# No Warmup Crystal Oscillator

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## ABSTRACT

During warmup, crystal oscillators often show a frequency offset as large as 1 part in $10^5$. If timing information is transferred to the oscillator and then the oscillator is allowed to warmup, a timing error greater than 1 millisecond will occur. For many applications, it is unsuitable to wait for the oscillator to warmup.

For medium accuracy timing requirements where overall accuracies in the order of 1 millisecond are required, a no warmup crystal concept has been developed. The concept utilizes two crystal oscillators, which are used sequentially to avoid using a crystal oscillator for timing during the trauma of warmup.

One oscillator may be a TCXO which preserves timing information during the warmup of the second crystal oscillator, which has a much higher frequency accuracy once warmed up.

This paper will show the accuracy achieved with practical TCXOs at initial start over a range of temperatures. A second design utilizing two oven controlled oscillators will also be discussed.

## TYPICAL WARMUP FOR AT CUT CRYSTAL

Figure 1 shows the warmup curve for a typical AT cut crystal oscillator with oven control. This particular warmup was done from room temperature (23°C) to crystal oscillator oven control temperature of 85°C. If one observes the point at which the curve crosses zero (nominal frequency) this oscillator has already gained approximately 11 milliseconds. During the next 5 minutes the oscillator loses approximately 60 microseconds. The negative overshoot due to stress is far too small to compensate for the large positive time error accumulation during oven warmup. If one cannot wait 20 minutes for the crystal oscillator to warmup and it is necessary to have less than 1 millisecond time error, another approach is required.

## TCXO TURNON

Figure 2 shows the phase difference between a TCXO (temperature compensated crystal oscillator) and a cesium beam standard from turnon of the TCXO to the end of the first minute. This shows a very regular beat frequency and is virtually the same as the nominal accuracy (2 parts in $10^7$) of the TCXO. There is very little trauma occurring with turnon of a TCXO.

## TIME ERROR OF CRYSTAL OSCILLATOR AND TCXO COMBINED

Figure 3 shows the theoretical time error accumulated if a clock is started with a TCXO oscillator at time $T_0$ and switched to an oven controlled crystal oscillator at time $T_1$. $T_2$ is the time at which the time error accumulated is determined, $f_0$ is the nominal frequency of 1 MHz, $f_1$ is the TCXO's frequency, $f_2$ is the oven controlled oscillator's frequency and $\Delta T$ is the accumulated time error.

In practice precision frequency sources are not readily available to determine when the oven controlled crystal oscillator goes through zero (nominal frequency). One source of information available for switching is the oven cutback of the oven controlled crystal oscillator. An experiment was performed at Naval Research Laboratory (NRL) using a TCXO with switching circuitry which allowed the TCXO to drive the clock when no other standard frequency was available.

## EQUIPMENT

Figure 4 shows a printed circuit card with a commercial TCXO and the switching circuitry required to switch quickly enough to avoid losing more than one microsecond during switching.

Figure 5 shows the modular construction of an AN/URQ-23 developed by NRL and containing a double proportional oven controlled crystal oscillator with a 5 MHz, fifth overtone AT cut crystal.

Figure 6 shows six SG 1157/U clocks with each containing the TCXO card shown in Figure 4. To the left of the clocks is the AN/URQ-23 shown in Figure 5. All of the equipment is in a temperature chamber.

## EXPERIMENT

Seven experimental data runs were conducted at seven different temperatures ranging from -18°C to 55°C. In between data runs, the equipment was allowed to equalize at the new temperature before power on. Prior to the first data run all clock oscillators were set to nominal frequency. Synchronization of the clocks with NRL's master clock occurred within 10 seconds of power on for each run. In these experimental runs, $T_1$ (switching time) was chosen as the time when cutback of the inner oven of the AN/URQ-23 occurred.

Figure 7 shows the data of the first run at -18°C. This temperature was below the spec limit for the TCXOs and so the data for the two clocks shown yield a larger than normal time error accumulated, but which is still less than 1 millisecond. The vertical line at 40 minutes shows the switching time $T_1$ (oven cutback of AN/URQ-23).

Figure 8 shows the data of the second run at -8°C. The data for clocks 1, 2, 3 and 5 are shown here and each yield an accumulated time error of less than 0.25 milliseconds. The vertical line at 25 minutes shows the switching time $T_1$.

Figure 9 shows the data of the third run at 7°C. Switching time $T_1$ is shown by the vertical line at 18 minutes. The accumulated time error for each clock is less than 0.25 millisecond. Clock #3 shows a negative time accumulation and a change in slope is noted when the switch over to the oven controlled oscillator occurs at time $T_1$ After switching, the positive slope of the oven controlled oscillator is observable in all the clocks and this slope becomes less as the stress on the crystal is relieved.

Figure 10 shows the data of the fourth run at 23°C (room temperature). Switching time $T_1$ is shown by the vertical line at 20 minutes. This plot shows data for two hours after power on. The oven controlled oscillator by itself over its entire warmup curve yielded an accumulated time error of -10 milliseconds while the ensemble of TCXOs and oven controlled crystal oscillator each yielded an accumulated time error of 0.1 millisecond or better.

Figure 11 shows the data of the fifth run at 27°C. Switching time $T_1$ is shown by the vertical line at 22 minutes. This plot shows the data for two hours after power on and the accumulated time error is less than 0.25 millisecond for each clock.

Figure 12 shows the data of the sixth run at 43°C. Switching time $T_1$ is shown by the vertical line at 22 minutes. This plot shows the data for 30 minutes. Clocks 1, 3, and 5 each yielded an accumulated time error of less than 0.2 millisecond.

The seventh and final run of data at 55°C is shown in Figure 13. This shows the performance of the TCXOs at 55°C for 30 minutes. The switching time $T_1$ would have occurred at 14 minutes. The oven controlled oscillator warms up much more quickly at this temperature and with less overshoot.

IMPROVEMENT WITH SC CUT CRYSTAL

When a crystal is warmed up very rapidly internal stresses are set up which cause a frequency perturbation. The use of a stress compensated crystal such as the SC cut improves the performance, but even with it there will be a minimum warmup time.

Figure 14 shows the SC cut crystal in fast warmup [1] showing less frequency dependence on temperature than the AT cut and no stress related overshoot. The warmup could be as short as 90 seconds. If a TCXO is used as an initial oscillator the optimum warmup time may in practice be several minutes to achieve the minimum accumulated time error.

## ALTERNATIVE TECHNIQUE

An alternative technique using two oven controlled crystal oscillators is shown in Figure 15. The oscillators shown have a self tuning capability so that an external frequency may be utilized to assure accurate initial frequency. In step 1 when oscillator A is holding, it maintains the external frequency while oscillator B is warming up.

It requires only a second for the serial time code to be shifted into the shift register and shifted into the counter driven by oscillator A. The counter of oscillator B is continually updated until oscillator B is warmed up. Oscillator B now becomes the master and in step 2 it holds the time while oscillator A warms up. In step 3, when oscillator A has warmed up, it also becomes a master and two independent clocks are now available for intercomparison.

## CONCLUSIONS

The experimental results show that the no warmup concept has an order of magnitude increase in timing accuracy for situations requiring instant turnon and deployment. If timing requirements are more stringent than the simple model tested, then the alternative suggestions should be utilized.

## ACKNOWLEDGEMENTS

The author would like to acknowledge the contributions of Joseph J. O'Neill and Ruth E. Phillips.

## REFERENCES

[1] Robert Burgoon and Robert L. Wilsen, Proc. 33rd Annual Symposium on Frequency Control, 1979, "Performance Results of an Oscillator Using the SC Cut Crystal" p 408

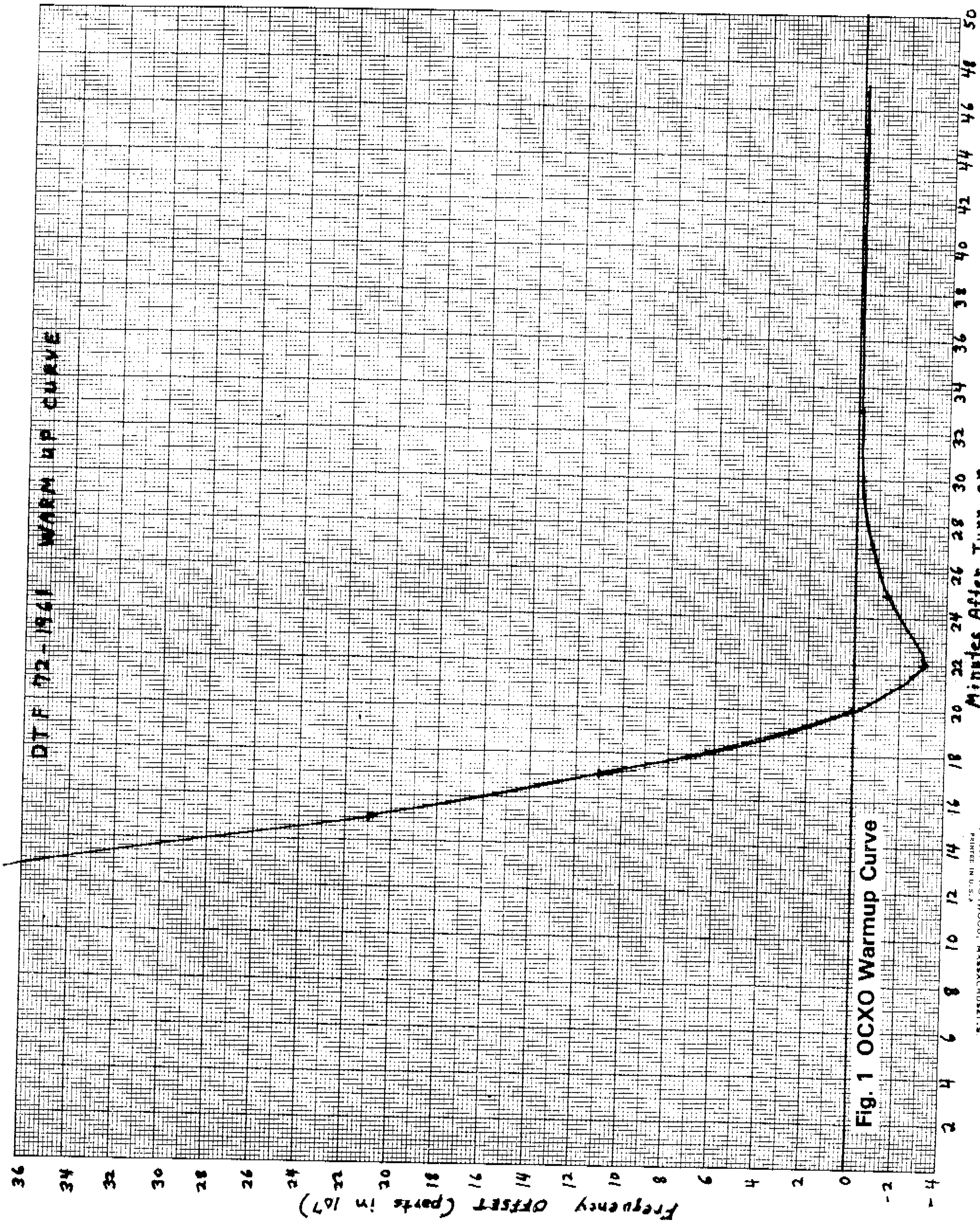



Fig. 1 OCXO Warmup Curve

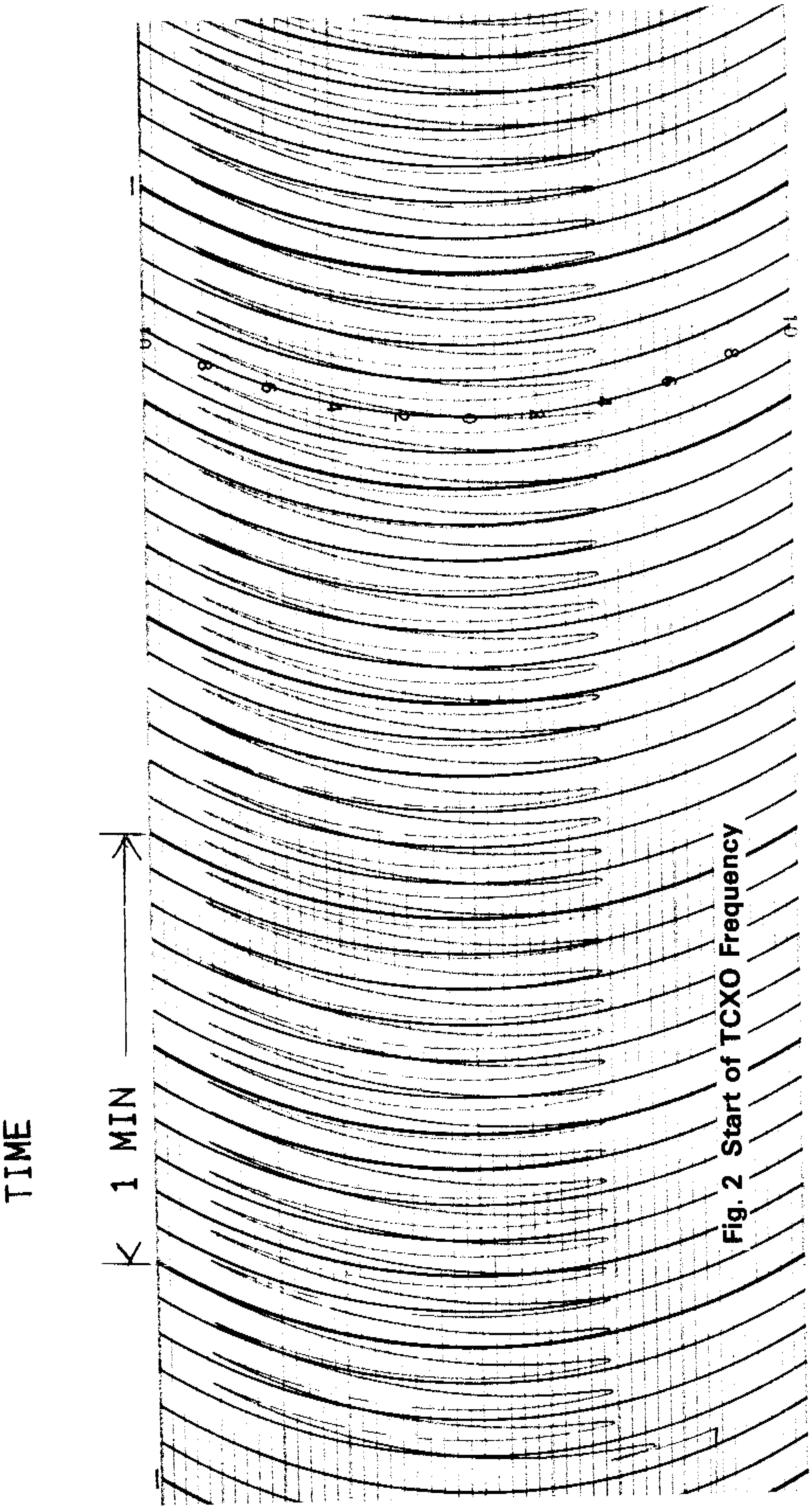



Fig. 2 Start of TCXO Frequency

$$\Delta T = \int_{T_0}^{T_1} \frac{\Delta f_1}{f_0} \, dt + \int_{T_1}^{T_2} \frac{\Delta f_2}{f_0} \, dt$$

$T_1$ = SWITCH IN TIME (OVEN CUTBACK TIME)

$T_0$ = STARTING TIME

$\Delta T$ = TIME ERROR

$f_1$ = TCXO FREQUENCY

$f_2$ = OVEN CONTROLLED OSCILLATOR

$f_0$ = NOMINAL FREQUENCY

Fig. 3 Equation of No Warmup

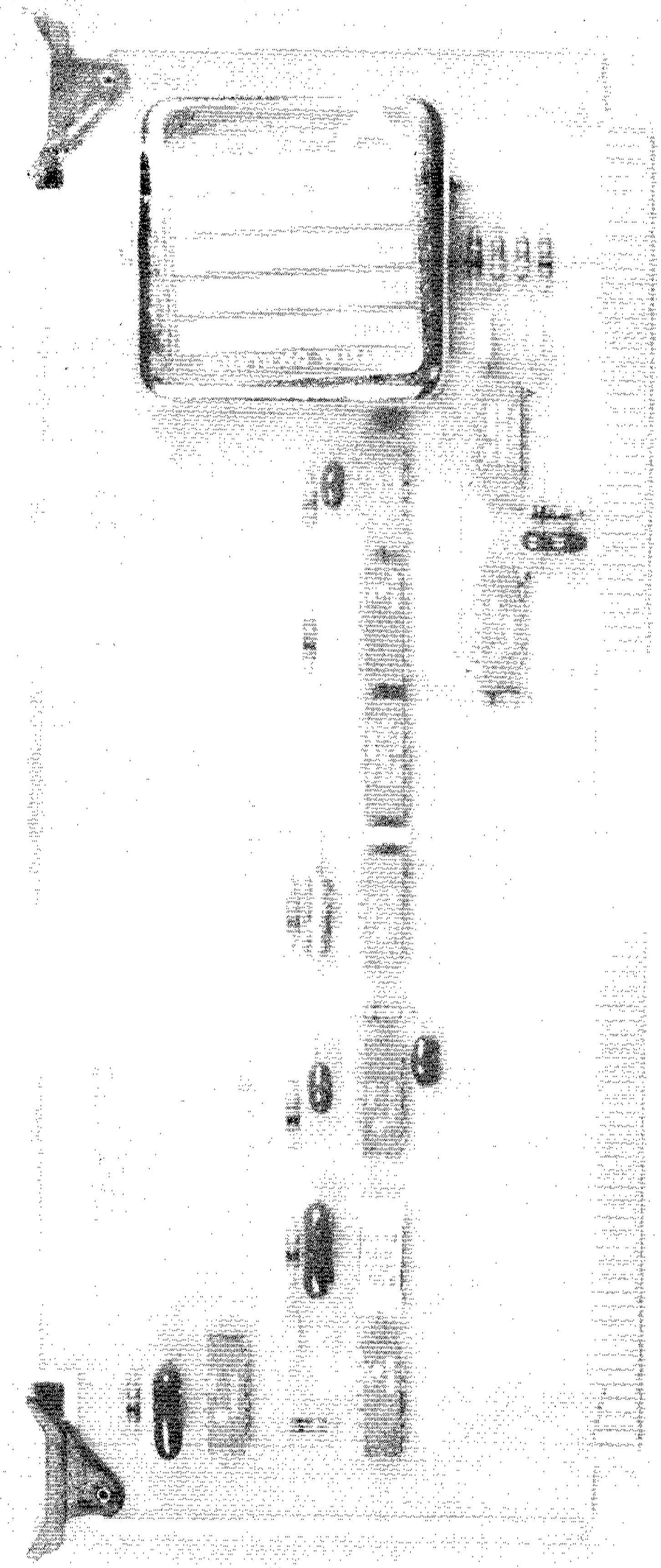


Fig. 4 TCXO and Switching Circuit

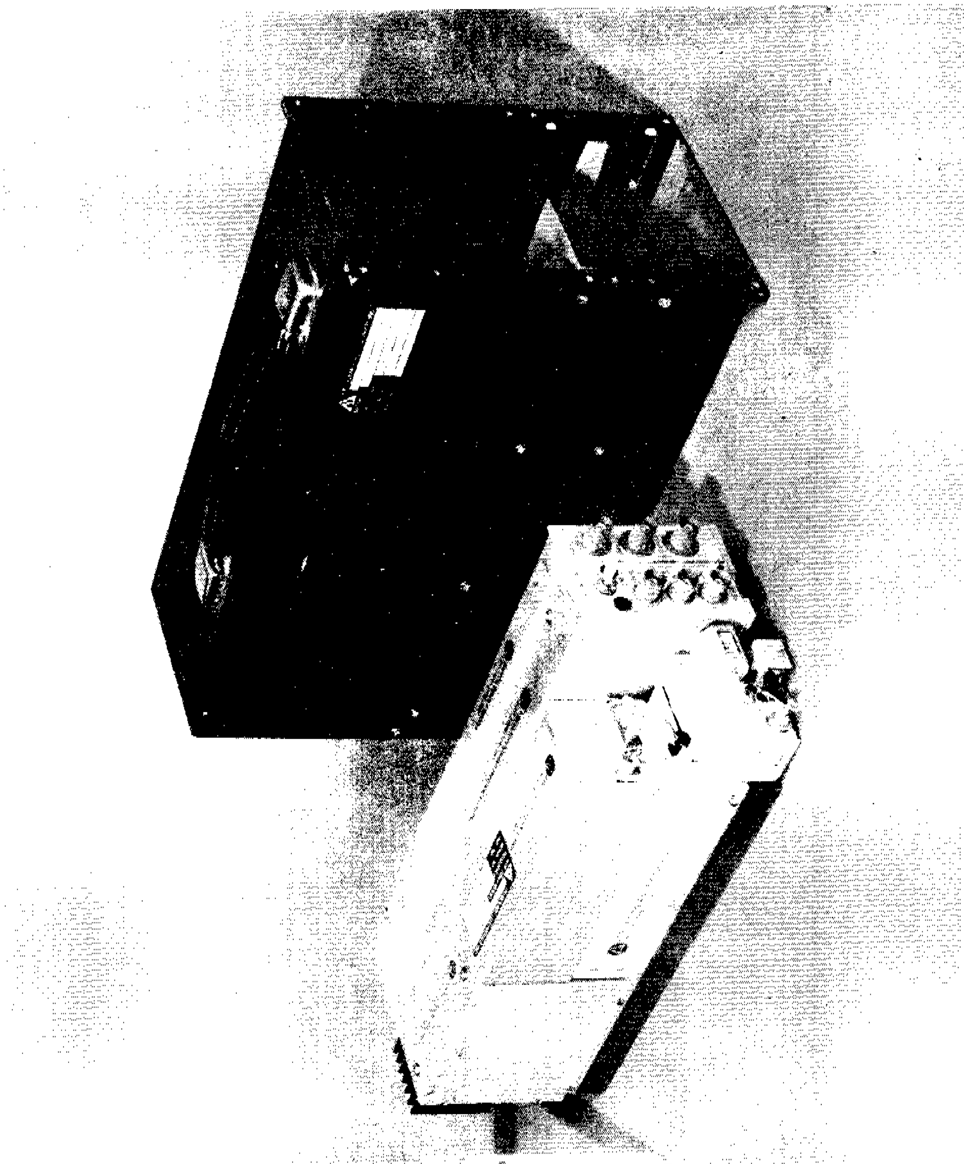


Fig. 5 Modular AN/URO-23 Showing OCXO

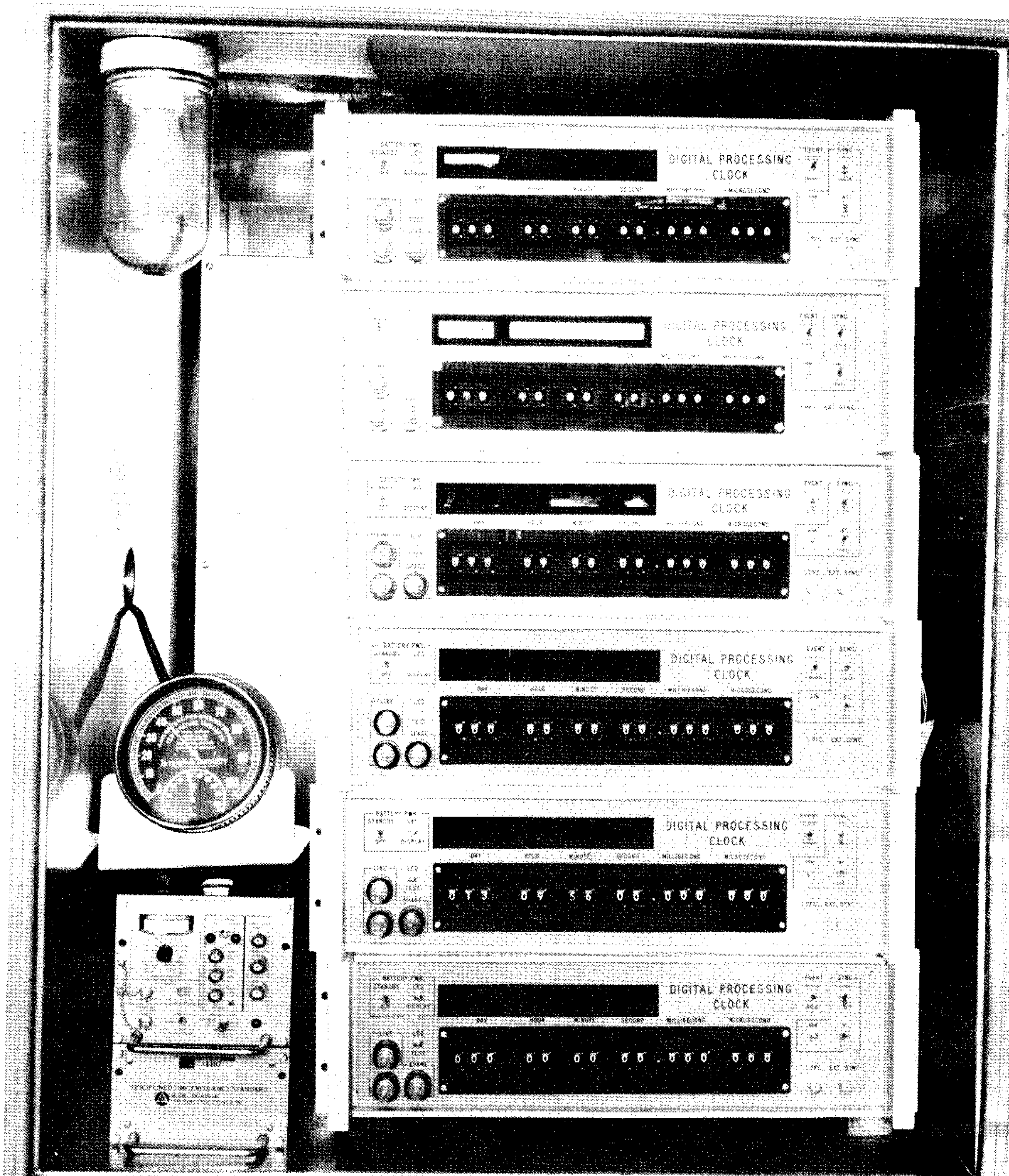



**Fig. 6 Six SG 1157/U Clocks & AN/URO-23**

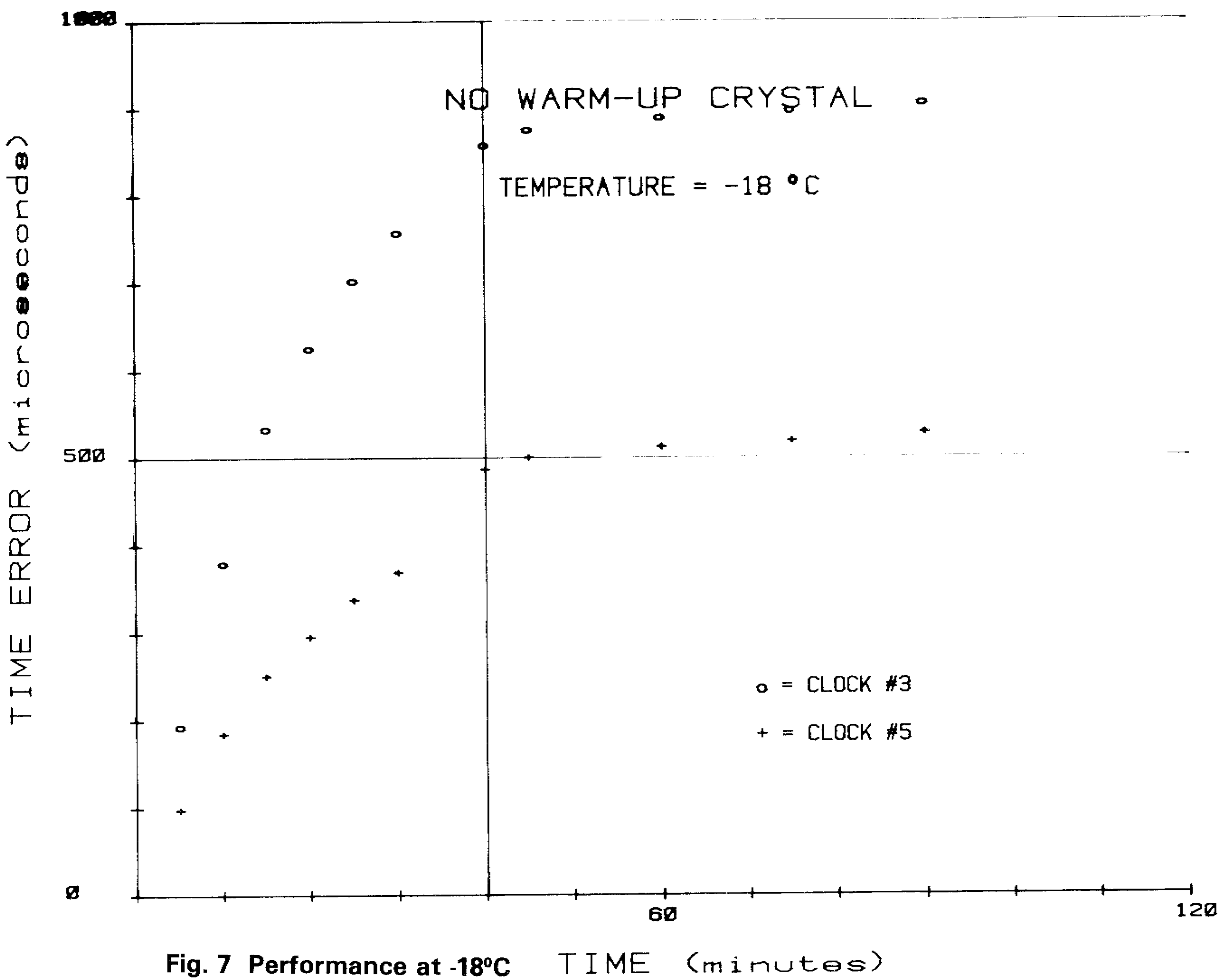



**Fig. 7 Performance at -18°C**

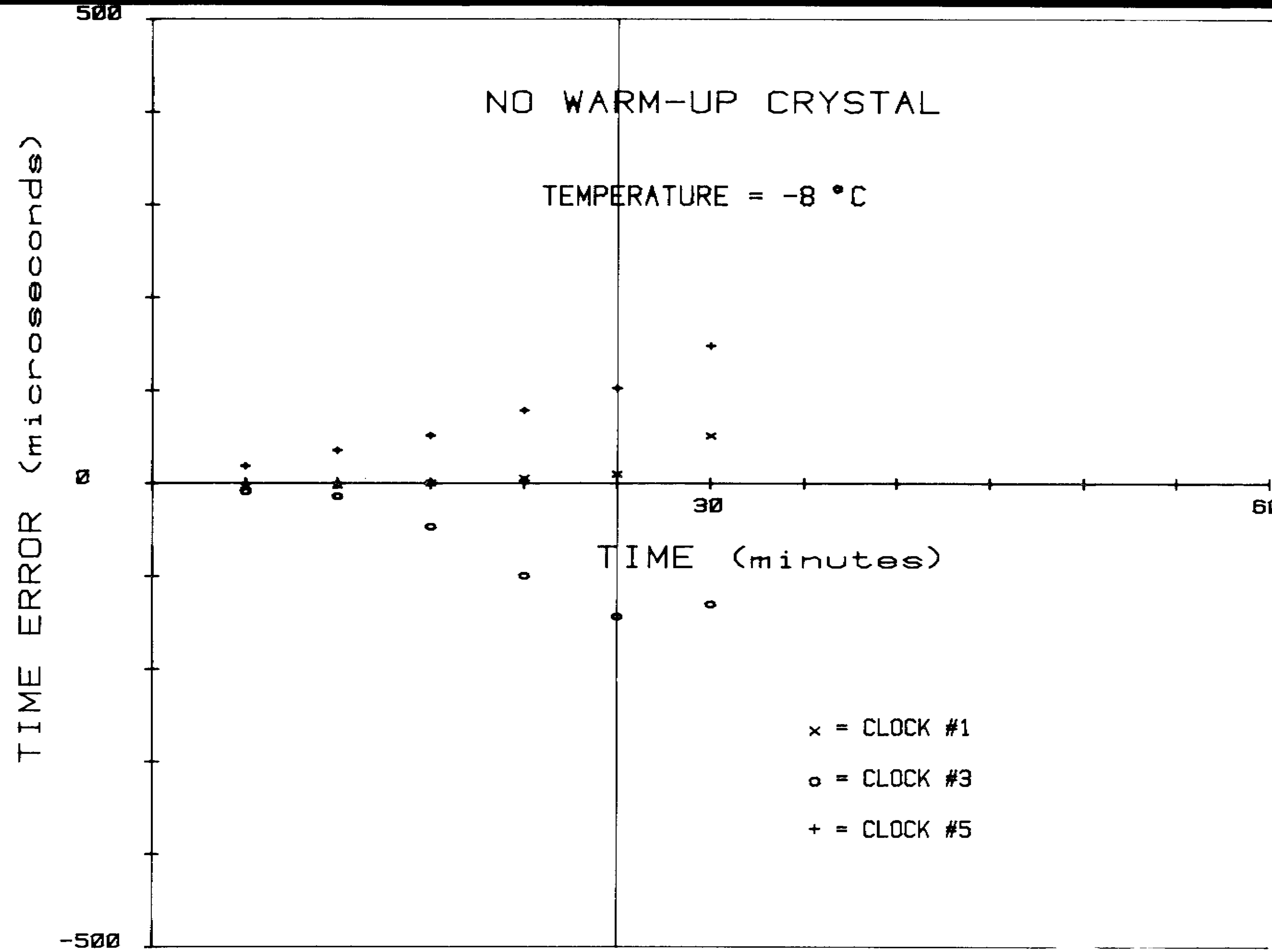



Fig. 8 Performance at - 8°C

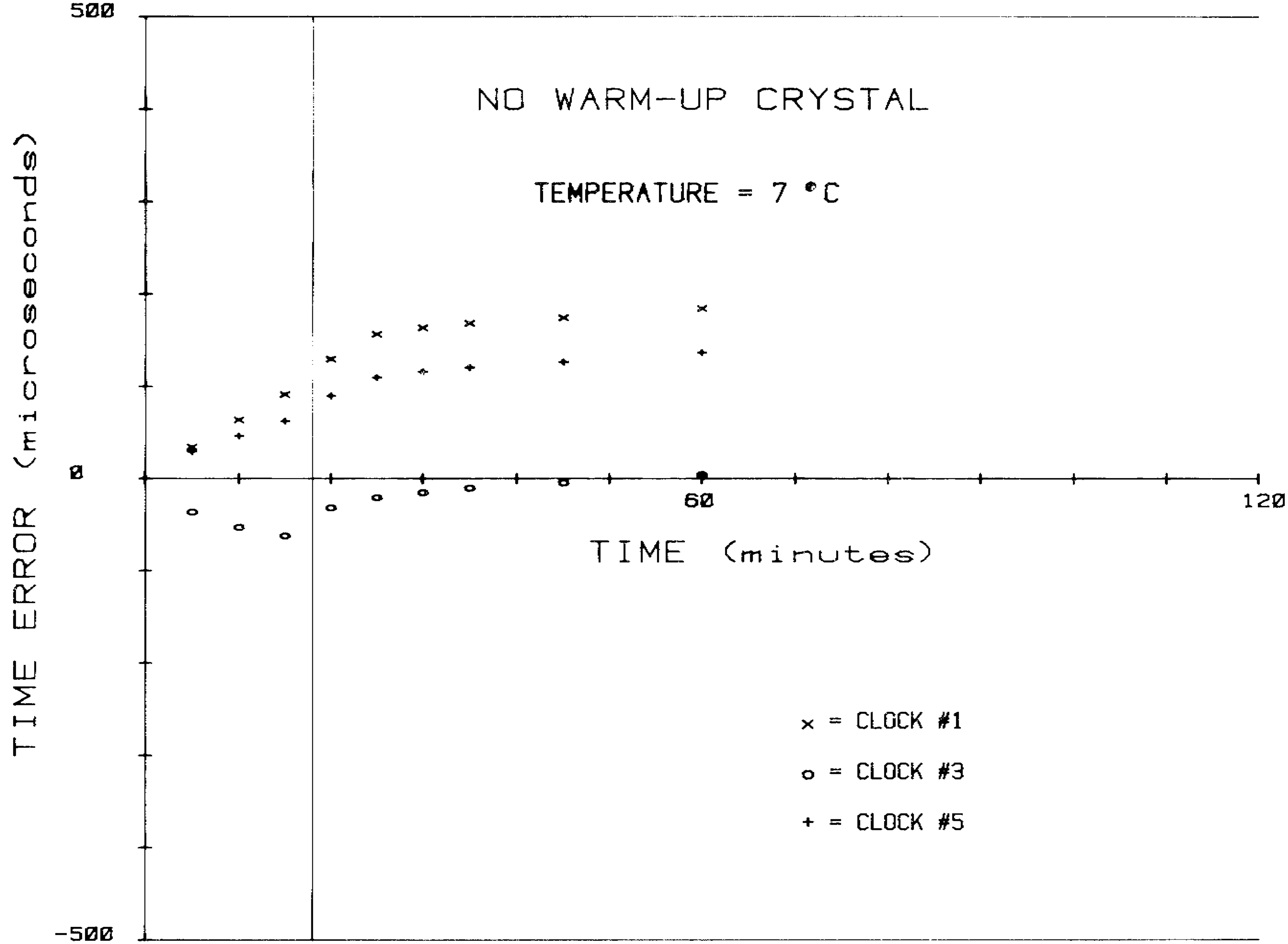



Fig. 9 Performance at 7°C

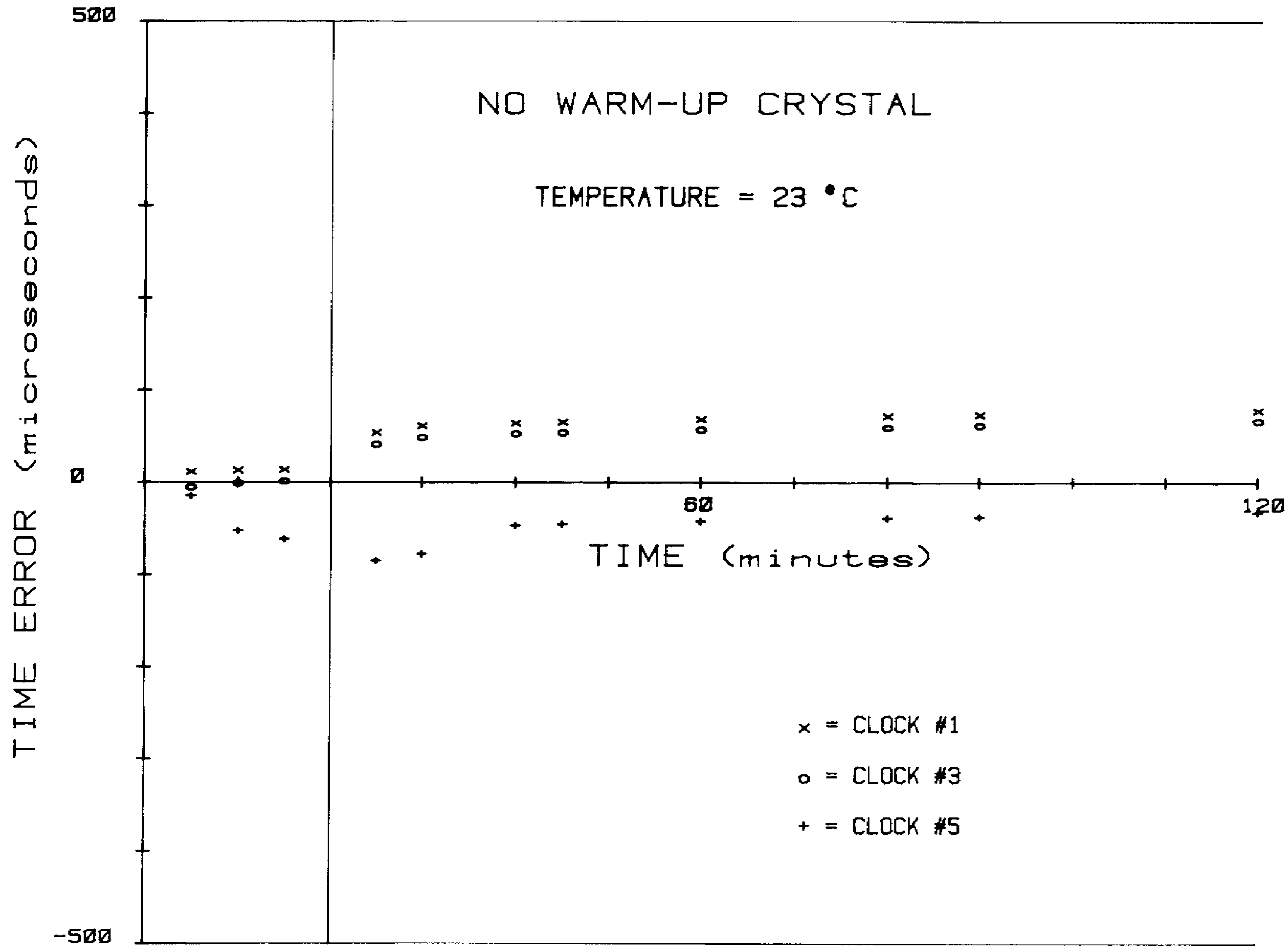



Fig. 10 Performance at 23°C

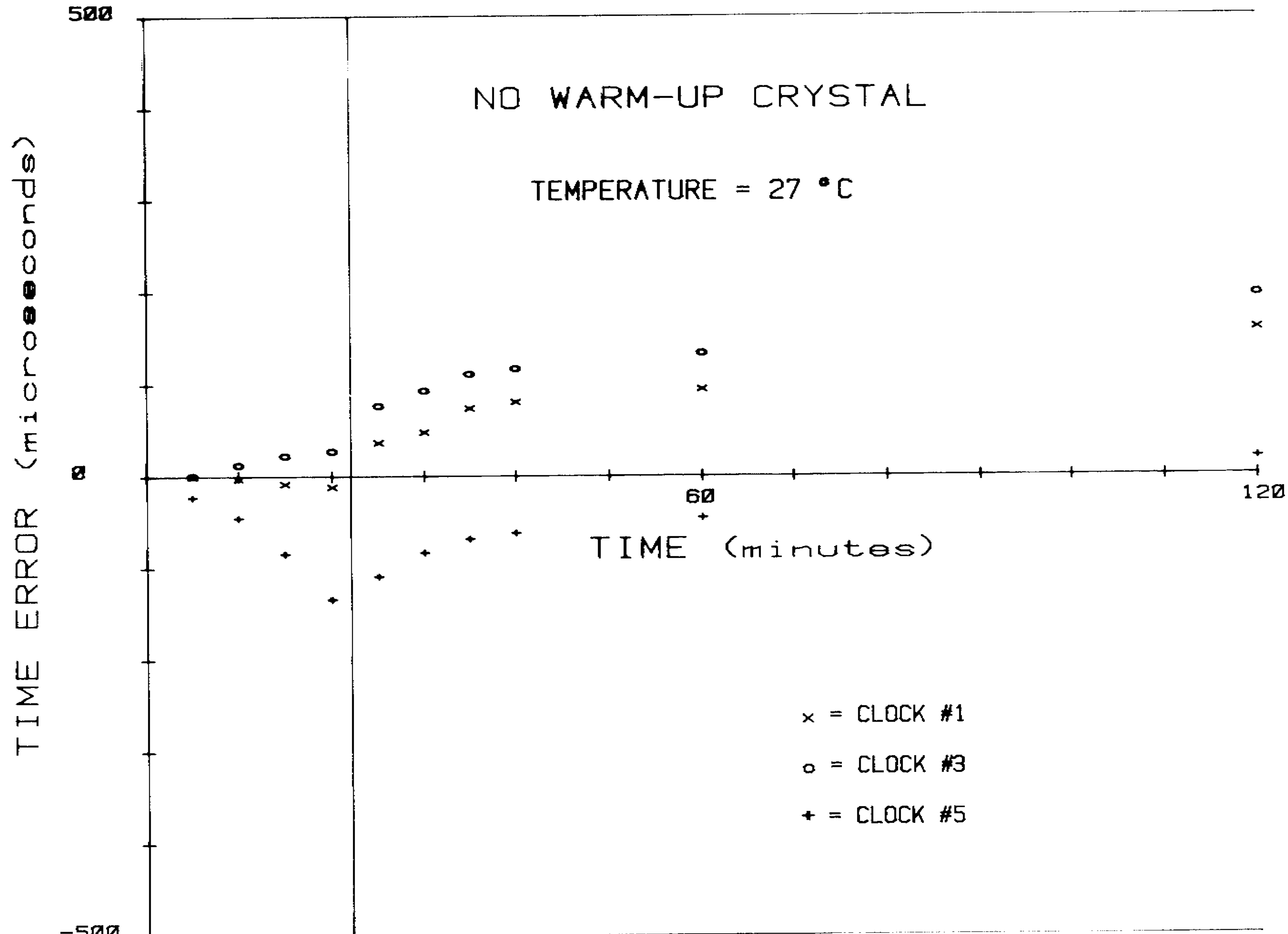



Fig. 11 Performance at 27°C

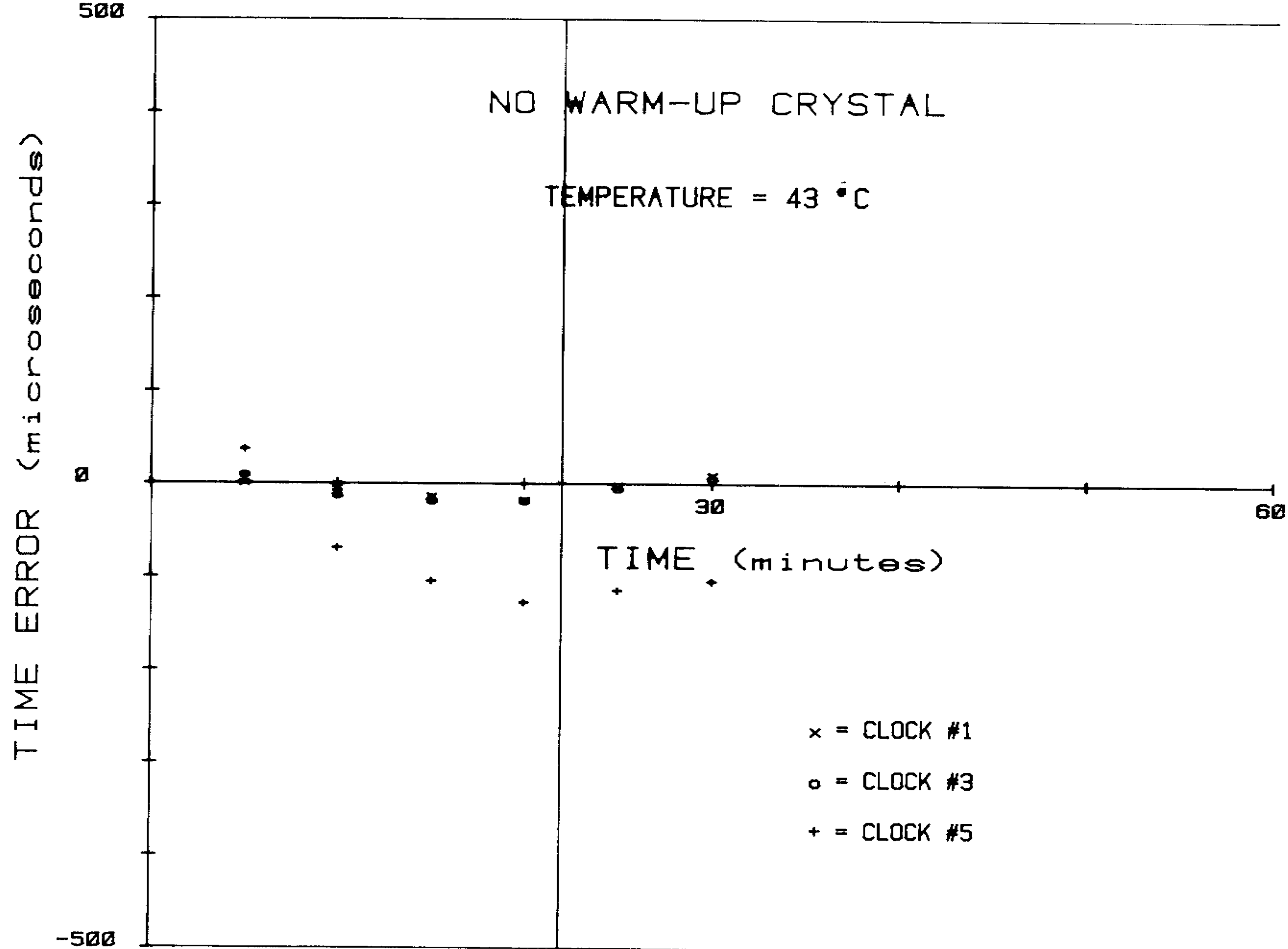



Fig. 12 Performance at 43°C

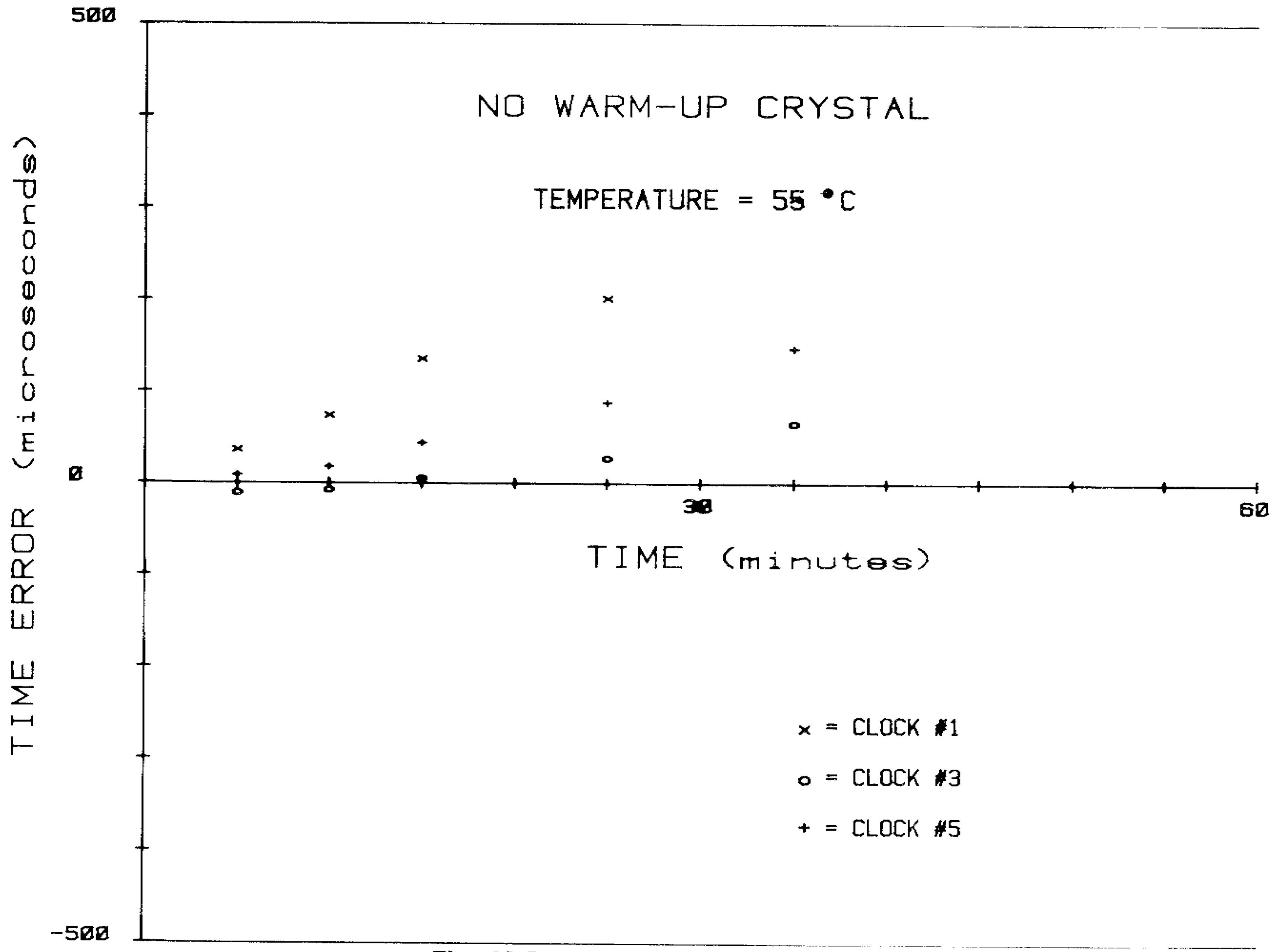



Fig. 13 Performance at 55°C

# PROCEEDINGS

# OF THE

# 33rd ANNUAL SYMPOSIUM ON FREQUENCY CONTROL

# 1979

PERFORMANCE RESULTS OF AN
OSCILLATOR USING THE SC CUT CRYSTAL

Robert Burgoon and Robert L. Wilson
Hewlett-Packard Company
Santa Clara, Ca.

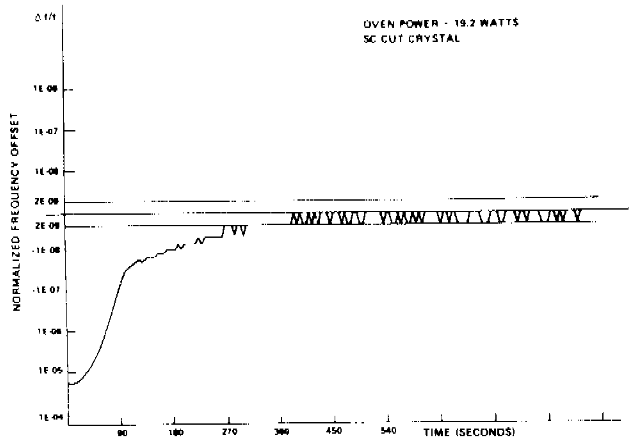



Figure 3. Oscillator Warmup for an HP 10544 Oscillator with an SC Cut Crystal

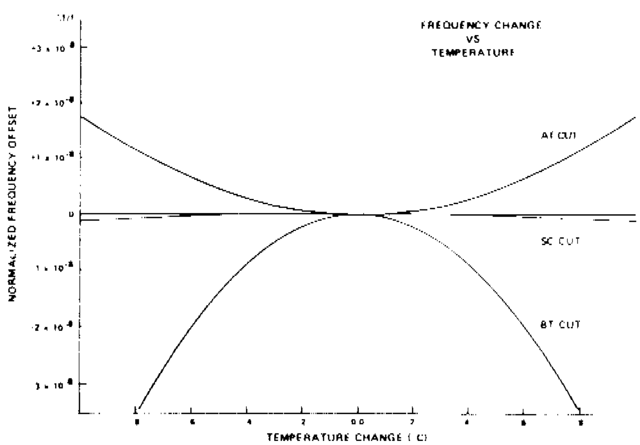
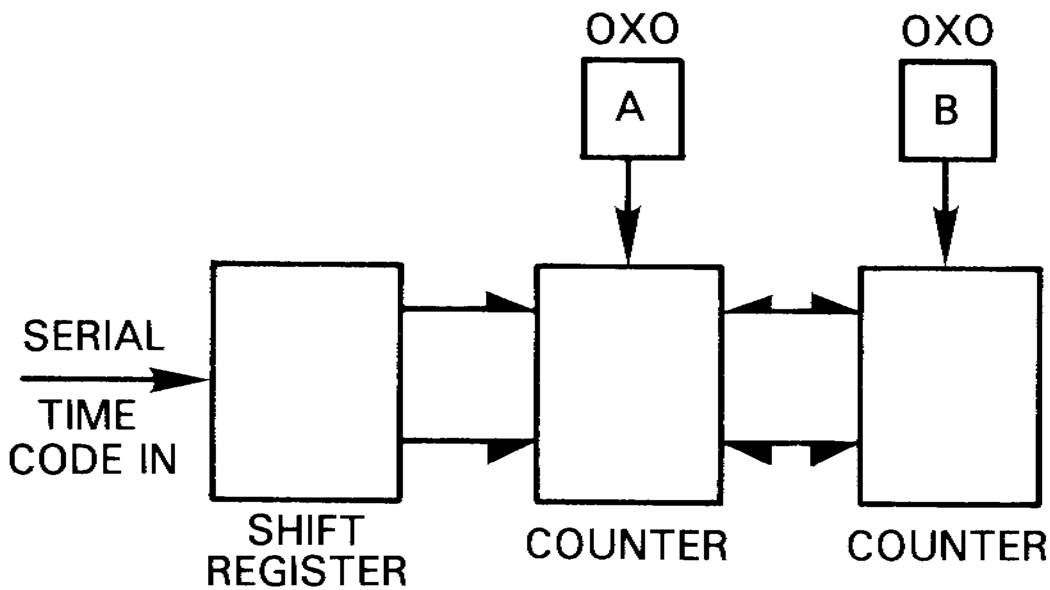



Figure 5. Crystal Temperature Performance Close to the Turnover Temperature

**Fig. 14 SC Cut Performance**

NO WARM UP CRYSTAL OSCILLATOR




OVEN CONTROLLED
OSCILLATOR SEQUENCE

1. OSCILLATOR A HOLDS TIME
   B WARMS UP
2. OSCILLATOR A WARM UP
   B HOLDS TIME
3. OSCILLATOR A HOLDS TIME
   B HOLDS TIME

**Fig. 15 Two OCXO Design**