Section 1.0 : Introduction

For the past several years, I have been working on simulating transmission line loudspeaker systems using MathCad[1] computer models. When I started the derivation of the transmission line's equation of motion, I wanted to be able to easily simulate tapered, straight, and expanding line geometries. To accommodate the geometry variable in the derivation, I merged the one dimensional exponential horn wave equation with an empirically derived fiber damping correlation. The fiber damping model was generated using data acquired measuring the electrical impedance and SPL output of a straight test transmission line speaker. The details of the transmission line modeling can be found on my Quarter Wavelength Loudspeaker Design website (www.quarter-wave.com).

There have been a number of major revisions to my MathCad transmission line computer models in the past couple of years. Some of the changes that were made corrected errors in the derived equations while others extended the capabilities of the worksheets to represent additional types of enclosures. Since September of 2000, versions of the MathCad worksheets have been available for downloading and have received wide use by transmission line and TQWT DIY speaker building enthusiasts. To the best of my knowledge, the speakers built based on these MathCad worksheets have been very successful and measurements correlate extremely well with the simulation predictions.

During the first six months of 2002, I made a major change in the transmission line calculation algorithm. This change increased the calculation flexibility allowing MathCad to model more complex transmission line enclosures. It also became apparent that this new calculation scheme could be used to accurately model sealed, bass-reflex, back-loaded horns, front-loaded horns, and isobaric enclosures. In addition, I was able to iron out all of the small mistakes and tricky details in my solution of the exponential horn wave equation and produce a clean start to finish documentation of the method of analysis.

Another significant upgrade to the MathCad worksheets occurred starting in March of 2006. These latest worksheets retained the original transmission line calculation algorithm but extended the model to include the position of the drive on the front baffle, the position of the port or mouth on the front or rear baffle, the shape of the front baffle, floor reflections, and rear wall reflections. These newer worksheets have continuously evolving and been updated as newer calculations/features were added.

The MathCad worksheets available for front and back loaded horns have not been used as frequently as the transmission line or closed and ported box worksheets. The horn models were correlated against two other popular computer codes, found on the Internet, and for the most part were in very close agreement. Recently I have seen a few very successful back loaded horn enclosures designed and built using the worksheets. Some of the finished back loaded horn designs can be seen in my Quarter Wavelength Speaker Design website gallery

The mystery of horn loaded loudspeakers started to pull me towards designing and building one of these exotic enclosures. This new challenge was too interesting to pass up even though I really did not feel that I adequately understood horn design theory. So my first step down this path was to look at the acoustics texts on my bookshelf and at all of the AES papers I had collected over the years. When I went to some of the classic acoustics texts to get started, I was left scratching my head for a very long time. What really confused me was seeing a horn described as an "acoustic transformer". I saw this description in the majority of the well respected acoustics textbooks[2,3,4,5,6]. I understood that a horn increases the output efficiency of a driver and that high pressure at the throat is converted to high volume velocity at the mouth. But what physically is an "acoustic transformer"? I still have no idea and consider this to be a poor term for describing the physics of a horn.

Since none of the texts or articles I had in my possession provided a full derivation of horn theory and application, I was left to fill in all of the missing steps on my own. A complete derivation of the one dimensional exponential horn wave equation and its subsequent solution was the first step. Then I worked with the solution to gain an understanding of exactly what the physics were that make a horn so efficient. During this process, I also recognized that I would need to include the cross-sectional shape of the horn and the properties of the mouth with respect to acoustic impedance and sound radiation directivity. Once I had all of these variables characterized, and the appropriate equations solved, I could start thinking about the methods I wanted to use to design horn enclosures. What follows is a narrative describing the path I have followed while working my way towards reaching these goals.

I don't think there is anything startling or brand new in what follows. Horns have been around for a very long time and there appears to be generally accepted methods for sizing a horn and describing its SPL performance. But in the time I have spent thinking about horns, casually and now seriously, I have never found one place where the complete derivation and application of the horn wave equations was laid out and explained. This may be due to my own limited research efforts. Since I was going to all of this effort to try and understand horns, I thought it would help me to document in detail everything that I was learning. In addition, I wanted to try and approach horns from the perspective of a mechanical engineer applying mechanical vibration theory. This would allow others to follow and learn with me and hopefully will generate feedback that improves and extends what is already presented in the following sections.

In all of the documentation that follow, the horn equation being manipulated describes an exponential flare geometry. There are one or two places where results for other horn flare geometries are included only for comparison. Also, the driver used in all of the sample simulations is generic but typical of an eight inch diameter full range driver from manufacturers such as Fostex, Audio Nirvana, Lowther, and AER. My goal is to build some horn projects using my personal inventory of eight inch diameter full range drivers. However, I believe that all of the results presented are also applicable to any other size or type of driver mounted in a front or back loaded exponential horn.

As always, comments and feedback are welcomed and I hope that improvements in the quality and scope of the documentation and MathCad worksheets will result.