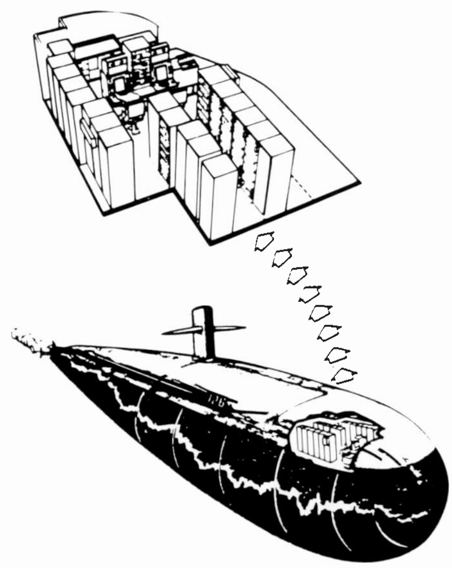
J. Hemschoot | K. Weir

Room at the bottom: The Trident integrated radio room



Undersea communications is not just a reality— it is a vital link in US strategic defense

Trident-class submarines dwarf the Polaris and Poseidon, their predecessors. Side by side in dry dock, the Trident and Poseidon look like mother and daughter. Trident displaces 18,000 tons, is 559 feet long, and is as tall as a five-story building. Nonetheless, it is extremely agile under the sea, and is as difficult to locate as the proverbial needle in a haystack. This paper describes communications with deployed Trident submarines through the Integrated Radio Room, or the "room at the bottom."

Abstract: *The Trident is the largest, most sophisticated strategic submarine in the US Navy. Its mission is to act as a nuclear deterrent. A Trident on patrol is completely mobile and virtually undetectable. It carries a destructive force that is unparalleled on one platform. However, the Trident can never be a credible deterrent unless it can maintain a constant, reliable communications link with the US national shore-based command centers. The Integrated Radio Room (IRR) provides this vital link. It is a computerized, automated communications suite that covers the radio bands from ELF through UHF. This article describes how automation and integration have combined to produce a sophisticated communications system that has more capability and is controlled by fewer operators than ever before.*

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Mission

The U.S. Navy has two types of submarines; attack submarines and strategic submarines. The Trident (SSBN 726 class) is a strategic submarine that represents one arm of the U.S. strategic defense triad—Minuteman and manned bombers are the other two arms. Trident submarines are extremely quiet, seldom transmit, and are virtually undetectable on patrol. A primary mission of a Trident while on patrol is to monitor radio frequencies for emergency action messages (EAM's). These messages contain the command and control information related to ballistic missile launch.

The Trident Integrated Radio Room (IRR), designed and manufactured by RCA, introduced communications automation into the US fleet. It is the first computer-controlled communications center on a submarine. Its function is to provide accurate and reliable exterior communications between the Trident-class submarine and satellites, aircraft, shore facilities, and other ships. Its official nomenclature is the AN/BSC-1 Communications Central. Figures 1 and 2, respectively, provide a simplified overview of Trident communications for surface operations while entering and leaving port, and for submerged operations while on patrol.

Program status

IRR is a mature system in production, and is fully supported logistically. At least 20 submarines are planned, with the first 11 ship sets already delivered or under construction. To date, RCA has delivered IRR equipment for the first seven ships. Four of these are operationally deployed out of the West Coast sub base in the Hood Canal at Bangor, Washington. Deployed submarines include:

- *USS Ohio*, SSBN 726
- *USS Michigan*, SSBN 727
- *USS Florida*, SSBN 728
- *USS Georgia*, SSBN 729

Submarines nine and above will operate out of the future East Coast Trident base at Kings Bay, Georgia.

System description

Figure 3 is a simplified block diagram of the Trident Radio Room depicting the seven major subsystems that make up the IRR, as well as the future growth subsystem (EHF).

A "to scale" physical layout of the radio room is shown in Fig. 4. As can be seen, the IRR comprises 23 racks of electronic equipment and two dummy loads. These racks are partitioned into subsystems as follows:

- VLF/LF subsystem
- HF/UHF subsystem
- ELF subsystem
- Control, monitor and test subsystem
- Data switching sybsystem
- Support subsystem
- Antenna interface subsystem

Radio signals to and from the Trident submarine are routed through one of seven antenna suites; two multifunctioned masts, two periscope masts, a towed buoy antenna, a buoyant cable antenna, or an emergency whip antenna.

Radio room electronic equipment consists of Navy inventory equipment such as AN/UYK-20 standard Navy minicomputer and OJ-326(V) standard Navy display, off-the-shelf militarized equipment, and RCA-designed equipment. Within the radio room, there is a large degree of commonality and standardization. Equipment rack enclosures are a common design. The majority of the racks are water-cooled and contain one of three standard water to air heat exchangers or thermal control units. Each rack contains a power control unit, again of common design. The various subsystems throughout the radio room contain standard mechanical hardware and common printed circuit boards for power distribution, switching, and processor interfacing.

Applicable specifications with respect to EMI, EMC, TEMPEST, environmental conditions, airborne and structureborne noise, and reliability and maintainability have been met or exceeded.

Communications capability

A broad overview of the radio room communications capability is shown in Table I. The primary communications, where the radio receivers and transmitters are physically located within the radio room, are described in the top half of the table. The bottom half of the table represents situations where the receivers are located externally to the radio room, and the radio room function is to provide an interface to an appropriate antenna.

The primary communications link to the submarine is via VLF secure data. UHF Satcom secure data and HF secure radioteletype are secondary or backup links. The submarine broadcast control authority assigns serial numbers to all messages for accountability. All strategic submarines are required to monitor the submarine broadcast and to maintain message accountability. Since VLF is the primary communications mode for transmitting to the submarine and is the normal way submarine broadcasts are received, many special features were designed into the VLF/LF subsystem.

VLF software calculates the transmission delay based on the latitude/longitude of both the transmitter and the ship, and adjusts the delay as the ship moves. Many of the VLF modes have quality indicators associated with received characters, such as

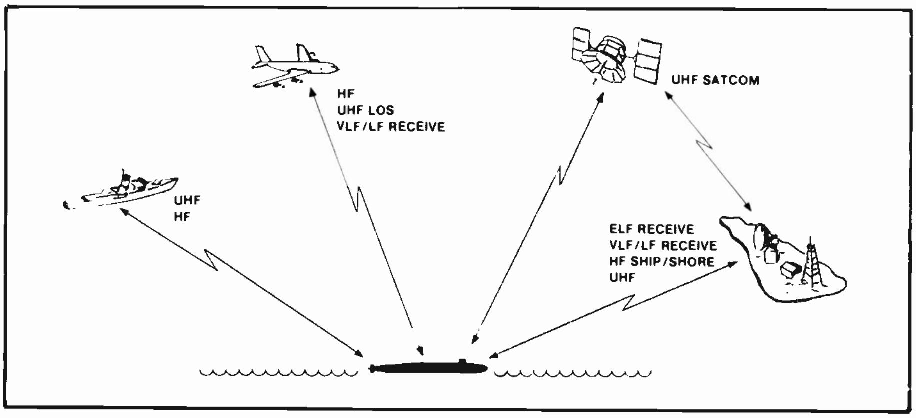


Fig. 1. *For surface communications, Trident must have an antenna broaching the surface of the water to transmit. Trident is normally only surfaced for entrance to and egress from port. Transmission may be over a high-speed satellite data link, radio/teletype or voice communications.*

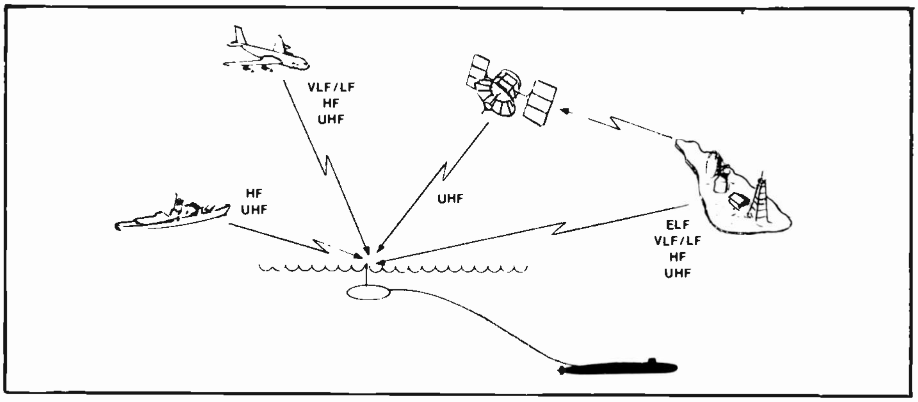


Fig. 2. *On patrol, Trident is normally submerged, listening to submarine broadcasts that can be received under water. In this mode of operation, Trident is virtually undetectable.*

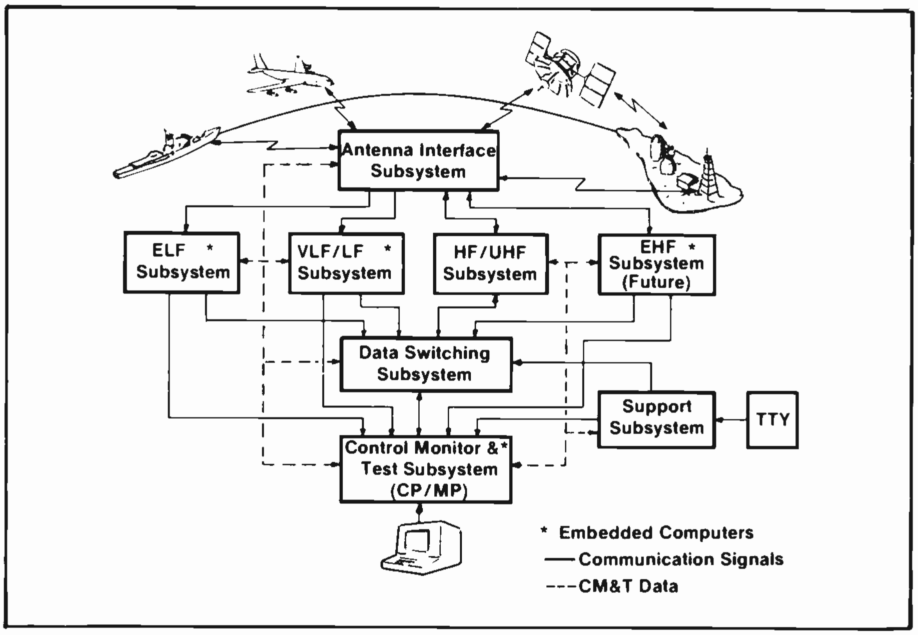


Fig. 3. *Simplified block diagram of the IRR, showing the seven major subsystems: antenna interface subsystem, VLF/LF subsystem, HF/UHF Subsystem, ELF Subsystem, Data Switching Subsystem, control monitor and test subsystem, and support subsystem. All subsystems are under centralized computer control.*

no errors detected, errors detected, errors detected and corrected.

Automation

The Integrated Radio Room provides enhanced communications capability while reducing the number of personnel required via processor-assisted operation. Centralized control of the AN/BSC-1 is accomplished via the Operator's Console. Using an interactive display and keyboard, the following can be accomplished:

- System initialization
- Remote control of communications links (configuration control)
- Operational readiness testing, and communications plan maintenance
- Single-point message reception, message transmission, storage, and retrieval
- Remote system monitoring, fault detection, and isolation

Supplementing these automated features, the AN/BSC-1 system provides both local and manual backup modes of operation for the vital communications links.

As with all other functions, configuration is accomplished by selecting items from a display menu. Menus are used because they are simple to program, easy to use, and they tell the operator all options at a glance. Once a circuit has been established from the configuration menu, the operator will select the option to perform an operational readiness test. Each portion of the circuit is individually tested. For a clear HF teletype circuit, four tests are run: a receiver self-test, a noise burst test, a teletype converter test, and an input buffer test. In the receiver self test, the internal receive circuitry is checked using built-in test equipment. A noise generator is then triggered, and a rf noise burst is sent through the receiver switch and detected to check the rf receive path. In a data circuit, the teletype converter is looped back on itself to check the teletype receive path. Finally, the input message buffer is checked for received teletype traffic.

If any problems are observed in the new link, the operator can use another set of menus to select a piece of equipment for automatic fault isolation. The computers are programmed to run a full set of tests on the equipment selected by the operator and to isolate the fault to a replaceable set of modules. After the repair, the operator runs a retest to verify that the equipment is now operational.

After the circuits have been configured, the control processor will spend its time

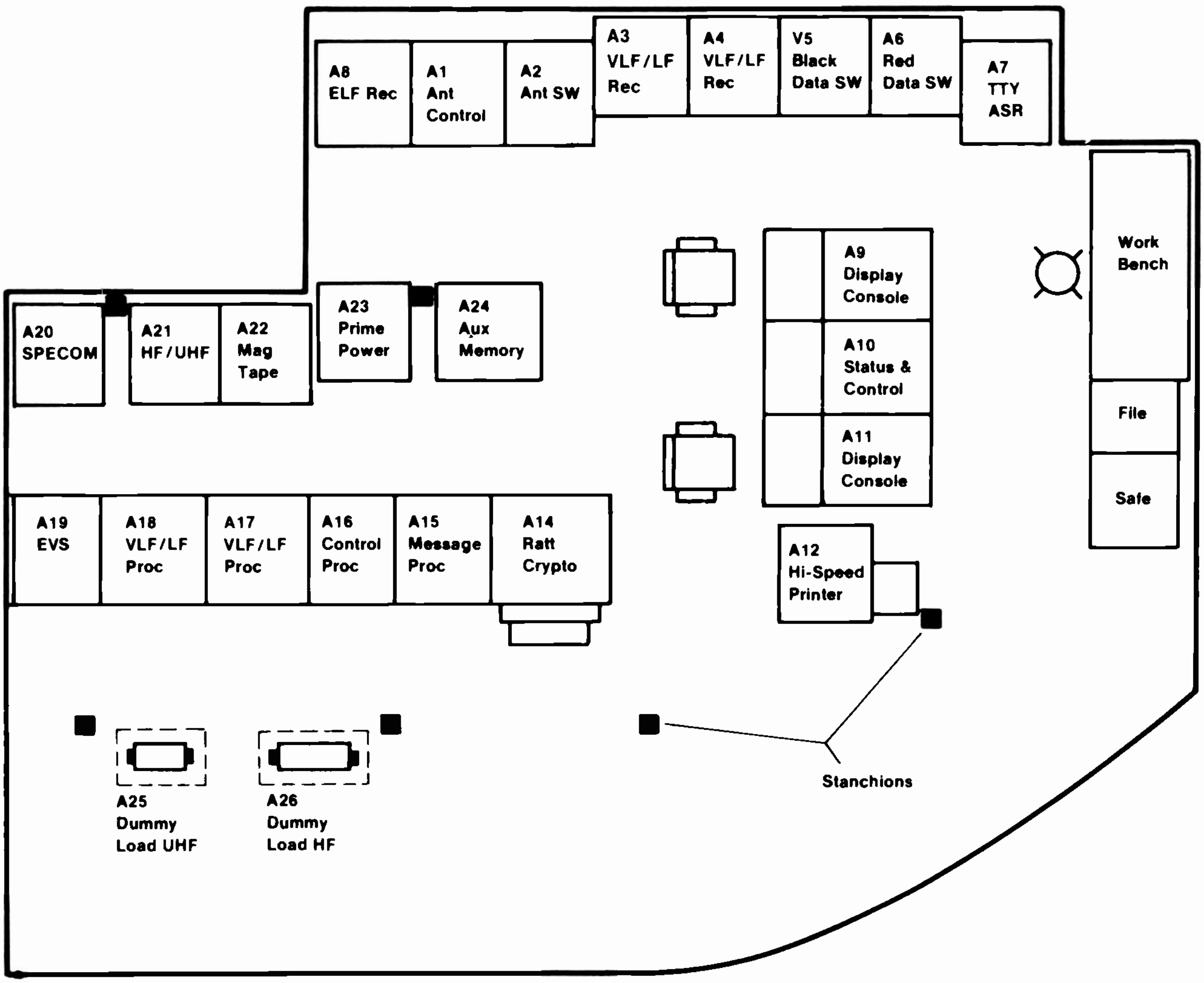


Fig. 4. *The Radio Room is located on the forward port side of ship on the top deck immediately in front of the sail area, which houses the antenna suites. Hull curvature is such that head room drops rapidly from approximately 8 feet behind the A14 thru A19 racks to 0 feet at the hull.*

automatically scanning the radio room for failed equipment or switches out of position. If any are found, it will raise an alarm and command the wayward switch back to the correct setting. This "performance monitor" function is repeated every 30 seconds and will not only pick up failed equipment, but operator setup errors as well.

Degraded mode system operation

In all complex electronic systems, failures are expected to occur at some point. The failure may involve a runaway computer, a failed radio, or an anomaly in the control circuits. It is important that the system not fail under these conditions, but that it should degrade to some lower but acceptable level of performance. Sustained performance is achieved through extensive use of redundant equipment for all critical operations.

In the case of a runaway computer, the operator can switch any affected equipment to local control and override the computer commands. After the faulty computer is stopped, the operator can load a backup program into the surviving computer. The backup program will maintain essential configuration control, performance monitoring, and message processing functions. Less important functions like fault isolation and message transmission will be dropped.

Failed radios and control circuits have redundant equipment to provide backup capability. When individual radios or control circuits fail, the submarine will not be able to monitor as many channels as before the failure, but essential communications will be maintained.

Message handling

The primary function of the Trident radio room is to continuously monitor the shore station broadcasts for an Emergency Action Message (EAM). These Emergency Action Messages control the readiness status of the ballistic missile system of each Trident submarine. In the event of a nuclear conflict it is the EAM that transmits the Presidential directives to launch the missiles. Needless to say, the EAMs are a critical element in our nuclear deterrent system. For this reason, should it ever be necessary to send a real EAM, it would be broadcast over many separate shore stations simultaneously. To allow for more reliable monitoring of a greater number of stations, automated message handling was included as an integral part of the radio room.

Table I. Radio room communications capability

Primary—inside radio room

Frequency	*Range*	*Links*	*Traffic*
ELF	3-300Hz	1 Receive	Secure Data
VLF	14-60 KHz	6 Receive	Secure Data
LF/MF	60-160 KHz 500	2 Receive	Clear & Secure radio teletype clear voice international distress
HF	2-30 MHz	2 receive 1 transceive 1 transmit	clear & secure radio teletype clear & secure voice secure data CW
UHF	225-400 MHz	1 transceive	clear and secure voice satcom secure radio teletype satcom secure data satcom secure voice

Secondary—external connectivity

Frequency	*Connectivity*	*Function*
LF	external loran receiver	navigation signals
VHF	external receiver	navigation signals
UHF	external receiver	navigation signals
MF/HF	external broadcast receiver	entertainment
WWV AUDIO	to navigation center	time signals
TV	to TV receiver	entertainment

Messages sent to submarines at sea may be addressed to individual submarines, to groups of submarines, or to all submarines copying a particular broadcast. The choice of address form is dependent on the message content and the tactical situation.

All incoming messages are sorted into addressed, non-addressed, and garbled categories based on information in the message header. Each category is further sorted so that the highest-priority message will be acted on first. Addressed messages are always displayed, printed, and filed. Non-addressed and garbled messages are displayed to the operator and await disposition.

The last 160 messages to arrive are kept on disk in the message file. Using the Logical Retrieval function, the operator can search the file for groups of messages by originator, date/time of the message, or by time of receipt. An editing function is also provided in case a service message directs the operator to correct a message in the file.

Maintenance

The following is a quick summary of the organizational, intermediate, and depot levels of maintenance on IRR.

Organizational maintenance (O-level)

O-Level maintenance includes all categories of authorized maintenance performed on IRR equipment by the submarine crew. Primary reliance is placed on the use of computer software routines in the execution of performance monitoring and fault isolation functions, the results of which are displayed on the operator's console. Additionally, certain equipment is provided with built-in test equipment (BITE) to augment or substitute for automatic performance monitoring and fault isolation. A manual troubleshooting capability is also provided through on-board general-and special-purpose electronic test equipment; however, reliance on manual troubleshooting has been minimized.

At sea, corrective maintenance is kept to a minimum by restricting it to modular replacement of printed circuit boards (PCBs), plug-in modules, and designated subassemblies and assemblies. Maintenance actions requiring more than four hours to complete have been relegated to Intermediate (I-Level) maintenance. Maintenance assistance modules (MAMs) and onboard repair parts (OBRPs) are provided on each submarine to support O-Level maintenance.

Intermediate level maintenance (I-level)

I-Level maintenance is performed during a refit period by Trident Refit Facility (TRF) personnel on board the submarine or in the Refit Industrial Facility (RIF) at the sub base. To be an effective nuclear deterrent, a strategic submarine must be on patrol. Time spent in port is time during which the submarine is not accomplishing its mission. In order to minimize the time off patrol, strategic submarines have two complete crews that alternate patrols. This gives them the highest ratio of on-patrol to in-port time of any class of ships in the Navy. The normal operational cycle of the submarine is 95 days, consisting of 70 days at sea on patrol and 25 days off patrol. A continuous 18-day period between patrols is planned for refit and resupply functions. Due to the requirements for system-level checkout and grooming, all maintenance and refit must be performed during a 13-day period.

I-Level IRR maintenance at TRF is subject to the capabilities of available personnel, tools, time, and test equipment. I-level maintenance tasks that exceed these capabilities will be referred to the appropriate depot. Major Shore Spares (complete drawers or racks) are available within 48 hours for substitution in the event of catastrophic failure. System-level repair and replacement of components (and some calibration) will be performed on board the submarine during the 13-day maintenance period. Support and test equipment that is defective will be exchanged for operable equipment at TRF.

Depot level maintenance (D-level)

D-level maintenance for IRR-unique equipment will be performed by RCA and other contractors assigned as designated overhaul points (DOPs). These DOPs are reflected in the current issue of the Master Repairable Items List. D-level maintenance includes all maintenance tasks authorized to be performed at specified facilities using the full range of capabilities, special features, and test equipment for maintenance that is outside the capabilities of O-and I-level maintenance personnel.

Support equipment

In addition to the tactical hardware, RCA designed, fabricated, and delivered ancillary support equipment that facilitates both training and maintenance. This equipment includes:

Trainer A—A fully-operational IRR tactical system used solely for realistic hands-on training. An expansion of the physical radio room layout as is found in the submarine was provided at the trainer to enable better equipment access and more room for multiple students to participate in training exercises.

Stimulation, monitor, and control equipment—Provides rf stimulation to Trainer A as well as simulation of all of the IRR interfaces with other ship systems. One innovative aspect of this design features prerecorded, encrypted rf signals on a 16-track, 14-inch magnetic tape. These analog scenario tapes (with their associated magnetic tape reproducer) simulate message traffic for all operational modes. The tape output simulates transmitted signals and interfaces with IRR equipment at the antenna junction. Substitution of modules from a prefaulted module set permits maintenance training. Computer programs for a training processor allow computer-controlled fault simulation, simulation of ships navigation data inputs, and storage and retrieval of IRR configuration data. This equipment also includes antenna input simulation equipment that replicates antenna suite control and status interfaces. A teletype simulation rack is provided for interactive teletype circuit simulation.

Trainer B—A computer-controlled IRR simulator that provides operator training in system operations under normal and casualty modes of operation. It utilizes commercial equipment, and unlike the tactical equipment, provides for trainee feedback. The instructor has complete control over the learning experience, including selecting the subject matter, prescribing the format of the exercise, and tailoring the feedback mechanism to each training situation. Incorrect trainee actions result in visual and audible alarms. After an instructor-selected number of trainee errors, the system will prompt the trainee with an indication of the correct action. At the conclusion of an exercise or training scenario, performance evaluation software generates a report indicating how well the trainee performed.

Trainer C—A composit of three separate training devices that provide for IRR maintenance training. The first device is the Tactical Equipment Trainer that consists of four selected pieces of IRR tactical hardware. All are electromechanical devices used for hands-on preventive and corrective maintenance. The second device is a Part Task Trainer that is designed to provide specialized training in cumbersome maintenance tasks on selected IRR equipment. With specialized simulation equipment the trainee can practice such tasks as removing/replacing an AN/UYK-20 memory, a disk memory pod, and a rotary switch in the antenna interface subsystem. The third device is the Signal Tracing Trainer, a computer-controlled training device that provides generic troubleshooting training. Accurate physical, mechanical, and electronic facsimilies of four selected pieces of IRR equipment (power control unit, AN/WRR-3 LF/MF receiver, R-1738 VLF receiver, and thermal control unit) are used for training. In a similar fashion to the B Trainer, student feedback and report cards are provided.

TRIME (Trident intermediate level maintenance equipment)—A combination of special maintenance test equipment, I-level technical manuals, and training videotapes. The majority of the special maintenance equipment is for on-board use dockside, and includes:

- An rf stimulation set
- A digital interface unit simulator
- An antenna control simulator
- An auxiliary diagnostic program loader
- Breakout boxes, special test cables, tool kits, and a drawer dolly

The remainder of the equipment is shop equipment and includes:

- A fan balancing set
- A NICAD battery maintenance set
- Shipping containers
- Alignment fixtures

TESS (test, evaluation and stimulation subsystem) equipment—Special test equipment that enables system acceptance testing in the factory.

Integration and testing

As with any large computerized system, the hardware and software must be integrated at various stages to assure a fully tested system. However, before the integration, each part must be thoroughly tested. Prior to assembly, the drawer and rack wiring is checked using automatic continuity testers. The modules are tested using automatic test equipment before they are inserted into the drawer. Similarly, the drawers are tested before they are put into racks, and racks are tested before they are delivered to the system integration area.

The most difficult problem in system integration is determining whether an observed malfunction is caused by hardware or software. Another possibility is a system design problem where the hardware and software were both built to specifications, but the specifications had a flaw in them. In order to minimize these problems, the system integration is performed by an engineering team well versed in both disciplines. This team is supported by the hardware and the software design groups.

The integration testing starts with a specific check of each change to the system since the last integration period. This is followed by a benchmark test that compares the present system performance against that of the last delivered version. Finally, a formal acceptance test is run before the radio room is shipped to the Navy's Land Based Evaluation Facility (LBEF) for another gamut of tests.

At the LBEF, the radio room goes on the air and joins the operational network. During this time, Navy testers and operational crew members dry-run a patrol scenario. Once the radio room has been proven "seaworthy," it is shipped to the shipyard for installation on the next Trident submarine.

Conclusions/future radio rooms

Future integrated radio rooms or communications centers for submarines, surface ships, aircraft, and land based installations will evolve and contain even more levels of sophistication. The mission of surface combatant ships, for example, has changed radically over the last twenty years. The role the cruisers (CG) and destroyers (DDG) play in a battle group is multipurpose and dynamically changes from antiair warfare (AAW) to surface warfare (ASUW) to subsurface warfare (ASW) as a function of the tactical threat. The multipurpose mission of these ships places highly sophisticated demands upon exterior communications suites, which are currently manually-operated to provide radio circuit reconfiguration. The same can be said about other communications centers, and leads to the inevitable conclusion that more automation and centralization is required. The following presents a broad-brush picture of some of the things that will be included in future communications centers.

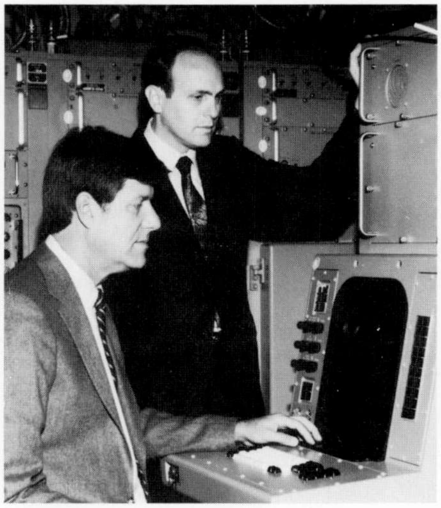
Local area networks (time division or frequency division multiplexed TDM/ FDM) will be used for control and signal distribution throughout the communications centers.

Integration of selected communications subsystems on platforms, and establishing communications links to provide effective management of a multi-platform communications system in a responsive manner will evolve. More specifically, interfaces between the interior communications systems (voice communications aboard a ship) and exterior communications systems (radio room) will expand, and because of commonality of both function and equipment, the ESM (electronic surveillance measures) system and the exterior communications system could merge in the future. Looking at the larger picture, communications links will be established between multiplatforms to enhance the battle group commander's ability to immediately view the status of all ships and manage the entire resources of the battle group.

The **man/machine interfaces** will change. Color graphic displays will be used to provide expanded status and decision making information. Operator input/output devices will change and include one or more of the following: light pens, touch screens, and voice synthesis and recognition. Prestored configurations will be used extensively. The increased display capability will be used for on-line training of crews when the activity in the communication center is low.

Automation will expand in the areas of link configuration, recovery, network management, quality monitoring, and trend analysis. Trends of equipment performance will be tracked and will indicate degrading equipment prior to actual failures. More decisions will be made by the computer, and additionally, more decision aid data will be presented to the operator.

Test equipment will be upgraded. Portable



Authors Hemschoot and Weir

James Hemschoot is Manager, System Integration and Test in the Systems Activity at Camden. He currently manages three Integration groups. One group is responsible for system integration and test of the Ground Wave Emergency Network (GWEN) program. The other two groups perform system integration and test on the Integrated Radio Room (IRR) Production Systems and the IRR Software Maintenance Contracts. He joined RCA in 1972 as a design engineer on the Small Terminal satellite communications program. After three years, he moved to integration of the Control Terminal on Small Terminal. In 1976 he joined the IRR program, as a Hardware/Software Integration (HSI) engineer. His group was responsible for the successful integration of 380,000 lines of code and 19 racks of equipment into the first Integrated Radio Room. Mr. Hemschoot received his BSEE degree from the University of Cincinnati, and his MSEE degree from Drexel University.

Contact him at:
Government Communications Systems
Camden, N.J.
Tacnet: 222-4965

Kendall Weir is currently a Program Manager in the Integrated Communications System Business Area. He is responsible for all Trident Integrated Radio Room (IRR) Programs, including E-Contract IRR production for four ship sets, TRIME, IRR Trainers B and C, and IRR software maintenance, training, and field support contracts. Mr. Weir joined RCA in 1958, and has been in system assurance, systems eingineering, and program management for 26 years. He has served as Manager in charge of an internal IR&D project, as a Unit Manager on the Trident IRR program, and was part of the initial systems engineering team that developed the system architecture and hardware configuration for the USPS electronic mail system. Mr. Weir holds a BSEE from Pennsylvania State University and an MSEE from the University of Pennsylvania.

Contact him at:
Government Communications Systems
Camden, N.J.
Tacnet: 222-3254

and fixed communications test sets will be developed that provide a flexible, all-digital approach to realistic encrypted message simulations for the testing of military communications centers.

Technology advances will be seen, some of which are highlighted below:

- Solid state HF/UHF antenna switches (PIN diodes) replacing coaxial, rotary, or patch panel switching.
- Non-volatile EEPROMs (electrically erasable programmable read only memories). Program changes won't require card or component changes, and will be accomplished via down-line loading.
- Bubble memories
- Digital signal processing techniques
- Plasma displays
- Next-generation NAVY standard computers and minicomputers (AN/UYK-43 and AN/UYK-44)
- Standardization of software language ADA
- Fiber optic cabling
- Next-generation radio equipment

Buzzards, eggs, and Diophenes

Or . . . Put chicken wire over your coop and you won't have all that messy math. . . .

In our May/June issue, Mike Keith posed some problems for readers in his article "Recreational mathematics." As promised, here are the answers.

1. From clue 1, one-and-a-third hens lay eggs at the rate of one per day. Therefore, one hen lays eggs at the rate of 3/4 eggs per day. Clue 2 yields 2/3 entries per day, and clue 3 yields 4/5 eggs eaten per entry. Multiplying these last two gives 8/15 eggs eaten per day by each buzzard. But $6\times(3/4)\times10 = 45$ eggs laid in the 10 days, and only 13 are left. Therefore 32 were eaten, which means there were $32/[10(8/15)] = 6$ buzzards.

2. This problem can be analyzed by a parity argument. At the start of a game of checkers, White has parity and will win if the game ends by blockage. In the problem, however, a capture was made by each side. Such an exchange causes parity to switch. Therefore Black won the game.

3. By straightforward counting for the 400-year cycle of the Gregorian calendar, we find that the probability of Christmas falling on a Sunday is 58/400, while the probability of Halloween falling on a Friday is 57/400. Therefore the former is just a hair more likely.

4. It is easy to see from clue 1 that P is greater than 4. For each value of P, there are only a few possible values for Q,R,S,T that fit clues 1 and 2 and such that U is greater than V (required by clue 3). Trying each of these in turn, we find only one combination that yields distinct values for all eleven variables and such that clue 5 can be met. The answer is

$$P\text{–}Z = [10,9,1,7,3,8,4,2,6,5,11].$$

The Bible verse is Esther 8:9, which contains $P^2-P = 90$ words.

5. There are 32 possible combinations of yes and no answers that Dr. Diophenes might have received. For 31 of these combinations, there are either no solutions or more than one solution. Only the answers (No, Yes, Yes, Yes, Yes) lead to a unique solution. Since he was able to determine uniquely the mailbox number from the answers to the questions, these must have been the answers he received. The mailbox number is 11.

6. By the prime number theorem, the probability of an n-digit number being prime is approximately $1/\ln(10^n)$. The nth term of the sequence is an n-digit number, so the total number of expected primes in the sequence would be

$$\sum_{n=1}^{\infty} 1/\ln(10^n) = \sum_{n=1}^{\infty} 1/n\cdot\ln(10) = 1/\ln(10) \sum_{n=1}^{\infty} 1/n$$

But this last summation is the harmonic series, which diverges. So the expected number of primes is infinity! In fact, I tested the first 12 terms of the sequence and found three primes:—2, 271, and 2718281. This agrees quite well with the expected number for the first 12 terms.

7. The only other solution is 1666/6468. This can be discovered either by brute-force search of the several million 4-digit fractions (not too hard with a computer) or, more elegantly, by solving a Diophantine equation (a single equation in several variables with integer solutions).