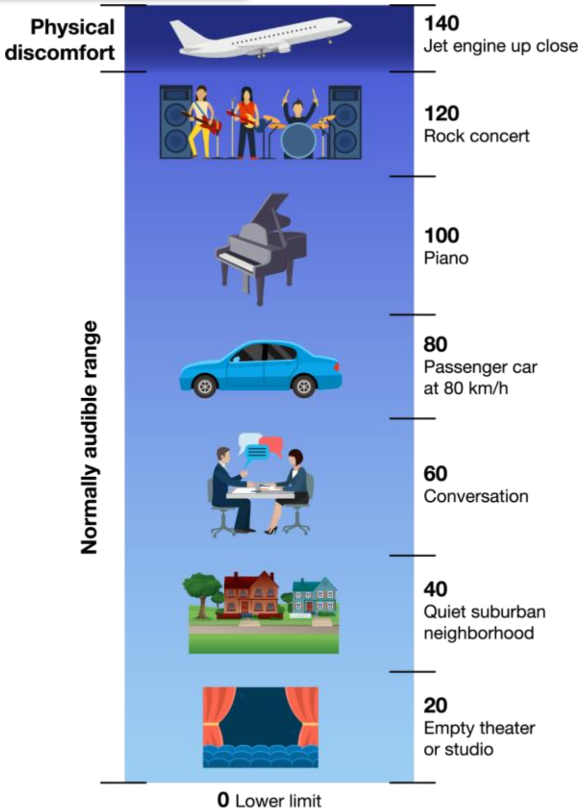
    dB= 20 * log (D_1/D_2) for distance
  - Replacing a 250 W amp with a 500 W amp, is a change of 3db in sound level

    (10* log 500/250 = 10* log 2 = 10*0.3)
  - Doubling the distance to a listener, is a change of -6db in sound level

    (20* log 2 = 20 *0.3)
  - It can be referenced to Sound Pressure Level (SPL), typically the threshold of hearing

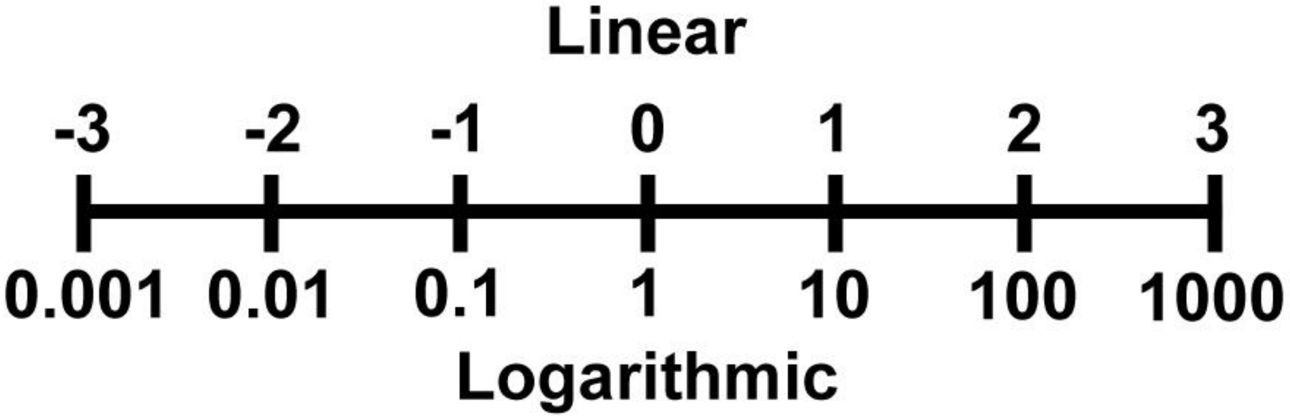
Audio

- Some values to remember:
  - 1 db is the smallest perceptible change in sound (most people will not notice it)
  - A “just” noticeable change requires 3 db
  - 10 dB is twice or half the perceived volume (uses $\log_2$)
  - Conversation = background noise of 35 db + 25 db min signal to noise ratio (to hear over the background) = 60 db
  - Beyond 194 db is called a shock wave (NASA rocket launch)
  - Loudest sound recorded 172 db, Karakatoa eruption



Logarithms

A logarithm is the exponent of base 10 that equals the value of a number.

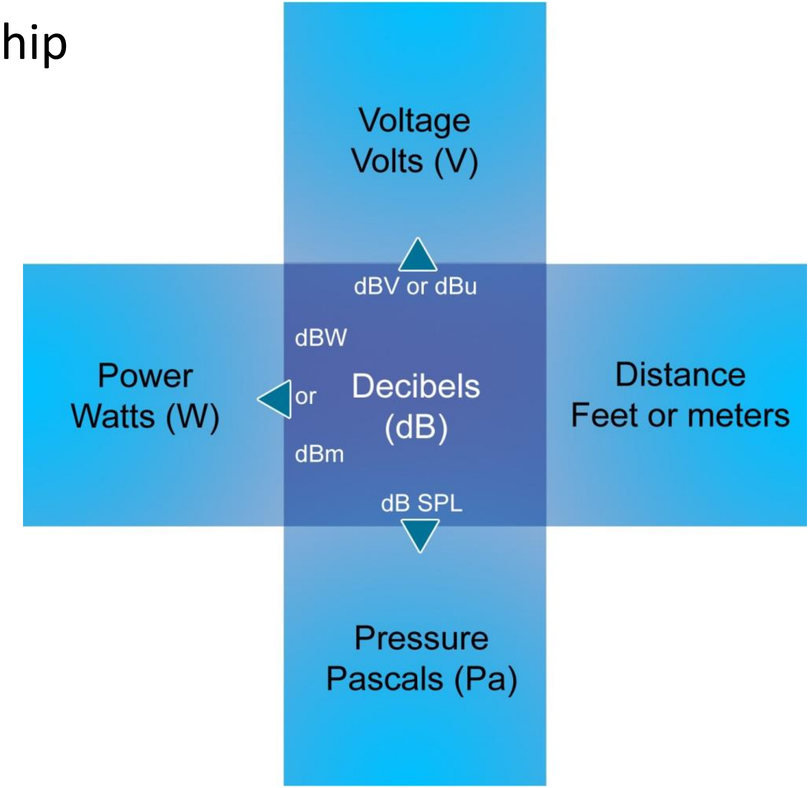


Introduction to the Decibel

- Describes a base 10 logarithmic relationship of a power quantity or root-power quantity (voltage, current, sound pressure/distance) between two numbers
- Logarithmic scale used to describe ratios with a very large range of values

Why Use Decibels?

- Describes a base 10 logarithmic relationship of a power ratio between two numbers
- Comparing two powers
- dB = 10 * log (P1 / P2)
- Comparing two distances, voltages, etc.
- dB 20 * log (D1 / D2)
- dB 20 * log (V1 / V2)



Calculating Decibel Changes

- By itself, a decibel doesn't measure anything
- It is a ratio: compares two numbers (number A to number B)
- It must have a reference

Reference Level

Quantity	Decibel Abbreviation	Reference Level
Sound pressure	0 dB SPL	0.00002 Pa at 1 kHz
Voltage (consumer electronics)	0 dBV	1 V
Voltage (pro AV equipment)	0 dBu	0.775 V
Power	0 dBW	1 W
Power	0 dBm	0.001 W, or 1 mW

Zero References: Voltage

- 0 dBu
- Reference: 0.775 Vrms
- Microphone level: -50 dBu / 0.002 V 20*log(0.002/0.775)
- Pro Audio line level: +4 dBu / 1.23 V 20* log(1.23/0.775)
- 0 dBV
- Reference: 1 Vrms
- Consumer line level : -10 dBV / 0.316 V 20* log(.316/1)

Commit to Memory

- Sound Pressure
  – 0 dB SPL to 140 dB SPL
- Microphone Level
  – Microphones: 0 dBu (0.775 V) to -60 to -50 dBu (0.002)
- Line Level
  – Pro Audio: 0 dBu (0.775 V) to +4 dBu (1.23 V)
  – Consumer: 0 dBu (0.775 V) to -10 dBV (0.316 V)

Example of 10 Log Decibel Calculations

10 Log:

- An audio amplifier is delivering 15 watts, and its output is decreased to 5 watts.

  What is the change in decibels?

10*log (5/15) = -4.8 db

Do not worry about A_1/A_2 or A_2/A_1 THINK about the physical REALITY

Example of 20 Log Decibel Calculations

20 Log:

- Assume a loudspeaker is generating 80 dB SPL at a distance of 22 feet (7m) away from the source outdoors.

  What would the level be at 88 feet (27m) away?

20 * log (22/7) = 12 db

Farther away, loss of db : 80db -12 db = 68 db

Do not worry about A_1/A_2 or A_2/A_1 THINK about the physical REALITY

Power Decibels Exercise

dB=10 * log (P_1/P_2)

P_1 is the power change (to) value

P_2 is the power reference (from) value

How many dB do we gain if we replace a 250w amp with a 500w amp?

$$dB = 10 * \log(P_1 / \mathrm{P_r})$$

$$dB = 10 * \log(500/250)$$

$$dB = 10 * \log(2)$$

$$dB = 3$$

10 and 20 Log Practice Problems

Q:

An existing audio amplifier is rated at 20 watts of output power. If the power is replaced by an amplifier rated at 8 watts, what is the expected change in decibels? Round your answer to the nearest decibel.

Hints

Power is calculated using the 10 log formula:

$$dB = 10 * \text{Log}\,(P_1 / P_r)$$

Your reference value, P_r, is the first value you measured. 20 goes on the bottom. 8 on the top.

Since power is reduced, you'd expect a loss. This will be a negative number.

10 log (8/20) = -4 db

10 log (20/8) = 4 db

10 and 20 Log Practice Problems

Q:

A listener in a meeting room is 10 feet (3,048 mm) from a loudspeaker. If the listener moves to a new distance of 25 feet (7,620 mm) away, what is the expected change in decibels? Round your answer to the nearest decibel.

Hints

Use the 20 Log formula to calculate decibel changes in distance:dB = 20 * log (D_1 / D_2)

D_1 should be your starting point: 120 inches (3084 mm).

The listener is moving farther away fron the loudspeaker, so you'd expect the answer to be negative, a loss.

20 * log (10/25) = -8 db

20 * log (25/10) = 8 db

10 and 20 Log Practice Problems

Q: What is the decibel change from a microphone signal of 0.004 volts to a line level signal of 0.775 volts? Round your answer to the nearest decibel.

Hints

Use the 20 log formula to solve for decibel changes in voltage:

$$dB = 20 * \log (V_1 / V_r)$$

Voltage is increasing, so you'd expect a gain, a positive number.

V_r should be your starting point, 0.004 volts.

20 log (.775/0.004) = 46 db

10 and 20 Log Practice Problems

- A loudspeaker is rated at 91dB@ 1W@1M. How loud will it play, if measured at 1 meter at 75 watts?

- 10 * log (P_1/P_2) = 10 * log (75/1) = 18.8 db
- 91 db + 18.8 db = 109.8 db

10 and 20 Log Practice Problems

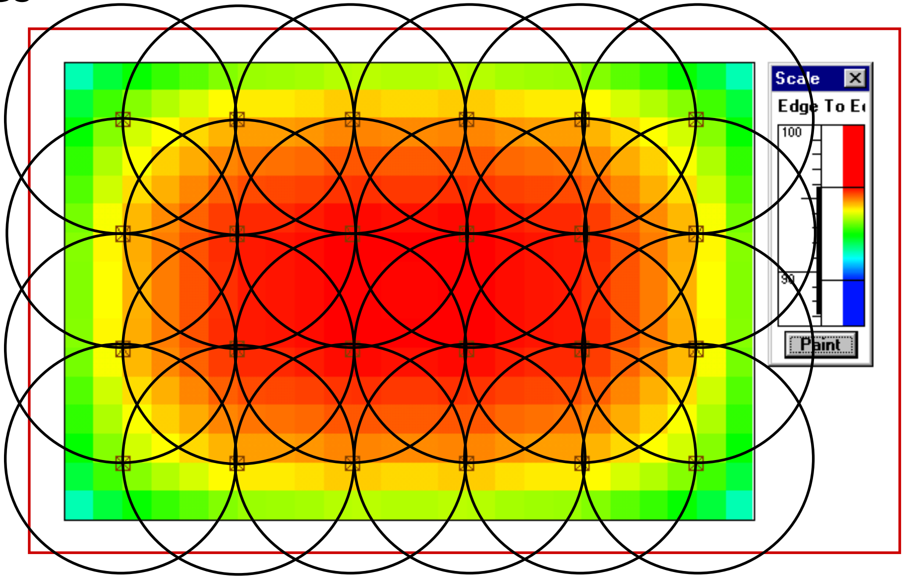
- A speaker is rated at 88dB@1W@1m. Using a 150 watt amplifier, what will the sound pressure level be at 6 meters?

- $10 * \log (P_1/P_2) = 10 * \log (150/1) = 21.76$ db
- $20* \log (D_1/D_2) = 20 * \log (1/6) = -15.5$ db

- 21.76 db – 15.5 db = 6. 2 db
- 88 db + 6.2 db = 94.2 db

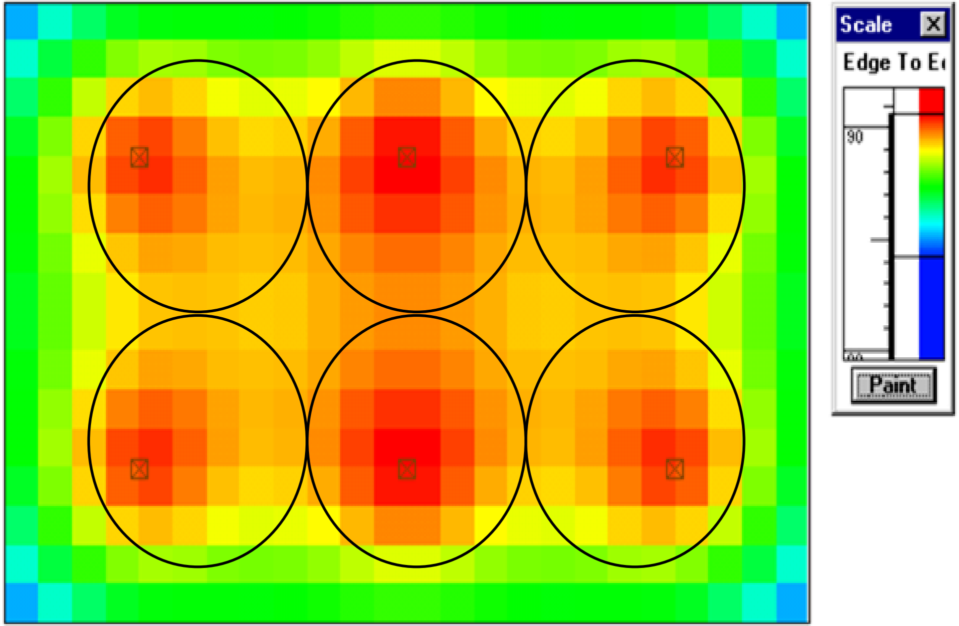
50% Overlap (center-to-center)

- Pros
  - Excellent coverage at most frequencies (1.2 dB variation)
- Cons
  - Costly
  - Maybe coverage is better than required
  - Negative interaction from nearby loudspeakers
  - Adds too much acoustical energy to space



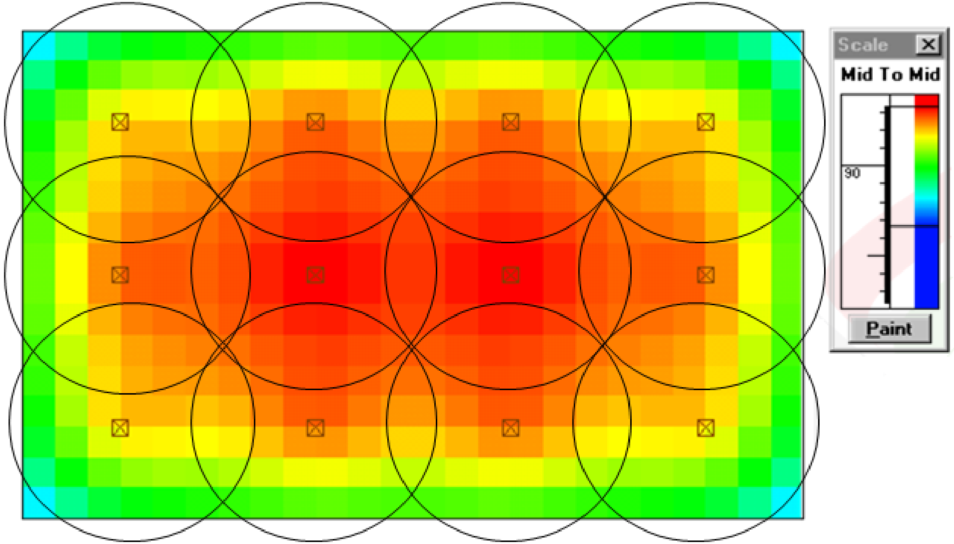
Edge-To-Edge

- Pros
  - Acceptable coverage at main speech frequencies (5.4 dB variation)
  - Inexpensive
  - Minimum interaction of loudspeakers with each other and room
- Cons
  - May have uneven frequency response
  - May have some low spots in corners



Partial Coverage at 2 kHz

- Pros
  - Good coverage
  - About a +/- 2.6 db variation in coverage
  - Good "middle-of-the-road" design
  - Ensures few or now low spots
- Disadvantages
  - Some interaction between loudspeakers
  - Not even frequency response
  - Some acoustical energy introduced



Questions?

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