MICROPROCESSORS AS A TOOL IN DETERMINING CORRELATION BETWEEN SFERICS AND TORNADO GENESIS

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ABSTRACT

It is believed that sferics, a word that stands for atmospheric electromagnetic radiation, can be correlated to the genesis of tornadoes and severe weather. Sferics are generated by lightning and other atmospheric disturbances that are not yet entirely understood. The recording and analysis of the patterns in which sferic events occur, it is hoped, will lead to accurate real time prediction of tornadoes and other severe weather. Collection of this data becomes cumbersome when correlation between at least two stations is necessary for triangulation; however, the advent of microprocessors has made the task of data collection and massaging inexpensive and manageable.

INTRODUCTION

My first exposure to extreme severe weather was at dusk on May 20, 1957, in Hickman Mills. My dad yelled "There's a tornado coming. Get in the basement." A few minutes later, we came upstairs and went outside. Half our block had disappeared into the evening sky. My favorite yard toys were gone. I was only six, but vivid memories of that event pique my interest in the system we call weather.

Many attempts have been made to detect and predict tornadoes using electronic means. Some earlier systems possessed good correlation, but generally the "prediction" came long after the fact because of the time necessary to review the data. Also involved in the 1957 tornado was R. W. Fergus, a fellow engineer who has been investigating methods of analyzing sferics since that year.

Sferics is a word that stands for atmospheric electromagnetic radiation. Sferics are generated by lightning and other atmospheric phenomena. The radiation spectrum for sferics includes frequencies from 10 kHz into the UHF bands. After a tornado has formed, there are continuous movements of electrical charge within the shaft of the funnel creating a tremendous amount of sferics. A number of warning devices have been designed to trigger a signal when the total sferic activity exceeds a preset value. However, if several storm centers are close to the detector and if their total activity exceeds this preset value, the detector will signal a false alarm. Each sferic event must be looked at relative to all other events. It is believed that locating the origin of each event (by triangulation) and monitoring the patterns in which the events occur, will lead directly to real time predictions of tornadoes and other severe weather.

Fergus has devised a system for monitoring and recording singular sferic events of one frequency. Radiation at 10 kHz was selected because of its long range and the ease of determining accurately the direction of origination. Data collection and analysis and system changes to date indicate that three pieces of data about each event and relative to other events are most important. They are time of arrival, direction of origin, and time difference between events from the same origin.

The current system used by Fergus is located in Lombard, Illinois, and has successfully logged data from events as far away as 1000 miles. The second system, a near duplicate of the first, is under construction in Hickman Mills, Missouri.

This report states present and future data collection and analysis objectives and gives a detailed explanation of the hardware system.

WORK TO DATE

The first major component assembled was the sferic monitor. Three antennas are used: two loops and one vertical. (Figure 1)

The loop antennas are flat coils built as nearly alike as possible. They are each electrostatically shielded and parallel tuned with capacitance to 10 kHz. They are excited by the magnetic portion of the electromagnetic sferic signal. Since the loop coils are used to sense direction, they must be aimed as accurately as possible with respect to true north.

The vertical antenna is simply a rod 3 to 10 feet long. This antenna senses the electric portion of the electromagnetic sferic signal and is used to indicate the arrival of an event. Signals from the antennas are amplified and fed to a CRT for display.

Events are depicted on the polar display by a strike mark. Direction of origin is the angle from straight up made by the strike mark as it appears on the CRT. Relative amplitude is the distance out from CRT center.

Polar information also is fed to a converter, which changes the polar data to X-Y data. For the X-Y display, direction is along the horizontal axis, and relative amplitude is along the vertical axis. Each event becomes a dot on the CRT screen.

The two sequential photographs shown in Figure 2 are actual 10 minute accumulations of data taken 5 hours apart on the X-Y display. All data above the centerline is relative amplitude versus direction and all data below the centerline is time between events versus direction.

Each received event puts two dots on the screen: one dot above the centerline for relative amplitude (increasing toward the top); and one dot below the centerline for time between events (increasing toward the bottom). Events more than 100 milliseconds from the last event will appear on the lower baseline for the delta-time display. Note the movement about the compass of the storm centers displayed.

Looking at the data accumulated in only 10 minutes, the most casual observer realizes that help is needed to massage and crunch all this data. The microprocessor is the tool that provides this help.

The sferic analysis system is shown in Figure 3. Sferic events are received, amplified, converted to X-Y, digitized, and fed to the microprocessor base computer. The computer looks for patterns, reduces the data to an easily understood format, and prints it out.

Before I bought and assembled the computer components, I established the following system objectives:

- The computer should be a microprocessor based, easily expanded, hardware and software development tool.
- Any hardware added should be not entirely software dependent.
- There should be provisions for plenty of RAM.
- There should be a complete math pack, including trigonometric functions, and so forth.
- There should be a video terminal.
- There should be a hard copy output.
- The system should be cost effective.

The present system (Figure 4) fulfills these objectives.

In Figure 4, in a semicircle from left to right, are shown the antenna matching boxes, the scope camera, the sferic monitor, the loop antennas, the computer, the teleprinter, the video monitor, the ASCII keyboard, the audio cassette, extra ICs in the foreground, a map in the background, and an auxillary lighting system sitting on the teletype.

SFERIC ANALYSIS SYSTEM

A block diagram of the entire hardware system to date is shown in Figure 5. The computer is a two board microcomputer system. Board 1 has the CPU and Board 2 has a 6-digit hex readout for address and data, a hex entry keyboard, eight special function keys, and the Kansas City standard audio cassette interface circuitry.

Using the 6800 microprocessor, I/O is treated as memory locations. The CPU board has a one-of-eight decoder on board. This decoder is used to divide all 64K of directly addressable memory into 8K blocks. A memory map is shown in Figure 6. Addresses listed for I/O devices are exclusive; any other addresses selected in that block might enable more than one I/O device.

The CPU board has a crystal clock, 6800 CPU, decoding circuitry, 1K x 8 ROM monitor, 128 x 8 RAM for use by the monitor, 256 x 8 user RAM, one ACIA for the audio cassette, one PIA used with display board, one user PIA and more (Figure 7).

Strapping options include RAM, ROM and EPROM to which has been added the extra 256 x 8 RAM for a total 512 x 8 onboard RAM. The user PIA is used by the ASCII keyboard and video terminal. The wire wrapping area provided has been filled with the sferics interface and calculator port.

The sferic monitor and interface begins with the antennas, cables and tuning boxes shown in Figure 8.

Preamplification, phase correction, and tuning are done in the sense antenna box powered through its output cable. The balanced loop antennas are 23-inch-diameter coils wound with 100 turns of copper wire in a screen door channel and electrostatically shielded with aluminum foil. They are positioned at right angles away from all metal objects and three or more diameters apart. They are shunt tuned to 10 kHz by a capacitor matching circuit located in the two small boxes.

The sferics monitor is built into an old scope chassis that was born again by completely remodeling it with all new plumbing inside and out (Figure 9).

The monitor uses a cathode ray tube for display; has a marker generator to put reference lines on the cathode ray tube; has a calibrator/simulator; and can display polar information, time between events versus direction, relative amplitude versus direction, and both time between events and relative amplitude versus direction. All tuned circuits are constructed with a low Q, so the oscillations damp out within a few cycles in preparation for the next event.

Currently, there are two kinds of information that are considered most important: the direction of origination of each event, and the time difference between events from the same origin. Logging this data for all events received by two stations allows an extensive data analysis and correlation to be conducted.

Output from the sferics monitor is in the form of a pulse, the width of which is relative to the direction of origination of an event (Figure 10).

A sferic event originating from due east would yield a pulse width of approximately 220 microseconds. Referring to the interface block diagram, clock pulses are counted during the event signal by an 8-bit counter. The clock frequency is adjusted so that each count equals three degrees of the compass. Counts during the first 220 microseconds are subtracted by software later. When the event signal ends, the interrupt request line is pulled low. During the interrupt service routine, a read of location 8040 forces the count to be driven onto the data bus, clears the IRQ flip-flop, and resets the two 4-bit counters for the next event signal. A complete circuit diagram of this simple interface is shown in Figure 11.

Once a sferic event count is inputted, the time between it and the last event must be determined. The time will be monitored by a software clock that will be incremented every 10 milliseconds by a nonmaskable interrupt referenced to a crystal clock. Eventually, a hardware clock set in sync with Coordinated Universal Time from WWV, traceable to the NBS, will be implemented.

Matching analyzed data to actual coordinate points on the earth requires a complete set of mathematical functions and extensive calculations. Instead of forcing the microcomputer to be tied up during all the necessary calculations, the 57109 number-oriented processor was selected to do the number crunching. Strapping this processor to a 6820 PIA forms the calculator port circuit, diagrammed in Figure 12.

Power for the 57109 must be supplied from a 9-volt source, which is accomplished here by +5 and -4 about ground. A CD4050 hex buffer and two PNP transistors are used for level shifting the RDY, HOLD, POR, R/W, and BR signals. A CD4049 hex inverting buffer is used to generate the 400 kHz, single phase clock input. Handshake line CA1 is programmed to sense a positive transition of the ready line. Handshake line CA2 is programmed as an output, which goes high when CA1 detects a ready pulse. In this manner, the 57109 is put in the hold state after each of its machine cycles. Data is input to the processor on the I1 through I6 lines, and formatted BCD data is outputted from the DO1 through DO4 lines. Handshake line CB1 is programmed to detect write pulses, which denote that valid output data is on the DO lines.

The 57109 has a rather complete set of instructions, some of which are listed in Figure 13. There are four registers (X, Y, Z, T) and a memory (M). Data entry is of reverse polish notation and is conducted sequentially by the 6800 processor as if it were using a regular desk-top calculator.

There are three main software routines used with this calculator port: initialization, input, and output. During initialization, the PIA is set up, then the POR input to the 57109 is forced high for 8 clock periods minimum, which initializes the number cruncher. When the 57109 sends out the first ready pulse, the hold input is automatically forced high by the PIA.

An input is done by simply latching the instruction or BCD number in the PIAs port A and then doing a dummy read of port A, which clears the CA2 hold. The cruncher chomps the data and returns to hold after one machine cycle.

An output is done by first inputting an OUT instruction for two ready pulses after which the cruncher shoves out the X register serially in one of two formats including one write pulse per digit. The two formats are scientific and floating point notation, which are demonstrated in Figure 13. A ready pulse is sent when the entire X register has been punched out, then the cruncher is put back in the hold mode.

People-oriented talking tools are the ASCII keyboard (Figure 14) and the video display generated by the video terminal board (Figure 15).

The video terminal is a full-blown serial terminal on a single board (Figure 16). A video monitor, ASCII keyboard, and 7-volt transformer are all that are required to have a complete terminal. The terminal has an extensive set of cursor commands, which are generated by the 3870 single chip processor around which the system is centered. There are more options than can be counted on 10 fingers. The terminal is used here as a development tool and as an interpreter for hard copy. As a development tool, the teleprinter is turned off and shorted out of the simplex current loop. Switches are set for 300 BAUD ASCII. Data is fed to the terminal in ASCII format by the 6800 processor. Serial data generated by the terminal and fed back to the terminal in the loop is also ASCII format.

When used for hard copy, the teleprinter is on and placed in the current loop. However, the teleprinter used here is a five-level BAUDOT machine requiring the terminal switches to be set for 45.45 BAUD BAUDOT code. Data is still fed to the terminal in ASCII format by the 6800 processor, but serial data generated by the terminal and fed back to the terminal in the loop is five-level BAUDOT. The terminal is manufactured using the 3870 programmed to communicate in both ASCII and BAUDOT.

Interfacing of the ASCII keyboard and video terminal to the microcomputer is done through a PIA as shown in Figure 17. The keyboard strobe line was brought off the terminal board and is used as a ready strobe.

When the terminal is given data, it stops strobing the input buffers until it finishes outputting that data to the serial port. Handshaking was provided so the 6800 processor could look for a ready signal instead of being stuck in a delay loop set for the correct BAUD rate.

A large amount of RAM is needed to store and analyze the sferic data. The amount of data analyzed is limited only by the amount of RAM available. Currently, only 8K x 8 is being used, but that will be doubled before the weather picks up next spring. The 8K x 8 static RAM board used is shown in Figure 18.

PRESENT DATA GATHERING

Now that we have these processors wired up and talking to each other, what's next? Well, look out. Figure 19 gives a brief graphic explanation of the real data printed out by Fergus' system in Lombard, Illinois (Figure 20).

In Figures 19 and 20, each horizontal line of data represents the tabulated information about one peak for an observation period. The first number is the angle from true north at which a peak number of events occurred during the observation period. The second and third numbers are the angles at which the half count point occurred about that observed peak. The fourth figure is the number of events per unit time occurring at that peak. The last three figures give an indication of the severity of the storm located in the observation band.

The plot in Figure 20 is a graphic illustration of the history for one peak during the observation period, which, in this case, was 140 minutes. There were nine peaks being tracked during this observation period.

FUTURE WORK

Armed with these sferic analysis tools, triangulation between Lombard and Hickman Mills will begin soon. The best resolution zones are depicted in Figure 21.

Short term work will be primarily involved with correlating actual tornado occurrences with the data recorded just prior to and during that tornado.

A long term goal is to establish a network of stations that can be acquisitioned to form a continuous data bank. One summarization of this data might appear as in Figure 22.

Here is shown a severe weather watch zone, X number of miles either side of a line extending from point A to point B. Radar information will show the outline of the storm system. Sferics information can be overlayed in the form of pixels, the density of which could denote the percentage chance of a tornado occurring at that moment.

COST TO DATE

This should be enough information to whet anyone's imagination. If not, perhaps listing the hardware cost to date will help.

Since this entire system is a home project and is entirely funded from the family budget, cost effectiveness was of particular interest to my wife. While scanning the following list of cost incurrences, keep in mind that the electronics components business is one of the few in which the prices continue to drop by the month.

• Sferics monitor including coils and homebrew camera (old scope chassis was donated)--	$200
• Microcomputer kit--	235
• Sferics interface circuit--	10
• Number cruncher and interface--	32
• 8K X 8 static RAM kit--	135
• Video terminal board (assembled and tested)--	180
• ASCII keyboard kit--	65
• Cassette recorder--	25
• Baudot teleprinter--	75
• Connectors and cables--	30
• Television set (donated)--	
• Miscellaneous parts from junk box--	
Total	$987

TR/13

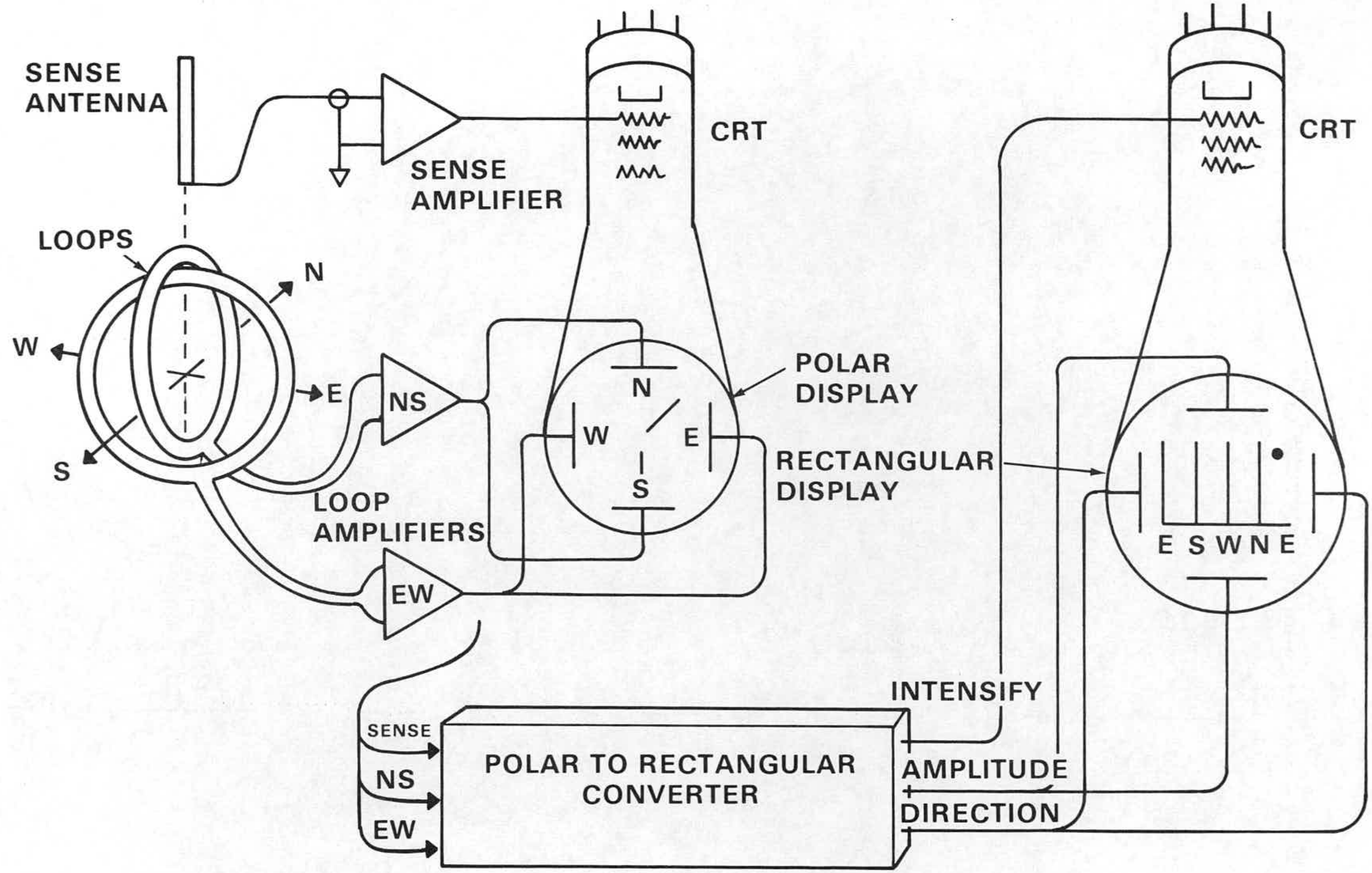


Figure 1. Polar and Rectangular Sferics Monitors

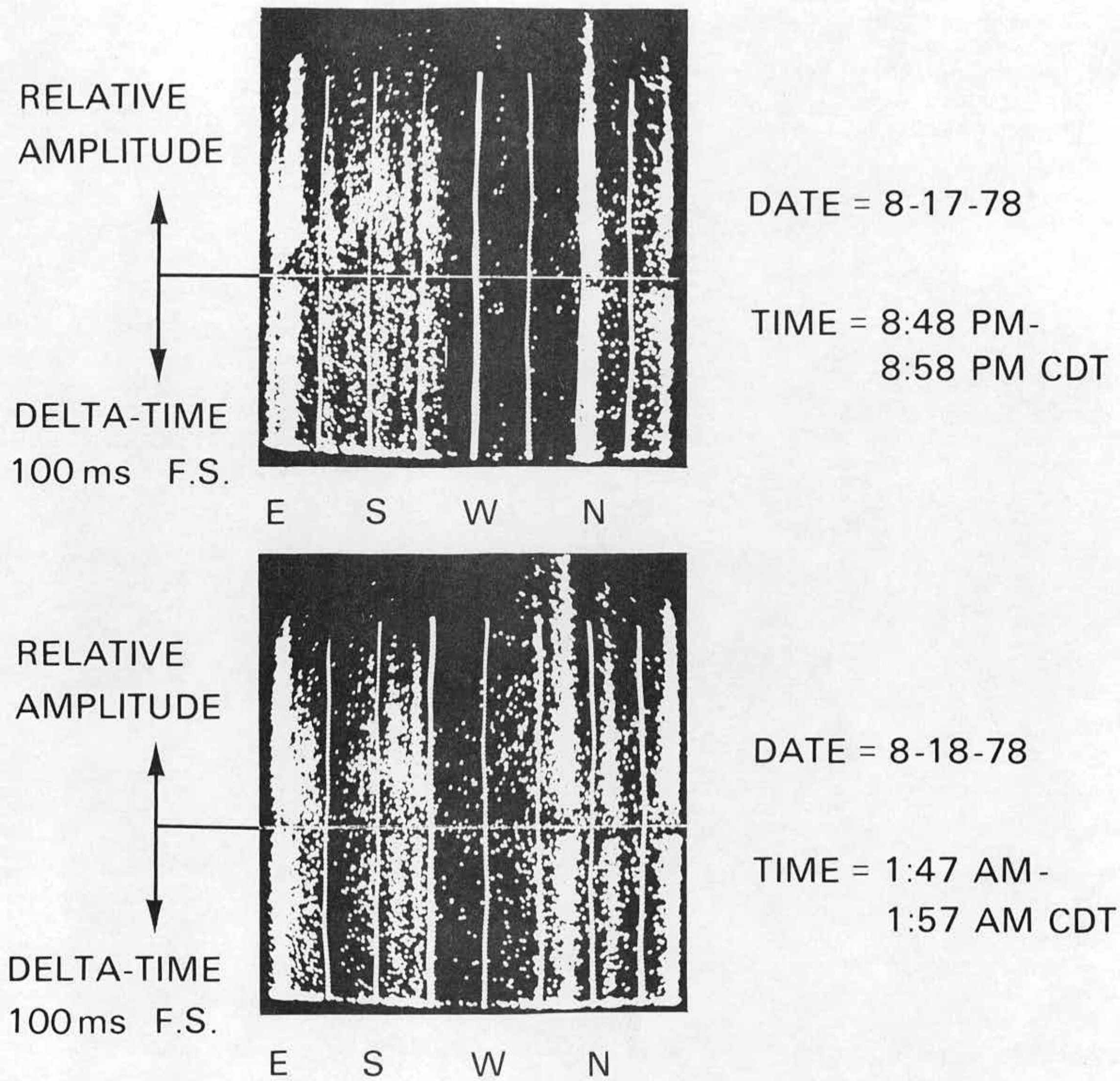


Figure 2. Sferics Data From Hickman Mills Monitor

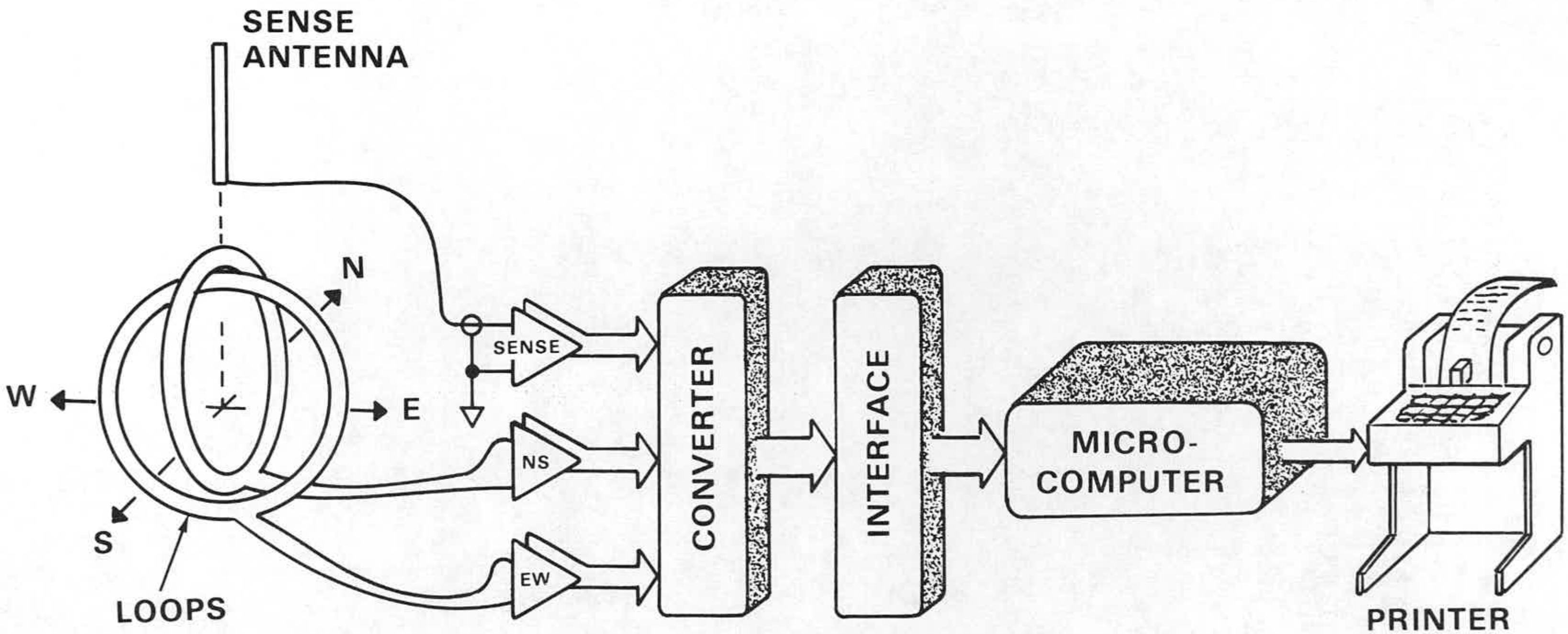


Figure 3. Sferics Analysis System

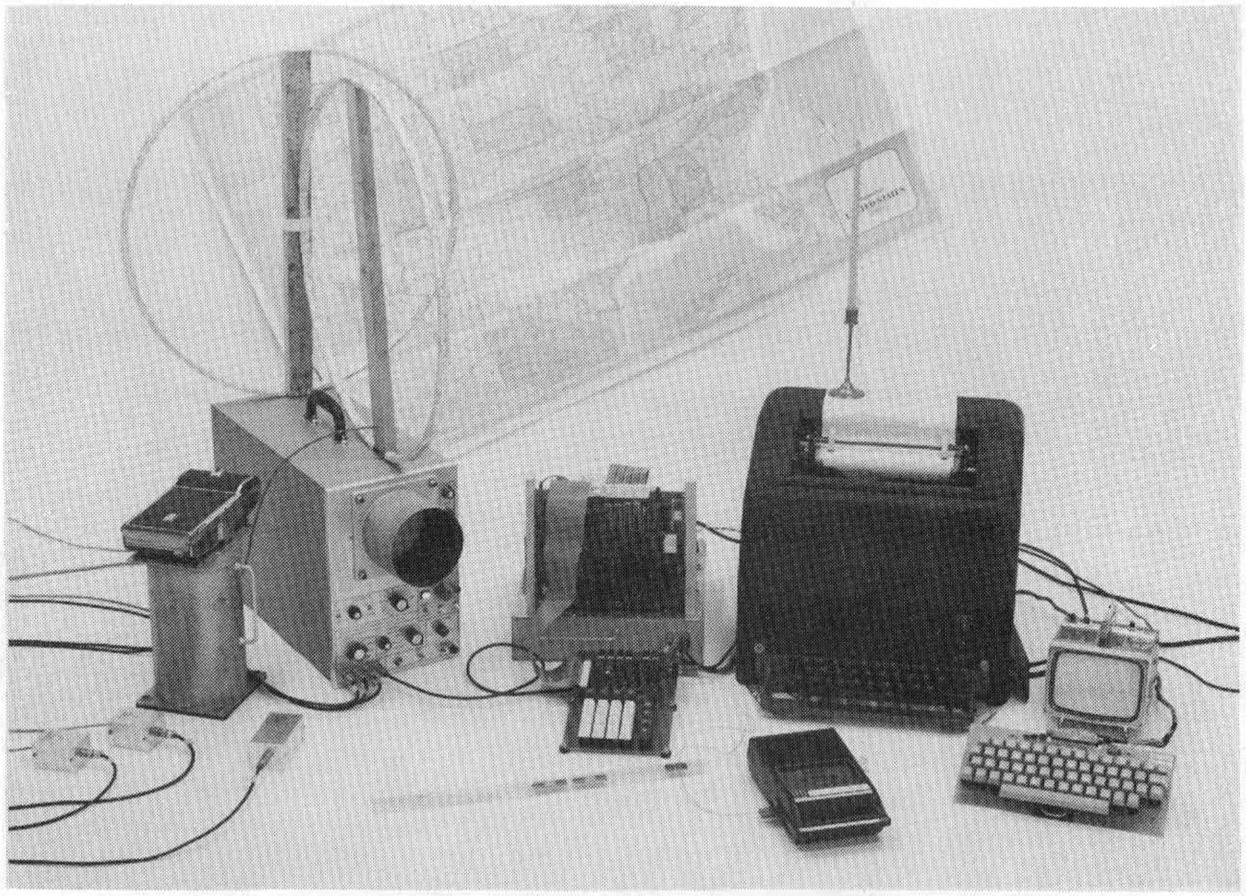


Figure 4. System to Date

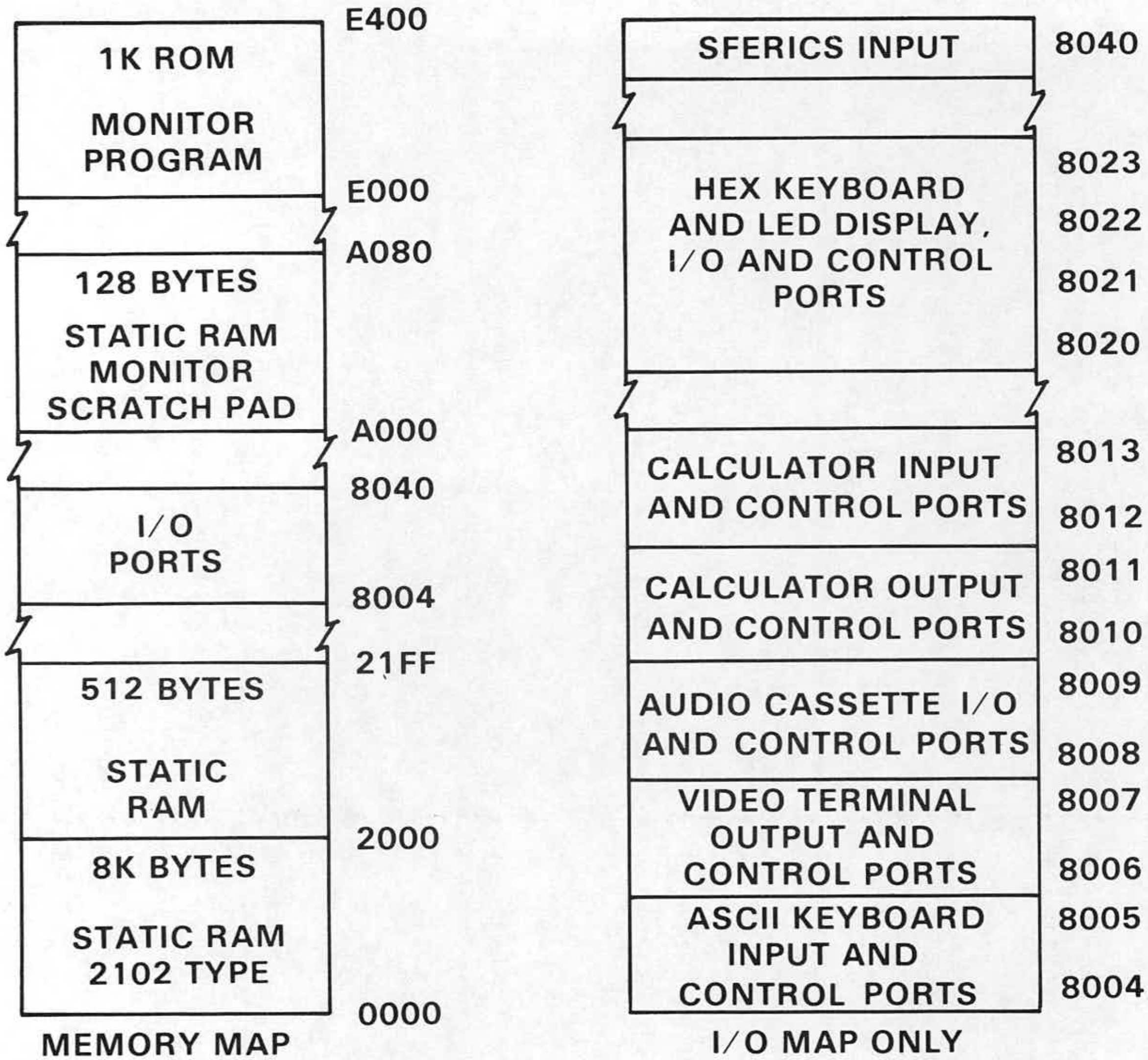


Figure 6. Memory and I/O Map

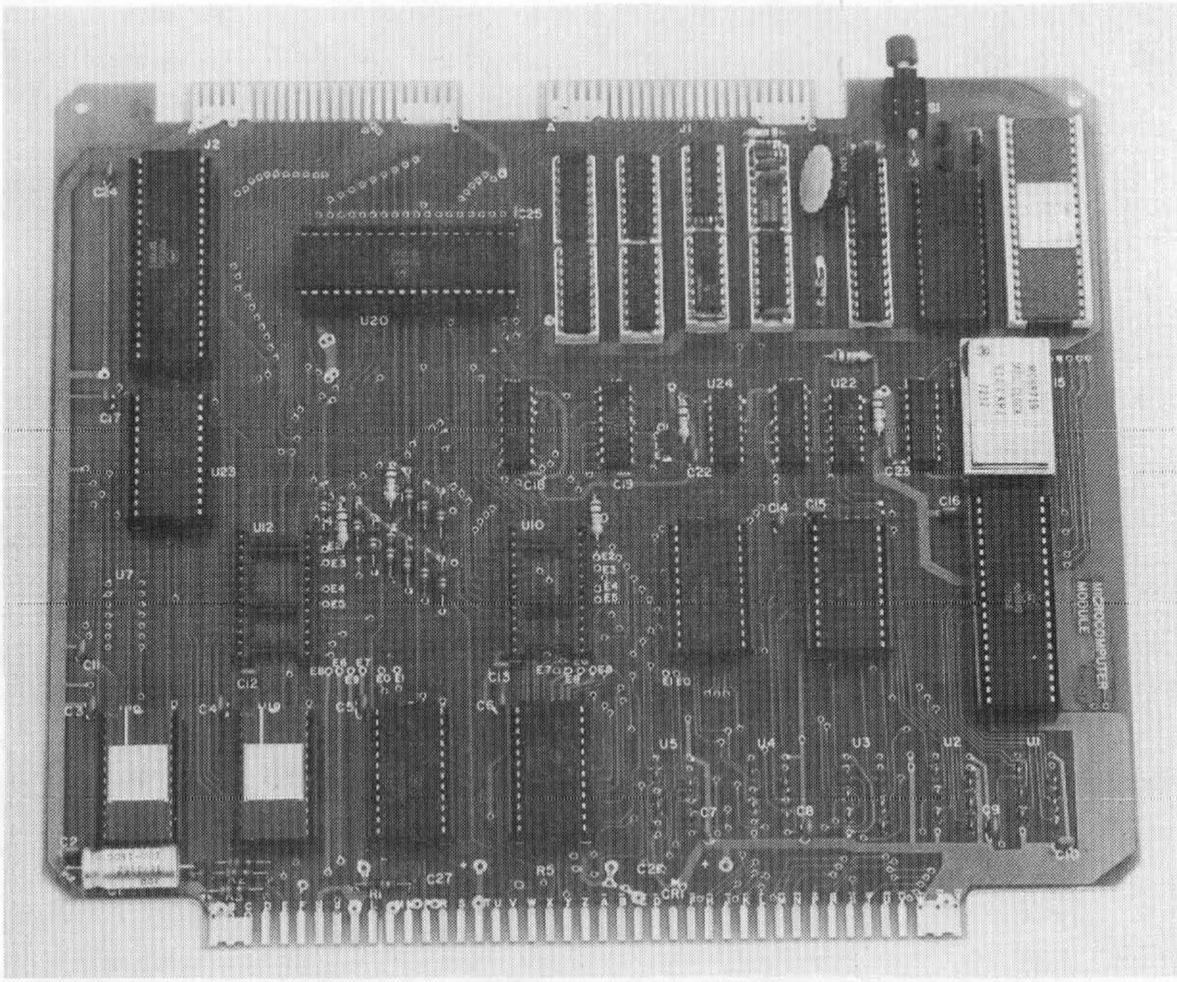


Figure 7. CPU Board

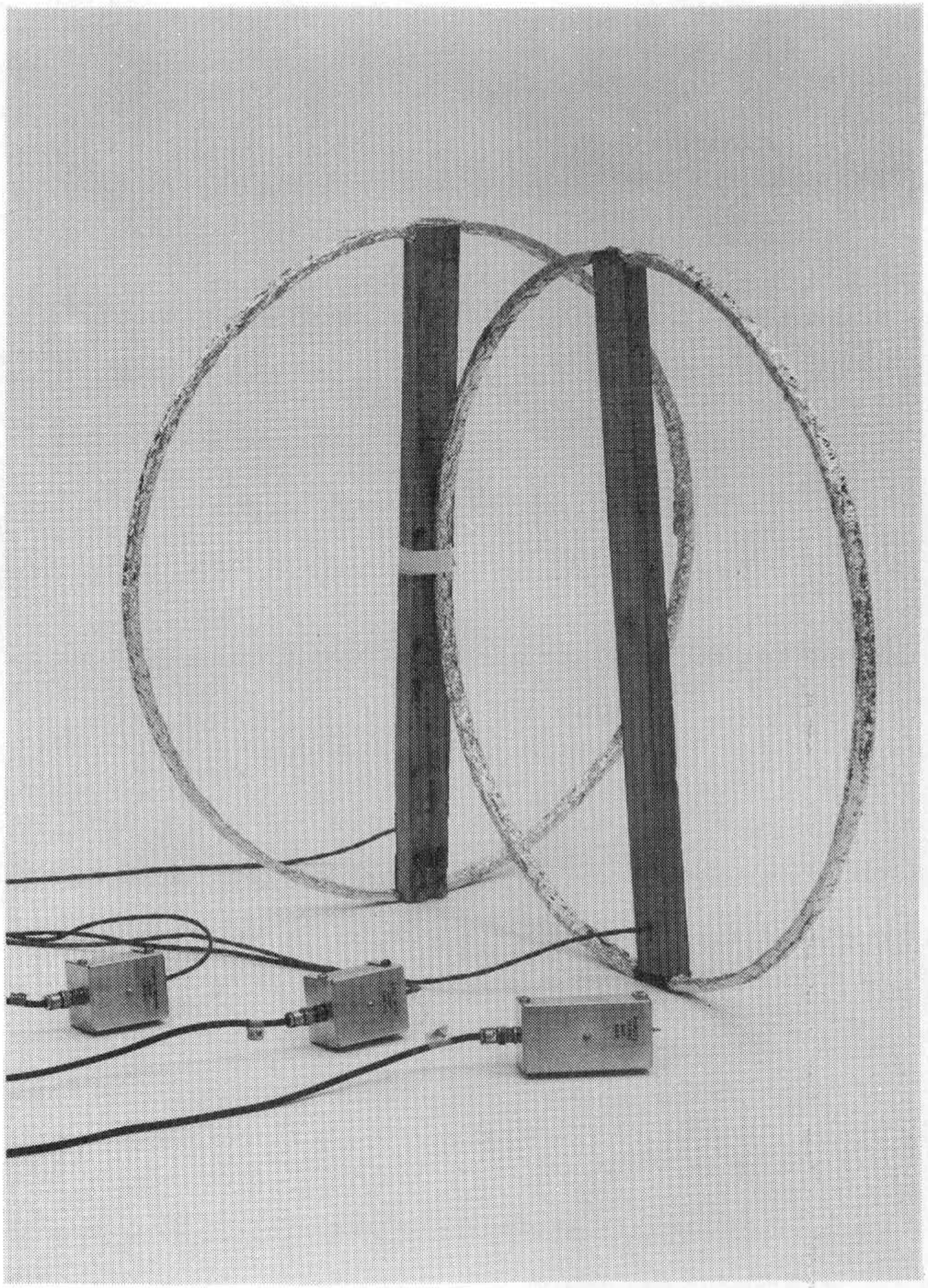


Figure 8. Balanced Loops

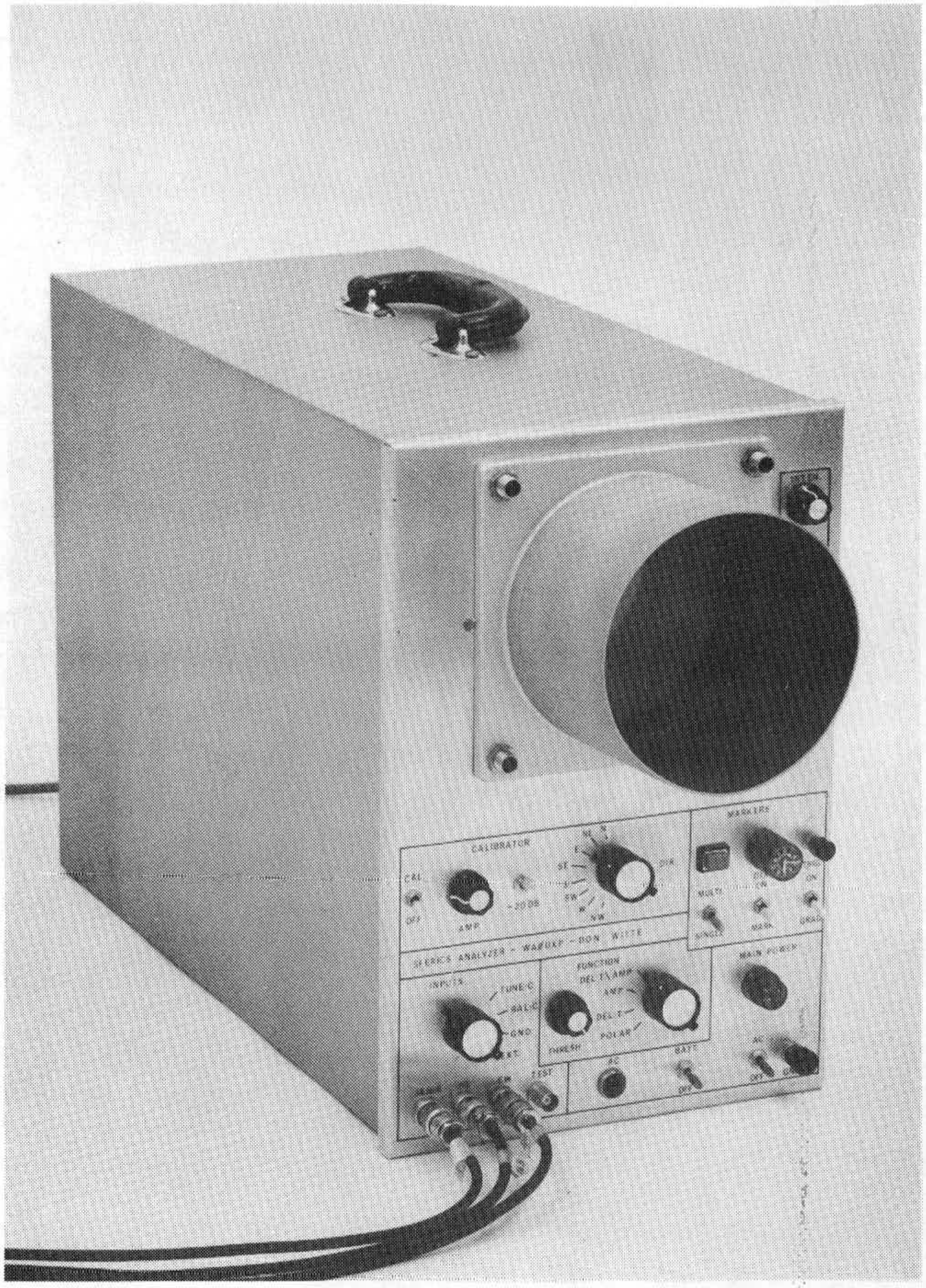


Figure 9. Sferics Monitor

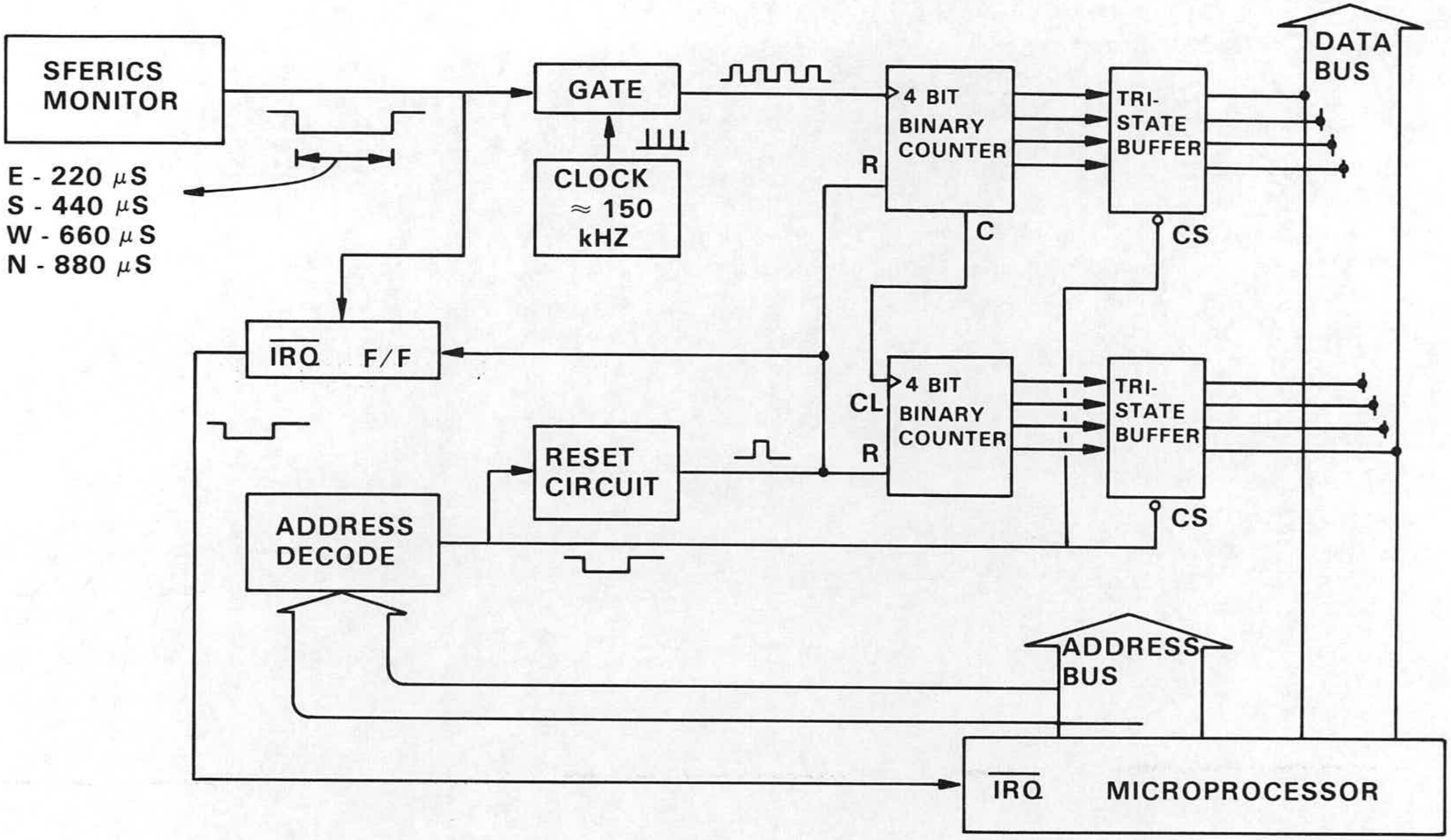


Figure 10. Sferics Interface Block Diagram

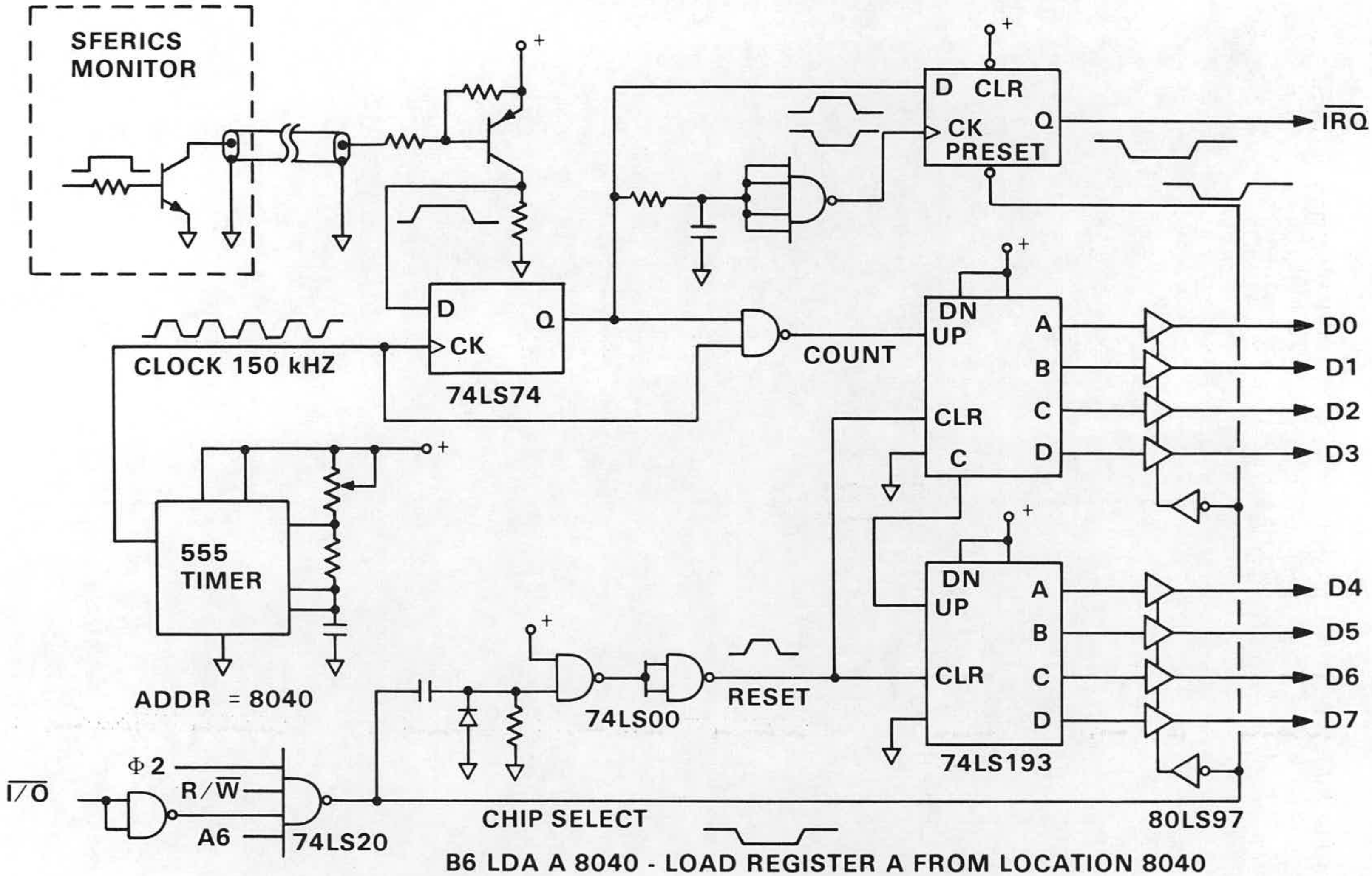


Figure 11. Sferics Interface Circuit Diagram

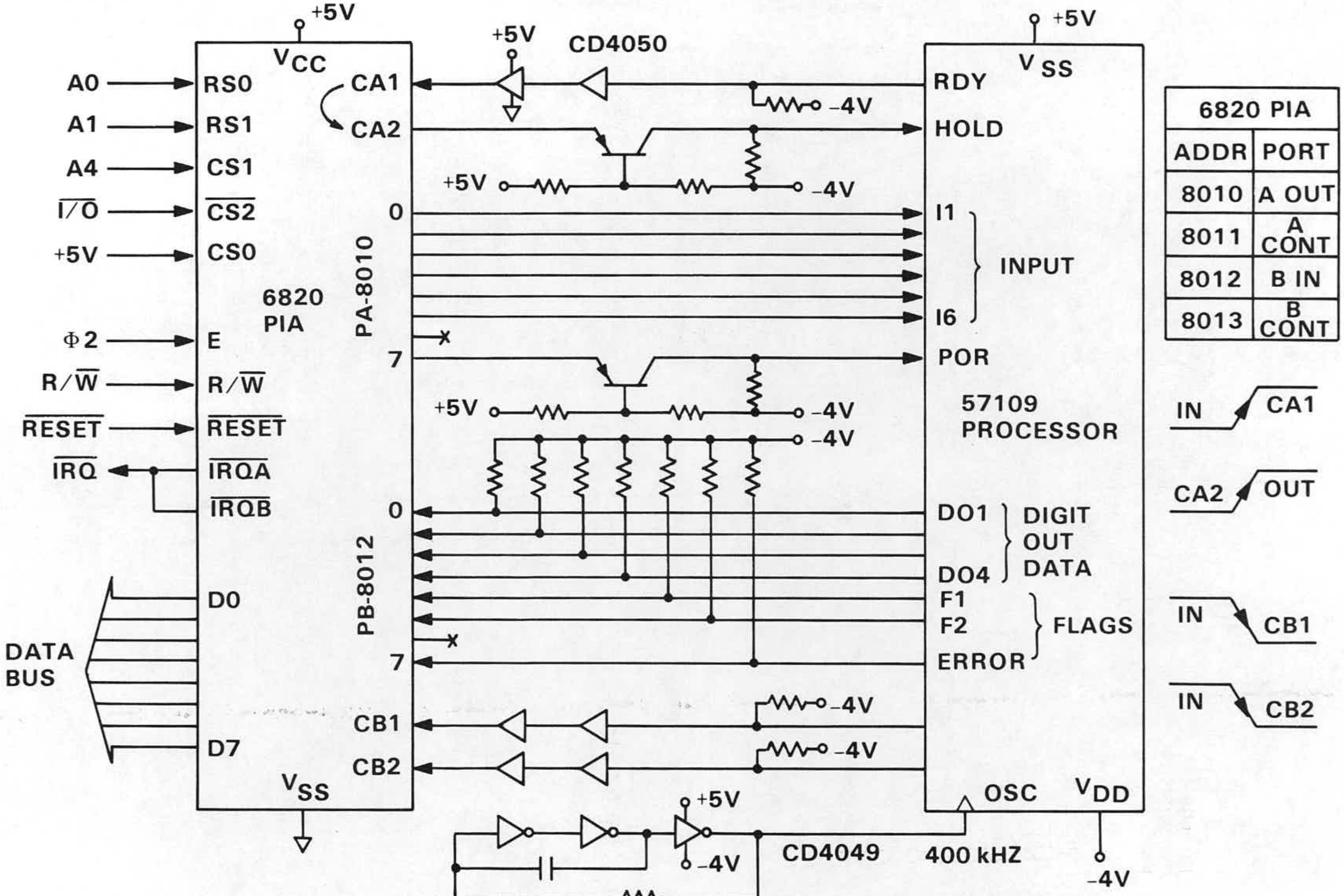
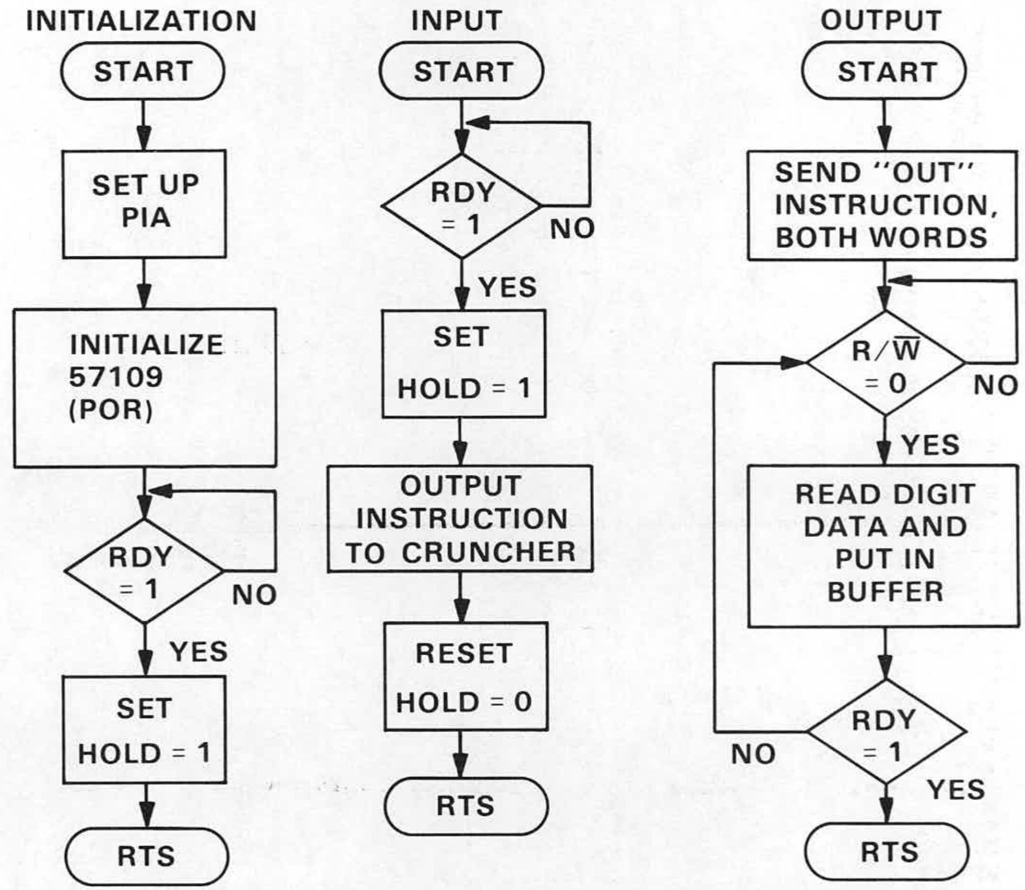


Figure 12. Number Cruncher Interface Circuit

FUNCTIONS			
DIGIT ENTRY	0→9	MATH	
	DP	+	M +
	EE	−	M −
	CS	X	MX
	PI	/	M/
	EN	1/X	SIN
	NOP	SQRT	COS
	HALT	SQ	TAN
MOVE	ROLL	10X	ISIN
	POP	EX	ICOS
	XEY	LN	ITAN
	XEM	LOG	DTR
	MS		RTD
	MR	MODE	TOGM
	LSH	CONT	SMDC
	RSM		INV
CLEAR	MCLR	I/O	OUT
	ECLR	BRANCH	

57109 NUMBER ORIENTED PROCESSOR



REGISTERS X, Y, Z, T, M

SCIENTIFIC	E	E	S	DP	D1	D2	D3	D4	D5	D6	D7	D8
FLOATING			S	DP	D1	D2	D3	D4	D5	D6	D7	D8

Figure 13. Number Cruncher Functions and Software

Figure 14. Encoded Keyboard

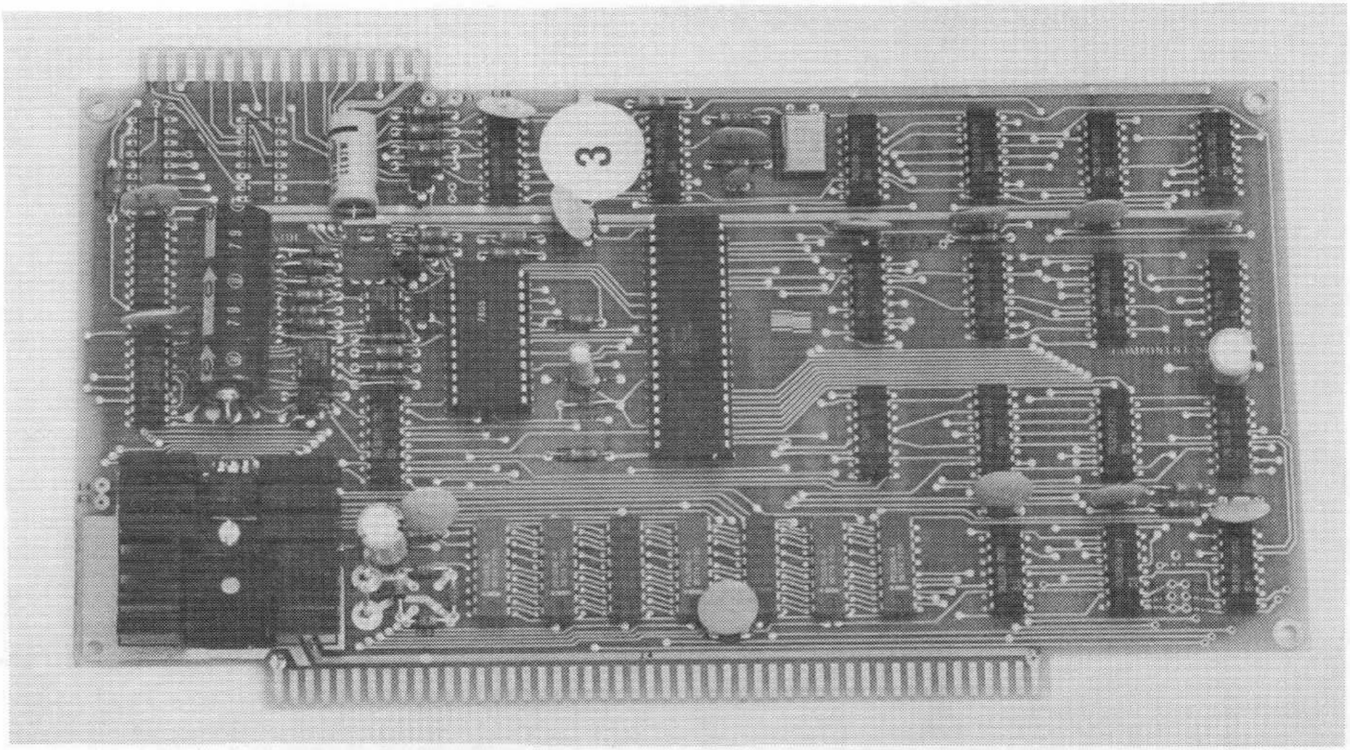
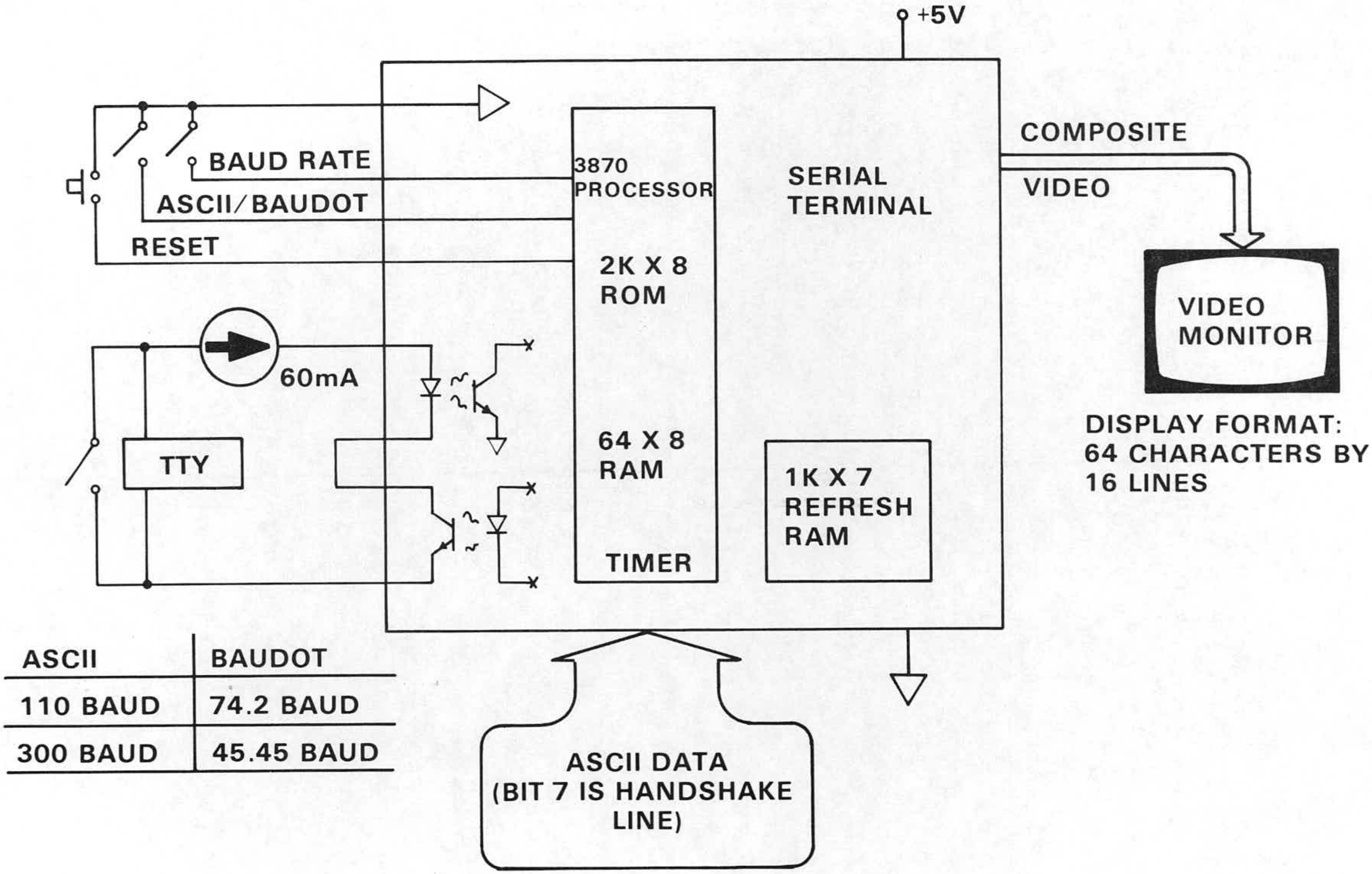
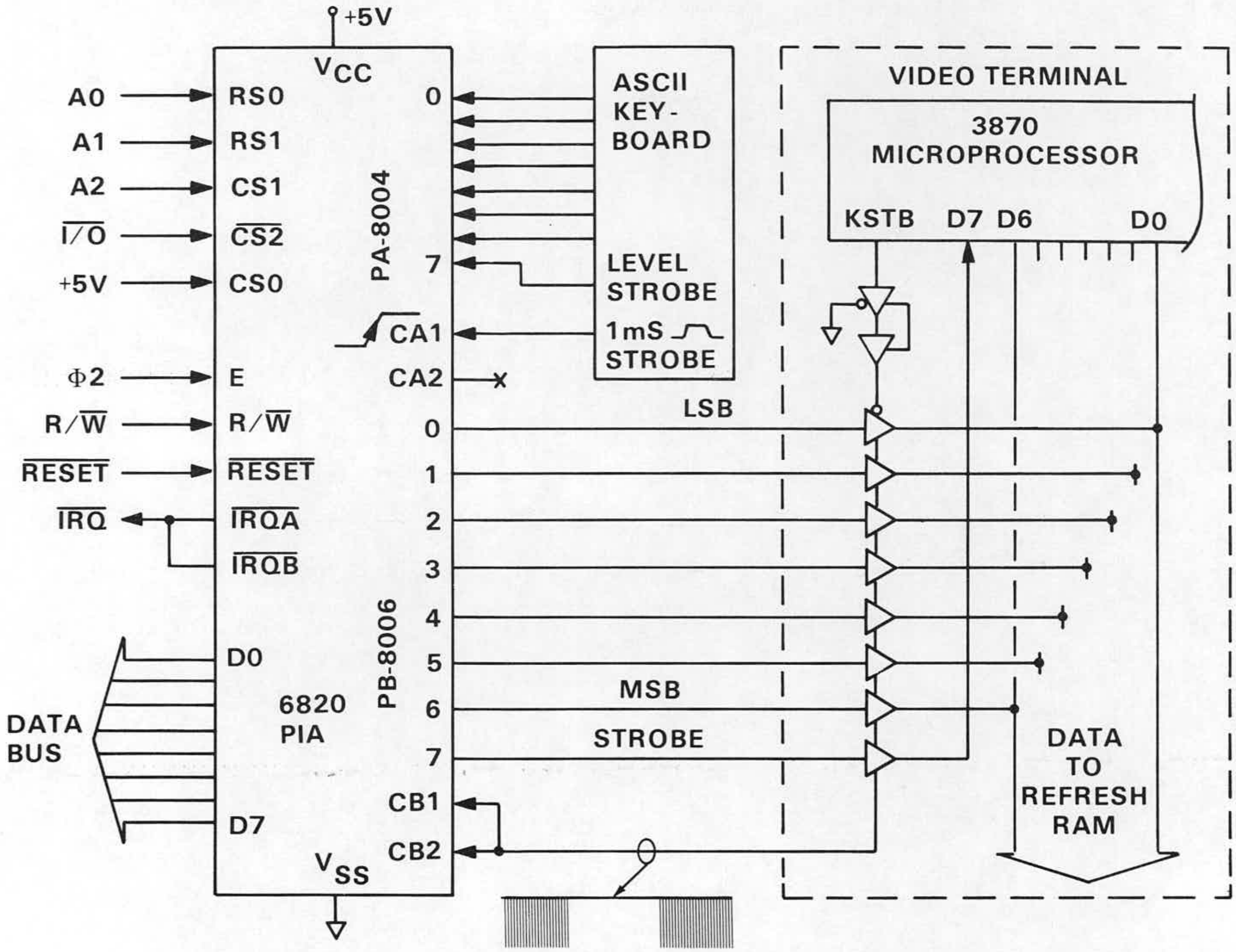


Figure 15. Video Terminal Board



ASCII	BAUDOT
110 BAUD	74.2 BAUD
300 BAUD	45.45 BAUD

Figure 16. Video Terminal Block Diagram



6820 PIA	
ADDR	PORT
8004	A IN
8005	A CONT
8006	B OUT
8007	B CONT

Figure 17. Keyboard and Terminal Interface

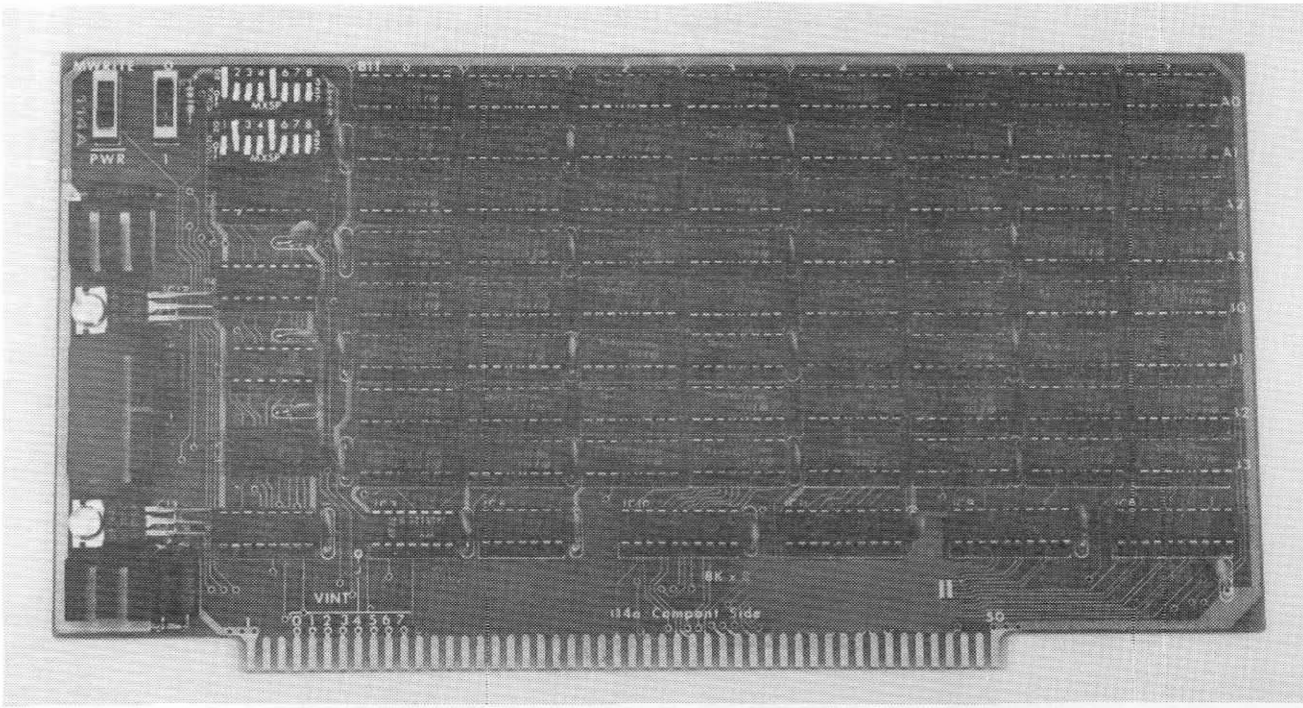


Figure 18. 8K X 8 Static RAM Board

DATA BLOCK FOR ONE OBSERVATION PERIOD 5 TO 80 MIN	127 - ⋮ 226 - ⋮	127 - ⋮ 226 - ⋮	133 - ⋮ 232 - ⋮	0280 - ⋮ 1008 - ⋮	133 - ⋮ 226 - ⋮	0009 - ⋮ 0057 - ⋮	0018 - ⋮ 0000 - ⋮	PEAK 1 ⋮ PEAK 5 ⋮
GRAPH SYMBOL	NO.	•	•	■		○	▲	
PRINTING PRIORITY	1	5	5	4		3	2	
REFERENCE	A	A	A	A	B	B	C	

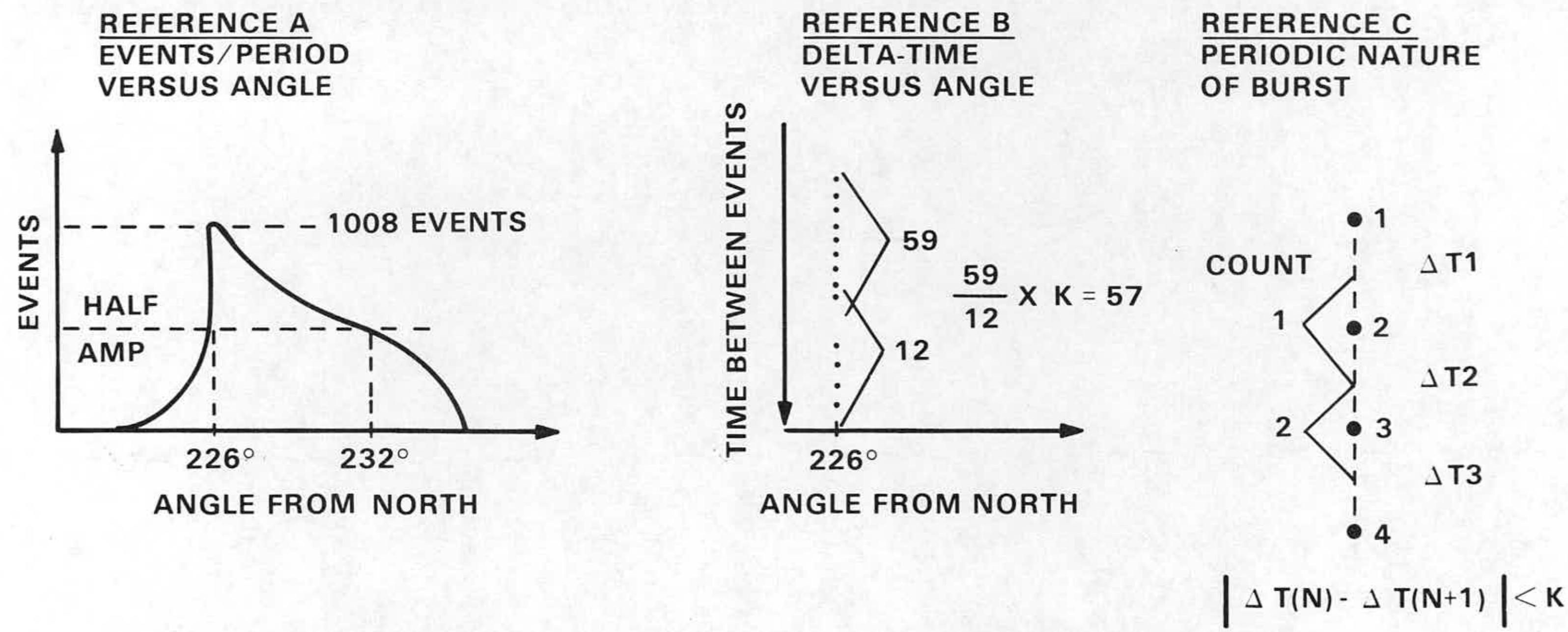


Figure 19. Current Data Logging

127-127-133-0280-133-0009-0018-
151-148-157-1312-151-0013-0000-
169-157-178-0192-178-0009-0000-
184-178-193-0088-193-0009-0000-
226-226-232-1008-226-0057-0000-
235-232-241-0456-235-0030-0000-
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0206-

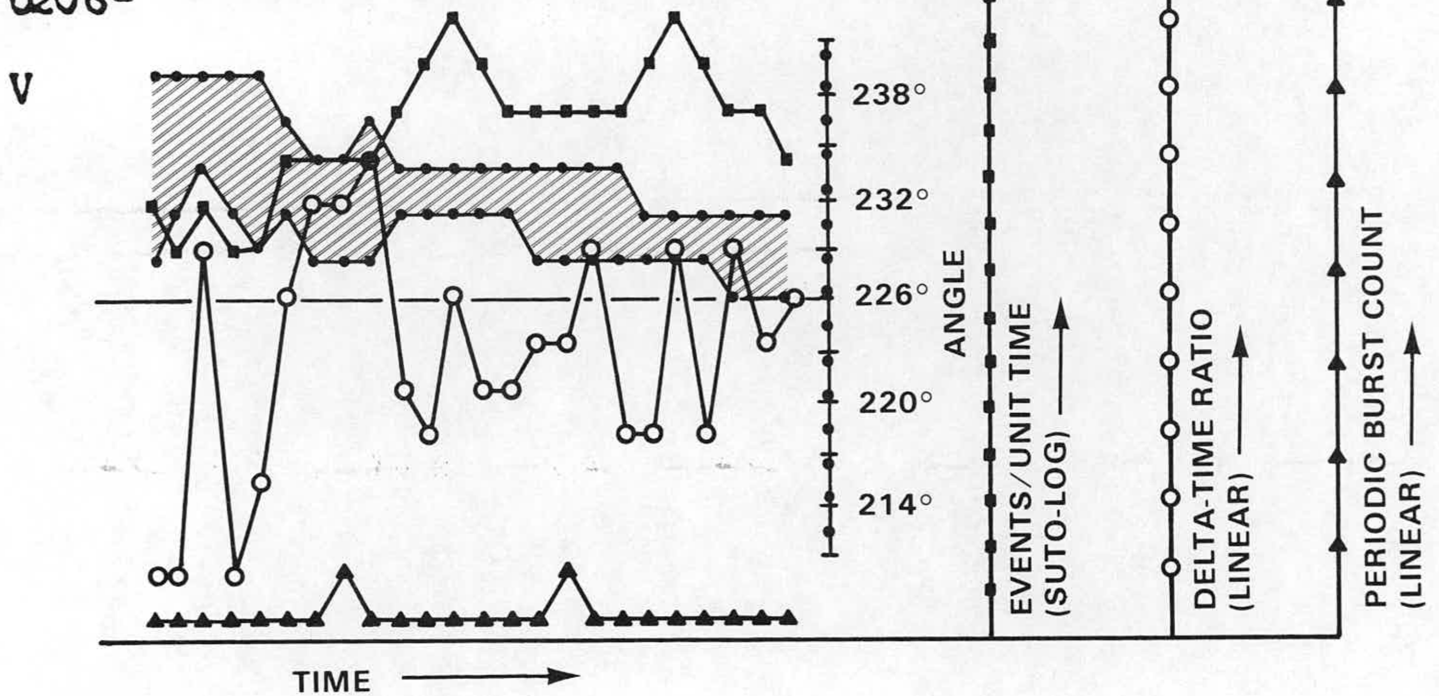

Figure 20. Printout From Lombard Station

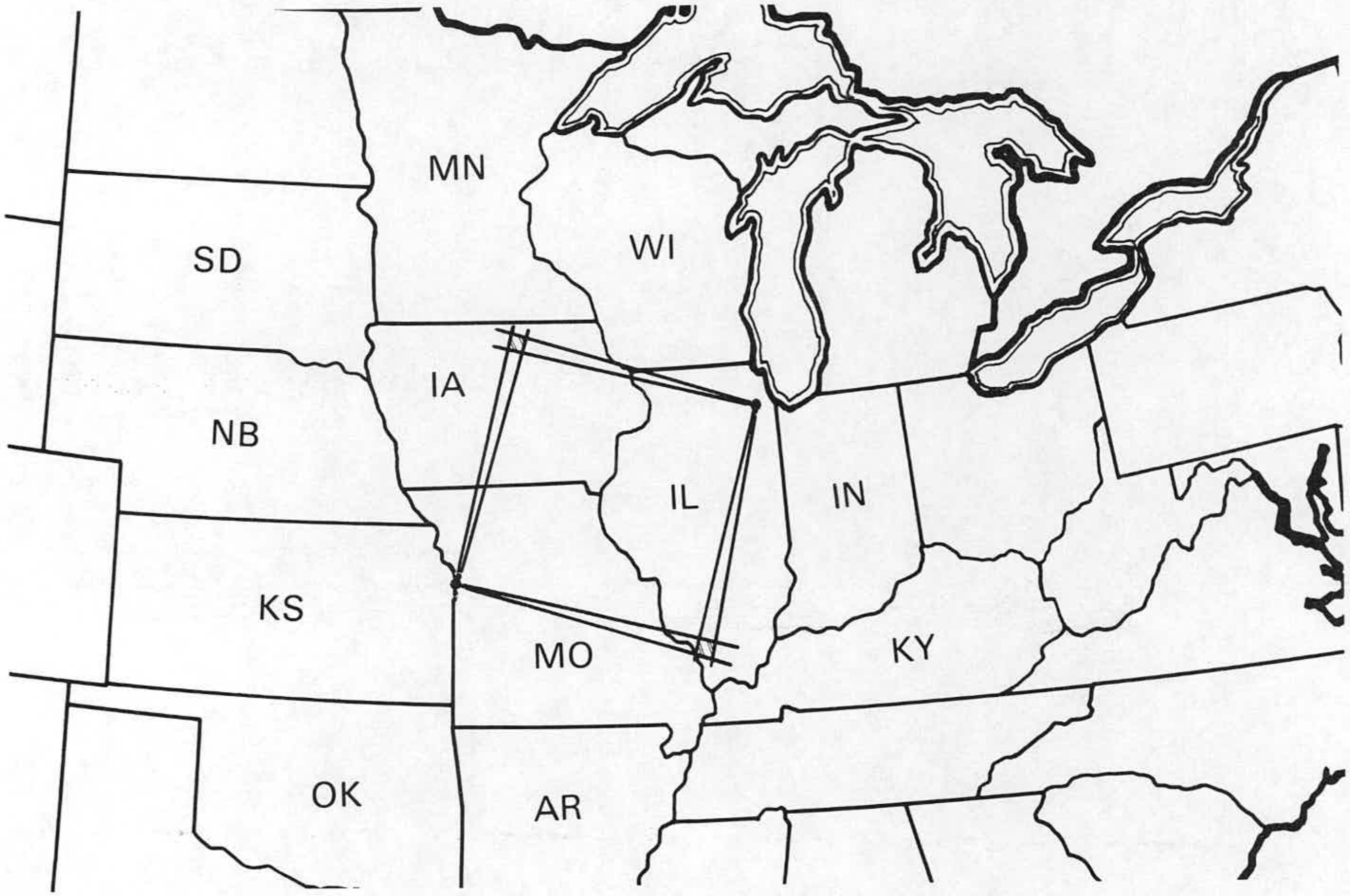

Figure 21. Triangulation Scheme

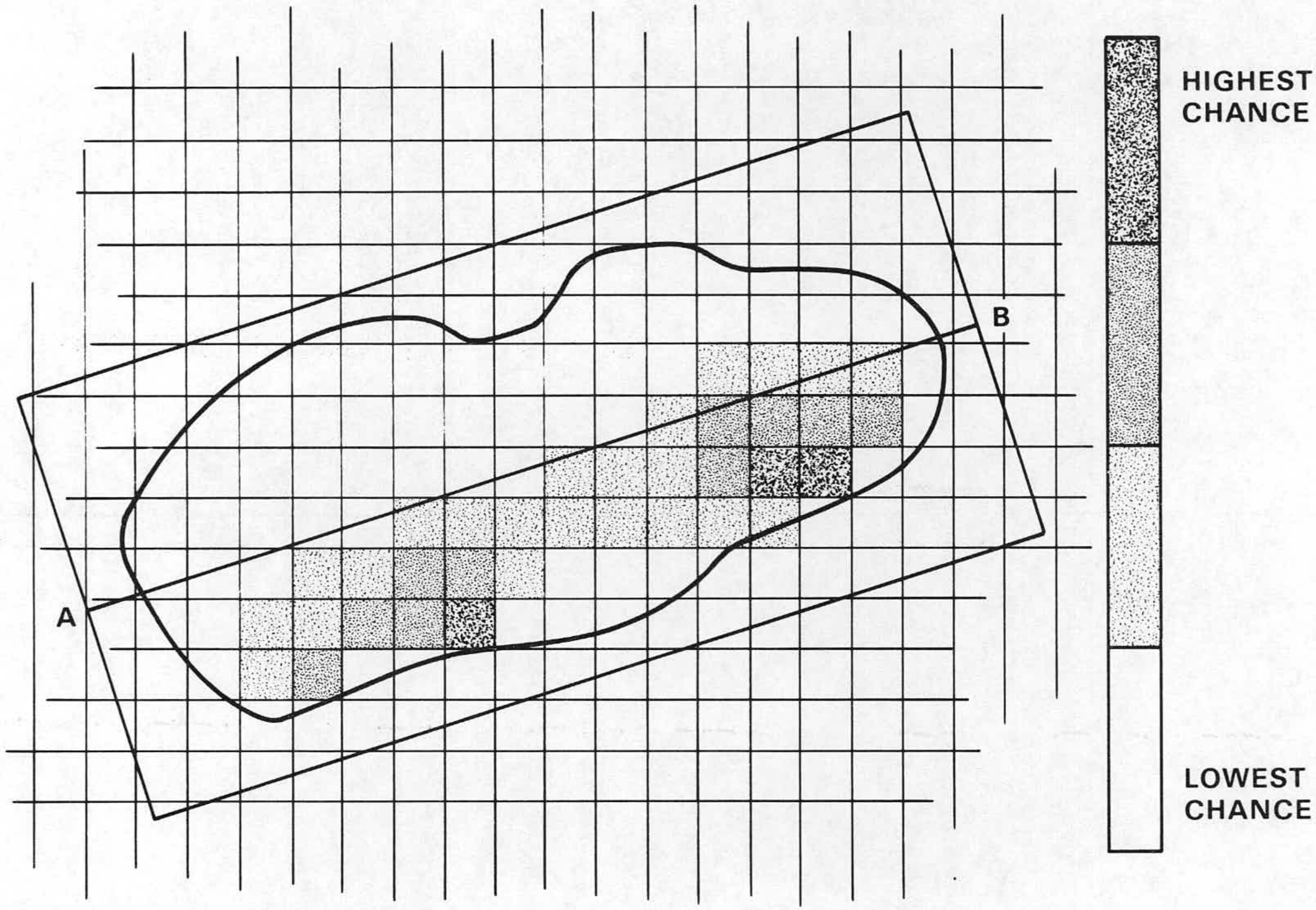

Figure 22. Tornado Probability Density Map