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Traveling-Wave Maser Closed-Cycle Refrigerator Data Acquisition and Display System

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This report describes a data acquisition and display system that automatically monitors the performance of the 4.5-K closed-cycle refrigerators used to cryogenically cool traveling-wave masers. The system displays and stores operating parameters for the purpose of providing status information, failure prediction, and analysis. A prototype of this system will be installed at DSS 12 in the near future. The advantages of using commercial data acquisition hardware with installed operating systems and BASIC programs for this application are discussed.

I. Introduction

Traveling-wave maser (TWM) closed-cycle refrigerator (CCR) systems have been used in the DSN for over 20 years. The CCR system consists primarily of a helium compressor and a refrigerator assembly (Fig. 1). The purpose of the system is to maintain the temperature of the low-noise maser amplifier assembly at 4.5 K. Maintaining this temperature is critical to the proper operation of the maser.

Closed-cycle refrigerator failures are responsible for a large percentage of unscheduled maintenance time in DSN tracking operations. The mean time between failures is relatively short (2500–3000 hours), and the time to return to operation after a failure is long (up to a few days). It would be very advantageous to improve the operator's ability to observe CCR conditions so that failures could be better diagnosed and so that imminent CCR failures could be predicted and maintenance scheduled in advance. Some CCR failures can be predicted by careful analysis of CCR performance data.

The monitoring of CCR operation is currently performed manually by station personnel on a daily basis. This involves reading a number of gauges and transducer readouts for each TWM/CCR system and recording the information in a logbook. These instruments are located at four separate locations at the antenna site (Fig. 2).[1] This data must then be analyzed by engineering personnel at the station. Unfortunately, this time-consuming and tedious task rarely results in timely failure prediction or accurate failure diagnosis.

Another problem associated with CCR monitoring is a lack of system operating-temperature data. Most DSN instal-

[1] *Operation and Maintenance, Traveling-Wave Maser Group, Block III, 26-Meter Antenna*, JPL Publication TM 00714 (internal document), Jet Propulsion Laboratory, Pasadena, California, May 3, 1976; and *X-Band TWM Equipment, Block I (34-Meter Antenna)*, JPL Publication TM 511967 (internal document), Jet Propulsion Laboratory, Pasadena, California, February 2, 1979.

lations have no provision for monitoring the operating temperature of the compressor or displaying temperature data from cryogenic temperature transducers installed in the refrigerators.

The TWM/CCR data acquisition and display system will provide a performance data base of both normal and abnormal operating characteristics, enabling engineering personnel to evaluate CCR failure dynamics and to develop failure prediction algorithms. The operator interface will be one central terminal (personal computer and printer), located in the maintenance facility. Maintenance personnel will be automatically notified of out-of-limit conditions, and performance data will be logged automatically.

II. Description

The CCR data acquisition and display system consists of refrigerator and compressor sensors and data acquisition assemblies, a communications and display processor, and communications expanders. CCR monitor equipment locations are shown in Fig. 2, and a block diagram of the system configured for DSS 12 is shown in Fig. 3. The DSS-12 system monitors three compressors and three refrigerators; each system is capable of monitoring four refrigerators and four compressors.

A. Sensors

Performance sensors in the present system are quite limited. They consist of gauges and transducers that must be read by an operator. Pressure data is obtained from conventional gauges located on the compressor. No provision is made for measurement of the compressor operating temperatures or compressor motor current.

JT flow is the only indicator of refrigerator performance that can be measured remotely from the refrigerator package. It is measured with a Hastings flowmeter installed near the compressor. Cryogenic temperature readings are limited in most cases to a vapor pressure thermometer mounted on the refrigerator package that indicates the vapor pressure of liquid hydrogen in a bulb mounted on the 4.5-K stage.

The system functions to be monitored in the new system were selected primarily to provide the information necessary to verify proper operation and predict failures. Most of the existing manual sensors are monitored in parallel. Additional sensors were chosen to monitor specific trouble points and to aid in the identification of long-term failure modes.

Another sensor selection and design criterion was the ability to install the sensors on a helium compressor in the field without opening the helium piping or altering the existing wiring, hardware, etc. The complete compressor sensor package can be installed on an operational compressor in a matter of minutes without warming the refrigerator. A comparison of sensors used on the current system and the new automated system is given in Table 1.

Helium pressure data is obtained from strain gauge-type pressure transducers connected to the CCR using self-sealing quick-disconnect fittings. Compressor temperatures are measured using Analog Devices monolithic temperature sensors connected to the outside of the helium lines. Motor current is measured using current transformer-type sensors connected in-line with the compressor power cable. The JT flow data is obtained from an analog output connection on the existing system flowmeter. The cryogenic temperature measurements are made using Lake Shore Cryotronics silicon diode thermometers that are being installed on DSN TWM/CCR systems as opportunity permits.

B. Passive Refrigerator Capacity Monitor

The system uses a real-time refrigeration capacity monitor based on a concept developed at JPL and implemented on early R&D CCRs [1]. Unlike most methods of measuring capacity, no heat is applied to the refrigerator, and therefore it can operate continuously. An operator can verify the relative health of the refrigerator in one glance. The new monitor has demonstrated an accuracy of 5 percent in laboratory tests.

C. Refrigerator and Compressor Data Acquisition Assemblies

The data acquisition assemblies for the refrigerators and compressors consist of a commercial Analog Devices data acquisition module, interface hardware, and a power supply. The hardware is the same for both the refrigerator and compressor data acquisition assemblies, with the exception that a current source (PC board) is added to the refrigerator assemblies to excite the cryogenic temperature transducers. The Analog Devices μMAC-5000 module is an 8088-based microprocessor with a 12-channel analog-to-digital converter and signal conditioning circuitry. The module provides 46 kbytes (later versions provide 56 kbytes) of user memory, two serial communications ports, and a socket for a user-installed EPROM (to contain the user's program). The software (resident in the EPROM) is the same for both the refrigerators and the compressors—the program is customized for either application by setting a DIP switch.

One data acquisition processor is used for each compressor, since all 12 available channels are required. The refrigerators require only five channels each, so one data acquisition assembly is used to monitor two refrigerators.

D. Communications and Display Processor

All communications and displays are controlled by the host processor, which is an IBM PC-XT microcomputer. The IBM standard motherboard has been replaced by a CTXT Terminator 286 board, and the standard 60-W power supply has been replaced by a 130-W power supply. In addition, a 30-megabyte hard disk drive and a hardware clock with an additional serial port have been installed. The hard disk holds both the accumulated data and the operating programs. The floppy drive is used to transfer both data and programs to and from one personal computer to another. As new versions of the program are developed, they can be easily installed in existing systems. Data can also be transferred from the TWM/CCR personal computer to other personal computers for further processing by engineering personnel, as is planned for the Parkes TWM/CCR implementation.

The displays and operating software will be described in detail in a separate report. Basically, each measured parameter of the system is displayed continuously (see Fig. 4). An out-of-limit condition is indicated with a reverse background screen around the data. A communications failure is also indicated by a reverse background screen around the applicable equipment heading. The operator can create a printout of status information and reset the limits using simple commands. A complete set of data is written to the hard disk automatically every 15 minutes. The hard disk is capable of storing up to 1 year of data.

E. Communications Expanders

Prototype communications expanders (JPL PN 9489463) were used to hook together four RS-232 ports into a wire-OR configuration (see Fig. 5). Each expander also establishes a current loop configuration to link the previous expander (or data acquisition assembly) to the next expander (or data acquisition assembly). The communications expanders were used to provide reliable long-distance communications (the RS-232C communication ports provided by the personal computer and the data acquisition modules specify 25 feet maximum). In addition, the expanders convert single-channel communications to multi-channel (up to four channels per expander). Standard eight-pin connectors are used for all ports.

III. Plans

The present data acquisition system represents Phase I of the automation plan. Phase II will expand monitor capabilities to enable remote fetching of data and a program for plotting the data. In addition, CCR system monitoring could be expanded to include maser electronics (pump sources and the superconducting magnet). The basic system could also be adapted to include control of the pump sources and magnet and of the automated cool-down control system. The system can also be modified to monitor HEMT or FET amplifier refrigerators as they are implemented into the DSN.

IV. Conclusion and Recommendations

The Phase I data acquisition system has gone through a long evolutionary cycle. The original design concept was to use CCM standard multibus modules (DSN standard practice) for both the communications and display processor and the data acquisition processors. After funding for this effort was reduced, it was decided to eliminate the control function from the equipment for the initial phase and to investigate commercial off-the-shelf equipment which had recently become available.

It was found that the Analog Devices data acquisition module had all the features required for the TWM/CCR application. An added benefit was the high-quality BASIC programming language standard on the module. This program is interactive rather than compiled (as is the case for PLM) and resulted in increased ease of programming. Additionally, the size of the packaged module is about one-half the size of the CCM module package, an important factor in the already crowded compressor and refrigerator areas. Also, commercial manuals are supplied, substantially reducing the effort required to produce a DSN operations and maintenance manual.

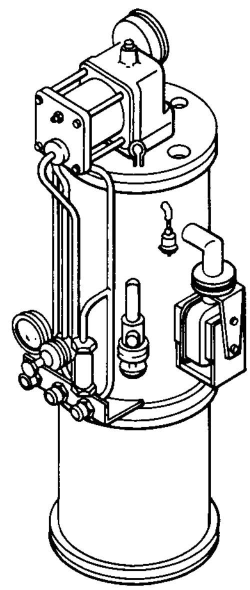
The benefits resulting from selection of the personal computer communications and display processor are similar to the data acquisition assemblies. The equipment is low cost, development time was cut drastically because the operating system was already built in, and the effort required to produce manuals is significantly reduced.

Reference

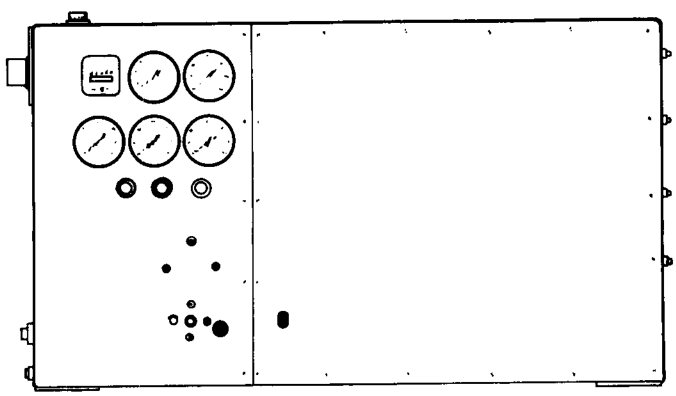
[1] W. H. Higa and E. Weibe, "One Million Hours at 4.5 Kelvins," *National Bureau of Standards Technical Publication No. 508*, pp. 99–107, April 1978.

Table I. Comparison of sensors on old system versus new system

Sensor function	Sensor type	
	Old system	New system
Compressor supply pressure	Gauge	Transducer
Return pressure from 1st and 2nd stage of refrigerator	Gauge	Transducer
Return pressure from JT stage of refrigerator	Gauge	Transducer
Compressor storage tank pressure	Gauge	Transducer
Pressure drop in compressor oil separator	None	Transducer
Temperature of compressor 1st stage	None	Thermometer
Temperature of compressor 2nd stage	None	Thermometer
Temperature of compressor motor	None	Thermometer
Compressor motor AC current	None	Transducer
JT circuit helium flow rate	Flowmeter	Flowmeter
Temperature of refrigerator 4.5-K stage	VP gauge	Thermometer
Temperature of refrigerator 2nd stage	None	Thermometer
Temperature of refrigerator 1st stage	None	Thermometer
Refrigerator cooling capacity	None	Monitor



CLOSED-CYCLE REFRIGERATOR



HELIUM COMPRESSOR

Fig. 1. Basic components of the closed-cycle refrigerator system

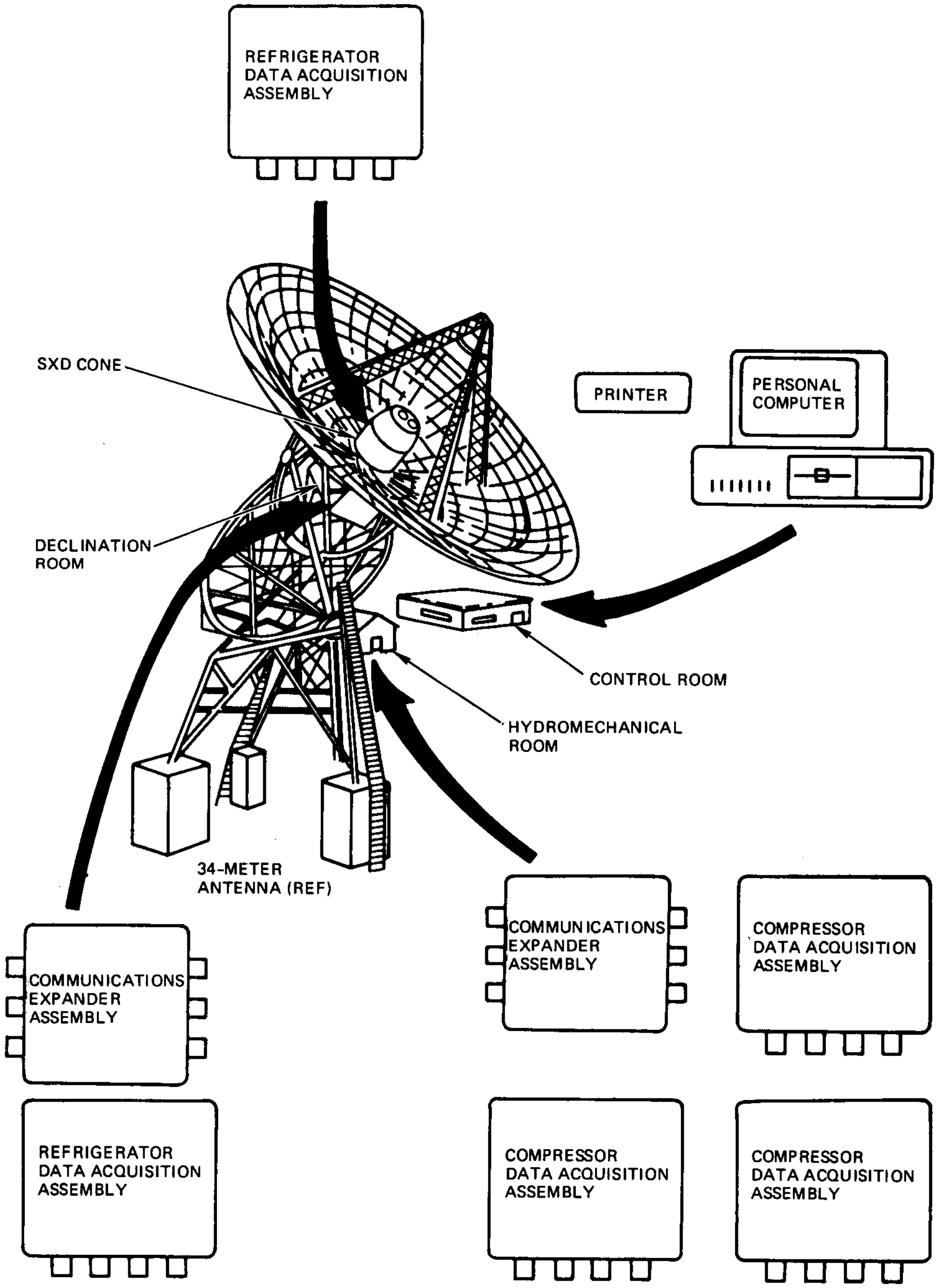


Fig. 2. CCR data acquisition equipment locations

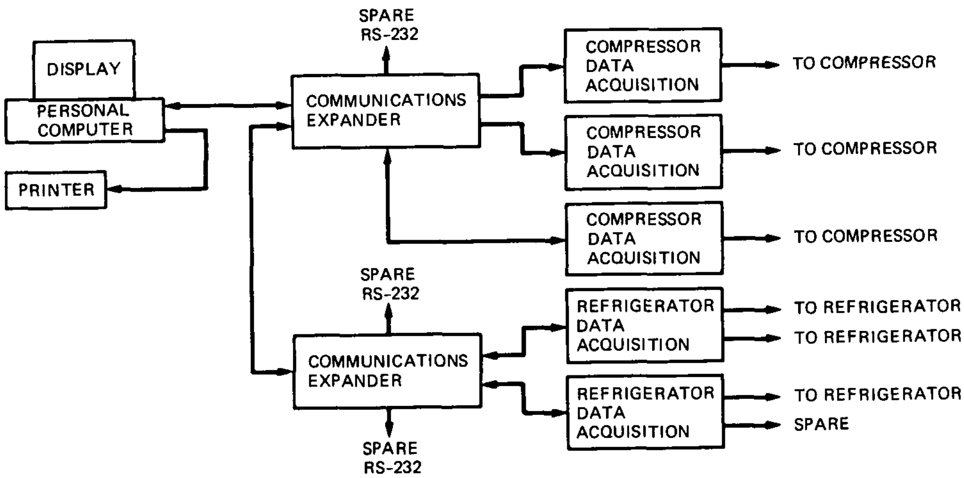


Fig. 3. CCR data acquisition system block diagram

Parameter	#1	#2	#3	#4	Units
System Communications	R C	R C	R C	R C	Status
4.5° Stage Temperature	4.62	4.97	-•-	-•-	Deg K
Heat Exchanger Temp.	12.7	13.8	-•-	-•-	Deg K
15° Stage Temperature	15.8	16.0	-•-	-•-	Deg K
70° Stage Temperature	68.1	67.5	-•-	-•-	Deg K
Reserve capacity	55.0	20.6	-•-	-•-	%
Vacuum	7E-8	9E-7	-•-	-•-	Torr
JT Flow	1.47	1.38	-•-	-•-	Scfm
Supply Pressure	245.	234.	-•-	-•-	Psi
Refrigerator Return	97.6	100.	-•-	-•-	Psi
JT Return Pressure	3.26	5.09	-•-	-•-	Psi
Storage Tank Pressure	185.	146.	-•-	-•-	Psi
Oil Separator Delta	15.8	14.3	-•-	-•-	Psi
Motor Temperature	83.4	87.7	-•-	-•-	Deg C
1st Stage Temperature	85.9	88.2	-•-	-•-	Deg C
2nd Stage Temperature	86.7	88.3	-•-	-•-	Deg C
AC Input Current ϕA	11.6	10.5	-•-	-•-	Amps
AC Input Current ϕB	13.3	12.0	-•-	-•-	Amps
AC Input Current ϕC	12.8	12.1	-•-	-•-	Amps

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Fig. 4. Sample display

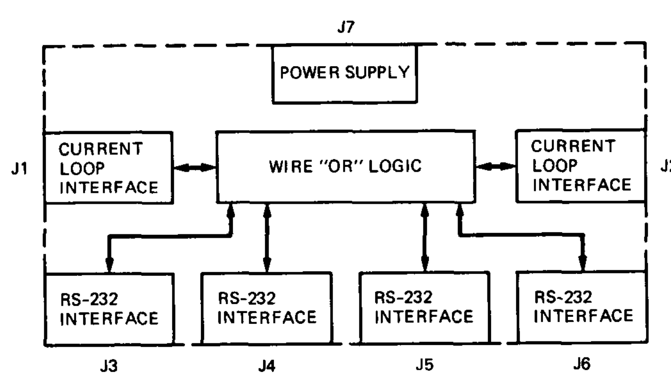

Fig. 5. Communications expanded block diagram