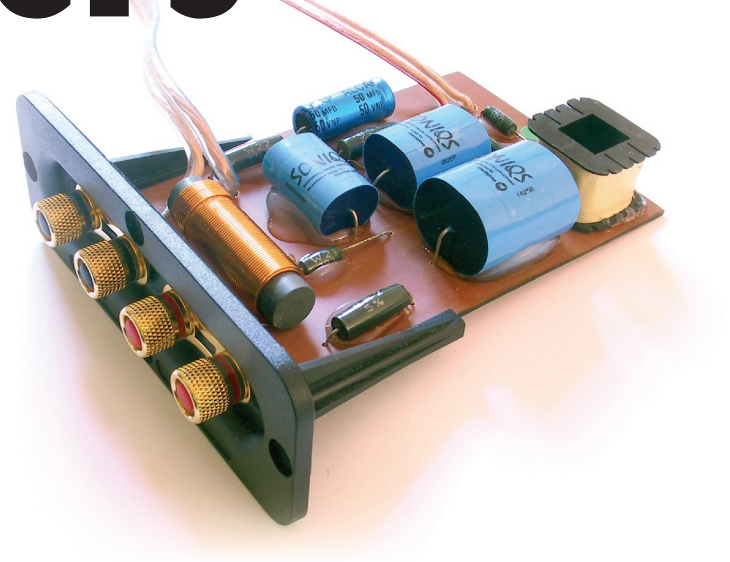
Designing Speakers

Part 7 Crossover Design continued



Plugging in calculated 'theoretical' crossover values into a speaker design is a recipe for disaster. Peter Comeau shows you why.

GETTING STARTED

In the previous article we showed that the simplest crossover is the first order – a coil in series with the bass unit and a capacitor in series with the treble unit. Although this is practically unusable with the majority of drive units that doesn't mean that it isn't a good place to start. We can build the crossover up piece by piece using this method and add further elements as we need them.

So the first item is to select an inductor for the series element with the bass unit. Now, if you have followed this series carefully, you will have seen that bass units have, almost without exception, a rising midrange response when put into a cabinet. So we need to use the coil not just to provide a crossover slope but also to 'flatten' the midrange output. If we don't do this then the speaker will sound bass light – a common characteristic of speakers where the designer has used calculation to decide the coil value.

To see how this works we'll look at a drive unit with a smooth response and put it in a cabinet. The SEAS H1217 is an 18cm driver offering a smooth midrange output, which is ideal for a simple crossover. Placed in a large baffle it measures like this: (see fig 1)

Now compare that to this graph where the driver has been put in a narrow, floorstanding loudspeaker with a baffle width only slightly wider than the driver. This is typical of the modern 'fashion' in loudspeakers, in fact some might say that 20cm is too wide to be commercially successful! (see fig 2) Now our baffle 'step' occurs where the wavelength starts to diffract around the baffle edges. This starts to happen where the minimum baffle size is a half wavelength and is calculated by: Fstep = 344/(width (m) x 2) Fig 3 shows the effect of putting a driver in a 45cm diameter spherical baffle. In a rectangular cabinet the baffle step is softened by the width to height ratio

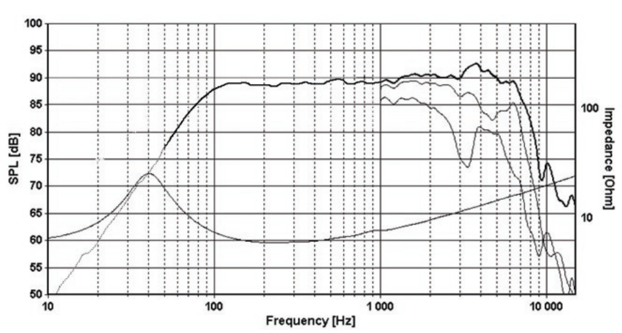


Fig 1 - SEAS H1217 drive unit in a very large baffle

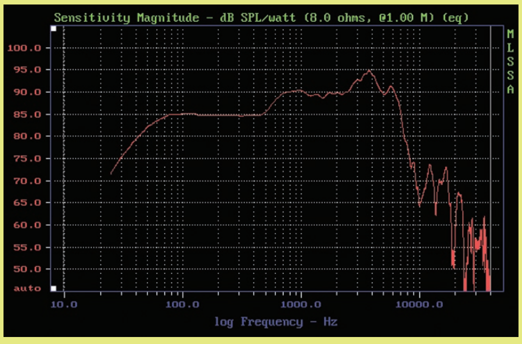


Fig 2 - SEAS H1217 drive unit in a 20cm wide baffle

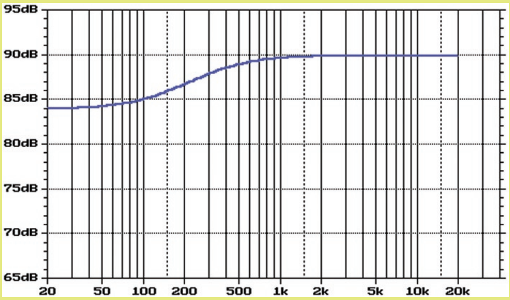


Fig 3 - SEAS H1217 drive unit in a 45cm spherical baffle

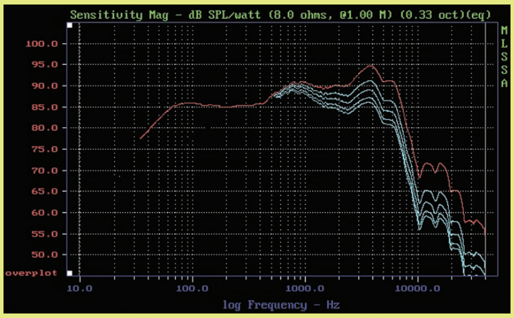


Fig 5 - Effect of series 0.4, 0.6, 0.8 and 1mH coils

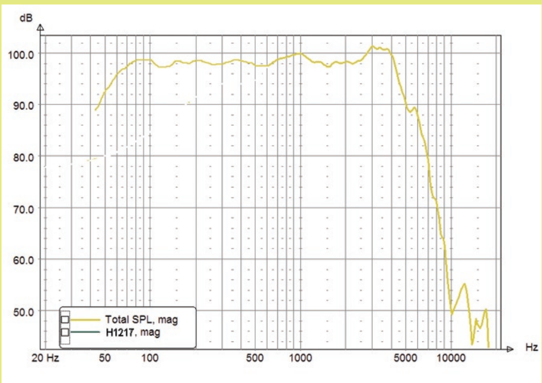


Fig 6 - SEAS H1217 drive unit with simple second order crossover

of the baffle, but is most noticeable at the minimum baffle dimension.

For our 20cm wide baffle this equation becomes: 344/0.4 = 860Hz. Above this frequency the output will be as flat as the drive unit can make it, while below this frequency the output begins to fall reaching a -3dB point given by the equation: F3 = 115/Bw where Bw = Baffle Width in m In our narrow, tower enclosure, then, the -3dB point occurs at 575Hz. This corresponds roughly to the -3dB point on the graph, not exactly because the baffle is bigger vertically than its width so the fall in output due to diffraction is reduced slightly. You can also see that the output continues to fall until it levels off at -6dB.

BAFFLE STEP COMPENSATION

Now what does this mean in practice? You would expect to have to put a complicated network in the crossover to give a -6dB step to equalise the output to make the overall response flat. But the more astute amongst you will already have noted that the impedance of the drive unit continues to rise through the midrange. As the impedance of the coil and the impedance of the drive unit are in series, we can choose a fairly large coil value to 'flatten' the baffle step without causing an early roll off.

So, let us put this into practice. The standard first order crossover calculation for an 8 Ohm drive unit and crossover frequency of, say, 3kHz would require a series coil of 0.42mH. Let's just see what this does to our response graph: (see fig 4) Well, yes, it does drop the upper mid and, thanks to the natural roll-off of the drive unit, give us a crossover of sorts, albeit at a high 4.5kHz. But it has no effect below 1kHz and certainly doesn't equalise the baffle step.

So just how big a coil do we need? I have traced several coil values so that you can see the effect: (see fig 5)

At 0.6mH or 0.8mH the baffle step is starting to be compensated better. But you can see how a first order crossover is still fairly disastrous in terms of achieving a flat frequency response. Don't worry about the apparent upper midrange dip and peak at the moment –we can sort that out fairly easily.

Of course the whole process could be made a lot easier by widening the baffle. This would lower the F3 of the baffle step (the -3dB point) and so reduce the 'peakiness' of the response around 800Hz as the coil would do a better job of smoothing the midrange. Bear this in mind when designing your cabinet!

For the meantime let's continue with this design exercise. What I would now do is start listening to coil values to see which gives the right sort of balance between bass and midrange. Why listen at this stage? Well the measurements don't take into account the room gain.

If you have been following this series you will have seen that room gain provides us with extra bass for free. As a result of reflections from local boundaries (floor, walls and corners) the bass output is commonly elevated by 3dB or more. Indeed if we were at liberty to place our 18cm bass unit at the base of the cabinet, close to the floor, we would see that the baffle step was reduced by close proximity to the floor boundary conditions, probably to around 3dB. Unfortunately, in this design, we want to use the driver as a bass-midrange, so it is about 0.5m above floor level.

Even here there is still some room gain at higher bass frequencies and we normally expect the baffle step to reduce by a dB or so. That's why it is important to listen. If we were to flatten the midrange response entirely with a massive 3mH coil then we would almost certainly find that the bass to midrange balance sounded too bass heavy when the speakers were played in a typical room.

So, back to the plot, we chose a series coil somewhere around 0.6 – 0.8mH and here I've listened and decided on 0.82mH. But it was fairly obvious when listening that there was a dip in the upper midrange and a peak towards the treble. You might not be too aware of this without crossing over to a treble unit, but you would certainly notice it as soon as you did!

It is also obvious, looking at our measurement graph, that there is a peak before the drive unit rolls off naturally at 4kHz. We need to control this, and flatten the response above 1kHz. This is fairly easy to do with a second order crossover.

Now this is where I'm going to take a short cut. I use a piece of software called LspCAD into which I can put the measured response and driver impedance. LspCAD then allows me to construct a 'virtual' crossover so that I can see the effects of adding components. I don't expect you to splash out on LspCAD for your home designs at present, but you can, of course, do exactly what I am doing by actually constructing a physical crossover and measuring the results.

Over in LspCAD I have inserted my series 0.82mH coil and have put

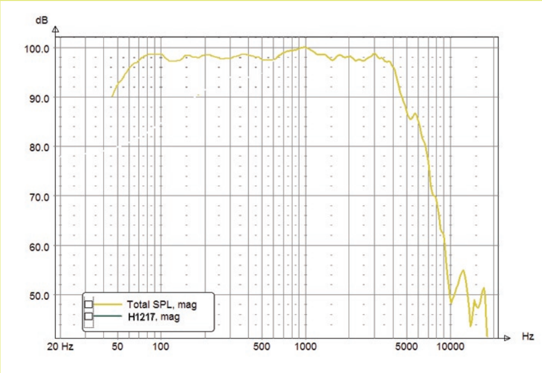


Fig 8 - SEAS H1217 drive unit with optimised second order crossover

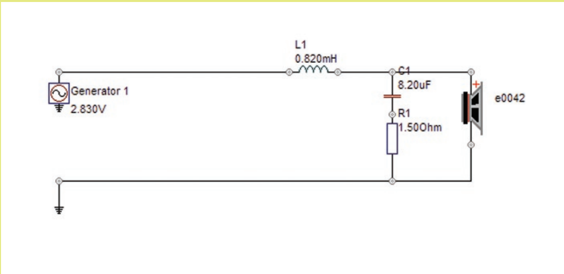


Fig 7 - Optimised crossover schematic

in a capacitor in parallel with the driver, thus forming a second order crossover. This is typical of a standard 'calculated' crossover and you can see the results: (see fig 6).

Again the 'calculated' crossover looks pretty disastrous. Far from smoothing the roll off the capacitor has made the treble peak even more 'peaky' and audibly obvious. A small adjustment to the capacitor value and the inclusion of a resistor in series with the capacitor (see fig.7) luckily solves the problem (fig 8).

Now at this point you might be thinking about objecting to the elevated 'plateau' about 800 – 1kHz, especially if you are aiming for a ruler flat response. Remember that this area is exactly where we calculated our baffle step to be. In fact this area is more obvious on-axis than it is off-axis which tells us that it is actually due to diffraction at the edges of the baffle. We could 'cure' this by extra elements in the crossover but, in my view, the extra complications cause more problems than they solve. This baffle diffraction area is not as audibly obvious as it appears on the graph. A better way of getting rid of it would be to opt for a wider baffle and you can smooth it by using a large radius on the baffle edges too. Yet another reason, in my opinion, of keeping clear of narrow baffle cabinets in your design!

MEASURING IS THE KEY

So I hope that you can see that, without some form of measurement system, it is almost impossible to put together a crossover just by traditional calculation methods and listening. Ideally you do need to experiment by measurement and listening.

There are several speaker measurement systems on the market. The traditional speaker designer's system is MLSSA – a combination of computer hardware and software that enables you to take measurements without having to use an anechoic chamber. The way it does this is by generating an MLS (Maximum Length Sequence) burst of 'noise' and measuring the output of the speaker in an adjustable time window so that you can cut out most of the reflections from nearby room boundaries.

Traditionally the anechoic chamber is used for speaker measurement, the idea being that only the output of the speaker reaches the microphone and all reflections are absorbed. Using a measurement system with a time window, however, enables you to do without the anechoic chamber and measure in a largish room instead. I have found that the most troublesome reflection is from the floor boundary as this reflection occurs very quickly after the initial impulse from the speaker and is difficult to 'dial out' using the time window.

One way round this is to put lots of absorbent material between the speaker, floor and microphone position. For example you could put the speaker at one end of a sofa with lots of soft cushions on it and position the microphone at the other end.

MLSSA is expensive to buy and difficult to install in modern computers (it is DOS based and uses a full length ISA slot), so is not ideal for the amateur even though it has become the professional's 'standard'. A simpler version of doing a similar job is CLIO which integrates more easily with Windows and comes as a complete system with microphone.

If you are only going to use a measurement system once, or occasionally, even CLIO might seem over-the-top on expense. So next month I will show you some cheaper 'kit' type methods that, with a little bit of ingenuity, you can assemble into a measurement system that will be more than adequate for the home speaker designer.

ROOM GAIN

It is very important to take room gain into account when designing our cabinet and crossover. Not only does room gain ameliorate the baffle step but it also helps us maximise the sensitivity of our speakers. If we take the worst case of a 6dB baffle step you can easily calculate the loss in sensitivity once we have added our correcting crossover. Suddenly our 89dB sensitivity bass-midrange drive unit has turned into an 83dB sensitivity speaker! You may want to consider using room boundary conditions to their maximum effect if you are designing a high sensitivity speaker. For example placing a bass unit, or bass units, close to the floor boundary can boost bass output considerably in a three-way speaker. But to manage this sort of design successfully you will still need to put your midrange driver on a wide baffle to make sure the baffle step doesn't result in a loss of lower midrange.

One cunning design trick is to incorporate the baffle step from the midrange unit into your bass-midrange crossover. Just calculate your baffle width so the F3 of the baffle step is at your crossover frequency. This might allow you to use just a single series capacitor as your midrange high pass crossover element.

Another way of putting drive units close to bass reinforcing boundaries is to design the speaker for close-to-wall positioning. As you can see in our WD25 design this is a favourite trick of mine. By designing a relatively shallow cabinet even a front mounted bass-midrange unit can integrate successfully with the wall behind to deliver remarkably powerful bass whilst maintaining the high sensitivity of the midrange performance.

Pundits will tell you that the downside of this 'back-to-the-wall' design is the loss of deeply spacious 3D stereo imagery due to early reflections of midrange and treble from the rear wall. Actually I haven't found this to be a problem in speakers I have designed. It is certainly true if the off-axis character of the speaker is vastly different to the direct sound (and overcoming this is part and parcel of good cross-over design), but if the reflected sound is similar in character to the direct sound from the speaker I find that the ear integrates the two very successfully.

I'll be using this back-to-the-wall technique in some of the speaker designs we will be covering in this series as it really is a very good way of providing an even and articulate bass performance in a wide variety of rooms.