Full Range Offset Bipolar MLTL Speaker Design
with Creative Sound Solutions (CSS) EL70 Drivers

Three years ago I designed a bipolar mass loaded transmission line (MLTL) speaker that used the Creative Sound Solutions (CSS) full range FR125S (front) and extended range WR125S (rear) drivers. The drivers in each box were connected in parallel which created a 4 ohms load but no crossover or compensation networks were employed within these speakers. Given the 4.5" diameter size of these drivers, various listeners were amazed how such small drivers could produce generate the bass level that they did. While the upper frequency response did suffer a bit because of the directivity of the full range drivers, the overall performance and low cost yielded a very satisfying speaker. While I did notice that there was a dip of 4 dB in the on-axis response in the 400 to 500 Hz range because of the wraparound of energy from the rear driver to the front driver when the front to rear spacing between the drivers was a half wavelength, I could not hear an appreciable degradation to the overall performance of these speakers.

Now ordinary free standing monopolar speakers radiate into 4 pi space (completely around the box) at lower frequencies but transition to 2 pi space (only forward radiation from the front baffle) as frequency increases. Hence, this transition in radiation characteristic is commonly called 'baffle step loss' as the listener hears 6 dB sound difference between the 2 pi radiation frequencies vs. the 4 pi radiation portion of the band. If the speaker is intended to be used away from the boundaries of the listening room, the designer typically will compensate for the sound difference between the 4 pi and 2 pi regions.

In contrast bipolar speaker enclosures have drivers on their front and rear baffles and the drivers are wired in phase so they produce appropriately near omni-directional sound within the room as they radiate into 4 pi space across their entire frequency band. Thus no baffle step compensation is needed with bipolar speakers to equalize their sound across frequency. Hence, bipolar speakers address BSC with an acoustical answer and no additional equalization is usually needed to balance their frequency response. Finally, because of their rearward radiation, bipolar speakers do require room placement at least three to four feet away from the rear wall boundary so that the rear firing wave does not produce too much reflected sound which raises the reverberant energy within the room.

Recently, I started to consider how to design a bipolar speaker that improved on my earlier efforts. Fortunately, my friend Duke LeJeune of AudioKinesis had developed an outstanding audiophile quality bipolar speaker. Duke's Dream Maker two-way speakers use premium 10 inch pro audio woofers combined with compression drivers situated in a low-coloration constant directivity waveguide. Duke generously documents his journey to design his speakers in a four-part posting on his Audio Circle forum entitled "The Case for the Controlled-pattern Offset Bipole". You can read his story at:

http://www.audiocircle.com/index.php?topic=56877.0

After reading Duke's four-part posting, my takeaway focused on the benefits from the offset bipolar arrangement. First, the offset configuration (difference in vertical spacing between the front and rear drivers) helps mitigate the wraparound cancellation effect between of the front and rear drivers. Furthermore, a wider front baffle increases the front to back driver path length which lowers the frequency region where the wraparound cancellation occurs. Second, if the rear driver is located low on the back side, then the offset driver placement provides boundary enhancement which can smooth the in-room bass response. Furthermore, an offset bipole can be implemented with various bass tunings such as sealed boxes, vented boxes, or transmission line enclosures.

Duke's efforts prompted me in new directions for an improved full range driver bipolar speaker configuration. To explore the offset bipolar configuration I wanted to use full range drivers and preferably a MLTL as this alignment can extract a pleasing amount of bass from small drivers. What I envisioned was a box that housed two back-to-back MLTLs within each enclosure. The front MLTL would have the driver near ear listening level with the port near the bottom of the box while the rear MLTL would be mirror imaged with the driver low on the rear baffle and the port near the top of the box. For simplicity the internal back wall of each MLTL would be shared within the enclosure. Although Duke's work to control the directivity of his speakers via a waveguide mounted tweeter can not be implicitly applied be to a full range driver, his notes on speaker toe-in will improve in-room sound with any speakers.

For my offset bipolar design I was fortunate to have access to a prototype set of Creative Sound Solutions (www.creativesound.ca) EL70 four inches diameter paper cone drivers. These drivers are nominal 4 ohms impedance so for my design I wanted to connect the two drivers in series to achieve 8 ohms impedance for the bipolar speakers. The CSS EL70s were designed, developed, and manufactured for CSS by Mark Fenlon of Mark Audio. The projected price for these drivers is less than $50 each so they should be an excellent value. Finally, recent parameter measurements averaged over the first production lot of EL70 drivers (see Table I) are similar to the prototype units.

To design the enclosure for the offset bipolar speaker I used Martin J. King's exceptional worksheets. Martin's worksheets will not explicitly model a bipolar speaker but they will model the individual MLTL within each box. The series connected combination of the two MLTLs in each enclosure will not increase the overall sound pressure level (although the radiating surface is doubled with two drivers the impedance is doubled so the net SPL remains unchanged). Iterations using the MLTL worksheet yielded a design that is a straight pipe with the following internal dimensions: 39 inches height, driver located 14 inches below the top, port located 37 inches from the top, a cross-sectional area of 27 square inches, and stuffing density of 0.54 pounds per cubic feet. The port diameter is 2.0625 inches with a length of 3.5 inches. For my prototypes I chose to use an internal cross-section for each individual MLTL of 3 inches depth and 9 inches width. With 0.75 inch thick material, the external dimensions of the overall bipolar enclosure (two sandwiched MLTLs) is 40.5 inches high with 8.75 inches depth, and a width of 10.5 inches.

The predicted performance of the individual MLTL is shown in Figure 1. The SPL response has a F3 point of 40 Hz with a port null at 45 Hz. The plots in Figure 1 are plotted for an input power level of one watt. Note that the deflection is well within maximum deflection (Xmax) limits and the impedance of the individual MLTL is typical for MLTL speakers (remember that when connected in series the overall impedance of the bipolar speaker will be nominally 8 ohms).

Figure 2 shows the enclosures that were constructed for this design. Walnut panels were used for the sides and top of the box with MDF employed for the front and rear baffles, the shared internal panel and bottom of the box. The terminal plate (I used the Parts Express #260-309) was located on the bottom of the box. Hardwood rails were used to stabilize the enclosure and raise it for access to the terminal plate. The port tubes are Parts Express #260-322 cut to the correct length.

For each pipe I stuffed the volume from just below the front driver to the top of the box with Acousta Stuf™. For the rear driver the volume from just above the driver to the bottom of the box was stuffed. No additional stuffing was used within the boxes. An alternative to Acousta Stuf is to use a 9 x 16 inches sheet of 1 ½ inch thick convoluted acoustical foam behind each driver. Again the front and rear drivers are connected in series within the enclosure and no equalization circuitry is in the signal path to each driver.

Early listening tests reveal a relatively well balanced response with a spacious sound within my listening room. Again you have to be careful when positioning bipolar speakers as too much reverberant sound can overpowers the basic presentation of the source material. Over the bass portion of the band the sound pressure level is surprising for the size of the speakers but that result was expected. While you don't expect 4 inch drivers to produce blow-you-over subwoofer kind of bass, you do hear an integrated, balanced musical statement. They have excellent sound for most types of music and I was particularly impressed with their performance with classical orchestral arrangements. They exhibit the typical magic of single driver speakers that we have come to expect.

Initially, my speakers imparted a very slight nasal sound to vocals but they seem to produce more pleasing sound as break-in progressed. In the future we will better understand whether any frequency contouring or other correction will be needed.

Overall I will say that for less than $200 worth of drivers you can yield a relatively small floor-standing pair of speakers that will satisfy listeners who have small to medium sized listening areas. An acoustical answer to an acoustical problem can be very pleasing.

Table I. CSS EL70 Parameters

Parameters	Value
Fs	64 Hz
Re	3.6 ohms
Sd	50.27 sq. cm
Vas	6.1 liters
Cms	1.7 m M/S
Mms	3.6 g
BL	2.8 TM
Qms	3.23
Qes	0.664
Qts	0.55
No	0.23 %
Le	0.251 mH
Spl	86 dB 1w/1m
Xmax	4.5 mm
Pe	20 watts

Figure 1. CSS EL70 MLTL Design (Production Parameters) Predicted Responses

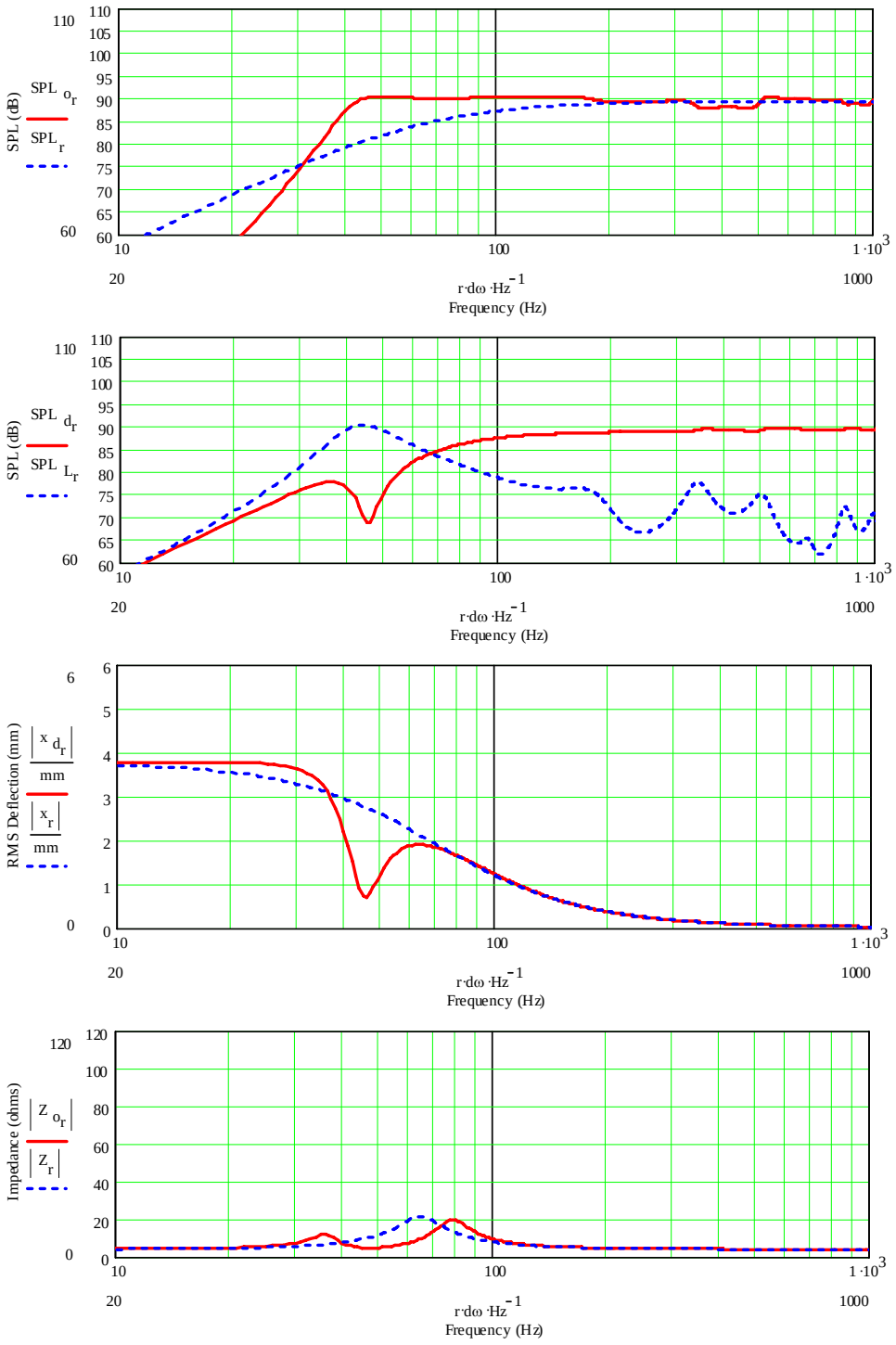

Figure 2. CSS EL70 Bipolar Speakers with Offset Drivers