Shipborne high-frequency direction-finding problems as applied to AN/SRD-501

Evans, E.

Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/21273583
Report (National Research Council of Canada. Radio and Electrical Engineering Division : ERB), 1959-04

ERB-524

SECRET

NATIONAL RESEARCH COUNCIL OF CANADA

RADIO AND ELECTRICAL ENGINEERING DIVISION

SHIPBORNE HIGH-FREQUENCY DIRECTION-FINDING PROBLEMS AS APPLIED TO AN/SRD-501

G. EVANS

OTTAWA

APRIL 1959

Secret

ABSTRACT

The problems of shipborne high-frequency direction finding, as revealed in the literature, are discussed with reference to a particular equipment being built by the National Research Council. This paper is intended to provoke wide discussion of these problems in the hope that some of the answers may be revealed more rapidly.

SHIPBORNE HIGH-FREQUENCY DIRECTION-FINDING PROBLEMS AS APPLIED TO AN/SRD-501

- G. Evans -

GENERAL

Shipborne high-frequency direction finding HF DF has many problems, mainly because of the type of aerial required and the large number of reradiators present. When the direction finder has to work against short-duration signals these difficulties are increased greatly. In this paper data from a variety of sources is collected and used to predict the performance of a short-signal shipborne high-frequency direction finder being developed by the National Research Council for the Royal Canadian Navy.

While this paper is primarily concerned with one particular equipment, the difficulties described are common to most shipborne HF DF's, especially those intended to handle short-duration signals. The difficulties are partly basic (since an attempt is made to perform a task in a fundamentally unsuitable environment) and partly arise from ignorance of the parameters involved. In the latter case, the areas of ignorance are outlined in the hope of provoking discussion (or even controversy) on these subjects.

INTRODUCTION

A shipborne high-frequency direction-finding equipment is being developed by the National Research Council for the Royal Canadian Navy. Main emphasis during development has been on handling the high-level burst signal, with secondary emphasis on providing cooperative DF facilities for homing purposes.

Since this equipment, known as "AN/SRD-501", has to operate on board a ship where both space and maintenance facilities are limited, it is being made as simple and reliable as possible. To do this has required compromises in the expected performance of the equipment, and it is part of the intention of this report to underline the conditions under which the performance of AN/SRD-501 will be unsatisfactory, and to give an idea of the cost (in extra equipment) of improving the performance.

BEARING ACCURACY

The PCC form for this project calls for instrumental accuracy of 1°, aiming at operational accuracy of 5°. The operational accuracy of shipborne HF DF equipment has never been measured as far as is known, but it seems probable that the 5° asked for is not realistic for any type of transmission when using the normal ship DF antennas. This is because of the large site errors, with the attendant re-entrant calibration curves, that are present in shipboard installations.

SHIPBOARD SITE ERRORS

A good discussion of site errors in shipborne high-frequency direction finding was given by Crampton et al. [1,2] in 1947, but in these papers the stability of the calibration curves with time was not dealt with. A later series of papers by Loveberg [3,4,5] provide an excellent appraisal of site errors, their dependence on the frequency and true direction of the signal, and the time stability of the calibration curves. Loveberg finally concludes [5] that correction of shipborne HF DF bearings by the use of calibration curves is unjustified when the normal crossed-loop or spinning-loop aerial systems are used.

Loveberg's conclusion was derived from a series of model and full scale experiments, which show that to obtain true calibration curves an impractically fine examination of the direction finder from the point of view of signal azimuth and frequency is required. And even if such a calibration was carried out, Loveberg's full scale experiments show that the calibration curves alter with time, even when extraordinary precautions are taken to maintain the electrical condition of the ship stable.

If these conclusions are accepted, an estimate has to be made of the site error's contribution to the total variance (square of the standard deviation) of bearing error when using a loop aerial or its electrical equivalent. In arriving at this estimate, it is assumed that the aerial site is correctly chosen, namely at the top of the highest mast 15 feet above any reradiator and with the most important reradiators arranged reasonably symmetrically about the mast. From Crampton's examples of calibration curves for frigates, etc., [1] an estimate of 180 degrees squared is obtained for the site error contribution to the total variance of bearing error. While, according to Loveberg [5] these curves could not be used to correct DF bearings, they do indicate the shape and maximum value of the true error curve.

Crampton [1] obtains a site error variance of 56 degrees (standard deviation = 7.5°) squared assuming that the calibration curves are reliable, but this also assumes that the signal frequency is known very closely. In the AN/SRD-501 equipment, however, the signal frequency is not known to better than within ±500 kc/s, and the 180 degrees squared figure (standard deviation = 13.4°) is more realistic even if the calibration curves could be relied upon. To improve the situation in this case, some form of frequency meter would have to be provided along the lines of the microwave instantaneous frequency meter [6].

There is a possibility of reducing site errors, which was suggested by Crampton [1], by using an aerial system with a multilobed pattern, such as the coaxial spaced loop. The Southwest Research Institute is developing a spinning spaced-loop system [7], which should reduce site errors but this system does not appear suitable for use against short-duration signals. The National Research Council is investigating the possibilities of an instantaneous crossed spaced-loop system which may reduce site errors by half [8] when working against ground wave signals. The bearings obtained would have a four-fold ambiguity and auxiliary equipment would be required to resolve the correct signal quadrant. This work is in its earliest stages and no estimate can be given of how long it would take to prove that the system did give the expected reduction in site error.

ROUGH-SEA EFFECT

It has been noticed that ground wave signals on frequencies higher than 8 mc/s produce a wandering bearing indication on the shipborne DF display [9]. This effect, which increases rapidly with frequency, depends on the sea state, and the wandering is in approximate synchronism with the sea swell. The maximum amplitude of the bearing swing is believed to be about half the signal frequency in megacycles, which at 20 mc/s gives a variance of 50 degrees squared due to this effect. On long-duration signals this bearing wander can be averaged out, but on short-duration signals this is not possible, and it is for this condition that 50 degrees squared variance is quoted. As with all other accuracy figures quoted in this report, this figure is likely to give only the correct order of magnitude of the errors involved.

The errors caused by this rough-sea effect are presumably due to interference between the direct ray and random reflections off the sea surface, and in this case, it seems likely that the use of crossed spaced loops (if this system is workable) would reduce this error by the same amount as site error.

POLARIZATION ERRORS

These errors occur when the signal being received is down-coming and has a horizontally polarized component. The amount of error introduced depends upon the type of aerial system used, and is about the worst with the loop or crossed-loop aerial; in fact, under bad conditions the loop aerial is unusable.

This type of error will be encountered with the AN/SRD-501 equipment on the lower frequencies (below 10 mc/s), when at the maximum range of 40 miles there will be interference between the ground ray and the ionospherically reflected ray. At the higher frequencies this effect should be less marked since there should only be ionospheric reflections under exceptional conditions.

The contribution of polarization error to the total variance of bearing error is indicated by the "standard wave error" of the loop (and crossed loop) aerial [10], which is 35°, corresponding to a variance of 1000 degrees squared. This is only an indication of the effect of polarization error, but it is a significant indication. With a narrow-band direction finder working against a long-duration signal an experienced operator can deduce the presence of polarization error from the bearing display and assess the reliability of the bearing. Against a short-duration signal this cannot be done, and the presence of polarization error will have to be inferred from knowledge of propagation conditions.

The crossed spaced-loop aerial system may also be seriously affected by polarization error since this system relies on the two aerial patterns having a sin 2θ law, which does not hold for down-coming horizontally polarized waves. The rotating spaced loop aerial working on the spaced loop null is, provided the aerial is carefully built, far less susceptible to polarization error.

If the signal is being transmitted from an aircraft with a trailing wire or any other type of predominantly horizontal aerial, polarization error will be present all the time. Table I provides a summary of errors expected with shipborne HF DF.

Table I provides a summary of errors expected with Shipborne HF DF.

BURST SIGNAL INTERCEPT PROBABILITY

Certain interception of a burst signal may be possible theoretically, irrespective of the frequency on which it is transmitted or its field strength. However, this would require an extremely large amount of equipment, and to ensure certain recognition of the signal would require even more equipment. This type of solution is impracticable even for a land-based equipment, and it is necessary to make assumptions about the burst signal to narrow the "area" (in time, frequency, and field strength) of search.

In the approach to AN/SRD-501 there have been five main assumptions made about the burst signal which have had great influence on the design of the equipment. These are:

1) the signal will be of interest only if it is transmitted at a distance of 40 miles, or less;
2) the radiated power will be at least 200 watts;
3) the frequency can be predicted to within ±500 kc/s;
4) the burst signal field strength will be greater than the combined amplitude of all the other signals in the band being watched;
5) the minimum time duration will be of the order of 100 ms.

The intercept probability of AN/SRD-501 depends on the correctness of these assumptions. The first was arrived at in 1954 by the Directorate of Operational Research (N) on the basis of submarine and convoy performance in 1954; it is not known how much this has changed since that time.

The estimate of transmitted power is not easy to justify completely — it is probably quite possible for a submarine to transmit 200 watts but it would also be possible for the submarine to make contact with its base using much less than 200 watts radiated power. The amount of power that need be used could be reduced with increased sophistication of the receiving apparatus, type of modulation used, and correct choice of frequency.

Prediction of the burst signal frequency also depends on the sophistication of the system. In the original Kurier system, the signal was transmitted on a frequency selected within ±200 kc/s of a known control frequency. Using a Rampage system the frequency band available may be as broad as 4 mc/s at some times depending on ionospheric conditions, or there may be two bands available widely separated in frequency.

Measurements of signal intensities in the HF band have been carried out which give a very rough idea of the interference problem [11]. These measurements were time-consuming, refer only to certain parts of the world, and are really valid only for the time at which they were taken. They indicated that for 22 out of 24 hours a day the field strength of a 200-watt signal radiated from a distance of 40 miles would be greater than the combined amplitude of all other signals in the band.

The minimum time duration of 100 ms was decided upon as a result of studies on the Kurier type of system, and the same duration has been chosen for the

Rampage system on different grounds. In the Rampage system much shorter durations (of the milliseconds order) could be used to send the same amount of information that could be conveyed by a Kurier system. This would make the recognition of the burst signal much more difficult since there are many naturally occurring signals of the same duration.

To use AN/SRD-501 with the highest intercept probability it must be known what transmission path the enemy is likely to be trying to work and his operating frequency must be known to within ± 500 kc/s. The receiver depends completely upon the burst signal being the outstanding signal in the band for most of the time. If it is not, either because of interference or low field strength, the band must be divided into a sufficient number of narrower bands in which this condition holds to give a reasonable intercept probability. This will mean, in effect, multiplying the number of receivers.

Intercepting a burst transmission is useless unless the signal is recognized. Burst signal recognition in the AN/SRD-501 receiver is achieved on the amplitude-time raster display. This is suitable only for obtaining the total time duration of the message and its coarse amplitude characteristics. For message lengths of 100 ms or longer these characteristics might be sufficient for identification of the burst signal. Present experience does indicate that signals with uniform amplitude characteristics lasting only for the order of 100 ms occur relatively rarely (four or five a week). However, if much shorter duration signals were transmitted (as is possible with a Rampage system) more refined recognition techniques would be essential. The addition of specific recognition devices, for example circuits that would permit recognition of a particular modulation rate or pulse width, might be useful adjuncts to the receiver provided they did not exclude other possible types of burst signals.

The probability of intercepting and then recognizing any burst signal with the AN/SRD-501 equipment can be discussed only vaguely because so many factors are unknown and the assumptions stated at the beginning of this section may all be wrong. In particular the assumed frequency band and the radiated power may be wrong. The former might reduce the intercept probability by 80% (i.e., to 20% of its value if the assumptions had been correct) assuming that there was a total bandwidth of 5 mc/s available for transmission, and overestimating the radiated power would reduce the maximum intercept range. If all assumptions were correct (with the exception of number 4) the available knowledge of traffic density indicates that the intercept probability would be 50% to 70% at the maximum range and would increase with decreasing range.

HOMING PERFORMANCE OF NR2

To cater for the burst signal which will be the outstanding signal in the band while it is occurring, a low sensitivity broad band receiver is being built which will contain a large number of spurious responses due to intermodulation and cross modulation products mainly generated in the mixer. It is believed that these will not significantly affect the performance of the receiver when working against the strong burst signal.

However, there is a requirement to provide bearings for homing ships and aircraft for which a completely different set of characteristics would be required. No target for the homing requirement has been set, neither the distance from which homing will be carried out nor the power of the transmitter to be DF'd on, but it seems reasonable to assume that the received signal will be in the microvolts rather than millivolts per metre region. In this case a highly selective receiver with high sensitivity would be required.

An adaptor to enable the AN/SRD-501 receiver to provide this performance has been proposed and is partially built. This adaptor consists of triple-channel 2 kc/s low-pass filters with amplifying stages that will be fed directly from the NR2 mixers providing in effect a final bandwidth of 4 kc/s centered around zero frequency. As a receiver this will not be of very high quality; in fact, it will probably be difficult to recognize the signal without cooperation from the transmitter, mainly owing to oscillator instability (in this model the audio output of the receiver will be garbled by the incidental frequency modulation of the oscillator) and spurious signals generated in the broad-band RF amplifiers.

A far simpler method of obtaining homing bearings might be to connect an auxiliary goniometer to the DF antenna and feed the output to a communications receiver. In this manner recognition of the homing signal would be much easier and the bearings on weak signals would be read more accurately.

However, the bearing accuracy on high-frequency signals transmitted from aircraft will often be very poor. The signal will be almost entirely horizontally polarized and will arrive at an angle above the horizon which will depend upon the aircraft's height and distance. Crossed loop aerials are completely unreliable under these conditions and it does not seem that the proposed crossed spaced-loop will be outstanding either. (With this type of signal the spaced loop polar diagram alters from that required to give correct bearings with the proposed system.) The presence of sky waves, more probable at night, will increase this error. A normal rotating spaced-loop antenna shows most promise for obtaining bearings on aircraft high-frequency signals but this would be a slow method.

CONCLUSION

An assessment has been made of the expected operational performance of the NR2 receiver.

This receiver is expected to have a large standard deviation of bearing error, when working against burst signals, mainly because of bearing wander which cannot be averaged out during the duration of the signal. This standard deviation may be as high as 15° or higher.

The intercept probability of the receiver is based on a number of assumptions which may or may not be correct. The main assumptions are that the frequency of the burst signal can be predicted to within ± 500 kc/s and that the transmitted power will be 200 watts. If these assumptions are correct, then the intercept probability during periods of high signal density will be about 50% at maximum range, and 100% when the signal density is low.

In its homing role the receiver will also give inaccurate bearings which will have to be corrected constantly, and it may be difficult to recognize the homing signal. No present shipborne HF DF system appears to have sufficient bearing accuracy for providing reliable aircraft homing bearings.

Improvements in bearing accuracy and intercept probability are possible at the cost of a large increase in equipment and time taken to develop it.

Acknowledgements

Many points of difficulty in compiling this report were resolved during conversations with the staff of the Naval Test Site; in particular, with Mr. C.W. McLeish, to whom the author gratefully acknowledges his indebtedness.

TABLE I

SUMMARY OF BEARING ERRORS EXPECTED WITH SHIPBORNE HF DF

Cause of Error	Variances in Degrees Squared			
	Crossed Loop Aerial		Vertical Coaxial Spaced Loop Aerial	
	Uncalibrated	Calibrated	Uncalibrated	Calibrated
Site	169	56	56	14
Rough Sea	$\left(\frac{fmc}{2}\right)^2$	$\left(\frac{fmc}{2}\right)^2$	$\left(\frac{fmc}{4}\right)^2$	$\left(\frac{fmc}{4}\right)^2$
Polarization	1000	1000	100	100

Notes:

1) Site error variance will be present at all times. The other variances will have to be added when the conditions causing these errors exist.
2) The columns headed "calibrated" assume that calibration is possible. This is unrealistic for the crossed-loop case.
3) The vertical coaxial spaced-loop figures refer to the rotating spaced-loop aerial. The proposed crossed spaced-loop system will not have the good performance of the rotating spaced loop with regard to polarization error (which usually operates on the "spaced-loop" null) owing to the deterioration of the spaced-loop pattern with down-coming horizontally polarized signals.
4) The variance of 100 degrees squared assumed for polarization error of the spaced loops is greater than normal to allow for the influence at the site.

References

1. Crampton, Struszynski, Marshall, and Woolley — The Performance of High Frequency Direction Finders in Various Types of H.M. Ships. IEE 1947, 94, Part III A, p. 798

2. Crampton, Whipple, and Mugridge — The Errors in Bearings of a High Frequency Direction Finder Caused by Reradiation from a Nearby Vertical Mast. IEE 1947, 94, Part III, p.815

3. Loveberg — Evaluation of Shipboard High Frequency Direction Finder Techniques by Scale Models. U.S. Navy Electronics Laboratory Report 711, August 1956

4. Loveberg — The Reliability of Shipboard High Frequency Direction Finder Calibration. U.S. Navy Electronics Laboratory Report 710, August 1956

5. Loveberg — Factors Affecting the Reliability of Calibration of Shipboard High Frequency Direction Finding Systems. U.S. Navy Electronics Laboratory Report 743, March 1957

6. Cairns — A Microwave Instantaneous Frequency Indicator. NRC Report ERB-484, July 1958 (Confidential)

7. Travers, Moore, Lincoln, Dubois, Donaldson — A Spinning Multiloop Direction Finder for the Reduction of Shipboard Site Error. Southwest Research Institute, San Antonio, Texas; Task Summary Report Number IV, September 1958

8. Hopkins and Horner — Direction Finding Site Errors at Very High Frequencies. Proc. IEE 1949, 96, Part III, p. 321

9. DeWalden and Swallow — The Relative Merits of Aural Null and Twin Channel Cathode Ray Direction Finders. Proc. IEE 1949, 96, Part III, p. 307

10. Barfield — Some Principles Underlying the Design of Spaced-Aerial Direction Finders. IEE 1935, 76, p.423

11. Evans — Interim Report on the Development of a Shipborne High Frequency Radio Direction Finder. NRC Report ERA-327, July 1957 (Secret)