An Eighth-Wave Transmission Line Loudspeaker

Neville Roberts

Transmission line loudspeakers can produce a tight and well extended bass response in a domestic environment and are reasonably tolerant of acoustically unhelpful room dimensions. The quarter-wave transmission lines that grace our sitting room (my wife would disagree with my choice of verb here, favouring "dominate"!) extend well down into the sub-audible range, without the sound becoming muddy or boomy. The deep organ notes around 16Hz in my recording of the second movement of Saint Saens Organ Symphony No. 3 are clearly reproduced on my system and are felt more than heard. So when I wanted to construct some low-cost bookshelf speakers for use in my study, I decided that an eighth-wave design would best meet my needs.

Enclosure Design

Before describing how to make a pair of these loudspeakers, a word or two on the choice of enclosure is in order.

All enclosure designs seek to tame the natural resonance of the bass driver, which causes a peak in the bass response at this resonant frequency and the various harmonics. Another requirement is to extend the bass below resonance and do all this without too great an efficiency loss. Finally, they have to acoustically couple the drive units to the room. This is by no means an easy task as a room suitable for living in is not best suited for listening, unless one is prepared to stick egg boxes in strategic places along the walls!

The simplest enclosure to build is the sealed box, which is also incorrectly called the infinite baffle design. The sealed box will certainly dampen the cone excursions around resonance. Unfortunately, it does nothing to extend the response below resonance and it is not the most efficient design.

Horn loudspeakers come in various guises, the most popular of these being the reflex enclosures. They are more efficient than the sealed box and will certainly control the resonance but, in my humble opinion, they are not much good at coupling with the room.

This brings us to the transmission line design. If one considers a quarter-wave line, the length of the line is chosen to be a quarter of the wavelength of the natural resonant frequency of the bass driver, with a few adjustments that will be discussed later. The line is simply a resonance tube, like any wind instrument. However, unlike an organ pipe, it needs to work over a range of frequencies. At the bass driver resonant frequency, the port will reflect the wave back to the driver, and this wave will be in anti-phase to the rear of the cone that produced it. This will control the resonance, as with a reflex enclosure.

These anti-phase resonances will also occur at every quarter wavelength and this will have the effect of controlling the various harmonics, unlike a reflex enclosure. It is also why an eighth-wave line will work at constraining the peaks in the bass response.

At frequencies below resonance, the anti-phase emanating from the rear of the cone (relative to the front of the cone) emerge from the exit port in-phase and therefore reinforce the response and extent the range of the loudspeaker. Another benefit is that the inevitable eigentones and other room resonances can be picked up by the port and fed back into the rear of the woofer cone, which can help to cancel them out. With correct positioning, the loudspeakers can adjust to suit your listening environment!

However, it is not all good news. Odd-order harmonics will reach the end of the line out of phase and would tend to reinforce unwanted resonances of the bass driver. This problem can be addressed by tapering the cross-section of the line, which spreads out and hence reduces the effect of these anti-resonances. The necessary folding of the line also contributes to this effect. Additionally, the introduction of some long-haired wool onto the port will also reduce these undesirable effects. This must not be too excessive though, as bass performance would suffer.

So is an eighth-wave line as good as a quarter-wave? Well, frankly no. Although it is still pretty good at taming the resonances, it is less effective in the other areas. However, a quarter-wave line would just be too big for a bookshelf design and these inefficiencies can be minimised with careful design, such as not over-tapering the line, etc.

A Practical Design

The first step is to choose the drive units. For a bookshelf speaker, a two-unit system is most suitable with one drive unit for the high frequencies (the tweeter) and the other for the midrange and low frequencies (the woofer). I was fortunate to have a pair of Kef T27 dome tweeters available. Alas, these are no longer made, but there are some good equivalents available. I recommend the use of the Seas H831 or H457 units.

A good match to the T27 for the woofer is the Kef B110, but once again these are no longer available. I therefore opted for a Seas P17-RCY/P, which is a 6.5” woofer and, like the B110, has a free-air resonance of around 35Hz. This particular flavour of the P17-RCY has a bullet-shaped phase plug in the centre that reduces resonances that would otherwise occur in the volume between the dust cap and the pole piece. The recommended frequency range of this unit is 40Hz - 4KHz. Kef recommend the T27 is used with a crossover frequency of 3.5KHz, which will suit the Seas P17-RCY nicely. This frequency is also suitable for the other Seas tweeters mentioned above.

As I touched upon earlier, there are some other factors that have to be taken into consideration when calculating the length of the line. Firstly, the introduction of long-haired wool as a dampening material also has the effect of reducing the effective velocity of sound due to the isothermal effect, causing a heat exchange between the air and the wool. This effectively reduces the speed of sound by a factor of about 0.85.

The other issue to consider is end correction. This is caused by the vortex effect at the exit port. This is where the air emerging from the port takes a while to realise that it is no longer in a line and is now in the room! This means that the line as seen by the drive unit is about 12cm longer than it actually is. This figure needs to be deducted from the overall calculation to work out the length of the line.

The length of our line is calculated as follows. Using:

$$\lambda = \frac{v}{f}$$

where:

λ = wavelength in metres
v = velocity of sound in long-haired wool = 330 × 0.85m/s
f = the resonant frequency of the woofer = 35Hz

$$\lambda = \frac{330 \times 0.85}{35} = 8\text{m}$$

For an eighth-wave line, the length is 1m minus the end correction of 12cm, or 88cm. The line is actually folded into a labyrinth to enable it to fit into the cabinet, so this length is used as the distance going along the centre of the cross-section of the line.

Building the Enclosure

The above calculations were used to design the enclosure shown in the diagram. The cabinet is quite a straightforward design and the dimensions will enable the appropriate pieces of wood to be cut. Remember to allow for the thickness of wood when cutting the panels. I used ½" chipboard, but MDF is equally suitable.

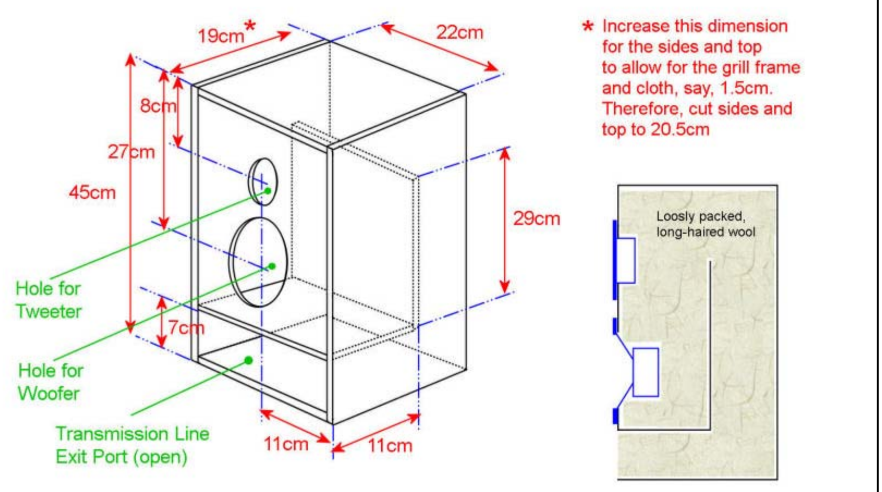

Figure 1. The Cabinet Design

If, as I did, you want to fit a grill into the front of the enclosure, you will need to increase the length of the top and sides as shown by the asterisk in the diagram. I used ½" square to make the frame, so the sides and top were cut to 20.5cm to make the rebate.

Batons are used to support the front and back panels in place, and also to support the internal baffles that form the labyrinth. The drive units are simply screwed to the front panel - no rebating is required, which would have exceeded my very limited woodworking abilities! The holes can be made marking out the required circles (85.5cm diameter for the tweeter, 145.5cm diameter for the woofer), drilling a circle of small holes around the inside of the circles, chiselling out between the holes and finishing off with a file. Cut a suitable hole to accommodate the speaker terminal block in the back panel.

I chose to veneer the sides and front with teak veneer as this not only matched the other furniture in my study, but also served to cover up the screws that were used to hold the batons supporting the labyrinth. A nice touch was to fit some lengths of black plastic angle around the inside edge of the recess to hold the speaker grill frame securely in position. Paint the back and front baffle with some matt black paint. This is especially important for the front panel as this prevents it from showing through the speaker grill cloth.

The crossover is a simple high pass and low pass filter, with additional resistors to compensate for the different sensitivities of the drive units. The crossover frequency has been chosen to be around 3.5KHz, which will suit any of the recommended drive units. It is constructed on a small piece of strip board. Glue the inductors onto the board in the correct position with some epoxy resin adhesive to hold them in place.

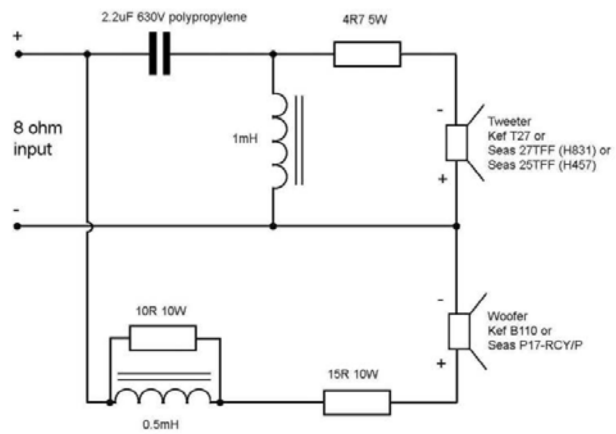

Figure 2. The Crossover Circuit Diagram

You will notice that the polarity of the tweeter is reversed with respect to the woofer. Reactive components in the crossover inevitably introduce different phase shifts at different frequencies and this is part of the reason for wiring them in this way. You may wish to experiment with the polarity, but I found this configuration sounded the best.

Figure 3. Rear View of Baffle

I recommend getting some additional resistors with values each side of the 15ohm and 4.7ohm for the woofer and tweeter respectively. The Kef T27 has a sensitivity of 80dB SPL for 1W at 1m on axis, while the SEAS H831 is more sensitive at 96dB. The sensitivity of the Seas P17-RCY/P woofer is 91dB. The easiest way to make any adjustments is to listen to a source of pink noise and move your ear between the two drive units. Neither should dominate the sound and you are listening for a smooth transition between the low and high frequencies. If you don't have a noise generator, an FM tuner tuned off-station with the muting disabled is a good source of pink noise.

Figure 4. Speaker Connection Terminal Block

Build the cabinets, but leave the front baffle and rear panel until last. Fit the drive units and crossover and wire everything up. Before screwing the panels into the cabinet, fill the line with long-haired wool. Tease it out, but keep it dense enough so that it will stay in place when the loudspeaker is finished.

Make the speaker grill by constructing a frame to fit inside the front rebate and wrap some speaker cloth around it and staple in place. Using a hair dryer, shrink the cloth to make it taut across the frame. If the frame turns out to be a loose fit in the cabinet, use some self-adhesive black Velcro on the top and bottom to hold it in place.

Siting the Loudspeakers

It is important to site the loudspeakers with the exit port at least 20cm from the floor. If they are not being placed on a bookshelf, they should be placed on stands to afford the maximum radiation of sound from the port and the correct loading of the speakers.

The total cost of the parts will be about £350, plus the chipboard for the cabinets, which is not bad for a pair of transmission lines using top quality drive units and components. Don't skimp on the components for the crossover as they have a huge effect on the sound. For example, do not be tempted to use a bipolar electrolytic for the 2.2uF capacitor. A good polypropylene such as the Wilmslow Supersound 630V will set you back about £2.70.

As far as sound quality is concerned, the high frequencies are clean and smooth, as you would expect from a good dome tweeter. The midrange is clear and open with vocals having a tremendous presence in the room. The bass, while lacking the drive and depth of the quarter-wave monsters in our sitting room, is extremely well-controlled and gives an effortless quality to the overall sound. It is this tightness and overall smooth response that sets these apart from other small loudspeakers that I have heard.

Figure 5. Front View with Grill Removed

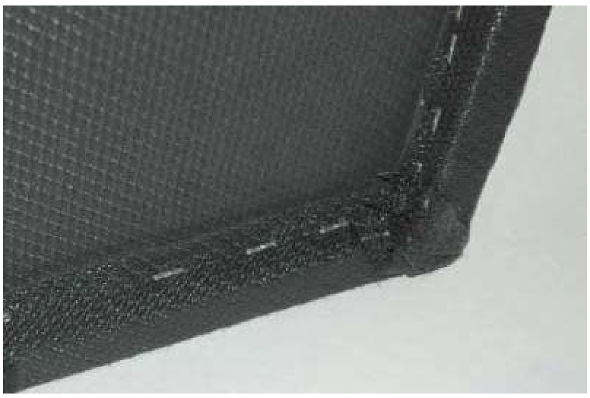

Figure 6. Fastening the Speaker Cloth to the Frame

Although I do not have the facilities available to measure the parameters of the loudspeakers, subjective assessment leads me to consider that these are reasonably sensitive, especially compared to their big brothers in the next room, which have a quoted sensitivity of only 84dB. They will accommodate amplifiers up to 50W per channel, but given their apparent sensitivity, they will be an ideal partner to the WAD KiT300 9W single ended 300B triode, having the clarity and control to do justice to an amplifier of that quality.

Figure 7. The Finished Loudspeaker

I thoroughly recommend that you introduce yourself to the delights of transmission line loudspeakers. An eighth-wave design means that you don't need a huge sitting room to accommodate them, and they even accommodate the idiosyncrasies of your environment. What more could you want?

--ooOoo--