Tonochi's Audio Room – Supplemental Information

Output power and Gains of Amplifiers

2021/02/20

Calculation of Output Power and Gain of Power Amplifier

Output Power of Power Amp

The required output power of the power amplifier is calculated from the maximum SPL (sound pressure level) the listener wants and the sensitivity of the loudspeaker.

Figuring Out the Max SPL

The required maximum SPL depends on the listener's preference in music genre and his/her way to listen.

I love jazz and fusion in particular, while I listen to all genres of music. And, I like orchestral music (symphonies and concertos) and wind music, too. High volume is desirable when these kinds of music are replayed.

To get right to the point, I measured the SPL at the listening position. The conditions were that the source was a hi-res music file of jazz, the volume was a little higher than usual and the measurement instrument was PHONIC PAA3. The peak level was about 100dB.

If the source can be limited to digital music files, it is right to regard the 100dB of SPL is the maximum in the audio system.
In that case, the gain of the amplifier is to be defined so that the SPL becomes 100dB for the maximum output of DAP (digital audio player), which is stipulated as 2V (rms). The maximum output power of the amplifier must be more than the output in this condition.

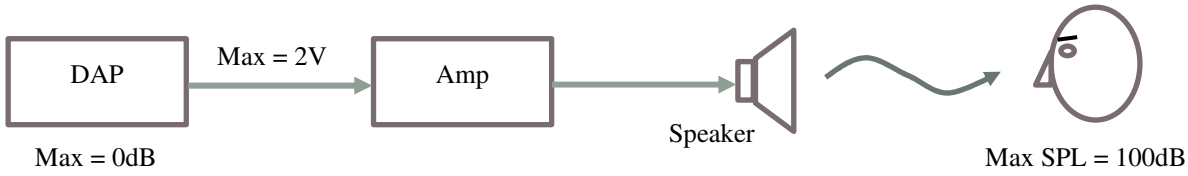

Fig. 1. Maximum SPL for digital source

For analog discs (AD), the actual dynamic range is wide. Especially for high-definition discs, for which a limiter is not used generally, the peak level is so high. The maximum SPL is needed to be 110dB at least.
The ideal maximum SPL is 120dB, though, a very high-power amplifier is necessary to realize it. To increase the SPL by 10dB, the output power of the amplifier must be increased by 10 times. The value of 110dB is reasonable.

The output voltage of a cartridge in its catalog isn't the maximum output. You should be careful about that. The value indicates the output voltage when the cartridge replays a standard signal (sine wave, recorded velocity = 3.54cm/s, frequency = 1kHz). The actual maximum output is higher than this standard signal by far.

The rough estimate of the maximum output is a 14 times higher value (+23dB) than the catalog data. Some analog discs may have a higher peak level, but they are so rare you can omit them.
For example, the output voltage of Audio Technica AT33PTG/II is 0.3mV. The maximum output is estimated to be 4.2mV.

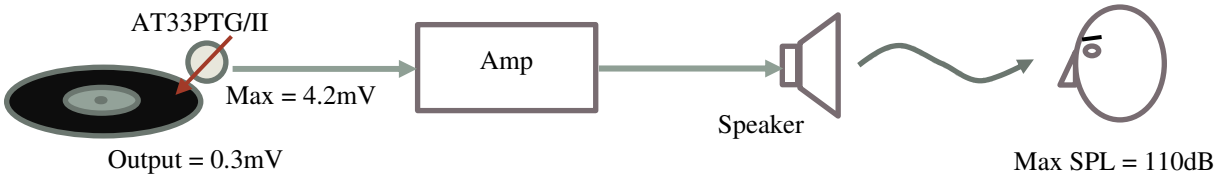

Fig-2 Maximum SPL for analog disc playback

I've decided the maximum SPL is 110dB for Gaudi II, since the main source of Gaudi II is AD.
This value is the sum of the sound pressure from the both loudspeakers at the listening position. The SPL of each channel is 107dB.
In Gaudi II system, the listening position is 2.5m away from each loudspeaker. The SPL should be more than 110 dB at 1m away from the speaker. But, in practice, the SPL is not so different between the 1m position and the listening position due to reflection by the walls.
It's rather rough estimation, but the total SPL at the listening position is expected to be around 110dB when each speaker's SPL at the 1m position is 110dB.

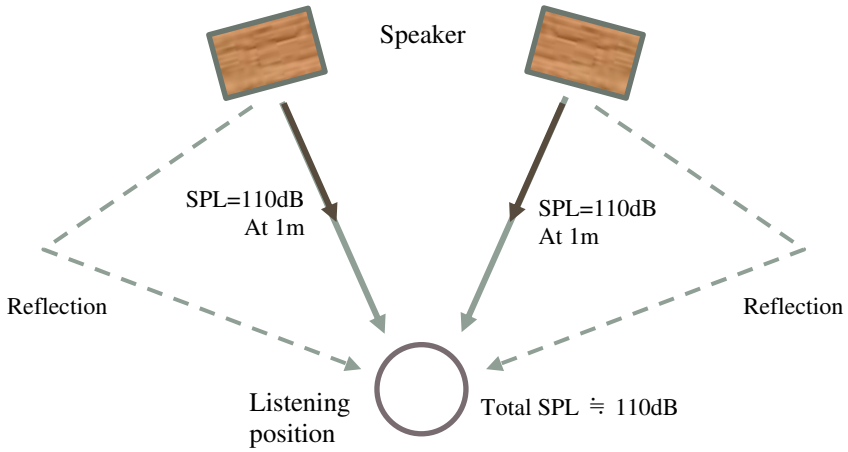

Fig. 3. SPL at the listening position

Sensitivity of the Loudspeaker units

The loudspeaker in Gaudi II system is SS-309B, which is an improved version of SS-309A in Gaudi system. The LS units (loudspeaker unit) are the same as SS-309A.

The table 1 shows the LS units to be used and their sensitivities. The gain of each amplifier will be determined according to these data.

Table 1. LS units to be used and their sensitivity

	LS unit		Sensitivity
	Manufacturer	Model number	
Tweeter	Fostex	T925A	108dB/W (m)
Squawker	Fostex	D1405+H400	104dB/W (m)
Woofer	Fostex	FW305	95dB/W (m)

Output Power of Each Power Amplifier

Let's calculate the required power for the SPL of 110dB at the position 1m away from the LS unit.

First, let's calculate the difference between the SPL at 1W and the required SPL.

- Tweeter: 2dB (=110dB-108dB)
- Squawker: 6dB (=110dB-104dB)
- Woofer: 15dB (=110dB-95dB)

Secondly, let's calculate the required output power by converting the decibel values into multiples and multiplying 1W by them.

- Tweeter: 1.58 * 1W = 1.58W ($1.58 = 10^{(2dB/10)}$)
- Squawker: 3.98 * 1W = 3.98W ($3.98 = 10^{(6dB/10)}$)
- Woofer: 31.6 * 1W = 31.6W (31.6 = $10^{(15dB/10)}$)

Sensitivity has a margin of error, so let's double the values above, and round them up.

- Tweeter: 5W
- Squawker: 10W
- Woofer: 80W

The output power of each power amplifier should be those values or higher.

Confirmation with Measurement

The table-2 shows the maximum outputs of the power amplifiers in Gaudi.
The 'usual volume' is the volume when I listened to music (as mentioned above, it is rather loud), and 'max volume' is the highest volume I can tolerate.

Table-2. Peak output power (measured data)

Range	Normal volume	Max volume
Tweeter	0.12W	0.49W
Squawker	0.49W	2.4W
Woofer	16W	47W

The peak output of the tweeter amp is less than the estimated value by far. It's because there are only harmonics in this range. I chose an AD I thought it contains a lot of trebles for this measurement, but the choice may not have been good. There may be an AD that contains more harmonics.
I picked the calculated value, 5W, as the maximum output of the tweeter amp.

As for the woofer amp, the peak output at the max volume exceeds the estimated value, though, it is less than 80W. So, an 80W power amplifier is suitable. The higher power produces more intense sound pressure, and that loud sound will probably damage the listener's ears. Such a powerful amplifier isn't necessary.

Gain

I'll show calculation of the gains of the amplifiers for the digital source, since the digital system is simpler than the analog one.

Gains of Power Amplifiers

The output power of each power amplifier was calculated in the previous section. The gain of each power amplifier is determined so that the power amplifier's output level reaches the value when the input level is 1V. That is, the sensitivity of the power amplifier is set to be 1V.

For example, the maximum output power of the tweeter amp is 5W, and the output voltage is 6.3V into the load of 8ohm.
6.3[V] = sqrt(5[W] x 8[ohm])
The input voltage is 1V. So, the gain is calculated by the following equation:
6.3 = 6.3[V] / 1[V].
In the decibel value:
16[dB] = 20 x log(6.3).

The other results are shown in the table 3.

Table 3. Max output and gain of power amplifier

Band	Output power (into 8ohm)	Max output voltage	Max input voltage	Gain
High (tweeter)	5W	6.3V	1V	+16dB
Mid (squawker)	10W	8.9V	1V	+19dB
Low (woofer)	80W	25V	1V	+28dB

The gains of the Amplifying Stages Preceding the Power Amplifiers

There's no need to amplify the audio signal in the preamplifier and the crossover network. That is, the gain should be 0dB (x1).

Gain Margin

While the maximum gain of the master volume is 0dB (x1), the virtual maximum is -6dB (1/2) in use (turned down a little). It's because the sensitivity of the power amplifiers is specified to be 1V. That implies the input more than 1V makes the power amplifier clipped. The maximum level of the audio signal is 2V, so the master volume has to attenuate the signal by 6dB (x1/2).
This 6dB is a gain margin. The margin is necessary, because the maximum levels of some music sources are less than 0dB (less than 2V).

Wrap-up

To visualize the gains of each amplifying stage, a diagram called 'level diagram' is used.

Before drawing the level diagram, I drew a system block diagram (fig.4) that indicates the configuration of the amplifying stages.

The gain of the phono EQ stage is +66dB. It is a little higher than the typical value.
Many commercial amplifiers have an attenuator to attenuate the signal from LINE IN in order to make its level equal to the signal from the phono EQ stage. But this kind of attenuator is not used in Gaudi II. There isn't apparent difference in volume between digital source and ADs with the high-gain phono EQ stage.

The volume control is placed between the crossover network and the power amplifiers. This layout will improve the actual SNR and dynamic range of the crossover network.

The maximum SPL results in around 115dB per channel due to the margins in the maximum output power.

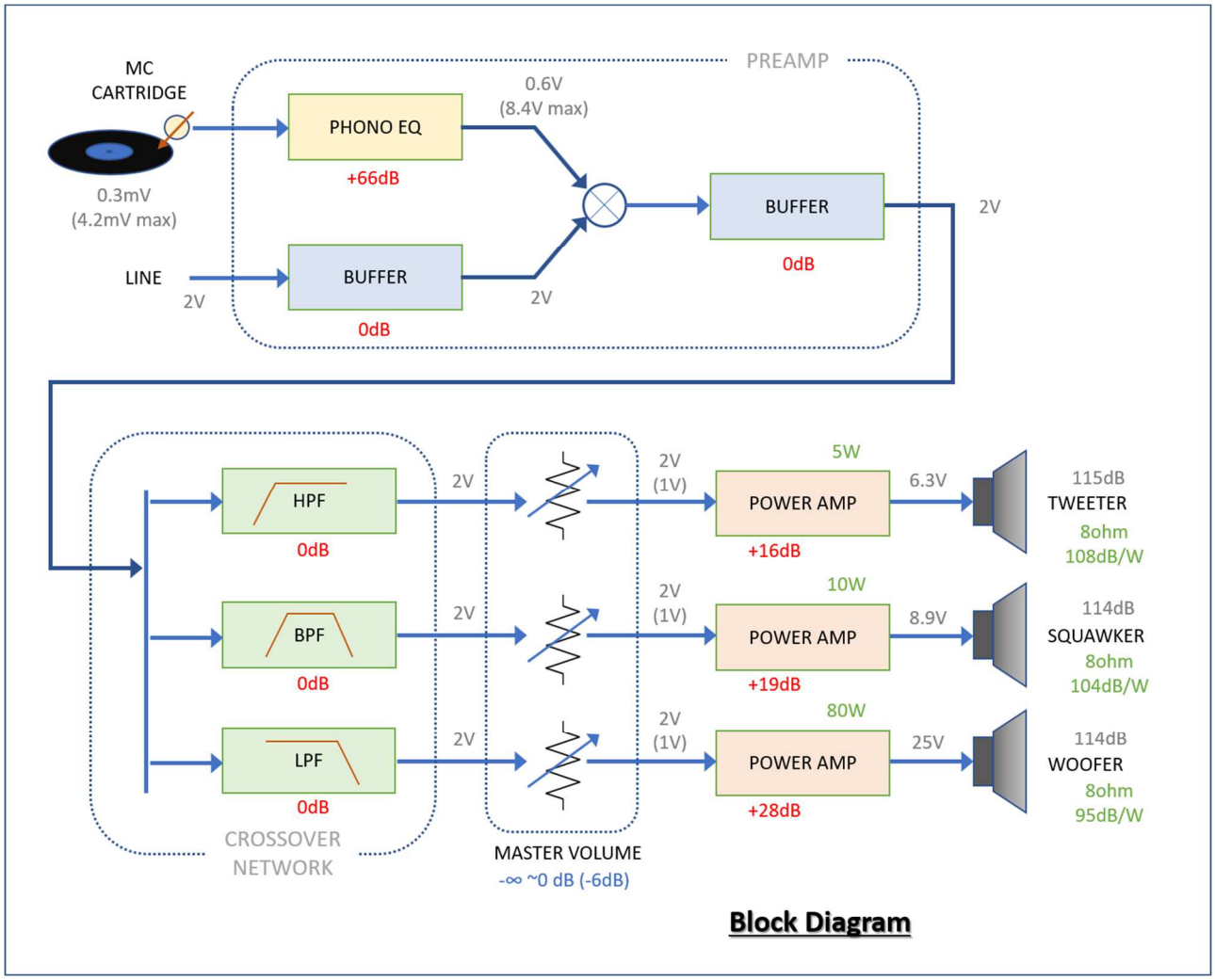

Fig.4. System block diagram

The level diagram is shown in Fig.5.

The signal from PHONO IN is amplified by +66dB and its level becomes 0.6V. It is rather smaller than the level of LINE IN, but, as described above, the output voltage of the cartridge doesn't mean the maximum value, and the actual voltage is higher than this. The difference in volume between PHONO IN and LINE IN isn't significant.

I suppose the cartridge is Audio Technica AT33PGT/II. Its putative maximum output is 4.2mV as mentioned above. This implies that the maximum output voltage of the phone EQ stage must be 8.4V or higher, because the gain of the phono EQ stage is 2000x (=+66dB). In addition, the maximum permissible input and the maximum output of the other amplifying stages, except the power amplifiers, must also be 8.4V and higher. Otherwise, the signal could clip before it reaches the power amplifier.

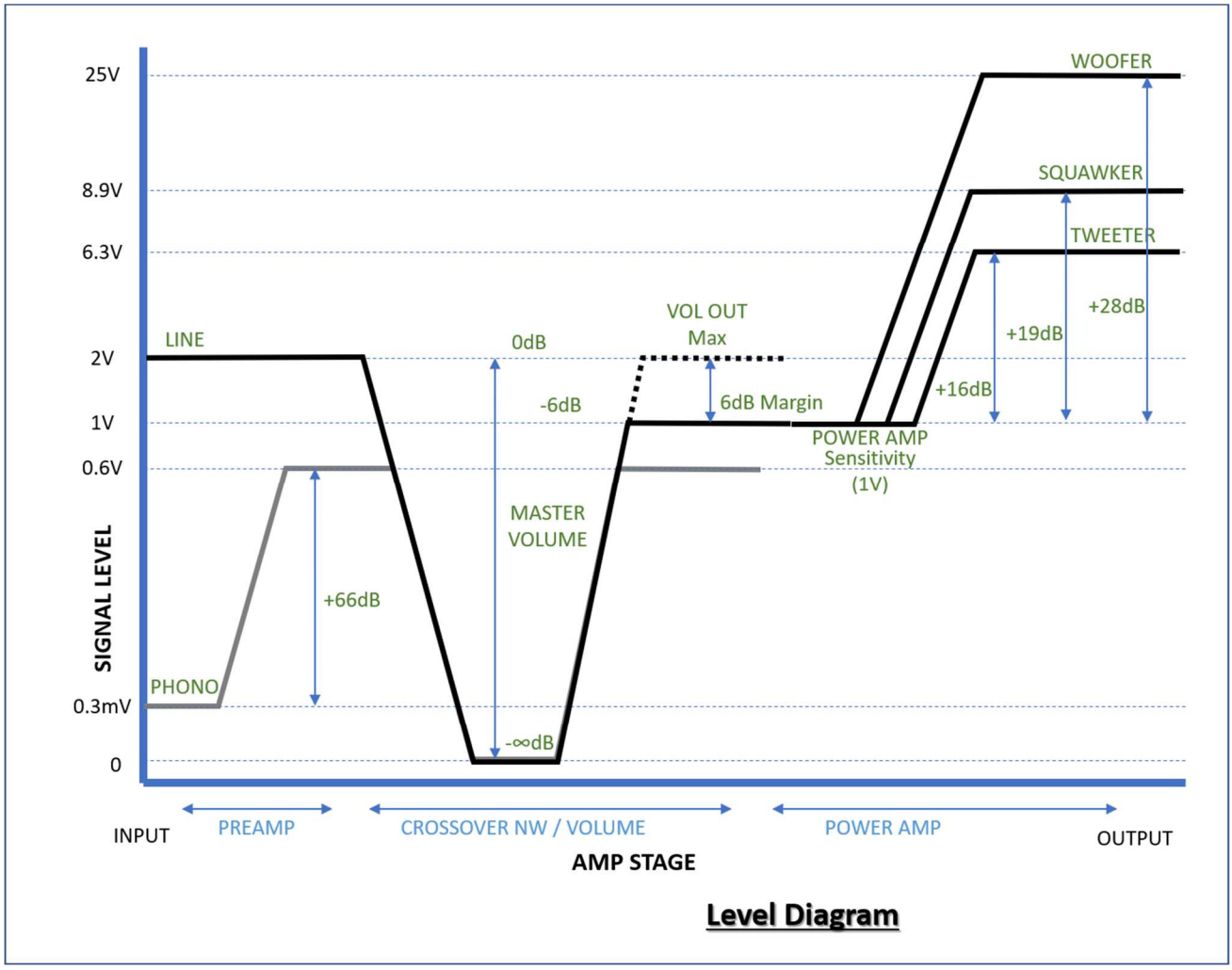

Fig. 5. Level diagram

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