E.J.JORDAN DESIGNS

The Parameter Game
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(Glossary at bottom of page)

In the design and development of loudspeaker drive units to clients' specifications, the so-called "Theil Small" parameters are often a contentious issue.

Apart from the occasions when we are asked for values that are mutually incompatible, we feel that the now almost universal use of these parameters for the computerised modeling of enclosure design can sometimes produce misleading results. Further, this totally aseptic approach to design is not always accompanied by the necessary understanding of the fundamental principles.

I have no argument with computer aided designs per sé, provided that the operative word is "aided". However, it seems almost as though parameter crunching has become a computer game where the object is to juggle parameters to achieve an often arbitrarily chosen response alignment to quite fatuous levels of accuracy.

In fact, such accuracy may be far less than imagined due to the difficulties in determining the drive unit parameters in the first place. (Words like "music" and "listening" seem almost outdated).

Firstly, a small point. Without wishing to denigrate the work of Messrs. Theil and Small, I am sure they would agree that the loudspeaker parameters were around long before they were. In my own book 'Loudspeakers', published in 1962, I derived all the essential parametric relationships from first principles and described methods of measurement. For this, I drew upon sources dating back to the 1930s. Therefore, nothing is new.

Any argument must be based upon accepted premises, so I will start with the basics. Figure 1 shows composite electromechanical circuit, including all the principal players in The Parameter Game.

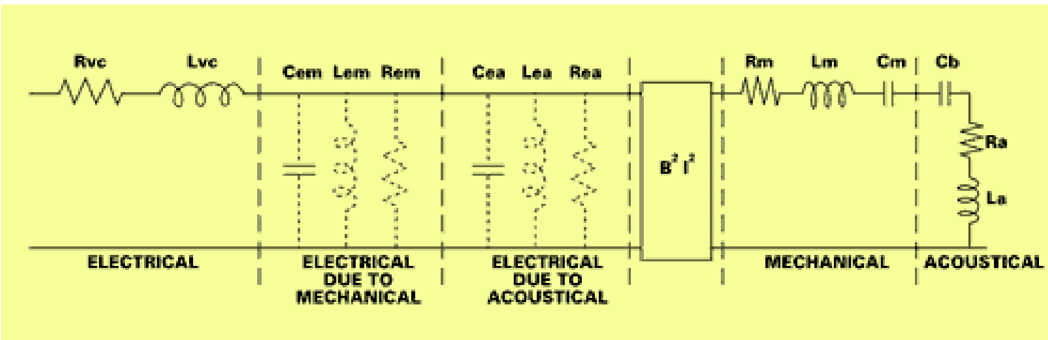


Figure 1

The dotted components to the left of the "B2 l2" box show what the amplifier "sees" and includes the effective impedance Zem due to the actual mechanical impedance of Zm.

The relationship is $Zem = \frac{B^2 l^2}{Zm}$

It will be seen that series LCR circuit of the mechanical system is represented by a parallel LCR circuit in the electrical side, where lm is represented by Cem, Cm by

Lem and Rm by Rem.

The resonant frequency of a simple circuit may be defined as:

1. Where the relative terms equate to zero
2. The frequency of maximum or minimum impedance.
3. The frequency of zero phase shift

With low loss (high Q) circuits, these occur at substantially the same frequency. For low Q circuits this is not so and this should be taken into consideration.

The quality "Q" of the circuit is defined as the ratio of resistance to reactance but is usually measured in terms of bandwidth at the -3dB points, but again this is only reliable for "Q" values greater than 4.o

Drive unit parameters are usually determined by measurement of the electrical impedance. An initial problem with this is one cannot "get at" Zcm because Rve and Lve are in the way, so all mechanical values are in effect "derived ".

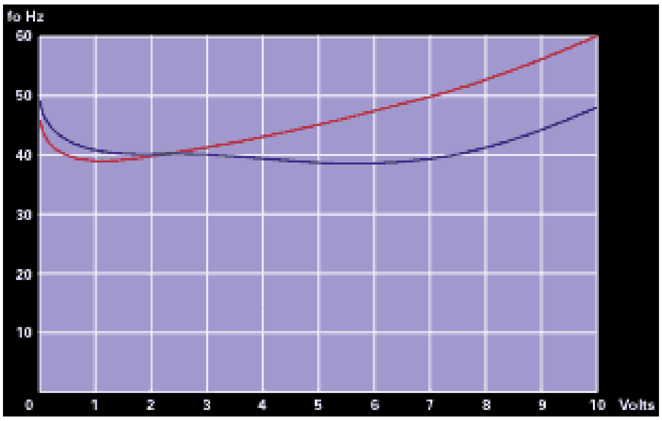
Two measurement options are "constant current" where the voice coil is connected in series with a high value resistor and the voltage across the coil monitored, or, where a "constant voltage" is applied across the coil and the current monitored. The resonant frequency ‘fo’ is that where Zem is at a maximum. The reactive terms are assumed infinite and Zcm = Rem.

Although the constant current method is the one most often used, the absence of electromagnetic damping results in large variations of cone amplitude around the resonant frequency, which will be shown to cause very significant measurement errors The constant voltage method is therefore preferred. This provides the electromagnetic damping experienced in normal use. Further, the voltage applied can be adjusted to examine the driver parameters at any level within the power rating of the drive unit. This cannot be easily done in the presence of a high value series resistor.

All the following tests were made with the constant voltage method at 20ºC ± 0.5º measured by a probe on the drive unit chassis (and, for the pedantic, at 20m above sea level, atmospheric pressure 1008 millibars at mid tide); fo is taken as the frequency for the minimum current.

Immediately obvious is the variation fo with applied V.

Figure 2 shows the characteristics of a conventional cloth centering device and our own linear suspension. Both drivers are otherwise identical.



The elasticity of materials used in conventional suspension systems is mainly due to the elastomeric nature of the materials used. Elastomers do not obey Hooke's Law and the "S" shape of the force/extension curve would largely account for the curves shown.

Since fo is proportional to the square of Cm it follows that based on these curves over the range from 0-3V (i.e. well inside the displacement limits), Cm and therefore Vas varies by about 60%. However, it gets worse.

Table 1 shows the parameters of a 7" bass/mid range unit derived from a typical programme sequence of calculations.

The sets of parameters are shown for a range of input voltages from 0.1-4V

Table 1

Vve	0.1	0.25	0.5	1	2	3	4
fo	27	26	24	22	22	22.5	24
Qt	.29	.24	.24	.22	.24	.29	.36
Vas	62.65	85.28	73.59	86.9	86.9	65.35	49.34
Mm	18.4	19.05	19.83	19.98	19.98	25.4	29.57
Bl	7.73	8.52	8.31	8.29	7.85	5.8	8.13

The variation of fo with voltage is clearly shown together with a corresponding variation in Vas. However, it will be noticed that the values for Vas are less than the predicted values based on frequency change alone. If we now look at values for Mm, we find perhaps surprisingly that this is also varying with fo.

The explanation is that the value of Mm was obtained by the "added weight method" where a known weight (Ma) is added to the cone and a new resonant frequency (fa) is noted.

Then $$Mm = \frac{Ma}{\left(\frac{fo}{fa}\right)^2 - 1}$$

A factor representing air load must be added to this. However, the additional weight not only lowers fo to fa but also increases the cone amplitude, which at low input levels is working on the positive slope of the compliance curve causing a downward shift in fa.

The above formula is very sensitive to small changes in fa, and the result is an apparent reduction in the calculated value of Mm.

For high level inputs where the compliance curve has a negative slope, we get an increase in the apparent values of Mm.

The value of Cm is obtained from the relationship $$Cm = \frac{1}{4\pi^2 f^2 Mm}$$

However, we have already seen Mm derived from a frequency ratio modified by a varying value of Cm in the first place: the classic Oozlum Bird syndrome.

"Q" values are obtained using the "bandwidth" method where

$$Qm = \frac{fo}{fh - fl}\left(\frac{io}{idc}\right)^{1/2}$$

Fh and fl are measured at points on the Zm curve where

$$Ih = Il = (ide \times io)^{1/2}$$

then

$$Qe = Qm \frac{Rdc}{Ro}$$

and

$$Qt = \frac{Qm \; Qe}{Qm + Qe}$$

The following force factor Bl is found as follows: assuming a value for Mm and its corresponding Qm (which should equal Qem) we can find the mechanical resistance of Rm.

Then

$$Rm = \frac{B^2 l^2}{Rem}$$

and

$$Bl = (Rm.Rem)^{1/2}$$

The conventional engineering approach can construct a whole edifice of parametric values from the unquestioned acceptance of a few initial measurements (which can be subject to substantial inaccuracies of parametric values can be built up, one upon another, from a few initial measurements, which are subject to inaccuracies.)

We offer the following pointers to enable a far more accurate and reliable approach.

There are of course computer programmes, which measure the "impedance" response and calculate "best fit" values but the same basic problems remain.

1. The measurements are made at a constant voltage, the value of which is adjusted to drive the cone to about half its maximum linear excursion. (1 – 2v in the above example) and the test conditions should be specified.

2. The moving mass could be obtained by actually weighing the cone/coil before final assembly.
The effective mass of the suspension could be reasonably estimated. This could at least provide one stable corner stone for the parametric edifice.

3. A measured rather than a derived factor for Bl would be desirable. Estimating the fringe flux might be difficult but not impossible.

4. Loudspeaker development could pay more attention to parametric stability. It must be 40 years since I last put pen to paper, and loudspeaker technology nowhere near matched the advances of all other components in the audio chain but some of us are at least making the effort.

To many of my customers and clients, it seems to matter a great deal. They have their system design programmes and want drive unit parameters to punch in. My message to them is, do not take the manufacturers' quoted figures for granted. If you make your own measurements be aware of the problems and make due allowances – this is where understanding and experience counts.

Now the practicality of design. Take a closed box system. There are several opening gambits.

The size of the box is chosen (a) to adjust the "Q" to some preconceived value; (b) to adjust and cutoff frequency to some preconceived value, and (c) to suit the market or the wife. If you chose (c) you may now just be able to fiddle a value V to satisfy (a) and (b).

Let's look at some practical examples and assume Cm to be the only variable with input V. The box volume is usually chosen in relation to Vas. Choosing a mid voltage value, let Vb = Vas then the resonant frequency fb=1.4fo. If, due to a change in input voltage, Cm decreases by 35% then fb=1.58 fo, an increase of 13% which may be considered unacceptable.

If now Vb=Vas/3 then fs = 2fo. If again Cm is decreased by 33% then fb =2.12fo

an increase of 6% which may be acceptable. Note that if we ignore all other variations Qb will increase in proportion to fb.

It may be of interest to observe that in the above two paragraphs we have calculated four "alignments" by mental arithmetic, plus a few calculator strokes for the square root values, probably in about the "boot up" time of a PC. A vented box system might take a little longer and will more susceptible to drive unit idiosyncrasies.

I think with our obsession with alignments we are in danger of losing sight of the fundamental fact that the primary function of a loudspeaker box is to prevent the rear radiation canceling that from the front at low frequencies and the ultimate way to do this is with an infinite baffle. Not practical, I agree, but a few of my customers have installed drive units in internal walls. In this case, the "system parameters" are very close to those of an unmounted drive unit. If fo were say 20-25Hz and the Qt around 0.8, it would be difficult to envisage a better arrangement. The Vas would be, of course, very high but in this case, it would not matter. This arrangement would be totally free from the usual problems associated with boxes, such as internal reflections, panel resonances and diffraction effects, not to mention the inevitable frequency and phase aberrations due to reflections from the rear wall extending right up through the mid-band. This in the wall mounted arrangement is frequently employed in most of the major recording studios.

II have read that the purpose of a box is to provide this alignment, or that alignment, and there are at least 15 recognised alignments. I would say that the purpose of a box is to provide a practical compromise solution to the rear radiation problem, whilst maintaining the closes possible performance to the ideal system.

Just as I was completing this article, my eye caught the following in an old business journal: "When the only tool you have is a hammer everything starts to look like a nail. The more sophisticated the tool the graver the risk that its use can seriously skew priorities". Hallelujah! There is another one of us out there somewhere.

I conclude with my favourite quotation from the "Te Tao ching" by Lao Tzu "The great way is very level, but people greatly delight in tortuous paths".

Glossary

Rdc	Electrical resistance
Lvc	Voice coil inductance.
Cem	Effective electrical capacitance due to mechanical mass
Lem	" " inductance due to mechanical compliance
Rem	" " resistance due to mechanical resistance
Zem	" " electrical impedance due to mechnical impedace
Cea	" " capacitance due to acoustical mass
Cm	" " mechanical compliance
Lea	" " inductance due to acoustical compliance
Rea	" " resistance due to acoustical resistance
B	Magnetic flux density
I	Length of voice coil winding in gap
Rm	Mechanical resistance
Lm	Moving mechanical mass
Zm	Mechanical Impedance

Ra	Radiation resistance
La	Radiation mass
Fo	Free air resonance
Fa	Reasonant frequency with the added mass Ma
Ma	Added Mass
Mm	Total moving mass
Qt	Total Qvc
Qe	Electrical Q
Qm	Mechanical Q
Vas	Equivalent volume

Oozlum Bird – The Oozlum Bird was a legendary creature of extreme narcissistic tendencies which eventually managed to achieve its supreme ambition by disappearing up itself, but had overlooked the fact that this not only made it extinct but also cast doubt on whether it ever existed at all.