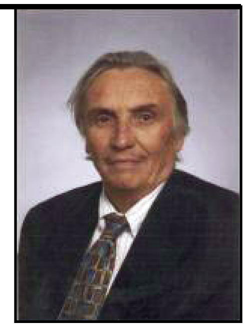
CAMPBELL'S CORNER - BY DICK CAMPBELL

Size Matters!

A Different Perspective on Plane Wave Tubes...



Dr. Patronis, in the SynAudCon Newsletter V36, #2, Spring 2008, gives us Part 6 -- his elegant explanation of acoustical behavior in a pipe. He calls it a 'plane wave tube', but I have always called it a 'standing wave tube' (SWT). Theoretical considerations are shown along with calculations illustrating the bandwidth limitations – he shows how size matters! The SWT [1] has been an essential tool in acoustical measurements for many decades. Here we will have a different look at how they operate.

The SWT is used to measure the complex acoustic impedance of any load attached to one end of a pipe. The other end has the driver, frequently a small loudspeaker. The idea is to establish a standing wave, use a moving microphone to observe the location of the positive and negative peaks with a (perfect) reflector at the end, and then do it again with the unknown load. The acoustic impedance of the load can be expressed in terms of the shift in magnitude and position of the standing wave peaks. Calculation of the absorption coefficient is straightforward.

In an SWT with pistonic excitation, for example a loudspeaker, the propagating wave is almost perfectly plane over a defined bandwidth. There are some propagation losses at the boundary (tube inside wall) and also due to length.

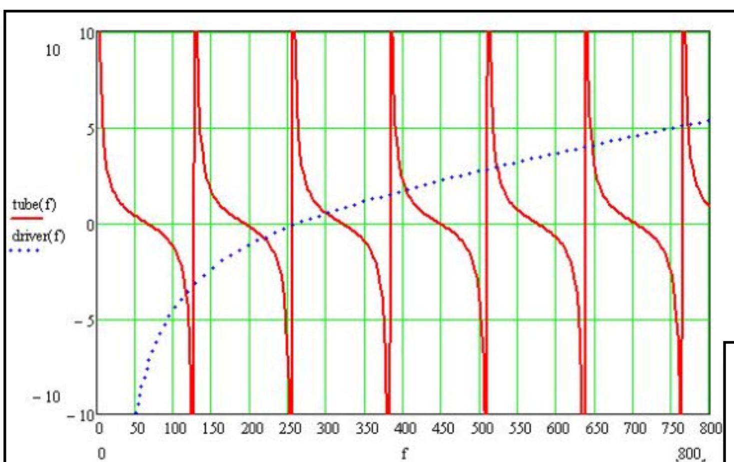


Fig. 1 - Two mechanical impedance functions estimated by a set of equations in Mathcad 14 [2] after [3]. The red curve shows the repeating standing wave pattern as frequency increases and the blue dotted curve shows the mechanical impedance function of the driver. Air absorption in the tube is included. At the points where the two curves cross the imaginary components sum to zero. This tube is 1.35m long and 5.35cm diameter.

Mathcad has a root function that allows extraction of these crossing points if a rough guess is given first. One can estimate these frequencies from Figure 1, and provide them to the root function which then calculates and presents the precise nearest value.

Since the actual SWT could be measured, MLSSA [6] was used to document the impedance of the loudspeaker driver. Remember that a loudspeaker can be modeled as a 'quadrapole' , an electrical input side, and an acoustic side that is responsive to its pipe load. When the acoustic load is zero, the driver voice coil has the highest velocity and the lowest pressure -- whereas when the acoustic load is infinite, the velocity is zero and the pressure is max. Therefore, peaks in the driver impedance should correspond to the crossings shown if Fig. 1, where the voice coil velocity is highest, generating a peak in the back-EMF.

There is yet a third method available to us for analysis of a driver-pipe coupled system – to do a physical model and observe the driver impedance peaks. The AkAbak [5] software allows just that by writing a simple script containing the variables for the driver, the pipe, and the termination. The script, shown in table 1, is deceptively simple.

First the driver definition, then the analysis System "S1" with four components: driver; free radiation from the back of the driver (open air); duct (pipe); and a very high acoustic resistance termination. The node numbers show how the parts are "wired" together. Note that the driver has two ports, electrical (nodes 1&0) and acoustical (nodes 2&3). Node 2 couples to the duct (which is defined as nodes 2&4), and the output of the duct at node 4 has a nearly rigid termination, 1000e3Pas/m3, between nodes 4&0.

Table 1 - AkAbak script for SWT model

```
Def_Driver   'Twiddler'
    Meas_DoNotModify |measured values follow
    dD=5cm    |Cone
    Cms=329um/N  Mms=1.09g  Qms=2  tD1=0.015m
    Bl=5Tm  Re=5ohm  Le=0.62mH  ExpoLe=0.618
  System 'S1'
  Driver 'D1'  Def='Twiddler'  Node=0=1=2=3
  Radiator  'Rear'  Def='D1'    Node=3
    x=0  y=0  z=0  HAngle=0  VAngle=0
  Duct    'Du1'  Node=2=4
    dD=5.35cm  Len=1.35m  Vf=0.1cm3  QD/fo=1
  AcouResistance 'Ra1' Node=4=0 Ra=1000e3Pas/m3
```

Figure 2 is a screen shot from AkAbak showing the electrical impedance of the driver from 0 to 800 Hz. Notice how the usual smooth resonance curve is modified by the wavelength-repetitive acoustic load impedance of the tube. This is not unlike an impedance measurement of the driver in a vented cabinet where we see one resonant load causing a twin peak

How do the three methods compare?

Mathcad	116.65	218.26	300.15	403.58	522.93	646.67	771.93
MLSSA	114.17	215.55	303.52	409.10	523.47	646.64	774.22
AkAbak	116.25	215.35	296.85	404.29	523.77	647.87	771.98

I was astonished to see this agreement. Of course all three used the driver constants measured by the MLSSA Speaker Parameter Option, but still -- -- this is a rather nasty coupled resonant system!

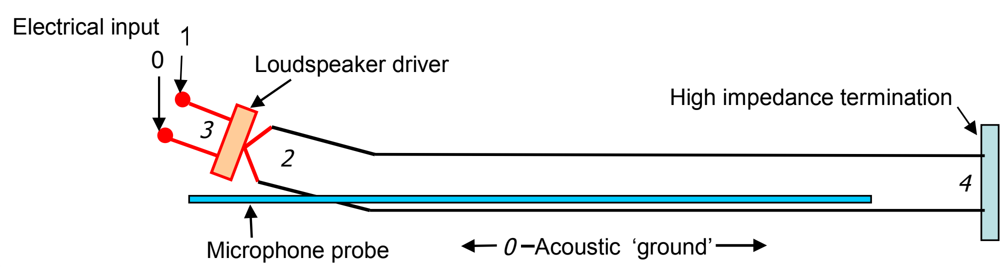
Size matters! What are the limits of the SWT as an acoustic measurement tool? Both the length and the diameter play a role in defining the useful bandwidth. At the low end it is essential to have two peaks present in the tube, and for the high end the propagation becomes non-plane as the wavelength approaches the radius.

The upper frequency were there is a significant sideways component of particle velocity (called the 'slosh' mode) is 0.586*c/d where c is the speed of sound and d is the diameter of a circular tube. For the SWT described above, this happens at ~3800Hz. Also, the smaller the diameter, the greater the propagation loss in the tube.

The lowest frequency can be seen from the comparison table – there are two peaks below 250Hz. Perhaps 250Hz to 4000Hz would produce acceptable values.

The measured impedance of an unknown termination is, of course, a plane-wave value [4]. In real life, especially in rooms, sound waves arrive from all directions so the SWT data is quite limited in its application to absorption data intended for room modeling. However it's useful for materials research. The load itself can also be another type of waveguide like a horn, thus documenting the input impedance seen by a compression driver. *dc*

[1] Kuttruf, H. "Room Acoustics", 4th edition, 2000, Spon Press, ISBN 0-419-24580-4, Chapter 8.6.
[2] Mathcad 14 is from Parametric Technology Corporation
[3] Kinsler, Frey, Coppens and Saunders; "Fundamentals of Acoustics", 1982, Wiley, ISBN 0-471-09233-5, page 210.
[4] Olson, H. "Acoustical Engineering", 1991, Chapter 10.7, Professional Audio Journals reprint.
[5] AkAbak was written by Joerg Panzer. The software may be downloaded free for non-commercial use from www.randteam.de.



Support Files:

PDF *Article with math*

MCD *MathCad Worksheet*

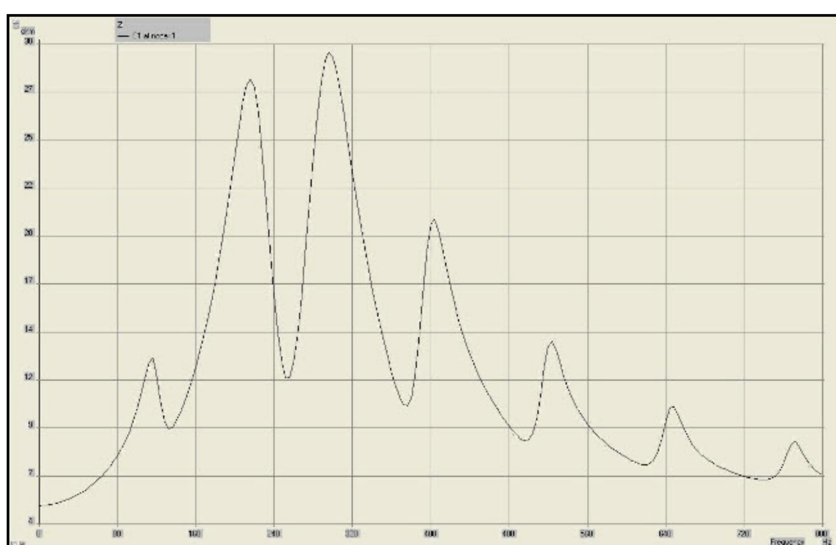


Figure 2. A shot of the AkAbak screen showing the electrical impedance of the standing wave tube driver. The impedance peaks in the figure are reproduced in the table below.