<u>**First Results from the HP 3562A Dynamic Signal Analyzer with Data Acquisition**</u>

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Abstract:

The arrival of the Hewlett Packard HP3562A Dynamic Signal Analyzer was a fine day for the physics of music laboratory. Some work has been done with this instrument (Moon 2002) but has been crippled by a lack of a method of displaying the data on the computer until now. A LabView program has been written that downloads the active plot from the instrument for storage and display, which allows the full potential of the instrument to be used in conjunction with the computer. A few of the possible experiments are discussed in this report as part of the program testing. The frequency response of a Gibson GA-8 amp was compared to a Peavey practice amp, the harmonic spectrum of the French horn was measured, and the vibrational resonances of a Strat-copy SAGA guitar were also measured.
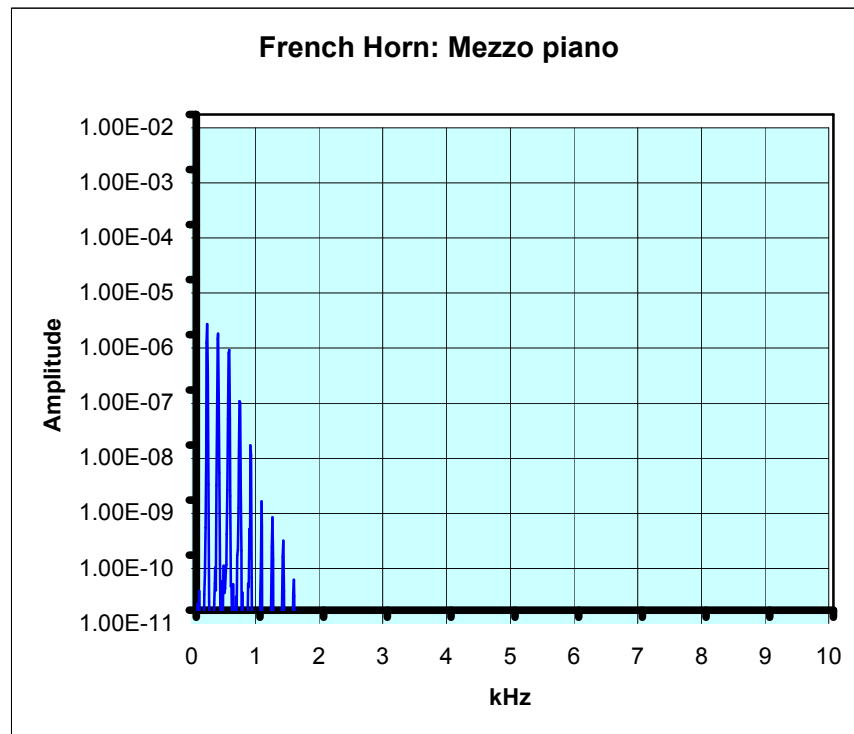
Introduction:

The Hewlett Packard 3562A Dynamic Signal Analyzer is an instrument that views the frequency components of an incoming signal to incredible accuracy. It analyzes the signal with a fast Fourier transform (FFT), which is an algorithm that determines the frequencies present in a signal and the magnitudes of those frequencies. This is the fundamental algorithm of all the different measurements that can be done with the instrument.

The brunt of the work of this project lies in the creation of a LabView program to download the data from the 3562A. The details of data acquisition (DAQ) are described in the appendices, as well as the structure of the program for future use. It should also be

noted that the program or VI for virtual instrument will be submitted to the National
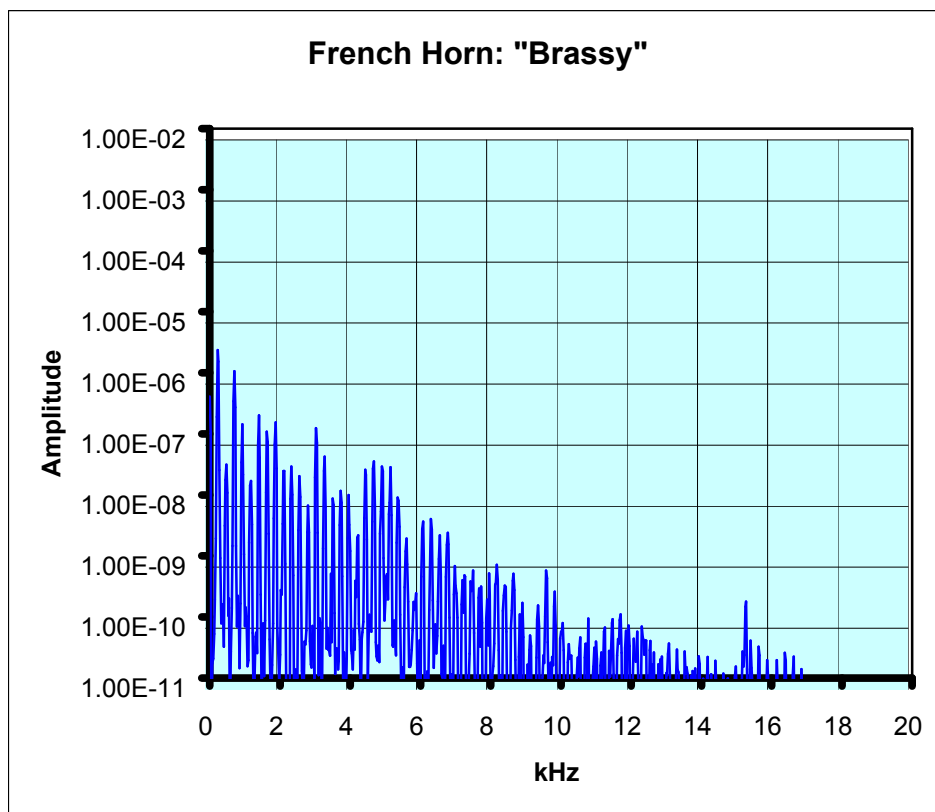
Instruments Database.

Basic Harmonics:

Few of the 3562A's that were made are now employed in analysis of musical

instruments, however its sensitivity that was meant for electronic analysis can easily

cross over into the audio spectrum with a microphone (or piezo electric transducer, as

discussed later). A particular musical instrument sounds the way it does because of the

harmonic content of the sounds it creates, and the variety of sounds that can be generated

from a single instrument are directly related to the harmonic content of the different

generated sounds. A Conn 8-D French horn was used with a Peavey Microphone to test

the DAQ program and demonstrate this effect.

French Horn: Mezzo piano

The graph above is the harmonic content of a middle C being played at mezzo

piano, which is a moderate volume for the French horn. The scale ranges from 0 to

10kHz. For reference, 10kHz is about halfway between the extremes of human hearing, which can detect sounds as low as 20Hz and as high as 20kHz. The amplitude is Volts squared, and displayed with a logarithmic scale. Keep in mind that for many audio applications it is only useful to compare amplitudes within the same measurement. It is apparent that there are many distinct frequency components accompanying the fundamental note.
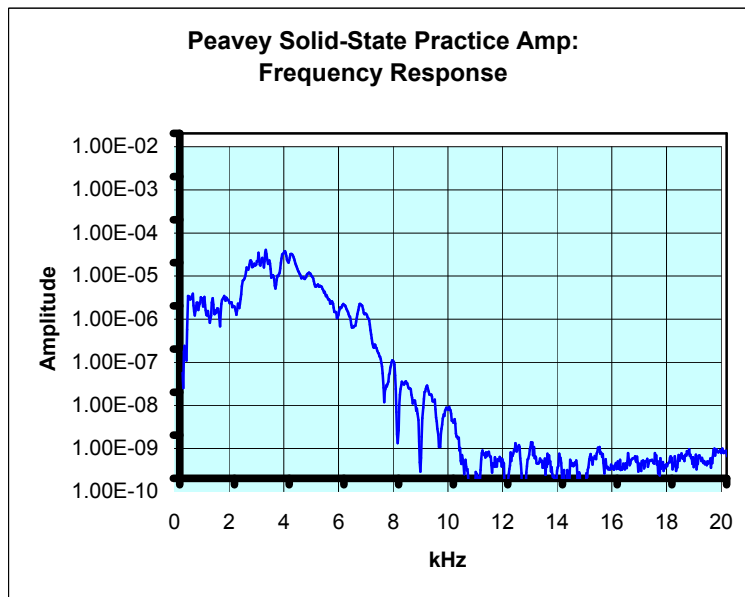
By increasing the volume and lip placement on the horn a "brassy" sound can be created that is often heard in exciting fanfares or glissandos. The following is the harmonic spectrum of "brassy" sound with a range of 0-20kHz.

French Horn: "Brassy"

Notice that the harmonics extend three-fourths of the way up the audio spectrum! For a French horn player, it is rather interesting to think that, theoretically, three-fourths of the audio spectrum at your command!
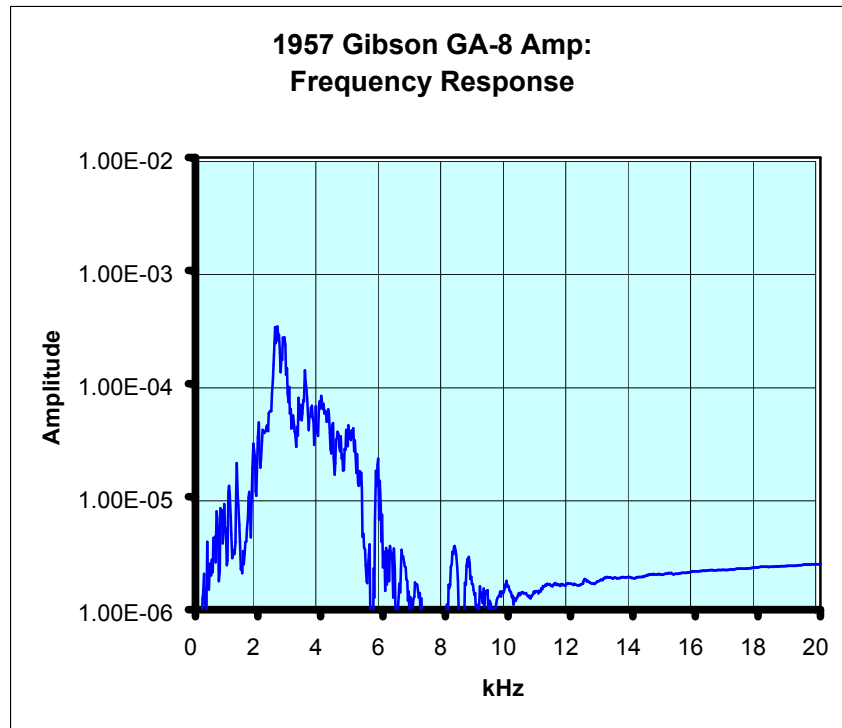
Frequency Response Measurements:

With electronic instruments such as the electric guitar the same sort of harmonic analysis can be done, and in the case of amplifiers, it is possible to send a well-defined input signal in and measure the output with a microphone. Although the French horn itself amplifies the buzzing of the lips, it is not possible to scientifically "disentangle" the lips so easily to analyze the horn alone. The HP 3562A can be set up to generate an output signal that sweeps through the audio spectrum, and simultaneously measure the intensity from the microphone as the sweep is made. This creates a frequency response plot that characterizes the amplifier. Given the harmonic spectrum of a signal from a guitar or other instrument, the frequency response plot can be used to determine the relative strengths of the harmonics after being amplified.

Peavey Solid-State Practice Amp:
Frequency Response

Although the volume of the amplifier, a solid-state Peavey practice amp, was not at its maximum during this test, it appears that for all practical purposes that frequencies above 10kHz do not get amplified enough to be audible since the graph returns to the

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noise level at that frequency. For comparison, the same test was done with a 1957 Gibson
GA-8 tube amplifier.

1957 Gibson GA-8 Amp: Frequency Response

From this graph it could be inferred that the superior tone or fidelity of the Gibson
amp from may be attributed to the peak at 2.5 kHz, and the system's flat response from 3-
5 kHz. Flat spectrum above 10kHz is an artifact of the noise of the system, and again, is a
consequence of the amp not being at a sufficient volume to amplify the high frequency
sounds to audible levels.

Observations of Mechanical Resonances:

One of the first scientific uses of the signal analyzer was in the calculation of
mechanical resonances of an electric guitar. These resonances are simply the frequencies
that the guitar structure itself experiences maximum vibrations. An analogy would be
standing by the viewing window of the Gateway Arch. If you stand still on a windy day,
you should be able to feel the structure sway back and forth. The frequency that the

structure sways at maximum amplitude can be called a resonant frequency. The sort of analysis possible with the 3652A can discover many different frequencies of resonance with great sensitivity.
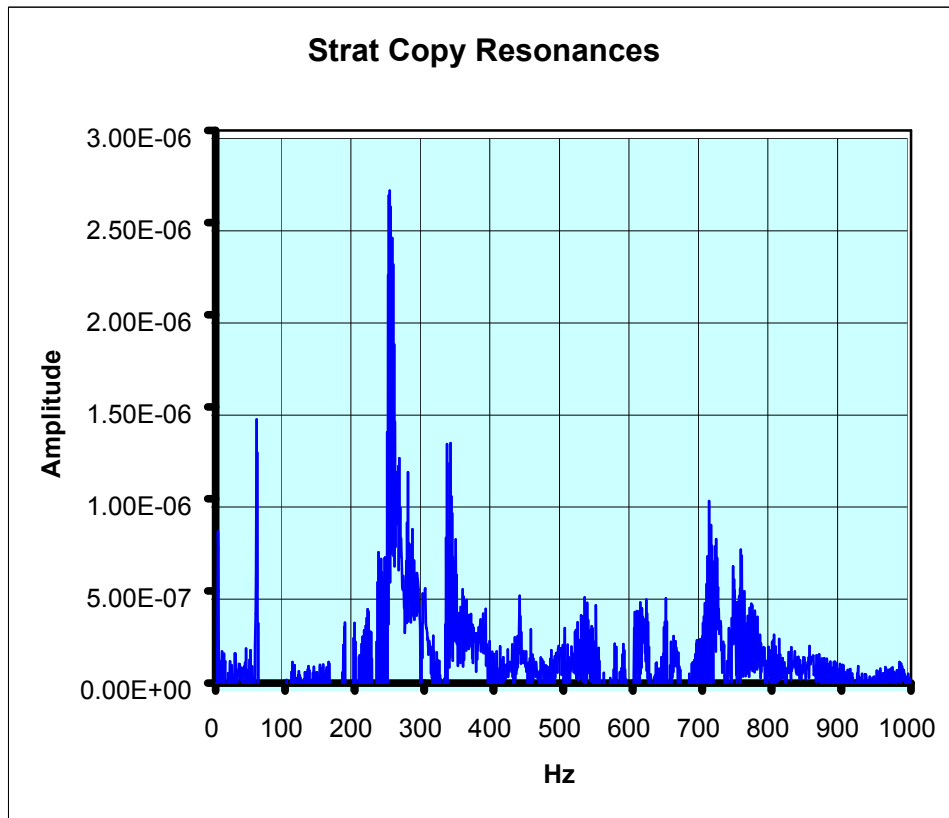

To demonstrate this principle with the DAQ system a "Strat copy" electric guitar from SAGA music kits was used with piezoelectric transducers to determine resonances in a similar way that the summer 2002 REU students performed their analysis of a Mako electric guitar. One piezoelectric transducer serves as a source of vibration, while the other transducer detects the vibrations. The cross correlation spectrum between the two transducers indicates the resonant frequencies. Since these vibrations may create nodes and anti-nodes on the guitar, for precision, it is necessary to place the detecting transducer at a variety of points. In musical operation the energy from strumming is dissipated from the strings into the body of the guitar, so the source transducer is always

placed near the saddle of the guitar where the strings connect to the body to simulate this effect. Much more information about this measurement can be accessed via the web at
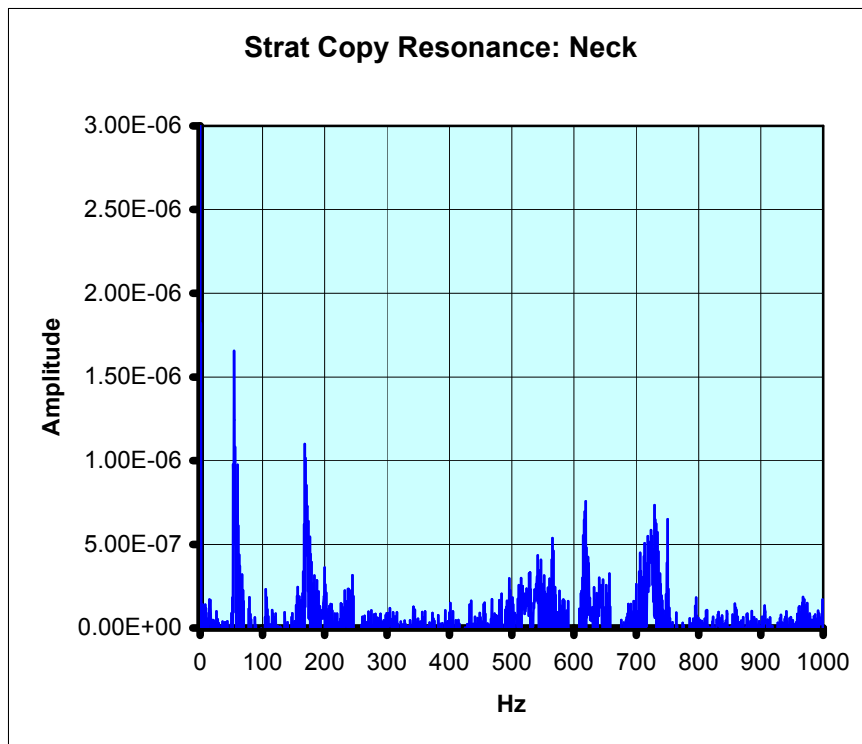
http://wug.physics.uiuc.edu/courses/phys398emi/398emi_reu.html

The following plot is the average of many points on the body of the guitar. It is easily seen that the resonances appear at 250, 333, and 710Hz. The spike at 60Hz is likely from the power supply for the transducers.

The points where the detecting transducer was placed are indicated by the red dots.

The same test was also performed with the detecting transducer placed on the neck. The cross spectrum has resonances of 168, 619, and 729Hz, which roughly confirms the 710Hz resonance discovered from the body, and again, reject the 60 Hz signal. It is no surprise that the neck pickup detected 168Hz, since the length between the two transducers has increased the vibrational mode of the neck is expected to be lower frequency than that of the body.

Conclusion:

The ability to download the data taken by the HP3562A Dynamic Signal Analyzer to a computer has opened up the door to a variety of measurements that can now painlessly be done and recorded with a computer. The program simply receives the data of the active plot on the signal analyzer and allows the user to save it to disk, plot it in a spreadsheet etc. The versatility of this method has been demonstrated with harmonic analysis, frequency response measurements, and the discovery of resonances with the generation of a cross spectrum. The physics of music lab, led by Professor Steve Errede will no doubt benefit greatly with the addition of this powerful tool.

References:

Moon, Eric. "Vibrational Analysis of Guitar Bodies."
http://wug.physics.uiuc.edu/courses/phys398emi/NSF_REU_Reports/2002_reu/Eric_Moon_REU_Report.pdf. August, 2002.

Kempton, Adam. "Modal Analysis of Guitar Bodies."
http://wug.physics.uiuc.edu/courses/phys398emi/NSF_REU_Reports/2002_reu/Adam_Kempton_REU_Report.pdf August, 2002.

Appendix A: Taking Measurements, and Program Operation with the 3562A

Introduction:

The following descriptions of experimental sequences used to take data are similar to ones mentioned in the operator's manual for the spectrum analyzer, a concise and straightforward guide with many pictures to illustrate the end result of operation. It contains a far more varied range of experiments, including analysis in the time domain, which is yet to be utilized by the music lab, although Ryan Lee, a 2002 P398 student, performed analysis on the harmonic decay of different guitar strings in an anechoic chamber using a Bruel and Kjaer microphone and Matlab analysis.

If you have trouble getting the measurement setup on the signal analyzer, you can press the "Help" button and then the button in question at any point in the sequence. All of the different measurements are accessed through the "MEASUREMENT MODE" button. The second most helpful button is the "STATE/TRACE" button, which shows the current settings for the measurement. Third most helpful is obviously the yellow "START" button for obvious reasons. After each data dump is made, you must push the gray "LOCAL" button in the HP-IB section of the instrument. The buttons to the right of the display are referred to as "softkeys" both here and in the manuals.

Harmonic Analysis:

This is the simplest measurement to make with the instrument, mainly because it boots up to a real time harmonic analysis screen after doing automatic calibration. Recording and averaging the data is a process of determining the frequency range, and timing.

Press the brown "MEASUREMENT MODE" button in the "MEASUREMENT" section of the 3562A and choose "LINEAR RES" in the top right of the graph with the button next to the text in the display. These buttons are called "soft keys". Press the brown "STATE/TRACE" button, which displays the default settings for the measurement.
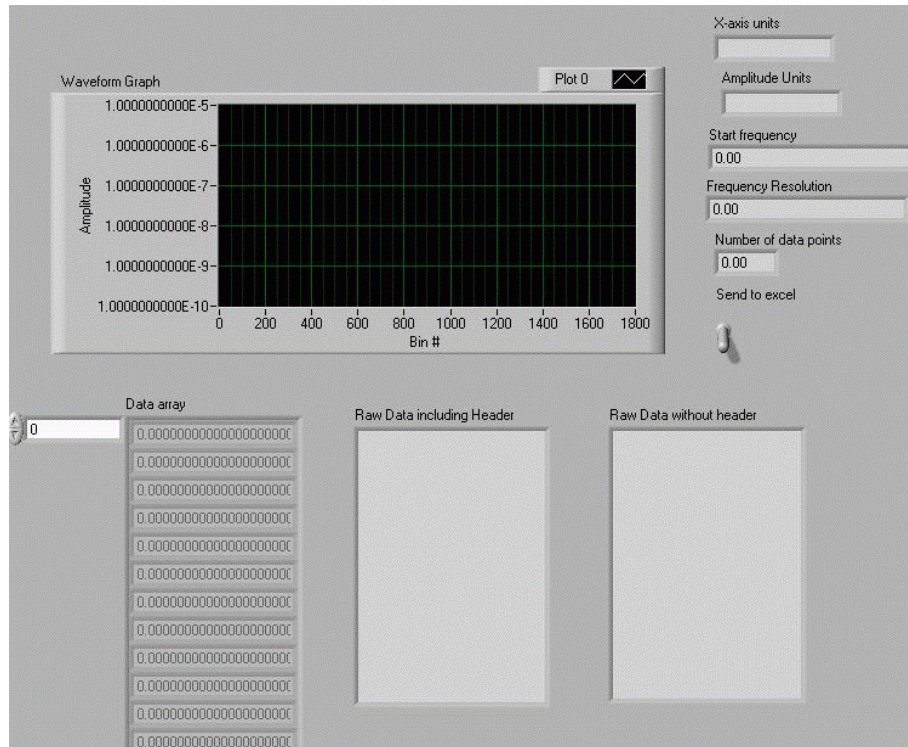
If you are using a microphone, connect it to channel 1 now and press the "INPUT COUPLE" button in the "MEASUREMENT" section. Hit the top softkey to select "CH 1 AC" so the machine knows that you're using a microphone-like device.

Determine the frequency range by pressing "FREQ" in the measurement section and press the "FREQ SPAN" softkey. For the audio range 0-20kHz is usually a good setting, so type "20" on the white keypad and press the "kHz" softkey.

Set the number of averages by pressing the "AVG" key in the measurement section, and press the "STABLE (MEAN)" softkey. Press the "NUMBER AVGS" softkey and set it to around 5 for a short measurement. The total time is determined by multiplying the number of averages by the time indicated by "REC LGTH" on the frequency section of the state/trace screen. (To set the machine back to its real-time harmonic analysis, simply turn off averaging and press start.)

Now press the yellow "START" button in the "CONTROL" section, and sing into the microphone. The harmonic spectrum should be recorded and displayed. Now you are ready do dump the data to the LabView program.

Open the HP3562A.vi program located on the desktop. The front panel of the program should appear like the following picture.

Click on the pull down menu labeled "Operate" at the top of the screen. Click run, and the data is sent to the computer. Click on the text tool, and copy and paste all the numbers under "Raw data without header" by highlighting it, pressing control+C and then pressing control+V in excel or another spreadsheet program. Useful information from the data dump is displayed to the right of the graph in LabWindows. It gives the units of the two axes, start frequency, resolution, and number of data points. (The frequency of each point is the start frequency of the bin. This is why many plots end up with strange numbers for the total points like 801)

To perform another measurement press the gray "LOCAL" button in the HP-IB section of the instrument. It is also wise to press "HP-IB FCTN" and aborting HP-IB operation.

Frequency Response Curves:

Frequency responses are obtained by connecting the input of an amplifier to the BNC "SOURCE" output on the HP3562A. Note that the source is on when its yellow light is illuminated. The microphone is connected to channel 1.

Press the measurement mode key; select swept sine and press state/trace. Select the Linear Sweep softkey, and set the frequency range from 100Hz to 10KHz. To configure the microphone, press the input couple button and set channel 1 to AC. Do not change the range of Channel 1, its default is auto-ranging, which is nice.

Although the amplifier testing done in this report did not average over more than one measurement, feel free to adjust it for as long as you want to wait. The estimated time of the entire measurement is displayed under "EST TIME" under "SWEEP". To complete the scan in a reasonable amount of time press "FREQ" and then the sweep rate softkey.

Now press the "SOURCE" button under the measurement section and select the source level softkey. Raise the level to 10mV or so, depending on how loud you want to have the amp. Do not set the level above 100mV it may damage the amp or your ears.

Press the source on softkey and the source will turn on, along with the yellow light. Test the volume of the amplifier on this tone, and then start the measurement with the yellow start key.

To dump the data, open HP3562A.vi on the desktop, select "run" under the operate menu. Copy and paste the data in the "Raw data without header" to a spreadsheet and use the information to the right of the LabView graph to create plots in the spreadsheet. Press "LOCAL" on the instrument to return the buttons to local control, in

order to perform another measurement. Also press "HP-IB FCTN" and abort HP-IB with the softkey.

Cross Spectrum:

The cross spectrum measurements are adapted from the REU 2002 project report. They are posted, as well as this document on

wug.physics.uiuc.edu/courses/phys398emi/index.html

This measurement requires a good bit more instrumentation than the others. In order to detect small amplitude resonances, the transducer must be connected to an op amp circuit to amplify its signal. The piezo that serves as the source is connected to the source output of the 3562A, but that signal is split and sent back into Channel 1. This prevents the source amplitude from being set to voltages over 1 Volt for instrumental damage considerations.

Connect the detecting piezo to its op amp with approximately 9 gain, turn on its 15V power supply and connect the output to channel 2.

Press measurement mode, select swept sine and then press the brown "MEAS DISP" button. Press the "CROSS SPECT" softkey, then press the state/trace key to set up the measurement. Set the source to random noise at 1 Volt and turn it on. You may want to hold the source transducer up to your ear to listen if it's working. Place the source transducer by the saddle of the guitar with weights on top of it, and an insulating layer between the transducer and the weights. Place the detecting transducer at the point of interest.
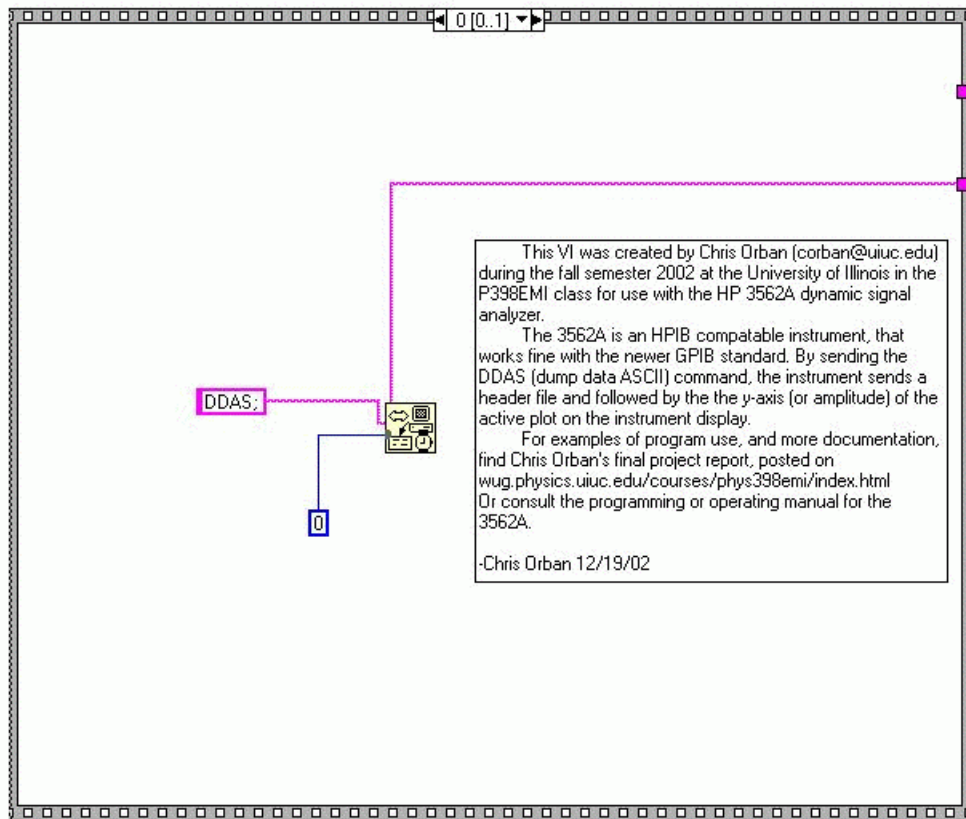
The cross spectra in this study used 40 averages to increase the resolution and decrease the noise of the plot. Press start to launch the measurement. Retrieve the data

from the machine by opening HP3562A.vi, and clicking "Run" under the "Operate" pull down menu. Copy and paste the data in "Raw Data without Header" to a spreadsheet using control+C and control+V. Press "LOCAL" on the 3562A to return it to local control.
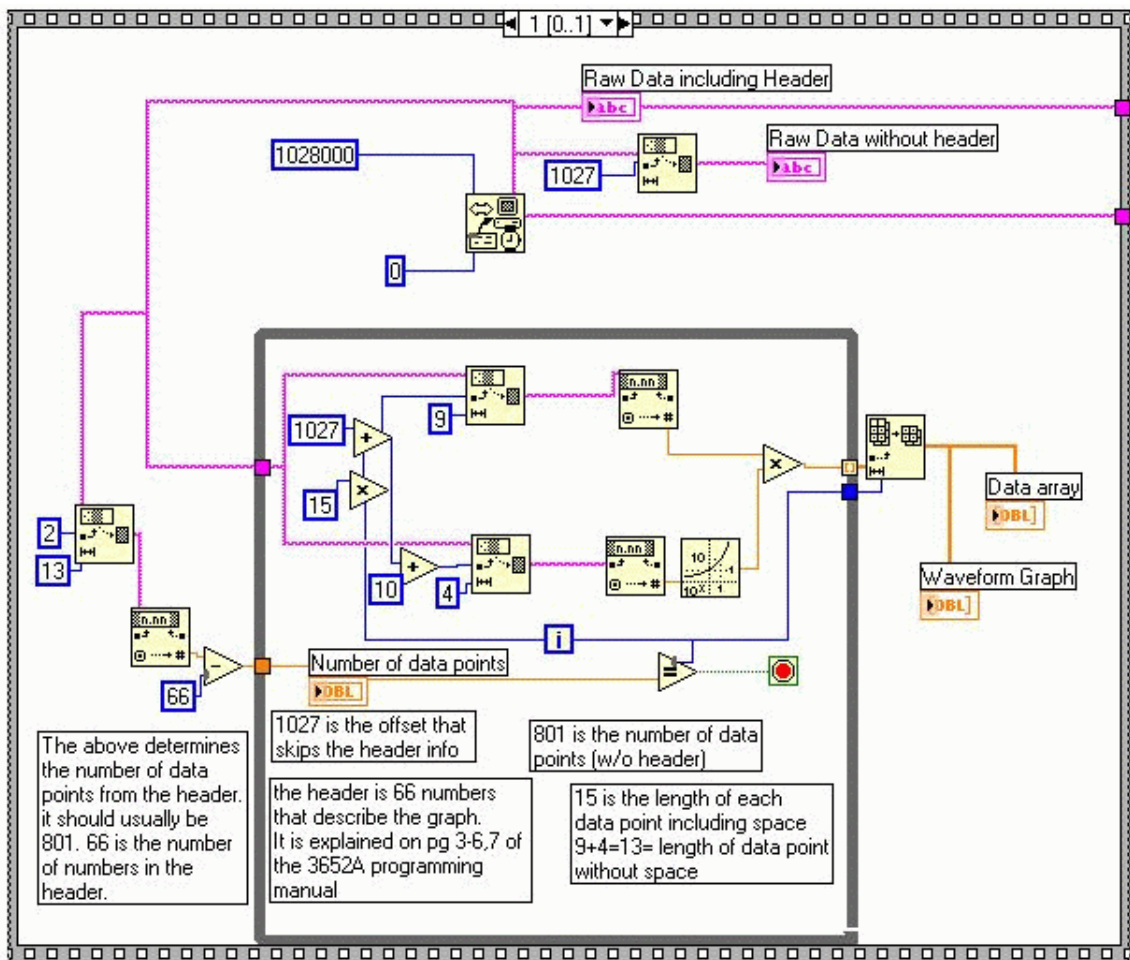
Appendix B: Program Design

The HP3562A conforms to the HP-IB standard, which, rather fortunately, still works fine with current GPIB structures. Only one HP-IB command is issued to the machine, and it is the DDAS command, which stands for Dump Data Ascii format. It is possible to dump the data in other formats, like binary, but it is not as easy to interpret. The instrument receives this command and sends a header file containing the instrument state, followed by the data itself.

The LabView program, HP3562A.vi, consists of two parts. The first is a simple GPIB send command that sends the DDAS command which is illustrated below.
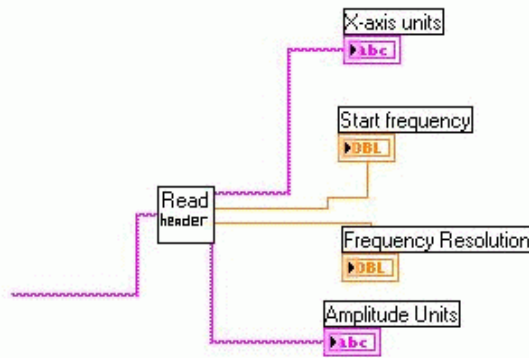

The second part is more complicated. It reads the header and data, extracts information regarding frequencies and resolution, and converts the data into an array for graphing.

The section that converts the data to an array is loosely based on the "Extract Numbers.vi" located in the examples included with the LabView software. The difference lies in that the HP3562A.vi program reads off the nine digit number and the three digit exponent separately and multiplies them together make sure that no precision is lost. It is cumbersome, and difficult to debug, but the comments along with the programming manual is of great help.

There is a separate virtual instrument (VI) that reads the header file and displays the pertinent information. It is connected to the pink colored raw data string wire at the top left of the diagram.

This separate program, also written by Chris Orban, allows the VI diagram to be less cluttered. Header information is defined on page 3-6,7 of the programming manual. The header describes every possible setting of the machine, so there is plenty of information that is ignored every run.