THE AMATEUR SCIENTIST

A transistorized drive for a telescope, and a sundial that keeps accurate time

Conducted by C. L. Stong

The slow parade of stars across the night sky appears to be greatly accelerated when it is observed through a stationary telescope of high power, because the instrument magnifies apparent motion as well as size. In consequence objects drift across the field of view and disappear in a matter of seconds unless some arrangement is made to keep the instrument trained on them. If the telescope is mounted so that it can turn, objects can be kept in view most of the time by moving the tube manually. Hand guiding is not precise enough, however, for many types of observation. The instruments used by astronomers and a large number of the telescopes made by amateurs are therefore equipped with a mechanism to keep celestial objects automatically in view.

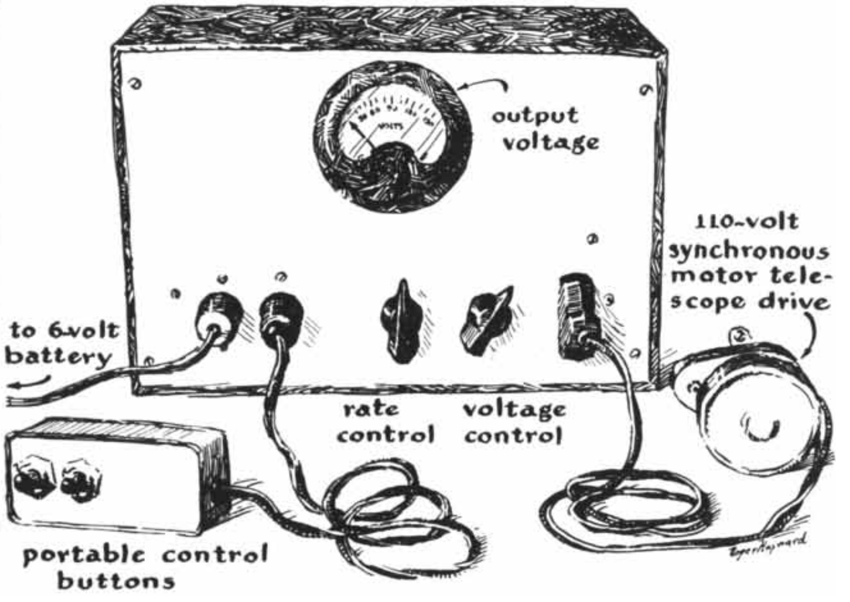
Most of the apparent motion of a celestial object is caused by the rotation of the earth, which amounts to one revolution in 24 hours with respect to the sun, and to one in about 23 hours, 56 minutes with respect to the stars. The fact that the hour hand of a clock turns at approximately twice this rate suggests that a clockwork could be modified to serve as an automatic drive by coupling it to the shaft of the telescope through a set of simple reduction-gears. This approach has been tried by many amateurs. Ordinary clocks, however, fall considerably short of meeting the requirements for an ideal drive. Few of them deliver enough power to overcome frictional losses in bearings of the type used by amateurs, and they do not provide enough range in speed. To track the moon accurately as it crosses the meridian a clock must run about 5 per cent slower than normal, a rate which in the latitude of New York would cause the clock to lose about an hour per day. This rate is beyond the range of the "fast-slow" adjustment of most clocks. Another serious limitation of clocks as drives for telescopes arises from the property to which they owe their usefulness as instruments for measuring time. Clocks run at constant speed, but the apparent motion of a star varies. Light from stars low in the sky passes through more of the earth's atmosphere than does light from stars higher in the sky; the light of a star near the horizon is so strongly refracted by the atmosphere that the image of the star can be seen several seconds after the star has passed below the horizon. Accordingly a drive that freezes an object in the field of a telescope pointed at the zenith permits the image to drift increasingly as the telescope is pointed at lower angles. In the most satisfactory drives provision is therefore made for continuously altering the tracking speed through a narrow range above and below its average value. Moreover, the best systems are equipped with a coarse control for changing the tracking rate by at least an order of magnitude so the tube can be quickly centered on a selected object.

All of these requirements are met in an inexpensive electrical drive utilizing transistors which was constructed last year by George W. Ginn, an engineer of Lihue, Hawaii. "Much of my observing," writes Ginn, "which has included a lot of photography, has been done at elevations above 10,000 feet on Mauna Loa and neighboring volcanic peaks, where seeing is exceptionally good nearly every night of the year. Most of these locations are reached by car and on foot by roads carved from lava, which is scarcely an ideal pavement. This means that my equipment must be light, portable and rugged enough to retain its accuracy during rough trips.

"The camera and guide telescope are supported on a tripod by a mounting of German manufacture which I acquired from the University of Hawaii in exchange for adapting one of their instruments for portable use. The mounting is of the equatorial type—one shaft turns in the plane of the earth's equator and the other in elevation—and is equipped with worm gears coupled to hand wheels for following objects in right ascension and declination as well as with clamps for locking the tube in any desired position. The arrangement is adequate for casual observing and even for making photographs of short exposure. But fine visual measurements and extended exposures require more precise guiding.

"Mechanical drives, such as those built around spring-driven clocks, are not satisfactory for use with portable instruments. The mainspring of most small clocks is not powerful enough to overcome frictional losses in the mounting, so an arrangement of weights must be added to supplement the energy stored in the spring. A clutch must also be inserted between the clockwork and mounting so that the tube can be disengaged for shifting the field of view from one region of the sky to another. In addition, the system must include a set of differential gears, a screw adjustment or some comparable means for making small corrections in the position of the tube without interrupting the basic motion of the clock. All this adds up to a cumbersome mechanism which is costly to make, inconvenient to use and difficult to maintain in satisfactory working order.

"Most of these difficulties can be overcome by substituting electrical parts for the springs and gear trains—with a distinct gain in the precision of tracking My present drive consists of a small synchronous motor of the type used in electric clocks which is energized by an oscillator-amplifier using transistors. The oscillator converts direct current into alternating current of a precisely known frequency. In effect it measures time and corresponds to the escapement of a clock. Power for the unit is taken from my automobile storage battery, which is thus analogous to the mainspring of a clock. The motor, somewhat smaller than a pack of cigarettes, is mounted on and geared directly to the mounting. A plug-in cord connects the motor to the oscil-



Transistorized drive for a small telescope

lator-amplifier. The unit is about the size of a miniature radio-receiver. Another plug-in cord from the oscillator-amplifier is connected to the battery by spring clips, and a third cord runs to a control box equipped with push buttons for changing the speed of drive as desired. The control box is held in and operated by one hand during observation. The complete system, less battery, weighs five pounds. It requires no lubrication or other maintenance, is unaffected by dust and retains its calibration over wide changes of temperature.

"The oscillator-amplifier circuit was designed for transistors instead of vacuum tubes primarily because I wanted to learn something about transistors. Perhaps the use of vacuum tubes would have been wiser at this stage of transistor development; the choice of circuit components designed expressly for transistors is still rather narrow, particularly in the case of transformers. On the other hand, the impressive reduction in size, weight and power consumption of apparatus which is made possible by the use of transistors more than compensates the builder for time spent in modifying parts.

"With the exception of the motor and the controls, the system contains no moving parts. During operation the oscillator draws direct current from the battery and converts it to alternating current at any desired frequency from 55 to 65 cycles per second. The frequency is controlled by a knob that corresponds to the fast-slow adjustment of a clock. The control covers a range of something more than 5 per cent, which is adequate for guiding telescopes and cameras less than five feet in focal length. The frequency can be doubled instantly by operating one of the two push buttons in the control box. The other button stops the oscillator. The action of the buttons corresponds to that of a set of differential gears and is used as a slow-motion traverse. By pressing the appropriate button the telescope can be moved forward or backward with respect to the stars at the rate of .25 degree per minute. The amplifier portion of the circuit steps up the output power of the oscillator to four watts at 115 volts for driving the motor, which is rated at 3.8 watts.

"The oscillator circuit is of the Wein bridge type and has excellent stability. The frequency is adjusted through the 5-per-cent range by dual potentiometers and is doubled by switching out half of the .5-microfarad capacitors shown at the far left in the accompanying circuit diagram [*page 188*]. Stopping the oscillator is accomplished by short-circuiting the 5,000-ohm (5K) variable resistor shown at the top of the diagram. This resistor controls the amount of energy fed back in reverse polarity from the output of the oscillator to its input and is normally set to the lowest resistance at which the oscillator will start and maintain stable operation. Switching is accomplished by relays, the coils of which are energized by the push buttons.

"The circuit includes a ballast lamp for stabilizing the output voltage. The

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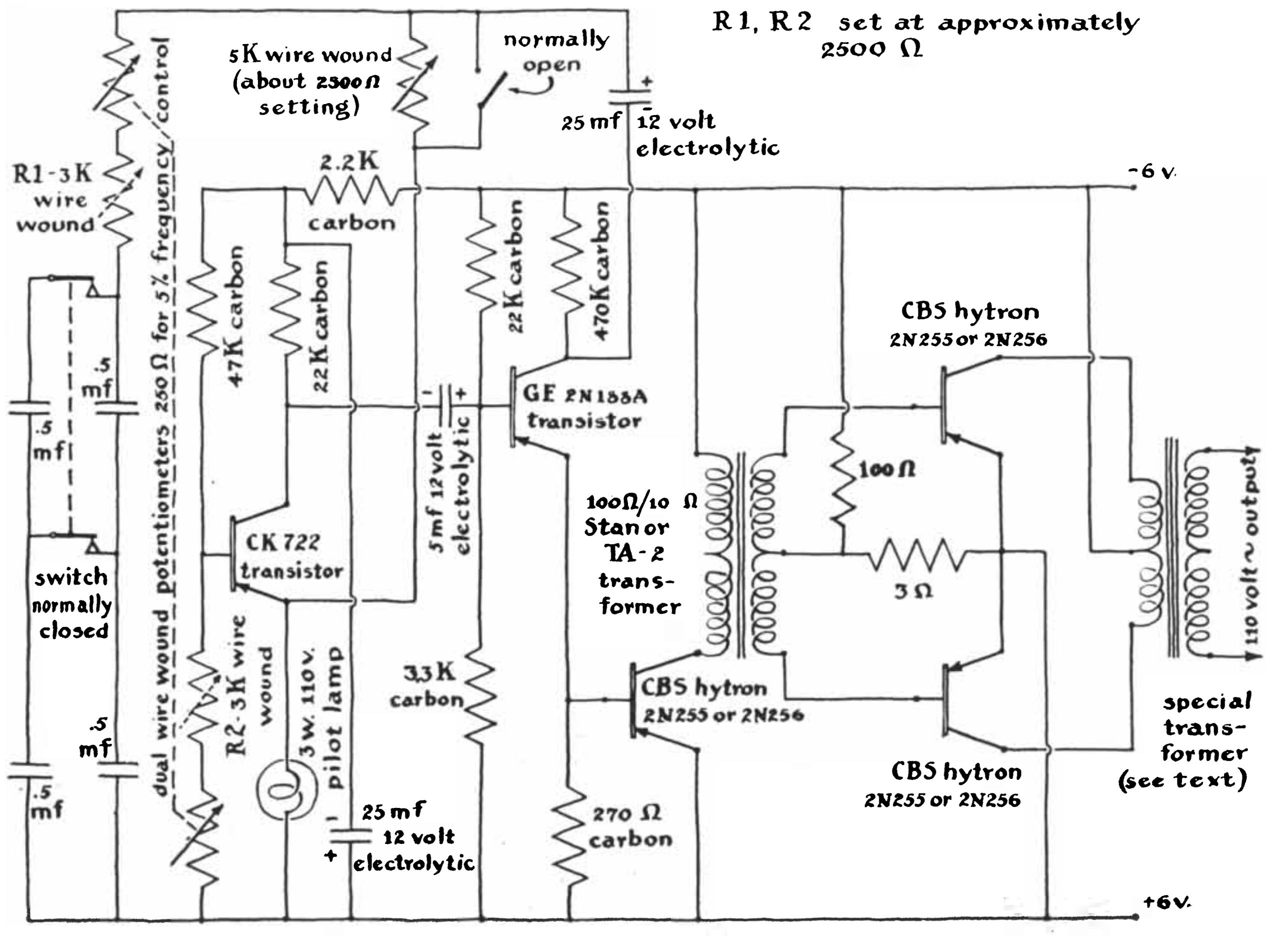
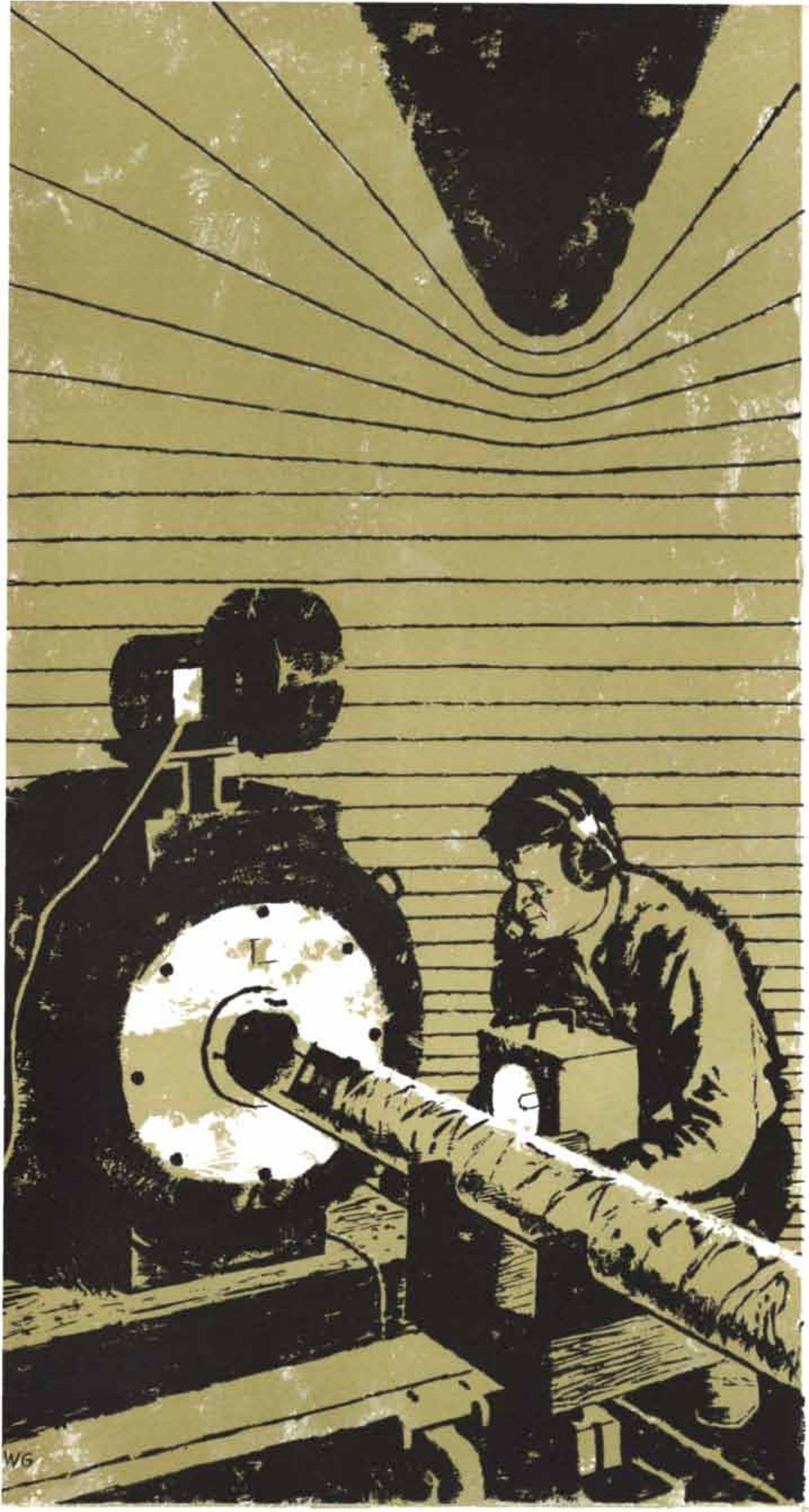
filament is connected in series with the feedback resistor so that the voltage of the circuit is divided between them. When the voltage rises, the filament warms up and the resistance increases. This has the effect of increasing the negative feedback, which in turn reduces the voltage to its normal value.

"Standard construction and wiring were used. The housing of the oscillator-amplifier unit is five inches wide, six inches deep and nine inches long and is available from most radio dealers. The aluminum panel and chassis were cut to fit the case. The small transistors were mounted along with the resistors on a strip of Formica by drilling small holes in the strip for the leads and making connections on the back. The cases of the power transistors function as 'collectors,' counterparts of the 'plate' electrode in vacuum tubes. Voltage is applied to the cases, so they must be insulated from the chassis. Kits are available for mounting power transistors which include mica washers and silicone oil to aid in the transfer of heat to the chassis. I did not use the oil because in this circuit the units operate substantially below their rated capacity for dissipating heat. Do *not* solder connections directly to the power-transistor terminals; transistors are easily damaged by high temperature. Clips for connecting transistors into the circuit can be made from contacts salvaged from miniature vacuum-tube sockets. Connections to the emitter electrodes of the power transistors must be tight because a peak current of two amperes flows in this circuit. Two other precautions are worth mentioning. First, transistors, unlike vacuum tubes, can be damaged by applying voltage of incorrect polarity to the terminals. Second, the output stage must not be operated without a load.

"The power transistors of this amplifier deliver about 4.3 volts on each side of the center tap. This must be stepped up by a transformer to 115 volts for driving the motor. Unfortunately dealers do not stock a suitable transformer. I tried to modify a conventional filament-transformer for the job by leaving the 117-volt winding intact and rewinding the 6.3-volt secondary for the lower input voltage. Sad to relate, only 50 volts came out of the high side. After stewing over this development for a day or so, and consulting *Radio Engineers' Handbook* for data on transformer design, it became apparent that heat losses in the iron core caused by the high density of the magnetic field were eating up the profits. Apparently 6.3-volt filament-transformers are designed with a minimum of iron and copper, adequate performance being achieved by operating the iron core at a high magnetic-flux density. If 25 per cent of the energy is wasted in heating the core, nobody cares because the energy is being taken from the 110-volt power line and amounts to only a few watts. After calculating the losses for several values of flux density and wire size, I picked the best combination and rewound both coils of the transformer. The primary was replaced



Circuit diagram for transistor amplifier-oscillator



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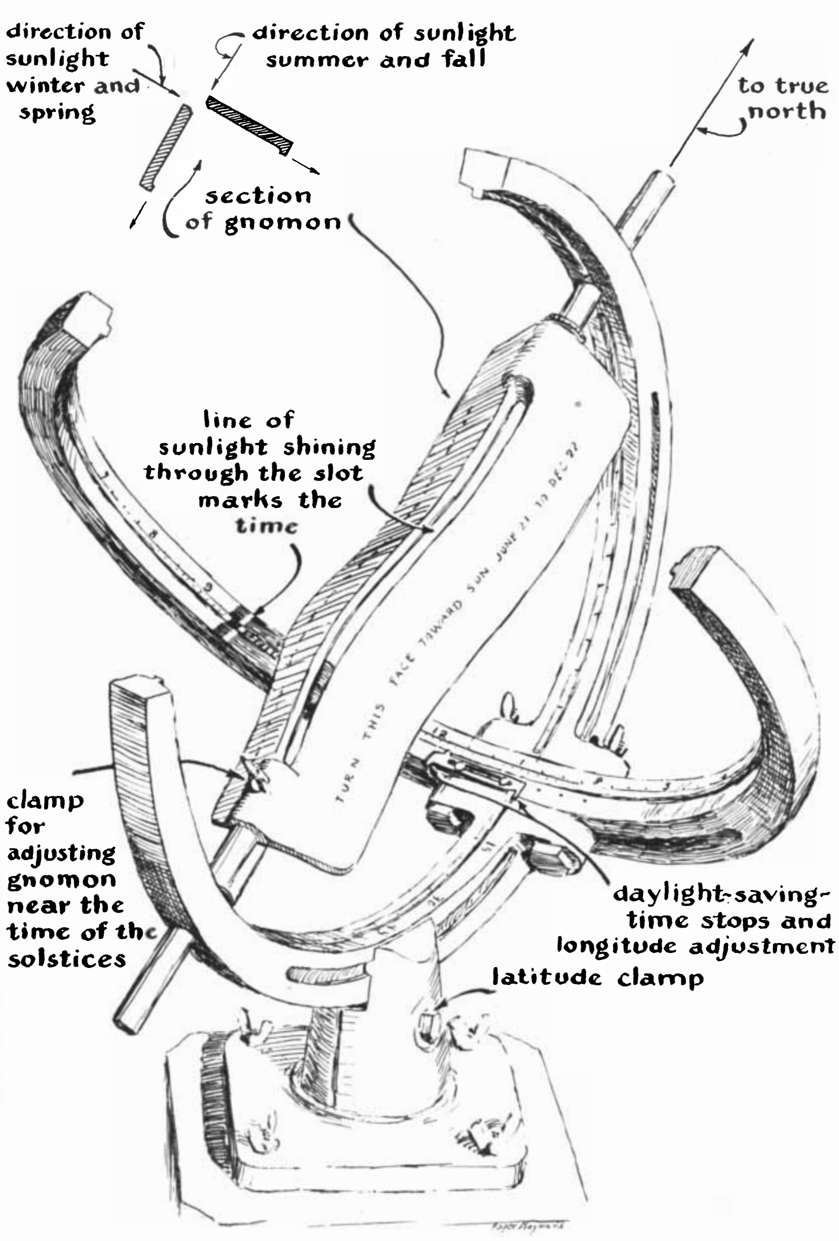
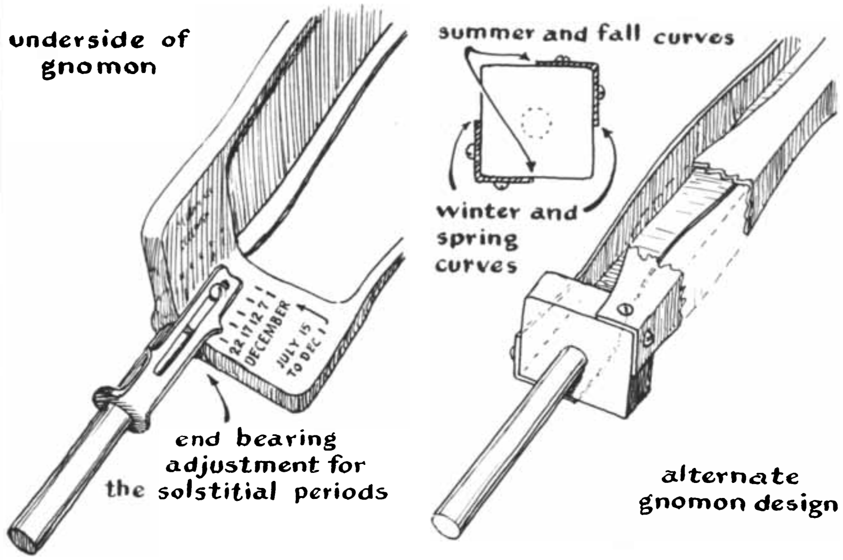
with 48 turns of No. 18 enameled magnet-wire on each side of the center tap; the secondary, with 1,560 turns of No. 32 wire. This reduced the flux density from 98,000 lines per square inch to 41,000 lines and reduced the core loss from four watts to one watt. The core weighs 10 ounces and has a cross-sectional area of 7/8 square inch. Any core of about this size and weight should work satisfactorily. Smaller cores would require more turns. The losses are proportional to the weight of the core and the square of the flux density. The core of an audio-frequency transformer would doubtless perform better because the laminations are thinner and are made of the highest quality magnetic iron.

"The power transistors operate alternately, so only half of the primary coil carries current at one time. If the transformer were operating from a conventional alternating-current source of four volts, the primary coil could be a single winding of 48 turns. If 12-volt operation is desired, the number of primary turns must be doubled. The output in this case would be about nine watts, so the wire size of the secondary winding would have to be increased to No. 30,



An amateur's sundial that indicates clock time



Detail of gnomon for sundial

and a larger core would be required to provide additional space for the larger wire size.

"The new set of coils delivered an output of 90 volts, as measured by a meter of the rectifier type. Further investigation disclosed that the low indication was caused by the irregular shape of the voltage wave, a response induced by the motor. A .5-microfarad capacitor connected across the output coil of the transformer corrected the wave form and raised the indication to 110 volts. The voltage rises somewhat when the frequency is doubled, but this is not a disadvantage because the torque of the motor would normally drop at the higher frequency. The higher voltage tends to maintain constant torque.

"A few bugs remain in this pilot model. The oscilloscope shows some highly unconventional and mysterious wave forms here and there. Other builders will doubtless find ways to improve the circuit, and I will welcome a report of their results. But the bugs have no discernible effect on the operation of the unit. When I compare its output with that of the 60-cycle power line, the power frequency varies most. Operation in the field is simplicity itself. Set up the telescope, plug in the cords, adjust the speed and you are in business.

"It is assumed that amateurs who undertake the construction of this drive will have some experience with electronic circuits. Others are urged to solicit the cooperation of a neighboring radio 'ham.' Some reading is indicated for those inexperienced with transistors; I can recommend the booklet on 2N255 and 2N256 transistors published by CBS Hytron of Lowell, Mass. Similar booklets covering equivalent transistors made by other manufacturers are available through most radio dealers. Should problems arise during the construction of this apparatus which cannot be solved by reference to current literature, I will try to answer them. My address is: Box 669, Lihue, Hawaii."

"In *The Amateur Scientist* for August," writes Richard L. Schmoyer, an engineer of Landisville, Pa., "you raise the question of why a man who owns an accurate watch and several clocks will go to the trouble of building a sundial. Few will disagree with your conclusion that he is motivated in part by the intellectual charm of a device which, without moving parts, can convert the sun's changing position directly into time. But sundial-making holds other attractions for its enthusiasts. In the course of developing a sundial one is exposed to a fascinating and well-defined mixture of mathematics, geometry, geography and astronomy. The design of a sundial challenges our creative talents, and its construction puts our craftsmanship to an exacting test. Finally, the designer who permits the primary time-telling function of the sundial to control its form adds spice to the project. Hardware in pleasing though strange and unexpected shapes often emerges from the equations which describe the ever-changing slant of the sun's rays.

"These inducements led me to design a sundial last year which has become a continuing source of pleasure both to me

and to my neighbors. With only a few simple settings during two seasons of the year the sundial can be made to indicate accurate clock time. It can be adjusted to the latitude and longitude of any point in the Northern Hemisphere, including those areas where clocks are changed for daylight-saving time. Clock time can be read from it to an accuracy of about one minute, even when the sky is covered by a light overcast.

"Most people find sundials attractive, so one must not altogether dismiss their ornamental properties. The structure of my dial was derived from the armillary, a traditional form which continues to enjoy wide popularity. Those primarily concerned with the appearance of a sundial admire the geometric perfection of the armillary's nested rings, representing latitude, longitude, tropics, celestial equator and the ecliptic. Much the same pleasing quality is found, however, in the unsymmetrical crescent of the early and late moon. The armillary can be converted to this form by eliminating all except the rings representing latitude and longitude and opening these at one of the sides where they join at right angles. When tapered and strengthened, these rings become nested crescents, as shown in the accompanying illustration [*page 190*].

"The transformation from armillary to nested crescents demonstrates how a pleasing shape can emerge from a functional necessity. A good time-telling device should always fulfill its mission. The armillary falls short of this ideal. During part of each day its pattern of ornamental rings casts shadows on the time-scale, which is carried on the inner face of the equatorial ring. Worse, in the seasons of the equinoxes (March 21 and September 23) the scale lies in continuous shadow because the plane of the ring then parallels the sun's rays. By eliminating the useless rings and opening the functional pair into crescents the time-scale is exposed to the sun without obstruction.

"The structure of a sundial which indicates clock time is simple in concept if not in the making. The crescents are supported at their edges by an arrangement of bolts, slots and clamps so they can be rotated in their respective planes. The latitude crescent is made in two parts with a flange at the inner end of each. Bolts pass through the flanges and through a slot in the longitude crescent. When the nuts are tightened, the assembly becomes a rigid unit. Similarly, the edge of one member of the latitude crescent is clamped between the jaws of a split pedestal which extends up from the base. By loosening a single wing-nut the whole assembly can be rotated in the plane of the latitude crescent and in azimuth.

"A pair of holes are drilled in the latitude crescent on the diameter which coincides with the axis of the equatorial crescent. These holes serve as bearings to support the gnomon. It is to the unique shape of the gnomon, which compensates for the effect of the eccentricity of the earth's elliptical orbit and the tilt of its axis, that this sundial owes its property of keeping clock time. If the earth followed a circular orbit around the sun, and if its axis were perpendicular to the plane of the ecliptic, the straight gnomon of the conventional sundial would indicate clock time. The time shown by clocks is that of a fictional sun which leads the real sun by as much as 16 minutes or lags behind it up to 14 minutes, depending upon the observer's location and the season. This difference is known as the equation of time and is shown graphically as the analemma on globes, a closed curve in the form of a figure eight.

"The gnomon of my dial is related to the analemma but differs from it in that halves of the figure are separated and the ends have been stretched somewhat. Structurally the gnomon consists of a strip of cast metal bent at a right angle along its length. The apex of the angle is opened to form a thin slot. It is supported at the ends by shafts which turn in the bearings of the latitude crescent. The halves of the gnomon are bent into almost symmetrical compound curves with respect to the long axis and are therefore complementary. When either half is turned to face the sun, the curved ribbon of light which passes through the slot corresponds with the equation of time for half of the year, the remaining six months being represented by the other half. Time is indicated by the thin line of light from the slot which falls on the time-scale between shadows cast by the halves of the gnomon.

"The portion of the curved slot through which the rays pass to the time-scale depends on the declination of the sun. In summer, sunlight falls on the dial at a high angle and reaches the time-scale through the upper part of the slot, where the curvature just compensates for a 'slow' sun. The reverse is true in the fall, when the sun is low. The winter sun is also mostly slow, and in the spring the sun goes from slow to fast to slow to fast again. Whatever the season, the sun's declination selects an appropriate portion of the curve to offset the equation of time.

"Some difficulty is encountered during

A pretty tough case

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the period from about December 1 through January 15, when the sun lingers close to its lowest path across the sky. During this same period, however, it speeds up with respect to the fictional sun. A lag of some 11 minutes becomes a lead of about nine minutes. The simultaneous change in declination is very small. A similar event takes place in reverse during the weeks preceding and following the summer solstice on June 21, when the real sun falls behind the fictional one, again accompanied by little change in declination. To accentuate the sundial's response during these periods, the curvature of the slot is stretched out. The gnomon must also be moved axially in its bearings, the amount of shift being determined by a stop on the shaft. The adjustment is made by hand according to a scale of dates engraved on the gnomon, as shown in the accompanying detail drawing [*page 192*].

"The designing of the gnomon, though tedious, is not difficult. One first determines the rate at which a ray of sunlight moves across the time-scale. This depends on the diameter of the crescent on which the scale is engraved and on the related distance between the scale and the gnomon. Multiply 3.1416 by the diameter of the equatorial crescent and divide the product by the number of seconds in a day. In the case of a 13-inch crescent the result is .000473. This number is used for computing the distance and direction by which the curved slot must depart from a straight line for successive weeks of the year. This procedure can be illustrated by constructing a graph of the curve for one face of gnomon. First draw a straight line equal to the radius of the proposed crescent and erect a perpendicular of about the same length above and below one end of the line. The base line represents the sun's mean elevation (0 degrees) on September 23. Next, with the end of the base line as the point of origin, extend a line to the perpendicular at an angle of 21 degrees, 34 seconds *above* the base line. This represents the sun's elevation on July 15. Now make a similar angle of 21 degrees, 47 seconds *below* the base line. This corresponds to the sun's elevation on December 1. Angles above the base line are regarded as positive and are designated 'plus'; those below are considered negative. Next, draw in angles at weekly intervals for all intermediate dates. A table showing the sun's angular elevation throughout the year can be found in any ephemeris and in many almanacs. These references also carry a table for the equation of time and list the difference between solar time and clock time in minutes and seconds. The curve for one face of the gnomon is plotted from these values. (If the thickness of the material from which the gnomon is constructed exceeds .01 inch, the curvature of the trailing edges must depart from that of the faces to avoid shadow. The same basic procedure is used in computing all curves, however.) For September 23 the equation of time has a value of —7 minutes, 35 seconds, which is equal to —455 seconds. Multiply this interval by the rate at which the ray of sunlight moves across the time-scale of the dial. In the case of my dial the computation is: $.000473 \times -455 = -.215$. This product represents the distance in inches by which the curve of one edge of the slot in my gnomon departs from the perpendicular. (In plotting the curves all negative values are directed to the left of the perpendicular and positive values to the right.) The remaining points of the curve are similarly plotted for all intermediate dates at weekly intervals.

"The ends of the curve must be stretched out, as mentioned earlier. To accomplish this a perpendicular line is drawn through the point of origin and divided by a series of four points spaced a quarter of an inch apart both above and below the base line. With these points as successive origins draw in the sun's declination *above* the base line for the dates July 8, July 1, June 26 and June 21 and *below* the base line for the dates December 7, 12, 17 and 22. Similarly draw in the sun's declination on the other half-face for June 1 to 21 and December 22 to January 15. The ends of the curves are then plotted from the equation of time by the method described. The full-scale drawing is then ready for translation into hardware. All major parts of my sundial were cast in aluminum. The layout was drawn directly on the wood from which the patterns were made. The time-scale is divided into hourly intervals of 15 degrees each and subdivided into minutes as desired. The graduation representing noon lies in the plane of the meridian."

This department will forward a copy in reduced scale of the layout of Schmoyer's gnomon upon receipt of a self-addressed, stamped envelope. Schmoyer advises that the patterns used in making the parts for his dial, including the gnomon, have been preserved. He has volunteered to have duplicate castings made by the local foundry upon request by those who wish to purchase a ready-made set. His address is Landisville, Pa.

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