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A NOTE ON SOME CONCEPTS FOR USING THE LMSC 'BARBER POLE' OPTICA--ETC(U)
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(6) A Note on Some Concepts For Using the LMSC "Barber Pole" Optical Correlator for Multichannel Sonar Signal Processing*

by

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<u>Introduction</u>

The purpose of this note is to present a conceptual approach for using the LMSC "Barber Pole" optical correlator to simultaneously process multichannel signals from large acoustic arrays. The principal of operation of the LMSC "Barber Pole" correlator, the description of the experimental model, and the description of test results are reported in reference (1). Briefly, the LMSC optical correlator is a non-coherent-optical correlation detector of the stored reference type. This correlator performs real time correlation of received signals with the stored reference without a priori knowledge of the signal delays. The use of real time integration in the correlation operation avoids the problems of recording received signals on film prior to correlation with the reference. The first experimental model achieved a processing gain of 20 db for a reference record that was theoretically capable of providing a processing gain of 23 db. A substantial increase in processing gain can undoubtedly be obtained by using more densely recorded reference records and by further refining the correlator.

Consideration is given here to the conceptual design of a sonar signal processing unit based on the principle of the LMSC correlator. The conceptual design is intended to be compatible with the requirements of both active and passive sonar signal processing. The topics to be discussed are:

- multichannel correlation - active mode
- reference signal choice
- Doppler considerations
- Modular design features
- presentation - active mode
- multichannel passive signal waveform analysis
- presentation - passive mode

- comparison on a rough estimate basis of the complexities of an optical signal processing unit, and an electronic digital signal processing unit of equal signal handling capability.
- recommended supporting research work.

Simultaneous Processing of Preformed Multibeam Signals From Large Acoustic Arrays

General Considerations:

The active or passive signal processing described here is considered to begin at the n-channel output of a sonar array beamforming circuit. The signals at the output of the beamformer are considered to be broadband signals each of which represents an acoustic signal received in a narrow azimuthal increment associated with one of the n simultaneously operating preformed beams of the acoustic array. The DIMUS system may be considered an example of such a beamformer. Fig. 1 is a block diagram of the receiving portion of a sonar system showing where the optical signal processing and signal presentation equipment would fit into the system.

Considerations for Active Sonar Signal Processing

a) Multichannel correlator description: In the active mode of operation a signal is read out of the reference record and transmitted as a sonar signal. Thereafter the signal coming in on a receiving channel is correlated with the stored reference at two locations on the reference record. The two correlation functions formed on the vidicon tube are alternately scanned out with a repetition period equal to twice the signal duration.* The correlation operation is continued until no more echo signals are considered to arrive. The principle of the single channel operation is described in detail in reference 1. For multichannel operation it is necessary to provide simultaneous access to the

*The alternating scan out of the two correlation functions is required in order to satisfy the integration requirements as explained in reference 3, page 5-4.

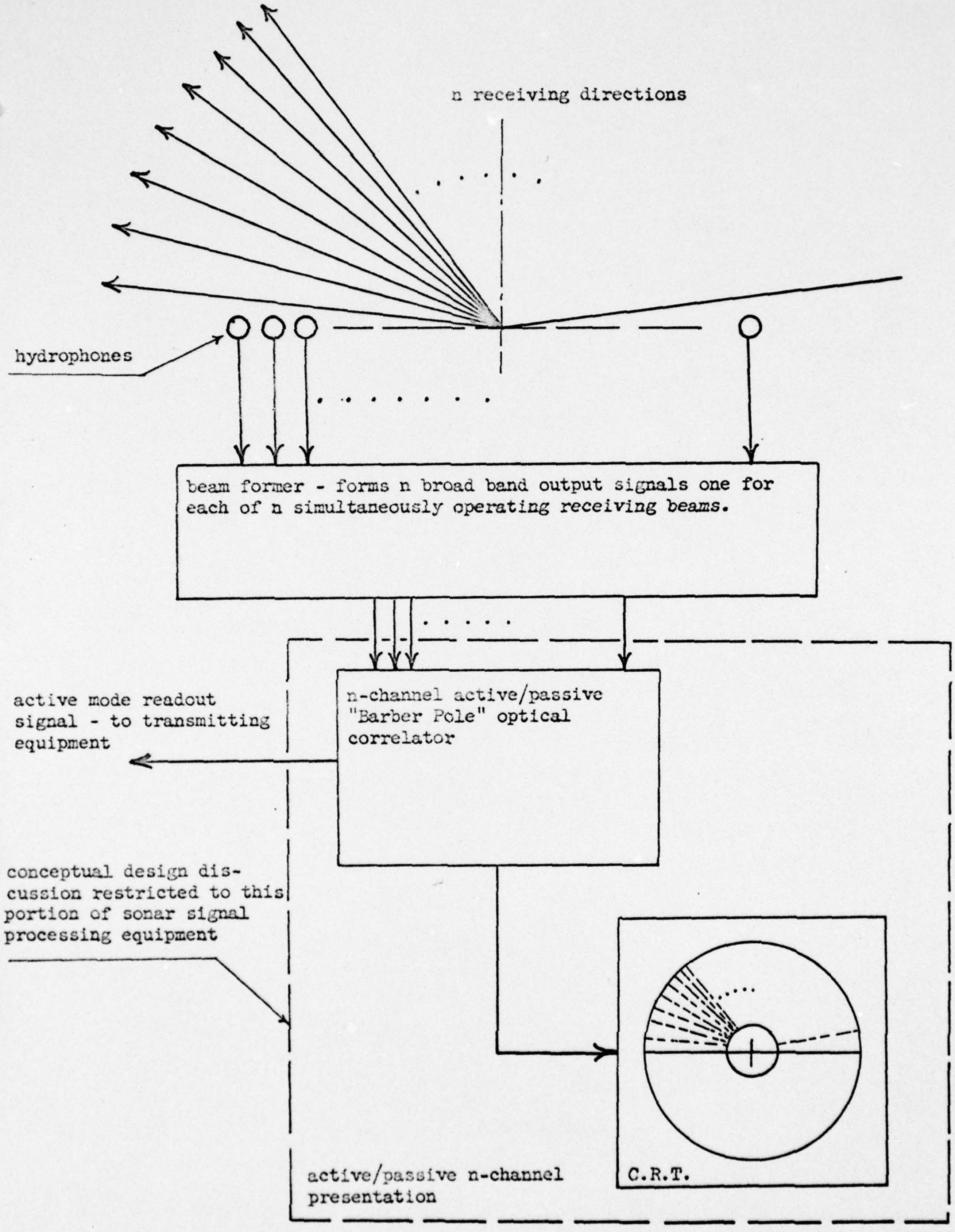

Figure 1. Block Diagram Showing Location of Signal Processing Unit in Receiving Portion of Sonar System.

reference record (at two locations) for each of the multiple channels to be operated.

An optical arrangement designed for multichannel operation is shown in Fig. 2. In this arrangement a single fan-shaped beam of light intensity-modulated by the received signal originates from an optical beam generating unit. This beam is split into two identical beams at a beam splitter. The two beams are incident on the rotating reference record at positions separated by one reference signal duration T. In the design shown in Fig. 2 the reference record and opaque portion are repeated four times around the cylinder instead of appearing once as was the case in the experimental model correlator. Thus, the two beams are incident on the record at locations angularly separated by 45°. The light transmitted through the rotating record is reflected by a mirror system which causes it to pass out of the inside of the cylinder and to be reflected back toward the vidicon tube. The two vertical lines of light appearing on the inside of the rotating cylinder are imaged on the vidicon tube face.

Additional fan shaped light beams originating from other optical beam generating units can be made to follow optical paths closely adjacent to the single channel paths shown in Fig. 2. These additional beams are made parallel by a group of narrow mirrors located near the center of the circle of optical beam generating units. These mirrors can be spaced closely at this point because the optical beams are thin there. Five beams aligned in this manner are shown incident on the beam splitter in Fig. 2. The complete optical paths are not shown in order to avoid confusion in the drawing. For a six channel arrangement like that in Fig. 2 there will be six closely spaced line pairs imaged on the vidicon tube face as shown in Fig. 3.

The vidicon scanning pattern is adjusted to provide three longitudinal scans in a width of a line. This insures that at least one complete longitudinal

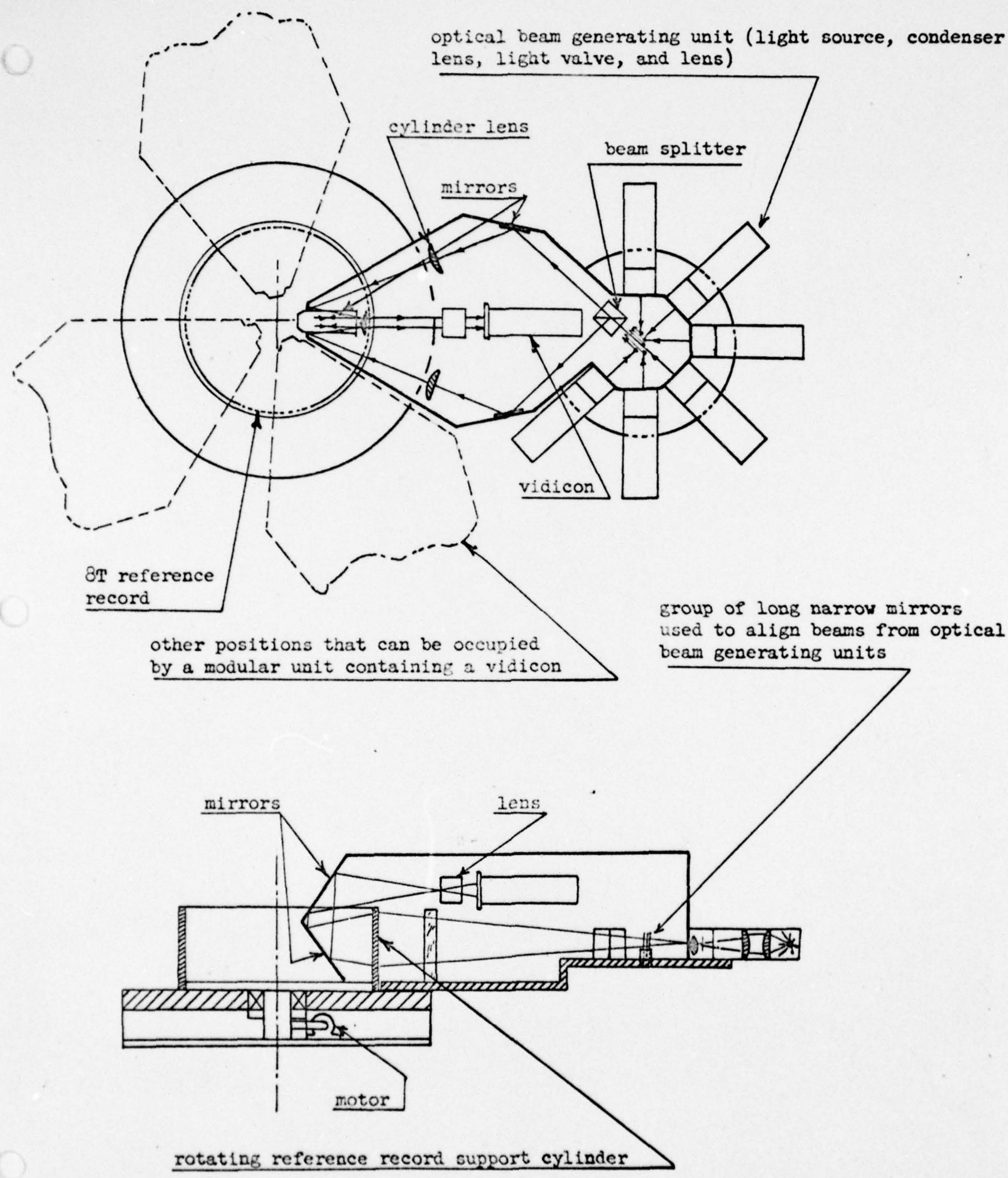

Figure 2. Optical Arrangement for Simultaneous Multichannel Processing of Sonar Signals

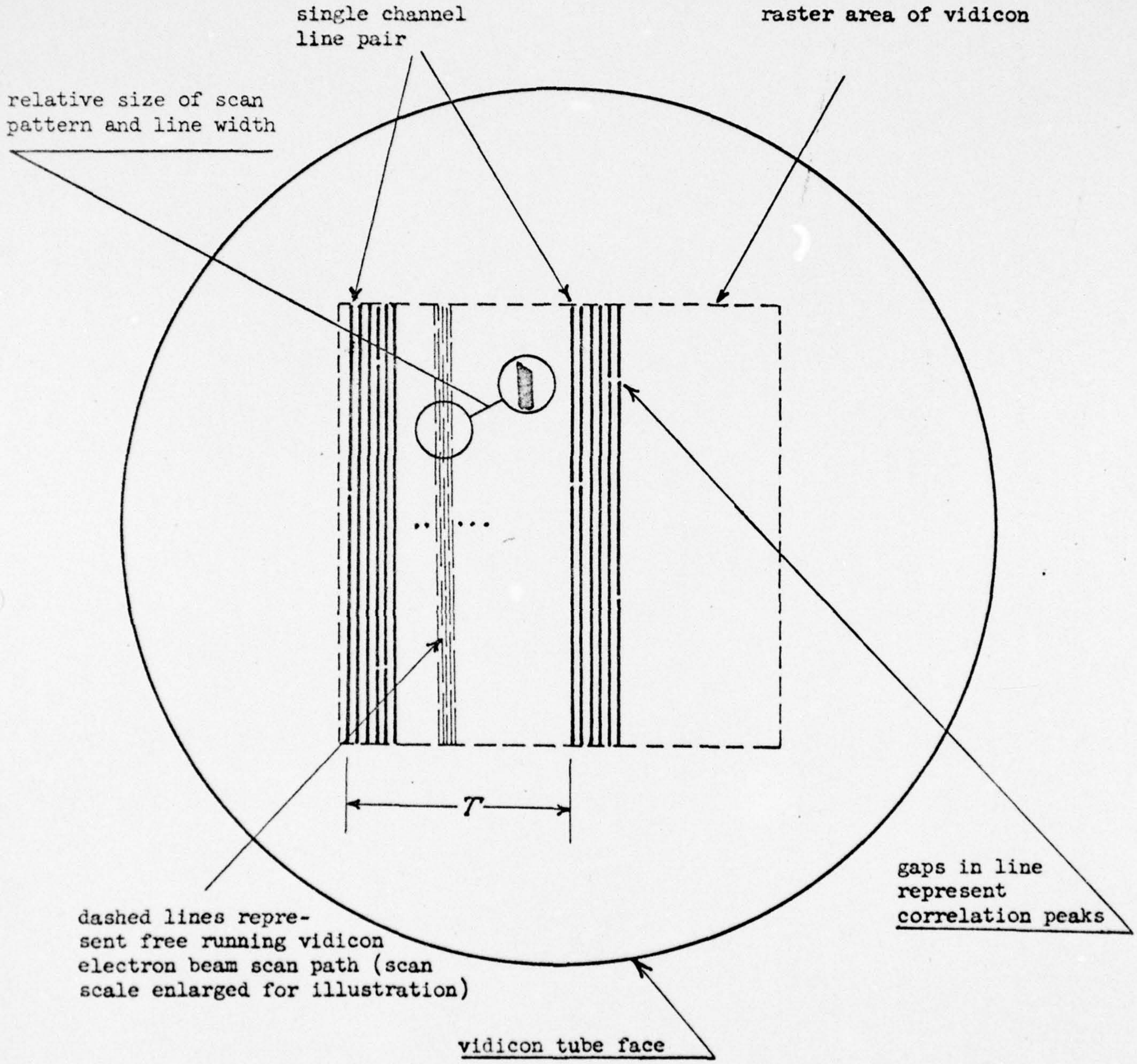

Figure 3. Location of Correlation Function Line Pairs on Vidicon Tube Face for Multichannel Operation. Scan must progress from one line of a pair to the other in a time equal to the signal duration T.

scan of each correlation function will occur regardless of its location on the tube face. Timing is not critical. It is required, however, to synchronize the transverse motion of the vidicon scanning beam with the drum rotation period so that the lines of a pair will be scanned out at times separated by T seconds, where T is the signal duration. Synchronization prevents the development of progressively increasing errors in the scan-out time.

b) Reference signal choice: Pseudo random noise signals were used in the experimental model correlator, however, it is not necessary to restrict the reference signals to such a class. Provisions can be made which allow changing the reference record easily. Thus instead of a pseudo-random signal an F.M. signal could be transmitted and the echo signals correlated. Other reference signals chosen for "optimum" propagation properties, target classification properties, or low detectability could also be recorded and stored for special tactical uses or for use when special propagation conditions exist.

c) Doppler considerations: The effect of Doppler is to stretch or shrink the echo signal with respect to the reference signal. The Doppler effect shows up in the correlator as movement of the instantaneous correlation peak along the correlation function line. This motion is easily seen by the eye. In the case of the vidicon the movement of the correlation peak has the effect of smearing the exposure differential along the correlation function line, thereby causing a reduction in peak exposure and hence, a reduction in the peak electrical output signal associated with the correlation peak. A recent LMSC patent disclosure describes how the Doppler effect can be compensated in the "Barber Pole" optical correlator. Without going into detail, the scheme amounts to image-motion compensation. Each correlation line imaged on the vidicon tube is split into a group of lines each of which has a different longitudinal image motion imparted to it. In this manner a set of Doppler bins are formed on the vidicon tube face for each input channel. All bins are read out just as if they were lines associated with additional channels. It is likely that the Doppler signal sorting unit when developed can be inserted into the optical path of a multichannel correlator such as that described above, without major modification.

d) Modular design features: The multichannel correlator layout shown in Fig. 2 is modular in nature. Channel capacity of a basic unit can be increased from one channel to six by adding the desired number of beam generating units (actually, more beam generating units can be mounted in a vertical plane and their beams can be interleaved with the others by using another beam splitter). When the channel capacity of one such basic unit is exhausted other basic units can be added in the positions shown by the dashed lines. It should be possible to obtain a channel capacity in excess of 50 channels with four basic units.

e) Presentation of multichannel information: The multichannel correlation functions can be displayed in P.P.I. scan form or in A-scan form after being scanned out by the vidicon electron beam. The former type presentation will be considered here. Fig. 4 shows one form of PPI presentation that could be used. In this example the correlator is a 24 channel correlator consisting of 4 basic units each containing 6 beam generating units. The output of the vidicon is put through a threshold circuit. If the threshold level is crossed by a correlation function peak this causes a standard size pulse to be generated. This pulse produces intensity modulation of a display tube such as a storage tube or a conventional cathode ray tube. The radial sweep time of the display tube is made equal to the time required for the vidicon beam to make one longitudinal sweep along a correlation function line. The azimuthal sweep of the

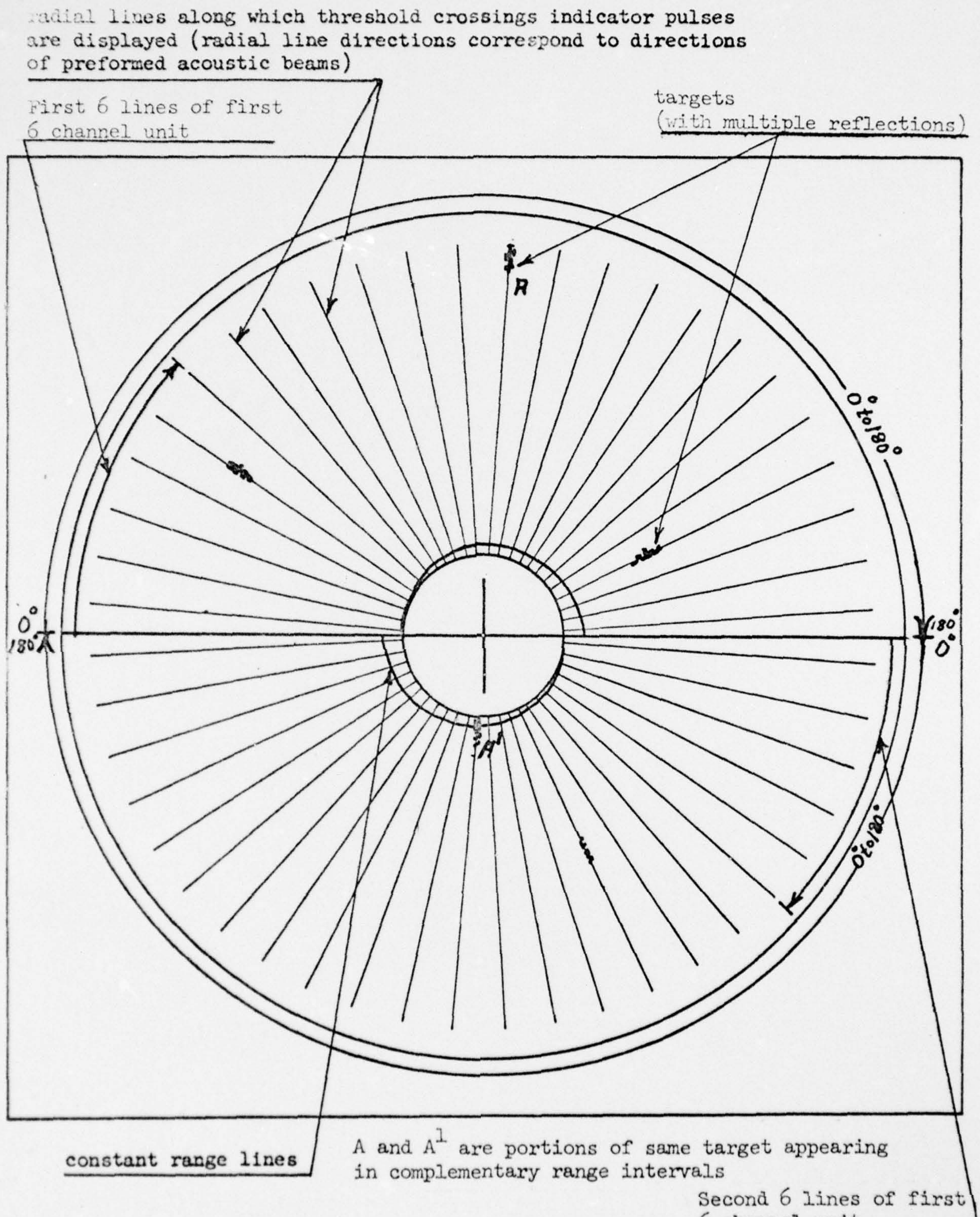

Figure 4. P.P.I. Type Presentation of Multichannel Optical Correlator Output. Maximum range on upper radial sweep coincides with minimum range on that lower radial sweep that is the extension of the upper. Doppler indication not shown.

display tube operates at two different rates during the course of one 360° scan. The high rate azimuthal scan starts when the vidicon electron beam begins to scan the first line in the first group of 6 lines formed by the first 6 channel unit. When these 6 lines have been scanned the second basic-unit vidicon beam starts to scan the first line in its first group of 6. This process continues until all 24 correlation function lines in the first beam split paths have been scanned out and their information content has been displayed on the upper half of the display tube. At the end of this time interval which might be say 5 percent of the signal duration (T) the azimuthal scan rate of the display tube is reduced to zero. After a rest period interval 5 percent shorter than T seconds the first basic-unit-vidicon beam has reached the first line in the second beam split group of 6 lines. At this time the azimuthal scan rate of the display tube returns to the former high rate and the information content of the second group of 24 lines is displayed on the lower half of the display tube. The finite writing rate of the display tube makes it desirable to progressively increase the physical angular separation of the four basic units around the reference cylinder. This has the effect of equally spacing the times at which the 24 lines are successively scanned out by the 4 vidicon tubes. As a consequence, lines of constant range take the form of spirals such as those shown in Fig. 4. If the display tube is a storage tube the frame can be held for closer examination or it can be erased and the succeeding frame containing all echoes arriving in the following 2T seconds can be displayed. A storage tube display would be advantageous in convergent zone echo ranging where only a relatively narrow range interval is of interest. In this case convergent zone echoes could be held for close examination without bothering to present echoes from intervening ranges.

A conventional cathode ray tube could also be used provided the persistance of the phosphor has the proper relationship to the azimuthal scan period. The use of a cathode ray tube would have the advantage of not requiring an erase period.

Doppler information can be presented in two ways. The first way may be considered a Doppler compensation method. In this method it is of interest to display all Doppler compensated signals without identifying the Doppler correction. The intent here is to insure maximum processing gain by providing a wide range of Doppler compensation. In this scheme each line would be split into a number of closely spaced Doppler compensated lines. The vidicon scan out of the Doppler split group would be presented in an azimuthal increment centered on a radial line. One good Doppler compensated signal out of the group would be sufficient to indicate the presence of a target.

The second way of presenting Doppler information would be to sort the Doppler shifted signals into identifiable Doppler bins and present the output of each bin in a manner that would permit easy Doppler resolution. This could be done by restricting the multichannel display to the direction the target is found to be in. The corresponding line could be Doppler split into a group of more widely spaced lines which in turn could be displayed with increased angular separation on the display tube. This procedure would require a second transmission to measure target Doppler.

Considerations for Passive Sonar Signal Processing (Target Detection and Identification

a) Non-coherent optical filtering: A common approach to passive sonar signal analysis is to pass the received signal through a bank of narrow band filters and to examine the energy in the output of each of the filters. A recent LMSC patent disclosure describes how an analogous operation can be performed using the identical multichannel equipment used for active sonar signal processing. All that is required is that the reference record be changed. The remainder of the correlator including the presentation can be used in the passive mode without modification. The form that the non-coherent optical filter record would take is shown in Fig. 5. To understand the action of the non-coherent optical filter it should be recalled that the output of an electronic filter can be expressed as the convolution of the input signal with the impulse response of the filter. In the case of a narrow band filter the impulse response is lightly damped sine wave. By using a reference record like that in Fig. 5 (which can be a binary approximation of the sine wave) an equivalent convolution operation can be performed optically. In this operation the received signal is multiplied (at a point) by a clipped sine wave of given delay. The product signal is integrated on the vidicon tube face at the imaged point. At a nearby point vertically displaced from the first point the received signal will be multiplied by a different delayed version of the clipped sine wave. The convolution result (or filter output signal) thus appears as a variation in exposure along a short segment of the line imaged on the vidicon tube. One complete period of the output signal will appear in the short line segment if 360° of clipped sine wave delay is recorded in the reference signal strip. Other clipped sine wave reference strips can be recorded on the reference record so as to provide the effect of a bank of filters. All filters in this group can be translated to a different frequency range by changing the reference record rotation rate.

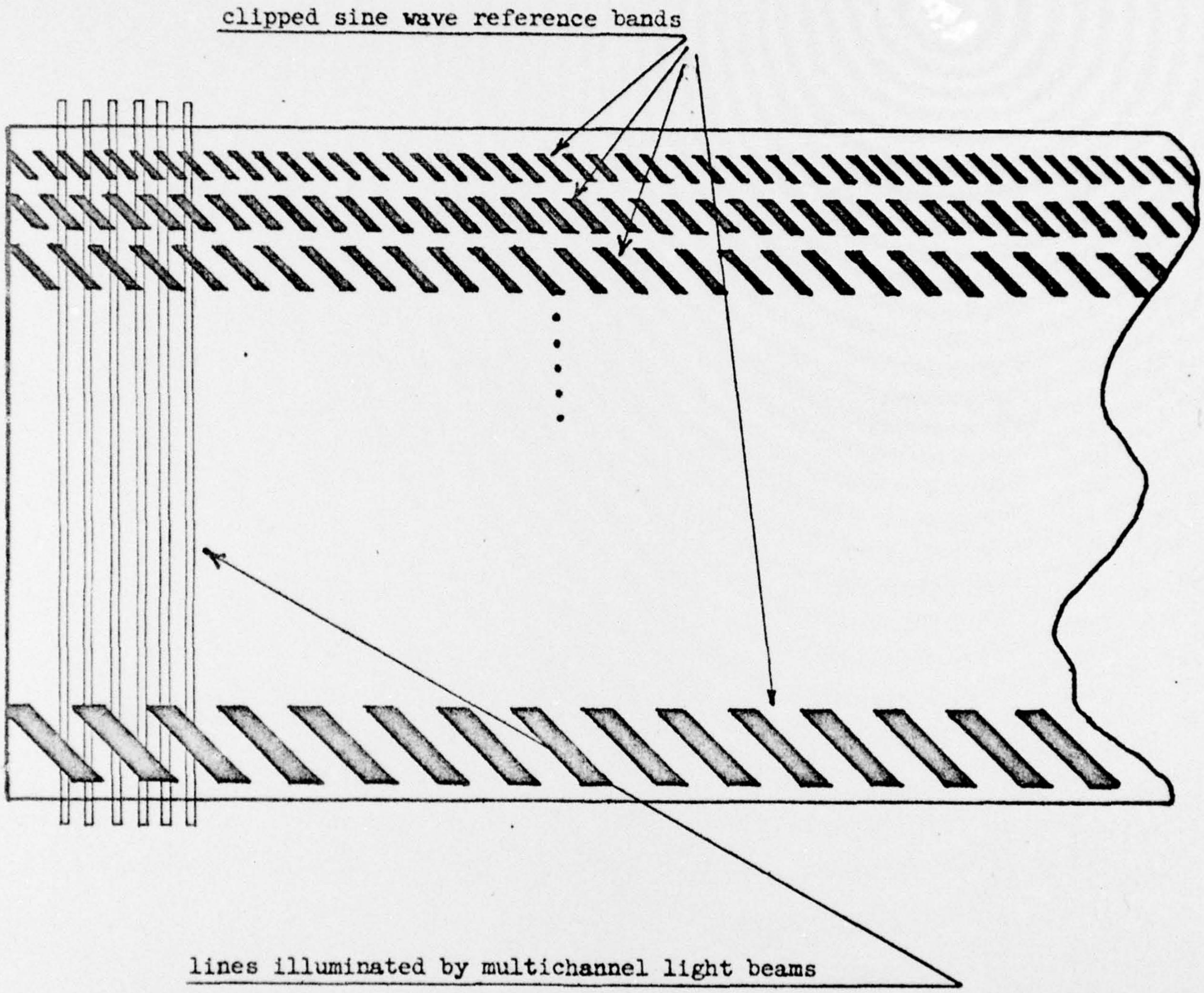

Figure 5. Noncoherent Optical Filter Record for Passive Sonar Signal Processing.

b) Multichannel presentation - passive mode: The presentation equipment used in the active mode can also be used in the passive mode by simply interpreting the presentation differently. With the passive filter reference record in place the radial dimension of the display will be automatically converted from range to frequency. The threshold circuit can be used if it is desired to display the filtered energy only if it exceeds a given level. In the passive mode of operation there is no requirement for restricting the integration time to exactly T seconds as there was in the active case. Consequently, only 24 lines need be displayed. By changing the transverse scan rate of the vidicon tube the integration time can be controlled. The passive mode display is shown in Fig. 6 where the presentations of the filtered signals of two passive sources are depicted on the display tube. Classification of the targets generating the passive signals could possibly be carried out by use of templates previously made to fit known spectral output patterns of targets.

Analyzed passive signals of two different targets lying in different directions.

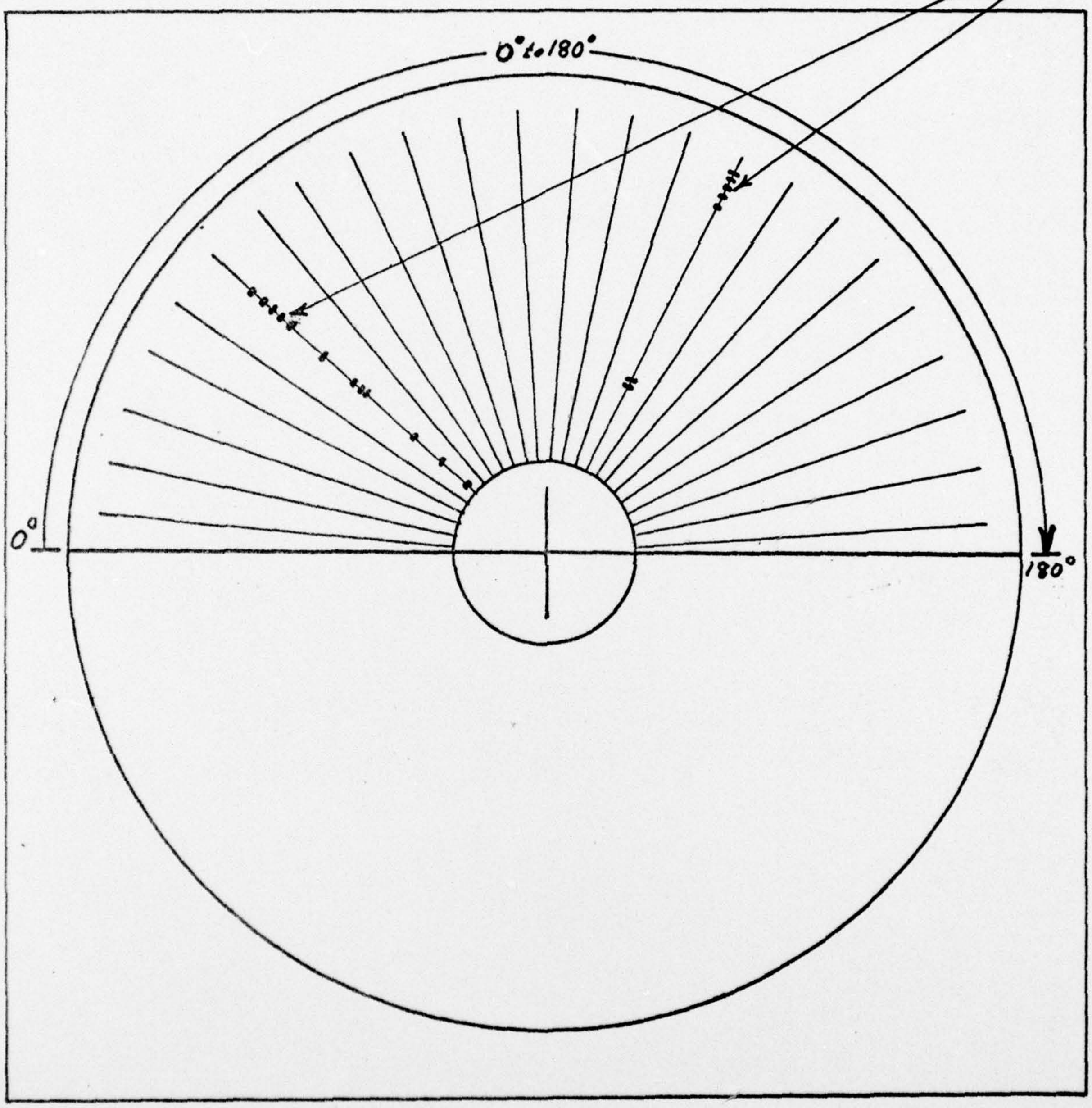

Figure 6. Display for Passive Sonar Signal Analysis. Signal energy as a function of frequency is displayed along radial dimension.

Comparison of the Complexities of Optical and Digital Electronic Signal Processors of Equal Signal Handling Capability

The relative complexity of the optical and digital electronic approach to sonar signal processing can be examined by comparing the number of active components (transistors) required in each system. For the purpose of comparison only the processing units will be considered. The beamforming and display portions of the system will be ignored. The comparison will be made on the basis that signals from 52 preformed beams are to be processed by correlation detection, and that 11 Doppler compensations are to be provided for each preformed beam signal. In an earlier analysis of multichannel digital signal processing an approximate relationship was derived giving the required number of active components.

$$\text{number of active components} \cong 19M(N + 1)+38N + 53$$

where M is the number of preformed beams and N is the number of Doppler bins. It should be stated that this relationship is based on limited information, and that it may not reflect the latest state of the art in digital electronic signal processing. For $M = 52$ and $N = 11$ the required number of active components is 12,000. In addition to this at least two 30 track magnetic storage drums would be required.

The same signal processing could be accomplished by using an LMSC "Barber Pole" optical correlator having 4 basic units each containing 13 light beam modulators. The arrangement in Fig. 2 would have to be modified in order to accommodate additional light modulators. The modification might consist of adding another pair of cylinder lenses alongside the first pair and of stacking another beam splitter on top of the first beam splitter. In this manner another layer of light modulators could be mounted above the first layer. Vertical beam alignment could be accomplished by a mirror arrangement. The number of active components required in the optical correlator for 52 preformed beams and 11 Doppler bins (assuming 4 basic units) is 631. It is evident that a significant reduction in electronic complexity is potentially possible by using such an optical signal processor. As for the optical-mechanical mechanism it is no more complicated than the two 30 channel magnetic storage drums required in the digital system. Experience has shown that the optical-mechanical portion of the correlator does not require precision optics or precision alignment of optical parts. The optical mechanical portion of the experimental correlator has proven to be highly reliable during the two years it has been operated. The major differences of the two systems lie in areas of electronic reliability, and types of presentation. When the versatility of the optical correlator with regard to active/passive operation is considered the contrast in the complexity of the two approaches to signal processing becomes even more apparent.

Recommended Supporting Research and Development Work

Work related to the correlator itself: The multichannel optical correlator and signal display designs discussed above are still largely in the conceptual stage of development. Considerable attention must yet be paid to engineering details before final designs can be formulated. It is necessary to have detailed information on the operational requirements of any sonar system for which the processor might be used before proceeding much further. For example there is need to investigate such system dependent design factors as spacing of correlation function lines on the vidicon tube, desired frame rates for presentation, desired combination of signal band width and duration, maximum practical Doppler resolution, and compensation. There is also a need to carry out analytical and experimental investigations of non-coherent optical filtering techniques with regard to bandwidth control, self noise effects, bias effects, preferred integration times, and preferred threshold settings.

Work related to the environment: The introduction of a new device into the field of sonar signal processing makes it desirable to review supporting research fields—in need of better understanding of the proposed as well as similar devices. Results of such research can aid in bracketing performance capabilities and limitations under realistic conditions and, also guide engineering design as it enters its advanced phases.

The experimental basic optical correlator can serve as a research tool for some of the proposed measurements related to investigations listed below.

Preferred Signal Selection for Correlation-Detection Applications

Objective: Determine preferred signals to be used in the correlation process for various applications of the optical correlator.

Background: At the present time the experimental optical correlator uses a pseudo-random noise signal. This is not necessarily the best choice for all situations in which the correlator will find applications. It was chosen because it permitted easy analysis and verification of the performance of the correlator. The purpose of this research program is to determine preferred signal waveforms to be used for various tasks the correlator is expected to perform. The analysis must take into account biasing and self noise effects in the optical correlator as well as sound propagation effects in the ocean.

Tasks:

1) Preferred signal selection for underwater communications in deep water and in shallow water (such as that along the continental shelf).

2) Preferred signal selection for echo ranging in deep and shallow water taking into account target type, shape, and size.

3) Preferred signal selection for I.F.F.

4) Preferred signal selection for depth sounding and secure depth sounding.

5) Preferred signal selection for long range communication along the deep sound channel.

6) Investigation of preferred signal selection for classification of signals reflected from a three dimensional target.

Justification: It is recognized that these are all formidable tasks. The information sought by such investigations is needed to effectively apply the correlators to the variety of underwater communication type tasks that arise in ocean system work. The foregoing investigations are also intended to help bridge the well-recognized gap between theoretical knowledge and experimental evidence concerning the optimization and optimality of signalling techniques in the presence of now poorly-described phenomenological conditions.

Investigation of the Effects of Underwater Sound Propagation on Correlation Detection Techniques

Objective: This program includes a group of research topics which are concerned with determining how the characteristics of sound propagation in an ocean medium effect correlation detection. The program is intended to yield information of the type needed to guide persons applying correlation techniques to the ocean system problems of echo ranging, sonic communications, sonic location, and I.F.F.

Investigation of Correlation Detection of Signals Propagated Through a Velocity Dispersive Medium

The propagation of sound in the lower audio frequency range in shallow water (depths less than several hundred feet) has always been difficult to predict. The reason for this is that much of the sound propagation is not through the water layer, but instead is through layered structures lying below the ocean bottom. These below the bottom propagation paths which are velocity dispersive influence the sound propagation more strongly than do the water paths. The resulting time dispersion of pulses and interference effects combine to work against the transmission of information by conventional acoustic means in shallow water. Such shallow water conditions exist over much of the continental shelf. The purpose of this investigation is to determine the conditions on signals and dispersion required to destroy the correlation process for all but the direct non-dispersive water path. The experimental approach will be to propagate a signal derived from the correlator reference through a simulated dispersive path and return the signal at the output of the dispersive path to the correlator. In this manner changes in the shape and amplitude of the correlation function can be investigated as a function of dispersion. Dispersive propagation paths can be simulated by propagating acoustic waves through tubes. The LMSC Palo Alto tunnel and the experimental correlator appear to be well suited for such an experiment.

Investigation of Correlation Detection of Doppler Shifted Signals

LMSC has done some theoretical work on this in the past, but the results need to be checked by experiment. The effect can be investigated experimentally by simulating the Doppler shifted signal by recording the signal derived from the correlator on tape and playing the tape back into the correlator at a different tape velocity than that at which the signal was recorded.

Investigation of Correlation Detection of Signals in the Presence of Interfering Noise of Various Types

In an actual ocean system the interfering noise is not likely to be band limited white Gaussian noise as it is often assumed to be for the convenience of analyzing correlation detectors. This investigation will be concerned with the interfering effects of impulse noise, ship noise, and non-uniform Gaussian noise (like that of ambient noise in the ocean). The experimental part of the program will consist of adding tape recorded noise of various characteristics to a signal derived from the correlator and returning the noise contaminated signal to the correlator for correlation with the reference signal. In this way the relative effects of various types of noise on correlation detection can be investigated. The results can be compared with recently reported theoretical results.*

Summary and Status of LMSC Work in Optical Correlation

- An experimental optical correlator has been built and operated successfully at LMSC.
- A more refined version of the basic optical correlator is now being developed.
- Concepts have been presented for using the optical correlator principal to process the multichannel outputs of large acoustic arrays. Experimental work has not yet been conducted.
- Concepts have been presented for Doppler compensation and sorting of multichannel signals. Experimental work has not yet been conducted.
- Concepts have been presented for using the optical correlator as a passive sonar signal analyzer by incorporating a non-coherent optical filter reference record. Experimental work has not yet been conducted.
- Concepts for signal presentation have been described, but not tested.
- A supporting research and development program has been recommended.
- Outside funding of research and development in this area of optical sonar signal processing is needed in order to cope with advanced Navy requirements.

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*D. Middleton, J. Acoust. Soc. Am. 35 65 (1963).

LMSC Reports Containing Information on Optical Processing of Sonar Signals

1) "An Optical Correlation Detector for the Audio Frequency Range" by J. K. Parks, LMSC 5-13-64-9 (August 1964).

2) "Optical Processing of Sonar Signals" (Department 52-40 informal note dated July 16, 1963).

3) "System Considerations for Random-Signal Sonars" by J. K. Parks and J. J. Downing, LMSD-895060, December 1960.