DECLASSIFIED

[redacted]

UNCLASSIFIED UNCLASSIFIED

2027

NRL Report 4847

[redacted]

FR-4847

A CENTRALIZED FREQUENCY-CONTROL SYSTEM FOR SHIPBOARD USE

[redacted]

F. C. Isely and D. A. Venn

Radio Techniques Branch
Radio Division

DECLASSIFIED by NRL Contract Declassification Team
Date: 27 MAR 2017
Reviewer's name(s): [redacted]
Declassification authority: NAVY DECLASS GUIDE/NAVY DECLASS MANUAL, 11 DEC 2012
06 SERIES

UNCLASSIFIED

December 14, 1956

UNCLASSIFIED

[redacted]

[redacted]

S-2028-1837 of 1/13/57

DEPARTMENT OF THE NAVY · OFFICE OF NAVAL RESEARCH

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by
UNLIMITED only.

NAVAL RESEARCH LABORATORY
Washington, D.C.

UNCLASSIFIED UNCLASSIFIED

[redacted]

[redacted]

DECLASSIFIED

[redacted]

CONTENTS

UNCLASSIFIED

[redacted]

[redacted]

ABSTRACT

[[redacted]]

Modern naval communication equipment, as well as other shipboard electronic systems, must have a frequency stability better than one part in 10^7 in order to meet present and future operational requirements. A centralized system requiring a precision oscillator supplying one part in 10^8 frequency stability for long periods is proposed for manual, sequential, or direct control of the end equipment. The method outlined in this report is based mainly on sequential operation; i. e., a repetitive automatic control. A centralized control system is outlined and the results of experimental work indicate that it would be feasible. By means of centralized frequency control, improved and more reliable communication would be obtained. The components such as the synthesizer, oscillator, and phase control for this method have been developed or are ready for engineering consideration.

PROBLEM STATUS

This is an interim report; work is continuing.

AUTHORIZATION

NRL Problem No. R01-30
Project No. NE 090-601 Sub task 10
Buships Problem No. S-1754

Manuscript submitted September 26, 1956

[redacted]

A CENTRALIZED FREQUENCY-CONTROL SYSTEM FOR SHIPBOARD USE

[redacted]

INTRODUCTION

The ever-increasing multiplicity of operations on shipboard and the need for greater coordination and cooperation between ships, especially in task-force formation, have overcrowded the available communication facilities to a point where rapid interchange of information is not always possible. During the last several years a number of reports have been published suggesting improved methods of communication to replace or implement those now in use. Enclosure (1) of CNO ltr Op-371 Ml/jbc Ser 223 p. 37 of 21 June 1956 further emphasizes the need. These new approaches probably would improve the over-all system by increasing speed and reliability of operation.

One factor common to all these proposals, and stressed by them, is the need for greater frequency stability of all communications equipment. This factor applies to other equipment and to operational uses such as radar, countermeasures, identification, crypto services, navigation, and missile control. Accurately timed pulses with adjustable rates could be controlled from the basic precision oscillator for the above purposes. The highest stability now required by any of these methods is ±5 cycles in the 1- to 30-Mc range. This approaches one part in 10^7, a value which should also be satisfactory, for the present, in the 225- to 400-Mc range. The precision oscillator stability must be continuously available and must be coordinated throughout the fleet. If this is done, accurate synchronization and time control, essential to certain types of proposed communication, would also be available.

This Laboratory has been studying the possibility of the establishment of centralized frequency control on each ship for the purpose of controlling all communication equipment as well as having it available for the frequency control of any other electronic equipment. Since the last report,* work has progressed on the sequential system which indicates that such a system is feasible and may be suitable for the frequency control of many of the present and proposed communication equipments of the Navy.

A centralized frequency-control system would establish in one or more areas of a ship equipment capable of producing a precision control frequency with a stability of at least one part in 10^8 per day and a future possibility of one part in 10^9 per day. This centralized frequency system would also have associated with it the necessary devices to control the frequency and timing of communication and other equipments on board where required. The transmitting and receiving equipment would be located in nearby areas, thus making for more efficiency in maintenance and operation by the technicians. The actual message handling by the operators or communicators would be done in other locations wherever most convenient for the function performed. It should be noted that this report deals only with frequency control, particularly one phase of it, and not with communication systems and methods except as related to the frequency control itself.

---

*Isely, F. C. "Considerations of and Proposals for a Centralized Frequency Monitor and Control System for Naval Communication," NRL Memorandum Report 510, 10 August 1955

UNCLASSIFIED

[redacted]

Before discussing any precision-oscillator frequency-control system, it would be well to outline the requirements any such system should embody. It should:

1. Be capable of controlling the frequency of any equipment, present or future, to one part in 10^7 or better, and be capable of correlation with a standard shore station or control ship.
2. Include a standard clock and a time-comparison system capable of one-tenth-millisecond resolution when directly compared with a shore-based, or other standard and be capable of providing time control for any shipboard functions requiring it.
3. Have provisions for emergency operation.
4. Be usable on small craft.
5. Include provisions for operation under adverse doppler shift or other propagation anomalies.
6. Be capable of preprogramming for rapid shift of frequencies.
7. Operate on a centralized basis and provide for the separation of equipment-control and maintenance personnel from message-handling personnel.
8. Be capable of gradual implementation without interruption of communication service of the fleet.

There are essentially three types of frequency-control systems considered herein: monitoring-control, direct-control, and sequential-control. All of these systems require a precision crystal oscillator with auxiliary equipment to obtain a frequency stabilized to at least one part in 10^8 per day, with provisions for checking against a standard shore station.

The simplest monitoring control method would be the manual monitoring of present equipment oscillators from the synthesizers. This would greatly improve the frequency setting and netting possibilities but would not provide the desired frequency stability of one part in 10^7 needed for proposed SSB transmissions.

If crystal oscillators, suitable for shipboard installation, with a frequency stability of one part in 10^7 per day were available and such oscillators were monitored and corrected once a day, they could be used in place of the precision-oscillator equipment for small installations. It would seem that the manual-monitor method is one to be used in the interim and in cases where size and weight might be a factor or where in emergencies it might be desirable.

The sequential-control method would require one synthesizer for from perhaps fifteen to thirty equipments. The end equipments would be controlled by individual free-running semiprecision oscillators, which would, in turn, be sequentially controlled through automatic-phase-control equipment from the synthesizer. This control would be applied to the oscillators sufficiently often to maintain a stability of one part in 10^7.

The sequential-control method should be considered for use in the control of shipboard equipment in which stability of one part in 10^7 is satisfactory. The direct-control system, of necessity, will be used for those cases where a greater degree of frequency stability is

[redacted]

[redacted]

required and the manual monitor control used where space and weight requirements would limit use of the precision-control equipment and where monitoring could be available perhaps once a day. Methods for establishing the monitoring- and direct-control portions of the system are being studied. This report, however, considers for the most part the sequential system.

COMPARISON OF FREQUENCY-CONTROL METHODS

Preparations are being made to carry out comparative tests of the three types of frequency control, i.e., monitoring, direct, and sequential. However, because of the diversity in applications of the methods, it is difficult at this time to assess one as the best. In general, each has its own advantages and disadvantages, so that the over-all centralized system should include a combination, with each type being used where best fitted.

The manual monitoring method, as previously indicated, has much to offer in the interim period before a complete centralized frequency-control system could be put into operation. This will make possible more rapid netting of teletype links. The system is dependent on the completion of development of a precision oscillator suitable for shipboard use with a frequency accuracy of one part in 10^8 or better at all times and a variable frequency generator controlled from this precision oscillator.

The direct or continuous-control method would definitely have the best frequency stability, being at least an order or two greater than that of the sequential method, and this method should be used where such stability is required.

The sequential-control method may offer certain advantages with respect to size, cost, and complexity of equipment and freedom from spurious signals. It lends itself to emergency operation, in the advent of failure of all of the precision oscillators and/or variable frequency generators, with a frequency stability as good as that of its own free-running oscillator (1 part in 10^7 per 2 minutes and 1 part in 10^5 per day). For the sake of standardization the sequential method might be used in small craft as well as in larger ships, and it is possible that miniaturization could make it competitive with the monitoring method. Since the sequential method uses controlled, free-running oscillators, it is believed that a technique could be developed which will utilize the incoming signal as a frequency reference under adverse doppler effects. Since the automatic phase control (APC) circuit employed in the sequential control system is a very effective filter, spurious responses, other than those developed in the final amplifier stages, should be greatly reduced. Another advantage is the possible reduction in the quantity of vacuum tubes required compared with the direct-control system.

SEQUENTIALLY CONTROLLED SYSTEM

In a sequentially controlled system, a single synthesizer would control all the required frequencies of a number of equipments, in an orderly and repetitive manner. There could be as many as 15 to 30 equipments controlled by one synthesizer and the repetition rate of this control sequence might be once every 2 to 5 minutes.

The basic block idiagram is shown in Fig. 1, the portion above the broken line being required for any control system. The frequency from the precision oscillator controls a frequency synthesizer,* associated with which is a programming and switching mechanism

---

*The NRL-developed synthesizer is composed of a fixed-frequency unit and any number of independent variable-frequency decade units as required.

[redacted]

for sequentially applying any required precision frequency to a number of automatic phase control devices. The phase control equipment includes a stable oscillator, whose output frequency is controlled and is applied to the necessary mixers, and/or multipliers to control in turn the final equipment (transmitters or receivers). These stable sequentially controlled oscillators are all similar and have a frequency coverage in portions of the radio spectrum where the required stability can be obtained.

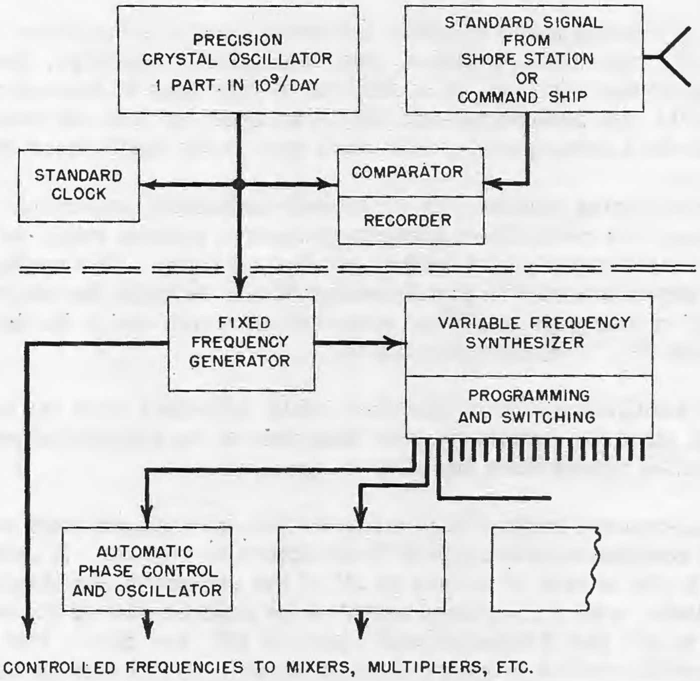


Fig. 1 - Basic sequentially controlled system

The "heart" of the system is the APC and its associated oscillator (Fig. 2). This is composed of the stable oscillator, a phase discriminator, and control circuits. The phase discriminator is essentially a balanced modulator with the precision reference frequency of the synthesizer applied in series to the two diodes, whereas the frequency of the stable oscillator that is to be sequentially controlled is applied to the diodes in parallel. As is shown in Fig. 3, when the two frequencies are equal and out of phase by 90°, the resultant voltage across the resistor "r", is zero. A phase less then 90° produces, say, a plus voltage, whereas if greater than 90° it is minus. It is interesting to note that at 270° zero voltage is again produced but if less than 270° the voltage is minus, (the same as above 90°), and if greater it is plus. Consequently, in the stabilizing process to be described, the balance may be at 90° or 270°.

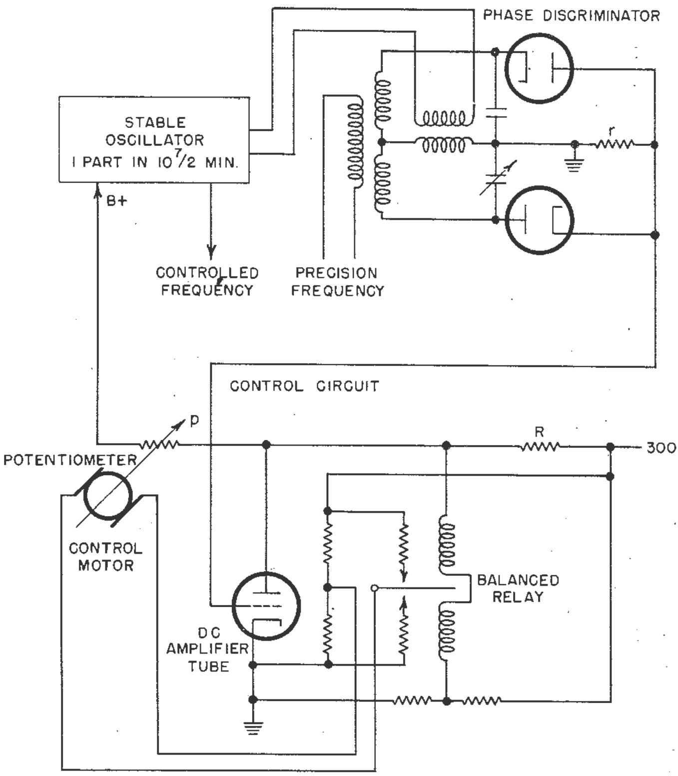
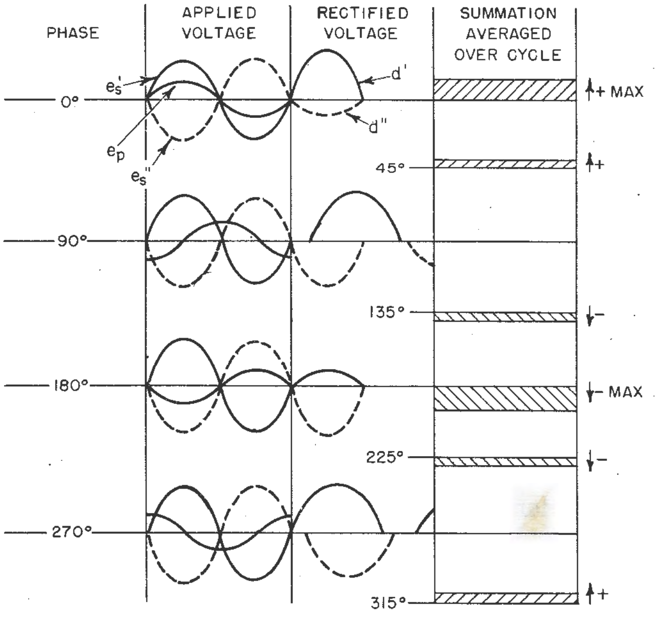


Fig. 2 - Automatic phase control and oscillator



e_s' (SERIES) VOLTAGE ON DIODE d'
e_s'' (SERIES) VOLTAGE ON DIODE d''
e_p (PARALLEL) VOLTAGE ON DIODES d' AND d''

Fig. 3 - Discriminator voltage-phase characteristics

[redacted]

Assuming that the oscillator has been tuned closely to the reference frequency, further adjustment could then be made by a variation of the plate supply voltage, which must be derived from a well stabilized source to prevent unintentional variation. A slight variation in frequency of the stable oscillator from that of the reference frequency generates an unbalance voltage across "r," which in turn is applied to the grid of the dc amplifier tube. This change in grid voltage and its resultant change in plate current produces a greater or smaller voltage drop across the resistor R, which is in the B+ supply lead to the stable oscillator. Consequently, this change in the oscillator B+ voltage changes the frequency, and if the original unbalance voltage in the discriminator is of the correct sense, and it can be made so, the oscillator frequency will be corrected in the proper direction to come into synchronization with the reference frequency. Such a correction cannot, of course, bring the two signals into the proper phase relationship for zero unbalance on the discriminator, since any approach to this condition will reduce the discriminator output with a consequent return to the original voltage drop across R. Thus, frequency lock is immediately accomplished but with a phase displacement which unbalances the discriminator and gives rise to the control voltage on the grid of the dc amplifier tube. If the reference frequency were removed under such unbalanced conditions the stable oscillator would revert to its previous frequency.

In order to make this change permanent (until the next correction is needed) by bringing the two oscillators into the proper phase relationship to achieve balance of the discriminator, a motor-driven variable resistance is included in the stable oscillator B+ voltage-supply lead. This resistance is associated with a bridge circuit, of which the dc amplifier tube is one arm. A change of plate resistance in the amplifier tube resulting from the change in grid bias, produces an unbalance which causes the variable resistance motor to operate. This operation may be direct (or by a polarized relay as shown), and is in such a direction as to add or subtract the necessary resistance to give the proper voltage drop to replace that previously obtained across "R." An exact balanced phase (90°) normally can only be approached but not achieved, the relative amount being dependent on the sensitivity of the bridge circuit and the motor drive. Actually, by a determinable overshoot of the motor, due to inertia, balance may be closely approximated. The discriminator unbalance voltage has now been reduced essentially to zero and the frequency of the stable oscillator will remain the same as that of the precision oscillator upon the latter's removal, until some other factor causes a shift in the stable-oscillator frequency.

The correction due to the voltage change across "R" can be considered to be in frequency, the correction at 10 Mc to one part in 10^7 taking place within a second; whereas the correction due to the variable resistance is normally a phase correction and its time of operation is dependent on the motor speed and the amount of correction needed. The action of the variable resistance takes care of long-term frequency drifts as well as the final phase correction. There is a limit to these actions beyond which a change in plate voltage cannot correct the frequency and which must be taken care of by a retuning of the oscillator through a capacitive or inductive change.

It would be possible, if desirable, to have the motor control connected to a capacitive device instead of to the potentiometer. However, the potentiometer method appears to be simpler and satisfactory. Faster operation, if needed, could be achieved by some other type of electromechanical device, such as a solenoid operating on a capacitive or inductive element in the oscillator. Such refinements would preferably be incorporated in the oscillator in its initial design.

The automatic-phase-control device may be used to compare frequencies on any integral relationship. Thus, the controlled oscillator could be disciplined to generate frequencies 2, 3, 4, etc., times the reference frequency. As the comparison is made at higher and higher

[redacted]

ratios, the dc voltage produced across "r" becomes less and less, so that more amplification must be added. Control has been achieved utilizing ratios up to and including four, but, because of the decreasing voltage it is questionable whether control at ratios greater than three is worthwhile.

A valuable adjunct of the automatic phase control is the elimination of spurious responses. If the stable oscillator is of good quality and well shielded, undesired frequencies should be attenuated to perhaps some 70 decibels or more.

Another advantage of this type of control is in connection with the doppler effect. This effect is produced when either a transmitter, receiver or transmission medium moves with relation to one of the other communication terminals. With the advent of higher and higher speed aircraft, it will become difficult to obtain reception of a signal within ±5 cycles in parts of the hf band and at vhf (Table 1). As can be seen, this cannot now be done at a speed of 500 miles an hour, when fixed frequencies are used. Methods using automatic phase control, which it is believed will solve this difficulty, are under consideration.

TABLE 1
Doppler Shift in Cycles at Varying
Velocities and Frequencies

Velocity (mi/hr)	Frequency Shift at		
	1 Mc	30 Mc	300 Mc
100	0.15	4.5	45
200	0.3	9.0	90
500	0.75	22.5	225
1000	1.5	45	450
1500	2.25	67.5	675
2000	3.0	90	900

The values in Table 1 (being approximate) are suitable for either a moving receiver or a moving transmitter. They are computed from the formula for a moving receiver

$$f' = f\left(1 \pm \frac{v}{V}\right), \text{ or } \Delta f = \frac{vf}{V}$$

where f' is the new frequency, v is velocity of receiver, and V is velocity of radio waves.

EXPERIMENTAL WORK

As previously indicated, the basis of sequential operation is the automatic-phase-control equipment. Consequently, much of the experimental effort has gone into the design of that equipment. The goal of the work was to obtain the control of a power oscillator (6 watts) at 75 to 135 Mc for use in connection with the 225- to 400-Mc transmitters. If this could be accomplished, the complete presently needed frequency range would be covered, since the lower frequency (0.5 to 30 Mc) would also be available.

[redacted]

[redacted]

Control of a 96-Mc oscillator of 6 watts power has been achieved. At present the work has been confined to a fixed frequency (96 Mc) but with proper engineering it should not be difficult to obtain the necessary coverage of 75 to 135 Mc. Figure 4 is a block diagram of the present equipment and Fig. 5 of the experimental circuit. A commercial 2.5- to 3.5-Mc oscillator of good stability mounted in a temperature-controlled box provides frequency stabilities of at least two parts in 10^7 for 2 minutes and at times one part in 10^7 for 5 minutes, depending on the ambient temperature conditions. Temperature control is the most serious limitation in obtaining stability, but it is believed that with this present oscillator and improved temperature regulation, one part in 10^7 for 2 minutes can be reliably obtained. This oscillator with an 8X multiplier feeds 24 Mc into an APC which is also fed with a standard 24-Mc signal from an NRL frequency synthesizer, thus controlling the free-running oscillator. A 2X multiplier raises the frequency to 48 Mc which feeds another APC, operating at 2 to 1 frequency ratio to control the 96-Mc power oscillator. Thus, the power oscillator, which inherently is quite unstable frequency-wise, is continuously controlled by the 2.5- to 3.5-Mc stable oscillator and consequently is stabilized to the same high order.

A stable oscillator of 12 to 24 Mc would be preferable since it would eliminate an 8X multiplier. However, such an oscillator is not available and may be too difficult to obtain. If so, an improvement on the present 2.5- to 3.5-Mc oscillator is in order. Plans call for an investigation of the procurement of the desired oscillator for use in this work as well as improved temperature control of such an oscillator.

It will be noted that the vhf automatic phase control circuit compares the phase of frequencies differing by two to one. This is accomplished effectively and may be extended to cover higher ratios. Up to four-to-one control has been obtained and could thus eliminate frequency multiplication, but would necessitate greater and greater voltage amplification as the comparison ratio increases. Engineering feasibilities will dictate the final choice of frequency comparison ratios.

The lower frequency (24-Mc) APC circuit is used only when periodically comparing the precision oscillator to the reference standard to correct for long-term frequency drift. Emergency operation with all of the inherent stability of the precision oscillator (0.001% per day) can be obtained without the use of the reference standard. Further emergency operation can be obtained in the vhf-uhf region with the use of only the power oscillator and its inherent stability.

In the system as developed and demonstrated, the 96-Mc power oscillator is pulled in and phase locked by means of reactance-tube control of rather conventional design. The output of the phase discriminator is applied directly to the grid of a cathode follower and/or dc amplifier, which in turn supplies the control bias to the reactance tube. Frequency pull-in and lock occur when the oscillator is tuned to within 200 kc of the appropriate frequency. This appears to be adequate when considering the automatic-tuning mechanisms available at present.

In any equipment design, the power oscillator should have a calibration accuracy of at least 0.2% unless some form of self-seeking oscillator tuning is employed. The same factors that govern the above limitations indicate that the power oscillator should not possess a drift tendency of more than 0.2% during operation.

In the present equipment, instantaneous lock-in is accomplished when the precision oscillator is manually tuned to within 100 cycles of the reference standard, but a form of automatic self-seeking tuning is anticipated. Some form of mechanically variable reactance will also be added to the precision oscillator to increase the pull-in or locking range.

[redacted]

[redacted]

DECLASSIFIED

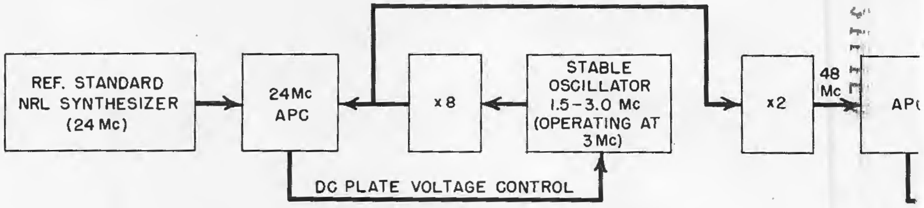


Fig. 4 - Block diagram of experimental equipment

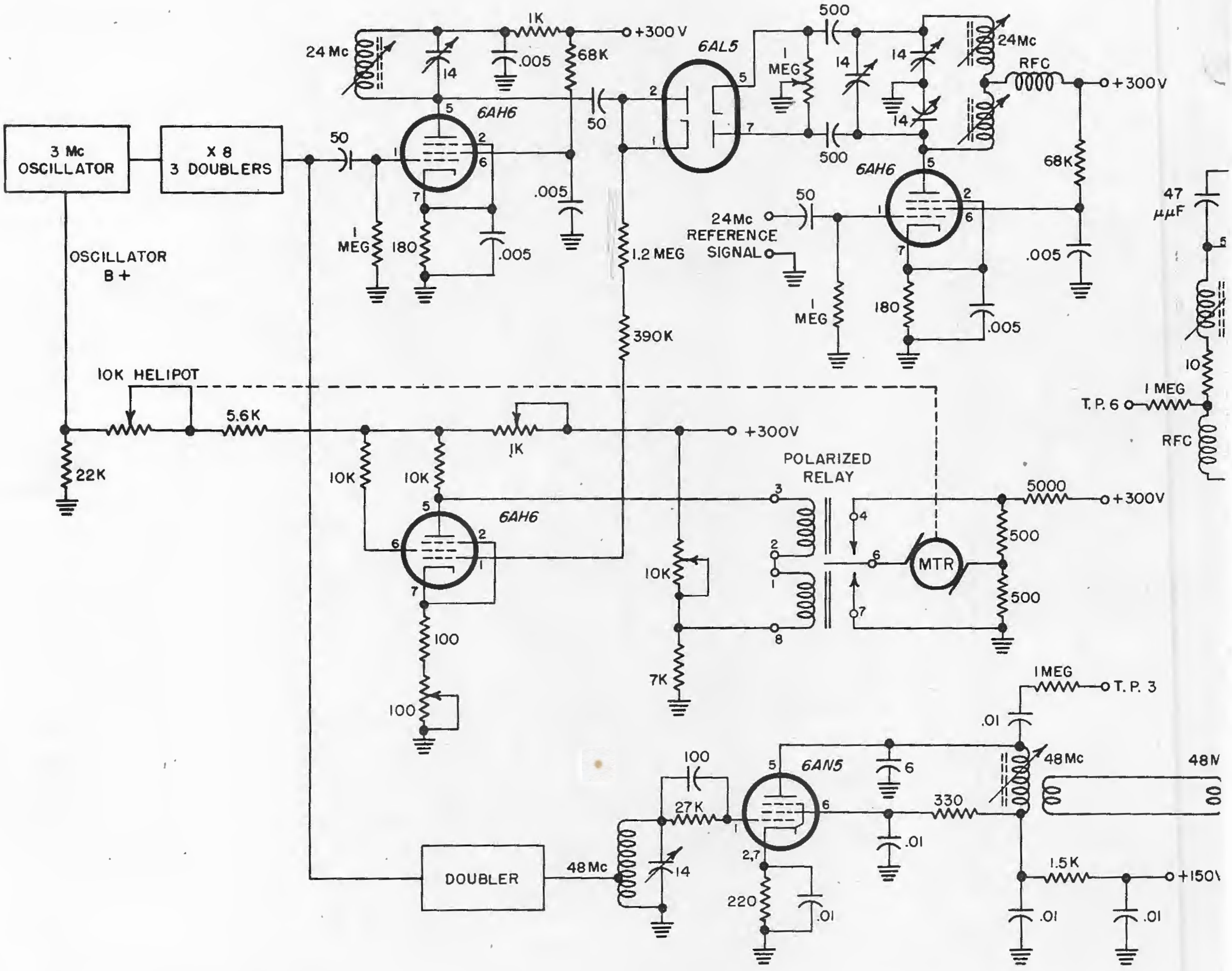


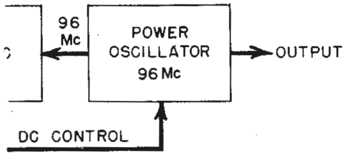
Fig. 5 - Schematic diagram of experimental circuit

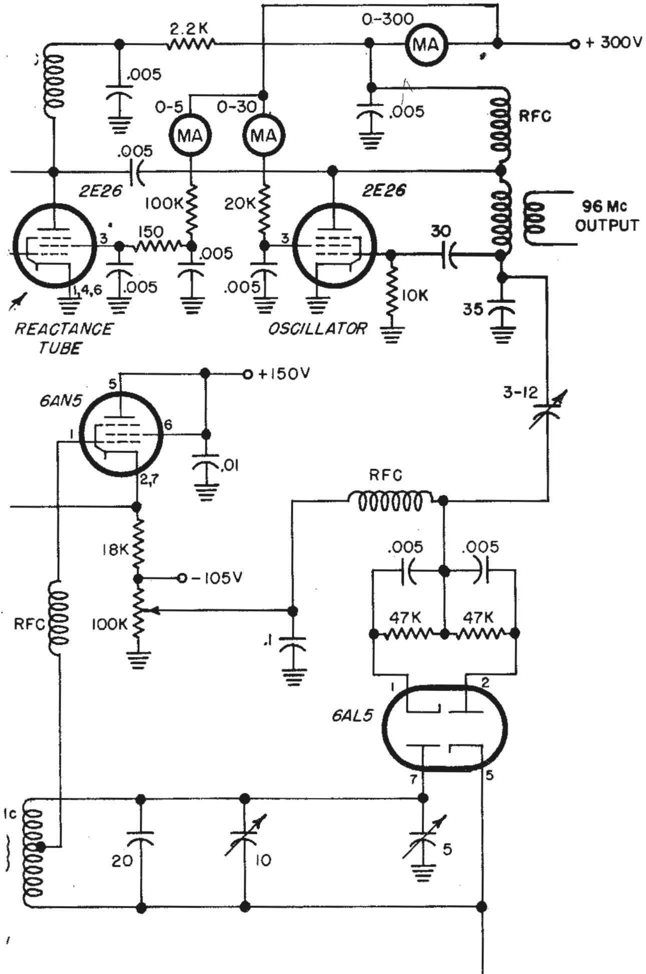
DECLASSIFIED

[redacted]

DECLASSIFIED

UNCLASSIFIED





[redacted]

PROPOSED CENTRALIZED FREQUENCY-CONTROL SYSTEM

The proposed system could be sequentially controlled as indicated in the block diagram of Fig. 4. This is similar to the proposal (method 3 in NRL Memorandum Report 510) previously mentioned; however, as a result of further study and experimental work, certain changes have been made. Direct control by the synthesizers, in many cases, will be desirable in order to obtain a stability as great as that of the precision oscillators. This of course is possible since the concepts of sequential control and direct control are compatible. As indicated in the introduction, all equipment and control thereof are in charge of technicians. Those with the highest technical ability set up the allocated frequencies in the control center; others make any required final adjustment of the transmitters and receivers. Qualified personnel connect the appropriate tie lines from the equipment to the communicators, through the console or plug boards.

The following discussion is based on the premise that all control equipment will be centralized in one or more rooms, depending on the amount of equipment to be controlled, whereas the controlled equipment will be located in adjacent rooms if possible. The precision-frequency units, shown above the broken line in Fig. 1, include two precision-frequency oscillators, a source of signal from a shore station or command ship, a frequency comparator and recorder, and a standard clock.

Three oscillators should be used for reliability, their frequencies being compared and recorded on the appropriate equipment. After the original installation, as well as at given intervals thereafter, the recording should definitely include time comparison from a fixed position with a precision shore station, and the recording or comparison should be over a long enough time to establish the drift rate of the oscillators as well as to take into account any doppler effect from propagation anomalies. Any necessary correction of these precision oscillators, as a result of drift due to aging, would be made when required, though probably not oftener than once a month. The three oscillators probably will not have the same drift rate and, in the absence of a shore-station signal, if the relative rate is always the same, the probability would be that they were accurate within the corrections. If there were only two oscillators and no shore-station signal, and one had a change in rate, it would be impossible to distinghish the correct one without a third isignal (shore station or another oscillator). Since it may not always be possible to receive the shore-station signal, the use of three oscillators is suggested. Three signals are required for comparison in order to detect quickly a change in frequency of one of the precision oscillators. The standard clock would be essential for time comparisons and with the addition of a time generator would be used for possible time-sharing and time-control methods.

The first step in the control area is a frequency synthesizer. The one proposed for the sequentially controlled system is the NRL-developed frequency synthesizer designed to cover the 12-to 24-Mc range. This unit is made with a fixed-frequency section, which generates a number of fundamental frequencies, and a second, or variable frequency-control section, from which all the desired frequencies may be obtained. Thus, any number of second sections may be tied to the first one for separate simultaneous control at a considerable saving of tubes and components. Basically, a fixed-frequency section and a variable-frequency section would be required. However, the total number of these latter sections needed would depend on the amount of end equipment to be controlled. Integral with each second section is a progamming and switching mechanism which would sequentially control from 15 to 30 equipments, depending on the rapidity of the control action. The fixed-frequency unit will also supply the needed fixed frequencies for conversion purposes. A monitoring synthesizer would be a valuable asset and a discussion of it will be given later. For reliability a larger quantity of these equipments than needed basically will be required. This, of course, is true for other equipments to be described but consideration of this is not pertinent at this time.

[redacted]

The automatic phase control equipment has been considered in detail except for the required frequency range, which would be the same as that for the synthesizers, i.e., 12 to 24 Mc. The choice of this frequency range is based on several factors which will develop as the system is outlined. However, the primary consideration was to operate above 10 Mc because of the time element in the stabilizing operation. At 10 Mc only one second is required, whereas at 1 Mc 10 seconds would be needed, as can be seen from Fig. 6. These times do not include the mechanical adjustment of the potentiometer control. A free-running oscillator is an essential part of the APC, but it must have a stability of one part in 10^7 for from 2 to 5 minutes. A Collins Radio Company oscillator operating at 1.5 to 3.0 Mc, when modified by proper oven control, will, it is believed, meet this requirement. Since all of the APC's, one of which is required for each equipment, are exactly the same, the procurement, stock piling, and servicing are simplified.

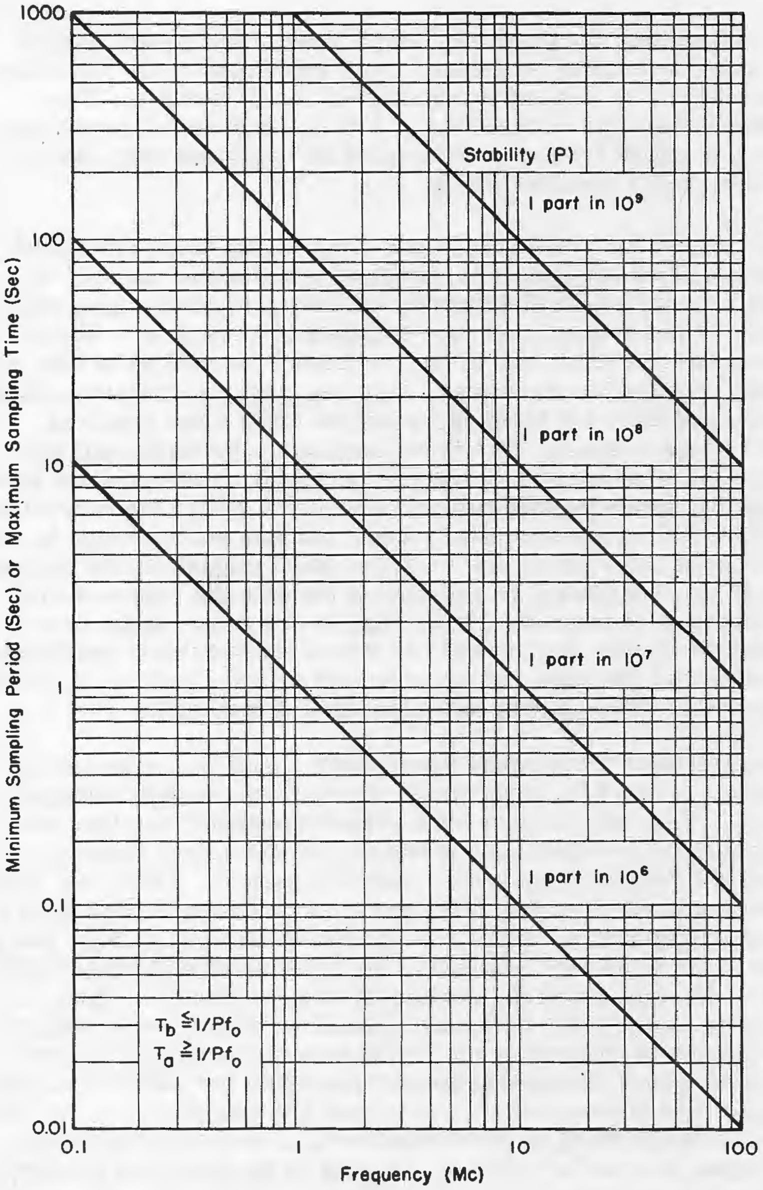


Fig. 6 - Minimum sampling period (T_b) or maximum sampling time (T_a) vs. frequency for values of stability (P)

$$T_b \leqq 1/Pf_0$$
$$T_a \geqq 1/Pf_0$$

[redacted]

[redacted]

The method of frequency derivation and control of the transmitting and receiving equipment in the range of 0.5 to 30 Mc is illustrated in the left-hand column of Fig. 7. The frequency from the stabilized oscillator is applied to a mixer, in which the other frequency of 24 Mc is obtained from the fixed-frequency synthesizer. The resultant of this conversion is then tripled, which will give the frequencies needed. For control of a receiver, it would also be possible to include one third of the receiver intermediate frequency in the mixer frequency obtained directly from the synthesizer (i.e., for a 456 kc i-f use 24.152 Mc) to simplify the calculations of the required synthesizer and APC control frequency for a required end-equipment frequency. The desired frequency then passes to a second APC and oscillator, whose purpose is both to provide a continuously operating oscillator and a filtering action for elimination of spurious responses. This APC and oscillator could be eliminated, but they are believed worthwhile additions, and since the oscillator is controlled continuously, it is not as critical in adjustment as the previous unit and normal oscillators could be used. The signal is still of low level at this point and can be "piped" to the desired amplifier and end equipment without causing undue interference. In anticipation of operation under emergency conditions, it would be possible to place this APC and oscillator in the end equipment since it can be controlled from the control room.

The 220-to 400-Mc range is covered in a similar, though perhaps simpler manner, since present transmitters triple in their output stage. A second APC operating at a 3 to 1 ratio as previously described and obtaining its control frequency from a doubler following a 12-to 24-Mc APC supplies 72 to 144 Mc to the transmitter amplifier. It might be found that an APC will operate at a 6 to 1 ratio satisfactorily and thus eliminate the doubler; however, the determination of this is in future plans. For the receiver, a tripler would be added at the output of the APC. The required frequencies for other communication needs or for radar and other equipment can be worked out in a similar manner.

A spare synthesizer should be available for the original setting up of a frequency on the APC's, since it might take more time for the initial adjustment than the five to ten seconds allocated to each channel merely to correct for frequency drift. This could also eliminate several minutes delay in the sequential procedure required before a given APC is controlled, when a quick shift in frequency is needed.

Another frequency synthesizer would be desirable for monitoring purposes, and could be used for the initial adjustment procedure. This synthesizer would have a frequency coverage of perhaps 1 cycle to 400 Mc and with its associated programming and switching mechanism and a comparator, recorder, and alarm would monitor all frequencies. This alarm feature plus other alarms indicating malfunction would notify the technicians or other qualified personnel of trouble. For the purpose of reporting unusable channels or interference, there is need of a good communication system between the communicators and personnel in the centralized control room; a combination of voice with lights or similar indicators on a wall panel might serve the purpose.

It is believed that, with proper terminal equipment, any type of communication method could be used. The one type that will be more difficult to obtain is FSK where the controlled oscillator is not amenable to discipline external to the control portion of the system. This, however, would be true of any precision frequency-control design and probably has been considered by those concerned with FSK. The latest information indicates that suppressed carrier SSB will be used in future equipments, so that this is a field in which further work must be done.

[redacted]

[redacted]

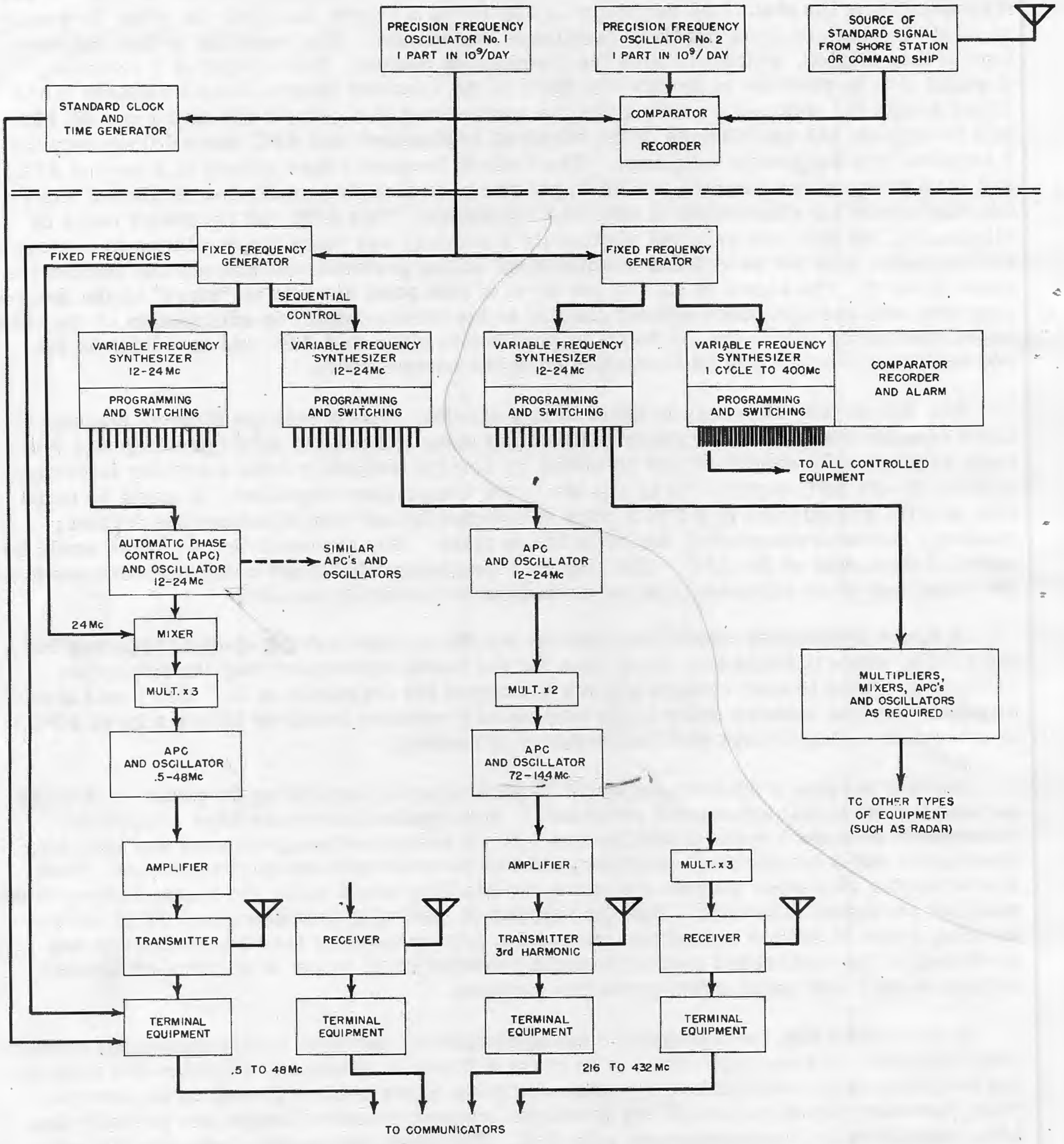


Fig. 7 - Sequentially controlled system

[redacted]

[redacted]

Consideration should be given to air conditioning for the centralized control room, at least enough to protect the oven-controlled precision oscillators, and the temperature-compensated stabilized oscillators from any frequency shift due to sudden temperature changes. The placement of transmitters and receivers in adjacent rooms will help by reducing excess heat from the control equipment. Figure 8 is a possible floor plan of the control room and Fig. 9 is a sketch of the console for a ship having a total of 100 transmitters and receivers. Figure 10 is a sketch of detailed elements to show the simplicity of the programming method. It should be noted that all switching is of dc controls and not of rf, making for greater simplicity and ease of handling. These suggested drawings are preliminary and are included only to give an idea of approximate space requirements and operation methods. Further consideration of plans needs to be given by those familiar with shipboard requirements, limitation of space, and similar matters.

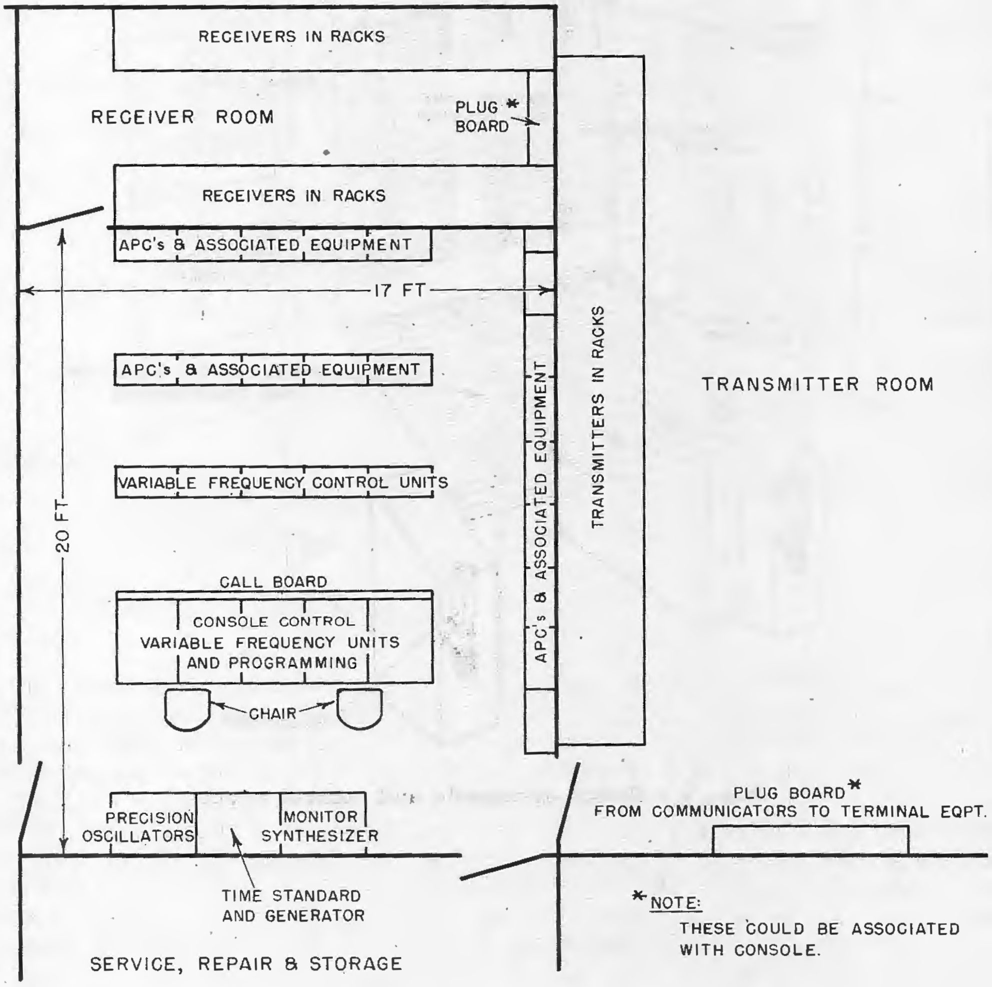


Fig. 8 - Possible layout of centralized control room (for 50 transmitters and 50 receivers)

[redacted]

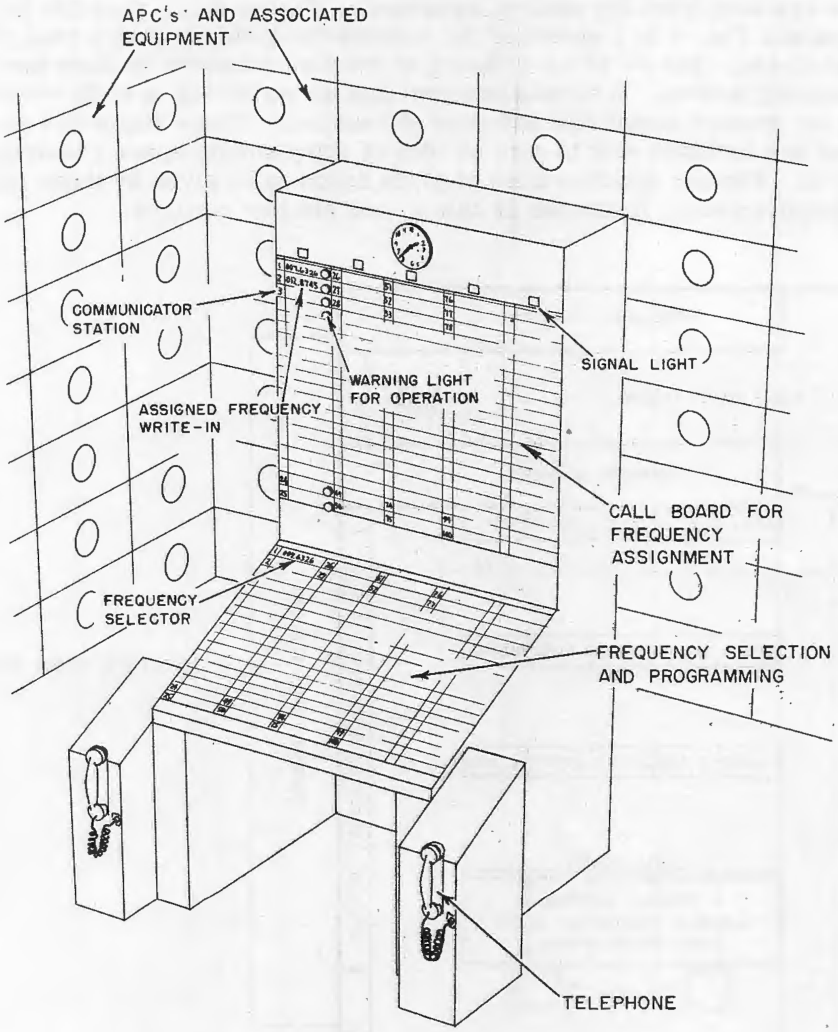


Fig. 9 - Sketch of console and control room

[redacted]

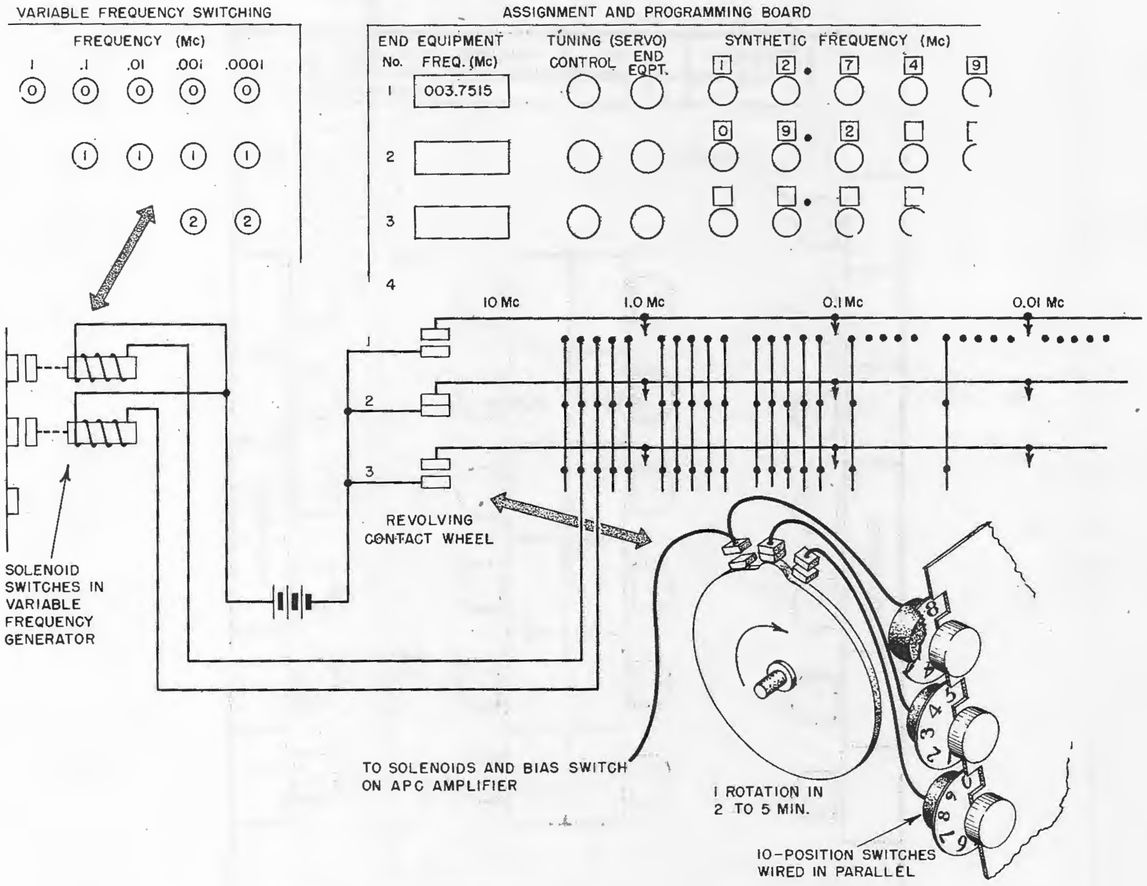


Fig. 10 - Possible programming board

IMPLEMENTATION

It is essential that any centralized system to be used in the near future be capable of using the present transmitters and receivers and that the system can become fully operable through gradual implementation. The proposed system has been conceived with this in mind.

The first step (Fig. 11) would be the installation of the precision oscillators with their comparator and at least one synthesizer. For flexibility, a wide-coverage synthesizer should be supplied to each radio room. Only a single precision comparator and recorder would be needed, since it is connected to all the precision oscillators. A simple means of comparison in each room will facilitate checking of the end equipment by the synthesizer. This is a simple monitor method and would not maintain the equipment on frequency but would result in a better frequency setting than is now obtainable. Further, this step would familiarize the personnel with the capabilities of the new equipment.

[redacted]

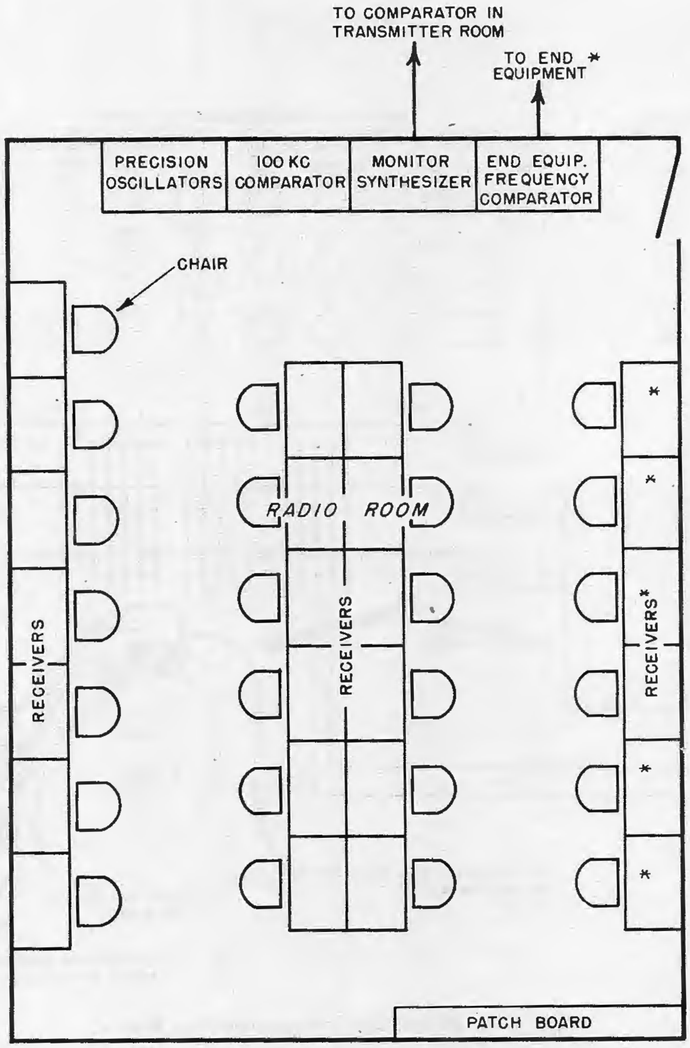


Fig. 11 - First step in implementation

The second step (Fig. 12) would be the inclusion of the control board, one or more of the sequentially controlled oscillators and/or a number of synthesizers, for direct control purposes.

Some of the latest transmitters, now being purchased or considered, incorporate a synthesizer of sorts. These synthesizers can be disabled or used for emergency operation only, and the proposed centralized control used for normal operation. In receivers, double- and triple-conversion frequencies can be obtained from the fixed-frequency generator (Fig. 1) without the use of a synthesizer in the equipment itself.

Task force operation would appear to be the condition under which stability is needed the most; consequently, those equipments used particularly for this purpose should receive first attention, with the other equipment being considered at a later date.

[redacted]

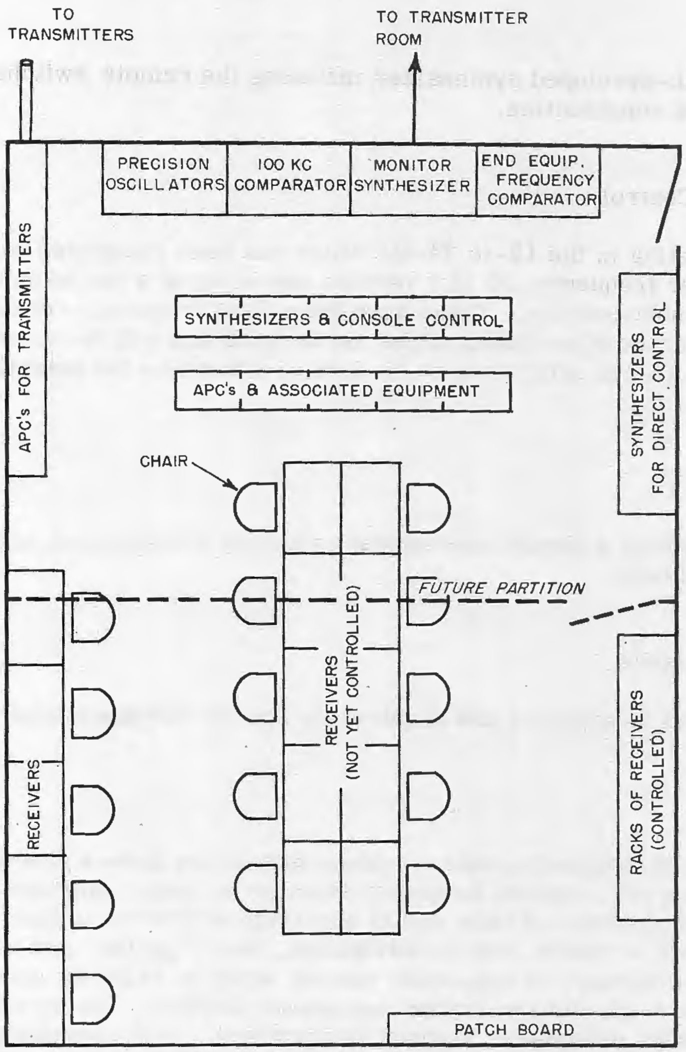


Fig. 12 - Second step in implementation

EQUIPMENT STATUS

Precision Oscillators

The Bell Telephone Laboratory has developed a crystal oscillator (5 Mc) with oven and associated circuitry that has a stability of better than one part in 10^8 per day with the possibility of 1/2 part in 10^9 per day after a drift period of two months. There is also a Collins crystal oscillator that has been produced with a stability of one part in 10^7 per day, which costs somewhat less but at present is not seaworthy.

Comparator and Recorder

Several of the comparators and recorders (Fig. 1) have been produced for the Navy, from an NRL design, by the Davies Laboratories of Riverdale, Maryland.

[redacted]

Synthesizer

The latest NRL-developed synthesizer including the remote switching mechanism is in the final stage of construction.

Automatic Phase Control

A model operating in the 12-to 24-Mc range has been completed and operates satisfactorily. A higher frequency (96 Mc) version operating at a two to one frequency ratio has also operated successfully. These have been fixed frequency versions, but a two to one frequency coverage type should not be too difficult and will be constructed. A considerable amount of work still needs to be done to determine the potentialities of this type of equipment.

Programming

This requires only a simple mechanical switching arrangement and is not considered to be difficult to obtain.

Multipliers and Mixers

This equipment is standard and requires no special developmental work.

CONCLUSIONS

The centralized frequency-control system may prove to be a practical and reliable method of providing the required frequency stability in major shipboard radio installations, effecting marked economies of time and rf spectrum utilization in fleet communications and other functions such as radar, sonar, navigation, identification, and electronic countermeasures. The advantages of sequential control would warrant its consideration for use with most of the present communication equipment; however, the direct and monitoring control methods offer advantages in many applications. It is considered that a centralized system is essential for controlling frequency or timing of modern weapons.

FUTURE PLANS

A centralized frequency system is to be set up to permit application of various methods of control to communication and other equipments requiring precision timing or frequency adjustment. Tests with this experimental system will be made to determine its operating characteristics and to determine its adaptability to shipboard requirements. It is anticipated that all component units of the system will be available for assembly and preliminary tests during fiscal year 1958.

* * *

[redacted]