

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 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 is image 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 the 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 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 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 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 SNR of image intensifier tubes have been presented in in 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 is repeated with only some minor modifications in every new issue of such standards. Equivalent Chinese standard that regulate 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 Russian standard that present 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 idea to illuminate tube photocathode using a pinhole target of 0.2 mm diameter at illuminance level 10^{-5} fc (0.108 mlx) using light source of 2856 K colour temperature and later to measure temporal variations of total flux of output image of this target at tube screen.

Image of screen of IIT during SNR measurement is shown at Fig. 1. As we can see it presents a small bright spot on dark noisy background. Rudimentary visual analysis of pinhole image suggest that the image of the pinhole only slightly overfills 0.2 mm circle (Fig. 1a). However, careful analysis using software for image processing can show also very faint halo up to about 1 mm diameter (Fig. 1b). The halo effect is more clearly seen in Fig. 2 that presents light intensity cross section of image of 0.2 mm pinhole. It is clear that total image of 0.2 mm pinhole target is much bigger than the original 0.2 mm circle due to image blurring caused by different types of halo effects. Therefore, analysing pinhole of diameter significantly bigger than 0.2 mm is needed to record total flux of image of the pinhole target and output signal differs depending on diameter of this analysis window.

Further on, the 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.

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 photocathode plane of the tested tube.

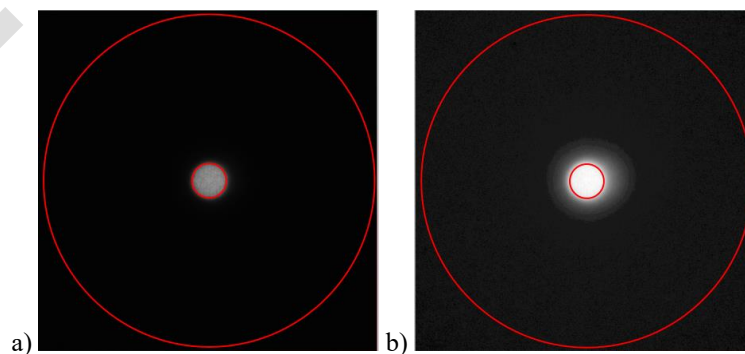


Fig. 1. Image of a pinhole target a) linear scale; b) logarithmic scale with 0.2 and 2 mm area marked.

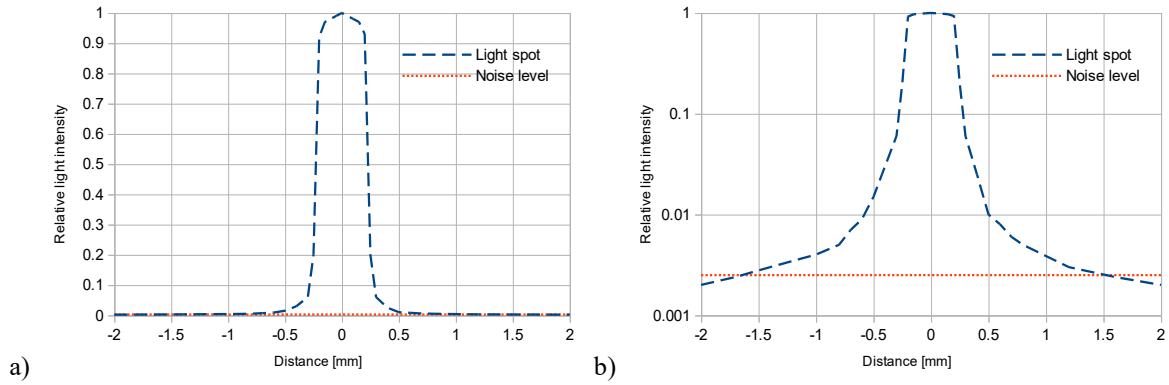


Fig. 2. Relative light intensity of image of 0.2 mm pinhole target a) linear scale, b) logarithmic scale.

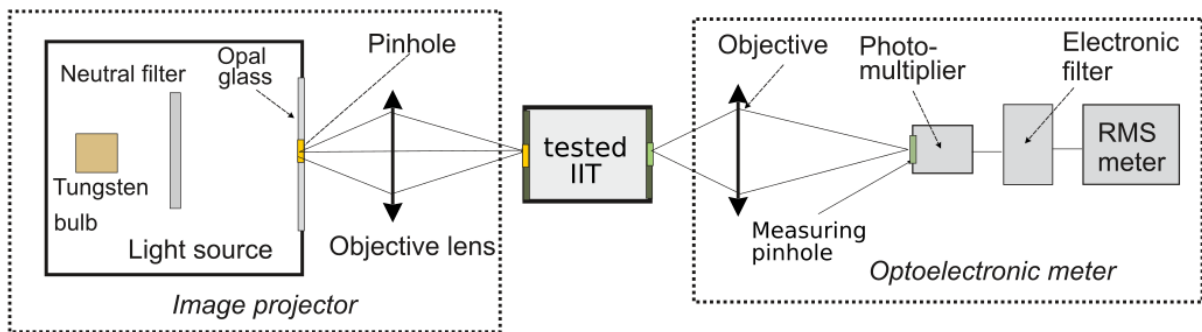


Fig. 3. Graphical concept of a system for measurement SNR of IITs according to MIL standards.

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 image of the pinhole target created at the tube screen at specified equivalent noise bandwidth.

The objective lens projects image of image of pinhole at tube screen to photomultiplier photocathode. Measuring pinhole located at photomultiplier plane determines diameter of sensing circle around the pinhole image. Later, the photomultiplier converts total optical flux into electrical signal. Electronic filter regulates spectrum of transmitted electrical signal. Finally, 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:

$$SNR_{raw} = \frac{S-B}{K \sqrt{\sigma_S^2 - \sigma_B^2}} \quad (1)$$

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

Detail technical requirements on 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.

3. Situation in image intensifier metrology

SNR is one of most important parameters of IITs and is included in 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 FOM criterion (product of resolution and SNR) [12].

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 input pinhole	0.2	0.2	0.2	0.2
Pinhole illuminance	10^{-5} fc	$1.2 \cdot 10^{-6}$ fc	10^{-5} fc	10^{-5} fc
Tolerance on pinhole illuminance	$\pm 10\%$	$\pm 10\%$	-	-
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 neutral filter	$\pm 10\%$	$\pm 10\%$	-	-
Diameter of measuring pinhole	> 0.2 mm	> 0.2 mm	-	< 0.3 mm
Frequency band of 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

The measurement method recommended by MIL standards presented in previous section has been practically used for several decades worldwide to measure SNR of hundreds of thousands of IITs. The concept of MIL method for SNR measurement is apparently accepted by all major manufacturers of IITs, manufacturers of *night vision devices* (NVDs), manufacturers of test equipment and 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 $\pm 3.5\%$ of developed test station [20]. Therefore, it apparently looks that situation in metrology of image intensifiers related to measurement of SNR is good. However, real situation in metrology of II tubes is rather gloomy.

First, 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 centres) located in different countries occur frequently.

Second, it is commonly known that non-US manufactures of IITs often use SNR measurement methods that are supposed to be equivalent to 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 geographical location of test laboratory. Such a situation with measurement results of this important EO device can be surprising for most readers, but such a situation is a true fact. The best confirmation for this

claim on poor SNR reproducibility can be a paper written by scientists from main US military institution in 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 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 delivered test station with SNR values obtained from data sheets delivered by tube supplier. Such comparison tests of identical test station can generate different results depending on geographical location of test laboratory that has delivered data sheet for tested IITs. 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 analyse metrological situation and find out what are the reasons that generate poor reproducibility of measurement of SNR of IITs carried out by different teams in different countries.

In author opinion, the prime reason of poor reproducibility is the use of myriads of measurement methods that technically differ at some details. In detail, 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 team that try to faithfully implement recommendations of MIL standards.

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

Computerized MIL methods are methods that use image/data processing carried out by computers to calculate SNR of tested IITs. Computerization can be applied to both original MIL methods or 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 recommends basically the same test system described in Section 2. However, 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. called later as 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 light source,

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

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

5.1. Spectral band of light source

The MILs require that colour temperature of the light source equals to $2856\text{K} \pm 50\text{ K}$. However, colour temperature of typical calibrated halogen bulbs used as standards in majority of national photometric laboratories is measured only in visible band when spectral band of II tubes is much wider: 400-950 nm (band of newest tubes can be up to 1200 nm). Spectrum of halogen bulbs of the same colour temperature at visible band can differ noticeable in *near infrared* (NIR) range (Fig. 4). It can be estimated that test station built using light source with halogen no. 1 from Fig. 4 will generates SNR higher by about 2% comparing to SNR obtained using the same station employing halogen bulb no. 2. This calculation is based on assumption that SNR is proportional to square root from radiometric signal incoming to photocathode of tested tube.

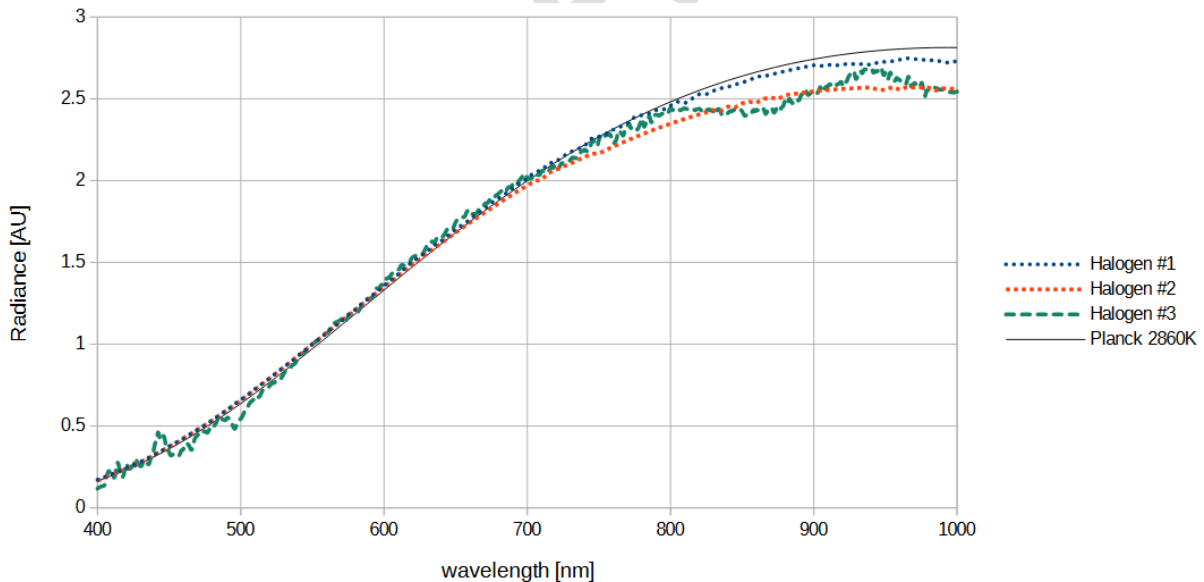


Fig. 4. Relative spectral intensity of two halogen bulbs of the same visible color temperature.

5.2. Color temperature of light source

The MIL standards specify $\pm 50\text{ K}$ tolerance for the colour temperature of the source. It means that light sources of colour temperature in range from 2806 K to 2906 K are acceptable. However, use of two light sources generating the same illumination of tube photocathode, but of such different colour temperatures will generate different radiometric stimulus to photocathode. It can be estimated that test station built using using light source

with halogen of 2906 K colour temperature will generate SNR higher by about 2% comparing to SNR obtained using the same station employing halogen bulb of 2806 K colour temperature.

5.3. Transmission of 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 offer only step regulation. However, this method of regulation of light illuminating photocathode of tested IITs was commonly used in old test stations that are still used in many high vision labs. The problem is that neutral filters available on the market are not fully neutral in typical spectral band of IITs from about 450 nm to about 900 nm (Fig. 5). Therefore, use of even best neutral filters (OD100-OD200) calibrated at visible band can lead to noticeable measurement errors of SNR. The MIL standards accept use of neutral filters of rather poor spectral uniformity ($\pm 10\%$ from nominal value) and the measurement error of SNR can be significant (up to 4%) in worst case scenario (transmission at NIR is 10% higher/lower comparing to transmission at visible band).

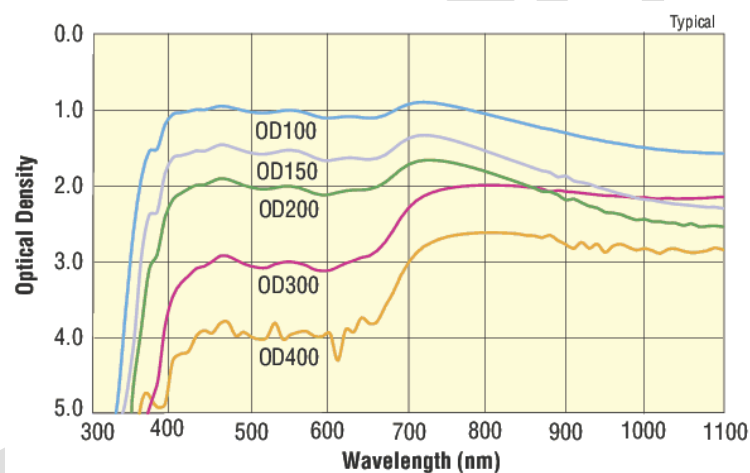


Fig. 5. Transmission of exemplary set of neutral filters offered on market [23].

5.4. Illuminance of light source

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

5.5. Diameter of measuring pinhole

As shown in Fig. 1 tested IITs generate image in form of a bright circle surrounded by the faint halo. Therefore, it is logical that measured output signal shall depend on diameter of measuring pinhole. The rule is larger pinhole – higher SNR. The explanation is that larger

pinhole enables measurement of flux from not only image of bright light spot of diameter about 0.2 mm pinhole but also from faint but large secondary halo.

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

5.6. Opto-electronic meter

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

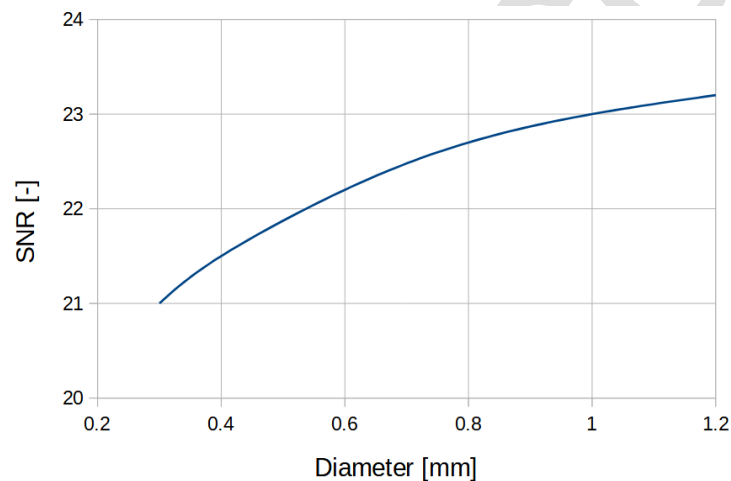


Fig. 6. Relationship between measured SNR on diameter of the measuring pinhole for exemplary II tube.

There are some subtle differences in requirements on 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. Station using filter of electronic bandwidth of 10 Hz shall generate SNR result up to about 4% lower comparing to result generated by station that use 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 MIL that clearly say that they talk on noise equivalent 10 Hz bandwidth. However, there is another source of variability of SNR results related to 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 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 vary in range from 1 Hz to 3 Hz [24-26].

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

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

5.7. Correlation factor K

As presented Section 2 the MIL standards recommend to divide raw measurement of SNR by correlation factor K that depends on type of phosphor used coat screen of II tube. In detail, the MILs present 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 situation when K factor for all popular phosphors used to built IITs is known, these standards give almost no room for manipulation with 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 phosphor decay time characteristic fulfils requirements presented in Fig.7. Use of $K = 1.09$ produces SNR result 6%/10% higher comparing to SNR values obtained when using typical values $K = 1.15/1.19$. Therefore, some manufacturers claim that phosphor used in their IITs fulfil requirements in Fig.7 and use $K = 1.09$ in calculation of final SNR measurement results.

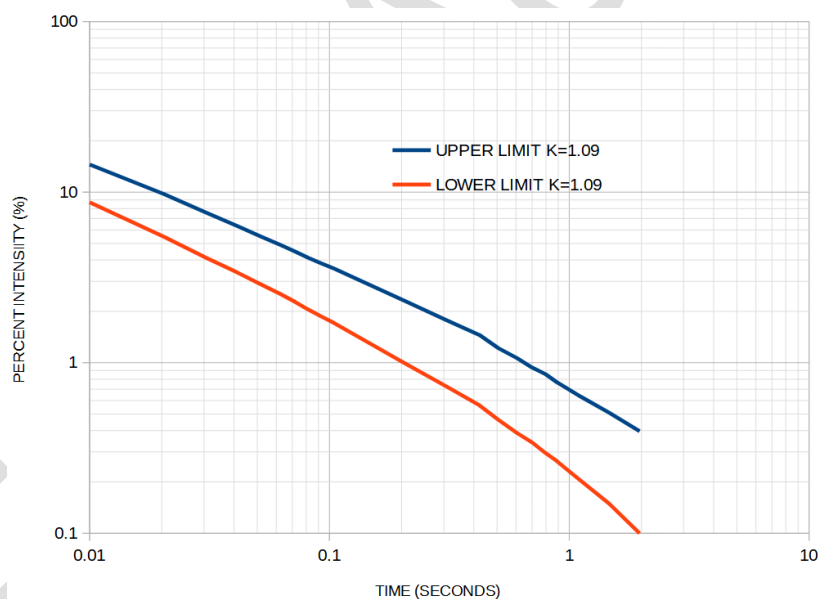


Fig. 7. Requirement on phosphor decay time characteristic as per MIL-I-49052F standard.

6. MIL equivalent methods

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

$$SNR_{cor} = \frac{SNR_{raw} D_{ref} \sqrt{E_{ref} \Delta f}}{K_{new} D \sqrt{E \Delta f}}, \quad (2)$$

where: SNR_{raw} – raw SNR results obtained using the non-MIL method, D – diameter of input pinhole used for measurement, D_{ref} – MIL recommended diameter of 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 electronic filter used during measurement, K_{new} – new correlation factor that replace factor proposed directly by MILs.

6.1. Modified test conditions

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

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

According to physical principles about random photon noise of light incoming to tube photocathode, measured raw SNR should be proportional to diameter D of 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 situation is more complicated and MIL equivalent methods often generate results that differ comparing to results generated by MIL original methods.

MIL equivalent measurement method is formally supported only by a Russian standard that regulates SNR measurement of IITs [7]. However, on basis of author experience it can be said 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 developed independently SNR measurement methods that deviate at some details from original MIL method presented in Section 2. Each of non-US methods uses at least one test condition that differ comparing to test conditions shown in Section 2.

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

6.2. Modified correlation factor K

Old paper written at end of 1970s by employees of US Night Vision Laboratory (predecessor of US Night Vision & Electronic Sensors Directorate) suggests that the aim of introduction of K factor was to correct influence of temporal characteristics of different phosphors on final SNR measurement results [27]. In detail, the aim was to avoid situation

when measurement method favours tubes with phosphors of long temporal inertia like P20 or P22 over tubes with phosphors of short temporal inertia like P52, or P43.

Nowadays, tubes screens built using fast phosphors like P43 or P45 of very short temporal inertia dominate market of IITs. Therefore, the author has met some manufacturers/sellers who claimed that use of K factor is nowadays not needed 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 1970s by employee of renowned US Night Vision Laboratory propose to calculate K on basis of phosphor power spectrum [27]:

$$K = \sqrt{\frac{\int_0^{10\text{Hz}} \text{Power}(\text{white})df}{\int_0^{10\text{Hz}} \text{Power}(\text{phosphor})df}}, \quad (3)$$

where $\text{Power}(\text{white})$ is a power spectrum of ideal meter-tube system built using tubes o zero temporal inertia and $\text{Power}(\text{phosphor})$ a power spectrum of a real meter-tube system built using real phosphor screen of not negligible temporal inertia.

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

$$K = \sqrt{\frac{B_F}{NEB}}, \quad (4)$$

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

The author of this paper is not a specialist in phosphor technology and has not carried out measurement of factor K . Here can only say that he had met some test teams that claim that both (3) (4) generate lower (less pessimistic) values comparing 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 strong influence of temporal inertia of phosphor screen on noisiness of output image. However, decay time of P-43 phosphor is not longer than 3 ms [29]. Therefore, it is not clear how so fast phosphor can create such significant smoothing of output signal measured using optical meter of low frequency band equal up to 10 Hz.

Further doubts about values of K coefficient in MILs can arise after detail analysis of [27]. It presents K value for P-52 phosphor at level of 1.1. P-52 phosphors are still used for CRT displays [30]. Temporal properties of P-52 phosphor are almost the same as of P-43 phosphors used for the same applications. Therefore, there is no logical explanation why K coefficient for P-43 phosphor is 50% higher comparing to value of K coefficient 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 K factor. The author has met non verified opinion from one of the manufacturers of IITs that they can use phosphors of the same type (like P20 phosphor) but of different temporal inertia depending of phosphor technology.

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

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

It should be also noted that the main reason to introduce K factor was to eliminate unfair competition from IITs having phosphors of long temporal inertia. Nowadays, only fast

phosphors (P43, P45) of the same K factor are used. Therefore, technically it is possible to drop the use of K factor while keeping the ability to objectively compare of SNR of different tubes.

7. Computerized MIL methods

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

Concept of measurement of SNR presented in MIL standards has been developed before era of mass use of computer technology. Therefore, it is logical that MIL standards describe measurement procedure based on use of simple non-imaging analogue optoelectronic meter. It can measure total flux of image of pinhole target well, but its use is not convenient due to necessity of time consuming positioning/focusing of the meter relative to screen of tested II tube. In such a situation, it is attractive to replace the non-imaging optoelectronic meter by a modern digital camera to capture sequence of images of tube screen and carry out analysis of temporal changes of brightness of pinhole image using modern software (Fig. 8). Such modern imaging tools enables easy positioning/focusing of camera working as the optoelectronic meter. Software can precisely locate 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.

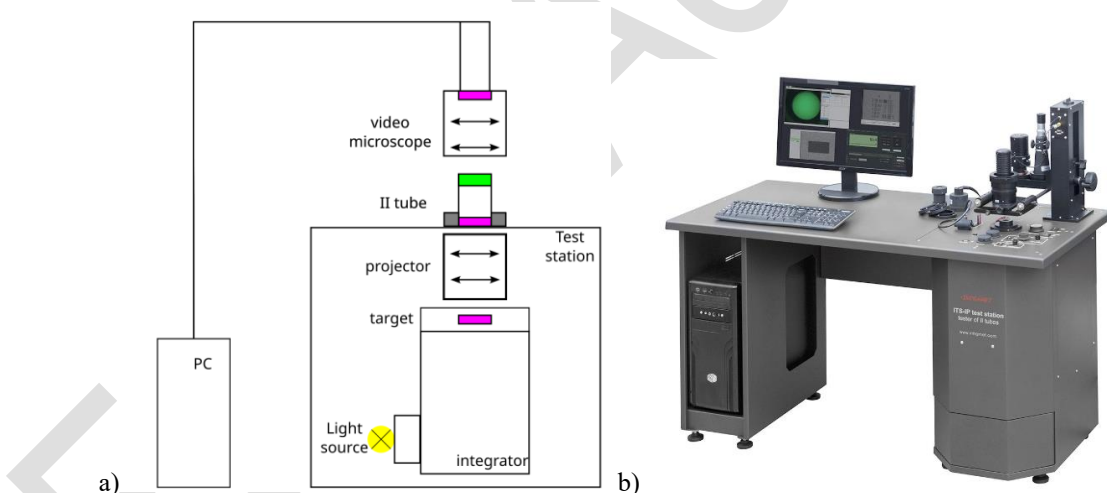


Fig. 8. Computerized station for testing IITs: a) block diagram, b) photo of exemplary test station [22].

Such computerized methods can generate result identical to MIL original methods, if linear imaging cameras are used and proper temporal filtering is achieved:

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

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

8. Non MIL methods

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

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

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

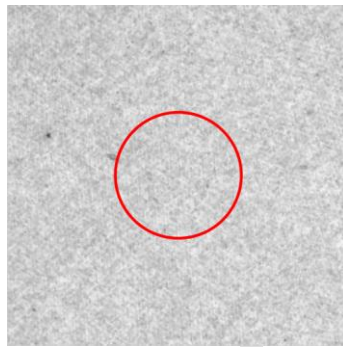


Fig. 9. Magnified image of tube screen during SNR measurement using uniform photocathode method.

Simplicity is a big advantage of the uniform photocathode method. No need to project image of pinhole target (no projection optics). No need to for precise alignment of the measuring pinhole with the image of 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 array pinhole method). Implementation of uniform photocathode method is easy when using digital camera for image analysis.

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

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

9. Reproducibility of SNR measurement

Previous sections present a series of technical factors that reduce reproducibility of SNR measurements carried out by different test teams. These sections present also rough numerical evaluation of maximal difference of SNR result generated by these factors. Detail 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, total max relative difference of SNR measurements obtained by different teams can be very high: 60%. It is correct that this is the worst case scenario of low probability. However, if we assume Gaussian distribution at 3σ limit then we obtain standard deviation σ at 10% level. It suggest that differences between different teams in range $\pm 10\%$ 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 measuring pinhole	10% (section 5.5)
6	Frequency spectrum of opto-electronic meter	14% (section 5.6)
7	Modified test conditions in MIL equivalent methods	10% (section 6.1)
8	Modified K factor	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) non perfect technical design of test station (no 1-4), 2) differences in measurement method used by different teams (no 5-8). Influence of non perfect design (max relative difference 11%) is several times smaller comparing to influence of differences in measurement method (max relative difference 49%). The final conclusion is that improved precision standard accepted worldwide is urgently needed in order to improve present day poor reproducibility of SNR measurement of IITs.

10. Systemic reasons of poor reproducibility

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

In author 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 centres.

10.1. Limited specialized literature

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

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

It should be also noted that majority of 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 calibrated light source of 2856 K colour temperature capable to create illuminance of tube photocathode at level of 10^{-5} fc (0.108 mlx) is needed in systems for measurement of SNR.

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

First, great majority of national metrological institutes offer calibration of illuminance meters only at range over 10^{-2} fc (0.1 lx) when meters of three decades higher sensitivity (10^{-2} fc) are needed. This situation is valid even in 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 national metrology institutes.

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

10.3. Variable design of equipment for testing IITs

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

Situation on 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]. However, majority of test systems used world wide are specialized (one parameter - one station) systems developed by manufactures. Great majority are old customized test systems of age at least 20 years. 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 team at different time periods due to different design or different calibration standards.

10.4. Domination of industrial centres

In contrast to thermal imaging both image intensifier technology/metrology has been developed not by scientific institutes but by commercial companies. The latter ones have a natural tendency for secrecy and unwillingness for publication of 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 of manufacturing and in lesser degree also on testing IITs.

11. Future improvements of standardisation of testing IITs

Previous sections of this paper present a series of reasons that create strongly pessimistic overview of present day status of image intensifier metrology in field of measurement of a crucial parameter like SNR. The positive news is that a new NATO scientific group has been founded recently [33]. The group main task is to improve standardisation of testing of image

intensifier tubes and night vision devices. Therefore, it can be expected that in near future measurement of SNR of image intensifier tubes shall be fully standardised and reproducibility/accuracy of measurements of this important parameter shall be improved worldwide.

It should be also noted that present day metrologic chaos is a real problem only for international scale. Locally – only a minor technical problem. The reason is that in most technologically advanced countries there is typically one government authorised centre that do testing IITs and generate results that are accepted locally. This system enables 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. The paper explains that significant differences between measurement results obtained by different test teams (differences at level of 20% or more) are caused mainly by metrological chaos due to poor standardisation of testing of IITs and not due to technical limitations of modern test stations. Therefore, significant improvement in field of standardisation of measurement of the SNR is urgently needed in order to enable improvement of reproducibility and accuracy of measurement of this important parameter of IITs.

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