UDC 621.373.8+621.391+681.88 **DOI:10.30837/rt.2025.1.220.06**

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TARGETED INTERFERENCE TO LASER ACOUSTIC RECONNAISSANCE

Introduction

At present, methods and characteristics of laser acoustic reconnaissance (LAR) of information voiced at information activity objects (IAOs) are being improved. As a counteraction to this, certain sets of measures and means of protection against technical channels of information leakage (TCIL) of this nature exist and are used [1 – 3].

Methods of protecting speech information include organizational, passive and active. The latter are divided into methods using acoustic devices and methods using vibroacoustic devices.

Organizational methods of protecting speech information from possible leakage include a set of organizational measures aimed at ensuring a minimum risk of speech information leakage from protected premises. These measures include choosing a suitable room for confidential negotiations, ensuring the functioning of the relevant security service on the official territory, closing windows during a confidential conversation in order to prevent the conversation from being monitored by acoustic directional microphones, etc.

In the case of LAR, the passive methods of protecting speech information include choosing the optimal size of the window glass, since the smaller the window pane, the greater the elasticity of the window, which will ensure a lower amplitude of glass oscillation as a result of acoustic wave pressure.

Another passive method of protection against «laser microphones» is to stick a special film on the window pane, which results in the superposition of the beam reflected from the film with the beam reflected from the glass itself in the opposite phase, which ensures that the LAR cannot receive the signal reflected from the window pane. For this purpose, a special film of a given thickness is selected, which should correspond to a quarter of the laser wavelength, although, unfortunately, it is impossible to determine it precisely in advance.

An active method of protecting speech information using special acoustic noise-reducing devices involves creating powerful random acoustic noise in the room, which causes the window pane to vibrate according to a random law and makes it impossible for the LAR to detect a dangerous signal from the reflected laser beam.

By generating powerful acoustic noise, the corresponding devices affect the vibration of the window pane, which ensures the masking of the dangerous signal.

The law of unity of opposites determines the further development and improvement of measures to protect speech information on information activity objects (IAO), which emphasizes the relevance of research in this area.

This paper analyzes the peculiarities of the components of the said TCIL, and presents the corresponding general and individual models of this channel. A new method of protecting information broadcast in a dedicated room (DR) is formulated by using the reflection of the probing signal from the side lobes of the laser beam to influence the processing of a dangerous informative signal in the LAR.

An indirect method for estimating the amplitude of vibration of a window pane

Estimation of the parameters of window pane oscillation under the influence of the acoustic field in the DR is the basis for making a decision on the application of protection measures against LAR.

The determining factor in this is the amplitude of window pane oscillation $\Delta(t)$. The real value of this can be theoretically estimated using the following approach (Fig. 1).

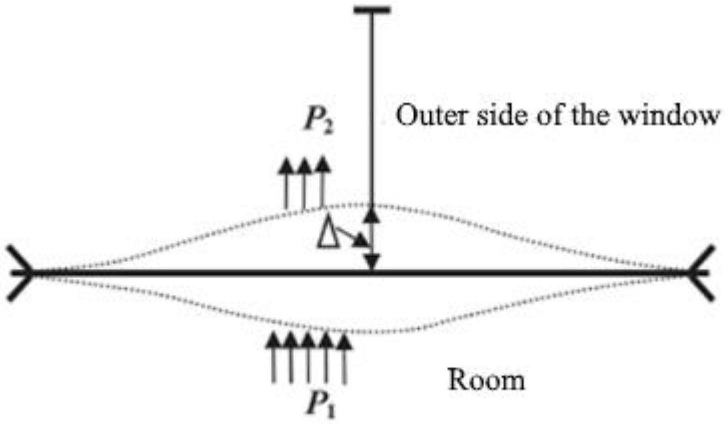


Fig.1. Window pane – the source of the optical part of the TCIL LAR

In the proposed model, P_1 is the sound pressure in front of the glass (in the room), P_2 is the sound pressure behind the glass, and Δ is the amplitude of the window glass vibration.

From the physics course, it is known that at any given time the pressure of a sound wave can be defined as:

$$P(t) = v(t)rc, \tag{1}$$

and for the case of harmonic oscillations as:

$$P(t) = P\sin 2\pi ft, \tag{2}$$

where P – is the pressure value of the sound wave;

$v(t)$ is the vibrational velocity of air molecules under the action of a sound wave;

r is the density of the atmosphere;

c is the speed of sound wave propagation in the atmosphere;

f is the frequency of harmonic oscillation of the acoustic wave.

To estimate the amplitude of window glass oscillation under the action of an acoustic wave, the following model of window glass oscillation with a clamped fixture in the frame was used.

The instantaneous value of the window glass oscillation $\Delta(t)$ is actually an integral of the velocity of the window glass molecules oscillating under the action of the sound wave, which in turn coincides with the velocity of the air molecules behind the window glass $v2(t)$:

$$\Delta(t) = \int v_2(t)dt = -\frac{P_2}{2\pi frc}\cos 2\pi ft \tag{3}$$

From this, it is possible to determine the maximum vibration amplitude of the window pane Δ for a given sound frequency f and sound pressure behind the pane P_2:

$$\Delta = \frac{P_2}{2\pi frc} \tag{4}$$

For normal atmospheric conditions, rc=420Н·С/м^3. Use to determine the maximum amplitude of vibration of the window pane of a window Δ for a given sound frequency f and sound wave pressure in the room P_1:

$$\Delta = \frac{P_1}{2\pi frc\cdot 10^{R/20}} \tag{5}$$

The value of R is taken from the formula for calculating the sound insulation of a window: $R=10lg(R_1/P_2)$.

Generalized illumination model of interference-type LAR photodetector

In this work, we use the LAR model based on the principle of the Michelson interferometer (Fig. 2).

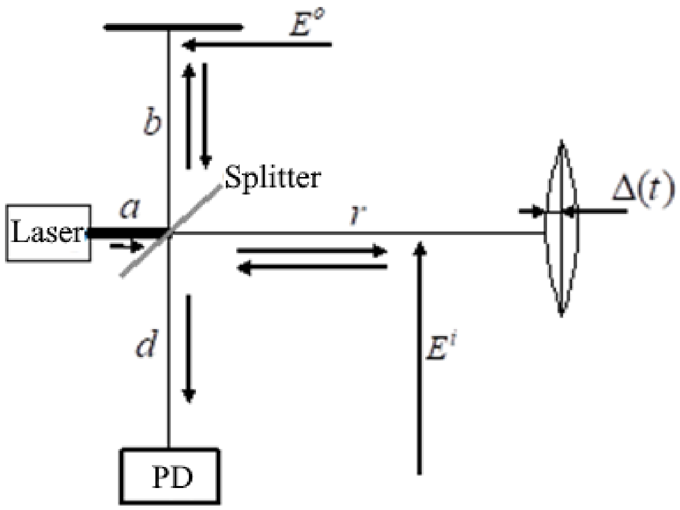


Fig. 2. Laser interference-type acoustic reconnaissance device

The information leakage is carried out through a conventional window pane, which is a kind of membrane that oscillates at the sound frequency under the pressure of acoustic waves of the conversation content. The emission generated by the laser propagates in space and, reflected from the surface of the window pane, is modulated by an acoustic signal. This reflected emission is then perceived by a photodetector, which reproduces the speech information in the room.

The splitter allows the incident and reflected beams to be brought together in one point. This makes it possible to combine the laser and the detector.

Interferometry can increase the sensitivity of a «laser microphone» if the reflected beams are coherent.

The wavelength of the laser can be between visible and infrared radiation. Even the far-infrared spectrum can be used. But the best wavelength is the near-infrared range. Modern lasers operate at frequencies of approximately $3{\cdot}10^{13} \div 3{,}75{\cdot}10^{14}$ Hz, i.e., the wavelength is in the range of 0,8 ÷ 10 micrometers, which is invisible to the human eye.

LAR have a range of 100 ÷ 500 meters or more.

When using a «laser microphone», it should be borne in mind that rain, snow, and fog can significantly affect the reflected signal, weakening it mainly due to scattering.

The illumination of the LAR photodetector is proportional to the square of the sum of the light vectors of the reference $E^o(t)$ and reflected $E^i(t)$ laser beams from the window pane:

$$I(t) \sim \left(E^i(t) + E^o(t)\right)^2, \quad (6)$$

For the field strength of the reference signal $E^o(t)$ of laser emission on the photodetector (PD), we can express (7):

$$E^o(t) = E^o \sin\big(2\pi f t + k(a + 2b + d)\big), \quad (7)$$

and for the field strength of the reflected signal on the PD $E^i(t)$:

$$E^i(t) = E^i \sin\Big(2\pi f t + k\big(a + 2r + d + 2\Delta(t)\big)\Big), \quad (8)$$

where E^o and E^i – are the amplitudes of the field strength of the reference and reflected signals, respectively;

f is the frequency of laser radiation;

k is the wavenumber;

a is the distance from the laser to the splitter;

b is the distance from the splitter to the laser reference mirror;

d is the distance from the splitter to the PD;

r is the distance from the splitter to the window pane;

Δ(t) is the function of window pane oscillation at the point of laser beam irradiation, which depends on the pressure of acoustic waves of the speech signal in the room.

The neutral filter sets the amplitudes of the field strengths of the reference E^o and reflected E^i signals so that $E^o = E^i = E$.

The illumination of the photodetector will be [4]:

$$I(t) \sim 4E^2 \left(\frac{1+\cos\frac{4\pi}{\lambda}(\Delta(t)-b)}{2} \right), \tag{9}$$

After the conversion, we can express it as:

$$I(t) \sim 2E^2 \left(1 + \cos 2\pi \left(\frac{\Delta(t)-b}{\lambda/2} \right) \right), \tag{10}$$

For the simplest case of a sinusoidal oscillation of a window pane:

$$\Delta(t) = \Delta \sin 2\pi F t, \tag{11}$$

where Δ is the amplitude of oscillation of the window pane at the irradiation point;
F is the oscillation frequency of the window pane.

In this case, the illumination of the photodetector *I(t)* will be determined by the expression:

$$I(t) = 2E^2(1 + \cos 2\pi(\beta - \alpha \sin 2\pi F t)), \tag{12}$$

where β – is the ratio of the difference in the path of the reference and reflected laser beams to half the laser wavelength, otherwise, the relative parameter of the laser reference mirror position setting; a – is the relative amplitude of oscillation of the window pane (relative to half the laser wavelength).

This expression makes it possible to visually check the correct choice of the LAR by minimizing the distortion of the detected signal.

Features of the lateral characteristics of the LAR emissions

LAR beam model plays an important role in the substantiation of the protection method proposed in this work.

The beam of the LAR is formed by an optical system from an infrared light source. On a window pane, the light spot usually has a size between 2 and 20 mm.

The emission pattern of such a beam can be determined theoretically based on the following assumptions characteristic of a circular field source with, for example, a uniform energy distribution [5]. In this case, the diameter of the lens d and the wavelength of the emission λ are determined. It was also determined that the normalized emission pattern of the field *F(θ)* of such a site can be determined quite accurately by the expression:

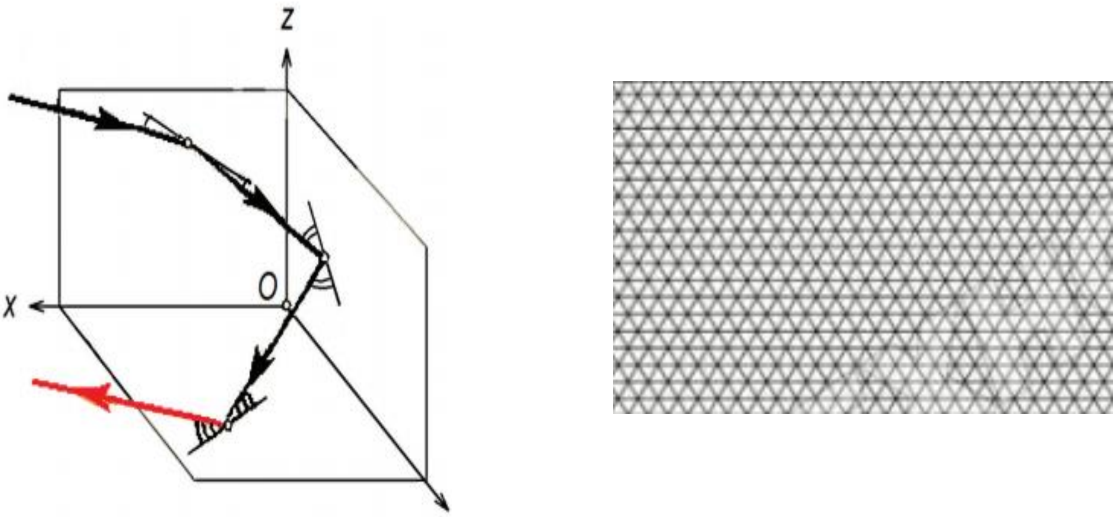
$$F(\theta) = \frac{sin\left(\frac{\pi d \sin\theta}{2\lambda}\right)}{\frac{\pi d \sin\theta}{2\lambda}}, \tag{13}$$

where: θ is the angle relative to the laser beam axis (within the direction of the window pane plane);
d is the diameter of the LAR lens.

It follows from (13) that, in addition to the main beam of the laser, emission sidelobes also hit the window pane, their intensity decreases with an increase in the angle θ.

Corner reflectors of the LAR beam

The lateral radiation field of a LAR beam represents coherent laser frequency signals. The possibility of using them to create frequency-targeted interference to the photodetector of the laser is almost perfect. The problem of returning these reflected signals to the side of the LAR lens is simply solved by using corner reflectors (Fig. 3).



a - Single corner reflector with the beam paths in it   *b* - Composite corner reflector – retroflector

Fig. 3. Varieties of corner reflector designs that can be used to create frequency and direction-targeted interference for LAR

The main characteristics of corner reflectors depend on their design and structural dimensions.

The work uses the effective surface, the value of which significantly depends on the ratio of the size of the corner reflector edge *a* and the wavelength of the infrared (IR) emission LAR beam λ.

If a corner reflector with triangular faces of size *a* is used, the radar cross section (RCS) equals

$$\sigma = \frac{4\pi}{3\lambda^2} a^4, \quad (14)$$

If the corner reflector consists of quadrilateral faces, the RCS is

$$\sigma = \frac{4\pi}{3\lambda^2} 3a^4, \quad (15)$$

As reflectors, you can use retroreflectors (cataphote), which are an assembly of several (dozens) corner reflectors.

Effect of a corner reflector on the perception of a reconnaissance signal

The use of corner reflectors to interfere the LAR is based on the addition of the reflected signal onto LAR PD (Fig. 4).

In contrast to the standard interference-type LAR usage scheme with applied settings, a corner reflector (CR) is installed behind the window pane in the DR at a distance R_{cr} from the window pane, in the area of LAR scanning. The RCS value of the CR is known for the working wavelength of the LAR beam.

The mass of the CR is so large that it cannot change its position under the influence of the sound pressure of the dangerous signal field, so as not to be an additional source of this signal.

Alternatively, the CR mount can be moved along the «laser – CR» line. Artificially, the movement can be carried out in time with amplitude M (to create a phase modulation of the reflected signal). This case will be investigated separately in the course of further research.

Optical signals on the PD (expr. 6) will create a light field

$$E(t) \sim E^{i}(t) + E^{o}(t) + E^{CR}(t), \quad (16)$$

The amplitude E^i $E^i(t)=E^i(\Delta(t))$, the component of the information signal modulated by the window pane vibration $\Delta(t)$, is determined by the distance *r*, the beam reflection coefficient from the window pane. It should be assumed that the operator can direct the LAR beam to the point of the window plane where the window pane vibrations $\Delta(t)$ have the optimal amplitude value for interception.

The amplitude $E^o(t)$ of the reference signal can be adjusted by the LAR operator to adjust it to receiving a signal with a filter bandwidth (not shown in the figure). In [4], it is determined that the optimal amplitude setting will be when it coincides with the amplitude value of the information signal. The transparency range of the filter should be expected to be from 1 to 0. In addition, the phase of the signal is selected by the location of the distance to the mirror b, to minimize the distortion of the received signal.

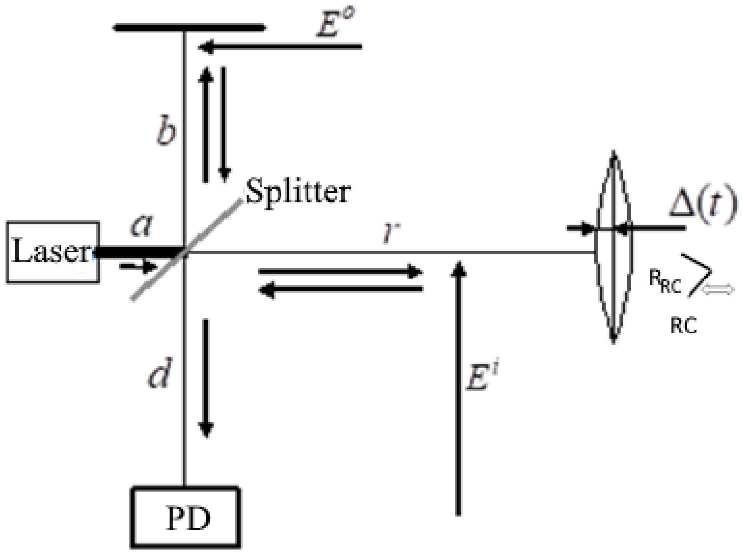


Fig. 4. LAR with an applied corner reflector (CR),
the mark ⟺ shows the option of artificially moving the CR

The amplitude of the $E^{CR}(t)$ component reflected from the CR depends on the level of lateral LAR emission, the distance to the CR (practically, the distance r), and is determined by the value of the CR effective surface σ of formulas (14), (15), which depends on the actions of the IAO protection service.

From the analysis of LAR principle of operation in the conditions of the CR usage, it can be noted that the total signal of the beams $E^o(t)+E^{CR}(t)$ will play the role of a reference (in the Michelson interferometer).

Setting up the optimal LAR performance according to the criterion of amplitude equality with the information signal field $E^i(t)$ will not always be achieved due to the control of settings by different parties – the LAR operator and the IAO protection service, which must counteract each other.

Thus, due to the addition of unmodulated signals $E^n(t)$ from the sidelobes, a component appears that does not allow the reconnaissance device to ensure the optimal reception of signals with a given quality.

The specific ratio of the interference signal to the information signal should be determined when introducing regulations for this method of protection against LAR.

Corner reflectors can be located in dedicated rooms in front of window panes, preferably near the expected location of the LAR beam. The weight of such devices, as mentioned earlier, should ensure their stable position (no vibration) under the influence of the sound field of the conversation).

Evaluation of the corner reflector usage possibility in the protection against LAR

The physical realization for the usage proposal can be assessed on the basis of energy ratios accepted in the practice of electronic warfare research.

The energy assessment of the effect of CR on the received dangerous signal is based on the ratio of the effective illumination of PD I_{CR} from CR to the effective illumination I_i by the dangerous signal from the window pane – the suppression factor:

$$C_s = I_{CR}/I_i, \tag{17}$$

The numerator of this expression can be written as:

$$I_{CR} = \frac{I \cdot F(\theta)^2}{4\pi r^2}\sigma(1 - C_R)^2 \frac{C_R}{4\pi r^2} = \frac{I \cdot F(\theta)^2}{(4\pi r^2)^2}\sigma(1 - C_R)^2, \tag{18}$$

where F(θ) – normalized diagram of the electric field directivity of the LAR (13);

C_r – coefficient of reflection of the LAR beam from the window glass;

$$I_i = \frac{I \cdot C_R \cdot F(\theta = 0)^2}{4\pi (2r)^2}, \tag{19}$$

After substituting into (17) and making the necessary simplifications, we can obtain an expression for the suppression coefficient C_s:

$$C_s = \frac{I_{CR}}{I_i} = F(\theta)^2 \cdot \frac{(1 - C_R)^2}{C_R} \cdot \frac{4\sigma}{\pi r^2}. \tag{20}$$

From this expression, it is possible to estimate the requirements for the characteristics of a corner reflector that is advisable to use for protection against LAR. So, for example, a square-faceted corner reflector for an infrared wave of 800 nm, a window with $C_R = 0{,}1$ and 3 distances of 100 m should have a face size of 0,053 m to ensure $C_s = 10$ at a laser emission sidelobe level of 0,001. This is quite possible to implement at IAO.

Conclusions

The work analyzes the possibility of using a new method of protection against interference-type LAR when trying to obtain information voiced at the objects of information activity.

Separate quantitative models of the LAR elements and the method of creating targeted interference are proposed.

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Received 04.01.2025

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