Synergy Calc V5

A calculator for cutting dimensions and build instructions of wooden constant-directivity rectangular conical waveguides (w/anti-waistbanding second flare); or for DIY Danley-style Synergy Horns

This document is intended as a detailed guide for use with the spreadsheet *Synergy Calc v5.xls*, a spreadsheet calculator that runs within Microsoft Excel. If you don’t have Excel, *Synergy Calc* runs equally well in the freeware spreadsheet program Gnumeric:

(http://www.gnumeric.org)

Gnumeric for Windows can be downloaded from:

(http://people.gnome.org/~mortenw/gnumeric/gnumeric-1.10.16-20110616.exe).

About Conical Horns or Waveguides

The main benefit of a conical horn is that it provides a constant directivity pattern over its frequency range, so that off-axis response is very similar to on-axis response but reduced in level. This very nice characteristic provides exceptional image stability over a range of seating positions, for either high fidelity or home theater. A benefit for DIYers is that rectangular conicals are relatively easy to make since the inside surfaces are primarily flat sections simplifying construction from plywood or MDF.

A conical horn doesn’t provide the same loading to low frequencies as some other flares like exponential or tractrix. It primarily controls directivity rather than providing maximum horn loading or efficiency (though efficiency is still normally higher than low frequency sections it would usually be paired with). Like most horns, a single-driver conical normally operates over a limited frequency range of typically under 10:1.

A conical horn also has a tendency toward “waistbanding”, a characteristic in which the directivity increases and the pattern becomes narrower near the low end of the operating frequency range. Don Keele investigated this effect and found that if the section near the mouth of the horn was widened with a sharper second flare or large roundover, the waistbanding effect could be mitigated. That second flare is included in horns designed with this spreadsheet.

About Danley Unity or Synergy Horns

Tom Danley invented a way for a single conical horn to be used over much larger bandwidths than could normally be used. He took advantage of the fact that a conical horn’s “flare rate” (relative area increase per unit length) changes continually from throat to mouth. The usable lower frequency of a horn depends on the flare rate, which must not be too rapid for lower frequencies. Danley found that lower frequency drivers could couple to the same horn as a high frequency driver if they enter the horn further up from the throat at positions where the flare rates matches that needed for the intended frequency. If you are designing your own, you should refer to the Danley US patents and applications for Unity and Synergy horns (6411718, US 2002/0106097 A1). Designing these from scratch is NOT easy, though, and will usually take a number of builds to get right.
Danley’s invention provides a number of benefits besides wideband horn sensitivity. Larger drivers can be used for lower frequencies instead of forcing a small HF driver to move air at lower frequencies, so wideband SPL capability is higher. This is similar to the reasons for making a multi-way cone speaker system rather than a single driver speaker. But perhaps most significant with the Synergy is the fact that the entire horn, with all its drivers, acts as a point source – the frequency balance doesn’t change with angle or distance within the coverage range – or even if you listen right at the mouth. This gives a nice easygoing and natural effect as opposed to how the usual multi-way loudspeakers behave where different parts of the spectrum originate at different points in space. Having the lower frequency drivers closer to the mouth can be used to achieve a linear phase response (with some crossover tricks), so that the horn acts just like a single wideband driver with a remarkably clean waveform-coherent impulse response. When that is done, crossover points are not audible or even findable from measurement and the assembly acts like a high SPL, high efficiency, single-driver speaker with controlled directivity. The lower frequency drivers fire through compression chambers which provide a low-pass filter, reducing the radiation of any distortion products that might get generated in the drivers. Synergy horns can play very loud and very clean with good efficiency, smooth response, and outstanding radiation characteristics – about as close to an ideal loudspeaker as can be achieved at this time.

Danley Sound Laboratories (“DSL”) currently concentrates on the “pro audio” market for arenas, large churches and concert systems, where the ability to play very loud from point sources with well controlled patterns is particularly beneficial in the very difficult acoustic conditions. While those pro Synergy speakers can be used in the home, they tend to be large, industrial and not well suited for home decor. They are rather expensive, though not when compared to “high end” hi-fi loudspeakers. It is hoped that in the future DSL will more directly address the high end audio and HT markets, for which the Synergy loudspeaker concept is uniquely well-suited.

Note, however, that the Unity and Synergy inventions are patented by Tom Danley and CAN NOT BE LEGALLY SOLD in assembled or kit forms without express permission from Tom Danley and his company Danley Sound Labs. Tom has kindly provided encouragement for DIYers to make their own renditions of these speakers, but not to sell kits or finished speakers using the Unity or Synergy principles. Please respect this situation if you are making Synergy horns – make some for yourself, but don’t sell! (Any single driver horns you make with this spreadsheet can, however, be sold – no patents involved then).

About Synergy Calc v5

This spreadsheet is the fifth version, developed from an original calculator used to figure dimensions of a wooden horn I build several years ago. It has developed as needed for builds I’ve worked on over that time. Compared to previous versions of SynergyCalc, this type design has the following updates:

- Dimensions are now named with less complicated symbols (A, B, C… rather than stuff like “k1(h)”’. That should make the overall build less confusing and intimidating.
- Board joint designs modified for easier assembly and to remove need for doing any less safe “vertical” cuts on the table saw. The boards can be cut with the surface always parallel to the top surface of the table saw, which is more repeatable and safer.
• New methods of attaching panels before glue-up to avoid using duct tape or hot melt glue during assembly. All sections can be assembled before gluing to make sure everything fits or to make any trim adjustments needed while gluing sections.
• Allows for construction from pre-veneered boards, guiding orientation of the wood grain when cutting panels. That allows you to make nice-looking wood grained horns from ply. Doing it this way requires very careful and precise cutting though! MDF or other materials that can be filed, ground down, filled with bondo or wood filler, and then painted for appearance, would be much, much easier to do. But wood grain does look nice, if you want to go to the trouble. Before trying a wood-grained version, trying a less precise build type is strongly recommended!
• More detailed instructions (such as this document!)

As before, the pre-filled values in the spreadsheet are for a Synergy horn set I designed, dubbed the “CoSynes” (because of all the trig the spreadsheet goes through calculating them!). Some of the dimensions given by SynergyCalc are dependent on details of the particular horn type that is being designed. For those horns, explicit values for the CoSyne build are shown in green colored characters. For other designs, you’ll have to determine for yourself some of the dimensions of the #2 panels by looking at the driver arrangement to see how much panel size is needed. The cuts for those dimensions aren’t critical and do not need beveled cuts, and aren’t difficult to determine though.

And about the CoSyne design

My CoSyne horn isn’t being held out as any kind of great design or ideal, but only as a finished design that worked out pretty well (after several tries, anyway). It is, though, the best overall speaker I’ve heard - kudos for this are to Danley, not me. I only followed his guidelines and worked out trig details for cutting and construction. Hardly a day goes by that I’m not again stunned by the sound of these things. A wideband horn is quite different from the usual hi-fi speaker. You may find yourself spending a lot more time listening (that effect on me has often delayed the writing of this document!).

CoSyne is a 90° Horizontal x 60° Vertical horn made from half-inch thick board stock. I aimed for a linear phase (waveform coherent) design, to operate as a point source. Efficiency was not a major consideration (though it still came out to be about 94dB SPL@2.84V, not bad at all), the main desire is for directivity and point source behavior. With a large ported box for the back waves of the woofers, it can go as low as around 50Hz but will do better if crossed to a subwoofer at about 80Hz. In a small 1.5 cubic foot sealed box, it should get into the 70s. Here are the midbass and higher frequency and phase responses using a passive crossover, unsmoothed and measured in-room at moderate distance:
Impulse response:

But, of course there’s a catch…

CoSyne was done as three-way design, using a Celestion CDX1-1445 tweeter (HF) driver, four Gento SP99023A midranges, and four Aurasound NS6-255-8A woofers. But the midranges and woofers were both “buyout” drivers (from Parts Express, Madisound or MPJA.COM). The prices on these were almost absurdly low (the drivers were apparently manufactured for some big projects that were cancelled). But the woofers are no longer available and the supply of the midranges is limited. If you are lucky enough to have stockpiled the very nice NS6 drivers, and can buy some Gento drivers (check eBay), then you can just follow the given CoSyne plans. Otherwise, you’ll need to do at least a little crossover design and port optimization (sorry).

I’ve been working to find some commercially stocked, non-buyout drivers that will work with this basic design plan, and have found a few. But so far, none that give that kind of near-linear phase response, at least not without crazy complicated crossovers. But if you want to tackle designing your own crossover (not hard if you don’t insist on linear phase -- which I don’t believe actually makes an audible difference, though theoretically attractive), or will design with a DSP crossover which gives more variables to tweak, here are some drivers that appear to be reasonable and that were mostly modeled in HornResponse and tested in this horn with some smallish changes to ports:
Woofers (note: woofer box size should be designed and verified using a box modeler such as WinISD, as these will not exactly match the NS6 drivers at low bass!):

- Dayton DC130AS-8
- Visaton W130S-8
- Not tried but looks likely: FaitalPRO 6FE100

Midranges:

- FaitalPRO 3FE25-8 (3” driver, nice high output but harder to get in close)
- Visaton FRS5-8 (not pro, but easy to mount and inexpensive; probably most similar to the Gentos), and seem to work about the same.

I’ve been asked why I don’t use “better” drivers on this. One reason is that in this design the drivers are acoustically bandlimited by the horn feed structures – distortion or out-of-band signals that are generated within the driver are filtered (reduced) by the air chambers and waveguide ports (in direct-radiator speakers, the distortions are radiated out directly unimpeded). And the directional characteristics of the mid and woofer drivers for this design don’t really matter at all - those are handled by the waveguide. So the usual reasons for using premium drivers aren’t very relevant. They aren’t even visible in the completed speaker. More important is that the drivers have usable sensitivity, well-behaved response within their intended bands, can mount close together, and work well as horn drivers. Since there are nine total drivers in each CoSyne horn, it’s a good thing that drivers in the $300 each range aren’t needed!

Here is the schematic for the original CoSyne passive crossover, which worked quite well as shown in the graphs above. There was a fair bit of beginner’s luck on this, I haven’t been able to get as lucky (yet) with currently stocked drivers:
Designing and Building A Horn with the Spreadsheet

If you are making a CoSyne build using original drivers, you can skip to Step 4.

**Step 1: Selecting the Horn Characteristics**

Near the top of the spreadsheet is a section like the one shown above. Select your conical horn’s main characteristics here. The coverage angles ThetaW and ThetaH are illustrated in the large photo at top of the spreadsheet. The low frequency value (“lowest frequency at which horizontal pattern control to be kept”) is next, followed by the square throat size. Then, “Keele’s constant” is given followed by the “ratio of final horizontal...” which Don Keele recommended be in the range of 0.6 to 0.7. Those values will determine the overall horn size, which can be read from the section just below the selection area:

<table>
<thead>
<tr>
<th>Overall Size (inside and outside horn):</th>
</tr>
</thead>
<tbody>
<tr>
<td>width ( L ) = 23.961 [inches] 0.6086 [meters]</td>
</tr>
<tr>
<td>height ( J ) = 15.274 [inches] 0.3879 [meters]</td>
</tr>
<tr>
<td>depth ( M ) = 9.211 [inches] 0.2340 [meters]</td>
</tr>
</tbody>
</table>

In most cases, the allowable horn *width* will be the main limitation, so you would adjust the pattern control minimum frequency to keep the horn size down to something you are willing to tolerate in your room (with horns, bigger is better!). In the CoSyne design (for which the values I used are in the figures shown above), I adjusted for a width of 24 inches and so found that would control horizontal pattern to about 385Hz. Not bad. The vertical pattern control frequency will be much higher, however.

That is not the lowest frequency you can play from the horn, though. The larger drivers toward the mouth of a Synergy may be capable of going much lower, though the horn itself no longer has any gain or pattern control. But the clustering of the larger drivers near the axis of the other drivers inside the horn walls still contributes to the point-source behavior for the system; it will sound like one very good driver. The coverage pattern will begin to become omnidirectional below the pattern frequencies and the efficiency will drop, requiring equalization in the crossover or elsewhere. For frequencies below the range of about 200Hz to 500Hz (value is room dependent) directivity will become less relevant because of modal behavior, however, so that isn’t a big problem. I have CoSyne horns mounted in large ported boxes which with four NS6
woofers can provide more than decent bass down to about 40Hz even though the acoustic boost from the horn ends below about 380Hz.

The next value in the selection section has its description (“[inches] synergy port distance from throat”) on a yellow background to indicate that the value is used for generating other values to be entered into David McBean’s “HornResponse” software (http://www.hornresp.net.ms/). This value will only be relevant when designing a Synergy type horn and is the distance from the HF throat that lower frequency drivers are to be ported into the horn walls. You’ll probably find that you want to get the midrange drivers as close as possible to the HF driver’s throat position. This will be covered further in the next section.

The last value to enter into the calculator is “[inches] board thickness”. If you are working with pre-veneered wood, this should be filled with the measured value (not the nominal value) of the thickness of the material you will be using to build the horn panels.

**Step 2: HornResponse**

You can skip this section if you are making a horn with a single driver or are building a copy of the already-designed CoSyne horn with original driver types.

If working up a custom design for a Synergy horn, you can use HornResponse to estimate the frequency response you will get from each type driver mounted on the horn walls. This will depend on a number of factors that you enter into HornResponse, seven of which will also depend on the value you entered for “[inches] synergy port distance from throat”. You will need to interactively play with this value, generating those seven values shown in the yellow section of the spreadsheet each time, and entering those into HornResponse for simulation. Then you will need to change other parameters in HornResponse to try to reach an acceptable design. For a three-way horn, you will need to do all of this at least twice (once for the midrange drivers, once for the woofer drivers).

Probably you should make your first Synergy horn just functional rather than pretty, because it will likely need changes (in other words, “an entirely new build from scratch”!) to get it to what you want.

First enter the values from the spreadsheet from the yellow region of the SynergyCalc spreadsheet. Only some of them will need to change each time if only the “port distance” is moved. You may have to click on the labels “L12” (etc.) to get them to change to the label “Con” (conical). Don’t enter anything in the bottom row (S4..S5..L45..F45) or the right column (Fta, F12..F45). The top row should be: Ang=2.0xPi, Eg=2.83, Rg=0; Fta will self-calculate).
You need the Thiele/Small values of the drivers you plan to use. These will be entered in the fields Sd, Bl, Cms, Rms, Mmd, Le, and Re. First fill out all the values you know for these (usually from a data sheet or a measurement from a Woofer Tester device). The values are generally metric. If you are from the USA and still chained to the imperial system of measurement units, you can click your cursor in the box for the data and then push F6 to get a form that lets you enter imperial units. If you don’t know Sd, it will usually be about 0.5 * (NominalDiameter)^2. Then, for the values you don’t know, double click in the relevant box and it will prompt you for other values you probably have which it will then use to calculate the unknown one; pretty slick.

Those values are for a single driver of course. Indicate how many of that driver you plan to use and how they are wired by the value “OD”, in which S means series and P means parallel. The values below the driver section –

<table>
<thead>
<tr>
<th>Vrc</th>
<th>Ap1</th>
<th>Vtc</th>
<th>CAUTION:</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.60</td>
<td>9.00</td>
<td>47.00</td>
<td>Ca &gt; 1 for 54</td>
</tr>
<tr>
<td>Lrc</td>
<td>Lpt</td>
<td>Atc</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>1.02</td>
<td>81.03</td>
<td></td>
</tr>
</tbody>
</table>

are for controlling the back chamber (Vrc and Lrc), the port area and length (Ap1 and Lpt) and the compression chamber (Vtc and Atc) for the drivers. You may have to click on the label that should be “Ap1” until you get that text to appear – make sure it is “Ap1” and not just “Ap” that is for a different type horn! For a given set of drivers at a given port location (defined by those “S12”, etc., values), these are what you will mostly work with to try to achieve a usable response. As elsewhere, these values are metric but you can use F6 to allow you to enter imperial units if needed. When your mouse is over one of the labels, text will appear at the bottom of the form briefly describing what the value means.

Watch out for a pitfall here. The area and volume dimensional values entered are for the sum shared by all the drivers being modeled for. For instance, if the port cross-sectional area for one driver here is 2.25 square centimeters, and you have 4 such drivers, then the value to enter there is 4*2.25. The same is true for Vrc, Vtc, and Atc. But it’s not true for the lengths (Lrc and Lpt) – those are for each driver. If the “port tube” length in front of each driver is 1.02 centimeters, then that’s the value you should enter there.
The warning in red above ("CAUTION: Cir>1 for S4") is an indicator that the simulation will not be exact in some way. I’ve been ok with that, and just ignored the warning. It is a bit annoying (it will prompt you about it every time you try to Calculate the results), but doesn’t seem to be a big deal. YMMV, however...

Vtc and Atc will usually be the volume and average area inside the cone of the driver. For ease, try first with the results of mounting the drivers right on the outside surfaces of the horn so their front volume is all that is in the compression chamber (Atc and Vtc). Otherwise you will need to fill in under the cone with something or raise the driver to adjust the chamber volume. Atc will be something less than the sum of the areas at the rim of the driver, so estimate: remember it’s the average area, but the cone is...cone-shaped. I’ve assumed that with the “frustrum” (look it up!) type beveled ports that Danley suggests in his patent application, a shorter effective Lpt value (maybe half?) can be assumed to exist (with some of the volume in the port instead acting as a slight increase in Vtc). I’m not sure that’s exactly correct, but it gave a more accurate simulation result than assuming the Lpt is the entire thickness of the board material. I used short values for Lrc so I wouldn’t see reflections off the back chamber (which I have either stuffed or lined in the actual horns). For the open backed midranges, a back enclosure will have to be calculated and used. I used 2” mailing tubes for mine, you could alternately use pvc pipes or other creative ideas.

The “distance from throat” you find from the spreadsheet is measured on the horn axis. If designing your own, a little basic trigonometry (sines, cosines) will be needed to determine where those holes will lie along the #2 board. Try to keep the holes so that they approximately lie on the corners of an (imaginary) square when the horn is viewed from the mouth, even if this brings them in from the corners; try to keep the distance between the centers any of the midrange holes within ¼ wavelength (for 1kHz, 3.4 inches; for 2kHz, 1.7 inches) so that all radiate as one driver.

Here are the simulations used for the original CoSyne midranges (left) and woofers (right).
Comparison to measured plots 1/6th octave smoothed, levels adjusted to match, red is simulated:

**Step 3: Figuring the driver mounting areas**

The four main panel types are called #1, #2, #3, and #4, as given within circles on the spreadsheet drawing. Two of each are used in each horn. In the designs made from this spreadsheet, all the midranges (and woofers, if used) are mounted on the #2 panels. If you aren’t duplicating my horn design, you will need to decide the outer dimensions of this board. The values for E, and the minimum widths A and G are pre-calculated for you from previous values you entered. The region marked “as required for mounting drivers” needs to accommodate any midrange or woofers where you mount them, but not be too much larger than needed for weight and ease of construction. The values shown in green are for the CoSyne horn.

The best way to figure is to lay it all out on a large sheet of paper, taking into consideration where your port holes (if used) need to be. Also make sure that your arrangement allows for access to the HF driver’s mounting bolts and for the midrange drivers’ mounting screws beneath the HF driver. The corner cuts shown at the left and right bottom are to avoid interference when panel #2 gets assembled.
with the other panels. They cuts need to meet right at the points indicated with dimension G on the inside surface of the panel and be at an angle around 45 degrees (not critical). The corner cuts at top left and right (“trim excess”) are just to minimize weight and make handling easier.

- Print out the spreadsheet, and write those measurements you’ve determined on the drawing (if different than mine). This will also determine the initial cutting dimensions for the #2 panels.
- Write those values in the Initial Board Cuts area of the printout where I have the green CoSyne values.

For some of the dimensions for the Initial Board Cuts you’ll also need to know half the value when later making cutting and guide lines. Those are pre-calculated for you when possible.

**Step 4: Initial Board Cuts (for panels 1, 2, 3 and 4)**

The time consuming part of making these horns is the setup of the jigs and fixtures for the compound angle cuts. Once each of those is set up, it’s nearly trivial to cut additional numbers of each board. So I always make enough for at least one extra horn, so I have a spare should a later error ruin one of the boards. And if that doesn’t happen, I have an extra horn for experiments or an added center channel.

Two charts are shown on the spreadsheet for the Initial Board Cuts, one for imperial units and one for metric. If you want to do your horns in wood grain and want all the grain to run right to left horizontally, then the initial dimensions for each panel are given as “along the grain” or “across the grain”. If you are going to instead paint your horns (which greatly eases construction, you don’t have to be as precise!) then those labels can be ignored.

- Cut your boards to the dimensions shown, making sure all cuts produce square corners. Dimensions are only approximate at this point, but don’t cut any smaller than the dimensions shown. The boards will be further trimmed later. These are best done on a table saw so that edges remain square, but could also be done with a circular saw, clamps, and guides. Write the appropriate identifier (1, 2, 3 or 4) on each panel, near the center on the side that is to be on the outer surface of the horn.

**Step 5: Marking guide lines (for boards 1, 2, 3 and 4)**

Unless otherwise directed, do all guide lines on the surfaces of the panels that will be INSIDE the horn. If you are using wood veneered boards that you want to keep the grain showing on, don’t mark too hard as some of these guide lines will later have to be erased or sanded out.
• Use a metal rule and/or caliper, and a very sharp pencil (or better, a 5mm mechanical pencil) to make two marks on the ends of each board at the appropriate “half” distance (both measured from the same edge) as given on the “Initial board cuts” chart.

• Use the metal rule and pencil, draw lines (down very near the middle of each panel) joining those marks. These lines would be vertical on the underside (inside surface) of the finished panels, if the panels were arranged like this (this arrangement will be assumed in future descriptions that mention “top”, “left”, etc.):

• Draw a line across, about 0.1 inch (or 2.5mm) from and parallel to the bottom edge (the edge where dimensions C, G, J or L are shown in the drawing) of each board. These lines are perpendicular to the center lines you previously drew.

• Then use the ruler and/or caliper to mark each end of a new line on each board, parallel to the line from the previous step, at a distance (B, E, H, or K, as appropriate) from the previous line. Connect the marks to draw the new line. This needs be as parallel as you can make it to the bottom line.

So far, the “horn inside” surfaces of your boards are marked something like this:

The “Panel Dimensions” chart gives values for A, C, G, J, and L. It also gives half dimensions for each (A/2, C/2, etc.) and those are shown in bold print because the half values are the ones you will use to mark and draw the next guide lines. Again, all these marks are on the HORN INSIDE surfaces.

• On boards “1”, draw marks at A/2 to either side of the drawn center line and on the line at the top of the board, and C/2 to either side of the center line and on the line at the bottom of the board. With the metal straight-edge, draw lines connecting the pair of marks on the
left side and then connecting the pair of marks at the right side. See sketch:

- Similarly do the same for boards “2”, but use A/2 at the top and G/2 at the bottom.
- For boards “3”, use C/2 and J/2.
- For boards “4”, use G/2 and L/2.

- On boards “2”, draw lines to mark the outline as previously determined in Step 3 (or, for CoSyne builds, with the dimensions as given in green text on the diagram).

**Step 6: Making table saw sleds**

The trick to making precise cuts at compound angles with a common home-grade table saw is to use a “sled”. You can do it nearly perfectly with even a cheap table saw, even if you’re a hack cabinetmaker like me and use an old craigslist-obtained SkillSaw. The sled lets you make a cut as accurately as you’re able to align and clamp your guide lines to an edge.

A sled is just a board to which you can clamp the actual work piece, and which slides along on a well-controlled path across the table saw to make the cuts. I’ve made some sleds that just followed a low fence on the table saw surface (to use it, just keep the end of the sled pushed against that fence), see pic at right. The “low fence” was an “edge clamp”, available from Rockler or Harbor Freight and doing it that way worked pretty well. But a bit of distraction could allow the sled to drift away from contact with the fence.

The latest sleds I’ve made use the guide slots that are machined into the top of my table saw (and on most table saws). Rockler sells some pre-made “Miter bars” made to be mounted on the bottom of the sled to ride in the guide slot. My saw has unusual slot widths, though, so I had to make my own bars to follow them from some UHMW plastic I had. The bars could also be made from thin hardwood, aluminum, or even acrylic plastic. The bar mounts to the bottom of the sled board, so that when the board rides down the track it always follows the same path. If you make your own bar, make sure it fits snugly in the slot but allows smooth travel of the sled (hint: use car wax on the top of the table saw and bottom of the sled).
I make separate sleds for “right side of the blade” and “left side of the blade” cuts on the table saw. The side to use depends on the angle you need to achieve. On my saw, the blade tilts toward the left.

When setting up the sled for a cut, you set the saw angle (per the charts in the spreadsheet) and then make your first cut without the work piece but into the sled itself. That sets the line you’ll align your penciled guide lines to. Then you arrange your clamps to hold your work pieces so that the previously penciled cut lines are precisely matched up to the cut you made into the sled. The saw will cut the same path as before, this time into the work piece also, following the same path and cutting right on your guide line. Accuracy is limited only on how picky you are on lining up your piece’s guide lines with the cut edge in the sled. Keep re-adjusting till you are satisfied with it.

If you don’t want to make an entirely different sled for every different bevel angle you have to cut, you should make your sleds with a replaceable “sacrificial strip” end piece. Notice in the photo at right that there is a thin line in the sled top in parallel with the saw blade. That’s where a narrow piece (about 2 or 3” wide) meets up with a wider piece. These pieces form the top of the sled and are separately wood screwed to the main sled board so that when the sled needs to be re-cut into for a new angle setup, you need only replace the narrow sacrificial piece each time. I used 3/8 inch MDF for the top pieces; the main board is ¾ inch ply, or MDF will work as well.
The critical dimensions of the cuts are those on the INSIDE of the horn, that is, the ones around the under surfaces of the pieces shown in the diagram above. So when you are making your cuts, the work pieces will be lying with the surfaces shown in the diagram clamped facing UPWARD (so you can see the circled ID numbers). Or in other words, the INSIDE horn surfaces (with pencil guide lines) will be face DOWN on the sled, as those surfaces have the guide lines which you’ll align to the (pre-cut) sacrificial strip of the sled. Understood?

The clamps are called “toggle clamps” available inexpensively from Harbor Freight or more expensively from Rockler or Woodcraft. You’ll probably have to shim them up with a small thin piece of board (with a couple of holes for the mounting screws). Two screws each seemed to hold them ok for me. **Plan on moving the clamps for every cut setup**, so they can be in optimum locations to hold the work pieces securely. Mounting or moving the clamps is just a matter of driving some wood screws with a drill/driver, pretty quick. You may want to take a file or wood planer to smooth any raised bumps that result after screws are removed from one location so that the work pieces lay flat.

**Step 7: Cutting the compound angles**

With the sleds built (and with plenty of spare “sacrificial strips” ready at hand) and the #1, 2, 3, 4 boards all marked with guide lines, now is the time to do the compound angles. After the preparation in the previous steps, this is now pretty easy to do. The only even slightly tricky part is making sure you cut the angles onto the correct sides of the panels, and proper choice of right or left side sleds. Just a matter of double checking before cutting. If you are trying to preserve a wood grain look, be quite careful. If you are using mdf and/or are painting the panels after building, you can be a little sloppier if you want.

**Step 8: Cutting Port Holes**

If you are making only a single-driver horn, you can skip to Step 9.

The Port Holes for a Synergy horn are easiest cut when the panels are still flat and unassembled. Cut your port holes for midranges and woofers into the #2 panels where determined previously in step 2 (if designing your own) or, if you are building a CoSyne horn with original drivers, as shown in the figure below. The midrange driver positions shown below have a 2” dia, shallow volume cut (with a Forstner bit) to provide clearance for the driver surround. With some other drivers, this may not be necessary; I didn’t do that for the woofers on mine, the NS6 surrounds were recessed enough to not touch (the horns shown in the photos for illustration have a clearance area cut for the woofer surrounds, but those horns didn’t work well enough for some other reasons). Note that the top horizontal line in the figure
below, is the corner of the top outside edge of board #2. No precision is implied in the dimensions shown, do as close as you reasonably can.

The oval cuts are done by drilling two holes of the diameter shown, then drawing lines between them with a straightedge and then cutting the connecting lines with a jigsaw, easy to do. Using a router (or a file, the harder way but more versatile) mill frustrums on the outside edges of the port holes at about a 45 degree angle, in areas where they won’t cause a leak when the driver later gets mounted. Make sure you don’t damage the area where the drivers need to seal against the #2 panel (patch with wood filler, if you do).

**Step 9: Assembly**

You *could* assemble the wall panels for the horn the way I did on my first several, by using duct tape to hold things while the white or yellow wood glue dries. But that’s pretty messy and hard to keep neatly arranged, and doesn’t hold the glue joints very tightly. Probably not a good technique unless you are working with mdf or another material that is conducive to filling gaps and filing mismatched edges.

Or you can use Tony Seaford’s method of holding a wood glue joint together with dots of hot melt glue in dry spots between the glue, which is a faster and more stable method, sort of like having a bunch of little helping hands. This is a better choice than duct tape, less difficult and needing very little tooling, though it doesn’t allow for repositioning of joints as you will need if you’re trying to make perfect wood-grained horns.
Ideally, we’d like a way that allows all the horn walls to be dry-fit and adjusted as necessary before assembly, followed by permanent gluing of each joint. Hence, this new design. You may have noticed in the current version of the spreadsheet several wood pieces (#5, 6, 7 and 8) in addition to the wall panels. The #6 pieces provide a way to dry-fit and assemble panels #1 and #2.

The #6 pieces are to be first glued (use a clamp) to the back of the #1 panels where the #1s edges meet up with the “inside” surface of the #2 panels. The #6 pieces won’t be on the inside of the horn, but outside, since those #2 pieces are wider than the horn’s actual inside. Make sure you have the proper surfaces matched to each panel so that they fit correctly (notice the angled edge of #6). Then, mark a line on panel #2 where it meets up with panel #6, and use it to position and drill mounting holes through panel #2 as shown. Then, with 8 wood screws, both #1 and #2 panels can be fit and attached temporarily for adjustment, and later after you’re happy with the fit of all panels (1 through 4) together, permanently glued together. The wood screws can be removed afterwards, if desired.

No extra wood pieces are needed to assemble the #3 and #4 panels to each other, but an inexpensive tool and another (easy to make) fixture are needed to allow for a similar dry-fit, adjustment, and final glue-up.

The tool is the Mini Kreg Jig Pocket Hole kit, http://www.kregtool.com/kreg-jigreg-mini-prodview.html or http://www.rockler.com/mini-kreg-jig-pocket-hole-kit. Don’t go for the fancier pocket screw jigs for this -- you want the Mini, as it doesn’t have a “fence” edge on it. It’s also the least expensive (about US$20). You’ll also need a small C-clamp or F-style clamp to hold the Kreg Jig to the work pieces during drilling, and some “#6x1inch” pocket screws. The pocket screw and jig can best be described in the way it was recommended to me by a friend: “it’s just ****ing cool”. It’s one of those things that works so well, particularly when you need to join pieces of wood edge to edge such as the strange widely – splayed horn walls we’re making from the #3 and #4 panels of this project.

The first thing to make with the Kreg tool is a holding fixture that will be used to position the #3 and #4 panels when drilling and attaching them next. Take a piece of two-by-four wood stud (38 mm × 89 mm outside the USA), and saw it into two relatively short pieces, with one end cut so that
they can attach at an angle as shown at the left. The angle needs to be the one that will be formed by the #3 and #4 panels when they meet. In other words, one piece of each piece of the stud should be cut at angle “q” as determined by the spreadsheet. (For the CoSyne design, that’s 71.5 degrees, for a total angle when joined of 143 degrees). Use the Kreg jig and pocket screws per the instructions included with them to join up the pieces with a clean well-matched seam. I added some pocket screws to the sides of the fixture pieces as well, to strengthen the joint further. If you haven’t used pocket screws before, you’ll soon see why they are recommended here!

Next, use this fixture and some clamps to position and hold each joint of the #3 to #4 panels together, then drill for pocket screws on these (see photo at right). When you have all the corners temporarily attached, it will resemble a picture frame as in the photo below.

Then, position this assembly over the one made with the #1 and #2 panels, loosen and readjust any joints in any of the panels as needed for a good overall fit. Glue the #1 panel to #2 panel joints one at a time. Do the same for the #3 panel to #4 panel, then glue the two assemblies together with some weight on top to keep them tight while the glue dries.

**Step 10: Tweeter Plate and Mounting Surface**

The wood piece #5 is the plate for mounting the tweeter, and the process for gluing it to the back of the horn should be self-explanatory, just pile on some weight (a jug of water?) to hold it tight and in place while glue dries. You may need to file the back of the horn flat a little first to make a good joint; also trimming of the #5 piece may be needed to assure clearance for the midrange drivers of a Synergy. The dimensions shown are for a 1” diameter
compression horn such as CDX1-1445. After the glue is dry, open the throat area inside the #5 piece’s hole with a drill bit the same diameter as your tweeter’s throat. I used a Forstner bit for that in the photo, but other types worked as well.

The mounting surface is added to the horn using pieces #7 and #8. The surface’s purpose is to make the back side of the horn mouth parallel with the tweeter driver and eventual system baffle. This allows the finished horn to mount in a way similar to a cone driver, onto a flat baffle. In the full CoSyne design, the horn was mounted via this surface, with foam gasket between, to a rectangular frame around which the cabinet was built. The #7 and #8 pieces are glued to the back of the horn mouth edge using a staple gun to hold the piece until the wood glue dries as in the photo (pull out the staples afterward). After attaching the mounting surface pieces, use wood filler to seal any possible air leaks around the mounting surface.

**Step 11: Mounting the Drivers**

The midrange and woofer driver mounting process should be pretty obvious. Use wood screws short enough to not come through into the inside of the horn and long enough and coarse enough (#6 type for woofers, #4 for midranges) to hold the drivers securely and without any leaks. Again, wood filler can be used to touch up for a smooth, not leaking surface to put the drivers’ edges on.

The midranges I used have open backs, so the backs need to be sealed with the appropriate volume. For the CoSynes I used 2” diameter mailing tube (from Staples), cut to 3” long, stuffed with polyester fluff and capped off with the mailing tube caps. The tubes were glued to the back of the Gento drivers before mounting, leaving enough of the drivers’ mounting holes exposed to allow for the mounting screws. The wires were fed through a small hole, also sealed with adhesive caulk. If designing your own Synergy type horn, use the back volumes as determined with Horn Response to determine the back volume for the mids (remembering that the value shown is for the total of all midrange drivers in the horn!). Another possibility for sealing the back of midranges is to use a PVC cap made for PVC pipes of the appropriate diameter. That may require some tooling of the PVC cap, though, to sit well on the back of the driver, and may also limit how close together you can push the drivers.

The backs of woofers in mine were left open to drive the ported box the horn was mounted in. How you do yours (ported, sealed, separate back enclosures) is up to you.