ELECTROMAGNETIC COMPATIBILITY OPERATIONAL PROBLEMS ABOARD THE APOLLO SPACECRAFT TRACKING SHIP

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INTRODUCTION

In support of the Apollo mission to put a man on the moon and return him safely to earth, a complex network is being built to monitor, control and communicate with the spacecraft. Part of this network will include three instrumentation ships built by General Dynamics at their Quincy, Massachusetts shipyard. These three tracking ships were converted from World War II T-2 tankers by cutting the mid-body section of each ship free of its bow and stern and replacing it with a new, larger mid-body (see Picture 1 in the Appendix). This method made possible salvage of the sterns which contain the propulsion, steering and other machinery, and saved the time and expense of building new bow sections.

The converted ships are 595-feet long, 75-feet at the beam, and carry over 455 tons of electronic equipment (see Picture 2 in the Appendix). The new mid-body sections provide space for the electronic equipment and living quarters for the instrumentation crew; each ship carries a complement of 85 marine and 108 instrumentation personnel.

Conversion of the ships was a joint venture by several divisions of the General Dynamics Corporation. The electromagnetic compatibility (EMC) tasks were accomplished by the Convair division. Before EMC problems can be discussed it is necessary to identify the 11 major systems within the instrumentation complex and to describe their functions.

1. The Ship's Position and Attitude Measurement System provides data relative to the ship's location on the earth's surface, converts deck-referenced coordinates into earth-referenced coordinates, and includes an inertial navigational system.
2. The Mission Control Center System includes the aeromedical and space vehicle monitor consoles and the flight dynamics officer consoles. All the information needed to make any decision regarding the spacecraft and the mission is available in this control center.
3. The Operations Control Center System provides ship's operations control and instrumentation systems monitor and control.
4. The Central Data Processing System contains digital computers and peripheral equipment for computing antenna pointing data, and spacecraft position data. It supplies decision-making information to the Mission Control Center.
5. The Acquisition and Stabilization Network furnishes the target acquisition and antenna stabilization signals required to interconnect position and stabilize the various tracking antennas.
6. The Timing System provides accurate time to the instrumentation complex and contains frequency standards, a WWV receiver, buffers, and digital readouts.
7. The C-Band Tracking Radar System contains an FPS-16 radar and operates in the 5.4 to 5.8 GHz range with a peak power of one megawatt. The C-Band system employs a 16-foot parabolic antenna, the primary function of which is to track the spacecraft and provide information to the Acquisition Stabilization Network which, in turn, provides accurate pointing of the other antennas.
8. The Unified S-Band System is a tracking, ranging and communications system. Its 30-foot antenna transmits and receives data simultaneously in the 2.0 to 2.2 GHz region, and is capable of handling a 20 KW output.
9. The Command Control System employs a 10 KW 400 to 500 MHz transmitter and helical antenna to send digital data to the spacecraft.
10. The Telemetry System provides data separation and decommutation, data distribution, data recording and processing. Associated with this system are two antennas which provide reception in the following frequency ranges:

105	-	140 MHz
216	-	260 MHz
2,200	-	2,300 MHz

The Telemetry System has tracking capability, using a 30-foot parabolic antenna in the 216 to 260 MHz and 2.2 to 2.3 GHz bands, and employs the most sensitive receivers on the ship (-127 db).

11. The Communications System includes HF, VHF, and UHF radio communications equipment, in addition to the marine radio equipment. The system provides voice and high speed data communications — ship-to-spacecraft, ship-to-ship, and ship-to-shore. The system includes:

    Six 10 KW PEP, 2 to 20 MHz transmitters
    Four 100 W UHF transceivers

    A receiving capability is provided as follows:

    One 15 KHz to 30 MHz general purpose receiver

    Three 200 KHz to 30 MHz general purpose receivers

    Eight 2 to 30 MHz stable receivers

    HF radiation is via two log periodic antennas located atop the Balloon Room and on the King Posts, and three helical antennas — two on the main deck and one atop the Balloon Room. One requirement of the Communications System is to relay telemetry data to other stations in real time. We do not have the prerogative of recording data as it is received and relaying it at a later time.

DOCKSIDE EMC PROBLEMS

Having briefly touched upon the makeup of the major systems in the instrumentation complex, it is now possible to discuss some of the EMC problems associated with the systems. Most of these problems occurred during operation of the HF transmitters due to the high output power of these transmitters; more specifically, they were due to the illumination of a number of potential interference generators on the weather decks.

The first indication of the severity of the topside illumination occurred when the HF transmitters were operated into the main deck helical antennas. Simultaneously with this operation, one of the watertight metal doors became a shock hazard, resulting in two instances of shock. The metal hinges did not make adequate electrical contact between the door and the rest of the structure throughout the door's complete swing. To prevent recurrence, ground straps were installed on all topside doors, hatchcovers, and nearly all other hinged devices. (Figures 1, 2, and 3).

A second problem occurred when a safety guide cable, extending from the aft superstructure to a forward deck house, absorbed enough energy from the helical transmitting antenna to become heated and melt a piece of nylon rope that was lying over it. The cable, a marine safety requirement, was for the purpose of guiding sailors on deck during rough seas. Following the rope-melting incident, the requirement for a safety cable was re-examined, and the cable removed (Figure 4).

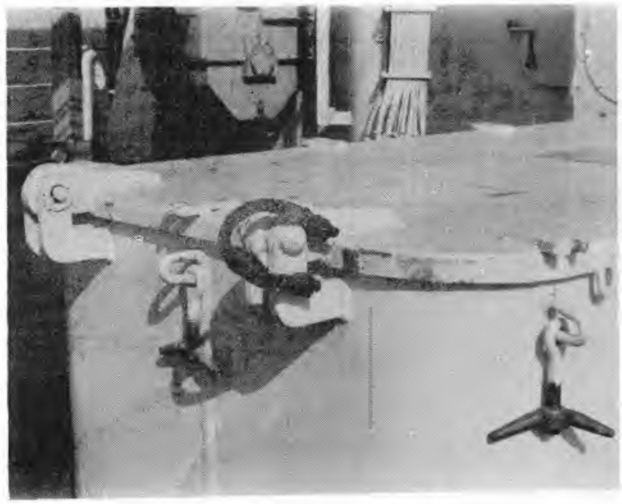


Figure 1. Ground Strap on Hatch Cover

Figure 2. Ground Strap on Water Tight Door

The problems discussed thus far occurred while the ship was docked in the Quincy Shipyard. However, the most severe problems did not occur while the ship was docked. There are several reasons for this. First, the interference levels in the yard were quite high due to yard activity (welding, crane and power tool operations, etc.). Ignition noise from autos using a nearby highway bridge was another interference source. The second factor limiting interference detection in the yard was the absence of the vibration and rolling that occurs when a ship is underway. A third limitation impeding

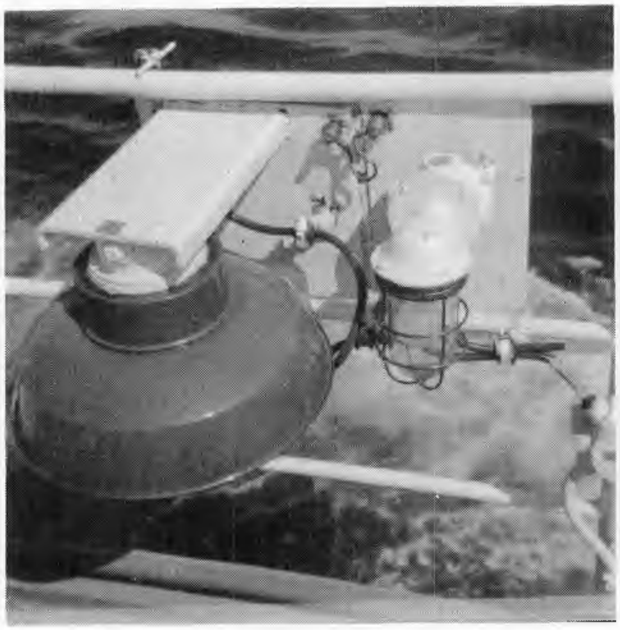


Figure 3. Ground Strap on Hinged Side Light

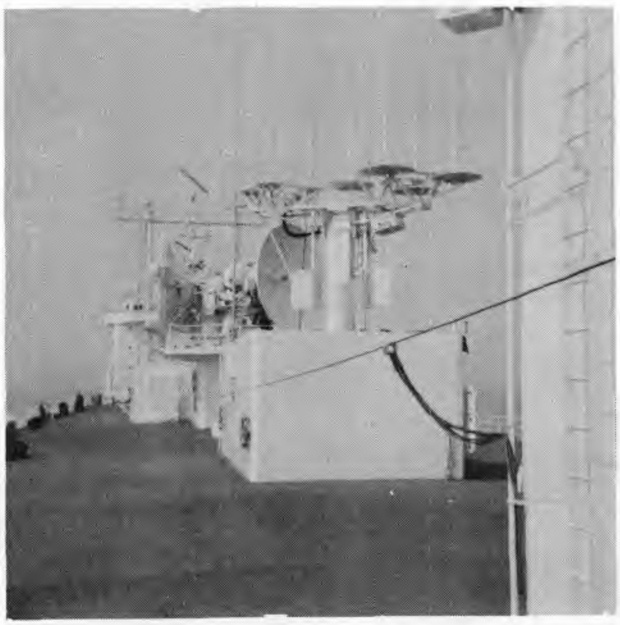


Figure 4. Rough Sea Safety Cable Removed After Absorbing HF Energy From Helical Antenna

EMC evaluation was the restricted frequency authorization for transmitters while at dock. Because of these three limitations, the most serious problems did not appear until the ship put to sea.

SEA TRIAL EMC PROBLEMS

The first problem encountered at sea was so serious that that shipboard receivers could not be used during HF transmission. When the HF transmitters were put on the air the noise level in the telemetry receivers increased about 20 to 30 db — a result of the safety barrier chains installed on the weather decks to prevent crew members from being washed overboard. Generally the safety barriers are permanent guard rails, welded in place. However, where the rails must be removable to provide normal ship operations, a chain is required. Another requirement is that at least some of the chains must be quickly removable to permit lifeboat access in event of an emergency. Most of these chains are attached to an eyelet at one end and have a clip at the opposite end. Being slack, the chains swayed with the roll of the ship; in addition, those in the after parts of the ship vibrated excessively due to the vibration caused by the ship's screw.

The motion of the chains created, in effect, a small "switch" at each link-to-link connection. Each of these "switches" operated for the most part, independently of the others in time. Where the chains were illuminated with RF each link became an interference generator, providing (1) broad band interference detected in the 200 to 400 MHz region, and (2) strong harmonics of the impinged RF, detected as high as S-Band. If two frequencies simultaneously excited the chain then broadband noise plus an entire family of intermodulation products were generated (Figure 5).

When it was first established there could be no simultaneous operation of transmitters and receivers due to this chain-generated interference, the chains were made taut by tieing them with cords, thus preventing the intermittent contact between links. The results were amazing. The environmentally generated noise was reduced to a level that permitted continuation of the tests being conducted at that time.

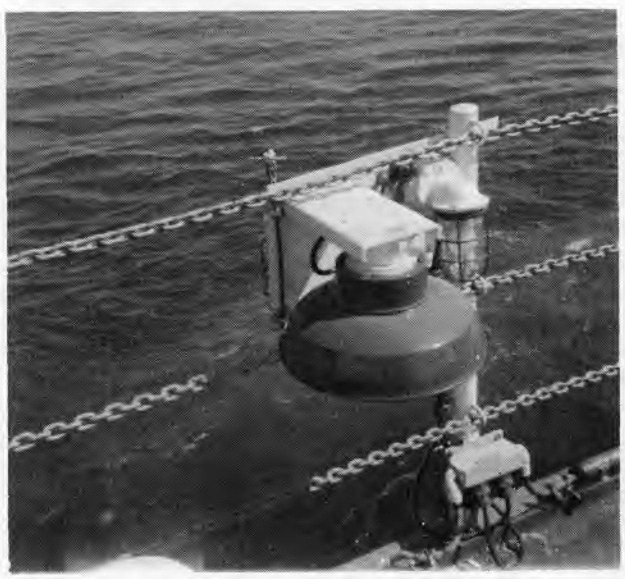


Figure 5. Barrier Chains on Outside of Ship Producing Harmonics and Intermodulation Products.

The final solution to this chain generated interference problem was securance of an approval by the Coast Guard to replace the chains with a chemical line similar to Dacron (Figure 6).

Figure 6. Dacron Rope Replaced the Safety Barrier Chains to Prevent the Production of Harmonics and Intermodulation Products.

It should be pointed out that environmentally generated noise misleads engineers and technicians to conclude that the offender is the transmitter since noise at frequencies harmonically related to the transmitter frequencies is considerably increased. Often the transmitter can be eliminated as the source of the problem, however, since transmitter harmonics are usually constant in amplitude, at least if the transmitter output is constant. On the Apollo ships the variations of the interference amplitudes were correlated with the ship's motion and the interference origin was thus traced to the safety barrier chains.

In addition to removing the topside chains many other items stowed on weather decks were relocated inboard. Items that could not be relocated or removed were secured against intermittant contact with hand lines. Procedures were documented in a Ship's Marine Crew Manual for prevention of interference generation through proper maintenance (Figures 7 and 8).

After the topside environmentally generated interference was reduced to an acceptable level, it was possible to again proceed with the scheduled systems evaluations. The next serious problem occurred when operation of the HF transmitters in the 3.5 to 7.0 MHz region caused the Klystron ready lights in a Telemetry Monitor Console located below decks to go out. The problem was traced to HF saturation of a Zener diode in the Klystron filament supply. The malfunction was remedied by installing an RF bypass capacitor on the input power line.

Figure 7. Flexible Vent Hose Stowed Topside was Relocated for Storage Inside.

Figure 8. Ladder Accessories Stowed Topside were Relocated Inside the Door.

Another troublesome area in the telemetry antenna was impulse interference associated with the roll of the ship. As it rolled from side to side a high level, single shot impulse was detected in nearly all receivers. At times the level was high enough to upset teletype reception. At other times the noise was not present at all. In trying to use the directional qualities of the telemetry antenna to locate the source it was found that the interference was a function of the position of the telemetry antenna itself.

Trouble shooting with a noise and field intensity meter identified the source as the pinion and sector gear that position the antenna in elevation. Backlash between these two gears, necessary to prevent excessive wear, was allowing the gears to make intermittent contact and thereby generate a large RF transient. Wiping the sector gear clean and mounting a brush on the pinion gear solved the problem (see Picture 3 in the Appendix).

Another problem in the telemetry antenna was traced to a rotary joint assembly in the telemetry antenna feed when the HF transmitters were up. A brush and slip-ring assembly was installed on the rotary joint, solving the problem temporarily, but the brush soon wore out. A more reliable brush assembly will be installed. (see Picture 4 in the Appendix.)

It should be restated that these problems occurred only when the HF transmitters were up. The HF field intensity at 25 feet from the helical antenna can approach 200 volts per meter.

Identification of yet another problem occurred when the HF transmitters were operated at frequencies of about 25 MHz — the C-Band tracking radar malfunctioned. The C-Band employs a 30 MHz IF, and enough RF leaked into the IF to disable the radar. The C-Band Radar is a government-furnished system and the government accepted responsibility for the corrective action which is still in process.

Another government-furnished system which required corrective action and for which the government accepted responsibility was the detection of interference from the Unified S-Band Receiver Local Oscillator in the TLM receiver. Corrective action is still in process on this problem also.

During the sea trials the HF transmission system was also plagued with problems that had an EMI aspect. Excessive vibration on the ship caused arcing in the antenna tuning device. Although the antenna vendor replaced the shorting device with a more sturdy unit, there are still problems remaining to be solved in respect to arcing in the helical antennas.

As a result of exposure of the Balloon Deck Log Periodic Antenna to stack gas at about 600° F (see picture 5 in the Appendix), the insulating guy wires that hold the elements parallel melted. Also, a heavy deposit of carbon builds up on the antenna. There have been at least two cases of arcing in the Balloon Deck Log Periodic Antenna, possibly due to these carbon deposits. Normal maintenance now calls for periodic cleaning of this antenna.

CONCLUSIONS

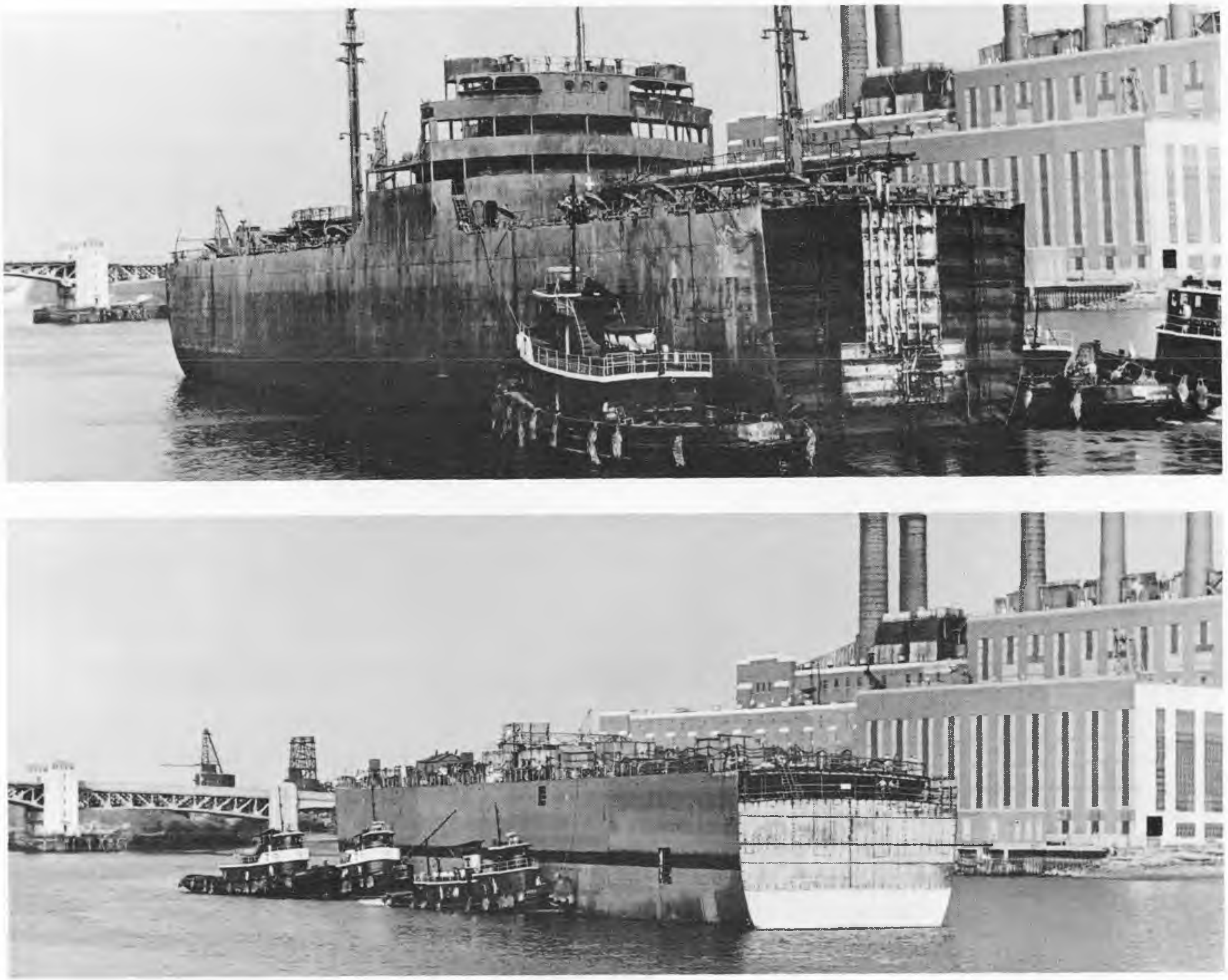
Most of the major EMC problem areas have been mentioned. Problems are still occurring and undoubtedly as the ship becomes older normal deterioration will generate new problems.

At present the ships are undergoing a modification to include a Satellite Communication System (SATCOM) as a backup for the HF communications systems. Upon completion of the SATCOM installation an EMC evaluation will be again performed. (see Picture 6 in the Appendix).

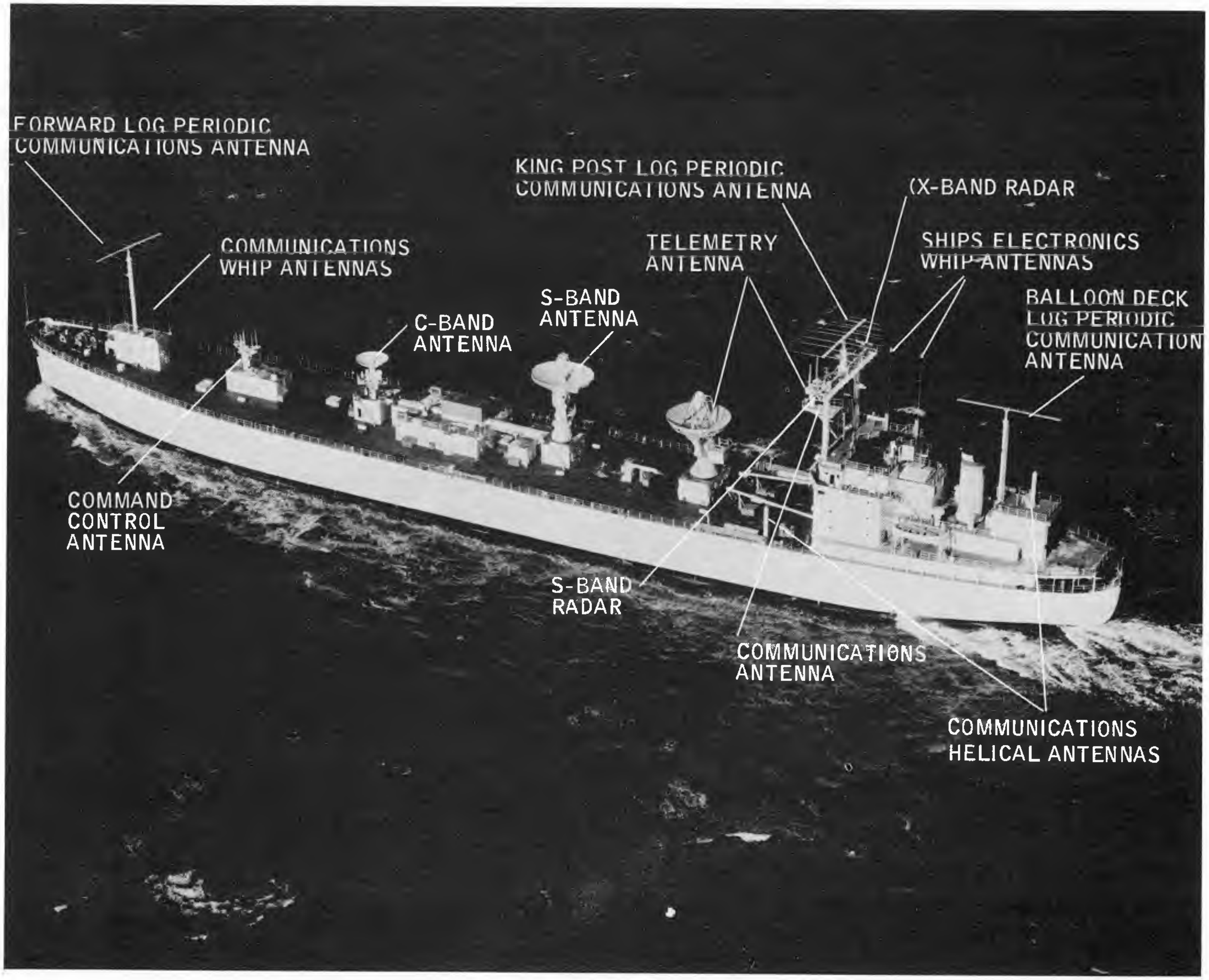
It is evident from this paper that bonding and grounding played an important role in establishing a compatible tracking ship. A document prepared by the Navy Department titled Shipboard Bonding/Grounding Specification, will soon be released. The document contains detailed instructions on specific shipboard solutions and should prove very beneficial to those EMC engineers who are responsible for the design of future tracking ships.

In the procuring and design stages of future instrumentation ship programs, it is advisable to evaluate the functions of all topside hardware in view of the actual ship's mission. In the case of the Apollo Instrumentation Ships, a significant amount of the deck hardware was installed to comply with Marine Safety Requirements and/or general shipbuilding procedures; i.e., the safety barrier chains discussed in this paper. In future programs, if non-mission requirements might result in mission impairment, the requirements should be re-evaluated for optimum mission performance.

APPENDIX



Picture 1. Top — Old Mid-body Being Towed Away.
Bottom — New Preconstructed Mid-body Being Towed into Place.



Picture 2. Completed Apollo Instrumentation Tracking Ship (U.S.N.S. Vanguard, January 1966).

Picture 3. Telemetry Antenna Showing Elevation Gear. Intermittent Contact Between the Mating Gear Teeth Generated Interference.

Picture 4. Telemetry Antenna Showing Antenna Feed Box. Inside, a Rotary Joint Assembly Generated Electromagnetic Interference.

Picture 5. Balloon Deck Log Periodic Antenna Located Above Smoke-Stack. Hot Exhaust was Very Detrimental to the Antenna.

Picture 6. Apollo Instrumentation Ship Undergoing Modifications to Incorporate a New System to Enable Satellite Communications (U.S.N.S. Redstone, July 1966).