# APPLICATIONS OF FM-CW LASER RADAR TO ANTENNA CONTOUR MAPPING

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## FM-CW COHERENT LASER RADAR CONCEPT

The FM-CW coherent laser radar concept is based on the FM radar principle which makes use of the coherence and tunability of injection laser diodes. The optical frequency of the laser is swept linearly as a function of time. This signal is divided and used both as a local oscillator and as the signal to be transmitted. In addition, it is injected into a reference path of known length to provide a calibration mechanism, as shown in Figure 1. After being time delayed by the round trip time delay to the target, the received signal is mixed with the optical local oscillator onto an optical detector. The resultant beat frequency is equal to the sweep rate of the optical signal multiplied by the time delay between the received signal and the local oscillator. Since the time delay is proportional to target distance, the RF beat frequency will also be proportional to target distance. In a similar manner, since the reference distance is known, the reference beat frequency is proportional to the optical sweep rate of the laser.

Thus, it is not necessary to directly measure the optical sweep rate, $\Delta F$, if the reference arm length, $X_{ref}$, is known precisely. In this system the range is given by the ratio of the number of range counts to the number of reference counts multiplied by $X_{ref}$.

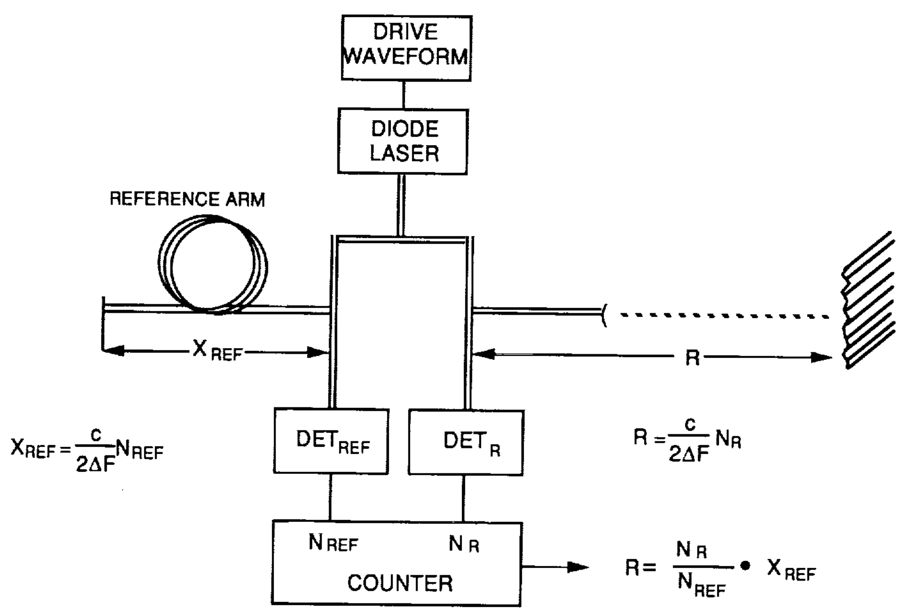



Figure 1

## LASER RADAR PRECISION/TIME TRADEOFFS

The laser radar system precision/time tradeoff is given by:

$$dR(\tau)^{\frac{3}{2}} \alpha \frac{((NEP)_h P_s)^{\frac{1}{2}}}{dF/dt}$$

where dR is the measurement error, $\tau$ is the measurement time, $(NEP)_h$ is the heterodyne noise equivalent power, $P_s$ is the optical power collected from the target and dF/dt is the time rate of change of the laser frequency sweep. Figure 2 shows the expected measurement error as a function of the time based upon currently available laser diode source parameters. Due to the inability of current laser sources to sweep more than ~30 GHz before becoming spectrally unstable, long sweep rates are not possible. Thus, precision measurements (i.e., 1 mil in 1 sec) are achieved by averaging many laser sweeps. This incoherent averaging increases the measurement time needed to achieve precise measurements and is indicated in the figure by a change in the slope of the tradeoff line. Electronically tunable lasers that can be swept both faster and further have been produced. Once available, the precision/time tradeoffs will improve as indicated on the graph.

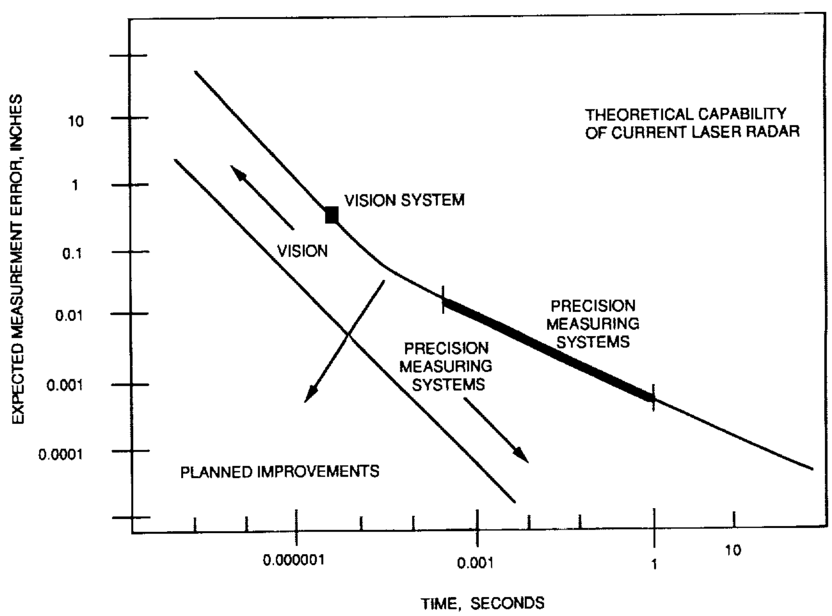



Figure 2

## LASER RADAR SYSTEM BLOCK DIAGRAM

As shown in the system block diagram given in Figure 3, the laser source is frequency modulated via a waveform provided by the laser driver. The optical output of the laser is divided between the radar optics and the calibration optics. The calibration optics consist of a temperature controlled fiber optic Mach Zehnder interferometer with an optical path length of 4 meters. The ranging beam is directed to the target area of interest via an X-Y galvanometer scanner and the beam is focused on the target by means of an autofocus unit consisting of a lens arrangement mounted in a linear translator. Both the reference and ranging signals are detected and processed by the RF section. Prior to being counted, each signal is sent to a tunable standing acoustic wave (SAW) filter controlled by a frequency synthesizer to minimize the measurement bandwidth. A microprocessor controls the autofocus unit, galvanometer scanner, and frequency synthesizer and converts the counter output to range information. Coordinate transformation functions and a graphics package are also included with the microprocessor. Output data are available on both an RS-232 line and an IEEE-488 line. User control is implemented via the IEEE-488 line.

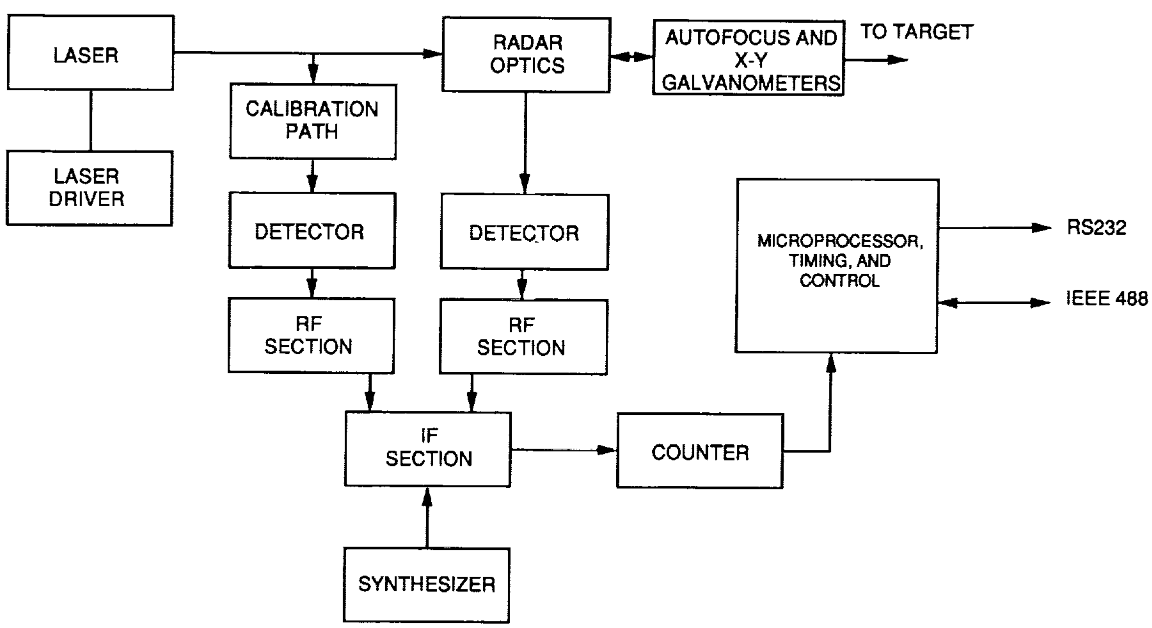



Figure 3

## LASER RADAR SYSTEM PERFORMANCE

A number of laser radar measurement systems have been constructed. The maximum operating range of these units is 5 meters, which corresponds to the coherence length limit of the 30 mW laser diode sources. A new type of diode laser has recently become available with a maximum output power of 100 mW and a coherence length an order of magnitude greater than the currently employed sources. It is anticipated that these lasers will extend the operating range limit to 60 meters.

The galvanometer scanner range is ±20° horizontal and vertical with 50 μradians short-term scan repeatability. The autofocus unit allows instantaneous range coverage over the entire operating range. However, the time needed to implement the autofocusing routine does effect the time/precision product as illustrated in Figure 4. With the autofocus disabled (AD), the system achieves a range accuracy or measurement error of 2.5 mils in 0.1 sec and 0.63 mils in 1.0 sec. With the autofocus enabled (AE), the measurement error increases to 1.2 mils in 1.0 sec. Finally, the system design permits operations with target reflectivities as low as 10 dB below that of an isotropic reflector.

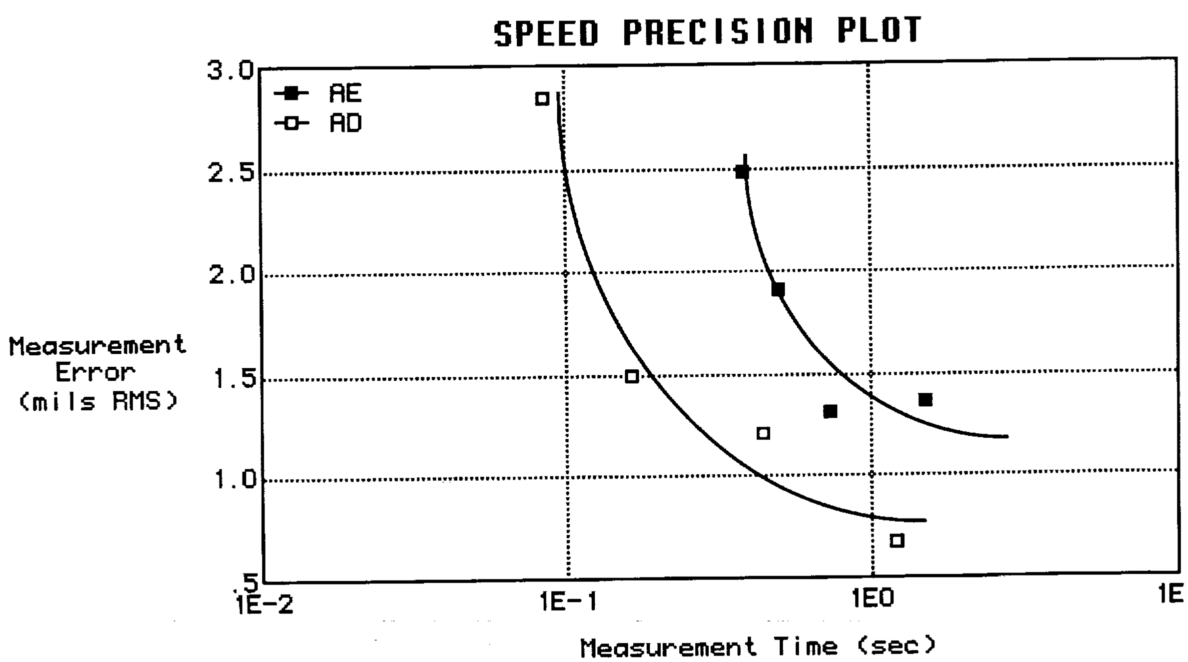



Figure 4

FIBER OPTIC SYSTEM IMPLEMENTATION FOR 15-METER HOOP/COLUMN ANTENNA

To reduce the size and weight of the optical sensor head for space applications, the entire optical subassembly can be implemented entirely in optical fibers. Figure 5 shows a configuration suitable for the 15-meter hoop/column antenna geometry. In this configuration, the laser light is injected into the input fiber after passing through an optical isolator. Using fiber optic power dividers, part of the optical energy is diverted to the reference interferometer and the rest of the energy is divided up between the four quadrants of the antenna. While a scanner can be used to point the beam to the antenna sections of interest, the measurement speeds needed for closed-loop control of the antenna surface are such that a more preferable geometry would be to incorporate a fiber optic switch with a fiber/lens combination for each measurement point. This allows rapid and programmable monitoring of the desired points.

The use of a fiber optic implementation provides a great deal of geometric flexibility in the sensor head design. To overcome laser coherence length limitation to the measurement range, a delay loop is added to the local oscillator path as illustrated in Figure 5. This configuration extends the working range of the system by a factor of one-half of the delay added.

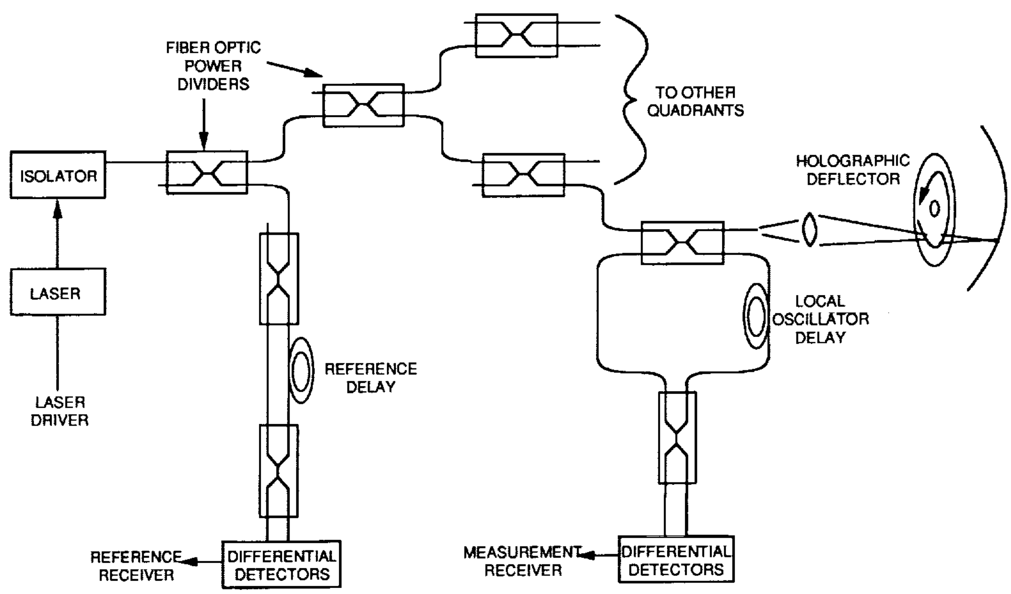


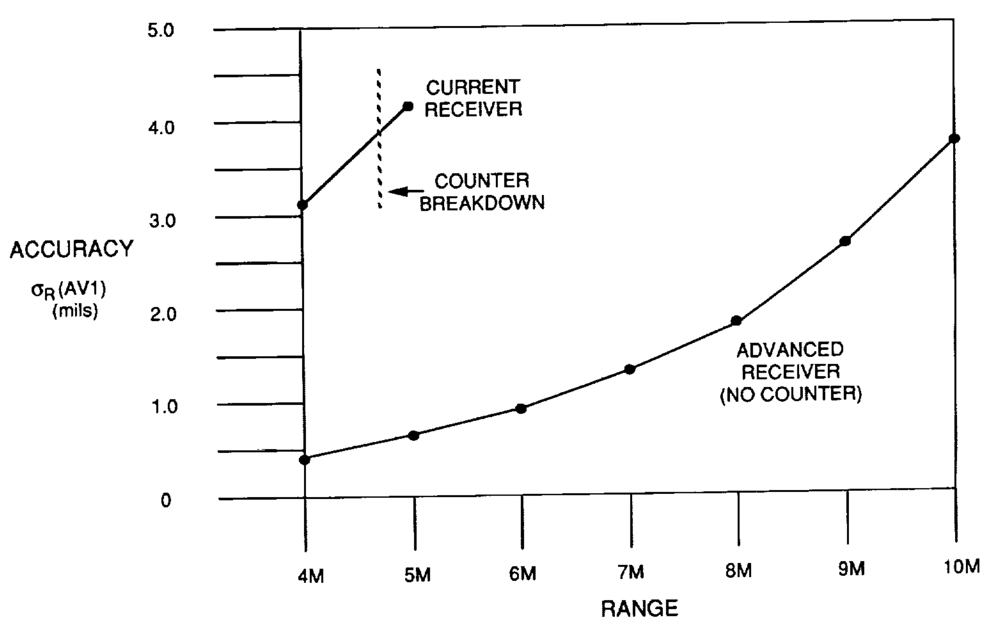

Figure 5

## RECEIVER IMPROVEMENTS

With the use of extended coherence length laser diode sources and various system geometries, such as the delayed local oscillator concept, the effective measurement range can be extended beyond 60 meters. By optimizing the receiver electronics system performance can further be improved. The current counter-based receiver suffers from unnecessary breakdown at a 12 dB SNR while the non-linear drive waveform causes excessive receiver noise bandwidth and gate bias noise. Also, the use of a single counter for both the measurement and reference arms doubles the needed measurement time.

By linearizing the drive waveform and developing a receiver based upon spectrum estimation, a faster system can be developed. A digital processor based receiver allows for parallel processing of the reference and measurement arms, extended source FM sweep, and implementation of future improvements with no hardware changes.

Figure 6 shows a graph of the current receiver performance versus the advanced receiver under similar conditions for a 10 msec integrated measurement time. Not only does the accuracy increase by an order of magnitude but the range performance also increases since a 12 dB SNR is no longer a limiting factor.




ACCURACY VS. RANGE FOR 10 msec INTEGRATED MEASUREMENT TIME

Figure 6