<u>QuantAsylum QA403 Tutorial</u>

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Introduction

This tutorial is based on the Release 1.215 QA 403 software. It is a step-by-step run-through for measuring a power amplifier. The amplifier being tested is the BC-1 power amplifier conservatively rated at 140 Watts for one channel into 8 Ω with power rails that are ±65 V at idle and ±59 V at 140 Watts [1-3]. It is rated at 230 W into 4 Ω with the power supply sagging to ±54 V. Clipping points are 175 W and 280 W, respectively. The BC-1 is capable of more power with higher supply rails or stiffer supply rails.

The BC-1 is a class-AB bipolar design that employs two output transistor pairs in a Locanthi T triple emitter follower configuration. It is a refined version of the power amplifier described in Chapter 4 of "*Designing Audio Power Amplifiers*" [1]. It is also described on the *cordellaudio.com* website [2]. Printed wiring boards and detailed BOMs are available on eBay [3]. If you don't have a power amplifier to test, many of these QA40x test procedures can be run on a small-signal amplifier, such as an op amp gain stage.

Most of the tests below are written in a stand-alone format for all of the setup steps required. A great many of those tests have the same setup steps in common. In practice, a test has a group of setup steps to be done first using the control panel and the "*add measurements*" selections. To a very large extent, these setup steps are common to all of the tests. Most of the setup can be entered from a file that has been stored via the *File > Save Settings* command from a previous test that has been run. For a new test, like one of the ones below, most of the setup steps can be accomplished via the *File > Load Settings* command using a previously stored command. If needed, those settings can be tweaked a bit to better suit the test to be run. Those setup files are provided on this site.

If making a setting is not mentioned in the setup for one of the exercises below, it means that that setting is simply left at its default setting. For example, the *XLOG* frequency range default is 20 - 20 kHz. After entering the *File > New Settings* command at the beginning of a measurement, all settings will be at their default values.

The QA40X software creates a *QuantAsylum > QA40x* folder on your PC. That folder contains several folders, like *UserWeighting* and *CalibrationData*. For convenient storage of measurement setup files, create a folder called *Measurement Settings* in the *QA40X* folder. Similarly, create a folder named something like *Figures* in the *QA40X* folder for storage of screen shots, *Visualizer* images, etc.

Contents

Routine Settings

Many of the settings are similar for the different measurements, and many are not really critical. When just one channel of an amplifier is being measured, the right channel is usually turned off. The full-scale input (FSI) is usually set just so that the analyzer is not overloaded, and has some operating margin. This is not critical, but it is helpful in cases where noise is being measured to make sure that the analyzer noise (which is very low) is not influencing the measurement. An input signal that exceeds the FSI value will likely be clipped. Signals to be measured should be below the FSI value by some margin if analyzer distortion is to be kept low.

The maximum value of FSI=42 dBV does NOT mean that the maximum input to the analyzer can be +42 dBV. The maximum input to the analyzer is 32 dBV, corresponding to 40 Vrms and 200 Watts into 8 Ω, and must not be exceeded.

In going between FSI=18 dBV and 24 dBV, you will hear a relay click. This is a 24-dB signal-level hardware scaling attenuator that is being activated or not. It will change the noise floor of the QA40X by about 20 dB. If you can stay on the 18 dBV (or less) side of that divide, there will be a much lower analyzer noise floor, and analyzer noise is far less likely to influence what you see. Analyzer distortion is also lower for FSI < 24 dBV.

The FFT and data acquisition settings include sample rate, FFT size and averaging. These are relatively uncritical for most tests, and often a sample rate of 48 kHz and FFT size of 32k with no averaging is adequate. On the other hand, using a high sample rate, such as 192 kHz, makes the measurement time shorter for a given FFT size, and there is little downside. It allows using a large FFT size to make some measurements more precise while mitigating the associated increase in measurement time.

The use of a higher sample rate is necessary if the measurement is to extend to higher frequencies, such as the rough maximum of 80 kHz with a sample rate of 192 kHz. Measurements down to low frequencies below 20 Hz, such as some frequency response measurements, will often require a larger FFT, sometimes as large as 256k or even 512k. To no surprise, measurements at such low frequencies can take a long time. A THD measurement at 20 Hz requires a 128-k FFT. A smaller FFT will result in excess distortion being reported and some possible signal level attenuation. When in doubt, in many cases a sample rate of 96 kHz and FFT size of 64k usually is satisfactory.

Averaging helps with measurements of noise and visibility of harmonics that might otherwise be buried in the noise. However, it increases the initial measurement run time (the averaging is a moving average). In the measurements below, we err on the side of higher sample rates and larger FFT size as long as the measurement time is convenient. Averaging should not be used when doing the automated measurements. If you have averaging enabled, the system will reset averaging between each run of an automated test.

There is the option to restore measurement state after an automated test is performed. This is enabled by default (see Edit->Settings "*Restore State After Automated Test Run*"). What this means is that if you are making manual measurements at 1 kHz, and then you run an automated test that finishes at 20 kHz, the system will revert to the settings before the Automated Test was run IF you have opted to *Restore State* and you will again be working at 1 kHz. If you have not opted to restore state, then after the Automated Test run, the settings will be at the final Automated Test state.

Saving Settings

The measurements below require that certain commands and features of the tests be set up before the test is run. These include things like sample rate, FFT size, measurement results to be displayed, etc. These setups can be saved and recalled for later running of the same type of tests.

In preparation for subsequent running of the tests to follow, save the settings currently in place. Go to *File > Save Settings*. In the dialog that comes up, name the file something like "*THD*". Navigate to your QuantAsylum > QA40X > Measurement Settings folder where you will store the settings and click *save*. The settings will be saved as *THD.settings*. It will be available for use as an existing setup as you left it here and can be loaded by going to *File > Load Settings > Measurement Settings* the next time you run this type of test. Permanent settings files can be loaded at any time. Loading them will save a lot of setup effort when such measurements are done again. The measurements to be done below, like frequency response, will result in different settings that can be stored in the same QA40X folder with a different file name.

Loading Settings

There are normally several setup steps to do a measurement, such as sample rate, FFT size, measurement types needed, etc. These can be seen in the measurement procedures below. For virtually all of these measurements, the group of setup steps will have been saved into a setup file after the first time the measurements are made. This makes doing measurements later quite fast, allowing one to bypass most of the setup steps. The setup files created in these exercises include the following:

- Gain.settings
- Frequency Response.settings
- Noise.settings
- Noise Density.settings
- SNR.settings
- THD.settings
- THD vs Frequency.settings

- Burst Power.settings
- CCIF 19_20.settings
- SMPTE IM.settings
- Multitone.settings
- Crosstalk.settings
- Output Impedance.settings
- Default.settings

Saving the Screen Image

Go to *File* > *Save Bitmap as* ... There you will have the choice to save the screen image as a JPEG, PNG or Bitmap to your QA40X folder. This makes it easy to embed graphic QA40X measurement results into documents, PowerPoint presentations, etc. If you prefer a dark-on-light presentation of the screen, go to Edit > Settings > Display Options and select "*Dark-on-Light*". This procedure will save the screen image, including the dashboard presentations of setup and numerical results.

In the automated tests to be described later, if you prefer to capture just the plot, right click on the plot instead and hit "*Save Image as* ...", and choose "*New Plot*".

Markers and Cursors

A marker can be placed on an FFT line by clicking at the top of the line. The frequency and dBV amplitude of the line will be displayed in pink in the upper right of the display. If a marker is first placed on the line of maximum amplitude to make it a reference (often the fundamental frequency), a second value for other markers will display the relative amplitude to the marked reference in dBc. Markers will be numbered and ordered in accordance with their amplitude. Adding a new marker may change the assigned number and order of the previous markers.

All markers can be deleted by right-clicking in the marker display area and selecting *Delete All Markers*. In a dense FFT display, or where some lines are of small amplitude, it may be easier to place markers on some lines by zooming in on those areas of the FFT display by clicking and dragging in the display. The display can be un-zoomed by clicking in the small square that is displayed in the lower right corner of the display.

Two cursors, C1 and C2, are available in the *CURSORS* section of the control area. They can be moved left or right by clicking on their number designation and dragging them left or right to a location whose frequency and amplitude will be read out in white characters in the cursor data area at the bottom left of the screen. Pushing the *CENTER* button for a cursor moves it to the center of the display. Pushing the *PEAK* button moves it to the center of the nearest FFT line. Note that it may be moved to a peak of very small amplitude that is next to a larger desired peak. Markers can only be added when just the left channel is active.

Markers can be moved in a zoomed-in screen, and this can be helpful in marking a desired line or marking its peak in a crowded FFT. However, if a marker is activated while zoomed in, it appears off-screen in the center of the un-zoomed screen. In this case, push its *CENTER* button to move it to the center of the zoomed screen area so that it can then be dragged to the desired location. The screen can subsequently be un-zoomed by clicking on the lower-right square to see the big picture.

Idle Mode for Continuous Output

In the normal GEN mode used for most measurements, the QA40x makes the measurement with successive signal bursts that are then analyzed by an FFT. In some special cases, one may wish to have the Generator produce a continuous sine wave to stimulate the DUT. An example might be when one wants to precondition a power amplifier at a certain power level, such as 1/8 rated power, and measure the heat sink temperature after an appropriate amount of time, maybe as much as an hour. The *IDLE* mode of the QA40x can be used to create the continuous generator signal. With the *RUN* mode off, simply press the *IDLE* button to turn the tone on. The analysis side of the QA40x is not functional in the IDLE mode, so one needs to set the amplifier power level by first using the *RUN* mode to set the power level, then switch to the *IDLE* mode for the continuous signal stimulus.

Minimizing Hum and Noise in Measurements

Hum and noise from the testing arrangement can be problematic in sensitive measurements like those for noise. These unwanted corrupters of signals and the measurement can come from the environment, not the devices being measured. Ground loops, dirty AC lines, noise from associated computers, USB connections and even radiated emissions can be typical culprits. A sensitive FFT measurement on the QA40X can reveal 60-Hz hum and many of its harmonics due to pickup from the environment, and not necessarily due to the power supply in the amplifier under test. Devices like switching power supplies and converters, including those in CFL and LED lights, can create a spray of harmonics in the upper audio band that will be visible in the FFT display.

Best noise measurement results are obtained when CFL and LED lights are turned off. For best results on all noise measurements, especially those including both input and output of the QA403 connected to the output and input of the amplifier, use a laptop running on its battery as the computer for the QA40X. Results with a desktop computer can sometimes be improved by passing the computer's USB through a powered USB hub. This will also largely guarantee that the QA40X has adequate voltage from its USB connection. The computer and the amplifier under test should be connected to the same power outlet.

Balanced/differential connections to the QA40X using shielded twisted pair cables (e.g. microphone cables) can be used to improve matters even if the amplifier has a single-ended input. This helps to avoid ground loops that involve the input and output cables to and from the amplifier and QA40X. In one approach, connect the negative conductor of the balanced cable driving the DUT to the shield at the input to the amplifier under test. Connect the shield to one of the BNC output grounds at the QA40X. Connect the shield of the cable driving the QA40x to the negative signal lead where the cable connects to the ground side of the amplifier output. Connect the shield of that cable to one of the BNC input grounds of the QA40X input. This interconnect arrangement is not Gospel, and some experimentation may be required. The QA40X FFT is brutal in unmasking hum and noise that gets into the test setup from the environment.

Another quasi-balanced/differential approach is also recommended, especially for damping factor measurements, but also effective in reducing pickup of hum and line harmonics. Connect the single-ended output of the QA40X directly to the single-ended input of the amplifier under test with a single-ended shielded cable.

Connect the conventional single-ended output of the amplifier to the balanced differential inputs of the QA40X through a shielded twisted pair interconnect, like a microphone cable. The twisted pair should be connected with its cold and hot wires with stripped ends to the amplifier's output jacks, screwed down and through the inner holes of the usual banana speaker connectors, or equivalent. The load resistor is then connected with banana plugs or spades to the output terminals after the twisted pair measurement cable. This is somewhat like a Kelvin connection, minimizing effects of load current on what the balanced measurement cable sees. Do not connect the shield at the amplifier end. Connect the shield to one of the BNC connector grounds at the QA40X balanced input.

The ground of the QA40x is connected to the ground of the amplifier by only one wire - the shield of the single-ended cable driving the amplifier. An approach like this is especially helpful in obtaining accurate measurements of damping factor, where very low amplifier output resistances are involved. Depending on the amplifier and environment, some experimentation with interconnections and grounding between the QA40X and amplifier may be helpful.

The interconnect from the QA40X output to the input of the amplifier should be short and direct. It should not pass anywhere near the amplifier's output transistors. Remember, with a typical power amplifier with a gain of about 20, this interconnect is 20 times more sensitive to corruption than the interconnect from the amplifier output to the QA40X input.

Measuring High-Power Amplifiers

In light of the analyzer maximum input signal level of +32 dBV, corresponding to 40 Vrms or 200 W into an 8-Ω load, external attenuation of the amplifier signal must be used for high-power amplifiers. In fact, the analyzer should be operated with some margin against the 32-dBV limit to ensure good performance. Note that the full-scale input setting of +42 dBV does NOT mean that a +42 dBV signal can be applied to the analyzer. It merely means that an internal 42-dB attenuator precedes the ADC.

The external attenuator may take many forms, with one or more amounts of attenuation and physical implementation, such as a load power resistor equipped with one or more taps. It may also take the form of a simple resistive divider as long as the source resistance it shows to the input of the analyzer is fairly low so that there is no extra loss or high-frequency response degradation due to resistive and capacitive loading.

Because the QA40X has selectable input attenuation in 6-dB steps from 0 dB to 42 dB, few external attenuation taps are usually required. For best noise performance, different measurements may require different amounts of external attenuation, with noise measurements generally requiring that there be little or no attenuation.

With external attenuation there comes the need to inform the QA40X of how much attenuation is being applied so that the analyzer can take that into account so that voltage levels are measured and reported accurately. If external attenuation is in play, click on the dBV button and enter the amount of external attenuation into the external input gain box as a negative dB number, such as -20 dB.

One approach to external attenuation is to use a 24-dB attenuator, which accurately shifts the 24- to 42-dB FSI settings of the QA40X down into the 0- to 18-dB FSI range where QA40X noise and distortion performance is superior. 24 dB corresponds to a loss ratio of 15.85. If a 1-kΩ shunt resistor is used in the divider, then the series resistor should be 14.85 kΩ. The fairly low source resistance of the divider will create thermal noise of only about 4 nV/√Hz. An amplifier delivering 400 W into an 8-Ω load will produce 56.57 Vrms. This will result in 3.57 mA flowing in the total 15.85-kΩ resistance of the divider, for power dissipation of 202 mW.

Note that a total cable-plus-QA40X capacitive load of 160 pF on a source resistance of about 1 kΩ will limit 3-dB bandwidth to 1 MHz. For minimal resistor heating and low-frequency thermal distortion, resistor power ratings should be at least 10 times the working power dissipation. For example, use a 1-Watt 1-kΩ shunt resistor and a 2-Watt resistor trimmed to 14.85-kΩ for the series resistor.

Shorting Blocks

Many measurements below specify the use of shorting “plugs” or “blocks” on the unused inputs (never use them on the analyzer outputs!). These can be 0/50/75 ohms and are commonly available from Amazon if you search for “*BNC shorting blocks*”. A good starting point before a measurement session is to install 4 shorting plugs on the QA403 inputs, select *File->New Settings*, set the *Full Scale Input* (FSI) to 0 dBV, sample rate to 48 kHz, increase FFT size to 64k or so, add RMS dBV and RMS Volts measurements, and verify you are seeing -117 dBV or so on both the left and right channels. You should see no power line components displayed. Change the sample rates to 96 kHz and 192 kHz and confirm the noise measurements aren't changing.

The shorting blocks will wear out in time. If you see noise or power line sensitivity related to slight lateral forces applied to the block, then throw the block away. Remember, you are trying to measure hundreds of nV in some cases, and so a shorting block that isn't reliable can consume hours of debugging effort.

If you are seeing power line components in this baseline configuration, look for nearby environmental factors, especially including equipment with large transformers.

FFT Size, FFT Bin Size and FFT Window

In an ideal world, amplifier THD falls as signal amplitude falls, while THD+N increases as amplitude falls as a result of the fixed value of noise voltage. This is not always the case in real-world measurement results when the actual distortion is considerably lower than THD+N. This is because the amplifier noise can influence the THD reading when THD is very low.

FFT bin size can be very important when measuring very low values of distortion, especially in the presence of even fairly small noise. This is because a larger-frequency bin span (bandwidth) will have more noise leak into that bin and be counted as a distortion contribution. This applies to the fundamental and all of its harmonic's bins. FFT bin size is inversely proportional to FFT size. In principle, noise leakage contributions into the bin will fall as the square root of FFT size. A 128-k FFT size should be the minimum for low-distortion measurements. An FFT bin size of 1 Meg is not out of the question when measuring very low distortion at small signal levels, where the relative noise present in the signal is larger. However, it takes a long time to complete the measurement (about 7 seconds at a 192 kHz sample rate). If you see reported THD increase as signal level is decreased, that is not usually how an amplifier should behave, and it is a possible result of noise leakage into the FFT bin (we are not talking about THD+N or crossover distortion here).

The data below illustrates a typical relationship between FFT size and FFT window versus reported 1-kHz THD using the BC-1 power amplifier producing a 100-mV output with no load. FSI was set to 0 dBV and sample rate was 192 kHz. In all cases THD+N read 0.033%, dominated by noise. This amplifier has a respectable SNR of 100 dB with respect to 1 Watt (2.83 V) and input-referred noise of about 7 nV/√Hz.

Table 1: THD-1 Reading vs. FFT Size and Window Type

Window	32k	64k	128k	256k	512k	1M
RECT	0.0038	0.0031	0.0024	0.0019	0.0014	0.0011
Hann	0.0045	0.0037	0.0028	0.0023	0.0017	0.0013
FLAT	0.0065	0.0054	0.0043	0.0033	0.0024	0.0019
BH	0.0048	0.0042	0.0032	0.0026	0.0019	0.0014

Here we have an amplifier whose reported THD can range from 0.0011 up to 0.0065, depending on the choice of FFT size and FFT windowing type. For a "typical" setup of a 64-k FFT and a Hann window, THD-1 reads 0.0037%, about 10 dB worse than its "true" THD-1 of equal to or less than 0.0011%. Taking 4 FFT averages can reduce this number to 0.0027%, but averaging cannot be employed in automated measurements. A 1 Meg FFT with a rectangular window and 4 averages can reduce this number by about 3 dB to 0.00073% (still, no harmonic lines are visible above the FFT noise floor at -135 dB).

As a general rule, the number of dB by which the THD measurement can be lower than the THD+N measurement is dependent upon, and limited by, the size of the FFT. Below a certain signal amplitude, the decibel distance between the THD+N and THD readings will be roughly constant due to noise leakage into the FFT bins. The THD number will no longer accurately represent the true THD of the DUT at amplitudes below a certain value. In the table above, and with a rectangular window, this "distance" between THD and THD+N was limited to 18 dB for a 64-k FFT, while the difference was 30 dB for FFT size of 1 Meg. Here there were 4 doublings of FFT size and the "distance" increased by 12 dB, as expected.

As a matter of interest, at 2.83 V and with FSI=18 dBV, THD-1 for this amplifier with no load was 0.00012% and third harmonic (dominant) was down 120 dB. With an 8-Ω load, THD-1 was 0.00019% and third harmonic was down 115 dB.

FFT size is also important in measuring frequencies below 100 Hz. More time needs to pass to collect adequate information about low-frequency tones. This is why larger FFT sizes are needed to obtain accurate FFTs for low-frequency signals.

Loop Back Performance

Here the QA403 used in these measurements of the BC-1 power amplifier is configured in a single-ended loop back configuration and the performance metrics are shown for reference. The 1-kHz loop back is done at 0 dBV with FSI = 12 dBV. Sample rate is 192 kHz, FFT is 256k with 10 averages and a Hann window. These settings, including the large number of averages, will demonstrate the achievable performance of the analyzer in a typical situation.

Measurement tiles activated include RMS dBV, RMS Volts, THD dB, THD+N dB, THD %, THD+N % and SNR dB. The RMS noise voltages recorded are with *Gen 1* off. The FFT noise floor is the approximate dBV value where the center of the noise portion of the FFT lies. The FFT noise floor of -150 dBV is important in seeing and determining the amplitudes of the smaller-amplitude harmonics. These performance numbers will differ from unit to unit, and, in fact, between left and right channels, as can be seen below.

Table 2: 1-kHz Loop Back Performance at 0 dBV, FSI=12 dBV

Measurement	1 kHz Left	1 kHz Right
THD, dB	-121	-115
THD+N, dB	-108	-106
FFT noise floor, dBV	-150	-150
2nd harmonic, dBV	-137	-132
3rd harmonic	-127	-120
4th harmonic	-143	noise
5th harmonic	-125	-120
SNR, dB	109	108
RMS noise, µV	3.3	3.3

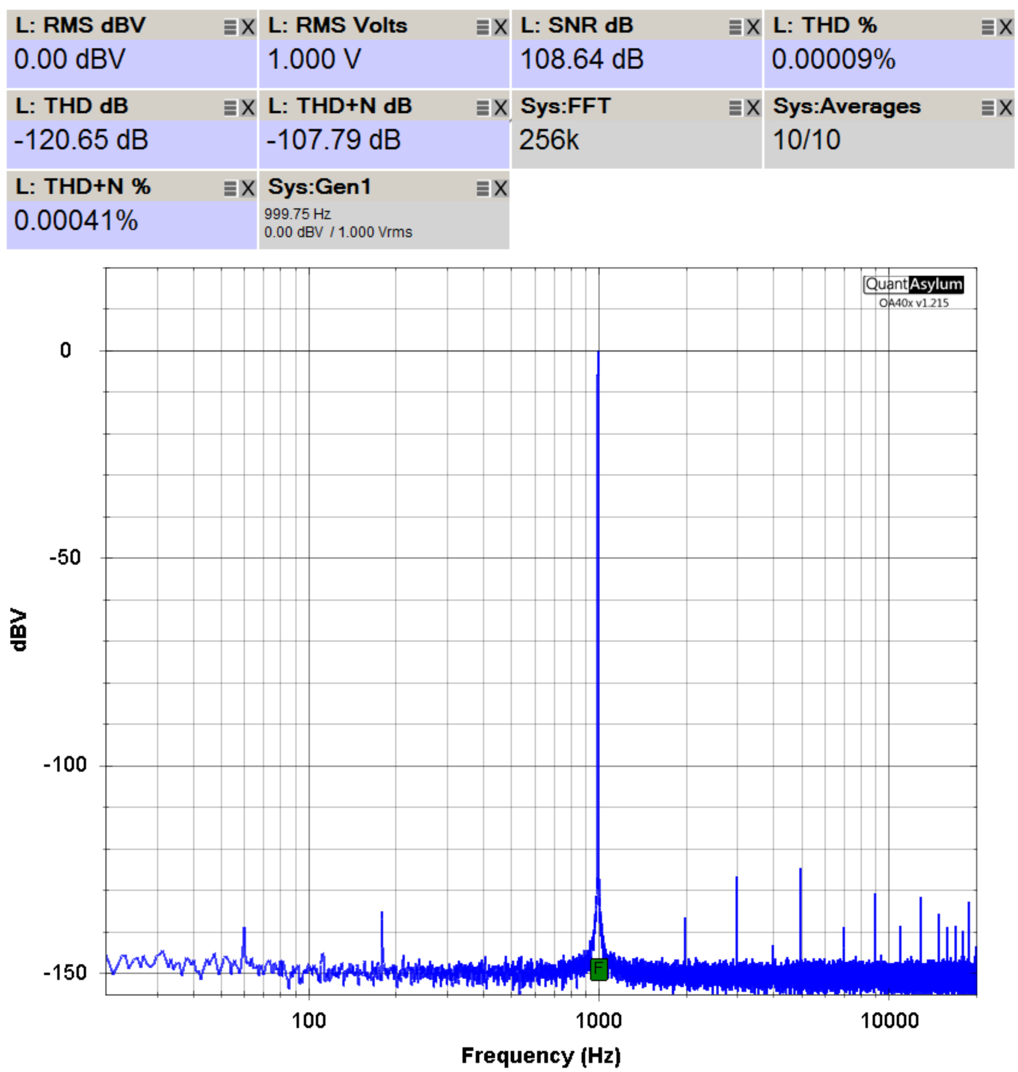

Figure 1: Screen Shot of the QA403 Loop Back Measurement

If one does loop back testing at higher frequencies like 5 kHz and above, XLOG and RMS or THD should be set to top measurement frequencies of 85 kHz to capture upper-frequency harmonic products and noise. A screen shot of the 1-kHz loop back results is shown in Figure 1.

The FFT noise floor depends on FFT size. If you have enabled RtHz (in dBV Context Menu) then the noise floor will show the same regardless of FFT size. However, peaks may then be rendered wrong.

The *Full Scale Input* (FSI) is set to +12 dBV for the above loop back measurements of a 0 dBV signal. There is a tradeoff between analyzer SNR and analyzer distortion floor. The value of FSI is the amplitude at which the ADC in the QA403 is being driven to its maximum rated input level. As such, its distortion will be a bit higher than at other settings, like at +12 dBV where headroom against maximum input level is 18 dB. Conversely, the analyzer SNR is best when FSI with a 0 dB signal is set to 0 dBV, since there is less input attenuation ahead of the ADC. FSI settings at and above 24 dBV incur a significant amount of attenuation that ends up eating into the SNR and distortion floor.

Analyzer Noise vs. FSI Setting

The FSI setting places different amounts of attenuation or gain in the signal path in front of the ADC. A 0-dBV FSI places no attenuation in front of the ADC and in fact means that 1 Vrms will drive the ADC to its maximum rated full scale input voltage (not the same as 1 Vrms). This means that noise contributed by the QA403 to a measurement will tend to be larger for larger values of FSI. With no input, the noise reported by the QA403 is listed below as a function of the FSI setting. Measurements were done with a 192 kHz sample rate, a 256k FFT and 4 averages. All inputs were shorted.

Table 3: Analyzer Noise vs FSI Setting

FSI, dBV	Noise, dBVrms	Noise, µVrms	FFT Floor, dBV
0	-118	1.3	-150
6	-114	2.0	-146
12	-110	3.3	-142
18	-104	6.1	-136
24	-83	71.4	-116
30	-83	74.8	-115
36	-81	85.0	-115
42	-79	117	-110

The noise measurements above were made with the default measurement bandwidth of 20 kHz. This is also the noise bandwidth. Noise increases by 3 dB for each doubling of noise bandwidth. If we quadruple the maximum value of the measurement bandwidth by setting *XLOG End Frequency* and *RMS Measured Stop Frequency* to 80 kHz, you will see the measured noise go up by 6 dB, as expected.

Analyzer THD vs. FSI Margin

One would normally like to use as much of the ADC's dynamic range as possible if having the least analyzer noise contribution is the priority for the measurement. This means using the lowest FSI setting possible, applying the maximum allowable signal amplitude to the ADC. However, this can increase ADC distortion. So there is a tradeoff. The amount by which the signal voltage is below the FSI setting is the FSI margin. A conservative FSI margin is 18 dB, but this sacrifices dynamic range. It is thus useful to know what the QA403's own THD is as a function of input signal dBV and FSI dBV in a loop back. The data below shows this.

Maximum QA403 output is +18 dBV, so only 4 input signal levels are shown. In an ideal world, one might expect THD to be the same for a given FSI margin, but that is not always the case in the real world. Measurements with FSI margin of greater than 24 dB do not make sense; this is obvious from the table. FSI settings too high allow analyzer noise to influence THD readings and increase reported THD.

Table 4: 1-kHz Analyzer THD vs. FSI Margin

Input Amplitude: **FSI Margin**	**0 dBV**	**6 dBV**	**12 dBV**	**18 dBV**
0 dB	-115	-113	-115	-111
6 dB	-119	-116	-119	-113
12 dB	-121	-116	-116	-113
18 dB	-121	-114	-116	-117
24 dB	-108	-109	-113	-112

Performance with Analog Oscillator

A THD analyzer comprises an oscillator to feed the DUT and analyzer to measure the THD. In a loop-back the lower limit of distortion measurement is determined by the oscillator the analyzer. Distortion of one or the other may dominate. It is generally the case that a digital oscillator produces more THD than an analog oscillator. The THD of the digital generator in the QA403 tends to dominate the attainable lower limit of THD. In order to better measure the lower limit of THD measurement of the QA403 analyzer, it was driven with an ultra-low distortion analog 1 kHz oscillator producing 1 Vrms (0 dBV). It's THD is in the neighborhood of -135 dB or better, confirmed by many. The QA403 sample rate used for the measurement was 192 kHz and the FFT size was 1024k with 10 averages to minimize noise. A Hann window was used and FSI was set to 6 dBV.

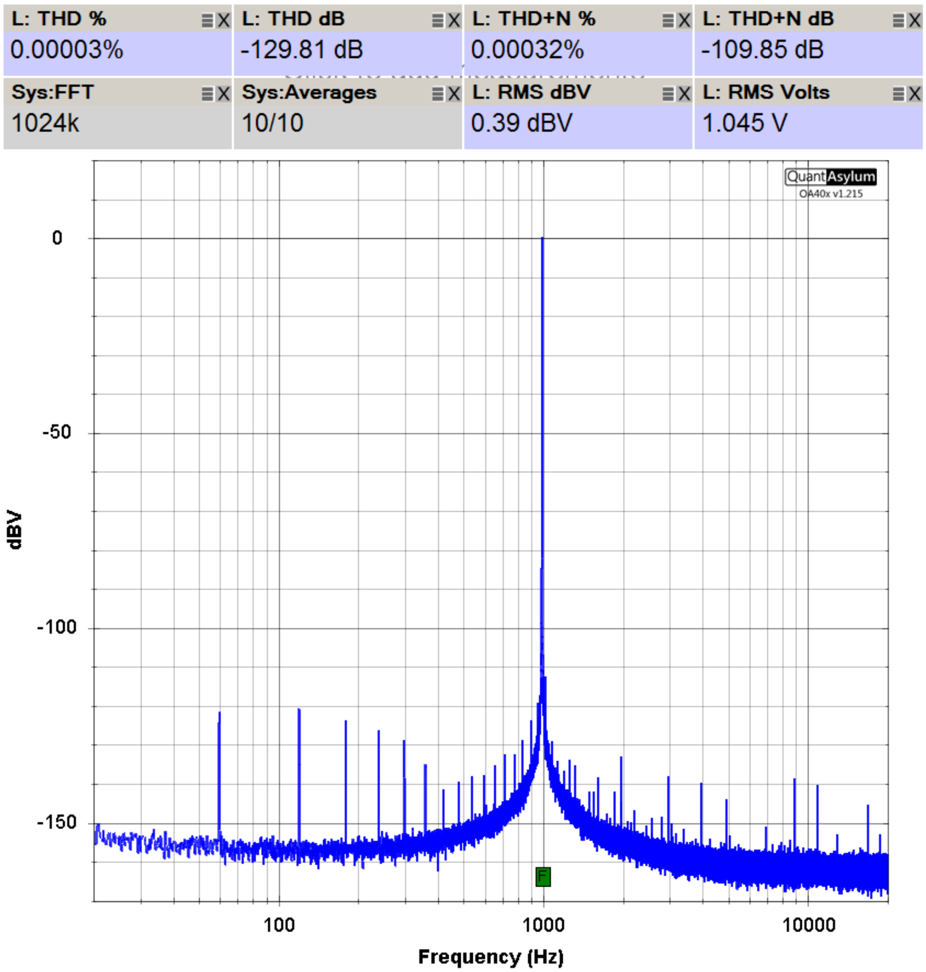

Figure 2: FFT and THD Result Using Analog Oscillator Source

As shown in the figure, the QA403 was able to report -130 dB THD when fed the output from the analog oscillator, with the harmonics visible with an FFT noise floor below -150 dB. Second and third harmonics were each at -133 and 138 dBV, respectively.

Gain Measurement

Gain and frequency response of the amplifier will now be measured. The left channel will be measured. Begin by hitting *File > New Settings* to start with known default settings. Make sure that the current or previous measurement has been stopped first. If a totally clean slate does not result, hit *New Settings* again. Connect an 8-Ω load resistor to the amplifier.

Measure the gain of the amplifier as follows:

Click on the right channel to turn it off.
Set the sample rate to 96 kHz.
Increment the FFT size to 64k and increment System Averages to 4.
Set the full scale input to 18 dBV and *Ymin* to -140 dBV.

Add the measurements Gain dB, *RMS Volts, RMS dBV* and *RMS Pwr Watts*.
Click the *Gen 1* button, right click and set amplitude to -20 dBV.
Click on the *GAIN* button.
Click *RUN*.

An FFT line appears at 1 kHz and the *Linear Gain Tile* will show gain as 28.4 dB (i.e, linear voltage gain equals 26.4).

Click on the FFT peak at 1 kHz and see the marker show +8.4 dBV.

Go to *File* > *Save Settings*. Name the file **"*Gain.settings*"** and save it in the *Measurement Settings* folder.

If gain has been measured previously, just hit *File* > *Load Settings* and load the file *Gain.settings* from the *Measurement Settings* folder, then hit *RUN*.

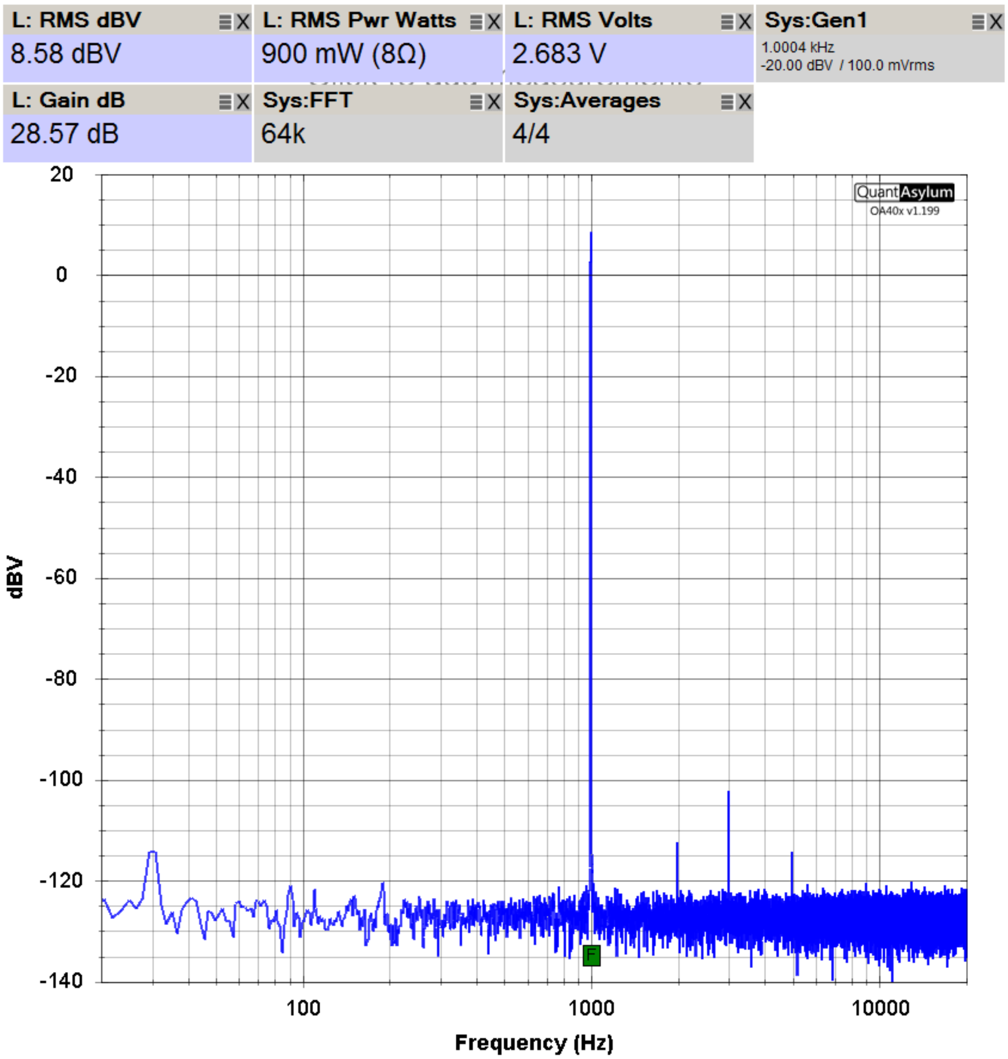

Figure 3: Screen Shot of the Amplifier Gain Measurement

The same gain measurement results as from the previous run will appear. This demonstrates how easy it is to do a measurement at any time if the settings from a previous measurement have been loaded. Before hitting RUN, one can make any desired modifications to those settings.

The tiles at the top of the display area form a dashboard of settings and readings, as shown in the screen shot above. The screen shot is taken by going to File > Save Bitmap as ... and choosing the format as png, jpg or bitmap. Most of the figures in this document are shown as Dark on Light by going to Edit > Settings and clicking on the *Dark on Light* button.

This will be your first test of the amplifier, so some additional measurements are added to the dashboard in the *Click to Add Measurements* section. This will give an early indication of basic amplifier functionality and performance. It may spot troubles, such as high hum, high noise, high distortion, etc., before proceeding to further tests

Frequency Response

Measure the frequency response of the amplifier driving an 8-Ω load.

Begin by hitting *File* > *New Settings* to start with a clean slate.
Turn off the QA40X right channel.
Set the sample rate to 192 kHz and Increment the FFT size to 128k.
Click on *Frequency Response* in the *Generator* section.
The *Sys: GenEx* tile provides the *Exponential Frequency Chirp* stimulus.
Decrement the *GenEx* amplitude to -20 dBV to feed the amplifier 100 mV.
Set the full-scale input to 18 dBV.
Set the *XLOG* range at 10 Hz to 80 kHz.
Click the RMS button and set the frequency range to 10 Hz to 80kHz.

Click *RUN*.

Go to *File* > *Save Settings*. Name the file ***"Freq Response.settings"***.

The frequency response of the amplifier is shown over a range of 10 Hz to 80 kHz with a large y-axis dB range. Right click on *dBr* and select "*Set 1 kHz Level to 0 dBr*". Hit "*1 to -1*" on *Y PRESET* in the Axis control area to see the frequency response in a ±1 dB window. The amplifier is seen to be down 0.35 dB at 10 Hz and 0.1 dB at 20 Hz. The amplifier is down 0.04 dB at 20 kHz and 0.9 dB at 80 kHz.

Go to the *Cursors* control section and add *Cursor 1* by clicking on *C1* and center it in the plot by clicking on *Center*. If the *Cursor* area is not visible on the screen and you are on a laptop without a mouse wheel, click the down arrow key to scroll the control area down. Similarly, if you have scrolled down and the *Run/Stop* area is not visible, scroll with the up arrow key. Ignore a warning that performance may suffer with a large FFT. The 128k FFT is necessary to measure the response down to 10 Hz.

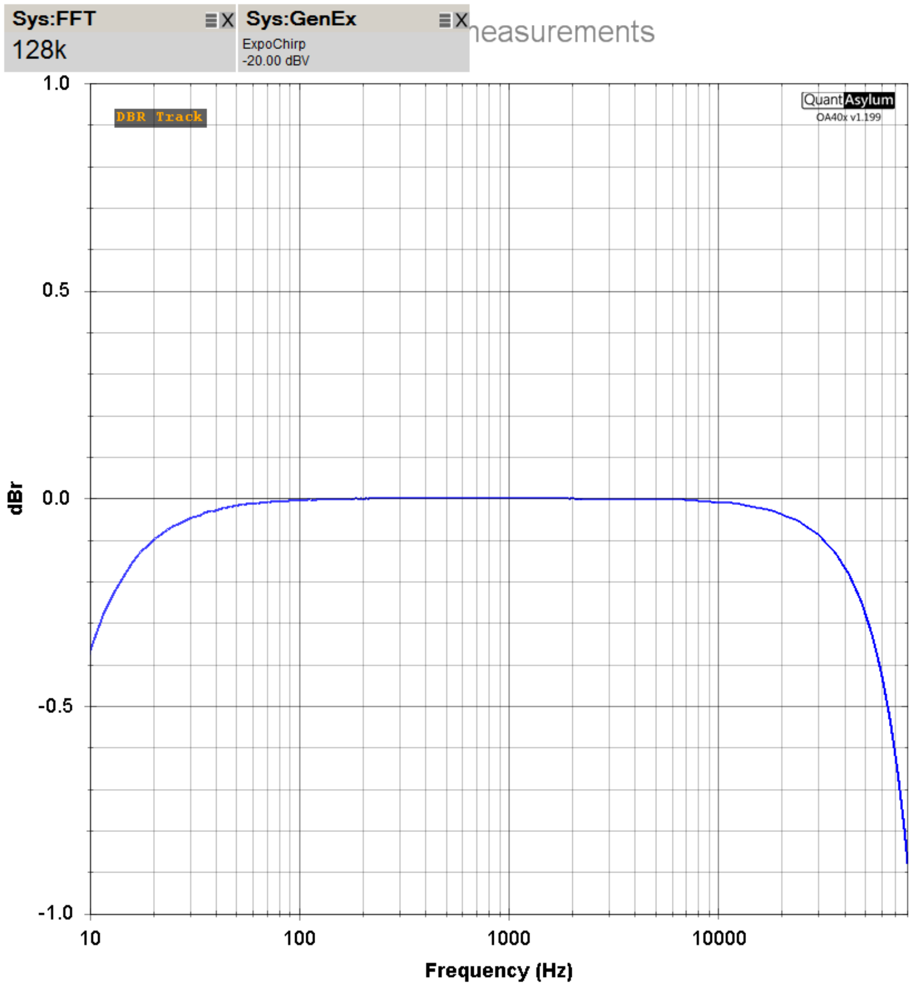

Figure 4: Frequency Response Measurement 10 Hz to 80 kHz

Move the cursor to 20 Hz by dragging its label to the left. See in the lower left of the display that the enunciator indicates the frequency X1 is 20 Hz and that the amplitude Y1 is -0.1 dBr. Move the cursor to 20 kHz and see that the response is -0.04 dBr. Alternatively, invoke *Cursor 2* and drag it to 20 kHz and see both the 20-Hz and 20-kHz responses in the enunciator. Frequency response is down 0.35 dB at 10 Hz, down 0.1 dB at 20 Hz, down 0.04 dB at 20 kHz, down 0.3 dB at 50 kHz and down 0.9 dB at 80 kHz.

The output impedance of most power amplifiers increases with frequency. This is usually due to a combination of the negative feedback loop gain falling at high frequencies and the output inductor if one is used. Figure 5 below shows the frequency response of the amplifier with a 2-Ω load. There is significant roll-off at very high frequencies, but the response is still down only 0.3 dB at 20 kHz.

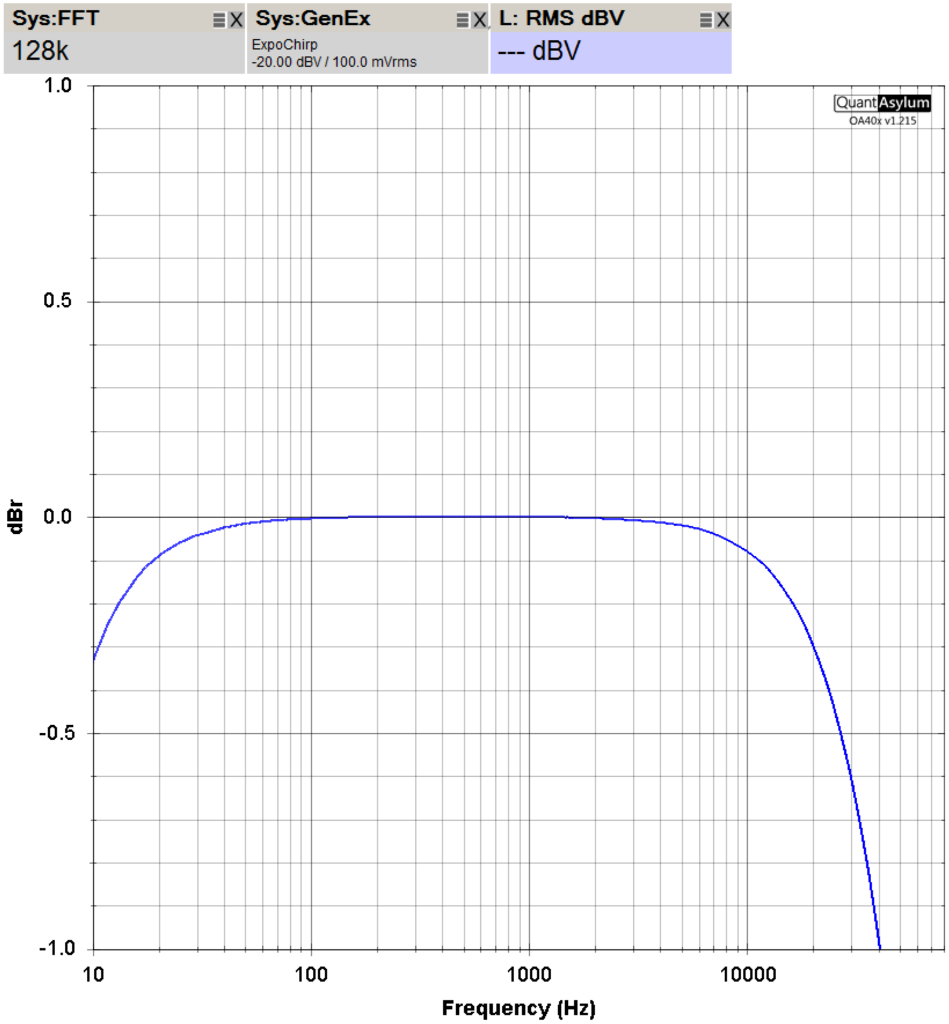

Figure 5: Frequency Response with 2-Ω Load

Noise

Here the noise of the amplifier with no input will be measured. Disconnect the amplifier input from the QA40X and ground the input of the amplifier with an RCA shorting plug (or with an XLR grounding plug with pins 1, 2 and 3 connected together). The noise will be first measured with no weighting in the default 20-kHz bandwidth and then with A weighting.

Ground the input of the amplifier. Do this right at the RCA input jack without any other ground connected at the jack. It is important to eliminate the possibility of ground loops for this sensitive test.

Begin by hitting *File* > *New Settings* to start with a clean slate.
Turn off the right channel.
Set the full scale input to 0 dBV and set the sample rate to 192 kHz.
Set the *FFT* size to 128k with 10 averages and a *Hann* window.

In *Add Measurements* select *RMS Volts* and *RMS dBV*.
Set *Ymin* to -160 dBV and *Ymax* to 0 dBV.
Hit *RUN*.

Go to *File* > *Save Settings*. Name the file "***Noise.settings***".

The large FFT size and 10 averages yields the best possible result, but it takes time - about 18 seconds for each round of 10 measurements. Wait for 2 rounds to complete, for a total of 36 seconds. An FFT of 64k with 4 averages will provide acceptable results. Keep the sample rate at 192 kHz to minimize the noise measurement time and also to provide the best FFT presentation at low frequencies like 60 Hz. Large FFTs are required to make good presentations of results at low frequencies.

The display for the measurement in Figure 4 shows hum and noise with an RMS total of 21 μV in a 20 kHz bandwidth. The only predominant hum-related line was at 120 Hz at -104 dBV as indicated by the marker placed on the 120-Hz line. Other lines were in the vicinity of -130 dBV or less. The band of random noise is centered at about -132 dBV.

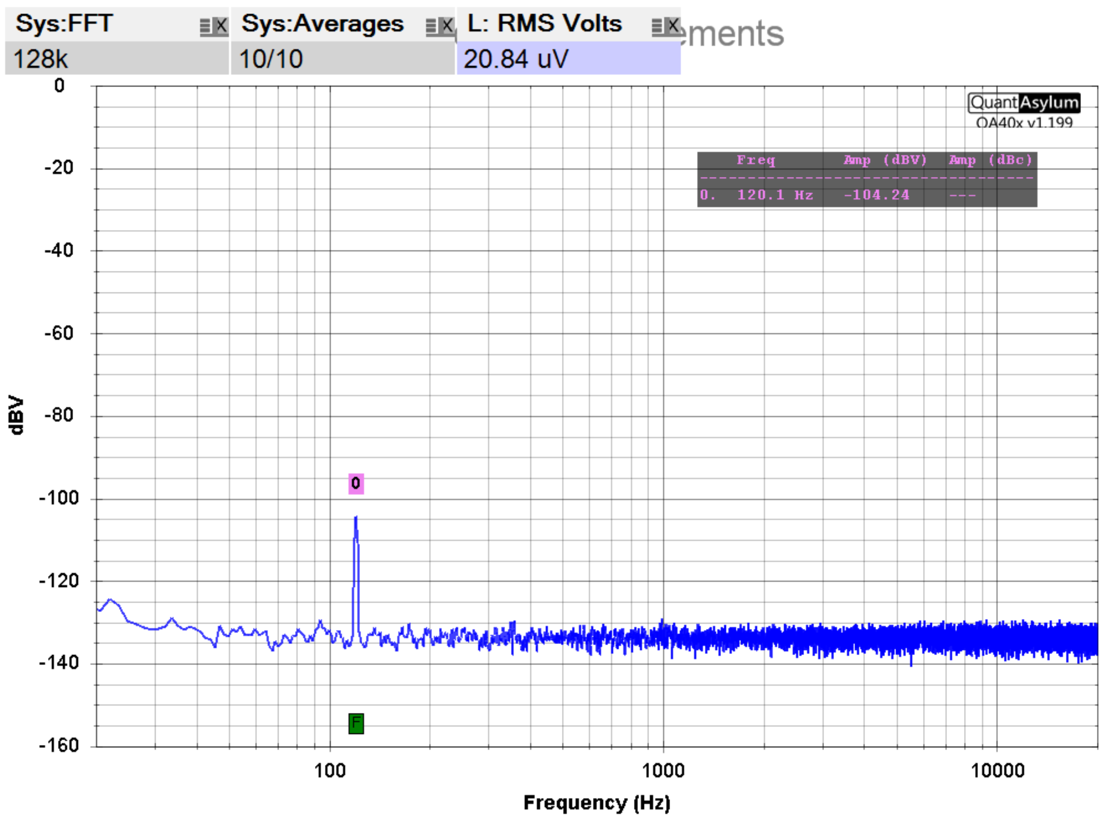

Figure 6: Amplifier Un-weighted Output Noise

The BC-1 noise was measured un-weighted with measurement bandwidths of 20 kHz and 80 kHz. Noise readings were 28.5 uV (-91 dBV) and 55.3 uV (-85 dBV), respectively. The latter was almost exactly up 6 dB as expected. Note that 1W=2.83V=+9 dBV. BC-1 SNR is thus 100 dB for 20 kHz bandwidth and 94 dB for 80 kHz bandwidth.

This amplifier shows quite a low amount of hum and its harmonics, but to further reduce the influence of hum and its harmonics and get a better picture of the audible noise, hit the *A Weighting* button in the *Weighting* section of the control area.

Load the file "Noise.settings".
hit the *A Weighting* button.
Hit *RUN*.
Save the measurement file as "***Noise A wtd.settings***"

The RMS noise drops to 15.8 µV, with the 120-Hz line falling to -121 dBV. The difference in the frequency response of the noise due to A weighting is easily apparent in Figure 5. Dividing 15.8 µV by 2.83 volts yields A-weighted SNR of 115 dB. The power supply for this version of the amplifier is in a separate chassis, reducing hum and line harmonics. Most amplifier implementations will have more hum and line harmonics due to the power supply being in the same chassis.

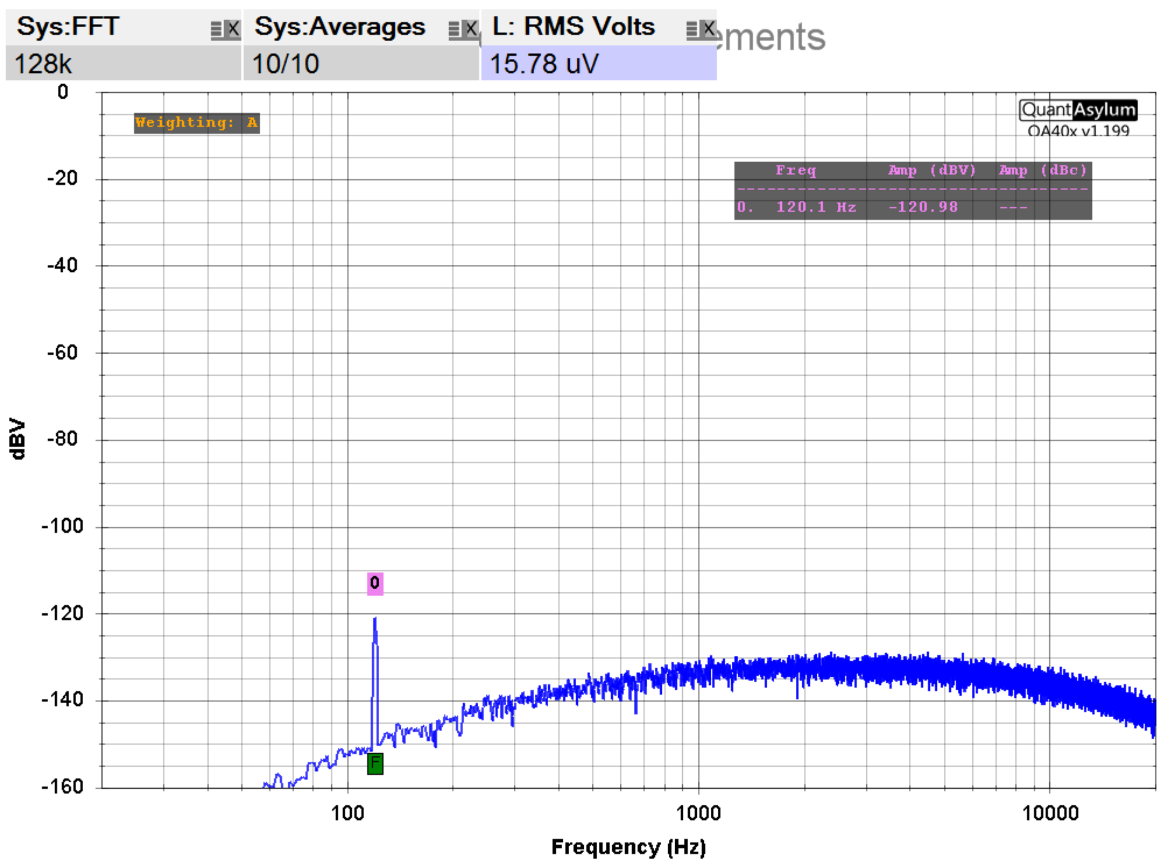

Figure 7: A-weighted Amplifier Output Noise

Right click on the *dBV* button and enter the gain of the amplifier as 28.6 dB. The A-weighted input-referred noise is shown as 0.585 µV or 585 nV.

User-defined Noise and Other Weighting

Notice that in the *Weighting* section there are two weighting selections labeled *USER1* and *USER2*. These allow user-defined weighting of results by entering a file that lists frequencies and their corresponding weighting attenuation. Two examples of such weighting are the pre-loaded RIAA phono record and playback equalization curves. Here we will demonstrate this feature by entering the ITU R 468 noise weighting curve as an alternative to A-weighting [4]. The file should be in the form of frequency followed by a comma, a space and a dB amount of attenuation as shown below for an ITU R 468 file.

C-weighting has less low-frequency roll-off than A-weighting. Relative to 1 kHz, it is down 3 dB at 31.5 Hz, 6.2 dB at 20 Hz and 14.3 dB at 10 Hz. Its high-frequency roll-off is similar to, but not identical to, A-weighting, differing by a dB or two in either direction between 1.6 kHz and 20 kHz. C-Weighting is more representative of human hearing at high sound levels like 90-100 dB SPL, as suggested by the Fletcher-Munson curves.

The *User Weightings* files are located at *Quantasylum > QA40x>UserWeighting*. When you press the User 1 button, a dialog will come up that asks you to select a file from the list in the folder. Double-click on it and the click OK. An annunciator in the upper left hand corner of the screen will show enabled weightings. If a User Weighting has previously been selected, right click on the button to bring up the same dialog with an opportunity to clear the existing weighting and select a new weighting. *User1* and *User2* can be enabled at the same time. In addition, the A or C weighting can also be enabled, for a total of 3 weightings enabled at the same time. Pre-loaded user weighting files include the RIAA playback and record characteristics. If you want to know how flat an RIAA phono preamp is, you can invoke the RIAA record characteristic, which is the inverse RIAA playback characteristic. If you want to know the effective A-weighted noise of a moving coil preamp after RIAA equalization, you would invoke both A weighting and RIAA record weighting.

Note that the ITU R 468 weighting curve is specified as 0 dB at 1 kHz, as shown below, but it has high-frequency regions where there is actually gain, as designated by a minus sign in the file listing. The gain peaks at 6300 Hz with a value of 12.2 dB. At low frequencies, the weighting falls at just 6 dB/octave. At frequencies over 10 kHz the weighting falls off at an increasing slope with frequency, starting at about 12 dB/octave and increasing to over 24 dB/octave at 20 kHz. The weighting files can be conveniently stored in the folder *QuantAsylum > QA40X > UserWeighting*.

It should be noted that ITU R 468 noise measurement is intended to be made with a quasi-peak detector in its standard implementation for professional audio, which will not happen here. However, the Dolby CCIR/ARM (now called ITU-R ARM) measurement method is intended for use with a less-expensive average detector. Its weighting function is that of ITU R 468 with the exception that its zero-dB point is shifted from 1 kHz to 2 kHz [4]. Because ITU R 468 is 0 dB at 1 kHz and CCIR/ARM is -5.6 dB at 2 kHz, the CCIR/ARM curve values are obtained by adding 5.6 dB to all values in the ITU R 468 table below.

Table 5: User-defined Weighting Files

ITU R 468	Pink Noise	Twin T Compensation
31.5, 29.9	15.63, -18.0	
63.0, 23.9	31.25, -15.0	
100, 19.8	62.5, -12.0	20, 10.0
200, 13.8	125, -9.0	100, 9.0
400, 7.8	250, -6.0	250, 7.0
800, 1.9	500, -3.0	500, 4.0
1000, 0.0	1000, 0.0	1000, 0.0
2000, -5.6	2000, 3.0	1500, -10.0
4000, -10.5	4000, 6.0	1650, -10.5
5000, -11.7	8000, 9.0	1800, -10.0
6300, -12.2	16000, 12.0	2000, -9.1
7100, -12.0	32000, 15.0	2200, -8.0
8000, -11.4	64000, 18.0	2500, -6.67
9000, -10.1		3000, -5.14
10000, -8.1		3500, -4.06
12500, 0.0		4000, -3.31
14000, 5.3		6000, -1.68
16000, 11.7		8000, -1.00
20000, 22.2		9000, -0.8
		10000, -0.66
		15000, -0.30
		20000, 0.0

Connect the output of the QA40X to the amplifier input.
Go to *File* > *Load Settings*. and load the file "***Noise.settings***".
Change the full scale input to 24 dBV.
Change FFT to 64k, Averages to 4.
Set *Ymin* to -80 dBV.
Select *White Noise* in the *Generators* section. Retain the default level of -12 dBV.
Click on *USER1* and enter the file *ITU R 468* in the dialog box. Select it from the *User Weighting* folder.
Double click on the desired file and hit OK.
Hit *RUN*.

See a flat noise frequency response at about -30 dBV and with an RMS total of 60 mVrms. Turn on A Weighting and see the A weighting frequency response with a peak of about -28 dBV at between 2 and 3 kHz, and RMS noise of 62 mVrms. Turn off A weighting and select USER1 and see the ITU R 468 response with a peak of -18 dBV around 6-7 kHz and RMS noise of about 220 mVrms.

The aggressive FFT settings provide a cleaner noise frequency response profile. An orange note indicating the weighting(s) in effect will appear in in the upper left display area. You can enter more than one weighting, e.g. *A* and *USER1 together*, even though it does not make sense here. Different weighting can be chosen while the measurement is in progress. To change the *USER1* weighting file, click *USER1* to off and then right click *USER1* to get back to the *USER1* file selection dialog box.

The User Weighting files in Table 4 include *Pink Noise* and *Twin T Compensation*. Pink noise is often used in audio frequency response measurements, such as for rooms when using a measurement microphone. This is usually done with a noise source whose frequency response drops by 3 dB/octave. However, here the use of the pink noise weighting is applied at the analyzer end to achieve essentially the same result in the measurement, with white noise from the generator as the actual source.

User-defined weighting can also be used to enter other weighting of responses like a response to correct the attenuation of a passive twin-T notch filter at the harmonic frequencies. These losses are approximately 9.75 dB, 5.14 dB, 3.31 dB and 2.29 dB at the second through fifth harmonics of 1 kHz. These losses are significant in affecting the results of a THD measurement that uses a passive twin-T notch filter in front of the QA40X. Such an arrangement allows greater distortion-measurement dynamic range by using the 0-dB full scale input setting because the higher-amplitude fundamental has largely been rejected. Use of the *Twin T Compensation* weighting file can correct these losses of the passive twin-T notch filter.

The plot below shows the twin-T response of an actual 1-kHz passive twin-T notch filter inserted into the loop back path of the QA40x with the *Twin T Compensation User Weighting* file. The frequency response is flat within tenths of a dB from 2 kHz to 10 kHz. The compensation also deliberately introduces 10 dB of attenuation at low frequencies.

If you want to change the weighting file being called by USER1 or USER2, right-click on the *USER* button and a dialog will come up. Select *Clear Weighting* and hit OK. Then right-click again and select File and browse to the desired file in the *User Weighting* folder and double-click on it. Then hit OK.

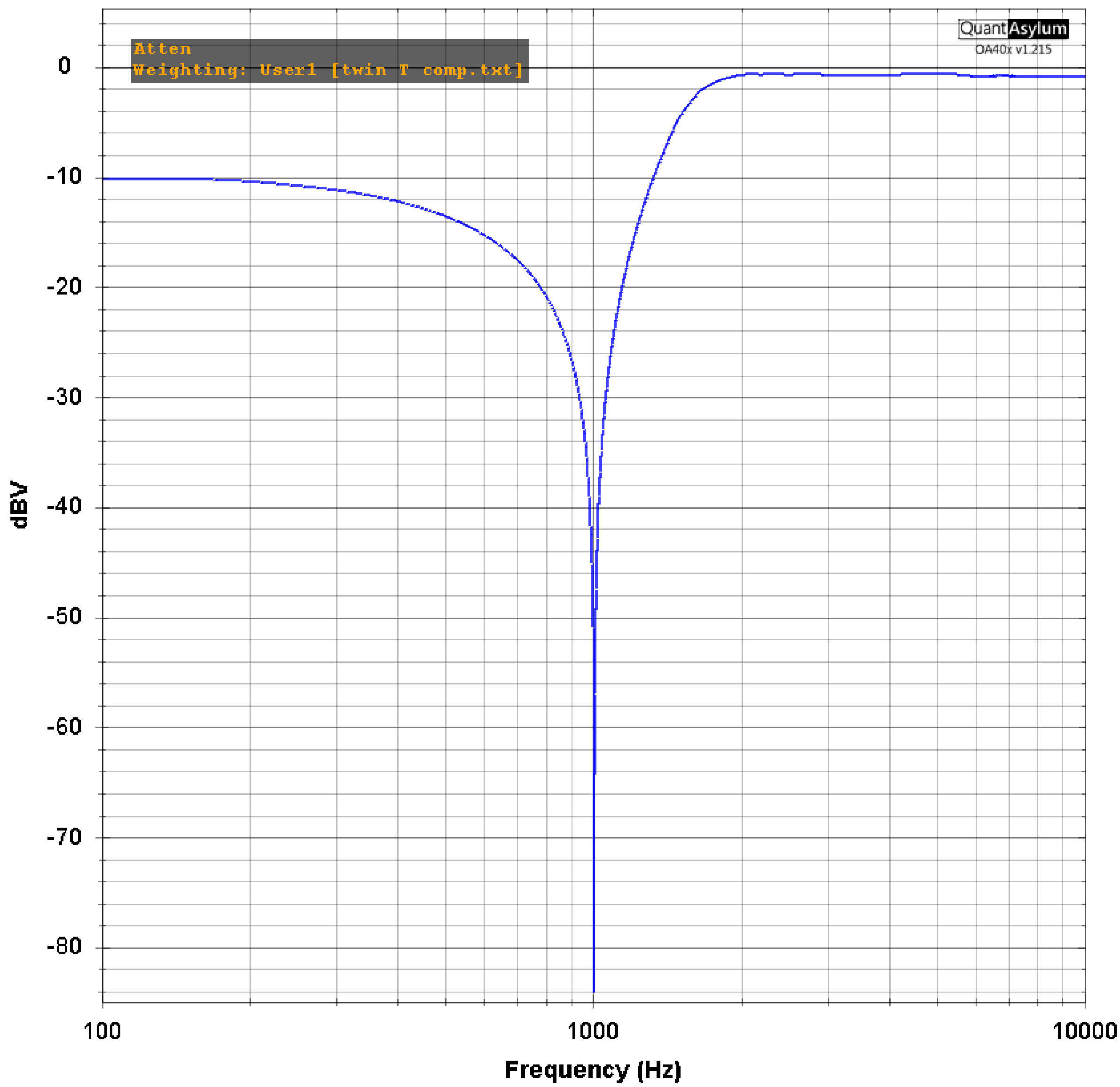

Figure 8: Twin-T Frequency Response with Response Compensation

SNR

Signal-to-Noise Ratio (SNR) of the BC-1 amplifier will be measured here. It is essentially a measurement of the amplifier noise (not including harmonics) as described above, with the output noise voltage divided by an output signal voltage of 2.83 Vrms, corresponding to 1 W into 8 Ω. 2.83 Vrms is +9.0 dBV, so if the amplifier has 28 dB gain, a -19 dBV input signal will yield a 1-Watt output into 8 Ω.

The SNR is usually measured in a defined bandwidth, and is often weighted. Un-weighted SNR will often be measured in a 20-kHz or 80-kHz bandwidth. Weighted noise will usually be measured with the A-weighting frequency curve, which attenuates the measurement at low and high frequencies to account for the way that hearing sensitivity varies with frequency.

It should be pointed out that the frequency response of hearing sensitivity is not the same for a single tone as opposed to narrowband noise [4]. A weighting was actually developed using the audibility of single tones, so it is rather imperfect. The QA40X includes A-weighting and C-weighting as options. It can also apply weighting in accordance with a weighting file provided by the user, designated *USER1* and *USER2*. Connect the output of the QA40X to the input of the amplifier. Connect the input of the amplifier to the output of the QA40X.

Go to *File* > *LOAD Settings*, and load the file "***Noise.Settings***".
Set Full Scale Input to 18 dBV.
Push the *SNR* button and the *SNR* tile will appear.
Click on Gen 1, then right-click and set amplitude to -19 dBV,
Set *Amplitude Knob Sensitivity* to 0.2 dB.
Add the *RMS Pwr Watts, RMS Volts* and *RMS dBV* measurements.
Reduce FFT size to 64k and Averages to 4.
Increase *Ymax* to +20 dBV, and increase *Ymin* to -140 dBV.
Hit *RUN*.

Increment/decrement the *Gen 1* level to achieve 1 Watt (+9 dBV) within ±0.5 dB. Go to *File* > *Save Settings*. Name the file **"*SNR.settings*"**.

Observe the un-weighted SNR as 100 dB for this amplifier with bandwidth of 20 kHz. Notice that the FFT noise floor is centered around -127 dBV. 60-Hz hum is at -113 dBV, 122 dB below 1 Watt. See also a 3rd harmonic line at -106 dBV, 115 dB below 1 Watt, corresponding to 0.00018% harmonic distortion. Press the A weighting button and see the SNR increase to 102 dB.

Go to *File* > *Save Settings*. Name the file **"*SNR A wtd.settings*"**.

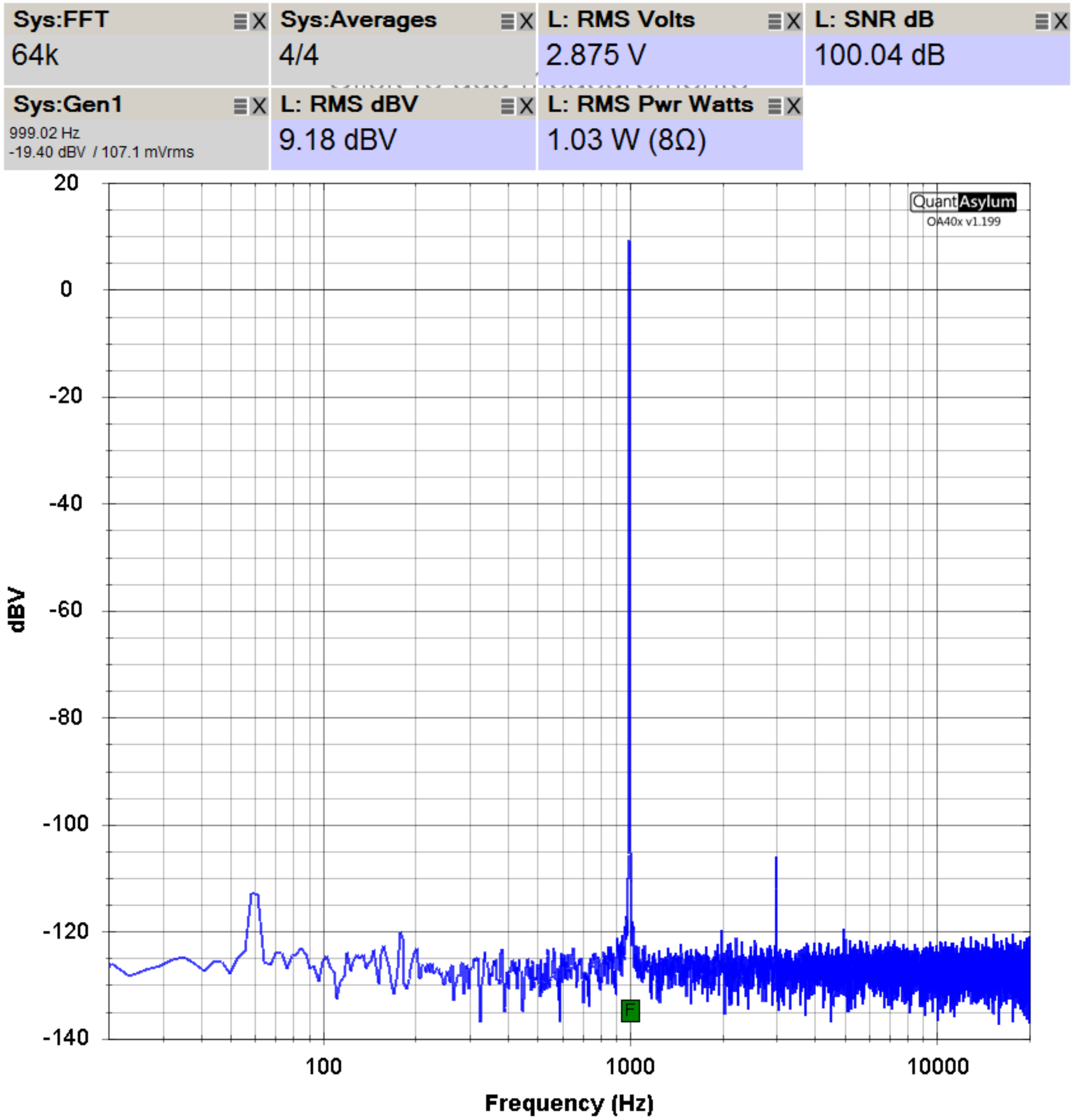

Figure 9: Un-weighted SNR in 20-kHz Bandwidth

Sometimes the un-weighted SNR in an 80-kHz bandwidth is quoted. This can be measured as follows: turn off the A weighting. Right click on *XLOG* and set the end frequency to 80 kHz. Right click on RMS and set the stop frequency to 80 kHz. The un-weighted 80-kHz SNR is reported as 94 dB. White noise power increases as the square root of the measurement bandwidth, going up 3 dB for each doubling of bandwidth. Thus going from 20-kHz bandwidth to 80-kHz bandwidth the noise should go up by 6 dB and the SNR should go down by 6 dB.

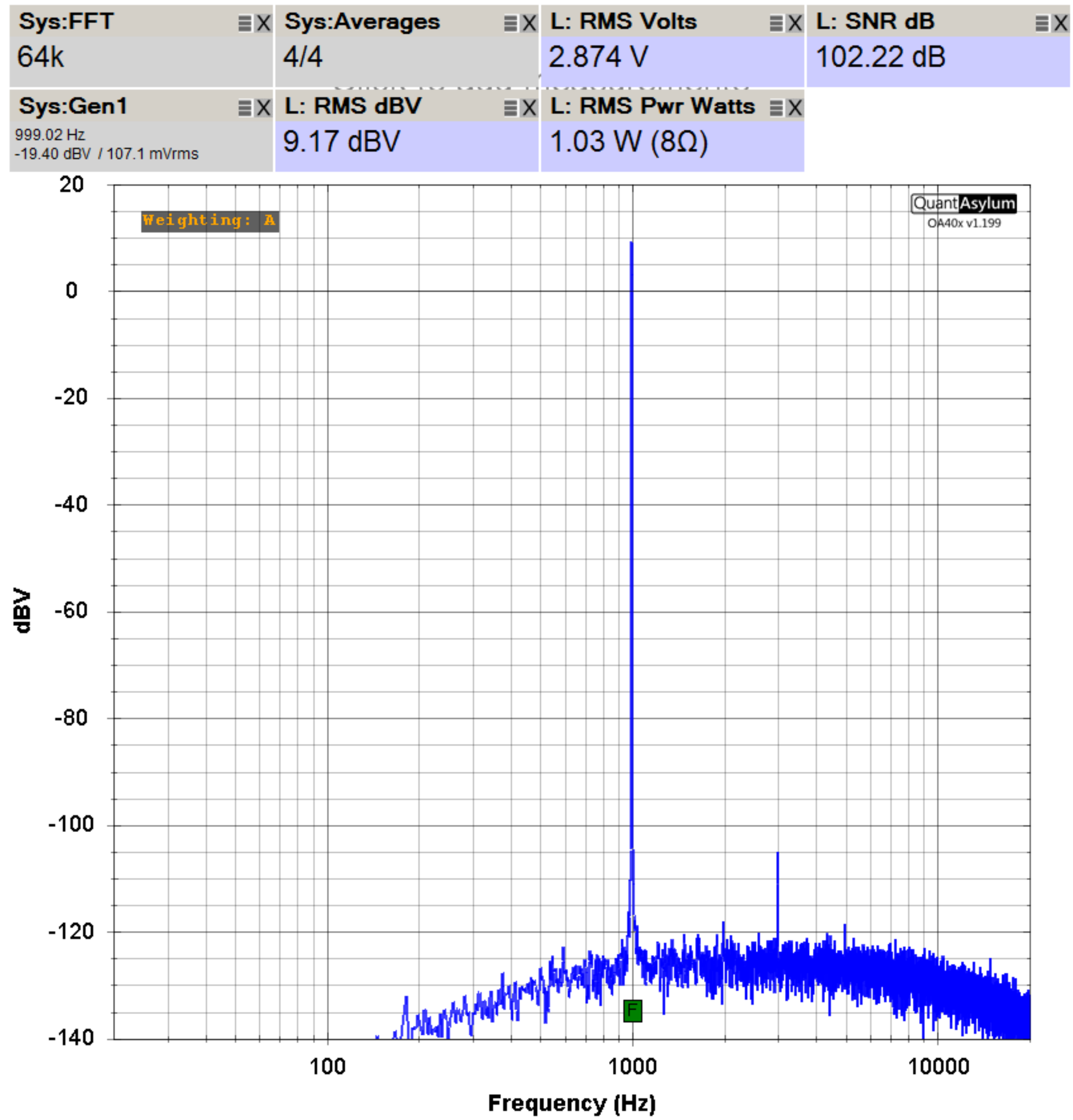

Figure 10: A-weighted SNR

Noise Density

Input-referred noise density is expressed in nV/√Hz. It is the RMS output noise over a known frequency range divided by the amplifier gain. This is a special mode of the analyzer for noise measurements, and it shouldn't be used for measuring tones. Consider an amplifier whose output noise is 15 μV in a 20-kHz bandwidth and whose gain is 26 dB. Input-referred noise is 0.75 μV or 750 nV. A 20-kHz bandwidth contains 141 √Hz. Dividing 750 nV by 141 √Hz yields 5.3 nV/√Hz. This would be quite good for a power amplifier. For context, the input noise for a moving coil preamplifier should be about 1 nV/√Hz or less [4]. If one right clicks on the *dBV* button in the *Axis* section a dialog box will come up where the units for the *Y* axis can be selected. One of those selections is *Rt Hz*.

Short the input(s) to the amplifier.
Go to *File* > *Load Settings* and load the file *Noise.settings* created earlier.
Click on *dBV* in the *Axis* settings.
Right click on *dBV*, and in the dialog select *dBV* and check *Rt Hz*.
Set input gain to that of the amplifier, here 28.6 dB.
Adjust *Ymin* to -180 dBV, which is shown as 1.0 nV/√Hz on the right axis.
Hit *RUN*.

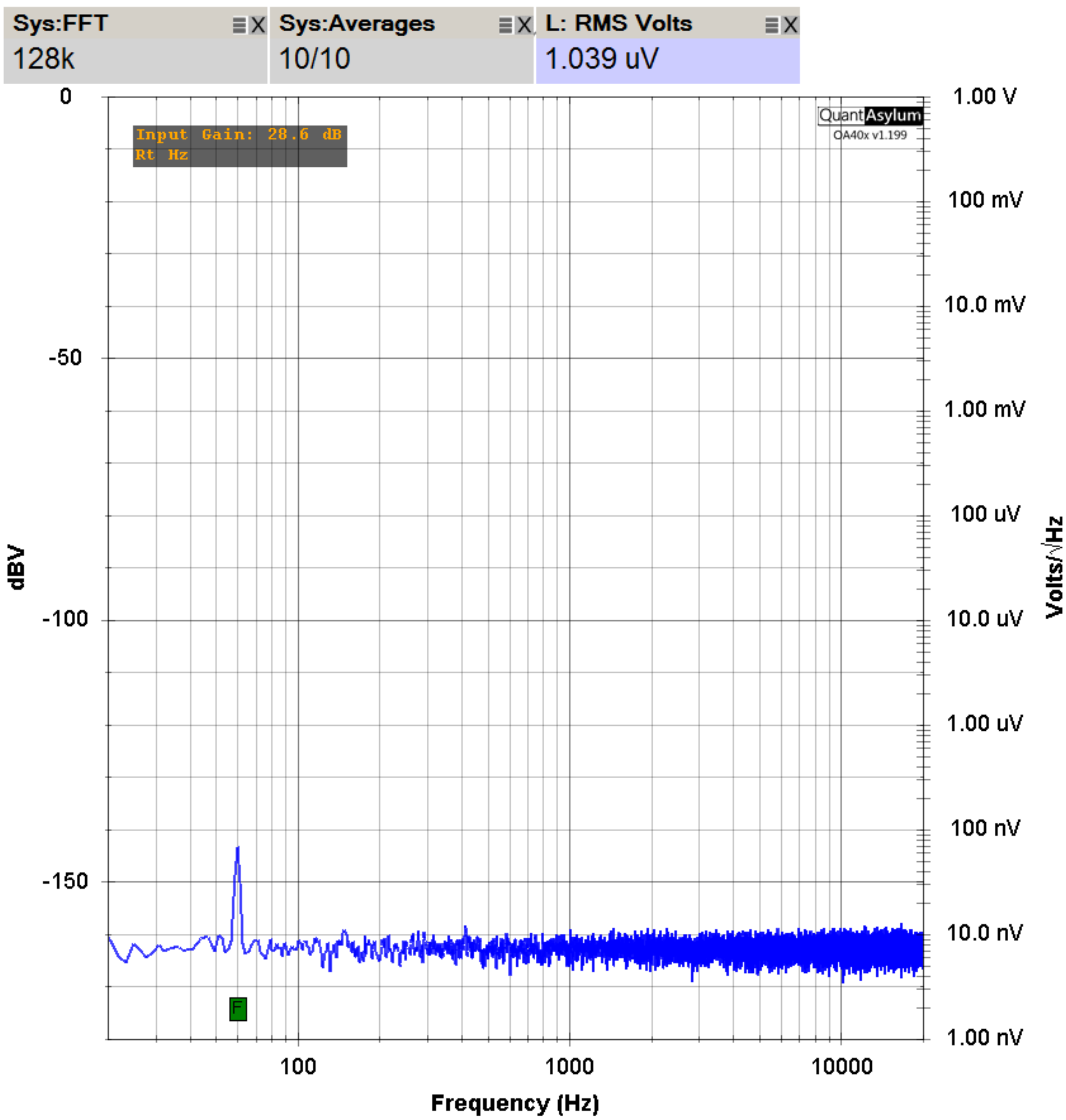

Figure 11: Input-referred Noise Density

Go to *File > Save Settings* and save this setup file as **"*Noise Density.settings*"**.

The noise density is displayed in Figure 11 on the right-side Y axis in nV/√Hz, with that value being properly referred with respect to the input by the entered amplifier gain. The aggressive FFT settings provide a cleaner noise frequency response profile. This amplifier exhibits input-referred noise of about 7 nV/√Hz, as seen by the body of the amplifier noise floor and ignoring the 60-Hz hum and harmonics.

THD and THD+N

The THD and THD+N of the left channel of the amplifier will be measured at 1 kHz with the amplifier connected to an 8-Ω load . Note that for measurements with a 4-Ω load (or other load not the 8-Ω default) the load impedance in the *dBV* settings must be set accordingly for proper calculation of power.

FFT bin size can be very important when measuring very low values of distortion, especially in the presence of even fairly small noise. This is because a larger-frequency bin span will have more noise leak into that bin and be counted as distortion contributions. FFT bin size is inversely proportional to FFT size. In principle, noise leakage contributions into the bin will fall as the square root of FFT size. A 128-k FFT size should be the minimum. An FFT bin size of 1 Meg is not out of the question when measuring very low distortion at small signal levels, where the relative noise present in the signal is larger. However, it takes a long time to complete the measurement. If you see reported THD increase as signal level is decreased that is not usually how an amplifier should behave, and it is a possible result of noise leakage into the FFT bin (we are not talking about THD+N or crossover distortion here).

Connect the left channel output of the QA40X to the left channel input of the amplifier.
Ground the right channel input of the amplifier.
Connect the left channel output of the amplifier (DUT) to an 8-Ω load.
Connect the left channel output of the DUT to the left channel input of the QA40X.

Start fresh by entering *File>New Settings*.
Click RIGHT channel to off in the *Display* section.
Set the *Sample Rate* to 192 kHz.
Set *FFT* size to 256k, *Averages* to 4, and *Window* to *Hann*.
Push *THD* and *THD+N* buttons in *Measurements*; right click *THD* to note options.
Add the measurements *THD %, THD+N %, THD dB, THD+N dB*.
Add the measurements *RMS Volts, RMS dBV* and *RMS Pwr Watts*.
Push *Gen 1* button if not enabled; right click and set amplitude to -20 dBV.
Set *Gen 1 Amplitude Knob Sensitivity* to 0.2 dB.
Hit *RUN*.

The display will show a fundamental line at 1 kHz, and other lines at harmonics, hum frequencies, etc. The 1-kHz line will likely be between 0 and +10 dBV depending on amplifier gain. Here it is +8.6 dBV because the gain of this amplifier is 28.6 dB. This corresponds to 900 mW. The noise floor is at about -115 dBV.

Change the full scale input (FSI) from the default 42 dBV to 18 dBV. The noise floor drops to about -127 dBV, since this reduces any noise contribution due to the analyzer when FSI is 42 dBV.

Increment or decrement *Gen 1* until the power is about 1 watt. THD and THD+N now read -114 dB (0.0002 %) and -99 dB (0.0011 %). Note the *Gen 1* input level is now at -19.40 dBV.

Return the *Full Scale Input* (input attenuator) to 42 dBV (the default).

Go to *File* > *Save Settings* and save this setup file as "***THD_1 1_W.settings***".

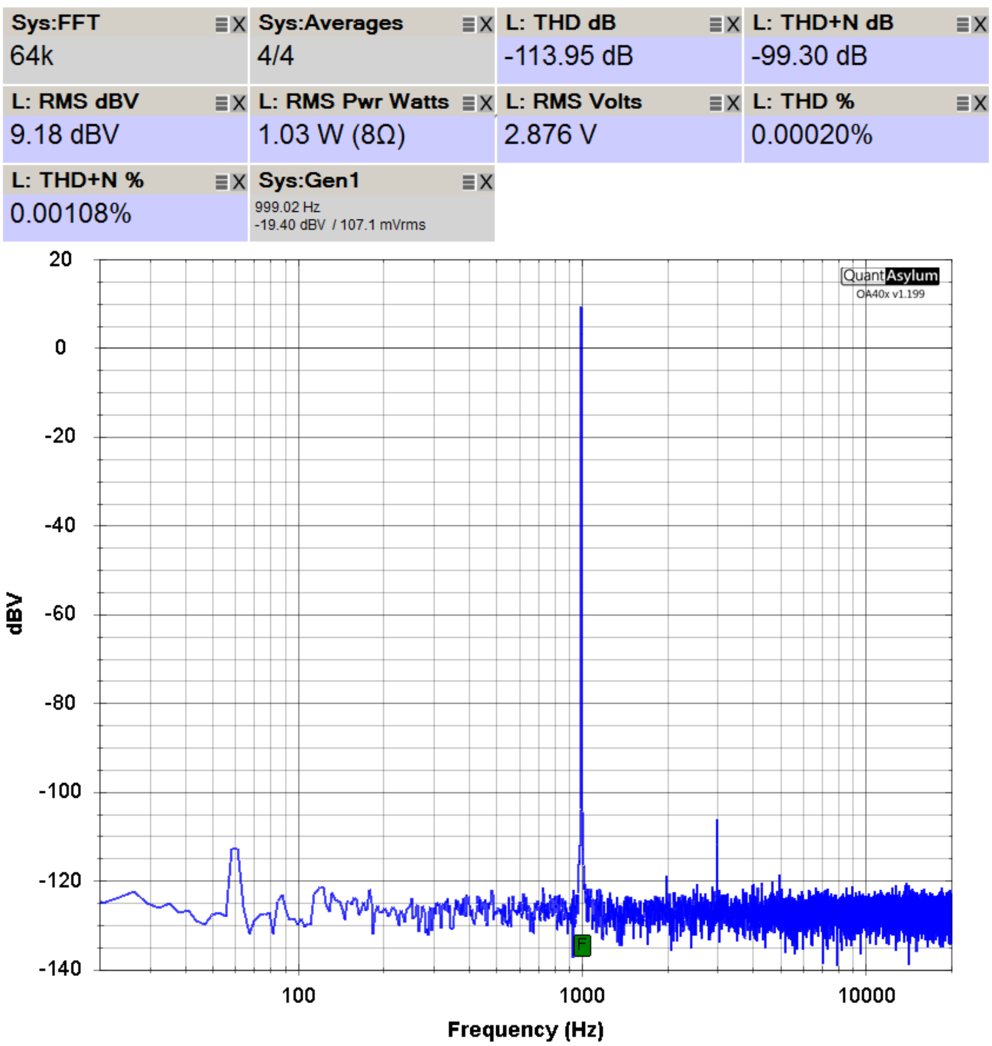

Figure 12: THD-1 Measurement at 1 Watt

Increase the power level to about 10 Watts by incrementing the level of *Gen 1* with its up arrow. Output voltage is now 8.9 Vrms. THD is now 0.00027% and THD+N is now at 0.0014%. Increase *Ymax* to +40 dBV. Increase the power level to about 100 W. THD is now 0.00019 % and THD+N is now 0.00052 %. Increase amplifier power to its rated 140 W. THD is now 0.00018 % and THD+N is now 0.00048%. Note that the rated power of 140 W is obtained with a Gen 1 input level of +1.75 dBV.

THD vs Output Power into 8-Ω and 4-Ω Loads

Now push the amplifier to its power limit at the onset of clipping at 1 kHz. Start at approximately the rated power of 140 W into 8-Ω by setting the Gen 1 signal level to +1.75 dBV. Note that for measurements with a 4-Ω load (or other load not the 8-Ω default) the load impedance in the *dBV* settings must be set accordingly for proper calculation of power. Note that this measurement does not conform to the FTC power rating measurement standard because there is no continuous 1/8-power preconditioning. the test here is done with signal bursts and it is done with only one channel operating.

Go to *File* > *Load Settings* and load the file **"*THD_1 1_W.settings*"**.
Increase the *Gen 1* setting to +1.75 dBV, corresponding to 140 W into 8-Ω.
Hit *RUN*.

Go to *File* > *Save Settings* and save this setup file as **"*THD_1 140_W.settings*"**.

THD-1 reads 0.00013%. Increment the *Gen 1* level until you see a marked increase in THD and the FFT harmonic lines, approaching but not exceeding 1%. At 175 W, with Gen 1 level at +2.90 dBV, soft clipping is apparent with THD at 0.034 %. A further increase of 0.2 dB pushes THD-1 above 1 %. Clipping power is thus about 175 W.

Now push the amplifier to its power limit with a 4-Ω load at the onset of clipping at 1 kHz. An ideal amplifier will double its rated power with a 4-Ω load with the same relative amount of margin against clipping as with an 8-Ω load. This will not be the case for real amplifiers due to power supply sag at the higher current demand. Connect a 4-Ω load to the amplifier. Start at approximately 70% of twice its 8-Ω rated power, or 200 W into 4-Ω by setting the Gen 1 signal level to +0.8 dBV. Connect a 4-Ω load to the amplifier.

Go to *File* > *Load Settings* and load the file **"*THD_1 140_W.settings*"**.
Right click the dBV button and set the load impedance to 4 Ω.
Change the *Gen 1* setting to +0.8 dBV, corresponding to about 200 W into 4-Ω.
Hit *RUN*.

Go to *File* > *Save Settings* and save this setup file as **"*THD_1 4_Ohm.settings*"**.

Observe a reported power level of about 200 W with THD-1 of about 0.00017%. Increment the *Gen 1* level until you see a marked increase in THD and the FFT harmonic lines, approaching but not exceeding 1%. At 280 W, with the Gen 1 level at +2.0 dBV, soft clipping is apparent with THD at less than 0.1 %. Clipping power is thus slightly over 280 W. A marketing person would happily say that this amplifier fulfills the ideal power doubling of 8-Ω rated power into a 4-Ω load.

Burst Power into 4-Ω and 2-Ω Loads

You can have the QA40X do a test with a single burst, allowing a very small average power duty cycle. Set the sample rate and FFT size and initiate a single measurement burst by hitting *CTRL+space*. The measurement will be made at 1 kHz. If you select a sample rate of 192 kHz and a very small FFT size of only 2k, the burst will last only about 11 ms. In this case, the result of the measurement will largely reflect the burst power of the amplifier achievable before the power supply sags. For the test below, the BC-1 was equipped with 40,000 µF for each power supply rail.

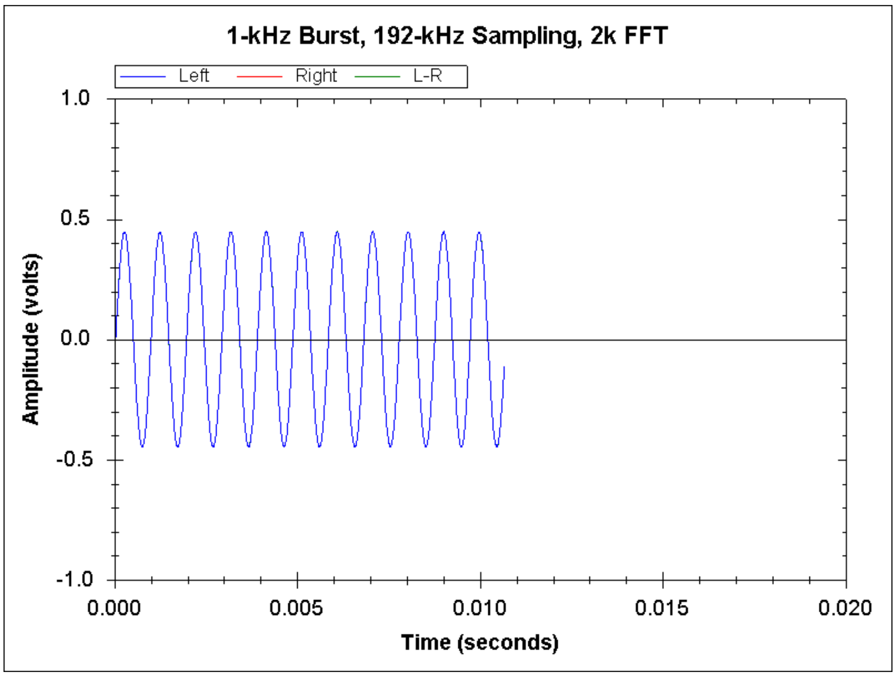

Figure 13: Burst Signal Lasting Only 10.4 ms

This test will also reflect the performance of the amplifier without any significant amount of thermal output stage bias change. If the output of the amplifier is captured on a DSO or if you shift to the *Time Domain* display on the QA403, near-instantaneous clipping performance can be safely observed. Finally, measuring an amplifier when driving a 2-Ω load can be done safely. Such brief drive signals can also be useful in safely evaluating protection circuits and evaluating peak output current capability. Connect a 4-Ω load to the amplifier for this test.

Start fresh by entering *File>New Settings*.
Set *Full Scale Input* to 42 dBV.
Click *RIGHT* channel to off.

Set *Sample Rate* to 192 kHz, FFT size to 2k and FFT window to *Hann*.
Push the *THD* button.
Push *Gen 1* button if not enabled; right click and set amplitude to +2.0 dBV.
Set *Gen 1 Amplitude Knob Sensitivity* to 0.1 dB.
Right click the dBV button and set the load impedance to 4 Ω.
Right click on *XLOG* and increase its start frequency to 100 Hz.
Right click on THD and increase its start frequency to 100 Hz.
In *Add Measurements*, select *RMS Pwr Watts, RMS dBV* and *THD%*.
Set *Ymin* to -120 dBV and set *Ymax* to +40 dBV.
Hit *CTRL+space*.

Go to File > Save Settings and save this setup file as "***Burst Power.settings***".

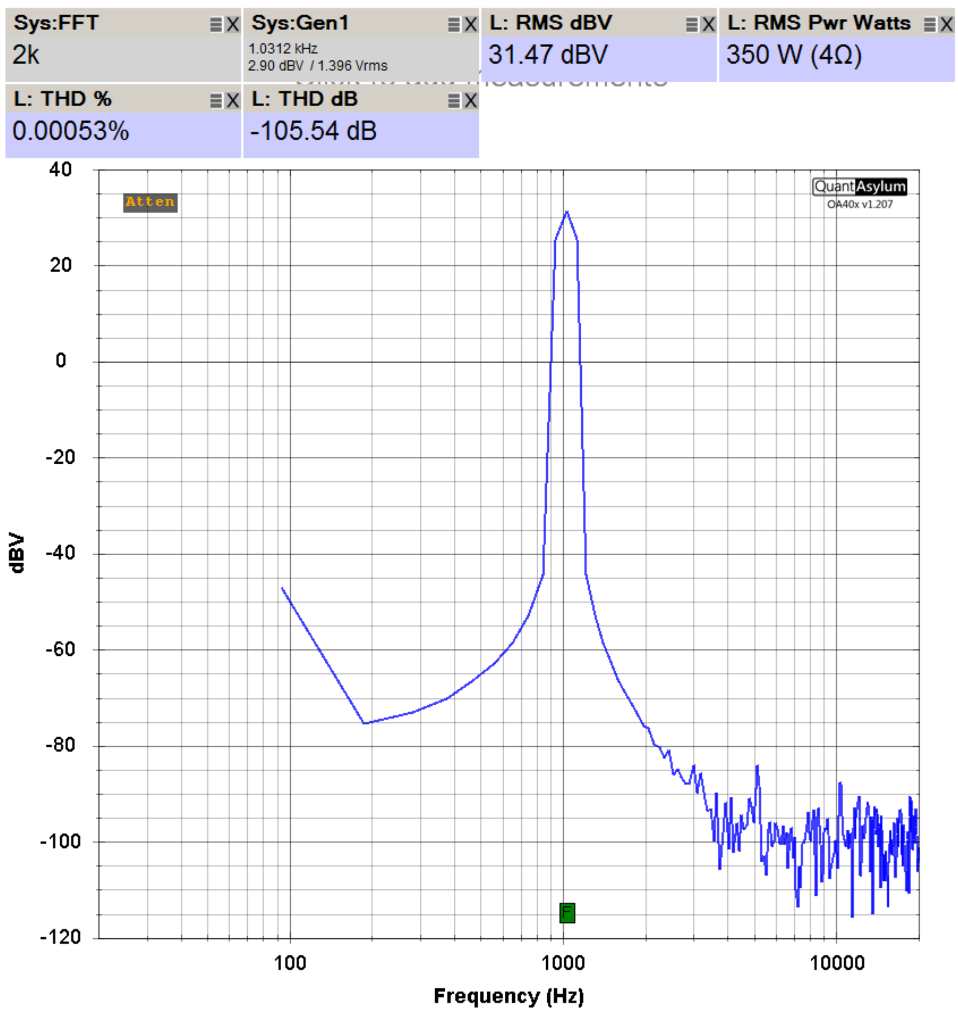

Figure 14: Burst Power of 350 W into 4-Ω Load at 1 kHz

A single measurement will be run, with reported power of 280 W and THD below 0.001%. Increase the Gen1 amplitude in 0.1-dB increments, hitting *CRTL+Space* with each increment, until the THD reading rises steeply, indicating the onset of clipping.

For this amplifier that occurs at an input amplitude of about +2.9 dBV, where burst power reported is 350 W and THD-1 is still below 0.001%. Distortion rises sharply above this amplitude. This will be the maximum burst power of the amplifier with a 4-Ω load. This is considerably higher than the continuous clipping power of 280 W reported in the conventional measurements above. The maximum output voltage in this test at 346 W was +31.4 dBV, just a hair below the 32 dBV maximum input of the QA403. This is an example of a test where use of an external attenuator can be a good idea. Notice that the FFT looks wrong below 200 Hz. This is due to the too-small size of the FFT for accuracy at 200 Hz and below.

We will now punish this modest amplifier, rated at 140-W, 8-Ω, by loading it with a 2-Ω load. First set the Gen1 output amplitude to 0.5 dBV to check amplifier stability driving a 2-Ω load. This setting will deliver 200 W into the 4-Ω load. Connect the 2-Ω load and set the dBV load impedance to 2 Ω. Hit *CTRL+space*. The amplifier delivers 398 W, about 14% more than the burst power into a 4-Ω load, which is a good sign. THD-1 is 0.007%. At 426 W, 22% over the 4-Ω burst power, THD-1 has risen to 0.1% and we will stop there. Current limiting has probably come into play at this point. This power level corresponds to a peak current of over 20 Amps. The triple emitter follower output stage in this amplifier makes such high current delivery at fairly low distortion possible [1].

Burst performance into 2 Ω loads can matter. Some loudspeakers can dip that low or lower at certain frequencies. Also, if the amplifier is bridged with a 4-Ω load, the amplifier on each side of the bridge will effectively see a 2-Ω load. This modest amplifier might not last long in such a bridged arrangement into 4 Ω, however.

THD vs. Frequency

Now drop the power to approximately 1 Watt (with an 8-Ω load) and measure its THD for different frequencies up to 20 kHz by incrementing the Gen 1 frequency. At 1 Watt, THD-1 is 0.00018% and THD-20 is 0.0028%. After the 1-Watt tests, raise the power to 5 Watts and measure THD as a function of frequency.

Start fresh by entering *File>New Settings*.
Set *Full Scale Input* to 30 dBV.
Click *RIGHT* channel to off.
Set *Sample Rate* to 192 kHz, FFT size to 128k, averages to 4, FFT window to *Hann*.
Push *Gen 1* button; right click and set amplitude to -12.6 dBV for 5 Watts.
Set the Gen 1 frequency to 1 kHz.
Set *Gen 1 Frequency Knob Sens*. to 1/3 octave, *Amplitude Knob Sens.* to 0.2 dB.
Click the THD button.
In *Add Measurements*, select *RMS Pwr Watts, RMS dBV*.

Add the measurements THD dB, *THD% and THD+N%*.
Right click on *XLOG* and increase its end frequency to 85 kHz.
Right click on THD and increase its stop frequency to 85 kHz.
Hit *RUN*.

Go to File > Save Settings and save this file as **"*THD_1 5_W.settings*"**.

Or load the file **"*THD_1 5_W.settings*"** if it already exists.

The *Gen 1* amplitude setting of -12.6 dBV puts the output power at about 5 W. THD-1 for this amplifier reads -106 dB, or about 0.0005%. The 1-kHz fundamental is at 16 dBV. The harmonic spectrum can be seen out to 80 kHz, but there is not much there other than some 3rd and 5th harmonic lines.

Increment the *Gen 1* frequency to 20 kHz in 1/3-octave steps and watch the THD and harmonic content increase. Note that at 10 kHz, harmonic lines can be seen out to 80 kHz, and THD is 0.0024 %. As expected, 3rd and 5th exhibit the highest amplitude. At 20 kHz, THD is up to 0.0038 % and the 2nd, 3rd and 4th harmonic lines are visible.

Go to File > Save Settings and save this file as **"*THD_20 5_W.settings*"**.

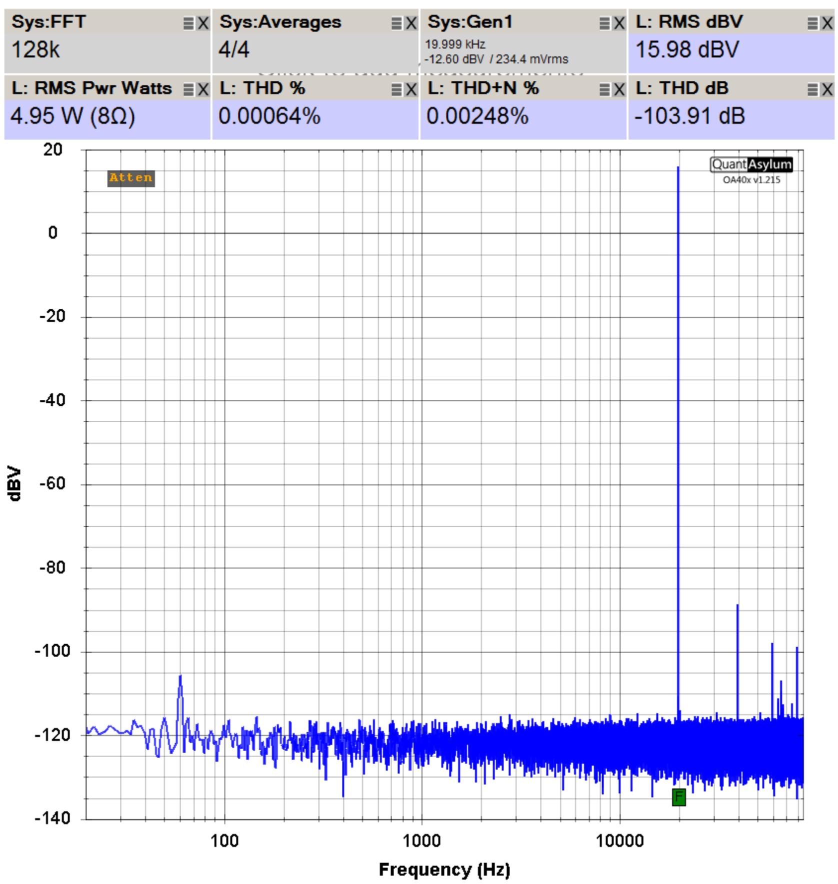

Figure 15: THD-20 Spectrum at 5 Watts

Note that if the fundamental frequency is incremented above about 40 kHz, the THD reading goes down precipitously, as a result of the second and higher harmonics being no longer in the measurement range.

Now we will measure THD at a power of 140 Watts. Set the full scale input to 42 dBV, return the frequency to 1 kHz and increment Gen 1 until the output power is 140 watts. THD-1 will read about 0.00025 % (see *THD_1 140_W.settings*).

Increment the frequency to 10 kHz in 1/3-octave steps and watch the THD and harmonic content increase. See THD rise to THD-10 of 0.0015 %. Harmonics up to the 8th at 80 kHz are clearly visible.

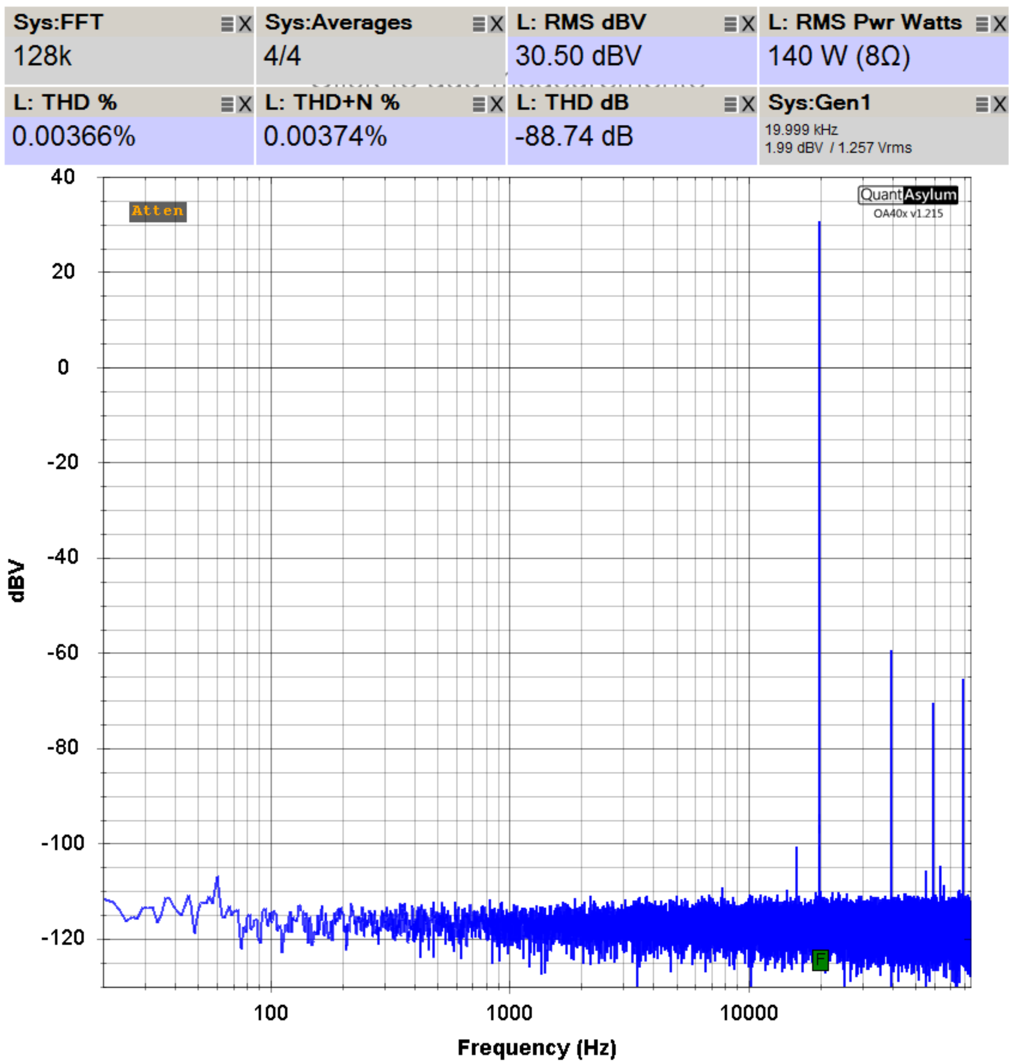

Figure 16: THD-20 Spectrum at 140 Watts

Increase the frequency to 20 kHz and see THD rise to THD-20 of 0.0037 %. Harmonics up to the 4th at 80 kHz are clearly shown. The FFT noise floor is at about -110 dB, about 140 dB below the fundamental. The reported THD-20 value does not include any contribution from the 5th harmonic because it is above the measurement bandwidth. For this reason, sometimes THD-16 will be measured, here 0.0026%

Go to File > Save Settings and save this file as **"*THD_20 140_W.settings*"**.

THD vs Frequency vs Output Power

In this test, THD vs. frequency is measured for several different power levels. This will be accomplished with one of the automated tests discussed later under "*Automated Tests*". If this measurement is done manually, it must be executed at individual frequencies by measuring THD at different power levels, making note of THD as power level is increased.

THD Visualizers

The QA40X software includes some *Visualizers* that present measured data in different ways that can be quite helpful. Among the visualizers are two for THD - the *Bargraph Display* and the *Residual Display*. The former provides a bargraph that shows the relative amplitudes of the THD harmonics. The latter provides an oscilloscope-like voltage vs time display of the distortion residual, just as does the residual output of a conventional distortion analyzer.

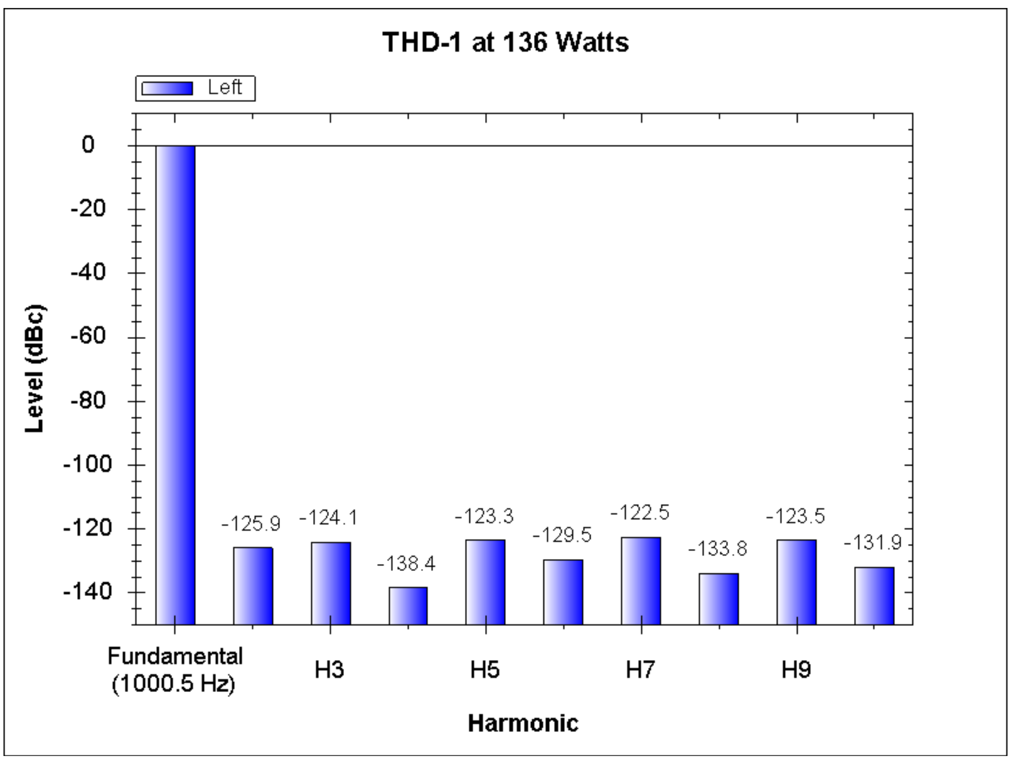

Figure 17: THD-1 Bargraph Display at 136 Watts

Load the file "*THD_1 1_Watt .settings*". The frequency will be at 1 kHz. Set the Gen 1 level to +1.8 dBV to obtain an output power level of about 136 Watts. Hit *RUN*. THD-1 reads about 0.0002 %. Distortion is low, but with a rich harmonic structure as seen on the FFT.

Go to *File* > *Save Settings* and save this setup file as **"*THD_1 136_W.settings*"**.

Stop the measurement and go to *Visualizers* > *THD Bargraph Display*. A bargraph comes up displaying harmonics H2 through H10, all referenced to the fundamental at 0 dB. The dB level is shown at the top of each bar. Right click on the bargraph and select "*Save Image as* ..." and save the image in the chosen format to a folder.

Close the bargraph display and increase the Gen 1 level until the indicated power level is about 162 Watts at about +2.6 dBV and clipping is occurring.

Go to *File* > *Save Settings* and save this setup file as **"*THD_1 162_W.settings*"**.

Go to *Visualizers* > *Residual Display*. A residual signal voltage display of the fundamental and residual versus time will be displayed. Signal voltage is shown on the left *Y* axis and residual signal voltage is shown on the right axis. The waveforms are too dense to see. Drag the plot from upper left to lower right to zoom in to about 4 cycles of the fundamental. Clipping at the top of the waveform is evident. The signal voltage has a peak value of about 45 volts and the residual has a peak value of about 1 V.

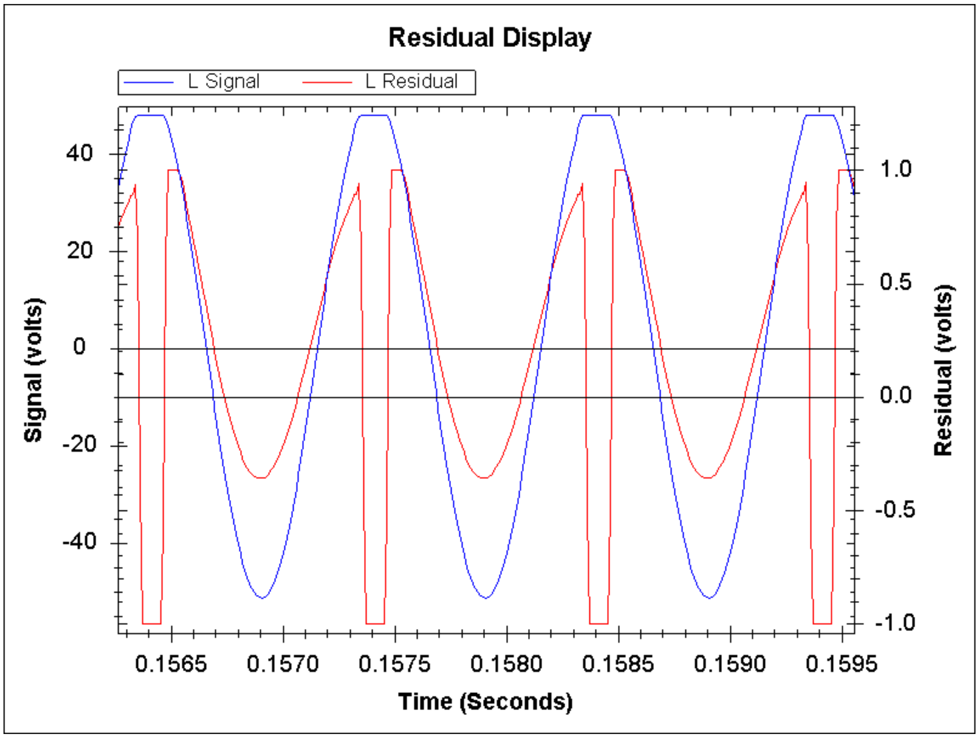

Figure 18: THD-1 Distortion Residual at 162 Watts Clipping

Close the residual display and go to the oscilloscope visualizer. Zoom in to about 3 cycles of the fundamental. The output waveform will be displayed, with the positive peak exhibiting clipping.

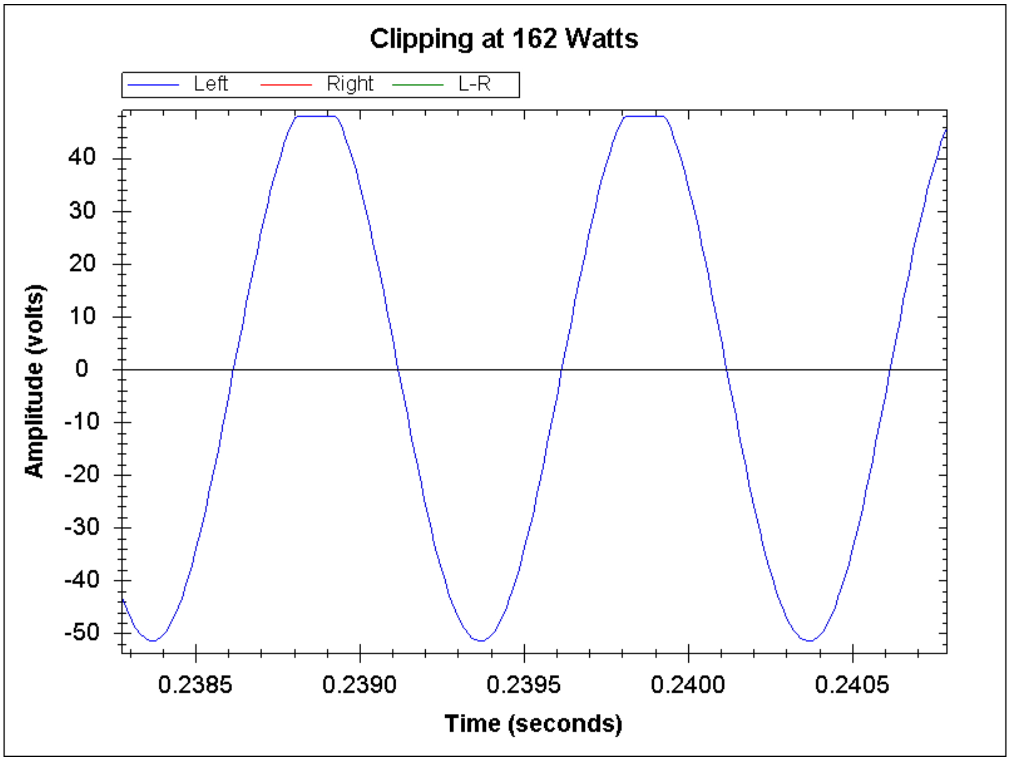

Figure 19: Oscilloscope Display Showing Hard Clipping of the Amplifier

GenEx Burst Waveform

Measurements are made with a stimulus signal burst during which FFT data points are taken. The bursts are followed by a signal-off calculation interval. Depending on the settings for sampling rate and FFT size, the duty cycle of the repeated measurements can change, but is often in the range of 70% to 90%. The duration of the burst is approximately the ratio of the FFT size to the sample rate. A 32-k FFT with a sample rate of 48 kHz will have a burst of about 680 ms. For a given FFT size, a higher sample rate will result in a shorter burst interval. A typical 64k FFT with a 96 kHz sample rate was measured to have a burst duration of about 720 ms and a subsequent off interval of about 180 ms, for a total measurement time of 900 ms and a duty cycle of 80%.

The burst duty cycle influences how hot the load resistor gets and how much the amplifier output transistor junction and heat sink temperatures rise during repeated measurements. A smaller duty cycle allows the use of a load resistor with a lower power rating. A smaller duty cycle also allows for less power transistor heating and less output stage bias change during the measurements (which can influence distortion readings).

The duty cycle of repeated measurements can be reduced by introducing a pause interval during the signal-off time. This can be done by going to *Edit > Settings > Pause Acquisitions* and entering a pause time of up to 2 seconds. This can reduce a typical measurement duty cycle to as little as about 25%. An even smaller duty cycle and burst duration can be had with a 32k FFT at a 192 kHz sample rate.

You can also have the QA40X do a test with a single burst, allowing an almost arbitrarily small duty cycle. After you set the sample rate and FFT size, you can initiate a single measurement burst by hitting *CTRL+space*. If you select a sample rate of 48 kHz and a very small FFT size of only 2k, a 1-kHz burst will last only about 40 ms. In this case, the result of the measurement will largely reflect the burst power of the amplifier achievable before the power supply sags. This will also reflect the performance of the amplifier without any significant amount of thermal output stage bias change. If the output of the amplifier is captured on a DSO, then near-instantaneous clipping performance can be safely observed. Finally, measuring an amplifier when driving a 2-Ω load safely can also be done. Such brief drive signals can also be useful in safely evaluating protection circuits and evaluating peak output current capability.

Below is an image of a 350-ms burst carried out during a frequency response measurement using the oscilloscope visualizer.

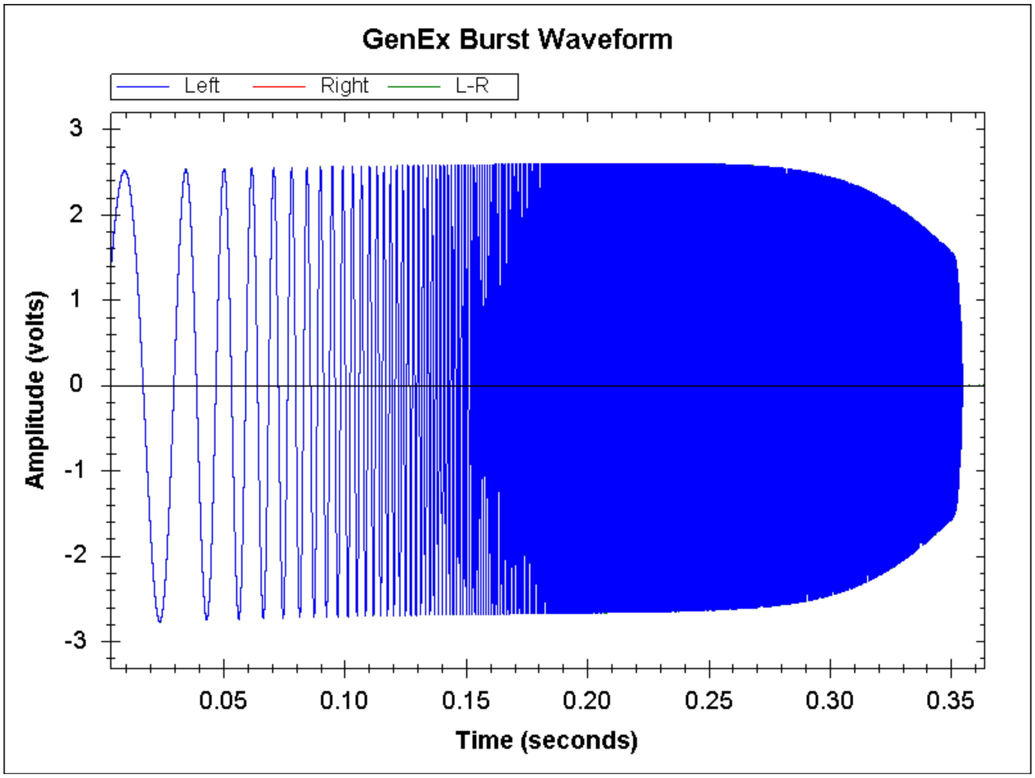

Figure 20: A *GenEx* Burst Waveform for Frequency Response Measurement

CCIF 19+20 kHz (ITU-T)

The two-tone CCIF IM measurement using equal-amplitude tones at 19 kHz and 20 kHz will be made here. This measurement of high-frequency intermodulation distortion is especially attractive because the IM products to be measured are all in-band at frequencies below 20 kHz (IM products exist above the audio band, but they are not of interest in this test). Those are usually centered in the vicinity of 39 kHz. An advantage of the two-tone test is that the individual tones need not be of extremely low distortion, as with THD measurements, since IM products are being measured, not harmonic products. These observations also apply to the SMPTE IM tests further below.

This test will be carried out with a peak stimulus voltage that is the same as the peak voltage of a sine wave that is the equivalent test power of the amplifier into 8 Ω. Even-order IM products will be at 1 kHz, 3 kHz, etc., while odd-order IM products will surround the twin tones of 19 kHz and 20 kHz, at frequencies like 18, 21, 17, 22 kHz, etc.. Some prefer to use 18.5-kHz and 19.5-kHz tones so that high odd-order products do not overlap any even-order IM products.

This test is especially important for testing class D amplifier high-frequency performance, since THD is virtually useless when most if not all of the harmonics may lie at frequencies above the output low-pass filter frequency. With this test, the IM products lie in-band and they accurately depict the performance of amplifiers that have significant roll-off above the audio band.

Here the BC-1 amplifier will be measured at 125 Watts equivalent power, corresponding to 31.6 Vrms or 44.7 Vpk into 8 Ω. This means that each tone should be 22.35 Vpk, corresponding to 15.81 Vrms, which corresponds to 24.0 dBV. With amplifier gain of 28.4 dB, each tone from *Gen 1* and *Gen 2* should have amplitude of -4.4 dBV.

Hit *File* > *New Settings* to start with a clean slate.
Set *Full Scale Input* to 42 dBV.
Turn off the right channel.
Set *Gen 1* to 19 kHz at -4.4 dBV.
Set *Gen 2* to 20 kHz at -4.4 dBV.
Add *Pk dBV*, *Pk Vrms* and *RMS Power Watts* measurements.
Add *Sys: FFT* and *Sys: Averages*.
Set the sample rate to 192 kHz.
Set the FFT size to 128k with 4 averages.
Select the *Hann* FFT window.
Set *XLOG* for 500 Hz to 45 kHz.
Go to the *dBV* dialog and set *Load Impedance* to 8 Ω.
Hit *RUN*.

Go to *File* > *Save Settings*. Name the file **"*CCIF 19_20.settings*"**.

Increase *Ymin* to -140 dBV and increase *Ymax* to +30 dBV.

The display shows the 19 and 20-kHz tones, each at +24.0 dBV, surrounded by IM products. Note the 39-kHz IM even-order frequency sum product at -65 dBV also surrounded by other IM products. It is down 89 dB from each of the 19 kHz and 20 kHz tones. The even-order frequency difference IM product at 1 kHz at -85.5 dBV, is down 110 dB from each tone.

The two tones are at +24 dBV and they are surrounded by sideband distortion products every 1 kHz away. The 3rd-order product at 18 kHz is at -88 dBV, putting it down about 112 dB from each tone. The 5th-order product at 17 kHz is at -97 dBV, putting it down 121 dB from the tones. The 7th-order product at 16 kHz is at -98 dBV, putting it down 122 dB from the tones. The relative values of the distortion products with respect to the tones can be easily seen by hitting the dBr button and selecting the display peak as the 0 dBr reference.

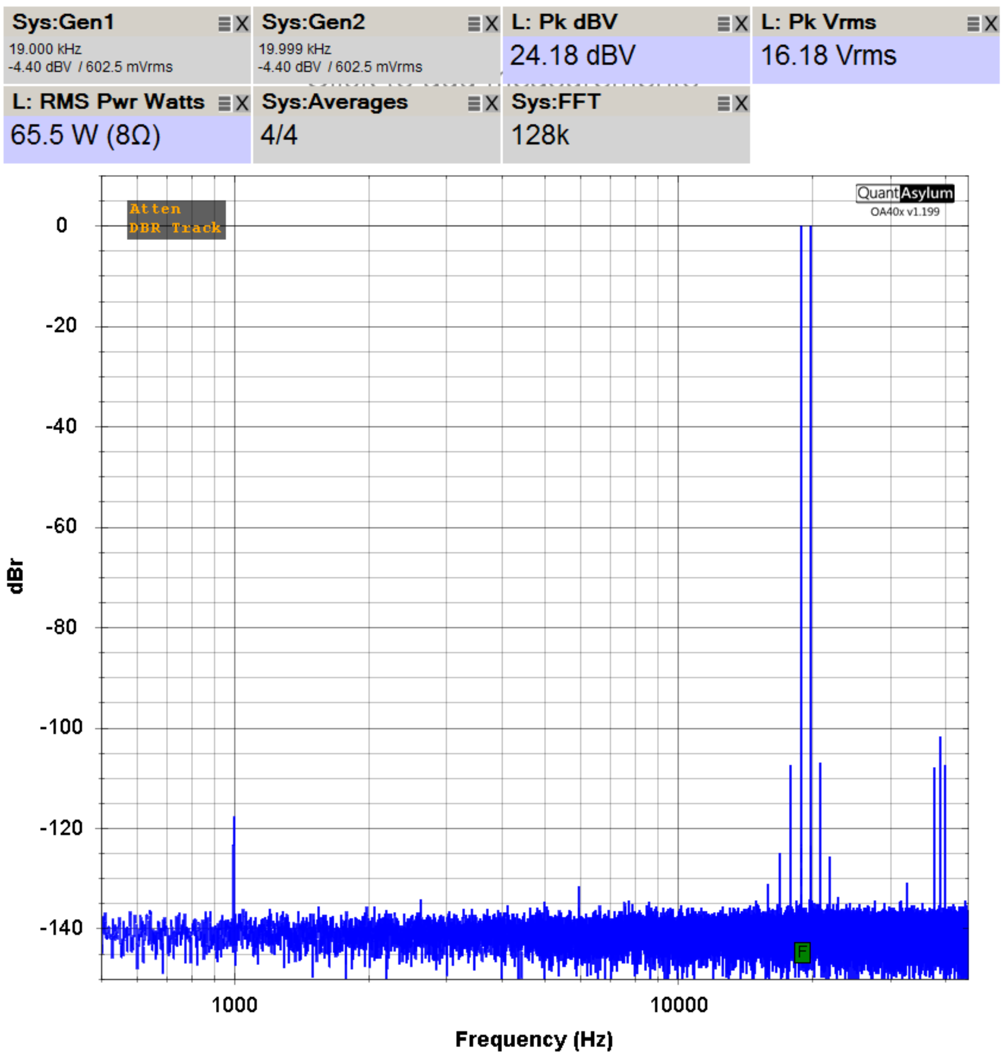

Figure 21: CCIF 19+20 kHz Spectrum at 125 Watts Equivalent

With the amplifier operating at an equivalent 125 Watts, note that the QA40X is reporting RMS power of 64.8 Watts. This means for a test with two equal tones, the actual power is 52 % of the power that corresponds to the peak voltage swing with the two tones. This means, for example, if you are testing a 100-Watt amplifier at its rated power, then you should adjust the levels of the two tones to achieve a target value of 52 Watts as reported by the QA40X. Put another way, each tone should be down by 5.7 dB from the level that one tone alone would produce the desired effective power level.

SMPTE IM 60 and 7000 Hz

The SMPTE IM test is a low-frequency intermodulation distortion test using two tones at 60 and 7000 Hz in a 4:1 ratio. The tone amplitudes thus differ by 12 dB. The larger low-frequency tone at 60 Hz modulates the gain seen by the 7000-Hz high-frequency tone (the carrier) by way of the amplifier nonlinearity. This results in distortion product sidebands that surround the 7 kHz carrier at intervals of 60 Hz. The sidebands of greatest interest are those 60 Hz and 120 Hz away from the carrier, representing the 2nd-order and 3rd-order products, respectively.

This test will be carried out with a peak amplifier output voltage corresponding to the test power for the amplifier into 8 Ω. The BC-1 will be tested at equivalent power here of 125-W. That corresponds to a sine wave of 31.6 Vrms or 44.7 Vpk into 8 Ω. The low- and high-frequency tones should be 35.76 and 8.94 Vpk, respectively. These, in turn, correspond to 25.29 Vrms (28.0 dBV) and 6.32 Vrms (16.0 dBV). With amplifier gain of 28.4 dB, the *Gen 1* and *Gen 2* signal levels should be -0.4 dBV and -12.4 dBV.

Begin by hitting *File* > *New Settings* to start with a clean slate.
Set *Full Scale Input* to 42 dBV.
Turn off the right channel.
Set *Gen 1* to 60 Hz at -0.4 dBV.
Set *Gen 2* to 7 kHz at -12.4 dBV.
Add *Pk dBV*, *Pk Vrms* and *RMS Power Watts* measurements.
Add *Sys: FFT* and *Sys: Averages*.
Set the sample rate to 96 kHz.
Set the FFT size to 64k with 4 averages.
Select *Hann* FFT window.
Go to the *dBV* dialog and set *Load Impedance* to 8 Ω.
Set *Ymax* to +30 dBV and *Ymin* to -120 dBV.
Hit *RUN*.

Go to *File* > *Save Settings*. Name the file **"*SMPTE IM.settings*"**.

The 60-Hz tone amplifier output at +28.2 dBV and the 7 kHz tone at +16.2 dBV. Reported amplifier RMS power is 87.1 Watts. The rated power of this amplifier is 125 Watts. This is 3.1 dB higher than the current reported level.

Zoom in to see IM products surrounding 7 kHz at 60-Hz intervals. The even-order products 60 Hz away from the carrier are at -88 dBV and -87 dBV, respectively, down 116 and 115 dB down from the 60 Hz tone. The odd-order products 120 Hz away from the carrier at 6880 and 7120 Hz are both at -95 dBV, 123 dB down from the 60-Hz tone.

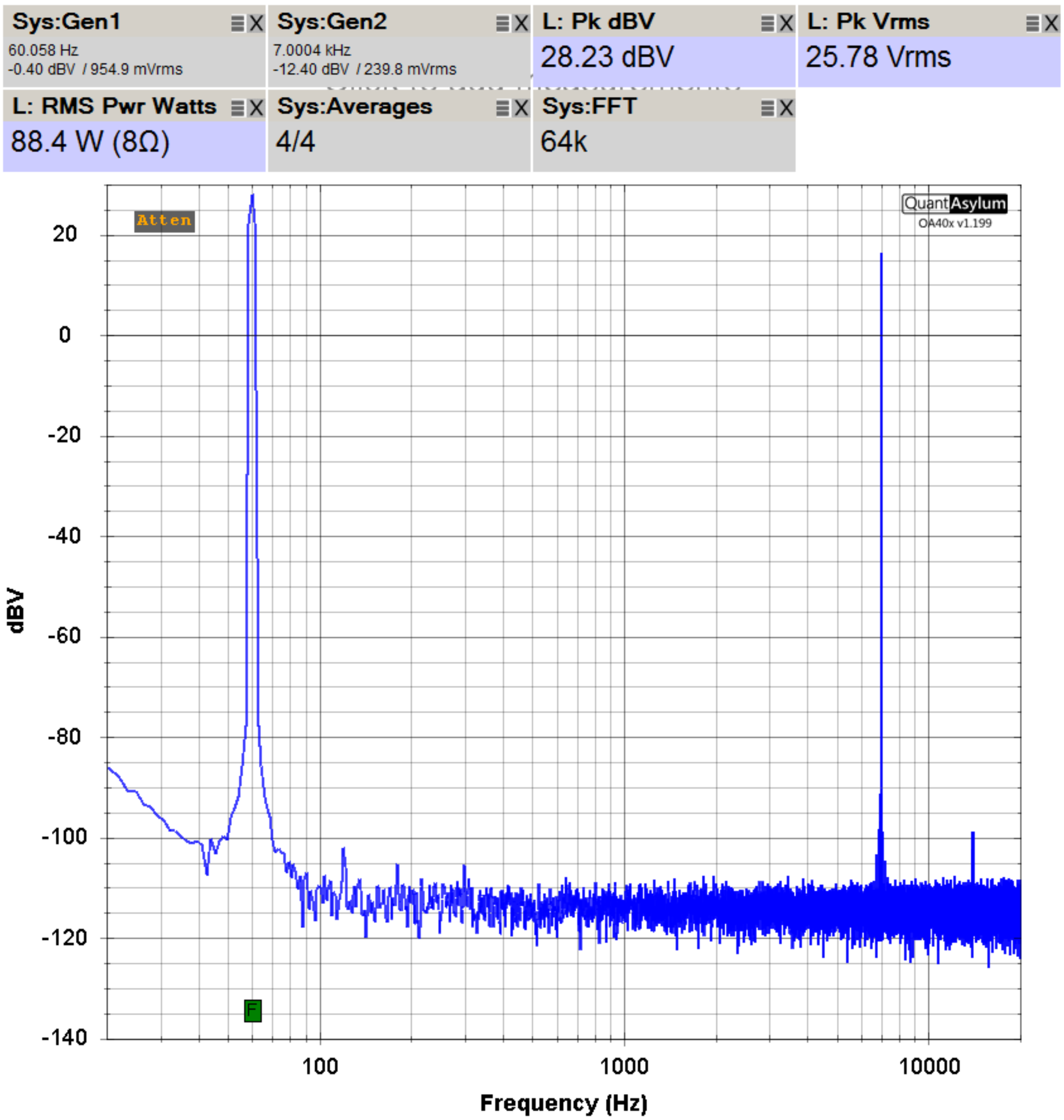

Figure 22: SMPTE IM 60 and 7000 Hz Spectrum at 125 Watts Equivalent

Multitone IM

In this test a large number of tones at different frequencies will be applied to the DUT in order to stimulate the production of many intermodulation products. Those intermodulation products will mainly appear in the frequency space between the tones where the FFT noise floor will be. The IM product lines may or may not poke above the FFT noise floor, depending on their amplitude and the noise level. For this test it is important that the FFT noise floor is minimized, which means larger FFT sizes and use of averaging.

In the test illustrated below, the multitone stimulus is set for 1 tone per octave. There are 10 octaves in the span 20 Hz to 20 kHz. This setting will thus produce 11 tones over the frequency range from 20 Hz to 20 kHz, all of whose peak values will add in-phase in the worst case. For example, if the value of each tone applied to the amplifier is only 14 mV peak (-40 dBV RMS), the maximum peak value applied to the amplifier will be 11 times that, or 140 mVpk. If the amplifier gain is 28.4 dB (factor of 26.4), the output will be 4.7 Vpk, corresponding to the peak voltage of a 1.4-Watt sine wave into 8 Ω.

The multitone level specified in the dialog box is the total RMS level, meaning the sum of all of the tones added on a power basis. A greater number of tones will mean a lower amplitude for each tone. For reference, with *RMStotal* = -20 dBV, individual tone amplitudes for 1, 2 and 3 tones per octave, are 31.6 mV, 22.3 mV and 18.2 mVrms, respectively. The peak value for each tone at 1 tone/octave is 44.7 mVpk, so 11 tones creates 492 mVpk. In the case here, with amplifier gain of 26.4, the multitone voltage for 1 tone/octave and *RMStotal* setting of -20 dBV is 13.0 volts peak.

It is instructive to calculate the peak voltage of the multitone waveform as a function of the number of tones per octave for a given total RMS value of the tones. From this the crest factor of the multitone signal can be determined. Well-recorded music with little compression can have a crest factor exceeding 15 dB, while a sine wave has a crest factor of only 0 dB. This is an important difference for testing with sine waves as compared to the real world of music.

For a multitone RMS total of -20 dBV, the individual tone levels are shown below as a function of number of tones per octave. The level of each tone decreases as the number of tones increases. In going from 1 to 2 tones/octave, the amplitude falls by 3 dB. Going from 2 to3 tones/octave drops the tone values by 1.8 dB. The peak voltage of the waveform after multiplication by the number of tones and the RMS and dBV values of a sine wave with the same peak value are shown. The difference in equivalent dBV of the waveform and the multitone RMS total dBV is the crest factor.

Table 6: Multitone Peak Signal Swings and Crest Factor

Tones/ octave	tone dBV	RMS mV	peak mV	equiv RMS	equiv dBV	Crest Factor
1	-30.0	31.6	492	348	-9.2	10.8 dB
2	-33.0	22.4	665	470	-6.6	13.4 dB
3	-34.8	18.2	798	564	-5.0	15.0 dB
4	-36.1	15.7	910	644	-3.8	16.2 dB
5	-37.0	14.1	1017	719	-2.9	17.1 dB

To test the amplifier at 50 Watts equivalent, corresponding to 28.3 Vpk into 8 Ω, the amplitude of the multitone signal should be 28.3 Vpk. For an amplifier with a gain of 26.4, the amplitude of the test signal should be 1.07 Vpk. If testing with one tone per octave and an RMS total setting of -20 dBV is selected, the amplitude of the test signal will be 492 mVpk. This is less by a factor of 2.17 than 1.07 Vpk, or 6.73 dB. The test signal level for a 50-W equivalent power should therefore be -13.7 dBV RMS total.

One way to calculate the multitone distortion value is as the ratio of the RMS value of the test signal as compared to the RMS value of the sum of all of the many distortion products created. This is essentially the same as how THD is calculated. It is just the power ratio between the test signal and the distortion products.

In a simplified estimate, each combination of tones at frequencies f_1 and f_2 will create intermodulation distortion products at frequencies of m±n for all integer values of m and n, resulting in an exceedingly large number of products, especially when the number of unique combinations of two tone frequencies existing is large. Even with one tone per octave and 10 octaves, there are 11 tones and 55 combinations of two different tone frequencies. At 5 tones per octave and 51 tones, the number of combinations is 1275.

The simultaneous addition of the voltages of many sine waves means that the effective peak power level can be large. This invites the possibility that the input level to the QA40X may exceed the rated maximum of +32 dBV (40 Vrms, 56.5 Vpeak, 200 Wrms into 8 Ω). For this reason, it will often be desirable to include external attenuation in front of the QA40X input for amplifiers that could achieve peak voltages of 56.5 V at clipping. If external attenuation is in play, click on the *dBV* button and enter the amount of external attenuation into the external input gain box as a dB number, such as -20 dB.

More tones per octave is not necessarily better for the same total RMS signal level. The close spectral spacing of a high number of tones per octave makes it difficult to distinguish IM frequency products from noise. A less-dense multitone choice, like 1 tone per octave can make individual IM products more visible and distinguishable from noise.

Interpretation of the multitone measurement results is very subjective due to the very large number of distortion products produced, resulting in a dense group of very closely-spaced FFT lines, especially in the frequency range above 1 kHz, giving the appearance of "noise". How far down from the signal lines are the highest distinguishable distortion product lines is one useful result.

Begin by hitting *File > New Settings* to start with a clean slate.
Turn off the right channel.
Set the full-scale input to 42 dBV.
Set the sample rate to 192 kHz.
Set the FFT size to 256k, averages to 10 and window to Hann.

Hit the *MULTITONE* button in the *Generator* area.
Right click on it to bring up its dialog and select one tone per octave.
Select -13.7 dBV total RMS level for 50 Watts equivalent peak output swing.
Add the measurements *RMS dBV*, Pk dBV and *RMS Pwr Watts*.
Set *Ymin* to -140 dBV and decrement *Ymax* to +20 dBV.
Hit *RUN*.

Go to *File* > *Save Settings* and save this setup file as **"*Multitone IM.settings*"**.

The large FFT of 256k and the 10 averages helps provide a clearer display of the complex result and a smaller amount of noise, but increases the amount of time for a complete result to appear after all of the averages are taken. Be patient.

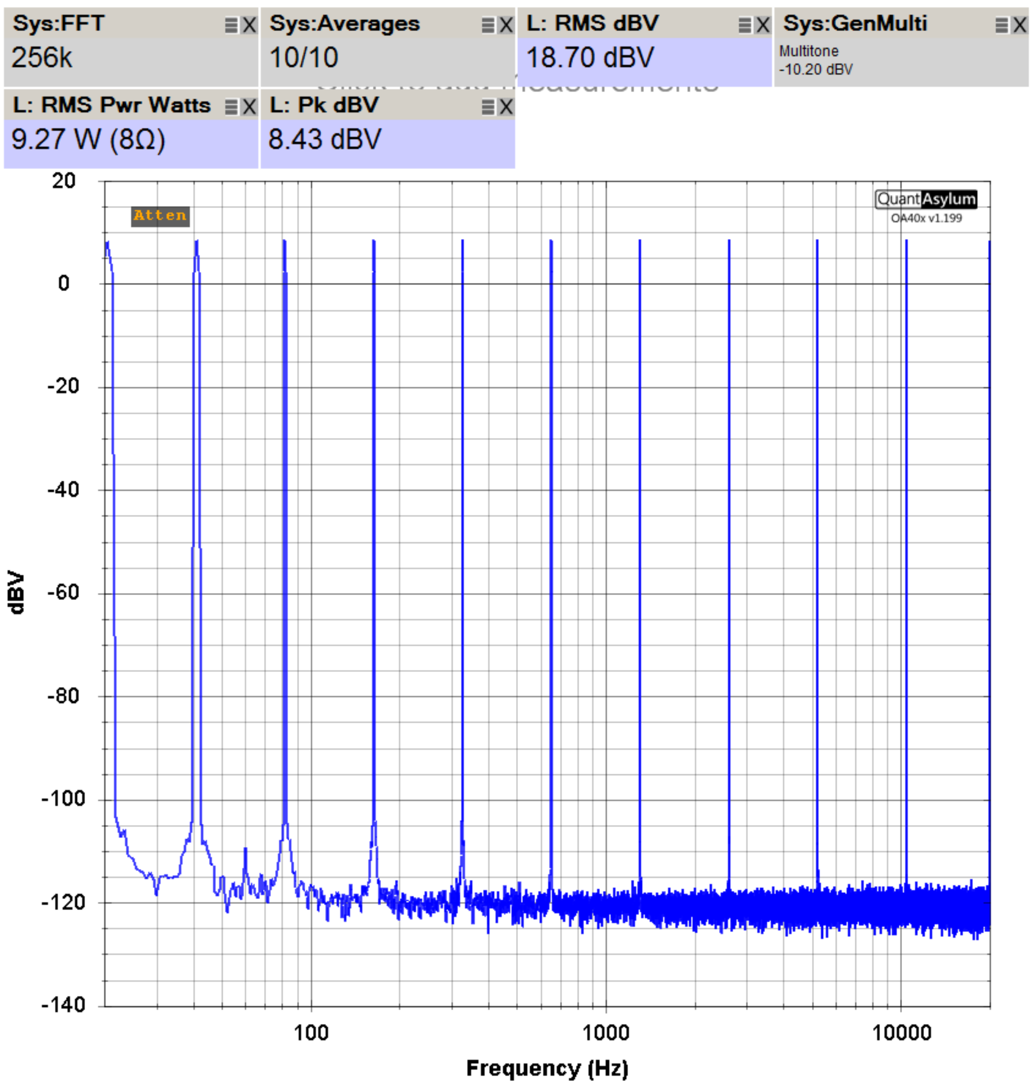

Figure 23: Multitone IM, 50 Watts Equivalent

Observe the multitone FFT display with 11 sinusoids each at +8.7 dBV (2.72 Vrms, 3.85 Vpk, 42.3 Vpk total, 112 W; The scope shows about 28 Vpk) and average power of 9.13 Watts. The top of the apparent FFT noise floor between the tones includes the multitone IM products. This floor is rising with frequency, especially as 10 kHz is approached and exceeded. It has reached about -102 dBV at 20 kHz. This is partly due to reduced negative feedback loop gain at higher frequencies. Click on the *Multitone* button to turn the tones off. Notice that the FFT noise floor is now largely flat with frequency at about -120 dBV at 20 kHz.

Since multitone distortion is seen here to be a function of frequency, it makes sense to quantify its value at a specified frequency, such as 20 kHz. Here the highest value of the products is about -102 dBV at 20 kHz and the 50-Watt peak-equivalent power level corresponds to a 26 dBV sine wave, so it seems reasonable to refer to the multitone distortion here as -128 dB at 20 kHz.

Crosstalk

Crosstalk versus frequency is measured by looking at the frequency response of the undesired signal path from one channel of an amplifier to the opposite channel in a stereo amplifier. Here we illustrate measuring the frequency response of the crosstalk path from the left channel of the amplifier to the right channel of the amplifier.

The QA40X sends a signal to the left channel amplifier (the aggressor) and receives the crosstalk signal from the output of the right channel amplifier (the victim). The right channel of the QA40X receives and measures the crosstalk output of the right channel amplifier. The QA40X receives the signal from the left channel of the amplifier and uses it as the dBr signal reference against which the crosstalk signal from the left channel is measured.

Crosstalk is measured by connecting the left amplifier's input to the QA40X left channel output, making the left channel amplifier the aggressor. The left amplifier is delivering 10 Watts (19.1 dBV) to its 8-Ω load. The right channel amplifier is the victim. Its input is shorted. Its output is the small crosstalk signal, which is delivered to the QA40X right channel input. A frequency response measurement is then run on this arrangement. Note that in some amplifiers measured crosstalk can change a bit with the power level at which the aggressor is set. Having no load on either the aggressor channel or the victim channel may also yield a different reading. Always load both amplifier outputs.

Short the right channel input of the amplifier.
Connect the right channel amplifier output to the right input of the QA40X.
Connect the left channel input of the amplifier to the left output of the QA40X.
Connect the left channel amplifier output to the left input of the QA40X.
Connect an 8-Ω load resistor to each amplifier output.

Hit *File* > *New Settings* to start with a clean slate.

Set the full-scale input to 42 dBV.
Increment the FFT size to 64k, increment averages to 4.
Set the sample rate to 96 kHz.
Increment *Ymin* to -100 dBV and leave *Ymax* at +20 dBV.
Click on *Frequency Response* in the *Generator* section.
The *Sys: GenEx* tile provides the *Exponential Frequency Chirp* stimulus.
Set it to -6.3 dBV to feed the left channel amplifier with 25.4 dB gain for 10 Watts.
Click *RUN*.

Go to *File* > *Save Settings* and save this setup file as "***Crosstalk.settings***".

A flat frequency response for the left aggressor channel will appear. A crosstalk frequency response with a lot of loss (hopefully) will appear in the plot for the right channel.

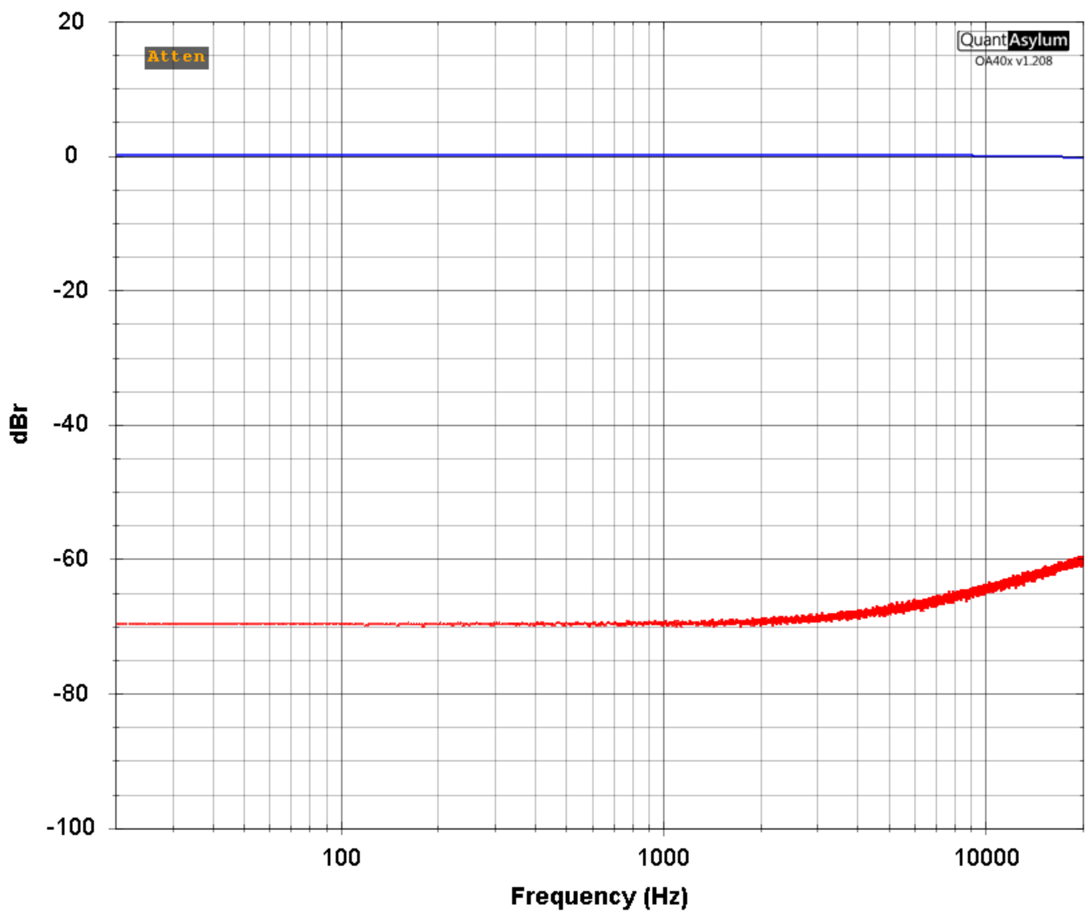

Figure 24: L2R Crosstalk of The Super Gain Clone Stereo Amplifier

Hit the *dBr* button, right-click and choose the 1-kHz signal level to be at 0 dBr
Re-adjust *Ymin* to -100 dBr.

This is the crosstalk level and frequency response. The BC-1 amplifier was not measured for crosstalk because the version used in the tests in this tutorial was configured as a monoblock. Instead, the *Super Gain Clone* LM3886 stereo amplifier designed was measured for crosstalk [1, 5]. Crosstalk is -70 dB at 1 kHz, rising to -60 dB at 20 kHz.

Output Impedance and Damping Factor

Here the output impedance of the BC-1 amplifier will be measured as a function of frequency. A convenient way of measuring amplifier output impedance and damping factor (DF) as a function of frequency in the lab with a stereo amplifier is to back-drive the right-channel output with the left-channel output through a resistor, like 100 Ω. The input of the right channel amplifier is grounded. The frequency response of the resulting signal at the output of the right channel is then measured.

The BC-1 amplifier used in these tests was configured as a monoblock, so a different testing amplifier was used to drive the output of the BC-1 through the 100-Ω resistor. This approach is completely valid, and is independent of the voltage gain of the driving testing amplifier. A single-channel damping factor measurement is demonstrated in the automated measurements further below.

Here the right-channel QA40X output drives the input of the testing amplifier. The output of the testing amplifier is connected to the output of the BC-1 through a 100-Ω resistor. The input of the BC-1 is grounded. The output of the BC-1 drives the QA40X right-channel input. The output of the testing amplifier is connected to the left-channel input of the QA40X, so we see what goes into the back-drive resistor.

The 100-Ω series back-drive resistor forms a voltage divider with the shunting output impedance of the BC-1, resulting in a large amount of attenuation when the frequency response of this path is measured.

This arrangement is similar to that for measuring crosstalk, but here the "crosstalk" is from the back-drive arrangement. If we use a 100-Ω back-drive resistor, and the loss from the left-channel testing amplifier output to the right-channel (BC-1) amplifier output is 60 dB, then the output impedance of the BC-1 is 0.1 Ω. Amplifier output impedance is measured and plotted as a frequency response in dBV at the right-channel (BC-1) amplifier output.

Damping factor is defined as 8 Ω divided by the amplifier output impedance. If the measured output impedance is 0.1 Ω, then DF is 80. The DF need only be spot checked at a few frequencies (e.g., 20 Hz, 1 kHz, 20 kHz) rather than plotted.

Short the right-channel input of the amplifier (BC-1).
Connect the right amplifier (BC-1) output to the right input of the QA40X.
Use the quasi balanced/differential arrangement described on page 7.
Connect the left input of the (testing) amplifier to the right output of the QA40X.

Connect an 8-Ω load to the left (test) amplifier output.
Connect the left (testing) amplifier output to the left input of the QA40X.
Connect a 100-Ω 5-Watt resistor between the testing and BC-1 amp outputs.
You will measure the frequency response in the right channel of the QA40X.

Hit *File* > *New Settings* to start with a clean slate.
Set the full-scale input to 18 dBV.
Set the sample rate to 96 kHz.
Increment the FFT size to 64k and increment system averages to 4.
Set *Ymin* to -100 dBV and leave *Ymax at* +20 dBV.
Click on *Frequency Response* in the *Generator* section and set its level to -20 dBV.
The *Sys: GenEx* tile provides the *Exponential Frequency Chirp* stimulus.

Click *RUN*.

Go to *File* > *Save Settings* and save this setup file as "***Output Z.settings***".

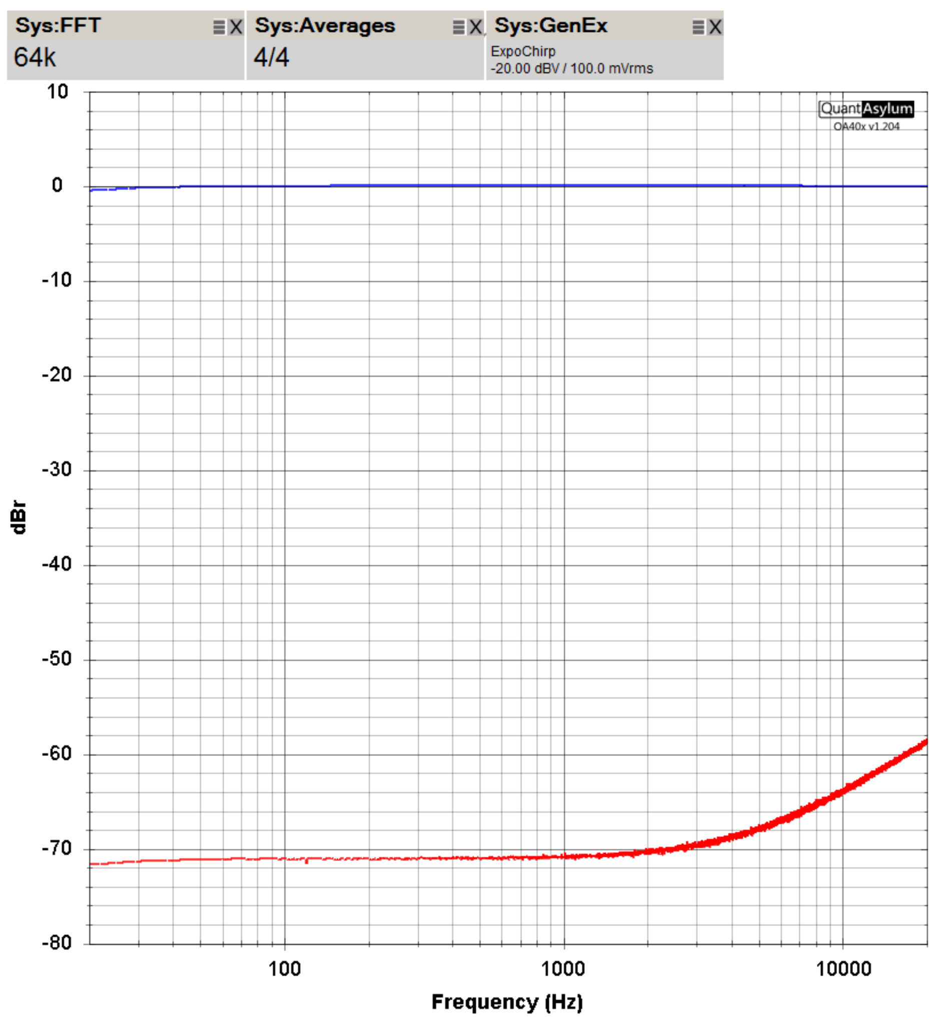

Figure 25: BC-1 Output Impedance Frequency Response

A frequency response plot with significant loss will appear in the right-channel FFT display. This is the frequency response of the right channel (BC-1) amplifier's output impedance. A loss of 60 dB would correspond to output impedance of 100 Ω/1000 = 0.1 Ω, which would result in a damping factor of 80. Hit the *dBr* button, right-click and choose the 1-kHz signal level to be at 0 dBr. Re-adjust *Ymin* to -100 dBr.

Add a cursor *C1* to the right channel (red) by pushing the *C1* button and clicking on the *RIGHT* button. You may have to scroll the control area upward to see the cursor buttons. Drag the cursor left and right to see that the right channel is down by 71 dB at 100 Hz, 71 dB at 1 kHz, 64 dB at 10 kHz and 58 dB at 20 kHz. The corresponding dB ratios are 3550, 3550, 1580 and 800. Output impedances are 0.028 Ω at 100 Hz, 0.028 Ω at 1 kHz, 0.063 Ω at 10 kHz and 0.125 Ω at 20 kHz. Damping factors are 286 at 100 Hz, 286 at 1 kHz, 127 at 10 kHz and 64 at 20 kHz.

While the DF is 286 at low frequencies, it falls to about 64 at 20 kHz. The DF of most power amplifiers decreases at higher frequencies because there is less negative feedback and/or as a result of the inductance of its output coil. A damping factor of 64 at 20 kHz is quite good. The BC-1 has an output coil whose inductance is roughly 1.5 μH, and whose impedance is 0.19 Ω at 20 kHz, actually a bit higher than measured by this test. Measurement of such low impedances at high frequencies like 20 kHz can vary by minor differences in the measuring arrangement.

Automated Measurements

The measurements made above were carried out manually. Using saved analyzer settings, those measurements were not too difficult. However, the QA40X software includes automated measurements that can make some of those measurements easier and faster. Automated measurements can also make possible measurements that could not usually be made manually, such as plotting THD vs. frequency for several different power levels, all on the same graph. The measurements illustrated below were made using automated measurements.

The Automated tests include:

- Power Output - THD vs. Power at 1 kHz
- THD vs Power at 16 kHz
- THD versus Frequency
- THD vs. Frequency vs. Output Power Level
- Frequency Response
- Frequency Response by Chirp
- Output Impedance and Damping Factor
- Crosstalk
- Intermodulation Distortion vs. Power
- Intermodulation Distortion vs. Power Alternative

The following automated amplifier tests are available and most are covered in detail in this tutorial. Key user-selectable test parameters are shown here.

AMP Crosstalk
    dBV Gen level range and increment, frequency range and increment
AMP Dynamics
    Test frequency, waveform time and dBV amplitude characteristics
AMP Frequency Response+
    dBV Gen level range and increment, frequency range and increment
AMP Frequency Response Chirp
    dBV Gen level, frequency range is over measurement range
AMP Gain and Distortion versus Amplitude+
    dBV Gen level range and increment, single test frequency
AMP IMD (ITU and SMPTE)
    ITU (CCIF) or SMPTE, dBV Gen level range and increment
AMP THD versus Frequency
    dBV Gen level range and increment, Frequency range and increment
AMP THD versus Input/Output Level
    dBV Gen level range and increment, single test frequency, plot in or out level
AMP THD versus Input/Output Level Using the QA480
    Requires QA480
PWR IMD (ITU and SMPTE)
    ITU (CCIF) or SMPTE, dBV Gen level range and increment, specify Zload
PWR Output Impedance
    Frequency range and increment, dBV Gen level
PWR Output Impedance with QA45x
    Requires QA45x
PWR THD versus Frequency+
    THD or THD+N, target Watts level, frequency range and increment, Zload
PWR THD versus Power
    dBV Gen level and increment, single test frequency, Zload
PWR THD versus Power Watts+
    THD or THD+N, Watts power range and increment, single test frequency, Zload

Each one of the automated tests below is written in a stand-alone format for all of the steps required. Many of those tests have the same or similar setup steps in common. In practice, an automated test has a group of setup steps to be done first using the control panel and the "*add measurements*" selections. Most of the setup here can be entered from a file in the folder *Measurement Settings* that has been stored from previous tests via the *File > Save Settings* command. Those measurement settings can then be entered via the *File > Load Settings* command. The *THD Settings* file can usually be loaded to avoid having to do many of the settings steps.

Browse to Setup in Automated Test

Alternatively, one can go directly to the desired automated test and browse in the upper right box to the *Measurement Settings* folder and load the measurement settings you want. Note that if the prior version of that automated test had a file entry in the browse box, and you first manually put a differing setup in before invoking the automated test, those manually entered measurement settings will be ignored and replaced by the measurement settings from the earlier automated test. Just as the automated tests remember their own setup from the last running of the test, they also remember the measurement settings that were previously entered. In this case, an automated test can be brought up and immediately be run, without loading a measurement setup file. This can be convenient if changes need not be made to the measurement settings, but can interfere with making such changes if desired.

If after running an automated test you want to go back to the measurement settings in the main display and change them, your changes will also be over-ridden when you invoke that automated test again. For example, let's say you did an automated run with no external attenuator. Then you insert a 6-dB external attenuator and change the dBV input setting gain value to -6 dBV in the dashboard settings view after the automated run. This will not give the desired and expected same result. The next automated run will proceed based on the 0 dBV value that was previously used and which is still in the measurement settings file. When that next automated run starts, it will literally change the dBV input gain value back to what is in the measurement settings file entered into that automated test. The same thing will happen if, for example, you change *Ymin* between automated runs. The new *Ymin* will not be used.

If you want to make measurement settings changes for an automated test, it is better to start with no browsed setup files in the automated test. Alternatively, change the setup and save the new setup to the same-named measurement setup file.

Set-up Options

Some measurement settings shown in the setups below are optional, such as an extra tile to display THD in percent. The actual value of some measurement settings is also often non-critical to a given test, such as the sample rate or FFT size. A sample rate of 96 kHz and FFT size of 64k will almost always work, but the higher frequency of 192 kHz will speed up the measurement, and a larger FFT will provide better accuracy at lower frequencies. Do not use averaging in any of the automated tests.

Automated Test Dialog Box

After the measurement setup is completed, one of the automated tests is chosen for the measurement from the "A*utomated Tests*" tab. At that point, a dialog box for that automated test will come up where the user sets values and parameters for the test. In some cases a default automated test setting comes up in the dialog box that is perfectly fine. When the user hits "*OK*" upon completion of the dialog entries, the automated test is run. A typical automated tests dialog box for a measurement is shown below.

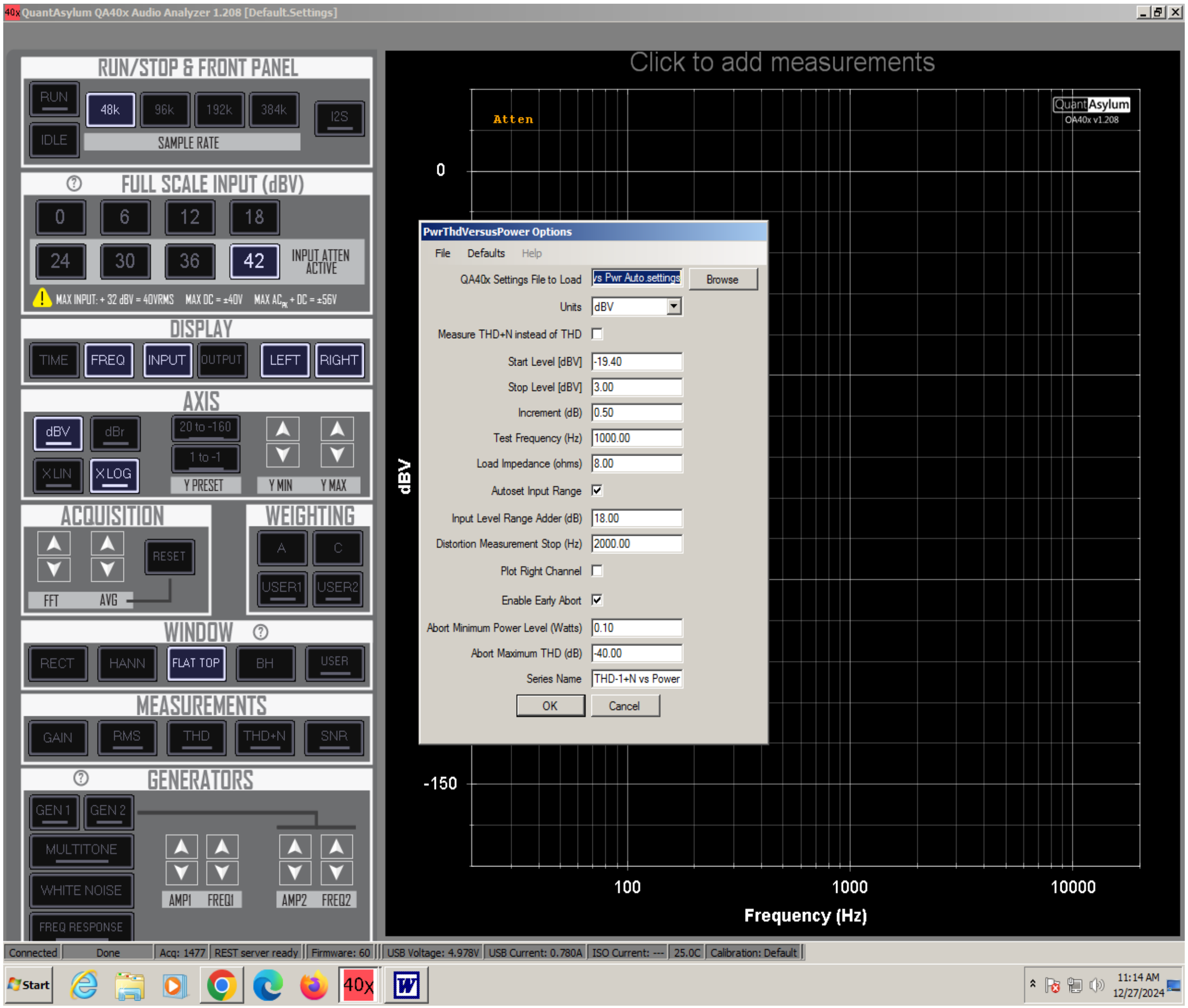

Figure 26: Screenshot showing an Automated Test Dialog

Stacking

At the completion of most automated runs, a small dialog box will come up with the radio-button plot options of *Add to New Graph* or *Add to Existing Graph*. Choose the former to just get the graph for the first run. If you choose the latter for a subsequent plot, you can put the result of that plot onto the same graph. This is called "stacking" plots.

After making a selection in the brief plot dialog, you can hit *F3* to bring back up the automated test dialog where you can make changes in its settings and then re-run the automated test. If a plot is still on top of the main window, click on an area of the main window to bring the full main display forward, then hit *F3*. Clicking out of the plot forecloses on additional stacking.

Frequency Response

This test will use the newer ***AMP Frequency Response+*** automated measurement. We will measure the frequency response of the amplifier at one or more amplifier power levels, starting with 1 Watt. The measurement parameters will include input signal amplitude in dBV, load impedance and measurement frequency range. The test can make the measurement at a plurality of amplitude levels applied to the input of the DUT, with start and stop dBV input levels and dB increment sizes.

One Watt into 8 Ω corresponds to 2.83 Vrms which equates to +9 dBV. If amplifier gain is 28.4 dB, an input level of -19.4 dBV will deliver 1 W. The measurement is carried out with FFTs at a large number of discrete fundamental frequencies to determine the output amplitude at each frequency. The baseline measurement will first cover 20 Hz to 20 kHz, then measurements as low as 2 Hz and as high as 80 kHz will be made.

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 42 dBV (the test does not auto-scale FSI).
Set the sample rate to 192 kHz.
Increment FFT size to 128k, leave averages at *Off*, choose the flat top window.
Add the measurements RMS Watts and THD %
Right-click on *XLOG* and set the *Stop* frequency to 85 kHz.
Right click on *THD* and set the *Stop* frequency to 85 kHz.
Hit the *Frequency Response* button
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.

Go to *File* > *Save Settings* and save this file as **"*Freq Response Auto.settings*"**.

Go to *Automated Tests* > ***AMP Frequency Response+***.
Set the Start amplitude to -19.4 dBV for output of about 1 W.
Set the Stop amplitudes to 0.6 dBV for output of about 100 W.
Set the *Increment dB* setting to 10 dB. (1 W, 10 W and 100 W will be tested)
Set the frequency range to start at 20 Hz, and end at 20 kHz (default).
Ignore the *Hz per Step* value. (It doesn't matter when using *Log Step*.)
Check the *Log Step* box and set *points per octave* to 3.
Check the *Plot as Gain* box and enter the series name.
Hit *OK*.

The choice of *log step* means that the physical distance between the steps across the log scale of the *X* axis will be constant. If the *log step* option is not used, the measurement will take an extremely long time, stepping by a fixed frequency increment at a time all the way to 20 kHz. That increment would need to be small for adequate resolution at low frequencies.

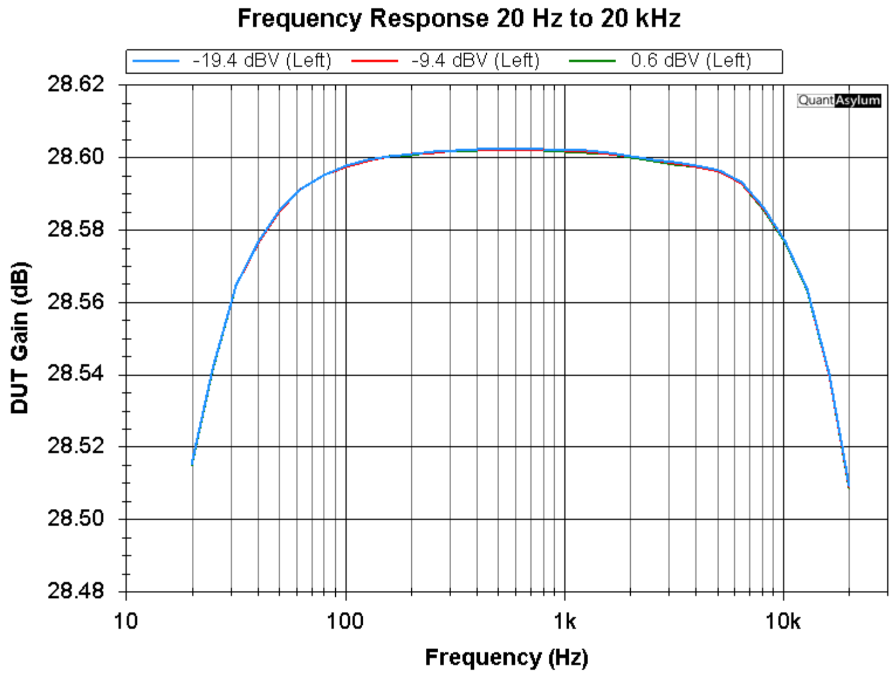

Figure 27: Frequency Response 20 Hz to 20 kHz

The FFT is shown as the measurement is in progress, with the fundamental frequency marching from left to right. You can watch the power level and THD on the dashboard as the measurement progresses. When the sweep is completed, a plot of amplifier gain vs. frequency will appear. Choose "*Add to New Graph*" when the small dialog box appears. On the dialog panel that appears on the left, type in the plot title. Hit the Traces tab and choose distinguish colors to identify the 3 separate traces. The plot shows a flat response that falls by about 0.1 dB at 20 Hz and 0.04 dB at 20 kHz. All of the frequency response traces at different power levels overlap each other, as expected for a good-performing amplifier. For many power amplifiers, the power level need be only a single one at 1 Watt by making the start and stop power levels both the same, here -19.4 dB.

The use of the high sample rate makes the measurement go more quickly and keeps open the possibility of measuring the frequency response to 80 kHz. The FFT size is set to a generous value of 128k because a smaller FFT will result in serious measurement anomalies (errors) at the lowest frequencies like 20 Hz. The measurement steps through all of the frequencies, such as 20-20 kHz in steps of 3 points per octave. With a sampling rate of 192 kHz and a 128-k FFT, such a run can take about 42 seconds for each power level to be tested.

Now the frequency response over a wide bandwidth of 2 Hz to 80 kHz will be measured. The FFT will need to be much larger (512k) to provide satisfactory results down to 2 Hz. X out of the plot and make the following changes to the setup and the *Frequency Response* measurement settings:

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 42 dBV.
Set the sample rate to 192 kHz.
Increment FFT size to 512k, leave averages at *Off*, choose the flat top window.
Add the measurement RMS Watts.
Right-click on *XLOG* and set the top frequency to 85 kHz.
Right click on *THD* and set the top frequency to 85 kHz.
Hit the *Frequency Response* button.
Set *Ymin* to -120 dBV and *Ymax* to +20 dBV.
Right click *XLOG* dialog, *Start* frequency 2 Hz, *Stop* frequency 85 kHz.
Right click *RMS* and set measurement *Start* at 2 Hz and *Stop* at 85 kHz.

Go to *File* > *Save Settings,* save file as **"*Freq Resp Wide Auto.settings*"**.

Go to *Automated Tests* > ***AMP Frequency Response+***.
Set the Start amplitude to -19.4 dBV for output of about 1 W.
Set the Stop amplitude to -19.4 dBV for output of about 1 W (1 power level).
Ignore the *Increment dB* setting.
Set frequency range to start at 2 Hz, end at 80 kHz.
Ignore the *Hz per Step* value.
Check the *Log Step* box and set *points per octave* to 3.
Check the *Plot as Gain* box and enter the series name.
Hit OK.

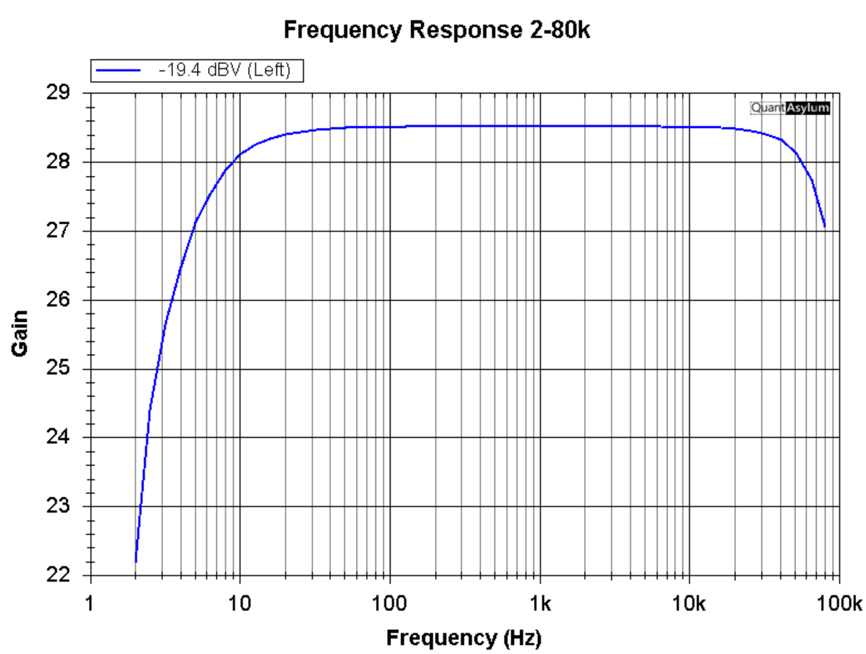

Figure 28: Frequency Response 2 Hz to 80 kHz

The plot shows that the response is down by the following amounts at key frequencies:

2 Hz	-6.4 dB
10 Hz	-0.4 dB
20 Hz	-0.2 dB
1 kHz	0 dB
20 kHz	-0.1 dB
50 kHz	-0.4 dB
80 kHz	-1.4 dB

This measurement requires a much larger FFT to avoid low-frequency anomalies. The measurement will thus take much, much longer. It is a long way from 2 Hz to 80 kHz, especially when one must use 512-k FFTs to avoid anomalies at the very low starting frequencies. This plot took 5 minutes to complete.

Frequency Response by Chirp

This is an alternative way of measuring amplifier frequency response, the ***AMP Frequency Response Chirp*** test, using a chirp stimulus signal. This approach takes less time than the frequency response measurement described above. The measurement result will cover the frequency range from 2 Hz to 80 kHz.

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 18 dBV.
Set the sample rate to 192 kHz.
Increment FFT size to 512k and set the FFT window to flat top (default).
Press the *Frequency Response* button. Right click to see *Expo Chirp Options (ECO)*.
Note *End Frequency* fixed 96 kHz and *Octaves* fixed at 12. (both grayed out)
They set the span over which the frequency measurement extends.
Set ECO Amplitude to dBV for 1-Watt output.
Set *Ymin* to -120 dBV and *Ymax* to 20 dBV.

Go to *File* > *Save Settings* and save as **"*Freq Resp Chirp Auto.settings*"**.

Go to *Automated Tests* > ***AMP Frequency Response Chirp***.
Set *Output Level* to -19.4 dBV for about 1 Watt output.
Set O*ctaves Smoothing* to 3.
Do not check *Right Channel as Reference* or *Plot Right Channel* or *Plot Phase*.
Check *Plot as Gain*.
Enter 1000 (Hz) where it says "*Normalize Frequency to 0 dB*".
Enter the series name "*Frequency Response by Chirp*".
Hit *OK*.

The choice for *Normalize Frequency to 0 dB* sets the frequency at which the plotted response is normalized to read 0 dB for the frequency response. This will usually be set to 1000 Hz. A plot of frequency response will appear that runs from about 0.8 Hz to 96 kHz, a wider range than is needed or reliable, given the 512-k FFT size and 192 kHz sample rate. A 256-k FFT will take a bit less time, but will be reliable only down to about 5 Hz. A 128-k FFT will be reliable down to only about 8 Hz. In the plot options panel to the left, set *Xmin* to 2 Hz and *Xmax* to 80 kHz. Set *Ymin* to -10 dB. The figure below results.

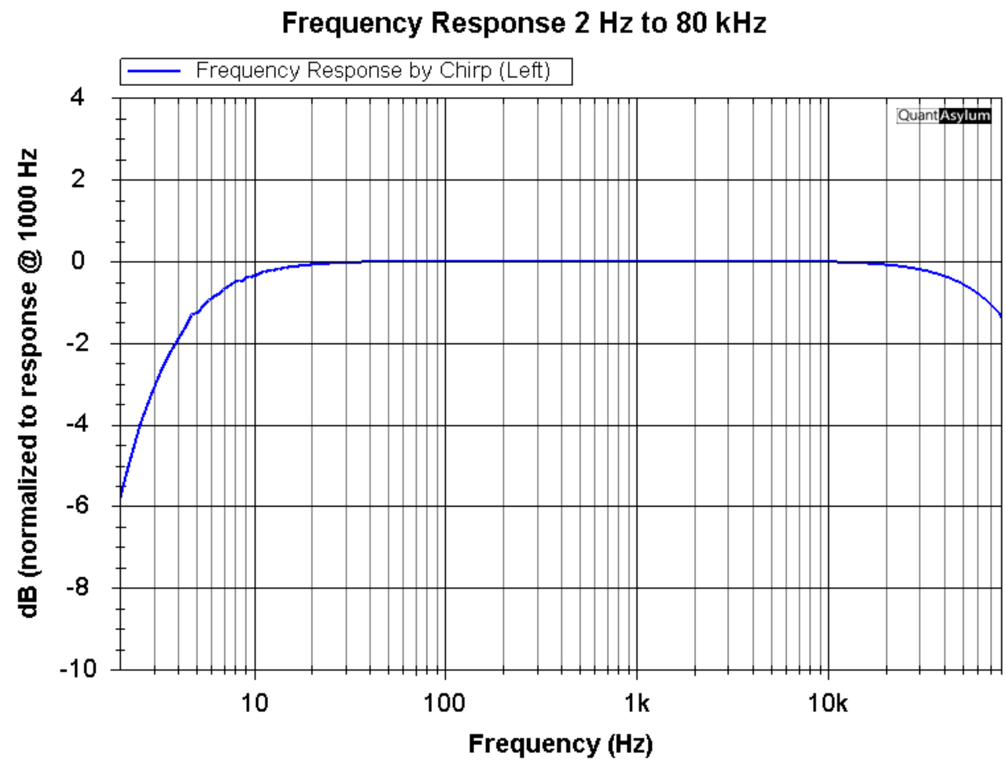

Figure 29: Frequency Response by Chirp

Frequency response is shown as down 5.9 dB at 2 Hz, 1 dB at 5 Hz, 0.35 dB at 10 Hz, 0.1 dB at 20 Hz, 0.1 dB at 20 kHz, -0.6 dB at 50 kHz and 1.4 dB at 80 kHz.

Power Output - THD vs. Power in Watts at 1 kHz

Here the newer automated test ***PWR THD Versus Power Watts+*** will be employed to plot THD or THD+N as a function of amplifier power output. Maximum power output was determined manually in the THD-1 vs. output power section above by watching THD increase as the power was increased by manually incrementing the *Gen 1* signal level. Here we will use an automated test to plot THD-1 as a function of power level. This can be done for other selected frequencies as well.

The automated *PWR THD Versus Power Watts+* test executes a large number of measurement runs, each with an increased signal level driving the power amplifier to higher power output while recording THD. The test is run at a selected frequency and the increments in the power output are chosen by selecting the number of points per decade of power. The test is started at a selected power and ended at a selected power. The test can be stopped (aborted) at a selected value of THD percentage, such as 1%. Conveniently, the full-scale input (FSI) attenuation is auto-incremented as the amplifier output voltage increases. This helps maintain the best analyzer noise floor while avoiding overload.

In normal use, this test will keep increasing the amplifier power level until clipping is reached or approached. For some amplifiers it is possible that the input level to the QA40X will exceed the rated maximum of +32 dBV (40 Vrms, 56.6 Vpeak and 200 Wrms into 8 Ω). Moreover, it is recommended that some margin against the +32 dBV maximum analyzer input be allowed, like 1 dB or more. This means that the user should be mindful of this issue for amplifiers rated at more than 100 W.

For this reason, it will often be desirable to include external attenuation in front of the QA40X input. If external attenuation is in play, right click on the *dBV* button and enter the amount of external attenuation into the external input gain box as a negative dB number, such as -6 dB. Here a 6-dB external attenuator is used. It can be made from a pair of 1-k, 2-Watt metal film resistors, one in series and one in shunt. Alternatively, a 24-dB attenuator can be used (15.8:1) to shift the actual FSI used in the measurement to be mainly within the range of 0 dBV to 24 dBV, improving the analyzer's operating SNR to be better for THD+N for most of the measured power levels. This can be accomplished with an external attenuator comprising a 7563-Ω series resistor and a 511-Ω shunt resistor. The 24-dB external attenuator was used in the tests here.

The burst nature of this test can be made to relax the necessary power rating of the load resistor by setting the analyzer to insert up to a 2-second pause between the repeated measurement runs. Go to *Edit > Settings > Pause Acquisitions* to do this. The reduced duty cycle of the measurement bursts will cause the load resistor to have less time to reach a high temperature during the repeated measurements. This will also reduce heating of the amplifier.

This measurement can take some time. Measuring from 1 W to 180 W (22.6 dB in power range) with a maximum of 10 points per decade will require about 23 runs. Choices of generous FFT sizes can make the time for the measurement quite long. For the BC-1 amplifier here, the measurement range will be set to go from 1 W to near clipping at about 180 W. With 192-kHz sampling and a 128-k FFT, this test took about 35 seconds. For various choices of points per decade and ending power, this test will add an extra point if necessary to always have a point at the ending power level.

Connect the left channel positive output of the QA40X to the input of the amplifier. Connect the amplifier to its 8-Ω load and to the QA40X left channel positive input. Unused analyzer inputs should be grounded with BNC terminators.

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 42 dBV and set the sample rate to 192 kHz.
Increment FFT size to 128k, averages should be *Off,* choose the *Hann* window.
Add the measurements *Sys: Gen 1*, Vrms, *RMS dBV* and *RMS Power Watts*.
Add the measurements THD %, THD+N %, THD dB, THD+N dB.
Use a 24-dB external attenuator in this test to optimize THD+N.
Right click on *dBV*; set input gain to -24 dB.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.

Go to *File* > *Save Settings* and save this setup file as **"*THD-1 vs Pwr Auto.settings*"**.

Go to *Automated Tests* > ***PWR THD Versus Power Watts+***.

In the *THD Versus Power Watts+* dialog do the following:
Uncheck the "*Measure THD+N Instead of THD*" box.
Select *Start Level* and *Stop Level* as 1 Watt and 180 Watts
Set the *Points Per Power Decade* to 10 (the maximum allowed).
Set the frequency to 1 kHz.
Set the load impedance to 8 Ω.
Check the box "*Autoset Input Range*".
Set the *Input Level Range Adder* (ILRA) to 12 dB. (see below near end of section).
Set *Distortion Measurement Stop* to 20 kHz.
Check the box "*Enable Early Abort*".
Set *Abort Minimum Power Level* to 0.05 W. (see below near end of section)
Set *Abort Maximum THD* to -60 dB (0.1%).
Set the *Series Name* to "*THD-1 vs. Power*" or the like to appear on the plot.

Hit *OK* - the THD vs. power measurement runs will begin.

The gain of the amplifier will first be measured in the background and then a box will come up that tells you what the amplifier gain is, the dBV input signal level that will be applied for the starting power and the dBV input value for the ending power. Then hit OK to start the automated measurement.

Observe the dashboard voltage and power increase with each measurement run. The full scale input (FSI) attenuator will increment as power is increased, sometimes causing a relay click, with the *Autoset Input Range* box checked. In this test, FSI starts at 0 dBV and increments up to 18 dBV. The low FSI values are due to the use of the 24-dB external attenuator. As the power level increases, the THD will tend to increase at some point as clipping is approached if a high enough *Stop* power level is chosen. The measurement may be stopped after the *Abort Maximum THD* level has been exceeded.

A plot of THD-1 vs. power will appear in blue after the run is completed. We will be stacking the THD-1 and ensuing THD-1+N plots here, so don't do anything to this first THD-1 plot.

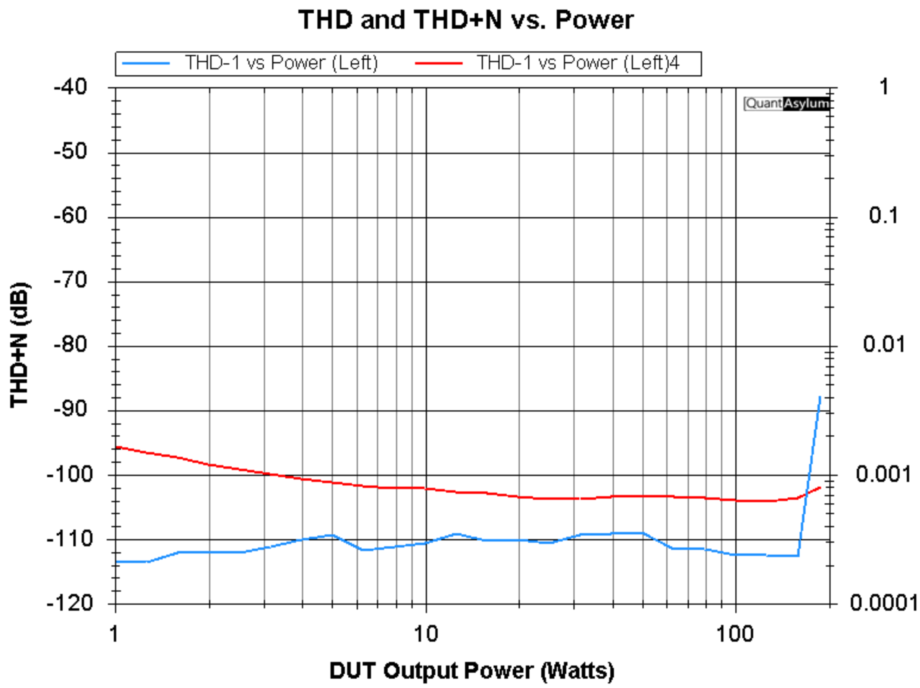

Figure 30: THD and THD+N vs. Power at 1 kHz

To measure THD+N and stack it on top of the THD plot, click on the side of the display area to hide the plot and bring forward the FFT and dashboard display. Hit *F3* to bring back the automated test dialog. Check the box "*Measure THD+N instead of THD*". Change Set the *Series Name* to "*THD-1+N vs. Power*" to appear on the plot. Proceed with the THD-1+N measurement.

When the THD+N plot appears, a box will appear with a choice. Choose "*Add to Existing Graph*". The plot may be hidden behind the main window. A plot dialog will appear on the left. Add the title "*THD-1 and THD-1+N vs. Power*". Select "*Distinguish Trace Colors*". The THD+N result in red has been stacked on top of the THD plot in blue. Set *Y1min* to -120 dB and *Y1max* to -40 dB. Set *Xmin* to 1 Watt and *Xmax* to 200 Watts. Right click on the plot and select "*save image as ...*". and save it in the form you want (PNG, GIF, JPEG, TIFF or BMP) to the folder where you are storing plot results.

Note in the plotted result that THD+N rises at lower power levels because of noise in the amplifier (or analyzer). This test was run with a measurement bandwidth of 20 kHz. Some analyzers will run this test with a bandwidth of 80 kHz, which will result in more noise, by as much as 6 dB (noise increases as the square root of measurement bandwidth).

Note that the I*nput Level Range Adder (ILRA)*, whose default is 18 dB, is the amount of signal headroom for the measurement. It is the amount of headroom above the full-scale input (FSI) value for the expected input signal amplitude. It controls the input level at which the FSI attenuator is automatically set to greater attenuation as the input signal amplitude increases as the THD vs. power test progresses. If the ILRA is set to 18 dB, and the input signal increases above 0 dBV, for example, the FSI setting will be automatically increased to the next higher amount of attenuation, in this case +24 dBV. In most cases, an ILRA of 12 dB is adequate. Higher FSI settings can increase the analyzer's noise contribution in some cases because the analyzer is having to work with a smaller input signal amplitude. If noise measurement is the priority, an ILRA of 6 dB may be a good choice, at the expense of a very small increase in the analyzer's THD floor. For most measurements, ILRA=12 dB is a good choice.

The A*bort Maximum THD* setting will stop the test if the THD reaches the chosen maximum level, like -40 dB (1%). This prevents the amplifier from going into heavy clipping or overload if the input level is further automatically incremented beyond the point at which THD reaches the set percentage. For this abort to work, the amplifier power level must be greater than the power level specified by the A*bort Minimum Power Level* setting. The *Enable Early Abort* box must be checked for this feature to act. For amplifiers with a sharp knee where THD increases very fast with increased power level, the measurement may not be stopped until after the threshold is exceeded due to the quantization of the applied test levels, such as 10 points per decade (1-dB increments).

THD vs. Power in Watts at 16 kHz

This test is the same as the ***PWR THD Versus Power Watts+*** one above, but conducted at 16 kHz to see the effects of distortion at higher fundamental frequencies. In this test, the QA40X will show FFT harmonics out to 85 kHz, well beyond 16 kHz, to capture many of the lower-order harmonics up to the 5th (choosing 16 kHz allows measurement of the important 5th harmonic within the maximum analyzer bandwidth of 85 kHz). The 24-dB external attenuator will be used in this test.

Hit *File > New Settings*.
Turn off the right channel.
Set the full-scale input to 42 dBV.
Set the sample rate to 192 kHz.
Increment FFT size to 128k and choose the *Hann* Window.
Add the measurements *Sys: Gen 1*, *RMS Volts*, *RMS dBV* and *RMS Power Watts*.
Add the measurements *THD %*, *THD+N %*, *THD dB*, and *THD+N dB*.
Use a 24-dB external attenuator in this test to optimize THD+N.
Right click on *dBV*; set input gain to -24 dB.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.
In *XLOG* dialog, *Start* frequency 1 kHz, *Stop* frequency 85 kHz.
Hit the *THD* button. Right click, set *Start* frequency to 1 kHz, *Stop* 85 kHz.

Go to *File* > *Save Settings* and save this setup file as ***"THD-16 vs Pwr Auto.settings"***.

Go to *Automated Tests* > ***PWR THD Versus Power Watts+***.

In the *THD Versus Power Watts+* dialog do the following:

Uncheck the "*Measure THD+N Instead of THD*" box.
Select *Start Level* and *Stop Level* as 1 Watt and 180 Watts
Set the *Points Per Power Decade* to 10 (the maximum allowed).
Set the frequency to 16 kHz.
Set the load impedance to 8 Ω.
Check the box "*Autoset Input Range*".
Set the *Input Level Range Adder* (ILRA) to 12 dB. (see below near end of section).
Set *Distortion Measurement Stop* to 80 kHz.
Check the box "*Enable Early Abort*".
Set *Abort Minimum Power Level* to 0.05 W. (see below near end of section)
Set *Abort Maximum THD* to -60 dB (0.1%).
Set the *Series Name* to "*THD-16 vs. Power*" or the like to appear on the plot.

Hit *OK* - the THD vs. power measurement runs will begin.

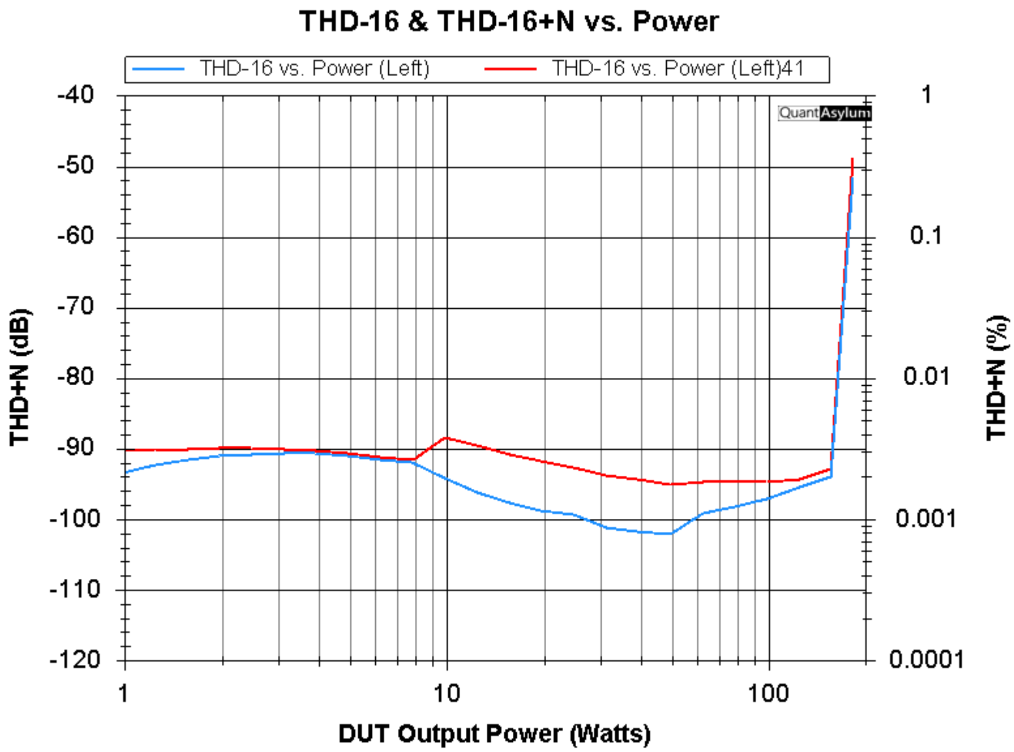

Figure 31: THD-16 and THD-16+N vs. Power

Repeat the above THD and THD+N tests, but with instances of 1 kHz replaced with 16 kHz and with an 80-kHz *Measurement Stop* frequency. Set the *Series Name* to "*THD-16+N vs. Power*" or the like to appear on the plot.

Stack the THD+N traces on the THD plot.

THD vs. Power in Watts with 4-Ω Load

This test measures THD-1 as a function of power with a 4-Ω load. An ideal amplifier would produce twice as much power into a 4-Ω load as into an 8-Ω load, but this will rarely be the case, mainly because the power supply will sag with the higher current demand. For measurements with a 4-Ω load (or other load not the 8-Ω default) the load impedance in the *dBV* settings must be set accordingly. For the automated test, the load impedance entry must be changed from the 8-Ω default to the 4-Ω value.

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 42 dBV and set the sample rate to 192 kHz.
Increment FFT size to 128k, averages should be *Off,* choose the *Hann* window.
Add the measurements *Sys: Gen 1*, *RMS Volts* and *RMS Power Watts*.
Add the measurements *THD %*, *THD+N %*, *THD dB*, *THD+N dB*.
Right click on *dBV*; set *Load Impedance* to 4 Ω for correct power calculation.
Right click on *dBV*; set *Input Gain* if an external attenuator is being used.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.

Go to *File* > *Save Settings*, save setup file as **"*THD_1 vs Pwr 4 Ohms Auto.settings*"**.

Go to *Automated Tests* > ***PWR THD Versus Power Watts+***.

In the PWR *Versus Power* Watts+ dialog do the following:
Select units as *dBV*.
Leave unchecked the *Measure THD+N Instead of THD* box.
Select *Start* and *Stop* levels as 1 Watt and 280 Watts.
Set the *Points Per Power Decade* to 10.
Set the frequency to 1 kHz.
Set the load impedance to 4 Ω.
Check the box "*Autoset Input Range*".
Set the *Input Level Range Adder* to 12 dB (see below).
Set *Distortion Measurement Stop* to 20 kHz.
Check the box "*Enable Early Abort*".
Set *Abort Minimum Power Level* to 0.1 W.
Set *Abort Maximum THD* to -60 dB (0.1%).
Set the *Series Name* to "*THD-1 vs Power into 4 Ohms*".

Hit *OK* - the THD vs power measurement runs will begin. THD begins to rise sharply at about 275 Watts into the 4-Ω load, indicating the early onset of clipping. Almost double the rated power of 140 W is produced, but not with respect to the higher clipping power at 8 Ω.

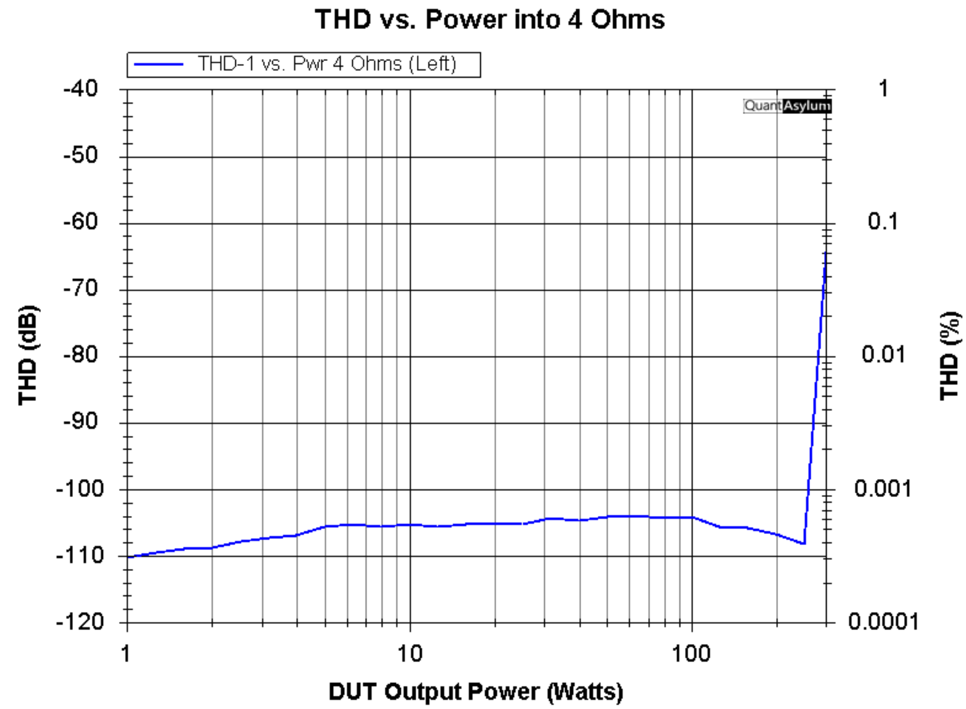

Figure 32: THD vs. Power at 1 kHz into 4-Ω Load

THD Versus Input/Output Level in dBV

The **AMP THD Versus Input/Output Level** test is much like the one above, but is more directed at line-level circuits like preamplifiers. Its mention is included here for completeness. It is essentially the same as the in the earlier versions of the software, where the input signal amplitude was specified in dBV and incremented in dB. Although this test is more important for line-level circuits, the BC-1 power amplifier will be used here as if it was a flat-gain preamp with the same gain. For this reason, it will be operated with no load. For real line-level circuits, apply a 600-Ω load. Some line-level circuits will be a bit more quiet than the power amplifier. In this test, THD+N as a function of input to the amplifier in dBV will be measured.

Hit *File* > *New Settings*.
Turn off the right channel.
Disconnect the amplifier load.
Set the full-scale input to 18 dBV and set the sample rate to 192 kHz.
Increment FFT size to 512k, averages should be *Off*, choose the *Hann* window.
Add the measurements *Sys: Gen 1*, *RMS Volts* and *RMS dBV*.
Add the measurements *THD %*, *THD+N %*, *THD dB*, *THD+N dB*.
Set the *Gen 1* level to -28.6 dB to achieve 0 dBV output.
Set *Ymin* to -150 dBV and *Ymax* to +20 dBV.
Optionally, hit *RUN* and verify expected performance at 1 Vrms output.
Optionally check 20-kHz performance (*XLOG* and *THD* top settings at 85 kHz).

Go to *File* > *Save Settings* and save this setup file as **"*THD_1 vs IO dBV Auto.settings*"**.

Go to *Automated Tests* > ***AMP THD Versus Input/Output Level***.

In the *THD Versus Input/Output level* dialog do the following:

Un-check the "*Measure THD+N instead of THD*" box.
Select *Start Level* and *Stop Levels* as -48.6 dBV and -8.6 dBV.
Set the amplitude *Increment* as 1 dB.
Set the frequency to 1 kHz.
Check "*Autoset Input Range*" and set the *Input Level Range Adder* at 6 dB.
Set *Distortion Measurement Stop* to 20 kHz.
Leave unchecked "*Plot (analyzer) Input Level Instead of Output Level*"
Check the box "*Plot Vrms for X axis*".
Set the *Series Name* to "*THD_1 vs Vout Voltage*" to appear on the plot.

Hit *OK* - the THD vs. dBV measurement runs will begin.

This run will take about 2 minutes because of the choice of a 512-k FFT for reasons explained below. Notice that this test does not include an abort provision at a specified level of THD. This means that the device can be accidentally driven to hard clipping if the *Stop Level* is set too high. Note that you can optionally plot input level instead of output level. This is useful if you want to look at input overload behavior of something like a phono preamp. In the test here, the amplitude on the X axis will be in volts RMS instead of dBV.

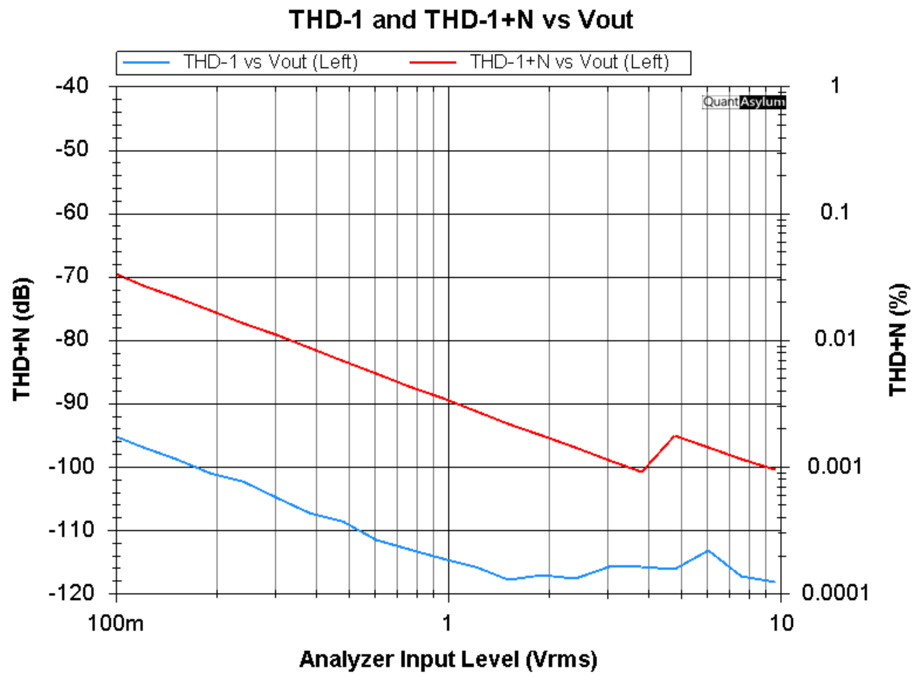

Figure 33: THD-1 and THD-1+N vs. Vout

Repeat the measurement with the "*Measure THD+N instead of THD*" box checked and the series name "*THD-1+N vs. Vout*". Stack the new plot with the THD-only plot. Notice that both THD and THD+N grow together, separated by a constant 25 dB as the signal level decreases below 1 V. THD should not be increasing at a steady rate as amplitude is decreasing, and in reality it does not here.

THD vs. Frequency vs. Power in Watts

Here the automated ***PWR THD vs. Frequency+*** test will be used to measure THD vs. frequency at several different target output power levels in Watts. The frequency range will be 20-20 kHz and the first measurement will be performed at a target power level of 1 W. Subsequent runs will be at 10 Watts, 50 Watts and 100 Watts.

If 3 points per octave are chosen, over the 10 octaves from 20 Hz to 20 kHz, then each power level will require 30 runs. Each measurement will typically take about 90 seconds with the high sample rate of 192 kHz and a 128k FFT; the latter is required for accurate results for reported distortion and output amplitude down to 20 Hz. The amplifier may heat up during the high-power runs.

The gain of the amplifier is first measured in the background and then a box will come up that indicates what the amplifier gain is and the dBV input signal level that will be applied for the selected target amplitude. Hit OK to start the measurement.

Measurement bandwidth will be 85 kHz so as to capture as many high-frequency harmonics as possible. This allows the 5th harmonic to be captured up to a fundamental frequency of 17 kHz. Distortion may fall above 17 kHz due to loss of the 5th harmonic contribution.

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 18 dBV and set the sample rate to 192 kHz.
Increment the FFT size to 128k with no averaging and select the *Hann* window.
Increment *Ymin* to -120 dBV and *Ymax* to +40 dBV.
Add measurements *Sys: Gen 1*, *THD %*, *THD dB* and *RMS Power Watts*.
Add measurements *Volts dBV* and *RMS Volts*.
Set Gen1 amplitude to -19.4 dBV.
In the *XLOG* dialog, set start frequency to 20 Hz, stop frequency to 85 kHz
Hit the *THD* button, right click and set start frequency 20 Hz stop 85 kHz.
For *Fundamental Selection* select *Use Channel Peak* in the THD dialog.
Use a 6-dB external attenuator and set the dBV input gain to -6 dB.

Go to *File* > *Save Settings* and save setup file as ***"PWR THD vs Freq Auto.settings"***.

Go to *Automated Tests* > ***PWR THD Versus Frequency+***.
Leave unchecked the "*Measure THD+N Instead of THD*" box.

Set the *Target Power Level* to 1 Watt.
Set the *Start* and *Stop* frequencies to 20 Hz and 20 kHz.
Ignore the Hz *per Step* value. (It doesn't matter when using *Log Step*.)
Check the *Log Step* box and select 3 points per octave.
Set *Load Impedance* to 8 Ω.
Check the *Autoset Input Range* box.
Set the *Input Level Range Adder* to 6 dB.
No *Series Name* need be set. Plot series titles will indicate target powers.
Hit *OK*

A box will come up indicating the amplifier gain and the dBV input signal level that will be applied for the selected target power. Then hit *OK* to start the measurement.

The result is shown in blue in the figure below, after about 90 seconds. Results for higher power levels of 10 W, 50 W and 140 W will be stacked on the graph in accordance with the directions below.

Now re-run the above test at 3 additional target power levels of 10 W, 50 W and 140 W. Stack the resulting plots together on the same graph. To re-run your previous test at a different target power level, press *F3*. This will send you back to the automated menu to change the target power for the next run. If a plot is still on top of the main window, click on an area of the main window to bring it forward, then hit *F3*. When all plots are completed, minimize the main window to see the graph.

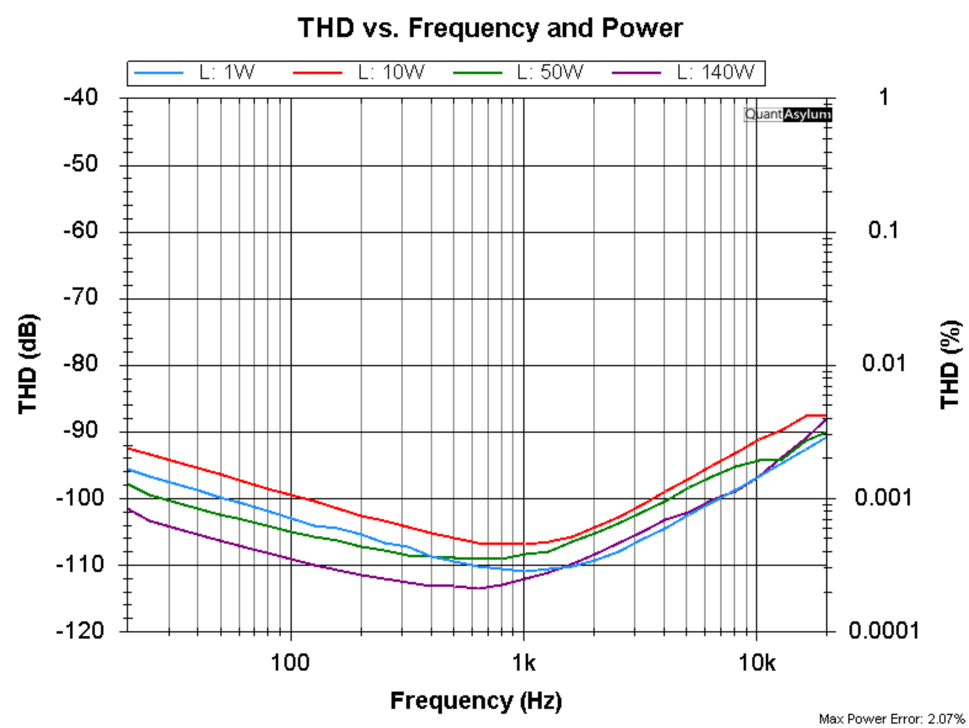

Figure 34: THD vs. Frequency for Various Power Levels

Output Impedance and Damping Factor

The damping factor (DF) of a power amplifier can be measured by the ***PWR Output Impedance*** test. DF is inversely related to its output impedance (Zout). It is technically defined as the ratio of the load impedance to the amplifier output impedance. In practice, on specification sheets it is always specified as the ratio of 8 Ω to the amplifier output impedance. Here the output impedance of the amplifier will be determined by measuring amplifier gain with and without an 8-Ω load. With the impedance data, the software will calculate and plot DF.

It is crucial that the load resistor be non-inductive and no more than 2 feet from the amplifier output terminals for this impedance measurement technique to be reasonably accurate for frequencies above 1 kHz. Stray inductance of as little as 1 μH will adversely affect the reported DF.

Zout and DF will be measured as a function of frequency from 20 Hz to 20 kHz. The measurement will be done at an output voltage level of 2.83 Vrms (+9 dBV), corresponding to 1 W into 8 Ω. If amplifier gain is 28.4 dB, as it is here, an input level of about -19.4 dBV will be applied to the amplifier. Choosing FSI of 18 dBV (i.e., below 24 dBV) optimizes QA403 sensitivity for potentially more accurate results. The measurement is done in two phases, the first with an 8-Ω load and the second with a specified 1-MΩ load (open circuit).

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 18 dBV.
Set the sample rate to 192 kHz.
Increment FFT size to 128k, averages should be *Off*, and choose *Hann* window.
Add the measurements *Sys: Gen 1*, *RMS dBV*, *RMS Volts* and *RMS Power Watts.*
Hit *GEN 1* and set the *GEN1* level to -19.4 dBV if amplifier gain is 28.4 dB.
Set the *RMS* measurement *Stop* frequency to 20 kHz.
Right click on *dBV* and set the load impedance to 8 Ω.
Set *Ymin* to -120 dBV and *Ymax* to 20 dBV.

Go to *File* > *Save Settings* and save file as **"*Output Z Auto.settings*"**.

Go to *Automated Tests* > ***PWR Output Impedance***.
Set QA40X output power level to -19.4 dBV for 1 Watt (not critical).
Set *Start* and *Stop* frequencies to 20 Hz-20 kHz.
Ignore the *Hz per Step* value. (It doesn't matter when using *Log Step*.)
Check the *Log Step* box and choose 3 points per octave.
Enter load impedance of 8 Ω for the first pass.
Enter load impedance of 1000000 (1 Meg) for the second pass.
Check the box *Plot Damping Factor*.
Hit *OK*.

The choice of a 192 kHz sample rate makes the measurement go more quickly. The choice of a 128 kHz FFT helps preserve accuracy down to 20 Hz.

The program will ask you to connect an 8-Ω load, then hit *OK*.
You will see an FFT line march across the screen, at about 1 Watt.
When complete, it will ask you to set the load impedance to 1000000 ohms.
Disconnect the 8-Ω load and hit *OK*.
You will see an FFT line march across the screen.

A plot of the output impedance vs. frequency will appear. Enter the title of the graph as "*Zout and Damping Factor*". The plot spans Zout and DF ranges that are auto-scaled by the QA40X.

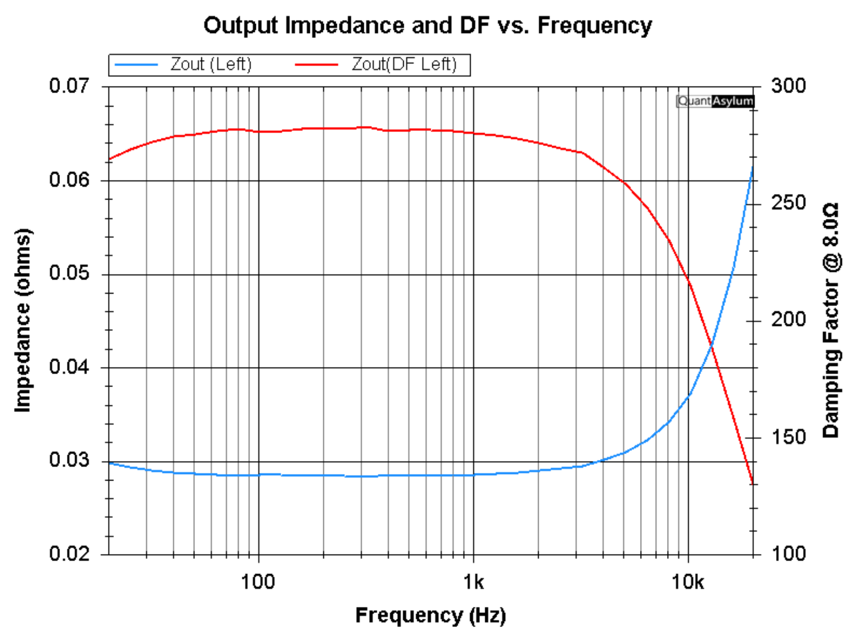

Figure 35: Output Impedance and DF vs. Frequency

For the BC-1, the reported output impedance at low frequencies is 0.028 Ω (DF=286), rising to 0.038 Ω (DF=211) at 10 kHz and rising further to 0.066 Ω (DF=121) at 20 kHz, as seen in the figure. The rise in Zout at higher frequencies is mainly due to the output inductor in the BC-1 (not necessarily due to the falling amount of negative feedback). A DF of 121 is quite high at 20 kHz.

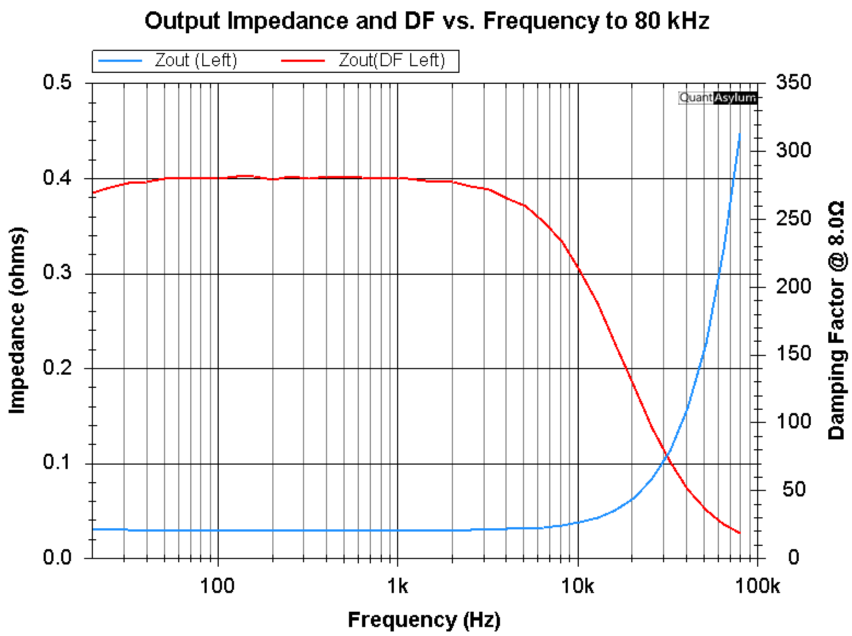

Figure 36: Output Impedance and DF vs. Frequency to 80 kHz

If you set the stop frequency to 80 kHz, after changing the setup *XLOG* and *RMS* measurement stop frequencies to 80 kHz, the Zout will be plotted up to 80 kHz. Here the output impedance rises to 0.36 Ω at 80 kHz, corresponding to DF=22.

Crosstalk vs. Frequency

Here the automated test ***AMP Crosstalk*** will be used to measure the crosstalk vs. frequency for a stereo amplifier. Crosstalk is measured by looking at the frequency response of the undesired signal path from one channel of an amplifier to the opposite channel. Here we illustrate measuring the frequency response of the crosstalk path from the right channel of the amplifier to the left channel of the amplifier (R2L).

One channel will be the "*aggressor*", amplifying the test signal and delivering about 1 W to an 8-Ω load. The other channel will be the "victim", whose output will be measured as the frequency response of the crosstalk. One channel of the QA40X will be used to measure the frequency response of the crosstalk path from the output of the aggressor channel to the output of the victim channel.

The frequency response is measured by stepping the frequency through the frequency range at a chosen number of steps per octave at a fixed amplitude, while measuring the output of the aggressor channel and the victim channel. The dB difference in the received signal levels is reported as the crosstalk value. In the first run, the left channel is the victim, with the left output of the QA40X muted so that the left channel of the amplifier gets no input.

The QA40X right output sends a signal to the right channel amplifier (the aggressor) and receives the crosstalk signal from the output of the left channel amplifier (the victim) into its right input.. The left channel of the QA40X receives and measures the output of the left channel amplifier. The right input of the QA40X receives the signal from the right channel of the amplifier and uses it as the dBr signal reference against which the crosstalk signal from the left channel is measured. A frequency response measurement is then run on this arrangement.

The BC-1 amplifier was not measured for crosstalk here because the version used in the tests in this tutorial was configured as a mono-block. Instead, the Super Gain Clone LM3886 (SGC) stereo amplifier was measured for crosstalk [1, 5]. Both amplifier outputs should be loaded by an 8-Ω load resistor. Crosstalk will be measured at only one power level, which should be about 1 Watt (2.83 Vrms, +9 dBV), but is not critical.

Connect the left output of the QA40X to the left input of the amplifier.
Connect the left output of the amplifier to the right input of the QA403.
Connect the right output of the QA403 to the right input of the amplifier.
Connect the right output of the amplifier to the left input of the QA403.

Hit *File* > *New Settings*.
Set the full-scale input to 42 dBV.
Set the sample rate to 192 kHz, FFT size to 128k and averages *Off*.
Set *Ymin* to -120 dBV and *Ymax* to +20 dBV

Go to *File* > *Save Settings* and save this setup file as **"*Crosstalk Auto.settings*"**.

Go to *Automated Tests* > ***AMP Crosstalk***.

Set the QA40X aggressor output *Start* level to -17 dBV and *Stop* level to -17 dBV. SGC gain is 26 dB, so -17 dBV provides +9 dBV at the SGC output.

Only one signal level will be measured, here 1 Watt.
Ignore the *dBV Increment*.
Set *Start* and *Stop* frequencies to 25 Hz and 20000 Hz.
Ignore the Set *Hz per Step* value. (It doesn't matter when using *Log Step*.)
Check the *Log Step* box and select 1 point per octave.
(this avoids the influence of 60-Hz hum by starting at 25 Hz, then to 50 Hz.
Check *Autoset Input Range* box and leave *Range Adder* at the 18-dB default.
Check *Measure Right to Left Crosstalk* (left channel is the victim).
Enter a *Series Name*.
Start the run by hitting *OK*.

As the test progresses, the aggressor signal is at about +9 dBV and its frequency increases as its FFT line moves to the right. The orange annunciator in the upper left will indicate which QA40X output is muted. At the conclusion of the measurement run, a plot showing crosstalk will appear. Give the plot a title. Set plot *Xmin* to 20 (Hz) and *Xmax* to

20,000 (Hz). Crosstalk for the Super Gain Clone amplifier is about -69 dB at low frequencies, rising to about -64 dB at 1 kHz, and rising further to -51 dB at 20 kHz.

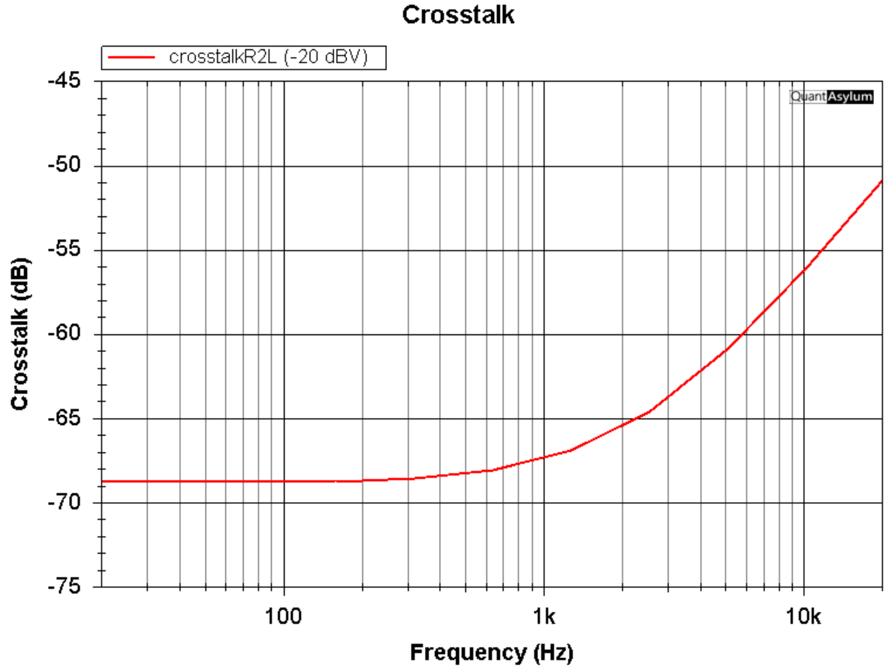

Figure 37: Crosstalk of Super Gain Clone Stereo Amplifier

Intermodulation Distortion vs. Power

Both CCIF 19+20 kHz (ITU) and SMPTE intermodulation (60 Hz and 4 kHz, 4:1) distortion will be measured as a function of amplifier output power in this test. Load impedance will thus have to be entered for this test.

CCIF 19+20 kHz (ITU) IM Distortion

CCIF IMD will now be discussed and measured. At rated sine wave average (aka RMS) power of 140 W, peak output voltage is 47.3 Vpk. With two equal tones in the CCIF test, this corresponds to two tones, each of 23.7 Vpk, further corresponding to 16.7 Vrms, still further corresponding to 35 W per tone, for total two-tone RMS power of 70 W (conveniently half the rated sine wave power of 140 W). At 16.7 Vrms, each tone will be at 24.5 dBV. Thus, when each tone is at 24.5 dBV, the amplifier is operating at its equivalent full power rating of 140 W. This is the per-tone amplitude at which CCIF distortion should be measured at full "rated" power.

With amplifier gain of 28.4 dB, this corresponds to per-tone amplifier input voltage of -3.9 dBV. If the measurement is stopped at a dashboard reading of 70 Wrms, then the resulting FFT will depict performance at rated amplifier power. The CCIF IMD test signal is shown below using the oscilloscope visualizer.

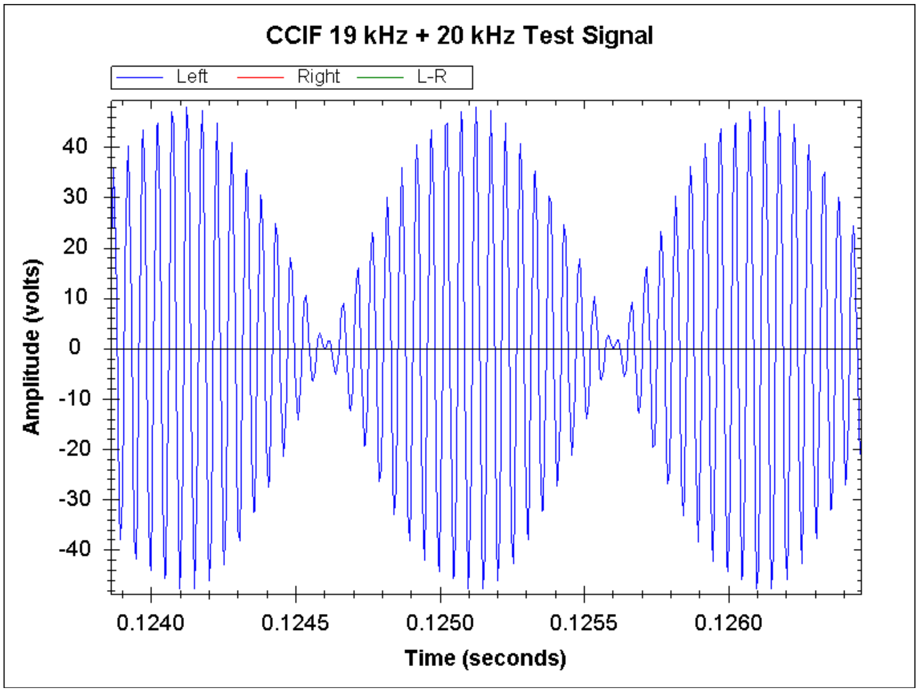

Figure 38: CCIF 19+20 kHz IM Distortion Test Signal at 140 W Equivalent Power

Hit *File* > *New Settings*.
Turn off the right channel and set the full-scale input to 42 dBV.
Set the sample rate to 192 kHz, increment FFT size to 64k, set window to Hann.
Add measurements *Sys: Gen1*, *Sys: Gen2*, *RMS Power Watts* and *RMS dBV*.
Set *Gen1* and *Gen2* to -3.9 dBV
Set *XLOG* and *RMS* measurements to start at 500 Hz and stop at 50 kHz.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV

Go to *File* > *Save Settings* and save setup file as **"*CCIF IMD vs Pwr Auto.settings*"**.

Hit *RUN*.

The CCIF distortion products at 140 W equivalent power are shown below. They lie at (m±n) Hz where M=19 kHz and n=20 kHz. Primary even-order products lie at 1 kHz, 3 kHz, etc. Prominent odd-order products surround the 19 and 20 kHz pair of tones. Higher-order out-of-band products can be seen surrounding the second harmonics of the tones in the vicinity of 39 kHz.

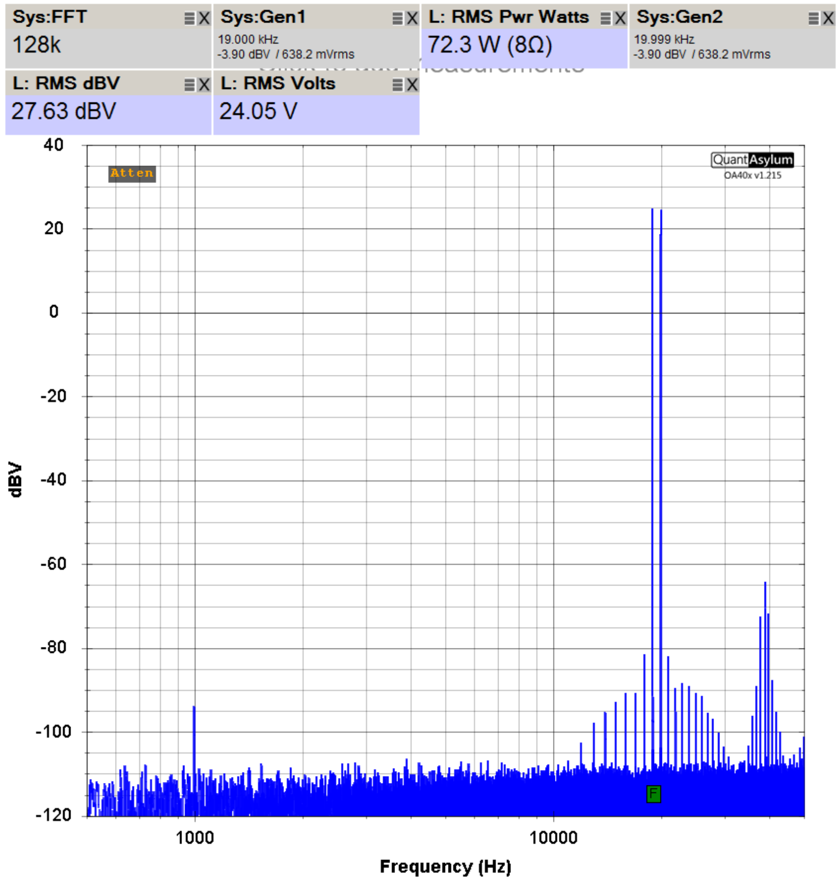

Figure 39: CCIF 19+20 kHz IM Distortion at 140 W Equivalent Power

The highest in-band products measured here lie at 18 kHz and are 106 dB down from the amplitudes of each tone here 21 kHz will be considered in-band. However, with respect to the 30.5 dBV amplitude of a 140-W sine wave, these products are down by 111 dB. The 1-kHz 2nd-order product lies 119 dB below each tone. The RMS sum of the highest in-band products is about -82 dBV. The RMS sum of the two tones is about +28 dBV. CCIF distortion at 140 Watts equivalent is thus about -110 dB.

Change *XLOG* and *RMS* measurements to start at 500 Hz and stop at 30 kHz to exclude from measurement the high-order products that surround 39 kHz.

Go to Automated Tests > ***PWR IMD (ITU and SMPTE)***.

Check ***ITU***.

Set *Start* and *Stop* levels to -19.5 dBV and -0.9 dBV, respectively.

(adjust *Stop* dBV level to achieve about 70 Wrms average power)

Select *dB increment* as 0.5 dB and set *IM order* to 3.

Set *Load Impedance* to 8 Ω

Un-check *Autoset Input Range*.

Set *input level range adder* to 18 dB.

Hit *OK*.

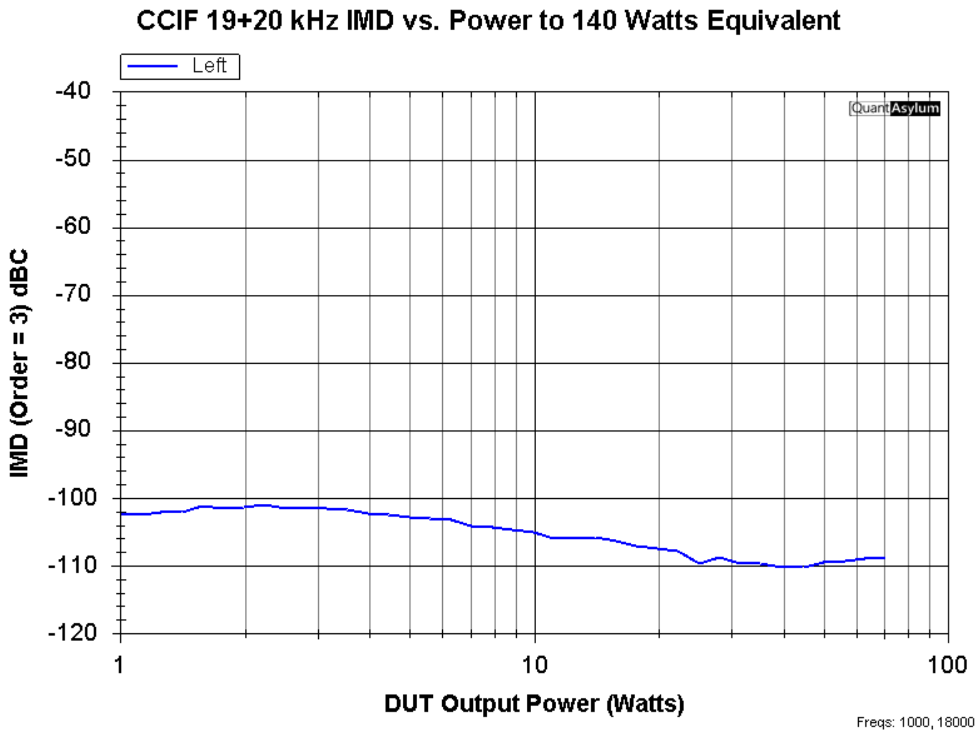

Figure 40: CCIF 19+20 kHz IM Distortion vs. Amp RMS Power Output

With 0.5 dB amplitude increments, this measurement will take about 1 minute. A larger increment will take less time, but granularity of results as a function of power will suffer. A plot showing CCIF 19+20 kHz (ITU) will appear. Note that power indicated on the X axis is the RMS power of the 2 tones combined, not the same as the equivalent single-tone sine wave average power.

SMPTE IM Distortion

SMPTE IMD will now be discussed and measured. At rated sine wave average (aka RMS) power of 140 W, peak output voltage is 47.3 Vpk. With 60 Hz and 7000-Hz tones in a 4:1 ratio, the 60-Hz tone will be at 80% of the peak voltage, or 37.8 Vpk, and the 7-kHz tone will be at 20% of the peak voltage, or 9.46 Vpk. This corresponds to 26.7 Vrms and 6.69 Vrms, respectively. This further corresponds to 89.1 W and 11.2 W, respectively, for a total average power of 100.3 W. At 26.7 Vrms and 6.69 Vrms, the tones are at 28.5 dBV and 16.5 dBV. Thus, when the tones are at these amplitudes, the amplifier is operating at its equivalent full power rating of 140 W. These are the per-tone amplitudes at which SMPTE distortion should be measured at full "rated" power. With amplifier gain of 28.6 dB, this corresponds to tone input amplitudes of -0.1 dBV and -12.1 dBV. If the measurement is stopped at a dashboard reading of 100.3 Wrms, then the resulting FFT will depict performance at rated amplifier power.

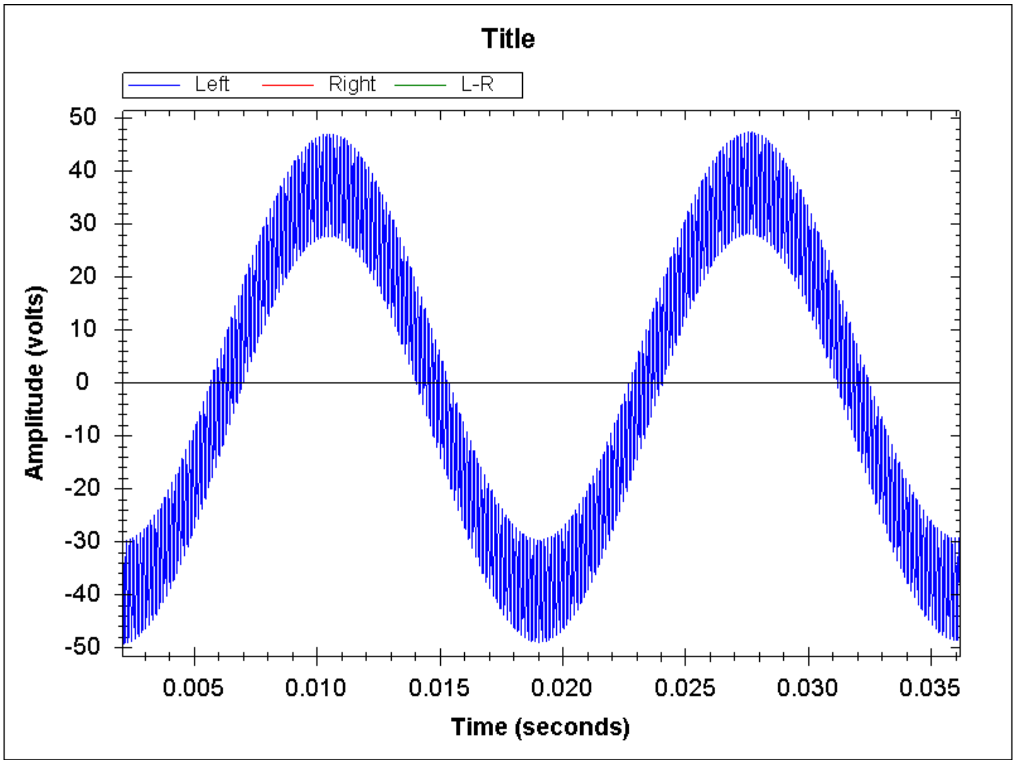

Figure 41: SMPTE IM Distortion Test Signal at 140 W Equivalent Power

Hit *File* > *New Settings*.
Turn off the right channel and set the full-scale input to 42 dBV.
Set the sample rate to 192 kHz, increment FFT size to 128k, set window to Hann.
Add measurements *Sys: Gen 1*, *Sys: Gen 2, RMS Power Watts* and RMS *dBV*.
Set Gen1 to 60 Hz with amplitude -0.1 dBV.
Set Gen2 to 7000 Hz with amplitude -12.1 dBV.
Set *XLOG* and *RMS* measurements to start at 20 Hz and stop at 20 kHz.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.

Go to *File* > *Save Settings* and save setup file as **"SMPTE *IMD vs Pwr Auto.settings*"**.

Hit RUN.

An FFT will appear that shows SMPTE distortion products when the amplifier is driven to 140 equivalent Watts. Notice that the dashboard indicates RMS power of 98.3 W and RMS voltage as 28.96 dBV. Thus, because of the nature of the STPTE test waveform, when the amplifier is operating at the voltage equivalent of 140 W, the actual RMS power will be only 98.3 Watts. This must be taken into account when setting the starting and stopping dBV values in the automated test to follow. Distortion products are seen at 7 kHz ± n*60 Hz and at 14 kHz ± n*60 Hz.

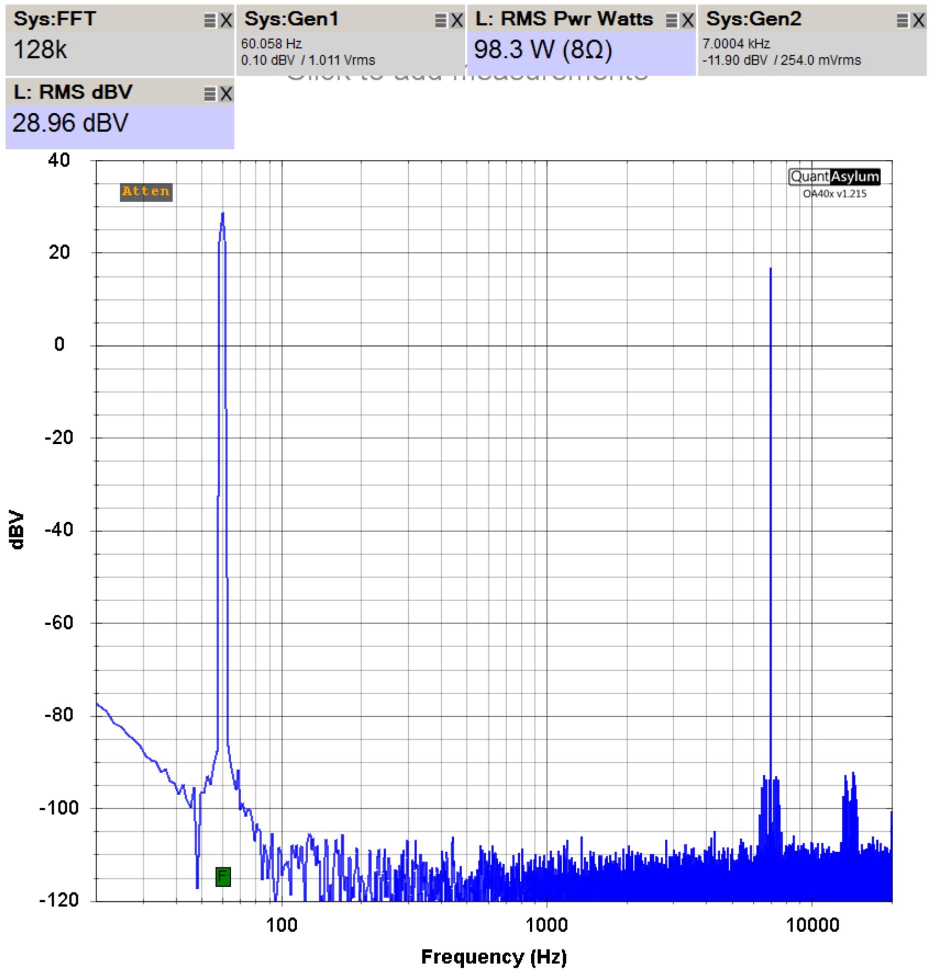

Figure 42: SMPTE IM Distortion at 140 W Equivalent Power

The X axis of the SMPTE automated test indicates RMS power of the SMPTE test waveform, which is less than the equivalent amplifier power on a peak voltage basis. In fact, when the latter is 140 W, the RMS power will be 98.3 W, as displayed on the X axis of the plot, less by 1.5 dB. This must be taken into account when choosing the starting and stopping dBV values in the automated test dialog.

Go to Automated Tests > ***PWR IMD (ITU and SMPTE)***.
Check ***SMPTE***.
Set *Start* and *Stop* levels to -20 dBV and +1.7 dBV, respectively.
Select *dB increment* as 0.5 dB.
Set *IM order* to 5.
Set *Load Impedance* to 8 Ω (or 4 Ω) (for proper power calculation)
Do not check *Autoset Input Range*.
Set *input level range adder* to 18 dB.
Hit *OK*.

A plot showing SMPTE (60 Hz and 7 kHz, 4:1) intermodulation distortion as a function of power will appear. Note that power indicated on the *X* axis is the RMS power of the 2 tones combined, not the same as the single-tone sine wave average power. 99 Watts here corresponds to 140 Watts on a peak-voltage basis.

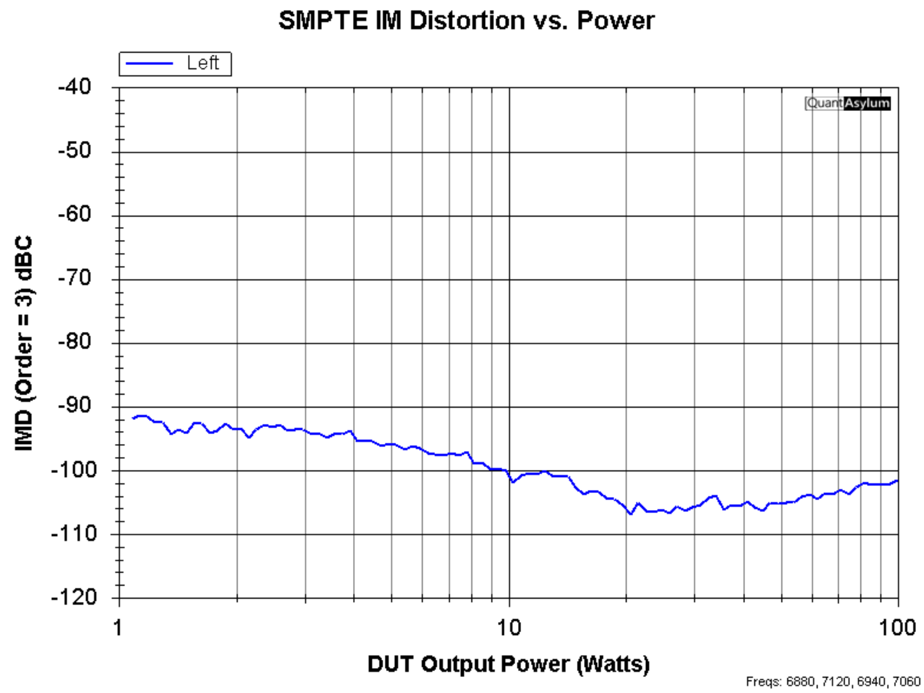

Figure 43: SMPTE IM Distortion vs. Power

Intermodulation Distortion vs. Amp Input dBV

Both CCIF 19+20 kHz (ITU) and SMPTE (60 Hz and 4 kHz, 4:1) intermodulation distortion will be measured as a function of amplifier input voltage (dBV) in this test by using the ***AMP IMD (ITU and SMPTE)*** test. This test is much like the one above, but is more directed at line-level circuits like preamplifiers. Its mention is included here for completeness. Input signal amplitude is specified in dBV and incremented in dB.

Although this test is more important for line-level circuits, the BC-1 power amplifier is used here as if it was a flat-gain preamp with the same gain. For this reason, the BC-1 will be operated with no load. In this test, IMD as a function of input to the circuit in dBV will be measured. Because it is a voltage-based line-level test, no output impedance is specified. There are also no provisions for *Autoset Input Range* or *Input Level Range Adder*. With these exceptions, the test is carried out in virtually the same way as the *PWR IMD (ITU and SMPTE)* test.

Both CCIF 19+20 kHz (ITU) and SMPTE (60 Hz and 4 kHz, 4:1) intermodulation distortion will be measured as a function of output power in this test by using the ***AMP IMD (ITU and SMPTE)*** test.

CCIF 19+20 kHz (ITU) IM Distortion

The CCIF signal level will be set for an equivalent 100 mVrms to 10 Vrms output. The maximum corresponds to 14.14 Vpk, or 7.07 Vpk for each tone.

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 24 dBV.
Set the sample rate to 192 kHz and increment the FFT size to 128k.
Add measurements *Sys: Gen 1*, *Sys: Gen 2, RMS dBV* and *RMS Volts.*
Set the *GEN1* and *GEN2* amplitudes to -14.5 dBV to achieve 14.14 Vpk output.
(7.1 Vrms on the dashboard for the CCIF waveform)
Set *XLOG* and *RMS* measurements to start at 500 Hz and stop at 50 kHz.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.

Go to *File* > *Save Settings* and save file as **"CCIF *IMD vs dBV Input Auto.settings*"**.

Go to Automated Tests > ***AMP IMD (ITU and SMPTE)***.
Check ***ITU***. (CCIF 19+20 kHz)
Set start and stop levels to -31.6 dBV and -11.6 dBV, respectively.
(these are the analyzer RMS dBV output levels.)
(with amplifier gain of 28.6 dB, max corresponds to DUT output of 17 dBV.
Select *dB Increment* as 0.5 dB.
Set *IM order* to 3.
Hit *OK*.

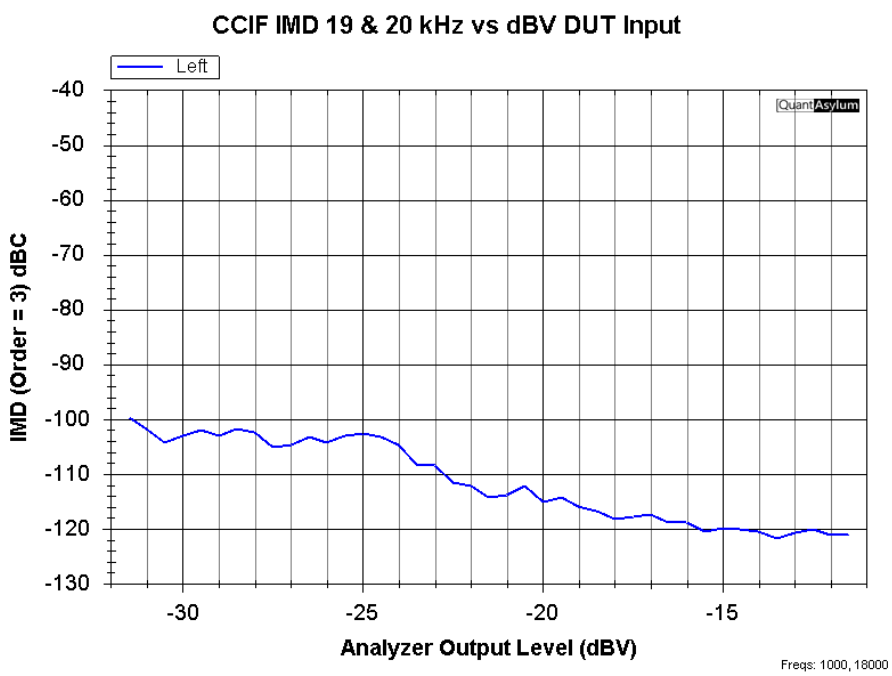

Figure 44: CCIF 19+20 kHz IM Distortion vs. dBV Input to Amp
(100 mVrms to 10 Vrms sine wave equivalent DUT output)

With 0.5 dB amplitude increments, this measurement will take about 75 seconds. A larger increment will take less time, but granularity of results as a function of input amplitude will suffer. A plot showing CCIF 19+20 kHz (ITU) IMD versus DUT RMS dBV input of the CCIF waveform will appear. This corresponds to a DUT output range of 100 mVrms to 10 Vrms sine wave equivalent peak voltage of 14.14 Vpk.. CCIF IMD is below -120 dBc at maximum output. Reported IMD increases at smaller signal levels and that may be an artifact caused by noise.

SMPTE IM Distortion

Hit *File* > *New Settings*.
Turn off the right channel.
Set the full-scale input to 24 dBV.
Set the sample rate to 192 kHz and increment the FFT size to 256k.
Add measurements *Sys: Gen 1*, *Sys: Gen 2, RMS dBV* and *RMS Volts*.
Set the *GEN1* amplitude to -10.6 dBV.
Set the *GEN2* amplitude to -22.6 dBV.
(8.2 RMS Volts at the DUT output for the SMPTE waveform)
(-10.3 RMS dBV max analyzer output of SMPTE waveform)
Set *XLOG* and *RMS* measurements to start at 20 Hz and stop at 20 kHz.
Set *Ymin* to -120 dBV and *Ymax* to +40 dBV.
Hit *OK*.

Go to *File* > *Save Settings* and save file as **"SMPTE *IMD vs dBV Input Auto.settings*"**.

The FFT shows each sideband 120 Hz above and below 7 kHz reads -117 dBc relative to the 7 kHz tone amplitude. Adding the two sidebands results in SMPTE IMD of -114 dB at the maximum equivalent output of a 10 Vrms sine wave (14.4 Vpk). Other sidebands are considerably lower, so ignoring them causes little error.

Hit F3 to go back and change the ***AMP IMD (ITU and SMPTE)*** automated test settings.
Check ***SMPTE***.
Set *Start* and *Stop* levels to -20 dBV and +2 dBV, respectively.
Select *dB Increment* as 0.5 dB.
Set *IM Order* to 3.
Hit *OK*.

With 0.5 dB amplitude increments, this measurement will take about 2 minutes. A plot showing SMPTE (60 Hz and 4 kHz, 4:1) intermodulation distortion will appear. SMPTE IMD is at about -114 dBc at the maximum 10 Vrms equivalent amplitude. This is in agreement with the earlier estimate of SMPTE IMD made from examining the FFT. The rise in IMD at lower signal levels seems anomalous and may be due to noise.

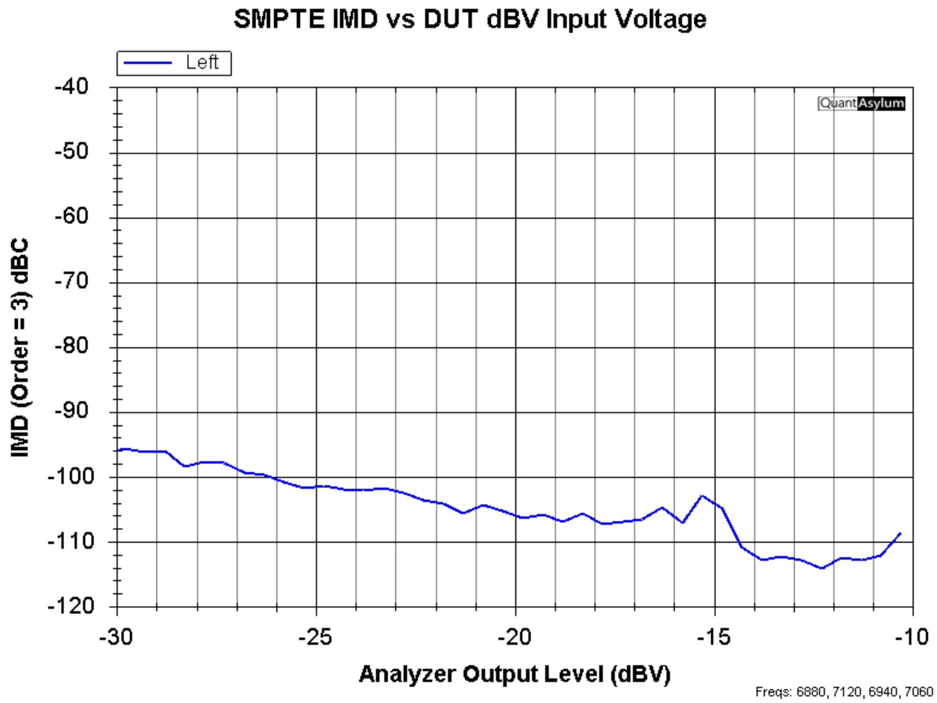

Figure 45: SMPTE IM Distortion vs. dBV Input to Amp
(100 mVrms to 10 Vrms sine wave equivalent DUT output)

References

1. Bob Cordell, *Designing Audio Power Amplifiers*, 2nd edition, Routledge, New York, NY, 2019.

2. www.cordellaudio.com, the BC-1 Power Amplifier.

3. BC-1 Power Amplifier, eBay, search "*BC-1 Amplifier*".

4. Bob Cordell, *Designing Audio Circuits and Systems*, Routledge, New York, NY, 2024.

5. www.cordellaudio.com, *The Super Gain Clone*.