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Demonstration of High Sensitivity Laser Ranging System

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Background:

The small size, high efficiency, high reliability and direct modulation capabilities of semiconductor lasers make them extremely attractive for space flight applications. In this paper we report on a high sensitivity semiconductor laser ranging system developed for the Gravity And Magnetic Earth Surveyor (GAMES) for measuring variations in the planet's gravity field [1].

The GAMES laser ranging instrument (LRI) consists of a pair of co-orbiting satellites, one which contains the laser transmitter and receiver and one with a passive retro-reflector mounted in an drag-stabilized housing. The LRI will range up to 200 km in space to the retro-reflector satellite. As the spacecraft pair pass over the spatial variations in the gravity field, they experience along-track accelerations which change their relative velocity. These time displaced velocity changes are sensed by the LRI with a resolution of 20-50 um/sec. In addition, the pair may at any given time be drifting together or apart at a rate of up to 1 m/sec, introducing a Doppler shift into the ranging signals.

An AlGaAs laser transmitter intensity modulated at 2 GHz and 10 MHz is used as fine and medium ranging channels. Range is measured by comparing phase difference between the transmit and received signals at each frequency. A separate laser modulated with a digital code, not reported in this paper, will be used for coarse ranging to unambiguously determine the distance up to 200 km.

Introduction:

Direct detection Laser diode-based ranging systems reported [2,3,4] to this date have been designed to measure static range. The GAMES application requires a unique ranging system capable of precise determination of velocity changes in the presence of Doppler up to 1m/sec. In order to achieve the accuracies for this measurement, the transmitted signal is intensity modulated at 2 GHz with a modulation index of 90%, and the receiver must be capable of single photon detection. We have developed a breadboard ranging system with moving target capable of measuring these velocity changes.

Breadboard Description:

A block diagram of the ranging breadboard is shown in Fig. 1 with nominal system parameters listed in table 1. Electrical drive signals for both the fine and medium ranging channels are derived from the 10 MHz master oscillator. Each channel has a phase lock loop (PLL) which generates a local oscillator (LO) signal offset from the main frequency by precisely 10 kHz. The 2 GHz and 10 MHz sinusoidal output signals are combined to drive the laser diode along with a DC bias. The 820 nm optical signal generated by the laser is reflected off the moving retro-reflector target onto the photocathode of a photomultiplier tube (PMT). The output signal of the detector is split into three channels and amplified. Two are filtered for 2 GHz and 10 MHz respectively and the third is reserved for photon counting.

The signal processing is similar to that described in references [2] and [4]. Each ranging signal is independently downconverted to the 10 kHz intermediate frequency (IF) by multiplying them with their respective phase-locked LO signals. The fine and medium IF signals are then independently digitized at 40 kHz each by a 16 bit analog-to-digital converter. The computer calculates phase for the signal by computing the average inphase and quadrature fourier components of the sampled sinusoidal signal over 32 cycles (312 Hz) of the IF. The phase is then converted to range. The fine ranging chan-

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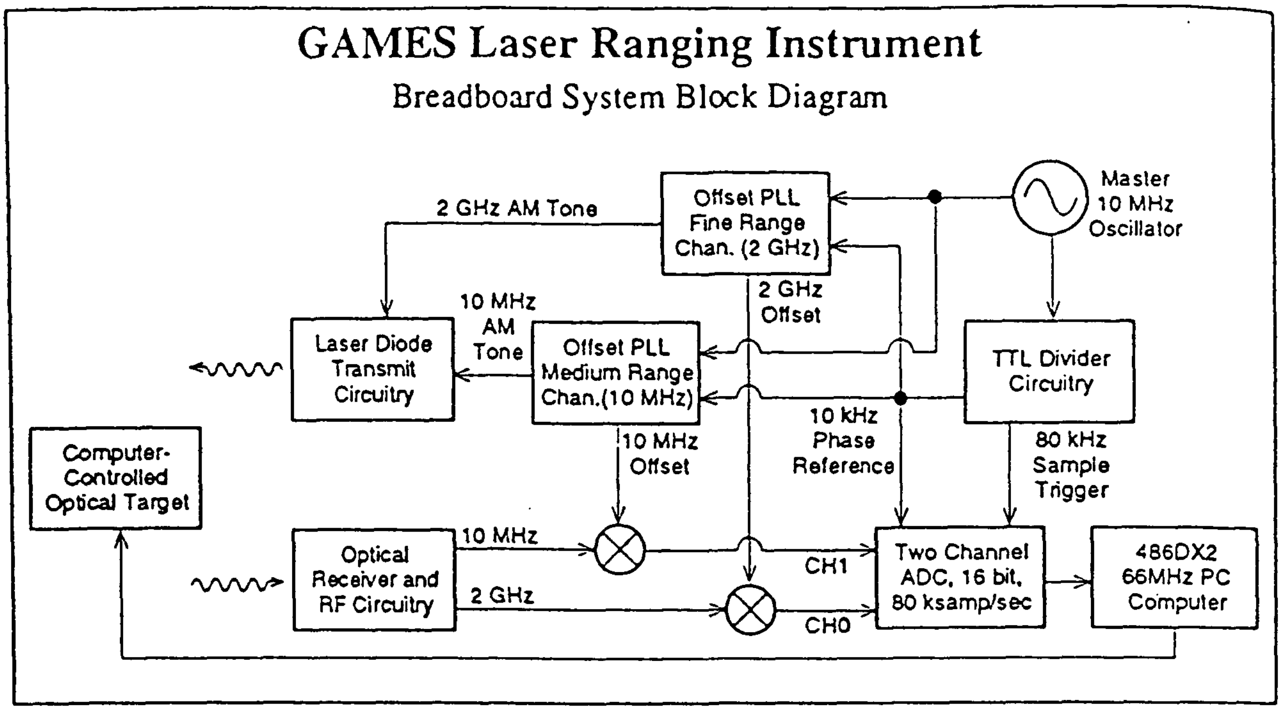

Figure 1. System block diagram of the GAMES laser ranging instrument breadboard.

nel has a cyclical range of 75 mm while that of the medium ranging channel is 15 m. In order to satisfy the range resolution for the GAMES LRI the 2 GHz cycle must be resolved to 0.25 ° (50 μm) while the 10 MHz cycle only needs to be resolved to 1° (40 mm) in order to overlap the fine ranging cycle.

Performance:

One of the main parameters which influences the accuracy of a range measurement is the number of cycles averaged. Fig. 2 shows this dependence for static range. For statistically independent data, the standard deviation should decrease by the inverse of the square root of the number of cycles averaged. A linear regression fit shows that when more than 8 cycles are averaged, the standard deviation decreases as $n^{-0.45}$ for the 2GHz channel and $n^{-0.5}$ for the 10 MHz channel.

For our application the Fourier components computed over 32 IF cycles are recorded so as to be well above the Doppler frequency. After removing the constant

Laser Transmitter	AlGaAs laser diode, 820 nm 5 nW avg power incident on detector
Detector	MCP-PMT, Hamamatsu 3809U-11 Q.E. of detector spec'd ~ 5% @ 820 nm
Master Oscillator	10 MHz, TRAK, frequency drift ~10^{-13}/sec
Cyclical Error	±75 mm in 37 mm cycle, due to image frequency interference at 2 GHz - 20 kHz
Fine Ranging Tone	2 GHz, 75 mm range cycle 48% optical modulation depth
Med. Ranging Tone	10 MHz, 15 m range cycle 6% optical modulation depth
IF	10 kHz
Sampling Rate	80 kHz total, 40 kHz for each channel, 4 samples/cycle
ADC	16 bit, 2 channels, ±1 volt full scale
Phase measurement	compute I & Q components from avg'd values at $\pi/2$ intervals, 312 times/sec (>10x max. expected Doppler shift: 26.6 Hz)
Track	Computmotor L5-A, 3 m max. optical path length controlled with Labview 3.1 software for windows velocity: 100 μm/sec up to 1 m/sec acceleration: 100 μm/sec^2 up to 3 m/sec^2

Table 1. Summary of Ranging System Parameters

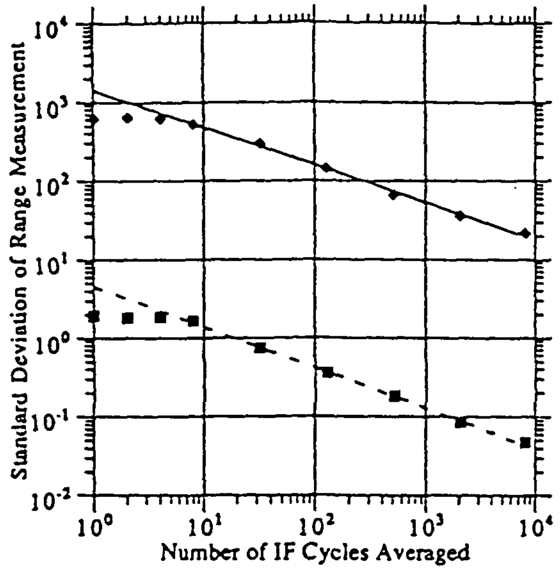

Figure 2. Range measurement standard deviation vs. IF cycles averaged. Top line is 2GHz range in microns, bottom line is 10 MHz range in meters.

Doppler velocity by linear regression, acceleration are computed by quadratic fit to 20 second long segments of the residues. The velocity changes induced by the gravity field are expected to take place over 10 second intervals and will allow us to fit the velocity data over this time period to achieve the required accuracy.

In Fig. 3 the target was computer controlled to move at 99 mm/sec for 25 seconds. A linear regression of the data yields a velocity uncertainly of 0.8 µm/sec. This is well within the accuracy requirement for GAMES.

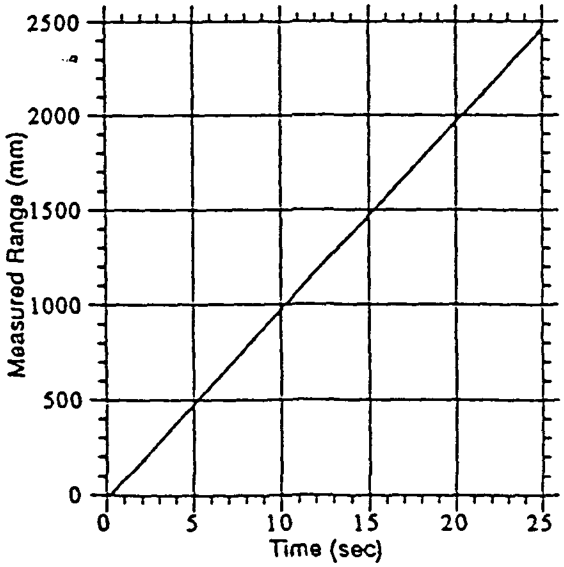

Figure 3. Constant velocity range measurements.

Conclusion:

A semiconductor laser ranging breadboard has been developed for the GAMES mission. Preliminary results indicate that it is possible to achieve the required velocity resolution 20 µm/sec. A summary of system performance data will be presented.

References:

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