Attenuation Tests of the HDice RF Attenuation and Switching Unit

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For an NMR scan, an RF signal is sent to the target and to the lock-in amplifier via an RF Attenuation and Switching Unit (RF Box)[1]. This note discusses the attenuation test results of the new RF Boxes that were fabricated by DSG for HDice.

For the attenuation test, Fig. 1, a LabVIEW program was developed to inject 1 MHz, 5 V, peak-to-peak sine waves into an RF Box, whose attenuation settings were varied by LabVIEW from -63 dB to 0 dB in 1 dB steps. At each step, 100 samples of the output waveform were acquired.

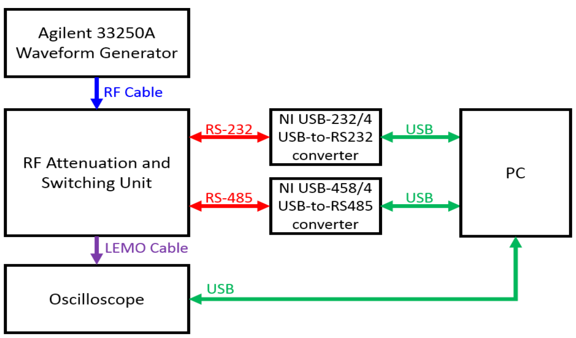

FIG. 1. System diagram for RF Box attenuation test. The Agilent Waveform Generator is manually controlled; all other equipment is remotely controlled with test PC.

The RF Box's internal splitter splits and routes the input RF signal to its NMR attenuator, AFP attenuator, and the Lock-in Amplifier front panel output [1], causing ~ -5.09 dB attenuation for all signals that pass through either the NMR attenuator or AFP attenuator.

To take into account the baseline attenuation, first the LabVIEW program prompts the user to connect the waveform generator directly to the oscilloscope to measure the RF Box's input signal. Next, the user is prompted to reconnect the waveform generator to the RF Box input and the RF Box output to the oscilloscope to measure the 0 dB attenuation baseline. This 0 dB baseline result is used to calculate the attenuation for all other attenuation settings.

For the analysis, initially the LabVIEW program was used to fit the output waveform and to calculate the attenuation. The total time taken to read all 64 output data files and calculate the attenuation was ~2.5 hours.

To speed up the analysis, a Python program was developed to read the LabVIEW output data files and calculate the attenuation. Like the LabVIEW program, the Python program processes the LabVIEW program's output data files, makes the sine fit of the output signal and calculates the attenuation. The Python program completed the analysis in ~2 minutes, 75 times faster.

As a check, the average absolute difference of the calculated attenuations by LabVIEW and by Python were computed and noted to be ~10^{-6} dB (full comparison in Table I). Because of its speed, the Python program was selected for analysis.

The RF Box splitter's attenuation was calculated to be -5.083 dB ± 0.004 dB, a 0.136% difference from its -5.09 dB specification for a 1 MHz signal.

Results indicated that the NMR attenuator had an average difference of 0.390 dB ± 0.133 dB from set attenuation values over all settings, Fig. 2 and Table II.

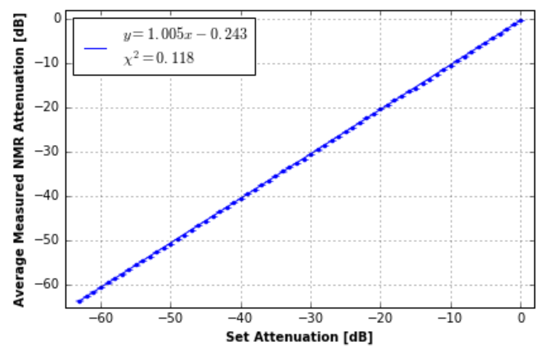

FIG. 2. NMR attenuator set value versus mean measured attenuation.

Results indicate that the AFP attenuator had an average difference of 0.307 dB ± 0.123 dB from set attenuation values over all settings, Fig. 3 and Table III.

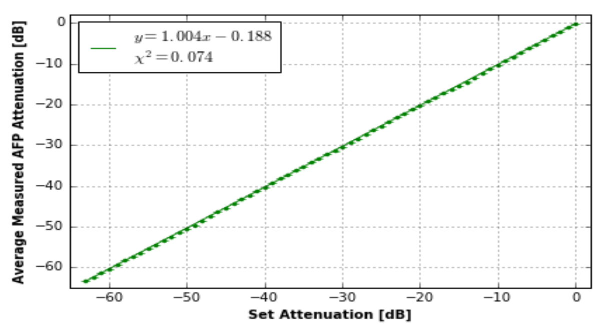

FIG. 3. AFP attenuator set value versus mean measured attenuation.

Overall, the results of the RF Box attenuation tests show that the output signal from the RF Box will be within 0.349 dB ± 0.181 dB with respect to the RF Box's set attenuation values.

[1] M. A. Antonioli, et al. *HDice RF Attenuation and Switching Unit Fabrication and Upgrades* DSG Note 2018-10, 2018.

Set attenuation [dB]	LabVIEW		Python		Absolute difference	
	Average attenuation [dB]	Standard deviation [dB]	Average attenuation [dB]	Standard deviation [dB]	|LabVIEW average− Python average| [dB]	Standard deviation [dB]
-5.09	-5.083	0.004	-5.083	0.004	5.000E-06	0.005
0	-0.112	0.003	-0.112	0.003	0.000E+00	0.005
-1	-1.118	0.004	-1.118	0.004	4.000E-06	0.005
-2	-2.143	0.004	-2.143	0.004	0.000E+00	0.005
-3	-3.167	0.004	-3.167	0.004	3.000E-06	0.005
-4	-4.215	0.004	-4.215	0.004	3.000E-06	0.006
-5	-5.244	0.004	-5.244	0.004	1.000E-06	0.006
-6	-6.252	0.005	-6.252	0.005	4.000E-06	0.006
-7	-7.260	0.005	-7.260	0.005	4.000E-06	0.007
-8	-8.309	0.005	-8.309	0.005	1.000E-06	0.008
-9	-9.352	0.006	-9.352	0.006	5.000E-06	0.008
-10	-10.386	0.006	-10.386	0.006	4.000E-06	0.008
-11	-11.418	0.007	-11.418	0.007	3.800E-05	0.010
-12	-12.470	0.008	-12.470	0.008	3.300E-05	0.011
-13	-13.496	0.009	-13.496	0.009	2.800E-05	0.013
-14	-14.523	0.009	-14.523	0.009	2.500E-05	0.012
-15	-15.582	0.011	-15.582	0.011	3.600E-05	0.016
-16	-16.241	0.003	-16.241	0.003	1.300E-05	0.005
-17	-17.245	0.003	-17.244	0.003	1.100E-05	0.005
-18	-18.250	0.003	-18.250	0.003	1.600E-05	0.005
-19	-19.254	0.003	-19.253	0.003	4.000E-06	0.005
-20	-20.275	0.003	-20.275	0.003	5.000E-06	0.005
-21	-21.266	0.004	-21.266	0.004	3.100E-05	0.005
-22	-22.276	0.004	-22.276	0.004	3.300E-05	0.006
-23	-23.289	0.004	-23.289	0.004	4.200E-05	0.006
-24	-24.328	0.004	-24.328	0.004	1.000E-05	0.006
-25	-25.346	0.005	-25.346	0.004	3.300E-05	0.006
-26	-26.350	0.005	-26.350	0.005	8.000E-06	0.007
-27	-27.357	0.005	-27.357	0.005	5.000E-06	0.007
-28	-28.406	0.005	-28.406	0.005	1.000E-06	0.008
-29	-29.444	0.006	-29.444	0.006	1.100E-05	0.009
-30	-30.470	0.006	-30.470	0.006	3.300E-05	0.009
-31	-31.506	0.007	-31.506	0.007	2.300E-05	0.010
-32	-32.308	0.003	-32.308	0.003	1.600E-05	0.005
-33	-33.309	0.003	-33.309	0.003	4.400E-05	0.005
-34	-34.300	0.004	-34.300	0.004	3.100E-05	0.005
-35	-35.304	0.004	-35.304	0.004	2.500E-05	0.005
-36	-36.324	0.004	-36.324	0.004	1.300E-05	0.006
-37	-37.344	0.004	-37.344	0.004	2.500E-05	0.006
-38	-38.352	0.004	-38.352	0.004	4.800E-05	0.006
-39	-39.353	0.005	-39.353	0.005	4.900E-05	0.007

-40	-40.397	0.005	-40.397	0.005	4.500E-05	0.006
-41	-41.419	0.006	-41.419	0.006	4.700E-05	0.008
-42	-42.433	0.006	-42.433	0.006	3.600E-05	0.008
-43	-43.436	0.007	-43.435	0.006	4.700E-05	0.009
-44	-44.482	0.007	-44.482	0.007	3.400E-05	0.010
-45	-45.511	0.009	-45.511	0.009	1.200E-05	0.012
-46	-46.546	0.010	-46.546	0.010	2.900E-05	0.014
-47	-47.565	0.009	-47.565	0.009	4.400E-05	0.013
-48	-48.689	0.010	-48.689	0.010	1.000E-06	0.014
-49	-49.703	0.012	-49.703	0.012	3.300E-05	0.017
-50	-50.710	0.015	-50.710	0.015	3.600E-05	0.021
-51	-51.506	0.008	-51.506	0.008	1.000E-06	0.012
-52	-52.523	0.009	-52.523	0.009	3.400E-05	0.013
-53	-53.508	0.011	-53.508	0.011	1.400E-05	0.016
-54	-54.498	0.011	-54.498	0.011	3.500E-05	0.016
-55	-55.432	0.011	-55.432	0.011	4.000E-05	0.016
-56	-56.539	0.014	-56.539	0.014	2.300E-05	0.020
-57	-57.443	0.016	-57.443	0.016	1.900E-05	0.022
-58	-58.427	0.017	-58.427	0.017	1.700E-05	0.024
-59	-59.427	0.018	-59.427	0.017	3.500E-05	0.025
-60	-60.464	0.021	-60.464	0.021	3.800E-05	0.030
-61	-61.448	0.019	-61.448	0.019	2.300E-05	0.027
-62	-62.439	0.028	-62.439	0.028	2.800E-05	0.039
-63	-63.446	0.027	-63.446	0.027	0.000E+00	0.038

TABLE I. Comparison of attenuation test results when attenuation is calculated in LabVIEW vs. Python. Because the difference between calculation methods is so small, Python was chosen as the calculation method due to the calculation only taking ~2 minutes, as opposed to ~2.5 hours for LabVIEW.

NMR attenuator test results					
Set attenuation [dB]	Average calculated attenuations [dB]	Standard deviation of calculated attenuations [dB]	Set attenuation [dB]	Average calculated attenuations [dB]	Standard deviation of calculated attenuations [dB]
Splitter (-5.09)	-5.083	0.004	-32	-32.308	0.003
0	-0.112	0.003	-33	-33.309	0.003
-1	-1.118	0.004	-34	-34.300	0.004
-2	-2.143	0.004	-35	-35.304	0.004
-3	-3.167	0.004	-36	-36.324	0.004
-4	-4.215	0.004	-37	-37.344	0.004
-5	-5.244	0.004	-38	-38.352	0.004
-6	-6.252	0.005	-39	-39.353	0.005
-7	-7.260	0.005	-40	-40.397	0.005
-8	-8.309	0.005	-41	-41.419	0.006
-9	-9.352	0.006	-42	-42.433	0.006
-10	-10.386	0.006	-43	-43.435	0.006
-11	-11.418	0.007	-44	-44.482	0.007
-12	-12.470	0.008	-45	-45.511	0.009
-13	-13.496	0.009	-46	-46.546	0.010
-14	-14.523	0.009	-47	-47.565	0.009
-15	-15.582	0.011	-48	-48.689	0.010
-16	-16.241	0.003	-49	-49.703	0.012
-17	-17.244	0.003	-50	-50.710	0.015
-18	-18.250	0.003	-51	-51.506	0.008
-19	-19.253	0.003	-52	-52.523	0.009
-20	-20.275	0.003	-53	-53.508	0.011
-21	-21.266	0.004	-54	-54.498	0.011
-22	-22.276	0.004	-55	-55.432	0.011
-23	-23.289	0.004	-56	-56.539	0.014
-24	-24.328	0.004	-57	-57.443	0.016
-25	-25.346	0.004	-58	-58.427	0.017
-26	-26.350	0.005	-59	-59.427	0.017
-27	-27.357	0.005	-60	-60.464	0.021
-28	-28.406	0.005	-61	-61.448	0.019
-29	-29.444	0.006	-62	-62.439	0.028
-30	-30.470	0.006	-63	-63.446	0.027
-31	-31.506	0.007			

TABLE II. Results of RF Box attenuation test for NMR attenuator. Under "Set Attenuation [dB]" column, "splitter" refers to the measurement of the RF-Box splitter attenuation with respect to the input signal. All other values in that column are measured with respect to a 0-dB reference signal.

AFP attenuator test results					
Set attenuation [dB]	Average calculated attenuations [dB]	Standard deviation of calculated attenuations [dB]	Set attenuation [dB]	Average calculated attenuations [dB]	Standard deviation of calculated attenuations [dB]
Splitter (-5.09)	-5.166	0.004	-32	-32.173	0.004
0	-0.108	0.004	-33	-33.178	0.004
-1	-1.095	0.004	-34	-34.170	0.004
-2	-2.103	0.004	-35	-35.176	0.004
-3	-3.115	0.004	-36	-36.209	0.004
-4	-4.168	0.004	-37	-37.228	0.004
-5	-5.187	0.004	-38	-38.235	0.005
-6	-6.190	0.005	-39	-39.238	0.005
-7	-7.194	0.005	-40	-40.269	0.005
-8	-8.233	0.006	-41	-41.297	0.005
-9	-9.273	0.006	-42	-42.308	0.006
-10	-10.301	0.006	-43	-43.311	0.006
-11	-11.335	0.007	-44	-44.369	0.007
-12	-12.397	0.009	-45	-45.400	0.008
-13	-13.434	0.009	-46	-46.434	0.009
-14	-14.462	0.010	-47	-47.455	0.009
-15	-15.515	0.011	-48	-48.573	0.011
-16	-16.173	0.003	-49	-49.597	0.011
-17	-17.176	0.003	-50	-50.601	0.013
-18	-18.180	0.004	-51	-51.407	0.009
-19	-19.185	0.003	-52	-52.436	0.009
-20	-20.216	0.004	-53	-53.423	0.010
-21	-21.209	0.004	-54	-54.421	0.011
-22	-22.219	0.004	-55	-55.368	0.012
-23	-23.233	0.004	-56	-56.447	0.013
-24	-24.259	0.004	-57	-57.361	0.015
-25	-25.278	0.005	-58	-58.335	0.019
-26	-26.277	0.005	-59	-59.328	0.017
-27	-27.290	0.005	-60	-60.377	0.021
-28	-28.345	0.006	-61	-61.371	0.023
-29	-29.385	0.006	-62	-62.378	0.024
-30	-30.413	0.007	-63	-63.364	0.025
-31	-31.447	0.008			

TABLE III. Results of RF Box attenuation test for AFP attenuator. Under "Set Attenuation [dB]" column, "splitter" refers to the measurement of the RF Box splitter attenuation with respect to the input signal. All other values in that column are measured with respect to a 0-dB reference signal.