Chapter 5 – PILASTER SYSTEMS DESIGN

5.1 GENERAL

An important achievement of this research was the design, and initial construction/testing of the PILASTER Sensor Tracking and Measurement Unit (STU) and Monitoring and Control Station Unit (MSU). In the following, the STU/MSU combination will be denoted PILASTER Laser Tracking and Monitoring System (LTM).

The PILASTER LTM system allows accurate measurement on the ground (i.e., target location) of various important laser parameters (beam pointing accuracy, energy received at the target location, spot geometry on the target, etc.), display at a remote location (i.e., control room) of the information required for real-time eye-safety and test/training missions management, and recording (both at the STU and MSU locations) of the relevant information.

During this research, the architecture of the LTM system was progressively refined, based on sensors/ systems test results and additional monitoring station (control room) requirements. Furthermore, the PILASTER permanent and modular targets were constructed, after various design calculations and performing field tests with prototype targets and target modules (useful guidelines for the target maintenance/reconstruction during real test/training missions were also identified). This chapter presents the current status of the PILASTER development, with results of the main design activities performed.

5.2 PILASTER LTM DESIGN

As illustrated in Chapter 4, the PILASTER LTM system is composed by the Sensor Tracking and Measurement Unit (STU) located in the vicinity of the target, and the Monitoring and Control Station Unit (MSU) located in the remote control room (PCC). This architecture approach was dictated by eye-safety and operational considerations. In fact, the sensor unit must be placed in the vicinity of the illuminated target to perform its functions (i.e., within the "Buffer Zone" for non-eye safe systems), where all unprotected personnel has to be evacuated. Furthermore, in general, it should be possible to perform "laser attacks" with both "dummy" or reduced-warhead weapons (hard targets), and the real-time availability of the "spot-on-target" information at the control room enhances the Laser Safety Officer (LSO) situation awareness and, in the case of test missions, gives to the Trial Officer (TO) an immediate perception of the laser LOS stability and a way of promptly verifying the success of the various test runs being performed, therefore increasing the probability of overall test mission success.

5.2.1 PILASTER LTM Architecture and Functions

According to the operational requirements described in Chapter 4, the PILASTER LTM main functions (already implemented) are the following:

- Measuring the pointing accuracy of LTD/LRF systems, using reference ground targets;
- Measuring the temporal power distribution of the laser footprint on the target;
- Measuring the laser spot geometry on the target;
- Processing the above measurements, transmitting the results via LAN/WAN, and displaying the data in real-time at the control room; and
- Recording all measurements, together with the relative time tags, in order to allow post-mission visualisation and plotting of the data.

Essential to the LTM design was the definition of the size and location of the targets. The STU is a fixed or mobile unit, to be placed at a distance of 100 m from the FRCT and FXDT targets (these targets have a dimension of approximately 10×10 m^2 in order to be extended for the majority of laser systems currently in service, at ranges and grazing angles of practical interest). The STU employ a data-link for sending in real-time all information required to the MSU. The distance and relative displacement of the STU and MSU is optimised in order to guarantee a minimum number of RF repeaters.

Once the Weapon System Operator (WSO) on board the aircraft initialises the LTD firing procedure, a portion of the designated target is illuminated (i.e., a function of the beam output diameter/divergence and aircraft-target distance). The STU tracks the laser spot on the target (NIR cameras) and records the relevant spot frames. At the same time, for each spot, the data relative to the incident laser radiance are collected, and the energy centroids of the laser spots are determined and recorded. Similarly, the spots geometric centres are determined and recorded.

The STU will also determine and record the laser spot effective dimensions on the target (allowing an estimation of the effective laser beam divergence, using the aircraft/system trajectory data), and compute various parameters for charactering the degree of distortion of the laser spot.

Using Arrays of Detectors (DEAs) installed on the FXDT target, the STU also provides laser energy measurements on the target and therefore allows, in post-processing, atmospheric extinction determination for both airborne and ground laser systems (by using the known aircraft/system positioning data). Furthermore, the FXDT detectors allow time laser signal measurements for CW and pulsed systems (pulse duration $P_D \geq 2$ ns and PRF = $1 \div 100$ Hz). These features allow to verify the impact of atmospheric and geometric mission parameters on system effectiveness.

The STU is currently capable of analysing laser signals at 1.064 μm and 1.54/1.55 μm wavelengths and will be capable, in future upgraded versions, to analyse signals from other sources, such as the 10.6 μm CO_2 lasers.

Real-time aircraft trajectory data are currently obtained using the tracking radars operating at the PILASTER range, and presented the PCC. More Accurate positioning data, relative to both the aircraft and the LGW, are obtained in post-processing using cinetheodolites (existing CITE with filtered optical sights and/or automatic CITE systems) and/or Differential GPS (DGPS).

5.2.1.1 PILASTER Sensor and Tracking Unit

The general architecture of the PILASTER STU is shown in Figure 5-1. The STU electro-optical sensors include an Array of Detectors (DEA) for direct energy/signal measurements on the target, two IR cameras (one for real-time spot monitoring and one for post-processing laser spot analysis) and a TV camera (for LGW impact data collection). The computer units perform the following functions:

- STU configuration control;
- Acquisition, processing and recording of the IR/TV cameras raw data (i.e., digital images); and
- Data exchange, via LAN/WAN, with the MSU.

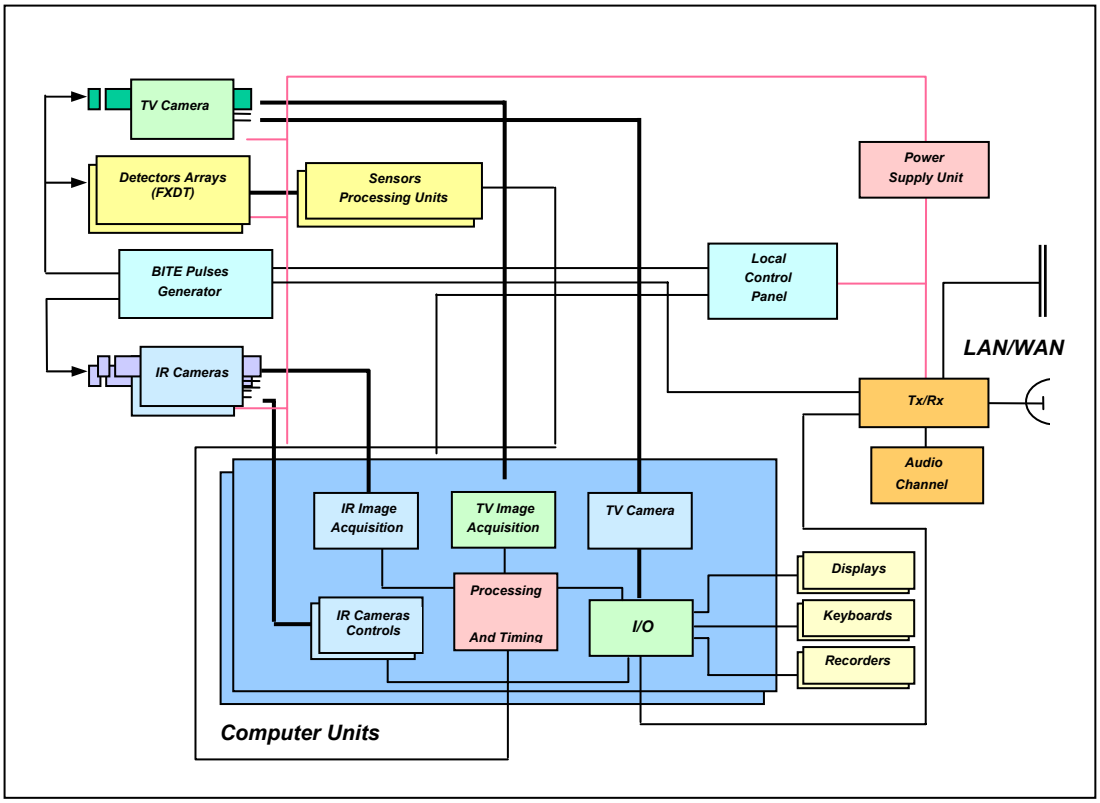

Figure 5-1: PILASTER STU Architecture.

The BITE pulse generator, commanded by the local control panel or by a remote MSU operator (via LAN/ WAN) is activated in the system BITE MODE. The audio channel is available for communications with the MSU during the STU location and calibration phase.

After calibration has been performed, the STU can work as an automatic unit, executing the commands received from the MSU. For certain specific locations of the STU in the test range (6 possible and 2 existing FXDT/FRCT locations), a permanent hard-wired link (fibre-optics cables connected to the PISQ existing network) has been adopted for data exchange and communications with the MSU. The power supply unit generates all stabilised low voltages required by the other units.

In the operational mode (OPR MODE) of the LTM (see Section 5.2.2), the FXDT DEA's detect the laser spot on the target and their Processing Units (DPUs) measure the temporal and energetic characteristics of the laser signals incident to each detector. The Synchronisation Module (SYM) generates the "time label" used to synchronise the TV/IR cameras images and the DEA measurements.

The TV and IR cameras acquire the target and laser spot images, and send the video signals to their respective Frame Grabbers (FRGs). The FRGs convert the video signals into a digital format, associate to the converted signals the relative "time labels", and send the labelled digital signals to the computer processors. The computer units process the frame grabbers and DPU outputs and associates synchronised DEA measurements to each IR frame (post-processing IR camera), and a TV frame to each IR frame (real-time IR camera). The real-time IR camera and TV camera images can be viewed by an operator at the STU (e.g., during the initial installation/calibration of the STU) through a computer monitor.

During the mission, the raw data (the valid images acquired with relative time labels, the frequency data, etc.) are processed at the STU to obtain the required outputs. Both the raw and the final data are then recorded in the computers mass memories and also downloaded to external memory devices.

5.2.1.2 PILASTER Monitoring and Control Station Unit

The general architecture of the PILASTER MSU is shown in Figure 5-2. The computer, with its peripherals, allows the operator to select the LTM operational mode and the data exchange with the STU. The MSU receives, via LAN/WAN, the data processed by the STU computer. The computer displays show the laser beam pointing data (real-time IR camera raw frames and computed pointing data) and the visible target images (TV camera data) to the MSU operator. If requested by the MSU operator, the raw data acquired in a certain number of test runs by the STU (real-time/post-processing IR cameras and TV camera data) are compressed by the STU computer and transmitted to the MSU. The audio channel allows communications with the STU operator, during the STU placement and calibration phases.

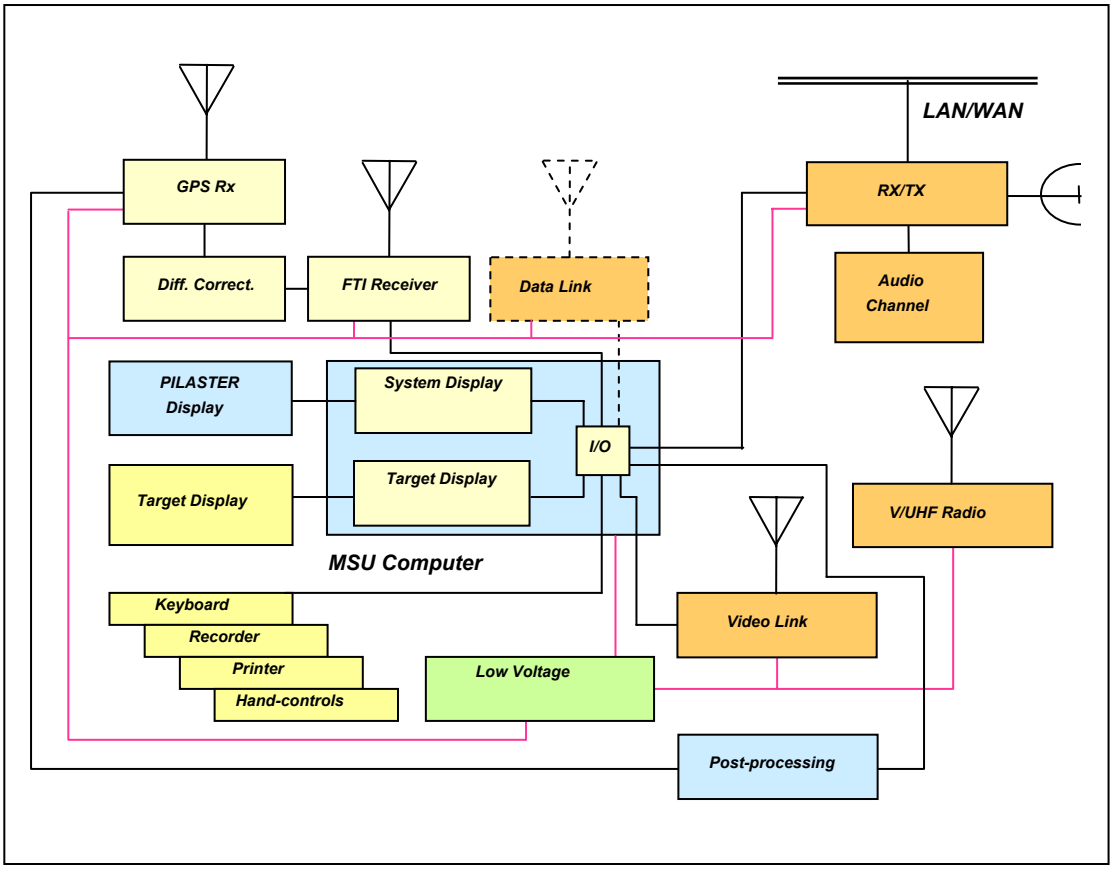

Figure 5-2: PILASTER MSU Architecture.

Currently, a dedicated software tool is also being developed for automatic post-mission correlation between the aircraft cinematic data, stored by the aircraft on-board recorders or by dedicated (D)GPS data recorders, and the laser footprint data. This tool will also serve as a mission debriefing aid for training activities performed with airborne laser systems.

5.2.2 PILASTER LTM Functional Modes

Currently, the following PILASTER LTM functional modes have been implemented:

- **INST MODE**, required for the installation (alignment, calibration, etc.) of the STU TV and IR cameras in the vicinity of the selected target. In this mode, the TV and IR target images can be viewed on the STU computer displays, allowing an initial alignment of the sensors. After this

operation has been completed and the relevant data have been inputted to the STU computer, the LTM system fully defines the target-sensors relative geometries.

- **BIT MODE**, required to check the correct functioning of the complete LTM system, including DEA and camera sensors. To obtain this, an array of LED's generates a signal with characteristics similar (i.e., energy, time and frequency) to a laser beam on the target. Using this signal, all units are activated in turn, allowing a complete system check. The BIT cycle execution time is about 60 seconds.
- After the BITE sequence has been completed successfully, the system automatically enters the **OPR MODE** (Operational Mode). In this mode, the system determines the laser footprint dimensions, the laser footprint geometric centre, the location of the beam energy centroid, the energy measured by each DEA detector, the laser PRF and P_D, the total number of pulses received, and the time labels associated with the acquired laser pulses. The instantaneous laser spot images and the geometric centre data are presented in real-time at the MSU. All other information are available in about 1 minute after each test/training mission run, and presented at the MSU operator through a dedicated software menu (the design time interval between one test/training mission run and the following is 2 minutes).
- The **TRF MODE** (Transfer Mode), is a reversionary mode for transferring the STU recorded data (relative to the last 10 test/training runs) to the MSU computer (via LAN/WAN). The compressed data relative to the 10 mission runs are transferred from the STU to the MSU in a time not exceeding 5 minutes.

5.3 PILASTER SENSORS CHARACTERISTICS

According to PILASTER general requirements presented in Chapter 4, various types of sensors were selected for the laser range. Particularly, the PILASTER STU and the FXDT target were equipped with sensors for laser spot monitoring and geometric/energy measurements. Furthermore, appropriate meteorological sensors were selected for laser beam atmospheric propagation data analysis.

Selection of the PILASTER sensors was the result of many engineering design calculations, compromise of various technical and operational requirements (use with airborne and ground laser systems, constraints imposed by the other STU hardware and software component, FXDT target design, etc.), actual laboratory and field tests, and last (but not least), cost-effectiveness considerations. In the following sections, the design characteristics of the main sensors selected for the PILASTER program are presented. More information about the STU sensors selection process is given in Chapters 7 and 8 (Laboratory and Ground Experimental Activities).

5.3.1 IR Cameras and Digital Image Acquisition Systems

The IR cameras integrated in the STU (real-time spot monitoring and post-processing spot data analysis), had to be equipped with suitable optics (barrels and filters) and digital image acquisition systems in order to match the PILASTER requirements. Particularly, according to the calculations performed, they had to be able to acquire, both in day and night conditions, laser spots with minimum dimensions of 0.1 × 0.1 metres and with a minimum energy density of a 10 μJoule/m^2, produced by lasers beams at λ = 1064 nm and λ = 1550 nm incident on targets with 5% minimum reflectivity. Furthermore, both raw and processed data (i.e., acquired NIR camera frames and measurements/analysis results) had to be transferred to the PILASTER LAN/WAN networks for real-time and off-line reading at the MSU. Finally, a remote control system (through LAN/WAN) was required for the NIR cameras. In order to match these requirements, the following NIR cameras/optics, digital image acquisition systems and interface electronics were integrated in the PILASTER STU:

- *Phoenix*™ *NIR* camera produced by *Indigo Systems Inc*., for post-mission laser spot data analysis (i.e., determination of laser spot geometric and energetic characteristics).
- *Merlin*™ *NIR* camera produced by *Indigo Systems Inc*., for real-time laser spot monitoring (i.e., laser spot position determination for real-time monitoring at the STU and/or MSU locations).
- The barrels for the *Phoenix*™ *NIR* and *Merlin*™ *NIR* cameras required to frame (entirely) a target with dimensions 10 × 10 metres (located on the ground), and also to frame a central portion of the same target with dimensions 4 × 4 metres (about 3 metres above the ground), from a distance varying between 50 metres and 250 metres.
- Narrow band filters for the *Phoenix*™ *NIR* and *Merlin*™ *NIR* cameras suitable for laser radiation at λ = 1064 nm and λ = 1550 nm.
- A Digital Acquisition System (DAS) for the *Phoenix*™ *NIR* camera composed by a rack with a portable PC, the hardware peripherals and the software (based on *Media Cybernetics* IMAGE-PRO PLUS™ version 4.1) necessary for digital image acquisition, determination of the geometric/ energetic characteristics of the laser spots, and memorization of raw data (acquired frames) and measurements data (off-line analysis results).
- A Digital Image Acquisition Computer (DAC) for the *Merlin*™ *NIR* camera composed by a portable PC, the hardware peripherals and the software (based on *Media Cybernetics* IMAGE-PRO PLUS™ version 4.1) necessary for real-time digital image acquisition and memorization of data.
- A real-time remote control system (hardware and software) for the *Phoenix*™ *NIR* and *Merlin*™ *NIR* cameras, integrated with the PILASTER LAN/WAN networks.
- The interface electronics for the *Phoenix*™ *NIR* camera, required for processed (off-line) data transmission through the PILASTER LAN/WAN networks (and visualisation at the PCC), and for real-time remote control of the camera.
- The interface electronics for the *Merlin*™ *NIR* camera, required for real-time data transmission through the PILASTER LAN and WAN networks (and real-time visualisation at the PCC), and for real-time remote control of the camera.

5.3.2 STU-FXDT Sensors and Processing Units

A Laser Energy Measurement System (LEMS), constituted by various Laser Energy Meter (LEM) electronic units, equipped with 4 ÷ 16 Pyroelectric Probe (PEP) sensors (FXDT-mounted), were also integrated in the PILASTER STU. The LEMS is suitable for measuring pulsed laser signals with very short pulse duration (P_D) and low peak energy (E_P), at λ = 1064 nm and λ = 1550 nm (10 mJ/m^2 ≤ P_D ≤ 10 μJ/m^2, P_D ≥ 2 nsec, PRF = 1 ÷ 400 Hz).

Together with the PEP sensors, eight sensors-heads connected via fiber optics cables to a modified version of the Marconi Selenia Communications S.p.A. RALM-01 Laser Warning Receiver (M-RALM-01) were installed on the FXDT target. A remote control and display unit of the M-RALM-01 system was also installed in the STU, and the system data were sent to the MSU through the LAN/WAN networks. The M-RALM-01 system was used to accurately measure the PRF of the incident laser signals, and as an additional back-up sensor for confirming the presence of laser signals on the PILASTER FXDT target, for safety purposes during both test and training missions (see Chapter 7 for more details about the LEMS/ PEP and M-RALM-01 systems characteristics).

5.3.3 Meteorological Sensors

Two wireless commercial meteorological stations, equipped with all sensors required for measuring relative humidity (*RH*), pressure (P_a), temperature (*T*), differential temperatures (T_d), rainfall-rate ($\Delta x/\Delta t$), wind speed (W_s) and wind direction (W_d), were used to collect the relevant data at the FXDT target location and at the transmitter locations (for ground systems testing), necessary for propagation and performance analysis. Furthermore, two additional sensors were employed for measuring the turbulence structure constant (C_n) and turbulent heat flux (H_f) at the FXDT target and ground laser systems locations. Particularly, the following systems/sensors were employed:

- Two Wireless Meteorological Stations (WMS) constituted by a 0 ÷ 10 metres tower for sensors installation (i.e., hygrometers, barometers, thermometers, thermocouples, rainfall-rate meters and anemometers) and a local display unit (maximum distance from the sensor tower: 100 metre) with standard PC interfaces.
- A portable Display and Recording Station (DRS), connected to the WMS (RS232 serial port), for real-time data display (touch-screen display with retro-illumination) and recording (data from all meteorological sensors acquired during a period of 24 hours at a sampling frequency of 1 Hz).
- Two calibrated thermometers with 0.1°C precision (*T* range: –20°C ÷ +60°C).
- Two calibrated hygrometer with a precision of 1% (*RH* range: 15% ÷ 100%).
- Two barometers with 1 hPa precision, for atmospheric pressure measurement.
- Two rainfall-rate meters for measurement of relative and total $\Delta x/\Delta t$, with a precision of 0.1 mm/hr.
- Two anemometers for wind speed (precision 1 km/h), and wind direction determination (precision 2°).
- A scintillometer (composed by a laser transmitter and a remote measurement unit) for determination of the turbulence structure constant (C_n), and turbulent heat flux (H_f), with measurement baselines between 500 m and 5 km.

5.4 PILASTER TSPI SYSTEMS

During test and training activities with Airborne Laser Systems (ALS) and Laser Guided Weapons (LGW) at the PILASTER range, accurate Time and Space Position Information (TSPI) can be provided by using existing cinetheodolite systems (with filtered operator optical sights), tracking radars (or laser tracking systems), and various ground-based radio positioning systems. These systems, however, have a variety of limitations. First of all, they provide a TSPI solution based on measurements relative to large and costly fixed ground stations. Weather has an adverse effect on many of these systems, and all of them are limited to minimum altitudes or to limited portions of the PILASTER range area. The number of participants each system can support is very limited, and correlation with other systems is extremely difficult, if not impossible. These limitations greatly increase instrumentation costs and impose severe constraints on test/training scenarios. Clearly, a more cost-effective TSPI source was needed for the final PILASTER implementation.

5.4.1 DGPS Range Applications

The Global Positioning System (GPS) provides a cost-effective capability that overcomes nearly all the limitations of existing TSPI sources. GPS is a passive system using satellites which provide universal and accurate source of real-time position and timing data to correlate mission events. The coverage area is unbounded and the number of users is unlimited. The use of land-based Differential GPS (DGPS) reference stations improves accuracy to about one metre for relatively stationary platforms, and to a few metres for

high performance tactical aircraft. Further accuracy enhancement can be obtained by using GPS carrier phase measurements, either in post-processing or in real-time. Accuracy does not degrade at low altitudes above the earth's surface, and loss of navigation solution does not occur as long as the antenna has an open view of the sky.

However, DGPS performance in terms of data continuity and accuracy during high dynamics manoeuvres, even if sufficient for many tasks, can not cover the entire flight envelope of modern high performance fighter aircraft. Moreover, the update-rate of GPS receivers is too low for many tasks. Currently, the integration of GPS with an inertial navigation system (INS) is considered to be the optimal solution to the above mentioned shortcomings. This integration, performed either in real-time or in post-processing, can provide in fact the required update rate and have a higher data continuity and integrity. The other advantages of an INS: low short term drift and low noise, are combined with the advantages of GPS: high position accuracy and no long term drift. Moreover, the combination of an INS with (D)GPS is a natural evolution of existing airborne navigation systems, the majority of which is currently based on an INS, updated by other positioning systems to compensate for the shortcomings of the inertial system.

5.4.2 PILASTER DGPS Equipment Selection

As discussed in the previous paragraph, accurate determination of aircraft TSPI is a strong requirement for both flight test and training applications with ALS/LGW. The foreseen capabilities of GPS, in terms of data accuracy, quickness of data availability and reduction of cost, moved to undertake a study aimed at defining the requirements of a DGPS based system for integration in the PILASTER range. The study was mainly addressed to GPS using C/A code, with post-flight differentiation. This was preferred to GPS using P-code due to both simplicity of use and high accuracy attainable notwithstanding its lower cost. After contacting many potential suppliers, an initial assessment of different systems was conducted in order to select the DGPS systems best matching the technical requirements. The technical specifications were submitted to a number of companies producing GPS systems. Of the 12 companies contacted, four were able to provide systems with good technical characteristics. Therefore, a comparison was necessary in order to select the system with the best performance. The results of the technical analysis are shown Table 5-1. The system proposed by ELMER (ELMER R202 P-code airborne receiver) did not satisfy the essential accuracy requirements. The system proposed by this company could only operate in P-code and therefore its quoted accuracy (16 m SEP) was better than any other stand-alone GPS system operating with the C/A code (100 m 2d-RMS), but less than the accuracy normally provided by a GPS in differential mode (1 – 5 m SEP). Moreover, the number of channels available was less than required and the overall cost of the system was very high. Also the system proposed by TECHNITRON (GPS120 airborne receiver and ASHTECH-XII ground receiver) was unsatisfactory. Particularly, the airborne system was a 5-channel receiver and the quoted accuracies were inferior to the other systems. Moreover, the RTCM-SC-104 standard protocol was not available. The system proposed by ASHTECH ITALY (ASHTECH XII for both the AR and the ground RS) satisfied the essential requirements stated in the specification document. Even if the interface available on the ASHTECH XII receiver (RS-232) was different from the one desired (RS-422), the technical problem could be easily solved. Also the system proposed by TRIMBLE ITALY (TANS airborne receiver and 4000SE ground receiver) fulfilled the essential requirements stated in the PILASTER specification documents. As a result of the technical analysis, the systems proposed by ASHTECH and TRIMBLE were selected.

Table 5-1: Technical Comparison of Four DGPS Systems for the PILASTER Range

REQUIREMENTS		WEIGHT	MARCONI-ELMER			ASHTECH ITALY			TECHNITRON			TRIMBLE ITALY		
			PERFORM.	MARK	MARK × WEIGHT	PERFORM.	MARK	MARK × WEIGHT	PERFORM.	MARK	MARK × WEIGHT	PERFORM	MARK	MARK × WEIGHT
Airborne equipment	N. of channels (6 min.)	3	5 parallel	3	9	12 parallel	5	15	5 parallel	5	9	6 parallel	5	15
	C/A code (L1)	5	C/A + P	1	5	C/A	5	25	C/A	5	25	C/A	5	25
	Aided Mode (vel. a/o alt.)	1	YES	5	5	(Alt. only)	5	5	YES (option)	5	5	YES (option)	5	5
	Acc. Pos. w/o SA (25m SEP)	1	16 m SEP	5	5	25 m SEP	5	5	25 m SEP	5	5	25 m SEP	5	5
	Acc. Pos. with SA (100m 2dRMS)	3	16 m SEP	5	15	100 m 2dRMS	5	15	100m 2dRMS	5	15	100m 2dRMS	5	15
	Acc. Vel. w/o SA (0.02 m/s RMS)	1	0.1 m/s RMS	3	3	0.1 m/s RMS	5	5	0.1 m/s RMS	5	3	0.02 m/s RMS	5	5
	Acc. Vel. with SA (0.1 m/s RMS)	3	0.1 m/s RMS	5	15	0.1 m/s RMS	5	15	0.1 m/s RMS	5	15	0.1 m/s RMS	5	15
	Standard I/O	5	OK	5	25	RS232	3	15	RS232	5	15	OK	5	25
	SUBTOTAL				**89**			**100**			**92**			**110**
Ground Station	N. of channels (9 min.)	5	5 parallel	3	15	12 parallel	5	25	12 parallel	5	25	9 parallel	5	25
	Code	5	C/A + P	1	5	C/A	5	25	C/A	5	25	C/A	5	25
	(L + L option)	5	YES	5	15	YES	5	15	YES	5	25	YES	5	15
	Recording memory	3	UN	1	3	20 h	5	15	20 h	5	15	6 h	5	15
	RCTM format	5	NO	1	5	OK	5	25	NO	1	5	OK	5	25
	SUBTOTAL				**43**			**105**			**95**			**105**
Software Accuracy	Real-time differential mode:													
	- Position (10 m SEP)	3	-	"	N/A	3 m SEP	5	15	25 m SEP	1	3	10 m SEP	5	15
	- Velocity (0.02 m/s)	3	-	"	"	0.01 m/s RMS	5	15	0.1 m/s	3	9	0.02 m/s	5	15
	Post FLT differential mode:													
	- Position (5 m SEP)	5	-	"	"	3 m SEP	5	25	10 m SEP	1	5	5 m SEP	5	25
	- Velocity (0.02 m/s)	5	-	"	"	0.01 m/s RMS	5	25	0.05 m/s RMS	3	15	0.02 m/s RMS	5	25
	SUBTOTAL				**N/A**			**80**			**32**			**80**
Tech. ass.		5	-	5	25		5	25		5	25		5	25
TOTAL		**64**			**150**			**310**			**244**			**320**

ACC. = Accuracy, POS. = Position, VEL. = Velocity, SA = Selective Availability, W/O = Without, I/O = Input/Output, A/O = And/Or, N/A = Not Applicable, UN = Unknown.

5.5 PILASTER EXTINCTION MEASUREMENT TECHNIQUES

The standard techniques used for PILASTER laser extinction measurements (atmospheric propagation tests) are the following:

- Extinction Measurement Technique N° 1 (EMT-1), using the PILASTER non-calibrated *Phoenix*™ NIR camera and the FXDT-mounted PEP sensors measurements.
- Extinction Measurement Technique N° 2 (EMT-2), using the PILASTER calibrated *Phoenix*™ NIR camera measurements.

The rationales of the EMT-1 and EMT-2 techniques are described below. An additional technique (EMT-3), developed to perform extinction measurements when PILASTER standard techniques (EMT-1 and EMT-2) could not be implemented (e.g., laser transmitter characteristics not compatible with the standard PILASTER STU sensors response), and a Control Technique (EMT-CT) for systems field calibration and preliminary verification of the EMT-1 and EMT-2 techniques, are described in Chapter 8 (Ground Experimental Activities).

5.5.1 Description of PILASTER EMT-1

This technique is based on direct measurements of laser energy at pre-defined locations on the target (DEA detectors) and use of the *Phoenix*™ NIR camera spot frames (NIR camera non-calibrated) to reconstruct, by means of the IMAGE-PRO PLUS™ pixel intensity matrixes (associated to each frame), the overall energy intensity profile (from which atmospheric extinction is computed). The logical steps involved in this technique are shown in Figure 5-3.

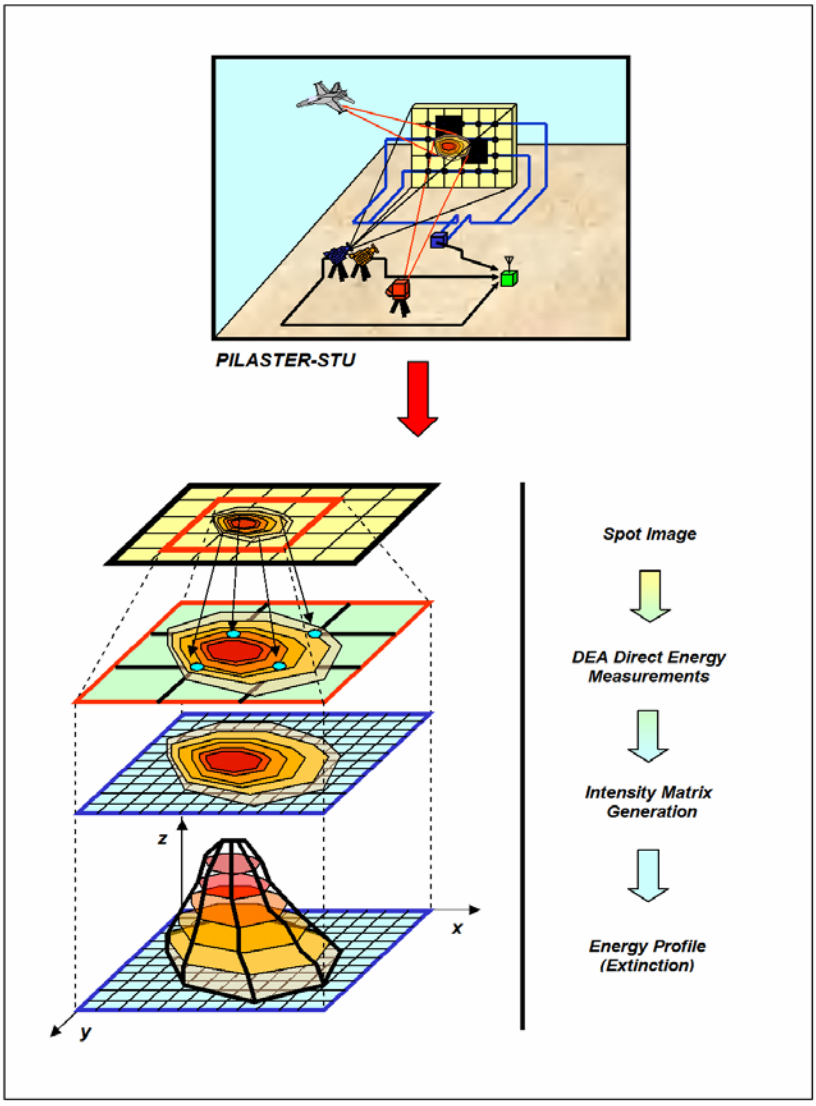

Figure 5-3: EMT-1 Laser Spot Energy Profile Reconstruction.

5.5.2 Description of PILASTER EMT-2

This technique is based on use of the calibrated *Phoenix*™ NIR camera (calibration performed in the laboratory using an Integrating Sphere, as described in Chapter 7) and successive adoption of a dedicated energy profiling function implemented with the IMAGE-PRO PLUS™ software. This function permits to obtain the overall spot energy by directly converting pixel intensity data into energy measurements. Using these measurements, atmospheric extinction is computed.

As an example, a spot measurement performed using the ELOP-PLD system (λ = 1064 nm) and EMT-2 is shown in Figure 5-4. The test was performed with a laser slant-path of 4 km, during a day with V = 11 km, RH = 65% and T = 18°C. In this case, an energy (E) of 52.76 mJ was measured by the *Phoenix*™ NIR camera. Using the ESLM model presented in Chapter 3, the following propagation factors were found:

- τ_{si} = 0.54 contribution due to scattering only;
- τ_{ai} = 0.79 contribution due to absorption only; and
- τ_{atm} = 0.43 total atmospheric transmittance.

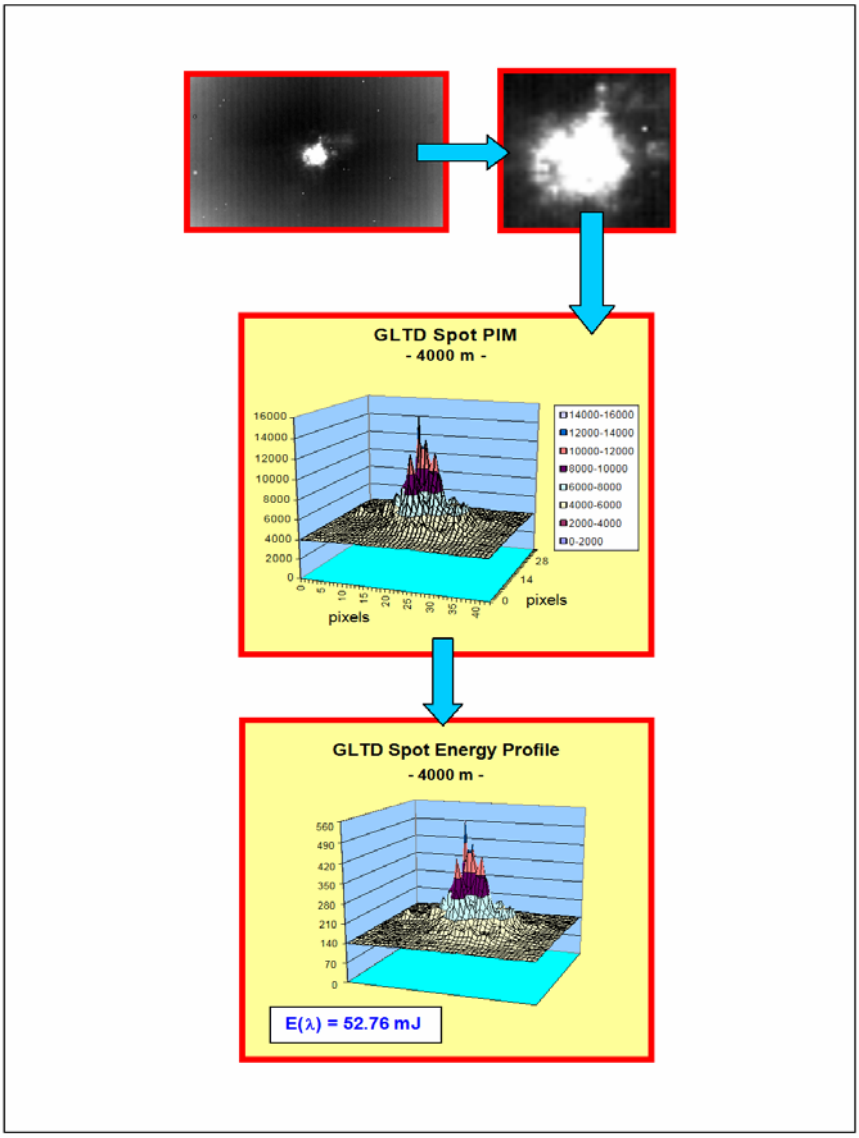

Figure 5-4: EMT-2 Laser Spot Energy Measurement.

Knowing the output energy (LOE) of the ELOP-PLD system (i.e., LOE = 130 mJ), the calculated energy incident on the target was 55.9 mJ. Therefore, in this case, the difference between the transmittance calculated with the ESLM model and the measurement performed with EMT-2 was about 5.6%.

5.6 PILASTER TARGETS

Currently, three different types of targets have been designed and constructed at the PILASTER range. Particularly, according to the definitions given in Chapter 4, the following targets are now available:

- Fast-recoverable Target (FRCT);
- Fixed Target (FXDT); and
- IR Reference Target (IREF).

In the following sections, the final design of the PILASTER FRCT, FXDT and IREF targets is presented.

5.6.1 FRCT Target

In order to fulfil the general requirement described in Chapter 4 (i.e., large frontal area and MTTR of 1 hour), the FRCT was designed as a vertical modular target, composed by a number of light-weight wood modules (covering the frontal target area), mounted on a load bearing wood planks structure (also modular and easy to repair), installed on a permanent concrete base. The rigidity of the load bearing structure was also increased by using tension cables. The FRCT target front surface dimensions are 9.76 × 7.925 metres. According to the PILASTER requirements, the FRCT target front surface was painted with highly diffusive white and dark grey paints (see Chapter 8). Some phases of the PILASTER FRCT target construction are shown in Figure 5-5.

Figure 5-5: PILASTER FRCT Target Construction.

At a distance of about 250 metres from the PILASTER FRCT target, along the target normal (i.e., well outside the CEP of most current laser armaments), a hardened shelter (HSH) was constructed for installation of the STU sensors/systems.

5.6.2 FXDT Target

The PILASTER FXDT target is a concrete wall with a frontal surface of 10 × 10 metres. The wall is provided with a number of apertures for installing various types of target panels (painted Al alloy) on the front surface (illuminated by the laser). The apertures are accessible at various levels of the wall using permanent stairs on the back side of the target. In the vicinity of the FXDT target, there are two permanent

shelters, one for permanent installation of STU sensors/systems and one for electric power generation (EPG). The general layout and locations of the PILASTER FRCT, FXDT, HSH and permanent STU is shown in Figure 5-6.

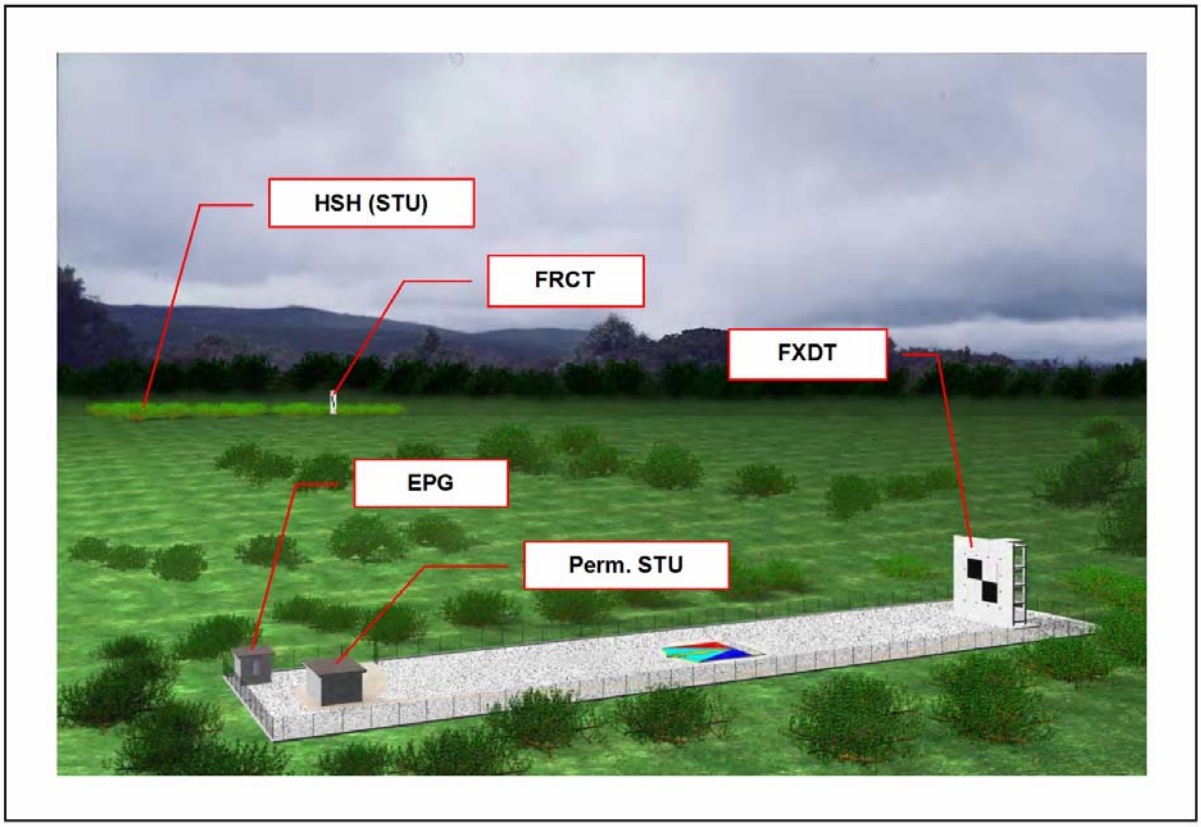

Figure 5-6: PILASTER FXDT Target Layout.

The Figure 5-7 and Figure 5-8 show the layout of the three FXDT target panels. Various apertures are present on the panels for installation of the STU target detector units (lenses and optical fibers). These apertures are occluded if not occupied by sensors during the PILASTER activities.

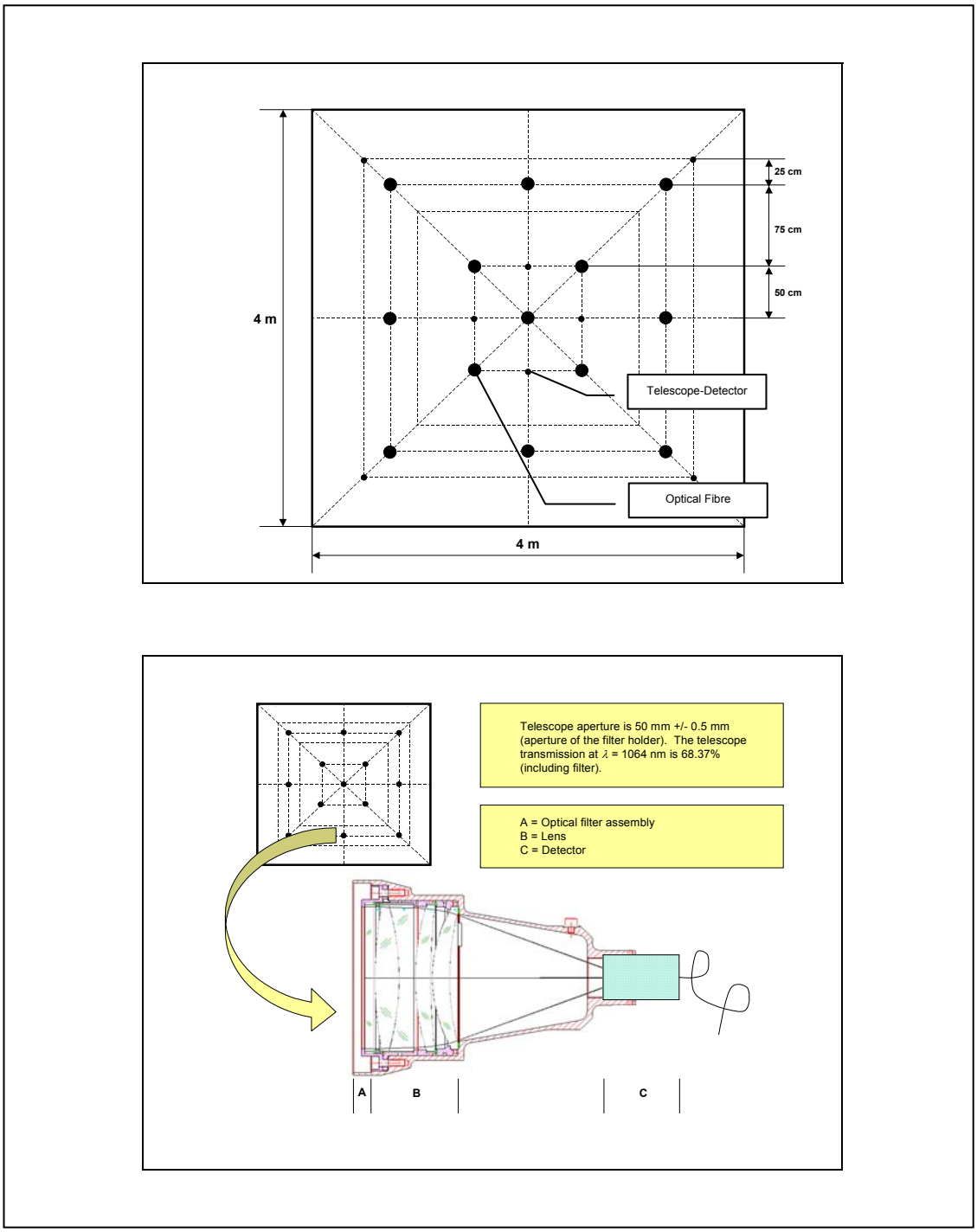

Figure 5-7: PILASTER FXDT Target Standard Panel N° 1.

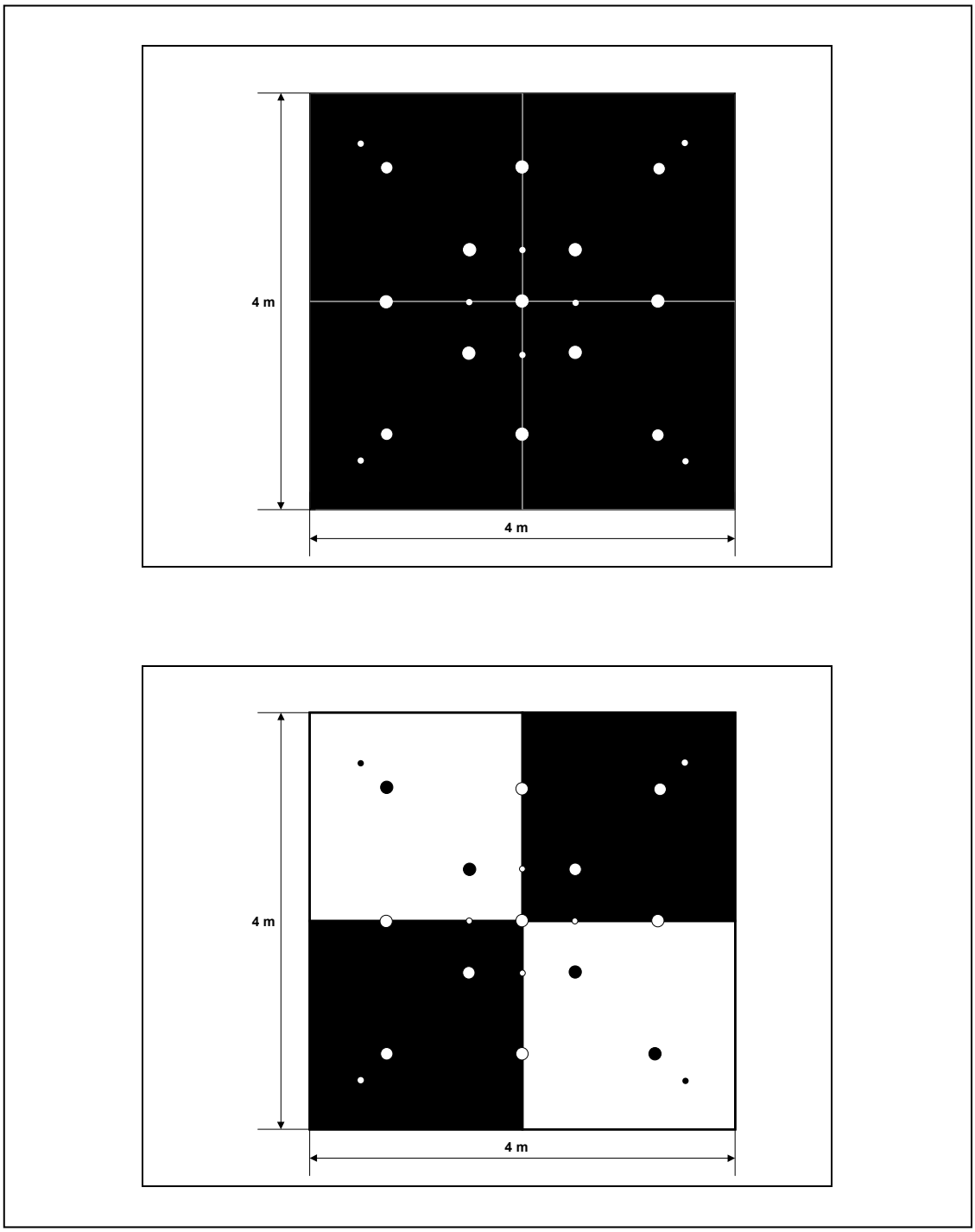

Figure 5-8: PILASTER FXDT Target Standard Panels N° 2 and N° 3.

According to the PILASTER requirements, the FXDT target panels were painted with highly diffusive paints (of known BRDF at λ = 1064 nm and known NIR reflectance characteristics), in order to perform STU spot energy measurements. After various laboratory experiments (see Chapter 7), the *Nextel*™ paints and coatings produced by *Mankiewicz Gebr. & Co.* (Georg Wilhelm Straβe, 189 D-21107 Hamburg – Germany), were selected for the FXDT target panels. The *Nextel*™ paints used for the PILASTER FXDT target panels

are listed in Table 5-2. Further details about the reflection properties of the *Nextel*™ paints are given in Chapter 7.

Table 5-2: Nextel™ Paints Used for the PILASTER FXDT Target

♦ **Nextel Primer 5523 including Hardener 5524** • White 9125 • Anthracite 7525
♦ **Nextel Suede Coating 428-22** • White 919X • Black 9218 • Hardener 405-12
♦ **Nextel Thinner 8061**

5.6.3 IREF Target

The PILASTER IREF is a thermal target panel with eight vertical bars of equal width, four of which are heated at specified temperature differences (ΔT) with respect to the unheated bars and background. Particularly, the IREF target bars ΔT is tuneable with steps of 0.5°C (temperature controlled by thermocouples and thermography). Using the IREF target, the Minimum Resolvable Temperature Differences (MRTD) with spatial frequencies (cycle/mrad) corresponding to various 2-D discrimination levels, can be determined for the FLIR systems integrated with modern laser designation devices. Furthermore, using experimental data collected in flight, it is possible to calculate the detection, recognition and identification ranges of the FLIR systems, for targets of given aspect dimensions. The technical approach adopted at the PILASTER range for collecting and analysing flight test data using the IREF target, is described in Chapter 9.

The IREF thermal target panel front dimensions are shown in Figure 5-9. The target reflectance is about 0.1 in the NIR waveband. This is obtained by painting the panel surface with dead matt black *Trimite*™ J133 paint, coated with *Bubbleflex*™ B792 (*Playlite Ltd.)*. The IREF target elevation is adjustable with mechanical devices from horizontal to vertical through 90°. The IREF target panel can be used independently, or can be installed on the PILASTER FXDT permanent structure (like the standard panels used for laser spot measurements, with an additional mechanical device for elevation control).

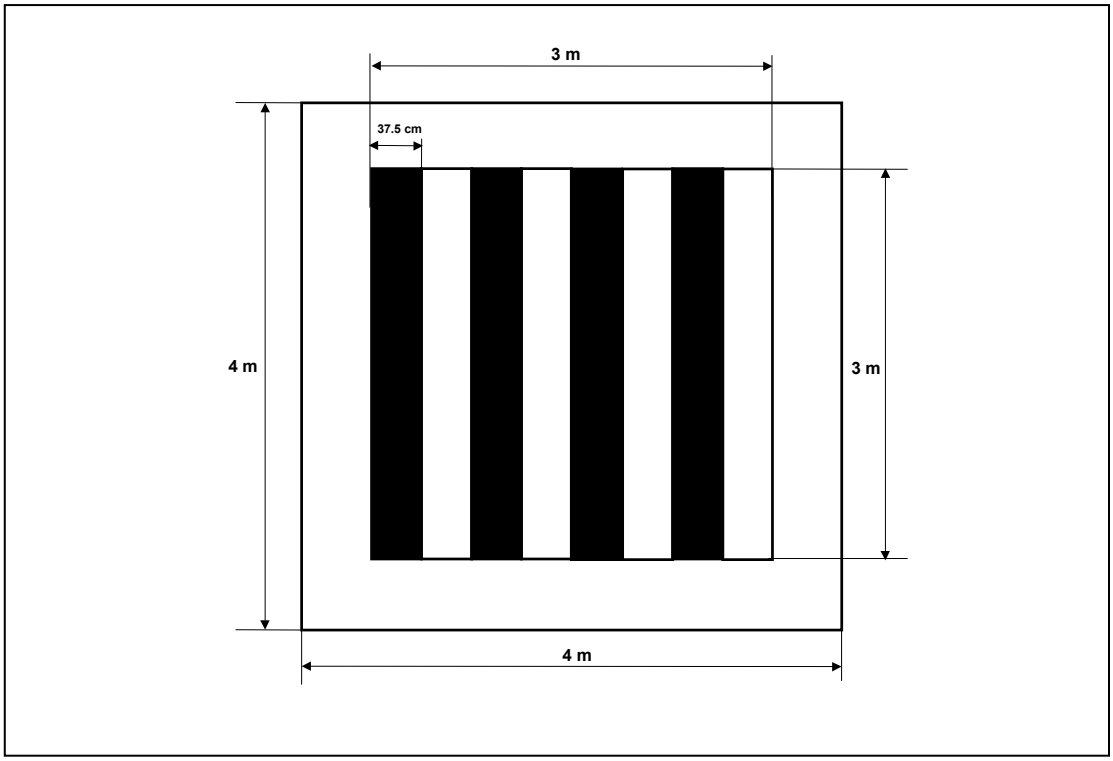

Figure 5-9: PILASTER IREF Target for FLIR Systems Testing.