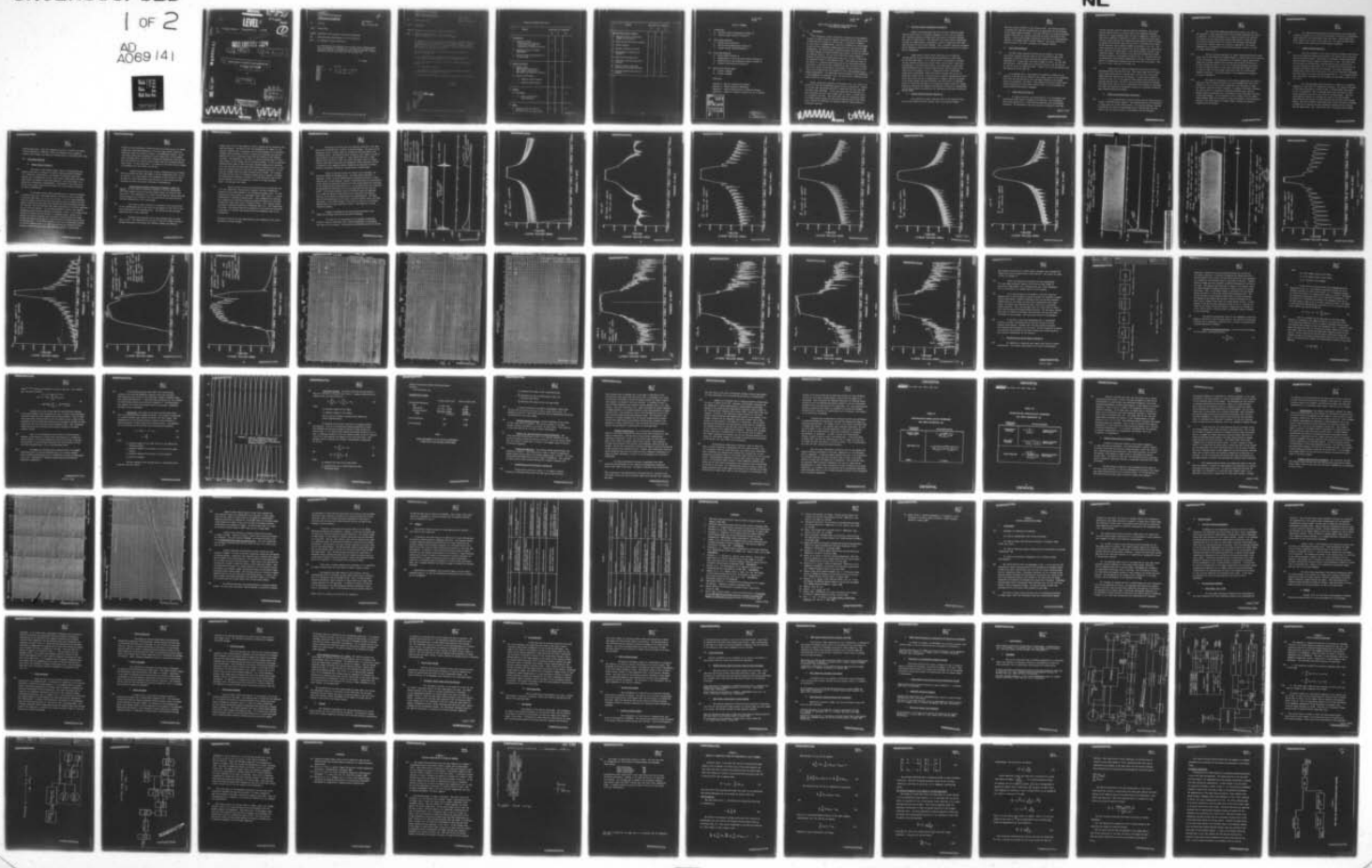
AD-A069 141 TEXAS UNIV AT AUSTIN DEFENSE RESEARCH LAB F/G 17/1
SIGNAL DESIGN AND COMPUTER AIDED DETECTION FOR THE AN/SQS-26 VA--ETC(U)
MAY 69 K W HARVEL

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1 OF 2

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(12) 102 p.

(11) 21 May 69

(6) SIGNAL DESIGN AND COMPUTER AIDED DETECTION FOR THE AN/SQS-26 VARIANT,

by

(10) K. W. Harvel

DDC
RECEIVED
MAY 30 1979
D

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107 500 Lm

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

00V1D:GCM:pb
Ser 74
DATE: 21 March 1969

TO : PMS 387

FROM : SHIPS 00V1D

SUBJECT: AN/SQS-26 Variant Program; Information Concerning

REF : SHIPS 00V1 Memo 00V1D:GCM:pb Ser 56 dtd 10 Mar 69

ENCL : (1) AN/SQS-26 Variant 00V1B Chart

1. Enclosure (1) was developed from a cursory look at 00V1B programs and is in response to reference (a). The list will be modified as required as dialogue is developed between 00V1B and PMS 387. Further, some inputs such as reliability are not available yet.

G.C. MOORE

Copy to:
00V1D
00V1C
00V1E
00V1H
00V1G
00V1J
00V1S
00VS

00V1C3
DO YOU WANT TO SET UP A FILE FOR THIS ?



5010-106

Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

MAY 1952 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

00V1D:GCM:pb
Ser 96
DATE: 23 April 1969

TO : Distribution List

FROM : SHIPS 00V1D

SUBJECT: AN/SQS-26 Variant Program; Information Needed for

REF : (a) Memo C0V1D:CCM:pb Ser 74 dtd 21 Mar 69
(b) Memo 0CV1D:GCM:pb Ser 83 dtd 3 Apr 69 (NOTAL)

1. References (a) and (b) provided information to PMS-387 with respect to 00V1E Projects of potential interest to subject program. Informal communications with PMS 387 have determined that all projects listed in references (a) and (b) are of interest. However, only alternatives (1) and (2) are pertinent at this time.

2. It is requested that the following be provided in support of references (a) and (b):

a. A brief summary of the Project, relating what is to be accomplished and why the AN/SQS-26 will be the better for it.

b. When the above could be completed if needed resources were available.

c. Some major milestones.

d. Increase in funding level, if any, that might be required to reorient effort to subject requirements.

3. It is requested that above information be provided by 15 May 1969.

G. MOORE

Distribution List:
SHIPS 00V1C
00V1E
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PMS 387
00V1D
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00VS



Buy U.S. Savings Bonds Regularly on the Payroll Savings Plan

AN-SQS-26 VARIANT OOV1B CHART

SUBJECT	APPLICABLE TO ALTERNATES #1	#2	#3
1. Transducers			
a. Parametric study: to determine all important trade-off's pertinent to broadening of frequency spectrum.	X		
b. Nearfield array for IN-SITU MEASUREMENT	X	X	X
c. Optimum design and specification for new design			X
2. Signal Processing			
a. Signal design: Recommendations relative to type signals needed for a particular environmental situation.	X		
b. Computer Utilization:		X	
1. Computer driven displays			
2. Computer aided detection			
3. Support			
a. USS GLOVER	X	X	X
1. Mutual interference investigations			
4. Domes			
a. Recommend areas for study to minimize draft and drag of dome	X	X	X

SUBJECT	APPLICABLE TO ALTERNATES		
	#1	#2	#3
5. Systems Effectiveness Support			
a. Technical manual specification (DATOM) and assistance	X	X	X
b. Human factors maintenance analysis	X	X	
c. Safety analysis	X	X	X
d. Central supervisor's station		X	X
e. Re-packaging of displays and consoles		X	
f. Human factors program plan			X
g. Operability and maintainability analysis			X
h. Display concepts from OOV1G exploratory development program			X
i. Training analysis and operators' handbook	X	X	X

21 May 1969
KWH:jm

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   A. Own Ship's Motion Compensation (Variant 2)
   B. Passive Torpedo Detection (Variant 1)

II. Short Range Subsystem
   A. Signal Design (Variant 1)
   B. ODT Receiver Normalization (Variant 2)
   C. Digital Display Storage (Variant 1)

III. Long Range Subsystem
   A. Signal Design (Variant 1)
   B. Normalization of the cw Receiver Channel (Variant 1)
   C. Normalization of the FM Receiver Channel (Variant 2)
   D. Computer Aided Detection (Variant 2)

IV. Modification Summary Chart
   A. Variant 1 Summary
   B. Variant 2 Summary

References

Appendix A: Baseline Classification System
Appendix B: Digital Quadrature Beamformer
Appendix C: Computer Normalization in Range and Bearing
Appendix D: Design of a Digital Processor for the cw Channel

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21 May 1969
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B-1-

SIGNAL DESIGN AND COMPUTER AIDED DETECTION FOR
THE AN/SQS-26 VARIANT (U)

I. Introduction

(U) This memorandum outlines the portion of Exploratory Development's research in signal design and computer aided detection and display which is applicable for inclusion in the Variant 1 and Variant 2 programs. Mr. Bob Courts of UNITECH and Mr. Jerry Dow of TRACOR have written major sections of this memorandum, summarizing work which has been previously accomplished. Mr. Kermit Harvel of Applied Research Laboratories (ARL) has added comments concerning the ODT search system, and ARL has combined the separate sections. Mr. Pat Pitt of ARL has recently prepared a Baseline Classification System outline which was, in part, written with the AN/SQS-26 Variant 1 requirements in mind. This baseline outline is the result of a committee representing most of the exploratory development effort in ASW active sonar classification over the last five years; many of the system considerations which appear in the discussion of the short range subsystem also are discussed in this outline, ~~which is included as Appendix A.~~ Two additional subjects related to the performance of the AN/SQS-26 are mentioned first: own ship's motion compensation and passive detection of torpedoes.

(C) Mutual interference reduction is discussed in Sec. III, where it is pointed out that the transmission signals should be bandlimited. However, it is clear that additional bandwidth is needed for both the long range and short range subsystems. In the long range modes the addition of a lower frequency band will allow another ship to search in bottom bounce or convergence zone mode. With a new dome, which is necessarily a part of a PADLOC passive system, the ODT search frequency may be moved above 5 kHz, leaving the additional low frequency band for bottom bounce or convergence zone use.

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A. Own Ship's Motion Compensation (Variant 2)

Target track history has been one of the most important target classification clues, as discussed in Appendix A, and it can be expected that increased accuracy in target track will result in increased accuracy and speed in classification. The accuracy of own ship's motion compensation required for classification is generally an order of magnitude better than that specified for fire control systems. Also, cw Doppler detection processors can be expected to perform more reliably with increased accuracy of own ship's motion compensation.

(U) Large errors in ship's motion along the line of sound are incurred when pit log and relative bearing information are used alone. It has been shown (Refs. 1, 2, 3, and 4) that it is necessary to include pit log, relative bearing, roll, pitch, ship's course (yaw), a three axis accelerometer, wind speed and direction, and rudder angle to reduce the expected maximum errors in ship's motion along the line-of-sound to less than ±2 kt in sea states of 3 to 4. Compensation using a stabilized single axis accelerometer, stabilized relative bearing, and pit log information is shown in Ref. 4 to allow errors in motion compensation of ±4 kt. While these errors may not be significant to a Doppler detection processor or the weapon system, the errors severely limit the ability to establish track of a slowly moving target or to measure the Doppler shift of a target. Reference 2 describes the computer load required to perform the computations for own ship's motion correction for the PAIR system, which may be used as a Variant model.

(C) B. Passive Torpedo Detection (Variant 1)

It is possible to detect passively many of the torpedoes which may be fired toward an escort; however, there is no passive torpedo

detection display available in the current system. The display provided is designed for long term averaging which is appropriate for the detection of long range submarine targets. To be most effective the torpedo detection display should have an automatic alarm with an output indication of true bearing. A short term averager suitable for this task is a straightforward addition to the DIMUS system currently employed. The output could be an unstored strobe on the Unit 1 displays, or a separate display.

II. Short Range Subsystem

(C) The short range subsystem currently has two displays. The three ping history display shows the output of the 72 detector-averager time processors, and the PPI display presents the output of the scanning beamformer for a single ping. Four pulse lengths are used: 30, 100, 300, and 1000 msec. Both displays can be used for detection, and the PPI can be used for track (in difference mode). Signals can also be presented on the SSI display for track (Unit 3).

(C) It is expected that a large number of nonsubmarine targets will be detected in the ODT mode at relatively short range, along with the submarines which have not been detected by the long range subsystem in the bottom bounce and convergence zone modes. These targets will require rapid classification response and every effort should be made to aid the operator in making submarine/nonsubmarine judgments.

A. Signal Design (Variant 1)

(C) To improve detection and classification, it is recommended that transmission pulse types be changed for the ODT mode. The transmission pulse should perform well in reverberation-dominated and noise-dominated conditions. The bandwidth of the pulse should be increased to cover the

receiver spectrum, and this spectrum should be broadened. The current receiver band of 130 Hz is a severe limit on the bandwidth available. Addition of a higher frequency band (5-8 kHz as suggested in Appendix A) would allow additional flexibility in choice of transmission pulse type. With the current receiver the transmission pulse used for detection should be between 30 and 60 msec long, and should be a linear FM slide of about 130 Hz bandwidth, with a spectrum shaped as described in Sec. III. The input spectrum to the AGC receivers will not be varying with reverberation level, allowing the simple AGC's in the current system to provide a more normalized output. The usefulness of the FM slide transmission without coherent processors is discussed by Fridge in Ref. 5. The gain which can be expected from the broadband transmissions is about 3.5 dB for 30 msec pulses in reverberation (assuming ideal AGC action for both cases). (See Fig. H-1 of Ref. 6 and Fig. J-3 of Ref. 7.)

(C) Target track is readily accomplished with the 30 to 60 msec transmitted pulse with the PPI or SSI. This pulse length does not allow useful range resolution for classification, however, and a short pulse length should be provided for this purpose. A 7 msec pulse, shaped as described in Sec. III, is the shortest signal which can be passed by the existing receiver band. The SSI is the only display capable of handling this short pulse; the PPI could be improved for this purpose by increasing the video scan speed and by expanding a sector for a sum-minus difference mode classification/track display.

B. ODT Receiver Normalization (Variant 2)

(C) It is straightforward to perform useful receiver normalization in a small, dedicated digital computer. The normalization can be accomplished in range alone, as in the current system or in range and bearing. Bearing normalization is useful in eliminating rings of reverberation from the display, and can also be useful in eliminating side-lobe responses.

(C) The current ODT beamforming system can be used as an input to the normalizer. Some characteristics of the existing beamformer may need to be modified: the time constants will no longer be critical and should be slow acting, and the output pulse dynamic range should be large (40 dB). An alternative approach would be to replace the existing ODT beamformer with a serial, digital version as outlined in Appendix B. The digital beamformer has no advantage over the existing version, however, in terms of target detectability.

(C) With the existing beamformer the output scanning multiplexer should select each of the detected and averaged beams at a rate of twice the reciprocal of the pulse length. This information is converted to digital words with a single A/D converter operating at an average rate of about 4.8 kHz for a 30 msec transmission pulse. It will be a software programming convenience to input 72 beams of data at a much higher rate than the average 4.8 kHz, in order to leave the time between input data blocks for uninterrupted computer processing. A brief description of the computational procedure is given in Appendix C.

(U) The computer normalization can be used to simplify AGC the signal by taking the ratio of range resolution cells and outputing these data on the display, or it can be used to mark targets which are localized in range and bearing, and which exceed an operator (or computer) determined threshold. The second choice is a single-ping automatic detection mode, and will greatly reduce the operator load. Any display of this information should be a multi-ping display. If the threshold is set to select only the largest twenty targets (which are localized in range and bearing), a 20-ping history requires a very small amount of storage (range, bearing, and signal-to-background for 400 points).

(U) The computer-aided processing and normalization is excellent for a detection display, but it will also be desirable to maintain an essentially linear system for use during target track and attack. False target cans, ship's wake in the vicinity of the target, etc. can cause the target echo to be masked by the strong returns from adjacent reflectors.

C. Display Storage (Variant 1)

(C) The scan converters in the current system are expensive and are not particularly desirable display drive devices. The dynamic range of the converters is severly limited. The amount of maintenance training required for these particular devices remains an unknown, but is high. The entire tube must be erased at the same time, requiring multiple scan converters for continued viewing of past history. It is recommended that these devices be replaced with digital drives for the displays. The digital information storage may be either core or delay line. Five bits of amplitude information have been shown to be useful for some systems (Ref. 9). A few programs which have used digital information for the displays are described in Refs. 8, 9, 10, and 11.

(C) The existing BB/CZ display provides for storage of six pings of information at the output of twenty-four processors. The display resolution of 875 lines corresponds to 10,000, 20,000, or 30,000 yd/875 lines, about 12, 24, or 36 yd/line. This is somewhat poorer than the nominal 10 msec (8 yd) resolution available at the output of the FM processor. The scan converters over-average, or integrate the output of the FM processor. Some attention must be given to providing this same function in the digital system. The scan converter provides about 875 lines by 144 units of storage. A digital core to provide the same information storage could be a 40-bit 16K word memory (Ref. 11A). Each 40-bit word in the memory would contain

eight display words. Cost of a commercial quality (0 to 50°C) core should be around $.06/bit, or $38,400. Delay line storage or drum storage is several times cheaper, and delay line storage should be considered (Ref. 11B).

III. Long Range Subsystem

A. Signal Design (Variant 1)

(C) The words, "sonar signal design," take on a meaning which may depend on the type of receiver to be used in processing sonar functions, i.e., detection, classification, or tracking, the dominant sonar background, i.e., reverberation or noise, time of day, target aspect and speed, water depth, and number of sonar sets operating in the same locale, i.e., mutual ship interference, considerations. The purpose of this note is to discuss sonar signal design for the variant '26 in the context of some of the above considerations.

(U) If the sonar receiver under consideration is a coherent processor or matched filter and if the sonar function is detection, then we can draw on previous work (Refs. 12, 13, 14, 15, and 16). In all of these referenced works the authors conclude variously that signals with flat spectra are best against reverberation and noise, that signals with large TW products are best for detection, and that FM slides with large TW products are excellent approximations to the best waveform. All of these statements, however, are based on assumptions which have some important consequences. First, it is assumed either tacitly or directly that the receiver is a matched filter. Second, it is assumed that neither bandwidth nor time duration have any effect on target strength and energy splitting--i.e., that the echo is an exact replica of the transmitted pulse. In the first instance it may not be economically possible to construct matched filters, in which case all bets are off when we start choosing, indiscriminatly, large time-bandwidth products. This is true

because in the reverberation limited portion of the echo cycle if we choose longer and longer pulse durations, we can lose signal excess as well as extend the range over which the receiver is reverberation limited. We can lose signal excess when increasing the pulse length fails to give target level increases which, coupled with increased processing gain, keep up with the loss incurred (at a 10 log [pulse length] rate) by increasing reverberation levels. In the second case, it is simply not true that target strength is independent of T and W (Refs. 17 and 18).

(C) Waveform design should also include consideration for the effects that the waveform can have with regard to mutual interference (Refs. 19, 20, 21, and 22). It is the purpose of the remainder of this section to treat the topic of sonar signal design from the point of view of detection with incoherent receivers and mutual interference considerations.

(C) Signal Design for Mutual Interference (Variant 1) (Refs. 23 and 24. In recent mutual interference analyses it has been demonstrated that sonar systems utilizing isolated frequency bands can interfere with each other. This interference is a result of the transient signals generated by the ringing of the filters of the one system due to the high level but off-band transmissions of the other system.

(C) The power in these transients is contained in the receiver band of the offended sonar and is the result of the keying "on" and "off" of the pulse transmitted by the offending sonar. This effect has been analyzed extensively and is well understood.

(C) Although these transients are of short duration they are quite high in level. The consequence of this fact is that even though a detector-averager may grossly over-average the transient signals, the detector-

output level is still high enough to exceed a display marking threshold, and mark the display. The effect of the over-averaging is to "smear out" the original transient into a long pulse such that the duration of the detector-averager output waveform is likely to remain above threshold and mark the display for a time considerably longer than the duration of the original transient. The magnitude of this effect is directly proportional to the RC time constant of the averager and the threshold setting. A rule of thumb for determining the length of time the output waveform remains above threshold is to note how much the peak output value exceeds a threshold in dB; at that point the elapsed time is on the order of the transient duration*. To this time the averager decay time above threshold must be added. The averager will decay at the rate of 8.7 dB/time constant after an impulse is removed. The peak-threshold difference divided by 8.7 gives the decay time for the output waveform to go below threshold in units of RC time constants. Figure 1 illustrates this effect.

(C) Figure 2a shows the power spectral density of a pulsed FM slide. It is well understood, through Fourier analysis, why this transmission produced so much energy outside of the fundemental transmit band. In radio communications this results in a phenomenon called "key click" i.e., mutual interference in different broadcast bands. Radio communication techniques have combatted this problem by shaping the amplitude function of the keyed transmission rather than using a rectangular pulse. Pulse shaping reduces the energy transmitted outside the fundamental band (i.e., post-transmission filtering), thus greatly reducing the amplitude of the transients that would be produced in a receiver band isolated from the fundamental band of the transmission.

*Transient durations are well approximated by the reciprocal of the filter bandwidth for linear systems.

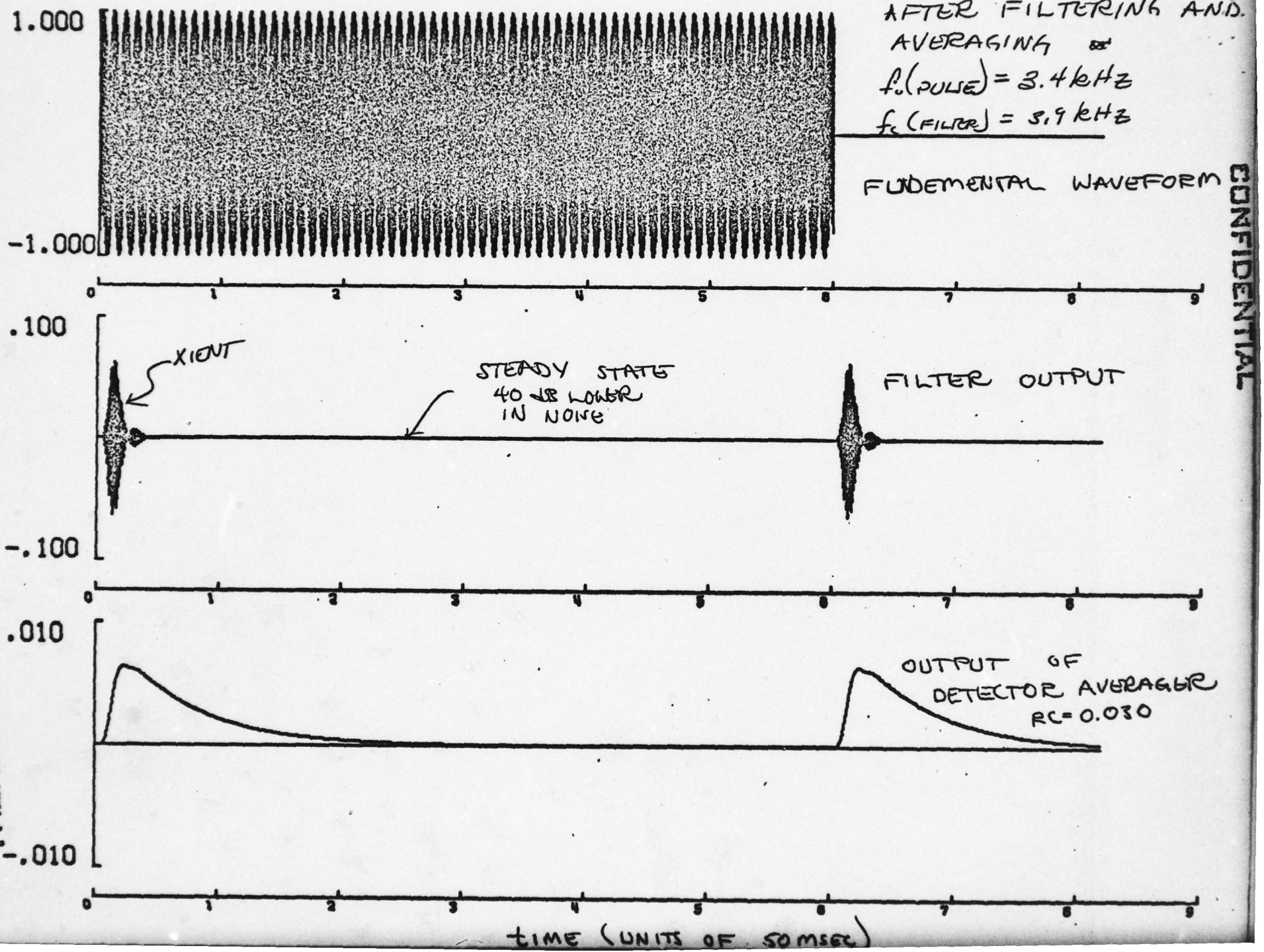
(C) Figures 2b and 2f show the power spectral densities of the same pulse used to generate Fig. 2a after it had been shaped. The nature of the shaping use was to linearly taper the leading and trailing edges of the rectangular pulse. The amount of taper is given on each figure in terms of some fraction of the pulse length T. These figures show that a pulse shaping factor as small as T/20 will reduce the power level in a narrow receiver band 1000 Hz away from the fundamental center frequency by 30 dB. A reduction of this magnitude should ordinarily be sufficient to reduce off-band interference between two isolated sonar receiver bands.

(U) Figures 3a through 3f show the results of an experiment conducted for shaped and unshaped pulses. The shape factor was T/20. A comparison of Fig. 3a and 3b demonstrates the expected reduction in filter transient due to pulse shaping. Another interesting effect is the generation of two additional transients resulting from the abrupt shutoff and beginning of the leading trailing edge tapers (i.e., at the points where the transients are generated the derivatives of the pulse amplitude function does not exist). This second transient could be eliminated easily by smoothing (i.e., make derivative of amplitude function continuous) the shaping function at the shutoff and beginning of the shaping tapers. One might also use some smoothing at turn-on and turn-off to further reduce the first transients. A well-known example of this would be the use of a modified Hanning window as a pulse amplitude function. This approach is being studied at present.

(U) Figures 3c through 3f show the spectral densities of the shaped and unshaped pulses before and after filtering.

(C) For this to be an acceptable fix for reducing interference effects it must be shown that only a nominal degradation in processing the pulse will be incurred. An experiment was performed on the full linear

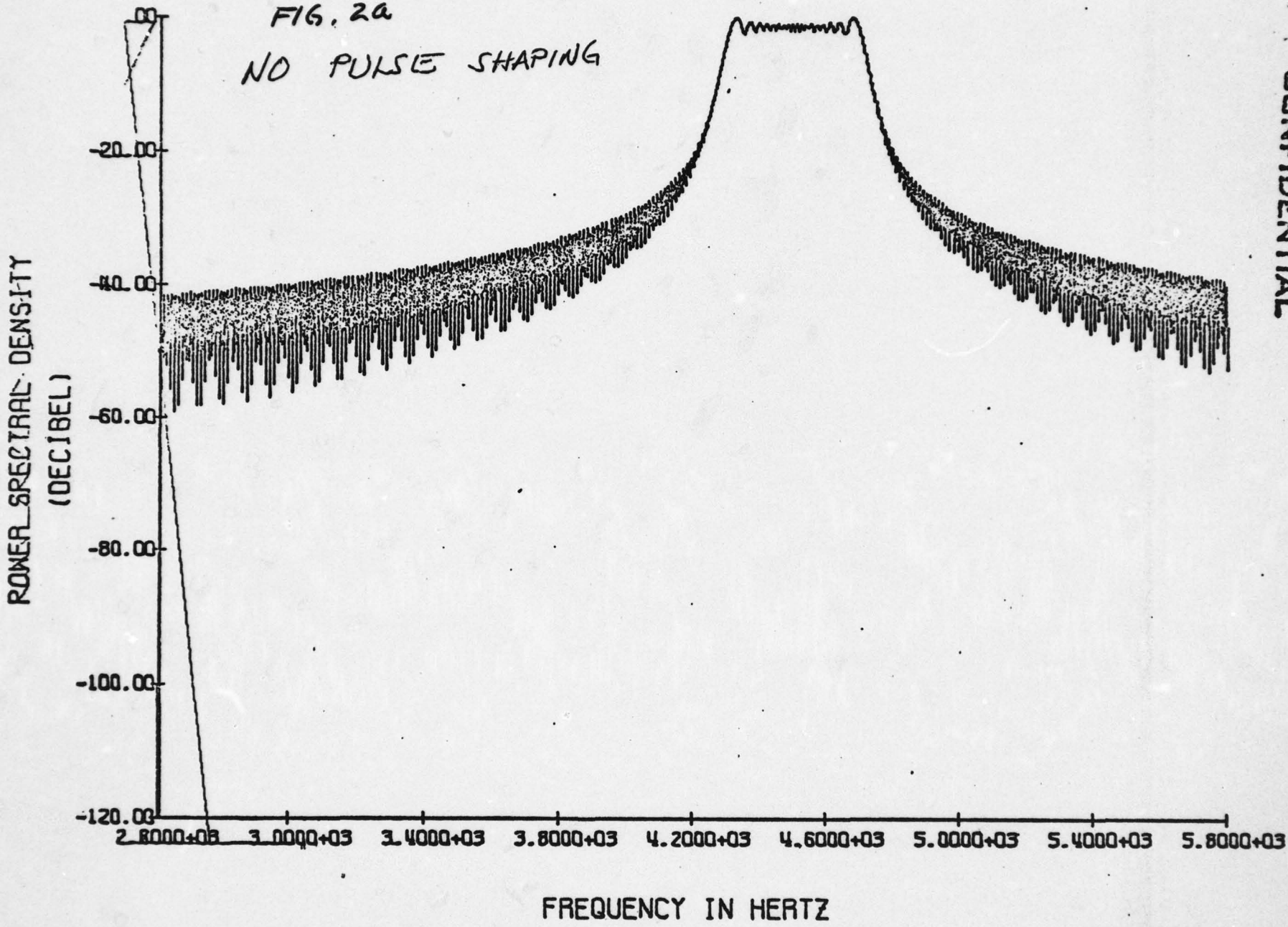
Figure 1


PULSE BEFORE AND AFTER FILTERING AND AVERAGING
f_o (PULSE) = 3.4 kHz
f_c (FILTER) = 5.9 kHz
1.000
-1.000
FUDEMENTAL WAVEFORM
.100
-.100
XIENT
STEADY STATE 40 dB LOWER IN NOISE
FILTER OUTPUT
.010
-.010
OUTPUT OF DETECTOR AVERAGER RC = 0.030
time (UNITS OF 50 MSEC)
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CONFIDENTIAL

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FIG. 2a

NO PULSE SHAPING

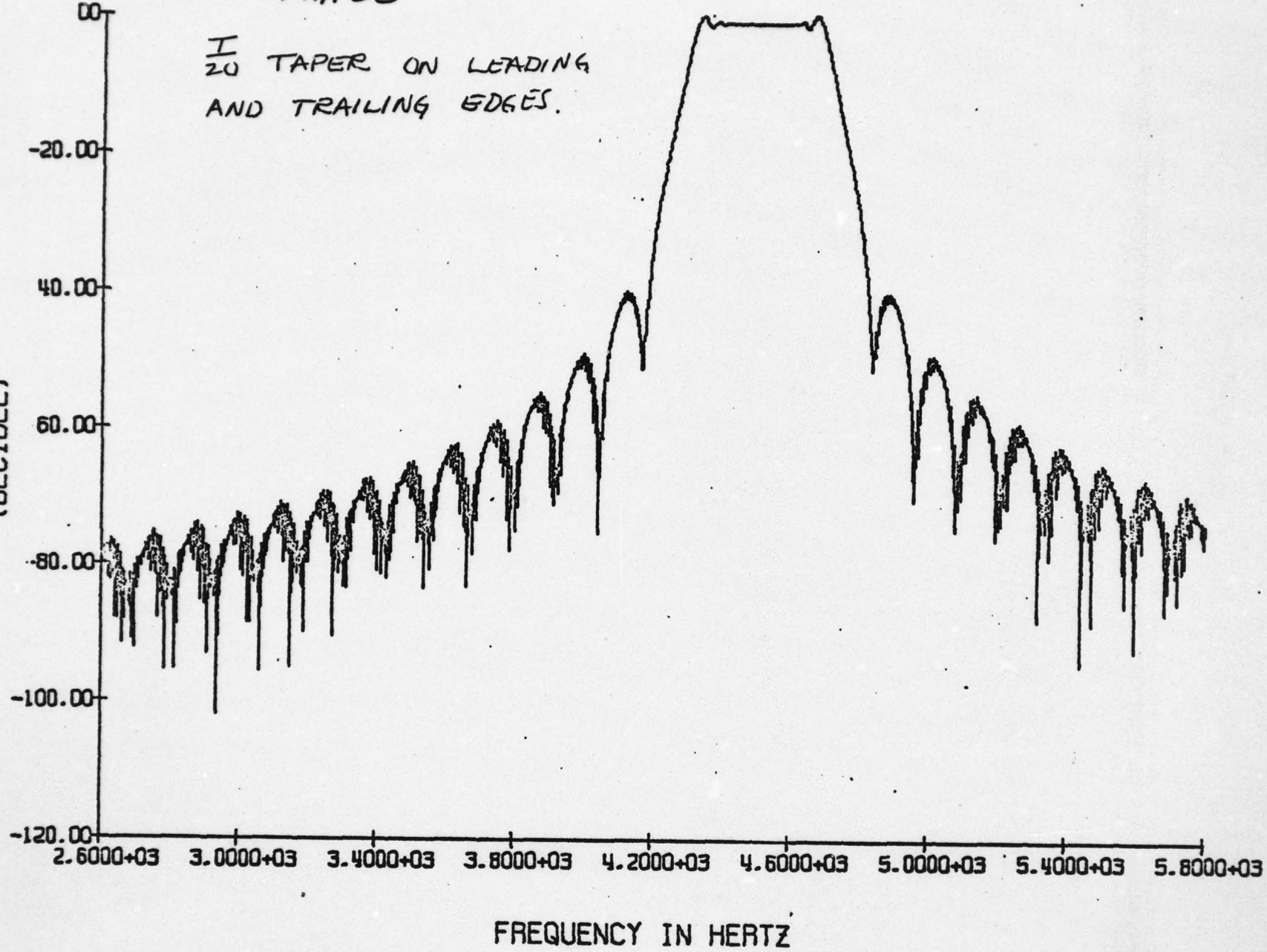


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FIG. 23
1/100 TAPER ON LEADING
AND TRAILING EDGES
.00
-20.00
-40.00
-60.00
-80.00
-100.00
-120.00
2.6000+03
3.0000+03
3.4000+03
3.8000+03
4.2000+03
4.6000+03
5.0000+03
5.4000+03
5.8000+03
POWER SPECTRAL DENSITY
(DECIBEL)
FREQUENCY IN HERTZ

FIG. 2C

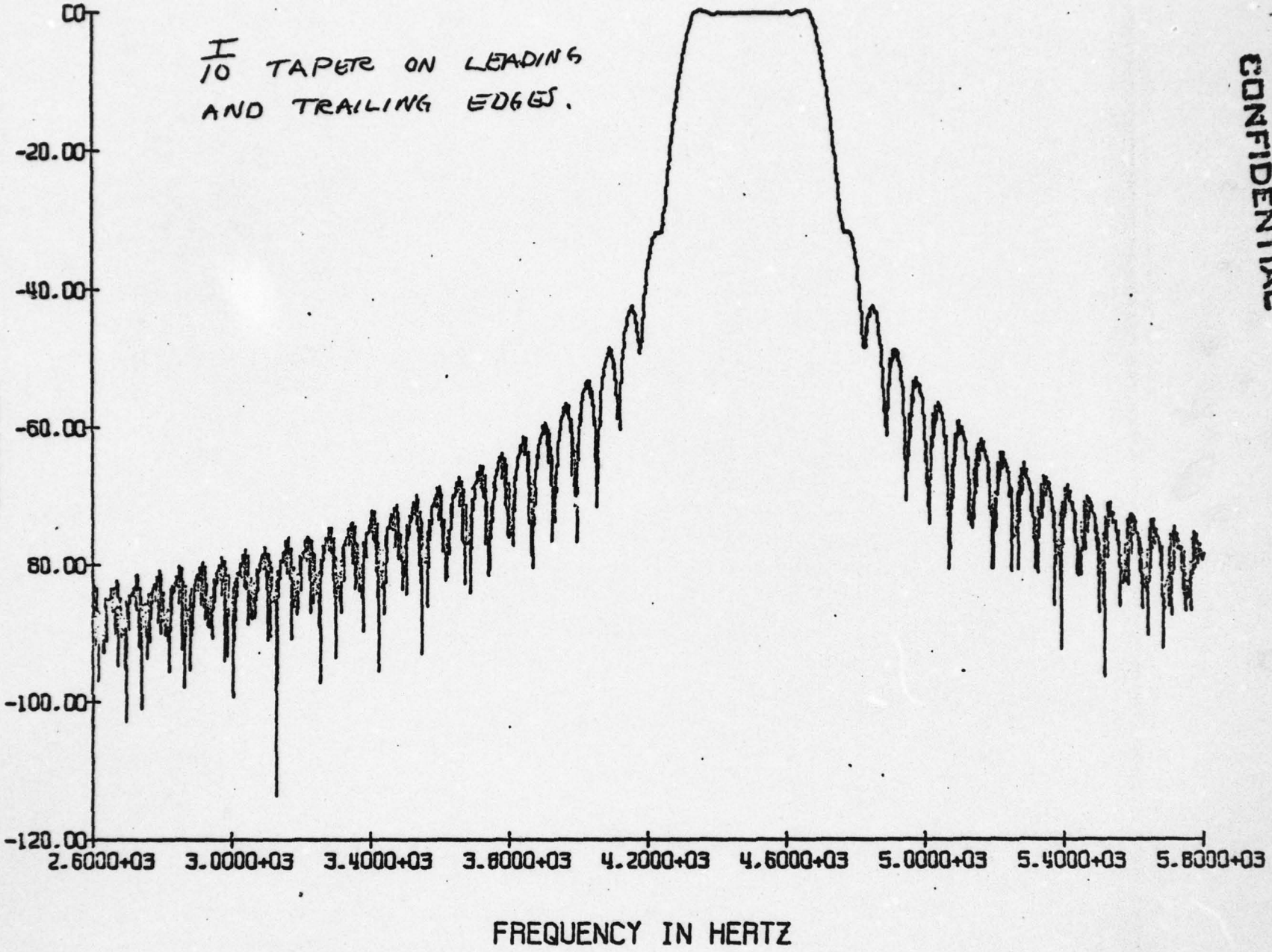
$\frac{I}{20}$ TAPER ON LEADING AND TRAILING EDGES.



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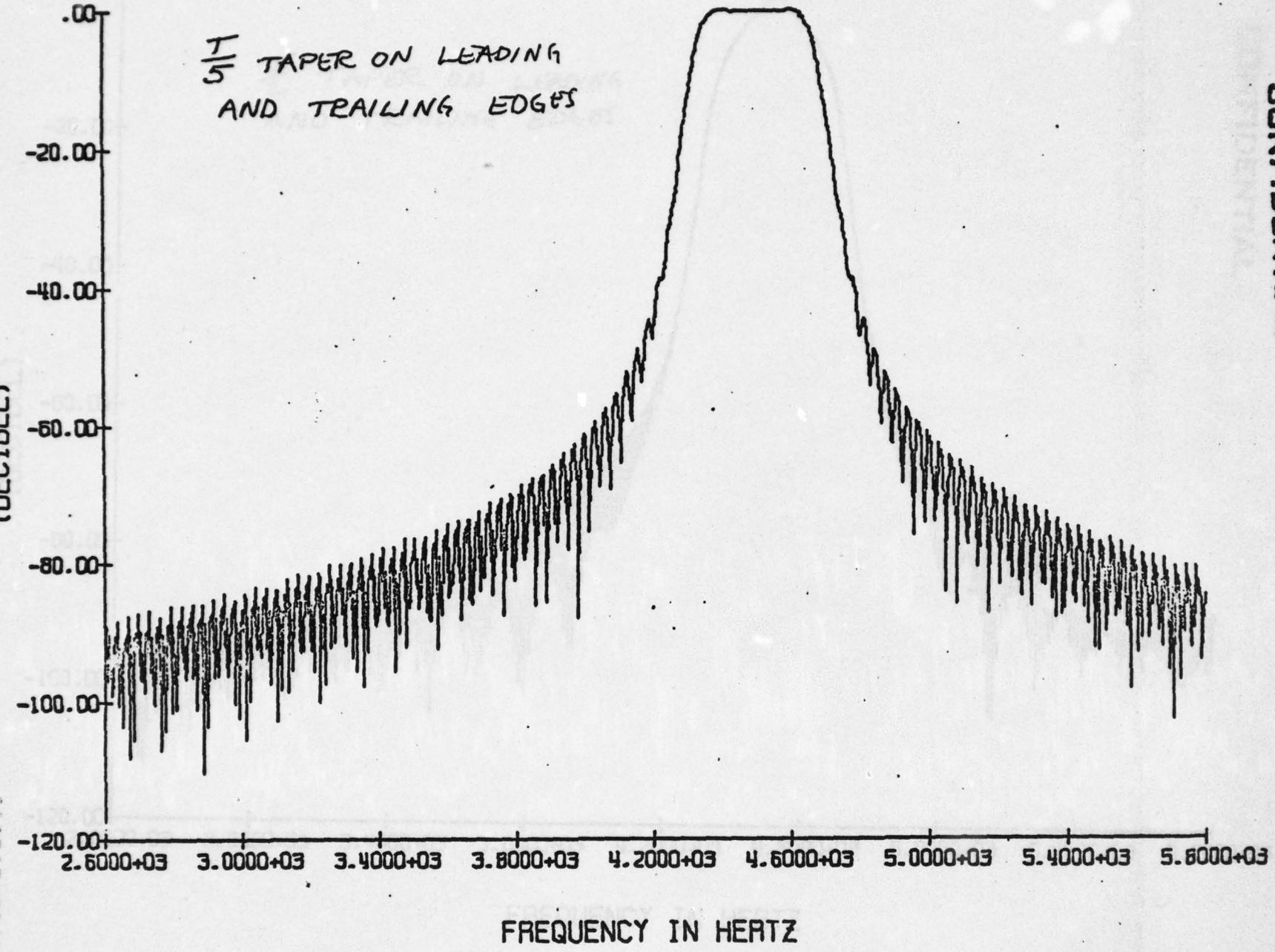
FIG. 24



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FIG. 2c



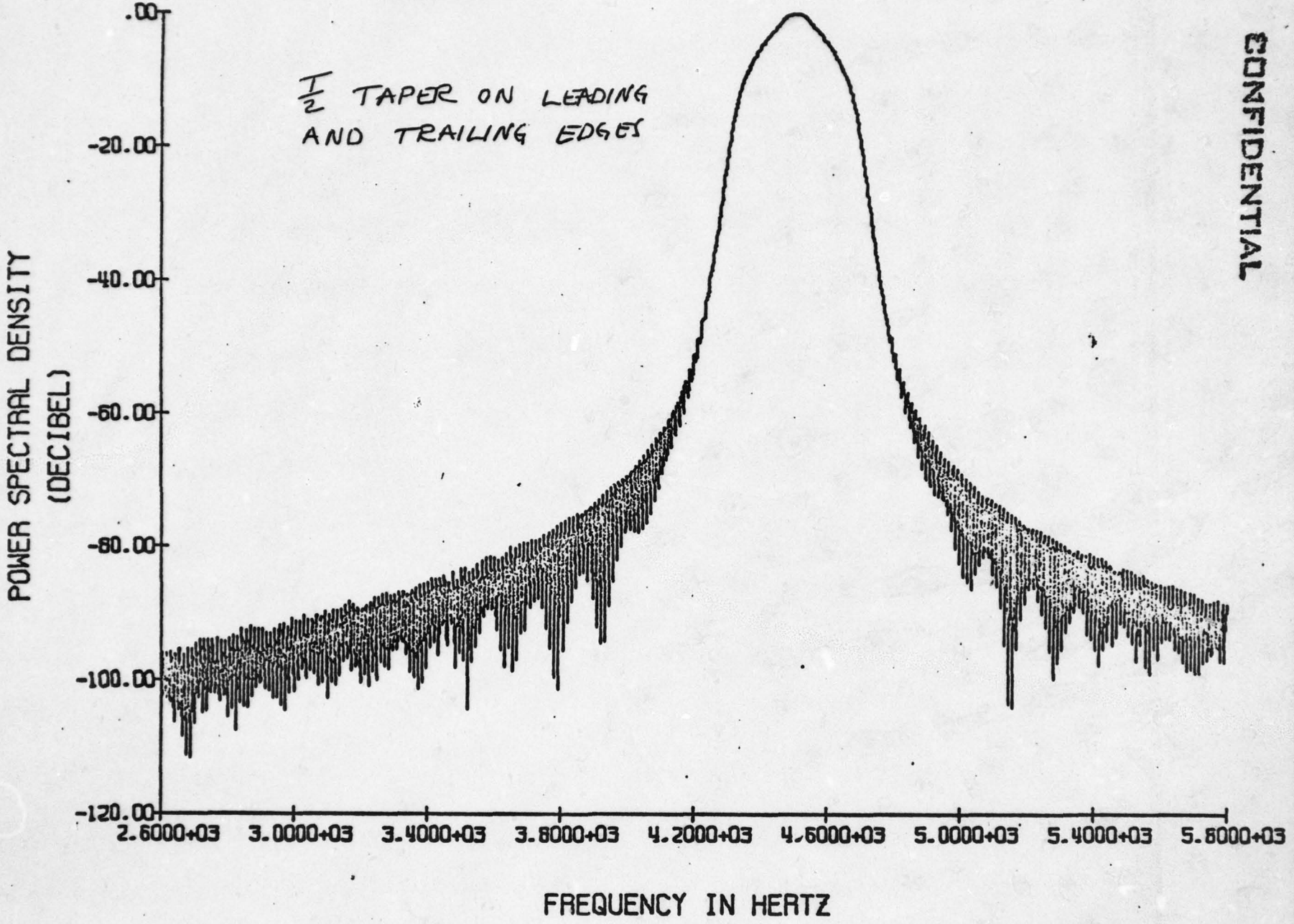
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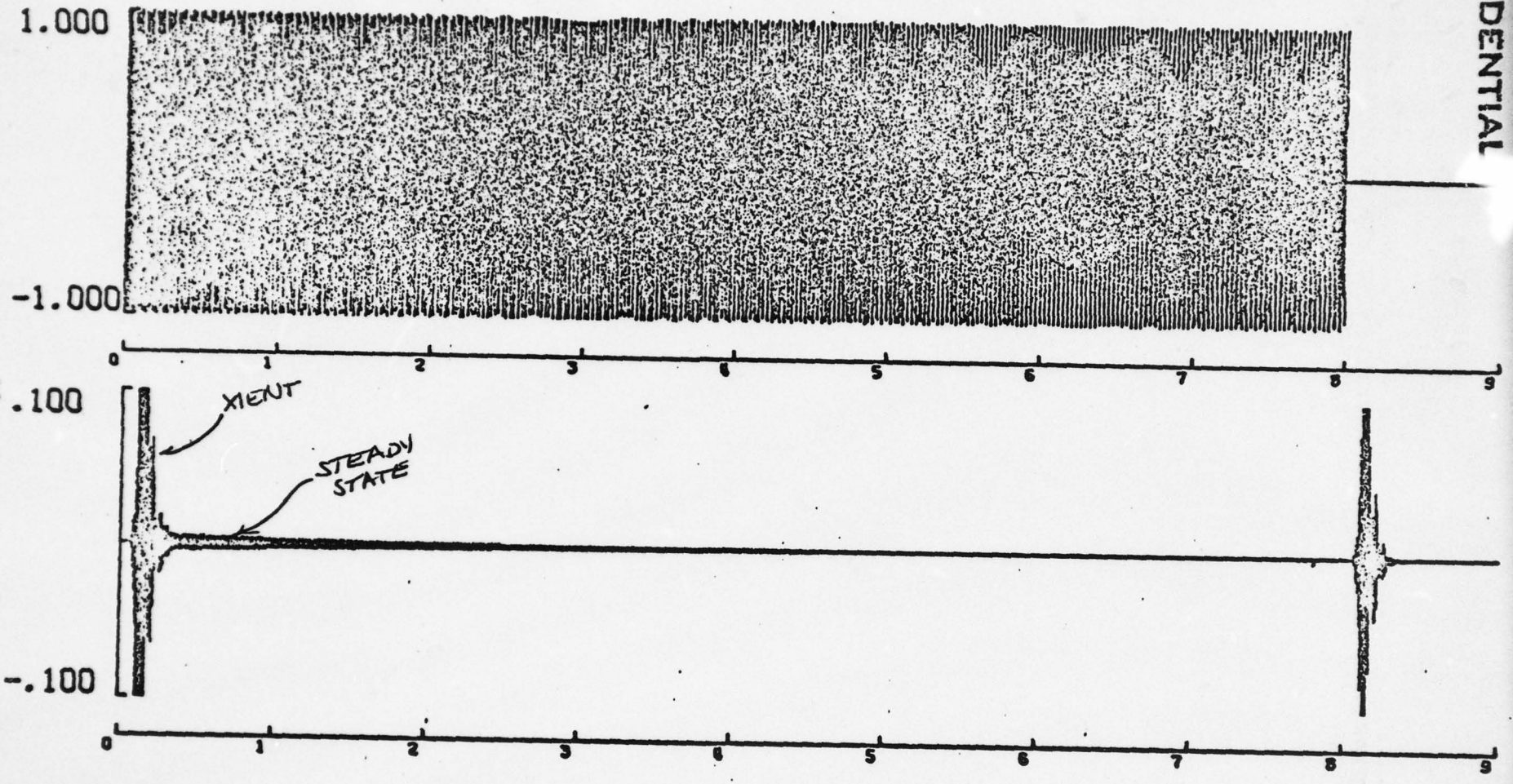
FIG. 2f



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FIG. 3a PULSE BEFORE AND AFTER FILTERING
WITHOUT PULSE SHAPING
f_o(pulse) = 3.7 kHz f_c(filter) ≈ 3.4 kHz B ≈ 200 Hz



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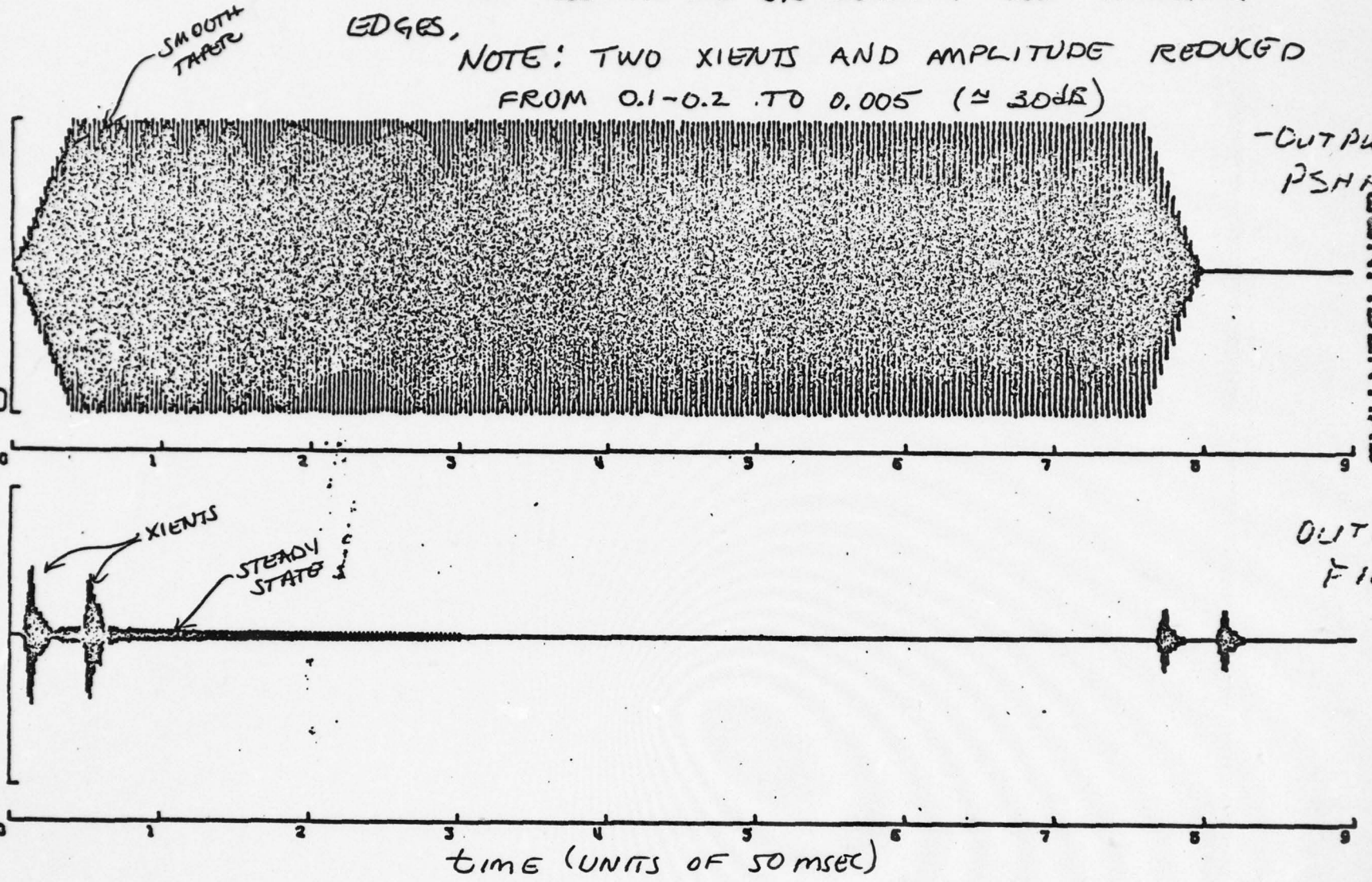
14

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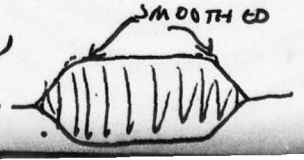
CASE 1 3655 - 3755

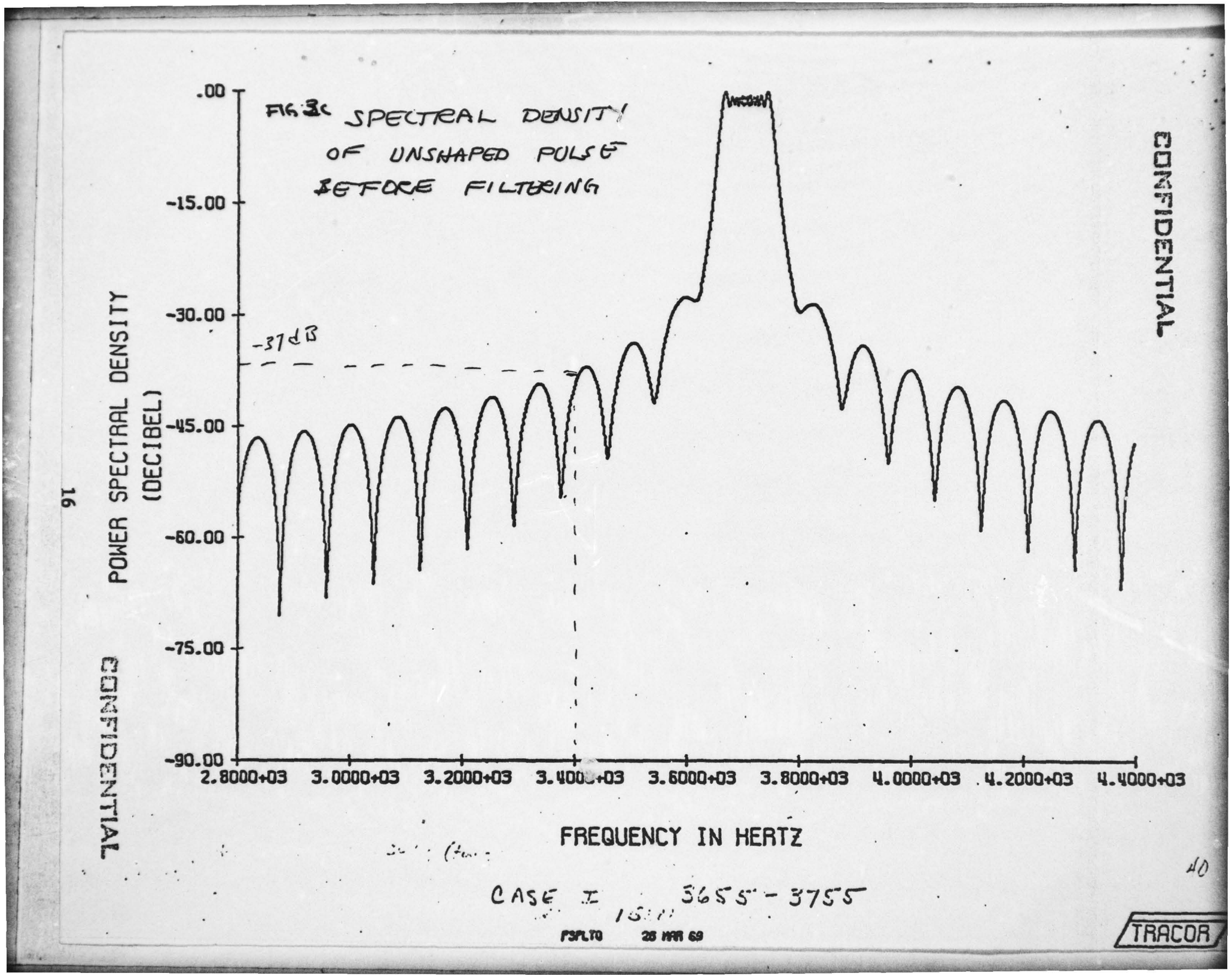
FIG. 6 PULSE BEFORE AND AFTER FILTERING WITH A T/20 TAPER ON LEADING AND TRAILING EDGES.

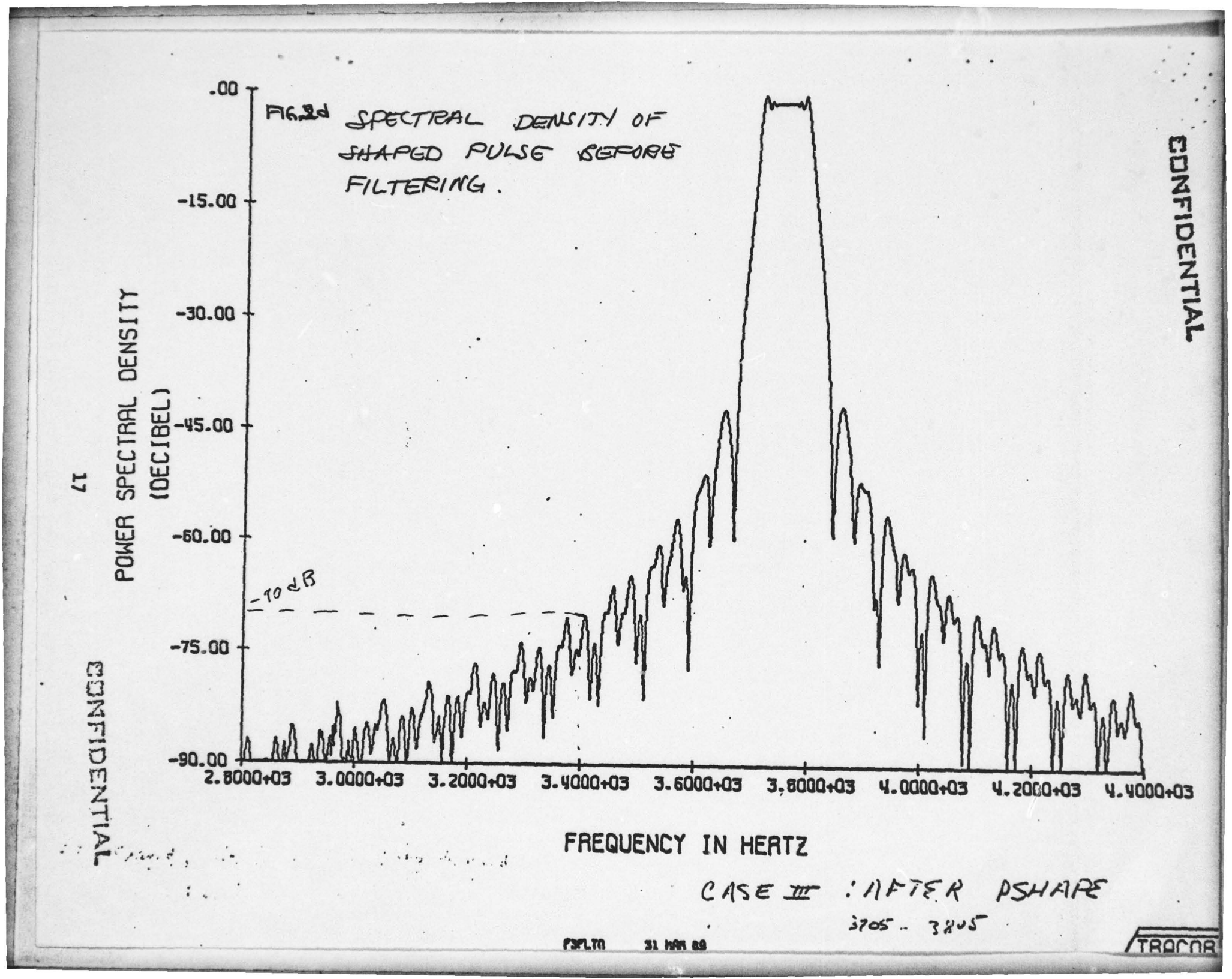
NOTE: TWO XIENTS AND AMPLITUDE REDUCED FROM 0.1-0.2 TO 0.005 (≃ 30dB)



NOTE: THE SECOND XIENT CAN BE REMOVED BY SMOOTHING THE TAPER INTO THE STEADY STATE. e.g.,




FIG 3c SPECTRAL DENSITY OF UNSHAPED PULSE BEFORE FILTERING
.00
-15.00
-30.00
-45.00
-60.00
-75.00
-90.00
-37 dB
POWER SPECTRAL DENSITY (DECIBEL)
2.8000+03
3.0000+03
3.2000+03
3.4000+03
3.6000+03
3.8000+03
4.0000+03
4.2000+03
4.4000+03
FREQUENCY IN HERTZ
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CASE I 3655 - 3755
PSPLTO 28 MAR 69
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Fig.2d SPECTRAL DENSITY OF SHAPED PULSE BEFORE FILTERING.
.00
-15.00
-30.00
-45.00
-60.00
-75.00
-90.00
POWER SPECTRAL DENSITY (DECIBEL)
-10 dB
2.8000+03
3.0000+03
3.2000+03
3.4000+03
3.6000+03
3.8000+03
4.0000+03
4.2000+03
4.4000+03
FREQUENCY IN HERTZ
CASE III : AFTER PSHARE
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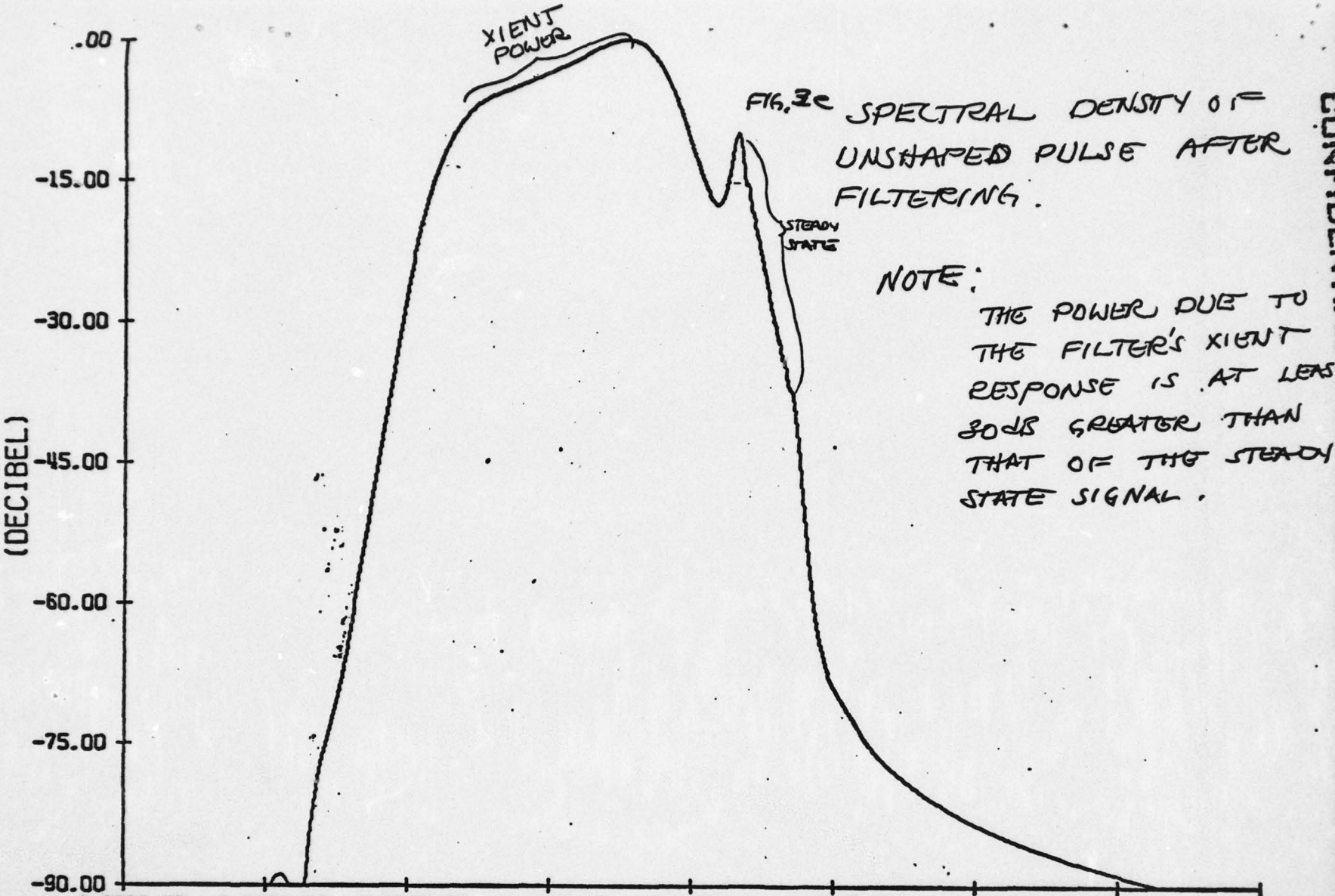


FIG. 3c SPECTRAL DENSITY OF UNSHAPED PULSE AFTER FILTERING.

NOTE:
THE POWER DUE TO THE FILTER'S XIENT RESPONSE IS AT LEAST 30dB GREATER THAN THAT OF THE STEADY STATE SIGNAL.

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CASE I 3615-3755

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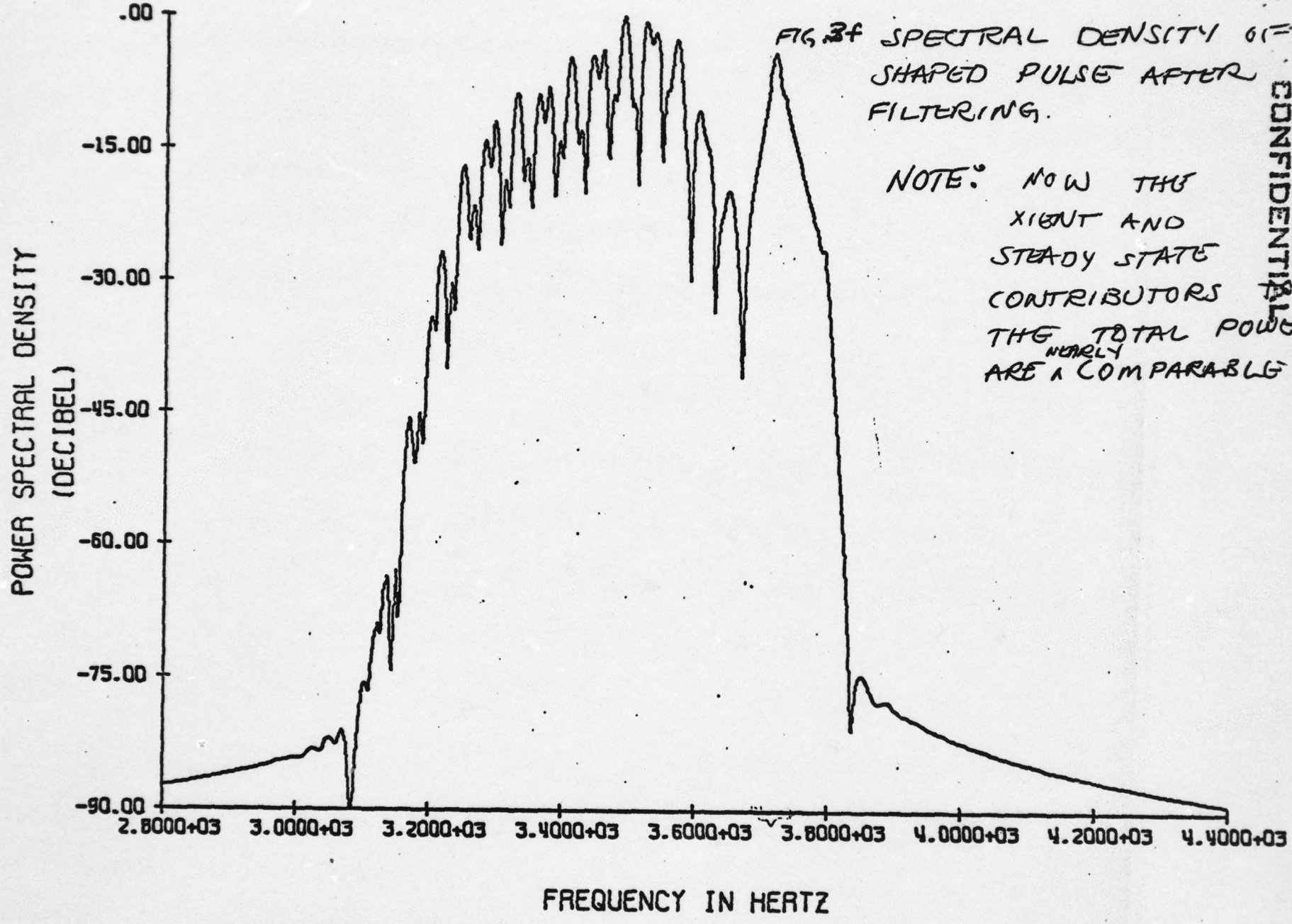


FIG. 3f SPECTRAL DENSITY OF SHAPED PULSE AFTER FILTERING.

NOTE: NOW THE XIENT AND STEADY STATE CONTRIBUTORS ARE NEARLY COMPARABLE THE TOTAL POWER

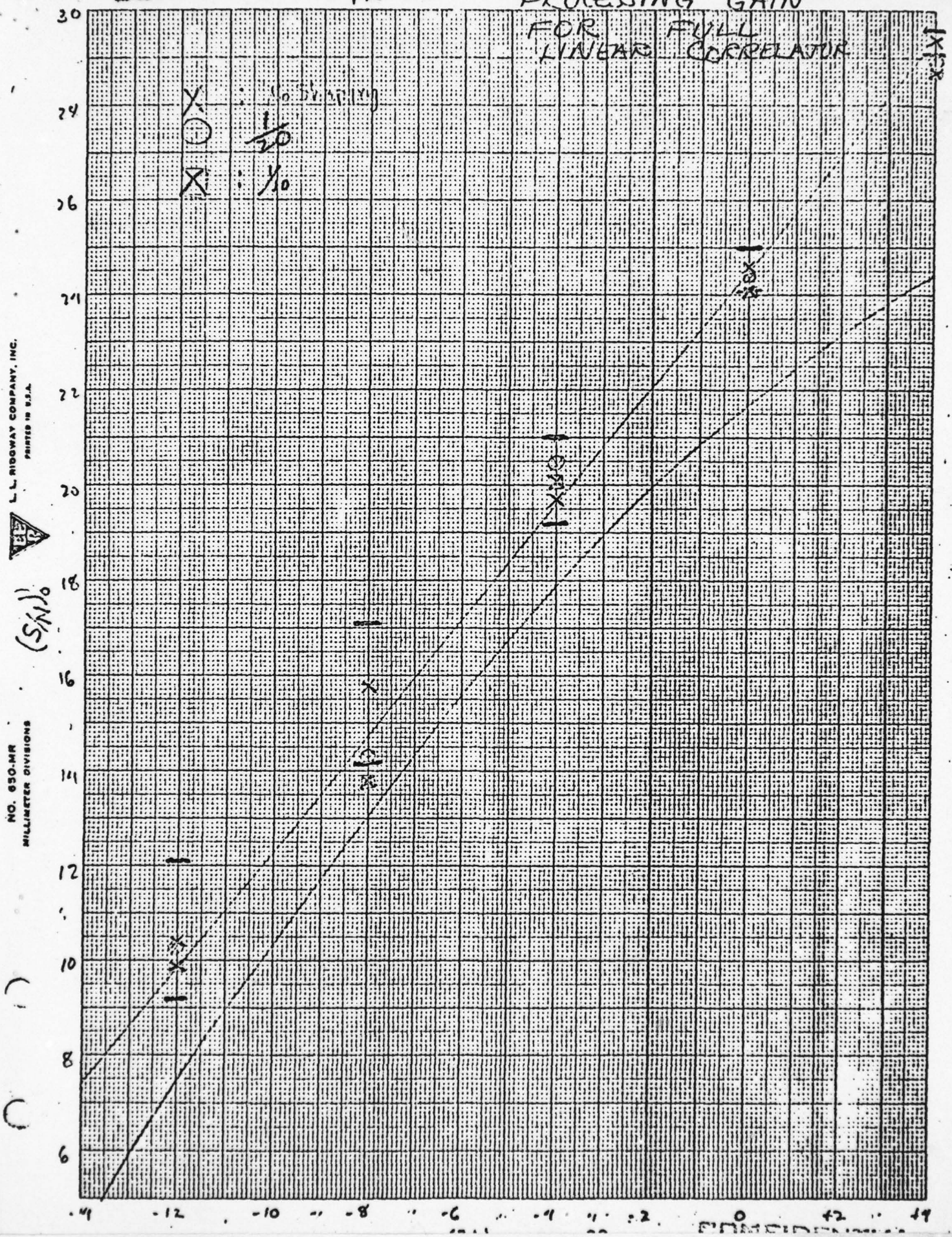
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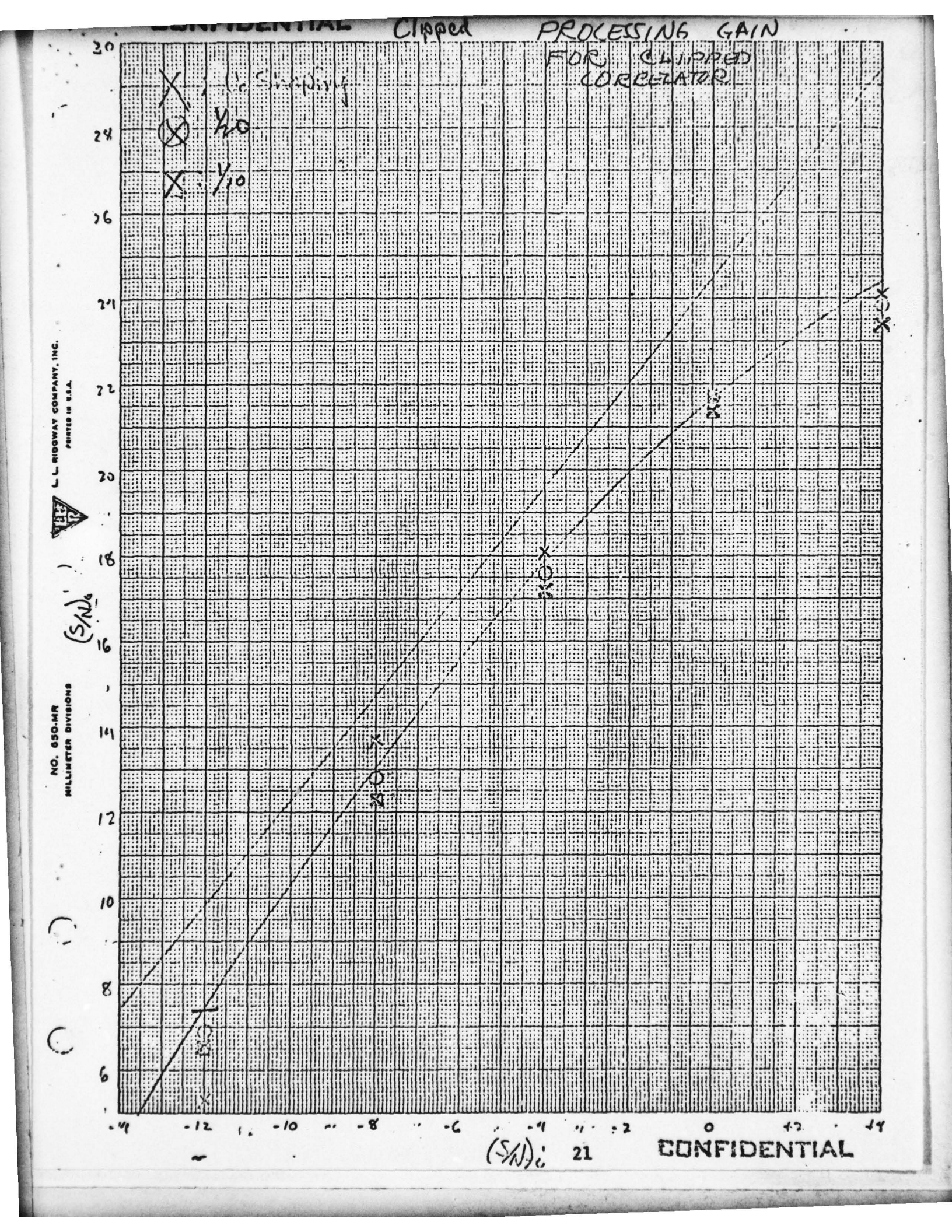
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FIG. 4a

PROCESSING GAIN FOR FULL LINEAR CORRELATOR



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CONFIDENTIAL Peter Brown Curve FIG. 4C

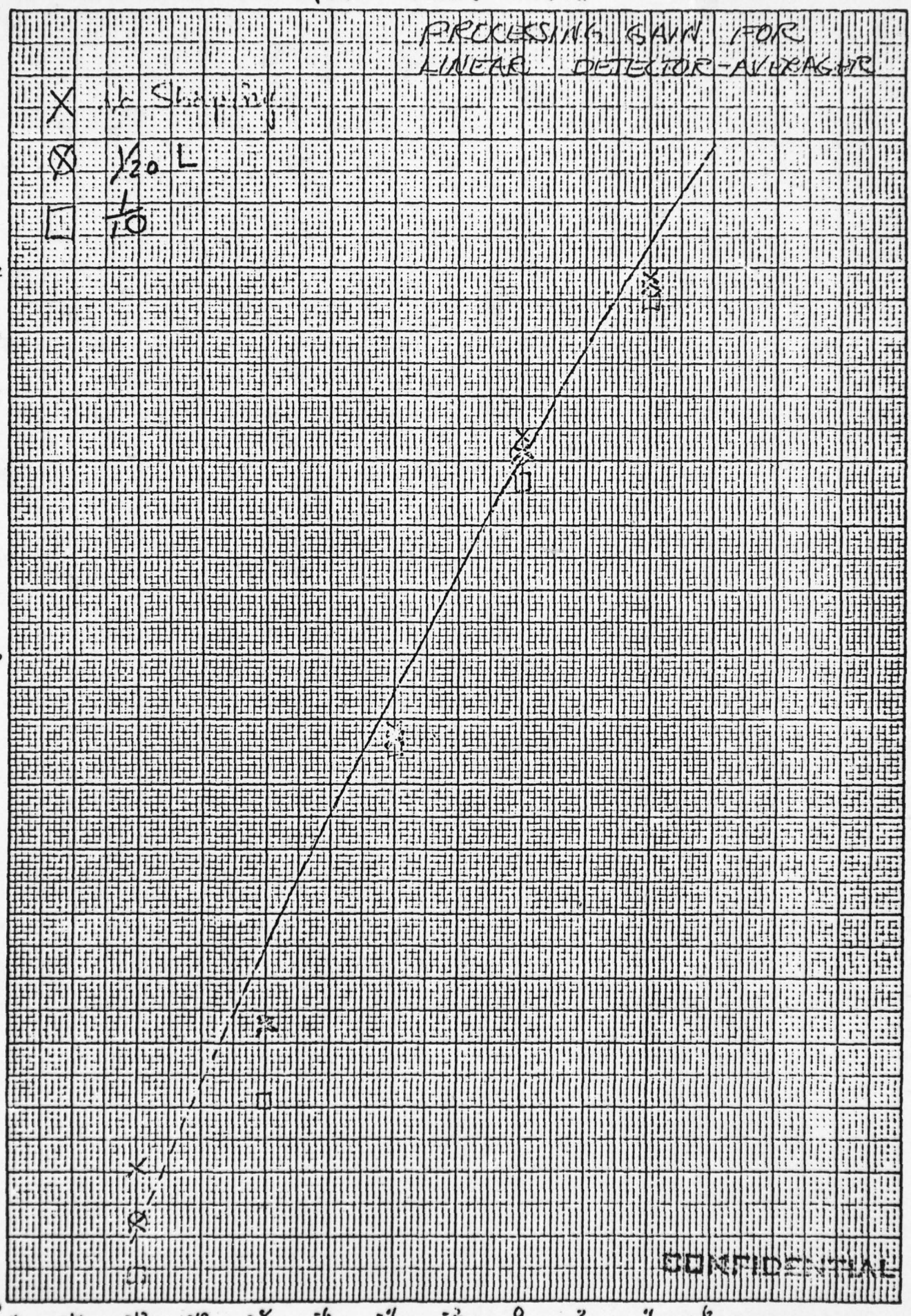
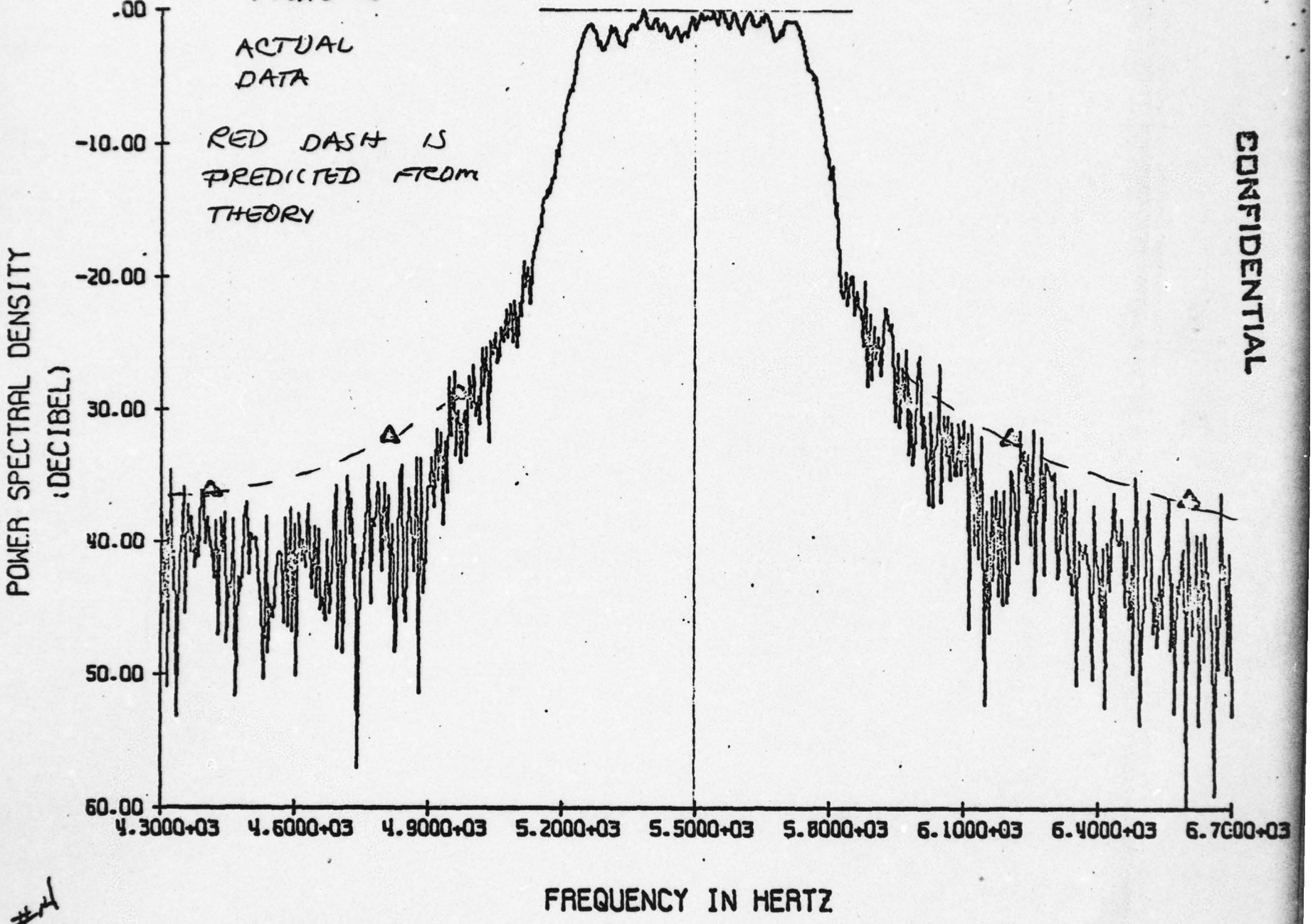


FIG. 5a



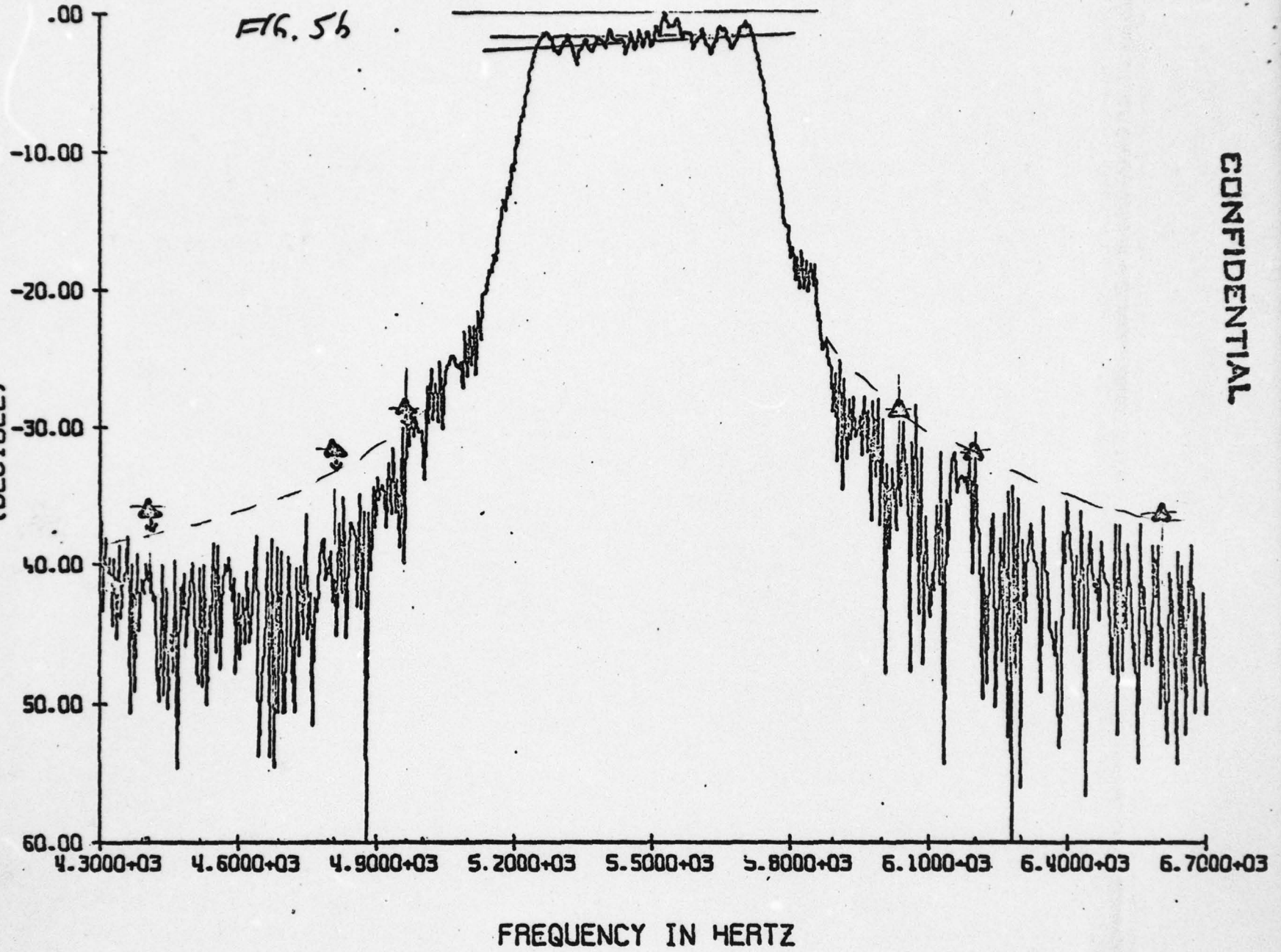
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FIG. 5b



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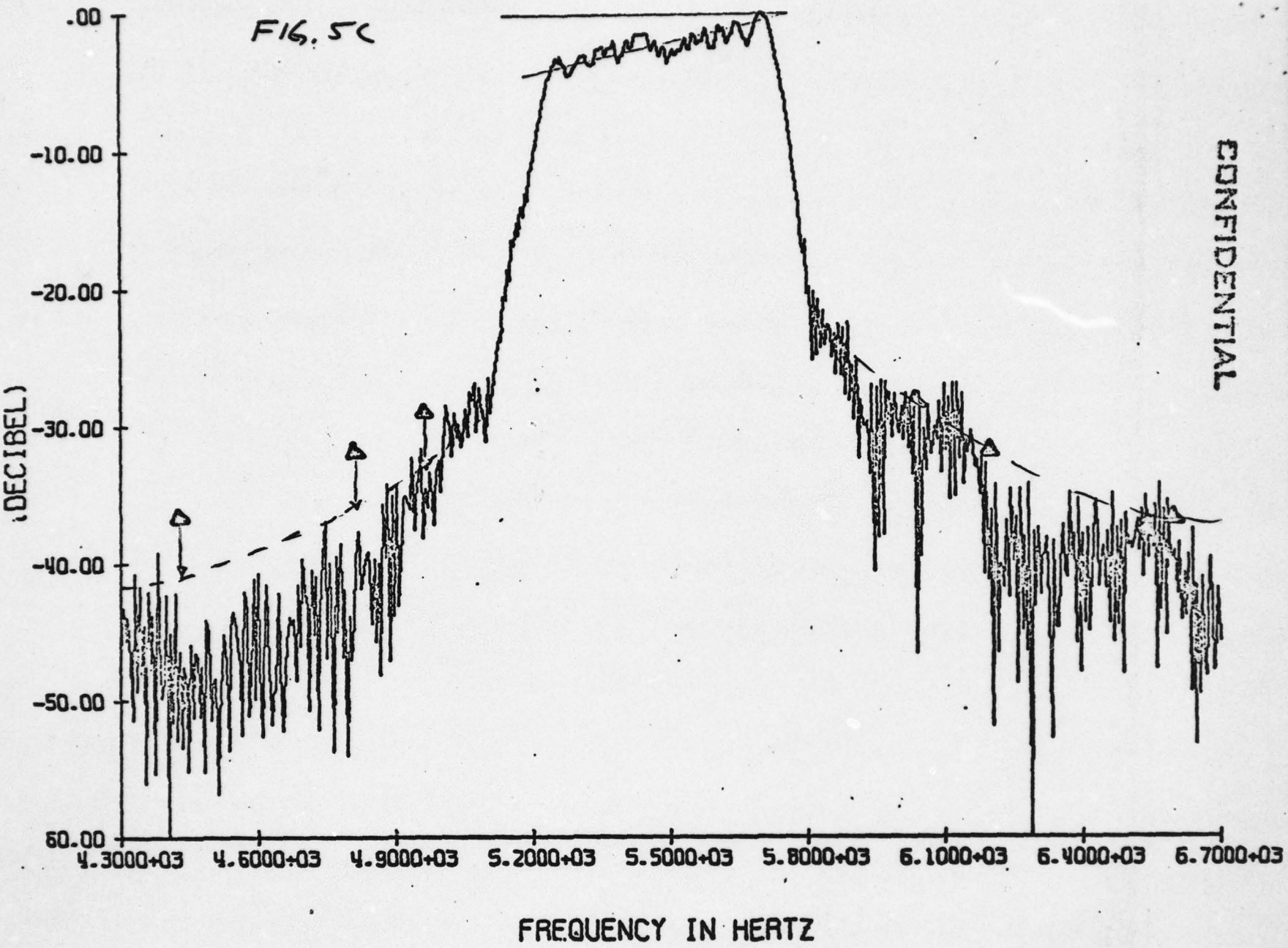
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FIG. 5C



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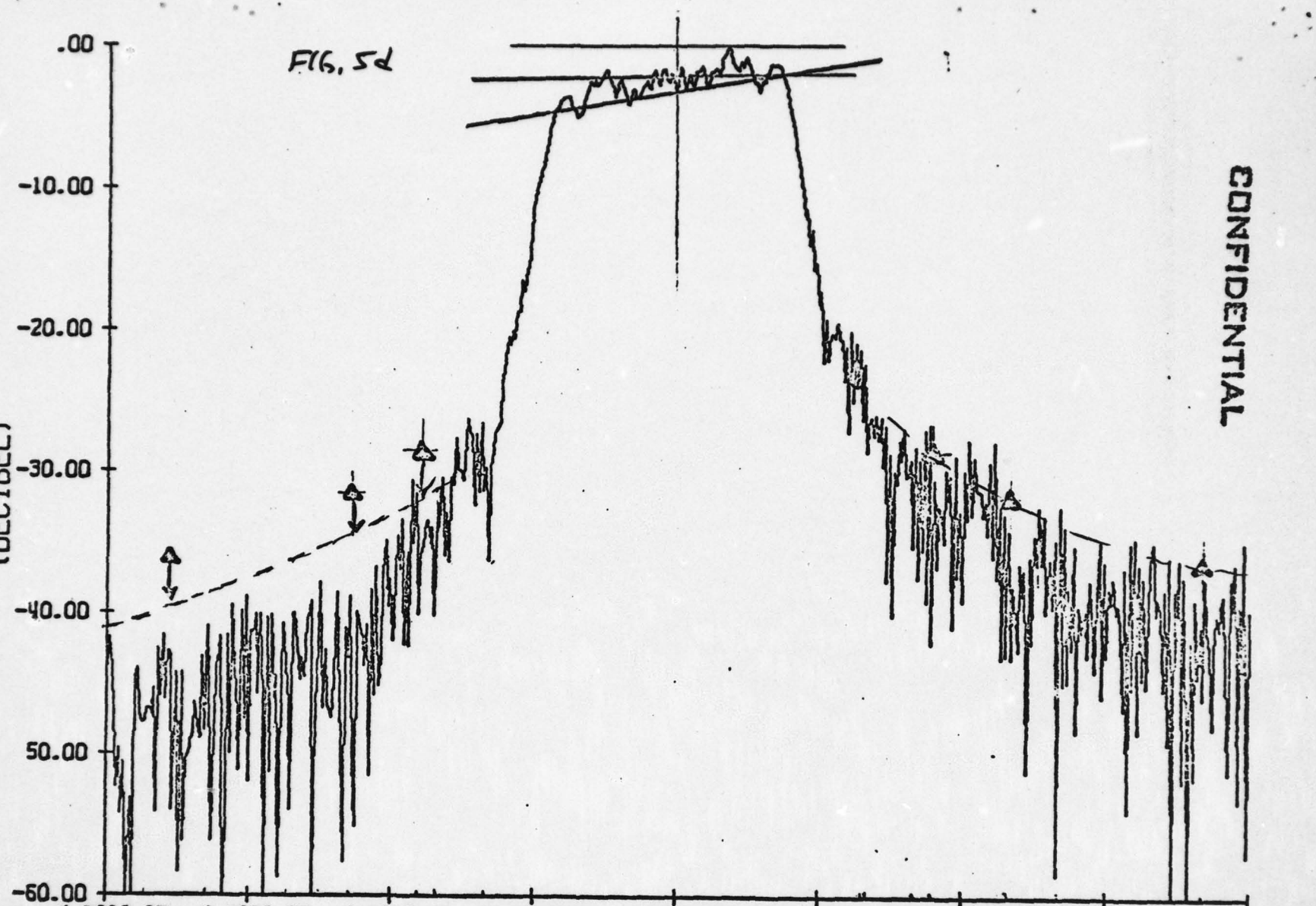
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FIG. 5d



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and clipped correlators and a linear detector-averager using unshaped and shaped pulses with a shaped factor of T/20 and T/10. The results are shown in Figs. 4a through 4c.

(C) Within the statistical uncertainty of these measurements for a one sigma confidence interval ($\simeq \pm 1.5$ dB for small $(S/N)_i$ to ± 0.5 dB for large $(S/N)_i$) it is concluded that very little degradation will be encountered for a nominal amount of pulse shaping.

(C) It is also necessary to ask whether a sufficient amount of shaping would be incurred while the pulse traverses the transducer elements and the water medium. Figures 5a through 5d show the spectral densities computed from the recordings of actual sonar transmissions from a test barge. The dashed lines indicate the power levels that a theoretical analysis predicts. Thus, one concludes that, for these pulses at least, very little transducer and medium shaping resulted. One may argue, however, that these are nearfield recordings and operational data may have shown the effects of more shaping. This possibility should be investigated.

(C) To conclude, it has been demonstrated that a considerable reduction in mutual interference can be affected through the use of transmit pulse shaping. Although there are some problems associated with achieving pulse shaping in so far as the '26 type transmitter circuitry is concerned, this approach to the mutual interference problem should be given serious consideration for the Variant 1.

B. Normalization of the cw Channel (Variant 1)

(U) The AN/SQS-26 cw system now uses simple notch filter to reject reverberation. This filter cannot adapt to the varying reverberation

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FIGURE 6

CW CHANNEL DIGITAL PROCESSOR

BLOCK DIAGRAM

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conditions, limiting the current system performance for certain sea and target conditions. One method of improving the system would be to provide adaptive notch filter--a filter which varies its notch parameters to normalize the reverberation power in the middle of the band. General Electric Company has been sponsored to perform development of a filter of this type. The approach described here is similar to an adaptive notch, but takes advantage of digital processes to obtain accurate and uniform processing. Also, a zero-Doppler target is detectable with the digital system, provided it is above the reverberation background level. The digital processor accepts signals either before or after the existing AGC amplifiers and replaces the processes currently performed by the notch filter, Doppler filter banks, and output gating circuits. A block diagram of the digital steps required is shown in Fig. 6. The D/A converter at the output returns the signals to analog form for storage, as in the current system. Digital storage is preferable, however, because of its flexibility.

(U) The adaptive prewhitening filter for the AN/SQS-26 cw detection system is described in the following sections. The process is derived and described from a mathematical viewpoint first, and then is described from a systems application viewpoint.

(U) <u>The Basic Prewhitening Technique.</u> We will start by describing a linear digital convolving filter as,

$$Y_i = \sum_{j=0}^{N} L_j X_{i-j} \quad , \qquad (1)$$

where

X_i is the sampled input to the filter,

Y_i is the sampled output of the filter,

L_j is a sequence of N+1 numbers.

(U) A wide variety of linear filters can be implemented by the application of Eq. (1). One particular application of Eq. (1) is to attempt to predict the future of the input, i.e., to attempt to design the filter such that Y_i is a prediction of what X_{i+1} will be. Techniques for designing a predicting filter will be described in Appendix D. For the moment, it is convenient to proceed on the assumption that the L_j has been picked in such a way as to form a predicting filter. Of course, in most practical applications the prediction will not be perfect and an error sequence, E_i, may be defined as,

$$E_i = Y_{i-1} - X_i = -X_i + \sum_{j=0}^{N} L_j X_{i-j-1} \quad . \tag{2}$$

(U) Now if we consider how the mean square of the error might change as we increase N, the number of terms in the predicting filter, we can anticipate that this will be a monotonic decreasing function which will approach some asymptotic value (not necessarily zero). Physically, this means that after some value of lag has been reached, samples of the input with larger lags do not provide any additional information useful for prediction. We will assume that N has been chosen sufficiently large that further increases in N would not significantly reduce the mean square error. Next, it is interesting to examine the autocorrelation function of the error sequence,

$$R_k = \overline{E_i \cdot E_{i-k}} \quad , \tag{3}$$

where $\overline{\qquad}$ denotes an average on i, and k is the lag. If we combine Eqs. (2) and (3) we have,

$$R_k = \overline{E_i \cdot \left(X_{i-k} + \sum_{j=0}^{N} L_j X_{i-j-k-1}\right)}$$

$$= -\overline{E_i \cdot X_{i-k}} + \sum_{j=0}^{N} L_j \cdot \overline{E_i \cdot X_{i-j-k-1}} \quad . \tag{4}$$

(U) From Eq. (4) it can be seen that the autocorrelation function of the error sequence can be expressed as a sum of scaled cross-correlation functions between the error sequence and the input sequence. Each of these cross-correlation functions must be zero for nonzero lag as a result of the assumptions that the predicting filter has been designed to minimize the mean-square error and that N has been chosen adequately large. This observation leads directly to the conclusion that the power spectrum of the error sequence is flat.

(U) Next, it is interesting to note from Eq. (2) that the error sequence is the output of a linear filter consisting of N + 2 terms the first of which is -1 and the remainder of which are the terms of the predicting filter. Since the power spectrum of the error sequence is flat the filter described by Eq. (2) is a prewhitening filter.

(U) In summary the discussion above indicates that if an optimal predicting filter of the form indicated by Eq. (1) has been designed than an optimal prewhitening filter is immediately available by application of Eq. (2). Techniques for designing optimal predicting filters are described in Appendix D.

(C) The prewhitening filter output may be D/A converted and returned to the existing AN/SQS-26 cw Doppler filter-bank processor. Some attention must be given to the output AGC, however, preferably using the existing AGC amplifiers. A small dedicated arithmetic unit will perform the prewhitening process as can be seen in Appendix D. The prewhiteners can, however, be combined with further digital processing to accomplish the tasks of the cw processor.

(U) Digital AGC. The output of the digital prewhitening filter must be renormalized before bandpass filtering. This process is equivalent to a digital automatic gain control for each of the twelve beams. The implementation of this process requires a digital linear rectifier, a digital recursive low pass filter, and a divide operation. The operation of the AGC process can be described by the following two equations,

$$Y_i = |X_i| \cdot L - K \cdot Y_{i-1} \quad , \tag{4}$$

and

$$Z_i = \frac{X_i}{Y_i} \quad , \tag{5}$$

where

X_i represent samples of the input (output of the digital prewhitening filter),

Y_i represent samples of the output of the recursive low pass filter,

Z_i represent samples of the output of the AGC process,

L and K are constants.

The time constant of the low pass filter is controlled by the numerical value of L and K.

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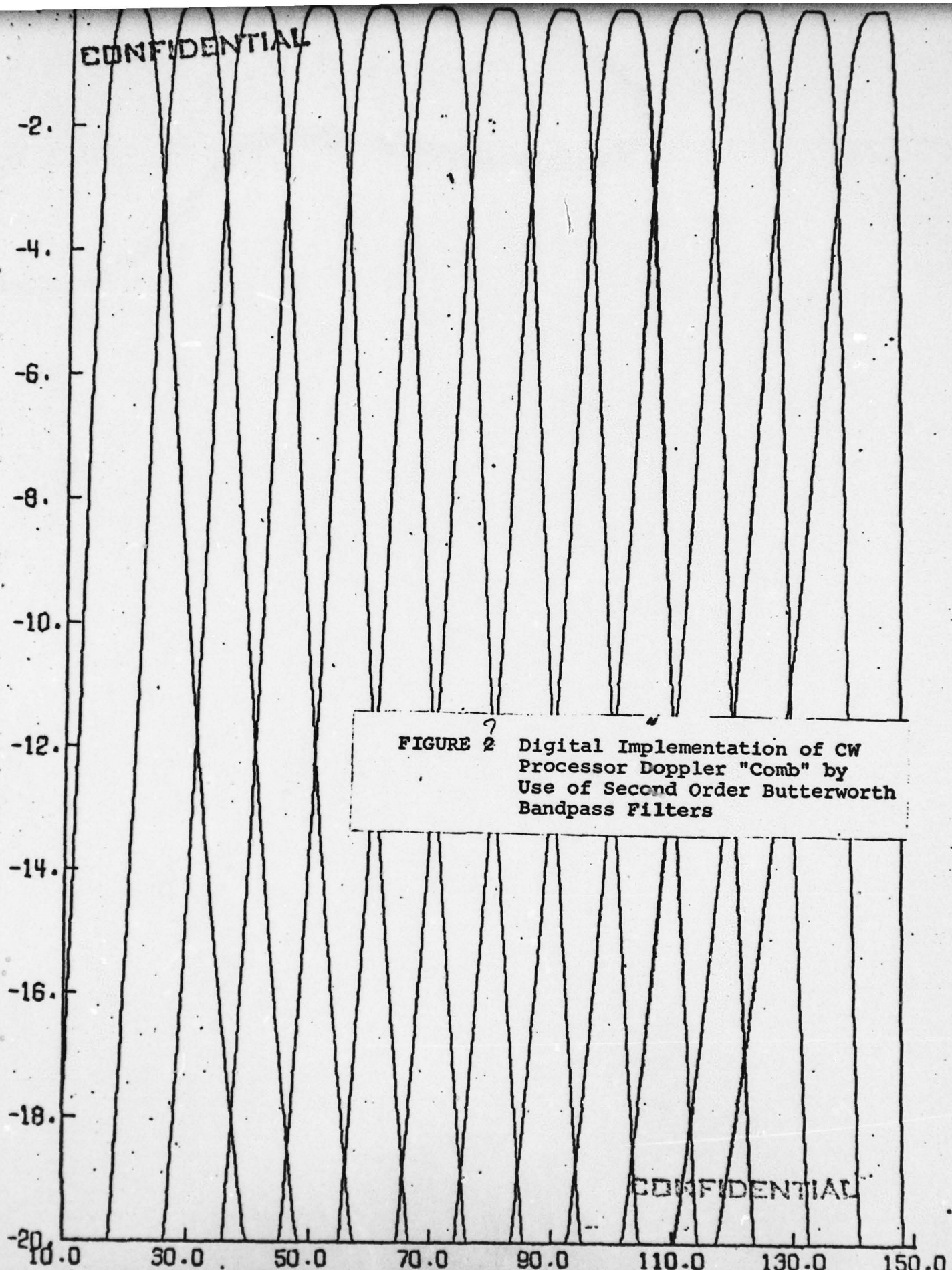


FIGURE 2 Digital Implementation of CW Processor Doppler "Comb" by Use of Second Order Butterworth Bandpass Filters

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(U) Comb Filter Process. The fourth functional process shown in Fig. 6 is the bank of recursive comb filters. A general expression for a digital linear recursive filter is,

$$Y_i = \sum_{j=0}^{N} X_{i-j} \cdot L_j - \sum_{j=1}^{M} Y_{i-j} \cdot K_j \quad , \tag{6}$$

where

X_i represent samples of the input,

Y_i represent samples of the output,

the L's and K's represent constants which define the filter characteristics.

(U) To implement the recursive comb filter 13 bandpass filters are required. A set of 13 second-order bandpass Butterworth filters were designed and the power transfer functions of these filters are shown in Fig. 7. For second-order bandpass Butterworth filters N = M = 4. Also an important property is that the numerical value of the L's required in Eq. (6) is the same for each member of the comb filter bank. This property allows a reduction of arithmetic requirements by expressing Eq. (6) as

$$Z_i = \sum_{j=0}^{4} X_{i-j} \cdot L_j \tag{7}$$

and

$$Y_i^{\ell} = Z_i^{\ell} - \sum_{j=1}^{4} Y_{i-j}^{\ell} \cdot K_j^{\ell} \quad , \tag{8}$$

where

X_i represent the input to the comb filter

L_j represents the set of coefficients of a pure convolving filter

Adaptive Prewhitening System Timing Requirements

Function:

A/D Conversions, etc.

AGC/COMB Filter System

	Single Channel Rate	Twelve Channel Rate
Multiply/Add Operations		
AGC	2 x 300 = 600	7,200
Comb Filter	55 x 300 = 16,500	198,000
Envelope Detector	26 x 300 = 7,800	93,600
TOTAL	24,900 Hz	298,800 Hz
Divide Operations	300	3,600
D/A Conversions	300	3,600

TABLE 1

TIMING REQUIREMENTS FOR THE ADAPTIVE PREWHITENING SYSTEM AND FOR THE AGC/COMB FILTER SYSTEM

Z_i represents the output of the convolving filter

K_j^{ℓ} represents the set of coefficients of the ℓ'th recursive comb filter

Y_i^{ℓ} represents the output of the ℓ'th comb filter.

(U) A further reduction of arithmetic requirements results from the fact that the desired value of L_1 and L_3 in Eq. (7) is zero. To implement a bank of 13 comb filters requires that 55 multiply/add operations be performed for each input sample.

(U) Envelope Detection Process. Envelope detection of the output of each comb filter is required. This process consists of a linear digital rectifier followed by a recursive low pass filter. This operation is also described by Eq. (4) under "Digital AGC Process."

(U) Digital OR Gate and Digital-to-Analog Conversion. The final functional process shown in Fig. 6 is a digital "greatest of" (OR) process followed by digital-to-analog conversion. As in the current system this will yield an output which is equal to the largest output of the set of envelope detectors.

(U) Timing Considerations. The required timing characteristics are summarized in Table 1. The values given in Table 1 should be regarded as nominal values and are based on an assumed sampling rate of 300 Hz. The total multiply/add requirement for all twelve beams is 370,000 Hz. This quantity is easily within current state-of-the-art for a single arithmetic unit.

C. Normalization of the FM Channel (Variant 2)

(C) During typical sonar echo cycles, it is common to observe background interference whose power level may vary as much as 80 dB.

This variation may be somewhat less if the sonar is operating in the bottom-bounce mode rather than the surface duct or convergence zone modes, but even then, the range of variation usually exceeds the dynamic range of some element or elements of the sonar receiver. In addition to this, a time variable background also produces variable marking rates on the sonar display. When such variations occur, target detectability becomes dependent on target position on the display instead of only being dependent on signal-to-noise ratio. This problem--a lack of time stationarity--is one of the most severe problems facing sonar designers today. The solution to the problem is to design equipment that can achieve normalization*--restoration of time stationarity--with maximum efficiency and a minimum of degradation in signal detectability. Some techniques which may be used to achieve varying degrees of normalization are described below.

Temporal Normalization. As is well-known, nonstationarity effects in the sonar background are usually dealt with in practice by some form of normalization. The objective of any receiver normalization technique is three-fold. First, all data which enter the sonar must be made to fall within the dynamic range of the receiver. This naturally includes every element of the receiver from beamformer output through the display. Second, the normalization technique must tend to produce stationarity in the receiver output background noise. Finally, the normalization technique should accomplish the first two objectives with a minimum of degradation in signal processor performance, relative to its performance with stationary backgrounds.

(C) An ideal normalization technique accomplishes these three objectives with perfection in the presence of nonstationary background noise at the input to the sonar. As might be expected, ideal normalization

*The normalization and nonstationarity discussed here are confined to the time domain rather than the more general usage which includes time, frequency, and space.

does not exist in real world environments although relative improvements in sonar performance may be achieved through the use of normalization.

(C) Examples of techniques used in obtaining improved normalization are given in Tables II and III. Generally, normalization techniques may be categorized as either preprocessing or postprocessing normalizers. Typical of the preprocessing normalization techniques listed in Table II are "leading-window" automatic gain control (AGC), "split-window" AGC, and clippers. As shown in the right-hand column of Table III, the first version of AGC normalizes data samples with respect to an estimate of the standard deviation of the background taken from a window which occurs earlier in time relative to the sample to be normalized. The so-called split-window AGC performs the same operation except that the estimate of the standard deviation is obtained from windows earlier in time and later in ti e relative to the sample being normalized. (Because this technique requires some type of storage device, it has not been used as widely.) The clipper normalizes by utilizing only the zero-crossing behavior of its input, but with modest storage such as might be employed with alternatives of the variant '26 this scheme could be employed.

(U) Postprocessing normalization techniques listed in Table III seek to achieve additional normalization when the signal processor, such as a correlator coded for linear FM slides, has produced pulse compression. Such a normalizer can respond with a shorter time constant than its pre-processing counterpart because of the shorter signal durations at the processor output. Postprocessing normalizers can also remove power variations that arise in the processor output because of input background bandwidth variations such as that usually encountered in the transition from reverberation to ambient or self noise. The leading-window normalizer shown in Table III simply normalizes each output sample with respect to an estimate of the mean obtained from a window which leads in time and sample to be normalized. The

version of the split-window device shown here performs the same operation, but does so with a mean estimate based on data behind the sample to be normalized. These techniques are adequate normalizers for Rayleigh output statistics since the Rayleigh distribution depends on only one statistical parameter which is proportional to the output mean. The last postprocessing technique normalizes with respect to estimates of the mean and standard deviation and is required for distributions, such as Gaussian, which depend on two statistical parameters.

(C) Although these normalization techniques improve sonar performance by improving background stationarity, they may also degrade performance by reducing processing gain. An example of this is the replica correlator with a clipped data channel. For constant input background bandwidths, the output noise power is time invariant regardless of input power variations. Hence, as far as insensitivity to input power variations is concerned, the processor is normalized. In order to obtain this normalization, however, a price is paid in terms of processing gain. It has been shown by Reeder (Ref. 25) that the processing gain for a clipped correlator can be several dB lower than that of a linear correlator. This is particularly true when the echo contains multipath structure.

(U) Even for those normalization techniques which do not degrade the signal processing performance of the sonar, imperfection in the techniques must be considered. A familiar example demonstrating this is the preprocessing AGC whose response time must be several times as great as the pulse duration in order that the signal not be suppressed. This normalizer does not seriously affect processor performance, but since it cannot act instantaneously, it cannot remove completely all power variations in the sonar background. It, therefore, does an imperfect job of normalization and hence gives performance which is still somewhat degraded relative to that obtainable with a stationary background.

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TABLE II

PREPROCESSING NORMALIZATION TECHNIQUES AND THEIR PROPERTIES (U)

Preprocessing Techniques	Mathematical Operation
Standard "Leading Window" AGC	$X_i = \dfrac{y_i}{\sqrt{\frac{1}{N-1}\sum_{j=i-k-N}^{i-k-1}(y_j-\bar{y})^2}}$
"Split Window" AGC	$X_i = \dfrac{y_i}{\sqrt{\frac{1}{N-1}\sum_{j=i-k-N}^{i-k-1}(y_j-\bar{y})^2 + \frac{1}{N-1}\sum_{j=i+k+1}^{i+k+N}(y_j-\bar{y})^2}}$
Clipper	$X_i = \text{sgn}(y_i)$

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TABLE III

POSTPROCESSING NORMALIZATION TECHNIQUES AND THEIR PROPERTIES (U)

Postprocessing Techniques	Mathematical Operation	
"Leading Window" normalizer	$X_i = \dfrac{y_i}{\frac{1}{N}\sum_{j=i-k-N}^{i-k-1} y_j}$,	Adequate for Rayleigh output statistics
"Split Window" normalizer	$X_i = \dfrac{y_i}{\frac{1}{N}\sum_{j=i-k-N}^{i-k-1} y_j + \frac{1}{N}\sum_{j=i+k+1}^{i+k+N} y_j}$	Adequate for Rayleigh output statistics
Postprocessing AGC	$X_i = \dfrac{y_i - \frac{1}{N}\sum_{j=i-k-N}^{i-k-1} y_j}{\frac{1}{N-1}\sum_{j=i-k-N}^{i-k-1} (y_j - \bar{y})^2}$,	Necessary for Gaussian output statistics

(C) Recently conducted tests (Ref. 26) have shown that on typical bottom-bounce echo cycles a linear correlator preceded by an AGC circuit and followed by a split-window, post-correlation normalizer can provide normalized performance to within approximately 1.5 dB relative to a perfect normalizer. This 1.5 dB is in terms of the recognition differential or detection threshold. On the other hand, a clipped replica correlator is known to be 2 dB inferior to an ideal normalizer operated in conjunction with a replica correlator (Ref. 27). This means that the pre- and post-normalization techniques are superior to the clipping method of normalization by 2.0 - 1.5 = 0.5 dB. This difference may be increased when energy splitting losses are considered. Thus, it may be concluded that temporal normalization is most likely to be best achieved by means of pre- and post-correlation normalization. It is strongly recommended that this approach to temporal normalization be considered for the Variant '26 in its Alternative 2 configuration.

D. Computer Aided Detection (Variant 2)

(C) A method of performing automatic ping-to-ping integration on sonar data has been developed. This method utilizes a digital computer to examine these data from the sonar signal processor, reduce the volume of data, perform ping-to-ping integration, make simple decisions, and provide the operator with display of target tracks in the presence of reduced clutter rates. The method is based upon the statistical decision procedure known as sequential hypothesis testing, or sequential likelihood ratio (SLR) processing.

(C) The SLR process is applied to data emerging from the output of the sonar signal processor, so that full advantage can be taken of the single-ping signal processing gains of the existing system. In the SLR process, a data sample from the sonar signal processor's output which exceeds a

preliminary threshold is transformed by a function dependent on the output statistics of the sonar processor to form an approximation to the logarithm of the likelihood ratio of this sample. Two thresholds are then utilized to continue processing these sonar data. There is an upper threshold above which the log likelihood ratio is accepted as a possible target and is displayed as a mark proportional to its intensity. The log likelihood ratio is also stored in the computer along with other information such as the range and bearing for which this particular ratio is valid. The other threshold is a lower threshold below which the log likelihood ratio is considered noise alone and is rejected. If the log likelihood ratio is between the two thresholds, then it is retained in computer storage.

(C) On the next ping, as output data and new log likelihood ratios are formed, computer logic links new data to old stored data. This is done on the basis of dynamic constraints on target motion in range and bearing. That is, linkages are formed from ping to ping by linking data which is within the maximum bearing Doppler, and range limits defined by maximum target motion within one ping period. The volume within which these linkages occur is called the search volume. If such a linkage is found, that is, if a peak from the present ping is within the search volume defined for the stored peak, the joint likelihood ratio of the two peaks is formed. This joint likelihood ratio is then compared to the two thresholds described above, and is either stored and displayed, retained in storage alone, or rejected. As the track develops and becomes more firm, the dimensions of the search volume is reduced, thus narrowing the tracking "gate" dimensions.

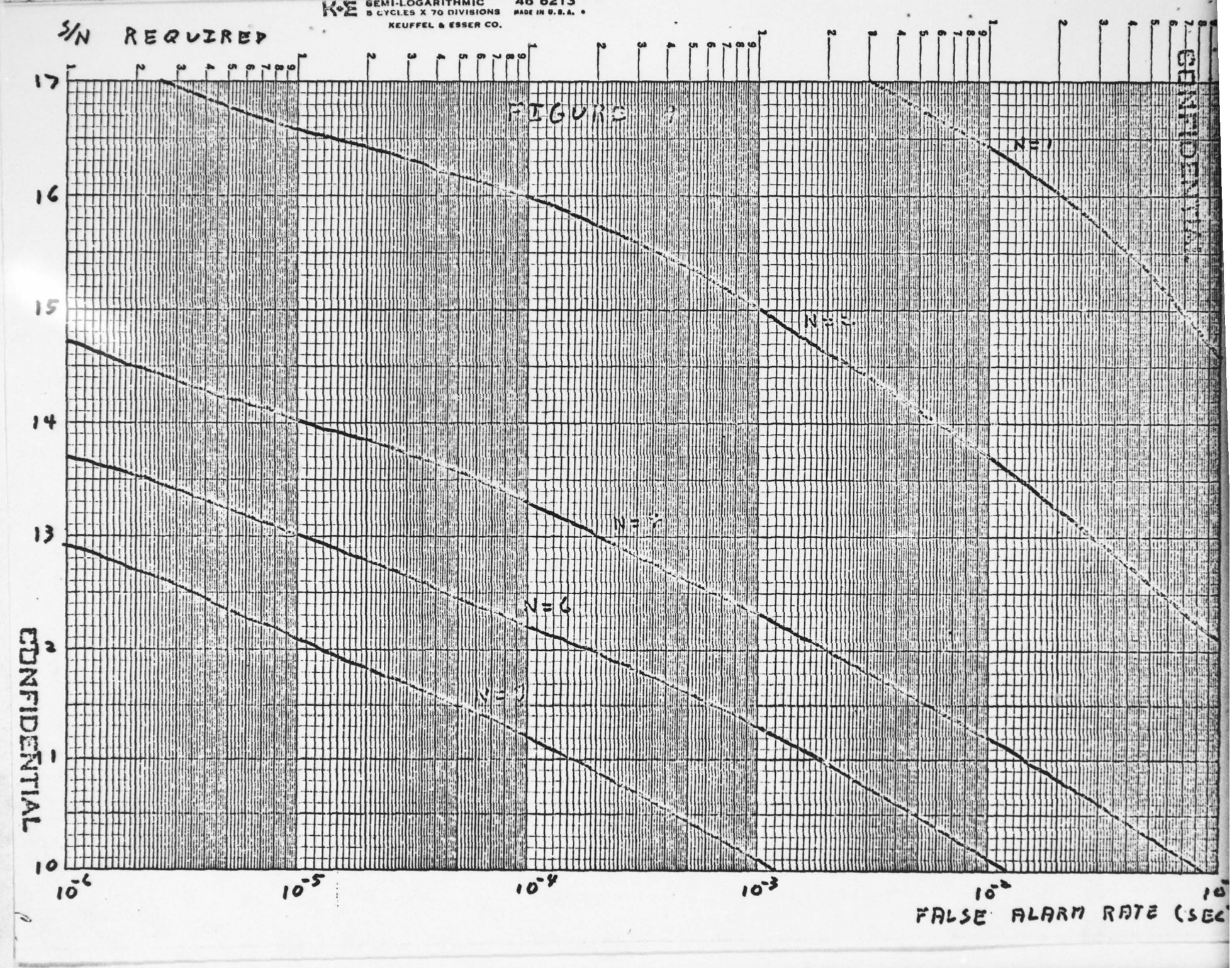
(C) This computer-aided technique will reduce the volume of data and allow the operator to achieve the same probability of detection in a shorter time using the same clutter rate. It should be noted that the basic SLR algorithm is not dependent on a particular sonar system; rather, it is applicable to any one of a large class of active sonar systems. Although

the adaption to passive systems has not been studied in detail, there is no doubt that the concepts could be applied in that area too. Since the necessary logical and arithmetic calculations are simple, the real-time implementation on a reasonably modest digital computer is to be expected.

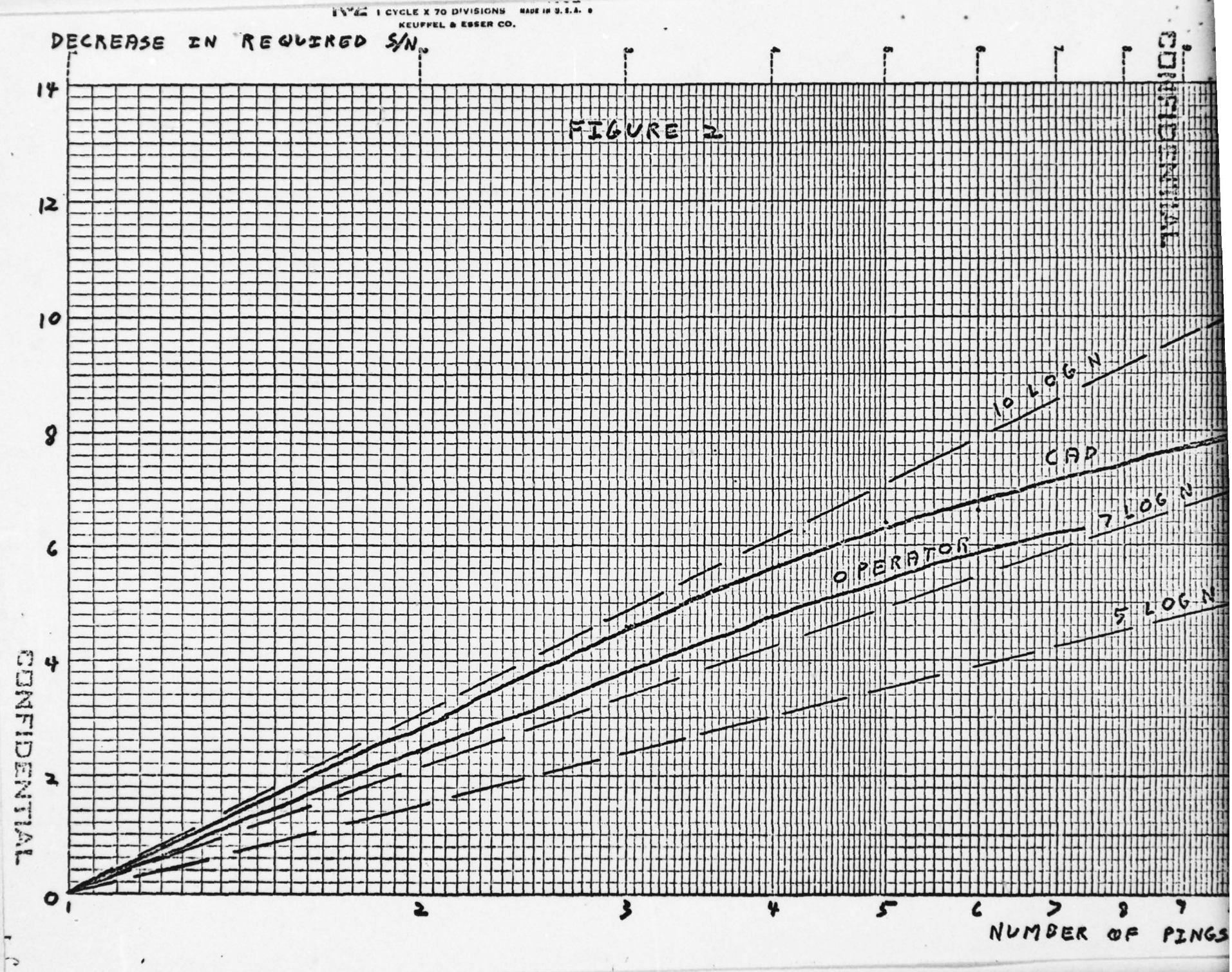
(C) Implementation. The computer requirements necessary for carrying out the SLR process have been analyzed by considering the probabilities of certain events and averaging over the number of pings required to reach a decision, whether the track is noise or signal plus noise. These estimates of computer requirements are dependent on sonar parameters such as ping period, temporal processor output statistics and bandwidth, display resolution, etc., as well as the threshold setting used. This analysis makes it possible to estimate computer requirements for implementing the SLR algorithm on either existing or planned sonars. A simple example demonstrating this method of estimating computer requirements has been carried out. Sonar data from the clipped correlator which were recorded during the AN/SQS-26 technical evaluation were processed with the detection/tracking algorithm on the CDC 3200 computer. An input threshold setting of approximately 9.5 dB signal/background was used. The CDC 3200 executed the detect/track program in 20 msec for the single beam data. This computer is approximately equivalent in speed to the Univac 1219. It is estimated that roughly 30% of the 1219 time would be required to process the twelve beams of correlator outputs.

(C) Computer Aided Detection Performance. The performance expected from computer-aided detection has been analyzed using recordings of bottom bounce echoes. These results have been obtained by UNITECH and are summarized in Figs. 8 and 9.

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(C) Figure 8 shows average signal-to-noise ratio required (at the correlator output) for 50% probability of detection vs false alarm rate with the number of pings allowed in the "LOOK",N, parameterized. Signal-to-noise ratio is defined as, 20 Log $\frac{P-\bar{x}}{\sigma}$, where P is the peak output in the presence of signal, $\bar{x}$ and σ are the mean and standard deviation respectively in the absence of signal. The false alarm rate is in units of reciprocal seconds based on 100% duty cycle of a single beam.

(C) Figure 9 shows decrease in required signal-to-noise ratio vs number of pings. Curves of 10 Log N, 7 Log N, and 5 Log N are included for reference. The curve labeled "OPERATOR" was obtained from Fig. 3-53 of the AN/SQS-26CX Sonar Signal Processing Review. The curve labeled CAD was obtained by reading values from the curves in Fig. 8 at a false alarm rate of 10^{-6}.

(C) Another comparison of performance has been carried out with displays at TRACOR. In order to provide a comparison between SLR and NON-SLR processing methods, a simulation was conducted using the UNIVAC 1108 computer and the TRACOR color display facility. The simulation included generation of six beams of replica correlator output. These outputs were generated for 20 pings and included a target with motion in both range and bearing. Data were generated according to the output statistics of a conventional replica correlator, and included a target closing from outside its detectable range and moving across several beams. The resulting data were recorded on digital magnetic tape for use with each type of processing system. In effect, this tape contained simulated recordings of the processed outputs of six beams of an active sonar for 20 echo cycles with a single moving target.

(U) The recorded data were then passed through the simulated display system. For each type of processor, SLR and NON-SLR, a statistical analysis

was performed on output data for noise alone at the input to the processor. The output noise statistics (probability of exceeding threshold vs threshold) were used to set display intensity thresholds for each type of processor such that the noise clutter density would be the same on the average for each processor.

(C) Initially, a black and white display similar to the AN/SQS-26A-scan was used for the comparison. However, on the black and white CRT, all levels of intensity* were not readily discernible. By a simple change of data format, it was possible to display these data from each processor on a color CRT. With the color display, each level of intensity was coded as a different color, so that marks of different intensities were readily discernible. The results of the color display comparison were quite favorable to the SLR processing. The SLR processor produced target marks which were on the average, about one level of intensities greater than the NON-SLR target marks. Also, the SLR processor possessed the capability to propagate strong, established tracks when the signal-plus-noise output in a ping cycle is small (fluctuates downward), whereas the NON-SLR processor has no such capability. This produced more consistent tracks.

(U) Since only a limited comparison was undertaken, it is impossible to judge how much sooner one would expect the SLR to produce a track.

(C) By weighting the target marks for each processor with the corresponding level of intensity, the SLR target tracks show an intensity about 1.75 dB greater than the NON-SLR tracks. Thus, the SLR processor produces consistently higher intensity of target marks given equal noise clutter densities for each processor. It should be pointed out that the 1.75 dB improvement due to SLR processing probably constitutes a lower bound on improvement. This is true because the display dynamic range for

*Eight levels of intensity were used for the comparison.

the SLR was kept equal to that of the NON-SLR. Thus, target tracks which could have integrated to intensities higher than the maximum intensity were not permitted to do so.

IV. Summary

(U) The several changes discussed as being appropriate for Variant 1 and Variant 2 are listed here.

(C) It should be noted that there is no magical way to gain detectability and positive classification by changing a few wires. The changes proposed represent applying additional flexibility to the sonar through the use of small, general purpose digital computers (or a dedicated portion of a UYK-7) which will allow the rapid calculations necessary for real time data presentation. In essence, we are proposing particular types of digital receivers to allow optimal normalization of all displays, a higher frequency surface duct receiver to reduce self-interference and gain resolution for classification, a "shaped" FM transmit pulse for mutual interference reduction, an integrated passive subsystem for classification and torpedo alert, and a display subsystem with digital storage to optimize the operator interface.

(C) Specifically not addressed, but of obvious import, are the control subsystem (Units 5, 15, and 23), performance monitoring and fault location, and the transmitter.

VARIANT 1

Item	Description	Requirements
Passive Torpedo Alarm	Short term averager with automatic spoke suppressor and automatic alarm. CRT relative bearing display.	Modification of DIMUS Processor, 3 in. CRT display.
DDT Transmission Pulse	Linear FM slide for detection and fire control, 7 msec pulse for classification/classification track.	AGC circuit time-constant modifications.
	Bandlimited transmissions.	Linear transmitter with filtering, or controlled pulse rise/fall rates.
Digital Display Storage	Delay line or core readout.	Replace three scan converters with two digital storage units.
BB/CZ Transmission Pulse	Bandlimited transmissions.	Linear transmitter with filtering, or controlled pulse rise/fall rates.
cw Signal Processor	Digital prewhitening filter.	Digital arithmetic section.
	Digital cw channel processor.	Digital arithmetic section with high speed multiply/add special purpose hardware.

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VARIANT 2

Item	Description	Requirements
Passive Torpedo Alarm	(As before)	(As before)
Own Ship's Motion Compensation	ODN correction for precision classification/track and target Doppler measure	10% Univac 1219 or equivalent 3 axis accelerometer
ODT Transmission Pulse	(As before)	(As before)
ODT Receiver Normalization	Computed signal-to-background. Elimination of reverberation ring. Marking of targets localized in range and bearing.	Dedicated high speed computer. Univac 1219 equivalent.
Digital Display Storage	(As before except must also accept computer generated signals)	(As before)
Track Classify Display	Provide multi-target SSI capability. Computer driven display stabilization.	Combine ODT track functions of Unit 3 and Unit 1.
Normalization of the FM Receive Channel	Post-correlation AGC	10% Univac 1219 combined with ODT receiver normalization
Computer Aided Detection for Coded Processor System	Computer generated track and likelihood ratio. Multi-ping estimate of signal-to-background ratio.	Univac 1219 - 30%

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REFERENCES

1. PAIR Sonar Dome Instantaneous Velocity Study, by Sperry Gyroscope Company of May 1967.
2. PAIR Sonar Dome Instantaneous Velocity Study, dated 15 September 1967.
3. Pennoyer, B., "Doppler Errors Introduced by Rotational and Translational Movements of the Ship," NUWC Memo Serial S2140-M109-67, 24 August 1967.
4. Pennoyer, B., "Comparison of the Sperry Gyroscope Company Proposed Accelerometer Design and the DRL Accelerometer Design for ODN Compensation," NUWC-SD Memo Serial D554-M152-67, 5 December 1967.
5. Firdge, H. E., "An Analysis of AN/SQS-23 Sonar System Performance and A Related Performance Prediction Model (U)," USL Technical Memo No. 2040-061-67, 25 August 1967. CONFIDENTIAL.
6. Wilkinson, J. F., "Summary Report, Reformulation of the Sonar Equations (U)," TRACOR 66-392-C (Part II), TRACOR, Inc., Austin, Texas, 8 July 1966. CONFIDENTIAL.
8. McDonald, L., J. Michalek, E. Daniels, and H. Mathieu, "Final Report Application of a Digital High Definition Display (DHDD) to Active Sonar Classification (U)," Raytheon Company, Submarine Signal Division, Portsmouth, Rhode Island, 25 September 1968. CONFIDENTIAL.
9. Goodnow, R. K., "An Investigation of the IBM Sonar Classification Display System (U)," DRL-TR-68-20, 29 May 1968. CONFIDENTIAL.
10. Augusti, F. A., W. R. Remley, and R. C. Webb, III, "The IBM Program in Acitve Sonar Classification (U)," Proceedings of Symposium on Active Sonar Classification, Vol. III, p. 261. CONFIDENTIAL.
11. Microdimus display for the AN/BQR-2B.
11A. Hendrickson, Herbert C., "A High-Precision Display System for Command and Control," Information Display, July/August 1967.
11B. Barney, Walter, "New Terminals in Display Picture," Electronics, January 8, 1968.
12. Kooij, Theo, "Optimum Signals in Noise and Reverberation," Proceedings of the 1968 NATO Advanced Study Institute on Signal Processing with Emphasis on Underwater Acoustics, Enschede, The Netherlands, 1968.

690527-0348

13. Stewart, Westerfield, and Prager, "Processing Gain Against Reverberation (Clutter) Using Matched Filters," IEEE Trans. Info. Theory, June 1960, pp. 342-348.

14. DeLong and Hofstetter, "On the Design of Optimum Radar Waveforms for Clutter Rejection," IEEE Trans. on Info. Theory, July, 1967, pp. 454-463.

15. Turin, "An Introduction to Matched Filters," IEEE Trans. Info. Theory, June, 196 , pp. 311-328.

16. Hayes and Tucker, "Optimum Pulses for Detection, Classification, and Identification of Sonar Targets (U)," TRACOR Document 66-488-C, 30 November 1966.

17. Menke and Horton,"An Analysis of Energy Splitting and Reverberation Effects for Large Time-Bandwidth LFM Sonar Transmissions (U)," TRACOR Doc. SD-68-016-C, 11 November 1968.

18. Lobdill, J. J., "Interim Report Shallow Water Systems Study (U)," TRACOR Doc. 69-185-C, 28 January 1969.

19. Brown, B. M. and M. R. Kostoff, Technical Memorandum, "Self and Mutual Interference in the Proposed PAIR Active and Passive Modes (U)," TRACOR Document 66-635-C (Rev), 20 July 1967.

20. Kostoff, M. R., et al., Technical Memorandum, "Simulation of the PAIRAActive Displays in the Presence of Mutual Ship Interference (U)," TRACOR Document 67-915-C, 25 October 1967.

21. Gullatt, John, Final Technical Report, Vol. I, "Performance Degradation of AN/SQS-26 CX Sonars by Intership Acoustic Interference (U)," TRACOR Document 68-310-C (Rev), 22 August 1968.

22. Gullatt, J. H., et al., Final Technical Report, Vol. II, "Intraship Mutual Interference Between Sonars on the DE 1052 and AGDE-1 (U)," TRACOR Document 68-866-C, 1 August 1968.

23. Gullatt, John, op. cit.

24. Gullatt, J. H., et al. op. cit.

25. Reeder, High, "Performance of a Linear Correlator and a Clipped Correlator," TRACOR Document 67-323-U, 10 April 1967.

26. Dow, J. J. and J. Wildinson, U. S. Navy Journal of Underwater Acoustics, Vol. 18, No. 3, July, 1968.

27. Brown, Peter B., Technical Memorandum, "A Comparison of the Performance of Several Signal Processors," TRACOR Document 66-203-U, 10 March 1966.

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APPENDIX A
BASELINE CLASSIFICATION SYSTEM

I. Introduction

(C) Statement of constraints for baseline:

(1) Must be implementable with current technology,

(2) Must be useful with real sonar parameters, (frequency, bandwidth, size, etc.),

(3) Must be tactically useful--nonalerting with consideration for mutual interference, and

(4) Must be functionally integratable with a detection system. (One operator.)

(C) The system outlined below and diagrammed in Fig. 1 is the result of the consensus of a group representing most of the exploratory development effort in ASW active sonar classification over the last five years, operating under the four constraints listed. Techniques considered, but not included in the baseline system, (although they satisfied the constraints) are listed at the end of the system description, with comments on the reasons for not being considered and references to documents concerning their evaluation. Techniques requiring more study to demonstrate their usefulness are, via the first constraint, left to subsequent systems. The baseline system includes only techniques which could become useful hardware at this time.

(C) The baseline system divides naturally into two subsystems determined by target range. While the information useful for classification depends

primarily on the target, the ability to estimate some of this information, specifically cross-range information, depends in a known way on target range. The usefulness of other types of information which can still be measured at long ranges may also depend on distortion introduced by the propagation path (e.g., bottom bounce).

(C) The primary classification problem is judged here to be surface duct (or short range) targets, especially as to be encountered in convoy operation. This judgment is based on the following considerations:

(1) To date, no false contact problem has been documented for the long range modes of operation. The target strength required for detection in these modes for current systems seems to preclude detection of many false contacts and even off-beam aspect submarines. Because the operational systems have not at this time been deployed, it is impossible to meaningfully discuss a classification problem.

(2) The operating modes used for long range and the long range itself preclude accurate estimation of cross-range related target attributes, such as length-to-width ratios and axis angle, and degrade the estimation of range-related attributes, such as structure. The information available for classifying is primarily related to track, Doppler, and perhaps structure history. The implementation and display of this information is straightforward, and the performance is not expected to be high.

(3) Assuming the primary utility of classification and track information to be in the protection of convoys, and especially anticipating the primary threat to be fast, deep diving nuclear submarines, the majority of detections are expected to be at short range. Additional requirements addressed, but not adequately resolved here are the detection and classification of submarines interior to the convoy and the detection and classification of torpedoes.

II. Baseline System

A. Own Ship's Motion Compensation

(C) Fundamental to the measurement of parameters useful for classification is the requirement for very accurate own ship's motion compensation. The accuracy required for classification is generally an order of magnitude better than that specified for fire control systems. Because of the coherent processing necessary for providing classification information, this compensation must be in real time; in other words, horizontal stabilization of beams used for classification must be obtained. While the advantages obtained by very accurate OSM compensations are not realized without the proper handling of the resulting information, the usefulness of the classification information generated by the system described here is negated without proper compensation (compensation here includes very accurate measurement of own ship's speed). Acoustically measuring ship's forward motion (via a high-frequency transducer at the receiver arrays) is particularly attractive, and the development of such a system should be considered. It should also be noted that compensation to the extent proposed here would probably result in improved performance of a cw - Doppler system for both detection and classification, the implementation of which is not emphasized here because of lack of actual experience with systems at sea to date. In any case, the importance of correctly performing this task cannot be over-emphasized.

B. The Long-Range Subsystem

1. Active Mode, 2.5 - 5 kHz

(C) The long range transmission frequencies are constrained to the lowest frequencies for which reasonable systems can be implemented for

detection. The coincidence with current systems is obvious; the constraint for compatibility of the classification transmissions with the detection transmissions strongly suggests the best way to obtain the classification measurements discussed below. Typical detection transmission types are long (.5 sec) linear FM slide and cw pulses. The FM transmissions are most useful for detection of low Doppler targets, while the cw signals are used to detect high Doppler targets. Since the detection systems employ filter banks or other frequency analysis hardware, it is assumed that this information will be available to the classification subsystem.

(C) Figure 2 shows a block diagram of the component processor used to obtain the measurements discussed below. These measurements are made from a properly compensated split-beam pointed in the direction of the contact, as indicated in Fig. 1. One such beam is required for each target to be classified. The handling and display of the processed data is controlled by the "general-purpose" computer, (Fig. 1), which interfaces with the operator. One operator will be required to perform the tracking functions and make classification decisions based on the measurements displayed in either "raw" or processed form. Details of the operational requirements beyond this are left to the system designer.

(C) The active sonar measurements which provide information useful for classification can be divided into target motion analysis measurements (Doppler and track) and target physical attributes measurements (structure, shape, orientation, target strength and depth). There measurements are related to sonar parameters through the Doppler, range and bearing (or cross-range) resolution of the sonar system, and are so discussed below.

a. Doppler

(C) Because of the low data rates, the measurement of Doppler (single-ping target motion) is a prime requirement for the long-range

sybsystem. It is assumed that a measurement of Doppler from the detection system is available; the measurement from the FM system is afforded by transmitting in the direction of the target an inverted split housetop linear FM slide compatible with the detection pulse (and, hopefully, non-alerting), as shown in Fig. 2. The up and down sweep slides are processed separately by appropriate correlators and the time shift between the resulting correlation functions is preserved in storage. This time shift is a measure of Doppler, as discussed in Ref. 1. The correlators used are designed in Fig. 2 to minimize the hardware required to obtain all the desired measurements; this is the reason for separate correlators for each half of the split beam. It is suggested that the Doppler measurement from one ping be used for compensation on the next, so that the operator need only "track" the difference in Doppler from ping-to-ping. This processing might also aid in estimating structure information, as discussed in (2) on p. A-2.

b. Range Resolution

(C) Range resolution is also achieved through the correlator processing of the beamformed data. To minimize the distortion of the structure information introduced by target Doppler, it is recommended that the target Doppler information generated on one ping be used to frequency compensate the correlator processing of the following ping. The range resolution will be limited by the bandwidth constraints, which are in turn limited by mutual interference constraints, and is, roughly, 25 ft. This resolution is sufficient for range tracking, but quite marginal for obtaining structure information. This "marginality" is offset by the distortions introduced via the propagation paths for long-range operation, so that any net loss is probably small. The correlator processor output (range gated around the target), along with accurate range to the range gate, is entered into storage, as shown in Fig. 2. Ten such functions are stored for display.

c. Bearing Resolution

(C) Cross-range (or bearing) measurements are afforded by appropriate processing of the split-beam. Several equally effective ways of processing these data can be used (Ref. 2), one of which is given here (Fig. 2). The use of coherent processing of each half of the split-beam has been found to be useful in improving bearing estimate accuracy of the phase comparison technique given here, both by improving the signal-to-noise ratio of the signals used in phase comparison and in compressing the waveform for display. Again, frequency compensation prior to correlating is desired.

2. Passive Subsystem

(C) The classification subsystem utilizing passive information is identical for both long and short range modes. This system involves, again, one horizontally stabilized beam for each target of interest. Experience to date (Ref. 3) indicates that processing from two receivers widely spaced is necessary to achieve detection capabilities sufficient to be potentially useful for surface ship operation under realistic conditions. Two receivers and two domes are thus required for any passive capability, and it is assumed here that such a system is available.

a. Detect and Track

(C) As seen in Fig. 3, the passive subsystem involves a "detection" processor with a controllable integration time. This processor utilizes the stabilized beam to determine whether a passive source is present in the direction of an active target. The mechanics of the processor are those of the PADLOC system: Cross-correlation of the outputs of corresponding beams from each receiver. This correlation function (which has a variable integration time) is computed for relative delays corresponding to ±15 deg

centered on the bearing determined by the active sonar (either short or long range) cursor. The correlation function is entered into computer-controlled storage.

b. Spectrum Analyzer

(C) The second processor for classification involves spectral analysis of the incoming passive information from the bearing of the target. This information can be obtained either by adding the outputs of the beams from the two arrays after compensating for the relative phase shift or by treating only the information from the array with the greatest processing gain (directivity). This information to be gained from spectral analysis is redundant in the case where an active sonar contact can be found to be a noise source via the tracking beam and the "target" is known not to be a surface ship, self noise or friendly submarine. In a convoy operation, however, where radar may be prohibited and self noise pattern may be made unstable, the use of spectral analysis may provide direct classification information. In addition, if conditions are stable enough to allow long averaging times, the spectrum may allow detection of a passive target at the bearing of an active contact when the detect/track processor does not.

C. Short-Range Subsystem

(C) The short range (surface duct)system, it is expected, will be the primary classifier for the sytem. The frequency band is raised for two purposes: 1) to allow for utilization of wide band signals while staying within the mutual interference constraint, and 2) to allow for higher directivity so as to improve performance against reverberation and provide more accurate bearing information. The higher frequency would also provide better Doppler sensitivity, should Doppler processing be used. It is assumed here that the primary detection mode for the short-range system will be a wide band signal with a relatively short duration, thereby precluding the use of Doppler

processing under the compatibility and non-alerting constraint. In a tactical convoy situation, however, the use of cw Doppler processing may be the better strategy, especially with a high likelihood of torpedoes (batter conditions with stricter mutual interference requirements). It is assumed that for this mode of operation the detection system will provide the Doppler information useful for classification. The passive system is not modified for short range operation.

(C) Active Subsystem Processors (5 - 8 kHz). The active processors for short-range are identical to the long-range system, with the exception that the FM Doppler mode is not employed. The emphasis here is on obtaining accurate track and target shape information as quickly as possible. With the greater bandwidth (range resolution) and improved bearing accuracy, coupled with a higher data rate, it is expected that this will provide the most effective classify and destroy system. Also, while it is not specifically proposed here, it is recommended that a design study be undertaken to determine the feasibility of obtaining sufficient vertical directivity at the higher frequency to allow detection of submarines interior to the convoy. Commensurate with this mission should be the provision for overlay of radar information on the sonar display, as discussed below.

(C) The processors for the short range system will thus enter into storage the range-gated output of a correlation on the "sum" beam, and the phase difference function between the replica correlated halves of the split beam, along with accurate digital measurement of the range to the gate and the bearing to the center of the scanned sector.

D. Display

(C) The information generaged by the various processors is to be displayed through the use of recirculating core memory. The format for display shown here is merely suggestive; decisions about the most efficient organization

of controls and displays should follow analysis of ease of operation. The important points here are (1) the information should be stored in such a say that the presentation is controllable after data have been entered, (2) the information should be recycled so that the presentation is "flicker-free," and (3) the organization of controls and displays should allow operation smooth enough that a single operator can easily track a target at 1000 yd. The only computations done are smoothed track estimation to obtain target course and speed, unless it proves judicial to compute spectral information from digital data.

1. Active Sonar Display

(C) Both the low and high-frequency active sonar systems generate essentially the same track/classify information, so that the operator can choose the desired mode and retain the same presentation format. The signal difference is the FM-Doppler mode utilized in the long-range system.

a. FM Doppler and/or Range Resolution Display

(C) The information used here is the output of either the "up" (or "down") correlator (Fig. 2) or both, depending on the mode. The sample density required at this point is directly proportional to bandwidth, so the high-frequency system will require about four times the number of samples (words) to cover the same range interval covered by the low-frequency system. Because of the lower data rate expected in the low-frequency mode, a more logical use of the information would be to store the same number of samples, independent of mode, thereby providing four times the range interval coverage for the low-frequency system. The interval(s) displayed should be the same for both modes, to eliminate any need for operator adaptation.

(1) Long-Range Mode

(C) In this mode both up and down correlation functions are to be displayed, one delayed from the other by the (ship's motion corrected) time between transmission of the up and down FM sweeps. The range to the center of the display is known, so the displacement from the center of the display represents a range correction for track computations. The correction is entered by control of the recirculation timing so that a desired portion of the target appears in the center of the display interval. One control should align the "down" correlation function (whereby the range correction value is obtained) while another control should align the "up" function, giving a Doppler correction value. These correction values should be used to predict the next range and move the center of the interval accordingly (aided track in range), and correct the correlators for Doppler shift, so that a perfectly tracked target should, on each ping after a solution is obtained, produce perfectly centered and aligned "up" and "down" correlation functions. A ten-ping (twenty correlation function) history of this information should be provided. The Doppler and target course and speed parameters obtained from tracking will be read out numerically.

(2) Short-Range Mode

(C) Since the FM Doppler measurement is not used, a twenty-ping history is provided. Otherwise, control and interval displayed are the same as the long-range mode.

b. SSI Display

This display is the same for both modes. The information is, again, recirculated from memory at a flicker-free rate, with the position of a target in the sector controllable such that the target can be made to appear in the center. Positioning in range should be controleed by the range gate interval positioning for the range resolution display just described,

since that display will provide accurate range track information at S/N's and ranges such that the SSI display is not useful. The bearing track is then obtained from the correction to move the target to the center of the display. The sector displayed should be at least 30 deg wide, so that multiple targets in the vicinity of a contact (such as decoys) can be seen and evaluated.

2. Passive System Display

(C) The passive information useful for classification is primarily the presence of a source of noise on the bearing of an active contact. The advantage of having an active contact, with good own ship's motion compensation, is to allow longer integration times. The operator should be able to select either a short, medium, or long integration time, as the tactical situation allows. This also holds for the spectral analysis information, which should aid in separating submarine type signatures from surface ship's signatures (including own ship's signature). The usefulness of this information will be highly dependent on the tactical situation.

a. The Detection System

(C) This information is in the form of a correlation function, where delay corresponds to bearing. The portion of the function corresponding to the SSI bearing sector should appear below the SSI display, and follow the SSI track. Means for making the SSI and the passive correlation function independent should be provided, especially for instances of false targets and torpedoes.

b. Spectral Analysis System

(C) This information is in the form of a frequency scan, and should be displayed as a LOFARGRAM. The bearing being analyzed should correspond to the passive detection system bearing just described. Since the information

is not dimensionally related to any of the other measurements, a great deal of freedom can be allowed in the display and controls. Again stabilization of the beam is critical to providing adequate integration time and stability in the spectra so that visual integration can be utilized.

III. Unused Techniques

(C) Devices considered but not acceptable (or at least not acceptable in the original form) are listed below along with references.

A. ASPECT (Acoustic Short Pulse Echo Classification Technique)

(C) The fleet version of this system employed two principles: high data rate and the use of short (high range resolution) pulses. The range resolution is incorporated into the baseline system via correlation processing, but the short pulse, high data rate capability violates the non-alerting constraint.

Fleet Operational Investigation of ASPECT Modification Kits to AN/SQS-23 and AN/SQS-29-32 Sonars, COMOPTEVFOR Project F.O. 115 FY 62. Final Report January 1963, Confidential.

Fleet Operational Investigation of ASPECT A, COMOPTEVFOR Project F.O. 115 FY 63. Final Report January 1964, Confidential.

B. SCDS (Sonar Classification Display System)

(C) The essential operational features of this system are incorporated into both the long and short-range systems; the display format has been changed to an A-scan, and storage increased to make operation smoother.

Test and Performance Evaluation of IBM Sonar Classification Display System (U) IBM Final Report, Contract NObsr-95269, 19 August 1966.

An Investigation of the IBM Sonar Classification Display System (U), R. K. Goodnow, DRL-TR-68-20, 29 May 1968.

C. DHDD (Digital High Definition Display, also HDD)

(C) The principle, phase comparison for split beamforming, is employed in the system; the change involves the use of long FM pulses and correlation on each beam to improve the information provided for phase comparison. The usefulness for target shape analysis decreases with increasing range and decreasing S/N, but as long as S/N is sufficient, bearing track in improved over sum beam processing.

Application of a Digital High Definition Display to Active Sonar Classification (U), L. McDonald, E. Danials, J. Michalek, and H. Mathieu, Raytheon Company, 22 September 1968, Confidential.

A Laboratory Investigation of the Raytheon Digital High Definition Display (DHDD) (U), R. K. Goodnow, ARL-TR-69-1, 22 January 1969.

D. HHIP (Hand-Held Information Processor)

(C) A mechanical aid to an operator in evaluating visually-extracted clues from the sonar display, requires too much operator effort, in violation of constraint 4.

The Development and Use of the Hand-Held Information Processor (HHIP) for Sonar Target Classification (U), R. R. Mackie, Human Factors Research, Inc. August 1963, Confidential.

E. MITEC (Modular Integrated Target Echo Classifier)

(C) Essentially identical to HHIP, only less troublesome to use, but still the same deficiency.

Technical Evaluation of the MITEC Mod 2 Target Classification Aid (U), L. D. Hampton, K. McCormack, and J. D. Williams, DRL-A-215, June 1963, Confidential.

Operational Investigation of the Modular Integrated Target Echo Classification (MITEC) (U), OPTEVFOR Project F/O 140 FY 63, Final Report, 14 August 1963, Confidential.

F. TRESI (Target Recognition by Extraction of Statistical Invariants)

(C) An attempt to automate the HHIP/MITEC clue extraction process, this sophistication is not yet state-of-the-art as required by constraint 1.

Technical Evaluation of the TRESI Classification Equipment for the AN/SQS-23 Sonar (U), K. J. Diercks, L. D. Hampton, and R. K. Goodnow, DRL-A-253, 23 August 1967, Confidential.

G. Phase Rate, or Instantaneous Frequency Devices

(C) The several devices below utilize a measure of rate of change of phase to estimate the frequency, and therby the Doppler, of an echo. This measurement has been found to be highly noise dependent, and the information obtained not particularly useful in classification with the limited amount of testing done.

1. DACIM (Digital Axis-Crossing Internal Measurement System)

Digital Axis-Crossing Internal Measurement System (DACIM I), J. A. Nesheim, NURDC TM(to be published).

2. MONOPPLER (Monopulse Doppler)

Monoppler Sea Test Results (U), COMDESDEVGRU/PAC, Quarterly Progress Report, February-April 1963, Confidential.

Evaluation of the Bendix Monoppler Using the SME-AN/SQS-23 Playback Facility (U), L. D. Hampton and R. K. Goodnow, DRL-TM-66-2, May 1966, Confidential.

3. SDD (Sonar Doppler Discrimination)

The Development of a Prototype Sonar Doppler Discrimination and Display System (U), R. A. Gavin, HFR, Inc., Tech. Report 75L-F, January 1966, Confidential.

4. Interferometry

Sonar Target Classification Using Optical Interferometry: An Exploratory S (U), D. A. Davidson, W. F. Dorsett, and R. J. Hall, Human Factors Research, Inc., Technical Report 206-235, December 1965, Confidential.

H. CHATTERBOX

(C) The use of a particular type of wideband transmission to, estensibly, improve the detection of submarines relative to nonsubmarines violates the first constraint with no demonstrable effectiveness for classification.

Classification/Detection Enhancement Through Controlled Transmission Modes (U), E. Longerish, E. W. Rudy, Bendix Corporation Electrodynamic Division, 20 November 1967, Eng. Report 92-369-1, Confidential.

Quarterly Progress Report No. 1 under Contract N00024-68-C-1149 (U), Defense Research Laboratory, 27 May 1968, pp. 15-22, Confidential.

BASELINE SYSTEM: ACTIVE / PASSIVE CLASSIFICATION

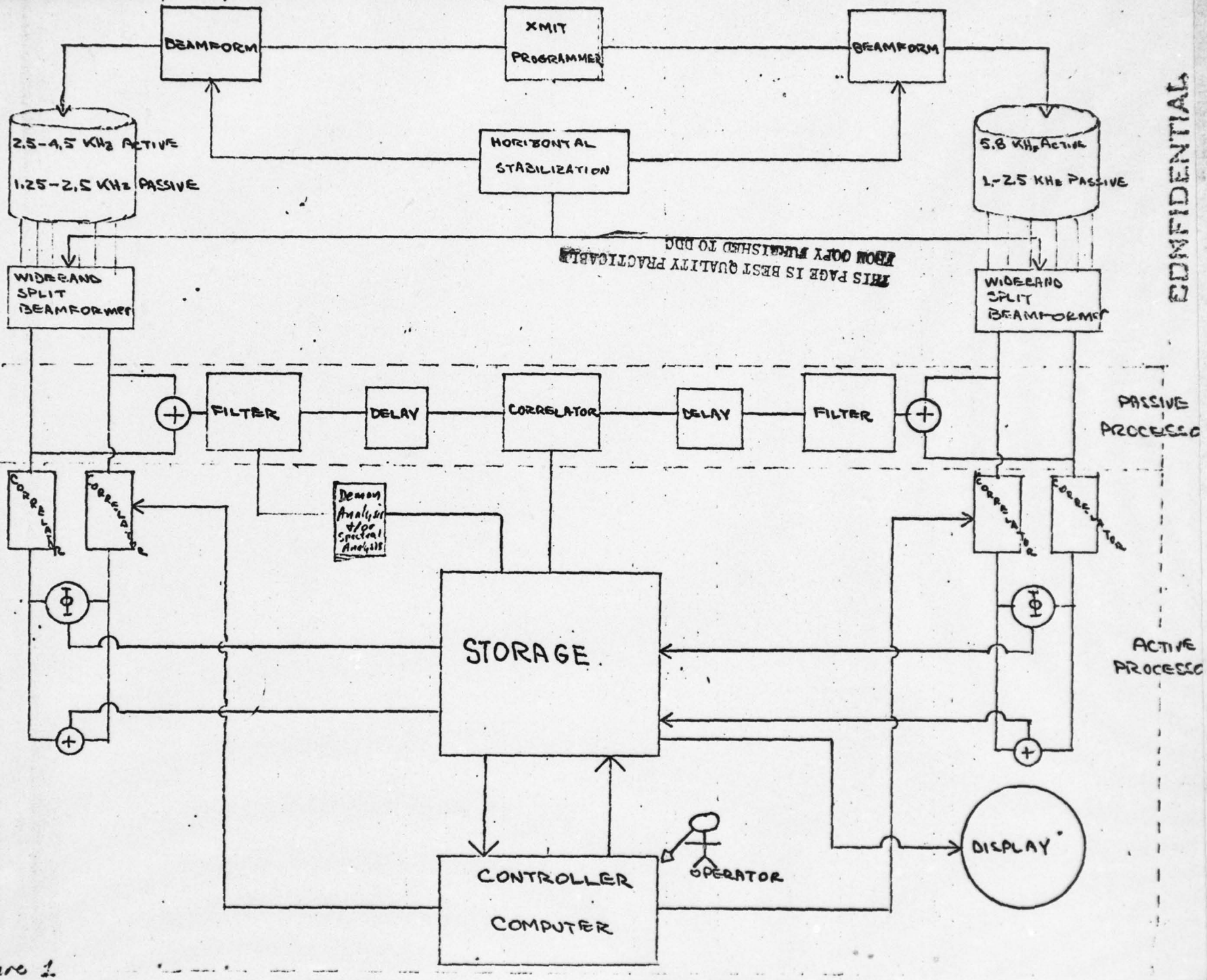


Figure 1.

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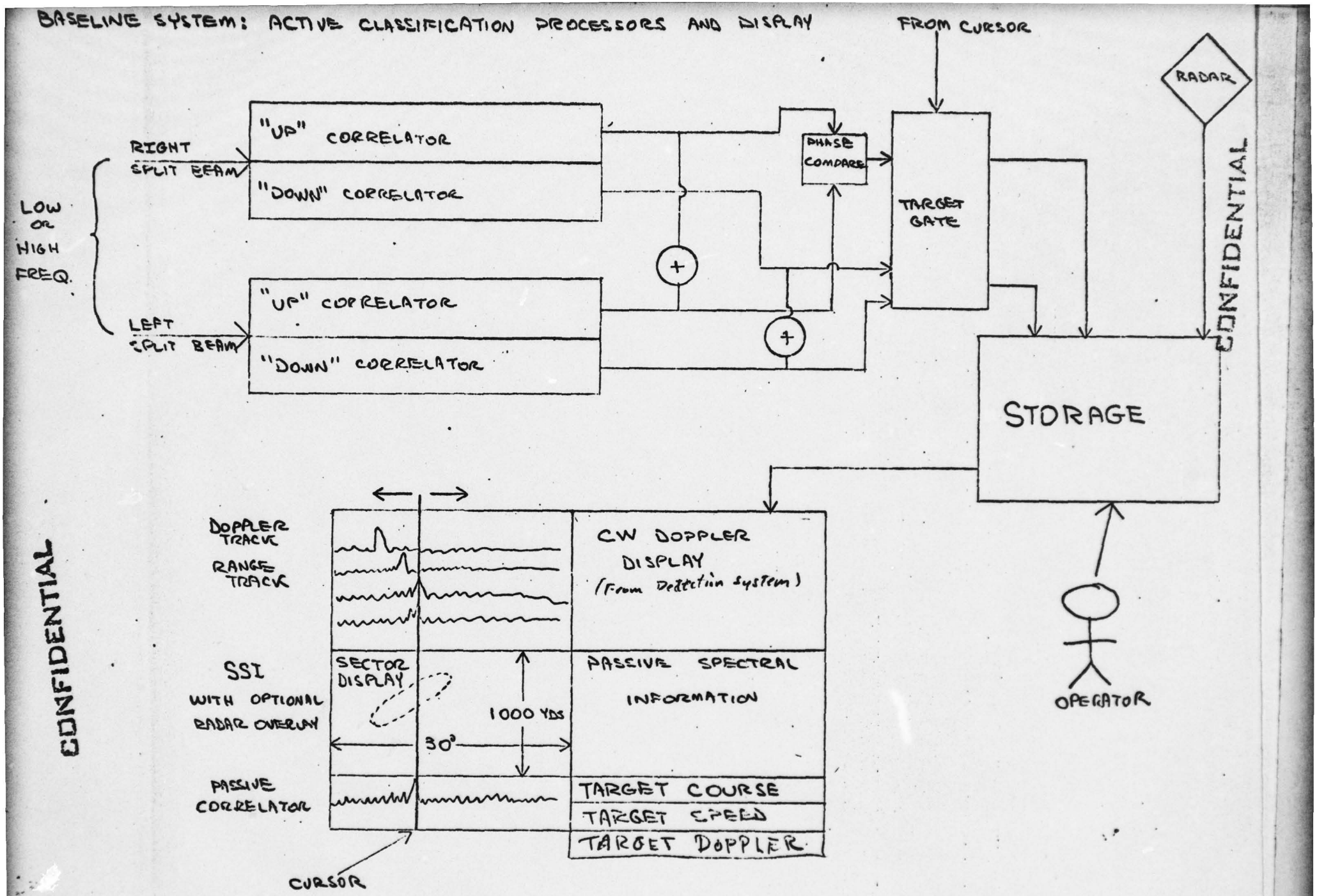

BASELINE SYSTEM: ACTIVE CLASSIFICATION PROCESSORS AND DISPLAY
FROM CURSOR
RADAR
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RIGHT SPLIT BEAM
"UP" CORRELATOR
"DOWN" CORRELATOR
LOW OR HIGH FREQ.
LEFT SPLIT BEAM
"UP" CORRELATOR
"DOWN" CORRELATOR
PHASE COMPARE
TARGET GATE
STORAGE
DOPPLER TRACK
RANGE TRACK
CW DOPPLER DISPLAY
(From Detection system)
SSI
WITH OPTIONAL RADAR OVERLAY
SECTOR DISPLAY
1000 YDS
30°
PASSIVE SPECTRAL INFORMATION
OPERATOR
PASSIVE CORRELATOR
TARGET COURSE
TARGET SPEED
TARGET DOPPLER
CURSOR
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Figure 2

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APPENDIX B

DIGITAL QUADRATURE BEAMFORMER

(U) This appendix is a general description of the design of a hardware version of the digital quadrature beamformer described in Ref. B-1. The parameters used are for forming 48 beams sequentially at a 36 kHz rate. These parameters are based on the AN/SQS-23 system but are directly adaptable to the AN/SQS-26. Figure B-1 shows the method of using the beamformer with the AN/SQS-23. The inputs to the beamformer will be the AN/SQS-23 preamplifier outputs. Figure B-2 is a block diagram of the beamformer. The beamformer essentially performs two operations:

(U) A. The beamformer assembles the quadrature components (Ref. B-2) of the beam;

$$X = \sum_{i=1}^{16} (X_i \cos \theta_i + Y_i \sin \theta_i) \quad , \qquad (1)$$

$$Y = \sum_{i=1}^{16} (X_i \sin \theta_i - Y_i \cos \theta_i) \quad , \qquad (2)$$

(U) B. The output logic forms the sum of squares of X and Y, and then takes an average of these components over 16 msec.

(U) In order to obtain the instantaneous components of the beam (X_i and Y_i, of Eqs. (1) and (2)) the analog-to-digital converter forms two words, 90 deg apart in phase, for each sample from the quadrature multiplexer (Refs. 2 and 3). Since the multiplexer sample rate is 36 kHz (determined by the AN/SQS-23 preamplifier 18 kHz frequency), the geometric A/D converter output frequency is 72 kHz. Five bits in the geometric format provide 90 dB of converter dynamic range (Ref. B-4).

(U) The control logic is decoded to shift the instantaneous X and Y values from the stave samples to the proper position in the 155 bits of shift-register memory. These values will be multiplied by the rotational

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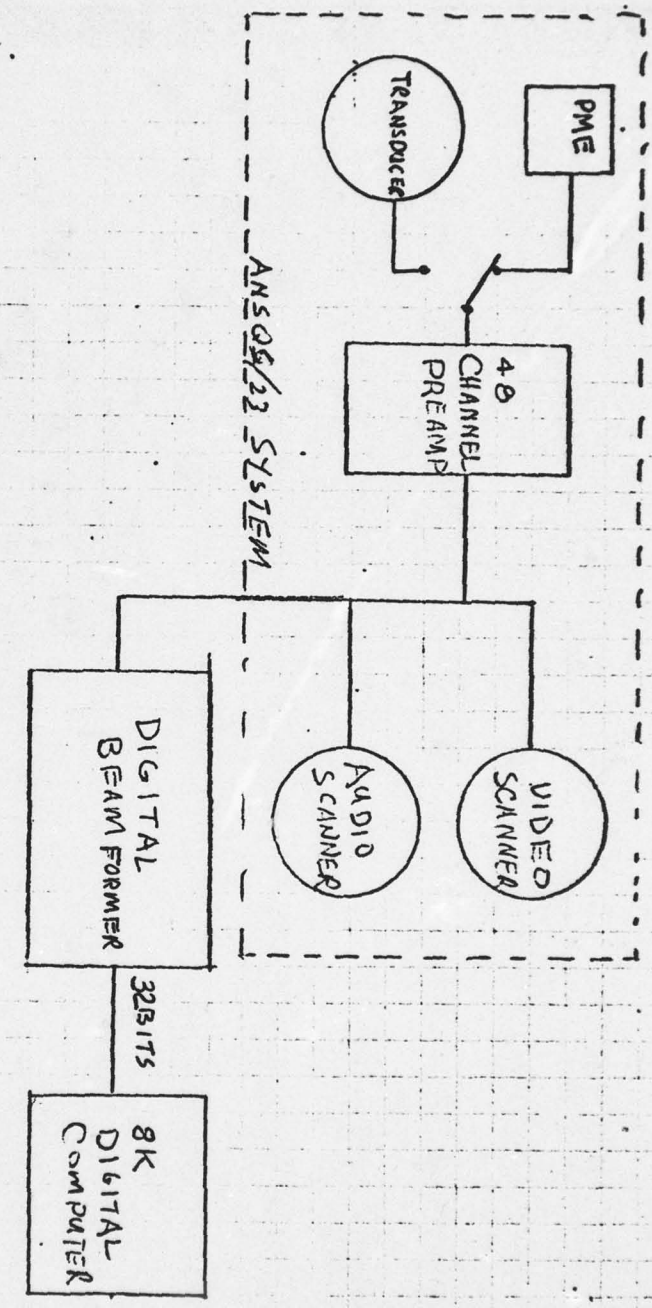


Figure B-1

Integration of Beamformer with the ANSQS/23

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Figure B-2

Beamformer Block Diagram

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components, $\pm \cos \theta_i$ and $\sin \theta_i$, to form the four products ($X_i \cos \theta_i$, $X_i \sin \theta_i$, $Y_i \sin \theta_i$, and $-Y_i \cos \theta_i$, in that order) necessary in Eqs. (1) and (2). Since the individual components are in geometrical format, a parallel adder can perform the multiplication in gate switching time. The words in geometrical format are decoded to give 2's complement binary form. The summations needed to give the quadrature components X and Y are accomplished by a parallel adder and two storage registers. The input frequency of the adder is 2.304 MHz. Since the two quadrature components are formed from sixty-four different products, the output data rate gives both quadrature components at a 36 kHz range. (Left half and right half beams are generated by summing over the first 8 and last 8 times in Eqs. (1) and (2), but are not output in this beamformer.)

(U) The output logic of the beamformer sequentially squares each of the quadrature components and sums these squares. An output accumulator sums twelve groups of 48 words to give msec average on each beam. After the averaging process is completed, the 48 words are buffered into the computer for normalization.

(U) The digital portion of the beam former is simple, small, and straightforward to build. The input multiplex switch will probably limit the dynamic range of the beamformer. Obtaining an 80 or 90 dB dynamic range from this switch should be an easy task in applying this beamformer to a system with no previous normalization (AGC or TVG). The A/D converter only has 32 states, and the speeds required are readily obtainable with 32 parallel integrated circuit voltage comparators.

REFERENCES

B-1 Quarterly Progress Report under Contract N00024-69-C-1129 for the period January through March 1969 in preparation at Applied Research Laboratories.

B-2 Pitt, S. P. and O. D. Grace, "Signal Processing by Digital Quadrature Techniques," DLR-TR-68-39, 30 December 1968.

B-3 Pitt, S. P. and O. D. Grace, "Quadrature Sampling of High-Frequency Waveforms," J. Acoust. Soc. Am., 44, 1453-1454, November 1968.

B-4 Harvel, K. W., K. J. Vaughan, and S. P. Pitt, "Wide Dynamic Range Correlator for Envelope Preservation--A Floating-Point Technique," ARL-TM-69-5 in preparation at Applied Research Laboratories.

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APPENDIX C

COMPUTER NORMALIZATION IN RANGE AND BEARING

(C) The computational procedure which has been analyzed for immediate programming locates areas which contain a larger than average signal level. These areas must be localizaed in both range and bearing in order for the computer to respond to the signals. Twenty-four samples of each beam are stored in memory, in a 24 by 72 word array. A sequential testing procedure is used to evaluate the presence or absence of a target in each bearing cell across the center of this array as shown in Fig. C-1. At the new data sample time the array is updated and the test is reapeated. Several criteria can be used to accomplish the normalization, but no study has yet been performed to determine the relative merits of each. The procedure diagrammed on Fig. 1 is one of the more complicated, but even so readily processable in a small computer.

(C) The selected target is shown on bearing 6. The first step of the procedure is to add the four cells labeled "target" (representing 60 msec in range), then to scale this value with an operator adjustable input threshold control. The area labeled "1" is added together and tested against the scaled target area. If the scaled target area is less than the sum of area 1, then the target is not localized in bearing and the test is discontinued. If it is greater than 1, test 2 is tried, etc. Areas 3 and 4 are selected to cancel the effects of reverberation from an RDT transmission, and are not needed when only ODT transmissions are used. Areas 5, 6, 7, and 8 further determine that the target is localized. Area 9 is split into two areas for the purposes of providing the split window normalization as described in Sec. III.C. If the average value of the target is sufficiently large to pass all of these tests the signal-to-background ratio is calculated, and range, bearing, and signal-to-background are stored for further use. They may be used for further computer processing for automatic detection, or used for direct display.

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3 4 5 6 7 8 9 10 11 12 13 14 15 16 . . . 35 36 37 38 39 40 . . . 71 72 1 2

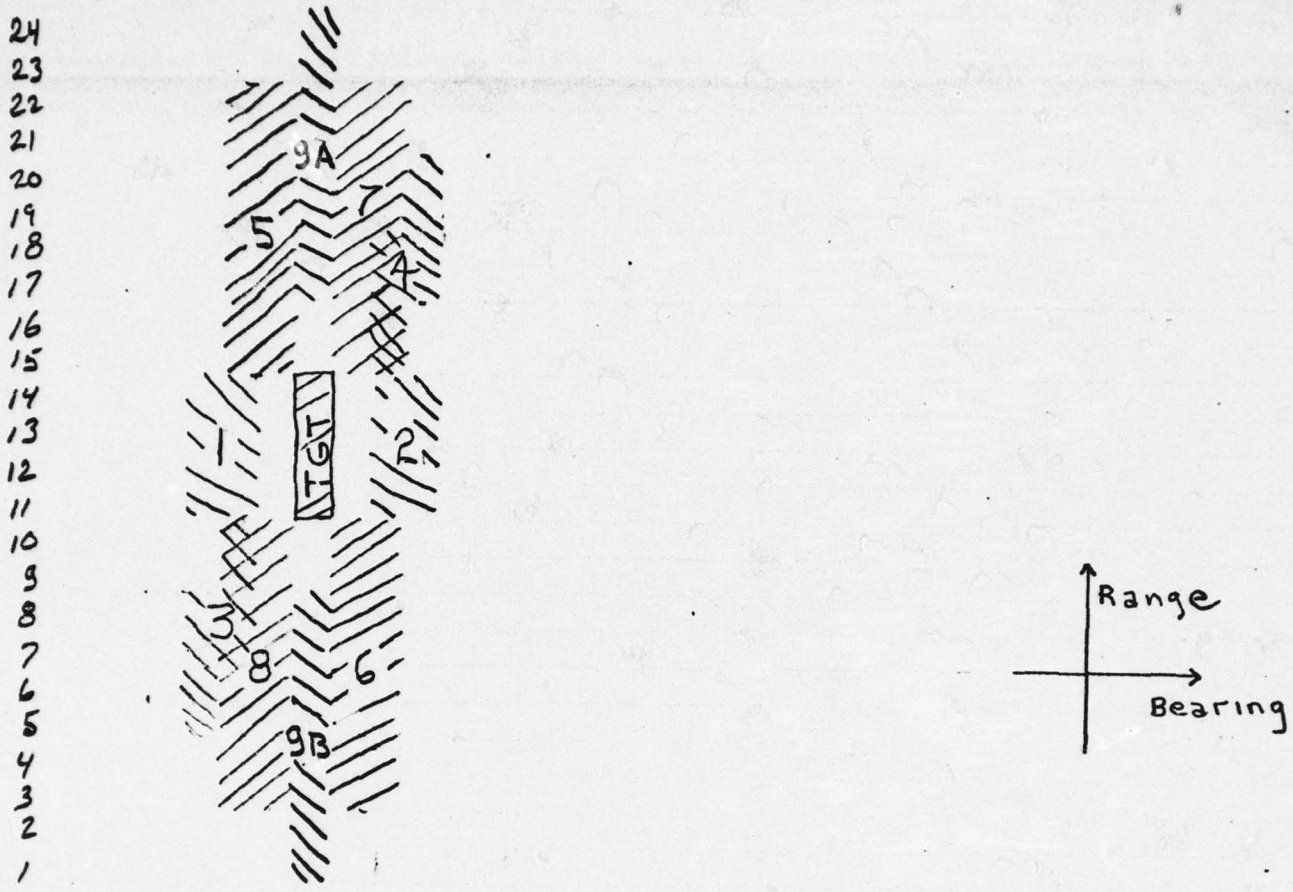


Fig 1: Test array

(C) The number of computations required is large. All nine tests can be accomplished for the 72 beams with approximately the following instructions:

Add instructions:	8712
Store instructions:	148
Compare instructions:	720
Clear instructions:	648

Accomplishing these instructions in real time allows just over a microsecond per instruction. However, it is clear that all 72 x 9 tests are not required. Any time <u>any</u> test is passed it is necessarily required that several others will fail,* and any test that fails saves computation steps. A computer reduction load of at least a factor of 3 will result from this consideration.

*If a test is passed for one range cell, it is necessary that the compliment must fail.

APPENDIX D

DESIGN OF A PREDICTION FILTER FOR PREWHITENING OF THE CW CHANNEL

In Section III.B. it was noted that one way to prewhiten the background in the cw channel is to first form a filter which predicts its next input, and then to subtract the prediction from the acutal input. There will always be an error in this process which was given as Eq. (2) in Section III.B. and is repeated here:

$$E_i = Y_{i-1} - X_i + \sum_{j=0}^{N} L_j X_{i-j-1} \qquad (1)$$

This error has a flat spectrum and becomes the output of the prewhitener. The problem addressed here is the design the filter of Eq. (1).

Matrix Approach

The mean square error, ϵ, associated with a predicting filter may be expressed as,

$$\epsilon = \frac{1}{M} \sum_{k=1}^{M} E_k^2 \quad . \qquad (2)$$

The process of designing an optimal predicting filter consists of determining a set of L's which will minimize the mean square error as indicated by Eq. (2). This can be accomplished by setting the derivative of ϵ with respect to each L equal to zero.

$$\frac{\partial \epsilon}{\partial L} = \frac{1}{M} \sum_{k=1}^{M} 2 \cdot E_k \cdot \frac{\partial E_k}{\partial L} = \frac{1}{M} \sum_{k=1}^{M} 2 \cdot E_k \cdot X_{k-\ell-1} = 0 \quad . \qquad (3)$$

Combining Eqs. (1) and (3) one obtains,

$$\frac{1}{M} \sum_{k=1}^{M} \left(-X_k + \sum_{j=0}^{N} L_j \cdot X_{k-j-1}\right) \cdot X_{k-\ell-1} = 0$$

or

$$\sum_{j=0}^{N} \left(\frac{1}{M} \sum_{k=1}^{M} X_{k-j-1} \cdot X_{k-\ell-1}\right) \cdot L_j = \frac{1}{M} \sum_{k=1}^{M} X_k \cdot X_{k-\ell-1} \qquad (4)$$

The notation of Eq. (4) can be simplified by noting that,

$$\frac{1}{M} \sum_{k=1}^{M} X_{k-j-1} \cdot X_{k-\ell-1} = \rho_{j-\ell} \quad , \qquad (5)$$

and

$$\frac{1}{M} \sum_{k=1}^{M} X_k \cdot X_{k-\ell-1} = \rho_{\ell+1} \quad . \qquad (6)$$

where ρ_i is the autocorrelation function of the input sequence.

Combining Eqs. (4), (5), and (6) one obtains,

$$\sum_{j=0}^{N} \rho_{j-\ell} \cdot L_j = \rho_{\ell+1} \quad . \qquad (7)$$

Expressed in matrix notation Eq. (7) yields,

$$\begin{bmatrix} \rho_0 & \rho_1 & \cdots & \rho_N \\ \rho_1 & \rho_0 & \cdots & \rho_{N-1} \\ \vdots & & & \\ \rho_N & \rho_{N-1} & \cdots & \rho_0 \end{bmatrix} \begin{bmatrix} L_0 \\ L_1 \\ \vdots \\ L_N \end{bmatrix} = \begin{bmatrix} \rho_1 \\ \rho_2 \\ \vdots \\ \rho_{N+1} \end{bmatrix} . \qquad (8)$$

The procedure described above is primarily useful for time stationary situations. Note that the design procedure yields one set of filter coefficients which may be used in Eq. (1) to implement a prewhitening filter.

The Iterative Approach to the Design of a Predicting Filter

The design of a predicting filter was shown above to require solving a set of simultaneous linear equations. It is well known that one way to obtain the solution of a set of simultaneous linear equations is to iterate starting from some initial guess. The iterative approach offers the advantage of being able to track the optimum solution if time variable conditions exist. To derive appropriate iterative equations suitable for the design of an optimum predicting filter it is convenient to start with the Newton iterative equations,

$$L_j^N = L_j^O - \frac{E_i}{(\partial E_i / \partial L_j)} , \qquad (9)$$

where L_j^N is a "new" filter coefficient and L_j^O is the "old" filter coefficient. Using Eq. (1) one can obtain,

$$\frac{\partial E_i}{\partial L_j} = X_{i-j-1} . \qquad (10)$$

Combining Eqs. (9) and (10) one can obtain,

$$L_j^N = L_j^0 - \frac{E_i}{X_{i-j-1}} \quad . \qquad (11)$$

Direct application of Eq. (11) calls for a correction of L_j each time step by an amount $-\frac{E_i}{X_{i-j-1}}$. It is often desirable to limit the response time of an adaptive process. This can be accomplished by passing the updated filter coefficients, L_j^N, through a low pass filter after applying the correction. Such a low pass filter can be implemented by a recursive equation of the form,

$$L_j^N = (1-\ell^{-\frac{1}{K}})\,(L_j^0 - \frac{E_i}{X_{i-j-1}}) + \ell^{-\frac{1}{K}} L_j^0$$

$$= L_j^0 - (1-\ell^{-\frac{1}{K}}) \cdot \frac{E_i}{X_{i-j-1}} \quad , \qquad (12)$$

where K is the desired time constant in samples. When $K > 10$ (as will usually be the case) $1-\ell^{-\frac{1}{K}}$ may be approximated very accurately by $\frac{1}{K}$. Using this approximation Eq. (12) reduces to,

$$L_j^N = L_j^0 - \frac{E_i}{K \cdot X_{i-j-1}} \quad . \qquad (13)$$

The corrections indicated by Eq. (13) are such that the amount that the error is reduced is the same for each filter coefficient which is

modified. This characteristic leaves something to be desired since it results in very large changes to filter coefficients when they come in registration with samples of the input which are near an axis crossing. This difficulty can be eliminated by multiplying each correction term by

$$\frac{(N+1)\cdot|X_{i-j-1}|}{\sum_{k=0}^{N}|X_{i-k-1}|} \quad .$$

The physical justification for this multiplication is that filter terms which are currently in registration with large input samples contribute heavily to the numerical value of the predictijon and by implication to any errors which may exist. When this weighting factor is included the final form of the iterative equations becomes,

$$L_j^N = L_j^0 - \frac{\text{SIGN}(X_{i-j-1})(N+1)\cdot E_i}{K\cdot\left(\sum_{j=0}^{N}|X_{i-j-1}|\right)} \quad . \qquad (14)$$

The final iterative equations have these interesting and useful properties.

(1) The equations are normalized so that a scaling change of the input does not change the iterative process.

(2) For each iterative step the magnitude of the change made in each filter coefficient is the same, the sign of the change will vary from one filter coefficient to the next as indicated by the sign of X_{i-j-1} .

The iterative process described above has been applied to a computer generated set of test data and the results are proesented in the section below.

An Example Application

To demonstrate the effectiveness of the proposed prewhitening process a set of test data was generated. The characteristics of the test data set were chosen to be representative of the problems encountered in dealing with time variable CW reverberation. A block diagram of the test data set generation procedure is shown in Fig. 1. Two statistically independent channels of white noise were used as input to the generation procedure. The sampling rate of the input noise was 1000 Hz. Noise channel 2 was passed through a bandpass filter with bandwidth of 10 Hz, center frequency of 250 Hz, and center frequency gain of 17 dB. The center frequency gain of 17 dB was introduced to hold the power level of the filter output equal to the power level of the filter input. The narrow band noise was amplitude modulated with an exponentially decaying envelope and summed with the broadband noise scaled down by a factor of 10. The time constant of the exponential envelope function was set to decrease the power level of the narrow band noise channel by 2 dB per second. Initially the power level of the narrow band channel was 20 dB above that of the broadband channel. Also the narrow band channel spectral density level was initially 37 dB above that of the broadband channel. A total of 20 seconds of data was generated and in this time interval the test data set carries out a transition from being totally dominated by the narrow band noise at the start to being totally dominated by the broadband noise at the end.

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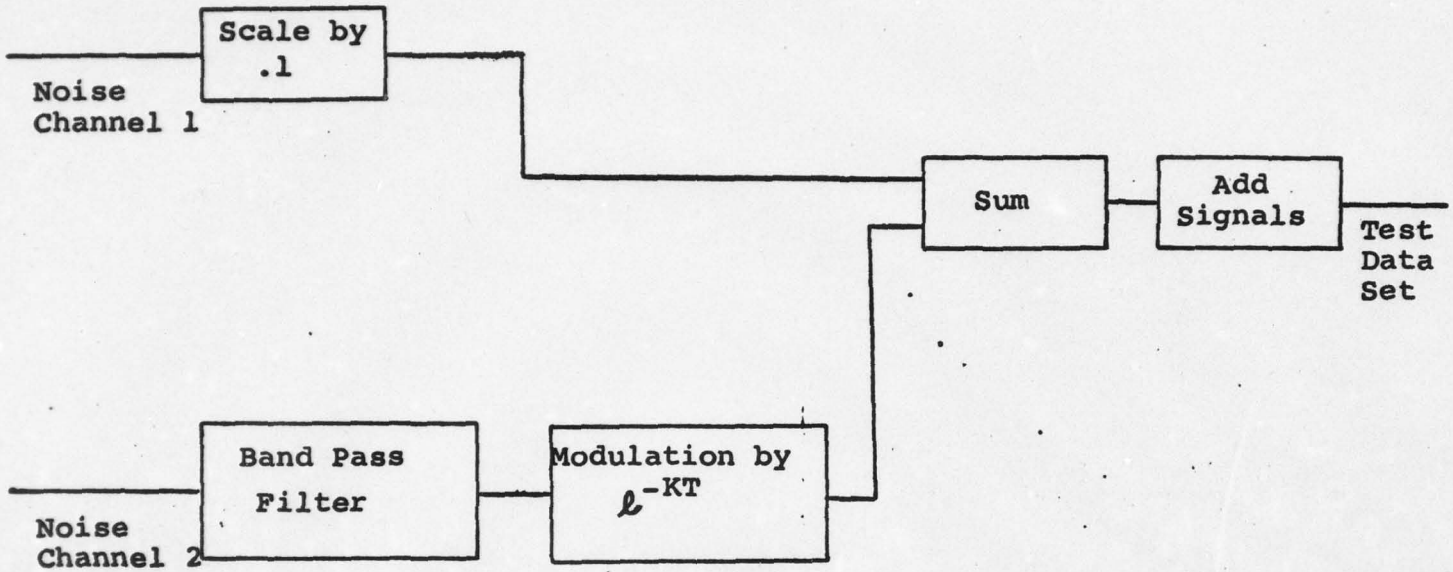


Figure 1

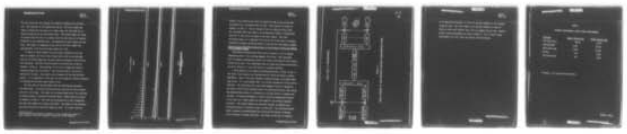
TEST DATA SET GENERATION PROCEDURE BLOCK DIAGRAM

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SIGNAL DESIGN AND COMPUTER AIDED DETECTION FOR THE AN/SQS-26 VA--ETC(U)
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Two 1/2 second sine wave signals were added to complete the test data set. The frequency of the signals was 150 Hz. The first signal was added 5 seconds from the start in a region where the test data set is heavily dominated by the narrow band noise. The second signal was added 16 seconds from the start in a region where the test data set is heavily dominated by the broadband noise. The amplitude of both signals was the same. The signal to background noise ratio of the first signal was approximately -15 dB and the second signal was -3 dB.

To obtain a visual display of how the power spectrum of the test data set changes with time it was divided into 40 end to end sections each of 1/2 second length and the power density spectrum of each section was calculated. The power density spectra are plotted end to end on channel 1 of Fig. 2. Each spectrum is 1/2 inch in length and covers a frequency range from 0 to 500 Hz.* The vertical scale is in units of square root of power. The signals can be observed in the 11th and 33rd spectra. It is important to note that the first signal is heavily dominated by reverberation and the second signal is not.

The test data set was processed using the prewhitening procedure described above. Ten filter coefficients were used and the time constant was set to 1/2 second. The output of the prewhitening filter was processed to obtain a group of spectra as described above. These spectra are shown on channel 2 of Fig. 2. Note that the reverberation is well compensated and that both signals are clearly detectable. The output of the prewhitening filter does show a long term change in level. To correct this the

*Unfortunately the frequency resolution of the reproduction shown in Fig. 2 does not match the frequency resolution of the analysis.

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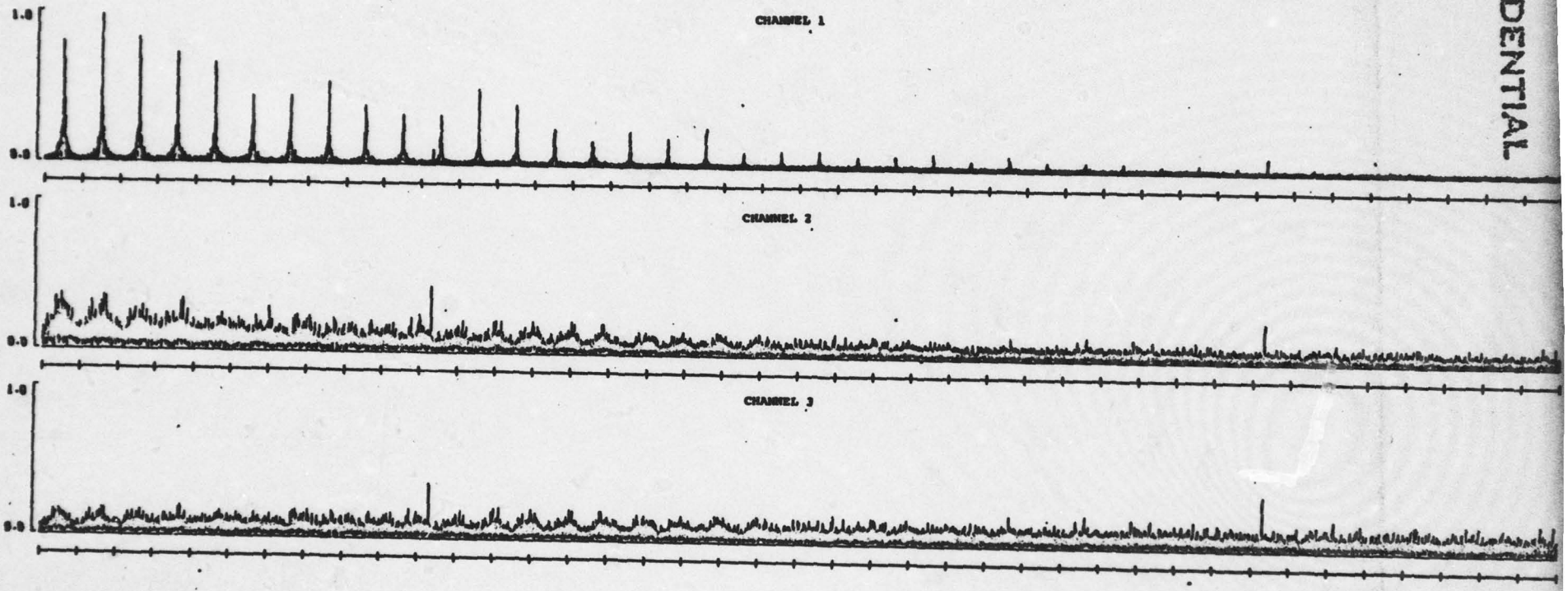


FIGURE 2

POWER SPECTRA RESULTING FROM APPLICATION OF THE ADAPTIVE PREWHITENING FILTER TO THE TEST DATA SET

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output of the prewhitening filter was passed through an AGC process and the spectra were calculated after the AGC. These spectra are shown on channel 3 of Fig. 2. Note on channel 3 that the signal-to-noise ratio for the signal which was added in the reverberation region is essentially identical to that which was added in the noise region. This very satisfying result is in agreement with the way one would expect a properly normalized CW signal processing system to perform with high Doppler signals.

Application of the Prewhitening Process to the CW Signal Processing Channels of the AN/SQS-26 Sonar

The adaptive prewhitening filter will be inserted in the CW channel immediately prior to the existing Doppler filter bank. When operating with the adaptive prewhitening filter the current reverberation notch filter should not be used. This requirement does not imply any system modifications since the insertion of the notch filter is currently optional.

A block diagram of the adaptive prewhitening filter is shown in Fig. 3. The twelve input channels are obtained from the twelve CW channel receiver amplifiers. Each of the input channels is passed through a very sharp bandpass filter. It is anticipated that a 6 or 8 pole Butterworth filter will be required. The requirement for a very sharp bandpass filter is imposed by the need to shift the CW frequency band to be positioned between 0 and 130 Hz. The downshifting modulator is followed by a low pass filter to suppress the sum band. An analog multiplexer is used to switch the appropriate channel to the input of a single sample and hold amplifier and analog-to-digital converter. The digital samples are processed through the adaptive prewhitening process as indicated by Eqs. (1) and (14). The resulting digital output sequences are demultiplexed and converted from digital-to-analog with 12 digital-to-analog converters. The output of each DAC is supplied

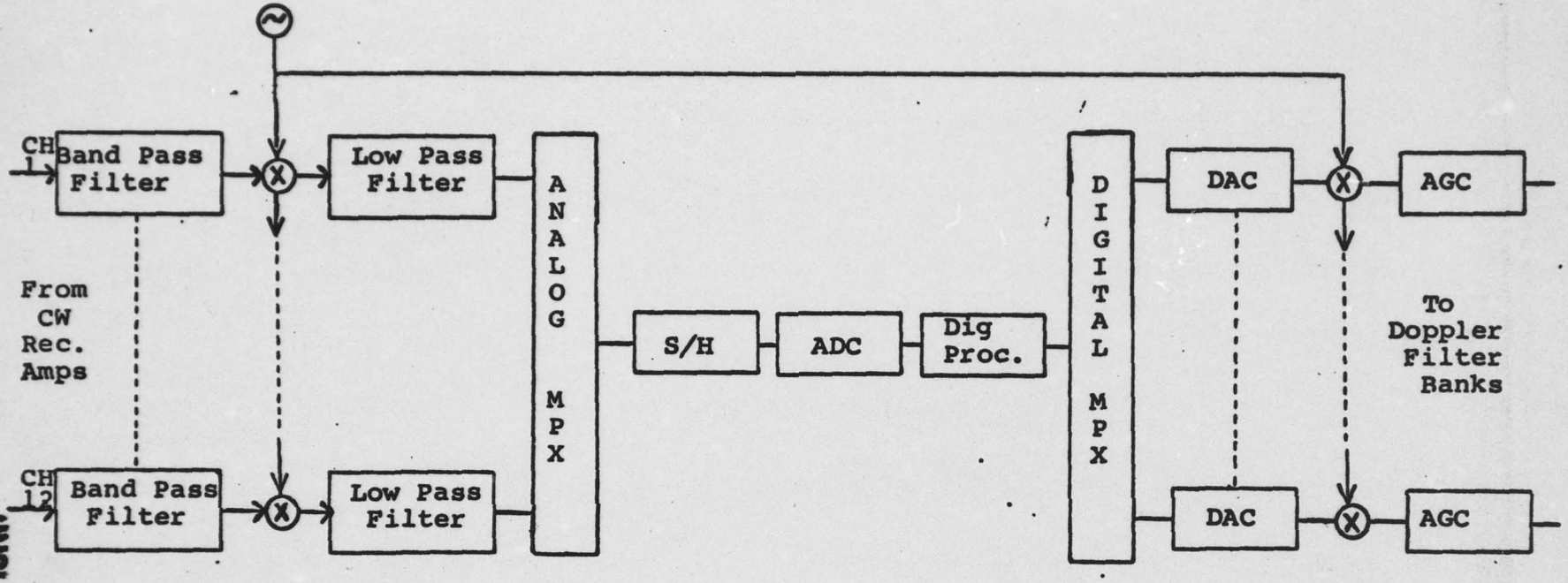


Figure 3

BLOCK DIAGRAM OF THE PROPOSED ADAPTIVE PREWHITENING FILTER

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to an upshifting modulator to return the CW data channel to the original frequency band. The final stage of the process consists of a AGC to obtain a relatively constant level into the Doppler filter bank. Nominal system timing requirements are shown in Table I. All of these timing requirements are well within the present state-of-the-art.

TABLE I

ADAPTIVE PREWHITENING SYSTEM TIMING REQUIREMENTS

Function	Single Channel Rate	Twelve Channel Rate
A/D Conversions	300 Hz	3,600
Multiply/Add*	3,000	36,000
Additional Adds	3,600	43,200
Divide	300	3,600
D/A Conversions	300	3,600

*Assumes a ten term predicting filter.

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