range at which we may expect to sight a light. The luminous range is almost always greater than the geographical range and reference must be made to the Geographical Range Table in the Admiralty *List of Lights* to find out what the latter will be.

The Hydrographic Department comments:

Commander Clissold contends that the changing of light range on the chart from the geographical range to luminous or nominal range is a retrograde step for the practical navigator. Whilst sympathizing with Commander Clissold's view the Hydrographer of the Navy cannot agree.

The decision to adopt nominal or luminous range both on the chart and in the light lists was taken after protracted international debate in which the needs of practical navigation were comprehensively considered. The Hydrographer contended that to quote the range of a light on the mere basis of an observer's height of eye of 15 ft was unrealistic since this height was no longer applicable to the majority of ocean-going ships. Thus any observer whose height of eye was not this magic 15 ft was already having to look in the tables in the front of the light list (or other appropriate tables) to find the range at which the light would be raised.

The long established practice of charting the lesser of geographical and luminous ranges made comparison between charted lights well nigh impossible. It was felt that a measure of the practical strength of the light was needed and thus the use of one type of range—nominal range—gives more realistic basis for comparison and represents a mean performance figure for global use; as Mr. Reynolds points out on page 115 of the January *Journal*.

The sighting range of a light depends on so many variable factors, of which the observer's height of eye is but one, that it could be argued that to show any range at all on the chart is to present the mariner with misleading information. However, nominal range, or luminous range for those countries which use a greater transmission factor than 0·74, does provide a much more consistent figure upon which to base the calculation of the sighting range of a light. There is no short cut to the determination of this range; nor has there been since the navigation platform moved upwards from a representative 15 ft height of eye. When the changeover to nominal range was made the attention of mariners was drawn to the preliminary pages in the Admiralty *List of Lights* which form an essential adjunct to the chart for obtaining sighting ranges.

A Polar Compass

Captain F. G. Wolff

THE basic premise of compass adjusting (that is compensation aboard ship for magnetic fields caused by the vessel itself and the determination of residual deviation) is that a reference direction must be available during the operation. Normally visual ranges or the azimuth of a celestial body—usually the Sun—are used, but in some areas and climates reduced visibility often does not permit the

https://doi.org/10.1017/S0373463300044404 Published online by Cambridge University Press

use of either. Compass adjusters are frequently driven in desperation to use gyro-compass, radar, or radio bearings—with highly speculative results as the errors of these instruments are generally unknown, and fairly large compared to the accuracy required of the magnetic standard compass ($\pm\frac{1}{2}°$) which is the primary direction standard aboard ship.

Since lack of visibility, primarily due to fog, is the rule rather than the exception in the area in which I have to adjust compasses (Nova Scotia, Prince Edward Island and Newfoundland), I have for years searched for some other accurate method of determining direction. About two years ago I first heard of sky polarization and although I was—like Benjamin Franklin—'much in the dark about light', I determined to put it to practical use. It appears that small particles in the atmosphere polarize sunlight from the vicinity of the zenith in a direction perpendicular to a line from the observer to the Sun. Although heavy clouds and fog tend randomly to depolarize the light again, even with a fairly dense overcast some degree of polarization is still present.

The usual approach to the detection of sky polarization seems to be visual observation through a pair of crossed polaroid filters, arranged in a pattern so that equal brightness indicates that both filters are at 45° to the Sun's azimuth (Fig. 1). For my purpose this was too cumbersome a procedure, I therefore constructed a small instrument utilizing two photo-resistors in a wheatstone bridge circuit, each of the photocells being exposed to the zenith through a tube of approximately 20° circular beam angle and through polaroid filters at 90° (Fig. 2). A microammeter indicates zero centre when the instrument is turned so that the polaroids bracket the direction of the Sun's azimuth. Actually there are four directions in which the bridge circuit is balanced; Sun's azimuth (desired), the reciprocal of Sun's azimuth, and the two directions at right angles to these. The four latter can be eliminated by observing the direction of current flow on either side of the null point; the Sun's reciprocal must be

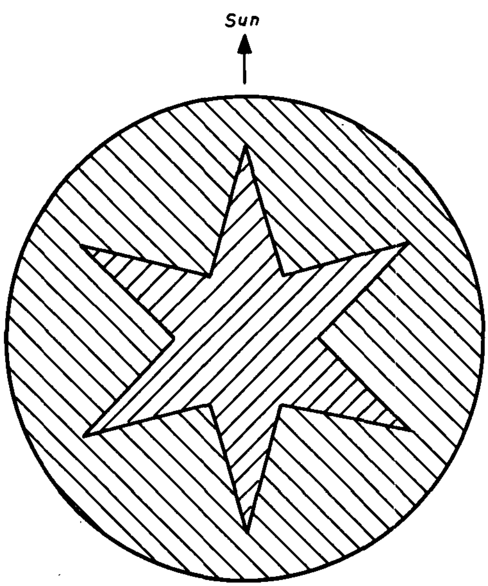

FIG. 1.

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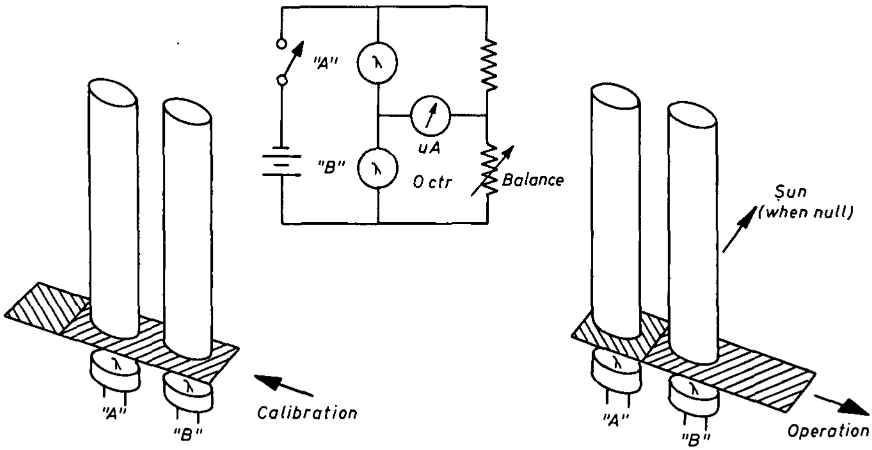

FIG. 2.

eliminated by other means. It is also necessary to balance the circuit from time to time as the components—especially the photocells—cannot be accurately matched over a wide range of ambient light levels. Balance is obtained by nulling the bridge while both photocells are exposed through identically oriented polaroid filters.

This little instrument, with parts, cost under ten dollars and proved very useful even under rather severe conditions; it would reliably indicate the Sun's azimuth when the altitude was as high as 40°, and would even track the Sun to about 10° below the horizon, at which point ambient light levels generally became too low. By replacing the microammeter with two light-emitting diodes, driven through integrated-circuit voltage comparators, the usefulness of the instrument was further extended, with typical accuracies of plus or minus ten minutes of arc.

It was still necessary to rotate the instrument manually to find the null point, and to balance the circuit from time to time as ambient light levels changed. Driving the array around with a small servo-motor to find the null would give a continuous indication of the Sun's azimuth (and even automatically eliminate the two wrong 90° points) but it would still require occasional balancing.

It then occurred to me to use a single photocell, exposed to the zenith through a polaroid filter continuously rotating about the vertical axis, thus providing a sine-wave output at twice the frequency of rotation. Maximum output occurs when the filter is at right angles to the Sun's azimuth or its reciprocal. By generating another sine wave of the same frequency, fixed in space to indicate the ship's heading (actually an electronic lubber's line) the phase difference between the two sine waves is an indication of the ship's heading relative to the Sun's azimuth, which is just what is desired (Fig. 3). The fixed sine wave is easily generated by a light source illuminating an additional photocell through a fixed polaroid filter and the rotating filter. Since the amplitude of the photocell outputs is of no consequence no calibration or balancing is required and continuous direction indication is provided.

Direction indicated by this instrument is of course relative to the Sun's ever-changing azimuth. While this is usually the case when working with celestial

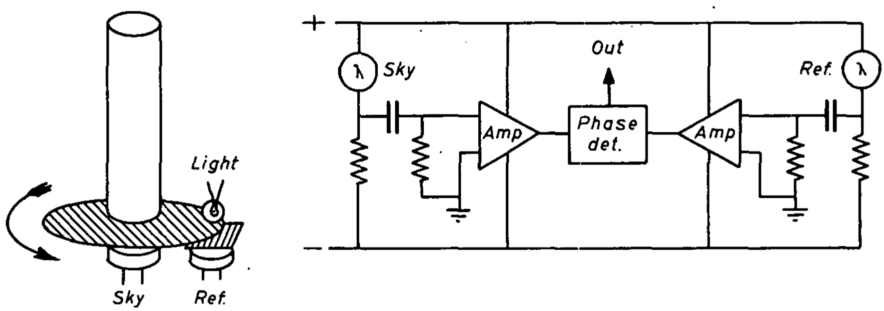

FIG. 3.

bodies, it still requires the calculation (usually in advance) of the Sun's azimuth for the place and during the time interval of interest. A hand-held preprogrammed calculator can easily perform the required calculations in close-enough-to-real time for our purpose, provided we feed in latitude, longitude, Julian day and Greenwich mean time.

$$\tan Z = \sin t/(\cos L \tan d - \sin L \cos t)$$

where Z = Sun's azimuth

t = local time (from GMT, longitude, and equation of time from Julian day)

L = latitude

d = Sun's declination (from Julian day and GMT)

A clock 'chip' can provide the time, while the other entries are only required at the beginning of the operation. Indeed, by feeding the output of the compass into the calculator we can directly and continuously obtain the ship's true or magnetic heading. This can be accomplished by digitizing the analog output of the compass, which consists of a phase difference between two sine waves, and feeding it into the modified calculator.

We now have a compass which will work accurately from well before sun-up to well after sun-down, except when the Sun is more than about 40° above the horizon. Except for compass adjusters in the fog this may not be a very useful device in normal latitudes, but there are two areas of the Earth where the determination of direction by traditional means is extremely difficult—the North and South polar regions. In both the Arctic and Antarctic the navigator—on land, at sea, and in the air—faces the problem that the proximity to the magnetic pole renders a magnetical compass unreliable and finally useless. The gyro-compass has its own problems near the geographic poles and becomes useless in very high latitudes. Because of propagation variability (and to some extent magnetic influences) radio bearings are also relatively inaccurate in the polar regions. Electronic navigation systems, including satellites, can provide excellent information regarding position, but not direction of travel. There remain only celestial azimuths, requiring the usual tedious methods and providing only intermittent indication of direction. What is worse, there are two twilight periods each year during which the Sun is still below the horizon (and can thus not be observed) but yet is bright enough to render the stars and planets invisible. These periods can last several weeks.

It is precisely under these conditions (Sun at or near the horizon) that the polarization compass works best, and may eventually achieve its widest application. It is offered as an inexpensive, simple-to-build but highly accurate instrument for desperate fog-bound compass adjusters and others who have difficulty determining which way they are headed.

The Conception and Development of Weir's Diagram

Charles H. Cotter

JUST a century ago, in 1876, Patrick Weir, an officer of a vessel trading between London and Australia, conceived the idea of a diagram that might facilitate finding the Sun's true azimuth for the purpose of checking the magnetic compass. Some thirteen years later Captain Weir's Diagram was the subject of a paper communicated by Sir William Thomson (later Lord Kelvin) to the Royal Society of Edinburgh. In his paper[1] Weir outlined the train of reasoning by which he succeeded in constructing a novel diagram which was described by Professor P. G. Tait[2] as 'a singularly elegant construction which, not only puts in a new and attractive light one of the most awkward of the problems of spherical trigonometry, but it practically gives in a single-page diagram the whole content of the two volumes of Burdwood's Azimuth Tables'. Tait also remarked that the method supplied an interesting graphical plane construction of a function of three independent variables.

As a result of Weir's original conception a complete diagram[3] covering all latitudes from 0° to 60° and all hour angles at 4 min. (1°) intervals was professionally drawn and published by the well-known nautical publisher J. D. Potter of the Minories in London. The original published diagram was mounted on card and appended to it were Captain Weir's instructions 'simplified by Professor George Darwin and Sir William Thomson'.

Weir related that to simplify the problem of finding the Sun's true azimuth he conceived the idea of 'projecting the Sun's path on to the plane of the horizon'. The line of his subsequent reasoning proceeded thus: To an observer at the Earth's north (or south) pole the projection of the Sun's diurnal path onto the plane of the observer's horizon is a circle and that, no matter what its declination, the Sun's bearing is the same at any given time each day—only its altitude being affected by a change in declination. To an observer on the equator the projection of the Sun's daily path onto the plane of the observer's horizon, when the Sun's declination is 0°, is a straight line which joins the east and west points of the horizon. Also, to an observer on the equator, the rising and setting amplitudes and the Sun's meridian zenith distance are equal in magnitude and name to the Sun's declination.

Weir then posed the question: If the Sun's path is projected as a circle for an observer in lat. 90°, and as a straight line for an observer in lat. 0°, what is its