MASTER

CONF-8010136--1

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

By D.R. Witte

BDX-613-2531, Published September 1980
Prepared for the United States Department of Energy
Under Contract Number DE-AC04-76-DP00613.

Technical Communications Bendix Kansas City Division

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

By D.R. Witte

BDX-613-2531
Distribution Category
UC-38

Manuscript Submitted
MAECON '80 - "A New Decade in Electronics"
Kansas City Section IEEE
October 14,15, 1980
Kansas City, Missouri

The Bendix Corporation
Kansas City Division
P. O. Box 1159
Kansas City, Missouri 64141

A prime contractor with the United States Department of Energy under Contract Number DE-AC04-76-DP00613

Microprocessors as a Tool in Determining Correlation Between Sferics and Tornado Genesis - An Update -

By D. R. Witte
Senior Engineer
The Bendix Corporation
Kansas City Division

ABSTRACT

Sferics--atmospheric electromagnetic radiation--can be directly correlated, it is believed, to the genesis of tornadoes and other 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 sferics events occur, it is hoped, will lead to accurate real-time prediction of tornadoes and other severe weather.

Collection of the tremendous amount of sferics data generated by one storm system becomes cumbersome when correlation between at least two stations is necessary for triangulation. Microprocessor-based computing systems have made the task of data collection and manipulation inexpensive and manageable.

The original paper on this subject delivered at MAECON '78 dealt with hardware interfacing. Presented were hardware and software tradeoffs, as well as design and construction techniques to yield a cost effective system.

This updated paper presents an overview of where the data comes from, how it is collected, and some current manipulation and interpretation techniques used.

INTRODUCTION

Sferics is derived from the words atmospheric electromagnetic radiation. Sferics are generated by lightning, high wind sheer, and other atmospheric phenomena. The radiation spectrum includes frequencies from 10 kHz to well above 100 MHz. The crackling noise you hear on your AM radio and the flashes you see on your television screen during a storm are caused by sferics.

On the market now is an instrument for aircraft that pinpoints sferics occurances so that high activity areas may be circumnavigated. These high activity areas represent the location of the more turbulent air masses.

Lightning is one mechanism of sferics generation. Charged particles within a cloud are separated by convection, causing the cloud to take on a polarity. This polarity is most often positive charge on top and negative charge at the cloud base (Figure 1).

Positive charge in the earth rushes to a point directly below the cloud base and accumulates there. When the charge gradient between the ground and cloud becomes large enough, a leader ionizes a stepped path to the ground. A retrace discharge then occurs along that path. This lightning stroke, sometimes carrying millions of amperes, acts as an antenna, transmitting band-limited white noise.

A cloud-to-ground lighting stroke is at the left of Figure 2. A receiver at point A could monitor any of the frequencies contained in waveform A. The waveform represents one sferics event: an electromagnetic pulse containing frequencies from below 10 kHz to above 100 MHz.

At point B, the high frequencies have been attenuated out by trees, buildings, mountains, and over-the-horizon effects. Amplitude is also reduced as represented by waveform B.

As a ground wave for long distances, 10 kHz stands out. The earth and ionosphere, acting as a wave guide, cause 10 kHz signals to propagate thousands of miles undistorted, which is why 10 kHz was selected as our monitoring frequency. Also, by using a low frequency, determining the direction of origin is simplified.

SFERICS MONITOR

Detecting sferics signals is easy. As I have mentioned, they can be heard on any AM radio. But determining the direction of origin of each event is more difficult.

Richard W. Fergus, a fellow engineer, has designed and built a monitor and analysis system located in Lombard, IL. The second station, a near duplicate of the first, is located here in Hickman Mills, MO. The basis of the monitor are shown in Figure 3. Three antennas are used: two loops and one vertical dipole.

The loop antennas are flat coils built as nearly alike as possible. Both are electrostatically-shielded and parallel-tuned with capacitance to 10 kHz. They are excited by the magnetic portion of the electromagnetic sferics signal. They must be placed several diameters apart, one orientated north-south and one orientated east-west. Since they are used to sense direction, they must be aimed as accurately as possible with respect to true north.

The sense antenna, a vertical rod 3 to 10 feet long, is used to sense the electric portion of the electromagnetic sferics signal.

Signals from the antennas are amplified and fed to a cathode ray tube (CRT) for display (Figure 3). Events are depicted on the polar display by a strike mark. The angle from straight up is the direction of origin from North and the length from CRT center is the relative amplitude of the sferics signal as it strikes the loops.

Polar information is fed to a converter and changed to X-Y. Each event then becomes a dot on the CRT face with direction along the horizontal axis and relative amplitude along the vertical axis. Note the compass points: East, South, West, North, East. An elapsed time exposure of the dots presented on the X-Y display shows a profile of received sferics events.

The two sequential photographs shown in Figure 4 are actual 10-minute accumulations of data taken five hours apart on the Hickman Mills monitor. Each received event puts two dots on the photo record. Dots above the center line are relative amplitude versus direction (increasing toward the top), and dots below the center line represent the time between the last event versus the direction (increasing toward the bottom). For the lower half display, an event longer than 100 milliseconds after the preceding event will appear on the base line.

Note the movement about the compass of the storm centers seen in these views. To look at the time patterns of events being generated by each of these storm cells, we need a real-time computer.

SFERICS ANALYSIS SYSTEM

By adding a computer to the sferics monitor, we have the sferics analysis system shown in Figure 5. Events are received, amplified, and converted to X-Y. The direction is digitized and fed to the microprocessor-based computer. The computer looks for patterns, reduces the data to an easily understood format, and prints it out. The clock is a real-time clock with a 10-millisecond resolution.

Both stations mentioned are designed to operate on a 24-hour basis. Events from as far away as 1000 miles have been logged at each station and triangulation has been checked on a number of storms.

The method of triangulation for the two stations is depicted in Figure 6. Each station has a resolution of 3° which can be increased by adding more sophistication to the interface electronics. Highest resolution zones, where the triangulation would be the most accurate, are two areas enclosed by radials from both stations. Obviously, more stations will be needed to adequately cover the tornado belt.

Hardware for the Hickman Mills station is pictured in Figure 7. In a semicircle from left to right are the antenna matching boxes, scope camera, sferics monitor, loop antennas, microcomputer, teleprinter, video monitor, ASCII keyboard, audio cassette for program storage, extra ICs, and a map. You can guess what the candle is for. All the components were purchased for around $1000, not including design and assembly labor.

DATA GATHERING, ANALYSIS, AND CHARACTERIZATION

Having discussed the hardware to gather the sferics data, all that remains is the software to analyze that data. Once again, the hardware receives signals at 10 kHz only. An event is recorded when the original electromagnetic spectrum of that event contains enough energy at 10 kHz to trigger the threshold level of the monitor when it reaches the antennas of the monitor. The hardware determines two parameters: direction of origin and time of arrival. Software routines to analyze information from just these two parameters are endless.

For example, Figure 8 shows two types of representations. The graphical representation is from the Hickman Mills station and the tabular representation is from the Lombard station. Both were recorded at about the same time.

Looking at the Hickman Mills station data, each X represents one sferics event. Events were accumulated into 120 channels representing a full circle of 360°. Data was collected for two minutes and 26 seconds, then printed out in this graphic form. Number of events is the vertical scale and azmuth is the horizontal scale. Notice the eight compass headings. The largest count (peak) occurred at 213° at a rate of 26 events per minute. The half-count width around the peak we will call the region of interest (ROI).

Looking at the Lombard station data, the numbers in the first column are the angles of six peaks monitored at this time. The next two columns are the azmuth edges of the ROIs associated with the peaks in the first column. We were interested in peak 3 at 226°, which corresponds to the 213° peak at the Hickman Mills station.

The storm we triangulated was located near Ponca City, Oklahoma, where the media there reported 80-mile-per-hour winds. A Kansas City TV station radar did not display the storm because, as they explained, it was out of their range. For radar, cloud tops must be high enough to be seen beyond the horizon.

How do radar returns correlate with sferics count rates? Figure 9 was taken from a report Herbert L. Jones of Oklahoma State University made 25 years ago. The idea of using sferics to detect severe storms is not new. However, the sferics data shown here were counted by hand from a photographic oscillograph record of events from all directions. With the inexpensive computing power of the microprocessor available today, we can do that automatically.

Current data logging is illustrated by Figure 10. The nine rows of numbers in the data table represent information about the nine peaks being tracked by the system. The graph is a history plot of the fifth peak at 226° for an observation period of 140 minutes. The right edge of the graph is at printout time, with the left edge 140 minutes earlier. Shaded area is the ROI. Events per unit time are represented by the uppermost line which has two large peaks; the bottom line is the burst count, which will be defined later.

Notice how, as the ROI narrows, the burst count and then the events per unit time increase. This pattern occurs a second time. Many patterns like this have been recorded.

So much for isolating peaks of activity from the full 360° of incoming events. But what does the raw data coming from one active area look like? If we isolate the sferics data from one ROI, one storm cell, we do the following. (Look at the top line of Figure 11.)

Imagine stepping through a memory, one address at a time, at 10-millisecond intervals. If no event is detected from the ROI at a particular address, its content is set to zero. If an event is detected, the content is set to 1. From this record, we evaluate parameters such as time between events (TBE) and events per unit time.

Looking at a longer data record (the middle line on Figure 11), we notice close groupings of events called bursts. We expect two patterns to emerge for severe convective storms illustrated by the bottom line. We are very interested in finding out if a burst becomes periodic and if there is a periodicity of the bursts as a storm becomes tornadic.

It would be convenient to simply apply the Fourier transform on our data record to yield a Power Spectral Estimate (PSE) versus frequency. As a storm becomes severe, we might expect to see the PSE of Figure 12 emerge. The high frequency peak would indicate the presence of bursts and the low frequency peak would indicate that the bursts are periodic. It is not, however, that simple.

Our data record looks like a frequency-modulated pulse-carrier signal. Not only is the maximum frequency important, but the change in frequency with respect to time is also important. An algorithm must be developed that will process the sferics data to generate a PSE. This estimate can then be correlated to tornado genesis.

We can set three limits on our data now. Our maximum frequency is 100 Hz, because our clock period is 10 milliseconds. Data seldom exceed this rate. Our minimum frequency will be set at 0.4 Hz, assuming data at a lower rate to be random noise. The maximum change in frequency is 100 Hz which can occur in 10 milliseconds, yielding a delta F over delta T maximum of 10 Hz per millisecond.

While other software is being developed, a "burst table" will be used to show what a burst looks like statistically (Figure 13). After recognizing that a burst has occurred, the time between the first and second events (TBE 1) is determined. One is added to the proper vertical cell. Each vertical cell is a multiple of the sampling time (TS) which is 10 milliseconds. Then, time between the second and third events is determined and one is added to the proper vertical cell over (TBE 2), and so on.

If the data within a burst become periodic, a horizontal row of large numbers will emerge. Other patterns also will emerge. This table technique helps us process and analyze the burst data.

FUTURE WORK

We hope eventually to have a library of pattern signatures that regularly occur before or during a tornado. Then when those patterns are detected, the probability of a tornado occurring can be evaluated. One long-term goal is to establish a network of stations that will be data-acquisitioned to form a continuous probability data bank.

Figure 14 represents a summary of this data bank. It shows a severe weather watch zone, X miles either side of a line extending from point A to point B. Radar information will show the outline of the particulate matter in the air. Sferics information can be overlayed in the form of pixels, whose color or density will denote the percentage chance of a tornado occurring at that moment. Tracking the movement of these high probability pixels will lead to accurate, advance warnings.

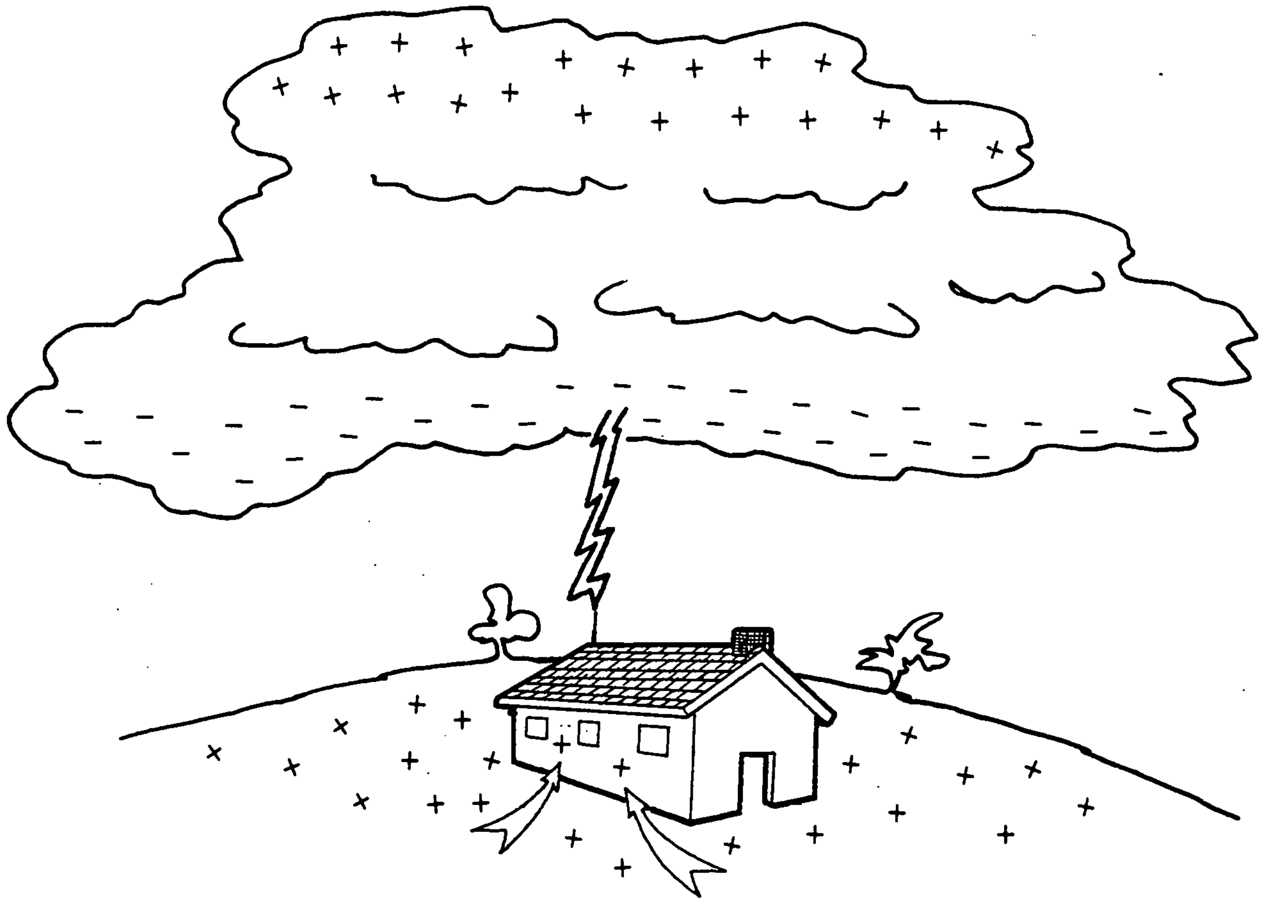


Figure 1.

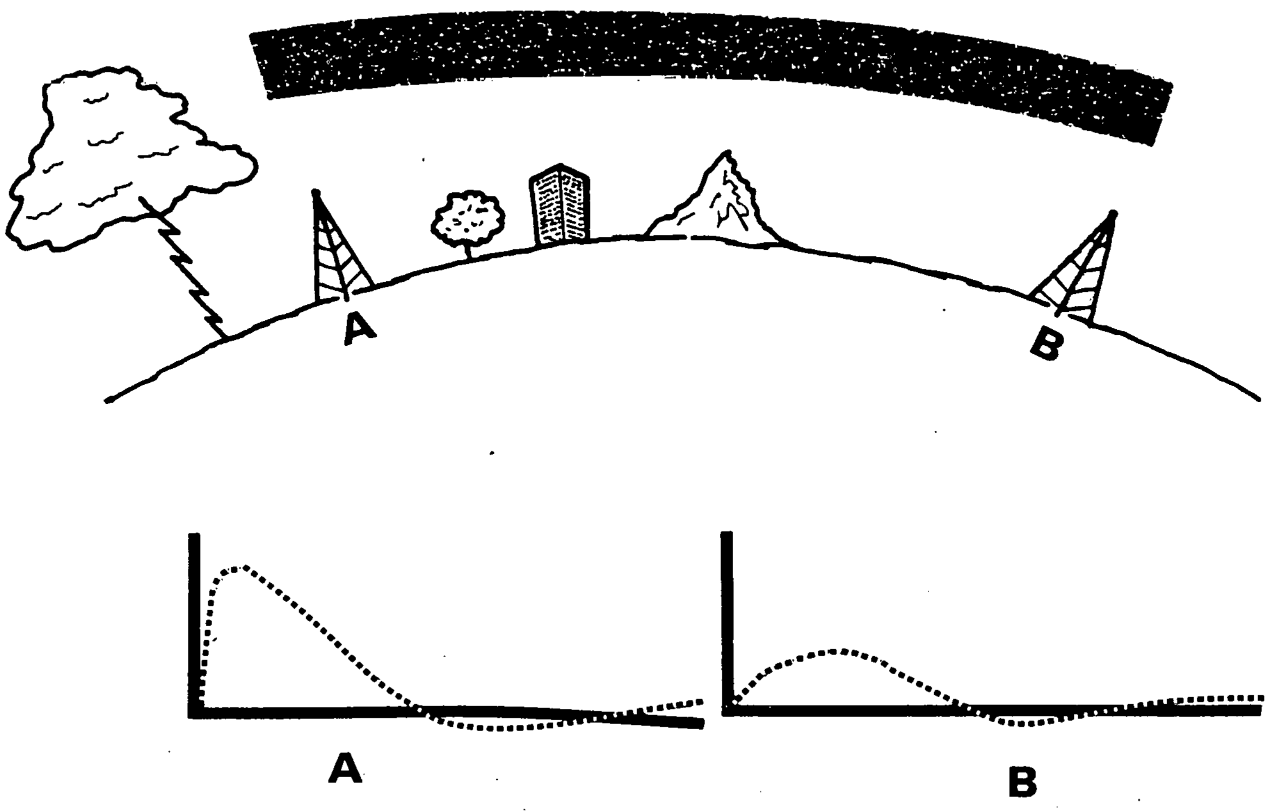


Figure 2

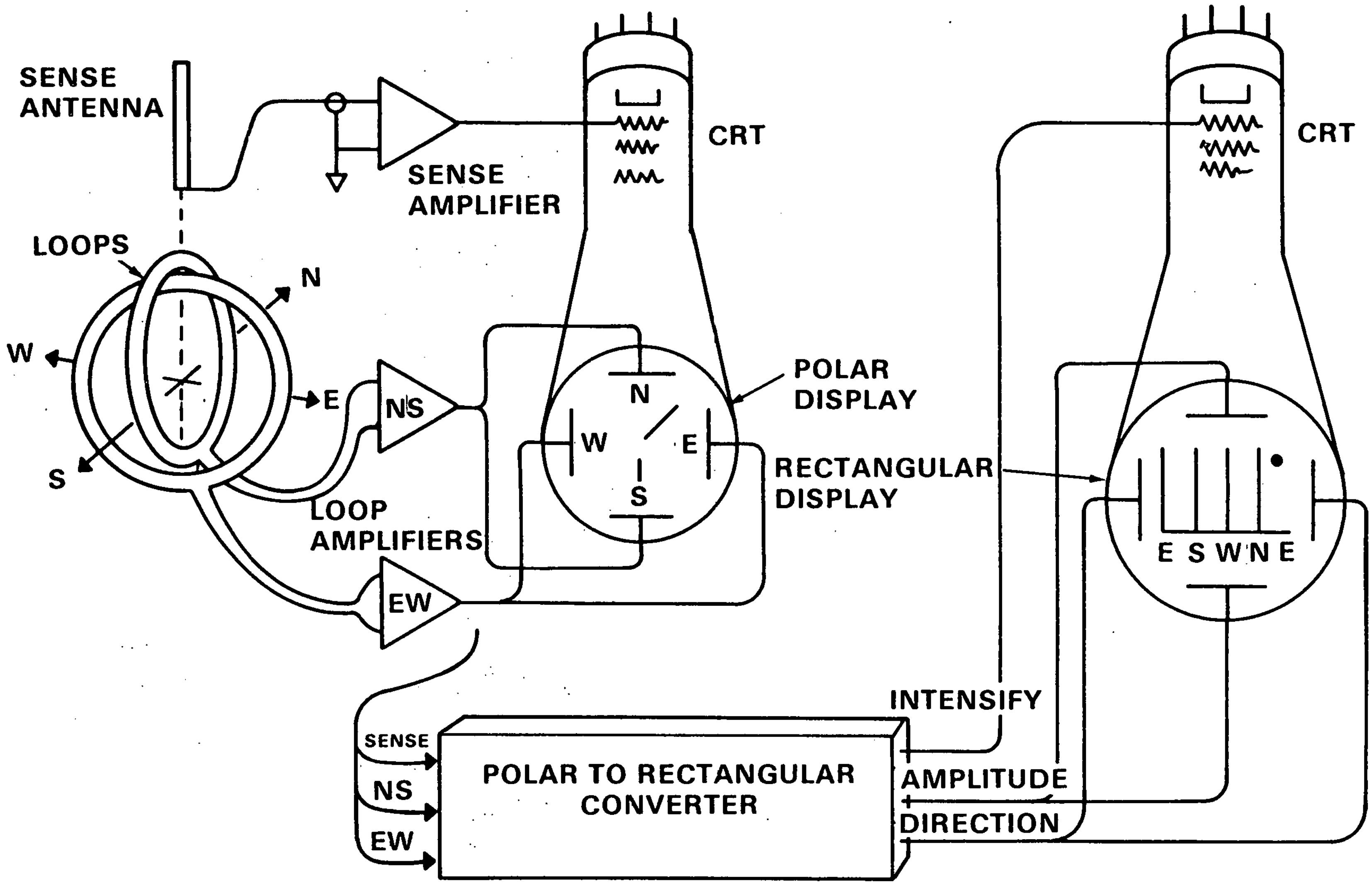

SENSE
ANTENNA
SENSE
AMPLIFIER
CRT
LOOPS
N
W
E
S
NS
LOOP
AMPLIFIERS
EW
N
W
E
S
POLAR
DISPLAY
RECTANGULAR
DISPLAY
CRT
E S W N E
INTENSIFY
SENSE
NS
EW
POLAR TO RECTANGULAR
CONVERTER
AMPLITUDE
DIRECTION

Figure 3

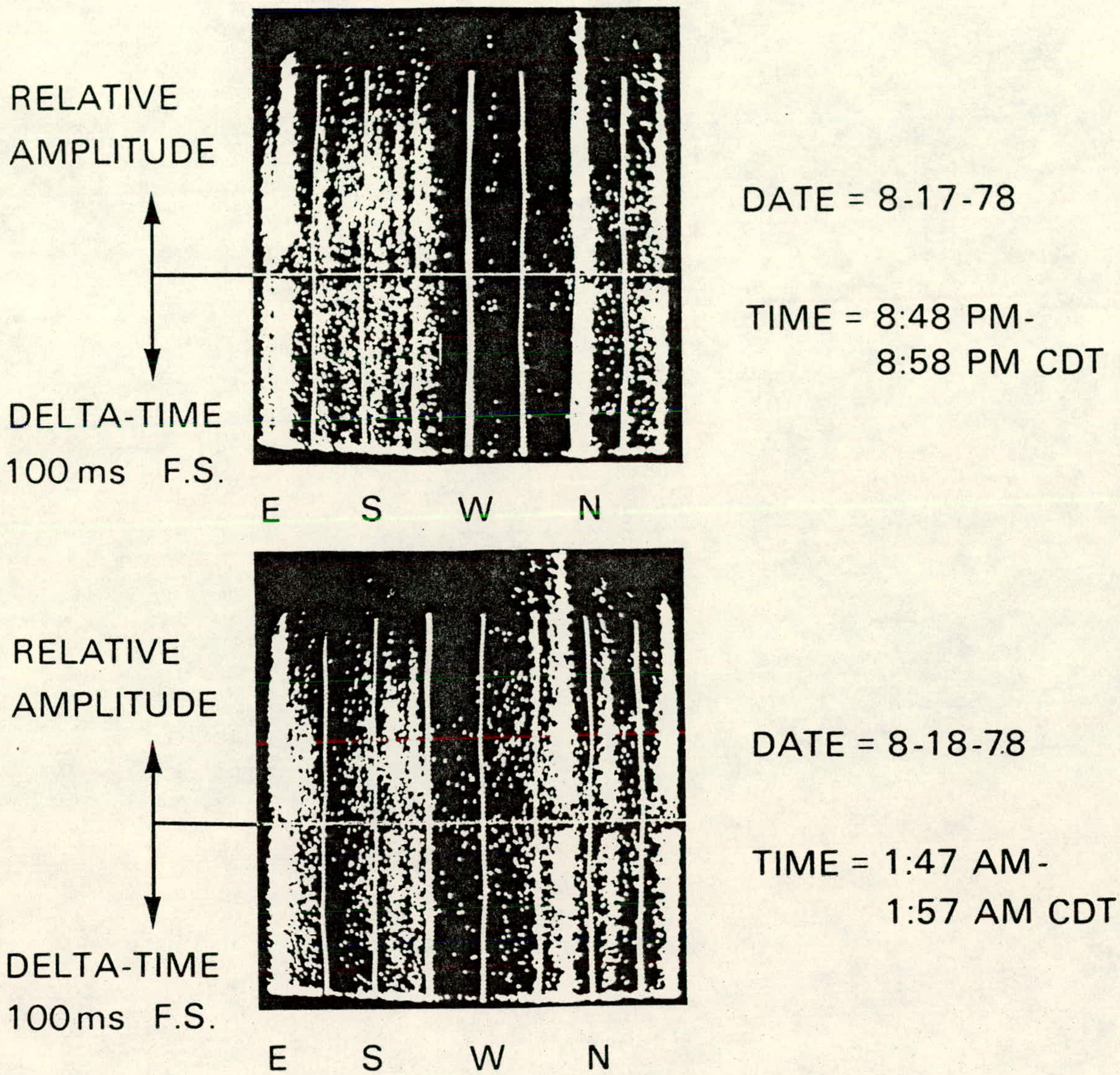

RELATIVE
AMPLITUDE
DELTA-TIME
100 ms F.S.
E S W N
DATE = 8-17-78
TIME = 8:48 PM-
8:58 PM CDT
RELATIVE
AMPLITUDE
DELTA-TIME
100ms F.S.
E S W N
DATE = 8-18-78
TIME = 1:47 AM-
1:57 AM CDT

Figure 4

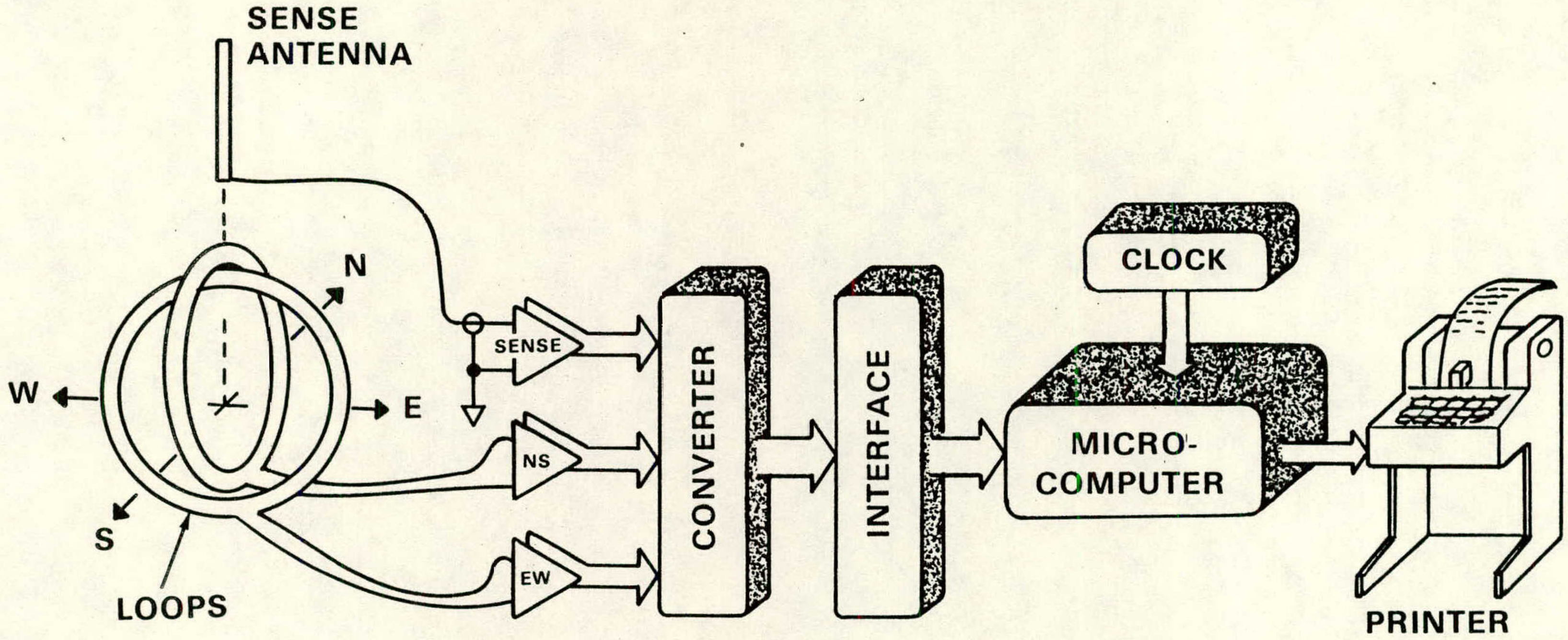

SENSE
ANTENNA
N
W
E
S
LOOPS
SENSE
NS
EW
CONVERTER
INTERFACE
CLOCK
MICRO-
COMPUTER
PRINTER

Figure 5

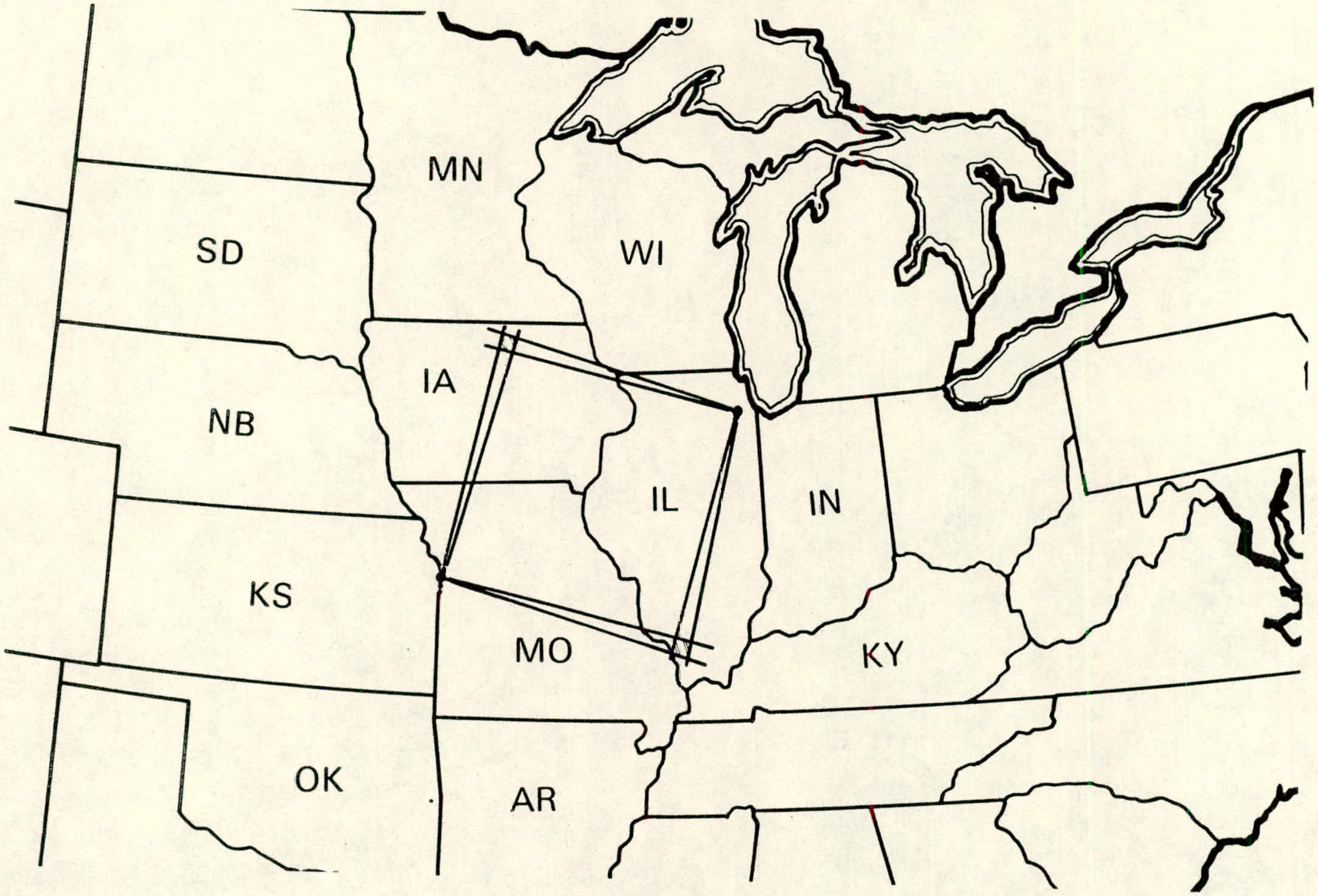


Figure 6

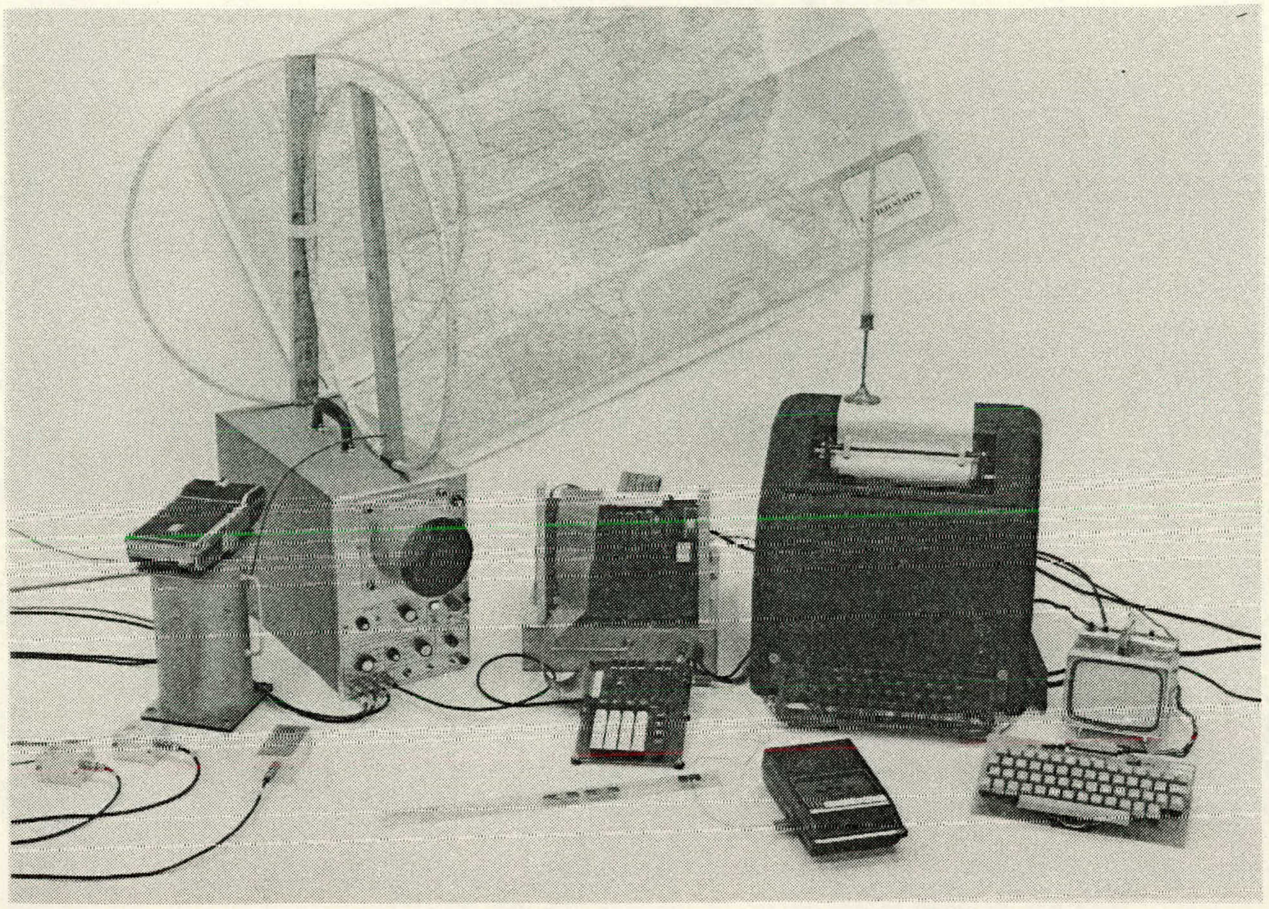


Figure 7

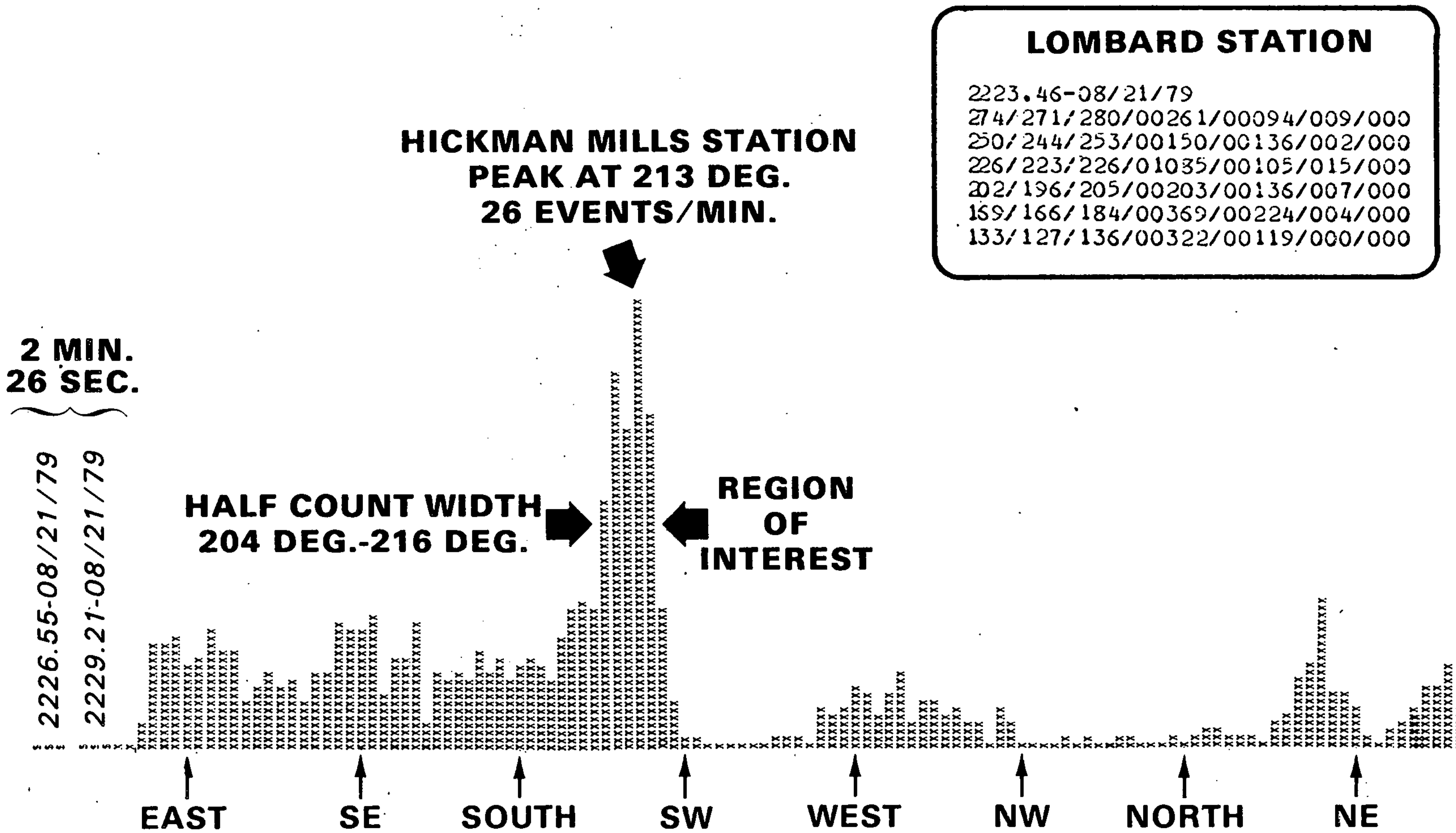

LOMBARD STATION
2223.46-08/21/79
274/271/280/00261/00094/009/000
250/244/253/00150/00136/002/000
226/223/226/01035/00105/015/000
202/196/205/00203/00136/007/000
169/166/184/00369/00224/004/000
133/127/136/00322/00119/000/000
HICKMAN MILLS STATION
PEAK AT 213 DEG.
26 EVENTS/MIN.
2 MIN.
26 SEC.
2226.55-08/21/79
2229.21-08/21/79
HALF COUNT WIDTH
204 DEG.-216 DEG.
REGION
OF
INTEREST
EAST
SE
SOUTH
SW
WEST
NW
NORTH
NE

Figure 8

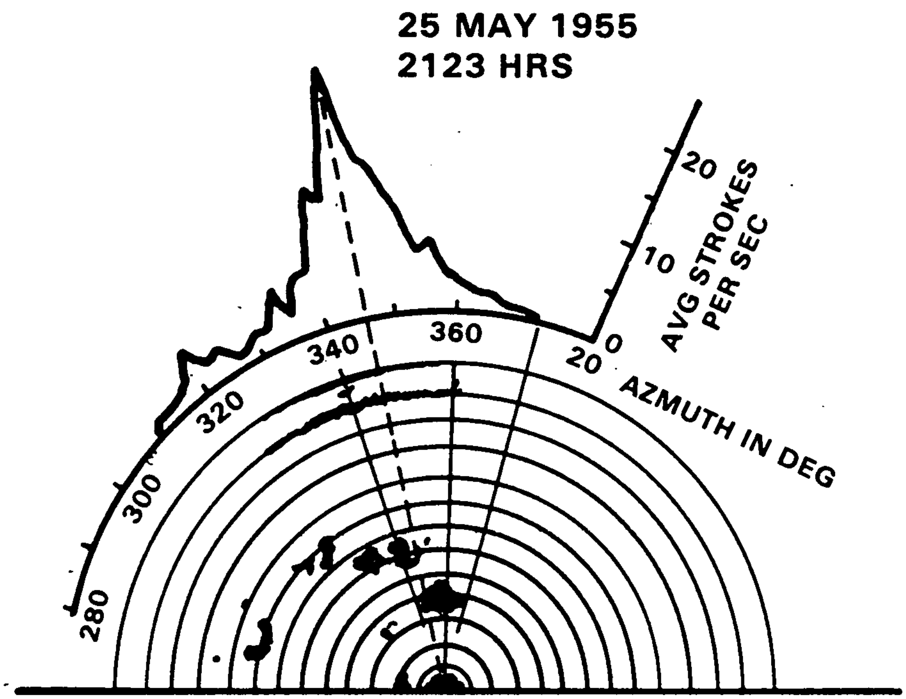

25 MAY 1955
2123 HRS
AVG STROKES PER SEC
0
10
20
280
300
320
340
360
20
AZMUTH IN DEG

Figure 9

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-
226-225-232-1008-225-0057-0000-
235-232-241-0456-235-0030-0000-
250-247-253-0144-253-0009-0000-
256-253-259-0112-259-0009-0000-
265-265-268-0160-268-0009-0000-
0206-

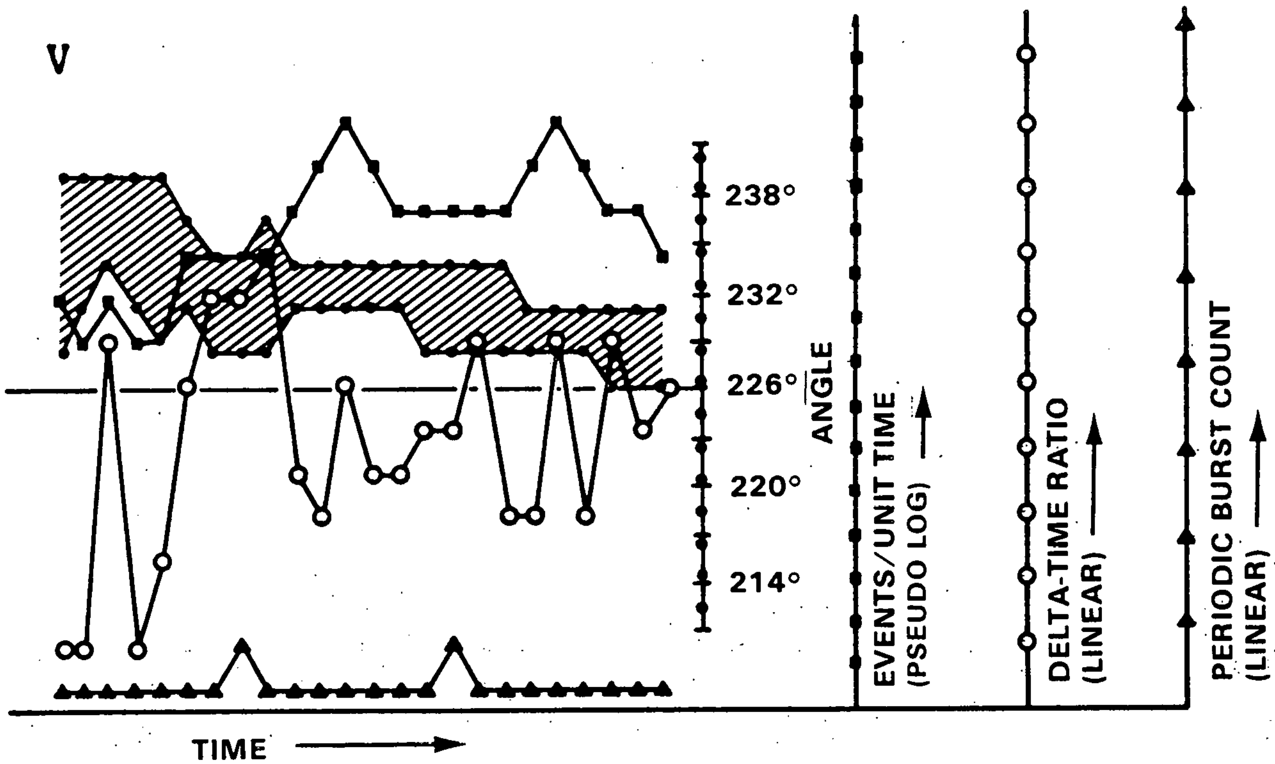


Figure 10

DATA FROM REGION OF INTEREST

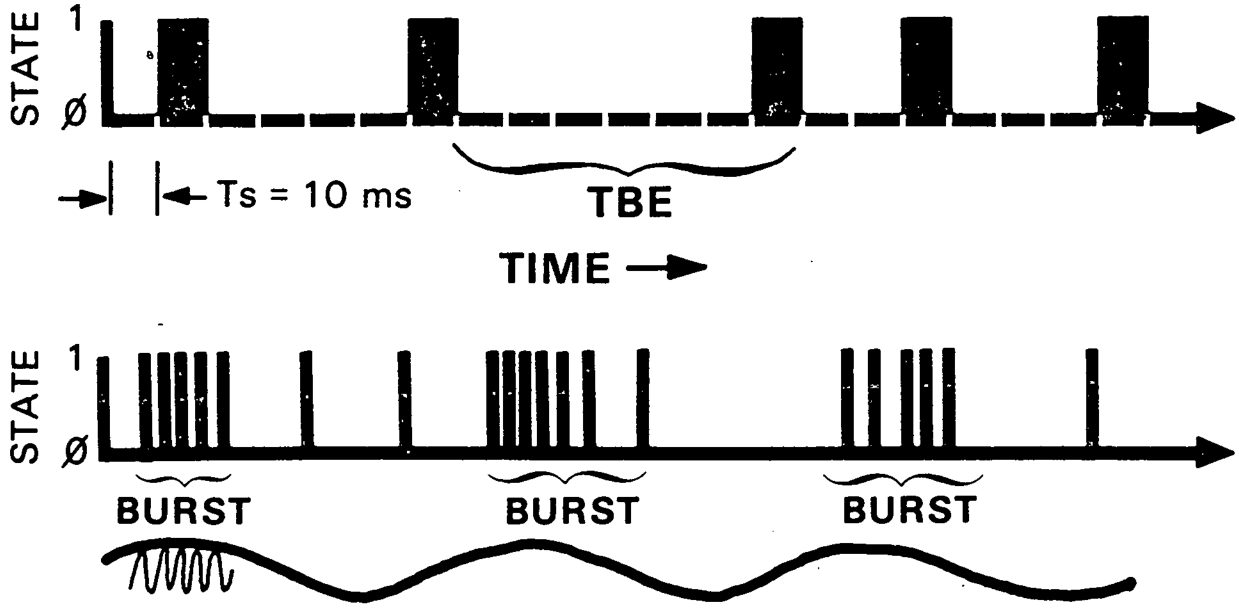
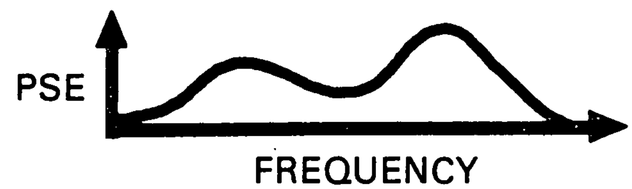


Figure 11

POWER SPECTRAL ESTIMATE



FREQUENCY MODULATED PULSE CARRIER

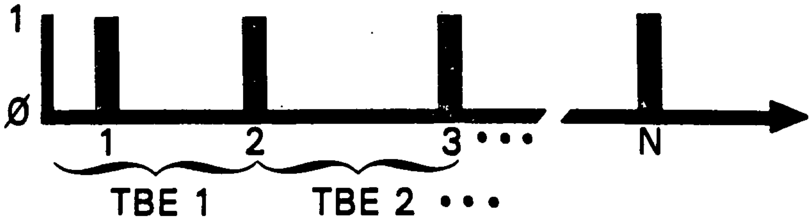
$$F_{MAX.} = 100 \text{ Hz}$$

$$F_{MIN.} = 0.4 \text{ Hz}$$

$$\frac{\Delta F}{\Delta T}_{MAX.} = \frac{100 \text{ Hz}}{10 \text{ ms}} = 10 \text{ Hz/ms}$$

Figure 12

BURST CHARACTERIZATION



	TBE1	TBE2	TBE3	• • •	TBEN
MTS					
⋮					
3TS	10	11	10		8
2TS	5	4	3		1
1TS	0	0	0		0

BURST TABLE

Figure 13

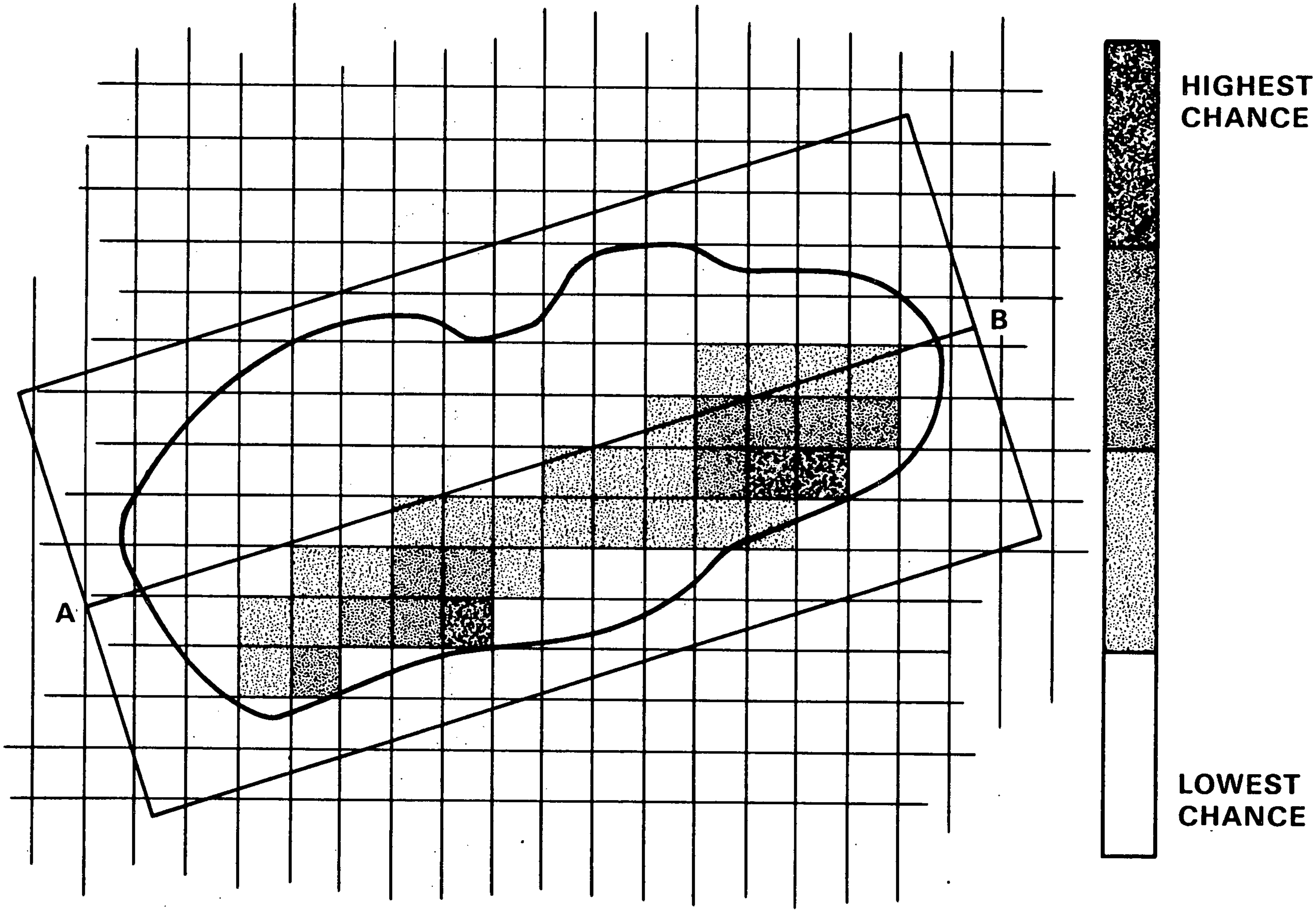


Figure 14