Audio Precision®

2700 Series
ATS-2
APx500 Series

Introduction to
the Six Basic Audio Measurements

by David Mathew

About this Technote

Technote 104 discusses methods of making a set of basic measurements using an Audio Precision 2700 Series or ATS-2 audio analyzer.

Much audio testing is concerned with a small number of performance benchmarks, which we call the Big Six measurements. These are

- Level
- Frequency Response
- THD+N
- Phase
- Crosstalk
- Signal-to-Noise Ratio

In Section 1 we'll start out by looking at what testing is required for different audio devices, and we'll choose a device to test and a signal path. Section 2 discusses basic setup considerations. In Section 3 we'll look at each of the six measurements in detail and make each of the measurements using analyzer reading meters and one frequency sweep.

For simplicity, we'll make all the measurements in the analog domain, and we'll test a common audio device. The concepts and approaches shown here can be extended to the digital domain, to cross-domain measurements and to other types of audio equipment.

1: Device Under Test and Signal Path

DUTs

The equipment you want to test may be a receiver for a home theater, an audio power amplifier or a DVD player, or one of hundreds of other devices that require audio testing. When discussing a measurement, we refer to the equipment to be measured as the *Device Under Test*, or *DUT*.

Signal paths, connections and more

Different DUTs may require different signal paths. Let's look at the signal paths associated with the three types of devices mentioned above. For example:

- A home theater receiver has many inputs and outputs, and you must choose which you are going to test. Both the inputs and the outputs may be analog or digital.
- An audio power amplifier has both inputs and outputs. The inputs may be analog or digital, and the output is invariably analog.
- A stand-alone DVD player has no audio inputs, only outputs. The audio outputs may be carried as analog audio or as digital audio.

For the examples in this technote, we will use a home theater receiver as a DUT. This receiver has many inputs and outputs, and we have chosen to test the path from the CD Left and Right analog inputs to the Left and Right power amplifier outputs. See the illustration on the next page.

In most cases, DUTs with different signal paths will be tested using very similar techniques, simply re-connecting cables or using the digital domain generator or analyzer. Playback-only devices (such as a stand-alone DVD player) require discs or other media with pre-recorded test signals and external sweep or external source measurement techniques.

Connecting the DUT to the analyzer

Most professional, industrial and broadcast audio devices use *balanced* analog inputs and outputs; consumer analog equipment is typically *unbalanced*. Whether or not your DUT has balanced or unbalanced inputs or outputs will determine your selection of generator and analyzer connections and the type of cables you must use. Our home theater receiver has unbalanced inputs, but its power amplifier outputs are balanced. This is not always the case, but power amplifier outputs are often balanced, even in consumer devices.

Using terminating loads

Certain DUTs must have their outputs terminated in a specific load impedance to perform as designed or to match specified measurement conditions. An obvious example is the power amplifier, which in use must deliver its output voltage at the current drawn by its load (the loudspeaker). For amplifier measurement, the loudspeaker is typically replaced by a power resistor of the specified resistance, usually 8 Ω.

Choosing a measurement level

Most audio equipment has a nominal operating level within a few decibels of 1 Vrms. Specialized equipment such as mi-

crophone preamplifiers or high-power amplifiers are designed to operate well below or above this range, and certain tests may require very low or very high levels.

Our home theater receiver has the typical 1 volt nominal input levels, and power amplifier stages that can deliver up to 100 Vrms at each speaker output.

Choosing DUT gain and effects settings

Some DUTs have no settings at all, just input and output connections. Others may have gain controls, equalization or bass and treble controls, even surround and reverberation effects accomplished using internal digital signal processing (DSP). These settings will affect the measurements you make, so you must be careful to set them properly for testing (usually by disabling them). The gain or volume control is typically set to a nominal operating level, and other effects and controls are set to their **OFF** or **NEUTRAL** positions. Other gain settings may be specified or necessary for certain tests, and in rare cases there may be a reason to set other controls or effects to **ON**. See **Gain considerations for level measurements** on the next page or more information.

We will connect our DUT as shown here:

8 Ω non-inductive power resistors
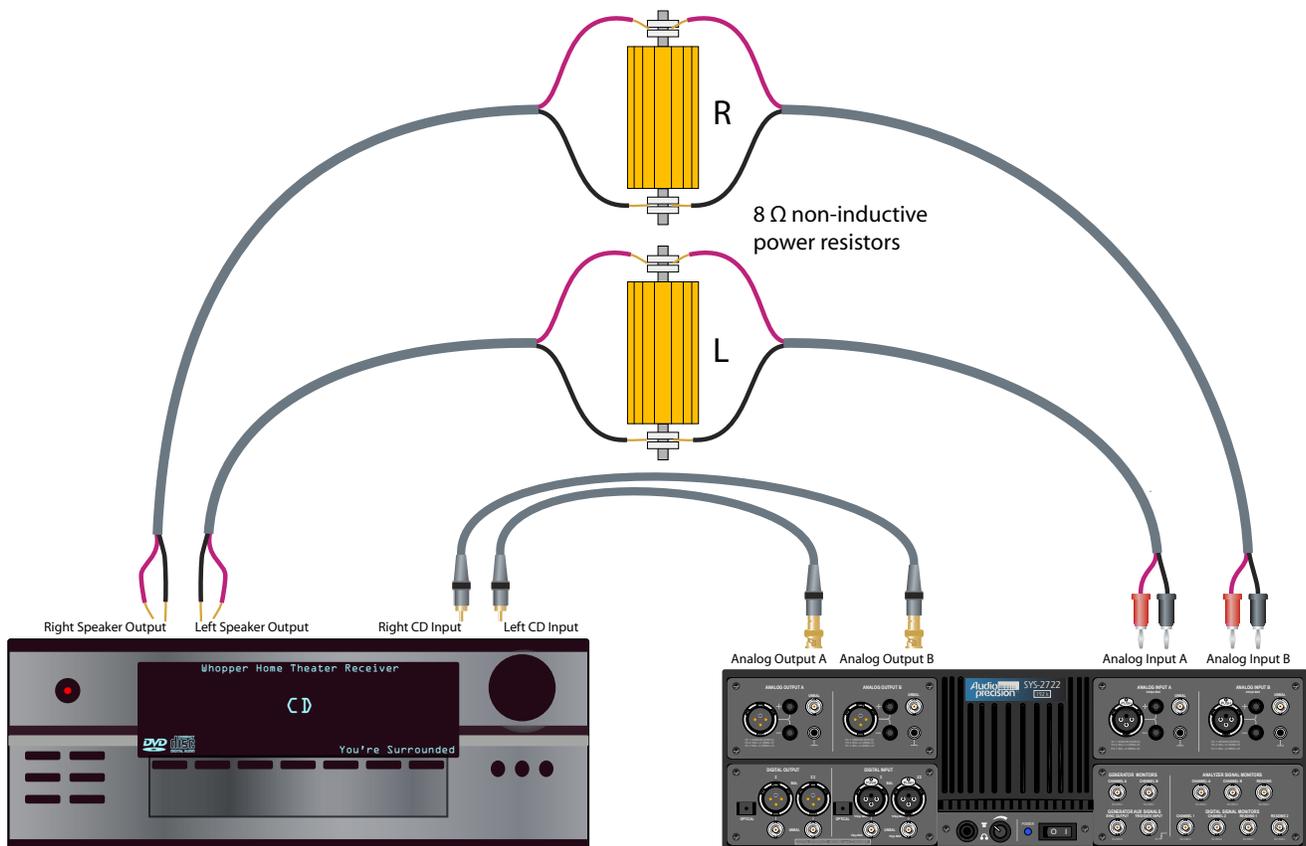
2: SETUP

So, let's set up our home theater receiver. We will use this setup (with one minor change for input/output phase) for making all the measurements.

Connecting the DUT in the measurement signal path

We have chosen to use the CD inputs in the measurement signal path for our receiver. These are unbalanced RCA jacks, and we're assuming they have a typical nominal operating level of 1 Vrms. We will connect these to our instrument generator unbalanced analog outputs.

We will measure our DUT at its power amplifier outputs (speaker connections), using the left and right channels. These are available as spring clips for connecting speaker cable. For our test we will ignore the surround and subwoofer channels. We will connect the left and right outputs to a pair of 8 Ω power resistors as a terminating load, and will also connect parallel lines from the resistors to our instrument analyzer balanced analog inputs.

Setting the DUT controls

► Turn the DUT **ON**.
► Turn the DUT Volume control to **minimum**.
► Select **CD**. (Our signal path choice).
► Set DSP to **OFF**. (In our DUT, other choices were Stadium, Theater, Club, etc. These all add processing that would adversely affect measurement.)
► Set SURROUND MODE to **STEREO**. (In our DUT, this bypasses surround processing for a stereo input).
► Set BASS and TREBLE to **0**.

Setting up the analyzer control software

► Turn on your Audio Precision analyzer, and launch the AP2700 or ATS control software.
► If you have already been working in the control software, open a New Test (this step ensures that all the analyzer default settings are in place).
► Double-click the title bar of the Analog Generator panel to open the larger panel display.
► Set **Configuration** to **unbalanced**.

3: The Big Six Measurements

This section provides step-by-step instructions to make the Big Six measurements using an Audio Precision analyzer and our home theater receiver DUT.

The instructions are written assuming the use of a SYS-2722 audio analyzer. Where instructions for the ATS-2 differ, notes are added in [brackets].

LEVEL

About Level measurements

Each DUT may have a number of level measurements that are of interest. You must choose which level you are seeking. Target levels include

■ an input level that produces a given output level, such as 1 volt, or 1 watt, or unity gain (see below for a discussion of DUT gain);
■ an input level that produces a certain output distortion, such as 1% THD+N;
■ a level that provides good noise performance with comfortable headroom, often called the *operating level*;
■ an input or output level specified in a testing document.

Any of these levels may be used as a reference level on which we can base further measurements. Frequency response measurements, for example, are expressed relative to the level of a mid-band frequency; THD+N measurements are made at specified levels, which should be reported in the results.

Gain considerations for level measurements

The ratio of a DUT's output voltage level to its input voltage level is the *voltage gain* of the DUT. For example, in a DUT with a gain of 2, an applied input of 2 volts will produce an output of 4 volts. A gain of 1, where the output voltage equals the input voltage, is called *unity gain*.

Some DUTs offer no gain adjustments, and are said to have *fixed gain*. The gain may be fixed at unity, or at some other value.

Measuring level in variable gain DUTs

A DUT with a volume control or other setting that affects gain is a *variable gain* device. When setting and measuring level, it is essential to consider whether or not the DUT gain is variable (not only volume controls, but tone controls and other settings can change gain), and, if it is, how to set the DUT controls for the desired test results.

Making Level measurements

We will make level measurements using three different methods that produce results that are commonly used in audio specifications.

With a 1 Vrms applied signal, we will set the volume control to the position that produces 1 Vrms at the speaker outputs (actually, across the 8 Ω terminating load resistors). Then we will readjust the volume control to produce 1 W in the load, and then we will drive the amplifier into distortion to find the level in watts at 1% THD+N.

Hint: making very small level adjustments

Our DUT has a stepped volume control, with steps of a few decibels. Very fine adjustment is not possible. To find the precise level where the DUT clips, we use a Bar Graph control in the AP software to make small adjustments in Generator level.

Here's how: first find the highest distortion less than 1%, using the DUT volume control. Then set up a Bar Graph to control the generator level, using very small steps.

Create a bar graph by right-clicking in the Amplitude setting field. Then set the **Increment** to 1 mV in the Bar Graph Setup dialog. Slide the bar control with the mouse, or click in the bar to engage the keyboard arrow keys. Click the arrow keys to adjust the level in these small steps until you find the highest THD+N reading you can get that is less than 1%.

Initial Setup

Start with the DUT and control software setup instructions listed in Section 2.

Adjust DUT for Unity gain

► Turn the Generator outputs **ON**. With the default New Test settings, this will output a 1 kHz sine wave at a level of 1 Vrms.

► Observe the Level meters on the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], and slowly increase the DUT volume until you have a reading of about 1 V. Since our input is 1 Vrms, this volume setting produces unity gain.

Adjust DUT for 1 W

► On the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], drop down the units menu for each of the Level meters, and select the watts units.
► Observe the Level meters on the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], and slowly increase the DUT volume until you have a reading of about 1 W.

Adjust DUT for 1% THD+N

► Double-click the title bar of the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer] to enlarge the panel, drop down the Function Reading [ATS-2: Measurement Function] menu and select **THD+N Ratio**.
► Observe the Function Meter and slowly increase the DUT volume until you have a reading of about 1%. You may find that the distortion jumps suddenly from some ratio just below 1% to a very high ratio of distortion. This is caused by the onset of amplifier clipping. Find the volume that produces the highest distortion that is below 1%. For our DUT, this output level was about 97 W (about 28 Vrms in 8 Ω). This level is often called *Maximum Output Level*, or *MOL*.

CAUTION: At this level, the amplifier will be producing its greatest undistorted output. Depending upon the design of the DUT and its output rating, this condition may stress the amplifier, and may heat the amplifier heat sinks and the terminating load resis-

tors. Be sure that your load resistors are designed to safely handle the rated output of your DUT, and that they are well ventilated. Leaving the amplifier at its maximum output may damage the amplifier, the load resistors and may be a fire hazard. Generally, you should make maximum output levels tests brief, and be sure you turn the generator OFF and / or the volume control down as soon as you have your measurement.

Setting a reference testing level for subsequent measurements.

Once you have found a useful level using one of the above methods, you can set it as a reference in the 2700 or ATS-2 memory. To set the current Analyzer input levels as a references, select **Edit > Set Analyzer dBr Ref** or press **F4** in the control software. Separate references are set for analyzer input channels A and B, called *dBrA* and *dBrB*. To set the current Generator output level as a reference, select **Edit > Set Generator dBr Ref** or press **F3**.

Since the DUT gain setting affects level, you should note the DUT volume setting as a reference as well.

Frequency Response

About Frequency Response measurements

A frequency response measurement reports the output levels of a DUT when stimulated with different frequencies of known level. The simplest of all frequency response measurements consists of only two or three tones, the first near the middle of a DUT's usable frequency range, and followed by a tone near the higher extreme of the range and sometimes a tone near the lower extreme. Assuming the tones are all generated at the same level, the DUT's output levels describe its response to these different frequencies.

Full-range frequency response measurements can be made by a number of different methods, the classic being a sweep of a sine wave from the lowest frequency in the range to the highest, the results plotted on a graph. A "flat" response describes the shape of a graph where the DUT responds equally at all frequencies, producing a trace with a slope of 0 and with minimal variations.

Making a Frequency Response measurement

As mentioned above, it is possible to make a basic response measurement using only two or three tones. However, the expectation is usually a full sweep across the audio spectrum, and that's what we'll do here.

We will set up a level versus frequency sweep and view a graph as the output.

First we have to decide on a level. We could make the sweep at a very low level, but we might see noise or other spurious signals in our response. We could make it at a very high level, but there is the possibility of amplifier distortion affecting the response.

A common level for frequency response in a power amplifier is at the 1 W output level, and that's what we will use here.

Initial Setup

Start with the DUT and control software setup instructions in Section 2.

Make a Frequency Response sweep

► Open the Sweep panel.

► Set **Data 1** to **Anlr.LevelA** [ATS-2: **Analyzer.Level A**].

► Set **Source 1** to **Gen.Freq** [ATS-2: **Analog Generator. Frequency**].

► Turn the Generator **ON.** With the default New Test settings, this will output a 1 kHz sine wave at a level of 1 Vrms.

► On the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], drop down the units menu for each of the Level meters, and select the watts units.

► Observe the Level meters on the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], and slowly increase the DUT volume until you have a reading of about 1 W.

► Start the sweep by clicking the **GO** button on the Sweep panel.

► A frequency response graph will be plotted, as shown here:
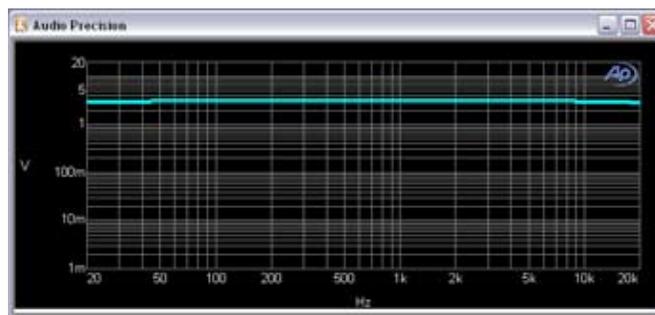
For a more useful display of the same data, you can set the Analyzer dBr input reference to your 1 W level. This will display 0 dB at the center frequency of 1 kHz, if you set the Sweep units to dBrA. You can also adjust the graph axis scales for a more useful display. Since our DUT is quite flat, we can narrow the view to just a few decibels above and below the reference.

Here is the graph with units set to dBrA and range set to ±1.5 dB:
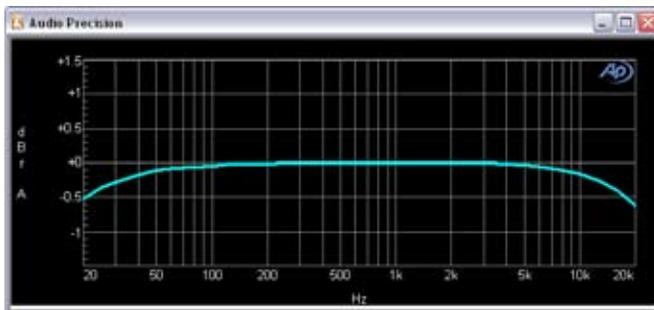
THD+N

About THD+N measurements

THD+N stands for *Total Harmonic Distortion plus Noise*.
Harmonic distortion is the unwanted addition of new tones to the audio signal. These tones are harmonically related tones to the original signal. When the signal is one sine wave of frequency f1, harmonic tones are f2, f3, etc., integral multiples of the original tone. Total harmonic distortion is the sum

of all of the harmonics measured in the DUT's bandwidth.

Why THD+N? Why not just measure THD (the distortion) and N (the noise) individually?

Well, at first glance it makes sense. However, in the pre-FFT days of audio measurement it was difficult to measure the THD by itself, without the noise, but it was relatively simple to measure the THD and the N together. So the accepted techniques handed down from years past specify THD+N, because that's what was practical. In addition, THD+N is a convenient and telling single-number mark of performance, widely understood and accepted.

Bandwidth and THD+N

The measured THD+N of a device will vary with the measurement bandwidth. You will almost always want to restrict the measurement bandwidth using high-pass and low-pass filters, and you must include the bandwidth used when you state the result. THD+N is typically measured and reported in a 20 Hz–20 kHz bandwidth.

Level and THD+N

The measured THD+N of a device will also vary with level and the frequency of the applied signal. Audio THD+N is typically measured and reported at a mid-range frequency (1 kHz or so) at the either the device's nominal operating level or at its maximum output level (MOL).

Making a THD+N measurement

We've already done this in **Adjust DUT for 1% THD+N** in the **Level** topic above, but we'll go through the procedure again here.

Initial Setup

Start with the DUT and control software setup instructions in Section 2. We have decided to make this THD+N measurement at the 1 W output level. The frequency setting for THD+N is typically 1 kHz, which is what we will use.
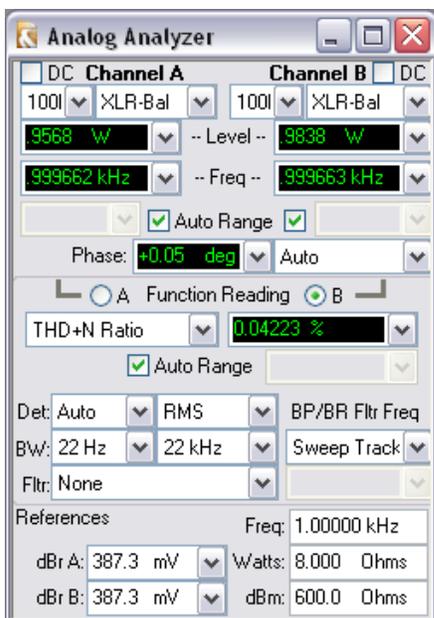
► Turn the Generator outputs **ON**. With the default New Test settings, this will output a 1 kHz sine wave at a level of 1 Vrms.

► On the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], drop down the units menu for each of the Level meters, and select the watts units.

► Observe the Level meters on the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], and slowly increase the DUT volume until you have a reading of about 1 W.

► On the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], drop down the Function Reading [ATS-2: Measurement Function] menu and select **THD+N Ratio**.

► In the two BW filter fields, set the high pass and low pass filter selections to define the measurement bandwidth. THD+N measurements should be made in a limited, defined bandwidth, typically about 20 Hz to 20 kHz. This measurement bandwidth must be stated with the distortion result. We will use the built-in Audio Precision filters at 22 Hz and 22 kHz. [ATS-2: 22 Hz and 20 kHz LP.]

► Observe the THD+N Ratio reading on the Function meter. Our DUT reads 0.04223%.

Other THD+N techniques

The method just described provides a quick, single-number result for THD+N, and is often the method of choice. However, other techniques can provide much more information about a device's distortion performance. A THD+N versus frequency sweep or a THD+N versus amplitude sweeps will show how a DUT performs under varying stimulus. Fre-

quency-domain FFTs or a dedicated Harmonic Distortion Analyzer (as found in AP2700 and ATS) can reveal details of the individual distortion products.

Phase

About Phase measurements

In audio engineering, phase measurements are used to describe the positive or negative time offset in a cycle of a periodic waveform (such as a sine wave), measured from a reference waveform. The reference is usually the same signal at a different point in the system, or a related signal in a different channel in the system. This choice of references defines the two most common phase measurements: device input/output phase, and interchannel phase.

Phase shift varies with frequency, and it is not uncommon to make phase measurements at several frequencies or to plot the phase response of a frequency sweep. Phase is expressed in degrees.

Making an Interchannel Phase measurement

Once again, we have to decide on a level. Phase measurements are not particularly level-sensitive, as long as we are above the noise and below distortion. We will make our test at 1 Vrms, with the DUT set for unity gain. These steps assume a DUT like our home theater receiver.

Initial Setup

Start with the DUT and control software setup instructions in Section 2.

Adjust DUT for Unity gain

► Turn the Generator outputs **ON**. With the default New Test settings, this will output a 1 kHz sine wave at a level of 1 Vrms.

► Observe the Level meters on the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], and slowly increase the DUT volume until you have a reading of about 1 V. Since our input is 1 Vrms, this volume setting produces unity gain.

► Observe the Phase meter on the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer]. At our default 1 kHz setting we read +0.05 degrees.

Making an Input/Output Phase measurement

The other common phase measurement compares the phase of the signal at the input of the DUT to the phase of the same signal at its output. A simple way to make this measurement for the Left channel in our DUT is to select GenMon as the Channel A analyzer input and then connect the left channel DUT output to the Channel B analyzer input.
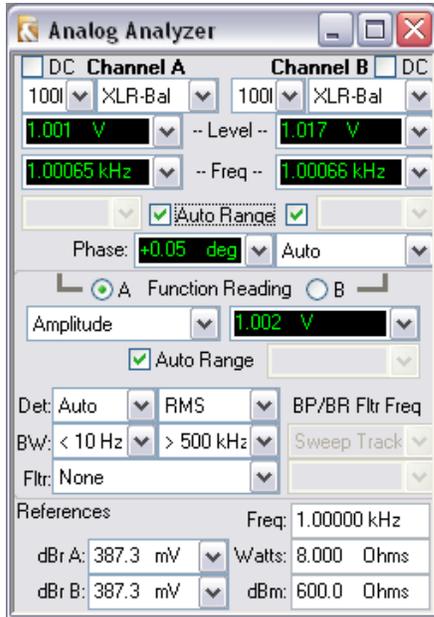
Phase between channels often varies with frequency. Experiment by changing the Generator frequency to 100 Hz, and then to 10 kHz. The results varied slightly in our DUT: +0.02 degrees at 100 Hz, and +0.51 degrees at 10 kHz. To view a complete phase response, a sweep measurement plotting interchannel phase versus frequency is often made.

► Reconnect the connector cable for the Left channel and set Channel A to **GenMon** on the Analyzer panel. [ATS-2:
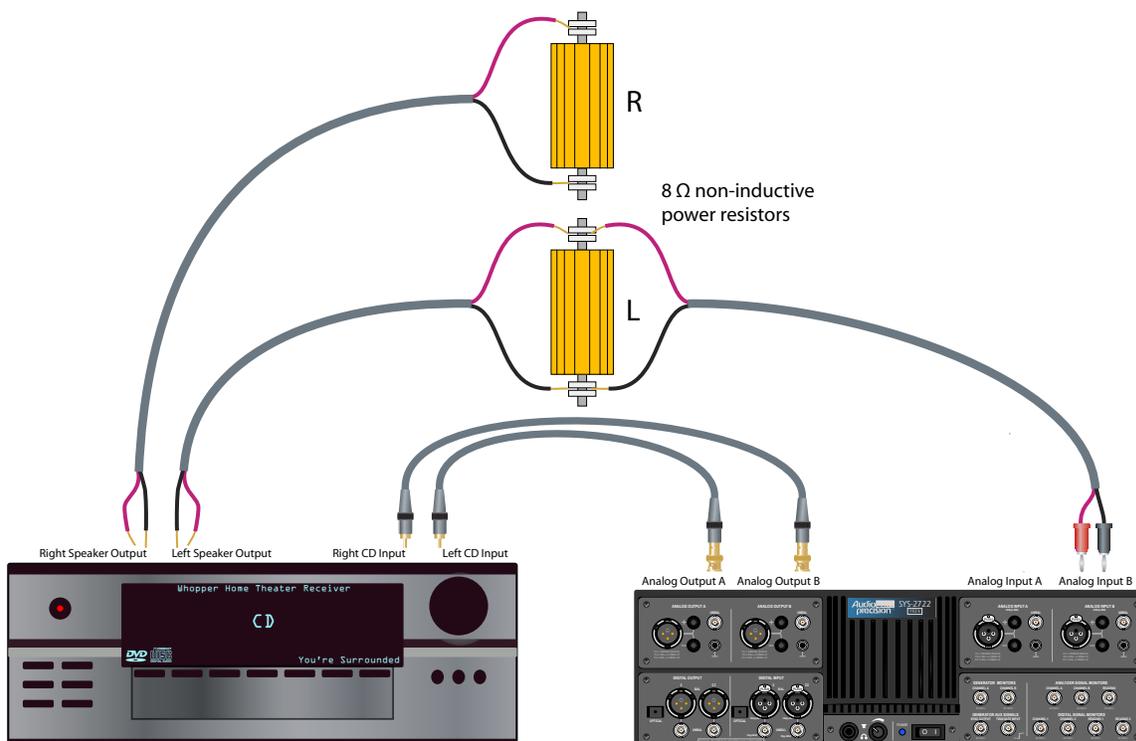
Analog Input panel.] See the illustration on the facing page for the cable reconnection.

Notice that we now show a phase difference of +179.17 degrees at 1 kHz. Results at 100 Hz and 10 kHz are similar (+187.50 and +163.73 degrees, respectively). This indicates that the output of our DUT is out of polarity with its input (180 degrees out-of-phase at all frequencies) with some additional phase shift at the frequency extremes.

> NOTE: Be sure to re-connect the cables for further testing.

Crosstalk

About Crosstalk measurements

In audio systems of more than one channel, it is undesirable for the signal in one channel to appear at a reduced level in the output of another channel. This signal leakage across channels is called *crosstalk*, and in practical devices it is very difficult to eliminate. Crosstalk is expressed as the ratio of the undesired signal in the unstimulated channel to the signal in the stimulated channel. Crosstalk is largely the result of capacitive coupling between channel conductors in the device, and usually exhibits a rising characteristic with frequency.

Making a Crosstalk measurement

Initial Setup

Start with the DUT and control software setup instructions in Section 2.

Crosstalk A into B

► Set the Analog Generator amplitude and the DUT volume for the reference level you would like for your crosstalk measurement. Unity gain, 1 Vrms output or 1 watt are typical choices.

► On the Analog Generator panel, Set the frequency to **10 kHz**.

► On the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], drop down the Function Reading [ATS-2: Measurement Function] menu and select **Crosstalk**.

► Turn on the generator, but only on channel B. Read the crosstalk in the Channel A Function reading meter. Our DUT reads −50.959 dB.
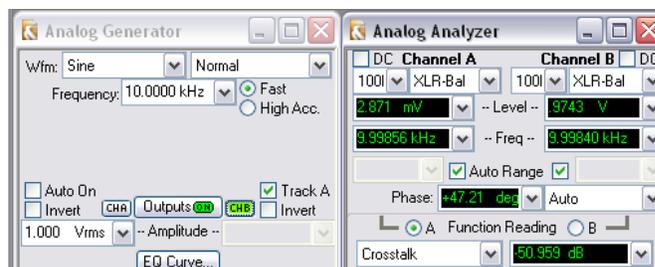
Crosstalk B into A

► Turn on the generator, but only on channel A. Read the crosstalk in the Channel B Function reading meter. Our DUT reads −50.661 dB.

> NOTE: If you are testing a power amplifier using terminating resistors, be aware that your resistor connections could add capacitive coupling between the channels, increasing the measured crosstalk.

Other Crosstalk techniques.

The method just described provides a quick, single-number result for crosstalk, and is often the method of choice. However, a crosstalk versus frequency sweep will show how a DUT performs across its operating bandwidth.

Signal-to-Noise Ratio

About SNR measurements

How much noise is too much? That all depends on how loud your signal is.

Signal-to-noise ratio (or SNR) is a measure of this difference, providing (like THD+N) a one-number mark of device performance. The signal is usually set to the nominal operating level or to the maximum operating level of the DUT. When SNR is made using the MOL, the result can also be called the *dynamic range*, since it describes the two extremes of level possible in the DUT. (Dynamic range in digital devices has a somewhat different meaning). SNR is usually stated in decibels, often shown as negative.

Using traditional methods, SNR requires two measurements and a bit of arithmetic. First you measure the signal level, then turn off the generator (and often, terminate the DUT inputs in a low impedance as well, to fully reduce the noise in the device). Then the noise level (often called the noise floor) is measured, using filters to restrict the measurement bandwidth. The ratio between the two is the SNR.

Making SNR measurements

Since SNR is the relationship between two measurements, first we measure the value at a specified signal level. For convenience we will store the value as analyzer input dBrA and dBrB references.

Then we measure the noise in the channel, using the dBr references as the units reference. This result is the SNR.

Initial Setup

Start with the DUT and control software setup instructions in Section 2.

Measuring and calculating SNR

► Set the Analog Generator amplitude and the DUT volume for the reference level you would like for your SNR measurement. We are setting our test up for MOL.

► On the Analog Analyzer [ATS-2: Analyzer: Audio Analyzer], drop down the Function Reading [ATS-2: Measurement Function] menu and select **Amplitude**.

► In the two BW filter fields, set the high pass and low pass filter selections to define the measurement bandwidth. SNR measurements should be made in a limited, defined bandwidth, typically about 20 Hz to 20 kHz. This measurement bandwidth must be stated with the distortion result. We will use the built-in Audio Precision filters at 22 Hz and 22 kHz. [ATS-2: 22 Hz and 20 kHz LP.] For noise measurements, *weighting* filters are often used instead of bandwidth-limiting filters.

► Turn the generator **ON** and adjust the DUT volume for the desired level, in our case the MOL level we established

in the Level measurement.

► Set the analyzer dBr (**F4**) to capture this reference.

► Turn the Generator **OFF**. In the function meter for Channel A, set the units to dBrA and read the SNR. Our DUT reads –92.651 dB.

► In the function meter for Channel B, set the units to dBrB and read the SNR for that channel. Our DUT reads –92.707 dB

Ensuring low noise measurements

Getting the best noise measurement depends upon connections and the electromagnetic environment. For best results you should use

■ high quality shielded cables and test jigs
■ keep your analyzer, your DUT and measurement cables away from magnetic and electrical fields
■ be sure that the mains power to your analyzer and your DUT is clean of interfering signals
■ connect a large gauge ground strap between your analyzer and your DUT.

In conclusion

We've looked at easy ways to make six basic audio measurements on a home theater receiver using Audio Precision analyzers. We worked in the analog domain, and confined our testing to two channels using meter readings and a simple sweep.

The methods practiced here can be transferred to other types of audio devices and digital domain and cross-domain testing. While these basic approaches will often be all that is required, understanding their principals will provide an excellent framework for working with faster and more informative techniques such as FFT analysis, multitone testing and the continuous sweep (log chirp) method used in the APx Series of analyzers.

NOTES

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