

**ANALYSIS OF TECHNOLOGY
FOR COMPACT COHERENT LIDAR**

CONTRACT No. NAS8-38609

Delivery Order No. 172

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NASA/MSFC
Marshall Space Flight Center, AL 35812

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June 30, 1997

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1.0 INTRODUCTION

In view of the recent advances in the area of solid state and semiconductor lasers has created new possibilities for the development of compact and reliable coherent lidars for a wide range of applications. These applications include: Automated Rendezvous and Capture, wind shear and clear air turbulence detection, aircraft wake vortex detection, and automobile collision avoidance.

The work performed by the UAH personnel under this Delivery Order, concentrated on design and analyses of a compact coherent lidar system capable of measuring range and velocity of hard targets, and providing air mass velocity data. The following is the scope of this work.

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- b. Analyze and specify the coherent laser radar system configuration and assist with its optical and electronic design efforts. Develop a system design including its optical layout design. Specify all optical components and provide the general requirements of the electronic subsystems including laser beam modulator and demodulator drivers, detector electronic interface, and the signal processor.
- c. Perform a thorough performance analysis to predict the system measurement range and accuracy. This analysis will utilize various coherent laser radar sensitivity formulations and different target models.

2.0 Compact Coherent Lidar Techniques

A number of different coherent lidar techniques were studied under this Delivery Order (DO) and the merits and disadvantages of each technique were defined. The lidar techniques, that were considered and studied, are listed in Tables 1 and 2. Tables 1 and 2 summarize the basic characteristics of each technique including their measurement capabilities and limitations, target type, and size estimates. The development status for each lidar technology is also listed in Table 2. The coherent lidars can be divided into three different categories based on their principals of operation. These categories of coherent lidars may be referred to as: Frequency-chirped, Doppler, and Feedback Interferometry . The former category of coherent lidars does not match the goals of this project, and was not studied in detail under this DO.

Table 1. Compact Coherent Lidar Techniques

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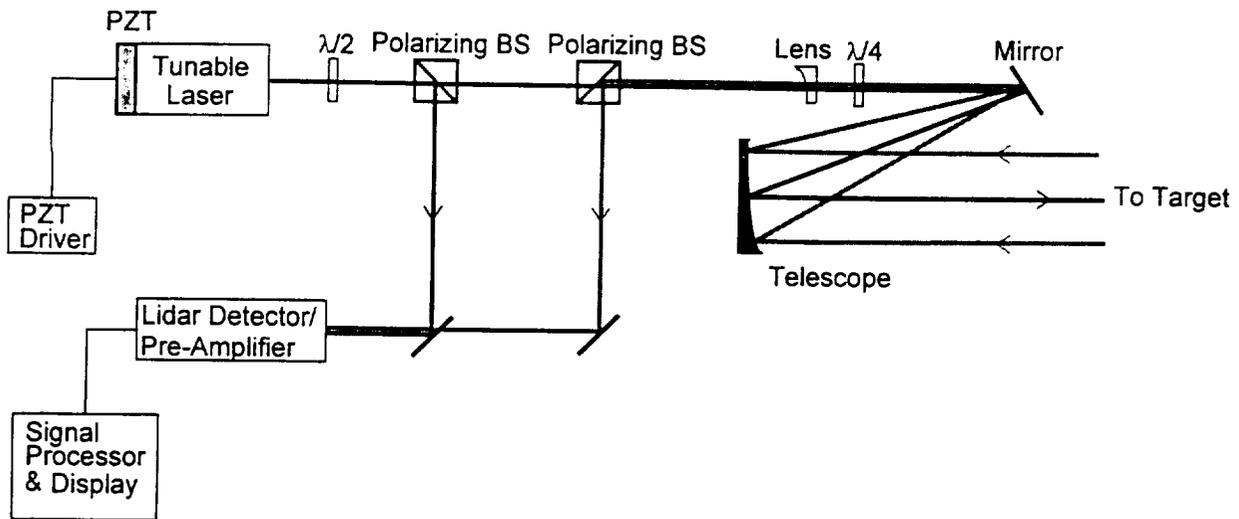


Figure 1. Frequency-chirp Lidar Using A Cw Tunable Laser

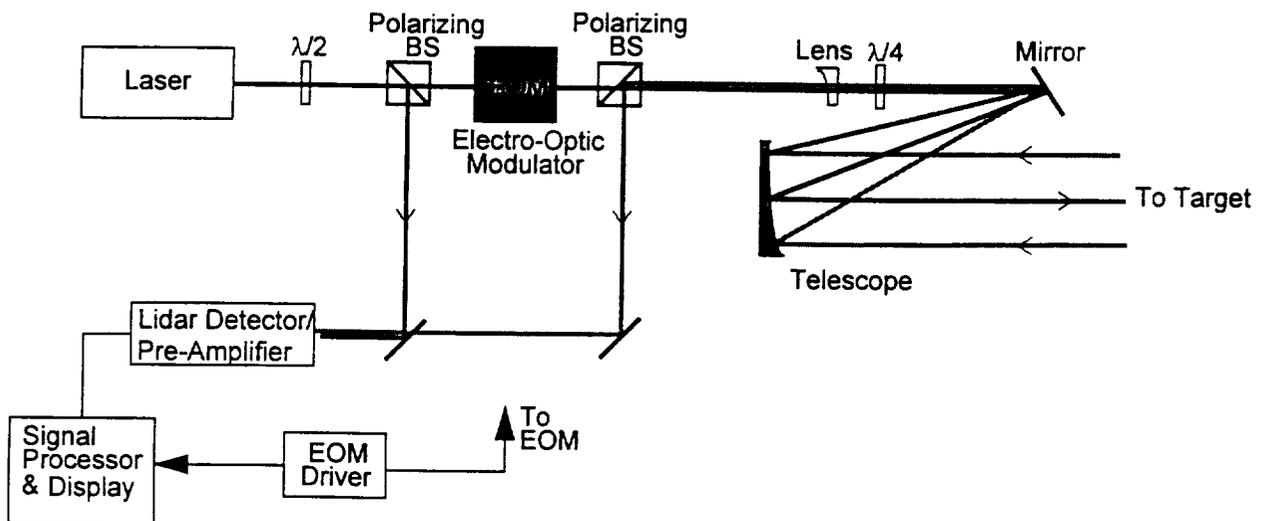


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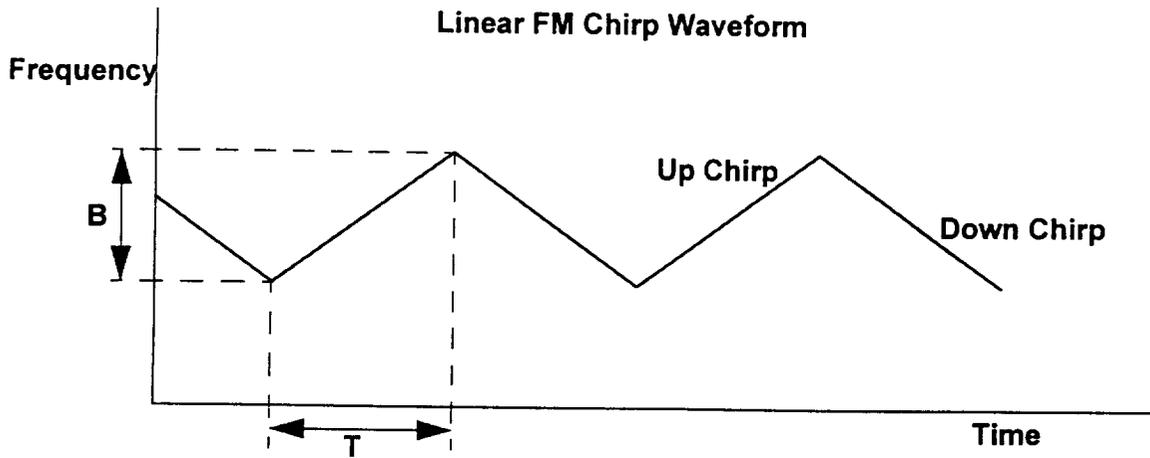


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$$f_a = \left(\frac{B}{T}\right)\left(\frac{2}{c}\right)R_{\text{target}}$$

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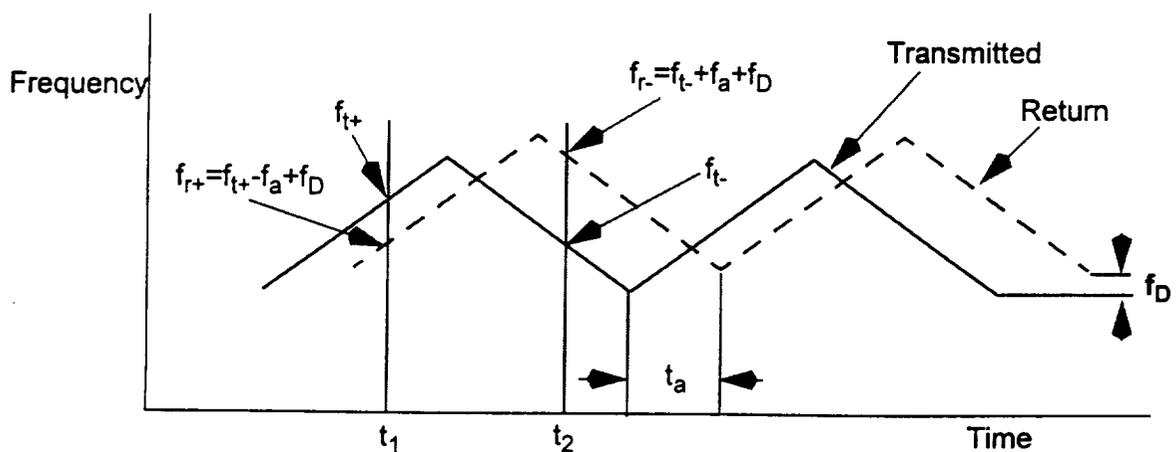


Figure 4. Transmitted and target return frequency waveforms.

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$$f_{IF+} = f_a - f_D$$

$$f_{IF-} = f_a + f_D$$

Both target range and velocity can be then extracted directly from the IF signal:

$$R_{\text{target}} = (f_{IF-} + f_{IF+})cT/4B$$

$$V_{\text{target}} = (f_{IF-} - f_{IF+})\lambda/4$$

The maximum target range and range measurement accuracy can be obtained by the using the equations below.

$$\text{Maximum Range } R_{\text{max}} = \frac{CT}{2} \Rightarrow T \geq \frac{2R_{\text{max}}}{c}$$

$$\text{Range Accuracy } \delta R = \left(\frac{T}{B}\right) \frac{c}{2} \sqrt{\frac{S}{4\sqrt{\pi}T_s}}$$

Where:

B/T = Chirp Rate

S = Laser Linewidth

T_s = Measurement Time

The frequency modulation bandwidth required to achieve 1 cm range measurement accuracy was calculated and provided in figure 5 and 6 as a function of signal averaging time. For figure 5, a Distributed Bragg Feedback (DBF) diode laser was used as the source and a micro-chip solid state laser was used for the data in figure 6. These figures

indicate that an averaging time of about 5 msec is required to achieve 1 cm range accuracy with a reasonable frequency-chirp bandwidth.

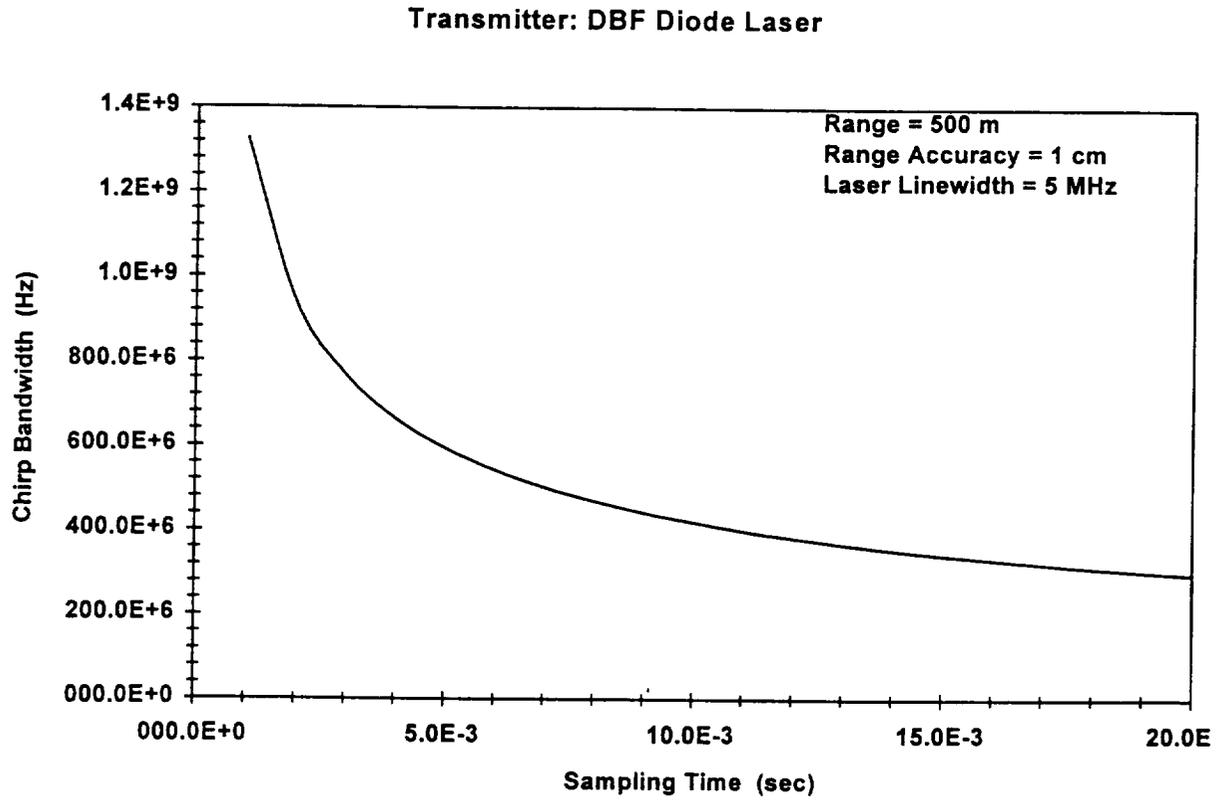


Figure 5. Frequency-chirp bandwidth versus averaging time using a DBF Diode Laser.

Transmitter : Microchip Solid State Laser

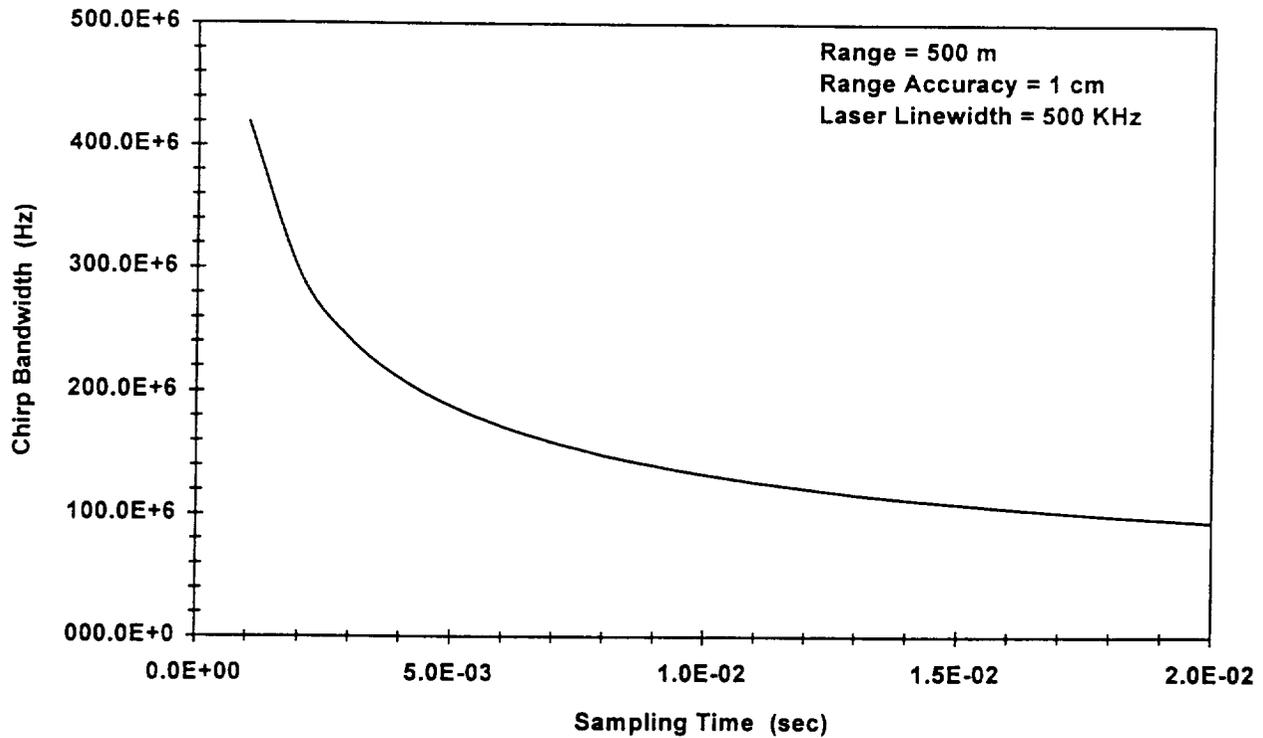


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From the results of these analyses, it was then concluded that the frequency-chirped coherent lidar is ideal for the hard target applications, such as Automated Rendezvous and Capture (AR&C). However, this technology can not be applied to the measurements of fuzzy targets. For example, the wind or air mass velocity measurements require pulsed lidar with a relatively high peak power. Another issue associated with the frequency-chirped lidar technology is the non-availability of a narrow linewidth laser source meeting the operational and physical requirements of the applications considered for this work.

3.0 Doppler Coherent Lidar

Based on the trade analysis described earlier, the Doppler coherent lidar was selected to be pursued. And further the self-seeded coherent lidar technique was selected over the more conventional injection-seeded coherent lidar technique. The advantages of self-seeded coherent lidar technique, compared with the injection-seeded coherent lidar

technique, are much reduced complexity of the lidar optical and mechanical designs, elimination of the a separate highly stable, single frequency, CW laser, and simpler system control electronic design.

In an effort toward the development and laboratory demonstration of this lidar technique, a flash lamp-pumped, and an acousto-optic Q-switch suitable for self-seeded lidar technique were specified by the UAH personnel and was procured by the MSFC. In addition, a compact and efficient diode-pumped laser resonator was also specified to be procured by the MSFC. The diode-pumped laser will be used in the development of an actual prototype system. The prototype system will be developed upon These lasers will be initially used to develop a laboratory type lidar system. Then upon successful demonstration of the laboratory system using the flash lamp-pumped laser. Both laser radiate several milli joules of energy at 2 microns wavelength.

The lidar feedback control electronics was designed to be built by the MSFC engineers. Once completed, the UAH personnel will perform the necessary tests and then implement the lidar control unit. The lidar control electronics will control the laser Q-switch transmission to allow the generation of single frequency pulses. Another function of the control electronic is to control the transmission of an external acousto-optic modulator for generation of a local oscillator beam. The control electronic will also provide all the necessary timing signals for the lidar signal detection and processing. A detector amplifier was also designed that will be used in the laser feedback control loop. This detector will monitor the level of the energy build-up inside the laser resonator prior to firing of the Q-switched pulse.

As part of effort for the laboratory demonstration of this coherent lidar technique, the design of the lidar control electronics was started. This electronic will control the laser Q-switch transmission to allow the generation of single frequency pulses. Another function of the control electronic is to control the transmission of an external acousto-optic modulator for generation of a local oscillator beam. The control electronic will also provide all the necessary timing signals for the lidar signal detection and processing. Much of the control electronic was designed in this period and the remaining parts will be designed over the next reporting period. A detector amplifier was also designed that will be used in the laser feedback control loop. This detector will monitor the level of the energy build-up inside the laser resonator prior to firing of the Q-switched pulse.

Two acousto-optic modulators meeting the requirements of the lidar system were specified and procured by NASA/MSFC. One of these modulators has been integrated into the laser resonator as a Q-switch and the other will be used outside the laser resonator as the local oscillator beam regulator and the frequency-shifter. A acousto-optic RF driver was also specified by the UAH personnel and procured by MSFC.

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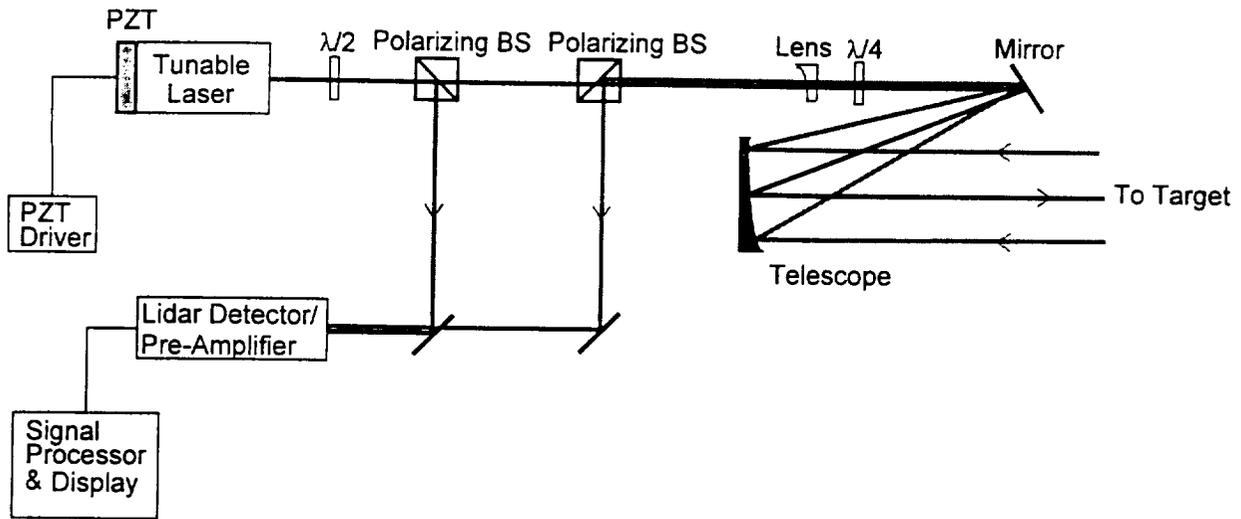


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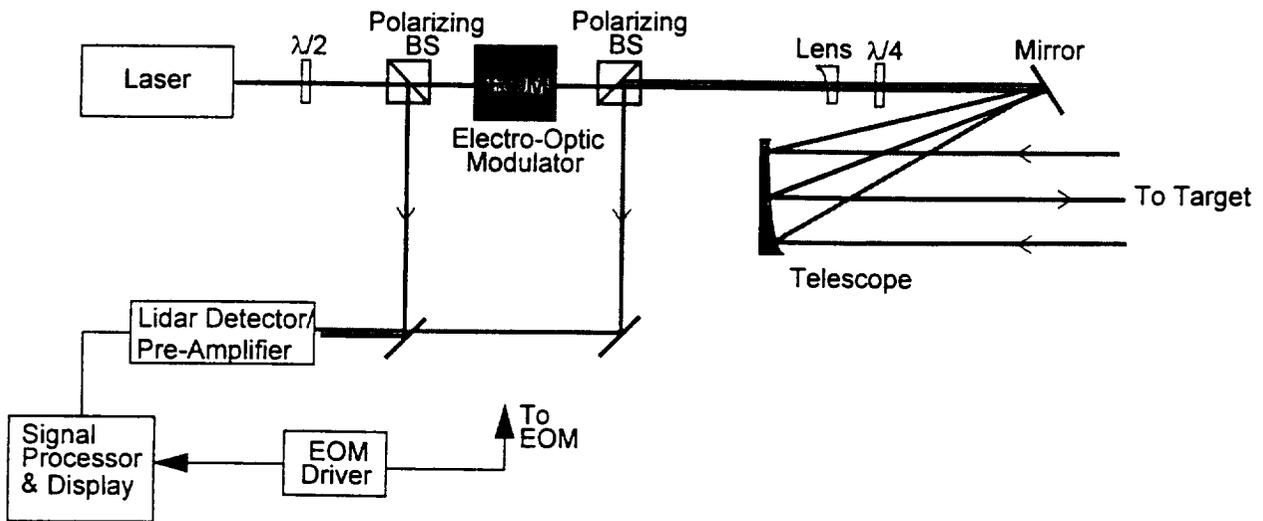


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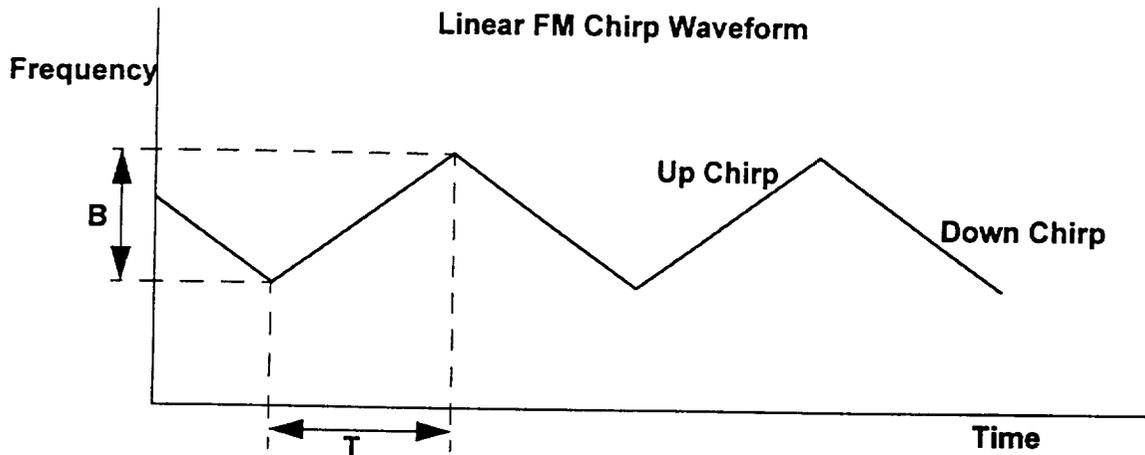


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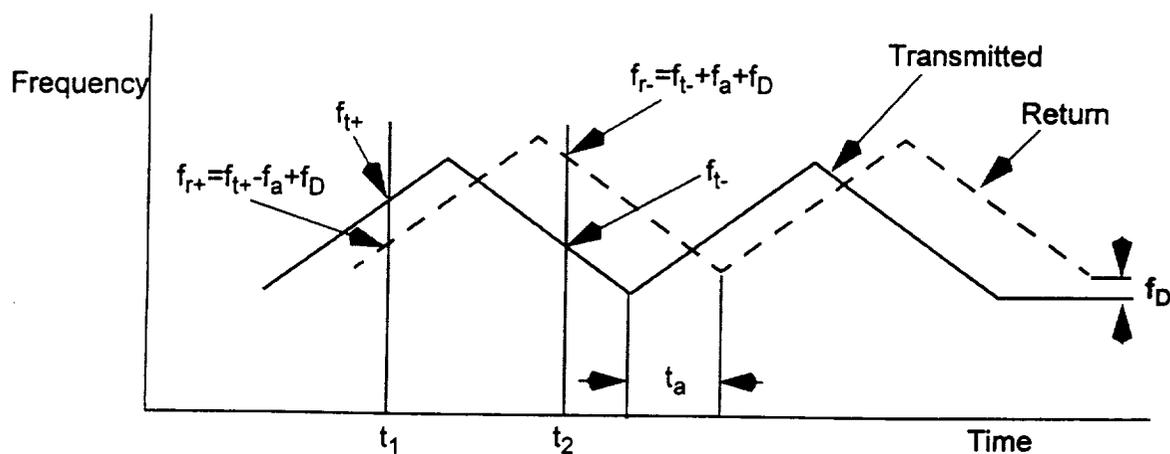


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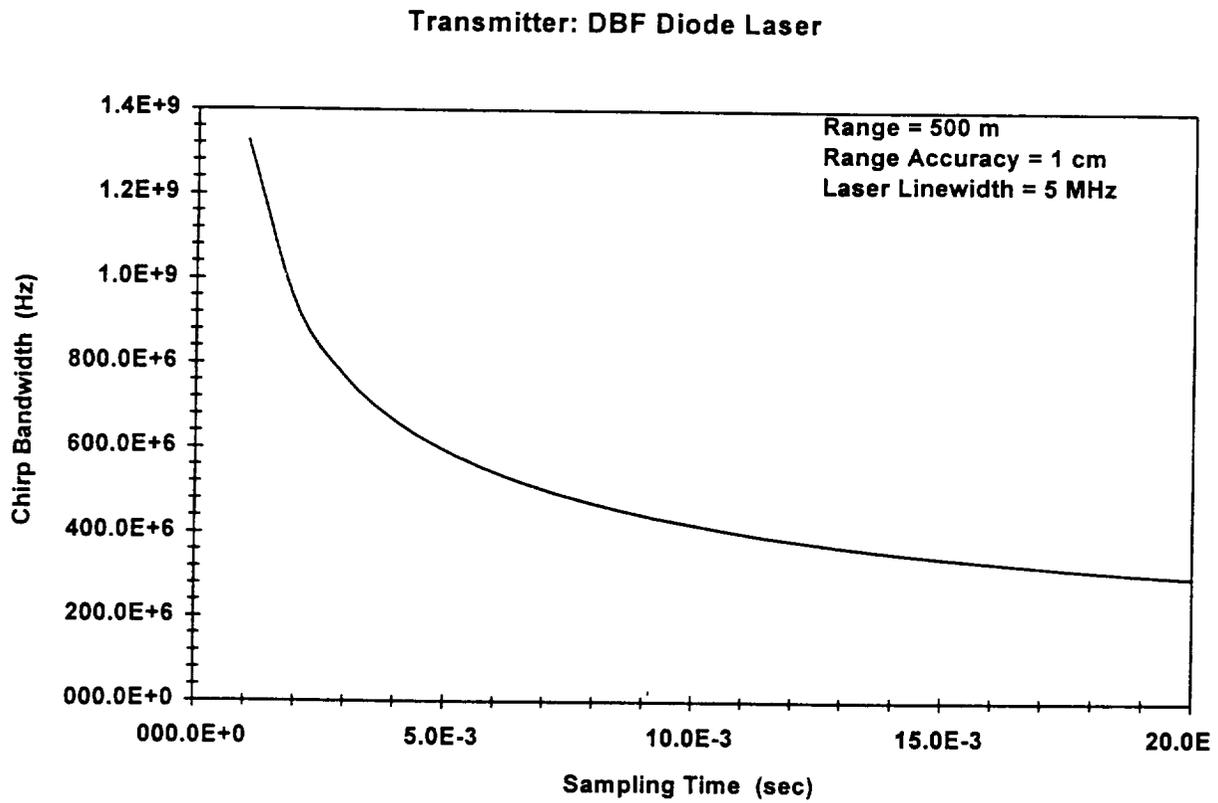


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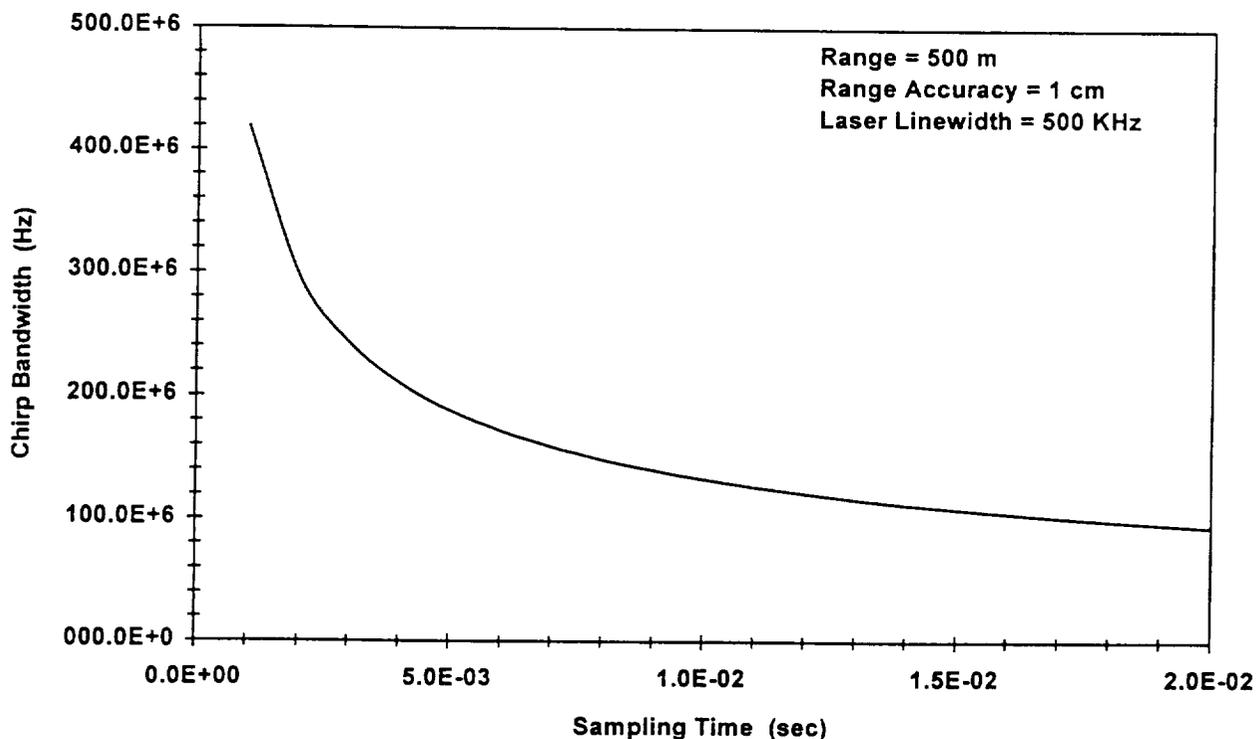


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