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Laser Communication Component Technologies: Database; Status and Trends

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ABSTRACT

A database of component and subsystem technologies for free-space laser communications has been compiled. This document discusses technology assessment for free-space lasercomm components, and contains a collection of characteristics of commercially available and one-of-a-kind components that were made for laser communication and other relevant applications. The document also includes quantitative data on laser communication systems that were constructed in the past, along with plots of development trends for specific component technologies as a function of time. We intend to continually update this information with the assistance of lasercomm community and industries involved. First draft of the document will be distributed by mid 1996 for comments and corrections. It is expected that this collection of data will serve as a handbook to lasercomm system engineers and designers.

1. INTRODUCTION

in the past, optical communication flight systems have been hampered by immaturity of th c component technologies, and excessive mass and power requirements for subsystems. Also, there is an ever increasing demand, particularly for deep-space missions, to reduce mass, power-consurnption, size, and cost of the spaceborne terminals. To satisfy these requi rements, the system designer has to rel y on the latest available component technologies and innovative optical architectures to reduce system complexity and t o "improve performance. Assessment of the status of commercially available components and subsystem technologies often consumes a significant portion of the system's design and development time. Therefore, a continually updated document, containing nearly all relevant components required for the design of an optical communication system, could serve as a refei ence document that might reduce valuable time and cost.

A database of component and subsystem technologies for free-space laser communications has been compiled. Current status of component and subsystems has been assessed, and identification of technology development needs has been attempted. Development trends for some of the components and subsystems have been plotted as a function of time. Current capabilities arc traded against a generic set of requirements. For each component, essential remaining technology development needs and those activities that can enhance the performance of the components has been identified. This database is about 70 pages at this time,

The status of electronic drivers, controllers, and control algorithms for the flight terminals have not been elaborated upon in detail since they arc often subsystem unique. Much of the data compiled in the database will change with time as the technology for the components is advanced. Thus, the database wilt continual] y be updated.

II. DATABASE CONTENTS

Since the database can not be presented in its entirety here, only a top-level summary of its contents is given here. The database covers the following areas of component technologies:

I. ACQUISITION & TRACKING
- I.A. Detectors
- I.B. Fine-Pointing/Point-Ahead Mirrors
- I.C. Coarse-Pointing Gimbals
- I.D. ACQ/TRK Algorithms
- I.E. Acquisition Beacon Lasers

II. DATA RECEPTION
- II.A. Detectors
- II.B. Coherent Detection Receivers

III. LASER TRANSMITTER
- III.A. Downlink Lasers
- III.B. Laser Modulators
- III.C. Frequency Converters

IV. OPTICS & STRUCTURES
- IV.A. Filters
- IV.B. Radiation Hardening of Optics
- IV.C. Materials for Optics & Structures
- IV.D. Telescopes

V. APPENDIXES
- V.A. Other Relevant Technologies
- V.B. Characteristics of Optical Comm Projects
- V.C. Technology Trends
- V.D. Technology Needs
- V.E. NASA Technology Readiness level (definition)

Each of the above topics includes a general discussion of that component (or subsystem). They include a generic set of requirements, current technology status, assessment of current technology, remaining essential activities, and activities that will enhance current capabilities, followed by quantitative data on pertinent components. For example, the section on detectors for acquisition and tracking include a description of viable direct-detection acquisition and tracking detectors, followed by a discussion of status of quadrant Si-APDs, CCDs, and active pixel sensors (APSs).

III. EXAMPLES

Presented below are three examples from the database that contains dozens of tables and figures. Table (I) summarizes the status of high-speed data detectors at a variety of wavelengths. Table (II) tabulates the status of narrow-band filters for both space-borne applications and ground receivers. Figure (I) is a sample of trends in technologies for space-applications. Electrical-to-optical efficiency of cw diode-pumped solid-state lasers are shown as a function of time. A pulsed-output modulated version of this laser will be the laser of choice for most deep-space laser-communication payloads. These data are preliminary and will be refined and updated.

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TABLE (I). **DATA DETECTOR TECHNOLOGY STATUS**
(Preliminary)

DETECTOR TYPE	**Detec. (D*)** cm-**WHz**$^{1/2}$ x 10^{10}	Quantum Efficiency (%)	Excess **Noise** Factor **(F)**	Frequency Response (3 **dB** Points) **(GHz)**	**Gain** (max.)	Ionization Coefficient **(K)**	**Dark** Current (Amp.)	Estimated Lifetime (Hours)	Estimated **NASA Technology Readiness Level**	Remarks
Si PIN (0.2-1.2 µm) @ 1.064 µm @ 0.850@ (peak) GaAs **PIN** (0.83 µm) **InGaAs PIN** (1.3-1.5)	10 10000	0.5 0.9	N/A	> 1 I 18	1	N/A			9 used in space	No gain preamp noise domin.
Si APD (0.4-1. 15 µm) @ 1.064 µm @ 0.532 µm @ 0.850 um (peak)	10 5000 10000	0.4 0.8 0.9	2.8	DC -3.8	300 300 300	0.002- 0.007	10 p	(5-50) x 10^7	9 used in space	Gain is not noise-free Antel ARS5
Geiger-Mode Si APD @ 1.064 µm (0.6-1.1 µm)		0.22 (0.S3 µm)		0.001 (pas.) 0.01 (act.)	10''-10^5				4	Gain is not noise-free
AlGaAs Staircase APD (0.6-1.1 µm)		0.8 (0.83 µm)	1.4	>0.5	300	0.01			3	Develop-mental
InGaAs APD (0.8-2) (1.6 µm peak) @1 . 1.6 um	40	0.13@0.83 0.74@1.06	5.5 5	DC-5 I-3	10 to 50 30	0. I to 0.4	10 n 5 - 10 n		6/7	High inter. noise AT&T -127
PMT (0.145-1.2 µm) @ 1.064 µm @ 0.532 µm @ 0.400 µm (peak)		<0.01 0.31 0.33	N/A	to 1	10^5- 10^7	N/A			8/9 used in space	Near mix-free gain
Ge APD (0.8 to 1.8 µm) **InAs** (1-3.8 µm) **InSb** (2-5.5 pm) **HgCdTe** (1-5.5 µm) **HgCdTe** (8-14 µm)	 50 15 4 2.5	0.78@1.06 0.s5 0.85	6.5 6 N/A N/A	5-7 DC -0.005 DC- 0.01 DC - 5 DC-2	200 I 1	I N/A N/A N/A N/A	1 m	> 10^5	6/7 617 9 9 617	300 K 77-300 K 77 K 77-195K 77 K

TABLE (II). NARROW-BAND FILTERS
(Preliminary)

Filter Type	Mechanism	**Band-** width ( )	**Trans- miss-** ion (%)	**Maxim.** FOV **(deg.)**	Clear **Aper-** ture (cm)	**Respon.** Tiie **(ns)**	**Tun-** ability (rim)	**Com- plexity**	Noise Reject Factor **(dB)**	**Requir.** Laser **Line-** width	Estimated **NASA Technol.** Readiness **Level**
Atomic Resonance (ARF)	signal in reso- nance w/ atomic transition	0.01 ~1GHz	10-50	± 60	> 1	10 to 10.000	<0.002	High	40-60	0.25 GHz	4
Faraday Anom- alous Dispers. (FADOF)	isolation of polarization-shifted passband	0.01	>20	± 60	> 1	0.2 to 1	minute	.Md- erate	50-60	0.25 GHz	4
Stark **Anom-alous** Dispers. (SADOF)	FADOF +electric field for tuning	0.01	>20	± 60	> 1	< 1	400 GHz	Mod.	4040	0.25 GHz	1
Fabry-Perot a. Interference b. Single cavity c. Double cav.	principle of interference	<7 < 5 <2.5	20-80	0.1 0.02 0.01	15 5 3	cavity length depe- ndent	60 (FSR)	Low Mod. Mod.	35	1	9
Birefringent (CdS & Quartz. Lvot & Solc)	cascaded birefringent crystals	0.3	B.W depend. 10-25	90 CdS 30Quart.	> 7			Mod.		0.1	6
Acousto-Optic Tunable Te02 **Quartz**	bandpass of an AO material is tuned via applied rf signal	33 5	95 (P.)	14 w PO., 6 w/o P. ± 3°	≥ 0.5 ≥ 1		450- 3900 > 300	High	40	8 1.25	6
Thin Film Interference	interference in dielectric layer	1	40	±2° to ± 30°	no real constr.	0.0001	None	Low	30-40	0.25	9
Fraunhoffer Etalon		17 GHz	> ().7							4 GHz	5
Holographic	refl. recorded stand. wave	100	90		> 1		400	Low		20	5

DIODE-PUMPED Nd: LASER ELECTRICAL-TO-OPTICAL EFFICIENCY VS. YEAR

(Preliminary)