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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963-A
USE OF THE GPIB
FOR
DATA COLLECTION AND DISPLAY

by

Thomas Taylor

June 1985

Thesis Advisor: John P. Powers

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Use of the GPIB for Data Collection and Display

by

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Lieutenant, United States Navy
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Keywords: computer program.
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I. INTRODUCTION

Spurred by the low cost and availability of microcomputers and other similar products of the integrated circuit revolution, new uses of microcomputers and other programmable equipments are becoming widespread. The use of microcomputers to control data acquisition, and, once the data has been acquired, to optimally display results is much faster and often more accurate than manual methods. Basic electronics laboratories for courses such as EC-2211, EC-2212 and EC-2215 taught at the Naval Postgraduate School, and basic digital courses such as EC-2811 and EC-2812 currently use non-programmable test equipment. The use of a microcomputer controller and programmable test equipment could provide the following advantages over the current manual methods:

(1) More consistent results in repeated measurements, since a computer-controlled system is not subject to operator fatigue.

(2) Greater throughput because computer-controlled systems are generally faster than manual methods.

(3) More thorough testing because system speed allows more parameters to be measured in a shorter time.

(4) Results expressed in scientific or engineering units, since many system controllers are capable of on-line data manipulation.

(5) Greater accuracy because system errors can be measured automatically by comparison to theoretical or pretabulated values, stored and accounted for in the results.
Adaptive data acquisition where a system can be programmed to branch to other measurements to help pinpoint problems when it measures an abnormal condition.

Capability to store measurement results in computer memory, on disk or tape, or on a hard copy.

Better data display, since microcomputer-generated graphs and plots have obvious advantages in time and accuracy over those done by hand.

Immediate feedback to students since data plots are readily available for interpretation.

The objective of this study was to show how the use of a microcomputer and programmable test equipment could replace the current procedure for conducting basic electronic laboratories. Methods for data collection and display were examined and compared to manual methods.

To meet the objectives of this study various programmable test equipments were evaluated. Programs for the HP-85 computer were written to aid in the evaluation. Chapter II discusses the General Purpose Interface Bus and gives some background on its adoption as IEEE Standard 488-1978. Chapter III is an introduction to the equipment used in this study including a summary of each equipment's capabilities. Chapter IV discusses the use of programmable test equipment for data collection. The frequency response of a simple circuit is evaluated as a demonstration. Chapter V discusses the display of data acquired from programmable test equipment including computer-generated plots examples of which are shown. Appendix A is an ASCII and IEEE 488 code chart and Appendix B is a collection of the programs developed to demonstrate and evaluate the programmable test equipment.
There are many applications where the measurement power of interactive instruments can be further enhanced by coupling them to a desktop computer or minicomputer. Operating in a remote mode can provide more exact, error-corrected results as compared with conventional manual operation techniques.

Presently, three major factors have combined to reduce significantly the engineering development costs of configuring measurement systems:

1. Distributed computing through the growing number of instruments with internal microprocessors,

2. The broad choice of computers ranging from inexpensive, easy-to-program desktop computers to more sophisticated computer systems capable of managing multi-station instrument clusters and complex data bases, and

3. The availability of standard interface equipment such as the GPIB which allows the easy interface of different equipments from different manufacturers.

In 1972, the U.S. Advisory Committee, composed of diverse interests representing both users and manufacturers established initial goals and then adopted an interface concept. The Hewlett-Packard Corporation had for some time been a leader in measurement technology research, and the HP Interface Bus was adopted by the committee as an appropriate starting point. A draft document was subsequently written and evaluated by members of the committee, and then
submitted as the U.S. proposal to the International Electro-technical Commission (IEC) in the autumn of 1972. Since then, the interface has undergone a number of minor changes to accommodate various needs at the international level.

In September 1974, the parent technical committee, IEC TC76, approved the main interface draft document for a formal ballot among the member nations of the IEC. Balloting took place in 1976, and IEC recommendation 625-1 was adopted. The IEC recommendation, using a different connector, is totally compatible with the current HP-IB.


The standardized interface concept is now well accepted. More than 2000 products that are compatible with the IEEE Standard are today available from more than 250 manufacturers over 14 countries.

The GPIB has a party line structure where all devices on the bus are connected in parallel as shown in figure 2.1. The 16 signal lines, shown in figure 2.2, within the passive interconnecting GPIB cable are grouped into three clusters according to their functions as follows:

1. Data Bus (8 signal lines)
2. Data Byte Transfer Control Bus (3 signal lines)
3. General Interface Management Bus (5 signal lines)
Figure 2.1  GFIB Bus Structure. (from Ref. 7).

The Data Input-Output (DIO) Bus consists of eight signal lines that carry data in a bit parallel, byte serial format across the interface. These signal lines carry addresses, program data, measurement data, universal commands and status bytes to and from devices interconnected in a system. Identification of the type of data present on the DIO signal
Figure 2.2  GPIB Signal Structure. (from Ref. 7).

Lines is indicated by the ATN (attention) signal. When the ATN signal is true (asserted), either address or universal commands are present on the data bus and all connected devices are required to monitor the DIO lines. When the ATN message is false, device dependent data (e.g., programming data) is carried between devices previously addressed to talk and listen.

Transfer of each byte on the Data Bus is accomplished via a set of three signal lines: DAV (data valid), NRFD (not ready for data), and NDAC (not data accepted). These signals operate in an interlocked handshake mode. Two signal lines, NRFD and NDAC, are each connected in a logical AND (wired OR) to all devices connected to the interface.
The DAV signal is sent by the talker and received by potential listeners whereas the MRFD and NDAC signals are sent by potential listeners and received by the talker.

The General Interface Management Lines manage the bus to effect an orderly flow of messages. The IPC (interface clear) message places the interface system in a known quiescent state. SRQ (service request) is used by a device to indicate the need for attention or service and to request an interruption of the current sequence of events. REN (remote enable) is used to select between two alternate sources of device program data. ECI (end or identify) is used to indicate the end of a multiple byte transfer sequence or, in conjunction with ATN, to execute a polling sequence.

Data byte transfer on the DIO signal lines is accomplished using an interlocked handshake sequence on three signal lines: data valid (DAV), not ready for data (MRFD) and not data accepted (NDAC). The talker uses DAV to signal the presence of a valid byte of data on DIO1-DIO8. Each listener indicates its acceptance of the data by asserting RFD message false and DAC message true. The talker then asserts the DAV message false and the listener, when it is able to receive a new data byte, asserts RFD true and DAC false. Thus the handshake sequence is complete. When two or more devices are "listening" each device participates in the same handshake cycle. Data is transferred asynchronously at the rate of the slowest listener.

A more complete discussion of the GPIB can be found in the IEEE Standard [Ref. 7].
III. EQUIPMENT

In this chapter various GPIB compatible equipment will be discussed. That equipment which seem most likely candidates for basic electronic laboratory use are discussed first and in greater detail. Equipment whose use is less readily apparent and some equipment where less research was conducted are discussed last.

A. HP-85 COMPUTER AND HP-IB

The Hewlett-Packard Interface Bus (HP-IB), is Hewlett-Packard’s implementation of the IEEE-488-1978 interface standard (GPIB). As discussed in Ref. 1, the purpose of the HP-IB is to provide mechanical, electrical, timing, and data compatibilities between all devices adhering to the standard. Interfacing other devices to computers has been greatly simplified by the HP-IB. In general the use of the HP-IB allows the operator to concentrate on what is to be communicated and give little thought to compatibility and handshaking. The HP-IB uses standard ASCII and easily understood control signals.

If one uses the HP-IB option accessory, the Hewlett-Packard Model 85 microcomputer has the necessary capabilities to allow it to function as system controller. Using the HP-IB, the HP-85 can take control of programmable test equipment, direct their operation, and store test data returned from the equipment. The computer can store data on magnetic disk or tape, display the data using built-in graphics capabilities or a remote plotter, or print a hard copy of the data.
Three primary commands that the HP-85 uses to control programmable test equipment are the "OUTPUT", "ENTER" and "TRANSFER" commands. The "OUTPUT" command is used to send data from the computer to the test equipment. The statement must contain the destination device address and a list of items to be output (e.g., the command OUTPUT 720; X, outputs the variable X to device 720). The "ENTER" command is used to send data from a designated equipment to the computer. The statement must contain the source device address and a list of items to be entered (e.g., the command ENTER 720; X, enters data to variable X from device 720). The "TRANSFER" command is used to move data to and from a established buffer area. This command is used to move data from one device to another when neither device is the bus controller (e.g., the command TRANSFER 706 TO Z$ COUNT 100, will transfer 100 bytes of data from device 706 to the buffer space designated as Z$. The command TRANSFER Z$ TO 710 PBS, will transfer the data in buffer space Z$ to device 710 using fast-handshake).

When a device encounters a situation which requires the controller's attention or action, it signals the controller with a service request (SRQ). A service request may be generated whenever an event such as an error or change of status occurs. A service request is handled by the controller as an interrupt and may be processed or ignored. If the controller is programmed to process the SRQ Interrupt it must first determine who sent the interrupt, and then why the SRQ was generated. The controller can determine who sent the service request by performing a parallel poll. This is like a discussion leader asking those persons with problems to raise their hands. Once the controller determines which device generated the SRQ, it can determine the specific problem by performing a serial poll. This involves
querying a device as to its status. The information returned by each device is dependent upon the nature of the device and can be found in the instruction manual for that specific equipment (e.g. error code 98 indicates an execution error for the Tektronix PS 5010 but could indicate a different type of error for some other device). A complete discussion on handling service requests can be found in Ref. 1.

B. WAVETEK FUNCTION GENERATOR

This section discusses the Wavetek Model 270 Programmable Function Generator and how to control it using the HP-85 Microcomputer.

As described in Ref. 2, the Wavetek Model 270, 12 MHz Programmable Function Generator, is a 0.01 Hz to 12 MHz multifunction generator that can operate in continuous, trigger, gated or burst modes, at generator levels to 20 volts peak-to-peak. The generator produces sine, triangle, and square waves, with from +5 to -5 volts of DC offset. The function generator settings can be made from the front panel or, with the General Purpose Instrument bus, from a microcomputer controlling the experiment. Numbers can be input in free format, (i.e. fixed point, floating point, or exponential notation). Parameters may be entered in any order. All entries are checked for errors and displayed on the front panel. Current parameter settings may be checked by pressing the corresponding button on the front panel. Up to 80 complete sets of programming may be stored in the generator and rapidly recalled.

The Wavetek Model 270 Programmable Function Generator can be controlled by the HP-85 Microcomputer over the Hewlett-Packard Interface Bus (HP-IB). The handshaking and
data transfer is accomplished as discussed in Chapter 2. The Model 270 is controlled by sending commands over the GPIB data lines. The function generator interprets the commands and responds as directed. When the function generator is directed by the computer to send data, it uses the same data lines that the computer used to send commands. Table I is a partial list of function codes used by the computer to control the function generator.

**TABLE I**

<table>
<thead>
<tr>
<th>Wavetek Function Generator Programming Commands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control and data Names</td>
</tr>
<tr>
<td>Change Sign</td>
</tr>
<tr>
<td>Decimal Point</td>
</tr>
<tr>
<td>Amplitude</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Function</td>
</tr>
<tr>
<td>Offset</td>
</tr>
<tr>
<td>Exponent</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Execute</td>
</tr>
<tr>
<td>Output Cn/Cff</td>
</tr>
<tr>
<td>Recall Setting</td>
</tr>
<tr>
<td>Reset</td>
</tr>
<tr>
<td>GPIB Address</td>
</tr>
</tbody>
</table>

The computer and function generator are connected using the HE-IE. The function generator's factory-set address can be found by pressing the "ADRS" button on the front panel. If some other address is desired it can be entered from the front panel by pressing "ADRS", entering desired address and pressing "EXEC". The address must be used in all computer-to-generator communications. The function generator output is connected to provide waveforms to desired destinations (an oscilloscope is good for demonstration purposes), the computer program is loaded, and the system is ready for operation.
The sample program provided in Appendix B, was written to provide a simple hands-on means of system familiarization. It does not demonstrate all the Model 270's capabilities. To use the sample program configure a system such as the one shown in Figure 3.1. A simplified flow diagram of the program is shown in Figure 3.2.

![Diagram of Model 270 Demonstration](image)

**Figure 3.1 Model 270 Demonstration.**

When the program is initiated the computer display will provide instructions for entering a function into the function generator. The user should respond to the displayed questions. The "END LINE" key is used to enter the user's response into the computer. Numbers may be entered using integer (e.g., "1000"), floating point (e.g., "15.2"), or exponential (e.g., "12e6") forms. The user will be asked to enter waveform type, amplitude, frequency, and DC offset. As each entry is made, the Wavetek Function Generator display will show that entry. After a function has been
Figure 3.2 Wavetek 270 Demonstration Program Flow Diagram.
fully selected, the function will be gated to the function generator output and displayed on the oscilloscope, and the computer will query the function generator as to its status. The function generator's response will be printed on the computer's printer.

The sample program also contains a section on the use of the function generator's memory. It allows the user to store functions in the Model 270's memory and to recall and display previously stored functions. This demonstrates the ability of the Wavetek function generator to store and recall up to eighty waveforms.

For a more detailed description of the function generator's capabilities, the user should refer to the Instruction Manual for the Wavetek Model 270, Programmable Function Generator [Ref. 2].

C. PS 5010 PROGRAMMABLE POWER SUPPLY

The Tektronix PS 5010 Programmable Power Supply provides a floating dual supply and a ground-referenced logic supply. Each supply has independent constant voltage modes or constant current modes with automatic crossover.

The floating supply provides 0 to +32 volts DC and 0 to −32 volts DC, both with respect to a common front panel terminal. All floating supply terminals can be elevated above ground to a maximum 150 volts peak. Voltage differences from 0 to 64 volts are available across the dual supply terminals. The floating point supplies are programmable in increments of 10 millivolts from 0 to 10.0 volts and in increments of 100 millivolts from 10.1 volts to 32.0 volts. The current is programmed in 50 milliamp increments from 50 milliamps to 1.5 amps.
The logic supply provides 4.5 volts DC to 5.5 volts DC at currents to 3 amps. The logic supply is programmable in increments of 10 millivolts from 4.50 volts to 5.50 volts and in current increments of 100 milliamps over a range of 100 milliamps to 3 amps.

The front panel LED display is divided into three sections. Each section indicates the programmed current or voltage for one supply. In the operating mode, the displays show the true output voltage when operated in the constant voltage mode or current when operated in the constant current mode. A more complete description of the PS 5010 specifications can be found in Ref. 3.

Table II is a condensed list of commands used by a system controller to direct the PS 5010.

A demonstration for the PS 5010 and the DM 5010 combination is included in Appendix E. This program is discussed in the following section covering the DM 5010 Programmable Digital Multimeter.

D. DM 5010 PROGRAMMABLE DIGITAL MULTIMETER

The Tektronix DM 5010 Programmable Digital Multimeter measures and displays dc voltages, resistance, true rms ac voltages, and voltages consisting of a dc level plus an ac waveform. Range selection is automatic or manually incremented. A diode test function provides a 1 milliamp current output for diode testing. Measurements are made via front-panel connectors or a rear-interface connector.

The DM 5010 also performs calculation for averaging, scale and offset, conversion to dBm or reference dB, and comparison. Measurements and calculations are indicated on a signed 4 1/2 digit LED display. The decimal point is automatically positioned and leading zeros are blanked.
TABLE II
PS 5010 Commands and Descriptions

<table>
<thead>
<tr>
<th>Command</th>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER</td>
<td>&lt;num&gt;</td>
<td>Returns error code</td>
</tr>
<tr>
<td>ILOG</td>
<td>&lt;num&gt;</td>
<td>Sets the logic supply current limit</td>
</tr>
<tr>
<td>INEG</td>
<td>&lt;num&gt;</td>
<td>Sets negative floating supply current limit</td>
</tr>
<tr>
<td>INIT</td>
<td></td>
<td>Resets instrument settings to power-on state</td>
</tr>
<tr>
<td>IPOS</td>
<td>&lt;num&gt;</td>
<td>Sets positive floating supply current limit</td>
</tr>
<tr>
<td>CUT</td>
<td>ON</td>
<td>Connects all supplies to the output terminals</td>
</tr>
<tr>
<td>SET?</td>
<td>&lt;num&gt;</td>
<td>Returns instrument settings</td>
</tr>
<tr>
<td>VLOG</td>
<td>&lt;num&gt;</td>
<td>Sets logic supply voltage limit</td>
</tr>
<tr>
<td>VNEG</td>
<td>&lt;num&gt;</td>
<td>Sets negative floating supply voltage limit</td>
</tr>
<tr>
<td>VPOS</td>
<td>&lt;num&gt;</td>
<td>Sets positive floating supply voltage limit</td>
</tr>
<tr>
<td>VLOG?</td>
<td>&lt;num&gt;</td>
<td>Returns setting for respective supply (i.e. VNEG &lt;num&gt;)</td>
</tr>
<tr>
<td>VNEG?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VPOS?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The operation of the DM 5010 is programmable via high-level commands (ASCII) sent over the GPIB. The DM 5010 can send information about front panel control settings, measurements, and calculations via the bus to the GPIB controller. Measurements and calculations are triggered by internal circuitry (at a normal or fast rate), front panel push button, GPIB command, or external signal via the rear-interface connector. A more detailed description of the DM 5010 specifications and operating instructions can be found in Ref. 4.

Table III is a condensed list of commands used to control the DM 5010 via the GPIB.
### TABLE III

<table>
<thead>
<tr>
<th>Reader</th>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACDC</td>
<td>&lt;num&gt;</td>
<td>Selects the ACV+DCV function. Argument selects range.</td>
</tr>
<tr>
<td>ACV</td>
<td>&lt;num&gt;</td>
<td>Selects the ACV function. Argument selects range.</td>
</tr>
<tr>
<td>DCV</td>
<td>&lt;num&gt;</td>
<td>Selects the DCV function. Argument selects range.</td>
</tr>
<tr>
<td>ERR?</td>
<td></td>
<td>Returns error code.</td>
</tr>
<tr>
<td>FUNCT?</td>
<td></td>
<td>Returns the current function and range.</td>
</tr>
<tr>
<td>INIT</td>
<td></td>
<td>Initializes to power-on settings.</td>
</tr>
<tr>
<td>OHMS</td>
<td>&lt;num&gt;</td>
<td>Selects OHMS function. Argument selects range.</td>
</tr>
<tr>
<td>SEND</td>
<td></td>
<td>Returns latest measurement.</td>
</tr>
</tbody>
</table>

**Note:** negative or omitted argument selects auto-range capability.

A demonstration program for the PS 5010 Programmable Power Supply and the DM 5010 Programmable Digital Multimeter is included in Appendix B. A simplified flow diagram for this program is shown in Figure 3.3. To run the program the system is configured as shown in Figure 3.4. The program is loaded and run in the HP-85 computer following the instructions displayed on the screen. The program guides the user through the setup of each of the PS 5010's voltage supplies. At each step the DM 5010 will measure and display the voltage level. The computer will also read the DM 5010 and print the reading or the printer. A WAIT 1000 (1 second delay) command is used in the program just before the computer reads the meter. This delay ensures that the computer will not try to read the meter before the reading has settled. Reference 4 shows the maximum settling time when reading AC volts (true RMS) to be 1.2 seconds. Table IV shows a sample printout.
Figure 3.3  PS 5010 and DM 5010 Demonstration Flow Diagram.
TABLE IV
PS 5010 and DH 5010 Demonstration Program Printout

ICGIC VOLTAGE IS: 4.9
NEGATIVE VOLTAGE IS: -17.5
POSITIVE VOLTAGE IS: 24.4

Figure 3.4  PS 5010 and DH 5010 Demonstration Setup.

This discussion and the demonstration program cover only a small percentage of the DH 5010's capabilities. For more details refer to the programming manual [Ref. 4].

E. OTHER GPIB EQUIPMENT

This section discusses equipment which was not incorporated in the research discussed in later chapters, but which might have uses in future research.
1. The Photodyne Model 488XLI GPIB Interface and Model 22XLI Fiber Optic Multimeter

The Photodyne Model 488XLI GPIB Interface Adaptor provides the logic and control functions necessary to interface the Model 22XLI Fiber Optic Multimeter with a GPIB controller. The combination of the 488XLI and 22XLI can operate in either the talk-only or addressable mode, as determined by the setting of an internal switch. In the talk-only mode, it can send data to a GPIB compatible listener at one of eight switch selectable rates, from 2.5 readings a second to one reading per hour. In the addressable mode, readings may be triggered or non-triggered, depending on whether its odd or even address is received from the controller. The Model 488XLI provides an output of ASCII data, sign, and terminator. A short demonstration program is provided in Appendix B. The 488XLI and 22XLI combination is very easy to use and program.

2. Hewlett-Packard 1615A Logic Analyzer

The Hewlett-Packard 1615A Logic Analyzer offers asynchronous timing diagram measurements and synchronous state measurements for use in the design and troubleshooting of digital systems. Measurement setups are simplified with a menu system which reduces the number and complexity of front panel keys. With the format specification menu, the desired mode of operation: timing, state, or simultaneous dual-mode, is selected. The corresponding trace specification menus then allow entry of the desired triggering and data parameters.

The 1615A Logic Analyzer was found to be not completely compatible with the HP-85 Computer. Using the HP-85 as system controller, it was possible to set all parameters into the 1615A, but data could not be transferred from the 1615A to the HP-85. The problem in data transfer
seems to be one of a not fully compatible handshake. When the HP-85 directs the 1615A to send its data, the 1615A goes to the talk mode and places the first byte of data on the bus, however the DAV (data valid) line is not set. Since the HP-85 does not receive DAV it does not accept the first byte of data and the entire system locks up with neither the HP-85 nor the 1615A responding to keyboard inputs.

Hewlett-Packard engineers who were consulted on this problem suggested that this problem might be circumvented by directing the 1615A to transfer its data to a printer or buffer space rather than to the HP-85 directly. Further research is needed to see if this solution will work. The 1615A Logic Analyzer would be a very valuable piece of equipment for basic digital laboratories. Efforts should be made to solve the compatibility problem or to find a compatible controller.

3. **Hewlett-Packard 9111A Graphics Tablet**

The Hewlett-Packard 9111A Graphics Tablet is used to input coordinate points to the microcomputer. It also has sixteen menu softkeys to allow option selection away from the computer keyboard.

It was thought that the Graphics Tablet could be used to annotate computer generated plots, however this proved not to be very workable due to the small screen on the HP-85 computer. A demonstration program, included in Appendix B, provides an introduction to the 9111A and its uses.

4. **The Hewlett-Packard 59401A Bus System Analyzer**

The HP-59401A Bus System Analyzer is invaluable as an aid to GPIB users in hardware design and in diagnosis of hardware and software problems encountered in GPIB compatible systems. When in the listen mode the 59401A monitors Bus traffic and can accept and store up to 32 characters.
from the bus for later examination. It can slow down data transfer and handshaking so they may be observed. When used in the talk mode the 59401A is used to drive the Bus. The Bus can be driven one character at a time by setting the DIO switches to the appropriate code and outputting this information to the Bus.

While the 59401A Bus System Analyzer is not itself a piece of programmable test equipment, its importance in setting up and testing a GPIB system cannot be overstated. The ability to observe and control the handshake and data transfer lines on the bus greatly simplifies the design and trouble-shooting processes.

5. **Hewlett DC 5009 Universal Counter/Timer**

The Tektronix DC 5009 Universal Counter/Timer features reciprocal frequency, period, counting events on channel B during time gates applied to channel A and totalizing measurements to 135 MHz. It also has time interval and width features of 10 ns resolution for timing measurements. For repetitive timing measurements, averaging and pseudorandom time base modulation circuitry provides increased accuracy over a wide range of input signals. The DC 5009 provides trigger level outputs at both the front panel and rear interface for increased measurement convenience.

The DC 5009 is GPIB programmable and allows any manually selectable function or mode to be operated over the GPIB bus, including all input conditioning controls. After the DC 5009 is set to the remote state by a system controller, its operating modes and settings can be set and read by programming mnemonics sent to it in ASCII code over the bus. The instrument settings may also be read while in the local state. The DC 5009 connects to the bus through a GPIB-compatible connector on the TM 5000-series power module.
Measurement results are displayed in an eight-digit LED readout, with the decimal point automatically positioned. The displayed count overflow is indicated by a flashing display. The counter also uses three digits of the seven-segment LED display to indicate internal or operating error codes and two digits for external signal probe compensation results.

Table V is a condensed list of commands used with the DC 5009. A more detailed description of the Counter/Timer's specifications and operating procedures can be found in Ref. 5.

**TABLE V**

DC 5009 Commands and Description

<table>
<thead>
<tr>
<th>Commands</th>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUTO</td>
<td></td>
<td>Sets trigger level to signal midpoint (both channels).</td>
</tr>
<tr>
<td>AVE</td>
<td>&lt;num&gt;</td>
<td>Sets number of measurements averaged.</td>
</tr>
<tr>
<td>CHA</td>
<td>A or B</td>
<td>Selects channel for succeeding input settings.</td>
</tr>
<tr>
<td>EVE</td>
<td>(BA)</td>
<td>Counts Channel B during Channel A pulse width.</td>
</tr>
<tr>
<td>FREQ</td>
<td>(A)</td>
<td>Measures frequency of input signal on Channel A.</td>
</tr>
<tr>
<td>INIT</td>
<td></td>
<td>Resets to current front-panel settings and power-on parameters.</td>
</tr>
<tr>
<td>PER</td>
<td>(A)</td>
<td>Measures the period of Channel A signal.</td>
</tr>
<tr>
<td>RAT</td>
<td>(B/A)</td>
<td>Measures ratio of B events to A events.</td>
</tr>
<tr>
<td>SEND</td>
<td></td>
<td>Obtains and formats new measurement results.</td>
</tr>
<tr>
<td>SET?</td>
<td>(AB)</td>
<td>Query returns current instrument settings.</td>
</tr>
<tr>
<td>TIME</td>
<td>(AB)</td>
<td>Measures time from A event to B event.</td>
</tr>
<tr>
<td>WID</td>
<td>(A)</td>
<td>Measures pulse width of channel A signal</td>
</tr>
</tbody>
</table>
IV. DATA COLLECTION

In the previous chapter several GPIB programmable test equipments were introduced. In this chapter it will be shown how combinations of those equipments can be used to conduct basic electronics laboratory measurements. A student in a basic electronics class, such as EC-2211 at the Naval Postgraduate School, might be asked to build and evaluate the frequency response of a simple common-emitter amplifier similar to the one shown in Figure 4.1.

![Common-Emitter Amplifier Diagram](image)

**Figure 4.1 Common-Emitter Amplifier.**

To complete an evaluation of his circuit performance he would need a signal generator, power supply, frequency counter, AC voltmeter, and an oscilloscope. He would need
to become familiar enough with each of these equipments to ensure that any data obtained from his tests was correct. Problems encountered must first be investigated for equipment setup problems.

A greatly simplified procedure for investigating the same common-emitter amplifier would use programmable test equipment and a microcomputer controller. A program would insure proper equipment setup and could even perform a check to verify a proper circuit to be tested. This check would help the student identify problems in his circuit before time was lost in taking useless test data. Finally the microcomputer controlled test could take a greater number of data points at a much faster rate.

To test a common-emitter amplifier and obtain a printout of frequency and gain, the following test equipment could be used: HP-85 Microcomputer, Model 270 Function Generator, PS 5010 Power Supply, and the DM 5010 Digital Multimeter. The equipment configuration for this type of an experiment is shown in Figure 4.2.

A sample program for the HP-85 Microcomputer which uses the equipment as configured in Figure 4.2 to test a common-emitter amplifier is included in Appendix B. The program uses the Wavetek Model 270 Function Generator to provide a known input to the circuit under test. The Model 270 is shifted through a range of frequencies at a constant voltage. At each frequency the test circuit's output voltage is read by the DM5010. The HP-85 Computer computes the gain at each frequency using the DM5010 readings and the known input voltage value. A simplified flow diagram for this program is shown in Figure 4.3. This program allows the user to select power supply voltages, frequency range, and number of data points to be taken. It prints out the
frequency and gain (in dB) for each point. All user entries are made from the HP-85 keyboard in response to displayed questions. A sample of the type of output generated is shown in Table VI.

The sample program is not limited to use with simple common-emitter amplifiers; it can test the frequency-vs-gain characteristics of any desired circuit, such as an amplifier or filter. A frequency counter is not needed due to the good frequency accuracy of the Model 270 Function Generator (but could easily be incorporated in the measurement system). Many more advanced electronics courses could use the same test equipment and program for frequency-vs-gain characteristics.
Figure 4.3 Data Printout Demonstration Program Flow Diagram.
### TABLE VI
Sample Output from Freq-Gain Program

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.000 Hz</td>
<td>-182.824 dB</td>
</tr>
<tr>
<td>20.000 Hz</td>
<td>-182.824 dB</td>
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<tr>
<td>30.000 Hz</td>
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<td>40.000 Hz</td>
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<tr>
<td>60.000 Hz</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>1110.000 Hz</td>
<td>-182.824 dB</td>
</tr>
</tbody>
</table>

Note: The table continues with similar frequency and gain values up to 1100.000 Hz.
V. DATA DISPLAY

In the previous chapter it was shown how computer controlled test equipment could obtain faster, more accurate test data. If this was all the computer could do it would be a major savings of time, however the computer can also provide a display of the data.

A. HP-85 GRAPHICS CAPABILITIES.

The HP-85 Microcomputer provides two different display areas or modes: alphanumeric and graphics. Normally the display is in the alpha mode, but the user can view the current graphics display at any time by pressing the "GRAPH" key or by executing the statement, GRAPH. The graphics capability of the HP-85 enable the user to:

1. Plot data on the graphics display, thus clarifying a complex set of information in pictorial form.
2. Scale the display to desired proportions.
3. Generate a number of lines, curves, diagrams and designs on the display.
4. Copy anything from the graphics display to the printer with one command.
5. "Draw" and label graphs with ease.
6. Interact with the graphics display from the keyboard.
7. Execute any graphics command from the keyboard or in a program.
If the HP-85 is equipped with the Printer/Plotter ROM, graphics programs for the HP-85 can be plotted directly on the Hewlett-Packard 7470A Plotter by using the "TRANSLATE" command.

In Chapter 4 it was shown how the frequency verses gain characteristics for a common-emitter amplifier could be measured and printed. The same data could be plotted by the HP-85 directly. This would provide the student with a quick graphical display of the amplifier's gain characteristics. Included in Appendix B is a program which will test the amplifier, print frequency and gain for each test point, graph the data, and copy the graph on the printer. Figure 5.1 is an example of the printed graph for the circuit shown in Figure 4.1. A simplified flow diagram for the demonstration program is shown in Figure 5.2.

Figure 5.1 C-E Amplifier Characteristics.
Figure 5.2 Graphics Demonstration Program Flow Diagram.
As was previously discussed this type of program is not limited to testing one circuit. More complex circuits can also be tested using the same program. Figure 5.3 is an example of a Butterworth bandpass filter.

![Butterworth Bandpass Filter Diagram]

Figure 5.3 Butterworth Bandpass Filter.

Figure 5.4 shows the printed output for the circuit shown in Figure 5.3 using the same program that was used to test the common-emitter amplifier.

B. VISICALC PLUS

For some graphics applications, such as a logarithmic graph, a simple HP-85 program is not sufficient. For extensive or specialized graphics a pre-written graphics program package is desirable; one such program is the Hewlett-Packard VisiCalc Plus package. Briefly the HP-87 VisiCalc Plus package is a group of graphics and calculation programs for the HP-86/87 Microcomputers. The package contains the following programs:
Figure 5.4  BP Filter Characteristics.

VZCALC: A binary program that is the main VisiCalc program.

VZLINE: A BASIC program that uses VisiCalc data to graph line charts.

VZCURV: A BASIC program that allows you to fit standard regression curves to VisiCalc data.

VZPIE: A BASIC program that uses VisiCalc data to plot pie charts.

VZEAR: A BASIC program that uses VisiCalc data to create bar charts.

LINCURG: A binary program that is automatically loaded and executed by the four graphics programs.

REDZERg: A binary program that is automatically
loaded and executed by VZLINE, VZCURVE, and VZBAR.

VZREAD: A BASIC program that allows you to read data files created by VisiCalc.

VZWRITE: A BASIC program that allows you to create VisiCalc data files from numeric arrays.

A detailed description of VisiCalc Plus can be found in Ref. 6.

The HP-87 version of VisiCalc Plus was used to generate the graphs shown in Figures 5.5 and 5.6. A HP-85 version of VisiCalc Plus is available, but was not tested in this study. In order to use VisiCalc Plus to plot the common-emitter amplifier data, the data must be put on disk as a numeric data array. An HP-85 program to take the data samples and write them on a disk correctly formatted is provided in Appendix B. Once the data is on disk it can be used by VisiCalc Plus on a HP-86 or HP-87 microcomputer system. VZWRITE is used to create a VisiCalc data file from the data on the disk. Figures 5.5 and 5.6 show VisiCalc graphs of the common-emitter amplifier data.

Many graphics programs such as VisiCalc Plus are available for data display. The Standard Programming Package for the HP-85 Microcomputer contains some graphics programs which could be used to display acquired test data.
AMPLIFIER FREQUENCY RESPONSE
(Test1 and Test2 data--1/30/85)

VCC = 20 v
VCC = 10 v

Figure 5.5 C-E Amplifier, Low Frequency.
Figure 5.6 C-E Amplifier, High Frequency.
VI. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

It has been demonstrated, for at least a simple experiment, that programmable test equipment could replace the presently used manually operated test equipment. The question that must be answered is, whether replacing current test equipment with programmable test equipment is a good decision in terms of cost compared to benefits received? As has been previously discussed, some of the benefits of a computer controlled system over conventional manual methods are:

(1) More consistent results in repeated measurements, since a computer controlled system is not subject to operator fatigue.

(2) Greater throughput because systems are generally faster.

(3) More thorough testing because system speed allows more parameters to be measured in a shorter time.

(4) Results expressed in engineering or scientific units, since many system controllers are capable of on-line data manipulation.

(5) Greater accuracy because system errors can be measured automatically, stored and accounted for in the results.

(6) Adaptive data acquisition where a system can be programmed to branch to other measurements to help pinpoint the problem when it senses an abnormal condition.
(7) Measurement results can be stored in computer memory, on disk or tape, or on hard copy.

(8) Computer graphics and plotting provide improved data presentation capabilities.

(9) Students would gain some familiarity with the uses and operation of a microcomputer.

Some of the disadvantages of a computer controlled system are:

(1) Cost, since computer-controlled test equipment systems are currently much more expensive than manually operated test equipment. A quick study of Ref. 8 shows HP-IB compatible test equipment to be from two to five times as expensive as similar test equipment without the HP-IB option.

Hewlett-Packard has recently (May, 1985) introduced a new line of programmable test equipment called the PC Instruments system. This equipment is not GPIB compatible without optional hardware, but it does provide computer-controllable test equipment using a different bus structure. The cost of this equipment is roughly twice that of manual test equipment. Hewlett-Packard has software available for several of their computer types for use with this equipment.

(2) Students would not be required to be as familiar with the test equipment if it is computer-controlled.

(3) Students could complete an experiment in a cookbook fashion and not really understand what they are doing.
B. RECOMMENDATIONS

Based on this study the following recommendations are made:

(1) As replacement test equipment is needed, the replacements should be GPIB compatible. The large cost difference between GPIB compatible and manually operated test equipment should become less as GPIB equipment becomes more common. The advantages of computer controlled systems discussed in the previous section are greater than the disadvantages.

(2) Software development should begin immediately covering all the basic electronics laboratories. If the software development is done now it would be available and tested before the equipment is purchased. Even if the decision is made not to purchase GPIB compatible equipment, the software development would be worthwhile material for future thesis students.

(3) Other GPIB compatible test equipment should be purchased and tested. This would ensure that future purchases of large numbers would be based on in-house research and not on slick salesmanship. Also other equipments could lead to uses not currently anticipated.
### APPENDIX A

ASCII & IEEE 488 (GPIB) CODE CHART

<table>
<thead>
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<th>B7</th>
<th>B6</th>
<th>B5</th>
<th>B4</th>
<th>B3</th>
<th>B2</th>
<th>B1</th>
<th>A7</th>
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<th>A4</th>
<th>A3</th>
<th>A2</th>
<th>A1</th>
<th>A0</th>
</tr>
</thead>
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### KEY TO CHART

- **Addressed Commands**
- **Universal Commands**
- **Listen Addresses**
- **Talk Addresses or Commands**

**Octal**: 25 **FFU**: GPIB code

**NAK**: ASCII character

**Hex**: 15 (21) **Decimal**: 25

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APPENDIX B
GPIB PROGRAMS

A. WAVETEK MODEL 270 DEMONSTRATION PROGRAM

The following program provides an introduction to the WAVETEK Model 270 Function Generator using the HP-85 computer as controller.

"WAVETEK Function Generator"

10 ! program to control
20 ! WAVETEK Model 270
30 ! Function Generator
40 CBT IS 1
50 ! Slave WAVETEK to HP-85
60 REMOTE 720 ! assumes WAVETEK address is 20
70 ! Lockout WAVETEK front
80 ! Panel control
90 LOCAL LOCKOUT 7
100 ! Select function
110 CLEAR
120 DISP "ENTER FUNCTION NUMBER"
130 DISP
140 DISP "SINE WAVE = 0"
150 DISP "TRIANGLE WAVE = 1"
160 DISP "SQUARE WAVE = 2"
170 DISP
180 INPUT C
190 CINPUT 720; "C", C
200 ! select amplitude
210 CLEAR
220 DISP "ENTER AMPLITUDE IN VOLS"
230 DISP "(MAX 10 V. PEAK)"

49
240 DISP
250 INPUT A
260 OUTPUT 720; "A", A
270 ! select frequency
280 CLEAR
290 DISP "ENTER FREQUENCY IN HZ"
300 Disp "(MAX 12MHz)"
310 Disp
320 INPUT F
330 OUTPUT 720; "F", F
340 ! select DC offset
350 CLEAR
360 DISP "ENTER DC OFFSET"
370 DISP "(+ OR - 5 V. MAX)"
380 Disp
390 INPUT D
400 OUTPUT 720; "D", D
410 ! select DC offset
420 CLEAR
430 DISP "ENTER 0 TO EXECUTE"
440 DISP "YOUR FUNCTION"
450 DISP "ENTER OTHER THEN 0"
460 DISP "TO CHANGE PARAMETERS"
470 Disp
480 INPUT B
490 IF B <> 0 THEN 110
500 OUTPUT 720; "B", E
510 OUTPUT 720; "P11"
520 ! input status of Wavetek
530 OUTPUT 720; "XT3I"
540 ENTER 720; F, A, D, B, C, P, G
545 !print Wavetek parameters
550 PRINT "WAVETEK PARAMETERS"
560 PRINT
570 IF C=0 THEN LET C$="SINE WAVE"
580 IF C=1 THEN LET C$="TRIANGLE WAVE"
590 IF C=2 THEN LET C$="SQUARE WAVE"
600 PRINT "FUNCTION",C$
610 PRINT "FREQUENCY(Hz)",F
620 PRINT "AMPLITUDE(VOLTS)",A
630 PRINT "DC OFFSET(VOLTS)",D
640 PRINT
650 CLEAR
660 ! ask for next function
670 DISP "DO YOU WISH TO ENTER"
680 DISP "ANOTHER FUNCTION (Y/N) ?"
690 INPUT Y$
700 IF Y$="Y" THEN 110
710 CLEAR
715 ! store function in memory
720 DISP "DO YOU WISH TO STORE"
730 DISP "YOUR FUNCTION IN MEMORY"
740 DISP "(Y/N) ?"
750 INPUT N$
760 IF N$="N" THEN 860
770 CLEAR
780 DISP "ENTER MEMORY ADDRESS"
790 DISP "(1 TO 80)"
800 INPUT M
820 CLEAR
830 DISP "YOUR FUNCTION IS"
840 DISP "STORED IN MEMORY"
850 DISP "LOCATION: ",M
860 DISP
865 ! recall a function from memory
870 DISP "DO YOU WISH TO"
880 DISP "RECALL AND EXECUTE"
890 DISP "A PROGRAM STORED IN"
900 DISP "WAVETEK MEMORY(Y/N) ?"
910 INPUT NS
920 IF NS="N" THEN 1130
930 CLEAR
940 DISP "ENTER MEMORY LOCATION"
950 DISP "OF STORED FUNCTION"
960 INPUT Y
970 OUTPUT 720; "Y",Y,"I"
980 CLEAR
990 DISP "FUNCTION FROM MEMORY"
1000 DISP "LOCATION: ",Y
1010 DISP "IS NOW BEING EXECUTED"
1020 DISP
1030 DISP "DO YOU WISH TO RECALL"
1040 DISP "ANOTHER FUNCTION (Y/N)?"
1050 DISP
1060 INPUT Y$
1070 IF Y$="Y" THEN 940
1080 CLEAR
1130 DISP "DO YOU WISH TO ENTER"
1140 DISP "ANOTHER FUNCTION (Y/N)?"
1150 INPUT Y$
1160 IF Y$="Y" THEN 110
1170 DISP "GOODBYE"
1180 STOP
1190 END
B. PS 5010 AND DM 5010 DEMONSTRATION PROGRAM

This program demonstrates some of the capabilities of the Tektronix PS 5010 Programmable Power Supply and the DM 5010 Programmable Digital Multimeter. The HP-85 computer is assumed as controller. If some other controller is used, the code may need modification.

10 ! Program to demonstrate
20 ! the PS 5010 and DM 5010
30 ! Addresses must be
40 ! DM = 16
50 ! PS = 22
60 ! must poll PS & DM
70 ! before sending any inst.
80 ! after power up
90 S=SFCLL(716)
100 S=SFOLL(722)
115 ! set PS to power-on state
110 CUTFUT 722;"INIT"
120 PRINT
130 CLEAR
135 ! logic supply demo
140 DISP "CONNECT DM TO LOGIC SUPPLY"
150 DISP
160 DISP "ENTER LOGIC SUPPLY VOLTAGE"
170 DISP "(+4.5 TO +5.5 VOLTS)"
180 INPUT L
190 IF L>=4.5 AND L<=5.5 THEN 230
200 DISP "YOU HAVE MADE AN ERROR"
210 DISP "TRY AGAIN"
220 GOTO 150
225 ! set DM to read dc volts
230 CUTFUT 716;"DCV"
235 ! set PS logic supply
240 CUTFUT 722;"VLOG",L
245 ! turn PS output on
250 OUTPUT 722;"OUT ON"
252 ! delay to give meter time
253 ! tc read voltage
255 WAIT 1000
260 ! enter meter reading
270 OUTPUT 716;"SEND"
280 ENTER 716;A$
290 PRINT "LOGIC VOLTAGE IS:"A$
300 PRINT
310 DISP
320 DISP "THE DM READING SHOULD AGREE"
330 DISP "WITH THE PRINTOUT AND THE"
340 DISP "LOGIC SUPPLY DISPLAY"
350 DISP
360 DISP "DO YOU WISH TO TRY AGAIN(Y/N)?"
370 INPUT Y$
380 IF Y$="Y" THEN 150
385 ! set PS to power-on state
390 OUTPUT 722;"INIT"
400 CLEAR
405 ! negative supply demo
410 DISP "CONNECT DM TO NEGATIVE"
420 DISP "FLOATING SUPPLY"
430 DISP
440 DISP "ENTER NEGATIVE VOLTAGE"
450 DISP "(0 TO -32 VOLTS)"
460 INPUT N
465 ! check for input within tolerance
470 IF ABS(N)>=0 AND ABS(N)<=32 THEN 510
480 DISP "YOU HAVE MADE AN ERROR"
490 DISP "TRY AGAIN"
500 GOTO 430
505 ! set negative supply voltage
510 OUTPUT 722;"VNEG",N
515 1 turn on PS output
520 OUTPUT 722;"OUT ON"
525 1 delay for meter
530 WAIT 1000
535 1 read DM
540 OUTPUT 716;"SEN I"
550 ENTER 716;N$
560 PRINT "NEGATIVE VOLTAGE IS:" ,N$
570 PRINT
580 DISP "TRY ANOTHER VALUE (Y/N) ?"
590 INPUT Y$
600 IF Y$="Y" THEN 400
605 1 set PS to power-on state
610 OUTPUT 722;"INIT"
620 CLEAR
630 1 positive supply
640 DISP "CONNECT DM TO POSITIVE"
650 DISP "FLOATING SUPPLY"
660 DISP
670 DISP "ENTER DESIRED VOLTAGE"
680 DISP "(0 TO 32 VCLTS)"
690 DISP
700 INPUT P
705 1 check for input within tolerance
710 IF P>=0 AND P<=32 THEN 750
720 DISP "YOU HAVE MADE AN ERROR"
730 DISP "TRY AGAIN"
740 GOC 660
745 1 set positive supply voltage
750 OUTPUT 722;"VPOS",P
760 OUTPUT 722;"OUT ON"
765 1 delay for meter
770 WAIT 1000
775 1 read DM
780 OUTPUT 716;"SEND"
790 ENTER 716;PS
800 PRINT
810 PRINT "POSITIVE VOLTAGE IS:";PS
820 DISP "DO YOU WISH TO CHANGE VPOS"
830 DISP "(Y/N) ?"
840 INPUT Y$
850 IF Y$="Y" THEN 660
860 OUTPUT 722;"INIT"
870 CLEAR
880 DISP "GOODBYE"
890 END
C. 488XLI AND 22XLA DEMONSTRATION PROGRAM

This program provides a simple demonstration of some of the capabilities of the Photodyne 488XLI and 22XLA combination. An input may be provided to the 22XLA but is not necessary for this demonstration.

10 ! 488XLI and 22XLA Demonstration
20 ! Non-trigger address is 02
30 ! Termination sequence is CR-LF
35 ! Set termination sequence
40 CONTROLL 7,16,: 130,13,10
50 CLEAR
60 DISP "488XLI SAMPLE PROGRAM"
70 ! read data from 22XLA via 488XLI
80 ENTER 702;A
90 LET A=A/100
100 ! Display data on CRT
110 DISP USING 120;A
120 IMAGE DDDD.DD,"LEM"
130 GOTO 70
140 END
D. PROGRAM TO DEMONSTRATE THE HP-9111A GRAPHICS TABLET.

This program demonstrates some of the uses of the Hewlett-Packard Model 9111A Graphics Tablet when used with the HP-85 Microcomputer. The HP-85 and HP-9111A are the only equipment needed for this program. This program is a modification of a program found in Ref. 9.

10 ! program for 9111A Graphics
20 ! Tablet
30 ! Tablet address = 06
35 ! Print softkey menu
40 PRINT "SOFTKEY 1 = COPY CRT TO PRINTER"
50 PRINT "SOFTKEY 2 = ERASE CRT AND CLEAR FILES"
60 PRINT "SOFTKEY 3 = SINGLE-SAMPLE MODE"
70 PRINT "SOFTKEY 4 = SWITCH-FOLLOW,"
80 PRINT "CONTINUOUS-SAMPLE MODE"
90 PRINT "SOFTKEY 5 = SWITCH-NORMAL,"
100 PRINT "CONTINUOUS-SAMPLE MODE"
105 ! set variables and IC's
110 CPTCN BASE 0
120 DIM K$(25)
130 K$="BP36,50,3;BP34;BP32;BP30"
140 SHORT X(1000),Y(1000),
150 INTEGER P(1000)
160 X(0),Y(0),P(0),J,F1=0
170 FLOTTER IS 1
175 ! initialize tablet
180 OUTPUT 706;"IN:CN:SF"
185 ! initialize graph
190 GCLEAR
200 GRAPH
210 LIMIT 0,97,0,70
220 FRAME
230 SCALE 0,301,0,218
240 FOR I=1 TO 5
250 READ V
260 I$[I,I]=CHR$(V)
270  NEXT I
280 DATA 4,4,31,4,4
285  ! check for interrupt
290 CN INTR 7 GOSUB 390
300 OUTPUT 706;"IN,132"
310  ENABLE INTR 7,8
315  ! input tablet coordinates
320 OUTPUT 706;"OC" 2 ENTER 706;x,y
330 X=X/40  & Y=Y/40
340 IF X<5 OR X>300 THEN 320
350 IF Y<1 OR Y>216 THEN 320
360 MOVE X-5,Y+2  @ BPL  T$,1 & MOVE
   X-5,Y+2  @ BPL  T$,1
370 GOTO 320
380  ! Check status of interrupt
390 STATUS 7,1;A
400 OUTPUT 706;"OS"
410 ENTER 706;S1
420 IF BIT(S1,2) THEN GOSUB 450
430 IF BIT(S1,7) THEN GOSUB 530
440  ENABLE INTR 7,8 & RETURN
450 IF F1=1 THEN PLCT X(J),Y(J),P(J)
460 J=J+1
470 IF J>1000 THEN 590
480 OUTPUT 706;"OD"
490 ENTER 706;S,T,U
500 X(J)=S/40  & Y(J)=T/40  & P(J)=U
510 FLOT X(J),Y(J),P(J)
520 RETURN
530 OUTPUT 706;"RS1"
540 ENTER 706;K
550 OUTPUT 706;K$
560  ! Call subroutine dependant on menu softkey
570     CH K GOSUB 670,700,750,800,850,730,730,730,
        730,730,730,730,730,730,730,730
580     RETURN
590     GCLEAR
600     FRAME
610     MOVE X(1),Y(1)
620     FOR J=1 TO 1000
630     PLOT X(J),Y(J),P(J)
640     NEXT J
650     END
660     ! Subroutine to copy graph
670     COPY
680     RETURN
690     ! Subroutine to clear graph
700     GCLEAR
710     FRAME
720     J=0
730     RETURN
740     ! Subroutine for single-sample mode
750     OUTPUT 706;"SG"
760     F1=1
770     P(J)=0
780     RETURN
790     ! Subroutine for switch-follow, continuous-sample mode
800     OUTPUT 706;"CN:SF"
810     F1=0
820     P(J)=0
830     RETURN
840     ! Subroutine for switch-normal, continuous-sample mode
850     OUTPUT 706;"CN:SN"
860     F1=0
870     P(J)=0
880     RETURN
B. FREQUENCY-VS-GAIN PROGRAM (PRINTED OUTPUT)

This program will test and print out the frequency and gain at that frequency for a circuit connected to the programmable test equipment:

10 ! Program for freq-gain
20 ! Test equipment addresses
30 ! Function generator = 20
40 ! Power supply = 22
50 ! Multimeter = 16
60 ! Poll test equipment
70 LOCAL LOCKOUT 7
80 S=SPOLL(722)
90 S=SPOLL(716)
100 ! Initialize test equipment
110 OUTPUT 716;"ACV"
120 OUTPUT 722;"INIT"
130 ! Set power supply
140 CLEAR
150 DISP "ENTER NEGATIVE VOLTAGE"
160 DISP "(0 TO -32 VOLTS)"
170 INPUT N
175 ! check input within tolerance
180 IF ABS(N) <= 32 THEN 220
190 DISP "YOU HAVE MADE AN"
200 DISP "INCORRECT ENTRY"
210 GOTO 150
220 OUTPUT 722;"VNEG",N
230 DISP "ENTER POSITIVE VOLTAGE"
235 DISP "(0 TO 32 VOLTS)"
240 INPUT P
245 ! input within tolerance?
250 IF P>=0 AND P<=32 THEN 290
260 DISP "YOU HAVE MADE AN"
270 DISP "INCORRECT ENTRY"
280 GOTO 230
290 OUTPUT 722: "VPOS", P
300 ' Enter other parameters
310 DISP "ENTER STARTING FREQUENCY"
320 INPUT F1
330 DISP "ENTER ENDING FREQUENCY"
340 INPUT F2
345 ' check frequencies
350 IF F1<F2 THEN 400
360 DISP "ENDING FREQUENCY IS"
370 DISP "LESS THEN STARTING"
380 DISP "FREQUENCY"
390 GOTO 310
400 DISP "ENTER NUMBER OF POINTS"
410 DISP "(100 POINTS IS USUALLY ENOUGH)"
420 INPUT N1
430 ' Display parameters
440 CLEAR
450 DISP "NEGATIVE VOLTAGE =", N
460 DISP "POSITIVE VOLTAGE =", P
470 DISP "STARTING FREQ =", F1
480 DISP "ENDING FREQ =", F2
490 DISP "# OF POINTS =", N1
500 DISP
510 DISP "DO YOU WISE TO CHANGE"
520 DISP "(Y/N)?"
530 INPUT Y$
540 IF Y$="Y" THEN 140
550 ' Turn on power supply
560 OUTPUT 722: "OUT CH"
570 ' Set up function generator
580 OUTPUT 720; "COA1C0F", F1, "P1I"
590 ' Start taking data
600 PRINT
610 PRINT "FREQUENCY-VS-GAIN"
620 PRINT "FREQ:               GAIN:"
630 F2=F1
640 B=(F2-F1)/(N1-1)
650 FOR I=1 TO N1
660 WAIT 1000
665 I read meter
670 CUTPUT 716;"SEN1"
680 ENTER 716;P1
685 I compute gain
690 G=20*LOG(P1*P1 /.5)
695 I print frequency and gain
700 PRINT USING 710;F2,G
710 IMAGE DDDDDDD.D,"Hz",DDDD.DD,"dB"
720 F2=INT(B)*I+F1
725 I set 270 to next frequency
730 CUTPUT 720;"F",P2,"I"
740 NEXT I
750 DISP "DO YOU WISH ANOTHER RUN"
760 DISF "(Y/N)?"
770 INPUT Y$
780 IF Y$="Y" THEN 100
790 DISF "GOODBYE"
800 END
I. FREQUENCY-VS-GAIN PROGRAM (GRAPH OUTPUT)

This program is a modification of the frequency-vs-gain program of Section E using the HP-85 graphics capabilities. The data points are graphed on the computer display and then the display is copied on the printer.

10 ! Program for freq-gain (graphic)
20 ! Test equipment addresses
30 ! Function Generator = 20
40 ! Power Supply = 22
50 ! Multimeter = 16
60 ! Pcll test equipment
70 LOCAL LOCKOUT 7
75 ! initialize variables
80 DIM P1(2,150)
90 S=SPOLL (722)
100 S=SPOLL(716)
110 ! Initialize test equipment
120 OUTPUT 716;"ACV"
130 CUTPUT 722;"INIT"
140 ! Set Power Supply
150 CLEAR
160 DISP "ENTER NEGATIVE VOLTAGE"
170 DISP "(0 TO -32 VOLTS)"
180 INPUT N
185 ! input within tolerance?
190 IF ABS(N)<=32 THEN 230
200 DISP "YOU HAVE MADE AN"
210 DISP "INCORRECT ENTRY"
220 GOTO 160
230 CUTPUT 722;"VNEG",N
240 DISP "ENTER POSITIVE VOLTAGE"
250 INPUT P
255 ! Check if input within tolerance
260 IF P>=0 AND P<=32 THEN 300
DISP "YOU HAVE MADE AN"
DISP "INCORRECT ENTRY"
GOTC 240
OUTPUT 722;"VPOS",P
! Enter other parameters
DISP "ENTER STARTING FREQUENCY"
INPUT F1
DISP "ENTER ENDING FREQUENCY"
INPUT F2
! check frequency order
IF F1<F2 THEN 410
DISP "ENDING FREQUENCY IS"
DISP "LESS THEN STARTING"
DISP "FREQUENCY"
GOTO 320
DISP "ENTER NUMBER OF POINTS"
DISP "(150 POINTS MAX)"
DISP "(100 POINTS IS USUALLY PLENTY)"
INPUT N1
! Display parameters
CLEAR
LISP "NEGATIVE VOLTAGE =",N
DISP "POSITIVE VOLTAGE =",P
DISP "STARTING FREQ =",F1
DISP "ENDING FREQ =",F2
DISP "# OF POINTS =",N1
LISP
DISP "DO YOU WISH TO CHANGE"
DISP "(Y/N) ?"
INPUT Y$
IF Y$="Y" THEN 150
! Turn on power supply
OUTPUT 722;"OUT CN"
! Set up function generator
OUTPUT 720;"COA1E0F",F1,"P1I"
610 ! Start taking data
620 PRINT
630 PRINT "FREQUENCY-vs-GAIN"
640 PRINT "FREQ: GAIN:
650 F1(1,1)=F1
660 B=(F2-F1)
670 FOR I=1 TO N1
675 ! delay for meter
680 WAIT 1000
690 OUTPUT 716;"SEND"
700 ENTER 716;G
705 ! compute gain
710 F1(2,I)=20*LOG(G*G/0.5)
715 ! print frequency and gain
720 PRINT USING 730;P1(1,I),P1(2,I)
730 IMAGE DDDDDDD.D,"Hz",DDDD.DD,"dB"
740 P1(1,I+1)=INT(B/(N1-1))*F1
745 ! set 270 to next frequency
750 OUTPUT 720;"F",F1(1,I+1),"I"
760 NEXT I
770 ! initialize plot
780 GCLEAR
790 SCALE F1-2*B,F2,-20,110
800 XAXIS 0,.1*B
810 YAXIS 0,10
815 ! plot points stored
817 ! in array p1
820 FOR I=1 TO N1
830 PLOT P1(1,I),P1(2,I)
840 NEXT I
850 PENUP
855 ! label plot
860 LDIR 0
870 MOVE .3*B,80
880 LABEL "MAG(dB) vs FREQ"
G. FREQUENCY-VS-GAIN PROGRAM (DISK OUTPUT)

This program is a modification of an earlier frequency-vs-gain program. This program writes a file onto a disk which is compatible with the VWRITE subprogram of VisiCalc Plus. Output is stored by rows, frequency and then gain. The data disk is assumed to be "INITIALIZED" and the microcomputer must be using that disk as its mass storage device.

10 ! Program for Freq-Gain (disk)
20 ! Test equipment addresses
30 ! Function Generator = 20
40 ! Power Supply = 22
50 ! Multimeter = 16
60 ! Pcll test equipment
70 LOCAL LOCKOUT 7
80 S=S$POLL(722)
90 S=S$POLL(716)
100 ! Initialize test equipment
110 OUTPUT 716;"ACV"
120 OUTPUT 722;"INIT"
130 ! Set Power Supply
140 CLEAR
150 DISP "ENTER NEGATIVE VOLTAGE"
160 DISP "(0 TO -32 VOLTS)"
170 INPUT N
175 ! input within tolerance?
180 IF ABS(N) <=32 THEN 220
190 DISP "YOU HAVE MADE AN"
200 DISP "INCORRECT ENTRY"
210 GOTO 150
215 ! Set negative supply
220 OUTPUT 722;"VNEG",N
230 DISP "ENTER POSITIVE VOLTAGE"
235 DISP "(0 TO 32 VOLTS)"
240 INPUT P

68
245  I input within tolerance?
250  IF F>=0 AND P<=32 THEN 290
260  DISP "YOU HAVE MADE AN"
270  DISP "INCORRECT ENTRY"
280  GOTO 230
285  I set positive supply
290  OUTPUT 722:"VPOS",P
300  I Enter other parameters
310  DISP "ENTER STARTING FREQUENCY"
320  INPUT F1
330  DISP "ENTER ENDING FREQUENCY"
340  INPUT F2
345  I frequencies in order?
350  IF F1<F2 THEN 400
360  DISP "ENDING FREQUENCY IS"
370  DISP "LESS THEN STARTING"
380  DISP "FREQUENCY"
390  GOTO 310
400  DISP "ENTER NUMBER OF POINTS"
405  DISP "(MAX 150)"
410  DISP "(100 POINTS IS USUALLY PLENTY)"
420  INPUT N1
430  I Input disk filename
440  DISP "ENTER FILENAME FOR DISK"
450  INPUT A$
460  I Display parameters
470  CLEAR
480  DISP "NEGATIVE VOLTAGE =",N
490  DISP "POSITIVE VOLTAGE =",P
500  DISP "STARTING FREQ =",F1
510  DISP "ENDING FREQ =",F2
520  DISP "# OF POINTS =",N1
530  DISP "FILENAME =",A$
540  DISP
550  DISP "DO YOU WISH TO CHANGE"
560 DISP "(Y/N)?"
570 INPUT Y$
580 IF Y$="Y" THEN 140
590 ! Turn on power supply
600 OUTPUT 722;"OUT CN"
610 ! Set up function generator
620 OUTPUT 720;"COA1BOF",F1,"P1I"
630 ! Set up disk
640 CREATE A$,300,10
650 ASSIGN# 1 TO A$
660 ! Start taking data
670 PRINT
680 PRINT "FREQUENCY-vs-GAIN"
690 PRINT "FREQ GAIN"
700 F2=F1
710 P=(F2-F1)/(N1-1)
720 FOR I=1 TO N1
725 ! delay for meter
730 WAIT 1000
735 ! read meter
740 OUTPUT 716;"SENI"
750 ENTER 716;P1
755 ! compute gain
760 G=20*LOG(P1*P1/.5)
770 PRINT USING 810;P2,G
780 ! Write to disk
790 PRINT# 1,2*I-1;P2
800 PRINT# 1,2*I;G
810 IMAGE DDDDDDD-.D,"Hz",DDDD.DD,"dB"
820 F2=INT(B)*I+F1
825 ! set 270 to next frequency
830 OUTPUT 720;"F",P2,"I"
840 NEXT I
850 ! Close disk file
860 ASSIGN# 1 TO *
870 DISP "DO YOU WISH ANOTHER RUN"
880 DISP "(Y/N) ?"
890 INPUT Y$
900 IF Y$="Y" THEN 100
910 DISP "GOODBYE"
920 END
LIST OF REFERENCES


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