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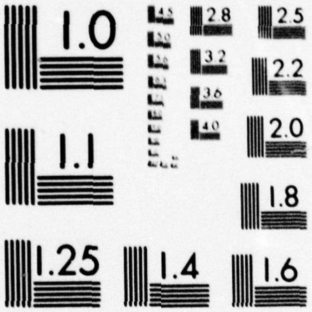
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(6) SHIP ELECTRONIC SYSTEM DEGRADATION

(10) Clyde E. Gartley, Jr

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ABSTRACT

The purpose of this article is to emphasize the necessity of the various technical disciplines within the naval shipbuilding community to appreciate, or at least be aware of, how the non-electronic community's decisions influence the performance of electronic systems. Many times during the design process the superstructure requires changes to accommodate new mechanical or structural requirements. Sometimes a modest structural change can cause, directly or indirectly, degradation to an electronic system which, in turn, can interfere with other electronic systems.

This article will review some of the "who-would-of-thought-it" items that contribute to electromagnetic interference (EMI) and system degradation on navy ships.

BACKGROUND

The ship design process is initiated as a supportive element of the broad national defense policies and objectives as defined by the Secretary of Defense. The Joint Chiefs of Staff then translate these into military policies and objectives which constitute the framework for planning and programming at the service level.

The Chief of Naval Operations, after numerous studies and tradeoffs, develops the specific mission requirements. NAVSEA/NAVELEX converts the mission requirements to performance and technical requirements. Finally, a configuration containing every functional element is established such that the top level ship system requirements are satisfied. NAVELEX/NAVSEC during the detail design phase undertakes the challenge of integrating the communications, navigation, surveillance, search, and control electronics systems in the limited space available. This is done in conjunction with the Naval Ocean Systems Center (NOSC), which uses a 1/48 scale brass model of the proposed ship to tailor or integrate broadband communications antennas with other systems in the ship superstructure. This defines the exact topside location and manner of physical installations of the ship's hardware. NAVSEC then evaluates electromagnetic compatibility (EMC), electromagnetic interference potential, radiation hazards (RADHAZ) and initiates a ship performance prediction study.

If no problems arise which require additional compromises the details of how each component is to be mounted and installed are developed. This detail design instructs the shipbuilder on how to construct the ship.

When the ship finally arrives in the fleet, all electronic systems should work in harmony, electromagnetic compatibility should exist, i.e., the ability of electronic equipment, or systems, to operate in a fixed environment within design levels of performance without degradation due to electromagnetic interference. As the years increase, resources decrease, new systems added and topsides changed, budgeting for EMC analysis is usually neglected and the ship becomes a patchwork of structural and electronic system compromises. This is where electromagnetic interference enters, i.e., electromagnetic energy which interferes with the detection and analysis of the desired signal or causes a malfunction in equipment. EMI has been with us a long time. One of the first reported instances took place in 1899 when a young man named Marconi demonstrated wireless communication to the Navy. Wireless devices were installed aboard the USS NEW YORK, USS MASSACHUSETTS, and a shore station. Paraphrasing from "History of Communications-Electronics in the United States Navy," by L. S. Howeth the test critique stated -

"The Chief objection to it is known as interference. When signals are being transmitted from one station to another, as between the USS NEW YORK and the shore station, and another vessel comes within signaling distance and attempts communications with the shore station, then the signals from the two ships become confused and the receiving station on shore is unable to destinguish between them."

Other excerpts from the report - "The spark of the sending coil or of a considerable leak due to faulty insulation of the sending wire, would be sufficient to ignite an inflamable mixture of gas or other easily lighted matter."

The report goes on -

"The shock from the sending coil of wire may be quite severe and even dangerous to a person with a weak heart."

and

"The sending apparatus and wire would injuriously affect the compass if placed near it."

There we have with the first shipboard test of radio, the immediate appearance of EMI, and hazards to personnel, fuel and equipment.

Have we made any progress over the past 75 years? Certainly the design and installation process has changed since that first test, although it has frequently been said that after trash, garbage, parking and scheduling, EMI is a major fleet problem.

This paper will discuss a few of the unusual interference problems suffered by the fleet, problems that require a team effort by the various engineering disciplines of NAVSEC to resolve.

COMMUNICATIONS PROBLEMS

1.

Every ship requires dependable communications to perform assigned missions effectively. A ship is useless as a combat system, a repair vessel, an aircraft carrier, or a harbor tug if it loses its ability to communicate.

Figure 1 shows a 2-6 MHz transmit fan antenna. A shipboard communications antenna is not an isolated, independent system. It must be tailored carefully to a particluar ship type so that it can operate effectively within the general constraints of space, weight, and high ambient RF fields. From mast to keel the whole ship is an intricate mass of interacting RF currents making up the antenna system and having a direct influence on individual communications antenna system performance characteristics. Antenna radiation pattern, feed point impedance, and intercoupling data depend not only on frequency and the antenna location, but also on the surrounding structures. The restricted area available on ship for placing antennas causes most of the communications antennas to be affected by the presence of adjacent radiators and parastic structures. Examples of topside modifications which can seriously affect antenna performance include adding deck houses; mast and yardarm configurations revised by Christmas lights, wires, installation of mast lights, etc. Since each antenna is custom fitted to its environment, it becomes a victim of that environment. All the dimensions shown in Figure 1 and their relationship to surrounding structures are critical to the proper operation of the antenna. Any modification of the antenna or environment can have severe, adverse effects on performance. That means if the shipyard makes a mistake during construction or the topside is modified after the design is firm, and the impact of the change not assessed, the ship's ability to communicate may be impaired. The impairment would be in the form of antenna radiation pattern degradation and a change in antenna impedance which could lead to high Voltage Standing Wave Ratios (VSWR), which can cause equipment damage.

Another problem facing communications systems is improper construction techniques. Recently a number of ships have been found to have cold solder joints in their antenna systems, Figure 2. A small installation error like a cold solder joint can render an effective combat system impotent. As energy travels from the transmitter through the multicoupler to the antenna and reaches the cold solder joint, which makes and breaks contact as the ship vibrates, the energy is reflected back, when contact is broken, to the multicoupler at which time connectors in the multicoupler begin to arc because of an overload. See Figures 3, 4 and 5. The AN/SRA-34 multicoupler is part of the Navy Tactical Data Systems (NTDS). In this example, whenever a transmitter was keyed in the 2 MHz range, arc energy was observed above 400 HMz. Every electronic receiver onboard ship was jammed. Figure 6 shows a plan position indicator (PPI) display of the AN/SPS-40 radar. Each time the transmitter was keyed a wedge of electromagnetic interference appeared.

Another major problem associated with communications is local self jamming of the High Frequency (HF), 2-30 MHz, receive system by intermodulation product generation.

2.3.

Intermodulation products are generated in a manner similar to that in which the intermediate frequency (IF) of a superheterodyne receiver is generated. Two signals are mixed, or beat, in some electrically nonlinear device which, in turn, produces various signal frequencies. In a superheterodyne receiver, the incoming, or received, RF signals are mixed with a second signal generated by the local oscillator. The signals are mixed in a nonlinear device, which may be a vacuum-tube or solid-state device. When the two signals are mixed, the output frequencies of the nonlinear device will include the two fundamental frequencies and both sum and difference (IF) frequencies A spectrum analysis of the output frequency of the nonlinear device will show that many additional signals are also generated.

INTERMODULATION PRODUCT THEORY

Assume that an RF signal or freauency f1 is applied to an electrically nonlinear element. The output frequency spectrum of this nonlinear element will contain not only the fundamental frequency f1, but also frequencies harmonically related to f1, that is, frequencies 2f1, 3f1, 4f1, etc. If two fundamental signals of nonharmonically related frequencies f1 and f2 are applied to a nonlinear element, the output from the nonlinear element will contain not only harmonic frequencies 2f1, 3f1, 4f1, etc., and 2f2, 3f2, 4f2, etc., but also frequencies which are related to the fundamentals in the following manner:

FREQUENCY COMBINATION	PRODUCT ORDER
F1 ± F2	2nd order
2F1 ± F2	3rd order
2F1 ± 2F2	4th order
3F1 ± 2F2	5th order

These frequencies are called intermodulation products. The coefficients of the fundamental signals are always integral, or whole, numbers. One would not, for example, find a signal of frequency 1.1f1 at the output of the nonlinear element. The sum of the absolute values of the coefficients of the fundamentals is the order of the intermodulation products, so that f1 + f2 and f1 - f2 are both second-order products. A third fundamental, f3, would produce third-order products including f1 + f2 + f3, f1 - f2 - f3, 2f1 + f3. Fourth-order products resulting from two fundamental signals would include products of 2f1 + 2f2 and f1 + 3f2. Figure 7 illustrates that the number of products increases very rapidly with increasing order. It may be noted that 10 simultaneously radiating transmitters will theoretically produce approximately 670 third-order products and 20,758,530 13th order products. It is not unusual to find 50th order on ships.

Figure 8 illustrares the effect of adding one more transmitter to a given number of transmitters already radiating. M is the number of transmitters radiating, and Pa is the number of discrete products that would be generated as a function of nonlinear order if one additional transmitter were to radiate. For example, if 12 signals are being radiated and one additional transmitter, the 13th, is added, the additional products generated due to the presence of the 13th signal are approximately 25 second-order products, 300 third-order products, 2500 fourth-order products, and 12,000 fifth-order products. Therefore, the curves illustrate the potential additional interference that a single transmitter can contribute.

The numbers generated in the foregoing example, which utilized the curve of Figure 8, are the theoretical number of discrete products which can be generated. The term "discrete" means that where identical frequencies are generated for both lower and higher order products, those frequencies are counted only once.

NONLINEAR JUNCTIONS

Nonlinear junctions are any metallic items, objects, appendages or the like that exhibit nonlinear voltage - current transfer characteristics. If a nonlinear element has a voltage-current transfer characteristics curve which is asymmetrical, all orders of intermodulation products will appear at the output. If the characteristic curve is symmetrical only odd-order products will be generated by the nonlinear element. Most natural (shipboard) nonlinear devices maintain a high degree of symmetry, and measurements of odd-order intermodulation products are usually higher than even-order products.

4.

With the increasing number and power level of transmitters and increasing sensitivity of receivers the hull generated intermodulation interference (IMI) phenomenon has become a problem of major proportion in the fleet and seriously affects the operational capability of many ships. Successful reception of incoming traffic on a small platform can be hindered by interference that is independent of the care taken in design of communications equipment and the system they comprise. Protection of the receivers from local transmissions, purification of radiated signals and careful choice of recive - transmit frequency separations are all important and necessary means of establishing compatibility. But these controls do not guarantee unhampered reception during time of collocated transmissions. Obscure nonlinear items inherent in the shipboard environment are significant sources of intermodulation signals. When a sufficiently strong intermodulation signal occurs on a frequency coinciding with one used for reception, the threat can be overcome only by locating and removing the source of intermodulation interference.

During the struggle to detect this insidious but important deterrent to communications on naval platforms, a number of techniques have been devised to locate proven sources of intermodulation interference. Valuable as this information is, it does not allow any listing of source by order of importance. A more effective method is to concentrate on finding the worst of an unknown number of contributing sources, remove it, and then repeat the process with the remaining sources until a low-level intermodulation signal floor is reached. The worst source can be defined as the nonlineraity most strongly excited by currents at the local transmit signal frequencies. It is also likely to be the most efficient radiator of intermodulation signals because of its antenna-like characteristics. Experience has proven that finding and destroying the worst intermodulation source, often a surprisingly "mickey-mouse" item, leads to a dramatic decrease in the number and strength of interfering signals.

Conventional investigations of intermodulation signals have tended to concentrate on the 3rd, 5th, 7th, and 9th orders, arbitrarily ignoring those greater than the 11th as unimportant. Deliberate concentration on abnormally high orders is the basis for locating the worst source. The highest detectable order will be produced in the most potent source, while a number of sources will contribute to the usually investigated lower orders. Once found, this signal can be used to locate its generator by simple, even crude, direction finding techniques.

Some of the items that have been found jamming shipboard communications are totally divorced from electronics and most unsual. On several ship classes the boat davits and associated standing rigging, Figure 9, located in the vicinity of high power transmitting antennas have been identified as the primary source of IMI generation. Energy from high power transmitting antennas couples into the davit system, which simulates a loop antenna, and reradiates IMI products into the ships receiving antennas, hence immersing the ship in its own self jamming. Other unusual IMI sources that have been uncovered are life lines, garbage chutes, ensign staffs, inclined ladders, yardarm foot ropes, and safety life nets (see figures 10, 11 and 12). These items are under the control of non-electronic codes, but each item can seriously influence the shipboard communications receive capability. There are three alternatives to eliminate these items as sources:

a. remove them entirely

b. replace them with non-metallic items

c. properly bond around the nonlinear junction

These techniques are being implemented in todays ships by application of MIL-STD-1310, "Shipboard Bonding, Grounding and Other Techniques for Electromagnetic Compatibility and Safety."

NELC TD 338 titled "A Dialogue on Conducting Shipboard RFI surveys and Locating Interference Sources" dated 10 July 1974 is available for those who wish to pursue the topic.

OTHER SYSTEM TO SYSTEM INTERFERENCE PROBLEMS

There are numerous examples of electromagnetic interference situations on Navy ships; a few of the more interesting, and unclassified, are briefly discussed below. By the way, most of these are resolved - but new ones keep popping up.

Problem. AN/SPS-10 radar causes interference to the HF receivers. The interference had the characteristic sound of the AN/SPS-10 radar (625-650 PRF), as detected from approximately 19 MHz through 28 HMz.

Cause. The source of the interference was found to be the newly installed AN/SSR-1 receiver. The four down-converter cables run from radio central, up through the deck of the AN/SPS-10 radar room to overhead cable ways, at a point directly over the AN/SPS10 RECEIVE/ TRANSMIT unit, a violation of MIL-STD-1310.

High order harmonic energy from the AN/SPS-10 modulator was present on several of the cables in the cable way. The energy was carried to the AS-2815/SSR-1 antennas then radiated from the antennas and associated post support and was picked up by the HF receive antennas. See Figures 13 and 14.

Problem. AN/SPG-53 radar causes interference to HF receivers.

Cause. The interference is generated from the fast rise time and narrow pulse width of the modulator. Measurements showed that the interference energy was emanating from the entire topside structure associated with the MK 68 gun fire control system. The structure acts as an HF transmitting antenna and radiates the energy which is picked up by nearby HF receiving antennas, masking incoming low-level communications signals. See Figures 15 and 16.

Problem. AN/SPS-37/43 radar causes interference to the majority of topside electronic receivers.

Cause. AN/SPS-37/43 series radar generates broadband energy via an arc discharge occurring in either the antenna rotary joint and/or loose metallic items in the radar's main beam. While the severity of this arcing will vary greatly between individual ships, it is not unusual for the arc-type energy to be detected on receivers operating above 3.5 GHz. Figure 17 shows an example of AN/SPS-43 (operating frequency 225 MHz) interference on the AN/SPN-43 (operating at 3.5 GHz) display. Try to find an airplane on the display.

Figure 18 shows flight deck flood lights, one source of arcing that disabled most of the receive systems on the ship when the AN/SPS-43 was operating in excess of 100 KW. The phenomenon occurred when energy radiating from the 2-6 MHz HF transmitting antenna impinged upon the flight deck flood lights inducing current flow in a non-linear device (the flood lights) causing the generation and reradiation of intermodulation products. Also, when energy from the AN/SPS-43 antenna illuminates the flood lights, already sustaining current flow from communications transmissions, arcing occurs in all the joints that comprise the flood light and flood light structure.

Again a non-electronic item that can disable an effective combat system. This problem was resolved by relocating the flight deck flood lights.

INTERFERENCE CAUSED BY TOPSIDE OBSTRUCTIONS

Oftentimes the design that satisfies all requirements is impossible to achieve. There just isn't enough room at the top of the mast for the antennas of all the electronic systems and many compromises have to be made. Below are two examples of compromises that have caused system degradation because of poor antenna location. The antennas were placed in such a manner that the systems suffered from mast reflections and blockage. When the radar is pointing toward a flat surface, incident energy is reflected from the obstruction to a target and then returned to the radar system as a false target, in the direction of the obstruction, appearing on the radar display. This means the operator has two targets to contend with. Only one is real.

Figure 19 shows an AN/SPS-10 surface search radar located on the after mast. In order to "see" forward, the radar has to look through many obstructions. Also, to add a challenge to the operators ability to distinguish true targets, two communications antennas on either side of the radar interfere with its operation. Figure 20 demonstrates the interference phenomenon associated with the AN/SPS-10. Sea clutter is missing around the area of 110° to 120° because of superstructure blockage. The land mass appearing at 145° is a reflection, off the mast support, of the large land mass. The "banana" at 205° is a reflection of the land mass off the starboard communications antenna.

As in the case of the AN/SPS-10, the AN/SPQ-9 also suffers from "ghosting." Figure 21 shows the SPQ-9 radar system situated next to the forward mast. Figure 22 shows the SPQ-9 display as the ship entered San Diego harbor. Note in Figure 23 how certain targets have enlarged and smeared as the ship came closer to the harbor. The smeared returns are the result of objects near the harbor which have large cross sections and because of the reflections off items in the mast area which appear as targets.

This situation certainly offers a challenge to the surface search radar operators.

CONCLUSION

Ship designers must address the ship as a total system and take into account the possible degradation of electronics systems when subsequent modifications are made to the ship. Without topside EMC consideration, the most expensive and sophisticated equipment below decks possibly won't function properly. As pointed out in the [5]"Tactical Electromagnetic Systems Study Action Council (TESSAC) report to the Chief of Naval Material "it is indeed unfortunate when it becomes necessary to occasionally shut down certain equipment in combatant ships to prevent degredation of other systems, thereby decreasing operational effectiveness." The TESSAC report further states in part "the most significant factor contributing to the lack of EMC consideration in Navy programs is not a lack of technology but a lack of application of existing technology by management."

To counter this lack of application NAVSEA has issued NAVSEAINST 2410.2 which states that within the Naval Sea System Command an EMC program shall be incorporated as a requirement in each phase of an equipment, system, and platform life cycle. All developments require an EMC Program Plan (EMCPP) and all platforms and major systems, during acquisition phases and industrial availabilities, require an EMC Advisory Board (EMCAB) to insure the latest knowledge is applied.

If this instruction is adhered to, future Naval development and platforms stand a good chance of having electronic systems compatible with their environment.

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1. Naval Ship Systems Command Technical News - March 1973 - Unauthorized Topside Appendages
2. NAVSHIPS 0967-000-0150, Electronics Installation and Maintenance Book, Electromagnetic Interference Reduction
3. NAVSHPIS 0967-266-1010
   Hull Generated Intermodulation Interference Reduction Techniques for Forces Afloat
4. A Method of Detecting Significant Sources of Intermodulation Interference, NELC TR 1883 dtd 20 August 1973
5. Electromagnetic Environment Effects, Summary Report to the Chief of Naval Material

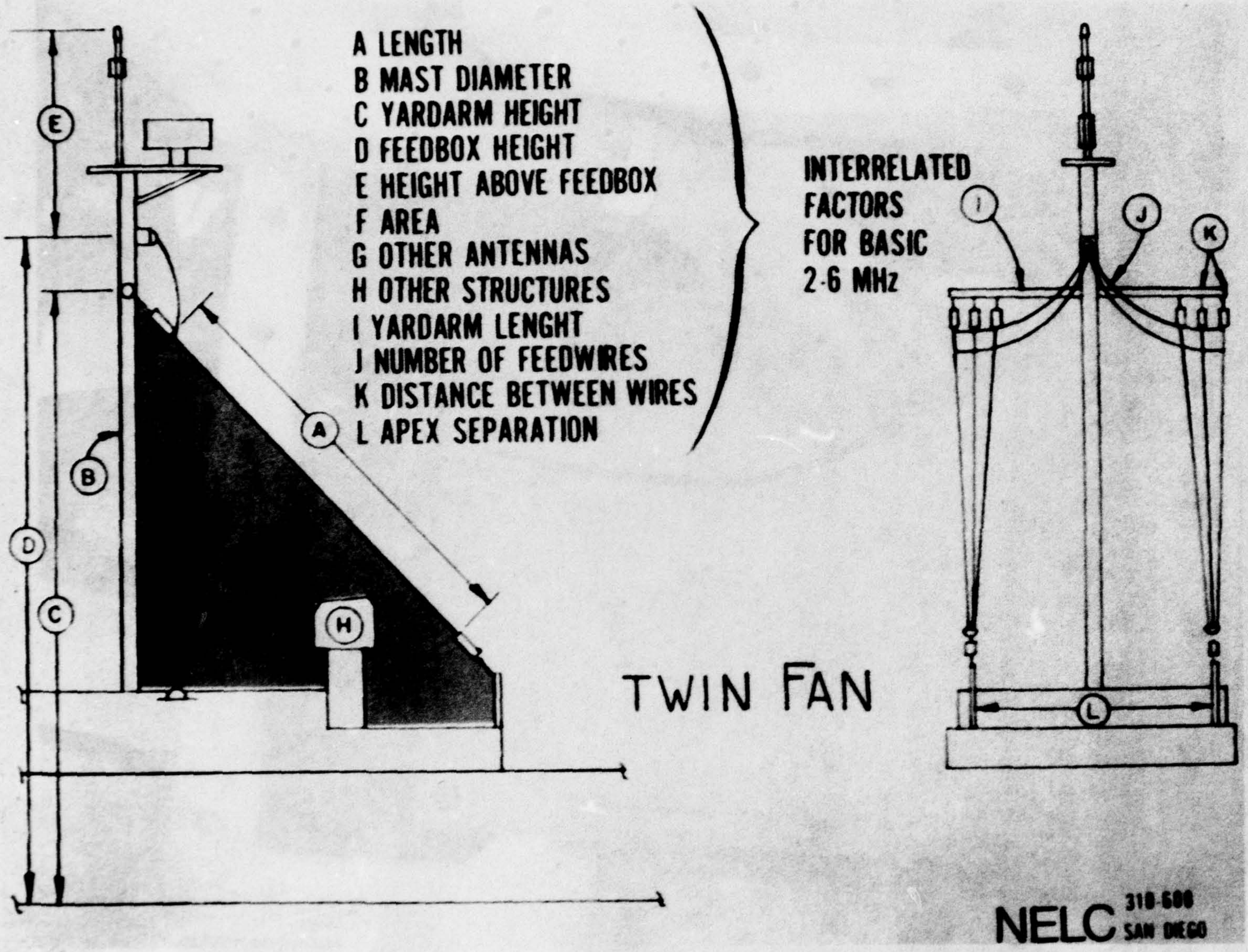

FIG. 1 2 - 6 MHz BROADBAND TRANSMIT FAN ANTENNA DISPLAYING CRITICAL FACTORS WHICH INFLUENCE THE ANTENNAS IMPEDANCE

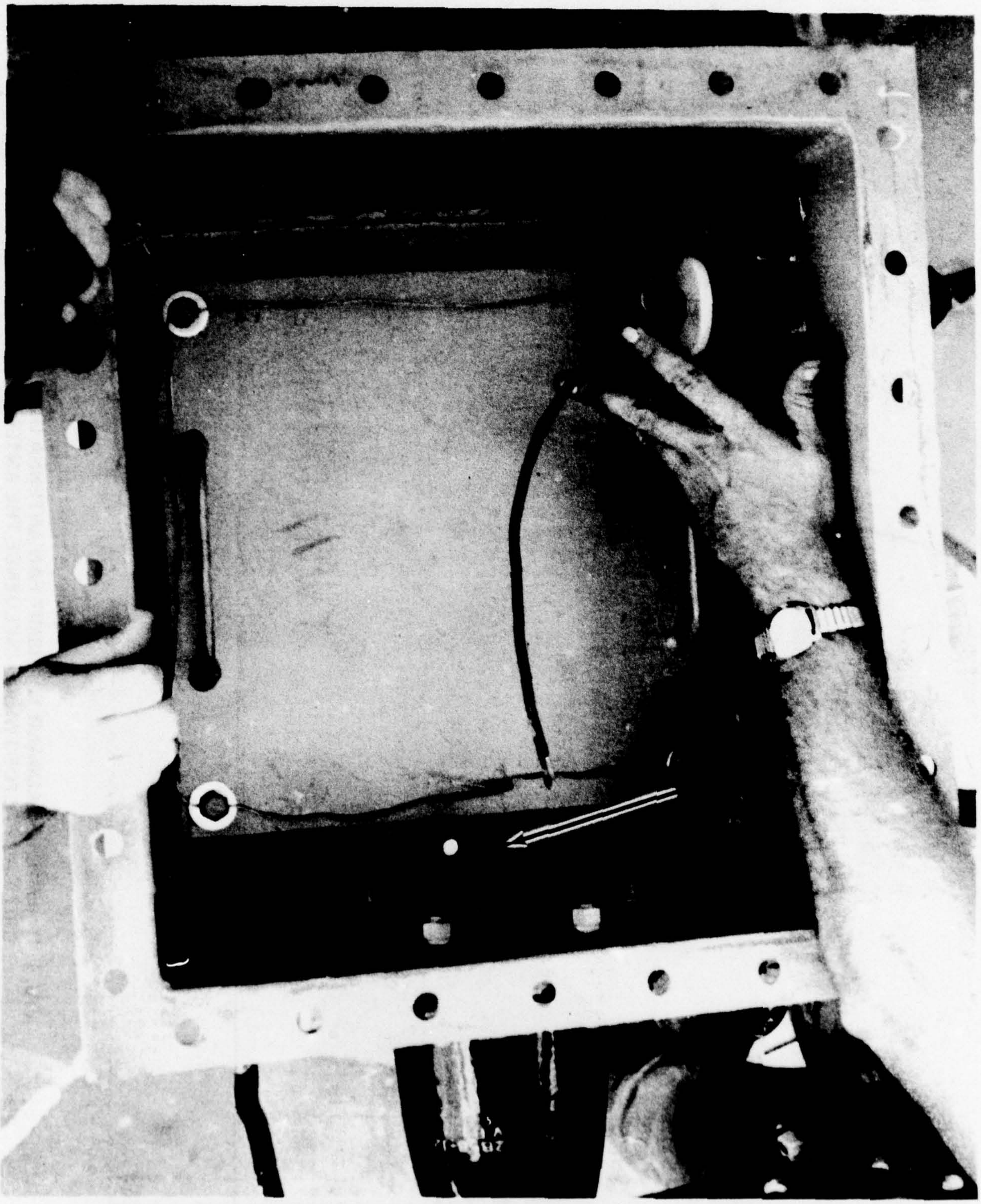

FIG. 2 THE ARROW POINTS TO THE COLD SOLDER JOINT IN ANTENNA MATCHING NETWORK

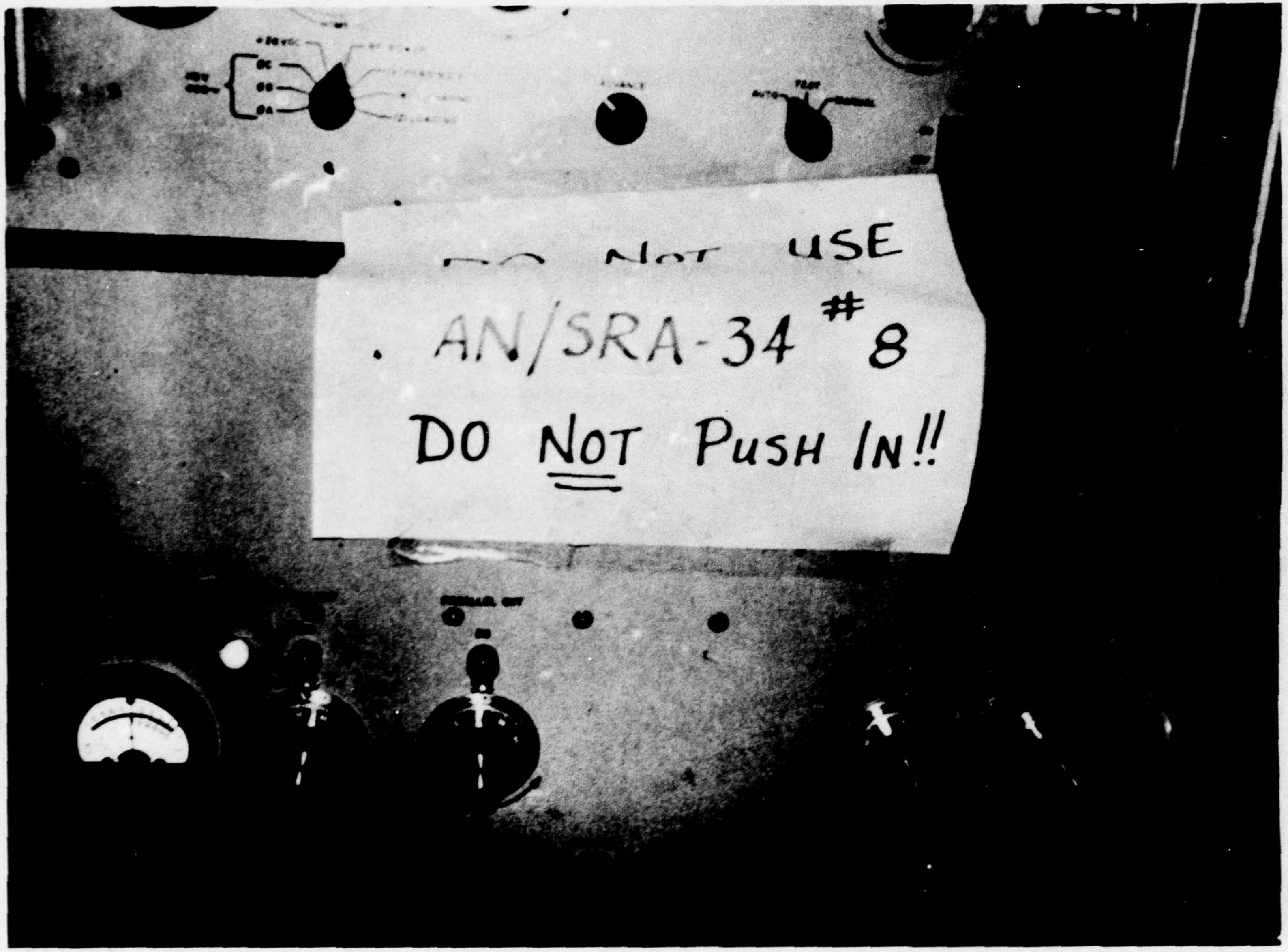

FIG. 3 BROKEN AN/SRA-34 MULTICOUPLER DRAWER

FIG. 4 BURNED CONNECTOR ON THE BACK OF THE AN/SRA-34 COUPLER DRAWER

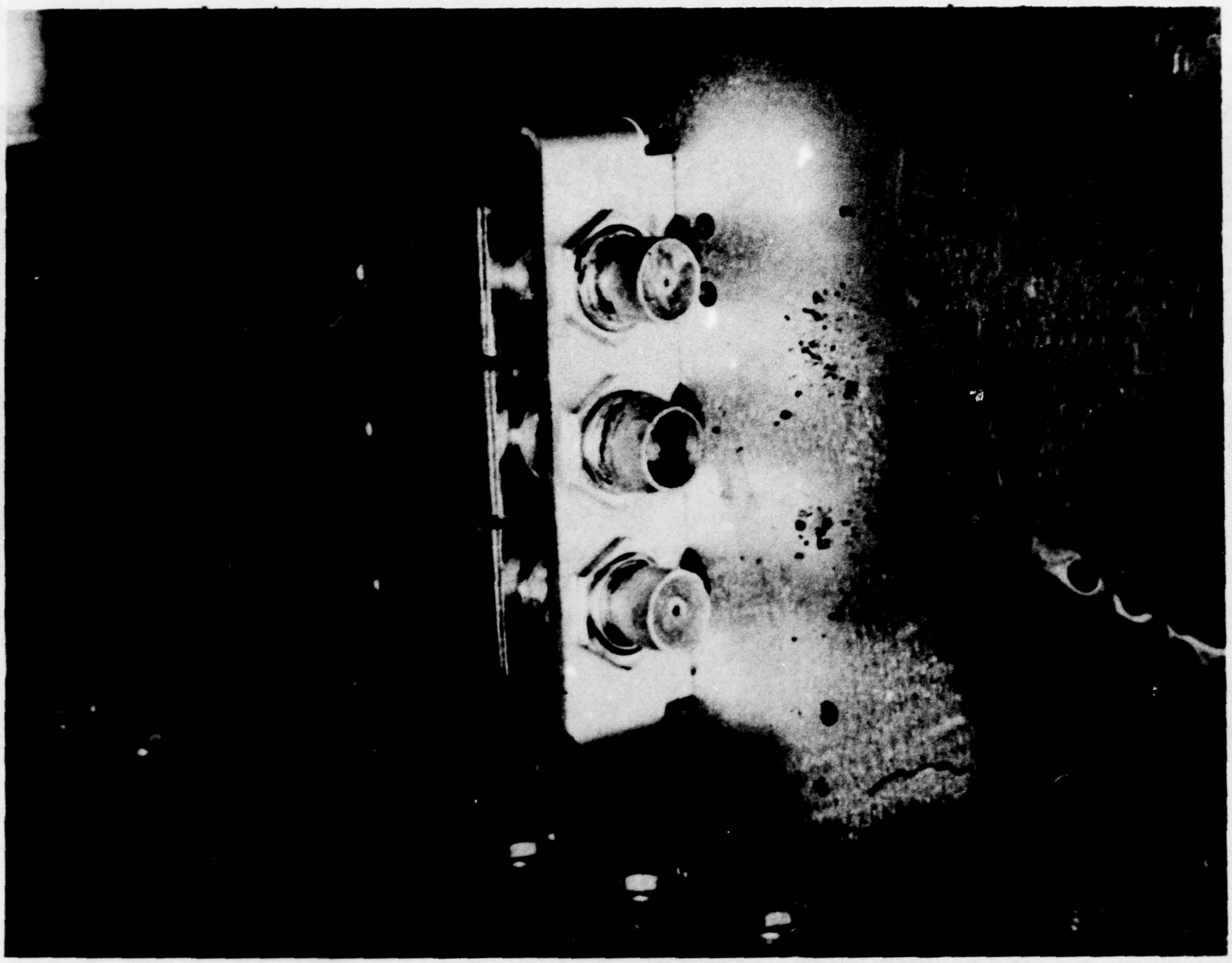

FIG. 5 BURNED CONNECTOR ON UNIT THAT CONNECTS THE COMBINER TO THE MULTICOUPLER DRAWER

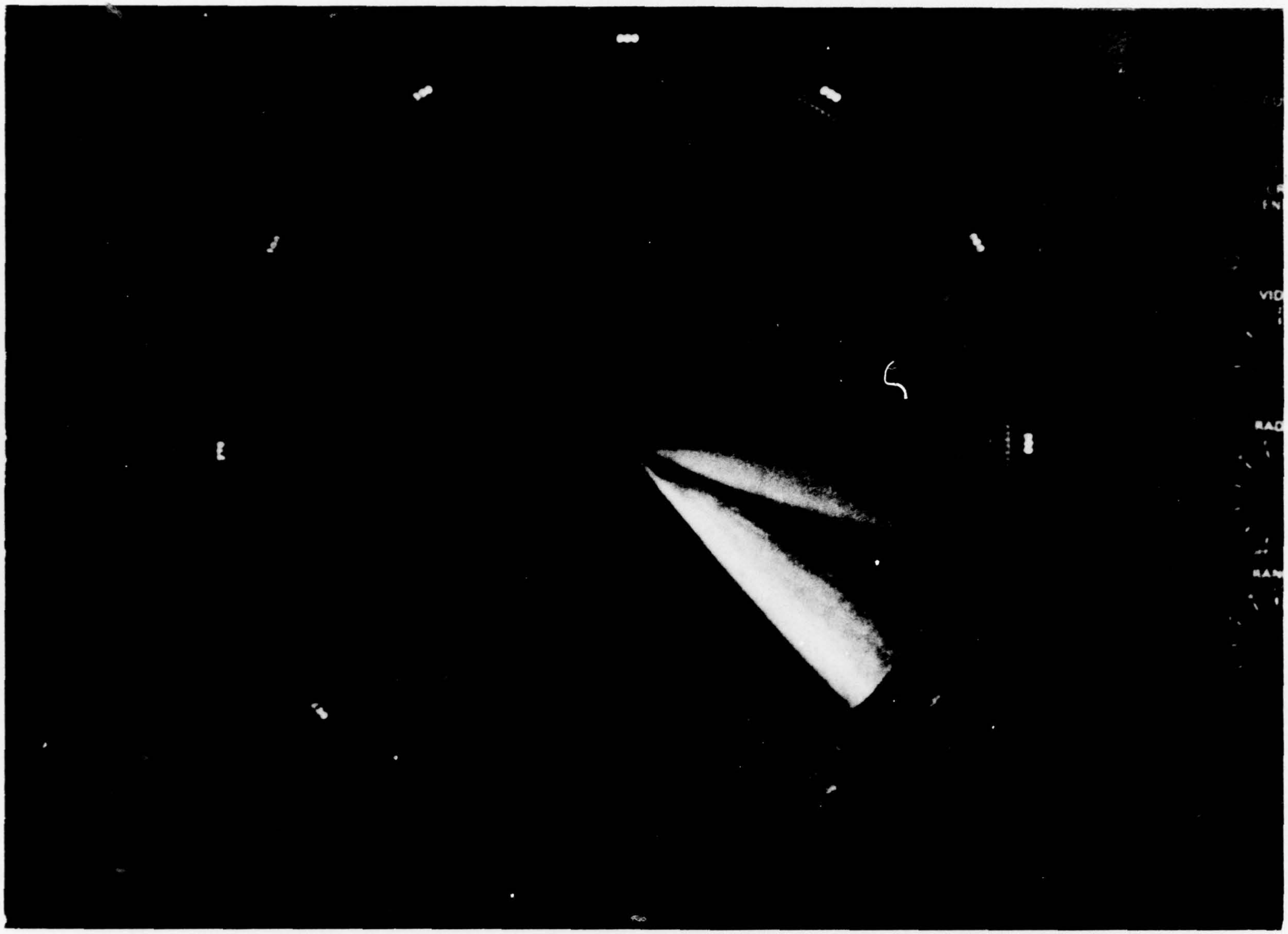

FIG. 6 INTERFERENCE DUE TO ARCING FROM THE AN/SRA - 34 JAMMING THE PLAN POSITION INDICATOR (PPI) OF THE AN/SPS -40

NO. OF TRANS-MITTERS	NUMBER OF ODD-ORDER PRODUCTS					
	3	5	7	9	11	13
1	1	1	1	1	1	1
2	6	10	14	18	22	26
3	19	51	99	163	243	339
4	44	180	476	996	1,804	2,964
5	85	501	1,765	4,645	10,165	19,605
6	146	1,182	5,418	17,718	46,530	104,910
7	231	2,471	14,407	57,799	180,775	474,215
8	344	4,712	34,232	166,344	614,680	1,866,280
9	489	8,361	74,313	432,073	1,871,845	6,539,625
10	670	14,002	149,830	1,030,490	5,188,590	20,758,530

FIG. 7 NUMBER OF POSSIBLE ODD-ORDER PRODUCTS FOR THE CASES OF ONE TO TEN TRANSMITTERS OPERATING SIMULTANEOUSLY

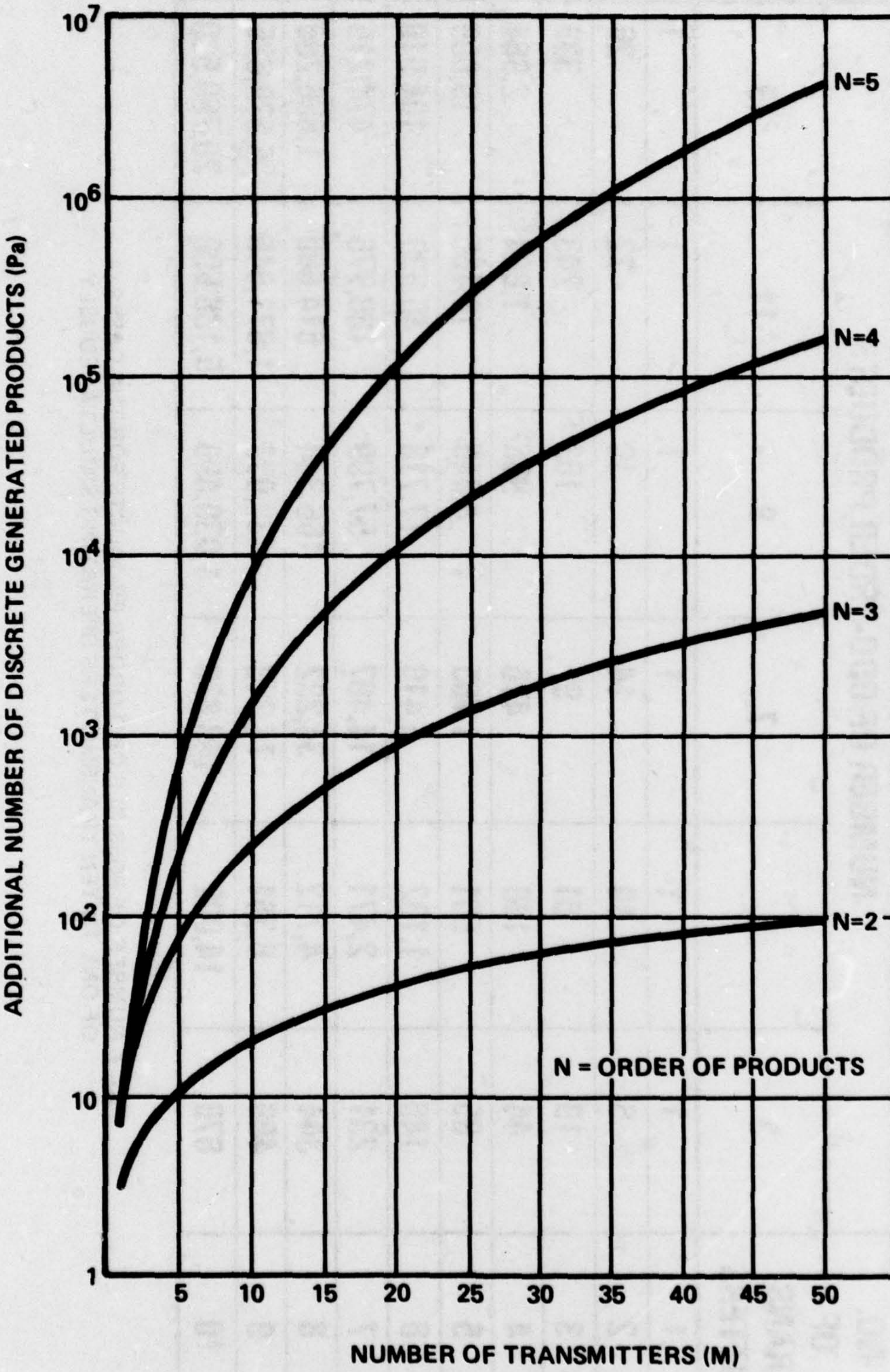

FIG. 8 ADDING ONE MORE TRANSMITTER

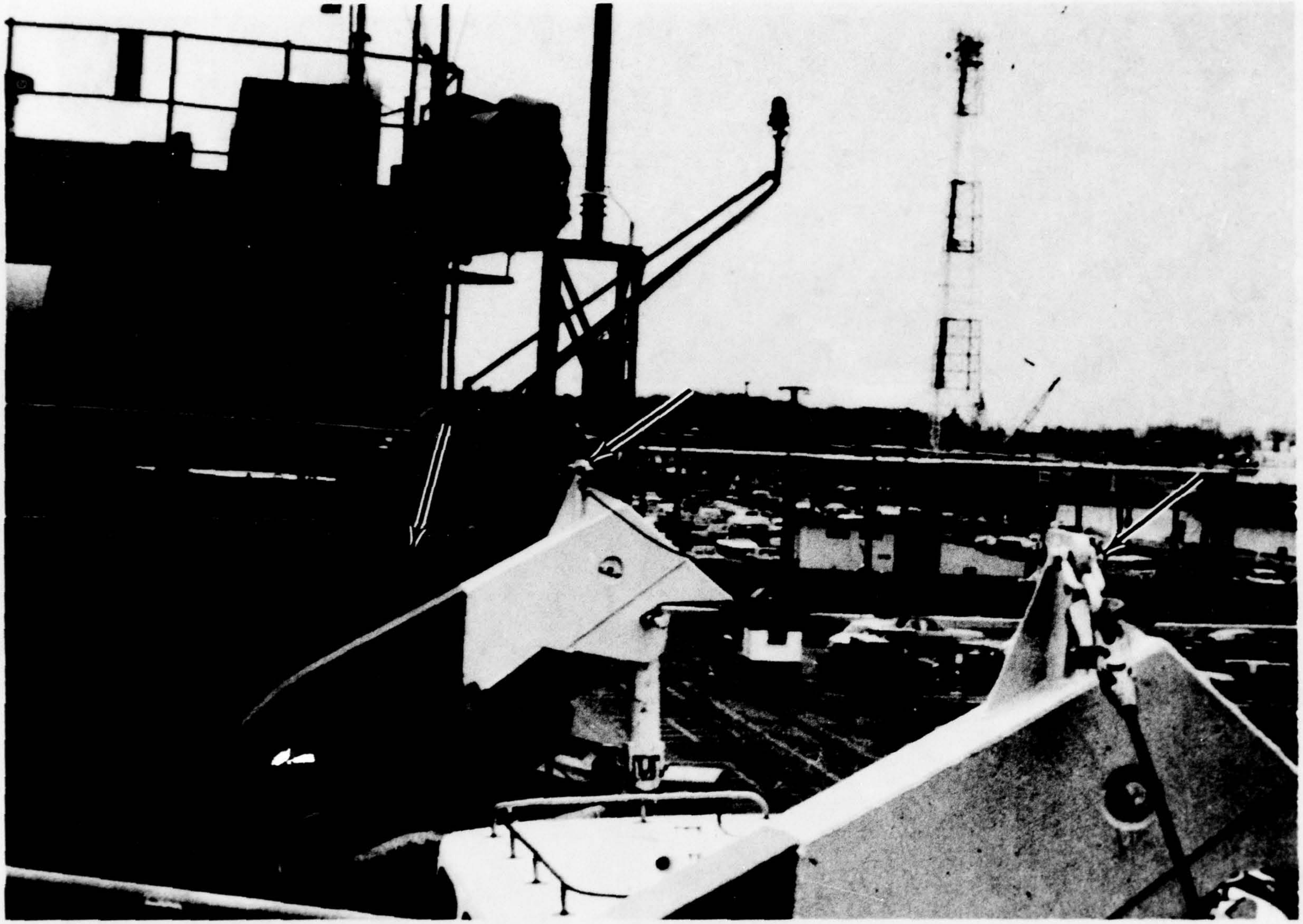

FIG. 9 BOAT DAVIT COMPONENT HARDWARE ASSOCIATED WITH STANDING RIGGING WHICH FORMS NON-LINEAR JUNCTIONS THAT GENERATE IMI PRODUCTS

FIG. 10 LIFE LINES, SISTER HOOKS, AND TURNBUCKLES WHICH FORM NON-LINEAR JUNCTIONS THAT GENERATE IMI PRODUCTS

FIG. 11 INCLINED LADDER - TOGGLE BOLTS, WHERE LADDER MATES TO DECK, FORM NON-LINEAR JUNCTIONS THAT GENERATE IMI PRODUCTS

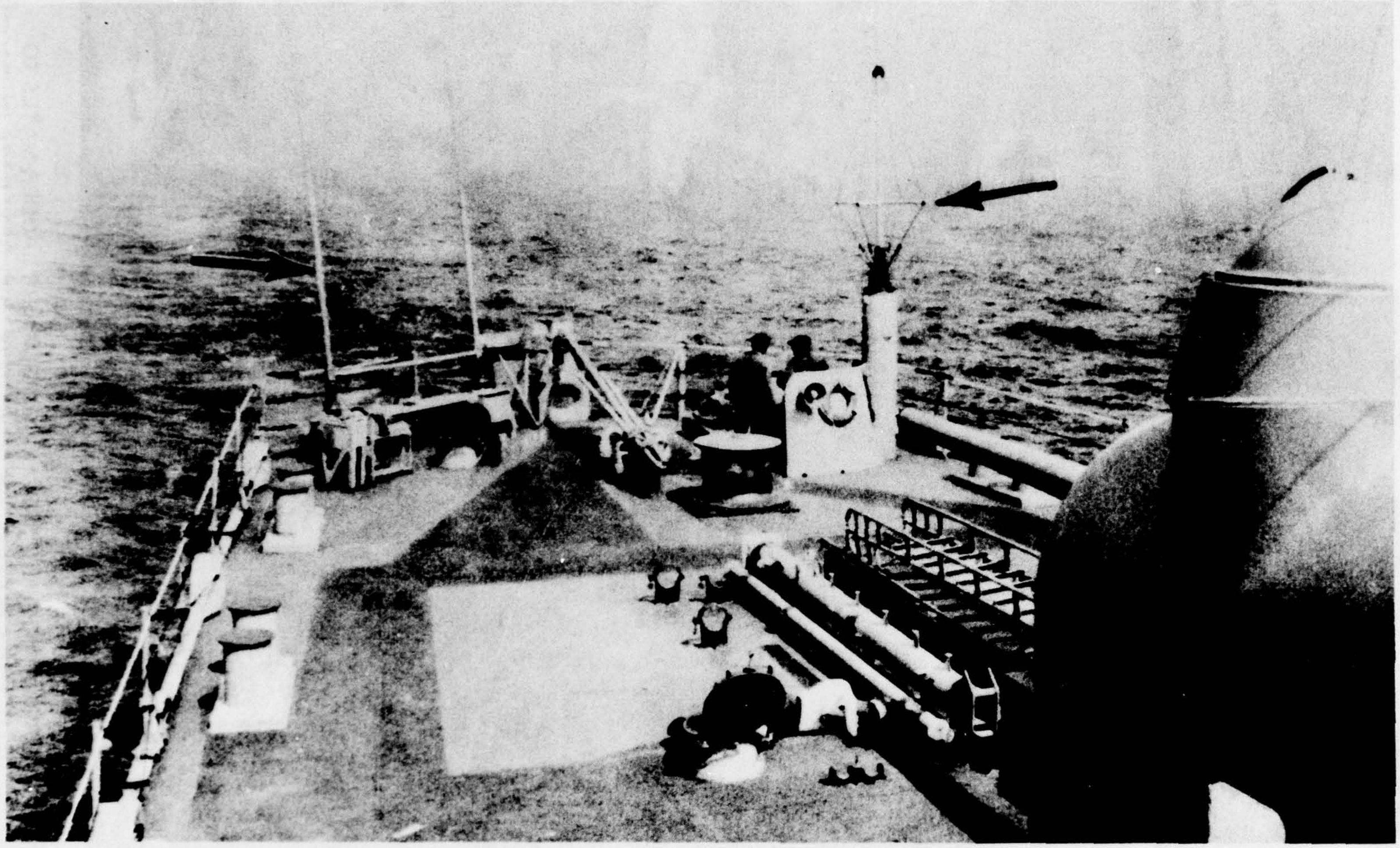

FIG. 12 WHEN EXCITED BY TWO TRANSMITTERS THROUGH THE TRANSMITTING ANTENNA (RIGHT ARROW), NON-LINEAR JUNCTIONS IN THE ENSIGN STAFF, GARBAGE CHUTE, AND METALLIC LIFELINES CAUSED IMI TO THE TWIN-WHIP RECEIVING ANTENNA (LEFT ARROW)

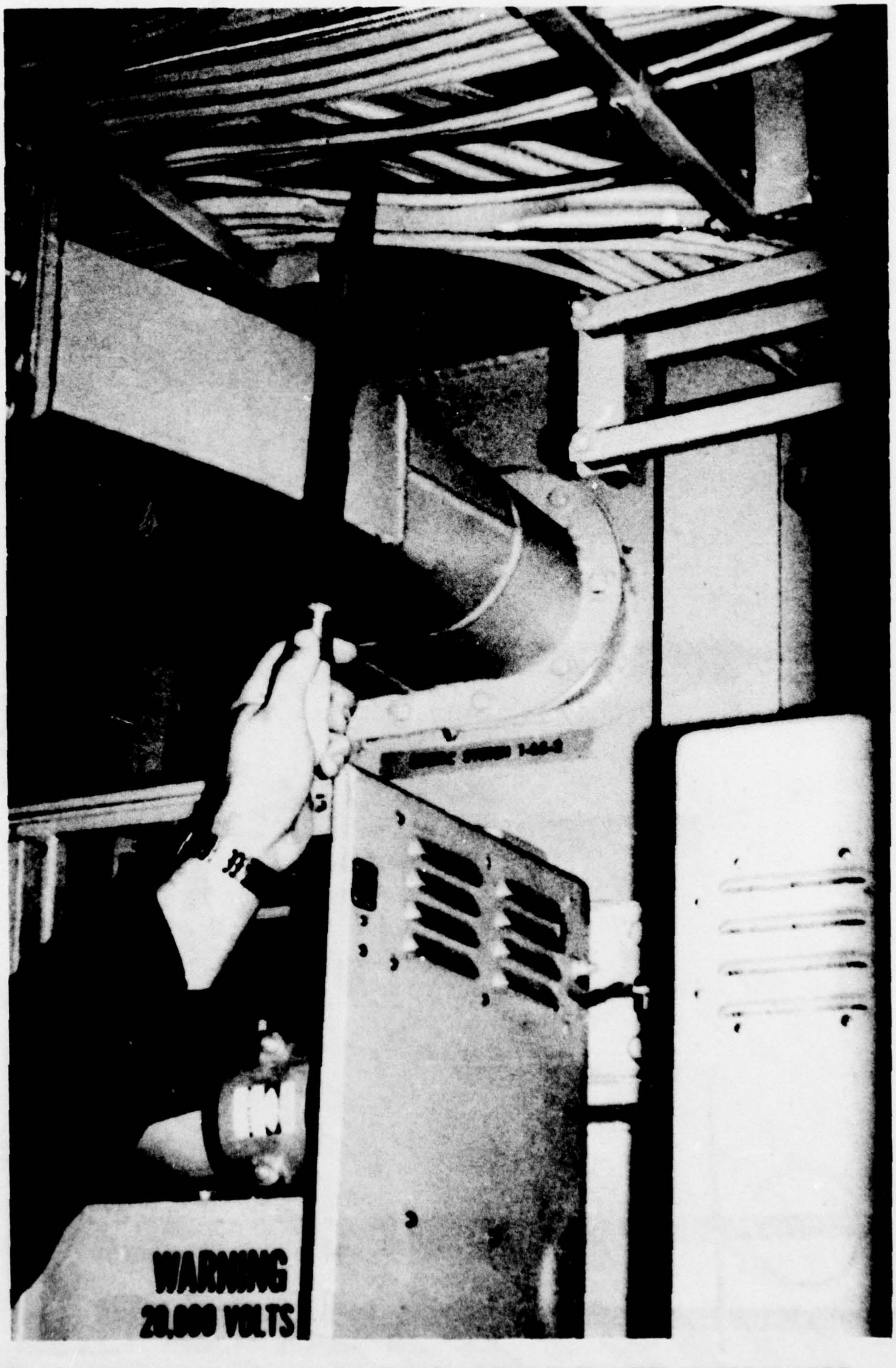

FIG. 13 AN/SSR-1 CABLES THAT PASS ABOVE THE AN/SPS-10 MODULATOR

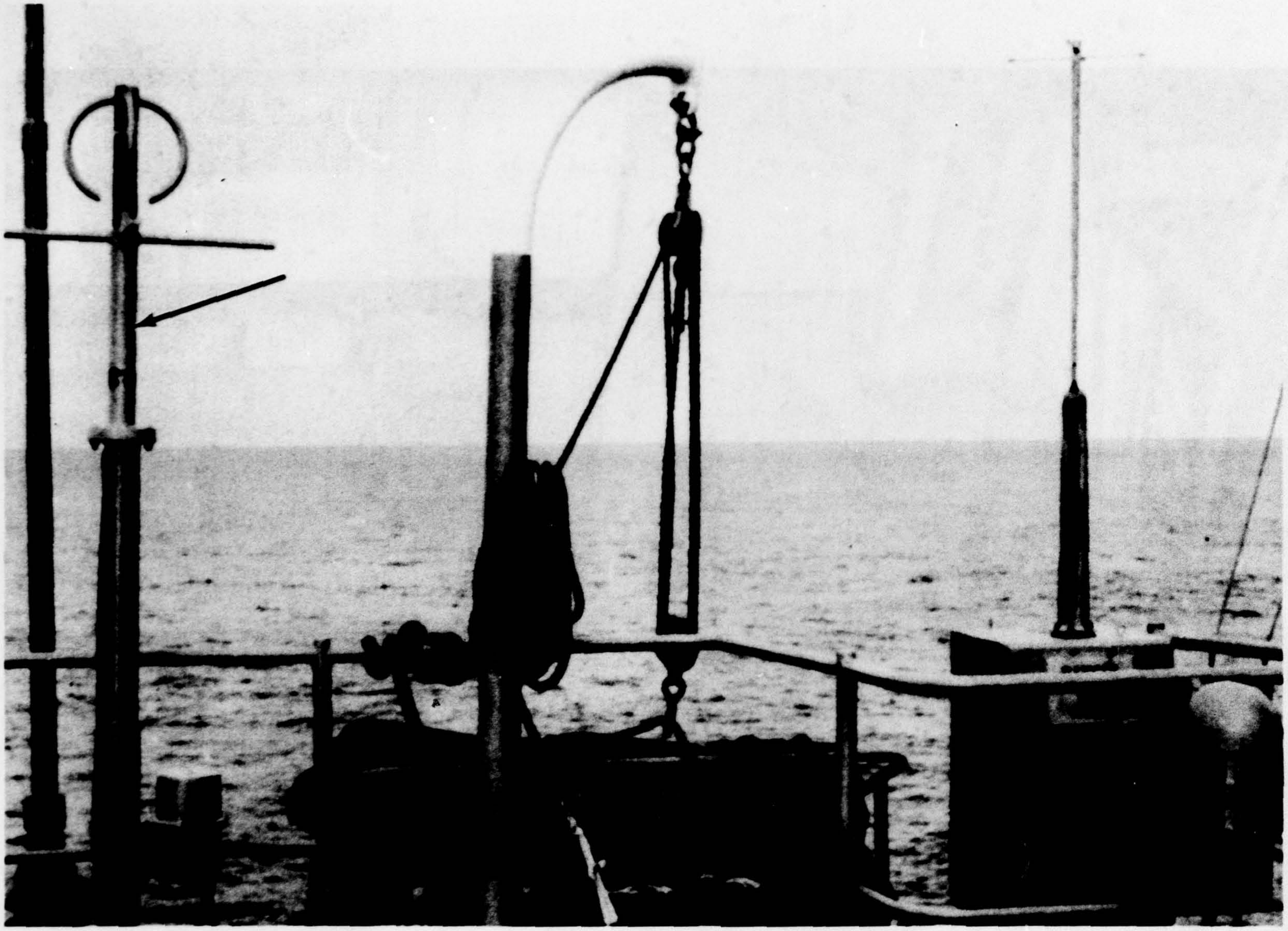

FIG. 14 ARROW POINTS TO THE AN/SSR-1 ANTENNA THAT IS TRANSMITTING THE AN/SPS-10 PRF

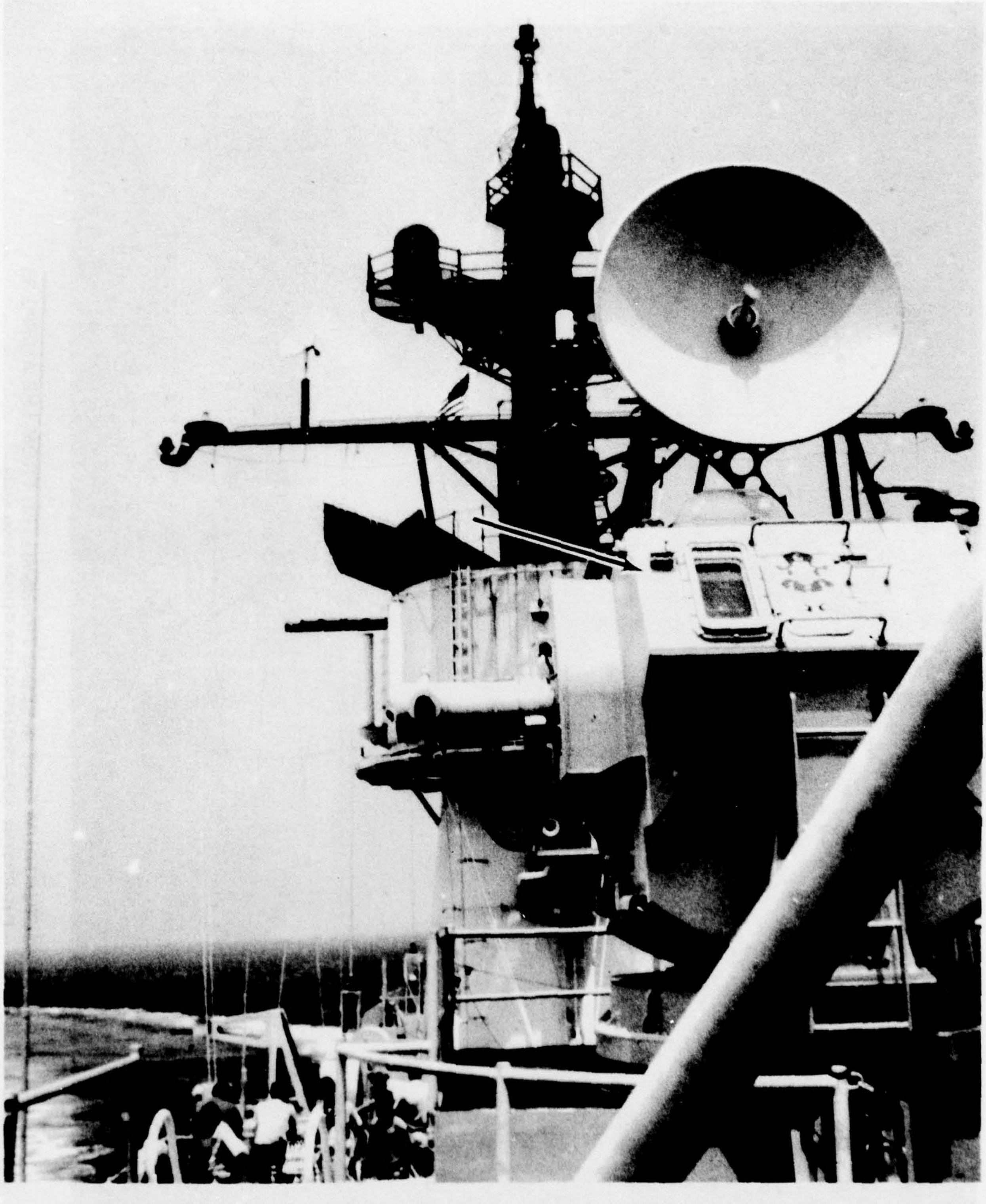

FIG. 15 AN/SPG-53 DIRECTOR THAT IS ACTING AS AN HF TRANSMITTING ANTENNA

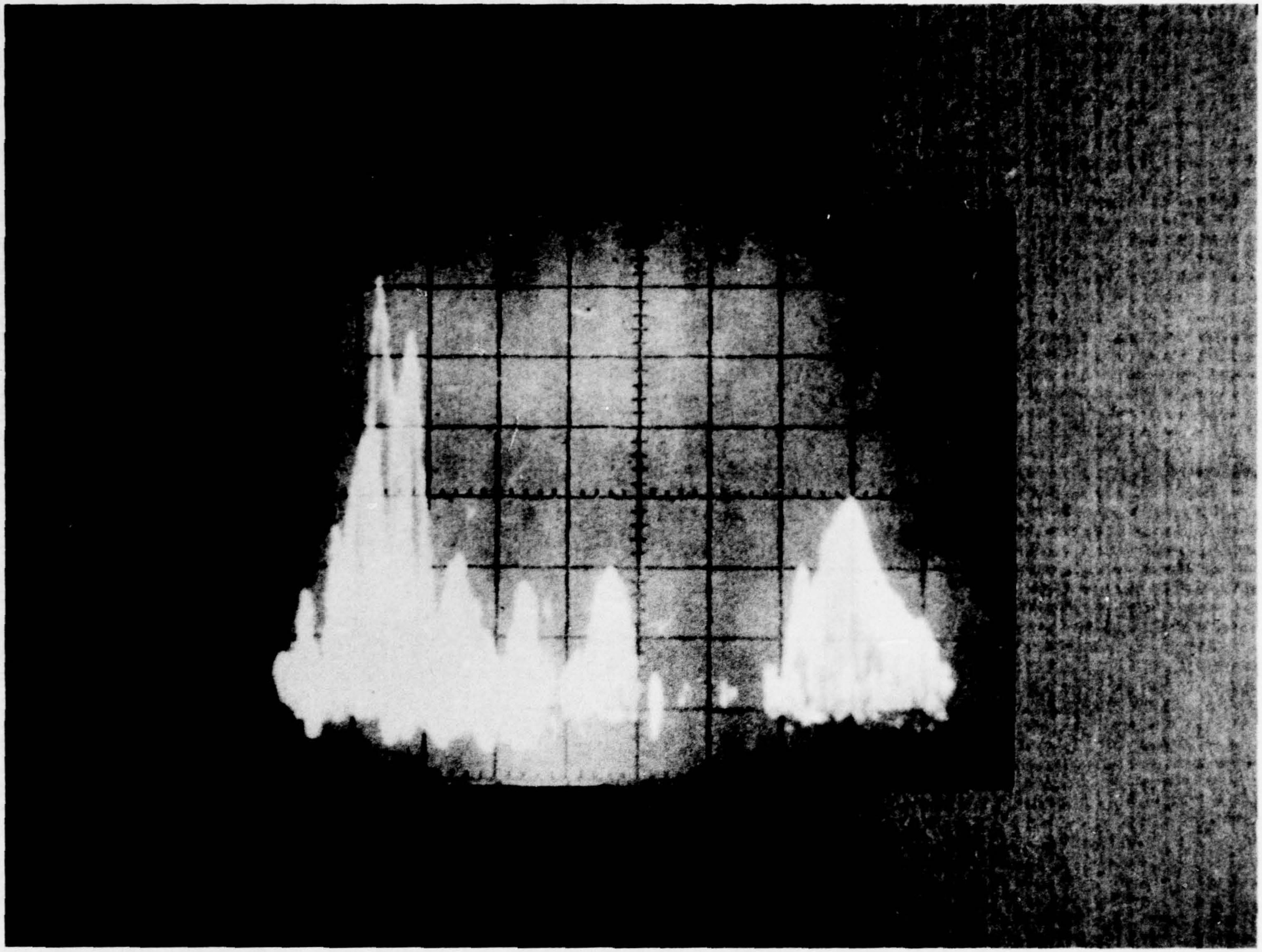

FIG. 16 SPECTRUM THAT IS BEING TRANSMITTED FROM THE AN/SPG-53 DIRECTOR. SPECTRUM RUNS FROM 0-50 MHz

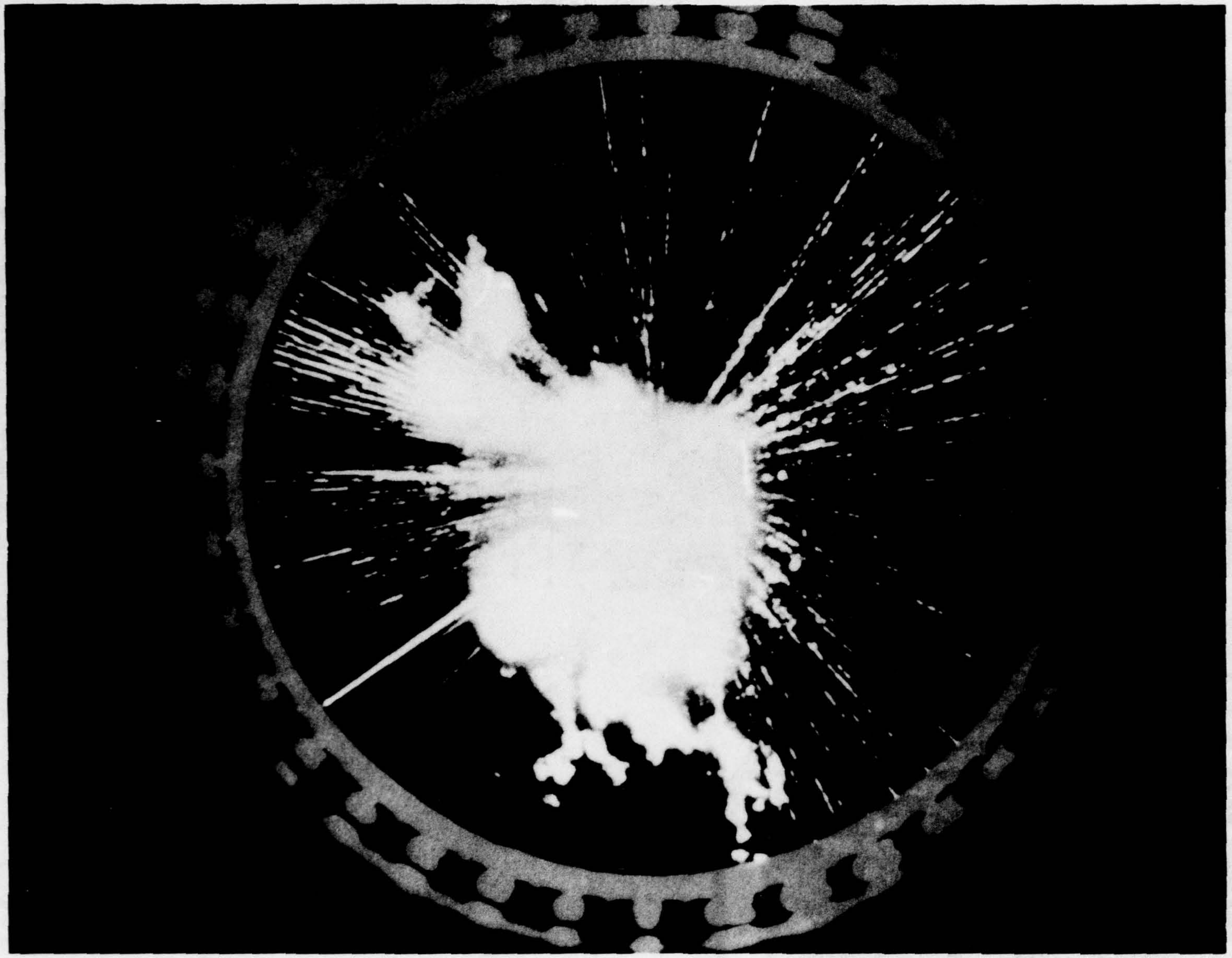

FIG. 17 AN/SPN-43 PPI DISPLAY SHOWING AN/SPS-43 INTERFERENCE

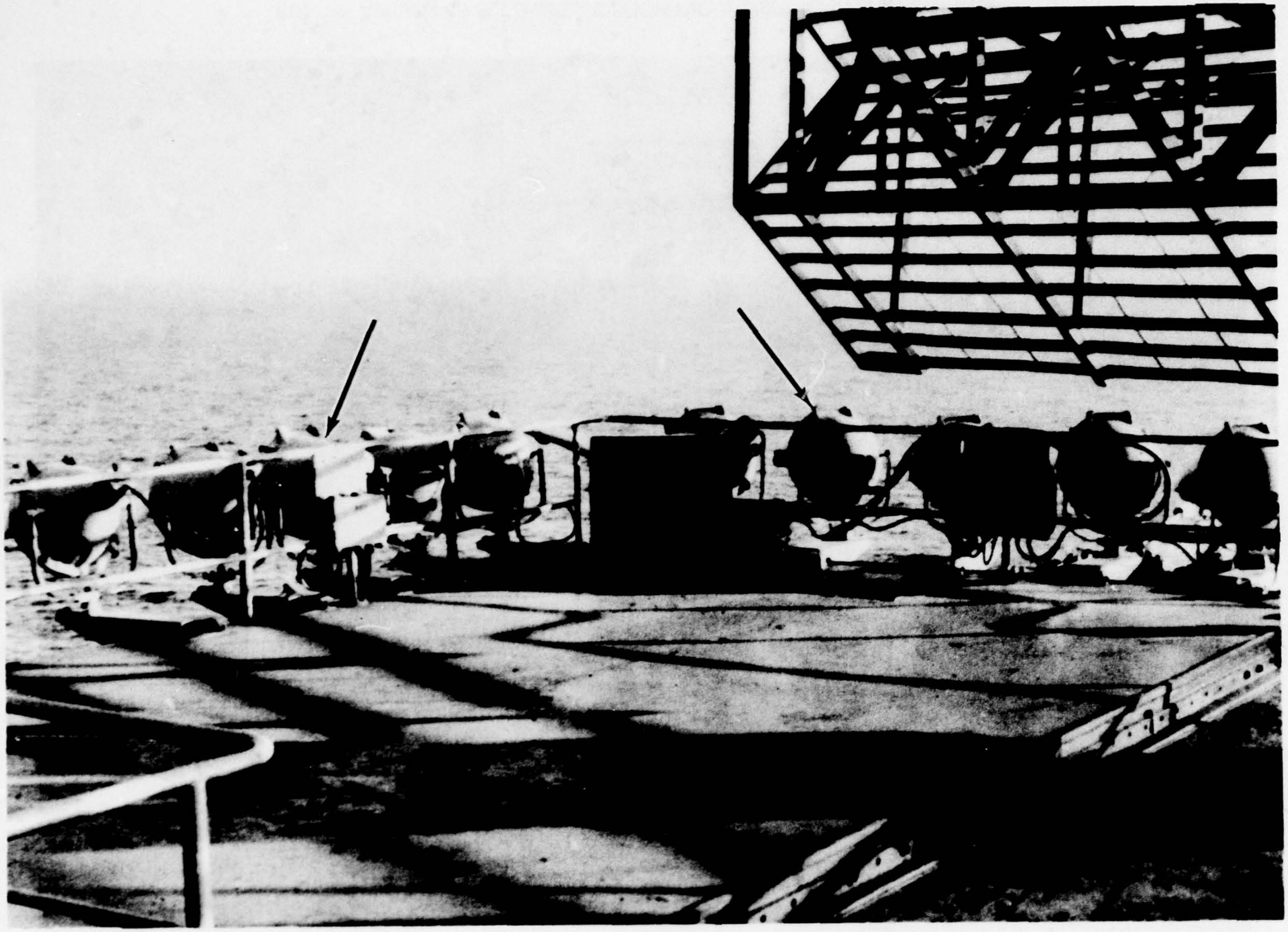

FIG. 18 FLIGHT DECK FLOOD LIGHTS THAT ACT AS NON-LINEAR GENERATORS OF IMI PRODUCTS

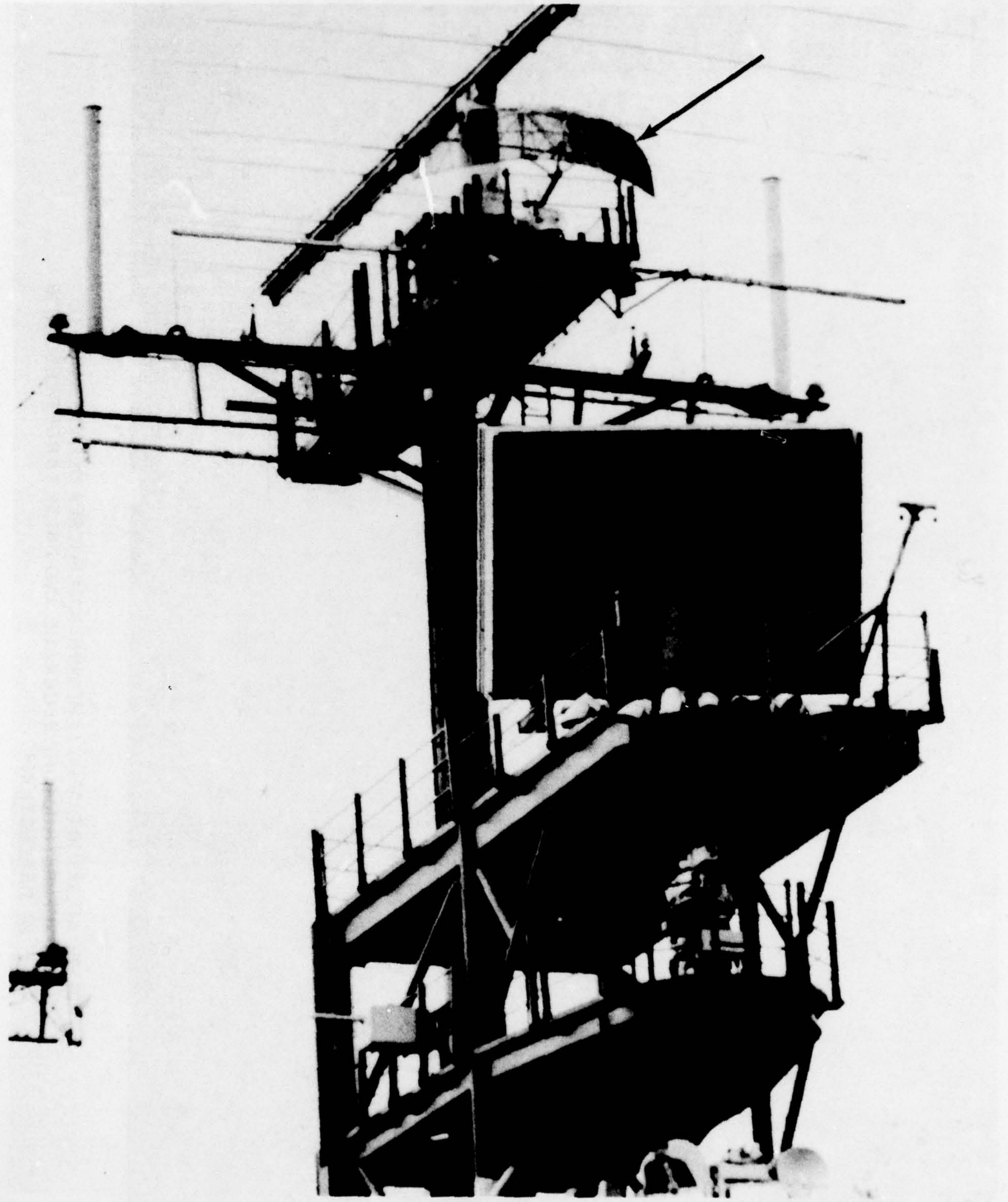

FIG. 19 AFT MAST, SHOWING FOWARD BLOCKAGE OF AN/SPS-10 RADAR

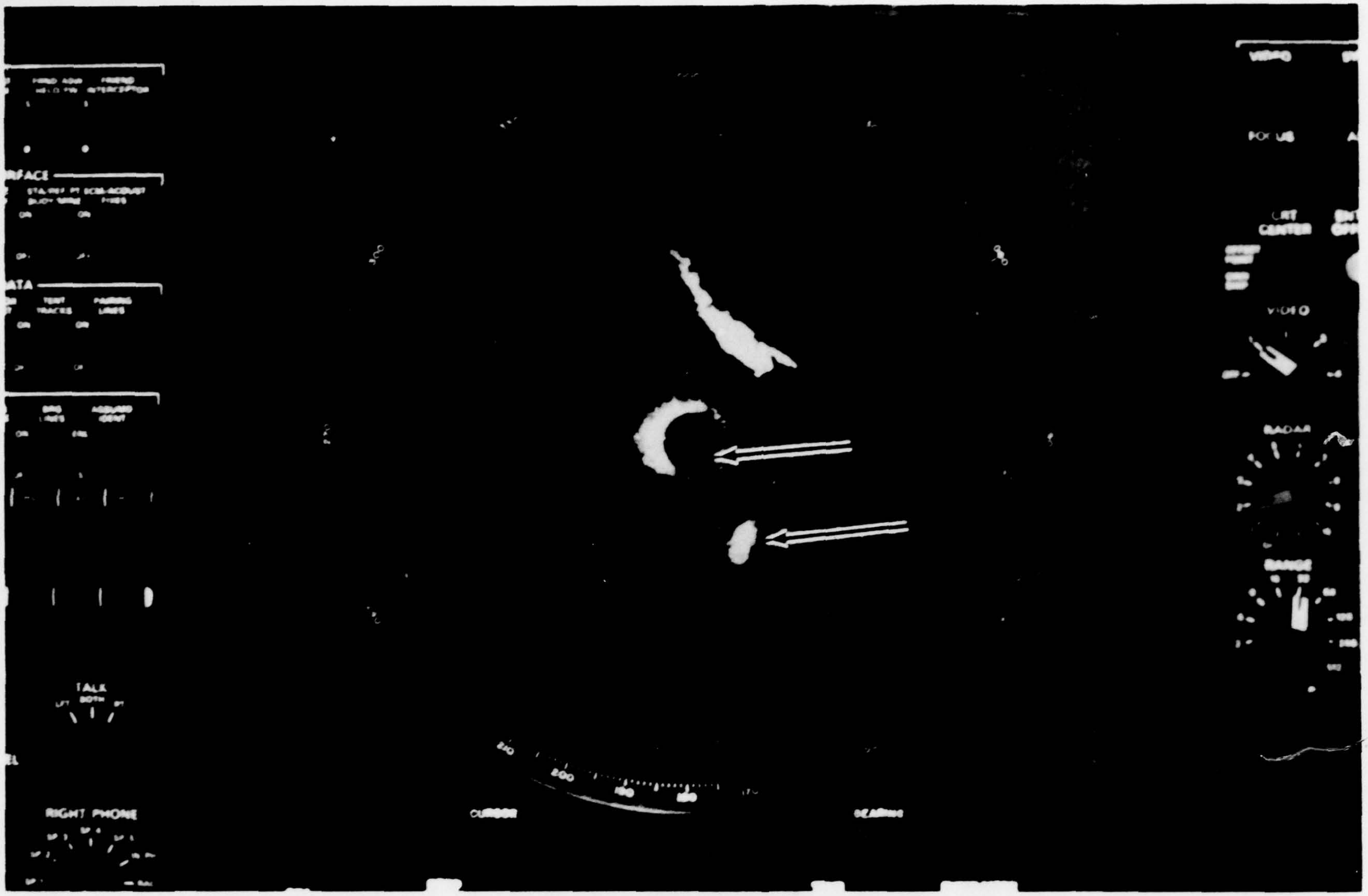

FIG. 20 AN/SPS-10 DISPLAY SHOWING MISSING SEA CLUTTER DUE TO SUPERSTRUCTURE BLOCKAGE AND FALSE TARGETS BECAUSE OF REFLECTIONS

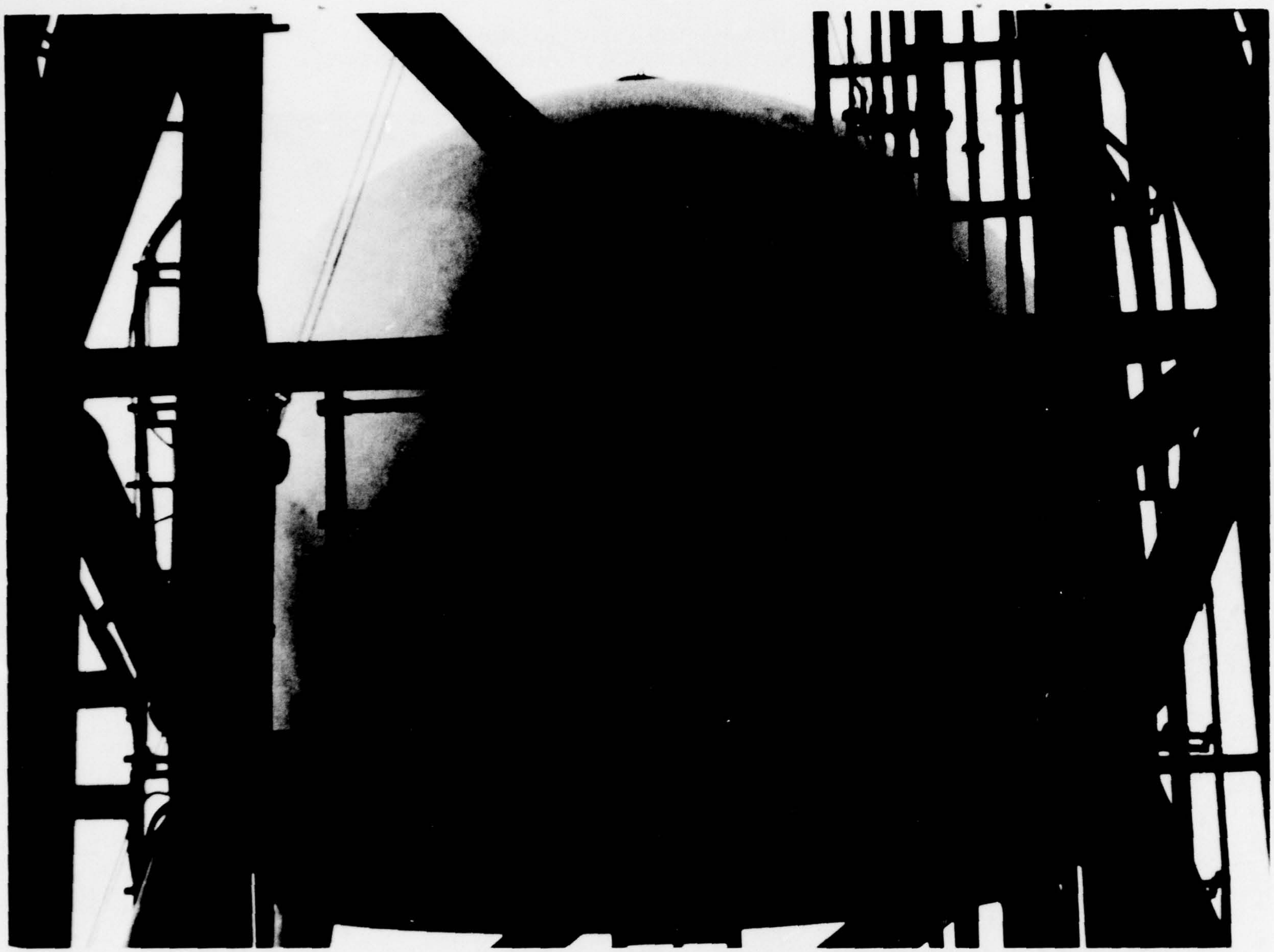

FIG. 21 AN/SPQ-9 RADAR INSTALLATION SHOWING AFT BLOCKAGE

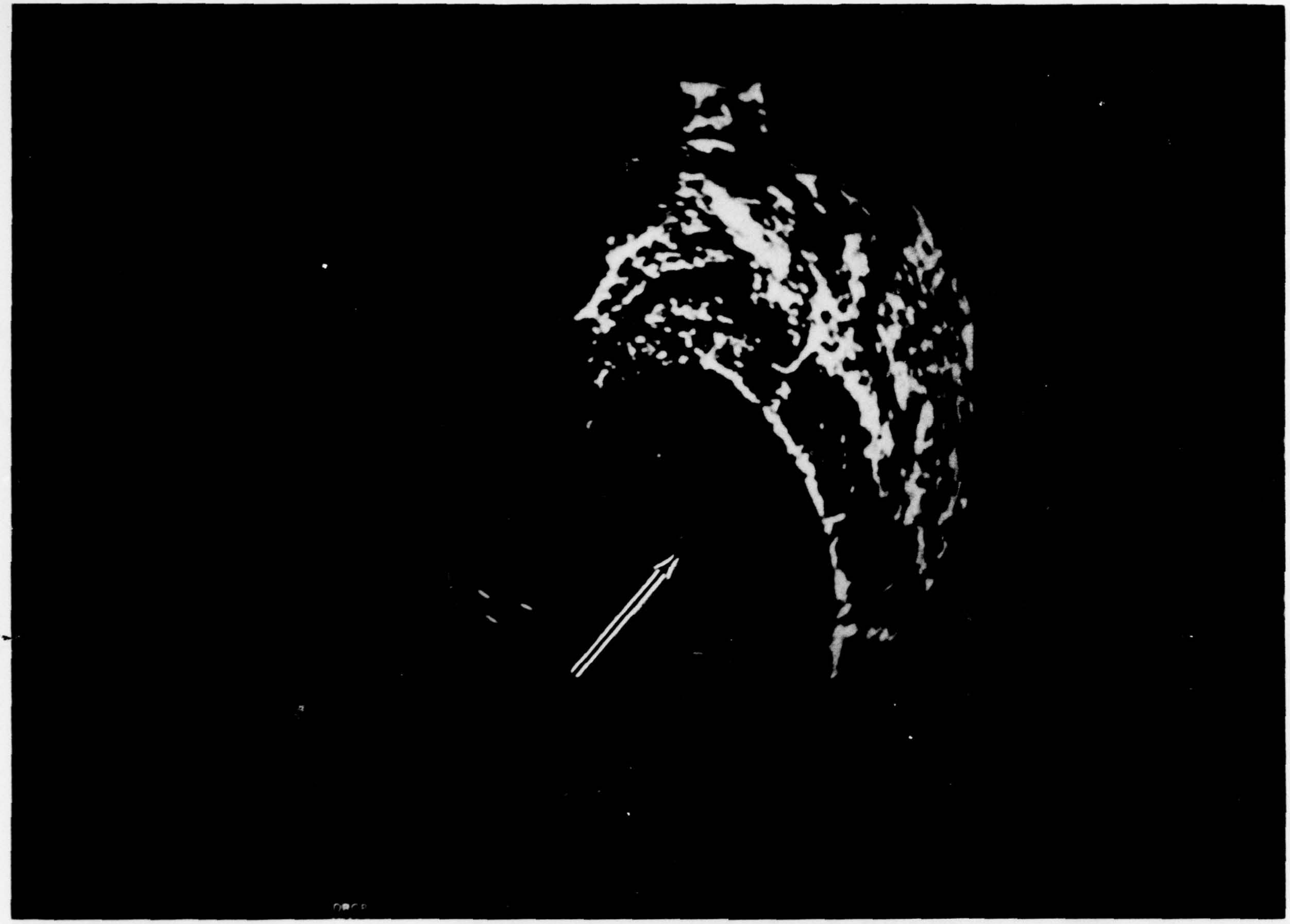

FIG. 22 AN/SPQ-9 PPI DISPLAY SHOWING FALSE TARGETS DUE TO REFLECTIONS OFF VERTICAL WAVE GUIDE RUNS

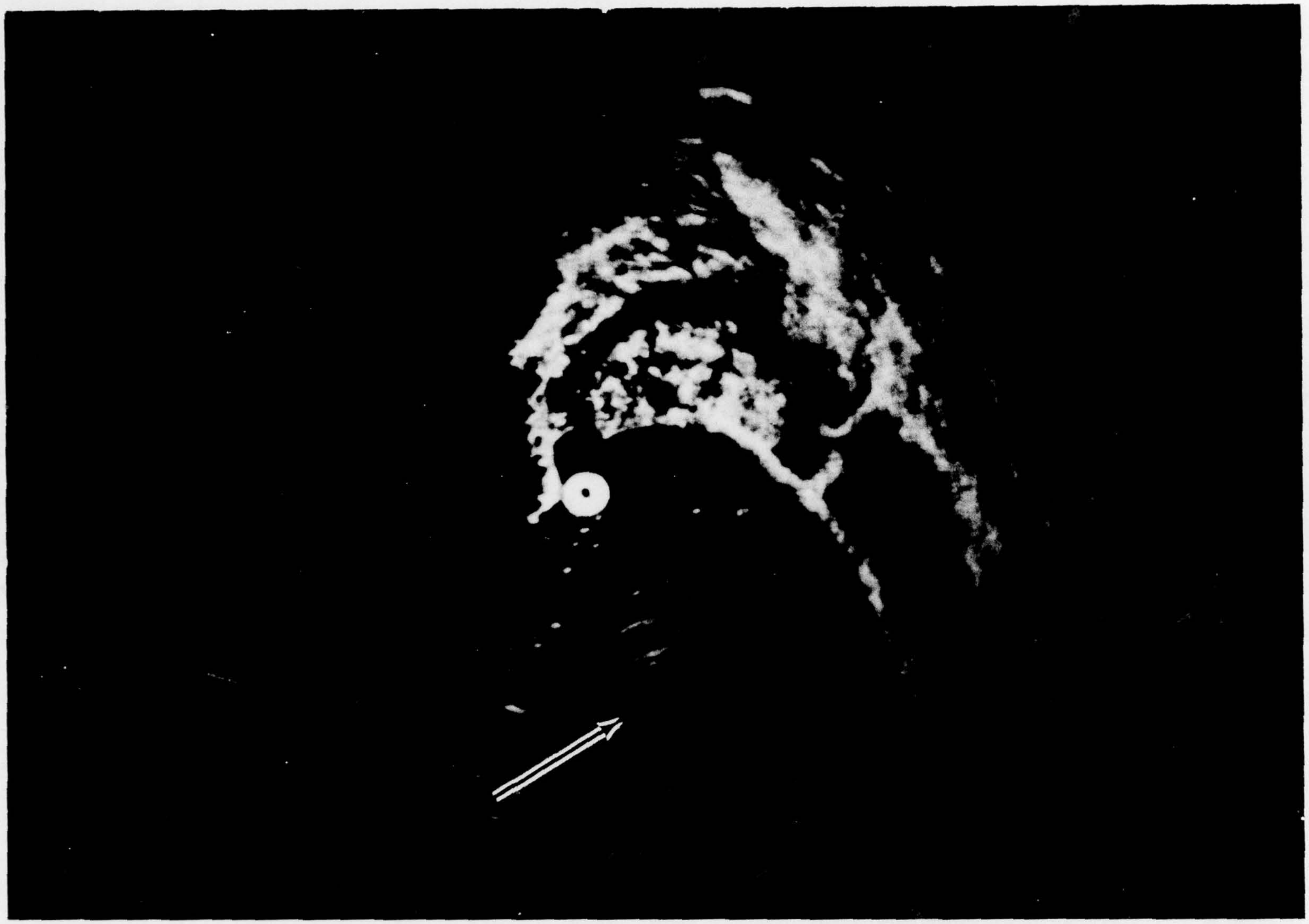

FIG. 23 AN/SPQ-9 PPI DISPLAY SHOWING SAME INFORMATION AS FIG. 22
EXCEPT AS RETURNS BECOME STRONGER THEY TEND TO SMEAR