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THE PASSIVE COUNTERMEASURES PROGRAM AT THE NAVAL RESEARCH LABORATORY

R. A. Carpenter

RADIO DIVISION

1 July 1957

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by
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Countermeasures Branch
Radio Division
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Washington 25, D. C.

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ABSTRACT

The following summary of the Naval Research Laboratory's Passive Countermeasures Equipment program covering the fields of intercept and signal analysis was presented to the Electronics Warfare Committee on 10 April at Langley Air Force Base, Virginia, by Mr. R. A. Carpenter.

The program of passive countermeasures at the Naval Research Laboratory is determined by the requirements of the Chief of Naval Operations as interpreted and financed by the various Naval bureaus and the Office of Naval Research.

The Bureau of Aeronautics is sponsoring the development of airborne wide-open direction finder equipment to cover the frequency range from 50 mc to 40 kmc with a companion program for flush mounted antennas. Some parts of this task have been completed.

A Complex Modulated Pulse Demodulator has been designed and is now in production for the Bureau of Ships. This device is capable of extracting intelligence from essentially all practical types of pulse modulated signals. A countermeasures receiver and analysis system has also been developed for BuShips. By utilizing rapid frequency scanning and a vastly superior display system, the signal acquisition probability approached a new high for superheterodyne receivers. Improved presentation of analysis data simplifies photographic recording, and frequency memory circuits can quickly store new signals and reset the receiver to previously acquired intercepts. Preproduction shipboard models are now being built with the designation AN/WLR-1.

Jointly sponsored by BuShips and the Office of Naval Research is the Wullenweber type hf direction finder system. Improved bearing accuracy and higher signal-to-noise ratios have been demonstrated. Recently, new instrumentation has greatly increased the utility of this device. Future plans for this project include a new antenna array to further increase bearing accuracy.

THE PASSIVE COUNTERMEASURES PROGRAM AT THE NAVAL RESEARCH LABORATORY

The research and development program in countermeasures at the Naval Research Laboratory is aimed at satisfying the requirements of the Chief of Naval Operations as interpreted by, and financed through, the cognizant Naval bureaus and Office of Naval Research. In addition, there is also some work done for other government agencies. This discussion is primarily concerned with the programs sponsored by the Bureau of Aeronautics and the Bureau of Ships; it covers only the passive countermeasures work of the Naval Research Laboratory and not the problems in active countermeasures which include jamming and deception.

There are several problems of interest sponsored by BuAer. One provides for the development of wide-open direction finder equipment and the components necessary to cover the frequency range from 50 mc to 40,000 mc. This is a four-channel crystal video set covering the frequency range from 2,000 through 11,000 mc in two bands. Figure 1 depicts the units of this system. The four horn antennas constituting the directional array for horizontally-polarized waves are mounted inside the cylinders with their apertures spaced 90° apart (see slots in cylinders); the corresponding dipoles for receiving vertically-polarized waves are visible below the horn apertures. Figure 2 shows several essentially-simultaneous radar intercepts. The maximum intercept range of this equipment at 5,000 feet altitude is 100 miles against an SX S-band radar and 90 miles against an APS-44 X-band set. The standard deviation is 11 degrees. This means that 68% of the bearings will be less than 11 degrees in error for the full frequency range when installed on an R4D aircraft. It is expected that some reduction in bearing error will result on other aircraft having smoother bottom lines. This equipment is the predecessor of the AN/ALD-2 being produced on an outside contract. The AN/ALD-2 is the same except that the antenna has been repackaged to include coverage from 1,000 through 10,000 mc in one unit.

Another phase of this problem is the development of equipment to do the same sort of job for the frequency range from 10,000 to 40,000 mc. Figure 3 shows a set of horns to cover this range. These antennas have been installed on P4M and A3D type aircraft in conjunction with a single-channel receiver switched between 3 sets of antennas. These tests have not been completed and no quantitative data are available yet.

Other aspects of this problem are concerned with component studies, for example, the development of crystals and crystal mounts and the deterioration of sensitivity of various crystals when subjected to high level rf power and high accelerations.

Another major phase of these projects provides for the design of flush-mounted antennas for use on high-speed aircraft. These antennas are to be incorporated into direction finding systems covering the frequency range from 50 to 4,000 megacycles. At the present time NRL is experimenting with flat spirals. Figures 4A and 4B are pictures of one model that covers the range from 500 to 2,000 mc. A modification of the cavity shape is expected to increase the coverage to 5,000 mc. This antenna is 7 inches in diameter and about 4 inches deep and exhibits a gain of about 5 decibels over an isotropic antenna. This type of antenna has several very interesting and promising characteristics: it is indeed flush mounting, it has extremely wide bandwidth (approximately 10:1), which means fewer elements to cover the required frequency range. It responds to waves of any polarization, and apparently has constant gain and beamwidth over these wide frequency ranges. NRL is not the only experimenter with this type of antenna. Hallicrafters has produced, on an Air Force contract, an antenna for jamming applications covering approximately 500 to 1500 mc. Glenn L. Martin, also on an Air Force contract, is working on a phase-comparison type of direction finder using these antennas. Farnsworth, on Air Force and Navy contracts, has produced the AS-849/APR intercept antenna covering about 2,600 to 10,000 megacycles. Theoretical studies have also been made by TEMCO and MIT.

The work in passive countermeasures at NRL which is sponsored by BuShips will now be briefly discussed.

There existed a CNO requirement to develop the circuitry necessary to accomplish the complete analysis of signals and types of modulation as well as the modulation components determined by the technical limitations imposed by the frequency bands of interest.

In partial compliance with this requirement the Naval Research Laboratory has developed the Complex Modulation Pulse Demodulator. This device is capable of demodulating pulse signals with respect to pulse amplitude, pulse position, pulse width, pulse period, and pulse frequency over a pulse repetition rate range of 20 cycles to 1 mc and a pulse width range from 0.1 to 100,000 microseconds.

A gating system is included which, in conjunction with a multiple slave-sweep type display, enables the operator to visually select for demodulation any desired pulse from a pulse train. Slicing circuits are provided for reducing the effects of receiver noise so that information from signals only slightly above the noise level can often be obtained. The output signal is an accurate reproduction of the modulation envelope carried by the original video pulse signals.

It is expected that this demodulator will be an invaluable tool in detecting information carried by complex-modulated pulse signals, and it is probable that future secure guided missile and communication systems will utilize some kind of pulse modulation that can be handled by this demodulator.

In basic principle, all types of pulse modulation are converted to amplitude and demodulated by a "box car" generator having a linear frequency response from 2 cycles to 800 kc.

At the present time there are several of these units in operation and a contract is being negotiated for an additional twenty-some units.

For many years one of the basic Countermeasures problems has been to find a method for providing a high probability of signal acquisition, rapid signal identification, and a useful storage of the pertinent information. The Naval Research Laboratory's approach to this problem has resulted in the development of the laboratory equipment shown in Figure 5. The production version of this equipment for shipboard use is the AN/WLR-1. BuAer is also obtaining an airborne model utilizing most of the basic principles of this system.

Basically, the system consists of (1) a high resolution, high-sensitivity superheterodyne receiver which is rapidly scanned throughout the frequency range of any tuner, (2) a signal acquisition indicator, (3) frequency storage and control circuits, (4) a unified data display, and (5) a photographic recorder (which is not shown in Figure 5). The AN/APR-9 receiver was adapted for this system by installation of a two-phase servo motor in each tuner, geared to scan the complete frequency range of a tuner in two seconds. When the receiver is scanning, signal presence is shown as a spot on the acquisition indicator. This display uses a long-persistence (P 25 phosphor) cathode-ray tube to present data on a time-frequency raster. The horizontal position of the spot is determined by the tuned frequency of the receiver and the vertical position of the spot drifts slowly downward with time to present a raster. Signals are indicated as intensity modulation, and the degree of intensity is a function only of signal amplitude. Figure 6 is a photograph of the acquisition display, indicating typical signals in the presence of a noise background. This picture was taken with the camera open for the entire raster to show the relative frequency of signal intercepts from different signals. Figure 7 is a snapshot of the display which shows persistence of the pattern, and indicates what is actually seen.

To analyze a signal, scanning is stopped by pressing one of the "store" pushbuttons on the control panel of the system. Receiver tuning is then controlled by a potentiometer which is adjusted until the spot on the acquisition indicator coincides horizontally with the persistence spot that indicated the possible presence of a signal. Any signal at this frequency is then within the passband of the receiver, and an analysis can be made on the unified indicator. After an analysis is completed, scanning may be resumed by pushing the acquisition button. At any time that it is desired to re-examine a stored frequency, it may be done by again pressing the particular store button that was used previously.

The unified data indicator provides signal analysis information, df bearings, and a receiver panoramic display on a five-gun cathode-ray tube. Analysis is performed on the first three traces, which use non-linear slave sweeps. The first sweep is a 0-5 μsec exponential which is triggered in synchronism with the incoming signal. The termination of this sweep initiates the second, which is a 5-500 μsec, two-decade, approximately logarithmic sweep. The termination of the second sweep in turn initiates the third, which runs from 500 to 50,000 μsec and is also a two-decade approximately logarithmic sweep. The fourth gun in the cathode-ray tube is used for the linear df display, which consists of two traces of 180° each. The sweep progresses from 0° at the center to 90° at the right of the upper trace, from 90° at the right to 270° at the left of the lower trace, and from 270° at the left to 360° or 0° at the center of the upper trace. Video is displayed downward from the upper trace and upward from the lower trace. The receiver panoramic display is produced by the fifth gun in the cathode-ray tube. Photographs of signals observed on this display are shown on Figures 8 and 9. The frequency indicator of the AN/APR-9 receiver is displayed below the face of the CRT in the unified indicator, and is servo controlled to the receiver frequency when scanning is stopped. The frequency indicator is automatically reset for the tuner in use when tuners are switched.

Also available from the unified indicator unit is an audio output which is valuable for distinguishing between signals and noise when a single large spot appears on the acquisition indicator.

The best method of recording the type of data displayed on the unified indicator is by photography. The field of view of the camera should enclose the five-gun cathode-ray tube face, the frequency indicator, clock, data card, and true-relative bearing indicator, all of which are located together for this purpose. Photographs shown in the preceding figures were taken with a KD-2 camera, whose field of view covers only the CRT display. The frame counter, data card, and clock are built into this camera. Coding lights are available in the camera for true-relative bearing indication, but so far no means of incorporating the frequency indication into this camera has been devised.

Operational use of this instrument at the Naval Research Laboratory indicates a decided superiority over previous intercept systems.

The Naval Research Laboratory has been investigating methods of improving hf direction finding for many years. The principles underlying Wullenweber type systems have been under investigation since about 1946 and a report on the advantages of this type of df was issued as early as 1948. Tests were conducted in 1951 to prove the accuracy advantages of wide aperture arrays. The results of these tests with a fixed array were so spectacular that work was started on the construction and instrumentation of this installation (Figure 10).

This array covers the frequency range from 5 mc to 25 mc and consists of forty vertical half rhombics. The supporting poles are arranged in a 300 foot circle. A ground plane of copper wires covers a circle 1000 feet in diameter. Each element is 200 feet long, that is, about one wavelength at 10 mc.

The heart of this type of system is the phasing mechanism or goniometer, NRL was somewhat fortunate in its early work by being able to obtain, from the British, one of the original German goniometers which was captured near Hjorring, Denmark, during World War II. Figure 11 shows a simplified schematic of a Wullenweber type goniometer. Each antenna element is connected to a stator capacitor plate through an impedance step-up transformer. The rotor consists of non-cogging capacitors connected to a tapped delay line. In operation, the goniometer and its built-in delay line efficiently make a portion (12 - 13 elements) of a circular array look like a rotating broadside. Using the original German goniometer, this array operating on mobile targets (weather ships in the North Atlantic) has resulted in a standard deviation of 2.5 degrees. The gain of the array is about 12 decibels; the half-power beamwidth is about 15 degrees at 10 mc and is of course inversely proportional to frequency.

NRL has just installed some new instrumentation at the site, which is located on Coast Guard property just south of Alexandria, Virginia. Multi-couplers have been added to the antenna elements, and also a new dual goniometer that appears to have a little better accuracy and response. The addition of this new instrumentation now gives the capability of three complete operating positions, each with facilities to operate independently. The output of each goniometer is split and provision has been made to add these two outputs through a hybrid network in antiphase or in phase. This arrangement allows the operator to split the antenna pattern and take bearings on the notch or in the case of weak signals, to work on the maximum of the pattern.

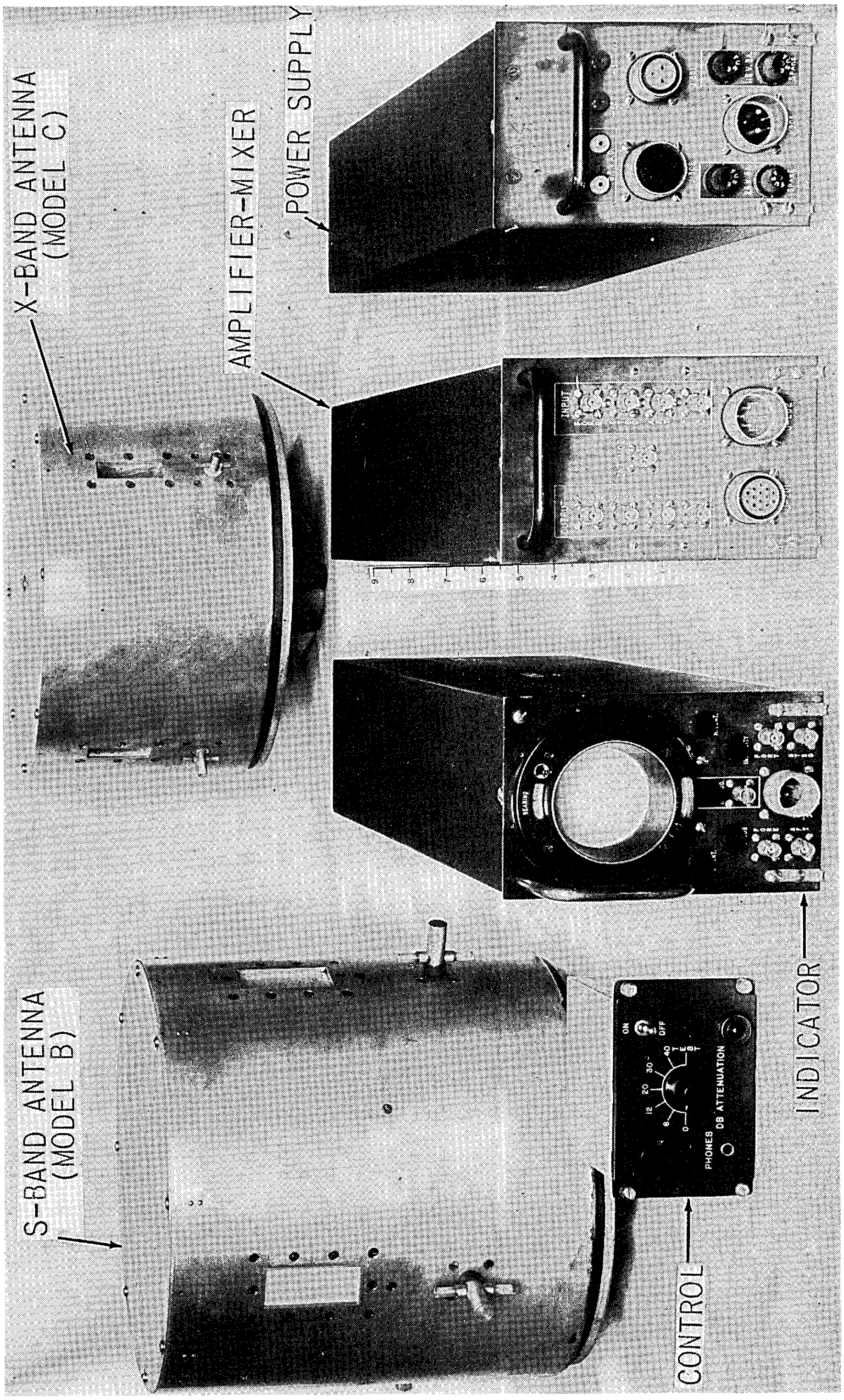
During some recent tests the high gain (that is, high for this frequency range) allowed operators to take good bearings on signals too weak even to be detected by the more conventional direction finders.

This type of rhombic array has several advantages: one, it is relatively cheap, two, it is very easy to construct and three, has extremely wide bandwidth. But it also has at least one disadvantage and the extent of it could only be determined by a full scale trial: that is, the elements around to the sides of the section being used respond to the horizontal component of an ionospherically propagated wave. This results in substantial polarization error. If this polarization error were eliminated, the standard deviation would be reduced to about one degree.

There are several other types of array that offer promise in effecting the desired results. Some scale models of comb and fishbone elements have been tested which, of course, do not respond to horizontal polarization. Also calculations of the radiation patterns of sleeve monopoles with and without screens have been made. At first glance it would not appear that a circular array of vertical sleeve monopoles would result in a unidirectional radiation pattern, but, owing to the depth of the array, the delay lines add in such a way that a unidirectional pattern is formed.

Future plans for this project include further calculation and experimentation on the rejection of horizontal polarization and the construction of a new antenna as well as further improvements to the multicouplers and instrumentation.

Navy - NRL, Bellevue, D. C.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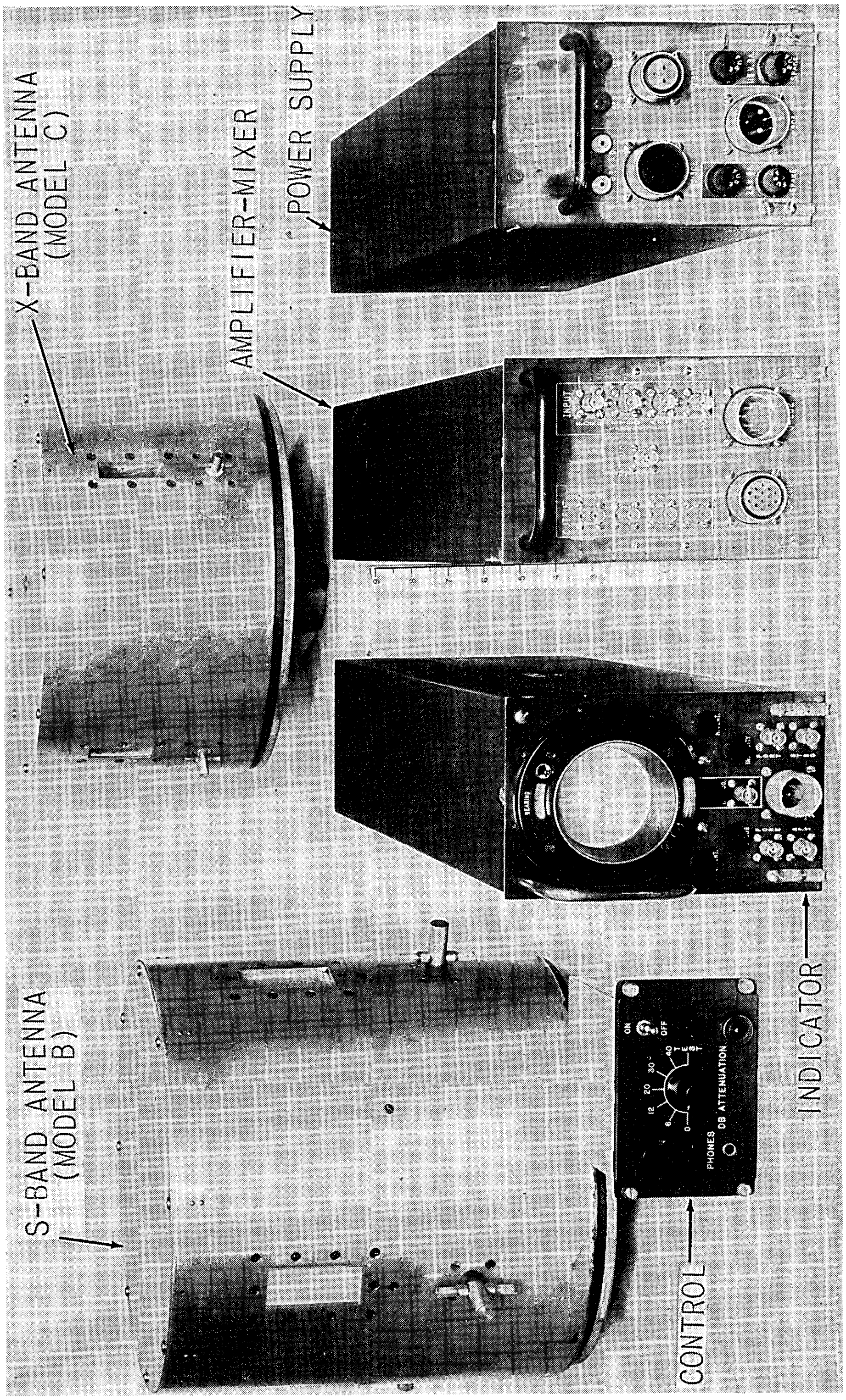
(MODEL B)
X-BAND ANTENNA
(MODEL C)
AMPLIFIER-MIXER
POWER SUPPLY
CONTROL
INDICATOR
DB ATTENUATION
PHONES
ON
OFF

Figure 1


S-BAND ANTENNA
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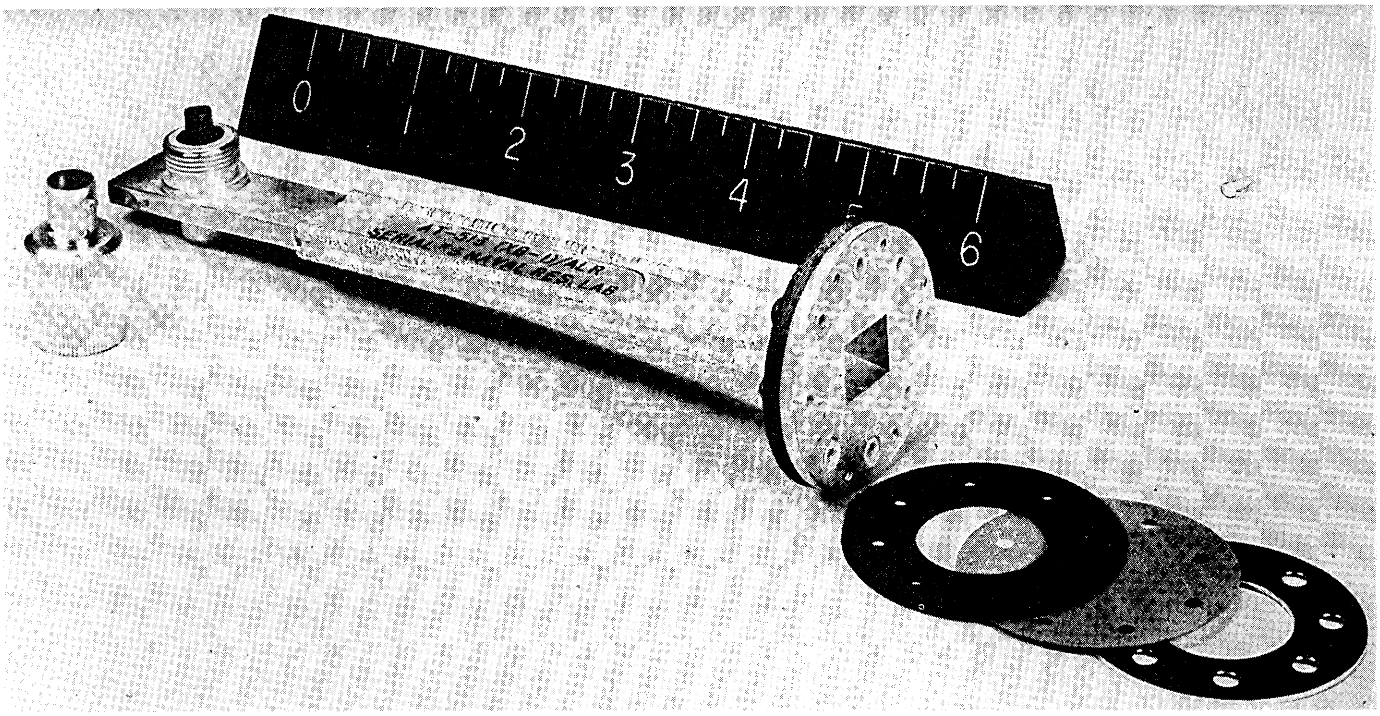
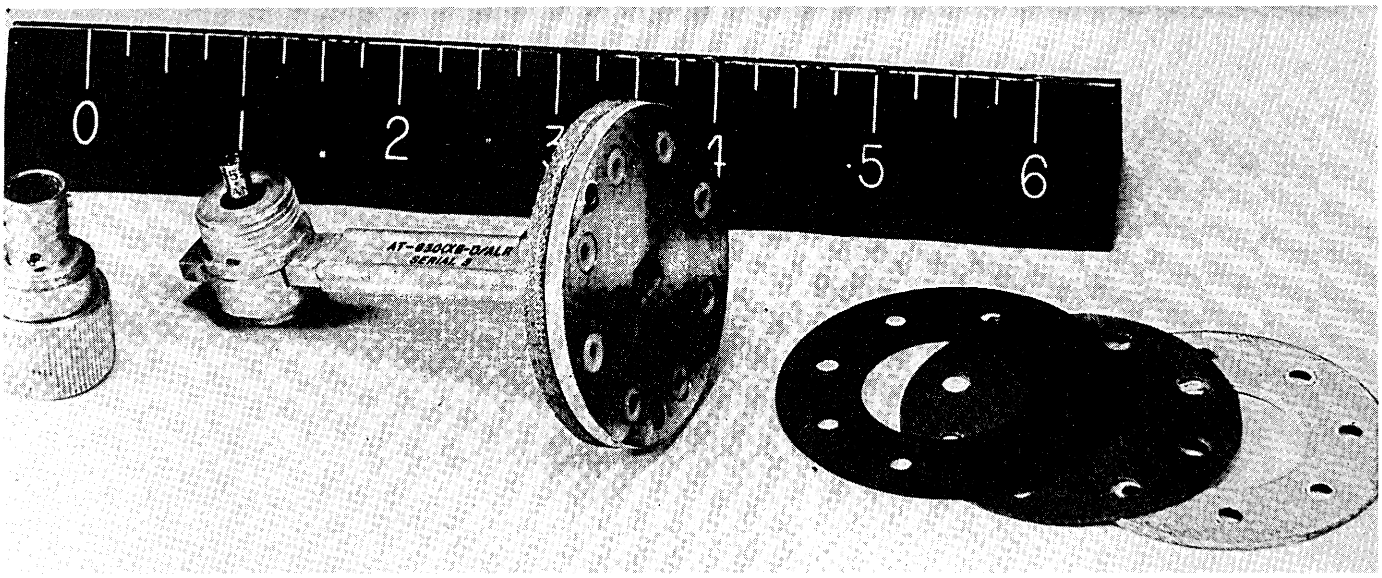
CONTROL
INDICATOR

Figure 1



AT-513(XB-1)/ALR Antenna Assembly



AT-630(XB-1)/ALR Antenna Assembly

Figure 3

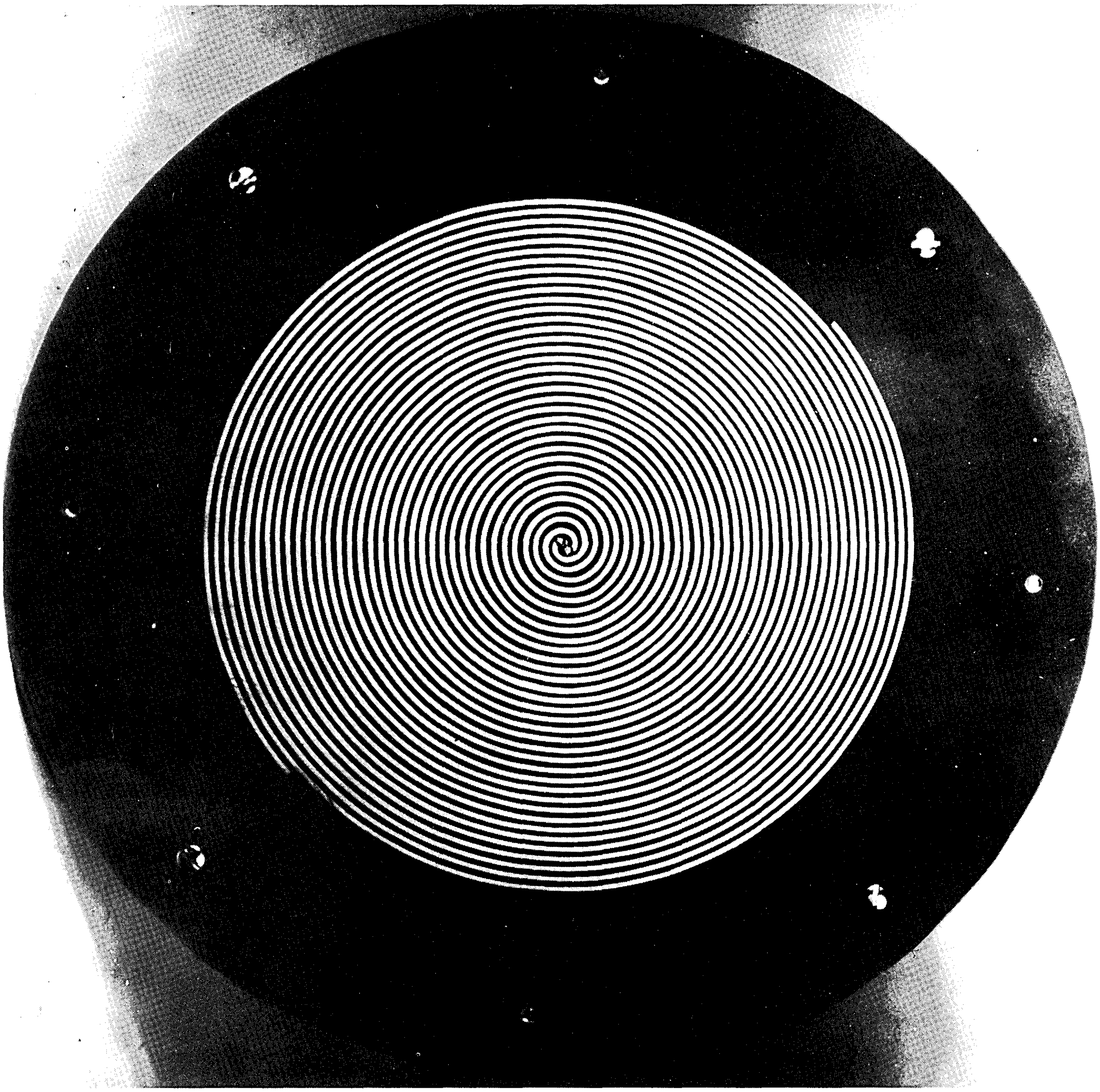
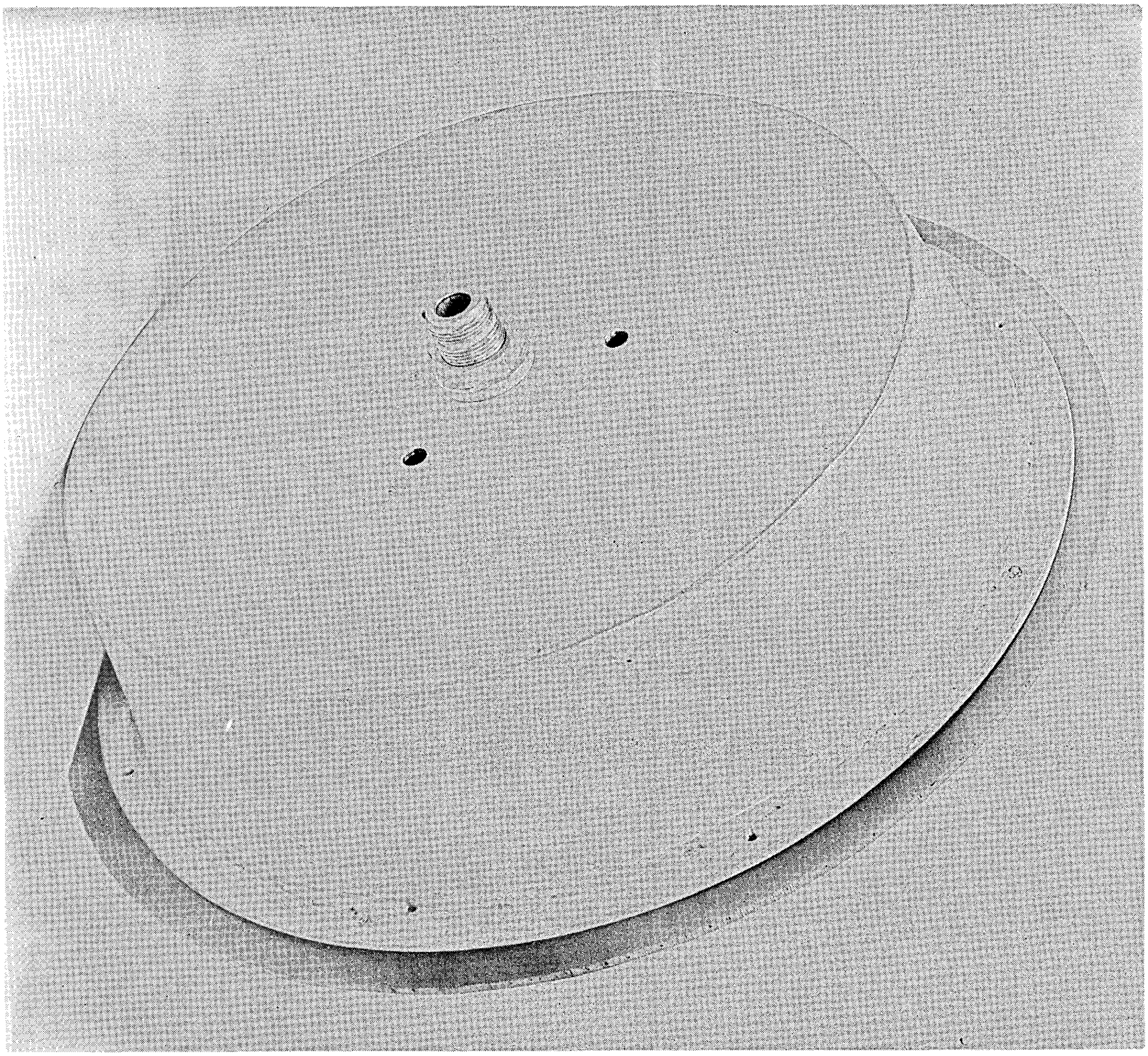


Figure 4a



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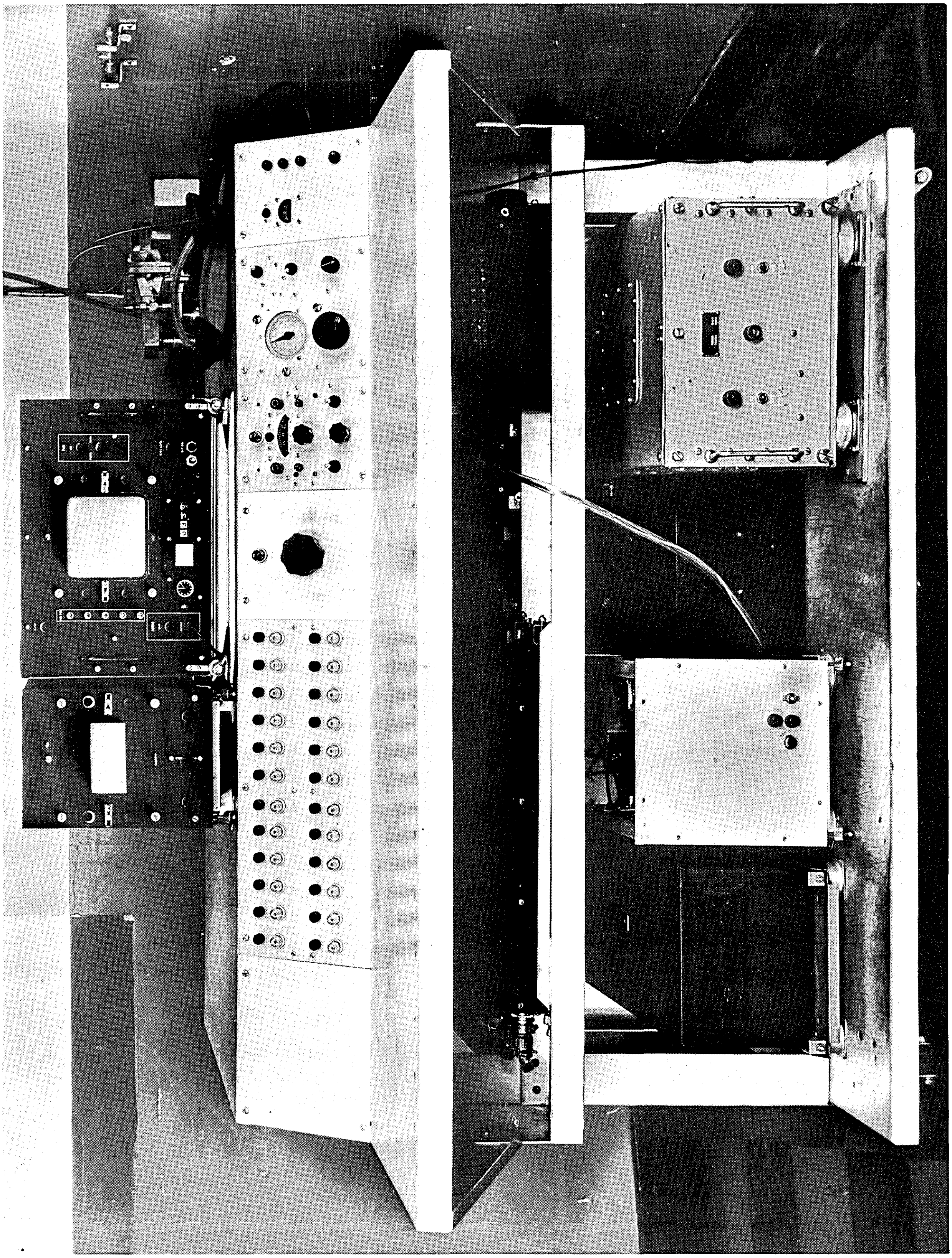

Figure 5

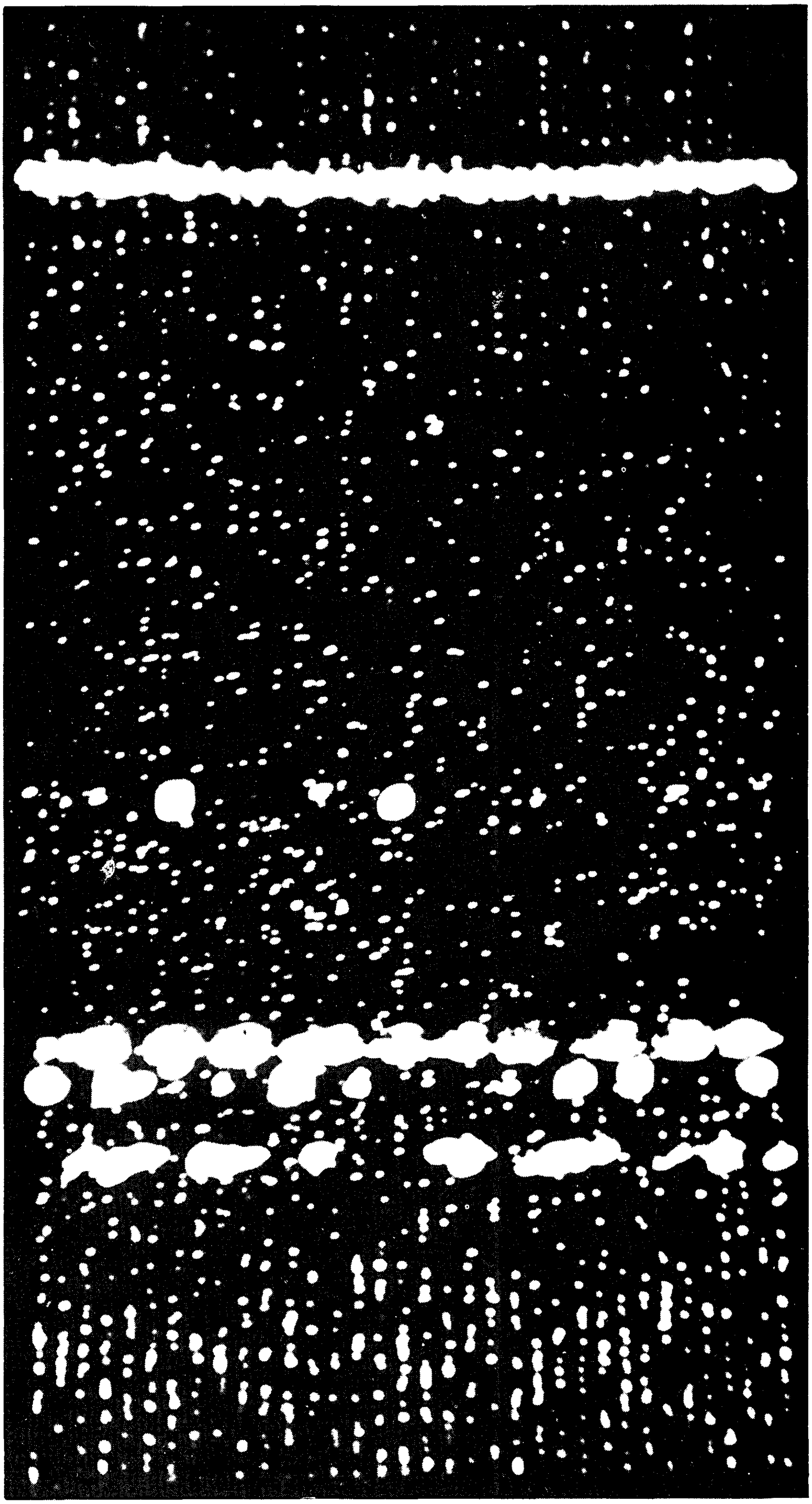

Figure 6

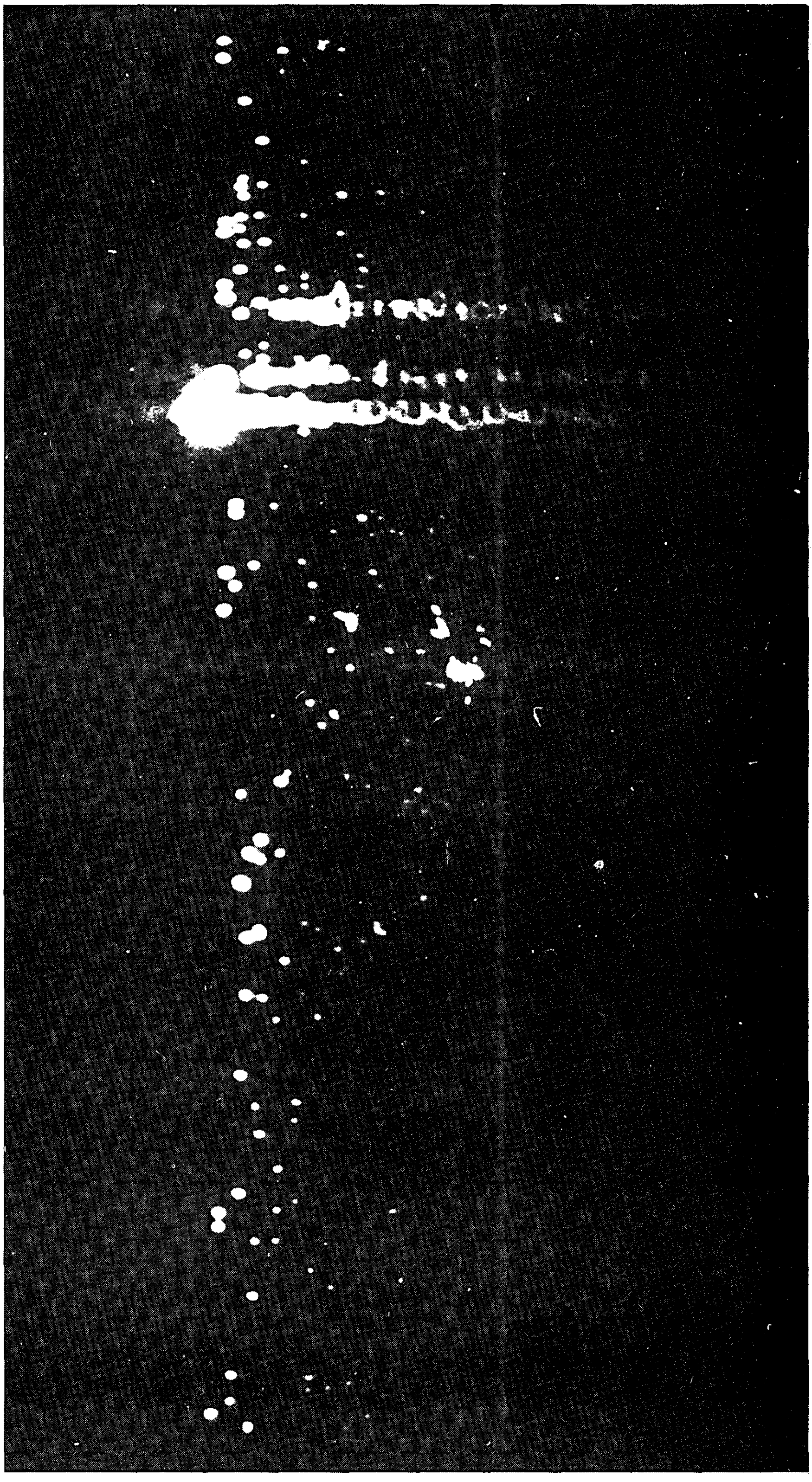

Figure 7

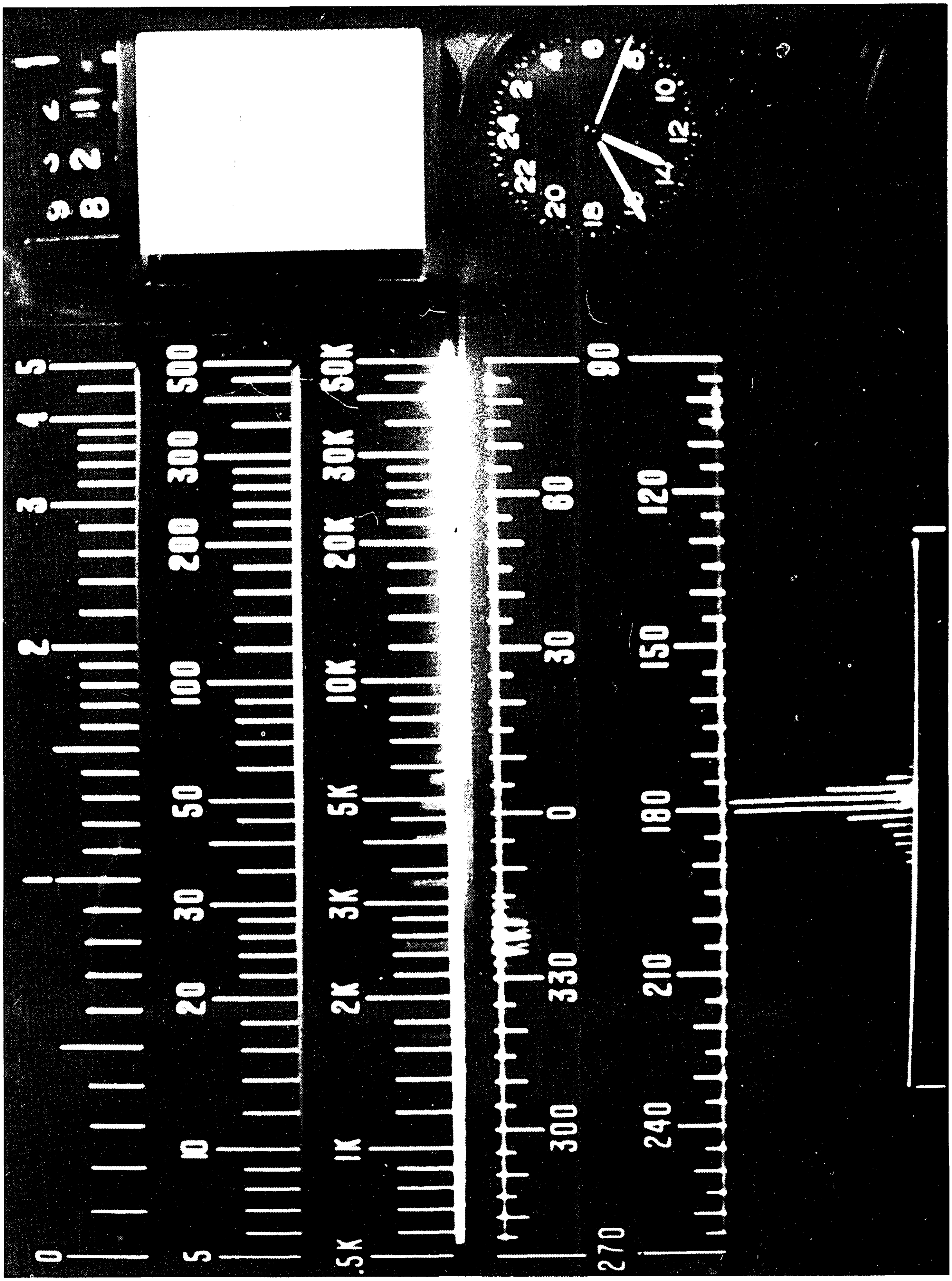
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Figure 8

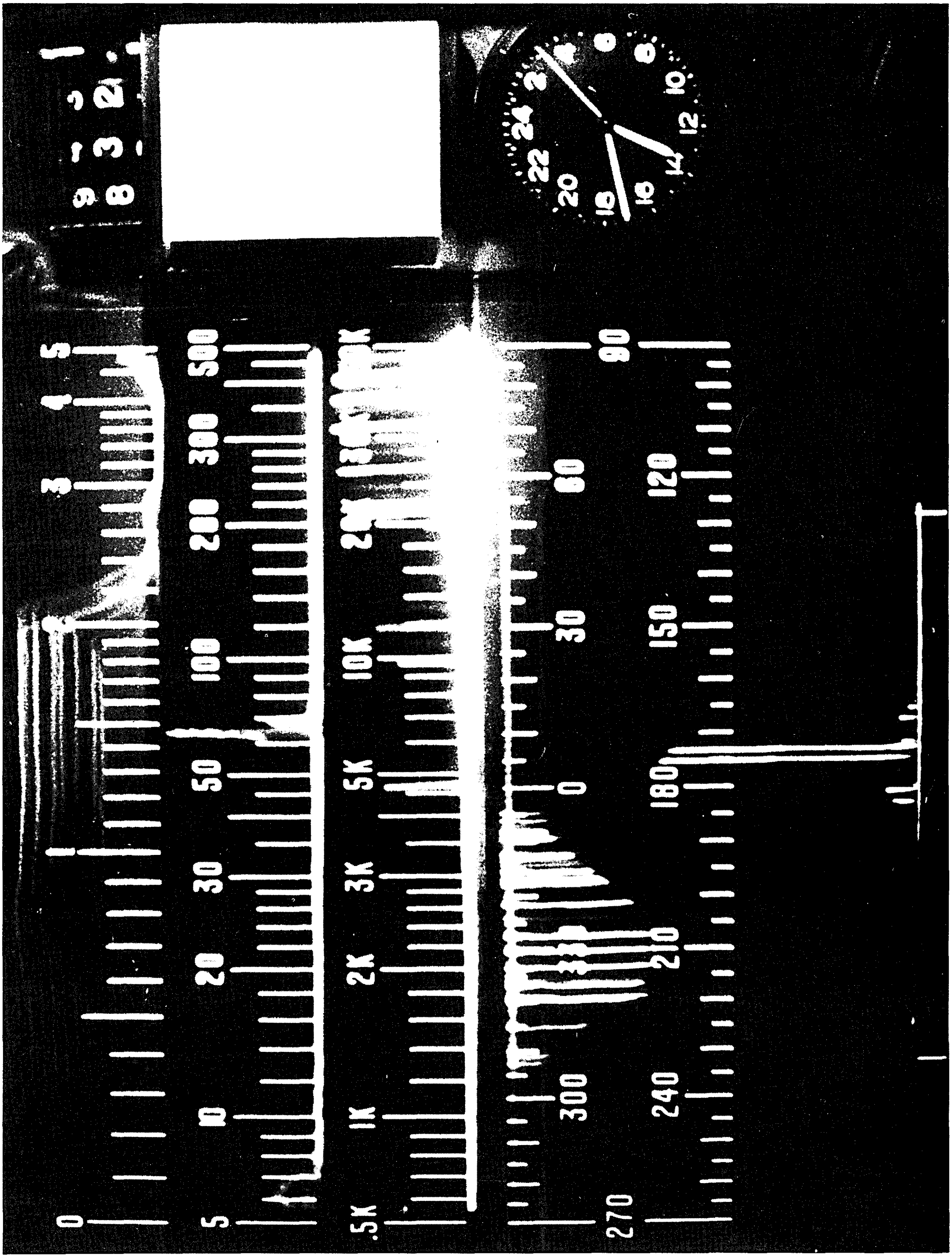
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Figure 9

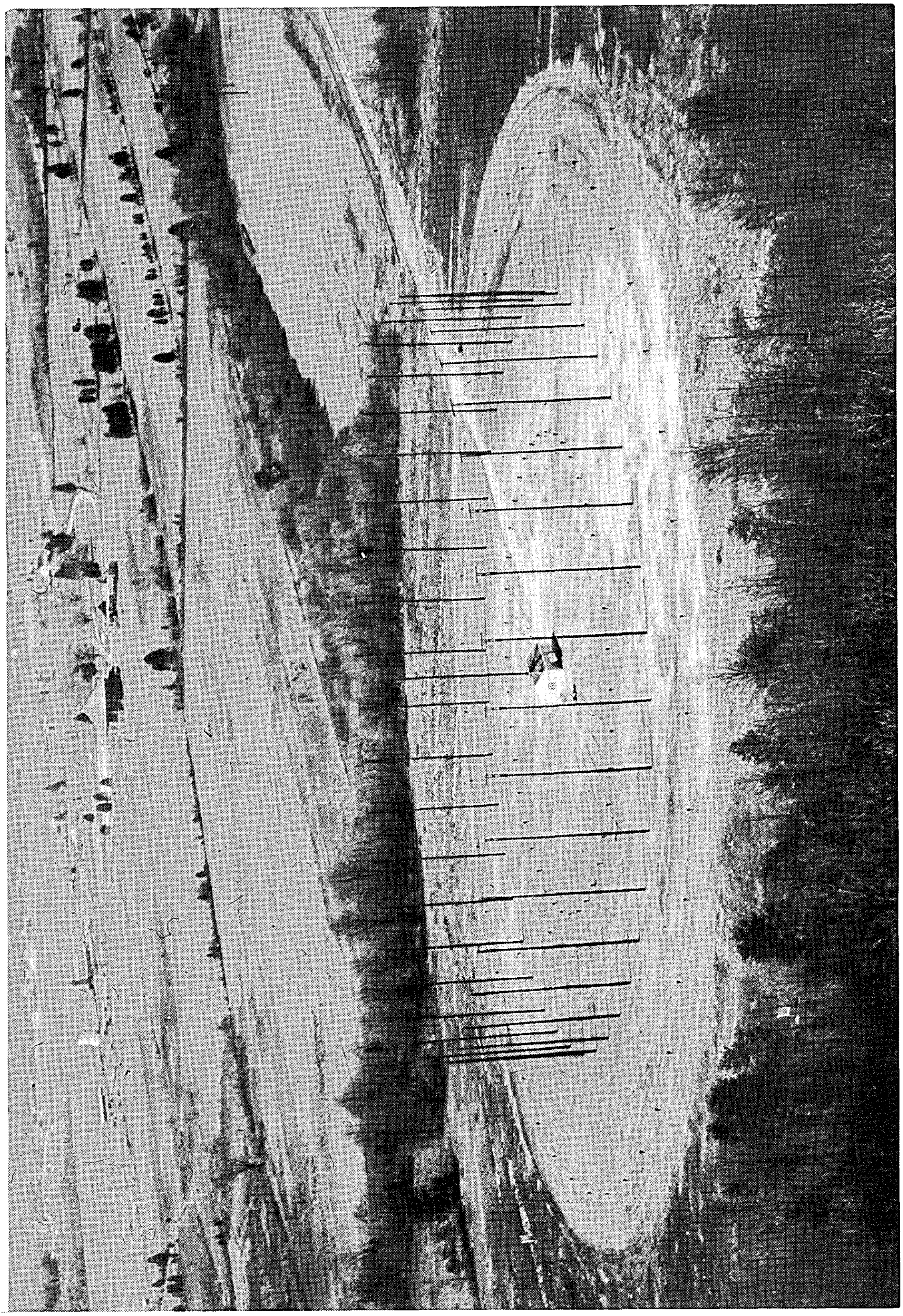
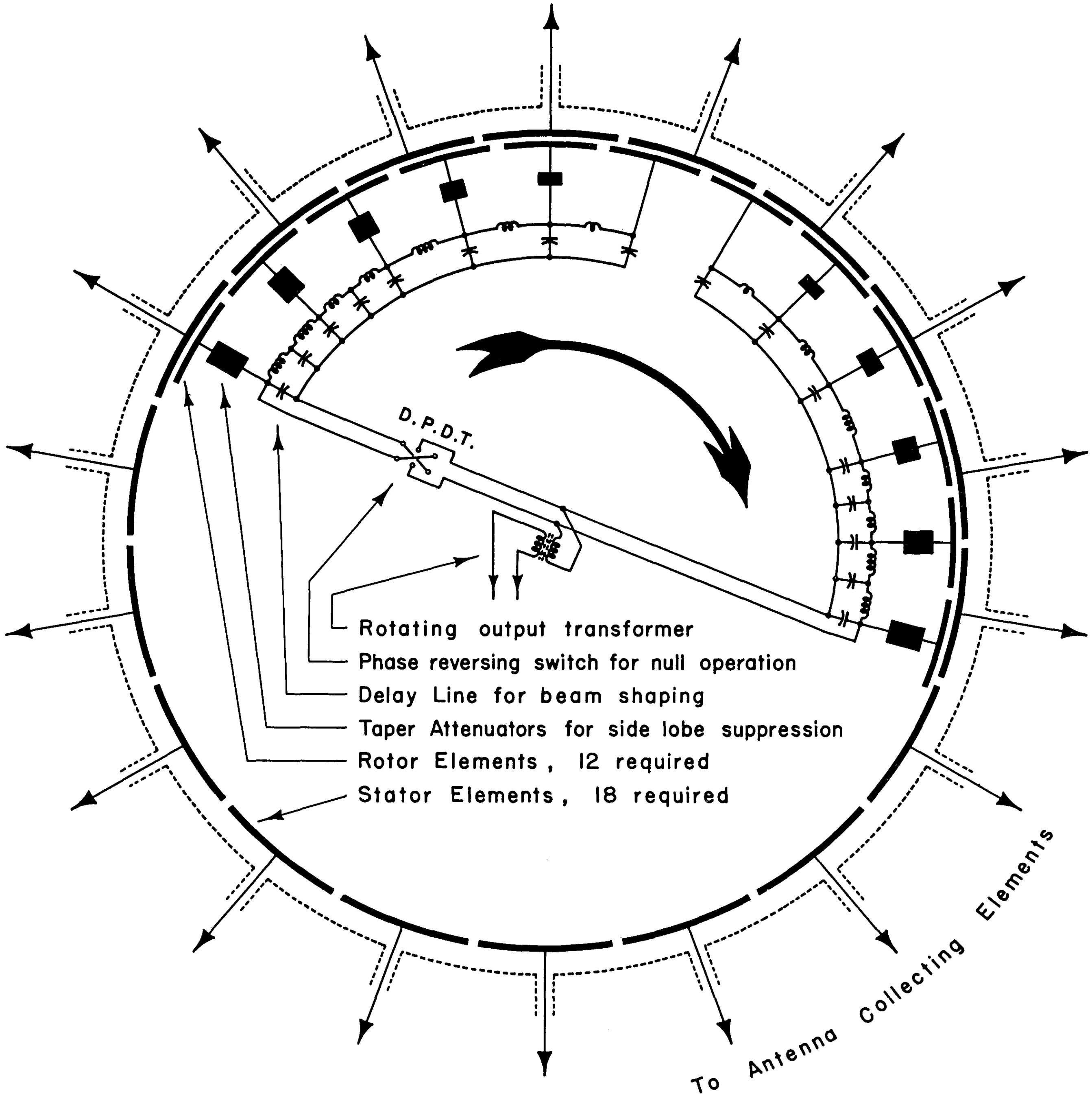


Figure 10



A "9/18" CDAA TAPERED GONIOMETER

Figure 11