**Improved Calibration of Electric Field Instrumentation**
**Filter and Amplifier Characterization**

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In-situ measurements of the electric field of the upper layers of the atmosphere where the air becomes ionized, require precision instruments able to measure weak and noisy signals. Filters and amplifiers play an important role in processing these signals in order to send meaningful data back to the ground where it can be analyzed. Upgrades on the filter and amplifier calibration system for NASA's Electromagnetic branch at Goddard Space Flight Center were made. Specifically, the upgrades can be divided in two phases. The first phase reproduces the old system's capabilities, adding important new features that make it much more versatile. The second phase removes one of the two auxiliary measuring devices (the gain-phase meter), leaving that task to the new acquisition card and computer; thereby reducing the system's number of components and weight. A simple cost analysis is displayed to account for the choices made in hardware and software implementation. Comparisons between the old system and the two phases is made of the expected input signal to evaluate their performances.

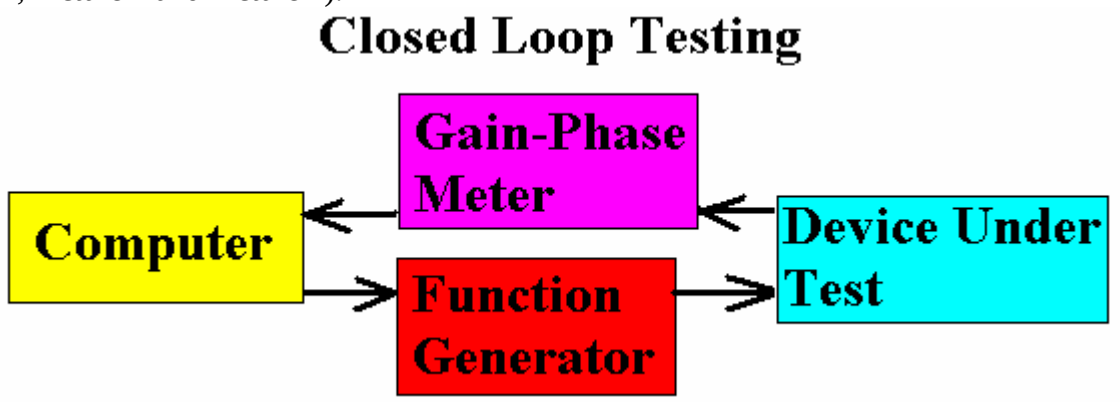
Introduction

At about 80 km above the Earth's surface, the molecules composing the atmosphere are ionized and begin to form a plasma in a region called the ionosphere, which goes all the way up to around 400 km. Studies of the atmosphere at this height center then mostly on the magnetohydrodynamic behaviour of the plasma. In-situ measurements require sounding rockets and satellites to carry precision instruments able to measure the plasma's electric and magnetic field, electron density, impedance, etc. Obtaining this data, however, is not an easy task given the weak and noisy nature of the signals measured. For this reason, filters and amplifiers are an essential part of the instrument's signal processing electronics to extract the necessary data. Hence, it becomes a necessity to have equipment that characterize the behaviour of these filters and amplifiers well; to verify and assert they're functioning the way they're expected to. Calibration systems that do this kind of verification form part of the Ground Support Equipment (GSE), which is responsible for the development, testing and running of the instruments that fly to the ionosphere.

During the past three decades, many missions have been flown by this group in which the instruments have had filters and amplifiers that were characterized by a calibration system that was developed in the early 1980's. This system was now old and in need of major upgrades. The upgrades were done in two stages. In Phase I, a new computer replaces the old one, imitating its functions and keeping its stored file format. In Phase II, one of the systems components, the Gain-Phase Meter, is removed and its task is given to the computer to perform. Each stage of the upgrade was then compared against the old system to assess the reliability of its characterization.

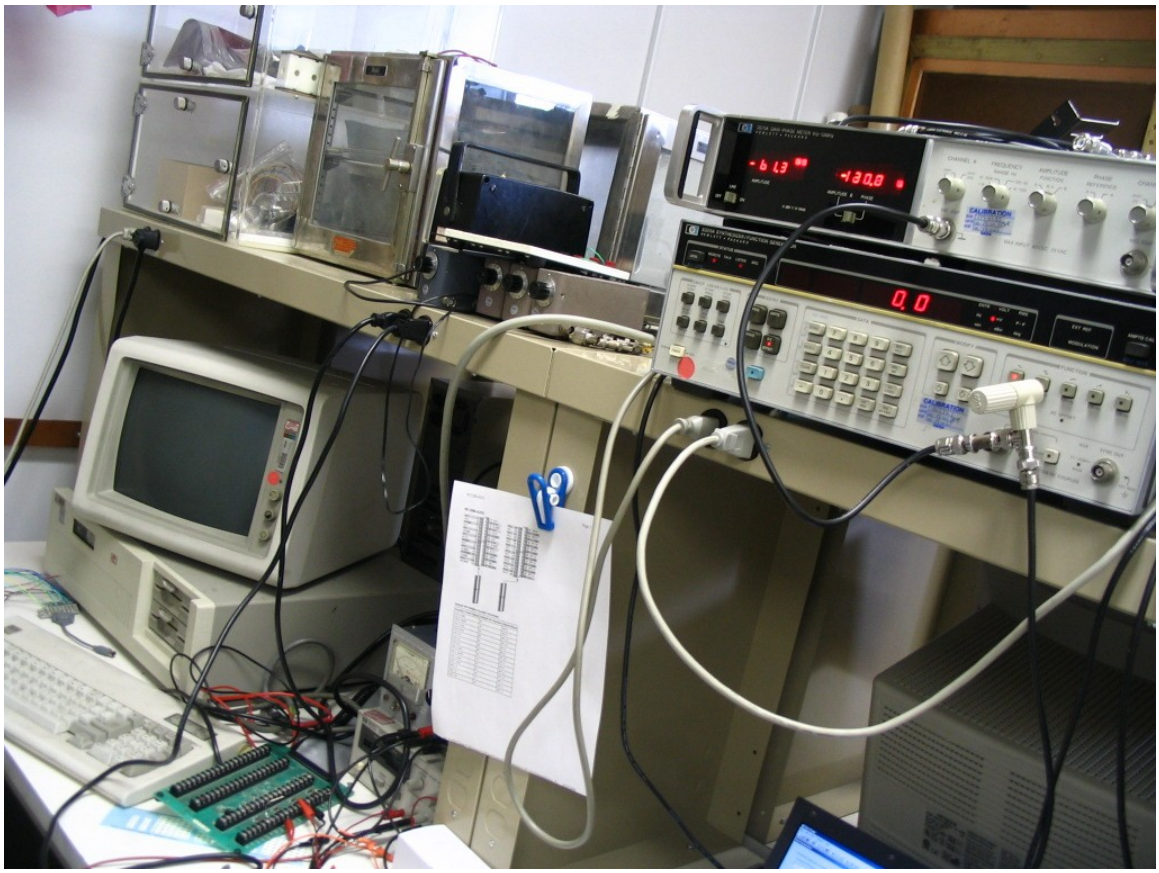
The Old Calibration System

The old calibration system consisted of an IBM Personal Computer AT running on a 286 processor, a Hewlett Packard 3325A Synthesizer/Function Generator and a Hewlett Packard 3575A Gain-Phase Meter that analyses signals in the 1Hz – 13MHz range. These elements were hooked up together in a closed-loop testing configuration (See Fig 1, Picture 1 and Picture 2).




(Figure 1)

IBM PC AT with 286 processor
(Picture 1)



IBM PC AT on bottom left.  HP 3575A Gain-Phase Meter on top right with HP3325A Synthesizer/Function Generator underneath it.
(Picture 2)

Basically, the system's running procedure was the following:

1. Computer sends a request to the Function Generator to produce a specific sine wave.
2. The Function Generator sends a sine wave to the Device Under Test.
3. The Device Under Test modulates the sine wave and sends it to the Gain-Phase Meter.
4. The Gain-Phase Meter analyses the modulated sine wave and sends the gain and the phase shift that the original sine wave underwent to the Computer.
5. The Computer stores the results from the Gain-Phase Meter .
6. The process is repeated for different frequencies.
7. The stored results are displayed numerically and graphically.

Reliable as it had been, with the passage of time, this system was now presenting big inconveniences:

1. The use of 5 ¼' floppy diskettes is now obsolete, making it increasingly harder to find on the market new diskettes on which to store and transfer the information gathered.
2. Hardware repair is also becoming increasingly hard because of the diminishing supply of certain components.

3. Plotting and printing of data is very time consuming, since it must be done on another computer.
4. Quite simply, the system is dying.

Phase I

This first stage of the upgrade consisted in replacing the IBM PC AT with 286 processor (or simply, the 286) with a modern laptop that could run one of the latest versions of Windows. This choice was based on the necessity to easily transport the calibration system to different launch locations at times. The new computer then had to be able to reproduce the behaviour of the old 286: ask the user the same questions for running, communicate with the Function Generator, obtain data from the Gain-Phase Meter, and store and display the data in the same format. For ease of debugging and later improvements, the program had to be written in a common programming language. Likewise, it was required that the program be user friendly.

With these requirements in mind, alternatives for implementation were analyzed. The following simple cost analysis table shows the alternatives that were taken into account:

| **Acquisition Card for Laptop** | | |
|---|---|---|
| USB | $1350 | 1.25 MS/s. 16 Channels |
| PCMCIA | $1200 | ~200kS/s. 16 Channels |
| **Function Generator Interface** | | |
| GPIB | $530 | FG recognizes GPIB commands |
| **Programming Language** | | |
| Labview | $3000 Upgrade | Known |
| Simulink | $2800 | Not well known |
| Visual Basic | Have it | Well known. Ease of Development |
| C | Free | Known. |
| **System** | | |
| Laptop | Free | Excess Warehouse |

Cost analysis of the alternatives for implementation of the upgrades.
(Table 1)

In order to receive data from the Gain-Phase Meter, an acquisition card for the laptop had to be bought. The two alternatives were using one that connected to it through a USB port or a PCMCIA card that would go inside the laptop itself. Being the prices comparable, the NI USB-6251 data acquisition card was selected because of its higher sampling rate. This rate was not very important during the development of Phase I, since the fastest period the DC signals that the Gain-Phase Meter transmits is 30ms. However, it proved to be quite crucial for the development of Phase II, where the incoming signals are sine waves that can have high frequencies (in the MHz range) for certain circuits under consideration.

The choice was clear on the type of interface to have between the laptop and the Function Generator, in order for the laptop to tell the Function Generator what specific sine wave to send to the device under consideration. The HP 3325A Synthesizer/Function Generator came already with the ability to recognize GPIB (General Purpose Interface Bus) commands. Thus, the NI GPIB-USB-HS was acquired. This GPIB controller uses high speed USB (transfers of up to 7.2 MB/s). The fact that both the data acquisition card and the GPIB controller use USB ports to connect to the computer, make them ideal to run on any laptop that contains the calibration program.

To develop the calibration program there were many choices. Nevertheless, the data acquisition card and the GPIB controller both came with drivers written in a few common programming languages: Labview, Simulink, Visual Basic and C. From these, Visual Basic was chosen because it was already owned by the group and because of its ease of development.

Lastly, the laptop on which the program was going to run ended up being free, as it was acquired at the Excess Warehouse owned by NASA.

With these choices, Phase I was developed, reproducing the functions of the old 286 computer. The new system is now able to make the same beginning query to sequentially send commands to the Function Generator (within the Gain-Phase Meter's settling time) to produce sine waves of different frequencies at the desired voltage amplitude through the GPIB controller; and obtain and average 100 samples from the DC signals coming from the Gain-Phase Meter with the data acquisition card. It then saves the data in the same format as the old system and displays the results graphically and numerically much like before.

In addition to this, new features were added to make this application more versatile and useful. Multiple window display now allows the user to view plots and data from different runs simultaneously. Besides saving data files, the new system also saves files of manually entered frequencies (as opposed to automatically generated series of frequencies). There is a stop button that brings a run to an end without closing the program and then having to go every time through the series of questions for the initialization of parameters for runs. This series of chained questions that had to be answered one after the other without the possibility to go back and change, has itself been reformatted so that it is all viewed in one screen with default parameters already filled

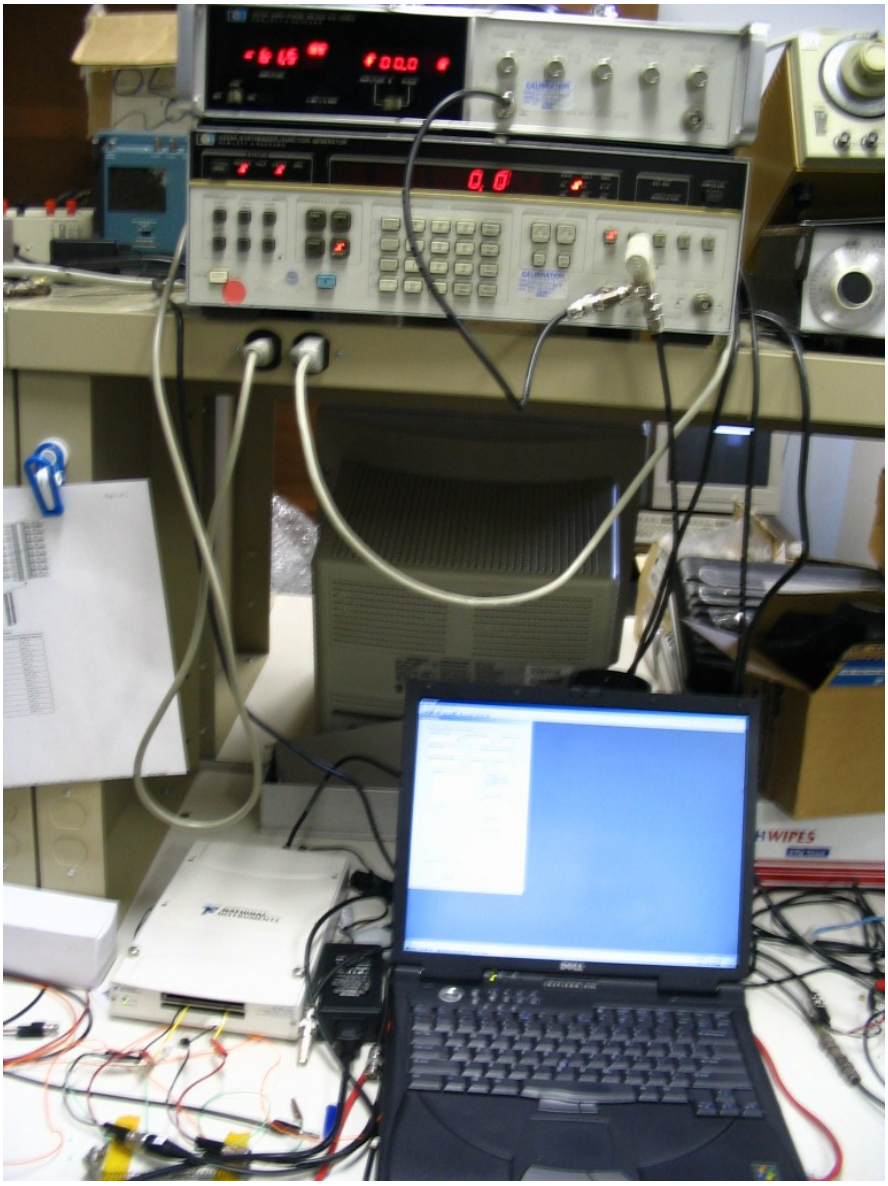
and so that changes to any parameter can be made efficiently before pressing the run button. A phase unwrap option is now available, making it possible to see the phase continuously beyond +180 deg or –180 deg. Because it is run on an operating system like Windows, the new system inherits the advantage of network capabilities, permitting the access to remote device handling (specially important when working both at the lab and the launching site). Also, because of the widespread familiarity with this operating system, Visual Basic provided an intuitive interface that results in an automatic user friendliness. With the touch of a button, the shown graphs can now be printed. Double clicking on the image itself enlarges or restores the image size for better view of details. One of the most important new features, is the real time feedback the graphs give the user as it plots data points as their being read with the option of displaying the graph or the table interchangeably in the process; in contrast with the old way in which the data points where displayed on the table as they were being read (not being able to go back and read them) and showed the graph only at the end, when all the points were gathered. The graphs now include the numerical value of frequencies on the frequency axis for an immediate rough estimate of frequencies to look for in the table for interesting features on the graph. The progress bar is a nice add-on that gives an idea of the time left on a run and is specially appreciated when performing long runs in the late hours of the evening. Finally, there is a comments box that enables the user to add comments about specific details of the run onto the data files that will be saved. These comments are also displayed on the top bar of the individual run windows, making it easier to recall what each set of data corresponds to when comparing them.

The output channels for the Gain-Phase Meter are connected to the analog inputs of the NI-USB-6251 data acquisition card in the following manner:

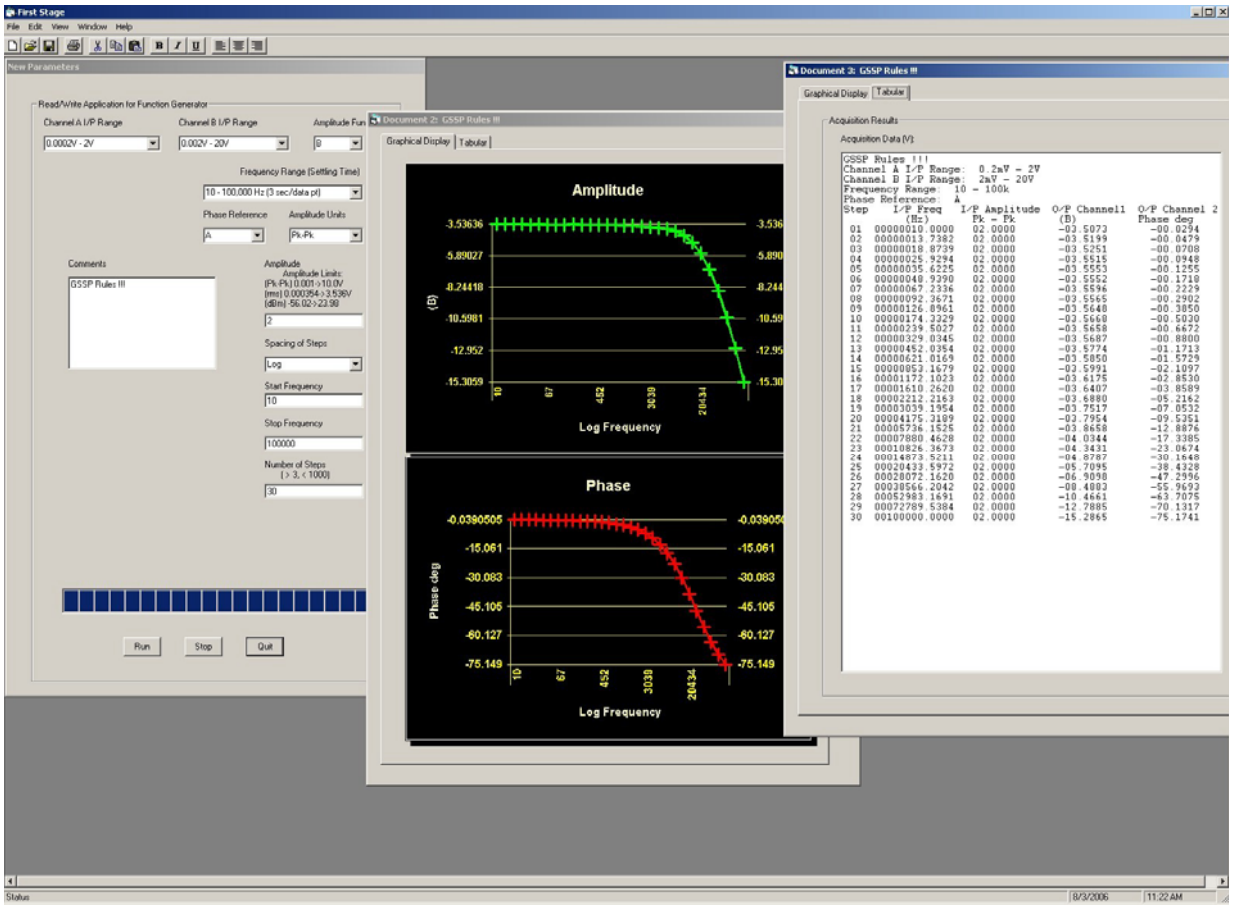
| | | | |
|---|---|---|---|
| AI 0 | pin#1 | +Gain | Labeled 21 |
| AI 8 | pin#2 | -Gain | |
| AI 1 | pin#4 | +Phase | Labeled 22 |
| AI 9 | pin#5 | -Phase | |

Pin #3 (AI GND) is connected to pin#2 (-Gain) to kill off the 60Hz AC wave on which the signals would otherwise be riding on.

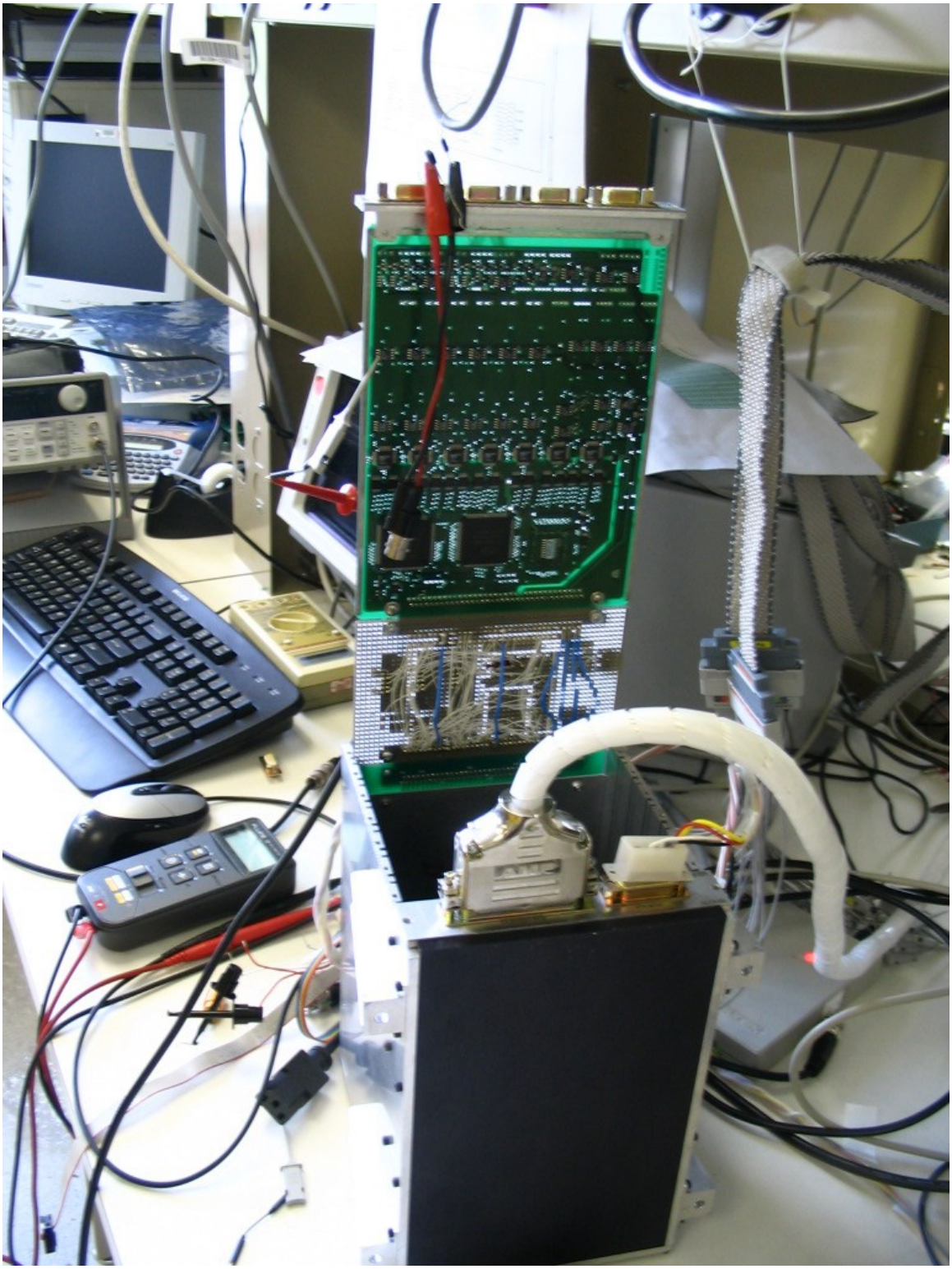
Phase I is now more portable and versatile than the old system. For a look at the new image of the system, see Picture 3. Picture 4 is a screen shot of the user interface for Phase I. Picture 5 and Picture 6 show the electronic circuits that are connected to the measuring instruments that will be launched and the probe on which the instruments are mounted before it is placed on a sounding rocket, respectively.



Picture of Phase I. On top, Function Generator and Gain-Phase Meter. On bottom, laptop on which the implementation was made. Bottom left, data acquisition card NI-USB-6251. GPIB controller connecting back of Function Generator and laptop. (Picture 3)




Screen shot of the user interface for Phase I.
(Picture 4)



Circuit to be connected to measuring instruments being tested.
(Picture 5)

12.064 Test Rocket payload on which measuring instruments are mounted before being placed on sounding rocket.
(Picture 6)

## Phase II

This second stage of the upgrades on the calibration system for filters and amplifiers was intended to remove the Gain-Phase Meter, transferring its tasks to the laptop. The idea behind this is to take advantage of the NI-USB-6251 data acquisition card to measure the incoming signals from both the device under test and the Function Generator and of the much higher computational power of the modern laptop to assume the role of the Gain-Phase Meter. The reason for this was to make the system smaller and more portable, since the Gain-Phase Meter is 18¼ pounds heavy and 16 ¾ x 13 ¼ x 3 15/32 $in^3$ big. Also, it was naturally expected that Phase II have all the functionalities that Phase I did.

A box to vary the number of samples and another to vary the sampling rate was added to the previous stage with default values of 30 sampling points and a sampling rate of 10 times the frequency of the signal to be sampled. In this default configuration, three cycles per signal are sampled with 10 points per cycle. Assuming that both the Function Generator and the signal from the device under test are almost perfect sine waves and that their frequencies are equal to the one programmed on the Function Generator; a least squares fit is performed with the sampled points to obtain the amplitude, offset and phase difference of the two sine waves. With this information, the gain and the phase are recorded and plotted. An additional display window pops up to show the signal from the Function Generator, the device under test and the fitted data. This allows the user to evaluate the quality of the fit as well as monitor the incoming signals for every frequency.

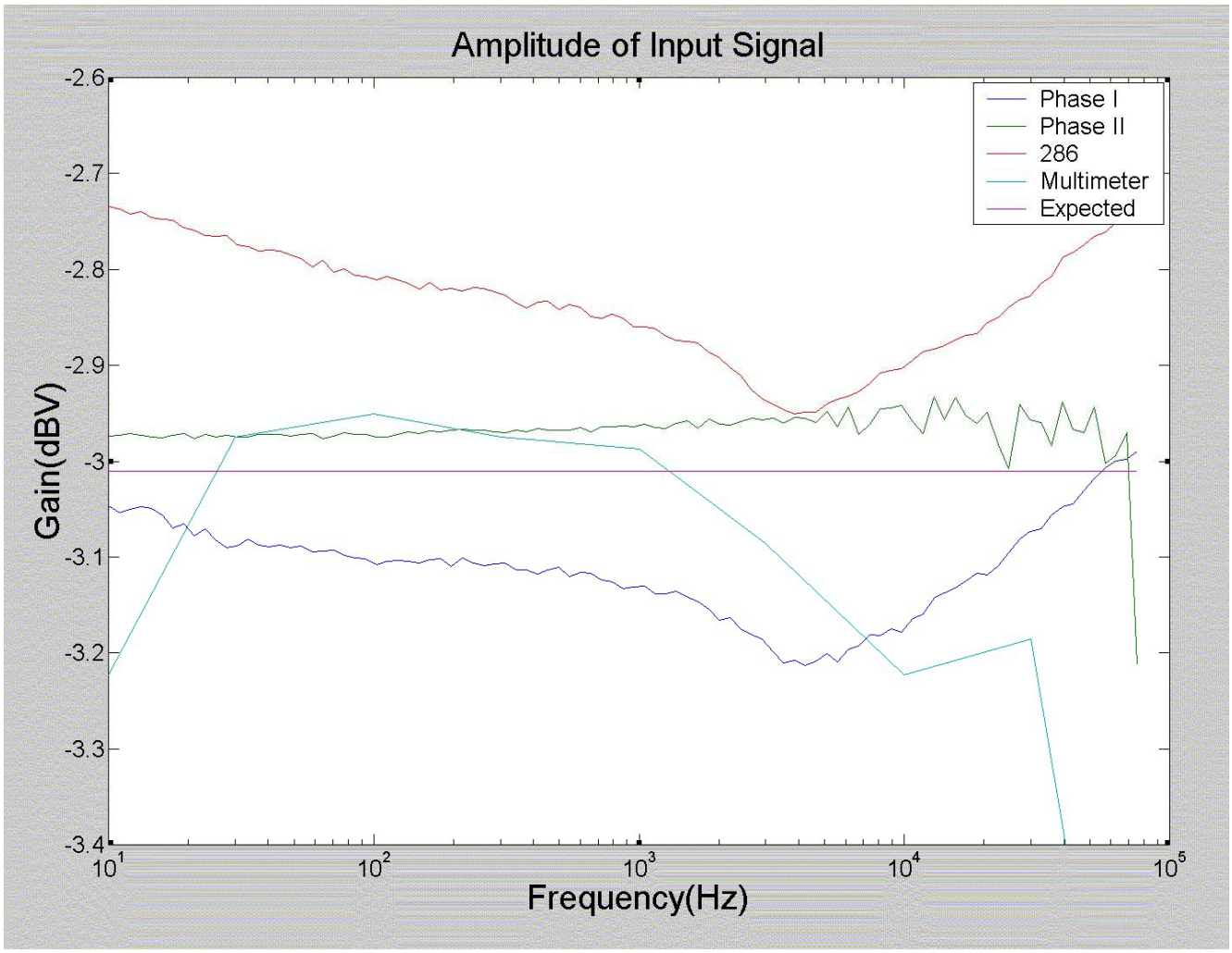
The analog inputs of the NI-USB-6251 data acquisition card are connected in the following manner:

| | | | |
|---|---|---|---|
| AI 0 | pin#1 | +Device Under Test signal | Labeled 21 |
| AI 8 | pin#2 | - Device Under Test signal | |
| AI 1 | pin#4 | +Function Generator signal | Labeled 22 |
| AI 9 | pin#5 | - Function Generator signal | |

Pin #3 (AI GND) is connected to pin#2 (-Function Generator signal) to kill off the 60Hz AC wave on which the signals would otherwise be riding on.

## Results Comparison

When put to the test to reproduce the data from different devices that the old 286 computer had taken, Phase I and Phase II delivered similar results. To account for the discrepancies, which had the look of an offset, a different test had to be made, since there was the possibility that the new system could be measuring better than the old one. Therefore, in order to assess the reliability of the new system in the two stages, a known signal had to be compared: mainly, the one coming from the Function Generator. A 2V p-p sinusoidal signal was measured for at different frequencies by the old 286 computer, Phase I, Phase II and a multimeter. For each frequency, the gain with respect to a 1 V RMS was plotted (0dBV ≡ 1V RMS). A constant –3.01dBV gain is then expected for each of the 4 systems. Figure 2 shows the results.




Comparison between the different measuring devices for a 2V p-p sine wave input. Gain taken in decibels with respect to 1V RMS
(Figure 2)

The first thing we notice from this graph is that the 286 computer starts at about 3% difference from the expected value, approaches it, and then deviates again. This behaviour suggests a capacitance in the line. The exact phenomenon is reproduced by the new system in Phase I, albeit shifted closer to the expected value. The result from the Phase I, thus, not only gives us confidence that the new system behaves in the same way as the old one, but that it actually improves its accuracy. Now, the fact that the graph for Phase II is mostly a straight line shows that the data acquisition card comes closer to the behaviour of the expected signal than Phase I or the old 286 computer; specially for low frequencies. The changes in the shape and shifts of the graph can be accounted by the differences in input impedances. Both Phase I and the 286 computer are connected to the Gain-Phase Meter, which has an input impedance of 1MOhm, while the data acquisition card has an input impedance of >10GOhm. The higher impedance of the data acquisition card does not see the capacitance in the line that the Gain-Phase Meter does. Therefore, Phase II stays within 1% error range until about 70kHz. At this frequency, given the default values of 30 sampling points with a sampling frequency of 10 time the incoming

signal's frequency, the data acquisition card reaches its sampling frequency limit and stops the run. The multimeter's readings are within the 3% error until it reaches the higher frequencies (~20kHz).

## Conclusions

Phase I clearly shows it can replace the old system, not only improving its performance within a smaller percentage error, but also adding important new features, like the real time feedback from the plotting and the ability to save and open a file of manually entered frequencies (as opposed to the linear and logarithmic sweeps). These new features make the system much more versatile and user friendly. With Phase II, the Gain-Phase Meter was removed, transferring its tasks to the data acquisition card and the laptop. This implementation reduced the size and weight of the whole system, making it much more portable to the different launching sites where testing must sometimes be done. In addition to that, Phase II also proved to acquire data more in accordance to what would be expected from the system than either Phase I or the old 286 computer. However, the limitations on the sampling rate of the data acquisition card hinder Phase II from analyzing signals with high frequencies. Hence, it is expected that when high frequencies are required to properly characterize a filter or an amplifier, Phase I of the new system will be preferred (with the Gain-Phase Meter) over the use of Phase II.

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