Building a Minimally Baffled Dipole Loudspeaker: Supplementary Material

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Measurement Methodology Driver Alignment

Before making a set of acoustic measurements there is a preliminary step in which the midrange and tweeter are physically aligned on the wireframe scaffold. Once these drivers are physically moved to the appropriate position their acoustic output will be as identical as possible as seen from the front and rear. This is a goal for the dipole loudspeaker and is why drivers with identical forward and rear response within their passband are utilized. In a dipole speaker only a physical adjustment of the relative driver positions can achieve the desired effect. In contrast, only the forward radiation from the drivers of a boxed loudspeaker reaches the listener and misalignment of driver acoustic centers can be removed using a digital delay or compensated for using an all-pass or other filter. But this does not work for a dipole. When you delay the tweeter signal, for example, as seen from the front it is akin to “moving the driver backwards”. But when observed from the rear, the driver would apparently be moved forward by delay. This means that, if the physical acoustic center is too far forward, using delay will have the apparent effect of moving it towards the rear as seen from the front, but from the rear the effect is to move it even farther forward, which would only make the offset problem worse. A better way to think about the delay is that an impulse sent to the speaker would be moved farther back towards the amplifier in the speaker wire and has the same effect on both the front and rear outputs. In a dipole system the acoustic centers of two drivers must be physically manipulated - this is not “aligning” the acoustic centers per se, only making the acoustic center offset between any two drivers the same as seen from both front and rear.

In general, if a planar tweeter and a moving coil “cone” midrange are used the appropriate tweeter position will lie near the plane of the midrange mounting flange. For those who wish to check the alignment via measurement, a technique for measuring the relative acoustic offset of two drivers has been described previously by Jeff Bagby and David L. Ralf [[[1]](#endnote-2),[[2]](#endnote-3)]. The reader is referred to these documents for more information. In general, a series of measurements is performed in front of the loudspeaker and repeated at the rear. The interference technique is then employed to determine the offsets using software. When both the front and rear acoustic center offsets have been determined, the builder then physically moves one driver (typically the midrange) forward or backwards so that the offset as seen from the front and the offset as seen from rear become equal. Note that this will not necessarily result in either offset being zero. As long as the front and rear offsets are identical the crossover will have an identical effect at both the front and rear, which is the desired result. Keep in mind that, at 2kHz, an error in the alignment of one centimeter will result in approximately 17 degrees of phase error.

Acoustic Measurement Procedure

Once the tweeter and midrange physical alignment has been performed, the next step is to obtain a set of measurements that are sufficiently “clean” to permit accurate crossover design. In this context clean implies free of significant peaks and dips due to reflection from room boundaries. Often the technique that is employed is to window the time domain response to exclude the reflections and to move the loudspeaker as far away from boundaries as possible during the measurements. The loudspeaker design is a floorstander and the tweeter and midrange will be about 1 m above the floor level. Attempting to directly measure 1m above the ground, at a typical listening distance of 2-3 m and to a sufficiently high resolution and low frequency, would result in contamination of the measurement by ground reflection in the midrange band. For the midrange and tweeter, we can instead elevate these drivers by another meter or more, and measure at a close distance. This will largely eliminate the ground reflection problems for these drivers. On the other hand, our design relies on the ground reflection to augment the woofer panel output. As a result, the measurement on the woofer panel will be carried out on the listening axis at a distance and will include the floor reflection. These two different measurement conditions will subsequently be adjusted to a consistent basis before designing the crossover. I will now explain a somewhat DIY friendly measurement procedure that is based on this principle.

Find an open area outdoors with a flat and relatively smooth surface. I use a long patio area adjacent to my home but the end of a long driveway or the walkway in front of the home can work as well. There must be free space in the “on axis” direction both in front of and behind the loudspeaker of at least 30 feet or more. To the “side” there can be objects or structures as long as they are at least 15 feet away. The dipole nature of the loudspeaker makes it possible to measure closer to structures when they are only to the side of the loudspeaker, since the relative SPL is less there compared to the front, so the energy in the reflection will be weak. The goal is to get a frequency resolution that is around 50Hz for the midrange and 20-50Hz for the woofer panel, in order to have sufficient resolution within these bands.

With the loudspeaker positioned as described above, following measurements are conducted:

* Midrange and tweeter: quasi-anechoic measurements are performed on the midrange and tweeter one at a time. The microphone is placed at a known and relatively close distance (e.g. 0.3 to 0.5 m) for these drivers, with the drivers elevated above the ground by 2m or more to minimize the ground plane reflection. Make sure to record the exact distance between the microphone and the plane of the driver’s acoustic center – this information will be needed later. Locate the microphone directly in front of the center of each driver’s diaphragm when making the measurement. Since the acoustic centers have been aligned previously, the microphone stand only needs to be adjusted straight up or down in between measurements.
* Woofer panel: Place the woofer panel on the ground. The microphone is placed on-axis in the far field, at 3m to 4m away from the loudspeaker and elevated to the listening height (e.g. at the intended tweeter height for the final loudspeaker). Record the distance along the ground between the plane of the woofer panel and the plane of the microphone. Choose measurement conditions that will result in a frequency resolution of 50Hz or better and minimal wind and environmental noise contamination. This will ensure good quality low frequency information. Note that, for each angle on and off axis, a new measurement set must be collected.

Measurement Post-Processing

Next, additional processing is done to the tweeter and midrange response measurements. The goal is to mimic the propagation of their acoustic outputs from where they were measured, out to where the woofer panel measurements were made. The SPL and phase values are adjusted to account for SPL loss and phase rotation that takes place as sound travels through the air. The SPL adjustment is computed using the equation:

where R2 is the distance at which the woofer panel measurement was made, and R1 is the distance at which the midrange and tweeter measurements were made. For example, if the midrange and tweeter are measured at 0.5m and the woofer panel at 3m, ΔSPL is **-**15.56 dB. This value is added to the SPL level of both the midrange and tweeter to reflect the lower SPL that would have been recorded if those measurement were made at a distance of (in this example) 3m instead of 0.5m. Next, we account for the phase rotation that would have occurred during the time sound was traveling the “extra” 2.5m between the measurements made at 0.5m and 3m. The phase rotation Δθ is equal to -2πdf/c radians or -360df/c degrees, where c is the speed of sound (343m/sec at 20C at sea level), d the distance in meters, and f the frequency of interest in Hertz. The amount of additional phase rotation is frequency dependent. Because a separate calculation is required for each frequency in the measurement file this is best done using software such as a spreadsheet or using the functionality of the crossover design program itself, and then saving the resulting data to a new file.

Once these adjustments have been made to the measurement data, all measurements have been brought to the same location in space and the crossover design process can begin using crossover modeling software.

**References**

1. J. Bagby, “How To Use Passive Crossover Designer To Find The Relative Acoustic Offset”, http://audio.claub.net/tutorials/Finding\_Relative\_Acoustic\_Offset.pdf [↑](#endnote-ref-2)
2. D.L. Ralph, “Finding Relative Acoustic Offsets Empirically”, https://www.speakerdesign.net/sbarticle.html [↑](#endnote-ref-3)