Classic Transmission Line Enclosure Alignments

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Introduction :

Ever since I first made my MathCad transmission line worksheets available, now over 20 years ago, the subject of alignment tables has come up again and again. Different alignment schemes for transmission line speakers can be found on the Internet and in print articles by transmission line designers and builders. The problem with these various attempts at alignment tables is that they are limited in scope to specific driver parameters or specific enclosure geometries. I have never seen a set of general transmission line alignment tables that encompass a wide range of potential drivers and span the same amount of enclosure design space as the alignment tables available for sealed and ported enclosures.

Alignments for sealed and ported speaker systems are based on the lumped parameter circuit models used in the classic papers by Thiele[1] and Small[2-4]. These papers derive alignments using the coefficients of 2nd and 4th order high pass filters. Vance Dickason's Loudspeaker Design Cookbook[5] contains comprehensive tables, covering a large range of Thiele / Small driver parameters, again fit to various types of high pass filters. In the tables, the enclosure volume and system tuning frequency are expressed as functions of the driver's Thiele / Small parameters. These alignment tables are a proven method for designing sealed and ported enclosures with predictable results.

If available, similar comprehensive alignment tables for transmission line enclosures would allow quick scoping analyses of drivers and enclosure geometries with similar predictable results. These scoping calculations could become the basis for a final transmission line enclosure design or the starting point for further optimization using simulation software.

Over the past few years as I continued to work on transmission line enclosure theory and designs, I accumulated several interesting observations in my personal notes. Keeping in mind the desire for alignment tables, about a year ago I tried a method for specifying the transmission line enclosure geometry as a function of a driver's Thiele / Small parameters using the alignment tables for ported enclosures. Looking back at it now a design procedure was there, and I just failed to see it. Maybe others have already discovered this method, but I have not seen it presented or discussed (or maybe it also went unnoticed at the time).

What follows is a description of the procedure and sample problems showing the calculated SPL response of a ported enclosure and a family of transmission line enclosures derived from the same ported enclosure alignment tables. I have exercised the method on quite a few different drivers, with vastly different Thiele / Small parameters, and it has worked consistently.

Method Description :

To design a bass reflex enclosure using the alignment tables in the Loudspeaker Design Cookbook[5], enter one of the tables and for the driver's Q_{ts} obtain values for the parameters H, α, and f_3/f_s. The value of α is used to calculate the volume of air in the enclosure V_b from the driver's V_{as} property. The value of H is used to calculate the enclosure tuning frequency f_b from the driver's resonant frequency f_s. Finally, the -3 dB point can be calculated relative to the driver's resonant frequency f_s using the ratio f_3/f_s.

$$V_b = V_{as} / \alpha \text{ and } f_b = H \times f_s$$

To size a ported enclosure, knowing the enclosure volume and the tuning frequency, a physical port length L_{port} is then calculated based on the port's internal radius r_{port}. In the equation below, the resulting calculated port length will have units consistent with those of c, r_{port}, and V_b (be very careful). The last term accounts for acoustic boundary conditions at the port's entry and exit.

$$L_{port} = [c^2 / (4 \times \pi)] \times [(r_{port})^2 / (f_b^2 \times V_b)] – 1.463 \times r_{port}$$

That's it, you have a volume and port internal radius and physical length that when combined with the driver's small signal Thiele / Small parameters produces a predictable SPL response curve. The shape of the enclosure, the position of the driver, and the position of the port are not important for the enclosure alignment calculation (in reality, these are acoustically important and impact the speaker's performance).

To size a transmission line enclosure, the same alignment table procedure is followed to determine the enclosure volume V_b using α and the tuning frequency f_b using H. Knowing the enclosure volume and tuning frequency, a line length L is calculated consistent with the tuning frequency f_b and the transmission line's taper ratio, TR = S_L / S_0, as defined in Figure 1. Unlike the ported enclosure, the internal geometry of the transmission line enclosure determines the tuning frequency.

$$V_b = ½ \times (S_0 + S_L) \times L$$

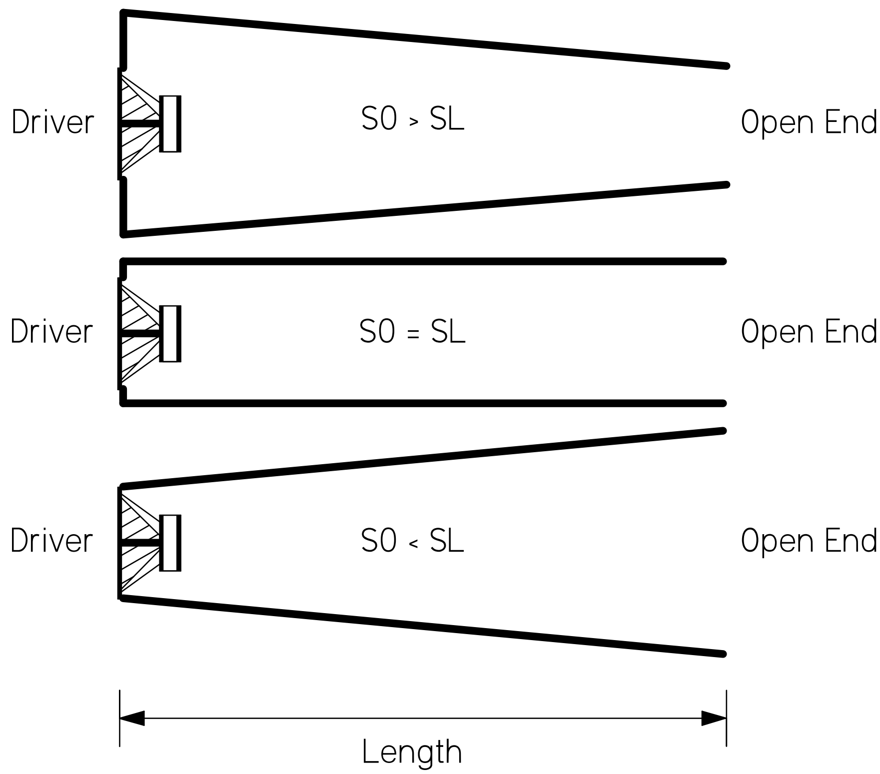
Substituting $V_b = V_{as} / \alpha$ and $S_L = TR \times S_0$ into this equation, solve for the cross-sectional areas at the closed end S_0 and the open end S_L.

$$S_0 = (V_{as} / \alpha) \times \{1 / [1/2 \times (1 + TR) \times L]\} \text{ and } S_L = TR \times S_0$$

Make sure that a consistent set of units is used in the calculations so that the resulting areas make sense. I usually express the cross-sectional areas as multiples of the driver's cone area S_d to eliminate the unit issue which some people find helpful, and others do not like at all.

The best way to demonstrate and investigate the trade-offs in transmission line design, using the ported enclosure alignment tables, is with a sample problem.

Figure 1 : Classic Transmission Line Geometries



where : L = length of the pipe
S_0 = cross-sectional area at the closed end, Length = 0
S_L = cross-sectional area at the open end, Length = L
TR = taper ratio, $TR = S_L / S_0$
D = density of fiber stuffing

Note : The woofer is not offset along the length of the transmission line, the figures depict an end loaded transmission line geometry. Offsetting the woofer and adding fiber stuffing are common methods used to mitigate the ripple produced in a transmission line's SPL response.

Driver Selection :

The driver selected for the sample problem is the SB Acoustics Satori WO24P-4. The Thiele / Small parameters were copied from the manufacturer's data sheet (they are consistent which is a nice result from a manufacturer) and shown in Figure 2.

Figure 2 : Satori WO24P-4 Manufacturer's Thiele / Small Parameters

Nominal Impedance	4 Ω	Free air resonance, Fs	28 Hz
DC resistance, Re	3.3 Ω	Sensitivity (2.83 V / 1 m)	91 dB
Voice coil inductance, Le	0.29 mH	Mechanical Q-factor, Qms	6.7
Effective piston area, Sd	255 cm^2	Electrical Q-factor, Qes	0.42
Voice coil diameter	49.5 mm	Total Q-factor, Qts	0.40
Voice coil height	23 mm	Moving mass incl.air, Mms	42 g
Air gap height	6 mm	Force factor, Bl	7.6 Tm
Linear coil travel (p-p)	17 mm	Equivalent volume, Vas	71 liters
Magnetic flux density	1.1 T	Compliance, Cms	0.77 mm/N
Magnet weight	1.36 kg	Mechanical loss, Rms	1.1 kg/s
Net weight	3.7 kg	Rated power handling	90 W

* IEC 268-5, T/S parameters measured on drive units that are broken in.

Sample Design Problem :

The alignment selected for this sample problem comes from Table 2.3 of Vance Dickason's Loudspeaker Design Cookbook[5] which corresponds to a BB4 alignment with a Q_L of 15. Moving down the table until reaching the entries corresponding to a Q_{ts} of 0.395 (non-rounded value derived from Q_{ms} and Q_{es} in Figure 2) yields the following parameters.

$$H = f_b / f_s = 1.0000$$

$$\alpha = V_{as} / V_b = 1.5198$$

$$f_3 / f_s = 1.1059$$

This means the enclosure will be tuned to the driver's resonant frequency of 28 Hz, have an internal volume V_{ab} of 71 liters / 1.5198 ~ 47 liters, and produce a -3 dB frequency of 1.1059 x 28 Hz ~ 31 Hz. These are the input parameters used to design the ported enclosure and a family of transmission line enclosures.

For the ported enclosure, all that remains is to calculate the port dimensions. Assuming r_{port} = 1 inch, the port length is calculated in inches using the equation previously shown.

$$L_{port} = 1.463 \times 10^7 \times (1)^2 / (28^2 \times 2868) - 1.463 \times 1 \sim 5.0 \text{ inches}$$

The design of the equivalent tapered transmission line enclosure, top geometry in Figure 1, is a little more challenging. The tuning of a transmission line is set by the length, but the length is tied to the taper ratio TR. One of the most common mistakes in transmission line design is to calculate the length for any geometry using the classic equation.

$$L = c / (4 \times f_b)$$

This equation is only accurate for a straight constant cross-sectional area transmission line, $S_0 = S_L$ as shown in the middle geometry in Figure 1. Table 1 contains the corrected length equation for classic transmission line enclosures. The length is a function of both the tuning frequency f_b and the taper ratio TR. A scale factor SF is applied to the classic length equation, shown above, to account for the transmission line's geometry. Most transmission lines are tapered, TR < 1. Expanding transmission lines, TR > 1, are sometimes referred to as TQWTs (Tapered Quarter Wave Tubes) or Voigt Pipes and often labeled as BLHs (Back Loaded Horns) in Internet discussions.

Table 1 : Transmission Line Length Calculation

Length = SF x (344 m/sec) / (4 x f_b) result is in meters

$TR = S_L / S_0$	SF	
0.1	0.62	Tapered
0.2	0.71	|
0.33	0.80	|
0.5	0.87	V
1.0	1.00	Straight
2.0	1.14	|
3.0	1.22	|
5.0	1.32	V
10.0	1.42	Expanding

Assume a tapered transmission line geometry with $S_0 : S_L = 5 : 1$ corresponding to a taper ratio TR = 0.2. The length and cross-sectional areas are calculated below for the enclosure volume V_b.

$$L = 0.71 \times (344 \text{ m/sec}) / (4 \times 28 \text{ Hz}) = 2.181 \text{ m}$$

$$S_0 = [(0.071 \text{ m}^3) / 1.5198] \times \{1 / [1/2 \times (1 + 0.2) \times 2.181 \text{ m}]\} = 0.0357 \text{ m}^2 = 1.4002 \times S_d$$

$$S_L = 0.2 \times S_0 = 0.0071 \text{ m}^2 = 0.2800 \times S_d$$

$$V_{TL} = 1/2 \times (0.0357 \text{ m}^2 + 0.0071 \text{ m}^2) \times 2.181 \text{ m} = 0.0467 \text{ m}^3 \sim 47 \text{ liters (check)}$$

Reversing the taper to create an expanding transmission line, assume $S_0 : S_L = 1 : 5$ corresponding to a taper ratio TR = 5.0. The length and cross-sectional areas are calculated below for the enclosure volume V_b.

$$L = 1.32 \text{ x } (344 \text{ m/sec}) / (4 \text{ x } 28 \text{ Hz}) = 4.0543 \text{ m}$$

$$S_0 = [(0.071 \text{ m}^3) / 1.5198] \text{ x } \{1 / [1/2 \text{ x } (1 + 5) \text{ x } 4.054 \text{ m}]\} = 0.00384 \text{ m}^2 = 0.1506 \text{ x } S_d$$

$$S_L = 5.0 \text{ x } S_0 = 0.0192 \text{ m}^2 = 0.7531 \text{ x } S_d$$

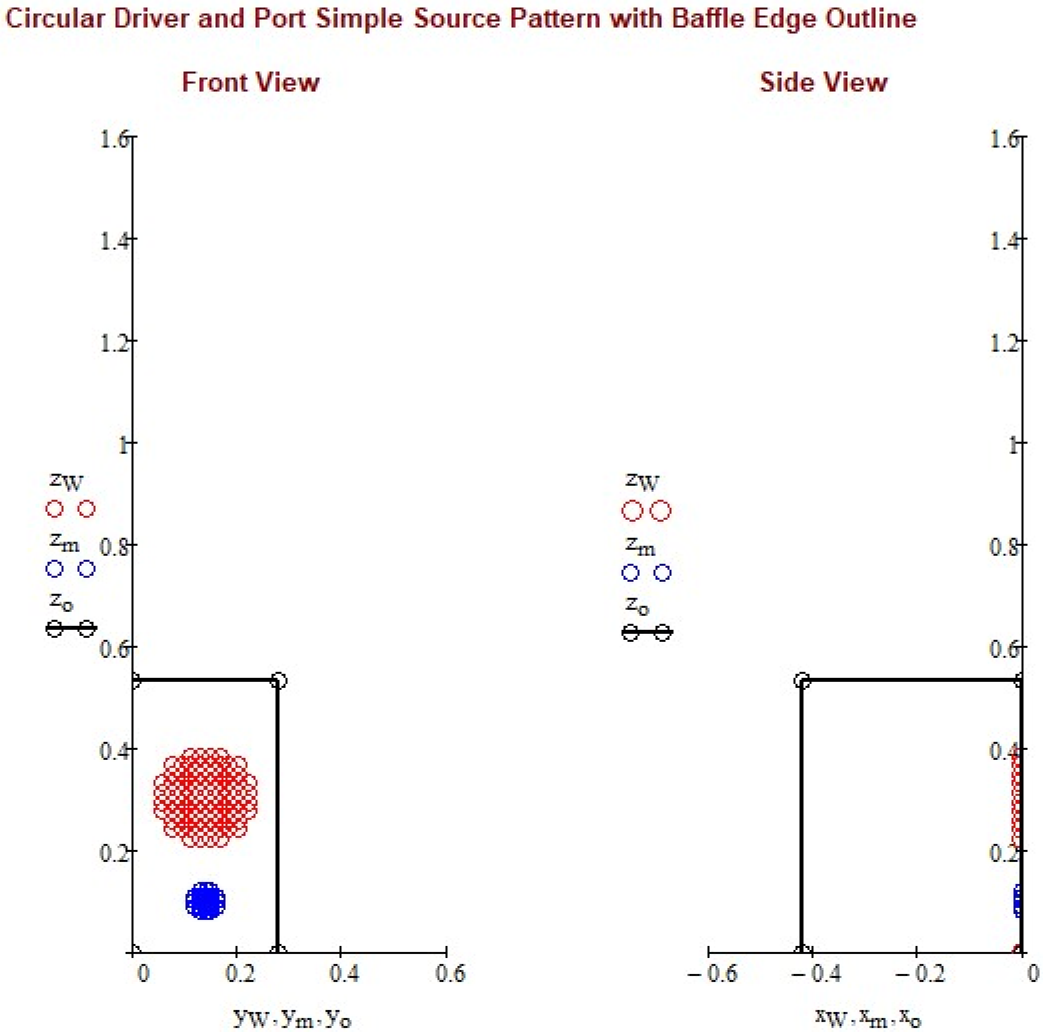
$$V_{TL} = 1/2 \text{ x } (0.00384 \text{ m}^2 + 0.0192 \text{ m}^2) \text{ x } 4.0543 \text{ m} = 0.0467 \text{ m}^3 \sim 47 \text{ liters (check)}$$

The bass reflex enclosure and the two transmission line enclosures were both modeled in my latest MathCad worksheets. The bass reflex enclosure was simulated as a stand mounted speaker and the transmission line enclosures as floor standing speakers. All three speakers have the same internal volume V_b, same tuning frequency f_b, and are initially modeled without fiber stuffing to show the internal standing wave resonances. Figures 3, 4, and 5 present the results for the ported and the two transmission line enclosures respectively.

The models shown in Figures 3, 4, and 5 include the effects of the baffle shape and size, the location of the woofer and open-end (port or terminus) on the baffle, a second order low pass crossover designed to also correct for baffle step and exclude the effects of room boundaries (anechoic response). The driver is located at a height of 27 inches above the floor, the mic is located at a height of 33 inches (anticipated tweeter position) above the floor on the driver's axis, and the distance from the front baffle to the mic is defined as 3 meters. For the idealized transmission line models, the cross-sectional area is assumed to be monotonically changing along the length without any sudden discontinuities created by folds or a constriction at the terminus. In both transmission line models the driver is offset along the length to eliminate the 3/4 standing wave resonance cleaning up the plots below 100 Hz. The simulation results are intended to be accurate representations of the actual driver, baffle, and the enclosure geometry in free space. These methods have been verified using measurements on previously designed and built speaker systems.

The SPL response plots all show the woofer output (dashed red curve), the port or terminus output (dashed blue curve) and the combined system output (solid red curve). The enclosure tuning frequency can be easily identified by the first deep null in the woofer's SPL response which as expected occurs at 28 Hz. The impact of internal standing waves can be seen as sharp peaks and narrow dips in the SPL plots at frequencies above 100 Hz. The response plots for the bass reflex and the tapered transmission line correlate well below 100 Hz with any differences driven mainly by the baffle size and the source locations. The expanding transmission line has a similar SPL response but there are some differences which will be discussed later. In general, the bass outputs are comparable in all three simulations. Looking at results from simplified modeling (not shown), typically used in most share-ware program that assume the woofer and open-end are coincident and the speaker is mounted in an infinite baffle (2 pi radiation), the calculated SPL curves become even closer below 100 Hz and the -3 dB point is located just above 30 Hz as predicted.

Figure 3 : Bass Reflex Enclosure Results



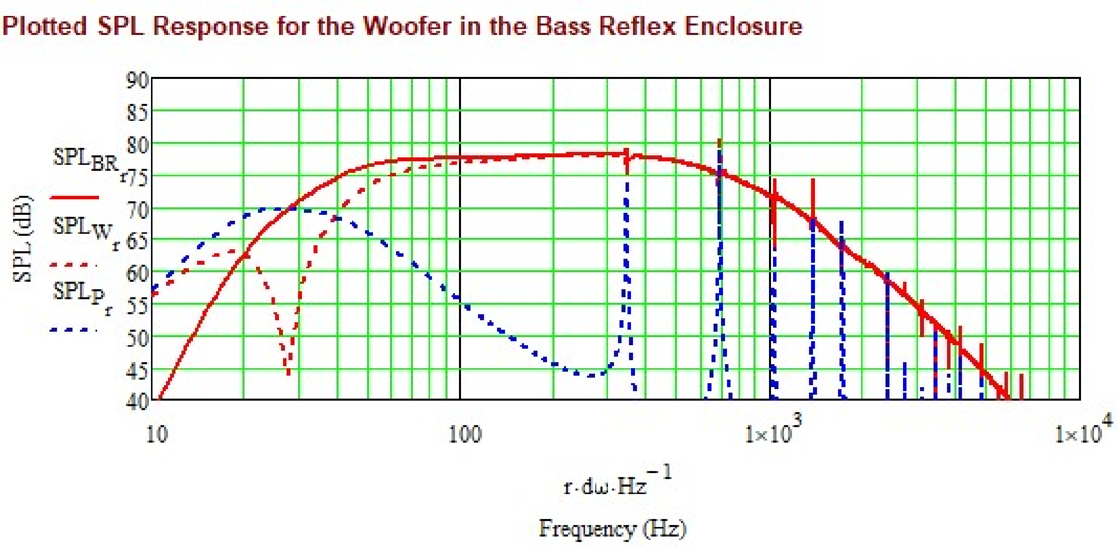
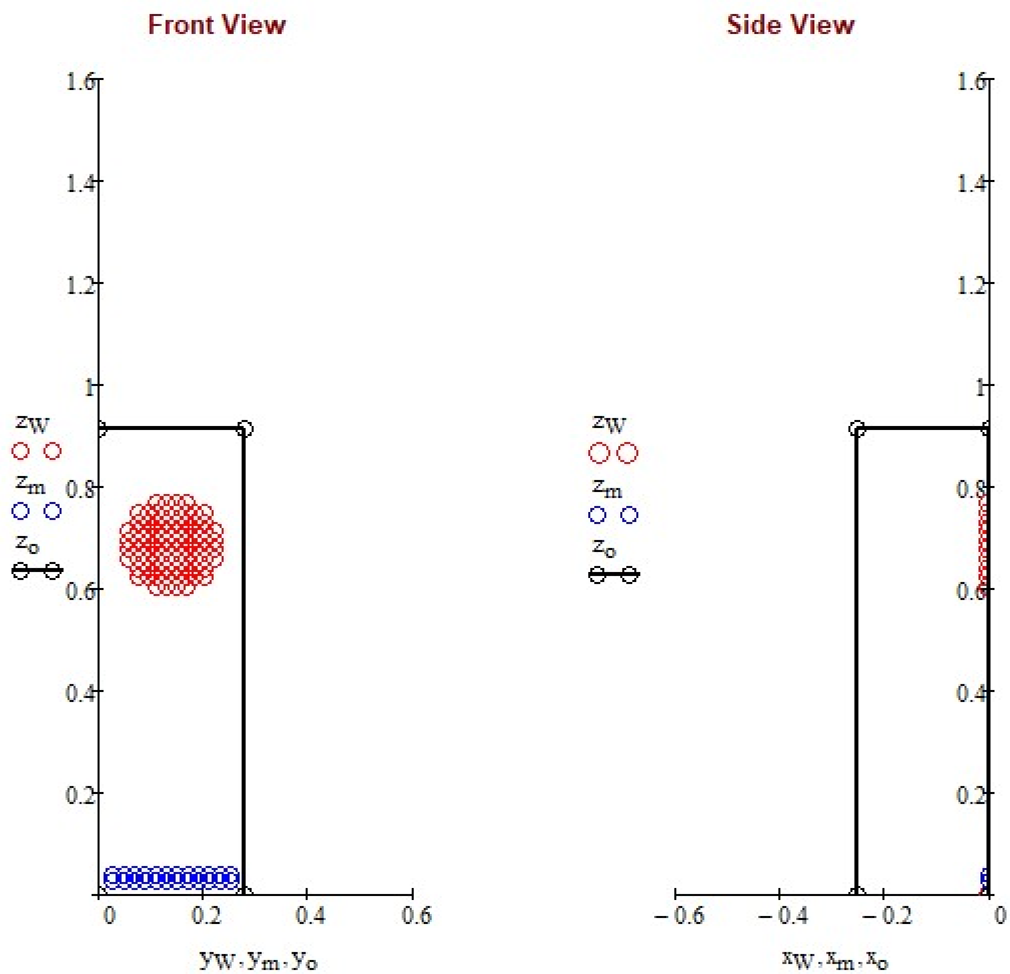


Figure 4 : Tapered Transmission Line Enclosure Results

Circular Driver and TL Terminus Simple Source Pattern with Baffle Edge Outline



Plotted SPL Response for the Woofer in the 5:1 Tapered Transmission Line Enclosure

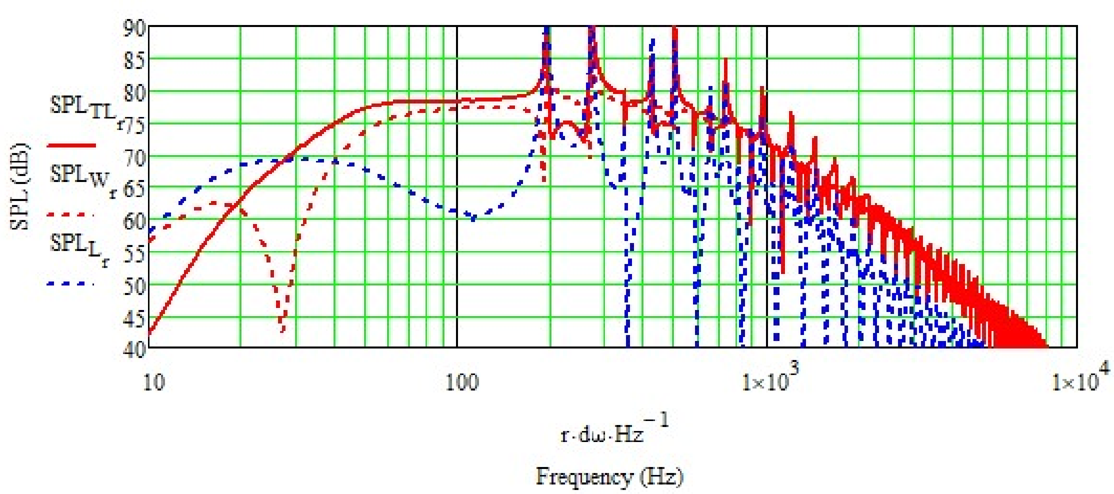
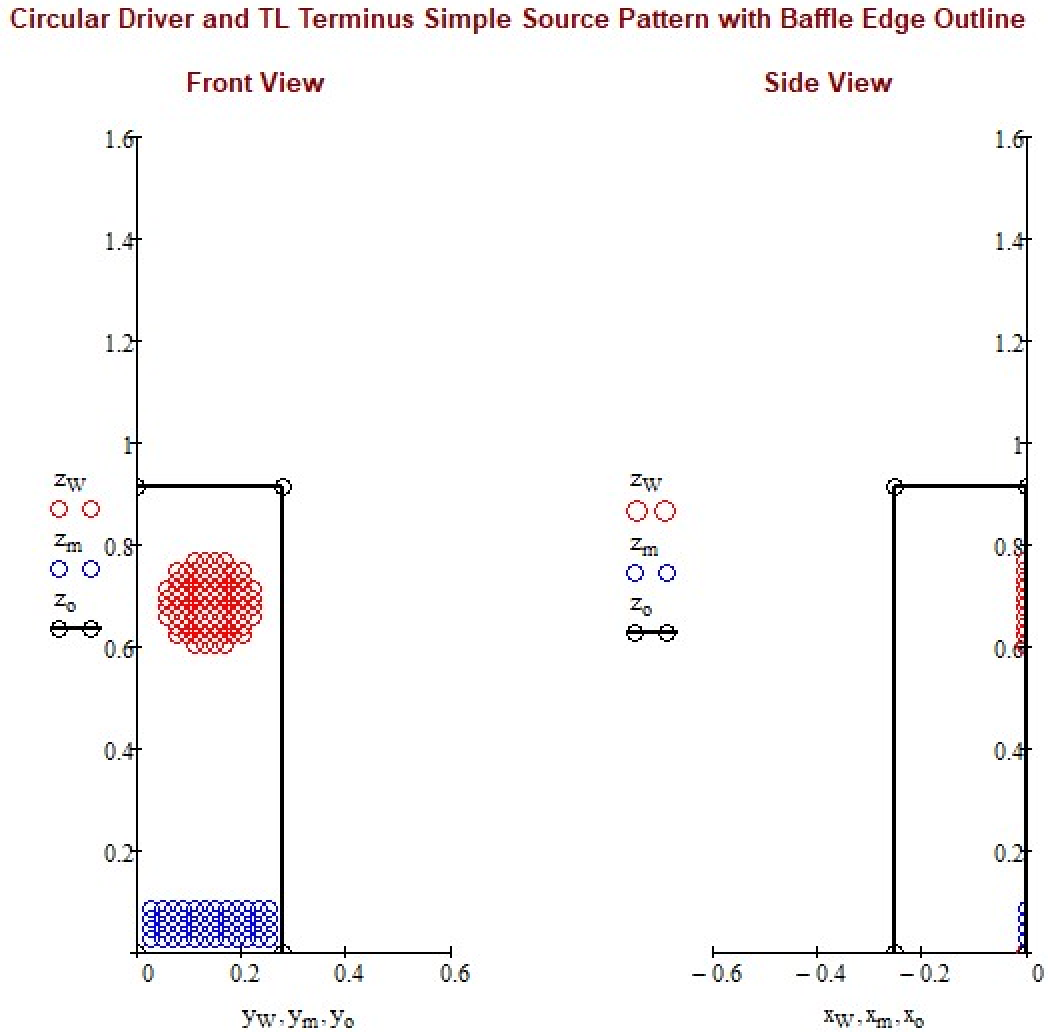
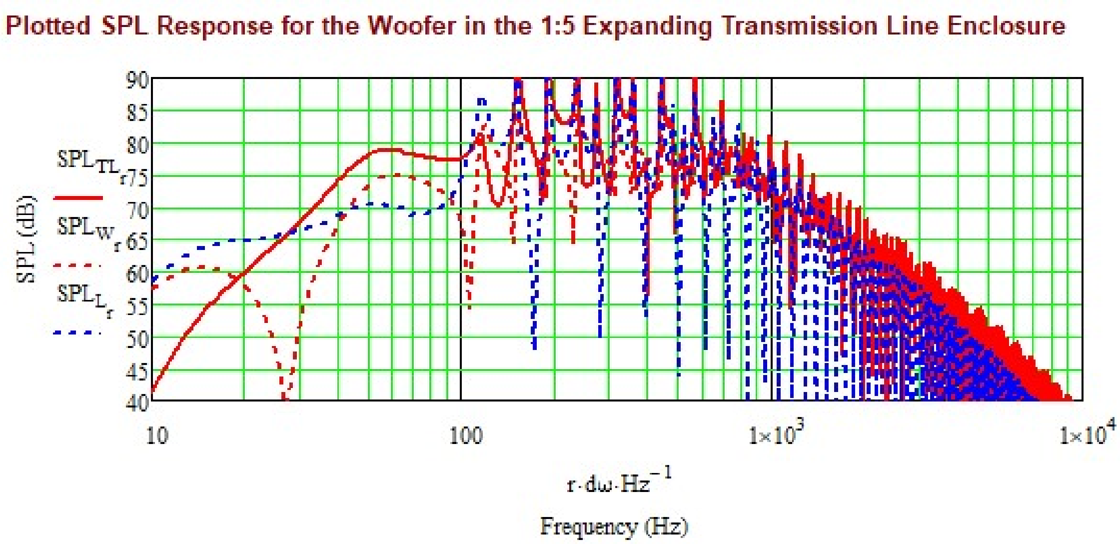


Figure 5 : Expanding Transmission Line Enclosure Results





Digging a little deeper into the SPL plots presented in Figures 3, 4, and 5; the simulation results were replotted between 10 and 1000 Hz. The SPL, electrical impedance, driver cone displacement, and port or terminus oscillating air velocity are shown from top to bottom respectively in Figures 6, 7, and 8. Again these results do not include any fiber stuffing so enclosure resonances are easily identified in the curves.

Remember the alignment selected for this sample problem specified H = 1, so f_b = f_s. Starting with the electrical impedance plots (second from the top in Figures 6, 7, and 8) and focusing on the frequency range 10 to 100 Hz. The dashed blue curve is the driver's impedance in an infinite baffle, the impedance peak at 28 Hz corresponds to the driver's resonant frequency and the enclosure's tuning frequency. When the driver and enclosure are combined into a speaker system, the electrical impedance becomes the solid red curve which now shows a pair of resonance peaks at approximately 15 Hz and 50 Hz (there are no longer any resonances at the tuning frequency of 28 Hz). Looking closely at the frequencies and magnitudes of the two peaks, the bass reflex exhibits the tallest (strongest, maximum Q) peaks followed by the tapered and then the expanding transmission line systems. The lower peaks in the tapered and expanding transmission lines also drop a little in frequency compared to the lower peak in the bass reflex design.

The low frequency range of an electrical impedance curve is a function of the driver's cone velocity which in turn generates the driver's SPL output. Three features of the speaker system impedance curve are important properties to identify and track. The two resonance peaks in the impedance curve are produced by maximums in the driver cone's velocity response (derivative of the cone displacement curve, third plot from the top in each figure). Between the two impedance peaks is a valley which approaches R_e indicating that the driver's cone velocity is significantly attenuated in this frequency range. If the two peaks and valley of an impedance measurement match the simulated impedance then the model has accurately captured the driver cone's motion as it passes through the system resonant frequencies.

The key take-away from the impedance curves is that a resonant driver is combined with equivalent resonant enclosures (volume and tuning) to produce very similar speaker system electrical impedances regardless of the enclosure geometry. Two new resonances result, one below and one above the original resonant frequency f_s of the woofer and the tuning frequency f_b of the enclosure. The bass reflex enclosure exhibits stronger resonances due to the lumped nature of the mass (port volume) and stiffness (enclosure volume) while the transmission lines produce an infinite number of resonances (standing waves) due to the continuous distributions of mass and stiffness along the enclosure lengths. The resulting pair of low frequency resonances for the transmission line are slightly weaker than the corresponding resonances for the bass reflex enclosure. This series of resonances produced by transmission line enclosures creates the differences in the low frequency impedance curves compared to the simpler bass reflex enclosure.

Moving up to the top plots, the SPL responses in Figures 6, 7, and 8, the observations made about the impedance curves are reflected in these results. The motions of the driver and the air at the exits of the port or terminus are similar for the different enclosures as seen in the dashed red and blue curves in the SPL plots. At the first system resonances, at approximately 15 Hz, the driver and the port or terminus outputs are out of phase combining destructively resulting in the solid curve system SPL response being below both dashed curves. At the second system resonances, at approximately 50 Hz, the driver and the port or terminus outputs are in phase combining constructively resulting in the solid curve system SPL response being above both dashed curves.

At the original tuning frequency of 28 Hz, the impedance curves indicated that the driver's cone motion has been significantly attenuated which can be seen in the woofer's SPL output (dashed red curves) as the deep null. The broad humps in the port or the terminus responses (dashed blue curves) at 28 Hz are produced by the first two system resonances combining and yielding a maximum air velocity in the port or at the terminus of the transmission lines. At this frequency, the outputs from the port and terminus reach a maximum producing almost all the bass output from the speaker system.

But as the two peaks in the electrical impedance plots spread in frequency and decrease in magnitude for the tapered and expanding transmission lines, a flattening and then a depression is produced in the terminus output compared to the nicely rounded bass reflex port's output (dashed blue curves). At the original tuning frequency, a resonance no longer exists but the linear combination of the first two system resonances at approximately 15 and 50 Hz results in attenuation of the driver's motion and a maximum port vibration or a quarter wavelength standing wave in the transmission line's air column. The flattening and slight depression in the transmission line terminus SPL output can be restored to the more rounded shape seen in the bass reflex design by increasing the internal volume of the transmission line, this also causes the impedance peaks to align better with the bass reflex impedance peaks, but that changes the assumed system alignment (more comments on this later).

Finally, the lower two plots in Figures 6, 7, and 8 present the driver's cone displacements (dashed curves for an infinite baffle and solid curves for the enclosure results) and the port or terminus oscillating air velocities as functions of frequency. As expected, the woofer's cone displacements show a deep null at the original tuning frequency of 28 Hz. The real interesting result is that the oscillating air velocity in the terminus of a transmission lines is significantly reduced compared to the bass reflex port since the terminus typically has a much larger cross-sectional area. This is probably the most significant difference between a transmission line and a bass reflex enclosure, the chuffing or compression sometimes heard at higher volume levels in a bass reflex design may be avoided by using a transmission line design.

Figure 6 : Bass Reflex Enclosure w/o Fiber Stuffing

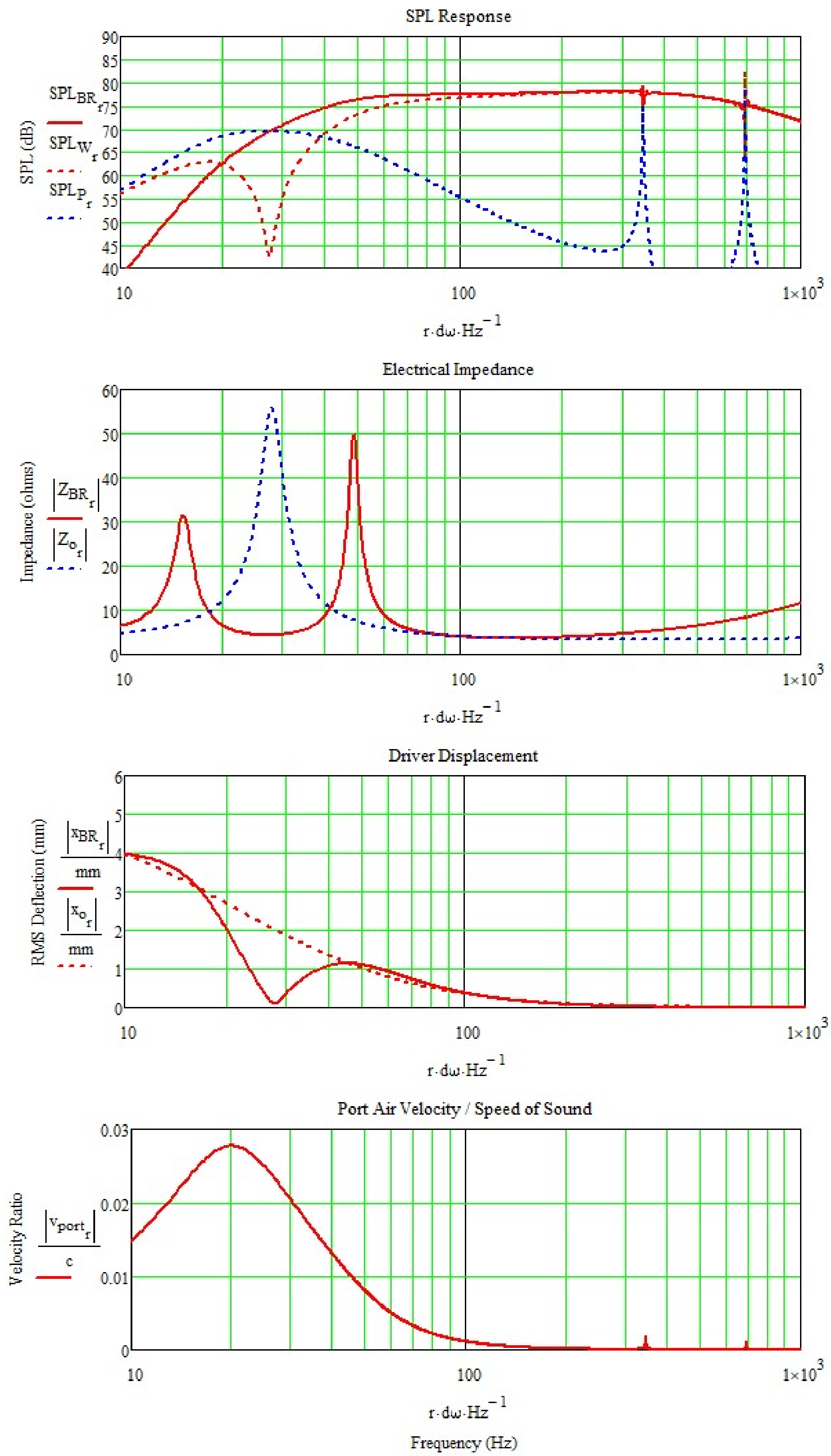


Figure 7 : Tapered 5:1 Transmission Line Enclosure w/o Fiber Stuffing

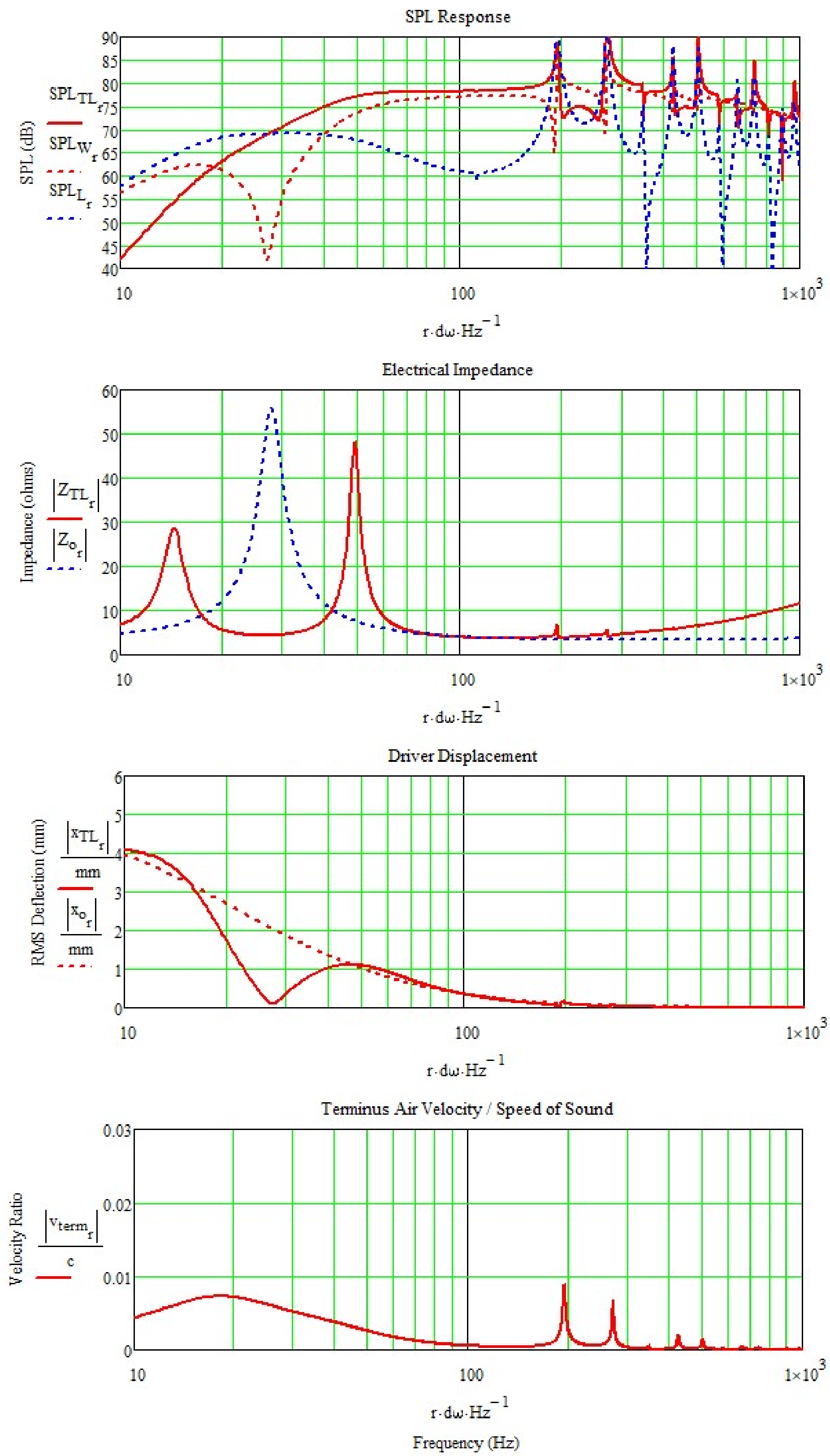
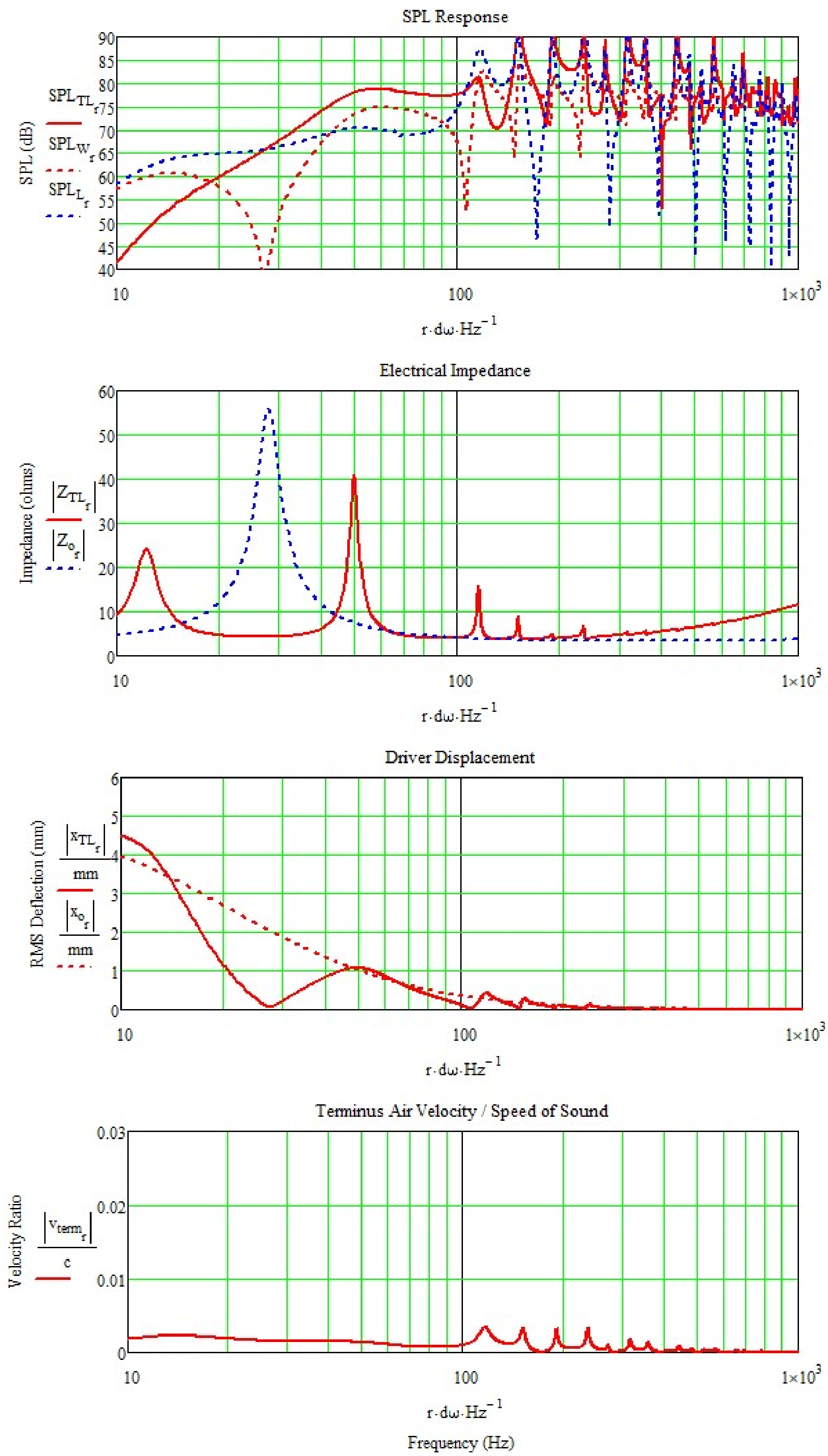


Figure 8 : Expanding 1:5 Transmission Line Enclosure w/o Fiber Stuffing



The primary methods for controlling the peaks and dips in a transmission line enclosure's SPL response are driver offset (already included in Figures 6, 7, and 8) and fiber stuffing or foam. Polyester fiber stuffing was added to the models in Figures 6, 7, and 8 and the results are plotting in Figures 9, 10, and 11. I do not have adequate data for foam at this time so I can't address the pros and cons relative to fiber stuffing. The impact and properties of different foam materials is of great interest and will be investigated in a future transmission line build.

The bass reflex results shown in Figure 9 include 0.25 In/ft^3 of fiber stuffing distributed evenly in the enclosure volume (the port is left empty). The density of fiber stuffing was selected to just damp the internal standing waves. Comparing the results in Figures 6 and 9 shows that the changes are minimal; the most obvious difference is a cleaning up of the higher frequency internal standing waves (above 300 Hz) seen in Figure 6.

The tapered and expanding transmission line results shown in Figures 10 and 11 respectively include 0.5 lb/ft^3 of stuffing in the first 3/4 of the line's length. Changing the amount and location of fiber stuffing in a transmission line is a tweak often used to fine tune a transmission line's SPL results. In Figures 10 and 11 the sharp peaks and nulls in the SPL results (top plot) of Figures 7 and 8 have been reduced to a ripple which looks reasonable for the tapered transmission line but is still significant for the expanding transmission line.

The interesting results in Figures 10 and 11 start with the electrical impedance plots (second from the top). The lower peak has been reduced to almost flat and the upper peak has been significantly attenuated and broadened. The first two system resonant frequencies and mode shapes are highly damped by the fiber stuffing. Damping these resonances in the transmission line enclosures leads to a rolling-off of the bass SPL response. Consequentially the transmission line does not reach as deep compared to the equivalent bass reflex enclosure in Figure 9 producing a less resonant (dryer) low frequency response. A benefit of the transmission line design is seen in the driver's cone displacement, third plot from the top, which is much better controlled compared to the bass reflex enclosure result. And finally, the terminus output shown in the very bottom plots is also cleaned up with the addition of the fiber stuffing.

As mentioned earlier, increasing the internal volume of the transmission line enclosure can push the unstuffed SPL response and electrical impedance results seen in Figures 7 and 8 closer to the bass reflex enclosure's results shown in Figure 6. But after adding fiber stuffing the benefits are much less apparent, the first two resonances in the impedance plot are still heavily damped in the larger transmission line enclosure. There is a slight increase in bass extension but in my opinion not enough to justify the required significant increase in the transmission line enclosure's size.

Figure 9 : Bass Reflex Enclosure w/ 0.25 lb/ft^3 of Fiber Stuffing

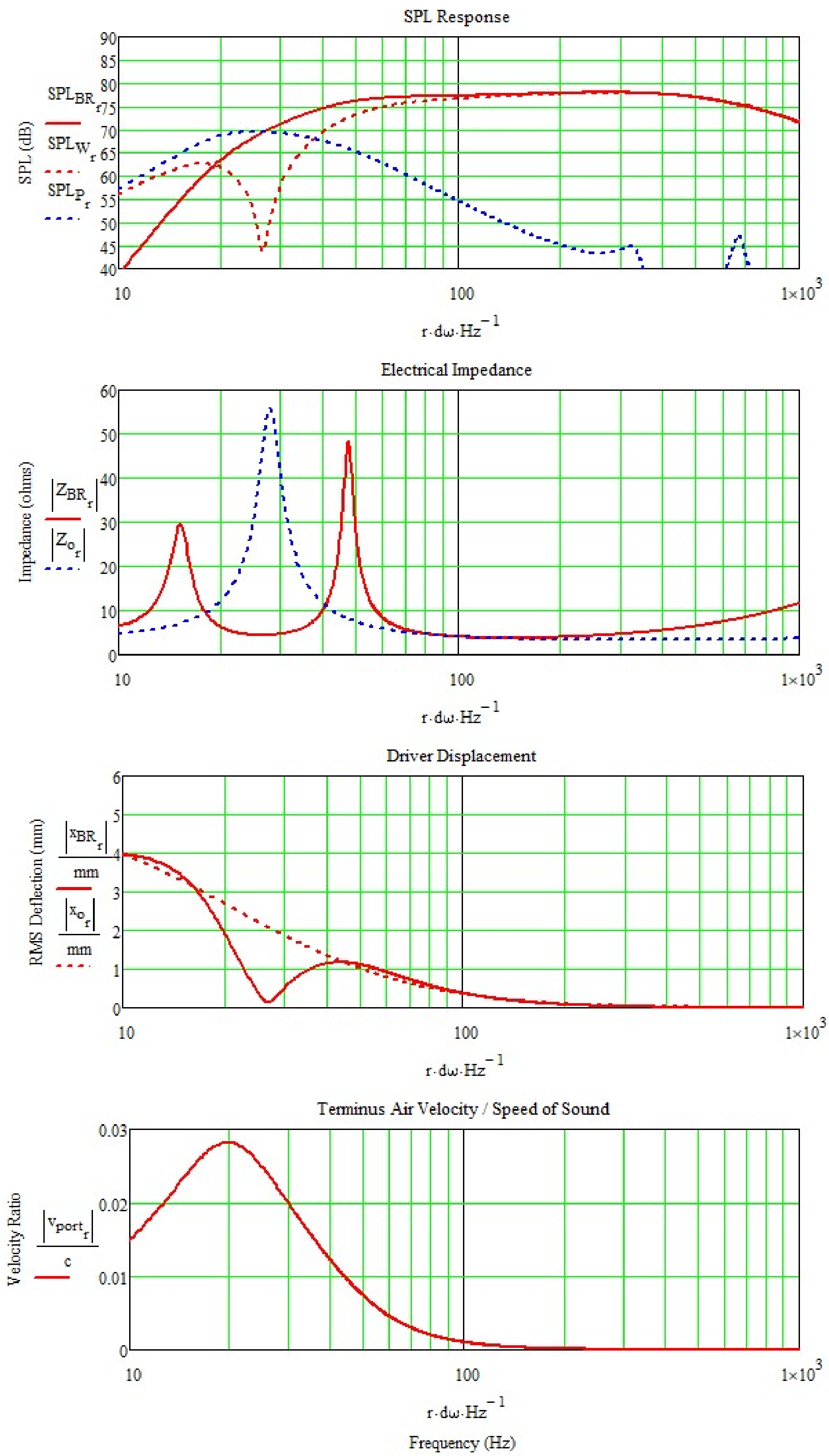


Figure 10 : Tapered 5:1 Transmission Line Enclosure w/ 0.5 lb/ft^3 of Fiber Stuffing

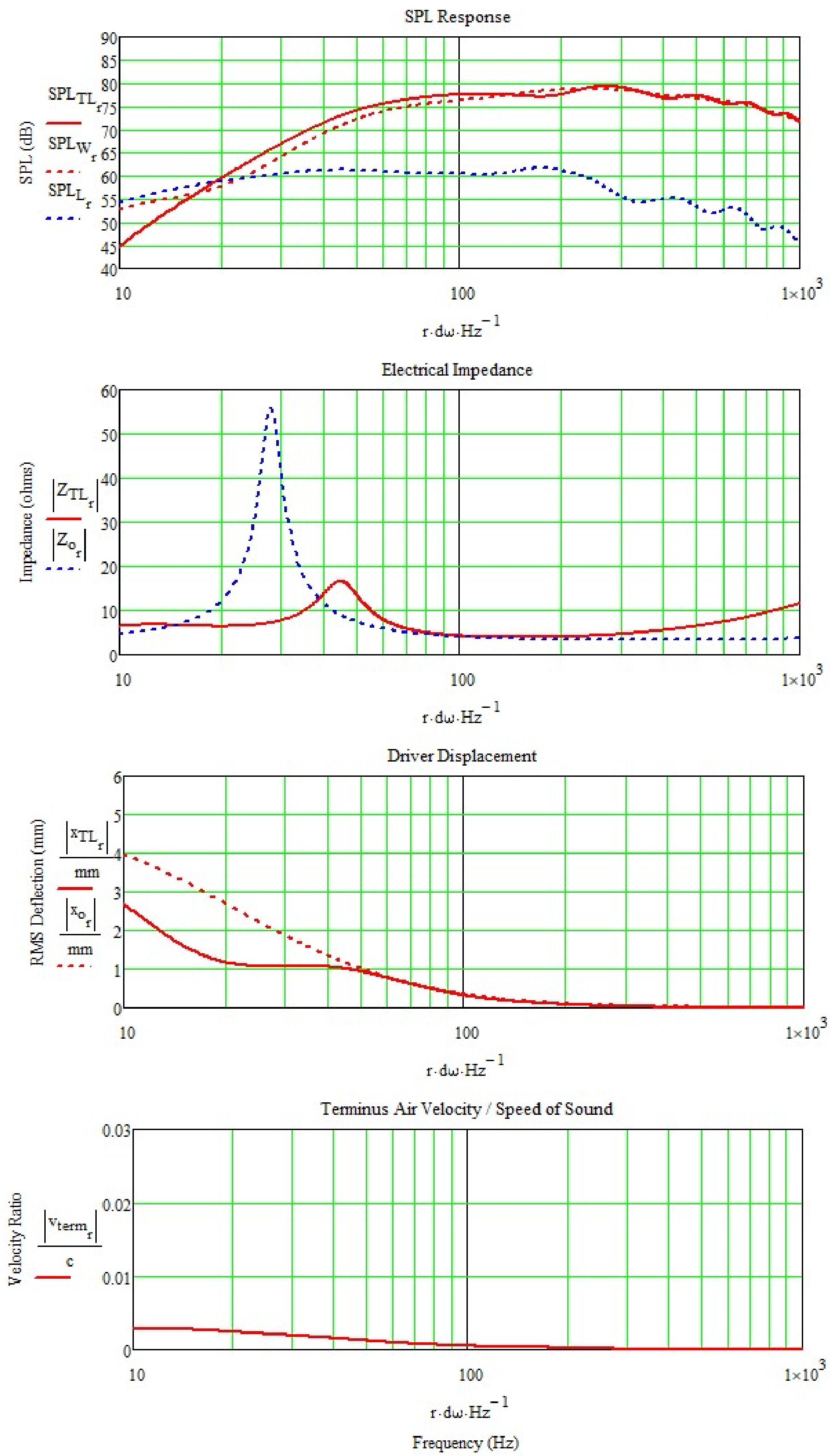
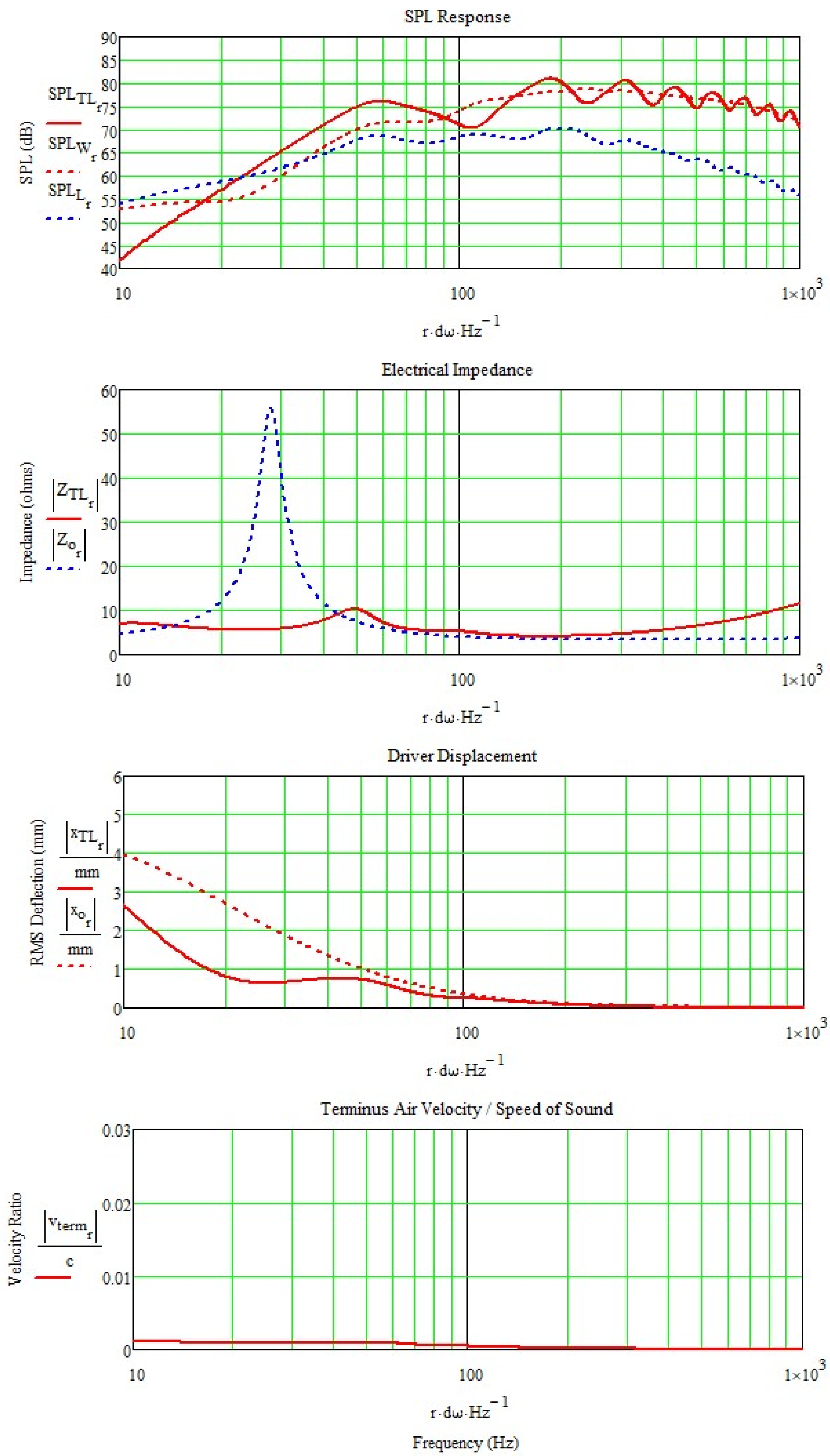


Figure 11 : Expanding 1:5 Transmission Line Enclosure w/ 0.5 lb/ft^3 of Fiber Stuffing



Figures 12 and 13 are a comparison set of plots spanning the range of classic transmission line geometries defined in Figure 1 and Table 1. The top plots are calculated for a 10 : 1 tapered transmission line, the middle plots are for a 1 : 1 straight transmission line, and the bottom plots are for a 1 : 10 expanding transmission line. Each model includes an offset driver to suppress the 3/4 wavelength resonance and has monotonically changing cross-sectional area along the length as depicted in Figure 1. Figure 12 shows the results for empty transmission lines and Figure 13 adds 0.75 lb/ft^3 of fiber stuffing to the first 3/4 of each transmission line's length. The observations made earlier while discussing Figures 7 and 8 and then Figures 10 and 11 are all still applicable to this last set of results. Visualize a gradual transition in the SPL response curve properties, as you move from the top to the bottom plots in Figures 12 and 13, to picture the responses of the intermediate geometries in Table 1.

Reviewing the plots in Figures 12 and 13, the advantages of tapered transmission line geometries is clear. The taper pushes the standing waves higher in frequency where the fiber damping is more effective producing a smoother SPL response. The top plot in Figure 13 is the best result for the different transmission line geometries in Table 1. Expanding transmission lines, sometimes referred to as TQWTs (Tapered Quarter Wave Tubes) or Voigt Pipes and often labeled as BLHs (Back Loaded Horns), drop the standing waves lower in frequency resulting in significant ripples in the SPL response even with dense fiber stuffing. To make an expanding transmission line workable requires design effort beyond the alignment table geometries such as including a coupling volume behind the driver, stub tubes or resonance trap volumes placed along the length, sudden transitions in cross-sectional area at the folds, or a significant mass loading (constriction) at the terminus end.

Figure 12 : Comparison of SPL Responses for 10 : 1, 1 : 1, and 1 : 10 Constant Volume Empty Transmission Lines

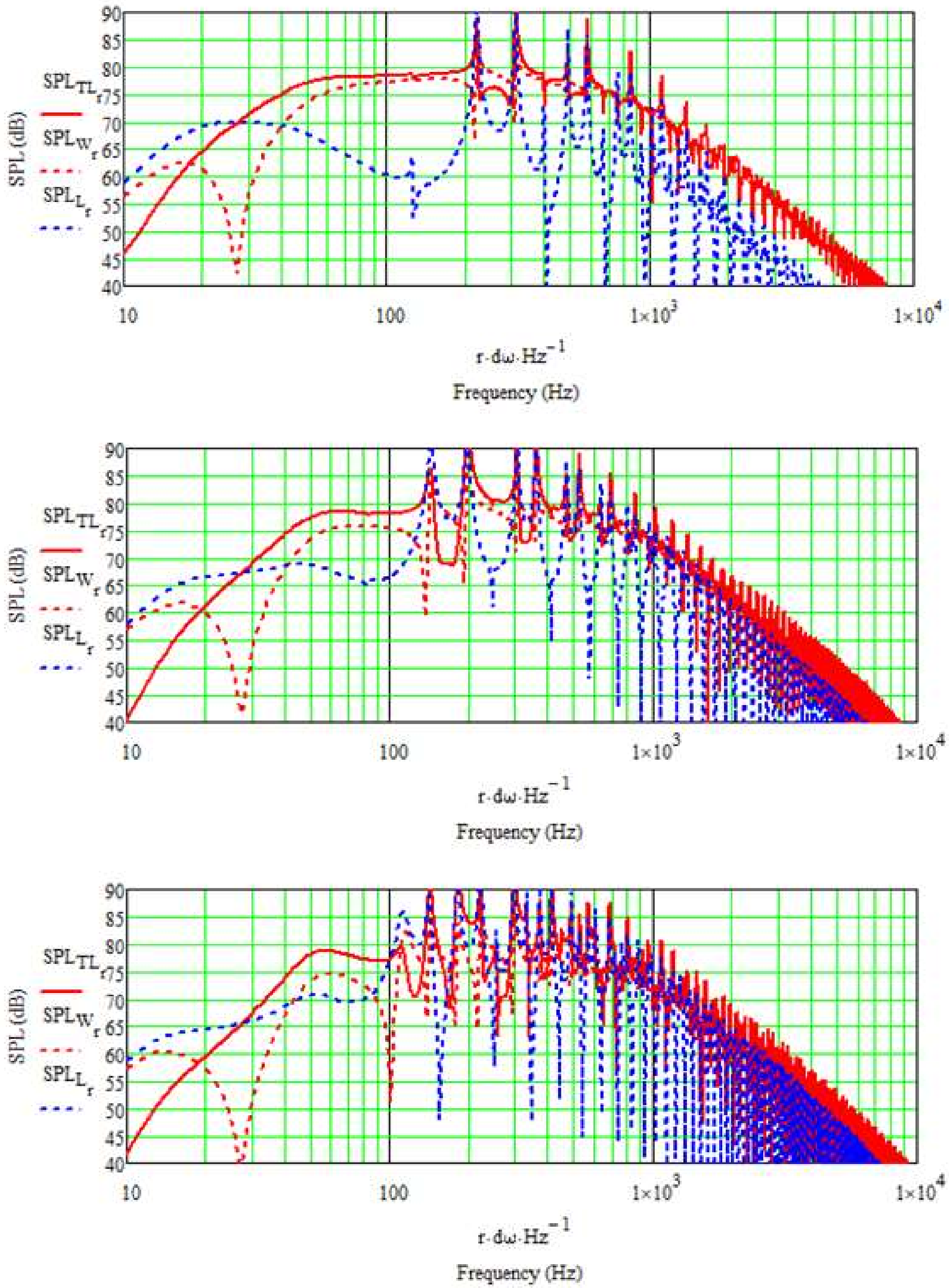
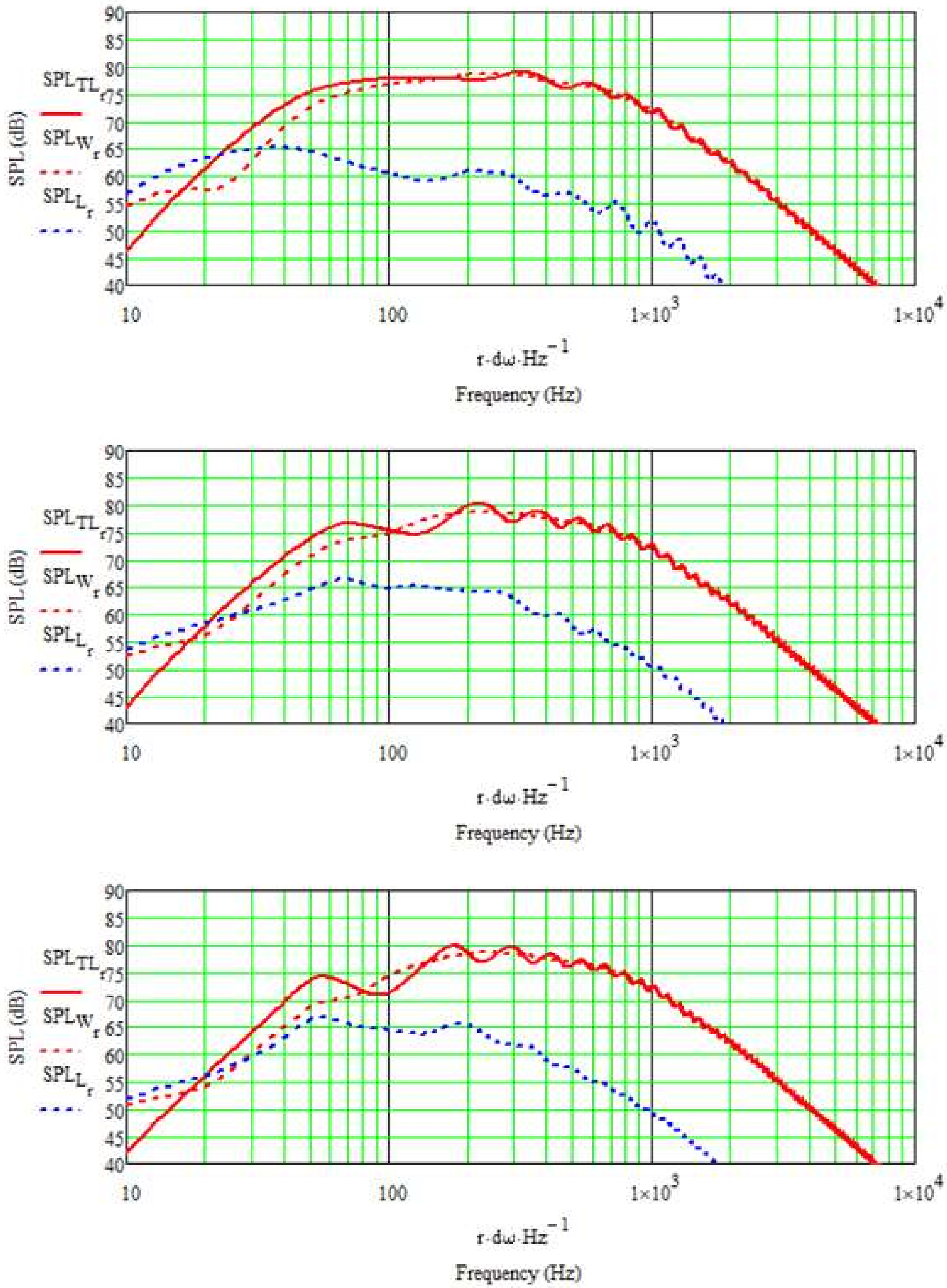


Figure 13 : Comparison of SPL Responses for 10 : 1, 1 : 1, and 1 : 10 Constant Volume Transmission Lines w/ 0.75 lb/ft^3 of Fiber Stuffing



Conclusions :

Equivalent bass reflex and transmission line enclosures have equal internal air volumes V_b and tuning frequencies f_b. These two types of enclosures have more acoustic properties in common than different. If a driver works well in a bass reflex enclosure, it should also work well in an equivalent transmission line enclosure. An apples-to-apples comparison between the performance of a bass reflex enclosure and an equivalent transmission line enclosure requires the same internal volume and tuning frequency, anything else is an apples-to-oranges comparison.

The ported enclosure alignment tables can be used to define an enclosure's internal volume V_b and tuning frequency f_b. With V_b and f_b, either a bass reflex or a transmission line enclosure (preferably tapered) can be sized and simulated yielding comparable low frequency performance before the addition of fiber stuffing. Undamped bass reflex and transmission line enclosure designs with common alignments are approximately the same size and can produce very similar low frequency SPL, electrical impedance, and cone displacement responses.

Adding fiber stuffing to a transmission line enclosure will roll-off the bass output compared to the equivalent bass reflex enclosure. But on the plus side, the stuffing will better control the driver's cone displacement while taming the higher quarter-wave harmonics reducing the ripple often associated with a transmission line's SPL response. Another advantage of the transmission line enclosure design is a much lower oscillating terminus air velocity compared to the equivalent bass reflex port oscillating air velocity.

Figure 14 shows a comparison of equivalent bass reflex and tapered transmission line designs. Claims that a transmission line enclosure produces significantly deeper bass compared to a bass reflex enclosure is probably misguided and not accurate for equivalent enclosure alignments as demonstrated in this figure. The claims are probably based on an apples-to-oranges comparison where the enclosures have different internal volumes.

While alignment tables have been the mainstay for designing ported enclosures, there is still a huge continuum of additional potential enclosure volumes and tuning frequencies that lie outside of these tables. Designing equivalent bass reflex and transmission line enclosures, using the same volume and tuning frequency, outside of the alignment tables, and then relying totally on simulations is also a good method for predicting an enclosure design's performance and optimizing the results. All the observations regarding the behavioral properties of the enclosures are still applicable to these non-table-based alignments.

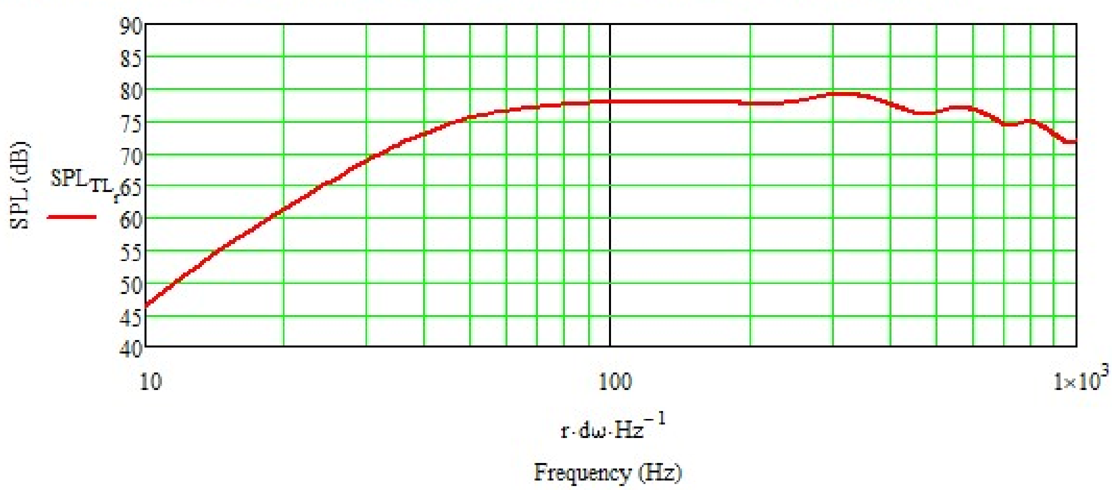
I hope this document is useful and enlightening. As always, questions and comments are welcome, they help me to move my own understanding of transmission lines forward.

Figure 14 : Performance of Equivalent Bass Reflex and Transmission Line Enclosures

SPL Response of the Bass Reflex Enclosure

SPL Response of a 10:1 Tapered Transmission Line Enclosure w/o Fiber Stuffing

SPL Response of a 10:1 Tapered Transmission Line Enclosure w/ Fiber Stuffing



References :

1) Loudspeakers in Vented Boxes Parts I and II by A. N. Thiele; Loudspeakers an Anthology, Volume 1 through 25 of the Journal of the Audio Engineering Society, pages 181-205.

2) Direct Radiator Loudspeaker System Analysis by R. H. Small; Loudspeakers an Anthology, Volume 1 through 25 of the Journal of the Audio Engineering Society, pages 271-284.

3) Closed-Box Loudspeaker Systems Parts I and II by R. H. Small; Loudspeakers an Anthology, Volume 1 through 25 of the Journal of the Audio Engineering Society, pages 285-303.

4) Vented-Box Loudspeaker Systems Parts I, II, III, and IV by R. H. Small; Loudspeakers an Anthology, Volume 1 through 25 of the Journal of the Audio Engineering Society, pages 316-343.

5) The Loudspeaker Design Cookbook 3rd Edition, ©1987, by Vance Dickason.