The 'Big Fun' horn

Or: The story of Another Back Loaded Lowther Horn

Why a horn?

Much has been said (and written) about horn speakers over the years, and I'm not going to repeat all of it here. Rather than that, I'll try to point out the obvious advantages, and my personal points of view. First, let's kill some of the myths about horns:

Bass reproduction from a horn is NOT 'tinny/screaming', etc. etc. Some poorly-designed systems may have a tendency to produce big, 'empty' bass sound. In these cases, chances are that the designer compromised to much, and foreshortened the horn in order to get the physical size down. Also, poor wood quality may have these negative effects.

You do NOT need a vinyl record player and tube amplifiers to make a horn sound good. All the advantages of a horn system will be noticeable regardless of equipment.

Treble is NOT poor from a one-way horn system. I guess there's a number of 'full-range' drivers out there that really aren't full range. Not so with the Lowthers. They WILL take you all the way up there.

Apart from these myths, there seems to be a wide agreement on the following pros:

Efficiency: A horn system is a lot more efficient than closed/vented box systems. For a given Signal Peak Level (SPL), the driver's excursion is accordingly smaller, thus he driver will operate with linear excursion, giving less distortion. Also, if you're low on amp power, this will be a clear advantage.

Sound: The sound from a horn will be more dynamic and more life-like than that from closed/vented boxes.

DIY: There is a thumb-rule in constructing/building your own speakers that goes: Multi-way systems in vented/sealed boxes can go really wrong. A horn doesn't.

Personally: I think it's the awesome dynamics and natural sound character from a horn that give me the best musical experience. From a DIY point of view, I find that crossovers are a real pain in the butt. They're hard to construct, and the results are always unpredictable. So I build one-way horns.

Research/ Defining the goals

Why construct a new horn?

There are a number of well-designed horn systems out there, and strictly speaking, there's no need to go through the pain of calculating your own horn. However, upon reviewing some of the existing constructs, they didn't appeal to me for various reasons. The modern designs seem to compromise to much in order to limit their physical dimensions. The older designs are probably good, but they look OLD (nothing wrong with that really, it's just that I'm not into the retro-stuff, I want my speakers to look new).

When I set out on this project, the only goal that was really well-defined was that I was building a back-loaded horn. Bass reproduction was to go well below 40 Hz. The Physical size wasn't an absolute restraint, since I'd just moved into a new house with a BIG livingroom

The research that I had to go through in order to get the specifics in place, consisted of:

Reading through all the theory on horn construction that I could get my hands on (see reference list); calculating alternative expansions/space requirements/sketching designs.

Learning from the old and wise; re-iterating the steps taken by people like Dinsdale, Edgar, Voigt, and the engineers at Lowther when they were designing their good stuff.

Theory

This section merely scratches the surface of horn theory. Readers that would like to fold their own horns, are referred to the literature list for more in-depth reading. However, I'll provide all the theory relevant to the design of this horn, so it should be sufficient for those who'd like to alter the design/make their own based on these ideas.

A horn is an acoustic transformer that couples the speaker cone's movement to the air, transforming high-energy/small movement to low-energy/large movement of air. That's where the efficiency comes from.

The horn forms a funnel starting at the throat (closest to the driver) and ending at the mouth. The funnel's cross-sectional area will expand as described by the formula used (The contour).

One of my friends dropped by as I was building these horns, and immediately made the remark: 'It's like a really big funnel' when he saw the half-built cabinet. That's how I thought of the name for the project; BIG FUN(nel)…

Any given horn will only be effective down to a certain, chosen frequency. We call that the cut-off frequency (fc) of the horn.

Now, to calculate the horn, we need the following parameters: The mouth and throat area, the cut-off frequency, and the chosen contour.

Mouth Dimension

The mouth area that we want, is calculated from the fc. The circular mouths circumference should be equal to one wavelength of fc, which gives us:

rm = c / (2 * pi * fc)

Where

c = the speed of sound, 34290cm/s (1125ft/s).

Now, if we try stuffing a sample value in the formula (let's say 30Hz), we'll get an outrageous mouth size with a radius of 182 cm (6'). This, however, is a mouth size calculated for free space loading. That means that the dimensions are good if the horn is hanging from the roof, radiating into all 8 quadrants of the space. For wall placement, we'll be radiating into 2 quadrants, and we can then safely reduce the size by a factor of 8/2=4. For corner placement, it gets even better. We'll be radiating into 1 quadrant only, and we can reduce the size by a factor of 8. Which in our example will bring the huge mouth down to rm / sqr(8) = 64 cm (2,1'). In a square horn, this corresponds to a square side of 114 cm (3,7'), so we're still talking about a big mother.

We're going to be able to reduce the mouth size pretty much still, even without compromising the overall design. Read on to find out how. For the moment we'll just stick to what we know now.

This horn's fc was set at 32Hz, and calculated for corner placement.

Throat Dimension

Theory here is somewhat more obscure. However, there are some valid thumb rules in calculating the throat area. I'll just recite something out of an article by Dinsdale[KP1]i here; "For Maximum Bandwidth of a horn, one uses throat to driver ratios of 0,50 to 0,30; for maximum efficiency one uses ratios of 0,50 to 0,70.".

Personally, I chose the throat area of my horn as a result of empirical research. I browsed through 10-20 comparable horn designs, and decided on the basis of the designs most resembling mine. The unit that we're going to use has an effective area of 211 cm2 (33 in2). Which tells us that the throat area should be somewhere between 63 cm2 (9,8 in2) and 148 cm2 (23 in2). I decided on a throat area of 100 cm2 (15,5 in2). That gives us a throat radius (tr) of 5,65 cm (2,2 in). So now that's out of the way.

Horn contour

The horn contour is the expansion (flare) rate of a horn. Different contours include Conical, exponential, hyperbolic, and the tractrix contour.

Of these, the conical is the easiest one to calculate and stuff into a box, but it's also the least efficient. Conical contours are never employed for bass horns, because of the poor response and the impossibly long horns that result.

The exponential is the most commonly used, and is easy to calculate.

The hyperbolic contour is actually a variety of the exponential, and is the most efficient type. The trade-off is more distortion in the deep bass region. Hyperbolic horns are also somewhat longer than exponential horns.

Combinations of all these types may also be found.

The tractrix is a curve well-known in the world of mechanics, that the late P.G.A.H. Voigt by a stroke of genius re-invented and applied to horn speaker acoustics in 1926. The tractrix contour has characteristics similar to the exponential, but has the advantage of being shorter (the curve expands faster). The disadvantage is that it's somewhat awkward to calculate, since you can't directly calculate the area A(x) at a distance x from the throat.

In this design, I decided to employ the tractrix contour, to save some space (and wood, for that matter).

Calculation of the tractrix contour

The formula for calculating a tractrix contour is as follows:

x = a * log((a + sqrt(a2 - r2)) / r) - sqrt(a2 - r2).

Where:

x is the distance from the mouth of the horn.
a is the radius at the mouth.
r is the radius at distance x from the mouth.

The most convenient thing to do is to write a small program to calculate the curve, if you have access to a computer and a compiler of some sort. Consider the following piece of code, written in a 'generic' Programming Language (pseudo-code):

```
;Sample code
Def var r as decimal . ;See the above formula
Def var x as decimal . ;See the above formula
Def var a as decimal . ;See the above formula
Def var r_throat as decimal . ;Radius at throat
Def var r_ fe_mouth as decimal . ;Radius for a Fully Expanded mouth (free space loading)
Def var hl_ fe as decimal . ;Horn Length when Full Expansion (free space loading)
Def var Size_factor as integer . ;See below
Def var step as integer initial 1 . ;See below
Def var oldx as decimal initial -1 .
Def var xfromthroat as decimal .
Def var prec as decimal initial 0.001 .;Prec(ision) - simulate radius growth with a
;precision of…
Input r_throat ;Get the radius of the throat
Input Size_factor ;Get the size factor (1 for free loading, 2 for the middle of a floor,
;4 for wall placement, 8 for corner placement
Input r_fe_mouth ;radius for free loaded mouth
Input step ;Get the desired step value (output for every <step> length units)
r = r_throat * sqrt(Size_factor). ;Start at the size-factor adjusted r.
a = r_fe_mouth. ;End at the fully expanded mouth.
hl_fe = a * log((a + sqrt(a * a - r * r)) / r) - sqrt(a * a - r * r). ;Calculate the length of the
```

```
;horn
do while r <= r_fe_mouth: ;Leave the loop when we're at the mouth.
x = a * log((a + sqrt(a * a - r * r)) / r) - sqrt(a * a - r * r). ;Calculate the x (dist from
;mouth)
xfromthroat = hl_fe - x. ;Find dist from throat
If trunc(xfromthroat / step, 0) > oldx then do: ;Did we just step over to a new value of x?
display ;Yes, print the line out...
xfromthroat at 1 column-label "Dist. throat"
sqrt(r * r * M_PI / Size_factor) column-label "Square"
r / sqrt(Size_factor) column-label "Radius"
(r * r * M_PI / Size_factor) column-label "Area".
oldx = xfromthroat / step. ;And keep the current step value.
End. ;New step value
r = r + Prec. ;Increase radius by Prec
end.
;End Sample code
```

Coupling the driver to the horn

Now, before we attempt to stuff the whole thing into a box, some attention needs to be directed to the volume of air (the cavity) between the driver's back side and the horn throat. We'd like to keep higher frequencies out of the horn. A good thumb rule is to let the horn play 3-4 octavesii or less. One should therefore dimension the cavity in such a way that it will act as a low-pass filter with an upper cut-off freq. 3-4 times the horn's fc. Also, the upper cut-off should be set at a frequency where the horn's length equals an odd multiply of the wavelength (because the horn is loaded from the back of the driver, 180 degrees out of phase). This is to avoid a canceling of the frequencies around the upper cut-off. Calculate the volume of the cavity (Vc) using this formula:

Vc = (C * Throat area) / (2 * PI * upper cut-off freq.) iii

In the 'BIG FUN' horn, this wasn't considered, because I wanted to leave plenty of space available for experimenting with different upper cut-off frequencies and damping of the cavity. However, I would recommend DIY constructors to take advantage of this math.

Folding a bass horn

This is by far the hardest part of constructing a bass horn. Let's take up some column real estate (sorry, editors) in analyzing what the problem is.

The horn length should be measured along the middle of the duct. Through a bend, the length should be measured along the middle of the duct, all the way around the bend. That makes it a little hard to construct the bend correctly, but by employing a pair of calipers and a ruler, it's doable.

If you try this yourself, you're going to find that you'd like to keep one wall of the horn straight, while expanding the horn with the other wall. This provides for a convenient way of making the cross-sectional areas match the distance. However, it also makes it harder to measure the distance, since the distance will be on an angled line. The formula will give you an x measured along a straight center line in the middle of the duct, while the radius (and calculated squares/rectangle heights) will expand in

both directions from the center line .

I solved this trigonometric problem in a spreadsheet. I stuffed the output from the tractrix contour program into the spreadsheet, and added a number of columns. One of the columns contains the length along the straight wall of the horn, corresponding to the length along the center line (x). This makes it a whole lot easier to draw the thing out.

The horn expansion

Tractrix horn (from throat)

Distance	*Radius*	*Square*	*Area*	*Const. width*	*L. straight*	*Distance, Inches*	*Const. W, Inches*	*L.straight, Inches*
				37,00			14.6	
0	5,64	10,00	100,00	2,70		0,00	1,06	
10	5,99	10,61	112,53	3,04	9,93	3,94	1,20	3,91
20	6,35	11,25	126,64	3,42	9,93	7,89	1,35	3,91
30	6,73	11,94	142,48	3,85	9,88	11,82	1,52	3,89
40	7,14	12,66	160,36	4,33	9,89	15,76	1,71	3,90
50	7,58	13,43	180,48	4,88	9,87	19,70	1,92	3,88
60	8,04	14,25	203,03	5,49	9,80	23,62	2,16	3,86
70	8,53	15,12	228,61	6,18	9,85	27,57	2,43	3,88
80	9,05	16,04	257,31	6,95	9,78	31,50	2,74	3,85
90	9,61	17,03	289,85	7,83	9,81	35,45	3,08	3,86
100	10,19	18,07	326,35	8,82	9,73	39,37	3,47	3,83
110	10,82	19,17	367,65	9,94	9,72	43,31	3,91	3,83
120	11,48	20,35	414,22	11,20	9,67	47,25	4,41	3,81
130	12,19	21,61	466,81	12,62	9,63	51,18	4,97	3,79
140	12,94	22,94	526,27	14,22	9,59	55,12	5,60	3,78
150	13,75	24,36	593,56	16,04	9,54	59,06	6,32	3,76
160	14,60	25,88	669,75	18,10	9,48	63,00	7,13	3,73
170	15,51	27,50	756,05	20,43	9,41	66,94	8,04	3,70
180	16,49	29,22	853,78	23,08	9,32	70,88	9,08	3,67
190	17,53	31,06	964,84	26,08	9,23	74,81	10,27	3,64
200	18,64	33,03	1090,96	29,49	9,11	78,75	11,61	3,59
210	19,82	35,14	1234,48	33,36	8,99	82,68	13,14	3,54

Distance	Radius	Square	Area	Const. width	L. straight	Distance, Inches	Const. W, Inches	L.straight, Inches
220	21,10	37,40	1398,57	37,80	8,86	86,62	14,88	3,49
230	22,47	39,82	1585,84	42,86	8,68	90,56	16,87	3,42
240	23,94	42,44	1800,80	48,67	8,50	94,50	19,16	3,35
250	25,53	45,25	2047,51	55,34	8,25	98,43	21,79	3,25
260	27,25	48,30	2333,01	63,05	8,01	102,37	24,82	3,15
270	29,12	51,61	2663,60	71,99	7,68	106,30	28,34	3,03
280	31,16	55,23	3049,89	82,43	7,33	110,24	32,45	2,89
290	33,40	59,20	3504,50	94,72	6,91	114,18	37,29	2,72
300	35,88	63,59	4043,91	109,29	6,40	118,11	43,03	2,52
310	38,66	68,52	4694,61	126,88	5,83	122,05	49,95	2,30
320	41,82	74,13	5494,64	148,50	5,15	125,98	58,47	2,03
330	45,54	80,71	6514,42	176,07	4,37	129,92	69,32	1,72
340	50,14	88,87	7898,07	213,46	3,43	133,86	84,04	1,35
350	57,04	101,10	10221,90	276,27	2,17	137,80	108,77	0,86

In this spreadsheet, the first 4 columns are created by the tractrix calculation program (Distance, Radius, Square, Area).

Const. Width: This column shows the height of the duct with a width of 37.

L straight: This column shows the length of the straight duct wall over the corresponding distance. This has been found by applying simple trigonometric functions to the angles given by the increase in height vs. the length increase (Distance column).

At this point we're in pretty good shape to continue with the folding. In the spreadsheet that I used, I also calculated the minimum space requirements for each row of the table, giving a good indication of the overall size I would have to anticipate given the horn length.

And a time to compromise…

Comparing the spreadsheet to the drawing will reveal that the mouth area of BIG FUN appears to be to small. It has been foreshortened (terminated at a mouth smaller than the actually calculated mouth area).

An accepted method of foreshortening the horn, is to base the mouth opening on a higher frequency than the fc used to determine the flare rate. Normally, a horn's 'true cut-off' will be at a frequency ca. 1¼ * fc. This would allow us to terminate this horn at an area of 7314 cm2 (7.9 ft2). Corresponding to a duct height of 198 cm (78") in our 37 cm constant-width horn.

Purists will tell you not to foreshorten the horn any more than this, and they're right. However, reviewing a large number of bass horns, I've found that even some of the most acclaimed designs are foreshortened more than this, in some cases a lot more. The resulting design will theoretically yield an uneven response vs. frequency curve in the 1-2 octaves above the fc. However, so will any speaker located in any room. Depending on the acoustical damping characteristics of the speaker's surroundings, this natural reflection phenomenon may (or may not) be well in excess of the irregularities of the horn.

So, after having done some thorough research on the subject, I've found a number of thumb rules for foreshortening horns. One of them is that the mouth area should be at least 5 times the area of the throat (probably best-employed for frontloaded horns, though). Another is to cut the horn when the length is at ¼ of the theoretical fc wavelength.

The 'BIG FUN' horn's foreshortening is well within these thumb rules. I cut the horn at an area of 91 cm (35.8") by 37 cm (14.6"), giving the horn a length of 288 cm (9,45'). Because of the mouth geometry of this design, the mouth will in fact be somewhat larger.

The woodwork

What you need, apart from the wood: ca 100 wood screws, ca 2 liters of wood glue, ca. 2 * 1,5 meters (4'-5') of decent speaker wire, terminal posts.

The horn is constructed as a constant-width horn, which is not optimal seen from the propagating wave's point of view. Ideally, the cross section of the horn should be circular. This is kind of hard to do working with wood, so most horns are built from square/rectangular cross sections. Constant-width horns are well within the reach of hobbyists, whereas you'd need a professional woodworking shop to build a square horn.

Prepare the work: The first thing you want to do, is to draw out all the inner board positions on one of the sidepanels. This will take you an hour or two, but it is necessary.

Cut the triangular side panel holes: Use a jigsaw with a new, medium/heavy duty blade. Make yourself a ruler from a perfectly straight board, about 1 meter (40") long. Fix that ruler to a piece of scrap board. Guide the jigsaw along the ruler and make a cut about 10 cm (4") into the board. Measure the exact distance from the cut to the ruler. Now fix the ruler to the side panel, and cut away. Take your time. If you use MDF, you'll see that the board tries to twist the blade out of position. Move the saw back and go over the cut again, until the blade angles 90 degrees out from under the board.

Cut all the inner boards: Use a hand-held (or table-mounted) circular saw with a sharp blade. Measure the exact length of each of the boards, and the angle at each end. Start at the board closest to the throat of the horn. You'll want to save some time cutting boards for both speakers at once. Now, start off with two lengths of board. Adjust the blade's angle according to the first angle you've measured (should be apx. 4 degrees). Cut both boards at the measured length (the ruler technique can be employed here too, if you have a hand-held saw). You now have the first inner board. The adjoining board also has an angle of 4 degrees, so you're now well-prepared to do the next board. Now set the sawblade to the next angle (should be apx. 6 degrees), and repeat the process (10 degrees, 22,5 degrees, a.s.o). Most circular saws won't cut any sharper than 45 degrees, so you'll find that there are two angles that will have to be made with a planer. Just cut them at 45 degrees.

Drill holes. Put the sidepanel with your artwork on it, on top of the other so that the triangular holes and the edges align. Drill screw holes for the top/front/back/bottom and all the inner boards, through both the sidepanels. One screw per inner board should be sufficient for the short boards. For the long ones, make two.

Gluing it all. Put the sidepanel with your drawings on it, on top of a workbench. Start with the boards closest to the center of the sidepanel. Put plenty of glue on the sideboard where the inner panel is drawn, place the sideboard and screw it tight from under the sideboard. Put plenty of glue on the edges of adjoining boards. Press adjoining edges together, and use a staple gun or a small screw/nail to keep them in position while the glue dries.

Mount the outside panels. When all the innards are fastened, allow a day for all the glue to harden real well. Then mount the outside boards in the following sequence: Top, Back, bottom, Front, and finally side panel. Attach the terminal posts to the back of the speaker and fit the wire before you mount the side panel (glue the wire to the topmost innerpanel with silicon or some other suitable glue). Put plenty of glue on all the joins before mounting the final side panel. Flip the speaker around so that the recently glued-on sidepanel faces the floor. Leave it there to dry thoroughly before you move it.

Mount the drive unit. Take great care when handling the Lowthers, the magnetic gap is open, and small metal objects can easily be drawn in to the gap, as well as saw dust and other unwanted particles. If that happens, the unit needs to be serviced. A useful tip is to cover the whole unit with a thin pantyhose as soon as you remove the plastic bag it's shipped in, and then mount the driver with the pantyhose in place. Use a sharp knife to cut holes for the lead terminals and mounting holes on the back of the driver.

About the plans/tips for building/dimensions

The inner dimensions are as follows:

Dimension	cm	in
Width (IW)	37,00	14,57
Depth (ID)	85,00	33,46
Height (IH)	115,00	45,28

Since there's a number of options with regards to wood quality, thickness, etc., I'll leave it to the reader to decide on the desired quality of the cabinets. Using the original drawing, the outer board dimensions can be calculated like this (qty is for two speakers):

Qty	Board	Width	Depth	Height
2	Top panel	IW	ID + Front Panel thickness + Back Panel thickness + 1	
2	Bottom panel	IW	ID + Rear panel thickness + 1	
2	Front panel	IW		IH + Bottom panel thickness
2	Rear panel	IW		IH
4	Side panels		ID + Front Panel thickness + Back Panel thickness + 1	IH + Top thickness + Bottom thickness

I used 22 mm MDF for the top/front and side panels, and 16 mm MDF for the back/bottom and inner boards. My advice to the reader would be to use marine plywood, as thick as you can get your hands on/afford.

Also, if I were to build these speakers again (which I'm sure I will, incidentally), I'd cut some boards for bracing the cabinet, at the following places; between the top panel and the topmost inner board, between the front board and the middle (vertical) inner board, and between the side panels toward the mouth opening.

Try ordering the boards pre-cut, it's well worth the extra money. At the very least, try to get the inner widths cut for you.

Finish

I veneered the cabs with birch. It looks really good. If you build the cabs the way the plans show, you'll have to glue the veneer on after having assembled the whole cabinet, which is kind of awkward, so the best thing to do is obviously to join the whole cab with 45 degree angles at all the edges, and veneer all the panels before joining them. This will however cost you some extra grief in screwing the cabs together, since you can't screw them in from the outside panels.

We proudly present: The 'Big Fun' horn

Pictures: Drawing and the finished cabinet

Having reached the moment of truth, I'll try to be as unbiased as possible in presenting the 'Big Fun' design's performance.

The bass from this pair of speakers is pure and simple GOOD. It's deep, very much alive, and very well-defined. Acoustical bass never sounded so much like - uh - acoustical bass before. The bass from organ pipes flows effortlessly from the cabs. The kind of warm, deep bass that gives you a strong feeling of presence.

I don't have the tools to measure freq. Response, but bass response seems reasonably flat in the deep end. I suspect, however, that there's a small dip in the response in the high bass region. This may go away/be reduced after some careful experimentation on cavity damping/room placement.

The midrange from the Lowthers is extremely dynamic and very transparent. Jazz people who listen to a lot of trumpet/saxophone music are going to love the 'smack' and the definition.

These drivers are often criticized for having peaks in the high mids/low treble regions, and I think the critics are, to some extent, right on this. There is a pronounced peak somewhere in that region, making some vocals/guitars sound a little harsh. There are some common tweaks to remedy this, loosely stuffing some clean, long-hair wool between the whizzer-cone and the main cone is one of them.

Treble is surprisingly good for a full-range speaker, the drawback is of course that it's extremely directional. Even at a distance of 10m (30'), you must still be at ear-level with the driver to really hear the higher frequencies.

One of the most amazing things about this speaker, is the sheer volume that it's capable of, even with tiny, tiny power amps. Just for the hell of it, I tried powering them up using a CD walkman (!), and they actually filled my basement (a BIG room) with sound just from that. According to my measurements, I will rarely, if ever, go beyond 2-3 watts of power driving these speakers. At 1 single Watt, they're loud enough for most people to start holding their ears.

Horn speakers require a little bit of tweaking to perform at their best. Seemingly insignificant adjustments in room placement can shift the sound from beautiful to lousy. At this point, I'm still not 100% sure that my speakers are optimally placed, and some of the above noted problems may still go away.

While writing this, the Lowthers haven't been properly broken in, and I expect the highs and mids to sound even better in a couple of weeks.

Conclusion

Money-wise, this project shouldn't scare anyone off, the total price for both speakers added up to apx. $570.-, and that's really cheap for speakers performing as good as these do. For a horn, it's extremely cheap, compared to the commercially available products.

Building these babies was a good time all the way, and when I got around to testing them for the first time, I was really amazed at the end result.

Musically, if you play a lot of jazz /pop and classical music, go ahead. If you're tired of your sealed speaker's dull, flat sound or your vented speaker's woolly, daft, overexposed bass, and want something more dynamic, alive and kicking, go for it.

And then the downsides:

Building a horn is more work than building a sealed/vented box. The woodworking is more difficult, and you need some power tools, a lot of work space, and some basic woodworking skills.

Finally, there's something to be said about the Wife Acceptance Factor of a pair of speakers this size. Fortunately, I have a very big living room and a forgiving wife, so I was able to convince her that we didn't need the floor space for anything anyway. Even so, they ARE kind of big. I call it 'BIG FUN'...

Recommended reading

- "The Show Horn", Bruce Edgar, Speaker Builder, 2/90
- "The Monolith Horn", Bruce C. Edgar, Speaker Builder, 6/93
- "The Edgar Midrange Horn", Bruce C. Edgar, Speaker Builder, 1/86
- "Solving the Klipschorn Throat Riddle", Bruce Edgar, Speaker Builder 4/90
- "The Klipschorn Throat Revisited: Or, Oooops", Bruce C. Edgar, Speaker Builder, 6/90
- "The Function and Design of Horns For Loudspeakers", C.R. Hanna and J. Slepian, JAES, Sep 1977 Vol. 25, No. 9, pp. 573-585. (Reprint of 1924 article)
- "Discussion: The Function and Design of Horns For Loudspeakers", JAES, Mar 1978, Vol. 26, No. 3, pp. 131-138. (Reprint of 1924 article)
- "Elements of Acoustical Engineering" (Book), Harry F. Olson 1957
- "Hi-Fi Loudspeakers and Enclosures" (Book), A. Cohen
- "High Quality Sound Reproduction" (book), James Moir

References

i)"The tractrix horn contour", Bruce C. Edgar, Speaker Builder 2/81
ii)"Horn Loudspeaker Design", J. Dinsdale, three part article Wireless World, March - June 1974. NOTE: There are errors in the tables of tractrix horn lengths.
iii) The Lowther Club pamphlet of Lowther Club of Germany/Denmark [KP1]