# IMPROVEMENT IN THE CONTROL ASPECT OF LASER FREQUENCY STABILIZATION FOR SUNLITE PROJECT

ABSTRACT

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Flight Electronics Division of Langley Research Center is developing a spaceflight experiment called "Stanford University and NASA Laser In-Space Technology" (SUNILTE). The scientific objective of the project is to explore the fundamental limits on frequency stability using a FM laser locking technique on a Nd:YAG non-planer ring (free-running linewidth of 5 KHz) oscillator in the vibration free, microgravity environment of space. Compact and automated actively stabilized terahertz laser oscillators will operate in space with an expected linewidth of less than 3 Hz.

To implement and verify this experiment, NASA engineers have designed and built a state of the art, space qualified high speed data acquisition system for measuring the linewidth and stability limits of a laser oscillator [1]. In order to achieve greater stability and better performance, an active frequency control scheme requiring the use of a feedback control loop has been applied.

In the summer of 1991, the author had the opportunity to further investigate the application of control theory in active frequency control as a frequency stabilization technique. The results and findings were presented in 1992 American Control Conference in Chicago, and have been published in Conference Proceedings [2].

The main focus of this project was to seek further improvement in the overall performance of the system by replacing the analogue controller found in [2] by a digital algorithm.

## DIGITAL VERSUS ANALOGUE CONTROL

Replacement of the analogue controller Gc(S) , by a digital predictor/controller as shown in [2], is certainly an option, specially in the case of the SUNLITE project. Implementation of the control algorithm by the TMS320C30 microprocessor which is being used in the system for data acquisition and measurement purposes, is very much tempting. However, before attempting to design a new digital controller or to replace the existing analogue controller, which is a routine engineering job, it seemed appropriate to obtain an appreciation of the possible effects of the quantization.

It is obvious that the existing analogue controller provide continuous processing of the signal and can be used for very high bandwidth systems. It also gives almost infinite resolution of the signal it is measuring. On the negative side, like any other analogue device, it may suffer from component aging and temperature drift which is particularly important in the case of SUNLITE experiment.

Digital controllers on the other hand, sample the signal at discrete time intervals, this limits the bandwidth ( bandwidth is 1/6 to 1/10 sampling rate) that can be handled by the controller. The processing of the signal takes a finite amount of time, adding to phase delay in the system. In addition, the resolution of the signal is limited by the resolution or wordlength of the processor which brings us to the well known quantization problem. Therefor a thorough analysis of finite arithmetic has been conducted to ensure that system performance will not be degraded.
However, it must be reminded that in almost every control application, the inability to place controller poles with perfect precision, due to finite word length of the computer used for implementation, is quite insignificant in the overall design.

In an effort to determine the impact of noise due to quantization,

$$SNR_Q=10\log_{10}\left(\frac{\sigma_x^2}{\sigma_e^2}\right)$$

the following definition of signal-to-quantization ratio is used It has been shown in [3], that it is directly related to k the AGC constant and b.

$$SNR_Q=10\log SUB10\frac{1}{k^2\sigma_e^2}=6b+10.8-20\log_{10}k$$

$$SNR_Q\approx 6b-20dB$$

**In the case of SUNLITE project assuming a 24 bit ADC, and k = 10, the $SNR_Q$ = 118dB . This indicates that the quantization noise power is approximately 118dB below the signal and background noise power. Therefore, the noise added by the ADC can be considered negligible.** Based on that conclusion, the algorithm for the PID digital controller has been written and will be implemented. For details of the algorithm please see the Appendix. As an alternative, the transfer function of existing analogue compensator has been transformed in to digital, using bilinear (Tustin) transformation method. I it the authors hope that after trying both options the best be used.

**REFERENCES**

**1. SUNLITE project Preliminary Design Review, Electronic Branch, Flight Electronics Division, LaRC, NASA, 1990**

**2. O. Zia "On the Control Aspect of Laser Frequency Stabilization" Proceedings of 1992 ACC conference. Chicago , Il.**

**3.David J. Defatta " Digital Signal Processing" 1988, John Wiley.**

Appendix A

DIGITAL PREDICTOR CONTROLLER DESIGN

$$e_m(t)=K_p e_1(t)+K_i\int e_1(t)\,dt+K_d\frac{de_1(t)}{dt}\ldots\ldots\ldots(1)$$

$$e_2(nT)=K_p e_1(nT)+K_i\sum_{k=1}^{n}e_1(kT)\,\frac{K_d}{T}[e_1(nT)-e_1((n-1)T)]\ldots\ldots\ldots\ldots\ldots(2)$$

Where T is the sampling time, $K_p$ , $K_i$ , and $K_d$ are the proportional, integral and differential coefficients of the controller.

$$e_1(nT)=e_1((n-T)+[e_1((n-1)T-e_1((n-T))]\ldots\ldots\ldots\ldots(3)$$

$$e_2(nT)=K_p[2e_1((n-1)T)-((n-T)+K_iT[\sum_{k=1}^{n-1}e_1(k)+2e_1((n-1)T)-e_1((n-2)T)]+\frac{K_d}{T}[e_1((n-1)T$$

$$e_2(nT)=[2K_p+2K_iT+\frac{K_d}{T}]e_1((n-1)T)-[K_p+K_iT+\frac{K_d}{T}]e_1((n-2)T)+[K_iT]e_s((n-1)T)$$

$$e_s((n-1)T)=\sum_{k=1}^{n-1}e_1(k)T\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$e_s((n-1)T)=e_s((n-2)T)+e_1(n-1)T)\ldots\ldots\ldots(7)$$

$$e_2(nT)=k_1e_1((n-1)T+K_2e_1((n-2)T)+K_3e_s((n-1)T)\ldots\ldots\ldots\ldots(8)$$

$$K_1=2K_p+2K_i+\frac{K_d}{T}$$

$$K_2=-K_pK_i-\frac{K_d}{T},K_3=K_iT$$

Appendix B

**DEVELOPMENT OF DIGITAL COMPENSATOR BASED ON EXISTING ANALOGUE CONTROLLER**

The S-Domain transfer function of the analogue compensator has been determined in [2].

$$G(S)=\frac{\frac{R_F}{R_1}\frac{R_F}{R_X}(1+\frac{S}{\frac{1}{R_1C_1}})}{(1+\frac{S}{\frac{1}{R_FC_F}})(1+\frac{S}{\frac{1}{R_FC_F}})}$$

$R_1 = R_F$ = 1MEG, $R_X$ = 100K , $C_1$ = 33pF , $C_F$ = 0.0047UF
Substituting numerical values ,

$$G(S)=\frac{10+(3.3E\text{-}5)S}{1+(9.4E\text{-}3)S+(2.2E\text{-}5)S^2}$$

Using biliear transformation technique, with frequency prewarping before transformation, the following discrete transfer function has been obtained.

$$H(Z)=\frac{0.65E\text{-}3+0.56E\text{-}3Z^{-1}-0.09E\text{-}3Z^{-2}}{1-1.978Z^{-1}+0.9789Z^{-2}}$$