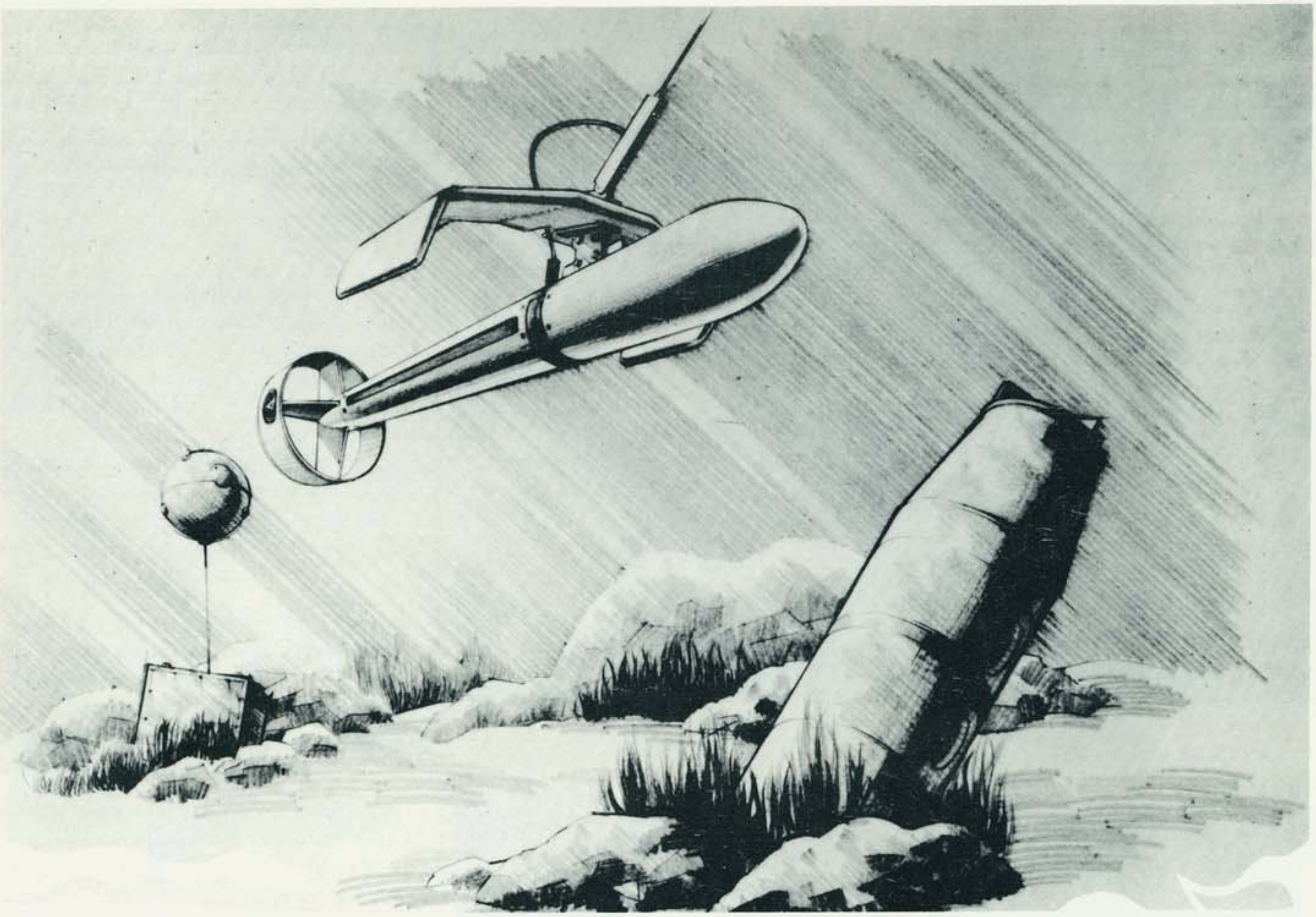

"Side Scan Sonar And Mine Counter Measures; The Technology, The Problems, The Tactics"

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INTRODUCTION

Today, Navies the world over have realized that lightweight commercial side scan sonar systems are a viable tool for Mine Hunting, C.O.O.P. (Craft-of-Opportunity Programs) and Q-Route monitoring. The attractiveness of the lightweight commercial systems is due to off-the-shelf availability, relative low cost, and performance that rivals its more exotic military counterparts. A basic understanding of the technology available and the inherent limitations allows one to develop tactics to maximize the full potential of the "tool." This paper addresses these issues.

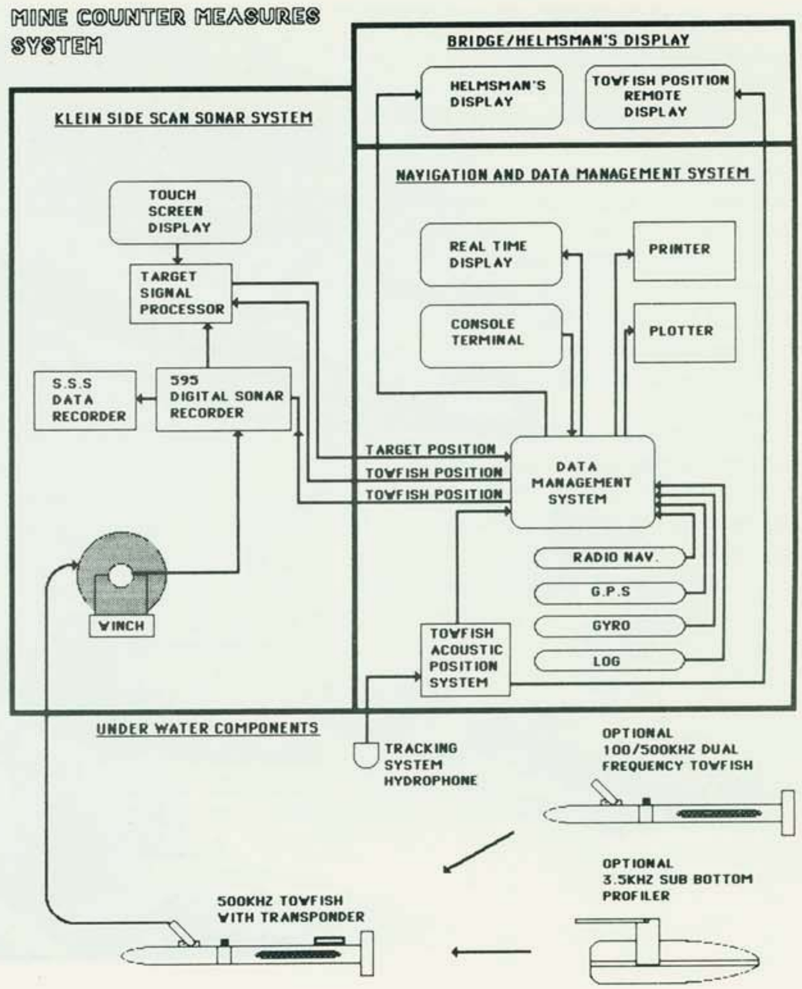


Figure 1

THE TECHNOLOGY

The Integrated Side Scan Sonar System

Lightweight commercial Side Scan Sonar (S.S.S.), when integrated with a positioning and data management system, is very effective for M.C.M. The purpose of the integrated system is to control accurately the survey lines, to determine geographic position of targets found on the S.S.S., and to conveniently log all the information for future use. The use of S.S.S. processors, such as the Klein/Tracor Target Signal Processor (T.S.P.) can help automate the M.C.M. operation by computer assisting the operator in target selection and calculating real-time, target position.

A typical integrated M.C.M. system would be composed of:

1) Side Scan Sonar System
2) Target Signal Processor
3) Vessel Positioning System
4) Acoustic Towfish Positioning System
5) Data Management System

A block diagram of a typical M.C.M. system is shown in Figure 1. A fully integrated M.C.M./C.O.O.P. package recently evaluated by the U.S. Coast Guard is shown in Photo 1.

Photo 1 - Typical Integrated Side Scan Sonar System for MCM

Lightweight Side Scan Sonar (S.S.S.)

The basic S.S.S. system is comprised of three major components: the Towfish, the Tow Cable, and the Graphic Recorder (See Photo 2 - 590 System). Advances in the last two years have seen dramatic changes in the performance and capability of these systems. The systems are very compact, mobile, and well suited to rapid development on craft-of-opportunity vessels.

The Towfish

The frequencies typically used in commercial S.S.S. vary between 50kHz and 500kHz. Lower frequency systems give good range performance but low resolution and vice versa for the higher 500kHz frequency. Both low and high frequency sensors find application for M.C.M.

Low frequency towfish, such as the 50kHz or 100kHz, are the desired tool for Q-Route selection. The long range performance allows rapid wide area mapping of bottom features, so that a Q-Route that is relatively free of rocks and debris can be selected from a strategic port. The selection of a low clutter Q-Route simplifies greatly the task of monitoring over time the Routes for any mine-like targets.

The high frequency 500kHz sensors have the necessary resolution required to locate and classify if a target is mine-like. However, due to attenuation of the high frequency, range is usually limited to 100 meters.

Today's towfish are available with both 100kHz and 500kHz integrated into one sensor. This allows switching frequencies from the surface recorder easily, without physically having to change sensors on the tow cable. Klein Associates of Salem, NH, manufactures a dual frequency sensor that even goes one step further by operating both frequencies simultaneously. It has been found that some mine-like targets as well as other bottom features are frequency sensitive. The use of two different frequencies simultaneously increases the probability of detection of frequency sensitive targets as well as giving the sonar operator twice the information to help with the task of target selection. (See Photo 3 - Klein Simultaneous 100/500 kHz Sonographs.)

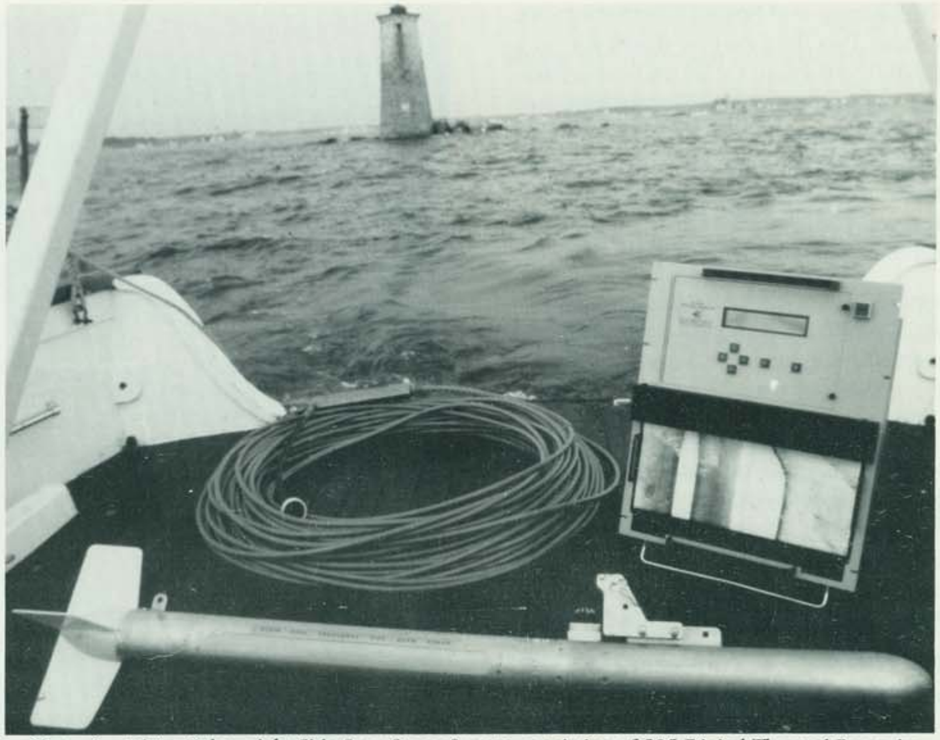
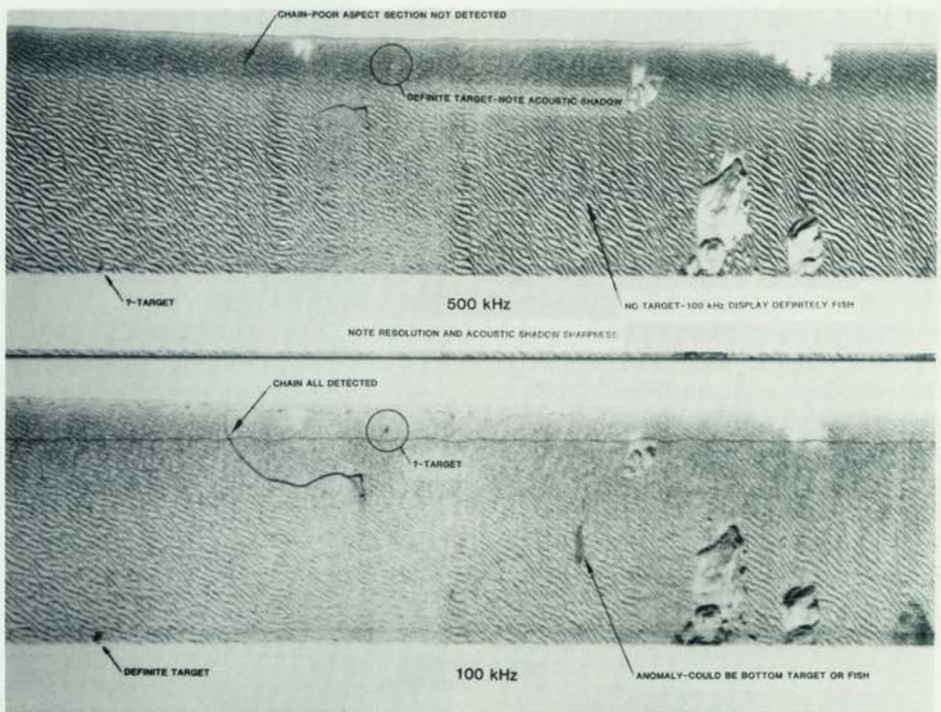


Photo 2 - Klein Lightweight Side Scan Sonar System consisting of 595 Digital Thermal Recorder and Simultaneous 100/500 KHZ Dual Frequency Towfish



KLEIN SIMULTANEOUS 100 kHz/500 kHz SONOGRAPH

Photo 3 - Klein 100/500 KHZ Simultaneous Dual Frequency Sonograph Display. Note frequency sensitivity of the chain, school of fish, and bottom targets.

The Recorder

Through the use of sophisticated computer control and digital signal processing, the S.S.S. recorder of today is very powerful and yet user friendly. The 595 recorder, the newest generation of recorder from Klein Associates, is a good example of the technology available. This recorder incorporates the latest in high resolution printing using a fixed thermal printing head with 203 dots per inch of resolution. The printing is done on a plastic based thermal paper which is odorless, scratch-proof, archival and dimensionally stable.

The recorder is designed to process internally six channels of data: four channels for the Dual Simultaneous 100/500 kHz S.S.S. Towfish, one channel for an optional 3.5 kHz Sub-Bottom Profiler, and a sixth channel for an external input, such as a boomer seismic system, etc. All six channels are outputted to the tape port for recording on a magnetic tape recorder for post processing and archivability. Through the control menu, selection of any two, three, or four of the six channels of data can be displayed on the hard copy records. Operators need minimal training for system operation since all tuning is computer controlled and automatic.

Slant Range and Speed Correction are standard so data can be displayed in a corrected format. Delay and expansion functions are available allowing any portion of the sonar record to be "Zoomed" and displayed over the full channel width. This feature allows full extraction of the resolution in the sonar signals.

Sophisticated Annotation and Positioning Interfaces are standard allowing events to be annotated on the records in a variety of ways.

The systems are compact and lightweight and will operate on both AC and DC power, making them suitable for even small boat operations.

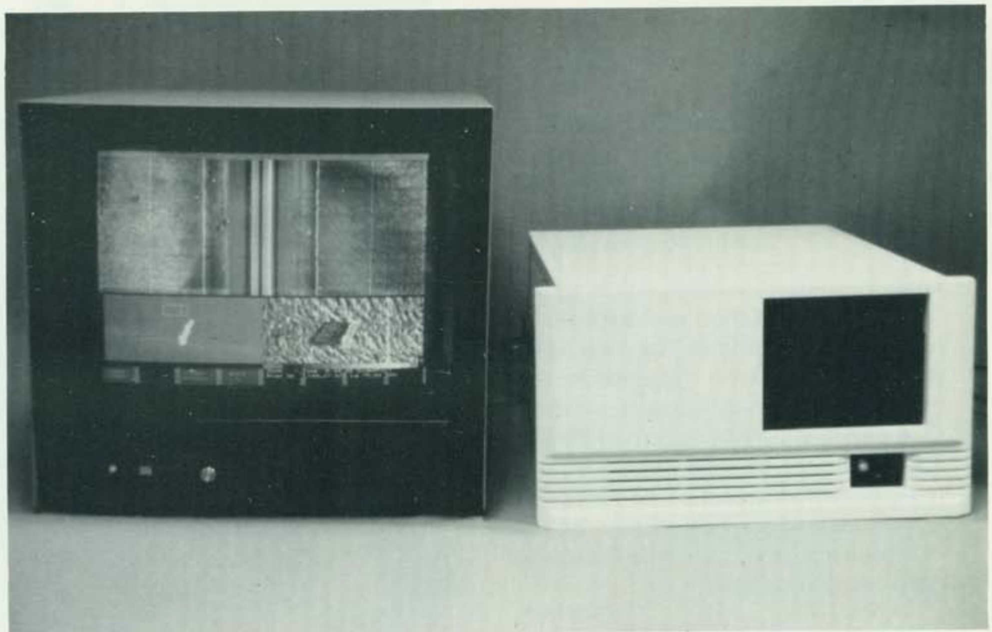


Photo 4 - Klein Target Signal Processor displaying a ground mine.

Target Signal Processor (T.S.P.)

The power of the computer has found its place in aiding the sonar operator in selecting mine-like contacts. The T.S.P. (see Photo 4) integrates positioning data with computer aided target selection. The T.S.P. can be programmed with the approximate dimensions of a mine. A "cue" is now generated on the video display next to targets for comparison by the operator. If the target and shadow size is close to the generated cue size and shadow, then it is a valid mine size contact.

The T.S.P. has a touch active screen which allows the logging off of the target geographic position simply by the operator touching the target with a finger. This is all done real time. The T.S.P. also has processing which will suppress on the video display all targets that are outside the programmed "target window size." This is useful on a cluttered or rocky bottom because it reduces the number of contacts on the display that the operator must make a decision on being a valid mine-like target.

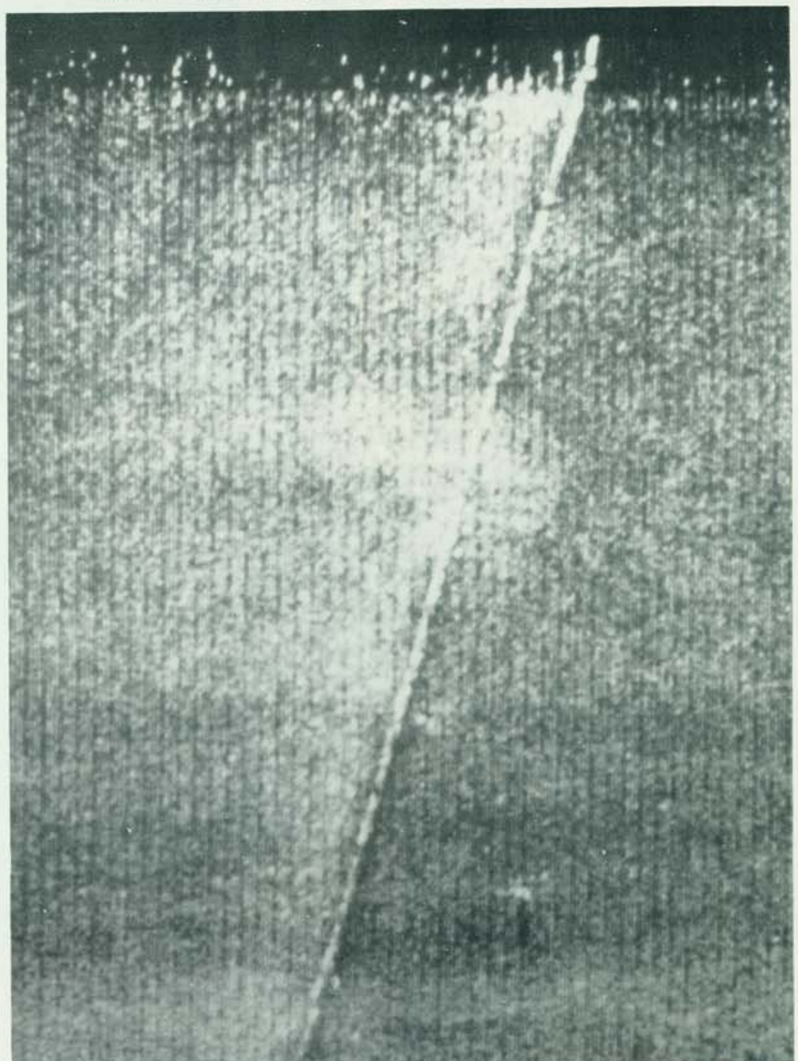


Photo 5 - Sonograph of a mine-like target next to an oil pipeline made by the Westinghouse AN/AQS14 Side Scan Sonar.

Performance - The Bottom Line

How well does the commercial S.S.S. system of today really compare (for detection and resolution) to a dedicated military mine hunting S.S.S.?

Two such exotic military S.S.S. systems are the Navy's AN/AQS-14 and the Thompson-CSF DUBM-41. These systems are considered as the best in dedicated military mine hunting side scan sonars. For a performance comparison, Photo 5 is a sonograph of a mine-like target made on the AN/AQS-14. A sonograph record from the DUBM-41 of a ground mine is shown in Photo 6. Photo 7 is a sonograph from a Klein 500Khz S.S.S. of a ground mine made under similar conditions. The old saying, "a picture is worth a thousand words" is definitely true here. The imaging ability of the low cost commercial S.S.S. does rival that of the high cost military sonar.

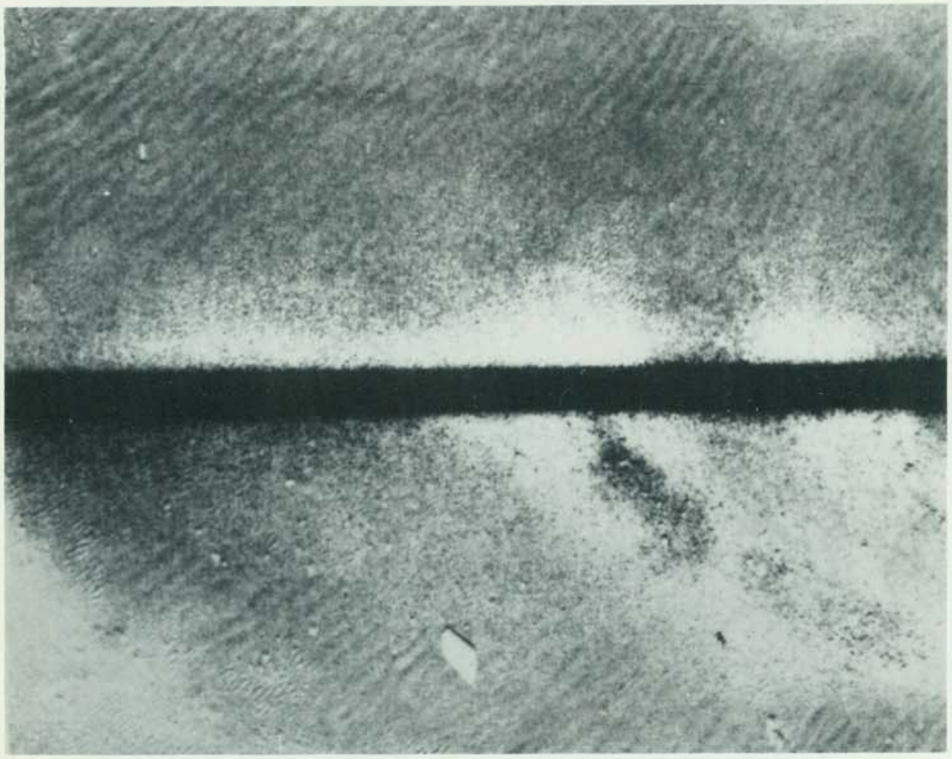


Photo 6 - Sonograph of a ground mine made by the Thompson-CSF DUBM-41 Side Scan Sonar.

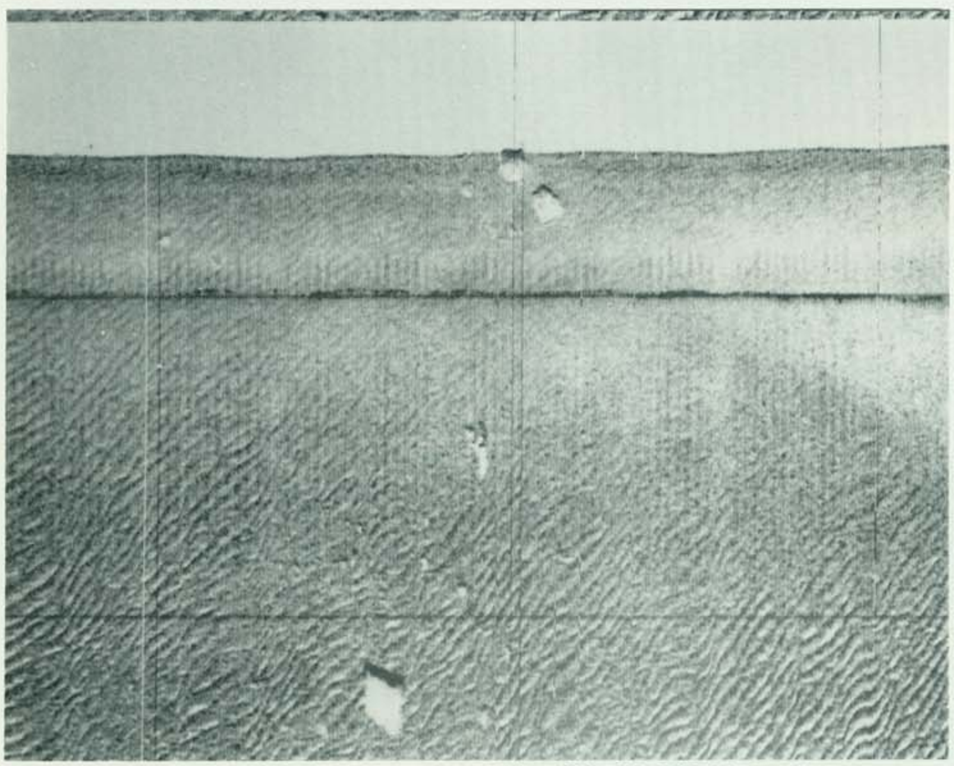


Photo 7 - Sonograph of a ground mine made by a Klein 500 KHZ Side Scan Sonar.

THE PROBLEMS

The problem of mine detection relates to the basic fact that the targets being sought are all relatively small in size. A typical small ground mine such as the U.S. Navy's Destructor Mark 36 Mine is 2.1 meters long by 0.4 meters in diameter. The detecting of a mine is not as straightforward as just looking at the traditional sonar equation components. The equation basically looks from a signal strength perspective if the sonar parameters are suitable for a target echo to be detected.

Unfortunately, the question of whether an operator will detect a mine is not as black and white as the sonar equation predicts. A more pragmatic view and understanding is needed to fully maximize the potential of side scan sonar for mine detection.

The major factors determining detectability for mine size targets are:

A) target acoustic reflectivity
B) target aspect
C) contrast with background and surrounding clutter
D) number of pings
E) near field target compression
F) acoustic shadowing
G) towfish stability
H) operator experience

Target Reflectivity

The traditional steel mine, whether a sphere or cylinder, is a good reflector of acoustic energy. This type of target on a clean, uncluttered bottom or midwater is detected and classified relatively easily. However, today the more exotic mines are being constructed of materials such that they are becoming "stealth mines" for sonar detection. Mines are being manufactured with fiberglass casings, which are acoustically low in reflectivity or coated with anechoic materials to absorb the incoming sonar energy. With these new mines, detection is made more difficult especially in cluttered or high ambient noise conditions.

Detection of frequency sensitive mines (those constructed of fiberglass or with anechoic coatings) can be increased through the use of a simultaneous 100/500 kHz frequency system.

Target Aspect

Cylindrical mines, due to their basic geometry, are aspect critical. When viewed by the sonar from an end aspect, very little surface is presented for sonar reflection. If the end of the mine is "pointed" such as the U.S. Navy's "Destructor" series of mines, the problem is compounded even more. In this case, the incoming sonar energy grazes off of and away from the pointed end of the mine, with very little echo returning to the sonar. Viewing this pointed type of mine from the end aspect will result in the operator having a very low probability of recognizing or detecting a meaningful signature on the sonograph display.

When a search is performed for targets that are aspect critical, two survey grids with a relative orientation of 45 to 90° to one another may be necessary. This insures that the target will be seen from a good aspect.

Background Contrast and Clutter

Mines do not always sit proud of the seabed. A good percentage of time they will partially bury into soft mud or be scoured into sand bottoms. The new high-tech mines are being designed to be self-burying with low profiles resembling shell or turtle shapes. The end result is that only the top of the mine may protrude out of the seabed. Under this condition no edges or normal reflecting surfaces are available to reflect the sonar energy back. The low profile of the partially buried mine produces very little, if any, detectable acoustic shadow to be used in classifying the target. The only mechanism left for the operator to use to recognize a suspicious target is the backscatter contrast ratio between the mine's surface texture and the surrounding seabed texture. If the mine is totally covered by sediment, it is not detectable by S.S.S. frequencies.

Clutter, which is defined as any unwanted echos such as surface return, mine size rocks or debris, mid-water schools of fish, refraction patterns, etc., can mask or confuse the very subtle clues to targets on the sonographs. If the clutter is severe, visual identification on the sonograph display is nearly impossible, even for the experienced operator.

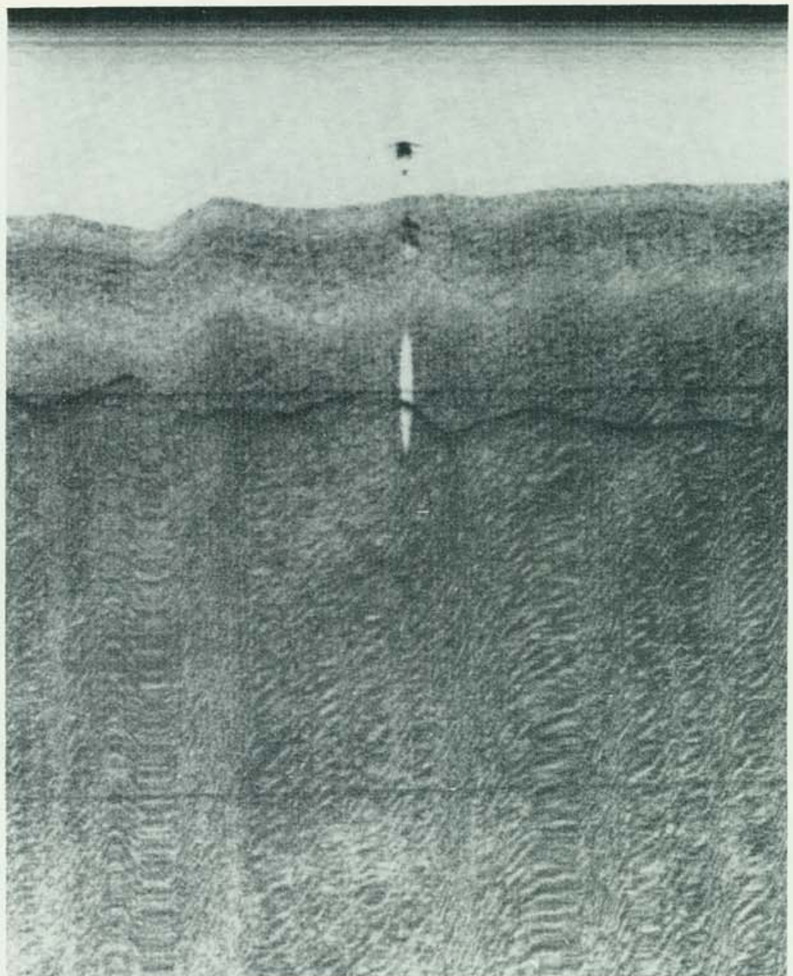


Photo 8 - A Klein 500 KHZ Sonograph of a moored MK6 mine. The mine is displayed in the water column which would have been lost if a 'mapping' display was being used.

A Q-Route should only be selected after an initial S.S.S. survey to define where the cleanest, clutter-free bottom is. Placing a Q-Route over a rocky bottom, when only 500 meters away is clean sand, could turn into a fatal mistake.

Q-Route monitoring, especially in shallow water, should only be done when sea conditions are relatively good. In rough seas, the echos from the surface waves and turbulence can mask mine-size targets on the sonograph. Bad or unreliable survey data is worse than no data at all.

Number of Sonar Pings

The higher the number of sonar pings hitting the target, the higher the probability of the sonar operator detecting it on the sonograph. The parameters affecting just how many "hits" the target receives are:

a) Sonar Range Scale (which sets ping rep. rate)
b) Tow Speed
c) Horizontal Beam Directivity

Example: To illustrate this relationship, if the sonar is set on a 150M range, the ping rate is 5 pings/sec. A tow speed of 4 knots is approximately 2M/sec. The result is that each .4 meters of bottom travelled, one sonar ping is sent out. If the along-track resolution due to horizontal beam angle is for example also .40 meters, then each .4 meters of sea bottom receives one sonar ping. A small ground mine viewed from an end aspect may only present a .40 meter reflecting surface in this along-track direction. What all this means is that under these very realistic operating parameters, the mine will only be pinged once. This shows up essentially as a point contact on the sonograph which can be overlooked easily in clutter by the operator.

Increasing the number of pings hitting a target increases the probability of operator detection. The two parameters effecting this that the operator has control over are tow speed and range scale (ping rate). Slow tow speeds (3 to 4 knots) and short ranges (75 m a side or less) should be used, if possible.

Near Field Target Compression

The area of the seabed viewed under the towfish is one of poor resolution. This is due to the inherent geometry in towing the sonar fish above the seabed.

A severe compression of all targets on the sonograph occurs in the seabed area displayed from the first bottom return out to a slant range of 1.5 x height of towfish.

The practical consequence of this is that the return from a mine beneath the towfish is compressed on the sonograph display to a point contact. The operator will have a low probability of recognizing this point contact as a possible mine-like target.

Today's S.S.S. offers a mapping mode function which corrects for this near field or slant range compression. However, this correction is only meant to produce a linear scale on the sonograph. On rough bottoms, such as an area with rock outcrops, the mapping function actually introduces distortion on the sonograph. This is due to widely varying detected towfish altitudes which are used for the slant range correction. Slant Range Correction cannot and does not correct for poor geometry. Detection of mines under the towfish is poor regardless of whether the sonar is run with mapping on or in the traditional uncorrected display format. Another negative artifact of the mapping mode is it removes the water column portion of the record. At times this contains valuable mid-water target data when dealing with moored mines. Photo 8 is an example of a moored MK6 mine that is detected in the water column area of the sonograph. This contact would not have been displayed if the sonar had been run in a mapping mode.

Survey line spacings must always be set up to put the area being seen under the towfish, off to the side midrange on the next adjacent line. This is to insure a mine-like target is not missed in the near field compression zone. Mapping mode should not be used to search for mine-like targets.

Acoustic Shadowing

The first U.S. Navy Mine Hunting S.S.S. was named the C-MK-1 SHADOWGRAPH for a very good reason. The acoustic shadow generated from bottom targets is the single most important clue to classifying a target as mine-like. Photo 9 shows the interesting acoustic shadows from a "finned MK82 Mine." The geometry of the shadow tells us the shape of the target, and the length of the shadow tells us the height above the seabed. The clean geometric shadows from mines are not typically generated by natural features such as rocks. Photo 10 shows a ground mine laying near some rocks. Note how the rocks give a pointed triangular shadow compared to the mine's parallelogram shaped shadow.

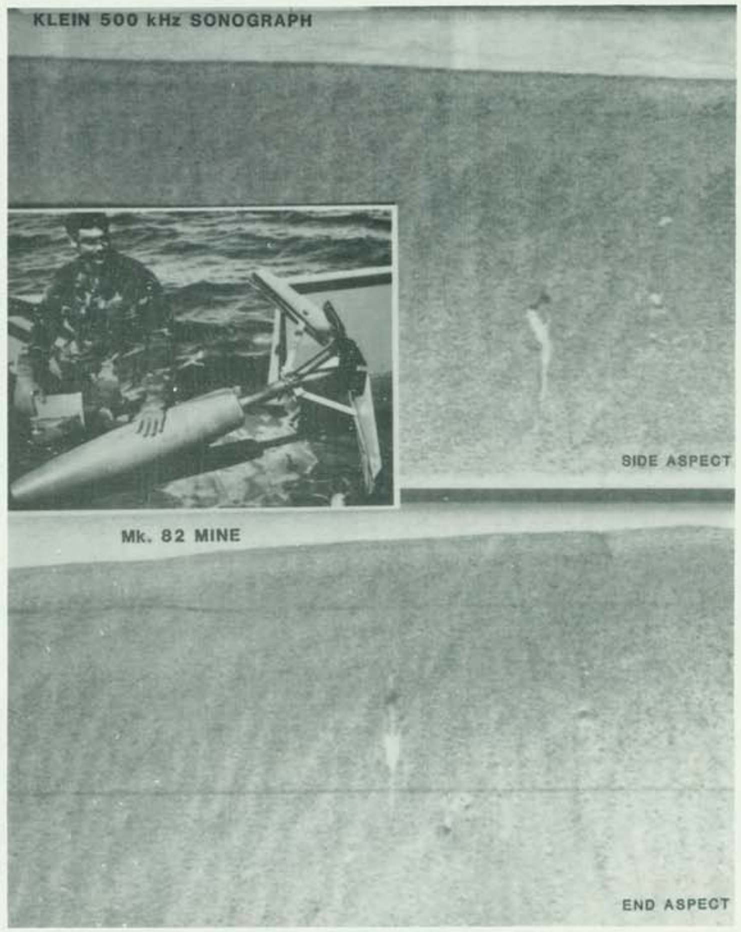


Photo 9 - Side and end aspect of a MK82 mine. Note the acoustic shadows that are generated. Klein 500 KHZ Sonograph.

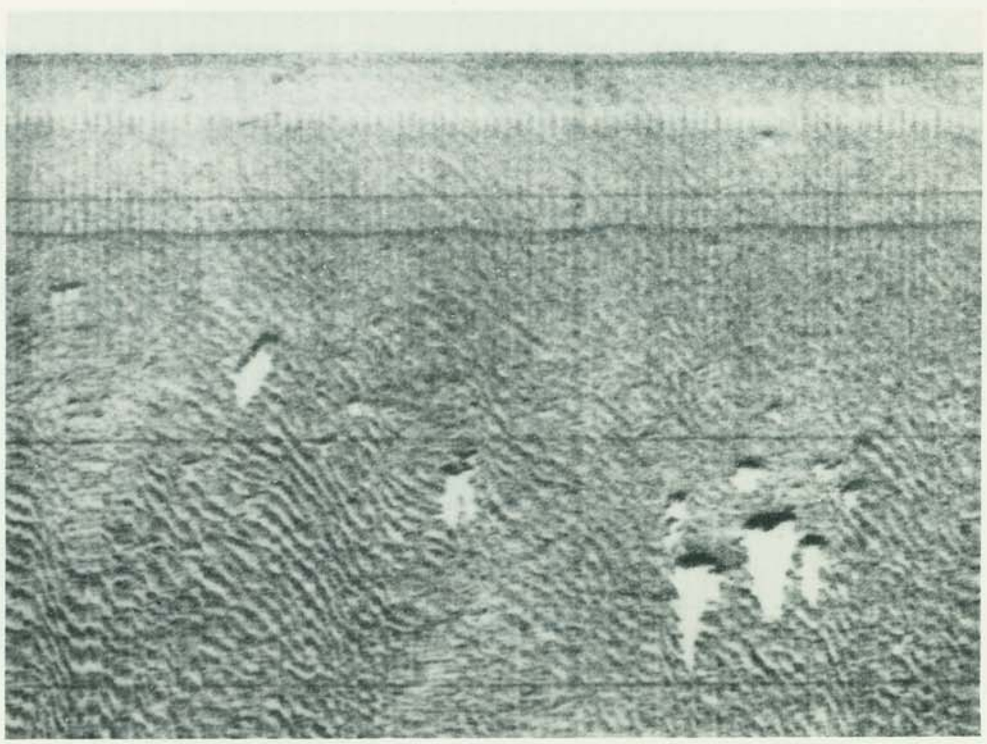


Photo 10 - A Klein 500 KHZ Sonograph of a ground mine near rocks. Note the mine shadow geometry versus the rock shadows.

Acoustic shadowing, however, is not always seen on the sonograph from a bottom mine. There are two ways this can occur. First, if the mine is partially buried, there may not be enough relief to produce an acoustic shadow. Second, for a shadow to be displayed, a reasonable contrast ratio is required between the bottom reverberation (backscatter) and the acoustic shadow area where there is only ambient noise. There are times when ambient noise is dominant over bottom reverberation, and in this case no shadows will be generated. This usually occurs on low reverberation seabeds of clay or mud and at the end of range where grazing angle effects come into play.

The lack of an acoustic shadow behind a mine-size contact is not a guarantee the target is not a mine.

Towfish Stability

Often overlooked is the detrimental effect an unstable towfish can introduce on the sonograph. A good analogy can be made in comparing the towfish to a camera. If a camera is being moved at the instant a photo is taken, you end up with a blurred or distorted picture. The same is true for the S.S.S. system. The towfish is the S.S.S. "camera," and if it is pitching or yawing due to, for example, turbulence or heave action on the tow cable, the sonograph images can become quite distorted. This distortion can easily cause targets to be missed by the operator.

Operators should learn to recognize distortion due to towfish pitch or yaw and take the necessary preventive action such as using wing depressors to reduce this movement.

Operator - The Last Link

Ideally, an M.C.M. system would locate mine-like targets automatically with no human intervention. The reality is, the detection of mines from sonograph analysis is not an on/off or black/white situation. This requires the final analysis and selection of mine-like targets to be done by a human operator.

The effect of the operator parameter on probability of mine detection cannot be quantified. It can only be looked at qualitatively, and it is fair to say some operators will develop a "knack" for this while others will not. Training and experience increases the efficiency of the operator, but because of this intuitive element in sonograph analysis, not all operators will be equal.

The military philosophy of rotating people frequently needs to be abandoned for M.C.M. personnel. The specialization of personnel for M.C.M./C.O.O.P. operations will greatly increase their operational effectiveness with Side Scan Sonar systems.

The fact that finding mines with S.S.S. is part "science" and part "art" means that the longer people practice, the more training done, the better they will become for their assigned task.

THE FUTURE

The area where the greatest improvement will be seen is in the processing of data for better probability of detection and classification by operators.

Some of the problems inherent in the single beam commercial S.S.S., such as requiring slow tow speeds and short ranges, will be overcome with the introduction of high speed (12 knot) multibeam, dynamically focused S.S.S. systems. Such commercial systems are now in the development stage.

However, many of the inherent limitations found in the side scan technique will still remain. The best solution for these problems is, of course, knowledge and understanding blended with the latest state-of-the-art technology.