# UNATTENDED TV TIME TRANSFER RESULTS

John A. Waak and John H. Spencer
E. O. Hulburt Center for Space Research,
Naval Research Laboratory, Washington, D. C. 20375

ABSTRACT

We report on the results of more than eight thousand relative television time transfers to Maryland Point Observatory over a 14 month period beginning in December 1981. The data were taken at intervals of 30-60 minutes using a Hewlett-Packard 1000 computer operating in an unattended mode. After correction for linear drifts of our maser with respect to the master clock of the USNO, the results are internally consistent to within roughly ±65 nsec over timespans up to three months, under the assumption of invariant propagation delay. The major disadvantages to this method of time transfer are the relatively poor precision and the dependency upon constant propagation times.

## INTRODUCTION

The Naval Research Laboratory operates the Maryland Point Radio Observatory for a variety of projects that require a very precise station clock including very long baseline interferometry (VLBI). It is therefore necessary to conduct regular clock checks and time transfers from the U.S. Naval Observatory (USNO) master clock. The station clock used in the conduct of these experiments is a Smithsonian Astrophysical Observatory (SAO) VLG10 hydrogen maser. A Hewlett-Packard 5065A rubidium clock is also present at the observatory and is used for testing and backup.

The traditional method of transfering time involves the use of a portable clock which is compared to the master clock before and after being transported to the remote site. This procedure is time consuming and requires the commitment of significant manpower and other resources if it is to be done frequently on a continuing basis. An alternative to the traditional method is to make use of transmitted signals which are simultaneously monitored at the USNO and at the remote site. The Global Positioning Satellite (GPS) system and commercial television broadcasts provide facilities which can be used as such an alternative. The television method requires no moving parts, and when controlled by a multi-user computer, promises more or less continuous operation and a high data return in exchange for the small amount of resources it requires. Various schemes for and uses of television time transfers have previously been discussed in these conferences (cf. Inouye and Takeuchi 1975; Kovacevic 1977; Kaarls and de Jong 1979; Chiu and Shaw 1981), but large numbers of such measurements have not been presented.

Since December 1981 we have been carrying out automatic unattended television time transfers to both the hydrogen maser and the rubidium clock at Maryland Point Observatory. Occasional portable clock time transfers were also conducted, and the data from these can be used to aid in evaluating the suitability of the TV measurements as a time transfer method between the USNO and Maryland Point. In the course of approximately 14 months we have obtained 9744 measurements.

## REVIEW OF THE TV TIME TRANSFER METHOD

The video transmissions from Channel 5 (WTTG) in Washington, D.C. are synchronized such that the line 10 odd TV horizontal pulses are transmitted on particular seconds of a UTC scale referenced to the USNO master clock (Lavanceau and Carroll, 1971). It is termed a "time of coincidence" or "TOC" when the TV line 10 odd pulse occurs at the same instant as a one second pulse of the master clock. The rep-rate of the TV pulse train is 29.97003 pps, which means that TOC's occur at intervals of 1001 seconds (i.e. every 30000 TV pulses).

One consequence is that the local atomic clock should be preset to better than 33.366 milliseconds so that the TV pulse identity is correctly established. The quantity actually measured is the time interval between a 1 pulse per second pulse from one of the local clocks and the next TV line 10 odd pulse. Our station clock is compared to the television signal emitted by Channel 5, whose signal is phase locked to a cesium frequency standard, and is monitored daily by the USNO. This TV signal is easily received at Maryland Point, which is approximately 70 km from the transmitter. The daily monitoring by the USNO enables us to obtain USNO master clock-Maryland Point station clock comparisons by permitting the removal of the effect of cesium drift at the transmitter.

## THE MEASUREMENTS

Employing an IEEE-488 interface bus, our Hewlett-Packard 1000 computer is used to read an HP 5345 time interval counter, which has a dual 4-position vhf switch in front of it. A measurement consists of taking a reading from each of the 16 possible stop/start combinations. The start pulses were: rubidium 1 pps, the maser 1 pps, the Mark II VLBI formatter 1 pps (slaved to the maser 5 Mhz), and a delayed pulse from the maser having a period of 1.001 sec. The stop pulses were the TV (the signal out of the McBee Industries line 10 decoder, the maser 1 pps, the Mark II formatter 1 pps, and a switch position where a portable clock or other miscellaneous clock could be read.

A complete measurement is obtained over a short time span (roughly thirty seconds), thus the entire matrix can be considered as virtually simultaneous. For the purpose of this paper, we adopt the convention of referring to a measurement as "identity of stop pulse minus identity of start pulse". In addition to real time and near real time displays at Maryland Point, the data log is dumped to magnetic tape and brought back to NRL for further processing at intervals of approximately two months.

Because of the nature of our measurement technique, the internal clock of the HP 1000 computer is involved in the processing of the over-the-air measurements. The non-rational rep-rate of the TV signal (as described above---29.97003 pps; period = 33.36666 millisec), means that an error by the computer clock will produce an offset of 1000 microseconds per second of clock error in the (TOC-start pulse) data. As long as the computer clock reads the correct second, the software correctly identifies the TV pulse, so for example, a 0.5 second error by the computer clock will produce no offset. Offsets arise from both software misidentification of the TV pulse and computer clock error. The HP clock runs on an internal crystal which drifts. In view of the 1000 microsec/sec effect of computer clock error, all of the TOC (over-the-air) data is subjected to a modulo 1000 correction before plotting.

While the raw counter readings are a measure of the interval between the 1 pps from a station clock and the next TV line 10 pulse, a correction is made to the readings by applying an offset due to the time elapsed since the most recent TOC. If the time since the last TOC is large or small enough that the clock error caused the misidentification of the correct TOC, the irrational part of the period is added or subtracted causing a few of the reduced readings to be offset by ±633.3, ±266.7, and ±900.0 μsec. Due to the large number of good readings we obtain, we did not bother to correct these data.

## DISCUSSION OF RESULTS

### A. Maser Comparisons

Figure 1 depicts the relationship between the transmitted WTTG television signal and the master clock of the USNO obtained from Series 4 of the USNO Time Service Announcements, interpolated to the time of each of our measurements, and plotted against modified Julian date (MJD is defined as JD-2440000.5). The maximum excursion in this data was less than 4.5 microseconds over the time spanned by this experiment, and the maximum long term rate of drift was less than 40 nsec/day.

A time plot of the relationship between our maser and the WTTG signal received over the air at Maryland Point is presented in Figure 2a, and exhibits a large amount of scatter. Note that these points are all the actual observed values corrected only for the time since last TOC offset and the modulo 1000 corrections already mentioned. We attribute the large scatter to a variety of causes including improperly set trigger levels and the computer aliasing mentioned above. Five days per week, WTTG goes off the air from about 0230-0530 local time. If a TOC measurement is attempted in the absence of a TV carrier, the result is random. Accordingly, we have excluded from the figure all TOC data taken from 0630-1030 UT (the four hour range accomodates the changes between standard and daylight times). There still remain 8200 measurements which include admitted TOC measurements. No measurement has been excluded from the figure for any other reason. A histogram of this data is given in Figure 2b, which shows that more than 70 percent of the observed values lie within a 60 μsec range near 220 μsec.

A number of low-level local maxima are seen in this histogram. Most of them occur at the discrete offsets from the nominal value which were predicted above. Those occuring near 600, 950, and 320 are likely due to the recovered reading being off by 1, 2, and 3 periods, respectively. The maximum near 860 μsec is probably due to the reading being off by one period in the opposite sense. The peaks near 430 and 170 μsec are extremely localized in time (as can be seen in Figure 2a). We know that the 170 μsec readings were obtained when the rubidium clock served as the station clock. The data at the predicted offsets could be recovered, but because of the large number of "good" points that require no recovery, we elected to "clip" all data outside of the 60 microsecond range. This constitutes an error in our procedure of reducing readings to TOC's in the presence of known computer clock errors, and is not intrinsic to the TV time transfer method. Application of recovery techniques would increase the percentage of points within the 60 μsec window by about 15 percent.

The 70 percent of the data within the window is replotted in Figure 3a, where it is clearly seen that the maser drifted slowly relative to the over-the-air TV signal. The breaks in the data were the result of various malfunctions which required us to (among other things) resync the maser, after which the drift rate was somewhat changed. We found the three most extended groups of continuous data (those beginning near MJD 5030,5130, and 5220) to have linear drift rates of 157, 52, and 48 nsec/day, respectively. These rates are not significantly larger in magnitude than that of the TV signal relative to the master clock. Note the extended break in data coverage from MJD 5060-5130. Most of that break was the result of computer software failure, and not due to maser problems.

One of our built in observational redundancies is the direct over the air observation of (TV-Maser) via hardware using a time base generator which transforms the 4 mhz pulse from the maser into a pseudo 1/1.001 pps, which triggers the counter. This hardware measurement is independent of the computer clock, for there are exactly thirty line 10 odd pulses in each 1.001 second interval. If all is well, this data should be identical to the (TOC-Maser) results, but with none of the clustering seen in that data which resulted from computer clock error. These "TV-1001" data are shown in Figure 3b. The similarity between this data and the (TOC-Maser) data of Figure 3a is reassuring.

The relationship between our maser and the USNO's master clock as measured over the air and shown in Figure 4 results from combining the data from Figure 1 (WTTG-master clock) with that from Figure 3a (TOC-Maser). The gross characteristics of this data are rather similar to those of Figure 3a. The rates of drift for the (master clock-Maser) results are 147, 23, and 53 nsec/day, respectively, for the three groupings of data mentioned previously. These results do not include any correction for delay due to the time required for the TV signal to travel to Maryland Point. When the above mentioned slopes are removed from the three data groupings, the resulting distributions suggest an uncertainty of ±65 nsec (HWHM). We saw no evidence of systematic diurnal differences. Kaarls and de Jong (1979) previously reported a TV time transfer experiment where "except for throw-out measurements the average over these 3 months seems to be well within 500 nsec." Our error may be smaller because we have a data density almost two orders of magnitude greater than theirs, a shorter baseline, and a fully automatic recording system.

We attempted to apportion our 65 nsec uncertainty among independent sources of error. Such sources include our maser, counter, the atmosphere, and the transmitter-receiver combination. Adopting a scale height of 7 miles for atmospheric water vapor, taking into account the distance from the transmitter, and noting that the uncertainty due to the maser is ±1 nsec (based upon VLBI data), and that due to the counter is ±2 nsec, we find that the transmitter-receiver combination is responsible for almost all of the uncertainty.

B. Propagation Delay

There have been a number of occasions when a high quality cesium portable clock was brought to Maryland Point from the USNO in connection with VLBI experiments. Such trips permit the direct comparison of our clocks to the master clock without the inclusion of TV propagation delay. The differences between the (master clock-Maser) results over-the-air and those via portable clock is the propagation delay. In the latter half of 1978 the result of ten portable clock trips to Maryland Point showed a total range of 120 nsec with an rms deviation of 40 nsec. Since only four portable clock transfers were performed within the time interval spanned by our data, there is little that can be said about systematic propagation delay variations. The four delay values thus obtained yield an average of 224.1±3.3 (rms) microseconds for the transmitter-Maryland Point delay. Chiu and Shaw (1981) have reported that the delays they measured over the 30 km path between WTTG and the Johns Hopkins University Applied Physics Laboratory during a span of approximately 15 months in 1980-1981 had a total range of <60 nsec and an rms deviation of 11 nsec, based upon 30 portable clock trips. We do not obtain a similar result over our 70 km path. Instead, there is a range of almost 11 microseconds in our delay measurements (see Figure 5). The antenna at Maryland Point is beyond the direct line of sight from the transmitter, and thus the signal is subject to considerably more complex propagation paths.

We experienced a number of hardware problems during the period of the December 1981 delay measurement, so its value (the smallest in our new sample) should be regarded as suspect. If this delay is discarded, the remaining 3 determinations yield an rms of $\pm 0.3$ μsec. At the time of the delay measurement on 19 October 1982 we noticed the following phenomenon: just before 1400 UT, the over-the-air TV signal exhibited an apparent 34 microsecond jump. We saw a similarly abrupt return to the normal value eight hours later (just before 2200 UT). These points can be seen as a "clump" near 198 μsec and MJD=5262 in Figures 3. On this day the portable clock was at Maryland Point 1600-1800 UT, and we used the average of TV data taken before 1400 and after 2200 in computing the propagation delay. We know from the consistency of the propagation delay that the 34 microsecond jump was a problem with the television transmitting system rather than with the Maryland Point system.

### C. Rubidium Clock Comparisons

Figure 6 shows the over-the-air relationship between the master clock and our rubidium clock determined in a manner analogous to that used on the maser data. The sharp jumps in this data result from the resetting of the Rb clock. The drift rates are of the order of 1 microsecond/day, significantly larger than those observed for the maser.

Another of the redundancies built into our automatic data acquisition system is the direct on-site intercomparison of the maser and rubidium clocks. A plot of this data along with a histogram of its distribution is provided in Figure 7. Much of the apparent width of this distribution is due to the drift of the Rb clock relative to the maser, and not to inherent measurement scatter. The two clocks can also be compared indirectly by combining the TV measurements of both. Ideally, both the direct and indirect determinations of Maser-Rb should yield the same value (since the effect of TV propagation delay should cancel), and certainly their differences should cluster about zero. When this is done, 56 percent of the differences cluster within 5 μsec of zero.

## CONCLUSIONS

With the possibility of undocumented errors as large as 34 microseconds in the transmitted TV signal, and the inability to determine the propagation delay,the unattended television time transfer method appears to be primarily useful as a tool for the detailed monitoring of the station clocks.

For the future, since only slightly more than 55 percent of the direct and indirect intercomparisons of the station clocks give consistent results, we need to monitor more often the performance of the data taking system. The addition of a battery backup system to the Mark II formatter is also desirable. Finally, we must acquire propagation delay measurements much more frequently, so that we can track any significant changes and remove their effect from our (future) data.

REFERENCES

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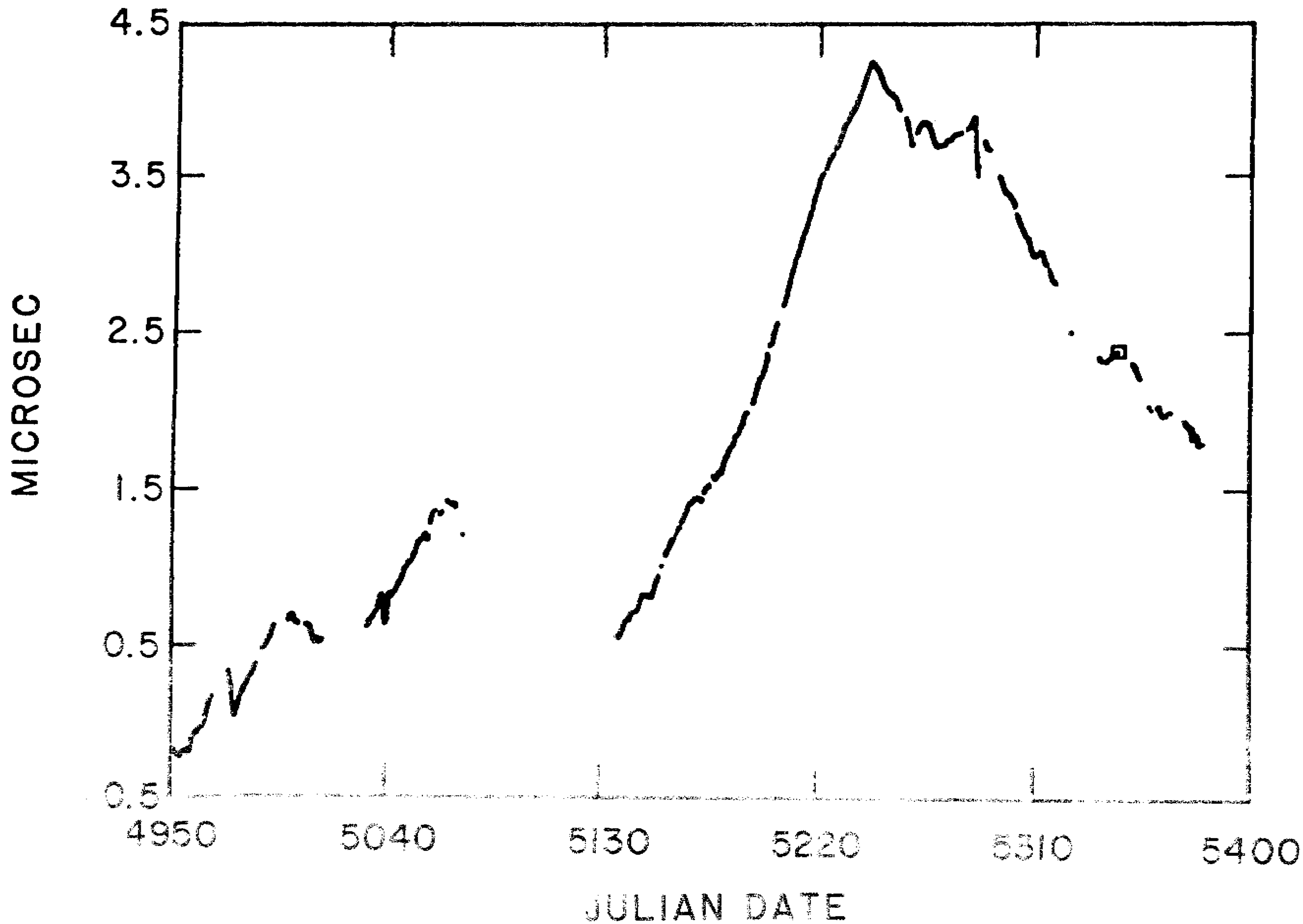



Figure 1 - Drift of WTTG television signal relative to the USNO master clock interpolated to the times of our measurements from the daily values given in Series 4 of the USNO Time Service Publications.

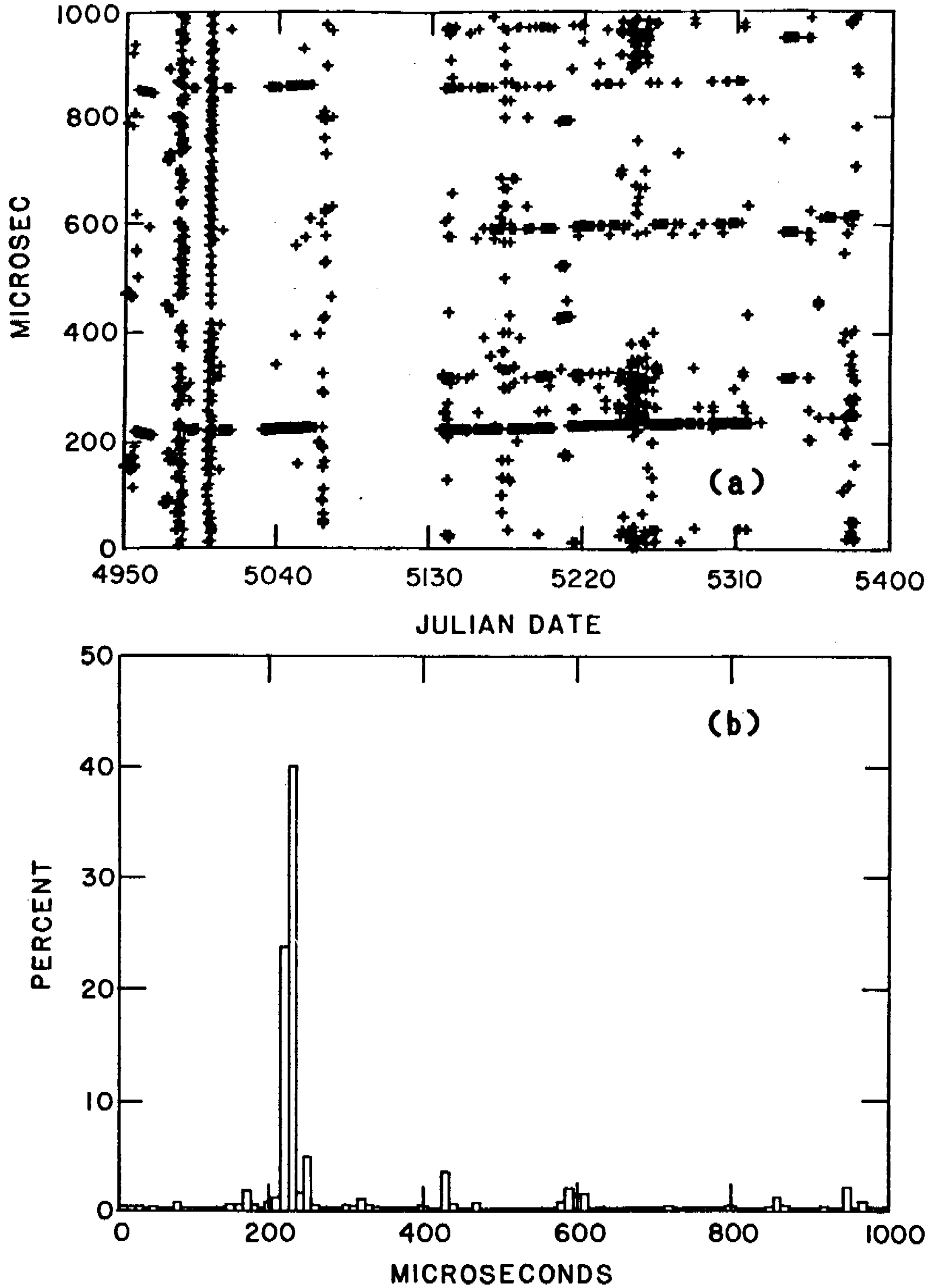
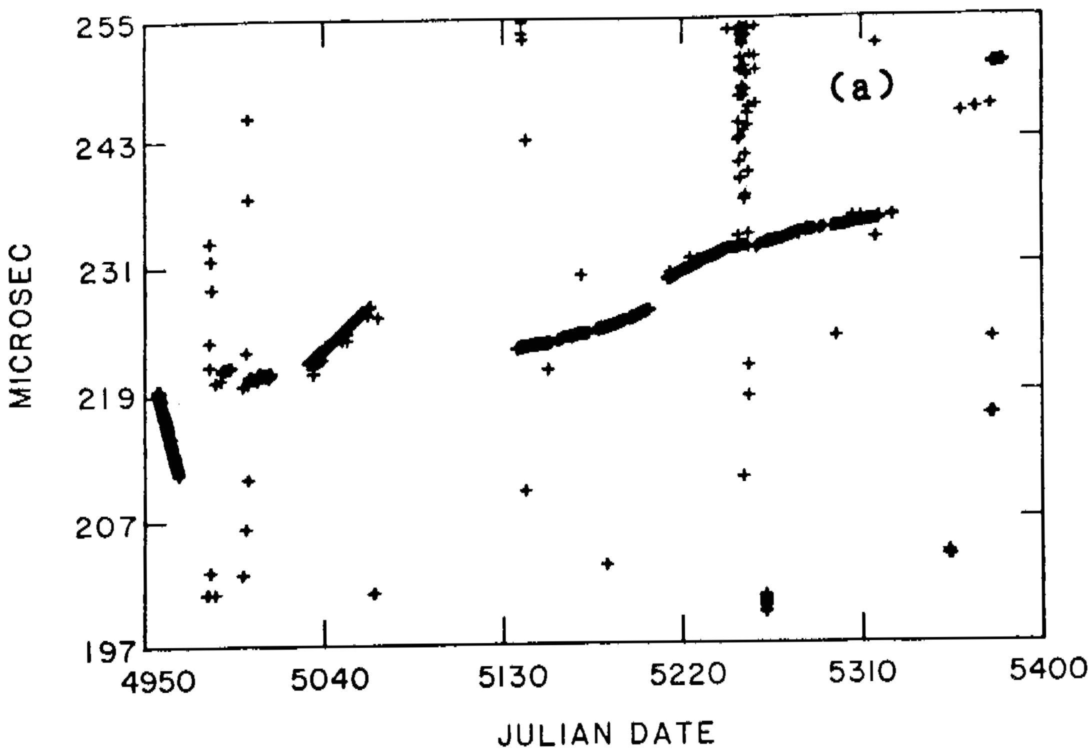



Figure 2(a) - Drift of NRL maser relative to WTTG television signal as received at Maryland Point. No correction for propagation delay has been applied. (b)-Frequency distribution of the data shown in 2(a).



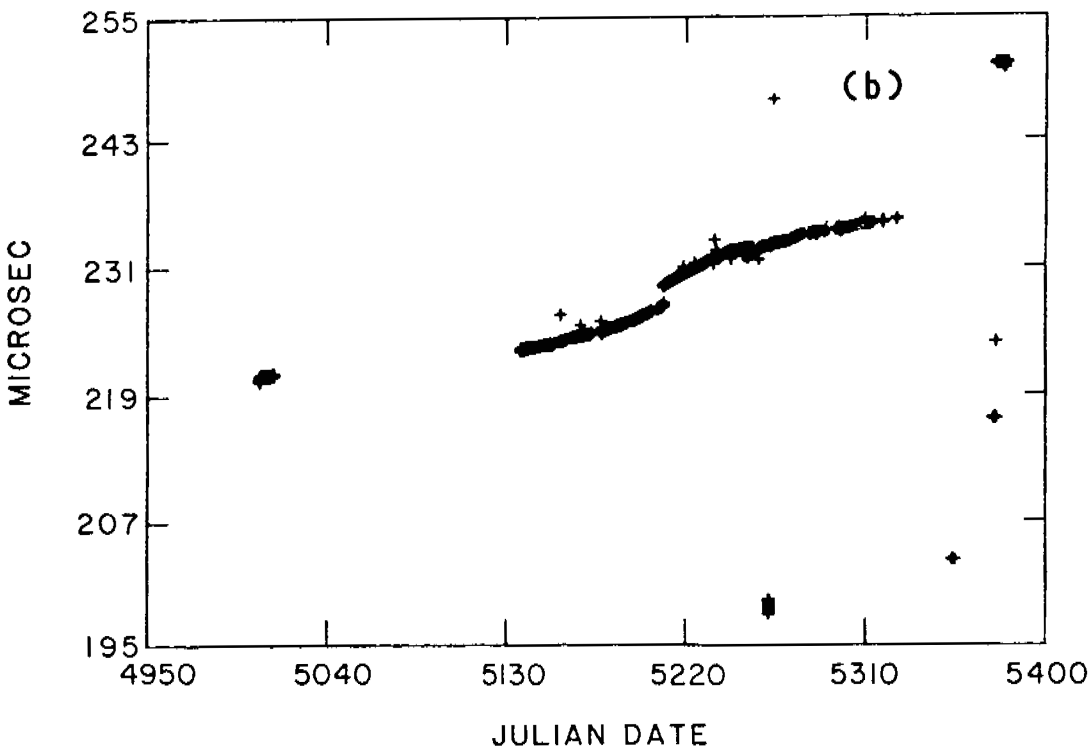




Figure 3(a) - Expanded and clipped view of drift of NRL maser relative to the received WTTG television signal. The clump at 198 μsec is discussed in the text. (b) - Hardware measurement of maser/WTTG drift using pseudo 1/1.001 pps.

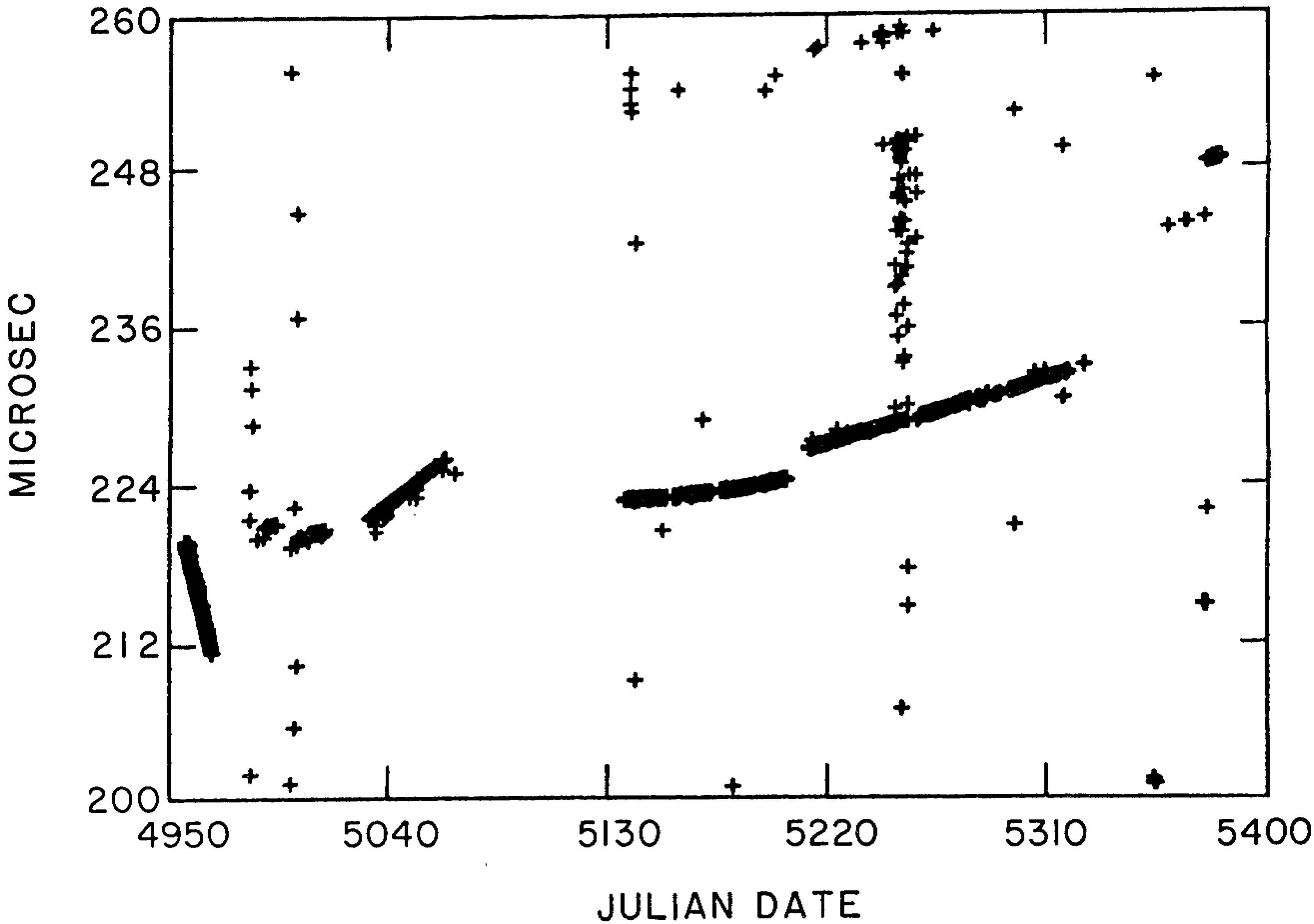



Figure 4 - Clipped view of drift of NRL maser relative to the USNO master clock.

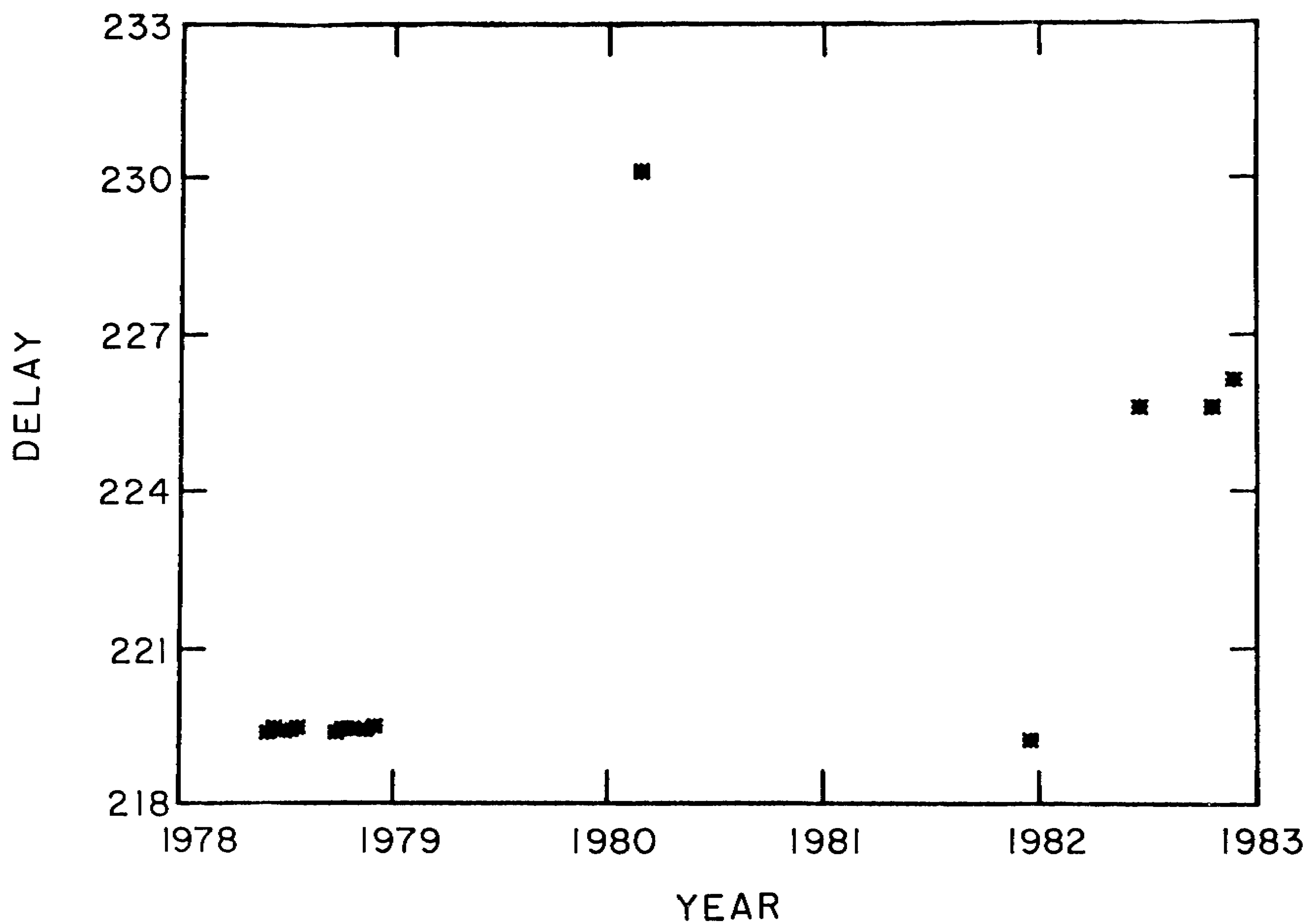



Figure 5 - Propagation delay between WTTG and Maryland Point determined by portable clock trips.

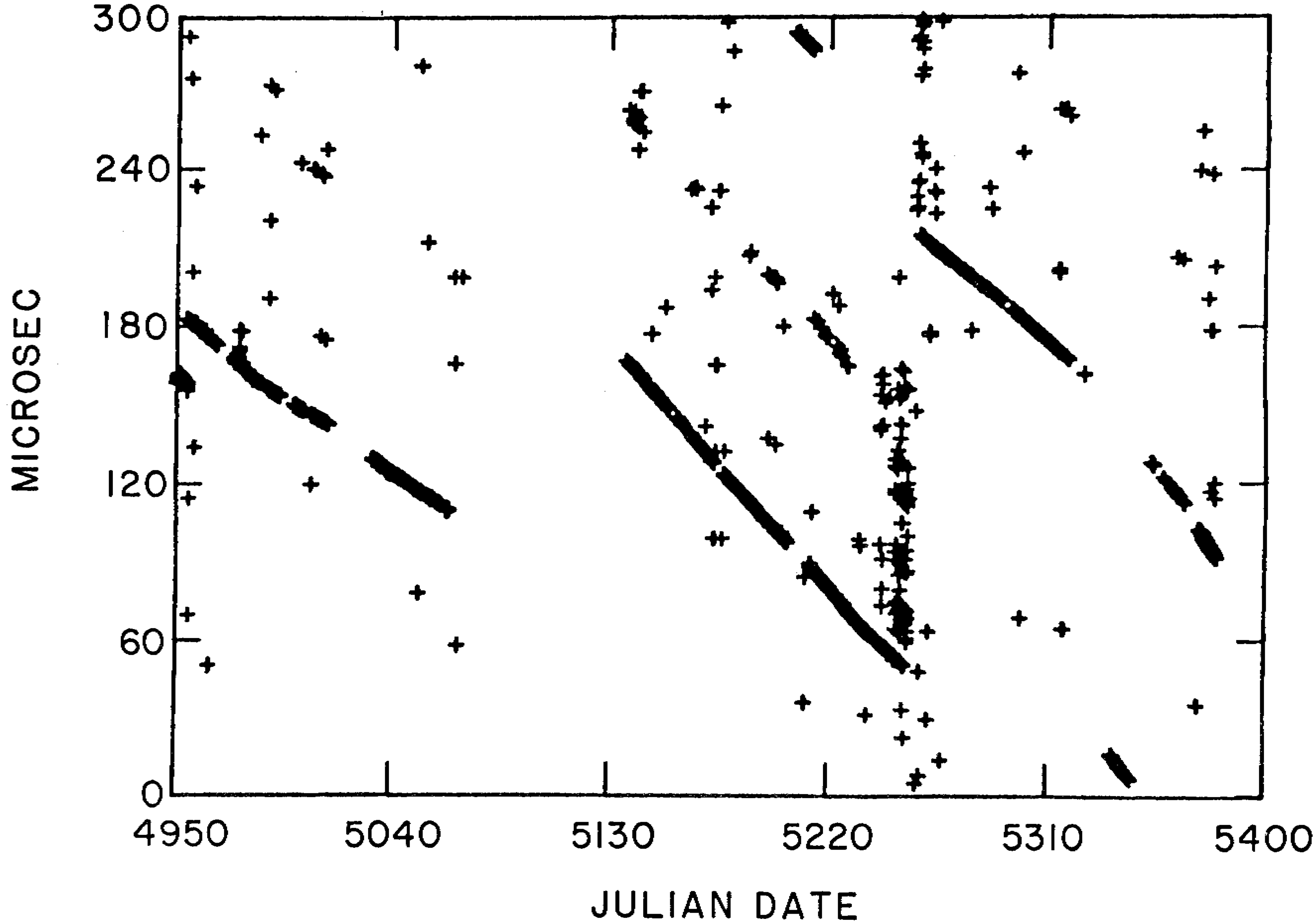



Figure 6 - Clipped view of drift of NRL rubidium clock relative to the USNO master clock.

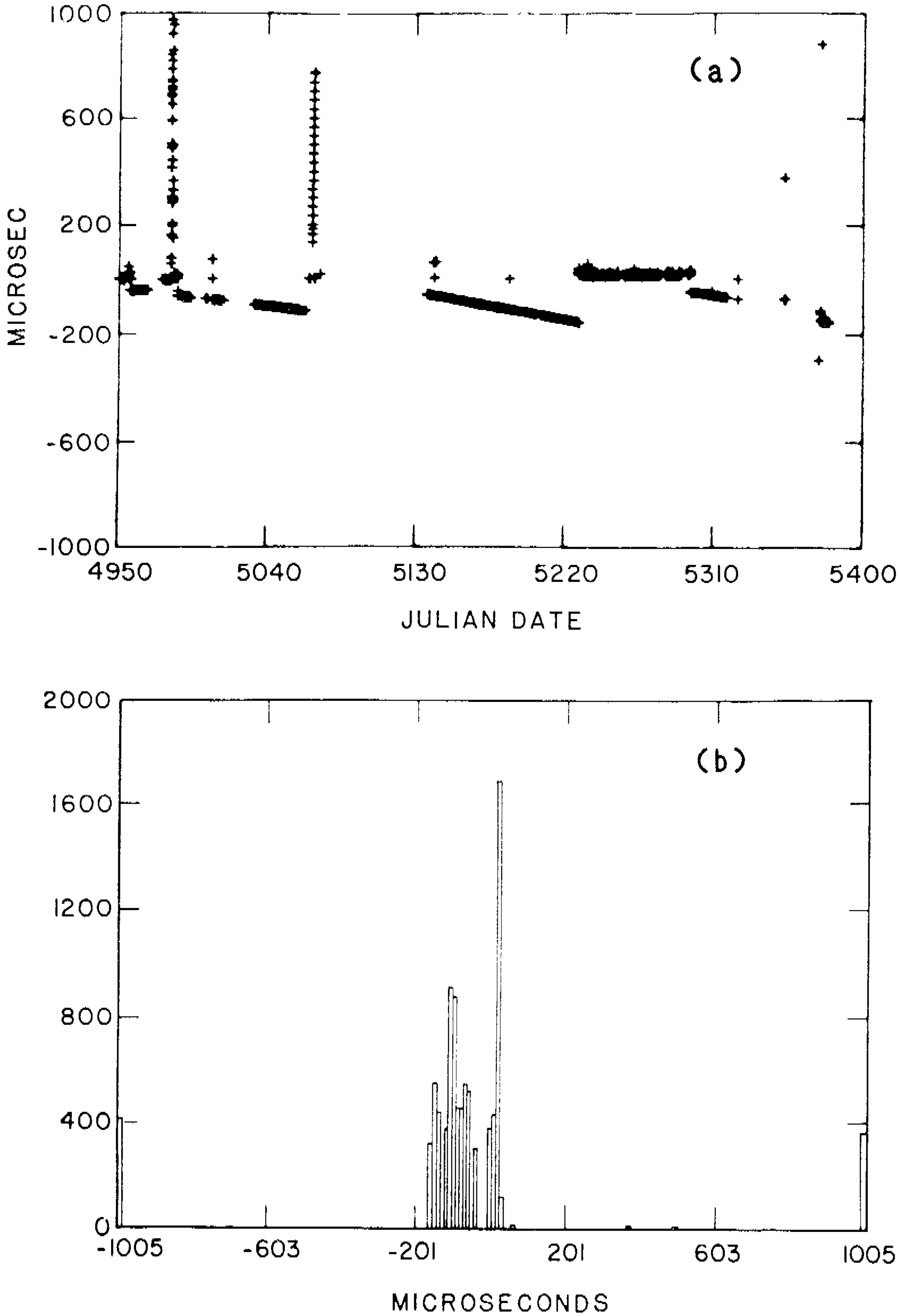



Figure 7(a) - Direct on site comparison of Maryland Point station clocks not involving any television signal. (b) - Frequency distribution of the data shown in 7(a).

## QUESTIONS AND ANSWERS

None for Paper #18.