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TAPE SONAR CORRELATOR (TASC).(U)

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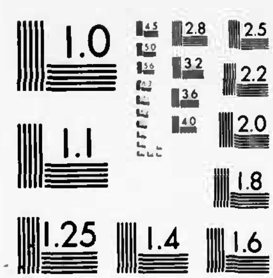

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MOST Project

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TAPE SONAR CORRELATOR
(TASC)
INTERIM REPORT

NVR-2894

November 1963

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6 TAPE SONAR CORRELATOR

(TASC).

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PREFACE

Under the Hydrospace Electronics W.A. (Project 9925) a feasibility study was initiated during July of 1963 on a Tape Sonar Correlator. This work has now been carried to the point of having successfully demonstrated the ability of the system to extract its correlating wave form from background noise and also to differentiate between two such wave forms even when they overlap each other. The purpose of this report is to describe the use of the TASC in a sonar system, to present the test program and its findings to date and to discuss briefly plans for future work.

CONTENTS

FIGURES

INTRODUCTION

One of the basic problems inherent in the use of an active sonar is the difficulty which the operator has in discriminating between desired targets and all other received echos. Many techniques have been tried for this purpose, but so far the most effective has been the use of a recorder with an expanded range scale in conjunction with a short sonar pulse. A short pulse permits fine range discrimination which shows up small discontinuities in a target such as individual fish in a school or irregularities in a man-made object. Use of the recorder permits a ping-to-ping

highlight correlation from ping to ping

comparison to be made showing up consistency or inconsistency in target irregularities. Man-made objects tend to have consistent irregularities while other reflectors tend to vary in their irregularities.

Unfortunately, sonar range is proportional (approximately) to the fourth root of the total power contained within each sound pulse. Thus, use of a short pulse effectively limits the range at which a target classification can be made. The Tape Sonar Correlator (TASC) operates to provide a sharp spike of energy at the point in time when an incoming wave correlates with the mask representing the expected incoming wave. Effectively, then, the TASC acts as a pulse compressor, providing an equivalent short pulse capability to a sonar which is actually using a long pulse. The sonar's range is then determined by the total energy contained in the long pulse.

1.0 THEORY OF OPERATION

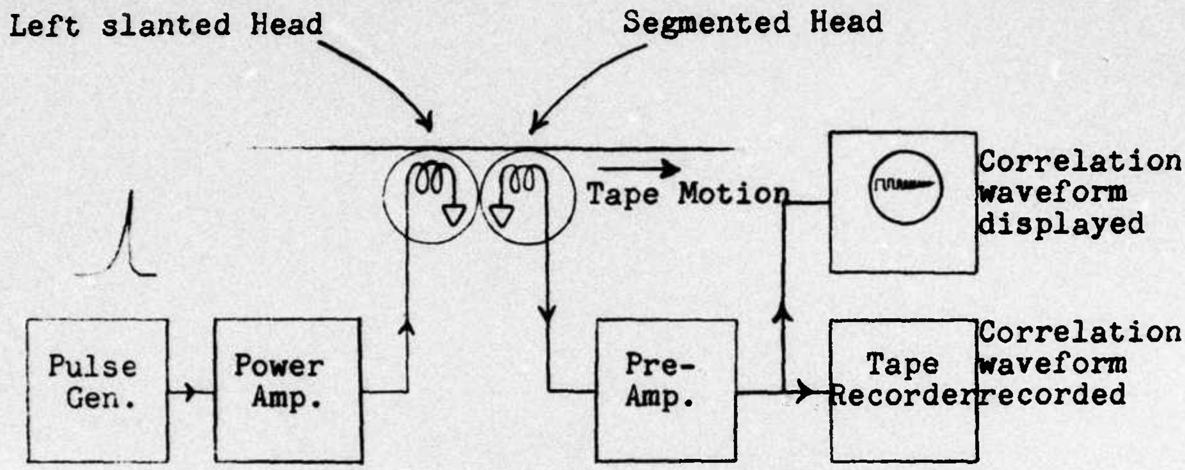
As detection devices, the cross-correlator and matched filter are mathematically equivalent for any given sonar pulse. However, probability of detection of a given target can be improved by selecting the type of pulse which is used in the system. In our particular case, we wish to provide maximum range discrimination, and we therefore choose a pulse form which has maximum bandwidth. We also wish to obtain maximum range and must therefore select a pulse of as large a duration as possible in order to contain, in the total pulse, as much total energy as possible.

A pulse which has both long duration and broad bandwidth is not easily matched with a filter; however, such a pulse would provide maximum range and sharpest definition. Swept frequency or "chirp" radars have used dispersive filters for detectors. Such filters are time-delay networks in which the delay time is a function of frequency. Dispersive networks for sonar purposes would be prohibitively large and unnecessarily complex. Consequently, effort has been directed toward finding some means of using the large time delays possible with magnetic recording methods to produce a dispersive time delay which would be usable in sonar signal processing. It appeared that such a dispersive time delay might be achieved using a magnetic head in which the gap is segmented into lengths varying according to variation in frequency with time. For each segment, sensitivity to frequencies related to its length occurs when the head is inclined with respect to magnetic information recorded on the tape. To provide the effect of sweeping the recorded information past each of the different-length head segments in turn, either the segmented read head or the write head may be inclined.

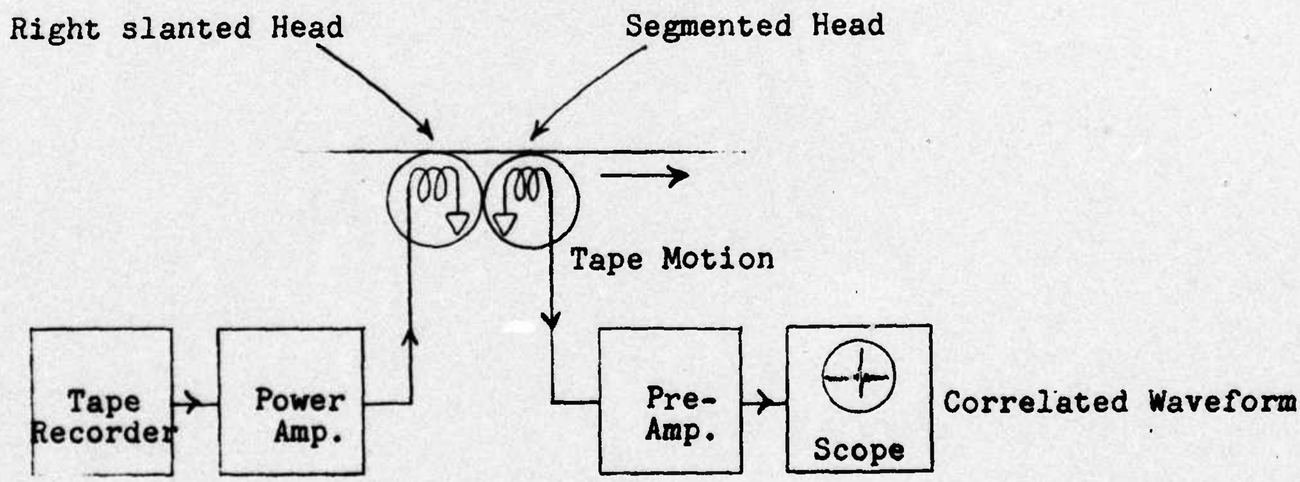
To confirm the validity of this idea, a head has been purchased, made up of groups of laminations of a magnetic material alternated with groups of a non-magnetic material. Two heads with continuous gaps also have been obtained to provide write heads. These have been put together into a system in which very short pulses are expanded to obtain a wave shape for correlation. The expanded pulses are recorded on a tape recorder, and then played back into the correlator to obtain the $\frac{\text{Sin } x}{x}$ characteristic pulse of a cross correlator. Figure 1 is a block diagram of the system used to perform the validity tests.

A sonar system would use TASC in conjunction with a paper recorder such as a TRR or ASPECT recorder, but would obtain an effective short pulse from the longer pulse of the sonar, modulated with the correlation wave form and correlated within the TASC. Figure 2 is a simplified block diagram of such a system. In Figure 2, the sonar is modified to key the TASC wave form generator instead of the standard oscillator. A modulator and amplifier bring the signal up to the level required for beam forming, at which point the signal goes back into the standard sonar circuitry. In standard circuits, the beam is formed, amplified, and projected.

Echos are received by the hydrophones, are given low level amplification, and are formed into beams. The signal is then taken out of the sonar receiver and injected into TASC which



1(a) Obtaining correlation waveform from sharp pulse using TASC

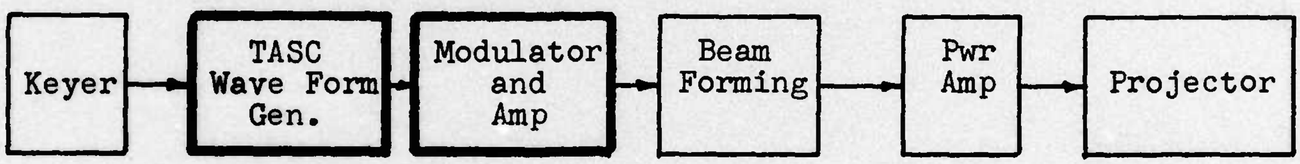


1(b) Obtaining compressed pulse from correlation waveform

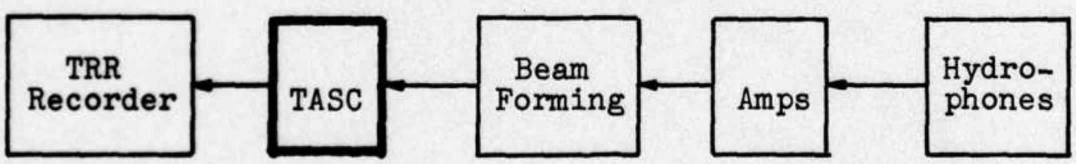
Figure 1. Block Diagram for Validity Tests

performs the correlation, replacing the detector. A TRR or ASPECT recorder is then used to display lines from successive pings adjacent to each other to allow an operator to make a visual ping-to-ping comparison.

The pulse power of the sonar will thus be increased by the ratio of length of the long TASC pulse to the short ASPECT pulse. Classification range will thus be correspondingly increased.



2(a) Sonar Transmitter transmits the TASC waveform.



2(b) Sonar Receiver uses the TASC in place of the ordinary detector.

Figure 2. Sonar Adapted to TASC

2.0 ACCOMPLISHMENTS TO DATE

2.1 TESTS PERFORMED

As a first step in the test program, a segmented head and two continuous gap heads have been ordered from Idaho-Maryland Industries of Burbank. These were received during the first week of August and mounted on an Ampex type 300 tape deck in place of the regular heads. Test runs have been made by using 1-in. bulk-erased tape pulled past the three heads. Signals are written onto the tape by means of one of the continuous heads and read out on the segmented head. Each time, the tape is bulk erased before being used over. A picture of the experimental setup is shown in Figure 3.

Initial efforts have been to produce the expanded pulse by writing a sharp spike onto the tape using a continuous gap head inclined to 45 deg. This was unsuccessful, however, and it has been necessary to reduce the inclination angle to 30 deg. to reduce the tape speed to 7.5 in./sec and to undertake a rather extensive quieting exercise. August 23, we were able to obtain pictures of the expanded pulse as shown in Figure 4. These pulses have been recorded on a continuous loop tape recorder, played back, and re-recorded by means of the second continuous gap head inclined to an equal but opposite angle of -30 deg. The output pulse obtained is shown in Figure 5. An answer has been provided to the first question whether or not the system would in fact compress pulses.

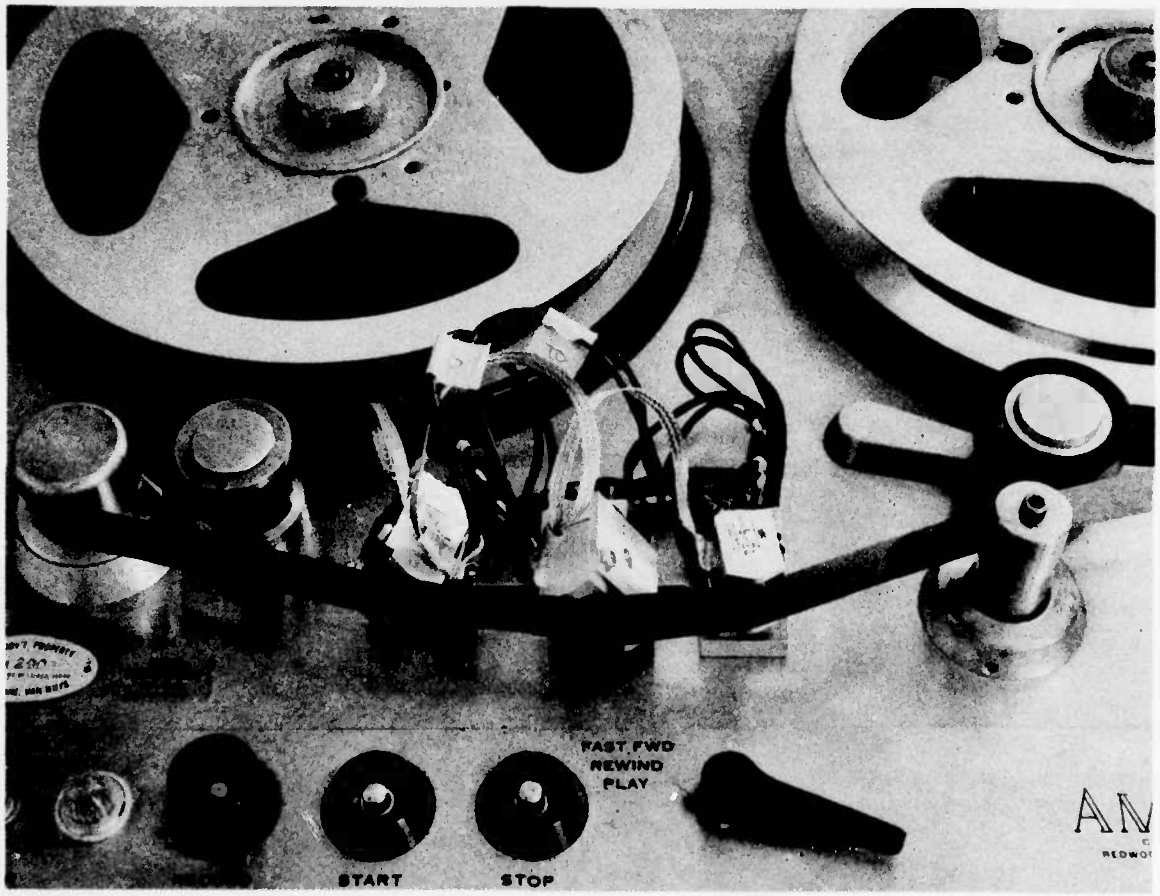


Figure 3. Experimental Setup

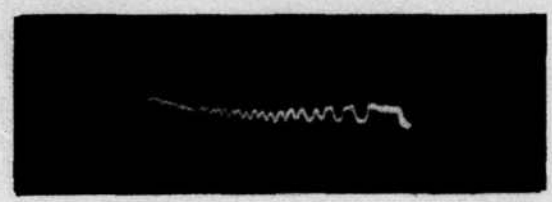


Figure 4. Response of Correlating Head to a Single Sharp Pulse (recorded at an Angle of 30 degree to the direction of tape motion)

Figure 5. Correlation Obtained from the Correlator Head from Waveform of Figure 4 (recorded by slanted head)

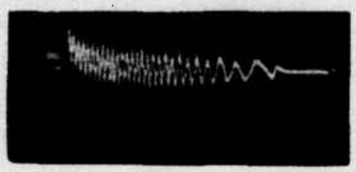


Figure 6. Electronically Generated Correlating Waveform

Figure 7. Response of Correlator to Electronically Generated Waveform

Next, attention was directed toward determining the minimum pulse separation which could be resolved by the system. For this exercise, expanded pulses were recorded on one track of a two-track loop-tape recorder. With only a very slight change in pulse rate, pulses were also recorded on the second track of the two-track loop-tape recorder. The loop-tape recorder was then used as a signal source by linearly adding the signal from the two-tracks and using this combined signal as the source for the pulse compressor. As observed on the oscilloscope, the compressed pulses were seen to pass through each other with no apparent interference. From this the conclusion was reached that interference did not occur between pulses which were separated from each other by as little as 1 msec. Since the source pulses were approximately 33 msec long, an overlap of at least 32 msec was shown to produce no mutual interference. Thus, it appears that resolution in a system using TASC will exceed 1 msec or 2-1/2 feet of range. Motion pictures of the oscilloscope display were taken as a means of illustrating the minimum resolution capability of the system.

As an alternate method of generating a signal, a voltage controlled oscillator was driven with a pulsed ramp function. This provided a signal which could be recognized by the correlator, but which itself did not have the complete characteristic of the self-generated signal. The advantages of such a flexible signal source at the present seem to outweigh the principal disadvantage of a slight mismatch of wave form. Figure 6 is an oscillogram of the electronically generated wave shape. How well it correlates with the head pattern is shown by the output of the correlating head recorded in Figure 7.

Curves of signal response vs head inclination were taken by first of all generating a whole series of expanded pulses and recording them on an auxiliary tape recorder. The expanded pulses were then played back and the inclination of the write head changed while the output of the head was recorded. The results of this measurement are shown in Figure 8.

2.2 TEST PROGRAM

The test program as originally envisioned included

a) Validity tests

b) Pulse interference tests

c) Alternate methods of signal generation

d) Doppler tests

e) Compatibility tests

f) At-sea demonstration.

The validity tests at the beginning of the program were to prove that the concept would in fact work when translated into hardware. They consisted of recording a pulse at an inclined angle on a 1-in. tape and obtaining the swept frequency output from the read head. This was followed by re-recording the swept frequency pulse on the tape at the opposite inclination and observing the compressed pulse output from the read head.

Pulse interference tests have been to determine the minimum separation attainable between pulses before they began to interfere. Theoretically in a linear medium, interference should

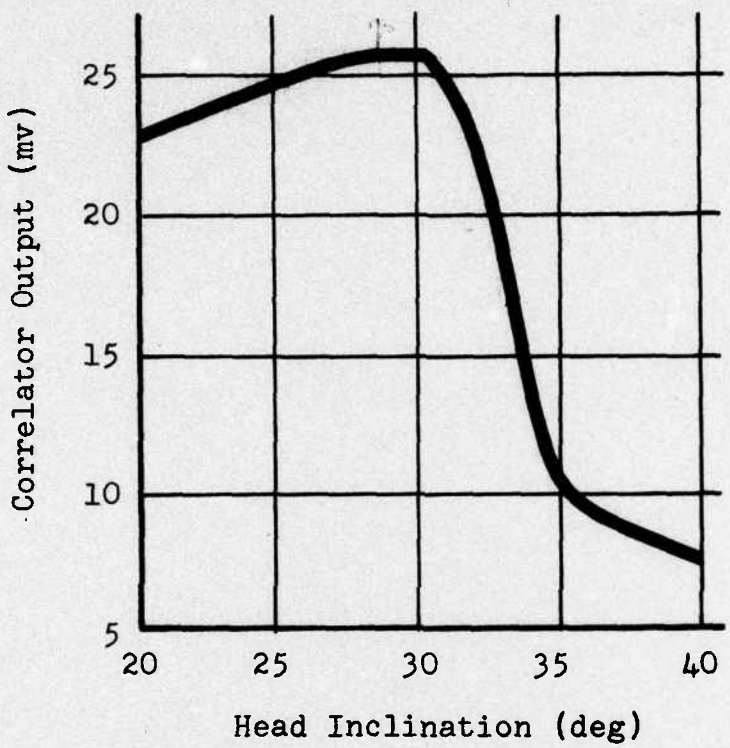


Figure 8. Variation of Response of Correlator with Inclination Angle of Record Head

not be observed between adjacent pulses even with the pulses overlapping. This has been found to be the case and pulses of less than 1-msec separation in time are clearly distinguishable (i.e. pulses overlapping by 32 msec).

Alternate methods have been considered. In order to provide flexibility in pulse generation, a swept-frequency signal source was sought. For test purposes, a pulsed, ramp function is used to drive a standard voltage controlled FM telemetering oscillator to provide the swept frequency signal. This has worked very successfully.

The best method of handling doppler signals is to be studied, implemented and tested. Some ideas for consideration include dual heads with a combination up and down sweep in frequency; combinations of angles of inclination to produce a sum-and-difference signal processing of up-doppler and down-doppler signals; and alternating types of pulses transmitted, tailoring of one of the pulses to the doppler problem. This represents one of the problems still to be resolved.

To be useful, the TASC must be compatible with the frequency, pulse-length and band-width requirements of the sonars currently in use. Compatibility tests thus require a study of the restrictions which sonars place on system operation followed by tests of a TASC system constrained to these requirements. This study is just starting.

Final operational proof of the TASC is to be an at-sea demonstration of TASC used in an A-B comparison test with the standard sonar detector circuits. For this purpose a sea-going breadboard is to be built up which can be plugged into an operating sonar to substitute for its normal detection circuits. If possible, it will be arranged so that a single switch can perform the changeover. Runs will be made under test conditions simulating actual user conditions in so far as possible. Planning and scheduling for these tests is currently underway.

2.3 HARDWARE CONSTRUCTED

During the program, certain pieces of hardware have been built up to implement the tests. These include:

a) Transistorized preamplifier (Figure 9)

b) Transistorized power amplifier (Figure 10)

c) Electronic keyer and swept-frequency oscillator circuit (Figure 11)

d) Adjustable-angle tape head mountings (Figure 12)

2.4 SYSTEM ANALYSIS

A cross correlator must perform the mathematical operation:

$$E(\tau) = \int_{-\frac{T}{2}}^{+\frac{T}{2}} f(t)\, g(t+\tau)\, d\tau$$

which mathematically states that the correlator takes the expected wave form f(t) and multiplies it point-by-point with the actual received wave form $g(t+\tau)$, and then integrates the products to obtain the correlation function $E(\tau)$.

An analog type of cross correlator performs this process of multiplication and integration continuously so that output of

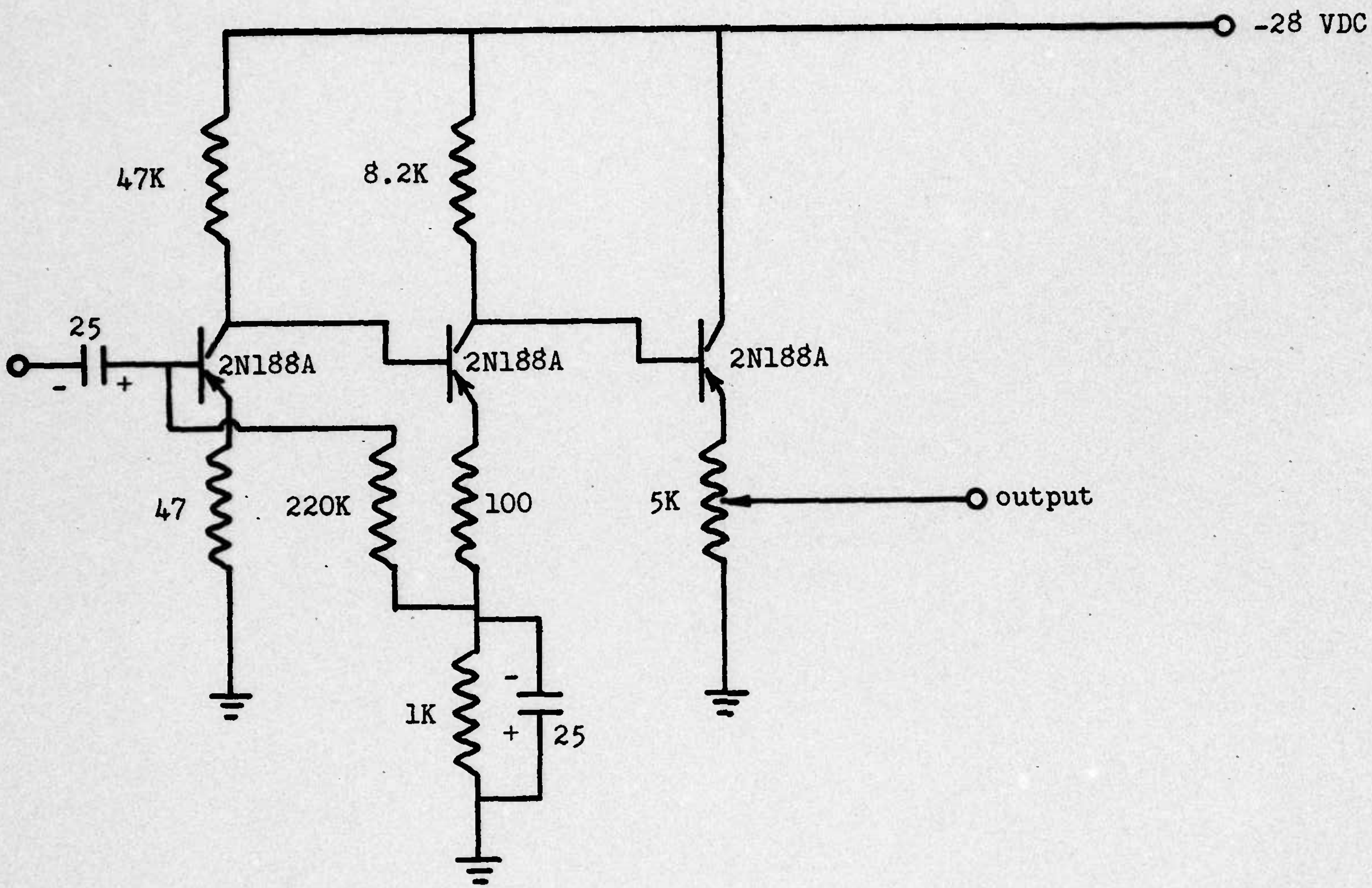


Figure 9. Transistorized Read Head Preamplifier

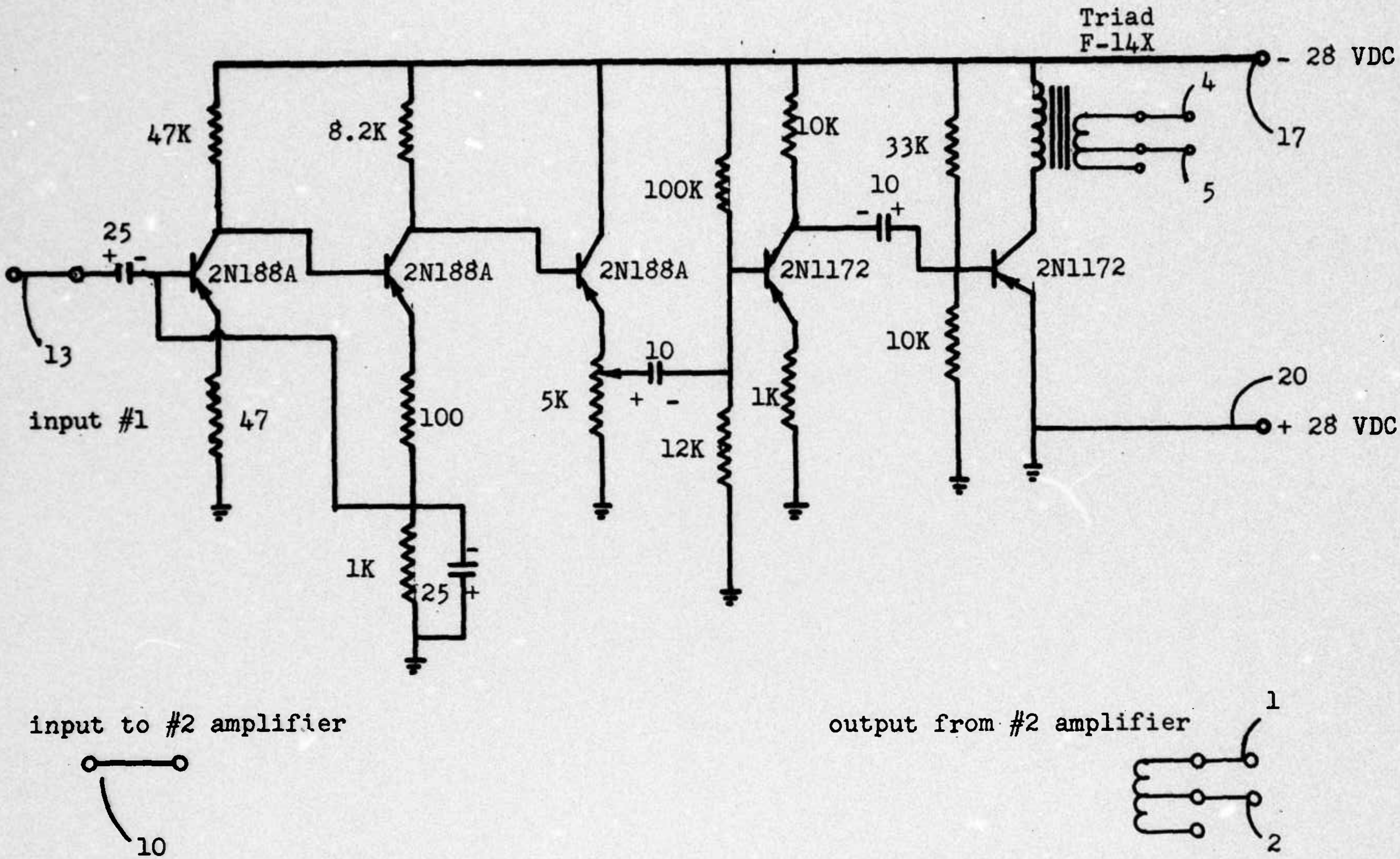


Figure 10. Transistorized Power Amplifier (tape head recorder)

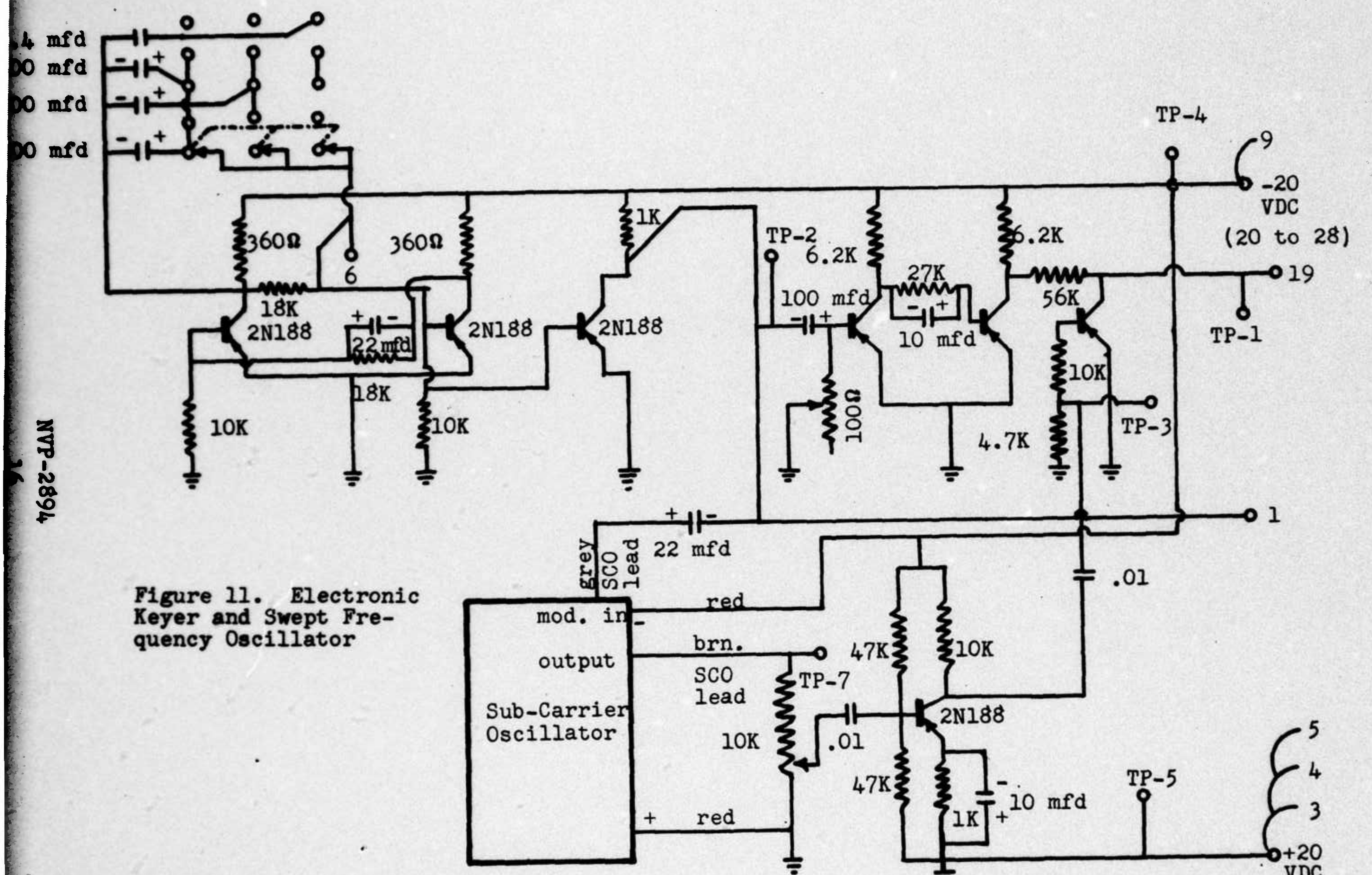


Figure 11. Electronic Keyer and Swept Frequency Oscillator

All transistors 2N188 or 2N1172
All resistors 1/2 w 5 or 10%
All capacitors mmfd. unless noted otherwise

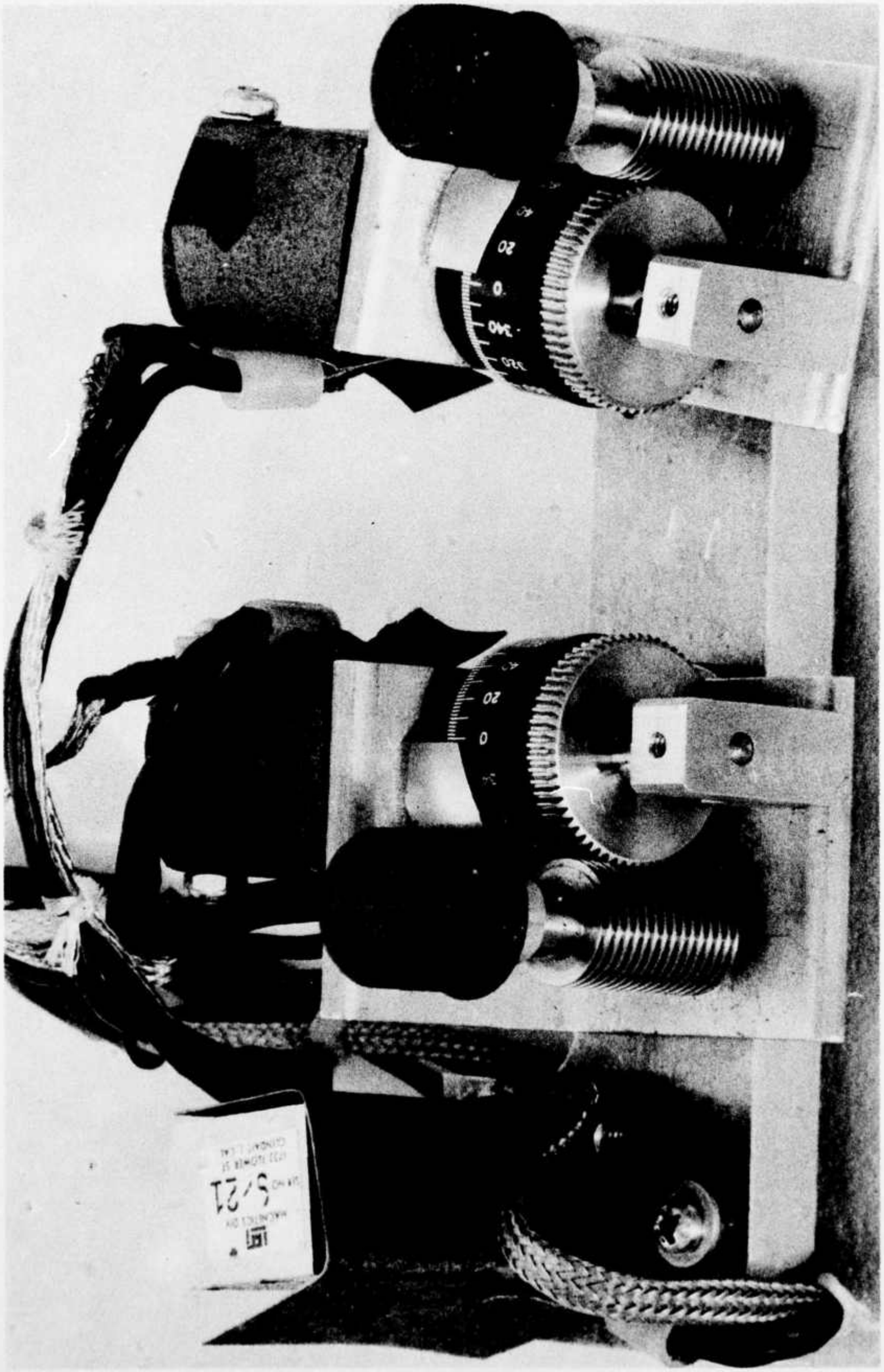


Figure 12. Adjustable Angle Tape Head Mounts

the correlator at any instant is the value of the correlation function for that instant of time (τ).

Both experimental and analytical studies of the segmented tape head as an analog correlator are being made. In the TASC, the principal requirement on the record function is that the system be linear with amplitude and independent of frequency so that the process of multiplication is linear. However, studies by Rudnick* and others indicate that only about 1 to 2 db of signal-to-noise ratio is lost by the use of amplitude limited signals. At present, a linear system is to be used.

From Magnetic Recording Techniques by Stewart, we have the relation between the output of a playback head and its gap length including the effect of head inductance as:

$$\text{db output} = 20 \log \sin \frac{\pi \ell}{\lambda},$$

where ℓ = gap length λ = recorded wave length. Also from the same reference, we have the effect of skew between the recorded information and the read head given as

$$\text{db output} = 30 \log \frac{\sin \phi}{\phi},$$

where

$$\phi = \frac{W \tan \alpha}{\lambda}$$

W = gap width

α = angle of skew

λ as defined above.

Both of the above effects are present in the TASC where the frequency and gap width vary, the one with time and the second with position on the tape.

*Phillip Rudnick, "Small Signal Detection in the Dimus Array," JASA, 32, No. 7, July, 1960.

For TASC

$$\text{db output} = 20 \log \sin \frac{\pi l}{\lambda} + 30 \log \frac{\sin \phi}{\phi}.$$

Assuming a gap length of 0.00025 in., and a tape speed of 7.5 in./sec, the relative output may be calculated.

Figure 13 is a plot of the relative output of the read head vs frequency for signals recorded on the tape with record and readout gaps parallel and with a tape speed of 7.5 in./sec. This is a standard curve descriptive of normal tape recorders of comparable gap width, showing the output increasing with frequency until the recorded wave length approaches the size of the head gap. A null occurs at approximately 30,000 cps where the gap equals a wave length. Additional nulls are found at frequencies where the gap length equals some higher multiple of a wave length.

Figure 14 shows the effect on output of inclining the record head with respect to the read head. This is plotted relative to the dimensionless parameter $\frac{W \tan \alpha}{\lambda}$. From this figure, it is apparent that increasing inclination rapidly reduces the output which can be obtained from a head. However, it must be remembered that our purpose is not to obtain maximum output from the head, but to obtain maximum discrimination between the desired signal and all unwanted signals.

The output of the head as a function of frequency is then the product of the two response factors; that due to head gap size and that due to inclination of either the read or the write head. Again, considering TASC as a system using a filter matched to a particular waveshape, one method of obtaining the desired wave

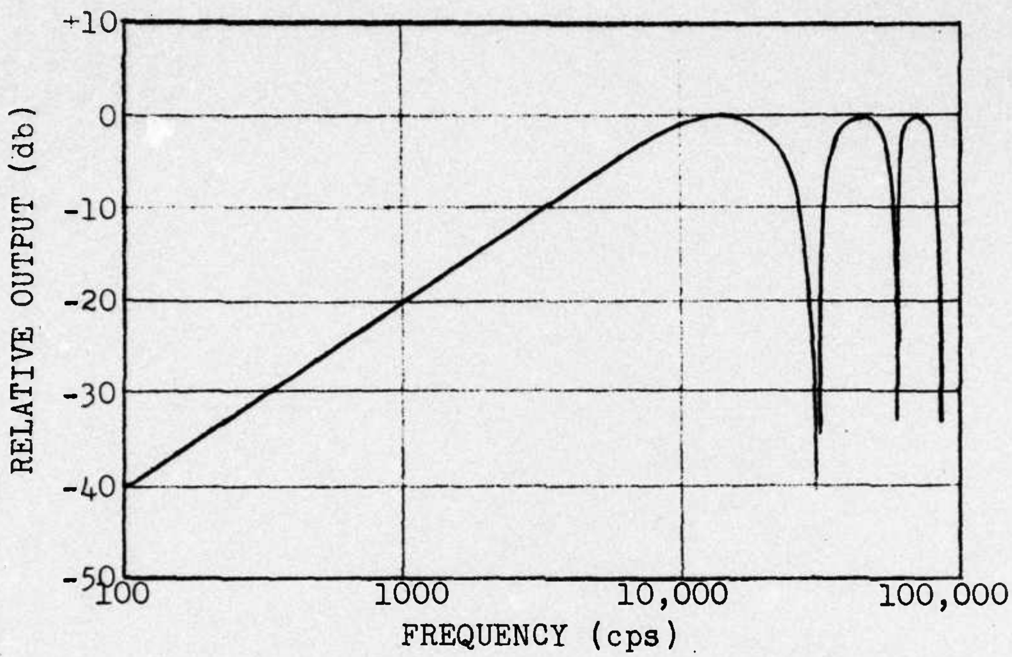


Figure 13. Tape Head Response at 7.5 ips

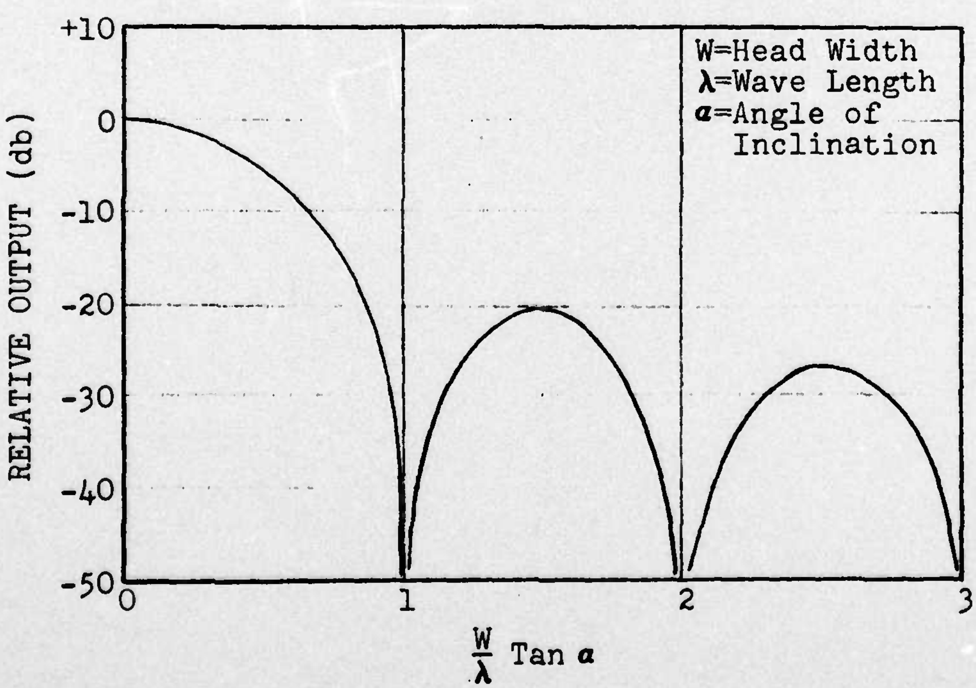


Figure 14. Tape Head Response Vs Parameter $\frac{W}{\lambda}$ Tan α

shape is to use the filter as the wave generator. This is accomplished by playing the desired output pulse back through the filter and accepting that which comes out. In the case of TASC, this is accomplished by recording a sharp spike of energy onto the tape using a record head of the opposite inclination to that used in the recovery process. This method of generating the desired wave form may be used as the definition of the signal which matches the filter.

Thus if W is the width of the segment crossed by a sharp spike of energy recorded at an angle of inclination of $\alpha°$, also assuming gap length ℓ negligible with respect to all other quantities, then the wave length λ is given by:

$$\lambda = 2W \tan \alpha ,$$

from which $\frac{W \tan \alpha}{\lambda} = \frac{1}{2}$, the significant point on Figure 14.

Maximum response to the swept-frequency wave then occurs when frequency, segment width, and gap are all matched. A source for a segmented head with a variable gap width is to be sought and comparative signal/noise measurements are to be made to establish whether or not such a refinement is practical.

Effort to reduce the expression for the transfer function of the tape recorder to the form of the cross correlator is continuing as time is available.

3.0 INTERIM CONCLUSIONS

Work to date has included successfully compressing a 33-msec pulse into less than one millisecond by using a bandwidth of approximately 1600 cycles. Correlation is unaffected by the presence of other pulses, even when they overlap. The correlation shows a distinct output for each such pulse. Correlation is somewhat affected by noise. Noise spikes occasionally appear on the output indicating occasional groups of noise frequencies which have a rather high correlation with the segmented head.

From these effects observed to date, TASC should be able to provide short pulse capability to long range sonars, permitting the use of ASPECT with 30- to 50-msec pulses and thus correspondingly longer ranges. Similarly, TASC may be applied to acoustic depth sounders to provide deep operation with lower peak powers and less complicated equipment. It is possible that TASC may even allow subbottom penetration and strata recording with electronically generated signals instead of, as is currently done, with the boomer, gas exploders, spark gaps, or explosive charges.

System applications may thus include

1) Equivalent short pulse operation with longer pulses for
   a) Increased range ASPECT
   b) Better range discrimination of target in reverberatory backgrounds

c) Possible better classification of targets because of characteristics not previously noted with longer pulse sonars

d) Possible different applications of existing sonars not previously possible because of the longer pulses

2) Greater range and better range definition for acoustic depth sounders

3) Application of acoustic depth sounders to fields previously restricted to higher power sources.

4.0 CONTINUING PROGRAM

The continuing program includes the construction of equipment which demonstrate, for the benefit of the Navy and others, the advantages of a simplified pulse compressor in sonars and other acoustic devices. The program also includes a more exact mathematical analysis of operation of the TASC, and it is to include efforts to simplify, miniaturize, and in other ways improve the hardware implementation of TASC. As currently planned these are:

1) Continued development of a seagoing breadboard.

2) Comparative tests of TASC used with a conventional sonar aboard a Naval ship for comparison.

3) Continued mathematical analysis.

4) System improvement program incorporating ideas for simplifying, miniaturizing, and reducing the costs of future systems.

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