Contribution of HP Clocks to the BIH's International Atomic Time Scale (IATS)

Application Note 52-4

Table of Contents

Introduction

Since the introduction of the HP 5060A in 1964, HP's Cesium Beam Frequency Standards (atomic clocks) have continued to play a major role in the time-keeping community. These clocks were first used at timekeeping observatories to calibrate crystal oscillators and to establish independent atomic time scales. Soon the need arose for time comparisons between observatories to improve the worldwide accuracy of time and time interval requested for precise navigation, geodesic measurements, space probe localization, etc. This led to the creation of International Atomic Time (IAT), formally defined by the 14th General Conference of Weights & Measures in October 1971. Responsibility was given to the Bureau International de L'Heure (BIH) to keep the unit interval of the IAT as close as possible to the definition of the second, based on the hyperfine transition of the Cesium 133 atom.

Precision time comparisons are made using LORAN-C, television networks and, since 1983, through the Navstar Global Positioning System (GPS). The BIH computes the IAT by averaging the clock data over a sample time of two months using an algorithm called "ALGOS". From this computation, the participating laboratories are informed about the "bimonthly" clock drift rate of each individual time standard referred to the now steered IAT scale. The long-term stability of each time standard is indicated by assigning a "weight," which ranks from zero (lowest performance clocks) to 200 (upper limit for the best clocks). Both of these figures are published bimonthly and annually by the BIH.

Actual clock performance, as "seen" by the BIH through their intercomparison network, provides valuable data which can be used to highlight various aspects of clock behavior, especially when comparing the results of different models and options of commercial cesium clocks.

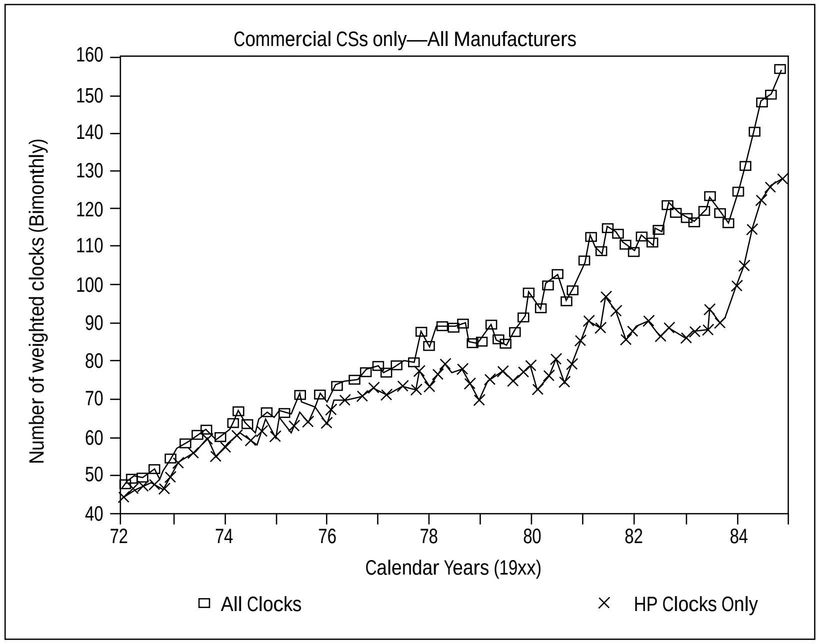

Figure 1. Clocks Participating in BIH/IAT Scale

International Atomic Time Scale

The IAT is elaborated by comparisons among all clocks in the data base, both those sold commercially, and those developed independently by the participating laboratories. In the thirteen years since the BIH started publishing results, it is interesting to compare the participation of various clocks in the system. Figure 1 illustrates the evolution for commercial cesium standards only. The lower graph shows the growth of HP clocks in the IATS. The actual number of different commercial clocks appearing at least once in the BIH publications was 337 by the end of 1984. However, for various reasons, a number of commercial clocks show up only once or for a very short period of time.

A proper comparison can be made only for those clocks actively involved in the IATS and which have participated at least once during an uninterrupted period of at least one year. On this basis, only 236 clocks qualify.

This leads to Figure 2, where HP's contribution to the IAT over the past 13 years is shown through its three commercially available models:

- HP 5060A: First commercially available cesium clock. Discontinued from active manufacture in 1969, a number are still actively participating in the IATS. Some are equipped with the high-performance cesium beam tube.

- HP 5061A: Model with a standard cesium beam tube.

- HP 5061A/004: The high-performance version with a dual cesium beam tube.

The evolution of the various models and options is shown in Figure 3, where the growing use of the high-performance version (option 004) of the HP 5061A demonstrates customer satisfaction in an application where the highest stability and accuracy is required.

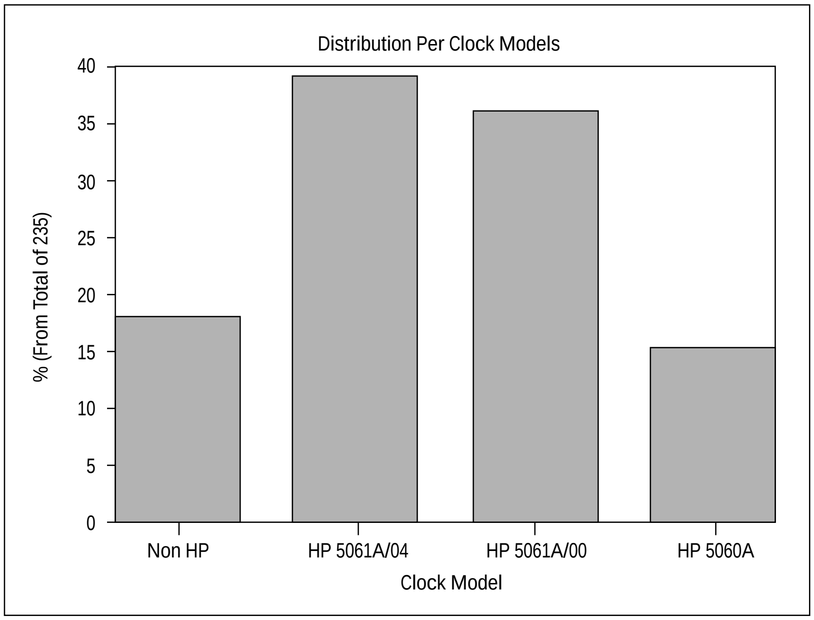

Figure 2. Cesium Clocks in BIH/IAT Scale (1972-84)

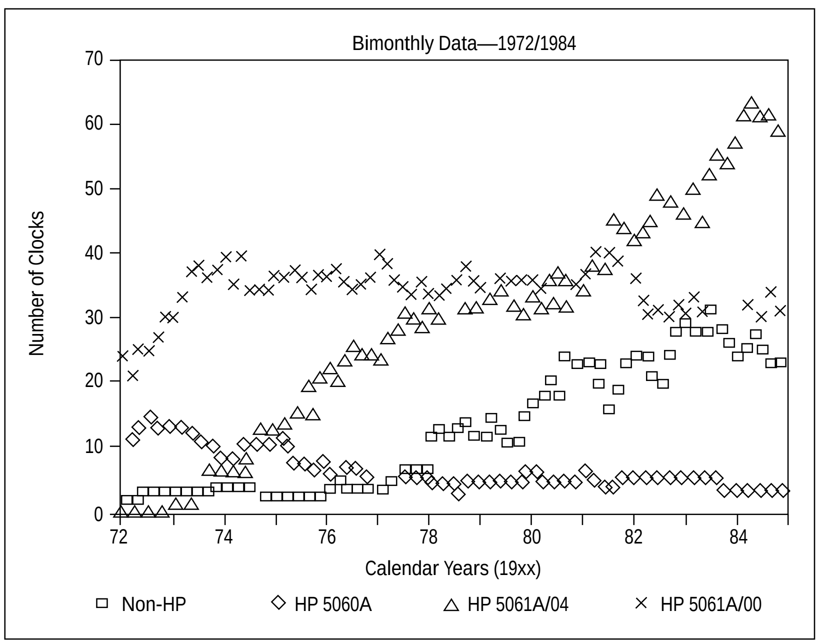

Figure 3. Active Cesium Clocks in BIH/IAT Scale

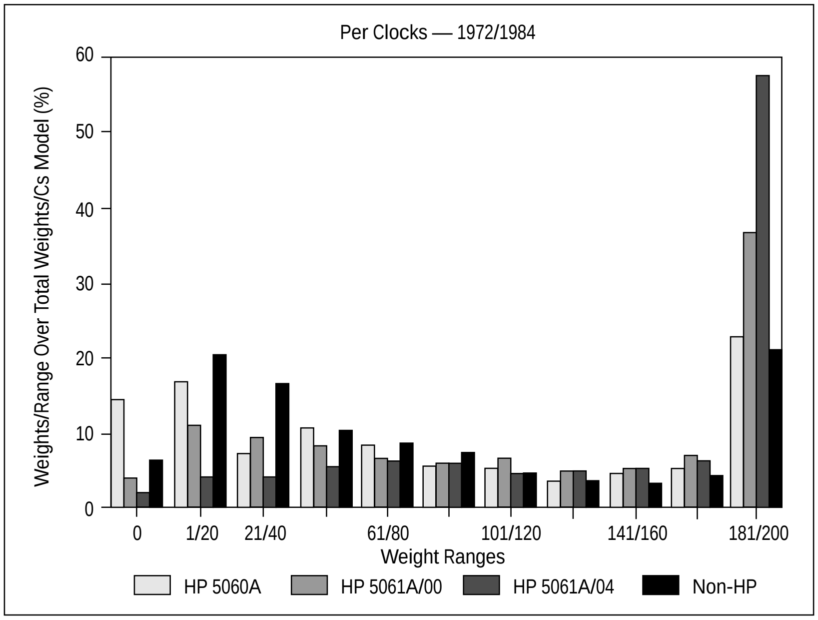

Figure 4. BIH Attributed Weights Distribution (0/200)

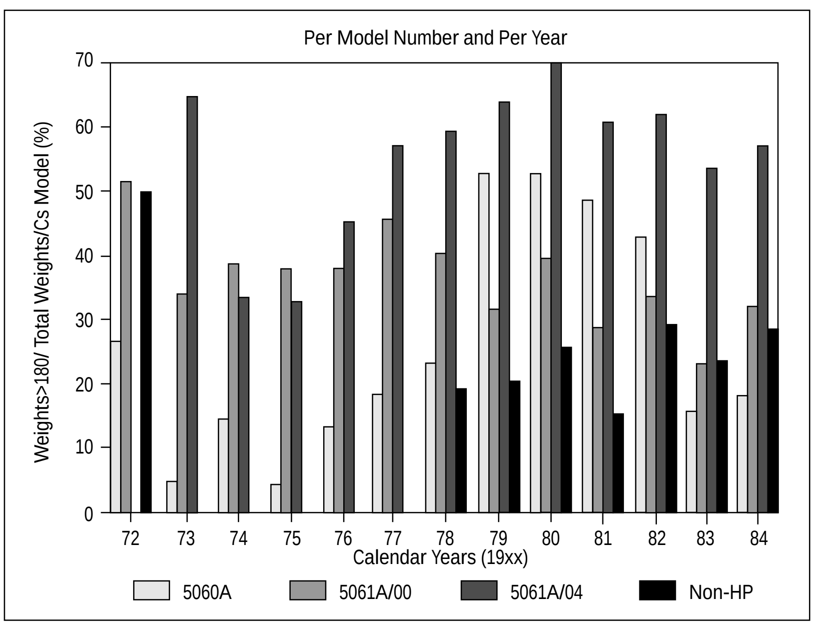

Figure 5. Clock Performances — Worldwide

Clock Weighting

As mentioned above, the BIH computes the clock inter-comparison data and attributes a "weight" which quantifies — by a number from zero to 200 — the long-term stability over a 2 month interval for both the clock and the intercomparing system (LORAN-C, TV, GPS. . .). A weight of zero means that the BIH noticed a frequency change of $\geq 5.4 \times 10^{-13}$ (or a change in clock rate of ≥47 ns/day) over the previous 2 months averaging period. A weight of 200 denotes a frequency instability of $\leq 8.1 \times 10^{-14}$ (or ≤7 ns/day) and a weight of >180 is $\leq 1.3 \times 10^{-13}$ (or ≤11 ns/day).

Until December 1980, the maximum clock weight was limited to 100. In order to simplify the analysis of clock weightings, values published before January 1981 have been doubled. In doing so, the apparent clock performance no longer strictly corresponds to its actual one, but this is of no real importance when making clock comparisons. At introduction into the IATS, clocks are assigned a weight of zero. These are not included in the analysis to follow.

Clock-Weight Distribution

Figure 4 shows the clock-weight distribution for actively participating clocks in the IATS. Again, notice the dominance of the HP 5061A/004 (high performance) over the others, with 56% of their total number of attributed weights within 181 to 200. Also notice the dominance of all HP clocks over all other commercial units at clock weights greater than 100.

Clock Performances

Also of interest is the evolution of clock quality as shown by analyzing the number of weights ≥180 that each received during the past 13 years. Figure 5 plots this by year. It also shows a general behavior for all models consisting of up and down trends, which may be due to both technical and economic reasons.

Figure 6 shows the clock-weighting data obtained at one laboratory, (the PTB in West Germany), compared to that seen for similar HP 5061A/004 instruments in the IATS. This demonstrates a possible performance limit for the HP 5061A/004. In this case too, several reasons may underlie such an outstanding and unique performance achievement.

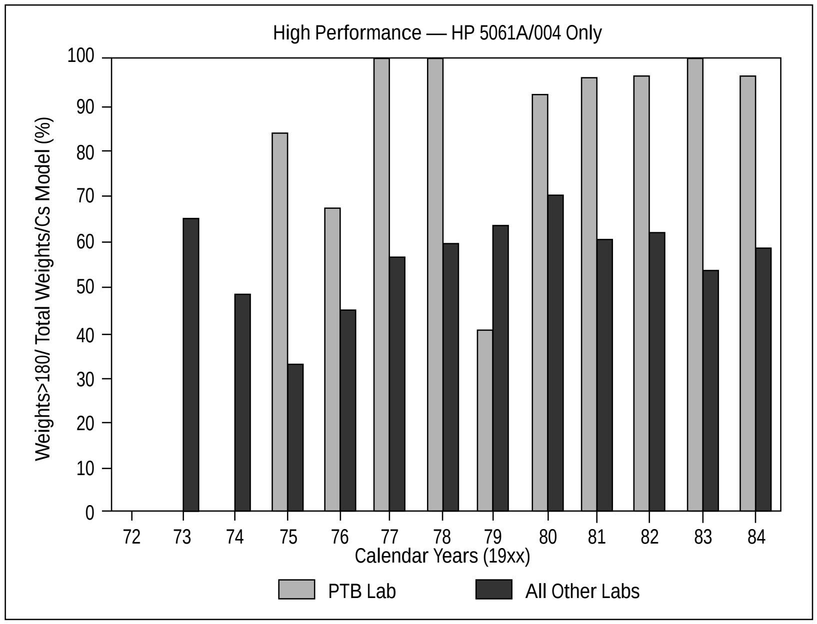

Figure 6. PTB's Clocks Performance vs. Others

Clock Efficiency and Merit

From Figures 5 and 6 one may conclude that the arbitrary ratio of "Weights >180/Total Weights per Cs Model (%)" quantifies, to some extent, the clock quality (together with the intercomparison system) and, if expressed in %, represents its efficiency in the time scale. As for any aging device, after a certain time of operation, a fatal performance degradation process causes a decay of its long-term stability. The highest figure of efficiency, therefore, corresponds most likely (and theoretically) to new clocks or to those with a new

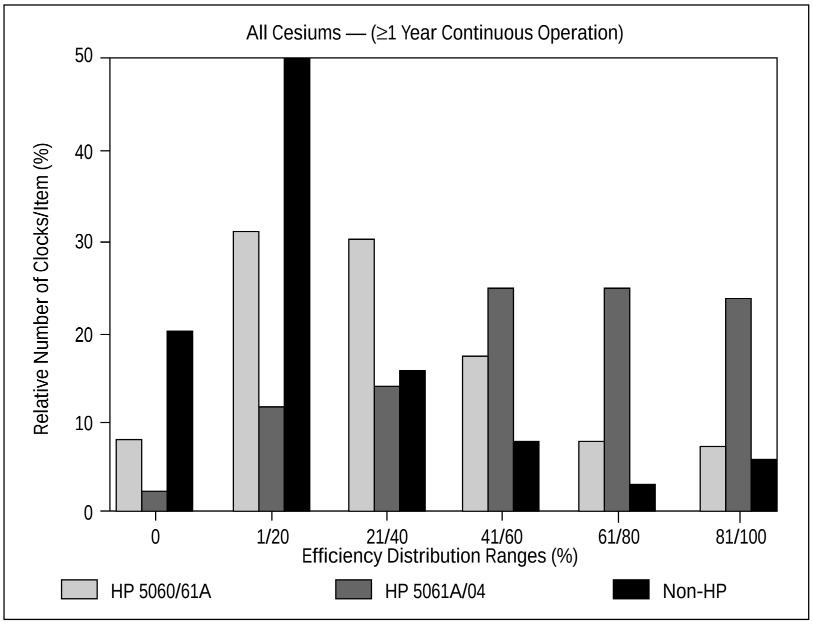

Figure 7.
Efficiency of IATS
Cesium Clocks/
MFR-OPT

Cesium Beam Tube.
Another approach might be to evaluate the clock on its overall lifetime contribution. One method may be to formulate the two arguments involved in the efficiency (weights >180 and total weights) so that each one contributes to a figure of merit — by multiplying them. Therefore, the figure of merit of a clock represents the product of the number of weights >180 by the total number of weights this clock received during all the time it was participating in the IATS. Table 1 shows the lists of the first 35 highest ranked clocks (out of 236) for each above defined figure.

It may be seen that only 8 clocks succeed in appearing in both tables and, not surprisingly, 7 of them are the high performance version of the HP 5061A. The superior performance of the HP 5061A/004 is also illustrated in Figure 7, which outlines the "efficiency" distribution for HP clocks and commercial models from other manufacturers. Here the outstanding dominance by the HP standards is clearly evident, especially at the higher efficiency factors.

Conclusion

Although the BIH published data are subject to restricted usage and subtle interpretation, it may be seen from the above that a careful selection of evaluation parameters allows one to highlight distinctive characteristics of commercial Cesium clocks participating in the IATS.

Table 1. Merit vs. Efficiency of Cesium Clocks Participating in the BIH/IAT Scale

LAB. Commercial Cesiums ≥1 Year Continuous Operation	CLOCK	MFR.	:MERIT #	<RANK> MER. (of 236)	EFF.
NPL	12	418	HP : 3850	1	50
ON	12	285	HP : 3800	2	48
USNO	14	571	HP : 2914	3 - - - -	35
USNO	12	532	HP : 2432	4	60
PTB	14	867	HP : 2295	5 - - - -	16
PTB	12	389	HP : 2145	6	42
PTB	24	103	HP : 2100	7 - - - -	22
USNO	14	834	HP : 1944	8	45
NBS	11	167	HP : 1890	9	81
PTB	12	320	HP : 1881	10	63
USNO	12	549	HP : 1848	11	61
RGO	14	868	HP : 1568	12	49
RGO	12	348	HP : 1512	13	80
PTB	12	462	HP : 1508	14	65
F	12	347	HP : 1495	15	109
OMSF*	14	896	HP : 1440	16	55
RGO	11	123	HP : 1430	17	84
IEN*	14	893	HP : 1376	18	37
F	12	439	HP : 1342	19	107
VSL	22	34	HP : 1325	20	85
F	12	594	HP : 1295	21 - - - -	9
F	12	158	HP : 1220	22	119
PTB	12	395	HP : 1160	23	40
OMSF	22	223	HP : 1150	24	88
NRC*	14	267	HP : 1088	25 - - - -	10
APL	14	793	HP : 1080	26 - - - -	23
PTB	12	394	HP : 1053	27	44
F	14	753	HP : 1007	28	108
PTB*	14	395	HP : 992	29 - - - -	7
NBS*	14	601	HP : 924	30	71
STA	14	900	HP : 912	31	99
NBS	14	316	HP : 888	32	51
TP	12	335	HP : 871	33	150
PTB*	14	394	HP : 870	34 - - - -	8
NBS*	14	323	HP : 861	35	75

LAB. Commercial Cesiums ≥1 Year Continuous Operation	CLOCK	MFR.	:EFF. %	<RANK> EFF. (of 236)	MER.
USNO	24	423	HP :100	1	66
USNO	34	98	HP :100	2	143
USNO	12	651	HP :100	3	154
F	24	712	HP :100	4	174
USNO	12	862	HP :100	5	175
USNO	24	452	HP :100	6	173
PTB*	14	395	HP : 97	7 - - - -	29
PTB*	14	394	HP : 97	8 - - - -	34
F	12	594	HP : 95	9 - - - -	21
NRC*	14	267	HP : 94	10 - - - -	25
USNO	22	362	HP : 93	11	102
FTZ	24	656	HP : 91	12	130
OFM	17	206	OSQ : 90	13	75
USNO	14	778	HP : 89	14	81
F	24	842	HP : 89	15	140
PTB	14	867	HP : 88	16 - - - -	5
TUG	24	654	HP : 87	17	63
F	14	873	HP : 86	18	71
NBS	12	601	HP : 86	19	116
IEN	12	893	HP : 86	20	164
FTZ	24	217	HP : 85	21	78
PTB	24	103	HP : 84	22 - - - -	7
APL	14	793	HP : 83	23 - - - -	26
VSL	24	190	HP : 83	24	88
F	14	51	HP : 82	25	94
USNO	14	875	HP : 81	26	37
F	14	500	HP : 81	27	104
OFM	17	208	OSQ : 81	28	76
USNO	24	35	HP : 79	29	86
USNO	24	301	HP : 77	30	124
USNO*	12	778	HP : 76	31	58
USNO	24	688	HP : 76	32	60
ON	24	156	HP : 76	33	59
USNO	24	605	HP : 76	34	61
USNO	14	571	HP : 76	35 - - - -	3

* = HP CLOCK HAD PREVIOUSLY ANOTHER TUBE OPTION (STD OR HI PERF/004)

BIH'S CLOCK DESIGNATION

11 = HP 5060A		HP
12 = HP 5061A/STD	- S/N < 1000	HP
13 = B5000		EBAUCHES
14 = HP 5061A/004 (HI PERF)	- S/N < 1000	HP
16 = 3200 17 = 3000		OSCILLOQUARTZ
18 = 4000 20 = 5000		FTS
19 = XSC		R&S
22 = HP 5061A/STD	- S/N ≥ 1000 < 2000	HP
24 = HP 5061A/004 (HI PERF)	- S/N ≥ 1000 < 2000	HP
34 = HP 5061A/004 (HI PERF)	- S/N ≥ 1000 < 3000	HP

For more information on HP precision frequency and time standards, please request any of the following:

AN 1289: The Science of Timekeeping

HP 105A/B Quartz Oscillator Data Sheet

HP 5087A Distribution Amplifier Data Sheet

HP 5089A Standby Power Supply Data Sheet

Instrumentation Catalog

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Hong Kong
Tel: (852) 2599 7777
Fax: (852) 2506 9285

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