Room Acoustics Design

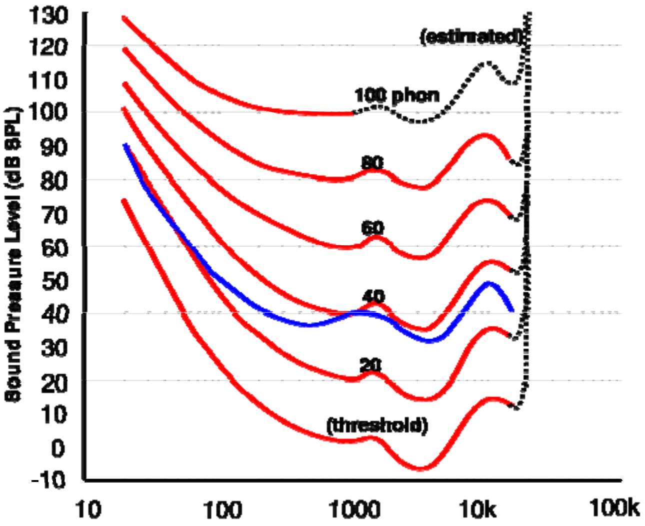
and the Frequency/Power Spectrum

Human perceived "loudness" varies logarithmically with the output power of the sound source.

Other inversely proportionate factors are; frequency, number and material of objects through which the sound waves travel, as well as distance between source and listener.

A given change in the output power of a sound system produces a much smaller change in perceived loudness. We express perceived loudness in the logarithmic decibel (dB) scale; a change of 1 dB is considered to be the smallest change in sound power level perceivable by the average human ear. An increase/decrease of 3 dB corresponds to a doubling/halving of power or distance of average perceivability.

The perception of loudness is not proportional to the sound pressure or the sound intensity. Our hearing does not have the same sensitivity for all pitches.



Equal-loudness contours (red) (from ISO 226:2003 revision)
Original ISO standard shown (blue) for 40-phons

These Equal-Loudness contours (on left) describe the inverse frequency response of the ear. The surprising thing about the curves is that they reveal that perceived loudness varies greatly with frequency and sound-pressure level. The ear is less sensitive to bass notes than mid-band notes at low levels. There are wiggles in the ear's high-frequency response that are relatively less noticeable.

Also this bass problem of the ear means that the quality of reproduced music depends on the volume-control setting. Listening to background music at low levels requires a different frequency response than listening at higher levels.

This is why manufacturers include the loudness switch on home stereo equipment for low level listening and also why most engineers will mix and master at average levels of 75 to 85 decibels.

The chart (below) describes the percentage of power per 1/3 octave band. This chart takes into account the response of the human ear and the relative power levels required to achieve the same perceived level in each 1/3 octave band. I have compensated the required change in decibels with the data found in the 80 phon curve of ISO 226:2003.

Since mixing and mastering is done at an average level of 80db, let's assume that the speaker system being used has an efficiency rating of 1 watt = 80 db @ 1 meter and the power used at 1000 Hz is 1 watt.

The chart below shows 1 watt at 1000 Hz and the perceived loudness is 80 decibels, 25 Hz will be perceived as 80 db with 173 watts. This is a 17,178% increase in power to give the same sense of loudness. At 125 Hz the same perceived level requires 6.71 watts – a 570% increase in power. The output power required for a perceived flat response increases almost logarithmically as frequency decreases. This enormous increase in the power of low frequency sound waves will cause the modal frequencies to ring, thus creating a long decay time for these frequencies.

Relative Power/db levels vs. Frequency

Average mix levels from 75 to 85 Decibels

1/3 oct freq	Correction Factor in db At 80 Phon	Decible level w/o correction	Power level w/o correction	percent of power increase / decrease	Reference Freq.	Decible level w/ correction (At 80 Phon)	Power level w/ correction (At 80 Phon)	percent of power increase / decrease
16 Hz		17.96 db	6.02 Watts		1000 Hz			
20 Hz		16.99 db	5.47 Watts					**Percent**
25 Hz	35.5 db	16.02 db	4.96 Watts	**396.32 %**	Reference Watts	51.52 db	172.79 Watts	**17178.71**
31.5 Hz	29.5 db	15.02 db	4.49 Watts	**348.93 %**	1 Watts	44.52 db	85.77 Watts	**8477.17**
40 Hz	26.5 db	13.98 db	4.05 Watts	**304.69 %**		40.48 db	57.28 Watts	**5627.93**
50 Hz	22.25 db	13.01 db	3.67 Watts	**267.31 %**		35.26 db	33.99 Watts	**3298.88**
63 Hz	18.25 db	12.01 db	3.32 Watts	**232.23 %**		30.26 db	20.61 Watts	**1960.76**
80 Hz	15.5 db	10.97 db	2.99 Watts	**199.49 %**		26.47 db	14.11 Watts	**1311.04**
100 Hz	13.5 db	10.00 db	2.72 Watts	**171.83 %**		23.50 db	10.49 Watts	**948.56**
125 Hz	10 db	9.03 db	2.47 Watts	**146.72 %**		19.03 db	6.71 Watts	**570.66**
160 Hz	8.25 db	7.96 db	2.22 Watts	**121.64 %**		16.21 db	5.06 Watts	**405.75**
200 Hz	6.5 db	6.99 db	2.01 Watts	**101.17 %**		13.49 db	3.85 Watts	**285.35**
250 Hz	4.25 db	6.02 db	1.83 Watts	**82.59 %**		10.27 db	2.79 Watts	**179.28**
315 Hz	3.25 db	5.02 db	1.65 Watts	**65.15 %**		8.27 db	2.29 Watts	**128.57**
400 Hz	2 db	3.98 db	1.49 Watts	**48.88 %**		5.98 db	1.82 Watts	**81.84**
500 Hz	1 db	3.01 db	1.35 Watts	**35.12 %**		4.01 db	1.49 Watts	**49.34**
630 Hz	0.5 db	2.01 db	1.22 Watts	**22.22 %**		2.51 db	1.28 Watts	**28.49**
800 Hz	0 db	0.97 db	1.10 Watts	**10.18 %**		0.97 db	1.10 Watts	**10.18**
1000 Hz	0 db	0.00 db	1.00 Watts	**0.00 %**		0.00 db	1.00 Watts	**0.00**
1250 Hz	2 db	-0.97 db	0.91 Watts	**-9.24 %**		1.03 db	1.11 Watts	**10.86**
1600 Hz	4 db	-2.04 db	0.82 Watts	**-18.46 %**		1.96 db	1.22 Watts	**21.64**
2000 Hz	1 db	-3.01 db	0.74 Watts	**-25.99 %**		-2.01 db	0.82 Watts	**-18.21**
2500 Hz	-1.5 db	-3.98 db	0.67 Watts	**-32.83 %**		-5.48 db	0.58 Watts	**-42.19**
3150 Hz	-3 db	-4.98 db	0.61 Watts	**-39.24 %**		-7.98 db	0.45 Watts	**-54.99**
4000 Hz	-1.5 db	-6.02 db	0.55 Watts	**-45.23 %**		-7.52 db	0.47 Watts	**-52.86**
5000 Hz	1 db	-6.99 db	0.50 Watts	**-50.29 %**		-5.99 db	0.55 Watts	**-45.06**
6300 Hz	5 db	-7.99 db	0.45 Watts	**-55.04 %**		-2.99 db	0.74 Watts	**-25.87**
8000 Hz	11 db	-9.03 db	0.41 Watts	**-59.47 %**		1.97 db	1.22 Watts	**21.76**
10000 Hz	12 db	-10.00 db	0.37 Watts	**-63.21 %**		2.00 db	1.22 Watts	**22.14**
12500 Hz	8.5 db	-10.97 db	0.33 Watts	**-66.61 %**		-2.47 db	0.78 Watts	**-21.88**
16000 Hz		-12.04 db	0.30 Watts					
20000 Hz		-13.01 db	0.27 Watts					

The average listening room frequency response is colored by these low frequency modes or standing waves. The associated decay times can only be reduced with the use of well placed and properly constructed bass traps. (Modal resonances in a room will increase / decrease the level of sound at the frequency of resonance by ±3db to ±12db or more.)

When treating a room acoustically, the percentage of relative increase or decrease shown above can be a starting point for the absorption required in the average room for an average listening level of 80 decibels. Please note that an average listening level of less than 80 db will show even more drastic discrepancies, due to the non-linear response of the human ear.

To obtain the most accurate listening room, room dimensions complementing a balanced modal distribution is required. This is only a starting point. Treatment of critical mixing / mastering rooms must maintain a uniform decay response. Too many audio control rooms are ineffectively and improperly treated with the extensive use of absorption products that cover the frequency spectrum from around 400 Hz to 20 kHz. This technique leaves the control room with an unbalanced decay response which can adversely effect to quality of production in that room.

If the data on the chart above is an indicator, notice that in the frequency range from 500 Hz to 1.6 kHz little if any absorption is required, and from 2 kHz to 6.3 kHz we have a negative number. A negative number here would suggest diffusion is needed and not absorption. Again from 8 kHz to 10 kHz some absorption may be needed.

Many home studios and even larger, owner-designed facilities suffer from too much absorption in the mid-range and too little in the bass region. A case study of well designed, modern mixing/mastering facilities will reveal what has been described above. Notice the absence of wall padding and obvious mid-range absorption and also note that diffusors on the walls and ceilings (depending on design philosophy – RFZ, NE, Ambechoic, etc.) stand out as prominent features in these well designed modern facilities.

The absence of obvious absorption material in these modern facilities is not evidence of the lack thereof, but it is evidence of minimal mid-range absorption. The absorption is allocated to its intended job: low frequency standing wave control and diffusion.

In conclusion, the first and most needed acoustic control product for the listening room is bass traps. The average studio will need 600% more bass traps than mid-range absorption. And it will need the same amount of diffusion at 3 kHz as absorption is needed at 500 Hz.

I am not denying that absorption in the mid-range is useful and necessary, but that careful allocations should be made as to which frequency bands need more absorption. Absorption in the mid-range and above is necessary and required for accurate decay times but not without neglecting the low end which may need at least 6 times as much.

My intent with this paper is to provoke critical thinking. The data and statements above need to be tested in a lab, but I am convinced from measurements I and others have made that this information is closer to the truth than not.

These are a few recommended priorities for treating a premium mix/master room:

1. The room must have dimensions favoring a dense balanced modal response and include appropriate isolation from noise.
2. Appropriate acoustic damping in the form of bass traps must be designed into the room to bring the LF decay down to the decay of the mid range frequencies plus 20%.

These priorities are accomplished by focusing on the true needs of the facility. A proper balance of trapping, absorption and diffusion is absolutely required. The actual percentages will depend on the dimensions, design and on-site testing.

Sincerely, -- John H. Brandt