The Signal Corps Astro-Observation Center, Fort Monmouth, N. J.*

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Summary-Many **months of active participation in the satellite and missile observation program have resulted in a number of new and improved concepts which have been put to practical use in the establishment of the U.S. Army Signal Research and Development Laboratory's Astro-Observation Center, Fort Monmounth, N. J.**

This paper will describe the capabilities of the Research and Development station and several of the instrumentation techniques in use, including the use of phase-locked audio-frequency tracking filters, and high-speed digital readout equipment for precision Doppler measurements.

The extreme flexibility of frequency coverage of the station has been of exceptional value in the rapid acquisition of signals transmitted from. foreign satellites and space probes.

INTRODUCTION

THE U. S. Army Signal Research and Development Laboratory operates an advance design satellite and missile observation station known as the USASRDL Astro-Observation Center near Fort Monmouth, N. J., to study wave propagation phenomena associated with radio transmissions from space objects.

This facility consists of two stations; one is located at the center of a 208-acre tract of land previously used by the Bell Telephone Laboratories as a fixed site for early transoceanic radio telephone experiments. The property, called the Deal area, has been employed by USASRDL since 1953 as a site for testing and evaluating newly developed Signal Corps receiving systems, and for wave propagation research. The second station is located on Shark River near Belmar, N. J., and is the original site of the first moon radar contact made by the Signal Corps in 1946. Called the Aircraft Warning Area for its early history in aircraft detection research during World War II, it is more commonly called the Diana Site since the first moon radar reflections were received.

When the Soviet Union launched the first artificial earth satellite, Sputnik I, on October 4, 1957, the Deal station embarked on a new phase of operation, that of satellite observation. Existing station equipment permitted the reception and recording of transmissions on 20.005 and 40.002 mc. A total of 273 orbits of Sputnik I were observed and recorded covering approximately 500 hours of continuous monitoring. As the space program continued to grow, so did the instrumentation and the concept of this portion of the observation center. Improved instrumentation was added to the station during the early part of 1959 (Figs. 1 and 2). Currently, the station operates on a 24 hour per day basis, and to (late has recorded over 12,000 orbits of all satellites, foreign and domestic. The recordings, both Doppler and amplitude, have been cataloged and placed on file in the station's library for analysis and are available for reference by interested research groups. Many important results on radio transmission from space and ionospheric parameters have been observed and reported elsewhere.

During the past two years an extended effort has been put into the investigation and improvement of satellite and missile Doppler measuring equipment, with the view of developing a system which affords extreme flexibility of frequency coverage. Such a system has been designed and is in operation at the USASRDL Astro-Observation Station.

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The frequency coverage of the station is currently covering the range 15 kc to 900 inc. Within this range it is possible to make precision Doppler measurements at random frequencies with automatic digital readout accuracies of I part in 10^8.

DEAL STATION DOPPLER MEASUREMENT SYSTEM

The low intensity of signals being transmitted from earth satellites or space probes requires that methods be employed at the ground station to greatly improve the signal-to-noise ratio of the Doppler signal by obtaining a reduction in circuit bandwidth. In effect, an electronic band-pass filter whose center frequency automatically tracks the Doppler signal frequency fulfills this requirement.'

The tracking system presently in use at this station employs a phase-locked, audio-frequency electronic tracking filter with adjustable bandwidths between 2.5 and 50 cps which permits lock-on capabilities at signal input levels as much as 30 db below the noise. The center frequency of the electronic band-pass filter tracks the input frequency by means of a phase-locked servo loop. Easily accessible Controls allow for immediate adjustment of bandwidths under dynamic flight conditions, thus it is possible to take advantage of the maximum signal-to-noise ratio by permitting the use of the narrowest possible bandwidth without losing lock.

The tracking filter may be used with any receiver coin bination capable of detecting the incoming signal which is heterodyned against a precise frequency standard and mixed at the input to the receiver. The heterodyned note produced by the mixing of the incoming signal with the frequency standard may be anywhere in the range of 100 to 20,000 cycles. The audio output of the receiver containing this signal is fed to the input of the tracking filter. This level is usually about 3 volts rms. The output of the tracking filter now contains a sinusoidal wave form which is varying in frequency as the received Doppler frequency. The maximum tracking error over the entire range of the filter is less than 0.02 degree and so can be neglected for all practical cases. The resultant frequency is counted and recorded on magnetic tape for future reference. The tracking filter block diagram is shown in Fig. 3.

The system as described so far lends itself very satisfactorily as a means of detecting and recording the Doppler shift of a satellite or missile in flight. However, the great speeds at which these vehicles travel allow little time for the manual conversion of the recorded data for rapid transmission to computer centers. The requirement for such a system has resulted in the development of a digital data readout unit which has the capability of recording frequency measurements simultaneously with real time, both in printed numerals and in coded perforations at the rate of 60 digits per second.'

Frequencies are alternately measured by two 10-me electronic counters, and time is measured in hours, minutes, and seconds by a 24-hour digital clock driven by a 100-kc frequency standard. Two or more stations at widely separated locations may be phased together by means of a Digital Phase Shifter which permits the clock and the counter gates to he synchronized within plus or minus 1 msec of the standard time signals being transmitted by the Bureau of Standards Station WWV, or from any other reference standard. Start and stop control pulses for the two electronic counters are derived from a common electronic switch in the digital phase shifter. The gate of either one electronic counter or the other is open at all times except for the transition time of the switch gates. (Less than 1 μsec.) The time between adjacent stop and start signals is one second, with accuracy equal to the 100-1c reference standard. Digital readout is recorded in printed form on a standard three-inch paper tape. A punch coupler-perforator combination records identical data in coded perforations on standard teletype tape for transmission over wire line circuits. When the tape produced by the tape perforator is fed into a standard teletype punched tape reader, a teletype page printer will produce columns of figures.

' Phase-lock tracking filter, product of Interstate Electronics Corp., Anaheim, Calif.

' Digital Data System DY-5236A, mfd. for USASRDL by Dymec Inc., Palo Alto, Calif.

Each line reading horizontally will contain six digits of time in hours, minutes, and seconds followed by a space and then a series of eight digits representing the Doppler frequency from the electronic counters. Fig. 4 shows a block diagram of the complete digital Data System DY-5236A.

It must not be overlooked that the accuracy of this system is strictly dependent on the accuracy of the injection oscillator employed. Serious consideration should be taken, therefore, in the selection of a suitable frequency standard for this purpose. It is highly desirable that the frequency standard selected be capable of variable frequency output which can be multiplied to cover the frequency range of the Doppler system. For this purpose, the USASRDL station employs a group of frequency synthesizers with a basic range of 30 cps to 30 me in steps of 10 cps, locked-in with an external I00-kc frequency standard.' The synthesizers are also capable of continuous variable frequency output in between the 10-cycle points with somewhat reduced accuracy. The output voltage is sinusoidal, free from spurious frequencies, and adjustable between 0.1 my and I volt, which is used to drive frequency multipliers up to the systems limit of 900 inc. Local frequency standards are calibrated against a 100-kc signal transmitted over cable facilities from the main laboratory's Atomichron, located approximately four miles away. Plans are currently being formulated to drive the synthesizers directly from the remote Atomichron for improved accuracy.

The output of the frequency multipliers is passed through attenuators to the inputs of standard Signal Corps R390A/URR receivers with converters continuously tunable to 55.0 me. The remainder of the VHF and UHF ranges tip to 900.0 me are covered by the use of commercially available special-purpose receivers.' The LF range (15-1500 kc) is monitored by the use of standard Signal Corps R 389/URR receivers.

The extreme flexibility of frequency coverage of this system offsets to a great extent the current limitation of 20,000 cycles of Doppler excursion. However, full Doppler excursion can be had up to 375 me at velocities of 18.2K mph. The circuitry of the tracking filter readily lends itself to modification for this increased excursion. It is contemplated that such a modification will be initiated in the near future.

This system has been of invaluable use at USASRDL for immediate acquisition and measurement of Doppler shift of foreign satellites and space probes operating at various frequencies throughout the spectrum, whereas fixed frequency microlock systems have been unable to meet this challenge. The use of these techniques has been instrumental in immediate evaluation of the success or failure of space vehicles launched from Cape Canaveral. This is especially true for those launchings made in a northeasterly direction.

SIGNAL LEVEL MEASUREMENTS

During the course of observing signals transmitted from earth satellites and space probes, it has become more important to obtain a permanent record of the behavior of propagated radio signals as they pass through the ionosphere. Instrumentation has been set up at the USASRDL Observation Center to provide for the permanent recording of such signals for use by propagation study groups.

The instrumentation for this project required the modification of the AGC circuits of the R390-A/URR receivers to remove all delay so that the slightest change in signal would cause a change in AGC voltage, and would in turn activate a recorder. In reality, the R390-A receiver is used as a recording voltmeter. The modification is a relatively simple one resulting in a change in the AGC voltage curve as illustrated in Fig. 5. The curves shown are representative of the AGC voltage change of the R390 receiver operating without the addition of VHF converters, which materially increases the gain of the system.

Eight-channel Sanborn recorders are provided for readout of the relative strength of the received signal. One-second time markers are recorded on the extreme edge of

' Rhode & Schwarz frequency synthesizers types XUA and XUB, with associated frequency standards and multipliers.

' Nems Clark 1302A (55-260MC), range extension units REU-300 (250-900mc).

the chart which accurately marks the time of events recorded on the main channels of the recorder. Each recording is identified and indexed to the corresponding Doppler recording for the particular event being observed, and then is filed in the station's library for further reference. As mentioned previously, the library now contains over 12,000 recordings dating back to the early orbits of Sputnik I. This represents the most complete reference library of its type known to exist in the entire country, if not the entire scientific world.

TELEMETRY RECEIVING SYSTEM

In order to meet the operational commitments in a station of this size, it was planned that the basic design of the station include adequate telemetry receiving facilities with sufficient channels to accommodate all future demands.

The telemetry system currently in use at the USASRDL station consists of ten channels of encoder-decoder equipment coupled to the output of a bank of Nems-Clark telemetry receivers equipped for crystal-controlled operation on any one of 44 assigned RU channels within the band 225 to 260 mc.[5]

The outputs of ten subcarrier oscillators are fed to Sanborn chart recorders and to magnetic tape recorders. Ten audio-frequency discriminators are available for the playback of magnetic tapes, or to decode telemetry data from signals received from satellites or space probes.

ANTENNA FACILITIES

A wide variety of antennas are used at the USASRDL station. Generally, several antenna systems are used on each intercept depending on the particular experiment in progress. The normal complement of antennas consists of horizontal and vertical polarized high gain Yagis, circular polarized Yagis, and broad-band conical helices with right- and left-hand polarization.

DIANA STATION

The Diana station is a basic research facility for the study of wave propagation, communications, and radio astronomy research. At this site, as described previously, the first moon radar echoes were received. At the present, routine moon transmissions to the University of Illinois, are undertaken to determine the electron content of the ionosphere and the diurnal and seasonal variations. Measurement of the Faraday rotation of lunar radio echoes on a frequency of 151 me are used to determine the time variation in the total ionospheric electron content. Absolute values of ionospheric electron content are determined front these measurements in conjunction with information on the electron content below the F^2 peak computed from vertical incidence sounding data."

The Diana station has undertaken many other experiments, for example, the determination of tipper usable frequencies for ionospheric scatter, meteor scatter, and the calibration of "Minitrack" receiving systems in the western hemisphere by moon relay at 108 mc. Numerous verifications of reception of these signals were received from radio amateurs throughout the world. A specially designed verification card was sent to all stations reporting reception of the moon-bounce signal' (Fig. 6). Radio astronomy techniques now usable for space probe tracking were developed, and many of the first parametric amplifiers were used at this site.

The antennas at the Diana station, Fig. 7, consist of 50- and 60-foot paraboloidal antennas. The 50-foot antenna has an azimuth-elevation mount, a maximum speed of rotation of 0.5 degree per second with a positional accuracy of 0.1 degree. Its use is limited by the steel mesh reflecting surface to frequencies below 1500 mc. The transmission line is a 6%-inch rigid coaxial line capable of withstanding high-power RF transmission. The 50-foot system serves a dual purpose as a radar transmitting system for moon studies, propagation experiments and the like; and as a receiving system equipped with parametric amplifiers for space probe tracking. Dipole feeds at the focal point of the dial are changed for each frequency, although one triple feed covering 108 mc, the telemetry band at 240 mc, and 960 me is available.

The Diana and Deal stations are integrated by the use of a microwave link which has the capability of handling several data channels. Precision Doppler measurements can be made at Deal from the Diana 50-foot antenna, by transmitting over this microwave link the audio output of the receivers containing the heterodyned note produced by the mixing of the incoming signal with a frequency standard. Tracking filters at the main station accept this signal, and the Doppler is automatically printed out by the Dymec system described earlier in this paper.

[5] Telemetry equipment mfg. by Hallamore Electronics Co., Anaheim, Calif.

[6] S. J. Bauer and F. B. Daniels, "Measurements of ionospheric electron content by lunar radio technique," *J. Geophys. Res.*, vol. 64, pp. 1371-1376; October 10, 1959.

In addition to the 50-foot antenna, a 60-foot parabola is also available for use. Marked success was achieved using the 60-foot antenna on the Russian Lunik II shot, as well as on the Pioneer space probes. This 60-foot parabola is also of the azimuth-elevation type with a rotational speed of 10 degrees per second. The reflector has an aluminum mesh usable as high as 3000 mc. The antenna will automatically track any device transmitting in the 225-mc to 250-mc region to within 0.1 degree accuracy.

Two transmitters are in use for the propagation experiments_ One operates at 151_11 me with 50-kw power output in the CW mode. Pulse widths from 600 p.sec to 4 seconds at various repetition rates are available. The second radar operates at 413.25 mc, with 20 kw in the CW mode and 50 kw peak in pulse operation. Pulse widths from 6 to 2000 u.sec are available at various repetition rates.

These equipments have been instrumental in determining significant results in radar range errors, refractive errors, and as previously noted, in ionospheric densities. Experimentation on detection of high altitude nuclear blasts and the determination of parameters affecting tropospheric, ionospheric, and meteor scatter communications have also been investigated.

The data taken by the Astro-Observation Center have provided scientific results in many aspects. For instance, they serve to determine the tumbling and spinning of the satellites, the natural decay of the satellites spin rate, and ionospheric parameters.' These results will be valuable for the design of future controlled aspect satellites and space vehicles, and of satellite communications systems.

The planning of a receiving station possessing the versatility of the USASRDL station encompasses the compilation of many ideas and a wide variety of experiences. Primary consideration must be given to unlimited flexibility and ease of operation. For example, on missile launchings maximum effort is placed on the accurate acquisition of Doppler data which must be transmitted to a network of computer centers. Once the satellite is determined to be in orbit, a complete change of data acquisition techniques is required. Instrumentation must be switched instantaneously with the least possible confusion in the instrumentation area.

With this country's growing capability, leading to the launching of bigger and more sophisticated satellites, a research program to keep this type of ground station up to the state of the art is also underway. Research tasks for the development of wide-band antenna feeds, wide tuning range parametric amplifiers, electronic scanning techniques, and other investigations to increase the capabilities of ground tracking stations are underway. As these techniques and equipments are developed, they will be tested at the Astro-Observation Center before installation at other stations around the world.

' P. R Arendt, "Review of USASRDL satellite propagation studies," this issue, p. 357. .