DATS Loudspeaker Parameter Measurement Overview and Impedance Accuracy Evaluation

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Small-Signal Loudspeaker Parameters:

The so called "small-signal" parameters characterize the resonance of a speaker in normal operation. Like many other electronic devices, loudspeakers have an input signal range where they work normally. Above that range is some threshold above which the speaker exhibits misbehavior such as increasing distortion, reduced output, or even catastrophic failure. The signal range where the speaker operates normally is called the "linear region," versus the "non-linear region" where distortion rises rapidly. The small-signal region is that region between the noise floor and the point where the system is no longer linear. This is the signal range where a loudspeaker's small-signal parameters are measured. Small-signal testing is usually performed at the lowest signal level where there is adequate signal-to-noise ratio. See Figure 1 for a comparison of small-signal and large-signal ranges of operation.

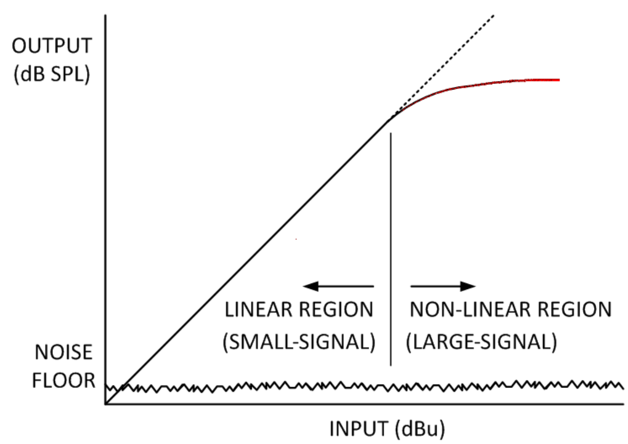

Figure 1: Small-signal versus large signal operating ranges

DATS calculates a loudspeaker transducer's small-signal parameters from its impedance measurement, using techniques established by Thiele[1] and Small[2] themselves. In addition to the small-signal parameters DATS measures directly, it also calculates various other parameters.

The small-signal parameters of a loudspeaker are[1]:

f_S	The free air resonance
Q_{ES}	The electrical Q
Q_{MS}	The mechanical Q
Q_{TS}	The total Q
S_D	The piston area
V_{AS}	The equivalent volume of the suspension
R_E	The DC resistance of the voice coil

In contrast to the small-signal parameters, the large-signal parameters are intended to characterize the driver's performance limitations as it becomes non-linear. Large-signal parameters are usually best left to the manufacturer to measure, as they may require disassembly or destructive testing. The large-signal parameters include:

$P_{E(MAX)}$	The thermally limited input power
X_{MAX}	The maximum linear excursion
X_{MECH}	The mechanical excursion limit
VD	The maximum displacement volume

There seems to be a bit of confusion in some DIY speaker circles about what signal level is appropriate for measuring small-signal parameters, so let's look at this question more closely. In his groundbreaking paper titled "*Loudspeakers in Vented Boxes,*" Neville Thiele[1] discusses the test signal level and states:

> **"The value is not of great importance, but a standard test figure is 1 volt."**

In his excellent book titled "*Testing Loudspeakers,*" Joe D'Appolito[3] writes:

> **"The T/S parameters are *"small signal"* parameters. It is important …to keep drive levels as low as your instrumentation will allow while still providing reliable results."**

So there is no reason to measure Thiele/Small parameters at any particular level, as long as the measurement is not contaminated with noise and is well below the large-signal threshold. DATS allows the user to set the level of the test signal sweep anywhere in the range from +5 dBu (2 volts peak) to -10 dBu (0.35 V peak) within the software. This constitutes the small-signal range for the vast majority of speakers, but note that some micro-speakers could be pushed into the non-linear region at DATS maximum output level.

The objection is heard occasionally that f_S can change with drive level, so it would seem that the parameters should be measured at higher power levels. It is easy to demonstrate—in the case of well-designed transducers that are operating normally (i.e., not damaged)—that the f_S of a driver does not change significantly over a very wide range of operation. In fact, a shifting in f_S at high drive levels would indicate the onset of nonlinearity and would not constitute a valid small-signal measurement. At the other extreme, a shift in f_S at low drive levels is an indication that a driver has mechanical obstructions such as debris in the magnetic gap. This behavior is the basis for the DATS rub and buzz test. For example, Figure 2 shows the impedance of a transducer (Dayton Audio RS-100) measured at eight different drive levels over a 70 dB range in 10 dB steps. At the lowest drive levels, the resonance vanishes into the noise but the shape (Q) and center frequency (f_S) remain unchanged over the 70 dB range of measurement signal level. This is typical behavior for a good driver.

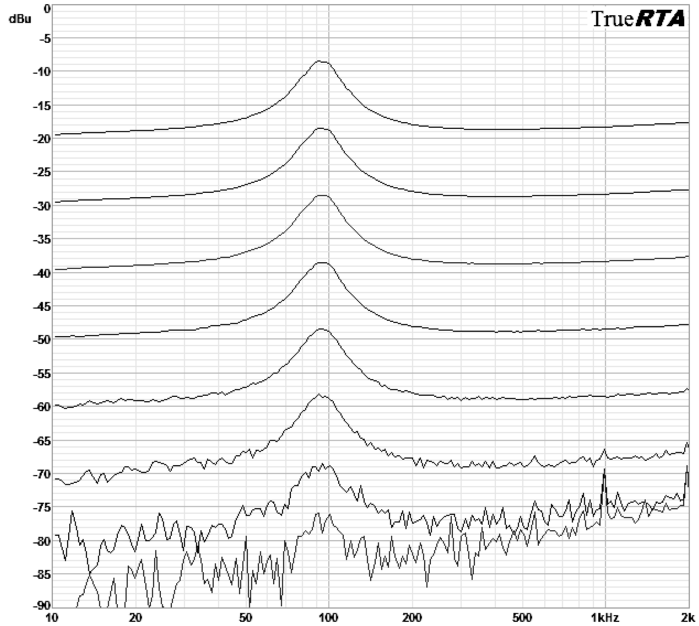

Figure 2: Impedance Response at Progressively Lower Signal Levels for a Properly Functioning Loudspeaker.

In comparison, Figure 3 shows the same test repeated on a different driver with a rubbing voice coil.

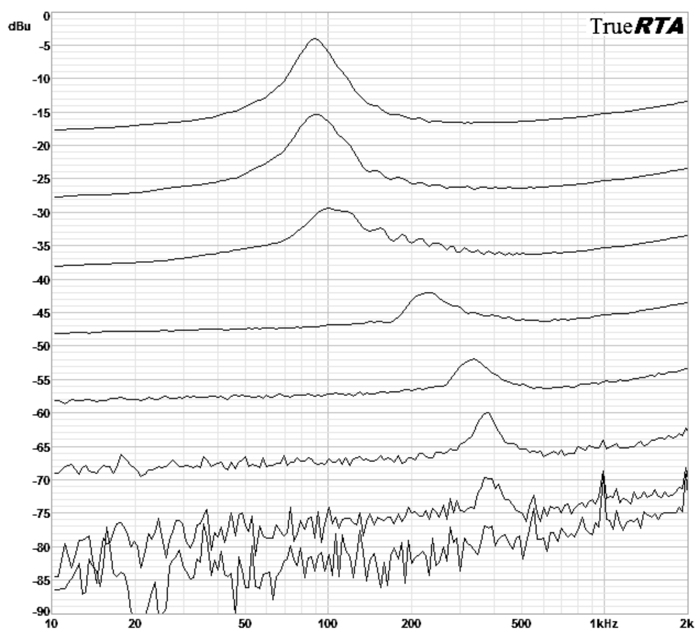

Figure 3: Impedance Response at Progressively Lower Signal Levels for a Defective Loudspeaker.

DATS Accuracy and Precision:

The Dayton Audio Test System, DATS, sets a high standard for speed, accuracy, and precision in audio impedance testing and loudspeaker parameter measurement. While the unofficial accuracy specification for DATS impedance measurements is +/- 2%, the product actually performs much better than this and is limited primarily by the 1% tolerance of the calibration resistor. Basic accuracy and repeatability (precision) test results for six randomly selected DATS units are given in Appendices A through F. A summary of the results is given in Figure 4 and shows a worst case error of -2.179% at 1 Ohm compared to error under 0.5% at higher frequencies. The error at 1 Ohm may seem like a high percentage, but never exceeds 0.025 Ohms. From the raw measurement data shown in the appendices it is clear that the repeatability of DATS measurements is excellent, and in some instances the same value is measured for all ten measurements. Frequently the first three digits are constant for all ten measurements, indicating excellent measurement precision.

Unit ID	1000 Ohms	100 Ohms	10 Ohms	1 Ohms
A	-.032%	+.040%	-.131%	-2.179% (-.022 Ω)
B	-.023%	+.034%	-.108%	-1.899% (-.019 Ω)
C	+.132%	-.329%	-.482%	-2.142% (-.021Ω)
D	+.162%	+.146%	+.065%	-.815% (-.0081Ω)
E	+.047%	+.301%	+.284%	-.083% (-.0008Ω)
F	-.032%	-.015%	-.299%	-1.604% (-.016Ω)

Figure 4: Mean measurement error for ten trials at each impedance for each unit.

The six test units performed with accuracy better than +/-1%, except at 1 Ohm, where the highest percentage error was -2.179% for unit A. This may sound high until you realize that the actual error never exceeded 0.025 Ohms. **The accuracy specification for these six units (calibrated to +/- 0.1% at 1k Ohms) would be +/- 0.5% or .025 Ohms, whichever is greater.** When calibrated with a 1% resistor the accuracy specification would be degraded to +/- 1.5% or .035 Ohms, whichever is greater. Similar testing on capacitors and inductors reveals this same high level of accuracy. Out of the box and uncalibrated, it is normal for DATS units to exhibit a basic accuracy of around +/-5%.

References:

[1] A. N. Thiele, "Loudspeakers in Vented Boxes: Part I and II, Loudspeaker Anthology, vol. 1 (Audio Eng. Society, New York, 1978).

[2] R.H. Small, "Vented-Box Loudspeaker Systems, Part I: Small-Signal Analysis, "*J. Audio Eng. Soc.*, vol. 21, (June 1973).

[3] Joseph D'Appolito, "Testing Loudspeakers", published by Audio Amateur Press, 1998.

Appendix A: Unit A Evaluation Results

DATS Accuracy and Precision Evaluation

Date: 23-Nov-13

Test Unit ID: A

Calibrated at: 1000 Ohms +/- 0.1%

Known Value: 1000 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	999.86	0.183	0.018%
2	999.8	0.123	0.012%
3	999.32	-0.357	-0.036%
4	999.82	0.143	0.014%
5	999.94	0.263	0.026%
6	999.92	0.243	0.024%
7	998.31	-1.367	-0.137%
8	999.88	0.203	0.020%
9	999.97	0.293	0.029%
10	999.95	0.273	0.027%
	Mean =	**999.677**	
	Error =	**-0.323**	**-0.032%**
	Std Deviation =	**0.5159**	**0.0516%**

Known Value: 100 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	100.04	0	0.0000%
2	100.04	0	0.0000%
3	100.04	0	0.0000%
4	100.04	0	0.0000%
5	100.04	0	0.0000%
6	100.04	0	0.0000%
7	100.04	0	0.0000%
8	100.04	0	0.0000%
9	100.04	0	0.0000%
10	100.04	0	0.0000%
	Mean =	**100.04**	
	Error =	**0.04**	**0.040%**
	Std Deviation =	**0.00000**	**0.0000%**

Known Value: 10 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	10.009	0.02210	0.22129%
2	9.9849	-0.00200	-0.02003%
3	9.984	-0.00290	-0.02904%
4	9.9843	-0.00260	-0.02603%
5	9.9845	-0.00240	-0.02403%
6	9.9847	-0.00220	-0.02203%
7	9.9839	-0.00300	-0.03004%
8	9.9841	-0.00280	-0.02804%
9	9.9851	-0.00180	-0.01802%
10	9.9845	-0.00240	-0.02403%
	Mean =	**9.9869**	
	Error =	**-0.0131**	**-0.131%**
	Std Deviation =	**0.00777**	**0.0778%**

Known Value: 1 Ohms, 1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	0.9781	-0.00011	-0.01125%
2	0.9789	0.00069	0.07054%
3	0.9782	-1E-05	-0.00102%
4	0.9789	0.00069	0.07054%
5	0.978	-0.00021	-0.02147%
6	0.9786	0.00039	0.03987%
7	0.9784	0.00019	0.01942%
8	0.9783	9E-05	0.00920%
9	0.9778	-0.00041	-0.04191%
10	0.9769	-0.00131	-0.13392%
	Mean =	**0.97821**	
	Error =	**-0.02179**	**-2.179%**
	Std Deviation =	**0.00059**	**0.0599%**

Appendix B: Unit B Evaluation Results

DATS Accuracy and Precision Evaluation

Date: 23-Nov-13

Test Unit ID: B

Calibrated at: 1000 Ohms +/- 0.1%

Known Value: 1000	Ohms		0.1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	999.87	0.097	0.010%
2	999.8	0.027	0.003%
3	999.9	0.127	0.013%
4	999.86	0.087	0.009%
5	999.69	-0.083	-0.008%
6	999.68	-0.093	-0.009%
7	999.74	-0.033	-0.003%
8	999.67	-0.103	-0.010%
9	999.8	0.027	0.003%
10	999.72	-0.053	-0.005%
	Mean =	**999.773**	
	Error =	**-0.227**	**-0.023%**
	Std Deviation =	**0.0847**	**0.0085%**

Known Value: 100	Ohms		0.1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	100.03	-0.004	-0.0040%
2	100.04	0.006	0.0060%
3	100.03	-0.004	-0.0040%
4	100.04	0.006	0.0060%
5	100.04	0.006	0.0060%
6	100.04	0.006	0.0060%
7	100.03	-0.004	-0.0040%
8	100.03	-0.004	-0.0040%
9	100.03	-0.004	-0.0040%
10	100.03	-0.004	-0.0040%
	Mean =	**100.034**	
	Error =	**0.034**	**0.034%**
	Std Deviation =	**0.00516**	**0.0052%**

Known Value: 10	Ohms		0.1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	9.9895	0.00028	0.00280%
2	9.9889	-0.00032	-0.00320%
3	9.9892	-0.00002	-0.00020%
4	9.9893	0.00008	0.00080%
5	9.989	-0.00022	-0.00220%
6	9.9893	0.00008	0.00080%
7	9.989	-0.00022	-0.00220%
8	9.9888	-0.00042	-0.00420%
9	9.9893	0.00008	0.00080%
10	9.9899	0.00068	0.00681%
	Mean =	**9.98922**	
	Error =	**-0.01078**	**-0.108%**
	Std Deviation =	**0.00032**	**0.0032%**

Known Value: 1	Ohms		1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	0.981	-1E-05	-0.00102%
2	0.9814	0.00039	0.03975%
3	0.9809	-0.00011	-0.01121%
4	0.9804	-0.00061	-0.06218%
5	0.9806	-0.00041	-0.04179%
6	0.9814	0.00039	0.03975%
7	0.9803	-0.00071	-0.07237%
8	0.9811	9E-05	0.00917%
9	0.9808	-0.00021	-0.02141%
10	0.9822	0.00119	0.12130%
	Mean =	**0.98101**	
	Error =	**-0.01899**	**-1.899%**
	Std Deviation =	**0.00056**	**0.0572%**

Appendix C: Unit C Evaluation Results

DATS Accuracy and Precision Evaluation

Date: 23-Nov-13

Test Unit ID: C (flaky unit)

Calibrated at: 1000 Ohms +/- 0.1%

Known Value: 1000 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	1000	-1.32	-0.132%
2	1002.7	1.38	0.138%
3	1001.1	-0.22	-0.022%
4	1002.5	1.18	0.118%
5	1000.7	-0.62	-0.062%
6	1002.5	1.18	0.118%
7	1000.4	-0.92	-0.092%
8	1000.1	-1.22	-0.122%
9	1002.6	1.28	0.128%
10	1000.6	-0.72	-0.072%
	Mean =	**1001.32**	
	Error =	**1.32**	**0.132%**
	Std Deviation =	**1.1233**	**0.1122%**

Known Value: 100 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	99.668	-0.003	-0.0030%
2	99.673	0.002	0.0020%
3	99.674	0.003	0.0030%
4	99.672	0.001	0.0010%
5	99.672	0.001	0.0010%
6	99.669	-0.002	-0.0020%
7	99.673	0.002	0.0020%
8	99.668	-0.003	-0.0030%
9	99.669	-0.002	-0.0020%
10	99.672	0.001	0.0010%
	Mean =	**99.671**	
	Error =	**-0.329**	**-0.329%**
	Std Deviation =	**0.00226**	**0.0023%**

Known Value: 10 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	9.9532	0.00140	0.01407%
2	9.9507	-0.00110	-0.01105%
3	9.9522	0.00040	0.00402%
4	9.952	0.00020	0.00201%
5	9.9511	-0.00070	-0.00703%
6	9.9514	-0.00040	-0.00402%
7	9.9519	0.00010	0.00100%
8	9.9518	0.00000	0.00000%
9	9.9519	0.00010	0.00100%
10	9.9518	0.00000	0.00000%
	Mean =	**9.9518**	
	Error =	**-0.0482**	**-0.482%**
	Std Deviation =	**0.00067**	**0.0067%**

Known Value: 1 Ohms, 1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	0.9785	-8E-05	-0.00818%
2	0.9784	-0.00018	-0.01839%
3	0.9783	-0.00028	-0.02861%
4	0.9784	-0.00018	-0.01839%
5	0.9781	-0.00048	-0.04905%
6	0.9784	-0.00018	-0.01839%
7	0.9789	0.00032	0.03270%
8	0.9784	-0.00018	-0.01839%
9	0.9792	0.00062	0.06336%
10	0.9792	0.00062	0.06336%
	Mean =	**0.97858**	
	Error =	**-0.02142**	**-2.142%**
	Std Deviation =	**0.00038**	**0.0391%**

Appendix D: Unit D Evaluation Results

DATS Accuracy and Precision Evaluation

Date: 24-Nov-13

Test Unit ID: D

Calibrated at: 1000 Ohms +/- 0.1%

Known Value: 1000	Ohms		0.1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	1002.1	0.485	0.048%
2	999.95	-1.665	-0.166%
3	1002	0.385	0.038%
4	1001.9	0.285	0.028%
5	1002	0.385	0.038%
6	1002	0.385	0.038%
7	1000	-1.615	-0.161%
8	1002.1	0.485	0.048%
9	1002.1	0.485	0.048%
10	1002	0.385	0.038%
	Mean =	**1001.615**	
	Error =	**1.615**	**0.162%**
	Std Deviation =	**0.8667**	**0.0865%**

Known Value: 100	Ohms		0.1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	100.15	0.004	0.0040%
2	100.15	0.004	0.0040%
3	100.15	0.004	0.0040%
4	100.14	-0.006	-0.0060%
5	100.15	0.004	0.0040%
6	100.15	0.004	0.0040%
7	100.15	0.004	0.0040%
8	100.12	-0.026	-0.0260%
9	100.15	0.004	0.0040%
10	100.15	0.004	0.0040%
	Mean =	**100.146**	
	Error =	**0.146**	**0.146%**
	Std Deviation =	**0.00966**	**0.0096%**

Known Value: 10	Ohms		0.1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	10.007	0.00050	0.00500%
2	10.007	0.00050	0.00500%
3	10.006	-0.00050	-0.00500%
4	10.006	-0.00050	-0.00500%
5	10.008	0.00150	0.01499%
6	10.006	-0.00050	-0.00500%
7	10.007	0.00050	0.00500%
8	10.006	-0.00050	-0.00500%
9	10.006	-0.00050	-0.00500%
10	10.006	-0.00050	-0.00500%
	Mean =	**10.0065**	
	Error =	**0.0065**	**0.065%**
	Std Deviation =	**0.00071**	**0.0071%**

Known Value: 1	Ohms		1 % tolerance
Trial	Measurement	deviation from avg.	% deviation
1	0.9912	-0.00065	-0.06553%
2	0.9914	-0.00045	-0.04537%
3	0.9923	0.00045	0.04537%
4	0.9914	-0.00045	-0.04537%
5	0.9927	0.00085	0.08570%
6	0.9924	0.00055	0.05545%
7	0.9924	0.00055	0.05545%
8	0.9922	0.00035	0.03529%
9	0.9912	-0.00065	-0.06553%
10	0.9913	-0.00055	-0.05545%
	Mean =	**0.99185**	
	Error =	**-0.00815**	**-0.815%**
	Std Deviation =	**0.00060**	**0.0602%**

Appendix E: Unit E Evaluation Results

DATS Accuracy and Precision Evaluation

Date: 24-Nov-13

Test Unit ID: E

Calibrated at: 1000 Ohms +/- 0.1%

Known Value: 1000 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	1000.3	-0.17	-0.017%
2	1000.4	-0.07	-0.007%
3	1000.5	0.03	0.003%
4	1000.3	-0.17	-0.017%
5	1000.4	-0.07	-0.007%
6	1000.6	0.13	0.013%
7	1000.5	0.03	0.003%
8	1000.6	0.13	0.013%
9	1000.5	0.03	0.003%
10	1000.6	0.13	0.013%
	Mean =	**1000.47**	
	Error =	**0.47**	**0.047%**
	Std Deviation =	**0.1160**	**0.0116%**

Known Value: 100 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	100.3	-0.001	-0.0010%
2	100.3	-0.001	-0.0010%
3	100.3	-0.001	-0.0010%
4	100.3	-0.001	-0.0010%
5	100.3	-0.001	-0.0010%
6	100.31	0.009	0.0090%
7	100.3	-0.001	-0.0010%
8	100.3	-0.001	-0.0010%
9	100.3	-0.001	-0.0010%
10	100.3	-0.001	-0.0010%
	Mean =	**100.301**	
	Error =	**0.301**	**0.301%**
	Std Deviation =	**0.00316**	**0.0032%**

Known Value: 10 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	10.029	0.00060	0.00598%
2	10.028	-0.00040	-0.00399%
3	10.027	-0.00140	-0.01396%
4	10.029	0.00060	0.00598%
5	10.028	-0.00040	-0.00399%
6	10.029	0.00060	0.00598%
7	10.028	-0.00040	-0.00399%
8	10.028	-0.00040	-0.00399%
9	10.029	0.00060	0.00598%
10	10.029	0.00060	0.00598%
	Mean =	**10.0284**	
	Error =	**0.0284**	**0.284%**
	Std Deviation =	**0.00070**	**0.0070%**

Known Value: 1 Ohms, 1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	0.9984	-0.00077	-0.07706%
2	0.9998	0.00063	0.06305%
3	0.9992	3E-05	0.00300%
4	0.9994	0.00023	0.02302%
5	0.999	-0.00017	-0.01701%
6	0.9998	0.00063	0.06305%
7	0.999	-0.00017	-0.01701%
8	0.9987	-0.00047	-0.04704%
9	0.9992	3E-05	0.00300%
10	0.9992	3E-05	0.00300%
	Mean =	**0.99917**	
	Error =	**-0.00083**	**-0.083%**
	Std Deviation =	**0.00044**	**0.0438%**

Appendix F: Unit F Evaluation Results

DATS Accuracy and Precision Evaluation

Date: 24-Nov-13

Test Unit ID: F

Calibrated at: 1000 Ohms +/- 0.1%

Known Value: 1000 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	999.81	0.126	0.013%
2	999.78	0.096	0.010%
3	999.82	0.136	0.014%
4	999.78	0.096	0.010%
5	999.51	-0.174	-0.017%
6	999.68	-0.004	0.000%
7	999.64	-0.044	-0.004%
8	999.67	-0.014	-0.001%
9	999.69	0.006	0.001%
10	999.46	-0.224	-0.022%
	Mean =	**999.684**	
	Error =	**-0.316**	**-0.032%**
	Std Deviation =	**0.1227**	**0.0123%**

Known Value: 100 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	99.849	0.0013	0.0013%
2	99.845	-0.0027	-0.0027%
3	99.849	0.0013	0.0013%
4	99.847	-0.0007	-0.0007%
5	99.847	-0.0007	-0.0007%
6	99.845	-0.0027	-0.0027%
7	99.847	-0.0007	-0.0007%
8	99.849	0.0013	0.0013%
9	99.846	-0.0017	-0.0017%
10	99.853	0.0053	0.0053%
	Mean =	**99.8477**	
	Error =	**-0.1523**	**-0.152%**
	Std Deviation =	**0.00241**	**0.0024%**

Known Value: 10 Ohms, 0.1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	9.9695	-0.00056	-0.00562%
2	9.9699	-0.00016	-0.00160%
3	9.9704	0.00034	0.00341%
4	9.9698	-0.00026	-0.00261%
5	9.9703	0.00024	0.00241%
6	9.9701	0.00004	0.00040%
7	9.9704	0.00034	0.00341%
8	9.9703	0.00024	0.00241%
9	9.97	-0.00006	-0.00060%
10	9.9699	-0.00016	-0.00160%
	Mean =	**9.97006**	
	Error =	**-0.02994**	**-0.299%**
	Std Deviation =	**0.00030**	**0.0030%**

Known Value: 1 Ohms, 1 % tolerance

Trial	Measurement	deviation from avg.	% deviation
1	0.9841	0.00014	0.01423%
2	0.9838	-0.00016	-0.01626%
3	0.9833	-0.00066	-0.06708%
4	0.984	4E-05	0.00407%
5	0.9836	-0.00036	-0.03659%
6	0.9843	0.00034	0.03455%
7	0.9841	0.00014	0.01423%
8	0.9841	0.00014	0.01423%
9	0.9836	-0.00036	-0.03659%
10	0.9847	0.00074	0.07521%
	Mean =	**0.98396**	
	Error =	**-0.01604**	**-1.604%**
	Std Deviation =	**0.00040**	**0.0407%**