Glaser

Re: FCC SC-65 Meeting

SPERRY MARINE SYSTEMS

CHARLOTTESVILLE, VIRGINIA 22906

PROPOSED SPECIFICATION

FOR

A SECONDARY RADAR SYSTEM

SOMETIMES CALLED

A MARINE RADAR TRANSPONDER SYSTEM

FOR USE IN THE

MARITIME MOBILE SERVICE

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JA 165-0010 • PD 3026 • 3 July 1974 -- Rev. C

INTRODUCTION

This "Proposed Specification for a Secondary Radar System" is the result of an analytical study, some preliminary experimentation, and is intended only as a framework upon which a universal system could be established.

Experimental verification of the fundamentals of the system is underway. This experimental system has a 4-bit sync word, a 4-bit address word (15 addresses), a 4-bit mode word, a 4-bit intelligence word, and an odd parity bit for a total of 21 bits. It is intended to demonstrate the operation of the CQ, Normal, and Broadcast types of calls. This experimental equipment is not fitted for precision ranging. As the transmitted power is only 0. 5 watt, the range is severely limited.

Three Interrogator-Transponders (I-T's) were built. One was installed ashore at the U. S. Merchant Marine Academy, Kings Point, New York, in conjunction with a Sperry Mk 3 Radar. The second was installed on the U. S. Merchant Marine Academy's (USMMA) T. V. NEREID in conjunction with a Sperry Mk 8 Radar. The third was installed on the R. V. SPERRY STAR in conjunction with a Sperry Mk 16 Radar.

The preliminary test results were generally as expected, including very limited range. Figure 1 illustrates the nature of the results achieved. In Figure 1A, the SPERRY STAR is about a mile and a half NNE of the USMMA at Kings Point and is headed west. Several small targets are visible on the PPI. In Figure 1B, a CQ call (see paragraph 5. 1) has been sent out and a reply (the quarter-mile radial mark) from the TV NEREID is shown superimposed on the radar picture. The near end of this mark is about a half-mile to the SW of the SPERRY STAR, and if the reader had been watching as this mark appeared, he would have noted that the near end fell on the radar paint at that point, thereby identifying that vessel.

In Figure 1C, the radar picture has been switched off. The reader will now observe a second I-T paint on the PPI. This is the return from Bowditch Hall and if the reader will now look back at Figures 1A and 1B he will find the paint on Figure 1B as it should be in answering a CQ call. This illustrates the power of I-T response in removing clutter, be it sea, rain, or land from the PPI.

The identities of the TV NEREID and Bowditch Hall were obtained (in accordance with paragraph 5. 1. 4. 2 of this specification) by the operator's sequentially range and azimuth gating his CQ replies into separate address stores in the I-T. By using separate interrogate pushbuttons associated with each of these address stores, selective or Normal Calls (see paragraph 6. 0 of this spec) were demonstrated at will. A directed type of communication was also demonstrated in the form of a Ring-the-Bell Call. Sending out this call caused an alarm to sound on the addressed vessel. Broadcast Calls (see paragraph 7. 0 of this specification) were also demonstrated.

During the tests, in addition to the limited range, some random triggering of the transponders was experienced. This was especially apparent in the broadcast mode which had an especially simple code structure. This will be eliminated by the proposed 9-bit Barker code sync word which has now been adopted.

Further testing with transmitter powers in the order of 200 watts is expected to begin in the near future.

The work so far was done for the Maritime Administration of the U. S. Department of Commerce under contract 3-36249. H. A. Feigleson is the Marad Project Engineer.

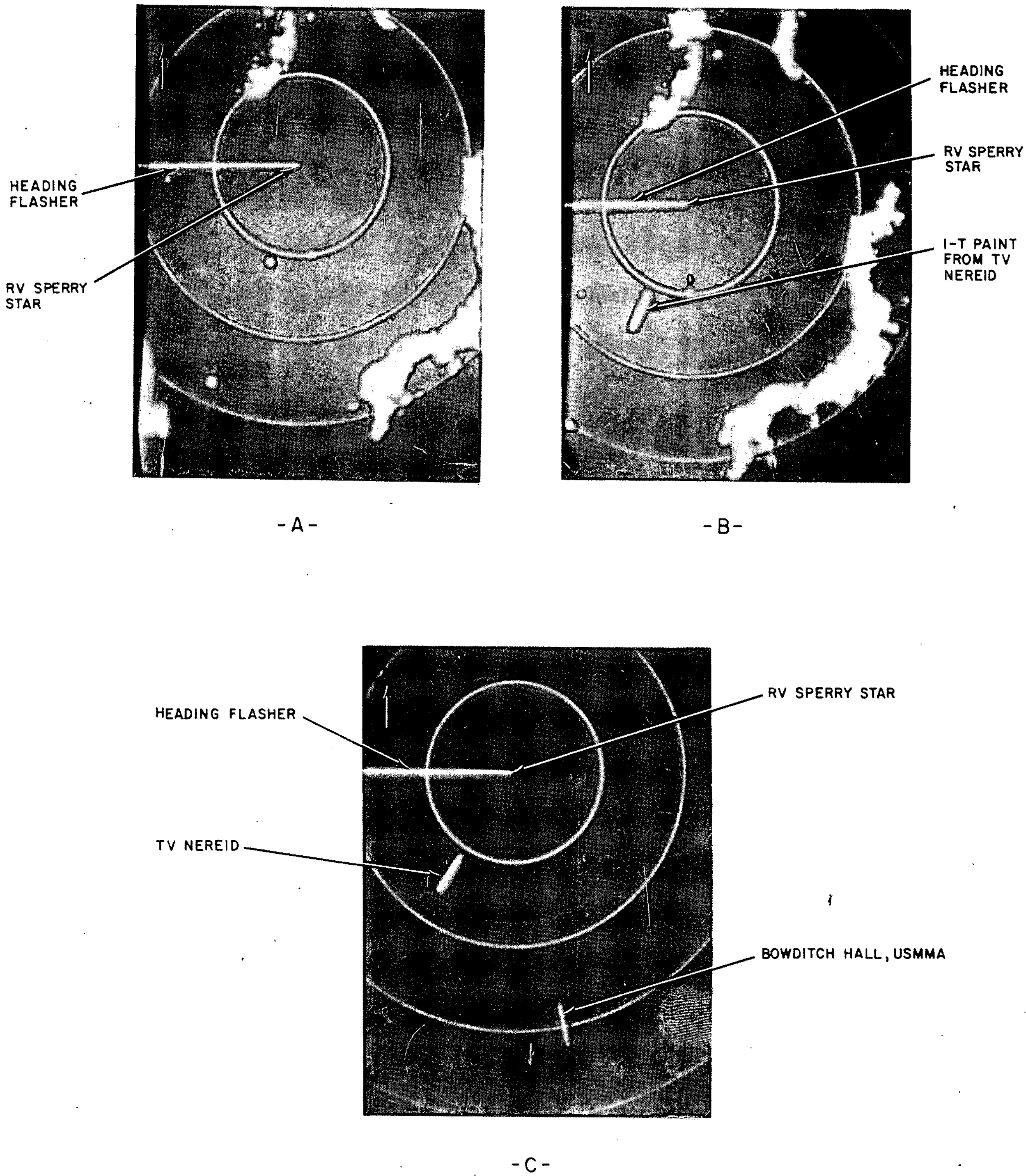

Figure 1. Radar PPI Illustrations (2967)

DEFINITIONS

Aid to Navigation[1]	A device, external to a craft, designed to assist in the determination of position of a craft or of a safe course or to warn of dangers. (See also Navigational Aid.)
Beacon[1] (General)	1. A fixed aid to navigation. 2. An unlighted aid to navigation. 3. Anything serving either for guidance or warning.
Beacon, Radar[1]	A radio beacon transmitting a signal on the radar frequency which permits a craft to determine the bearing and, with some types, the distance of the beacon. (Implies shore mounting.) (See also Racon and Transponder.)
Beacon, Radio[1]	A radio transmitter emitting a characteristic signal to permit a craft with suitable equipment to determine its direction, distance or position relative to the beacon. (The characteristic signal identifies the beacon.)
Beacon, Transponder[2]	(See Transponder.)
Clutter	Extraneous own radar echoes as distinct from noise (which see) which tend to obscure the reception of a desired signal. The clutter is not only visible on the radar display, but will also affect automatic target detection. (See also Land, Rain, and Sea Clutter.)
Clutter, Land	To an observer interested only in ship traffic, the normal land return may be thought of as clutter.
Clutter, Rain	Extraneous own radar echoes as distinct from noise (which see) returned from rain, which tend to obscure the reception of the desired signals.
Clutter, Sea	Extraneous own radar echoes as distinct from noise (which see) returned from waves which tend to obscure the reception of the desired signals.
CQ Call	Article 31 of the ITU defines the CQ call as a general call to be used to call stations in the mobile service.
Fix[1]	A relatively accurate position determined without reference to any former position.

Fruit[2] or Fruit Pulse[2]	A pulse reply received as the result of interrogation of a transponder by interrogators not associated with the responsor in question.
Garbling	Reception of the signals from two or more transponders at the same time which, because of the overlapped codes, invalidates the information in the message.
Interrogation[2] (transponder system)	The signal or combination of signals intended to trigger a response.
Interrogator[2] (electronic navigation)	1. A radio transmitter and receiver combined to interrogate a transponder and display the resulting replies. (This is the definition used in this specification.) 2. The transmitting part of an interrogator-responsor.
Interrogator-Responsor (IR)[2]	A combined radio transmitter and receiver for interrogating a transponder and displaying the resulting replies.
Interrogator/Transponder	A device, proposed in this paper, that combines the functions of interrogation and replying (transponder) in one piece of equipment.
Navigation[1]	The process of directing the movement of a craft from one point to another.
Navigational Aid[1] or Navigation Aid	An instrument, device, chart, method, etc., intended to assist in the navigation of a craft. In light of "Aid to Navigation," which see, this implies use onboard the craft.)
Noise	Sometimes called "white" because it is uniform at all frequencies, or "thermal" because it is generated by the motion of the electrons in any material exhibiting the phenomenon of resistance due to their temperature, or "Johnson" after the scientist who first described it in a formal manner. These signals are present in all electrical devices but are so small as to be negligible in all but sensitive receivers such as a radar receiver. A signal to be detected by a radar must be stronger than the noise generated by the effective resistance at the

Noise (cont)	front end of the radar receiver. Noise causes the "grass" on a radar A scope, the general background on the PPI when the gain is turned up, the "snow" in a television picture, and the "hiss" in a sensitive radio receiver when no signal is present. Noise should not be confused with clutter. Clutter consists of the radar's own signals reflected from so many small targets that the result may appear as noise but, in fact, is not.
Racon[1]	A non-directional radar beacon which returns a coded signal when triggered by a radar signal. (Use of the word beacon in the definition implies shore mounting. In European usage, a Racon is any type of radar beacon or transponder either shorebased or shipborne.)
Radar (after Bowditch)	A device using electromagnetic radiation and normally having a highly directive antenna used for determining the distance to an object by measuring the time interval between transmission of a signal returned as an echo or by a transmitter (transponder) triggered by the outgoing signal. The bearing of the object can be determined by observing the orientation of the directive antenna at the moment of signal reception.
Radar, Primary[1]	Radar using only reflection for indication of targets. (See also Radar, Secondary.)
Radar, Secondary[1]	Radar using automatic retransmission when triggered by a radar signal. (See also Radar, Primary.)
Radar Target[1]	An object which reflects a sufficient amount of signal to produce an echo on the radar screen.
Ramark[1]	A radar beacon which continuously transmits a signal appearing as a radial line on the PPI, the line indicating the direction of the beacon. (Implies shore mounting.)
Reply	The message returned by a transponder (radar beacon) to the interrogator in response to an interrogation.
Sea Return[1] or Clutter	Radar echoes returned from the sea.

Signal to Noise Ratio	The ratio of the desired signal power to the noise power at the same point in the receiving system.
Selective Calling	Encoding of an interrogation so as to elicit a reply from a particular transponder only. The address of the transponder must be known in advance.
Transponder[2] also Transponder Beacon[2] (electronic navigation)	A transmitter-receiver facility whose function is to transmit signals automatically when the proper interrogation is received.
Transponder, crossband[2] (electronic navigation)	A transponder that replies in a different frequency band from that of the received interrogation. (Unless specifically mentioned to the contrary, all transponders in this specification are of the crossband type.)

(1) American Practical Navigator
Bowditch
1958 Edition
U. S. Navy Hydrographic Office

(Parenthetical notes are by the author.)

(2) IEEE Standard Dictionary of Electrical and Electronic Terms
(IEEE Standard 100-1972)
Wiley-Interscience Div. of John Wiley & Sons, Inc.
1972 Edition

Parenthetical notes following word to be defined, are in the original. In the definition, they are by the author.

1.0 PURPOSE

1.1 This specification describes and delineates the system operational parameters of a secondary radar service, sometimes called a marine radar transponder system, for use in the maritime mobile service. The use of this system is intended to improve and supplement the effectiveness of the primary radar system and not in any way to replace it.

2.0 SCOPE

2.1 This specification describes the integration into a universally applicable system of a family of devices of various degrees of complexity that will provide compatible services between ship stations and between ship and shore stations in the maritime mobile service in accordance with their need and owner's interest.

2.1.1 The services to be provided are:

2.1.1.1 Radar target enhancement -- this means improving visibility of the primary radar echo on the radar PPI. It may be accomplished selectively or for all vessels in range. As the interrogation and reply frequencies are different (crossbanded), all sea, rain and land clutter is eliminated from the return. Very small boats will return the same strong signal as superships.

2.1.1.2 Radar target identification -- this means identification of the vessel represented by a particular primary radar echo on the radar PPI in such a way that it can be selectively called for subsequent communication purposes.

2.1.1.3 Directed (selectively called) communication for the automatic interchange of information between ships and between ships and shore. This could be but is not necessarily limited to ascertaining the other vessel's course, speed and draft.

2.1.1.4 Directed (selectively called) communication for the purpose of the interchange of information between the persons on watch on the respective vessels. This can be limited to a request to establish radio communication or extended to the interchange of maneuvering information and such other information as can be encoded in a standardized form.

2.1.1.5 Broadcast communication to all in range with the source of the broadcast identified on each recipient's radar PPI. This could be used and is proposed as an extension of the present system of whistle signals used in maneuvering situations.

2.1.2 Three basic types of device are specified although each may have several levels of complexity in accordance with the owner's need and interest. These devices are:

2.1.2.1 An interrogator-transponder used in conjunction with a radar.

2.1.2.2 An interrogator-transponder used independently with only an omniantenna.

2.1.2.3 A transponder only.

2.2 Interrogator-Transponder.

2.2.1 The interrogator-transponder is designed for use in conjunction with a shipborne or shore-based radar or by itself and is the principal device around which the system is built.

2.2.1.1 The interrogator-transponder may be used at will by the operator as an interrogator to initiate calls, but when not being so used it will standby as a transponder and automatically reply to all interrogations addressed to it selectively or to those addressed to all transponders in range.

2.2.2 Interrogation mode in conjunction with a radar.

2.2.2.1 When used as an interrogator in conjunction with a radar, the interrogator-transponder will make interrogations and display the replies for the purposes of:

2.2.2.2 Radar target enhancement of the crossbanded type, displayed on the radar PPI.

2.2.2.3 Determination of target identity; its display on the interrogator-transponder control and display panel and enhancement of the responding vessel's radar paint on the radar PPI.

2.2.2.3.1 Transmission of a communication directed to a selected recipient and to which an automatic reply is required, display of the answer on the interrogator-transponder control and display panel and enhancement of the responding vessel's paint on the radar PPI.

2.2.2.3.2 Transmission of a communication directed to a selected recipient, which may or may not require an answer by the receiving watch officer, receipt of which will be automatically made but which will also alert the person on watch on the interrogated vessel to the receipt of the message, display of the acknowledgment on the interrogating interrogator-transponder's control and display panel and enhancement of the responding vessel's paint on the radar PPI.

2.2.2.4 Transmission of a broadcast message to all in range.

2.2.3 Transponder mode in conjunction with a radar.

2.2.3.1 When used in conjunction with a radar and when standing by in the transponder mode, the interrogator-transponder will automatically make appropriate replies via its omnidirectional antenna as required by the different types of interrogation to provide for the following:

2.2.3.2 Crossbanded enhancement of the associated radar return on the interrogating vessel.

2.2.3.3 Identification on the interrogating vessel of the interrogated vessel by return of a discrete address which can then be used by the interrogator for future selective interrogation of that transponder.

2.2.3.4 Automatic reply to that type of directed interrogation to which an automatic reply is to be made and automatic inclusion in the reply of the information requested by the interrogation.

2.2.3.5 Automatic acknowledgment to the interrogating vessel of the receipt of a directed interrogation requiring the attention of the person on watch on the interrogating vessel, sounding an alarm to alert that person and the display to him of the message received.

2.2.3.6 On all receiving vessels, receipt of a broadcast alert, sounding of an alarm to alert the person on watch on the receiving vessel to receipt of a broadcast alert so that he may perform the manual operations required to complete a broadcast communication. At the completion of the manual operations, identify to that person the source of the broadcast message by causing a characteristic mark to appear on his radar PPI adjacent to the radar paint of the source of the broadcast communication and display of the broadcast message on his interrogator-transponder control and display panel.

2.2.3.7 When fitted with suitable range measuring circuitry and using either the radar or omnidirectional antenna, selective interrogation of known transponders installed as fixed aids to navigation (hereinafter called radar beacons) for the purpose of measuring range thereto. Measurement of ranges to two different radar beacons will allow determination of the interrogating vessel's position. When using the omnidirectional antenna, interrogation of two or possibly three beacons will, therefore, take place in short bursts and the burst repetition rate will be limited to a low value to prevent system saturation.

2.2.4 Interrogation mode -- non-radar equipped vessels.

2.2.4.1 When an interrogator-transponder is installed in a non-radar equipped vessel and thereby limited to using an omnidirectional antenna, the types of interrogation possible are limited to the following:

2.2.4.2 Transmission of a broadcast message to all in range.

2.2.4.3 When fitted with suitable range measuring circuitry and using the omnidirectional antenna, selective interrogation of known radar beacon aids to navigation for the purpose of measuring range thereto. Measurement of ranges to two different transponders will allow determination of the interrogating vessel's position. When using the omnidirectional antenna, interrogation of two or possibly three beacons will, therefore, take place in short bursts and the burst repetition rate will be limited to a low value to prevent system saturation.

2.2.5 Transponder mode -- non-radar equipped vessels.

2.2.5.1 When an interrogator-transponder installed on a non-radar equipped vessel is on standby in the transponder mode, it will perform all the same functions as when operated in conjunction with a radar except to receive a broadcast message. It will, therefore, provide the following:

2.2.5.2 Crossbanded target enhancement as in paragraph 2.2.3.2.

2.2.5.3 Identification of the interrogated ship as in paragraph 2.2.3.3.

2.2.5.4 Automatic information transmission as in paragraph 2.2.3.4.

2.2.5.5 Alerting the person on watch to the receipt of a directed interrogation and its content as in paragraph 2.2.3.5.

2.3 Transponder-Only.

2.3.1 There are two applications in which transponder-only devices are of interest. These are: one, to provide the lowest cost device to the very small boat that would provide it with many of the benefits of the system, and two, the use of shore-based transponders as fixed aids to navigation, i.e., radar beacons. The low cost device is called a least-transponder.

2.3.2 Fitting a transponder-only on the small boat would provide:

2.3.2.1 Crossbanded target enhancement of the small boat's radar return on the PPI's of all interrogating vessels as in paragraph 2.2.3.2.

2.3.2.2 Identification of the small boat to the interrogator as in paragraph 2.2.3.3.

2.3.2.3 Means of sending to the small boat a directed communication requiring automatic reply as in paragraph 2.2.3.4.

2.3.2.4 Means of alerting the small boat operator to the receipt of a communication directed to his vessel as in paragraph 2.2.3.5.

2.3.2.5 Fitting small boat transponders limited to target enhancement (paragraph 2.3.2.1) and identification (paragraph 2.3.2.2) is amply justified on the basis of providing major assistance in search and rescue operations.

2.3.2.6 Adding means of receiving directed communications as in paragraph 2.3.2.4 provides a means of communication from harbor surveillance radars with either manual or automatic input at the radar that will ease the burden on voice radio communications in Vessel Traffic Systems (VTS).

2.3.3 Installation of transponders with a standard, precisely known and stable delay in answering an interrogation, as shore-based fixed aids to navigation or radar beacons provides a means of precision range measurement to a known point and of improved accuracy in bearing determination due to reduction in signal-to-noise and signal-to-clutter ratios. Limiting them to replying only when selectively interrogated prevents any confusion between transponders fitted as aids to navigation and those used in the ship-to-shore and shore-to-ship modes.

2.4 Precision Ranging.

2.4.1 As each owner at his option may fit his interrogator-transponder with range measuring means, it is required that all transponders maintain a known standard delay between the receipt of each bit of a message and its reradiation in a reply. The control of the delay, however, may vary slightly in accordance with the application.

2.4.2 Therefore, it is required that all transponders fitted as fixed aids to navigation (radar beacons) control their delay most precisely so as to be able to provide precision navigation data such as is required by superships' navigation in narrow channels.

2.4.3 As one of the major justifications for this secondary radar system is improvement in the accuracy in the determination of relative range and bearing between two ships, all ships subject to the Safety of Life at Sea Convention (SOLAS) shall maintain the same level of control on the delay through their transponders as is required for the radar beacons of paragraph 2.4.2. The degree of precision required in the ranging circuits in the interrogator may, however, be left to the interest of the owner.

2.4.4 Small vessels not under SOLAS may be permitted wider latitude in control of the delay through their transponders and even more in the precision of their ranging circuitry, if fitted.

3.0 CALLS AND MESSAGES

3.1 Intelligence is exchanged in this system by means of digitally (binary encoded) calls and messages. Their format must, therefore, be in accordance with a fixed standard. This standard is established in this section (3.0).

3.2 The basic message consists of 109 bits.

3.2.1 For a system using English units, the bit length shall be 97.6330 nanoseconds (ns) which equals 16 yards or 48 feet. The bit rate is, therefore, 10.2424 MHz. A message burst is 10642 ns long in time or 1744 yards in space.

3.2.2 For a system using metric units, the bit length would be 100.101 ns which equals 15 meters (m) or 49.2 feet. The bit rate would, therefore, be 9.98993 MHz. A message burst would be 1635 m (1.0355 n.m) long in space.

3.3 A call consists of a number of words or groups of bits as follows:

3.3.1 Sync -- the first 13-bit word (bits 1 through 13) is the synchronizing or sync word. It is always a unique code. No interrogator-transponder will accept for further processing any input signal which does not begin with the sync word. This prevents the interrogator-transponder from being triggered by normal radar or other pulses which may be present in the band.

3.3.2 Intelligence to be transmitted -- the second block of 51 bits (bits 14 through 64) contains the intelligence or message to be transmitted. Its division into words can take many forms which will be discussed in detail when the various types of calls are explained.

3.3.3 Delay code -- an 11-bit word, known as the delay code, is needed in the general target enhancement or CQ mode. When used, it will occupy bit spaces 54 through 64 in the message.

3.3.4 Mode code -- the next 4-bit word, called the mode or mode code, occupies bits 65 through 68 and specifies the type of message being transmitted.

3.3.5 Called party's address -- the next word, a 20-bit word, occupying bits 69 through 88, is the called party's address. This address is included in all calls of message formats except the CQ and Broadcast Alert Calls. Therefore, in all except the CQ and broadcast alert modes, only the particular transponder whose address is included in the message will reply. Use of the called party's address in this manner provides the selective calling feature of the system. As the CQ Call is the one used to initially identify, meaning determining the address of the source of a particular radar paint, obviously its address cannot be included in the CQ Call. As the location and, therefore, address of fixed aids to navigation must be known for them to be useful, transponders of this system type used as radar beacons shall be programmed not to reply to the CQ Call. As they must, therefore, always be selectively called, they cannot be confused with other transponders operating in the system.

3.3.5.1 Binary to bit conversion and its inverse -- although the called and calling parties' addresses will be presented to the operators as decimal numbers (000,000 to 999,999), they will be converted to straight binary and back for transmission in either direction. Although this adds some small cost to the equipment, it will shorten the message by 8 bits or 0.8 microseconds.

3.3.6 Initiator's address -- this is normally the calling party's address except in the broadcast mode. In the broadcast mode, as will be explained later, there are many calling parties, first the broadcaster and then each of the recipients. The use of the name initiator saves much confusion in understanding this mode. As each transponder is programmed to return the initiator's address in its reply and as all interrogators are programmed to accept only calls containing their own address, all "fruit" (display on the radar PPI of mutual interference caused by unwanted replies from other transponders) is eliminated in this system.

3.3.7 Parity -- as in most digitally encoded systems, a parity bit is included as a first level check against errors in the transmission.

3. 3. 8 Data -- various forms of data can be transmitted over this link or used internally. Their nature required precision and, therefore, the number of bits needed is:

3. 3. 8. 1 Course or heading in BCD format.

3. 3. 8. 1. 1 360° in steps of 1 degree or 9 bits.

3. 3. 8. 1. 2 360° in steps of 0. 1 degree or 13 bits.

3. 3. 8. 2 Speed in BCD format.

3. 3. 8. 2. 1 100 knots in steps of 1 knot or 8 bits.

3. 3. 8. 2. 2 100 knots in steps of 0. 1 knot or 12 bits.

3. 3. 8. 3 Distance in BCD format.

3. 3. 8. 3. 1 3990 yards in steps of 10 yards or 10 bits.

3. 3. 8. 3. 2 131,072 yards = 64 nautical miles in steps of 2 yards = 16 bits.

3. 3. 8. 3. 3 39. 9 nautical miles in steps of 0. 1 mile or 10 bits.

3. 3. 8. 3. 4 39. 999 nautical miles in steps of 0. 001 mile or 18 bits; 0. 001 miles = 6. 07612 feet.

3. 3. 8. 4 Direction -- an indication of port or starboard direction is needed in some messages. One bit is sufficient.

3. 3. 8. 5 Draft in BCD format.

3. 3. 8. 5. 1 From less than 10 to greater than 90 feet in steps of 10 feet or 4 bits.

3. 3. 8. 6 Size, type and whether or not the cargo is classified as dangerous. The following table of letters is proposed.

3. 3. 8. 6. 1

Size in Tons		Type	Cargo Dangerous
VS	GT < 5	Y Pleasure Craft	D
S	5 ⩽ GT < 1,600	P Passenger	Blank if not dangerous
M	1,600 ⩽ GT < 50,000	C Cargo	
L	50,000 ⩽ DWT < 100,000		
VL	DWT ⩾ 100,000		

3.3.8.6.2 Typical statements might be:

VSY meaning most any kind of small nonprofessional craft; or

VLCD meaning a cargo vessel of greater than 100,000 DWT carrying a dangerous cargo. This would include VLCCs or the like.

3.3.8.6.3 Eight (8) bits are required to transmit this table.

3.3.8.7 A category called "OTHER" meaning the transmission of other information by use of a modified form of the international single letter signal code. As the transmission will be limited to one letter per message, only 5 bits are required to transmit the information.

3.3.8.7.1 The international code is shown in the table with the addition of the letter R to mean "I AM ANCHORED" for this system use. As can be seen, the single letter codes cover the information needed for this type of system. This code would be used in two senses. For use in intership and ship-to-Vessel Traffic System (VTS) control would be as written. For VTS to ship, however, more of the statements might shift to the "YOU SHOULD" form. A for instance might be "I/YOU SHOULD ALTER YOUR COURSE TO STARBOARD" rather than "I/I AM ALTERING MY COURSE TO STARBOARD."

3.3.8.8 Latitude and longitude are needed in navigation calculations. They are expressed as:

	BCD
180° in steps of 1.0 degree	9
60' in steps of 1 minute	7
60" in steps of 0.1 second	11
N-S or E-W	1
	28 bits

0.1 second of latitude equals approximately 10 feet.

4.0 TECHNICAL PARAMETERS

4.1 Carrier Frequencies and Bandwidths.

4.1.1 The interrogation carrier frequency (F_I) shall be 9320 ±2.5 MHz.

4.1.2 The reply carrier frequency shall be 9430 ±2.5 MHz.

4.1.3 A large percentage of modern marine radars use end-fed, slotted waveguide antennas and, unfortunately for this program, in this type of antenna the direction in which the beam points, as measured with respect to the line perpendicular to the face of the antenna, is a function of frequency. The common name given to this effect is "squint." In a sample 8-foot, 0.9° horizontal beamwidth antenna, this squint measured 0.00818° per MHz. For the given frequencies stated in paragraphs 4.1.1 and 4.1.2, the squint amounts to ±0.46° with respect to a beam at the midfrequency of 9375 MHz.

As a result, the round trip loop is closed only down the sides of the beam. Therefore, for a 6-foot, 1.2° antenna which has a peak radar gain of 29 db, the interrogator-transponder peak loop gain is about 28 db. For a 9-foot, 0.8° antenna which has a peak radar gain of 32 db, the interrogator-transponder loop peak gain will still be only about 29 db.

4.1.3.1 As a result of the squint, in order for the interrogator-transponder beams to be effectively collimated with the associated radar beam, the radar will have to operate at the midfrequency of 9375 MHz.

4.1.3.2 Antennas of the parabolic reflector type do not suffer from the squint problem.

4.1.4 The instantaneous bandwidth shall not exceed 20 MHz. As this system is but a special form of marine radar with the same instantaneous bandwidth as that used by a radar with a 50 nanosecond pulse, designed to operate in the marine radar band between 9300 to 9500 MHz (normally called the X-band), no special frequency allocations are required nor will it be necessary to protect these frequencies for this use.

4.2 Bit Rates, Lengths and Shapes.

4.2.1 Given standard atmospheric conditions, the velocity of light in air is such that 2.03402 nanoseconds = 1 foot.

4.2.2 Assuming English units, the bit rate shall be 10.2424 MHz. For SOLAS ships and radar beacons, the tolerance shall not exceed ±0.004% (1 foot in 20 nautical miles).

4.2.3 This makes the pulse or bit width 97.6330 ±0.004 nanoseconds (16.0000 ±0.00064 yards).

4.2.4 The pulse shape shall be as follows: The pulse width of 97.6330 nanoseconds shall be measured at the half voltage point (-6 db power).

4.2.5 For SOLAS ships and radar beacons, the rise and fall times between the 10% and 90% voltage points shall not be longer than 35 nanoseconds.

4.3 Transponder Delay.

4.3.1 In the transponder mode, the delay through any transponder, between the leading edges of the same numbered pulses, shall be 12.595 microseconds (109-bit message = 10.642 microseconds plus an adjustable delay of approximately 2 microseconds to provide for adjustment of the overall delay to 12.595 microseconds or message +20 bits).

4.3.2 For SOLAS ships and shore beacons, the tolerance on this delay shall not exceed ±20 nanoseconds (10 feet).

4.4 Transmitter Powers and Receiver Sensitivities.

4.4.1 When in the transponder mode and, therefore, radiating through a low gain omniantenna, all shipboard interrogator-transponders shall have sufficient transmitter power to lay down a field strength of at least 5 microwatts per meter squared (-53.4 db (W/m^2)) on the peak of the beam at 1 nautical mile from the antenna.

4.4.1.1 When in this mode, the receiver shall operate satisfactorily with a field strength at the antenna of 0.04 microwatts per meter squared (-73 db (W/m^2)).

4.4.2 When in the interrogator mode on a radar-equipped ship and, therefore, radiating through a radar antenna with a minimum gain of 29 db (9-foot antenna with 3-db squint loss), the interrogator-transponder shall have sufficient power to lay down a field strength of at least 0.9 milliwatt/meter squared (-30.4 db (W/m^2)) at 1 nautical mile from the antenna.

4.4.2.1 When in this mode, the receiver shall operate satisfactorily with a field strength at the antenna of 0.0002 microwatt per meter squared (-97 db (W/m^2)).

4.4.3 When the interrogator-transponder is installed as a radar beacon (aid to navigation) and operating through a moderately directive antenna with medium gain, its transmitter shall have sufficient power to lay down a field strength of at least 2.9 microwatts per meter squared (-45.4 db (W/m^2)) at 1 nautical mile from the antenna.

4.4.3.1 When in this mode, the receiver shall operate satisfactorily with a field strength at the antenna of 0.007 microwatt per meter squared (-81 db (W/m^2)).

4.4.4 When the radar-equipped ship of paragraphs 4.4.2 and 4.4.2.1 is working with the transponder of paragraphs 4.4.1 and 4.4.1.1, the two paths are balanced and the free space, clear weather range is 153 nautical miles with a total message (100 bits long) error rate of 10^{-1}. The error rate drops an order of magnitude with each 2 db increase in signal-to-noise ratio (S/N).

4.4.4.1 Assuming sufficient antenna heights so that the range to the radar horizon exceeds 20 nautical miles, neglecting any vertical multipath (Lloyds Mirror) effects and with continuous heavy rain (16 mm/hour) between the antennas, the error rate at 20 nautical miles will be 5×10^{-5}. With 1 inch/hour continuous rain between the antennas, an extreme condition not too likely to occur, the error rate at 20 nautical miles will be 5×10^{-1}. It would improve to 10^{-2} at 18 nautical miles.

4.4.5 When the non-radar equipped small vessel of paragraphs 4.4.1 and 4.4.1.1 is range finding with the beacon of paragraphs 4.4.3 and 4.4.3.1, the paths are balanced and the free space, clear weather range is 30 nautical miles with a message error rate of 10^{-1}.

4.4.5.1 Assuming sufficient antenna heights so that the range to the radar horizon exceeds 20 nautical miles, neglecting any vertical multipath (Lloyds Mirror) effects and with continuous heavy rain (16 mm/hour) between the antennas, the 10^{-1} error rate will occur at 12.5 nautical miles. With an inch per hour rain, the error rate at 10 nautical miles will be 5×10^{-1}. It will be 10^{-1} at 9 nautical miles.

4.5 Radar Triggering and Video Delay.

4.5.1 When the interrogator-transponder is used with a radar, the interrogator-transponder and radar triggers must be synchronized with the interrogator-transponder trigger preceding the radar trigger by a fixed amount.

4.5.2 In order not to garble the interrogator-transponder transmission, the radar trigger must be delayed with respect to the interrogator-transponder trigger by at least a message length of 10.642 microseconds. In order not to garble the reply from a zero range transponder, it must not be delayed more than 12.595 microseconds less the length of the longest pulse used by the radar. It will be noted that the difference between 12.595 and 10.642 microseconds is 1.953 microseconds or 20 bits.

4. 5. 2. 1 The interrogator-transponder must, therefore, be designed so that this delay may be accomplished either by diverting the normal radar trigger generated within the radar through a delay device in the interrogator-transponder and back to the radar or by a trigger generator within the interrogator-transponder which may be used to supply delayed triggers to the radar. In this latter case, in order to prevent synchronous mutual interference, the interrogator-transponder manufacturers must take care not to use highly stable trigger generators all set exactly to the same frequency.

4. 5. 3 As the video output from a decoded transponder reply is coincident with the last pulse in the message, the radar video and the radar sweeps must be delayed in order to make the transponder signal paint on the radar PPI display fall on or near the radar video paint. In the CR mode for range gating using the VRM and for any other range measurements, the radar and interrogator-transponder paints must be coincident on the radar PPI, but otherwise it is convenient to delay the transponder return somewhat more than the radar return thereby producing a double pulsed display which will serve to identify the vessels replying to the interrogation.

4. 5. 3. 1 This is accomplished by inserting the required additional delay in the trigger lead between the radar transmitter and the radar display. By inserting the delay prior to the display, the relationships between the sweeps, the fixed range rings and the variable range marker are not disturbed. In like manner, the radar video must be delayed an identical amount.

4. 5. 3. 2 If the radar trigger occurs at what would be the start of the 110th bit in the interrogation message, the delay required above in paragraph 4. 5. 3. 1 shall be equal to the standard delay through a transponder less one bit length or 128 bits, which equals 12. 497 microseconds. If the radar trigger starts later than the 110th bit time, this delay must be shortened by the amount the radar trigger is delayed.

4. 5. 4 The switching required in paragraphs 4. 4. 5. 2 and 4. 4. 5. 3 shall be done in such a way that loss of power to the transfer relays, either by turning off the interrogator-transponder or by accident, returns the radar to its normal mode of operation. In addition, both the inputs and the outputs of the delay devices shall be switched so that in the deenergized relay state nothing other than the relay contacts is left connected to the radar. In this way normal radar operation is made fail-safe against open circuits, short circuits to ground, and other troubles in the interrogator-transponder input circuits.

4.5.5 The additional operator-selectable delay of the transponder return to cause the interrogator-transponder paint to appear further out in range than the radar paint is done internally in the interrogator-transponder and is, therefore, under the interrogator-transponder designer's control.

4.6 Use of Radar Variable Range Marker in Radar Target Identification.

4.6.1 In the CQ mode, it is necessary to azimuth and range gate a particular interrogator-transponder reply into a readout on the interrogator-transponder display panel. The range gating is controlled by use of the radar's variable range marker. The variable range marker pulse that is used to brighten a range ring or spot on the radar PPI is picked up and transferred to the interrogator-transponder where it is used to open the necessary range gate. The azimuth gating is accomplished simply by having the operator press the interrogation button on the interrogator-transponder control and display panel as the radar scan line on the CRT approaches the target of interest on the PPI.

4.6.1.1 The pickup of the VRM pulse shall be by means of a high input impedance device, mounted in the radar, that shall not disturb operation of the variable range marker and that will protect it against shorts to ground and other troubles on the lead to the interrogator-transponder.

5.0 MESSAGE FORMATS

The various message formats and the means of initiating them are explained in the following paragraphs.

5.1 CQ Call.

5.1.1 The CQ Call is the one used for general target enhancement and to discover the identity of neighboring vessels. It can only be made by interrogator-transponders associated with a radar and which makes transmissions and receptions through the radar antenna.

5.1.2 To make the call, the watch officer simply sets the mode switch on the interrogator-transponder control and display panel to the CQ position and pushes the interrogate pushbutton. Setting the mode switch sets the proper mode code in the message and also own ship's (called the Initiator's address in the message. The watch officer is presumed to be watching the radar PPI while making this call. He will, therefore, press the interrogate button when the scan line on the PPI shows the radar antenna is coming to bear on the area of interest and release it when the area has been covered. This may, of course, be a complete 360° scan.

5.1.2.1 Pressing the interrogate button transfers the interrogator-transponder output to the radar antenna and releasing it returns the interrogator-transponder to its omnidirectional antenna and leaves it in standby in the transponder mode.

5.1.2.2 The CQ interrogation message format is:

Bits 1-13	SYNC WORD	
Bits 14-64	BLANK	
Bits 65-68	MODE	0001
Bits 69-88	BLANK	
Bits 89-108	INITIATOR'S ADDRESS	
Bit 109	ODD PARITY	

5.1.3 When this message is received by any and, therefore, every transponder in range, each will recognize the CQ mode code and automatically reply to the interrogation. The message will be returned exactly as received except that each transponder will insert its own vessel's address in the Called Party's Address space in the message (bits 69 through 88).

5.1.3.1 The CQ reply message format is:

Bits 1-13	SYNC WORD	
Bits 14-64	BLANK	
Bits 65-68	MODE	0001
Bits 69-88	CALLED PARTY'S ADDRESS	
Bits 89-108	INITIATOR'S ADDRESS	
Bit 109	ODD PARITY	

5.1.3.2 When this message is received back at the initiating interrogator-transponder, the interrogator-transponder will recognize the CQ mode code and its own address, and therefore accept the message. Because they contain a different initiator's address, it will reject all CQ replies which are being sent back to other interrogator-transponders that happen to be making a CQ Call at that time. In this way no "fruit" (mutual interference from other interrogator-transponders) is displayed on the radar PPI.

5.1.3.3 When any incoming message is accepted, meaning that it has been successfully decoded, a video pulse is generated equal in width to and coincident with the last bit in the message. Besides performing a number of functions internal to the interrogator-transponder, this pulse is mixed with the radar video to cause a brightening of the prime radar paint.

5.1.3.3.1 Because of the crossbanding, there are no sea, rain, or cloud clutter echoes associated with these video signals. Therefore, if sea return is obscuring the normal radar target returns, the radar signals may be turned down or even off leaving the transponder replies as bright white-on-black signals. This provides a high level of target enhancement.

5.1.4 These same returns are also used to identify the radar targets. In this system 20 bits, forming a binary number, are used for ship and shore point addresses. A 20-bit binary number when translated to a decimal number for display purposes is slightly over a million. Its limitation to 999,999 will provide at least that many discrete addresses for unique assignment to ship and shore points. Hopefully, this will reduce the probability of finding two ships with the same address in the same area to negligible proportions.

5.1.4.1 It is obvious that these cannot be displayed directly on the radar PPI in any readable manner. In fact, if one examines the long dot-dash identity codes used to identify RACON replies on the PPI, it is obvious that only a few can be displayed at one time and they become useless on short range scales.

5.1.4.2 In this system the watch officer can range and azimuth gate a particular target's address into a readout on the interrogator-transponder control and display panel. The range gating is accomplished by using the video pulse generated by the radar's Variable Range Marker to brighten the radar video at the indicated range to also open a range gate in the interrogator-transponder. The azimuth gating is performed by the watch officer pressing the interrogate button as the rotating scan line on the radar PPI comes to bear on the target of interest. Once gated into the readout, the target's address will remain until erased by some positive action of the watch officer.

5.1.4.2.1 Means to store at least 4 addresses shall be provided.

5.1.4.3 A prudent operator, having gated an address into a readout, will promptly convert to a Normal Call (see paragraph 6.2.2) or Selective Call using this address to confirm that he had in truth gated the desired vessel's return into the gate.

6.0 NORMAL CALLS

Because of its selective nature, the Normal Call is expected to be the workhorse call of the system, hence its name. As it is made only by interrogator-transponders associated with radars, it may be radiated only in the direction of target of interest thereby keeping down system saturation.

6.1 The Normal Call comes in two variations: one, where information is sent, and the other, where information is requested. There may be more than one form of the information sent calls such as one to interchange course, speed and maneuvering data between ships, and another to convey position data and other information from a shore-based harbor surveillance radar station. The information sent form may require different information to be included in the reply.

The limitations in complexity envisioned for small boat transponder-only forms of equipment may limit the amount of information that can be exchanged.

Much standardization will, therefore, be required before a world-wide universal system can be specified in detail. In order to start the debate, the following are proposed.

6.2 Consider first a message to be sent by a radar-equipped vessel to a small non-radar vessel equipped with least-transponder equipment. Although the small vessel will be given the identity (address) of the vessel interrogating her, she will have no way of locating it so there is little point in sending her much information. One might consider an audible alert which would ask her operator to pay attention to his VHF radio; channel 16. This latter can be done by the use of a special mode code rather than an extra character in the main message space. Furthermore, in the interests of least-transponder simplicity, this type of transponder will not be able to send information back. Its use, however, provides the major advantages of the crossbanded type of target enhancement to interrogating radars and the means for this vessel to be identified to the interrogating radar operator. As the above type of call can also be used by harbor surveillance radars, the harbor radar operator can be sure he is conducting his radio conversation with the right vessel.

6.2.1 Remembering that even the least-transponder can be identified via the CQ Call and that the reply will be identical to the call, the:

6.2.2 Target Enhancing - Continuing Information of Identity Call will have the following format:

Bits 1-13	SYNC WORD	
Bits 14-64	BLANK	
Bits 65-68	MODE	0010
Bits 69-88	CALLED PARTY'S ADDRESS	
Bits 89-108	INITIATOR'S ADDRESS	
Bit 109	ODD PARITY	

6.2.3 Ring-the-Bell Call.

The form of the above call that will sound the audible alarm, which will therefore be called the Ring-the-Bell Call, will be the same except for the mode code. Its format will therefore be:

Bits 1-13	SYNC WORD	
Bits 14-64	BLANK	
Bits 65-68	MODE	0011
Bits 69-88	CALLED PARTY'S ADDRESS	
Bits 89-108	INITIATOR'S ADDRESS	
Bit 109	ODD PARITY	

6.3 Ship-to-Ship Exchange of Information Where Both Ships are Radar and Interrogator-Transponder Equipped.

6.3.1 It is expected that this type of call could become quite common being used on a regular basis by the watch officer, or on ships with sophisticated computer assisted collision avoidance radar displays, automatically by the computer. On small vessels, the information to be sent can be set in by hand, whereas on larger vessels it might well be set in automatically from the primary sensors. In either case, once this is set into the interrogator-transponder, all the watch officer need do to make a call is to set in the identity of the party to be called and press the interrogate button. The identity will, of course, have been previously determined via the CQ Call routine. In order to make this operation as easy as possible, the interrogator-transponder control and display shall contain means of storing and continuously displaying the identity of at least four other vessels, and each of these readouts will have its own interrogate button.

6.3.2 A suggested message format for the Ship-to-Ship Exchange of Information Call is:

	Interrogation		Reply	
Bits 1-13	SYNC WORD 1010		SYNC WORD	
*Bits 14-26	MY HEADING IS ---)		MY HEADING IS ---)	
*Bits 27-38	MY SPEED IS ---)	Initiating	MY SPEED IS ---)	Called
Bits 39-42	MY DRAFT IS ---)	vessel	MY DRAFT IS ---)	vessel
Bits 43-50	I AM A ---)	data	I AM A ---)	data
Bits 51-55	LETTER** ---)		LETTER** ---)	
Bits 56-64	BLANK		BLANK	
Bits 65-68	MODE 0100		MODE 0100	
Bits 69-88	CALLED PARTY'S ADDRESS		CALLED PARTY'S ADDRESS	
Bits 89-108	INITIATOR'S ADDRESS		INITIATOR'S ADDRESS	
Bit 109	ODD PARITY		ODD PARITY	

6.3.3 This raises the interesting question as to whether or not a message format which could be used to indicate intentions to maneuver would be of interest. The initiator would continue to send this message to the vessel concerned until he received agreement or disagreement from the recipient. The recipient would indicate his agreement or disagreement by inserting the letter C for yes or the letter N for no in his reply. The mode code for this message would cause a special alarm to sound on the recipient's vessel. In this case, the heading and speed data would indicate the proposed new heading and/or speed and would have to be set in by the initiating watch officer before making the call.

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* When any of the letters A, E or I which call out changes in course or speed appear in the Letter readout, the watch officer or the computer will know the vessel is making a deliberate maneuver and should watch for the data to settle to quickly determine the new course and speed.

** A letter with meaning as defined in the modified single letter signal code shown in Table 1. The presence of a letter in this space will sound audible and visual alarms.

6.3.4 The message format for this Intending-to-Maneuver Call would be:

	Interrogation	Reply
Bits 1-13	SYNC WORD	SYNC WORD
Bits 14-26	MY NEW HEADING WILL BE ---	MY HEADING IS ---
Bits 27-38	MY NEW SPEED WILL BE ---	MY SPEED IS ---
Bits 39-42	MY DRAFT IS ---	MY DRAFT IS ---
Bits 43-50	I AM A ---	I AM A ---
Bits 51-55	LETTER A, E or I	LETTER C or N
Bits 56-64	BLANK	BLANK
Bits 65-68	MODE 0101	MODE 0101
Bits 69-88	CALLED PARTY'S ADDRESS	CALLED PARTY'S ADDRESS
Bits 89-108	INITIATOR'S ADDRESS	INITIATOR'S ADDRESS
Bit 109	ODD PARITY	ODD PARITY

6.4 Calls From a Harbor Radar.

6.4.1 The CQ Call as described above will, of course, be available to the harbor radar and used for crossbanded target enhancement and target identification. The Target Enhancement and Identity Confirmation Call and the Ring-the-Bell Call are also available to work least-transponder equipped vessels.

6.4.2 In addition, the harbor radar operator may wish to exchange other information with properly equipped ships. This may take two forms, depending on whether the philosophy of the harbor is for the harbor radar to locate the vessels or the vessels to locate themselves.

6.4.3 A convenient form for the harbor radar to use in conveying position and other data to a properly interrogator-transponder equipped vessel or vice versa is to divide the harbor into a series of tracks, usually along channels or natural routes, and to number the points where these tracks cross. The numbered points are called "way points." The information to be transmitted from the radar is, therefore, of the form "You are enroute from, say, 3 to 4 and 5 miles from 4 and you are X yards to port or starboard, as the case may be, of the centerline of the track." In the case where the ship is self locating, the format can be the same, but the meaning shifts from "You are" to "I am."

6.4.4 Position Reporting Call.

6.4.4.1 With the above shades of meaning being understood, the format is illustrated below. The reply echoes the interrogation and a comparison at the interrogating interrogator-transponder will confirm that the proper message was received.

	Shore Radar to Vessel	Vessel to Shore Radar
Bits 1-13	SYNC WORD	SYNC WORD
Bits 14-17	YOU ARE LEAVING WAY POINT "X"	I AM LEAVING WAY POINT "X"
Bits 18-27	YOU ARE "Y" MILES FROM "W"	I AM "Y" MILES FROM "W"
Bits 28-31	YOU ARE GOING TOWARD WAY POINT "W"	I AM GOING TOWARD WAY POINT "W"
Bit 32	YOU ARE TO "P" OR "S" OF TRACK	I AM TO "P" OR "S" OF TRACK
Bits 33-42	"Z" YARDS	"Z" YARDS
Bits 43-51	YOU ARE MAKING GOOD A COURSE* OF "A" DEGREES	I AM MAKING GOOD A COURSE* OF "A" DEGREES
Bits 52-59	YOUR GROUND SPEED IS ---	MY GROUND SPEED IS ---
Bits 60-64	LETTER (WITH TABLE 1 MEANING)	LETTER (WITH TABLE 1 MEANING)
Bits 65-68	MODE 0110	MODE 0111
Bits 69-88	VESSEL'S ADDRESS	RADAR'S ADDRESS
Bits 89-108	RADAR'S ADDRESS	VESSEL'S ADDRESS
Bit 109	ODD PARITY	ODD PARITY

7.0 BROADCAST CALLS

7.1 A Broadcast Alert.

To initiate a Broadcast Call or message, the initiator transmits a broadcast alert made up as follows:

Bits 1-13	SYNC WORD
Bits 14-64	BLANK
Bits 65-68	MODE 1100
Bits 69-88	BLANK
Bits 89-108	INITIATOR'S ADDRESS
Bit 109	ODD PARITY PULSE

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*Note: These are course being made good, not heading as in earlier messages.

7.2 The initiator makes this call using his interrogator-transponder in the interrogate mode and radiating through the radar antenna. He has first to set in the information (message) he wants to broadcast and sets the mode switch on the interrogator control and display panel to the Broadcast Alert position. Upon release of the interrogate button, the interrogator-transponder reverts to its standby transponder mode retaining the information to be transmitted and set to receive and reply only to Broadcast Alert replies addressed to it.

7.2.1 On a non-radar equipped vessel, the initiator makes the call through his omnidirectional antenna, holding the interrogate button down for a few seconds. Otherwise the operation is as in paragraph 7.2 above.

7.3 When an interrogator-transponder on a radar-equipped ship which is standing by in the transponder mode receives a Broadcast Alert, it stores the address in its shift register and sounds a visual and audible alarm to attract the watch officer's attention. It indicates the initiator's address in the readout on the interrogator-transponder control and display panel.

7.3.1 When the watch officer is ready to reply to the Broadcast Alert, he transfers the original initiator's address into the normal Called Party's Address space (bits 69 through 88) in the message. He then sets his mode switch to the Broadcast Recipient's position and makes the interrogation by holding down the interrogate button until he receives a reply. As he has now become a calling party, putting the mode switch in the Broadcast Recipient's position automatically sets his vessel's address in the Initiator's Address space (bits 89 through 108) in the message and transfers the broadcaster's address to the Called Party's space (bits 69 through 88).

7.3.2 This is effectively a Normal Call with a Broadcast Alert Reply mode code of 1101 in the Mode Code space in the message (bits 65 through 68).

7.3.2.1 The message format for this Broadcast Alert Reply is:

Bits 1-13	SYNC WORD
Bits 14-64	BLANK
Bits 65-68	MODE 1101
Bits 69-88	CALLED PARTY'S ADDRESS
Bits 89-108	INITIATOR'S ADDRESS
Bit 109	ODD PARITY

7.4 When this Broadcast Alert Reply is received by the interrogator-transponder on the original broadcaster's vessel, it will recognize its own address and the Broadcast Alert Reply mode code and will reply automatically.

7.4.1 Just what information should be transmitted is still subject to debate. As this call was conceived as a means of broadcasting maneuvering information, a for instance message could be, say, the letter E from the Signal Letter Signals Code (Table 1) meaning "I am altering my course to starboard." This piece of data would be transmitted by the 5 bits in the Other space (bits 51 through 55). Additional information might be: "My new heading will be XXX." If this is reported to the nearest 0.1°, 13 bits in spaces 14 through 26 in the message will be needed; "My new speed will be YYY." If this is reported up to 99.9 knots in steps of 0.1 knots, 12 bits in spaces 27 through 38 will be needed; "My draft is YY" will take 4 bits in spaces 39 through 42 ; and finally "I am a WWW" will use 8 bits in spaces 43 through 50.

7.4.1.1 The message format for the Broadcast Message is:

Bits 1-13	SYNC WORD 1010
Bits 14-26	HEADING
Bits 27-38	SPEED
Bits 39-42	DRAFT
Bits 43-50	TYPE OF VESSEL AND CARGO
Bits 51-55	OTHER DATA
Bits 56-64	BLANK
Bits 65-68	MODE 0101
Bits 69-88	CALLED PARTY'S ADDRESS
Bits 89-108	INITIATOR'S ADDRESS
Bit 109	ODD PARITY

7.5 This Broadcaster's Reply message will be automatically received by the recipient's interrogator-transponder. The interrogator-transponder will recognize its own address and the 0101 code. It will, therefore, know how to read the information bit stream and will output the data to the appropriate readouts on the interrogator-transponder control and display panel.

7.5.1 The successful decode video pulse will be stretched before sending to the radar PPI. It should be stretched to about 6 microseconds and so will draw a half-mile long, radially outward tail from the radar blip representing the vessel originating the broadcast, thereby identifying it to the watch officer.

7.5.1.1 It is the fact that this pulse occurs only while the interrogating radar beam is scanning the target and that it cannot be easily stored, that requires the presence and attention of the watch officer when making this call. The rest of the data, including the broadcaster's address, will however continue to be displayed until erased by appropriate action of the watch officer.

8.0 MODE CODES

A list of the mode codes assigned so far is:

Mode	Interrogation	Reply
CQ Call	0001	0001
Normal Calls		
Target Enhancement and Identity Confirmation	0010	0010
Ring-the-Bell	0011	0011
Ship-to-Ship Exchange of Information	0100	0100
Intending to Maneuver	0101	0101
Shore Radar to Vessel	0110	0110
Vessel to Shore Radar	0111	0111
Broadcast Alert	1000	
Broadcast Alert Reply which is really a new interrogation	1001	
Broadcast Message which being the reply to the Broadcast Alert Reply interrogation carries the same mode code		1001
Ranging	1011	1011

9.0 PRECISION RANGING AND POSITION FINDING

An important feature of this system is its ability to do precision range finding.

9.1 The shipboard units needed are just the standard interrogator-transponder equipments with added precision range counters.

9.2 The shore-based units, which are properly called radar beacons -- or in what follows just beacons, are basic transponder units with precision control of the delay the signal experiences in passing through them. As they have only one function, that is to act as a transponder capable of handling only one type of call, the signal processing circuitry is kept to a minimum.

9.2.1 Because of the Lloyds Mirror effect (nulls in the propagation due to reflection of the radio waves from the surface of the sea, sometimes called vertical multipath) and because it is convenient to use omni-directional antennas on the interrogating interrogator-transponders as well as on the beacons, it may be necessary to use vertical space diversity and higher transmitter power for those beacons that have to lay down signals at long ranges.

9.3 Achievement of Accuracy.

9.3.1 Random errors are reduced by automatically averaging a large number of measurements. If large is defined as 128 or 2^7, a convenient binary number, the errors will be reduced by the square root of 128 or a factor of about 11. As a result, even in a system whose range counter is running at the bit rate of 10.24 MHz or 16-yard increments, the error in range measurement would be only ±1.6 yards.

Running the clock at any higher frequency will proportionately reduce the error. In this way the random error can be reduced to 0.2 yards (1 sigma).

9.3.2 As in the ranging mode, the beacon reply is the same as the interrogation and this can be checked at the interrogator-transponder. The range count for each interrogation will be accepted only if the received message is the same as the transmitting message. This will eliminate grossly erroneous range measurements from being included in the averaging process.

9.3.3 Bias errors and geometrical dilution of the position error -- if the variation in the delay through the system does not exceed 17 nanoseconds, the random errors 0.2 yards, and the crossing angles of the two necessary LOP's are between about 30 and 150 degrees, the fix error should be less than 16 yards 95% of the time (2 sigma).

9.3.4 ±16 yards is considered adequate accuracy to keep a vessel safely in her half of a 128-yard, or approximately 400-foot, wide channel.

9.4 The number of vessels that can be working in one area at the same time is based on two constraints: one, that large ships will be limited to updating their position once every 3 seconds, and two, that small craft will be limited to once in 30 seconds. To make a two-LOP fix will take each vessel 3500 μs so that it takes 850 large ships or 8500 small ships working the same two beacons at the same time to bring them to saturation. A more useful combination might be 300 large ships and 5570 small craft. Defining large as commercial plus fishing vessels and small as pleasure craft, the U. S. Coast Guard has forecast that in U. S. harbors in the year 1990 the maximum number of vessels using a system like this at any one time would be 200 and for pleasure craft about 350 and these maximum densities did not occur in the same harbor.

9.5 Method of making the fix -- for small vessels it is assumed that the operator will measure his two ranges and plot the result on his chart. His fix accuracy will, therefore, be much less than the 16 yards quoted above. The 16-yard accuracy was based on the use of a small dedicated computer to convert the two LOP's to the distance along and the error perpendicular to the track form.

TABLE 1

MODIFIED INTERNATIONAL SINGLE LETTER SIGNALS

A	I am changing speed.
*B	I am taking in, or discharging, or carrying dangerous goods.
C	Yes (affirmative or "The significance of the previous group should be read in the affirmative").
*D	Keep clear of me; I am maneuvering.
*E	I am altering my course to starboard.
F	I am disabled; communicate with me.
G	I require a pilot. When made by fishing vessels operating in close proximity on the fishing grounds, it means: "I am hauling nets."
*H	I have a pilot on board.
*I	I am altering my course to port.
J	I am on fire and have dangerous cargo on board; keep well clear of me.
K	I wish to communicate with you.
L	You should stop your vessel instantly.
M	My vessel is stopped and making no way through the waters.
N	No (negative or "The significance of the previous group should be read in the negative"). This signal may be given only visually or by sound. For voice or radio transmission the signal should be "NO."
O	Man overboard.
P	In harbor -- All persons should report on board as the vessel is about to proceed to sea. At sea -- It may be used by fishing vessels to mean: "My nets have come fast upon an obstruction."
Q	My vessel is "healthy" and I request free pratique.
R	I am anchored.
*S	My engines are going astern.
*T	Keep clear of me; I am engaged in pair trawling.
U	You are running into danger.
V	I require assistance.
W	I require medical assistance.

TABLE 1

MODIFIED INTERNATIONAL SINGLE LETTER SIGNALS (Cont)

X	Stop carrying out your intentions and watch for my signals.
Y	I am dragging my anchor.
Z	I require a tug. When made by fishing vessels operating in close proximity on the fishing grounds, it means: "I am shooting nets."

NOTES:

1. Signals "A" and "R" are added or modified for secondary radar use only.
2. Signals of letters marked by an asterisk (*) when made by sound may only be made in compliance with the requirements of the International Regulations for Preventing Collisions at Sea, Rules 15 and 28.
3. Signals "K" and "S" have special meanings as landing signals for small boats with crews or persons in distress. (International Convention for the Safety of Life at Sea, 1960, Chapter V, Regulation 16.)