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CONSIDERATIONS IN THE AUTOMATION OF A 'INNING-GONIOMETER RADIO DIRECTION FINDER

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Abstract

This paper discusses some aspects of instrumentation design in making a spinning-goniometer radio direction finder essentially automatic in operation. Also discussed is the application of narrow-band synchronous post-detection filtering for improving the bearing sensitivity.

CONSIDERATIONS IN THE AUTOMATION OF A
SPINNING-GONIOMETER RADIO DIRECTION FINDER

1. INTRODUCTION

There are some applications for direction finders in which it would be desirable to have the system operate automatically. In taking large amounts of data for purposes of establishing statistical parameters this would eliminate the operator variable for purposes of making an analysis of variance. An automatic system would be desirable as a research tool in order to test some of the concepts and operations for feasibility of implementing these into actual field operations. Because of a number of as-yet-unknown parameters it is not presently feasible to make a system completely automatic, but only partially automatic. In order to progress toward the completely automatic system we must first obtain experience with a rather simple system. This report describes the breadboard version of a simple, partially-automated readout system which was adapted to the AN/TRD-4 direction finder. This system is intended to enable us to determine the feasibility aspects of using such a system in a realistic DF environment. There are two principal problems that can be resolved only by experience. These are the detrimental effects of pulsed signals on the bearings read out by an automatic system and the weights that might be assigned bearings, depending on such things as signal level, etc. The considerations set down here may be applied to any spinning-goniometer direction finder (SGDF), however, they have been applied directly to the AN/TRD-4. They would not preclude using the basic equipment in the usual mode of manual operation.

In a narrow-aperture SGDF the simulation of a spun antenna is achieved by balanced amplitude modulation of the incoming wave at a rate set by the spin frequency of the goniometer. If sense voltage (from an omnidirectional antenna) is added to this, the effect is the restoration of the carrier component, and it becomes a conventional amplitude-modulated signal. These two modes of operation will be referred to as the DSB and the AM cases, respectively. The AM wave may be expressed as:

$$e(t) = E(1 + k \cos \omega_1 t)\, e^{j\omega_o t} \qquad (1)$$

Taking the real part:

$$R_e\left[e(t)\right] = E \cos \omega_o t + \frac{KE}{2}\left[\cos (\omega_o + \omega_1)t + \cos (\omega_o - \omega_1)t\right] \qquad (2)$$

The detected envelope of the AM wave is

$$e_d = \left[-(1 + k \cos \omega_1 t)\right], \qquad (3)$$

while the detected envelope of the DSB wave (AM wave minus the carrier) is:

$$e_d = -K_1 \left[1 - \frac{2}{1.3} \cos 2\omega_1 t - \frac{2}{3.5} \cos 4\omega_1 t - \dots \right]. \qquad (4)$$

In the above expressions ω_1 is the modulation frequency of the spinning-goniometer, while ω_o is the center frequency of the incoming radio-frequency wave. It will be noted in (2) that the sideband frequencies are displaced from center frequency by only 30 cps, the spin rate of the goniometer. It is also noted that in the detected envelope of the DSB wave only even harmonics of modulation frequency appear; there is no fundamental component. The detected envelopes of both the DSB and the AM waves are shown in Fig. 1. In this type of system the bearings are determined by the position of the null of the antenna pattern with respect to a point of reference, usually North. It is seen that in

Fig. 1(a) there are two such points, thus the familiar 180° ambiguity, while in Fig. 1(b) there is only one point at which the signal goes through the null in a specified direction of slope of the wave. If it is kept in mind that the figures show the upper halves of the envelopes of the signals as they appear before detection then it is evident that a different situation exists for the DSB and AM cases. In the DSB case the null point of the antenna pattern occurs at a point of zero level in the receiver, whereas in the case of the AM signal this is not true. The antenna null point has been shifted to a somewhat arbitrary level, represented by the dotted line in Fig. 1, which in a nonideal receiver will vary depending on the amount of envelope distortion and other nonlinear effects. This "arbitrary" level may be established in any one of several different ways. It is some kind of average value of the detected waveform. It may be the true average or a weighted average. In this particular case the true average is obtained by simply decoupling with a coupling capacitor in an ordinary amplifier. For this reason when the character of the receiver is changed in such a way that the envelope distortion is affected, then the points at which the sine wave (the displaced zero-crossing points) crosses the dotted line in the changed condition will be different from those in the original condition. This is not true in

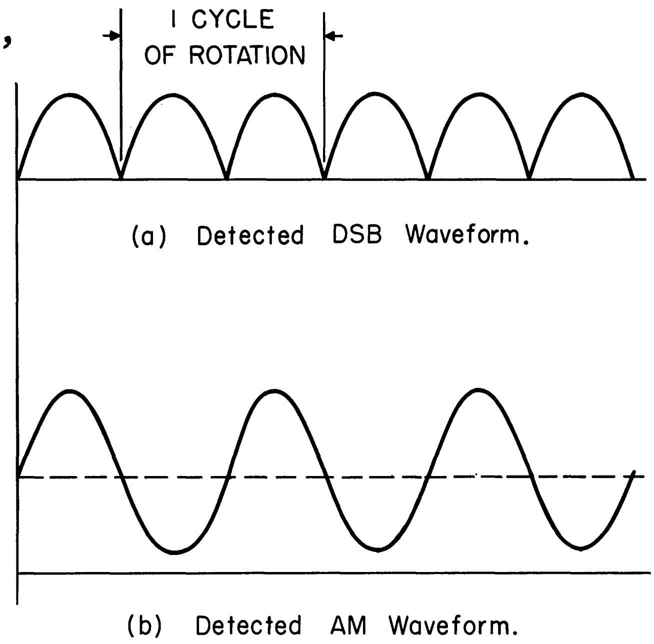


Fig. 1. Waveforms for detected DSB and AM mode signals.

the DSB case, since the null point is at zero voltage, and changing the shape or character of the envelope does not affect this condition. The envelope distortion does change when the gain of the receiver is changed. If the gain control is varied over its range of operation, the bearing in the AM mode will change by several degrees. This represents, at present, perhaps the most obvious shortcoming of the system. It does, however, point up the need for receivers that are designed for purposes such as this as well as for communications. What is needed, in a receiver, is simply one which will alter the incoming signal information as little as possible. This means, in effect, that it must have linear phase and amplitude characteristics with good dynamic range. If the signal is pulsed, then the problem of determining the correct average is more difficult because dc components are introduced by the pulsing action of the signal. These will average out over a period of time, but for short periods will disrupt the bearing determination. In viewing the DSB and AM situations certain things come to mind with regard to performing (1) instrumental measurement of the bearing angle, and (2) improvement of the signal-to-noise ratio by applying narrowband synchronous post-detection filtering.

In the DSB case the null-point region is that of the lowest signal-to-noise ratio in the entire cycle of rotation; thus, in a noisy situation, the null position is imperfectly defined and indeed the whole structure of the wave, that is, the collection of even harmonics which define the structure, is needed in order to determine just where the average null point is located.

The bearing may also be determined by filtering out the second harmonic term in (3) and noting the relative phase of this wave to a reference wave. In fact, an increase in signal-to-noise ratio comparable to the AM case may be achieved, but since an additional ambiguity is introduced this is not so attractive as using automatic sense if one wants to use narrowband filtering. If it is desired to keep the DSB information as is, except for filtering the noise from it, then a comb filter may be used. This may be either the discrete-frequency type or, more likely, the commutated or electro-mechanical type. In either case it is considerably more involved than a simple narrowband single-frequency filter. In the AM case the phase measurement is made on a varying sine wave (for a continuous signal) which has the same fundamental period as the goniometer rotation; therefore the ambiguity is removed, and one may now apply filtering at the basic scan frequency rather than at twice the scan frequency. A description of the means of obtaining automatic sense, the design of the bearing readout system, and a discussion of narrowband post-detection filtering with some operational illustrations follow. An important aspect of the design is its minimum cost with reasonable performance.

2. AUTOMATIC SENSE

The addition of a carrier or sense signal to the goniometer output changes the receiver input to a standard amplitude-modulated signal, modulated at the spin rate. The phase of this modulation relative to the phase of the rotation gives an unambiguous bearing. It can be shown that, if the phase of the injected carrier is within plus or minus ninety degrees of the correct value, it distorts the envelope, but only to the extent of adding harmonics (which may be filtered out) and causing a decrease in fundamental amplitude. It does not affect the relative time phase of the fundamental. If the sense signal is from one to several factors larger than the directional signal and is held to within plus or minus forty-five degrees of the proper value, adequate performance, to within the limitations already mentioned, may be obtained.

The simplest means for obtaining the sense signal is to insert an antenna in the center of the DF array. Since the goniometer output has suffered some loss, as well as being the difference between two signals, the injected sense voltage can easily be made sufficiently large. If the distance across the array is small compared to a wavelength, a fairly simple network will maintain the phase margin within the required limits (Ref. 1). In fact, with rather heavy filtering, satisfactory operation has been obtained in the case illustrated with no additional phasing over the band of operation. The R-390 receiver is conveniently designed with both a balanced and unbalanced input so that the sense signal may be fed directly into the unbalanced antenna input jack.

The instrumentation for producing the proper pattern on the screen of the CRT is depicted in Fig. 2. This unit serves two functions: (1) it full-wave-rectifies the sine-wave output of the receiver to give the usual propeller-type display, and (2) it causes a blanking signal to be applied to the grid of the CRT in such a manner that only one half of the propeller appears on the screen. In the AN/TRD-4 equipment the display is filled in with a 72-kc carrier. Figure 3 shows the usual input to the indicator goniometer during one complete revolution during DSB-type operation. It can be seen that the propeller is described on the face of the tube twice during each revolution. During period T_1 the tube must be blanked during the negative excursions of the 72 kc

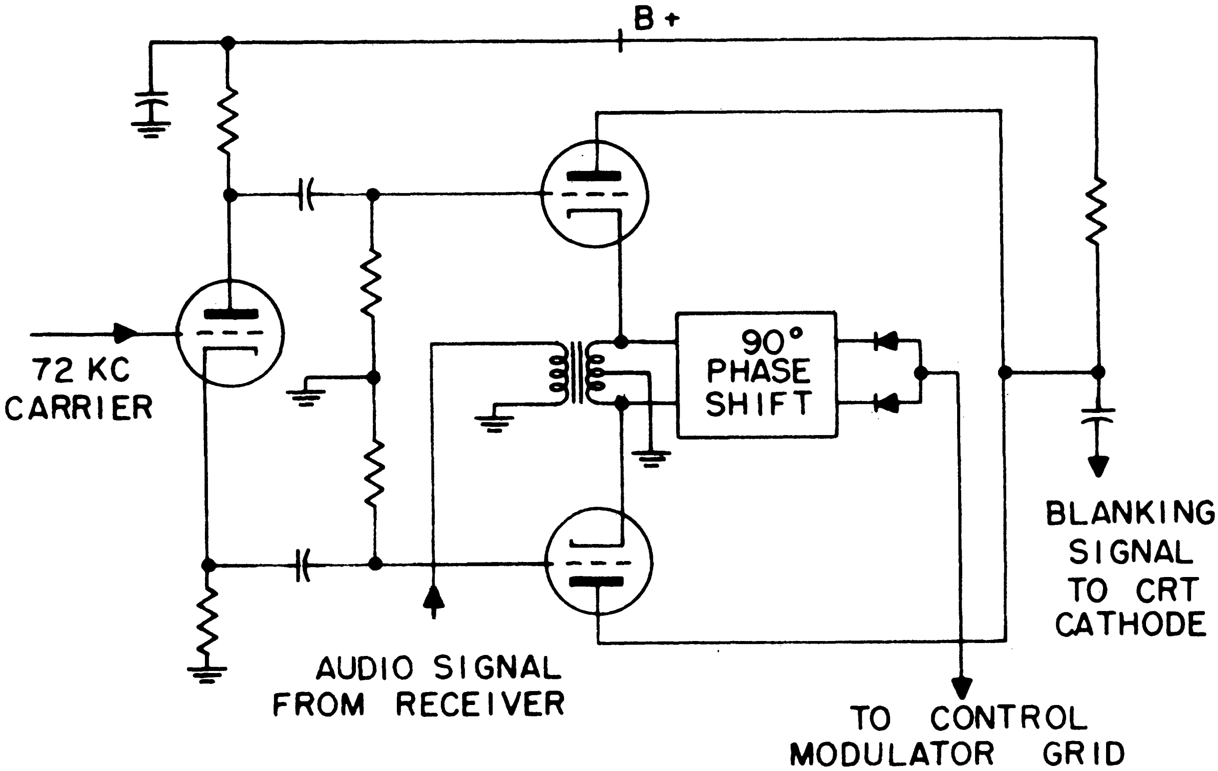


Fig. 2. Automatic sense circuit.

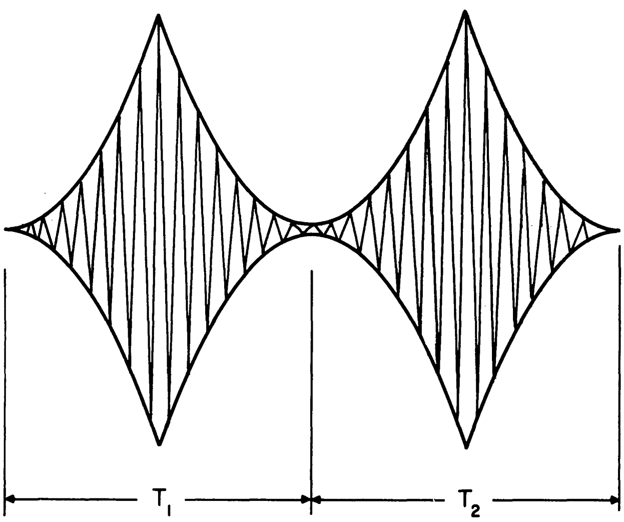


Fig. 3. Input to display goniometer during conventional DSB operation.

carrier. During period T_2, since the goniometer has rotated 180-degrees, the blanking must occur on the positive excursions if the same half of the propeller is to be displayed. It can be seen from the circuit that with no signal from the receiver both triodes will conduct equally, and, since their inputs are 180-degrees out of phase, cancellation will occur in the plate circuit. In the presence of a signal from the receiver (ideally a sine-wave) the tubes will alternately conduct fully and be cut off. It is this alternating operation which causes the proper half of the display to always appear as discussed above. The resultant 72 kc signal, when applied to the CRT grid, blanks during the negative excursions and brightens or enhances the desired half of the propeller during the positive excursions.

3. BEARING READOUT COMPUTER

The basis for the computer design is that of zero-crossing comparison, as has been used by others (Refs. 2, 3). Once the zero-crossings of the reference and DF signals have been determined they may be used to activate either an analog-type coincidence detector or a digital-type bearing computer. It was concluded that for visual monitoring purposes the analog was the more suitable, and for detailed processing of the information the direct digital readout was the more suitable. For the purpose at hand there was no need to eliminate the 180-degree ambiguity from the analog readout.

The analog coincidence detector is fed into one channel of a two-channel Brush Recorder. The second channel is used to record signal strength. The particular Brush Recorder used has a frequency response up to about 50 cps. It is desirable to have an adjustable readout rate in the digital system so that the bearing readout rate can be adjusted to fit the study being made.

For studying the fast-fade variations, Bain (Ref. 4) indicates that one should be able to take at least several bearings per second. Of course the rate for slow fluctuation studies should be much less than this; thus there exists the need for variable readout rate.

Reference is made to Fig. 4, a block diagram of the readout system. The goniometer bearing scale was removed and machined out under the thumb rim, and one-degree slits were cut on the outer surface of the rim with an indexing head. Thus, with a light in the wheel and a photo-transistor on the outside, a tone wheel is available. A properly adjusted slit in front of the transistor is a necessity. The output of the photo-transistor is fed into a two-stage transistor preamplifier and a pulse-forming circuit, then to the counter. There are of course several other available methods for generating and reading out these pulses for bearing indication. The reference generator is a

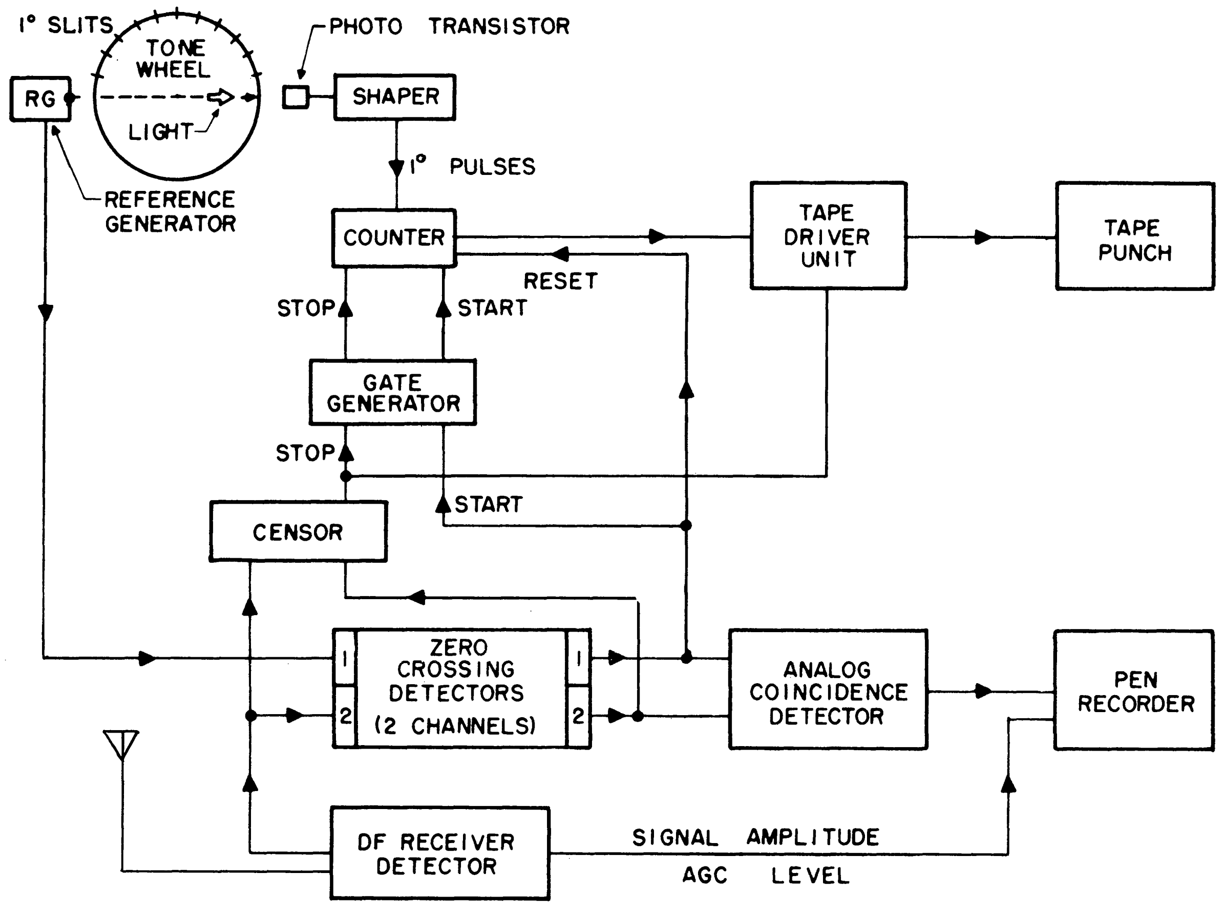


Fig. 4. Block diagram of automatic bearing computer and readout.

small permanent-magnet-type alternator which was built on the end of the goniometer and is coupled directly to the shaft. The output from the reference generator is squared and formed into the start pulse in the zero-crossing detector. The output from the DF receiver is similarly treated in the zero-crossing detector unit. The squaring circuitry outputs from these units are fed to the analog coincidence detector and thence to the pen recorder for the visual record of bearing. The pulse output from the reference channel starts the counter, and the pulse output from the receiver stops the counter. The censor unit at present is to be used as a yes-no stop pulse control depending on signal level. The start pulse is delayed slightly in the gate generator in order that the same signal may be used as a reset control at North position. When the censor unit says "no" then the counter will cycle on a 360-degree count until the censor unit says "yes". The reference point, North in this case, may easily be moved to some other point around the compass if desired. The problem here is that of averaging through the cut point. For example, if the bearings were symmetrically distributed about North, then the average of these would be South, obviously the wrong answer. One simple solution to this is to have two cut points with two counts and pick the output that is farthest removed from a cut point. The counter output is then fed to the tape-punch driver, which is controlled by the censored stop pulse, and thence punched onto paper tape. Since this unit is to be transistorized, the Tally 8-channel punch was chosen. Eight channels allow a sector coverage of 255 degrees. In order to cover the full 360 degrees, sequential channel coding must be used, which still allows a maximum of 30 readings per second.

4. NARROWBAND SYNCHRONOUS POST-DETECTION FILTERING

The application of NBSPD Filtering has been mentioned in the literature (Ref. 5). However, little seems to have been done to exploit its potential to improve bearing sensitivity. In fact, as Busignies and Dishal state, it appears that the capability of utilizing this is one of the fundamental advantages of this type of DF system over the co-operative navigational-type system. This stems from the simple fact that in the great majority of situations the determination of the average direction of arrival over periods even as short as just a few seconds is a very narrowband process. From an informational point of view the channel capacity required, in terms of bandwidth, is approximately the frequency of variation of the bearing one wishes to observe. This is of course determined exactly by the reading time of the specific receiving system in use. This means that for most purposes a bandwidth of a few cycles (say less than ten) will be adequate, unless there is some wideband information in addition to the bearing information, or if one is interested in studying the instantaneous rapid fluttering effects caused by wave interference, or for other specialized types of signals. There is more to be gained from a given factor of bandwidth reduction in the pre-detection circuitry than at post-detection. By the same token this is much more difficult to achieve. In applying post-detection narrowing if BW(IF) is the bandwidth of the IF in the receiver and BW(A) is the modified audio bandwidth, then the following relation gives the input carrier ratio for equal output in terms of bearing determination. This is done for purposes of comparison to the operational illustration shown later.

$$\text{Carrier Ratio} = K \left[\frac{BW(IF)}{BW(A)}\right]^{\frac{1}{4}} \qquad (5)$$

Substitution into (5) of the values:

$$BW(IF) = 2000 \text{ cps}$$

$$BW(A) = 5 \text{ cps}$$

gives

$$CR = K \left[\frac{2000}{5}\right]^{\frac{1}{4}} = K(400)^{\frac{1}{4}} \cong K(4.475)$$

This means a difference in terms of db of

$$CR \text{ Diff (db)} = 20 \log 10 \; (4.475)$$

$$= 13.0 \text{ db.}$$

Results from operation in this manner with automatic sense are given for purposes of illustration in Figs. 5 through 11. A single tuned circuit with center frequency at the rotational frequency of the goniometer is placed after the detector. This unit has adjustable bandwidth with the narrowest position at about five cps. This is the condition under which the pictures were made. This gives a reading time of about 140 milliseconds, which allows observation of bearing changes up to about seven cps.

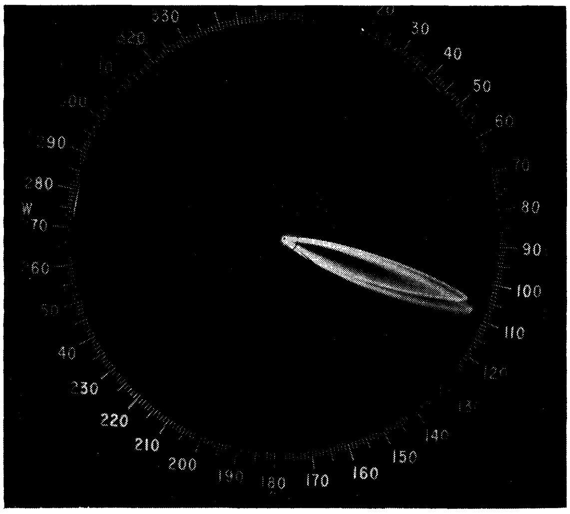
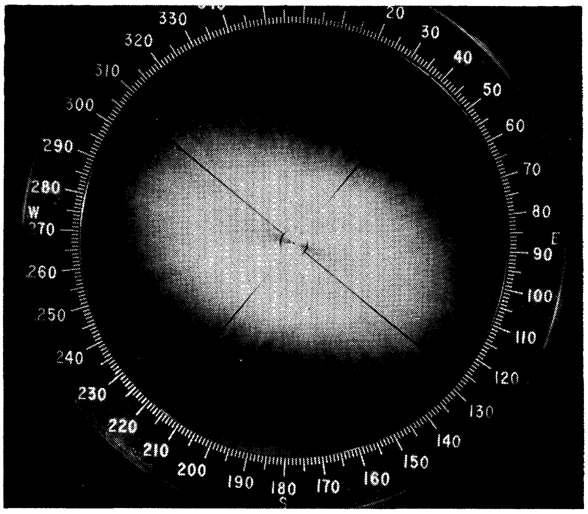
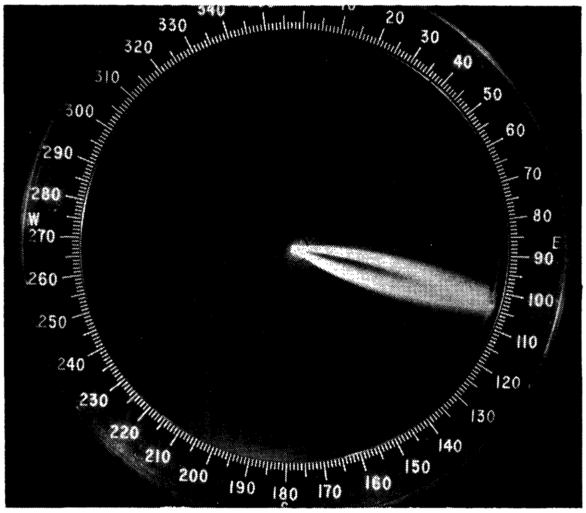


Fig. 5. Bearing indication on modified AN/TRD-4 for strong stable signal.

Figure 5 shows a strong stable signal in the broadcast band, station WJR in Detroit, Michigan. The double tip is due to imperfect fold-over in the automatic sense circuit, which is being corrected.



(a)



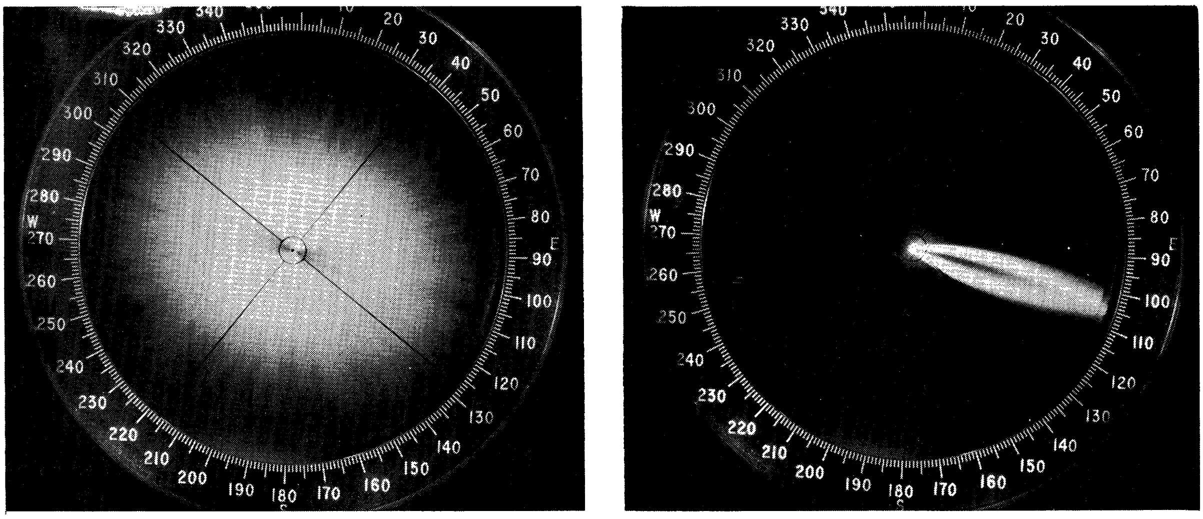
(b)

Fig. 6. Comparison of operational results from
(a) conventional AN/TRD-4 and
(b) modified AN/TRD-4.

In Fig. 6, (a) and (b) are, respectively, the conventional TRD-4 display and the modified display, in which the target signal, at 6.93 mc, was adjusted in level until one could just estimate a bearing at around 105 degrees, on the conventional TRD-4 display. These shots are all 4-second time exposures.

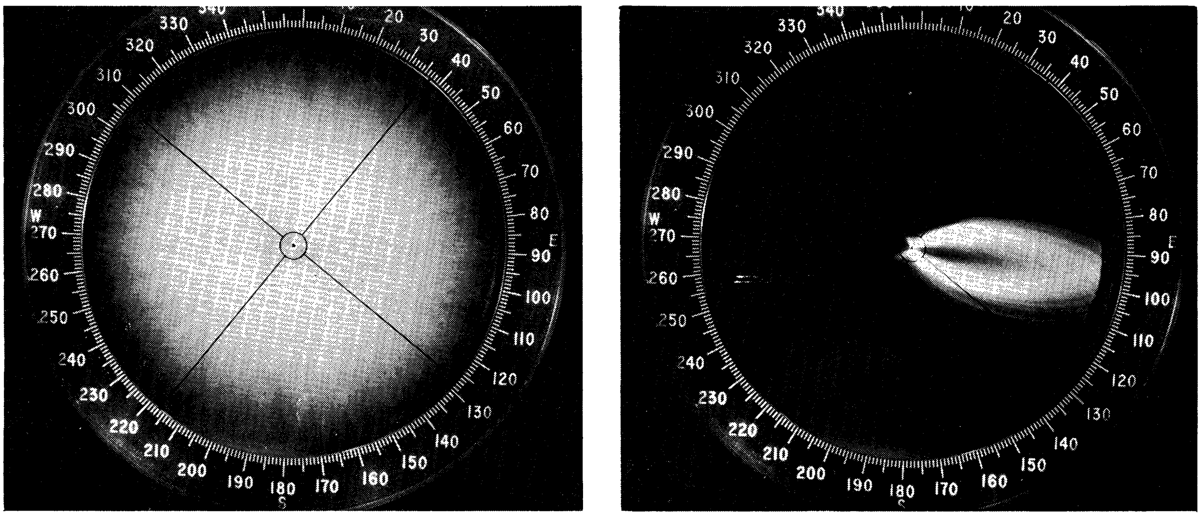
In Fig. 7, the signal level is reduced by 3.6 db, at which point the TRD-4 display is just barely discernible as a bearing indication.

In Fig. 8, the signal level is reduced from where it was in Fig. 6 by 9.6 db, which leaves nothing in Fig. 8(a), although it can be seen that there is still quite a good bearing indication in Fig. 8(b). The limit is reached by reducing the signal level by another 6.9 db, producing Fig. 9. One can still get a fair estimate of the bearing, and the pattern, which resembles a one-sided halo, is developing into the characteristic background for this mode of operation. With no



(a) (b)

Fig. 7. Comparison of operational results from (a) conventional AN/TRD-4 and (b) modified AN/TRD-4. Signal level reduced by 3.6 db from that in Fig. 5.



(a) (b)

Fig. 8. Comparison of operational results from (a) conventional AN/TRD-4 and (b) modified AN/TRD-4. Signal level reduced by 9.6 db from that in Fig. 5.

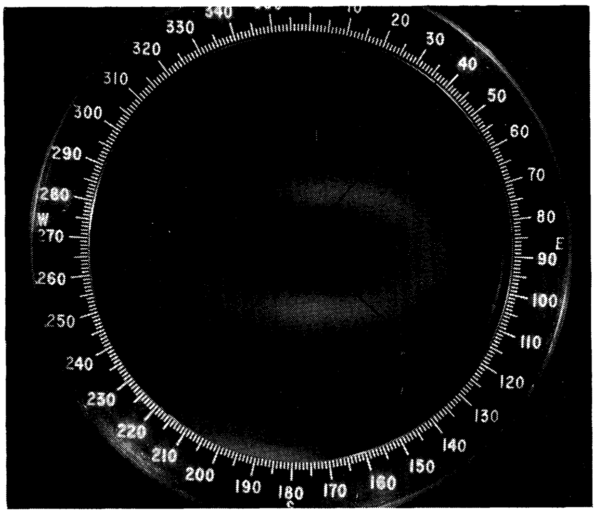
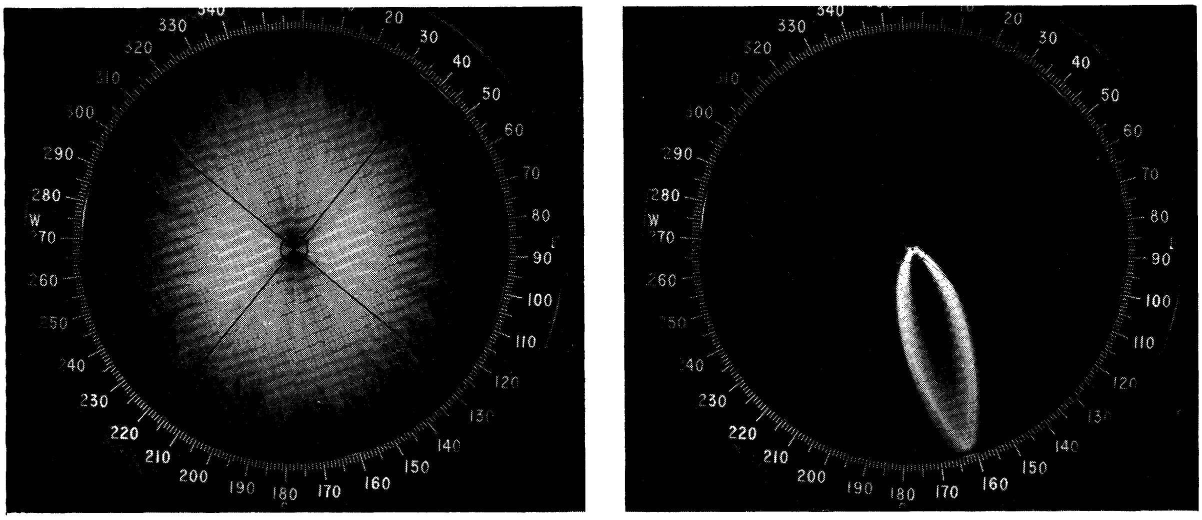


Fig. 9. Threshold condition for the modified AN/TRD-4.

signal there is a faint green background level on the CRT face. When a signal is tuned in the propeller half suddenly rises out of the hazy background as though by intensity modulation. The diffe- rence between the input signal level for Fig. 6 and that of Fig. 9 is 15.6 db.

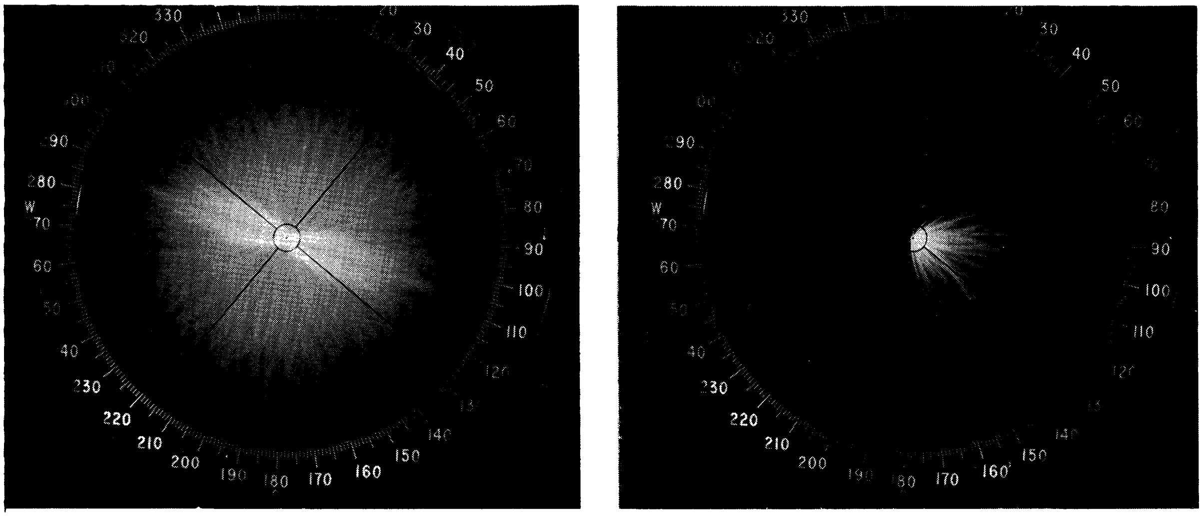
Figure 10, depicts the appearance of a typical, fairly-weak FSK signal at 6.901 Mc.



(a) (b)

Fig. 10. Typical, weak FSK signal, as obtained from
(a) conventional AN/TRD-4 and
(b) modified AN/TRD-4.

Figure 11 shows the target signal at 6.93 Mc being pulsed at 20 cps. This picture is included only for the purpose of illustrating



(a) (b)

Fig. 11. Pulsed signal, as obtained from (a) conventional AN/TRD-4 and (b) modified AN/TRD-4.

that the system does work on pulsed signals. The picture does not give the reader the same effect as can be obtained from direct viewing because of the integration effects of the film over the four-second exposure. The general opinion of those who viewed the live display was that they were either the same or that the modified version was slightly better.

5. STATUS AND SUMMARY

The system shown in Fig. 4 has been breadboarded and tested with the results as here described. The findings are very tentative and incomplete, however, they are sufficiently encouraging that we feel that a more integrated system should be built with some additional refinements for further feasibility tests. It has been demonstrated that the partial automating of an SGDF may be done in a very inexpensive and simple manner. The principal shortcoming, that of the deleterious effects of the receiver distortion being introduced by using automatic sense, is one that can be at least partially overcome by making suitable changes in the receiver design.

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