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REVIEW OF METHODS FOR MEASUREMENT OF SIGNAL TO NOISE RATIO OF IMAGE INTENSIFIER TUBES

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Abstract

Image intensifier tube is the most important block of night vision devices that enable vision at low illumination conditions and are of critical importance for military and security agencies. SNR (signal to noise ratio) is one of two most important parameters of image intensifier tubes. This paper presents a review of methods used to measure the SNR of image intensifier tubes. Reasons why SNR test results of the same tube carried out by different laboratories often differ significantly are presented.

Keywords: SNR, Image intensifier, Image intensifier tube, IIT.

1. Introduction

Signal to Noise Ratio (SNR) of *image intensifier tubes* (IITs) gives information how noisy an image is generated by the image intensifier tube working at low illumination conditions. In detail, it gives information about the temporal variation of brightness of image of the small pinhole (diameter 0.2 mm) projected at the tube photocathode. Low SNR can significantly degrade image quality at low illumination condition making it difficult to recognize small details and limits application of such a tube under dark night conditions. SNR is commonly considered as one of two most important parameters (the second one is resolution) of image intensifier tubes. The main performance criterion called *Figure of Merit* (FOM) of IITs is calculated as a product of SNR and resolution.

At present there are no international standards that regulate testing IITs. However, there have been issued a series of US MIL standards [1-5] that present a method to measure the SNR of IITs and have achieved status of semi-world standards. Almost all manufacturers of IITs claim that they present in data sheets results of SNR measurements obtained using measurement methods identical or equivalent to recommendations from US MIL standards. However, in spite of this apparent near perfect metrological situation, results of measurement of SNR of IITs carried out in different night vision laboratories often vary significantly.

The author of this paper is the CEO of a company that manufactures stations for testing IITs and often meets a problem of verification of accuracy of manufactured test stations. It is a typical procedure used by customers to compare SNR measurement results generated by the delivered test

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station with results obtained from manufacturer/supplier test certificate of a tested IIT. Unfortunately, it is a common situation that such comparison tests generate different results depending on tube manufacturer, tube supplier, customer country, or other factors. The same test station is sometimes considered to produce too optimistic results by some customers when others suggest that it generates too pessimistic results. Such situation is a metrological nightmare because there is no internationally accredited institution that could certify the test station and prove proper accuracy.

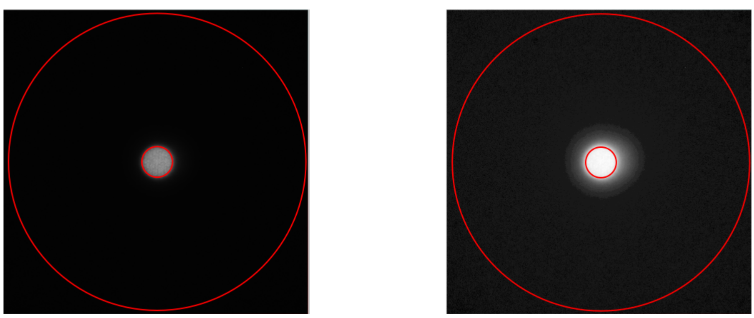
This paper presents an analysis of situation in a field of image intensifier metrology related to measurement of SNR of IITs. Reasons why SNR test results of the same tube carried out by different laboratories often differ significantly are presented.

2. SNR measurement methods recommended by standards

The methods to measure the SNR of image intensifier tubes have been presented in the form of US MIL standards [1–5]. However, it should be noticed that the measurement concept of SNR had been developed in 1970s-1980s and since that time it has been repeated with only some minor modifications in every new issue of such standards. The equivalent Chinese standard that regulates testing image intensifier tubes presents practically identical rules for measurement of SNR of such tubes as US MIL standards [6]. Therefore, almost all conclusions about MIL standards are valid also for the Chinese standard. There is also a Russian standard that presents recommendations that differ from both US/Chinese standards [7]. Here we are to concentrate on MIL standards that are followed by majority of labs worldwide.

The method to measure SNR recommended by MIL standards is based on the idea of illuminating a tube photocathode using a pinhole target of 0.2 mm diameter at illuminance level 10-5 fc (0.108 mlx) using a light source of 2856 K color temperature and later to measure temporal variations of the total flux of the output image of this target at a tube screen.

The image of a screen of an IIT during SNR measurement is shown in Fig. 1. As we can see, it presents a small bright spot on dark noisy background. Rudimentary visual analysis of pinhole image suggests that the image of the pinhole only slightly overfills the 0.2 mm circle (Fig. 1a). However, a careful analysis using software for image processing can show also a faint halo of up to about 1 mm diameter (Fig. 1b). The halo effect is more clearly seen in Fig. 2 that presents a light intensity cross section of an image of the 0.2 mm pinhole. It is clear that the total image of the 0.2 mm pinhole target is much bigger than the original 0.2 mm circle due to image blurring caused



(a) (b)

Fig. 1. Image of a pinhole target a) linear scale; b) logarithmic scale with 0.2 and 2 mm area marked.

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by different types of halo effects. Therefore, analyzing the pinhole of a diameter significantly bigger than 0.2 mm is needed to record the total flux of image of the pinhole target and output signal differs depending on diameter of this analysis window.

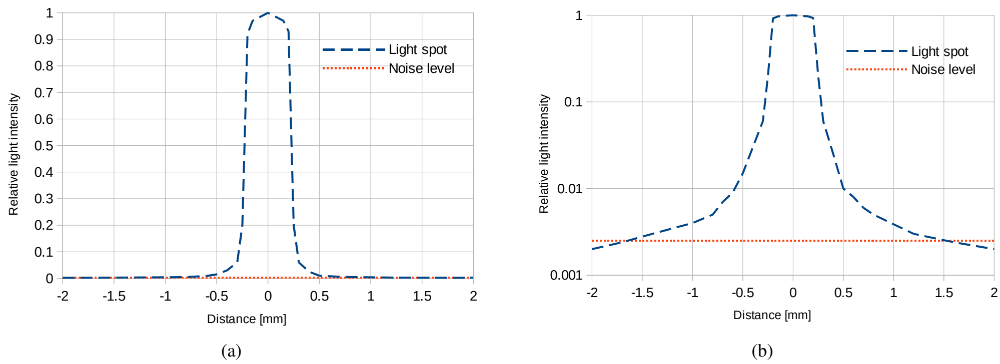

Fig. 2. Relative light intensity of an image of the 0.2 mm pinhole target a) linear scale, b) logarithmic scale.

Further on, MIL standards recommend measurement of SNR of IITs using a modular test system built from two main blocks (Fig. 3):

1. Image projector,
2. Optoelectronic meter.

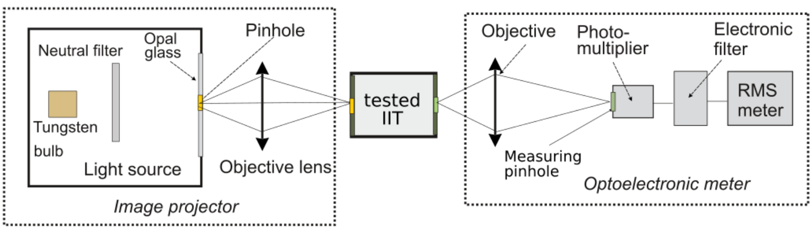

Fig. 3. Graphical concept of a system for SNR measurement of IITs according to MIL standards.

The first block is built as a pinhole light source (tungsten bulb, neutral filter, opal glass, pinhole target) integrated with an objective lens. The task of this block is to create an image of 0.2 mm pinhole target of 10^{-5} fc illuminance at the photocathode plane of the tested tube.

The second block is to be built as a set: objective lens, photomultiplier, electronic filter, and RMS meter. The task of this block is to measure temporal variations of brightness of the image of the pinhole target created at the tube screen at a specified equivalent noise bandwidth.

The objective lens projects the image of the image of the pinhole at the tube screen to the photomultiplier photocathode. Measuring the pinhole located at the photomultiplier plane determines the diameter of the circle around the pinhole image. Later, the photomultiplier converts the total optical flux into an electrical signal. An electronic filter regulates the spectrum of the transmitted electrical signal. Finally, the RMS meter enables measurement of both DC and AC component (true rms) of this electrical signal.

Calculation of raw SNR is to be carried out using the following formula:

$$\mathrm{SNR_{raw}} = \frac{S - B}{K\sqrt{\sigma_S^2 - \sigma_B^2}} \tag{1}$$

where: S – mean signal from the pinhole target when the photocathode is illuminated, B – mean signal from the pinhole target when the photocathode is not illuminated, σ_S – standard deviation of the signal from the pinhole target when the photocathode is illuminated, σ_B – standard deviation of the signal from the pinhole target when the photocathode is not illuminated, K – correlation factor.

Detailed technical requirements on the test station/measurement method of different MIL standards are presented in Table 1. As can be seen, there are some minor differences between different standards.

Table 1. Technical requirements of MIL standards

MIL number	**MIL-I-49453(CR)**	**MIL-I-49052F**	**MIL-PRF-A3256363C(CR)**	**Draft MIL-PRF-A3314408**
MIL date	1989	1992	2004	2019
Diameter of the input pinhole	0.2	0.2	0.2	0.2
Pinhole illuminance	10^{-5} fc	1.2 10^{-6} fc	10^{-5} fc	10^{-5} fc
Tolerance on pinhole illuminance	±10%	±10%	–	–
Light color temperature	2856±50 K	2856±50 K	2856±50 K	2856±50 K
Block to improve light uniformity	Yes (light source passing through opal glass)	Yes (opal glass or integration sphere)	No	No
Spectral uniformity of the neutral filter	±10%	±10%	–	–
Diameter of the measuring pinhole	> 0.2 mm	> 0.2 mm	–	< 0.3 mm
Frequency band of the electronic filter	electronic bandwidth of 10 Hz	equivalent bandwidth of 10 Hz	noise equivalent bandwidth of 10 Hz	noise equivalent bandwidth of 10 Hz
K factor	$K = 1.19$ for P20 phosphor	$K = 1.09$ for specified phosphor decay time	$K = 1.15$ for P43	$K = 1.15$ for P43

3. Situation in image intensifier metrology

SNR is one of most important parameters of IITs and is included in the data sheet of any of these imaging devices [8–11]. In addition, in many countries IITs are divided into three categories (military, dual use, civilian) depending on the FOM criterion (product of resolution and SNR) [12].

The measurement method recommended by MIL standards presented in the previous section has practically been used for several decades worldwide to measure SNR of hundreds of thousands of IITs. The concept of the MIL method for SNR measurement is apparently accepted by all major manufacturers of IITs, of *night vision devices* (NVDs), and of test equipment as well as scientific institutes working in field of night vision. This claim is supported by a series of scientific papers that present basic description of the classical SNR measurement method and some measurement results obtained using this method without any critical opinion on the MIL method of SNR measurement [13–19]. In addition, there is a paper that presents a newly developed test station to measure SNR using the classical MIL method that claims very good measurement accuracy ±3.5% of station developed test [20]. Therefore, it looks that situation in metrology of image intensifiers related to measurement of SNR is good. However, the real situation in metrology of II tubes is rather gloomy.

First, there frequently occur significant differences (level over 25%) between measurement results of SNR measurement of the same tube carried out by different test laboratories (manufacturers of II tubes, manufacturers of NVDs, scientific institutes, military quality control centers) located in different countries.

Second, it is commonly known that non-US manufactures of IITs often use SNR measurement methods that are supposed to be equivalent to the MIL method, but practically these modified methods are different.

The result is that measurement results of this very important parameter of an important military/dual use product vary significantly depending on the geographical location of the test laboratory. Such a situation with measurement results of this important electro-optical device can be surprising for most readers, but such a situation is a fact. The best confirmation for this claim on poor SNR reproducibility can be a paper written by scientists from a main US military institution in the field of metrology of night vision: US Army RDECOM CERDEC Night Vision & Electronic Sensors Directorate [21]. This paper confirms significant differences between measurement results of SNR of IITs generated by US laboratories and results from non-US (foreign) laboratories. In fact, the paper calls SNR results delivered by non-US laboratories as only "marketing information".

This gloomy metrological situation presented above is a nightmare for the author who is the CEO of a company that manufactures stations for testing IITs [22]. It is a typical procedure used by customers to compare SNR measurement results generated by the delivered test station with SNR values obtained from data sheets provided by the tube supplier. Such comparison tests of an identical test station can generate different results depending on the geographical location of the test laboratory that has delivered the data sheet for IITs tested. It is quite normal that one customer claims that the new test station generates too positive results when the other claims that the results are too negative.

4. Division of SNR measurement methods

Now let us analyze the metrological situation and find out what the reasons are that generate poor reproducibility of measurement of SNR of IITs carried out by different teams in different countries.

In the opinion of the author, the prime reason for poor reproducibility is the use of myriads of measurement methods that technically differ in some details. Specifically, the measurement methods of SNR can be divided into four groups:

1. original MIL methods,
2. MIL equivalent methods,
3. computerized MIL methods,
4. non-MIL methods.

Original MIL methods are methods of SNR measurement implemented by a team that tries to faithfully implement recommendations of MIL standards.

MIL equivalent methods are methods of SNR measurement implemented by a team that performs measurement of SNR at non-MIL measurement conditions (input pinhole aperture, frequency bandwidth, correlation factor) but later implement corrections to compensate for these differences.

Computerized MIL methods are methods that use image/data processing carried out by computers to calculate the SNR of the IITs tested. Computerization can be applied to both original MIL methods and to MIL equivalent methods.

Non-MIL methods are methods of SNR measurements that differ significantly from the MIL measurement principle: projection of image of single pinhole and analysis of temporal variations of flux of this pinhole.

Now, let us discuss all these groups of measurement methods in detail.

5. Original MIL methods

All MIL standards basically recommend the same test system described in Section 2. However, a test station built according to recommendations of these standards can generate different results due to minor differences, non-clear recommendations or technical limitation of solutions proposed by the standards, later called technical details. There are seven such technical details of stations built according to MIL standards that can degrade reproducibility of SNR measurements:

1. spectral band of the light source,
2. color temperature of the light source,
3. transmission of the neutral filter,
4. illuminance of the light source,
5. diameter of the measuring output pinhole,
6. frequency spectrum of the opto-electronic meter,
7. correlation factor K.

It should be also emphasized that US MIL standards are not intended as international standards but only as US military standards to set requirements and present test methods for specified IITs valid only for a certain period. However, some non-US labs use non-valid MIL standards, and therefore in this section we are to analyze all four exemplary standards listed in Table 1.

5.1. Spectral band of the light source

The MILs require that color temperature of the light source equals 2856K±50 K. However, color temperature of typical calibrated halogen bulbs used as standards in most national photometric laboratories is measured only in the visible band while the spectral band of II tubes is much wider: 400-950 nm (the band of the newest tubes can be up to 1200 nm). Spectrum of halogen bulbs of the same color temperature in the visible band can differ noticeably in the *near infrared* (NIR) range (Fig. 4). It can be estimated that a test station built using a light source with halogen no. 1 from Fig. 4 will generate SNR higher by about 2% compared to SNR obtained using the same station employing halogen bulb no. 2. This calculation assumes that SNR is proportional to the square root of the radiometric signal incoming to the photocathode of the tube tested.

5.2. Color temperature of the light source

MIL standards specify ±50 K tolerance for the color temperature of the source. It means that light sources of color temperature in the range of 2806 K to 2906 K are acceptable. However, the use of two light sources generating the same illumination of tube photocathode, but with so

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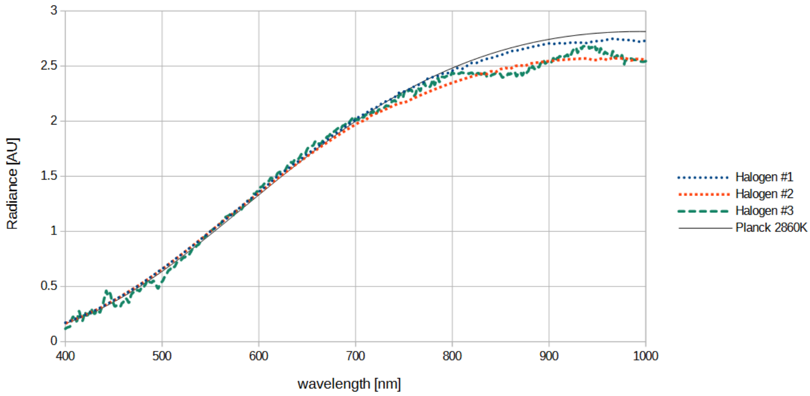

Fig. 4. Relative spectral intensity of two halogen bulbs of the same visible color temperature.

different color temperatures will generate a different radiometric stimulus to the photocathode. It can be estimated that a test station built using a light source with a halogen of 2906 K color temperature will generate SNR higher by about 2% compared to SNR obtained using the same station employing halogen bulb of 2806 K color temperature.

5.3. Transmission of the neutral filter

The MILs propose regulation of light intensity using a set of neutral filters of different optical densities. *Optical density* (OD) is defined as the logarithm of the ratio of incident light intensity to transmitted light intensity, indicating how much light is reduced (absorbed, reflected, scattered) as it passes through a substance; a higher OD means less light gets through. Using filters is a cumbersome regulation method that offers only step regulation. However, this method of regulation of light illuminating the photocathode of the tested IITs was commonly used in old test stations that are still used in many night vision labs. The problem is that neutral filters available on the market are not fully neutral in the typical spectral band of IITs from about 450 nm to about 900 nm (Fig. 5). Therefore, the use of even best neutral filters (OD100-OD200) calibrated in the visible band can lead to noticeable measurement errors of SNR. The MIL standards accept

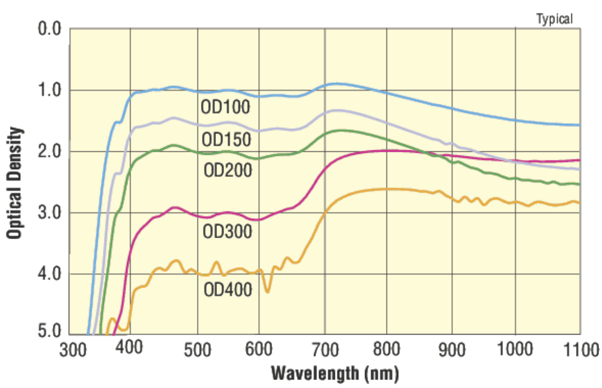

Fig. 5. Transmission of an exemplary set of neutral filters offered on the market [23].

the use of neutral filters of rather poor spectral uniformity (±10% of the nominal value) and the measurement error of SNR can be significant (up to 4%) in the worst case scenario (transmission at NIR is 10% higher/lower compared to transmission in the visible band).

5.4. Illuminance of the light source

The task of the light source is to illuminate the photocathode at 10^{-5} fcd (0.108 mlx) level. However, the actual illumination level can differ from the nominal one. The MILs accept light sources of 10% tolerance when measuring the SNR of IITs. It is a reasonable demand as it is not easy to design such a light source. However, the use of such limited accuracy light source can generate significant SNR measurement errors at the level of ±3.0%.

5.5. Diameter of the measuring pinhole

As shown in Fig. 1, the tested IITs generate an image in the form of a bright circle surrounded by a faint halo. Therefore, it is logical that the measured output signal shall depend on the diameter of the measuring pinhole. The rule is the larger pinhole, the higher SNR. The explanation is that a larger pinhole enables the measurement of flux from not only the image of the bright light spot pinhole with a diameter of about 0.2 mm but also from the faint but large secondary halo.

The latest MIL standard [5] recommends that the diameter of the pinhole of the optical meter used to measure the output signal at the screen plane should not be bigger than 0.3 mm. However, older standards required only that the diameter is equal or bigger than 0.2 mm. This blurred requirements of the older standards create potential variability of SNR measurement results because the measured SNR of some IITs depends on the diameter of the measuring analyzing pinhole (Fig. 6). Looking at the data from Fig. 6, increasing the sampling diameter from 0.2 mm to 1.2 mm boosts SNR results by 10%.

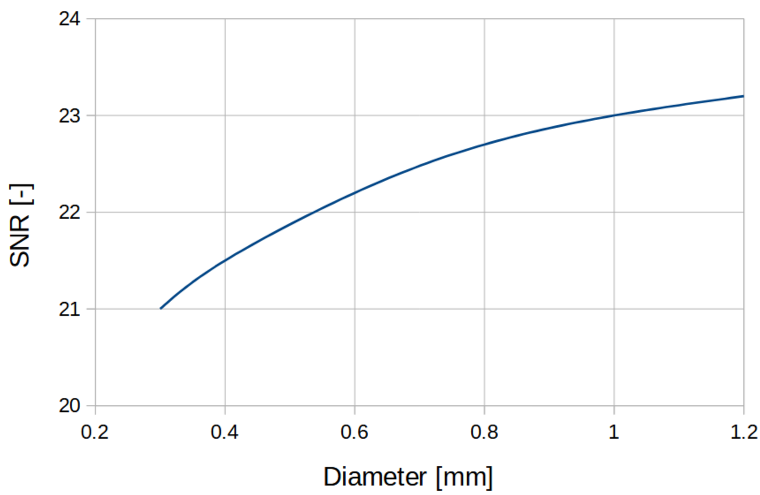

Fig. 6. Dependency of the measured SNR on the diameter of the measuring pinhole for an exemplary II tube.

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5.6. Opto-electronic meter

All MIL standards specify that the rms component of a signal generated by a photomultiplier shall pass through a low-pass filter of 10 Hz bandwidth or rms component of this signal before measurement. Most probably the aim of this filtration is simulation of temporal properties of the human eye that is sensitive up to about 10 Hz (equivalent to 20 frames per second). Therefore, typical MIL based test stations use an electronic filter for low pass filtration, prior to the RMS meter.

There are some subtle differences in requirements for the frequency bandwidth of the electronic filter:

– *MIL-I-49453*(CR): electronic bandwidth of 10 Hz,
– MIL-I-49052F: equivalent bandwidth of 10 Hz,
– *MIL-PRF-A3256363C*(CR), MIL-PRF-A3314408: noise equivalent bandwidth 10 Hz.

These apparently minor terminology differences can lead to noticeable differences in SNR results. A station using the filter of electronic bandwidth of 10 Hz shall generate the SNR result up to about 4% lower compared to that generated by station that uses an electronic filter of noise equivalent bandwidth of 10 Hz.

It can be agreed that this terminology drawback of old MILs has been eliminated in newer MILs that clearly say that they talk about noise equivalent 10 Hz bandwidth. However, there is another source of variability of SNR results related to the optoelectronic meter.

Low pass filtering of noise equivalent bandwidth equal to 10 Hz means that electrical signals of frequency from near 0 Hz to approximately 10 Hz reach the input of the RMS meter. However, due to design limitations, even the best of old analogue RMS meters could measure AC signal only at frequencies higher than a certain low frequency limit that varied in the range from 1 Hz to 3 Hz [24–26].

This limitation has been eliminated in modern digital RMS meters that are capable to measure signal of frequencies as low as 0.01 Hz or below (assuming long measurement time is acceptable). However, it appears that the majority of test labs still use old stations built with old analogue RMS meters as reference test stations.

Practically, it means that depending on the low frequency limit of the RMS meter, the measured SNR shall vary significantly. This influence varies depending on the noise spectrum of II tubes tested. However, it can be estimated that measurement using an RMS meter of a low limit at 3 Hz produces results that are up to 14% higher than those generated by a station based on modern computerized RMS meters with a low, near zero Hz, limit.

5.7. Correlation factor K

As presented in Section 2, the MIL standards recommend dividing the raw measurement of SNR by correlation factor K that depends on type of phosphor used in the coat screen of the II tube. In detail, the MILs present the values of correlation factor K for three most popular phosphors: $K = 1.15$ for P43 or P45; and $K = 1.19$ for P20 (Table 1).

In the situation when K factor for all popular phosphors used to build IITs is known, these standards give almost no room for manipulation of final SNR results. However, there is also one old exceptional MIL standard (MIL-I-49052F) that proposes to use K factor equal to 1.09, if the phosphor decay time characteristic fulfils requirements presented in Fig. 7. The use of $K = 1.09$ produces an SNR result 6%/10% higher compared to SNR values obtained when using typical values $K = 1.15/1.19$. Therefore, some manufacturers claim that phosphor used in their IITs fulfils requirements in Fig. 7 and use $K = 1.09$ in the calculation of final SNR measurement results.

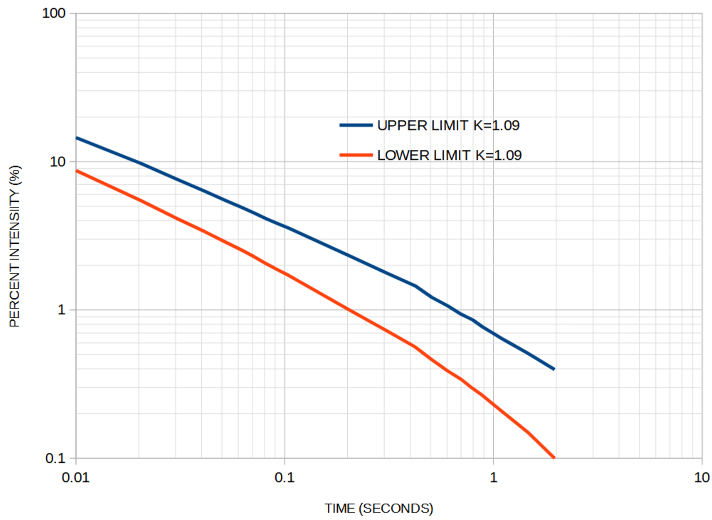

Fig. 7. Requirement on phosphor decay time characteristic as per MIL-I-49052F standard.

6. MIL equivalent methods

MIL equivalent methods are methods of SNR measurement based on the idea to carry out a typical SNR measurement as described in (1) at non-MIL test conditions (input pinhole aperture, photocathode illuminance, noise frequency bandwidth, correlation factor K) and later to correct the influence of non-standard conditions using a proper theoretical formula. In detail, SNR for MIL equivalent methods is to be calculated using the following formula:

$$\mathrm{SNR_{cor}} = \frac{SNR_{\mathrm{raw}}}{K_{\mathrm{new}}} \frac{D_{\mathrm{ref}}\sqrt{E_{\mathrm{ref}}\Delta f}}{D\sqrt{E\Delta f_{\mathrm{ref}}}} \tag{2}$$

where: $\mathrm{SNR_{cor}}$ – raw SNR results obtained using the non-MIL method, D – diameter of the input pinhole used for measurement, D_{ref} – MIL recommended diameter of the pinhole equal to 0.2 mm, E – photocathode illuminance during measurement, E_{ref} – MIL recommended photocathode illuminance equal to 0.108 mlx, Δf_{ref} – MIL recommended noise frequency band equal to 10 Hz, Δf – frequency bandwidth of the electronic filter used during the measurement, K_{new} – new correlation factor that replaces the factor proposed directly in MILs.

6.1. Modified test conditions

A big advantage of MIL equivalent methods is the possibility to measure temporal fluctuation of flux of an image of the input pinhole target (about 0.2 mm) using a bigger measuring pinhole (for example 1.7 mm) at a higher illumination level (for example 0.2 mlx). Such a test scenario enables us to use lower sensitivity optical meters to measure the total signal from both the bright spot and the wide circular halo. It is also easier to focus such a meter to find a bigger target.

In addition, it is convenient to eliminate the need to fix the noise frequency bandwidth of the electronic filter meter precisely to 10 Hz. Finally, this method enables the measurement of correlation factor K for phosphor as actually used in the tested IITs instead of relying on values given in MIL standards.

According to physical principles of random photon noise of light incoming to a tube photocathode, the measured raw SNR should be proportional to diameter D of the input pinhole, proportional to square root of illuminance level E and proportional to square root of frequency bandwidth Δf. Therefore, theoretically the (2) is correct and influence of non-MIL measurement conditions should be compensated. Practically, it is more complicated, and MIL equivalent methods often generate results that differ compared to results generated by MIL original methods.

The MIL equivalent measurement method is formally supported only by a Russian standard that regulates SNR measurement of IITs [7]. However, on the basis of the author's experience, it can be assumed that majority of non-US manufactures use SNR measurement methods that deviate from the MIL method. It should be noted that the author does not suggest that main non-US manufacturers follow Russian standards but only that they have independently developed SNR measurement methods that deviate at some details from the original MIL method presented in Section 2. Each non-US method uses at least one test condition that differs compared to the test conditions shown in Section 2.

Equation (2) is based on sound theoretical principles and theoretically should generate the same results as SNR measured under nominal test conditions. Practically SNR is relatively insensitive to photocathode illuminance and the frequency bandwidth of the electronic meter. However, SNR is at the same time sensitive to the diameter of the input pinhole used for measurement. It has been experimentally shown that by using a big 2 mm pinhole (instead of the typical small 0.2 mm pinhole), it is possible to improve SNR generated by (2) at least to 10%. Most probably this improvement is related to the blurring effect of the output pinhole image. If the pinhole is big, then the blurring effect is negligible.

6.2. Modified correlation factor K

An old paper written at end of the 1970s by employees of the US Night Vision Laboratory (predecessor of US Night Vision & Electronic Sensors Directorate) suggests that the aim of introduction of factor K was to correct the influence of temporal characteristics of different phosphors on final SNR measurement results [27]. In detail, the aim was to avoid a situation in which the measurement method favors tubes with phosphors of long temporal inertia such as P20 or P22 over tubes with phosphors of short temporal inertia such as P52, or P43.

Nowadays, tube screens built using fast phosphors such as P43 or P45 with very short temporal inertia dominate the market of IITs. Therefore, the author has come across some manufacturers/sellers who claim that the use of K factor is nowadays unnecessary and they use $K = 1$ in (1) (no correction at all).

Two different precise formulas how to calculate factor K can be found in two old papers.

First, a paper written in the 1970s by an employee of the renowned US Night Vision Laboratory proposes to calculate K on the basis of the phosphor power spectrum [27]:

$$K = \sqrt{\frac{\int_0^{10\ \mathrm{Hz}} Power(white)\,\mathrm{d}f}{\int_0^{10\ \mathrm{Hz}} Power(phosphor)\,\mathrm{d}f}} \tag{3}$$

where *Power(white)* is the power spectrum of an ideal meter-tube system built using tubes of zero temporal inertia and *Power(phosphor)*, the power spectrum of a real meter-tube system built using a real phosphor screen of considerable temporal inertia.

Second, an old MIL standard from beginning of the 1980s proposes a different way to calculate factor K as a ratio of two noise equivalent bandwidths [28]

$$K = \sqrt{\frac{B_F}{NEB}} \tag{4}$$

where B_F is the specified measurement noise equivalent bandwidth (10 Hz), and NEB is the actual value measured for the system.

The author of this paper is not a specialist in phosphor technology and has not carried out measurements of factor K. He can only say here that he had met some test teams that claim that both (3) and (4) generate lower (less pessimistic) values compared to MIL data.

There is some logic to support such claims. The values from MILs (K = 1.21 for P-22, K = 1.15 for P-43) suggest that there is a strong influence of temporal inertia of phosphor screen on noisiness of the output image. However, the decay time of P-43 phosphor is shorter than 3 ms [29]. Therefore, it is not clear how phosphor can so fast create such significant smoothing of the output signal measured using an optical meter of low frequency band of up to 10 Hz.

Further doubts about the values of coefficient K in MILs can arise after a detailed analysis of [27]. It presents K value for P-52 phosphor at the level of 1.1. As P-52 phosphors are still used for CRT displays [30], their temporal properties are almost the same as those of P-43 phosphors used for the same applications. Therefore, there is no logical explanation why coefficient K for P-43 phosphor is 50% higher compared to its value for P-52 phosphor.

It is also not clear if phosphors of the same type (P20, P43, P45, P22) are characterized by the same temporal inertia and the consequently the same factor K. The author has come across a non-verified opinion from one of the manufacturers of IITs that they can use phosphors of the same type (as P20 phosphor) but of different temporal inertia depending on phosphor technology.

At the same time, it is impossible to prove that values of coefficient K presented in the MIL standards were measured in a wrong way because newer standards do not offer a precise method of determination of this coefficient.

To summarize, factor K is of critical importance for accurate SNR measurements and present unclear situation enables manipulation with SNR measurement results.

It should be also noted that the main reason to introduce factor K was to eliminate unfair competition from IITs having phosphors of long temporal inertia. Nowadays, only fast phosphors (P43, P45) with the same factor K are used. Therefore, technically it is possible to abandon the use of factor K while keeping the ability to objectively compare the SNR of different tubes.

7. Computerized MIL methods

Computerized MIL methods are methods that use image/data processing carried out by computers to calculate the SNR of tested IITs but basically employ the measurement principle of the typical MIL original method. Therefore, computerized methods can be treated as the modern form of original MIL methods.

The concept of measurement of SNR presented in MIL standards was developed before the era of mass use of computer technology. Therefore, it is logical that MIL standards describe a measurement procedure based on the use of a simple non-imaging analogue optoelectronic meter. It can measure the total flux of an image of a pinhole target well, but its use is not convenient due to the necessity of time consuming positioning/focusing of the meter relative to the screen of II tube tested. Thus, it is attractive to replace the non-imaging optoelectronic meter with a modern digital camera to capture the sequence of images of the tube screen and carry out analysis of temporal

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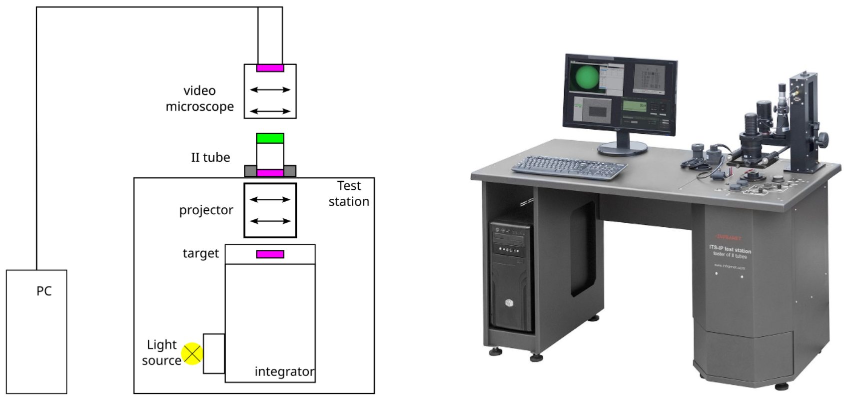
changes of brightness of the pinhole image using modern software (Fig. 8). Such modern imaging tools enable easy positioning/focusing of the camera working as the optoelectronic meter. Software can precisely locate the image of the input pinhole and calculate both DC and rms components of temporal variations of flux of this image needed by (1) to calculate SNR.



(a) (b)

Fig. 8. Computerized station for testing IITs: a) block diagram, b) exemplary test station [22].

Such computerized methods can generate results identical to those of original MIL methods, on condition linear imaging cameras are used and proper temporal filtering is achieved with:

1. a low pass filter of noise equivalent bandwidth equal to 10 Hz,
2. a high pass filter to simulate performance of old RMS meters used in SNR tests stations.

Both filters can be achieved by the Fourier transform of captured temporal profiles of brightness of the pinhole target/background and later modification of this transform to the desired form.

8. Non-MIL methods

Non-MIL methods are methods of SNR measurement that do not employ the typical MIL measurement principle, i.e., the projection of an image of a single pinhole and analysis of temporal variations of flux of this pinhole. In the opinion of the author, there is at least one such a method that is practically used.

This non-MIL method can be called the uniform photocathode method. It is based on idea to uniformly illuminate the photocathode of the tested II tube and carry out analysis of temporal variations of brightness of a small part of the screen (pinhole 0.2 mm) in order to calculate SNR.

Modified (1) is used to calculate SNR as the ratio of S and N that are signal/standard deviation from the total flux of a 0.2 mm circle of location at the central part of the screen of an II tube.

Simplicity is a big advantage of the uniform photocathode method. There is no need to project the image of the pinhole target (no projection optics). Nor is there a need to for precise alignment of the measuring pinhole with the image of the input pinhole. It is also possible to carry out the analysis of temporal variations of the array of circles in order to reduce random error (see the array pinhole method). Implementation of the uniform photocathode method is easy when using a digital camera for image analysis.

However, this method generates results that are significantly higher (25-50%) compared to the original MIL method. In addition, the ratio of results generated by both methods vary from case to case.

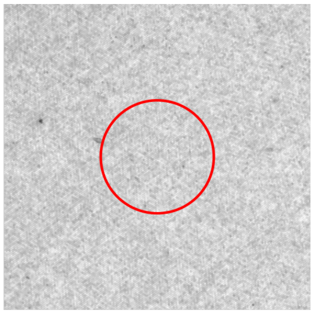


Fig. 9. Magnified image of the tube screen during SNR measurement using the uniform photocathode method.

The uniform photocathode method is supported formally by the Russian standard [7] and has some gained local popularity (in Russia and some Asian countries) due to its simplicity.

9. Reproducibility of SNR measurement

The previous sections present a series of technical factors that reduce reproducibility of SNR measurements carried out by different test teams. These sections present also a rough numerical evaluation of maximal difference of the SNR result generated by these factors. A detailed list of reproducibility factors with estimated max change of SNR results they can generate is presented in Table 2.

Two important conclusions can be obtained on basis of data in Table 2. First, the total max relative difference of SNR measurements obtained by different teams can be very high, i.e., 60%. It is correct that this is the worst case scenario of low probability. However, if we assume Gaussian distribution at 3σ limit, we obtain standard deviation σ at 10% level. It suggests that differences between different teams in the range ±10% should be common. This prediction is confirmed by present-day reality when SNR data delivered by different labs is compared.

Table 2. Reproducibility factors.

No	Factor	Estimated max relative difference [%]
1	Spectral band	2% (Section 5.1)
2	Source color temperature	2% (Section 5.2)
3	Neutral filter	4% (Section 5.3)
4	Illuminance photocathode	3% (Section 5.4)
5	Diameter of the measuring pinhole	10% (Section 5.5)
6	Frequency spectrum of the opto-electronic meter	14% (Section 5.6)
7	Modified test conditions in the MIL equivalent methods	10% (Section 6.1)
8	Modified factor K	15% (Section 6.2)
	Total max difference	60%
	Standard deviation (Gaussian distribution at 3σ limit)	10%

Second, the eight reproducibility factors listed in Table 2 can be divided into two groups: 1) imperfect technical design of the test station (nos. 1-4), 2) differences in the measurement method used by different teams (nos. 5-8). Influence of imperfect design (max relative difference 11%) is several times smaller compared to the influence of differences in the measurement method (max relative difference 49%). The conclusion is that an improved precision standard accepted worldwide is urgently needed in order to improve present-day poor reproducibility of SNR measurement of IITs.

10. Systemic reasons for poor reproducibility

In addition to a series of technical reasons of poor reproducibility discussed in the previous section, there are also some systemic reasons that aggravate technical problems.

In the author's opinion, there are four main systemic reasons:

1. Limited specialized literature,
2. Technical limitations of low-light photometry,
3. Variable design of equipment for testing IITs,
4. Domination of industrial centers.

10.1. Limited specialized literature

Testing of IITs has received very little attention from international scientific community compared to interest in testing thermal imagers. What is even more important, there are no widely disseminated materials presenting parameters, test methods, equipment, and evaluation methods needed for testing and evaluation of modern image intensifiers.

The main reason is that the demise of analogue imager intensifier technology was predicted at least three decades ago. This demise has not materialized but has significantly diminished interest of scientific institutions in this technology. In contrast to hundreds of papers on testing thermal imagers, papers devoted to testing IITs are a rarity.

It should be also noted that most recent scientific papers on testing image intensifier tubes are written by authors from Chinese scientific institutions who entered this technology too late to set internationally valid testing rules.

10.2. Technical limitations of low-light photometry

As mentioned in Section 2, a calibrated light source of 2856 K color temperature capable of creating illuminance of a tube photocathode at the level of 10^{-5} fc (0.108 mlx) is needed in systems for measurement of SNR.

It can be surprising for many readers but the calibration of a such light source is a challenge for manufacturers of systems for testing IITs for two main reasons.

First, a great majority of national metrological institutes offer calibration of illuminance meters only at the range over 10^{-2} fc (0.1 lx), while meters of a three-decade higher sensitivity (10^{-5} fc) are needed. This is valid even in the case of well-known national metrological laboratories [31]. Therefore, manufacturers of equipment for testing NVD/II tubes use indirect calibration of their light meters. In this way, they can still claim that the calibration is traceable to national metrology institutes, but it is a not a direct calibration by those institutes.

Second, photometric labs worldwide offer measurement of color temperature of halogen light sources. However, such measurement is typically performed only for the visible band (400-750 nm), while IITs are sensitive up to 950 nm (or 1200 nm for the newest ones). Practically, it means that spectrum of light sources can differ from the required one at 800-950/1200 nm band where tubes are the most sensitive.

10.3. Variable design of equipment for testing IITs

There are at least six manufacturers of systems for testing thermal imagers. However, the structure and measurement methods of these test systems are basically the same. What more, commercial test systems are used in mass by manufacturers of thermal imagers.

The situation on the market for equipment for testing IITs is different. There are two main manufacturers of commercially available quasi universal modern systems for testing IITs [22, 32]. Yet, most test systems used worldwide are specialized (one parameter - one station) systems developed by manufactures. A great majority of them are old, customized test systems, at least 20 years of age. There even operational systems of age up to 40 years. Further on, manufacturers often use old reference IITs to calibrate present day test systems. Such a situation creates automatically high variability of measurement results from test equipment designed by different teams at different time periods due to different design or different calibration standards.

10.4. Domination of industrial centers

In contrast to thermal imaging both image intensifier technology and metrology have been developed not by scientific institutes but by commercial companies. The latter ones have a natural tendency for secrecy and unwillingness to publish the results of their work or cooperation with competitors to develop common test methods.

In addition, IITs are dual use products. This character increases secrecy on matters concerning manufacturing and, to some extent, also on testing IITs.

11. Future improvements of standardization of testing IITs

The previous sections of this paper present a series of reasons that contribute to a strongly pessimistic overview of present day status of image intensifier metrology in field of measurement of such crucial parameter as SNR. The positive news is that a new NATO scientific group has been founded recently [33]. Its main task is to improve standardization of testing of image intensifier tubes and night vision devices. Therefore, it can be expected that in near future the measurement of SNR of image intensifier tubes shall be fully standardized and reproducibility/accuracy of measurements of this important parameter shall be improved worldwide.

It should be also noted that present day metrological chaos is a real problem only on an international scale. Locally, it is only a minor technical problem. The reason is that in most technologically advanced countries there is typically one government-authorized center that tests IITs and generates results that are accepted locally. This system enables us to keep quite good local reproducibility of measurements of SNR parameter of IITs but is a bad solution globally.

12. Conclusions

This paper presents a review of a series of slightly different measurement methods of SNR of image intensifier tubes. It explains that significant differences (at the level of 20% or more) between measurement results obtained by different test teams are caused mainly by metrological chaos due to poor standardization in testing of IITs and not due to technical limitations of modern test stations. Therefore, significant improvement in field of standardization of measurement of the SNR is urgently needed in order to enable good reproducibility and accuracy of measurement of this important parameter of IITs.

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