THE AMATEUR SCIENTIST

How to locate a thunderstorm and track it by detecting the radio waves it generates

Conducted by C. L. Stong

Lightning associated with thunderstorms radiates concentric patterns of electromagnetic waves known as sferics. With surprisingly inexpensive equipment an amateur can detect these waves and so track thunderstorms within a radius of several hundred miles. Indeed, with little more than a modified radio set a practiced observer can make reliable short-term forecasts of local thunderstorm activity simply by observing variations in the intensity of sferics and related fluctuations in the earth's electric field; increases in intensity are interpreted as meaning that a storm is approaching [see "The Amateur Scientist," March, 1959]. For several years Thomas P. Leary, an attorney in Omaha, Neb., has maintained a sferics station of this sort. Some months ago it occurred to Leary that his hobby might acquire additional interest if he could devise a radio compass with which to observe the bearing of storms as they meander through the Middle West.

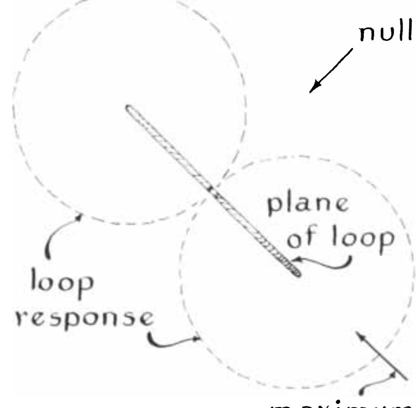
"There was nothing new in this idea," he writes. "Thunderstorm azimuth detectors were first put to use during the 1930's. No circuits have been published since World War II, however, and there appears to be little enthusiasm for such equipment except in Government weather projects. After investigating the general principles of radio compasses, I picked up a surplus cathode ray tube along with its accessories and finally succeeded in devising a simplified instrument that indicates the azimuth bearings of thunderstorms within three degrees of those given by our local weather radar station.

"The system consists essentially of two loop antennas crossed at right angles and oriented to the four points of the compass, together with amplifiers to actuate a cathode ray tube that displays the desired information. (As yet the system does not include any reliable provision for measuring the distance of storms. I have solved the problem to my own satisfaction for electrical disturbances within 300 miles of Omaha, but this feature of the instrument requires further development.) Watching this display and manipulating the controls during the passage of electrically active weather fronts has an almost hypnotic attraction. The active cells of storms can be seen to grow, move and decline; frequently it is possible to distinguish between cloud-to-cloud and cloud-to-ground strokes. The screen displays peculiar 'night effects' and other patterns, some of which are unexplained.

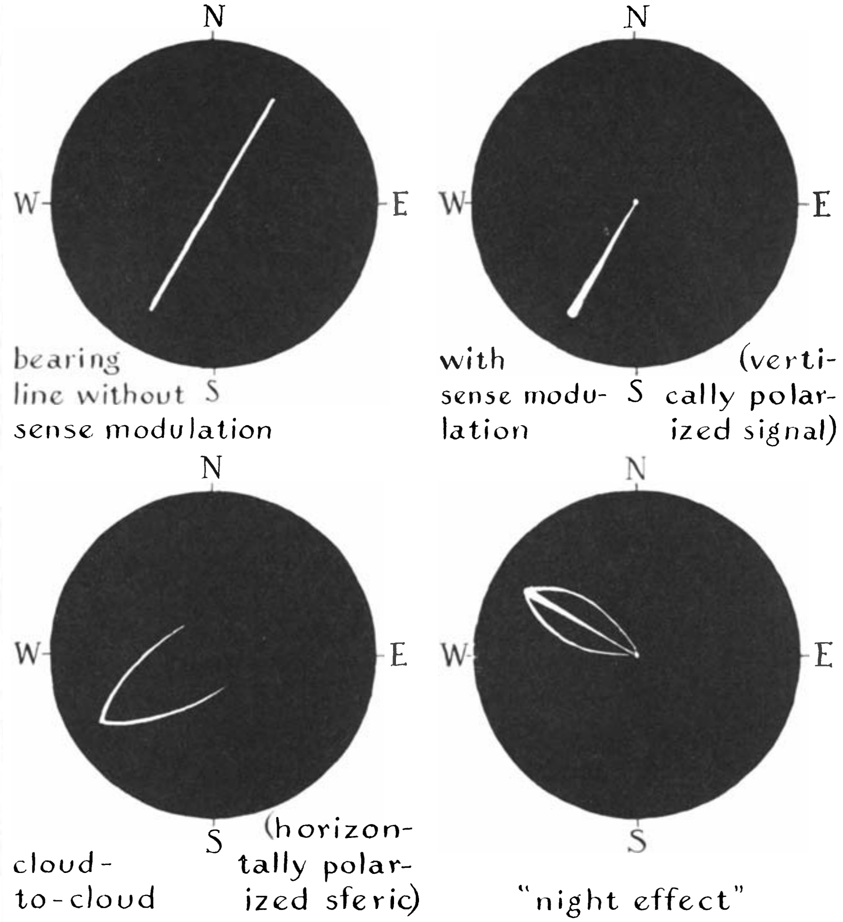
"The sensitivity of the system to the direction of electromagnetic waves derives from a property of the loop antenna. When a loop of wire that is half as wide as the waves are long from crest to crest is oriented in the direction in which the waves travel, a passing wave will induce a current in one direction in the leading side of the loop and in the opposite direction in the trailing side. The currents add and maximum voltage appears across the ends of the loop. (If the diameter of the loop differs from half of the wavelength, the output voltage is less than maximum but the same principle applies.) When the loop is oriented at right angles to the approaching wave, opposing currents are induced in the two sides. Destructive interference then occurs and no voltage appears across the terminals. (It is assumed that the loop is enclosed by an electrostatic shield so that fluctuations in neighboring electric fields, including the earth's field, do not induce spurious voltages.) The sensitivity of the loop to signals from various directions, when plotted on graph paper, takes the form of a figure eight, with maximum signal response in the direction of the plane of the loop and null, or minimum, response at right angles to this plane [*see illustration at right*].

"Two such loops are crossed at right angles and their amplified outputs are fed to the deflection plates of a cathode ray tube. If a storm occurs in the plane of one of the loops, the bearing of the incoming signal takes the form of a straight horizontal or vertical line across the face of the tube because the loop at right angles to the signal picks up no energy. When the direction of the signal is intermediate to the planes of the loops, however, each loop picks up energy in proportion to the angle between its plane and the impinging signal. The directivity patterns of the loop antennas are similar, with the result that as the signal source moves, voltage rises in one loop and falls in the other. The voltage changes deflect the beam, and the straight line displayed on the face of the tube rotates synchronously with the changing direction of the incoming signal. This assumes that the relative phase of the signal voltage induced in each loop is not shifted by the amplifiers and that the amplifiers have equal gain.

"In the elementary system just described the display, or bearing, line would have a 180-degree ambiguity. That is, it would indicate that a storm lies somewhere on a line extending through the antenna but it would not indicate on which side—whether east or west, for example. This information can be provided by a third signal picked up by a nondirectional antenna, such as a straight vertical wire. A separate circuit is arranged to amplify this 'sense' signal, shift its phase 90 degrees and apply the



Directional sensitivity of loop antenna



Cathode ray tube displays of various sferics

resulting voltage to the grid of the cathode ray tube. If a constant voltage that almost suppresses the beam is also applied to the control grid of the tube, the effect of the 'sense' signal is to black out half of the line displayed on the tube. The intensity of the remaining half varies from a faint trace at the center of the display to maximum brilliance at the outer end, as shown in the accompanying diagram [*above*].

"After experimenting with several circuits that employed narrow-band amplifiers operating in the range of 85 to 455 kilocycles, for which inexpensive intermediate-frequency transformers were available, I finally switched to broader-band components that operate in the audio- and low-radio-frequency spectrum. The construction was more difficult at the higher frequencies and the adjustments for maintaining proper phase-shift were critical. The simpler broad-band balanced amplifiers that were used in the final design dispensed with tuned circuits altogether and eliminated the necessity of matching the phase relation of signals in the two loop antennas. Sferics are essentially broad-band signals. A lightning stroke, particularly a cloud-to-ground stroke, dissipates an enormous amount of energy in a small fraction of a second. The potential difference between the earth and a cloud that discharges a 1,000-foot stroke can be on the order of a billion volts; the current varies between 10,000 and 500,000 amperes and the power amounts to as much as 100 kilowatt hours. The energy is radiated over a band of frequencies that extends from audio-frequencies through the spectrum of light.

"Part of the energy, in the form of low-frequency signals, impinges on the loop antennas directly and part after reflection from regions of the ionosphere. Reflection alters the polarization of the signals—the plane in which the waves vibrate. Loop antennas, although simple and dependable, are sensitive to polarization effects. Direct signals from cloud-to-ground strokes vibrate in the vertical plane; they are vertically polarized. My instrument displays them as a straight line on the face of the cathode ray tube. Reflection in the upper atmosphere can rotate the plane of polarization through a large angle that causes the line to broaden into an oval or wishbone-shaped display. This occurs in the case of cloud-to-cloud strokes. Two waves from the same stroke but of differing polarization (a sky wave and a ground wave) may reach the loops almost simultaneously. The superimposed signals are then displayed as an open oval bisected by a straight line. Because of ionospheric conditions this often takes place at night.

"I wound my loops on 'hula hoops,' those plastic rings that were such a fad among children a few years ago, primarily because I happened to find a pair priced at 19 cents each. One could substitute plastic hose or piping or some other material. A half-inch section was cut in the perimeter of the hoops, forming a channel to receive 50 turns of 20-gauge, plastic-insulated magnet wire. A coil of this size intercepts ample energy for detecting storms up to 600 miles away. The ends of the coil are connected to jacks of the type used in electric phonographs, mounted on small metal plates attached to the hoops [*see illustration below*]. Two identical loops are required. Each is wrapped with strips of aluminum foil about 1½ inches wide, which acts as an electrostatic shield. The foil is connected electrically to the metal plate that mounts the jacks and is covered with a wrapping of masking tape. A section of foil about half an inch wide is cut from the shielding at a point opposite the jacks to prevent the shielding from acting as a short-circuited turn. The loops are mounted at right angles, accurately aligned north-south and east-west, at least 20 feet above the ground and, as nearly as possible, directly over the receiving system. The loops should be placed as far as possible from vertical metal structures such as pipes.

"The loops and amplifiers are connected by four equal lengths of small-diameter coaxial cable such as type

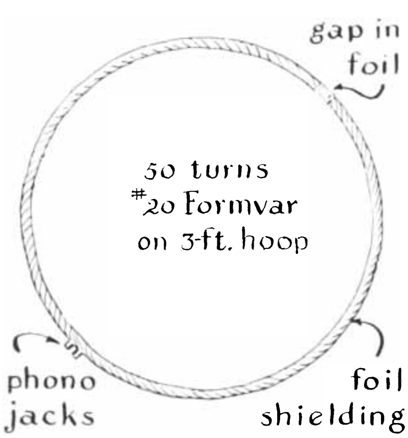


Diagram of loop antenna

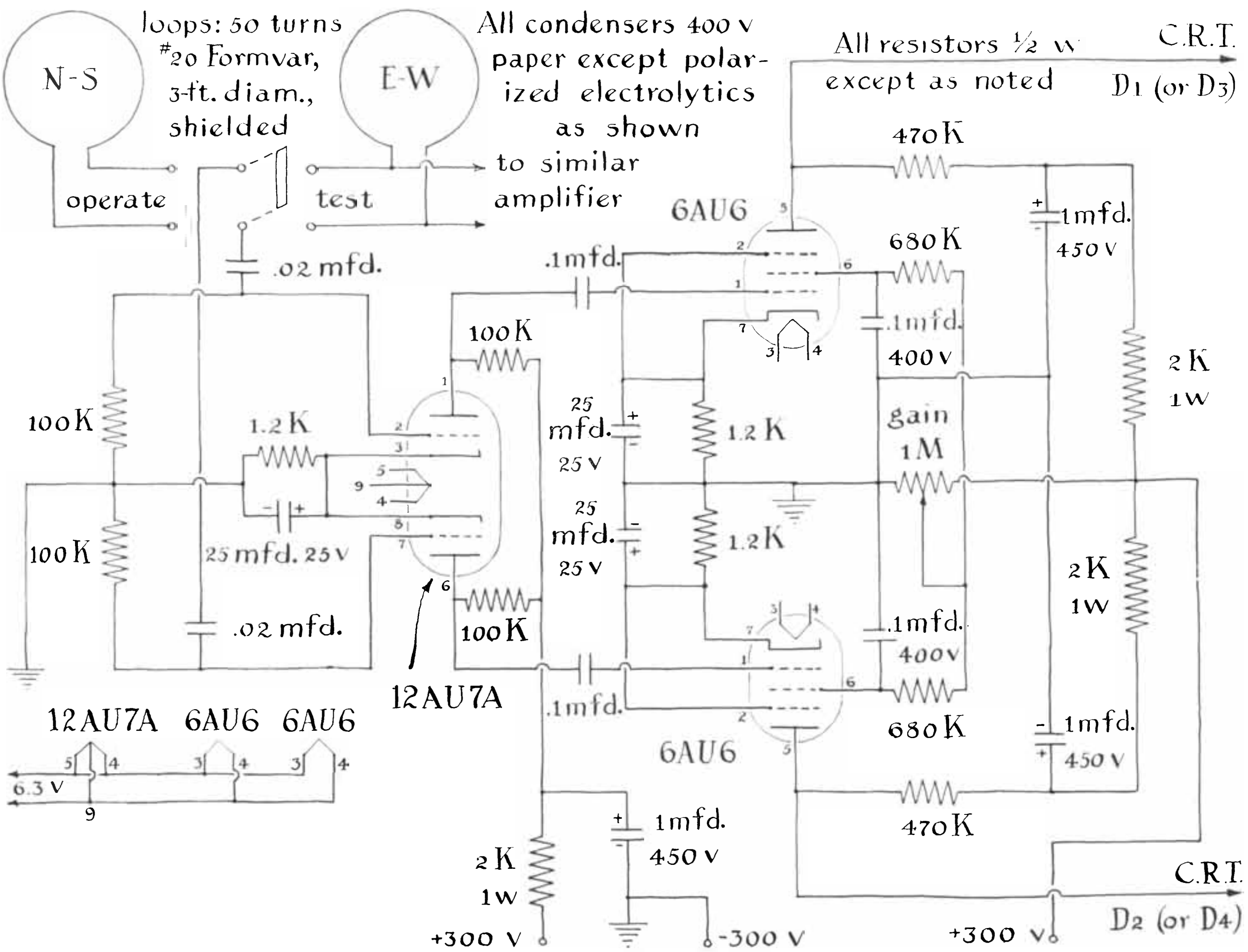
RG-78 U. The cables end in plugs that mate with phonograph jacks. The circuit includes a double-pole, double-throw toggle switch so that each amplifier can be connected to a different loop or both amplifiers to the same loop, depending on the position of the switch. The switch is to be used when the amplifiers are adjusted for equal gain.

"The amplifiers are of the push-pull, high-gain type designed for operation in the range of 100 to 12,000 cycles. As in all high-gain amplifiers, the ground connections for each tube should be made at a common point and the input and output circuits should be spaced as far apart as possible. Chance feedback and consequent oscillation will also be minimized by keeping the tubes widely separated. Decoupling filters made of appropriate resistors and capacitors are used in the plate circuits of both amplifier stages to prevent spurious currents from entering the units from the power supply, as shown in the accompanying diagram [*below*]. The amplifiers operate from any well-filtered power supply that delivers 250 to 300 volts at about 75 milliamperes of direct current and 6.3 volts at five amperes. A separate filament transformer is required for the cathode ray tube.

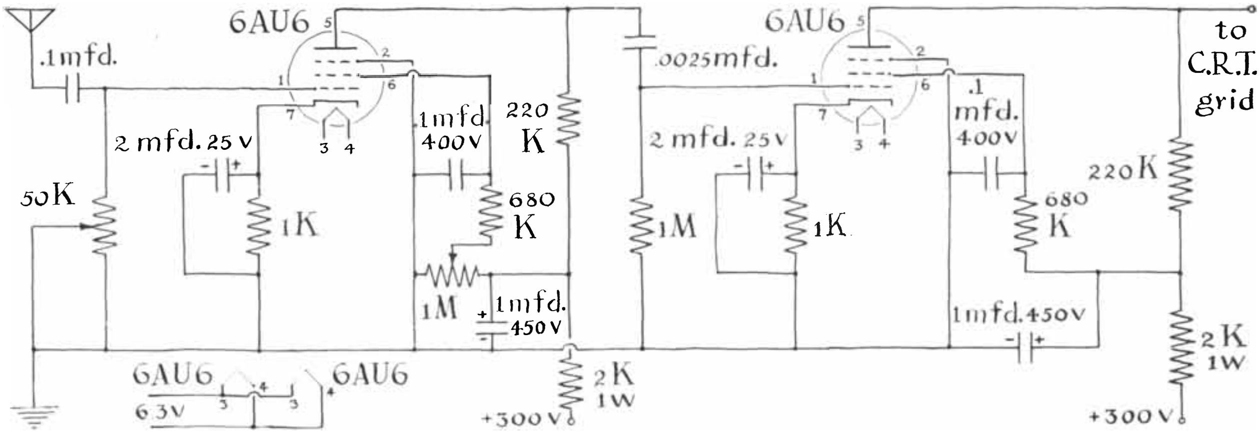
"The 'sense' antenna can be a vertical wire 30 feet or more in length suspended between insulators within a reasonable distance of the loops. If the distance between this antenna and its amplifier is more than 20 feet, the connection between the two should be made with coaxial cable. The signal enters the sense amplifier through a phase-shifting network composed of a series capacitor bridged by a 50,000-ohm potentiometer, which also serves as a control for reducing the intensity of the sense signal when sferics of exceptional strength are received [*see top illustration on page 172*]. The gain of the first stage of the sense amplifier is controlled by adjusting the potential applied to the screen grid. (This method of control does not influence the phase of the signal when the gain is altered, as would be the case if the gain were controlled in the cathode circuit.) The sense antenna should be equipped with a lightning arrester.

"The cathode ray tube is energized by a power supply capable of developing between 2,500 and 3,000 volts and two milliamperes of direct current. I am at present using a 3JP1 cathode ray tube. This component produces a brilliant display and is generally available from surplus dealers. Recently it was priced at $7.50 by Barry Electronics Corp. (512 Broadway, New York 12, N.Y.). This firm also offers for $10.90 a piece of apparatus that includes a 3JP7 cathode ray tube along with a magnetic shield, a milliammeter and other components useful in the construction. The 3JP7 tube is coated with a phosphor that produces a long-persistence image that must be viewed in the dark. (The long persistence may well produce confusing patterns when a really wild front comes through.) When working with any of these tubes, remember that the high voltage is lethal. Disconnect the line cord and short-circuit the capacitors with the blade of a screw driver before touching any part of the circuit.

"The arrangement of the parts on the chassis supporting the cathode ray tube



Circuit diagram of a directional amplifier



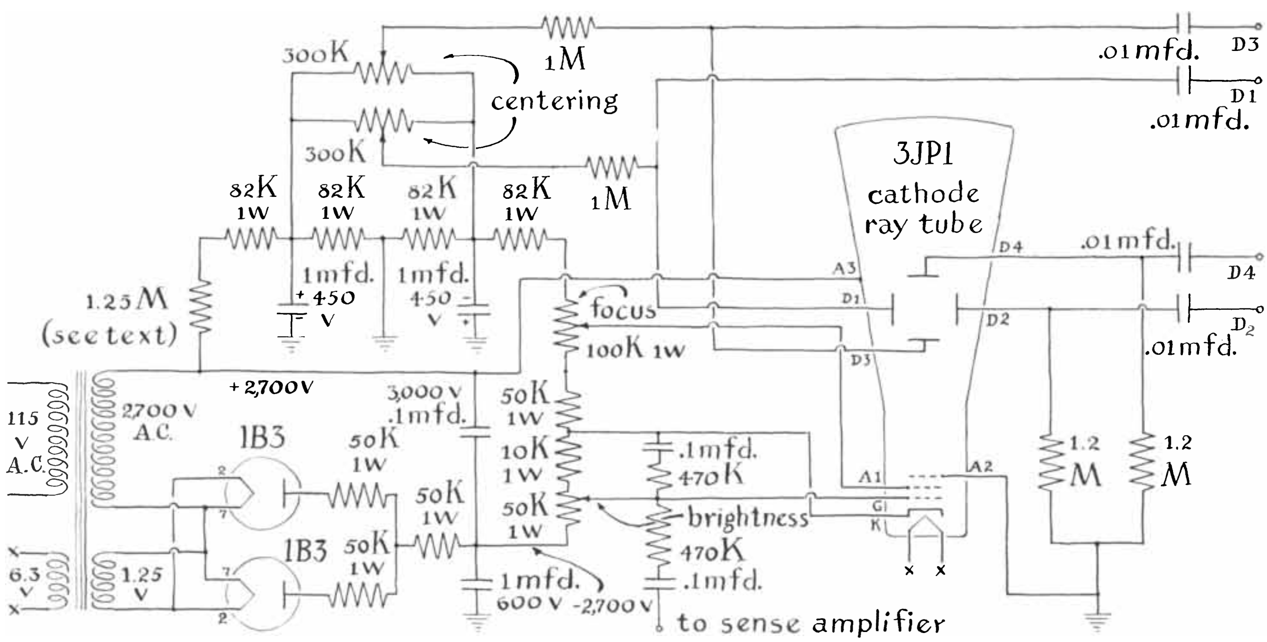
Schematic diagram of "sense" amplifier circuit

is not particularly critical. The controls used for centering the beam—two 300,000-ohm potentiometers—need not appear on the panel. They are adjusted only when a tube is installed or replaced. The focus and brightness controls operate at high potential and should be mounted under the chassis on insulating material and linked to knobs on the panel through an insulating coupling. The 1.25-megohm section of the voltage divider should be made up of four or five two-watt carbon resistors in series to prevent voltage breakdown [*see illustration below*]. The high-voltage transformer should be mounted as far away from the tube as possible to minimize the tendency of its alternating-current field to modulate the beam. The power supply and high-potential connection to the cathode ray tube should be wired with conductors specially insulated for high voltages. It is a good idea to inscribe the points of the compass or degree markings on the face of the cathode ray tube with a grease pencil or to attach a plastic compass rose to the face of the tube.

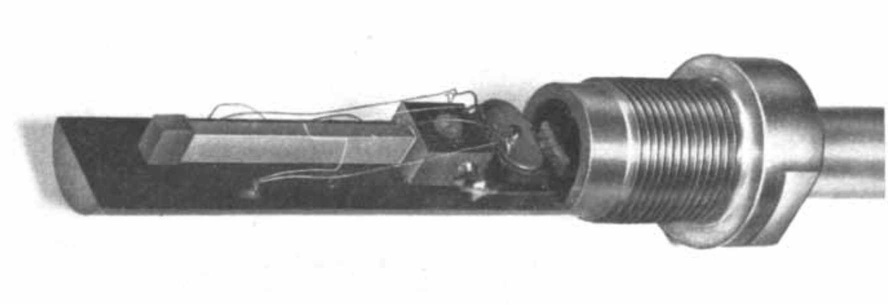
"To place the completed system in operation, first identify the two pairs of coaxial cables that are connected to the loop antennas by making continuity tests with an ohmmeter, and connect one pair to each of the signal amplifiers. (Do not make the mistake of connecting one end of each loop to each of the amplifiers.) Then connect the sense antenna to its amplifier. The shielding braid of all four loop cables must be electrically connected at each end and grounded to the amplifiers as well as to a water pipe.

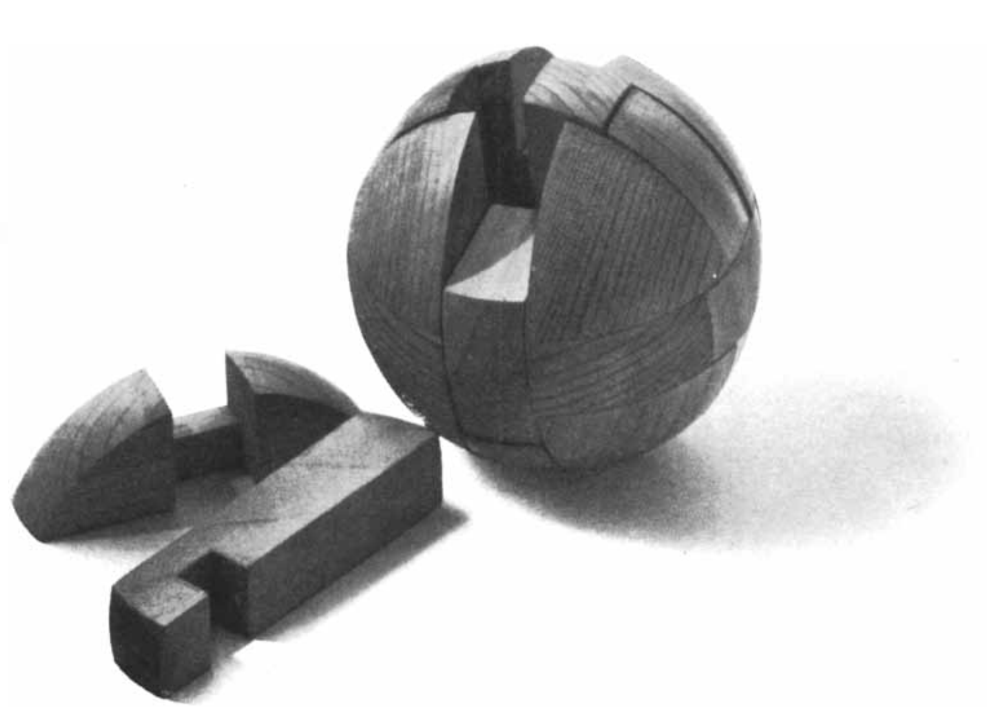
"Now turn on the power. Turn the gain controls of both signal amplifiers to maximum and operate the double-pole, double-throw toggle switch in the antenna circuit to connect both amplifiers across one loop. If there is a thunderstorm within range, its sferic signal should now produce a sharp line extending across the face of the cathode ray tube 45 degrees from the vertical. If the line is not at a 45-degree angle, the gains of the two amplifiers are unbalanced. Reduce the gain of either amplifier (but not both) until the display is properly aligned. Then restore the toggle switch to its former, or operating, position.

"You must now determine the true bearing of the approaching storm by some means external to the system in order to orient your cathode ray tube with actual north and south. A call to the local weather bureau will usually provide the information, particularly if



Schematic diagram of cathode ray tube circuit





you explain what you are up to, because most of the nation is now covered by weather radar stations that keep track of all disturbances within 200 miles or so. Failing this expedient, you can tune in on an aircraft radio-range station with a radio receiver that can pick up the band between 150 and 350 kilocycles. These stations transmit continuous weather reports, including the location of such thunderstorms as may be in progress. As a last resort, simply wait until a storm appears in your vicinity and take a look. Once the true bearing of a storm has been determined, check the display on the cathode ray tube and, if necessary, interchange the lead-in cables from the loop antennas until the display is aligned with the bearing of the storm. Only four input combinations are possible, so that the task is not difficult. The procedure should be repeated with another storm, about 90 degrees removed from the first, as a double check.

"The knack of interpreting displays comes with experience. The length of the line on the scope indicates the strength of the incoming signals, and it is possible with experience to judge the range of a storm with reasonable accuracy on the basis of this signal strength. A storm at long range produces a short, straight line when the gain is set at maximum; storms at medium range produce longer lines. The line broadens into an ellipse when horizontally polarized sferics are received from strong cloud-to-cloud discharges. Thunderstorms in the immediate vicinity set up confused patterns.

"As an aid in learning to judge range one can use the hourly low-frequency reports, broadcast by radio-range stations, of the movement of frontal systems. Many thunderstorms occur along the line of a cold front. A strong sferics display in the direction of such a front at a known distance provides an opportunity to co-ordinate the appearance of the display with a reasonable approximation of distance. Storms occurring simultaneously at widely separated bearings produce simultaneous displays. Isolated storms not associated with major fronts produce single displays. If a display of this type remains fixed in azimuth but increases in intensity, it can be assumed that the storm is headed in your direction. In summer most cold fronts move through the Middle West at 20 to 25 miles per hour, so that it is possible to estimate the arrival time of the bad weather.

"As signals grow in strength, the gain of both signal amplifiers must be reduced to keep the end of the display from going off the face of the tube. Whenever the gain is thus altered, the gain of amplifiers must be equalized by the procedure previously described. The intensity, or brightness, control is ordinarily set so that the bright spot made by the beam is barely visible. The spot should be centered accurately by means of the centering controls. The optimum positions of the sense-input potentiometer and the sense-gain control depend on the location of the storm and the intensity of the signals. The operation of the controls must be learned by experience. The circuit operates with maximum gain and minimum attenuation when both controls are set for maximum resistance with respect to the ground.

"A few verified tornadoes have been observed. Any storm that produces rapidly repeated pips on the same bearing is suspect, particularly if the display persists for an appreciable time. Some observers report that tornadoes produce no cloud-to-ground strokes and that the cloud-to-cloud discharges in a tornado funnel are radiated principally above 100 kilocycles. At close range, however, it is possible to detect the 'tornado oscillator' at low frequencies. An 85-kilocycle receiver in use at my station has produced an elliptical display with rapidly recurring sferic pips on the azimuth of a small tornado 24 miles away. Thunderstorms and precipitation are almost always accompanied by observable electrical activity, and some 'severe-weather warnings' issued by local weather bureaus can be discounted if the sferic indicator does not show corresponding electrical disturbances.

"Another phenomenon that may show up on the scope is the 'clear-weather sferic,' a lightning discharge in an area of calm, clear skies, usually in summer. These have also been observed visually, although little is known about them.

"Giant electrical storms can also be detected on occasion. The clouds in these disturbances sometimes reach 12 miles into the stratosphere and develop as many as 10 to 20 cloud-to-cloud strokes per second. These enormous thunderheads, which often give rise to tornadoes, can actually be seen when they are more than 150 miles away. The signals they produce are characterized, according to one report, by a series of sferic pips that occur a fraction of a second apart and, at long range, on the same azimuth.

"Two or three sferics azimuth stations, separated by 100 miles or so, could obtain accurate fixes on thunderstorms if the problem of establishing communications between stations can be solved. Perhaps the solution can be found in amateur radio."

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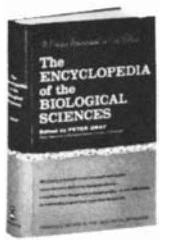

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