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MAS2-8 RADAR AND DIGITAL CONTROL UNIT

Remote Sensing Laboratory
RSL Technical Report 177-37

J. Michael Oberg
Fawwaz T. Ulaby

October, 1974

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ABSTRACT

MAS 2-8 (2-8 GHz Microwave Active Spectrometer) is a ground-based sensor system used by the Remote Sensing Laboratory at the University of Kansas. The system has been continually modified since its first use in 1972. The most recent major modification was that of a control subsystem to automate the data-taking operation. The system operation and a detailed discussion of the design and operation of the control unit will be presented.
1.0 **SYSTEM DESIGN**

1.1 **Background**

The desire for new and better microwave sensors has led to the continuing development of ground-based spectrometer systems. The first spectrometer built at the Center for Research, Inc. was a one-antenna 4-8 GHz slow-sweep pulse radar [1]. The pulse radar, however, was found to be unusable at the close ranges required to mount the system on a boom truck.

Moe [2] designed a 4-8 GHz spectrometer using FM-CW modulation and a single antenna. This operation requires the use of a circulator to separate the transmit and return signals. At the time, no circulator was available with sufficient isolation and the received data was obscured in local oscillator noise.

The current system, designed by Ulaby [3], uses FM-CW modulation with separate transmit and receive antennas to eliminate isolation problems. An early form of the system was used in the summer of 1972 to collect agricultural signatures from 4-8 GHz. The present system extends the frequency range to cover 2-8 GHz and allows automated data-taking.

1.2 **System Parameters**

The MAS 2-8 radar system is mounted on a 20-meter truck-mounted boom to provide an observation platform for obtaining agricultural signatures. The electric power is provided by a portable 15KW generator. An accompanying van carries major support electronics. The major system parameters are given below:

<table>
<thead>
<tr>
<th>Platform height</th>
<th>20 meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antennas</td>
<td>1-meter parabolic dishes</td>
</tr>
<tr>
<td></td>
<td>with f/D = .42</td>
</tr>
<tr>
<td>Feeds</td>
<td>2-8 GHz Log-periodic; single</td>
</tr>
<tr>
<td></td>
<td>linear polarization</td>
</tr>
<tr>
<td>Incidence angle capability</td>
<td>0-70° in 10° increments</td>
</tr>
<tr>
<td>Radar</td>
<td>FM-CW</td>
</tr>
<tr>
<td>Operation mode</td>
<td>2.25-7.75 GHz in .5 GHz steps</td>
</tr>
<tr>
<td>Center frequency</td>
<td>450 MHz</td>
</tr>
<tr>
<td>Frequency sweep</td>
<td>Triangle-wave</td>
</tr>
<tr>
<td>Modulation type</td>
<td>100-500 Hz</td>
</tr>
<tr>
<td>Modulation rate</td>
<td>57 KHz</td>
</tr>
<tr>
<td>IF frequency</td>
<td>10 KHz</td>
</tr>
</tbody>
</table>
Radar (Continued)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection type</td>
<td>RMS</td>
</tr>
<tr>
<td>Transmitt power</td>
<td>10 dBm (10 mW) minimum</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>80 dB minimum</td>
</tr>
<tr>
<td>Polarization</td>
<td>VV, VH, HH</td>
</tr>
</tbody>
</table>

The parameters varied during a data set are: center frequency (including a band change), polarization, angle, system configuration (calibration or data mode), and FM rate. All of these parameters except the last are usually controlled by the digital control unit. The received RMS signal for each combination of these parameters is recorded.

1.3 Method of Operation

The MAS 2-8 system consists of two major subdivisions: those components mounted on the boom and those mounted in the van. Signals between these two subdivisions pass through a 30-meter multiconductor cable. These signals may be further divided into control, power and IF signals.

The boom truck supports a 20-meter boom, to which the microwave subsystem and receiver hardware are mounted. The system generator is mounted on the truck bed. Controls for positioning the boom and for setting the outriggers are located on the side of the truck. After the boom truck and van have been parked near a target field, the boom truck should be stabilized with the outriggers and the boom raised and positioned over the field. As the boom is raised, the multiconductor cable will unwind from the truck bed. When the boom is positioned, the cable should be connected to the side of the van. Also the power cable from the generator should be connected to the power jack on the rear of the van.

Now start the generator and go inside the van. Throw the master circuit breaker in the breaker box located in the rear of the van. Adjust the lights and air-conditioning to comfortable levels. Turn on both van and boom power (switches are located on the operator’s panel) and allow time for the equipment to warm up.

There should now be a picture of the field on the TV monitor and an IF spectrum on the spectrum analyzer. Turn the angle positioner to scan the anticipated target area for irregularities. When this is found suitable, return to 0° and switch to automatic operation. Check the paper tape supply on the punch. Now press the CONT switch on the DCU and adjust the FM rate for a maximum reading on the RMS voltmeter. Press continue and the DCU will begin taking data.
All necessary parameters of the system can be controlled from the operator's panel, if desired. A brief description of the controls and their operation follows.

The master power switches control AC power to the boom and van subsystems independently. Normally, both switches should be energized.

The polarization switches control the polarization motors on the transmit and receive antennas. Their operation is self-explanatory.

The band select switch determines which oscillator is used as the frequency source and also selects the appropriate modulation parameters.

The manual FM override switch allows the FM rate to be adjusted by the potentiometer labeled FM rate. Otherwise, the FM rate will be automatically controlled to provide a constant IF. (This feature is currently inoperative and FM rate must be controlled manually).

The device selector allows either calibration or data modes of operation. The calibration mode replaces the antennas with a delay line.

The AUTO/MAN switch selects either automatic or manual control of the frequency, angle, polarization, band, and device.

The angle selector allows selection of any angle from 0° to 70° in 10° steps.

The frequency selector allows selection of the center frequency to be used within a selected band.
2.0 **DIGITAL CONTROL UNIT**

2.1 General Information

The Digital Control Unit (DCU) automatically changes all system parameters except FM rate and records the return signal on paper tape. The DCU is controlled by a programmable Read-Only-Memory, which allows the use of any desired control sequence(s). Separate data-taking and calibration sequences were used for our purposes. The programs used are listed in Appendix 1 and a sample output is given in Appendix 2.

The DCU uses TTL logic and a description of the 7400 logic family is given in Appendix 4. TTL was used because of its ease of design and availability, but was not necessarily the most suitable logic. TTL is a moderately fast logic and some additional noise problems resulted from this unnecessary speed capability. A much more suitable logic would have been CMOS, but this was more expensive and much harder to obtain.

2.2 Interfacing and Auxiliary Circuitry

In order to allow digital control of all major system parameters, various interface circuits were required. The first of these was a digital frequency control. A D/A converter is used with appropriate scaling to set the center frequency of the microwave oscillators. Then this voltage is summed with the FM triangle-wave and used to drive the frequency control of the oscillators. The frequency band is selected by switching the microwave transfer switch to the desired oscillator. Current amplifiers (relays and transistors) interface the switch with the DCU.

Polarization is selected by selecting the proper drive polarity for the polarization motors, which turn until the selected dish opens a limit switch.

Controlling the angle requires some form of angle indication. This function is accomplished by using a potentiometer with a plumb-bob attached to the shaft. As the antenna mount rotates, the potentiometer shaft is turned. By applying a constant voltage across the pot, a voltage proportional to the angle is obtained. Comparing this voltage with the output of a D/A converter and driving the positioner motor to decrease the error results in digitally-selected angles.
2.3 Method of Operation

When the system is ready to take data, switch the AUTO/MAN switch on the operator's panel to AUTO and the momentary CONT/PAUSE switch on the DCU to CONT. The RUN indicator should now be on. The system is now completely automatic and the operator's panel is disabled. To halt automatic control at any time, switch to PAUSE. To continue operations from the same point, switch back to CONT. If it is desired to start over again, press the momentary RESET switch and then switch to CONT.

If manual operation is desired at any time after automatic control has been initiated, switch the DCU to PAUSE and then switch to MANUAL on the operator's panel. Manual operation of the operator's panel with the DCU running will not harm the DCU but may result in extraneous output on the data punch.

NOTE: The indicators on the DCU Front Panel are valid only in the automatic mode of operation. When using the operator's panel for manual control, the switch positions indicate the parameter settings.

To follow the actions of the DCU, refer to Appendix 1, which lists the control program. If any irregularity arises, switch the DCU to PAUSE and try to determine the fault. If the trouble is isolated to the DCU, see Section 2.6 for troubleshooting and repair.

2.4 Theory of Operation

2.4.1 General

The DCU is a one-address machine with 256 eight-bit words of programmable Read-Only-Memory. All instructions are double-word; the first word contains the op code and the second word contains an address or ASCII character. The address determines the location of the next instruction to be executed if the current instruction sends a false return. Otherwise a true return causes sequential execution. By use of an instruction which always results in a false return, an unconditional branch operation can be achieved. The use of an instruction with a test operation results in conditional branches, which may be used to create iterative loops. Thus simple flowcharts may be easily implemented on this machine.

The DCU operates asynchronously; that is, every instruction, upon completion, generates a signal which initiates the execution of the next instruction. This allows the fastest implementation of many operations which require a variable amount of execution time.
All instructions are designed as independent modules, which allows easy insertion or deletion of instructions. Thus the instruction set may be changed as the system requires.

2.4.2 Logic Symbology

The DCU uses standard TTL positive logic with 0.0-0.8V representing "0" and 2.0-5.0V representing "1". The normal fan-in is one unit load: 40 uA @ 2.4V and -1.6 mA @ .4V. Most outputs can drive 10 unit loads. The DC noise margin is 400 mV minimum. Pin configurations for the 7400 family are given in Appendix 4.

2.4.3 Module Descriptions

2.4.3.1 Control Module—Board J

When the DCU is first powered-up or whenever the RESET switch is pressed, a 10ms reset pulse is generated by the P.O.R. monostable multivibrator (IC M). This signal initializes all flip-flops and counters and "jams" a HALT instruction into the instruction register (IC's E, F). This assures a stable startup condition after the reset pulse.

The rising edge of the POR signal causes the instruction monostable (IC D) to pulse the instruction flip-flop. The flip-flop then strobes the instruction register, loading the first instruction. The rising edge of Q causes the address monostable (IC G) to clock the address register (IC's B, C) which causes the first address to be read out of the pROM. The falling edge of Q retriggers the instruction monostable, clocking the instruction FF. This leaves all registers ready for a new memory cycle. The next rising edge of Q does not retrigger the address register, since the odd address disables it until the cycle monostable generates a cycle pulse.

The first instruction is always a PAUSE to prevent DCU operation until the CONT switch is pressed. Both the HALT and PAUSE instructions are ORed to produce the PAUSE signal. This signal fires the return monostable (IC N) and resets the RUN FF.

After 5ms (long enough for the memory cycle to finish), the RETURN Q goes high, clocking the Return FF, which goes low. Thus the A1 and B inputs to the Cycle monostable (IC J) are both low, and DCU operation is disabled until the CONT switch is pressed. The CONT switch presets the Run FF, logically enabling the DCU.
The rising edge of Q triggers the B input of the cycle monostable. This gates the T/F signal into the Address register and causes the second word of the last instruction to be loaded if the T/F signal is high.

The Q output triggers the address monostable, which immediately clocks the address register. However, if the T/F is high, the load will mask the clock transition and the address will not change. After 6μs, the instruction monostable is triggered and the instruction FF latches the new op-code into the instruction register. The instruction decoder then enables the proper instruction module.

6μs later, the address monostable is triggered again, clocking the second (odd) word of the instruction. The instruction monostable fires once more, resetting the instruction FF. The address monostable is now disabled since the address register contains an odd address. Thus all signals are stable until the return monostable is triggered by a RETURN signal from the return module, initiating a new instruction cycle.

2.4.3.2 Return Module

This board consists of two 16-input multiplexers which enable only the selected instruction module to send a RETURN or T/F signal to the control module. A low T/F input is true and a low-to-high transition generates the RETURN signal. The monostable generates a return for the SENSE instruction.

2.4.3.3 Data Module

This module generates the PUNCH command as well as the range and function digits for the data punch. The range from the DVM is converted to TTL levels and gated to the data punch when S is high. Otherwise, the range will be all zeros. The function digit uses only one bit, indicating which IF amplification is being used. (Currently, only one preset IF amplification is used).

The PUNCH command is generated according to the source. If the DVM is being read (S = "1"), the command is given after the last of the following conditions is met:

1) The data punch is ready to punch (HOLDOFF = "1"),
2) The POR or manual reset pulse is not on (POR = "1"),
3) The DATA enable has been given (DATA = "0")
4) The DVM is ready to be read (PRINT = "1"), and
5) The data monostable has timed out (Q = "1", 1.5 sec).

If S = "0", the PUNCH command is given immediately following the DATA enable. This assumes the frequency counter will be stable before it is read (see Appendix 1).
2.4.3.4 Multiplexer Module—Boards P, R

P and R form the data multiplexer that selects four BCD digits from either the frequency counter or the digital voltmeter. These digits are then sent to the data punch to be recorded. The monostable on Board P generates the return and clocks the select FF. The select FF controls which device the multiplexers will output. Board R contains hold-off circuitry which disables the display latch on both data devices, preventing changes while the data is being punched. IC-C is wired as a set-reset flip-flop which generates the BYPASS command to the data punch during the PUNCH instruction.

2.4.3.5 Frequency Module—Board D

As discussed earlier, the system center frequency is controlled by a digital code. The code is held in a counter/register, which is incremented each time an enable is received from the control module. The control outputs are decoded to produce separate signals for each frequency LED on the Front Panel. A monostable generates the return signal after allowing sufficient time for the oscillators to settle to the new frequency.

2.4.3.6 Angle and Band Modules—Board F

The angle module is identical to the frequency module discussed above, except the return is generated by the Digital Angle Control (Discussed in Section 2.2). The emitter-follower is used to improve noise immunity and drive capability of the return signal. The other flip-flop in IC-C is used to select the band. A monostable is used to generate the band return.

2.4.3.7 Polarization and Device Modules—Board H

A two-bit digital code generator creates the control signals for transmit and receive polarizations. The return signal is generated by the polarization control and is shaped by the level shifter and Schmitt trigger circuit to obtain a suitable TTL signal. The device module consists of a flip-flop and a monostable. The use of the Q output to clock the flip-flop results in the necessary edge inversion of the enable signal.

The other Schmitt trigger on the board is used to shape the angle return before it is sent to the return module from the angle module.

2.4.3.8 LED Drivers—Boards A, B, C

These boards each contain 16 darlington pairs with current-limiting base and collector resistors. All LED's are connected to 5V and are on when the base is driven by a "1". The +5V LED driver is tied to 5V and the -12V LED is driven by a
voltage-divider circuit which turns on the LED if the negative supply line is below -9 VDC (the minimum operating voltage of the pROM).

2.4.3.9 DVM Logic Converters—Board T

The voltage levels used by the HP3440A digital voltmeter are not standard TTL levels and have to be converted. The DVM logic levels are -30V for "1" and -2V for "0". The converters invert the logic levels which are later inverted again in the data multiplexer. The 16 converters on this board are identical and their operation is apparent from the schematic.

2.5 Programming the DCU

2.5.1 General

The control program for the DCU is stored in a pROM which can be programmed as described in Section 2.5.2. The language used in the pROM consists of double-word instructions; the first word is one of the cp-codes listed in Table 1 and the second word is the address of the next instruction to be executed if the present operation yields a false return. The second word is also used as data for the PRINT SPECIAL instruction. The program actually used is listed in Appendix 1.

2.5.2 Programming the pROM

The DCU is controlled by the program stored in the pROM. This program may be changed, as necessary, by re-programming the pROM. This process is facilitated by the use of an accompanying programmer unit.

The programmer unit consists of a programming board with socket and timing electronics plus a keyboard with the data and address switches. External power supplies are required to provide +12V, 13V (floating), -35V and 5V (floating). The -35V and the floating 13V supplies are used in series to obtain -48V, which must be able to supply 750 mA for 10ms periods with a low duty cycle (≤ 2%).

To use the programmer, first insert a blank pROM in the programming socket. Next, turn on the +12V and 5V (floating) supplies. Set the address and data switches for the first word of the new program. Now turn on the -35V and 13V (floating) supplies. Cycle the pulse switch 10 times, allowing approximately 1 second per cycle.

After the first word has been programmed, turn off the last two supplies and set the switches for the next word. Now turn the high voltage supplies back on and cycle the pulse switch. Repeat these steps until the entire program has been entered.
### TABLE 1

**DCU Op-Codes**

<table>
<thead>
<tr>
<th>Op-Code</th>
<th>Octal 1st word</th>
<th>2nd word</th>
<th>Functional Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATA</td>
<td>360</td>
<td>xxx</td>
<td>Punches data from selected device on HP3489A. Second word is ignored.</td>
</tr>
<tr>
<td>FREQ</td>
<td>361</td>
<td>A</td>
<td>Increments center frequency and branches to A if FREQ &lt; 8. When FREQ = 8, FREQ→0 and no branch occurs.</td>
</tr>
<tr>
<td>POL</td>
<td>362</td>
<td>A</td>
<td>Increments antenna polarization and branches to A if POL &lt; 3. When POL = 3, POL→0 and no branch occurs.</td>
</tr>
<tr>
<td>BAND</td>
<td>363</td>
<td>A</td>
<td>Changes frequency band and branches to A when BAND = 0. (BAND = 0 selects 2-4GHz; BAND = 1 selects 4-8GHz.)</td>
</tr>
<tr>
<td>ANGLE</td>
<td>364</td>
<td>A</td>
<td>Increments antenna angle and branches to A when ANGLE &lt; 8. When ANGLE = 8, ANGLE→0 and no branch occurs.</td>
</tr>
<tr>
<td>DEVICE</td>
<td>365</td>
<td>A</td>
<td>Changes system configuration. DEVICE = 0 configures system in radar mode, DEVICE = 1 allows calibration. Branch to A occurs on DEVICE = 0.</td>
</tr>
<tr>
<td>GO TO</td>
<td>366</td>
<td>A</td>
<td>Unconditional branch to A.</td>
</tr>
<tr>
<td>PAUSE</td>
<td>367</td>
<td>xxx</td>
<td>Turns off RUN mode; waits for a CONTINUE. Second word is ignored.</td>
</tr>
<tr>
<td>PUNCH</td>
<td>370</td>
<td>ccc</td>
<td>Causes ASC II character in second word to be punched in HP3489A.</td>
</tr>
<tr>
<td>SENSE</td>
<td>371</td>
<td>A</td>
<td>Senses condition of SENSE switch and branches to instruction stored in A, if SENSE = 1.</td>
</tr>
<tr>
<td>SELECT</td>
<td>372</td>
<td>xxi</td>
<td>Sets SELECT FF according to i; i = 0 selects the Frequency Counter, i = 1 selects the DVM.</td>
</tr>
<tr>
<td></td>
<td>373</td>
<td></td>
<td>Unused</td>
</tr>
<tr>
<td></td>
<td>374</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>375</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td></td>
<td>376</td>
<td></td>
<td>&quot;</td>
</tr>
<tr>
<td>HALT</td>
<td>377</td>
<td>xxx</td>
<td>Turns off RUN mode.</td>
</tr>
</tbody>
</table>
2.5.3 Erasing the pROM

If it is desired to change the program in the pROM or a mistake has been made in programming, the pROM must first be erased by use of an ultraviolet light. The memory should be placed within an inch of the light and left exposed for 1/2 hour.

When the memory is fully erased, all locations will contain "1's". Therefore, if a "1" is accidentally written, it may be reprogrammed to a "0" without erasing first. Unfortunately, if it is desired to change a "0" to a "1", the entire memory must be erased and reprogrammed.

2.6 Maintenance and Repair

The DCU is electrically reliable and most problems are due to faults in board connections or improper cable connections. However, if the problem is not remedied by checking these connections, Table 2 can be used to isolate most common faults. After the problem has been isolated to a board, refer to the theory of operation for that board.

2.7 DCU Cables and Pin Connections

A list of the pin connections and their functions for each connector is given on the following pages.
TABLE 2
Troubleshooting Hints

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Possible Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Display not lit.</td>
<td>Check +5VDC supply</td>
</tr>
<tr>
<td>2. Display lit, -12V LED off.</td>
<td>Check -12VDC supply</td>
</tr>
<tr>
<td>3. Display normal, RUN LED remains off after pressing CONT.</td>
<td>Press RESET and try again. If RUN still remains off, check MODE switch on Board J for NORM.</td>
</tr>
<tr>
<td>4. RUN on, but Display static</td>
<td>Check Cable connections on Board L for possible return errors.</td>
</tr>
<tr>
<td>5. RESET switch does not work and DCU does not come up in proper state when power is applied</td>
<td>Check POR monostable and RESET switch.</td>
</tr>
<tr>
<td>6. Angle LED's, POL, and DEVICE LED's not on.</td>
<td>Check Board A for solid connection or bad driver.</td>
</tr>
<tr>
<td>7. FREQ LED's off.</td>
<td>Check Board B.</td>
</tr>
<tr>
<td>8. Power and RUN LED's off, Display lit</td>
<td>Check Board C.</td>
</tr>
<tr>
<td>9. DCU &quot;hangs&quot; after FREQ instruction.</td>
<td>Check return from Board D.</td>
</tr>
<tr>
<td>10. DCU &quot;hangs&quot; after ANGLE instruction.</td>
<td>Check return from Board H and Board F.</td>
</tr>
<tr>
<td>11. Punched data from DVM is garbled.</td>
<td>Check logic converters on Board T.</td>
</tr>
</tbody>
</table>
## J1 -- DCU / Operator’s Panel Cable

<table>
<thead>
<tr>
<th>Connector Pin</th>
<th>DCU Backplane Pin</th>
<th>Function</th>
</tr>
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<tbody>
<tr>
<td>J1-1</td>
<td>D18</td>
<td>Freq Code (LSB)</td>
</tr>
<tr>
<td>J1-2</td>
<td>D19</td>
<td>Freq Code (2SB)</td>
</tr>
<tr>
<td>J1-3</td>
<td>D20</td>
<td>Freq Code (MSB)</td>
</tr>
<tr>
<td>J1-4</td>
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<td></td>
</tr>
<tr>
<td>J1-5</td>
<td>n.c post</td>
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</tr>
<tr>
<td>J1-6</td>
<td>F9</td>
<td>Angle Code (LSB)</td>
</tr>
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<td>J1-7</td>
<td>F10</td>
<td>Angle Code (2SB)</td>
</tr>
<tr>
<td>J1-8</td>
<td>F11</td>
<td>Angle Code (MSB)</td>
</tr>
<tr>
<td>J1-9</td>
<td>H26</td>
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</tr>
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<td>J1-10</td>
<td>H13</td>
<td>Transmit Polarization</td>
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<td>J1-11</td>
<td>H14</td>
<td>Receive Polarization</td>
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<tr>
<td>J1-12</td>
<td>F24</td>
<td>Band Control</td>
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<td>F25</td>
<td>Angle Return</td>
</tr>
<tr>
<td>J1-14</td>
<td>H15</td>
<td>Radar Mode</td>
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<td>J1-16</td>
<td>H16</td>
<td>Calibration Mode</td>
</tr>
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</tr>
<tr>
<td>J1-18</td>
<td>n.c post</td>
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</tr>
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<td>J1-19</td>
<td>N20</td>
<td>Function Bit</td>
</tr>
<tr>
<td>J1-20</td>
<td>T33 (GND)</td>
<td>Ground</td>
</tr>
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<td>J1-21</td>
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</tr>
<tr>
<td>J1-22</td>
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13
## J2 — DCU / Frequency Counter Cable

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<td></td>
</tr>
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<tr>
<td>J2-6</td>
<td>R3</td>
<td>FREQ $2 \times 10^1$</td>
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<td>P7</td>
<td>FREQ $2 \times 10^2$</td>
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<td>P3</td>
<td>FREQ $2 \times 10^3$</td>
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<td>J2-24</td>
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<td>R5</td>
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<td>R6</td>
<td>FREQ $4 \times 10^0$</td>
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<td>R2</td>
<td>FREQ $4 \times 10^1$</td>
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</tr>
<tr>
<td>J2-50</td>
<td>T83 (GND)</td>
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## J3 --- DCU / DVM Cable

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<th>DCU Backplane Pin</th>
<th>Function</th>
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</thead>
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<td>N24</td>
<td>RANGE (2)</td>
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<td>T31</td>
<td>DVM 1 x 10^9a</td>
</tr>
<tr>
<td>J3-4</td>
<td>T29</td>
<td>DVM 2 x 10^9a</td>
</tr>
<tr>
<td>J3-5</td>
<td>T23</td>
<td>DVM 1 x 10^9a</td>
</tr>
<tr>
<td>J3-6</td>
<td>T21</td>
<td>DVM 2 x 10^9a</td>
</tr>
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<td>T15</td>
<td>DVM 1 x 10^9a</td>
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<td>J3-8</td>
<td>T13</td>
<td>DVM 2 x 10^9a</td>
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<td>T7</td>
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<td>T5</td>
<td>DVM 2 x 10^9a</td>
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<td>DVM HOLDOFF</td>
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<td>DVM PRINT COMMAND</td>
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<td>RANGE (4)</td>
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<td>RANGE (8)</td>
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<td>R26</td>
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<td>GROUND</td>
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## J4 -- DCU / Data Punch (By-Pass) Cable

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*Function Values:*
- b1a, b2, b3, b4, b5, b6, b7, b8
- T/F
- LED RUN Control

*Pin Notation:*
Board L -- DCU Backplane Pin Connections

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25
**Board N -- DCU Backplane Pin Connections**

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## Board T -- DCU Backplane Pin Connections

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- **5V**: Power supply voltage
The system is currently undergoing several major modifications. These include: extending frequency to cover 1-8 GHz, adding minicomputers for data control and pre-processing, using dual-polarized feeds to eliminate dish rotation, and automating still more of the system’s operation. All these are natural and desirable changes. Not only do these additions make system use more convenient, they result in a system much closer to what would be necessary if the sensor were airborne.

If the scatterometer research is to prove practical, a sensor for use on an aircraft or satellite must eventually be developed. To make the transition to a longer range, thought will have to be given to such areas as effective antenna beamwidths and methods for beam limiting, such as IF filtering. Antenna alignment problems may push for another look at a one-antenna system. Not only are the sampling rate and timing critical; doppler effects may require some system modifications. Range variations caused by fluctuations in aircraft elevation will also have to be considered.

Obviously, much time and effort will be required before a usable airborne sensor can be obtained. However, it is nevertheless interesting to look ahead to such a time and predict possible uses for such a sensor. The MAPS II system and others like it have shown the potential for such a system to monitor soil moisture, crop type and crop maturity. If such a potential could be realized, irrigation and flood control could be optimized, crop harvest and therefore market conditions could be more accurately forecast, and a myriad of related land-use functions could be better fulfilled. Thus, such a sensor could prove to be quite a valuable tool for the soil scientist or agricultural economist.

3.0 CONCLUSIONS

The system is currently undergoing several major modifications. These include: extending frequency to cover 1-8 GHz, adding minicomputers for data control and pre-processing, using dual-polarized feeds to eliminate dish rotation, and automating still more of the system’s operation. All these are natural and desirable changes. Not only do these additions make system use more convenient, they result in a system much closer to what would be necessary if the sensor were airborne.

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4.0 REFERENCES


APPENDIX I
DCU CONTROL PROGRAM

000 367 377 START
002 371 134
004 370 123
006 370 324
010 370 101
012 370 322
014 370 324
016 370 215
020 370 012
022 370 306 BEGIN
024 370 115
026 372 000
030 367 377
032 360 377
034 370 215
036 370 012
040 372 001
042 370 120 B1
044 370 317
046 370 314
050 370 215
052 370 012
054 360 377 B2
056 361 060
060 361 054
062 370 215
064 370 012
066 363 070
070 360 377
072 361 074
074 360 377
076 361 100
100 360 377
102 361 104
104 360 377
106 361 110
110 370 215
112 370 012
114 360 377
116 361 114

PAUSE
SENSE CALBRT
PUNCH 'S'
PUNCH 'T'
PUNCH 'A'
PUNCH 'R'
PUNCH 'T'
PUNCH 'cr'
PUNCH 'L'
PUNCH 'F'
PUNCH 'M'
PUNCH FCNTR
PAUSE

* WAIT FOR OPERATOR TO SET FM
DATA
PUNCH 'cr'
PUNCH 'L'
PUNCH 'F'
PUNCH DVM

* 2-4GHZ
PUNCH 'P'
PUNCH 'O'
PUNCH 'L'
PUNCH 'cr'
PUNCH 'L'
PUNCH 'F'
PUNCH B1

DATA
FREQ *+1
FREQ B2

* 4-8GHZ
DATA
FREQ *+1
FREQ *+1
FREQ *+1
FREQ *+1
GET READY FOR SECOND LINE OF 4-8 DATA

* PUNCH 'cr'
PUNCH 'L'
PUNCH DATA
FREQ *-1
BEGINNING OF CALIBRATION

DEVICE

PAUSE

WAIT FOR FM ADJUST

DATA

SELECT FCNTR

2-4 GHZ

DATA

SELECT DVM

4-8 GHZ

BAND

DATA

FREQ

PUNCH 'cr'

DATA

FREQ

PUNCH 'lf'

DATA

FREQ

PUNCH 'cr'

DATA

FREQ

PUNCH 'lf'

DATA

FREQ

PUNCH 'cr'

DATA

FREQ

PUNCH 'lf'

DATA

FREQ

PUNCH 'cr'

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PUNCH 'cr'

DATA

FREQ

PUNCH 'lf'

DATA

FREQ
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APPENDIX 2

SAMPLE OUTPUT

The following page shows a sample output for a calibration and three data angles. This output is taken directly off of a teletype with the data paper tape input.

The calibration output begins with "CAL" and then lists the required FM rate in Hz. The next three lines list the recorded signal for 2.25 to 7.75 GHz in ascending order.

The data sequence begins with "START", which indicates that all system parameters have been initialized. The FM rate is then printed, followed by "POL". The first "POL" indicates that the following 12 points were recorded for VV polarization. The second "POL" indicates VH polarization and the third "POL" indicates HH polarization. The occurrence of the next FM reading signifies the start of a new angle. Thus the sample shows the output for 0°, 10° and 20°.
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APPENDIX 3. ASCII CODE (EVEN PARITY)

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<td>B</td>
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<td>C</td>
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</table>

42
APPENDIX 4
7400 TTL LOGIC FAMILY

This appendix will summarize the basic rules and pin configurations needed to use the IC's incorporated in the DCU. The loading rules have been discussed in Section 2.4.2 under logic symbology and only a few brief comments need be added. The maximum input voltages are -0.5V and +5.5V. The maximum supply voltages (Vcc to Gnd) are -0.5V and +7.0V. For further information concerning the 7400 family, see Texas Instrument's catalog on TTL.

The pin configurations for the IC's used in the DCU are illustrated on the following page.
7400 TTL Pin Configurations

7400

7404

7413

7414

7421

7415

7416

7417

7418

7419

ORIGINAL PAGE IS OF POOR QUALITY
APPENDIX 5

MAS 2-8 ANTENNA PATTERNS*

Purpose
The purpose of this memo is to document and calculate the effective antenna beamwidths using antenna pattern measurements made in February, 1974.

Procedure
The following steps were involved:
1) Antenna pattern measurements: The measurements were made at the antenna range. The first 16 polar plots (Figures 1 to 16) in the appendix show azimuth and elevation cross-sections of the transmitting and receiving antenna gains vs. angle. The horn was horizontally polarized and cuts were obtained at frequencies of 8, 7, 6, 5, 4, 3 and 2.5 GHz. Unfortunately, the two antennas were not aligned when the plots were taken for 2.5 GHz.

2) Effective antenna gains (gain of transmitting antenna x gain of receiving antenna) were then plotted against angle for every frequency and for each of the following conditions. See Figures 17 to 44.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Cross-Section</th>
<th>Transmitting Antenna</th>
<th>Receiving Antenna</th>
</tr>
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<tbody>
<tr>
<td>(a)</td>
<td>Azimuth</td>
<td>horizontally polarized</td>
<td>horizontally polarized</td>
</tr>
<tr>
<td>(b)</td>
<td>Elevation</td>
<td>horizontally polarized</td>
<td>horizontally polarized</td>
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<td>(c)</td>
<td>Azimuth</td>
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<td>(d)</td>
<td>Elevation</td>
<td>horizontally polarized</td>
<td>vertically polarized</td>
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</table>

*This appendix is a reprint of CRES Technical Memorandum 177-49 by Percy P. Batlivala.
3) For each plot, areas were calculated using the 9100B HP calculator—to a level of 30 dB below maximum. Beamwidths were obtained by dividing each area by 1000 (30 dB). Refer to Table 1 for beamwidths.

Table 1. Beamwidth in degrees for combinations of frequency and polarization for both azimuth and elevation.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Az*1 H,H</th>
<th>El*2 H,H</th>
<th>Az*3 H,V</th>
<th>El HV*4</th>
</tr>
</thead>
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<tr>
<td>2.5 GHz</td>
<td>7.2</td>
<td>6.2</td>
<td>6.2</td>
<td>7.0</td>
</tr>
<tr>
<td>3 GHz</td>
<td>4.23</td>
<td>5.21</td>
<td>4.3</td>
<td>4.41</td>
</tr>
<tr>
<td>4 GHz</td>
<td>4.17</td>
<td>3.67</td>
<td>3.73</td>
<td>3.79</td>
</tr>
<tr>
<td>5 GHz</td>
<td>3.44</td>
<td>3.3</td>
<td>3.24</td>
<td>2.97</td>
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<td>6 GHz</td>
<td>2.54</td>
<td>2.61</td>
<td>2.4</td>
<td>2.51</td>
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<tr>
<td>7 GHz</td>
<td>2.27</td>
<td>2.6</td>
<td>2.24</td>
<td>2.37</td>
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<td>8 GHz</td>
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<td>2.2</td>
<td>2.25</td>
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</table>


4) Beamwidths at intermediate frequencies were obtained as follows. Plots were made of frequency (on a log scale) vs. beamwidth in degrees (on a linear scale) for each of the four conditions stated previously. A straight line which resulted in a minimum mean squared error was fitted through the points. Beamwidths at intermediate frequencies were read from these graphs and are tabulated in Table 2. See Figures 45 to 48.
Table 2. Effective beamwidths tabulated at 12 frequencies, HH and HV polarizations and azimuth and elevation.

<table>
<thead>
<tr>
<th>Frequency in GHz</th>
<th>Az, H,H</th>
<th>El, H,H</th>
<th>Az, H,V</th>
<th>El, H,V</th>
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<td>5.60</td>
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<td>1.90</td>
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FIGURE 1:
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
F-PLANE POWER PATTERN
FREQUENCY = 9 GHZ
FIGURE 3
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER PATTERN
FREQUENCY = 6 GHz
FIGURE 4.
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER PATTERN
FREQUENCY = 5 GHz
FIGURE 5.
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER PATTERN
FREQUENCY = 4 GHz
FIGURE 6.
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
E-PLANE POWER-PATTERN
FREQUENCY = 3 GHz
FIGURE 7
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 8 GHZ
Figure 9:
COLOR CODE
BLUE = TRANSMIT ANTENNA
GREEN = RECEIVE ANTENNA
H-PLANE POWER PATTERN
FREQUENCY = 6 GHz
Figure 19
Color Code
Blue = Transmit Antenna
Green = Receive Antenna
H-Plane Power Pattern
Frequency = 5 GHz
Figure 15
H-plane power pattern
Frequency = 2.5 GHz
Antenna = transmit
FIGURE 14
H-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = RECEIVE
FIGURE 15
E-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = TRANSMIT
FIGURE 16:
E-PLANE POWER PATTERN
FREQUENCY = 2.5 GHz
ANTENNA = RECEIVE
Figure 17. Effective Principal Plane Power Pattern

Frequency: 2.5 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 6.2°
Elevation

Angle in Degrees

$G_T \cdot G_R$ (dB below maximum)
Figure 18. Effective Principal Plane Power Pattern

Frequency: 2.5 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 7.2°
Azimuth

*Assuming that both transmitting and receiving patterns are correctly aligned.
Figure 19. Effective Principal Plane Power Pattern

Frequency: 2.5 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 7.0°
Elevation

*Assuming that both transmitting and receiving patterns are correctly aligned.
Figure 20. Effective Principal Plane Power Pattern

Frequency: 2.5 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 6.2°
Azimuth

*Assuming that both transmitting and receiving patterns are correctly aligned.
Figure 21. Effective Principal Plane Power Pattern

Frequency: 3 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 5.21°
Elevation
Figure 22. Effective Principal Plane Power Pattern

Frequency: 3 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 4.2°
Azimuth
Figure 23. Effective Principal Plane Power Pattern

Frequency: 3 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 4.41°
Elevation

$G_T \times G_R$ (dB below maximum)

Angle in Degrees
Figure 24. Effective Principal Plane Power Pattern

Frequency: 3 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 4.3°
Azimuth
Figure 25. Effective Principal Plane Power Pattern

Frequency: 4 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 3.67°
Elevation
Figure 26. Effective Principal Plane Power Pattern

Frequency: 4 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 4.17°
Azimuth

Angle in Degrees

$G_T \cdot G_R$ (dB below maximum)
Figure 27. Effective Principal Plane Power Pattern

Frequency: 4 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 3.79°
Elevation
Figure 28. Effective Principal Plane Power Pattern

Frequency: 4 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 3.73°
Figure 29. Effective Principal Plane Power Pattern

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 3.3°
Elevation
Figure 30. Effective Principal Plane Power Pattern

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 3.44°
Azimuth
Figure 31 - Effective Principal Plane Power Pattern

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.97°
Elevation

Angle in Degrees
Figure 32. Effective Principal Plane Power Pattern

Frequency: 5 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 3.24°
Azimuth

Angle in Degrees

$G_T \times G_R$ (dB below maximum)
Figure 33. Effective Principal Plane Power Pattern

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.6°
Elevation

Angle in Degrees

$G^* R_T$ (dB below maximum)
Figure 34. Effective Principal Plane Power Pattern

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.54°
Azimuth
Figure 35. Effective Principal Plane Power Pattern

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.51°
Elevation

Angle in Degrees
Figure 36. Effective Principal Plane Power Pattern

Frequency: 6 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.4°
Azimuth

$G_T \cdot G_R$ (dB below maximum) vs. Angle in Degrees
Figure 37. Effective Principal Plane Power Pattern

- Frequency: 7 GHz
- Transmitting Antenna: H
- Receiving Antenna: H
- Effective Beamwidth: 2.60°

Diagram:

- \( G_T \times G_R \) (dB below maximum)
- Angle in Degrees

Graph showing the relationship between angle and gain for the effective principal plane power pattern.
Figure 38. Effective Principal Plane Power Pattern

Frequency: 7 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.27°
Azimuth
Figure 39. Effective Principal Plane Power Pattern

Frequency: 7 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.37°
Figure 40. Effective Principal Plane Power Pattern

Frequency: 7 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.24°
Azimuth
Figure 41. Effective Principal Plane Power Pattern

Frequency: 8 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.3°
Elevation
Figure 42. Effective Principal Plane Power Pattern

Frequency: 8 GHz
Transmitting Antenna: H
Receiving Antenna: H
Effective Beamwidth: 2.0°
Azimuth
Figure 43. Effective Principal Plane Power Pattern

Frequency: 8 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.245°
Elevation

Angle in Degrees

$G_T \times G_R$ (dB below maximum)
Figure 44 . Effective Principal Plane Power Pattern

Frequency: 8 GHz
Transmitting Antenna: H
Receiving Antenna: V
Effective Beamwidth: 2.2°
Azimuth
Figure 45. Effective Beamwidth vs. Frequency

Transmit Antenna: H
Receive Antenna: H
Elevation

Frequency in GHz

Effective Beamwidth in Degrees
Figure 4.5. Effective Beamwidth vs. Frequency

Transmit Antenna: H
Receive Antenna: H
Azimuth
Figure 47. Effective Beamwidth vs. Frequency

Transmit Antenna: H
Receive Antenna: V
Elevation

Effective Beamwidth in Degrees

Frequency in GHz
Figure 48. Effective Beamwidth vs. Frequency

Transmit Antenna: H
Receive Antenna: V
Azimuth
APPENDIX 6
SYSTEM CALIBRATION DATA

The following graphs were used in conjunction with the antenna patterns in Appendix 5 to calibrate the system against a Luneberg lens. The delay line attenuation (Figure 49) was used to estimate dynamic range of the system by adding attenuation to the delay line until the noise level was reached. The bandpass filter characteristics (Figure 50) determine when the filter will limit the antenna beamwidth determined from the patterns in Appendix 5. The RMS/DC linearity (Figure 51) places a maximum on the dynamic range of the system without changing the IF gain.
FIGURE 50.
Bandpass Filter Response

Attenuation vs. Frequency
FIGURE 51.
RMS/DC Converter Linearity

Percent Deviation vs. RMS Input

-7  -6  -5  -4  -3  -2  -1  0  1  2  3  4
1mV  10mV  100mV  1mV  10mV