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Author's Bio

John C. Herther was the founding President of the Iotron Corporation in 1969 and is currently Vice President, International Sales. Prior to that time, he was employed by the Itek Corporation, having started with Itek at its inception in 1957. He was Director of Research and Development for the Optical Systems Division. From 1953 to 1957, Mr. Herther served in the United States Air Force and provided technical management during the early development phases of the Air Force's first satellite program. Mr. Herther has a Bachelors degree in Mechanical Engineering from North Carolina State College and a Master of Science degree in Aeronautical and Electrical Engineering from M.I.T., where he performed graduate work on fire control, guidance and navigation projects at the Instrumentation Laboratory under Dr. C. S. Draper. He has served as President of the New England Chapter of the American Institute of Aeronautics and Astronautics and is a member of the United States and Royal (UK) Institutes of Navigation and of the Society of Naval Architects and Marine Engineers. For 8 years he was a member of RTCM SC-65 Committee on Ship's Radar and Collision Avoidance Aids.

THE POTENTIAL OF AUTOMATIC RADAR PLOTTING AIDS FOR MANEUVERING IN DENSE TRAFFIC AND RESTRICTED WATERS

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Abstract

Over the past twenty years, various radar interpretation aids have developed. In 1960, the U.S. Maritime Administration developed a 10 target automatic radar plotter with manual and **guard ring automatic acquisition**, true and relative vectors, and with collision threat alarms and a trial maneuver capability. In 1971, MARAD made this type of "computer aided" plotter mandatory on all MARAD subsidized tankers. Sperry developed a 20 target, manual acquisition, predicted area of danger plotting equipment and Iotron developed DIGIPLOT, which plotted 40 target vectors with **fully automatic all area acquisition** of the targets.

The International Maritime Consultative Organization (IMCO) deliberated over two years on the United States proposal for mandatory carriage of "MARAD equivalent" automatic radar plotters on all vessels above 10,000 grt. In November 1979, a minimum standard was agreed upon, as well as a worldwide fitting schedule, starting in January 1984 and continuing over a five year period, depending on vessel type and size. The original 1960 MARAD prototype could probably meet the IMCO standard with only minor changes.

The IMCO minimum operational ARPA standard sets requirements for an aid which will prevent collisions at sea and in relatively open ocean waters. Although the systems are also intended to function approaching or leaving harbors; the minimum IMCO standard does not require the radar plotting equipment to work in high traffic density or in narrow waters or restricted waterways when pilots would normally be aboard.

The technology is available today and reasonably priced third generation systems, exceeding the IMCO minimum standards that offer the potential for aiding a pilot in the safe navigation of the vessel in and out of harbors in dense traffic and in restricted waterways, are currently on the market. DIGIPLOT is an example.

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The U.S. Port and Tanker Safety Act and international (IMCO) agreements require all ships over 10,000 grt to be fitted with collision avoidance radar equipment, which meets the IMCO minimum standard for Automatic Radar Plotting Aids (ARPA). On all MARAD subsidy built tankers, an automatic system has been required for collision avoidance to provide "unattended monitoring of all radar echoes and automatic audio and visual alarm signals that will alert the watch officer to a possible threat." This feature is mandatory because lack of attention by watch officers is a factor that has been shown to cause many collisions, which have occurred in U.S. coastal waters, and which were considered avoidable. An additional watch officer on deck had been suggested as a solution, but this imposes economic penalties. To alert the watch officer, either auto-acquisition or a guard ring alarm associated with manual target acquisition is required. MARAD has determined that both approaches are adequate, **since the observer is presumed to have been alerted to the potential danger by the guard ring alarm prior to plotting.** The IMCO standard does not require an audio alarm in addition to the visual alarm for threatening vessels. The U.S. Coast Guard proposed rule states that this is a necessary additional feature on IMCO ARPAs required on all tankers above 10,000 grt in U.S. waters which must be fitted prior to July 1982. All equipment approved by MARAD has been capable of tracking 20 echoes, (although no number is specified), whether manual or automatically acquired. This tracking and plotting capacity is twice that required by the IMCO minimum operational ARPA standard. At the time the MARAD mandatory requirement for tankers was established in 1971, Iotron's patented, proprietary design for fully automatic acquisition was not available to other U.S. companies engaged in producing Collision Avoidance System (CAS) equipment. In order to preserve competition among manufacturers, **MARAD allowed manual acquisition and a guard ring as its operational acquisition requirement, the lowest common denominator**. Iotron, already a producer of an automatic acquisition system, was joined by IBM and Raytheon who entered the field much later with auto-acquisition systems. Raytheon uses a guard ring auto-acquisition approach, similar to the approach used by Goodyear in the original MARAD development in 1960. IBM uses a software, shipsize echo discriminator, all area approach. Iotron has granted IBM a license to use its automatic acquisition patents.

Radar contacts occur so infrequently in open sea operation that a manual acquisition Automatic Radar Plotting Aid can adequately handle the work load. However, when he operates in crowded waters with a manual acquisition system the watch officer is continually involved (or should be) in acquiring new, potentially threatening echoes, since their relative motion is unknown. If there is limited tracking capacity, for example, 20 or even 10 echoes, as presently specified as the minimum for IMCO manual acquisition systems, the operator must make room for new contacts by deleting the echoes whose relative motion and proximity are "safest." Any deleted echoes must be presumed to remain safe, since there can be no more plotted results shown on the deleted echoes until at least 3 minutes after the operator reacquires the target manually. Such a system results in almost as heavy a workload and uncertainty as occurs with manual plotting.- According to Captain Dan Charter of the U.S. Coast Guard, "There are no known studies that would indicate a 10 track manual system would be as effective as a 20 track automatic system. I believe the only reason for the difference is simply that the manual systems are unable to handle the density of traffic that the automatic systems can.'" In effect, the IMCO minimum standard is a dual standard allowing different ARPAs to be used for different traffic density situations.

The guard ring type of automatic acquisition is deficient when small or weak target echoes appear within the guard ring at a lesser range than that chosen by the observer. It must be recognized that guard rings typically are set at a long range near the radar horizon and as a result some smaller ships will not be detected. Also, sea conditions can create reflection nulls, which further inhibit detection. Dual guard rings partially correct this situation, but detection is, at best, uncertain. Guard ring automatic acquisition or zonal alarms are extremely sensitive to proper radar tuning and radar performance. Insufficient video gain will prevent a weak echo from being "seen" when it passes through the guard ring. Radar performance also affects guard ring capability. A weak transmitter and/or receiver can result in no acquisition, and no alarm to alert the watch officer. This is a serious operational deficiency.

In land confined, crowded waters, the guard ring type of acquisition becomes practically useless due to false land echoes. Raytheon has adopted the Limit Line approach, which eliminates the land echoes in certain areas from triggering the guard ring. However, it does not solve the problem of the target vessel, which enters the tracking zone after the guard ring or rings have, in effect, passed by. In simple terms, an "end run." Consequently, the operator must be continually involved just to be sure that nothing is missed. In practical operation the operator may as well have eliminated the guard rings and acquired all of the targets manually.

Discriminator type automatic acquisition, as implemented in DIGIPLOT, converts the entire radar picture to a digital form called "quantized" video. Each range element of 250 feet in length (1/20 mile) is a 1, if there is an echo return above a threshold level, or a 0 if there is no return. During installation, a service engineer adjusts the video threshold to a level very near to the signal level of the receiver noise in order to insure detection of weak, distant echoes. An automatic gain control circuit maintains the gain adjustment of the signal fed from the radar to the automatic plotter in order to compensate for signal variations that occur due to changes in the radar set or operator mis-adjustment of his gain control. The digital radar signal is then analyzed by a shipsized echo discriminator. As the antenna scans, if there are three successive radar pulses with 1's indicating an echo presence at the exact same range, a target "start" is initiated. Since receiver noise is random, it is not normally 3 bang correlated, and is filtered out and not classified as a shipsized echo. Electronic circuits track both the closest and most distant edges of the echo. At the end of the echo, the discriminator indicates the measured maximum range extent and total angular extent subtended by the echo. If the echo is larger than a shipsized echo in length and/or angular width, adjusted as a function of range, it is declared to be a coastline and a dotted outline of the closest edge is put into DIGIPLOT's memory. This land outline is used to inhibit further acquisition and tracking beyond the closest coast outline. Three successive scans of coastal outline are retained in memory to account for ship's rolling period. All smaller echoes are declared to be shipsized, and the middle of the leading edge is used to provide precise range and bearing coordinates of each echo on every scan. This range/bearing data is matched to previous data and analyzed from scan-to-scan for consistency. When it is determined to be as consistent as a real target, tracking is initiated. Continued tracking and subsequent calculations develop the relative course and speed of the target, just as a man would do when plotting a target on the scope with a grease pencil. The true course and speed of own ship are computed from own ship's gyro and speed input, and the resulting course and speed of each tracked target is easily computed by vector summing with own ship's course and speed. The resulting true or relative vector is displayed for each of the tracked targets. This process is updated continually for each target on every scan of the radar.

When vessels enter and leave ports, where traffic density is increased significantly, manual acquisition of echoes has been shown to increase the radar observer's work load by a considerable amount.

In this situation a large advantage can be gained by a system, which uses discriminator type, all area, automatic acquisition. Near shore, discriminator auto-acquisition is far superior since shipsized echoes are distinguished from receiver noise, other radar signals, random sea clutter, and large land echoes. The performance of discriminator auto-acquisition is much better than a guard ring type of acquisition, particularly when manually controlled Limit Lines are used. These chordal Limit Lines reject all auto-acquisition and tracking at ranges beyond the lines. This allows the operator to select the particular area around own ship where full automatic acquisition plotting is desired. The excluded zones are shown by chordal lines on the PPI. It also allows selection of a specific tracking zone when there are too many echoes for the ARPA to plot simultaneously with full accuracy. The IMCO minimum standard requires that an ARPA must automatically acquire and track 3 Tat least 20 targets. DIGIPLOT models are available which automatically acquire and plot 20, 40, or 60 echoes. In an area along a shoreline which has many small craft, buoys, etc.. Limit Lines can allow targets of no interest to be rejected. For some shorelines, particularly sandy sloping ones, radar land returns are broken-up and actually look like many shipsized echoes. These numerous echoes can "fool" the discriminator type automatic acquisition system and divert some of its plotting capacity. A Limit Line positioned between own ship and the shore inhibits this wastage and makes better use of the data processing capacity available. The Limit Lines are gyro stabilized and fixed in range relative to own ship and thus do not need frequent adjustment. Normally a 60 target ARPA does not need to use Limit Lines. When the radar echo density is high, a 20 target system requires more frequent use of Limit Lines than a 40 target system. When a ship is in a harbor approach, a discriminator type automatic acquisition system also automatically rejects ship sized echoes behind land returns, However, all ship sized echoes + 30^0 of dead ahead must be analyzed, particularly those echoes beyond a headland or a bridge. These are plotted to determine if they are stationary or moving objects.

Limit Lines have been introduced for use with guard rings to control land clutter and improve the guard ring automatic acquisition system and its alarms in order to work at all near a coastline. The primary and important difference is, again, detection. Discriminator type automatic acquisition systems take any echo of a strength near the receiver noise level crossing the Limit Line from the rejected area and acquire it automatically. Guard rings automatically acquire and/or sound an alarm only for those echoes that are strong and consistent at the exact range when they cross the outer guard ring. Targets that make an "end run" around an active zone of the outer guard ring are missed until they are acquired by the inner guard ring - the ring that is a last resort. This inner ring is usually set at 4 miles, which could be dangerous considering the three minutes, allowed for initial vector buildup.

As a ship sails in extremely narrow and restricted waters, a discriminator type automatic acquisition system will also eventually saturate, because most close-in land echoes appear to be ship sized, and the number of ship sized echoes from land eventually will saturate the computer. At this point, when a channel is 1/3 mile wide or less, the acquisition must be switched from automatic to manual. In the manual acquisition mode the channel ahead can be very narrow, and ship sized echoes in the waterway dead ahead can be manually acquired by the watch officer and tracked with full accuracy and response.

A major limitation of some plotting equipments is that they cannot process multiple echoes on the same bearing without incurring increasing time delays in the presentation of the collision avoidance vectors on echoes beyond the nearest echo. Some equipment can only track two echoes on the same bearing. When entering or leaving ports, it is quite common to see several ships in a line with each other. A discriminator type automatic acquisition system with an adequate computational speed has no bearing limitation and can track up to 20, 40, or even 60 echoes, on the same bearing, with full accuracy and response! The buoy pattern will be acquired and plotted and it is most often in a line with ships moving between the buoys. Multiple echo plotting on the same bearing should be a mandatory requirement for ARPAs intended for use in pilotage waters. There is no such requirement to provide it in the IMCO minimum ARPA standard, although the ARPA is intended to be used entering or leaving port.

The IMCO standard requires testing to determine that in 4 operational scenarios with specified input sensor errors the ARPA produce the required vector calculations to a certain level of accuracy within 1 and 3 minutes. There is no specified requirement for "anti-swap," a term used for automatic plotting of closely spaced echoes. The tracking calculations can result in errors if swap occurs, since the data for one target is mixed with that of another being tracked, or even with that of an un-tracked echo. For pilotage use, a distance of as little as 0.1 N. mile between echoes should be specified while maintaining full ARPA accuracy. The IMCO performance accuracy and response tests should be met with 20 target tracking capacity in use in order to insure that prompt maneuvering information will be provided for pilots. The wording of the IMCO standard requires calculations to be performed only on one target with full speed to attain accuracy. The ARPA does not have to be operating on 19 (or 9) other targets at the same time.
Both True and Relative vector displays are required by IMCO. The vectors show the direction of true and relative movement of all ship sized echoes. A true vector display easily enables a master, pilot, or watch officer to tell the difference between moving and stationary echoes. The relative vectors for those ships in the forward sector moving toward own ship indi-

cate the side of passing with more accuracy and much faster than with any other method, including visual observation! A graphic display which presents only the predicted areas of danger, has the serious limitation of showing a PAD[1] size that is not applicable to the close passing or meeting situations that apply in restricted waters. For several targets in close proximity, the graphic PAD display with a PAD of a useful size will show a pattern that is confusing and of little or no use for close maneuvering. This is true even at sea and particularly in restricted waters where the determination between several moving and stationary echoes can be critical.
Inherently, the relative vector is less sensitive to own ship's course and speed errors than a PAD calculation, or even a true vector.
Lack of good information on the side of passing is the major cause of collisions in restricted waters. Ironically, most of these collisions involving large vessels do not occur in fog, but in clear weather.'

SUMMARY MAJOR CONCLUSIONS:

1. In all 24 collision cases studied in which a vessel was detected by radar, this occurred at ranges greater than 1 mile and at consistently greater ranges than detections by sound signals or by direct sighting. (The IMCO quick start up performance requirement is sufficiently fast for this situation and ARPAs are considerably much faster than manual plotting.)

2. Fifty-eight percent of the 6 officers studied who were conning their vessels by radar interpreted the relative motion situation correctly before taking any action. Subsequent to maneuvering, the relative motion situation was estimated to have been correctly interpreted by only 39% of the 18 conning officers making such decisions.

3. All major collision-avoiding actions occurred within the two mile range and not earlier.

4. Under conditions where initial detection was made by radar, the vessels in the collisions studied made an equal number of course changes in the direction of the target as in the direction away from it.

5. It was found in the study that 56 percent of the conning officers of the large vessels and 42 percent of those in small vessels made their decisions to maneuver on the basis of incomplete information about either the status of their own vessel or the status and in-

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[1] PAD-Sperry's novel predicted area of danger, a patented ellipse of approximate CPA distance at the tip of a course line, that grew out of the companies US Navy work on high speed vessel concepts which was finally not permitted under IMCO ARPA standards

tentions of the other vessel.

6. In 90 percent of the cases a mutually understood passing agreement was not established and the subsequent passing action conflicted in about 60 percent of the cases.

The most significant benefit in using an ARPA as a pilot's aid is that it can provide a double check on the master's or pilot's visual impression. This can best be accomplished by viewing a relative orientation with a true vector display which appears like the other vessel's aspect as seen from the bridge visually. In this display mode, errors in own ship's course or speed (from a gyro or speed log that isn't operating accurately cannot influence the relative plot of the other vessels, including side of passing and CPA distance. The side of passing can be confirmed earlier and more quantitatively in order to reach a correct passing agreement and to make the correct avoiding maneuver sooner. ARPAs can be designed to indicate course changes of approaching vessels in as little as 15 seconds, which, although not as fast as visual, is independent, and thus serves as a double check on the observed vessel's maneuver. The IMCO ARPA standard should specify 15 seconds after the course change to show the current indication of an approaching vessel's relative motion, particularly for pilots. The system that uses auto-acquisition of the all area discriminator type, **will function "hands off" e.g. unattended!** This will provide a useful aid to the Captain or Mate on the bridge, which are already busy with their maneuvering duties.

Various manufacturers have designed equipment to improve the ease and accuracy of radar navigation, including radio or radar stabilized fairway lines, for improved navigation in restricted waters, Iotron, for instance, has developed and patented a NAV-LINE Anti-Stranding Option. This option makes use of the long proven "parallel index technique" to determine ship's position and keep it in navigable waters. What is new, is that up to 10 pairs of gyro stabilized lines can be pre-entered at a range from own ship and on a desired bearing. These lines can then be displayed, one or two pairs at a time on the DIGIPLOT display to show the operator where he is and where he ought not to be. In the latter case, he can readily determine the maneuver necessary to put the ship back in safe waters. The second pair of lines indicates "Time to Turn."

Collision avoidance aids should be able to provide useful data in restricted waters near shore as well as on the open ocean. Because of the heavy traffic found in these areas, and the frequent maneuvering required to conform to channel boundaries, bridge personnel do not have the time necessary to operate a manual acquisition Automatic Radar Plotting Aid. The only type of ARPA that is able to provide meaningful collision avoidance and radar data in restricted waters is one which uses a discriminator-type auto-acquisition system using Limit Lines, capable of tracking at least forty targets. This will minimize observer/operator workload. The full benefits of automatic radar plotting are achieved only with fully automatic acquisition systems of sufficient capacity to track and display all echoes which are in the immediate vicinity of own ship and which are of interest in evaluating own ship's maneuvers.

A discriminator type, automatic acquisition, automatic radar plotting aid is the only aid, which can provide prompt, accurate information to the pilot who operates in heavy traffic in restricted waters. By supplementing his visual information, a significant reduction in collisions is potentially possible since earlier passing agreements can be reached in clear weather.

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