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ON THE CONTROL ASPECT OF LASER FREQUENCY STABILIZATION

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Realization of frequency stable lasers is viewed as key to progress in many areas of research and therefore, search for more effective techniques of frequency stabilization has intensified significantly in recent years. Investigating and validating the fundamental linewidth and frequency stability limits of a Nd:YAG laser oscillator, locked to a high finesse reference cavity in the microgravity and vibration-free environment of space, is the objective of a NASA project called" **SUNLITE**" at Langley Research Center. As part of this project NASA engineers have designed and built a space qualified system for measuring the linewidth and stability limits of an ultra-stable laser oscillator in space. In order to achieve greater stability and better performance, not only passive but also active frequency control, requiring use of feedback control loop has been applied. In this technique of frequency stabilization, based on basic property of feedback control theory, the intrinsic frequency noise and drift of the laser are expected to be reduced to the measurement noise level.

The objective of this paper is to further investigate the application of feedback control theory in active frequency control as a frequency stabilization technique and determine the most appropriate control strategy to be used in general and in SUNLITE project in particular.

ACTIVE FREQUENCY CONTROL VIEWED AS A CONTROL SYSTEM PROBLEM.

The plant is the laser, the process that needs to be monitored and controlled is the frequency of the laser, which is a function of the optical path length of the laser. Optical path length of the laser can be varied by:

* Temperature control of the laser gain medium.
* Control of the current supplied to the diode laser pump.
* Use of a Piezo-electric transducer.

While the first two methods have proven to be too slow for this application, use of piezo-electric transducer has received general acceptance as a practical method to this date. The block diagram for the active frequency control system presently applied in the SUNLITE project is given in Fig.1. For the sake of simplicity of analysis, the combination of converter, multiplier and low pass filter has been represented by frequency discriminator Fig. 2. The role of the discriminator is to monitor and convert the optical frequency fluctuations into voltage fluctuations.

ROLE OF FEEDBACK LOOP IN NOISE REDUCTION AND MEASUREMENT

There are several noise sources that cause the phase of the laser to wander leading to an output signal not a perfect sinusoid, resulting in instantaneous frequency variation and drift. In an attempt to minimize the noise, the block diagram of Fig. 3. was analyzed. It was concluded that for sufficiently large K_c (controller's gain) the output noise can be reduced to a minimum as shown in Eq. 1. Use of block diagram given in Fig. 4. which is a very crude approximation of the system in Fig. 3. for the purpose of measuring the laser noise, $S_{f,\ laser}$, is inaccurate at best. The effect of large K_c on the stability of the control loop was examined next. Attempt was made to identify system components with crucial impact. The transfer function of the controller was derived (Eq. 2), which indicates that R_X can have significant effect on the K_c, provided that R_F is chosen to be equal to R_1 as is the case in SUNLITE project.

FUTURE WORK

1. Digital versus analogue control

Replacement of the analogue controller $G_c(S)$, by a digital predictor/controller as shown in Fig. 5, 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 other purposes, is very much tempting and must be perused. Ofcourse it is essential to obtain an appreciation of the possible effects of the quantization. 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.

2. Alternative control approaches

System identification and noise cancellation, using adaptive linear algorithm or NEURAL-NET approach is definitely worth trying. Adaptive linear algorithms, including the least mean square algorithm (LMS) and the Kalman filter algorithm, can be used effectively in different types of tasks provided the systems being monitored or controlled are reasonably linear. Noisy situations where the source signals are not ever available in noiseless form, have not yet been handled by neural network algorithms.

REFERENCES

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

2. Timothy Day, "Frequency Stabilized Solid State Laser for Coherent Optical Communication", Ph.D. Dissertation, Stanford University, Stanford California, 1990

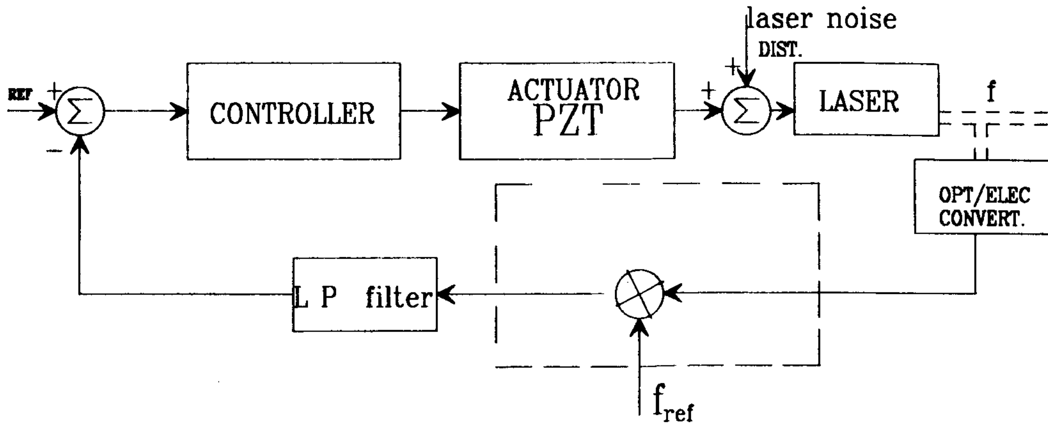

Fig. 1. Block diagram of the active control loop in frequency stabalization system.

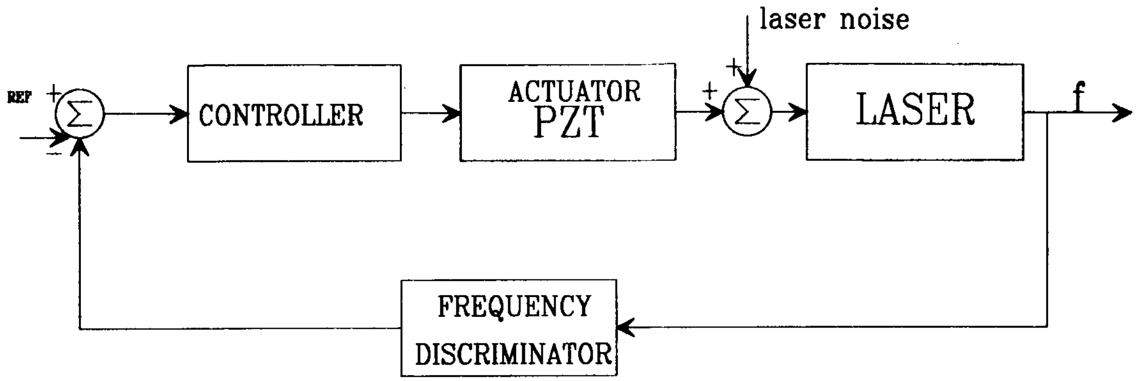

Fig. 2. Simplified block diagram of fig. 1.

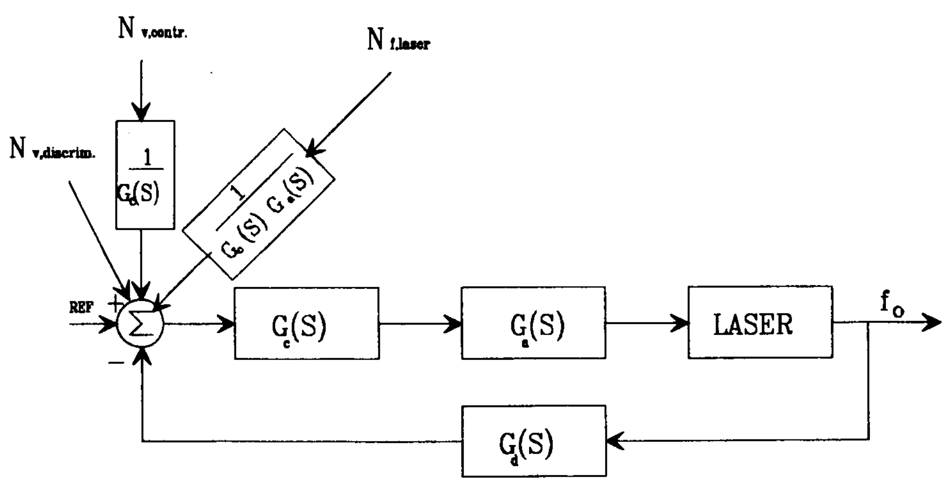

Fig. 3. Use of feedback loop for noise reduction

$$\left|\Delta f_o\right| = \frac{\left|N_{v,discrim} * K_c * K_a\right|}{\left|1 + K_c * K_a * K_d\right|} = \frac{N_{v,discrim}}{K_d} \quad \text{..... Eq. 1.}$$

$K_c >> K_a > 1$

$$G_c(S) = \frac{\frac{R_F}{R_i}\frac{R_F}{R_X}\left(1+\frac{S}{1/R_1 C_1}\right)}{\left(1+\frac{S}{1/R_F C_F}\right)\left(1+\frac{S}{1/R_F C_F}\right)} \quad \ldots\ldots\ldots \text{ Eq. 2..}$$

$R_1 = R_F = 1$ MEG $\quad C_1 = 33$pF $\quad C_F = 0.0047$UF

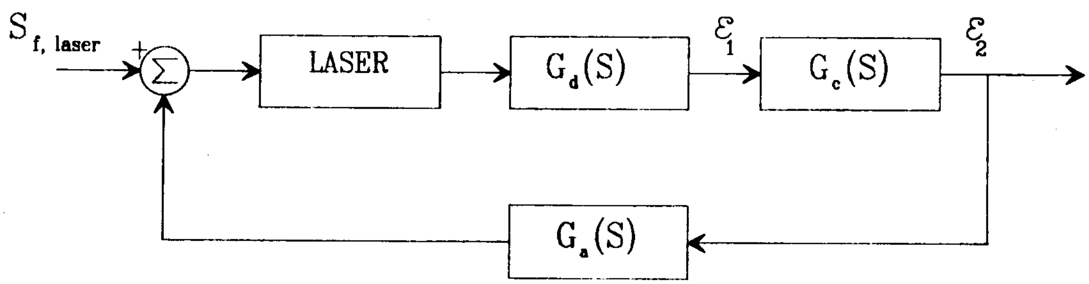

Fig. 4. Laser noise treated as the only input to the system

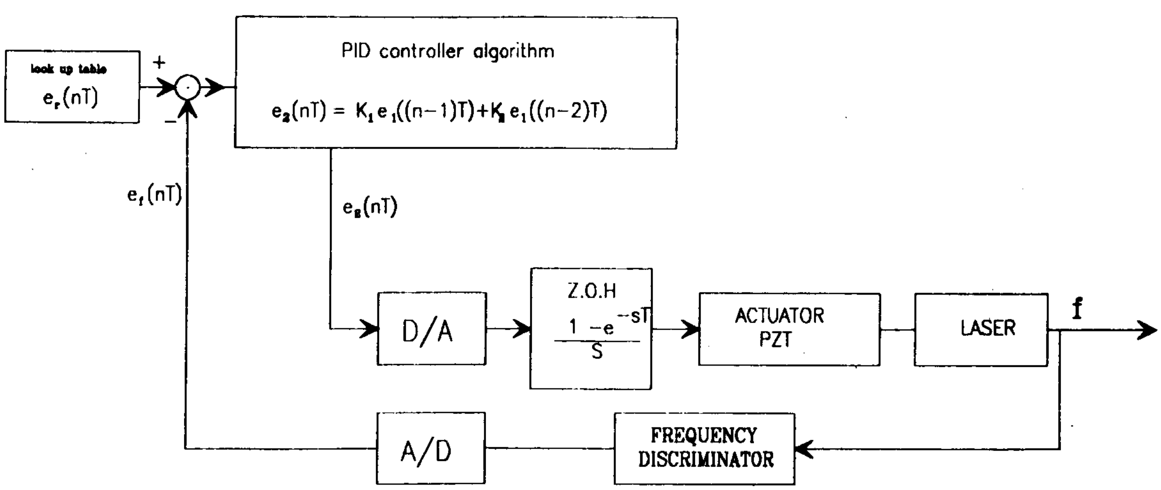

Fig. 5. Proposed discrete controller