Baffle Step Response Calculations
By Martin J. King, 11/06/04

Introduction :

Over the past few years, I have become very aware of the baffle step response phenomenon associated with drivers mounted in rectangular baffles. My first few quarter wavelength speaker designs suffered from a depressed bass response and a strong midrange and high frequency response. Sound pressure level measurements clearly showed the baffle step phenomenon and a correction circuit, designed using these measurements, easily resolved the problem. In every one of my completed designs, measurements and listening sessions were used to design and tune the final baffle step correction circuits. Initial enclosure design work, performed with my MathCad(1) worksheets, was done assuming the speaker system only radiated into 2π space. The baffle step response was treated as an unknown until the speaker was built and the actual acoustic performance measured.

Baffle step response calculation programs are available for downloading on the Internet. Two good examples are the BDS(2) Excel spreadsheet by Paul Verdone and the Edge(3) stand alone program by Tolvan Data. They are easy to use and each has its own set of strengths and weaknesses. I have used both to check my measurement results but always wanted to write my own version in MathCad. If I could write my own version, then I would gain more of an understanding of the physics involved and also be able to easily incorporate the routine into my MathCad quarter wavelength enclosure design worksheets. Incorporating baffle step response prediction, into the MathCad models, would provide some advanced insight into the correction filter requirements before actually building and testing a complete speaker system.

Over the past couple of weeks, I have programmed my own version of a baffle step response calculator in MathCad. It is not as efficient as the two programs mentioned earlier, it runs much slower and does not have as many features, but I have really gained a better understanding of the physics involved and have been able to easily incorporate the algorithm into some of my MathCad enclosure design worksheets. The first worksheets to include the calculated baffle step response loss at low frequencies will be the updated back and front loaded horn design worksheets currently under development. The intent of this document is to describe the algorithm, verify the calculations, and show preliminary correlation with the existing Lowther ML TL speaker system SPL measurements.

Calculation Algorithm :

The derivation of the equations for the velocity and the pressure generated by a simple source, as presented in Beranek(4), starts with a general expression for the pressure. Assume that a very small sphere is vibrating in free space; the oscillating velocity at the surface creates a disturbance in the surrounding air generating pressure waves that travel away from the sphere. The pressure waves can be expressed using the following equation

$$\mathrm{p}(r, t) = \frac{\sqrt{2}\, A\, \mathbf{e}^{(I(\omega t - k r))}}{r}$$

where A is the RMS magnitude of the outward traveling pressure wave. This definition of the pressure generated by a simple source is the key building block in deriving a method for calculating the baffle step response.

The pressure waves generated by a vibrating simple source travel away from it in the same manner that waves travel away from the point in a pond where a small pebble has been dropped. At any distance from the simple source, the pressure magnitude is equal and decreasing as a function of one over the distance. When two equal simple sources are present, spaced some prescribed distance apart, a summed pressure response pattern of reinforcement and cancellation is produced that is a function of the separation distance, the frequency, and the reference position of interest. An assemblage of simple sources will result in an even more complex summed pressure response pattern that is a function of the source distribution geometry, the frequency, and the reference position of interest. A collection of simple sources can be used to simulate almost any vibrating object when calculating the resulting pressure at some reference point in free space.

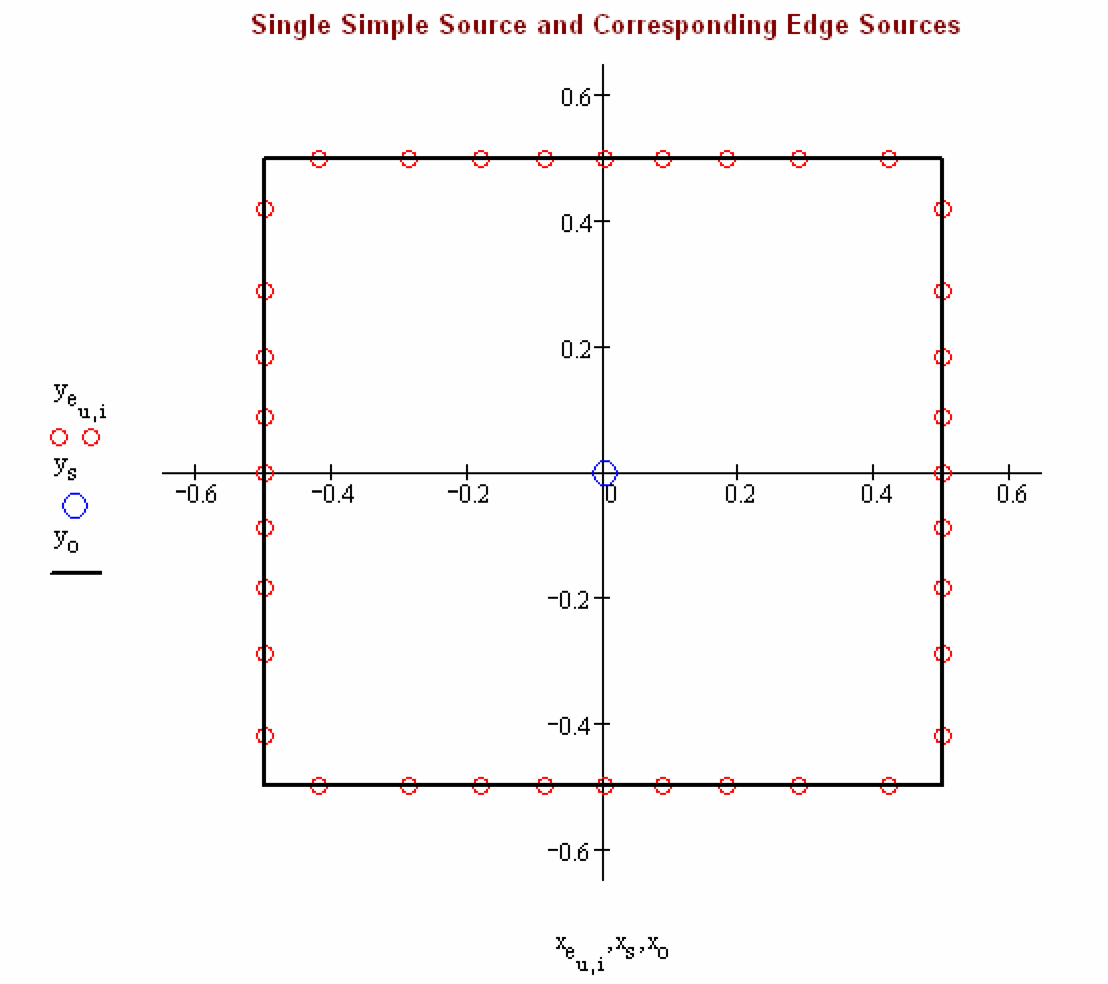
If a simple source is placed on a baffle, the pressure waves traveling along the baffle will have double the strength of the same simple source in free space. This doubled strength is created by the local pressure only radiating into 2π space. When the pressure wave reaches the edge of the baffle, the local pressure magnitude will drop due to the sudden change in the radiating space. This sudden drop in pressure magnitude can be simulated by adding a second simple source at the edge of the baffle, with a reduced magnitude, that is 180 degrees out of phase with the arriving source pressure. If many simple sources are located around the perimeter of a baffle, with the appropriate magnitude reduction and 180 degree phase shift, then the summed response will represent the impact of the baffle's size and shape on the total radiated sound field.

Assume that the original simple source has a magnitude of two, $A = 2$ in the equation for pressure shown earlier. At low frequencies, sound radiates equally in all directions and the responses from the original single simple source and the edge sources will add destructively producing a summed pressure response that is down 6 dB. Therefore, the summed response from just the edge sources at low frequencies must equal negative one, $A = -1$ in the equation for pressure shown previously. As the frequency increases, the phase shifts produced by the different path lengths from the original simple source and the edge sources, to the reference position, will cause reinforcement at specific frequencies and cancellation at others. This summation of the pressures generated by the original simple source, on the baffle, and the collection of edge sources, around the perimeter of the baffle, is what produces the baffle step response typically seen when measuring the SPL of a driver mounted on a speaker's front baffle.

Response of a Single Simple Source on a 1 m x 1 m Baffle :

As a first sample problem, consider a single simple source located at the center of a 1 m x 1 m baffle. The single simple source (blue circle) and the edge sources (red circles) are shown in Figure 1. The perimeter of the 1 m x 1 m baffle is represented by the solid black outline in the plot. The edge sources are spaced at 10 degree increments around the perimeter of the baffle.

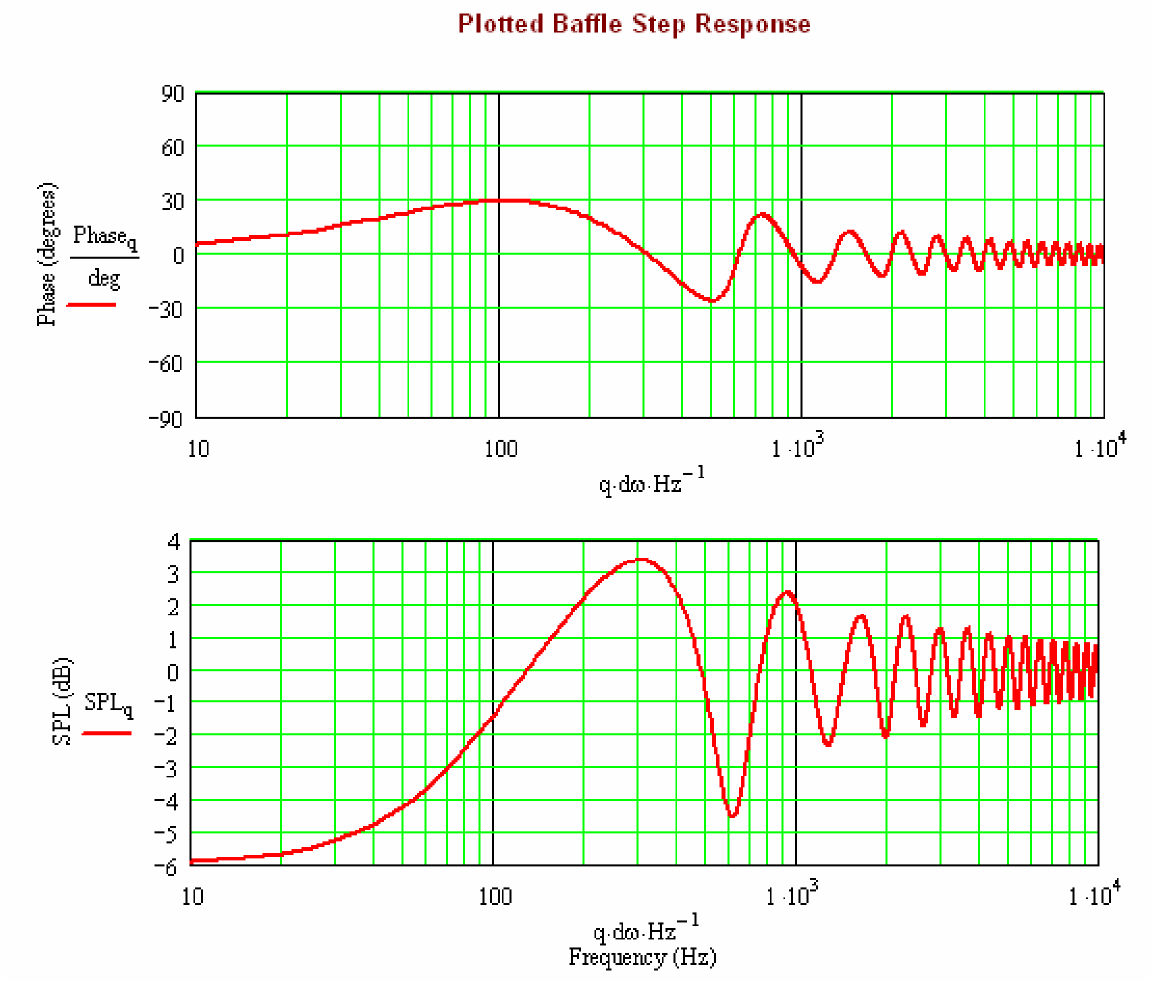
Figure 1 : Single Simple Source on a 1 m x 1 m Baffle



MathCad was programmed to sum the pressure generated by each of the sources in Figure 1 at a specified reference position. The specified reference position is 100 m away on an axis perpendicular to the baffle and passing through the center of the baffle. The 100 m distance is assigned so the response calculated is truely in the far field. Any position of interest, distance and angular location, can be specified in the MathCad worksheet.

When calculating the baffle step response, the number of edge sources is a user defined variable. If only a few edge sources are assumed, the calculation runs very quickly but is not very accurate. As more and more edge sources are assumed, the calculated pressure response continues to change until enough sources are present to accurately predict the pressure response as a function of frequency. For the situation shown in Figure 1, the number of edge sources was increased to 288 which generated a converged solution over the frequency range 10 Hz to 10000 Hz. The resulting calculated pressure response is shown in Figure 2.

Figure 2 : Baffle Step Response for a Single Simple Source on a 1 m x 1 m Baffle



The plotted response in Figure 2 exhibits a net 6 dB change in SPL, between low frequencies and high frequencies, with the transition centered at about 70 Hz. To check this frequency, the rule of thumb calculation provided in my “Simple Sizing of the Components in a Baffle Step Correction Circuit” article will be applied.

$f_3 = 4560 / W_B$

$f_3 = 4560 / 39.37$ in

$f_3 = 115.8$ Hz

This result is a little high but not too far off when compared to the -3 dB frequency in Figure 2.

The plotted pressure response also shows a series of peaks and nulls that appear to be multiples of one characteristic frequency value. After calculating the average distance from the source to the edge, the frequencies of the corresponding half and full wavelengths of sound are determined.

$$r_{average} = ((1\ \text{m} \times 1\ \text{m}) / \pi)^{1/2} = 0.5642\ \text{m}$$

$$f_{1/2} = c / (2 \times r_{average}) = (342\ \text{m/sec}) / (2 \times 0.5642\ \text{m}) = 303\ \text{Hz}$$

$$f_{2/2} = 606\text{Hz}$$

$$f_{3/2} = 909\ \text{Hz}$$

$$f_{4/2} = 1212\ \text{Hz}$$

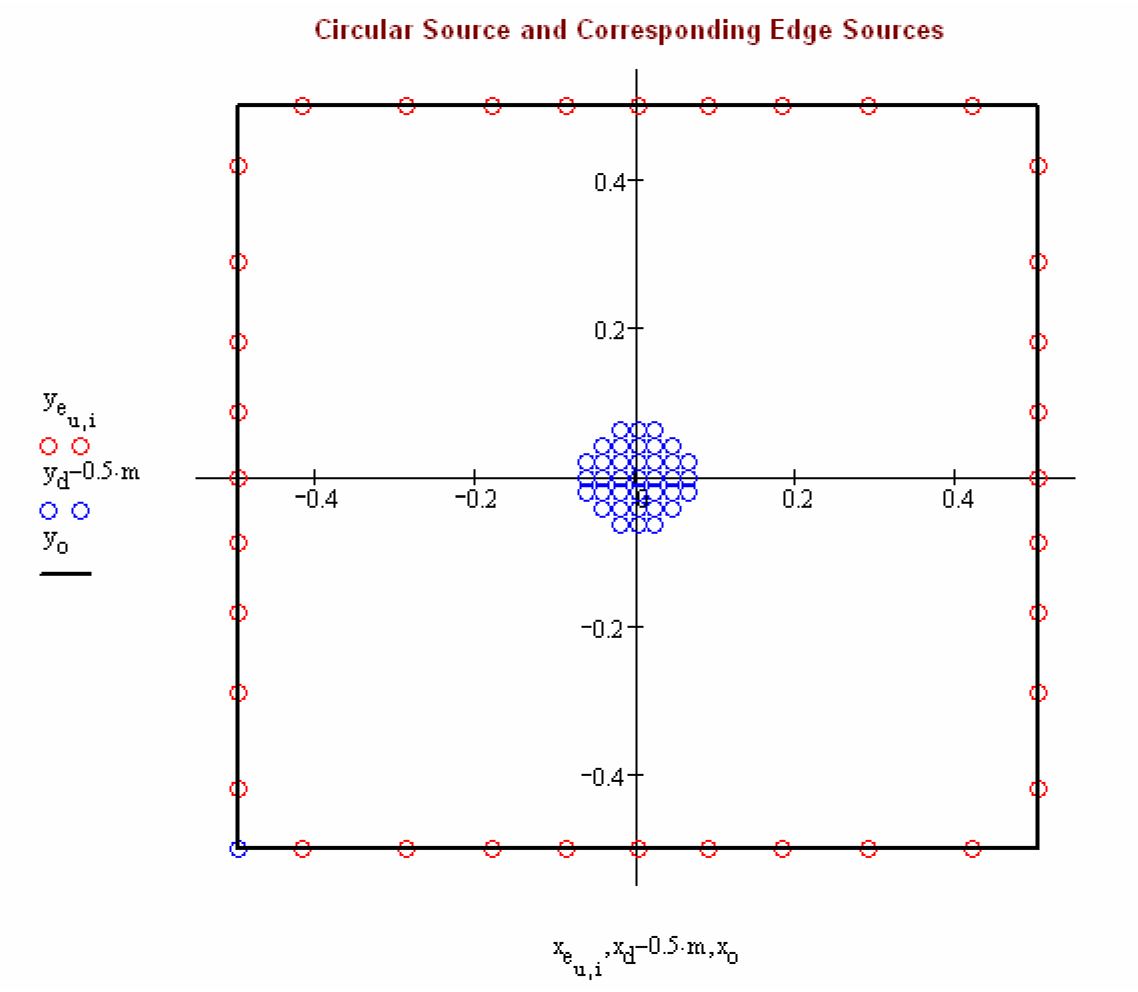
The first two peaks in Figure 2 occur at 303 Hz and 927 Hz while the first two nulls occur at 615 Hz and 1274 Hz. Correlation of the peaks and nulls with the half and full wavelength frequencies is very good.

Response of a Circular Piston Source on a 1 m x 1 m Baffle :

The next level of refinement in the calculation of the baffle step response is to upgrade the single simple source to become a circular piston. A circular piston's sound pressure response is closer to an actual driver's response since both have a directivity that increases with frequency. As the piston's directivity increases the ragged response above the baffle step -3 dB frequency, generated by the edges of the baffle, will decrease. To model a circular piston, the simple source is used again. The circular shape is divided into a collection of simple sources. The larger the number of simple sources used in the simulation to represent the circular piston, the closer the calculated pressure response will match an actual driver's response.

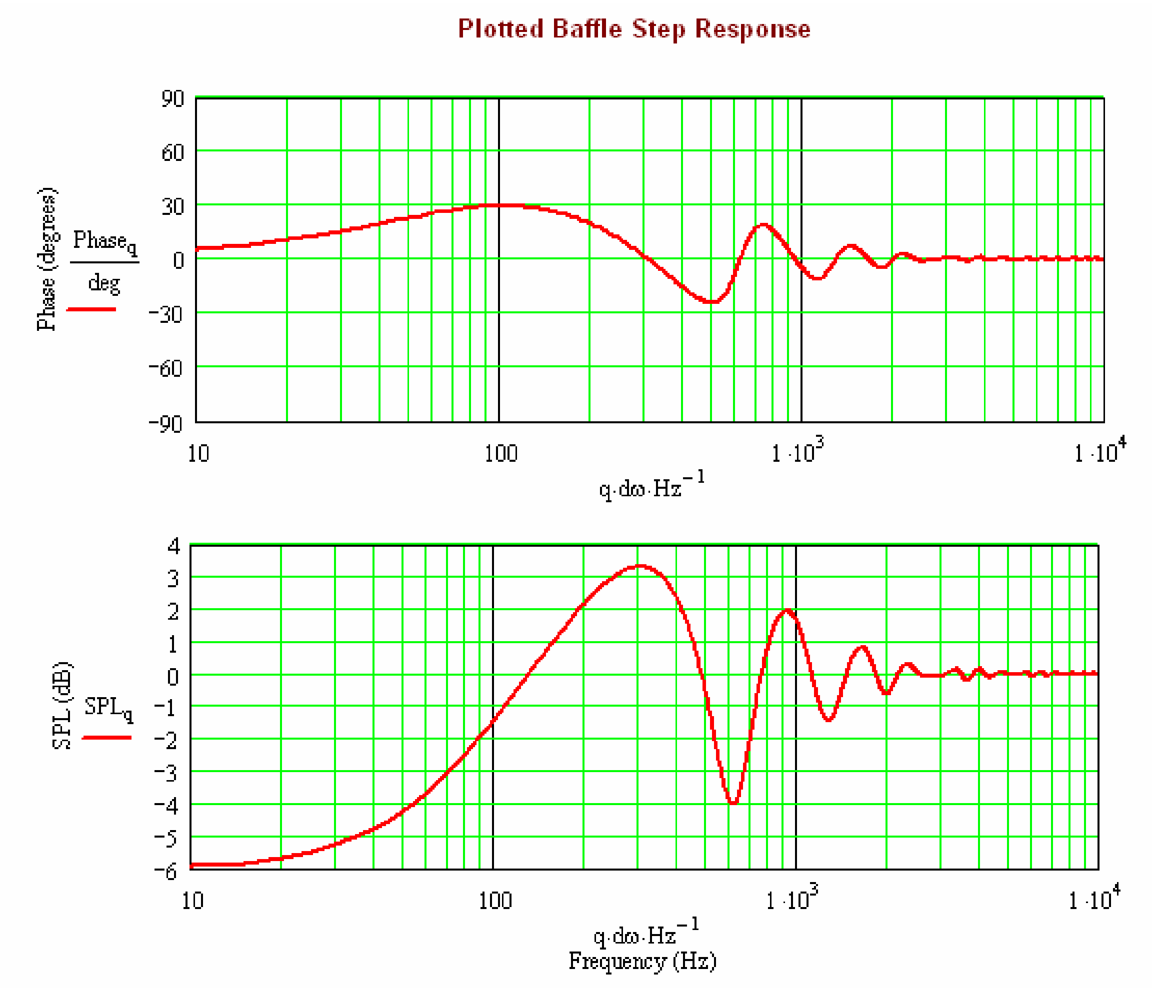
Continuing with the same sample problem, consider a circular piston source located at the center of a 1 m x 1 m baffle. The circular piston source (blue circles) and the edge sources (red circles) are shown in Figure 3. The 1 m x 1 m baffle's perimeter is represented by the solid black outline in the plot. Again, the edge sources are spaced at 10 degree increments around the perimeter of the baffle.

Figure 3 : Circular Piston Source on a 1 m x 1 m Baffle



When calculating the baffle step response, the number of sources used to represent the circular piston and the baffle edge are user defined variables. If only a few sources are assumed, the calculation runs very quickly but is not very accurate. As more and more sources are assumed, the calculated pressure response continues to change until enough sources are present to accurately predict the pressure response as a function of frequency. For the situation shown in Figure 3, the number sources used to represent the circular piston was increased to 112 while the number of edge sources was increased to 288 generating a converged solution over the frequency range 10 Hz to 10000 Hz. The resulting calculated pressure response is shown in Figure 4.

Figure 4 : Baffle Step Response for a Circular Piston Source on a 1 m x 1 m Baffle



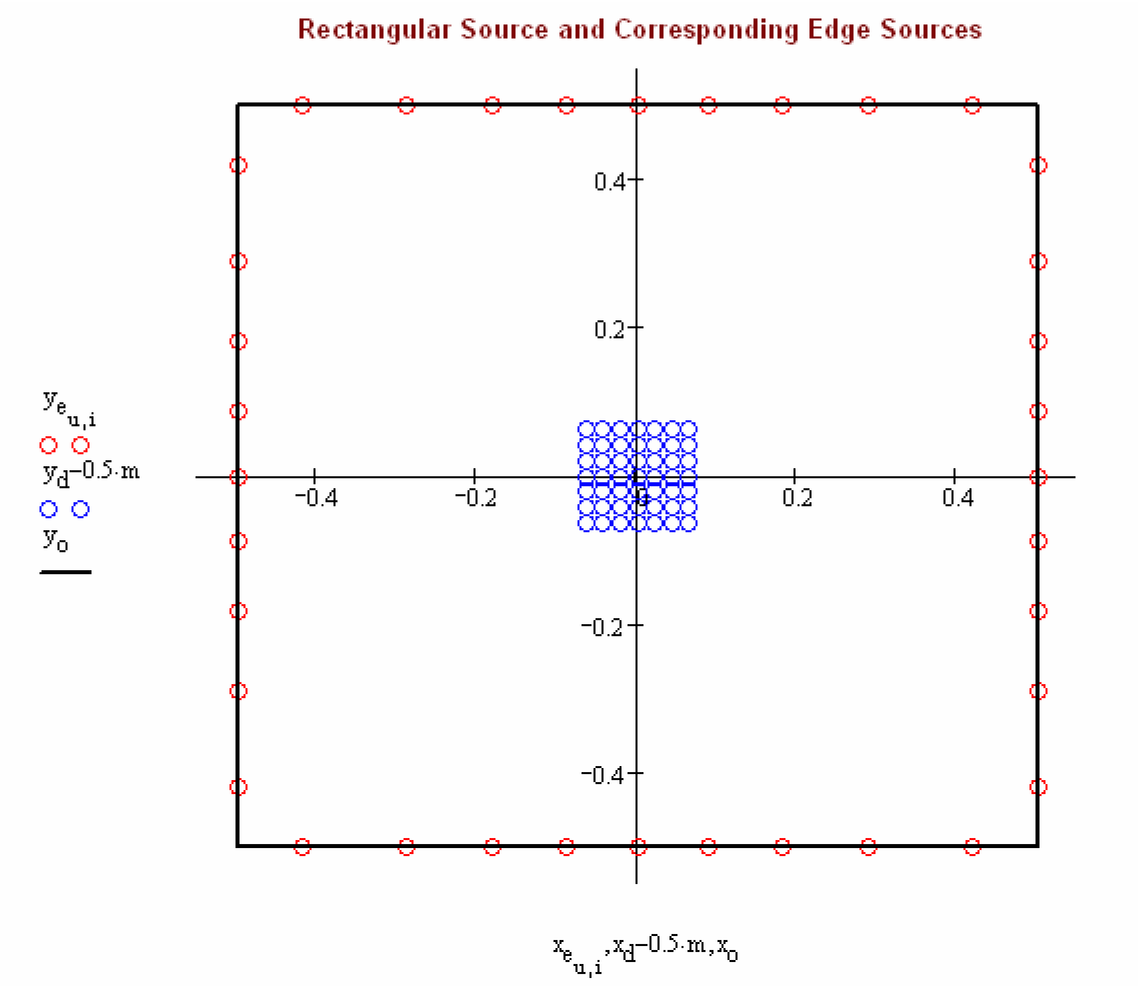
The plotted response in Figure 4 again exhibits a net 6 dB change in SPL, between low frequencies and high frequencies, with the transition still centered at about 70 Hz. Also clearly seen is the impact of the directivity of the circular piston source at frequencies above 1000 Hz, the previously seen ragged response is significantly attenuated.

Response of a Rectangular Piston Source on a 1 m x 1 m Baffle :

One more refinement in the calculation of the baffle step response is to change the shape of the circular piston source to be rectangular. As the rectangular piston's directivity increases, the ragged response above the baffle step -3 dB frequency, generated by the edges of the baffle, will decrease. To model a rectangular piston the simple source is used again. The rectangular shape is divided into a collection of simple sources. The larger the number of simple sources used in the simulation, the closer the calculated pressure response will match an actual response.

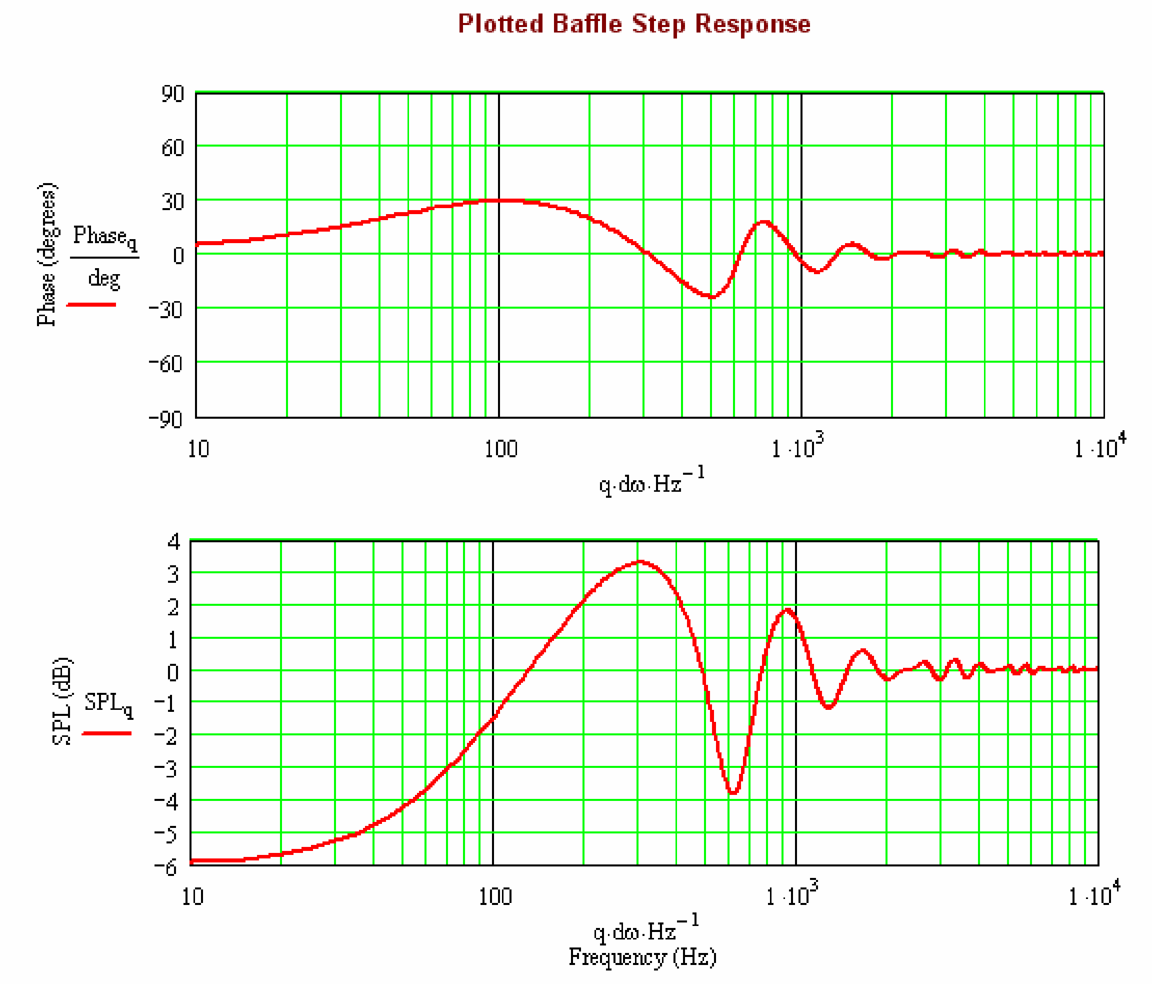
Continuing with the same sample problem, consider a rectangular piston source located at the center of a 1 m x 1 m baffle. The rectangular piston source (blue circles) and the edge sources (red circles) are shown in Figure 5. The 1 m x 1 m baffle perimeter is represented by the solid black outline in the plot. Again, the edge sources are spaced at 10 degree increments around the perimeter of the baffle.

Figure 5 : Rectangular Piston Source on a 1 m x 1 m Baffle



For the situation shown in Figure 5, the number of sources used to represent the rectangular piston was increased to 144 while the number of edge sources used was increased to 288 which generated a converged solution over the frequency range 10 Hz to 10000 Hz. The resulting calculated pressure response is shown in Figure 6.

Figure 6 : Baffle Step Response for a Rectangular Piston Source on a 1 m x 1 m Baffle



The plotted response in Figure 6 again exhibits a net 6 dB change in SPL, between low frequencies and high frequencies, with the transition centered at about 70 Hz. Also clearly seen is the impact of the directivity of the rectangular piston source at frequencies above 1000 Hz. Comparing Figures 4 and 6, the circular and rectangular (really square in this case) piston responses look very similar. This should not be too surprising.

Summary :

The previous MathCad baffle step response calculations were checked using the Edge(3) computer program and found to be in reasonably close agreement. The three types of sources that can be modeled are a single simple source, a circular piston source, and a rectangular piston source. The single simple source really serves as the building block for the piston sources, it is not really applicable to a real life source.

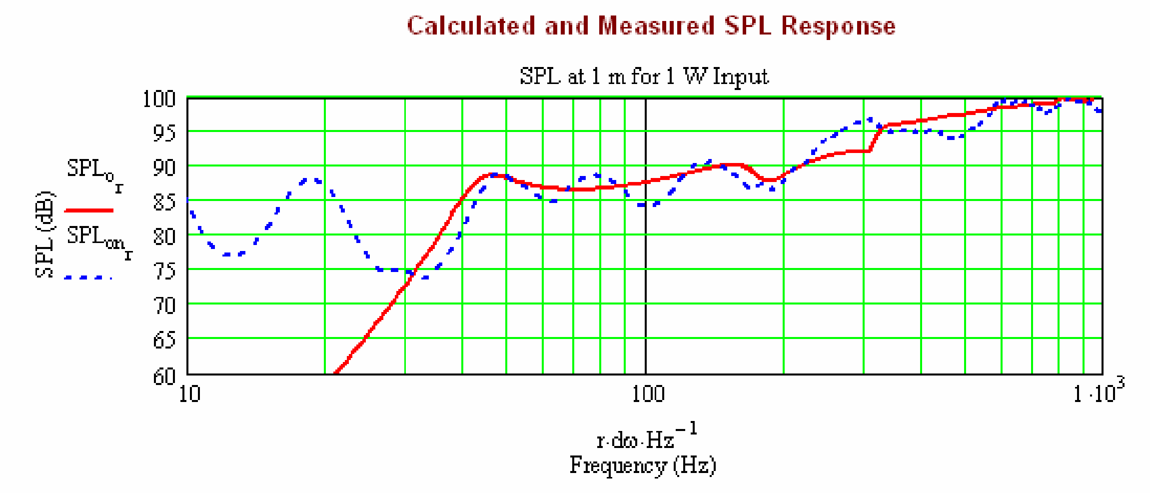
The circular piston source can be used to represent a driver, a port in a bass reflex enclosure, or a large circular mouth of a horn. The rectangular piston source can be used to model slotted ports in bass reflex or transmission line enclosures, a large planer source such as an ESL panel, or the large rectangular shaped mouth of a back loaded or front loaded horn. The baffle shape is limited to rectangular at this point in time but the worksheet could be easily modified to accommodate other baffle geometries. Also, with the changing of one constant the baffle step response algorithm can be configured to calculate the dipole response of an open backed baffle design.

Correlation of the Lowther ML TL Calculations and Measurements :

Immediately after constructing the Lowther ML TL speakers, using the DX3 model driver, a series of initial SPL and impedance measurements were made so that a BSC circuit could be designed. The recently completed speaker was located in the middle of my large basement and the SPL was measured at 1 m, on the axis of the driver, for a 1 watt input. These measurements are described and the results presented under Project #4 on this website.

The MathCad enclosure worksheets used to design the Lowther ML TL enclosure calculated the speaker's response as if it were radiating into 2π space. The baffle step response was not included in any design calculation. The method described in the preceding sections of this document was applied to the initial MathCad design calculations, a revised SPL frequency response was calculated, and the results compared to the SPL measurements taken in April 2003. Figure 7 shows the new calculated SPL response and the original measured SPL response.

Figure 7 : Measured and Calculated SPL Response for the Lowther DX3 ML TL Speaker



The correlation in Figure 7 is really very good. Above 30 Hz, the calculated and measured SPL responses match reasonably well. Below 30 Hz, the curves diverge but this is probably due to background noise present in the measured response. These speakers do not produce much bass below 40 Hz and low frequency measurements are extremely difficult to make using this test location and set-up.

Conclusion :

A calculation algorithm for the baffle step response phenomenon has been derived, programmed in MathCad, and verified against actual speaker SPL measurements. It is now ready to be integrated into the MathCad quarter wavelength enclosure design worksheets. The first planned application of this technique will be in the back loaded horn design worksheet currently under development.

References :

1) MathCad 11 by Mathsoft Inc., www.mathsoft.com.

2) BDS by Paul Verdone, www.pvconsultants.com/audio/frdgroup.htm.

3) The Edge by Tolvan Data, www.tolvan.com/edge.

4) Acoustics by L. L. Beranek, published by the American Institute of Physics for the Acoustical Society of America.