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Laser Receiver Detection Techniques used in Laser Radar Systems

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Abstract

There are two types of laser receivers used in laser radar systems: incoherent and coherent. The incoherent detection receiver at optical wavelength is similar to a video radiometer receiver. An optical receiver has an additional term beside the signal term, which is the optical background power. The received signal competes with these external noise sources at the receiver.
The coherent detection receiver is similar to the incoherent, but a portion of the laser signal is coupled to the optical detector via beamsplitters.

Key words: *laser range finder, receiver, detection*

Introduction

Modern laser radar systems combine the capabilities of radar and optical systems to allow simultaneous measurement of range, reflectivity, velocity, temperature azimuth, and elevation angle. These six dimensions of target information can be utilized in fire control and weapon systems applications to allow target acquisition, tracking, classification and imaging.

Receiver Detection Techniques

In figure 1, diagrams are shown for incoherent and coherent detection receivers. The incoherent detection receiver at optical wavelength is similar to a video radiometer receiver. However, the optical receiver has an additional term besides the signal term, P_{SIG}, the optical background power, P_{BK}, which is due to undesired signals such as sunlight, cloud reflections, and flares. The received signal comptes with these external noise sources at the receiver. The received optical power, after suitable filtering, is applied to the optical detector; square law detection occurs, producing a video bandwidth electrical signal.

The coherent detection receiver is similar to the incoherent; however, a portion of the laser signal f_0, is coupled to the optical detector via beam splitters. As a result, the optical detector has the local oscillator power, P_{LO}, in addition to the received signal power, P_{SIG}, and the competing background terms, P_{BK}.

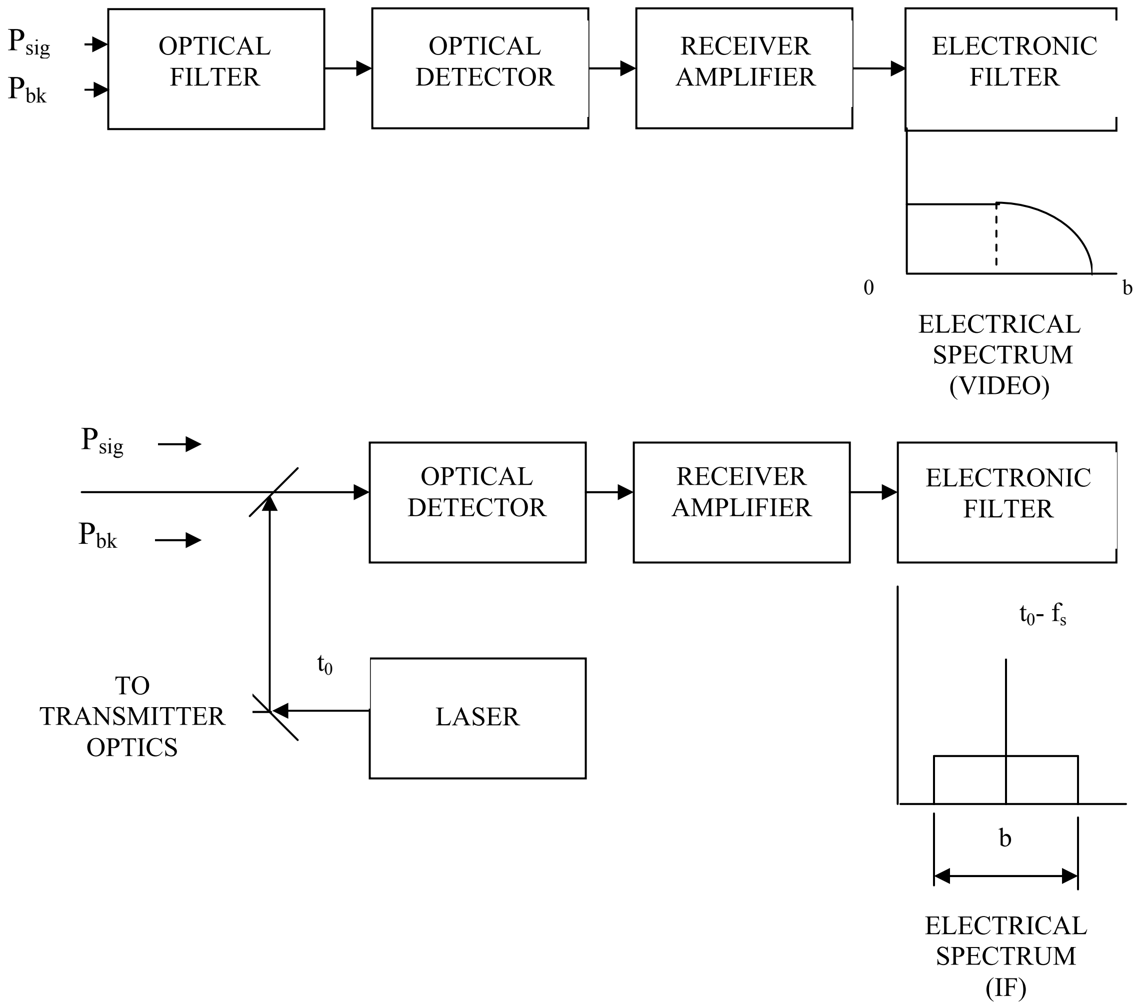

Fig 1. – Receiver systems

SNR expression development

The signal to noise ratio expression is:

$$SNR = \frac{i_{SIG}^2}{i_{SN}^2 + i_{TH}^2 + i_{BK}^2 + i_{DK}^2 + i_{LO}^2} \tag{1}$$

where:

i_{SIG}^2 - mean square signal current;

i_{SN}^2 - mean square shot noise current;

i_{TH}^2 - mean square thermal noise current;

i_{BK}^2 - mean square background noise current;

i_{DK}^2 - mean square dark noise current;

i_{LO}^2 - mean square local oscillator current.

The signal to noise expression above is shown to be related to mean squared signal current squared, divided by the summation of noise current terms squared. The summation of noise terms involves shot noise, thermal noise, background noise, dark current, and (with a coherent detection systems) a local oscillator. The photons or energy collected from the background results in a fluctuation of the carrier or electron densities in the detector, thereby contributing shot noise.

In the absence of photons at the detector, there is a current flowing, termed the *detector dark current*. Even tough the detector surface may be blocked from having any radiation applied to it, its internal physics causes this leakage current to exist. Thermal receiver noise, 1/f noise, and generation recombination noise can occur in both microwave and optical receivers. The thermal mean square noise current, which is conventionally referred to as the *receiver Johnson noise*, is expressed in terms of $4kTNBF/R_L$, where B is the electronic bandwidth, NF is the noise factor of the receiver following the detector and R_L is the detector load resistance. If a local oscillator signal is used for a coherent detection systems, the local oscillator signal itself generates a shot noise similar to the receiver signal and background radiation.

Comparison of Incoherent and Coherent Receivers

The SNR equation for incoherent detection may be expressed as:

$$SNR = \frac{\eta_D P_{SIG}{}^2}{hf\left[2B\left(P_{SIG} + P_{BK}\right)\right] + K_1 P_{DK} + K_2 P_{TH}} \tag{2}$$

The SNR equation for coherent detection may be expressed as:

$$SNR = \frac{\eta_D P_{LO} P_{SIG}}{hf\left(P_{LO} + P_{SIG} + P_{BK}\right) + K_3 P_{DK} + K_4 P_{TH}} \tag{3}$$

Where

SNR - signal noise ratio
η_D - detector quantum efficiency;
h - Plank's constant ($6,626 \mathrm{x} 10^{-34}$);
f - transmission frequency;
B - bandwith;
P_{SIG} - received pover signal;
P_{BK} - background power;
P_{DK} - equivalent dark current power = $A_d B/(D^*)^2$;
P_{TH} - equivalent receiver thermal noise $= \frac{4kTNBF}{R}$;
P_{LO} - reference local oscillator power;
k - Boltzmann's constant ($1,39 \mathrm{x} 10^{-23}$ J/^{o}K);
T - receiver temperature;
NF - receiver noise figure;

R_L - resistance;

$K_i = \dfrac{\eta_d}{\rho_i^2}$, i=1-2;

$K_j = \dfrac{hf}{2qp_i}$, i=3-4;

and:

ρ_i - the detector current responsivity (A/W);
D^* - specific detectivity (cm-Hz$^{1/2}$W);
A - detector area (cm^2);
q - the electron charge ($1{,}6\times10^{-19}$ C).

The SNR for the incoherent systems has the received signal power squared in its numerator, and has a summation of noise terms associated with the return signal, the background signal, the dark current, and the thermal noise of the receiver in the denominator. The return signal power and the background power are included as noise sources in the detection process because of the random photon arrival rate (Poisson noise). In the coherent detection systems, the local oscillator power is an additional noise source (compared to the incoherent system), and the numerator is related to the product of the received power and the local oscillator power The local oscillator power is very important in the detection process; here, it may be increased so that it overwhelms all of the other noise sources. As a result, the local oscillator power in the denominator cancels out the local oscillator power in the numerator; the SNR is directly proportional to the received power, rather than to the received signal power squared (as with the incoherent systems). Additionally, because the local oscillator power becomes the predominant noise source, the coherent detection systems typically is background immune, since only signals that are phase coherent with the local oscillator are efficiently detected.

For coherent detection where the local oscillator power is increased to provide shot-noise-limited operation of the receiver, the SNR expression for coherent detection can be reduced to:

$$SNR = \frac{i_{SIG}^2}{i_N^2} = \frac{\eta_D P_{SIG}}{hfB} \text{ or } SNR = \frac{\eta_D E_{SIG}}{hf} \tag{4}$$

where E_{SIG} is the received signal energy, B is the matched filter bandwith (B=1/T) and SNR represents the number of detected photons if η_D=1.

For a background noise-limited incoherent receiver, equation 2 becomes:

$$SNR = \frac{\eta_D P_{SIG}^2}{2hfBP_{BK}} \tag{5}$$

Figure 2 illustrates the reference transmitter power versus SNR relationship for coherent and incoherent detection laser radar systems using a typical 100 ns pulse width and the following parameters at 10,6 µm, η_D=0,5 and hf=$1{,}9\times10^{-20}$ J.

$D^*=2\times10^{10}\ \dfrac{cm\sqrt{Hz}}{W}$,

$\sqrt{A_d} = 0{,}03$ cm,

ρ_i=4 A/W

and R = 1 kΩ

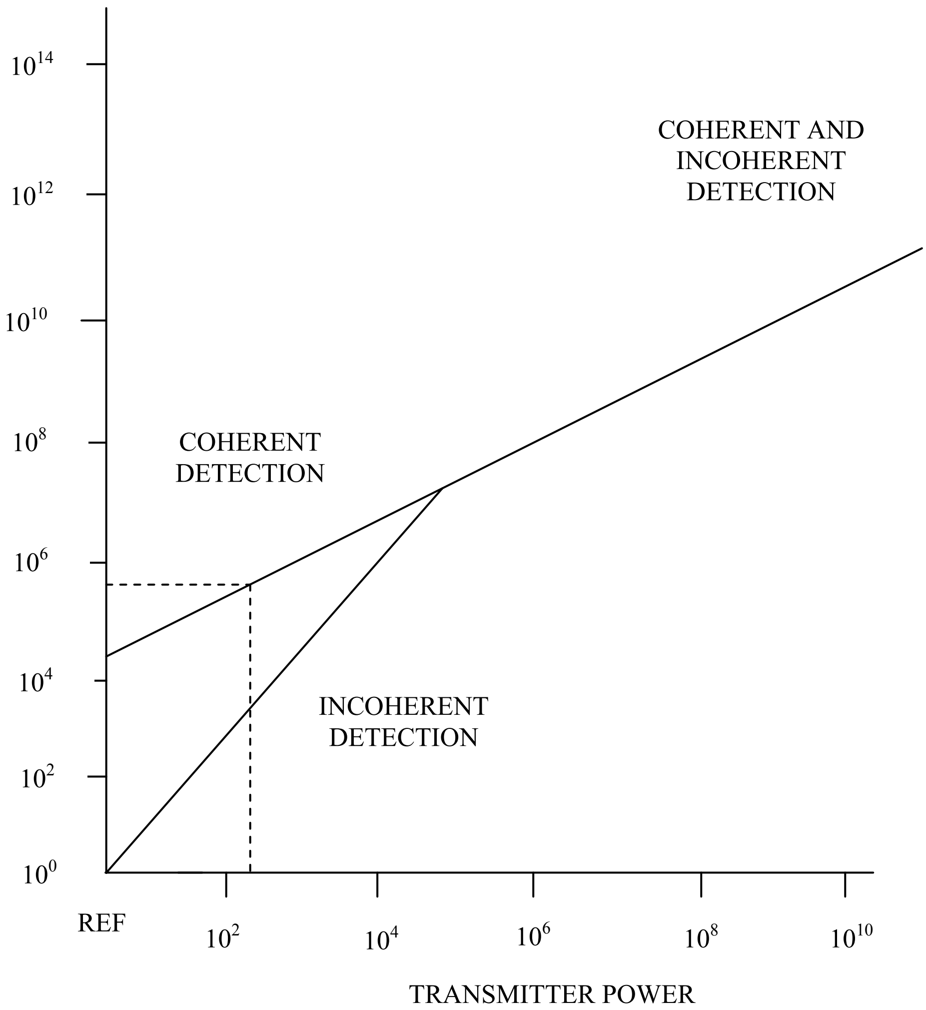

Fig 2. – Transmitter power versus SNR

It may be observed that as the SNR requirements increases, the transmitter power of the coherent systems increases linearly, and that of the ncoherent systems increases as the square root. In the limit, incoherent detection systems approach the sensitivity of coherent systems for very large SNRs. For a typical SNR requirement of 100 (20 dB), the coherent system is seen to have a 30 dB increased sensitivity over that of incoherent systems.

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Tehnici de detecție utilizate la receptoarele laser din compunerea sistemelor radar laser

Rezumat

Există două tipuri de receptoare de radiație laser utilizate în sistemele radar laser: coerente şi incoerente. Sistemele de detceție incoerente în domeniul optic sunt similare unui receptor de tipul unui radiometru. Receptorul optic are în plus, pe lângă termenul dat de semnal, un termen care exprimă puterea optică dată de mediul înconjurător. Semnalul recepționat se combină cu zgomotele date de diferite surse.

În ceea ce priveşte detecția coerentă, aceasta este similară cu cea incoerentă; dar au o porțiune a semnalului laser este cuplată cu detectorul optic printr-un sistem de divizare a fasciculului laser.