Subject: T/S Measurements
Posted by Wayne Parham on Sun, 23 Nov 2003 04:50:37 GMT
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A few weeks ago, Akhilesh Bajaj and I set about to measure a loudspeaker's T/S parameters. Our goal was two-fold: To find the T/S parameters of his speaker and also to check the varience between several methods. The equipment used included a PC for generating sine waves, a calibrated oscilloscope and two hand-held DVM's. We measured using the sealed box and added mass methods, and I had intended to compare the results with manufacturer published specs, but this dataset was not present because of the driver chosen.

My conclusions are that measurements are only as good as the instruments and conditions allow. No big surprise. Fortunately, T/S measurements are fairly simple, and only involve making electrical readings. Mechanical parameters are reflected back through the electro-mechanical transformation, and this interface is pretty straightforward. It does not include the complications of the listening room and microphones and what-not, so there is actually not a lot that interferes with the measurements to corrupt them.

There are advantages and disadvantages for both kinds of instruments used, oscilloscopes and DVM's.

Advantages of oscilloscopes:

Easy to verify sine waveform is undistortedLikely to be frequency linear from DC up through the audio bandwidth
Disadvantages of oscilloscopes:

Hard to read with high resolution; You have to read between gradient lines
Advantages of meters:

Inexpensive and easy to useHigh resolution; Reads at 0.001v resolution
Disadvantages of meters:

Can't verify sine waveform is undistortedLess likely to be accurate at very high and very low frequencies; Dependent on A/D circuit sampling speed and filtering; Hard to read display at low frequencies - Readings vascilate and become unuseable
My personal choice is to have both an oscilloscope and DVM on hand. Calibrated bench meters are much more accurate than hand-held units, so if using hand-held models, it might be good to use more than one and verage their results. But it is handy to have both DVM's and oscilloscopes when performing these measurements.

Now to the datasets.

First thing to do is to measure data points. A test resistor is measured and then used in series with the loudspeaker to be tested. Voltages at various frequencies are then measured:

8 ohm test resistor

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
N/A	N/A	N/A	10.3	8.0

Note: Speakers with higher Zmax are more accurately measured with higher value test resistors. Use of 100 or 1000 ohm values is not uncommon, shifting the test conditions more towards having constant current.

Voice coil resistance

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
N/A	N/A	N/A	6.3	6.52

Signal output from amplifier

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
N/A	4.0	1.41	1.462	1.448

Free-air measurements, across voice coil

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
20	2.8	0.99	0.974	0.964
25	3.0	1.06	1.069	1.057
30	3.1	1.10	1.100	1.089
35	3.0	1.06	1.074	1.062
40	3.0	1.06	1.019	1.007
45	2.9	1.03	0.956	0.945
50	2.8	0.99	0.898	0.887
60	2.4	0.85	0.805	0.795
70	2.1	0.74	0.742	0.732
80	2.0	0.71	0.700	0.690
90	1.9	0.67	0.670	0.662
100	1.9	0.67	0.650	0.641
125	1.8	0.64	0.618	0.608
250	1.8	0.64	0.602	0.591

Free-air measurements, across test resistor

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
20	1.4	0.49	0.490	0.477
25	0.85	0.30	0.314	0.302
30	0.80	0.28	0.277	0.267
35	0.90	0.32	0.339	0.329
40	1.35	0.48	0.450	0.442
50	1.8	0.64	0.592	0.584
60	2.0	0.71	0.674	0.666
70	2.1	0.74	0.720	0.711
80	2.2	0.78	0.746	0.738

Free-air resonant frequency is 30Hz.
fl is 20Hz.
fh is 40Hz.

2.15ft3 (60.78 liter) test box measurement, across voice coil

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
20	2.0	0.71	0.695	0.683
25	2.0	0.71	0.708	0.699
30	2.0	0.71	0.725	0.716
35	2.05	0.725	0.745	0.736
40	2.1	0.74	0.771	0.762
45	2.2	0.78	0.808	0.791
50	2.3	0.81	0.862	0.852
55	2.7	0.95	0.928	0.918
60	3.0	1.06	1.030	1.019
65	3.2	1.13	1.149	1.138
70	3.5	1.24	1.234	1.222
75	3.6	1.27	1.250	1.239
80	3.4	1.20	1.198	1.187
90	2.9	1.03	1.032	1.021
100	2.5	0.88	0.890	0.881

2.15ft3 (60.78 liter) test box measurement, across test resistor

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
20	2.1	0.74	0.754	0.744
25	2.12	0.75	0.757	0.745
30	2.1	0.74	0.754	0.745

35	2.1	0.74	0.749	0.739
40	2.1	0.74	0.739	0.730
45	2.1	0.74	0.721	0.712
50	1.95	0.69	0.691	0.682
55	1.9	0.67	0.648	0.640
60	1.6	0.57	0.571	0.563
65	1.3	0.46	0.494	0.437
70	0.9	0.32	0.317	0.311
75	0.9	0.32	0.295	0.289
80	1.1	0.39	0.398	0.391
90	1.75	0.62	0.609	0.601
100	2.05	0.72	0.715	0.707

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Sealed box resonant frequency is 73Hz.
fl is 64Hz.
fh is 83Hz.

15g added-mass measurement, across voice coil

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
10	2.1	0.74	0.759	0.740
15	2.7	0.95	0.959	0.949
20	3.2	1.13	1.133	1.126
23	3.3	1.17	1.175	1.165
25	3.3	1.17	1.179	1.170
30	3.2	1.13	1.140	1.130
35	3.0	1.06	1.056	1.045
40	2.7	0.95	0.972	0.963
50	2.5	0.88	0.852	0.843
60	2.3	0.81	0.787	0.777
70	2.1	0.74	0.748	0.738
80	2.1	0.74	0.724	0.715
90	2.0	0.71	0.708	0.699
100	1.95	0.69	0.697	0.689

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15g added-mass measurement, across test resistor

Frequency	Scope P-P	Scope RMS	Meter1 (RMS)	Meter2 (RMS)
10	1.9	0.67	0.690	0.669
15	1.6	0.57	0.579	0.564
20	1.1	0.39	0.384	0.370

23	0.9	0.32	0.317	0.305
25	0.9	0.32	0.329	0.317
30	1.15	0.41	0.421	0.411
35	1.5	0.53	0.542	0.533
40	1.75	0.62	0.628	0.619
50	1.9	0.67	0.686	0.677
60	2.15	0.76	0.768	0.758
70	2.25	0.80	0.791	0.782
80	2.25	0.80	0.805	0.795
90	2.3	0.81	0.813	0.803
100	2.3	0.81	0.819	0.809

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15g added-mass resonant frequency is 23Hz.

As you can see, there is pretty good correlation between instruments. There is some difference in resistance measurements, so there is some ambiguity there. But the signal measurements are all in fairly close agreement.

Source voltage is 4.0Vp-p and the voltage drop across the 8 ohm resistor is 0.8Vp-p at 30Hz free-air resonance, current flow is 0.1Ap-p. The voltage across the speaker is 3.1Vp-p at 30Hz, which indicates that (Zmax) impedance at resonance is 31 ohms. The voice coil resistance (Re) was measured at 6.3 ohms. Free air resonance (Fs) was found to be 30Hz and bounded by fl of 20Hz and fh of 40Hz.

To find mechanical and electrical Q values, the following formulas are used:

Qms = Fs * (Zmax/Re)0.5 / (Fh - Fl)
Qes = Qms / (Zmax/(Re - 1))
Qts = Qms * Qes / (Qms + Qes)

where

Fs is the resonant frequency of the speaker in free air (Hz)
Zmax is the impedance of the speaker at resonance in free air (ohms)
Re is the DC resistance of the voice coil (ohms)
Fh is the frequency above Fs where speaker impedance is (Zmax*Re)0.5
Fl is the frequency below Fs where speaker impedance is (Zmax*Re)0.5

Note: Fl and Fh can also be found at the points where voltage across the test resistor is equal to Vq in the follwing formula:

Vq = (Vmax*Vmin)0.5

where

Vmin is the voltage across the resistor at the speaker's resonant frequency
Vmax is the voltage across the resistor at a frequency far from resonance

Based on the free-air measurements, the driver was determined to have Fs of 30Hz, Qms of 3.3, Qes of 0.57 and Qts of 0.49.

To find Vas using the sealed box method, the following formula is used:

Vas = Vb((Fb / Fs)2 - 1)

where

Vb is volume of the sealed cabinet (ft3, m3 or liters)
Fb is the resonant frequency of the speaker in the box (Hz)
Fs is the free-air resonance of the speaker (Hz)

Vb is known to be 2.15ft3 or 60.78 liters. Fs was found to be 30Hz and Fb was found to be 73Hz. Based on these sealed box measurements, the driver was determined to have Vas of approximately 10.6ft3 or 300 liters.

To find Vas using the added-mass method, the following formulas are used:

Cms = 1 / (4<span style='font-size:14.0pt'>π[/notag]2M) * (((Fs + Fm) * (Fs - Fm)) / Fs2Fm2)
Vas = rho * c2 * Sd2 * Cms

where

Fs is free air resonance (Hz)
Fm is the mass-added resonance (Hz)
M is the added mass (grams)
Sd is the area of the radiating surface (m2)
rho is the mass density of air (approximately 1.20 kg/m3)
c is the speed of sound in air (approximately 343 m/s)

An accurate value of Sd is very critical, since it is squared to find Vas from Cms. Cms is fairly consistent, but deriving Vas from it can vary considerably depending on whether you consider the surround and dust cap to be part if the radiating surface. I estimated radiating surface area to include the dust cap but not the surround, and concluded that Sd should be approximately 70in2, which is 0.045m2. The mass added to the cone (M) was 15g and the resonant frequency with this mass added (Fm) was 23Hz.

From this, we find:

Cms = 1.3mm/N
Vas = 0.37m3, 372 liters or 13.1ft3.

Notice that Vas is approximately 20% higher using the added-mass method. This may be due to measurement ambiguity or it may be from an inaccurate estimate of the radiating surface area or another parameter. For example, if the radiating area is reduced by just 5in2 (0.003m2), Vas then calculates to about 11.43 (324 liters). This small change represents about a 10% difference.