What is a Waveguide?

This question comes up so often that I wanted to put down the history of this term as applied to acoustics. I will attempt to answer the following questions:

1. Does a waveguide differ from a horn and if so, how?
2. Where did the term come from and hasn't it already been defined?

To understand what a waveguide is you need to first understand what a horn is. Wikipedia defines a horn as a musical instrument and this terminology came from the close appearance of the shape to horns found on wild animals. This definition then is pretty generic and in fact its evolution lays the foundation for the use of the term "waveguide".

In the early part of the 20th century Webster developed an equation that he applied to the analysis of a "horn", or a conduit of varying shape. His intent was to study the loading/efficiency of the horn as used in a phonograph. This equation became known as Webster's Horn Equation or just the Horn Equation. For nearly 70 years this equation was used to develop the vast array of differing horn contours found in the marketplace.

In the late 80's, this writer became interested in "horns", but more as a practical means of controlling directivity than as a loading device. Amps were plentiful, powerful and getting inexpensive and compression drivers had more than enough output for most uses, so loading and efficiency were not major drivers of my research. In fact, they are not even a consideration.

In order to define the directivity of a horn, one has to know precisely what the shape of the wavefront in the device is at the horns mouth. Herein lies the main point – Webster assumed a flat wavefront in his equation development and as such it is impossible to use his equation for an analysis of directivity from these devices because the wavefront is most certainly not flat at the mouth. Basically the Horn Equation is only approximately correct in a small range of applications, and is very misleading in the vast majority of designs for which it has been applied.

As a direct result of my research, in 1991, I published a paper called "Acoustic Waveguide Theory" in the Journal of the Audio Engineering Society, JAES (www.aes.org/e-lib/browse.cfm?elib=6078). Why this particular title and not "Acoustic Horn Theory" or something similar? Here is the rational.

The equations that I used are completely different than the Horn Equation, so in a very real sense what I had developed were not "horns" as Webster was thinking about them. On the other hand they are indeed horns in the sense that a horn is any conduit of varying cross section (basically anything is a horn under this definition). My "Waveguide Theory" is based on a limited set of coordinate systems for which an exact solution to the problem could be found. This is very important because only an exact solution could determine the wavefront shape and hence the devices directivity. Horn Theory cannot predict directivity, only impedance or loading, but Waveguide Theory can predict both. This is a distinct difference in the two approaches.

It is true that the term “waveguides” had been used in microwaves and other electromagnetic wave applications prior to my usage of the term in my work (Wikipedia says “The original and most common meaning is a hollow conductive metal pipe used to carry high frequency radio waves, particularly microwave”, which I completely concur with), however, I was not aware of any usage of the term Acoustic Waveguide prior to mine in 1991. Being a physicist, I was very aware of the microwave usage and it seemed to me that the term ideally suited what I was doing at the time. It has come to take on a life of its own since then however.

It should be obvious at this point that all waveguides are horns, but not all horns are waveguides. The difference is if the directivity of the device can be analyzed analytically or not. If the directivity cannot be analyzed then the device cannot be said to be designed for directivity control. This is why it is sometimes said that waveguides are used to control directivity, but horns are used for loading. There is some truth in this, but it’s not completely correct either.

In the 70’s and 80’s the directional controlling devices were based on heuristic arguments that sometimes worked well and other times not. At that time, the idea was to diffract the wavefront with narrow slit or aperture of some kind and then to shape this wavefront with walls at a prescribed angle. This works to some degree but has a whole set of problems. With the “waveguide” approach, one can find that precise contour that allows the wavefront to progress to the shape that is required at the mouth to achieve the desired directivity. This is done with minimal diffraction and the resulting sound quality is distinctly improved. To me this is a waveguide – when there is a minimum of diffraction used to achieve the end result of directivity control. This can only be done through complex analysis and clearly, not every horn is a waveguide under this definition. This is a fairly strict definition, but makes far more sense that “everything is a waveguide” or “all waveguides are horns” and “any conduit is a horn”. These loose definitions end up meaning nothing. Marketing, of course, wants the word to mean as little as possible because that gives them as much wiggle room as possible to apply it to their products..

The term “Waveguide” has always had a nice ring to it and this name has caught on (I originally only used Acoustic Waveguide, but dropping the acoustic was inevitable as time went on). It is currently being used wherever and whenever possible even in situations which are not even remotely connected to what I was originally using the term to mean.

The application of “waveguide” to an acoustics problem that is slightly different than its microwave predecessor is not unlike, but certainly more reasonable, than the extension of the term horn from its predecessor in the animal kingdom.

These days it is possible to use FEA or a large number of other techniques on devices that have varying cross sections to calculate their directivity. Doesn’t this then make them waveguides? That’s actually a good question, but has been shown to be somewhat academic. A study was done by a graduate student somewhere in Australia which used a very complex computer program running a Boundary Element analysis to find that contour which gave the best control over the polar response or directivity. Not surprisingly, the contour that he found works best is virtually identical to the one that I found with my

"Acoustic Waveguide Theory" namely the Oblate Spheroidal or OS waveguide. Twenty years ago when I was doing this work, such a complex calculation would not have been possible and hence I was "stuck" with the complicated math I was forced to apply at the time. That this math actually foresaw the "ideal" shape is pretty remarkable, albeit, not really a surprise to me.

By necessity this discussion must fall short on details of what Acoustic Waveguide Theory is. That subject is well handled in Chapter 6 of my book **Acoustic Transducers** and the papers listed below (the book covers all of the papers and covers my understanding up to about ten years ago. My work since then has all remained unpublished, except for the many patents that I have obtained since then).

Bibliography

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