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PAIR - AN/SQS-26 PERFORMANCE COMPARISON.(U)
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MEMORANDUM

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To: R. D. Isaak (12) 27p.
From: B. M. Brown

(6) Subj: PAIR - AN/SQS-26 Performance Comparison

## 1. INTRODUCTION AND SUMMARY

Questions concerning the relative performance effectiveness of the PAIR and the AN/SQS-26 sonars can best be answered by describing the signal excesses available to the two systems

a. When they are operated in the same environment.

b. When they are operated with the pulse forms for which they are designed.

c. When they are operated with the same percent clutter on matched displays.

A comparison of two systems on this basis is fairly simple even when a number of environmental situations are considered. The complexity increases rapidly when all possible combinations of the systems are introduced into the comparison. This memorandum presents a performance comparison of (1) the PAIR and (2) the AN/SQS-26 system as presently constituted and in the active search mode. Two alternative systems are also considered (3) the PAIR pulse with the AN/SQS-26 processor and the (4) AN/SQS-26 system working at the AN/SQS-23 frequency.

The conclusions reached are summarized here:

(1) The PAIR processor requires 7 to 8 dB higher input signal-to-noise ratio for 0.50 detection probability than does the AN/SQS-26.

(2) Longer pulse length and higher source level employed by the AN/SQS-26 raises the reverberation level relative to the echo by 5.4 dB in comparison to PAIR. As a result the echo excess of the AN/SQS-26 relative to PAIR amounts to no more than 2 to 3 dB when reverberation limiting exists.

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(3) Substitution of the AN/SQS-26 processor for the PAIR processor while retaining the PAIR pulse would provide a 7 to 8 dB performance improvement with ideal signals. However, energy splitting degradation, that due to range-resolved scatterers and that due to differential doppler in the target, is known to affect the SQS-26 far more than PAIR, amounting to 3.5 to 5 dB in actual beam aspect target echoes and is expected to be somewhat greater for other aspects. Therefore the net improvement in performance expected by this substitution will be less than 3 to 4.5 dB.

(4) Substitution of both the AN/SQS-26 pulse form and processor at the AN/SQS-23 water frequency is considered prohibitive because of the likelihood that the existing AN/SQS-23 transducers and transmitters would have to be scrapped and because pulse form modification with the present systems will force the choice of lower source levels. Both of these alternatives introduce significant delays in providing improved sonar performance to the fleet.

(5) Since the decision has been made to make use of the AN/SQS-23 transmitters and transducers in the PAIR, the choice of the PAIR processor provides very good detection performance which is within 2.5 dB of that which could be provided by an AN/SQS-26 processor. Any deviation from this plan will introduce serious delays in providing improved sonar performance in the fleet.

In this comparison the PAIR passive performance relative to the AN/SQS-26 has not been considered. This improved capability is definitely a plus on the side of the PAIR as is the automatic normalization of the PAIR processor. This latter point has not been emphasized because by the time PAIR is on board a few ships the then-in-production AN/SQS-26 model will very likely have as good normalization characteristics.

## 2. THE PROCESSOR PERFORMANCES

When two signal processing systems are to be compared, it is necessary to determine the relationship between the signal-to-noise ratio at the input of each processor which will provide 0.50 detection probability under specified clutter conditions. In this case the comparison will be made in terms of the single-ping performance. The single ping comparison will be sufficient for describing the relative performances because similar display gain is planned for the two systems.* The single-ping clutter will be stated in terms of the percent of clutter in the matched displays.

## 2.1 PAIR

As presently planned the PAIR system will use a 144 ms, 450 c/s linear FM pulse. The receiver will consist of a wave-period processor. The performance of the processor is described in detail under Task 15 of the NEL letter report to Bureau of Ships, Code 1633, dated 22 September 1965. The pulse form, receiver bandwidth, and the range scales have been modified since that time. The present discussion is based upon a simulation of the processor performance using the modified PAIR characteristics.

The range scale employed in this comparison is 20 kyd; the range resolution obtainable with the 144 ms pulse is 0.12 kyd. The 48 display range bins on a single display bearing provide a range resolution of 0.416 kyd. In order to match the display to the processor range resolution (0.416)/(0.12) $\approx$ 3.6 independent processor output samples must be OR-gated into a single range display bin.

If $p_1$ is the probability that a single independent sample of noise exceeds a threshold, the probability $P_k$ that at least one of $k = 2.6$ samples will exceed the threshold is

$$P_k = 1 - (1 - p_1)^k \ .$$

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*A second memorandum is to be prepared in which maximum detection ranges will be estimated including display gain.

The simulation provides a plot of the processor input signal-to-noise ratio required for 0.50 detection probability as a function of $p_1$. The above expression with $k = 3.6$ was used to convert the curve in terms of $p_1$ to one in terms of $P_k$. The predicted processor performance appears in Fig. 1.

## 2.2 THE AN/SQS-26

A similar approach is made in estimating the performance of the AN/SQS-26. The first step is the simulation of the correlator (the AN/SQS-26 processor) performance with 500 ms, 100 c/s linear FM pulses. This simulation provides a plot of the processor input signal-to-noise ratio required to provide 0.50 detection probability as a function of $p_1$, the single sample probability that noise alone at the output of the processor will exceed the threshold.

The conversion to a similar plot in terms of $P_k$ depends upon the number of range bins in the display per beam, the number of beams in the display, and the time between independent samples at the output of the processor.

Resolution Time: The time between independent samples is determined by the reciprocal processor bandwidth; $1/B = 10$ ms which provides a range resolution of 8.33 .. yards.

Number of Beams: 12 beams are used in covering a 100° sector.

Number of Range Bins: With 12 beams 2400 range bearing bins will provide 100 range bins per beam on a 20 kyd scale, that is 200 yds per bin.

From these data it follows that $200/8.33 = 24$ independent noise samples must be OR-gated into a single range bin to achieve a matched display. In the expression for $P_k$, k must therefore be set at $k = 24$. The resulting predicted performance appears in Fig. 1.

## 2.3 PROCESSOR PERFORMANCE COMPARISON

The first and many times only comparison of the performances of the two systems is based upon the curves in Fig. 1. On the basis of these curves it is tempting to conclude that the AN/SQS-26 performance is so much better than the PAIR performance that the PAIR system should be dismissed without further consideration. That this conclusion is unjustified will be shown in the succeeding section where the target echo levels and background levels in which each system must operate are presented. Although Fig. 1 shows that the AN/SQS-26 processor can provide detections of signals 7 to 8 dB lower in input signal-to-noise ratio than the wave-period processor, it will be shown in the next section that the AN/SQS-26 pulse form presents its processor with a correspondingly higher reverberation level so that the 7 to 8 dB does not represent a comparison of the system performances.

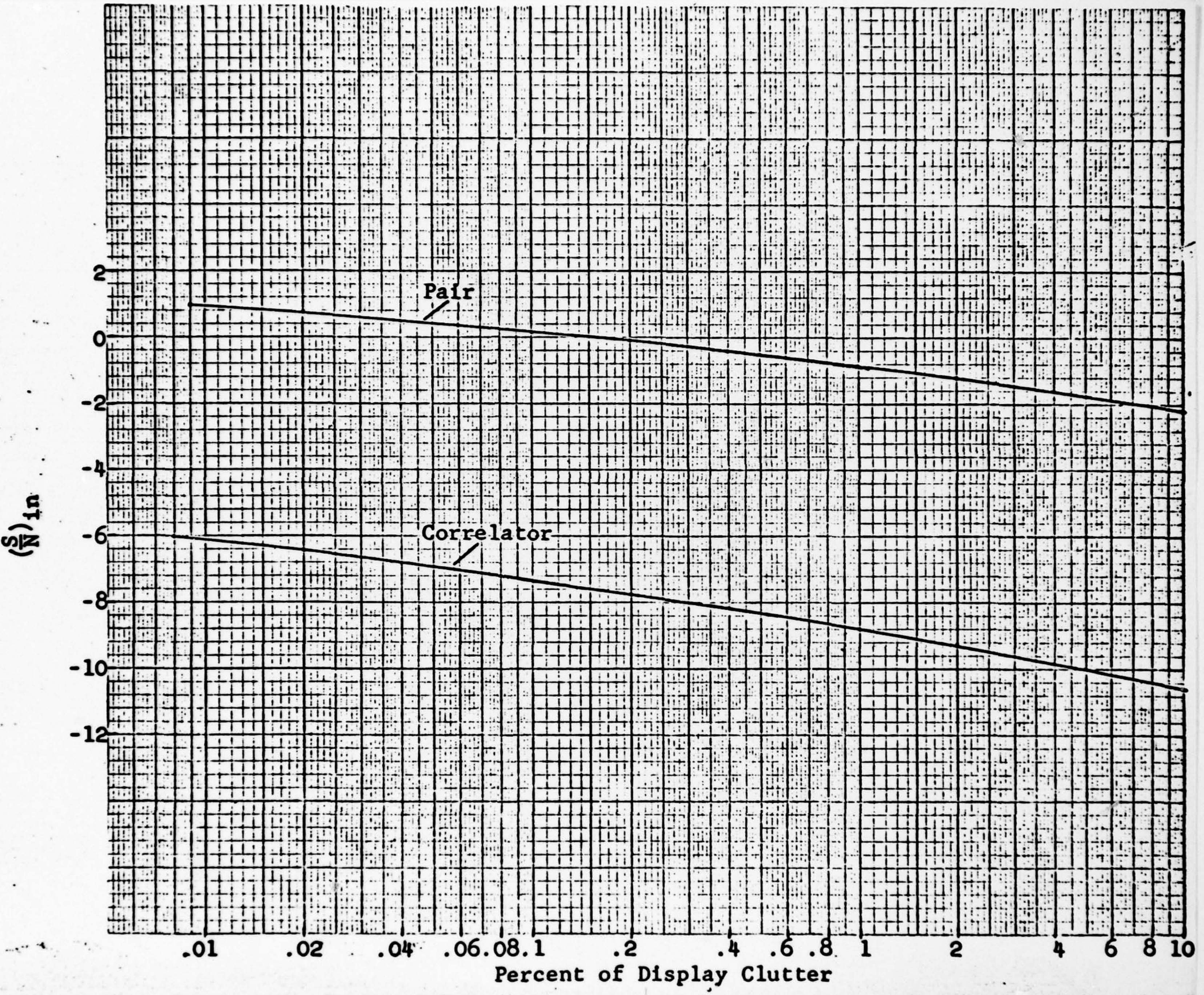

Figure 1 $\frac{S}{N}$ INPUT REQUIRED FOR 0.5 DETECTION PROBABILITY

## 3. THE BACKGROUND AND TARGET LEVELS

The source level, pulse length, and bandwidth determine the target levels and the reverberation levels with which the processors must operate. The effect on relative performance contributed by these quantities is comparable to the difference in processor performance shown in Fig. 1. The effect will be illustrated for specific operational conditions in this section.

### 3.1 THE PAIR AND AN/SQS-26 IN SHALLOW WATER

In order to compare the operational effeciveness of PAIR and AN/SQS-26, an example showing the echo levels, reverberation levels, and noise background levels has been prepared. The levels were computed using Dr. W. H. Watson's performance prediction program with the following system and environmental characteristics:

| | PAIR | AN/SQS-26 |
|---|---|---|
| Source Level (dB) | 135 | 140 |
| Pulse Length (ms) | 144 | 500 |
| Bandwidth (c/s) | 450 | 100 |
| Target Strength (dB) | 15 | 15 |
| Water Depth (fath) | 30 | 30 |
| Velocity Gradient | Negative to Bottom | |
| Sector Coverage (°) | 300 RDT | 110 |
| Depression (Mode) | 0°(SC) | 0°(BB) |
| Range Scale (kyd) | 20 | 20 |

The array patterns were computed using the array geometry and specified shading and phasing information appropriate to the two systems. Attenuation was estimated with the coefficient $0.033f^{3/2}$. The propagation involved paths which were refracted to the bottom one or more times in getting to the target; the bottom loss per bounce was set at 1.5 dB.

Figure 2 presents for PAIR four plots as a function of range: the target echo level at the input to the wave period processor as a function of range to the target, the reverberation level as a function of range on the display, the ship's self-noise level, and (dashed) the required target level for 0.50 detection probability as a function of target range. The position of the dashed curve is 2 dB below the background level; this corresponds to operation of the display at 5% clutter. (See Fig. 1).

It is clear that signal excesses lying between 4 and 17 dB exist out to 16 kyd. This performance is comparable to that which is expected with an "alerted" operator; the 0.50 probability of exceeding the threshold is usually not sufficient for 50% detectability with an unalerted operator on a single ping basis. It should also be noted that the detection range limit occurs near the point where noise limiting sets in.

The corresponding curves for the AN/SQS-26 are shown for the same environmental conditions in Fig. 3. In this figure signal excess lying between 6 and 20 dB is in evidence in the region of reverberation limiting. In this case also noise limiting exists at the maximum detection range of about 26 kyd.

The two systems provide almost equivalent operation in the region in which reverberation limiting exists, the signal excesses being only 2.5 dB less for the PAIR than for the AN/SQS-26. Significant differences begin to appear only after noise limiting occurs.

The reason for this equivalent performance is quite clear when considered in the light of the pulse length and bandwidth choices. The time-bandwidth product is 50 for the AN/SQS-26 and is 65 for PAIR. The incoherent character of the PAIR processor causes its performance to fall some 7 or 8 dB below the coherent AN/SQS-26 performance. That is, the AN/SQS-26 processor

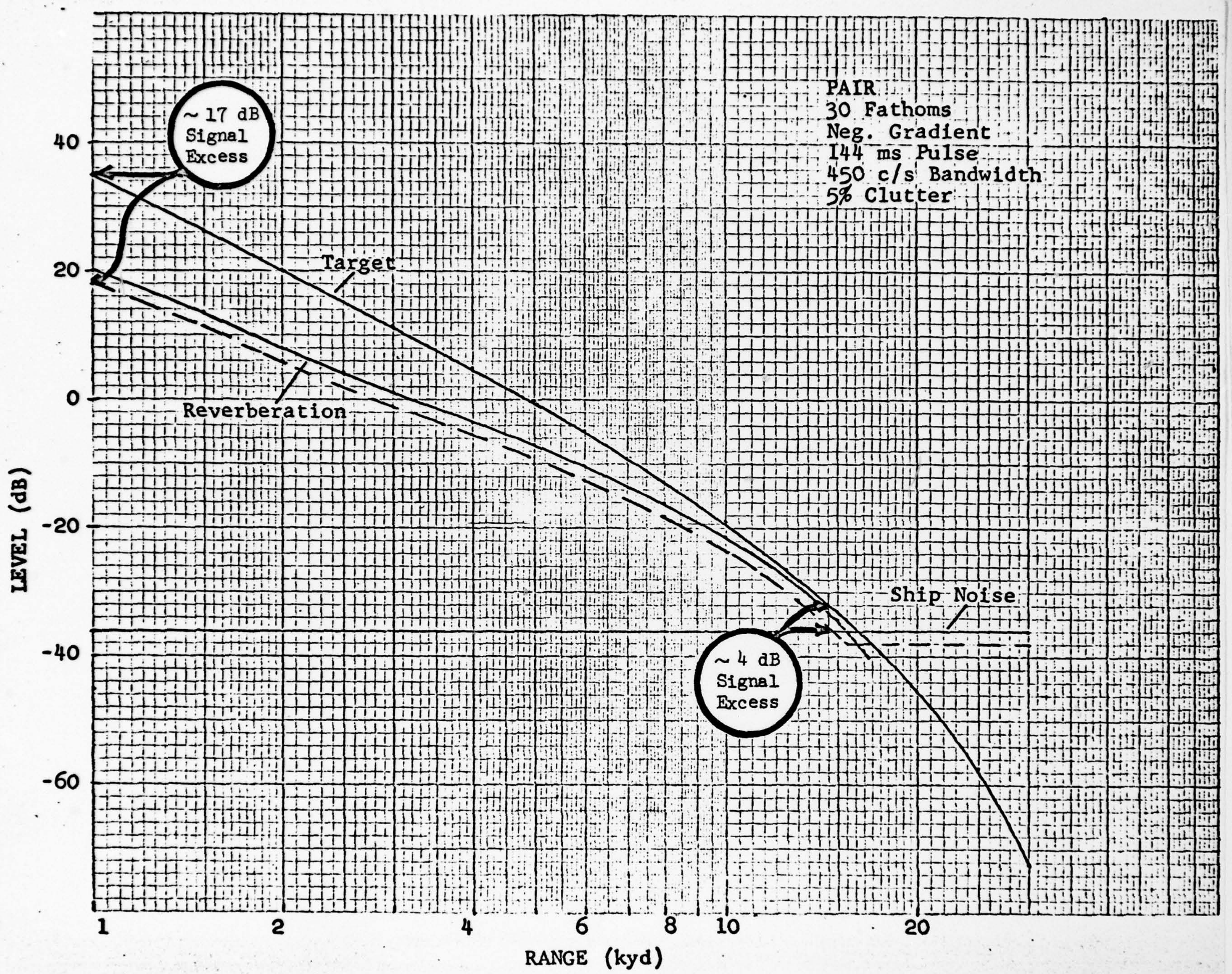

Figure 2 PAIR SHALLOW WATER PERFORMANCE

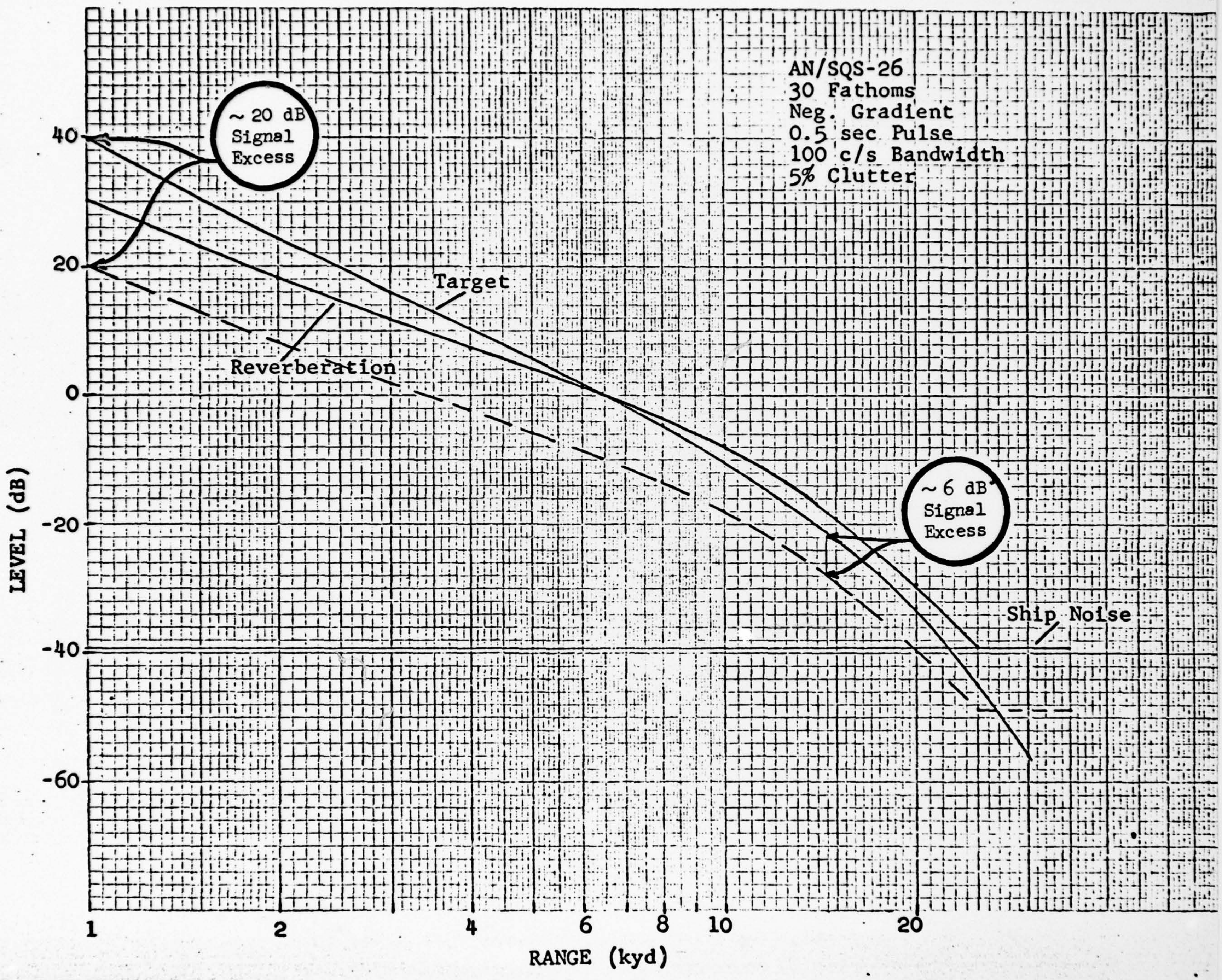

Figure 3 AN/SQS-26 SHALLOW WATER PERFORMANCE

can "dig down" 7 or 8 dB further into the background and bring up a signal than can the PAIR. However, the longer pulse length of the AN/SQS-26 raises the reverberation level 5.4 dB and its higher source level raises both the target level and the reverberation another 5 dB. This is a net 5.4 dB lower signal-to-noise ratio than for the PAIR. The net advantage of the AN/SQS-26 over PAIR in performance, measured in signal excess, then is not expected to be more than 1.6 to 2.6 dB when reverberation is the background.

The detection range comparison is also available from the plots in Figures 2 through 7(b). The range at which the target level passes through the 50% detection level is the single ping maximum detection range. The detection ranges have been read from the curves and are listed in Table I. The important shallow-water, negative-gradient and the below-layer performances are listed in the first three rows.

The detection range of the PAIR is comparable to that of the AN/SQS-26 in the difficult below-layer situation. This is a direct result of the 2 dB overall performance difference of the two systems under reverberation limited conditions.

The detection range of the AN/SQS-26 exceeds that of PAIR by a ratio of 1.47 in the shallow-water, negative-gradient situation. Both PAIR and the AN/SQS-26 seem to perform adequately in this situation since they reach 17 and 25 kyd. Over most of these range intervals the background is reverberation. Both systems become noise limited at maximum detection range. Approximately 1.33 of the range ratio is attributable to the higher source level of the AN/SQS-26.

The favorable sonar conditions used in the performance comparisons in the last two rows result in a AN/SQS-26 detection range 1.44 times the

## TABLE I

Detection Range (kyd)

| Water Depth (fathom) | Layer Depth (feet) | Target Position | Range PAIR | Range AN/SQS-26 | Range Ratio |
|---|---|---|---|---|---|
| 30 | Neg. Gradient | ---------- | 17 | 25 | 1.47 |
| 1400 | 100 | Below Layer | 1.60 | 1.68 | 1.05 |
| 100 | 100 | Below Layer | 1.60 | 1.75 | 1.09 |
| 1400 | 100 | Above Layer | 18 | 26 | 1.44 |
| 100 | 100 | Above Layer | 17 | 26 | 1.44 |

detection range of the PAIR. In this example also both systems have reached noise limited conditions at maximum detection range. Again a large fraction of this detection range ratio is attributable to the high source level of the AN/SQS-26. Since submarines have the option of operating below-the-layer, these cases are of less significance than the first three cases.

## 3.2 PAIR AND AN/SQS-26 WITH SURFACE CHANNEL

Figures 4(a) through 7(b) show plots similar to those in Figs. 2 and 3 for in- and below-layer targets for both the PAIR and the AN/SQS-26 in 1400 fathom water and in 100 fathom water. The conclusions listed in the preceeding section may be stated for these examples also.

One remark concerning the 100 fathom below-layer results is in order. The existence of downward refracted bottom bounce paths has been neglected. The possibility of such paths will upgrade the below-layer maximum detection range for both PAIR and the AN/SQS-26.

## 3.3 PAIR PULSE WITH AN/SQS-26 PROCESSING

An alternate approach is to use the PAIR pulse form with the AN/SQS-26 processing system. The prediction of the performance of this system can be made using the same set of correlator curves* used in specifying the AN/SQS-26 performance. The bandwidth of this postulated system is 450 c/s so that k for this processor is 4.5 times as large as the value employed previously for the correlator. When the curves are entered as before, the plot for this processor if added to Fig. 1 would fall less than 0.3 dB below the AN/SQS-26 correlator plot. The higher inherent clutter rate and the increased processing gain almost exactly compensate in the overall performance.

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*These curves are included in Appendix I.

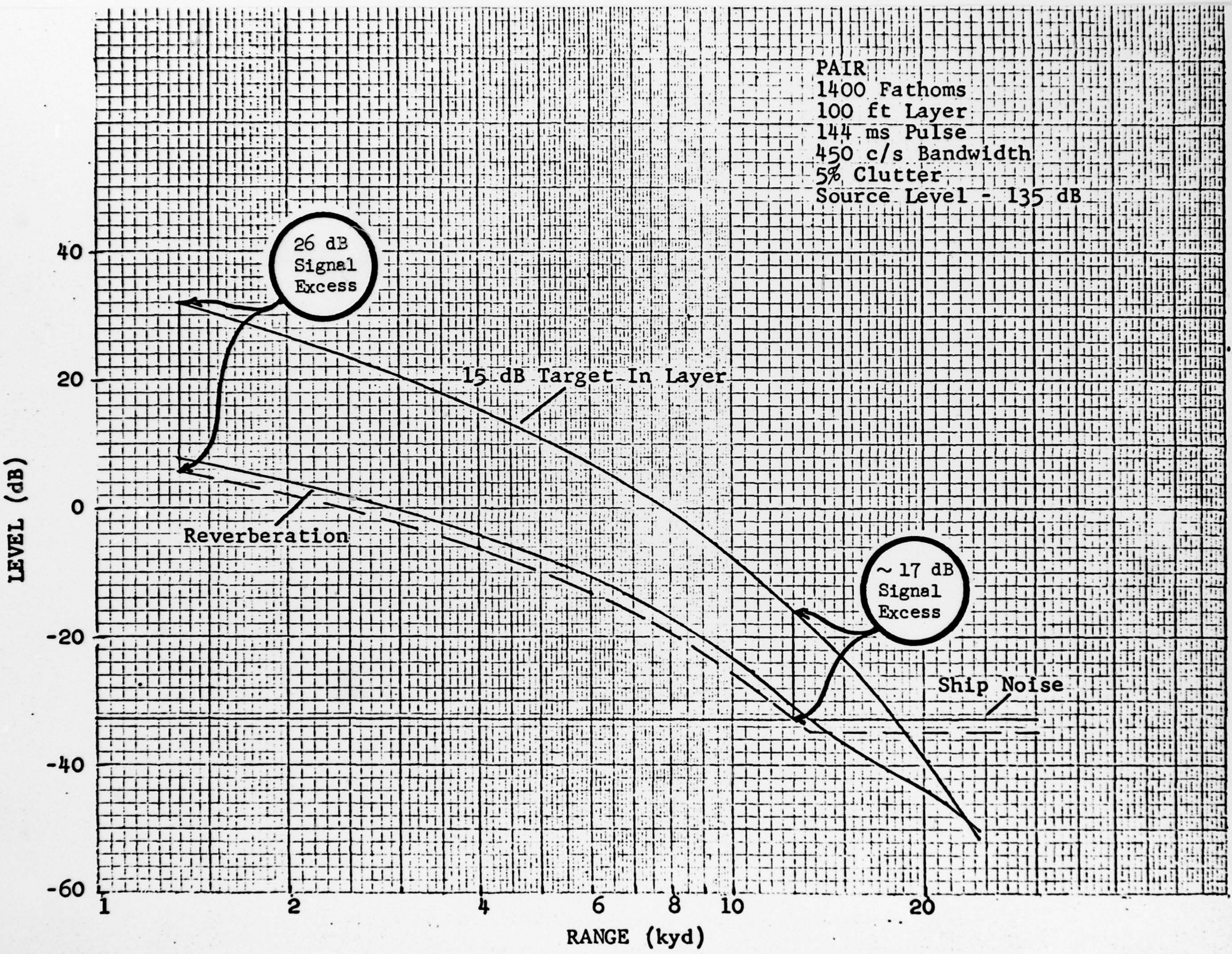

Figure 4(a) PAIR WITH IN-THE-LAYER TARGET, 1400 FATHOM WATER

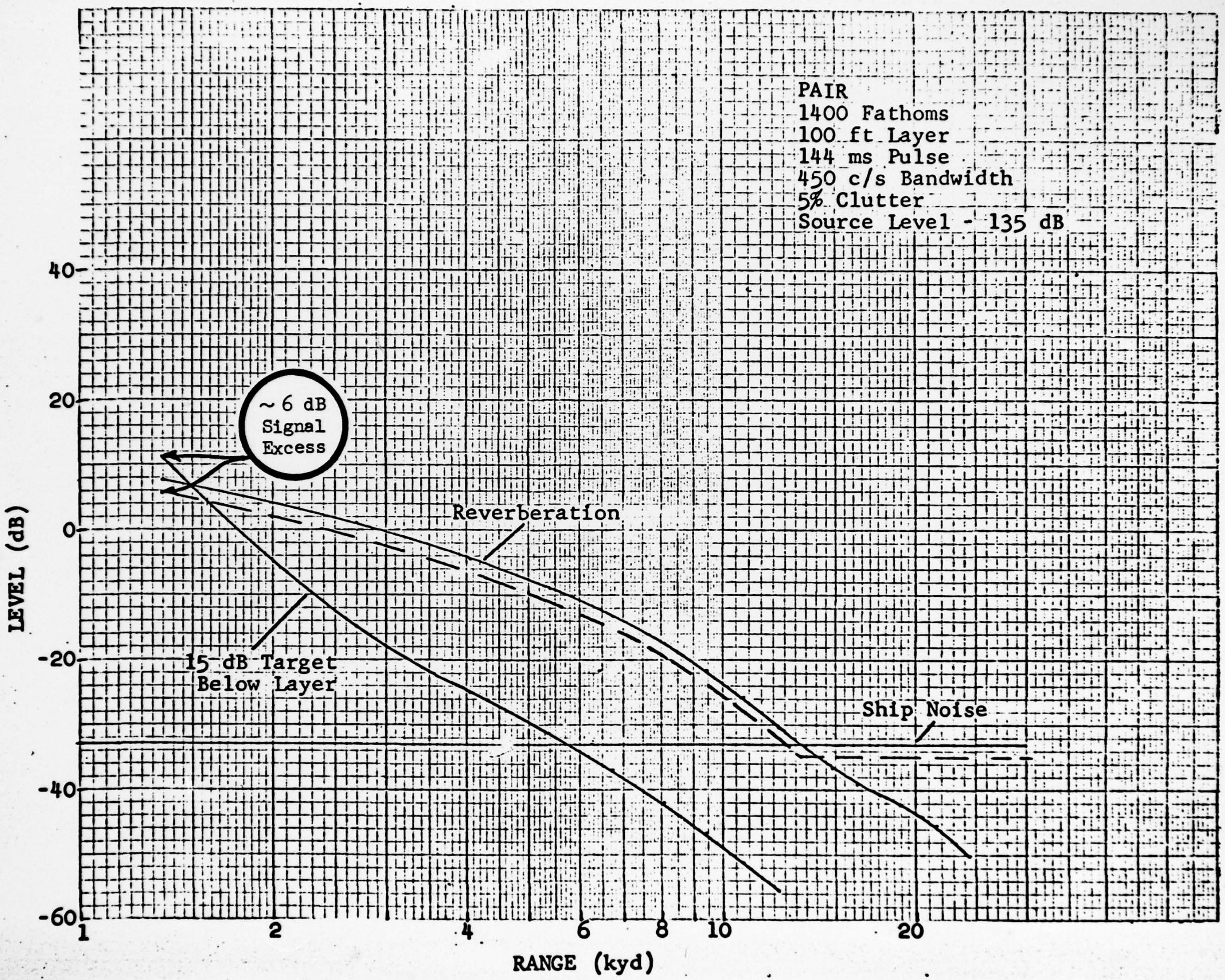

Figure 4(b) PAIR WITH BELOW-LAYER TARGET, 1400 FATHOM WATER

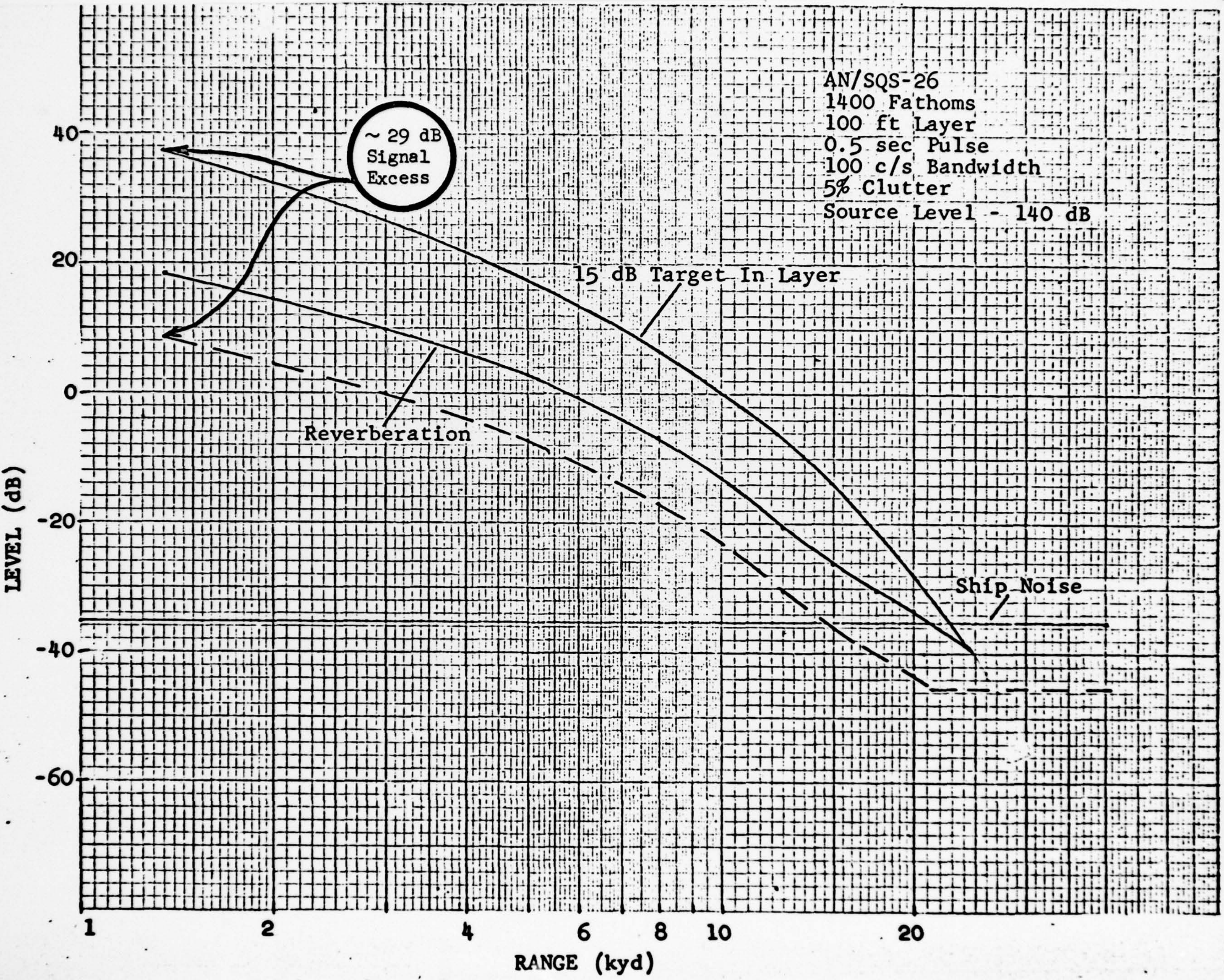

Figure 5(a) AN/SQS-26 WITH IN-THE-LAYER TARGET, 1400 FATHOM WATER

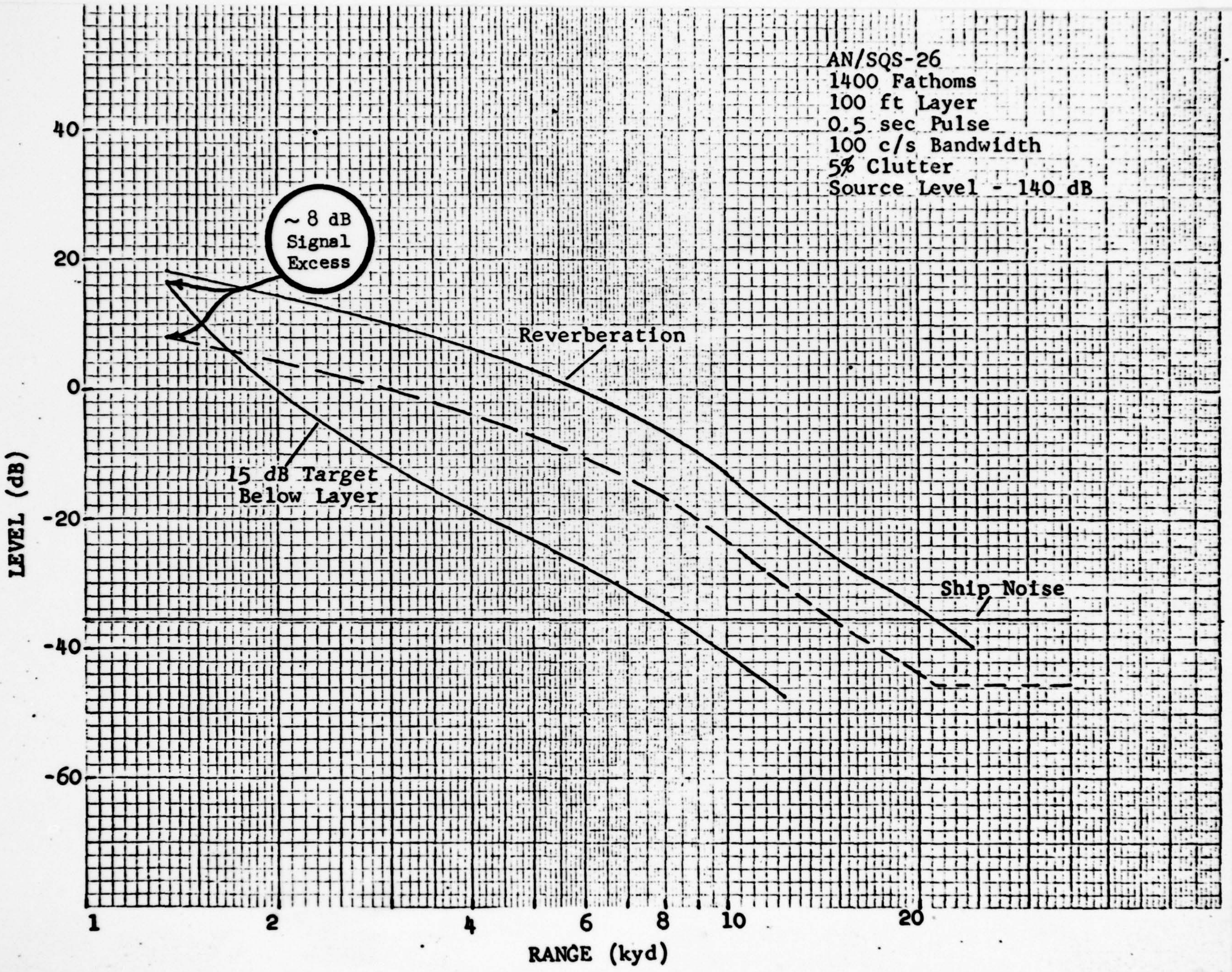

Figure 5(b) AN/SQS-26 WITH BELOW-LAYER TARGET, 1400 FATHOM WATER

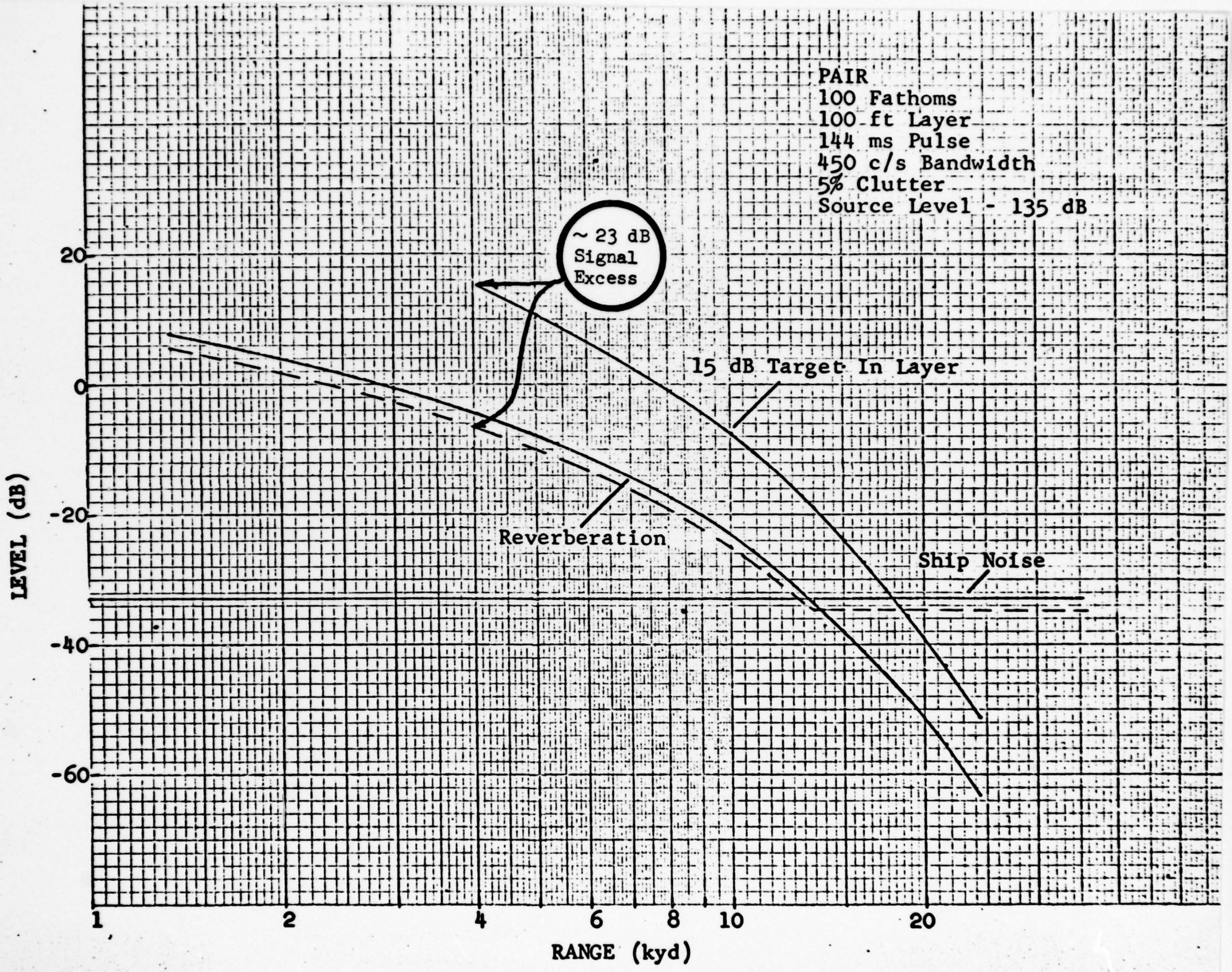

Figure 6(a) PAIR WITH IN-THE-LAYER TARGET, 100 FATHOM WATER

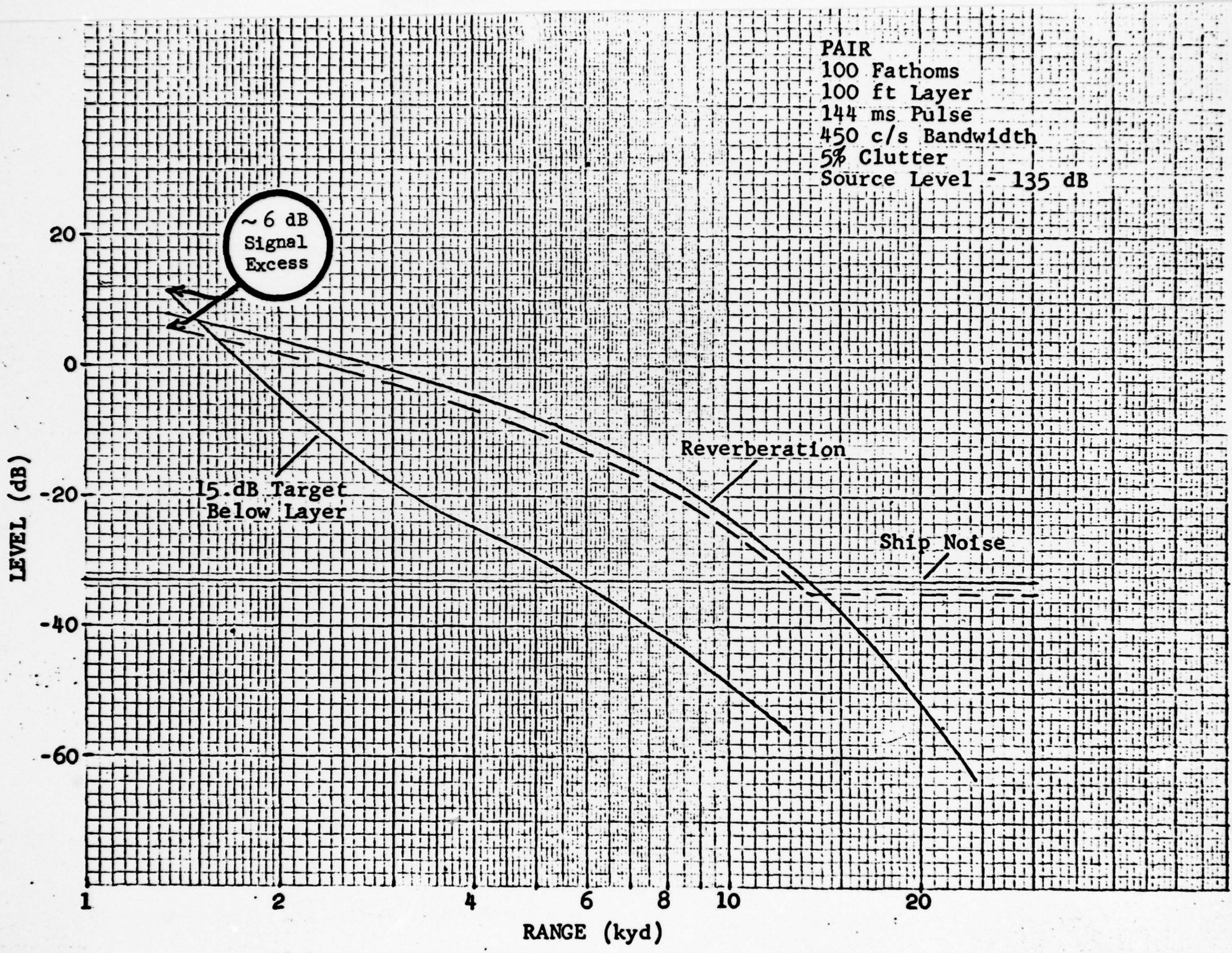

Figure 6(b) PAIR WITH BELOW-LAYER TARGET, 100 FATHOM WATER

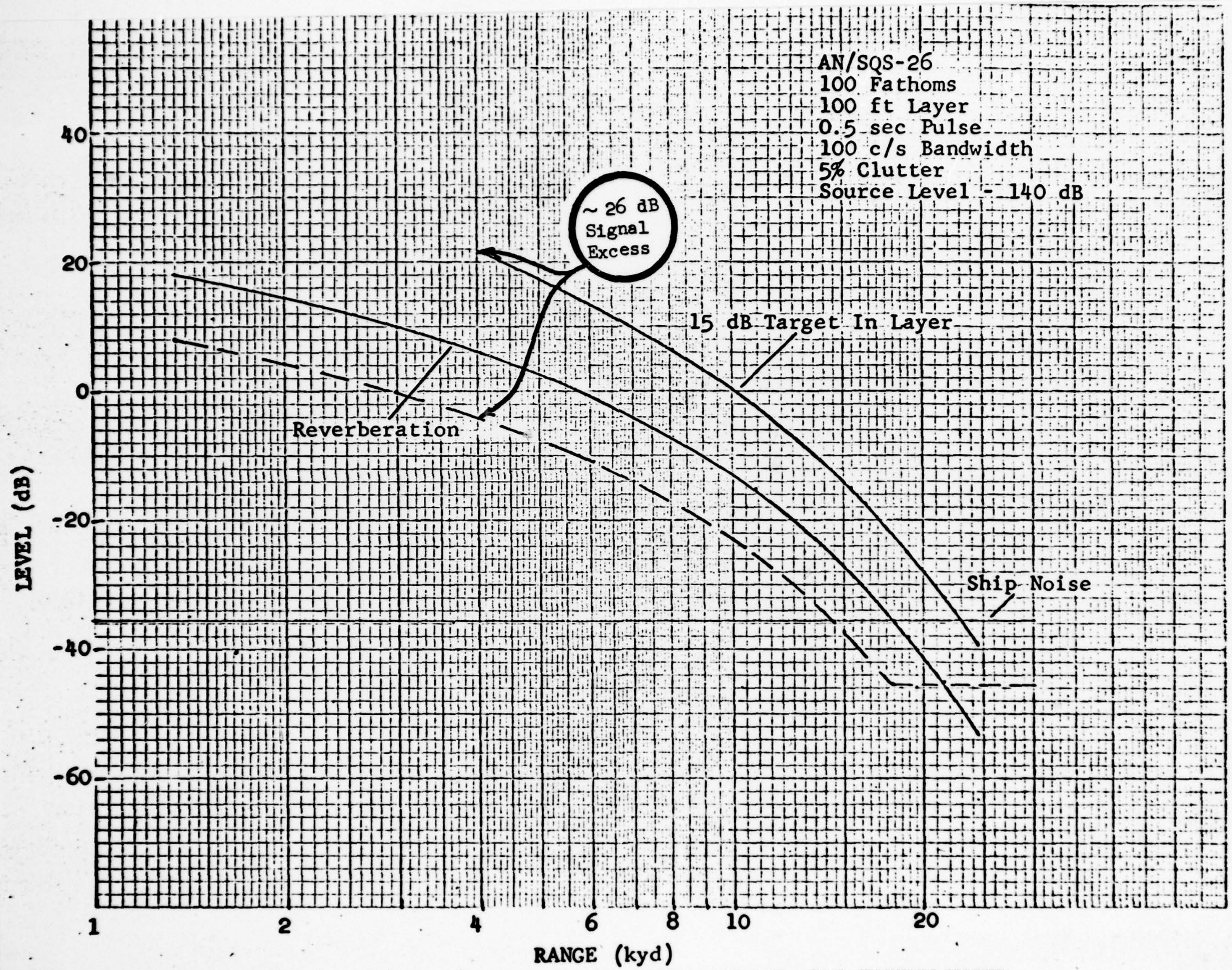

Figure 7(a) AN/SQS-26 WITH IN-THE-LAYER TARGET, 100 FATHOM WATER

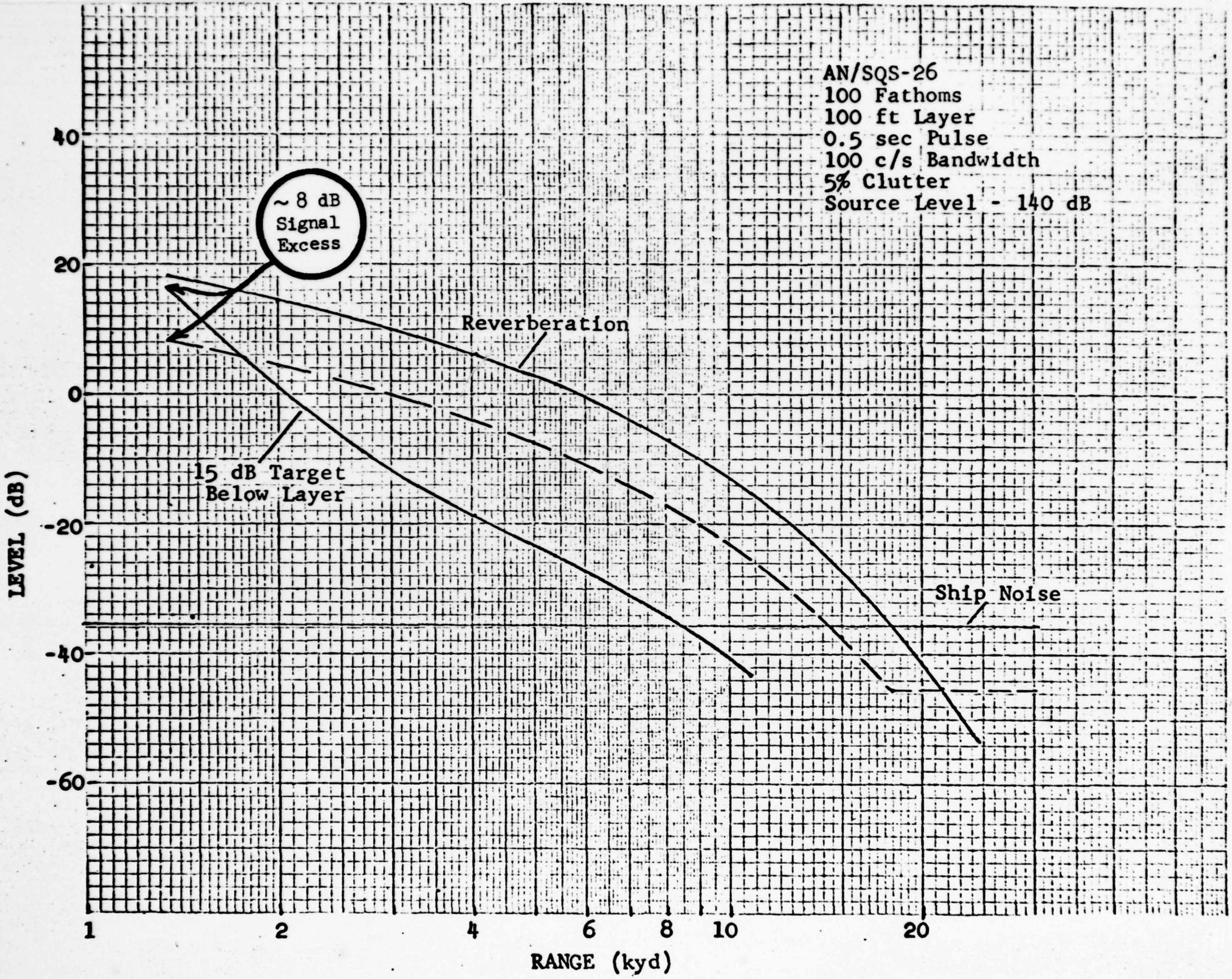

Figure 7(b) AN/SQS-26 WITH BELOW-LAYER TARGET, 100 FATHOM WATER

With this information alone one would predict that the PAIR could be improved by 7 to 8 dB in performance by substituting the coherent processor. Before such a step can be recommended, the relative susceptibility in "energy splitting" degradation* of the PAIR and the PAIR pulse - AN/SQS-26 processor systems must be investigated.

Limited data are available concerning the energy splitting degradation of the AN/SQS-26 performance for transmissions with different bandwidths with beam aspect targets. In Table II, doubling the bandwidth raises the processing gain by 3 dB but raising the threshold by 0.5 dB is required to maintain the clutter rate at a fixed value.

TABLE II**

Multipath Degradation with Beam
Aspect Targets

| | Performance Improvement | |
|---|---|---|
| Bandwidth | Ideal | Observed |
| 100 | 0 | -1.7 to -3 |
| 200 | 2.5 | +0.5 to -0.8 |
| 400 | 5.0 | 1.5 to 0.2 |

The net ideal performance gain is therefore expected to be approximately 2.5 dB. At 100 c/s the correlator energy splitting for beam aspect targets causes a performance degradation of 1.7 to 3 dB. Doubling the bandwidth to 200 c/s with typical echoes in the water provides 2.2 dB better performance, 0.3 dB less than ideal. Doubling again to 400 c/s provides an additional 1 dB. This represents a deficit of 3.5 to 5 dB below the ideal curve describing the correlator performance in Fig. 1.

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*The term "energy" splitting" is employed rather than multipath splitting because with FM slides, differential Doppler in the echo is converted to what appears to be multipath splitting in the correlograms. There are therefore two sources of energy splitting.

**These data were selected from TRACOR Document No. 65-336-C Contract No. NObsr-93140, "Analysis of Signal Processing and Related Topics Pertaining to the AN/SQS-26 Sonar Equipment (U) - A Summary Report III"

The energy splitting described for the beam aspect targets is largely attributable to rather low angular velocities in the target at the large bandwidths. The degradations in Table I are likely to be smaller than the corresponding multipath splittings expected for non-beam aspect targets. Any additional degradation will push the coherent processor performance still nearer to the wave period processor performance.

To this point the "multipath" degradation of the coherent processor has been discussed. What can be said about the "multipath" degradation of the wave period processor? A comparison can be made for the situation where the multipath arises because of a spatial distribution of the scatterers making up the target. Two arrivals of equal amplitude which emerge from the processors unresolved add and provide 3 dB higher output signal-to-noise ratio than when they emerge from the processor resolved into two distinct arrivals. With the 450 c/s FM transmission the time separation at which they will appear resolved in the correlator is about 2.3 ms in the case of the AN/SQS-26 correlator and about 72 ms in the case of the wave period processor. (We are still discussing the PAIR System with the PAIR pulse and the AN/SQS-26 processor.

On the surface this great difference in resolution points out the greater susceptibility to multipath of the wide-band-pulse-correlator combination. It must be admitted, however, that confidence in these statements can come only after the performances have been simulated with real signal inputs.

By way of conclusion it may be stated that the best performance advantage of the PAIR pulse - AN/SQS-26 processor system over the PAIR will be in the interval 3 to 4.5 dB. Because this estimate includes only the Doppler induced energy splitting effects in beam aspect targets, it is believed that the actual advantage which would be observed for the composite system will fall below this range.

## 4. ALTERNATIVES INCLUDING PULSE FORM MODIFICATION

There are still other alternatives, of course, as anyone who has taken part in a equipment specification program will recognize. They can be dismissed from consideration if one ground rule is accepted: The TRAM modification has been or is being made on most AN/SQS-23 equipments and utilization of these transmitters and transducers is preferable to scrapping them.

The desirability of having some ships which do not operate at the AN/SQS-26 water frequency is unquestioned from the mutual interference point of view. If the AN/SQS-23 transducers are scrapped, a whole new transducer design and development program is highly desirable to provide a system at the AN/SQS-23 water frequency capable of gaining the 3 or so dB which might result from converting to an AN/SQS-26 system. This approach will guarantee several years' delay in providing improved sonar performance in the present AN/SQS-23 ships.

If an attempt is made to force AN/SQS-26 pulse forms through the AN/SQS-23 transducers at the 5 kc/s water frequency, the long pulse length will very likely force operation at lower source levels. This expedient will also nullify the possible 3 or so dB potential gain which might be expected from the modification. This approach will also delay the availability of improved sonar operation of the AN/SQS-23 ships.

There may be other alternatives which should be considered but the conclusion to be drawn from this section of the discussion is that the expected gain from pulse form modification is bought at too high cost in delay and equipment replacement.

# APPENDIX I

## The Correlator Performance Curves

The correlator detection nomograph in Figure I(a) may be used to determine the signal-to-noise ratio required for 0.50 detection probability under a wide variety of clutter conditions. The curves on the right represent the correlator processing gain characteristics for several time-bandwidth products. The curves on the left represent clutter rate at the processor output for several values of processor bandwidth. The single independent sample probability of clutter is obtained for a value on the clutter axis by dividing by the processor bandwidth.

The procedure for use of this nomograph is illustrated in the following example:

1. It is required to find the processor input signal-to-noise ratio required for 0.50 probability that signal plus noise will exceed a threshold when the independent noise sample probability of exceeding the same threshold is 0.001. The processor bandwidth (FM slide bandwidth for an FM reference) is 100 c/s and the pulse length is 0.5 seconds.

2. Compute the clutter rate of exceeding the threshold.

$$\text{Clutter Rate} = (\text{Prob}) \times (\text{Bandwidth})$$
$$= (0.001)\,(100) = 0.1$$

c. Enter the clutter rate axis with 0.1 and draw a vertical line to the B = 100 clutter curve. This determines the required threshold setting in decibels referred to the power represented by the noise standard deviation.

4. Draw a horizontal line through the threshold into the curve on the right; it will be found that the value of threshold so determined is also the processor output signal-to-noise ratio required for 0.50 detection probability.

5. Compute the time-bandwidth product

$$BT = (100) \times (0.500) = 50$$

6. The intersection of the horizontal line drawn in Step 4 with the processing gain curve for BT = 50 determines the signal-to-noise ratio required at the processor input for 0.50 detection probability. The value obtained in this example is approximately -9 dB input S/N.

It should be noted that the nomograph is used for the correlator but is not applicable to the Wave Period Processor.

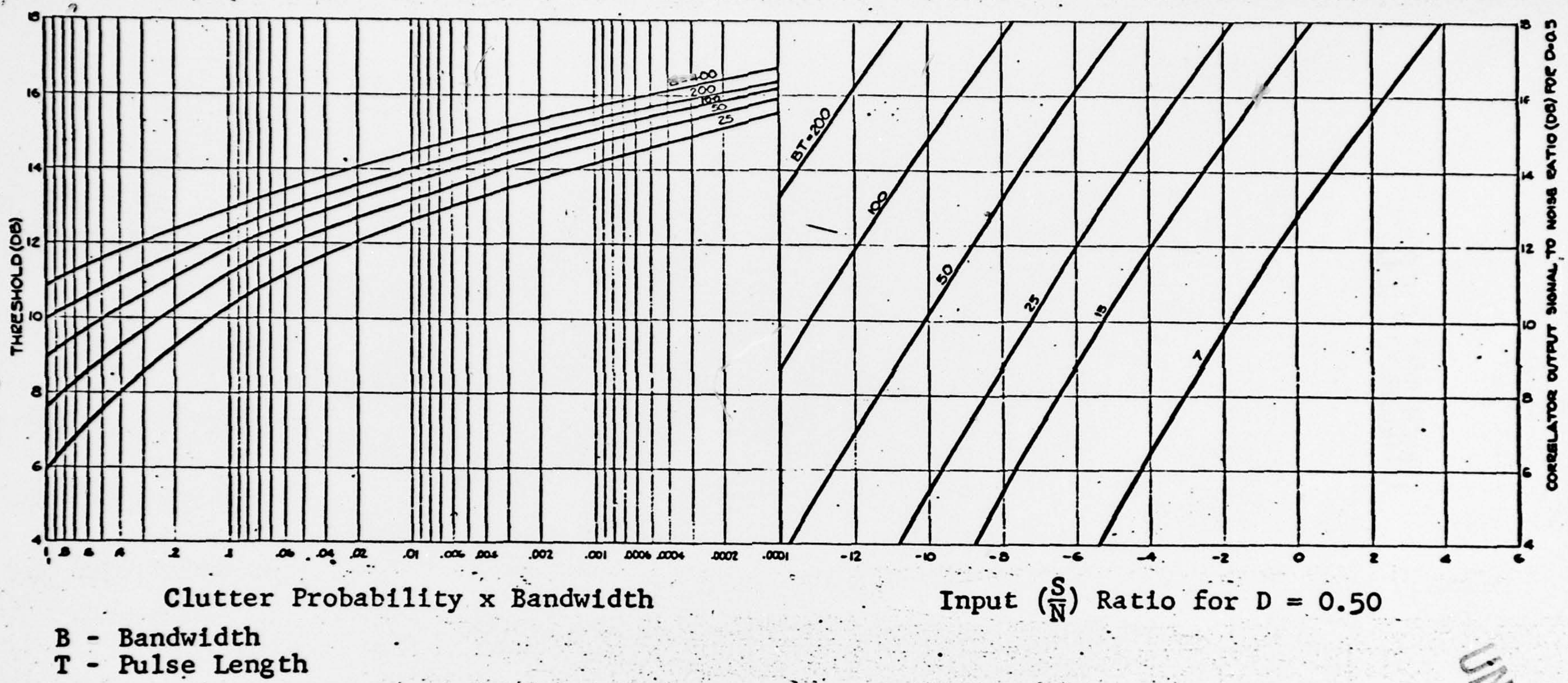

Figure I(a) CORRELATOR DETECTION NOMOGRAPH AT 0.5 DETECTION PROBABILITY