# Antenna Pointing System: Organization and Performance

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*This paper is a description of the antenna pointing system used in the satellite ground station at Andover, Maine. It is an introduction to the following five papers in this issue, which describe and discuss in some detail the various major parts and features of the antenna pointing system. In order that the antenna have sufficient gain for the Telstar experiment, it was necessary that it have a "pencil" beam of about $\frac{1}{5}$ degree in diameter. This requires an antenna pointing system of high accuracy. The equipment and methods required to achieve this accuracy are outlined.*

## I. OBJECTIVES

At the Andover, Maine, satellite ground station the 3600-square-foot aperture horn-reflector antenna[1,2] concentrates the microwave energy in a very narrow beam. This is needed to achieve adequate signal-to-noise ratio in the broadband communications channel provided by the system. Accordingly, it is necessary to provide means for pointing the antenna at the Telstar satellite. The guiding objectives used in engineering and constructing the antenna pointing system are briefly described here.

A demonstration of reliable satellite communications was a primary goal. This required acquisition and tracking of the satellite to an accuracy which would hold the resulting maximum loss in antenna gain to values acceptable to the communication link. It required a system with versatility sufficient to cope with a combination of unfavorable conditions such as deviations of the satellite from the expected orbit, variations in refraction effects, antenna misalignments, and equipment malfunction.

A basic objective of a communications satellite system is reliability. In the current state of the art (weight limitations, etc.) this can be best realized by designing the satellite so that it will be as rugged as possible and therefore relatively simple. The ground station, on the other hand, may have considerable complexity since it can be maintained and improved.

It was decided that the system must have sufficient flexibility for experiments to evaluate different methods of acquiring and tracking satellites. This required facilities for the recording, reduction, and evaluation of large amounts of pointing data.

### 1.1 *System Description*

The Telstar antenna pointing system performs two primary functions: (*i*) it establishes the communication connection by causing the horn-reflector communication antenna to acquire and continuously track the satellite throughout a communications pass, and (*ii*) it provides means for determining the satellite orbit so that pointing instructions may be generated for future passes to help meet the requirements of the first function. The most difficult problem encountered in providing these functions is one of accuracy due to the needle-like antenna patterns of the 3600-square-foot aperture of the communications antenna. The beam is nearly circular, with an angular diameter of 0.165° at the transmitting frequency of 6390 mc and 0.225° at the receiving frequency of 4170 mc when measured 3 db down from the beam pattern maximum. Furthermore, the requirement placed on the antenna pointing system is that mispointing of the antenna should contribute no more than 1 db of loss in carrier-to-noise ratio in the communications path. A 1-db decrease in carrier-to-noise ratio would be produced by pointing errors which produce approximately 1-db decrease in the 4170-mc down path transmission. A 1-db contour on the antenna pattern at 4170 mc would approximate a circle of 0.06° radius. Therefore, the maximum tolerable pointing error in antenna azimuth or elevation angle is ±0.06°. To meet this requirement, one must first know where the satellite is with commensurate accuracy and be able to calibrate and control the horn antenna precisely.

A block diagram of the antenna pointing system is shown in Fig. 1. Before a discussion of the operation of this system is undertaken, consider the characteristics of each block. All of the frequencies shown are approximate.

*Satellite:*[3] The satellite is not part of the pointing system, but it plays an important role in antenna pointing by radiating two CW beacons for tracking purposes, one at 136 mc and the other at 4080 mc. The 136-mc beacon is radiated continuously, but the 4080-mc beacon is

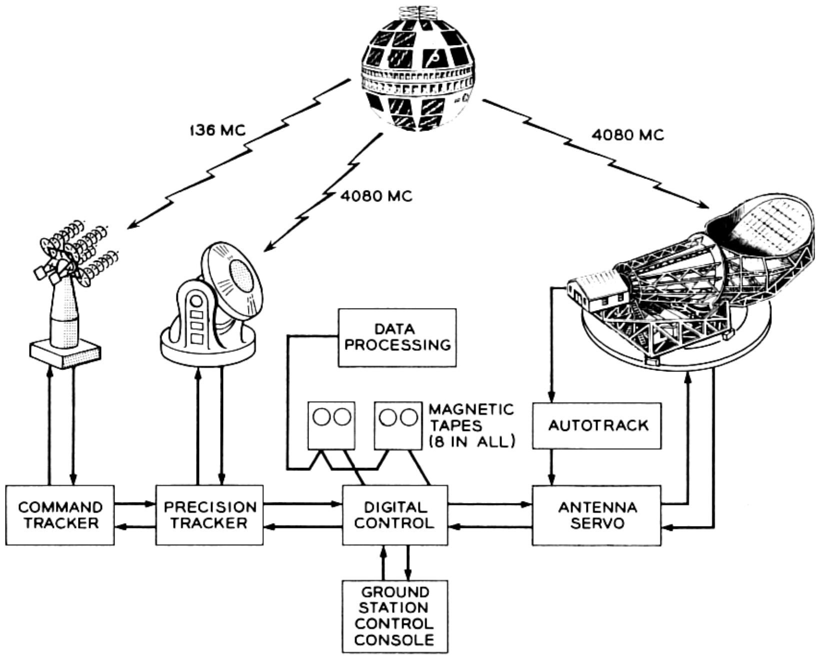


Fig. 1 — Block diagram of pointing system.

transmitted only when the traveling-wave tube amplifier in the satellite is turned on. In addition to its function in the antenna pointing system, the 136-mc beacon also permits the satellite to be tracked by the world-wide NASA Minitrack network. The 4080-mc microwave beacon provides a means of tracking using frequencies in the common-carrier band.

*Command Tracker:*[4] Tracking of the 136-mc beacon in the satellite is accomplished by the command tracker, a quad-helix antenna having autotrack capabilities. It has a 20° beam diameter and is capable of tracking with an accuracy of about ±1°. In addition to its tracking role, the command tracker also receives telemetry information, which appears as modulation on the 136-mc signal, and transmits commands to the satellite at 120 mc.

*Precision Tracker:*[5] The 4080-mc beacon is tracked by the precision tracker, a tracking system using an 8-foot Cassegrain dish antenna with a 2° beam. This antenna is capable of autotracking the microwave beacon with an accuracy of about 0.01°. The precision tracker provides the basic data from which the orbital position of the satellite is calculated.

Either of the two trackers, precision or command, can be slaved to the other. This feature is important during initial acquisition, when the position of the satellite is not well known, and will be discussed in more detail later.

*Autotrack:* The horn-reflector antenna is also capable of tracking the 4080-mc beacon in the satellite by means of its autotrack system.[6] Operating on the nature of the propagation of the received 4080-mc beacon signal in the horn and using a principle similar to the monopulse radar technique, this system produces error signals which indicate the satellite's position relative to the center of the antenna beam. This error signal is used to correct the position of the antenna automatically.

*Antenna Servo:* The antenna servo[7] controls the hydraulic drive system of the horn antenna. It does this on the basis of commands received from the digital control and/or the error signals received from the autotrack. The servo feedback loop may be closed in the digital control section, where a digital comparison is made between the commanded position and the actual position. An alternative mode of operation is available whereby the servo loop is closed through the autotrack system. This is an autotracking mode and digital control is not involved. These two modes can also be combined so that the autotrack serves to correct any errors in the commanded position.

*Data Processing:* The data-processing portion of the system consists of two general purpose computers.[8] These facilities perform two primary functions in the antenna pointing system: (*i*) they enable the system to keep track of the satellite by periodically up-dating the basic orbital parameters on the basis of track information derived from the precision tracker and the horn; and (*ii*) they predict future positions of the satellite and generate pointing instructions for both the precision tracker and the horn for future passes. The facilities are also used to record and process data for performance analysis.

*Digital Control:* The digital control[9] interconnects the various elements of the system and provides a variety of functions. It takes the pointing instructions, which were stored on magnetic tape by the data-processing section, and develops the "program commands" which point the horn-reflector antenna. Similarly, it generates position commands which provide the precision tracker with an acquisition track about which it can search for the satellite. Since, in both instances, these commands must be given at a much higher rate than the rate at which they are recorded on tape, the digital control incorporates interpolation circuits which yield commands at a 128-per-second rate. A second important function is the recording of track information for subsequent use by the data-processing section in up-dating the orbital elements. The digital control encodes the precision tracker and horn positions and records them on magnetic tape along with the time of each sample. Because of the accuracy requirements in positioning the horn antenna, the digital control also performs the major servo summing operation digitally. That is, the commanded position is compared with the encoded horn position digitally, and only after the error signals are thus derived, and the need for accuracy reduced, is this signal decoded to an analog quantity and used as an input to the antenna servo. The digital control contains the basic time reference in the system and synchronizes the whole operation with real time. Finally, this portion of the system incorporates a number of functions to permit manual supervision and control of the operation and to provide means for establishing the various operational modes and system configurations.

*Magnetic Tape Units:*[8] The magnetic tape units appear as a separate item on the block diagram because they are shared between the data-processing and digital control sections. These tape units contain a switching feature that permits connection to either the data processing units or the digital control. Thus, tapes which have been connected to digital control and on which track information is recorded during a pass may be switched following the pass to the computers for processing. Similarly, tapes containing pointing instructions prepared by the computers in the data-processing section can be switched onto the digital control to control the antennas during a pass.

*Ground Station Control Console:*[10] The ground station control console provides facilities for centralized monitoring and control of all antenna pointing operations. The positions of the antennas are displayed, along with the signals necessary to allow the ground station controller to make an instantaneous and continuous appraisal of the tracking performance. Means are provided for remote control of the antenna positions and operating modes, as well as for commanding the satellite itself. The provision of these facilities at a central position permits the operations performed in establishing the communications connection to be closely coordinated.

## II. OPERATION

Now that the functions of the components have been briefly described, consider the operation of the system. In preparation for an upcoming communications pass, the data-processing section, using its latest orbital elements, generates the pointing instructions and stores them on magnetic tape. The pointing instructions consist of time information, azimuth and elevation position, velocity and acceleration information, and range information. In addition, compensation factors, derived from the horn-reflector antenna calibration curves, are included to correct beam deflections caused by structural deformations which are functions of horn position. Such a set of information is called a data point, and data points are recorded for each four seconds of the pass. For error-correcting purposes, the data points are recorded in triplicate.

In preparation for the upcoming pass, this tape containing pointing instructions is switched to the digital control. Connections within the digital control are made so that these pointing instructions command both the horn antenna and the precision tracker. In addition, the command tracker is slaved to the precision tracker through a synchro connection. Thus, the tape pointing instructions bring all three antennas to the satellite rise point on the horizon. At the predicted rise time, the pointing instructions cause the three antennas to commence moving at the predicted rate along the satellite track.

At this point the satellite is radiating the 136-mc beacon only. In a typical pass, the command tracker acquires and tracks the satellite's 136-mc beacon and then transmits the command at 120 mc to turn on the telemetry and energize the radiation experiment circuits. The received telemetry is examined to determine the "health" of the satellite. The command tracker then transmits a sequence of commands that apply voltage to the traveling-wave tube (TWT) filament, turns on the TWT helix and collector voltages, and energizes the transistor circuits, and, finally, applies voltage to the TWT anode. This enables the 4080-mc beacon, and the precision tracker and autotrack system can then acquire and track its signal. At this point any one of the following modes of operation may be put into effect: (*i*) normal, (*ii*) autotrack, (*iii*) programmed command, (*iv*) precision tracker command, (*v*) initial, or (*vi*) search.

### 2.1 *Normal Mode*

As soon as autotrack acquires, the communications antenna is locked on the satellite and the communications connection is established. In this mode of operation the function of the pointing instructions (program command) is to place the horn antenna beam on the satellite to within the $\pm 0.15°$ acquisition range of the autotrack. The autotrack system will then center the beam on the satellite. This is considered the normal mode of operation and in the antenna servo, the program command loop has about twice the gain of the autotrack loop.

### 2.2 *Autotrack Mode*

Other modes are possible and have been used. A full autotrack operation is possible in which, after acquisition, the program command is removed and the autotrack loop has complete control. In this autotrack mode, the autotrack loop can and does have a higher gain than it does in the combined mode. The tracking, therefore, is accurate as long as the velocities required to track are within the maximum system capability of 1.5° per second. As an alternative to using programmed command for acquisition, the antenna may be positioned manually and acquisition effected as the satellite passes through the beam.

### 2.3 *Programmed Command Mode*

Similarly, a full programmed command can be obtained by removing the autotrack error signals. In this mode the tracking performance is entirely dependent on accurate orbit prediction and on a precise knowledge of antenna calibration. Experience indicates that the accuracy of prediction is sufficient to make this mode feasible. This mode has proven most useful in tracking radio stars or in deliberately offsetting the antenna for experimental purposes, as in measuring antenna patterns using the satellite. It is also useful as a back-up method in the event of an autotrack failure. In this case the full command mode can be supplemented by manual offsets to improve tracking.

### 2.4 *Precision Tracker Command Mode*

In the normal and autotrack modes described above, it was assumed that the orbit prediction was accurate enough to allow the horn antenna to acquire the satellite with the autotrack, from the pointing instructions, without assistance from the precision tracker or command tracker. That is, it was assumed that the pointing instructions were sufficiently accurate to place the beam center within an angular circle of 0.15° radius of satellite position. In general this is true. However, in unusual cases, as on the first few passes after launch, the orbit may not be accurately known, and the antenna pointing system incorporates a number of features to permit acquisition under these conditions. The command tracker gives a "broad brush" acquisition means with its 20° beam. The slave connection described above can be reversed so that the precision tracker is slaved to the command tracker. Then, the 1° tracking accuracy of the command tracker is sufficient to allow acquisition by the precision tracker with its 2° beam. The horn antenna may be slaved to the precision tracker by use of what is called the "precision tracker command" mode. In this mode the encoded precision tracker positions are transmitted directly to the antenna servo by the digital control, and these positions are used as the command input to the antenna servo. Thus, the 0.01° tracking accuracy of the precision tracker is more than adequate to enable acquisition by the autotrack. This mode of acquisition was used on the early passes of the Telstar satellite.

### 2.5 *Initial Mode*

A second form of slave-type operation is possible with this system in what is known as the "initial mode" type of operation. In this mode, the computer is put on line. The precision tracker positions are read directly into the computer, which smooths the positions and does a short-term prediction to produce pointing instructions with which it commands the antenna servo directly. This mode is designed to yield smoother operation than the precision tracker command mode, since the precision tracker jitter is averaged out and the antenna servo is supplied with rate information as well as the positional information.

### 2.6 *Search Modes*

In addition, to aid in acquisition, the precision tracker has a search mode in which it can search about the acquisition track provided by the digital control. Similarly, the horn antenna servo has a spiral scan capability which causes it to spiral scan about the programmed track. Actuation of a spiral scan causes the horn-reflector antenna to perform a ten-turn spiral out to about 2.5° from the programmed track. Two spiraling rates are available.

In the operational experience to date it has not been necessary to use either the spiral scan or the initial mode operation, and they have been used for experimental purposes only.

At the conclusion of the pass, the command tracker transmits a sequence of commands to turn off the transmission channel. Throughout the pass, the precision tracker and horn positions are measured at twice and once per second, respectively, and recorded on magnetic tape. At the conclusion of the pass these tape units are switched from the digital control to the data-processing section so that the information may be used to up-date the orbital elements. Note that the function of the data-processing section is an off-line operation and that the computers are not directly involved in pointing the antennas.

For calibrating the horn antenna, radiometry equipment and the communication maser are used to track the known positions of radio stars. In addition, a boresight tower on nearby Black Mountain provides a microwave beacon and satellite electronics for routine calibration of pointing and for autotrack adjustments.

## III. CONCLUSIONS

The program objectives were met and successful communication performance achieved, beginning with the first visible pass on July 10, 1962. In no case did antenna pointing performance detectably degrade the communication demonstrations and tests. For the first four months after launch, satisfactory acquisition and tracking were accomplished for all scheduled passes.

All of the modes of operation described were successfully tried. They made possible the high level of system reliability achieved.

Full horn autotrack with predicted pointing information for acquisition was found to be the most accurate mode of operation. It is the most economical and holds promise for application in operational systems. The full tape command system has proven useful for making radio star calibrations of the horn-reflector antenna.

Accurate tracking at azimuth velocities of 1.5°/sec has been achieved. This will permit tracking within a degree or two of the zenith for satellites with 5,000-mile circular orbits.

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