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Performance of the multifunctional CW CO_2-laserradar at the TNO-FEL laboratory and during the BEST TWO field test.

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ABSTRACT (UNCLASSIFIED)

CO(2) p

Measurements have been performed with the multifunctional CW CO_2-laserradar system, both at the TNO-FEL laboratory and at the BEST TWO field trial.
The BEST TWO (Battle field Emissive Sources Test under European Theatre Weather and Obscurants) trial was held in France, at Camp de Mourmelon, from July 26 to August 10 1990. NATO AC/243, panel 4, RSG 15 arranged this trial to test battlefield effects on longe range target acquisition by electro optical systems.
This report describes the results and experience gained from these experiments, and gives recommendations for further improvement of the multifunctional laserradar set-up. (25) → to p. 46

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SAMENVATTING (ONGERUBRICEERD)

Metingen zijn verricht met het multifunctionele CW CO_2-laserradar systeem, zowel op het FEL/TNO laboratorium als ook tijdens de BEST TWO veld oefening.
De BEST TWO (Battle field Emissive Sources Test under European Theatre Weather and Obscurants) oefening werd gehouden in Frankrijk, op Camp de Mourmelon, van 26 juli tot 10 augustus 1990. NATO AC/243, panel 4, RSG 15 organiseerde deze oefening om slagveld effecten op lange afstands doel detectie van electro cptische systemen te testen.
Dit rapport beschrijft de resultaten en ervaringen opgedaan tijdens deze experimenten, en geeft aanbevelingen voor verdere verbeteringen van het multifunctionele laserradar systeem.

1 INTRODUCTION

The multifunctional CW CO_2-laserradar system has been designed and built to study and test the properties of such a system with regards to a number of applications. Measuring range and velocity of targets can be performed, as well as obtaining and recording vibration spectra of target vehicles.

This laboratory system has been used for measurements under battlefield conditions by participating in the BEST TWO trial. For this purpose the set-up was installed into a van, as shown in Fig. 1.1.

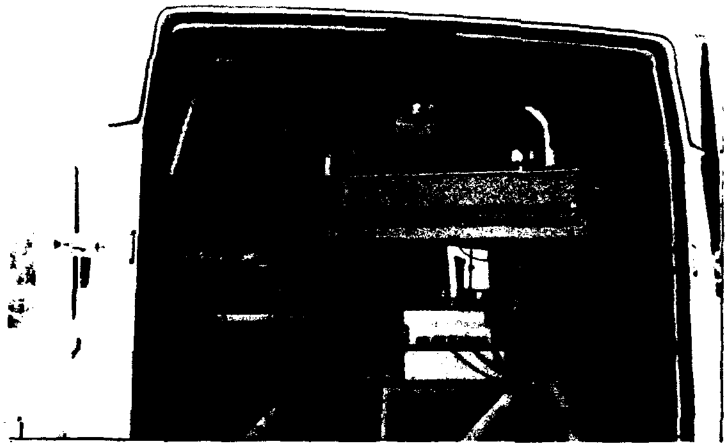

Fig. 1.1 The laserradar set-up in the van

This report first focusses in chapter 2 on the differences in conditions between the TNO-FEL laboratory and the BEST TWO location, the military site Camp de Mourmelon in France.

The experiences gained in using the system in these conditions are the base for chapter 3, where the system properties are discussed. These are treated seperately for optical, mechanical, and computer-based aspects.

Chapter 4 first describes the BEST TWO trial, and then focusses on the measurement results of the laserradar system.
Experiments performed at TNO-FEL established knowledge on qualitative aspects of the output, the performance, and the reproducability of the system under laboratory conditions. These are described in chapter 5.
Then in chapter 6 a list of recommendations is given for improving the set-up, both as the optics, the electronics, and the computer equipment are concerned.
Finally, some conclusions from the experience gained by participating in the BEST TWO field test are given in chapter 7.

2 OPERATIONAL CONDITIONS

The TNO-FEL multifunctional laserradar was primarily developed for use in a laboratory. It is not designed, nor built, to operate according to military specifications related to battlefield conditions. Because of their significance, attention is paid to some differences between the experimental conditions in a laboratory and in the field.
We will describe the specific conditions for performing measurements at the TNO-FEL laboratory and at the trial site Camp de Mourmelon in France.

2.1 Laboratory conditions

At TNO-FEL the laserradar system is placed in a wooden shed on the concrete roof of the laboratory, six stories high. The room measures about 8 m^2, and is supplied with electrical heating and cooling (airconditioning) equipment, in order to keep the temperature in a range that suits both the equipment and the operator.
Electricity supplies are available at both 220 V and 380 V.
All operational conditions are thus very stable, tools and technical support are at hand.
The shed has windows facing three directions, to perform measurements at a multitude of objects located around TNO-FEL.
For alignment and testing of the set-up, an assembly consisting of a pyro-electric detector and a retroreflector are mounted onto a tower, called the "Meteotower", at a distance of a good 300 meter from the roof shed. The detector signal is available at the roof shed through a coaxial cable.

2.2 BEST TWO conditions

The map of the test site at Camp de Mourmelon, France, is given in Fig. 2.1. From the main instrumentation area (MIA), the terrain sloped down gently, to curve up again at a distance of about 2 km. The far edge of a wood was a good 4 km from the MIA. The field between the MIA and the far edge of the wood will be called the scenario.
At the MIA the scientific teams set up their equipment in a line, so that everyone had a free view into the scenario.
As there was no central electrical power supply, most teams used their own generatorss, which were installed at the edge of the wood directly behind the equipment line.
The operational circumstances differed quite a lot from those at the TNO-FEL laboratory.

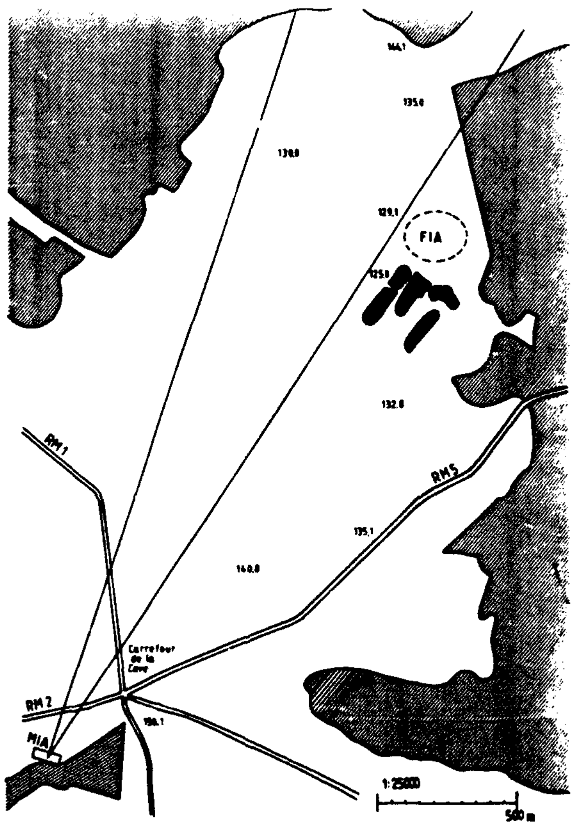

Fig. 2.1 Map of BEST TWO testsite, Camp de Mourmelon

The temperature varied between 24°C and 38°C, there could be some wind, and always there was a lot of sand dust in the air.

The soil of the site is described by the Bureau de Recherches Géologiques et Minières de Reims [1].

The location of Camp de Mourmelon is on the geological chalk layer of the Senonian period. There is only a few cm or dm of vegetable soil, which contains a lot of chalk particles.

The chalk in this region has two characteristics. First its chemical composition is particularly pure, containing 99.9% of calcium carbonate. Secondly, it has a very fine porous structure; the particles of size 1 or 2 µm are stuck together in a well spaced way, leaving 30% vacuum.
As a consequence of its structure, the chalk wears away easily and the atmosphere is full of dust. For example, it takes only one run of a vehicle to raise a substantial cloud of dust.
As the particles in these clouds of dust are extremely fine, comparable to flour particles, they can float in the air for a long time; this causes the clouds to be large and thick.
It is of interest that other soils in Europe, in the east of France, in Germany, and in Italy, give dust of the same chemical composition, but they differ from the Mourmelon chalk in two ways. First, they are much harder than the Mourmelon chalk, so that it would take several runs of vehicles to raise a substantial cloud of dust. Second, they contain traces of iron and manganese oxides, which gives the dust a yellow or ochre colour, whereas the Mourmelon chalk is very white.

Our electrical power was provided by a 3.6 kVA generator, supplemented by 2 kW power supplied by a 20 kW generator of the Dutch Army.
The set-up was built in a van, that was stabilized on four sides on piles of bricks. It goes without saying that little space is available inside the van. Care had to be taken in moving around the van, for two reasons. In the first place, moving around would cause the van, and thus the set-up, to wiggle. Especially vibration detection measurements are to be disturbed by movements of the set-up. In the second place, the risk of bumping into equipment, causing disalignment or damage, was very much present.
In contradiction to the situation at the laboratory, at the BEST TWO site there was no technical support, neither was the convenience of a telephone network. A radio communication system was used instead.
A significant problem at the field site appeared to be the alignment of the set-up. In our method at the TNO-FEL laboratory we use a detector/retroreflector at a distance of about 300 meter. In Mourmelon however, there was no such equipment readily installed. We performed the alignment in several steps as follows.
First the optical alignment on the laserplatform itself was checked, using fluorescence plates, to detect the laserbeams, as usual.
Next, a detector/retroreflector was placed at 55 m, connected to the oscilloscope in the van. After aligning at this distance, the vertical adjustment should be correct. Due to the paralax between transmitter and receiver axis, a horizontal misalignment remained.

The horizontal deviation of the transmitter and receiver axis could be calculated knowing that the beams coïncided at the range of 55 meter. Thus a correction was calculated for the horizontal adjustment of the HgCdTe detector. After optimizing the local oscillator beam to this new HgCdTe detector position, the set-up was finally aligned, using a retroreflector placed at a good 3 km. The last step was adjusting the local oscillator again.
During the BEST TWO trial the HgCdTe detector had to be removed from the laserplatform. After remounting the detector the problem arises of finding a position for it to start optimizing the alignment of the receiver beam.
It proved to be necessary to place a heat source with a chopper in front of it, as well as the detector/retroreflector, at a considerable distance. For this purpose the aforementioned equipment, together with an oscilloscope and a generator was transported 500 meter into the scenario. The operator who installed the equipment was in contact with the operator performing the alignment in the van, by means of a portophone.
The transportation and installation of the equipment, as well as the interactive alignment procedure, where two persons communicate using portophones, proved to be quite difficult and, more important, very much time consuming.

A major difference in performing measurements in a laboratory and a trial environment appeares to be the available time. At the laboratory, measurements are usually performed at stationary objects, intended to test a certain aspect of the system. In a field trial however, the targets are vehicles, moving according to a certain scenario. Measurements are to be performed at well chosen times when the target is either moving or, for a few moments, stationary. In addition, the operator may wish to perform measurements on different targets, and thus has to be able to redirect the transmitter laserbeam onto a new target in a very short period of time.

Another factor which amounts to the performance problem is the fact that in a field trial targets may be poorly or not at all visible by the operator; this might be caused by the dust/smoke raised unintentionally by the vehicles or intentionally as part of the trial scenario.
A last troubling circumstance during BEST TWO was the frequent use of eye-damaging lasers. Whenever this equipment was used, all personnel at the test site had to wear laser goggles. At temperatures of over 35°C, this definitely was quite a hindrance while carrying out the job.

During a measurement session, the transmitted laser beam could be aimed at a target using several aids.

The telescope viewer, having the best optical performance, was used to locate and aim at vehicles at large distances: > 3 km. However, when using the telescope viewer it was quite difficult for the operator to control the computer keyboard and so to start a measurement.
Furthermore it was impossible to read the oscilloscope at the same time to check the received signal.
At shorter distances the video camera was used to aim at a target. The visualizing of this video signal on the computer monitor presented the user with an advantage as well as a disadvantage. The monitor is mounted in the 19" racks as is the oscilloscope, so they can be viewed at the same time. But as the monitor is also used to visualize the computer output, video can not be viewed at the same time as computer output.
The method of combining the video with the oscilloscope proved very useful though at shorter distances, especially during the characterization (CHAR) scenario. Here vehicles would be stationary and sometimes hidden between bushes or behind trees. Scanning slowly, manually, over a target, the spots on a target that yield the best beam reflection can be determined using the oscilloscope.
A last method of locating objects was simply by eye: looking just over the scanmirror often proved to be much more practical to locate a particular spot in the scenario. As the video camera yields a monochrome picture and a limited angle of view, it could be very convenient to locate an object roughly by eye, and only then adjusting the beam upon the target using the electronic crosshair in the video picture.

A typical measurement would start with the announcement through the radio communication of the starting time of the scenario, that is the time that the target vehicle(s) would start moving into the scenario. The target(s) can move in a course towards the MIA, or maybe taking a place somewhere in the field with their engine either shut off or running. During this period explosions of different kinds could occur, either at 250 m from the MIA, or further in the scenario, at about 3 km distance. Finally the target vehicle(s) would leave the scenario, and the start time of the next scenario was announced through the radio.

3 OPERATIONAL PROPERTIES OF THE SYSTEM

In this report, the description of the system is separated in a part which emcompasses the computer hardware and software, and a part containing the rest of the set-up, being the laserplatform, the cooling system, and the additional electronics.
During the BEST TWO trial some properties of the multifunctional laserradar system became apparent causing performance reducing effects.
In sections 3.1 and 3.2 we will discuss the peculiarities of the system that were encountered during the trial. Some of these had already emanated during the last few years at the laboratory, but have not been described earlier.
In this chapter, we will merely list the items; the recommendations arising from them are to be discussed in chapter 6.

3.1 Mechanical and optical properties

In this section a number of properties will be discussed that proved to be impractical, or features that did not function properly. Furthermore some accessories will be suggested that are not yet part of the system, but would be very useful. At last some remaining imperfections of the set-up are discussed.

1) The choppers on the laserplatform are designed to modulate the beam with a frequency of about 30 Hz. It appears that this frequency is quite low with respect to the oscilloscope that is used to visualize the chopped beam. It results in an unstable display on the oscilloscope.
One chopper, which is not mounted on the laserplatform, but which was used in combination with an infrared radiation source in the alignment procedure, operates at more than 200 Hz. It appears that this signal results in a much more stable output on the oscilloscope screen, enabling easier and better optimization of the optics on the laserplatform.
2) The liquid nitrogen level in the dewar of the HgCdTe detector is indicated by a LED-bar indicator, which is controlled by a plastic tube with resistors, placed in the dewar as a sensor.
The bottom of the plastic tube tends to get frozen over in a warm environment, thus restraining the sensor system to accurately react to a change of the nitrogen level; it rather reacts with a delay of several tens of seconds.

The LED-bar itself is located at the side of the laserplatform. Although logical, it is not the most convenient placement. Perhaps it would be better to place a nitrogen level indicator into one of the 19" racks, that already contains the other electronics to control the set-up.

3) In the current set-up, a crude determination of laser power is possible, by visualizing the signal of pyro-electric detector #1 on an oscilloscope. However this does disturb the ability to monitor other signals on this oscilloscope at the same time. Thus, it would be very convenient to have an analog meter indicating the laser beam power; this should be mounted into one of the 19" equipment racks.

4) With our system, the operator cannot aim at, or locate, a target whenever it is dark, or even "early in the morning". Also the presence of smoke clouds, as well as sand and dust, raised by artillery explosions, will block the operators view onto possible targets.
For this purpose the operator of our set-up could be aided by the cooperation with a nearby located thermal imaging system.

5) The telescope viewer that was incorporated into the set-up proved to be useful. It supplied a more detailed view of vehicles than the current video-camera could provide. On the other hand, we encountered some problems as well.
In the first place, it appeared that the crosshair, which is incorporated in the objective, alters in vertical direction when the telescope is focussed. Thus an alignment performed at short distance is useless when ranging targets that are quite remote, and vice versa.
In the second place, the present mounting of the telescope onto the laserplatform is not optimal. The field of view of the telescope is not fully covered by the large scanmirror, which results in a loss of definition and light intensity of the target view.

6) Some of the optical elements (mirrors and beamsplitters) do not seem to be fixed ruggedly in their postition after alignment. This showed in the environment of the BEST TWO trial, where at times the set-up was subject to vibrations or shocks.

7) There are a lot of non-optical parts mounted on the laserplatform, that are not necessarily needed there. This causes the platform to be large, heavy, and difficult to manoeuvre when aiming at a target.

The same applies actually to the movable support that carries the laserplatform. It holds not only the optical set-up, but the cooling unit, the laser stabilizer, and the ETA control unit as well. This makes the total set-up quite inflexible, and vulnerable, with regards to using it at non-laboratory sites.

8) Some parts on the laserplatform are not accessible or adjustable without losing the optical alignment. This holds especially for the pre-amplifier; it is mounted onto the HgCdTe detector in such a way that the alignment is always seriously disrupted when the pre-amplifier must be dismounted from the set-up.

9) Some parts are difficult to access with tools. Though this is not an important inconvenience, it might be of consideration for future improvements or rebuilding of the set-up.

10) The placement and reading of fluorescence plates during the alignment procedures give rise to some difficulties. It would be convenient to designate some particular places in the beam paths, where the fluorescence plates can, and should, be inserted and examined. In this approach, any operator should adjust the set-up in the same way.

11) The laser beam is not screened at the sides of the platform. Thus there are positions at which one can easily burn oneself, or ones clothes, with the laserbeam when performing an adjustment.

12) The unit that cooles and circulates the coolant around the laser head and through the acousto-optic modulator proved to be not capable of maintaining a temperature of 12°C, whenever the ambient temperature was over than 35°C. During the BEST TWO trial, this implied that the set-up could not be operated either, until the temperature inside the van dropped below about 30°C.

By luck another cooling unit could be installed into the set-up during the trial (but this equipment had to be returned to the owner afterwards).

13) The ETA "strömungswächter" is very sensitive to electronic interferences. In Camp de Mourmelon this was experienced when a portophone was used within 3 meter of the set-up, which resulted in a shutdown of the power to the laserplatform. Another example of external influence on the ETA is the switching on or off of the choppers on the laserplatform; this will often have the same result.

14) The electronic equipment is connected to the laserplatform by a large number of coaxial-cables. As these cables all are separate, this might present chaos in a test site. The operator should therefore take care to correctly connect the equipment, for example by fitting all coaxial-cables with flags indicating the signals they carry.
In addition to this, most cables that are used now are too short. The provisional solution to this has always been to lenghten the cables with another coaxial-cable, or simply to restrain the distance between the 19" racks and the laserplatform. This means that the operator is again restricted in positioning the laserplatform.

3.2 Computer software and hardware properties

During the BEST TWO trial it appeared that a main limitation in using the CO_2-laserradar system is presented by the computer system, which controls the electronics of the set-up and which processes the measured data. This holds equally for both the software and the hardware.

The computer system in general was set-up and developed to support a multifunctional laserradar system. While the system performs its tasks quite well in laboratory environment, the field conditions of a trial like BEST TWO are much more demanding to the system with regards to flexibility, speed, and ease of use.

In section 6.3 we will focus onto the problems encountered in using the system, and suggest recommendations for future improvement.

4 BEST TWO TRIAL

The BEST TWO trial was held from July 23 to August 17 1990, at the military site Camp de Mourmelon in France. A map of the site and detailed descriptions of the experimental circumstances were given in section 2.2. The trial was arranged to test battlefield effects on long range (4 km) target acquisition, and was organized by NATO AC243 (panel 4) RSG15.
The objectives of BEST TWO were formulated as:

1. To determine the effectiveness of Electro-Optical EO systems under adverse European atmospheric conditions with and without battlefield events (e.g. simulated burning vehicles and simulated artillery barrages).

2. To examine the effects in the near and far fields of single and multiple emissive sources (simulated burning vehicles) and transient events (e.g. explosions).

3. To obtain data on the acquisition of static and moving ground vehicles in natural clutter conditions with and without battlefield events in a European environment at ranges out to 4 km.

4. To evaluate target acquisition models and models to characterize battlefield events and their effects.

5. To establish a database for the evaluation of aided target recognition ATR and SMART weapons.

In this chapter the scenarios of BEST TWO will be described, where special attention is given to those scenarios during which measurements were performed with our multifunctional laserradar system.
The results that are presented in this chapter are based on the actual output of the laserradar system. This consists of values for distance, velocity, and output prints depicting the received and processed signal. BEST TWO experiences with respect to the performing of experiments with our system were previously treated in chapter 3.

4.1 Description of BEST TWO scenarios

Each scenario involved single or multiple vehicles, either moving or stationary. The available vehicles were:

- AMX30, french tank, sometimes IR-camouflaged,
- AMX10, french armoured personnel carrier (APC), sometimes IR-camouflaged,
- Leopard 2, dutch battle tank,
- YPR/PRAT, dutch armoured anti tank craft (APC),
- YPR/PRI, dutch armoured personnel carrier (APC),
- army trucks, either dutch or french, sometimes IR-camouflaged.

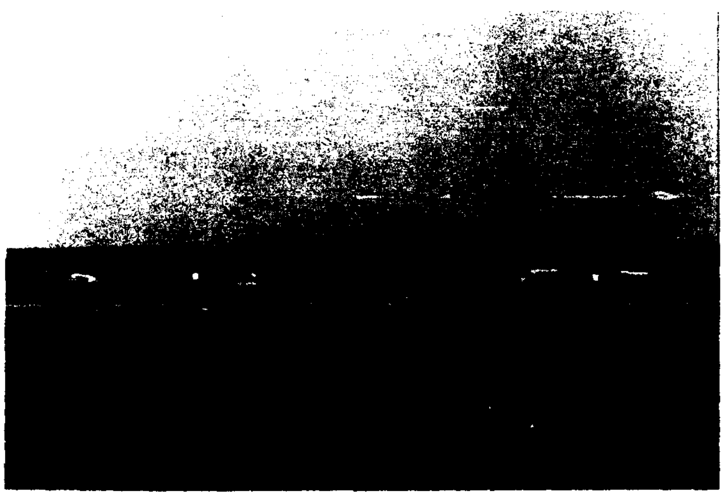

Fig. 4.1 **Photograph of five different vehicles.**

The trial provided five different scenarios:

scenario 1

A single vehicle starts its run into the scenario at the far wood edge and drives towards the Main Instrumentation Area (MIA), pausing at several fixed points along the route. Two different routes were available, called 1-left and 1-right. A typical run would be completed in 30 minutes.

All available vehicles were used in this scenario, that was performed several times during the trial.

scenario 2

Basically the same as scenario 1, but now battlefield effects were included: motion and vehicular dust, artillery raised dust, fires with their smoke. The battlefield effects would occur at about 3 km from the MIA.
In scenario 2A no effects were applied, scenario 2B provided fires in oil drums with their smoke, and during scenario 2C sandbags were exploded.

scenario 3

A line of 7 to 13 vehicles moved at a speed of about 20 to 25 km/h through the scenario towards the MIA.
The group consisted of armoured crafts and trucks. A run took typically 10 minutes to complete.
This scenario was performed either without battlefield effects (3A) or with fires in oil drums (3B).

scenario 4

4 tanks and 8 APC's formed an attack formation, the tanks leading the way, followed by the APC's. Thus a group of vehicles 750 m wide and 100 m long approached the observers at the MIA. This scenario was performed in five variations:

4A: no battlefield effects; a run lasted only 6 or 7 minutes,

4B: including simulated artillery barrage near the vehicles; duration 30 minutes, vehicles stopped at several positions, 4C: as 4B, but now including a simulated artillery barrage near the observers (250-300 m from the MIA),

4D: as 4A, but now including white phosphorous smoke near the observers at the MIA,

4E: as 4A, but now including a combined white phosphorous smoke screen and artillery raised dust.

Fig. 4.2 Photograph of scenario CHAR, showing vehicles at 500 m behind clouds of white phosphorous and black fire smoke.

<u>characterization (CHAR)</u>

In this scenario several vehicles were stationary at 500 m distance from the MIA. At intervals the vehicles turned to show another side to the observers at the MIA. Battlefield effects were also included: at some time simulated artillery barrages, white phosphorous smoke, as well as fires in oil drums were generated.

The vehicles were to be observed both with and without engines running.

4.2 Measurement results

The multifunctional CO_2-laserradar system was operational only during the last three days of BEST TWO, and thus the results of our measurements are restricted to the scenarios of these days:

Wednesday August 8: scenario CHAR

Vibration detection, determination of the characteristic spectra of the vibrations of several vehicles at 500 m distance.

Thursday August 9: scenarios 4D and 4E

4D: range measurements at and through white phosphorous clouds, ranging of vehicles and natural objects located behind clouds of white phosphorous smoke.

4E: range measurements at and through smoke/sand combinations, ranging of objects behind a combination of smoke and sand.

Friday August 10: scenarios 4C and 1-left

4C: reflection of sand/dust clouds; ranging of objects located behind the clouds of sand and dust.
1-left: distance and velocity of several vehicles (Leopard2, AMX, etc.).
1-left: vibration detection. Determination of the characteristic vibration spectrum of an army truck at various distances.

The measurements of wednesday August 8 are available as computer-processed graphics representations of the received signals, including the supplementary measurement values for the radial velocities and distances of the targets.
The measurements of thursday August 9 and friday August 10 are stored in disc-files as complete as possible, for later processing.
During the night-session of thursday August 9 no measurements could be performed.

4.2.1 FM measurements

Most of our measurements performed during BEST TWO concerned the determination of range and velocity of targets.

The measuring mode that was used applied frequency modulation of the transmitted laser beam. The targets consisted not only of the vehicles moving through the scenarios, but also of clouds of sand and dust raised by the exploding sandbags, white phosphorous smoke generated by LUST devices, and black smoke from the fires in oil drums.
It appeared that these clouds also yielded strong reflections from which range and velocity measurements were obtained.
Our measurements with the system would typically produce results showing multiple signal peaks, originating from the reflections of one or more cloud structures and targets.
The origin and some characteristics of the plots on the VIDIS graphics system, that are given in this section, will be described in section 5.1.

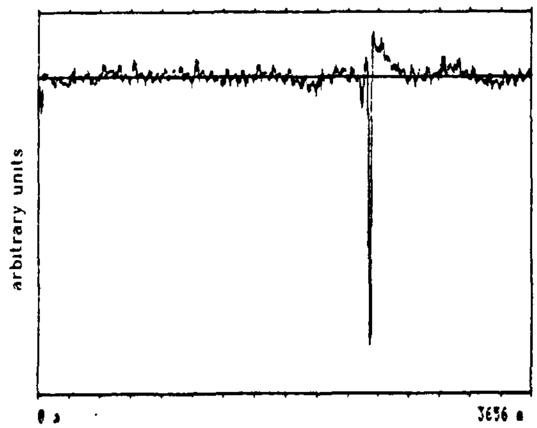

Fig. 4.3 Ranging at battle tank.

A plot of the processed received signal is given in Fig. 4.3. It was obtained from a single target, in this case a tank, stationary at a distance of 2453 m. The plot shows a clear and strong negative signal peak. It points to a position along the horizontal axis, indicating the range. Some "noise" and sidelobes are present on the signal. Note that the width of the pulse is narrow. This is a result when a target is "flat" in the direction perpendicular to the incoming laserbeam.

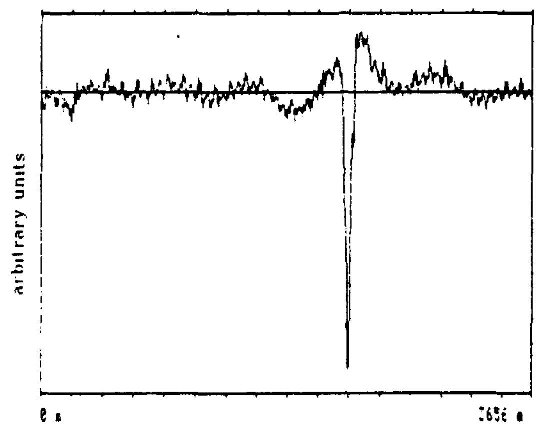

Fig. 4.4 Ranging at ground in front of battle tank.

Fig. 4.4 shows a target peak at about the same range, but this is in fact the reflection of the ground in front of the vehicle that was ranged in Fig. 4.3. In this case the signal peak is significantly broader as compared to the peak of Fig. 4.3, as expected.

The transmitted laser beam has a diameter of several decimeters to a meter (the beam divergence is about 0.3 mrad). For this reason the reflection of an extended target, a collection of reflecting objects at several ranges, results in a somewhat broader peak in the received signal.

This example of target/terrain discrimination by pulse broadening due to distributed reflections from the terrain can be applied to many measurements of the BEST TWO trial.

So, in practice it appears to be possible to distinguish between the singular reflections from e.g. vehicles and trees and distributed reflections from "targets" like grass-fields with grazing incidence of the laserbeam.

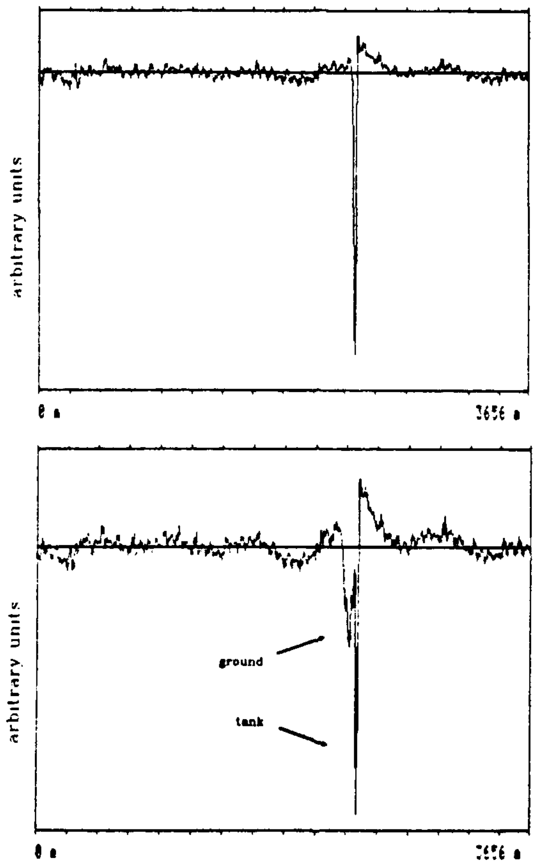

Fig. 4.5 a. Transmitter beam aimed on vehicle,
b. Transmitter aimed partly on vehicle.

Multiple targets are visualized in Figs. 4.5 a and b. In the first case a tank yields a clear reflection of a single target. The second plot shows the result when the beam was aimed upon the edge of the same vehicle, so that part of the beam reflects from the ground just in front of the tank.
The algorithm of our computer program XYRANGE provides in the processing of one or two targets from a measurement data set. Accordingly two results are printed. Moreover, the pulse broadening due to terrain is again visible.

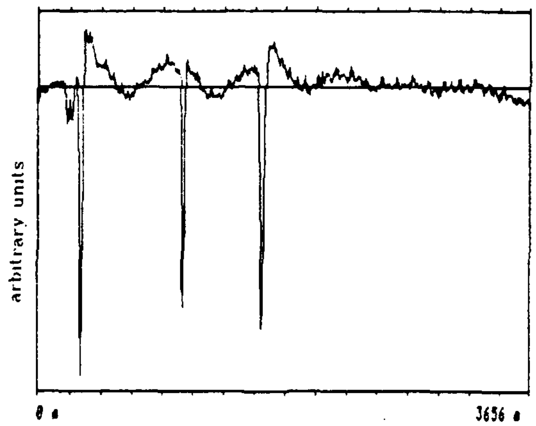

Fig. 4.6 Multiple targets measured through a white phosphorous cloud.

Electronically, our system can detect the presence of more than two targets, as can be concluded from Fig. 4.6, but the current implementation of XYRANGE is able to process values for range and velocity for a maximum of two targets. Presently, our program yields the output "unreliable measurement" in the case that more than two targets peaks are present that are approximately equally strong.

The influence of clouds of various sorts will be discussed on the basis of Figs. 4.7a, 4.7b and 4.7c, that depict the reflections of a target behind clouds of respectively sand/dust, white phosphorous smoke, and fire smoke. The edge of a cloud can be distinguished quite clearly, yielding a result for range and velocity. The target, located behind a cloud, often produces a good signal as well.

In Fig. 4.7a the second target peak is significantly smaller than is the case in Fig. 4.7 b and c. This was probably caused by the first measurement being recorded right after a simulated artillery explosion; obviously the cloud of sand/dust was at that moment less penetrable to our laser beam than it would become some seconds later.

During the trial we found that during the first 10 seconds after a sand/dust cloud is raised, objects behind the cloud are not detectable. In the cases of white phosphorous smoke and fire smoke this period is even shorter: usually about two seconds or less, depending on the intensity of the smoke generating mechanism.

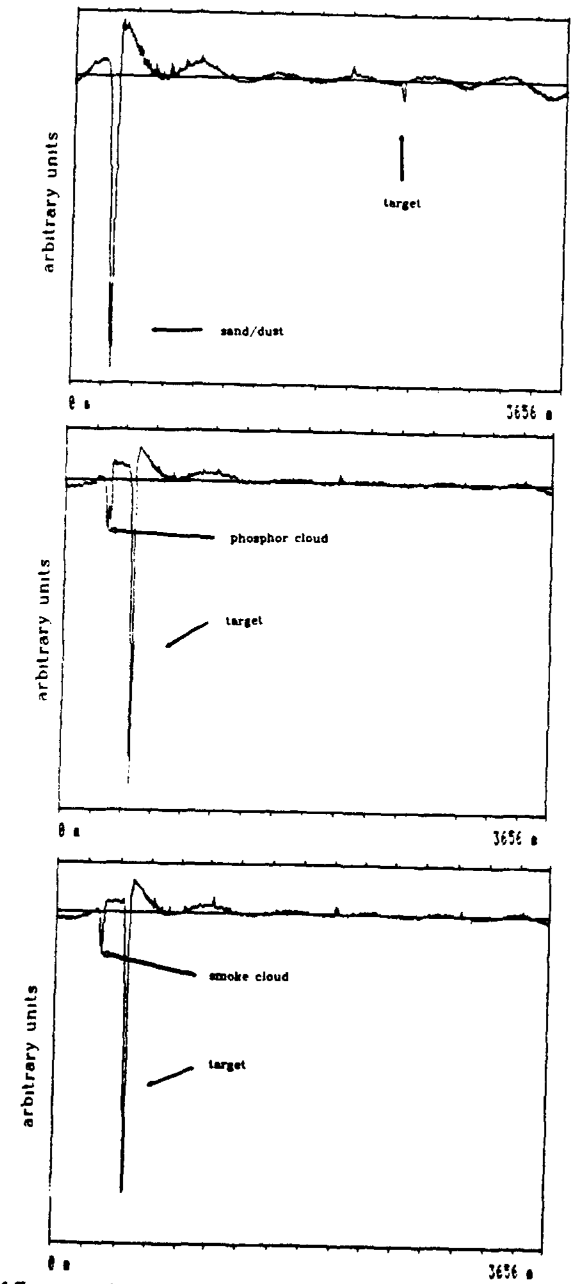

Fig. 4.7
a. object behind sand/dust cloud
b. object behind white phosphorous cloud
c. object behind fire smoke cloud

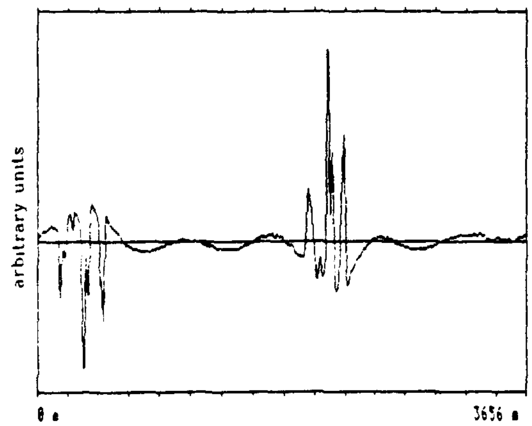

Fig. 4.8 Several clouds forming multiple targets, measurement in double (up/down) chirp mode.

After these initial periods, objects behind the clouds are detectable for our laserradar system at all times.
However in these experiments, as there was no IR-camera incorporated in our system to visualize the objects behind clouds, these targets could not be identified.

Fig. 4.8 gives an example of the multiple reflections that are generated when multiple clouds are in the line of sight.
This measurement was performed in double (up/down) chirp mode, which yields both distance and velocity as output. This double chirp measurements will be treated more extensively further on in this section. For now it suffices to observe that Fig. 4.8 shows bunches of down- and upward target peaks, originating from reflections at multiple clouds.
All clouds and a target, when present, may be detected simultaneously; the limitation of the program XYRANGE, namely that it could only distinguish two targets, has been removed later by expanding the program.

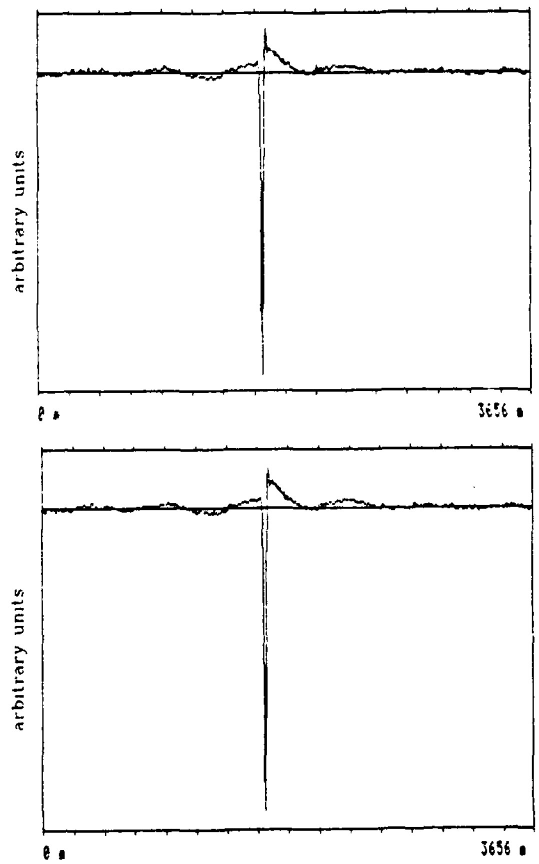

Fig. 4.9 a. camouflaged army truck
b. army truck, not camouflaged

During the trial two tanks were situated in an edge of a wood at about 1657 m. One of these had been thermally camouflaged. Measurements with our system yielded identical results for both

targets: no significant difference in signal strength and calculated range values occurred when ranging these two tanks.
The two corresponding plots are given in Figs. 4.9a and 4.9b.
Comparable measurements at french army trucks, of which one was camouflaged, yielded the same result. The latter experiment was performed during the characterization (CHAR) scenario; the trucks were placed at 500 m from the MIA.

On the ranging of target vehicles, especially tanks, it appeared during BEST TWO that it does make a difference where the laser beam is hitting the target. Specifically, if the target was located within 1 km distance, its side, front and top reflected significantly less than the tracks and the transition between tank and turret did. The operator could clearly visualize this difference in signal strengths on an oscilloscope, and in pratice may use it to optimize the aiming of the laserbeam upon a target.
Due to the limited period of time during which the system was operational, no sufficient data has been obtained to statistically support the conclusion, that from some parts of a tank much stronger signals were obtained than on the average.

Tabel 4.1 Ranges measured by by CO_2-laserradar system and the reference values.

position	range	reference
scenario 1-left : 0	3900 m	3900 m
2	3247 m	3187 m
3	2918 m	2912 m
5	2129 m	2353 m
10	1501 m	1493 m
15	990 m	1000 m
field instrument area3040 m	-	
tanks, left wood edge1637 m	-	

The reproducability of the FM-ranging was tested a number of times during BEST TWO, by measuring the distance to a specific stationary target: a white truck, located in the edge of the wood left of the scenario. This object was ranged several times at different days, each time producing the same result of 1660 m. Reproducability thus showed to be good.

The distances to fixed locations, that were measured during BEST TWO, are given in Table 4.1. In addition, reference values are given for the ranges to the points of scenario 1-left, as produced by French army battlefield radar. The rather large deviations in the ranges to positions 2 and 5 are probably caused by the target vehicle not having halted exacly at the marked location in the scenario. However, we can not verify this, because the values in Table 4.1, regarding the ranges to the fixed positions of scenario 1-left, are based on single measurements only.

A systematical error, a range offset, appeared to be present in the calculated value for distance. Measuring a person standing in front of the set-up, at about 5 m, yielded a processed result of 25 m.
The systematical error is caused by some software constants in the processing algorithm; these constants can easily be corrected later. The values in Table 4.1 have been corrected for this deviation, the ranges as printed in the VIDIS plots are not.

All the above presented results concerned single chirp measurements, where only the distance to a target is determined. Double chirp measurements, which yield additional information from which both range and radial velocity of a target is processed, were also performed extensively.
A VIDIS plot of a double chirp measurement shows not just one target peak downwards, but another one upwards as well; the latter emanating from the second up-chirp. Concerning the processing method the reader should refer to Bentvelsen [2].
The double chirp measurements were performed at both moving and stationary targets. The latter showed that the velocity of a target as determined by the system has a systematical deviation as well.
Figs. 4.10a and b show the double chirp measurement results of a target vehicle at longe range and of the ground in front of the vehicle, respectively. It appeared for stationary objects that the calculated speed could vary from 0.4 to 1.0 m/s. Further investigation is needed to determine the cause of this deviation, which is probably a matter of software.

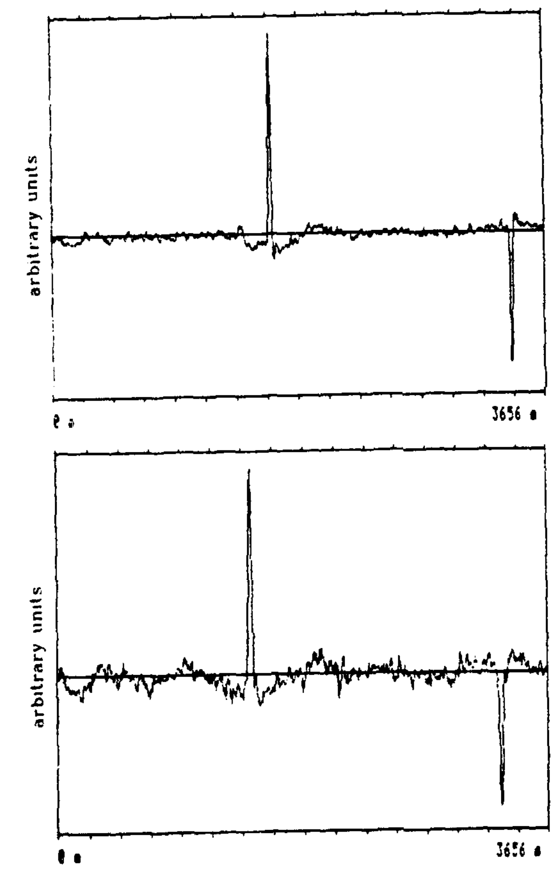

Fig. 4.10 a. double chirp measurement on target vehicle,
b. idem, on ground in front of vehicle.

From double chirp measurements at moving vehicles we obtained speeds up to 11 m/s (about 40 km/h).

During the trial measurements were performed at ranges of more than 4 km, the distance to the wood edge on the other side of the scenario. Vehicles as well as trees could be measured well with our system, but at these longer ranges the digital integrator should perform at least 100 integrations to obtain a reasonable signal to noise ratio. The measuring time was approximately 2.5 msec (with a laser power of 0.7 Watt).

4.2.2 Vibration detection measurements

During two sessions of the trial also vibration detection measurements were carried out. The first time was at wednesday August 8 during the CHAR scenario, and the second time at friday August 10 during a 1-left scenario.
The main objective was to record the characteristic vibration spectra of several military vehicles. The transmitted laser beam was not modulated, but a frequency shift of 100 MHz was applied by driving the AOM with a 100 MHz continuous wave signal. Upon reflection at a vibrating object the beam will be modulated in frequency by the Doppler effect. The beam as received by the HgCdTe detector was FM-demodulated by a radio receiver and recorded on audio tape. The signals could later be processed at the TNO-FEL laboratory, to serve the study of target classification by characteristic vibrations.
For the purpose of monitoring the aiming of the transmitter beam, the audio signal from the receiver was also sent directly to a loudspeaker.

The CHAR scenario of August 8 provided stationary vehicles, with engines either running or shut off. Once in a while the vehicles would turn to face another side to the MIA. The distance to all vehicles, as they were lined up, was about 500 m. All available target vehicles, as described in section 4.1, participated in this scenario.
Our measurements in this scenario thus resulted in the recorded vibration signals of several military vehicles.

On August 10, signals from a french army truck were recorded, as it approached the MIA during scenario 1-left. It gives the vibration spectrum of a single vehicle, but at varying distance, and while its engine is running at varying rates.

The execution of the vibration detection measurements at Camp de Mourmelon and the evaluation of the recordings at the TNO-FEL laboratory have been performed by ing. H.E.R. Boetz; his findings are described in [6].

Frequency analysis of the recorded vibration spectra yielded the following results:

1) Most of the vibrations measured at stationary vehicles were in the range of 3 to 200 Hz; the strongest peaks in the spectrum occurred between 10 and 50 Hz.

2) The vibration spectrum of any vehicle shows the same signal peaks, with varying amplitude, when this target is viewed from different sides and it is measured at varying distance.

3) spurious signals were clearly present, mainly caused by vibrations of the set-up and the electrical power supplies.

Especially this last issue should lead to further improvememts in the future set-up of the laserplatform.

4.3 Verification of measurement results

The distances as measured during scenario 1-left were compared to the corresponding values given by the french army battlefield radar. The velocities measured by our system have not yet been correlated with results of other teams that participated in BEST TWO.
The results of our vibration detection measurements are at stationary targets contrary to those made by one of the English participants; they measured acoustical spectra of all vehicles as they drove to the start of the scenarios.

4.4 BEST TWO conclusions

The multifunctional CW CO_2-laserradar has been operational during the BEST TWO trial. It has proven to be able to determine the ranges and velocities of multiple targets at a single line of sight, up to a good 4 km. The targets consisted of military vehicles and natural objects, often located behind clouds of smoke and sand. The measurement results have been printed and saved to disc-files for later processing.
In addition, vibration detection measurements have been performed. Low frequency vibration spectra have been recorded on audio tape. These are to be processed at the TNO-FEL laboratory.

It showed during the trial, that it can be difficult to keep a laboratory set-up operational in a battlefield environment. Many external influences can present problems with which the operator might not be familiar.
A factor which is very important is time. During a trial each scenario is scheduled; the measurements should thus be planned carefully too. This preparation should be very thorough, and so insure the succesful performance of the measurements that were planned.
Furthermore, one should not forget to provide for safety precautions to prevent human failure; a mistake is easily made when working in a unfamiliar, and perhaps stressful, environment.
Finally, one must realise that there will always be unexpected events that need improvisation. Therefore, the preparation should also account for a certain degree of flexibility.

5 MEASUREMENTS AT THE TNO-FEL LABORATORY

In January 1991 some measurements were performed to check the performance of the multifunctional laser radar system. Specific attention was given to test the reproducability of range and (post-detection) signal to noise ratio, both in amplitude and frequency modulation modes.
The set-up was first realigned, according to the procedures as described by Hebers [4].
The driver voltage for the local oscillator AOM was set to 16 V. The signal level of the pyro-electric detector #1, indicating the laser beam intensity, was 1.1 V at startup but decreased to 0.7 V after about 20 minutes of laser operation; it then stabilised. The transmitting laser beam power, after mirror M4, was 540 mW. Local oscillator beam power, after beamsplitter BS2, was 6.1 mW. The heterodyne noise signal levels, with and without the local oscillator reaching the HgCdTe detector, were about 150 mV and 100 mV respectively.

5.1 Characteristics of system output.

The results of measurements are presented on output devices as the computer monitor, the VIDIS graphical system, and possibly the printer. They consist of processed signals, and possibly calculated ranges, velocities, and a signal to noise ratio (SNR).
In the case of FM mode, the output signal of the HgCdTe detector, consisting of FM chirps and noise, is processed by pulse compression hardware in the HF-transceiver, followed by envelope detection. Then a number of measurements are added in the digital integrator, to increase the SNR. Finally, using a HP 9000 computer, the signal is subjected to some filtering. The resulting signal, with its noise, is plotted by the VIDIS system. An example of such a plot is given in Fig. 5.1. The position of the peak on the horizontal axis represents the range of the target.
The side-lobes, that are present next to the target reflection peak, are caused by software and hardware filtering effects.

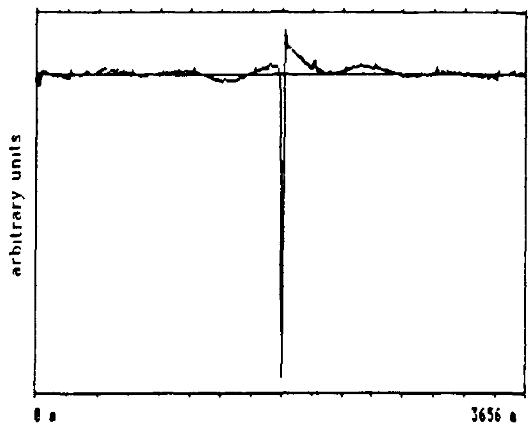

Fig. 5.1 Measurement output on VIDIS system, showing singular target reflection with side-lobes and noise.

Our measurements with the system would typically produce results showing multiple signal peaks, originating from the reflections of one or more cloud structures and targets.

5.2 Reproducability of measured range and SNR

In the measurements, several "hard" and "soft" targets were ranged. All measurements were performed in both the amplitude and frequency modulating modes, and using the tree possible sampling frequency settings for the Master Oscillator: 30, 35, and 42 MHz. Every measurement was repeated 10 times. Results were printed only numerically; the VIDIS system was not used, in order to enable a large number of measurements to be performed in a restricted period of time.

The "hard" targets were: the RNL-tower in Leidschendam (5 km), an appartement building (3 km), the small tower of Wassenaar (3 km), the watertower of Wassenaar (1.6 km), the SHAPE radar globe (0.8 km), and a bunker (0.5 km).

Spots of sand/grass were ranged at three distances: 1.7, 0.9, and 0.4 km.

Several bunches of trees were ranged; the distance varied between 2.4 and 0.4 km. The trees differed, some being covered with leaves, some having few leaves left, and others having lost all leaves.

FM) The measured range of the targets reproduced rather good; in most cases the 10 measurements showed variation over just one or two rangebins. This variation of 3 to 4 meters is partially caused by the algorithm which interprets the measurement.
The amount of variation did not depend on the sampling frequency of the parameter Master Oscillator, being either 30, 35 or 42 MHz. Neither was the SNR, as calculated by the program XYRANGE10, dependent of the master oscillator frequency.
As expected, the SNR of a measurement increased as the number of integrations was increased, but the calculated range would not vary.

AM) The previous conclusions also apply to the AM measurements; the range is even more constant, and the calculated SNR is somewhat higher.
Some additional remarks can be made regarding some of the measurement parameters: the AM binary codenumber (number of level changes in a period) and the bandwidth.
It appears that the measured range is independent of the AM codenumber. The SNR decreases slowly as codenumbers increase above 100, with the bandwidth set to 6 MHz. This is to be expected; the higher codenumbers result in a larger bandwidth of the modulating signal which becomes less compatible with the fixed bandwidth of the processing electronics.
It is recommended that future investigations address on the ways in which bandwidth parameters influence the properties of the SNR.
In our test measurements the settings of 30 kHz and 300 kHz resulted in a failure of the present algorithm to calculate a result for the range: the user is presented the message "unreliable measurement". The settings 3 MHz and 6 MHz resulted in a difference of 20 meter in calculated range. This is due to the difference in delay caused by the respective filters.

5.3 Qualitative and operational aspects of AM and FM modes

The FM mode has some advantages over the AM mode.
First, this method encompasses pulse compression, and thus should yield an improved SNR [5].
In our measurements this could not be directly verified from the printed values for SNR, as explained in section 5.1.
During our measurements it appeared that any target which could be detected, and ranged, by the system using the FM technique, was detectable using the AM mode as well. Moreover, in the AM mode the algorithm typically needed less integrations, by a factor 4 to 5, to be able to calculate a result from the measurement data.

Second, using the FM mode, the operator is able to find a target and optimize the aiming of the transmitted laserbeam onto this target. This is done by viewing the received detector signal, after pulse compression, with an oscilloscope. The height of the pulse, above the noise, is then a direct measure for the quality of the detector signal. Also this provides a direct test that the system is performing well.

Furthermore, for the FM mode there is the important feature that, by using double chirps, the velocity of a target as well as its distance can be obtained.

The AM mode allows the bandwidth and codenumber to be adjusted by the operator; this can be advantageous to optimize the performar of the system in particular measurements.

Another point of interest concerns the switching of AM to FM mode during a measurement session. As was previously described [4] any change of parameters involves quite a lot of computer keyboard input, but in this case there are two signal leads, to and from, the HF-transceiver that also need to be reconnected.
The output of the HF-transceiver, which is led to the digital integrator, is taken from the back panel of the transceiver. In FM operation connector #5, labeled "60 MHz, compressed pulse" is used. Should the user switch to the AM mode, then this lead has to be changed to connector #4, which is marked "10.7 MHz, AM".
The HF-transceiver front panel output which is led to the oscilloscope also needs to be changed: "OUT PFM" for the FM mode, and "OUT AM" for AM operation.

6 RECOMMENDATIONS FOR IMPROVEMENTS OF THE SET-UP

The recommendations as presented in this chapter are mainly based on experience gained from the BEST TWO trial. The items summarized in section 6.1 were previously and more extensively described in section 3.1.

6.1 Optical improvements

1) Should the optical part of the set-up been rebuild in the future, than it is strongly recommended that the laserplatform is redesigned with regards to the followings considerations:

- The current laserplatform is large and heavy. All non-optical parts, such as power supplies, should be removed from it. The only exception is the pre-amplifier of the HgCdTe detector, because it needs to be placed as close to the detector as possible to reduce high frequency interference.

- The laserplatform should be placed upon a tripod, instead of the car. Especially the laser cooling unit can cause unwanted vibrations. A tripod can be placed on any surface, regardless of its form.

- Locations in the beam paths should be provided where fluorescence plates can be inserted and illuminated with violet spotlights.

- Individual parts should be removable without disturbing the alignment of other components. Examples are the pre-amplifier, the receiver telescope, beamsplitter BS3 and lens L3.

- Screen the laser beam at the sides of the laserplatform so that the operator is protected from burning his clothes or hands.

- Ensure accessibility for tools, for example a screwdriver that could be needed to fasten/remove a particular component.

2) In the current system some mirrors and beamsplitters are not fully fixed in their holders. This only shows when the set-up is subject to vibrations and shocks, as was the case at some times during BEST TWO.

3) For the purpose of optical alignment a special accessory can be build.
This would consist of an assembly containing a pyro-electric detector, a thermal radiator with a chopper in front of it, a crossmark to aid in visual aiming, and some electronics. The latter would be designed to transmit a signal of frequency that is related to the intensity of the incident laser radiation onto the pyro-electric detector.
The detector, the thermal radiator and the crossmark should be positioned relative to each other, as are the emanating and incident beams at the scan mirror of the laserplatform. Thus the alignment of transmitter, receiver and video beams can be performed at short range.

4) It would be ideal if a thermal imaging system could be used sideby the laserradar system. This is a necessity if the laserradar is to be used again in trials like BEST TWO. It is essential that the operator can locate targets at night or when clouds block the view.

5) The beam choppers can be improved in two ways:

- increasing the rotational speed, so that the detector signal frequency shifts from 30 to about 200 Hz, will greatly improve readability of this signal on an oscilloscope.

- the chopper assembly and fitting could be redesigned to be more practical.

6.2 Electronical improvements

1) Leading the signal of pyro-electric detector #1 to an analog or digital meter would provide in a permanent monitor of laser beam intensity.

2) The current system to monitor the liquid nitrogen level in the dewar of the HgCdTe detector is not adequate. The plastic sensor tube tends to get frozen when the environmental temperature rises above 30°C, causing a delay in reaction on the LED-bar. Moreover, this LED-bar is placed very impractically at the side of the laserplatform; a better place would be next to other control equipment, for example in one of the 19" racks.

3) The ETA strömungswächter should be shielded from interferences that cause this apparatus to shut off the power to the laserplatform.

4) It is advised to attach one large plastic tube to the laserplatform. This tube can then contain all the cables going to and coming from the laserplatform to the 19" racks and the cooling unit.
This would very practical if the set-up is used again in an outdoor environment.

5) A monitor for the video display must be added. This gives better control of the system to the operator, who should be able to see the output of the computer and of the video camera at all times.

6) It is important that several controls which are spread over the system are brought together in a single area of the set-up.
Examples of currently divided controls are: liquid nitrogen level LED-bar, laser output reading, oscilloscope display of compressed pulse.

6.3 Improvements in computer hardware and software

The computer hardware that is currently used consists of a Hewlett Packard series 9000 model 220 computer, equipped with 1.7 Mbyte of RAM memory and a special purpose FFT (fast fourier transform) card. The standard IEEE-488 interface allows reliable and flexible control of up to sixteen periferals, which in our system consist of the computer, the printer, a disc drive, an additional VIDIS graphics terminal, the digital integrator, the HF transceiver, and the XY-controller of the scan mirror. This was all previously described by Bentvelsen [2].

The software, implemented in Pascal, consists of a program called XYRANGE, originally implemented for the HP workstation by Van der Vegt [3], and later adapted by Bentvelsen [2], and the author of this report. It controls the set-up in performing measurements in several modes, which were previously described [4]. Furthermore the software processes measurement data into resulting values for velocity and distance, and controls the printer and the VIDIS graphics terminal in providing a graphical and numerical representation of the measurement result.
The latest update to the program, which was not documented before, adds the option to save an extensive file to disc, which contains all relevant data concerning the measurement.
The version of the program, used in the experiments described in this report, is named XYRANGE10.

The computer system in general was set-up and developed to support a multifunctional laserradar system.

We will focus onto the problems encountered in using the software XYRANGE10, and treat the shortcomings of the computer hardware in the set-up.

1) The user-interface of XYRANGE10 was designed to be user-friendly. However it lacks some important features, and is not as fault tolerant as could be.
At the start of the program, XYRANGE10 interactively asks the user to choose a measurement mode, and afterwards to enter all paramenters relevant for the selected mode. User input is handled quite robustly by input routines; the permitted options for the user input are listed, and usually only one of these values is allowed to be entered. Then a measurement may be executed.
Should the user want to alter one of the parameters, then a part of the parameter entering routine is executed again; thus the user is forced to retype typically 5 to 8 inputs, where he needs to change only one. If the user decides to change to another mode of measuring, then all parameters have to be entered from scratch on; this is very inconvenient, as in practice most parameters will be the same in consecutive measurements, even for different modes of measuring.
It is not possible to enter or even to retain default values for the parameters in different measuring modes.
Noteworthy is also that the robustness of the input routines is not complete. In some cases the input routines will accept a not permitted input value, usually zero, or even treat the <BACKSPACE> as the <RETURN> key.
This will all cost a lot of time adjusting the system during measurements, time that is not available during a field trial.

2) XYRANGE10 lacks the option to perform any disc access, apart from one saving a measurement data/info file. Thus it is not possible to investigate the disc directory contents, available disc size, etcetera, during program execution.

3) It is not possible to make a printer hardcopy of the parameters concerning the current system configuration. Neither can a previously saved measurement be read from disc and plotted by the printer, as can be done with the measurement that is actually performed.
4) The program is not mouse controllable, as is more and more accepted as standard in modern computer applications.

5) The computer monitor is also utilised to display the picture of the video-camera of the optical set-up. This implicates that one has to switch between these two picture sources; they cannot be viewed at the same time.

6) The VIDIS system, which is used to plot a graphical representation of the measured data, is unacceptably slow. One measurement will take about 20 seconds to visualize on the VIDIS screen.

7) Should the operator want a printer hardcopy of the measurement result, as plotted by VIDIS, then this will take an additional 50 seconds. The printer is not adequately buffered.

8) The operation setting of the system is somewhat scattered over several hardware units. For example when, in FM-ranging mode, one switches from single chirp to double chirp measurement, not only the corresponding parameter has to be changed in XYRANGE10, but also a switch on the HF-transceiver needs to be flicked. This, and other details, complicate the operation and can induce mistakes during experiments.

9) The Hewlett Packard workstation Pascal does not offer an user-friendly and efficient environment for the programmer. Thus it takes relatively long to implement changes, however minor, into the complex software.

The implementation of a new computer configuration will be performed in the near future. Both hardware and software will be changed.

a) Hardware: a faster computer with extensive graphics capabilities is needed. Recommended equipment consists of:

- an MS-DOS compatible computer with 80386 main and 80387 mathematical processors,
- preferably a VGA color graphics card,
- a special FFT (Fast Fourier Transform) card.

b) Software: the current program XYRANGE will be reimplemented. As was described in detail in section 3.2 the software should provide in:

- a good user interface.
- the possibility to quickly alter any measuring mode or parameter.
- extensive disc access.
- the option to produce a hardcopy of any measurement or processing result, not only during the performance of experiments, but afterwards as well.

7 CONCLUSIONS

The multifunctional CW CO_2-laserradar system has been operational after the modifications that were implemented in 1990.
Measurements have been performed, both at the TNO-FEL laboratory and at the BEST TWO battlefield trial in Camp de Mourmelon, France.
Results consist of measured and processed distances and velocities of target vehicles and natural objects. The measurement data has also been saved onto disc, for later and further processing. Spectra of the characteristic vibrations have been recorded of several military vehicles at 500 m distance, and of an army truck at distances varying from 2 to 4 km. These recorded spectra have been processed, showing characteristic vibration frequencies.

Much experience has been gained on the various aspects of the performance of the multifunctional CW CO_2-laserradar system. From this experience, recommendations have been formulated for improvement of the set-up.

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MEASUREMENTS HAVE BEEN PERFORMED WITH THE MULTIFUNCTIONAL CW CO2-LASERRADAR SYSTEM, BOTH AT THE TNO-FEL LABORATORY AND AT THE BEST TWO FIELD TRIAL.
THE BEST TWO (BATTLE FIELD EMISSIVE SOURCES TEST UNDER EUROPEAN THEATRE WEATHER AND OBSCURANTS) TRIAL WAS HELD IN FRANCE, AT CAMP DE MOURMELON, FROM JULY 26 TO AUGUST 10 1990. NATO AC/243, PANEL 4, RSG 15 ARRANGED THIS TRIAL TO TEST BATTLEFIELD EFFECTS ON LONGE RANGE TARGET ACQUISITION BY ELECTRO OPTICAL SYSTEMS.
THIS REPORT DESCRIBES THE RESULTS AND EXPERIENCE GAINED FROM THESE EXPERIMENTS, AND GIVES RECOMMENDATIONS FOR FURTHER IMPROVEMENT OF THE MULTIFUNCTIONAL LASERRADAR SET-UP.

* Carbon dioxide lasers,

16. DESCRIPTORS	**IDENTIFIERS**
~~CO2 LASERS~~ * LASER RADAR, ~~(LIDAR)~~ INFRARED RADIATION DETECTION	HETERODYNE DETECTION FIELD EXPERIMENTS, Netherlands.

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