Active Hardkill Protection Systems –

Analysis and Evaluation of different System Concepts

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Since the beginnings of the biennial EUROSATORY exhibitions in Paris, armoured military supply and operation vehicles have been essential exhibits. Many companies took the occasion of the EUROSATORY 2008 to present their vehicles to the public which they had newly developed or improved.

These developments orientate themselves in particular to the actual challenges of a multitude of armed forces in their present worldwide peacekeeping or peacemaking out-of-area operations. These missions are characterized by the constantly changing and increasing asymmetric threat scenarios. Consequently the capability requirements for the protection of these vehicles and thus for the protection of life and limb of their crews continue to increase constantly. Until the beginning of the nineties, the highest ballistic protection was largely limited to the horizontal frontal vehicle areas.

Today's threat scenario

Today insurgents attack target objects with their highly efficient armour-piercing weapons from almost all directions, which results in a spherical threat scenario: small to medium calibre KE penetrators, anti-tank mines, improvised explosive devices (IEDs) and portable anti-tank rocket launchers, e. g. type RPG (Ruchnoy Protivotankoviy Granatomyot, NATO: Rocket Propelled Grenades). Though a well known device since 30 years, the russian antitank-hand grenades RKG-3 and RKG-3 EM and their variants from other countries, appeared recently in the crisis-areas as a serious threat to the roofs of vehicles, even of main battle tanks, thus increasing the 360° threat.

The RKG-3 contains a shaped charge warhead with 0,31 -0,39 kg explosive, is thrown by hand or simply dropped from buildings or bridges, stabilized by a small parachute released out of the grenades handle. Just to remind, other than the Russian T-80 U, T-72 B and T-90, the roofs of the most western main battle tanks are not protected against even small shaped charge warheads. Even by application of modern adapted passive and also reactive special armour, vehicles cannot be sufficiently protected against such all-around threats. In addition, increase of the vehicle dimensions and weights by these add-on armours lead to a significant reduction of the mobility as well as manoeuvrability.

During the last years, for missions in Afghanistan and in Iraq, all-round protruding grid armour elements (bar or slat armour) were mounted to the exterior structure of a number of wheeled and tracked vehicles to protect them against RPG attacks (e.g. the medium 8x8 wheeled US tank Stryker, main battle tank Leopard 2A6M CAN). Due to the adapted grid armour elements, manoeuvrability in urban missions as well as off-road capability of these vehicles are considerably reduced. Moreover, the additional protection effectiveness of these grid elements largely depends on the hit position on the grid structure and is thus to be classified as a "statistical" measure. Therefore grid armour can only to be regarded as an interim solution.

Soft-kill countermeasure

Soft-kill APS (Active Protection Systems) are a more sophisticated solution. They can defend anti-tank guided missiles (ATGM) to avoid being hit. It takes more than one second for the selected soft-kill countermeasure to interfere with the flight behaviour, e. g. by multispectral smoke or electro-optical jammers, depending on type and function principle of the ATGM guidance system.

Soft-kill APS have a reaction time of more than one second. To initiate a successful defeat of the incoming target, the interception point (IP) and the shortest possible distance from the vehicle can be several hundred meters. It also depends on the velocity of the missile. Most important: Soft-kill APS cannot defeat unguided rocket propelled grenades (RPG), which are used in asymmetric warfare. The aforementioned limitations do not apply to hard-kill APS. Therefore they are prioritized for the military missions in the crisis regions of the world.

Hard-kill protection

Hard-kill protection systems can be regarded as the "missing link" with respect to the urgently required improvement of the vehicle protection against further increasing and constantly changing threats, especially in urban mission scenarios.

The technical operating mode of a hard-kill protection system and the time schedule (Table 1) can be described as follows:

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Tab. 1: Processes of a hard-kill APS

APS Activity
1 Recognition, analysis and verification / classification of incoming threats
2 Tracking of the threat, selection and positioning / supply of a selected countermeasure
3 Decision for initiation of the selected countermeasure unit
4 Destruction or degradation of the threat by the selected countermeasure at the defined interception point (IP)

An approaching threat (e. g. missile, KE, EFP) is tracked by a sensor system scanning the upper hemisphere around the vehicle. A fast computer system analyzes, identifies and tracks the projectile. On the basis of several parameters, the system determines if this projectile represents a direct threat for the vehicle.
If it is classified as a threat, appropriate hard-kill countermeasures are initiated automatically. Various solutions for countermeasures exist: e.g. pure blast grenade, blast-fragment grenade, blast splinter cassetts, focused blast deflection warheads, beams of multiple explosively formed projectiles (MEFP), radial or axial SC warheads, backfire ammunitions, opto-electronically directable energetic charges, plates or bars accelerated by explosives or electrically, momentum transfer armour, birdcat nets etc.
At the calculated impact point the countermeasure interacts with the threat. The objective of this interaction is to destroy the threat itself or the ignition systems of SC warheads, or to fragment or deflect the KE penetrators in such a way that the physical penetration capability is significantly reduced and the passive armour of the vehicle is not penetrated. The known hard-kill APS systems can be divided into different interception point APS types and system reaction APS types.
The interception point (IP) is defined as the distance of the interaction point of the hard-kill countermeasure with the attacking missile or projectile, measured from the exterior structure of the vehicle (weapon carrier or object). Internationally, three classes of interception point APS types are currently distinguished (Table 2).

Tab. 2: Interception point (IP) APS Types

	Interception Point (IP) APS-Type	Distance between interception point and vehicle / target
1	Close-Range	< 2 m
2	Medium-Range	2 m to 30 m
3	Far-Range	> 30 m

Remark: Beside the sensor-controlled hard-kill APS, there are also integrated sensor-activated active armour systems. However, by definition, they do not belong to the active protection systems, as the countermeasure is only activated when the projectile hits the vehicle surface.
The total time required by an APS system for search, recognition and identification of the threat until the interaction with the countermeasure is defined as the system reaction time (SRT). Internationally, three classes of System Reaction Time APS types are distinguished (Table 3).

Tab. 3: Types of System Reaction Time APS

	APS Type	SRT	APS Category
1	Micro-second system	< 1000 µs (< 1 ms)	Hard-kill
2	Milli-second system	1 ms to 1000 ms	Hard-kill
3	Second system	≥ 1 s	Soft-kill

For a hard-kill APS, the minimum defeat distance (MDD) is of crucial importance. It depends on the following parameters:
- System reaction time (SRT)
- Velocity of the threat (V)
- Distance between interaction point (IP) and exterior structure of the platform

The minimum defeat distance of a threat is calculated as follows:

MDD = (SRT x V) + IP [m]

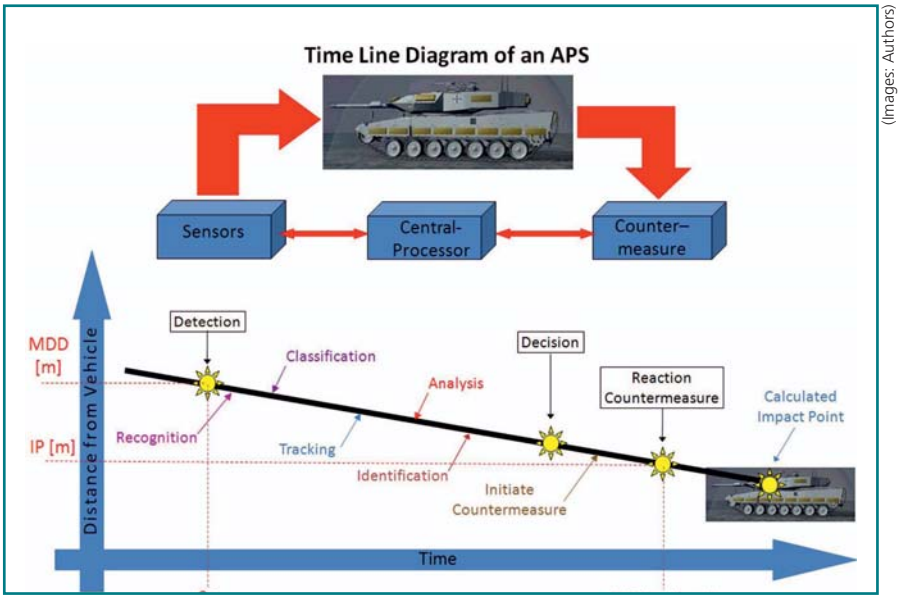
Figure 1 shows the general time line of a hard-kill APS from the recognition of a threat to the defeat. The equation shows that for a defined hard-kill APS, the MDD only depends on the velocity of the approaching threat. This leads to the conclusion:
- If a threat is fired from a distance which is shorter than the minimum defeat distance (MDD), the hard-kill APS cannot react to this threat and therefore cannot defeat it!

The aforementioned equation is illustrated using three examples:

APS System 1: Microsecond SRT APS type
– SRT = 600 µs
– IP = 1,5 m (close range interception point APS type)

Tab. 4: Minimum Defeat Distance (MDD) for three different Hard-kill APS

Heat Type	VThreat / m/s	Minimum Defeat Distance (MDD) / m		
		µs-APS	ms-APS 1	ms-APS 2
RPG-7 with PG 7VR	100	1,56	40	65
RPG-7 basis type	200	1,62	60	100
RPG-29	450	1,77	110	187,5
HEAT projectile	1100	2.16	240	415
APFSDS KE projectile	1800	2,58	380	660
EFP projectile (especially EFP-IEDs)	2000	2,70	420	730



(Images: Authors)

Figure 1: Time line diagram of an APS

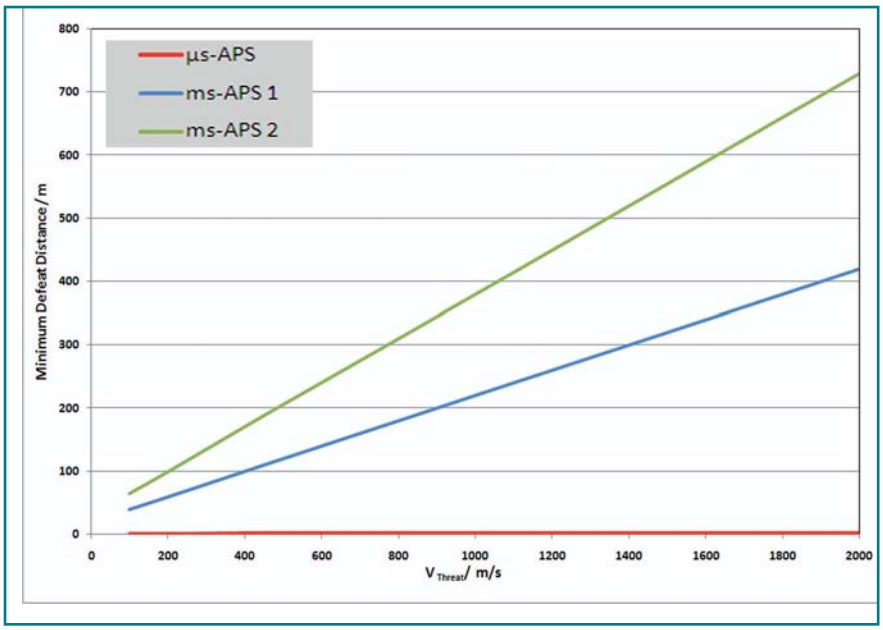


Figure 2: Minimum defeat distance (MDD) versus velocity of the threat

APS System 2: Millisecond SRT APS type
- SRT= 200 ms
- IP = 20 m (medium range interception point APS type)

APS System 3: Millisecond SRT APS type
- SRT= 350 ms
- IP = 30 m (medium range interception point APS type)

Figure 2 shows that:
- for millisecond APS, the Minimum Defeat Distance (MDD) is severely dependent on the velocity of the threat,
- for microsecond APS, the velocity of the threat is negligible.

Due to the short battle distances in asymmetric warfare and especially in urban environment, the following conclusions can be drawn with regard to the efficiency of hard-kill APS:
- Millisecond APS have a very limited efficiency in case of attacks from the immediate close range of the vehicle.
- Microsecond APS are efficient without limitations in case of attacks from the immediate close range of the vehicle.

In general, the technical performance, efficiency and reliability of currently known hard-kill APS can be evaluated by means of the following main parameters:
- Type and performance of the sensor system for recognition, analysis and verification/classification of different types of approaching threats
- Type and performance of the sensor-assisted tracking system for tracking of a threat
- Type and performance of the hard-kill launcher/firing mechanism and the countermeasure
- System reaction time (SRT)
- Minimum Defeat Distance (MDD) subject to the velocity of the threat
- Distance of the interception point (IP) from the vehicle
- Multi-hit capability, especially short time multi-hit capability (e.g. RPG-30)
- Detectability of the sensor systems
- Extent of collateral damages

These main characteristics of an APS are of significant importance for the improvement of the protection of military vehicles and consequently for the survivability of their crews.

For more than 50 years, the military technological research and development institutions of different states worldwide have been engaged in the research and development of active protection systems for application on military land vehicles. However, intensification of the international activities for development of hard-kill APS until readiness for serial production could not be observed earlier than since the mid-nineties. Until this time, sensor-controlled active protection systems were exclusively ranged in the category of protection aids under the internationally current designation of „Defensive Aid Suites" (DAS). Due to the changed threat situation, they have now become an essential component of modern modular comprehensive protec-

Figure 3: Operating method of RPG-30

Translation of text in Figure 3:

Header
- 1 Hit of the small-calibre precursor round resp. decoy missile with mono SC warhead on the turret armour of the vehicle and release of some adapted ERA protection elements
- 2 Hit on the ERA add-on armour, activated beforehand and now inefficient, by the main grenade with Tandem SC warhead following with a time delay (approx. 100 ms)
- Aiming point on the armour of the battle tank

Footer
- RPG launcher aiming with the RPG-30 launcher at a battle tank
- (1) Precursor resp. decoy missile arriving the target zone
- (2) Main grenade / missile following with a time delay (approx 100 ms) on a parallel flight path

Tab. 5: Selection of currently known hard-kill APS

Short Name	AMAP™ ADS (Germany) AAC (Akers/ Sweden) SHARK (Thales/ France)	AWiSS (symmetric threat)	AWiSS light (asymmetric threat)	Quick-Kill	ASPRO-A (Trophy) (for heavy platforms)	ASPRO-A-L (Trophy light) (for medium platforms)	Iron Fist	LEDS 150 (Land Electronic Defence System)
Company Country	ADS GmbH/ Germany	Diehl BGT Defence/ Germany	Diehl BGT Defence/ Germany	Raytheon/USA	Rafael/Israel	Rafael/Israel	IMI/Israel	Saab Avitronics / Sweden; South Africa
Sensor System	Passive wake-up sensor, tactical laser radar system	Ka band (MMW) radar IR sensor: fine tracking	IR sensor Ka band (MMW) radar	Electronically scanning solid-state phased array radar (active)	Flat panel radar, firmly arranged on 4 sides of the carrier vehicle	Flra panel radar, firmly arranged on 4 sides of the carrier vehicle	Flra panel radar, firmly arranged on 4 sides of the carrier vehicle	Active radar, IR tracker
Type of countermeasure / defeat mechanism/ arrangement on the vehicle	Opto-electronically directable energetic charge with low volume expansion, arrangement of the single ADS elements on the exterior vehicle surfaces	Blast grenade (3 kg) (alternatively: fragmentation grenade) 2 launcher units, each with 2 (3) tubes, arranged at the vehicle sides	Blast grenade (3 kg) (alternatively: fragmentation grenade) 2 launcher units, each with 3 tubes, arranged at the vehicle sides	Blast grenade, focused blast, vertical soft launch, 1 launcher unit with 8 guided defeat missiles or 18 unguided defeat missiles	Multi-EFP (radial bundle of 35 MEFP), 2 orientable launcher units, each with 3 charges / tubes	Multi-EFP (bundle of 35 MEFP), 1 or 2 orientable launcher units, each with 3 charges / tubes	Grenade with blast warhead, 2 orientable launcher units,each wit 2 tubes	Blast grenade, Type Mongoose-1, 2 launcher units, each with 6 grenades, arranged on the roof of the vehicle
Distance of the interception point (IP) from the target	1,5 m	10 – 30 m	10 – 20 m	~ 30 m	~ 10 – 30 m	~ 10 – 30 m	~ 5 – 20 m ?	> 5 – 15 m
System reaction time (SRT)	560 µs Microsecond APS type	> 355 ms Millisecond APS type	> 300 ms Millisecond APS type	~ 350 – 400 ms Millisecond APS type	~ 300 – 350 ms	~ 300 – 350 ms	~ 300 – 350 ms	~ 200 ms ? (high-speed directed launcher)
Minimum defeat distance (MDD) for different threats	10 m (almost independent of the speed of the attacking projectile)	RPG >= 50 m ATGM >100 m KE > 600 m	RPG >= 30 m ATGM > 100 m	RPG-7: 100m/s: ~ 70 m RPG-7: 200 m/s: ~100 m RPG-29: 450 m/s: ~170 m	RPG-7: 100m/s: ~50m RPG-7: 200 m/s: ~80 m RPG-29: 450 m/s: ~150 m	RPG-7: 100m/s: ~50m RPG-7: 200 m/s: ~80 m RPG-29: 450 m/s: ~150 m	RPG-7: 100m/s: ~45 m RPG-7: 200 m/s: ~75 m RPG-29: 450 m/s: ~150 m	RPG-7: 100m/s: ~30m ? RPG-7: 200 m/s: ~50 m ? RPG-29: 450 m/s: ~100 m ?
Dependence of the MDD of the projectile speed	not significant (µs-APS)	significant (ms-APS)	significant (ms-APS)	significant (ms-APS)	significant (ms-APS)	significant (ms-APS)	significant (ms-APS)	significant (ms-APS)
Defeat capability towards non-RPG-threats, *	yes	yes	limited	yes (application of the guided defeat missile)	limited	limited	limited	yes
Schutzfähigkeit im Nahbereich gegen RPG und IED-EFP	yes, without limitations	limited	limited	limited	limited	limited	limited	limited
Risk of collateral damages caused by the countermeasure in immediate neighbourhood of the vehicle	very low risk (fragment-free countermeasure with low volume expansion)	low risk (blast grenade)	low risk (blast grenade)	low risk (blast grenade)	high risk ? (radiallly accelerated MEFP of high speed / energy)	high risk ? (radiallly accelerated MEFP of high speed / energy)	low risk (blast grenade)	low risk (blast grenade)
General multi-hit capability	yes	limited ?	limited ?	limited ?	limited ?	limited ?	limited ?	limited ?
Short-time multi-hit capability	yes	limited ?	limited ?	limited ?	limited ?	limited ?	limited ?	limited ?
Detectability of the sensor system by enemy's reconnaissance	low	high (active radar system)	high (active radar system)	high (active radar system)	high (active radar system)	high (active radar system)	high (active radar system)	high (active radar system)
Integration capacity for different types of vehicle platforms	proven, no limitations	proven, no limitations	proven, no limitations	proven, no limitations	proven, no limitations	proven, no limitations	proven, no limitations	proven, no limitations
System weight	light vehicles: 140 kg; heavy vehicles: 500 kg	~ 500 kg	~ 350 kg	~ 140 kg	~ 780 kg ?	~ 490 kg ?	~ 400 kg ?	
Development state	Prototype phase	Analysis phase	Financing ?	Development phase until 2011	Development: completed in mid-2007	Development/ prototypes	Development/ prototypes	Development Pre-series: 2008 ?
Readiness for series production, planned	2009	~2011	~2011 ff	after 2011	Series production: started in 2007			2009/2010 ?

tion concepts. Development activities of APS for vehicles of all weight classes have still been intensified since the fatal experiences the Israeli armed forces made during their mission in southern Lebanon with the modern anti-tank weapons in summer 2006. In Table 5 (page before), a selection of currently known hard-kill APS systems is presented and compared with regard to their characteristic features, such as technical performance, operating method, development status, protection capabilities, as well as advantages and disadvantages. It has to be pointed out that detailed performance data of the single APS are classified. Thus, the data in the table are exclusively based on information from publicly available sources.

In the light of new developments, the characteristics "Multi-hit Capability" and especially „Short Time Multi-hit Capability" become more important. On 19 November 2008, ARMS-TASS / Moscow reported on the capabilities of the newly developed RPG-30.

The RPG-30 was unveiled in 2008 by the State Research and Production Enterprise Bazalt as a modern anti-tank grenade launcher, designed to address the threat of active protection systems on military vehicles. Active protection systems such as ARENA-E, Drozd and Trophy defeat anti-armour ammunitions by destroying them before they reach the vehicle. The RPG-30 is a response to the introduction of these systems. It has cleared its testing program and is waiting to be included in the Russian state arms procurement program as of November 2008.

The RPG-30 shares a close resemblance with the RPG-27. It is a man-portable anti-tank rocket launcher with a single shot capacity. However, unlike the RPG-27, there is a precursor round with smaller calibre in addition to the main round. This precursor acts as a false target deceiving the APS into engaging it and opening the main round (following the precursor with a delay in the 100 ms range) a clear path to the target while the APS is stuck in the 0.2 – 0.4 second delay which it needs to start the next engagement. The PG-30 is the main round of the RPG-30. The round is a 105 mm tandem shaped charge and has a range of 200 meters and a stated penetration capability of more than 600 mm RHA (according to ERA).

Figure 3 illustrates the operating method of the RPG-30.

View ahead

In view of the upcoming introduction of the new Russian anti-tank weapon RPG-30 and its foreseeable worldwide proliferation, it is mandatory to examine all APS presently in development with regard to their capability to defeat this new anti-tank weapon system. Especially all currently known millisecond APS are certainly affected. Microsecond APS have surely an advantage, such as e. g. the AMAP™-ADS. With a system reaction time SRT of approx. 560 µs and its countermeasure units arranged all around the vehicle it has the ability to defeat both the precursor and the main grenade.

The multitude of worldwide APS activities allows the conclusion that the "Missing Link Hard-kill APS" will reach readiness for series production shortly. A comprehensive upgrade resp. retrofit will start to equip operation and supply vehicles of all relevant weight categories with such hard-kill APS systems. This includes the light 4x4 operation and patrol vehicles, medium 8x8 infantry fighting vehicles and heavy main battle tanks.

With the introduction of the APS it needs to be determined which tactical advantages and modified operation principles can be derived from the availability of fighting and support vehicles equipped with modern protection concepts. ■