SUMMARY TECHNICAL REPORT ON RADIO DIRECTION FINDER BEARING COMPUTERS

by

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RADIO DIRECTION FINDING SECTION
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Radio Direction Finding Section
Electrical Engineering Research Laboratory
Engineering Experiment Station
University of Illinois
Urbana, Illinois

ABSTRACT

Sixteen systems are proposed for sector-type and omnidirectional-type analog bearing computers for use with small aperture radio direction finders. Certain of the systems have been realized in the laboratory. Others remain in the paper stage, either because of the relative complexity, or non-immediate application. Several of the analog systems yield data in a form that is ready for immediate processing by digital computers that function in real time.

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ILLUSTRATIONS

1. INTRODUCTION

Special purpose bearing computers for radio direction finders have recently received considerable interest which is due in part to the impact of the development of the accurate computers of modern technology and in part to the active interest in research in the field of propagation. The principal reason for such interest is, of course, not in the computers as such, but rather in what may be done, in addition to what has been or is now being done.

The radio direction finder is a measuring device consisting of (1) a directional collector, (2) a radio receiver for processing the RF data, and (3) an indicator for sensory presentation of the data. Coupled with the above three functions is the need for an operator-observer, who usually is an important link in the data readout. Often he must do some correlating of collector orientation versus indicator operation in addition to estimating the indicated bearing, i.e., "getting the bearing."

It now appears that although an operator as such may be needed, the important coordinating and observing functions can be assumed by a computer. A computer permits vastly increased speed in bearing data accumulation and reduction and removes the important source of operator error and bias. With all due respect to the human observer, it does not seem that he has been endowed by nature to be particularly competent or adept at following the fluctuating data that appear on an RDF bearing indicator. He may be instructed in what he should attempt to do, but his transfer function is not linear, it is band-limited, and, at times, is unpredictable. Computers have been built and operated which independently sample the bearing data 25 times per second, compute the corresponding bearing, integrate the bearings, and give at their output a cumulative mean of all of the indicated bearings over some selected period of sampling in time, say, 1 to 180 seconds.

If one recognizes and accepts the premise that it is ultimately the *decision* resulting from the bearing determination that is really important, then it appears logical and necessary to eliminate any extraneous instrumentation that gives only partial answers, and build devices that lead most directly to the decision, or that ultimately provide the decision itself. The mean indicated bearing is the most useful of the of the simple statistics that a direction finder may provide. Decisions are based upon this type of statistic. Electronic computers can most quickly ascertain this type of statistic. Hence, it appears that efforts that are directed toward obtaining this type of statistic are not only of interest, but are desirable.

Several proposals for special purpose bearing computers for radio direction finders have been, or are being, actively investigated at the University of Illinois. The progress along these lines is summarized in the sections that follow.

2. A CLASSIFICATION OF RDF BEARING COMPUTERS

Radio direction finder bearing computers may be subdivided into analog and digital types and these types may be further subdivided for purposes of classification. In order to provide a perspective of the several computers that have been, or are being, proposed, a a block diagram has been prepared and is shown in Fig. 1.

Analog computers have been subdivided into systems having limited effective range of azimuthal vision (sector systems) and those that are not thus limited (omnidirectional systems). Further subdivision is made on the basis of application to a particular radio direction finder class, e.g., the spinning goniometer or matched twin-channel radio direction finder. The breakdown at this level is not completely comprehensive--only those direction finders of immediate and pertinent interest were considered.

The final criterion for subdivision in the classification is based upon the nature of the particular analog that is used or is proposed for use. As an example, the pulse length analog computer is a system in which the length of an electrical pulse in time corresponds to a direction of arrival. Each analog computer has a number associated with it (see Fig. 1) and each will be discussed in this preassigned numerical order.

One can conceive of situations where the above analog devices could not effectively cope with the data at hand. For such instances, a statistical approach may be advised. Here one could attempt to "best fit" an idealized pattern to that which is observed. Three such approaches have been indicated as an extension of the spinning goniometer bearing recorder problem and will be treated later in greater detail.

Digital computers have been subdivided into sector and omnidirectional systems, and further subdivision does not seem indicated at this time. Currently operating radio direction finders must have an analog-to-digital data converter to permit digital computer processing of the data. Any one of the several proposed pulse-type analog bearing computers may serve this purpose, and, accordingly, it is assumed that the satisfactory realization of an analog bearing computer of the pulse type will also realize an analog-to-digital bearing data converter which may then permit digital computer operation.

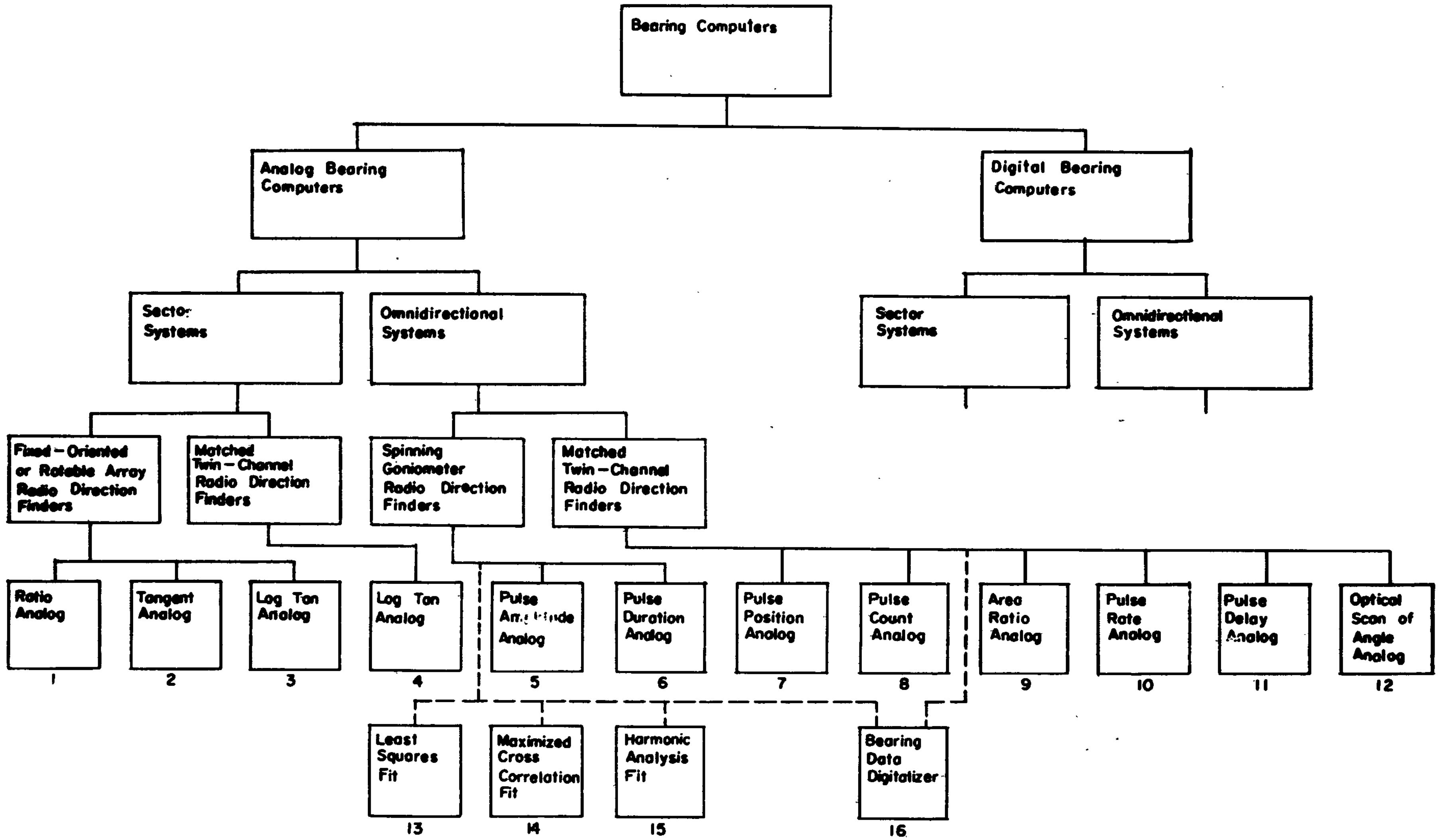


Figure 1. Partial Classification of RDF Bearing Computers

The *ILLIAC* has been made to run in "real time" to process time sequences of data, hence there is little difficulty remaining in connection with digital bearing computer.

3. BEARING COMPUTER PRINCIPLES

The design of any RDF bearing computer begins with the consideration of the nominal radio direction finder data that one has at his disposal. Because the computer will in every case replace the indicator, it is logical to consider the data presentation as it appears on each of the indicators of the several systems. For each such system one must recognise that bearing displays exhibit many instances of split, multiple, or otherwise indefinite bearing indications due to polarization, multipath, and possibly other wave interference effects. For these latter instances one requires some simple characteristic of the bearing indication that is easily and directly measurable and, in addition, is also closest to the truth.

The overlying decision principle that is applicable in all that follows is that one always attempt to obtain the best *single* estimate of the indicated bearing during each *display interval*, i.e., the maximum likelihood estimate. Multiple and/or split decisions are not admitted. By display interval is meant the rotation period of the goniometer rotor, reciprocal of the twin-channel CRDF last intermediate frequency, or the basic sampling period for fixed orientation arrays, respectively.

In the case of the twin-channel cathode ray direction finder, the bearing display is ideally a straight line, but generally an ellipse. Here one assumes that the major diagonal of the bearing ellipse is the best estimate of the bearing at any given instant. Alternatively, the major diagonal of the rectangle that bounds the bearing ellipse may be used under restricted circumstances as the best estimate of the indicated bearing.

In the case of the spinning goniometer system, the bearing display is a pointed, propeller-shaped pattern in the ideal case, but more generally is a blunt propeller pattern with blurred nulls and with possibly multiple or "split" patterns. Under conditions of pulsed signal reception, the pattern is only piecewise continuous, although its complete continuity may often be inferred by extrapolation. For any given display interval, one attempts to symmetrically bisect the resultant pattern in the most stable fashion and the bisector is considered the best single estimate of the bearing for that display interval. Some illustrative examples are indicated in Fig. 2.

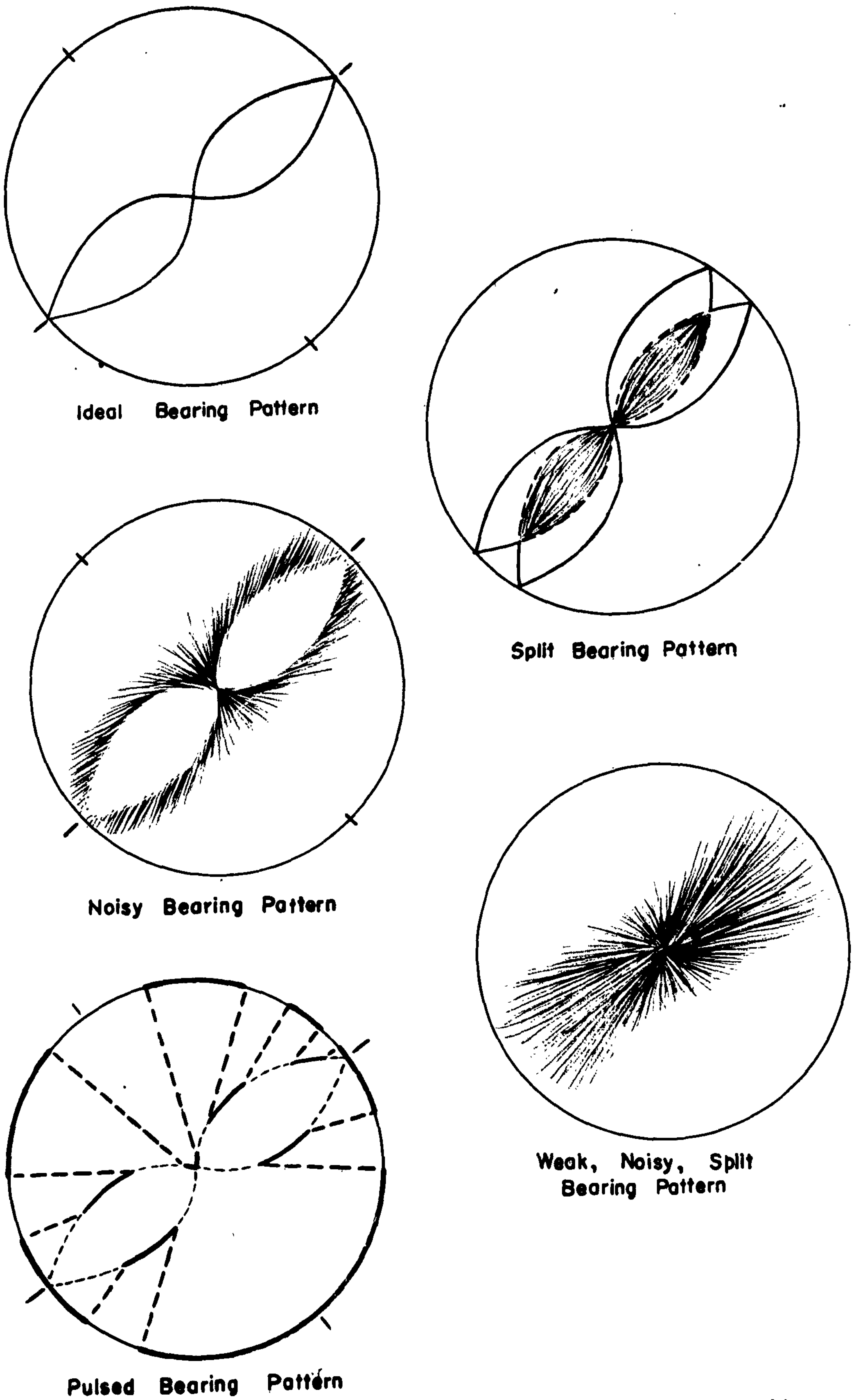


Figure 2 Spinning-Goniometer Cathode-Ray Tube Bearing Display Patterns

In the case of rotatable or fixed-orientation arrays it is the azimuth of maximum output, the minimum signal output, or the symmetrical split or balance that determines the indicated bearing. Analog bearing computers are directly applicable to those array systems for which bearing deviation is linearly related to the output. As an example, a spaced loop array exhibits an almost linear relationship between bearing deviation from the line of the space nulls and the output signal, provided the maximum deviation is limited to plus or minus seven degrees. Ratio circuits are indicated, of course, in order that one may divorce output variations due to bearing deviations from output variations due to signal level fluctuation.

With the above in mind, one attempts to find for the case at hand an analog computer principle or technique that will obtain the "best single estimate of the bearing" over the period of any given display interval, and perform the additional computations that are necessary to the data processing. Thus we seek some analog function of the major diagonal of the bearing ellipse, of the bounding retangle, of the instant of goniometer ''nulling'', or of the instant of best fit of some reference pattern.

Analog computers perform most of the elementary mathematical operations, and, of these, addition, multiplication, differentiation, and integration are particularly attractive. If, for example, the output voltage of a rotating goniometer is differentiated, the times of null coincidence in the ideal case are singled out and emphasized because the greatest rate of change occurs. Of course, differentiation fails for pulsed, split, multiple, and noisy bearing displays. All is not lost, however. These latter cases can be handled by least squares, correlation, or Fourier analysis techniques, and the analog operations of subtraction, multiplication, and integration are applicable . These latter techniques are more complex to devise, but at the same time the signals to be analyzed are also more complex and consequently require more complexity in the operational circuits.

Little has been said here about digital computers. However, most of the above techniques that provide pulsed outputs may be used as analog-to-digital data converters, and from this point conventional digital computer routines for real time operation would be applicable.

It should be recognized that short-time bearing data fluctuate and any indicated bearing obtained over a single display interval is subject to error. Proper time integration is absolutely necessary for smoothing of the bearing data, to obtain a "good bearing." The small aperture direction finder is a "long time constant" system--it is not capable of giving accurate, instantaneous bearings on fluctuating bearings. Proper integration is therefore an absolute necessity.

4. SUMMARY STATEMENTS OF PROGRESS ON THE SEVERAL BEARING COMPUTERS

4.1 Sector-Type Analog Bearing Computers for Fixed Oriented- or Rotatable-Array Radio Direction Finders - A. D. Bailey

4.1.1 The Plane Loop Radio Direction Finder

One of the simplest conceivable sector-type analog bearing computers is that of Fig. 3. Given a loop antenna or an Adcock antenna pair, it

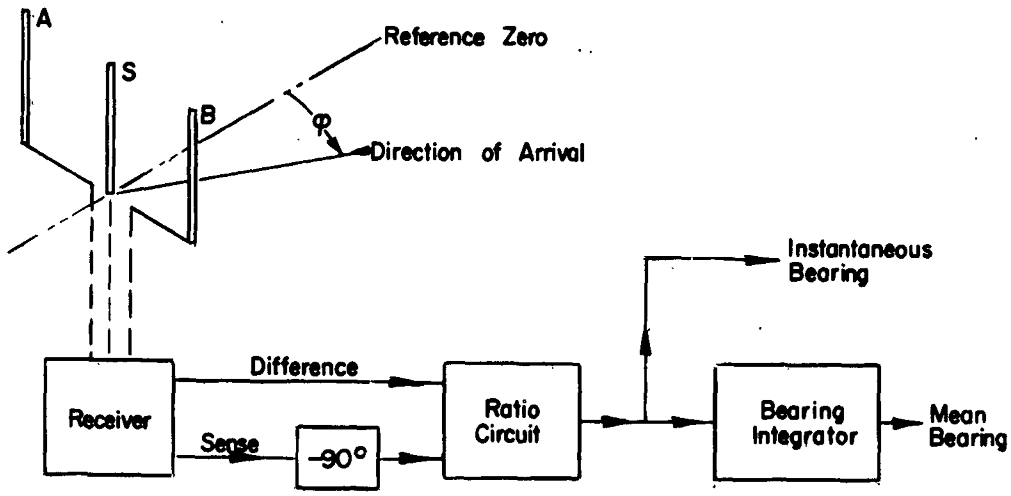


Figure 3 Simplest Conceivable Sector-Type Analog Bearing Computer

can be shown that if the sense antenna voltage has the form $e_s = k_s E\cos\omega t$ (where k_s is the pickup factor and E is the vertical component of field intensity), the loop (or Adcock pair) output is $e_\Delta = (2\pi D/\lambda)E\sin\varphi \sin\omega t$ (where D is the loop diameter or Adcock spacing, λ is the wavelength, and φ is the angular deviation of the arriving ray from the line of the "loop null." The ratio of the loop output voltage to the 90° phase retarded sense voltage is $(2\pi D/\lambda)\sin\varphi$, and for any given frequency the output voltage is linearly related to φ within one percent for all $|\varphi| \leq 14°$. This computer is an example of the ratio analog type.

4.1.2 The Coaxial Spaced Loop Radio Direction Finder

The differential output voltage of a coaxial spaced loop direction finder having small linear dimensions relative to the wavelength is proportional to sin 2φ, where the reference for φ is measured from the line of the "space nulls." Now $\sin\theta \approx \theta$ to within one percent for

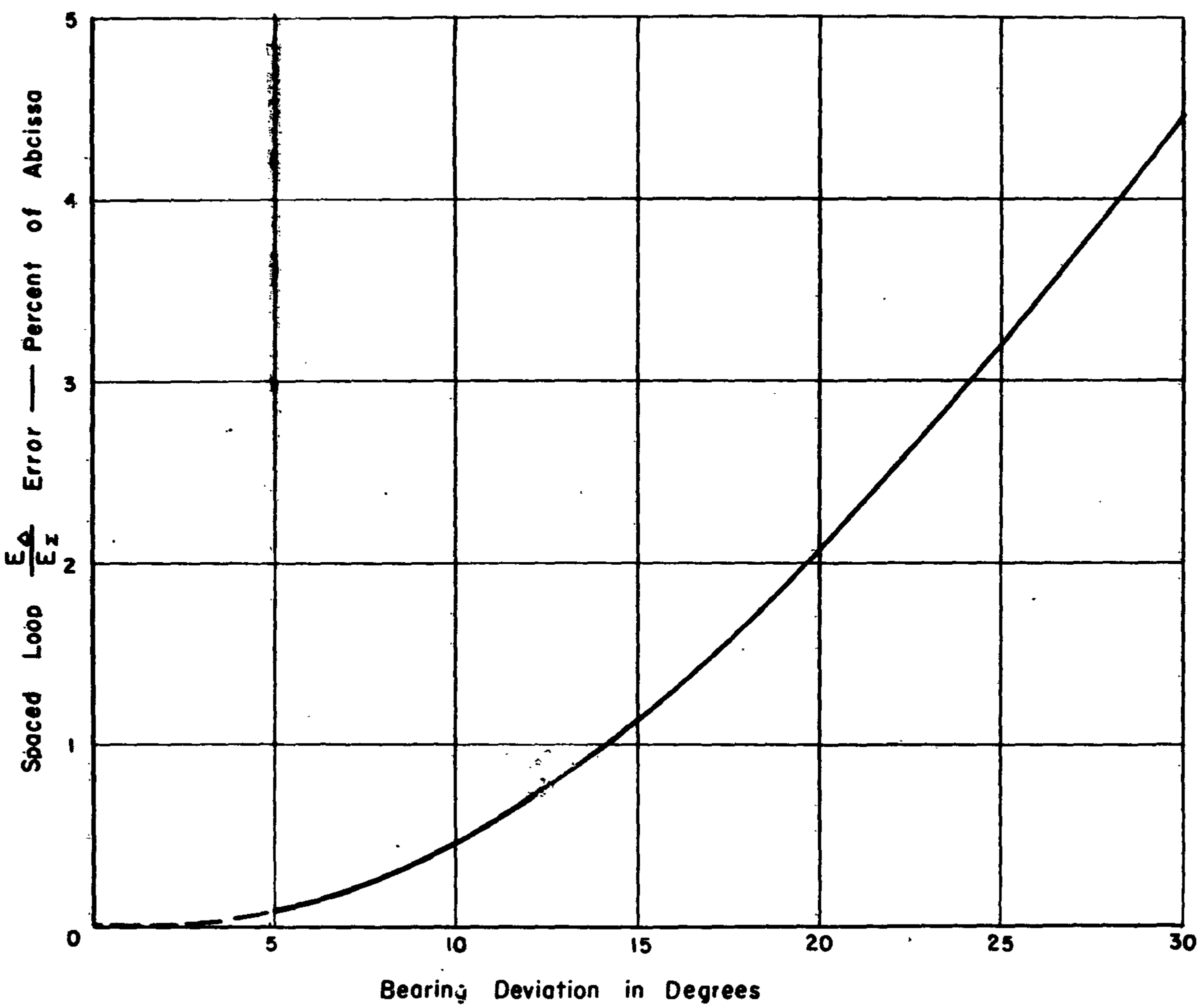


Figure 4. Plot of $\left[2\theta - \frac{\sin 2\theta}{\cos \theta}\right] 100$

$|\theta| \leq 14^{o}$ and hence, for $|\varphi| \leq 7^{o}$, the above output voltage is linearly related to bearing deviation with less than one percent error for the differential output voltage.

A sector-type analog bearing computer could be premised upon the above relation if one could distinguish between output signal variations due to bearing deviation and those due to signal amplitude fluctuation. A sense antenna or the sum output voltage of the coaxial loop antenna will provide a signal which is essentially independent of bearing fluctuation and which is principally a function of the incident intensity. It can be readily shown that the ratio of differential voltage to the 90^{o} phase retarded sum voltage of the coaxial loop system is given by $(D/4\pi\lambda)$ $(\sin 2\varphi/\cos \varphi)$, provided the linear dimensions are small compared to the wavelength. For any given frequency the departure from linearity is given by $[2\varphi - \sin 2\varphi/\cos \varphi]$. Figure 4 is a plot of percent error as a function of bearing deviation from reference zero. It is seen that no more than one percent error is made for bearing deviations within $\pm$ 15^{o} of reference zero.

The basic circuitry for a sector-type analog computer-recorder is shown in Fig. 5. An advantage of the coaxial spaced-loop system over

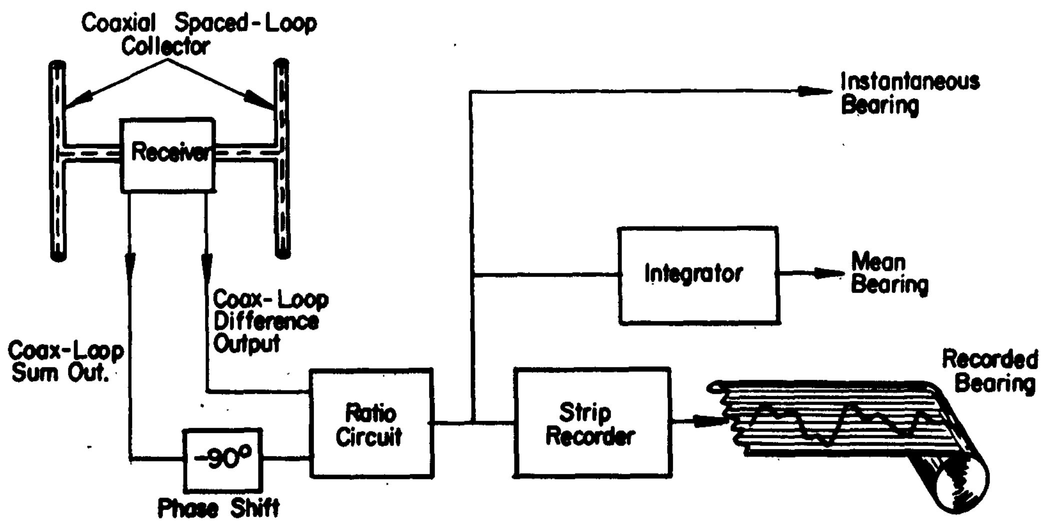


Figure 5. Coaxial Spaced-Loop Sector Type Analog Bearing Computer

the simple loop system is the complete freedom of the former from polarization error in the direction of the "space nulls" or reference zero in the case of the analog computer. The latter system experiences its greatest polarization error along the line of reference zero. The computer is an example of the simple ratio analog.

4.2 Sector-Type Analog Bearing Computers for Matched Twin-Channel Radio Direction Finders - A. D. Bailey and R. L. Sydnor

A third example of a sector-type analog bearing computer is that of Fig. 6. This system will compute bearing deviations with respect to a

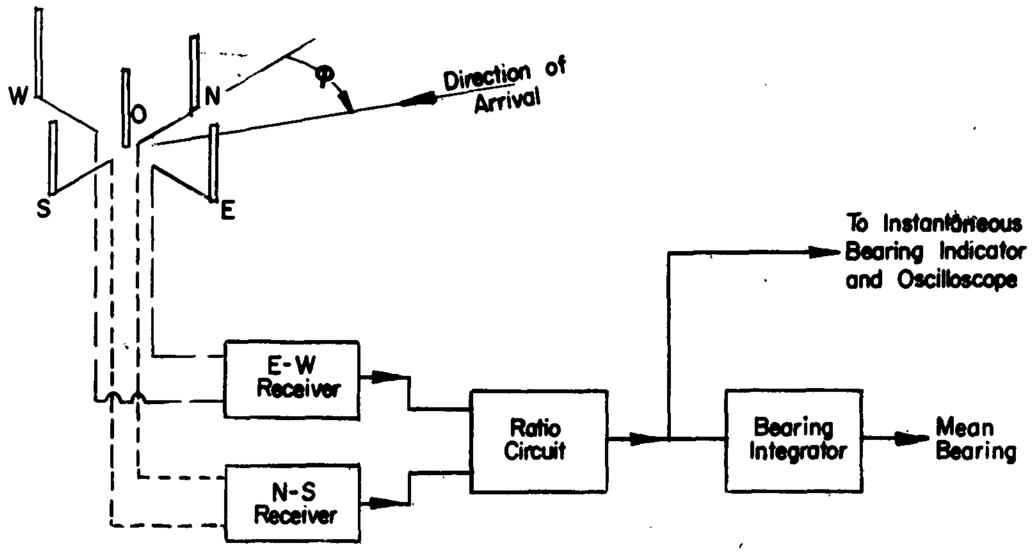


Figure 6 Twin-Channel Sector-Type Analog Bearing Computer

reference zero established by any plane that contains two antennas, i.e., the line of the N-S pair, or E-W pair, or either diagonal of the collector system. The ratio circuit may simply consist of two logarithmic circuits that are *differentially* connected at the output. This would then be an example of a *log tangent analog* computer. It can be shown that for bearing deviations less than ± 10°, less than 0.2° error is experienced in accepting log (tan φ) for (φ - 45°). Alternatively the ratio circuit may consist of a tangent analog computer. For the latter case it can be shown that less than 0.2° error accrues in accepting tan φ for φ provided the bearing deviation is less than 12.5°.

Considerable effort has already been devoted to the development of sector-type bearing computers for matched twin-channel RDF systems and these have been described in detail in earlier reports of this laboratory.[1,2,3] The systems that have been devised all utilized the log tan θ analog and a bearing shifter was incorporated to shift (when necessary) the bearing data of the received signal into the linear range of the computer.

4.3 Omnidirectional-Type Analog Bearing Computers for Spinning Goniometer Radio Direction Finders - R. L. Sydnor

4.3.1 Pulse Amplitude Analog Radio Direction Finder Computer

If the spinning goniometer system were fitted with a device to generate a pulse at the instant of north search, the *time* between this pulse and the null of the receiver output would be directly proportional to the angle of arrival of the signal. By using the north reference pulse thus generated to start the linear run-down of a phantastron or similar device, and using a coincidence circuit to obtain the magnitude of the voltage on this run-down at the instant of null of the receiver output, a pulse is obtained with an *amplitude* which is proportional to the angle of arrival of the signal. Pulse stretching circuits would be used to produce pulses of usable, fixed duration with this amplitude, so that the circuit output could be integrated readily with an electronic integrator.

It has been found that this device produces a usable output with a small error, except in the region near 0° and 180°. These are near the starting and stopping parts of the linear sweep, wherein the linearity is not good. Errors in these regions may be as high as 2° or 3°. Errors in the mid-portion of the sweep are on the order of 0.2°. While these errors are functions of the circuitry, and not of the time-analog, considerable work would be necessary to reduce the end-region errors appreciably.

4.3.2 Pulse Duration Analog Radio Direction Finder Bearing Computer

As in the pulse amplitude analog type of computer, the time between a north reference pulse and receiver output null can be used to produce a fixed amplitude, variable duration pulse with a *duration* which is proportional to the bearing.

An experimental model of such a device has been tested. The error in this system was less than 0.2° over the entire range of bearings.

1. Bailey, A.D. "An Investigation of the Direction of Arrival of Radio Waves," Research thesis submitted in partial fulfillment of the requirements for Ph.D. degree, University of Illinois, 1954.
2. Technical Report No. 20, Contract N6-ori-71 Task No. XV, Electrical Engineering Research Laboratory, University of Illinois, August 1954.
3. Technical Report No. 22, Contract N6-ori-71 Task No. XV, Electrical Engineering Research Laboratory, University of Illinois, August 1955.

In both of the above systems, difficulties occur when the signal out of the receiver has any of the following faults:

1) "blurring," which, if bad enough, causes the null position to be very poorly defined and difficult to detect.
2) noise
3) modulation
4) "split" bearings

(2–4) Each of these produces extra nulls in the receiver output, in which case the above computers accept only the null corresponding to the smallest angle of arrival (with respect to true north).

5) pulsed signals, when the minimum pulse duration is less than the scan time of the receiver, in which case the nulls due to "shut-off" are as "good" as those due to goniometer scan and the desired nulls have a relatively low probability of being included in "signal-on" time.

The effects of modulation may be removed by means of a narrow band-pass filter, with the consequent loss of response speed.

The output of the receiver or computer may be censored electronically so as to eliminate the output when any of the above conditions occur. However, this would appear to be a bearing of 0° and would thus introduce error. A double-integration circuit, or rate integrator could be used to minimize this error.

4.4 Omnidirectional-Type Analog Bearing Computers for Matched Twin-Channel Radio Direction Finders

4.4.1 Pulse Position Analog Radio Direction Finder Bearing Computer - D.L. Bitzer

The major diagonal of the bearing ellipse of the Watson-Watt type cathode-ray direction finder display is generally accepted as the best estimate of the indicated bearing for the particular instant. Accordingly, analog bearing computers that obtain the angle of inclination of the major diagonal of the bearing ellipse are of paramount interest. The following sequence of linear operations on the output signals of the directional channels of a Watson-Watt system are sufficient to determine the angle of inclination of the major diagonal of the bearing ellipse. Let the output voltage of the N-S directional channel amplifier be given by $y = A_1 \cos \omega t$ and the corresponding voltage of the E-W channel be given by $x = A_2 \cos(\omega t + \psi)$. Perform the linear operations necessary to obtain

$$y_1 = A_1 \cos(\omega t + a) \qquad y_2 = A_1 \cos(\omega t + c)$$

$$x_1 = A_2 \cos(\omega t + b + \psi) \qquad x_2 = A_2 \cos(\omega t + d + \psi).$$

Combine to obtain $Q = x_1 + y_1 \qquad P = y_2 + x_2$.

If one adjusts the parameters a, b, c, and d, such that

$$b = a - \pi/2,\ d = c + \pi/2, \text{ and } J = c - a,$$

then it can be shown that the phase angle between Q and P is precisely J plus twice the angle of inclination of the major diagonal of the bearing ellipse. Because J is under the control of the observer, the desired indication may be obtained. Any type of phase measuring equipment may be used to ascertain the indicated bearing. The resultant output voltage is in a functional form that readily permits processing by analog or digital computers. If pulse techniques are used, it is a simple procedure to convert the given data into pulse form. Because the relative position of any such pulse in time is linearly related to the angle of inclination of the major diagonal of the bearing ellipse, the name *pulse position analog bearing computer* has been assigned. The principle has great potential and it has been satisfactorily demonstrated in the laboratory.

4.4.2 Pulse Count Analog Radio Direction Finder Bearing Computer - R. L. Sydnor

By the use of a system similar to the Pulse Position Analog, but eliminating the very fast rise time circuits, the first or "initiating" pulse can be used to turn a gate on, and the second or "brightening" pulse can be used to turn this gate off. By using this gate to pass a series of short pulses of a fixed repetition rate one obtains a chain of pulses having a number that is proportional to the angle of arrival. Several applications can be made of these pulses:

a) The pulses from this gate circuit may be integrated with a long time constant integrator so that the average bearing may be determined from the integrator reading after a fixed length of time.
b) These pulses may be used in a digital computer to calculate the average bearing. When used in this manner, this system makes a relatively simple analog-to-digital converter which is capable of a high degree of accuracy, provided the output frequency of the Watson-Watt set is not too high. It is difficult to achieve accurate time division and to build reliable counters at counting rates over 8 or 10 megacycles. This limits the IF to not over 550 kilocycles, and it should preferably be on the order of 10 to 100 kilocycles to achieve high accuracy in the pulse shaping circuits.

4.4.3 Area Ratio Analog Radio Direction Finder Bearing Computer - A.D. Bailey and A.J. Wavering

In the operation of a sector-type bearing computer for use in conjunction with the twin-channel CRDF, a bearing shifter was needed. Several schemes have been proposed for eliminating the need for the bearing shifter. The several omnidirectional-type computers of this section are pertinent examples. One novel proposal was the procedure of first integrating or averaging the components of bearing data in the separate channels of the twin-channel CRDF *before* combining the data to obtain the indicated bearing. Early consideration of this proposal in its simplest form indicated prohibitive instrumental errors under conditions of wave interference. However, further consideration showed that, if the sense antenna voltage is used as an active criterion for determining the instants for sampling of the two separate channel outputs, the wave interference error is reduced significantly. Figure 7 is a

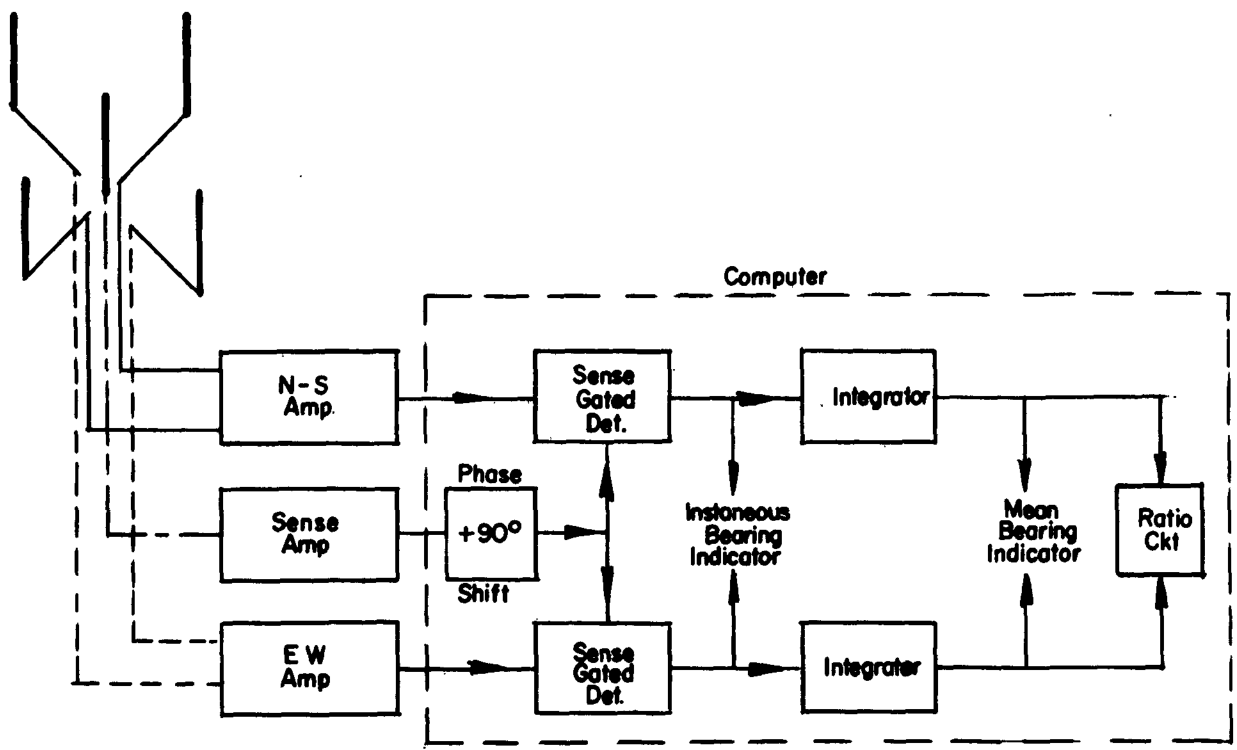


Figure 7. Functional Block Diagram of a Proposed Sense-Gated Separate-Channel Averaging Radio Direction Finder

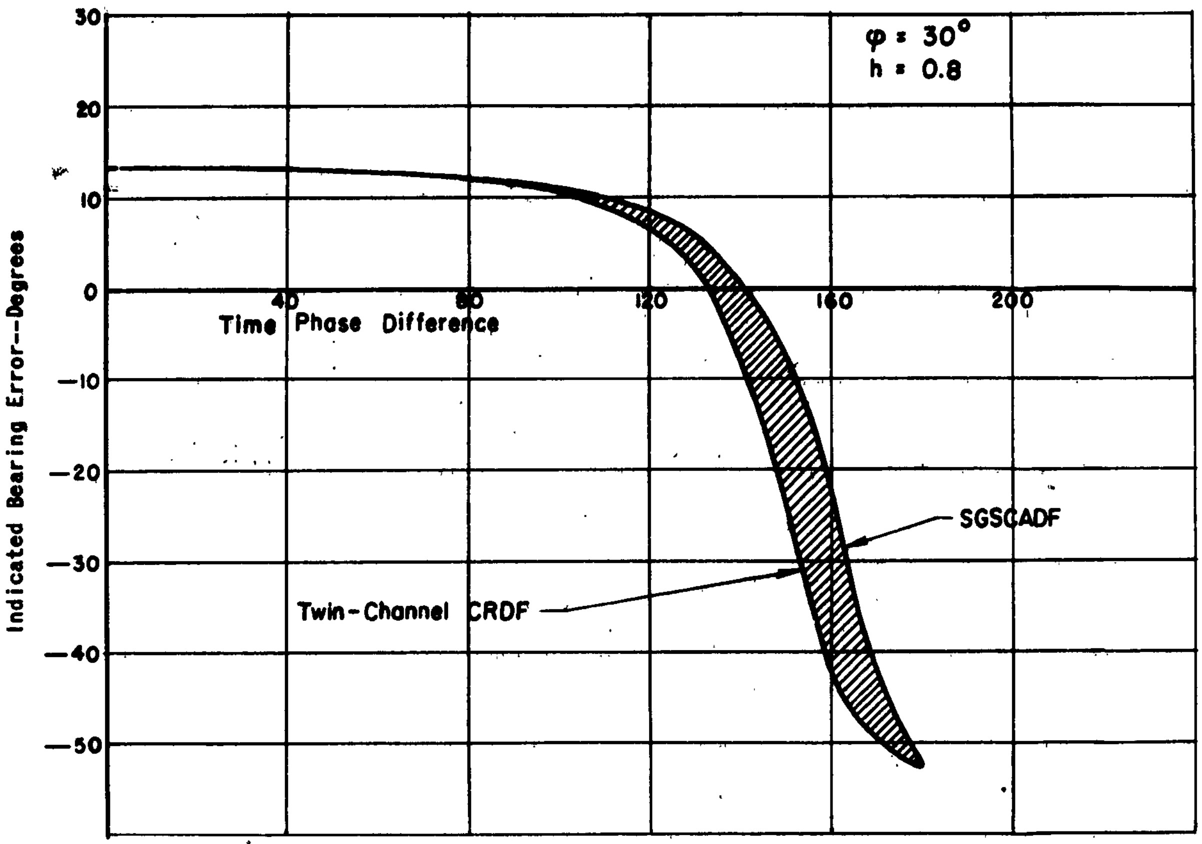


Figure 8. Two-Ray Wave Interference Error Characteristics--30° Azimuthal Separation

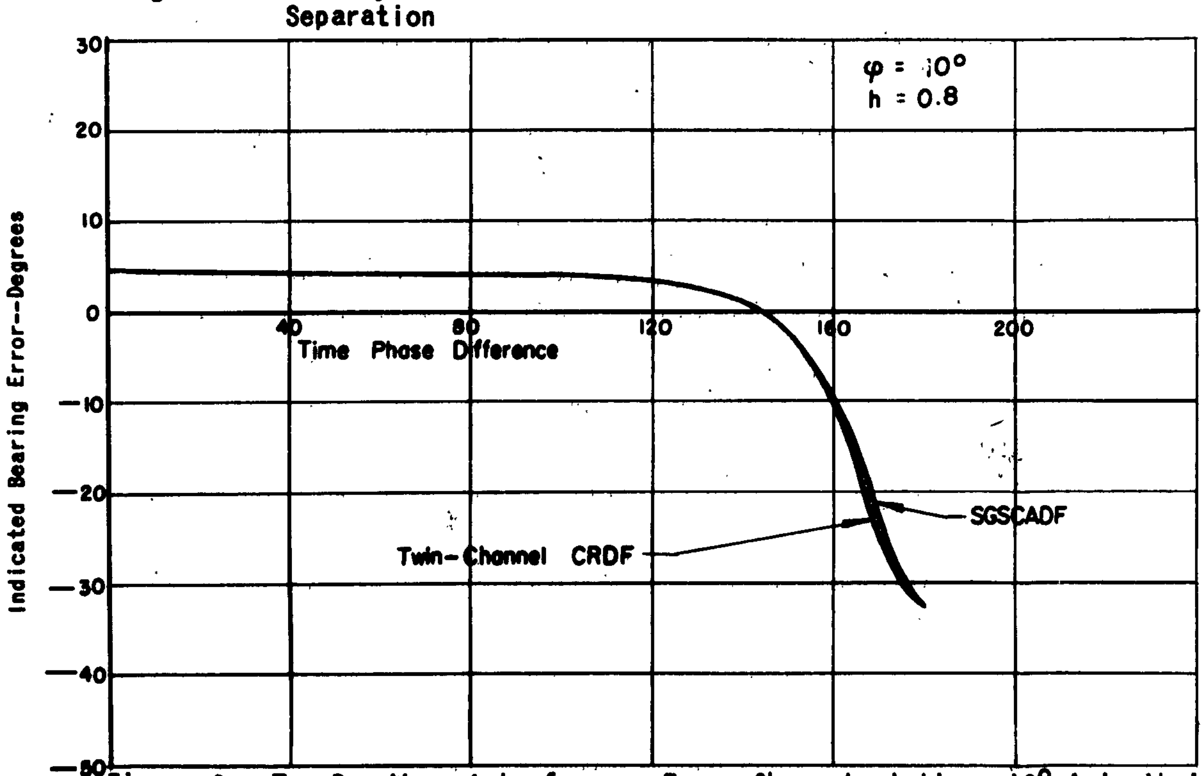


Figure 9. Two-Ray Wave Interference Error Characteristics--10° Azimuthal Separation

block diagram for the circuitry of the device. Figures 8 and 9 are comparative error curves for the sense-gated separate-channel averaging system and the conventional twin-channel cathode ray system. The details of the system are to be given in a separate report. The fact that there is selective rectification of the intermediate frequency amplifier waveforms of the separate channels followed by integration has suggested the "area ratio analog bearing computer" designation.

4.4.4 Pulse Rate Analog Radio Direction Finder Bearing Computer - R. Sydnor

An alternative to the Pulse Count Analog would be to turn a flip-flop circuit on and off with the "initiating" pulse and "brightening" pulses, detect and filter the output of the flip-flop, and use the DC thus obtained to furnish the plate return voltage of a phantastron. This scheme would produce a series of pulses having a repetition rate proportional to the angle of arrival. A direct-reading frequency meter then would indicate the bearing. These pulses could be integrated by conventional integrator circuits, or could be used in a digital computer to determine the average bearing. However, the range of such a system is quite limited because of the characteristics of the phantastron. The limit is probably a range of 300 to 1 in frequency.

4.4.5 Pulse Delay Analog RDF Bearing Computer - A. D. Bailey

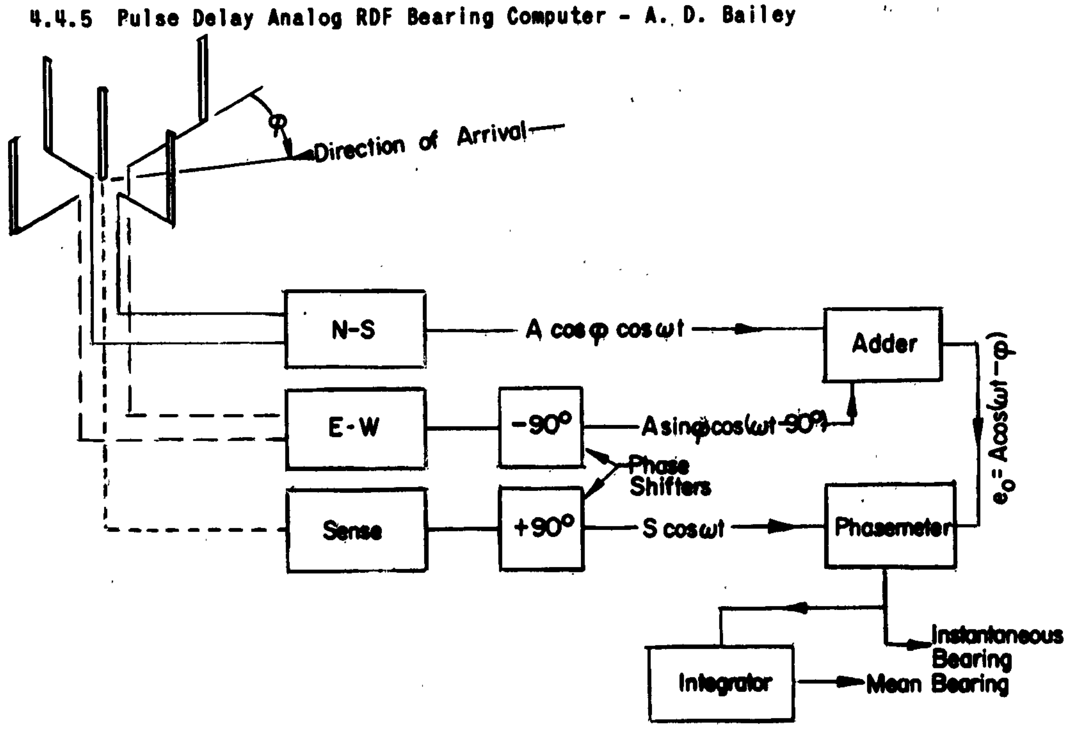


Figure 10. Pulse Delay Analog RDF Bearing Computer

An analog bearing computer of the omnidirectional type is shown in Fig. 10. An adcock array, a sense antenna, and three matched channel receivers are required. The computer consists of the two phase shifters, a linear adding circuit and a device or means (phasemeter) for determining the phase difference between the phase-advanced sense voltage and the adder output. For the case of a single arriving ray there is no error. The phase difference is the bearing--unambiguously determined. For the two-ray interference case the error is given by

$$\tan^{-1}\left(\frac{h \sin \psi}{1 + h \cos \psi}\right) - \tan^{-1}\left(\frac{h \sin(\psi - \alpha)}{1 + h \cos(\psi - \alpha)}\right)$$

where h is the relative amplitude of the two interfering signals, α is the azimuthal separation, and ψ is the time phase between the two signals--both assumed to have the same frequency. The mean error function of time is zero. Hence time integration will give the bearing of the stronger signal. Figure 11 compares the two-ray wave interference error functions of the conventional Watson-Watt type CRDF and the proposed system. The particular case is for relative signal amplitude of 0.5 and an azimuthal separation of 30°. The majority of cases have much smaller angular separation and there is little significant difference between the error functions for such cases. If the E-W channel voltage had been advanced in phase by 90°, the error curve would have shifted 30° to the left of its given position in Fig. 11.

The output of the phasemeter may be presented as a time series of double pulses where the time delay between the first and second pulses of each pair is linearly related to the indicated bearing. The designation of "pulse delay analog" is accordingly assigned to the system.

The need for the third matched channel radio receiver may be circumvented by performing additional linear operations on the N-S and E-W channels to obtain a resultant signal which has the same phase as the 90° phase advanced sense voltage. It can be seen by inspection that if the *amplitude* variation of either directional channel voltage is smoothed out, one has immediately the desired signal. Such smoothing is done, for example, in the limiter circuit of an FM receiver.

The system developed by Mr. D. Bitzer and described earlier under Section 4.4.1 is another procedure for eliminating the need for the third channel.

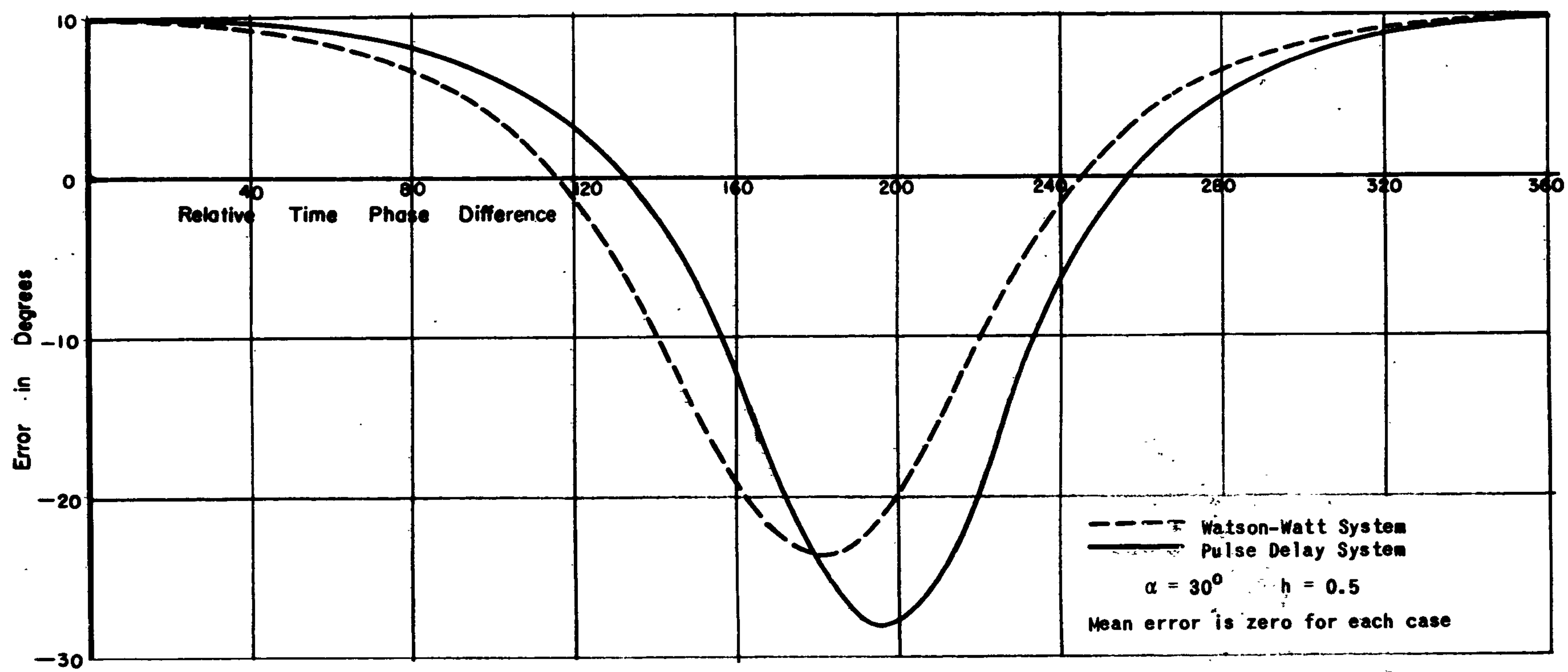


Figure 11. Comparative Wave Interference Error as a Function of Time Phase Difference

4.4.6 Optical Scan-of-Angle Analog Radio Direction Finder Bearing Computer- R. L. Sydnor

Alternatively to taking bearing information from the IF amplifier output, the conventional display may be used as a source of information, the cathode ray tube actually performing an arc tan operation. All that is necessary is some method of obtaining an electrical output which is amenable to computer application. Several methods are possible:

a) A scanning device consisting of a photocell and collimating slits or lenses mounted such as to scan a circle on the face of the cathode ray tube may be used in conjunction with a reference pulse produced by magnetic or other means and rotated on the same shaft as the scanner. Then the angle of arrival is proportional to the time between the reference pulse and the pulse produced when the photocell scans the display. Any of the methods mentioned above for using such a system may be employed for computer work. Because of the rather long response time of photocells, the scan rate of such a system must be rather slow.

b) A circular array of small photocells may be accurately positioned on the screen of the CRT at 1° intervals. The Ektron detectors made by Kodak are admirably suited for this purpose. The beam may be gated on and off to provide sampling of the information. The output from each photocell is connected to an individual gate circuit so that when a particular cell is activated, the gate turns on and produces a pulse which is proportional to the angle corresponding to that particular photocell. The outputs of all the gates may be connected in parallel to produce an output of evenly spaced pulses, having an amplitude which is proportional to the angle of arrival.

These are several examples of the many types of systems which may be devised around the optical scan principle. They have, in common with all others, the fault that any appreciable amount of ellipsing or noise may cause faulty operation due to excitation of large areas of the screen of the CRT. While suitable circuits for resolving these difficulties have been devised, it is probably not worth the large amount of added complexity that is present in these circuits. Other methods work much better with less expense and complexity.

4.5 Application of Statistical Methods (Least Squares, Correlation and Fourier Series Analyses) to Analog-Type Bearing Computers for Spinning Goniometer-Type RDF Systems - A. D. Bailey

It was observed earlier that relatively simple analog computers could be devised for operation with spinning goniometer-type radio direction finding systems. However, the computers were incapable of resolving the bearing for instances of pulsed bearings, noisy bearings, split bearings, and indefinite bearings. It is now proposed to generate an ideal propeller pattern and attempt to find the best single fit between the ideal pattern and the indicated bearing. Two procedures will be considered and these are the "least squares" fit and the "maximum cross-correlation" fit.

In the "least squares" procedure, one attempts to fit the ideal pattern to the actual pattern so that the sum of the squares of differences is minimized. Let f(t) be the indicated bearing function of time and g(t) be the idealized pattern. We are directed to evaluate the integral

$$l(\tau) = \int_0^T [f(t) - g(t-\tau)]^2 \, dt$$

over the period of one cycle, T, for different values of τ and take that value of $l(\tau)$ that is *least*. Each value of τ can be put into one-to-one correspondence with azimuthal angle of arrival and accordingly one has an indication of the "least squares" estimate of the bearing.

Figure 12 is a proposed block diagram of the circuitry that will permit estimation to the nearest two degrees and probably less.

In the "maximum cross-correlation" fit, one attempts to fit the idealized propeller pattern to the indicated bearing so that the sum of the products of the two patterns as a function of time is maximized. Again, let f(t) be the indicated bearing function of time and let g(t) be the idealized pattern. By definition, the cross-correlation function is

$$h(\tau) = \int_0^T f(t)\, g(t-\tau)\, dt.$$

and we are directed to find that value of τ that *maximizes* the integral. Each value of τ can be put into a one-to-one correspondence with azimuthal

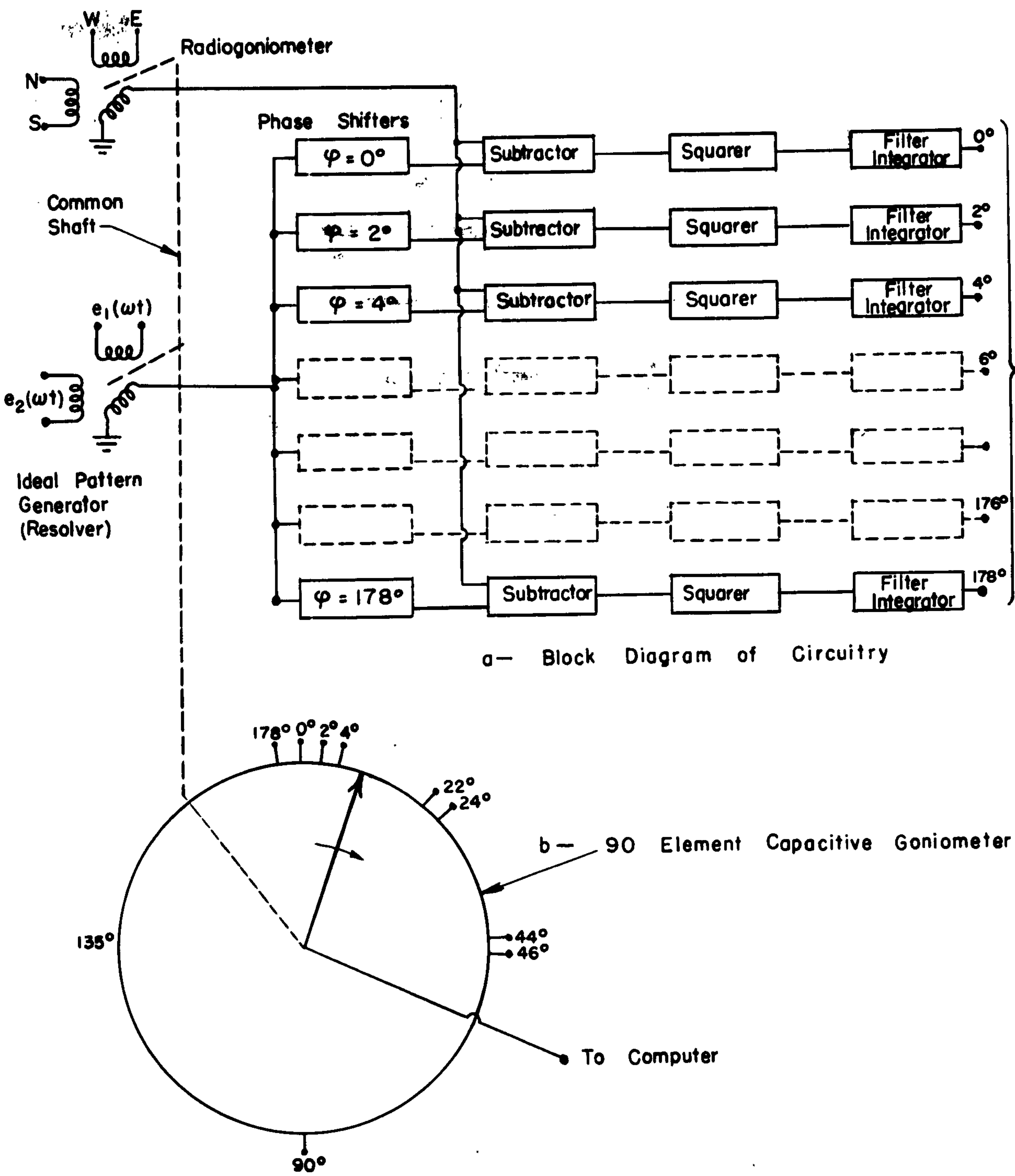


Figure 12. Proposal for Least Squares Estimate of Spinning Goniometer RDF Indicated Bearing

angle of arrival and, accordingly, one has an indication of the maximized cross-correlation estimate of the bearing.

Figure 13 is a proposed block diagram of the circuitry that will permit such estimation to at least the nearest two degrees and probably less.

It is in order now to ask, "Which of the two methods is better?" To show the difference consider the expansion of the expression for $l(\tau)$.

$$l(\tau) = \int_0^T [f(t) - g(t-\tau)]^2 \, dt$$

$$= \int_0^T [f^2(t) - 2f(t)\, g(t-\tau) + g(t-\tau)^2] \, dt$$

$$l(\tau) = \int_0^T [f^2(t) + g^2(t-\tau)] \, dt - 2h(\tau)$$

$$= \overline{\overline{f(t)}} + \overline{\overline{g(t)}} - 2h(\tau)$$

where $\overline{\overline{f(t)}}$ is the sum square value of $f(t)$ and $\overline{\overline{g(t)}}$ is the sum square value of $g(t-\tau)$. Because the sum square values are independent of τ and constant over any period,

$$l(\tau) = K - 2h(\tau)$$

and for small incremental changes

$$\Delta l(\tau) = -2\Delta h(\tau),$$

hence the least squares approach is seen to be twice as sensitive to change in bearing as the cross-correlation approach; however, circuit-wise it is probably easier to carry out the cross-correlation technique.

A third proposal which is the most ambitious and the most complex is to attempt a Fourier analysis of the indicated bearing. The procedure is similar to the cross-correlation attack except that the correlating function becomes $K_n(t)$--a sine wave having harmonic order n, where n is any integer from 1 to N.

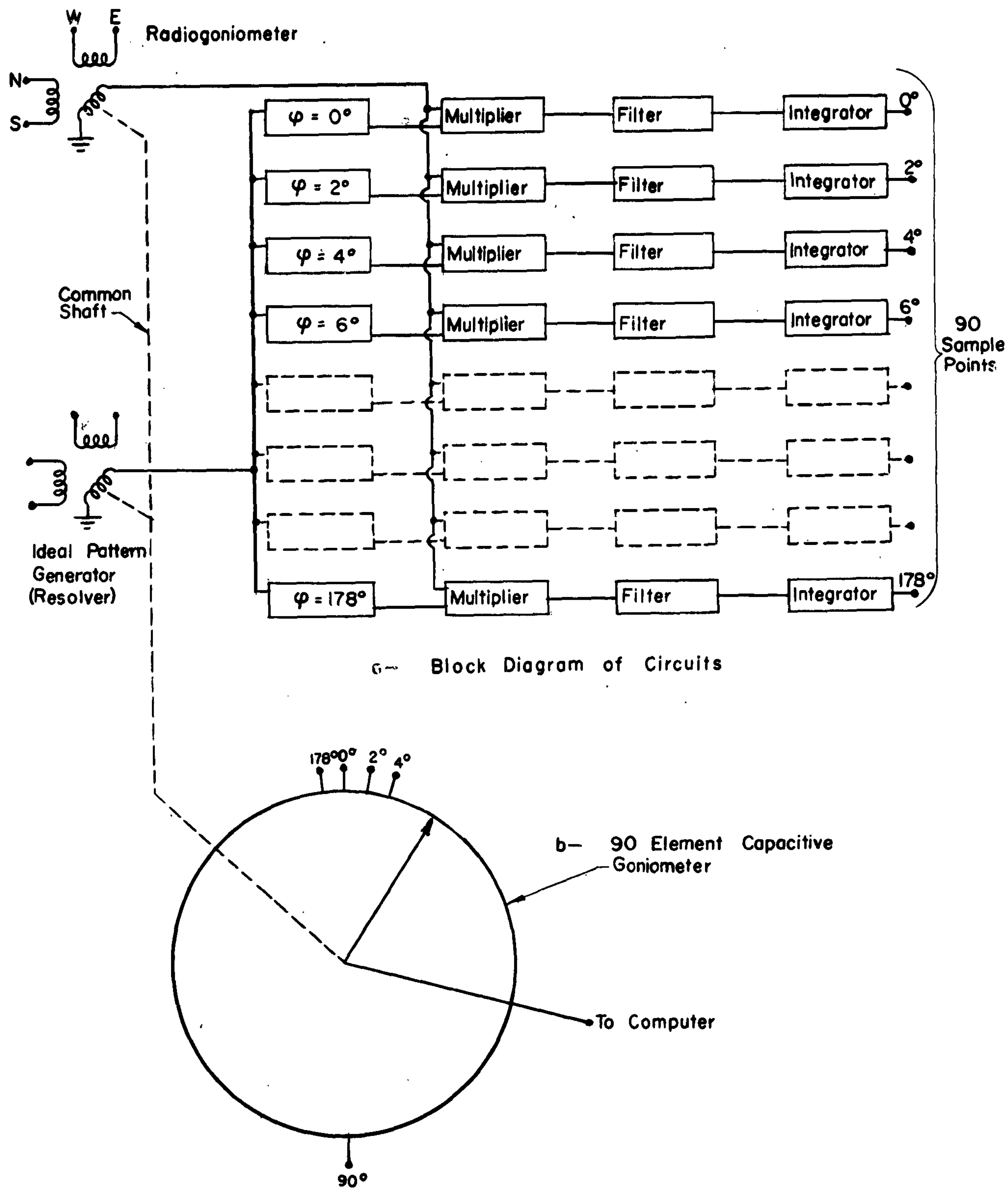


Figure 13. Proposal for Maximized Cross Correlation Estimate of Spinning Goniometer RDF Indicated Bearing

For each value of n we are directed to maximize the integral

$$k_n(\tau) = \int_0^T f(t)\, K_n\, (t - \tau)\, dt.$$

The series of resulting terms

$$\sum_1^N k_n(\tau) \sin n\omega(t - \tau)$$

may be correlated with the corresponding representations of predetermined patterns. The block diagram for such a circuit would be similar to that of Fig. 13 but duplicated N times in order to obtain the totality of $k_n(\tau)$ terms. This is possibly the ultimate in bearing analysis and is little more than an idealized attack at this time.

4.6 Method for Digitalizing and Reading-Out Bearing Indications From A CRT - H. D. Webb

In Fig. 14 is diagrammed a device that may be used to digitalize a bearing indication as shown on the face of a cathode ray tube. The device, or scheme, will work equally well for the Watson-Watt type of bearing indication, either a straight line or an ellipse, or for the ABI propeller-shaped bearing indication. The method makes possible a reduction of operator functioning in that it takes away the tedious procedure of reading and recording the bearings.

In using the device the operator decides on an "average" bearing, sets a cursor to this bearing position, presses a button, and lets the "device" read-out and record the bearing reading. There is a servo motor with the rotor attached to the cursor, so that the servo follows all cursor positions. This servo is coupled to a second servo which positions the read-out system. The button "flashes" a light which activates the read-out system. For the read-out there is a modulated light in a box. Covering the box is a slotted coding disk, which is stationary and properly positioned with respect to the cursor. Over the coding disk is a disk with a slit which is coupled to the second servo. This disk must have proper reference with respect to the slotted disk and cursor. Mounted directly above the slit is a bracket with several photocells, one for each "digit." When the modulated light is flashed, the photocells generate a set of pulses which is decoded to give a bearing read-out recorded as a number. The slotted disk must be

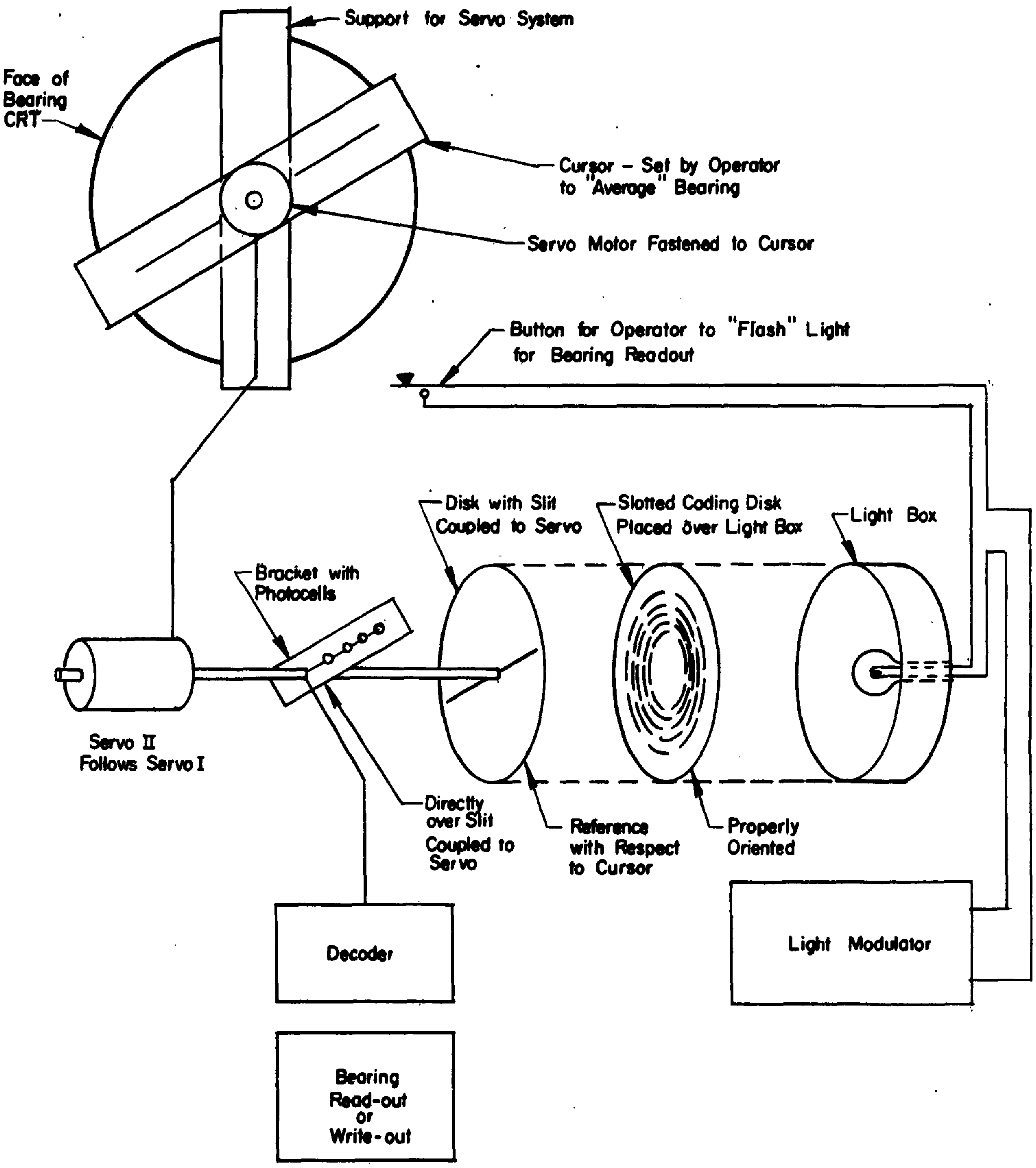
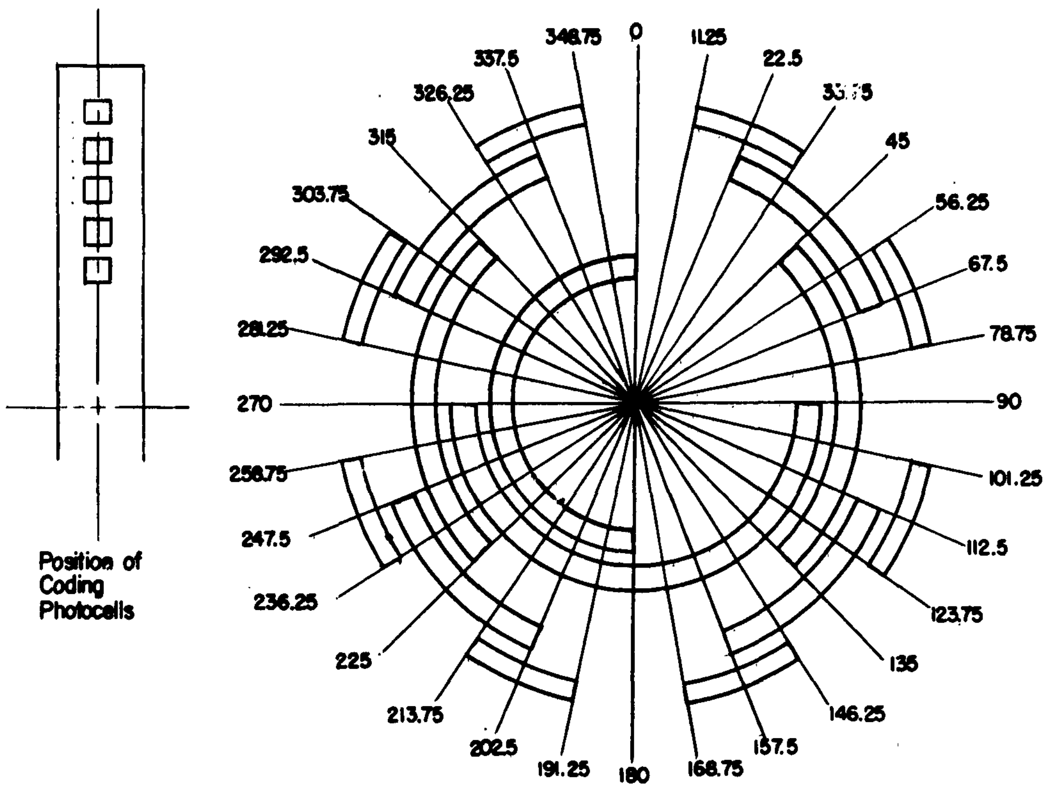


Figure 14 Method of Digitalizing and Reading-Out Bearing Indication from CRT. Watson-Watt Type or ABI bearings may be read out with this device.

made in such a manner that all bearing positions are discretely coded. A possible way of accomplishing this with a binary digit code is shown in Fig. 15.

This system has not been tested. It appears fairly simple in principle, and probably could be made rather easily. It can be made for use with present RDF systems and could be used with pointer indicators by having the bearing servo follow the pointer. The read-out procedure would then be accomplished in the manner just described.



Unambiguous coding disk, every sector is discrete with no uncertainties at interfaces.

FIG. 15. DIAGRAM OF SLOTTED CODING DISK FOR DIGITALIZING BEARING INDICATIONS.

As shown, five coding photocells are needed to give 11.25° sectors. Four more coding photocells and corresponding sets of slots would make each sector 0.703°

5. RECOMMENDATIONS AND CONCLUSIONS

Sixteen proposals have been presented for analog-type radio direction finder bearing computers. Four are of the sector-type and the remainder are of the omnidirectional-type. With reference to the classification shown in Fig. 1, analog types numbered 4, 6, 7, and 9 have been actively investigated. Type number 4 has been reported upon. Types 6, 7, and 9 will be reported upon in greater detail in separate reports that are now in preparation. Types 8, 10, and 11 will be considered in later work on analog-to-digital bearing data converters. The statistical type computers, 13, 14, and 15 are probably too complex for the problems at hand; however, it is recommended that the proposals be tested in principle at least. The digitalizer type 16 requires some judgment on the part of the human operator for its proper functioning during the times of observation. This is in contrast with the earlier computers, each of which has the decision-making process set or built into it prior to time of observation. It is recommended that the two procedures (performance of analog computers with *a priori* instructions versus performance of human-operator-implemented analog computers) be compared.

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