Eyesafe Coherent Laser Radar using Solid State Lasers
A comparative study:
towards longer or shorter wavelength?
by: Sugata Pikatan (K.H.Tan)

1. Introduction

Laser radar systems operate on the same basic principles as conventional radars in microwave region of electromagnetic spectrum, the difference being that they operate at much shorter wavelengths. The accuracy of their measurements is therefore higher and the resolution is more precise than microwave radars. From this point of view alone, radars using shorter wavelengths are more desirable. The other advantage of using short wavelengths is the small angular beamwidth produced, it enables radars to do fine imaging and precise target tracking.

Hard targets can be divided into two regimes: extended targets, when the beamwidth is smaller than the size of the targets, and point targets otherwise. Due to the narrow laser beamwidth, therefore most of hard targets can be treated as extended targets. Returning signal power from an extended target has a proportionality to inverse square of the radar range, not to inverse of the fourth power of the range as in the case of signal power from point targets.

Carbon dioxide lasers which operate at 10.6 µm have become an important device in laser radar technology. They have many advantages over the microwave radars including their very high electrical efficiencies, but unfortunately the systems typically require large rf power supplies and detectors cooled with liquid nitrogen. The development of solid-state lasers, which operate at shorter wavelengths and can use detectors without cooling requirement, offers a relatively light weight and small size laser radar. The solid-state laser radars also take advantage from the fast development of high efficiency and high power laser diodes for their pump source. This trend makes radar systems more compact and potentially less expensive to build.

Of course, it does not mean that shorter wavelengths do not have disadvantages. For coherent laser radars (CLR), which apply coherent detection systems, the major drawback of using shorter wavelengths is the greater coherence loss due to atmospheric turbulence [1]. If the wavelength goes shorter even further, another important deficiency appears — the laser is not safe to human eyes. Lack of eye safety occurs at wavelengths shorter than 1.4 µm, which lies in the infrared region of the electromagnetic spectrum.

Based on its biological effects, the infrared (IR) region is divided into 3 bands [2]:

- IR-A band : 0.78 µm - 1.4 µm
- IR-B band : 1.4 µm - 3.0 µm
- IR-C band : 3.0 µm - 1 mm

It is obvious that wavelengths in IR-A band are not eye-safe. Nd:YAG lasers, which operate at 1.06 µm have proven to be efficient and powerful devices for laser radar applications [3], except that they lack eye safety. The consideration of eye safety in laser radar technology has demanded alternatives to the versatile Nd:YAG. For this purpose
researchers have developed Tm,Ho:YAG laser radars in the last few years [1],[4],[5]. Tm,Ho:YAG laser operates at 2.09 µm, so the eyesafe solid-state laser radar study is now progressing in the IR-B band.

There are 3 atmospheric windows in the IR-B band : 1.55-1.74 µm, 2.08-2.14 µm, and 2.26-2.33 µm, as shown in the atmospheric transmittance graph in appendix 1. All other wavelengths in this band have strong atmospheric absorption, hence they cannot be applied in radar uses. To decide which window will be the best is not obvious, because their wavelengths are close to each other. Moreover, both short and long wavelengths have their own advantages as described above.

This comparative study will evaluate the three windows when they are applied to laser radar systems. In the calculation for laser radar performance, they are represented by wavelengths 1.63 µm, 2.09 µm and 2.30 µm, irrespective of the types of laser used. The study will start by reviewing the laser radar equations in section 2, and propagation in the atmosphere in section 3. Section 4 will describe parameters needed for the calculations of laser radar performance. The calculations themselves are in section 5 and will be followed by the latest development of Er:YAG (at 1.63 µm), Tm,Ho:YAG (at 2.09 µm) and Tm:YLF (at 2.30 µm) lasers in section 6. All assumptions and limitations are discussed in the corresponding sections.

7. Conclusions

There is a trade-off between the quality of the measurements and the required transmitted power for a given performance level shown by the SNR. It is evident from these calculations that longer wavelengths need less power, but have worse errors. Thus, economical CLR systems should use long wavelengths at the expense of worse quality measurements.

If the comparison is based on equal transmitted power, for a given range, short wavelength cannot compete with the longer ones, both in the resulting SNR and in the consequent measurement errors. In this case, the choice would undoubtedly be the longer wavelengths.

The Tm:YLF, which represents the longest wavelength in the atmospheric window within IR-B band, could be a promising candidate for applications in CLR systems. However, it has some disadvantageous lasing properties compared with the other lasers as discussed above. From the lasing characteristics point of view, apparently Tm,Ho:YAG is leading in all aspects over the other two. Further, since the wavelength of Tm,Ho:YAG is only slightly shorter than that of Tm:YLF, it would appear that Tm,Ho:YAG is the best choice so far.
References


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