63-3-2

402139

AD

BRL

TECHNICAL NOTE NO. 1278
SEPTEMBER 1959

II-A-3

SYNCHRONIZATION OF TRACKING ANTENNAS

ARPA Satellite Fence Series
Report No. 6 in the Series

R. E. A. PUTNAM

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

$1.60

Destroy when no longer needed. DO NOT RETURN

BALLISTIC RESEARCH LABORATORIES

(11) (TECHNICAL NOTE NO. 1278)

(12) N/A
(13) N/A
(9) SEP[redacted]59, (10) 19p. incl. illus. table

(6) SYNCHRONIZATION OF TRACKING ANTENNAS.

ARPA Satellite Fence Series,

(7) Report. No. 6 ~~in the Series~~

(8) Ralph E. A. Putnam.

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

TECHNICAL NOTE NO. 1278

REAPutnam/djp
Aberdeen Proving Ground, Md.
September 1959

SYNCHRONIZATION OF TRACKING ANTENNAS

ABSTRACT

A proposal to adopt sky-scanning techniques for the detection of passive satellites using doppler principles is dependent on the ability to synchronize sweeping fan-shaped beams and to maintain them co-planar to within $\pm$ 1 degree for transmitter and receiver spacings up to 1000 miles.

The discussion mentions types of antennas under consideration, covers alternative synchronization methods, indicates sources and possible magnitudes of synchronization errors, and leads to the conclusion that antenna sweep synchronization under the requirements specified is entirely practicable.

INTRODUCTION

In connection with the problem of detecting passive (non-radiating) satellites using doppler methods, various investigations have indicated the desirability of adopting sky-scanning techniques as a means of achieving the required operating ranges with a minimum of ground transmitter power.

Antenna radiation patterns presently contemplated are fan-shaped beams about 4 degrees wide and 40 degrees long. These beams are to sweep the sky from horizon to horizon with angular sweep velocities of perhaps 10 degrees per second.

Beam sweeps may be achieved with fixed antenna structures by progressive switching of radiating elements, or by the use of electronic phase shifting techniques. An alternative method is physically to rotate the antenna structure about a suitable axis.

The basic requirement of the sky-scanning technique is that transmitter and receiver beam patterns, in the narrow dimension, be co-planar throughout the sweep cycle to within $\pm$ 1 degree. Transmitter and receiver sites are expected to be from 500 to 1000 miles apart.

The specific purpose of this report is to discuss the feasibility of establishing and maintaining antenna sweep synchronization at such widely spaced installations, to explore prospective procedures for accomplishing this synchronization with maximum system reliability and minimum costs, and to indicate the limitations, if any, of the various system elements.

NOTES ON ANTENNA STRUCTURES

Rotatable structures for operation at 108 megacycles are estimated to be about 20 feet wide and 100 feet high. Sky-scanning may be accomplished by antenna rotation in one direction continuously, or, alternatively, by reversal of the angular direction of motion after each 180 degree sweep.

Drive power for the continuously moving antenna is estimated to be 100 horse power or more at the angular velocities contemplated. Drive power requirements for the reciprocating antenna appear to be so large and the structural stresses so excessive that this type of antenna motion becomes impracticable for any application except at very low cycling rates. Accordingly, the reciprocating type will not be considered further in this discussion.

Fixed antenna structures may be physically much larger than the rotatable types described, but power requirements for driving the associated beam scanning devices will be relatively insignificant.

PROSPECTIVE METHODS FOR STATION SYNCHRONIZATION

Interconnecting Communication Circuits

One obvious method for synchronizing station activities at widely separated points is to let one station act as a control center and generate command signals for transmission to the second station over a wire or radio communication channel. This arrangement is workable, but has the disadvantage of being costly and subject to loss of synchronization in the event of circuit interruption.

A second method with improved reliability is to provide at each of the two stations a precision time generator with high stability; to synchronize these generators once or twice daily by pulses transmitted over an interconnecting circuit; and to utilize these generators directly as the primary sources of control signals for independently programming the respective station activities. This arrangement has the advantage of reduced costs for communication channels, and the ability to maintain the two stations in virtual synchronism for reasonable periods in the event of temporary loss of the communication channel.

Station Synchronization with WWV

A third method discards the idea of synchronizing stations directly with each other. Instead, it proposes to synchronize all stations, individually and independently, with some common reference event or timing source such as WWV time signals. This calls for a precision time generator at each station and its utilization substantially as described in the preceding paragraph. This arrangement possesses one minor disadvantage in that it requires two independent efforts to achieve transmitter and receiver synchronization, hence doubling the relative timing error that may exist in station synchronization.

It is to be noted that this synchronization method is of interest only for stations following a prearranged program of activities, such as sky-scanning at fixed times and rates. In the event variable rate tracking capabilities are desired to permit following the course of a specific satellite across the sky, then a communication channel connecting transmitter and receiver stations must be continuously available for the exchange of command signals.

STATION TIMING

WWV Time Signals

Radio Station WWV, on one or other of its assigned frequencies, can be received at virtually all points in the United States, at least for brief periods daily. Field experience indicates that these signals constitute very satisfactory reference events for station synchronization, and that they rarely display a time jitter of more than $\pm$ 2 milliseconds. Transmission delay times can be determined to within $\pm$ 1 millisecond, hence station timing errors that cannot be compensated should not exceed $\pm$ 3 milliseconds.

Precision Time Generator

Crystal-controlled oscillators are commercially available which can be operated in the field for periods of several days without exceeding a 1 millisecond time drift with respect to WWV. If equipped with dividers to produce output pulse trains of 1 pps and 1 ppm, these local time generators may be checked against, and synchronized with, the corresponding pulse trains from WWV. An oscilloscope display is capable of providing a generally satisfactory visual indication of signal synchronization.

The local time generator should, of course, be synchronized with WWV signals at the transmitting point, rather than at the receiving point. This objective can be achieved by artificially delaying the local signal input to the comparison oscilloscope (or other coincidence checking device) by an amount equal to the transmission delay suffered by the WWV signal.

ANTENNA SWEEP RATES

The choice of antenna sweep rate is important from two standpoints. First, it should be such as to minimize the possibility of operator error in synchronizing antenna beam sweeps. Second, it should preferably be a rate that makes the elevation angle of the scanning beam a simple function of time. Both objectives will be attained if the scan rate is selected to provide a whole number of scan cycles per minute. For example, 2, 3, and 4 scan cycles per minute correspond, respectively, to angular scan rates of 6, 9, and 12 degrees per second in the case of horizon to horizon scanning.

The advantage of this arrangement is that the antenna beam pattern assumes the same elevation angle every minute, and can be set up to generate an identifying pulse when in the vertical, or other established reference position. When correctly synchronized, every 1 ppm pulse from the local time generator will be coincident with a pulse generated by the beam pattern sweeping through the reference position.

Similarly, a whole number of scan cycles per minute furnishes a time sequence of elevation angles which is recurrent from minute to minute. As a result, this elevation-time sequence may be stored in the memory of the orbital computer for use as needed, thereby eliminating the need for a data transmission channel to handle this information continuously.

SCANNING BEAM DRIVE

Power Considerations

Sky scanning by phase shifting techniques may not require power driven devices; instead, purely electronic devices under the control of the local time generator may be utilized for establishing and maintaining sweep synchronization with WWV signals.

Sky scanning by progressive switching of antenna elements may call for the use of small electric motors. If these are of the synchronous type, driven by suitable frequencies derived from the local time generator, antenna sweep synchronization, once established, will be maintained indefinitely except when interrupted by equipment or power failures. Phase shifting devices, either manual or servo-driven, will of course be needed in the motor supply circuits to permit a temporary speed-up or slow-down of the motor drives while making the initial synchronization adjustment.

If rotatable antennas are involved, the drive system becomes somewhat complex because of the large power requirements. To drive a 100 horse power synchronous motor from the local time generator seems impracticable. A more promising alternative would be a synchronous motor driven from commercial power, with a servo system set up to correct for moment by moment deviations in motor speed resulting from frequency variations in the commercial power supply. In the event a hydraulic drive system proves advantageous, the servo loop would be set up to operate the control valve to the hydraulic motor.

Servo System

The servo system for the rotatable antenna structure should operate to produce the same elevation-time relationships for the scanning beam as would be produced were the antenna driven directly by a synchronous motor fed from the local time generator. This suggests that a miniature mock-up of the latter unit would constitute a very appropriate reference for servo control, and that basic error signals could be derived from resolvers mounted on the axis of the actual antenna, and on the axis of the miniature mock-up, respectively.

REPRESENTATIVE STATION EQUIPMENT

On an accompanying sketch is displayed in block form the essential equipment elements needed for synchronizing the antenna sweep with WWV timing, and this sketch is applicable to either a transmitting or a receiving station. The drive system shown is for a rotatable antenna, because this is more complex than for other antenna types.

The timing equipment outlined would remain substantially unchanged for other antenna structures.

The fixed delay unit, as explained previously, serves to compensate for the transmission delay in the arriving WWV signals, and thereby enables the local time generator to be synchronized with timing signals at the WWV transmitting station.

The coincidence checking circuit may be set up to record minute by minute errors in antenna synchronization, and to initiate alarm signals when such errors exceed a preset maximum figure of $\pm$ 40 milliseconds ($\pm$ 0.4 degree), for example.

The miniature antenna mock-up is shown driving an indicating device which displays for the benefit of the station operator the correct pointing angle of the antenna beam at every instant. When initially synchronized by manipulation of the continuous phase shifter, this mock-up unit remains permanently synchronized with WWV, at least until equipment or power failures interrupt its operation.

A second and similar indicating device, mounted preferably on an axis concentric with the first, displays the pointing angle of the actual antenna. These indicators are not intended to be precise enough for an evaluation of antenna synchronization, but instead are to assist the operator, when starting up the big antenna drive motor, by indicating the proper moment to close the switch in order to achieve near-synchronization initially. This relieves the servo motor of unnecessarily long grinds and permits an optimum design with the primary purpose of correcting minor deviations from sychronism.

The servo system, as previously described, acts to produce the same angular motion in the actual antenna axis as exists in the synchronously-driven miniature antenna mock-up.

The block diagram indicates the presence of two V-shaped antenna beams 180 degrees out of phase. The one in solid line pointing upward represents the radiating antenna, while the one pointing downward is dotted to imply no energy radiation. Actually, two independent antenna systems mounted back to back on the common axis would be needed, with provision for alternately and automatically switching antennas as the beams cross the horizon, in order to achieve a continuous scan.

Antenna synchronization is established only when the antenna reference position sensing device gives an output pulse coincident with the 1 ppm output of the local time generator. Minor adjustments of the continuous phase shifter to achieve pulse coincidence may be made initially, and at later dates if necessary to compensate for wear in mechanical parts.

ERROR SOURCES AND POSSIBLE MAGNITUDES

Synchronization Errors

The extent to which transmitter and receiver beam patterns are not coplanar may be expressed in angular degrees, or in equivalent time units where fixed sky-scanning rates are specified. For example, the requirement that the respective beams be position synchronized to within $\pm$ 1 degree, is equivalent to a requirement for timing synchronization to within $\pm$ 100 milliseconds at an angular scanning rate of 10 degrees per second.

Synchronizing a two-station complex to within $\pm$ 1 degree, relative to each other, requires that each individual station be synchronized to within $\pm$0.5 degree, relative to a common reference standard. This latter figure will appear in subsequent discussion as the maximum total of synchronization errors permissible for any one station. Errors will be expressed in degrees, and conversion to milliseconds may be accomplished by multiplying by 100.

Error Sources

The following items constitute the major sources of synchronization errors:

1. Station Timing Error. This will be zero for any station acting as a control center and generating synchronizing or command signals for transmission to other stations. For all other stations the timing error will be evidenced as a time-jitter in the reception of synchronizing or command pulses, resulting from unstable wire line characteristics or multipath radio propagation. It may also include appreciable errors introduced by slow drifts in the transmission delay time suffered by the arriving signals, or by inability to compute or measure this figure accurately.

2. Antenna Orientation Error. This is concerned with the placement of the physical structure to give correct beam pointing angles. Errors may be introduced by inaccurate surveys, careless construction practices, or by subsequent uneven subsidence of foundation elements. Basic survey data available at any local installation site may prove to be rather loosely coordinated with similar data for an area 1000 miles away, hence this factor may warrant special consideration. Fortunately, survey data errors can be reduced to insignificant proportions by special surveys when justified.

3. Antenna Pattern Irregularities. This refers to errors in beam pointing angle produced by lack of electrical and mechanical symmetry in the construction and assembly of the antenna radiating elements.

4. Phasing Errors. Minor errors in the phasing of signals to or from the multiplicity of antenna radiating elements are capable of introducing angular distortion in narrow fan-shaped beam patterns.

5. Antenna Structural Deformation. This refers to the possibility that physically large antenna systems above the ground, with high supporting structures, may be deformed under heavy wind loading with resultant shifts in beam patterns.

6. Scanning Beam Drive. This error source includes such factors as phase lag in servo and drive motors under variable loading, gear backlash, mechanical imperfections in drive or switching mechanisms, and deterioration in moving elements resulting from wear.

Error Magnitudes

In the table which follows are presented estimates of the relative component and total error magnitudes which might be expected from each of the three types of scanning antenna designs capable of meeting performance requirements.

	Estimated Error Magnitudes for Various Antenna Types		
Error Source	Rotatable	Element Switching	Controlled Phase Shift
1. Station Timing	$\pm 0.03^{\circ}$	$\pm 0.03^{\circ}$	$\pm 0.03^{\circ}$
2. Antenna Orientation	$\pm 0.02^{\circ}$	$\pm 0.02^{\circ}$	$\pm 0.02^{\circ}$
3. Antenna Pattern	$\pm 0.05^{\circ}$	$\pm 0.05^{\circ}$	$\pm 0.05^{\circ}$
4. Phasing	$\pm 0.05^{\circ}$	$\pm 0.10^{\circ}$	$\pm 0.35^{\circ}$
5. Structural Deformation	$\pm 0.15^{\circ}$	$\pm 0.05^{\circ}$	$\pm 0.05^{\circ}$
6. Scanning Beam Drive	$\pm 0.20^{\circ}$	$\pm 0.10^{\circ}$	$\pm 0.00^{\circ}$
Totals - - - - -	$\pm 0.50^{\circ}$	$\pm 0.35^{\circ}$	$\pm 0.50^{\circ}$

It is to be noted that error ratings of the three antenna systems are identical for the first three error sources, and are believed to be reasonably representative of values that can be maintained under ordinary operating conditions. Incidentally, they add up to 20 percent of the total error permissible.

The remaining error ratings are educated guesses, based on a general knowledge of the design problems and limitations of the respective antenna systems. The rotatable antenna, for example, can be expected to be primarily susceptible to errors associated with structural deformation and mechanical drive factors; whereas the antenna system utilizing phase shift techniques can be expected to be most susceptible to phasing errors. In between these extremes is the switched element antenna which is only moderately susceptible to mechanical and phasing errors.

Inasmuch as error magnitudes from almost any source can be progressively reduced by concentrating on equipment and circuit refinement, it is reasonable to suppose that all three antenna types under discussion can be developed to the point where they meet the necessary performance requirements for this proposed project, if costs are not a factor. However, comparative figures tabulated above strongly indicate that the switched element type of antenna has the distinct advantage of a lower error susceptibility, hence the probability that it will carry the lower price tag and a simplified maintenance problem.

LIMITATIONS TO EXPANDED SYSTEM REQUIREMENTS

A question naturally arises as to what prospects exist for synchronizing similar antenna systems should there develop a need for higher scanning rates, narrower beam widths, or both simultaneously. The governing factors are somewhat as follows:

1. The station timing error, expressed in milliseconds, is a fixed quantity, but expressed in degrees is a function of the scanning rate, and proportional thereto. With minor exceptions, the other sources of error are unaffected by the scanning rate. Hence, if the scanning rate were quadrupled

to a value of 40 degrees per second, the timing error would rise from ± 0.03 to ± 0.12 degrees, thus increasing the error totals by something like 20 percent.

2. If beam widths were to be decreased, the result would be far more serious, because all error sources would be affected. A synchronization requirement tentatively specified for the general case is that transmitter and receiver beams must be co-planar throughout the sweep range to within ± 1/8 the beam width in degrees. Therefore, if the beam width were changed from 4 degrees to 2 degrees, the total permissible synchronization error at any station would be reduced from ± 0.5 to ± 0.25 degrees. In other words all error magnitudes would have to be cut by a factor of two.

3. An example of a limiting condition is provided by assuming that a beam width of 1 degree is desired, together with a scanning rate of 40 degrees per second. In this case the timing error (± 3 milliseconds) at any station would become the equivalent of ± 0.12 degrees. The permissible synchronization error at any station would be ± 1/8 of 1 degree, or ± 0.125 degrees. The result would then be a timing error equal to the total allowable error - an obviously unworkable system.

It is not to be inferred that the station timing figure of ± 3 milliseconds used in the above examples is the very minimum that can be achieved. Actually, this error may be reduced appreciably by using some rather sophisticated terminal circuitry for the reception of timing signals via radio. Possibly the error may be reduced by one or two orders of magnitude by utilizing television quality transmission channels over cable or microwave links for the reception of timing signals, where justifiable.

As mentioned in previous discussions, the timing error for one of a pair of stations may be reduced to zero by allowing that station to act as a control station and generate synchronizing or command signals for transmission to the second station. This possibility appears to be of minor importance under ordinary conditions, but in otherwise marginal cases it might be utilized advantageously.

CONCLUSIONS

1. Sky-scanning antennas, synchronized to within ± 1 degree, appear to be technically feasible for station spacings up to, and somewhat in excess of, 1000 miles.

2. Each station should include a precision time generator to permit continuing operation for a reasonable period following interruption of the external source of synchronizing signals.

3. Economic and other considerations indicate the desirability of synchronizing each station directly with WWV timing signals.

4. Sky-scanning rates influence station synchronization procedures and data transmission problems. It is desirable that a scanning rate be selected such that the resulting number of scan cycles per minute becomes a whole number. (An angular scanning rate of 9 degrees per second for a 180 degree sweep meets this requirement, producing 3 scan cycles per minute.)

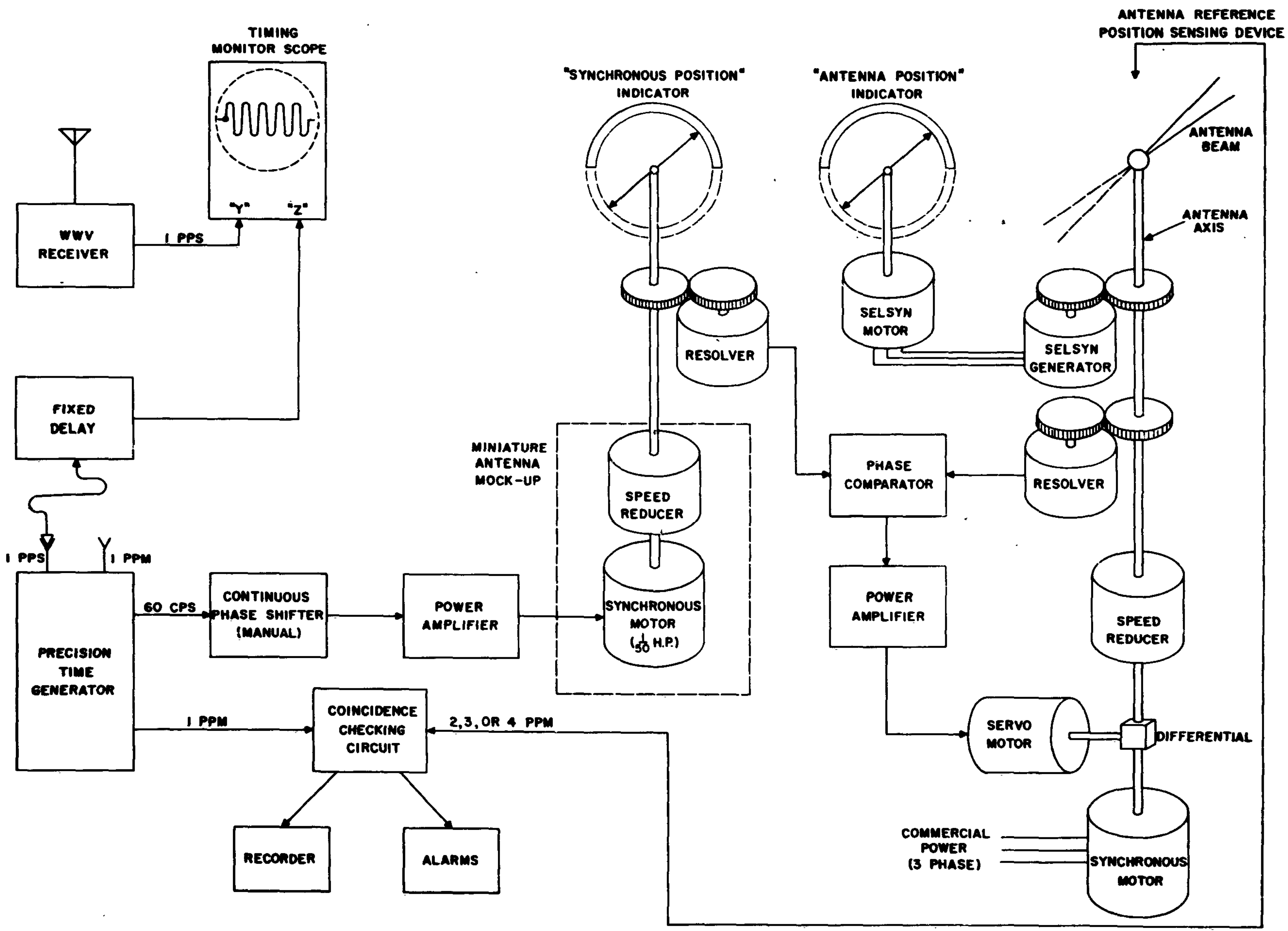
5. It is not essential that the angular scan rate be completely uniform throughout the sweep range, but it is important that any non-linearities introduced be identical for both stations of a pair.

6. Sky-scanning arrangements with a reciprocating sweep may be subject to non-linear components of motion in one direction that are not duplicated in the reverse direction, thus complicating synchronization procedures. For this reason, beams which sweep continuously in the same direction are to be preferred.

7. A fixed antenna structure, wherein a scanning beam is generated by progressive switching of radiating elements, appears to be the most practical antenna type.

8. Some moderate decrease in beam widths, or some increase in beam scanning rates, appears to be feasible, if desired. However, such changes tend to impose increasingly severe requirements on the synchronization problem, and at some point a limit will be reached beyond which further changes will be found impracticable. Whether synchronization requirements can be met with beam widths of only 1 degree is problematical.

Ralph E. A. Putnam
RALPH E. A. PUTNAM



STATION EQUIPMENT FOR ROTATABLE ANTENNA

DISTRIBUTION LIST

No. of Copies	Organization
1	Chief of Ordnance Department of the Army Washington 25, D. C. Attn: ORDTB-Mr. Stetson
4	Director Advanced Research Projects Agency Washington 25, D. C.
1	Director Naval Research Laboratory Washington 25, D. C. Attn: Mr. Easton
1	Commanding Officer U. S. Army Communications Agency Washington 25, D. C.
1	Director Jet Propulsion Laboratory Californis Institute of Technology 4800 Oak Grove Drive Pasadena 3, California
1	Project Officer ARPA-BRL DOPLOC Satellite Tracking Station Box 629, East Road Forrest City, Arkansas
1	Chief ARPA-SATRAC Station Bldg. 4110 Fort Sill, Oklahoma
1	Chief ARPA-BRL Satellite Tracking Station Box 1245 Socoro, New Mexico