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LASER WARNING RECEIVER

by

Jin Mei

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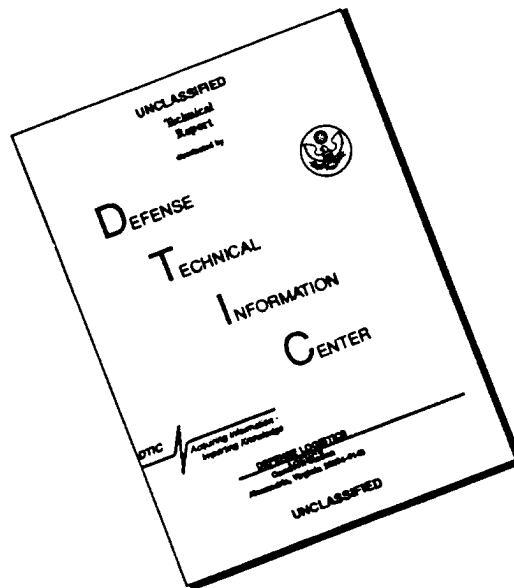


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LASER WARNING RECEIVER

Jin Mei

I. ROLE OF LASER WARNING RECEIVERS

In the last 20 years, the applications of lasers in military affairs have grown wider by the day. Laser range finding causes the first round hit probability for guns to very, very greatly increase. Laser guidance then increases in an extremely large way weapon launch precisions and hit probabilities. Cost benefit ratios are very high. The combat power of U.S. military forces has already improved an order of magnitude relying on these small energy laser systems.

How should fire control systems having laser range finding and laser guided weapons systems be handled? This simply requires timely discovery of the laser operations of the hostile side. Laser warning receivers are the basic materiel for implementing laser countermeasures. Their role is to detect in a timely and accurate manner enemy laser range finders, laser radiation emitted from such things as target indicators, laser beam guidance illumination devices, and so on, to send out warnings, and to make notification of certain types of weapons of a threatening nature (for example, artillery shells, bombs, or missiles) having a possibility of coming in immediately, in order to facilitate the adoption in a timely manner of friendly emergency measures, or evasion, or the laying of smoke screen aerosols to protect themselves, or to notify associated weapons systems (for example, guns or laser blinding weapons, and so forth) to implement countermeasures. As a result, laser warning receivers are very significant with regard to effectively protecting oneself and destroying the enemy on the battlefield.

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II. IDEAL LASER WARNING RECEIVERS

Designing a flexible laser receiver unit to use with "cooperating" laser transmitters would be much simpler. However, in "noncooperating" systems, receiver design becomes quite complicated. The reason is that, in noncooperating systems, laser devices belong to someone else (in military terms, the enemy side). All such parameters as laser wave length, angle of incidence, and so on, are unknown.

Before clarifying the performance requirements which laser warning receivers should satisfy, let us first make an analysis

in a general way of the characteristics of possible (illegible) laser threats. At the present time, laser devices used in laser range finding are primarily 1.06 μ m neodymium lasers. A new generation of laser range finders has already been successfully developed and mounted first of all on tanks (illegible) which use 10.6 μ m CO₂ and 1.54 μ m Raman frequency shift neodymium laser range finders. Laser pulse repetition frequencies with regard to ground artillery and tank range finders are mostly around 10 iterations per minute. With respect to antiaircraft and airborne range finders, they are 1-20pps. Target indicators used in laser homing guidance are almost all 1.06 μ m Nd:YAG laser devices. Through pulse encryption outputs, repetition frequencies are 10-20 pps. Functional ranges associated with laser range finding and target indication devices are generally around 10km. Laser illumination devices used in laser beam guided antitank and air defense missiles are primarily wave guide (illegible) CO₂ laser devices associated with 10.6 μ m and 0.9 μ m GaAs semiconductor lasers. They are spacial output pattern encryption or polarization encrypted continuous beams or ouput encrypted modulation pulse beams with pulse repetition frequencies between 1-100kHz. Laser beams associated with illumination devices go through variable focus optical system transmission, maintaining laser light spot diameters as constant at a few meters. Functional ranges are normally around 5km. Typical parameters associated with the main military lasers are seen in Table 1.

Table 1 Typical Military Laser Parameters

	① 测距机	目标指示器 ②	照明器 ③
④ 波 长 (μm)	0.69、1.06 1.54、10.6	1.06	0.9、10.6
⑤ 作用距离(km)	5~20	≤10	≤5
⑥ 束 散(mrad)	0.5~2	0.2~0.5	保持光斑直径为 8m左右 ⑦
⑧ 脉 冲 特 性	⑨ 峰值功率(W)	10 ⁶ ~10 ⁷	10 ⁶ ~10 ⁷
	⑩ 脉 宽(ns)	10~20	10~20
	⑪ 重复频率(Hz)	10 ⁻¹ ~20	10~20
	⑫ 编 码	-	⑬ 脉冲编码 脉冲编码或空间花样 编码, 或偏振编码。⑭

Key: (1) Rangefinder (2) Target Indicator (3) Illuminator (4) Wave Length (5) Effective Range (6) Beam Divergence (7) Light Spot Diameter Maintained Around 8m (8) Pulse Characteristics (9) Peak Value Power (10) Pulse Width (11) Repetition Frequency (12) Encryption (13) Pulse Coding (14) Pulse Coding or Spatial Pattern Coding or Polarization Coding

In the end, the crews of aircraft, tanks, or warships hope to know what type of laser beam detected laser beams are. Are they range finding lasers, target indicating lasers, or beam guidance lasers? It is only necessary to analyze out enemy laser pulse characteristics or wave lengths, and it is then possible to make this type of determination. Once range finding laser beams are detected, there will then normally be the approach of a missile after 4-8s. If laser guidance beams are detected, generally, targets will be hit by laser guided weapons (bombs,

artillery shells, or missiles) after around 20s. As a result, laser warning receiver reaction times must be adequately rapid. Only then is it possible to adopt corresponding countermeasures within the extremely short time periods described above. Due to the fact that one does not know at what time and from what direction enemy laser beams will come, as a result, warning receiver view fields must be quite large. It is best to be able to do fixed stare monitoring of the entire hemisphere air space. If that is not possible, it is then necessary to carry out scanning of the warning air space. In order to be able to accurately implement fire power countermeasures, it is also necessary for warning receivers to be able to do accurate direction finding with regard to laser devices.

Summarizing what was described above, ideal laser warning receivers should satisfy the following requirements: large reception view field, adequately wide spectral band width to be able to include all possible enemy laser wave lengths, detection probabilities approaching 100%, high positioning accuracy, reaction time close to 0, false alarms close to 0, output indications of wave length, incidence direction, and laser pulse characteristics, small volumes, light weights, and cheap prices. In actual battlefield environments--in situations where there is man made and natural background light interference--it is quite difficult if one wants to satisfy all the requirements described above. There are a number of requirements which are also mutually contradictory. As far as pursuing large fields of view is concerned, it is usually necessary to sacrifice positioning accuracy. If one wants to reach 100% detection probabilities, false alarms may be unacceptably high. The more parameters one wants to detect, the more time is spent... . It is necessary for designers to spend their efforts with a view to utilization objectives in order to appropriately handle these contradictions and carry out optimal compromises. /29

III. SEVERAL TYPES OF TYPICAL LASER WARNING RECEIVERS

Seen from the point of view of materiel that is in hand at the present time--as far as various types of laser warning receivers which have been studied and developed outside China are concerned--it is possible, in accordance with operating principles, to roughly divide them into the three classes of spectrum identification types, coherence identification types, and scattering detection types.

1. Spectrum Identification Types

Military laser wave lengths must have good atmospheric

transmission characteristics. At the present time, there are only a few already known wave lengths such as $1.06\mu\text{m}$ and $10.6\mu\text{m}$. If energy associated with a certain wave length among them is detected, then, it is very possible that it is created by nothing other than a laser device. This is nothing else than the principle of spectrum identification types of warning receivers. This type of warning receiver is also divided into types with imaging and without imaging.

(1) Nonimaging Types. This type of warning receiver normally uses one or a number of photoelectric diodes as detectors. Norway's Simrad company and the U.K.'s Lasergage company have developed and produced an RL1 model laser warning



Fig.1 RL1 Model Laser Warning Receiver

receiver which is a typical product. See Fig.1. This is a type of laser warning system supplied for use in armored vehicles. It is already mounted in units. It is composed of a detector fitted on the top of vehicles and a display device mounted inside vehicles. Detectors contain 5 pin silicon photoelectric diodes-- 4 in horizontal directions and 1 in a vertical direction. Display devices show the rough direction of laser sources by 9 light emitting diodes. Among these, 8 light emitting diodes are arranged in a ring, representing, respectively, 8 45° fan regions in horizontal directions. The center light emitting diode indicates the receiving of laser radiation coming from the space above. Each time a laser pulse is received, displays also simultaneously put out sustained 2s sound warnings. The main technical indices are seen in Table 2.

The detector sensitivity of this type of receiver is high. However, (1) following along with increases in the number of military laser wave lengths, structures become very complicated. (2) Directional resolution is very bad. It is only possible to determine in a general way the direction laser attacks are coming from. (3) False alarms are comparatively high. This type of receiver is primarily used in situations where positioning precision requirements are not high. As far as temporary detectors without imaging are concerned, it is possible to use them in intermediate and far infrared wave bands. This type of diode array is also practical.

(2) Imaging Types. Following along with the development of solid pick up devices, at the present time, we have already seen the appearance of fixed view type warning receivers associated with structures making use of wide angle centrifugal fish eye lenses and CCD photographic devices. The U.S. Army's photoelectric weapons countermeasures office and the Xiantong (illegible phonetic) company jointly developed the LAHAWs laser homing and warning system, which is a typical representative. In regard to LAHAWs--with the support of the U.S. Army--development began in 1973. In 1979, development was successful, and, in conjunction with that, reports were made public. It was composed of the two detection and display components. Optical system set up was as shown in Fig.2. Detection components used wide angle centrifugal fish eye lenses as objectives. Option was made for the use of dual light path background elimination as well as CCD imagery device detection. Among display components, option was made for the use of frame storage and image background subtraction method techniques. Only when pin photoelectric diode light paths detected the existence of laser light were enemy laser source positions shown on fluorescent display screens (azimuth and elevation). In light paths, option was also made

for the use of automatic optical gain control in order to prevent strong light saturation.

Table 2 Principal Technical Indices for RL1 Laser Warning Receiver

Detector Components		Indicator Components	
Detector No.	Horizontal 4 Vertical 1	Directional Discrimination	Horizontal 45° Vertical 45°
Detector Field of View	360°	No. of Fan Sectors	Horizontal 8 Vertical 1
Detector Type	pin photoelectric diode	Display Brightness Adjustment Range	>100x
Spectrum Bandwidth	0.66-1.1μm	Display Period	Sound 2s Light 8s
False Alarm Rate	<10 ⁻³ /h	Operating Voltage	10-32V (Nominal 24V)

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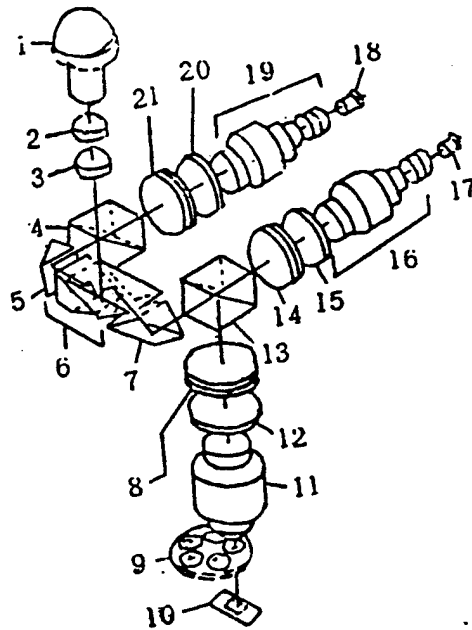


Fig.2 LAHAWS System Optical Lay Out Diagram

Key: 1. Wide Angle Objective 2. Blocking Light Filter 3. Field Lens 4. Beam Splitter 5. Folding Prism 6. Medium Beam Splitter System 7. Folding Prism 8. Collimation Lens 9. Automatic Electrical Level Control Light Filter 10. CCD 11. CCD Imagery Lens 12. Optical Filter (Laser) 13. Beam Splitter 14. Collimation Lens 15. Light Filter (Laser) 16. pin Diode Relay Lens 17. pin Diode (Laser) 18. pin Diode (Background) 19. pin Diode Relay Lens 20. Light Filter (Background) 21. Collimation Lens

The primary characteristics of imagery type receivers are:
 (1) opting for the use of wide angle centrifugal fish eye objectives, it is possible to realize full air space fixed view monitoring. It is not necessary to scan. The detection omissions given rise to by scanning do not exist. (2) Opting for the use of CCD imagery devices, the image element dimensions are very small (on the order of μm). Resolutions are high in order to supply prerequisite conditions for precision positioning. (3) Option is made for the use of dual light path frame subtraction technology, eliminating background interference, bringing out laser signals, and very, very greatly reducing the false alarm rate. (4) Due to opting for the use of narrow band filters, multiple wave length operations are comparatively difficult.

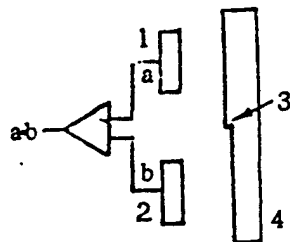


Fig.3 Fabuli-Poluo (Phonetic) Model Standard Device
 Key: 1,2. Detectors 3. Step Notch 4. Standard Device

(1) Using a piece of transparent parallel plate (fused quartz or germanium), the two surfaces are plated with half reflecting and half transmitting film, composing a Fabuli-Poluo (phonetic) standard device as shown in Fig.3. Part of the incident light penetrates through the flat plate. Part is reflected back by the rear surface to the front surface and again penetrates through the back surface after reflecting off the front surface. Light transmitted out will create interference. Light path differences associated with the two adjacent light rays sent out are:

$$\Delta = 2nd \cos \theta' \quad (1)$$

$$n \sin \theta' = \sin \theta \quad (2)$$

The intensity of light transmitted out is

$$I = \frac{I_0}{2} (1 + \cos \varphi) \quad (3)$$

(Illegible) is the phase difference associated with two adjacent light rays sent out /31

$$\varphi = \frac{2\pi \Delta}{\lambda} = \frac{4\pi nd}{\lambda} \cos \theta' \quad (4)$$

When there is rotation at uniform speed of flat plates around the axis line perpendicular to the light axis, intense light signals detected by photoelectric detectors (as in Fig.4) are in direct proportion to $T(\theta)$:

$$T(\theta) = \frac{1 + \cos \left(\frac{4\pi nd}{\lambda} \cos \theta' \right)}{2} \quad (5)$$

But (illegible), strong light signals are a frequency modulated (illegible) wave. Distributions are symmetrical to the two sides of $\theta = 0$. Making use of frequency discriminators, it is very easy to determine positive and negative signs associated with θ . Frequency discriminator output signals are fed back into stepped electrical equipment, causing standard devices to rotate until they sweep past the lowest point of frequencies associated with frequency modulated waves. It is then possible to measure out the size of laser beam incidence angle θ . Cycle intervals associated with frequency modulated signals corresponding to lasers of different wave length are different. As a result, it is possible to determine the wave lengths of laser light. The laser warning subsystems developed by the U.S. Perkin-Elmer company for multiple sensor warning receivers is designed on the basis of this principle. In order to reduce background light interference, the company in question opted for the use of level divided Fabuli-Poluo (phonetic) standard devices as shown in Fig.5. What is different from Fig.3 is that the front surface of the standard device has a "step". The upper half stands out above the lower half by an odd number multiple of $(\lambda/4n)$ (normally, one multiple is adopted as $\lambda/4n$, and vacuum plated films are used for realization). There are two photoelectric detectors corresponding to the rear surfaces of standard devices. Their bias voltage polarities are opposite. The two outputs are sent to summation amplifiers and added together algebraically. Because of this, frequency modulated signals formed by laser interference are not subject to influences. Moreover, direct current background signals--no matter what the angle of

inclination of standard devices is--are offset in all cases. The subsystems in question were successfully developed in 1978. In 1979, tactical demonstrations achieved success. The primary technical indices which were achieved were: operating wave length 0.45-1.1 μ m, reception view field 90°, detection probability 95%, false alarm rate $\leq 10^{-3}/h$.

The primary characteristics associated with Fabuli-Poluo (phonetic) coherence identification methods are that it is possible to specify laser wave length as well as direction of incidence, and false alarms are low. However, they require going through mechanical scanning. Only then is it possible to precisely specify whether laser light is present or not as well as technical parameters. As a result, there is no way to capture single iteration short laser pulses. This is the primary drawback. They are normally used in detecting light beams associated with laser beam guidance illumination devices.

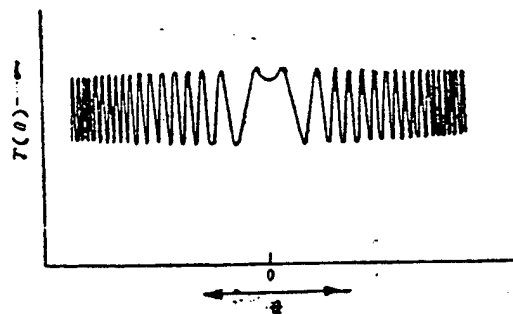


Fig.4 Strong Light Signals Associated with Detection by Photoelectric Detectors

(2) Maikersun (Phonetic) Models. In 1981, the U.S. electronic warfare system research laboratory made reports public with regard to experiments on the principles associated with LARA laser receiver analyzer instruments, obtaining the investment support of the U.S. Air Force avionics command. Fig.6 is a structural schematic of this type of warning receiver. The basic section is an interferometer composed of beam splitting prisms and two spherical reflector surfaces. Interference striations

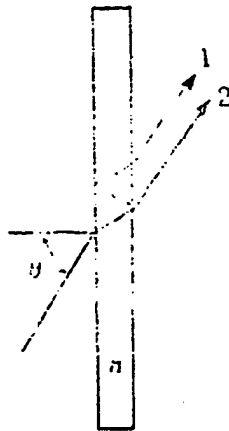


Fig.5 Divided Level Fabuli-Puluo (Phonetic) Standard Device Schematic /32

detected by a two dimensional array of detectors are put onto an observation screen. Noncoherent light does not produce interference striations. However, laser light produces a type of

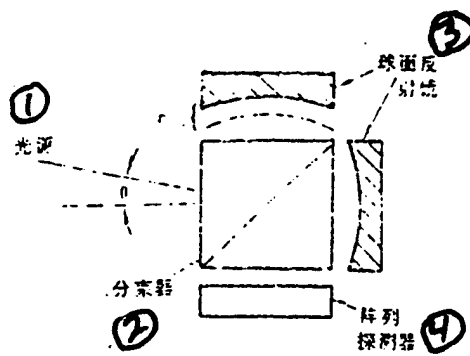


Fig.6 LARA Structural Schematic (1) Laser Source (2) Beam Splitter (3) Spherical Surface Reflector (4) Detector Array

"bull's eye" shaped concentric interference ring as shown in Fig.7. The center position of interference rings is

$$\vec{U}_c = -f'\theta$$

(6)

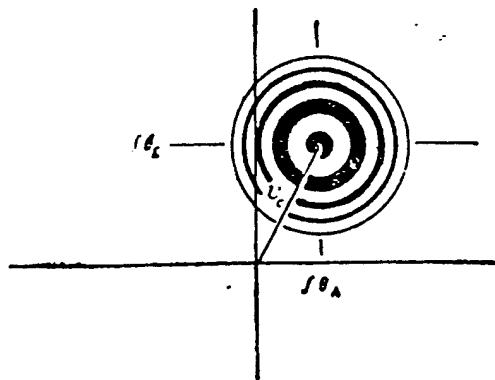


Fig.7 LARA Interference Striation Diagram

In this, f' is the system focal length. $\vec{\theta}$ is direction of incidence. Light intensity distributions are

$$I = \frac{I_0}{2} (1 + \cos\phi)$$

(7)

Phase function ϕ is

$$\phi = \frac{2\pi}{\lambda} \left(P_0 - \frac{2}{\epsilon} \left| \vec{u} \right|^2 - \frac{2}{\epsilon} \left| \vec{u}' - \vec{u} \right|^2 \right) \quad (8)$$

The first two terms of equation (8) and observation screen coordinates \vec{u} are not related. The remaining term

describes the spacial relationships associated with interference forms on observation screens. It is only necessary for array detectors to read interference rings and the explanation is then laser light irradiation. From circle center positions associated with interference rings, it is possible to precisely determine directions of incidence, and laser light wave lengths can be precisely determined from striation intervals.

The primary advantages associated with Maikeersun (phonetic) model coherence identification methods are that they are capable of precisely determining laser wave length and precisely specifying directions. It is not necessary to mechanically scan, and, as a result, they are able to capture short single iteration laser pulses. This is a type of laser warning receiver method which has great prospects.

3. Scattering Detection Models

The several types of warning receivers above need to intercept laser beams. Only then are they able to detect laser radiation. As far as detecting laser energy associated with atmospheric sol scattering is concerned, since it is not necessary to intercept laser beams and it is also not dependent on target surface characteristics, the only relationship is to the status of the atmosphere. Through analysis, it is possible to know that detection of laser energy associated with atmospheric scattering is one workable type of warning method.

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When lasers are transmitted in the atmosphere, they will be

subject to atmospheric absorption and scattering resulting in attenuation. Energy lost to absorption has been transformed into thermal energy. Energy lost to scattering, by contrast, produces reradiation. The wave lengths generally do not change (with the exception of when there is the occurrence of Raman scattering). In visible light to near infrared regions--within low altitude ranges in the vicinity of the surface--scattering effects surpass absorption. It is possible to come close to recognizing that atmospheric effects removing light are creating by scattering. Scattering is given rise to primarily by minute particles associated with gaseous sols suspended in the atmosphere--in particular, water droplets and dust--as well as atmospheric molecules. With regard to light of a certain wave length, the strength or weakness and distribution of scattering is related to visibility. When the sky is particularly clear, scattering elements are primarily atmospheric molecules. Molecular dimensions are very, very much smaller than optical wave lengths. As far as the the occurrence of Rayleigh scattering is concerned, it approaches a distribution which is homogenous in all directions. When weather is relatively bad, primary scattering elements are gaseous sols. Because the dimensions of minute particles associated with gaseous sols approach or are larger than wave lengths--as far as the development of Mishi (phonetic) scattering is concerned--small angle forward directed scattering occupies the dominant position. Calculations clearly show that scattering signals are very weak. Generally, they are quite a few orders of magnitude lower than radiated laser energy. In order to lower the influence of background light, it is necessary to reduce fields of view and opt for the use of spectral light filters. The U.K. Plessey radar company designed a set of scattering detection optical systems (see Fig.8). They are capable of supplying full air space warning and also very, very greatly reducing needed fields of view. Because the angles of outgoing rays are very small, it is a help in opting for the use of narrow band light filters to raise signal discrimination capabilities--reducing false alarms. Fig.9 explains the basic concept associated with this type of scattering detection warning receiver called "laser and infrared searchlight detector". Receivers are composed of scattering detectors and display devices. Scattering detectors are installed on the tops of vehicles. Fields of view develop out and down--forming a cone shaped cover completely "covering up" vehicles. Fields of view on perpendicular planar surfaces are 6°. Fields of view in horizontal directions are 360°. Lasers coming from any direction and shot onto any vehicle location, in all cases, necessarily pass through this "cover". When the "cover" is penetrated, laser energy scattered by gaseous sols is then able to be detected by detector devices. In the bottom of scattering detection devices, there is also a direct detection system. The two are sealed

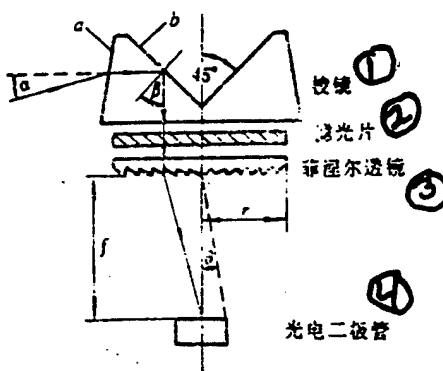


Fig.8 Optical Systems Associated with the Plessey Company's Scattering Detection Warning Receiver

Key: (1) Prism (2) Light Filter (3) Fresnel Lens (4) Photoelectric Diode

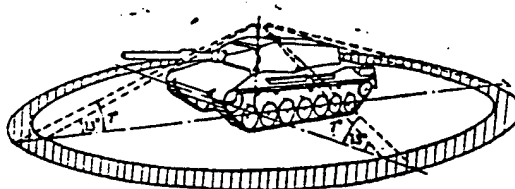


Fig.9 Concept of Plessey Company's Scattering Detection Warning Receiver

together into one entity. Direct detection systems are 12 silicon photoelectric diodes arranged in a circular array. Angular resolution is 15° . When direct detectors acquire laser beams, information associated with the directions they come from is the shown on display devices. The receivers in question have already had evaluations carried out on them by units in 1978. Under unusually clear skies, effective ranges exceeded 20km. After that, they entered production model development.

Table 3 Comparisons of Five Types of Laser Warning Receivers

① 类型	④ 光谱识别		⑤ 相干识别		⑩ 散射探测
	⑥ 非成像型	⑦ 成像型	⑧ 法布里-珀罗型	⑨ 迈克尔逊型	
② 优点	⑪ 简单 ⑫ 视场大 ⑬ 灵敏度低 ⑭ 成本低	⑮ 视场大, 可固定监视 ⑯ 虚警低 ⑰ 角分辨率较高	⑱ 使用单管探测器 ⑲ 虚警低 ⑳ 角分辨率高 ㉑ 能测激光波长	㉒ 虚警较低 ㉓ 无需机械扫描 ㉔ 能捕获单次激光短脉冲 ㉕ 角分辨率高 ㉖ 能测激光波长	㉗ 无需直接拦截激光束 ㉘ 使用单管探测器 ㉙ 可凝视监视
③ 缺点	㉚ 角分辨率低 ㉛ 不能测激光波长 ㉜ 虚警高	㉝ 不能测激光波长 ㉞ 成本高 ㉟ 需用窄带滤光片	㊱ 需机械扫描 ㊲ 不能捕获单次激光短脉冲 ㊳ 视场较小	㊴ 视场较小 ㊵ 成本较高	㊶ 光学系统难加工 ㊷ 要用窄带滤光片 ㊸ 不能分辨方向

Key: (1) Type (2) Advantages (3) Disadvantages (4) Spectrum Identification (5) Coherence Identification (6) Nonimaging Types (7) Imaging Types (8) Fabuli-Puluo (Phonetic) Model (9) Maikersun (Phonetic) Model (10) Scattering Detection (11) Simple (12) Large View Field (13) Low Sensitivity (14) Low Cost (15) Large View Fields, Capable of Fixed View Monitoring (16) False Alarms Low (17) Angular Resolution Comparatively High (18) Makes Use of Single Tube Detection Devices (19) False Alarms Low (20) Angular Resolution High (21) Capable of Measuring Laser Wave Length (22) False Alarms Relatively Low (23) No Need for Mechanical Scanning (24)-(25) Capable of Capturing Single Iteration Short Laser Pulses (26) Angular Resolution High (27) Capable of Measuring Laser Wave Length (28) No Need for Direct Intercpetion of Laser Beams (29) Makes Use of Single Tube Detection Devices (30) Capable of Fixed View Monitoring (31) Angular Resolution Low (32) Not Capable of Measuring Laser Wave Length (33) False Alarms High (34) Not Capable of Measuring Laser Wave Length (35) Costs High (36) Need to Use Narrow Band Light Filters (37) Need Mechanical Scanning (38) Not Capable of Capturing Single Iteration Short Laser Pulses (39) View Field Comparatively Small (40) View Field Comparatively Small (41) Costs Relatively High (42) Optical Systems Difficult to Machine (43) Need to Use Narrow Band Light Filters (44) Not Capable of Resolving Direction

IV. CONCLUSIONS

Above, several typical types of laser warning receivers just in the midst of test manufacture and development outside China are introduced. Comparisons of their advantages and disadvantages are seen in Table 3. Spectrum identification models are simple and cheap. Coherence identification models are the only warning systems at the present time capable of detecting laser wave lengths. Scattering detection models detect atmospheric scattering of laser light. There is no need to directly intercept laser beams. The principles still belong to spectrum identification. No matter which type of warning receiver it is, in all cases, it will be subject to limitations associated with the development of current technologies. Obviously, without wide spectrum detection devices with good performance, it would then be impossible to make laser warning receivers in the whole laser wave band from the visible to the far infrared. We should select different detection methods with a view to different utilization objectives to carry out optimized design. It is possible to confirm that laser warning receiver performance will follow along with the development of optical devices, optical working, photoelectric detection devices, and very high speed integrated circuit technologies as well as imagery processing technologies and improve by the day.