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SEMI-ANNUAL STATUS REPORT 1

ON

THE INFLUENCE OF POLARIZATION ON MILLIMETER WAVE PROPAGATION THROUGH RAIN

C. W. BOSTIAN AND W. L. STUTZMAN

SUBMITTED TO: NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C.

NASA GRANT NUMBER NGR-47-004-091

COVERING THE PERIOD JANUARY 1 - JUNE 30, 1972

JULY 1, 1972

ELECTRICAL ENGINEERING DEPARTMENT
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
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PROJECT PERSONNEL

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1. Introduction

This report describes a program for the measurement and analysis of the depolarization and differential attenuation that occur when millimeter wave signals propagate through rain. Initial data will be taken along a 1.43 km path at 17.65 GHz and a supporting theoretical model will be developed to relate the propagation effects to rainfall rate and wind velocity.

Figure 1 presents a block diagram of the overall experiment. It consists of (1) an RF system (millimeter wave transmitter and receiver), (2) transmitting and receiving antennas, (3) a weather system with rain gauges, wind sensors, and drop counters, and (4) a digital control, processing, and data storage system built around a Raytheon PB 440 computer. The sections to follow report the status of these systems in detail.

2. Revised Choice of Polarization

Our first intent was to transmit and receive horizontal and vertical polarization, but a careful review of the theory led to a decision to begin with polarizations $\pm$ 45° from vertical instead. The reasons follow.

Depolarization would not occur if raindrops were spherical and if single-drop forward scatter were their only mode of interraction with millimeter waves. These conditions are not realistic; multiple scatter, oblique scatter, and departures from a spherical geometry all cause

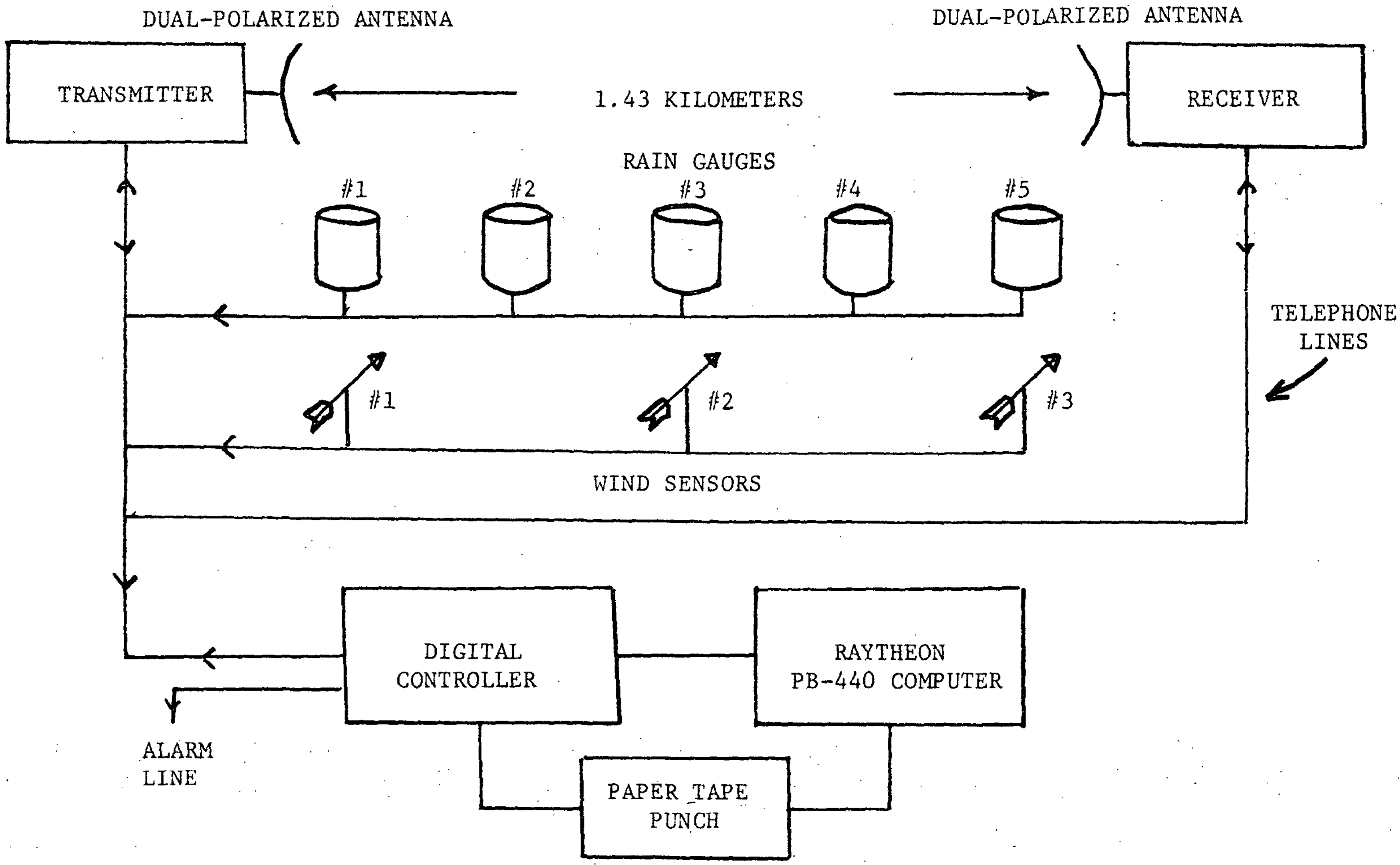


Figure 1. Experiment Block Diagram

depolarization. Non-sphericity is the most important factor in rain depolarization and the only one treated by contemporary theory.

Real raindrops resemble spheroids with symmetry about a major and minor axis, and the flatness of a drop increases with its size. Because of the symmetries involved, waves polarized along the principal (major and minor) axes of a drop are not depolarized during forward scatter. They are depolarized in oblique scatter, an effect that present theory ignores.

Waves polarized along the major axis are attenuated more strongly than waves polarized along the minor axis. This differential attenuation depends on the rainfall rate R, and for the path and frequency covered in this report its theoretical value ranges from 0.19 dB at R = 12.5 millimeters/hour to 2.9 dB at 150 millimeters/hour. The degree of cross polarization that the differential attenuation will produce is a function of the angle between the incident E vector and the minor axis (for purposes of discussion the angle could be measured from either axis) of the raindrop. An angle of 0° produces no depolarization while an angle of about 45° maximizes the depolarization.

Raindrops are usually canted at an angle determined by the local wind velocity. Workers at Bell Telephone Laboratories have estimated an average canting angle (between the minor axis and vertical) of 15° during heavy rains, and one might expect to observe average canting angles between 0° and 15° as the rain progresses from light to heavy.

In this experiment we want to observe rain depolarization as often as we can--i.e., in the lightest rain possible. This means that the transmitted polarizations should be $\pm$ 45° from the expected canting angle, and not horizontal and vertical. Since the expected canting angle range is 0-15°, polarizations of $\pm$ 45° from the vertical were selected. The advantages to the experiment of this choice of polarizations are evident from Figure 2, which compares the expected cross polarization levels for vertical and for $\pm$ 45° polarization. For vertical polarization, expected cross polarization levels lie below the bottom curve, while for $\pm$ 45° polarization the data should fall between the top two curves. The differences are major; for antennas with -31 dB cross polarization discrimination and $\pm$ 45° polarization, depolarization would be measured at 33 mm/hour rain at 0° canting angle and at 38 mm/hour for a 15° angle. Vertically polarized signals on the other hand would result in no depolarization for 0° drops and would require a rainfall of 60 mm/hour to produce detectable depolarization with drops canted at 15°. Therefore polarizations of $\pm$ 45° from the vertical were chosen for this experiment.

3. RF System

3.1 Introduction

The RF and associated control equipment were designed to measure three basic parameters: (1) the simultaneous attenuation of the +45° and -45° polarizations, (2) +45° attenuation and +45° to -45° cross-polarization conversion, and (3) -45° attenuation and -45° to +45° cross-polarization conversion. The RF system was fabricated to interface with a Raytheon PB 440 computer using negative 8 volt logic.

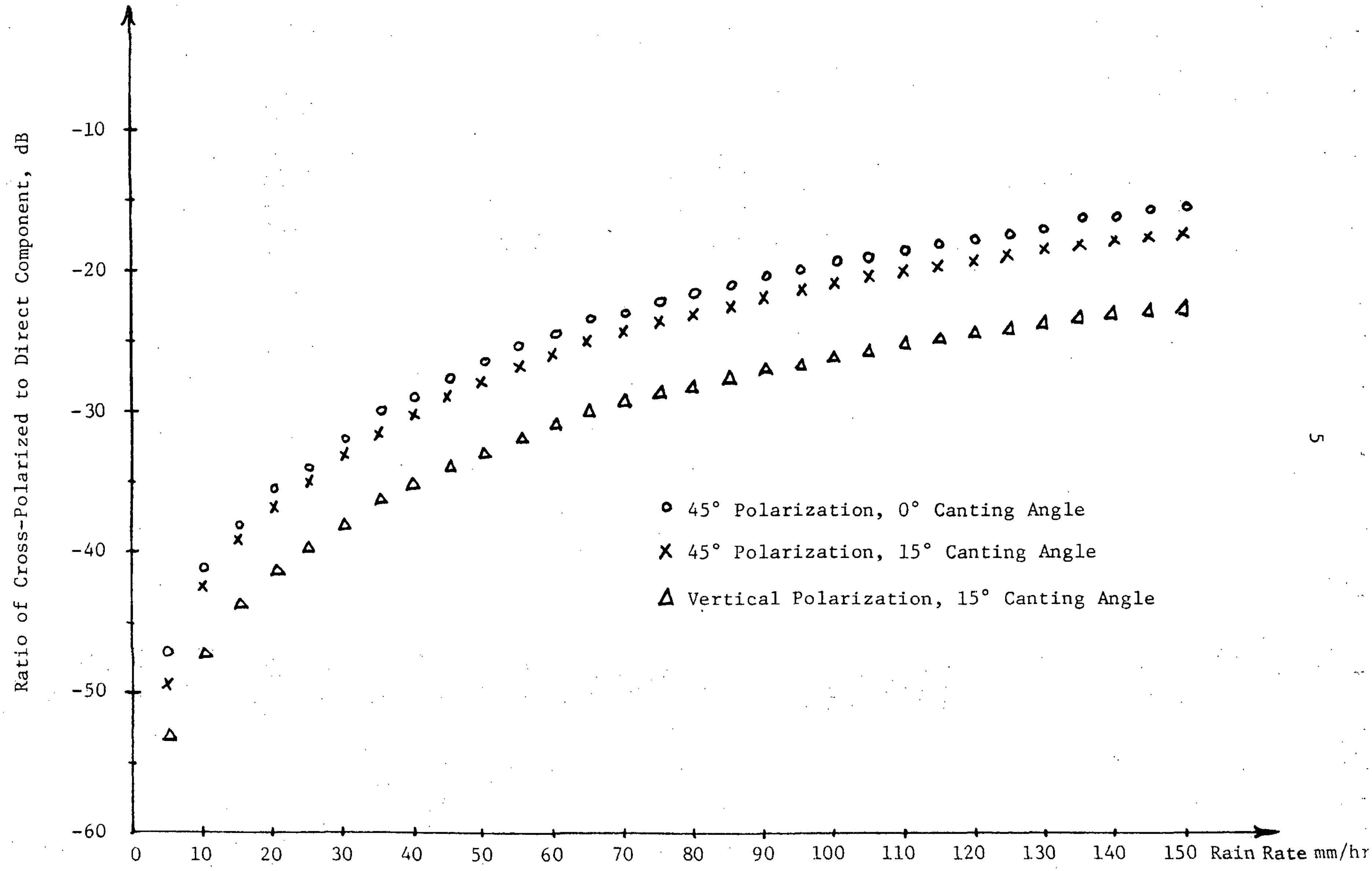


Figure 2. Predicted Cross Polarization for Selected Incident Polarizations and Drop Orientations

3.2 Work Schedule

The period from 1 January to 31 March 1972 was devoted to subsystem design, procurement, assembly, and testing. Subsystems designed included: the receiver, the transmitter, emergency power systems for the transmitter and receiver, waveguide switching circuits, transmitter remote on-off circuit, and receiver and transmitter alarm logic. These designs are complete and their construction status is discussed individually below.

The period from 1 April to 30 May 1972 was spent aligning the receiver and transmitter and testing both for reliability.

3.3 The Transmitter

The transmitter was designed to meet these specifications:

1. Operating Frequency: 17.650 GHz $\pm$ 0.005%
2. Operation Mode: CW
3. Operating Independent Channels: 2 (+45° and -45° polarization)
4. Operating Minimum Output Power: 25 milliwatts per channel
5. Switching Capability: transmit or no transmit remotely selected for each channel.

The heart of the transmitter (Figure 3) is an RDL, Inc., 17.65 GHz source, model POOK 131. This unit meets the frequency and power specifications listed above. An attenuator follows the source to permit field adjustment of the output so that the receiver will operate over its full dynamic range. The signal from the source is monitored by a General Microwave 460B power meter through a 40 dB coupler. The

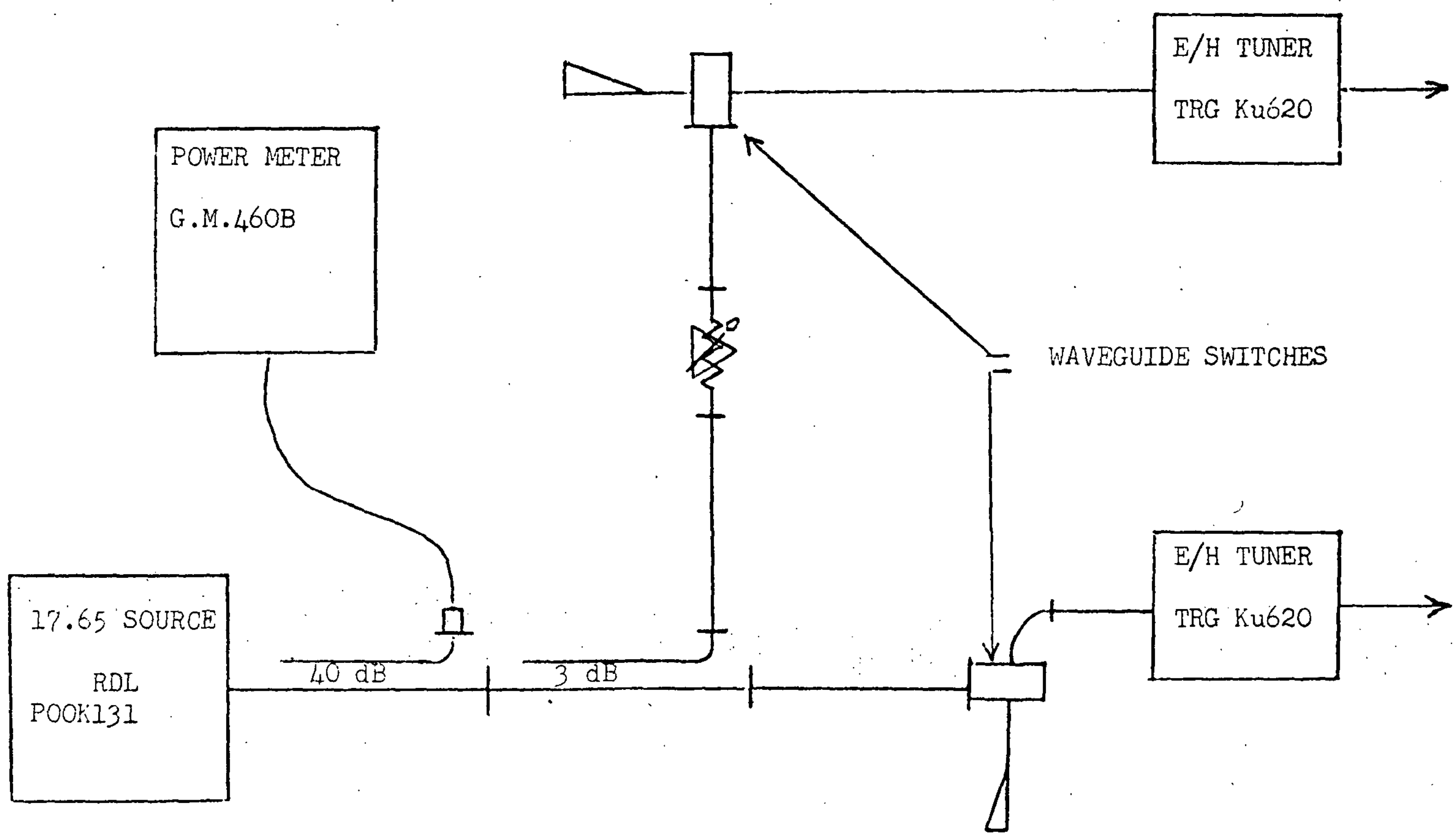


Figure 3. 17.65 GHz Transmitter

source output is split by a 3 dB coupler into a +45° and a -45° channel. The attenuator in the +45° channel insures that both channel outputs are identical. Each channel contains a waveguide switch that can either terminate the signal in a matched load or send it on to the antenna.

The transmitter has been built and bench tested and now is undergoing reliability tests. Data taken during the bench tests are listed below.

1. Frequency: 17.65 $\pm$ 800 KHz
2. Power Output: 26 milliwatts per channel
3. Isolation Between Channels: $>$ 60 dB

The transmitter output power was set in the laboratory after a consideration of path loss, antenna gain, and receiver sensitivity. It can be changed in the field to coincide with the dynamic range of the receiver.

The transmitter has been licensed by the Federal Communications Commission as a contract developmental station in the experimental radio service. Its assigned call letters are KQ2XOC.

3.4 Transmitter Control System

A remote control system for the transmitter was designed to allow the PB 440 computer to operate the waveguide switches and receive malfunction alarms. A remote positive "on-off" control was required for the transmitter for compliance with FCC Regulation 5.106 Subpart C, Experimental Radio Services. A power switching circuit was designed to switch automatically from 60 cycle power to battery power in case of power failure.

3.5 Waveguide Switching Circuit

Figure 4 illustrates the waveguide switching circuit. Pins 2 and 3 and 4 and 5 carry 28 volts for the +45° and -45° channel waveguide switches respectively. Pins 1 and 7 are the -8 volt lines from the PB 440. Both switching circuits are shown in the transmit position--i.e., the waveguide switches are activated and are routing power to the antenna. Q101 through Q104 are high-beta transistors to insure a high input impedance and low current drain.

3.6 Malfunction Alarm System

The transmitter alarm system generates a negative 8 volt logic signal if the transmitter power supply fails or if the waveguide switches assume different positions from those specified by the PB 440. Figure 5 illustrates the alarm circuit and its associated dual inverter, NOR gate, and pulse filter. This circuit has been bench tested and operated reliably.

3.7 Remote "On-Off" Circuit

Figure 6 represents the transmitter "on-off" circuit. The entire circuit, less S1, is located at the transmitter. S1 is a key switch which is located next to the PB 440 in a secure enclosure. Only properly authorized personnel have access to the switch. The circuit has been built and tested; it operated for 346 continuous hours without failure.

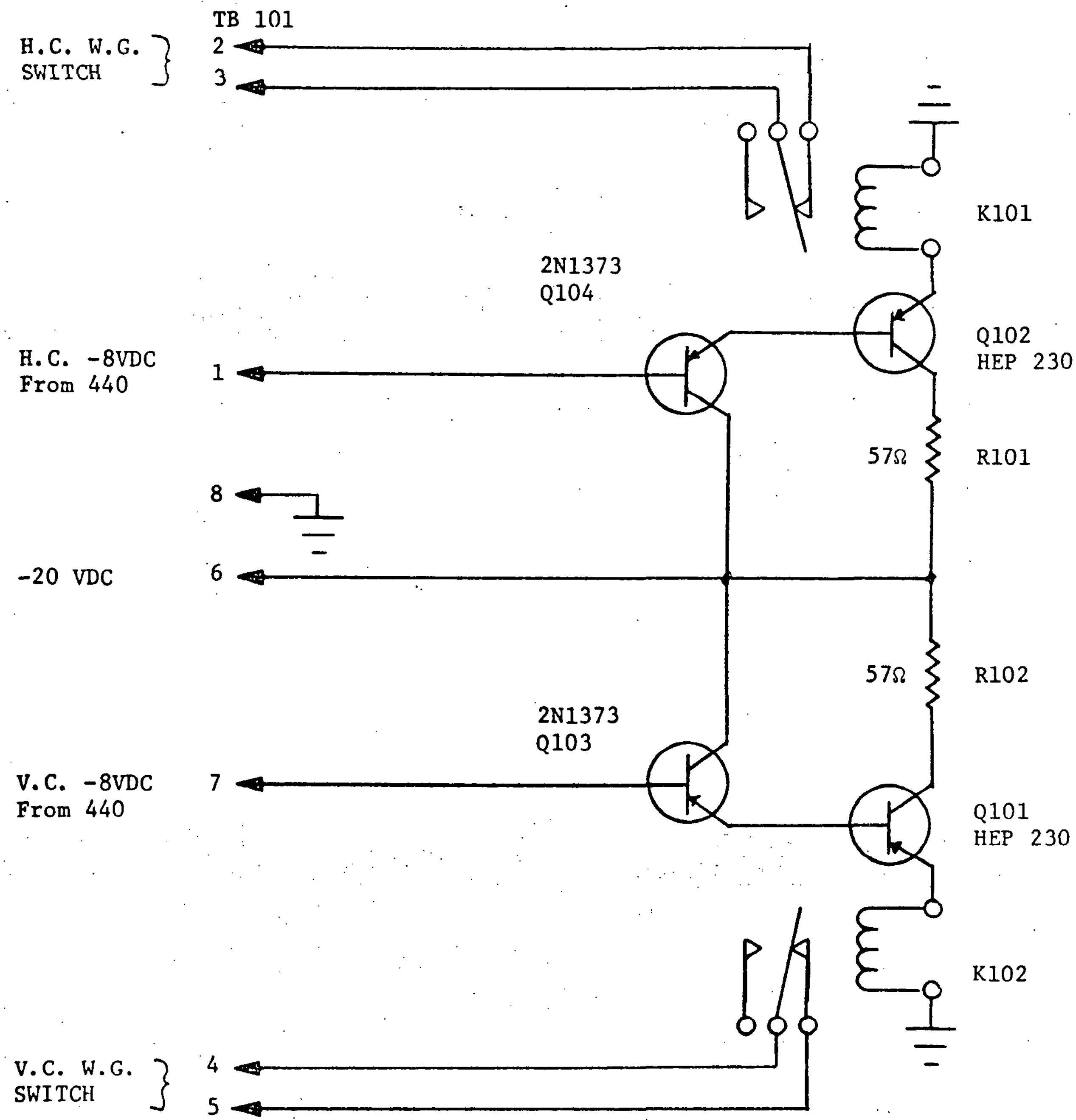


Figure 4. Waveguide Switching Circuit

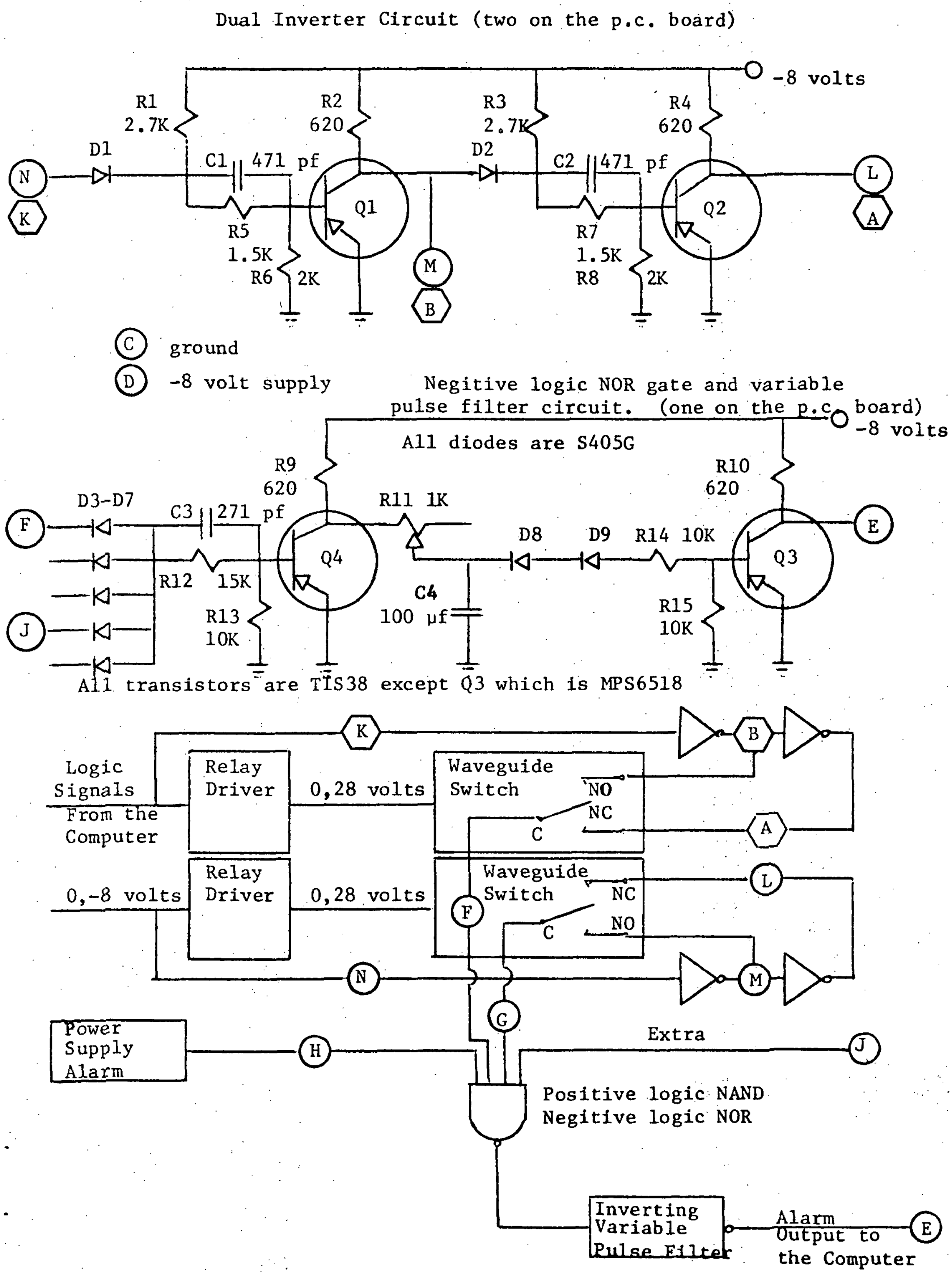


Figure 5. Alarm Circuit

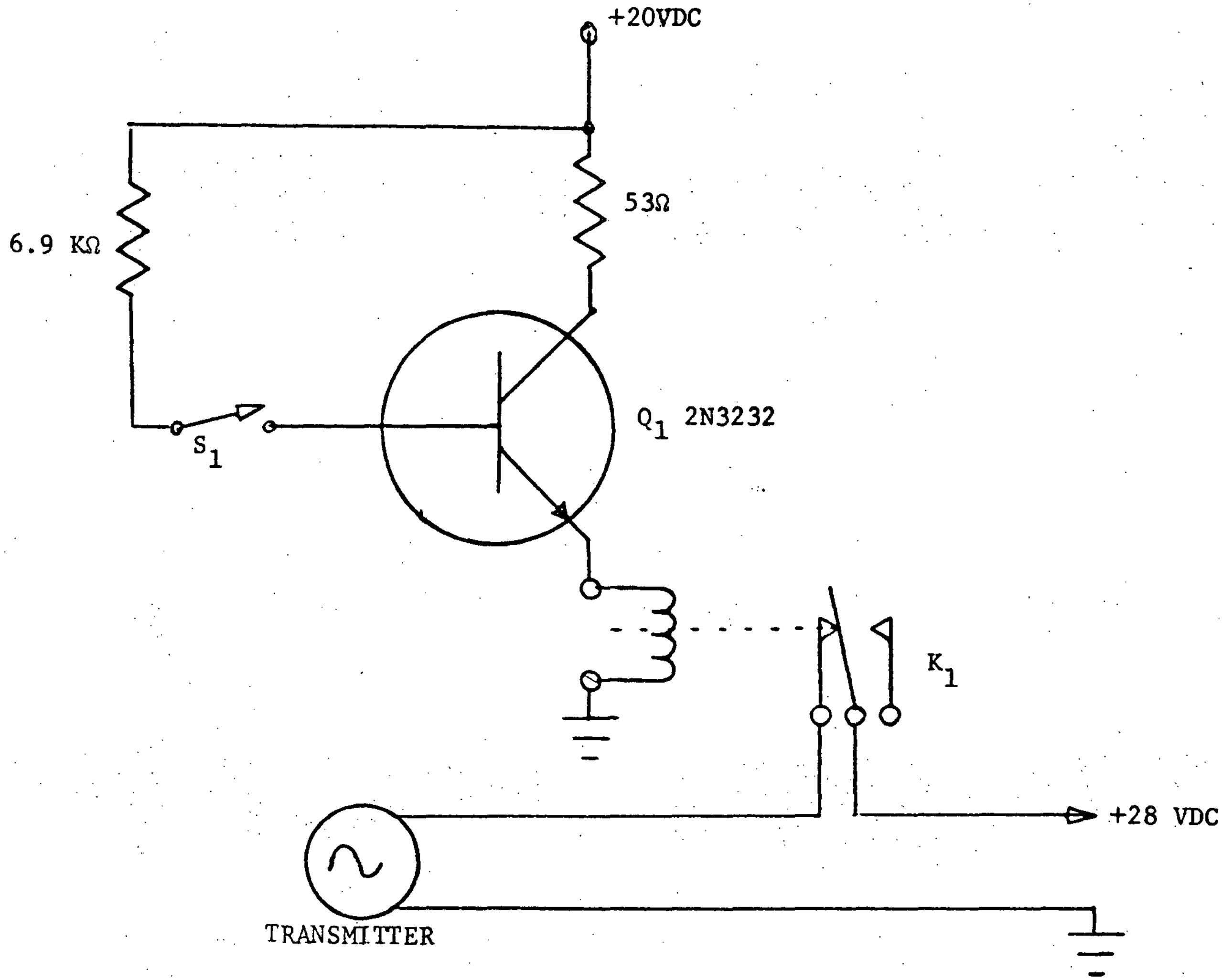


Figure 6. Transmitter Control Circuit

3.8 Transmitter Power Switching Circuit

This circuit (1) regulates the +28 volts to the transmitter, (2) trickle charges the batteries, (3) switches over from line power to battery power when necessary, and (4) produces a -8 volt signal for the alarm circuit if a power loss occurs. Figure 7 shows the entire switching circuit. It has been built and bench tested, and it performs all required functions.

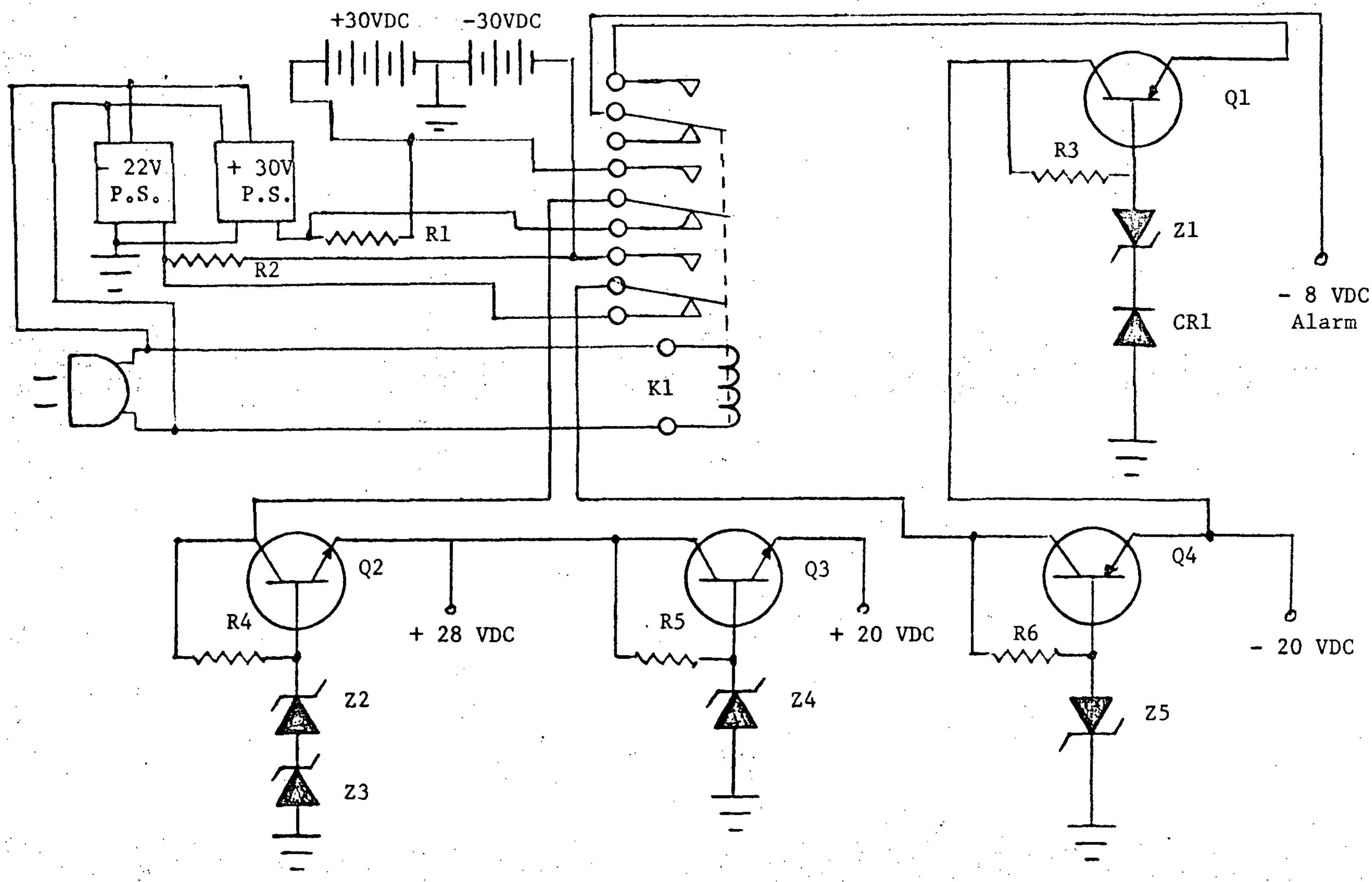
3.9 Receiver

The receiver was designed around these specifications.

1. 2 Channel CW Mode Operation at 17.65 GHz
2. -70 dBm Sensitivity/Channel
3. Isolation Between Channels -60 dB
4. Easily Interpreted Transfer Function

The receiver, shown in Figure 8, is a single-conversion CW receiver. The local oscillator is tunable over a wide range but is set at 17.68 GHz in order to produce a 30 MHz IF. Neither sweeping the local oscillator nor AFC circuitry were found to be necessary. The gain of the receiver is flat over the 10 MHz IF bandwidth and the local oscillator frequency never drifts far enough to take the IF signal out of the passband.

The attenuators in each leg adjust the receiver sensitivity, and the isolators insure isolation between channels. The isolator at the local oscillator output protects the LO from any mismatch. The 30 MHz



CR1 - 1N486	Q4 - HEP230	R5 - 25 Ω	Z4 - HEP Z2525
K1 - KRP14AG	R1 - 100 Ω	R6 - 120Ω	Z5 - HEP 104
Q1 - HEP230	R2 - 100 Ω	Z1 - 1N756	
Q2 - 2N3232	R3 - 160 Ω	Z2 - SU6033	
Q3 - 2N3232	R4 - 400 Ω	Z3 - SU6033	

Figure 7. Transmitter Power Circuit

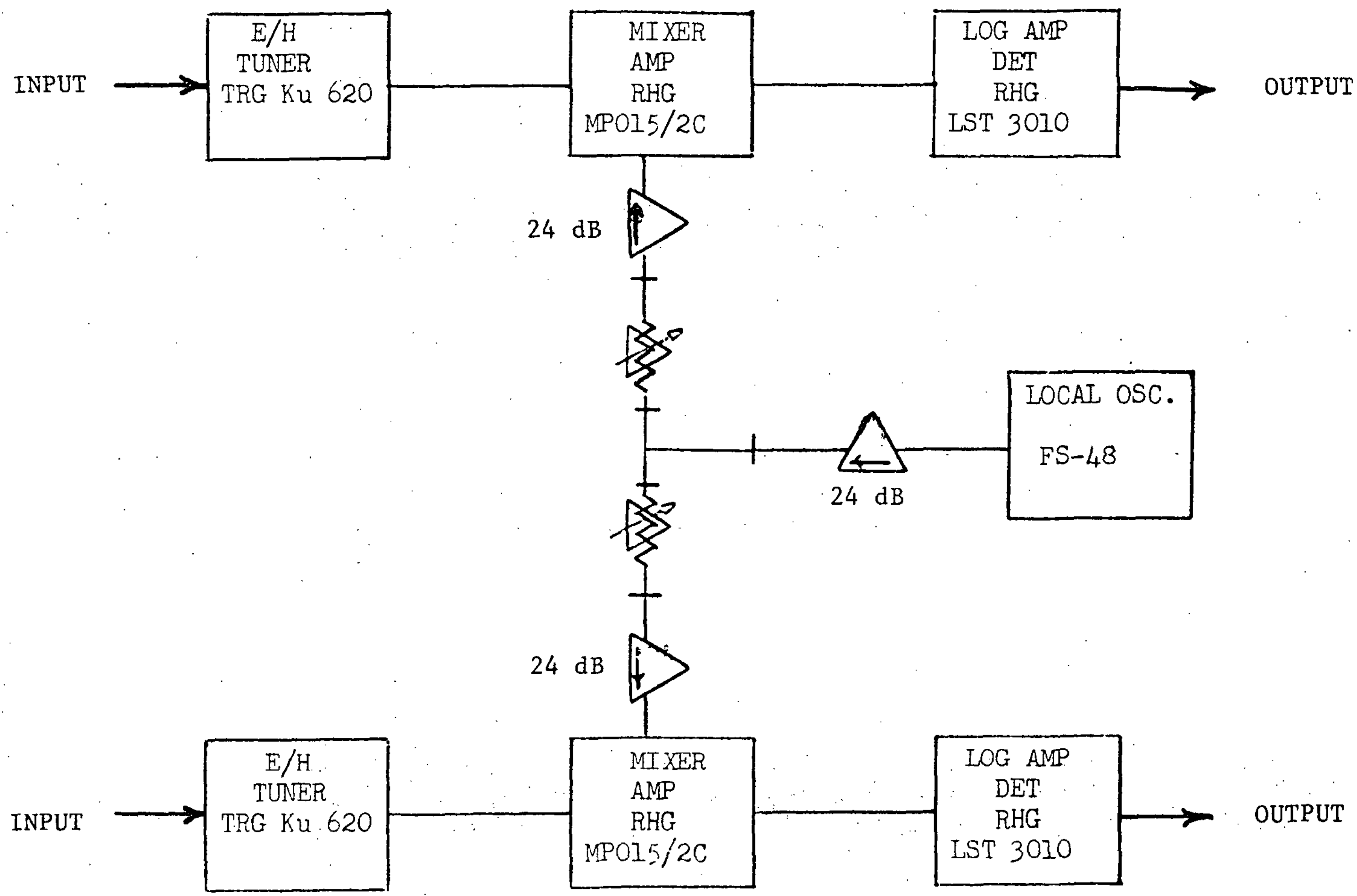


Figure 8. Receiver Block Diagram

IF presented to the logarithmic amplifier produces a linear DC output which is then fed to an A to D converter for interpretation. Several tests were run on the receiver and the results are listed below. It should be noted that because of the specialized function of the receiver, standard definitions of specifications do not always apply. Therefore an attempt to define the terms has been made.

1. Smallest Input Signal Detectable (at 0 dB SNR):-80.78 dBm
2. Input Signal for 3 dB Signal to Noise Ratio at Log Output: - 60.78 dBm
3. Mixer Gain: 16.78 dB at 30 MHz
4. Inter-Channel Isolation: > 60 dB
5. Gain Variation Over IF Bandwidth: $\pm$ 1 dB
6. Dynamic Range: 64 dB
7. Linearity: See Figure 9

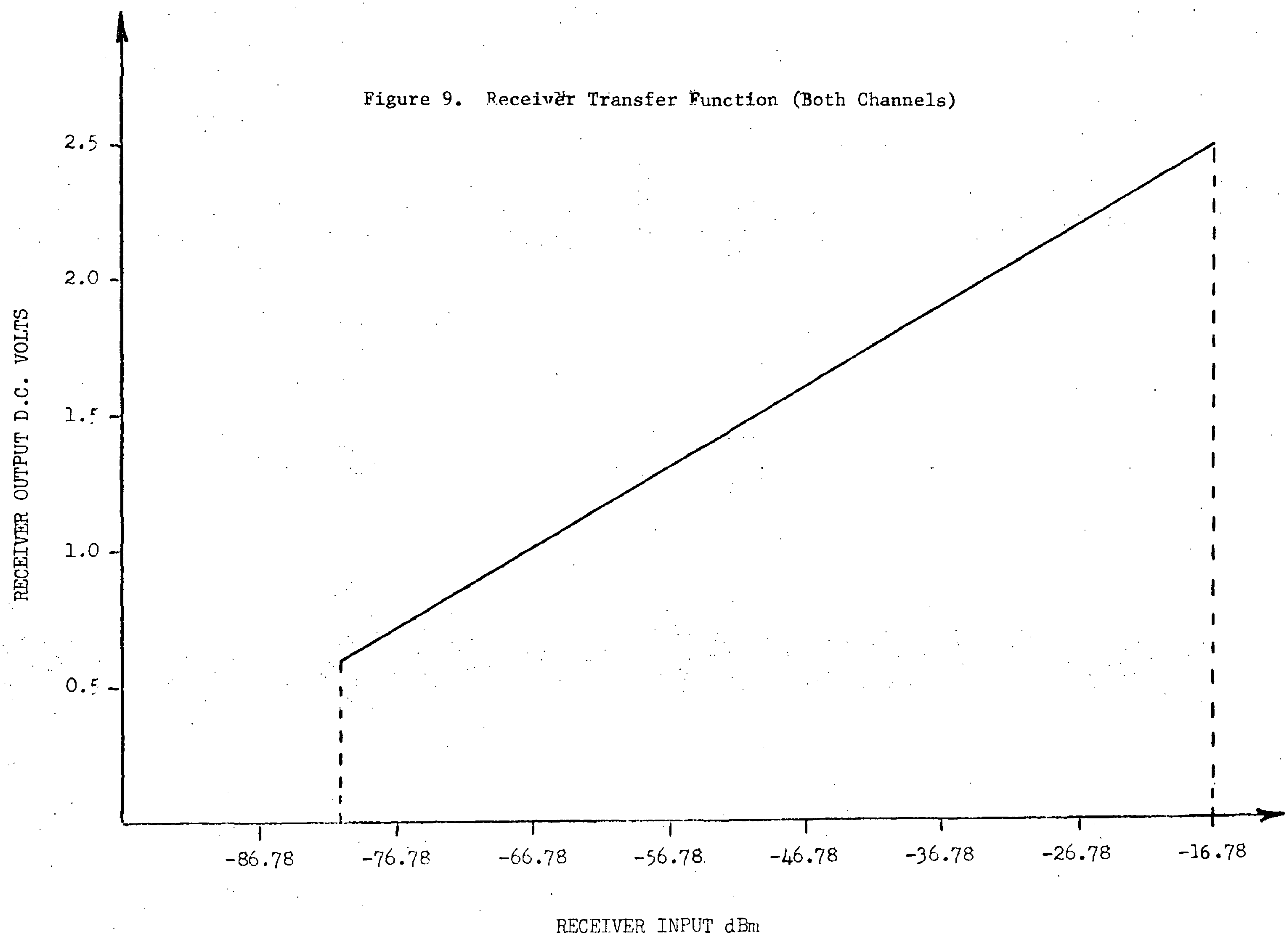
The receiver will have auxilliary power capabilities similar to the transmitter. These circuits are under construction now.

4. Antenna System

4.1 Antennas

The antennas to be used are Control Data Corporation 48 inch parabolic reflectors. There will be one dual polarized antenna at each end of the path. Question-mark waveguides through the center of the reflector are connected to an orthomode transducer and a scalar feed at the focal point. The question mark feed together with a symmetrical four-spar support structure is expected to produce the lowest possible cross-polarization level (30 to 35 dB below the

Figure 9. Receiver Transfer Function (Both Channels)



main beam peak in the principal planes). Test data will be supplied by the vendor. Boresight telescopes will be mounted on each reflector to facilitate antenna alignment. Delivery of the antennas is expected about 28 June 1972.

4.2 Antenna Mounts

The mounts for each antenna consist of an Ainslie Antenna Company Space Frame Model S-4 plus an adapter structure to attach the reflectors. The space frame is an off-the-shelf item which can withstand up to 150 m.p.h. winds. It may be adjusted $\pm$ 5° in elevation and $\pm$ 7 1/2° in azimuth and can be locked into final position. The adapter structures have been built by our technicians.

4.3 Path Considerations

After a long search of possible antenna locations, a path which is nearly east-west was selected as sketched in Figure 10. The transmitter is located on a hill on a university farm on the west side of campus. The path extends over a pasture, a golf course, and between campus buildings to the receiver site on top of McBryde Hall in the main part of the campus. The main beams of the antennas do not intercept the ground or any other obstacle. In fact, the angle to ground from the transmitter location to mid-path is 2° and the angle from the main beam maximum to the first null of the radiation pattern is about 1°. The path profile is shown in Figure 11. The path length is 1.43 Km (4700 feet).

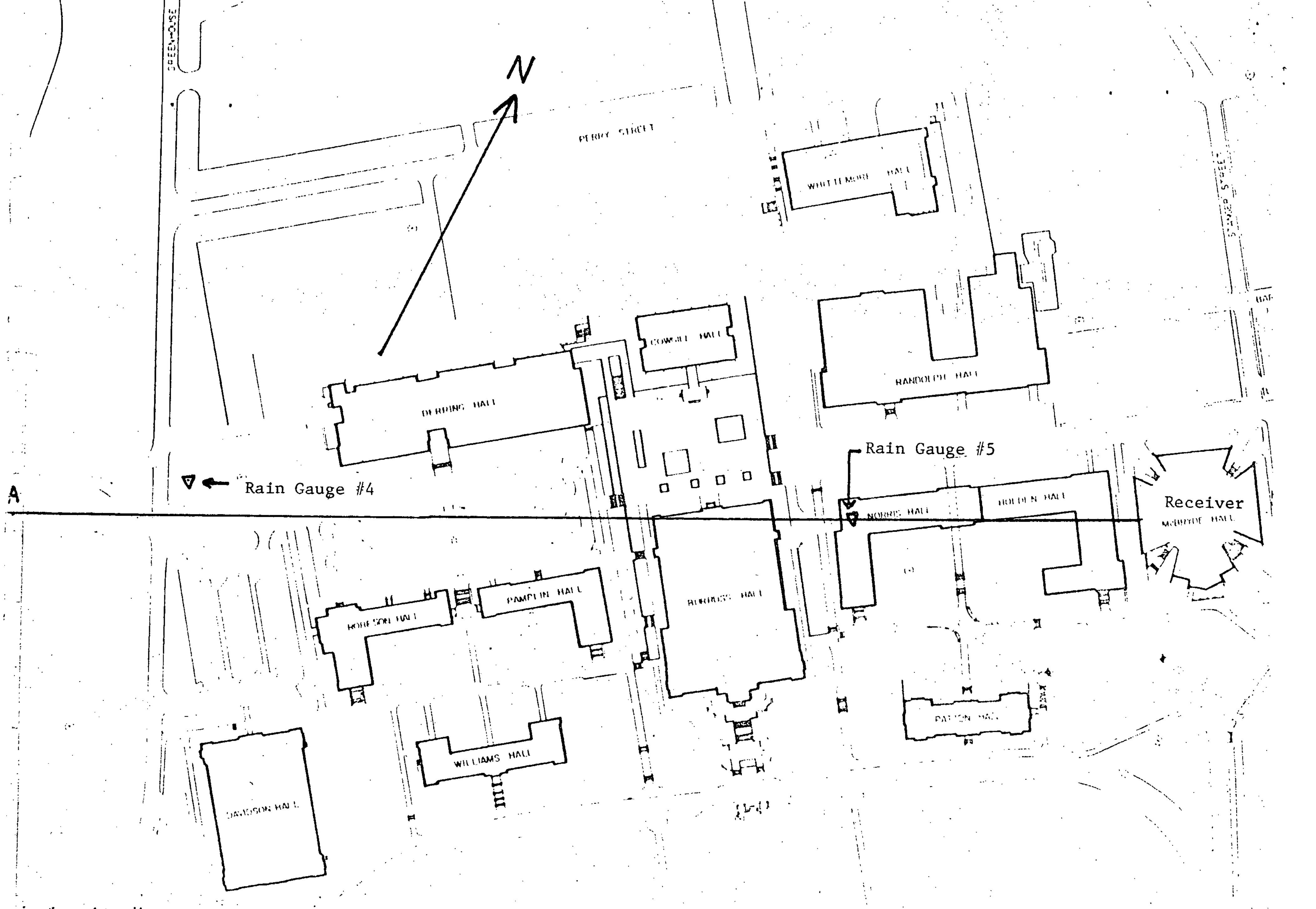


Figure 10a. Propagation Path. Scale 1" = 200'.

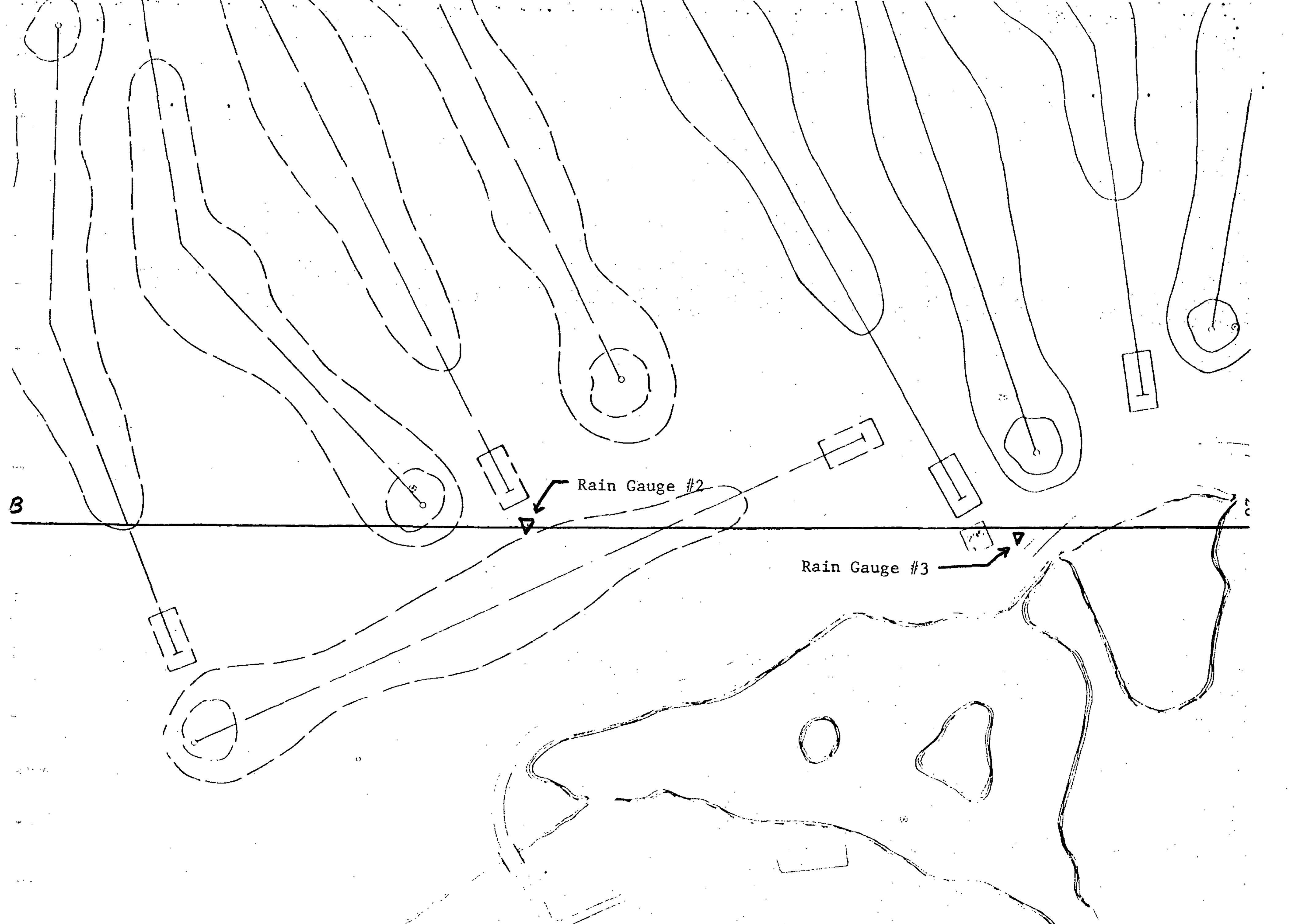


Figure 10b. Propagation Path Continued

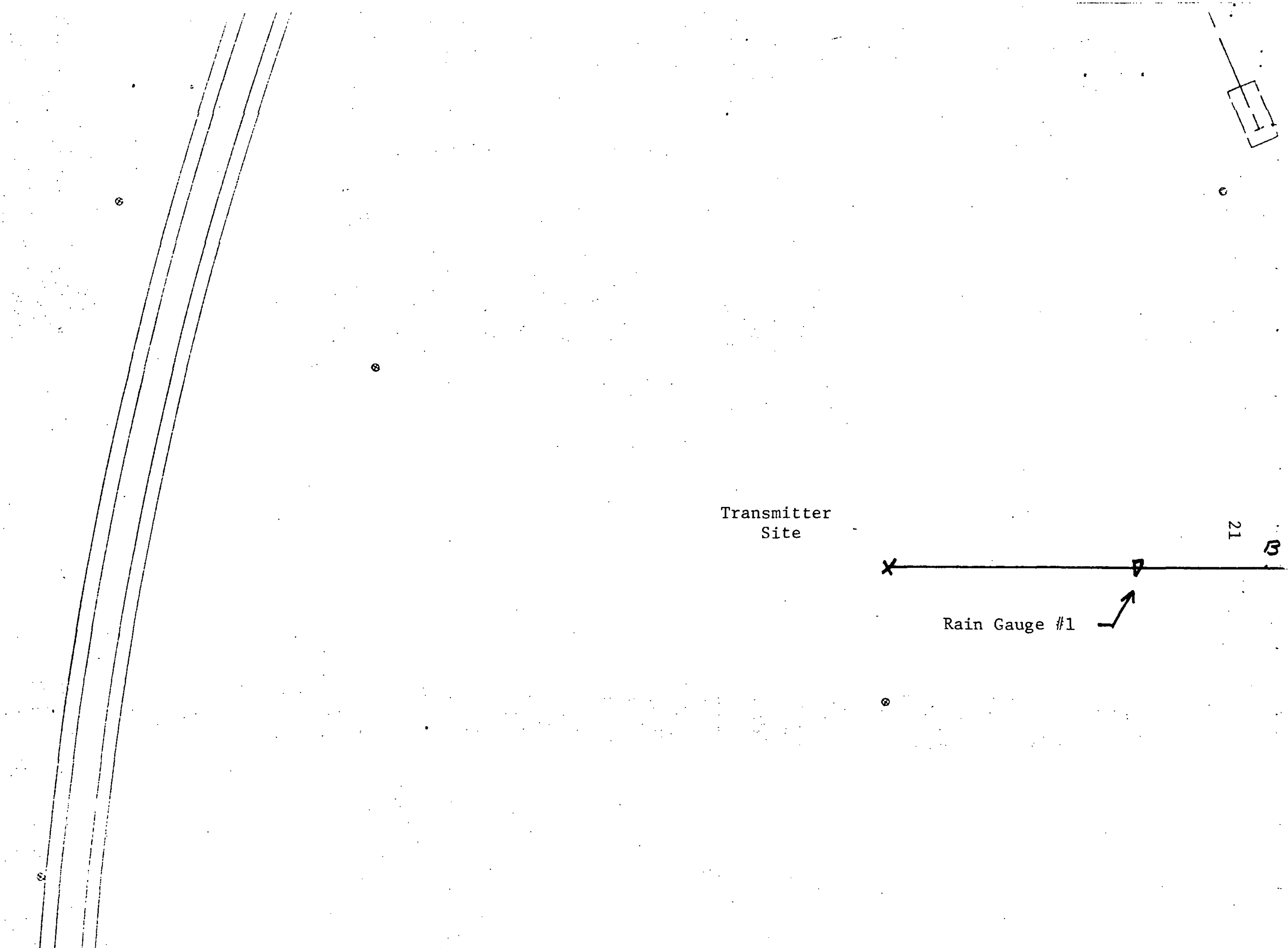


Figure 10c. Propagation Path Continued

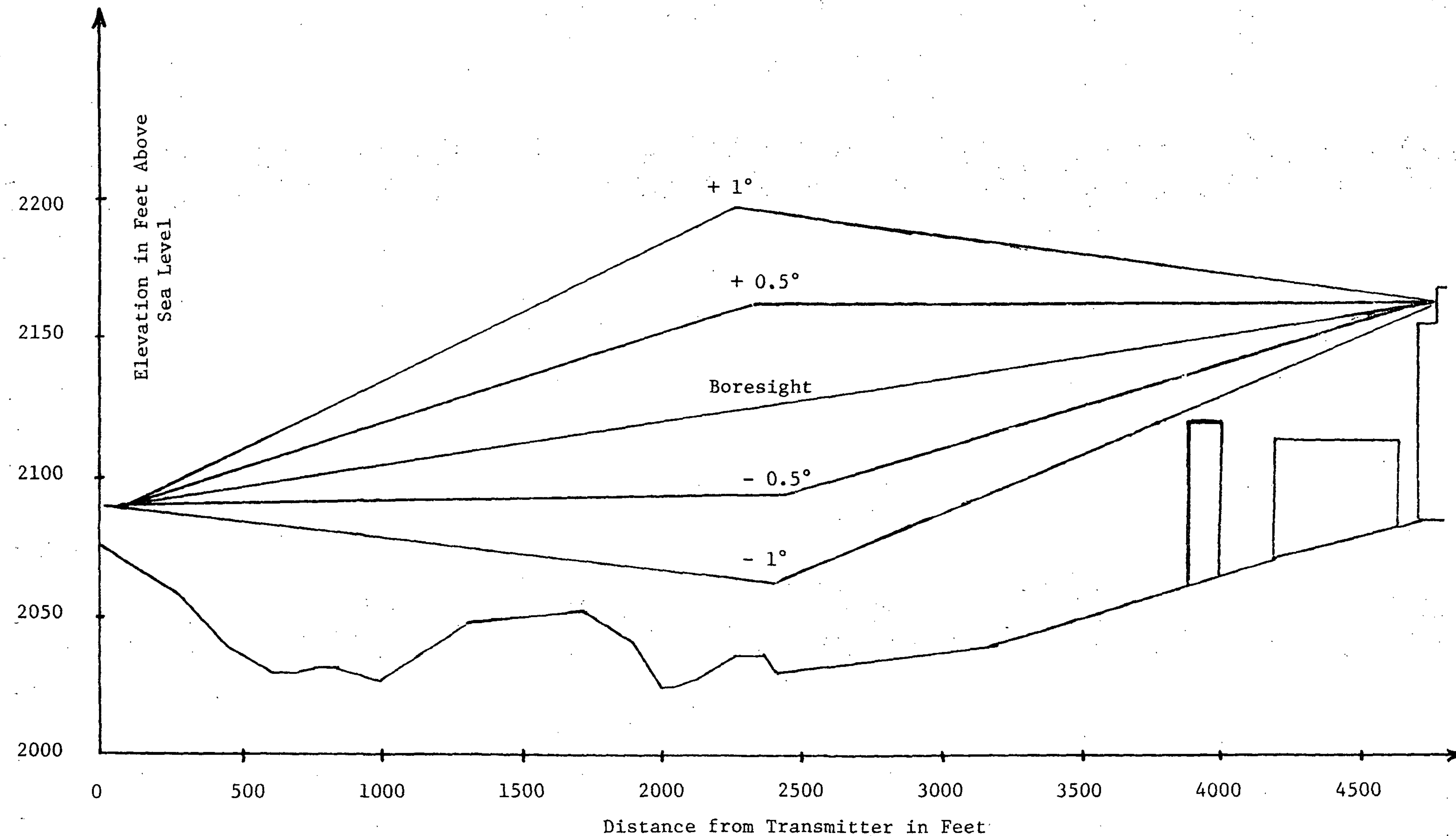


Figure 11. Path Profile

5. Transmitting and Receiving Sites

5.1 Receiving Site

The receiving antenna will be mounted on to an air-conditioning penthouse on top of the sixth floor of McBryde Hall. The space frame has been mounted to the side of the penthouse. The waveguides for the feed will go through the wall and connect to the receiver inside the penthouse. Space has been provided for an additional antenna for future work.

5.2 Transmitting Site

The transmitter will be housed in a tower constructed from poles and lumber. The current stage of construction is shown in the photograph of Figure 12. A roof will cover the transmitter house and porch in front of the house. A partial drawing of the tower in Figure 13 shows the front face to which the antenna will be mounted. The cross beams are 3 1/2" x 4 1/2" x 8' utility pole cross arms. The position of the mounting pads for the space frame and the antenna itself are shown in Figure 13. The center of the antenna is 12 feet above ground level. Space has been provided on the right side for an additional antenna for future work.

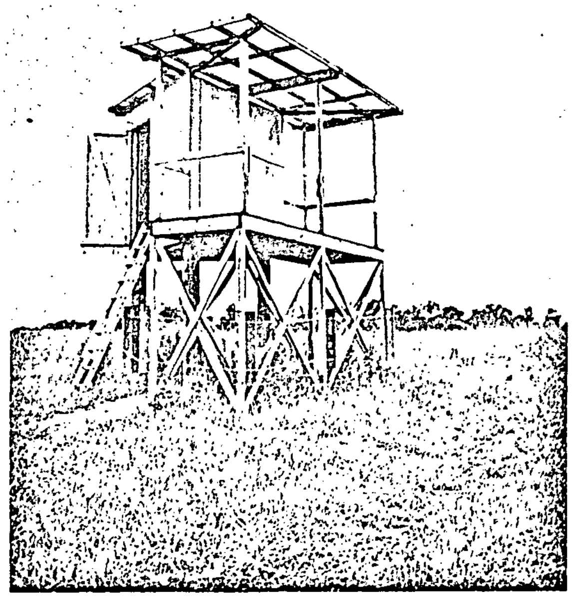
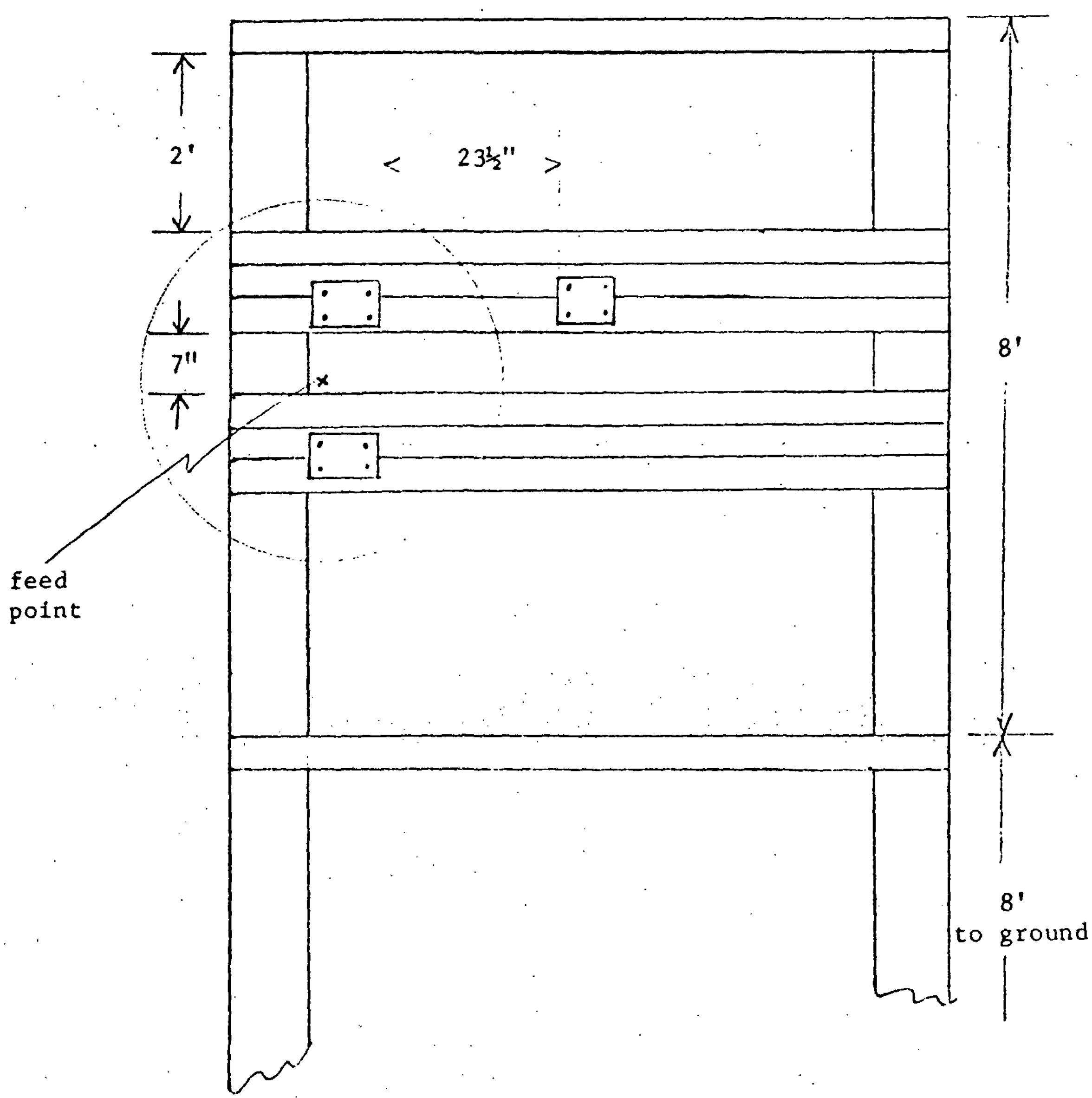


Figure 12. Present Status of Transmitter Site

Figure 14. Transmitter Tower Showing Antenna Mount



Scale:

$\frac{1}{2}$" = 1'

6. Weather System

6.1 Rain Gauges

Six Weather Measure P501 remote recording tipping-bucket rain gauges were purchased. Five of these will be placed along the propagation path with an average spacing between gauges of 268 meters. The sixth gauge will be held in reserve as a replacement in case one of the others malfunctions or is damaged.

When installed the gauges will be numbered 1 through 5, beginning at the transmitter. Numbers 1 and 2 will be located in open pastureland. Number 3 will be on the edge of a golf course, and number 4 will be between Derring Hall and Greenhouse Road. Gauge 5 will be on the roof of Norris Hall. Roof locations are less favorable rain gauge sites than ground locations, but all unoccupied ground beneath this part of the path is shielded by buildings.

Each rain gauge will be enclosed by a Weather Measure P565 windshield for increased accuracy under conditions of high wind. The first windshields received from the manufacturer were defective (drilled with the wrong size holes) and have been returned to Weather Measure. Replacements are in transit and field installation by July 1 is expected.

The rain gauges have been interfaced with the PB 440 computer and a program was developed which counts the number of trips and records the time of each trip. The program is now in 24 hour operation with the gauge nearest the receiver. Table 1 in the Appendix displays the data that this gauge gathered during tropical storm "Agnes," June 19-22, 1972. The processing was done by an IBM 370/155. The remaining gauges will be on line as soon as their field installation permits.

6.2 Drop Counters

A rain gauge records the volume of water falling into its collection area. Of equal importance in analyzing rain effects in millimeter wave propagation is the size distribution of the raindrops. When large amounts of data are analyzed, the Laws-Parsons size distribution gives good agreement for average propagation effects, but in many experiments reported in the literature sizeable departures from theory are observed during occasional storms or during intervals of a single storm, and these may result from changes in the instantaneous drop size distribution.

To reduce uncertainty about the raindrop size, some efforts to develop an inexpensive but reliable drop counter for this project have been made using volunteer undergraduate assistants. An accoustic approach failed, but an electro-optical counter gave good results in preliminary trials and prototype model is now under construction. It is expected to count the total number of drops falling in a known area, and indications are that it may have enough resolution to make useful size measurements. But even the total number of drops falling per unit time will be valuable, since it plus the rain gauge output for the same time period provide sufficient information to calculate the median drop size. The instantaneous drop size distribution can then be approximated as a standard one with its median shifted to the measured value. If the prototype model is successful, drop counters will be installed beside each rain gauge.

6.3 Wind Sensors

Three Weather Measure W121 wind sensors have been ordered and delivery by 1 July is expected. They will be installed near the transmitter, the midpath point, and the receiver. The wind sensors will generate data on wind velocity along the path; this factor is expected to be of major importance in rain depolarization.

7. Digital Control and Data Storage System

7.1 Introduction

There are three major factors involved in choosing a digital rather than an analog system for control and data storage in this experiment. The first consideration is the amount of data needed to provide an adequate model for the depolarization phenomenon. There will be at least 21 data inputs to the system: two from the receiver, five from rain gauges, five from drop counters, six from wind sensors, one from the transmitter power meter, one from a possible rain-temperature sensor, and one from system alarm sensors placed at key points in the experiment. The necessity for 21 inputs precludes data collection by the analog chart recorder method. The second consideration is the amount of time required to translate data from chart recorder paper to a form suitable for computer processing. An IBM 370/155 computer will ultimately extract statistical information from the data and with a digital recording system the data is already in the proper form. The third consideration is the additional benefits which an on-line digital computer would lend to the experiment. These include routine and automatic checkouts of the entire system, preliminary data processing and reduction, automatic variation of sampling intervals with changing weather conditions, and continuous monitoring of the entire system to provide immediate notice of failure.

Figure 14 illustrated the control and data acquisition system used in this experiment. The following sections outline its major components.

7.2 The PB 440 Computer

The Raytheon PB 440 computer is a second generation special purpose machine intended for digital control applications and the modeling of larger computers. The unit used in this experiment has 8K of core storage and both magnetic and paper tape capability. It has operated almost continuously for the past six months with no significant failures.

7.3 Analog to Digital Converter

The data inputs from the receivers, the wind sensors, the power meter, and the temperature sensor are analog voltages which must be converted to digital form for computer use. An 8 bit analog to digital converter has been built to perform the conversion, since PB 440 logic is incompatible with the A to D converters presently owned by the department. Tests on the converter revealed a maximum conversion error of one part in 256 or 0.4%.

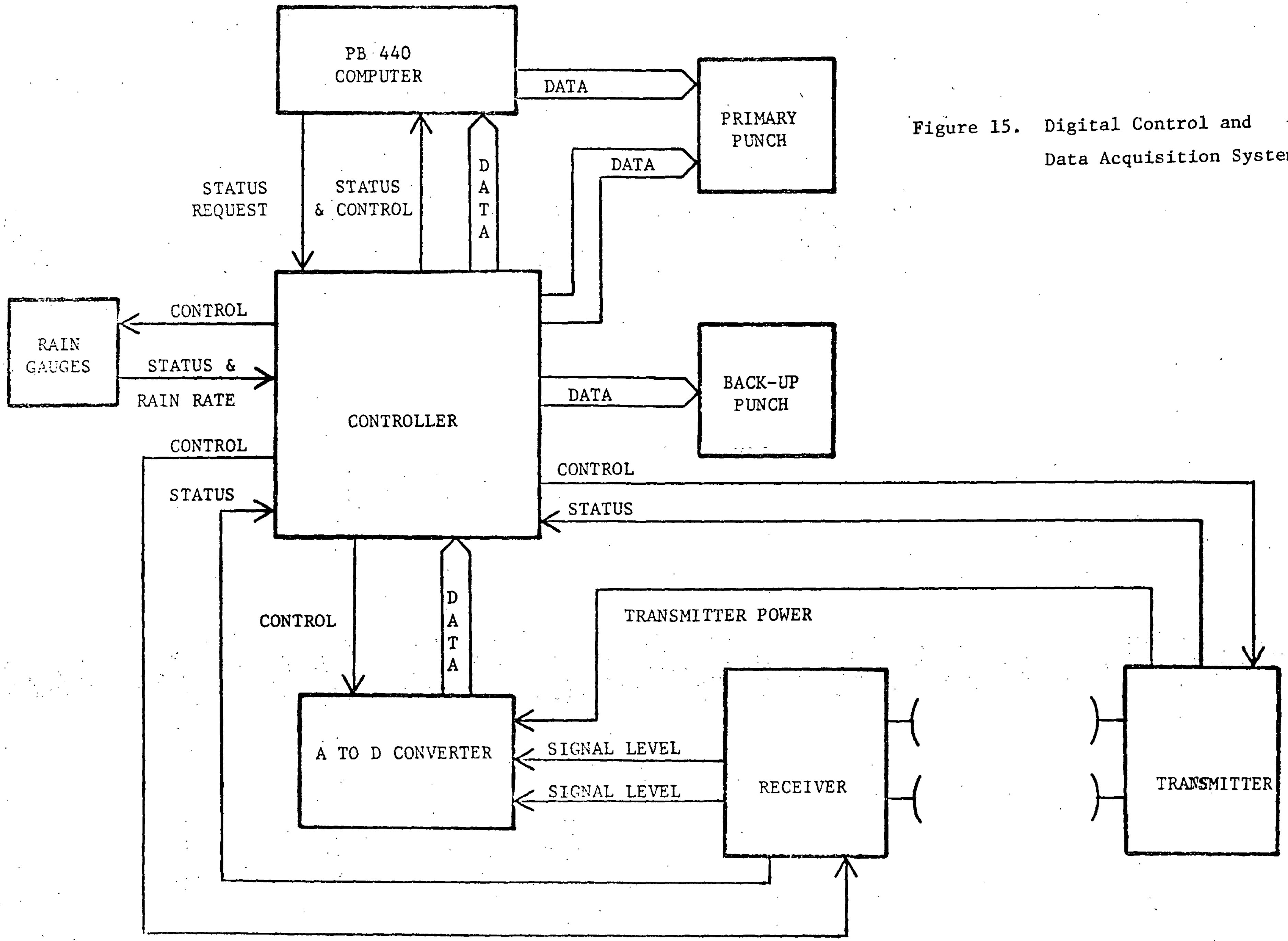


Figure 15. Digital Control and Data Acquisition System

7.4 Controller

The controller is the name given to the interfacing and timing circuitry which connects the various inputs to the computer. As shown in Figure 15, the clock is the heart of the controller.

The clock is an oscillator followed by a chain of frequency dividers. The oscillator is a stable source with a square wave output at 100 KHz which has been checked and adjusted with the standard signal of WWV. The frequency dividers are a series of divide-by-ten stages and provide the outputs down to 0.01 Hz which the rest of the system requires.

The clock register stores the time of day which is used to record the time that a particular piece of data is taken. The clock register counts the 5 Hz output from the clock and therefore records time to the nearest 0.2 second. The clock register is reset when the count reaches 432,000 (decimal) which represents midnight and the beginning of a new day.

The interrupt system is used to sequence the data inputs to the computer since any number of inputs may occur simultaneously. There are 24 flip-flops, each of which is set by the presence of data from one of the sources. The interrupt system scans these flip-flops in turn, stops when it encounters one which has been set, records the appropriate data, resets the set flip-flop, and moves on to the next flip-flop in the sequence.

The encoder combines the appropriate data with the time which it occurred (as contained in the clock register). It then generates a

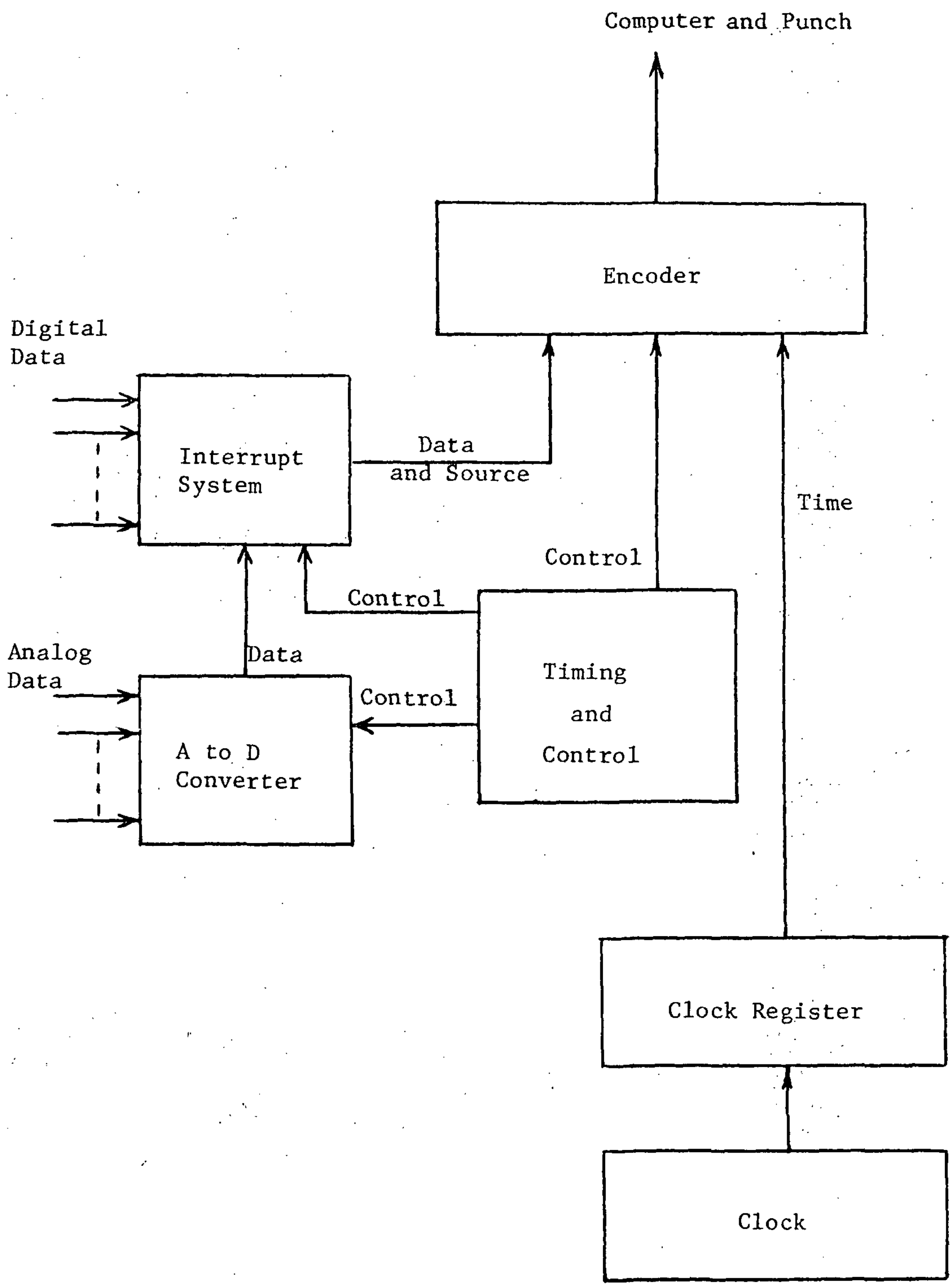


Figure 15. Controller Block Diagram

five-bit code representing the source of the data and gates this into the computer along with the data and the time.

The timing and control section was built to handle the timing problems encountered when the controller and the computer are operated simultaneously. This section signals the computer when data is ready and gates it into the computer at the appropriate time. If the computer does not respond within two milliseconds the controller channels the data directly onto tape for storage until the computer is ready to receive it.

Complete circuit diagrams for the various parts of the controller will be furnished with the final report. The controller will have a backup power source and will continue to record data on tape in the event of a power failure.

7.5 Alarm System

As stated previously alarm sensors are being placed at key points in the experiment. These will all be fed back to the PB 440 for monitoring in case of failure. In addition the status of the entire system will be monitored continuously by project personnel. A multiplex transmitter is being installed at the computer and a matching receiver at the home of Paris Wiley via telephone lines. Up to 64 error codes can be transmitted over the lines and will permit immediate action in case of failure of any system component including the computer and controller.

8. Appendix. Sample Rain Data

RAIN DATA FOR 19June 1972 DETAIL LIST FOLLOWS PAGE 1

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
1	1116:42.8		
2	1117:39.4	0.643	16.33
3	1122:53.6	0.115	2.91
4	2032:21.6	0.001	0.03
5	2257:34.6	0.004	0.10
6	2341:27.0	0.014	0.35
7	2344: 9.2	0.222	5.64

DAILY MAXIMUM RATE 0.643 IN/HR OR 16.33 MM/HR AT 1117:39.4

DAILY ACCUMULATION 0.07 INCHES

RAIN DATA FOR 20JUNE 1972 DETAIL LIST FOLLOWS PAGE 1

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
8	0 5:18.0	0.028	0.72
9	2 6:10.4	0.005	0.13
10	313:33.8	0.009	0.23
11	320:15.2	0.090	2.28
12	332:47.0	0.048	1.22
13	338:48.2	0.100	2.53
14	348:14.4	0.064	1.62
15	4 8: 3.6	0.030	0.77
16	413:36.6	0.108	2.75
17	416:53.2	0.184	4.67
18	420:13/0	0.181	4.59
19	424:13/4	0.150	3.81
20	428:50.2	0.130	3.31
21	433:42.6	0.123	3.13
22	442: 4.2	0.072	1.83
23	447:38.8	0.108	2.74
24	452:55.0	0.114	2.89
25	5 3:20.2	0.058	1.46
26	511:16.6	0.076	1.92
27	518:21.4	0.085	2.16
28	523:26.6	0.118	3.00
29	528:51.6	0.111	2.81
30	534:45.0	0.102	2.59
31	539:22.8	0.130	3.30
32	552:45.6	0.045	1.14
33	555:54.8	0.190	4.84
34	6 0:11.0	0.141	3.57
35	619: 4.8	0.032	0.81
36	627:18.2	0.073	1.85
37	629:18.4	0.300	7.62
38	631:18.2	0.303	7.68
39	633: 4.0	0.343	8.71
40	634:48.8	0.346	8.79
41	635:45.8	0.632	16.04
42	636:60.0	0.486	12.36
43	638:31.6	0.396	10.05
44	640:30.8	0.303	7.68
45	641:53.0	0.439	11.15
46	643:43.2	0.327	8.31
47	645:35.8	0.321	8.16
48	647: 1.4	0.424	10.76
49	648:35.0	0.387	9.83
50	651: 9.4	0.234	5.94
51	653: 6.8	0.308	7.82

RAIN DATA FOR 20JUNE 1972 DETAIL LIST FOLLOWS

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
52	655:19.2	0.273	3.93
53	656:49.6	0.400	10.16
54	657:46.4	0.643	16.33
55	658:21.4	1.029	26.13
56	659:24.6	0.571	14.51
57	7 1:16.6	0.321	8.16
58	7 3:43.2	0.247	6.26
59	7 6: 8.2	0.248	6.31
60	7 7:18.4	0.514	13.06
61	7 8:35.4	0.468	11.88
62	710:54.4	0.259	6.58
63	735:45.2	0.024	0.61
64	749: 7.2	0.045	1.14
65	818:12.6	0.021	0.52
66	820:36.4	0.252	6.39
67	822:20.6	0.316	8.02
68	824: 8.8	0.367	9.33
69	825:41.4	0.391	9.94
70	828:24.6	0.221	5.61
71	833:39.6	0.114	2.90
72	920:31.8	0.013	0.33
73	1015:27.6	0.011	0.28
74	1239:23.2	0.004	0.11
75	1247:37.0	0.073	1.85
76	1313: 2.2	0.024	0.60
77	1536:23.2	0.004	0.11
78	1557:22.0	0.029	0.73
79	1559: 8.6	0.340	8.63
80	16 0:43.9	0.379	9.63
81	1653:48.4	0.196	4.97
82	1616:49.1	0.046	1.17
83	1843:54.2	0.004	0.10
84	1848:45.2	0.124	3.14
85	1849:42.6	0.632	16.04
86	1850:12.0	1.241	31.53
87	1850:40.6	1.286	32.66
88	1851:22.2	0.878	22.30
89	1852:17.0	0.667	16.93
90	1854:37.8	0.257	6.53
91	1856:40.2	0.295	7.50
92	1859: 1.4	0.255	6.49
93	19 0:48.6	0.336	8.55
94	19 2:34.6	0.340	8.63
95	19 4:49.6	0.267	6.77
96	19 7:11.6	0.254	6.44

RAIN DATA FOR 20JUNE 1972 DETAIL LIST FOLLOWS PAGE 3

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
97	19 9:20.4	0.281	7.14
98	1912: 7.2	0.217	5.51
99	1914:45.6	0.228	5.79
100	1917:38.8	0.208	5.29
101	1920:31.8	0.208	5.29
102	1923:57.0	0.176	4.46
103	1926:47.6	0.212	5.38
104	1928:49.6	0.295	7.50
105	1933:11.0	0.138	3.50
106	1940: 7.2	0.087	2.20
107	1944:32.1	0.136	3.45
108	1948:23.6	0.156	3.96
109	1955:13.6	0.088	2.23
110	20 5:35.2	0.058	1.47
111	20 6:46.5	0.507	12.88
112	20 9:29.8	0.221	5.61
113	2015:31.4	0.100	2.53
114	2022:46.8	0.083	2.10
115	2029: 7.2	0.095	2.41
116	2037: 6.4	0.075	1.91
117	2040:57.6	0.156	3.96
118	2041:47.4	0.735	18.66
119	2042:27.6	0.900	22.86
120	2043:29.6	0.581	14.75
121	2044:17.6	0.750	19.05
122	2044:59.0	0.878	22.30
123	2045:29.8	1.200	30.48
124	2045:53.4	1.565	39.76
125	2046:15.1	1.714	43.54
126	2046:34.2	1.895	48.13
127	2046:56.2	1.636	41.56
128	2047:24.6	1.286	32.66
129	2047:57.8	1.091	27.71
130	2048:39.9	0.857	21.77
131	2049:30.0	0.720	18.29
132	2051:16.8	0.340	8.63
133	2053:35.6	0.261	6.63
134	2055:55.2	0.259	6.58
135	2057:34.2	0.364	9.24
136	2059:36.8	0.295	7.50
137	21 1:35.4	0.305	7.75
138	21 5: 7.6	0.170	4.31
139	2111:23.8	0.096	2.43
140	2121:24.0	0.060	1.52
141	2130: 3.8	0.069	1.76

RAIN DATA FOR 20JUNE 1972 DETAIL LIST FOLLOWS PAGE 4

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATIN IN IN/HR	RATIN IN MM/HR
142	2136:32.4	0.093	2.36
143	2140:47.0	0.142	3.60
144	2143:34.4	0.216	5.48
145	2146:27.8	0.208	5.29
146	2149:10.5	0.222	5.64
147	2150:41.0	0.400	10.16
148	2154:54.2	0.142	3.61
149	22 7: 3.4	0.049	1.25
150	2213:23.6	0.095	2.41
151	2218:10.6	0.125	3.19
152	2221:16.4	0.195	4.94
153	2224:20.4	0.196	4.97
154	2228:11.3	0.156	3.96
155	2231:30.0	0.182	4.62
156	2235:56.9	0.135	3.42
157	2239:45.8	0.158	4.01
158	2241:55.2	0.279	7.09
159	2248:37.2	0.090	2.27
160	2254:58.6	0.094	2.40
161	2259:42.4	0.127	3.23
162	23 3:36.6	0.154	3.91
163	23 7: 6.4	0.172	4.38
164	2311:41.6	0.131	3.33
165	2315:21.6	0.164	4.16
166	2320:12.9	0.124	3.14
167	2324:55.6	0.128	3.24
168	2329:35.2	0.129	3.28
169	2333:22.6	0.159	4.03
170	2338:28.0	0.118	3.00
171	2342:38.4	0.144	3.66
172	2345:45.2	0.194	4.92
173	2348:41.6	0.205	5.20
174	2350:43.6	0.295	7.50
175	2352:19.4	0.379	9.63
176	2355:41.8	0.178	4.53
177	2358:36.2	0.207	5.26

DAILY MAXIMUM RATE 1.895 IN/HR OR 48.13 MM/HR AT 2046:34.2

DAILY ACCUMULATION 1.70 INCHES

RAIN DATA FOR 21JUNE 1972 DETAIL LIST FOLLOWS PAGE 1

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
178	0 1:19.2	0.221	5.61
179	0 2:25.6	0.545	13.85
180	0 3:10.6	0.800	20.32
181	0 4:52.8	0.353	8.96
182	0 6:40.0	0.336	8.55
183	0 7:52.4	0.500	12.70
184	0 9:20.0	0.414	10.51
185	0 9:51.2	1.161	29.50
186	010:14.6	1.565	39.76
187	010:38.6	1.500	38.10
188	011: 5.0	1.385	35.17
189	011:26.6	1.714	43.54
190	011:49.0	1.636	41.56
191	012:21.2	1.125	28.57
192	012:58.8	0.973	24.71
193	013:41.6	0.857	21.77
194	015:24.2	0.353	8.96
195	019:19.4	0.153	3.89
196	026:51.8	0.080	2.02
197	031:54.8	0.119	3.02
198	033: 9.2	0.486	12.36
199	033:37.6	1.286	32.66
200	034: 5.4	1.333	33.87
201	034:59.0	0.679	17.25
202	039: 0.2	0.149	3.79
203	045:33.8	0.092	2.33
204	046:32.6	0.621	15.77
205	047:22.0	0.735	18.66
206	048: 5.8	0.837	21.27
207	048:45.8	0.900	22.86
208	050:41.2	0.313	7.95
209	057:18.2	0.091	2.30
210	058:45.8	0.414	10.51
211	1 0:41.8	0.310	7.88
212	1 3:37.2	0.206	5.23
213	1 6:35.2	0.202	5.14
214	1 9:35.6	0.200	5.08
215	110:39.4	0.571	14.51
216	111:14.6	1.029	26.13
217	111:54.2	0.923	23.45
218	112:44.8	0.720	18.29
219	113:33.0	0.750	19.05
220	114:26.6	0.679	17.25
221	115: 3.8	0.973	24.71

RAIN DATA FOR 21JUNE 1972 DETAIL LIST FOLLOWS PAGE 2

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATIN IN IN/HR	RATE IN MM/HR
222	115:35.8	1.125	28.57
223	116: 4.4	1.286	32.66
224	116:36.0	1.161	29.50
225	117:16.8	0.900	22.86
226	118: 8.4	0.705	17.93
227	119:23.4	0.450	11.43
228	121:16.4	0.333	8.47
229	122:33.8	0.468	11.88
230	123:52.2	0.462	11.72
231	124:42.2	0.720	18.29
232	125:21.8	0.923	23.45
233	126: 1.6	0.923	23.45
234	126:36.0	1.059	26.89
235	127:23.2	0.766	19.46
236	128.10.6	0.766	19.46
237	128.50.2	0.923	23.45
238	129.36.4	0.783	19.88
239	130:16.0	0.923	23.45
240	130:49.4	1.091	27.71
241	131:16.0	1.385	35.17
242	131:36.8	1.800	45.72
243	131:57.6	1.800	45.72
244	132:19.4	1.714	43.54
245	132:40.4	1.714	43.54
246	133: 1.0	1.800	45.72
247	133:28.4	1.333	33.87
248	134:10.0	0.878	22.30
249	134:51.8	0.878	22.30
250	135:34.2	0.857	21.77
251	136:16.6	0.857	21.77
252	137:29.0	0.500	12.70
253	138: 5.8	1.000	25.40
254	139:13.0	0.537	13.65
255	140:32.4	0.456	11.57
256	141:25.2	0.692	17.58
257	142:53.0	0.414	10.51
258	144:22.2	0.404	10.27
259	145.21.2	0.610	15.50
260	146: 4.8	0.837	21.27
261	146:42.2	0.973	24.71
262	147:15.8	1.091	27.71
263	148: 4.2	0.750	19.05
264	150: 3.2	0.303	7.68
265	151:51.2	0.333	8.47
266	153:59.4	0.281	7.14

RAIN DATA FOR 21JUNE 1972 DETAIL LIST FOLLOWS PAGE 3

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
267	156:13.8	0.269	6.82
268	158: 5.8	0.321	8.16
269	159:31.4	0.424	10.76
270	2 0:52.6	0.444	11.29
271	2 1:53.0	0.600	15.24
272	2 2:32.0	0.923	23.45
273	2 2:57.6	1.440	36.58
274	2 3:13.0	2.400	60.96
275	2 3:28.4	2.400	60.96
276	2 3:47.2	2.000	50.80
277	2 4:11.6	1.500	38.10
278	2 4:35.0	1.565	39.76
279	2 4:54.4	1.895	48.13
280	2 5:18.4	1.500	38.10
281	2 5:52.4	1.059	26.89
282	2 6:42.0	0.735	18.66
283	2 7:22.4	0.900	22.86
284	2 8:30.0	0.537	13.65
285	2 9:46.8	0.474	12.03
286	212: 6.6	0.259	6.58
287	214:59.2	0.209	5.32
288	217:40.6	0.224	5.68
289	220:16.0	0.232	5.90
290	223:55.8	0.164	4.18
291	227:46.2	0.157	3.98
292	235:25.2	0.078	1.99
293	251:53.0	0.036	0.93
294	3 3:11.8	0.053	1.35
295	3 7:60.0	0.125	3.17
296	3 9: 9.8	0.522	13.25
297	310: 6.6	0.643	16.33
298	312:24.0	0.263	6.67
299	320:10.8	0.077	1.96
300	327: 3.8	0.087	2.21
301	332:18.6	0.115	2.91
302	335: 9.4	0.212	5.38
303	338:12.2	0.198	5.02
304	340:50.8	0.228	5.79
305	344:44.0	0.155	3.92
306	348:47.4	0.148	3.76
307	352:18.6	0.171	4.33
308	356: 9.2	0.157	3.98
309	359:32.6	0.177	4.50
310	4 4:54.4	0.112	2.85
311	411:17.4	0.094	2.39

RAIN DATA FOR 21JUNE 1972 DETAIL LIST FOLLOWS PAGE 4

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
312	423. 2.6	0.051	1.30
313	433:35.8	0.057	1.44
314	440:10.4	0.091	2.32
315	458:53.6	0.032	0.81
316	517:58.8	0.031	0.80
317	538:31.6	0.029	0.74
318	549: 6.2	0.057	1.44
319	558:21.2	0.065	1.65
320	6 9:40.6	0.053	1.35
321	616:55.8	0.083	2.10
322	624:21.6	0.081	2.05
323	628:14.2	0.155	3.94
324	634:22.8	0.098	2.48
325	639: 8.4	0.126	3.21
326	642:44.4	0.167	4.23
327	645:47.2	0.198	5.02
328	648:41.6	0.207	5.26
329	651: 5.4	0.252	6.39
330	653:43.6	0.228	5.79
331	655:14.4	0.400	10.16
332	656: 4.4	0.720	18.29
333	657:21.2	0.474	12.03
334	659: 3.2	0.353	8.96
335	7 1:19.8	0.265	6.72
336	7 4:14.0	0.207	5.26
337	7 6:39.0	0.248	6.31
338	7 8:28.2	0.330	8.39
339	7 9:38.2	0.514	13.06
340	710:39.0	0.600	15.24
341	711:10.0	1.161	29.50
342	711:49.2	0.923	23.45
343	712:40.0	0.720	18.29
344	713:57.2	0.468	11.88
345	715:16.6	0.456	11.57
346	717:20.6	0.290	7.37
347	719:34.2	0.271	6.88
348	720:32.0	0.632	16.04
349	721:17.0	0.800	20.32
350	721:56.0	0.923	23.45
351	722:40.8	0.818	20.78
352	723:35.0	0.667	16.93
353	724:41.4	0.545	13.85
354	725:33.6	0.692	17.58
355	726:25.8	0.692	17.58
356	727:27.4	0.590	14.99

RAIN DATA FOR 21JUNE 1972 DETAIL LIST FOLLOWS PAGE 5

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
357	728:22.4	0.655	16.63
358	728:53.4	1.161	29.50
359	729:24.4	1.161	29.50
360	730: 3.6	0.923	23.45
361	730:47.4	0.837	21.27
362	731:49.4	0.581	14.75
363	733:55.8	0.286	7.26
364	736:45.0	0.213	5.41
365	738:55.6	0.277	7.03
366	741:14.2	0.261	6.63
367	744:31.6	0.183	4.64
368	747:41.6	0.189	4.81
369	751:32.2	0.157	3.98
370	755: 8.8	0.167	4.23
371	757:33.2	0.250	6.35
372	8 0: 8.4	0.232	5.90
373	8 2:24.6	0.265	6.72
374	8 5:11.0	0.217	5.51
375	8 7:37.0	0.247	6.26
376	8 9:49.2	0.273	6.93
377	812: 0.8	0.275	6.98
378	814:13.4	0.273	6.93
379	816:18.0	0.290	7.37
380	818:12.4	0.316	8.02
381	819:58.0	0.343	8.71
382	822:25.6	0.245	6.22
383	825: 1.8	0.231	5.86
384	828:25.0	0.177	4.50
385	830:36.4	0.275	6.98
386	833:45.8	0.190	4.84
387	836: 6.4	0.257	6.53
388	838:16.0	0.279	7.09
389	840:48.8	0.237	6.02
390	844:44.6	0.153	3.89
391	849:32.6	0.125	3.17
392	855:37.4	0.099	2.51
393	9 9:21.2	0.044	1.11
394	934:29.4	0.024	0.61
395	957: 4.6	0.027	0.67
396	1018:27.8	0.028	0.71
397	1053:45.6	0.017	0.43
398	2214:50.2	0.001	0.02

DAILY MAXIMUM RATE 2.400 IN/HR OR 60.96 MM/HR AT 2 3:13.0

DAILY ACCUMULATION 2.21 INCHES

RAIN DATA FOR 22JUNE 1972 DETAIL LIST FOLLOWS PAGE 1

ACCUMULATION IN .01 INCHES	LOCAL TIME	RATE IN IN/HR	RATE IN MM/HR
390	321: 3.4	0.002	0.05

DAILY MAXIMUM RATE 0.002 IN/HR OR 0.05 MM/HR AT 321: 3.4

DAILY ACCUMULATION 0.001 INCHES

FOR THIS STORM MAX RATE OF 2.400 IN/HR OR 60.96 MM/HR OCCURRED

AT 2 3:13.0 ON 21 JUNE 1972

TOTAL ACCUMULATION FOR THIS STORM WAS 3.99 INCHES