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COMPARISON STUDY OF GONIOMETER AND TWIN-CHANNEL RDF SYSTEMS

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ABSTRACT

This report is a comparison of the Watson-Watt and goniometer radio direction-finding systems as applied to the tactical situation, where mobility and ease of maintenance are prime requirements. Speed of response, sensitivity, circuit complexity, etc. are discussed. It is concluded that the goniometer system, if properly designed, offers distinct advantages over the Watson-Watt system.

COMPARISON STUDY OF GONIOMETER AND TWIN-CHANNEL RDF SYSTEMS

1. INTRODUCTION

This report discusses some of the considerations involved in comparing the twin-channel or Watson-Watt radio direction finding system and the goniometer system. It is assumed that certain requirements of mobility and ruggedness must be met.

Since, ideally, the instantaneous bearing indicated by the two systems is identical for identical signal environments, the comparison reduces to the discussion of certain practical considerations which make it more or less difficult to realize the ideal behavior of each system.

While the pros and cons of these systems have been treated in the literature and in discussion for years, it is hoped that some of the considerations mentioned here, while not novel, may, by being reduced to print, be given a more objective appraisal than has often been done in the past.

2. DEFINITIONS

2.1 Twin-Channel

A two-channel radio direction finder will be defined as follows. Referring to Fig. 1, the NS and EW antenna voltages are fed to individual receivers A and B. Here they are amplified, perhaps shifted to an IF frequency and applied respectively to the vertical and horizontal plates of a cathode ray tube. The resultant display is an ellipse whose major axis indicates the bearing. The two receivers, together with any ancillary circuits and equipment for sense determination, etc., will be termed a Watson-Watt, or two-channel, system for the purposes of this report.

2.2 Goniometer

A goniometer system will be defined as follows. Referring to Fig. 2, the outputs of the EW and NS antenna pairs are multiplied by V_1 and V_2, respectively, in the boxes marked "MULT." V_1 is a sine or square wave with a basic repetition rate in the audio range, and V_2 is a similar signal shifted in time by one quarter of a period. The two resultant signals are added together in the box marked "SUM" and fed to an AM receiver, where the composite signal is amplified and detected. The multiplications, the summing operation, and the generation of V_1 and V_2 are all done in the mechanically-spun goniometer in the usual system. The time interval between the zero crossings of V_1 and those of the fundamental component of the receiver output gives the bearing. Since, however, the fundamental frequency of this signal is twice that of V_1 there is an ambiguity involved which gives the bearing to within $\pm$ 180 degrees. Or, to look at it in the usual way, the basic antenna pattern is a figure eight with identical lobes. The addition of a sense signal resolves this ambiguity. The above, together with any auxiliary circuits for sense determination, readout, etc. will be said to constitute a goniometer system for the purposes of this report.

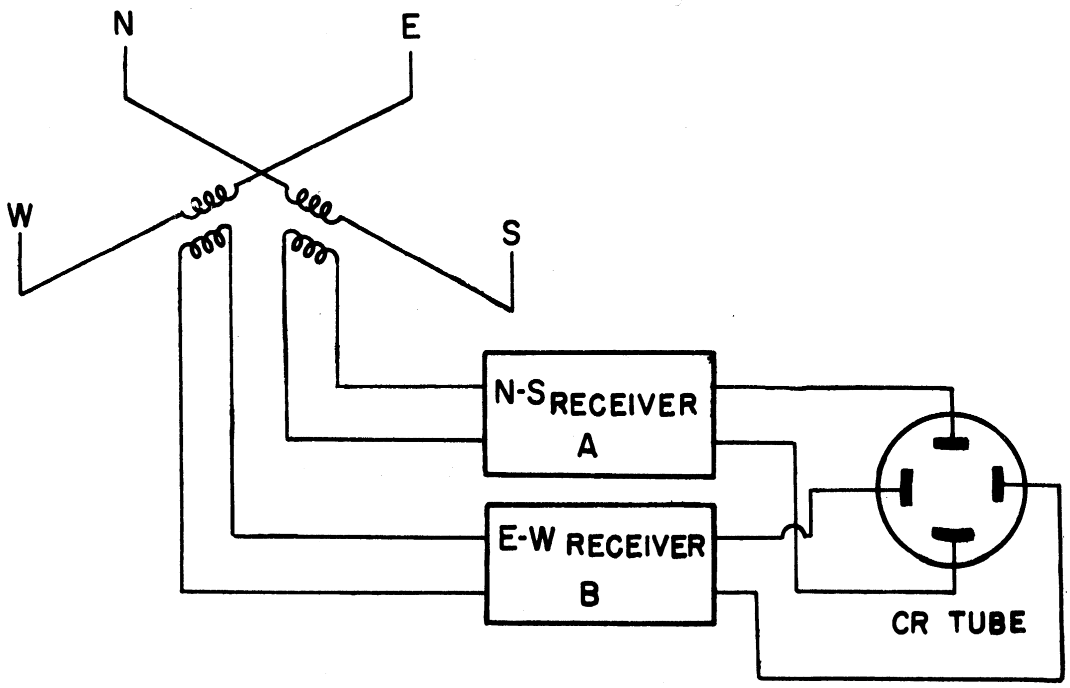

Fig. 1. Twin-channel system basic block diagram.

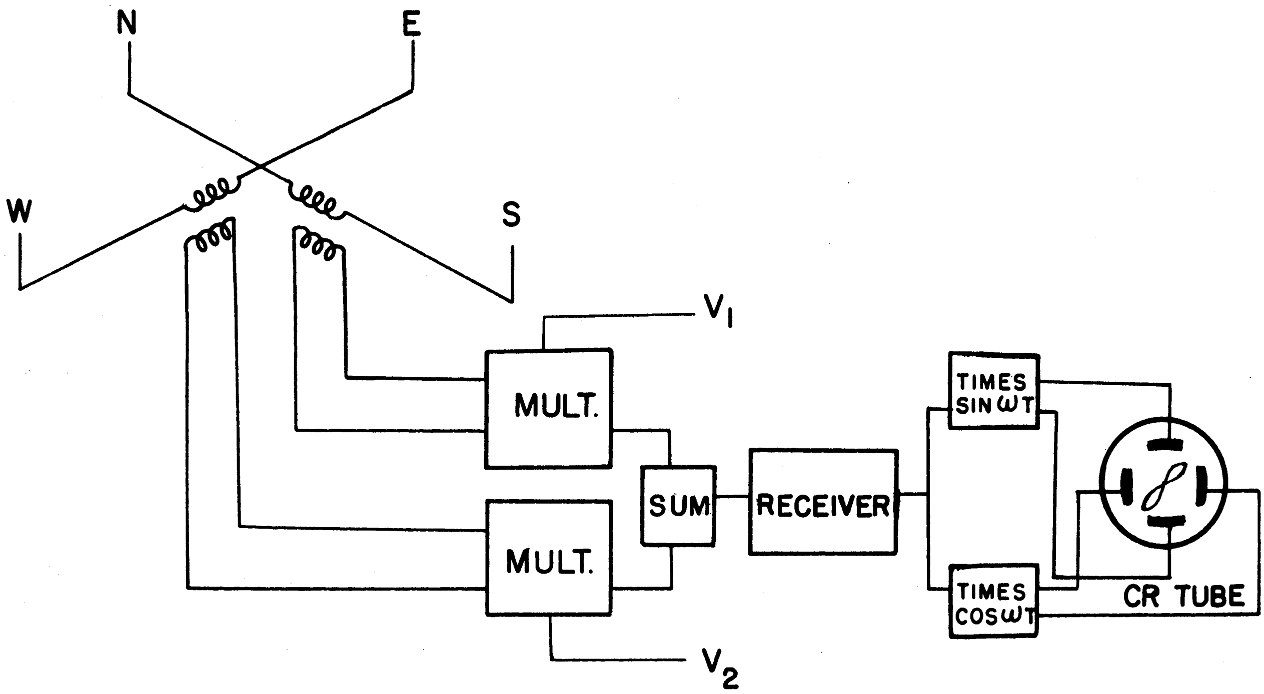

Fig. 2. Goniometer system basic block diagram.

3. COMPARISON CRITERIA

In the selection of the criteria upon which the study was to be based it was assumed that the equipment was to be used in a ground-based tactical situation. While many of the criteria apply in a strategic, or shipboard, situation the relative emphasis would, in general, be somewhat different.

Since under any given signal condition the instantaneous, indicated bearings of the goniometer and the twin-channel systems are the same, the study will attempt to deal with practical considerations which would be involved in actual development of a usable piece of equipment. Below are given the criteria used, with brief statements of the reasons they were chosen. Following sections compare the two systems in the light of these criteria.

Mobility is, of course, a prime requirement. Not only must the equipment operate under field conditions with little corrective maintenance, but those faults which do appear should be readily apparent and relatively simple to correct. The number of parts must be held to a minimum. The logistic problem of supplying spare parts to a modern electronic army in the field is difficult at best. Any effort spent in reducing this load is equivalent to increasing operational reliability.

Speed of response is considered. The advent of modern communication techniques and their ability to transmit information in very short periods of time suggests that consideration be given to a possible future time when burst-type transmissions become a part of the tactical scheme.

Automatic sense is considered. This is felt to be a definite requirement rather than a luxury. The traffic load on a tactical DF net will be quite large, and anything which shortens the time to take a bearing and relieves the operator of additional operations and decision-making processes will be sorely needed. Automatic sense will not only speed up the taking of individual bearings (in some cases there would not be time to take a sense reading) but in many cases will enable the operator to quickly reject bearings of no interest. Also there is no guarantee that the operator will take a sense reading; he may trust instead his own assumed a priori knowledge. Lives and property are known to have been lost as a result of this tendency.

Adequate sensitivity is, of course, an ever-present requirement.

The problem of co-channel interference is discussed. Today's crowded signal environment sometimes makes it difficult, with the usual bandwidth employed, to avoid errors due to interfering signals on adjacent frequencies.

3.1 Mobility

Under the general heading of mobility are simplicity, number of parts, etc.

The mechanically-spun goniometer is difficult to approach in reliability. Together with the drive motor, it is, however, somewhat bulky. The goniometer system utilizing electronic-balanced modulators requires one receiver channel and four balanced modulators, two in front of the receiver and two in the audio section. The use of diode switches in place of the balanced modulators, giving quadrature-square-wave rather than sine-wave modulation appears to be a simple compact scheme. The principle requirement on the receiver for the goniometer system is a reasonably flat time-delay characteristic across the pass band. Variations in amplitude across the pass band have no effect on the indicated bearing.

The twin-channel system requires two complete receivers, accurately phase- and gain-matched. The total number of components whose operation must remain within fairly-narrow limits for acceptable operation is approximately 25% greater than for the goniometer system, and the spare parts complement likewise. The total expenditure of money per unit delivered in the field would be expected to be higher.

3.2 Speed of Response

For present-day normal operation, both systems have sufficient response time. The following would apply only in the advent of the use of burst-type signals in the tactical situation.

It is estimated that a capability for detecting and obtaining a bearing on a signal of 15 milliseconds duration would be adequate. There is no question that for systems in operational use in this country today the twin channel is the only system having the requisite speed of response. This results because existing goniometer systems have scan rates on the order of 30 cycles per second. If this rate could be increased to something on the order of 200 cycles per second the goniometer system response time would be adequate for burst-type transmissions. The obvious approach to this problem is the use of electronic-balanced modulators in place of mechanical goniometers. Preliminary tests at the Electronic Defense Group, however, indicate that existing mechanical goniometers operate satisfactorily at the required speeds (12000 rpm) with modifications in the drive mechanism and the addition of high-speed bearings. This being the case, the high reliability and ruggedness of these units would certainly make them preferable to balanced modulators.

The use of square-wave modulation with solid-state diode switches as modulators provides a feasible, extremely-compact solution to the problem.[1]

3.3 Automatic Sense

Most feasible schemes presently known to the author for automatic sense determination in the Watson-Watt system require a third receiving channel. In the usual method the sense signal, after being amplified in the sense channel, is used to blank the undesired half of the ellipse to present an unambiguous display.

In the goniometer system the sense signal is added to the outputs of the multipliers. The resulting RF signal is a standard AM wave rather than the DSB suppressed carrier which occurs in the usual equipments. The resulting receiver audio output has a fundamental component at the modulation frequency. The phase of this fundamental relative to the fundamental audio input to the modulator gives the bearing directly with no ambiguity. Several means for display present themselves. Perhaps the simplest would be to create the usual propeller pattern on the scope and blank the undesired half.

In any case, the complexity introduced by the addition of a third receiver channel would seem to exceed that of the circuitry required in the goniometer system. Thus, from the standpoint of automatic sense, the goniometer system appears to offer practical advantages over the Watson-Watt.

From this point on it will be assumed that the equipment utilizes automatic sense.

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1. New York University is working on this problem under Signal Corps Contract DA-36-039 sc-72806.

3.4 Sensitivity

Tracking and matching problems in the Watson-Watt DF usually limit the number of tuned RF stages prior to mixing to one. Another alternative sometimes seen is the use of broadband, fixed-tuned RF stages ahead of the first mixer. Either of these alternatives tends to degrade the noise figure in a practical receiver to below that obtainable with a communications receiver. The goniometer system, on the other hand, will suffer a certain loss in the goniometer or modulators, although in well-designed units this can be held to within reasonable bounds. The degradations due to the above-mentioned factors would be expected to be of comparable magnitude in the two systems. It will be assumed, then, that the noise figures of the RF and first-mixer sections of the two systems are approximately the same. This being the case, the relative sensitivities of the two systems will be determined by their respective IF and audio bandwidths.

Assume a bandwidth of 600 cycles for the twin-channel instrument.[1] The bandwidth of the goniometer system will be limited by the modulation rate. Assume an IF bandwidth of 800 cycles for normal operation.[2] Assume further that the audio section contains a bandpass filter having a center frequency of 30 cycles and a 3 db bandwidth of 4 cycles.[3] Allowing at most a 2 to 1 reduction in rms S/N ratio in the audio detection process (this could occur only on the weakest signals), the equivalent bandwidth would be 4 x 4, or 16 cycles. The relative rms S/N ratio of the goniometer

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1. This is a representative figure for commercially available equipments.

2. Bandpass amplifiers with this bandwidth and with phase characteristics sufficient to guarantee a bearing error of less than one degree are being constructed at this laboratory.

3. Experience with the use of post-detection filtering has shown that a bandwidth of 4 cycles is adequate for most signals.

system output would be $\sqrt{\frac{B_{twin\ channel}}{B_{goniometer}}} = \sqrt{\frac{600}{16}} = 5.9$ times that of the twin-channel equipment.

For short duration or burst-type transmissions the minimum IF bandwidth is determined not by component and construction limitations, but rather by maximum intercept-probability considerations. It is assumed here that only incomplete knowledge of the frequency of transmission exists. Thus the direction finder must, due to the short time available, provide both DF and intercept functions. Assume an IF bandwidth of one magacycle, which is a reasonable figure for this type of operation. The audio bandwidth of the goniometer equipment would have to be increased to something on the order of 300 cycles and the scan rate to 200 cps. Again assuming a 2 to 1 reduction in rms S/N ratio in the audio detector gives an equivalent bandwidth of 1200 cycles for a relative rms S/N ratio of $\sqrt{\frac{10^6}{1200}} =$ 28.9 times that of the twin-channel equipment.

The above considerations suggest that the goniometer system is capable of significantly-greater sensitivity than the Watson-Watt system.

3.5 Co-Channel Interference

The problem of co-channel interference is an ever present one. The obvious means of alleviating this is to use as narrow a bandwidth as possible. It is felt that there exists a need for a study of the relative frequency of occurrence of the phenomenon and what bandwidth would be required to keep it within acceptable limits.

Present-day twin-channel equipments have a bandwidth narrower than the 800 cps contemplated for the goniometer equipment. This should give it an advantage in this situation; just how much of an advantage is difficult to estimate in the absence of statistical data. One may, however, go over to aural null operation in the goniometer equipment, and for most signals this probably represents the best solution.[1] The major disadvantage of present systems in this respect is the length of time required to go from automatic to aural null operation. Some sort of brake on the motor might help.

4. SELECTIVE-MODULATION AUTOMATIC DIRECTION FINDER

It has been suggested by USASRDL personnel that the two-frequency or selective-modulation DF be considered in this report. This system has been described elsewhere[2,3] so no detailed description will be given.

The operation of the system can be seen from the block diagram in Fig. 3. Instead of modulating the EW and NS antenna outputs by two voltages, V_1 and V_2, of the same frequency but in quadrature phase as in the goniometer system, they are modulated by signals at distinct frequencies, f_1 and f_2, respectively. The information is extracted by synchronous rectifiers at the receiver output. The indicated bearing is identical to that in the goniometer system and has all the features of that system with the exception that the receiver must have both a reasonably-flat amplitude and a linear-phase characteristic across the pass band. Since the lower frequency is restricted by the short-signal capability to some minimum value

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1. Simple means for separating the effects of two coexisting signals in the goniometer system are being investigated at EDG.

2. "Selective Modulation Automatic Direction Finder," D. S. Heim, Electronic Defense Group Technical Memorandum No. 62, The University of Michigan Research Institute, October 1958.

3. Cleaver, R. F., "The Development of Single-Receiver Automatic Adcock Direction Finders for Use in the Frequency Band 100-150 Mc/s," JIEE (London), v. 94, Pt. IIIA, pp. 783-797, 1947.

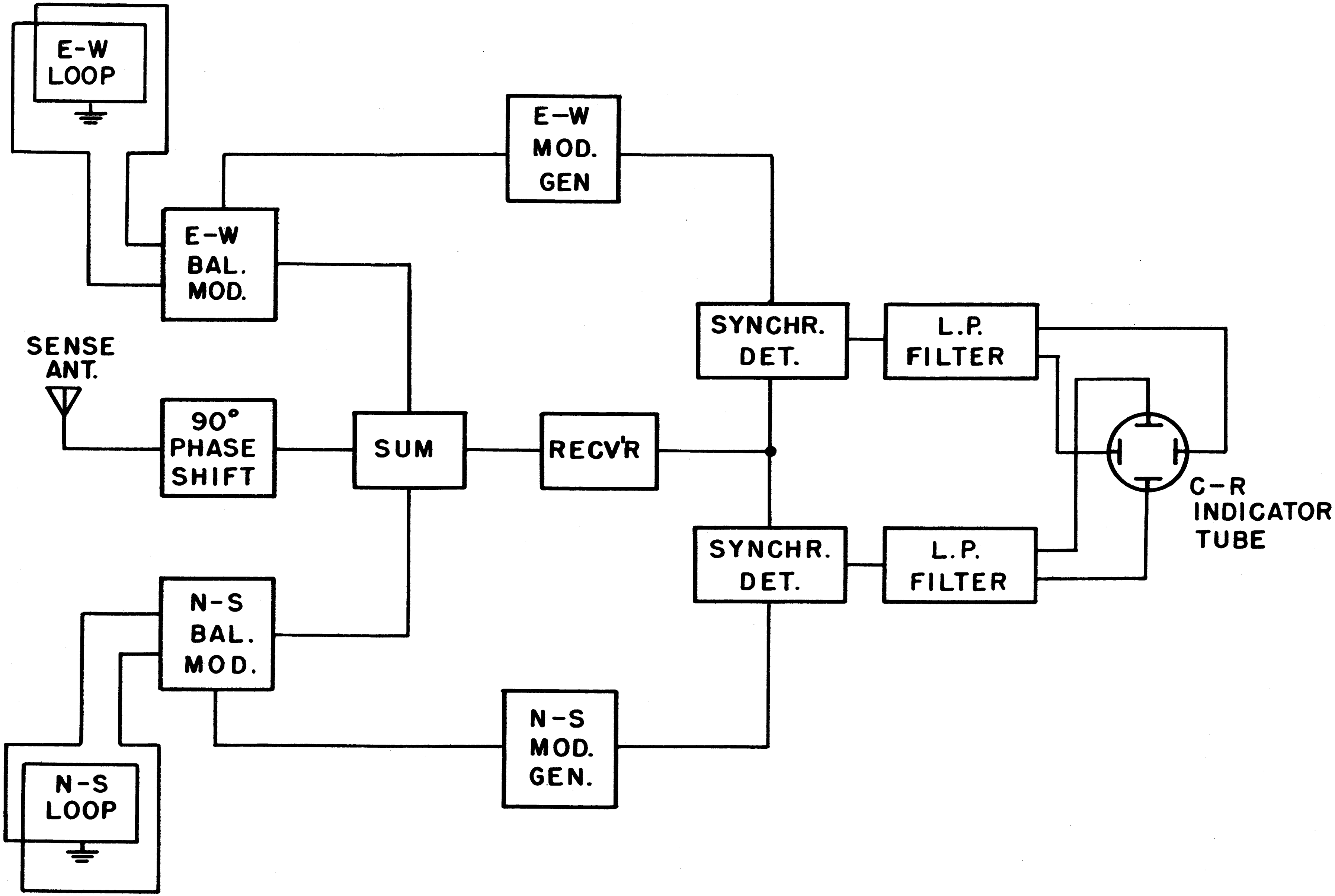

FIG. 3 BLOCK DIAGRAM OF SELECTIVE-MODULATION ADF

to prevent cross-modulation products from passing through the low-pass filters to the CR tube, the upper frequency should be on the order of one and one half times this. Thus, the system requires a larger receiver bandwidth than the goniometer system. Also, two audio frequency signal sources are required rather than one. These are features which make it less desirable than the goniometer DF. Since the two systems are operationally equivalent, it appears that the gonio or quadrature-phase system has the advantage as a piece of tactical radio direction-finding equipment.

5. CONCLUSIONS

In inherent capabilities the goniometer system appears to have the advantage in simplicity, ruggedness, expense, sensitivity, and ease of providing automatic sense. In a situation involving co-channel interference its aural null provision gives it the advantage. With respect to speed of response, both systems are adequate in the light of present-day tactical operational requirements. The selective modulation DF, while being more complex, offers no operational advantages over the goniometer system.

On the basis of the above one can conclude that effort spent in developing an "optimum" goniometer system would pay greater dividends than in either the twin-channel or the selective-modulation systems.

The results of this development would contain the following:

1) The addition of automatic sense;

2) The use of post-detection filtering to improve the overall sensitivity;

3) Some care in designing linear-phase pass-band receivers, or

modifying existing communication receivers before their insertion into the DF system.

4) The maintenance of as narrow a bandwidth as possible consistent with 3) (800 cycles or less).

5) The continued inclusion of the aural null provision with perhaps some consideration of means for making the transition from automatic to aural null more rapid.

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