LONG TERM AGING of OSCILLATORS

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ABSTRACT

A search performed in connection with a recent review of the literature on aging has revealed very few reports on the long term (e.g. for periods greater than 1 year) aging of oscillators. The purpose of this paper is to report aging results for more than 40 oscillators, from a variety of sources, for periods ranging from 1 year to more than 10 years.

The aging data were accumulated with an automated aging facility. The oscillators that have been on test include TCXO's and OCXOs. The TCXO's were maintained in a controlled temperature environment. Several of the TCXO's were built for a gun-launched sensor application and have been shown to be capable of surviving more than 30,000 g shock levels of 12 ms duration. The aging of these ruggedized TCXOs are surprisingly good (<2 x 10^{-10} per day). The better OCXOs exhibit long term aging of a few parts in 10^{12} per day.

INTRODUCTION

Aging is the systematic variation of frequency with time when all environmental parameters are held constant.[1] A search performed in connection with a recent review of the literature on aging[2] has revealed very few reports on the long term (e.g. for periods greater than 1 year) aging of oscillators. The purpose of this paper is to report representative aging results from tests on more than 40 oscillators, from a variety of sources, for periods ranging from 1 year to more than 10 years. (Since many of the commercial oscillators were purchased 10 or more years ago, the aging results reported below may not have much relevance to current capabilities.) Some of the oscillators were not well behaved, i.e., exhibited short-term instabilities much greater than the aging per day. Oscillators that were not well behaved initially did not improve upon extended aging. Only the aging of well behaved oscillators are shown in Figures 1 - 33.

The oscillators that have been on test include commercially available and prototype temperature compensated crystal oscillators (TCXO), commercially available ovenized crystal oscillators (OCXO) and prototype bulk-wave crystal resonators in specially built ovenized test oscillators.[3]

Data was collected while the TCXOs were maintained in a controlled temperature environment at +60° or at -40°C. The ovenized oscillators were in laboratory ambient where the internal thermal control circuit maintained a nominally constant temperature. In several instances, oscillators were subjected to extreme temperature changes, either a return to room temperature or an exposure to temperatures below -40°C. After the -40°C storage, the OCXOs were returned to room ambient before restarting.

The aging data were accumulated with an automated aging facility established in 1980.[4]

AGING GRAPHS

The aging graphs show aging behaviors and the effects of interruption and temperature change. On all of the aging graphs the ordinate is the reduced frequency, y, in units of parts per billion (ppb), where

$$y_k = \frac{\Delta f_k}{f_o} = \frac{f_k - f_o}{f_o},$$

f_o is the first frequency, measured (at time t_o), and the abscissa is the elapsed time from t_o.

On each graph there is a straight line included for reference. The slope and intercept of this straight line are determined from a least squares fit to all of the data between the days indicated. This straight line is not intended to indicate that the aging rate is constant but is included to facilitate comparison of aging behaviors.

LOGARITHMIC FIT

The function y = A ln(Bt +1) has been proposed as a candidate for extrapolation of the initial 30 days of aging data to periods in excess of 1 year.[2,5] For many oscillators, extrapolation of the log function obtained form fitting the first 30 days of data is a poor predictor of the subsequent aging. In general, for well behaved oscillators that are kept on continuously, curve fitting the data for a longer period results in a log function that may provide a better approximation to the actual long term aging. For example, as is shown in Figure 34 and in Table I, the log function obtained from the first 30 days of aging data is a poor predictor of the long term aging. The log function obtained from the initial 60 and 300 days provide better and better ability to predict the actual aging. Figure 35 shows an anomaly when the first 60 days is used although the 300 day fit is very good.

A review of the aging graphs will show that "non-logarithmic" behavior seems to be the norm not the exception. If the temperature changes or the power is interrupted, the situation is even worse. The parameters of the logarithmic aging model obtained from the first 30 days of data may be a good indicator of process control but are not very useful as a performance indicator during field use.

CONCLUSIONS

In conclusion, there were no major surprises in the data. The oscillators which started out good stayed good and the poor performers stayed poor. It is important to note that aging direction can reverse in time. This usually occurs early, but in one case it happened after 4.5 years. A logarithmic fit to the first 30 days is a poor indicator of long term performance especially with large environmental disturbances such as temperature changes. It is true, however, that the aging rate generally decreases with time, although for at least one case, it has been increasing for over eight years.

ACKNOWLEDGEMENTS

During the years of this project's existence, many of our colleagues contributed at one time or another. We thank P. Thompson for collecting the data on the high-shock TCXOs and for his work on the aging test oscillators, V. Rosati and J. Messina for TCXO aging measurements, J. Kosinski and R. Lindenmuth for OCXO and resonator aging measurements and software maintenance.

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2. J. R. Vig and T. R. Meeker, "The Aging of Bulk Acoustic Wave Resonators, Filters and Oscillators," Proc. 45th Annual Symposium on Frequency Control, pp. 77-101, 1991.

3. H. W. Jackson, "Update on the Tactical Miniature Crystal Oscillator Program," Proc. 36th Annual Symposium on Frequency Control, pp. 492-498, 1982.

4. R. L. Filler, et al., "Aging Studies on Quartz Crystal Resonators and Oscillators," Proc. 38th Annual Symposium on Frequency Control, pp. 225-231, 1984.

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Table I
Difference between predicted frequency and actual frequency for different curve fitting intervals

	1 - 30 days (ppb)	1 - 60 days (ppb)	1 - 300 days (ppb)
Oscillator A	-29	-22	+3
Oscillator B	-9	+16	-1

Figure 1. Brightline OCXO

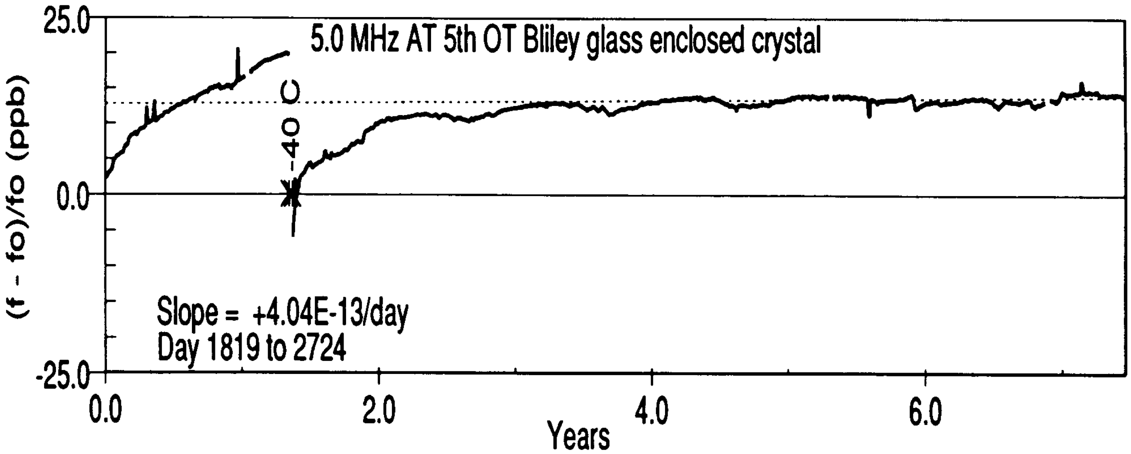


Figure 2. FTS OCXO

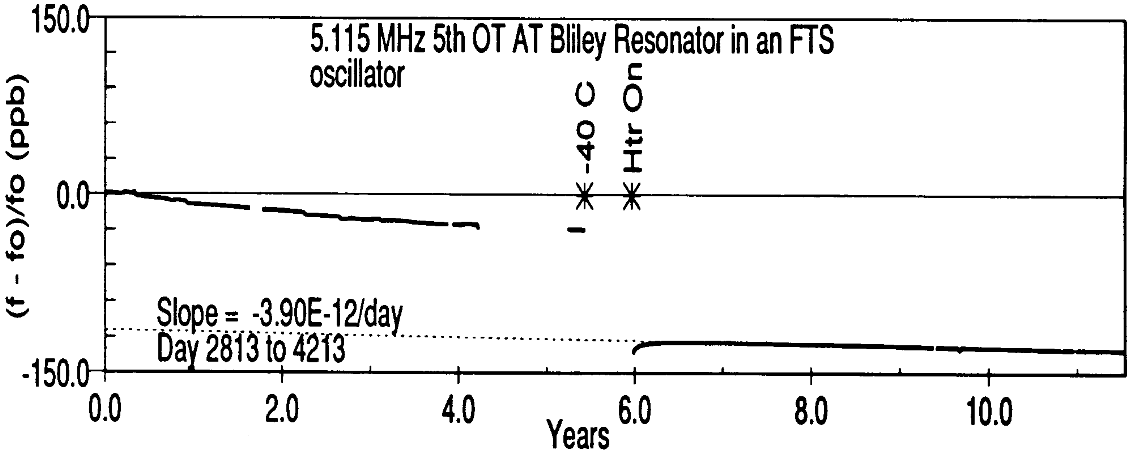


Figure 3. FTS OCXO

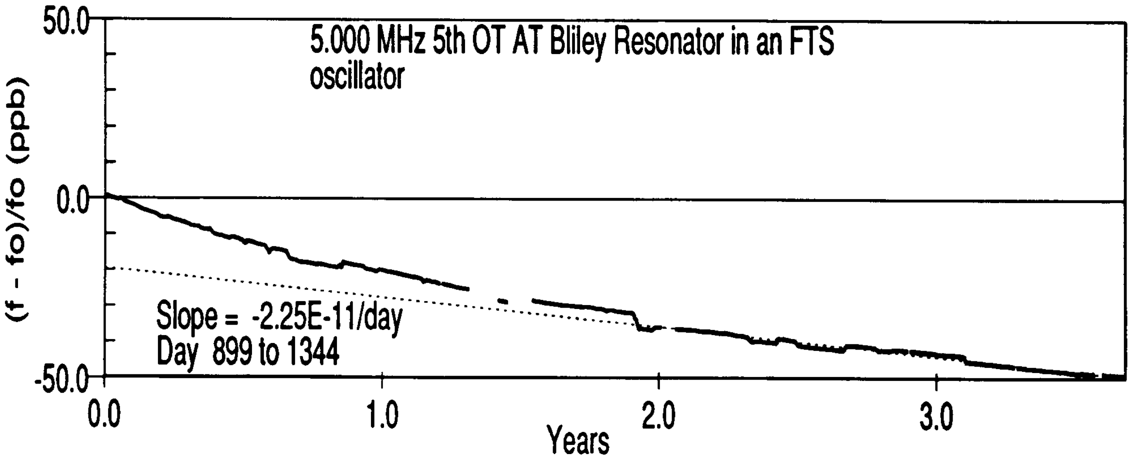


Figure 4. FEI 'MAXI' Resonator in a test OCXO

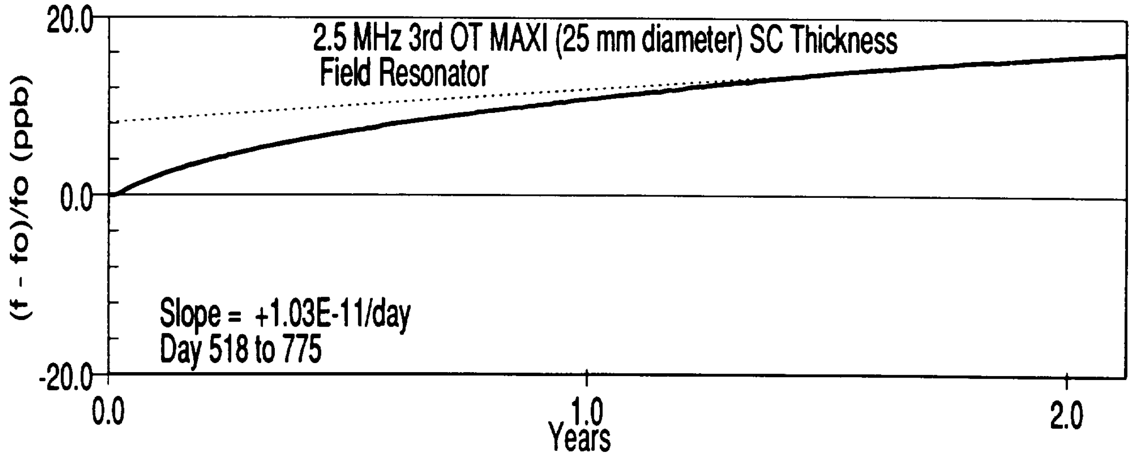


Figure 5. FEI 'MAXI' Resonator in a test OCXO

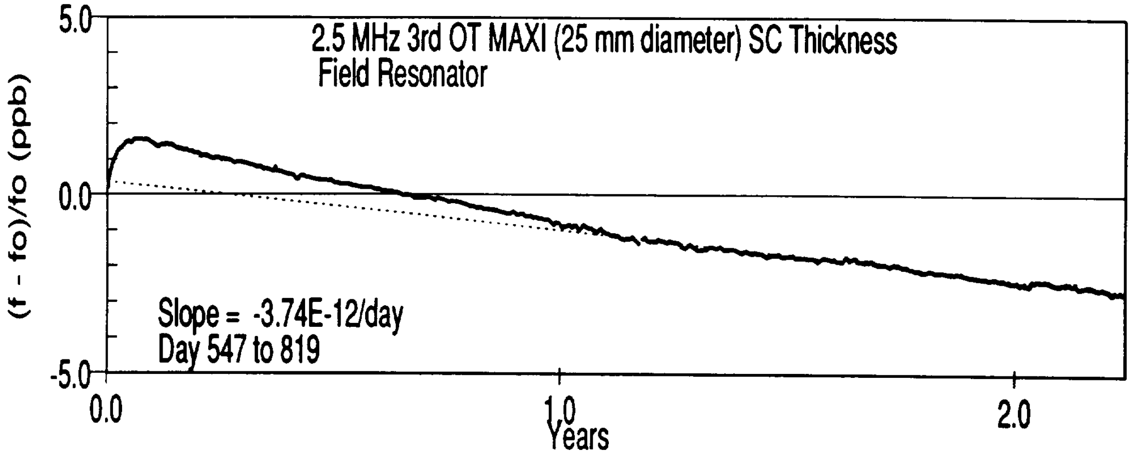


Figure 6. FEI Ceramic Flatpack with sapphire covers

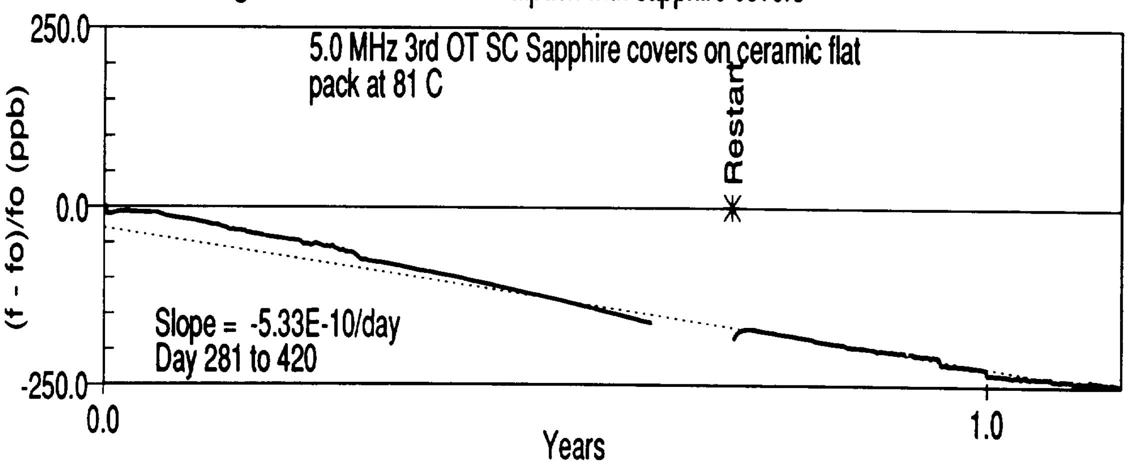


Figure 7. HP10811A OCXO

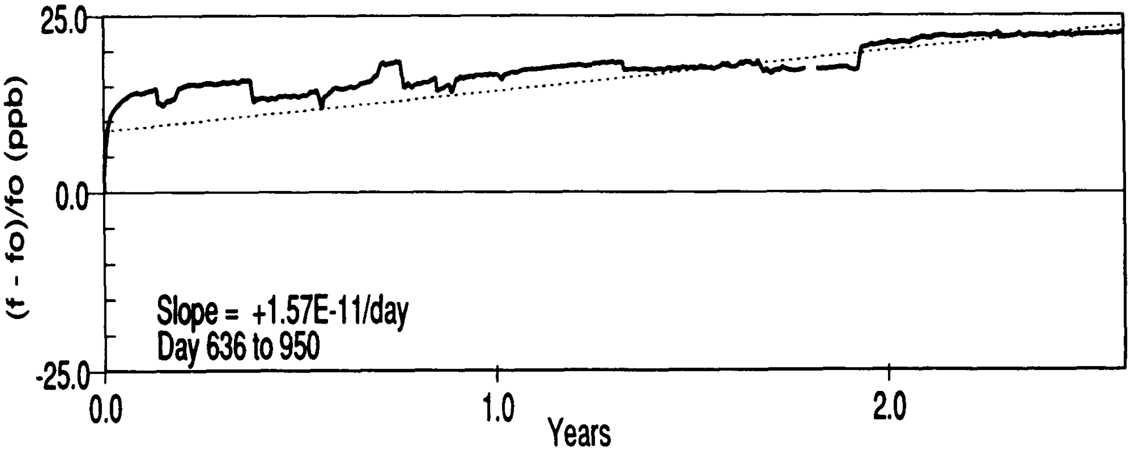


Figure 8. HP10811A OCXO

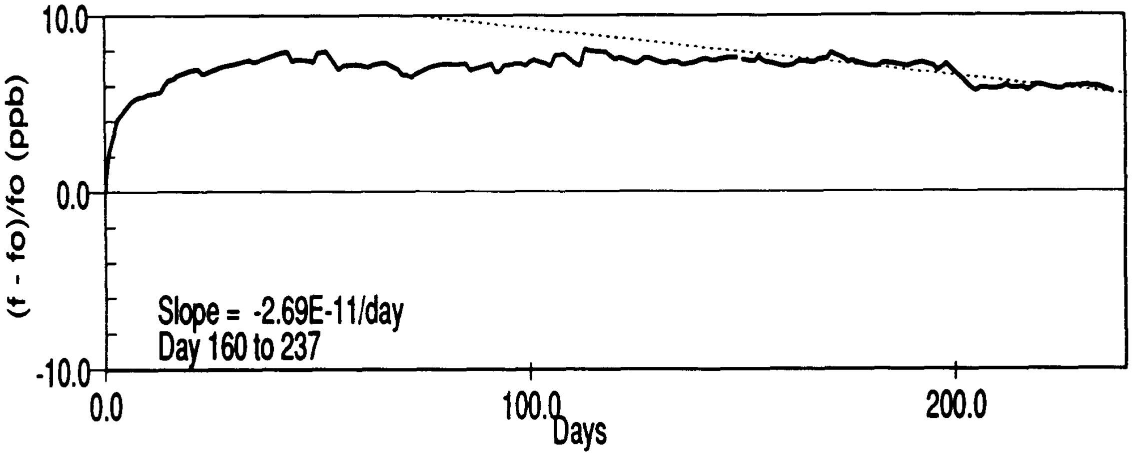


Figure 9. HP10811A OCXO

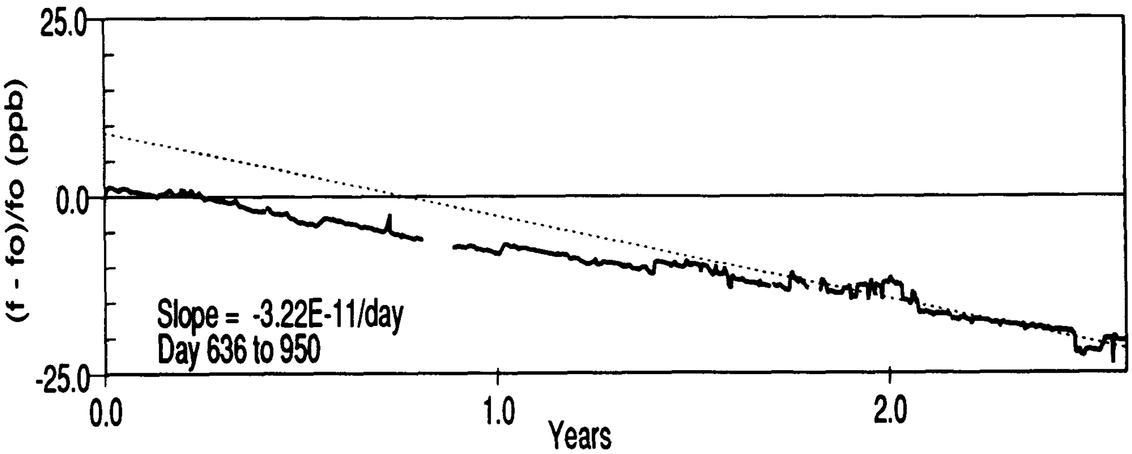


Figure 10. Piezo Crystal OCXO

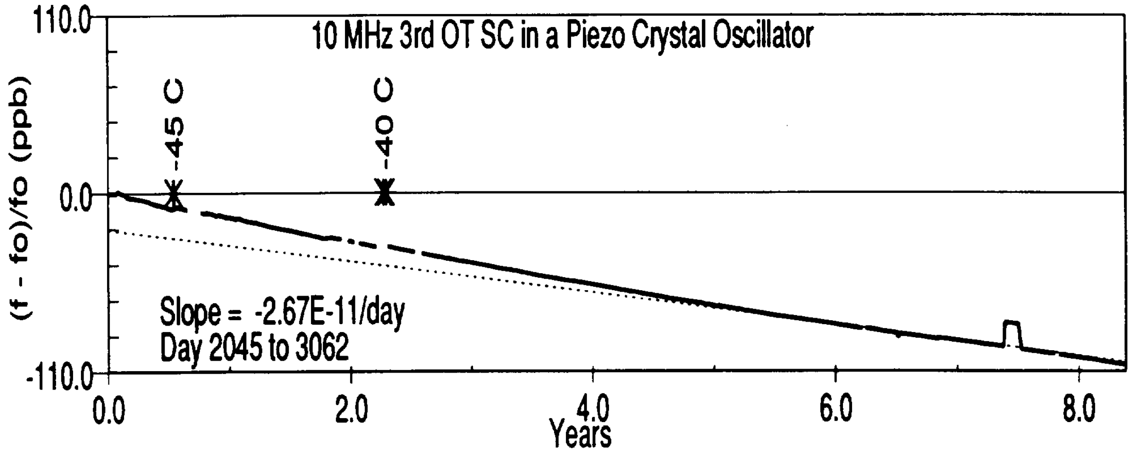


Figure 11. Piezo Crystal OCXO

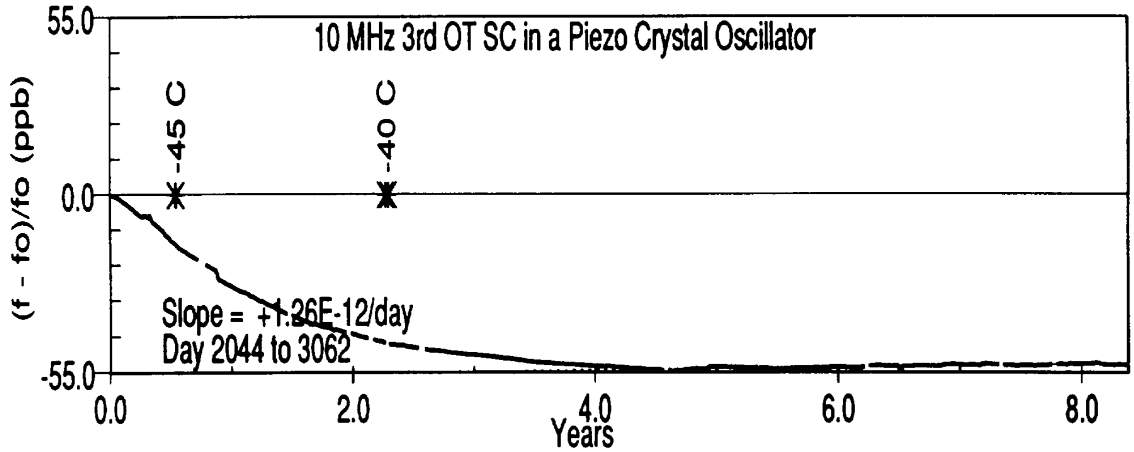


Figure 12. Piezo Crystal OCXO

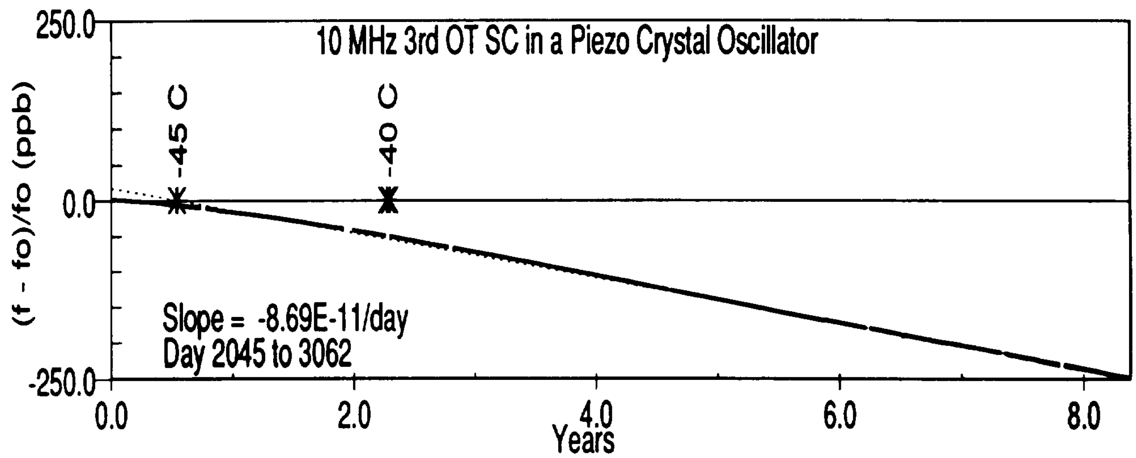


Figure 13. TMXO with Ceramic Flatpack Resonator

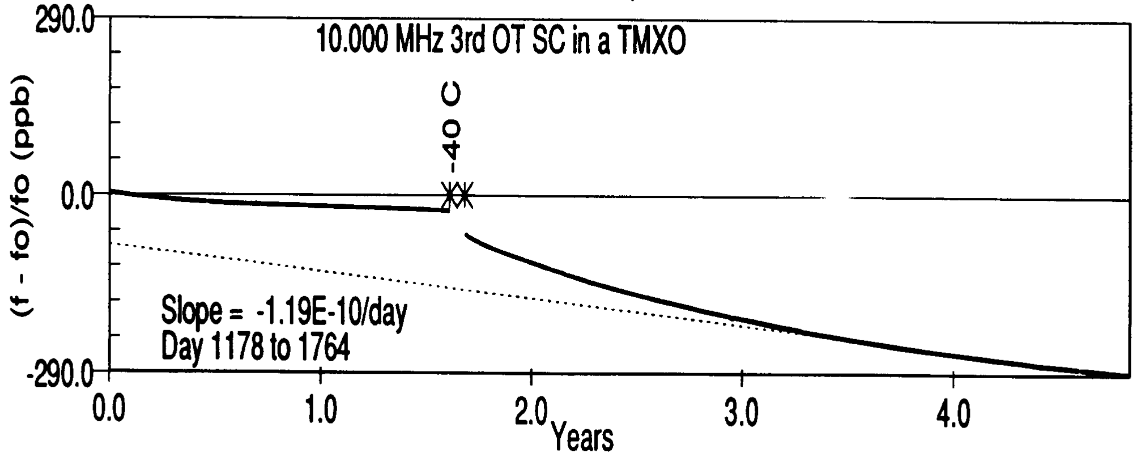


Figure 14. TMXO with Ceramic Flatpack Resonator

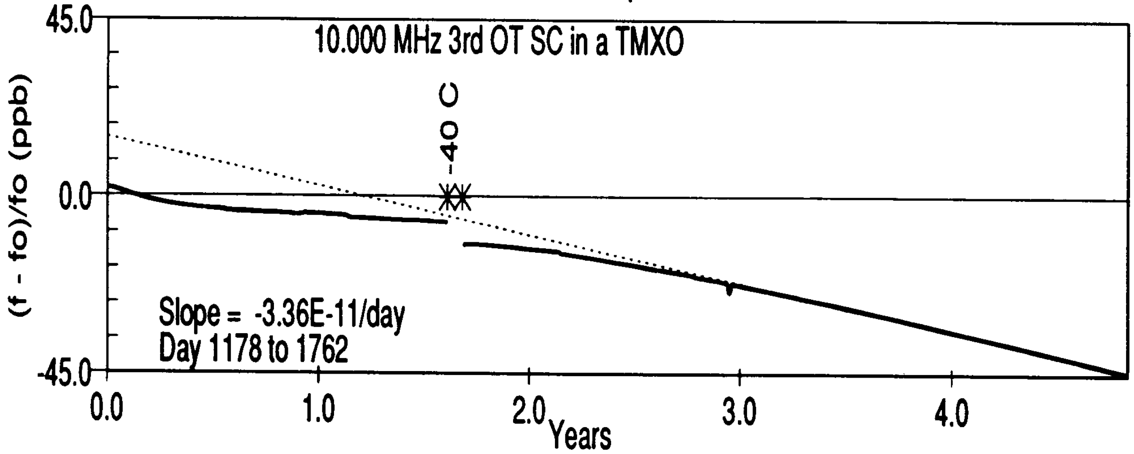


Figure 15. TMXO with Ceramic Flatpack Resonator

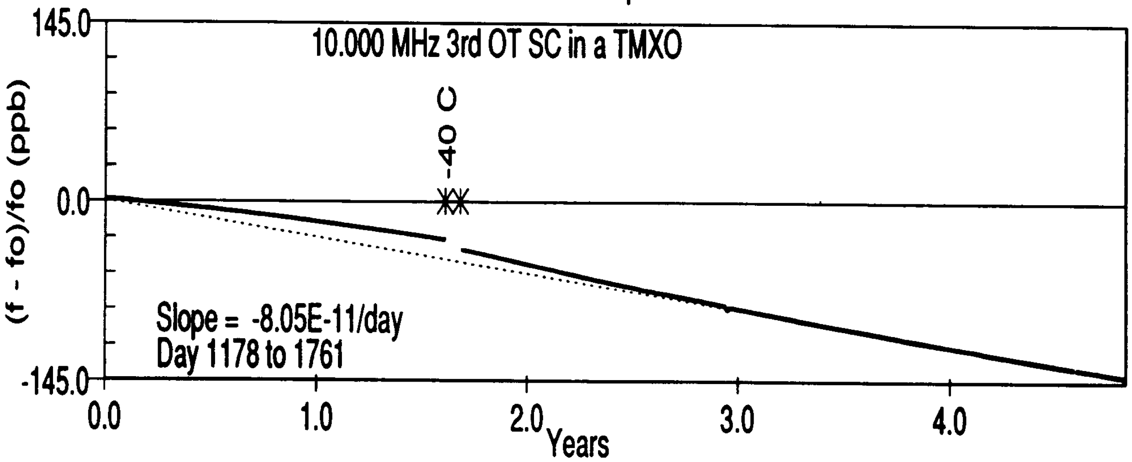


Figure 16. Shock Resistant Resonator in a TCXO

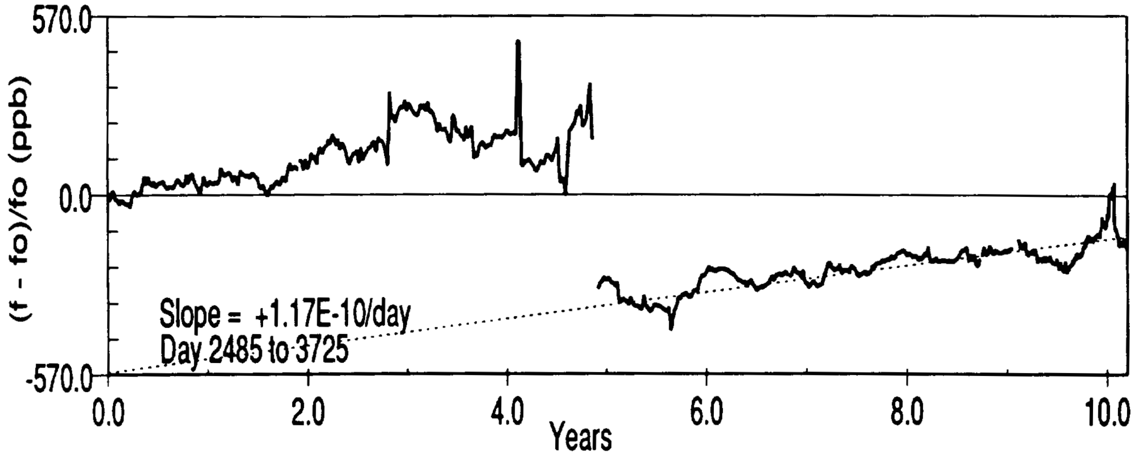


Figure 17. Shock Resistant Resonator in a TCXO

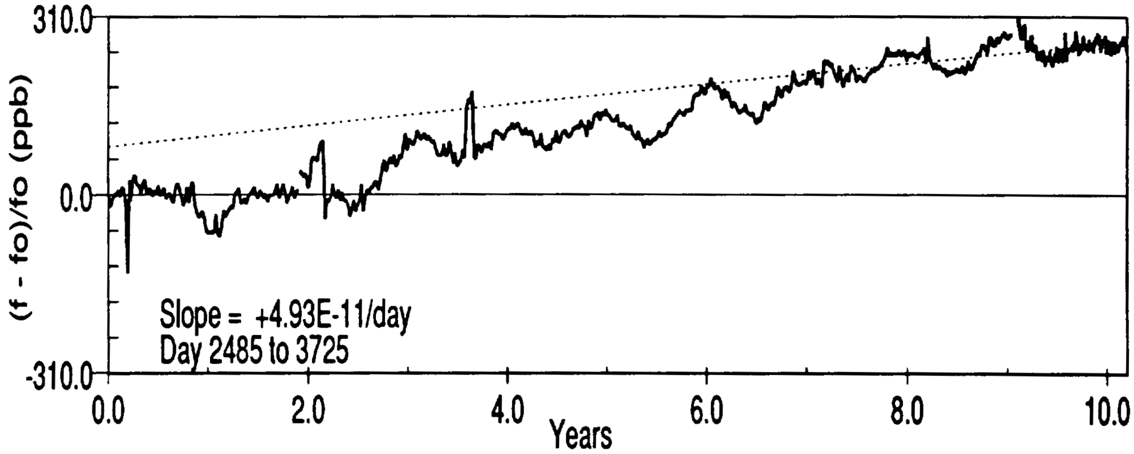


Figure 18. Shock Resistant Resonator in a TCXO

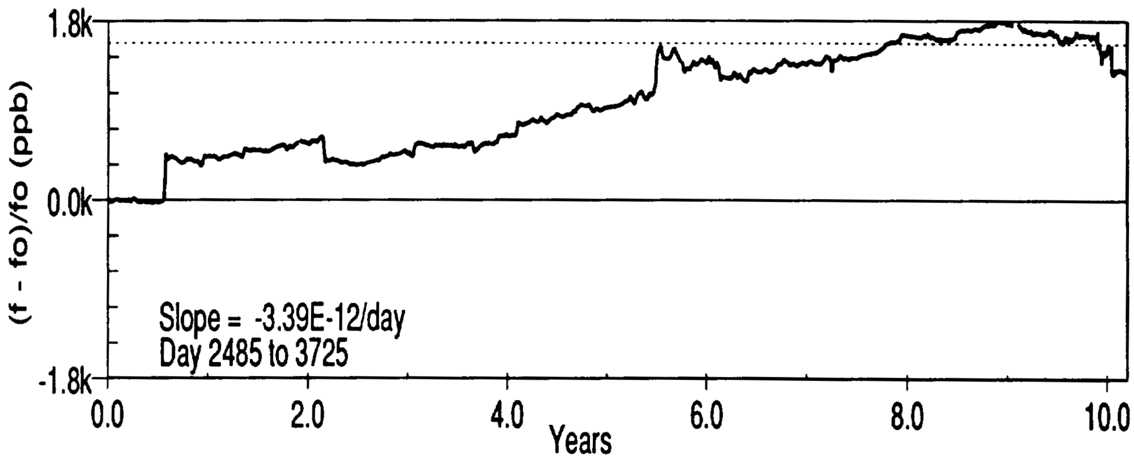


Figure 19. Shock Resistant Resonator in a TCXO

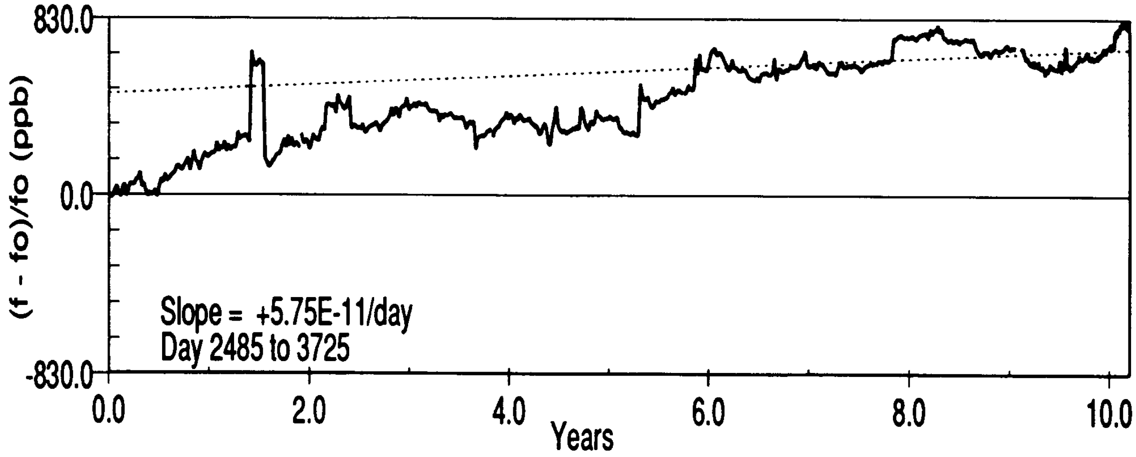


Figure 20. Shock Resistant Resonator in a TCXO

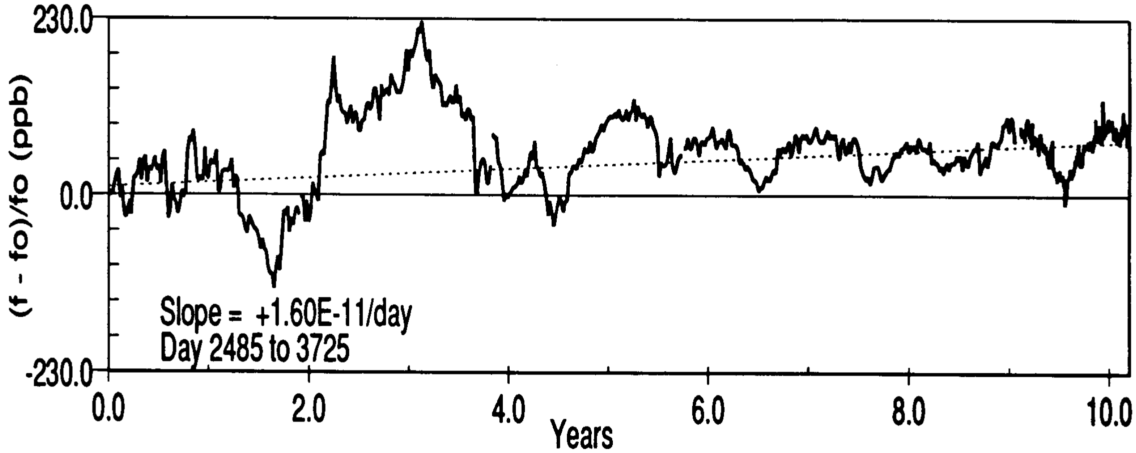


Figure 21. Shock Resistant Resonator in a TCXO

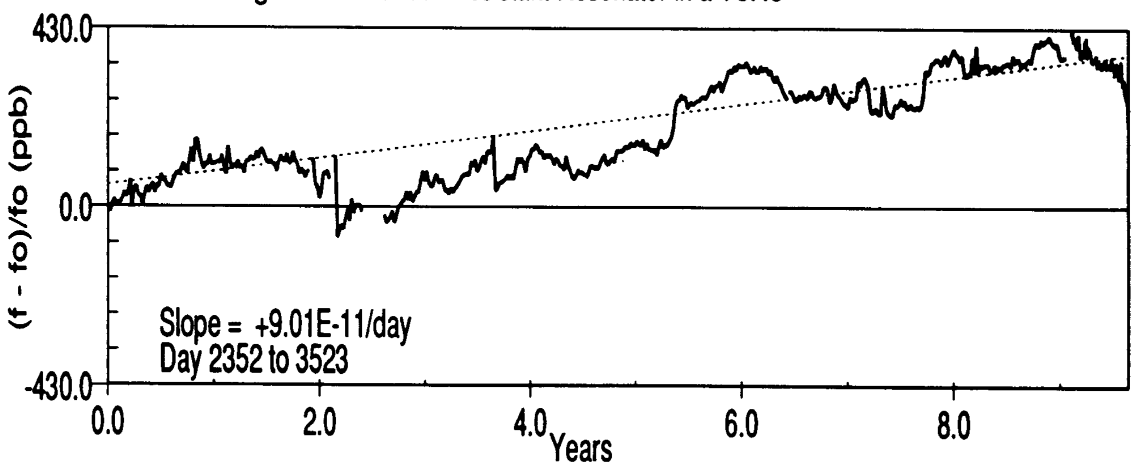
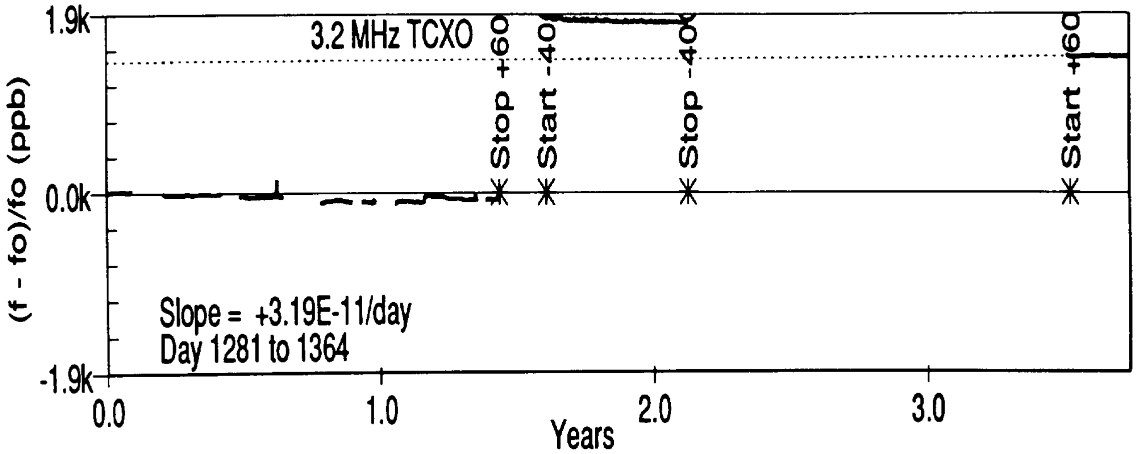


Figure 22. CTS TCXO



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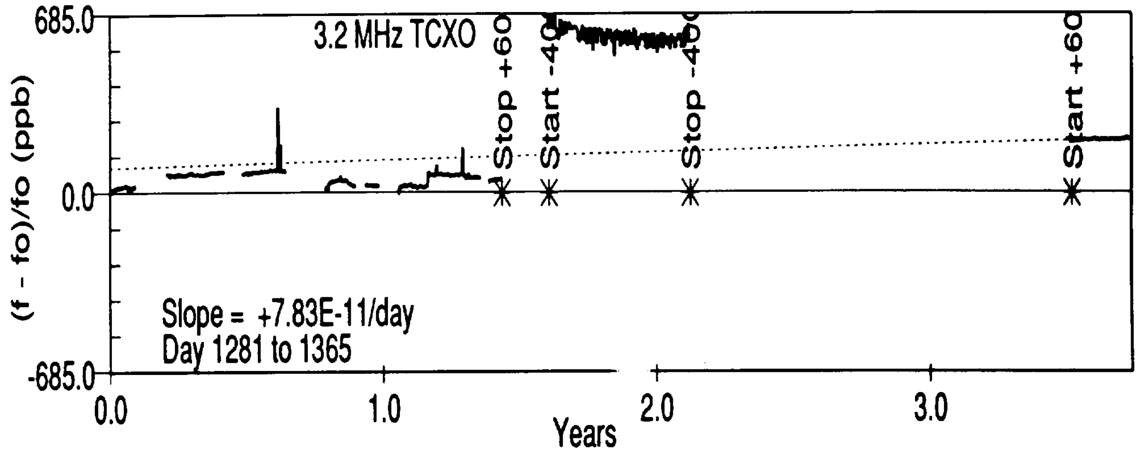


Figure 24. CTS TCXO

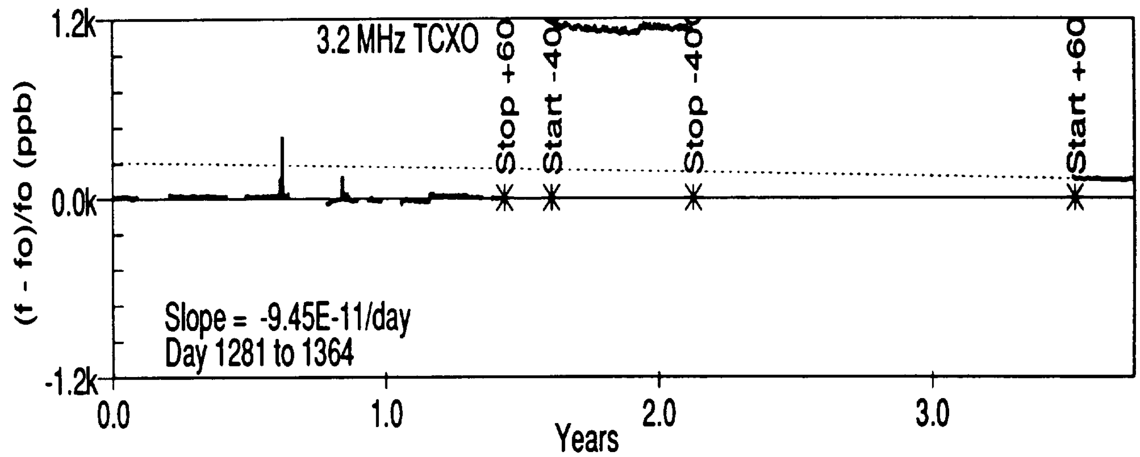
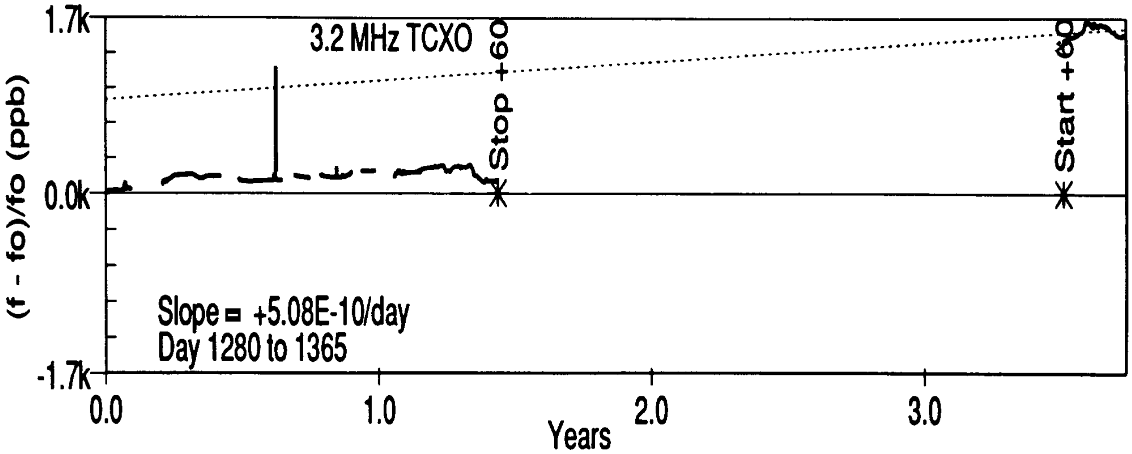


Figure 25. CINOX TCXO



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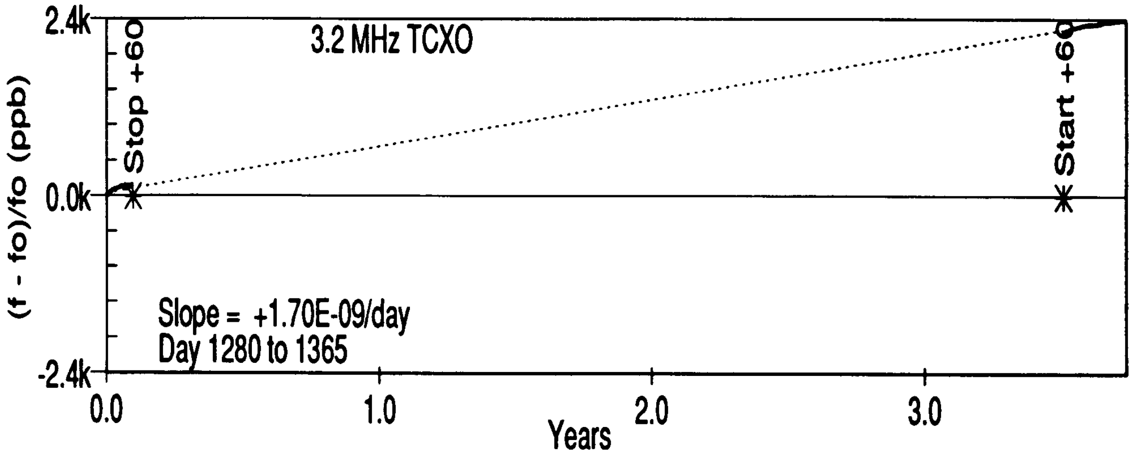

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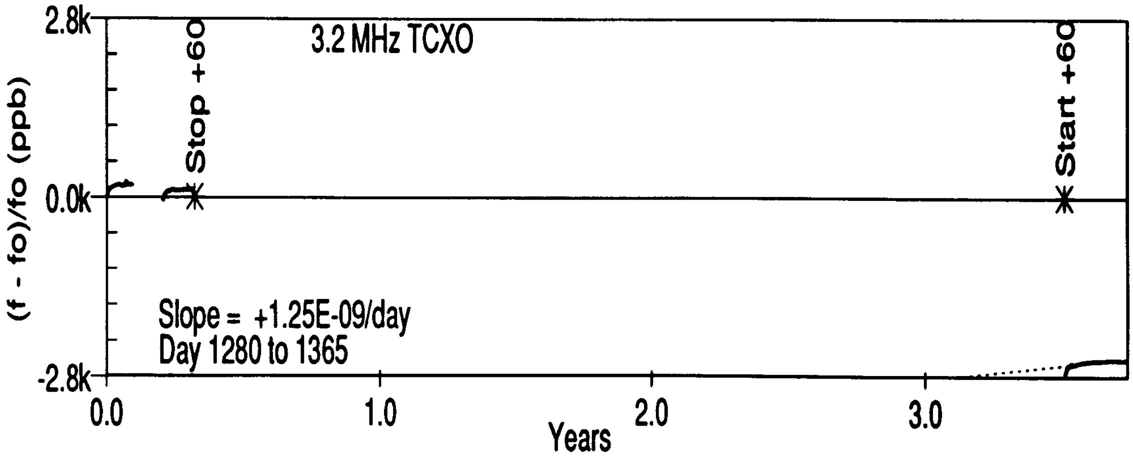


Figure 28. STC TCXO

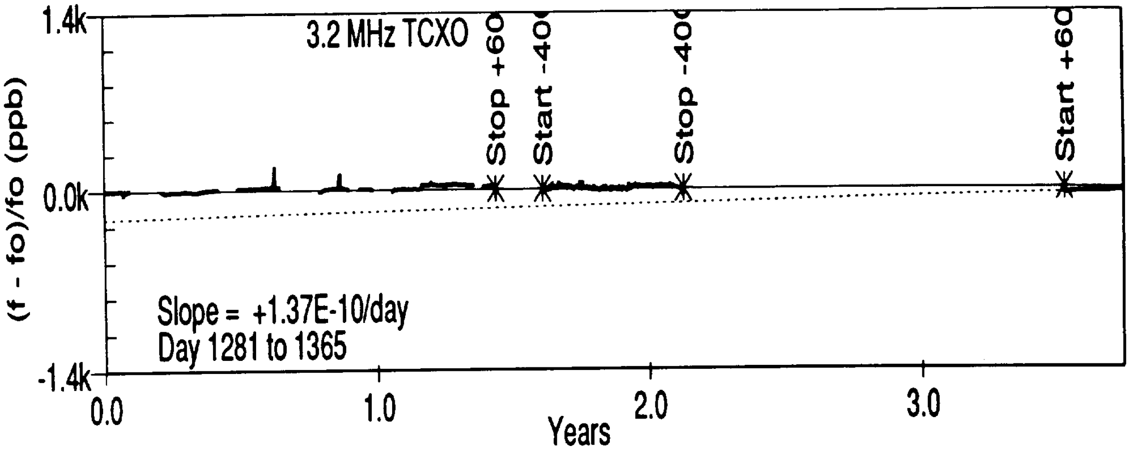


Figure 29. STC TCXO

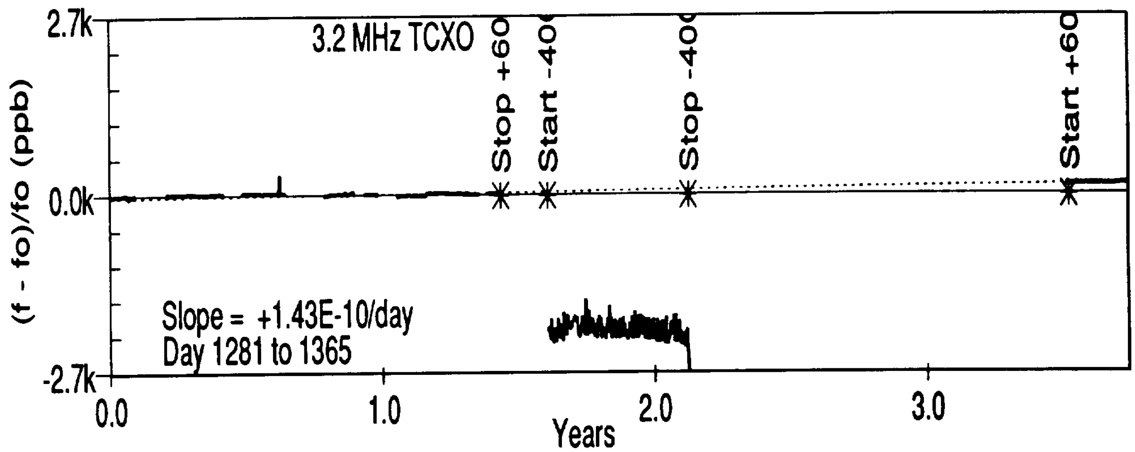


Figure 30. STC TCXO

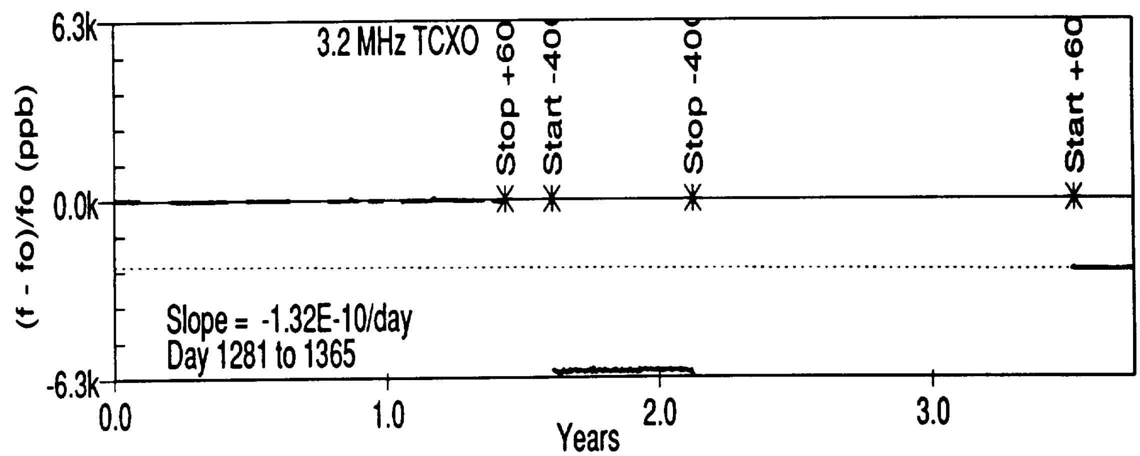
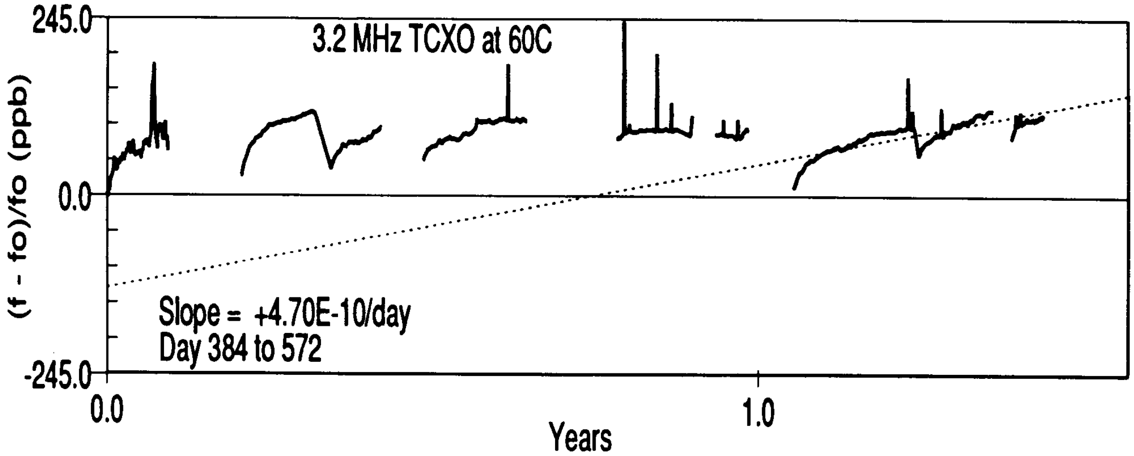


Figure 31. TFL TCXO



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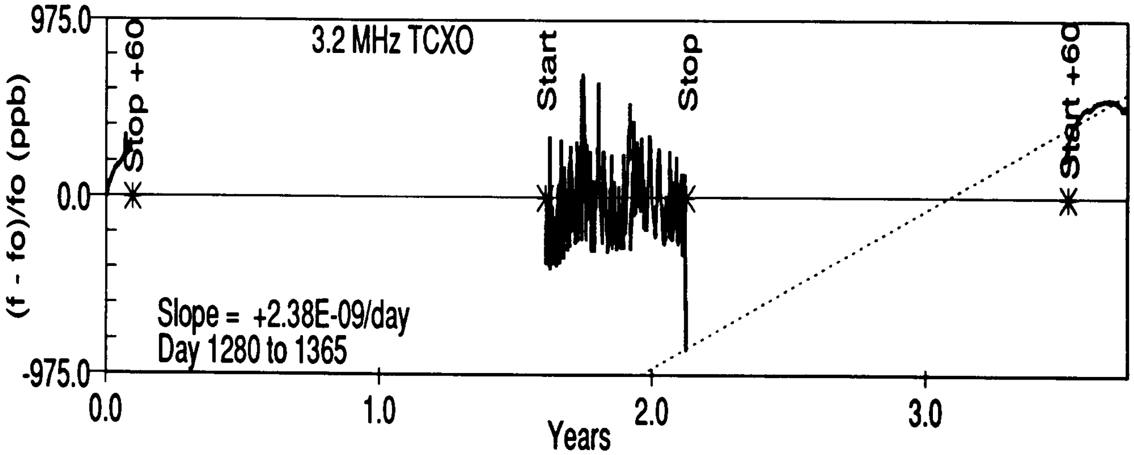

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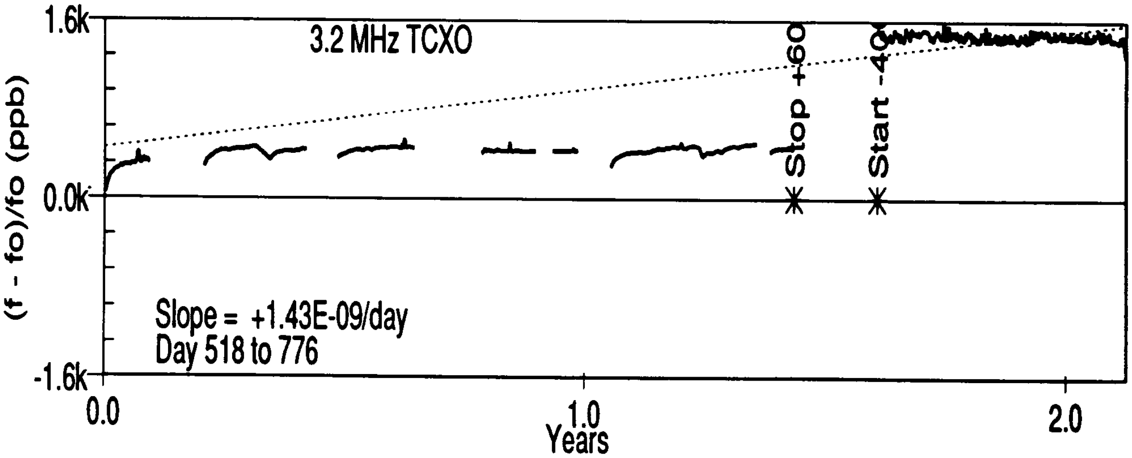

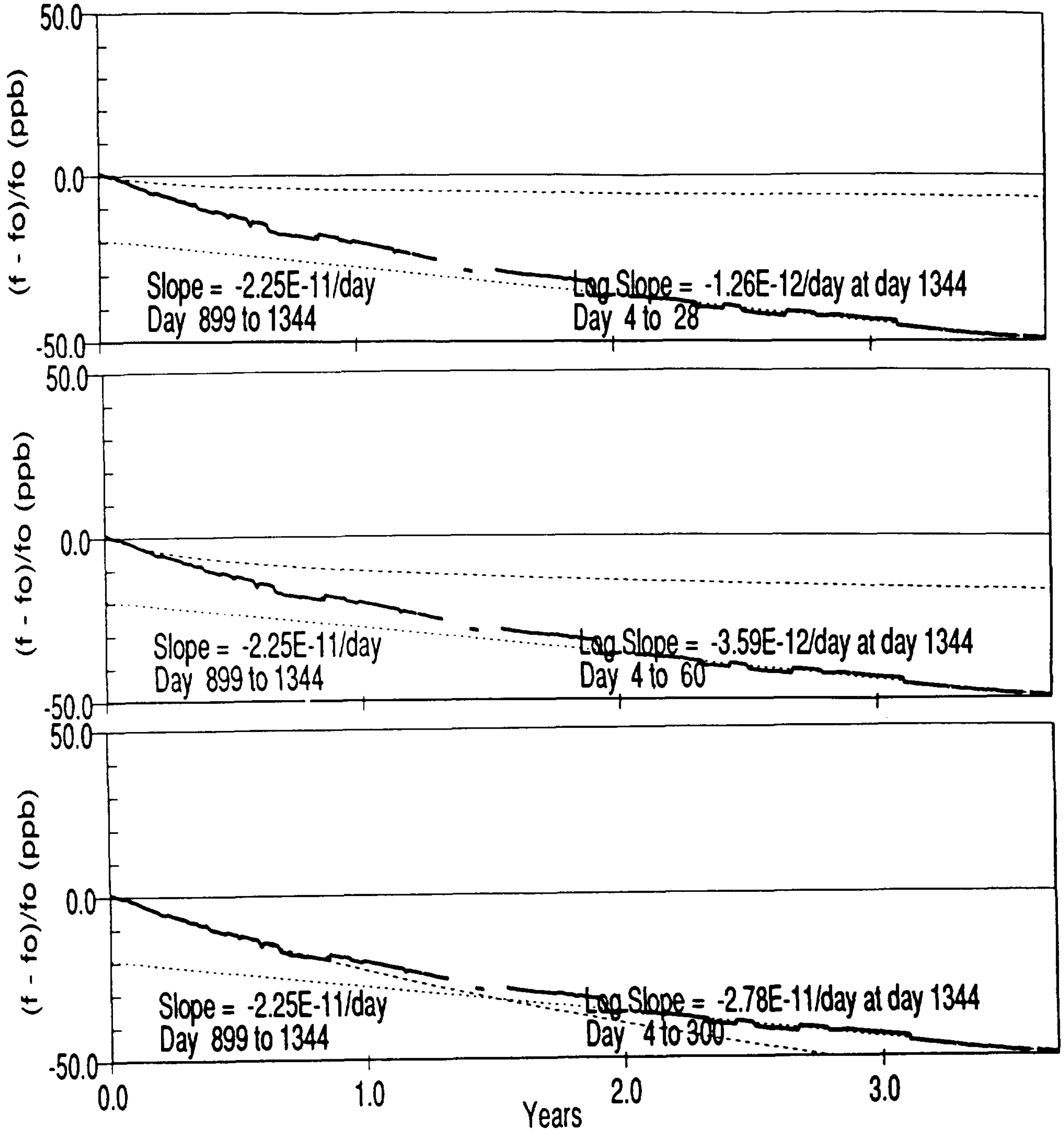

Figure 34. Oscillator A - Log fit using 30, 50 and 300 days of data .

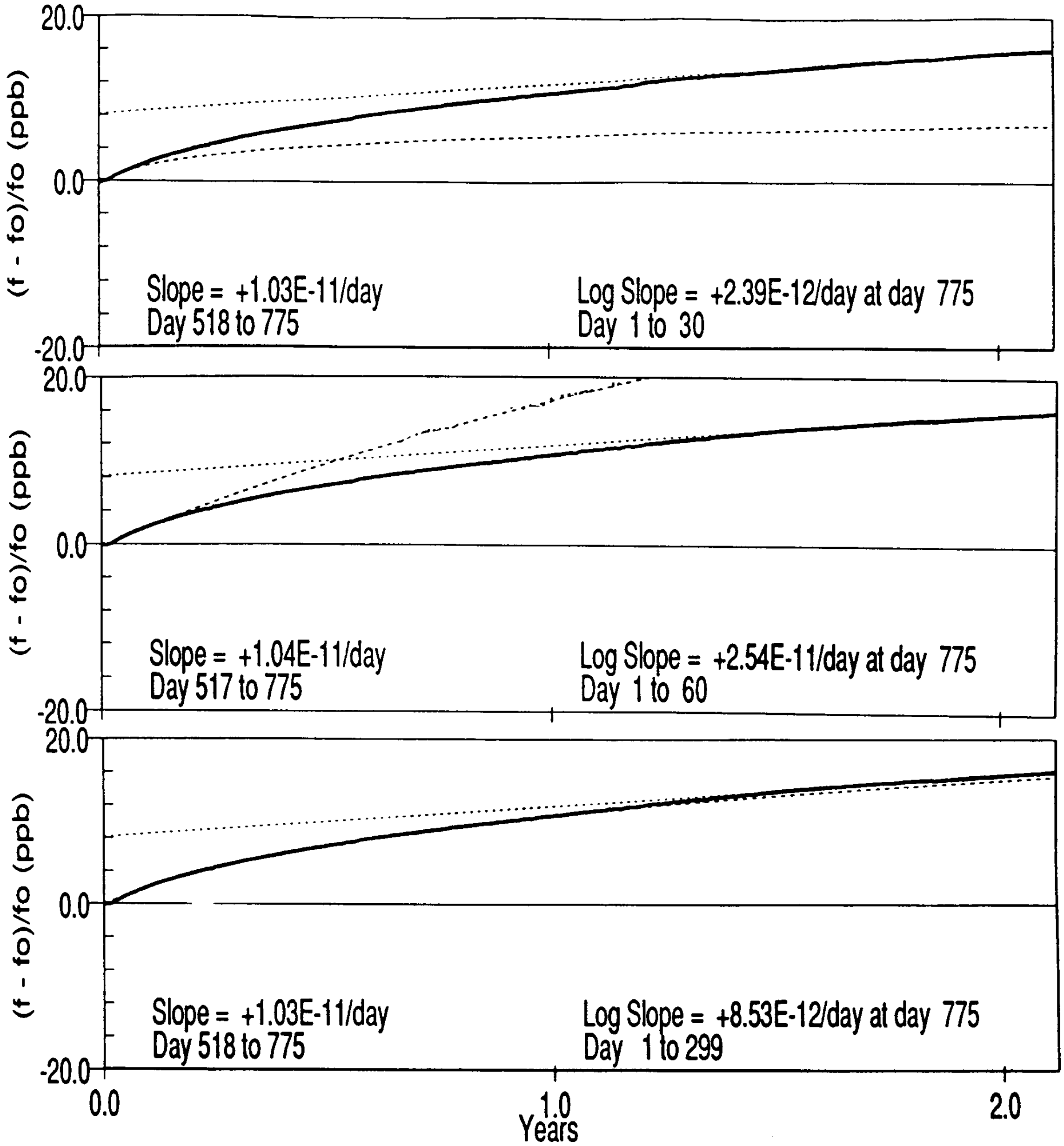

Figure 35. Oscillator B - Log fit using 30, 50 and 300 days of data.