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NRL Report 5155

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A VERY WIDE BAND INTERCEPT EQUIPMENT

[UNCLASSIFIED TITLE]

E. G. Becke, R. A. Carpenter, G. W. Kelley, Jr.,
R. D. Mayo, V. S. Rose, and W. E. Withrow

Countermeasures Branch
Radio Division

June 13, 1958

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NRL Report 5155

A VERY WIDE BAND INTERCEPT EQUIPMENT (QRC-2) FOR USE IN SUBMARINES

[CONFIDENTIAL TITLE]

E. G. Becke, R. A. Carpenter, G. W. Kelley, Jr.,
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Countermeasures Branch
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ABSTRACT

[Confidential Abstract]

The Naval Research Laboratory has developed a Radio and Radar Intercept system having an extremely wide frequency coverage for use in submarines to meet an urgent fleet requirement. The Communications Intercept system covers a continuous range of 15 Kc to at least 265 Mc, limited only by the availability of receivers, which were not part of the development. The Radar Intercept system is complete and is of the "wide open" crystal -- video type, the video amplifier being furnished with the equipment. It covers from 2.5 to 12 kmc, the important parts of the "S" and "X" bands. Two antennas are employed for the complete equipment, a specially developed antenna of the "sleeve-stub" type being used for the Communications system and a small spiral antenna for the Radar system. Both antennas are carried by a type 8 periscope, the sleeve-stub being clamped behind the periscope head and extending 17″ above the 'scope, while the spiral antenna is mounted within the 'scope head, protected by a heavy glass port. The sleeve-stub antenna is designed to withstand hydrostatic pressure in excess of 600 psi and cantilever loading of 150 foot pounds. Neither of the antennas interferes in any way with the optical system or the normal use of the periscope. Six complete equipments were furnished, complete with Handbooks of Operating and Maintenance Instructions.

PROBLEM STATUS

This is a final report on BuShips Problem S-1889. Work on the basic problem is continuing.

AUTHORIZATION

NRL Problem RO6-02
BuShips Problem S-1889

Manuscript submitted May 9, 1958

INTRODUCTION

On 2 December 1957, the Laboratory was requested by the Bureau of Ships to design, fabricate and provide six complete intercept equipments, for installation in submarines, to cover the radio spectrum from 15 kilocycles to at least 265 megacycles and the "S" and "X" band radar spectrum. The sailing date of the first vessel was 15 January 1958 and with an allowance of two weeks being necessary for installation and sea trials it was obvious that this was, indeed, a "crash program".

To add further difficulties to the problem, it was required that all antennas be carried on or in a single Type 8 periscope without in any way affecting the optical system of the periscope or compromising its normal function. This meant that an accelerated research program had to be entered into to develop antennas that would be mechanically suitable for periscope mounting, could withstand the pressures and vibrations to be encountered and at the same time possess sufficient gain to make them useable. Even without the mechanical complications, the design of a restricted number of antennas to efficiently cover the extreme frequency ranges involved presented a formidable problem, particularly when the "restricted number" was decided upon as two.

Because of the "crash" nature of the program and the fact that a relatively short life for the first six equipments could be tolerated, it was decided that it would be acceptable as well as necessary to employ as many commercial or pre-developed units and components as possible, putting the major research and development effort into the design of the antennas, which were not commercially available but which were the life blood of the installations.

Similarly, because time was of the essence, it was necessary to allocate different phases of the work to different scientists. Accordingly, it might be mentioned that Mr. R. A. Carpenter assumed responsibility for the development and electrical design of the 15 Kc - 265 Mc antenna and associated parts of this system; Mr. E. G. Becke for the mechanical design of the antenna; Mr. W. E. Withrow for the design of the spiral radar-intercept antenna; Mr. R. D. Mayo and Mr. V. S. Rose for the design of the remainder of the radar intercept system, while Mr. Withrow and Mr. Mayo supervised the installations in the first three vessels and conducted sea and diving trials.

As a final general comment it might be mentioned that the time schedule was met, all vessels sailing on schedule, and while the Laboratory does not believe that the design of the equipments furnished even approaches the ultimate, it does believe that their performance was entirely satisfactory for their intended purpose.

PRINCIPLE OF OPERATION

Figure 1 is a block diagram showing the various fundamental units comprising the system and their relationship to each other. It will be noted that, in reality, two separate and distinct systems are involved.

For the 15 Kc - 265 Mc system, the signals are picked up on a special sleeve-stub antenna mounted atop the periscope and fed down through a coaxial transmission line to the vessel's radio room. Here they are passed through a 54 Mc high-pass filter to a 54 - 265 Mc receiver as well as to the input of a wide-band (1 Kc - 200 Mc) amplifier. The output of this amplifier feeds a 15 - 600 Kc receiver and the input of a 550 Kc high-pass filter the output of which connects to a 500 Kc - 32 Mc receiver. The receivers are all part of the vessel's radio installation; only the amplifier and the filters were furnished by the Laboratory. It will be noted that the design involves only the antenna and the equipment between it and the receiver inputs. This provides for extreme future flexibility, permitting additional receivers, multicouplers, etc., to be used if required. Similarly, any analyzing or recording equipment may be employed, as such equipments involve only the receiver output circuits and do not influence the effectiveness of the antenna system. The reason for employing the wide-band amplifier and the high-pass filters is not pertinent to an understanding of the basic principle of operation and will be discussed in detail under DESIGN CONSIDERATIONS.

For the "S" and "X" band (2.5 - 12 kmc) system, the signals are picked up by a special spiral antenna mounted in the head of the periscope behind a heavy glass port. They then pass down through a coaxial transmission line to a combined high and low pass filter, the low pass covering "S" band and the high pass the "X" band with their cross-over at 4.7 kmc. The output of each filter has associated with it its own crystal detector. The outputs of these crystals pass through a three-position switch assembly which permits the crystals to be used individually or in combination, so that either "S" band, "X" band or simultaneous S and X band coverage may be obtained. The output of the switch assembly feeds the input of a high-gain video amplifier, outputs being provided for the use of headphones, cathode ray analyzing, or recording equipment. To keep the rf transmission line as short as possible and hence minimize its losses, the filters, crystals and switching assembly are all housed in a small unit, designated as the Filter-Crystal Unit, mounted in an extension of the periscope below the Eyepiece Box and riding with it. The amplifier is located close by so that its controls are available to the periscope operator. It is obvious that this system is effective only on pulsed or other amplitude modulated signals but has the advantage of being "wide open" frequency-wise and permitting the obtainment of the signal direction with reasonable accuracy, the spiral antenna possessing approximately a 50^{o} reception pattern.

DESCRIPTION OF THE EQUIPMENTS

As was mentioned in the INTRODUCTION, the equipments were required to cover the complete frequency range of 15 kilocycles through 265 megacycles for the interception and analysis of communications, guidance and similar radio signals, as well as the "S" and "X" band radar spectrum (2.5 - 12 kmc). Not only because of the spectrum gap and differences in the nature of the types of signals to be encountered, but the major differences in the types of antennas and associated equipment suitable for the two purposes, it was decided desirable, if not essential, to design and provide two completely separate and distinct systems for the job. These, insofar as possible, will be described independently starting at the antennas. In order to simplify terminology, the 15 Kc - 265 Mc system will be referred to herein as the communications intercept system (or equipment), while the "S" and "X" band system will be called the radar intercept system (or equipment).

The communications intercept antenna is of a specially developed "sleeve-stub" type that mounts near the top and to the rear of the periscope (with respect to the optical port), the antenna proper extending above the top of the 'scope. Its total length is but 37 13/16", the extension above the top of the periscope being 18". These antennas were tested to withstand a hydrostatic pressure of 600 pounds per square inch and a cantilever force of 150 ft. lbs. (A mechanically improved type of these antennas has been developed subsequent to the six installations described herein and is covered in detail in the Appendix). Figure 2 shows the antenna mounted on a periscope.

The radar intercept antenna is a specially developed "Spiral" type and is mounted in a protuberance near the top of the 'scope below the optical port. It is pressurized by a heavy glass cover on the protuberance, capable of also withstanding 600 pounds pressure.

The coaxial output cables from the two antennas are carried down the inside of the periscope in place of a wave guide formerly used for a type ST radar antenna, which was removed for these installations.

On the bottom of the periscope below the Eyepiece Box is secured an extension tube of the same diameter as the periscope (7") into which fits a small oblong unit (Fig. 3) designated as the Filter-Crystal Unit which is common to both systems. For the Communication Intercept equipment, its panel serves merely as a coaxial junction between the antenna lead and a cable running to a fixed junction box and thence to the vessel's radio room which it enters through a pressure-tight stuffing gland. In the radio room are located a wide-band amplifier and two high-pass filters as well as the required complement of radio receivers. Inasmuch as the radio room arrangement differs for different vessels, no arrangement for these three additional units can be prescribed, but, because none of them has any controls that require adjustment in operation, they can be stowed in any convenient location. Coaxial cables with proper fittings are supplied for interconnecting these units.

The wide-band amplifier is a commercial product manufactured by the Spencer - Kennedy Laboratories and designated as their Model 202D. It will be described in detail later in this report. The two high-pass filters are of NRL design and manufacture. For the radar intercept equipment the Filter-Crystal Unit houses a diplex (high and low pass) filter, each with its own crystal, a switch that permits the use of either crystal individually or the pair in combination, a crystal protective switch that disconnects the filter input from the antenna and throws it to a Test Receptacle on the panel, and a crystal output receptacle for connecting to the wide-open Video Amplifier.

The diplex filters cover the "S" and "X" radar bands respectively, each carrying its own crystal mount which is switched. By switching the crystals, i.e., the video signals, coverage of the "S" and "X" band or either band individually is obtained without switching losses. This permits band identification and some selectivity in areas of high signal density. The crystal protective switch is provided to afford maximum protection against crystal burn-outs when in the field of close-by radars by permitting the crystals to be disconnected from the antenna except when actually in use. The Test Receptacle permits the introduction of the output of a signal generator for test of the crystals and amplifier. It will be noted that the crystals are in the Filter-Crystal Unit at the base of the periscope where they may be readily changed, instead of at the antenna. While the Laboratory disliked the necessity of having to take the rf cable loss of some 3 db at "S" band and 9 db at "X" band, in the run between the antenna and the crystals, it was felt absolutely necessary to put the crystals at the base of the periscope to provide crystal accessibility. Access to the spiral antenna compartment is beyond the capability of a ship's force, so that it would have been inadvisable to attempt to place the crystals close to the antenna to eliminate the line losses. Furthermore, no space is available at the top of the periscope to put the filters, crystals and switching gear, even if ready access were possible.

On the overhead of the compartment from which the periscope is operated (the conning tower or the control room) close to the 'scope, are installed two junction boxes, each containing a coaxial receptacle of the pullaway type, one, as stated above, being wired to the radio room for the Communications Intercept system and the other to the Video Amplifier for the Radar Intercept system. The amplifier is mounted on a bulkhead close to the periscope. Two coaxial cables, with some slack, connect between the junction boxes and the output receptacles of the Filter-Crystal Unit, the Radar Intercept outlet being a telephone jack while the Communications Intercept outlet is of the BNC type. When it is desired to house the periscope it is necessary to disconnect the two connectors from the Filter-Crystal Unit to permit it and the lower end of the scope to go into the housing well. During operation, however, in order to permit the 'scope to be rotated, sufficient slack is allowed in these cables to permit them to wind up around the 'scope. In order to prevent these cables from being parted in the event too many turns of the scope are inadvertently made in the same direction, the pullaway connectors mentioned above are used on the terminal boxes to permit them to pull apart and thus preclude damage to the cables. This is far from a "happy" arrangement but is the best that could be made under the circumstances and in the time available.

Also located on the overhead is an additional jack box wired to the output of the Video Amplifier and containing a telephone jack into which the headphones worn by the periscope operator plug.

Figure 4 shows the location of the jack boxes on a typical installation while Fig. 5 shows the location of the Video Amplifier.

One final word with respect to the equipment associated with the periscope. This latter item must be maintained pressure tight at all times. But the Filter-Crystal Unit carried on its lower end is not pressure tight and cannot be made so, inasmuch as it must be opened to change crystals.

Pressure tight integrity of the periscope is maintained by the use of pressure-proof coaxial connectors in the bottom of the eyepiece box to which the Filter-Crystal Unit secures. The antenna leads within the 'scope connect to these pressurized fittings. Short jumpers connect their exposed sections to the proper receptacles in the Filter-Crystal Unit.

THE COMMUNICATIONS INTERCEPT EQUIPMENT

DESIGN CONSIDERATIONS

In viewing the problem of providing for relatively efficient radio reception in a submarine with a periscope mounted antenna, over such a tremendous frequency range as 15 Kc to at least 265 Mc, several factors became immediately apparent. Some of these might be listed as follows:

(a) More than one antenna was highly undesirable if not out of the question.
(b) An ordinary antenna under such conditions would go through extremely wide impedance excursions, possibly producing a multiplicity of "dead spots".
(c) The efficiency of any ordinary antenna suitable for 265 Mc reception would be extremely poor at frequencies as low as 15 Kc.
(d) It was highly desirable, if not essential, to use a multiplicity of standard shipboard receivers to cover the range.
(e) To attempt to operate such receivers with their inputs simply paralleled would be equally out of the question, as the reaction and power absorption would be prohibitive.
(f) No simple multicouplers having acceptable efficiency and noise factor over such an extended frequency range were available.

A review of these factors indicated that three approaches to the problem were essential:

(a) A special antenna would have to be developed and designed that would be reasonably small and light, capable of withstanding high hydrostatic pressures and mechanical strains but still be relatively efficient over the required frequency range.
(b) Means would have to be developed for coupling a multiplicity of receivers to such an antenna without interaction or prohibitive absorption of power.
(c) Means had to be developed to compensate, in some measure, for the inherently low efficiency of a very small antenna at very low frequencies.

THE ANTENNA

Electrical Design

While the problem of the electrical design of a single antenna to cover, with useable efficiency, a frequency range from the lowest vlf through the highest uhf (a coverage of some 17,000:1) is, in itself, a formidable one, when such a problem is further complicated by strict mechanical requirements, such as a height limitation of 18 inches, restricted diameter and the necessity of withstanding the high hydrostatic pressures and mechanical forces encountered in submarine use, it approaches the impossible. Obviously compromises are necessary. Therefore in designing this antenna it was finally decided to concentrate on obtaining maximum efficiency in that portion of the total frequency range that was considered most important, namely 100 to 150 megacycles and then attempt to improve the efficiency of the receiving equipment for satisfactory operation at the lower frequencies.

The antenna, as finally developed, is of the type known as a "sleeve-stub". It consists of three basic parts: an upper section, a concentric matching transformer or lower section, and a transmission line section. The effective length of the antenna extends from the top of the upper section to the ground plane, or, in this case, to the surface of the water. Under smooth sea conditions and with a normal extension of the periscope, the antenna resonates in the most important portion of the vhf spectrum, while in other parts of the spectrum it will have a reactive component. Any other known type of antenna suffers equal drawbacks but does not possess the many advantages of this design.

The antenna is fed across a one-inch gap seventeen inches from its upper end. This feed system has the advantage, when using a relatively thin element, of having a fairly flat impedance characteristic over about an octave of frequency. The impedance would be primarily capacitive at the gap unless compensated for. Several electrical methods are available to accomplish this. One experimental model utilized a short section of coaxial line above the gap, but this method was mechanically unsuitable and therefore was discarded in favor of a coaxial transformer having a high characteristic impedance. This transformer section serves the dual purpose of neutralizing the capacitive reactance of the antenna at the center of the 90 - 160 Mc band so that, over this band, the antenna is substantially resistive, and at the same time maintains the impedance at such a value that the VSWR does not exceed 3:1. Below 90 Mc the impedance increases with decreasing frequency and is, of course, capacitive.

The matching transformer is approximately ten inches long, and the rest of the antenna system consists merely of a 50-ohm transmission line.

A 50-ohm stainless steel transmission line plug-in section, with appropriate pressure-tight seals, connects the base of the antenna to another coaxial fitting in the periscope face plate. Inside the face plate an adapter consisting of a coaxial hermetic seal appropriately proportioned to reduce the diameter of the feed line to meet an RG-142/U flexible teflon cable. This short flexible section is necessary to connect to the main transmission line running through the length of the periscope.

For the cable runs inside the periscope, 3/8" Styroflex was employed. This cable has appreciably lower loss than any other available cable and was needed primarily for the "X" band of the Radar Intercept system where the losses between the spiral antenna and the crystal detector would have been excessive if ordinary cable had been used. In the interest of standardization, handling, etc., it was considered desirable to use the same cable for both systems. Special adapters were developed to permit the use of this 3/8" cable with regular "N" and "BNC" connectors.

A connector was also developed to provide a hermetic seal in the periscope bottom plate (lower section of the eyepiece box) and at the same time adapt the Styroflex to the type N series connectors. This was accomplished by utilizing the seal portion of a UG-665D/U fitting and designing a constant-impedance housing.

Mechanical Design

In effecting a satisfactory mechanical design for the "sleeve-stub" antenna it was necessary to give consideration to the following factors:

(a) The antenna must be capable of withstanding the full force of breaking storm waves which exert a maximum estimated force of 1000 pounds per square foot.
(b) The water-tight integrity of the periscope must not be jeopardized by the installation or failure of the antenna.
(c) Deterioration caused by corrosion must be held to a minimum.
(d) It must be capable of withstanding thermal shocks in the range of -10^{o} to 140^{o}.
(e) The antenna diameter must not exceed 1 1/2" nor the height above the periscope 18".

Because of the "crash" nature of the problem and the exceedingly short time available for design and fabrication of the required number of antennas (12 in all) the design described below is not considered ideal or ultimate but would, it was believed, result in antennas that would withstand all the rigors to which they might be subjected. This belief has been substantiated by the fact that, to date, no failures have been reported after many weeks of service use. However, after relief of the initial urgency, the antennas have been redesigned for future use and it is believed that the improved units will possess a much greater factor of safety. Details of the redesigned model are contained in the APPENDIX.

The antenna is fabricated in its entirety from stainless steel except for the insulated parts, for which Fiberglas filled epoxy is used. Externally it is a round member 1 1/2" in diameter and 36 13/16" long. Actually it consists of two metallic members of substantially the same length separated by a 1" insulated gap. Because of the slight porosity of the insulating material this gap is protected by a thin sleeve of neoprene vulcanized in place. (This is the black section shown in Fig. 6a.) The lower section of the antenna serves the dual role of a concentric matching transformer and the supporting member, the machined section shown in Figure 6 clamping into a mounting block secured to the head of the periscope. Figure 2 shows the antenna as mounted.

Because of the variable and unknown magnitude of the mechanical strains to which the antenna might be subjected in service and the importance of its not carrying away while in use, every effort was made to build as great a factor of safety into the design and fabrication as was compatible with the electrical performance, mounting limitations and available time.

While minute details of the various design features are not believed to be pertinent to this report, but can be obtained from available manufacturing drawings, an attempt will be made to cover the more important factors.

Figure 6b shows the main parts of the antenna, disassembled, the function of each being, in general, apparent. As a slight clarification it might be mentioned that the white oblong object in the upper left hand side of the figure is merely a six-inch scale included for size indication (although the markings are hardly visible in the photograph) and the four black rings standing alongside the insulator section are rubber "O" rings which, on assembly, slip into the four grooves on the insulator in a conventional manner.

The upper member of the antenna assembly is constructed of 1 1/2" stainless steel tubing with a 1/16" wall thickness. Its top is closed by a disc welded in place but provided with a small breather hole. To its bottom is welded a solid steel plug, approximately 2" long. The weld is just below the upper of the two small holes shown in Fig. 6b. This plug is "bottom" drilled and tapped with standard 3/8" threads and has a recessed groove to receive an "O" ring.

The Fiberglas insulator is drilled and tapped to receive a 4 1/2" steel stud, the upper section of which is visible in Fig. 6b. To further anchor this stud, four small rolled steel pins are driven transversely through the insulator and the stud and deeply recessed in the insulator, being kept in position by fiber screws sealed with epoxy resin. Before this stud is put into place, the inner conductor of a piece of RG-87/U is soldered into a hole in its lower end. This conductor, with its teflon dielectric passes through the insulator and can be seen below it in Fig. 6b.

The insulator is secured to the top section of the antenna by tightly screwing its stud into the threaded hole in the upper section. To preclude any possibility of these two members unscrewing, a recessed set screw is driven into the stud through the lower hole shown in Fig. 6b. The hole is then closed with soft solder to preclude water leakage around the threads. Mechanical strength between the antenna member and the insulator is obtained by the firm 1 1/2" diameter seating between the two as well as the strength of the stud, while the "O" ring adds additional protection against water leakage. Parenthetically, the small upper hole in the antenna member is merely the lower drain hole.

The lower section of the antenna is fabricated of two pieces, an upper piece, extending to just above the machined portion, being of 1 1/2" stainless steel tubing with a 1/16" wall. This is welded to a solid piece of suitably machined stainless steel, the bright machined section securing into the mounting block when installed. In order that the gland and the support member be of one piece, this was machined from 2" stock. The weld between the tubular and the solid section is not dressed in order to obtain the maximum strength and eliminate the appearance of blow holes. It might be mentioned that the "solid" section is drilled to pass the coaxial cable conductor and its teflon dielectric.

The insulator is machined so that it is a <u>very tight</u> fit in the lower tubular section of the antenna. In assembling the two sections of the antenna, the insulator, secured to the upper section, is pressed (with the four water-sealing "O" rings in place) into the lower section until the shoulder is tightly seated on its top. To preclude any possibility of its loosening, in the event the insulator should shrink, it is secured in place by a set screw driven through the steel tube with its recessed head soldered over to protect against water leakage. The neoprene sleeve is then vulcanized in place not only to protect the insulator but also to add additional protection to the two set-screw heads.

For mounting the antenna, the head of the periscope is provided (by the periscope manufacturer) with a heavy split block into which the machined section is clamped. As installed, the lower section just clears the periscope with the upper end extending approximately 17" above its top. Figure 2 shows the antenna installed on the periscope.

For effecting a pressure-tight connection between the antenna and the interior of the periscope, very special coaxial cable and end fittings had to be designed and fabricated. This cable consisted essentially of a stainless steel tube for the outer conductor, into which was pulled the conductor and teflon dielectric of a piece of RG-87/U cable. Welded to each end of the tube are flanges which bolt onto the bottom of the antenna and the periscope face plate respectively. The details of the connectors between this steel sheathed coaxial line and the antenna and periscope respectively are shown clearly in Fig. 7. When in place, this steel coaxial line encircles half of the periscope. The section leaving the antenna can be seen in Fig. 2.

THE RECEIVING EQUIPMENT

General

In order to cover the very wide frequency range of 15 Kc to at least 265 Mc, at least three and possibly four radio receivers are required, all operating simultaneously on the one antenna previously described. It was necessary to develop means whereby such receivers could be connected to the antenna without interaction or the prohibitive absorption of power. Similarly, means had to be developed to improve the sensitivity of the lower frequency receivers to compensate for the extremely low efficiency of the antenna at such frequencies.

It is axiomatic that the input circuits of ordinary communication receivers are designed to match, in some measure, the antennas on which they might be expected to operate. The input circuit impedances will vary through extremely wide limits over the wide frequency range involved in this system. Therefore if any attempt is made to operate such receivers by merely connecting their input circuits in parallel to the antenna, the 50-ohm impedance of the very-high-frequency receiver, would absorb all the power from the lower frequency receivers by, in effect, short circuiting their inputs. Similarly the distributed capacitance of the lower frequency receivers might appear as a very low impedance at the very high frequencies and seriously affect the performance of the vhf receivers. In the same way the hf receivers would be affected by both the very low and very high frequency receivers.

To circumvent this difficulty means had to be developed, on a crash basis, to effectively isolate the respective receivers from each other as viewed from the antenna. This is accomplished by the use of two high-pass filters in combination with a special wide band amplifier as shown by the block diagram in Fig. 1.

Referring to this diagram it will be noted that the vhf receiver connects to the antenna through a 54-Mc high-pass filter, this frequency being the low frequency limit of the receiver to be used. This filter has an approximate 50-ohm input and output impedance in its pass band so that both the antenna and receiver are essentially matched. Below 54 Mc, its impedance increases markedly. Connected in parallel with the input of this filter, i.e., to the antenna, is the input of the wide-band amplifier whose output feeds the lower frequency receivers. This amplifier serves to isolate these receivers from the vhf receiver. At the same time, the amplifier input does not affect this receiver, its input impedance being about 200 ohms.

The high frequency receiver connects to the output of the wide band amplifier through a 550-Kc high-pass filter, whose input and output impedances substantially match the amplifier output and receiver input impedances through its pass band. Across this filter input, i.e., across the amplifier output, is connected the input of the lf and vlf receiver. Inasmuch as the impedance of the 550-Kc filter increases rapidly below this frequency, it does not absorb appreciable power at low and very low frequencies and hence does not affect the performance of this receiver. Thus two simple filters plus an amplifier (required for other reasons to be described below) provide all the required isolation throughout the extremely wide frequency range involved.

A word now about the wide-band amplifier. As has been mentioned in the discussion on the electrical characteristics of the antenna, this antenna, because of its very low effective height, is quite inefficient at medium frequencies and below. While it is true that this low effective height is equally deleterious to both signals and atmospherics, so that apparently the system should be equally as effective as if a larger antenna were employed provided the receivers possess sufficient sensitivity, such is not the case. In the design of most hf and lf and vlf receivers, little attention is given toward obtaining the maximum in SENSITIVITY as well as gain because in practically all cases the limit on these characteristics is determined by the level of atmospherics. When used with an appropriate normal antenna, seldom, if ever, is the noise figure of the receivers the determining factor. Accordingly, the noise figure of such receivers is usually high. However, when an attempt is made to operate such receivers on an 18-inch antenna where both the signals and atmospherics are reduced to the vanishing point, the noise figure of the receiver becomes the determining factor, and as was just pointed out, this noise figure is not good. Additionally, in most cases, there is not sufficient gain available.

The SKL-202D amplifier furnished with the Communications Intercept system has a gain of approximately 20 db; but, of much greater importance, it has a noise figure of approximately 10 db. The noise figure of the average medium and lf and vlf receiver is between 20 and 30 db so that the use of this amplifier ahead of the receivers is equivalent to an increase in SENSITIVITY of the receiving system by some 10 to 20 db, and permits the use of the additional gain. This makes the difference between the system functioning and not functioning at these frequencies when used on such a minute antenna. Parenthetically it would seem hardly necessary to mention that such an amplifier would be useless on an ordinary antenna, when again, atmospherics rather than receiver noise would "take over".

It might also be mentioned that this amplifier, while covering a sufficient frequency range, would not be advantageous and is not used at the very high frequencies, where the antenna is nearly optimum and the receiver itself has a very low noise figure.

Filters

Both the 54-Mc and the 550-Kc high-pass filters are circuitally identical, employing "M" derived end sections and one "T" intermediate section. An "M" of 0.6 was employed in the design in order to obtain a flat impedance characteristic throughout the pass band and a high impedance below cutoff. The circuits, with the electrical characteristics of their components, are shown by Fig. 8.

Physically, all the components are housed in individual small aluminum containers with BNC type fittings provided at opposite ends for input and output connections. Fig. 9 shows the interior and exterior view of the 550-Kc high-pass filter with the slug-tuned adjustment inductances being clearly visible. Figure 10 shows similar views of the 54-Mc filter. It might be of interest to note that no screw-driver adjustments are provided on this unit because of the small inductance values employed. In production, the inductances are wound to approximately the correct values and final adjustments are made by manually expanding or compressing the winding pitch while watching the response on an oscilloscope with the input fed from a sweep generator.

Figure 11 shows the attenuation and impedance characteristics of the two filters as shown by oscilloscopic views of their outputs with the inputs excited by a sweep generator. These are composite photographs and show, among other things, the output level of the sweep generator versus frequency to permit evaluation of the insertion losses of the filters.

Quantitatively it might be stated that the input and output impedance of these filters in their pass bands is approximately 50 ohms, their insertion loss does not exceed 0.2 db and their attenuation beyond cutoff is in excess of 30 db.

THE WIDE-BAND AMPLIFIER

The wide-band amplifier furnished as part of the system is a standard commercial product sold by the Spencer - Kennedy Laboratories of Boston, Massachusetts, and is often designated as a chain or distributed type amplifier. Its overall gain is approximately 20 db and it has a substantially "flat" frequency response between 1 Kc and 200 Mc. The appearance of the unit is shown by Fig. 12 while Fig. 13 is a schematic circuital diagram.

It has two "traveling-wave" stages of amplification, each stage consisting of 6 tubes. Type 6AK5 vacuum tubes are used throughout the amplifying circuits. Its nominal input and output impedance is approximately 200 ohms, although it can be operated with lower impedances without seriously affecting its performance. The following is a brief description of its principle of operation as given in its instruction book.

Each set of six tubes, constituting a single amplification stage, has its own grid and plate delay-lines, termination and associated power circuits. The control grids of each stage are connected to successive taps along the coil which forms the inductance of the grid delay-line. The socket and stray capacitance, as well as the control grid-to-ground capacitance, forms the total capacitance of each section of the delay-lines.

In a like manner the plates of the tubes are connected to successive taps along the coils forming the inductance of the plate delay-lines. In order to keep the surge impedance and the velocity of propagation of the waves along the plate line equal to that of the grid line, a small capacitance has been added at each plate coil tap.

Amplification is obtained by virtue of the fact that waves entering at the input travel down the grid delay-line, passing from grid to grid of successive tubes in the chain until they reach the end and are absorbed by the line terminating resistor. As each tube is energized by the traveling waves, plate current will flow, half forward, and half backward, down the plate delay-line. The forward component of the plate wave will be augmented at each successive plate by the current from that tube. As the delay between tubes is the same in the plate line as in the grid line, forward components of all the plate waves will arrive in phase at the output termination. Backward components are predominately out of phase and are absorbed in the plate resistor.

From the above description, it can be seen that the Model 202D Amplifier functions as if all the tubes in each stage had been connected in parallel at all frequencies up to the cutoff of the delay lines. Since the voltage gain is directly proportional to the transconductance, values of approximately 5,000 micro-mhos should be used for replacement. Tubes of this value will give a gain of approximately 10 db per stage; higher values of transconductance give a greater gain and lower values a smaller gain. Normal variations in tube performance will have the same effect as in conventional amplifier circuits. However, if a tube has a high gas content, or abnormally low input capacitance, some change in characteristics may be noted. This is particularly true if such a tube is used in the first or second tube socket of each stage. The effect may be an increase in standing wave ratio and a decrease in high frequency response.

RADAR INTERCEPT EQUIPMENT

DESIGN CONSIDERATIONS

In viewing the problem of Radar Intercept the following factors had to be considered:

(a) The system had to be "wide open", i.e., non-frequency selective over the complete radar S and X band (2.5 - 12 kmc) for basic intercept.
(b) Means had to be provided to permit reception on either "S" or "X" band only (as might be desired) for identification purposes and to provide some degree of selectivity.
(c) As much sensitivity as possible had to be provided.
(d) The antenna had to be sufficiently small to permit its being housed in and rotating with the periscope head without interfering with the optical system.
(e) The antenna had to be equally effective on either horizontally, vertically or elliptically polarized waves.
(f) A compromise had to be made on the beam width of the antenna pattern to give as much azimuthal coverage as possible without eliminating its effectiveness for directional indication.

After weighing all the above factors it appeared that the most satisfactory immediate solution rested in the use of a small spiral antenna mounted in the head of the periscope, feeding a combined S- and X-band filter with crystal detectors for each band, means for selecting either or both bands and the use of a high-gain video amplifier.

The elements of this system are shown, in block form, in Fig. 1 and each of the components of the system will be described in detail in the following.

THE ANTENNA

In considering the design of a suitable antenna for the Radar Intercept system it was apparent that such an antenna must possess six paramount characteristics:

(a) It must be capable of being pressure proofed.
(b) It must be as efficient as possible.
(c) Its response should be relatively "flat" over a 5:1 frequency range.

(d) Its pattern must be sufficiently sharp for direction finder purposes.
(e) It must be equally effective against signals of all polarizations.
(f) It must be relatively small.

The only type of antenna that appeared to even approach meeting all these requirements was a spiral, which, it was believed, could be developed to be satisfactory for the purpose. The antenna, as finally developed is shown in Fig. 14.

The over-all diameter of this antenna, in its housing is but 2.5" and its over-all depth but 1"; the latter dimension includes the reflector and the BNC outlet fitting.

The antenna proper consists of a flat strip double spiral, with an inner diameter of approximately .050" and an outer diameter of approximately 1.75". Each strip is .020" wide and the spacing between turns is .020". Printed circuit techniques were employed in the fabrication of the spiral, the turns being copper plated on a 1/16" teflon backing to a thickness of approximately .002". Each of the two spirals consists of 10 turns.

The disc on which the antenna proper is plated is secured into its housing by four machine screws, two of which serve as ground connections for the outer turns of the windings.

The housings are machined from solid brass stock into the rear of which, at a 90° angle, is secured a BNC fitting for output termination. This construction can also be seen in Fig. 14.

The reflector or cavity behind the antenna proper is machined into the housings and consists of a conical section with a diameter equal to the diameter of the winding, a maximum depth of 0.406" and a minimum depth at the edges of .125". The entire housing is silver plated.

Electrical connections are made by fine beryllium copper wires soldered to the two inside turns of the spirals. One connects to a small tube secured to the center of the conical reflector, through which the other passes to the center of the BNC fitting, the tube and wire forming a transmission line section to maintain proper impedance match.

Some mechanical difficulty was experienced in maintaining the integrity of the fine wire connections to the center of the spirals under conditions of marked temperature variations resulting from strain being put on these soldered connections as a result of deflection of the teflon disc. In an antenna of this type it is essential, in order to obtain the proper efficiency and broad banding, that the backing on which the spirals are plated be of very low-loss material with a reasonably low dielectric constant. Since time did not permit research into the determination of the best material from both an electrical and mechanical standpoint, teflon was chosen as possessing the best readily-obtainable electrical characteristics. Unfortunately its temperature coefficient of expansion is markedly different from that of copper so that, under wide temperature variations the disc attempts to bow outward, putting excessive strains on the soldered connections. This was corrected by machining the backs of the discs until the thickness of the section covered by the spirals was but .015". This did not relieve the tendency toward bowing but reduced the strain imposed on the wires by this tendency to a point that the finished antenna withstood temperature cycling between -42^{o} C. and 125^{o} C. without failure.

ELECTRICAL CHARACTERISTICS

Figure 15 shows the gain of the antenna in absolute terms, i.e., as compared to an isotropic antenna. It will be noted that the gain averages slightly better than zero db over the operating range. Figure 16 shows the VSWR with the antenna mounted behind a heavy glass pressure-proof window in the periscope, the glass being 0.59" in thickness. Figure 17 shows a comparison of the X band gain of the antenna versus an efficient X band horn. It will be noted that the gain of the wide band spiral antenna averages only approximately 10 db below that of the narrow-band horn. This figure also indicates the "X" band losses in the periscope transmission line between the antenna and the crystal. These average some nine db, but are appreciably less at "S" band. Figure 18 shows the half power beam widths of the antenna, for both horizontally and vertically polarized waves, at five frequencies in its working range. It will be noted that the beam widths vary between 40^{o} and 70^{o}, being less at the higher frequencies and that there is substantially no difference between the widths for the two polarizations.

FILTER - CRYSTAL UNIT

This unit is fundamentally a part of the Radar Intercept system and contains the following component items:

(a) A diplex filter unit.
(b) Two crystals in mounts.
(c) A frequency band selector unit with switch.
(d) A crystal protective switch.

In addition, the panel has mounted on it the following coaxial receptacles:

(a) Ouput of Communications Intercept antenna.
(b) Output of frequency band selector switch.
(c) Input test receptacle for crystal check.

All components of the unit, with the exception of the Frequency Band Selector switch are mounted on the panel. Because of the shape and limited size of the available housing, it is necessary to mount the Frequency Band Selector switch to the housing as a separate unit.

Figure 19 is a schematic diagram of the unit's circuitry which is of such simplicity as to require no elaboration. The mechanical features and particularly the housing will, however, require some detailed description.

In broad terms the unit mounts in, and rides with, the periscope so that it is accessible to the periscope operator when in use. The general method of mounting is shown by Figures 20 and 21. In a normal Type 8 periscope there is secured to the bottom of the Bottom Eyepiece Box Flange a type ST Radar Adapter. This is substantially a steel tube seven inches in diameter and four feet long and contains certain of the radar appurtenances. For the subject installations the ST Radar is removed as well as this adapter. In its place is secured to the periscope an externally similar member designated as the support column. These were fabricated by the Laboratory and serve the dual purpose of providing the housing for the Filter-Crystal Unit and also of providing a bottom support for the periscope when it is housed in its well. Oblong openings were provided on opposite sides of these columns to which were welded flat facings. The Filter-Crystal Unit (Fig. 22) secures to the rear facing by its panel and the front facing carries the Frequency Band Selector Switch and gasketed splash shields. While it may appear unusual to secure the panel of a unit to the rear of its housing, this was done in order to make the Frequency Band Selector switch (which is the only adjustable control on the unit) more readily available to the operator. Parenthetically, in order to avoid confusion as to which is the rear and front of a round object such as the support column, the front is considered as the surface immediately below the eyepiece of the periscope.

Figure 23 is a close-up view of the front of the support column with the splash shields removed to show how access is provided for changing the crystals. Figure 3 is a close-up view of the Filter-Crystal Unit panel, showing the Crystal Protective Switch and the outlet receptacles.

The Diplex Filter unit is a commercial product manufactured by the Microphase Corporation and designated as their type GR 1500 D. It is substantially a low- and high-pass filter in combination, pass characteristic curves of the low-pass section for S-band coverage crossing that of the high-pass section for X-band coverage at approximately 4.7 Mc. These filters have a negligible insertion loss in their pass bands and introduce an attenuation of approximately 50 db in their rejection range. They serve a dual purpose: primarily they permit the determination of the band (S or X) in which an interception is obtained, and secondarily they provide a degree of selectivity when working in an area of high radar density.

Carried on the output ends of this combined filter unit are two crystal mounts which are products of the American Electronic Laboratories, the S band mount designated as their type C-1200 and the X band mount as type C-1400. While selected type 1N23C crystals may be used in the S band mount, a type MA-408B (a product of Microwave Associates) is used in both bands. The latter crystal, while somewhat more expensive than the 1N23C has been found to be slightly more sensitive than the former at X band and much more uniform when used as a video detector for which it was developed.

The outputs of the two crystals connect to the Frequency Band Selector switch (which is a wafer switch, in a suitable housing, with coaxial input and output terminals). This switch is so wired that its output may be connected to either the S or the X band crystal or both in parallel.

In order to protect the crystals from burn-outs when in the vicinity of powerful radars (such as from the vessel's own equipment), a two-position coaxial switch, designated as the Crystal Protective Switch, is provided. This is a product of the General Communications Co., listed as type 2N60MC. When in the "OFF" position the filter input (and hence the crystals) is disconnected from the antenna and connected to the TEST receptacle to permit the introduction of a test signal from a generator furnished with the equipment.

Figures 20 and 21 show a rear and front view of the unit as installed in the periscope. In Fig. 21 the upper "splash" shield has been removed to show parts of the interior. For complete access the lower plate can also be removed after first removing the switch knob.

Figure 20 shows the two outlet receptacles with the output cables in place, the right one being the Communication Intercept output and the other the Radar Intercept outlet. The former receptacle is of the BNC type while the letter is a standard telephone jack provided with a snap-type water-tight cover. These cables must be removed when the periscope is housed and replaced when it is raised. The two different types of outlets were used to preclude mistakes when making these changes hurriedly. It will be noted that considerable cable slack is provided between the Filter-Crystal Unit outlets and the overhead junction boxes. This is to permit these cables to wind around the periscope when it is rotated in use.

THE VIDEO AMPLIFIER

The type R-467(XB-3) wide band video amplifier (sometimes designated as a receiver) was originally designed for aircraft use but was the most suitable amplifier available for rapid reproduction and was consequently employed for the subject system.

It is contained in an aluminum cabinet 7 5/8" high x 5 1/8" wide x 9 1/4" deep which mounts on an AN type MT - S - 1 shockproof mounting. The cabinet is finished in Navy gray. The amplifier operates on 115 volts, 60 cycles, single-phase ac for all power requirements.

Figures 24, 25 and 26 show the front, top and bottom views of the chassis respectively.

The circuit diagram of the receiver is shown in Fig. 27. The input stage of the receiver is designed to accommodate video signals of negative polarity. The first two tubes, V101 and V102, of the receiver are dual triodes connected as inverse feedback pairs. The step attenuator (S101) is located between these two tubes. It has a total resistance of 10,000 ohms and provides attenuation, in 10 db steps, from 0 to 60 db. The third tube, V103, is connected as a conventional R-C amplifier and it drives the first triode section of V104. This section of V104 is connected as a cathode follower and supplies the low-impedance video output at J103. It is also a low-impedance driving source for the pulse stretching circuit consisting of CR102, R126, R127, and C111. The pulse stretcher increases the length of the pulses applied to the audio amplifier. The pulse stretcher has a charge time of about 1.0 microsecond and a discharge time of about 150 microseconds. The second triode section of V104 is the audio amplifier stage feeding the headphones or recorder through transformer T102. The audio gain controls are individual 10K potentiometers for the headphones and a 100K potentiometer tapped off the plate of the output tube (through a blocking capacitor) for the recorder.

A positive dc bias of about 25 microamperes is applied to the crystal detectors via J104. This bias is obtained from the plate supply and the amount of current is determined by the 5.6 megohm resistor R103. This positive bias generally increases the rf sensitivity by several decibels, depending upon the crystal, and makes it possible to use a long video cable between the crystal holder and the receiver input without appreciable loss. The effect of the bias is to provide a better match between the crystal video impedance and the 93 ohm coaxial cable so that a cable length of 50 feet gives a loss of only 1.0 db (for a 1.0 microsecond pulse) in system sensitivity.

The power supply for the receiver consists of a full-wave rectifier, V105, and an inductor-capacitor filter followed by an R-C filter section. A pi-section line filter is used to minimize interference which may enter the receiver via the power line. No power from a dc source is required to operate the receiver.

Electrical Characteristics. The pertinent electrical characteristics of the amplifier are listed below.

Item	Description
Video gain	80 db $\pm$ 3 db (approx.)
Video bandwidth (3 db)	10 Kc to 1.2 Mc
Pulse rise time (10% to 90%)	0.6 microsecond
Pulse sag	40% in 10 microseconds
Video output impedance	135 ohms
Video output linear to	2 volts, peak to peak
Audio noise power (max. gain)	2.0 milliwatts
Audio output saturates	200 milliwatts
Audio bandwidth ($\pm$ 0.5 db)	100 to 10,000 cps

CONCLUSIONS

Reports from the Forces Afloat indicate that the equipments described herein have performed admirably and that the installations represent a real advance in submarine ECM facilities. Subsequent to the completion of the original six equipments, time has permitted improvements to be developed in certain features of the design. Accordingly, should specifications be prepared for additional similar equipments, it is suggested that the Laboratory be contacted in order that advantage be taken of these improvements.

APPENDIX

As has been mentioned in the basic report, the equipment described therein had to be designed and fabricated on a "crash" basis in order to meet the sailing dates of the six vessels equipped. This did not permit much research to be conducted or much consideration of refinements. However, after the equipments had been delivered it was possible to do some research on certain features and to consider certain improvements that might be valuable for future use. The more important of these are detailed below.

THE SLEEVE-STUB ANTENNA

Reports from a number of vessels carrying the subject equipment have indicated that the sleeve-stub antennas have performed satisfactorily after considerable service. No complaints have been received on their electrical performance and but one mechanical failure has been reported and that apparently resulted from the striking of a floating object, presumed to be a log. However, because the "crash" nature of the development necessitated compromises, the Laboratory has never been entirely satisfied with the electrical characteristics of these antennas and similarly has believed that greater mechanical strength should be built into them. Accordingly, in an effort to improve both their electrical and mechanical characteristics considerable research has been conducted as a result of which an improved model has been developed which, while entirely interchangeable with the original models, is believed to be superior in every way. The major points of improvement might be summarized as follows:

(a) The mechanical cantilever strength has been increased from 150 to approximately 1,000 foot-pounds.

(b) The electrical connections may be made after the antennas have been assembled and installed rather than having to be made during mechanical assembly.

(c) The VSWR ratio over a wide frequency band has been reduced from a maximum of over 10 to less than 3.

These improvements have been effected by the following design changes:

(a) Instead of the top section of the antenna seating on the flat top of the insulator, the solid section that is welded to it is counterbored for a distance of 2 inches, the insulator fitting snugly into this counterbore.

The insulator is constructed of pre-stressed longitudinally laid glass fibers impregnated with polyesterstyrene resin. The major part of the strength improvement results from the superior strength of this insulating material.

The 3/8" stud that was threaded into both the insulator and the top section, has been replaced by a hexagonal headed stainless steel bolt, the head of which fits into a recess in the bottom of the insulator. Thus the mechanical strain is taken on the head of this bolt instead of on threads as in the original antennas.

(b) In the original antennas, electrical connection was made by soldering the conductor of the coaxial cable into a hole in the bottom of the stud. This necessitated an electrical connection being made during mechanical assembly and in the event of a failure in this connection the complete disassembly of the antenna. In the improved design, the head of the bolt is drilled to receive a banana plug connected to the coaxial cable which may be put into place or removed without disturbing the antenna itself. Figure 28 is a disassembled view of the improved antenna showing its various parts. Externally its appearance and dimensions are identical with the original antenna and they are entirely interchangeable as an assembly.

(c) A sleeve monopole antenna normally tends to exhibit a capacitive reactance throughout its frequency range. In the original design, a line transformer matching section of a properly chosen electrical length and characteristic impedance was utilized to close the curve of the R-X plot of the antenna characteristics and to shift the curve to center it on the X axis of the plot. In the improved design, the counterbored section of the upper part of the antenna adds an inductive reactance to the impedance as a series network, making the impedance more susceptible to compensation. By substituting a larger diameter inner conductor in part of the line transformer matching section, the characteristic impedance of the matching section was modified to compensate for the added network. The resultant impedance curve is considerably improved with the maximum VSWR over a wide frequency range being less than 3:1. The R-X plot of the improved antenna is shown in Fig. 29.

THE FILTER-CRYSTAL UNIT

In the original units the Frequency Band Selector Switch (S, X or ALL) consisted of a wafer switch in which the movable contact discs had been hand "tailored" to effect the necessary switching operations. Recently it has been found possible to use a standard five-pole wafer switch to accomplish the same results. The connections for such a switch are shown in Fig. 30. It is also believed that the size of the container for mounting the switch can be reduced.

The output terminals on the panel of the unit consisted of a small BNC receptacle for the Communications Intercept equipment and a standard telephone jack (mounted in a shielding box) for the Radar Intercept equipment. This was done to facilitate the replacement of the plugs in semi-darkness without getting the cables mixed. Recent investigation has indicated that it would be advantageous for purpose of additional strength to replace the 'phone jack with a type UG-701/U connector. This is similar to a BNC in design but slightly larger, further helping to preclude the possibility of cable interchange.

GENERAL

Recent reports from vessels that have been using the subject equipments, received so recently that remedial comments cannot be made in this report, indicate the desirability of considering the following modifications to the equipment or its installation.

(a) Strengthening of the structure, and/or mounting of the Frequency Band Selector switch which is reported to be coming loose in service.

(b) Modification of the method by which the Communications and Radar leads plug into the Filter-Crystal Unit to make this operation more rapid but still fool-proof, if possible by a single operation.

(c) Development of some rapid and if possible automatic method of applying splash-proofing protection to the receptacles when the above cables are removed, to replace the present method of individually capping them.

(d) Development of a more satisfactory method of draping the leads between the Filter-Crystal Unit and the overhead jack boxes. It has been suggested that allowing more slack in these cables to permit them to dip into the periscope housing well, with the jack boxes possibly mounted on a bulkhead would be a more satisfactory arrangement, the fact that the cables might lie around the deck being acceptable.

(e) Improvements in the direction finding capabilities of the Radar Intercept equipment, it being reported that with strong signals no directional indication is obtainable. It is believed that this difficulty is the result of saturation of the second (vacuum tube) amplifier by strong signals even on the back lobes. The step attenuator is between the second and third amplifying stages and offers no protection to the tubes ahead of it. If this surmise proves true it should be readily correctable.

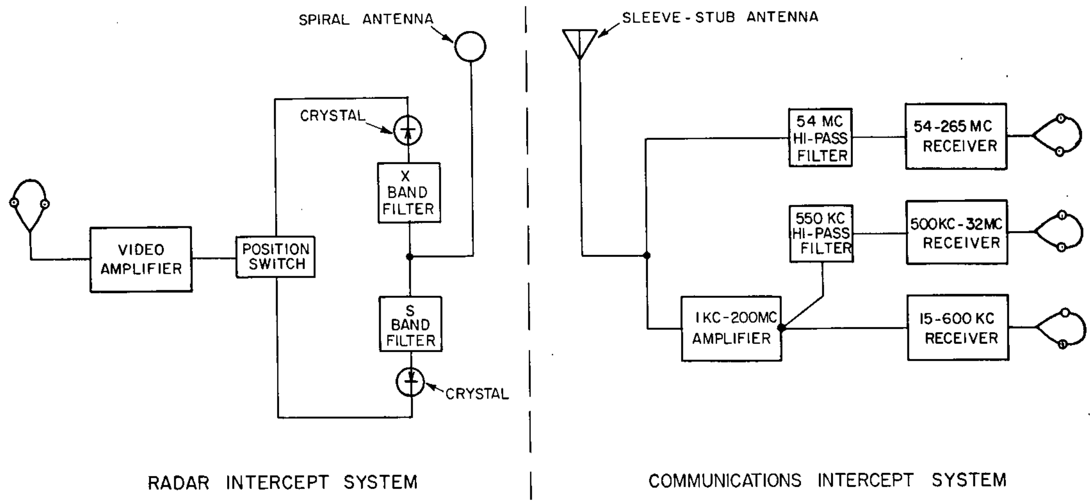


Fig. 1 - The complete intercept system — Block Diagram

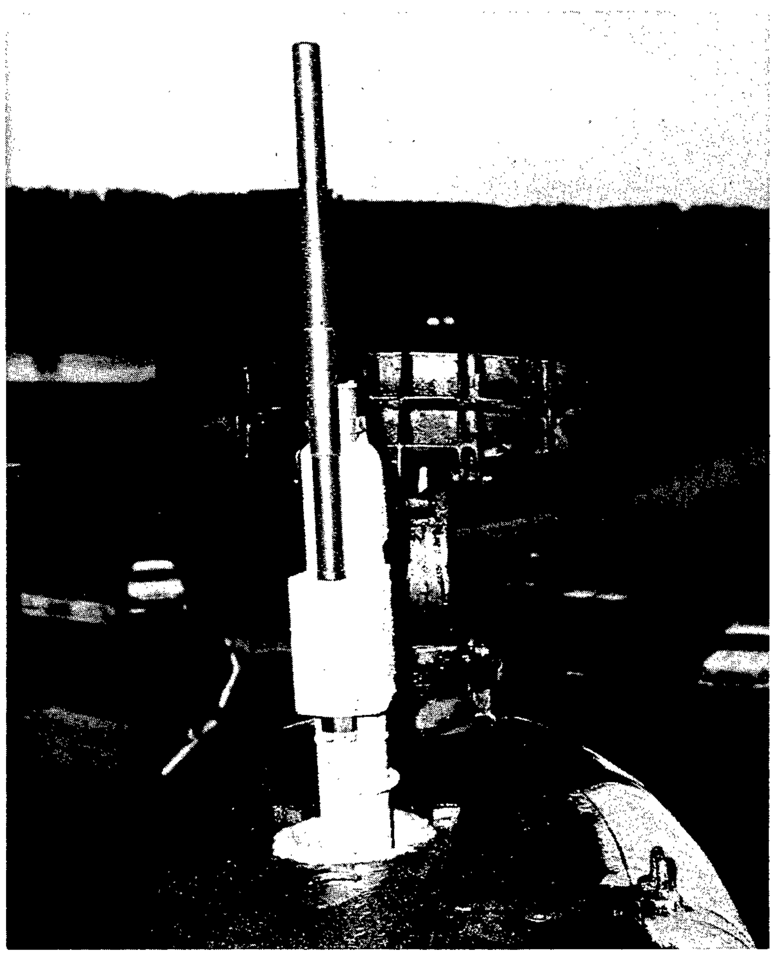


Fig. 2 - Sleeve-stub antenna mounted on periscope

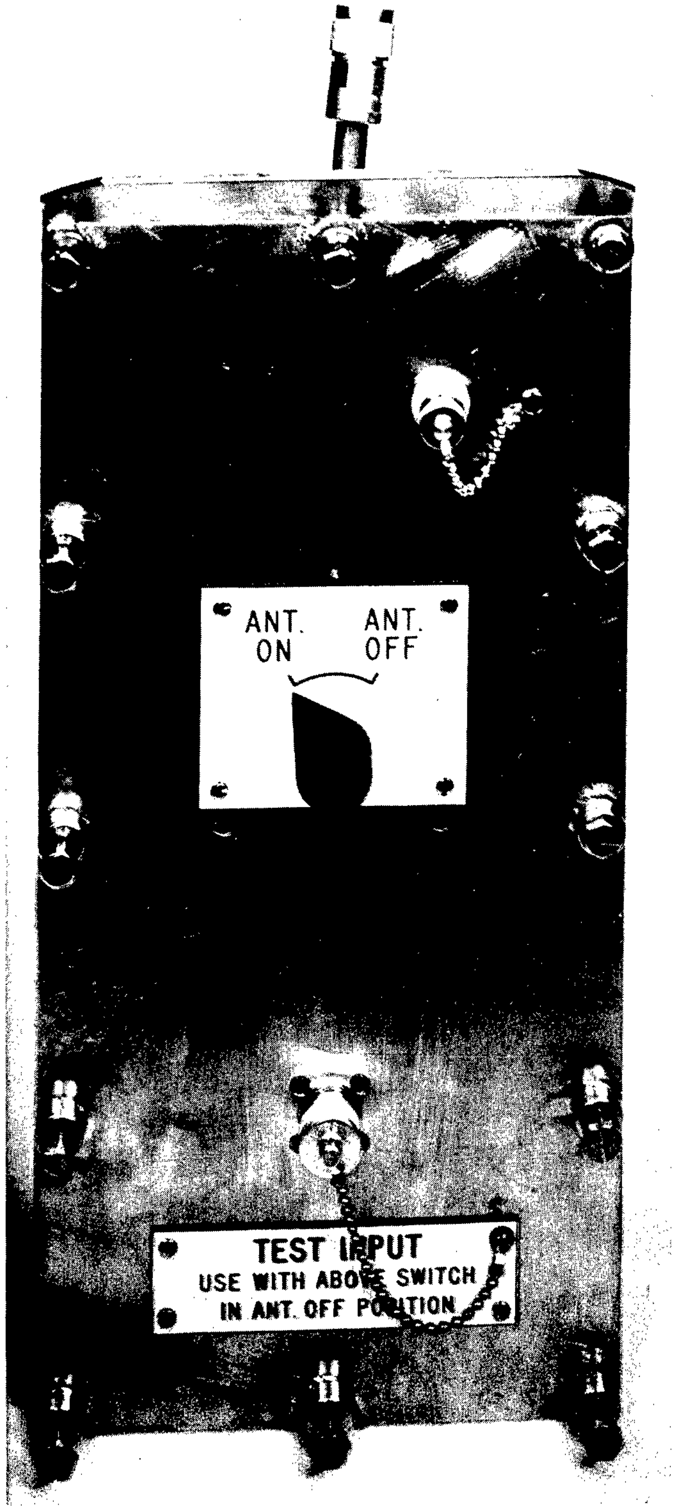


Fig. 3 - Filter-crystal unit panel

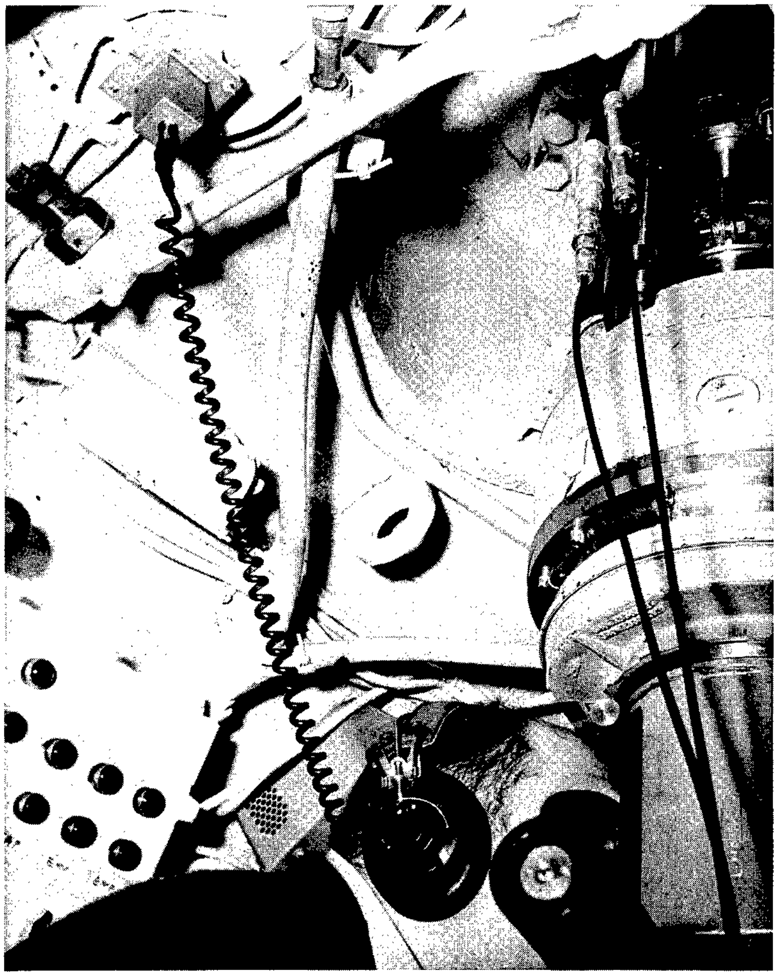


Fig. 4 - Submarine control compartment overhead showing cable runs

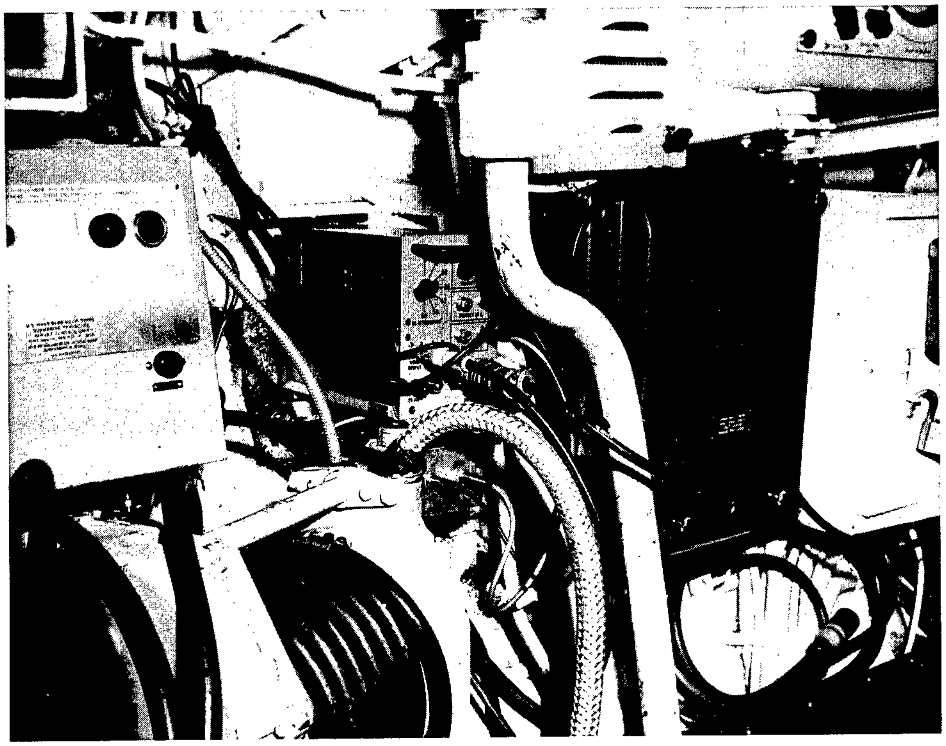


Fig. 5 - Submarine control compartment -- Location of video amplifier

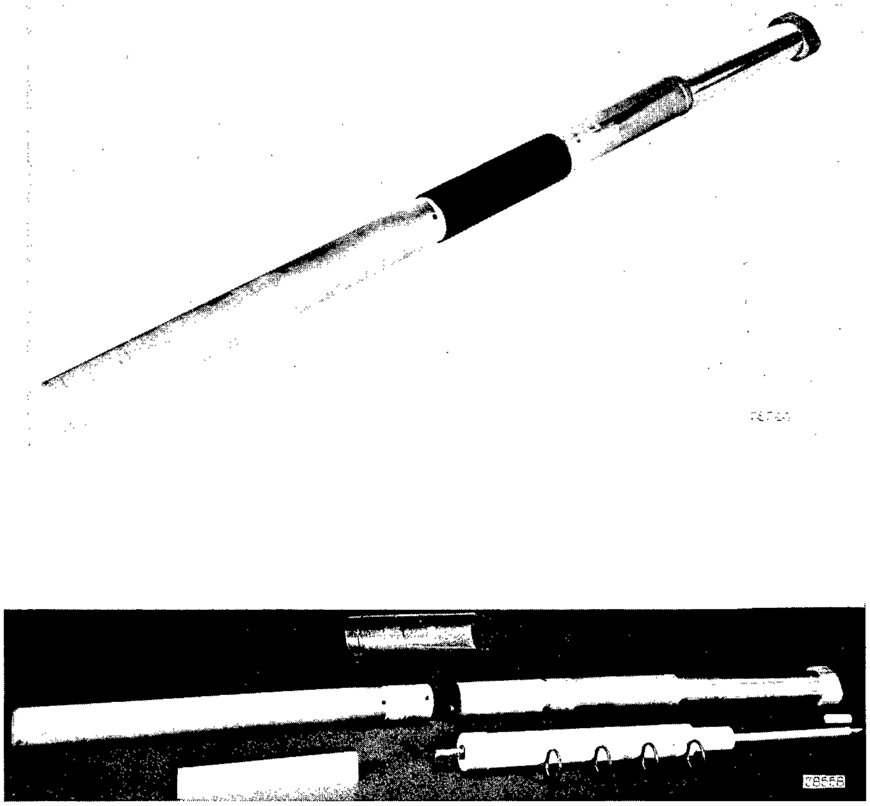


Fig. 6 - Sleeve-stub antenna -- Assembled and disassembled views

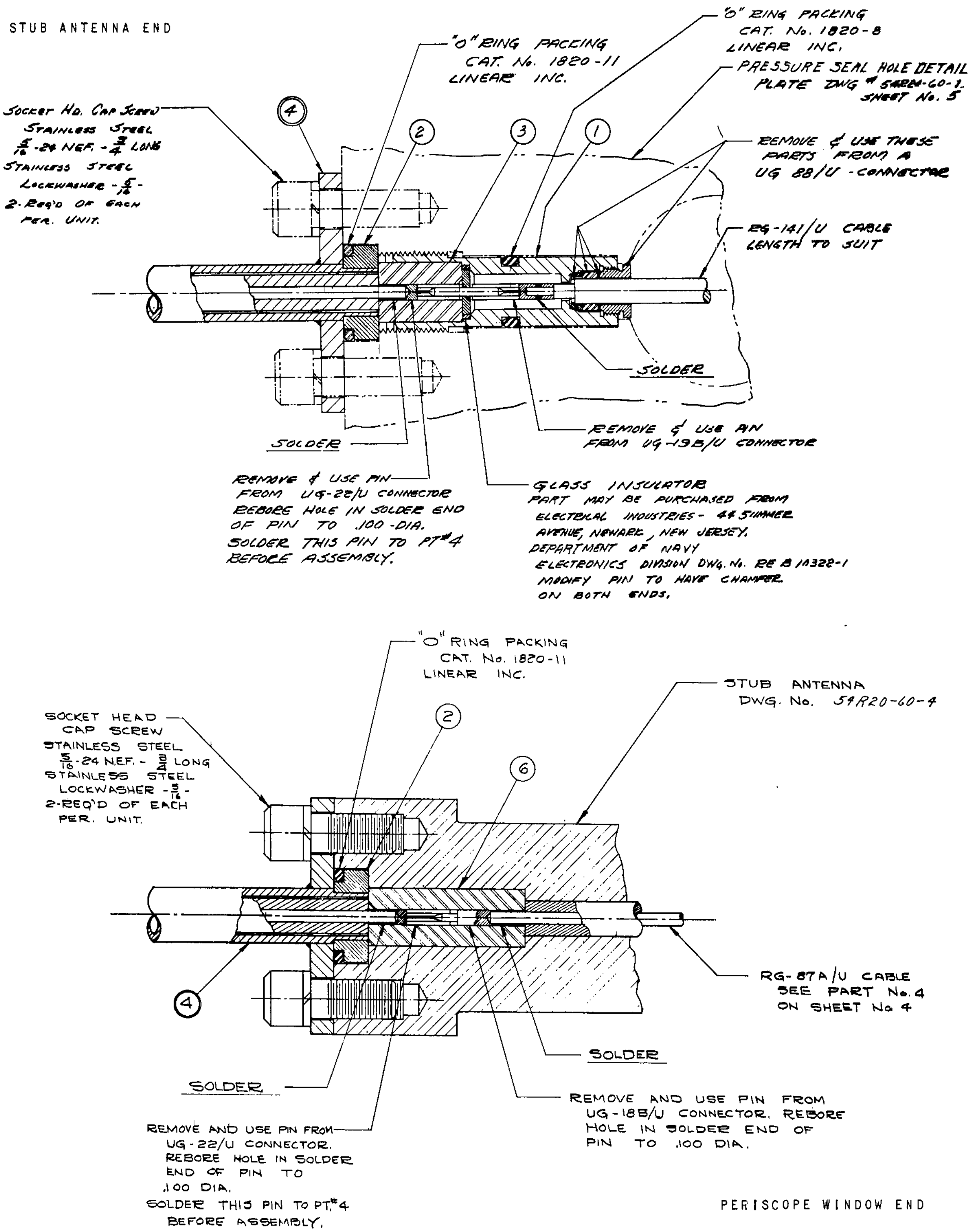


Fig. 7 - Antenna feed-line end fittings — Details

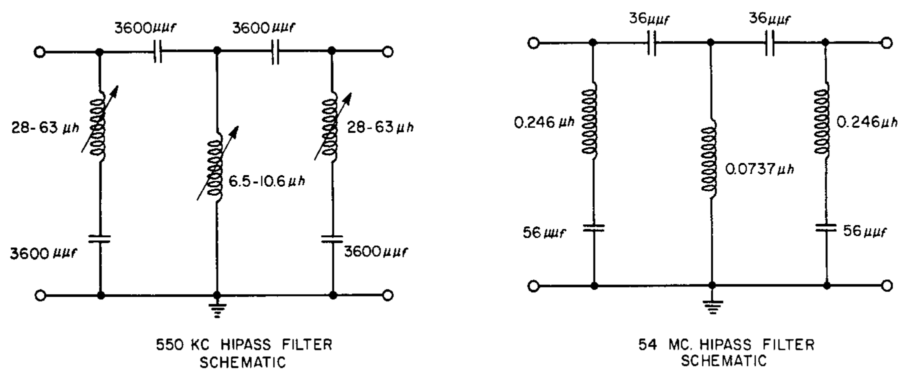


Fig. 8 - High-pass filters — Schematics

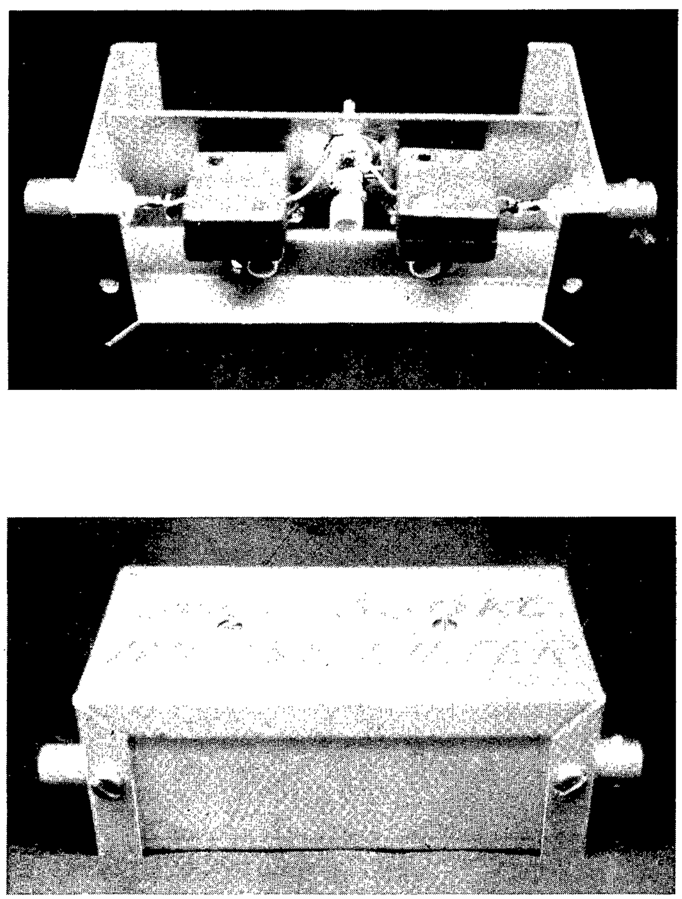


Fig. 9 - 550 Kc high-pass filter
interior and exterior views

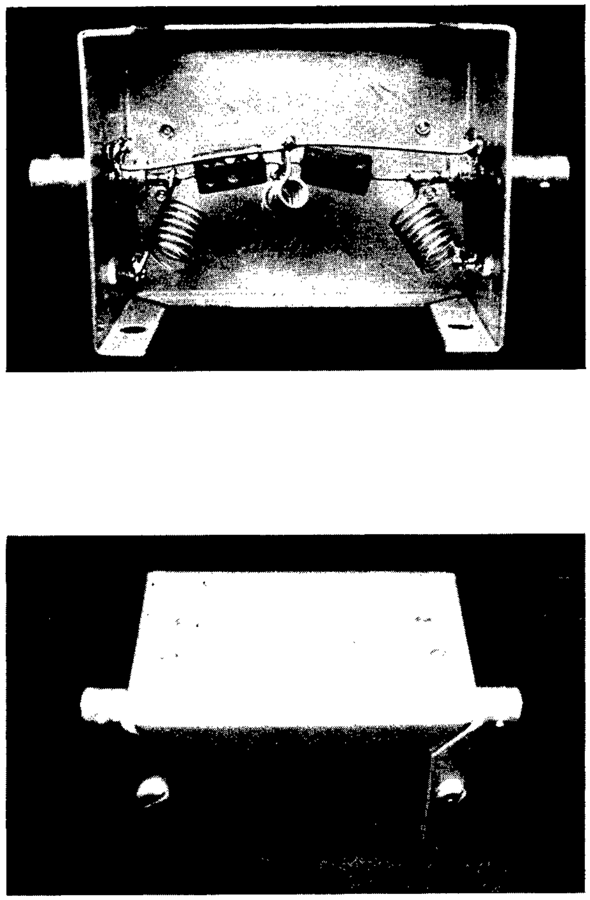
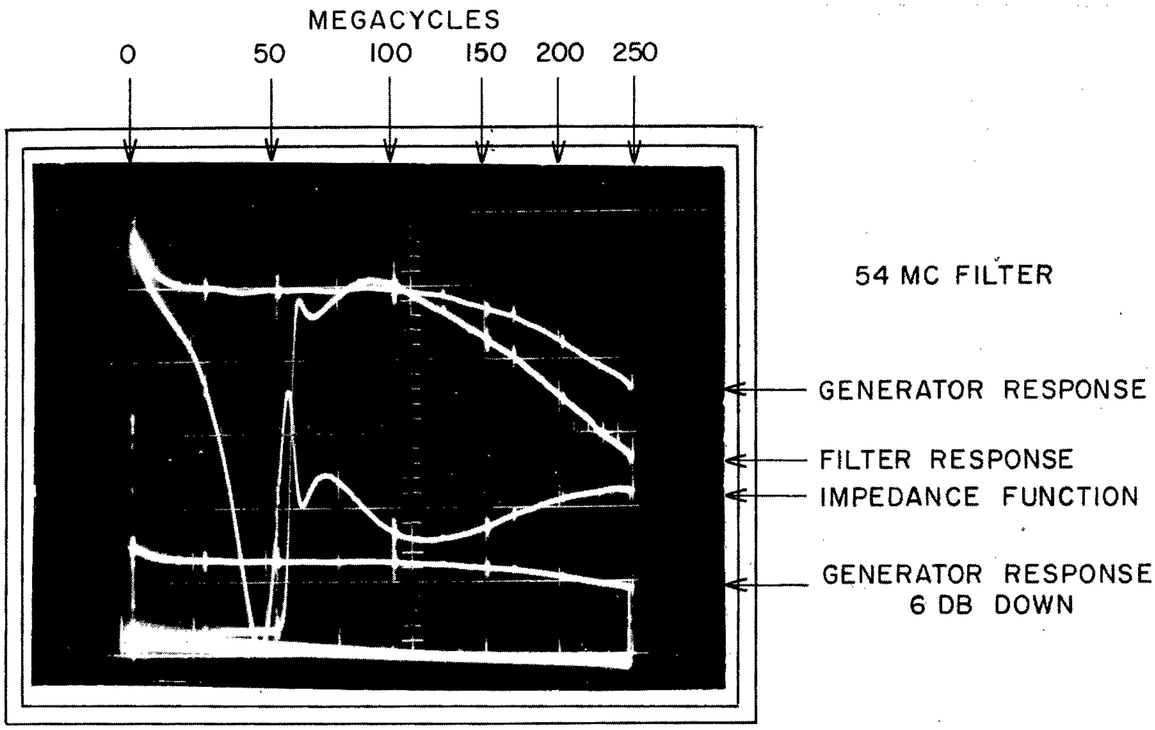


Fig. 10 - 54 Mc high-pass filter
interior and exterior views



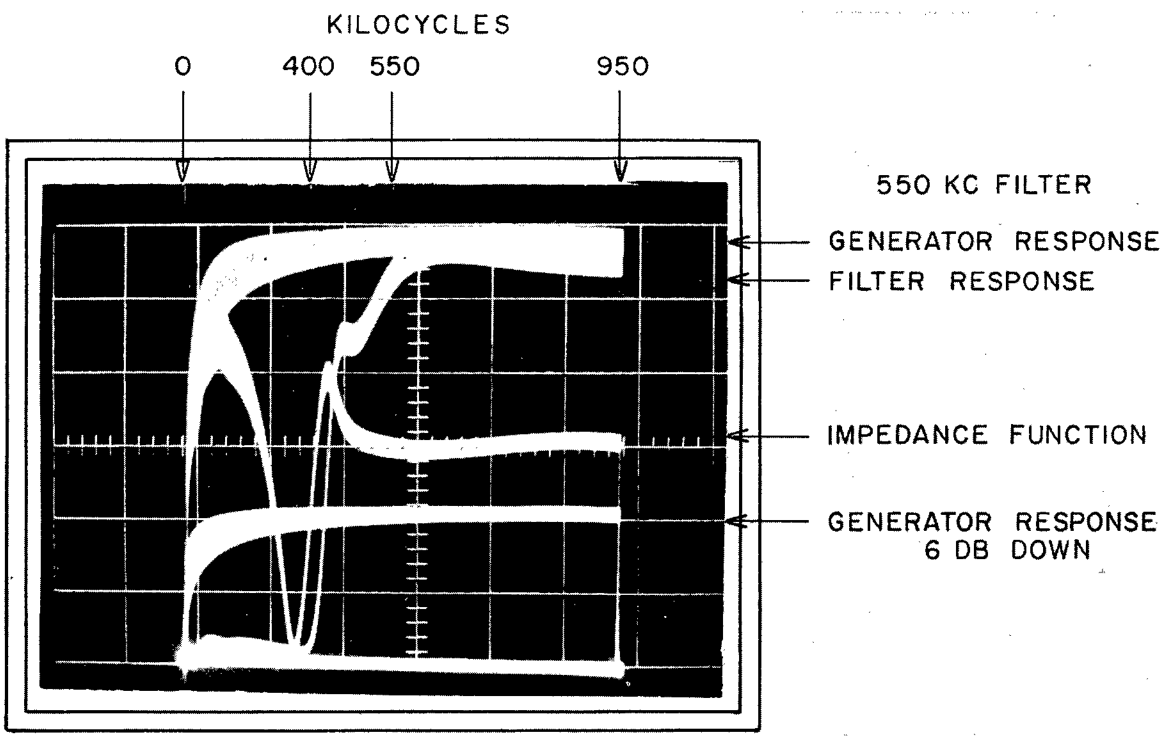


Fig. 11 - High-pass filters -- Characteristics

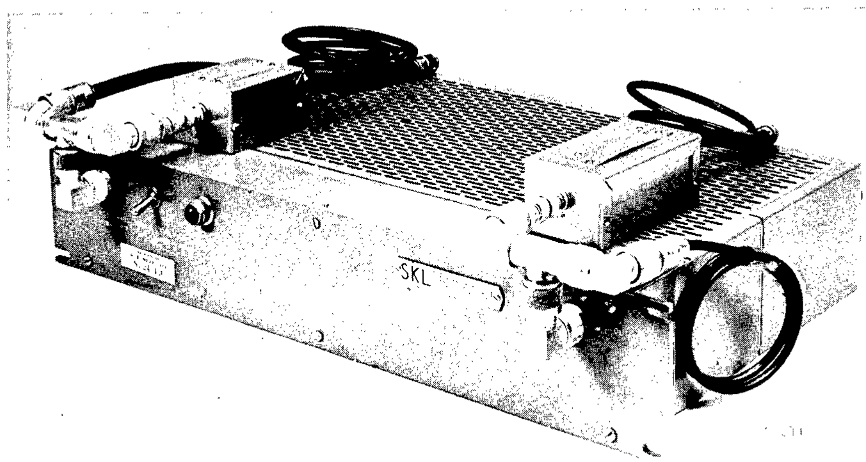


Fig. 12 - Wide-band amplifier -- Front view with filters mounted

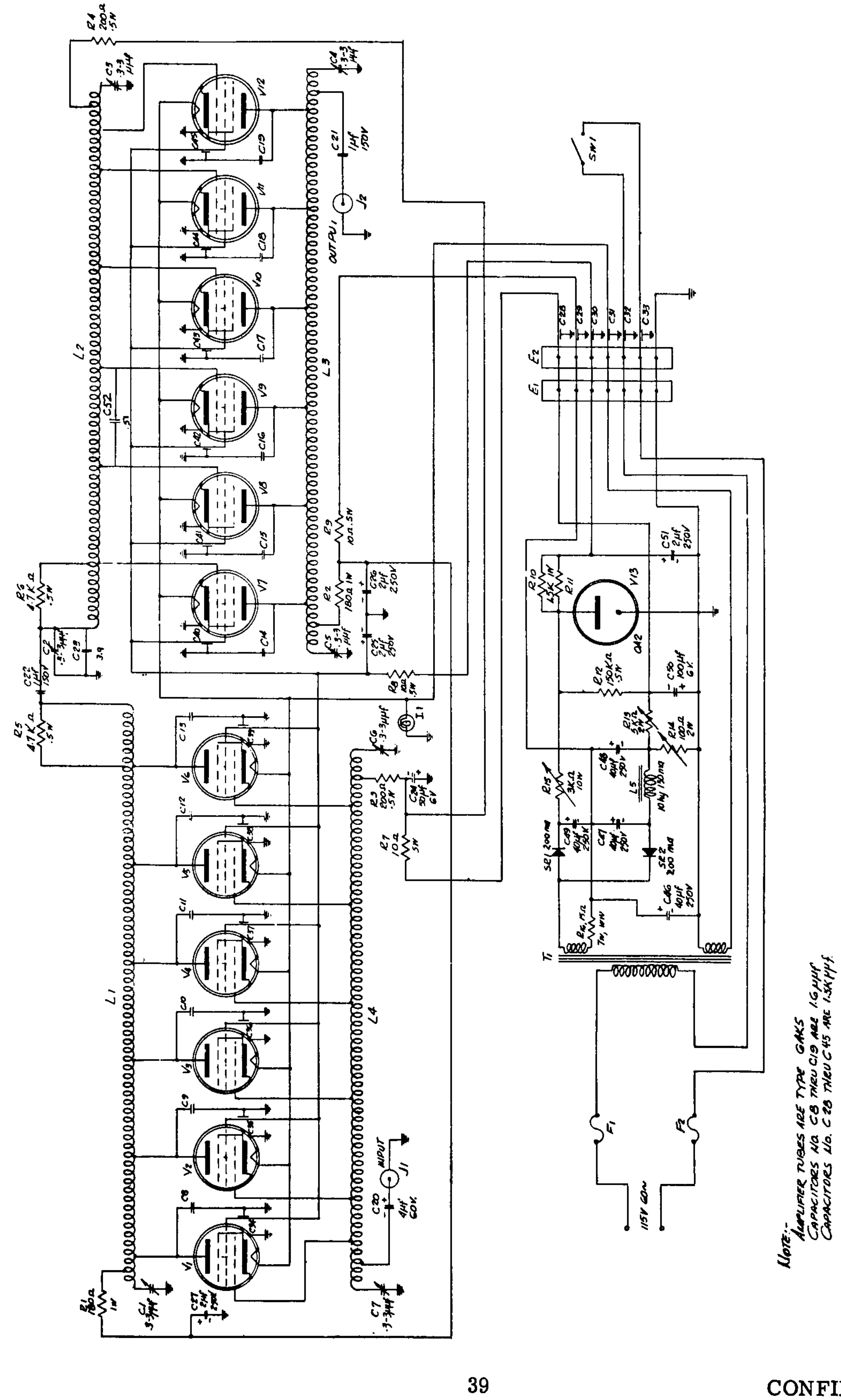


Fig. 13 - Wide-band amplifier -- Schematic

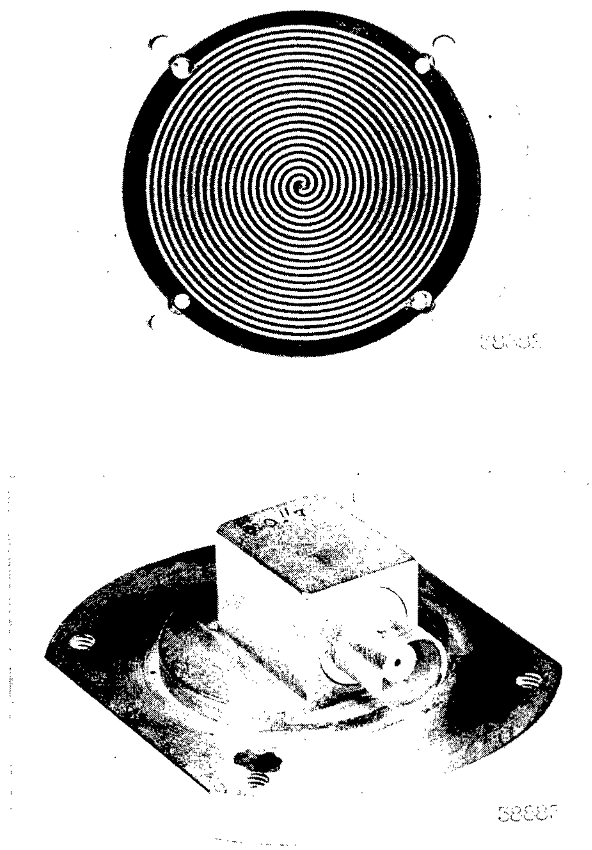


Fig. 14 - Spiral antenna — Front and side view

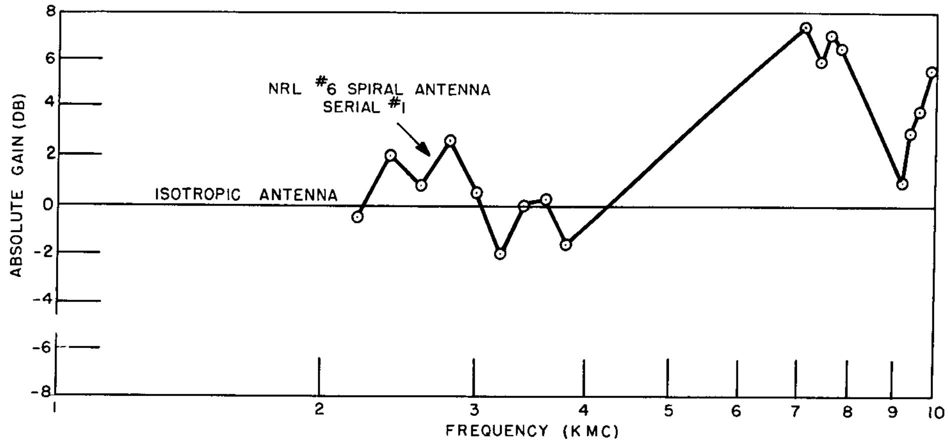


Fig. 15 - Spiral antenna — Gain curve

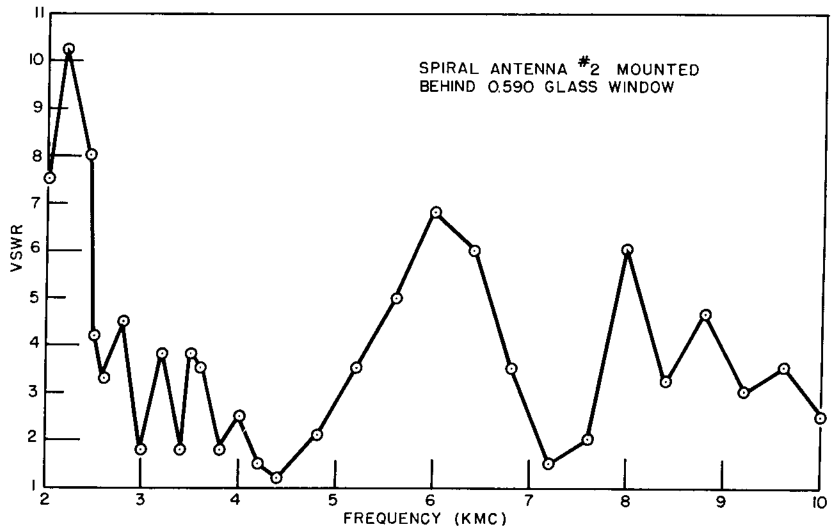


Fig. 16 - Spiral antenna - VSWR curve

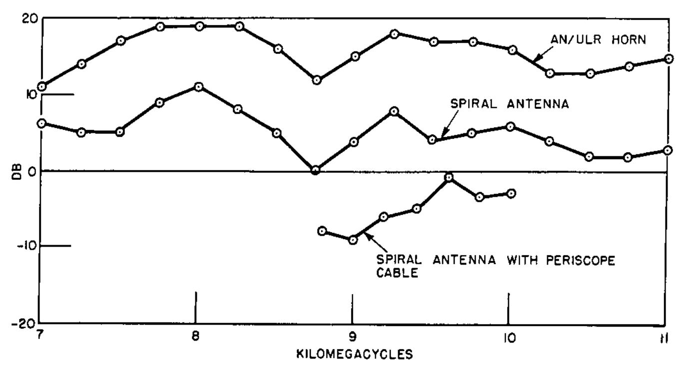


Fig. 17 - Spiral antenna vs horn — Gain curves

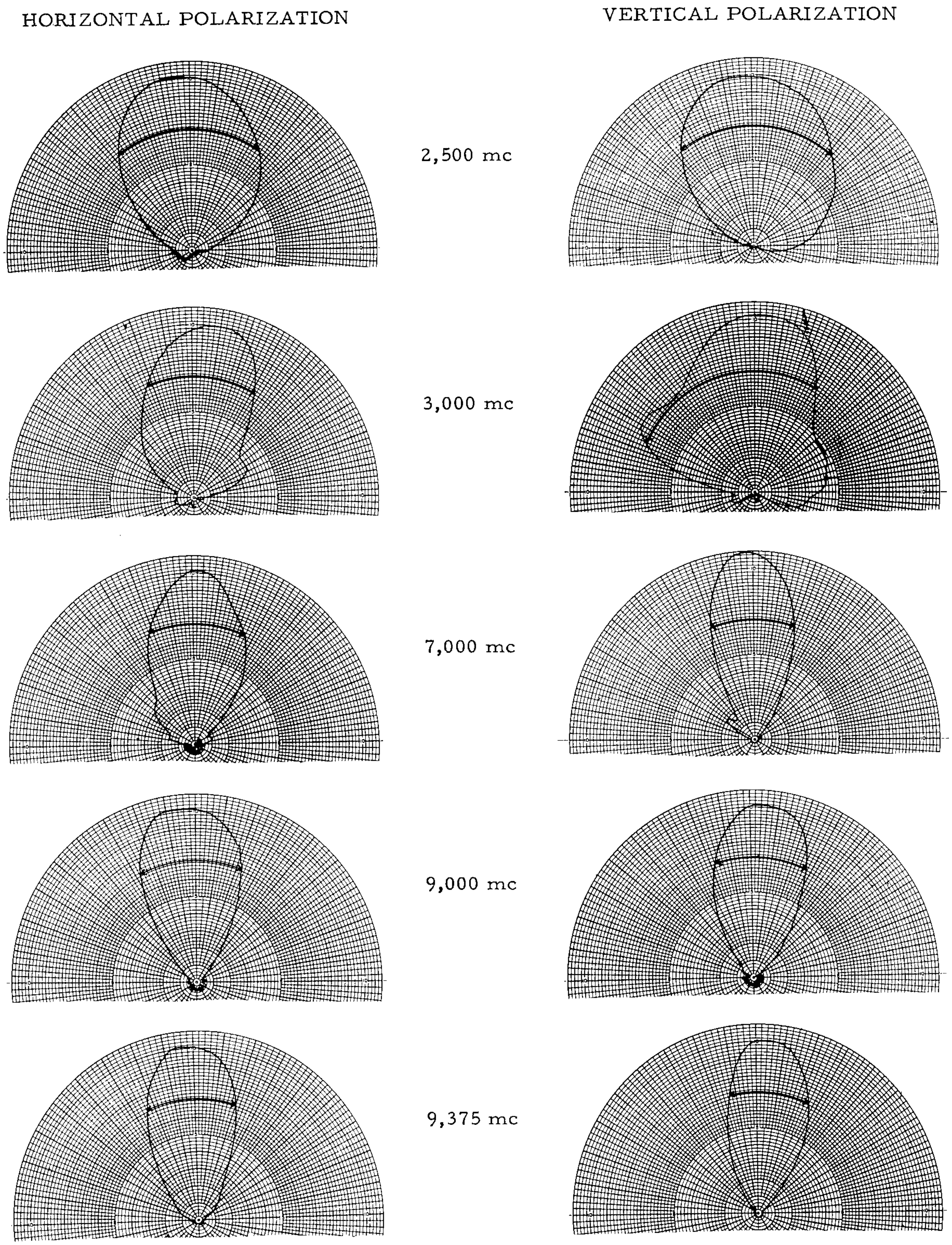


Fig. 18 - Spiral antenna patterns

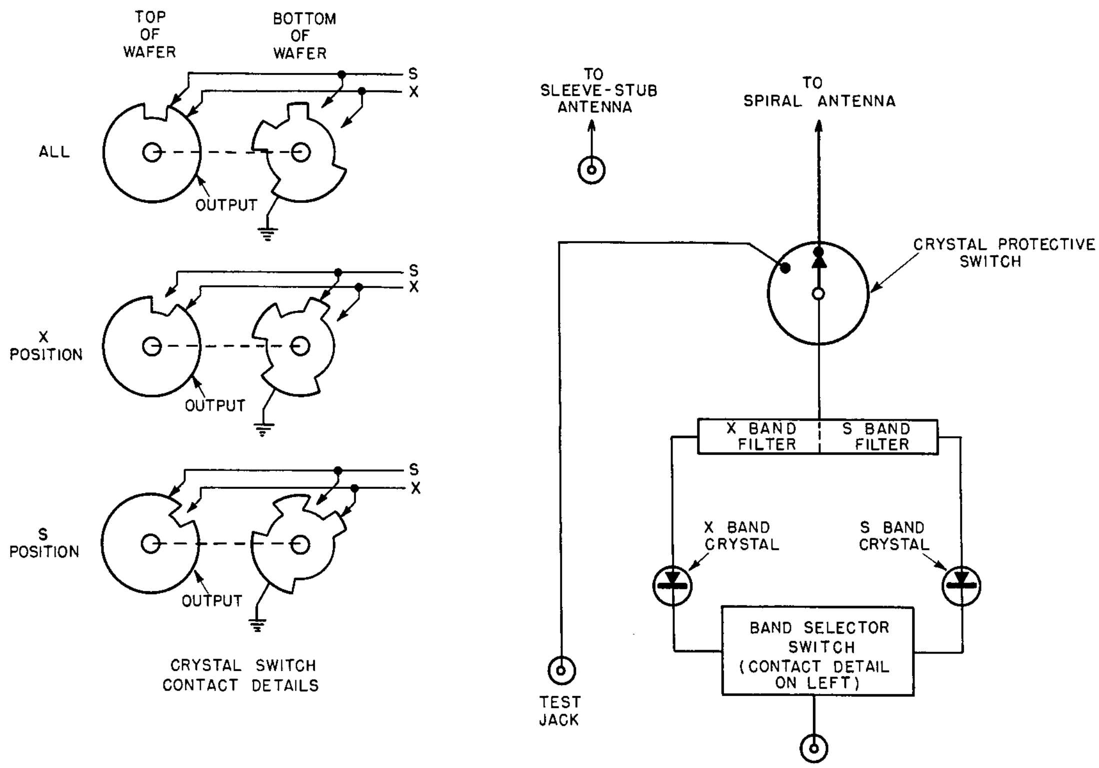


Fig. 19 - Filter-crystal unit -- Schematic

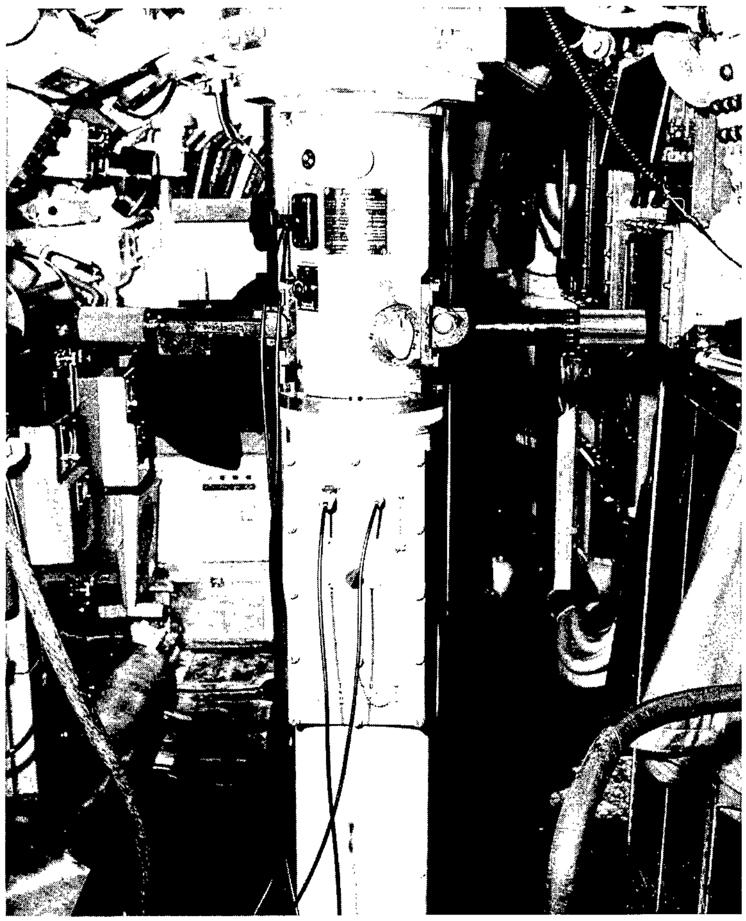


Fig. 20 - Filter-crystal unit support structure secured to periscope (rear view)

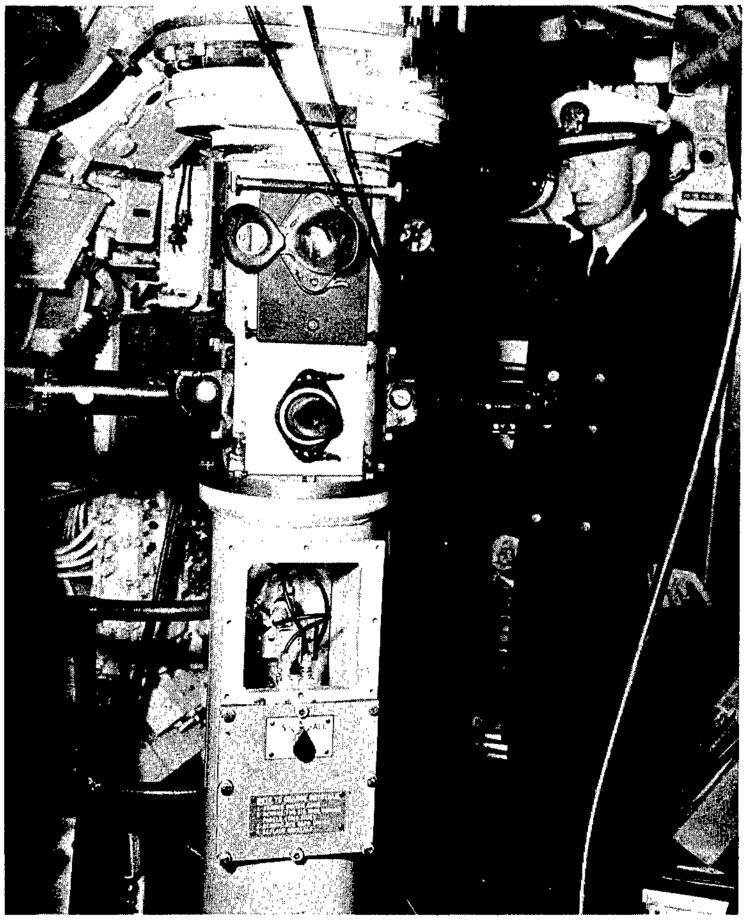


Fig. 21 - Filter-crystal unit support structure secured to periscope (front view)

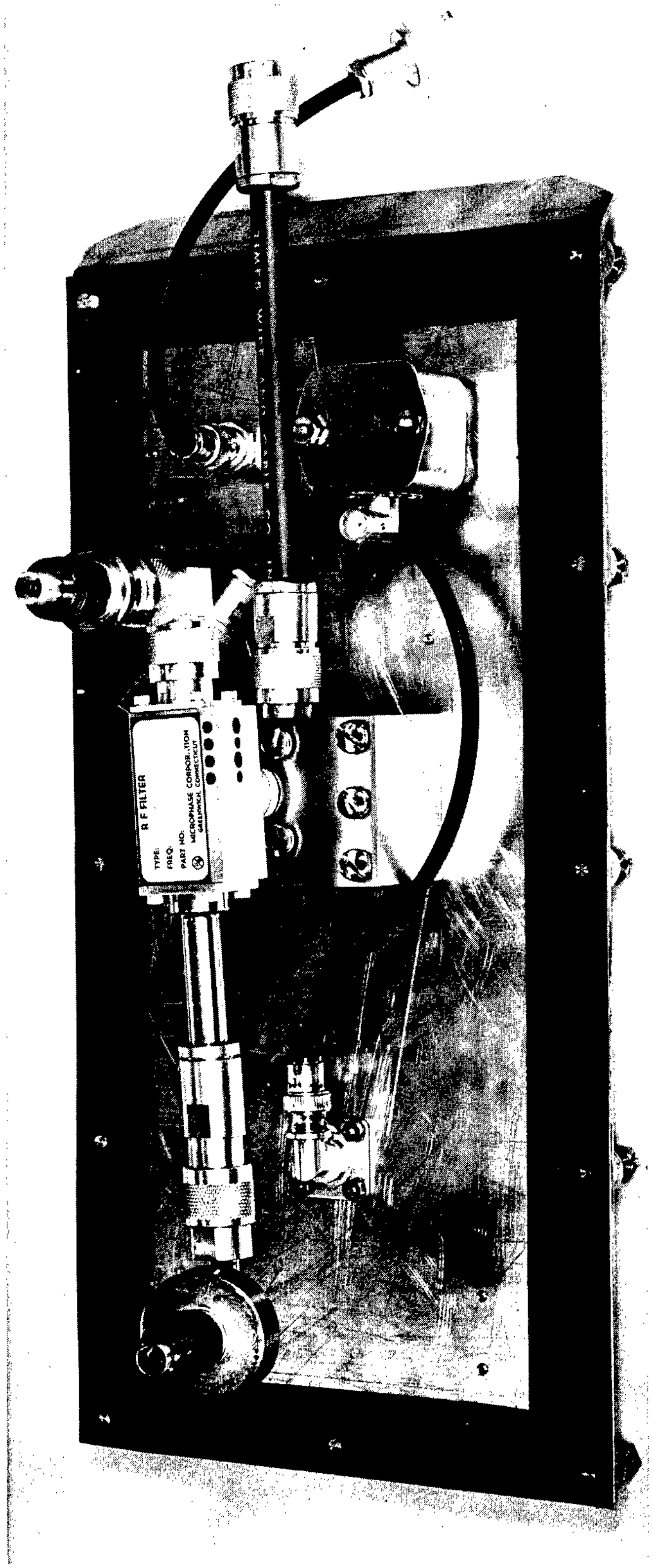


Fig. 22 - Filter-crystal unit -- Rear view

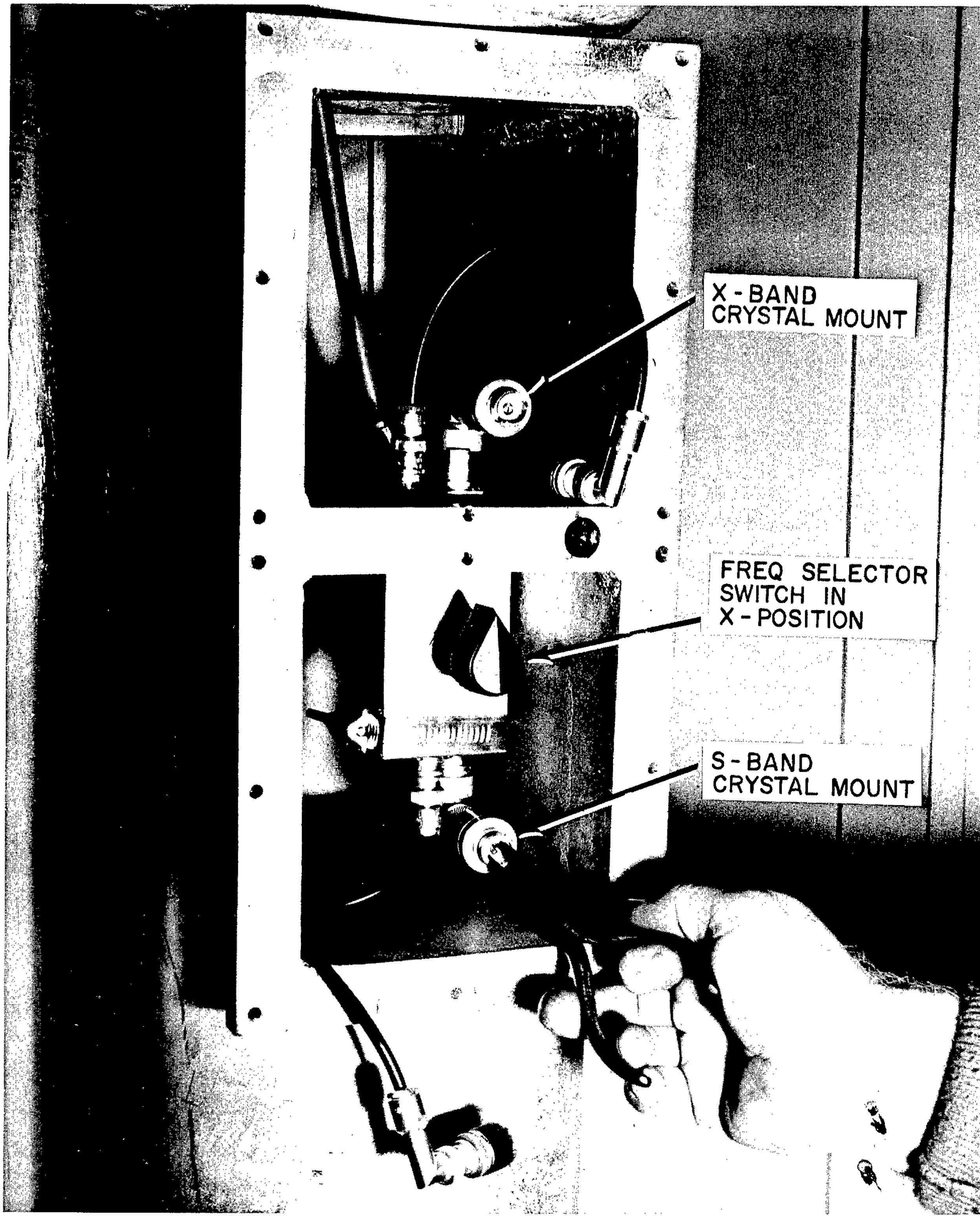


Fig. 23 - Filter-crystal unit -- Band selector switch mounting

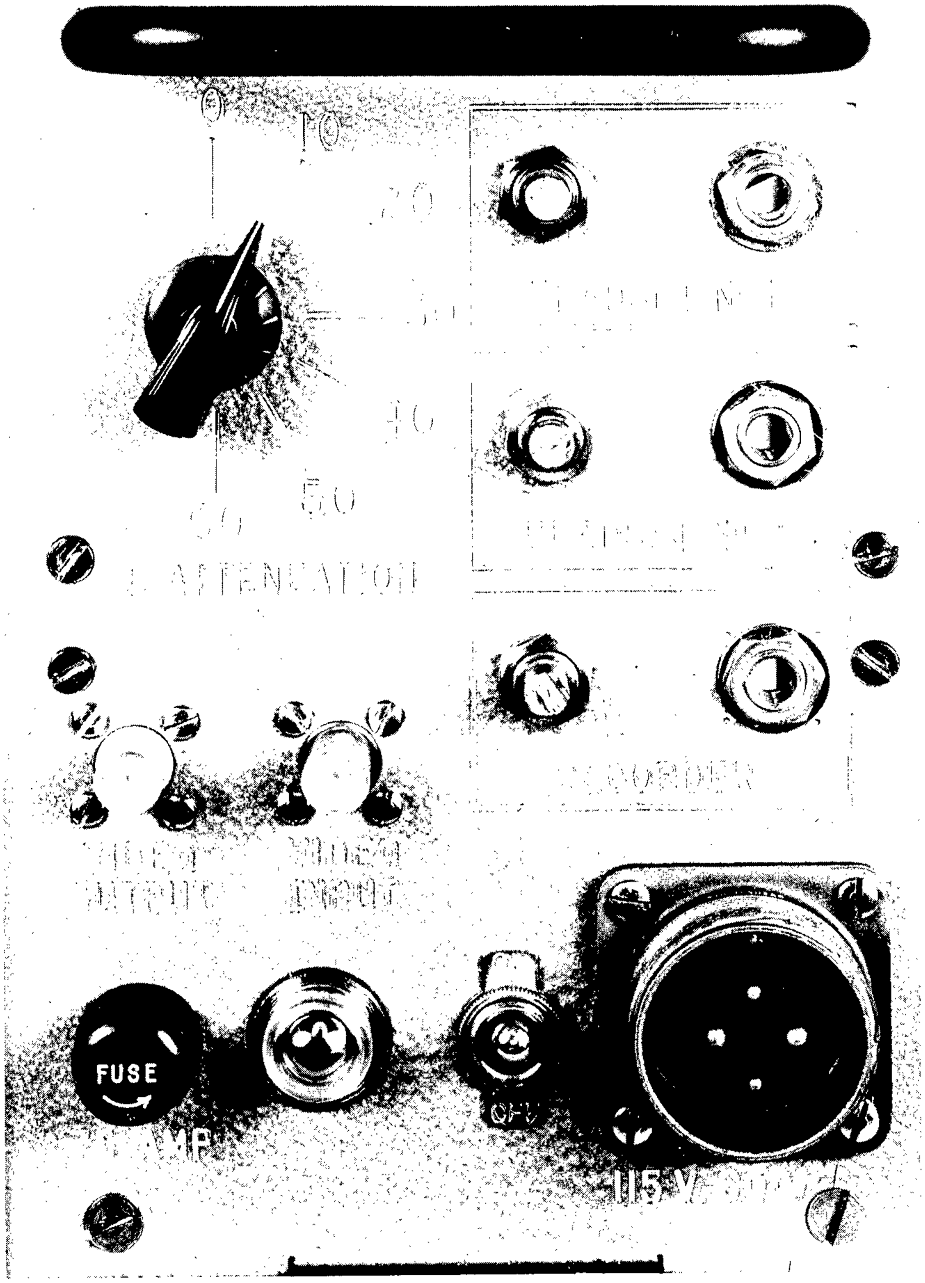


Fig. 24 - Video amplifier -- Front view

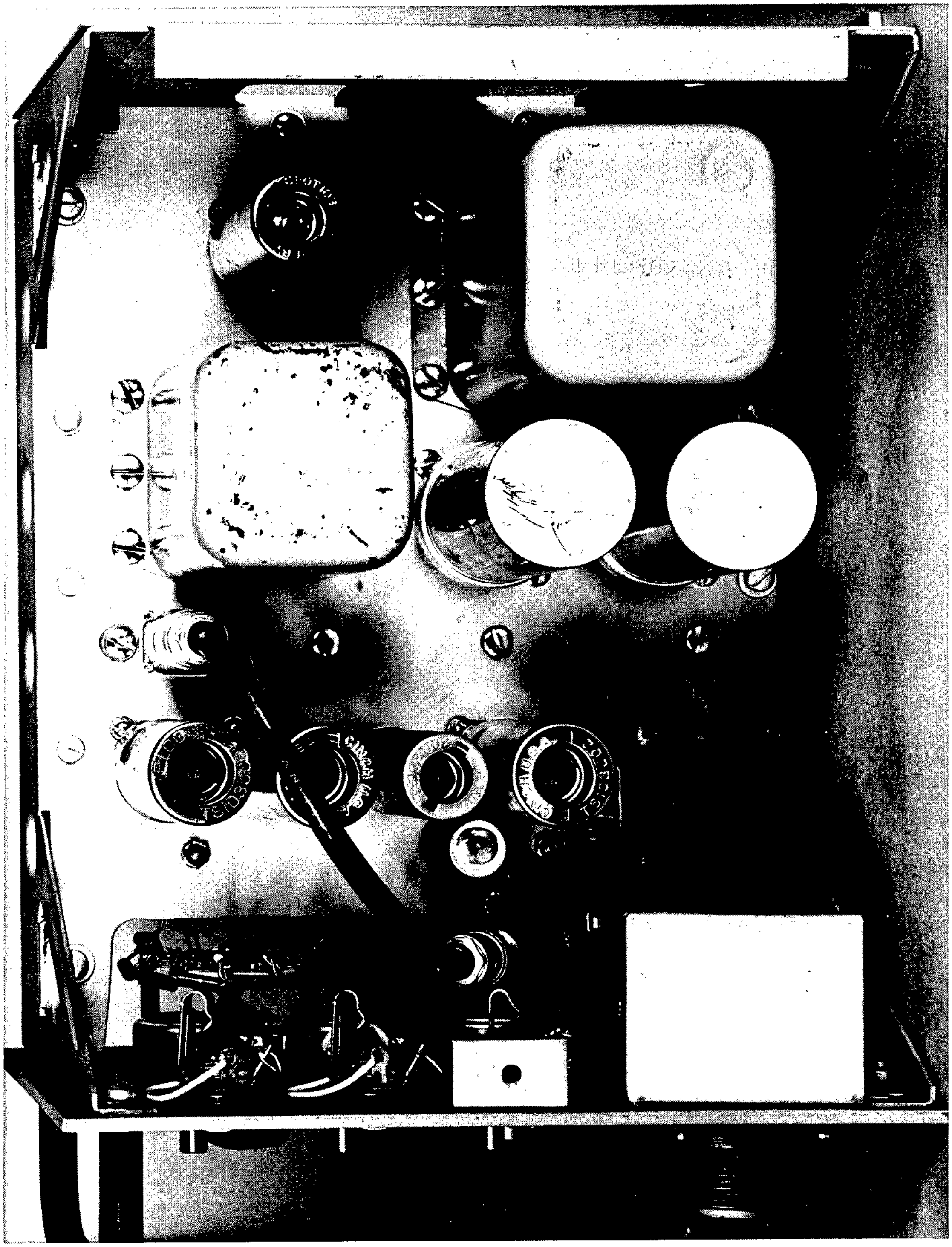


Fig. 25 - Video amplifier -- Top view

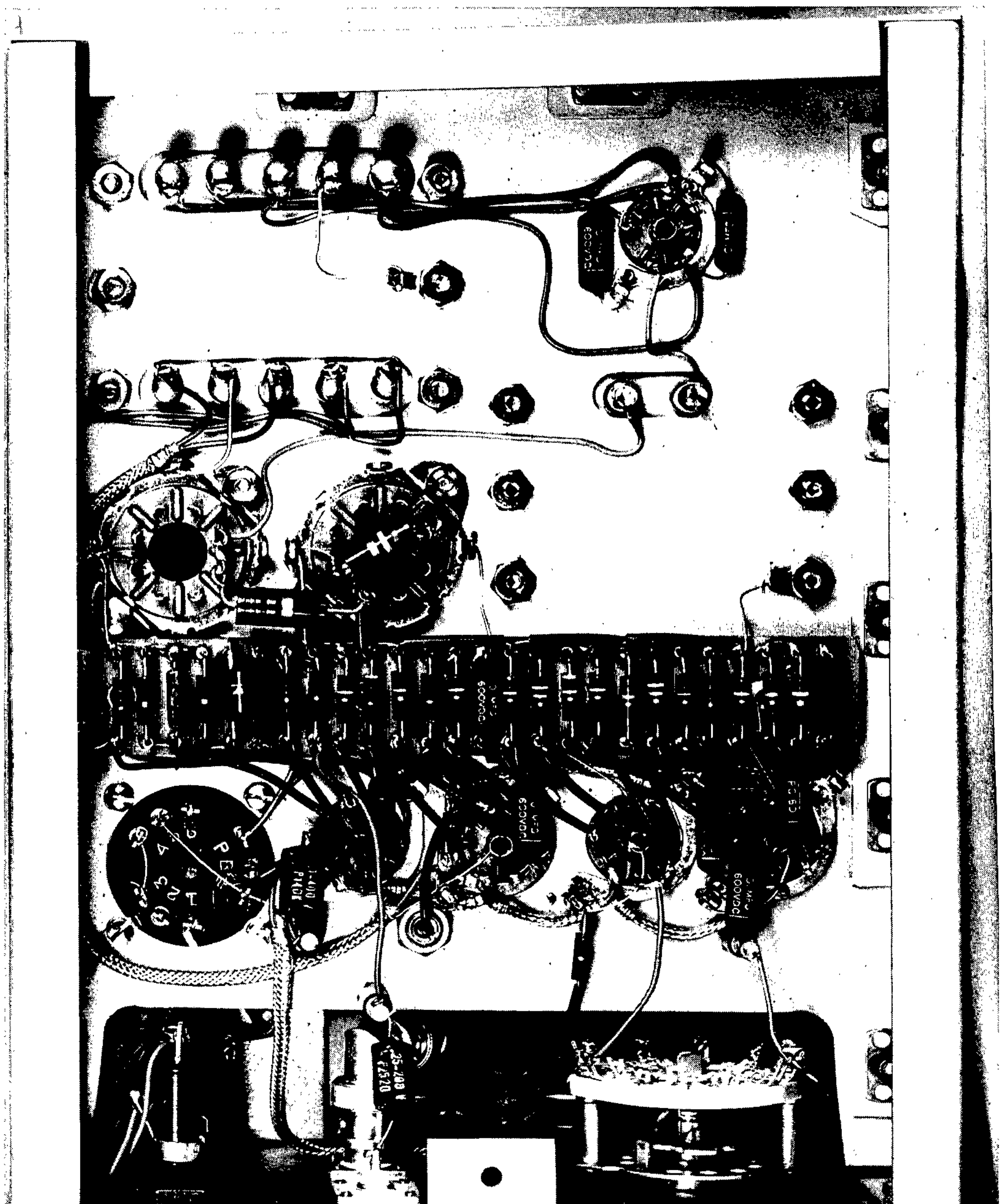
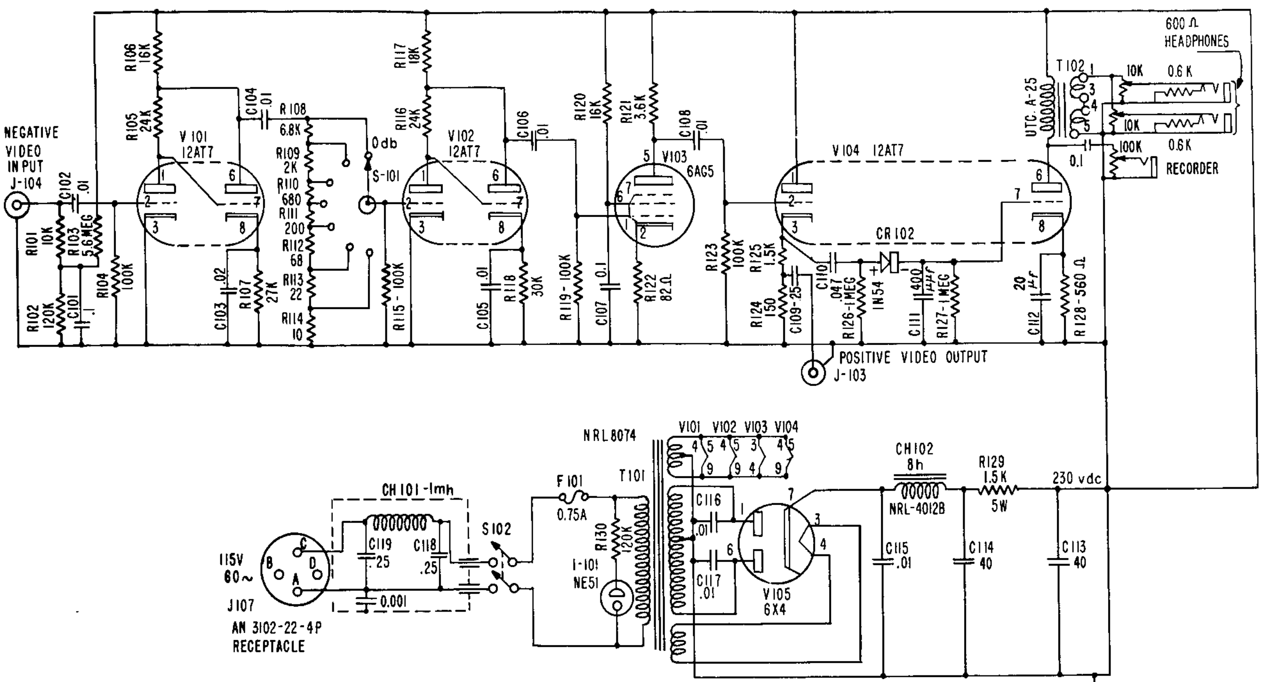


Fig. 26 - Video amplifier — Bottom view



NOTE = ALL CAPACITOR VALUES GIVEN IN MICROFARADS
RESISTORS ARE 1/2 WATT, 5% TOL. UNLESS OTHERWISE STATED

Fig. 27 - Video amplifier -- Schematic

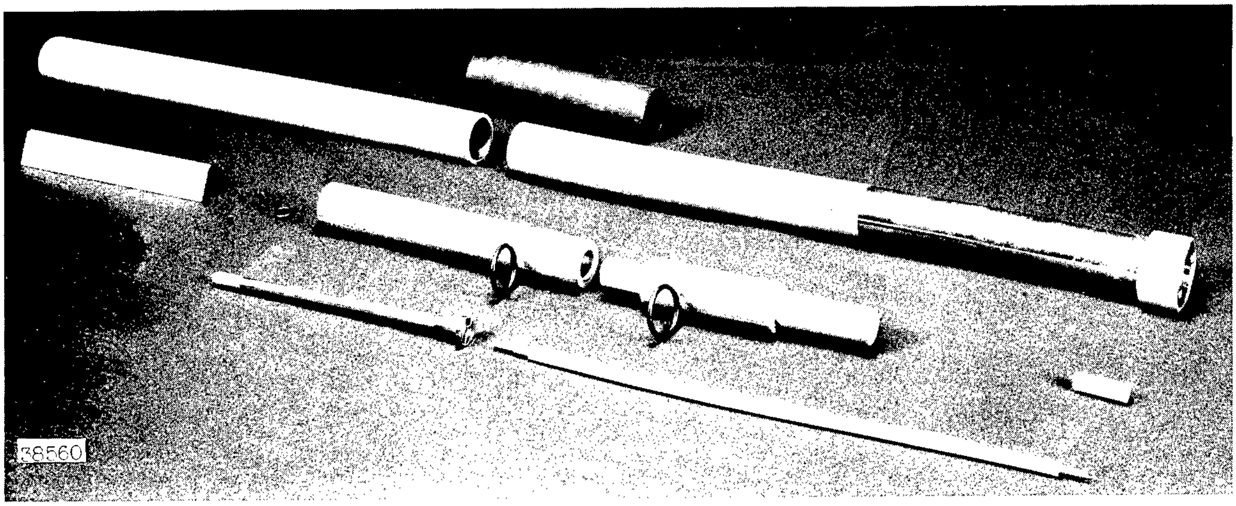


Fig. 28 - Improved sleeve-stub antenna — Disassembled view

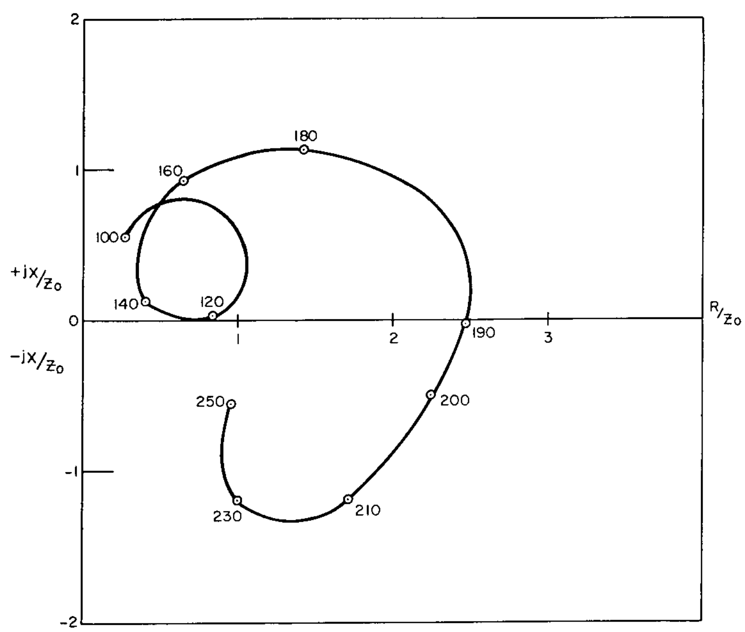


Fig. 29 - Improved sleeve-stub antenna impedance characteristics

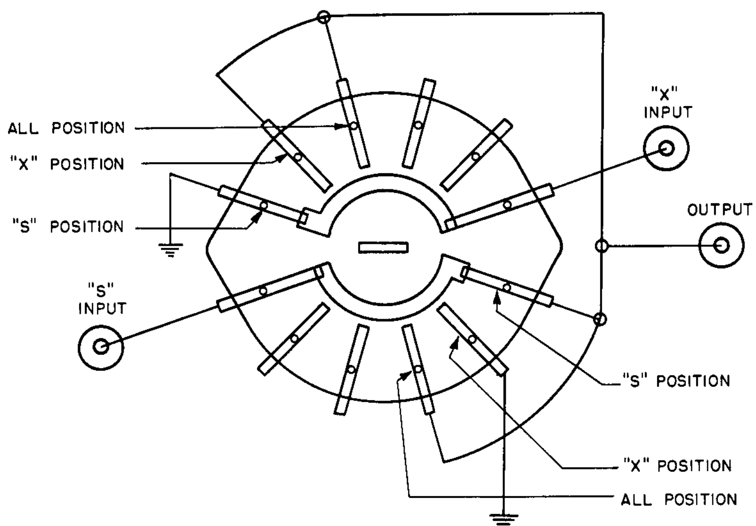


Fig. 30 - Improved band selector switch (for filter-crystal unit)

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