# LPI: Invisible Radars

## How the LPI Radars (Low Probability of Intercept) Can Change the Tactics

*" (...) there are not perfect tactics. They are good while they are better than enemy's ones."*
*(João Carlos Gonçalves Caminha* in Delineamentos de Estratégia*)*

*Capt. Marcello Lima de Oliveira*
*Lieutenant Commander João Candido Marques Dias*

*The* De Zeven Provincien *class frigate with LPI Scout radar designed for coastal surface and search*

Imagine a lookout lightning a small vessel with a searchlight. The light is sent, reflected by the target and used to visualize it. Now, imagine a searchlight with characteristics that, besides being capable of lighting and identifying the vessel, the crewmembers can see inside it. This is the purpose of the radars with LPI (Low Probability of Intercept) architecture, that is, to detect without being detected.

More than a type of radar, the LPI is a set of Electronic Protection Measures - EPM. Its purpose is to unbalance the classic situation between the radars and the equipment ESM (Electronic Support Measure), in which these have always had great tactical advantage, detecting the electromagnetic waves at great distances, even those originated from the secondary lobes of the radars.

### Concept

The radars that employ technology to minimize the probability of detection by the EPM and RWR (Radar Warning Receiver), can be divided into:

Low Probability of Identity (LPID): despite being easily detected, this radar causes difficulty to be identified by the receiver. In an electronically saturated environment, the simple interception of a signal is not useful until it is processed and identified. The introduction of agility into several parameters of the radar, such as frequency, PRF (Pulse Repetition Frequency) and PW (Pulse Width), scrambles signal classification process. This happens because the receiver needs to detect individual pulses and analyze them one by one in a minimum period of time, which does not happen when the parameters are quickly varied (agility).

Low Probability of Intercept (LPI): transmits such weak signals that the EPM receivers are not sensible enough to receive them. But such task is not simple. With some success, the radar tries to ensure a safe use of the electromagnetic spectrum, using the combination of a series of subterfuges and techniques as follows:

### Technology Used in the LPI Radar

Since World War II, the concept of radar has meant 'a transmission of the narrow energy pulse with high peak power, and its round trip to the target in a given time, which corresponds to the distance of detection.' This is the pulsed radar.

More recently, however, the use of continuous waves (CW) or long duration pulses (Figure 1), but with low peak power has caused difficulties to most of today's equipment of Electronic Warfare (EW), which were until then designed to intercept pulsed radars which use high peak power. This is only possible because the performance of the radar is determined by the mean power (the total transmitted power, divided by the time of transmission) and not by the pulse peak power. On the other hand, the performance of interception receivers (ESM, RWR) is the function of the peak power of the received signal, because its receivers depend on the (SNR) signal-noise relationship to validate the detection and proceed with the identification of the radar, as previously described in the LPID concept. Low power signals try to escape from this process, decreasing the SNR, hiding itself within the noise.

However, it is important to highlight that purely CW radars are not capable of measuring the distance from the target because there is no variation in the transmitted signal, impeding the correlation of received and transmitted pulses. Thus, when we deal with the techniques which make it possible to decrease the power signal, as well as the modulations which allow the measurement of distances.

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### a) Management of Power

Apparently, it seems impossible for a radar to avoid being detected by a target before managing to detect it. However, mathematically, there are numerical bands where this can happen. The Chart 1 revises important notions on the Radar Equation. While Chart 2 shows a numerical example of how this can happen.

The example suggests the introduction of power control systems, that is, devices that would emit only the precise amount of power to follow a target according to the variation of the distance. However, for a search radar, it is not possible to control the power transmitted in relation to the desired reach, because its task is to detect targets at any point of the scale. As for the radars designed for acquiring a target for later engagement, like on the interception aircraft, they can incorporate this resource. Concerning the search radars, the solution is to find subterfuges which allow to obtain the detection with least power possible.

### b) Compression of Pulses

As previously seen, the intercepting receiver needs individual detection of pulses to proceed with its analysis. Consequently, it has little or no capacity of integrating the signals, dealing with them separately one from the other. On the other hand, the radar does not have such limitation. It can integrate (add) coherently the received echoes in long intervals of time, decreasing the need for a high power peak (Chart 3). In terms of comparison, it is as if we were dividing the classic process of the pulsed radar into several small parts (Figure 2). This capacity also allows to develop countless variation in the transmitted signal, because the radar receiver can be synchronized with the transmission, different from the intercepting receiver that does not know the logic of the transmitter.

### c) Increase in the Band Width

As described above, pulses of long duration

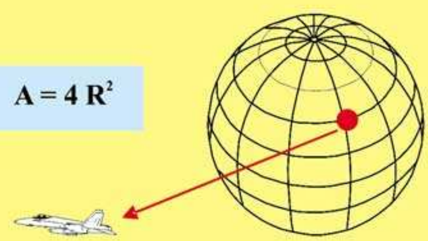
mean the distribution of power throughout a given period of time. In a similar way, a bandwidth transmission distributes the power along the frequency band, posing difficulty similar to the ESM receiver. This happens because the intercepting receiver needs to be capable of separating overlaid signals which are very close in frequency. Consequently, the bandwidth of each channel of the ESM receiver cannot be wider than that which is absolutely necessary to receive and measure such signals. A possible countermeasure would be to increase the bandwidth of the channel. However, as the noise in a receiver is proportional to the size of the band received, such an action would lead to a decrease in the SNR (Signal/Noise Relation) of the ESM, thus decreasing its detection sensibility. An additional advantage of the frequency variation is an increase in the resolution at distance, by the resolution of ambiguities, especially when applied together with continuous waves (CW), incapable of measuring distances directly.

### d) Reduction of Secondary Lobes

antennas have secondary lobes with power levels approximately 100 times lower than that of the main lobe. That is, the emitter reveals itself not only in the direction towards it is pointing to, but also towards any receiver positioned in the vicinities, with enough sensibility to detect

**Chart 1: RADAR EQUATION**

$$A = 4\,R^2$$



*Suppose a radar with a transmission power* $P_t$ *in the center of the sphere above, whose area is given by the formula which is in the box on the right, being* **R** *the radius of the sphere. The power received in the ESM of the target* ($P_{int}$)*, in the marked spot on the sphere, is calculated by* $P_t$ *divided by the area* **A** *and multiplied by a factor* **F***, function of gain of antenna and loss in the receiver, being then:*

$P_{int} = (P_t \cdot F) / A$*, substituting* **A** *and considering all the constants as* **K***, we have the following value:*

$$P_{int} = \frac{P_t \cdot K_{int}}{R_{int}^2} \qquad \textit{Equation 1}$$

*In the same way, we can determine the Power that reaches the receiving radar* ($P_{det}$)*, considering that the signal goes forward and back, consequently, it is divided by* $R^4$*. Then,*

$$\textit{Equation 2} \qquad P_{det} = \frac{P_t \cdot K_{det}}{R_{det}^4}$$

**Chart 2: MANAGEMENT OF POWER, PROBLEM 1**

***Condition:*** *A given radar can detect a target at a distance of* $R_{det1}$**=80MN** *when emitting a peak power of* $P_{t1}$**=5.000W**.

***Question:*** *How much power* ($P_{t2}$) *would be necessary for the radar to detect the same target at a distance of* $R_{det2}$**=5MN**?

***Solution:*** *The transmission power varies proportionally to the fourth power of the distance of the desired detection. Substituting the parameters of the Equation 2 of the Chart 1, we have:*

$P_{t2} = P_{t1} \cdot (R_{det2} / R_{det1})^{4}$
$P_{t2} = 5.000 \cdot (5 / 80)^{4} = 0{,}076\ W$

*: MANAGEMENT OF POWER, PROBLEM 2*

***Condition:*** *When transmitting a peak power of* $P_{t1}$**=5.000W**, *the radar of Problem 1 can be detected by the ESM of the target at a distance of* $R_{int1}$**=300MN**.

***Question:*** *At which distance can the radar be detected by the same ESM, when the transmission power is of only* $P_{t2}$**=0,076W**?

***Solution:*** *Because the signal only travels forward, the interception distance varies with the square root of the peak power sent. Substituting the parameters of the Equation 1 of the Chart 1, we have:*

$R_{int2} = R_{int1} \cdot (P_{t2} / P_{t1})^{0,5}$
$R_{int2} = 300 \cdot (0{,}076 / 5.000)^{0,5} = 1{,}2MN.$

Source: Stimson, George W., *Introduction to Airborne Radar*, 2 ed., New Jersey: SciTech Publishing Inc., 1998.

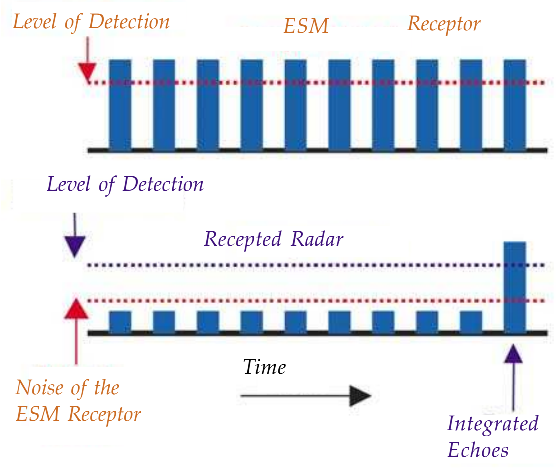



*Chart 3 – The drawing above shows the situation of the pulsed radars, easily detected by the ESM receiver. The drawing below shows small pulses which go to and fro up to the target, and when they reach the radar receiver, they are added cumulatively. If the addition result exceeds the Level of Detection, it will correspond to a valid target. However, individually, such pulses are similar to the level of the noise of the ESM receiver, not being capable of making a valid signal/noise relationship to be detected by that equipment.*

Source: Stimson, George W., *Introduction to Airborne Radar*, 2 ed., New Jersey: SciTech Publishing Inc., 1998.

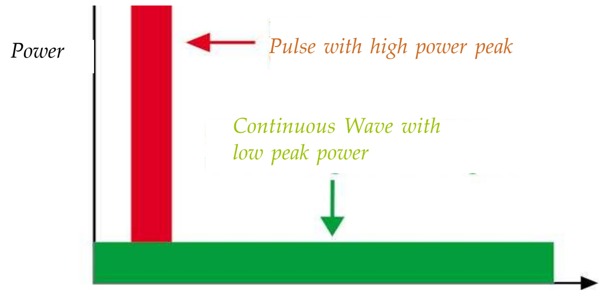



*Figure 1*

the power level of the secondary lobes of the antenna.

Antennas with reduced secondary lobes, or even suppressed, can have a decrease in power of approximately 10,000 times. Therefore, they reduce the probability of the radar being intercepted outside the main lobe.

## Types of LPI Radars

The main type of LPI radar is the FMCW Radar (Chirp), which is the result of the use of CW combined with frequency modulation.

Other types LPI radars use code phase modulation, which also allow for the measurement of distances, in addition to keeping the characteristics of low peak power and bandwidth. Among the types of modulations used, we find: Phase-Reversal (Binary-Phased-Shift Keying, BPSK), Quadrature-Phased–Shift Keying (QPSK) and Higher-Level Phase Modulation (M-ary PSK).

## Radars and Platforms

In the early 1980s, the first steps were taken towards the development of the LPI radars; it was built a CW radar with phased modulation, mounted with transmission antennas (Tx) and separated (Bistatic) reception (Rx). The next step was taken by the Phillips Laboratories which managed to avoid burning the receiver due to the RF (Radio Frequency) leakage of the transmitter, developing a FMCW radar with just one antenna (Monostatic). From this technology, the first radar known as LPI, the PILOT, was conceived and tested in September 1987, in a Swedish fast patrol boat of the SPICA II Class

Acquisitions and merges of companies gave birth to two major LPI radars in the period between the end of 1980s and the beginning of 1990s, both based on the PILOT radar: the FMCW SCOUT radar, manufactured by the Dutch company Signaal; the FMCW PILOT MK2 radar, by the Swedish company CelciusTech. Approximately 409 units of both radars have been manufactured to this day (294, between 1998 and 2007); today, both radars have as main platforms:

SCOUT: *Jacob van Heemskerck* Class Frigates, *De Zeven Provincien* Class Frigates (photo), *Karel Doorman* Class, *Poolster* Class Replenishment Ship (Netherlands); *Weilingen* Class Frigates (Belgium); *Kortenaer* Class Frigates and *Ban Yas* Class Fast Patrol Boat (United Arab Emirates); *Hamina* Class Class Fast Patrol Boat (Finland); *Super Vita* Class Torpedo Patrol Boat (Greece); *Singa* Class Torpedo Patrol Boat (Indonesia); in addition to 30 units for an Egyptian coastal patrol system; and MK2/MK3 PILOT: *Visby* Class Corvettes (photo) (Sweden). In Chart 4, we can see a table that shows the comparison between the radar reaches and ESM reach.

The popularity of this technology has led to the development of other radars, which have competed in this growing market. The VARIANT, manufactured by Thales is one of them. The radar has two transceptors, being one of them the FMCW (SCOUT) radar, LPI, with a 1W peak power or lower. The VARIANT is installed on the Dutch *Johan de Witt* Dock Landing Ship, (photo), *Pirpolitis* Class Patrol Boat (Greece) and *Todak* Class Patrol Boat (Indonesia).

## Tactical Applications

Since its conception, the radar has expanded the horizon of tactical detection of the Naval Forces, before limited to the visual reach. In addition to the detection, the radar has provided a new way to locate (to know the enemy's position in order to launch a successful attack) and designate targets (transfer data from the target to a weapon system to attack it). However, the advent of ESM created a dichotomy in this process; the radar that before, had increased the capacity of detection and location of the Naval Forces, also expanded the reach of detection of the enemy, allowing them to locate the objective, when obtained the fixed-ESM.

Furthermore, the constant increase in the capacity of signal digital processing, as well as the development of smaller, lighter and more sensible ESM equipment, led the Electronic Support Measures to such a level that the use of the conventional pulsed radar was questioned.

*LPD* Johan de Witt *with the LPI* Variant *radar*

Visby *class corvette with the LPI* Pilot *radar*

Theoretically, conventional radar can be detected up to 100 times or more, its maximum detection distance. The LPI radars offer a chance to avoid this dilemma. The improvement of technology and the knowledge of the potential use of these radars delineate a promising future.

Initially developed for navigation, the LPI radars have incorporated features to improve the moveable target detection (MTI), as well as the capacity of being integrated with weapon systems. The tasks they aim to accomplish have also been widened; we can mention the following:

| Power Output of the Radar | Distance of Radar Detection (km) | | Distance of Detection by an Intercepting Receiver (km) | | |
|---|---|---|---|---|---|
| | 100m² Straight Section | 1m² Straight Section | RWR-40dBmi | ESM-60dBmi | ESM high performance-80dBmi |
| *PILOT MK2*<br>*1W*<br>*0,1W*<br>*10 mW*<br>*1 mW* | *28*<br>*16*<br>*9*<br>*5* | *8,8*<br>*5*<br>*2,8*<br>*1,5* | *0,25*<br>*0*<br>*0*<br>*0* | *2,5*<br>*0,8*<br>*0,25*<br>*0* | *25*<br>*8*<br>*2,5*<br>*0,8* |
| 10KW Conventional Pulsed Radar | *25* | *7,9* | *25* | *250* | *2.500* |

Chart 4 – Comparison of nominal parameter between the *PILOT MK2* Radar and the *ESM*

. detection of periscopes to support the A/S operations;

. support to offensive mining or mining countermeasures operations in places where there is no control of the sea; and

. control of Ports and Coastal Patrol: not only on-board of ships but also installed on land (Radar CRM-100, Polish). The LPI radars enable to maintain coastal patrol, without being easily identified as target.

There are also other tactical aspects of the surface actions, electronic warfare and aerospace defense that should be considered:

. the presence of an LPI radar in a fast patrol boat can improve a great deal, its capacity of compiling the tactical picture without counterdetection, minimizing one of the main limitations of these type of platform and increasing the furtiveness of the asymmetric actions in a coastal combat environment;

. in a classical surface action, the LPI radars can protect the identity and location of ships of the Surface Action Group (SAG), denominated long range missile launcher;

. can contribute to protect the identity and location of the Highest Value Unit (HVU) of the Naval Forces;

. in the field of EW actions, they can make the use of anti-radiation missiles less efficient. On the other hand, if applied to the radars of the missiles, they will contribute to increase the discretion of these weapons;

. can make the use of electronic deception techniques difficult, for the Electronic Attack Measures equipment needs to analyze and imitate the received signals; and

. in the actions of aerospace defense, it will make the detection of an attack aircraft easy, because it will deny the location of the main lobe of the airborne radar, usually obtained by the RWR, which is used by the pilot to adjust the penetration altitude.

## The LPI Radars and Electronic Intelligence (ELINT)

Despite being relatively little disseminated, the LPI are slowly gaining ground among the sensors on ships, aircraft, submarines and missiles. The increase in production has contributed to reduce its cost, (the SCOUT costs approximately US$150,000.00).

Although equipment capable of detecting the LPI and LPID radars is being developed, the great difficulty is the fact that a modern interception system will be capable of operating in the presence of high power narrow pulses as well as low power long pulses.

## The Future

There are already passive radars, such as the *Silent Sentry* (photo) by Lockheed-Martin, which do not have transmission, and therefore, are detectable by intercepting receivers. It is a multi-static radar (has several receivers placed in different points), without transmitter. Their receivers collect and analyze the signals generated by open television stations and commercial radio stations. Computers with great processing capacity compare the signals that are directly received with those reflected, calculating the location of possible targets. As the radar does not have a transmitter, the ELINT enemy faces the problem of finding something which does not transmit. Obviously, because it is a passive radar, it depends on the transmission of signals which are not under its direct control and that are not present everywhere.

## Final Considerations

Tactically, the LPI technology can bring back the radar to the center of attention, increasing the importance of the tactical sensors of the ships. The idea of detecting the enemy in deep water, without necessarily revealing the presence of the transmitter platform, can bring a series of tactical changes, not only in the defensive requisites of Naval Forces but also in the offensive posture of the Surface Action Group.

As for the offensive actions, the LPI radar offers considerable advantage because it allows the attacking

Silent Sentry *Passive Radar*

forces that has to detect and locate the objective, to keep a high-level surprise factor, which is essential in the offensive actions.

On the other hand, the LPI radars do not allow that the offensive actions benefit from a previous ESM detection (as it happens with the pulsed radars), delaying taking evasive actions.

In the new context, supposing the equality of sensors, the mutual detection between forces would take place almost simultaneously, probably already within the reach of the enemy missiles. Therefore, the control of strategic sensors, such as satellites, can become a basic requisite for the defense of Naval Forces.

In the long run, one thing seems certain: the competition between the LPI radars and the ELINT will never be static. For each improvement of the LPI technology, there will be a reaction from the interceptors. The radar designers will continue exploring the coherent processing of signals which cannot be copied by the ESM equipment. As for the latter, it will continue exploring the fact that the signal travels just half of the way up to its receivers.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