Night Vision and Image Intensifiers market

"Veni, Vidi, Vici" (I came, I saw, I conquered), said Julius Caesar in year 47 BC about one of his victories, that was swift and decisive. The Roman general would probably say today: "I came, I saw in the darkness, I conquered" as the capability to see by night has become a key advantage of modern Armies. More "recently" … about Desert Storm, the last big conventional conflict, between a US lead coalition and the Iraqi Army, former Navy Secretary John Lehman told Congress during a 1991 hearing: "It was the ability to attack at night, when all of the rest of the world's defenses are at 10 percent of what they are in daytime, that gave us this huge immediate impact and edge." *https://taskandpurpose.com/night-rise-fall-us-militarys-night-vision-dominance/*

Seeing in darkness requires one of the three Electro-Optical (EO) technologies available for military purposes: (A)_Thermal Imaging - very often also called infra-red (IR), (B)_ Digital sensors based on CMOS or (C)_ Image Intensifiers (I2).

(A) Traditionally Thermal Imaging (TI) devices have being more bulky, power-hungry, more expensive and are more generally used on platforms or as a single device within a fighting unit (i.e.: Sniper Thermal weapon sight). Even uncooled versions need to be stabilized in temperature and the Thermal Electric Cooler (TEC) used for that purpose consumes a lot of energy too. Nevertheless, Thermal Imaging capability for long range detection (from a few hundred meters to a few kilometers for cooled versions) are indispensable on the battlefield.

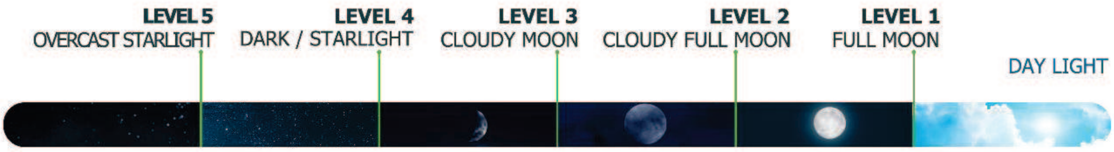
(B) The emerging technologies using CMOS (Complementary Metal Oxide Semiconductor) have the advantage of providing a digital signal that can be enhanced by software (i.e.: noise suppression, dead pixel replacement…), forwarded to other devices/displays (i.e.: headquarters), mixed with other information (i.e.: compass, tactical info) or fused/overlapped with another technology like Thermal Imaging. The CMOS technologies can be divided in two groups: (1) _Low Light Level (LLL) CMOS for which the night vision capability is determined by sensitivity of the CMOS sensor itself and (2) _Intensified CMOS for which the night vision capability is determined by "add-ons" to the CMOS sensor, such as EBCMOS (Electron Bombarded CMOS) and ICMOS (CMOS sensor coupled with I^2).

(1) Low Light Level (LLL) CMOS technology offers a day and night vision with a relatively low power consumption. But the performances by night are limited comparable to Intensified CMOS or I^2. The best LLL CMOS sensors on the market, developed for night vision, working at more than 120Hz (to be equivalent to an I^2 in terms of speed), with at least a 2Mpx resolution, can hardly see by night level 2 (cloudy full moon _Fig #1) whereas the best Image Intensifiers work below night level 5 (overcast starlight _ Fig #1). Nevertheless, this LLL CMOS technology is used for applications that do not require deep night vision capabilities and for which the digital output offered is considered leading (i.e.: use in small caliber weapon sights, driving systems or fused/overlapped with another technology like Thermal Imaging).

(2) The intensified CMOS technologies have the great advantage they combine clear vision even in the darkest conditions (meeting the night vision capabilities of Image Intensifiers, at night level 5) and the capability of delivering a digital signal. A signal that can be enhanced by software (i.e.: noise suppression, dead pixel replacement…), forwarded to other devices/displays (i.e.: headquarters) or mixed with other information (i.e.: compass…). Although less bulky and power-hungry than Thermal Imaging, their size and power consumption is higher than LLL CMOS, let alone Image Intensifiers. For that reason, Intensified CMOS

technologies will also be more commonly used on platforms (armored vehicles, helicopters…) than for use by dismounted soldiers.

Fig. #1: Night level classification



(C) I^2 equipment – or night vision device, NVD – currently range from handheld and clip-on weapon sights to helmet mounted devices such as monoculars and binoculars. Such equipment has been extensively deployed and used by special operational forces (SOF) like the US Navy Seals and Delta, French and British SF in recent conflicts in Afghanistan, Iraq, Syria, Libya and Mali. Regular army and navy individual soldiers are also using I^2 for situation awareness and target acquisition. Another very important use of I^2 is for driving vehicles or flying fixed wings or helicopters by night. I^2 technology has proven to be able to provide the best capabilities for night vision for the dismounted soldier: supreme vision in the deepest of dark and in dynamic light (i.e. on the battlefield and urban environments), small, light-weight, reliable and with very limited power consumption. Considering the continuous R&D in this field this advantage will remain so in the foreseeable future. Let's have a closer look.

I^2 _ Core Sensor Technology

The I2 architectures (size, format) has not fundamentally changed in the past two decades, although the latest high-performance examples are actually twice as good as what was made 10 years ago because the exclusive club of suppliers who can make them have become extremely good at it. Members of the club include two US suppliers, L3-Harris and ELBIT USA (which recently acquired the I2 factory of Harris,) and one European supplier, Photonis. These three are the top-end manufacturers.

Fig. #2: Example of I^2 image

Russians and Chinese are still manufacturing products with lower performance and reliability. Mastering all the technologies involved in making Image Intensifiers is extremely complex, but even more complex is to master the process yield and run factories in an economical way (produce good Image Intensifiers for an affordable price). Therefore, the entry barrier is so high in cost that no new player can enter this field without massive investment and little return on investment for many years.

How does an I^2 technology work?

The light (photons) that the I^2 intensifies comes from the moon, the stars, the high layer of atmosphere (night glow) and man-made sources. It includes visible wavelengths and portions of the UV (generated by the stars) and of the near IR (generated by the moon and night glow which is not always present). The I^2 collects the available light through the objective lens of the night vision device. The low level of incoming light, which consists of photons, enters the I^2 through its input window and strikes the photocathode. The photocathode is a very thin light sensitive layer deposited on the inside of the I^2 input window that uses the energy of the photons to convert it to electrons and releases them into the vacuum of the I^2. All modern I^2 operate under a vacuum of about 10-9 to 10-10 torrs, which is essential to allow the undisturbed transfer of the electrons and to protect the photocathode from oxidation and rapid destruction. Once released by the photocathode, these photo-electrons are accelerated and directed by a strong electric field towards the Micro Channel Plate (MCP).

Fig. #3: How does an I² work?

The MCP is a thin glass disc, less than a half a millimeter thick, which contains millions of small channels. When an electron coming from the photocathode strikes the inner wall of one channel, several secondary electrons are generated by the impact. Each of these secondary electrons will be accelerated

within the MCP channels by the high electric field, once again striking the inner wall of the channel, and generating even more secondary electrons. This process is repeated along the depth of the MCP channels like an avalanche. For each electron that enters the MCP, approximately one thousand electrons are generated and subsequently accelerated from the output of the MCP by a third electric field towards the phosphor screen.

The phosphor screen is a thin phosphorous light emitting layer deposited on the inside of the output window of the I² tube (usually fiber optics) which used the kinetic and quantum energy of the electrons to generate photons. When the multiplied and accelerated flow of electrons out of the MCP strike that layer, tens of thousands of photons will be generated for every single photon that was initially converted by the photocathode. This entire multistage process is controlled and powered by a so-called power supply unit and ultimately creates an “intensified” image, much brighter than the original image, which can subsequently be seen by the human eye through the magnifying eyepiece of the night vision device. The I² tube is thus able to generate a very sharp and clear (high resolution, low noise) image at very low light levels. In addition to high image quality, the I2 devices have a very low weight and use very little power in comparison with thermal imagers and other digital sensors such as the well-known CMOS sensors. The I² delivers direct images that just need to be observed through the eyepiece of the Night Vision Device (NVD) without the need for a power-hungry LCD or OLED display or screen. Two AA-batteries are more than sufficient for one week of night operations.

As a matter of fact, I² dominate the infantry night vision market. No other technology can today and in the foreseeable future replace I² for dismounted soldiers’ needs such as mobility, situation awareness, identification of the threats, for the same size, weight and power (SWaP) performance and with the same battle proven reliability. Infantry sectors such as helmet/head mounted and weapon mounted devices will be largely dominated by I^2 for the next decades.

Attempts to fuse I2 with Thermal Imagers (TI) to combine the image sharpness and more natural quality of the former with the ‘no light’ performance and better target detection of the latter have so far produced a small range of useful, but rather bulky and power-hungry devices, from the most capable and well-funded manufacturers. This technology has been adopted for fused weapon sights, fused binoculars, or multi-function devices such as observation devices, the thermal image superimposed on the I^2 image being able to display a target that could otherwise not be always seen (i.e. hot spot detection). The fused NVD remain expensive, heavier (generally about 1kg on the helmet) and bulkier and are most of the time reserved to limited numbers within Special Operations of very modern armies. A good alternative to complete fusion NVD is the clip-on thermal imager – COTI - (an add on thermal device that can be put/removed in front of a binocular/ monocular), which provides the ability to detect targets in complete darkness. The advantage of the COTI is that it can be removed when not required. The drawback is that it reduces the DRI performance of the NVD by 10 to 15%, especially in the darkest conditions.

What makes the I^2 Night Vision market tick?

Rush on high performances (FOM), drop of the “Generations” fake ranking. The photocathode nowadays mainly consists of either Gallum Arsenide, GaAs (as produced by L3-HARRIS and ELBIT USA, and branded as “Gen3”) or a Hybrid Multi-Alkali, HyMa (as produced by Photonis, branded as “4G”). Over time both photocathodes characteristics have been further developed and improved; and that process will definitely continue in the coming decades.

In 2001, the United States Government concluded that the “Generation” indicator of an I^2 sensor (or night vision I2 device), be it Gen2, Gen3 or whatever, was not a determinant factor in an I^2’s performance confirming the “Generation” indicator as completely irrelevant in determining the performance of an I^2 tube. For that matter the US Government also eliminated the term “Generation” as a base for its export regulations, ITAR Cat XII, part (e), §7.

Instead the Figure of Merit (FOM) became key in determining the export feasibility. The Figure of Merit (FOM) is indeed a reliable first (but not only) indication of the performance of an I^2 tube and is constituted by multiplication of the Signal-to-Noise-rate and the Limiting Resolution (the higher, the better) while the Generation was just an indication about the material used and not at all about the performance.

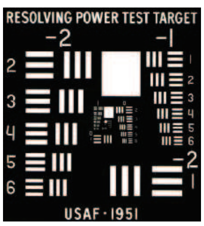
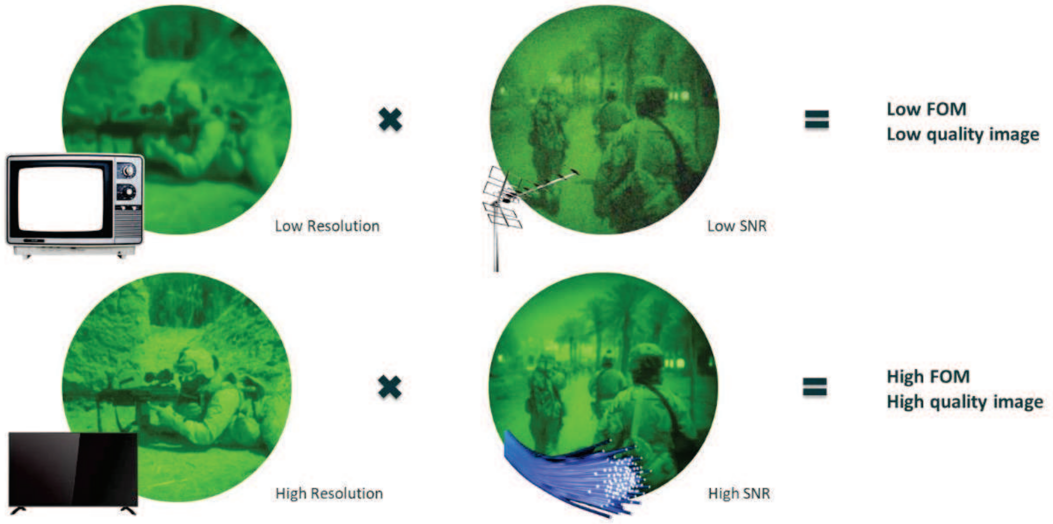


Fig. #4: USAF Resolution target

Any sensor-system preferably has the lowest possible noise-level (or highest so-called Signal-to-Noise-rate, SNR). This especially applies when it is very dark (night levels 3-5), so-called “low” light levels (less than full moon and partly clouded skies). A simple analogy can be made between the Signal-to-Noise-rate and the signal received by a TV set. If the TV set receives its signal from a cable the image will be clear and with any perturbation. However, in case the signal comes from an old antenna on the roof, the image will be full of twinkling dots.

The Limiting Resolution should to be as high as possible, like the number of pixels of a screen. To measure it, most commonly used is the USAF 1951 resolution test target (left hand picture), consisting of a pattern of 3 white-bar targets. The same simplistic analogy can be drawn between the Limiting Resolution and the definition of a TV set.

Fig. #5: SNR and Resolution - Low/High examples



Together SNR x Resolution constitute the Figure of Merit (FOM): the difference in ranges for detection of an I^2 with 1600 FOM and 2400 FOM is marginal at night levels 1-3, but it is very significant at night levels 4-5 (the higher FOM results in more than 45% increase of the Detection, Recognition and Identification ranges).

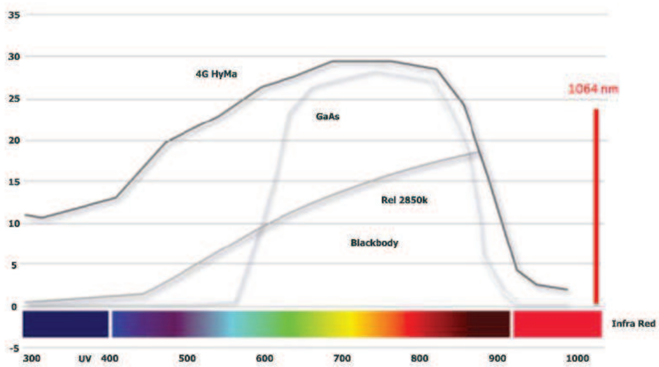
The FOM criteria is the key parameter of the technical specifications of all of the last 5 years large international tenders. Therefore, and as the modern armies want to keep their tactical advantages on the field over the "bad guys" a race to the highest FOM has been launched between the I^2 manufacturers in USA and Europe. With its 4G technology Photonis has without any doubt the best engine to win the first place of this race and can deliver in large quantities I^2 with minimum 2400 FOM.

And as a European company, Photonis Image Intensifiers (I2) are not bound by the US "International Traffic in Arms Regulations" (ITAR) that impose heavy restrictions on FOM that can be exported out of USA and require elaborate administration on the whereabouts of each I^2 ITAR (post control by US administration). Apropos, ITAR in itself constitutes no quality assurance in itself at all.

Use of every photon available, stretching the useful bandwidth… till new laser seeing capability

FOM is a very good indicator of the performances of the I^2 but the composition of the residual light by night is very complex and depends on many parameters (moon phase, starlight, clouds…) thus the ability to take advantage of any type of photons (wavelength) available, is a game changer.

Fig. #6: Spectral response HyMa (4G) vs GaAs



The main difference between GaAs and HyMa photocathodes is the bandwidth, or spectral range. In other words, the scope of types of light (from UV-blue to IR-red) that the photocathode is able to "absorb" and to transfer those photons into electrons substantially differs. The bandwidth of GaAs is approx. 500 (blue-ish) to 900 (red-ish) nanometers. The bandwidth of HyMa is approx. 350 (UV) to 1100 (IR) nanometers. It is clear that the bandwidth, or spectral range, of an I^2 tube with a HyMa photocathode is significantly extended and wider than that of an I^2 tube with a GaAs photocathode.

That extended bandwidth, spectral range of a HyMa photocathode has two important operational consequences. First of all, it ensures that the I² tube performs at its very best in all types of light that come in different theatres worldwide. From the desert-like high 'blue/UV spectrum' to the jungle-like high 'red/IR' sky illumination. It has to be noted that the HyMa photocathodes possesses a huge advantage over GaAs in the blue part of the spectrum where the photons are the most energetic and therefore the most useful in the process of generating electrons by the photocathode. Secondly, it provides the ability to see light sources outside the visual spectrum (and thus see light that the image intensifiers with GaAs photocathodes cannot see). Of course, all image intensifiers can image the beam and target point of conventional individual soldier's IR laser pointers (800-950 nm). But only the wider bandwidth of a HyMa photocathode allows it to also see laser-target designators used by JTAC units (like the French CILAS DHY208 or US ELBIT AN/PEQ-17), which the GaAs photocathode cannot. And the HyMa photocathode also provides other options (both on the UV as well as the IR side of the spectrum) to exploit for tactical use (next-generation lasers, illuminators, pointers and beacons). This can help the soldier to remain stealthy and thus less vulnerable.

Filmed or filmless? A matter of life time… and performance

From the beginning of its use for I² it has been obvious that the GaAs material is very vulnerable to the positive ion feedback that damages its cesium activation layer necessary for the electron release process. To protect the GaAs photocathode from deteriorating, an ion-barrier film needs to be installed on the MCP. This film is not at all to get a longer life time than HyMa photocathode based I² but just to prevent GaAs photocathodes to have a life time of few hundreds of hours only. That "ion barrier film" is not required with a HyMa (4G) photocathode as that is a much more robust material and has a cesium activation layer with a much better chemically bond to the photocathode material; all Photonis image intensifiers are filmless.

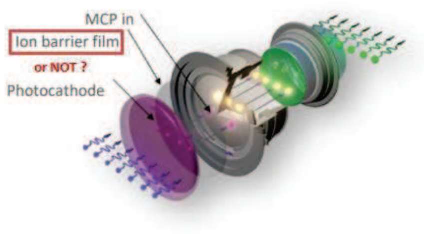


Fig. #7: Ion barrier film on GaAs I²

The major drawback of this film is that it captures a significant amount of the electrons released by the GaAs photocathode. Therefore, in the context of the race to the highest FOM, L3-Harris proposes GaAs filmless image intensifiers, even though this move jeopardizes the lifetime of their I². But it is a law of Physics that GaAs technology has reached its limits while HyMa technology (4G) has still a lot of improvements to deliver, hence removing the film is the last step available to US manufacturers to the detriment of lifetime.

4G image intensifiers have made formidable improvement in terms of lifetime in the past decade. All Photonis image intensifiers offer guaranteed lifetime characteristics of more than 10000 hours according Mil-Spec criteria with limited performance decrease over time. As far as 4G is concerned, and as recently again proven independently by the renowned Fraunhofer Institute (Germany), the SNR characteristics have a typical value drop of less than 5% over the full lifetime which largely supersedes the US MIL-SPEC.

Every light condition, an electronic iris as fast as the blink of an eye

The operator needs an I² tube that performs best under all light conditions (in the widest possible luminance range), but also including so-called dynamic light conditions (e.g. extreme light bursts of an explosion, flame bursts during shooting, a sudden illumination in a dark room, and pinpointed light such as a streetlight). That applies particularly when operating on the battlefield, in an urban environment and/or inside buildings. The **Auto-Gating (ATG)** is comparable to an electronic iris of a camera and enables the I² tube to reveal mission critical details (allow non-disrupted "eyes on target") at all times; a clear image in both dark nights and twilight (or even day time) conditions.

The 4G power supply unit (PSU) holds a super-fast Auto-Gating (SFATG). ATG is an electronic feature that gates the voltage applied to the photocathode and MCP in such a way that the best performance of the I² tube is maintained in all light conditions. The typical advantage of the 4G SFATG is best felt when using a weapon sight which experiences a flame burst during shooting. SFATG will avoid the temporary blindness experienced with standard image intensifiers and allow the soldier to continuously maintain "eyes on target". The SFATG developed and produced by Photonis for 4G, is not only the fastest available on the market now, it is tuned in such unique way that it ensures that the nominal MTF and resolution will remain at its highest quality, even at high light level (20 foot-candle) with a minimum of 57 lp/mm unlike what happens on Gen3 I2 that see their high light level resolution drop drastically to 45 lp/mm for the best ones and 36 lp/mm for the majority of them. Even if there is an explosion in the scene., the 4G SFATG reacts faster than the blink of the eye, so there is no problem as it presents a good image all the time. Conventional, much slower ATG image intensifiers will temporarily blind the user with the bright flash, and furthermore he would need to wait for it to return an image for a second or more. Now 4G SFATG can do this in tens of milliseconds, it is closer to normal eye perception.

Photonis, partner of Japanese Defence Forces

All current Image Intensifiers work on the same principle of 3 stages of photon-detection, electron multiplication and electron-to-photon conversion powered by a PSU. The Generation indication is (confirmed by US Government) obsolete to indicate performance. What really is decisive, is how each of the 3 stages and the PSU together result in the overall performance of the I^2 tube. And that performance can be determined in laboratories by measuring parameters like Figure of Merit, Signal-to-Noise-Ratio, limiting resolution, Modulation Transfer Function, Lay-out, Auto-gating, etcetera. Photonis' intention is to provide the end users better operational performance, it is not just about new technology invented in factories or theoretical criteria measured in laboratories; the proof of performance is in battlefield conditions.

First and foremost, Photonis pushed every component and every process parameter resulting in higher FOMs to increase the Detection, Recognition and Identification (DRI-) ranges, enabling the soldier to see at greater distance range and deeper into the darkness. With the broader spectral range, the 4G I2 not only uses of all natural light available, it can now also 'see' lasers that no-one else can see on the battlefield with NVD, as well as other light sources. This will help the soldier to remain stealthy, unnoticed by his opponents.

Photonis' 4G technology provides new capabilities that, based on performance specifications, not only outperform current (US) Gen3 Image Intensifiers, but could be used in ways for which existing Gen3 night vision would be blind, unable to see significant existing and evolving threats on the battlefield. Photonis' 4G image intensifiers feature a wide spectral sensitivity from 350nm to 1100nm, a minimum Figure-of-Merit (FOM) of 1,800 and up to 2400 (without any ITAR limitations), a high light resolution higher than 57 lp/mm and a halo size of less than 0.7 millimeters. The Super-Fast ATG ensures optimum functioning in all (dynamic) light conditions "as fast as the eye can blink".

All NATO countries have undergone the modernization of their Army night vision goggles fleets since a few years, with notably a large preference towards binocular goggles (with 2 I2s) that provide a much better image by night with depth perception. Large programs are ongoing in Germany, UK, France, Denmark, USA, Canada, Poland (but also UAE, Jordan, Morocco, KSA notably) to go for better FOM, lighter equipment (less than 450g) and lower power consumption. Old equipment using obsolete I^2 are usually being used for training purposes while the new gear is provided for combat and operations.

Photonis has been providing the Japanese Defense Forces with image intensifiers for more than a decade through various small programs but since 4G image intensifiers have been proposed, the won contracts are bigger and bigger, showing a shift in the Japanese market. 4G image intensifiers high performance starts to be considered as the standard versus the ITAR limited old Gen3 tubes. The newest development (apart from further performance improvements) is the low weight, small size 16mm image intensifiers that allow for a 30% smaller and lighter system.

Not only have enemy combatants begun to utilize I2 and TI systems on the battlefield (usually from stolen equipment from NATO forces or supplied by Russian and Chinese companies), but they also continue to develop tactics, techniques and procedures to counter the effective use of I2 and IR sensors by coalition forces (e.g. with help of camouflage or maneuvering in-between civilians; which increases the need for positive identification before engagement). Just the ability to see at night (when the enemy most likely could not) was considered a decisive advantage to forces that possessed it.

Fig. #8: 16mm I^2 (30% smaller 18mm ones)

Those days are long gone because the technologies involved have proliferated around the world, beyond military and paramilitary forces and into the hands of civilians and, inevitably, criminals and terrorists. Nowadays the availability of an advanced capability to see in the night, is crucial to operate effectively and safely.

Photonis continues to develop new features and improvements on the I^2 capabilities in close cooperation with OEMs and end-users in order to keep the advantage at night over any adversary. With the capabilities at hand in the Photonis 4G image intensifiers (and the R&D projects in progress) we will be able to meet the newest operational requirements of the Japanese Defense Forces in the years to come; allowing effective soldiers to operate safely. Moreover, it is Photonis' deep felt desire to extend our decade long relation with the Japanese Defence Forces and further improve sensors and systems for night vision in close collaboration. By doing so, we will help to ensure that Japanese Defence Forces will be always ahead of the threat. And to continue the Haiku trilogy of the famous warlords of Sengoku time Oda Nobunaga, Toyotomi Hideyoshi and Tokugawa Ieyasu...

Fig. #9: Warlord Oda Obunanga

"If the cuckoo does not sing, kill it.",
"If the cuckoo does not sing, coax it."
"If the cuckoo does not sing, wait for it",
*let's say : "**If the cuckoo does not sing, find it ... even in the dark**"*