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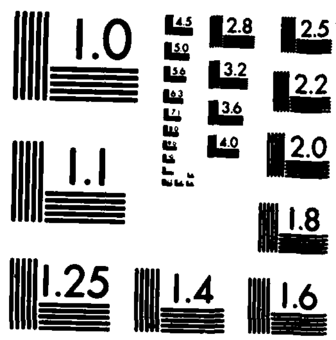

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AD A125886

A 10 cm Dual Frequency Doppler Weather Radar

Part II: A Quality Assurance/Fault Location Network

KENNETH J. BANIS

25 OCTOBER 1982

Approved for public release; distribution unlimited.

METEOROLOGY DIVISION
PROJECT 6670
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

83 03 22 041

This report has been reviewed by the ESD Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

Alva T. Stair, Jr.

DR. ALVA T. STAIR, Jr
Chief Scientist

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<table>
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AFGL-TR-82-0321(II)</td><td>2. GOVT ACCESSION NO.</td><td>3. RECIPIENT'S CATALOG NUMBER</td></tr>
<tr><td colspan="2" rowspan="2">4. TITLE (and Subtitle)
A 10 cm DUAL FREQUENCY DOPPLER WEATHER RADAR
Part II: A Quality Assurance/Fault Location Network</td><td>5. TYPE OF REPORT & PERIOD COVERED
Scientific. Final.</td></tr>
<tr><td>6. PERFORMING ORG. REPORT NUMBER
IP, No. 313 (II)</td></tr>
<tr><td colspan="2">7. AUTHOR(s)
Kenneth J. Banis</td><td>8. CONTRACT OR GRANT NUMBER(s)</td></tr>
<tr><td colspan="2">9. PERFORMING ORGANIZATION NAME AND ADDRESS
Air Force Geophysics Laboratory (LYR)
Hanscom AFB
Massachusetts 01731</td><td>10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
62101F
66700602</td></tr>
<tr><td colspan="2" rowspan="2">11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Geophysics Laboratory (LYR)
Hanscom AFB
Massachusetts 01731</td><td>12. REPORT DATE
25 October 1982</td></tr>
<tr><td>13. NUMBER OF PAGES
32</td></tr>
<tr><td colspan="2" rowspan="2">14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)</td><td>15. SECURITY CLASS. (of this report)
Unclassified</td></tr>
<tr><td>15a. DECLASSIFICATION/DOWNGRADING SCHEDULE</td></tr>
<tr><td colspan="3">16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.</td></tr>
<tr><td colspan="3">17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)</td></tr>
<tr><td colspan="3">18. SUPPLEMENTARY NOTES</td></tr>
<tr><td colspan="3">19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Doppler weather radar
Next Generation Weather Radar (NEXRAD)
Radar system performance monitoring
Fault tolerance
Fault location</td></tr>
<tr><td colspan="3">20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A functional description of an automatic radar system performance monitoring network is presented. A network of microprocessor controlled monitoring units were interfaced to various sensors at key areas in a Doppler weather radar in order to collect system status information and display it at a central point near the operator's console. This status information is displayed on a color terminal in a way that allows the systems operator to verify the proper operation of the radar with just a cursory glance at the terminal.</td></tr>
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20. Abstract (Continued)

Fault location and fault tolerant techniques were employed to provide the system user with quality assured data.

Preface

The author wishes to thank Graham Armstrong, Alexander Bishop, SSgt. Charles Klein, Ruben Novack and Edward Duquette for their contributions in developing this network. Special thanks are due to SSgt. Scott Douglas for his diligent efforts in completing the final design, layout, and software for the network. Thanks also go to Kenneth Glover for his support and valuable critique of this work.

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1. INTRODUCTION

Doppler weather radar systems are highly complex because they incorporate sophisticated automatic data processing and display equipments. The practicality of incorporating such a processing and display system into a network of weather radars will depend upon each system's ability to tolerate internal faults while operating unattended, or at least detecting and isolating faults to a unit replaceable by a person with little knowledge of the system's technical details. A fault tolerant concept or even an automatic monitoring of the system's critical outputs to signal a failure are needed to provide high quality input to a central forecasting center.

Fault monitoring is especially necessary in meteorological radar equipment because the quantities being measured, reflectivity and moments of Doppler spectra, are themselves random processes in both time and space. For this reason it is difficult to assess whether the system is operating correctly merely by observing its output. The meteorologist may, based upon faulty data which appears reasonable, reach false conclusions which would affect the quality of his forecast. The system user should not be burdened with concern over its integrity, but needs to be free to exploit its full potential in performing the primary task of providing operational weather support.

(Received for publication 22 October 1982)

This paper is the second of a series of three reports that have been written to describe the systems that were developed at the Air Force Geophysics Laboratory to lay the groundwork for the system development of the Next Generation Weather Radar (NEXRAD). The first of these reports by Bishop and Armstrong[1] describes the self-calibrating dual-frequency 10 cm Doppler weather radar that was built to simultaneously extend both the radar's unambiguous range and velocity characteristics while maintaining the system's ground clutter cancelling capability. The third report in this series by Major Carlton Bjerkaas[2] describes the Perkin-Elmer Model 3242 computer and its role in providing an automatic calibration and operator interactive control of the computer and data displays, as well as on-line data analysis to allow testing of various radar data processing algorithms in real-time. This paper describes the work done at AFGL to establish a quality assurance/fault location network to monitor the performance of the 10 cm radar (including the transmitter/receiver system, antenna system, and on-line special purpose data processing equipment) and to display their status at a single location in a way that allows the systems operator to recognize a serious system deficiency by a cursory glance at the console. The 10 cm radar system was used as a test-bed of various techniques of fault location and/or fault tolerance in an effort to assure that the meteorologist is provided with quality data.

Fault tolerance requires locating a failed device and automatically substituting a working device in its place. Fault location involves applying an appropriate sensor or sensors to a device and comparing the sensor output(s) to a known reference. Devices may have several kinds of output responses. The simplest are devices with a single fixed output such as a power supply. Locating faults in these devices is a matter of applying the appropriate conversion unit compatible with both the device and monitoring unit. For example, an analog-to-digital converter is required to properly monitor the output of the power supply.

The next level of devices are devices whose output is a simple function of their input. A digital-to-synchro conversion unit (of the type found in the antenna system) is an example of this type of device. A fault in this kind of device can be located by applying a reverse (synchro to digital) converter and comparing the output of this sensor to the input of the monitored device.

The third level of devices includes those whose outputs are a complex function of their inputs. One such device in the radar system is the pulse pair processor

1. Bishop, A.W., and Armstrong, G.M. (1982) A 10 cm Dual Frequency Doppler Weather Radar, AFGL-TR-82-0321(I).

2. Bjerkaas, C.B. (1982) The Radar Monitor, Control and Evaluation System (RMCES), AFGL-TR-82-0321(III).

(PPP) described by Novick and Glover.[3] The outputs of this device are the result of a complex algorithm acting on its input, which is statistical in nature. The only way to be sure the device is working properly is to incorporate a second device and compare the outputs of both devices.

In all of these examples, a failure of the sensor would erroneously be indicated as a failure in the device. However, the false alarms from monitoring device failures cost less technician time than standard repair procedures, because the fault indicator locates the problem, eliminating the need for a lengthy procedure to isolate the fault.

Fault tolerance for the first level of devices requires a second device to be switched on line in place of the failed one. Fault tolerance for the other levels of devices generally requires a triple redundancy scheme together with a majority decision unit. If a single device fails, the majority decision unit determines which device has failed and sets switches to connect a properly functioning device to the output. This action allows the process to continue without interruption. It can be seen from this discussion that fault tolerance requires much more electronics hardware than mere fault location. A fault-tolerant radar system would be ideal, but is far beyond the scope of our work. Our objectives are first, to ease maintenance, and second, to assure that only good quality data are passed through the system. The first objective is accomplished by automatically monitoring the system and by isolating and reporting failures. The second is achieved by monitoring key system parameters to verify that the system is operating properly. Although these objectives do not preclude the use of fault tolerance, they do limit the application of fault tolerant techniques to vital areas of the system where problems that would be difficult to isolate could develop.

In the next section, the configuration of the fault location network is defined. In succeeding sections, each of the major areas defined in the configuration section are discussed. The display unit is described first, then each monitored function. Finally, the fault-tolerant weather radar processor is discussed.

2. NETWORK CONFIGURATION

A dedicated fault location unit is assigned to each of the transmitter and antenna systems, and each is installed in close proximity to its monitored system. Both of the antenna and transmitter fault location units report the status of their monitored systems to a color graphics terminal via another fault location

3. Novick, L.R., and Glover, K.M. (1975) Spectral mean and variance estimation via pulse pair processing. Preprints, 16th Conference Radar Meteor., Am. Meteor. Soc., Boston, Mass.

unit which is designated as the master. The purpose of the master unit is to steer the system status data from the other fault location units to the terminal, steer the control information from the terminal to the proper unit, and monitor the performance of the other fault location units. The network terminal provides continuous radar status and scaling information to the Perkin-Elmer minicomputer for use in real time automated meteorological analyses.

Figure 1 shows the layout of the entire fault location network and the configuration and functions of each of the circuit boards in each of the fault location units. Common to each of the units is a Central Processing Unit (CPU) board. Each CPU utilizes an 8080 microprocessor with 8k bytes of read only memory (ROM) for the unit's instruction set and reference tables, 1k bytes of Random Access Memory (RAM) for storing system status information, communication data buffers, and scratch registers for the operation of the microprocessor itself. Because of the small amount of memory space needed for each unit, all of the I/O functions are memory mapped to facilitate a simple diagnostic routine to monitor the performance of the unit's I/O functions while the network is on-line. The CPU board also generates the address and control busses to be used on the other boards in the unit.

Each communication board has a 16-channel analog data acquisition system with differential inputs for monitoring various supply and slowly varying voltages. Each antenna and transmitter communication board has two redundant serial asynchronous channels which converse with the four serial asynchronous channels of the master communications board. These serial channels have differential line drivers and receivers to avoid potential ground loop problems between units. The master communications board also has two parallel channels, each consisting of separate eight-bit input and output ports which converse with the operator's terminal.

3. FAULT LOCATION NETWORK DISPLAY UNIT

An Intercolor 19-in. Color Graphics Terminal, model 8001H, is utilized as a system status display and serves as an input device to allow the systems operator to control the monitoring sequences, initiate internal test routines, and request actual values of measured parameters. As part of the display system, a dual 5-1/4" floppy disk drive is incorporated to store the display program, store antenna scan sequence control program data, and provide space for logging failure data for future reference.

The display, as can be seen in Figure 2, is partitioned into three major fields. The first field, located directly under the title block, is dedicated to the

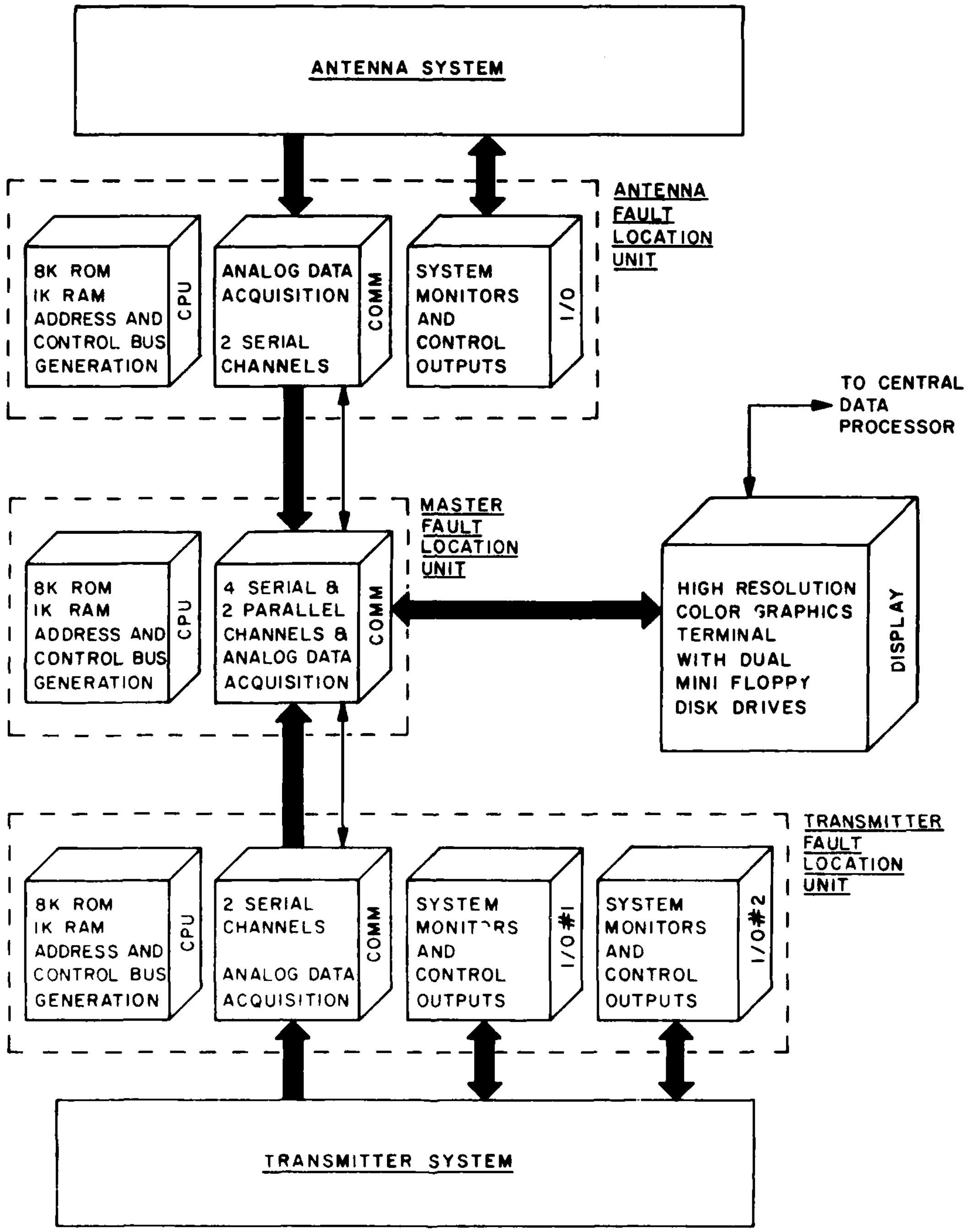


Figure 1. Fault Location Network Configuration

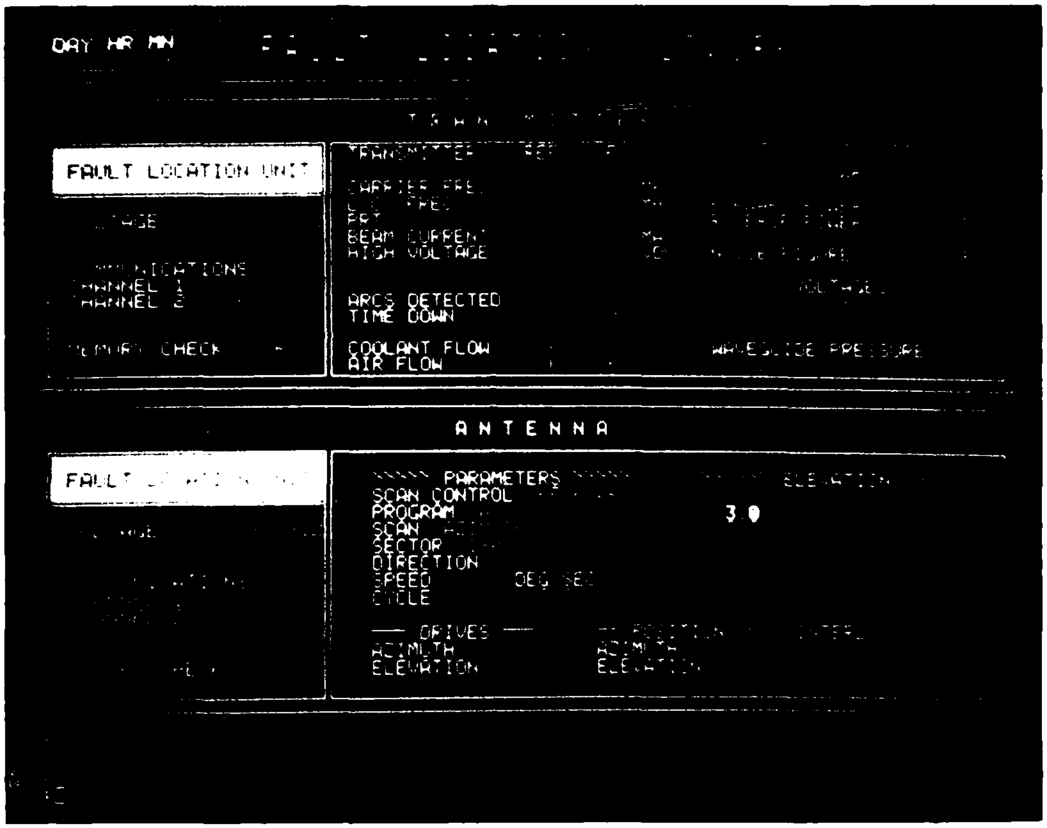


Figure 2. Fault Location Network Display

transmitter system. This area is divided into two sections. The right section displays the status of the monitored transmitter system parameter, and the section to the left of this area displays the status of key parameters of the transmitter fault location unit. The second field, located directly under the first, is dedicated to the antenna system and has the same format as the transmitter field. Below this area, the third field is reserved for displaying the operator interactive control inputs and responses.

When the system is first turned on, the terminal draws the boundaries for the status areas and fills these areas with the parameter names and values. The names have a greenish blue (cyan) foreground color, the values have a blue foreground color, and the background of the entire block is black. This indicates to the systems operator that the parameters have not yet been monitored or that the parameters have not been activated. When each monitored parameter is activated and checked out by the fault location network the corresponding displayed parameter value changes to a green foreground color indicating that it is functioning properly.

The scheme used to report a non-critical or critical failure is designed with the premise that the systems operator's time will be more productively spent observing the displayed outputs of the various weather radar data processors. This requires that an automatic monitor display the status of the system in a way that allows the systems operator to determine its condition with just a cursory examination of its output.

A non-critical failure, once detected by the network, causes the background color of the affected status block area to change to yellow. The foreground color of the failed parameter name and value then changes to red. To maintain the legibility of the properly functioning parameters, the foregrounds of both the names and values are changed from greenish blue and green to dark blue.

A critical failure causes the background color of the affected status block area to change to red. The foreground color of the failed parameter's name and value then changes to white, and for further emphasis, blinks. Any non-critical failure in the same block appears with a yellow background color and a red foreground color for the name and value characters. The properly functioning parameters are displayed with a greenish blue foreground color for the name characters and a green foreground color for the value characters.

A drastic color change over a fairly large area of the display serves well to fulfill the original design criterion of alerting the systems operator to a problem by displaying it in such a bold fashion. To further increase the noticeability of a change in system status, whenever the background color of a data field is changed, the new color and text are scrolled into the data block area.

When a failed parameter is fixed, or the problem clears up, the display will change its colors accordingly. If a non-critical failure still exists when a critical failure is cleared the background color in that block will go to yellow emphasizing that this condition still exists.

The lower four character lines of the display are reserved as a communications area where the requests, entered via the keyboard, are echoed and the responses to these requests are displayed. The 33 leftmost character spaces of these lines are reserved for a prompting character and conversation. The remaining 47 character spaces of these lines are reserved for operator aids which display the options available at any given time and the means by which they are accessed.

4. TRANSMITTER FAULT LOCATION UNIT

The radar transmitters are a pair of AN/FPS 18 units that were extensively modified to provide for better coherency and to allow two simultaneous channels (velocity and reflectivity) to operate at different pulse repetition frequencies (PRFs) using a single antenna (Bishop and Armstrong[1]). The final stages of these units were left virtually intact, including various interlocks that safeguard the system from physical component damage. Additional safeguards were installed to protect the system from the occurrence of damaging arcs. Instrumentation was also included to monitor the performance of the system including frequency sources, transmitted and reflected power (from which the VSWR is calculated), noise figure, and PRF generator. A block diagram of the transmitter fault location unit and the monitored parameters is shown in Figure 3.

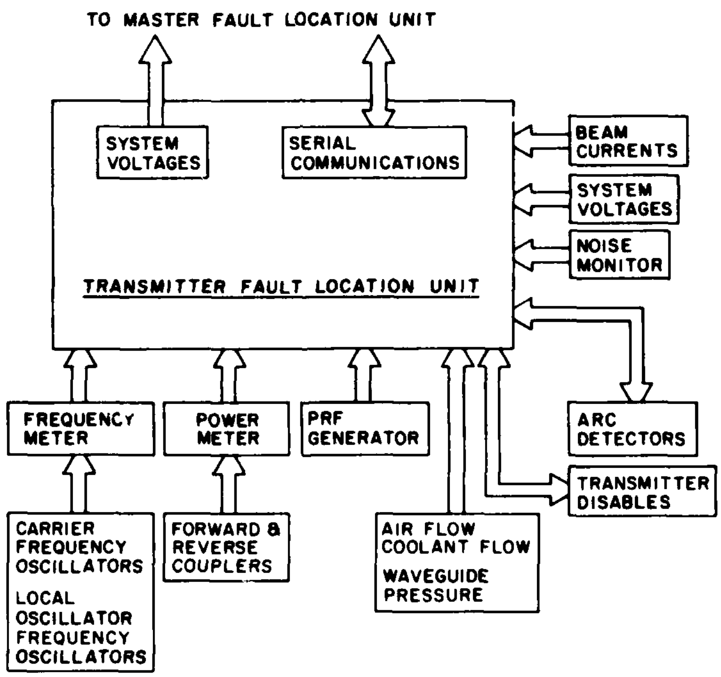


Figure 3. Block Diagram of Transmitter Fault Location Unit and Monitored Parameters

4.1 Frequency Monitoring

The local oscillators and carrier frequency oscillators for both the reflectivity and velocity channels are monitored by the transmitter fault location unit through an AIP Pulse Counter Model 451. As can be seen in Figure 4, these frequencies are inputted to the pulse counter through a PIN diode switch. Each frequency can be manually selected by the system operator, or can be automatically sequenced by the transmitter fault location unit. In a manual selection mode, the unit acknowledges this mode by releasing the control of the pulse counter and sending a message to the network terminal indicating this fact to the system operator. In the automatic mode, the unit selects the proper inputs to the pulse counter for range and sampling control. Once an oscillator is sampled and read into the unit, the PIN diode switch is sent the code for the next oscillator to be read, and the sampling process is then initiated. The unit then analyzes the most recent reading and reports any change to the system operator via the network terminal.

The pulse repetition frequency (PRF) generator is monitored by reversing the generation process and by comparing the results to the intended values. The PRF generator and monitor are depicted as a block diagram in Figure 5. The generation process is controlled by the operator, who enters the period between pulses (PRT), in microseconds, by means of a set of thumbwheel switches on the front panel of the generator. A comparator sends a signal to a pulse generator when the thumbwheel setting is equaled by the output of a counter whose clock input is derived from a crystal controlled oscillator. The signal from the comparator causes the pulse generator to send a signal that resets the counter and also to send a trigger pulse to the velocity channel transmitter, receiver, and processing equipment.

This output is also used to clock the reflectivity PRT counter. The output of the reflectivity PRT counter is input to a comparator that has as its other input the thumbwheel switch setting of the ratio of velocity to reflectivity PRT. When these two inputs to the comparator are equal, the comparator outputs a signal to another pulse generator that resets the counter and sends a trigger pulse to the reflectivity channel transmitter, receiver, and processing equipment.

The transmitter fault location unit monitors both the selected velocity channel PRT and the reflectivity channel PRF ratio factor. The unit multiplies the selected PRT and ratio factor, and forwards the resultant PRTs of both channels to the network display. The unit also monitors both trigger pulses. A counter in the unit, which is clocked by the crystal controlled 2 MHz clock, is free running until the velocity channel trigger is received. This trigger loads the count at this time to a buffer, resets the counter, and increments the transmitter PRF monitor counter. When a reflectivity channel trigger is received, the output of this counter

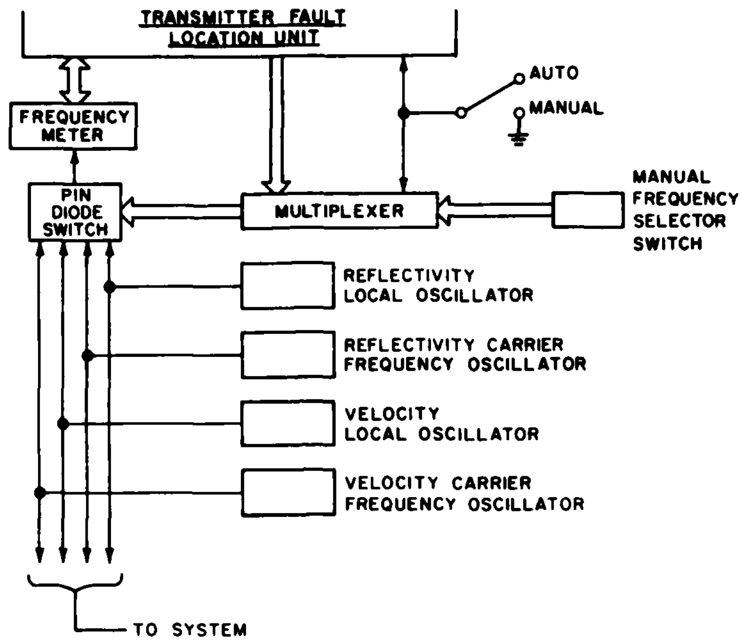


Figure 4. Frequency Measurement Scheme

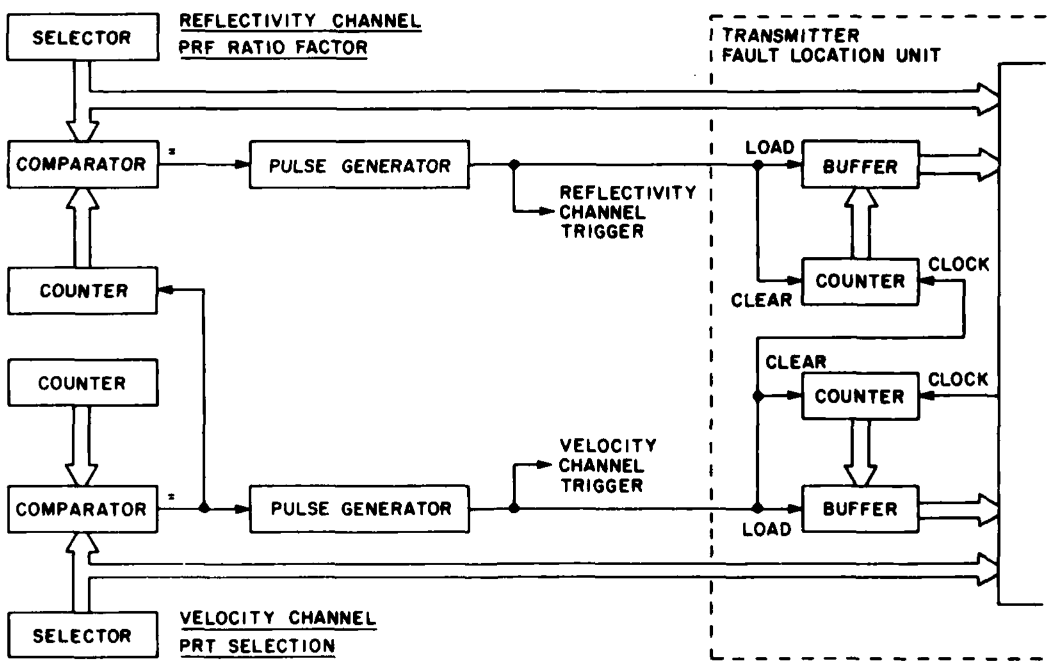


Figure 5. PRF Generator and Monitor

is latched into a buffer, after which the counter is reset. The output of both buffers is fed into the transmitter fault location unit and is compared to the selected values. Any discrepancies are forwarded to the system operator via the network terminal.

4.2 Forward and Reverse Power Measurement

A pair of Hewlett Packard model 436A power meters are utilized to monitor the transmitter forward and reverse powers. The transmitter fault location unit has total control over both power meters and programs the proper settings to have them read the monitored power in dB (referenced to 1 milliwatt). The forward power is monitored via a 60 dB coupler in the waveguide and is read into the fault location unit which then adds the loss of the coupler and cable between the power meter and head. This information is stored for later use in calculating the VSWR and it is forwarded to the network display. The reverse power is monitored in the same manner as the forward power except that a 35 dB coupler is used. Once reverse power is read by the fault location unit, the loss of the coupler and cable is added to the reading. This information is also stored for future use in calculating the VSWR, and is forwarded to the network terminal for display.

Currently, two power meters are used to monitor the power. A modification now underway will use only one meter, timeshared between the couplers and other power measurements that may be made. This multiplexing will be controlled by the transmitter fault location unit. This modification will not alter the hardware of the unit since the I/O ports that were dedicated to the second power meter will be utilized for this new control function. The software driver, of course, will have to reflect this change. Only a redefinition of the I/O ports used and a minor addition of a control loop to handle the modification will be required. This adaptability demonstrates the versatility of using a microprocessor for monitoring and control.

In conjunction with this modification, a display panel will be added in place of the second power meter. The panel will display the corrected value of the measured powers as well as the calculated VSWR. A manual override that will give the technician or engineer full control of the meter in order to run manual system power checks will also be provided. The transmitter fault location unit will sense the position of this override switch and will indicate this condition to the system operator via the network terminal. The power monitoring loop will cease executing until this switch is sensed to be in the automatic position. The circuitry for this modification will be similar to the circuit for frequency monitoring.

4.3 VSWR

Once the forward (P_f) and reverse (P_r) power measurements are made, the VSWR can be calculated and displayed. The proper relationship to use in this case is:

$$\text{VSWR} = \frac{1 + 10^{\left(\frac{P_r - P_f}{20}\right)}}{1 - 10^{\left(\frac{P_r - P_f}{20}\right)}}$$

Since this equation involves the only calculation of this nature that is performed by the fault location network, a general purpose math package to operate on the microcomputer was not feasible in terms of memory space and execution speed. Instead, a piecewise linear approximation is used to make this calculation. A regression analysis was performed on various portions of the VSWR expression. This resulted in the selection of the appropriate slope and intercept values to yield an accuracy which is consistent with the displayed two-decimal-place resolution. These values, found in Table 1, are selected by using the difference of reverse and forward powers. An offset factor is added to this difference to make the calculation simpler for the microprocessor by making all the values positive.

Table 1. VSWR Calculation Parameters

$P_r - P_f + 10$	SLOPE	INTERCEPT
-00 to 0	0	1.030
0.1 to 9	0.0082	1.028
9.1 to 14	0.0178	0.941
14.1 to 17.5	0.0326	0.734
17.6 to 21	0.0560	0.320

The graph in Figure 6 compares the VSWR calculation curve to the piecewise linear lines for the VSWR range of practical concern (1.1 to 1.5). Once this calculation is made, the results are transferred to the network display and a small display panel at the transmitter.

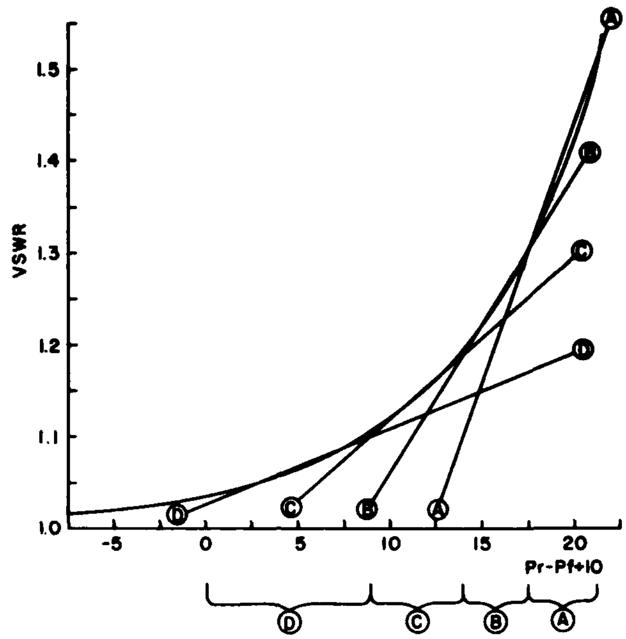


Figure 6. VSWR Calculation vs Piecewise Linear Approximation

4.4 Arc Detection

A pair of Varian model VES-8480 arc sensors has been installed in the waveguide between the final stage of each transmitter and the diplexer. When the sensor detects an arc, its output signal is latched low and remains low until the sensor is reset by the transmitter fault location unit. This action causes two responses: The RF drive is removed from the proper transmitter and the unit reads this condition. For the first arc detected, the unit resets the arc sensor after 1 sec for deionizing and cooling, enables the RF drive, and reports this occurrence to the network display. The display then activates a 5-min down counter, displays the number of arcs that have been detected, and also displays the countdown timer in the appropriate transmitter column.

If a second arc is detected within this 5-min period, the response is identical except that a second 5-min down counter is started but not displayed. A third arc occurrence in this time period causes the RF drive to be disarmed, and it is not automatically restored; rather, a manual restoration is needed to get back into operation. If the countdown timer goes to zero without any arcs being detected, the number of detected arcs are decremented, and the alternate countdown timer is displayed. If the number of arcs detected is zero after the decrement, the unit then responds as if no arcs had ever been detected.

There is a test lamp built into each of these sensors. The lamp glows and trips the photo-diode circuitry to cause the sensor to output a fault indication. This test is performed after power up and at the request of the system operator. To test the test lamp filament continuity, the arc sensor input should read +28 Vdc.

4.5 Air Flow

The output of each cooling fan is measured by a calibrated air vane attached to a microswitch located in the air flow path of each fan. When the air flow of any fan drops below its rated output, the air vane no longer deflects enough to keep its microswitch closed. When this switch opens, the event is remembered by a latched relay and is read by the transmitter fault location unit. The transmitter is shut down, and an indicator, mounted on a panel at the top of the cabinet containing the offending fan, is lit. This failure is also indicated as a critical failure on the network terminal. This fault can only be cleared at the location of the offending fan. This design feature insures that this problem will be checked and verified by a technician at its source.

4.6 Coolant Flow

The loss of the liquid coolant flow could cause serious damage to the hardware components of the transmitter system. Accordingly the coolant flow sensors are tied directly to the transmitter system interlocks, and a detected loss of flow will shut down the affected transmitter. This condition is reported to the network terminal and is displayed in the network terminal's transmitter data block as a go/no-go condition for each transmitter. A failure is depicted as a critical failure and cannot be cleared at the terminal. This failure can only be cleared at the transmitter by a technician.

4.7 Waveguide Pressure

The waveguide is pressurized with dry nitrogen to inhibit the occurrence of waveguide arcs. A pressure sensor is installed in the waveguide to provide a failure indication to the transmitter fault location unit if the pressure in the waveguide falls below the threshold of 5 lb/in.^{2}

4.8 Low Voltage Power Supplies

The transmitter low voltage power supplies are monitored by the 16-channel analog data acquisition system internal to the transmitter fault location unit. The condition of the voltages (+5, -20, +24, +28, -12, and two +12) are displayed in the transmitter data block on the network terminal.

4.9 High Voltage Monitoring

The high voltage for each transmitter is monitored locally by a meter mounted in a panel above the transmitter cabinet. This voltage is reduced to a safe level by a voltage divider which reduces it to about 100 mV and 1 ma for a full-scale reading at the meter. This low level signal is amplified to a 5-V level by an operational amplifier, to make full use of the range of the analog data acquisition system. This information is then converted to a BCD representation, forwarded to the network terminal, and displayed in the transmitter data block under the appropriate column.

4.10 Beam Current

The beam current of each transmitter is obtained by measuring the power amplifier cathode current and is displayed locally on a meter mounted on the panel at the top of the transmitter cabinet. A representative voltage is taken from across this meter and amplified to levels compatible to the analog data acquisition system. This number is converted to a BCD representation, forwarded to the network terminal, and displayed in the transmitter data block.

4.11 Noise Figure

An Ailtech Model 7370 Noise Monitor is used to monitor the performance of the radar receivers and to provide a noise figure measurement suitable for display at the network terminal in the transmitter data block.

5. ANTENNA FAULT LOCATION UNIT

The antenna system monitoring verifies that the input signals, synchro positioning, and axis rate drives are valid. The performance of the system is also evaluated by monitoring the response of signals which are normally internal to only the control units. A block diagram of the antenna fault location unit and its monitored parameters is shown in Figure 7.

To verify the proper operation of a positioning of the antenna a dual-axis, BCD angle to two-speed synchro converter, linked to a dual axis, two-speed synchro to BCD angle converter, Interface Engineering Model SDS 426, is employed. A block diagram of a single axis of this converter is shown in Figure 8. The antenna fault location unit outputs a BCD angle to this converter and the

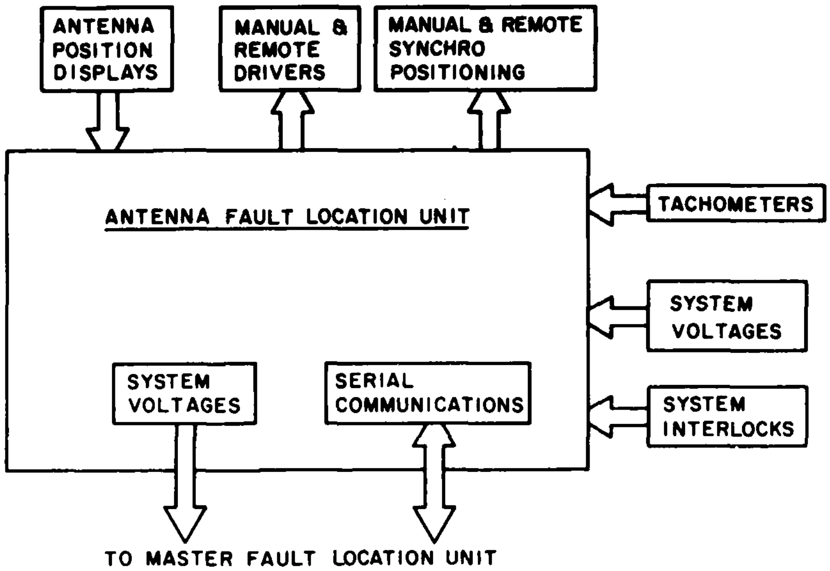


Figure 7. Block Diagram of the Antenna Fault Location Unit and Monitored Parameters

converter then translates this information to synchro levels. This synchro output goes to the antenna controls. Initially the antenna fault location unit inhibits the operate circuit for this axis. This synchro output is also fed into the reverse converter which translates it back to a BCD angle representation. The antenna fault location unit reads this echoed number and compares it to the angle outputted. If these numbers are in agreement, the antenna fault location unit completes the operate circuit of that axis. The unit then monitors the angle output of the display unit for that axis to verify that the antenna is indeed positioned properly. If the echoed BCD angle from the monitor does not agree with the output BCD to the BCD to two-speed synchro converter, the action taken by the antenna fault location unit depends on which axis is being monitored, and on the result of the test.

If the azimuth axis is being tested, then the antenna fault location unit completes the operate circuit, waits for the display to settle, and compares these three angles. If there is a single fault, and the output BCD angle equals the displayed BCD angle, then the problem obviously lies with the reverse converter (echo monitor). If the echo BCD angle and the display agree, the problem is in the original conversion unit. If none of these three angles agree, then there is a

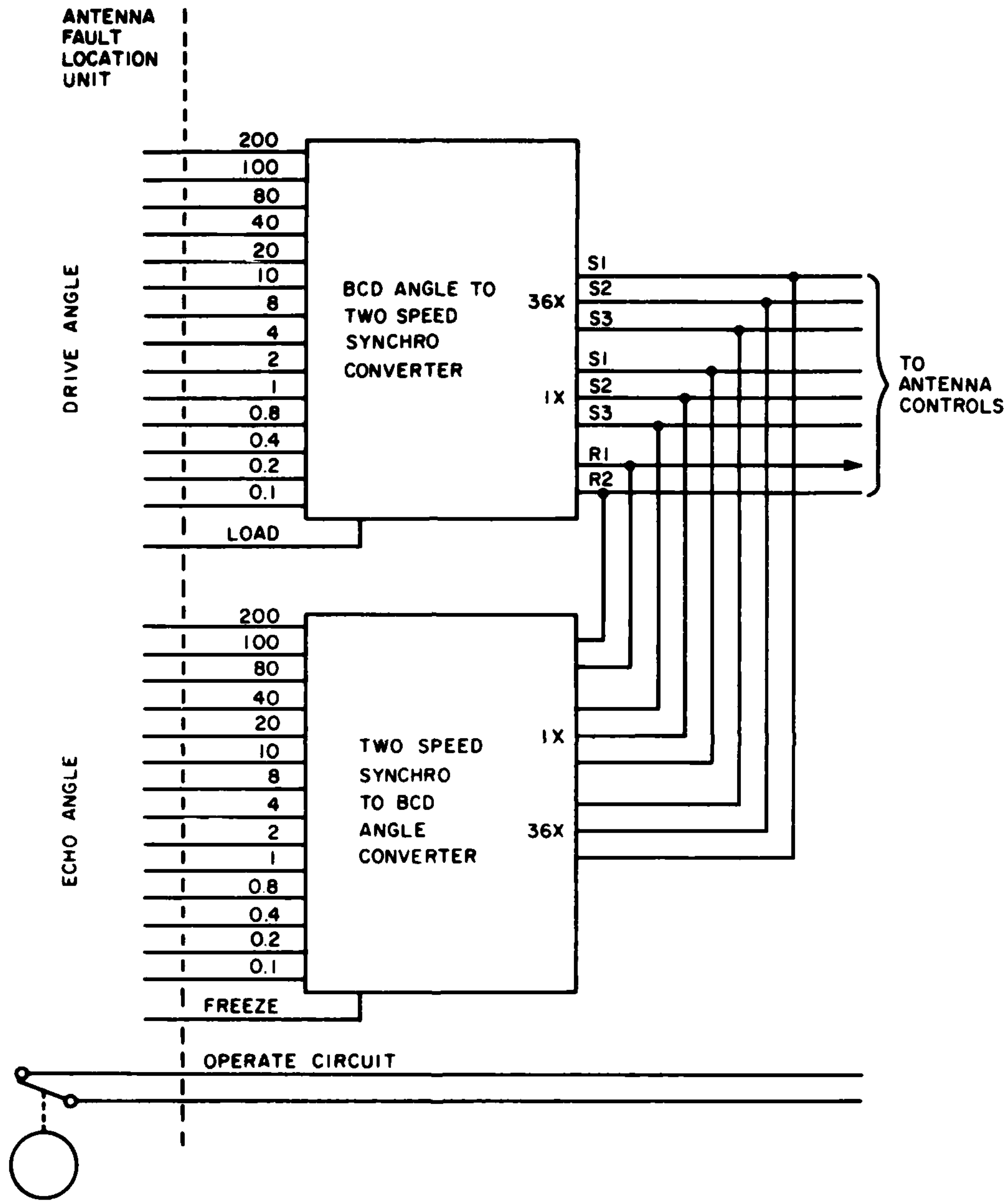


Figure 8. Block Diagram Showing One Axis of the Position Verifier

multiple failure, and the test is indeterminate. The results of this automatic test are forwarded to the operator's console.

If the elevation axis is being tested, an additional restriction is imposed. The test is not automatically performed if the echoed angle is beyond the physical travel limits of the antenna (90 deg). This test should be performed with a person stationed at the antenna controls, who will disable the antenna drive if necessary to prevent damage to the system.

The antenna fault location unit can produce a dc voltage that drives each axis of the antenna at a rate proportional to the dc voltage. This voltage is generated in the unit by outputting an eight-bit word, representing the desired rotational rate, to a digital to analog converter. The resulting output is fed into an operational amplifier that converts this signal to the levels required by the Scientific Atlanta control equipment. Before the operate circuit for an axis is activated, the fault location unit must first compare the digital word representing the rotation rate with its reconverted counterpart. If the output and its reconverted input are in agreement, the operate circuit for that axis will be energized. To further check the axis drive system, the return tachometer voltage is monitored by the analog data acquisition system and verified for proper operation. Assuming only a single failure in these parameters, a fault can be isolated by the fault location unit except for the case when the analog data acquisition system itself malfunctions.

5.1 Antenna Interlocks

An open interlock in the original antenna system configuration was indicated by a single lamp on the Scientific Atlanta control equipment. The voltage returned from these interlocks was then checked to determine which interlock is open. This function is handled automatically by the antenna fault location unit. The sensors consist of small 5-V power supply modules and a logic gate connected to the 115 Vac axis operate circuits as shown in the block diagram in Figure 9. These units provide a logic active, low-true signal to the fault location unit. Sensors are placed before and after each interlock in the chain of the axis operate circuit. An open switch is detected by the presence of a false signal, logical high, and verified by sensing false signals for the remainder of the chain. If a single false signal is not followed by others, the sensor itself has failed. The last sensor indication in the chain is verified by checking the motion of the operating axis. For this check, the desired antenna motion (scan rate/pointing angle) as indicated at the network display is compared with the actual antenna response. Once an open interlock is detected and verified or the system determines that a sensor has failed, the information is passed along to the system operator in the form of a statement in the antenna data block on the network terminal. The display

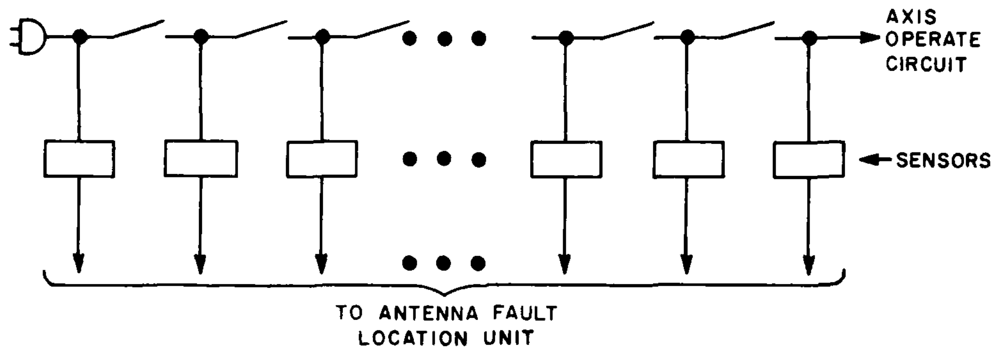


Figure 9. Block Diagram of Interlock Monitoring

indicates which of the interlocks or sensors is open or has failed. Any of the following conditions should cause an open interlock: (1) either of the manual handcranks is engaged; (2) any of the three stow pins is not properly seated in its storage slot; (3) the antenna disable switch is engaged; or (4) the antenna is driven beyond its preset elevation limits.

In addition, the source of each axis operate circuit is monitored to determine if a failure has occurred in the circuit ahead of the interlocks.

5.2 Automatic Scan Generator

The antenna fault location unit generates all of the antenna positioning and drive signals for each axis and monitors these signals to verify the proper operation of these controls. A natural extension of the function of this unit is to have it also act as an automatic scan sequence generator. This is a clear example of the integration of fault location techniques within a functional unit at the conceptual stage of its development.

An automatic scan sequence generator is incorporated into the fault location network; it generates a variety of volume scans and single axis sweeps. All scan capabilities are under program control by the system operator through keyboard entries. Up to 26 "standard" scan sequences can be stored on the fault location network mini disks and can be executed by the entry of a simple command. While the antenna scan sequence program is executing, the monitoring process continues to operate normally. Additional scan sequence programs can be generated by the system operator without affecting the operation of the network monitoring functions. The current scan sequence program is displayed in the antenna data block of the network terminal.

Programmed scan sequences are set up for volume scans in either the azimuth or elevation axes with up to 24 discrete angles to define a volume. A single angle PPI or RHI scan is handled as a subset of a volume scan and is realized by specifying only a single angle for the volume. After the antenna completes a single scan, the scan generator checks for the next pointing angle. If a scan is completed at the last angle in a sequence, the generator checks for a 1-cycle or continuous flag. If a 1-cycle flag is encountered, the sequence ceases operation, and the generator waits for its next set of instructions. If a continuous flag is encountered the sequence is repeated. Every time a new angle is fetched from the sequence buffer, the generator reports this action to the network terminal. A continuous scan sequence is terminated in two ways: first by a direct command to halt, or second, by changing the cycle flag from continuous to 1-cycle. This second action is accomplished manually at the terminal or automatically by entering a run instruction followed by the word "next". In this case when the executing scan is complete, the sequencer reports this condition to the terminal, which then transfers the new sequence parameters to the sequencer, which in turn starts executing the sequence.

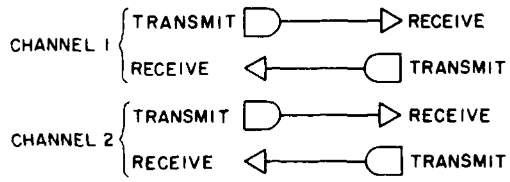
At any time during a scan, a new speed can be entered into the terminal. The new value is automatically forwarded to the sequencer for immediate execution. Additionally, for any single angle sequence, a new pointing angle can be implemented at any time by keyboard control. Neither of the changes affects the stored sequence parameters which are stored on the network's mini disks.

6. MASTER FAULT LOCATION UNIT

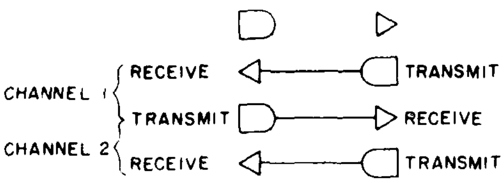
The primary purpose of the master fault location unit is to manage the communications between the transmitter and antenna fault location units and the network display. The communications scheme exhibits fault tolerance through redundancy and software management. Provisions for isolating line failures from the transmit/receiver device failures are also provided. The secondary purpose of the master unit is to monitor the performance of the antenna and transmitter fault location units.

Communications between the master fault location unit and the network display consist of eight bits in each direction and are made over a pair of parallel channels. The communications between fault location units occur via serial asynchronous channels. Each channel has a Universal Synchronous/Asynchronous Receiver/Transmitter (USART) unit which converses at a non-standard rate of 6,250 baud. Since this rate is internal to the network only, it was less expensive to derive this rate from the 2 MHz system clock than to provide a separate baud rate generator. Each channel has a built-in loop-back test which routes the transmitted data into the receiver port of the transmitting USART. This local echo verifies that a transmission has actually occurred and was valid at least up to the input of the line driver which interconnects the fault location units.

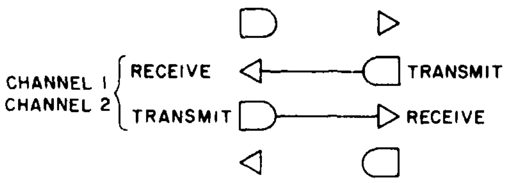
Data communication is of prime importance to the proper operation of the fault location network. Because of its importance, the communication function was made fault tolerant by the incorporation of two separate channels, each with its own distinct transmit and receive paths as shown in Figure 10(a). This redundancy is further enhanced by the use of effective software management to make the communications function as survivable as possible. When a failure occurs in a communication channel, the software of both fault location units performs a test to determine if the fault lies in the transmit or receive path. Following this test the channel is redefined as being comprised of the working path of the failed channel together with its counterpart of the working channel. This redefinition can be seen in Figure 10(b) which shows the two channels sharing one common path. The value of this exercise becomes evident when a second failure occurs in the non-shared path of the channel, which is comprised of its original transmit and receive paths. This event is depicted in Figure 10(c), which also shows the automatic reassignment of both channels as being comprised of the same transmit and receive paths. This series of events would have normally left the communications function inoperative. Incorporation of a redundant channel enhances the survivability of the communications function, but addition of a software manager results in still greater survivability.



a) Original Redundant Channel Configuration



b) Redefinition of Channel 1 after a failure



c) Redefinition of Channel 2 after a failure

Figure 10. Fault Tolerant Communications Scheme

The protocol followed by the fault location network is that the antenna and transmitter units report to the master unit after they complete each monitoring cycle. If these units have no new condition information to report to the user, they send an end of message character to the master fault location unit. This action lets the master unit know that these units are functioning properly and allows each communication channel to be periodically checked. The master unit also sends an end of message character to the network terminal if it also has nothing new to report. As soon as a condition change is detected in the monitored parameters, this information is forwarded to the master unit, which in turn immediately forwards it to the network display. The message train consists of a header, indicating the source unit and the type of message, followed by the message bytes and an end of message character. After each character is transmitted, the sending unit waits for a remote echo from the receiving unit in order to verify a proper transmission. If this character is in error, a backspace character is issued by the sending unit to inform the receiving unit to ignore the previous character. If the remote echo of the backspace character is in error, the sending unit aborts communicating over this channel. The sending unit then sets a flag which indicates the type of problem encountered (for later testing), and then proceeds to send the message over the alternate channel. Command messages, which originate from the user at the network terminal, are relayed to each fault location unit and use the same error checking scenario. A fault location unit is informed of an incoming message when it receives a complemented end of message character as a remote echo in place of the expected one. Upon receipt of this character, the unit will turn the channel around to receive its message. The message, once received, is acted on immediately.

Each communication routine has time-out count-down routines between messages, to indicate the loss of channel or communications, and between characters to indicate loss of transmission.

Another function of the communications card is to monitor voltages through a 16-channel analog data acquisition system. The master fault location unit monitors both the antenna and transmitter fault location unit power supplies and reports their condition to the network terminal. The terminal in turn displays these conditions in the data blocks reserved for each fault location unit. The antenna and transmitter fault location units measure various system voltages via the analog data acquisition system which is resident on their communication cards. The conditions of the monitored voltages are forwarded to the network terminal via the master unit and are displayed in the appropriate data block on the display. Any voltage failure is later qualified as a sensor failure if it is found that the function that is dependent on this voltage is working properly.

6.1 Random Access Memory Check

The memory check routine exercises the Random Access Memory (RAM) by storing various bit patterns throughout the 1k RAM area. All discrepancies are reported to the next higher unit through a simplified communications routine which flags the problem to the suspect bit plane. The communications routine described above depends on a working RAM to function properly. A RAM problem must therefore be reported without access to this routine. The simplified version of the communications for this problem is the character "R", which is transmitted to the next higher unit, which in turn alerts it for a memory failure, waits for the remote echo and then transfers a byte indicating which bit plane is in error and then terminates upon the receipt of a valid remote echo. This routine is accessed upon initial power-up and after any reset of the unit.

6.2 Read Only Memory Check

The instruction set and reference data for each fault location unit are contained in Read Only Memories (ROM). These ROMs are checked before power-up and after any reset of the unit. This check is made of the entire ROM section in 1k byte sections. To check the ROM, each byte of code is added to a three-byte accumulator until the entire 1k byte section is exercised. This number is then transferred to the next higher unit, either the master or the terminal. This number is then compared with a verification table, and if the numbers do not agree then the faulty numbers indicate which physical ROM should be replaced.

6.3 LOOK

This diagnostic routine takes advantage of the fact that all of the I/O and communications functions are memory-mapped in each of the fault location units. Every memory location in each of the units can be read or altered for troubleshooting purposes via the terminal keyboard. If an I/O function is not working properly, a technician enters the unit's name (antenna, transmitter or master) through the keyboard and the hexadecimal address location and carriage return. The address and data at that address are then displayed in the communications area on the display. A memory pointer is moved up or down by pressing the space bar or backspace key, respectively, and data in these memory locations are then altered by typing the desired hexadecimal number. The unit then outputs this number to memory and responds by reading the next higher address and presents this information on the display. The technician is thus able to make hardware checks at the unit. This procedure isolates the problem either to within the unit or the sensor making the measurement.

7. FAULT TOLERANT WEATHER RADAR PROCESSOR

The Pulse Pair Processor (Novick and Glover[3]) is the most complex unit in the weather radar data processing area. It is possible that a deficiency could develop internally that would not be immediately discernable by observing its output. The Pulse Pair Processor (PPP) is also the key unit in the data processing chain. Accordingly, the PPP was a candidate for the application of techniques to make it fault tolerant. One approach for fault tolerance called for the fabrication of two more PPPs and the incorporation of a majority decision unit to detect a failure and channel the valid data to the rest of the processing chain. At the time that a fault monitoring scheme was proposed for the processor, the state of the art was reaching a level where the hardware was sufficiently sophisticated and operated fast enough so that the PPP algorithms could reside in the software and share a processor instead of requiring a hardwired processor for each operation, while still achieving a throughput rate equivalent to the original instrument.

To take advantage of the new technology, a development contract for a Fault Tolerant Weather Radar Processor, FTWRP, (Jagodnik et al[4]) was awarded to Raytheon Company. The FTWRP is comprised of only two types of circuit boards: An I/O Controller (IOC) and a Common Element (CE). Each of the IOCs is unique because of different sets of input and output requirements. Each of the six CEs are identical and interchangeable with each other, and each CE is essentially a single board computer. Each CE is given a segment of the pulse pair algorithm to execute by an Intercolor Color Graphics terminal, which acts as the executive controller and status display for the processor. Whenever a CE does not properly respond to bus signals or if its own self-monitor finds a fault in its operation, the CE is taken off line and a spare CE is given the failed CE's task by the Executive. Spare CEs are not idle while waiting for another to fail. The spares execute self diagnostics to fully check their integrity. Each spare CE is also periodically rotated with an active board in order to verify the overall system integrity. Moreover, if a CE fails, and no spares exist, the executive then initiates a graceful degradation of the system performance and reconfigures the system by sacrificing the processing of data from the most distant ranges.

Each physical slot in the FTWRP board basket is periodically polled by the executive for the presence of a board, its type, function and condition. This data is displayed on the status block of the terminal. The system operator needs only

4. Jagodnik, A.J. Jr., Young, M.J., Banis, K.J., and Glover, K.M. (1980) A programmable fault-tolerant meteorological radar signal processor. Vol. 8, 1980 Digest of Papers, Gov't Microcircuit Appl. Conf., Naval Electronics Sys. Command, Washington, D.C., 270-273.

to read the display and to extract and replace a failed board. All other operations involving the FTWRP are completely automated.

8. CONCLUDING REMARKS

In order to assure that the meteorologist receives data of good quality, a fault location network was fabricated to monitor and verify the proper operation of the 10-cm dual-frequency Doppler weather radar. A dedicated fault location unit was assigned to each of the transmitter and antenna systems to monitor the performance of their various electronics and mechanical subsystems. One function that was lacking in the existing antenna system was an automatic scan sequence generator. In examining the antenna system for performance monitoring, it was found that access was required to the same signals which were needed to control the antenna. As a result, the task of the antenna fault location unit was extended to have it also act as the automatic scan sequence generator. Needless hardware redundancy was avoided by coupling these two functions. This exemplifies the benefits that are achieved when the incorporation of fault location techniques are considered in the design stages of a unit. Any changes in the monitored parameters of the two fault location units are sent to the network terminal via another fault location unit which is designated as the master. The primary function of the master unit is to manage the communications between the fault location units and the network terminal. Its secondary function is to monitor the performance of the other two fault location units. Once the parameter change information reaches the network terminal, it is displayed in a way that allows the system operator to check the status of the entire system by just a cursory glance at the terminal. The system operator is then free to determine the significance of the system's outputs.

Fault tolerance realized by the scheme employed in the fault tolerant weather radar processor offers continuous operational performance. Because most of the boards are identical, a relatively small inventory of spare boards is all that is needed. This fault tolerant structure further provides for a graceful degradation of operations if a failure occurs and the supply of spare boards is exhausted.

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