High efficiency Loudspeaker set for disco application

Applying exponential horn principles; the back loaded horn.

Introduction

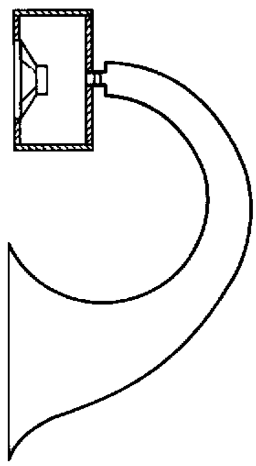
The current amplifier used in my son's drive-in disco is only rated 80 W RMS @ 8 Ohms driving two Karlson type enclosures with 12"loudspeakers which I built some 25 years ago. Although these speakers also perform quite well, they are limited when using for audiences of over 150 people. The midrange exponential enclosures recently built increased the sound level only partially.
The need for extended sound pressure level would normally be solved by buying a more powerful amplifier and accordingly higher rated loudspeakers.
In this case the challenge was however to achieve this goal by using the same amplifier and applying high efficiency speaker enclosures.

This high efficiency can be obtained from speakers driving exponential horn enclosures. Nowadays these enclosures are rarely used apart from large PA speakers that are used for open air concerts and can only be transported by truck. This looks not very suitable for a modest drive-in disco.
The disadvantage of the large volume of the horn enclosures can however be limited with some tricks. The final product was still within reasonable proportions and can be transported by car.

Principles

The principle of exponential horns is very old. Trumpets and similar instrument apply this shape of enclosure for centuries to enhance the sound pressure level. In the early 20th century, the first turn-tables used a horn to amplify the vibrations of the needle without any electricity.

This principle can also be used to amplify the sound level of loudspeakers. While HiFi speakers have a acoustical efficiency of 1 – 2%, applying a horn will increase this to a 30-50% efficiency.
The basic principle is to put the sound source (speaker) in a closed box, with only a small outlet. This outlet is connected to the rear end of the horn. The horn area is expanding according to an exponential curve.



Normally the frequency of these horns is limited to several hundreds Hertz.
In order to achieve a wider range, a back loaded horn is applied. Here the speaker is mounted in the front side of the enclosure and thus be allowed to transmit higher frequencies directly from the membrane. Still the small opening in the back can drive the horn for amplification of the lower frequencies (these bass frequencies would normally require the most electrical energy).

The size of the horn area is determined by the lower frequency. The lower the required frequency is set, the larger the horn mouth.

The second challenge is to limit the size of the horn to reasonable proportions. Folding the horn into a rectangular enclosure requires some experimental drawing, but results in a transportable enclosure with reasonable dimensions.

Calculated results

For determining the various parameters and dimensions, the following relationships can be found in literature:

$A_{mt}=c^2/(4\cdot p\cdot f_g^{\,2})$ [1]

A_{mt}= Area of horn mouth [m^2]
c= air speed = 345 m/s
f_g= lower cut-off frequency [Hz]

$0,3\cdot A_d < A_h < A_d$ [2]

A_d= effective area of speaker membrane

$A_x= A_h\cdot e^{2mx}$ [3]

A_x= Area at distance x from horn throat [m^2]
A_h= Area at horn throat [m^2]
m= widenings constant = $2\pi f_g/c$ **[4]**

Practice

Because of the initial desired volume and power to be handled, 30 cm. diam. Disco loudspeakers were chosen.
The effective membrane diameter is 29 cm, resulting in:

$A_d= 0,25\cdot\pi\cdot 29^2 = 572\ cm^2$

For the throat of the horn (the back opening of the enclosure), relation [2] is applied. In this case I chose $A_h = 0,7\cdot A_d$ approximately half way. So

$A_h = 0,7\cdot 572 = 400\ cm^2$

Furthermore the lower cut off frequency f_c is set at 30 Hz, which results in (using [4]):

$m = 2\cdot\pi\cdot 30 / 345 = 0,546$

The (inner) width of the enclosure is set at 40 cm for practical (read: transport) reasons. Now we can calculate the hight of the horn at a distance x from the throat, while keeping a constant width of 40 cm.

distance x [m]	Ax [cm^2]	hight h=Ax/40	circular [cm]	f-low [Hz] at x
0	400,6	10,0	100,0	172
0,1	446,8	11,2	102,3	169
0,2	498,4	12,5	104,9	164
0,3	555,9	13,9	107,8	160
0,4	620,0	15,5	111,0	155
0,5	691,6	17,3	114,6	151
0,6	771,4	19,3	118,6	145

0,7	860,4	21,5	123,0	140
0,8	959,7	24,0	128,0	135
0,9	1070,5	26,8	133,5	129
1	1194,0	29,9	139,7	123
1,1	1331,8	33,3	146,6	118
1,2	1485,5	37,1	154,3	112
1,3	1657,0	41,4	162,8	106
1,4	1848,2	46,2	172,4	100
1,5	2061,5	51,5	183,1	94
1,6	2299,4	57,5	195,0	88
1,7	2564,8	64,1	208,2	83
1,8	2860,8	71,5	223,0	77
1,9	3190,9	79,8	239,5	72
2	3559,1	89,0	258,0	67
2,1	3969,9	99,2	278,5	62
2,2	4428,0	110,7	301,4	57
2,3	4939,0	123,5	327,0	53
2,4	5509,0	137,7	355,5	49
2,5	6144,8	153,6	387,2	45

It appeared possible after some experimental drawing to fold the horn of 1,8 m length in the enclosure starting with a mouth hight of 71 cm.

A horn mouth of 71 x 40 cm would mean (applying [1]):

$$f_g^2 = c^2/(4 \cdot \pi \cdot A_{mt}) = 345^2/(4 \cdot \pi \cdot 0{,}284) = 33368 \text{ , } f_g = 182 \text{ Hz}$$

Specifications

Per enclosure:
Two Piezo horn tweeters SPL 100 dBa, 4 – 22 kHz, 200 W each
One LS unit, , 30,5 cm diam. 30 – 4500 Hz, 300 W max, SPL 91 dBa
No filters applied.

References:

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Mc Farlow Exciter, Elektuur maand, jaar
Lowther club Holland-Design of a horn subwoofer,
http://www.bd-design.nl/wwwpages/lowhorn.html