Audio Measurements with a Network Analyser

Peter D. Hiscocks, James Gaston
Syscomp Electronic Design Limited
`phiscock@ee.ryerson.ca`
`www.syscompdesign.com`
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1   Frequency Response

Much work in the audio field requires knowing the *frequency response* of some device, that is, its response to various frequencies.

For example, measuring the frequency response of an audio amplifier can be done with a signal generator and an AC voltmeter. Apply an AC signal at some frequency of interest to the input and measure the the magnitude of the input and output signals. The ratio of output voltage to input voltage gives the gain of amplifier at that frequency. To obtain the frequency response, repeat this measurement at various frequencies and plot the result. If the gain is equal at all the test frequencies, we say that the frequency response is *flat* over that frequency range.

Measuring frequency response by hand is tedious and error-prone. In some cases such as loudspeakers, the frequency response is too complicated to measure by hand. This is a measurement that should be done automatically.
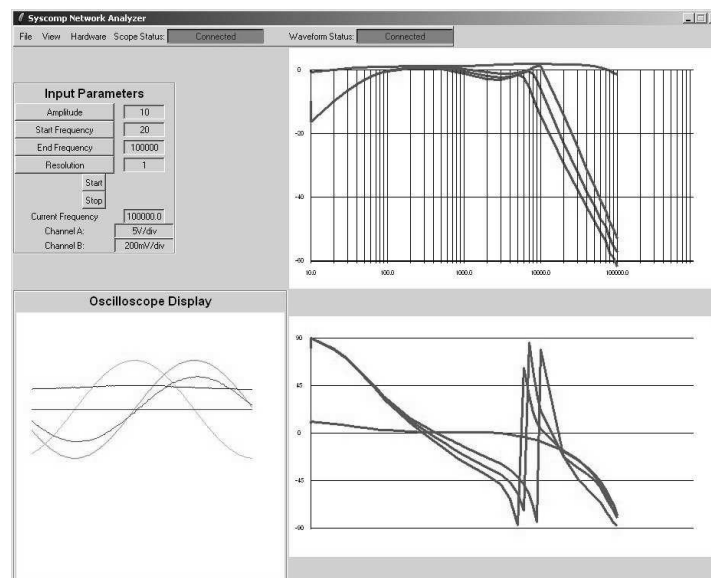

Figure 1: User interface of the Network Analyser.

2 Syscomp Network Analyser

Back in the 80's, the Department of Electrical Engineering at Ryerson University put together a system of instruments to measure frequency response. The equipment included several units of HP equipment in a 19 inch rack. An HP audio sweep generator drove the DUT (device under test). Attenuators adjusted the signals in db steps. A logarithmic converter generated a DC signal proportional to the output of the DUT. An X-Y pen plotter generated hard copy of the frequency response. The total cost must have been over $10k.

This equipment, for all its expense, was not portable[1], required that the input signal to the DUT be constant amplitude, and did not show phase response.

Fast forward to 2006. Two small instruments – the Syscomp WGM-101 waveform generator and DSO-101 oscilloscope – plus software running on a laptop computer, can generate the same measurements at a fraction of the cost of the original system. As a bonus, this system also measures phase response.
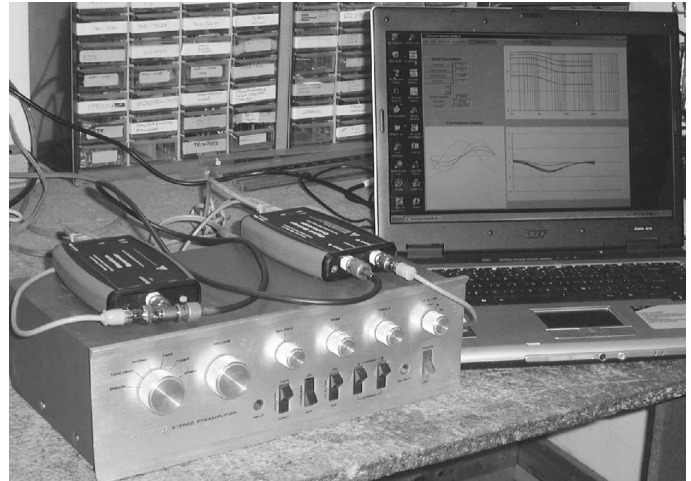

Figure 2: Network Analyser Setup. The waveform generator is on the left, the oscilloscope on the right, and the PAT-4 preamp at the bottom. The laptop shows amplitude and phase response curves.

2.1 Control Panel

The user interface of this network analyser is shown in figure 1 on page 1. Clockwise from the top left corner, the functions are:

- Controls for sweep frequency range and amplitude, along with status indicators.

- Amplitude plot, vertical db vs log frequency.

- Phase plot, vertical degrees vs log frequency

- Oscilloscope screen, for checking the integrity of the test waveform (to make sure it's not clipped, for example).

Another window – used primarily for debugging – shows messages that detail the progress of the sweep.

Figure 2 shows the equipment setup. In this case, the device under test is an ancient Dynaco PAT-4 preamplifier. The Syscomp WGM-101 waveform generator and DSO-101 Oscilloscope rest on the top of the preamplifier. The host laptop computer is off to the right.

2.2 Internals

The oscilloscope has a 7-step preamplifier in the usual 1:2:5 sequence. As the sweep proceeds the software adjusts the gain of the scope preamp for the largest possible signal without clipping.

The waveform detection is performed by correlating the signal against inphase and quadrature reference waveforms. As a consequence of the correlation process, the system is very noise immune and has a dynamic range in the order of 60db.

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[1]Although I did once borrow the rack for a measurement, which required the help of several strong students and a panel truck.

3 Preamplifier Frequency Response

3.1 Filters

The PAT-4 includes several switcheable filters, primarily for noise reduction in old LP records. Their frequency responses are shown in figure 3.
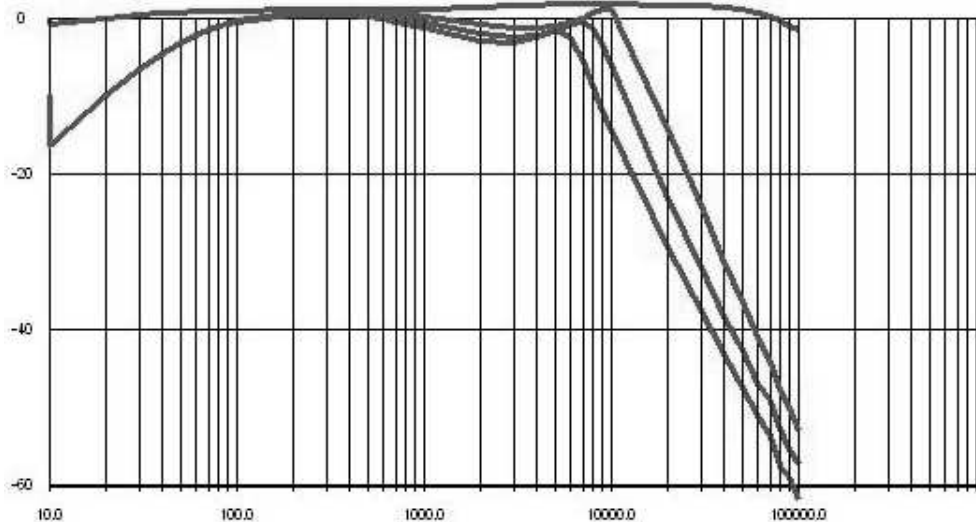

Figure 3: Low-Frequency and High-Frequency Filters

- The top trace is the response with all filters disabled and the tone controls centred. Notice that the response extends out to 100kHz.

- The low-frequency filter begins to decrease response below 1kHz.

- The three high-frequency filter settings: 7kHz, 10kHz and 15kHz, all show a certain degree of peaking in their cutoff region.

- The region 100Hz to 1kHz is unaffected by the filters.

3.2 Loudness

The PAT-4 includes a *loudness* switch. The sensitivity of human hearing at low frequencies decreases as sound level decreases. The loudness switch enables an amplitude-dependent low-frequency boost circuit[2]. The effect on frequency response is seen in figure 4.

Notice that the upper trace, corresponding to a higher volume control setting, is almost flat. At lower volumes, low frequencies are boosted relative to mid frequencies.

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[2]The effectiveness of the *loudness* control is questionable, since the amount of boost must depend on sound level and the sound level in the listening room is not known. An alternative approach is a *contour* control which shapes the low frequency response according to an operator setting. Then the listener can select the most pleasing setting.
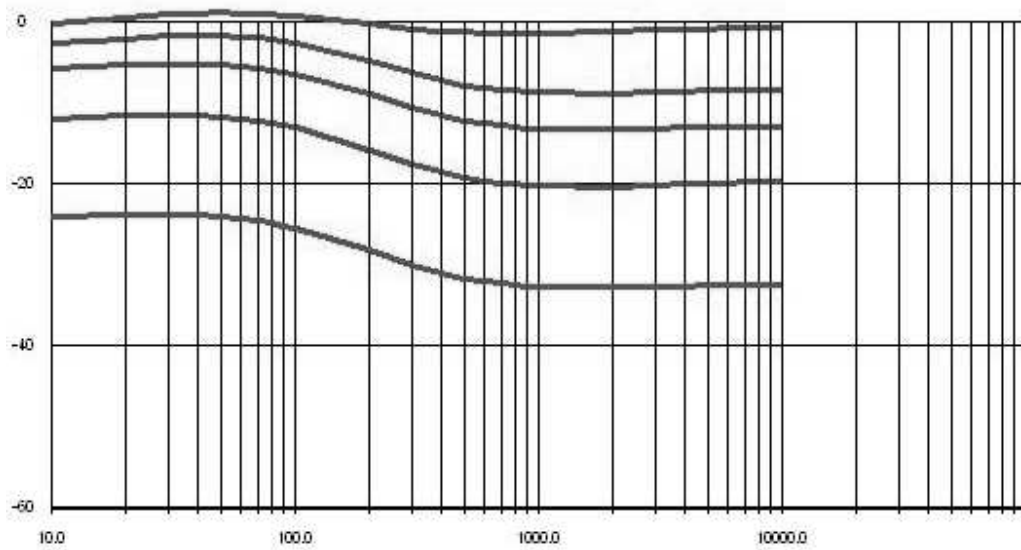
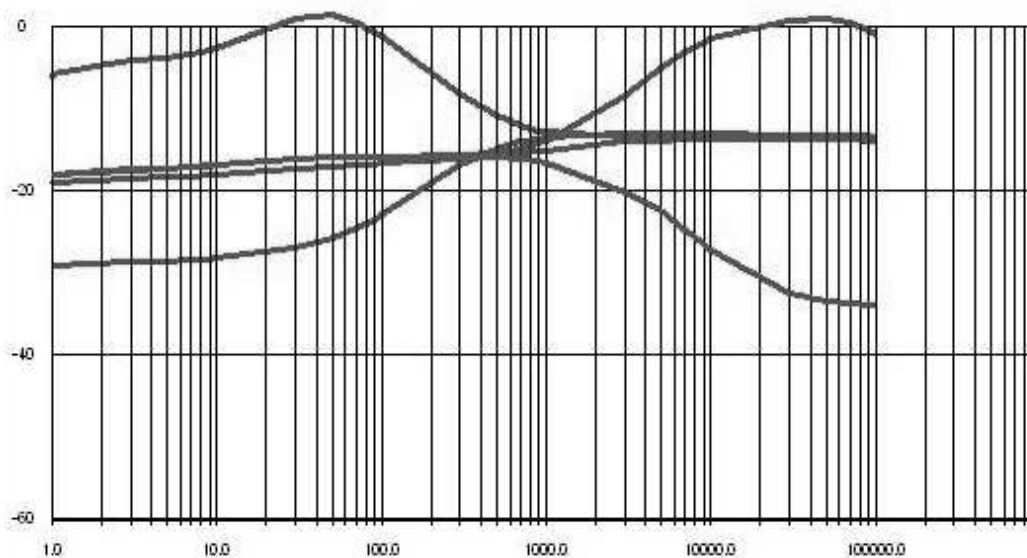Figure 4: Loudness

3.3 Tone Controls

Figure 5: Tone Controls

The PAT-4 has bass and treble tone controls, which may be set to *boost* or *cut* their respective frequencies. The effect of the these controls is shown in figure 5.

The oscilloscope display showed that the output waveform of the preamplifier was clipping with either control in the boost position. The preamplifier volume control was reduced to avoid clipping.

- The bass control boost and cut are not symmetrical: the available boost is greater than the available cut.

- The treble control continues to function well past the upper limit of audio frequencies (20kHz).

- In the *flat* position (tone controls centred), the frequency response actually rises a few db at high frequencies.

4 Loudspeaker Impedance

The impedance of a moving-coil loudspeaker driver is not constant. The moving cone and suspension form a massspring system which resonates at a particular frequency. The electrical impedance of the loudspeaker then appears as a parallelresonant circuit - the magnitude rises to a peak value and the phase swings abruptly from leading to lagging. At the resonant frequency, the phase of the impedance is zero, and this provides a precise method of identifying the exact frequency of resonance.

The resonant frequency of a driver unit must be known to design a suitable enclosure for the driver. For example, a *bassreflex* design requires that the resonant frequency of the port match the resonant frequency of the bass driver.

As well, in many speaker designs, the output sound pressure level of the speaker drops precipitously below the driver resonant frequency, so resonant frequency is an indicator of the low-frequency range of the driver.

Figure 6 shows the results of a measurement of loudspeaker impedance for a small bookshelf speaker (Realistic Minimus-7).

The output of the generator drives the loudspeaker via a 1k5Ω resistor. The resistor is much larger than the speaker impedance so the speaker current is approximately constant. The generator output feeds the network analyser reference channel and the loudspeaker voltage feeds the network analyser signal channel. As the frequency is swept, the varying speaker impedance creates a varying voltage which increases and decreases with speaker impedance.
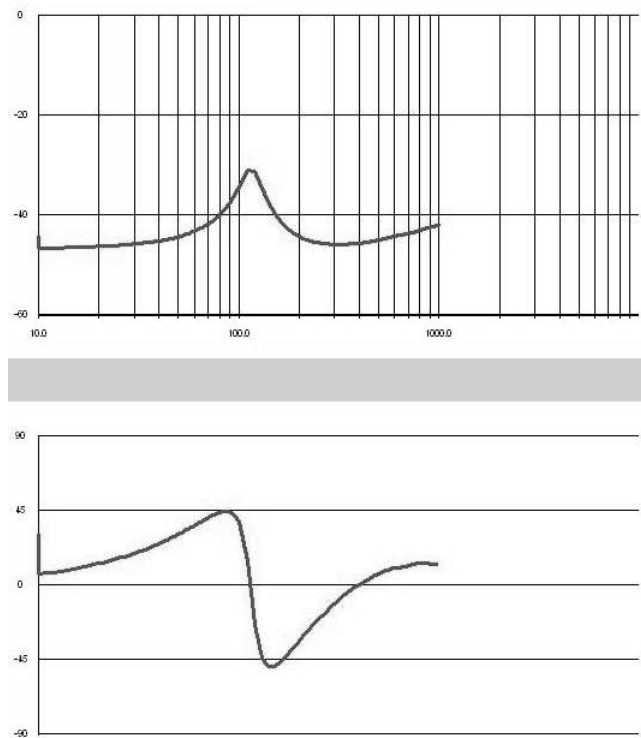

Figure 6: Loudspeaker Impedance

5   Note on the Diagrams

For the purpose of these measurements, the network analyser software was run under the Windows XP operating system. (It will run equally well under Linux or Macintosh operating systems).

Each screen image was captured using `<alt><PrtScr>` (press the `alt` and `PrtScr` (or `Print Screen`) buttons simultaneously). This captures the active window to a clipboard.

The clipboard was then pasted (using the `Edit->Paste` command) into Microsoft *Paint* (`Program->Accessories->Paint`). From the paint program, it was saved to a jpeg file and moved via usbkey to a Linux system.

In the Linux system, the image was cropped using the image manipulation program `xv` and then saved as a postscript file.

The postscript file was incorporated into the LATEXsource code using the `\includegraphics` command.

Capturing screenshots is a bit more straightforward under Linux, the `xv` program can capture an area of the screen directly.

6   Resources

The internals of the network analyser are explained in the paper *A Software-Based Network Analyzer*, Peter Hiscocks and James Gaston, June 2006 which is available from the Syscomp web site at `http:\\www.syscompdesign.com`.

A similar article, *A Network Analyser Using Programmable Instruments*, was published in the September 2006 issue of Circuit Cellar magazine.

Source code for the oscilloscope, waveform generator and network analyser is Open Software available under the GPL from Sourceforge at the Open Instrumentation Project, `http://sourceforge.net/projects/oip`.

Information on the oscilloscope and waveform generator hardware is available at `http://www.syscompdesign.com`.