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PROGRAMMABLE DATA ACQUISITION
SYSTEM FOR MICROWAVE CALIBRATION

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Metrology Laboratory Report MEP 74-78

J. W. Cable, Project Leader

Project Team:
J. Andregg
D. W. Stone

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Prepared by J. W. Cable, D/423

A fully automated, programmable data acquisition system has been developed to record by printout or on punched paper tape the data for microwave power calibration. The system programs, controls, and receives BCD, analog, and ASCII information from external instrumentation. Construction, requirements, and operation of the system are described, and wiring diagrams are included.

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SUMMARY

The calibration of microwave power-measuring instruments requires the rapid acquisition of data from several analog sources in a precisely timed, prescribed sequence. A fully automated, programmable data acquisition system therefore was designed and constructed to record by printout or on punched paper tape the data for microwave power calibration. Design objectives have been met or surpassed. The time required for data-taking has been greatly reduced from the time required by manual methods.

The data acquisition system has the capability for programming, controlling, and receiving BCD, analog, and ASCII information from external instrumentation. It provides a bidirectional link with all of the interface devices and controls the scanning and output of the analog channels; the relay-contact closure for the circuit switching; and the input, transfer, and output of information for the measuring, programming, and recording devices.

The system operates in a normal laboratory temperature with less than 500 W of power at a standard 115-Vac line voltage. The ROM control card can be programmed for approximately 2000 steps, and has subroutine and transfer characteristics which increase the efficiency of the operation. Data can be transferred internally at a speed of 200,000 characters per second and can be recorded at a rate of ten characters per second. The diagnostic panels permit program checkout before or during program execution.

This report describes the construction, requirements, and operation of the system. Wiring diagrams are included.

DISCUSSION

SCOPE AND PURPOSE

The calibration of microwave power-measuring instruments requires the rapid acquisition of data from several analog sources in a precisely timed, prescribed sequence. The accuracy of the system is enhanced by repeating the measurement cycles and later averaging the results. Because of the large quantity of data needed for proper evaluation, an excessive amount of time would be required for the data to be taken manually. The data acquisition system therefore was designed and constructed to fulfill the following design objectives:

- Rapid acquisition of analog data from at least ten different sources;
- Programmable control unit;
- Relay control unit;
- Printed and punched-paper-tape outputs;
- Internal timing unit; and
- Real-time analysis.

PRIOR WORK

A read-only memory (ROM) implementation study produced a ROM program card with electrically alterable ROM units.¹ A similar card was used as the major program source for the data acquisition system. Required changes and modifications are described, in detail, in this report.

ACTIVITY

Description

The data acquisition system is fully automated and has the capability for programming, controlling, and receiving BCD (binary-coded decimal), analog, and ASCII (American Standard Code for Information Interchange) information from external instrumentation, and for recording this information in the form of a punched paper tape or a printed output. The system controls the scanning and output of the analog channels; the relay-contact closure for the circuit switching; and the input, transfer, and output of

information for the measuring, programming, and recording devices. A block diagram of the data acquisition system is shown in Figure 1.

An internally and externally programmable control unit (Hewlett-Packard Model 2570A)² was used for the basic framework of the data acquisition system. This control unit has an ASCII back-plane to which the following peripheral interface equipment was attached: a binary-coded data-input unit (Hewlett-Packard Model 12797A) with sixteen independent floating-contact closures; a programmable channel scanner (Hewlett-Packard Model 12803A) with 10-channel reed relays; a clock/timer/pacer (Hewlett-Packard Model 12811A) with pacing, time-interval, and logging capability; a teleprinter interface (Hewlett-Packard Model 12801A); a calculator interface to a Hewlett-Packard 9100 Series calculator (Hewlett-Packard Model 12802A); and a ROM control card unit. Other major components consist of a teleprinter with keyboard, printer, tape punch, and tape reader (Hewlett-Packard Model 2752A); an auto-ranging digital voltmeter (Hewlett-Packard Model 3490A); a controller-diagnostic panel; and a ROM display panel.

The data acquisition system provides a bidirectional link with all of the interface devices. It operates in a normal laboratory temperature with less than 500 W of power at a standard 115-Vac line voltage. The ROM control card can be programmed for approximately 2000 steps, and it has subroutine and transfer characteristics which increase the efficiency of the operation. Data can be transferred internally at a speed of 200,000 characters per second and can be recorded as a printed output or on punched paper tape at a rate of ten characters per second. The diagnostic panels permit program checkout before or during program execution.

The following five sections of this report outline the electrical and mechanical design features and operating characteristics, performance requirements, construction requirements, required environment and utilities, and special requirements for the data acquisition system. The final section describes the operation of the system and the necessary modifications.

Design Features and Operating Characteristics

BCD Interface

- Receives and stores digital output from the system digital voltmeter (DVM) and existing DVMs, counters, etc, and converts it to ASCII; also provides data-format control and insertion of special characters.
- Accepts up to ten +8421 BCD digits in parallel operations.
- Provides flexibility in data format.

Figure 1. Block Diagram of Data Acquisition System

- Identifies source.
- Provides buffer data storage.
- Provides up to 13 ASCII characters, including special characters.
- Makes diode-transistor logic (DTL) and transistor logic (TTL) compatible.

Relay Register

- Has 16 ASCII programmable contact closures with predetermined initial states.
- Has floating contacts.
- Provides contact closure to ground, which occurs after relays have been programmed, for controlling external devices.

Channel-Scanner Relay

- Switches ten analog channels in a selectable sequence to a measuring instrument (system DVM).
- Provides automatic channel identification for recording, when needed.
- Consists of A-form, two pole relays with a two-line, common output bus.

Teletype Interface

- Converts eight-bit-serial ASCII to eleven-bit-serial ASCII.
- Converts eleven-bit-serial ASCII to eight-bit-serial ASCII.
- Provides eight-bit buffer data storage.
- Controls teletype, tape punch, and tape reader.
- Allows teletype system to act as the control unit.

Teletype Keyboard and Printer

- Sends and receives automatically.
- Has friction feed for paper.
- Has a typing rate of ten characters per second.

Tape Punch

- Operates automatically.
- Corrects errors.
- Has provision for chad collection.

Tape Reader

- Operates automatically.
- Has a tight-tape switch.
- Has an out-of-tape switch.

Control Unit

- Is internally programmable.
- Is externally programmable by teletype interface.
- Controls five interfacing units.
- Transfers data in ASCII.

Digital Voltmeter

- Has parallel BCD output to interface.
- Measures ac and dc voltage.
- Has 5-1/2 digit readout with 20-percent overrange.
- Has a variable measurement speed from one to five readings per second on all ranges.
- Has provision for manual, automatic, and remote range selection.
- Has 0.1-, 1-, and 10-Vdc ranges.
- Has 1- and 10-Vac ranges.
- Parallel input terminals are available at both front and rear.
- Provides sample/hole-capability.

Read-Only Memory

- Interfaces with ASCII control unit.
- Has reprogrammable memory units.
- Transfers preprogrammed control steps to control unit.
- Has capability for memory expansion to 4K words (eight-bit).
- Is externally addressable for diagnostic analysis.

Clock/Timer/Pacer

- Provides capability for days, hours, minutes, seconds, and tenths of seconds.
- Is compatible with control unit.
- Has internal line reference.
- Has a clock-error indicator.
- Provides selectable timing and pacing intervals.

Calculator Interface Card

- Is capable of transferring data and program instructions to and from the control unit to a HP 9100 calculator.
- Is capable of transferring 18 characters from the calculator memory at one time.

Control-Unit Diagnostic Display

- Displays logic states present on the ASCII bus.
- Is compatible with control unit.
- Has capability for reset, start, and stop functions on control unit in local or remote modes of operation.

Read-Only-Memory Diagnostic Display

- Displays program words, presenting ROM and ASCII bus in decimal form.
- Is addressable in octal code from front-panel switches.
- Displays addresses inserted or present.

Performance Requirements

BCD Interface

- Transfer time is ± 1 ms.
- Record command has a minimum amplitude of ± 4 V with a rise-time of $10 \text{ V}/\mu\text{s}$ and a duration of $10 \mu\text{s}$.
- Hold-off command is ± 15 V or -9.6 V from a $1\text{-k}\Omega$ source.
- Maximum input voltage is ± 20 V.

Relay Register

- Minimum continuous-current rating per contact is 500 mA.
- Voltage rating is 100 V peak or continuous across open contacts, between connectors, and with respect to controller ground.
- Settling time for pull-in and drop-out is ≤ 1 ms.
- Drive-output-current capability is at least 17 mA through 220Ω .

Scanner

- Has a scanning rate of 300 channels/second.
- Open-circuit voltage rating is 120 V.
- Short-circuit current rating is 75 mA at 2.5 W.
- Frequency range is 5×10^4 Hz with an error $< 10^{-4}$ for a $1\text{-k}\Omega$ resistive load.

Digital Voltmeter

- Minimum accuracy for a 90-day period: 0.1-Vdc range, ± 0.01 percent of reading plus 0.005 percent of range; 1- and 10-Vdc ranges, ± 0.01 percent of reading plus 0.002 percent of range; 1- and 10-Vac ranges, ± 0.1 percent of reading plus 0.025 percent of range, 0.05 to 30 kHz.
- Input impedance: $> 10^{10} \Omega$ for all dc ranges; $> 1 \text{ M}\Omega$ for all ac ranges.

Read-Only Memory

- Contains 15 or more starting addresses.
- Has internal subroutine capability.
- Has internal jump and transfer capability.

Clock/Timer/Pacer

- Includes external emergency power-supply capability of 5.0 Vdc at 1 A.
- Provides normalized reset and remote start to override delays to return to control unit.

Calculator Interface

- Is programmable.
- Provides selectable addressing.

Construction Requirements

System

- Requires 483-mm (19-inch) rack mount.
- Teletype is free-standing.

Components

- Requires BCD interface cable for system DVM.
- Requires relay-register input connector.
- Requires circuit-board extenders for maintenance.

Environmental and Electrical Requirements

- Operating-temperature range is from 10.0 to 32.2°C (50 to 90°F) ambient, outside cabinet.
- Storage-temperature range is from 4.4 to 37.8°C (40 to 100°F).
- Relative humidity must be no greater than 90 percent at 37.8°C (100°F).

- Line-voltage requirement is 115 Vac ± 10 percent at 60 Hz.
- Power is ≤ 500 W maximum, continuous.

Special Requirements

- Provides a bidirectional link with all interface devices.
- Provides the necessary interface-control signals for all input/output operations.
- Is capable of expansion to include a total of eight input/output devices of the type described.
- Accepts interfaces that are compatible with time-sharing computers and calculators.

System Operation and Modifications

The coupler-controller unit is the basis of the data acquisition system and contains the control card, the buss-plane connectors, card slots for eight interfacing card units, and a system clock.² It controls the input and output of all interface cards by address and by commands relayed along the backplane buss.

The teleprinter interface, when inserted in a coupler slot and coupled to an external teleprinter, provides external communication with the keyboards and the paper-tape reader and punch, and it assumes control of and acquires information from the buss-plane of the coupler.

The calculator interface, when connected to the coupler and a suitable calculator (such as the HP9100 series), may assume control and act as a processor for the data system. With the calculator peripherals of extended memory, printer, and X-Y plotter, data may be manipulated and results acquired in a real-time system operation.

ROMs are contained on the card within the ROM interface. These may be reprogrammed externally, inserted on the card, and then given control of the system to rapidly process long strings of commands in a predetermined sequence.

Changes in the original design included the relocation of the ROMs to a sequence that is easily identifiable on the board (Table 1), and the connection of +5- and +9-Vdc supplies through the front-edge connectors to the diagnostic panel. The following additional connections were made from the V_{cc} (+5 Vdc) power supply:

Table 1. ROM Location Changes

Address	Revised Location	Original Location
0000 to 0377	1	1
0400 to 0777	2	5
1000 to 1377	3	2
1400 to 1777	4	6
2000 to 2377	5	3
2400 to 2777	6	7
3000 to 3377	7	4
3400 to 3777	8	8

- J2 Connector Pins 26-27-28-29, 87-89, and 88; and
- Board Pins V on Row B, and V on Row W.

The following ground connections were added:

- J2 Connector Pins 4-65, 52-113, 53, and 66; and
- Board Pins G on Row H, and G on Row P.

Pin 5 of U3 on the original drawing was disconnected from Pin 5 of U11 and reconnected to Pin 2 of U32 to allow proper addressing. These described changes, together with those shown in Tables 1, 2, and 3 of this report, give the entire rewiring scheme in relation to the original drawings.¹

The ROM-card diagnostic panel (Figures 2, 3, and 4) is connected to the front-edge connector of the ROM card, as previously stated, and it facilitates the observation of commands from the ROM card to the coupler while supplying the 9 Vdc that is required to operate the ROMs. Data from the ROMs are read by light-emitting-diode (LED) indicators which decode the ROM words to octal code. This panel also contains a switch register which may be used to gain access to the ROM at specific addresses to check the contents. Power for the LED display (5 Vdc) is carried from the coupler to the panel by the front-edge connector. Figures 1 and 2 show the wiring of the circuits.

Table 2. Additional
Connections
From J1 to
Board

J1 Contact	J1 Pin	Board Pin
C	A	B59
J	K	L54
K	K	L55
L	K	L56
M	K	L57
N	K	L58
S	25	E26

The controller diagnostic panel (Figures 5 and 6) monitors the coupler signals through the use of LED indicators which may be decoded to determine the command and card for which a specific instruction has been initiated. The panel also contains mode, reset, and start switches for easy access. Wiring diagrams are shown in Figures 3 and 4.

The clock/timer/pacer card allows program-timing control of delays for stabilization and interactive demands of the operator. It may be connected to the ROM diagnostic panel as shown in Figure 5 to provide a time-and-day indication. The 16-bit relay register provides 16 parallel, isolated contact closures which can be controlled from the previously described sources to operate the relays and switches in an efficient manner.

The 10-channel scanner provides a means of sampling a large number of analog signals with the use of only one analog/digital (A/D) converter. The BCD interface with an A/D or digital voltmeter provides the data system with a measurement capability which is expanded by the scanner.

ACCOMPLISHMENTS

A fully automated, programmable data acquisition system for microwave power calibration has been designed, constructed, and tested. Design objectives have been met or surpassed. The

Table 3. Changes in Board Connections*

Board-Pin Reference	Connection Removed From Indicated Pin	Connection Made to Indicated Pin
B51	B52, V52-B	E51
B53	B59	V52-B, V30
B59	B60	B51
B60		V52-B
E51	V52-B	
S19	U18	V30
U18		V23
V53	W23	V30

*In addition to the changes indicated in this table, the connection from Pin 14 to Pin 15 on Unit 28 was removed, and all Pin-3 connections between all ROMs (Units 43 through 50) were removed.

time required for data-taking has been greatly reduced from the time required by manual methods.

The system that has been constructed is now being used in the development of a new power-calibration system.

FUTURE WORK

Additional programs should be developed to increase the flexibility and utilization of the data acquisition system. Consideration should be given to extending the capability of the system by interfacing it with a computer.

Figure 2. ROM Diagnostic Switch Register

Figure 3. ROM Diagnostic Display Indicators

Figure 4. Clock/Timer/Pacer Elapsed-Time Indicator

Figure 6. Wiring Diagram of Logic Indicators

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¹J. D. Anderson, *Read-Only Memory Implementation Study* (Final Report). UNCLASSIFIED. Bendix Kansas City: BDX-613-1053 (Rev.), August, 1974 (Available from NTIS).

²*Hewlett Packard 2570A Coupler Controller System Manual*. Palo Alto, California: Hewlett Packard Company, 1971.

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