

DECLASSIFIED

NRL REPORT R-3459

~~CONFIDENTIAL~~

~~_____~~
~~_____~~
~~_____~~

FR-3459

THE RELATIVE COUNTERMEASURE UTILITY OF THE
"BALANCED-RECEIVER" AND "LABELING"
DIRECTION-FINDING SYSTEMS

DECLASSIFIED by NRL Contract

Declassification Team

Date: 9 JAN 2017

Reviewer's name(s): ~~TO DO, P. [REDACTED]~~



Declassification authority: NAVY DECLASS
GUIDE / NAVY DECLASS MANUAL, 11 DEC 2012
DB SERIES

~~_____~~
~~_____~~
~~_____~~

DISTRIBUTION STATEMENT A APPLIES.
Further distribution authorized by _____
UNLIMITED only.

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.



~~CONFIDENTIAL~~ DECLASSIFIED

1800

CONFIDENTIAL

NRL REPORT R-3459

DECLASSIFIED

**THE RELATIVE COUNTERMEASURE UTILITY OF THE
"BALANCED-RECEIVER" AND "LABELING"
DIRECTION-FINDING SYSTEMS**

Richard L. Libby

May 3, 1949

Approved by:

Mr. E. A. Speakman, Head, Countermeasures Branch
Mr. L. A. Gebhard, Superintendent, Radio Division II



NAVAL RESEARCH LABORATORY

CAPTAIN F. R. FURTH, USN, DIRECTOR
WASHINGTON, D.C.

DECLASSIFIED

CONFIDENTIAL

~~CONFIDENTIAL~~

THE RELATIVE COUNTERMEASURE UTILITY OF THE
"BALANCED-RECEIVER" AND "LABELING"
DIRECTION-FINDING SYSTEMS

Richard L. Libby

May 3, 1948

Approved by:

Mr. E. A. Spensman, Head, Countermeasures Branch
Mr. L. A. Gehard, Superintendent, Radio Division



NAVAL RESEARCH LABORATORY
WASHINGTON, D.C.

~~CONFIDENTIAL~~

DISTRIBUTION

BuShips Attn: Code 933	10
BuAer Attn: Code AR-29 Attn: Code TD-4	2 2
BuOrd Attn: Code Re-9	2
CNO Attn: Code OP-314-B2 Attn: Code OP-341-D Attn: Code OP-201(X)	6 1 2
CO, ONR, Boston	1
Dir., USNEL	2
CDR., USNOTS Attn: Reports Unit	2
CDR., USNOL	1
ComOpDevFor	1
Ch. of Staff, USAF Attn: Code AFOAE	2
CO, Fleet Training Center, Norfolk	1
CO, C.I.C., Fram Training Center, Boston	1
CO, Fleet Training Center, Newport, R. I.	1
CO, U. S. Naval School Electronics, Great Lakes Attn: Lt. J. J. Bartko	2
OCSigO Attn: Ch. Eng. & Tech. Div., SIGTM-S	1
CO, SCEL Attn: Dir. of Eng.	2
BAGR, CD, Wright-Patterson Air Force Base, Dayton Attn: CADO-D13	1
CG, AMC, Wright-Patterson Air Force Base, Dayton Attn: Eng. Div., Electronics Subdiv., MCREEO-2	1

CONTENTS

Abstract	vi
Problem Status	vi
Authorization	vi
INTRODUCTION	1
COUNTERMEASURE VERSUS COOPERATIVE D-F SYSTEMS	2
THE "LABELING" SYSTEM	3
THE "BALANCED-RECEIVER" SYSTEM	4
COMMENT	5

AUTHORIZATION

MRL Problem 18R06-04D (Revised Problem 8-1010)

DECLASSIFIED

ABSTRACT

A brief discussion of radio direction-finding techniques for countermeasure use is presented. The prevalent trend of current literature on cooperative-type direction-finding equipments in de-emphasizing possible countermeasure requirements is noted. The principles of a typical cooperative-type direction-finding (labeling) system are compared with those of a typical countermeasure direction-finding (balanced-receiver) system from a countermeasure viewpoint. Comment is made on specific disadvantages frequently assumed for the direction-finding equipment based on the principles of the balanced-receiver system.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem 39R06-04D (BuShips Problem S-1010)

DECLASSIFIED

THE RELATIVE COUNTERMEASURE UTILITY OF THE
"BALANCED-RECEIVER" AND "LABELING"
DIRECTION-FINDING SYSTEMS

INTRODUCTION

In the development of radio direction-finding systems for countermeasure use, two distinct (but perhaps supplementary) procedures are possible. The first of these involves the development of d-f system principles which provide acceptable performance on signals of a type that is either currently, or expected to be, utilized by an enemy. The second procedure involves the development of d-f systems, the principles of which provide acceptable performance not only on signals having conventional or expected characteristics but also on those having characteristics not presently used or expected, but known to be in the realm of possibility.

It is not questioned that in d-f countermeasure work, say for example on long-range enemy communication, practical considerations place an apparent restriction on certain characteristics of the signal that the enemy might use for this purpose. When countermeasure equipments are developed with these restrictions in mind, economy in time and expenditure may be realized. Perhaps in addition to such economic savings, the apparent knowledge of the type of signals to be expected may allow a design that increases say the bearing accuracy of the equipment at the expense of its versatility with respect to the types of signals which it may receive. It is to be emphasized, however, that the value of such a development procedure is dependent on the enemy's laxity in the development of d-f evasive techniques.

From a theoretical countermeasure viewpoint considerable emphasis on the second procedure, that of development of noncooperative d-f principles, is most advisable. The principal factor impeding such emphasis is the practice by many of comparing all d-f system principles in terms of cooperative d-f requirements. The proponents of excellent cooperative-type d-f systems and others cite the apparent difficulties involved in the development and operation of noncooperative d-f equipments such as those utilizing the "balanced-receiver" d-f principles.^{1,2} While such literature seems to encourage and justify the development of cooperative d-f principles, unfortunately at the same time it tends to obscure the countermeasure value of the principles of the "balanced-receiver" type, and to indicate that their practical and useful physical achievement is a known impossibility. It is in an attempt to counteract such obscurity and erroneous connotations that the following discussion is presented. The discussion is confined to the "balanced-receiver" d-f principles (described herein) and those of the "labeling" d-f system reported in footnote 1. The choice of the "labeling" d-f principles is incidental to the discussion in the sense that a similar discussion can be based on many other cooperative d-f systems in use.

¹ Cleaver, R. F., Electrical Communication, 25: 337-362, December 1948.

² A Symposium on Countermeasures Intercept, Research and Development Board, Digest Series No. 8, LCS 5611, pp. 15-19, Confidential, 15 July 1948.

COUNTERMEASURE VERSUS COOPERATIVE D-F SYSTEMS

The differentiation between suitable methods of direction finding for countermeasure purposes and those of cooperative direction finding³ is certainly important but not generally appreciated. Many of the methods or systems having excellent performance characteristics in cooperative d-f work may be applied, with varying degrees of usefulness, to countermeasure d-f use. In examining this matter, questions at once arise as to the type of signals on which the countermeasure d-f may be required to operate. First, an enemy may be fully expected to make use of extremely short transmissions in his communication, detection, and control systems. It is to be emphasized that these transmissions may well be of the type conventionally considered impractical; that is, in an effort to obtain maximum security, even at a sacrifice of efficiency, the transmissions may utilize narrow pulse-widths not commensurate with the carrier frequency. Second, frequent "wobble" or discrete shifts in carrier frequency may be used. Third, it is very probable that use will be made by the enemy of masking or interfering signals designed to confuse and invalidate bearings obtained by countermeasure equipments. This last technique is especially probable if the enemy is aware of the vulnerabilities of the cooperative d-f systems currently in countermeasure use.

Briefly, a countermeasure d-f equipment should be capable of providing useful bearings on the following:

- (1) Extremely short transmissions.
- (2) Transmissions containing complex modulations or extremely narrow pulse widths and wide range of pulse rates.
- (3) Signals which are within the pass band of the d-f receiver, but not necessarily right on the frequency to which it is tuned. This requirement is based on the probability that only the approximate frequency of enemy transmission may be known.

The requirement that bearings should be obtained on extremely short transmissions implies that high-speed automatic-indicating d-f systems should be considered for maximum countermeasure utility. The characteristics of the principles of this type of direction finder may be separated arbitrarily into two groups. The first group will contain characteristics of the principles of systems not suited to countermeasure use. The second group will contain characteristics of system principles which are most suited for countermeasure utility.

Group I - Cooperative Systems

- (1) Required bandwidth is determined both by the signal components to be received and by the method of bearing analysis.
- (2) Bearing is influenced by the amplitude-versus-frequency pass-band characteristic of the system.
- (3) Bearing is influenced by the phase-versus-frequency pass-band characteristic of the system.

³Cooperative radio direction finding may be defined as a process for obtaining the bearing of a source of radio transmission when characteristics of the transmission are intended to assist with the bearing-obtainment process.

- (4) Bearing is susceptible to errors caused by interfering signals.

Group II - Countermeasure Systems

- (1) Required bandwidth is determined only by the signal components to be received.
- (2) Bearing is independent of the amplitude-versus-frequency pass-band characteristic of the system.
- (3) Bearing is independent of the phase-versus-frequency pass-band characteristic of the system.
- (4) Bearing of each of two simultaneous signals is indicated.

THE "LABELING" SYSTEM

Among the various automatic d-f systems which fall within Group I is a system utilizing what has been called the "labeling technique." Briefly, the system is as follows. An Adcock antenna array is utilized and the output from each pair of antennas is modulated with an identifying frequency (e.g. 5 kc and 6 kc). The modulating process, or "labeling," is accomplished with balanced modulators and the signal carrier frequency is suppressed. The carrier signal from the sense monopole at the center of the array (which does not change phase with bearing) is added to the labeled sidebands, and the result is amplified and heterodyned by a receiver of the conventional type. At the output of the receiver the sidebands are separated by filters and each is fed into phase-sensitive rectifiers, to which the original modulating voltages are supplied as phase references. The output of these rectifiers consists of two polarized d-c voltages which are applied to the orthogonal pairs of deflection plates of a cathode-ray tube to produce the bearing indication (and sense). A radial sweep is superimposed on the deflection plates to provide a line pattern which aids in the reading of the bearing.

Several pertinent factors are to be noted concerning the principles on which such a system operates.

- (1) The bearing information is contained in the relative amplitudes of the two sideband frequencies. This ratio is affected by the variation in amplitude versus frequency within the pass-band of the receiver.
- (2) Sense indication is contained in the relative phases of two sideband and carrier frequencies. This relation is affected by the fact that the phase varies with frequency within the pass-band of the receiver.
- (3) As the duration of the signals on which the equipment is to operate becomes shorter, higher labeling frequencies must be used requiring greatly increased bandwidths (i.e., greatly in excess of the bandwidths required to pass only the signal components of the received energy).
- (4) The ratio of voltages at two discrete frequencies is utilized to provide bearing information. The presence of these frequencies in the modulation of the received signal, or caused by the action of interfering signals, makes the system operationally useless.
- (5) The use of modulators at the antennas without use of preceding selectivity greatly increases the possibility of interference effects.

The effects of conditions noted in (1) and (2) may be diminished by the use of relatively low labeling frequencies. This technique would greatly enhance operation of the equipment in cooperative d-f work. It would, however, seriously limit the performance on pulsed signals or short duration signals such as are encountered in countermeasure work.

If, on the other hand, in an attempt to increase the countermeasure utility of the system, higher modulation rates were utilized, then the effects of considerations (1) and (2) would seriously affect d-f performance, and the bandwidth required to accommodate the labeling frequency sidebands would approach an absurdity.

The considerations noted in (4) and (5) have no serious drawback in cooperative d-f work in certain frequency bands, but provide extreme vulnerability to countermeasures.

THE "BALANCED-RECEIVER" SYSTEM

The "balanced-receiver" d-f system referred to in this discussion is one employing in principle an Adcock antenna array and utilizing three receivers to amplify the output voltages of the array. The two directional voltages derived from the antenna array are separately amplified and heterodyned in two receivers matched closely with respect to phase and gain characteristics. The i-f outputs of these two directional-channel receivers are applied to the two pairs of deflection plates of a cathode-ray indicator tube. The orientation of the resulting trace provides a bilateral indication of the bearing of the signal source. The output of the sense antenna, centrally located in the array, is amplified and heterodyned in the third receiver, which matches the other two with respect to its phase-versus-frequency characteristic. The i-f output of this third channel is applied to the intensity grid of the cathode-ray indicator tube in such a manner that the trace is cut off in the "wrong" quadrant and unilateral bearing indication is continuously obtained.

In principle the balanced receiver, or instantaneous system, completely satisfies the three major requirements listed previously, for a nonfrequency scanning countermeasure direction finder. The pertinent characteristics of the principles of such a system were listed under Group II. It is to be regretted that the difficulties experienced with low-frequency narrow-band cooperative d-f systems utilizing this principle, along with an ever-present fear of the difficulties, real and imaginary, that are associated with the practical development of the balanced-receiver principle, have seriously hindered progress toward this end.

Frequently, those who consider only cooperative direction-finder requirements make the following statements about the disadvantages of application of the balanced-receiver principle to d-f equipments:

- (1) A high degree of balance must be maintained between receivers.

COMMENT: This is certainly correct, but such balance has been obtained in a balance-receiver direction finder of narrow bandwidth operating in the high-frequency range. The countermeasure requirement of wider bandwidths certainly offers less difficulty in the balancing problem. Further improvements in circuitry and component development could well nullify this criticism.

- (2) Stage-by-stage matching techniques and frequent equalizing techniques are required.

COMMENT: Suitable mechanical and electrical design can make alignment procedure a routine, nontechnical procedure. Here also, effort along the line of stable-component development would result in improvement with respect to the periodicity of realignment.

- (3) Manual gain controls must be ganged with matching adjustment.

COMMENT: It is obvious that this statement is prompted by a system of manual gain control used in the past on such equipments. Investigation at the Laboratory has resulted in the use of a manual gain control which nullifies the detrimental implication of the above statement.

- (4) Automatic gain control involves considerable difficulty and is not used.

COMMENT: This statement also is obviously in reference to a former "state of the art." This Laboratory has developed a relatively simple automatic-gain-control circuit for use in balanced-receiver d-f systems.

- (5) Limitation of signal-to-noise ratio is required in order to maintain gain and phase balance.

COMMENT: This statement is possibly in reference to low-frequency and narrow-bandwidth equipments which sacrificed sensitivity for gain-phase balance because stable, matched, circuit-tuning elements have not been developed. In the 100 to 150 Mc range investigated at this Laboratory, no sacrifice in sensitivity was made to satisfy gain-phase balance requirements. The resulting sensitivity of the balanced-receiver d-f systems can certainly be expected to be as good as, if not better than, a labeling system (of comparable bandwidth) which utilizes a method of connecting antennas directly to modulators with no more preselection and preamplification than that afforded by a wide band-pass filter.

- (6) Directional accuracy is impaired by any inequality in transmission lines between antennas and receivers.

COMMENT: It is difficult to see the validity of such a statement as this. Certain equipmental designs may, perhaps, be extremely sensitive to such inequalities, but one certainly can not generalize this as a basic detrimental characteristic of the balanced-receiver direction finder.

- (7) The form of bearing presentation is not suitable for remote presentation.

COMMENT: The output of the balanced-receiver direction finder is essentially the output of a directive antenna array, amplified and heterodyned to a lower frequency. These output voltages contain the bearing information and are easily converted to forms more advantageous for transmission to remote locations. This is usually performed at the expense of bandwidth (slower response time) as is true with the "remoting" of other d-f-equipment outputs.

COMMENT

The intent of the foregoing has not been to provide a comprehensive discussion of a complex subject, nor to imply that the development of a practical countermeasure d-f system employing the balanced-receiver method is a simple matter. The success of such

a development could very well parallel the success attained in the development of stable, well-matched tuning elements, suitable cathode-ray tubes, and circuit components. It is to be re-emphasized, however, that the balanced-receiver d-f principle is a highly desirable feature in countermeasure work. The progress of the development of such principles has no doubt been hindered by the sweeping claims made for other d-f systems, and based on their performance under cooperative d-f conditions. Any trend to compromise on countermeasure d-f system performance requirements by attempting to extend cooperative d-f system principles to countermeasure use should be seriously considered in light of the probability of enemy efforts toward evasive transmission techniques.

* * *

DECLASSIFIED

CONFIDENTIAL