ACOUSTIC DIMENSIONS

Gain Structure

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Introduction

Over the years I have seen many applications when a haphazard approach has been taken in establishing gain structure through a system. Often rough adjustments can be made and not have it be an apparent problem since gain is easily and cheaply available in today's industry. Years ago when a 100 Watt amplifier was used to power the main speaker system, gain structure was a critical issue. Today, with the advent of amplifiers that can output levels of 1,000 watts or more per channel, proper gain structure can be easily overlooked as a critical element in the performance of a sound reinforcement system.

Powerful amplifiers, however, are not an excuse for an individual to lack a firm understanding of proper gain structure. Many of today's signal processors and amplifiers have jumpers, switches, or knobs that, if adjusted properly, will maximize the systems signal to noise ratio while ensuring the system will safely operate at the levels that are required. It is the intent of this paper to educate audio system designers to the proper techniques for setting gain structure. First we will determine how much gain is required throughout the system from the console to the listener. Once the overall gain requirements are known, we can then discuss the approach to setting the system's gain structure.

How Much Gain is Enough?

A good designer will always have an established Sound Pressure Level criteria for each system in which he or she is working on. Without this predetermined resultant SPL, you may often find yourself over or under specifying the total gain required in a system. Lets establish a criteria for the purpose of discussion. We will assume that we are designing a sound system for a church that has a contemporary music program. During the music portion of the program it is anticipated that peak levels in the room need to reach nominal levels of 95dB SPL, with peaks of 101dB. It is also the intent to provide 10dB of headroom. Our design criteria is now determined, and we can begin our discussion of the gain system.

The first criteria to determine in the system is the amount of loss due to distance. For the purpose of our example, lets assume that the furthest distance a listener will be from the speaker is 80 feet. Because sound radiates spherically, the attenuation is proportional to the square of the distance from the source, and hence there is a 6dB reduction for each doubling of distance. Assuming that the sensitivity of the speaker is given in reference to 1 meter, this can be represented mathematically by the equation:

$$SPL_{dist\text{-}loss} = 20 \log (\text{distance in feet} / 3.3) \qquad (1)$$

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The 3.3 factor is used to convert feet to meters. Using this equation we determine there will be a total loss of 28dB as a result of distance. We can now calculate the maximum output level of the speaker that we will require in order to achieve our design criteria. We have already determined that we need a maximum SPL level of 111 dB at the listener position (101 dB peaks with 10 dB of headroom). At the speaker we will need a maximum SPL level of 139dB (111 dB at the listener position + 28 dB of loss due to distance.)

The selection of the speaker is the next step in the process. Any speaker that is specified will have a sensitivity and a maximum power rating. The sensitivity is normally given in dB SPL at 1 meter when a 1 watt signal is applied to the input of the speaker, and is usually given in AES watts. This AES measurement is a clearly defined standard by the AES in which a band of pink noise from 125Hz to 8Khz with +6dB peaks is applied to the input of the speaker for a period of 2 hours. Any speaker that has its power rating in AES watts can very easily handle short-term peaks of +6dB above the AES rating.

The maximum output level at 1 meter away from a speaker will be derived from the formula:

$$SPL_{max\text{-}AES} = \text{sensitivity} + 10 \log(\text{AES power rating}) \qquad (2)$$

$$SPL_{max} = \text{sensitivity} + 10 \log(\text{AES power rating}) + 6 \qquad (3)$$

Any speaker we select must have an SPL_{max} of at least 139dB. We will take one particular manufacturer's speaker that has a sensitivity of 112dB @ 1 Watt/1 meter. The high frequency component can handle 200 Watts AES. Using equation 3 we find that the SPL_{max} = 141 dB. This speaker will have the ability of achieving our design criteria.

To complete the design, we must choose the correct amplifier size for the application. Amplifier power ratings are given in watts, but unlike speaker manufacturer's AES power rating, amplifier power ratings are the upper limits, and do not include any crest factors. For the purpose of discussion, lets assume that we have a 3-way speaker system, highs, mids, and lows, with the following AES power ratings and sensitivity ratings.

Speaker	**Highs**	**Mids**	**Lows**
Sensitivity	112	109	101
AES power Rating	200	400	1000
Peak SPL (Equation 3)	141	141	137

Table 1 – Speaker Sensitivity and Power Ratings

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The high and mid speakers in this design can handle the minimum SPL requirements of 139 dB @ 1meter. The low frequency speakers will require two cabinets. By doubling the number of cabinets we will obtain a +6dB gain, which results in a low frequency peak SPL of 143 dB. We can now go directly to our amplifier selection. In order to calculate the amount of power required, we need to use the following equation:

$$\text{PWR(dB)} = \text{SPL Criteria}_{\text{peak}} - \text{sensitivity} + \text{SPL}_{\text{dist-loss}} \qquad (4a)$$

$$\text{PWR (watts)} = 10^{\text{PWR(dB)}/10} \qquad (4b)$$

The peak SPL Criteria was established earlier at 111 dB SPL (96dB nominal + 6dB peaks + 10 dB headroom). The loss due to distance is 28 dB. By plugging these numbers into equation 4, we obtain the following results.

Speaker	**Highs**	**Mids**	**Lows (1)**
Calculated Minimum Power	27 dB	30 dB	32 dB
Power in Watts (2)	500 Watts	1000 Watts	1585 Watts

(1) One cabinet will be required to provide an SPL Criteria $_{\text{peak}}$ of 105 dB SPL since two cabinets will give us our required SPL Criteria $_{\text{peak}}$ of 111 dB SPL.
(2) This is peak power, not AES. The AES power handling would -6dB lower than this (divide by 4).

Table 2 – Amplifier Power Requirments

Console and Processing Output Levels

Now that the amplifier size has been determined, the next thing to look at are the processing level inputs and outputs. Most sound consoles can comfortably handle an output level between +18 dBu and +24 dBu. This in turn will feed the processing equipment. Analog processors can usually handle +18 dBu input and output signals. Here is the first place in line where attenuation or a pad may be required. If you are using a console that can output +24 dBu, you will want 6dB of attenuation at the input of the audio processor. This can usually be achieved by the input attenuators on the signal processor.

The outputs of the signal processors require a bit more discussion. Many DSP devices have either output switch settings or output jumper settings that can select between 0, +6dB, or +12dB, so the obvious questions are “Why are there different options?” and “When do you use them?”. To answer this, we must first continue our discussion about amplifiers.

Amplifier Input Levels

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Many manufacturer's have input selection settings than can choose between 0.775V, 1.4V, X20 (or 26 dB), or X40 (or 32 dB). For the purpose of discussion, Table 3 indicates the input level that 200, 400, and 800 watt amplifiers will accept before the amp clips. The 0.775V and the 1.4V input level settings indicate that all amplifiers will clip at the same input level. For the X20 (26dB) or the X40 (32dB) selection settings, the size of the amplifier and the load on the amplifier will determine the level at which the amp will clip. It is very important to be able to understand the clip levels and gains of the amplifiers in both dB and in voltage.

For 0.775V or 1.4V input sensitivity

Gain (volts) = sqrt [Max power rating * load (ohms)] / input sensitivty (5a)

Gain (dB) = 20 log[Gain (voltage)] (5b)

Clip Level (volts) = input sensitivity (0.775V or 1.4V) (5c)

Clip Level (dB) = 20 log [clip level (volts)] (5d)

For X20 (26dB) or X40 (32dB) Gain

Clip level (volts) = sqrt [Max power rating * load (ohms)] / gain (20 or 40) (6a)

Clip level (dB) = 20 log[Clip level (volts) / 0.775V] (6b)

Gain (volts) = gain (20 or 40) (6c)

Gain (dB) = 20 log[gain(volts)] (6d)

	200 Watts	**400 Watts**	**800 Watts**
X20 (26dB)	8.2dB	11.2dB	14.2dB
X40 (32dB)	2.2dB	5.2dB	8.2dB
0.75V	0dB	0dB	0dB
1.4V	+5dB	+5dB	+5dB

Table 3 – Amplifier Input Clip Levels

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Now that we have thrown all of these numbers out there for you to ponder over, we now need to know when we would want to use these different input settings. The primary factor in determining which settings to use is determined by the designer's requirment for the system's noise floor. If noise floor is not absolutely critical (NC-25 or higher spaces), then the amplifiers can safely be set on 0.775 (or preferably 1.4V if available). Because the actual gain of the amplifiers is quite high (~X40 for a 100 watt amp to ~X130 for a 2500 watt amp), the noise floor will be higher. The clear advantage, however, is that you do not need to calculate the attenuation needed for every channel of every amplifier. If noise levels are a critical concern, then constant gain settings should be used, but you will need to calculate the attenuation for each amp channel.

To conclude our discussion on signal processing and the output level switches on DSP devices, if you are using an amplifier that has its input sensitivity set on 0.775V, then the output of the DSP should be set at 0dB. This will provide 18 dB of attenuation between the console and the amplifiers. If the input sensitivity of the amps are set at 1.4V, then the output of the DSP should be set at 6dB. If you are using constant gain, then each output needs to be addressed on an individual basis.

One final note on gain structure worth mentioning is to always have a good sense for what is occurring with the system equalization. Let's assume that there is a large +10 dB boost in the EQ at 8K. During system tuning it may make the speakers sound very well and provide extended high end frequency response, but 8K signals will clip the amplifiers 10 dB sooner than the rest of the system. Similar problems may arise from very large EQ cuts, but if at all possible, for gain structure purposes, it is better to cut than to boost, and it will always be best to keep your cuts and boosts to an absolute minimum.

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