Delft Electronic Products B.V.
Dwazziewegen 2, 9301 ZR Roden
P.O. Box 60, 9300 AB Roden
The Netherlands
Tel : +31 (0)50-5018808
Fax: +31 (0)50-5011456
E-mail : sales@dep.nl
http://www.dep.nl
Trade Register No.: 04019659

Tube performance that matters
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Introduction

This technical paper deals with some fundamental characteristics of image intensifier tubes. The best way to evaluate a tube is a field test. The way the tube will perform there will strongly depend on the scenery observed:
- How much light is there?
- How much contrast has the scene?
- What are the spectral characteristics of illumination and scenery reflection?

It is very well possible that the best tube at low light conditions is not the best choice higher light levels. Because of differences in spectral behaviour it can also be that a tube is superior in a desert but not in a forest.

This paper is intended to give some knowledge of tube performance and assessment of this performance. Also the DEP's XD-4™ technology will be compared with GEN III Omnibus IV tubes.

Important tube characteristics

Usually the following data are used to describe tube performance:
- the limiting resolution (lp/mm)
- the generation (Gen I, Gen II, SuperGen, Gen III, XD-4™)
- the cathode sensitivity (µA/lm)
- the gain (cd/m²/lux)
- the maximum output brightness (cd/m²)
- the equivalent background illumination (EBI, µlux)
- the signal to noise ratio (S/N)

Not all of these parameters contribute to the performance that is beneficial to the user. This paper will deal with the parameters mentioned and discusses the consequences for the ultimate target: the field performance.

The two performance regimes

An I^2 tube is an amplifier of residual light. If there is no light, there will be no image. If there is only a small quantity of light, one will be confronted with the fact that light exists of individual particles called photons. As a consequence there will not be a continuos illumination but a 'hail like' bombardment by single photons. At very low illumination levels, there will not be enough photons for the human eye to form an image. Increasing illumination will increase the number of photons and a noisy image will pop up. With such a noisy image it will not be possible to see small details; the resolution will be dependent on the light level. This regime is called the ‘low light level’ or ‘shot noise limited’ regime. In this regime the quality of the picture will be dependent on the light level.
If there is enough light, the noisiness will disappear. The quality of the picture is much higher and must be described by sharpness and contrast. It will not depend on the illumination intensity.
Figure 1 shows that the limiting resolution in the low light level is dependent on the illumination, while at higher levels it is constant.

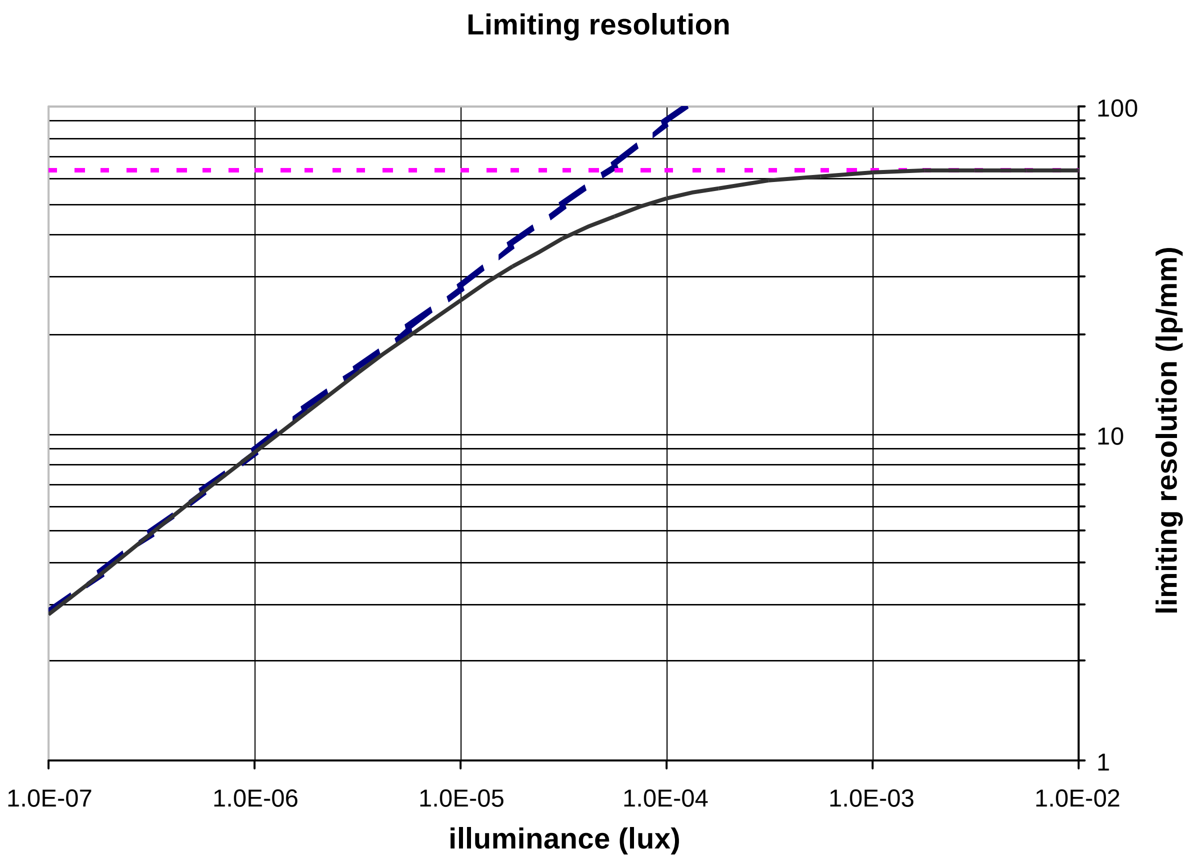

Figure 1. The limiting resolution as a function of illuminance showing the high and low light level regimes

Low light level performance

The Signal to Noise Ratio
In the low light regime the information density is mainly determined by the noisiness of the image. This effect is illustrated by the images in figure 2 below. At very low light levels no structures are visible at all. The 'image' consists of light speckles, but our eyes cannot make a picture from it. That the information is there could be demonstrated by integrating on a photographic film or with a CCD camera. If the light level increases the larger20lp/mm target becomes visible. The smaller 60lp/mm target is still hidden in the noise. At these light levels the information we get from the I^2 tube is mainly determined by its noise performance.

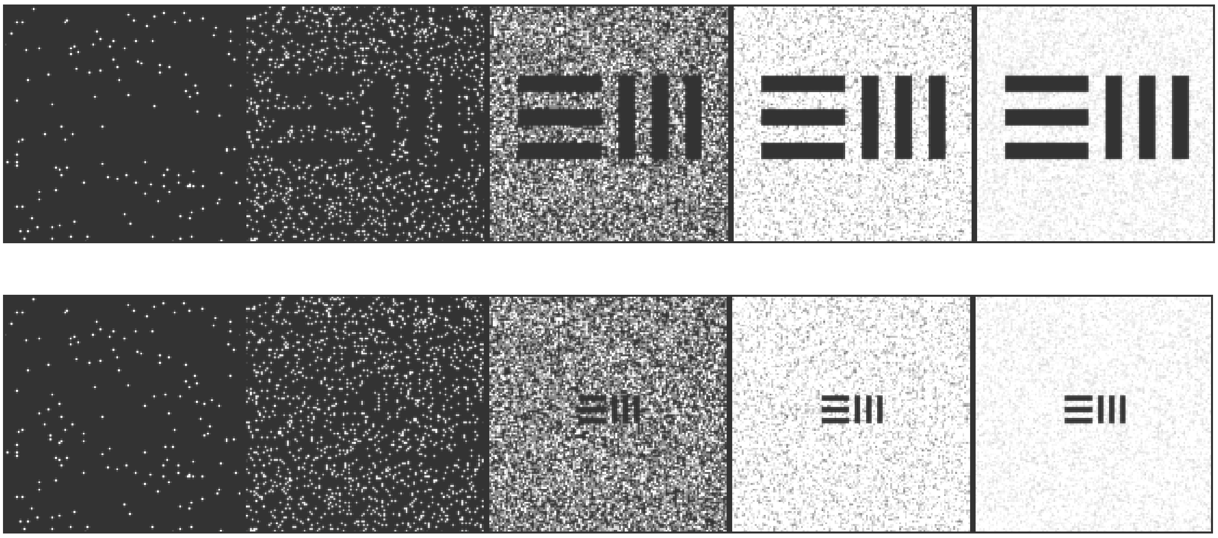

Figure 2. The 20lp/mm and 60lp/mm targets at different light levels

A number of factors play a role in the noise performance of an I^2:

- The amount of light available. The noisiness is a square root function of the light level. An increase of light by a factor of 4 yields a reduction of noise by a factor of 2.
- The cathode sensitivity. Not every incoming photon is transferred into an electron; the quantum efficiency of photocathodes is in the range of 10% - 30%. A photon which is not transferred into an electron does not contribute to the image, thus increases the noisiness above its theoretical minimum value.
  The MCP adds to the noisiness of the image by trapping photoelectrons. These trapped electrons will not be amplified. Especially the MCP film in 3rd GEN tubes, needed to protect the GaAs photocathode, is a photoelectron killer. More then 50% of the emitted electrons get trapped by the MCP film. A photoelectron formed at the cathode, but lost at the film, could as well not be formed. This process is a substantial reduction of the **effective** cathode sensitivity.

The best figure to describe the noisiness of the picture at low light levels is the signal to noise ratio (S/N). The test to assess this parameter uses a light level of 10^{-4}lux over an illuminated area of ∅ 0.2mm. Because of the limited light available, the output brightness will not be constant but will fluctuate with time. The average brightness divided by the sigma of the fluctuation is called the S/N.

At illuminations levels different to the test level of 10^{-4}lux, the S/N can be calculated by using the square root law described above.

Gain and EBI

A higher gain of the tube will not make the picture less noisy, it will only increase the intensity of the noise. Above a certain level, comfortable to the eye, increase of gain will not help to improve performance.
The Equivalent Background Illumination (EBI) is the thermal emission of the cathode. Because it is expressed in terms of illumination it can directly be compared to the cathode illumination by the scenery. At extremely low illumination levels the EBI adds a haze to the image.

Spectral behaviour

The S/N ratio (and cathode sensitivity) is measured with a tungsten source, having a defined spectral distribution, the so-called 2850K source. The spectral distribution of this source is chosen to be similar to the infra-red distribution of star light. The spectral distribution of a real scenery depends not only on the illumination circumstances (infra red starlight or blue/green moonlight) but also on the reflectivity of the scenery. Forest reflect more (infra)red light and coastal areas and deserts have a more blue/green character. To predict the performance of an I^2 tube, the **spectral** S/N is a useful piece of information. This graph indicates how the signal to noise ratio would be if the 2850K source would be replaced by a source with the indicated wavelength.

High light level performance

Limiting Resolution

From a certain light level on the image quality will no longer depend on the S/N ratio of the tube and the illumination level. The imaging quality of the tube has taken over. The most common parameter to describe high light level performance is the limiting resolution. This is the maximum line density on a USAF target which can be resolved by a human observer, using a 10x eye piece. This performance indicator has a number of drawbacks:

- it is subjective (there are optimistic and pessimistic observers)
- steps in the USAF target are large (the phantoms are separated by 13%, yielding steps of 8lp/mm in the region of 60lp/mm)
- the optics of the projection and observation system plays an important role
- different criteria are used (some want to see clearly distinguished lines, others want only to recognise the direction of the lines)
- not only the limiting resolution, but also the contrast for larger structures plays an important role for the field performance.

Taking the named factors into account the 'world-wide' systematic error of the measurement is more than 10lp/mm.

Contrast and MTF

A more objective performance indicator is given by the modulation transfer function (MTF). To discuss this, first the term contrast has to be introduced. By definition the contrast is:

C = (max. brightness – min. brightness) / (max. brightness + min. brightness)

Look at the example in figure 3. Both plots show the brightness as a function of position. The solid line shows a fluctuation from dark to bright, while the dotted line is modulated from dark grey to light grey. The associated contrasts are:

C_{solid} = (100 – 0) / (100 + 0) = 100% and C_{dotted} = (60 – 40) / (60 + 40) = 20%

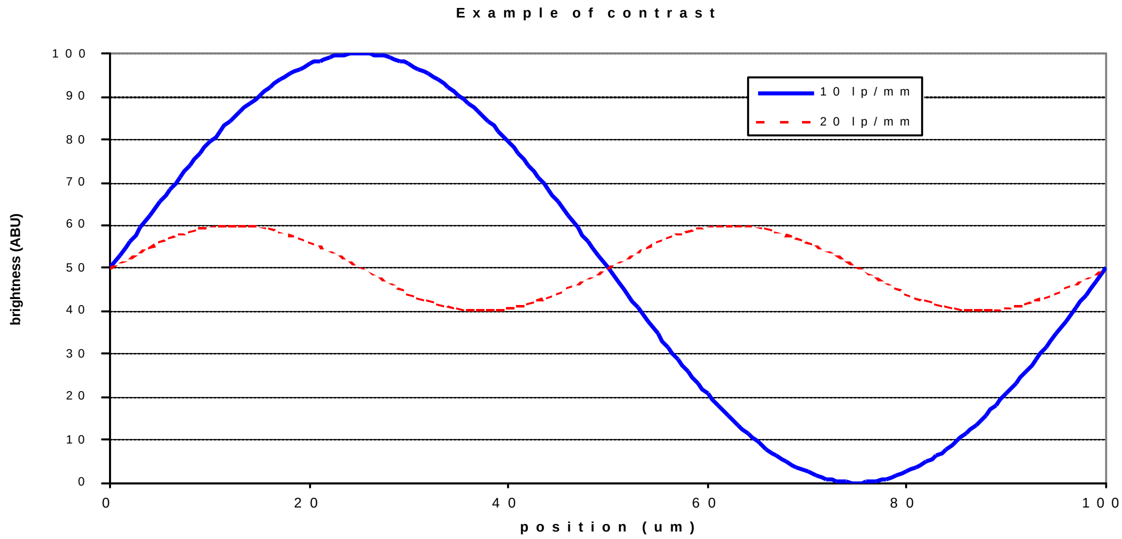

Figure 3. Example of contrast.

The modulation transfer function of an imaging system gives the contrast of the output when a 100% modulation at the input is applied. This output contrast is given as a function of spatial frequency (lp/mm).

The MTF at low line pairs gives the contrast for large objects, the MTF at high line pairs the contrast for small objects. The limiting resolution is closely related to the contrast at high line pairs. Usually it coincidences with a contrast of 5% - 10%, dependent on the way of measurement.
A good contrast at low line pairs (= 2.5lp/mm) gives a 'clear' image. A low MTF value gives a 'hazy' impression. In this case a lot of observers will have the impression of an un-sharp image. Despite the bad contrast at low line pairs, the limiting resolution can be high.
These differences are shown in the image processed photographs of Venice on the following page.

The MTF function for the left top of the image is relatively high at low line pairs but drops quickly above 30lp/mm. As a consequence the (10 times magnified) 60lp/mm resolution target is not visible. The MTF of the right bottom part of the image drops quickly at low line pairs (giving the hazy impression) but stays at an acceptable level for up to 60lp/mm. The (again magnified) 60lp/mm target is still clearly visible.

Most observers will prefer the top-left image with the lower limiting resolution !

Some care must be taken by comparing the MTF figures from different types of instruments. US measurements tend to give higher values for the same tubes than ODETA based European Measurements. It is always preferable to compare different tubes on the same instrument.

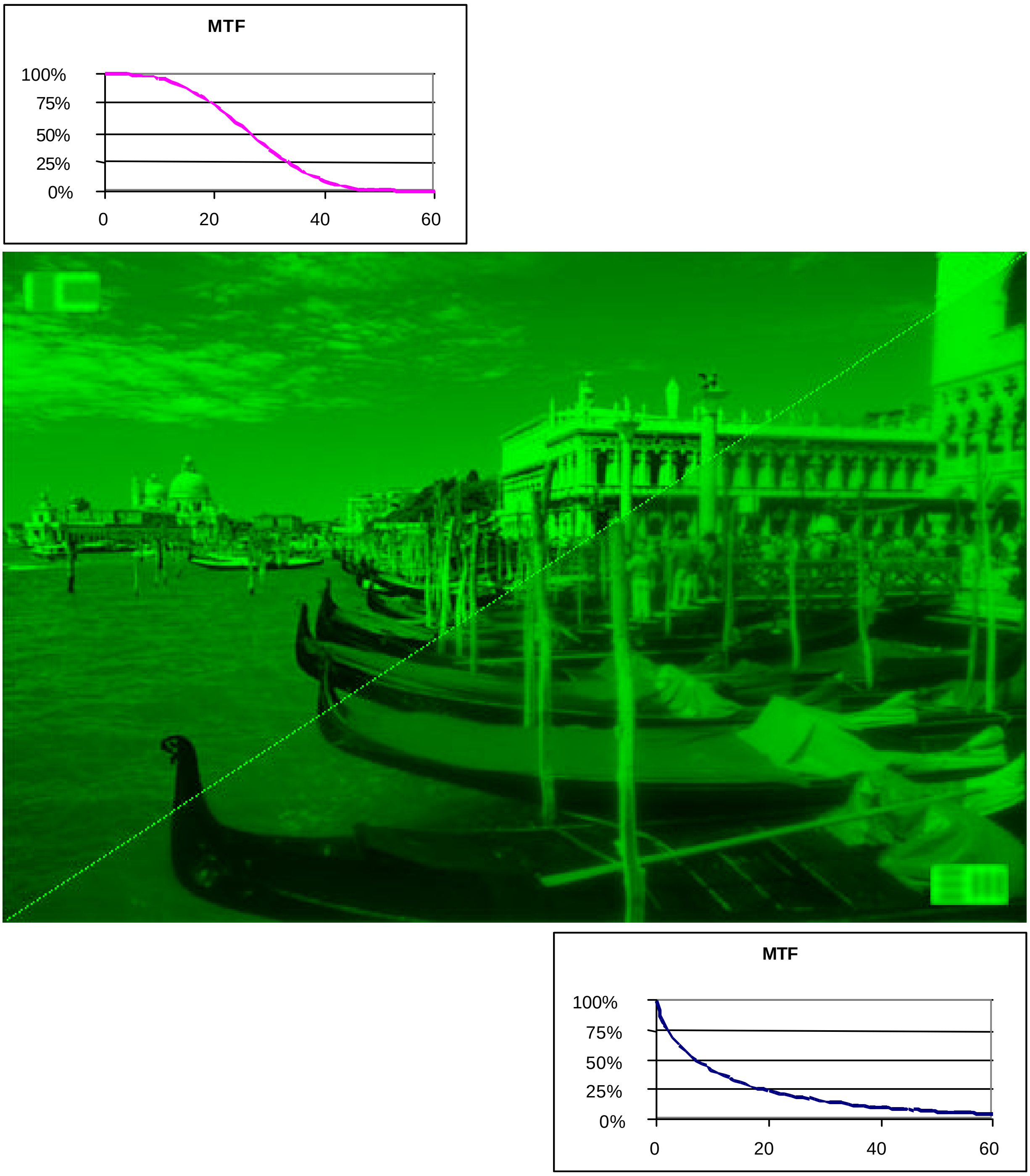

Figure 4. The image shows the consequence of MTF.

MOB

At high light levels the intensity of the screen will be determined by the setting of the 'maximum output brightness' (MOB). This value is usually set between $5cd/m^2$ and $15cd/m^2$. In this regime the gain is dependent on the light level and will be below the pre-set value of the low light level gain. The signal to noise ratio (and indirectly the cathode sensitivity) and EBI play no role in this high light level regime.

XD-4™ versus Omnibus IV

This last paragraph of this paper compares performance of DEP XD-4™ tubes with the performance of Gen III Omnibus IV tubes.

Low light regime
As mentioned in the paragraph about low light level performance, the best indicator for field performance in this regime is the signal to noise (S/N) ratio. The Omnibus IV requirement is 21, similar to the XD-4™ minimum specification. Also the typical values are 24 for both cases. EBI and gain of XD-4™ and Omnibus IV have comparable values

Figure 5 shows the spectral signal to noise ratio. The graph shows a slight advantage for the GEN III cathodes (dotted line) in the infra-red region and a clear advantage for XD-4™ (solid line) in the green/blue region.

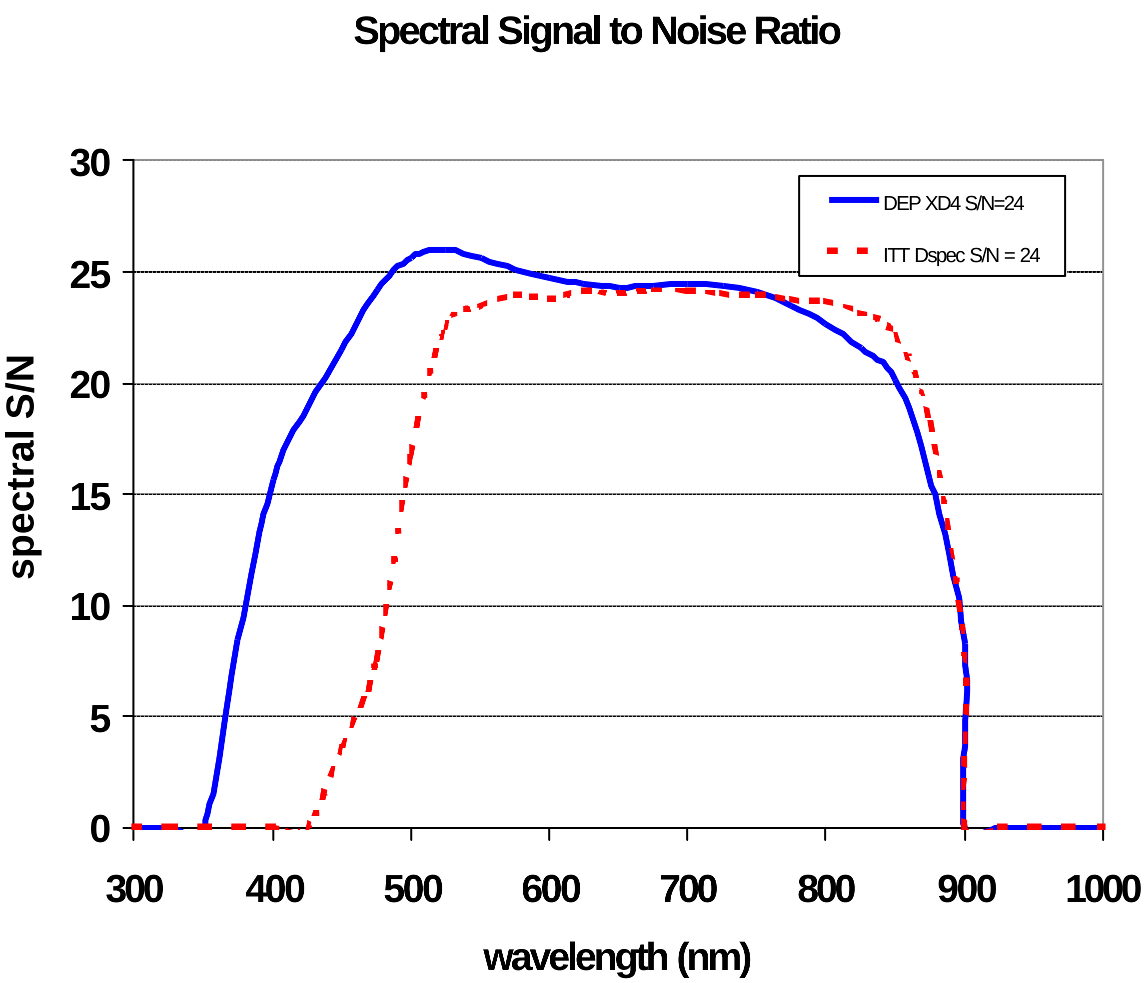

Figure 5. **The spectral signal to noise curve for XD-4™ and GEN III, Omnibus IV.**

The high light regime
The limiting resolution of XD-4™ (minimum 60lp/mm) and Omnibus-4 (minimum 64lp/mm) is comparable. When measured with similar test set-ups there is an advantage for the XD-4™ tubes. This is confirmed by the MTF graphs, measured with the same device, shown in figure 6.

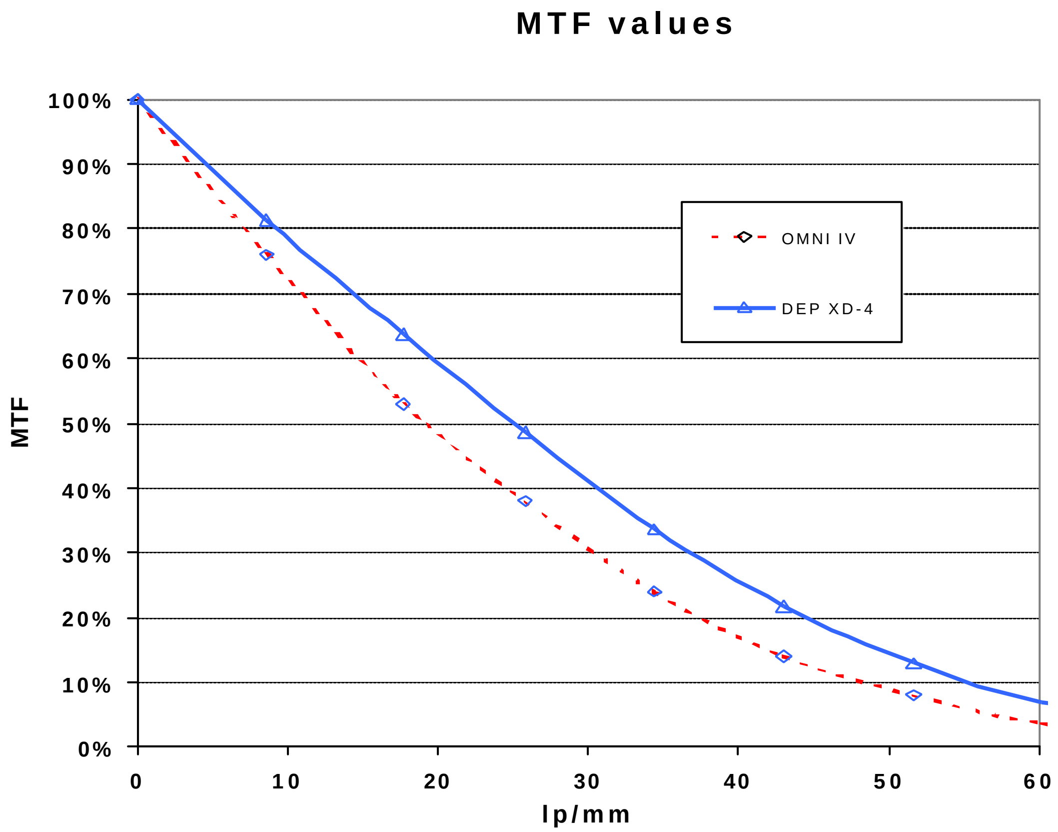

Figure 6. The MTF of Omnibus IV and DEP XD-4™.

Miscellaneous

Apart from the factors determining the image quality, there are a number of factors in advantage of DEP's XD-4™ technology. Namely:

- Robustness: XD-4™ will survive a shock of 500g, while the Omnibus-4 tubes are limited to 75g.
- Halo's: the halo's of XD-4™ are not only smaller but also less intense.
- Battery life.
- Burn-in and behaviour at over-illumination

Summary

This paper shows that for the assessment of an Image Intensifier tube it is essential to differentiate between low light level regime and the high light level regime. In the low light level regime the best performance indicator is the signal to noise ratio. A good cathodes sensitivity is just a way to achieve a good S/N value and has no benefit of it's own.
In high light level regimes the limiting resolution is a useful parameter, but the MTF is more objective and is a more valuable tool to predict image quality.

Comparing Gen III Omnibus IV tubes against DEP's XD-4™ there is a clear balance in performance and in addition a substantial better MTF for the XD-4™. This is confirmed by field tests of the tubes. Besides performance do come advantages for the XD-4™ in terms of robustness, smaller and less intense halo's, lower battery consumption, and better protection against over-illumination.