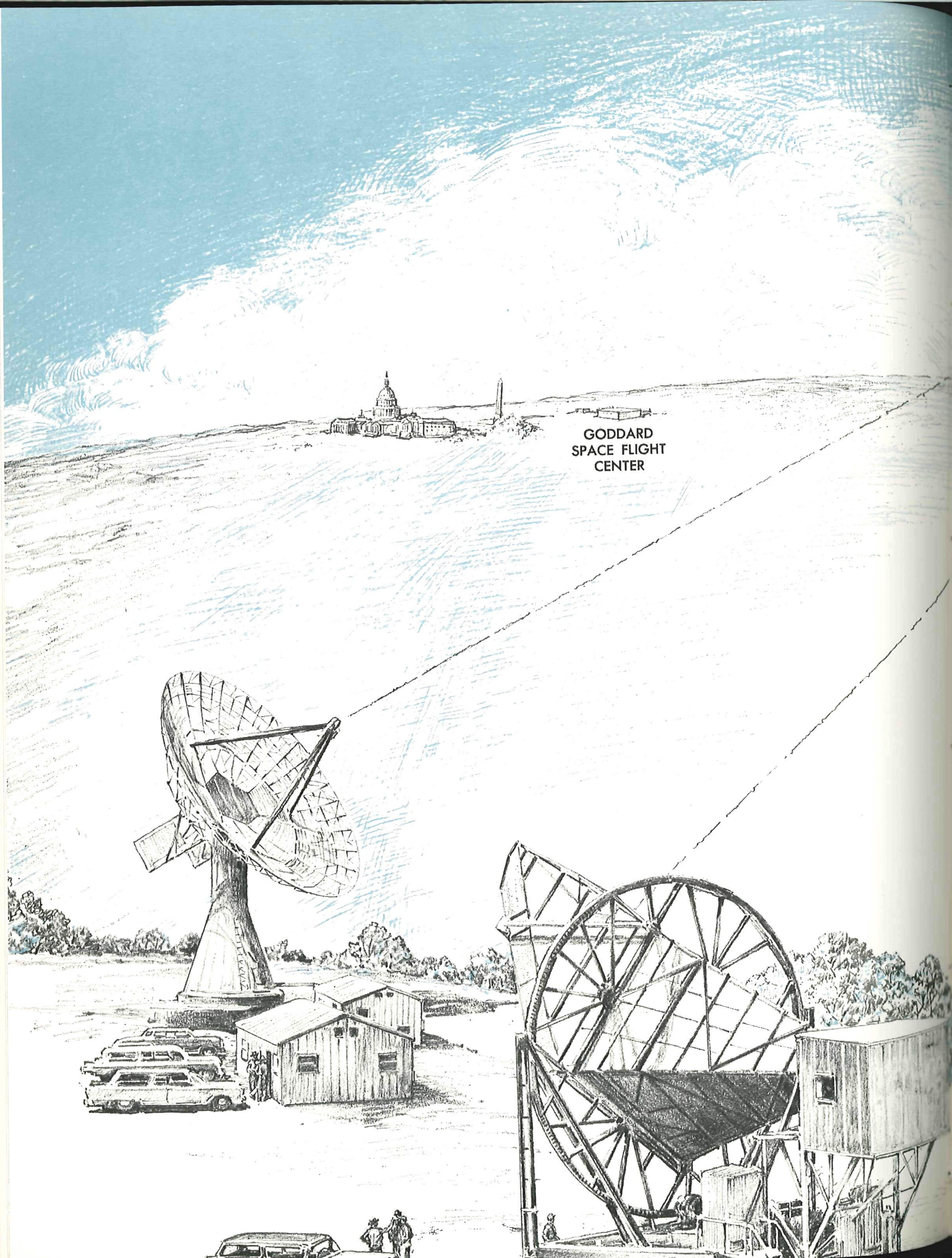
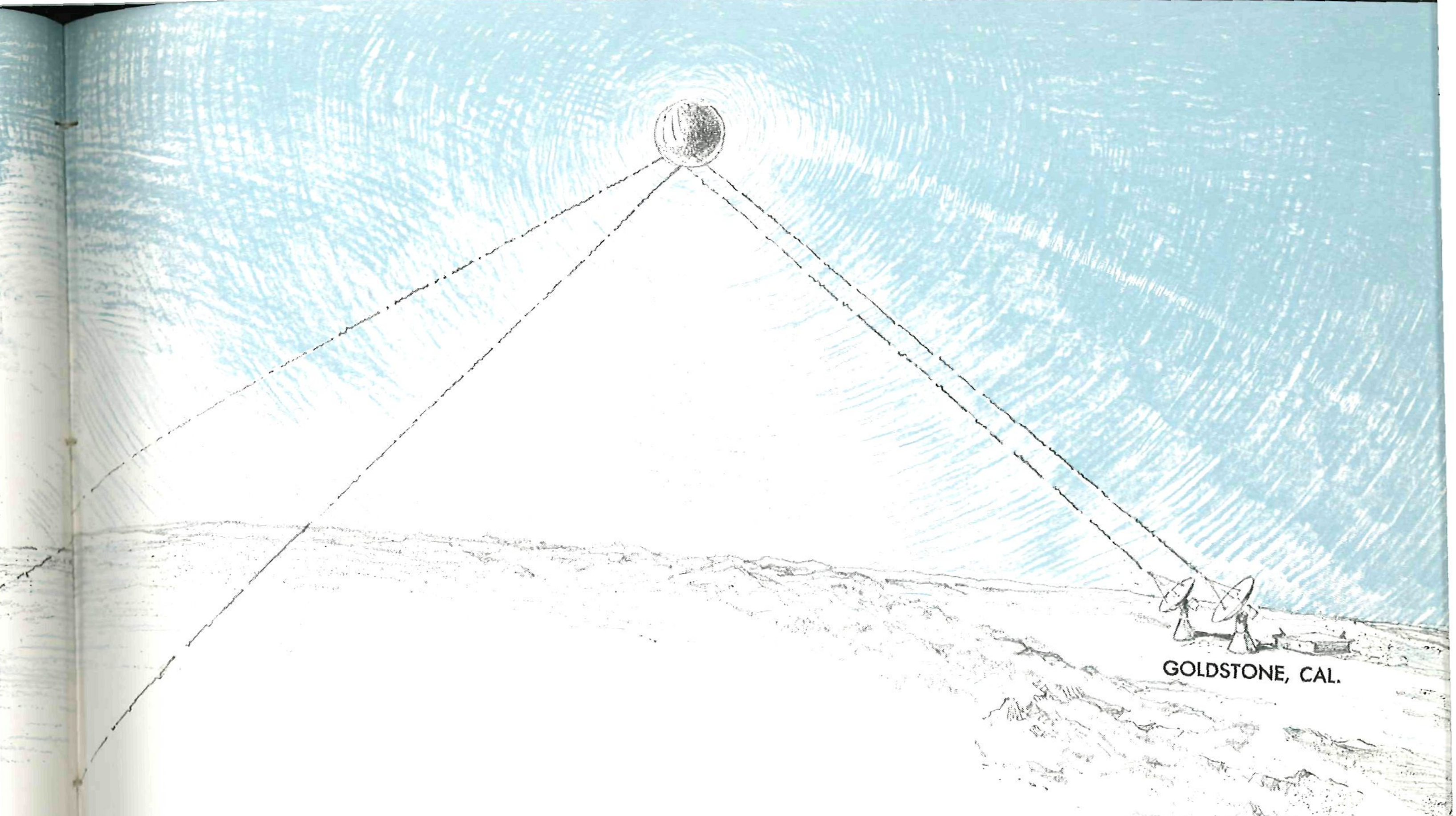
Bell Laboratories **RECORD**

Volume 39 • Number 9 • September 1961

Contents

Cover *D. O. Melroy inserts traveling-wave tube into permanent magnet; new backward wave oscillator is in foreground. Both devices are new signal sources for radio research (see page 320).*


GODDARD
SPACE FLIGHT
CENTER



W. C. Jakes, Jr.

PROJECT ECHO

With a justified sense of accomplishment, the Bell System can point to its pattern of growth over the years. But behind the annual increases in numbers of telephone instruments installed and telephone calls made is a vast network of equipment connecting millions of customers to each other. Much of this equipment is involved with transmission, and includes open-wire lines, coaxial cable, and microwave radio.

Wire lines and cable are not always economical, however, and the available space for microwave frequencies is becoming more and more crowded each day. Thus the Bell System must keep looking for new paths to transmit messages if it is to keep providing growth in communications for its customers. For this and other reasons the Bell System recently cooperated with the National Aeronautics and Space Administration (NASA) in an experiment to study long-range communications by radio relay using an orbiting earth satellite.

The study has had as its focal point the much heralded Echo balloon which NASA put into orbit on August 12, 1960. This sphere of aluminized mylar has since been used as a target for microwave signals in tests to determine the suitability of a passive satellite for voice communications.

In the year that has passed since the balloon was launched, the participants in the Echo I experiment have accumulated a large amount of data which must be studied and evaluated. To appreciate these results, we perhaps should first briefly review what the experiment has required in terms of its system equipment.

The over-all arrangement for Project Echo communications consists of radio transmitting and receiving equipment and satellite-tracking equipment located at Bell Laboratories in Holmdel, New Jersey, and at the Jet Propulsion Laboratories (JPL) in Goldstone, California. Also participating in many of the tests have been the Naval Research Laboratory (NRL) with a station at Stump Neck, Maryland, the General Electric Research Laboratories in Schenectady, New York, and a number of organizations overseas.

◀ *Echo was directed into near-perfect circular orbit 1000 miles high by Bell Laboratories Command Guidance System.*

A Thor-Delta missile containing a guidance system designed at Bell Laboratories placed the balloon in an almost exactly circular orbit 1,000 miles above the earth with an inclination of about forty-seven degrees to the equator. This provided the Laboratories site with mutual visibility of about 15 minutes with JPL and 25 minutes with NRL. The "slant range" from Holmdel to the balloon varied between 3,000 and 1,000 miles.

An east-west "channel" has connected a 60-foot paraboloid (or dish) antenna at Bell Laboratories to an 85-foot paraboloid at JPL via the balloon, on a frequency of 960.05 mc. A west-east channel, at 2390 mc has used transmission from another 85-foot dish at JPL to a specially constructed horn-reflector antenna at Holmdel.

The transmitter at Holmdel provides a 10-kw output for two signals. One signal, the communications channel, is centered at 960.05 mc. The other is centered at 961.05 mc, and is used for the tracking radar. The power output in each channel may be independently varied from 0 to 10 kw as long as their sum does not exceed 10 kw. Normally the communications channel is set to 7.5 kw and the radar channel to 2.5 kw. Characteristics of the transmitter can be monitored.

The 60-foot parabolic antenna can be positioned accurately to 0.05 degrees in winds up to 35 mph, at angular rates more than adequate for satellite tracking. From the feed horn to the transmitter output, the transmission line is waveguide, except for a short section of coaxial cable required for the two rotating joints.

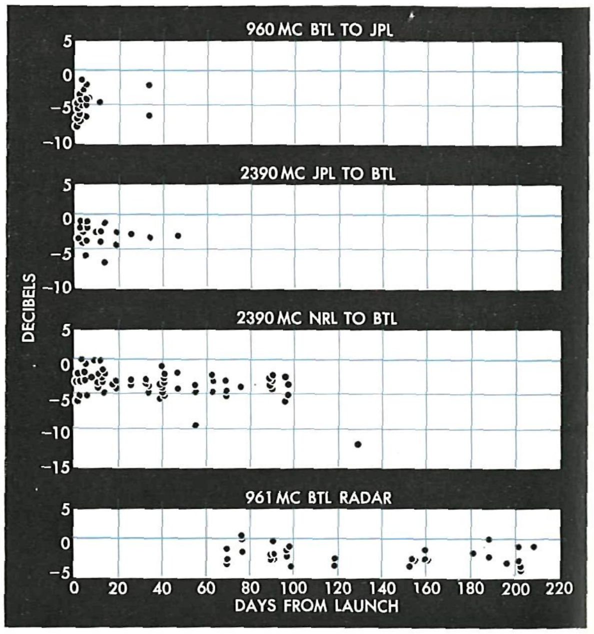
For receiving 2390-mc signals. Bell Laboratories has used the special horn-reflector antenna, primarily because of its demonstrated low-noise properties. In this antenna, the throat of the horn tapers to round waveguide inside an antenna cab. A rotating joint, having very low loss, couples the horn to the waveguide system.

The receiving system for the horn-reflector contains two maser amplifiers—one for each component of polarization of the incoming signal. Both are immersed in liquid helium in the field of a single magnet. In the event of maser failure, a dual 2390-mc parametric amplifier has also been provided, and can be switched into the system in place of the maser in a few minutes. The remainder of the receiving system is located in a control building and includes FM feedback demodulators, a four-channel pen recorder, a frequency monitor, and audio recording and distribution equipment.

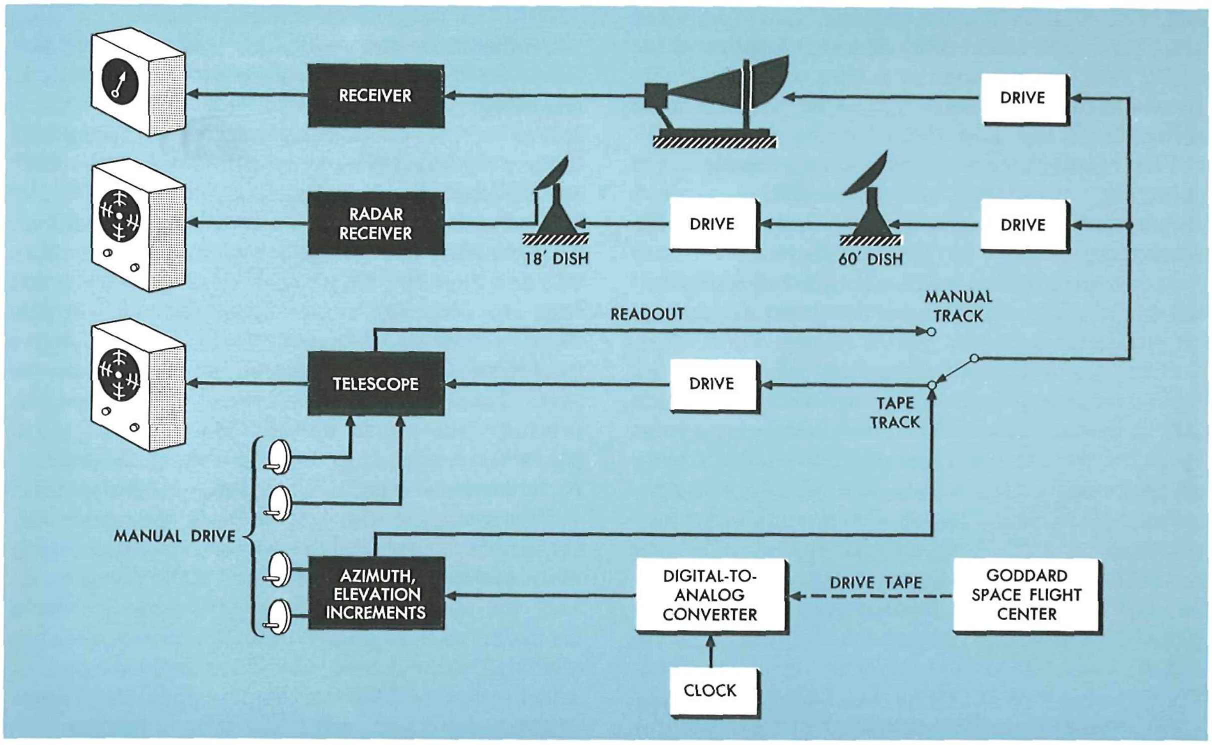
Laboratories engineers anticipated difficulty in tracking the satellite accurately enough to achieve hoped-for signal levels, and therefore set up a number of different methods of tracking. Primarily, the entire system was slaved to a teletypewriter tape containing predicted "look" angles for a given satellite pass. This tape was based on calculations of the orbits made at the Goddard Space Flight Center, Greenbelt, Maryland, from observations obtained from the center's Minitrack network—a series of radio-receiving stations spotted around the world.

During actual passes of the balloon, any differences between the position called for by the tape and the actual satellite position were corrected by information derived from optics, radar, or the radio signal. Alternatively, if no drive tape was available and if the satellite was visible, the system was slaved to the optical system which was then manually operated to track the satellite.

A Digital-to-Analog Converter (DAC) converts the digital information in the paper drive-tape to the analog (synchro) positional commands for controlling the antennas and optics (RECORD, *April,* 1961). The drive tape supplies, every four seconds, five separate quantities in a block called a "data point." Each data point gives time, azimuth, elevation, azimuth rate, and elevation rate of the satellite. These quantities appear on the tape in binary-coded decimal form—four bits for the digit and one for a parity, or error, check. The decoding equipment in the DAC uses the rate information to derive positional commands in between the four-second data points,



Measurements of scattering cross-section show change in shape of balloon over long period of time.



Steering information on the Echo satellite to and from the drive tapes is derived by three different methods. These are the optical tracker, the radar receiver, and information from radio signal itself.

and as a result, the antennas move smoothly.

For the first several months after launching, the computer at the Goddard Space Flight Center supplied the drive tapes. Since the beginning of 1961, most of the tapes have come from a computer at the Whippany location of Bell Laboratories, based on orbital elements supplied by the Smithsonian Astrophysical Observatory in Cambridge.

The drive tapes are read photoelectrically at a time corresponding to the time of the data point. As the tape advances from one point to the next, the angular quantities are read into transistorized logic circuits where they are sorted and decoded. The decoding process results in a rectangular pulse output whose duration corresponds to the input quantity, causing a motor to turn a gear to the appropriate angular position to an accuracy of 0.02 degrees. Fastened to the gear train are a number of synchro transmitters which supply positional command signals to the transmitting dish, receiving horn, and optical drives. The DAC also includes a stable clock for the time comparison in reading drive tapes.

The tracking telescope mounts on a large trailer and includes a periscope-type optical train leading to convenient operator positions inside. The telescope has a field of view of six degrees with a magnification of 8X. It can be slaved to the command signals originating from the DAC, or manually controlled to follow an object while sending suitable positioning signals to the antennas. Normally, the operator watches through the telescope while it moves in accordance with the commands derived from the drive tape. Then, if he detects errors, he inserts appropriate angular offsets, causing all the system antennas and the telescope to track the target accurately.

Tracking Radar

A separate tracking radar with an 18-foot paraboloid receives the 961-mc signal reflected from the satellite. A conically scanned beam of the radar obtains the angular position of the satellite with respect to the system axis. Error signals from the receiver then go to the optical trailer where they position the spot on a cathode ray tube. This shows the position of the satellite with respect to the system-pointing axis in much the same way as the tracking telescope. The operator manually inserts proper angular offsets to center the spot.

NRL has a single 60-foot dish equipped either to transmit or receive at 2390 mc. Ordinarily, both Bell Laboratories and NRL would receive JPL during the first part of a satellite pass while there was mutual visibility between Goldstone and Holmdel. After the balloon had "set" for JPL, NRL would then transmit to the Laboratories. On a few passes, JPL and NRL simultaneously transmitted to Holmdel and the two signals were recorded on the Bell Laboratories receivers.

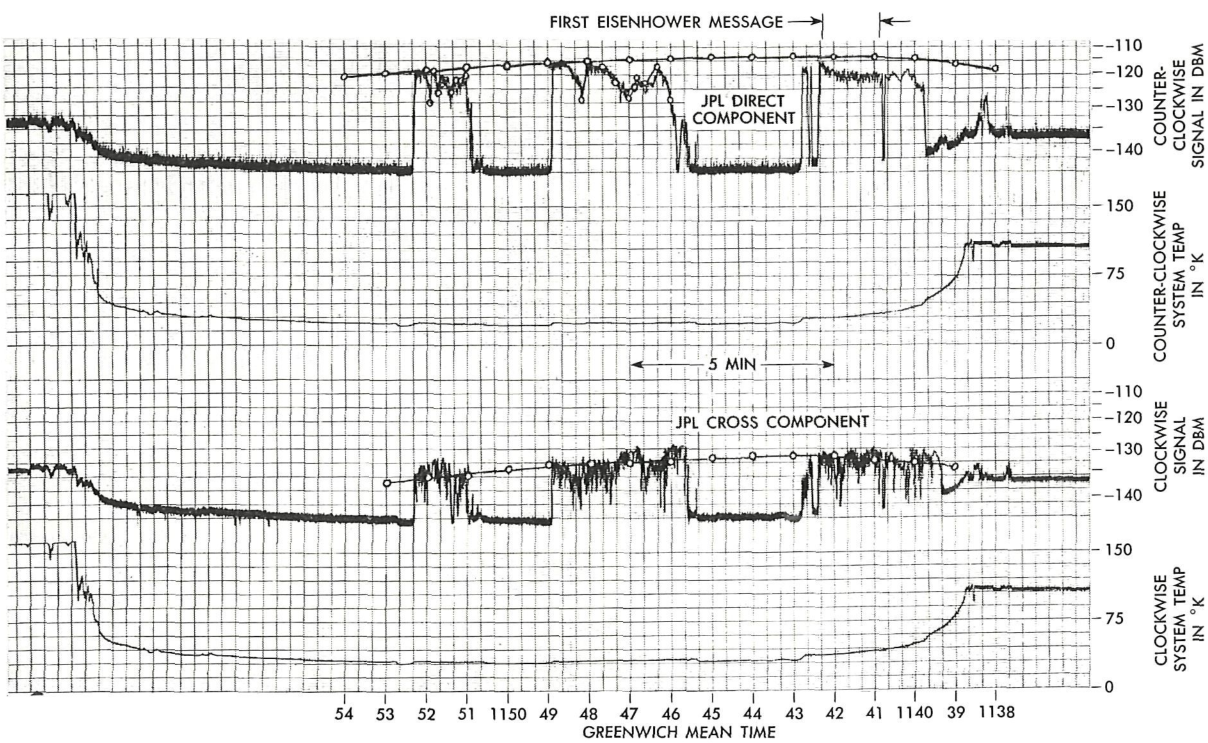
The communication tests were carried out primarily using frequency modulation with a special feedback arrangement invented over twenty years ago at Bell Laboratories. Other types of modulation were also available, including single sideband and narrow-band frequency, or phase, modulation.

Since the successful launching of the Echo I balloon, various operations, involving more than 150 passes of the satellite, have been carried out by Bell Laboratories. In general, the Laboratories project engineers feel they have achieved the objectives of the experiment. For example, measurements of the signal-to-noise ratio in the audio band were made during many of the passes for modulated signals. These measurements were very close to the predicted values for all types of modulation used. The quality of voice or music using FM feedback was excellent, and indistinguishable from that of a landline circuit. A successful demonstration of facsimile took place in September in which a photograph was transmitted from NRL to Holmdel via the balloon (RECORD, *October, 1960*). The project engineers have concluded that the balloon, in conjunction with the existing terminal equipment, provided an excellent circuit in the designed bandwidth of 200-3000 cps. Furthermore, any communication service that could be transmitted in this bandwidth could be handled equally well by the satellite circuit.

Comparison of actual received power with that predicted has been made for many passes at both 960 and 2390 mc. In general, the engineers found that the observed values differed from the predicted values by an approximately constant factor during the significant portion of most passes. On several early passes the average "scattering cross section" was equal to that corresponding to a perfectly conducting 100-foot sphere. From this it is assumed the balloon inflated as planned.

There apparently has been a long-term decrease, of a few db, in the average "scattering cross section." As of last May, Echo I was probably an approximately spherical object with a diameter no less than 70 feet, and a somewhat wrinkled skin. There may have been a few flattened areas, as indicated by occasional deep fades in the radar signal, but voice communication was then still possible as shown by successful tests with NRL on May 25.

Indication of near perfection in the launch and



Four-pen recording of first pass of satellite, August 12, 1960, showing polarization signals, temperatures.

guidance from Cape Canaveral came during the first passage of the balloon over the United States. At this time a signal was received from JPL for three periods of one to three minutes duration. The gaps in reception were caused by incorrect data points on the drive tape. The balloon could not be seen at Bell Laboratories during this pass because of cloudiness, and, since the radar was still relatively unproven, tracking was done by inserting appropriate angular offsets from the 2390-mc receiver. The drive tape used was prepared before launch and corresponded to the planned trajectory. Obviously, had the launching not been virtually perfect, there would have been no reception at all on the first pass.

Successful transmission took place from the Laboratories to JPL at 960 mc on a number of passes during the first eleven days after launch. At that time it was quite evident, from the steady signals, that tracking was excellent and that the balloon had a fairly smooth surface.

Later, occasional signal peaks greater than expected were observed. This is consistent with the hypothesis of a slightly distorted balloon surface. There may, for example, have been one or more flattened areas, any one of which could return more signal than the entire balloon when it was round. Or, it is possible that several signals reflected from these separate areas could add in phase, thus producing a signal stronger than that possible from a round balloon. Similarly, these various components could interfere destructively, and it is probably this mechanism that produced an occasional deep fade in the signal.

Probably the best example of a completely successful pass involving both JPL and NRL was the 70th, occurring several days after launch. By this time, the drive tape predictions were accurate to within a few tenths of a degree and personnel at all locations had become quite proficient in tracking and station operation. The level of received signal from both JPL and NRL agreed closely with theory almost throughout the pass.

Operations on subsequent passes were similar to those on pass 70. But the effects of shrinking became more and more pronounced, as shown by the increased scintillations of the received signal. By the end of 1960, the scintillations were fairly large, and the average signal level had dropped several db below the calculated value.

Greater scintillations were observed on all passes at low elevation angles of the satellite. This can be explained to some extent by operational effects, such as difficulty in acquiring and tracking the balloon at long range, but it is also probable that anomalous propagation through the earth's atmosphere contributed to the fading.

The DAC proved to be very reliable, requiring only minor repairs and adjustments. Occasional errors in pointing while the DAC was slaved to the drive tape were usually caused by errors in the tape itself. Moreover, DAC's error-checking circuits prevented about 90 per cent of these errors from appearing in the output positioning signals.

During each pass of the satellite the project engineers attempted to assess the accuracy of the drive tapes by appraising the angular offsets required to track the balloon. The results show that the predictions deteriorated progressively, with errors increasing from about 0.2 degree in August, 1960, to about 1 degree by December.

Several factors were responsible for these errors. For example, solar activities caused anomalies in upper air density. This effect became more pronounced as solar radiation pressure increased the eccentricity of orbit and the balloon traveled through denser air during part of each orbit. Also, the tracking beacons on the balloon itself gradually grew weaker, until, by the end of December, 1960, the signals were virtually useless for accurate determination of the orbit.

Additional Experiments

During the course of the Echo experiments, occasional tests were carried out with stations other than the principal participants. Transmissions were attempted, for example, to Jodrell Bank, England, using AM for voice and music. Reception was also reported at 960 mc by Centre Nationale d'Etudes des Telecommunications, France on August 18. On two later passes, CNET again reported receptions with a 30-foot dish which tracked the satellite optically.

Successful transmissions of a carrier signal to Malvern, England, occurred on three passes on August 29 at 960 mc. Also in August, Bell Laboratories transmissions at 960 mc were heard by the General Electric Company in Schenectady, New York. Later, a number of two-frequency transmissions were made with G. E. to study the amplitude and phase correlation of the signals.

Project Echo is now virtually completed. From it, a great deal of information has been filed on the properties of a satellite relay from microwave communications. But Echo I is a *passive* device, and to extend our knowledge of space communications, experiments must also be carried out with active repeaters. Only by such tests can we obtain the information needed to permit us to design working commercial systems.