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HIGH GAIN ANTENNA ARRAY FACILITIES
AT THE OHIO STATE UNIVERSITY

by

J. W. Eberle

Contract AF 30(602)-2166
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| Submitted by | J. W. Eberle Antenna Laboratory Department of Electrical Engineering |
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ABSTRACT

A description is given of an antenna array consisting of highly accurate 30 foot diameter parabolic reflectors that is being installed at the Ohio State University. The antenna is to be used in experiments dealing with communication systems employing passive reflectors in orbits about the earth. The techniques that will be used for coherently combining the signals, for acquiring the signals in the presence of doppler and for automatic tracking is given. Experiments that are planned using the array as a high gain low noise antenna are given.

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HIGH GAIN ANTENNA ARRAY FACILITIES AT THE OHIO STATE UNIVERSITY

I. INTRODUCTION

The purpose of this report is to describe a four element array that is now being installed at The Ohio State University. Work at the University has indicated that for extremely high antenna gain with accompanying low noise characteristics, the array approach is superior to the single aperture antenna.^{1,2} The array to be described is one phase of a program that deals with the development of an antenna having a gain of 70 db, a bandwidth of 10% of the operating frequency and scanning capabilities of 360° in azimuth and $\pm 60^\circ$ about zenith.

An artists conception of the array is shown in Fig. 1. Figure 2 shows the present state of the array construction. It consists of four highly accurate parabolic reflectors mounted so they be scanned throughout the range of 360° in azimuth and $\pm 60^\circ$ from zenith without aperture blockage. The mounts have additional range in elevation so that three of the elements may be used down to an elevation angle of zero degrees to the horizon.

The description to follow will cover in general terms each of the components in the array, including the hardware items and the electronic equipment for signal combination, the equipment for signal acquisition and the automatic tracking equipment.

Presently the array is being instrumented for operation in the 2000 mc band and the equipment to be described has been designed for this frequency band. At 2000 mc, the array will have a gain of 49 db and be the equivalent of a single aperture 60 foot in diameter.

II. ARRAY DESCRIPTION

This section will be divided into sections, with each section being concerned with one particular component in the array. References will be made to technical reports that describe in detail the various systems or concepts in more detail whenever possible.

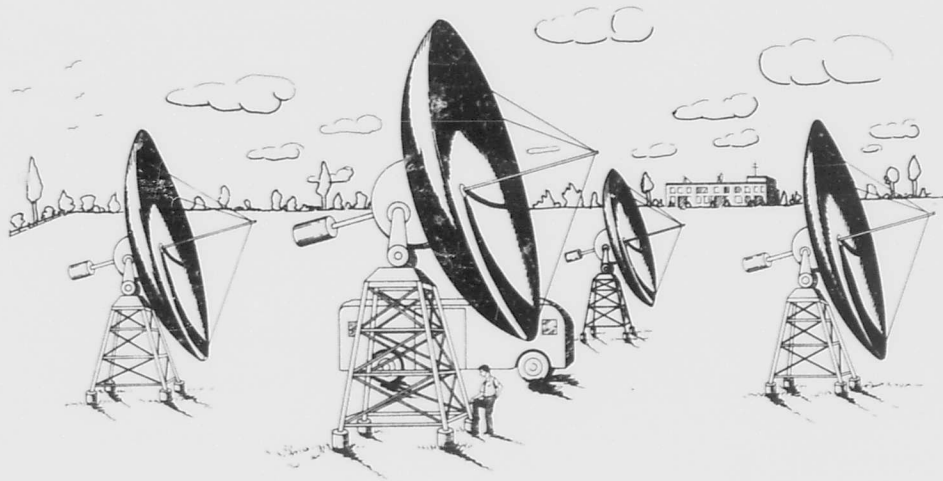


Fig. 1. Artists conception of the complete installation.

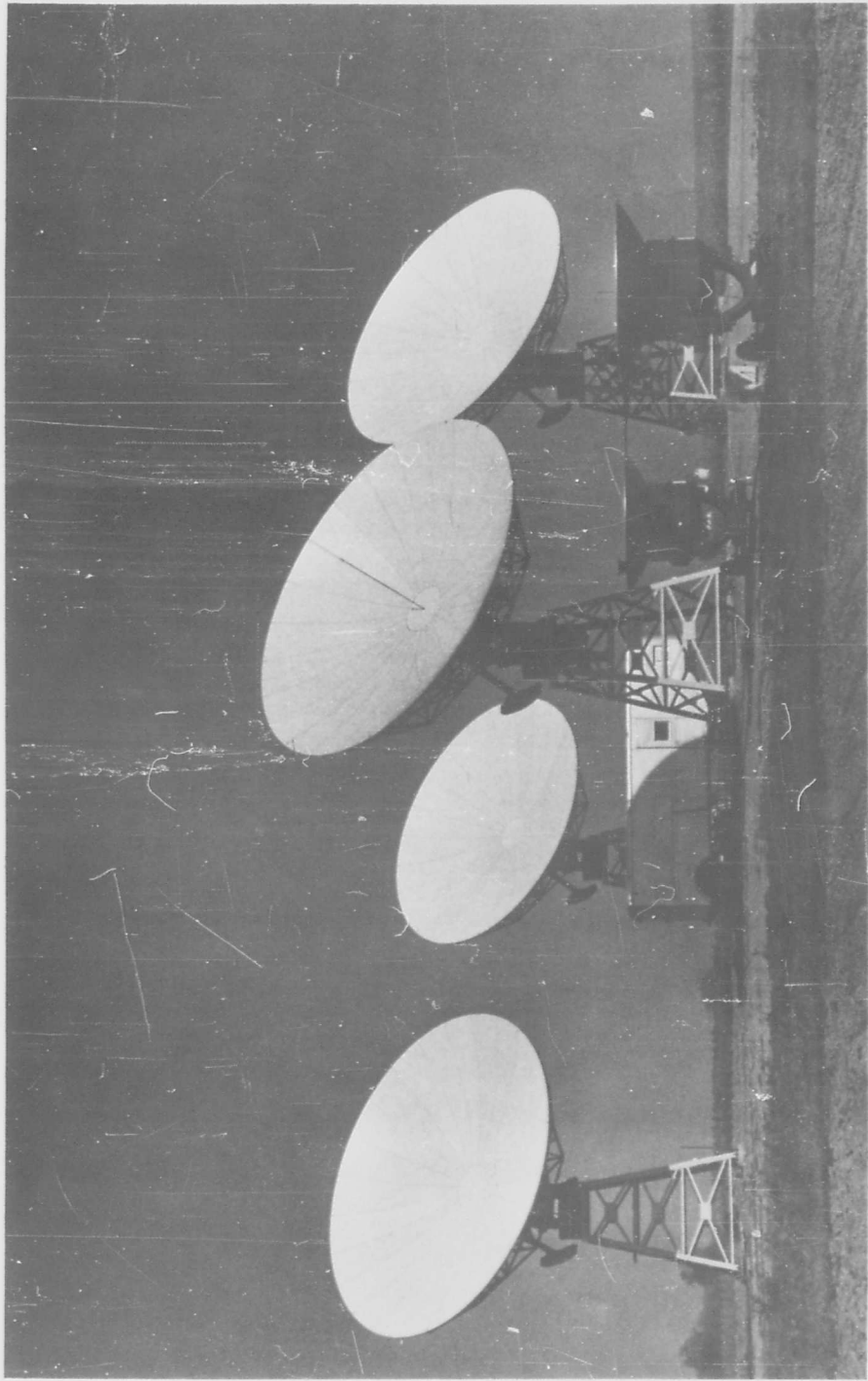


Fig. 2. Picture of array as it is now. (September 1961)

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A. General Description

The antenna array will consist of four large parabolic reflectors arranged on the corners of a square having a side length of 60 feet. The diagonals of the square are located in precise north-south and east-west directions. Approximate location of the antenna is at $40^{\circ} 0' 0''$ north latitude and $83^{\circ} 2' 30''$ west longitude. Elevation of the antenna above sea level is 775 feet. As can be seen in Fig. 1, an equipment van is located at the center of the array. This will be used as a central control center from which the array can be operated. Equipment in the van will consist of the signal processing system which coherently combines the signals from the four antennas; the automatic tracking electronics which processes an error signal from a tracking feed located at one of the antennas and feeds it to the servo controlled antenna mounts for automatic steering; and the necessary support and recording equipment.

The antennas, although completely independent mechanically, can be locked together by means of servo systems located in the antenna mounts. Thus the antennas can be made to collimate for all angles of scan or can be independently controlled depending on the desired mode of operation.

B. Foundations and Support Towers

For accurate collimation of the four antennas, an extremely sturdy structure is needed on which to place the antennas and mounts. It is imperative that the four axes of rotation in the azimuth plane be parallel in order that the antennas collimate throughout the scanning range. Thus such conditions as differential settling of the four support towers with respect to one another or with respect to themselves cannot be tolerated. For this reason, a concrete pad type of foundation was chosen for each of the towers. The concrete pads are 18 feet square, one foot thick and are located at a depth of 6 feet below grade. Steel reinforcing rods are placed in a mesh pattern through the pads to give it structural strength. Four concrete columns of reinforced steel construction are keyed to the concrete pad and extend approximately one foot above grade in order that the tower legs may be attached to them. Adjustable anchor bolt construction is used in order that final leveling adjustments can be made with the weight of the antenna and mount on the tower and foundation. When the final adjustment is made, the space between the top of the column and the bottom of the leveling plates on each leg of the towers will be grouted for protection of the adjustments and added strength.

The structural steel towers are constructed from standard angle stock and are designed, along with the foundations to withstand a 100 mph wind with a minimum of distortion. The tower has been designed so that at a later time when transmitters are incorporated into the array, the towers can be enclosed to make spaces for the final amplifiers of the transmitters. This would form a suitable enclosure having adequate RF shielding for personnel protection and equipment shielding.

C. Antenna Servo Mounts

The servo controlled mounts that position the parabolic reflectors are of the elevation azimuth type. The mounts, one of which is shown in Fig. 3, are designed to give a pointing accuracy of 0.1 degree in winds up to 35 mph. Maximum speed of rotation in both elevation and azimuth is 1/3 revolution per minute. The mounts can be controlled independently or together by manual control through their servo systems or can be automatically steered by means of an error signal from an auto tracking system. The mounts are designed to withstand wind loads of 100 mph when the antennas are stowed looking at the horizon. Stowing in this position prevents an accumulation of snow in the antennas.

D. Antennas

The parabolic reflectors used in the array are 30 feet in diameter and have a solid surface for extremely high frequency operation. The solid surface deviates from a true paraboloid by ± 0.080 inch maximum and has an RMS tolerance of 0.040 inch. The antennas have a focal length of 12.5 feet giving a standard f/d ratio of 0.417. The antennas are constructed entirely of aluminum in order to equalize thermal expansion in the structures.

The antennas will be used first at 2 KMC for communication experiments to be described. Due to the solid surfaces and the high accuracies, operation will be extended to 10 KMC and to 35 KMC. Figures 4 and 5 show one antenna during and after construction.

E. Antenna Feeds

Because of the low noise characteristics desired in the antenna, special consideration has been given to the design of the antenna feeds, as one of the major contributors to antenna noise is the amount of noise power from high temperature surroundings radiated into the antenna feed around the edge of the reflector. By



Fig. 3. Picture of the mount.

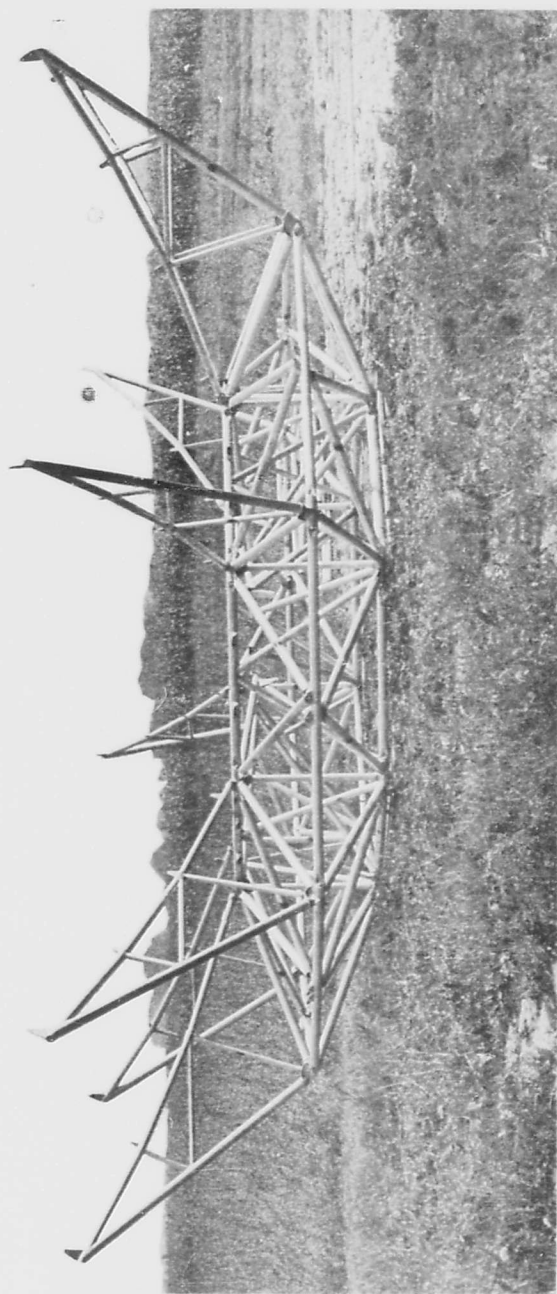


Fig. 4. Picture of partially assembled antenna.



Fig. 5. Picture of completely assembled antenna.

properly choosing the taper in field strength across the antenna aperture due to the feed, the noise introduced into the feed by the "spillover" around the reflector edge can be significantly reduced. Normally the feed taper is chosen around 10 db at the edge of the reflector for an f/d ratio of 0.417. This results in maximum gain from the reflector. When the feed taper is chosen around 16 db³ to the reflector edge, the gain of the antenna is reduced but the signal to noise ratio available from the antenna is increased because of a great decrease in the noise power radiated into the antenna. For this reason the antenna feeds have an amplitude taper of greater than 15 db from the center of the reflector to the edge.

The feeds have also been designed to have dual orthogonal linear polarization characteristics so that compensation can be made for a change in the plane of polarization due to Faraday rotation or to reflection characteristics of the passive reflectors.

F. Signal Processing Equipment

The equipment that coherently combines the signals from the four array elements makes use of the phase lock principle, which has been used extensively in receiving signals from deep space probes. A block diagram of such a system is shown in Fig. 6, where the input

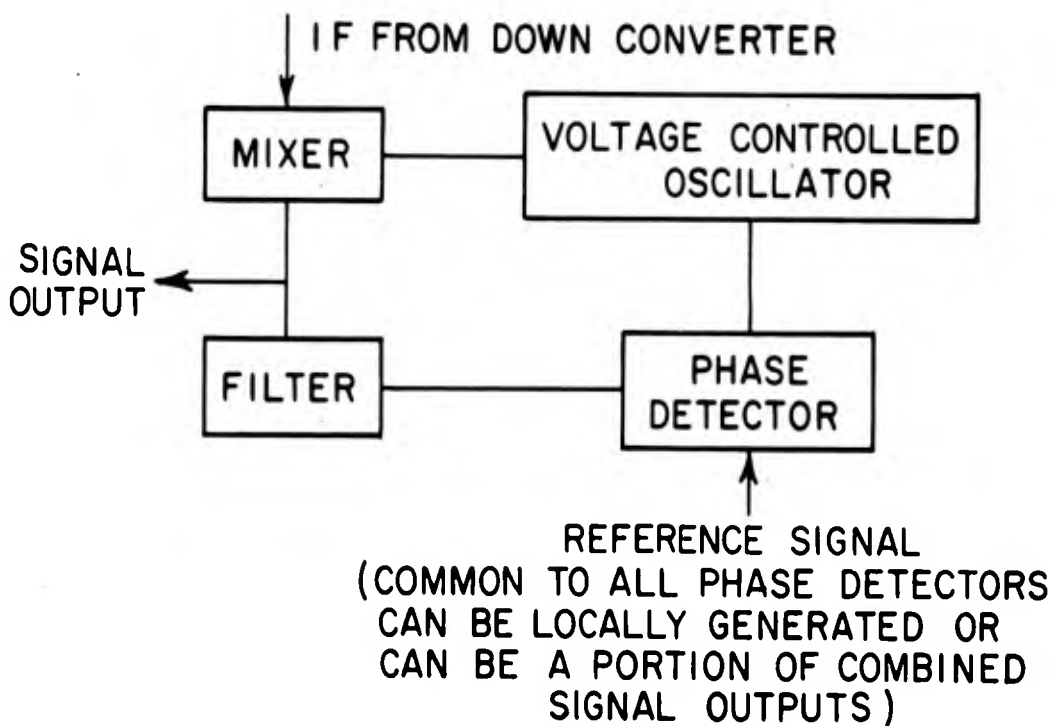


Fig. 6. Phase locked loop for coherent addition.

signal from the array elements are at an IF frequency. The operation of the loop is dependent upon the voltage controlled oscillator, which corrects for phase error effects between the IF input signal and the reference source.

The purpose of the narrow band filter in the loop is to decrease the bandwidth so that an increase in signal to noise ratio can be obtained for proper operation of the loop. The narrow band filter selects some component of the IF signal, such as the carrier. This component is then compared in phase with the reference signal in the phase detector. If the two signals are not in phase quadrature, an output error will exist at the phase detector. This error is then used to control the frequency of the voltage controlled oscillator, the output of which is mixed with the incoming IF signal, thus forming a closed loop electronic servo.

The effect of the feedback loop is to constantly maintain the incoming IF signal and the reference signal in phase quadrature, irrespective of a frequency or phase variation of the IF signal.

In the signal processing equipment, there will be four independent phase lock loops, one each associated with each of the array elements. The reference signal into the phase detectors will be common to all of the phase detectors, that is the reference signal will have the same phase at each of the detectors. Thus each of the IF signals will be kept in quadrature with the same reference and hence may be combined coherently with a resulting increase in signal to noise ratio of 6 db over one of the channels.

This system will correct for any doppler shifts or phase scintillations occurring because of atmospheric conditions. Because the data is taken out of the loop before the narrow band filter and because the sideband energy is coherent with the carrier, the phase locked loop may be used for data bandwidths approaching that of the mixer.

An additional advantage of equipment of this type is that it provides for high speed electrical scanning of the array pattern within the beamwidth of one of the element patterns. This can be very advantageous when phase scintillations are present due to atmospheric conditions. Usually atmospheric scintillations are less than the beamwidth of one of the elements, thus not requiring that the elements mechanically follow the variations. However, the scintillation can be on the order of the array beamwidth and some correction is needed when such conditions are present. This is referred to as "fine" tracking of the array, "course" tracking meaning mechanical tracking of the elements.

The signal combination equipment will have three modes of operation, with the various modes having to do with the way the common reference signal for the phase detectors is obtained. In Mode I, the reference signal is merely the output of one of the phase locked loops. In Mode II, the reference signal is the sum of the outputs from all four of the phase locked loops. In Mode III, the reference signal is derived from a highly stable crystal oscillator. The choice between the modes of operation will be made by taking into account the amount of doppler shift present, the range in frequency and stability of the voltage controlled oscillators, and the bandwidth of the phase detectors in the phase locked loops.

G. Signal Acquisition Equipment

Because the bandwidth of the data channels can be small compared with the amount of doppler shifts existing in a high frequency system, some provisions are required for acquiring the signal channel in the presence of doppler shifts. This is done by sweeping the first local oscillator over the expected doppler range until the phase lock loops acquire the signal. In the case of the array, the data channel has a bandwidth of from 4 KC to 20 KC while the amount of doppler shift is on the order of ± 120 KC.

The local oscillator that will be used is a klystron that is phase locked to a harmonic of a highly stable crystal oscillator, the frequency of which can be pulled so as to cause the klystron frequency to sweep over the expected doppler range. The crystal oscillator is controlled by either a search generator for doppler acquisition or by the phase lock loop when the signal is acquired. Switchover from the search generator to the phase lock loop control is automatic. The same first local oscillator is used to feed all four of the first down converters.

H. RF Amplification and Down Converters

The IF signals from each of the array elements will be derived from equipment located on the backup structure of each of the antennas. This equipment will consist of an RF parametric amplifier, a down converter and an IF preamplifier. The parametric amplifiers will have a noise figure of 2.5 db, a bandwidth of 25 mc, and a gain of 20 db. Conventional balanced mixers will be used for the down converters and IF amplifiers of conventional design having a gain of 70 db will be used. This equipment will be housed in a weather tight enclosure with no provisions for temperature control.

I. Automatic Tracking System

A conventional type monopulse system will be used for the automatic tracking function. This system will consist of a monopulse feed located in one of the reflectors and the other antennas will be slaved to this antenna so only one tracking system will be required.

In order to increase the acquisition range of the tracking system beyond that obtainable from the single antenna having the tracking feed, all four antennas in the array will be scanned so that their individual pencil beams form a fan beam. The fan beam can be controlled in azimuth and elevation by the antenna mount controls and the plane of the fan beam can be tilted by means of a programmer in the tracking system. The individual 1° pencil beams from each of the elements will be scanned so they form a fan beam 5° wide in one plane and 1° wide in the orthogonal plane. The fan beam will be located by means of ephemeris data along the expected path of the object to be tracked. When any one of the pencil beams receives a signal from the desired target, the remaining three antennas collimate with the one receiving the signal at which time the antenna with the monopulse feed takes over the automatic tracking with the remaining three antennas staying in collimation with it.

Sensitivity in the tracking system is achieved by using the low noise parametric amplifiers, a narrow bandwidth of 20 KC in the IF tracking circuits and a video bandwidth of 0.25 cps.

J. Array Bandwidth

Due to the wide spacing of the array elements, the bandwidth as a function of scan angle becomes limited. For the spacings involved in the array, the bandwidth vs scan angle from zenith is as shown in Fig. 7. At the extreme array scan angle of 60° , the bandwidth is seen to be 7 mcps, which is adequate for initial experiments. However to achieve the 10% bandwidth requirement, variable delay lines will be used at IF or video frequencies to correct the bandwidth as the scan angle is changed. The function of the delay lines is shown in Fig. 8.

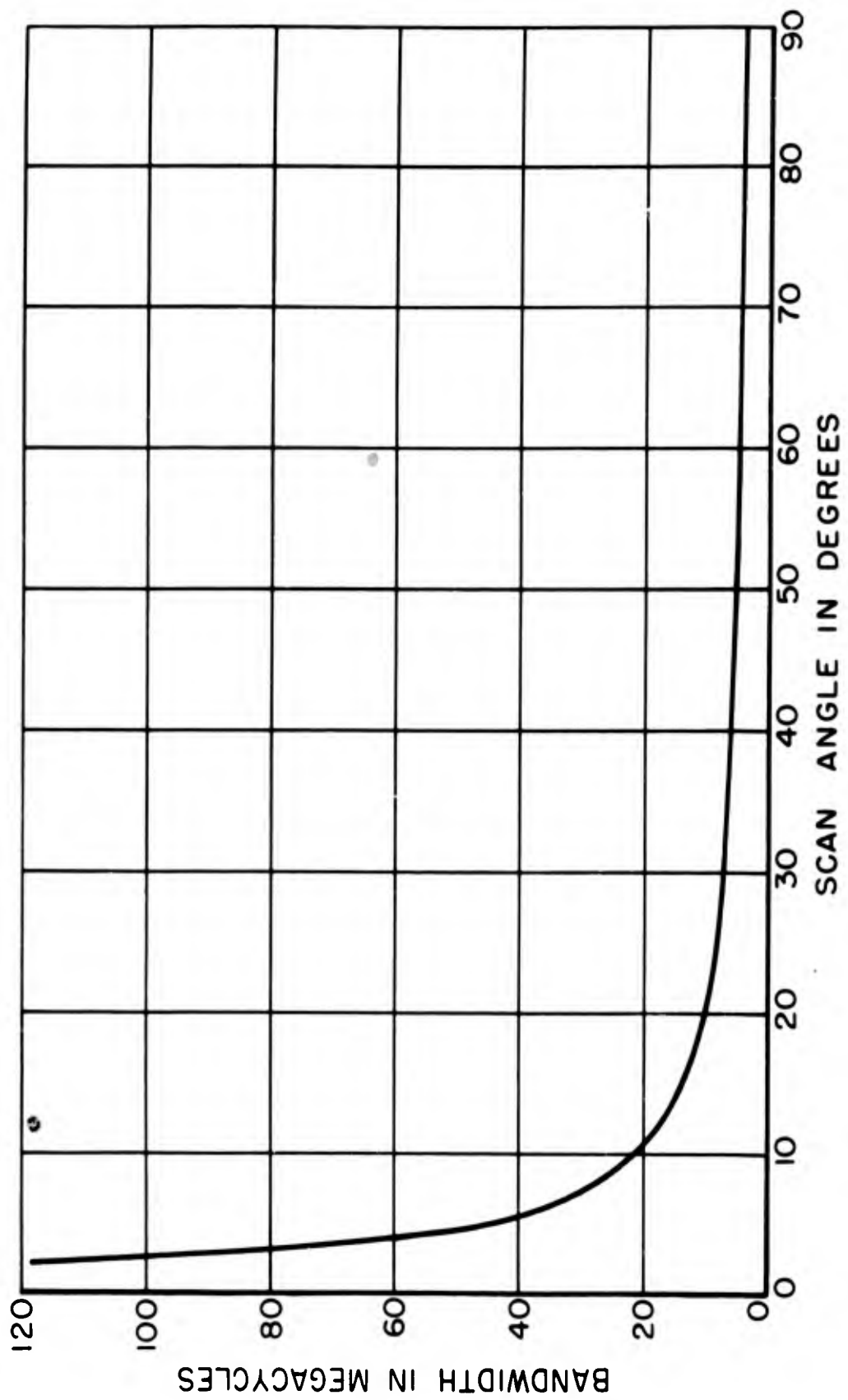


Fig. 5. Bandwidth vs scan angle for two isotropic point sources having separation of 30' and wavelength of 6".

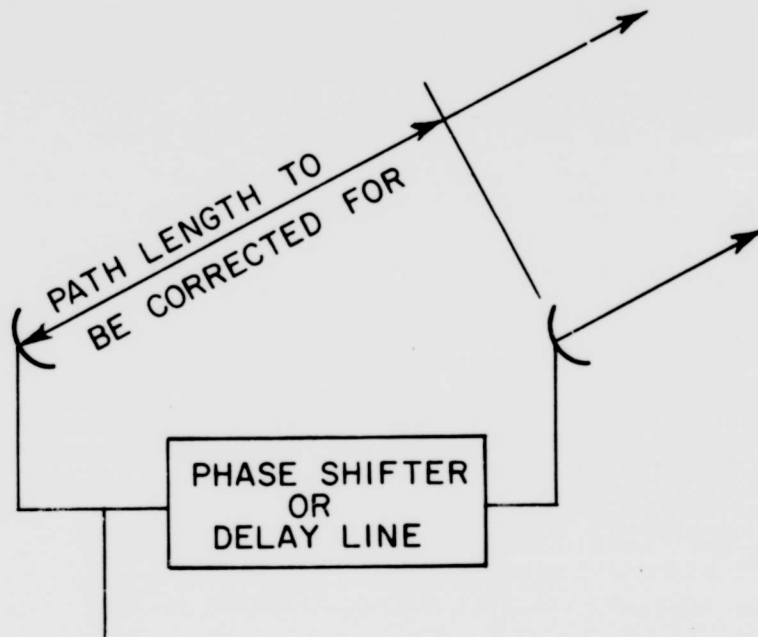


Fig. 8. Corporate fed two element array.

III. ARRAY CAPABILITIES

The array is presently being instrumented for receive capabilities and the equipment just described will be used for this mode of operation. However plans are made for making the array active, that is incorporating a moderate powered transmitter at each of the elements. In the initial active array investigations, transmitters having average power ratings of 10 KW will be used, thus making a total transmitted power of 40 KW. These transmitters will be operated in the 2000 MC frequency range. When this phase of the program is completed, the advantages of the array type antenna can be fully demonstrated.

IV. PLANNED EXPERIMENTS

The first experiment planned for the array will be communication experiments using a passive satellite in orbit about the earth. This satellite, named Echo II, will be a large rigidized sphere having a diameter of 135 feet. It will be placed in an orbit having an inclination of 85° in the Spring of 1962. Transmitters located in Trinidad, BWI and in Rome, New York will illuminate the sphere and the reflected

signals will be received by the array. Tracking of the array will be done on the data signals. The purpose of this experiment will be to determine the characteristics of signals reflected from such spheres. Points of interest⁴ will be polarization characteristics, fading rates, reliability, transmission medium bandwidth, doppler rates and the amount of doppler smear.

The second experiment planned will be associated with Project Westford⁵ and will use frequencies around 10 KMC. In this experiment, the array will again be used as a receive installation. The purpose of the experiment will be similar to those involving Echo II, however at a higher frequency.

Another experiment planned will make use of the transmitting capabilities of the array. The experiment will involve using the moon, existing satellites such as Echo I and II, and the chaff belt of Project Westford as the reflector and will be conducted to determine optimum types of modulation for various types of reflectors and for space communication, develop new techniques for tracking on an extremely low level signal, determine any factors other than receiver noise level that will act as a limit on the maximum distance of space communications, etc.

V. ARRAY APPLICATIONS

The array, when completed will be a very powerful research tool for the development of new techniques for array antennas and will serve as a model for larger antennas of this type that may be built.

The present array will be the equivalent of one 60' diameter parabolic reflector, of which there are many in existence. This will provide many opportunities for a comparison of the two types of antennas under different operating conditions such as tracking capabilities, performance when operating very near the horizon where atmospheric effects are most severe, signal to noise ratio comparison, maximum operating frequency, versatility and cost.

The full advantages of the array however cannot be fully demonstrated until a comparison with a larger paraboloid is made. This could be done by expanding the array to contain nine elements which would make the equivalent of a 90 foot paraboloid or a 4 x 4 array containing sixteen elements, thus making the equivalent of a 120 foot paraboloid, which is what the Haystack Hill antenna is to be, this being the largest single aperture designed for high frequency (10 KMC) operation.

In addition to the comparisons with large single apertures, the array will be very useful as a high resolution radar, a radio astronomy antenna, particularly at the higher frequencies or any other applications requiring a high gain antenna.

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