CO-ORDINATED UNIVERSAL TIME IN AUSTRALIA

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ABSTRACT

The Australian co-ordinated time scale UTC(AUS) has been in existence since January 1, 1973 and is based on a small variable ensemble of caesium frequency standards compared regularly by the television method. Due to its distance from Europe and America, this time scale cannot make use of LORAN-C or VLF methods for reliable comparison with other time scales, especially those of the United States Naval Observatory and the Bureau International de l'Heure. Hence it relies for its relation to these time scales on infrequent flying clock visits from USNO, its own stability and the Timation experiment described at previous meetings. UTC(AUS) is a free running time domain scale with a prediction capability of the order of 1 microsecond over a 600 day interval. Considerable problems have been experienced in maintaining the caesium standards and determining TV travel times which have changed due to characteristics of the transmissions and changes in location of the standards; yet careful selection of ensemble constituents and more sophisticated least squares analysis of portable clock trips, together with further Timation Satellite experiments, are expected to lead to an order of magnitude improvement over previous capabilities.

1. INTRODUCTION

Time keeping in Australia is characterised by its isolation from the major time scales of the world, at least at the microsecond level. Accordingly, the co-ordinated universal time scale UTC (AUS) was instituted on 1 January 1973 following a meeting of major interested parties on 6 June 1972. The time scale consists of a small number, usually about five, of Hewlett Packard commercial caesium standards compared daily using a commonly received television transmission from the Australian Broadcasting Commission's networked 1300 local newscast (Miller, 1970). The participating laboratories, and other caesium standards and time services in Australia whether linked by TV or not, are listed in Table I.

To determine TV travel delay times, to compare precisely the relationships between the clocks, and to provide time checks on State time services and remote clocks not receiving the networked television transmissions, National Mapping's portable caesium standard DNM590 has been used on many occasions as typified in Table II. One major activity associated with the DNM590 trips has been taking our best estimates of UTC (USNO MC) to the other establishments, particularly in July 1975 when DNM590 visits were made throughout the eastern half of Australia concurrently with the visits by the United States Naval Observatory portable clock PC 1117/IC-2. The successes of predictions made in June, prior to the visit, are shown in Table III, together with corrected 'predictions' made after the event as the result of the discovery of several anomalies in the TV travel delay times.

The initial relationships of Australian clocks with UTC (USNO MC) were based on the USNO portable clock trips in February and December 1973, and Timation II satellite time transfer experiments in July and September 1973 and January 1974 (Easton et al, 1973, Luck and Morgan, 1974). Subsequently, the relationships were estimated using UTC(AUS) as the indicator of superior clock performance, and only superior clocks were used to maintain the relationships. Specifically, VLF (Swanson and Kugel, 1972), LORAN-C (Potts and Wieder, 1972) and Moonbounce (Higa, 1972) techniques, all of which are available to National Mapping through the good offices of NASA, have not been used in any way. That is, the time scale has been constructed for the support of detailed investigations using precise time and time interval rather than as a by-product of the investigations.

2. TIME AND FREQUENCY USERS

The National Measurement Laboratories (NML) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) operate under Australian Government legislation (Australian Government Legislation, 1960, 1964) to maintain standards of frequency and time interval. NML in turn has chartered the Division of National Mapping (DNM) and the Australian Telecommunications Commission (ATC), formerly the Australian Post Office, to maintain local standards in support (Australian Government Authorization, 1971). ATC is also responsible under legislation for time dissemination which it does via radio station VNG at Lyndhurst, Victoria on frequencies of 4.5, 7.5 and 12.5 MHz, and by telephone landlines. Both these organisations serve a variety of civil and government users.

National Mapping is charged, under its function statement as a government organisation, with 'maintaining astronomical time scales', which includes the determination of UT1 with its Photographic Zenith Tube on Mount Stromlo and the consequent maintenance of precise time.

Sydney and Perth Observatories and the South Australian Post Office maintain their own local time scales for general public use, for example commercial radio time signals, while CSIRO's radio observatory at Parkes uses its caesium for frequency calibrations and pulsar timing (McCulloch et al, 1973). Hewlett Packard (Australia) maintains an active caesium for instrument calibration purposes and as a service to its customers who have all benefited considerably by HP's consequent in-house expertise.

There are two groups active in VLF and ionospheric research in Australia who also require precise frequency and time information. The first is headed by Dr. J. Crouchley of the Physics Department, University of Queensland. The second is under Dr. D. Robertson of Weapons Research Establishment, Department of Defence.

Australian defence establishments have a long recognised need for accurate frequency control and precise navigation, as does the Department of Transport, and as space-age navigation becomes a part of everyday Australian life, so does the need for precise time as well as frequency. The Joint Defence Research Facilities have a major investment in caesium standards but, in the past, have tended to remain isolated from the general time and frequency community here.

The NASA space tracking agencies each maintain their own local time scales by such means as LORAN-C skywave, Moonbounce, VLF and satellites, together with regular flying clock visits. Those in the Australian Capital Territory have always co-operated with UTC (AUS) although preferring to remain independent for their own purposes. However, with the current introduction of one microsecond accuracy requirements, they are well placed to play a major role in distributing stable and accurate time throughout Australia.

Finally, some local time services are known to rely on nineteenth century pendulum clocks which are compared audio-visually with radio time signals.

3. NATIONAL MAPPING'S INTERESTS

The function statement of the Positional Astronomy Section, drafted at the time of its transfer in 1971 from Mount Stromlo Observatory of the Australian National University, implies the maintenance of a precise and uniform time scale for its UT1 observations, to an accuracy and precision of 50 microseconds. For accuracy, one can not rely on VLF since it can only give time interval and is lost if either the receiver or the clock stops. In the absence of other reliable absolute time comparisons, the local time scale must remain continuous between flying clock visits. Since these may be in excess of 300 days apart, the frequency stability of the clock must be better than

2×10^{-12}, or have a drift rate rather less than 0.2 microseconds/day.

Recently, the Division has become involved with lunar laser ranging (Luck et al, 1973a, b; Bender et al, 1973). The maximum rate of change of range between the telescope and retro-reflector is about 0.6 km/sec., hence to achieve the maximum benefit of ranging at the 100 picosecond (3 cm) level, knowledge of absolute time is required to 10 microseconds to make all timing errors ignorable. Thus the stability requirement over a 300 day period is better than 5 parts in 10^{13}.

Figure 1 illustrates the frequency stability of clock DNM590 as determined from the UTC analysis. It is typical of clocks available to UTC (AUS). The variations are due to the number and distribution of the observations within the smoothing period which typically is of the order of 60 days. Long term stabilities for good clocks, such as DNM590, are better; however they are not consistently better than 5×10^{-13}. Moreover many clocks are either adjusted or fail before good statistics can be accumulated for periods in excess of 300 days. Thus in order to achieve the required accuracies for lunar laser ranging, it is necessary to run an ensemble of at least three standards all performing with stabilities better than parts in 10^{12}.

With the likely advent of combined Doppler and laser satellite tracking for geodetic purposes (Morgan 1974), the importance of precise time is further increased.

The Division maintains, of course, its own local time scale UTC (DNM) using rubidium standard DNM255 as master clock, rephased weekly after analysis of the UTC (DNM) ensemble, see Section 11. It is hoped that the NTS-1 (Timation III) satellite time transfer system can be incorporated into the system as a contributor of appropriate weight and as a condition on the remainder of the ensemble, depending on the application in hand.

4. UTC (AUS)

Let c_i, $i = 1 \ldots n$ denote the i-th clock in the ensemble.

Then UTC (AUS) is defined, after Guinot (Guinot et al, 1971), as

$$\text{UTC (AUS)} = (A + \sum_{i=1}^{n} c_i)/n \qquad (1)$$

where A is an initial constant chosen so that, on 8 February 1973, on which date the NML clocks and DNM590 were compared directly against a USNO flying clock, UTC (AUS) = UTC (USNO MC).

Explicitly, each clock is assigned unit weight. If its performance deteriorates, it is dropped from the ensemble, thereby implicitly assigning it zero weight. More sophisticated weighting schemes are not used because only TV or intra-laboratory comparisons are employed, and because the ensemble is not sufficiently large to assign weights with proper objectivity. However, with the ensemble expected to stabilise in the near future after its spate of discontinuities, and with the introduction of Timation observations as a regular factor, weighting schemes which consider the stability of the received pulse, the precision of the observations and the performance of the clock can be investigated.

The implementation of the algorithm that calculates UTC (AUS) is simple, since it is unweighted and since only individual clocks have ever been considered and not laboratory time scales as the BIH did once. Moreover, if one component clock missed a reading on any day, UTC (AUS) was not calculated on that day. Usually a missed reading is the result of TV transmission anomalies such as non-synchronised sporting telecasts, industrial trouble, or equipment failure in the receiving laboratory. Sometimes the cause of omission was late reading of the synchronising pulse which must be read at exactly $13^h\ 01^m\ 00^s \pm 0.02$ as the transmissions are not time controlled, see Section 8. This philosophy has resulted in some gaps in readings of periods as large as two weeks, particularly around the Christmas-New Year period. This is considered preferable to trying to patch up readings, as the only alternative interpolator is VLF which is notoriously ill-received here. It is possible to alleviate the problem by smoothing with appropriate intervals.

Before developing the reduction algorithm, it is to be stressed that UTC (AUS) is an independent time scale in the sense that, once its zero point has been set, it is the mean of its own clocks only; no overseas time scale affects it directly. For example, on addition of a new ensemble member, the constant A of the fundamental equation is adjusted to maintain continuity of UTC (AUS) itself. Moreover, no attempt is made at such times to maintain continuity in the first time derivative, rate, since it is considered scientifically realistic for the time scale to be the current mean of a number of actual clocks - remembering the past performance of clocks long since dead is certainly less realistic. However, notwithstanding our desire for independence, the estimated relationship to UTC (USNO MC) is calculated, separately from the algorithm, published, and used in certain analyses such as that given in Figure 1. The techniques used are given in the following development.

From the fundamental equation (1), UTC (AUS)-TV is calculated from

$$\text{UTC (AUS)-TV} = \left[\sum_{i=1}^{n} a_i + \sum_{i=1}^{n} ((c_i - \text{TV}) - t_i) \right] / n \qquad (2)$$

where $\sum_{i=1}^{n} a_i = A$, (3)

c_i - TV = a reading at 1301,

t_i = TV travel time relative to NML determined by DNM590 portable clock visits.

$$\text{Then UTC (AUS)} - c_j = (\text{UTC (AUS)-TV}) - ((c_j - \text{TV}) - t_j) \qquad (4)$$

where c_j may be either a constituent of the ensemble defining UTC (AUS) as in equation (1), or any other participant. The results of equations (2) and (4) are tabulated for each day on which all n current constituents have satisfactory readings, and published for interested Australians at nominally monthly intervals. Least squares straight line fits against MJD to each UTC (AUS) - c_j are also published. Table IV is an example of the published computations.

When a new clock c_{n+1} is added to the ensemble it is sufficient for continuity that A be re-evaluated (Guinot et al, 1971), resulting in a revised A^1:

$$A^1 = A + (\text{UTC (AUS)} - c_{n+1}) \qquad (5)$$

where (UTC (AUS) - c_{n+1}), is the actual value from equation (4) obtained using the previous ensemble on day T_1, the day on which c_{n+1} is added. Similarly, if clock c_k is removed on day T_1,

$$A^1 = A - (\text{UTC (AUS)} - c_k)$$

In practice, each run for publication is made with an unchanged ensemble, and the value of each UTC (AUS) - c_i on the last day of the previous run is used as a_i. This makes it very simple to control A adjustments when altering the ensemble.

The criteria on which changes occur are:

(a) A clock fails;

(b) A clock's performance against the ensemble deteriorates, as judged by its rate or standard error;

(c) A clock whose rate has been constant to within 0.02 microseconds/day over a period of, usually, two months or more, and which is in a properly controlled environment, will always be considered for admission.

Table V shows which clocks formed the ensemble between 09 February 1973 and 31 July 1975.

5. DATA FILTERING

Once all the data has been collected for a run, by telex and mail, it is checked in the office for obvious bad readings and known transmission anomalies (it is known, for example, that a jump of 10.8 microseconds occurs in the Canberra region when a change occurs in the linkage between the studio and transmitter). A preliminary run is then made for further editing, checking small errors (a reading is rejected if its UTC (AUS) - c_i residual exceeds 2 microseconds), and determining if any constituent is performing badly. A further iteration prepares the results for publication.

6. ANALYSIS

To obtain a clearer view of the long term behaviour of UTC (AUS) and its constituent clocks, a series of recomputations has been made, using only clocks of superior performance over hundreds of days as constituents. A typical set of results is presented in Figure 2. The large fluctuations are due entirely to computer plotter crossovers. Points worth noting are:

(a) The small number of clocks judged suitable for the ensemble, and the curves and jumps in the others;

(b) The number of clock failures in the period;

(c) Frequent correlated jumps in geographical areas, indicating local TV anomalies;

(d) The apparent instability of DNM590 and DNM205 after February 1975 when they were moved from Mount Stromlo to Orroral Valley is attributed to Fresnel effects due to an intermediate ridge in the line of sight path as well as to atmospheric effects. These problems are currently receiving attention.

(e) The fine performances of DNM590, despite its use as a portable clock, and of GWESF396 after its C-field adjustment in September 1973.

(f) Several apparently gradual changes in the ATC clocks, which occurred during sparse data periods, were only recently detected as real, and are evidently due to accumulative component changes in the television transmission network.

(g) The relatively small changes in (UTC (AUS) - UTC (USNO MC)) at ensemble changes.

Subsequent analysis has tidied up this picture and resolved many of the anomalies.

7. RELATIONSHIP TO UTC (USNO MC)

We use this time scale as reference, since it is directly accessible by flying clocks and Timation, and it is known to be stable.

The fundamental adopted relationship is

$$\text{UTC (USNO MC)} - \text{DNM590} = -34.70 - 0.08686\,(\text{MJD} - 42023.0) \qquad (6)$$

based on Timation II experiments for rate, and these and the flying clock visit of 7 December 1973 for the constant term. This relationship was transferred directly to the ensemble of Section 6 by means of:

$$\text{UTC (USNO MC)} - \text{UTC (AUS)} = (\text{UTC (USNO MC)} - \text{DNM590}) - (\text{UTC (AUS)} - \text{DNM590}) \qquad (7)$$

and is shown on Figure 2. As a check, back extrapolation to the flying clock visit of February 1973 reveals errors of rather less than one microsecond.

The UTC (AUS) reduction program contains a section in which equation (7) is updated conveniently from the fundamental period (July 73 to January 74), since the latest estimate of UTC (USNO MC) - c_i is always maintained in the input deck. The only assumption made in the update is that the ensemble clocks perform linearly, and this is checked by UTC (AUS) before the final ensemble for a run is chosen. This update makes it possible to estimate the performance of each clock against a nearly uniform reference without needing a great number of historical records. The performances can be gauged from Figure 2.

8. TELEVISION NETWORK

The transmissions originate at the Gore Hill, Sydney, studios of the Australian Broadcasting Commission, and are networked as shown in Figure 3.

Until the introduction of colour TV on 1 March 1975, the frequencies were crystal controlled with a rate of, commonly, 10 microseconds/second. Since the repetition rate is 50 Hz, the system accuracy was limited to 0.2 microseconds at best. Since 1 March 1975 rubidium standards control the frequency, hence errors are entirely due to propagation anomalies and receiving station malfunctions. There is no agreement with the ABC on controlling the precise time of transmission.

The pulse received in common is the first vertical synchronisation pulse in the vertical block (Miller, 1970). It is displayed in Figure 4. The pulse selector used in each laboratory is a simple pulse discriminator originally designed by E. Sandbach of ATC and now improved by C. Cochran of DNM.

As mentioned previously, the travel times are known to change without notice due to equipment and atmospheric changes. The latter changes affect the short term stability of the readings while the former changes affect the long term stability and are in general more easily detectable as major system changes. Table VI lists the determined travel times on the date of clock comparisons as well as 5 day mean values about the clock trip which average out the short term fluctuations. The 5 day mean values have proved their usefulness in improving our ability to predict values of UTC (USNO MC) from UTC (AUS). This is evidenced in Table III.

9. VLF

The quality of VLF reception at National Mapping was improved in 1973 following detailed discussions with Dr. Winkler. The receiver is now manually slewed each day to compensate for cycle slips which, in certain seasons, occur daily. This technique maintains all recording apparatus in a constant position, thereby minimising receiver and recorder non-linear performance. It yields acceptable results during periods of minimal transmitter misbehaviour. An example of the internal precision possible under favourable conditions is given in Table VII which reports on the status of clocks whose only connection to UTC (AUS) and UTC (USNO MC) is through these signals.

An investigation into the reliability of reception of signals from the US Naval Communications Station at North West Cape (NWC), Western Australia, was undertaken, and as a consequence weekly readings are exchanged with the University of Queensland to check on transmitter jumps before our readings are communicated to USNO. These checks can verify jumps as small as 0.2 microseconds and, along with similar checks on NLK, provide our only method of monitoring the Queensland clock. By forcing clock continuity over receiver outage periods, this monitoring agrees with DNM590 calibrations to 5 microseconds via NWC and 3 microseconds via NLK, while similar monitoring of USNO via NLK agreed with USNO flying clock calibrations to within 3 microseconds between 7 December 1973 and 16 July 1975. Considerable care had to be exercised to achieve these accuracies, however, and with the likelihood of regular satellite time rather than frequency transfers, our interest in VLF will remain observational rather than operational.

10. EQUIPMENT PERFORMANCE

While beam tube failure is undoubtedly of major importance, it has been our experience that the expected life of standard tubes is in excess of three years and that repairs by the local Hewlett Packard facility are well within specifications. However, there is an incomplete knowledge and understanding at many of the local laboratories of the fine adjustments necessary to run these instruments in an optimal manner.

At the Division of National Mapping, we were forced to move our ensemble of clocks and VLF equipment in February of this year from a well proven site, Mount Stromlo, to our new site at Orroral. All clocks were carried to Orroral on vehicle power for about 90 minutes. They were then placed in their new positions and C-fielded. Unfortunately, DNM153 did not travel well and, for a considerable time, attempts to adjust it in its new location were not successful.

This difficulty of adjustment has been experienced at a number of Australian laboratories, many of which have previously accepted lower levels of performance due to operational pressures to provide time and frequency at the levels specified by the manufacturers of the equipment or to an inadequate array of available equipment with which to detect and correct such misalignments. The experiences gained by us with DNM153 have allowed us to assist in the delicate task of fine tuning a standard.

As a preparation for the move to Orroral, we developed an analysis method almost identical to the triad method of Allan (Gray and Allan, 1974). Using this method we determined the performance of the standards before moving and upon installation at Orroral. Since we have a local scale UTC (DNM), see Section 11, we were able to compute the fractional frequency stability of each clock relative to the mean via the well-known Allen variance formula.

$$\sigma^2(t) = \frac{1}{2n} \sum_{i=1}^{n} (\Delta y_i)^2 = \frac{1}{2n} \sum_{i=1}^{n} (y_{i+1} - y_i)^2 \qquad (8)$$

The application of this equation assumes that an absolute standard is available.

When two clocks are intercompared, the above becomes

$$\sigma_{ab}^{2}(t) = \sigma_{a}^{2}(t) + \sigma_{b}^{2}(t) - \frac{1}{n}\sum_{i=1}^{n}(\Delta y_a)(\Delta y_b) \qquad (9)$$

where the final term is a correlation term which in the limit approaches zero as n approaches infinity.
Using equation (8) at Mount Stromlo before the move and equation (9) at Orroral upon installation, we were able to detect the anomalous behaviour of DNM153. To restore DNM153 to its original state, we made a full map of the resonance curve as a function of C-field setting. This showed a number of peaks with one particular peak very much more pronounced than the others. This peak was also very narrow. Attempts to set up directly on the maximum always resulted in under or over shoot as was indicated by solving the following equation set

$$\begin{aligned} \sigma_{ab}^{2} &= \sigma_{a}^{2} + \sigma_{b}^{2} \\ \sigma_{ac}^{2} &= \sigma_{a}^{2} + \sigma_{c}^{2} \\ \sigma_{bc}^{2} &= \sigma_{b}^{2} + \sigma_{c}^{2} \end{aligned} \qquad (10)$$

for σ_a^2, σ_b^2 and σ_c^2 using sample periods up to 30 hours.

We resolved the problem by obtaining an approximate setting of the C-field using the Zeeman frequency method as outlined in Hewlett Packard's equipment manual. This ensured that we were on the correct resonance peak. We then used our previously obtained C-field map to compute the final fine adjustment necessary to operate the instrument at this peak.

The operation of DNM153 in this position resulted in dramatic improvement in its stability. Figure 5 shows the fractional frequency stability of each standard before and after the move and, in the case of DNM153, during the period of adjustment.

These techniques were put to good use by the Division in a recent calibration trip to Parkes where PRKS 143 was experiencing amplifier instability problems.

11. UTC (DNM)

To evaluate the performance of our own clocks on a more regular basis and to free ourselves from our lack of knowledge of the TV delay time, a local time scale, UTC (DNM), was implemented in 1974. This is composed of the three caesium standards DNM590, DNM203 and DNM153 and is constructed from phase recordings at a scale of

20 nanoseconds per centimeter, read hourly. UTC (DNM) has an arbitrary but convenient zero which needs to be related to another reference scale. Generally this is not done as the scale is broken every time an ensemble member, usually DNM590, is unavailable for any period such as during a clock trip. Equation (1) reduces to the following simple form for an ensemble of three with a mean of zero:

$$\text{UTC (DNM)} - c_i = \frac{1}{3} \sum_{j=1}^{3} (c_j - c_i) \qquad (11)$$

Initially, the results were plotted and abnormal behaviour or impending failure detected by visual inspection. Currently a mini-computer, an HP21-MX, is being programmed to perform the data acquisition and reduction and to display this information in the form of residual plots and fractional frequency curves.

With the implementation of this more versatile data acquisition/ analysis system and with the advent of Timation III data, the limitation placed on UTC (DNM) due to ensemble breaks and unknown offsets will disappear.

12. THE FUTURE

It can be expected that the precision, regularity and accuracy of the time scale UTC (AUS) will continue to improve as problems surrounding the number of ensemble constituents, mode of comparison and accuracy of setting are resolved. At the same time, daily connections of this scale with those produced by other organisations such as USNO and the BIH will become a reality leading to a more truly universal time scale as well as a fully coordinated UTC (AUS) at an unprecedented level of accuracy.

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TABLE I

AUSTRALIAN TIME AND FREQUENCY LABORATORIES

LABORATORY	MNEMONIC	LOCATION	FREQUENCY STANDARDS	COMPARISON MODE
Division of National Mapping	DNM (formerly MSO)	Orroral Valley, ACT	CS205 CS590 CS153 Rb255	TV TV, TC TV Interpolator, TC
Orroral Valley STDN	ORR	Orroral Valley, ACT	CS163 Rb003	Weekly TC Interpolator, TC
Honeysuckle Creek	HSK	Honeysuckle Ck, ACT	Rb	Irregular TC
Tidbinbilla DSIF 42	TID	Tidbinbilla, ACT	CS188	Irregular TC
Australian Telecommunication Commission	ATC (formerly APO)	Melbourne, Victoria	CS288 CS902 Rb	TV TV Interpolator, TC
Hewlett Packard (Australia) Pty Ltd	HP	Melbourne, Victoria	CS052	TV
Defence Standards Laboratories	DSL	Melbourne, Victoria	CS241	Irregular TC
Australian National Radio Astronomy Organisation	PRKS	Parkes, NSW	CS143	TV

TABLE I (cont.)

LABORATORY	MNEMONIC	LOCATION	FREQUENCY STANDARDS	COMPARISON MODE
National Measurements Laboratories	NML (formerly NSL)	Sydney, NSW	CS201 CS338	TV TV
Guided Weapons Electronic Support Facility	GWESF	St. Mary's, NSW	CS396	TV
Sydney Observatory	SYDOBS	Sydney, NSW	RB	Irregular TC
University of Queensland	BNE	Bribie Is., Qld	CS331	VLF and Irregular TC
Weapons Research Establishment	WRE	Salisbury, SA	3 Xtal	Irregular TC
Weapons Research Establishment	WMRA	Woomera, SA	CS494 CS531	Irregular TC SATCOM and Irregular TC
TRANET	TRAN	Salisbury, SA	RB519	VLF and Irregular TC
South Australian Post Office	SAPO	Adelaide, SA	3 Xtal	Irregular TC
Perth Observatory	PERTH	Bickley, WA	RB	VLF and Irregular TC
North West Cape	NWC	Exmouth, WA	CS222 CS220	VLF and Irregular TC VLF and Irregular TC
JDSRF	JDSRF	Alice Springs, N.T.	CS103 CS... CS...	VLF and Irregular TC VLF and Irregular TC VLF and Irregular TC

TABLE II

MEASUREMENTS BY PORTABLE CAESIUM STANDARD DNM590
DURING CALIBRATION TRIPS OF JULY 1975

CLOCK	DATE(UT) DAY.HRMI	OBSERVED DNM590-CLOCK	OBSERVED TV TRAVEL TIME	ESTIMATED (USNO MC)-CLOCK
		UNIT: MICROSECONDS		
ATC 902	189.0548	74.88	3295.44	-8.86
ATC 288	189.0548	75.21	3295.44	-7.46
PC1117/IC-2	189.0548	85.45	-	-
HP 052	189.0745	93.5	3246.69	9.75
WMRA494	190.0030	83.9	-	0.12
WMRA531 (SATCOM TERMINAL)	190.0500	91.4	-	7.61
PC1117/IC-2	191.0030	85.5	-	-
JDSRF 103	192.0200	59.7	-	-
SAPOXA	192.0615	60.6	-	-23.3
SAPOXB	192.0615	-89.7	-	-173.6
SAPOXC	192.0615	127.7	-	43.8
WRE XA	192.0730	85.5	-	1.61
TRAN 519	192.0815	86.0	-	2.11
PORTABLE CLOCK DNM590 RETURNED TO ORRORAL AT THIS POINT				
ORR 163	196.1300	59.0	-	-25.09
BNE 331	197.0505	-15.4	-	99.53
GWESF396	198.0150	63.38	104.33	-20.79
SYDOBS	198.0510	2144.2	-	2060.03
NML 201	198.0550	87.05	0.0	2.88
NML 338	198.0550	102.13	0.0	17.96
PC1117/IC-2	198.0550	85.821	-	-
PORTABLE CLOCK DNM590 RETURNED TO ORRORAL AT THIS POINT				
PRKS 143	219.0709	-549.6	1049.15	-634.79
PORTABLE CLOCK DNM590 FINISHED JULY CALIBRATIONS AT THIS POINT				

NOTE: PC1117/IC-2 IS THE USNO PORTABLE CLOCK

TABLE III

ACCURACY OF UTC PREDICTIONS

CLOCK	DATE	MJD	UTC (USNO MC) - CLOCK (MICROSECONDS)				
			MEASURED	PREDICTED	Δ	REVISED PREDICTION	Δ
NML 201	75 JULY 03	42596.98	4.45	10.05	5.60	12.14	7.55
NML 338	75 JULY 03	42596.98	20.51				
DNM 590	75 JULY 07	42600.27	-83.69	-82.98	0.71	-76.03	7.65
DNM 205	75 JULY 07	42600.27	- 1.50	- 0.31	1.19		
DNM 153	75 JULY 07	42600.27	3.43	3.95	0.56		
ATC 902	75 JULY 08	42601.24	- 8.91	- 5.49	3.42	1.54	7.12
HP 052	75 JULY 08	42601.31	9.75	11.45	1.70	17.90	7.19
GWESF 396	75 JULY 17	42610.06	-20.79	-13.18	7.61	-11.49	8.76
PRKS 143	75 AUG 07	42631.30	-634.79	-655.44	20.65	-643.57	-8.78

NOTE: THE REVISED PREDICTIONS ARE DUE TO THE USE OF IMPROVED MEAN TRAVEL TIMES AS A RESULT OF THE JULY 1975 CALIBRATION TRIP, SEE SECTION 8

TABLE IV

A SEGMENT OF UTC(AUS) ANALYSIS

PART 3 UTC(AUS)-CLOCK FOR CLOCKS IN REGION OF MELBOURNE

DATE		MJD	HP 052	WT	ATC 288	WT
			UNITS	ONE	MICROSECOND	
74MAR	1	42107	-29.01	1	18.29	1
74MAR	2	42108	********	0	********	0
74MAR	3	42109	********	0	********	0
74MAR	4	42110	-28.86	1	18.14	1
74MAR	5	42111	-29.15	1	18.35	1
74MAR	6	42112	-30.70	1	16.50	1
74MAR	7	42113	-30.71	1	16.29	1
74MAR	8	42114	-31.31	1	15.89	1
74MAR	9	42115	********	0	********	0
74MAR	10	42116	********	0	********	0
74MAR	11	42117	********	0	********	0
74MAR	12	42118	-29.16	1	17.44	1
74MAR	13	42119	-31.21	1	15.99	1
74MAR	14	42120	-29.58	1	17.52	1
74MAR	15	42121	-29.51	1	17.29	1
74MAR	16	42122	********	0	********	0
74MAR	17	42123	********	0	********	0
74MAR	18	42124	********	0	********	0
74MAR	19	42125	-29.81	1	16.89	1
74MAR	20	42126	-30.31	1	16.49	1
74MAR	21	42127	-29.81	1	16.69	1
74MAR	22	42128	********	0	********	0
74MAR	23	42129	********	0	********	0
74MAR	24	42130	********	0	********	0
74MAR	25	42131	********	0	********	0
74MAR	26	42132	-29.93	1	15.97	1
74MAR	27	42133	-30.36	1	15.44	1
74MAR	28	42134	-29.18	1	16.52	1
74MAR	29	42135	********	0	********	0

SMOOTHING COEFFICIENTS FOR EACH UTC(AUS)-CLOCK = A+B(T-TO)
WHERE DATA IS SMOOTHED FROM T1 TO T2

A	-15.65	57.45
B	-.0355	-.1014
TO	41721.	41721.
T1	74FEB 1	74FEB 1
T2	74MAR 29	74MAR 29
STANDARD ERROR	.69	.69

TABLE V

CLOCKS FORMING THE REGULAR UTC(AUS) ENSEMBLE

PERIOD	ENSEMBLE
09 Feb 73-29 June 73	DNM 205, ATC 288, NML 201, DNM 590, NML 338
29 June 73-19 Oct 73	DNM 205, DNM 590, DNM 153, NML 338, ATC 288, HP 052
19 Oct 73-31 Dec 73	DNM 205, DNM 590, NML 338, HP 052, GWESF 396
27 Dec 73-26 Apr 74	DNM 205, DNM 590, NML 338, ATC 288, HP 052, GWESF 396
26 Apr 74-31 Aug 74	GWESF 396, DNM 590, NML 338, ATC 288, HP 052
29 Aug 74-15 Nov 74	GWESF 396, DNM 590, ATC 288, HP 052, NML 201
15 Nov 74-31 Jan 75	GWESF 396, DNM 590, ATC 288, HP 052, NML 201, DNM 205
28 Jan 75-23 May 75	GWESF 396, ATC 902, HP 052, NML 201, NML 338
22 May 75-31 July 75	GWESF 396, ATC 902, HP 052, NML 201

TABLE VI

MEASURED AND COMPUTED TV TRAVEL TIMES (MICROSECONDS)

CLOCK	DATE	MEASURED DELAY TIME	Δ	COMPUTED 5 DAY MEANS	Δ
ATC 288	73 FEB 12	3289.62		3289.62	
ATC 288	73 JUNE 11	3290.13	0.51	3290.07	0.45
ATC 288	74 APR 30	3289.98	-0.15	3292.28	2.21
ATC 902	75 MAR 13	3294.50	4.52	3295.27	2.99
ATC 902	75 JULY 08	3296.67	2.17	3295.44	0.17
HP 052	73 FEB 12	3269.40		3269.40	
HP 052	73 JUNE 12	3270.26	0.86	3271.64	2.24
HP 052	74 APR 29	3240.28	-30.02	3241.34	-30.30
HP 052	75 MAR 13	3245.24	4.96	3245.82	4.48
HP 052	75 JULY 08	3247.46	2.22	3246.69	0.87
DNM 205	73 FEB 08	989.78		989.78	
DNM 205	73 JUNE 19	989.37	-0.41	989.05	-0.73
DNM 205	74 MAY 06	987.38	-1.99	989.64	0.59
DNM 205	75 MAR 20	1100.59	113.21	1101.22	111.58
DNM 205	75 JULY 17	1102.98	2.39	1103.20	1.98
PRKS143	72 DEC 06	1049.20		1049.20	
PRKS143	73 JUNE 20	1049.75	0.55	1049.15	-0.05
PRKS143	74 MAY 15	1047.76	-1.99	1049.58	0.43
PRKS143	75 MAR 26	1046.64	-1.12	1048.11	-1.47
PRKS143	75 AUG 07	1049.15	2.51	1049.15	1.04
GWESF396	73 FEB 07	105.28		105.28	
GWESF396	73 JUNE 19	105.28	--	105.21	-0.07
GWESF396	74 MAY 06	104.19	-1.09	104.71	-0.05
GWESF396	75 MAR 20	104.58	0.39	104.58	-0.13
GWESF396	75 JULY 17	103.41	-1.17	104.33	-0.25

TABLE VII

THE VLF SEGMENT OF UTC(AUS) ANALYSIS

PART 5 UTC(AUS)-CLOCK FOR CLOCKS IN REGION OF VLF RECEPTION

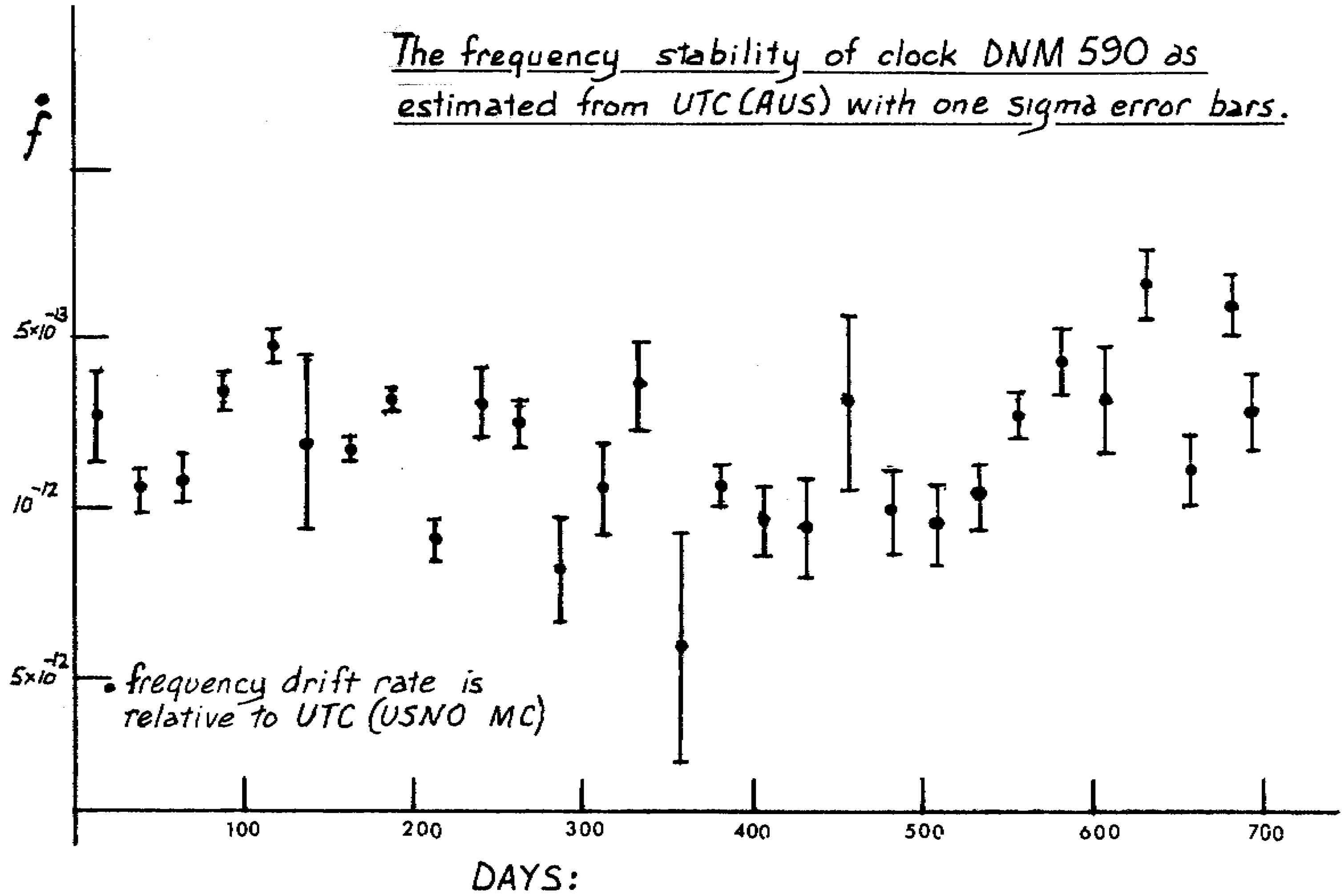
UNIT ONE MICROSECOND

DATE	MJD	USNO MC	WT	BN 331-NLK	WT	BN 331-NWC	WT
74MAR 1	42107	-4.45	1	-24.45	1	-22.95	1
74MAR 2	42108	********	0	********	0	********	0
74MAR 3	42109	********	0	********	0	********	0
74MAR 4	42110	-6.50	1	-24.30	1	-22.60	1
74MAR 5	42111	-5.59	1	-24.59	1	-23.19	1
74MAR 6	42112	-4.14	1	-22.94	1	-23.24	1
74MAR 7	42113	-4.55	1	-23.95	1	-23.05	1
74MAR 8	42114	-3.65	1	-22.45	1	-21.75	1
74MAR 9	42115	********	0	********	0	********	0
74MAR 10	42116	********	0	********	0	********	0
74MAR 11	42117	********	0	********	0	********	0
74MAR 12	42118	-6.10	1	-25.50	1	-22.70	1
74MAR 13	42119	-4.45	1	-23.65	1	-24.55	1
74MAR 14	42120	1.58	1	-23.82	1	-24.52	1
74MAR 15	42121	2.55	1	-16.45	1	-25.85	1
74MAR 16	42122	********	0	********	0	********	0
74MAR 17	42123	********	0	********	0	********	0
74MAR 18	42124	********	0	********	0	********	0
74MAR 19	42125	-6.45	1	-26.45	1	-24.55	1
74MAR 20	42126	-0.25	1	-22.25	1	-25.85	1
74MAR 21	42127	-2.65	1	-25.05	1	-26.55	1
74MAR 22	42128	********	0	********	0	********	0
74MAR 23	42129	********	0	********	0	********	0
74MAR 24	42130	********	0	********	0	********	0
74MAR 25	42131	********	0	********	0	********	0
74MAR 26	42132	-3.07	1	-26.07	1	-25.97	1
74MAR 27	42133	-2.80	1	-25.80	1	-26.00	1
74MAR 28	42134	-3.62	1	-26.62	1	-27.72	1
74MAR 29	42135	********	0	********	0	********	0

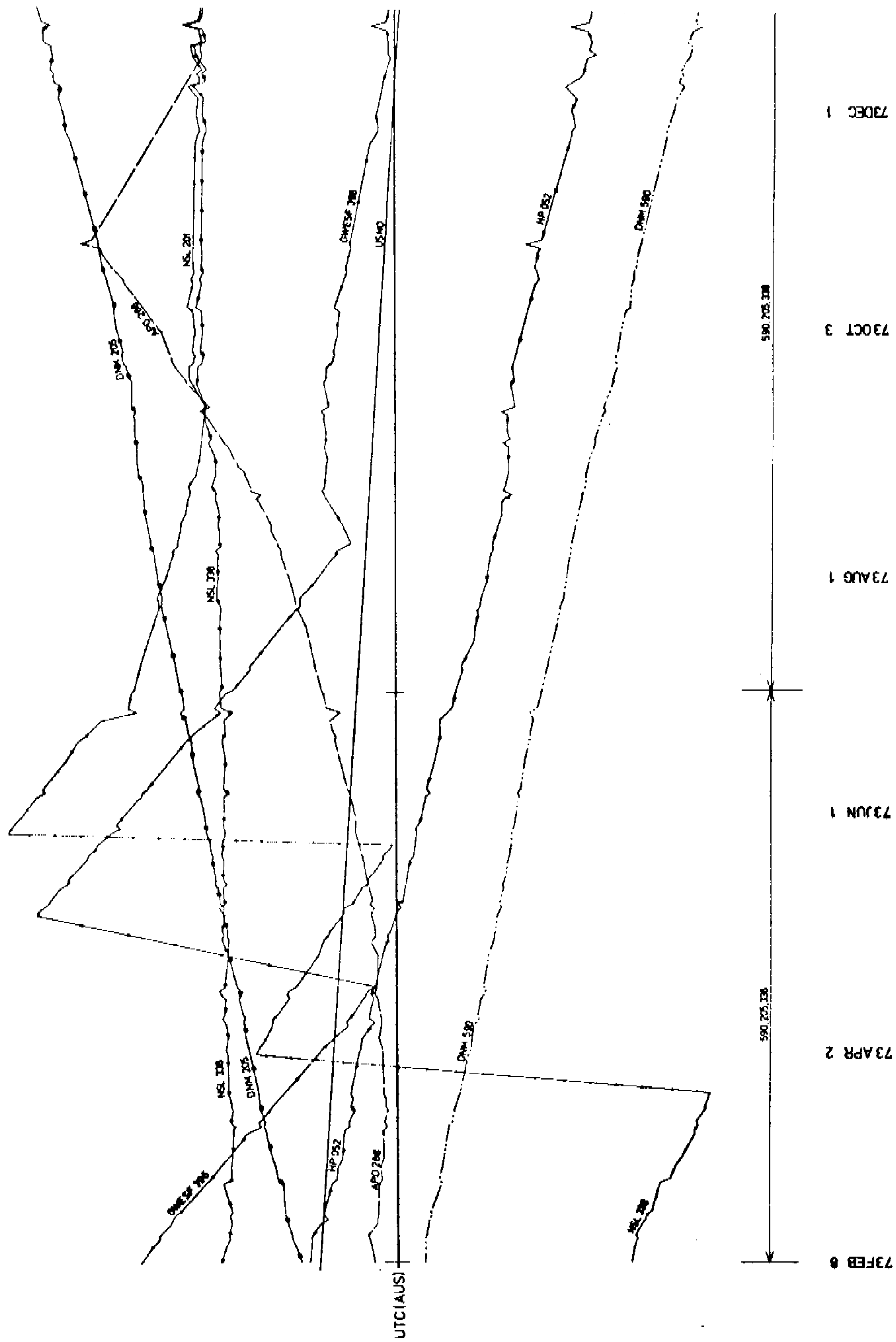
SMOOTHING COEFFICIENTS FOR EACH UTC(AUS)-CLOCK = A+B(T-TO)
WHERE DATA IS SMOOTHED FROM T1 TO T2

A	-137.75	-107.29	24.14
B	.3328	.2053	-.1220
TO	41721.	41721.	41721.
T1	74FEB 1	74FEB 1	74FEB 1
T2	74MAR 29	74MAR 29	74MAR 29
STANDARD ERROR	4.28	3.66	.89

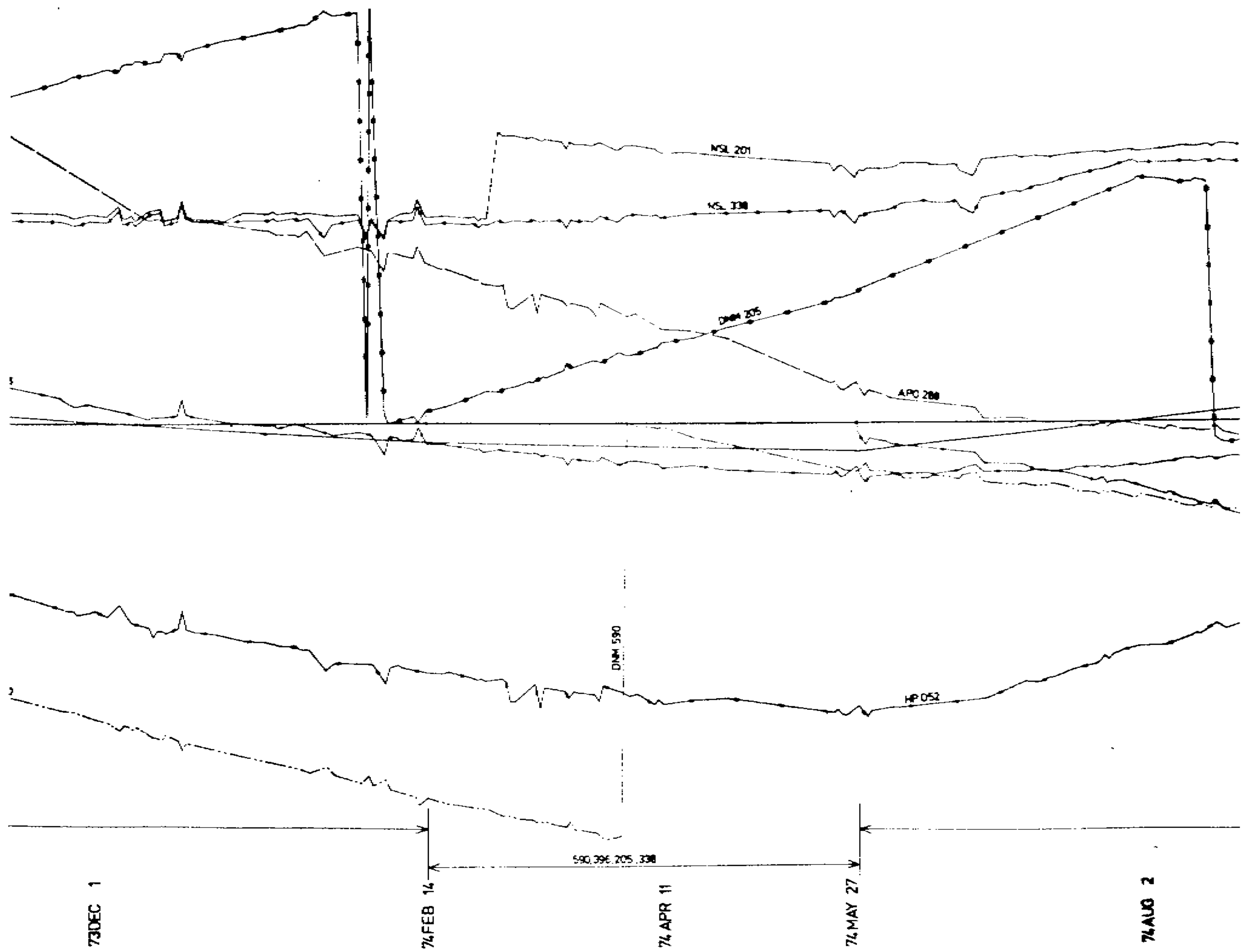
FIGURE 1



The frequency stability of clock DNM 590 as estimated from UTC (AUS) with one sigma error bars.
ḟ
5×10⁻¹³
10⁻¹²
5×10⁻¹²
• frequency drift rate is relative to UTC (USNO MC)
100
200
300
400
500
600
700
DAYS:


73FEB 8
73APR 2
73JUN 1
73AUG 1
73OCT 3
73DEC 1
590.205.338
UTC(AUS)
USNO
HP 052
NSL 338
DNM 205
APO 298
GWESF 398
DNM 590

UTC (AUS) — CLOCK
73 FEB 08 TO 75 MAY 23



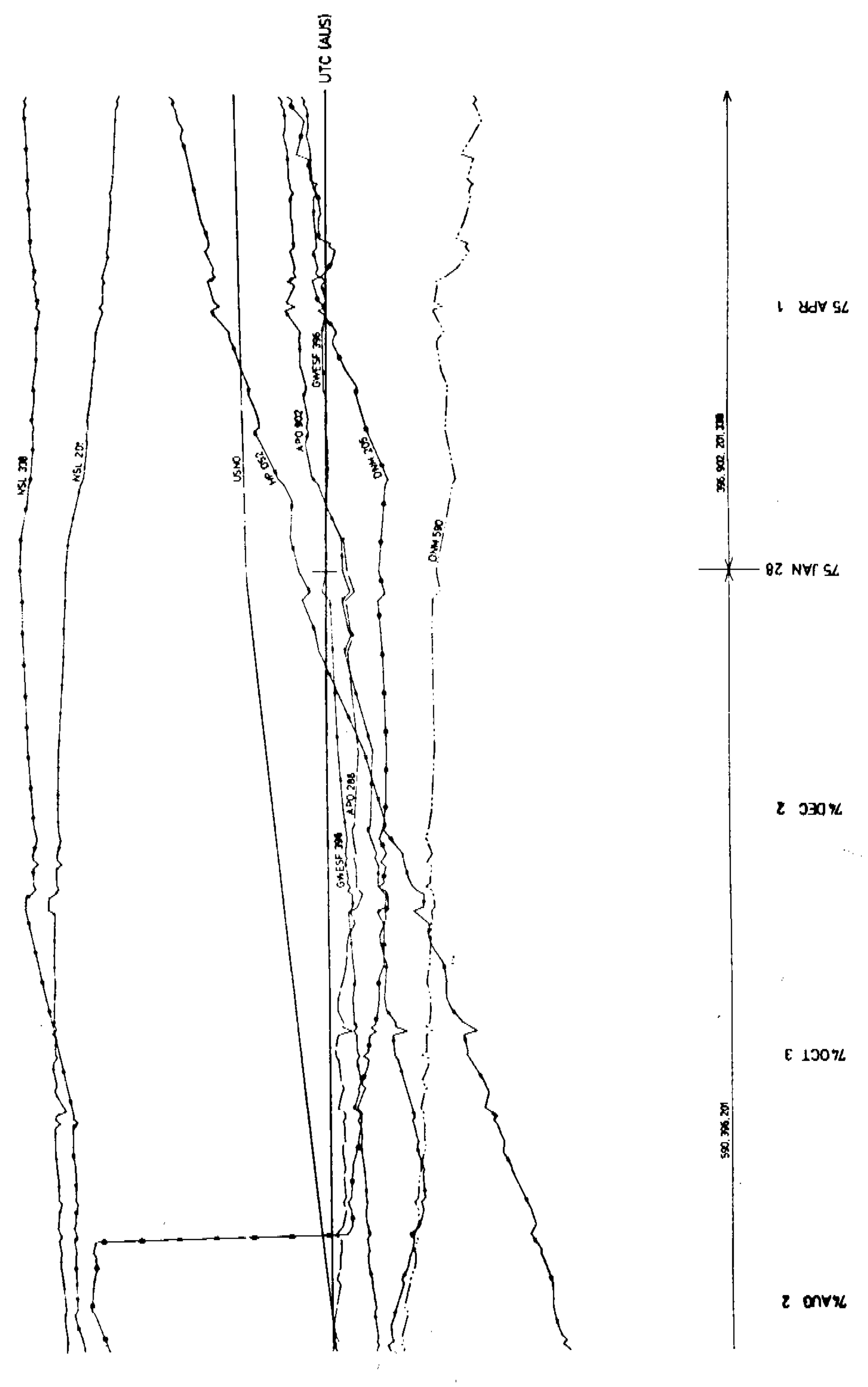

UTC (AUS)
NSL 338
NSL 201
USNO
NP 052
APO 902
GWESF 396
DNM 205
DNM 590
APO 288
GWESF 398
396, 902, 201, 338
590, 396, 201
75 APR 1
75 JAN 28
74 DEC 2
74 OCT 3
74 AUG 2

FIGURE 3.

TELEVISION NETWORKS

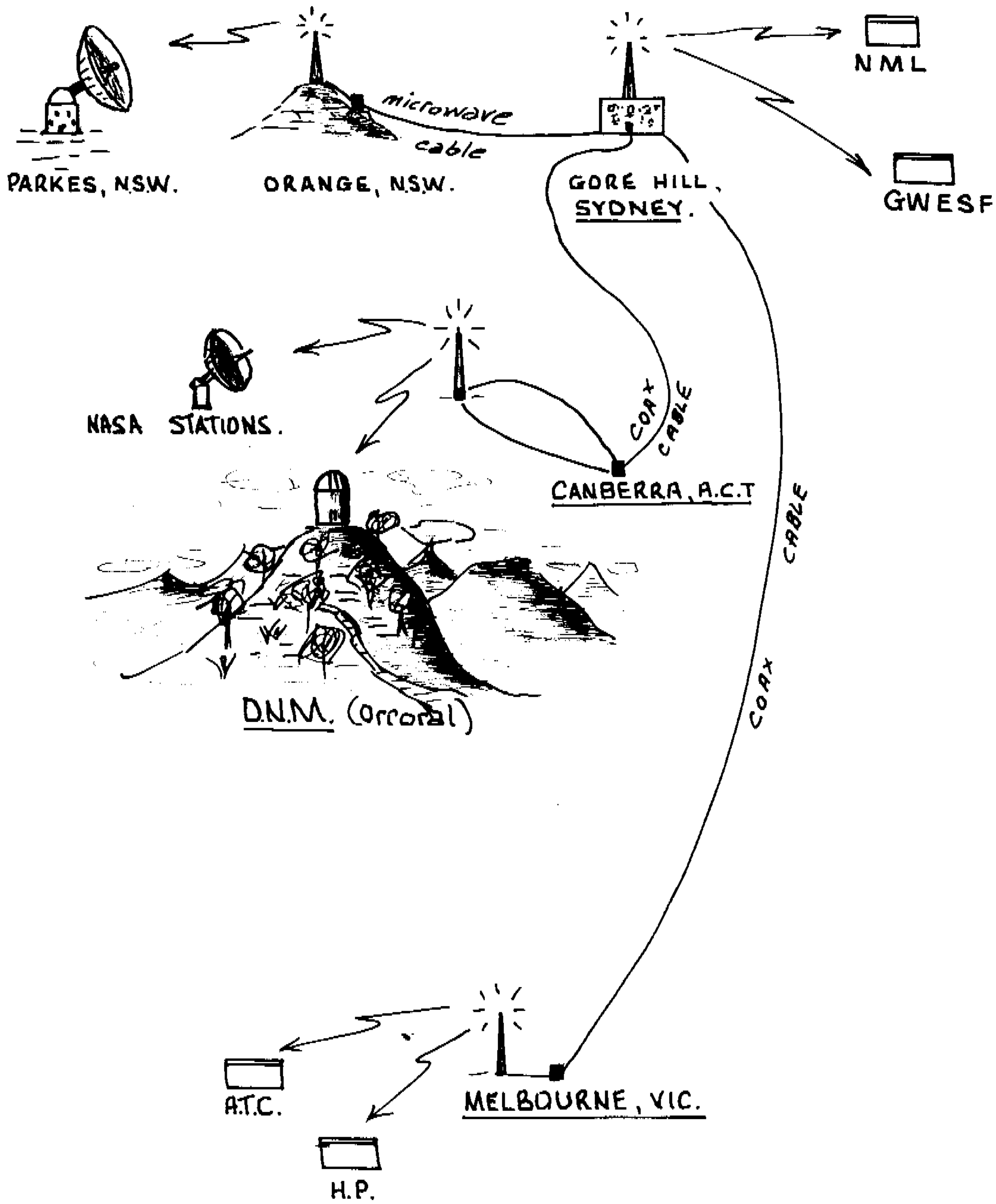


FIGURE 4

SCHEMATIC OF TV VIDEO SIGNAL AND VERTICAL SYNC PULSE BLOCK

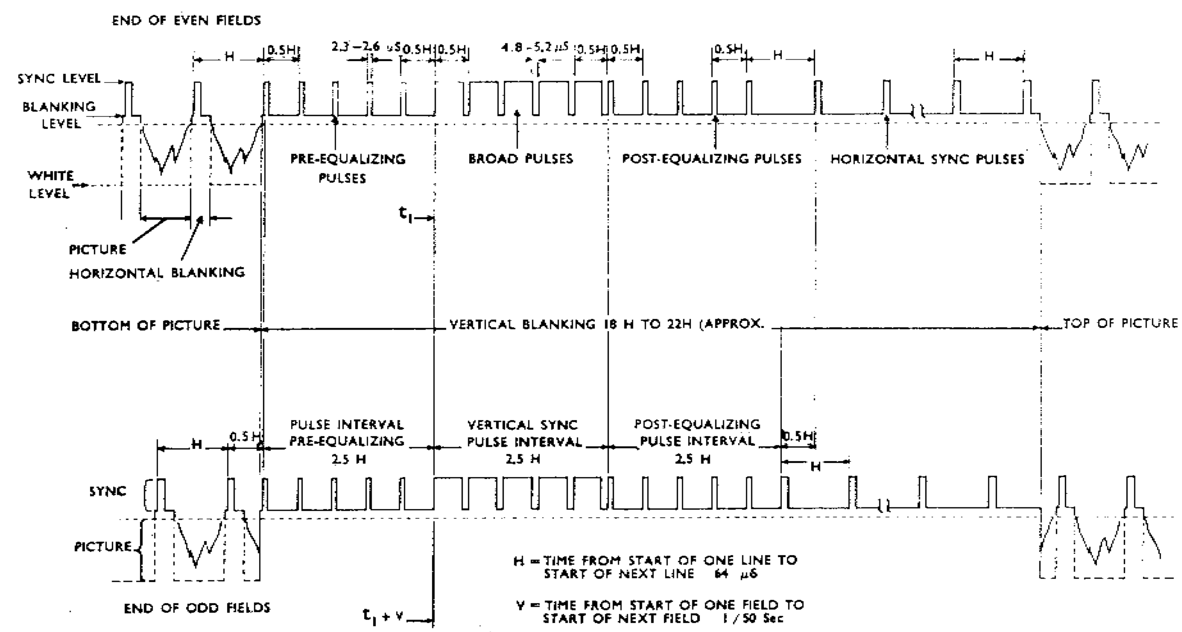
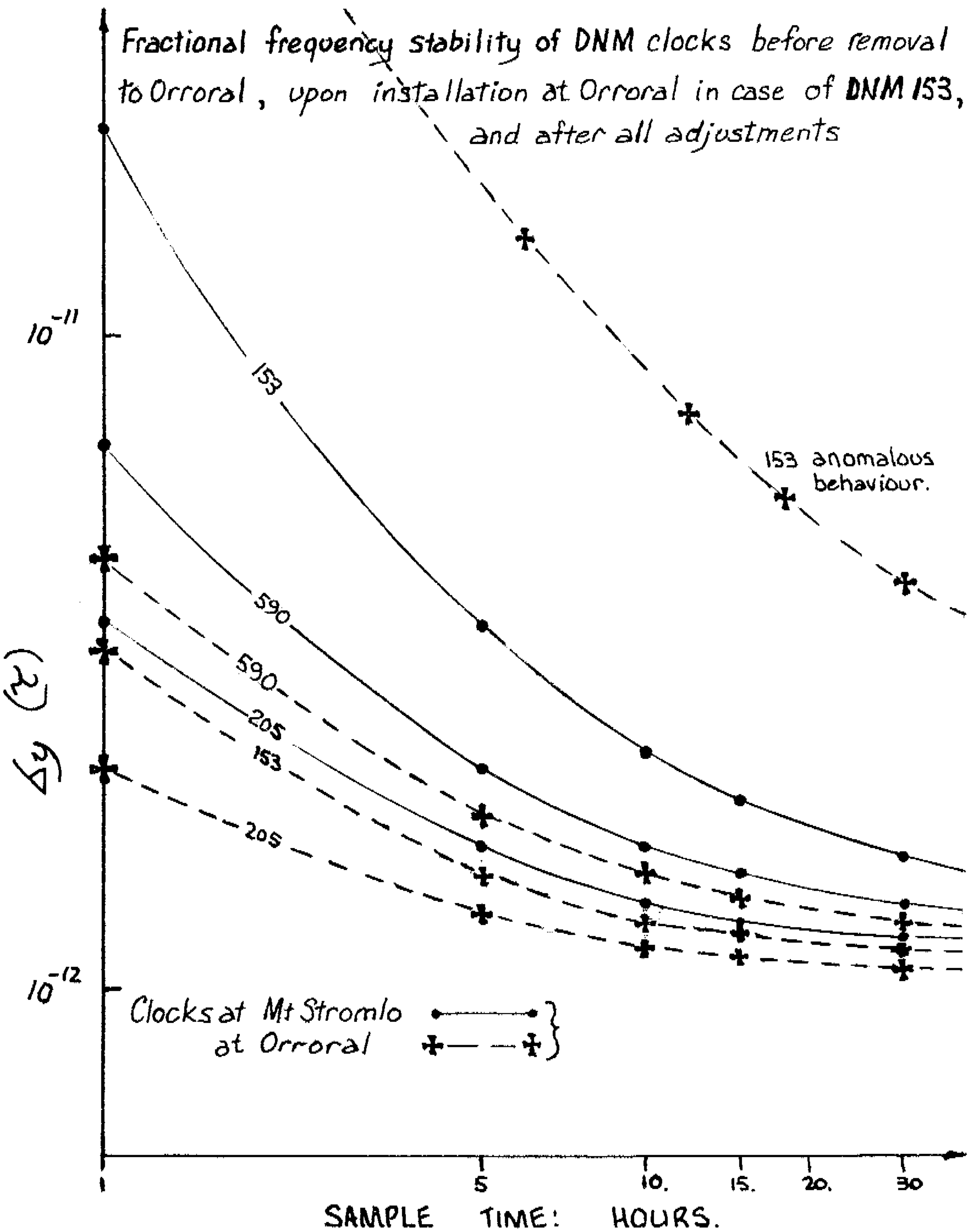


FIGURE 5


Fractional frequency stability of DNM clocks before removal to Orroral, upon installation at Orroral in case of DNM 153, and after all adjustments
153 anomalous behaviour.
153
590
590
205
153
205
10^{-11}
10^{-12}
$\Delta y\ (\tau)$
Clocks at Mt Stromlo
at Orroral
1
5
10.
15.
20.
30
SAMPLE TIME: HOURS.

QUESTION AND ANSWER PERIOD

DR. SHEPARD:

Leonard Shepard, ILC Industries.

The vertical re-trace interval which you had up there was NTSC and you said the timing pulse was in the upper left. Can you specifically identify which pulse and which edge of the pulse you used for timing?

MR. LUCK:

Unfortunately, I am not our technical person. I would have to think about that one.

DR. SHEPARD:

Do you know whether NTSC color standards are used in Australia on the television network?

MR. LUCK:

Is NTSC The American standard?

DR. SHEPARD:

Yes.

MR. LUCK:

No, it is the other one.

DR. SHEPARD:

PAL? I see.

MR. LUCK:

It was introduced on March the 1st, this year. Prior to that we were on black and white only.

DR. SHEPARD:

You do have color transmission now?

MR. LUCK:

Yes.

DR. SHEPARD:

How is the subcarrier stabilized?

MR. LUCK:

By rubidium standards.

DR. SHEPARD:

Do you know, with or without offset?

MR. LUCK:

It seems to be without offset.

MR. JOHNSON:

Johnson, Naval Observatory.

Do you avail yourself of the link back to the observatory that is available to you through the Womera satellite terminal?

MR. LUCK:

Yes, we are aware of it. We have visited the place with our portable standard and at the moment, our only comparison is by portable standards. We are going to investigate that further in the near future.