FEATURE ARTICLE

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Electromagnetic Radiation and Severe Weather

Building An Electrostatic and Magnetic Pulse Monitor

Unfortunately, not all severe storms turn out to be just a bad dream. So, if you're running toward the root cellar, you might want to bring Richard's electromagnetic radiation sensor so that you can directly monitor the severity and distance of approaching storms.

Sferics is an abbreviation for "atmospheric electromagnetic radiation" and is the subject of a severe-weather-monitoring project that I've been involved with for nearly 40 years. The monitoring techniques have progressed from an omnidirectional pulse counter to detailed measurement of pulse shape and relative timing with the appropriate data-analysis procedures. The results from each monitoring system dictated the requirements for the next step. This project has been a tedious journey because each step generally required one or more yearly seasons to determine the relevant factors for the next step.

Currently, the monitor consists of a crossed-loop antenna array, analog preamplifiers, microcontroller, and PC. The microcontroller performs real-time analysis of the input pulses to determine the direction-of-arrival and several pulse characteristics. A standard PC is used to display, store, and manipulate this data for pattern analysis and correlation with severe weather.

MONITORING PARAMETERS

Three parameters (pulse shape, pulse polarity, and relative timing) of the electromagnetic radiation are measured with reference to the direction-of-arrival. These measurements are used to observe changes in the spectral distribution rather than the exact magnitude of the parameter. In general, signal amplitude is disregarded.

A crude measurement of electrostatic pulse polarity/shape (width) component is made by noting the polarity of the first signal excursion and the time (width) to the next excursion of the opposite polarity. These factors are accumulated with and referenced to direction-of-arrival.

The relative timing between a series of events has been the primary monitoring parameter for many years. For this data, each series of three events that occur from the same direction in less than 1 s is sorted into one of two categories. Either the time between the first and second event is greater or less than the time between the second and third event. In a long series of events, each event will contribute to more than one comparison. Each series is also counted as a burst.

These accumulations are referenced to the signal direction-of-arrival (120 segments or 3°/segment). Periodically, (usually each 5 min.), the accumulations are analyzed and separated into categories of generated total activity, burst activity, percentage of positive events, percentages of long pulses (width), and a timing factor that is the ratio of the greater-than/less-than relative timing accumulators.

These summations are further reduced to peak activity descriptors (e.g., bands of activity concentration with reference to direction-of-arrival). Each peak descriptor includes direction, activity level (events per time period), timing factor, positive event percentage, and long pulse-width percentages. This data is the basis for the pattern analysis.

ANALYSIS PROCEDURES

All peak descriptor data is saved on disk for correlation studies at a later time. Raw data is retained in computer memory for up to 8 h and can be saved on disk by keypress or mouse button click. Several formats are available for data analysis. The two most useful are graphical plots of activity direction versus time and activity peak (descriptor data timing, polarity, and shape data) versus time.

The activity direction versus time is not useful for pattern detection but does help determine the location of the activity. The peak-width change and directional movement is used to estimate the activity location. This procedure is more subjective than analytical but is useful to limit the search for reported severe weather.

The peak-tracking format traces a selected peak (weather formation) over a period of time. The event activity is used as criteria for the trace function, which finds matching directional peaks from each periodic data record and plots the activity, timing factor, polarity percentage, and pulse-shape percentages as a function of record (time). This format produces the patterns that are the basis for severe-weather detection and prediction. During real time, a peak can be selected by keypress or mouse click and tracked for up to 8 h. Archived data can also be analyzed in a similar manner.

PATTERN OBSERVATIONS

The timing factors have cyclic variations with periods of nearly an hour. Large polarity variations with reference to direction-of-arrival (across a front) have been observed. Reoccurring patterns of the timing factor, polarity, and pulse shape are observed as a function of time. These patterns occur over a wide variation of timespans. The polarity distribution can change slowly throughout the day or rapidly in a few minutes. Generally, the pulse-width distributions are similar to the polarity patterns.

Distance effects (signal strengths and activity rate) are minimized by using graphic plots of distribution factors (e.g., ratios or percentages). Although quantitative data is available, it is seldom used for pattern observation.

The relative timing between events occurring in a short period (less than 1 s) has been studied for several years. This data is generated from the time between successive events that arrive from the same direction.

Each series of three events is used to determine one bit of data. As each event triplet arrives, the time between the first and second is compared to the time between the second and third event. If the time between the first and second is greater than the time between the second and third, one accumulator is advanced. The opposite condition advances a second accumulator.

There is an accumulator pair referenced to each of 120 direction channels. If the relative timing between events were truly random, you would expect the two accumulators to be nearly equal (there is some statistical error). When the timing factor (ratio of the two accumulators) is plotted with respect to time, it does not show a flat line but varies over a wide range.

The timing factor patterns have been compared with severe weather for several years. The earlier timing factor analysis sorted the time-between-events into two categories based on the actual time rather than the current less-than or greater-than comparison. This simpler comparison was incorporated after considering the Chaos Theory, which suggests that one event would influence the next event. The patterns from this comparison are similar to the earlier method of comparison.

The following interpretations are somewhat subjective because the data is from a single monitoring site with limited access to real-time weather information. When two or more weather formations are located in the same general direction or the activity is too distant (greater than 500 mi.), the confidence of the monitored data is reduced. In many cases, some evidence of the expected patterns are present. After many hours of observation, the following conclusions have been assembled.

In the early stages of the severe weather, the timing factor varies over a wide range in a periodic manner. The period of some of these variations can be nearly an hour. Minutes before severe weather (large hail, funnel cloud, tornado, etc.), the variation becomes much smaller. During the severe weather, the large variation returns. The quantity of multiple events also decreases at the time of severe weather.

Numerous severe weather occurrences have been analyzed with respect to the timing data with varying degrees of correlation. The best example is the Lemont, Illinois, tornado of March 27, 1991. In this case, the timing variation decreased about 35 min. before the tornado and remained low until a few minutes before the actual tornado. As you can see in Figure 1, the burst activity increased rapidly and then decreased at the same time that the timing factor variation increased. From the many observations of other severe occurrences, this seems to be a picture-book representation. Other observations generally have one or more of these unique patterns.

The Lemont tornado came from a rapid buildup. Some severe systems build up rapidly and then

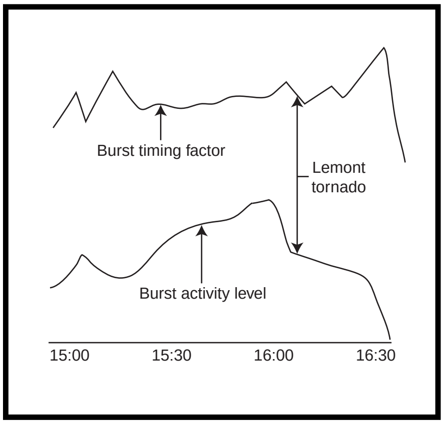


Figure 1—*This was the range and burst-level variation recorded for the Lemont Tornado.*

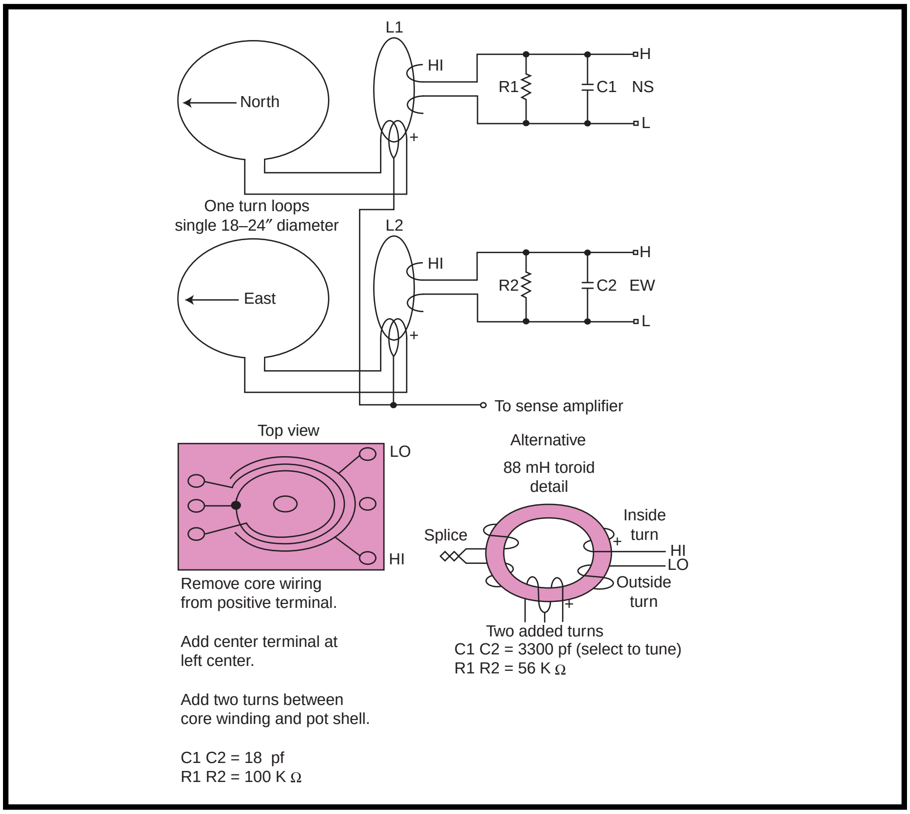


Figure 2—*The loop construction should be sturdy because the direction resolution is related to physical loop arrangement and stability.*

maintain a relatively constant activity level for several hours before the severe weather develops. During this constant activity level, the timing factor can vary across a wide range in a periodic manner. It appears that the severe weather will either occur during the rapid buildup or after several hours of relatively constant activity.

HARDWARE

The hardware consists of a remote antenna-preamp assembly and signal-analysis package (see Figure 2). The antenna assembly should be mounted clear of metal objects for several loop diameters—in most cases, several feet above a building roof will be satisfactory. Generally, the interconnect cable between the antenna assembly and analysis package can be up to 100¢ long. The system requires a power source of 12 VDC at about 25 mA. The RS-232 data format is used to transfer sferics data to the PC serial port.

Two concentric loops are used to sense the magnetic signal component. The remote preamps should be mounted directly below these loops. As an example, the loops can be constructed with PVC pipe and copper tubing by threading the tubing through two sets of perpendicular holes in the pipe about 18^{2} apart. At the top of the pipe, each loop of tubing can be bent slightly to eliminate any contact between the loops. A PVC pipe splice (secured with several screws rather than glue) can be used below the loops to provide access to the loop connections and remote preamps shown in Figure 3.

The magnetic signal component is inductively coupled through the two turn loops of the input transformers, which are tuned to 10 kHz. By connecting the two loops together at one point (center tap of coupling loops), the electrostatic signal component may also be sensed.

Additionally, the sense channel includes a low-pass amplifier stage that rolls off at 250 kHz to reduce local broadcast interference. Large signal protection (local lightning, etc.) is provided by a series of resistance and clamping diodes for all amplifier inputs.

Briefly, the U2c and U2d op-amps are connected as integrators with the dual four-position CMOS switch (U3) during a specific half-cycle of the-10 kHz component of the sense signal as detected by U7a/U7b comparators (see Figure 4). After this integration, the two integrators and U5a inverter are

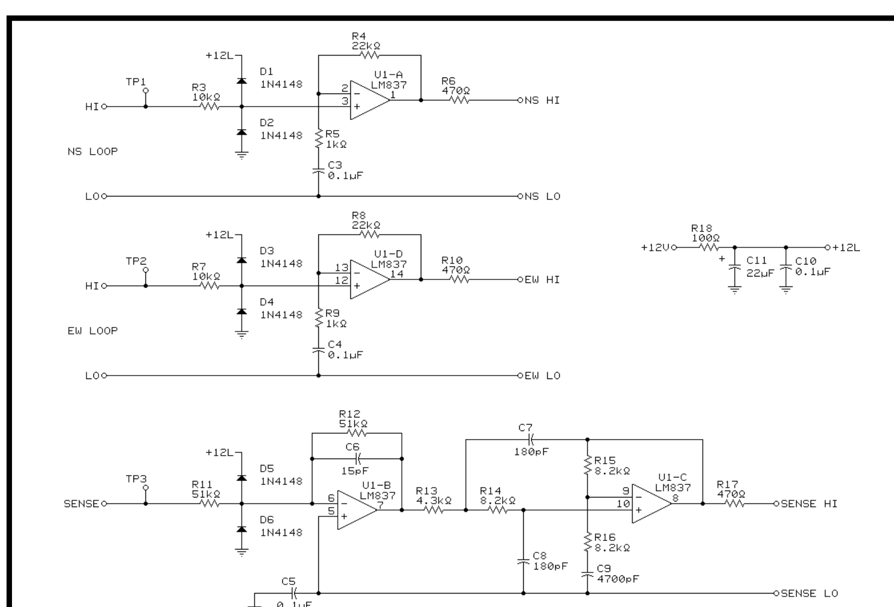


Figure 3—*The preamps are standard op-amp circuits that provide antenna-component isolation and cable-drive capability.*

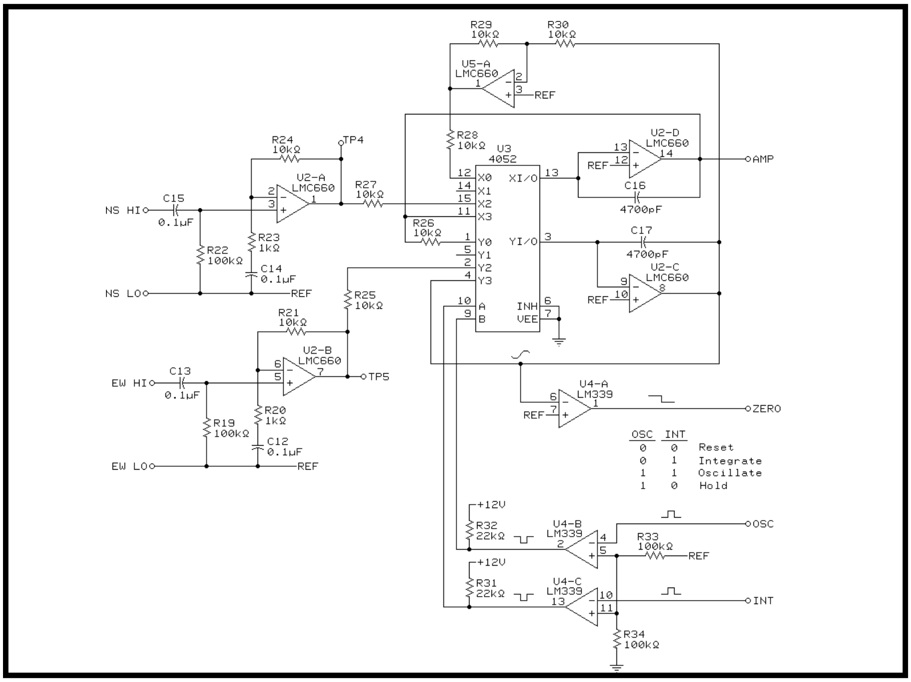


Figure 4—*Signals from the loops' preamps are applied to the comparator and converter circuitry (which interface to the microntroller). Direction-of-arrival, pulse polarity, and pulse width data are developed from analysis of these antenna signals.*

connected in a quadrature oscillator arrangement via U3 by the microcontroller. The time it takes the oscillator to reach a predetermined condition (U4a switch) is proportional to the signal direction-of-arrival. The virtual signal ground (REF) is biased at +5 V to allow for bipolar signal swings of all op-amp circuitry.

The output of a second low-pass filter is applied to a series resonate circuit (L3-C24) to select both the 0-kHz component and provide a 90° phase shift to align the electrostatic and magnetic signal components (see Figure 5). The two comparator circuits U7a and U7b generate both polarity trigger pulses for the microcontroller analysis. The comparator threshold level is adjustable by the microcontroller through the current source (U8) and resistor network (R42–45).

The microcontroller (U9) circuitry shown in Figure 6 generates a three-character serial data string for each input event. These characters (binary value) indicate the direction-of-arrival, time from the last event, and the pulse width. Also, several functions are available to control the direction calibration, timing factors, and signal threshold level (sensitivity). Several LEDs are used to indicate relative signal levels.

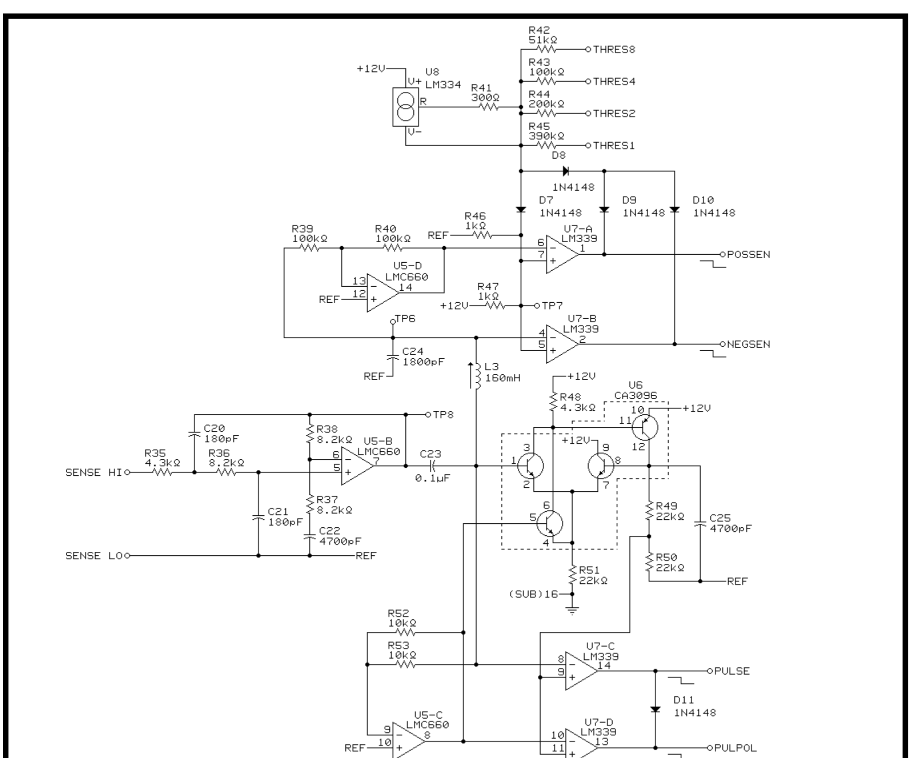


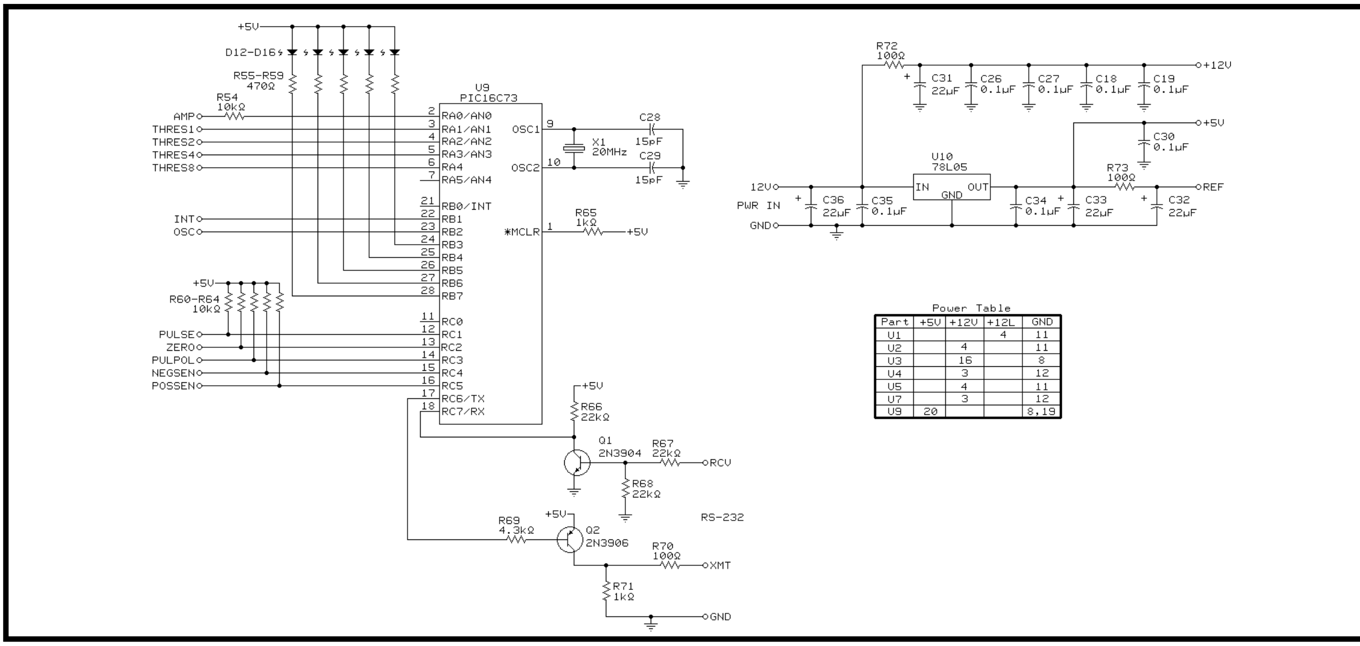
Figure 5—*The peak amplitude circuitry (U6) and comparators (U7c and U7d) generate signals for microcontroller analysis of pulse polarity and width factors.*

MONITOR PROGRAMS

A PC program sorts serial data from the loop antenna hardware/ microcontroller into categories with reference to direction-of-arrival. The raw data is accumulated in several categories: total and burst activity, time-between-events, pulse width, and polarity. This data is maintained in memory for 8 h. Periodically (every 5 min.), the data is reduced to several activity peaks with several descriptor parameters.

A number of options to view and save selected data are available via keypresses or mouse clicks. In Photo 1, the upper left is a plot of the last 8 h of data in 10-min. increments. The plot is updated every 5 min. with burst (white) and total activity (red). The horizontal axis is direction (3° resolution).

The upper-right display is a track of an activity peak for up to the last 8 h, which is selected by the operator (cursor not shown in the demo) for a specific direction from the histogram or a direction/time from the activity/time plot. This data is a summation of data within the peak (concentrated activity over one or more direction channels), which is also the source of descriptors for disk file archiving. From top to



Part	+5V	+12V	+12L	GND
U1			4	11
U2		4		11
U3		16		8
U4		3		12
U5		4		11
U7		3		12
U9	20			8,19

Figure 6—*The LEDs are pulsed for several milliseconds with each input event. There's even one LED (FAULT) to indicate a watchdog timeout or possible program failure, high signal rates, and so on.*

bottom, the following peak descriptors are plotted:

- timing factor change for the last three readouts (15 min.)—0 change at the top
- percentage of the narrow pulse widths
- the time-between-events timing factor
- logarithmic plot of burst and total activity
- range of percentage positive events for total activity across the peak
- range of percentage positive events for burst activity across the peak

Below the track display, numerical data (peak direction limits, timing factor, and burst polarity factors) for a selected time span are shown. Peak descriptor data is periodically saved to disk for later review. The running display can be saved to disk at any time by operator command. Specific histogram or track plots can also be saved to disk in a spreadsheet-compatible file (space delimited). All programs are written in the Forth language, specifically Pygmy Forth.

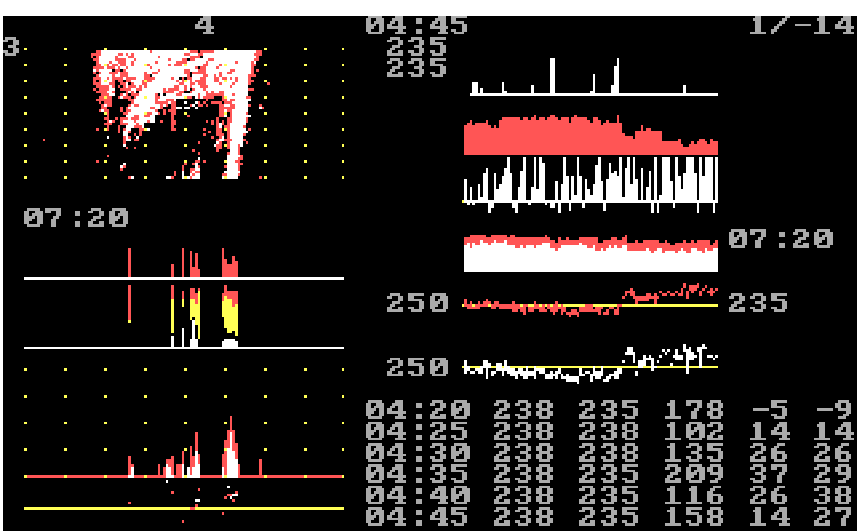


Photo 1—*Here's what the normal running display looks like*

FORECAST

The timing of the electromagnetic energy pulses from weather systems may provide a key to the prediction of their severity. This sferics project generates data that indicates a relationship between severe weather and the relative timing between bursts of electromagnetic energy emanating from the weather system. With the limited data collection (single monitoring location), it is difficult to determine the potential of this technique.

Polarity and pulse shape factors have not been fully evaluated, and the repeating nature of the patterns suggest that there must be conditions that cause the effect on electromagnetic energy pulses. Observations appear to support a relationship between the energy pulses and weather severity.

Obviously, additional effort will be necessary to prove or disprove the usefulness of this technique for severe-weather prediction. This technique is presented at this time to describe the current state of the project. To fully evaluate this system, more monitoring stations will be needed to provide better coverage and triangulation information.

These monitoring sites should be located on a grid 300–500 miles apart. The site equipment would operate unattended and communicate with a central analysis facility. The site equipment would consist of the 2'-diameter loop antenna system, amplifiers, and computer. In most cases, this could be accommodated in the top floor of an existing building.

The sites should not require attention that could not be handled through the communication link. Local readout or analysis equipment could be included but would not be necessary for the network to function. The communication link requirements are minimal. In general, less than 1000 bytes of data would be transmitted each 5 min. During extremely severe weather, the data rate from selected sites would increase by several times. A standard telephone line can fulfill this requirement.

With additional monitoring locations, the personnel at the analysis facility will be able to selectively analyze the data from the site with the best "view" (i.e., only one weather system within the usable range). Pattern analysis from one or more sites can be used to determine the severity of the weather system. When necessary, data would be available from other sites to locate an occurrence by triangulation. Because more better-quality data would be available at this analysis facility, you would expect to find additional patterns or signatures which relate to severe weather.

Richard Fergus is a retired electronic engineer with a background in instrumentation for safety systems. This severe weather project and amateur radio are his primary interests. You may reach him at rfergus@theramp.net.

RESOURCE

Project information and documentation, www.theramp.net/sferics