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PROPOSED SYSTEM OF ELECTRONIC RECOGNITION

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NRL REPORT R-3131

COPY NO. 67

PROPOSED SYSTEM OF ELECTRONIC RECOGNITION

by

C. E. Cleeton

June 1947

Problem 34R03-06

Approved by:

Dr. J. M. Miller Superintendent Radio Division I	Commodore H. A. Schade, USN Director Naval Research Laboratory

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ACKNOWLEDGMENT

The principles upon which this proposed system is based are not new. Many have been used before in previous IFF systems or for similar functions. It is impossible to give credit for their origin, for they evolved as a result of concentrated cooperative effort extending over a period from shortly before the past war to the present.

Nevertheless, much credit is due those who have developed these principles into workable devices. Appreciation is therefore extended to all those who have contributed to this work and especially to those members of the Security Systems Section of this Laboratory who, by their efforts in the field of IFF, have not only evolved methods of accomplishing desired functions but have assisted in the selection of a composite system by a practical evaluation of many proposed ideas.

Further appreciation is expressed to the leaders of the IFF work of the Section for their part in arriving at this proposal by discussion of various suggestions and the weeding out of the many possibilities to arrive at a common proposal.

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CONTENTS (Cont.)

AUTHORIZATION

The work reported on herein was done as a part of NRL Program R03, Identification and Recognition. This report is a summary of progress on Bureau of Ships problem S1234X-S, "Development of a New IFF System" assigned 6 November 1945, requesting "....that the basic problem of identification and recognition be investigated in all its phases...."

PROBLEM STATUS

Final conclusions have not been reached and the investigation will continue with appropriate reports on each phase of the problem. This report summarizes the thinking at NRL on the subject of electronic recognition as of this date.

ABSTRACT

An electronic recognition system is required to provide coverage equal to or greater than the associated detection device; to supply data at a rate equivalent to the radar detection rate; to provide unmistakable correlation with object-position information; to be secure against enemy use; to provide automatic features; and to perform secondary functions other than recognition.

A system is proposed of the pulse transpondor type having the novel feature of a transpondor transmitter which is electronically tuned to a reply channel determined by both the interrogation code and a chronometer-synchronized cryptographic code providing a high degree of security. Also the traffic capacity is materially increased since the replies are distributed over several channels, while the feature of continuous data at any interrogator is retained.

Provision is made for fixed-frequency reply in response to a pre-determined interrogation code for simplified operation. Individual identity of specially equipped transpondors in response to a given interrogation code is obtained directly by use of a reply pattern of letters or other characteristic symbols displayed on a PPI or similar indicator.

Emergency reply to any interrogator is included. Altitude data is transmitted by the transpondor.

The problems which arise as a result of the proposal are enumerated. Alternative techniques, not included in the proposal, are discussed.

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PROPOSED SYSTEM OF ELECTRONIC RECOGNITION

INTRODUCTION

The Security Systems Section of the Naval Research Laboratory has been pursuing a program in electronic recognition directed toward devising new techniques applicable to a new system. Though no specific device has emerged in a completed and tested form, enough information is available to lend encouragement to numerous ideas. It is appropriate to review the general situation at this time and attempt to indicate the trend of thought at this Laboratory.

The first part of this report reviews the problem and discusses in some detail the requirements of an electronic recognition system. These requirements, dependent upon numerous related factors, are projected into the future, as far as is now foreseeable, by estimating the limiting design factors of associated systems and determining how these factors influence the recognition system.

A system is proposed based upon the requirements and upon an estimate of what can be accomplished in due course. This proposal is extremely tentative and is likely to be modified by further work either because of new ideas or of unforeseen difficulties. It is, however, considered advantageous to present a proposal even in this state in order to obtain as much constructive criticism and discussion as possible before it becomes necessary to specify the system. The reasons for selecting the particular features of the system and other pertinent comments, such as anticipated difficulties, are stated.

The problems which require solution in order to accomplish the proposed system are listed, in order of importance and of anticipated difficulty. Numerous alternative ideas, not included in the proposal, are discussed.

THE PROBLEM

Briefly stated, the general problem in recognition is one of providing a means of immediate recognition of any hostile object upon detection. As an aid in its solution, detailed attention is given to that very important field restricted to objects detected by radar. Systems suitable for this purpose, and operating on similar principles, are defined as electronic recognition systems. The term IFF (Identification, Friend or Foe) is, however, an accepted abbreviated expression for such a system and will be used in this report in the above sense.

The problem as stated above may be considered the ultimate goal, but to be practical we must arrive at certain compromises and be content with building an interim system which will meet our needs for a finite time; else we shall have no system. The problem then becomes one of building a system which is sufficiently better than existing methods to warrant its cost.

Because of its magnitude, it requires considerable time to develop, produce and put into operation an IFF system. Many techniques, current for IFF and radar at the time specifications must be frozen, will be surpassed by the time the system is ready for use. When discussing a system to be used, say 10 years hence, every effort must be made to anticipate radar design and to provide for adaptation to characteristics which may now

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seem somewhat futuristic. Critics of such a proposal may well make a point of this and call attention to the fact that a system could be immediately put into production utilizing established techniques which would provide a system much better than anything we now have in service. The answer as to whether such a system should be built is based solely on economics. The purpose of this report is only to propose a system which meets the expressed requirements as nearly as possible by use of techniques which appear capable of development.

The problem may be better analyzed by examining specific requirements and discussing how they influence the system design. Appendix A gives the general military characteristics for a new recognition system which have Joint Service approval. The following requirements are in accord with these characteristics.

1. The coverage of the system should be equal to, or greater than, the associated detection devices.
2. The system should be capable of supplying up-to-date data at a rate equivalent to the radar detection rate.
3. The IFF data should be capable of unmistakable correlation with the object-position information.
4. The system should be secure against enemy use, interference or compromise.
5. The system should be adaptable to electronic devices for evaluation and interpretation of data without appreciable delay.
6. The system may be required to perform secondary functions for purposes other than recognition. All such uses must be examined from the viewpoint of the best way of meeting the over-all operational requirements.

Other requirements for a workable satisfactory system are: reliability, simplicity, light weight, etc., which are more a matter of good equipment design, and the techniques used, than of basic system operation. We shall discuss only items (1) to (6) above as having a bearing on present system considerations.

DISCUSSION OF REQUIREMENTS

GENERAL

The first three requirements: coverage, rate of collection of data, and correlation are closely associated with the characteristics of the detection system. Briefly what we may expect of future radars is:

1. Long-range search systems covering large volumes in space by use of multiple radar units, the number of units determined by the required rate of data collection. Possibility exists for low-frequency systems operating beyond the line of sight.
2. Shorter-range search covering large azimuth and vertical angles at high collection rates by use of scanning and/or multiple-units systems.
3. Control and guidance radars covering limited regions in space with high accuracy and resolution in all position coordinates.

The expected continual increase in speed of targets will force radar design to take maximum advantage of all characteristics to reduce delays in the provision of data. These characteristics will be reflected in the IFF system. Because radar systems may be

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designed for restricted functions while an IFF system must be capable of universal application, the IFF designer must make compromises between conflicting requirements or must devise methods of surmounting the difficulties by taking advantage of the inherent differences between the IFF and radar systems. It is therefore advantageous to examine the characteristics which are critical for the two systems and to see what differences may be taken advantage of.

The primary limitation on a conventional search-radar system is the necessity for sending energy to the target and waiting for its return before data becomes available. To obtain the greatest rate of data collection with appropriate accuracy and resolution, a particular system may resort to the following:

1. Use of as high a pulse repetition rate as is consistent with the maximum range desired.
2. Use of repetion rates higher than in (1) with methods to eliminate ambiguities in range measurements.
3. Limiting the angular coverage on any one set, and obtaining complete coverage by use of multiple sets.
4. Development of indicating devices which require the minimum of time for positive detection of the target.
5. Use of new techniques in radar systems to materially increase the performance in some particular. For example, reference 1 proposes a cw transmitting system rotating in azimuth at very high rates with receiving systems following at various angles of lag and receiving pulse signals of a duration determined by the time the target is in the transmitting beam.

The speed of data collection becomes less urgent as the initial detection range is increased. Continued effort to increase this range will result in:

1. Higher powers to the limit of the state of the art.
2. Use of large antenna structures to obtain greater gain. This will result in small angular coverage and therefore require more sets to give complete coverage.
3. Use of low frequencies when antenna size is not too critical in order to take advantage of the higher-power techniques.

The primary requirement for a control or guidance radar system is one of high accuracy and resolution which will result in; the use of frequencies as high as compatible with propagation phenomena, in order to obtain sharp beams, and in the use of short pulses with corresponding precise methods of indication.

A third general type of radar may be required, a radar to hand over the targets from the search system to the control and/or guidance system (target designation). However it appears that this will not impose special problems on an IFF system because its characteristics are intermediate between the search and the control systems and, recognition may not be required (since it is merely a tool for performing a certain operation and does not supply data from which actions are initiated).

We may now set down some of the characteristics of radar systems with which the IFF system will be presented:

1. High recurrence rates, ranging from a few hundred to several thousand per second.

2. Large number of radar units, each covering a limited volume of space which may be selected by dividing the coordinates in any possible fashion.
3. Long-range systems up to several hundred miles.
4. Very limited number of pulses per target per scan.
5. Use of frequencies ranging from relative low values (possibly a few megacycles for beyond the line of sight) through a few hundred megacycles for long-range fixed installations, to as high as permitted by propagation phenomena for short-range special-purpose systems.
6. Use of short pulse lengths with corresponding precision of range indication.

These characteristics tend to impose the following requirements and limitations on the IFF design:

1. Large free-space range.
2. High interrogation rates.
3. Short pulses and high range stability.
4. Provision of IFF service to a large number of radar units.
5. Operation with radars over a wide frequency spectrum.
6. Elimination of interrogator count-down in many cases, and considerable restriction in others. This includes interlaced interconnections.
7. Complex radar antenna structures which will make built-in IFF antennas difficult or impossible.

There are certain characteristics of an IFF system which differ from a radar system and which should be examined to determine how they may be utilized to ease the design requirements of the system. Such characteristics with possible uses are as follows:

If an IFF system is designed around the principle of recognition of foes by elimination of identified friends, wherein coordination with radar data is by position coordinates, energy does not have to travel out and back as in the radar case. That is, the position data may be determined by the friendly target and transmitted one way to the radar site. From considerations of traffic capacity, it is undesirable for a friendly unit to transmit an identification signal except when data is required. Therefore an interrogation process involving a two-way path will undoubtedly be retained. From a practical point of view the precise determination of absolute position coordinates is difficult for a moving vehicle. It does appear practical, however, to determine and transmit the altitude coordinate because of the ease with which it can be measured.

If the IFF system operates on the transpondor principle, the factor corresponding to radar-target cross section is independent of interrogation power as long as a reply is received. This permits better control of the free-space range and in general avoids the necessity for operation with small signal-to-noise ratios.

Since it is not a function of the IFF system to supply outgoing position data but only to use position data for correlation with the radar targets, resolution and relative accuracy assume greater importance than absolute accuracy.

COVERAGE

It appears that the first compromise with which we are faced is that of range coverage beyond the line of sight. Possible use of low-frequency radars and of microwave radars under anomalous conditions operating beyond the horizon lead to the following alternatives:

1. Use of sufficiently low frequency for IFF to give range coverage equal to any radar with the consequent disadvantage of poor directivity and large bulk, particularly in antennas.
2. Use of a multiple frequency system. At least two widely separated frequencies, one to give operation beyond the horizon and the other to give good angular performance within line of sight, would be required. This solution provides for complete coverage at the cost of duplicate systems.
3. Use of a single system for line-of-sight operation with no electronic recognition of targets outside this range.

The second major problem of coverage is that of supplying detailed IFF information to a radar system which may be composed of many individual radar units and may also employ high scan rates. It is certainly undesirable to provide in effect an IFF unit for each radar unit, that is, an interrogating system operating with a combined prf given by the product of radar units by the prf required to supply the desired data to a single unit. Since we may take advantage of the difference between a radar system and an IFF system in the matter of ease of transmitting altitude data by the transpondor, coverage may be reduced to one of range and azimuth only. This advantage may be more clearly visualized by specific examples:

Consider the AN/SPS-2 radar now under development which employs eight radar units feeding vertically spaced beams each scanning 360 degrees in azimuth but a limited vertical angle. One IFF unit could serve the eight radar units without increasing the prf or scan rates above that of the radar. This radar provides height finding by frequency channeling on the eight beams. If corresponding data were to be provided by the IFF interrogator-responsor, some channeling method would also have to be used. Time sharing (count down factor of eight) would be unsatisfactory since the radar design does not allow for any excess of pulses falling on the target per scan. The only alternative is to radiate at a higher effective prf using time division channeling or some form of coding channeling. However, with altitude data being furnished by the transpondor, the prf of the interrogator may be that of the basic radar system.

Consider the AN/SPS-3 radar, now under development, which scans vertically as it rotates in azimuth. While it has a prf of 3,000 per second, rotating in azimuth at 15 rpm, because of the scanning, only about 4 pulses per scan fall on a particular target. An associated IFF system, with azimuth scanning only, would then provide an equivalent quality of information with a prf of 120 per second. This reduction in prf by a factor of 25 is highly important in reducing the upper duty-cycle limit of the interrogator responsor. Also a high prf is undesirable because of the decrease in traffic capacity of the system and the possible saturation of the transpondor by a small number of interrogators. The AN/SPS-3 further consists of two radar units to cover the total vertical angle which would both be served by the single IFF.

DATA COLLECTION CAPABILITIES

To avoid delay in initiating defensive action, by the recognition function, it is necessary to be able to interrogate immediately and to receive the complete reply as soon as a newly detected object appears. With radars operating at high scanning rates and using the minimum of pulses falling on the target per scan, the IFF must in most cases be capable of making sweep by sweep comparison. This requires ability to:

1. Interrogate at the same rate as the radar pulse repetition rate.
2. Transmit complete reply for each interrogation.
3. Provide complete system capabilities without time sharing and interlacing except in the slower systems.
4. Supply IFF data automatically.
5. Handle traffic equivalent to the radar capabilities.

Certain techniques previously used in IFF systems do not satisfy the above requirements because:

1. Channeling by frequency scanning as in Mark III does not furnish continuous data.
2. Security coding extending over a considerable period of time as in Mark III and Mark V does not give complete data at the desired rate.
3. Interrogator count down as has been practiced with all high-repetititon rate radars must be restricted in order to provide sufficient IFF pulses to give complete information in a single antenna scan.
4. The type of personal identification as used in Mark V consumes too much time in identifying the individual. The process of requesting PI is a useless function; the information required for giving the vector should be continuously available.
5. The previous practice of observing a detected target on the radar and identifying by interrogation on a later scan introduces too much delay.

CORRELATION OF IFF AND RADAR DATA

Recognition of a target detected by radar is accomplished by association of a coded characteristic with the radar signal. Two general methods are available, one, a means of altering the radar signal itself, and the other, production of an IFF signal by a separate system which must be unmistakably associated with the radar signal. Although the former has the advantage of positive association, it's lack of flexibility makes it difficult to design practical equipment, because radars employ such a wide range of frequencies. For universal IFF use, unless radar design is to be severely limited, it seems apparent that no satisfactory techniques now exist that permit the consideration of other than the separate IFF system. This system introduces the problem of unique association of two signals - IFF and radar. This correlation is accomplished by comparing certain measurements made by both systems. The radar may be capable of measuring such things as: position coordinates, time derivatives of the position coordinates, and target size and/or shape.

It is necessary to obtain agreement on only one characteristic provided that the same values are not obtained, within errors of measurement, on another target. The likelihood of confusion is decreased by improved accuracy and resolution of the individual measurements and by increase in number of characteristics compared.

Determination of target shaped by radar is limited to rather special conditions for the foreseeable future. Target size may be more readily estimated but with a rather low degree of accuracy. For these reasons, and because it may be anticipated that many targets will exist having the same or similar size and shape characteristics, such measurements for IFF and radar correlation are considered impractical.

While measurement of the time derivative of the position coordinates may be very useful radar data for special purposes, it is not anticipated that such data can be depended on for universal use. Methods which require considerable time to arrive at accurate measurements are undesirable because of the delay in data collection.

Measurements of position coordinates are basic radar measurements, are essential information in the detection and control problems, and are of almost universal use. It is therefore beneficial to discuss these measurements in greater detail. Coordinates capable of direct radar measurement are slant range, azimuth angle, and elevation angle, all measured relative to the radar antenna as origin. In some applications it becomes convenient to change one or more of these coordinates. For example, in aircraft control where the aircraft measures altitude directly the elevation angle may be replaced by altitude above the earth. The origin may be shifted as found convenient in relay radar applications. It is obvious that positive coordination of IFF and radar data is accomplished by use of the position coordinates, provided that they may be measured with sufficient accuracy and resolution to insure that the signals being compared originate from a volume in space which can contain but a single target. Lacking this accuracy and resolution, the time derivatives of the position coordinates may be compared in a very simple manner, by observing the position data at a later time.

It is obvious that it is desirable for radar and IFF data to be equivalent in accuracy and resolution. The design problem of an IFF system is made particularly difficult since it has to operate with the radar having highest accuracy and resolution and at the same time be satisfactory in other respects for operation with radars having different characteristics that impose conflicting requirements. However, it is the purpose of this discussion to determine the limiting conditions. The radar data providing highest accuracy and resolution is furnished by the control and guidance radars. The limiting problem is that of a fire control radar which must deal with an enemy target closely associated with a friendly target. First it is necessary to know that there is an enemy among friends and second it is desirable to determine which is the enemy even before fire can be safely opened. This is necessary because the proper target must be tracked to supply data to the computer so that it can solve the problem.

The error in measurement, by radar, of a given coordinate is often less than the separation required to resolve two objects (other coordinates being equal). This resolution is dependent not only upon basic system design characteristics but also upon the purpose and method of use of the data and particularly upon the nature of the terminal equipment. Because of these differences, the term resolution in itself is difficult of definition. A given radar may have one resolution for tracking and another for target detection. When the term resolution is used it must be appropriately interpreted.

Comparison of the functions of a radar and an IFF system leads to the conclusion that while a given accuracy of radar data is required to supply data for control and guidance purposes, the accuracy of the IFF data is determined more by the resolution of the radar system than by its accuracy. That is, it is not the function of an IFF system to determine when more than one object is present, but the function of the radar; and until the radar performs this function there is no necessity for the IFF to resolve its data or to provide an accuracy of measurement greater than that required to correlate the two sets of information. We may say, then, that when both sets of data are used in the same manner the IFF system should have resolution equal to the radar. When this condition exists, it may be seen that the accuracy requirement for IFF is not rigid. If we assume any configuration of targets (all resolved) the data will appear in the same general pattern on the two systems. It needs only to be accurate enough to permit comparison with facility. The limiting case will be in use of electronic comparison circuits where resolution is maintained at the highest level which the system design will permit.

The system characteristic which affects the measurement of the range coordinate is primarily that of pulse width. Corresponding equipment characteristics are pulse shape. band widths, circuit stability, and methods of observation. The use of short pulses is desirable not only for improving range measurements but also for reducing the time required to transmit coded information, and for reducing the duty cycle of the transmitter. These advantages may be offset by the disadvantages of increased bandwidth and equipment design difficulties. If frequency channels are to be used a restriction on pulse width is imposed by the number of channels required. Increase of the number of channels by a corresponding increase in total band employed is undesirable owing to the crowding of services in the spectrum and to the requirement of further wide-banding of components. Wide-band amplifiers beyond a certain point require a considerable increase in number of componenets and in primary power drain.

The following criteria are suggested as a guide in the selection of pulse width:

1. The bandwidth required for transmission of the intelligence should be comparable with the bandwidth required as a result of frequency instability.
2. The frequency spectrum required to provide the necessary channels should not exceed about 20 percent of the center frequency.
3. The pulse characteristics of the transpondor equipment, transmitter pulse, and receiver bandwidth are basic system characteristics; certain interrogation characteristics may be relaxed as appropriate to the particular system application.

Although the above criteria do not specifically involve the consideration of range accuracy and resolution, they form a basis for arriving at the necessary compromise on the basis of good equipment design. This conclusion is based upon an assumption that associated radar systems will range between two extremes, that of high accuracy and resolution at the cost of considerable complication and restricted coverage. to that where accuracy and resolution are of secondary importance compared to extended coverage.

Angular accuracy and resolution are largely functions of the frequency and antenna size. Special techniques (lobe switching, etc.) may, however, be employed to meet special requirements. While in general the discussion may proceed along the line of the range measurements, there is one further consideration. If IFF and radar are to be presented in a composite display, some means must be provided for distinguishing between the two signals. This can be done by the use of different colors or by some characteristic distortion of one signal. It is preferable not to tamper with the radar signal; therefore if the IFF signal is to be marked by other means than color, it must be done by some distortion. Because precision is easier to achieve in range than in the angular measurements, it is not desirable to deteriorate the range data by such devices as artificial lengthening of pulses, which lowers the range-resolution capabilities of the system. The alternative is to distort the angular presentation such as by the chopping of the PPI arc. If this is done, the arc must be long enough to permit at least three individual dots to be formed.

The above argument may be supported by visualizing the volume in space with dimensions along the position coordinates, within which two objects may be located but be unresolved by the system. If one dimension (range) is small, the probability of resolution occurring (due to relative motion) within a short time is greater than if the same volume were bounded by comparable dimensions. Hence it is desirable to maintain high resolution in the most precise coordinate at the expense of much poorer resolution in a less precise coordinate. In practice, the altitude of a target is less likely to change within a short period of time than the azimuth or range coordinate, and, in general, there is equal probability of relative motion in azimuth or in range. Because of techniques permitting more precise measurement of range than of other coordinates, the system design should avoid any deterioration of range data. On the other hand it may be necessary,to broaden the antenna beam widths to produce an acceptable PPI display.

SECURITY

The problem of security has been reviewed in reference 2, where it is concluded that the primary requirement is to prevent the enemy from appearing as a friend. Various "degrees of security" are possible. The greater the security, the more complicated the system and the organization. It is practical to increase this complication only to the extent necessary to give reasonable assurance of protection against compromise during the life of the system. Unfortunately any conclusions on this subject are matters of judgment and are not subject to prior verification. (In the past, rather simple systems have given satisfactory protection because the possible gains derived by enemy use have not been large compared to the effort required. Such gains could very well become of the highest importance in the future, since the use of atomic weapons and of surprise attack would justify considerable effort by the enemy in effecting the compromise. One's judgment as to the degree of security required will be largely influenced by this evaluation of the seriousness of the penetration of one or more "super weapons".

It has also been concluded in reference 2 that inherent security can be obtained only by cryptographic coding methods which involve continual change in a random fashion. The highest security is obtained by manual changes carried out at random, provided that the changes are coordinated to the extent necessary to make the system workable. This implies a schedule which must be distributed by secure channels. The efficiency of maintaining this schedule will undoubtedly suffer when the period between changes becomes short. The codes and facilities for change will be determined by the frequency of the changes required. These changes may be carried out in practice at a frequency determined by the circumstances, but the system design must be capable of meeting the limiting conditions.

In order to form some opinion on this question, consider a hypothetical case of an enemy desiring to deliver a missile of great destructive power and assume that we would not take defensive action if he produced the proper electronic recognition signal. We may further assume a condition of active defense; otherwise the mission would, in any case, very likely succeed. The enemy may be expected to be familiar with our recognition equipment through capture or otherwise. In order to appear as a friend he must produce the proper IFF code. Assuming the reply channel is coded he may determine the correct code by observing the reply from one of our transpondors to his or to our own interrogation. Intelligence will provide him with an estimate of the probable duration of a given code. He can now initiate his mission with considerable confidence of success provided he has a workable transpondor which may be carried on the mission, and provided the remaining time of flight, after his last opportunity to set the code to the current value, is less than the expected duration of the code. The effort required to compromise the system is then largely dependent on when the code must be finally determined. It is then obvious that changes of once a day offer little discouragement to the planning of such a mission, with the perfectly reasonable assumption that in any extended region of hostilities monitoring of IFF signals will not be difficult.

On the other hand, manual changes of once a day, or more often, will certainly pose difficult operational problems. Having reached this conclusion, we are forced to be prepared to make more frequent changes and at the same time relieve the operational difficulties. This may be done only by chronometer-synchronized automatic changes at frequent intervals to supplement the less frequent manual changes. These automatic changes will be as secure as manual ones provided the cycle of change cannot be determined by monitoring alone, and provided a manual change is made as often as operating equipment is expected to fall into enemy hands, or, if this time is long, as often as necessary to avoid disclosing the particular cycle. As an estimate of the frequency of the automatic changes, a time of the order of the time of flight of a high-speed guided missile would appear to set a lower limit. To provide maximum flexibility, the system should be designed to make these changes as rapidly as possible without imposing undue design difficulties on the synchronization equipment.

While it is conceivable that an enemy would be able to design equipment capable of interrogating our transpondors, thereby obtaining the proper reply code for any interrogation and automatically setting his transpondor to the correct code, he may be discouraged from such attempts. Factors which may operate to his disadvantage are: (1) Uncertainty of the presence of our transpondors at the time and place suitable for his interrogation, and (2) Complication of monitoring as a result of specific system design.

This latter factor deservs more detailed examination. It may actually hold the key to the complete solution of security against an enemy appearing as a friend. As has long been recognized, the ideal system is one which provides positive recognition. This means that we should recognize enemies rather than friends. It is too much to hope that the enemy would provide us with operating transpondors. We may, however, design a system for recognition of friends which, for the enemy to compromise, requires him to disclose his presence by radiation of an "enemy" signal. A simple approach is to design a system which requires first, that the enemy interrogate in order to associate the reply signals with the proper interrogation code and, second, that he be forced to radiate unauthorized, interrogation codes thereby producing the "enemy" signal. While such an arrangement does not provide range, but only direction finding, it could be used as a positive warning system to direct attention to a particular sector where compromise was being attempted.

While prevention of unauthorized interrogation is of secondary importance, steps taken to provide such protection may, owing to the increased difficulty of monitoring discussed above enhance the primary security requirement of protection against an enemy appearing as a friend. For security purposes, an unauthorized interrogation is not considered complete unless the corresponding reply is observed. Cryptographic methods of coding are not applicable. We have only the "brute force" method of protection - that is, making unauthorized interrogation difficult by the number and complication of the codes. In general, such security may be measured in terms of the time required to "play through" the codes in order to obtain the desired information, and the frequency at which this process must be repeated. If the enemy is interested only in detection or positive identification, he need only interrogate until a reply is obtained. If, however, he is interested in obtaining information on how to set up transpondor replies for deception, he must, unless our design permits short cuts to be taken, examine all interrogator code combinations.

ADAPTABILITY TO AUTOMATIC DEVICES

Before determining design requirements for automatic operations it is necessary to determine what operations are expected. The ideal is the use of IFF to initiate defensive action which will result in elimination of all enemies. Less futuristic and more practical applications are: locking of gun fire when the target shows IFF, separation of echoes into friends and foes and, possibly, further separation of the friends into groups, and automatic warning of newly detected unidentified targets.

In order to meet these requirements, the IFF data should be continuous, stable, and free of any great quantity of spurious signals. The coverage should be good with the signal strength well above the noise.

FUNCTIONS OTHER THAN RECOGNITION

Because of the limitation of weight and space, particularly in aircraft, it is advantageous to examine any system to see what other important functions may be performed by it with an overall saving of equipment. Such functions as have been previously used or considered are:

1. Emergency (distress) signaling.
2. Short range navigation
3. Aircraft control.
4. Communication (voice and/or code).

Though there are many facilities for affecting rescue of aircraft pilots in trouble, the transpondor recognition system has demonstrated by experience its effectiveness in this respect. There seems to be no question concerning its incorporation in any system whose characteristics are adaptable to this use. To be most effective, the emergency signal should attract immediate attention of observers who are in the best position to render aid.

An IFF system and short range navigation systems have numerous requirements in common and the equipment techniques may be similar. For this reason, it would appear to be advantageous to coordinate such funtions. Possible disadvantages should, however, be carefully considered. They are:

1. Increase in traffic as a result of increased uses. If the two functions are separated by frequency channeling, consideration must be given to the possible difficulties introduced by additional broad banding of equipment components. If collision warning involving a transpondor is a feature of the navigational system, a separate frequency cannot be used without an additional radio channel in the transpondor or the use of time sharing, which is deleterious to the IFF system.
2. The navigational system is as important in peacetime as in war and because of the necessary coordination of civilian and military activities, including international use, there is the possible danger of future enemies obtaining information as to the nature of our IFF system, which would give him the advantage of being able to use a similar system for his own application even though our system were capable of use without loss of security.
3. Further consideration should be given to possible limitations to the navigational system which would be imposed by its coordination with the IFF. This problem should be approached by an independent study of the navigational requirements to

determine what is most desirable followed by an examination of the disadvantages of coordination.

Aircraft control is a broad field. One may be concerned with any of the following specific applications:

1. Overall control of flights throughout a large area.
2. Control of aircraft in the immediate vicinity of an airport.
3. Control of aircraft in the vicinity of ships at sea.
4. Control of individual aircraft preparatory to, or in the process of, landing.
5. Control of specific aircraft on a military mission such as bombing or fighter interception.
6. Guidance of missiles.

Examination of these functions in detail will undoubtedly lead to a conclusion that some are closely allied to a general navigational system while others are of such special application that they may be better performed by a separate system.

In order to avoid a lengthy discussion of systems not allied to IFF, let us attempt to establish certain criteria which may be used as a guide in determining what functions deserve further consideration as to incorporation in a system devised primarily for recognition:

1. Since an IFF system is purely a military system, the additional functions should also have military application.
2. Since the IFF system must be closely associated with detection and tracking radars, the additional functions should be those which may be associated with such radars rather than with a radar which does not require the recognition function.
3. Any additional function should be one which requires the use of coordinated equipment on a wide scale, particularly in aircraft.

Therefore, functions which may be advantageous to consider are:

1. Facilities for identification of friendly fighters in fighter direction. This is a military application which is performed by detection radar having a requirement for recognition. Although not universally required, this function must be coordinated on a wide scale. Also, because the fighter aircraft involved are crowded for space and weight, the use of a single equipment is a major advantage.
2. Facilities for identification of individual planes in order to select specific aircraft and take them under control, in the vicinity of a military base or carrier, preparatory to landing operations. This facility should be provided only in the absence of a satisfactory solution to the problem by more appropriate methods - for example, a coordinated traffic control and landing system.

The provision of beacon signals for use in guidance of missiles would appear to be so specialized that such functions could be better served by design of an independent system.

The function of communications is so important and extensive it is obvious that the required traffic cannot be accommodated by a single system. We should be concerned only with limited functions in this field. Assuming that communication channels exist in operating condition, there is no need for communication facilities on an IFF system unless the messages being transmitted require association with the radar data, and only then if there is necessity for rapid action.

PROPOSED SYSTEM - GENERAL DESCRIPTION

A system is now proposed which represents what is considered a reasonable solution of the problem in terms of meeting the requirements as far as possible by use of techniques existing or capable of development in due course. No claim is made that the ideal solution has been accomplished or that new principles of operation have been discovered, but only that a system design is proposed that more nearly meets the military requirements for electronic recognition than previous systems and that specifically offers material advantages in security, traffic capacity, and quality of data, characteristics which have not been adequately provided for in previous systems.

The system is described and reasons offered for the choice of each characteristic chosen.

GENERAL TYPE OF SYSTEM

A conventional pulse-type interrogation-transpondor radio-frequency system is proposed in which the foes are determined by eliminating friends which are identified by establishment of one to one correspondence, by one or more space coordinates, between the radar-detected target and a properly coded recognition signal.

This method has been chosen because no other proposal has been presented which appears capable of competing with the pulsed-transpondor system for universal use. See reference 3 for discussion of c-w systems.

INTERROGATION

The interrogation will be on a fixed-radio-frequency channel, differing from the reply channels but chosen within a portion of the same band, and will consist of a pattern of pulses formed by a start pulse in a first position always transmitted as a reference, followed by one to three additional pulses in second, third, and fourth positions forming a Baudot type code with seven combinations. Transmission of a pulse in the fifth position serves as a lockout signal which prevents the transpondor replying. The purpose of the lockout is explained on page 16 (Artificial Azimuth Sharpening).

A single interrogating frequency has been chosen rather than a selection from a number of channels, since no concrete justification is evident for the use of additional channels. Avoidance of jamming by availability of a wide frequency band and frequent shifting is considered impractical. If a navigational system is coordinated with the IFF, such equipments as necessary (airborne interrogator, etc.) may be required to operate on additional preset channels as required by the additional functions.

Pulse-pattern interrogation has been chosen in order to suppress unwanted triggering by radar and other single-pulse signals and electrical interference, to provide channeling for special functions, and to assist in security coding as described under that topic.

This particular form of pattern was selected for its compactness, and the resulting minimum of delay which is considered to outweigh the disadvantages of increased interrogator duty cycle necessitated by use of more than two pulses.

REPLY

The universal IFF reply will consist of a pair of narrow unmodulated pulses on a fixed carrier frequency, differing from the interrogation frequency, and chosen from seven possible channels in a manner to be described under security coding. The spacing between pulses will indicate altitude. If desired, the altitude pulse (second) may be wider than the range pulse (first) so that by use of proper decoding circuits the display can be provided with whatever information is desired.

Cross-band operation has been chosen to avoid radar type of operation and to separate the interrogation and reply traffic. The minimum number of pulses has been chosen in order to maintain high traffic capacity, high resolution in range, and simplicity of design. Altitude information is transmitted because of the extreme difficulty of determining accurately the elevation angle at the interrogator, and because such information is very valuable for fire control IFF and aircraft control and as a means for greatly reducing the traffic.

The emergency (distress) reply, applied to the airborne transpondor only, will consist of several reply pulses so spaced as to produce visual indication on various range scales with the first spacing controlled to an accuracy suitable for electronic decoding. Altitude data will not be transmitted while showing emergency. This type of signal was chosen because it has the advantage of very general application to display devices.

Replies carrying information for aircraft control and other operational functions in the nature of automatic communication which may be desirable to associate with an IFF system will be transmitted on a reply frequency channel, selected in response to a predetermined interrogation code, thus separating these special replies from those providing IFF information only. The information will be carried by a form of keyed range coding generated by a device carried only by craft involved in such functions (see reference 4). Non-equipped transpondors will give the normal two-pulse reply. Also the specially equipped transpondors will give normal replies to the other interrogation codes. Altitude data will be lost but security coding maintained for this mode of operation. This pulse pattern will generate characteristic symbols on appropriate displays, or certain portions of the signals may be electronically decoded. The modulation will be based upon a seven-element code. To illustrate the form of transmission which may be used, two examples are:

1. A series of letters, numerals, or other symbols generated by switching the range-code pattern at a rate which will draw a dot picture on an appropriate display (possibly and expanded section) which can be read visually.
2. A type of Baudot seven-element code repeated sweep by sweep which will provide a number of combinations depending on how it is used.

The types of information which may be transmitted are: (1) Individual identification, useful for aircraft control, which would permit continuous knowledge of the positions of particular units and would save time over the present methods of operating personal identity codes to local individuals. It would also be useful in maintaining checks on the identity of friendly tracks, and (2) transmission of special messages such as reporting, sighting, etc.

The method of providing the personal identity functions by use of a large number of identifying symbols, which are generated upon receipt of a predetermined interrogation was selected as being more desirable than use of a single signal, turned on only after a request had been made to the pilot. Operationally the requirement is to locate a plane of known identity so that the pilot may be given direction. Restriction to a single reply frequency was made in order to maintain high traffic capacity and freedom from clutter on the universal IFF channels. Although five pulses in range will permit formation of letters, etc., it is believed that the improved detail with seven pulses is worthwhile. A modulation requiring certain restrictions as to antenna rotation rates, sweep speeds, etc., is considered acceptable in view of the increased amount of information which can be transmitted, and the fact that universal use is not required.

SECURITY CODING

Security against enemy use of transpondors to appear as a friend is considered of primary importance. A cryptographic method will be employed to vary the reply frequency in seven discrete steps (channels). The frequency of a given reply will be a function of (1) the interrogation code -- all used simultaneously; (2) a code-wheel assembly or code tape--manually selected; and (3) the code-wheel configuration or tape position--chronometer selected.

Frequency was selected as the coding element since it is an element essential to operation of the system and since its use for coding does not adversely affect traffic capacity. duty cycle. and general clutter of signals as is the case with multiple pulses. The reply channel was chosen to make enemy monitoring more difficult since he must have available signals from our operating transpondors a condition that may be somewhat uncertain at any particular time. The enemy may be almost assured of interrogation signals when he approaches our forces. A manual change of code is provided to defeat enemy compromise by capture of operating equipment. Chronometer variation is used to force the enemy to monitor at the time he intends to use the transpondor against us. Dependence of reply frequency on interrogation code increases difficulty of monitoring by making it necessary to associate the interrogation code with the reply frequency. Also, the traffic capacity is increased by reducing the number of signals on any one reply frequency at a given time.

A simplified-system operation is provided by interrogation with a particular code which produces a reply on a fixed frequency. that does not depend upon the cryptographic coding. This reply contains altitude information. In this case the security of recognition is only that of a simple interrogator-transpondor system. This facility is provided for use if high-security features are not required under certain conditions. for example if there is little concern about enemy compromise or in interrogator installations where space and weight are extremely critical and high security not vital.

OTHER NEW SYSTEM TECHNIQUES

Certain techniques should be developed for limited installation. Provided initial provision is made in the equipment design the system will function without these special provisions but considerable improvement may result if they are used. Such devices are described below.

ARTIFICIAL AZIMUTH SHARPENING

Transmission of the interrogation code on a normal single-lobe antenna pattern causes triggering of the transpondor only if a pulse is not received in the "lock out" position. If this pulse is transmitted on a null pattern aligned with the central lobe, triggering will occur only over a narrow arc determined by the null pattern. It may be seen that the transpondors will reply to normal interrogation using a conventional antenna where broader response arcs are suitable. For further information on experimental results see reference 5.

Primary advantage of this technique is to obtain short arcs on a PPI type display with a small antenna but without going to extremely high frequencies. Secondary advantages are the possibility of elimination of secondary-lobe triggering and an increase in traffic capacity due to less triggering of transpondors. A difficulty of the system arises in the depth of the null which it is practical to obtain. This is not considered a serious disadvantage since it may be overcome by switching interrogator power with range scales (two values will suffice - short and long). It is anticipated this technique will be most valuable where the IFF is operating with radars of considerably higher frequency and for independent IFF installation.

DEFRUITING

Elimination of the unlocked signals arising from interrogation of the transpondors under examination by other interrogators is known as "defruiting". This equipment is localized at the interrogator and may be installed as desired. The circuits involved are similar to a "reversed" Moving Target Indicator (MTI).

It is anticipated that this technique will be of most use on long-range-search and fighter-director-type radars, particularly if low recurrence rates are used. It will be essential for electronic sorting.

INDEPENDENT IFF OPERATION

Development of signal-storage methods may make practical the collecting and storing of IFF information by a system which is independent of any radar, the stored information being played back to the radar as desired.

This technique will permit greater latitude in IFF equipment design. It may be particularly economical equipment-wise on shipboard. Here one IFF system could furnish information to several radars. Its effect on system performance would be to reduce interrogation and reply traffice because of the use of fewer interrogators, and to increase the traffic capabilities of shipboard transpondors by reduction of the percentage of dead time as a result of suppression required to avoid misidentification. See reference 6.

ELECTRONIC SORTING

In considering a new system, to be introduced several years hence one must plan on much higher speeds of targets resulting in less time to take action. Also, for improvement of accuracy, automatic methods must be used for recognizing facts and performing as many of the evaluation operations as possible. The systems should therefore be designed to supply signals suitable for such use and techniques should be worked out to take full advantage of them. The process of comparing the IFF and radar video channels to produce output channels of friends on one and foes on the other is termed electronic sorting. This technique should be adopted to the extent necessary on all installations.

PULSE-AMPLITUDE COMPARISON

Decoders which recognize a pulse pattern only if all pulses in the pattern are of approximately equal amplitude serve to reduce difficulties arising from multiple-path propagation and extraneous signals. A system which overcomes these difficulties and at the same time suppresses spikes arising from off-frequency reception has been worked out (reference 7) for patterns consisting of two pulses. Extension of these methods to more complicated patterns is straight-forward.

CIRCULARLY POLARIZED RADIATION

The sense of circularly polarized radiation is reversed upon reflection under certain conditions. This fact may be useful in an IFF system design to reduce the difficulties, ordinarily encountered in present systems, arising from reception of unwanted signals produced by reflection from ships and other objects and from the sea.

One serious situation now arising is that of misidentification resulting from IFF signals' being reflected by an enemy ship in such a manner as to produce an IFF reply on the display at the range and azimuth of the enemy target. Protection against such occurrences now involve suppression of the ship transpondors over long periods of time, thereby reducing traffic capacity. Other cases exist for which there is no protection. For detailed treatment of the problem see reference 6.

Sufficient data on the depolarization on reflection from practical targets is not available at this time to enable proper evaluation of this technique. Measurements should be taken and the possible use of circularly polarized radiation considered before a final system design is initiated.

SPECIFIC DESIGN FEATURES

The following discussions are presented for the purpose of illustrating how the previously described system features may be accomplished. Only those features which have not been used in previous IFF systems, and therefore may not be widely known are described in detail.

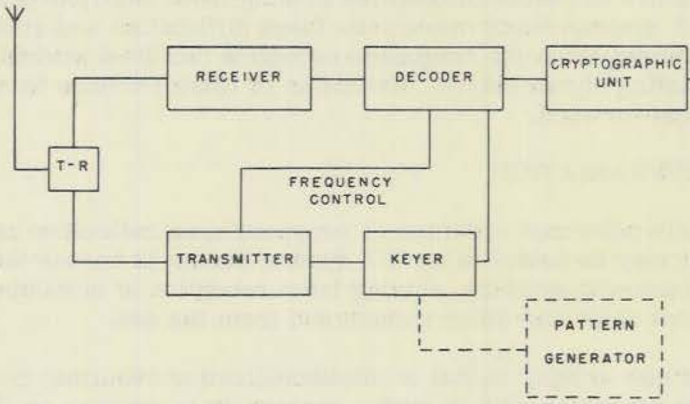

Figure 1 Block Diagram of Transpondor

A block diagram of the transpondor is given in Figure 1 and of the interrogator responsor in Figure 2 showing both the complete interrogator responsor diagram including all basic features plus azimuth sharpening and a simplified diagram which provides a fixed frequency reply of a simple interrogator-transpondor system. Reference should be made to these diagrams as the design features are discussed.

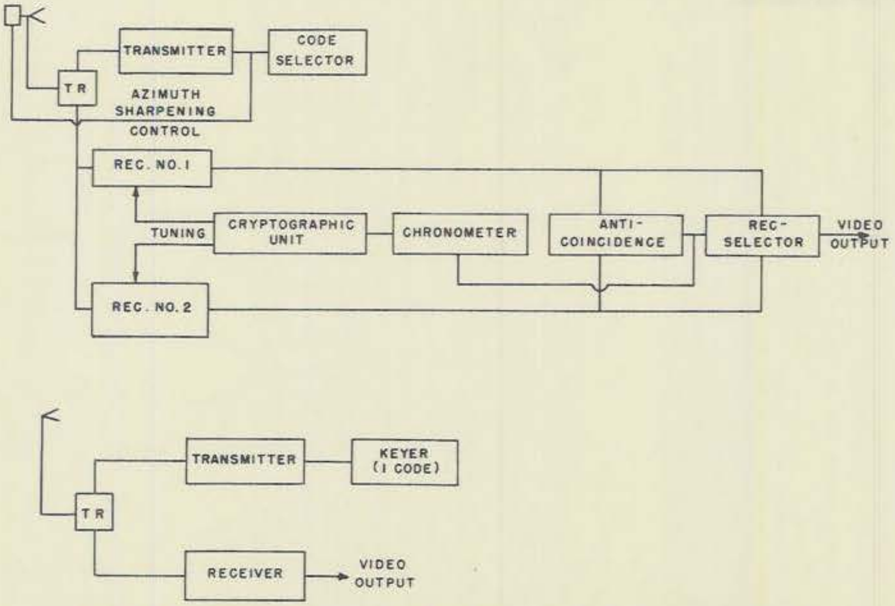

Figure 2. Block Diagram of Interrogator-Responsor and Simplified Interrogator-Responsor

SECURITY-CODING DETAILS

The interrogation codes are represented by the plots in Figure 3. A start pulse is always transmitted as a reference. The number of possible codes depend upon how many pulses and code positions are used. For four pulses (including the start pulse but not a lockout pulse) disposed in four possible positions, eight codes may be formed as illustrated. A single pulse however, is unsatisfactory because of its similarity to noise. This form of code may be expanded if more interrogation codes are required, first at the expense of greater time delay and secondly with an increase in the transmitter duty-cycle requirements. For example, if an additional position were permitted, there would be four two-pulse, six three-pulse, four four-pulse and one five-pulse codes, totaling fifteen usable codes. If the duty cycle restricts operation to three pulses maximum (not counting the lockout pulse) there would still remain ten usable codes, with the three pulses disposed in five positions.

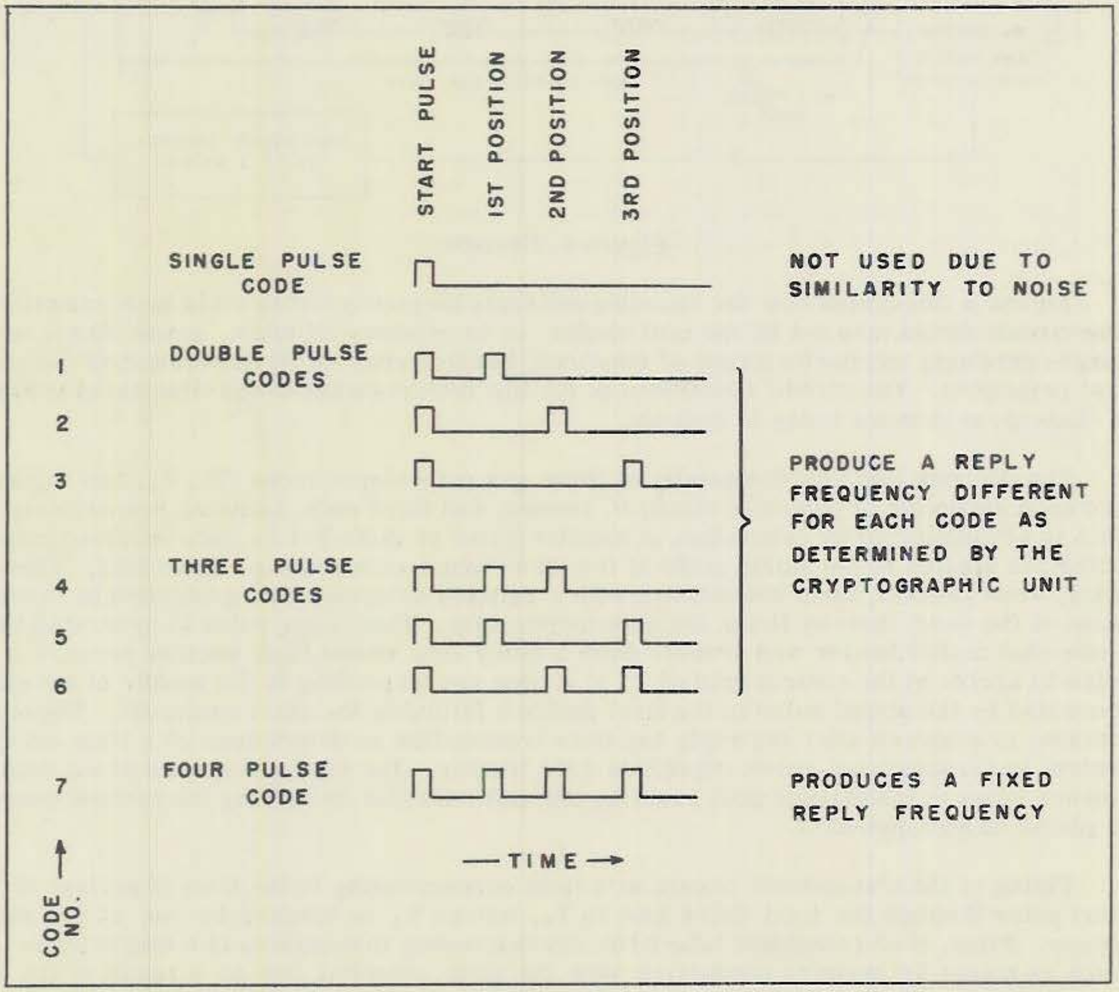

Figure 3. Proposed Interrogation Codes

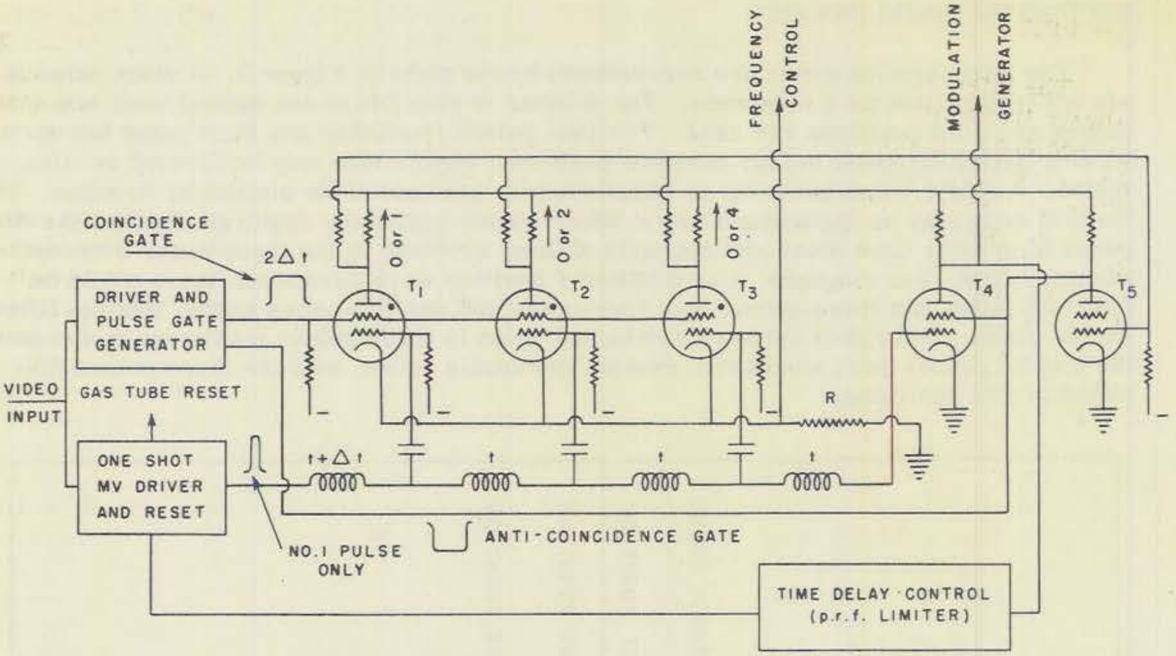

Figure 4. Decoder

Figure 4 illustrates how the decoding and reply frequency coding could be accomplished. The circuit drawn may not be the best choice as to economy of tubes, power drain, wide range operation, and performance of functions, but it serves as an illustration of the general principles. The circuit illustrated is for the interrogation codes illustrated in Figure 3. Extension to more codes is obvious.

The decoder consists essentially of three gas coincidence tubes (T_1, T_2, and T_3) which fire upon reception of pulses in the first, second, and third code positions respectively. This is accomplished by generation of positive gates of width $2\Delta t$ by each received pulse which are applied to the shield grids of the three tubes, overcoming a fixed bias. These gates, when present, form coincidence with a suitably delayed pulse, generated by the start pulse of the code, thereby firing the appropriate tube. This latter pulse is generated by a one-shot multivibrator and travels down a delay line whose first section permits a pulse to arrive at the control grid of T_1 at a time corresponding to the middle of the gate generated by the signal pulse in the first position following the start pulse, etc. The multivibrator is restored after the reply has been transmitted as determined by a time-delay control and transmitter-pulse-repetition-rate limiter. The conduction state of the coincidence tubes is maintained until reset by the multivibrator by driving the cathode positive or plates to zero potential.

Firing of the transpondor occurs at a time corresponding to the time of arrival of the start pulse through the total delay line to T_4, unless T_4 is blocked by one of two conditions. First, if no coincident tube fires, corresponding to reception of a single pulse (such as noise) T_5 remains conductive with its plate potential low as a result of the drop through the plate resistor which supplies the screen of T_4. Potentials are adjusted so that there is no output from T_4. If one or more coincidence tubes are conducting, T_5 is blocked and T_4 will pass pulses applied to its control grid on to the modulation generator thereby resulting in transpondor reply signals being transmitted. Secondly, a negative anti-coincidence gate is generated by each received pulse and applied to the screen of T_4 so that no output occurs from T_4 when this gate is present. It may be seen that if a lockout pulse is transmitted, an anti-coincidence gate will occur at the time of arrival of the delayed pulse to the control grid of T_4, and that therefore no transpondor transmission will occur.

The establishing of the reply frequency is accomplished as follows: First, the coincidence tubes T_1, T_2, and T_3, when conducting, pass currents (I) of 1, 2, and 4 units respectively through the common cathode resistor (R) which is small compared to the plate resistors. Thus the potential drop in R will take on values depending upon which tubes are fired, and this in turn is dependent upon the interrogation pulses received. The number of RI units corresponding to each interrogation code is given as the code number on the left hand side of Figure 3. Therefore, the potential across R may be used to control the frequency of an electronically controlled oscillator whose frequency would be a linear function of the code number received.

Further, it is proposed to change the frequency corresponding to any given interrogation code in a random manner. This is accomplished by use of tape-controlled switches which vary the plate resistors of T_1, T_2, and T_3 so that the currents of 1, 2, and 4 units are distributed at random between these tubes. Figure 5 illustrates a method for use of a six-element teletype tape to vary the plate resistors of the coincidence tubes. The numbers associated with the resistors in the figure indicate the number of units of current the resistor will permit to flow when the circuit is completed.

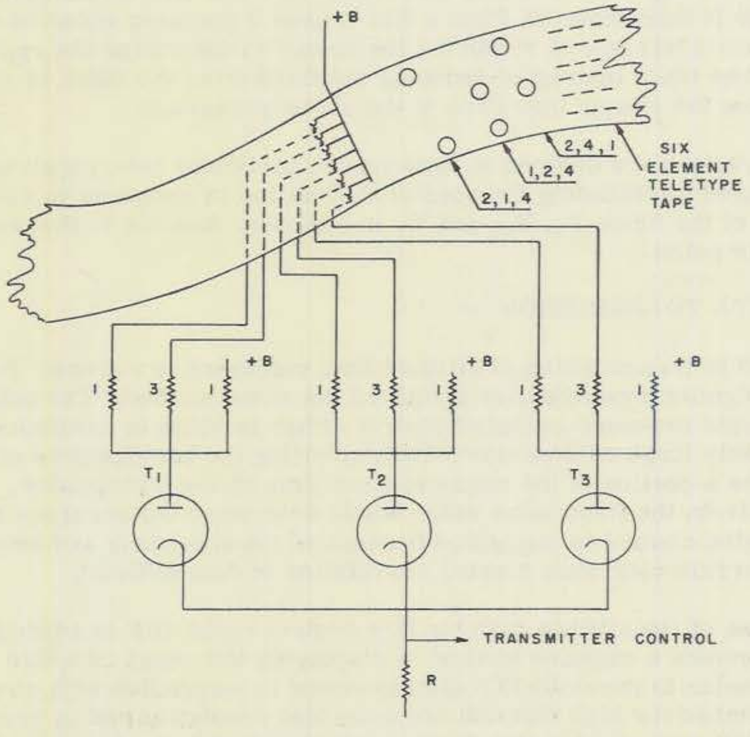

Figure 5. Enciphering Arrangement

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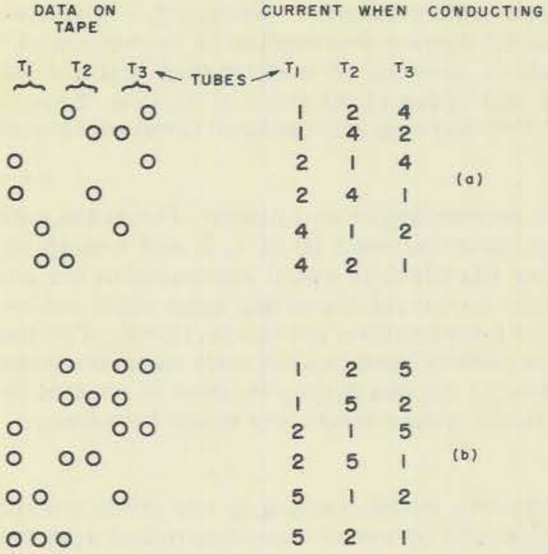

Figure 6. Tape Codes

For the four pulse code, all tubes are fired and therefore seven units of current flow in the control resistor regardless of the random switching of the plate resistors. This code may be used to obtain fixed frequency replies which are independent of the cryptographic operation, and is useful for simplified interrogator systems not desiring to provide the extra equipment required for the highest order of security.

If the frequency channels are designated by the corresponding code numbers, it will be observed that two pulse codes can produce operation only on frequency channels 1, 2, and 4 and three-pulse codes produce operation on channels 3, 5, and 6. Also it may be noted that the punching of the tape is restricted to certain two-hole combinations as illustrated by Figure 6(a). If other combinations were punched a different set of numbers from 1, 2, and 4 would be obtained. This would in some cases call for a frequency channel higher than 7 and in other cases cause the same frequency to be set up in response to two or more interrogation codes. These conditions would be acceptable if the transmitter would control over the required range and if traffic did not become too high on the common channel. An interesting case is that shown in Figure 6(b) where 5 has been substituted for 4. In this case, there is the advantage of requiring the enemy to determine the resistance combinations for all three tubes instead of deducing the third from the other two. However, one no longer obtains the simple operation of the above paragraph.

If special replies are desired in response to particular interrogation codes, this may be easily arranged by initiating the special modulation in response to a predetermined state of conductivity of the tubes T_1, T_2, and T_3 in a manner similar to that used to block the reply to a single pulse.

ALTITUDE-DATA TRANSMISSION

The method of transmission of altitude data suggested is not new. Several air-traffic-control and navigation systems have proposed the same method. The pulse spacing may be varied by a simple pressure-actuated control either in steps or continuously. The spacings may be reasonably large without appreciably affecting the performance of the system. This spacing would be a portion of the required dead time of the transpondor. The range data would be taken from the first pulse which would determine the accuracy and resolution. Pressure-actuated control is suggested because of its simplicity and because radar devices furnish terrain clearance making correlation of data difficult.

Possible use of the altitude data for fire control radar IFF is represented in Figure 7. Sketch (a) represents a common method of displaying the range on a fire control radar. Sketch (b) is simlar to previous IFF displays used in connection with such radars. The IFF is lobe switched for high azimuth accuracy and resolution and is presented as a back-to-back indication on a short sweep in the notch (lower) which corresponds to the range

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notch on the radar display. To utilize the altitude information, a second notch (upper) is generated at a range displacement corresponding to the altitude code spacing. The positioning of the notch is controlled by a computer which is fed elevation and range of the radar target being tracked. Since in this application the requirement is to identify a selected target by correspondence of the three position coordinates, and not to obtain position information, it may be seen that the suggested display fulfills the requirement by merely observing that equal right and left signals appear in the two notches. The above description involving the lobe switched replies was chosen for purposes of illustration only. Artificial sharpening methods applied to the interrogation could be used in a similar manner.

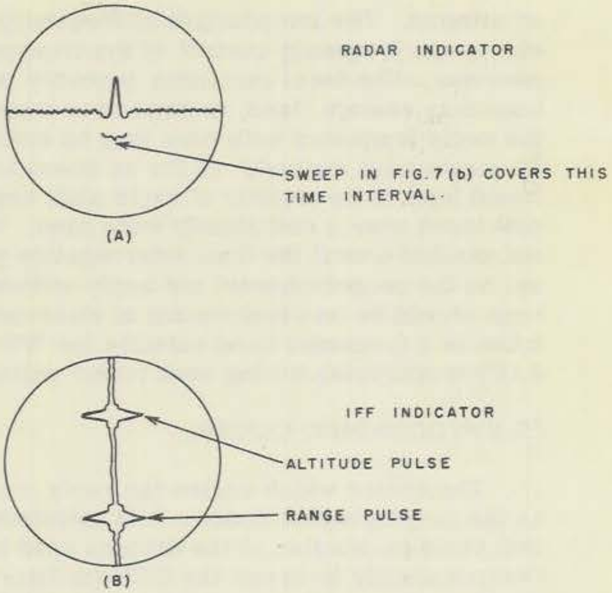

Figure 7. Suggested IFF with Altitude Indication for Fire Control

Another way in which the altitude information may be used is to determine and present three-dimensional position information from the IFF system (say for traffic control purposes) independent of a radar detection system. Where a radar system may resort to some form of vertical beam scanning, an IFF system such as suggested could accomplish equivalent results without vertical scanning by use of the conventional PPI indicator, as would be used in the radar case, plus a special form of range-height indicator (RHI) to present the height information in a manner similar to the radar RHI. The cathode ray tube sweep would trace out a television type of scan where the horizontal axis indicated range and the vertical displacement of the sweep, indicated altitude. The cathode-ray beam would be gated in accordance with the altitude data in such a manner that a spot would be painted on only the sweep corresponding to the proper altitude. To avoid false indication it might be necessary to code the signals, say by width, so that the range and altitude signals were different.

Previous paragraphs have indicated how transmissions of altitude data might be utilized (a) to improve upon the IFF discrimination in the fire control case, which represents the most difficult example in this respect and (b) to present the altitude data independent of a radar system such as for traffic control purposes. Undoubtedly many other special forms of display would eventually be used and it is difficult to anticipate them here. It is obvious that the altitude will be indicated by mere observation of the pulse spacings where these can be observed and correlated. It seems pertinent to terminate this discussion with the reminder that, as far as IFF is concerned, difficulty in association of the altitude pulse with the range pulse is largely eliminated by making use of the fact that the radar furnishes altitude data which may be used to mark the position in altitude where the altitude pulse of the IFF data should appear. If it appears elsewhere, then it does not originate with the target under observation.

ELECTRONIC TUNING

The suggestion that the reply frequency be varied for security coding presents some severe technical design problems. The advantages to be gained, however, warrant such

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an attempt. The introduction of frequency dependence upon interrogation code requires electronic frequency control of the transpondor transmitter and possibly of the responsor receiver. The local oscillator probably presents no problem since the interrogation code may remain fixed, at least over a considerable period of time, and the variation of the reply frequency with time may be anticipated. Probably the receiver could be tuned by mechanical methods as far as speed is concerned. The transpondor transmitter tube would have to be capable of rapid shift between channels. This rapid shift has not been developed over a sufficiently wide band. The information for setting the frequency is not available until the final interrogation pulse is received; then the transmitter must be set on the proper channel and reply without undue delay. It is obvious that the main effort here should be on development of electronic tuning methods for transpondor transmitter tubes in a frequency band suitable for IFF, for example, in a range between 1,000 and 4,000 megacycles having peak power outputs between 500 and 1,000 watts.

CRYPTOGRAPHIC CODER

The device which varies the reply frequency as a function of time will be referred to as the cryptographic coder. It is anticipated that its general construction for the basic unit could be similar to the devices used in cryptographic machines for communication. One possibility is to use the ECM (military cryptographic machine for communications) working into an adaptor which would punch a tape which would then control the switching of the IFF equipment. This has the advantage of furnishing a random cycle equivalent to the complicated machine without adding any great bulk to the IFF equipment. Further, the tapes could be produced on the spot in accordance with a centrally controlled code wherever there was an ECM machine and an adaptor. Also, short lengths of tapes, long enough to run only for the duration of the flight need to be carried by planes thereby reducing the amount of information an enemy would receive from captured equipment.

The adapter might be a special tape perforator operated by the ECM machine or use could be made of standard teletype tape enciphered by the ECM, which may be developed and adopted for military use.

SYNCHRONIZATION

The cryptographic coders (for transpondor-transmitter frequency and responsor-receiver frequency) would be driven by a clock mechanism similar to existing military airborne clocks, or possibly by a crystal-controlled or an electronic clock. The change would occur at uniform time intervals. The errors between clockworks would be allowed for by providing an overlap interval at the time of code change, at which time either the old or the new code are recognized as correct. This requires two receivers at the responsor. Since a signal should not occur on both receivers at the same range, an anti-coincidence circuit could be used to defeat enemy compromise by transmitting on all frequency channels in reply to each interrogation. Should the enemy stagger his replies in time on the different frequencies, we should have to monitor some other channel or widen the anti-coincidence gate which would result in loss of range resolution during the overlap period.

For convenience in setting up the codes and reassuring operators that the mechanism is operating satisfactorily, the clock mechanism will indicate time in days, hours, minutes, and seconds from a reference point. By knowing this reference point (basically a part of the code) the mechanism may be put into operation with the aid of a good timepiece, or its synchronization may be checked at any time.

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CHOICE OF FREQUENCY, PULSE WIDTHS, AND SPACINGS

Exact values of numerous characteristics of the system have not been stated. Many of these do not need to be fixed until development is started; however, for planning purposes it is well to have in mind an approximate value. Some comments will therefore be presented on this subject.

FREQUENCY

A study of the factors affecting the choice of frequency has been completed and reported in reference 8. The conclusion was that frequencies from a few hundred to about 3,000 Mc were suitable for such a system, the exact value being to a large extent a function of techniques available or capable of being developed for IFF within the allotted time scale for introduction.

The time scale factor and other policy decisions may possibly influence the choice of frequency in the following ways:

1. Ease of accomplishing electronic tuning over a sufficient number of channels. The number of channels desired and the bandwidth requried to transmit the intelligence are determined by other considerations. Assuming that stability is approximately independent of frequency, or that the bandwidth required to accomodate the frequency instability is not large compared to that required to pass the signal, frequencies near the upper limit may require less development time.
2. Availability of techniques and components already developed. General techniques are available for work in any portion of the band. Specific components are available in considerable quantity in the L_x band as a result of the IFF Mark V, and in the S band as a result of radar and radar beacons. Except for an emergency program, which would probably require considerable compromise in requirements, availability of specific components would be of little ultimate advantage.
3. Frequency Allocations. Frequencies allocated to other functions are unlikely to be available for IFF, particularly if equipment is already under development. Allocations of frequencies above 25 Mc are regional and were promulgated by reference 9. Those bands specifically set aside for IFF, for general navigational use (possible association of IFF and navigational system) and for pulse radar systems (not specifically assigned to equipment) are legitimate for consideration.
4. Interim system policy and changeover. Conceivably it may be considered serious to interrupt the recognition system for any length of time while changing from one system to another The Mark III system now in use is considered to be below the lower limit of frequency which would be satisfactory; therefore its frequency would not be used. The only other system now developed which might be used is IFF Mark V, whose frequency does fall within the band considered satsifactory. Should this system be adopted for interim use it might have considerable influence on choice of frequency.

We may reasonably restrict our consideration to the following bands as being most likely of selection as a final choice:

1. 960-1215 Mc. -- Mark V IFF is included in this band. It is allocated to navigational use in the United States and proposed for International Navigational use.
2. 2700-3700. -- Allocated to pulse radar and racon systems on noninterference basis to amateurs from 3300 to 3500 and to non-Government from 3500 to 3700.

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system of two equipments -- the control transmitter and the control receiver, while an IFF system must at all times give service between any transpondor and any interrogator. It is therefore practical to code the control system mission by mission while the IFF system must be either universally coded or at least by large areas.

2. The traffic of a control system is very low and between two terminals while an IFF system must be able to cope with very high traffic between many terminals. This difference permits a control system to have a very low operational duty cycle.

Of all methods suggested for security against interrogation, for any system, there is only one which has any real security, that is, the method of "brute force" wherein the enemy must discover the code by trial and error, and wherein the average time taken to try the code and to observe the result multiplied by the number of times he must repeat this process is comparable with the time available to him. Techniques which are immediately obvious are:

1. Availability of a large number of interrogation codes any of which may be used as far as the enemy knows. Care must be taken to insure that the enemy can not use short cuts which have the effect of reducing the number of codes.
2. Rapid and random change of code to avoid its detection by monitoring. In the limit a given code should not be successively repeated.
3. Restriction of the receptive period of the receiver to as short an interval as possible so that the working time available to the enemy is short. This may be either on a time basis, which requires synchronization, or on a duty cycle basis, which avoids the synchronization problem.

While these techniques may be exploited in a control system they unfortunately do not materially assist in the IFF problem. The use of a large number of interrogation codes is largely nullified by the probability that high traffic will give the information to a monitor. Likewise, the IFF system must be continuously responsive.

Another approach is often used, that of equipment complexity and secrecy of method of operation. While, practically, security may be attained for an indeterminate length of time, such techniques do not provide an inherently secure system and give no guarantee of the length of their usefulness against a determined enemy.

TRAFFIC CAPACITY

The traffic capacity on the reply path has been increased by a frequency-channeling method while retaining a continuous signal for display purposes. With seven interrogation codes, this gives a sevenfold improvement over any previous fixed-frequency system. More codes could be provided if the traffic conditions should warrant such expansion.

Further increase in traffic capacity will result from less triggering of transpondors by use of artificial azimuth sharpening, which reduces the interrogation beam and eliminates triggering by side and back lobes. The extensive use of independent IFF installations using the signal storage techniques for supplying several radars with information from interrogator-responsor will also increase the traffic capacity. Defruiting may be applied to installations as needed to enable operation during high traffic.

Transmission of altitude data decreases the traffic on the system without display countdown, by enabling a reduction of the interrogation rate, when operating with radars having multiple vertical beams or when scanning.

AZIMUTH ACCURACY AND RESOLUTION

Previous systems have not provided satisfactory azimuth information. This has been a result of use of IFF frequencies much below the associated radar frequency or to the impracticality of mounting sufficiently large IFF antenna structures to provide sharp beams. Propagation phenomena will not permit use of an IFF frequency, for universal use with full coverage, as high as may be useful for special radar applications. Further, it is impractical to mount IFF antennas of an aperture equivalent to the radar antenna. These difficulties are overcome by artificial azimuth sharpening methods which permit controllable high azimuth resolution and accuracy with a minimum of antenna aperture and at the same time permit the use of the optimum frequency as determined by propagation phenomena.

ALTITUDE DATA

Owing to the high accuracy required in measurement of small elevation angles to determine altitude by antenna scanning methods, the proposed system provides altitude data by direct transmission. Although the proposed pressure-actuated control will not furnish true altitude, it will probably be accurate enough for the required use. Good relative altitudes, useful for aircraft control, will be easy to furnish since little variation in atmospheric pressure will be experienced over limited areas. The resolution in elevation furnished for IFF correlation may not equal the resolution of the associated radar (fire control and height finding), but, even with the assumption that the same frequencies were used, it would probably be as good as it is feasible to attain by antenna vertical directivity.

SIMPLICITY AND RELIABILITY

No improvement in overall simplicity is likely to result without a corresponding decrease in tactical performance. The one major complication introduced in the proposed system is that of chronometer control of the security code. Since, however, the primary purpose of an IFF system is to provide security of identification, and since no system is worth the effort to build unless it has good inherent security, the complication of chronometer coding must be accepted. It is well known in the field of cryptoanalysis that security of codes can be maintained only by change. Since the system requires operational integration of many equipments, these changes must be accomplished at definite times. To make them entirely by manual means would impose a terrific burden on operating personnel, greater than if automatic changes were used to supplement less frequent manual changes. Where high security is not important or impractical to attain because of the difficulties of installation and operation of the necessary synchronizing equipment, a non-cryptographic reply may be obtained by use of the proper interrogation code to induce a reply frequency independent of the chronometer. The security of identification for such interrogators would be limited to that of a simple transpondor system.

Undoubtedly, dependent upon the state of the art, a great amount of simplification can be accomplished in equipment design. This should be apparent in any new system when compared to a past system. A similar statement may be made on reliability. Reliability may be measured in terms of the percentage of times a system provides the functions for which it is designed. To increase the reliability by a decrease in functions is hardly logical. One must be content with taking maximum advantage of possible design techniques to provide the required functions with as few failures as possible, both technical and operational.

Examining the proposed system by comparison with the proposed military characteristics, Appendix A, one may say that requirements (a), (b), and (c), are either fulfilled or may be fulfilled, by appropriate equipment characteristics; items (d) through (h) are not subject to factual evaluation but are a matter of judgment. One can say only that security against an enemy's effecting "friendly" indication, item (d), has been materially improved over previous systems; no outstanding features insure flexibility, etc., item (e), but the proposed design has considered possible future detection equipment and weapons as far as present knowledge permits; while unmistakable correlation between IFF and detection data, item (f), is an ideal probably never to be 100 percent perfect, it is believed that the proposed system permits reasonable correlation. Protection against enemy countermeasures, item (g), is largely a matter of detailed techniques, as is automatic operation, item (h).

PROBLEMS TO BE SOLVED

The problems which will be met in the development of the proposed system vary in degree and fall into two general groups. One group includes those involving the adaptation of existing techniques to the particular application, a type of problem common to all development projects which need cause no immediate concern. The second group includes those requiring the development of new techniques, the solution of which are uncertain. These problems need to be given immediate attention until one can foresee a solution.

ELECTRONIC TUNING

The proposed system is largely built around the requirement of electronic tuning of the transpondor transmitter. The requirement is to tune over a band of frequencies, somewhere between 1,000 and 4,000 Mc, as near instantaneously as possible. The tuning band required is associated with stability, the important requirement being a sufficient number of channels. The Bureau of Ships is negotiating a contract on the investigation of possible magnetron design of a satisfactory tube. This Laboratory is investigating possibility of electronic tuning methods applied to the cavity with conventional tubes.

CHRONOMETER DESIGN

While no chronometer synchronization problem of the proposed magnitude has been previously attempted, the fact that such a device is fundamentally a common one and also that there exist timepieces designed for planes according to military specifications lends encouragement to the problem. Furthermore, no exact stability need to be specified in advance since the overlap may be adjusted to accomodate any error which is found to exist.

CRYPTOGRAPHIC CODER

Considerable experience is available from the design of communication enciphering machines which may be applied to the design of a cryptographic coder suitable for IFF.

The major problems are size and weight. These may be solved by using a mechanical device to generate the data which is then recorded on a punched tape and used to control the equipments.

DISCUSSION OF ALTERNATIVE SUGGESTIONS

Undoubtedly many ideas will have occured to the reader, as the requirements were discussed, which have merit but which do not appear in the proposal. Some of the more obvious ones are anticipated and further discussed, and the reasons why they were not included stated.

MULTIPLE-INTERROGATION FREQUENCY CHANNELS

If cross-band operation is to be retained, interrogation channels must be assigned in addition to those required for the reply, since all reply channels are used simultaneously. Using more than the minimum of interrogation channels increases the frequency band necessary to be assigned (or reduces the number of reply channels available) and increases the broad-banding design difficulties. Furthermore, there does not appear to be any particular advantage to be gained by use of more than one interrogation channel. Simple use of one interrogation channel out of several does not materially increase security or provide additional tactical flexibility and is an inefficient use of the frequency-band assignment.

Chronometer variation of interrogation frequency in itself does not provide appreciably greater security, and if used would eliminate the facility of simple interrogation operation for small planes, etc. It would also require an additional transpondor receiver to provide continuous operation at the time of frequency change because of the lack of exact chronometer synchronization.

Simultaneous use to reduce traffic on the interrogation path would require a transpondor receiver for each channel, which is highly undesirable from the airborne viewpoint. Further, it is believed that the traffic capacity will be first exceeded on the reply path because of an expected large number of transpondors compared to interrogators.

SIMULTANEOUS USE OF MULTIPLE-INTERROGATION FREQUENCIES

Use of two or more frequencies forming an "interrogation lock" to prevent unauthorized interrogation by transmitting a portion of the total intelligence on each channel is not considered to offer sufficient security to warrant the additional complexity. The "lock" may be broken by merely trying each possible combination until replies are received. To be effective, such a large number of combinations must be available that the time to try them would discourage the enemy. To provide such a number is considered prohibitive in equipment complexity and in the delays introduced owing to the greater time required to transmit the code.

Of all proposals for interrogation-frequency coding, the one which appears to have the most merit and provides high complexity in a code of short duration is the use of frequencies in succession spaced critically in time. The frequencies would be varied with time and the second frequency would be dependent upon the pulse interrogation code, that is, the second interrogation frequency would be dependent upon its time separation from the first. All of this merely serves to increase the number and complexity of the interrogation codes and offers very little protection against a determined enemy. Further, there is no advantage in the generation of the interrogation codes required for channeling, over the proposed pulse pattern.

CW INSTEAD OF PULSE SYSTEM

The possible use of A CW system for IFF has been investigated and the conclusions which lead to its rejection in favor of a pulse system are contained in reference 3.

PULSE-PATTERN REPLY

The question may be raised of using a pulse pattern reply, similar to that used for interrogation, instead of frequency coding or of using both forms of coding to increase the number of codes available.

One outstanding advantage of frequency coding as proposed is the increase in traffic capacity by multichannel operation without affecting the quality of the data. Not only are the traffic capabilities increased by use of several frequency channels instead of one but also they are not reduced by use of several pulses for each reply signal.

Possibly the reply frequency code can be established and transmitted in a shorter time than a reply pattern of equal coding possibilities could be transmitted thus resulting in less range delay. This, however, would not be a deciding factor.

Some argument could center around the relative difficulty of monitoring the frequency channels and pulse patterns. Undoubtedly each could be done.

Use of both reply pulse pattern and frequency coding for security has not been proposed because it was not felt that additional codes were required and because it was desired to use reply pulse coding for showing emergency, specific identification and altitude.

TRANSMISSION OF ALTITUDE DATA WHEN SENDING INFORMATIONAL CODE

The proposed system drops the coding representing altitude when the pattern reply is being transmitted. (Altitude data would continue to be supplied to other interrogation codes.) Though such data could be transmitted at this time also, simplification is suggested because it is believed that any installation having requirement for the informational code interrogation will have facilities for independently determining altitude.

ARTIFICIAL SHARPENING IN THE VERTICAL PLANE

Since artificial sharpening has been suggested for azimuth, the question arises concerning use of similar techniques for the vertical plane. Expansion of the proposed technique to two planes could be accomplished in two ways. One would be to provide a second lock-out-pulse position for the vertical plane, the other to transmit a null pattern which has a null along a line in space instead of in a vertical plane. The latter method may be introduced at any time without affecting the general design of the system and is therefore available if required. It is not suggested initially because the advantages are somewhat dubious. The transmission of altitude data is an alternative as far as precision of data is concerned. The advantage of lowered interrogation traffic by restriction of the volume in space being interrogated is not always realized owing to the necessity for increasing the pulse repetition rate.

COMPLEX PULSE PATTERNS FOR ALTITUDE DATA

The use of additional pulses in the normal reply pattern would provide more codes for indicating a larger number of discrete altitudes. The duty-cycle increase might not be serious since both emergency and informational reply codes use several pulses. Such additional pulses were not suggested because of added equipment complication and less direct interpretation.

SYNCHRONIZING SIGNALS

Undoubtedly the security against an enemy appearing as a friend may be increased by increasing the rate at which the cryptographic unit varies the code, up to the point where the duration of any given code is less than the time required for an enemy to monitor the code and use this information to adjust his transpondor.

The rate at which the code may be varied is dependent upon the variation in time between the chronometers used throughout the system. This variation may be reduced by correcting the mechanism at specified intervals by means of a synchronizing signal transmitted from locations capable of maintaining high time accuracy (ships and ground stations) through use of equipment unsuitable for small aircraft use.

This feature has not been included in the initial proposal since its value and/or necessity is unknown at present. Further studies on the required rate of code change and evaluation of errors in timing mechanisms will clarify this point. In any case, it is desirable to give first consideration to techniques which will maintain the chronometer in the degree of synchronization required.

MODULATED-PULSE CODING PROPOSAL

A system has been proposed (reference 10) in which the interrogation and reply signals each consist of a 2 microsecond pulse divided into ten equal elements which may be transmitted as mark or space signals. The first element is always transmitted for reference, thereby leaving the combination of 9 elements providing 512 possible codes. It is proposed that the code be formed by selecting a binary number which represents the sum of the interrogation and reply binary numbers corresponding to the codes used. Any interrogation code could be transmitted and this would induce a reply code representing the difference between the code number and the interrogation number. The code number could be varied by manual or chronometer means.

It is obvious that there are common features between this proposal and others previously discussed. Comments are limited to features not previously treated and are not meant to be directed toward criticism of the system as a whole but merely to point out why certain choices were made in the system proposed in this report.

The formation of the pulse pattern code by crowding of the elements to the minimum is thought to impose undue difficulties on equipment design tolerances.

While system channeling is provided by inducing a reply code dependent upon the interrogation code used, the traffic handling capacity is not materially improved. The traffic problem is expected to arise from "fruit" (unsynchronized signals) which can be removed by circuits favoring the synchronized signals until these signals begin to occupy a large portion of the pulse period time. When this occurs, the decoding circuits used for sorting out the channels would also be overloaded. The only solution is to gain additional time by multiple-frequency channels.

The security of the proposal is very limited because of the use of a single code number, which includes all the data necessary to set up an operating transpondor to the correct code and which may be determined by an enemy using a single interrogation code. The security would be materially increased by a random association of the reply and interrogation codes, which would require the enemy to interrogate on all codes to obtain the data for setting up the transpondor. It should be noted that security is not necessarily measured by the number of codes in the system.

PULSE-TRAIN CODING

A proposal has been made (reference 11) for a pulse-coding method known as pulse-train coding in which narrow pulses are transmitted as mark or space signals forming the familiar Baudot code. The decoder has the novel feature of producing a single output pulse at the end of the pulse train whenever a proper combination of pulses passes through it.

The particular advantage claimed is that the decoder is not blocked by the first pulse to other signals arriving during the first code interval. The obvious disadvantages arise from the relatively long duration of the code (60 microseconds proposed for interrogation and for reply). Not only does the design of small, precise, high-fidelity, low-loss delay lines pose a problem but it seems undesirable to impose any more restrictions on future radar design than necessary. The timing difference between the IFF and radar data must be corrected either by triggering from a radar prepulse, delaying the radar video, or use of an independent IFF system. The tolerances on correcting delays become severe, in that good correlation between IFF and radar data is dependent upon small time differences arising from the difference of the timing circuits of two systems. As the timing intervals (IFF code and correcting delay) become larger, the error (being the difference between these values) becomes larger, since errors in timing components are proportional to the timing interval for present known methods. One may argue that it is better to reduce the time taken by the coding process to the minimum permitted by the component tolerances since overlap of two signals must not occur in such a way as to permit a pulse from the second signal to occur during the time the decoder is responsive to a pulse of the first code as determined by the component tolerances.

Failure to consider coding and decoding tolerances may lead to erroneous conclusions regarding the traffic capacity of an IFF system. Techniques which may be developed to maintain precise long delays can be applied to short delays, thereby permitting the code to be compressed into a corresponding short interval. It is doubted that any practical increase of traffic capacity would result by use of the long-pulse-train coding technique after design tolerances are considered.

VARIATION OF INTERROGATION CODE

Though the proposed system provides several pulse interrogation codes, each of which may be used at any time by any interrogator, no definite proposal for variation of these codes is made, primarily because it is a question which may be decided later. Some comments, however, may be pertinent.

In order to equalize the traffic on the reply channels, the number of interrogations per second on each code should be approximately equal. This may be insured either by doctrine, which assigns the codes to the interrogators by individual installation, class of service, or other means; or by switching from code to code in some manner as to insure proper distribution. It is to be noted that such switching does not require synchronization of different units. On the other hand, it may be operationally desirable to assign codes to various classes of operation, say fire control, fighter direction, air search, etc., in such a manner as to control and limit the traffic to different values for the various services.

From the point of view of security, control of interrogation codes may be desirable. For example, suppose that the enemy is suspected of compromising the system by setting up a transpondor to the proper reply code, using information gained by monitoring our transpondor transmissions. If we restrict the use of the interrogation codes, detection of such attempted compromise might be provided. First, if certain codes are not used for normal operation and the enemy is obtaining his information by interception of signals induced by our interrogators, he will not have complete data for setting up his transpondor. Therefore we can check a suspicious response by a brief interrogation on a code not normally used. Naturally, to be successful we must not use these check codes often and they should be varied from time to time. Secondly, if the enemy is using his own interrogator to induce replies from our transpondor in order to obtain complete data, he will be forced to interrogate on each code. If one or more codes were prohibited by doctrine, then these signals could be recognized as enemy transmissions and would therefore constitute a warning.

FALSE CODES

The transmission of codes which are recognized as unauthorized has often been suggested as an aid in confusing the enemy in his attempts to obtain the coding of the system by monitoring. The radiation of such false codes may be either on the interrogation or reply path. While such techniques may be found useful for certain system designs, they have not been included as a basic part of the proposal in this report because the difficulties which arise are considered to outweight the possible advantages.

To illustrate, consider use of false codes on the interrogation path. Their use would be to increase security against unauthorized interrogation. If a large number of interrogation codes were available and a limited number would unlock friendly transpondors, these could be easily discovered by an enemy monitor unless false codes were radiated. The number which would need to be used would be that number which would require the enemy in monitoring, analyzing, and interrogating these codes to consume as much time as if he simply interrogated on all possible codes to find which ones induced responses. In any case the number of possible codes would have to be large and the number of false codes radiated be considerable. Further care must be exercised in the radiation of such codes to insure that the conditions are the same as when the true code is radiated. If the true code is associated with a radar pulse, the false code must likewise be associated with the radar pulse in the same manner. This introduces count down between the radar and IFF data collection rates. False codes must be radiated by all types of interrogators. This increases the duty cycle requirements, and such increase is particularly undesirable for aircraft installations. Each code should occur with approximately the same frequency, including the true code. The true signals would then constitute only a small portion of the interrogation signals radiated. Those that occur on the same frequency channel would combine to overload the system and decrease the traffic capabilities.

The use of false or unauthorized interrogation codes to detect an enemy posing as a friend by his replying to any interrogation code, in systems in which the reply is uncoded, requires a display of replies to false interrogation. The addition of such display equipment may be undesirable.

False codes may be used on the reply path to confuse an enemy monitor. In this case it is more difficult to cover their identity. If they are radiated in response to an interrogation, then they become friendly but unauthorized signals. There is then no harm to the enemy in radiating such signals provided he radiates a proper portion of true signals. In fact we have merely changed the reply code to one having two parts (so-called true and false part). If the false reply signals are not radiated in response to an interrogation they become easily detected by this lack of association.

PROGRESS

Although a rather complete proposal of an electronic recognition system has been made and new techniques discussed, the exact status of the entire program has not been presented. The details on the projects which have been completed constitute a report within themselves and further information is available in published reports listed in the Table of References. In order, however, that this proposal may be viewed in the proper perspective, a brief progress report on the various phases of the problem at the Naval Research Laboratory as of July 1, 1947 is included.

PULSE STUDIES

Equipment has been constructed for generation of modulation pulses down to 0.1 microsecond in duration in groups with minimum spacings of 0.2 microseconds.

A laboratory amplifier with a bandpass from 100 Kc to 34 Mc, voltage gain of 100 and maximum input level of 0.4 volts rms has been completed.

A laboratory oscilloscope, having a writing speed of 100 inches per microsecond, for use in studying short pulses, is in operating condition.

Investigation of the factors influencing oscillator starting time has been initiated.

DECODERS

A decoder critical to pulse spacing and requiring equality of pulse amplitude has been designed (Report R-3080) for paired pulses. The project is continuing on the design for a greater number of pulses.

Tube studies for decoder coincidence applications have been initiated.

PATTERN GENERATORS

Flight tests have been conducted using an AN/APX-6 modified to be modulated by a mechanical keyer, which generates range coding to produce letters. Satisfactory display has been observed (Report R-2980). Present activity is directed toward obtaining a non-mechanical keyer which would be suitable for small aircraft use.

CRYPTOGRAPHIC CODER

Discussions have been held with Cryptographic Research Personnel of the Office of the Chief of Naval Operations and the conclusion has been reached that ECM techniques can be applied to IFF coding and further that projects now active in that office, when completed, will provide all facilities necessary for punching a teletype tape which will carry the coded information.

Studies have been initiated to explore the various methods (mechanical clocks, quartz crystal, and other means) of design of a suitable chronometer control.

Design studies have been initiated on a tape-pulling mechanism and a reading head is under construction.

SECURITY REQUIREMENTS

Studies of various methods of coding and their evaluation in terms of security are being made, and a report is in preparation titled "Cryptographic Security Applied to IFF."

ELECTRONIC TUNING

A project is being processed by the Bureau of Ships on the development of an electronic-tuned magnetron suitable for the proposed application.

The Vacuum Tube Research Section of NRL is working on a novel magnetron design which offers excellent possibilities for adaptation to electron-beam modulation.

Study of various alternative possibilities for electronic tuning has been initiated.

FREQUENCY STABILIZATION

Studies of methods of frequency stabilization applicable to an IFF system have been initiated.

ARTIFICIAL AZIMUTH SHARPENING

An experimental system has been flight tested at 1,000 Mc which produces arcs on the PPI equivalent to a frequency of 10,000 Mc using the same physical size of antenna (Report R-2871). Two transmitters were used in this test.

Effort is continuing on methods of producing an antenna pattern having a good null and whose sides cover all minor lobes of the single-lobe pattern over a wide frequency band.

Use of a single transmitter is dependent upon development of an rf power switch capable of switching the transmitter between two antennas during the interrogation code. A tube has been constructed which passes 8 kw power and deionizes reliably in 8 microseconds. The rejection (switching) ratio of the tube and cavity as tested is 38 db.

DEFRUITING

The mercury delay line has been used for the memory device in an experimental defruiting system. Report is in preparation. The system is capable of double defruiting.

Storage-tube techniques are being studied for application to the defruiting problem. Circuit problems have been largely solved. Capabilities of standard cathode-ray tubes have been investigated. Special tubes which show promise of solving the tube problem are progressing rapidly in the Vacuum Tube Research Section.

ELECTRONIC SORTING

This project has been inactive since its success depends upon satisfactory defruited signals. Some earlier work in connection with Mark V IFF has been reported in reference 12.

CIRCULARLY POLARIZED RADIATION

Steps have been taken to initiate studies which will supply data necessary to evaluate this technique for IFF.

DELAY-LINE TECHNIQUES

Various possibilities for obtaining an improved design in video delay lines have been examined with little advance in the art. Work is continuing.

CONCLUSIONS

It is concluded that a considerable number of techniques which have not been previously used for electronic recognition show promise of being applicable to a new system design. Also a system may eventually be developed which will provide material improvement over existing systems in the matter of security against enemy use to appear as a friend and in meeting future conditions of higher traffic and greater target speeds.

RECOMMENDATION

It is recommended that experimental work continue leading to more accurate evaluation of new techniques for IFF which have been suggested and which may be proposed.

It is further recommended that no active steps be taken for at least one year toward choosing a particular system or in initiating development of components other than those which may be applicable to evaluation of techniques, but that proposals be exchanged and reviewed with the view of producing the best combinations most likely to succeed should there be a requirement for immediate development.

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APPENDIX A

Military Characteristics of a Joint Recognition and Identification System

1. The following military characteristics of a joint recognition and identification (IFF) system are established as a guide for research and development agencies in their creation of a new system. While these characteristics are presently considered to constitute the ultimate objective, which may be unattainable but should be sought, it is not intended that they unnecessarily restrict research and development in IFF, but should be so interpreted as to permit correlation with the characteristics of the associated equipment.

2. The military characteristics considered essential to a new recognition and identification system to be developed in accordance with the directive of JCS Policy Memo 23, revised are:

a) The system shall be capable of continuously indicating the friendly or enemy nature of a target simultaneous with detection (or in the order of milliseconds thereafter).
b) The system shall be devoted, primarily, to the recognition and identification of detected targets. The application to target tracking, traffic control, or specifically air traffic control, i.e., objects known or previously detected, will be considered secondary to the recognition and identification of newly detected targets.
c) The operational coverage of the system shall be equal to, or greater than, the associated system(s) or detection device.
d) The system shall be capable of providing sufficient security to prevent the enemy from effecting "friendly" indication, through the use of captured or fabricated equipments, without possession of the basic operating schedule.
e) The system shall incorporate a maximum of tactical security and afford the enemy a minimum of useful information through capture on countermeasures action. The system should include sufficient flexibility to minimize obsolescence due to changing tactical and technical requirements or enemy action, including the capture of components or literature.
f) The system's resultant intelligence should be capable of unmistakable correlation with the object position information.
g) The system shall incorporate all feasible protection against enemy countermeasures action.
h) The operation and information interpretation of the system shall be as near automatic as practicable.

3. While the above outlined characteristics are considered the basic functional requirements, the following general equipment characteristics reflect directly upon system performance and therefore should be considered during the development and design of the system.

a) The reliability of the system should be of paramount importance at all times.
b) The various component equipments of the system should be of the smallest, lightest weight design practicable, consistent with good engineering practices.
c) The maintenance and operation of the system should be as simple as possible in view of the basic functional requirements.

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d) A maximum of joint standardization techniques should be incorporated where possible without prejudice to the function of the system.
e) Special attention should be given to minimizing interference and interaction with other equipments and/or systems.
