Calculations with loudspeakers

Meaning of and computations using decibels

A decibel (dB) represents the ratio of two variables on a logarithmic scale, and has no base unit (e.g. meters). Using a logarithmic scale is a much better approximation of human hearing than the linear variables. As well, the gigantic ratio of barely perceptible sound pressure (the auditory threshold) to the loudest tolerable sound pressure (pain threshold) of 1: 3,000,000 is compressed into a much more manageable scale of 0 to 130 dB. The general calculation is as follows: log (value/reference value). We use the logarithm to base 10, which is generally given as 'log' on calculator keypads. The result is the Bel, one-tenth of which is one decibel, i.e. a decibel. These are power ratios. For sound pressures, voltages and currents, the factor is 20.

Power ratio in dB: **10 x $\log_{10}$ (power/reference power) or 10 x $\log_{10}$ (P/P_0)**

Sound pressure, voltage or current ratios in dB: **20 x $\log_{10}$ (value/reference value)**

In the case of sound pressure ratios, the auditory threshold is used, having a value of 20 µPa. Because there is a defined reference value, in this case 'SPL' is appended to the unit 'dB'. Nowadays, however, it has become common to omit the 'SPL' when discussing sound pressure levels. Other references:

Reference value	*1 µV*	*1 mV*	*0,775 V*	*1 V*	*20 µPa*
Decibel	*dB µV*	*dB mV*	*dBu*	*dBV*	*dB SPL*

The following table shows a few relationships governing the calculation of physical values and decibel values, and the conversion between these types of values:

Physical	***Multiplication***	***Division***	***< 1***	***1***	***> 1***	***Negative***
	⇩	⇩	⇩	⇩	⇩	⇩
Decibels	***Addition***	***Subtraction***	***Negative***	***0***	***Positive***	***Not possible***

Example 1: An amplifier amplifies an input signal of 1 mV (millivolts) to an output signal of 1,000 mV. The gain is thus 1000-fold (1000: 1), or 20 x log (1,000 / 1) = +60 dB.

Example 2: An attenuator attenuates a voltage to one-tenth. The ratio between output and input is 0.1/1 = 0.1. Expressed in dB: 20 x log (0.1 / 1) = -20 dB.

Example 3: The attenuator (example 2) is connected to the output of the amplifier (example 1). The gain is thus: 1,000 x 0.1 = 100. Stated in dB: 60 dB + (-20 dB) = 60 dB – 20 dB = 40 dB.

Sound pressure level at a defined power

If the sound pressure level is stated in dB, this information can be used in calculations. For instance, a loudspeaker datasheet provides us with information for the characteristic sound pressure level (1 W/1 m): 95 dB. This means that at 1 watt of power, the loudspeaker generates a sound pressure level of 95 dB at a distance of 1 meter. The following table indicates by how many decibels the sound pressure level of the loudspeakers increases at a given power.

Power (W)	*1*	*2*	*5*	*6*	*10*	*15*	*20*	*30*	*50*	*100*
Increase in the sound pressure level (dB)	*0*	*3*	*7*	*8*	*10*	*12*	*13*	*15*	*17*	*20*

The table shows that at 6 watts, you need to add 8 dB to the 95 dB. Consequently, at 6 watts of power we obtain 103 dB SPL at a distance of 1 meter. There is also a mathematical formula for this calculation that yields the same result.

$p_1 = p_n + 10 \times \log (P)$

p_1: Sound pressure level (dB) p_n: Characteristic sound pressure level (dB) P: supplied power (W)

Each doubling of power gives us an additional 3 dB of SPL.

Sound pressure level at a defined distance

If you would like to calculate the sound pressure level produced by the loudspeaker not at a distance of 1 meter, but at e.g. 6 meters, there is a table/formula for this purpose as well.

Distance (m)	*1*	*2*	*3*	*4*	*5*	*10*	*20*	*50*	*100*
Decrease (dB SPL)	*0*	*6*	*9,5*	*12*	*14*	*20*	*26*	*34*	*40*

Based on the same example, we will have to subtract an amount, corresponding to the distance, from the calculated figure of 103 dB. The reduction resulting from a distance of 5 meters from the loudspeakers is 14 dB – which corresponds to a sound pressure level of 89 db. The formula for the calculation is as follows: **$p = p_1 - 20 \times \log (d)$**

p: Sound pressure level at a defined distance (dB characteristic sound pressure)
d: Distance (m)
p_1: Sound pressure level at a distance of 1 m

With each doubling in distance, the sound pressure level drops by 6 dB SPL.

Sound pressure level at a given power and distance from the loudspeaker

The formulas for sound pressure at a defined power and at a defined distance are combined. The sound pressure level at a given power and distance is calculated as follows: **$p = p_n + 10 \times \log (P) - 20 \times \log (d)$**

p: Sound pressure level (dB SPL) p_n: Characteristic sound pressure level of the loudspeaker (dB)
d: Distance from the loudspeaker (m) (m) P: supplied power (W)

Example: We want to install a loudspeaker in a room. The greatest distance to the audience is 8 m. The loudspeaker has a characteristic sound pressure level of 90 dB 1 W/1 m and an input power of 30 watts. How high is the sound pressure level at the maximum distance?

Sound pressure level
= 90 dB + 10 x log (30) - 20 x log (8)
= 90 dB + 15 dB - 18 dB
= 87 dB

If you use the values from the two tables provided above (the distance is composed of 4 m x 2m = 8 m, physical multiplication turns into addition of the decibel values) this yields:

Sound pressure level
= 90 dB + 15 dB (at 30 watts) - 12 dB (at 4 m) - 6 dB (at 2 m)
= 87 dB

A perceived doubling in volume requires around 10 times the amplifier power.

Public address with ceiling loudspeakers

Distance and minimum sound pressure level between TOA's standard ceiling loudspeakers at different degrees of speech intelligibility and 6 W of power:

	Ceiling height (m)	*3*	*3,5*	*4*	*4,5*	*5*	*5,5*	*6*
Best intelligibility	*Distance between loudspeakers (m)*	*2,3*	*3,1*	*3,8*	*4,6*	*5,4*	*6,1*	*6,9*
	min. Sound pressure level (dB)	*92*	*90*	*88*	*86*	*85*	*84*	*83*
Good intelligibility	*Distance between loudspeakers (m)*	*3,6*	*4,8*	*6*	*7,2*	*8,3*	*9,5*	*10,7*
	min. Sound pressure level (dB)	*90*	*88*	*86*	*84*	*83*	*82*	*81*
Background music	*Distance between loudspeakers (m)*	*8,2*	*11*	*13,7*	*16,5*	*19,2*	*22*	*24,7*
	min. Sound pressure level (dB)	*85*	*82*	*81*	*79*	*78*	*76*	*75*

Distributed Speaker System SPL Calculator

This distributed speaker system SPL calculator takes the guess work out of which speaker tap to use. It will tell you the correct power tap for each speaker in your design. The calculator is really useful when balancing levels of different speakers. Or when the speakers are mounted at varying distances from the listener. It also helps in determining the amplifier power needed to deliver the required Sound Pressure Level (SPL) at the target audience.

If you need help in using the calculator, below is an explanation of all the fields and some user tips.

Explanation of Distribution Speaker System SPL Calculator

As with any of my calculators, you just need to fill in the white blank fields. A short explanation of each field follows.

Starting with the table at the top of the calculator:

Select the units of measure, either meters or feet. The selected unit of measure will be used for the distance from the speaker to the target audience.

Enter the required SPL at the target audience. This will depend on the ambient noise level, the purpose of the sound system (background or foreground) and how loud the system needs to be among other factors. As a guide:

- 65dB – 75dB for quite areas like offices
- 75dB – 85dB for louder areas like shops
- 85dB – 95dB for loud places like sporting fields

Select amplifier power output. Most SPL calculators tell you the maximum SPL possible with the amplifier running at full power. This distributed speaker system SPL calculator will do that and more, (or should I say, and less). If required, you can select full power if you want the amp to run at full power with no headroom. Simply select “Full”

You can also calculate the SPL and speaker power taps with the amplifier running at less than full power, which is often the case, and mostly preferable. As the amplifier output power is reduced, the effective power of any connected speaker is similarly reduced, as is the amplifier output voltage. For your information, the following table shows the power and voltage levels along with the effective power rating of a 30-Watt 100-volt speaker for various levels.

Amplifier Power	Amplifier Voltage	Power of 30 watt 100 Volt speaker
Full	100 volts	30 Watts

Amplifier Power	Amplifier Voltage	Power of 30 watt 100 Volt speaker
1/2 power (-3dB)	70.7 volts	15 Watts
1/4 power (-6dB)	50 volts	7.5 Watts
1/16 power (-12dB)	25 volts	1.875 Watts
Low power (1/100, -20dB)	10 volts	0.3 Watts

I suggest you try "1/16 (-12dB)" first. If the speakers can deliver the required SPL at this power setting, then the amp is not going to work hard and you have plenty of room for extra level if required. If this selected level doesn't deliver sufficient power, try "1/4 (-6dB)", as this level stills offers headroom.

Select the acoustic space reflectivity/reverb. This is where any pretense of this calculator being accurate goes out the window. The calculation for SPL loss in the air is based on having no reflections to allow the sound the decay naturally. Specially designed rooms or outdoors are common examples of "dead" acoustic spaces. In such cases, select "Dead", and no allowance will be made for reflections.

In most rooms there will be some reflections which decrease the natural losses. This calculator allows you to select if the reflectivity or reverb time of the room is judged to be Low, Mid or High.

- Low (+2dB) would be for a space with lots of curtains, carpeted floor and soft furnishing. The small reflections within the room won't allow the sound to decay as well as if in the open air. So, the air loss might be around 2dB less than in the open air. Or in other words, the sound level at the target audience might be increased by around 2dB.
- Mid (+4dB) would be for a space with some reflections which might add around 4dB to the SPL at the target distance.
- High (+6dB) would be for a space that is highly reflective with substantial reverb. Large rectangular spaces with wood or concrete floors, and acoustically reflective walls will often increase the SPL to around 6dB at the target audience.

The selection you make here is very subjective, and maybe a guess, but at least you have the ability to allow for the different acoustic spaces. If in doubt, choose "dead" for outside open areas, and "Mid(+4dB)" for indoors.

Calculate Speaker Taps

OK, you have now entered the required SPL, amplifier power setting and selected the acoustic space. Now you can now have fun with different speaker arrangements and calculate the tap setting required.

Start with "Speaker 1" and work down the table for each speaker. The calculator allows up to four speaker types to be calculated.

Speaker Description: This field is optional. It can be used to describe the speaker and anything unique to it. For example, a ceiling speaker might be mounted at a height of 3.2 meters. A while a similar speaker might be mounted on ceiling that is 5.2 meters high. There might also be a box type speaker mounted 5.2 meters high. Entering these descriptions for each speaker install is useful to avoid confusion. If entered, these descriptions are also used in the graph at the bottom of the calculator.

Speaker Sensitivity: This figure is normally found in the specifications for the speakers. For example, a ceiling speaker specs might say "Sensitivity: 90dB (1w/1m)". For an explanation of speaker sensitivity and how we use it to determine the SPL of a speaker.

Distance to Target: This is the distance from the speaker to the listener. For ceiling speakers, it would be the height of the ceiling minus the sitting or standing height of the listener.

Once these figures are entered, the following are calculated for each speaker:

SPL loss due to Distance: This is the SPL loss through air. This figure is dependent on the distance between the speaker and the listener, and the acoustics of the room/space (that you entered at the top of the calculator).

Required Speaker gain over 1 watt: We hardly need a spreadsheet to calculate this. It is the SPL of the speaker at 1 watt, minus the air losses, compared to the required SPL. In the example calculator below, speaker 3 will produce 84dB with 1 watt going into it, when you measure the SPL 1 meter away. So, 84 minus the air loss (8dB) leaves us 76db. This is 6dB below the required 82dB, so the required gain from the speaker is 6dB. This is how much power over 1 watt we need from the amplifier for the speaker output to reach the required SPL.

Speaker power required: This calculation converts the required dB gain over one watt into watts. It also takes onto account any "de-rating" of the speaker power due to it not being driven to full capacity (see table above). This figure is the theoretical value the speaker tap should be set at to attain the required SPL at the target distance.

However, most speakers will not have a tap at that precise level. So, on the next line you need to input the value of the closest tap to the theoretical level.

Actual power tap setting: In the example below, the theoretical speaker power required for the ceiling speakers is 1 watt and 4 watts. However, let's say our ceiling speakers have taps at 10, 5, 2.5 and 1.25 watts. For speaker 1, we could use 1.25 watts instead of the theoretical 1 watt. For speaker 2 we could use 5 watts, instead of the theoretical 4 watts. Speaker 3, the box speaker might have taps at 30, 15, 7.5 and 3.75 watts. Choosing 15 watts instead of the theoretical value of 16 watts, results is only 0.3dB difference in SPL at the target audience distance.

Calculated SPL at target: is the SPL at the target audience distance with the actual speaker power tap. These results are displayed in the graph at the bottom of the calculator.

Difference to required SPL: is the difference between the calculated SPL for the speaker tap, and the required SPL. This number will be positive if the speaker output is above the required SPL. It will be negative if it is below the required SPL. If the difference is only 1-2 dB, it will be barely noticeable. If the difference is over 6dB, then a different speaker or different tap should be used.

The graph reflects any change to any of the values in the tables. It is interesting to change the amplifier power to "Full", you will see the SPL level raises, as you would expect. However, the dB difference between any of the speakers to each other is the same.

Once you know what taps you will be using for each speaker type, you can multiply the number of similar speakers by the actual tap value to determine what size amplifier you should use. Keep in mind, that good practice suggests to use an amplifier 20-25% greater than the total load.