

# Multi Entry Horn Modeling Methods

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# Introduction

The theory for modeling a single driver in a sealed, bass reflex, or horn enclosure has been derived, studied, and well documented. Equivalent lumped parameter acoustic and electrical circuits can be found in textbooks (Beranek's acoustics texts are excellent references), AES papers (the Thiele and Small papers in particular), and independent websites across the Internet. Based on these equivalent circuit models, accurate simulations of the low frequency performance of a driver in an enclosure can be performed using readily available loudspeaker design programs.

Modeling transmission line speakers, TLs, requires a more detailed model of the air in the enclosure. The length and shape of the TL geometry, along with the addition of damping materials, determine the low frequency behavior of the TL speaker system. Transmission line models need to account for standing wave resonances in the air continuum that cannot be modeled using simple lumped parameter techniques. This represents a significant step up in complexity.

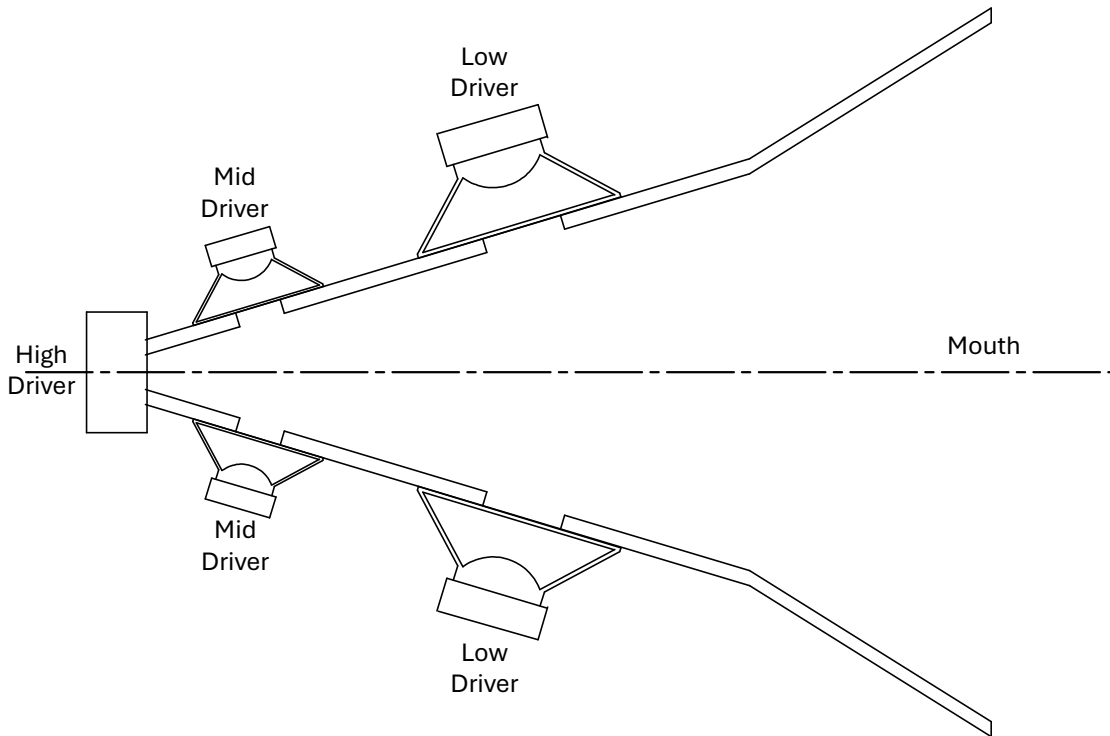
About 30 years ago I coded my first MathCad models capable of modeling TL speaker systems. The MathCad models were very flexible, continued to evolve, have been modified to model a wider range of speaker enclosure types, and eventually included additional details for determining the system's acoustic response in an anechoic environment or in a listening room.

Horn speakers have always been of interest to me. The MathCad TL worksheets use the 1D wave equation solution for an exponential horn to simulate tapered or expanding transmission lines, so the math and physics were already coded for exploring horn designs. But being honest, I probably do not have the building skills required to execute a large BLH or FLH speaker design.

The Multi Entry Horn MEH (also called a Synergy or a Unity Horn) has also interested me and I have spent the past five years dabbling on and off with MathCad worksheets based on this horn concept. I work on the worksheets for a while, put them down, think a little more, and then return later to make modification and advances. This has probably happened four or five times over the past few years. The results are by far the most advanced MathCad worksheet models I have ever produced with two or three drivers interacting acoustically in a horn with active or passive crossovers. I am also sure that these MathCad worksheets will continue to evolve.

The intent of this presentation is to show the method used in these preliminary MEH MathCad models for multiple drivers loading a common horn volume, present a sample problem for a three-way system, and discuss some lessons learned and next steps for extending the methods to more accurately model more ambitious MEH speaker designs.

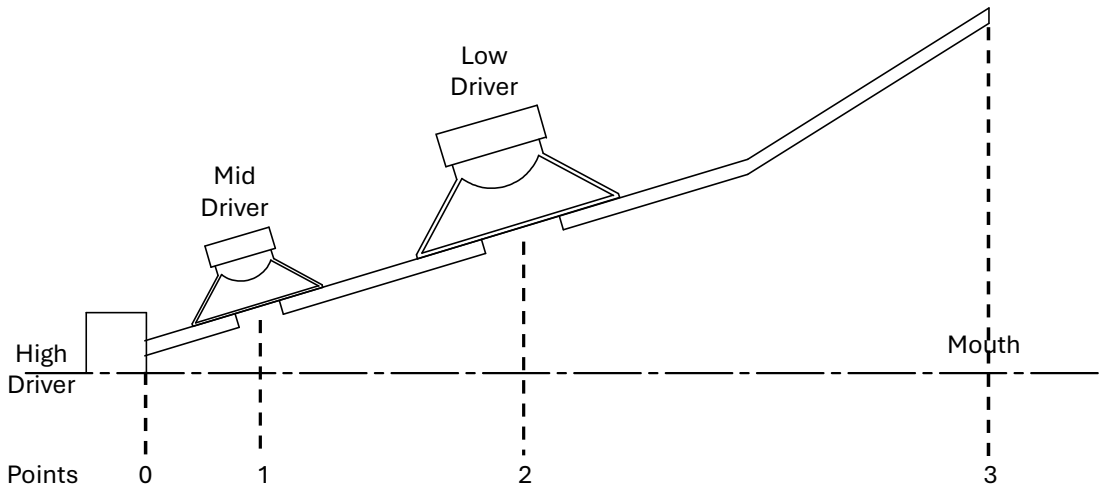
# MEH Geometry Definition



On the left is a crude sketch of a MEH with the features being modeled in the MathCad worksheets. The horn model has two independent expansion rates and can simulate any of the common horn profiles.

There are three drivers shown; a high frequency driver (compression driver or tweeter), a mid frequency driver, and a low frequency driver. The mid and low frequency drivers can be multiples wired in series and/or parallel and positioned anywhere along the horn's length.

Not shown are any enclosures on the back of the drivers. A sealed or ported enclosure can be added to the back of each driver but for simplicity will not be included in the figures or the following simulations.



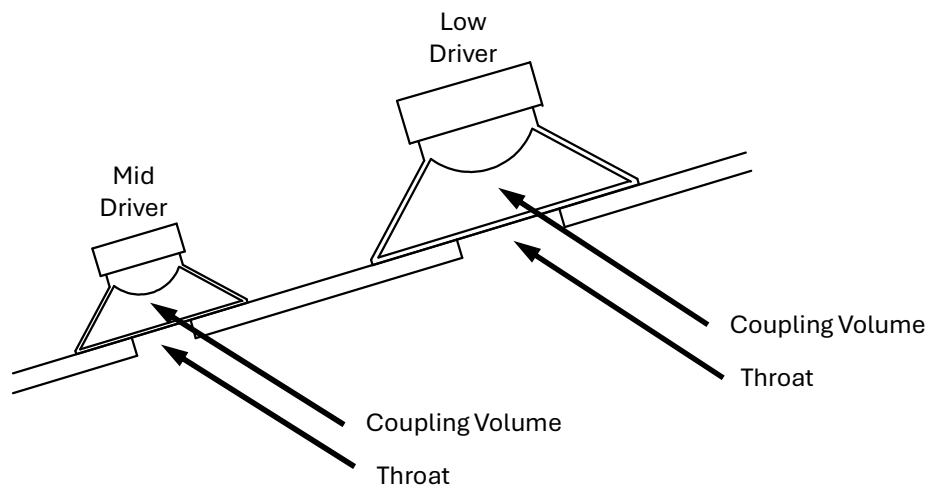
Horn Locations

$$[U_i \ p_i]^T = [\text{Transfer}_{i \leftarrow j}] \times [U_j \ p_j]^T \text{ where } i = 0, 1, 2 \text{ and } j = 1, 2, 3$$

Four axial locations are used to define the horn geometry.

- Point 0 – horn throat at the exit of the compression driver or at the tweeter face plate.
- Point 1 – center of the mid frequency driver’s throat.
- Point 2 – center of the low frequency driver’s throat.
- Point 3 – horn mouth

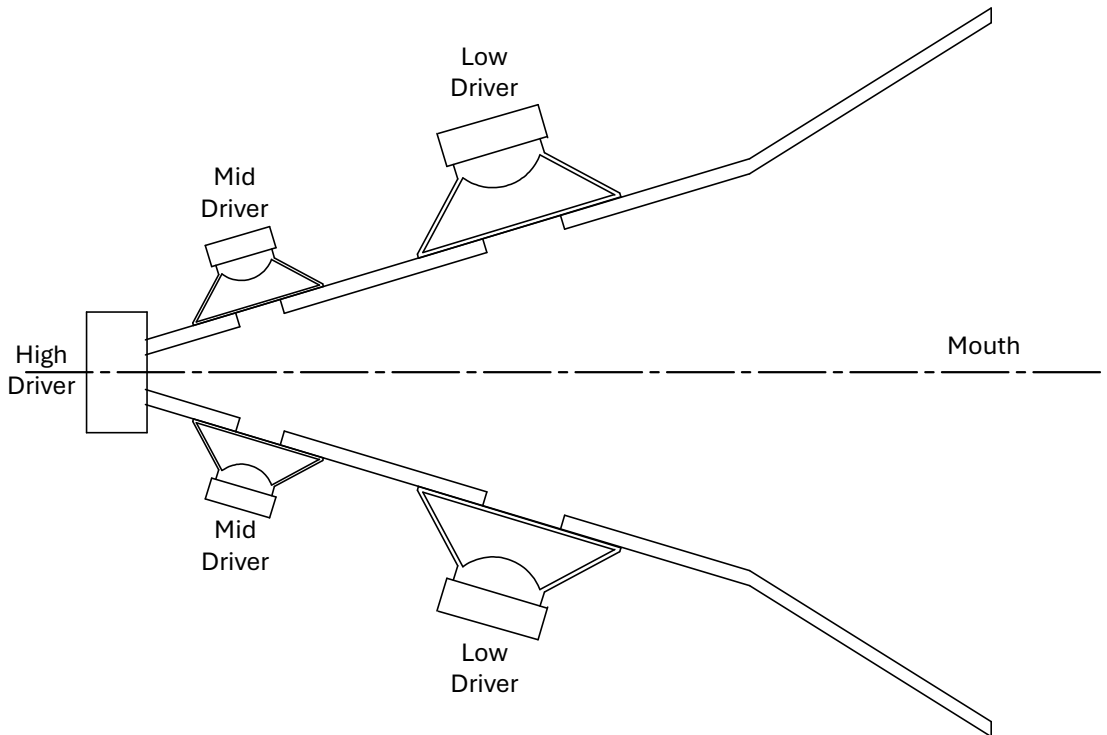
Transfer Matrices were derived between each of the horn axial locations. At each axial location, the volume velocity  $U$  and the pressure  $p$  are constant across the cross-section of the horn (dashed line). The transfer matrices, the volume velocities, and the pressures are all functions of frequency and have both magnitude and phase (real and imaginary components)



At each driver, a coupling volume and throat were also included in the model. These can be specified for the high, mid, and low frequency drivers. Transfer matrices were used to connect the driver cones to the axial locations in the horn defined on the previous slide, this creates branches in the acoustic circuit model. The coupling volume and throat create a secondary resonant system, like a bass reflex enclosure tuned relatively high in frequency, that will be seen in the simulated system response plots shown later.

The drivers can also be mounted directly to the inside surface of the horn's wall eliminating the coupling volume, throat, and secondary resonant system. Both cases will be presented in the sample problems.

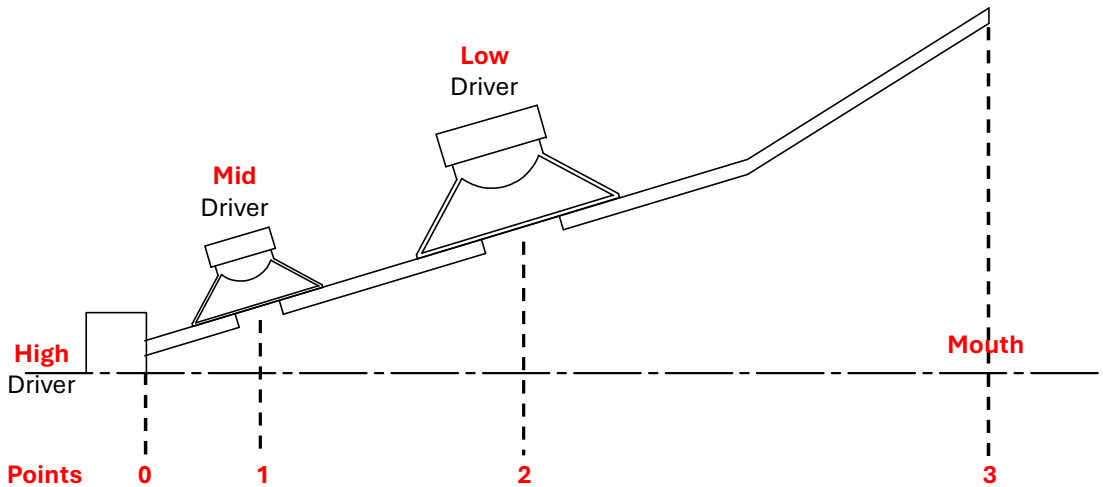
# MEH Horn Acoustics



To construct and solve an equivalent electrical or acoustic circuit model for multiple drivers in a shared horn enclosure, the acoustic impedance acting on each driver's cone was needed as a function of frequency. Acoustic impedance is defined as the ratio of pressure  $p$  to volume velocity  $U$  (area  $\times$  velocity).

$$Z_{\text{acoustic}} = p / U = p / (\text{area} \times u)$$

Considering each driver separately, motion of one driver's cone generates a pressure and volume velocity at the horn mouth and a pressure on each of the other two driver's cones (volume velocities defined as zero). Establishing these relationships was the key.



Horn Locations

Six transfer matrices (see Reference below) were formulated. Working from the mouth to the high frequency driver the following transfer matrices were evaluated.

#### Horn Path

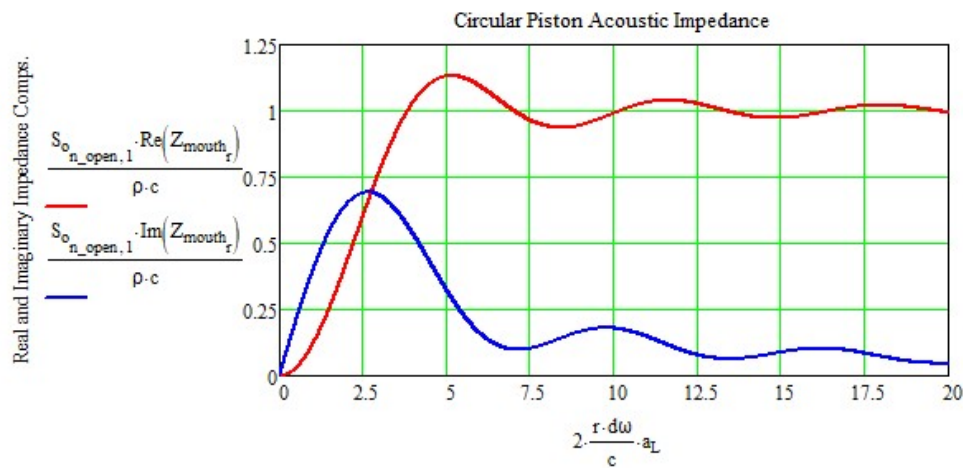
- $[U_2 \ p_2]^T = [\text{Transfer}_{2 \leftarrow 3}] \times [U_3 \ p_3]^T$
- $[U_1 \ p_1]^T = [\text{Transfer}_{1 \leftarrow 2}] \times [U_2 \ p_2]^T$
- $[U_0 \ p_0]^T = [\text{Transfer}_{0 \leftarrow 1}] \times [U_1 \ p_1]^T$

#### Throat - Coupling Volume to Driver Cone Path

- $[U_{\text{low}} \ p_{\text{low}}]^T = [\text{Transfer}_{\text{low} \leftarrow 2}] \times [U_2 \ p_2]^T$
- $[U_{\text{mid}} \ p_{\text{mid}}]^T = [\text{Transfer}_{\text{mid} \leftarrow 1}] \times [U_1 \ p_1]^T$
- $[U_{\text{high}} \ p_{\text{high}}]^T = [\text{Transfer}_{\text{high} \leftarrow 0}] \times [U_0 \ p_0]^T$

While volume velocity  $U$  and pressure  $p$  at each location are unknown, the  $2 \times 2$  transfer matrices between each location were calculated as functions of the geometry and frequency.

Reference : [http://www.quarter-wave.com/Horns/Method\\_Derivation.pdf](http://www.quarter-wave.com/Horns/Method_Derivation.pdf)



The goal was to calculate the acoustic impedance seen by each driver in the MEH enclosure. The complexity was that each driver has an influence on the other two drivers producing additional cross-coupling impedances.

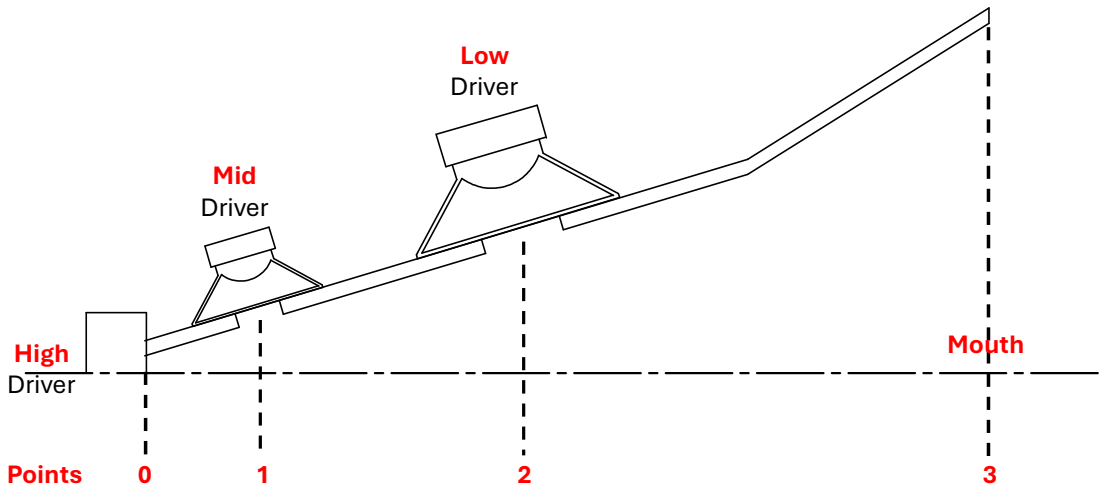
The starting point was the acoustic impedance of the mouth which is typically assumed to be a vibrating circular piston in an infinite baffle, as shown on the left.

$$\text{Assume } U_{\text{mouth}} = U_3 = 1$$

$$p_{\text{mouth}} = p_3 = Z_{\text{mouth}} \times U_3 \text{ so } p_3 \text{ and } U_3 \text{ are known inputs}$$

For each individual driver, the challenge was to calculate the volume velocity and pressure required to generate  $p_3$  and  $U_3$ . Assuming that the other two driver's volume velocities are zero, the pressures generated were used to calculate coupling impedances.

The resulting acoustic impedances are functions of frequency and have both magnitude and phase (real and imaginary components).



Horn Locations

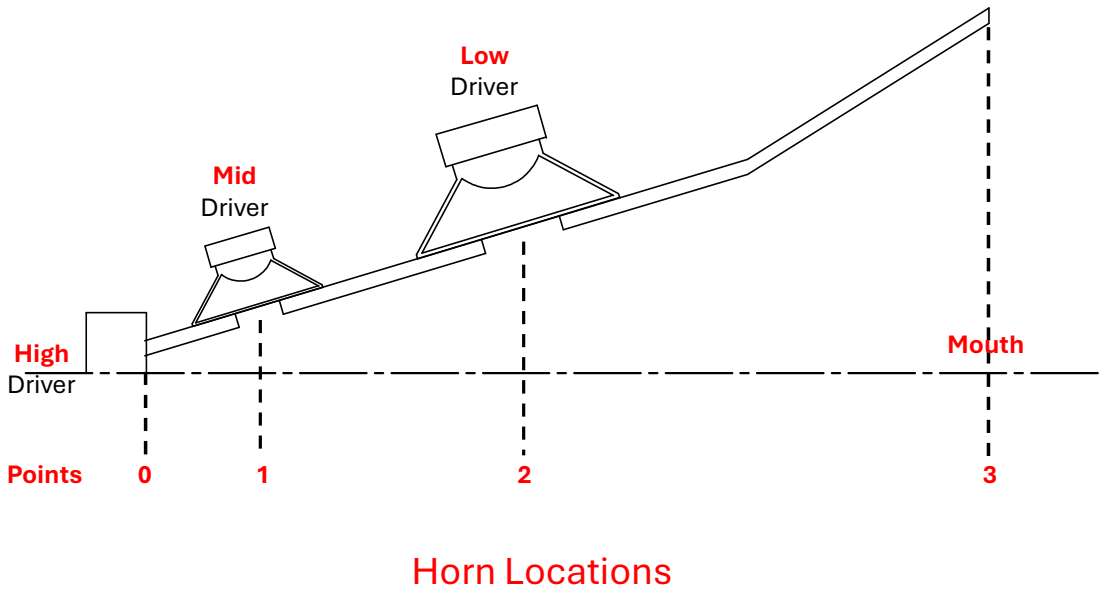
The last relationship needed defined what happens as you pass each driver location working from point 3 to point 0.

For example, at point 2,  $p_2$  was calculated and acts everywhere along the dashed line, on both sides of the line, and at the throat towards the low frequency driver. However, the volume velocity splits.

$$U_2'' = U_2 - U_2'$$

- $U_2$  = volume velocity arriving from 3
- $U_2'$  = volume velocity towards the low driver
- $U_2''$  = volume velocity leaving 2 towards 1

$U_2'$  was used to calculate  $U_{low}$  and  $p_{low}$ , the low frequency driver cone volume velocity and pressure needed to produce  $U_3$  and  $p_3$ . Note, the volume velocity leaving towards the closed end (points 1 and 0) is not necessarily equal to the volume velocity arriving from point 3.

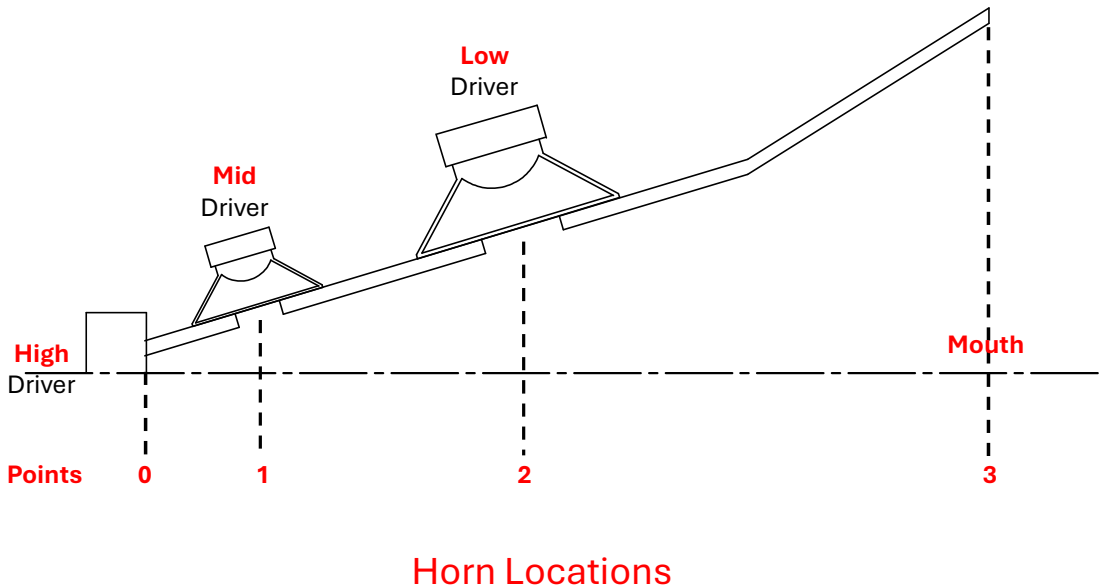


## Acoustic Impedance Calculations

The file “MEH Three Drivers Algorithm 05\_18\_26.pdf” linked on this web page contains the derivation/steps used for calculating the acoustic impedances of each driver, the coupling acoustic impedances between the drivers, and the velocity ratios between each driver’s cone motion and the MEH’s mouth output.

The acoustic impedances were programmed into MathCad worksheets to simulate the equivalent acoustic circuit for two or three way MEH speaker systems. Both passive and active crossovers were added to simulate the total SPL and Sound Power Response for a complete MEH speaker system.

# MEH System Models



Circuit models were drawn for the MEH horn with both active (DSP) and passive crossovers. The models are consistent with the Thiele/Small circuit modeling method for closed and ported enclosures and all other similar speaker equivalent circuit models. The complete circuit models for typical drivers in a MEH (low, mid, or high) are shown on the following slide.

The complete equivalent circuits have electrical, mechanical, and acoustic sections that are linked through the magnetic gap and the driver cone's cross-sectional area, respectively. The added complexity in the MEH modeling was the additional **current source** on the right-hand side of the acoustic circuit that represents the pressure load generated by motions of the other two drivers coupled through the common horn volume.

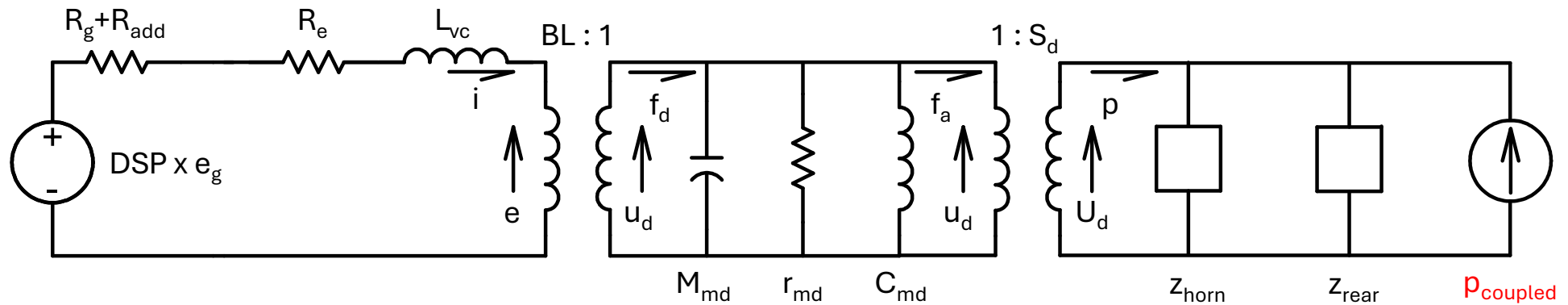
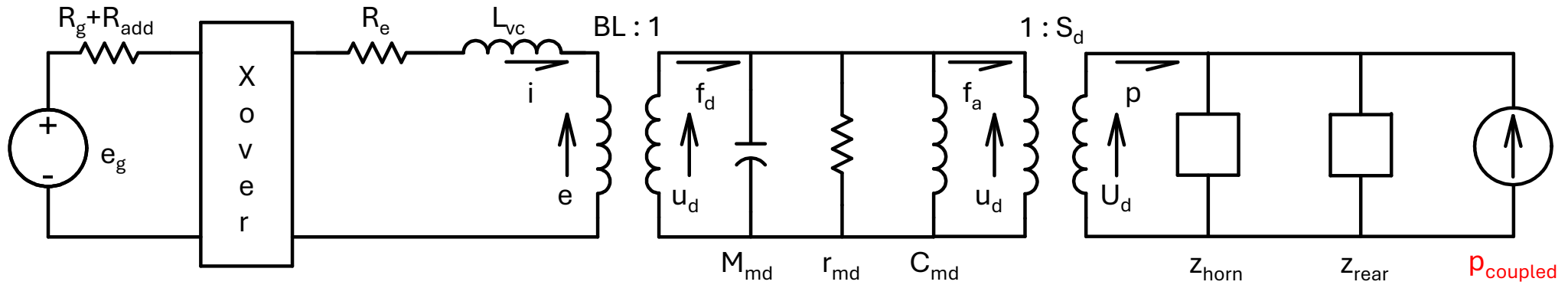
The complete circuit model of a MEH speaker system consists of three coupled equations with three unknowns that must be solved simultaneously. Again, all the variables have both magnitude and phase.

# Typical MEH Circuit Models w/ Passive (top) and Active (bottom) Crossovers

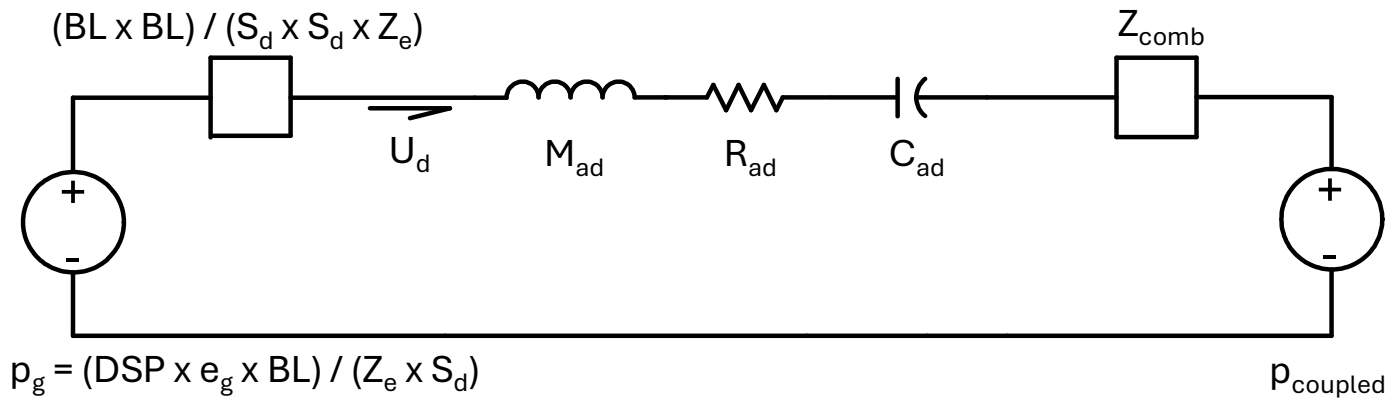
**Electrical**

**Mechanical**

**Acoustic**



## Typical MEH Acoustic Model w/ an Active Crossover



DSP = active crossover

$$Z_e = R_g + R_{add} + R_e + j \omega L_{vc}$$

$$Z_{comb} = Z_{horn} + Z_{rear}$$

For the low frequency driver in a three-way MEH

$$U_d = U_{d\_low}$$

$$p_{coupled} = Z_{low\_high} \times U_{d\_high} + Z_{low\_mid} \times U_{d\_mid}$$

Starting with the active crossover model on the previous slide, the electrical and mechanical parts of the circuit were pulled into the acoustic circuit. The resulting equivalent impedance analogy circuit for the low frequency driver in a three-way MEH is shown on the left. Similar circuits can be drawn for the mid and high frequency drivers.

An additional voltage source,  $p_{coupled}$ , seen on the right side of the circuit, represents the pressure on the low frequency driver cone resulting from the other driver cone motions. There will be three equations with three volume velocity unknowns ( $U_{d\_low}$ ,  $U_{d\_mid}$ , and  $U_{d\_high}$ ) that need to be solved simultaneously as functions of frequency.

For comparison, final equivalent circuit models for a front-loaded horn are shown on pages 2 – 4 of the white paper at [http://www.quarter-wave.com/Horns/Front\\_Horn.pdf](http://www.quarter-wave.com/Horns/Front_Horn.pdf)

## MEH Acoustic KVL Equations w/ an **Active** Crossover

- Low Frequency Driver

$$(\text{DSP}_{\text{low}} \times e_{g_{\text{low}}} \times \text{BL}_{\text{low}}) / (Z_{e_{\text{low}}} \times S_{d_{\text{low}}}) - [(\text{BL}_{\text{low}} \times \text{BL}_{\text{low}}) / (S_{d_{\text{low}}} \times S_{d_{\text{low}}} \times Z_{e_{\text{low}}}) + j \omega \times M_{ad_{\text{low}}} + R_{ad_{\text{low}}} + 1 / (j \omega \times C_{ad_{\text{low}}}) + Z_{\text{comb}_{\text{low}}}] \times U_{d_{\text{low}}} - (Z_{\text{low}_{\text{high}}} \times U_{d_{\text{high}}} + Z_{\text{low}_{\text{mid}}} \times U_{d_{\text{mid}}}) = 0$$

- Mid Frequency Driver

$$(\text{DSP}_{\text{mid}} \times e_{g_{\text{mid}}} \times \text{BL}_{\text{mid}}) / (Z_{e_{\text{mid}}} \times S_{d_{\text{mid}}}) - [(\text{BL}_{\text{mid}} \times \text{BL}_{\text{mid}}) / (S_{d_{\text{mid}}} \times S_{d_{\text{mid}}} \times Z_{e_{\text{mid}}}) + j \omega \times M_{ad_{\text{mid}}} + R_{ad_{\text{mid}}} + 1 / (j \omega \times C_{ad_{\text{mid}}}) + Z_{\text{comb}_{\text{mid}}}] \times U_{d_{\text{mid}}} - (Z_{\text{mid}_{\text{high}}} \times U_{d_{\text{high}}} + Z_{\text{mid}_{\text{low}}} \times U_{d_{\text{low}}}) = 0$$

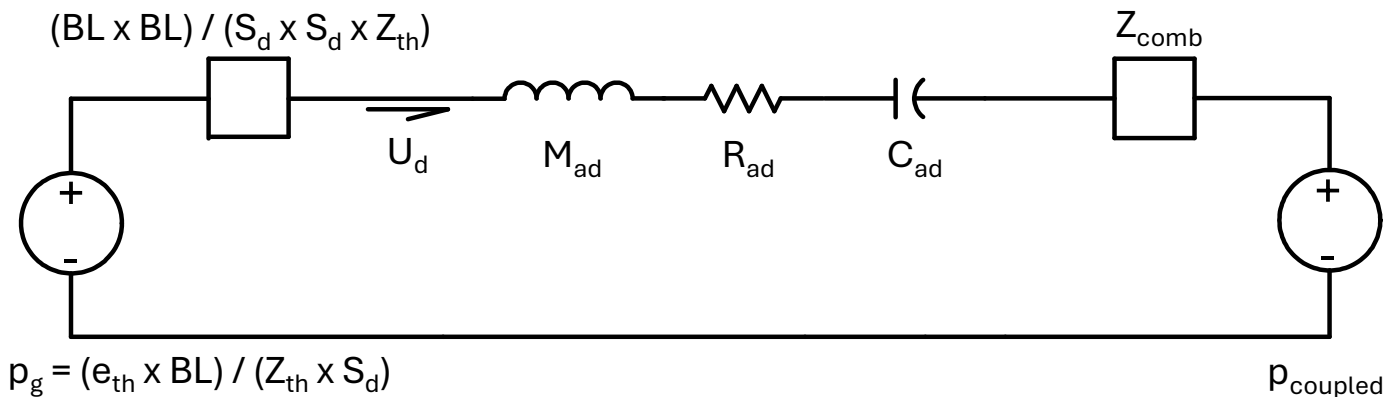
- High Frequency Driver

$$(\text{DSP}_{\text{high}} \times e_{g_{\text{high}}} \times \text{BL}_{\text{high}}) / (Z_{e_{\text{high}}} \times S_{d_{\text{high}}}) - [(\text{BL}_{\text{high}} \times \text{BL}_{\text{high}}) / (S_{d_{\text{high}}} \times S_{d_{\text{high}}} \times Z_{e_{\text{high}}}) + j \omega \times M_{ad_{\text{high}}} + R_{ad_{\text{high}}} + 1 / (j \omega \times C_{ad_{\text{high}}}) + Z_{\text{comb}_{\text{high}}}] \times U_{d_{\text{high}}} - (Z_{\text{high}_{\text{mid}}} \times U_{d_{\text{mid}}} + Z_{\text{high}_{\text{low}}} \times U_{d_{\text{low}}}) = 0$$

- Three Equations with Three Unknowns

$U_{d_{\text{low}}}$ ,  $U_{d_{\text{mid}}}$ , and  $U_{d_{\text{high}}}$  which all have magnitude and phase and are functions of frequency

## Typical MEH Acoustic Model w/ a Passive Crossover



$e_{th}$  = Thevenin equivalent voltage source

$Z_{th}$  = Thevenin equivalent impedance

$Z_{comb} = Z_{horn} + Z_{rear}$

For the low frequency driver in a three-way MEH

$U_d = U_{d\_low}$

$p_{coupled} = Z_{low\_high} \times U_{d\_high} + Z_{low\_mid} \times U_{d\_mid}$

Starting with the passive crossover model shown three slides ago, the electrical circuit contains a large boxed region representing the passive crossover and any other passive filters. Thevenin equivalent circuit elements were derived to simplify the crossover modeling. The electrical and mechanical portions of the circuit were pulled into the acoustic circuit, the resulting equivalent impedance analogy circuit for the low frequency driver in a three-way MEH is shown on the left. Similar circuits can be drawn for the mid and high frequency drivers.

An additional voltage source,  $p_{coupled}$ , is seen on the right side of the circuit representing the pressure on the low frequency driver cone resulting from the other driver cone motions. Again, there will be three equations with three volume velocity unknowns ( $U_{d\_ow}$ ,  $U_{d\_mid}$ , and  $U_{d\_high}$ ) that need to be solved simultaneously as functions of frequency.

## MEH Acoustic KVL Equations w/ a Passive Crossover

- Low Frequency Driver

$$(e_{th\_low} \times BL_{low}) / (Z_{th\_low} \times S_{d\_low}) - [(BL_{low} \times BL_{low}) / (S_{d\_low} \times S_{d\_low} \times Z_{th\_low}) + j \omega \times M_{ad\_low} + R_{ad\_low} + 1 / (j \omega \times C_{ad\_low}) + Z_{comb\_low}] \times U_{d\_low} - (Z_{low\_high} \times U_{d\_high} + Z_{low\_mid} \times U_{d\_mid}) = 0$$

- Mid Frequency Driver

$$(e_{th\_mid} \times BL_{mid}) / (Z_{th\_mid} \times S_{d\_mid}) - [(BL_{mid} \times BL_{mid}) / (S_{d\_mid} \times S_{d\_mid} \times Z_{th\_mid}) + j \omega \times M_{ad\_mid} + R_{ad\_mid} + 1 / (j \omega \times C_{ad\_mid}) + Z_{comb\_mid}] \times U_{d\_mid} - (Z_{mid\_high} \times U_{d\_high} + Z_{mid\_low} \times U_{d\_low}) = 0$$

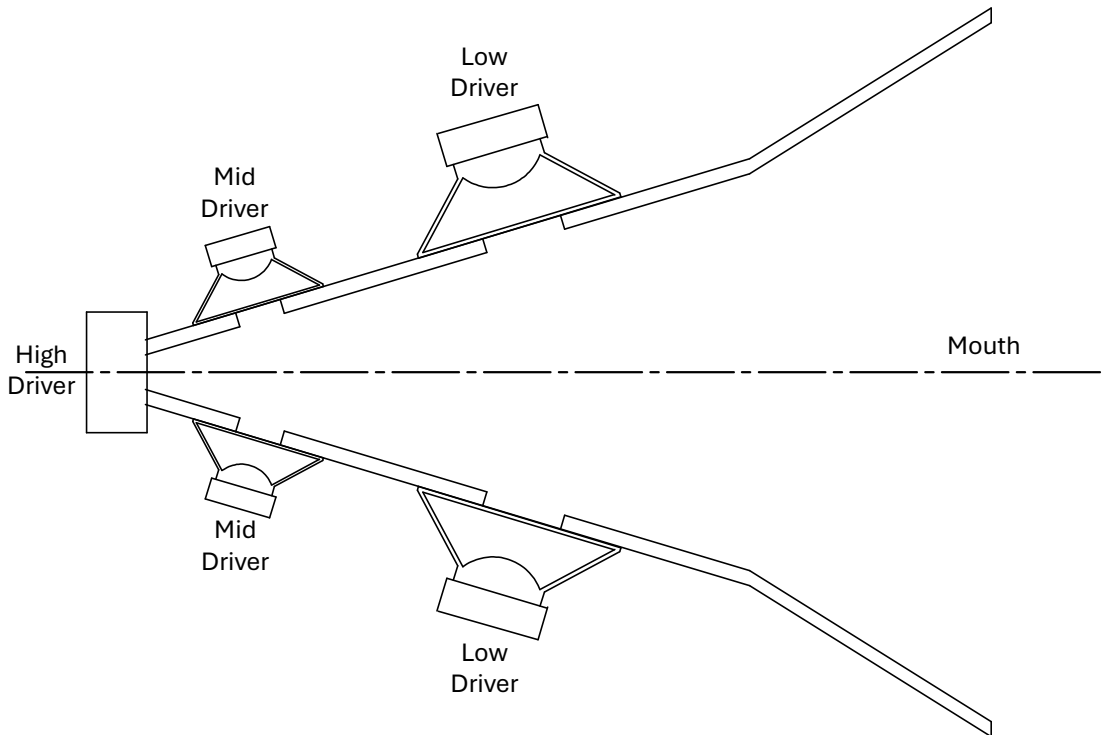
- High Frequency Driver

$$(e_{th\_high} \times BL_{high}) / (Z_{th\_high} \times S_{d\_high}) - [(BL_{high} \times BL_{high}) / (S_{d\_high} \times S_{d\_high} \times Z_{th\_high}) + j \omega \times M_{ad\_high} + R_{ad\_high} + 1 / (j \omega \times C_{ad\_high}) + Z_{comb\_high}] \times U_{d\_high} - (Z_{high\_mid} \times U_{d\_mid} + Z_{high\_low} \times U_{d\_low}) = 0$$

- Three Equations with Three Unknowns

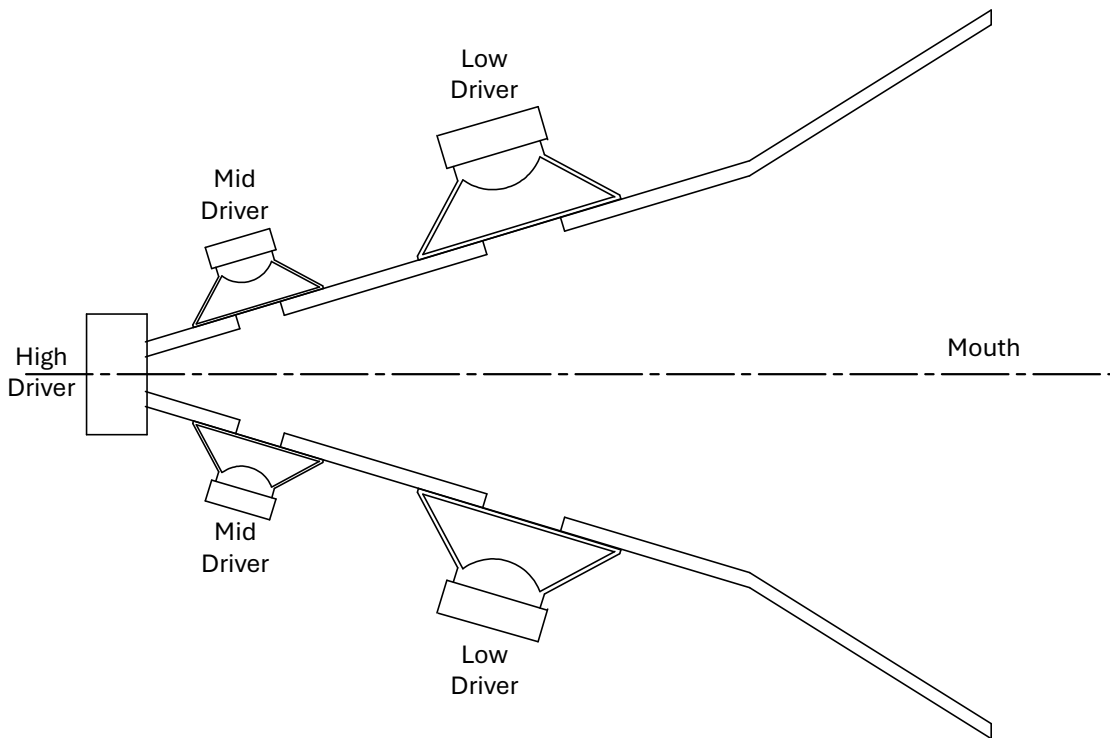
$U_{d\_low}$ ,  $U_{d\_mid}$ , and  $U_{d\_high}$  which all have magnitude and phase and are functions of frequency

# Three Way Sample Problem w/ Active Crossover



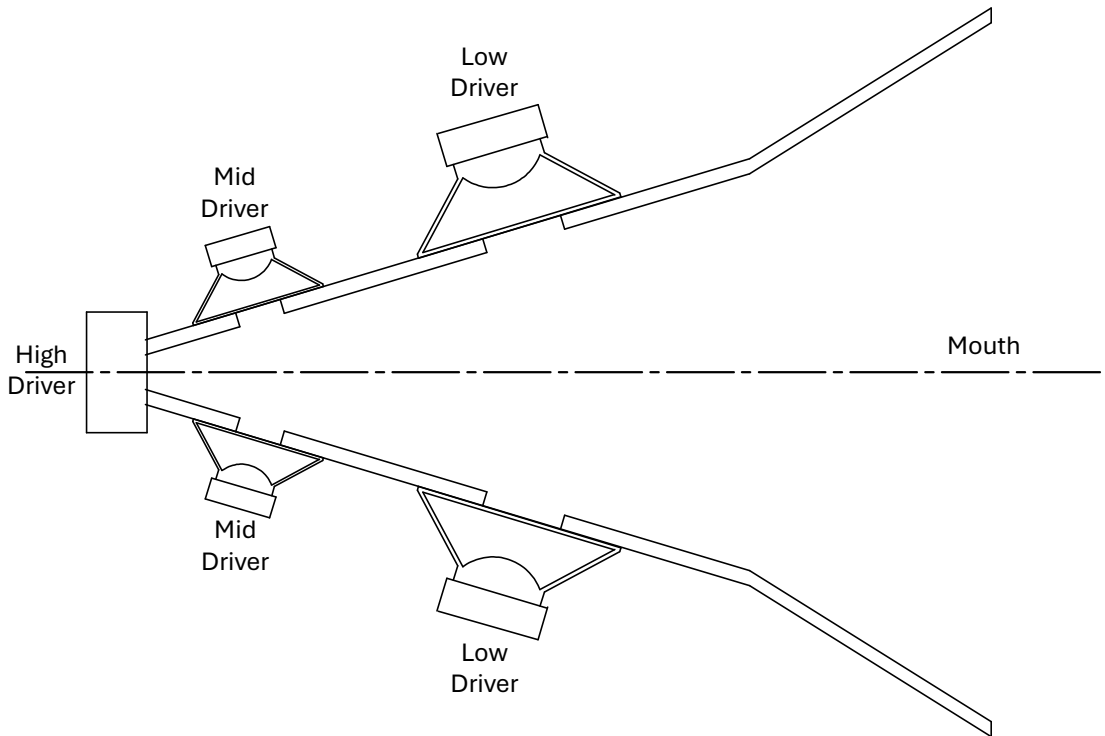
My primary interests in MEH speakers are the controlled directivity and the potential point source response. I am looking for a design that will perform well in my home listening room, I do not need extreme high efficiency since the design is not intended for a night club or stadium. I am open to using separate woofer(s) and enclosure(s) for the low frequencies below a few hundred Hz, but a full range design is preferred. The design can be active or passive, I typically try both in new speaker designs.

I do not have any experience with compression drivers, eventually that will change. For now, a tweeter, midrange, and woofer will be modeled for a MEH sample problem. The goals of the sample problem are to learn about the design trade-offs and get some feedback from other MEH designers/builders.



To avoid trying to juggle driver responses and the response produced by the MEH geometry, full range drivers seemed like good candidates for a quick initial study. Full range drivers have a resonant frequency  $f_s$  and a  $Q_{ts}$  defining the low frequency SPL response and an extended high frequency response unlike typical midrange and woofer drivers where roll off or cone break up determine their upper usable frequency limit. Since high efficiency was not a requirement, using a tweeter or small full range driver for the high frequencies was an option that allowed tapping into my experiences with single full range drivers and multi-way traditional speaker enclosures.

The rear waves from each driver were ignored, sealed or ported enclosures can be added later. The goal was to study the interactions between the drivers and the horn and identify some of the trade-offs that can be made.



## MEH Sample Problem Definition :

1 x High – Fostex FF85WK ( $f_s = 115 \text{ Hz}$ ,  $Q_{ts} = 0.57$ )

2 x Mid – Fostex FF125WK ( $f_s = 67 \text{ Hz}$ ,  $Q_{ts} = 0.43$ )

2 x Low – Fostex FF225WK ( $f_s = 44 \text{ Hz}$ ,  $Q_{ts} = 0.35$ )

Horn Throat Area – 3.25 in x 3.25 in

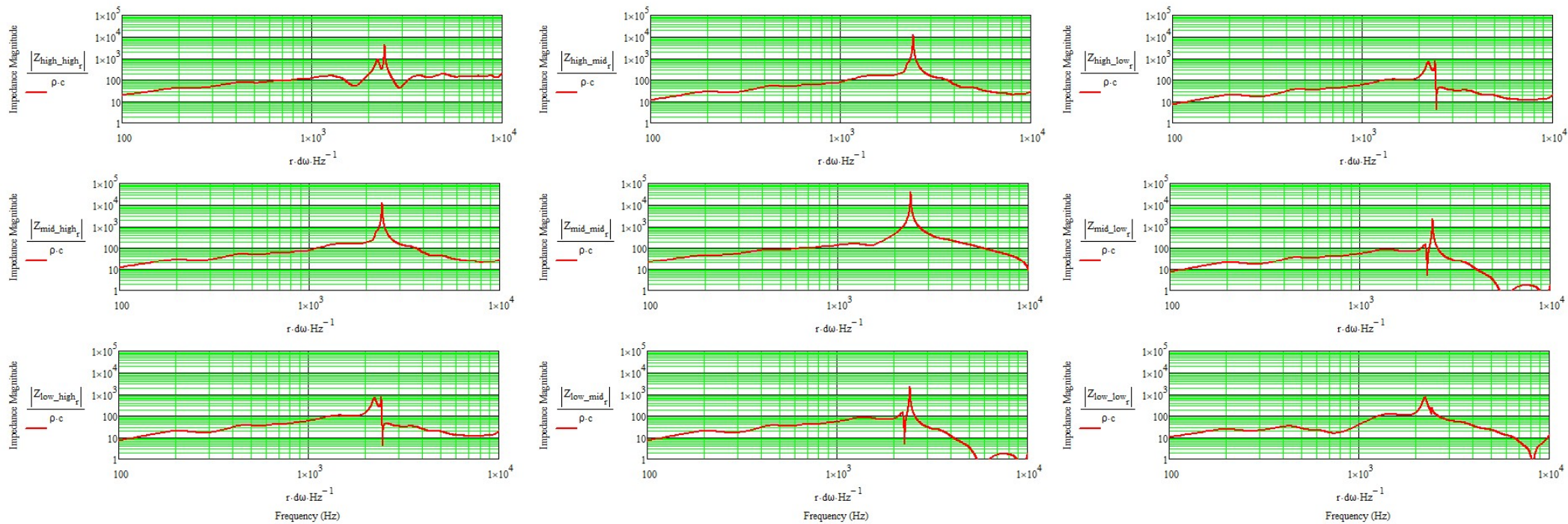
Horn Mouth Area – 24 in x 24 in

Single Expansion – Length is 18 in

Vertical and Horizontal Exit Angles – 60 degrees

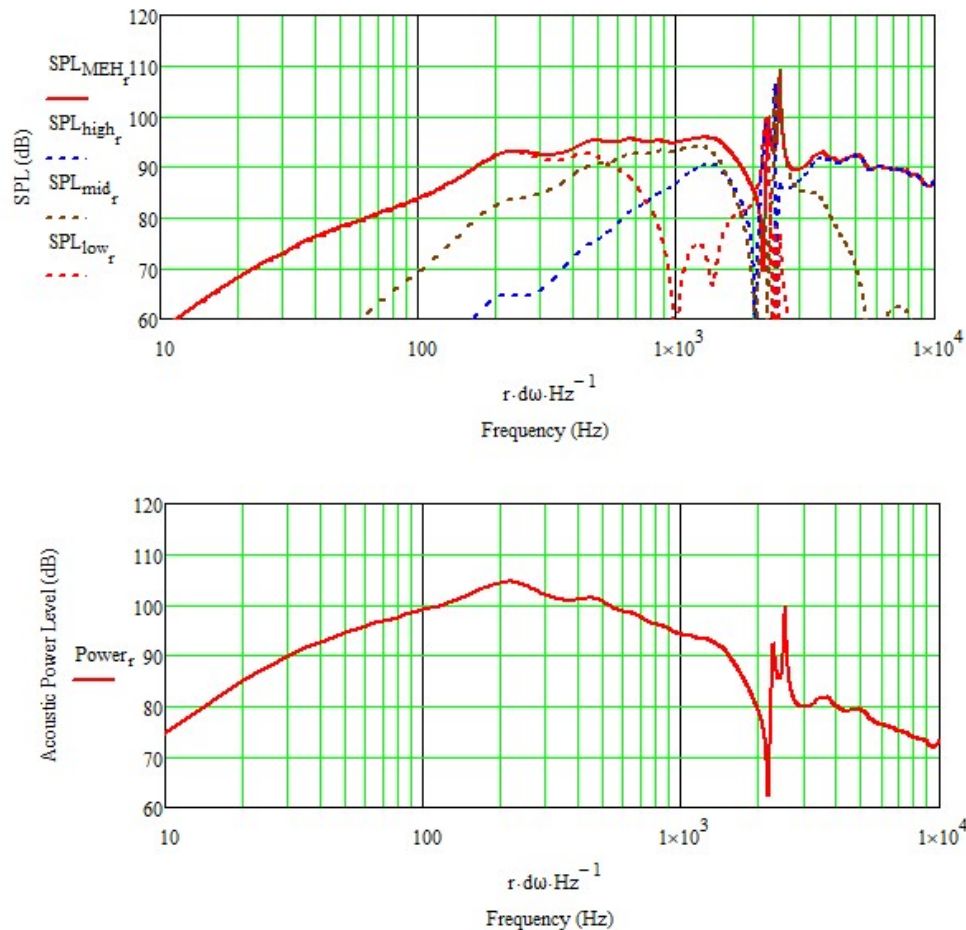
Coupling Volumes for the mid and low frequency drivers were approximately the concave volume created by the driver's cone profile. The Throat Area was 1/5 of the driver's cone area with a length equal to the horn's wall thickness. The high frequency driver was flush mounted at the throat of the horn.

## MEH Acoustic Impedance Matrix



The MEH's acoustic impedance is a symmetric 3 x 3 matrix with the top row used for the high driver, middle row used for the mid driver, and bottom row used for the low driver. These results were derived only from the horn geometry and do not include any of the driver T/S properties. The peaks and dips between 2 and 3 kHz are created by the throats and coupling volumes of the mid and low drivers. The nulls above 3 kHz in the mid and low driver columns are a result of the axial offset positions of the mid and low throats along the length of the horn.

## SPL at 3 m on Axis and Sound Power Level at the Mouth



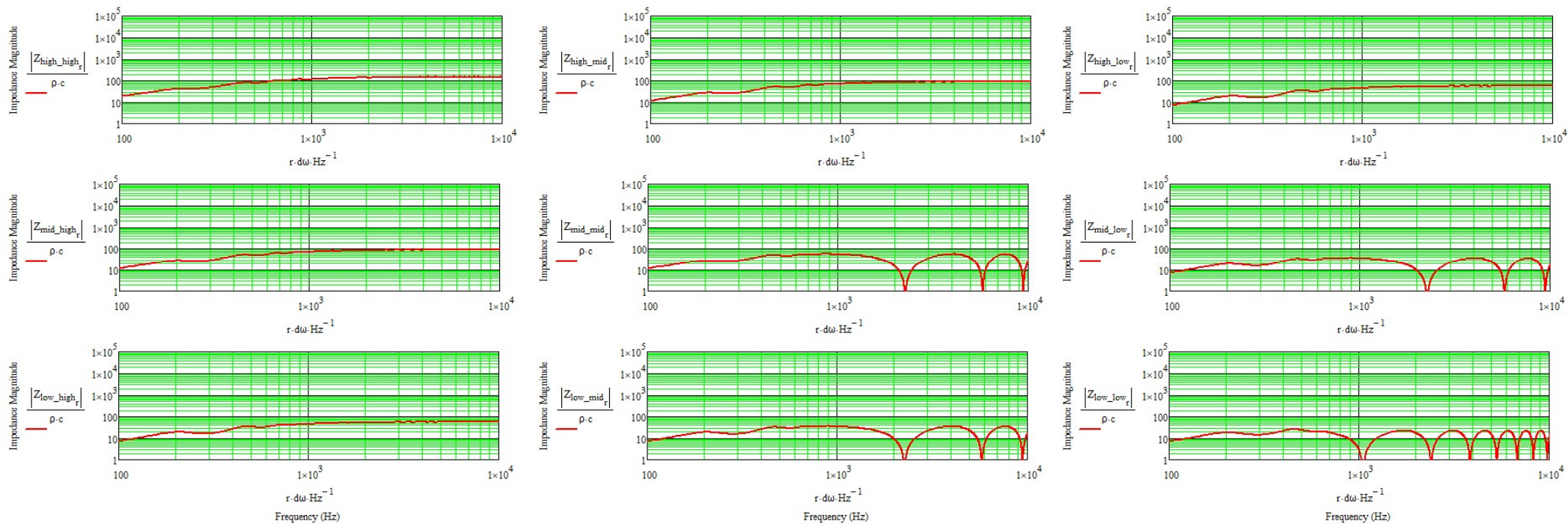
The top plot shows the SPL response at a 3 m distance on the axis of the horn, summed and individual drivers. Active crossovers were specified at 400 and 800 Hz. The lower plot contains the Sound Power Level calculated at the horn's mouth using the volume velocity and the acoustic impedance.

The peaks and dips between 2 and 3 kHz are due to the coupling volume and throat geometries in front of the mid and low drivers. Each coupling volume and throat produces a second resonant system as seen from the driver or an acoustic trap as seen by sound waves traveling along the horn.

Additional nulls were generated by the axial offsets of the mid and low drivers from the throat of the horn; this is the same phenomenon seen in an offset driver TL typically used to mitigate the 3/4 wavelength standing wave.

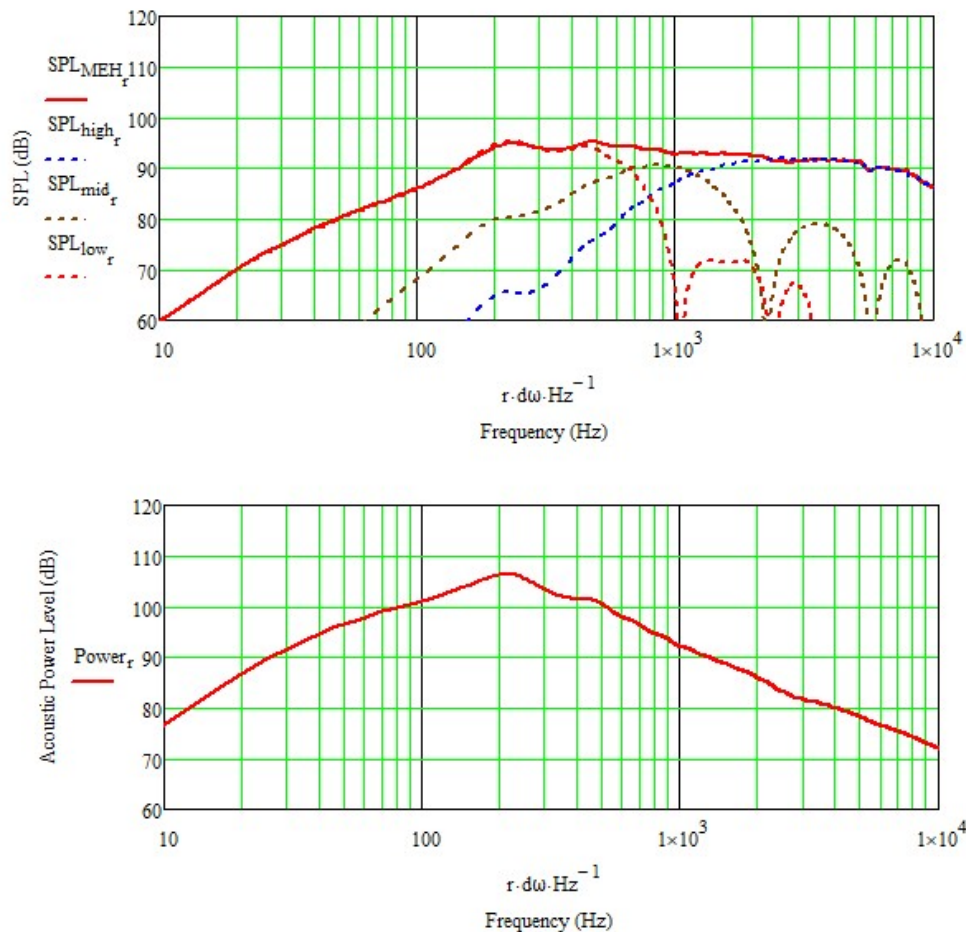
In this example, the MEH would be paired with a woofer or subwoofer to reinforce the output below 200 Hz. This example was not intended as a final design. It is only used to highlight potential trade-offs.

## MEH Acoustic Impedance Matrix



The MEH's symmetric acoustic impedance matrix was recalculated with the drivers mounted flush on the inside wall of the MEH eliminating the coupling volumes and throats in front of the mid and low drivers. The axial positions of the mid and low drivers were held constant. In these curves a series of nulls are seen in the mid and low driver results (bottom right 2 x 2 submatrix of plots) created by the axial offset positions just like in a TL with an offset woofer. These acoustic impedance results are much cleaner without the secondary resonances generated by the coupling volumes and throats.

## SPL at 3 m on Axis and Sound Power Level at the Mouth

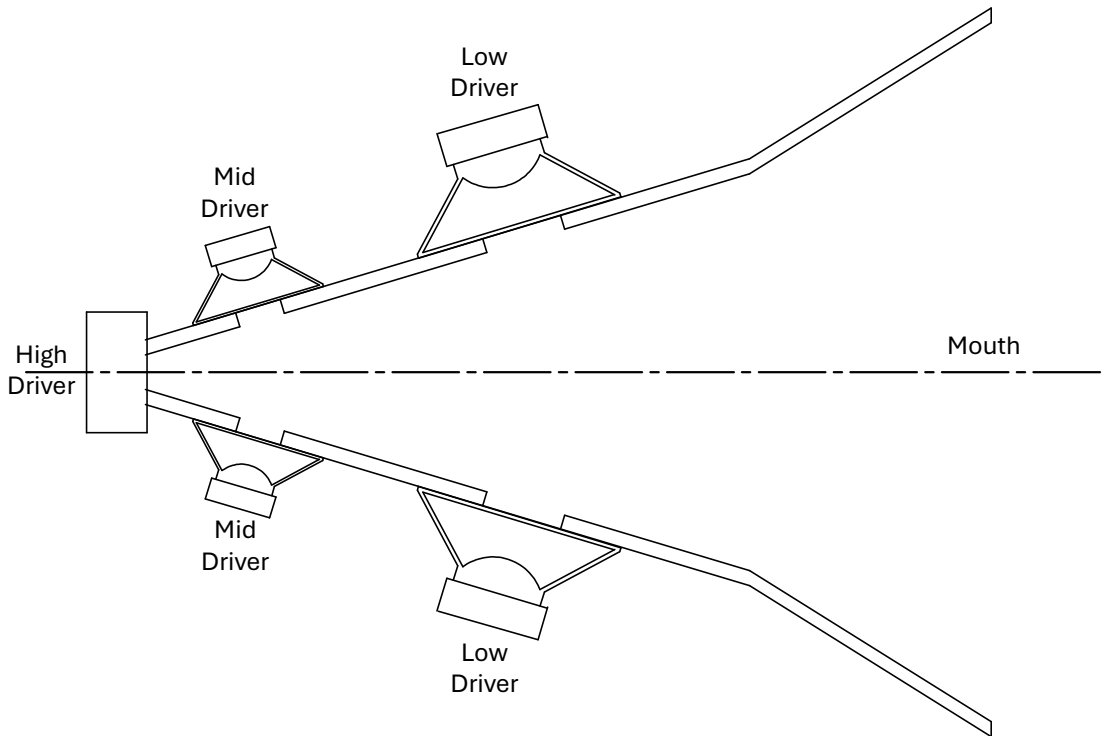


The top plot shows the SPL response at a 3 m distance on the axis of the horn. The same active crossovers were specified at 400 and 800 Hz. The lower plot contains the Sound Power Level calculated at the horn's mouth using the volume velocity and the acoustic impedance.

The sharp peaks and dips between 2 and 3 kHz have been resolved; the responses are much smoother. Nulls are still generated by the offset of the mid and low drivers from the throat of the horn. The crossover frequencies and slopes are used to remove the nulls from the summed SPL and Sound Power Level responses.

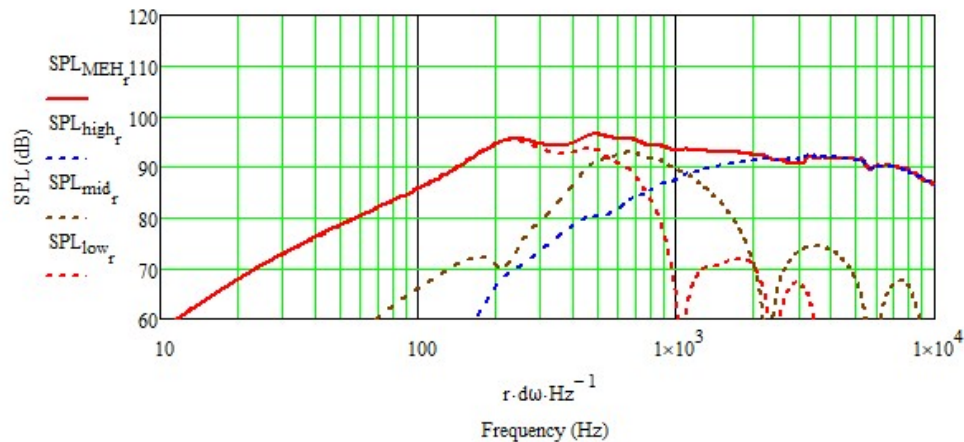
There are two obvious trade-offs between using coupling volumes and throats versus flush mounting the drivers on the inside of the horn. Flush mounting eliminates and peaks and nulls created by any resonant or trap behaviors of the coupling volume and throat. However, using a coupling volume and throat allows the entrance point to the horn to be much closer to the horn's throat since the horn only needs to be wide enough to accommodate the throat diameter which is smaller than the driver's cone diameter

# Three Way Sample Problem w/ Passive Crossover



The same horn geometry and drivers were used to simulate the responses but with a passive. The drivers are all flush mounted eliminating the resonances created by the coupling volumes and throats. Passive crossovers are specified at 400 and 800 Hz. An additional passive filter was applied to the mid driver cancelling the driver's resonant peak in the electrical impedance.

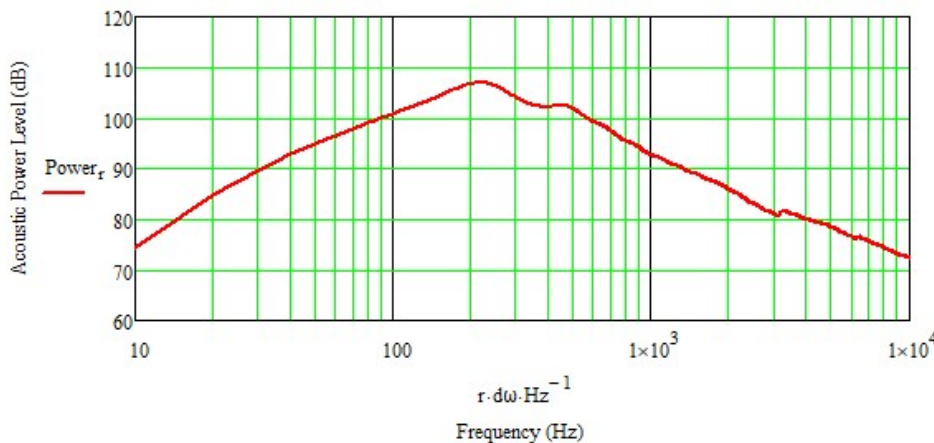
## SPL at 3 m on Axis and Sound Power Level at the Mouth



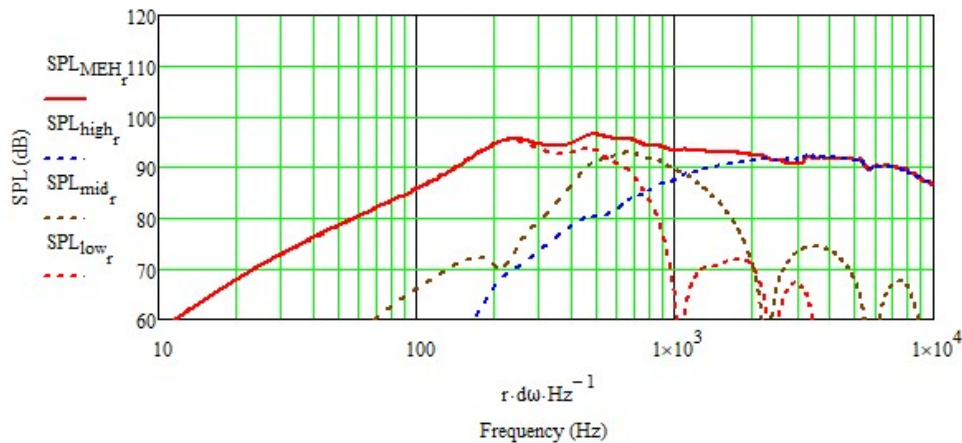
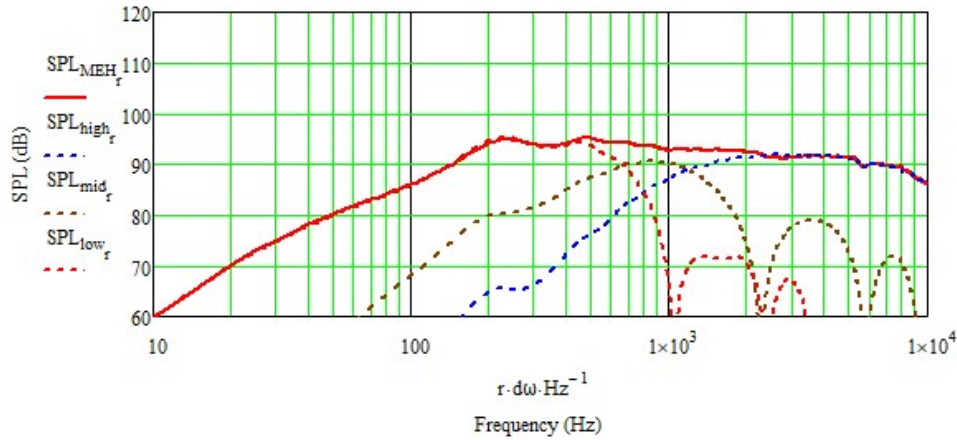
The top plot shows the SPL response at a 3 m distance on the axis of the horn. The lower plot contains the Sound Power Level calculated at the horn's mouth using the volume velocity and the acoustic impedance.

The peaks and dips between 2 and 3 kHz have been eliminated by surface mounting the mid and low drivers to the inside of the horn, the responses are very similar to the active crossover results. Nulls are still generated by the offset of the mid and low drivers from the throat of the horn. The crossover frequencies and slopes were used to remove the nulls from the summed SPL and Sound Power Level responses.

The passive crossover is not much more complicated than what is needed in a typical three-way boxed speaker. Designing and iterating the crossover in the MathCad worksheet allows a design to be finalized without needing to do a lot of guessing and tweaking of individual component values after the build is complete.. This represents a significant reduction in the on-hand part count for experimental trade-offs, the associated part costs, and the effort substituting different filter component values.

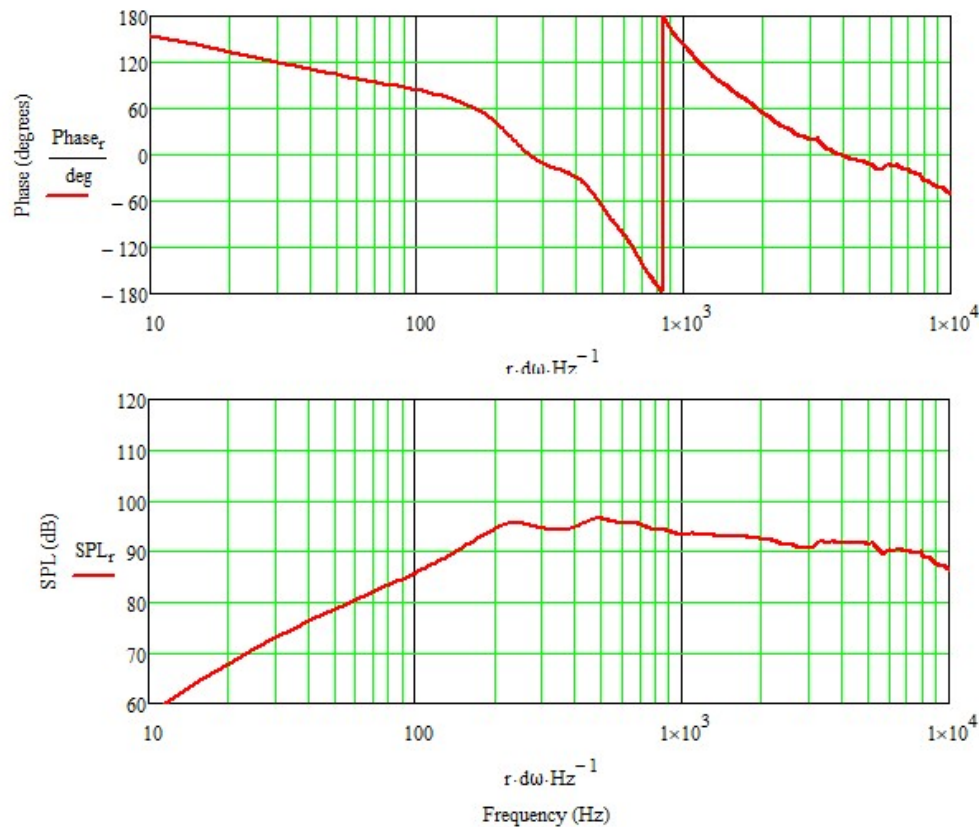


## SPL at 3 m on Axis Active versus Passive Crossover



Comparing the SPL response curves for the active crossover (top curve) against the passive crossover (bottom curve) shows that they are essentially the same. These results were arrived at with a minimal amount of effort or fine tuning; they represent a proof of concept that both active and passive systems are feasible, and the results serve as a check on the two crossover modeling methods.

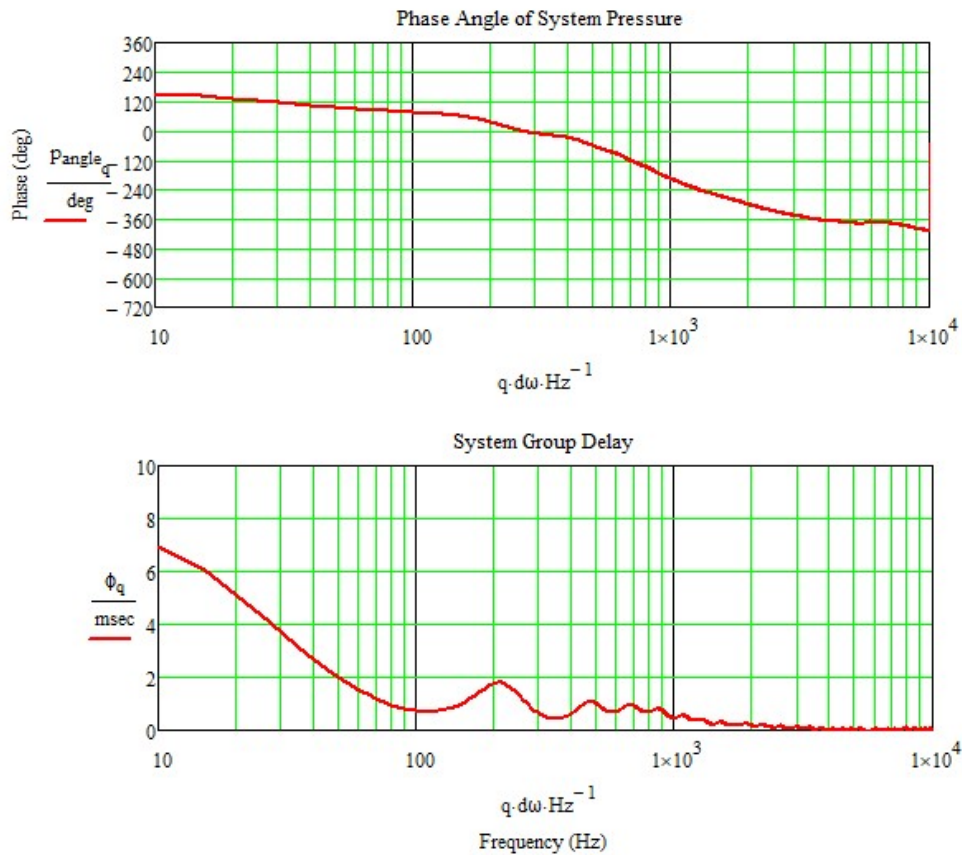
## SPL at 3 m on Axis after Removing Time of Flight



Another interesting result was found after removing an estimated time-of-flight distance from the SPL response curves. This distance was calculated using the 3 m on axis distance to the mic, plus the horn length, minus a small modifier of a few cm to estimate the best single source position that produced the linear phase plot shown in the upper curve on the left.

There are three drivers used in the model, the mid is connected out of phase, there are three crossovers modifying the SPL response and phase of each driver, and surprisingly the summed SPL phase response exhibits a single driver characteristic, there are no large phase swings indicative of a resonance in the response.

## Unwrapping the Phase and Calculating the Group Delay



Unwrapping the phase in the previous slide produces a monotonically downward sloping phase result as shown in the upper plot on the left.

In the lower plot, the Group Delay is calculated. I know that many speaker designers and builders use the Group Delay as an important quantity when evaluating the quality of a speaker system, I confess I am not one of them. But it is extremely interesting to compare this result with a typical resonant box speaker result (sealed, ported, TL, ...), the group delay is low without the large swings in values seen in resonant boxed speakers.

# Take Aways and Next Steps

The current MEH worksheets can model any combination of the following input variables.

- 2 or 3 drivers in parallel and/or series, single or multiples of each driver, different offset positions along horn length.
- Single or double expansion of any horn profile (linear, conical, exponential, ...).
- Square or rectangular mouth with independent horizontal and vertical exit angles.
- Coupling volumes with throats or direct internal wall mounted drivers.
- Open back, ported, or sealed rear chambers (modeling mostly complete).
- Passive or active crossovers.
- Flat or curved wavefronts (still under study/development).
- Driver Displacement, Electrical Impedance, SPL on or off axis, Sound Power Level, and Polar Plots are all Calculated.

The MathCad models for MEH systems have reached a point where actual design analyses can be performed, systems built, and measurements made and correlated. There are a few more upgrades that I would like to make including being able to measure and then model a compression driver. I am sure there will be additional upgrades, corrections, and tweaks as I learn more about horn loaded speakers, receive feedback, and look at creative changes to the currently available/accepted MEH geometric designs. Additional presentations will document the continued evolution of the worksheets.

Thanks for reading and more updates and information to come .....