

THE NBS FREQUENCY AND TIME SATELLITE EXPERIMENT USING ATS-3

by

D. W. Hanson, W. F. Hamilton, and L. E. Gatterer

Mr. Hanson, Mr. Hamilton, and Mr. Gatterer are with the Frequency and Time Dissemination Research Section, National Bureau of Standards, Boulder, Colorado.

1.0 INTRODUCTION

The work to be described is part of the National Bureau of Standards' (NBS) continuing effort to provide time and frequency information to a large number of users. This paper will discuss the current NBS time and frequency dissemination experiment using NASA's ATS-3 satellite. This work has been done partially supported by the Air Force Cambridge Research Laboratories.

2.0 CURRENT EXPERIMENT

The ATS-3 experiment is being conducted by the National Bureau of Standards operating under NASA's "User Experiment Program." Beginning on 1 August 1971, NBS began broadcasting the WWV time and frequency format from Boulder, Colorado, to the ATS-3 satellite, which then transponds the signals back to the earth. The uplink frequency to the satellite is 149.245 megahertz and the down link is at 135.625 megahertz. Figure 1 shows the transmit antenna at the Boulder Laboratories. It is a bifilar helix with 14-db gain and right circular polarization.

The signals transmitted from Boulder are frequency modulated and occupy a 30-kilohertz bandwidth. The signals are composed of voice

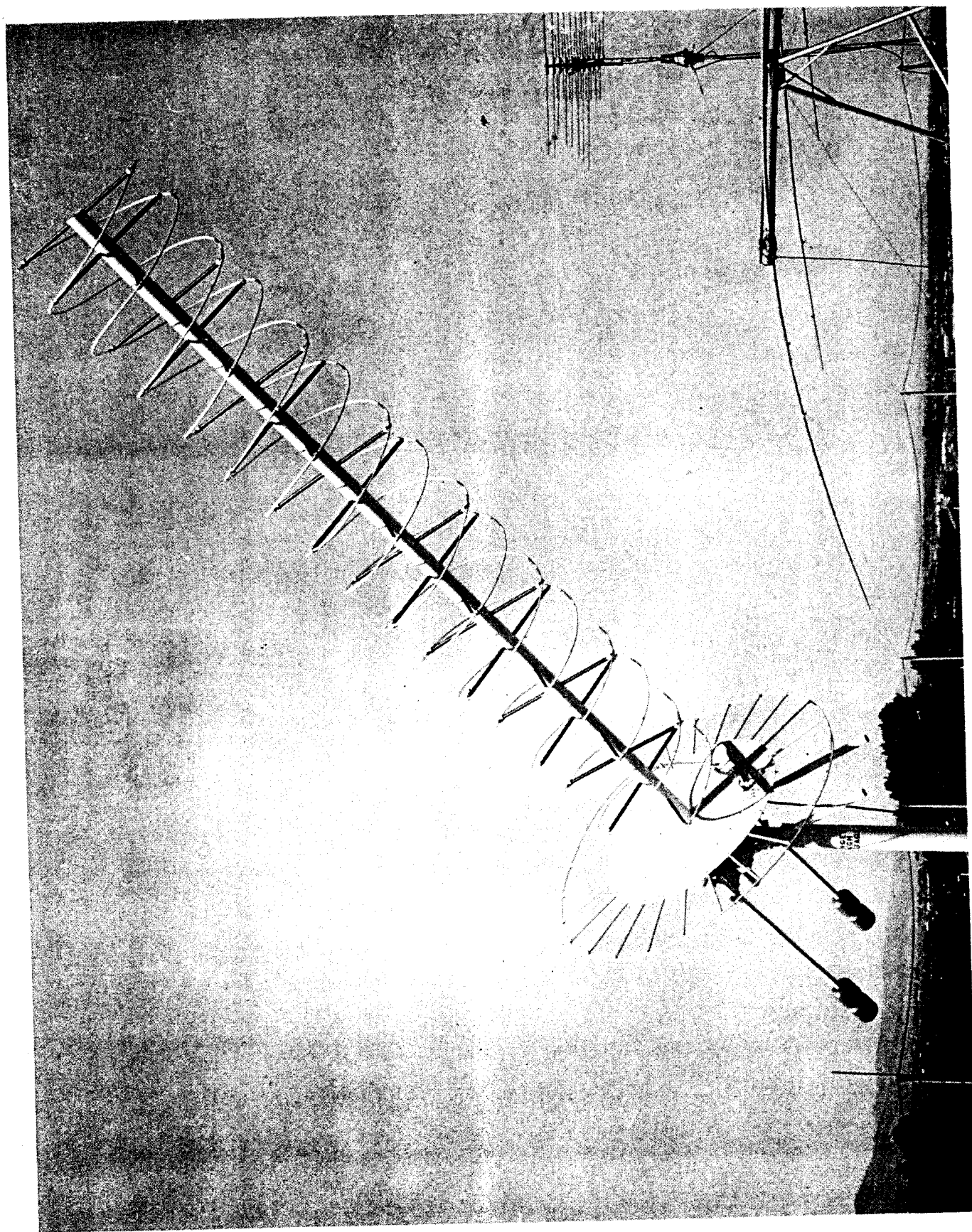


Figure 1. TRANSMITTING ANTENNA AT NBS, BOULDER COLORADO LABORATOIREIS

announcements of time-of-day, ticks every second, tones, and a time code. These signals are referenced to the NBS UTC time scale. The broadcasts take place between the hours of 1700 to 1715 and 2330 to 2345 Greenwich Mean Time, Monday through Friday, excluding holidays. This experiment is scheduled to continue until 1 August 1972.

The ATS-3 spacecraft is in synchronous orbit and is presently stationed at approximately 70 degrees west longitude over the Equator. The output power from the spacecraft during these frequency and time broadcasts is approximately 10 watts fed to an 8 db gain, linearly polarized antenna or, +48 db EIRP. The spacecraft antenna provides earth coverage as seen from synchronous altitude. In this case, the coverage includes North and South America, major parts of the Pacific and Atlantic Oceans, and a portion of Europe and Africa. In Figure 2 you will see a heavier line, or 5-degree elevation line, which approximates the periphery of usable coverage.

It has been a fundamental constraint in all NBS satellite experiments¹⁻⁴ that the user requirements for the reception and recovery of time and frequency signals be simple and inexpensive. Figure 3 shows the typical equipment used to receive the ATS-3 time and frequency signals. Shown are a 10-db gain Yagi antenna, linearly polarized, and an FM receiver. The receiver's noise figure has been improved by the addition of a transistor preamplifier to give a 5-db noise figure.

-
1. Jespersen, J.L., G. Kamas, L.E. Gatterer, and P.E. MacDoran (1968), "Satellite VHF Transponder Time Synchronization," Proc. IEEE Vol. 56, No. 7, July 1968, pp. 1202- 206.
 2. Gatterer, L.E., P.W. Bottone, and A.H. Morgan (1968), "Worldwide Clock Synchronization Using a Synchronous Satellite," IEEE Trans. Instr. and Meas., Vol. IM-17, No. 4, December 1968, pp. 372- 78.
 3. Hanson, D.W. and W.F. Hamilton (1971), "One-Way Time Synchronization via Geostationary Satellites at UHF," IEEE Trans. Instr. and Meas., Vol. IM-20, No. 3, August 1971, pp. 147- 53.
 4. Hanson, D.W. and W.F. Hamilton (1971), "Clock Synchronization from Satellite Tracking," IEEE Trans. Aerospace and Electronic Systems, Vol. AES-7, No. 5 September 1971.

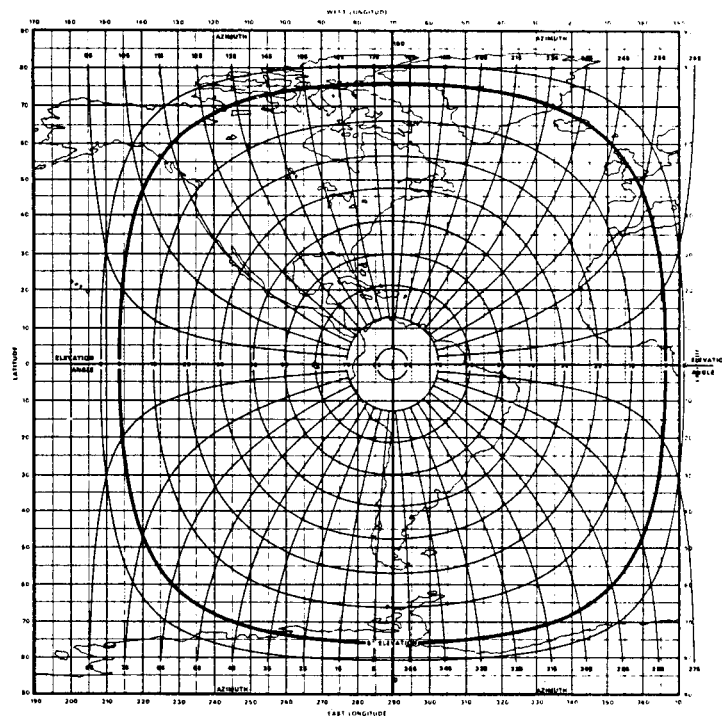


Figure 2. RECEIVER ANTENNA POINTING ANGLES

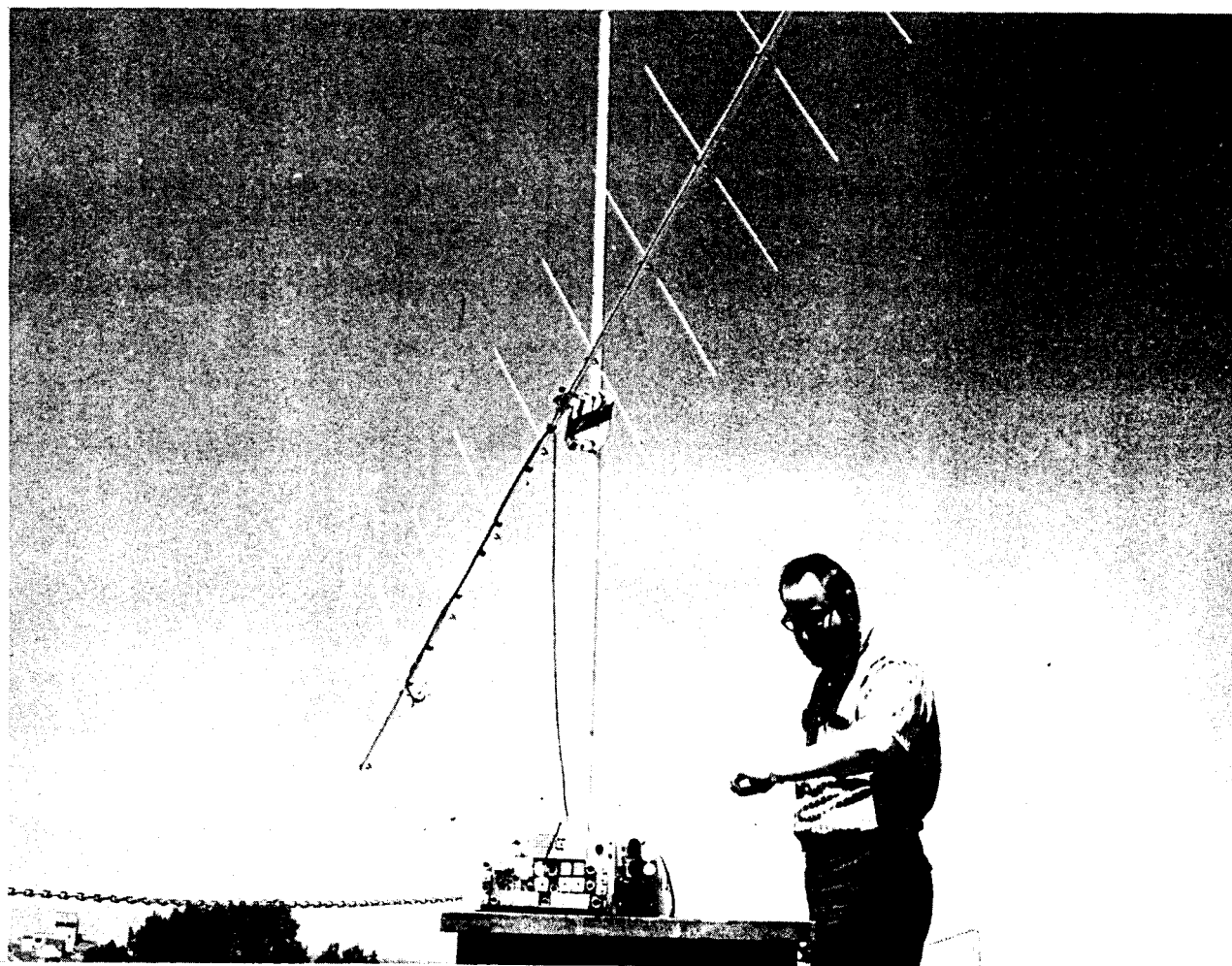


Figure 3. TYPICAL ATS-3 TIME AND FREQUENCY RECEIVING EQUIPMENT

We are now using a commercial circularly polarized receiving antenna, low-noise transistorized preamplifier (2.8-db noise figure) and FM receiver which sells for approximately \$150. Figure 4 shows the received signals from ATS-3 as seen on an oscilloscope. This is the 1 pps tick and 600 Hz tone which is typical of the WWV format. Figure 5 shows an expanded view of the 1 pps tick as received at Boulder, Colorado. The propagation delay is very stable and the signals at Boulder have been free from any noticeable fading which allows for excellent timing resolution.

3.0 LEVELS OF SERVICE

We think of the ATS-3 experiment as offering three levels of service. The first level is obtained by simply listening to the ticks and voice announcements from the satellite. The signals leave Boulder on time and, because of the satellite's 38,000-kilometer altitude, the signals arrive back on earth delayed by approximately one-quarter of a second.

The second level of service is realized when one measures accurately the arrival time of the transmitted "ticks" relative to ticks of his local clock. Referring to Figure 5, by observing the positive going zero crossing of the first cycle of the tick, one is able, with visual averaging, to achieve 10 microsecond resolution in the time of that crossing relative to his local clock. At Boulder, with our local clock on time, we have been measuring the delays from Boulder to ATS-3 and back to Boulder, including equipment delays. If our local clock had not been on time, that difference would have been included in that "apparent" delay measurement. In order for our listeners to determine what the delay should be to their location, we have prepared contours of delay for the user of this experimental service.

Figure 6 shows the delay contours for the 1700-1715 GMT broadcast. If one wished to know the delay from Boulder to Washington, D.C., via ATS-3, he would look at the contour line which runs through Boulder and add it to

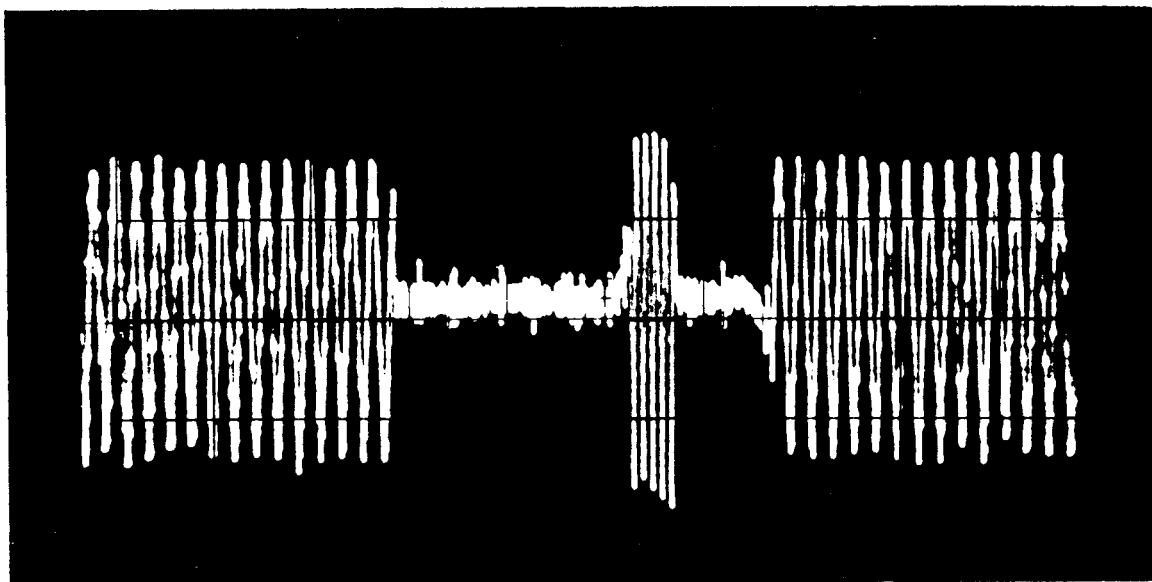


Figure 4. RECEIVED SIGNALS FROM ATS-3
(TICK AND TONE; SWEEP SPEED 10 ms/cm)

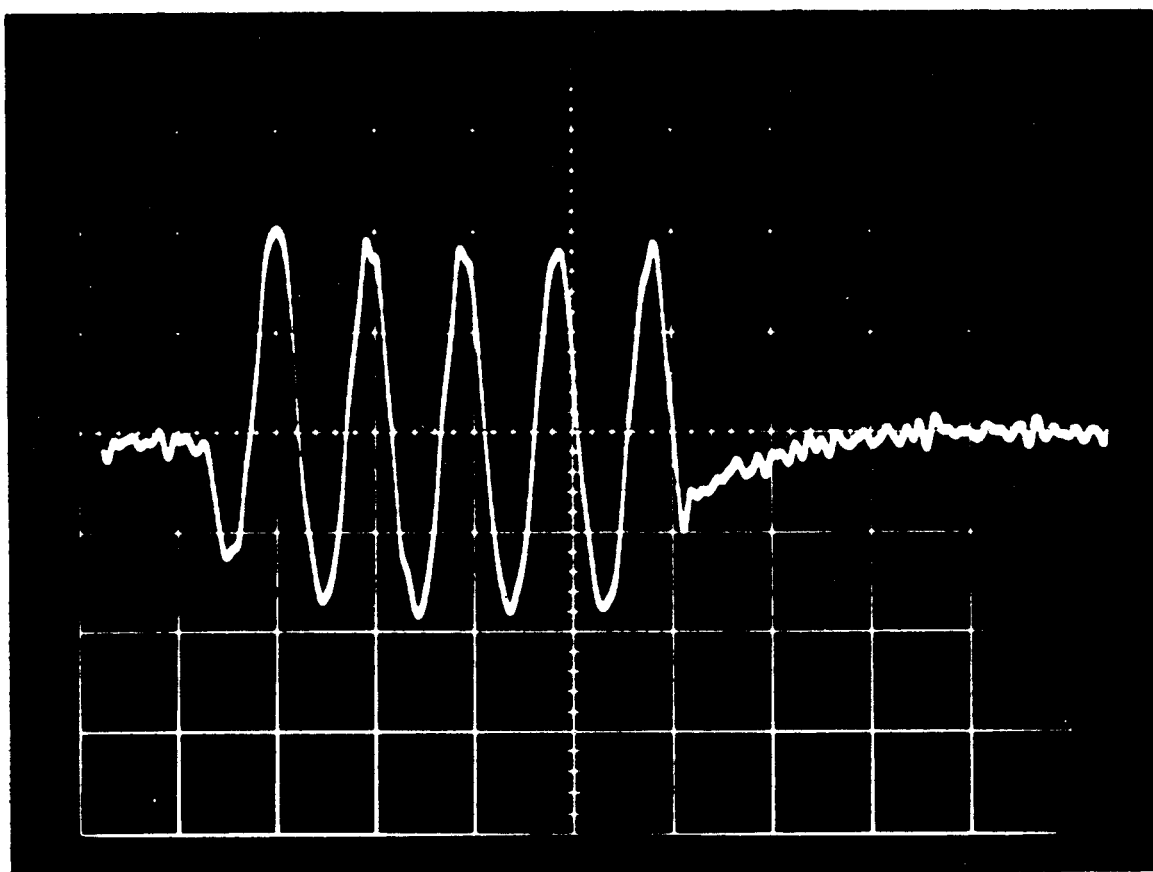


Figure 5. RECEIVED SIGNALS FROM ATS-3
(TICK; 1 ms/cm)

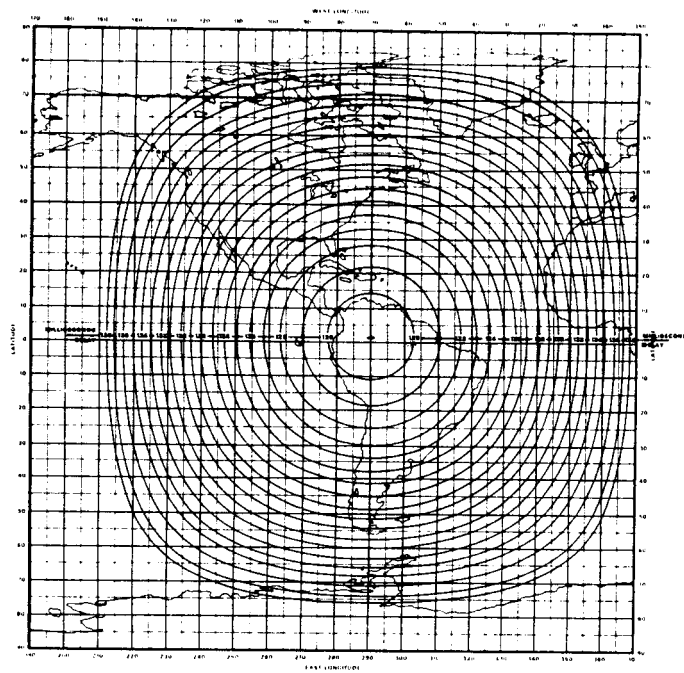


Figure 6. PROPAGATION DELAY 1700-1715 GMT

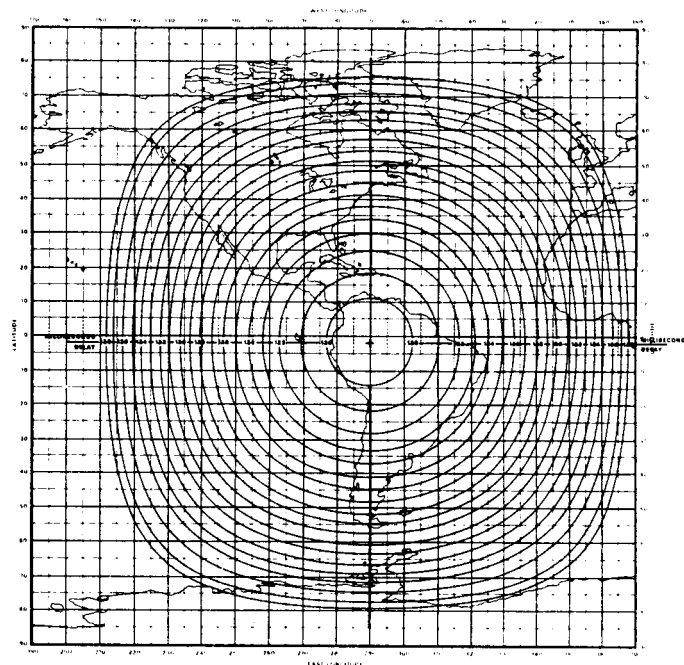


Figure 7. PROPAGATION DELAY 2330-2345 GMT

the one which runs through Washington, D.C. Figure 7 shows the delay contours for the 2330-2345 GMT broadcasts. These delay contours are generated from the orbital elements issued by NASA on ATS-3. From these elements we derive new contours monthly and publish them in the NBS Time and Frequency Services Bulletin.* In addition to the delay contours we include in the NBS Time and Frequency Services Bulletin contours of azimuth and elevation to enable our listeners to point their antenna at the satellite. Those contours are shown in Figure 2. It has been our experience that these delay contours allow timing to a few milliseconds. Figures 2, 6, and 7 were derived from NASA orbital elements issued for 23 October 1971.

The third level of service should be in effect by 1 January 1972. Our work with NASA's orbital elements has generally allowed us to predict the delays from Boulder to any point in view of the satellite to within 10 to 20 microseconds. To enable our listeners to benefit from this ability, we have designed a special purpose delay computer in the form of a circular slide rule. A prototype of this slide rule is shown in Figures 8a and 8b, which show the front and back of the rule, respectively. When we initiate this third level of service, we will broadcast by voice the satellite's longitude and latitude and a radius correction. The user will enter this information along with his longitude and latitude on the slide rule and compute the delay to his location to within 10 to 20 microseconds. This capability coupled with the path delay short-term stability should enable the user to obtain much better than a 50-microsecond timing.

A quantity of these slide rules are now being manufactured on a heavy plastic laminate. Since the program described is experimental, NBS requires

* For duration of this experiment, booklets, slide rules, and bulletins are available upon request. Write National Bureau of Standards, Frequency-Time Dissemination Research Section, Boulder, Colorado 80302.

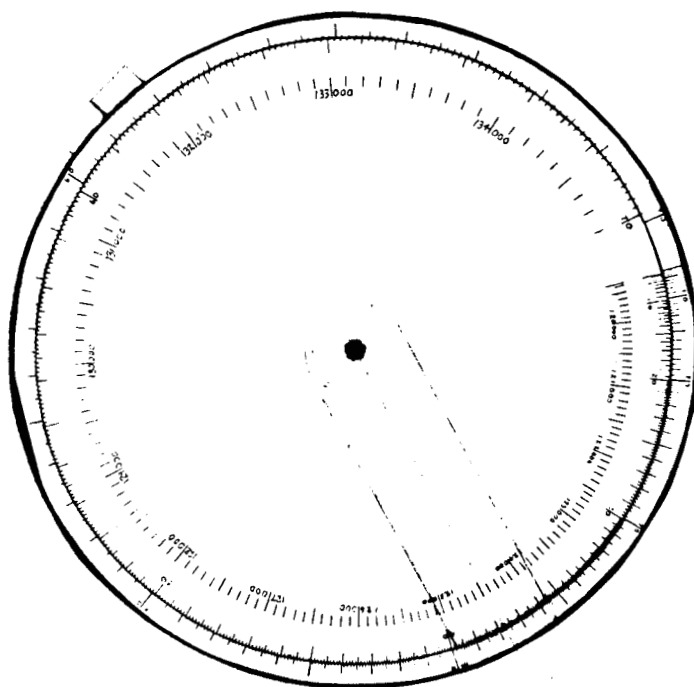


Figure 8a. PROTOTYPE DELAY COMPUTER (FRONT)

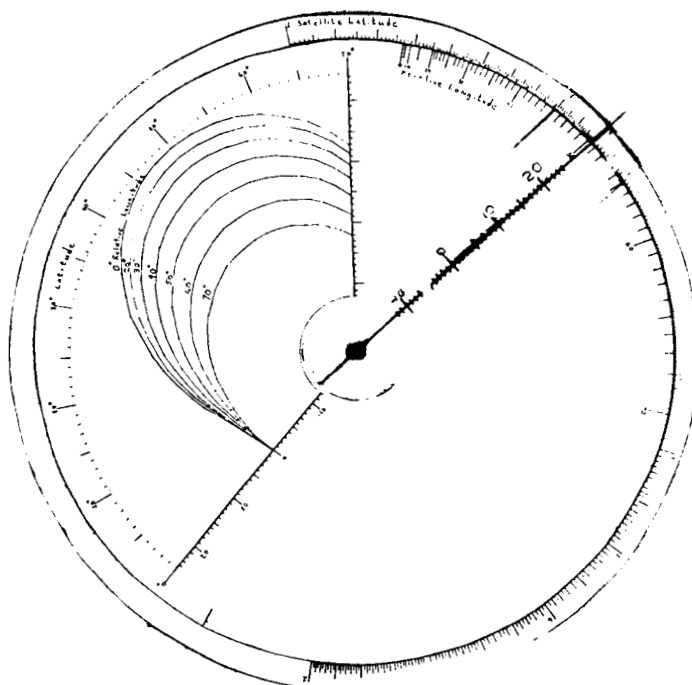


Figure 8b. PROTOTYPE DELAY COMPUTER (BACK)

data to verify its expectations. Anyone who has access to a good time reference and can provide NBS with data is being encouraged to use one of these slide rules when they become available. An informative booklet explaining this service is also available.*

Figures 9 and 10 show the results we have experienced at Boulder with the slide rule. The unbroken lines represent the delays obtained from the slide rule. The broken lines represent our measurements. The rms deviation over a period of months is less than 25 microseconds.

4.0 SUMMARY

In summary we believe that satellites can and will provide high accuracy timing to the public at low cost as NBS remains committed to that end.

* For duration of this experiment, booklets, slide rules, or bulletins are available upon request. Write National Bureau of Standards, Frequency-Time Dissemination Research Section, Boulder, Colorado 80302.

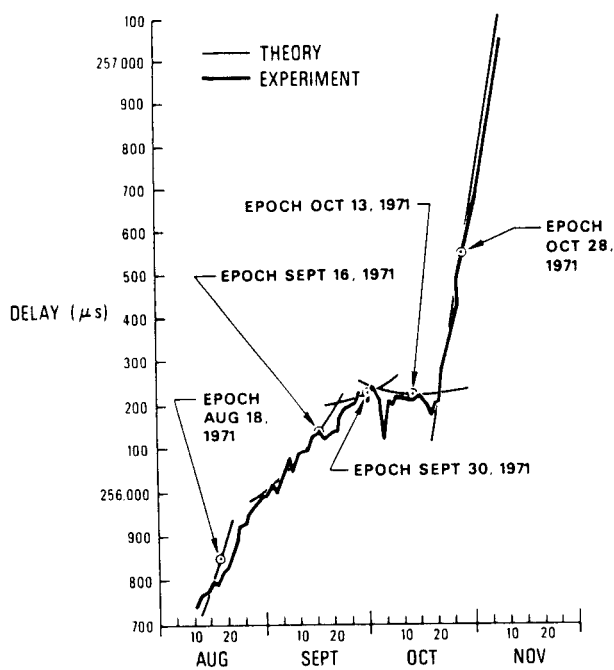


Figure 9. DELAY MEASUREMENTS AT NBS BOULDER FOR 1700 GMT

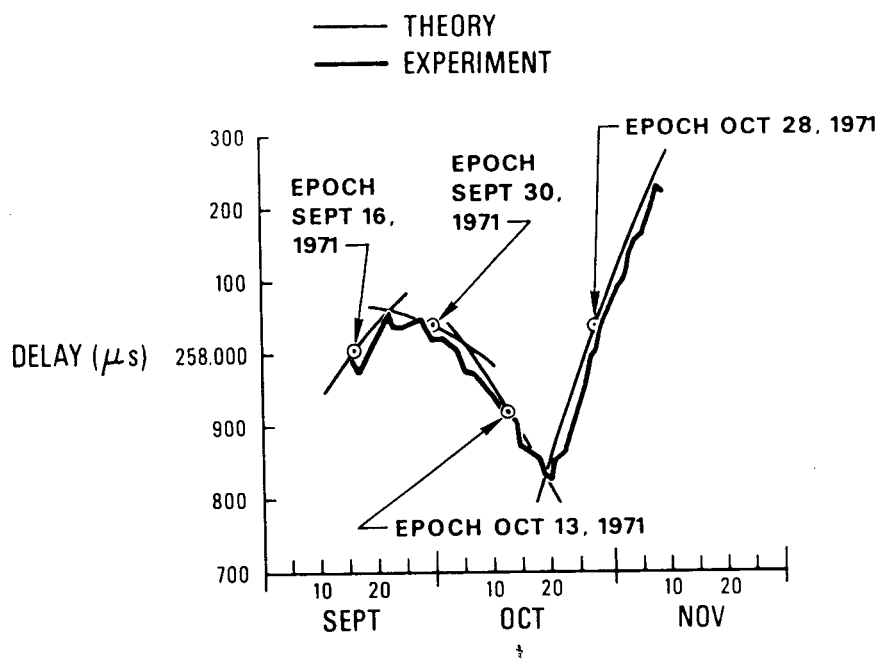


Figure 10. DELAY MEASUREMENTS AT NBS BOULDER FOR 2330 GMT