INTRODUCTION

Figure 1 Hornet Take Off

LaserLight Networks' predecessor (*LIGHTEC*) was awarded a Phase 2 SBIR from the Naval Air Warfare Center Aircraft Division in NJ (NAWCAD/Lk) to design and develop hardware to be incorporated as a Pre-Planned Product Improvement (P^3I) into a large procurement called VISuAL. This Program would improve and enhance subsystems used during aircraft landing and recovery operations on Navy carriers. The focus was on the Hornet, but upgrades would go fleet wide. NAVAIR System Command supported this work under contract number N68335-95-C-0169.

REQUIREMENTS

Functionally, the Navy desired a ***laser link*** between an aircraft carrier and aircraft during landing and recovery operations - see Figure 2. A laser link curtails use of more radio frequency emissions during recovery operations while providing a very low probability of detection and interception. This link must provide the following:

- Capability for real time voice communication between the Landing Safety Officer on the deck of the carrier and the pilot of an incoming aircraft,
- Capability to transmit to the carrier a modest amount of select data statusing aircraft parameters (such as the amount of fuel remaining), and
- Real time updated aircraft range from the carrier and aircraft speed of approach.

Additional requirements included:

- Laser transmitters must be eye safe.
- Eliminate both an optical tracker and laser transmitter onboard the aircraft (if possible).
- Minimize the impact on the aircraft – the airborne device must be small volume, low weight, and consume minimal power
- Engage aircraft at a minimum range of 3.7 km, provide range accuracy of 2 m, speed resolution of ± 1 m/s both at 10-20 Hz updates.

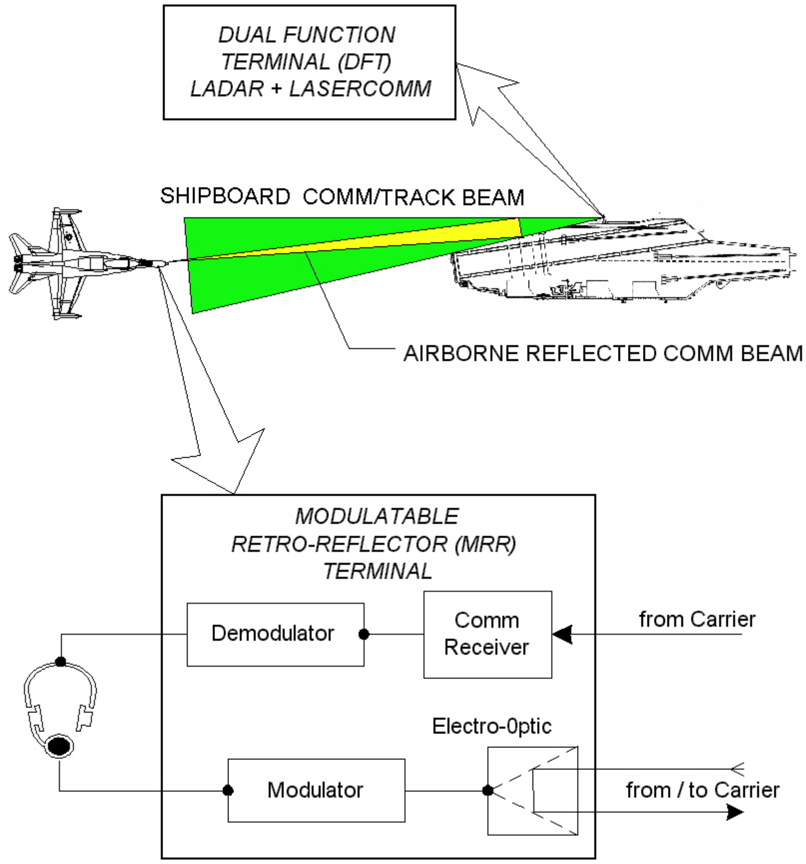

Figure 2 Scenario For Communication Link

PRODUCTS DEVELOPED

Two entirely new optical devices were created and developed in response to these specific requirements. One is called a **Modulatable Retro-Reflector (MRR)**, the second a **Dual Function Terminal (DFT)**.

The MRR (Figure 3) is a compact, lightweight, airborne laser communication terminal that transmits voice plus data. It does not require a built in laser transmitter. It acts as a pointing reference by reflecting an incoming laser beam directly back to its source (like a passive cube corner), and enhances the laser radar cross section of these cooperative targets (aircraft) thereby easing optical acquisition and tracking by the carrier. The MRR would be mounted to the landing gear of the aircraft.

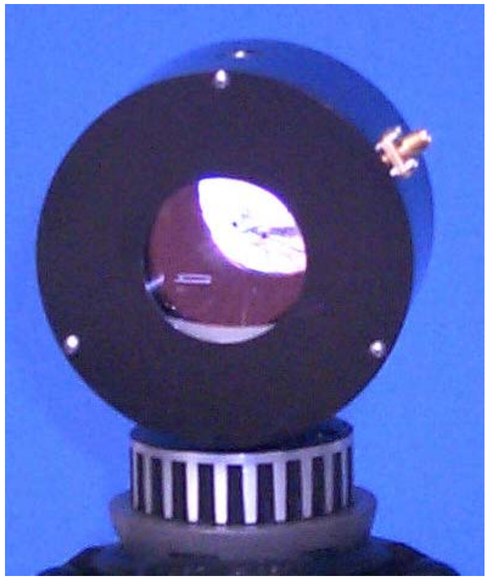

Figure 3 Modulatable Retro-Reflector

The **DFT** (Figure 4) **uses a *single laser for two different functions*: laser communication and laser radar**. Designed to operate in conjunction with the MRR, the DFT acquires and tracks the signal returned by the MRR to derive range and speed while simultaneously establishing and maintaining a communication link for two-way voice. The DFT would be located on the carrier near the "Ball" – the visible signal lights which act as a reference for the pilot to line up the aircraft with the deck centerline at the correct elevation angle during landing.

Figure 4 Dual Function Terminal

A device which functions like an ordinary retro-reflector while modulating the reflected return beam had been suggested since at least 1966 (see *Laser Receivers*, by M. Ross, John Wiley & Sons, NYC, NY 1966, pp. 322-333). This device was labeled a Modulation Inducing Retrodirective Optical System (MIROS), to be used for satellite communications. The advantages to any form of such a device are that both a laser transmitter and optical acquisition, pointing, and tracking (APT) subsystem are eliminated on one side of the link. This results in considerable system simplicity and also reduces size, weight, and power. The burden is still on the other side of the link to acquire, point, and track while transmitting a laser beam to the device. However, APT is considerably eased if the device is able to function as a cube corner. Additionally, in the scenarios where an MRR might be used beneficially, the tracker is on a platform where size, weight, and power have no impact such as a ground terminal or an aircraft carrier.

While there have been many suggested design configurations for an MRR, the MRR described here is one of a very few that actually works. Swenson, et al, of Utah State University, successfully tested an implementation using a ferro-electric liquid crystal in front of a cube corner in conjunction with the USAF Phillips Lab in 1996 (See Proc. SPIE Vol. 2990, *Free-Space Laser Communication Technologies IX*, 13-14 Feb. 1997). The device operated at 810 nm. ***LIGHTEC*** also developed and tested a similar device ***operating at 1500 nm***. Ferro-electric liquid crystals require temperature control and are not as rugged as the mirror used in our version of MRR. For these reasons, and due the scarcity of suppliers - our Israeli supplier ceased manufacturing the crystal – the liquid crystal was abandoned.

The final version pictured in Figure 3 used a proprietary mirror substrate that acted like a two dimensional diffraction grating when a voltage was applied. Voltage modulation modulated the diffracted intensity. At range, only the center lobe of the hexagonal diffraction pattern would be utilized. The mirror formed one third of a cube corner configuration, the remaining two sides consisting of high quality flats.

This device operated broadband – from the visible to the infrared – spectral performance limited only by the coatings. A high quality window protected the device and provided a seal for the partial vacuum needed for operation.

PERFORMANCE OF MRR & DFT

Tables 1 and 2 summarize the performances of the MRR and DFT, respectively.

TABLE 1 Modulatable Retro-Reflector (MRR)		
Features	**Advantages**	**Benefits**
Laser Transmitter and Pointer/tracker eliminated	Greatly simplified terminal	Low cost Greatly reduced size, weight, power demands on aircraft
Passive Multi-Wavelength Retro-Reflector Performance, Modulated or Unmodulated	Very large Laser Radar Cross Section Broad band	Provides cooperative target to track by DFT; Accommodates many different existing lasers
±20 deg. Acceptance angles with 4 cm dia. clear aperture	Accepts & returns off-normal incidence beams	Eases acquisition of aircraft by DFT
Return Beam Beam Width	Very narrow compared to RF	LPI/LPD
±10 deg. FOV InGaAs PIN Receiver	Best Spectral Responsivity, very simple optics; Large FOV eases acquisition & pointing	Low cost Greatly reduced size, weight, power demands on aircraft
10.0 cm dia. x 7.4 cm Long 1 Kg Weight	Simple form factor Moderate Size/Weight	Easy to handle & mount Minimal impact to aircraft
10 Kbps Data Rates < 0.001 BER	Accommodates voice & low data rate telemetry	High fidelity real time voice *or* Data only as required
PC Hosted all Digital Signal Processing Electronics	Simple signal processing, control Compatible with PPM schemes	Stable, repeatable digital electronics Easily upgradeable hardware & software
Equivalent OOK modulation	Pulsed laser transmitters utilized effectively; Simple electronics	Lower noise than analog schemes Compatible with PPM from DFT

TABLE 2 Dual Function Terminal (DFT)		
Features	**Advantages**	**Benefits**
Laser Radar: Range + range rate Laser Link: Communication	Two functions realized via single optical link	Simultaneous capabilities at lower system cost
	Common Features	
Laser: Single, 1 W Avg. Power Diode Pumped Solid State Laser or Fiber Amplified Device	Overall system simplicity	Fewer components Solid state reliability Easier maintainability Long operating lifetime
Transmitter properties: 1500 nm Wavelength < 1 mrad beam width	Irradiance meets FDA regulation Easier acquisition by aircraft	Fiber Telecomm industry components readily available; Eye safe; Narrow beam widths compared to RF = LPI/LPD
Single Receive Aperture < 30 cm with Single InGaAs APD or PIN Detector	Simple optics Best Spectral Responsivity High Bandwidth + Gain (APD)	Fewer components Small size compared to RF antenna Lower cost
PC Hosted all Digital Signal Processing Electronics	Simple signal processing & control; Compatible with pulse position modulation (PPM) schemes	Stable, repeatable digital electronics Easily upgradeable hardware & software
	Laser Radar	
1 m Range Resolution 1 m/s Range Rate Resolution @ 10 Hz update	Short pulse width, moderate pulse rate laser transmitters utilized effectively	Resolutions achieved with simple signal processing
	Laser Communication	
10 Kbps Data Rate < 0.001 BER	Accommodates voice + low data rate telemetry	High fidelity real time voice *or* Data only as required
Binary PPM	Pulsed laser transmitters utilized effectively	High SNR Compatible with laser radar

STATUS

The two terminals were successfully tested together in doors over a 100-foot range. The quality of the simultaneous two-way voice was excellent. Ranging was also successfully demonstrated to the required accuracy and time resolution. The original laser (Diode Pumped Solid State with conversion to 1500 nm) degraded over a 6 month period and no longer met specifications. An erbium doped fiber amplified laser was identified for follow on field testing. Ground tests were to be performed at ranges of 1-3 miles culminating in a ground to helicopter link at Lakehurst, NJ. The follow on phase was not funded.

Simultaneously and subsequently to this effort, NRL undertook extensive evaluation and internal development and test of its own version of MRR, which provided higher data rates.

APPLICATIONS

Application areas for the MRR include the following:

- Navy Aircraft Recovery/Incident Analysis,
- Secure Communication Links, such as Ship-Shore, Unmanned Aerial Vehicles,
- Maritime Channel Navigation,
- Terrestrial Perimeter Surveillance,
- Commercial Aircraft Guidance/Communication,
- Search and Rescue of Downed Pilots,
- Small Satellite Array Phasing & Communication, and
- Terrestrial Links.

Contact:
Dennis Wonica, Ph. D.
LaserLight Networks, Inc.
Tel: 310-560-3953
dwonica@laserlightnetworks.com