LARGE ANTENNA SYSTEMS FOR PROPAGATION STUDIES

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The large parabolic antenna systems to be described represent the state in the art which had to be achieved in order to provide antenna systems for the NBS Central Radio Propagation Laboratory propagation studies. NBS has a three to six year responsibility for compiling data and making investigations in a program, sponsored by the Air Force, which will promulgate a standard communication handbook. This handbook is pointed toward developing accurate reference material so that any group desiring to establish a communication station anywhere in the world, will have available all the data necessary for the site selection and construction of scatter communication stations. The data to be assembled during these propagation studies will include information on those parameters which must be known for the effective location and operation of the station.

Large antenna systems of the type shown in Figure 1, are required to make reliable measurements of the total refraction of radio propagation through the entire earth's atmosphere. The general study as to reliability and the measurement techniques employed in the scatter communication art is described thoroughly in the October 1955 Scatter Propagation issue of the IRE. The scope of the measurements to be made by NBS will involve collecting valid data confirming those fundamentals which cover Path Geometry, surface refractive index, frequency gain function, atmospheric absorption, path antenna gain and attenuation factors. As may be analyzed by referring to the IRE October 1955 issue this data must be collected by the proper application of large antenna systems.

The NBS site locations between Boulder and Haswell in Colorado, were selected for the VHF/UHF work as it provides the terrain conditions which are required to develop the necessary propagation data.

NBS, in evaluating its requirements, established the following fundamental specifications which the writer digested from the NBS advertised bid for large paraboloidal antennas for propagation studies. These antenna specifications anticipate the environmental conditions in the area as well as the operational requirements.

ANTENNA REFLECTOR SPECIFICATIONS FOR PROPAGATION STUDY WORK

The prefabricated paraboloidal reflector shall be made of aluminum alloy and shall have a diameter of 60 feet and focal length of 25 feet. The surface material shall consist of perforated aluminum, maximum diameter of opening to be 0.25 inches. The maximum deviation of surface from a true parabolic shape shall be no greater than ± 1/4 inch at any point on its surface. This parabolic reflector is to operate with full precision in winds up to 30 mph and slightly reduced precision in winds up to 50 mph. Slightly reduced precision shall be interpreted as ± 3/4 inch. The reflector, when properly secured, shall be capable of withstanding winds up to 120 mph, with a maximum radial ice formation of three inches. The precision and rigidity is to be carried into and apply to the antenna supporting structure.

Reflector Mount Specifications:

The pedestal is to be of sufficient height so that the rim of the reflector will be at least five feet above the ground when the antenna is directed at any point on the horizon. The pedestal forming the tower shall form a closed truncated conical shaped housing. (The closed-in tower of the type shown in Figure 1, which supports the pedestal, allows electronic equipment to be installed in rooms that can easily be built in the tower at various levels).

The azimuth drive shall consist of a ring gear with bearing and shall include a servo motor which drives, through an appropriate gear reducer, a pinion gear which meshes with the ring gear. The servo motor output shall contain an azimuth brake. A second pinion gear will be required on the ring gear which actuates a feed-back system that shall contain high speed synchro generators with a tachometer generator.

The elevation drive assembly shall be mounted on a platform on the ring gear of the azimuth drive assembly. The drive will consist of a pair of screw jacks mounted on trunnions, and shall be driven by a servo motor connected by means of a gear train. On the motor shaft shall be mounted an elevation brake and tachometer generator. The motor, brake and tachometer generator shall be housed in a weather-tight case. A sector gear shall be provided, which by precision gearing shall drive the elevation feed-back system. Two high speed synchro generators are required.

The drive assembly shall provide complete azimuth coverage and elevation coverage, and shall extend from minus three degrees to plus one-hundred degrees. The drive shall have a continuously variable speed adjustment range of from 0 to 36 degrees per minute of time. This shall be a servo controlled drive system which shall permit control by a computer or programmer in addition to manual control. The settling time for a ten degree step on position change for either elevation or azimuth shall not exceed 15 seconds for a maximum slewing rate of 36 degrees per minute of time.

The drive system shall be operable from 120/208 volt, 60 cycle, 3 phase, 4 wire power source.

Back lash or free motion of the drives shall be limited to that which will permit position repeatability to be maintained to within plus or minus two minutes of arc. A tracking accuracy of plus or minus 2 minutes, as well as a static position accuracy of plus or minus 2 minutes is required.

A control system shall be provided to permit operation of the drive system from a remote location. The necessary controls and indicators shall be mounted in a suitable cabinet and be appropriately labeled.

Direct reading position indicating dials shall be provided to indicate, at a remote station, orientation of the antenna relative to an arbitrary zero setting both in azimuth and elevation. These indicating dials shall be calibrated in degrees and minutes and shall be accurate to within one minute of arc. Provision shall be made for zero-setting the dials relative to any antenna orientation.

Limit switches shall be installed in the drive circuits so as to prevent accidental damage to the antenna. They shall be so designed that they will not become inoperative or will not operate unnecessarily in the presence of icing or deep wet, or blowing snow.

The bearings, motors, and other vulnerable parts shall be fully enclosed to permit trouble-free operation over indefinite periods of time under conditions of severe blowing dust and sand.

The drive mechanism and limit switches shall be operable at temperatures ranging from minus 20 degrees F. to 120 degrees F.

The supporting structure reflector and feed system shall be designed to allow the antenna to operate at full precision in winds of 30 mph and at reduced precision with winds of 50 mph. When properly stowed, the antenna must be capable of withstanding winds of 120 mph with a maximum radial ice (Density 50 lbs/cu. ft.) formation of three inches.

(Figure 2 shows the pedestal which drives the antenna shown in Figure 1 and the operation which conforms with the specification).

<u>Antenna Feed System Specification for Illuminating the 60' Propagation Study Reflectors:</u>

The antenna Feed Systems shall be supplied and shall be such as to be easily installed and easily removed for replacement. The feed shall be such that the voltage standing wave ration shall be no greater than 1.3 to 1 over a 6 mc band when operating the antenna from a 50 ohm source. The system shall either be tunable over a range of 5% of the center frequency or meet these specifications over this range. The feed systems described herein shall provide an aperture illumination such that the energy at the extreme edges of the reflector surface shall be between 10 and 12 db below the energy throughout the center part of the reflector. RETMA standard fittings shall be used throughout the feed systems.

<u>Transmitting Feed Systems:</u>

These systems shall consist of a suitable radiator fed by air dielectric 50 ohm coaxial transmission line and shall meet RETMA specifications. RETMA 3-1/8 inch rigid coaxial line shall be supplied from the primary feed to a location a few feet above the ground. For the transmitting antenna, rotary joints will be required which are capable of withstanding 4 kw of power. This line shall run along the main fiberglass spar from the primary feed through the reflector surface and to a location at the axis of the torque tube. From this location the 3-1/8 inch coax shall be routed to the center of the pedestal where the second rotary joint shall be installed. The final run shall be inside the pedestal from the rotary joint to a location a few feet above the ground. Radius bends shall be used in place of mitred joints. An impedance matching device shall be included at the end of the run. The 233 mc feed system shall be designed so that it can be attached to the feed ring when the 1046 mc antenna is removed. Since only 2 kw of power is used for the 233 mc feed system, the insertion of a section of 1-5/8 inch Heliax cable with adaptors to 3-1/8 inch coax will be allowed:

a. Frequency: 1046 mc

<u>Polarization:</u> Plane - The feed system shall be sufficiently adjustable as to permit rotation through all angles from the vertical to the horizontal planes. It should be understood that this adjustment of the plane of polarization would be accomplished manually between periods of operation.

<u>Power Delivered to Antenna:</u> 4 kw cw
<u>Gain:</u> A minimum of 43 db relative to an isotropic radiator.

<u>Side Lobes:</u> At least 20 db below main lobe.

<u>Half-power Beamwidth:</u> No greater than 1.2°.

<u>Width Between First Nulls:</u> No more than 3.5.

b. Frequency: 233 mc

<u>Polarization:</u> Horizontal

<u>Power delivered to the Antenna:</u> 2 kw cw
<u>Gain:</u> A minimum of 30 db relative to an isotropic radiator.

<u>Side Lobes:</u> At least 20 db below main lobe.

<u>Half-power Beamwidth:</u> No greater than 5.2°.

<u>Width Between First Nulls:</u> 16°

<u>Receiving Feed Systems:</u>

The feed system shall include two 7/8 inch Heliax cables from the primary feed to a location a few feet above the ground. The two cables shall be strapped to the fiberglass spar and pass through the reflector at a location where the spar is attached. One line shall be routed to the left-hand end of the torque tube and the other to the right-hand end of the torque tube. Two rotary joints will be necessary, one at each end of the torque tube and on its axis. The two cables shall then be carried to the center of the pedestal where a double rotary joint shall be used. This rotary joint shall be on the azimuth axis. The two lines shall then run inside the pedestal from the rotary joint to a location a few feet above the ground.

a. Frequency: 1046 mc

Polarization: Dual polarized to permit simultaneous reception of both horizontal and vertical polarized signals.

Gain: A minimum of 30 db relative to an isotropic radiator.

Side Lobes: At least 20 db down from main lobe.

Half-power Beamwidth: No greater than 5.2°.

Width Between First Nulls: No greater than 16°.

The above is the general NBS propagation study requirement which meets the state of the art. These performance specifications were exceeded by the equipment to be described.

The designers in reevaluating these key points of specification decided to approach the maximum which could be realized in the state of the art so that the performance of the system could be extended for future NBS X-band studies which would extend the versatility of the system for the Government's end requirement as propagation studies are planned in the overall handbook program. However, the NBS X-band studies would be limited by the surface accuracy of the large parabolas. The large antenna systems to be described are now in operation at Boulder and Haswell, and have met and exceeded many of the performance specifications outlined in the foregoing; specifically, the surface accuracy was improved to allow X-band operation. In order to develop the propagation antennas shown in Figure 1, it was necessary to make an analysis of both the structural and mechanical design considerations under the environmental conditions in conjunction with the control system necessary for precision positioning of the large antenna systems. The following is the analysis which promulgated the designed products:

STRUCTURAL AND MECHANICAL DESIGN OF LARGE ANTENNA REFLECTORS AND MOUNTS UNDER SPECIFIC ENVIRONMENTAL CONDITIONS:

The National Bureau of Standards antenna design bears the severe environmental conditions of having to survive 120 mph winds with a three inch ice load. This antenna system has to operate within the tolerances applied to the antenna against a 50 mph wind load. Under this operating condition, the design was made to realize a reflector surface accuracy of better than $\lambda/16$ the wavelength from the focal point to any point on the reflector. Another criteria for determining the condition under which the reflector is "working", is that the deflection shall be no more than 3/4 of an inch under the climatic operating conditions of 50 mph wind load. By setting up tight deflection requirements a reflector can be built that will be capable of withstanding very severe wind loads; i.e., the very low stresses required at the operating wind load in order to keep deflection at a low value, will result in moderate stresses at very severe wind loads.

Two views of the actual antenna reflector which incorporates those features of design and manufacture that allow compliance with the severe environmental specifications are shown in Figures 3 and 4. It may be noted, by referring to these figures that the design consists of the following components: the ring truss, which acts as the main supporting structure; the flat truss, which acts as the reflector supporting structure; the reflector panels, which provide the reflecting surface, and the three fibreglass feed supports. The ring truss is a triangular structure that carries the main load of the assembly. It has been designed to the specific shape and configuration shown to produce a unit that is capable of analysis by recognized methods. The fibreglass feed supports, called spars, shown in Figure 5, are specifically designed to preclude sag so that the antenna radiator and its position of accurate focus does not change due to rigorous operation or aging. This feat is accomplished by supporting the ends of the spars on the heavy rigid main structural support ring. The other end of the spar is provided with a moment connection that will prevent rotation under loading conditions. These spars are so designed that they can support a 1,000 pound cupola and feed with a maximum deflection of .015. A thorough investigation had to be made with those engaged in plastics research so that NBS could be guaranteed that these spar supports would maintain with full reliability their physical integrity under the rigorous operating environmental conditions over the longevity expected for these antenna systems.

Considerable study was made of the design of this structure, and its production tooling and fabrication was based upon the availability of large machine tools. By virtue of the tooling, the antenna's reflecting surface could be made up by assembling only three different sizes of panels, as may be noted by a close inspection of Figures 1 and 4. This design and associate tooling, besides cutting costs of production, solved a major problem of field replacement, since any panel is interchangeable with any other panel. This interchangeability can only be realized by precise production tooling. Further, the truss sections, which form the backbone of the design, are also standardized and interchangeable, should they become damaged in the field. This is important, as experience has shown, that field damage is common in remote areas with minimum skilled labor available or accidents due to installation work being done under arduous conditions. Figure 6a through Figure 6e show the installation and assembly of the NBS antenna system which can be made in accordance with the sequence of stages indicated to produce the product shown in Figure 1 by four men in six days with the assistance of a crane and normal installation tools, assuming good weather, and all material available at the installation site.

By reference to Figure 1, it may be noted that the reflector is linked to the antenna mount by means of a tubular steel shaft forming the elevation axis. This shaft is connected to the pedestal proper by means of a yoke, which acts to carry the loads imposed on the reflector down to the main azimuth bearing. The drive system utilized to give motion about the elevation axis consists of a pair of ball-screw-jacks linked to a servo controlled drive system. This same drive system is employed to give rotation about the azimuth axis. In this case, the drive system meshes with a gear cut on the main support bearing. In order to provide faster rates for tracking applications, the screw-jacks employed for elevation adjustment would be replaced by a large sector gear. The mechanical system, as designed against the rigid environmental specifications, will allow the application of 90' or larger antennas under less severe environmental conditions, or under the weather protection of a radome. A detailed study has enabled the design engineers to set up a table of designs for various sizes of reflectors under specific operating parameters which function with adaptions of this pedestal. In this way, a single design and production principle is employed to develop a number of antenna system equipment packages which can be used for numerous applications involving propagation and space studies, including satellite tracking. By relatively simple gear changes the antenna drive speeds may be adjusted for .1, .2, or .5 rpm. Motor changes are necessary for the higher tracking rates.

SERVO SYSTEM FOR PRECISION CONTROL OF LARGE ANTENNA SYSTEMS

The requirements of an effective servo control for large antennas are:

1) Smooth tracking at all speeds.
2) Rapid tracking.
3) High accuracy.
4) High speed slewing.
5) Reliability.

The NBS specification dictated that a separate low power servo motor, and high power slew motor, be used. These reasons for this were that servo motors having the power required to drive the antenna at the required slew speeds are generally not available, and if a special motor were to be built, the price would be prohibitive; and that when the power requirements for slew mode are low enough for a servo motor to be used, it is generally not desirable to do so because the speeds of the servo motor at signal levels would be too low. It is generally preferable to operate the servo motor near maximum speeds for maximum tracking rates as this will provide smooth tracking operating at the lower speeds. The problem is still further compounded by the requirement for complicated gearing and clutching arrangements when two motors are required. A satisfactory solution to the above was found in the eddy-current clutch system.

As a major control component, it would be fairly safe to say that the use of the eddy current clutch in the closed loop control of large antenna systems is a relatively new and little used technique. The eddy-current clutch consists of an output member and an input member where use is made of the fact that a metallic disk rotating in a magnetic field has eddy-currents induced in it, and electromagnetic forces are set up between the eddy-currents and the magnetic field, therefore, mounting an electromagnetic yoke to the shaft of a drive motor, which is considered the input member rotating at constant speed, and a metal disk, which serves as the output member, to the load shaft, power may be transferred from the driven shaft to the load through electromagnetic forces. The amount of power transmission between the input member and the output member will be proportional to the magnetic field, which in turn is proportional to the clutch excitation.

The use of the eddy-current clutch for the large antenna system application affords several distinct advantages:

A) There is a smooth transmission of power from the very lowest of speeds until slew speeds.

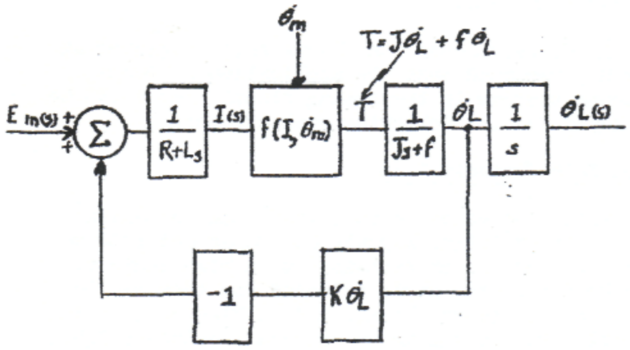
B) There are no commutators or slip rings, as there are on D.C. motor drives, and so higher reliability, and R.F. noise-free operation, is obtained. This R.F. noise-free condition is vital to propagation study work where the researcher is working with incremental signals.

C) The drive motor is continually turning at full speed. Thus, by utilizing the inertia of the motor, higher accelerations may be achieved with a smaller motor than would normally be necessary.

D) The servo system is made independent of the characteristics of the motor, and is dependent only on the clutch.

TRANSFER FUNCTION, WHICH CAN BE MADE VERY GOOD.

A brief linearized analysis of the eddy-current clutch is shown below:



R - Resistance of Clutch Field

L - Inductance of Clutch Field

$\dot{\theta}_m$ - Speed of drive motor

J - Inertia of Load and moving parts of clutch

f - Friction and Windage

$\ddot{\theta}_L$ - Acceleration of load

$\dot{\theta}_L$ - Velocity of Load

θ_L - Angular Position of Load

$f(I, \dot{\theta}_m)$ - Function relating torque to field current and motor drive velocity.

$K\dot{\theta}_L$ - Proportionality constant relating load speed to feedback voltage.

The torque developed is a function of the drive motor speed and the clutch field current. Since the drive motor speed is kept constant, $f(L, \dot{\theta}_m) \approx K_T$

Thus:

$$T = K_T(s)$$

Since the torque developed is a function of the slippage of the clutch, the higher the velocity of the load shaft, the greater voltage being fed back, producing a smaller torque. This accounts for the negative sign in the feedback transfer function. $K\dot{\theta}_L$ is merely the proportionality constant relating the output speed to the feedback voltage.

The overall transfer function is:

$$\frac{\dot{\theta}_L(s)}{E_m(s)} = \frac{\dfrac{K_T}{s(Js+f)(R+Ls)}}{1 + \dfrac{K\dot{\theta}_L K_T}{(Js+f)(R+Ls)}} =$$

$$\frac{K_T}{s\left[LJs^2 + (JR+Lf)s + fR + K\dot{\theta} K_T\right]}$$

However, $L \approx 0$

$$\frac{\theta_L(s)}{E_m(s)} = \frac{K_c}{s(T_c s + 1)}$$

$$K_c = \frac{K_T}{fR + K_L K_T}$$

$$T_c = \frac{JR}{fR + K_L K_T}$$

For high performance and fast response systems, it is desirable to have Tc as small as possible. In the eddy-current clutch now in use, Tc = 0.1 sec. However, through special construction, this could be made better.

The system using the eddy-current clutch was built for the National Bureau of Standards. The N.B.S. 60' antenna is positioned to an accuracy of 1 minute of arc while tracking at 0.1 r.p.m. in winds up to 30 m.p.h. Although these were minimum requirements, tests made on the system show much better performance under environmental conditions.

The transmission is a 2-speed (FINE-COARSE) synchro system, thus giving a high accuracy data transmission system. The amplified signal is fed to a pair of eddy-current clutches. Tachometer feedback is used to maintain system stability. The system built for N.B.S. contains a Speed Programmer. The Speed Programmer permits the following operating conditions:

A) Set the antenna to any desired position.

B) Drive the antenna at any desired velocity.

C) Rapidly slew the antenna system into position for missile tracking.

Speed programming is accomplished by driving the synchro transmitter by means of an instrument servo. The speed of the servo is determined by an accurately calibrated reference voltage. The position servo driving the antenna system is then used to track the output of the rate servo.

Tracking and speed programming could also have been accomplished by feeding rate information directly to the receiver, and using it in a rate mode. However, by using a separate rate servo, the accuracy in tracking can be made insensitive to varying wind loads and component gain changes. In addition, although the effective gear ratio changes in the elevation axis, the use of special non-linear pots is avoided.

In the N.B.S. system, a means was provided whereby the antenna system may be controlled either from a remote source, or from a local console. The advantages of this from a testing or servicing viewpoint is obvious.

THE SPECIFIC ANTENNAS EMPLOYED FOR THE NATIONAL BUREAU OF STANDARDS REQUIREMENT:

While the physical design of the fibreglass supports of the units, shown in Figure 5 can handle the loads of a wide band antenna radiator network, a conical scanner, or a monopulse feed system, security requirements preclude an analysis of these applications at this time. Therefore, the discussion which follows is confined to the requirements which were met by antenna designs specifically made for the N.B.S. propagation studies. The N.B.S. antenna systems consist of three (3) separate sixty foot paraboloidal reflectors with associated feeds. One antenna will be used for transmitting; the other two for receiving. Two separate frequency bands are employed, one centered at 233 mc/sec, and the other at 1046 mc/sec. The bandwidth is narrow, and amounts to ± 2-1/2% about the center frequencies aforestated. The reflector is made of aluminum alloy of mesh type construction. The respective feeds are located 25 feet in front of the vertex, and held rigidly by a fibreglass spar construction.

The transmitting antenna operates at both 233 mc and 1046 mc bands. The 233 mc band is achieved by placing an array of two British slot fed dipoles with parasitic reflectors at the focal point of the dish, as shown in Figure 7. The latter frequency is accomplished when the dipoles are replaced with a horn feed. At the 233 mc band, the polarization is horizontal, the power delivered to the antenna is 2 kw cw, the gain is 31 db, side lobes are at least 20 db below main lobe, the half-power beamwidth is 4.5° in both principal planes, and the null beamwidth is 11°. At the 1046 mc band, the polarization is linear, but can be oriented in any attitude from vertical to horizontal. The power delivered to the antenna is 4 kw cw, the gain is 43 db, side lobes are at least 20 db below main lobe, half-power beamwidth is 1.2°, and the null beamwidth is 3.5°. Figure 8 pictures the patterns described.

The two receiving antennas are alike. Each one will operate at both frequency bands by feed replacement. The 233 mc receiving feed is identical to the transmitting dipole array. The 1046 mc feed is a bipolarized horn. Consequently, there will be maximum sensitivity to either vertical or horizontal polarizations. Microwave characteristics of gain, pattern, and impedance, are the same as those mentioned in conjunction with the transmitter data.

Mr. A. F. Barghausen, the Electronics Engineer at N.B.S., reported that the application of large antenna systems in the coming fiscal year would be employed for the following evaluations:

Long Path Obstacle Gain:

The intent of which is to investigate the characteristics of fading signals at 100 mc and 1000 mc over the very rough terrain with a high angle to the horizon. The angle selected for test may be 5° or more. As may be noted from Figure 1, it is expected to use the upper antenna located on Table Mesa, North of Boulder, looking toward the West into the high mountains.

Medium Bandwidth Studies:

The purpose of this program is to evaluate the medium bandwidths at 400 mc and 1000 mc over scatter paths. N.B.S. plans to transmit and receive at slightly different frequencies, which may be variable, and investigate the amount of frequency separation that can be realized before the two signals become uncorrelated. This investigation will be conducted at both 400 and 1000 mc and multiple feeds will be required as the radiating source.

Loss in Antenna Gain:

The purpose of this investigation will be to determine the path antenna gain at 400 mc and 1000 mc by using antenna sizes ranging from the small 6' antennas to the 60' antennas described in this manuscript.

Antenna Patterns:

An investigation will be made to carefully determine the normal patterns at various frequencies of the 60 foot antenna to accurately evaluate the amount of back and side lobes present in connection with solving communication site problems.

Diversity Studies:

A study will be made of the comparison between signals received on spaced antennas at 400 and 1000 mc by employing the principle of space diversity.

Phase Stability Studies:

The intent is to study the mean value of the electrical length of the Boulder-Haswell path and its variation by means of phase measurement techniques at 400 mc using the 60 foot diameter antennas. Reference is made to the paper by J. W. Herbstreit and M. C. Thompson in the October 1955 issue of the Proc. I.R.E. for a detailed explanation.

Figure 9 shows a 250' antenna system design similar to the Jodrell Bank installation. This design and others of sizes from 60 feet to 210 feet are being scheduled for interstellar space program investigations in the near future. At time of writing, a 210 foot parabolic antenna system has been funded for 1960 installation in Australia.

Feed systems of the type shown in *Figure 10, which function from 300-3000 mc, are typical for the 250 foot antenna function where broadband operation is necessary for the wide scope of operations planned for future space investigation programs. These larger paraboloids have a 100 foot focal length so that the F/D ratio will be high enough to favor design of a feed system over the wide frequency range. While the smaller parabolas (60' - 140') antennas may allow secondary measurements to be made; the designer of the feed systems for the larger antennas must make complete primary pattern measurements over the wide band of frequencies involved if he is to effectively estimate the performance of the complete reflector and feed system.

There is considerable antenna research being done in all frequency bands as the art expands and more knowledge is gained. However, all future work anticipates the need for large paraboloidal antenna systems. These large antenna systems of the types described are destined to picket the earth as we race for leadership and continue investigations into the mysteries of the universe.

* "A Wideband Antenna System for Solar Noise Studies--IRE, Jan. 1958".

Fig. 1.

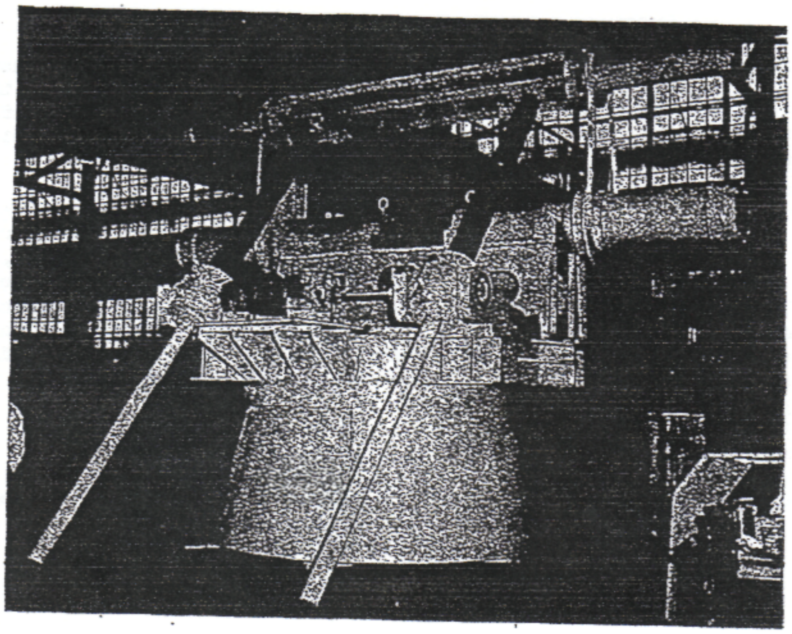


Fig. 2.

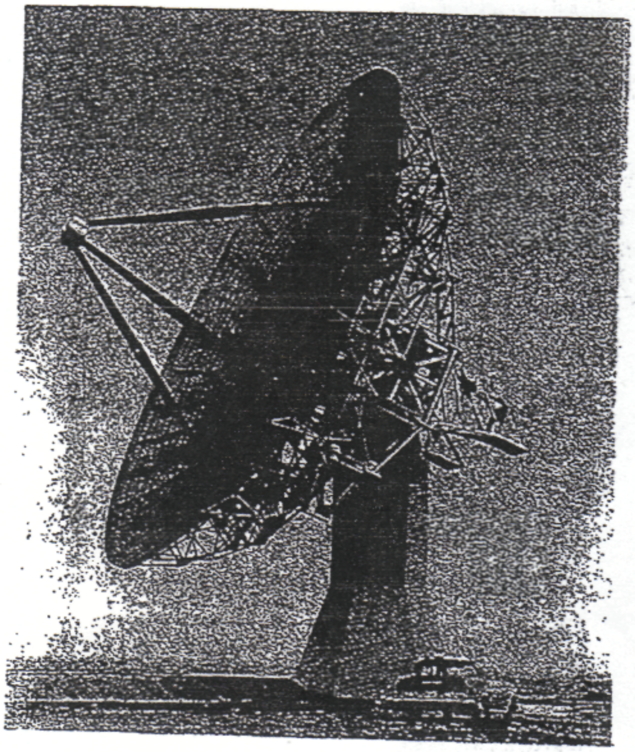


Fig. 3.

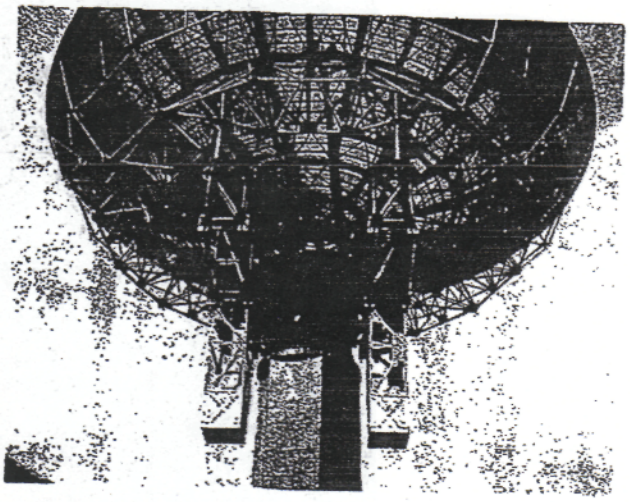


Fig. 4.

Fig. 5.

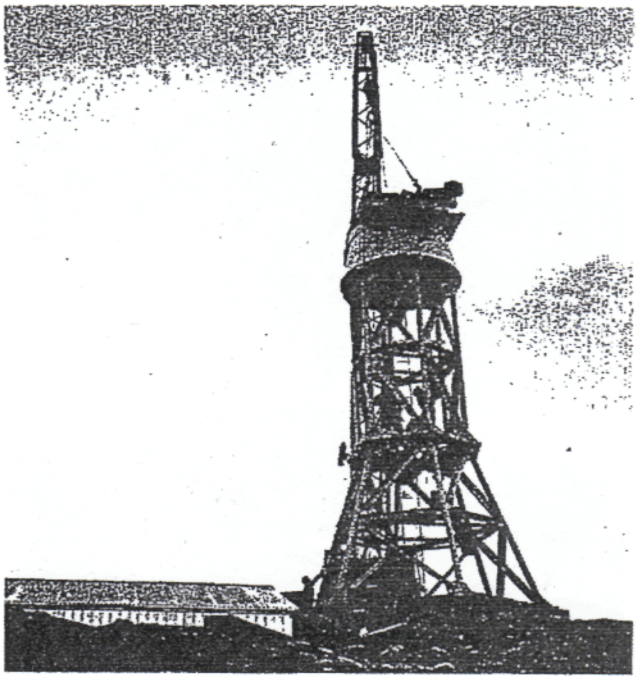


Fig. 6a.

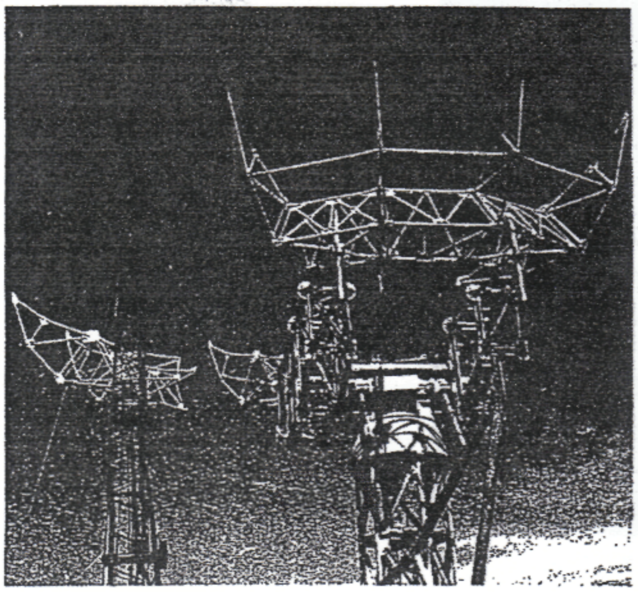


Fig. 6b.

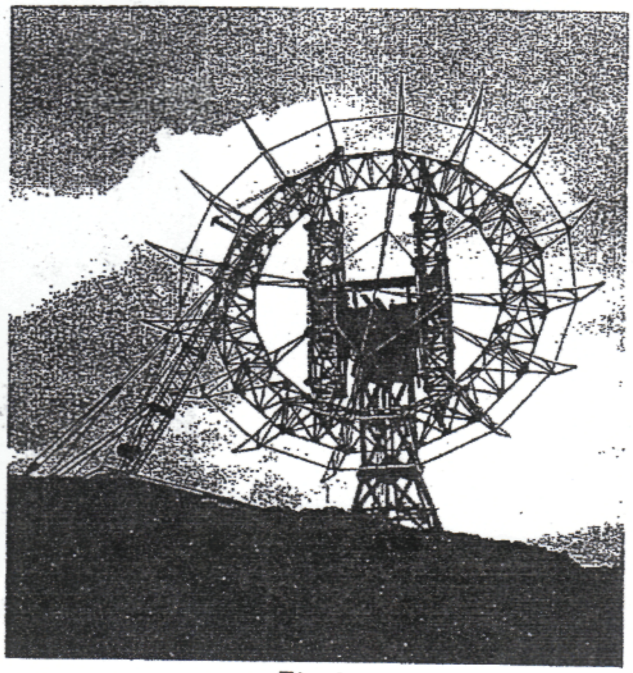


Fig. 6c.

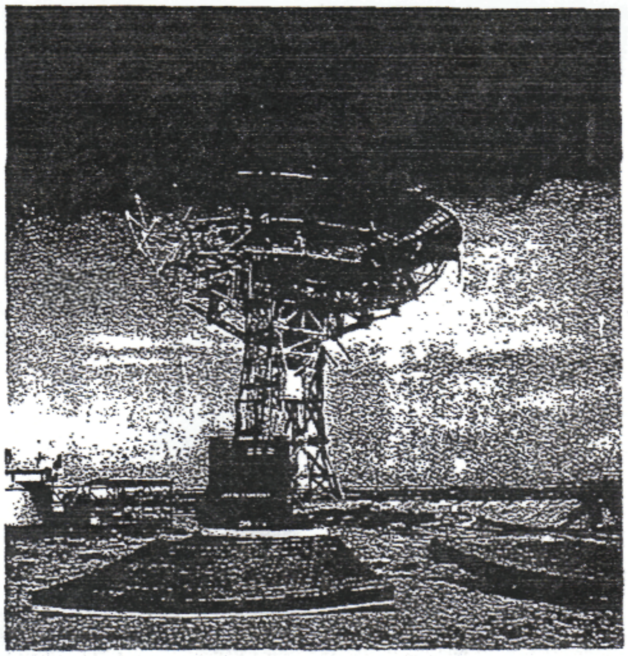


Fig. 6d.

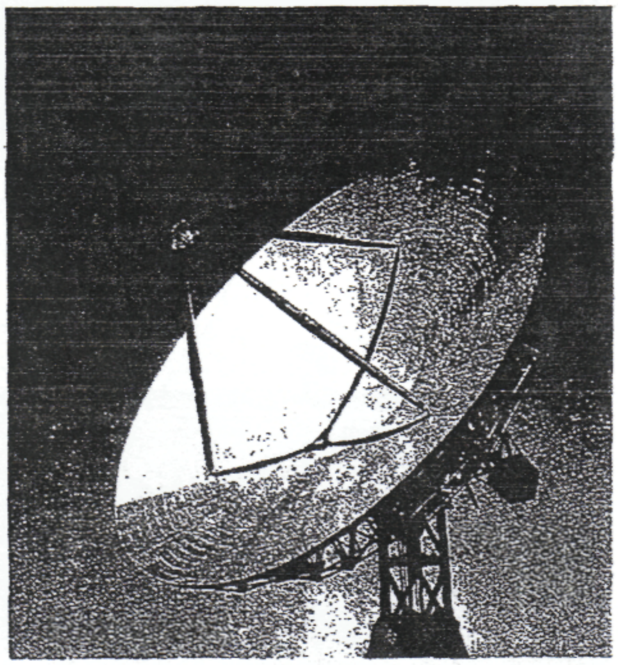


Fig. 6e.

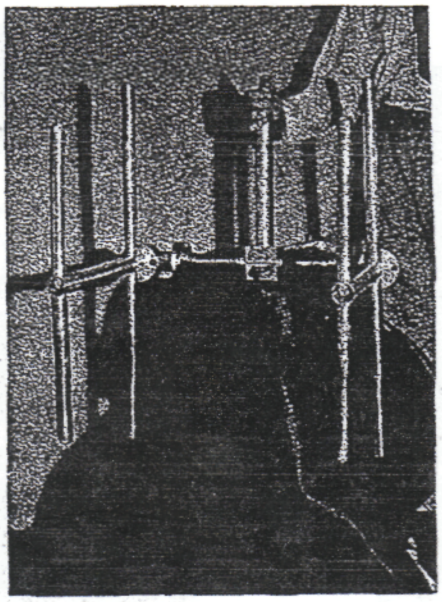


Fig. 7.

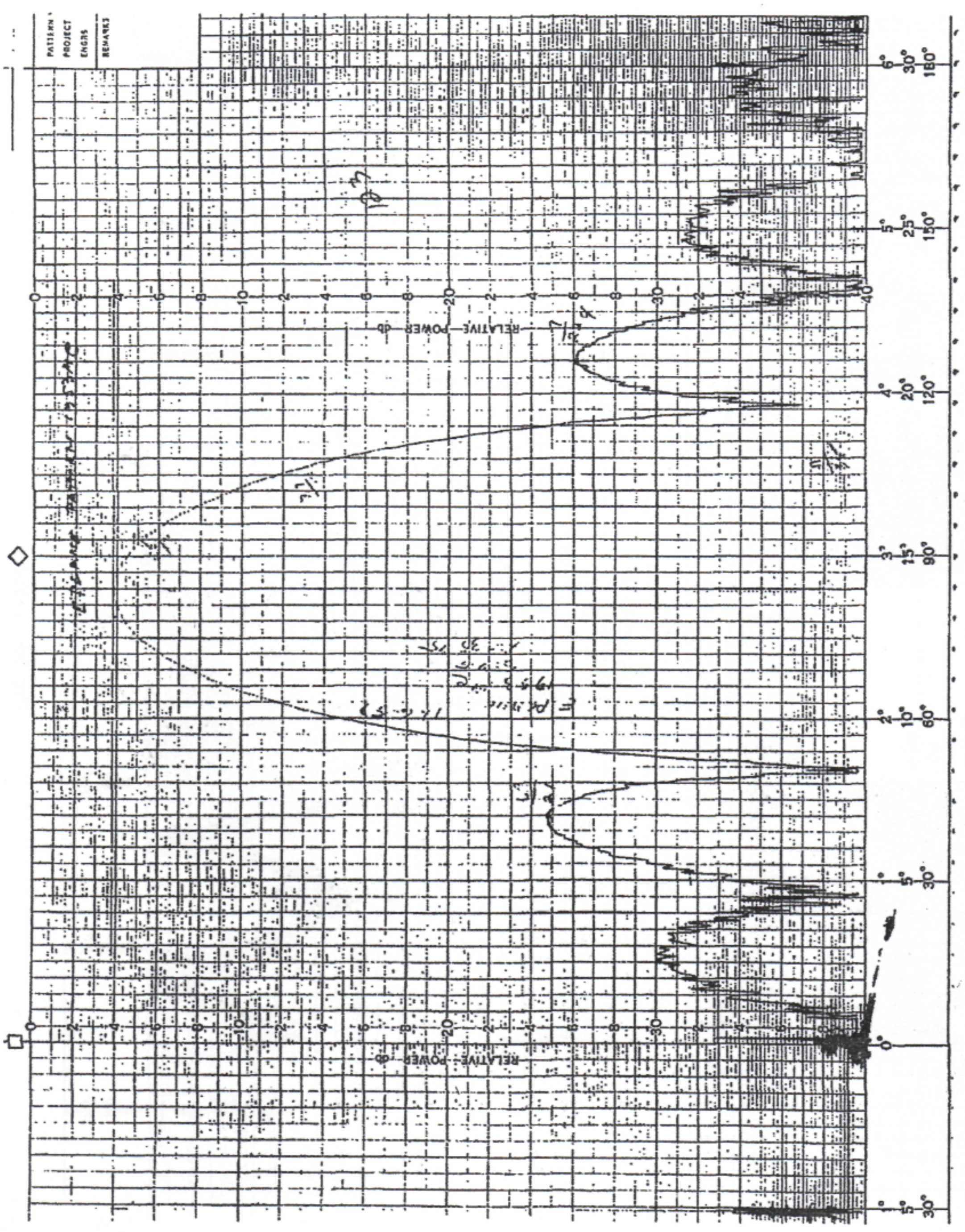


Fig. 8a. E plane.

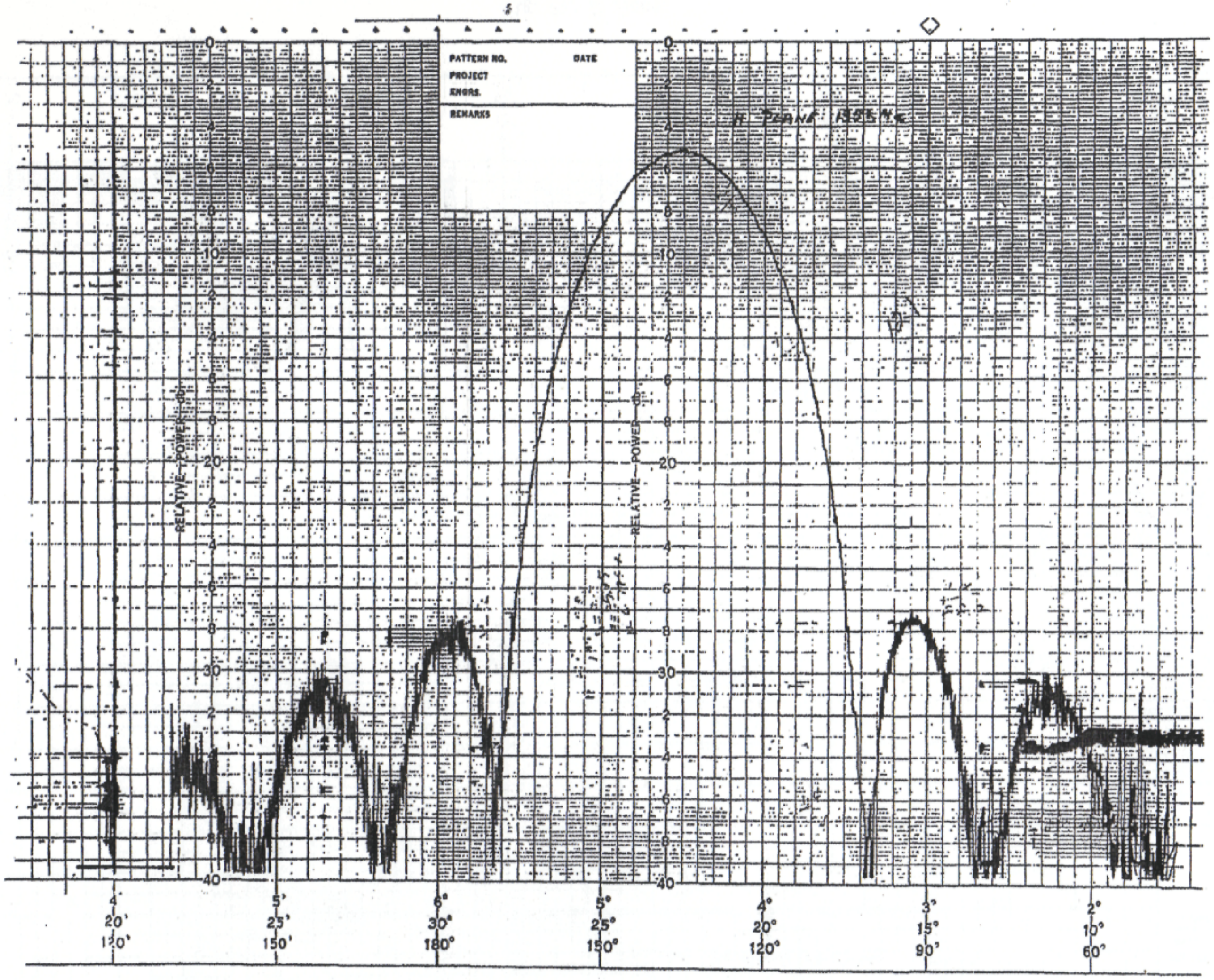


Fig. 8b. H plane

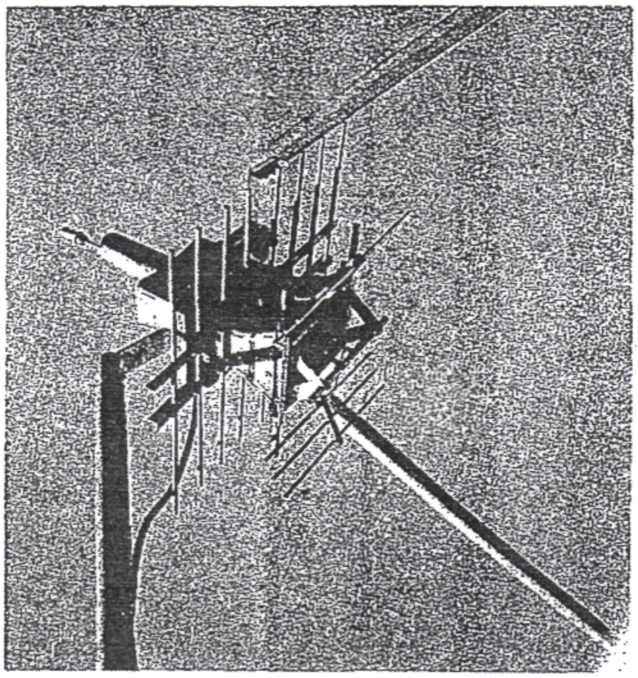


Fig. 9.

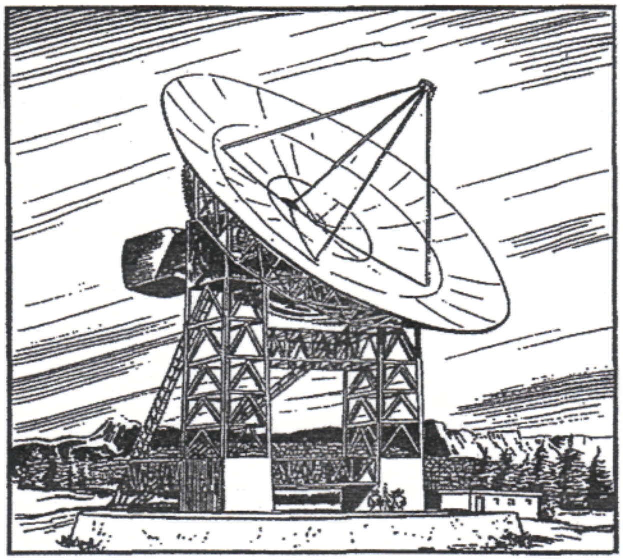


Fig. 10.