Development of NASDA MDS-LIDAR

T. Imai

(National Space Development Agency of Japan)

Development of NASDA MDS-LIDAR

Tadashi Imai, Yasuji Yamamoto, Noritaka Tanioka

National Space Development Agency of Japan (NASDA)

2-1-1 Sengen, Tsukuba-shi, Ibaraki-ken, 305 JAPAN

E-mail : timai@rd.tksc.nasda.go.jp

1. Abstract

The MDS(Mission Demonstration Satellite)-LIDAR is two wavelength backscatter lidar developed by National Space Development Agency of Japan(NASDA). MDS-LIDAR is planned to be launched in early 2001. The goals of the MDS-LIDAR are to demonstrate key technologies for spaceborne applications and to get basic data of clouds and aerosols. This demonstration will benefit the next spaceborne lidar on future earth observation satellite. This paper shows the performance of the MDS-LIDAR and the signal to noise ratio(S/N) is calculated by using the system parameters of this instrument.

2. Introduction

The MDS-LIDAR will be launched by H-ⅡA with Data Relay Test Satellite(DRTS) in early 2001. The MDS-LIDAR is expected to observe clouds, atmospheric density and aerosols for one year. This instrument consists of 6 sub-systems, LASER Transmitter, Receiver, Signal Processor, Thermal Controller, Power Supply and Structure. The appearance and the block diagram and the main system parameters of this instrument are shown in Fig.1, Fig.2 and Table 1.

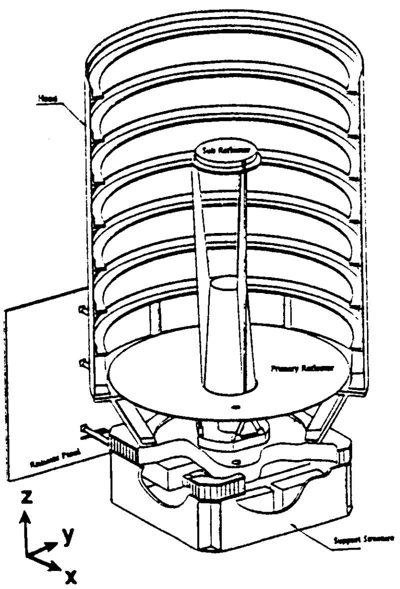


Fig. 1 The appearance of the MDS-LIDAR

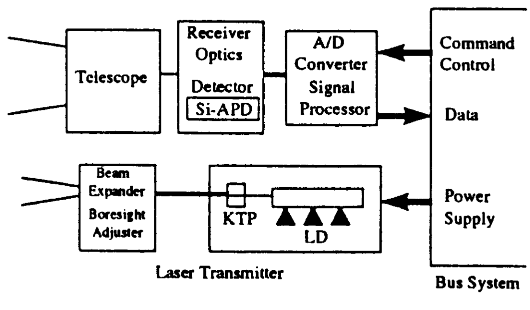


Fig.2 The schematic diagram of the MDS-LIDAR (This figure shows main sub-systems and components only.)

Table 1. Main System Parameters of the MDS-LIDAR(preliminary)

Transmitter		
Laser	LD-pumped : Nd:YLF (Neodymium Yttrium Lithium Fluoride)	
Wavelength [nm]	1053(Fundamental)	527 (Second Harmonics)
Laser output Energy [mJ]	90	4.4
Pulse Repetition Rate [Hz]	100	
Pulse Width [ns]	40±10	
Receiver Optics		
Primary Mirror Diameter [m]	1	
Detection Method	Analogue(AN) Photon Counting(PC)	Photon Counting(PC)
Filter Band width [nm]	0.3 (AN), 10(PC)	10
Total Transmittance [%]	39(AN), 5.9(PC)	60
Detector	Si-APD(Silicon Avalanche Photo Diode)	
Quantum Efficiency [%]	36(AN), 1.5(PC)	39
Resource		
Weight [kg]	about 210	
Power [W]	250 (maximum)	
Size [mm] (x×y×z)	1300×1400×2055	

3. Performance of main sub-systems

3.1 Laser Transmitter

Laser is LD-pumped, Q-switched Nd:YLF laser and the second harmonics is generated by $KTiOPO_4$(KTP). 60-Laser Diode(LD) is used for pumping. Laser oscillator consists of master oscillator only and produces 90mJ and 4.4mJ output energy at the wavelength of 1053 and 527nm respectively. The laser oscillator consumes 124W of power and most of which is converted to waste heat from the LD and the laser rod. This heat is removed by heat pipes to radiator panel. To avoid the misalignment of optical axis in the laser oscillator by the vibration and the shock in the time of launch, the self-compensation resonator is used. The beam divergence is 0.15mrad, so footprint is 82.5m diameter. Energy density at ground is under Maximum Permitted Exposure by JIS(Japan Industrial Standards). The boresight misalignment can be corrected in the Adjuster by a couple of rotatable deflecting prisms. Alignment Correcting range is ±2mrad and resolution is 0.01mrad.

3.2 Receiver

The telescope consists of 1m primary mirror and secondary mirror. The field of view (FOV) and F-number of the telescope is 0.19mrad and 6, respectively. The material of each mirror is Beryllium. The support structure of secondary mirror is made of Titanium. Received backscattered light is led to relay optics and separated by dichroic mirror into two colors. The fundamental wavelength light is separated in 9 to 1 ratio by beamsplitter and detected by two method, analogue and photon counting, respectively. Analogue detection uses 90% of received 1053nm light. The second harmonics is detected by photon counting only. For analogue detection, narrow bandwidth(0.3nm, FWHM) interference filter is used. On the other hand for photon counting detection, 10nm band width interference filter is used. Si-APD is used for detectors. Quantum efficiency is 0.36 for analogue mode Si-APD. For photon counting mode Si-APD, quantum efficiency is 0.39 and 0.02 at 527nm and 1053nm respectively.

4. S/N Simulation

4.1 S/N simulation of Analogue detection

Using the system parameters shown in above the S/N obtained by analogue detection is calculated by following formula.

$$S/N = \frac{N_s/\Delta t}{\sqrt{2B(N_s/\Delta t + 2N_b/\Delta t)F + 2\left(NEP \cdot \frac{\eta\lambda}{hc}\right)^2 B}} \cdot \sqrt{n}$$

$$\Delta t = 2\Delta Z / c$$

Where

N_s	the number of backscattered photons from cirrus, aerosol and atmosphere calculated by lidar equation		
N_b	the number of background noise	n	the number of laser shots
η	the quantum efficiency of Si-APD	M	the gain of Si-APD
F	the noise excess number	B	the band width of amplifier
λ	the wavelength of fundamental	h	the Plank's constant
c	the velocity of light	NEP	Noise Equivalent Power
ΔZ	the vertical resolution of atmospheric layer		

In this calculation, M, F, B, ΔZ, NEP and n are 100, 2.5, 1.5[MHz], 100[m], 0.013[pW/Hz$^{1/2}$] and 20, respectively. N_b is derived from the value of background reflected solar radiation, 0.17[W/sr/m^2/nm]. The vertical distribution of atmosphere and aerosol is respectively based on U.S. Standard Atmosphere model(1) and EOS Report(2). Cirrus model is based on Sasano and Kobayashi(3). Fig. 3 illustrates the calculated S/N obtained by analogue detection. We find the peak value of S/N over 10.

4.2 S/N simulation of Photon Counting detection

The S/N obtained by photon counting detection is also calculated by following formula using the system parameters shown in Table 1.

$$S/N = \frac{N_s}{\sqrt{N_s + 2N_d}} \cdot \sqrt{n}$$

where N_s and n are the same as 4.1. N_d is the number of dark counts of the detector. Because photon counting detection is operated only in nighttime the background noise is not in this formula. In this calculation, N_d and n are respectively, 250[counts per second] and 2000. The vertical distribution model of cirrus, aerosol and atmosphere is also same as 4.1. Fig. 4 illustrates the calculated S/N obtained by photon counting detection.

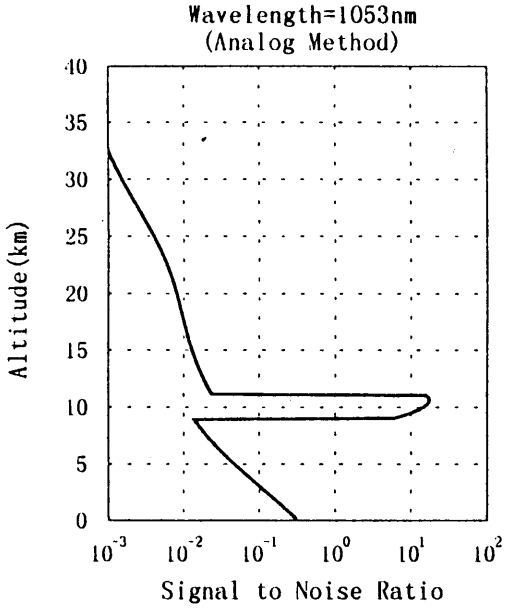


Fig. 3 The calculated S/N (AN) using this system parameters.

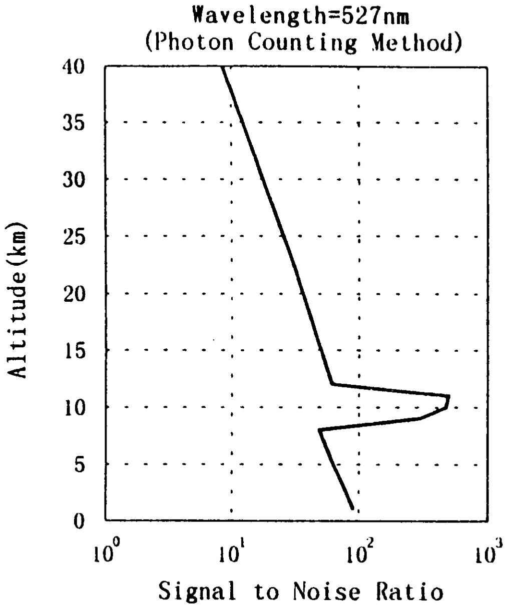


Fig. 4 The calculated S/N (PC) using this system parameters.

5. Production of Demonstration Model

The MDS-LIDAR is developed in 2 steps, Basic Test Model(BTM) and Demonstration Model(DM). BTM is produced and tested till March, 1998 to confirm the parameter of DM. DM is produced until the end of 1999.

6. Reference

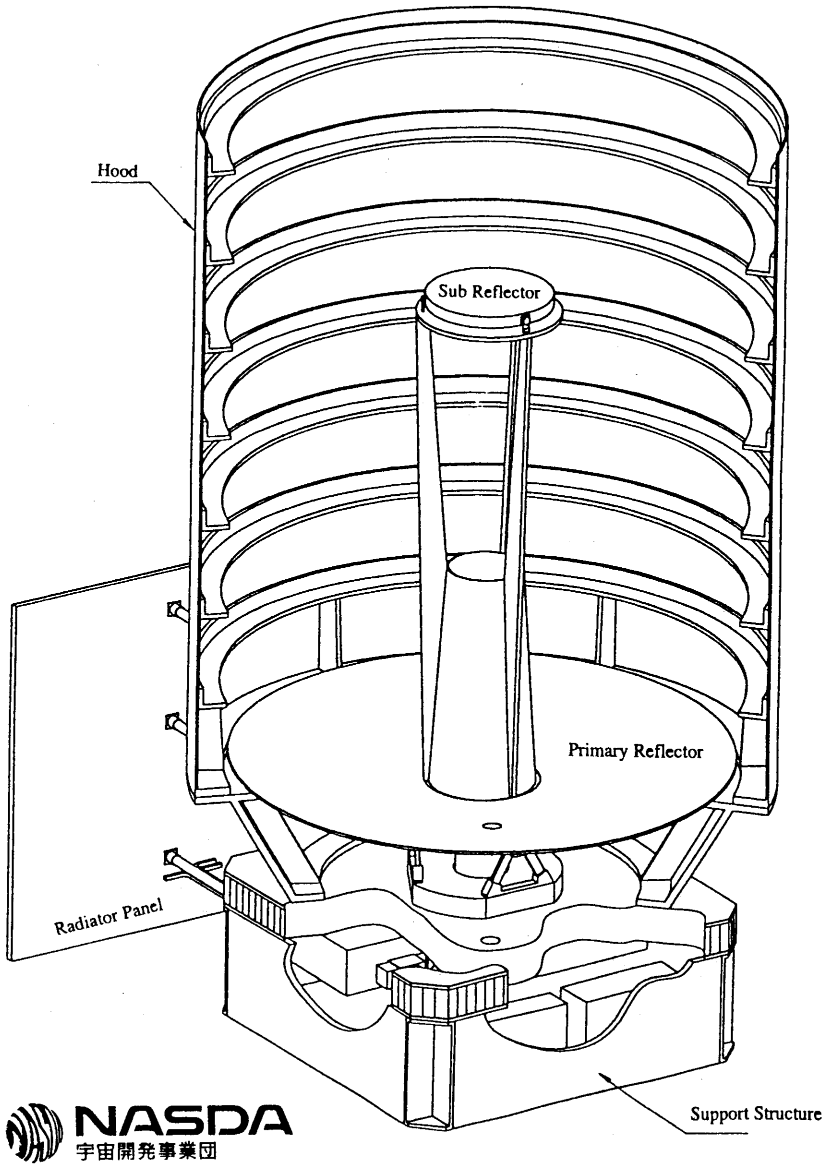
(1) NOAA, NASA, U.S. Air Force, "U.S. STANDARD ATMOSPHERE, 1976", NOAA-S/T 76-1562

(2) NASA, "LASA Lidar Atmospheric Sounder and Altimeter Instrument Panel Report", Earth Observing System Reports Volume IId, P17

(3) Sasano, Y. and T. Kobayashi(ed.) : Feasibility study on space lidars for measuring global atmospheric environment No.4 Final Report, F-82-1995/NIES(1995)

Development of NASDA MDS-LIDAR

Tadashi IMAI
Remote Sensing Technology Laboratory
National Space Development Agency of Japan
(NASDA)



NASDA
宇宙開発事業団

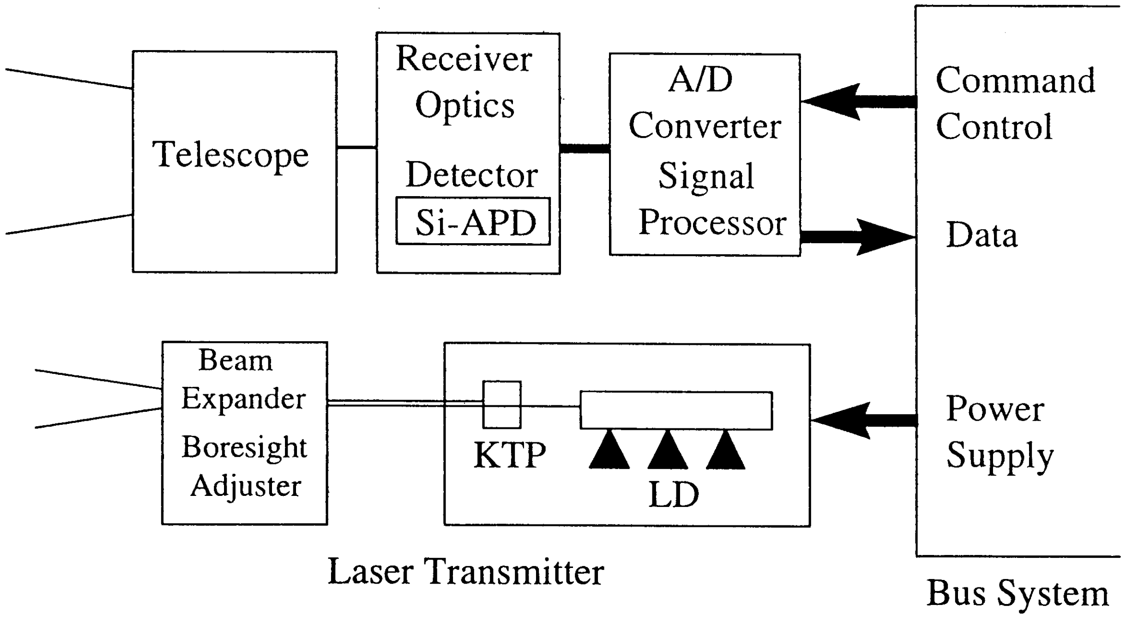


Fig. MDS - LIDAR Schematic Diagram

Table 1. Performance of MDS-LIDAR (Preliminary)

	Fundamental [AN]	Fundamental [PC]	Second Harmonics
Transmitter			
Wavelength [nm]	1053		527
Laser Power [mJ]	90		4.4
Pulse Repetition Rate [pps]	40		
Beam Divergence [mrad]	0.15		
Reciver			
Primary Mirror Diameter [m]	1		
Field of View [mrad]	0.19		
Filter Bandwidth [nm]	0.3	10	10
Total transmittance [%]	39	5.4	60
Detector Type	Si-APD	Si-APD	Si-APD
Detecting method	Analogue	Photon Conting	Photon Conting
Detector Quantum Efficiency [%]	36	2	39
Signal Processor			
Digitizer Resolution [bits]	12	12	12
Maximum Count Rate [Mcps]	-	5	5

Signal to Noise ratio (Photon Counting Detection)

$$S/N = \frac{N_s}{\sqrt{N_s + 2N_d}} \cdot \sqrt{n}$$

N_s : Number of backscatter photon from target (cirrus, aerosol, atmosphere)

N_d : Number of Dark Counts

n : Number of Laser Shots

Signal to Noise ratio (Analogue Detection)

$$S/N = \frac{N_s/\Delta t}{\sqrt{2B(N_s/\Delta t + 2N_b/\Delta t)F + 2B\left(NEP \cdot \frac{\eta\lambda}{hc}\right)^2}} \cdot \sqrt{n}$$

N_s : Number of backscatter photon from target (cirrus, aerosol, atmosphere)

N_b : Number of background photon

B : Baseband Amplifier bandwidth [Hz]

n : Number of Laser Shot

λ : Wave length [m]

c : Velocity of light [m/s]

NEP : Noise equivalent power [$W/Hz^{1/2}$]

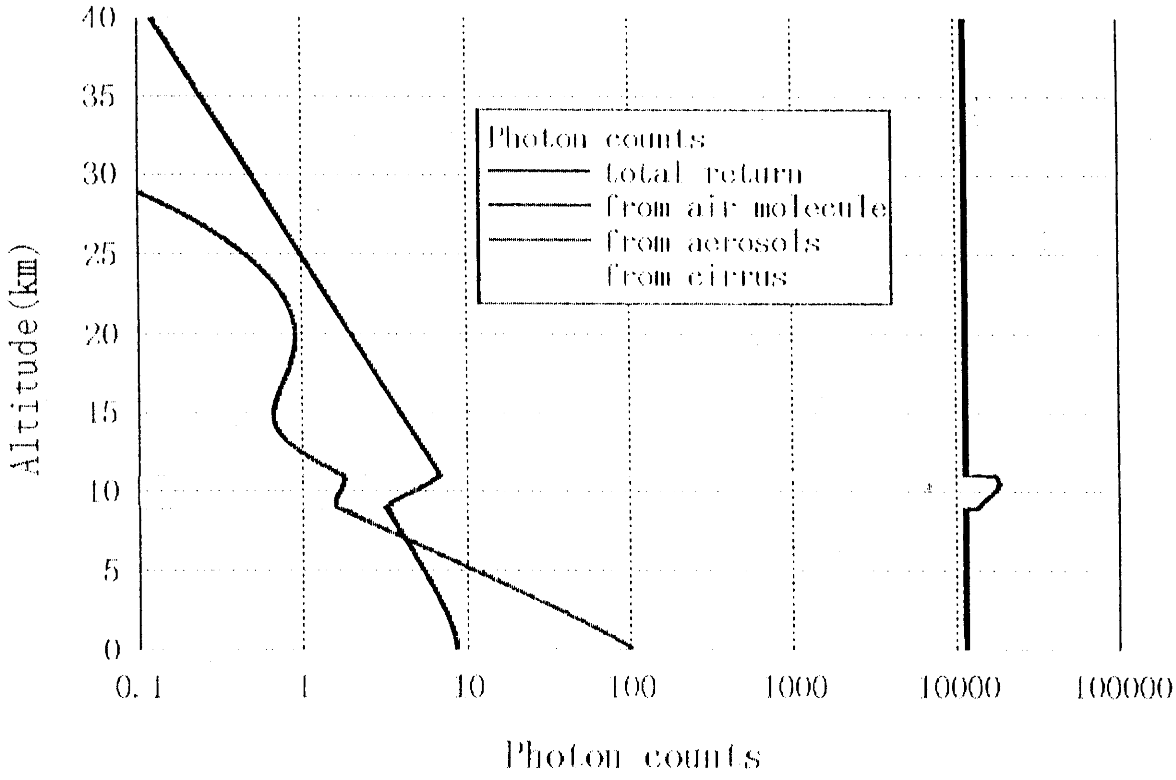
Δt : Gate time [s]

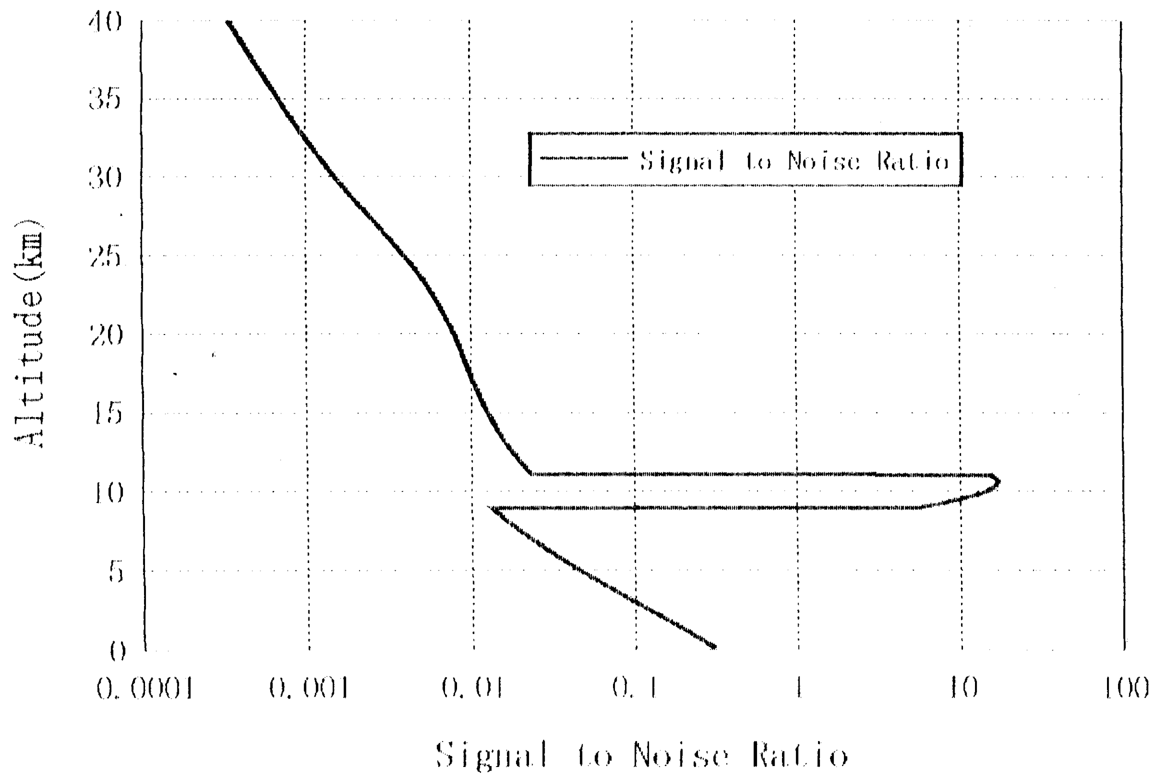
F : Excess noise factor

η : Quantum Efficiency

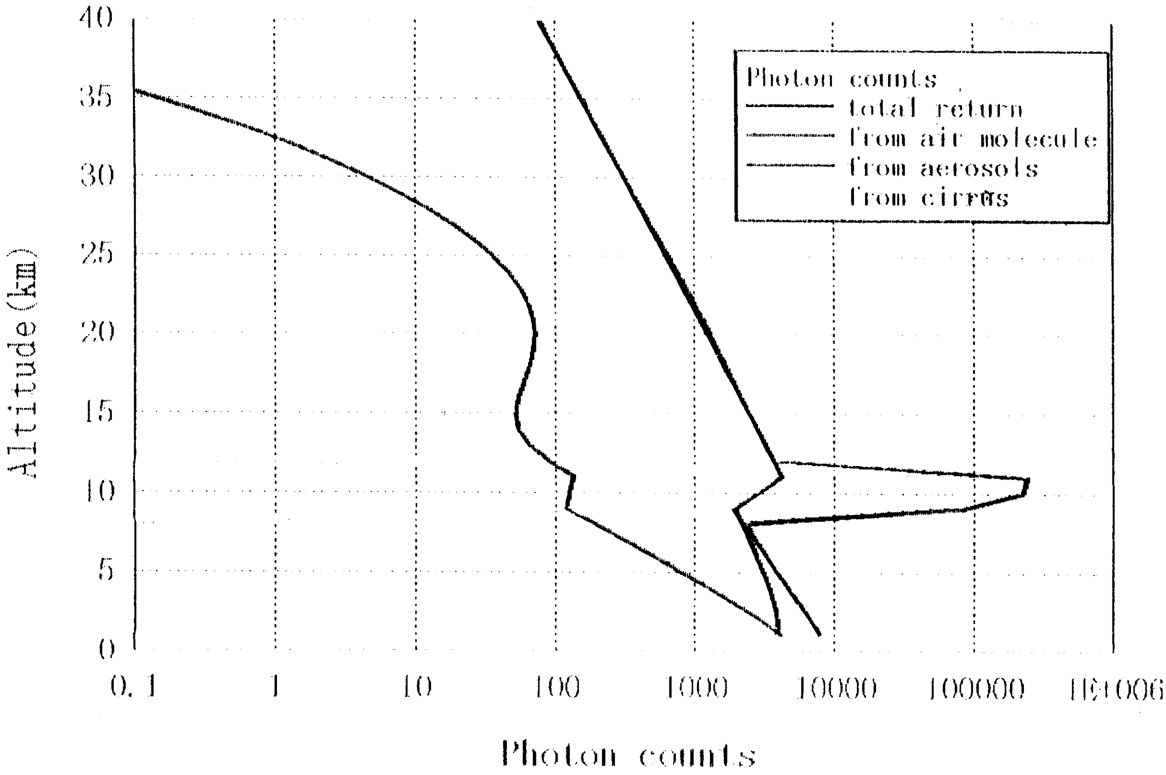
h : Plank's coefficient [J·s]

Wavelength 1053nm Analog Method





Wavelength 527nm Photon Counting Method



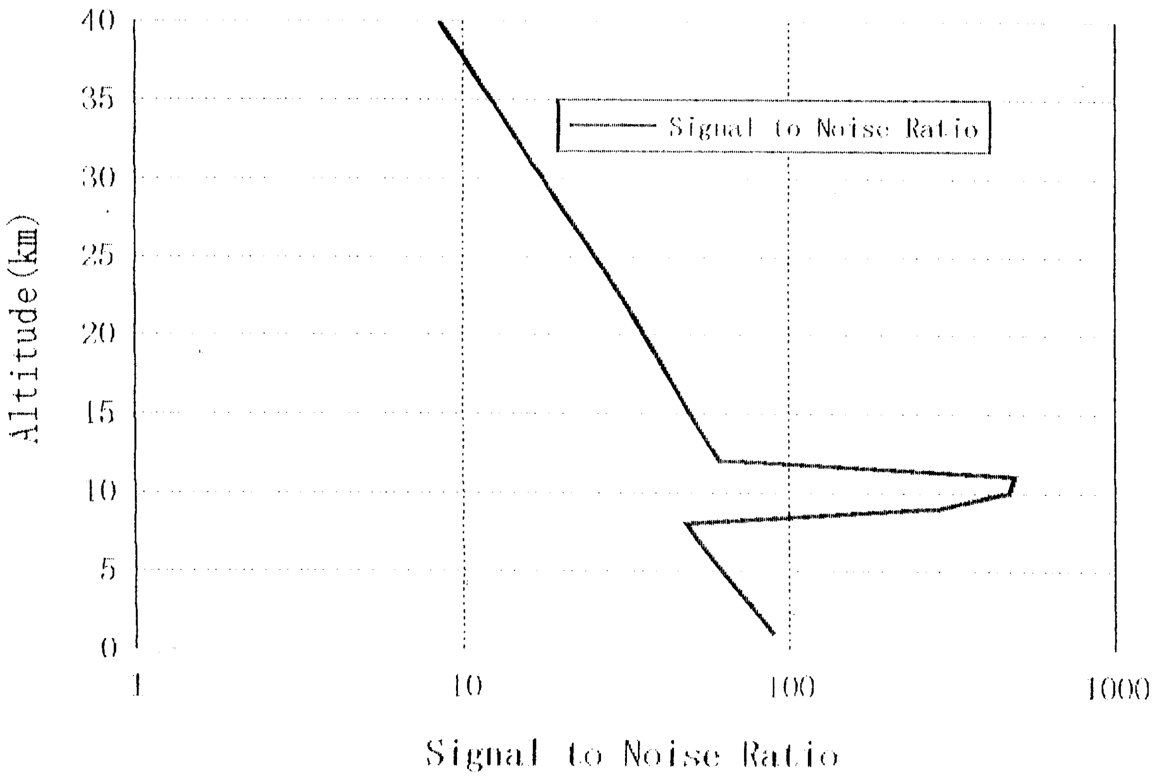
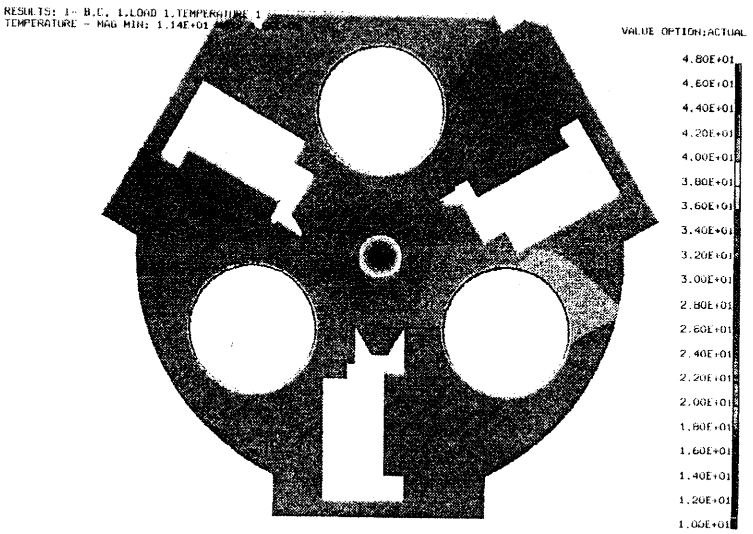


Table Performance of LASER Transmitter (Preliminary)

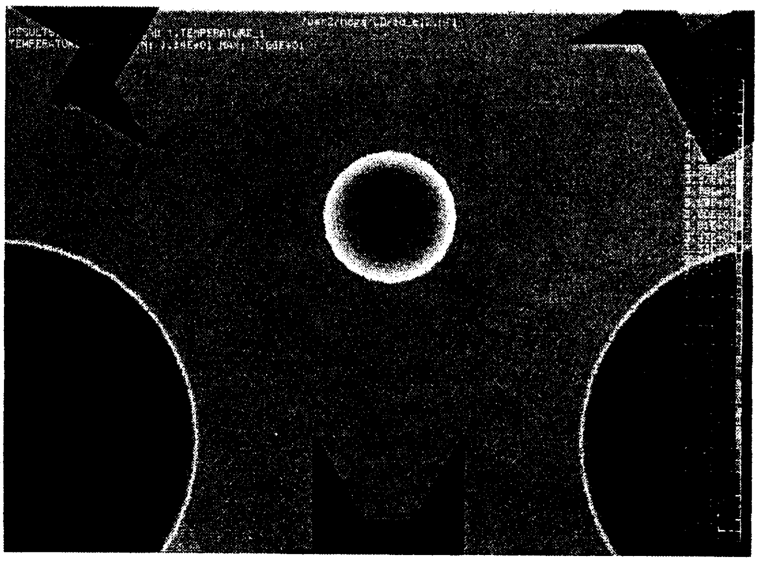
LASER	LD Pumped Nd:YLF LASER + KTP
Wavelength	Fundamental 1053 [nm] Second Harmonics 527 [nm]
Output energy	Fundamental 90 [mJ] Second Harmonics 4.4 [mJ]
Pulse Repetetion	100 [pps]
Wavelength Stability	±0.1nm
Pulse Width	40±10 [ns] (FWHM)
Power Stability	3 % per minute
Life	≧ 3×10^{9} shots
Heat Exchange	Heat Pipe

Thermal Analysis of LD pump module (Steady State)

NASDA

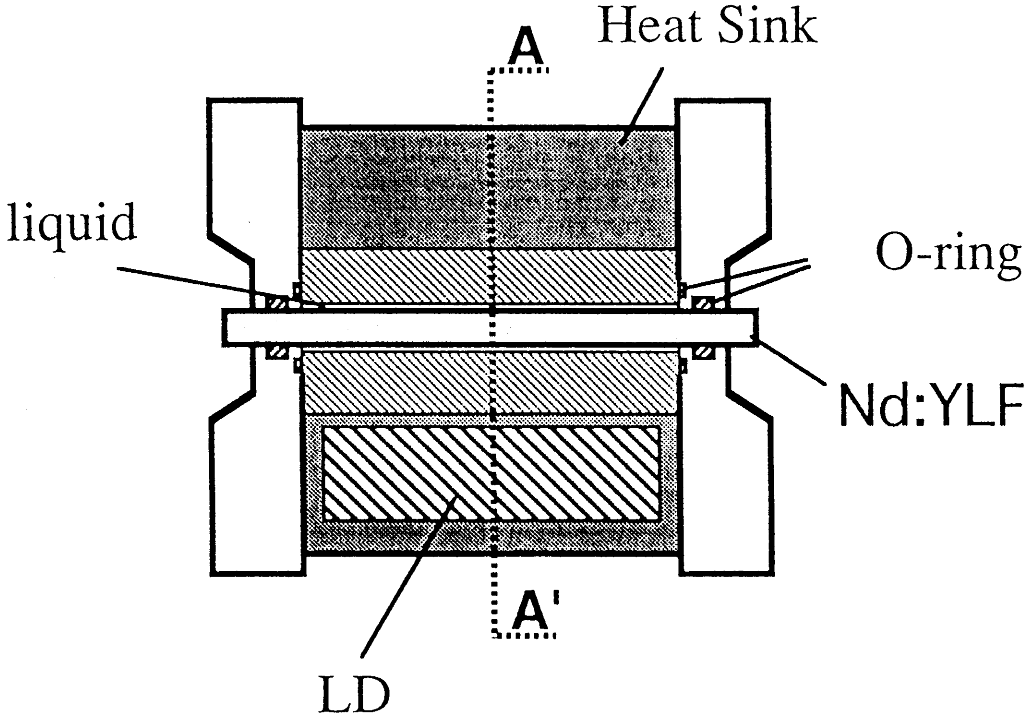


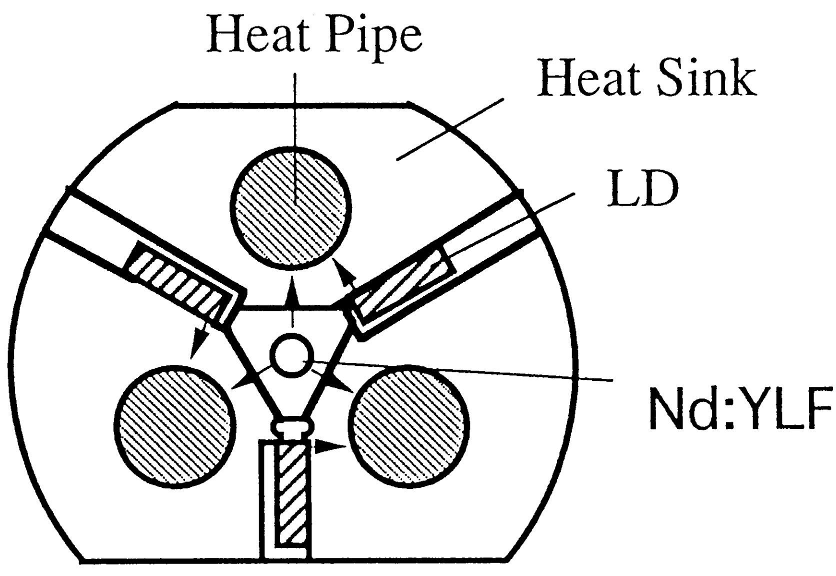
Symmetrical temperature distribution is formed in/around the Nd:YLF rod.



Temperature distribution of LD pump module

Analysis condition	
· Heat dissipation of LD	84.4 W
· Heat dissipation of Nd:YLF rod	30.4 W
· working fluid temperature	10 ℃
· Heat transfer coefficient of heat pipe	1450 W/m^2K





(Cross section A-A')

Fig. Cross section of LD pump module

Table. Performance of Alignment Adjuster (Preliminary)

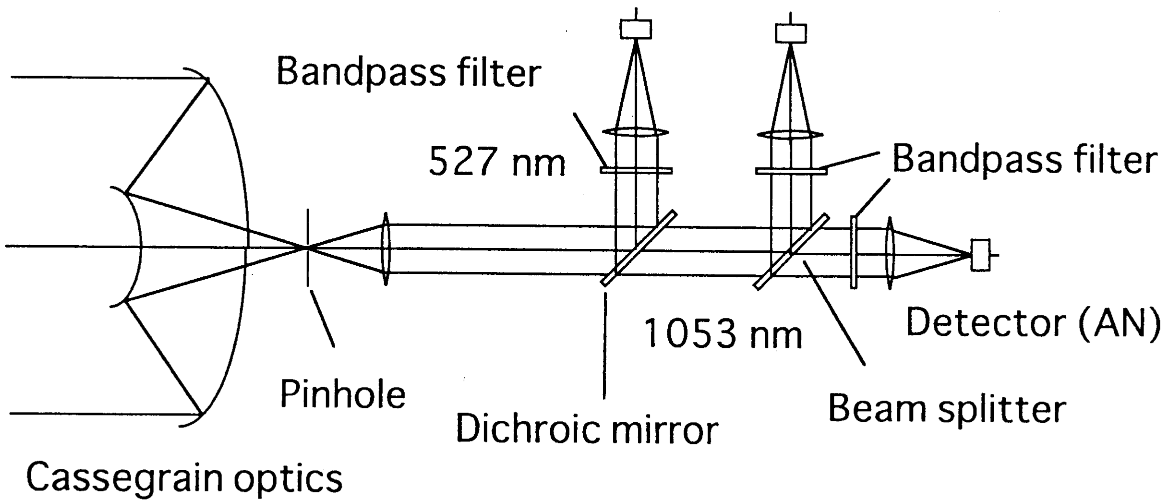
Optical System	A couple of deflecting prisms with rotator
Positioning Range	±2mrad
Positioning Resolution	≦0.01mrad
Positioning Accuracy	≦±0.01mrad

Table Material Tradeoff of Lightweight Mirror

Materials	Polishability	Deformation due to Thermal Change	Strength	Rigidity	Lightweight	Radiation Resistance	Actual Results	Total
Beryllium	○	△	◎	◎	◎	◎	◎	◎
SiC	◎	○	○	◎	◎	◎	△	○
ULE	◎	◎	△	△	○	○	◎	○
Fused Silica	◎	◎	△	△	△	◎	○	△
Zerodur	◎	○	△	△	○	△	○	△

Performance of Telescope (Preliminary)

Type of Optical System	Cassegrain
Effective Aperture Diameter	1000 [mm]
Field of View	0.19 [mrad]
Focal Length	6000 [mm]
Total Transmittance	81 [%] (including obscuration of secondary mirror and spider)
Material of Primary Mirror	Beryllium



NASDA 宇宙開発事業団

Fig. Shematic Diagram of Relay Optics

Table Performance of Relay Optics (Preliminary)

channel	#1 1053 nm AN #2 1053 nm PC #3 527 nm PC
Bandwidth of Interference Filter	10 [nm] (for PC) 0.3 [nm] (for AN)
Filter wavelength Shift	0.02 [nm / K]
Total Transmittance(*)	#1 39 % for 1053 nm AN #2 5.9 % for 1053 nm PC #3 60 % for 527 nm PC

(*) including Telescope, Dichroic mirror, Beamsplitter and Interference Filter

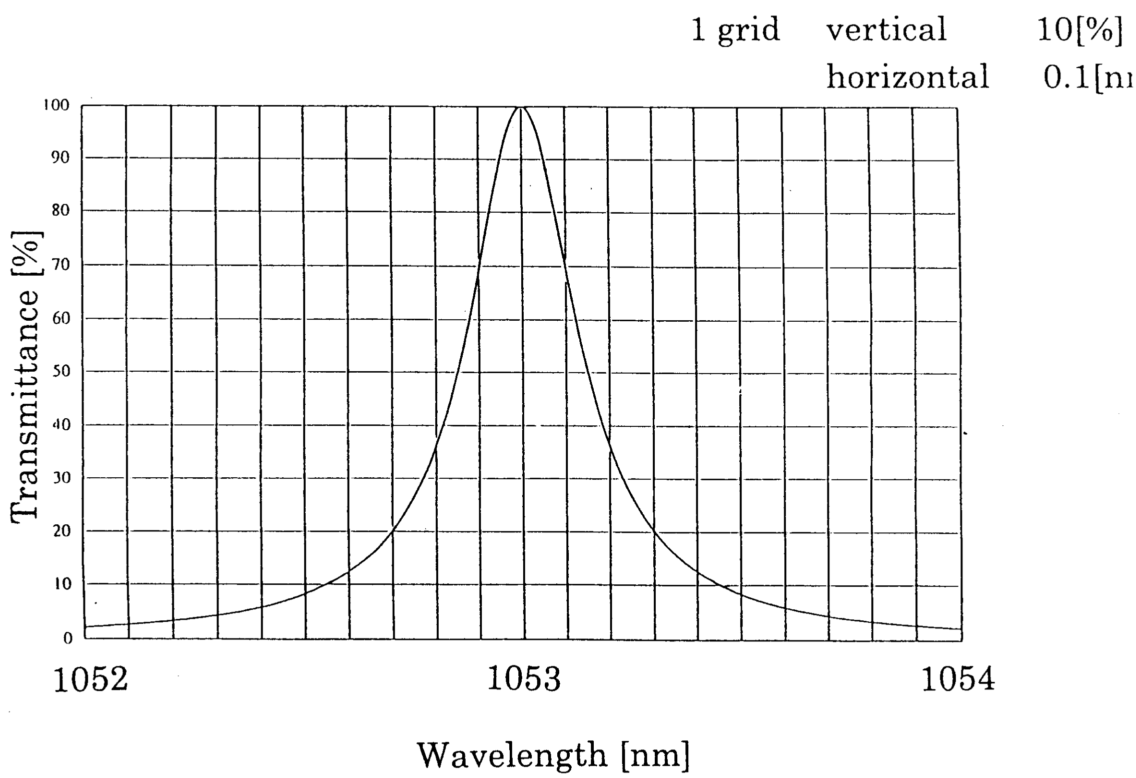


Fig. Characteristic of Interference Filter for 1053nm AN channel.

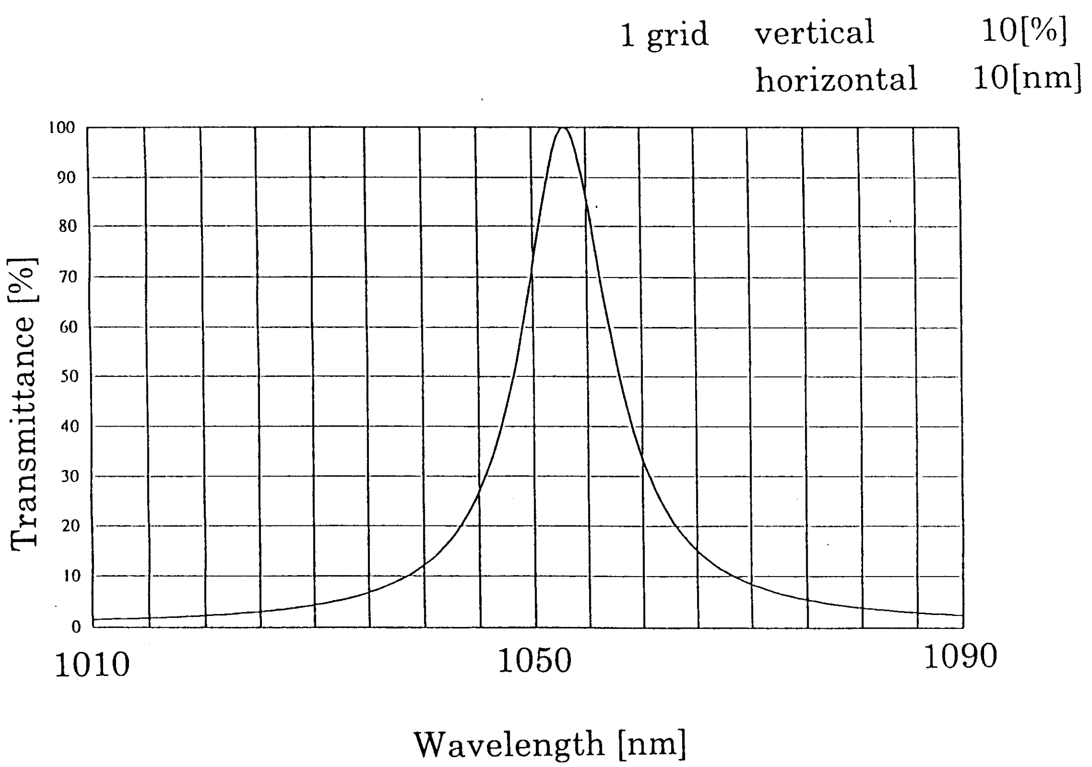


Fig. Characteristic of Interference Filter for 1053nm PC channel.

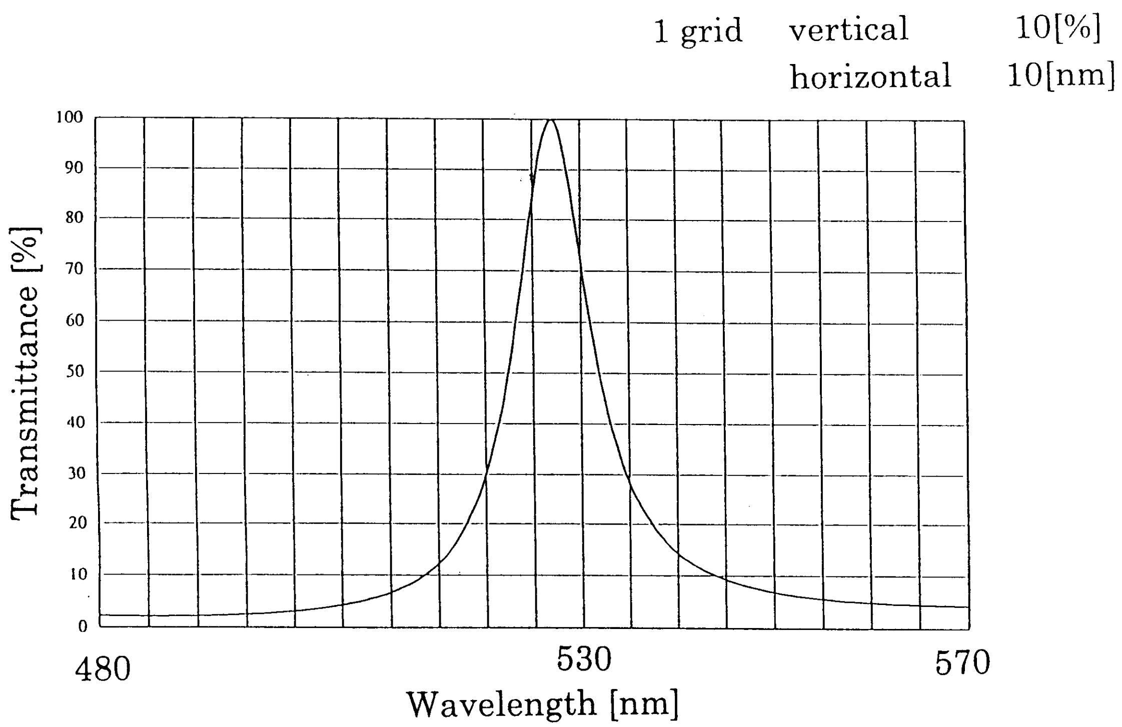


Fig. Characteristic of Interference Filter for 527nm PC channel.

Table Performance of AN Detector Module (Preliminary)

Detector Area Size	1.5 [mm] diameter
NEP	1.3×10^{-14} [W/Hz$^{1/2}$]
Gain	100
Quantum Efficiency	36 [%]
(Electrical) Band Width	1.5 [MHz]

Table Performance of PC Detector module (Preliminary)

Detector Area Size	0.5 mm diameter
Quantum Efficiency	39 % (at 527 nm) 1.5 % (at 1053 nm)
Maximum Count Rates	5 [Mcps]
Count Error	10 % (at 1 [Mcps])
Dark Count	250 [cps]

DM Progress Schedule