

## ASPECTS REGARDING SAFETY SYSTEM IN SURFACE-TO-AIR MISSILE FIRINGS

Viorel-Eugen BITAN, Valeriu CĂLIN

\*Training Camp and Surface-to-Air Firing Range, Romania (vbitan@roaf.ro,  
vcalin@roaf.ro)

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**Abstract:** *In present, the Air Defense Artillery & Missile branch became an essential component of Romania's air defense. In its history, Air Defense Artillery & Missile branch has evolved from modified field artillery to specialized antiaircraft artillery and complex surface-to-air missile systems and that evolution imposed setting up a specialized firing range to allow training firings in safe battlefield-like conditions. This role and mission was fulfilled by the Training Camp and Surface-to-Air Firing Range (TIPTSA), as a permanent firing range, large, open and complex, the only structure in the Romanian Armed Forces to organize and host firing activities that include the third dimension – the air. TIPTSA's activity is complex and includes mainly, to take every measure for the safety during live firing exercises, to provide the targets during the firing activities and to observe and evaluate the firing activities. The most important objective of range is named "No incident" objective, meaning that none of the participants, neighbors or equipment are injured/ damaged. During its evolution, the firing range was endowed with precise evaluation systems, able to measure the coordinates of every point in firing area. This paper presents how to highlight the precision of the evaluation systems using them in safety purposes during firing activities, and tries to offer an idea to modernize or develop new equipment to fulfill the safety issues in antiaircraft artillery and surface-to-air missile firings.*

**Keywords:** *antiaircraft missiles, surface-to-air missiles, antiaircraft firings, safety, evaluation systems*

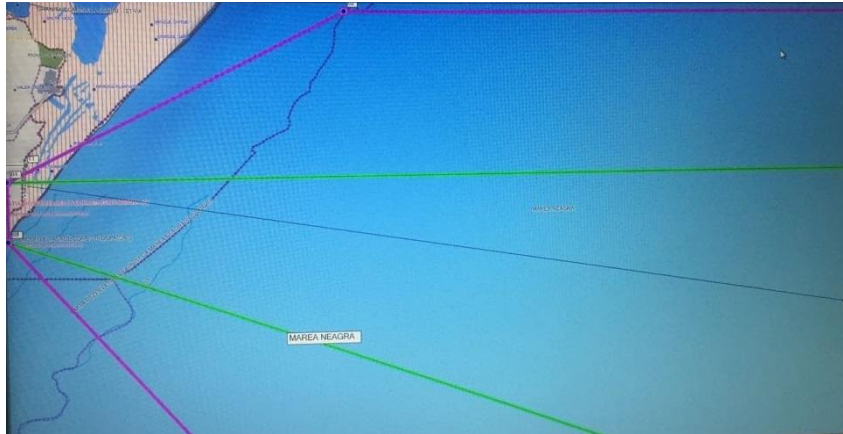
### 1. INTRODUCTION

Firing range – generally, and Capu Midia firing range – particularly provides facilities for complex training exercises in the field with multiple targets available to engage. The most important challenge for range safety personnel is to assure that every activity can be performed in safety circumstances.

In order to totally remove the risks, there are performed trainings regarding safety issues with all personnel involved in activities.

General safety measures are measures to observe any entrance or exit in firing sector or safety sector, people, vehicles, boats or animals. There are grouped in TERESTRIAL, MARITIME and AERIAL measures and uses specific equipment like radar, binoculars, communication equipment, etc.

Immediate safety measures are depending on the air defense system used for firings and are applied in firing position. In addition, there are taken specific measures that reveal the position of the launched missile within the limits of the firing sector. The limits of the firing sector or safety sector are stipulated in regulations and depends on the type of the SAM system and the area available for shooting in every firing range. This are input data for every standing operating procedure applied in surface-to-air firings.



**FIG. 1.** Safety sector (pink) and firing sector (green) in the case of medium range SAM systems in Capu Midia firing range

It is obvious the need to know the position of the missile to decide when to destroy it, if necessary, as specific standing operating procedure requires. In the same time, no missile can be left to leave firing sector or pass the target in the case of no impact.

There are SAM systems that provide data about missile position by default, due to the homing method, but this task could be difficult in the case of SAM systems that use semi-active radar homing (SARH).

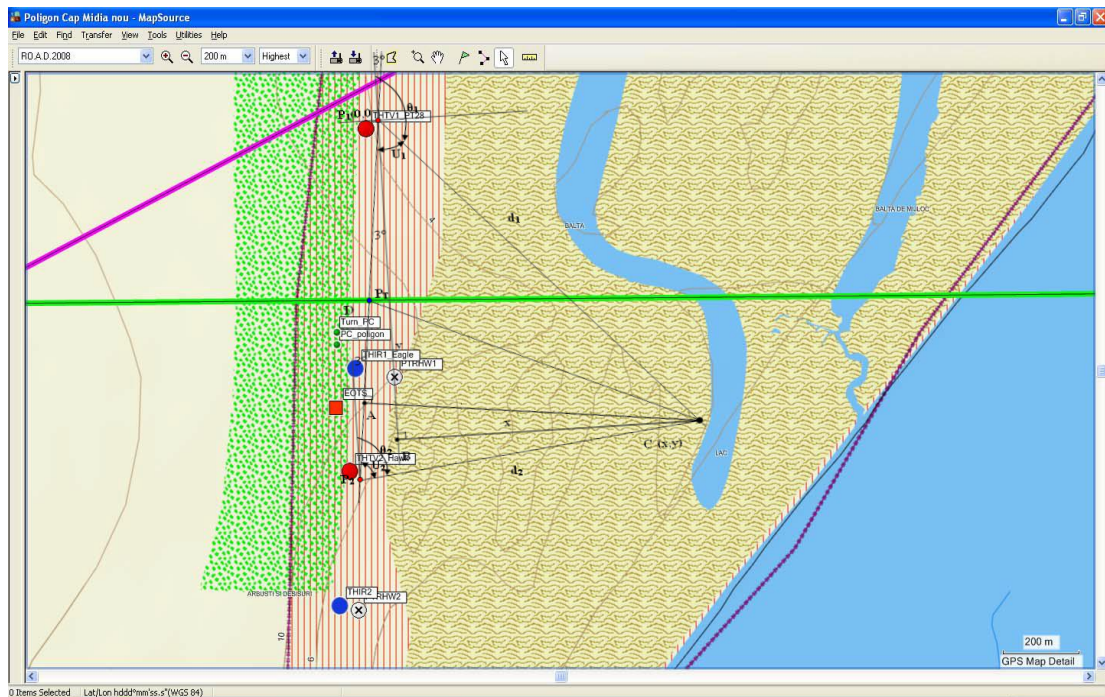
Semi-active radar homing (SARH) is a common type of missile guidance system, perhaps the most common type for longer-range air-to-air and surface-to-air missile systems. The name refers to the fact that the missile itself is only a passive detector of a radar signal – provided by an external source – as it reflects off the target[1]. Additionally, the missile will listen rearward to the launch platform's transmitted signal as a reference, enabling it to avoid some kinds of radar jamming distractions offered by the target. Therefore, we don't receive a signal from missile to determine its precise position. In a real combat this will be no disadvantage, but a firing range will need another system to get this information. Particularly, a such of system can be another radar, another weapon system that will track the launched missile without combat any target or a precise evaluation system, as it used in Capu Midia firing range.

## 2. EVALUATION SYSTEMS USED IN SAFETY PURPOSES

**2.1 Optical and electro-optical evaluation system used in TIPTSA.** For direct anti-aircraft artillery and V-SHORAD firing can be used the TZK binoculars or the Bosch binoculars, which are capable of observing targets and the results of the firing activities, measuring miss distances between the burst trails and the target, measuring horizontal angles (within the  $n \times 360^\circ$  range) and vertical angles (within the  $-18^\circ + 84^\circ$  range) and cueing the surface, air and water targets[2]. Due to their poor precision at big distances, these type of instruments can be used in safety purposes only for indication or can be used to cue objects entering the firing sector.

The electro-optical tracking system EOTS-F is meant to accurately determine the trajectories of the air targets, the errors between two air targets and between flares and an air target. Unlike the optical systems that are used, this is used for evaluating both anti-aircraft artillery firing and anti-aircraft/surface-to-air missile firing.

**2.2 Electro-optical evaluation system used in TIPTSA.** The EOTS-F system is primarily based on determining the angular coordinates of a point in space using bi-dimensional measuring instruments that have a highly accurate measuring system for the azimuth and elevation angles ( $2 \cdot 10^{-4}$  gons  $\equiv 3.14$  mm/km), set in accurately determined positions [3]. The cinetheodolite has either automatic infrared or visible tracking equipment to observe aerial targets by optical means and track them manually, automatically or by servicing at the central station, on a video signal (TV), or based on the radiated infrared (IR) signal. Output data of the EOTS-F cinetheodolites contains position information comprising coded azimuth and elevation angles ( $\alpha, \lambda$ ) and additional information, synchronized time, labels, etc. EOTS-F software uses mathematical triangulation method to process the spatial coordinates (x, y, z) of the tracked object, in its own Cartesian coordinate system.



**FIG. 2.** Observation position of cinetheodolite TV (THTV1, THTV2) marked with red points and IR cinetheodolite (THIR1, THIR2) marked with blue points, in Capu Midia firing range; EOTS reference point, marked with red square

A target/object must be tracked by a pair of cinetheodolites of the same type (visual spectre or IR spectre) and the coordinates will be obtained using formulas above:

$$\begin{aligned}
 x &= x_1 + \frac{D \cdot \sin(183 - \theta_2) \cdot \sin \theta_1}{\sin(\theta_1 - \theta_2)}; \\
 y &= y_1 + \frac{D \cdot \sin(183 - \theta_2) \cdot \cos \theta_1}{\sin(\theta_1 - \theta_2)}; \\
 z &= z_1 + \frac{D \cdot \sin(183 - \theta_2) \cdot \text{tg} \gamma_1}{\sin(\theta_1 - \theta_2)}
 \end{aligned} \tag{1}$$

where  $(x_1, y_1, z_1)$  represents reference point of EOTS, marked with red square in Fig.2, D is the distance between cinetheodolites in TV or IR pair and  $\theta_1, \theta_2, \gamma_1, \gamma_2$  represents determined azimuth and elevation angle determined by first and second cinetheodolite respectively.[4]

Considering that most of the trajectories are within the observation boundaries of the system the use of the EOTS-F for safety measures in the case of SAM with SARH guidance system.

### 3. AUTOMATIC AQUISITION, TRANSMISSION AND PROCESSING TARGET DATA FROM EOTS-F

As shown, EOTS-F determine precise coordinates of missiles/ targets but cannot determine if the missiles/ targets are within the boundaries of the firing sector/ safety sector. Those areas are defined considering every weapon system used and firing position so it is difficult to describe their limits in EOTS-F Cartesian coordinate system. In reverse, should be designed a method to convert the EOTS-F data in geographical coordinates.

Considering that the firing sector is defined as an angular sector pointed from the firing position, it appears that the problem is reduced at a method to convert the angle determined by EOTS-F in angular information usable from the firing position (to determine a correlation between this two angles) and to compare it with the angular limits of the sector.

Angular targeting / tracking data of the targets by the theodolites (azimuth and elevation angles) are transmitted by radio to central station (Master Station - MS), installed in the EOTS building, where it is performed post-mission analysis, so the extraction of the angle needs to identify a physical circuit from theodolite that contain angles information and the data format.

#### 3.1 Real-time transmission of azimuth angle value originating from cinetheodolite, in Firing Control Center

The solution assumes that from the Angle Measurement System of one cinetheodolite with infrared tracking (THIR1), placed in position, to be taken the electrical signals in digital BCD format, which contain the azimuth angle value and the command signal for reading the angle. It is important to place the theodolite right in the back of the firing position to minimize the errors recorded in the first part of the missiles trajectory, otherwise the missile would be seen much outside the sector.

The electrical signals, after a preliminary hardware adjustments, are inserted into a data acquisition card (DAQ), which is coupled via a USB port with a laptop (LP\_E) containing S/W of acquisition and processing signals, providing the instantaneous value of the angle. The azimuth angle value is transmitted in decimal format (gons and / or sexasimal grades) in the firing control center, downloaded to a laptop (LP\_R), being displayed in real time and available to the officer in charge (**Fig.3**)

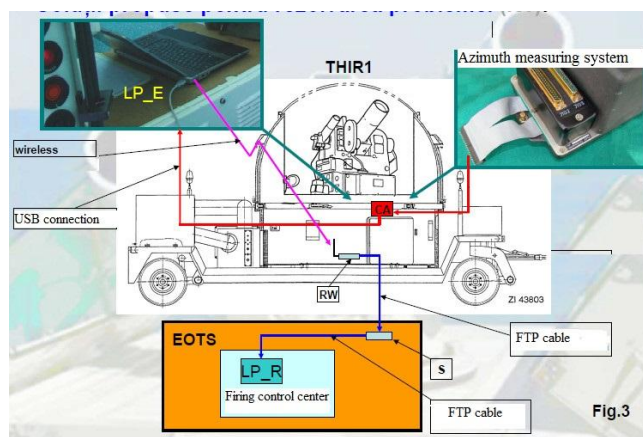


FIG. 4. Minimal configuration for acquisition, transmission and data processing system

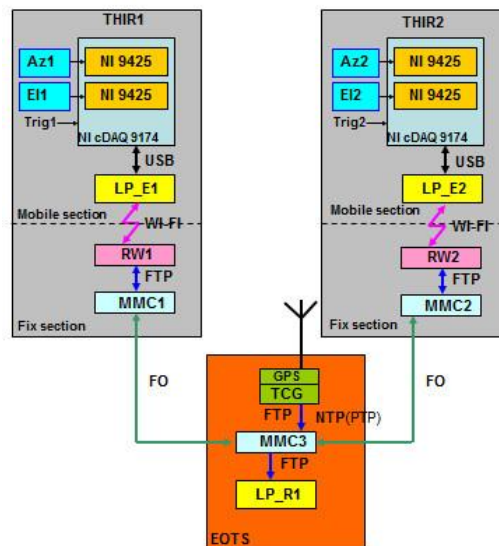
Data transmission between LP\_E (located in THIR1) and LP\_R (located in the firing control center) is carried out in the proposed configuration via an FTP cable network provided with a wireless router (RW). The cable route will have the total length of 150 m, including the laying configuration to it. In the case of bigger distances it is necessary to enter a switch (S). From the switch, the FTP cable is brought directly to LP\_R, in the firing control center (**Fig. 3**).

CA, LP\_E will be located inside the THIR1, in the mobile part, and RW in its fixed part (**Fig. 3**).

**3.2 Equipment used by automatic acquisition, transmission and data processing system.** In this configuration are necessary materials and equipment as follows:

- data acquisition cards (NI DAQ 9174 modules with two NI 9425 cards).
- 2 laptops (LP\_E, LP\_R),
- wireless router,
- switch with power supply,
- FTP cable.

For scenarios with more than one missile launched there is necessary a configuration with more cinetheodolites, at bigger distances, connected using optic fiber channel (**Fig.4**).



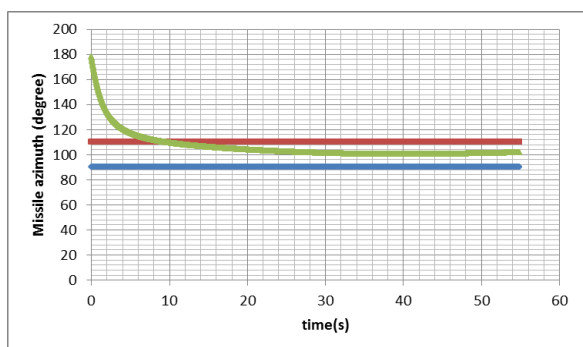
**FIG. 4.** Configuration for acquisition, transmission and data processing system for two cinetheodolites

Obvious, the equipment and materials will multiply to the number of missiles launched in the same time. The system needs a synchronized pulses for acquisition and transmission, so will be used a Time Code Generator with GPS time in the Master Station.

**3.3 Results obtained.** The minimal configuration used in testing activities proved to be satisfactory and reliable. Real time data used for making destroy missile decision are recorded for further evaluation.

One example of a missile's azimuth angle recorded is presented in **Fig.5 (a)**, marked with green. In the initial part of the trajectory, the missile is outside firing sector right and left boundaries, marked with red and blue respectively, and enters the sector after few seconds. In fact, the missile starts from firing position placed on the same alignment as the cinetheodolite ( $180^0$  azimuth) and enters the 90 -110 degrees sector.

In **Fig.5 (b)**, is displayed a part of a recorded file with azimuth and elevation data information, sampled at every 33 milliseconds.



(a)

0.000	177.82584	0.00000
0.033	176.64026	0.41535
0.066	175.46794	0.82584
0.099	174.30962	1.23055
0.132	173.16598	1.62997
0.165	172.03801	2.02328
0.198	170.92550	2.40965
0.231	169.82932	2.78969
0.264	168.74990	3.16224
0.297	167.68762	3.52796
0.330	166.64268	3.88582
0.363	165.61552	4.23605
0.396	164.60624	4.57854
0.429	163.61501	4.91323
0.462	162.64218	5.24009
0.495	161.68725	5.55900
0.528	160.75052	5.87002
0.561	159.83182	6.17280
0.594	158.93136	6.46810
0.627	158.04876	6.75567
0.660	157.18418	7.03513
0.693	156.33716	7.30703

(b)

**FIG. 5.** (a) Example of the azimuth information of a missile fired in  $90^{\circ} - 110^{\circ}$  firing sector; (b) Part of a file with azimuth and elevation automatically collected at every 33 milliseconds. In the first part of its trajectory, the missile is outside the limits of firing sector, marked with blue and red

Additionally, can be performed acoustic or visual alerts for the situation when a missile leaves the firing sector.

## CONCLUSIONS

The safety of firings is the main objective during all activities in a firing range, so it is essential to adapt safety measures for all weapon systems. This very need and the absence of range radar for tracking missiles led to the use of the equipment used to evaluate the firing in order to achieve safety.

In future upgrades of such equipment or, in the case of new ones, is required the provision of a stand-alone mission in the field of firing safety. Including in S/W digital representations of allowed/forbidden areas from a firing range is a necessity for evaluation systems in order to increase the number of aspects evaluated in complex combat situations.

Until then the automatic acquisition, transmission and processing target data system described in this paper proves there are unexplored possibilities of actual systems that can solve temporarily safety issues.

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