AEROSPACE RECOMMENDED PRACTICE

ARP4168™ **REV. B**

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Superseding ARP4168A

Night Vision Goggle (NVG) Compatible Light Sources

RATIONALE

This document shows recommended industry practices, requirements and design recommendations for Night Vision Goggle (NVG) compatible light sources within the crew station. The most recent revision to this document was to update the reference documents, add more technical details and expand design recommendations for LEDs. The recommendations contained within this document apply to both military and civilian aircraft.

ARP4168B has been reaffirmed to comply with the SAE Five-Year Review policy.

1. SCOPE

This ARP covers three common light sources, incandescent, electroluminescent and light emitting diode that, when NVG filtered, can be used to illuminate NVG compatible aerospace crew stations. It is recognized that many other different light sources can also be used for this purpose. Also see 2.1.1 for other SAE documents that cover particular applications within the crew station environment.

This ARP sets forth recommendations for the design of NVG compatible lighting, utilizing these light sources, that will meet the requirements of MIL-L-85762 Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible. This also includes the replacement document MIL-STD-3009: Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible.

Although this ARP concentrates on lamp light sources for illumination, the information contained within this ARP may be directly applied to incandescent, electroluminescent and light emitting diode information display devices. Regardless of the light source, the focus of this document is the understanding that the radiometric energy that can be amplified by the Night Vision Goggles (NVG's) must be filtered to such an extent that it will not impact the operational use of the NVG's while still allowing sufficient visible (photometric) energy to be viewed by the pilot.

1.1 Purpose

This SAE Aerospace Recommended Practice recommends certain basic considerations which the design engineer should observe when designing NVG compatible lighting. Key design issues include the right type of light source to use, how to match the filter to the light source and what trade offs need to be made in optimizing the design. Each of the various light sources have different spectral distributions from the 380-980NM wavelengths and therefore the filter selection must take that into consideration. For example, most LED light sources are very saturated (with the exception of white LEDs) and require little filtering in the near Infra-Red (IR) wavelengths to allow NVIS compatibility. However, incandescent light sources have the majority of their radiometric energy within the near IR wavelengths (780-930NM) and therefore require significant filtering that will in most situations also impact chromaticity and photometric outputs.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the

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For more information on this standard, visit
https://www.sae.org/standards/content/ARP4168B/

event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP881 Lamps for Aircraft Lighting

ARP1048 Instrument and Cockpit Illumination for General Aviation Aircraft

ARP4169 Night Vision Goggle (NVG) Filters

ARP4822 Night Vision Imaging System (NVIS) Compatible Illuminated Pushbutton Switches and Indicators

ARP4967 Night Vision Imaging Systems (NVIS) Integrally Illuminated Information Panels

AS5452 Night Vision Goggles (NVG) Compatible Lighting for Civil Aircraft

2.1.2 U.S. Military Specifications and Standards

Copies of these documents are available at http://quicksearch.dla.mil.

MIL-DTL-6363 Lamps, Incandescent, Aircraft Service General Specifications for

MIL-DTL-7788 Panels, Information, Integrally Illuminated

MIL-HDBK-310 Global Climatic Data for Developing Military Products.

MIL-L-85762 Lighting, Aircraft, Interior, Night Vision Imaging System (NVIS) Compatible

MIL-PRF-19500/708 Displays, Diode, Light Emitting, Solid State, Red, Numeric and Hexadecimal, with on Board Decoder/Driver Types 4N51, 4N52, 4N53, 4N54 Jan and Jantx

MIL-STD-750 Test Method Standard For Semiconductor Devices

MIL-STD-810 Environmental Engineering Considerations and Laboratory Tests

MIL-STD-3009 Lighting, Aircraft, Night Vision Imaging System (NVIS) Compatible

2.2 Definition

Night vision goggle compatible lighting is the condition in which the spectral wavelengths, luminance level and uniformity of the cockpit lighting do not interfere with the operation of night vision goggles while still maintaining the same (or nearly the same) level of photometric output as the previously non-NVIS compatible light source. This is done with a complimentary set of cut-off filters with one set on the NVG's only allowing radiant energy from 625nm or 665nm (depending on the Class version of the NVG) and above to enter the intensifier tubes. The complimentary filters over the visible light sources within the crew station are then added to greatly reduce the radiant energy in the far red chromaticity and near Infra-red region to the extent that it is far less than the possible radiometric energy within that wavelength coming from outside the crew station. This allows the goggles to only amplify the radiant energy originating outside the crew station area while allowing the operator to view the crew station under the goggles with the unaided eye. Class C (or Leaky Green) filtered NVG's also allow a small amount of radiant energy within the 540nm to 550nm bandwidth so care must be taken not to use LED's that have their peaks within this energy band or this will be detectable by this Class version of NVG's).

3. RECOMMENDATIONS

When designing for NVG compatible lighting, the designer must consider that all light sources require varying degrees of optical filtration to restrict emissions above 600 nm. The degree of restriction is dependent upon the color and NVIS Radiance (NR) as defined in MIL-L-85762A (or MIL-STD-3009). This is necessary since night vision goggles are most sensitive to long wavelength emission. Without the proper filtration, the light source will degrade or shut down the operation of a night vision goggle.

NVG filtered lighting must be dimmable to levels as low as 0.1 fL in order to allow use without NVG's since that is the typical luminance level that pilots have set their cockpit lighting when fully dark adapted. If a combination of NVG light sources is utilized in a single piece of equipment, it is desirable to have one control that will dim all the light sources simultaneously. When using a common dimming circuit, considerations should be given to the luminance tracking characteristics of the different light sources. The possible requirement for sunlight readability should also be considered when selecting the light sources.

When modifying a crew station for NVG operation, it is very important that the existing brightness levels, dimming setting and color match as closely to the legacy system to ease the transition to goggle and non-goggle operation. The only exception to the color requirement would be to allow green chromaticity to replace Aviation White for panel lighting. This exception is to reduce the overall amount of radiant energy within the crew station to improve NVG performance. Another slight change in chromaticity from the Aviation color to the NVIS color is for red. Since the spectral distribution of Aviation Red is within the wavelength area that is normally amplified by the NVG's, the NVIS Red color requirements is shifted to be more Orange in color. Recently, the use of red LED's have allowed a closer match to Aviation Red due to the saturated nature of LED's as compared to incandescent lamps.

3.1 Incandescent Lamps

3.1.1 Lamp Types

Some typical military specifications for incandescent lamps that are used in aerospace vehicle panels are listed in Table 1. The size and type of lamp should be selected to meet the specific requirements of the application. Military specified lamps should be used whenever possible. Additional tighter tolerance of brightness ranges should also be considered (i.e., 15% brightness range versus 25%). These tighter tolerance lamps will cost more, but will ensure that your brightness levels are being met with the more difficult NVIS filter application. Please refer to MIL-DTL-6363 since the lamp part numbers contained in Table I are obsolete but are still referred to due to their common use on existing aircraft. However, in some instances it may be necessary to deviate from MIL specifications in order to meet special lighting and packaging requirements.

Table 1 - Military specifications for Incandescent Lamps

Military Specification	Lamp Type
MS 90452	T-3/4, 5.0 Volt, Wire Terminals
MS 24367	T-1, 5.0 Volt, Wire Terminals
MS 90451	T-1, Short Length, 5.0 Volt, Wire Terminals
MS 24515	T-1, 5.0 Volt, Based
MS 3338	T-1, 28.0 Volt, Based
MS 25237	T-1 3/4, 2.5 to 28.0 Volt, Based
MS 25238	G-5, 28.0 Volts, Based
MS 15570	G-6, 6.0 to 28.0 Volts, Based
MS 25478	S-8, 6.0 to 28 Volts, Based
MS 25235	S-11, 28.0 Volts, Based

3.1.2 Design Considerations

3.1.2.1 Light Output

Incandescent lamps emit light by the resistance heating of a tungsten wire filament to incandescent temperatures above 1200 °K inside a vacuum or inert gas filled envelope. They are broadband emitters that follow the typical blackbody radiation curves. Most subminiature lamps operate in the 1600 to 2400 °K filament color temperature range as shown in Figure 1. Less than 8% of the energy emitted is within the visible spectrum from blue to red. The remaining energy is in the infrared where NVIS systems are most sensitive. When properly filtered, incandescent light sources will meet the NR and color requirements of MIL-L-85762A or MIL-STD-3009.

Incandescent lamps range from 0.001 mean spherical candelas (MSCD) to 1.0+ MSCD in the subminiature sizes. A NVG filter will reduce the available light and should shift the observed spectral distribution from white to the desired NVG color. Thus, incandescent lamps must be selected to provide sufficient illumination through the NVG filter. In general, the number of lamps required for a NVIS version of a panel and/or instrument will be greater due to the lower transmission levels of NVIS filters versus Aviation color filters.

3.1.2.2 Size of Lamp

The physical size of the lamp must fit within the available space. Miniature and subminiature incandescent lamps are available in a wide range of sizes from less than 0.030 inches to more than 1.5 inches in diameter. The selected lamp should be configured with the proper base design to meet maintenance requirements.

3.1.2.3 Power Dissipation

The designer needs to select an incandescent lamp that is compatible with available power. Either AC or DC power may be used. Typical incandescent lamps in aerospace applications use 5.0 or 28 V, 0.02 to 1.0 A. Please consider the additional power loads with an increase in the number of lamps with NVIS compatible crew stations. This may require changes in the current load of the step down transformers used to supply power to the lamps.

3.1.2.4 Thermal Considerations

Ambient temperatures of -55 to +100 °C will normally not affect the life or operation of standard incandescent lamps. It is recommended that the designer allow for sufficient heat dissipation, where applicable, in order to maintain the proper lamp surface temperature.

3.1.2.5 Dimming

Incandescent lamps are voltage operated devices. The light output is dimmed by reducing the applied voltage. The dimmed light output varies exponentially, as determined by Equation 1.

$$\begin{matrix}Dimmed\ Light\\ Light\ Output\\ (MSCD)\end{matrix} = \left(\frac{Rated\ Light\ Output}{Light\ Output\ (MSCD)}\right)\times\left(\frac{Dimmed\ Voltage}{Rated\ Voltage}\right)^{3.5} \quad \text{(Eq. 1)}$$

As an incandescent lamp is dimmed, a spectral shift occurs towards longer wavelengths. This is due to the shift in color temperature when lamps receive lower voltage levels thereby changing the spectral distribution of the lamp output. This spectral shift causes a color shift towards red, a change in the spectral relationship with respect to the filter's transmission characteristic and will affect the NR value. These effects must be factored into the overall lighting system design to assure that the spectrum (color) of the NVG filtered incandescent lamp is within the desired NVIS color range at the dimmed brightness level specified in MIL-L-85762A or MIL-STD-3009. This is critical when measuring for chromaticity compliance since they are taken in the dim level luminance levels. The filter selection must take this spectrum shift of the lamp into account so it will still be in compliance with the selected color requirement at this lower brightness value.

3.2 Electroluminescent (EL) Lamps

3.2.1 Lamp Types

AC thick-film electroluminescent lamps use phosphors to convert electrical energy into light energy. Only a small amount of infrared energy is emitted by an EL lamp. AC thick-film EL lamps are available in a wide array of colors with the most common being green for panel illumination applications. When NVG filtered, it may be used for NVG compatible lighting.

3.2.2 Design Considerations

3.2.2.1 Light Output

The spectral distribution of a blue-green AC EL lamp is presented in Figure 2 (the most common application for crew station). The light output for a blue-green EL is typically 20 fL at 115 V AC, 400 Hz. The light output will be reduced by an NVG filter and the designer needs to take this into account. The light output of an EL lamp degrades exponentially with operating life.

3.2.2.2 Size of Lamps

EL lamps are flat, thin (0.015 to 0.040 inch) capacitive devices. EL lamps are available in any size from 0.1 inch x 0.1 inch to 12 inch x 12 inch, or larger, if necessary. Each lamp design may be custom configured in shape, with cutouts and other features to meet the needs of a specific application.

3.2.2.3 Power Dissipation

AC EL lamps are typically driven from 0 to 115 V AC, 400 Hz. The drive current required is typically 2 mA/in^2 of illuminated area at full rated voltage. With a 70 or 80° leading phase angle, power dissipated is typically 40 to 80 mW/in^2. The power dissipated in an EL lamp is equal to the voltage applied to the lamp x current x cosine of the phase angle, Equation 2.

$$P(EL\ Lamp) = V \times I \times \cos\theta \quad \text{(Eq. 2)}$$

3.2.2.4 Thermal Considerations

Because no heating of the phosphor is required for luminescence, a low amount of heat is generated by an EL lamp. Long term, extended use at elevated temperatures (greater than 55 °C) is not recommended as operating life is reduced. During operation at elevated temperatures, light output degradation is accelerated. Light output degradation does return to normal when the ambient temperature falls below 55 °C.

3.2.2.5 Dimming

EL lamps should be considered to be voltage operated devices. Dimming is accomplished by reducing the applied voltage. Light output varies as shown in Figure 3. There is no shift in spectral distribution with voltage dimming. Since there is a small spectral shift with frequency variation, large frequency variations should be avoided.

3.3 Light Emitting Diode (LED) Lamps

3.3.1 Lamp Types

LED lamps are solid state devices in two basic configurations, individual lamps and light bars, and are available in military and plastic packages. With the correct NVG filters, LED lamps meet the NVG compatibility requirements of MIL-L-85762A or MIL-STD-3009. Typical LED colors are given in Table 2. White LEDs may have a dominant wavelength using some calculation methods, but generally their color is described using a correlated color temperature (CCT). They start at a color temperature of 2000K for LEDs that simulate "Incandescent" lamps or a "warm" white to 8000K for a "cool" white color. The spectral content of the red and blue determines if an white LED will be cool or warm with those having a higher red content having a lower CCT thereby being "warm" to those white LED's with a higher blue spectral content and having a "cool" or higher CCT.

Table 2 - Typical colors of LED devices used with night vision goggles

LED Color	Dominant Wavelength (λ_d)	Saturated Color
Blue	430 - 500 nm	blue
True Green	520 - 535 nm	green
Green	545 - 570 nm	yellowish-green
Yellow	585 - 595 nm	orange-yellow
Red-Orange	605 - 615 nm	red-orange
Red	625 - 660 nm	red

3.3.2 Design Considerations

3.3.2.1 Light Output

Colored LED devices are narrow band emitters that generate light by electron-hole recombination across a semiconductor p-n junction. The radiated spectra for various color LEDs are shown in Figure 4. The light output of an LED lamp is specified as luminous intensity, flux per unit solid angle. The unit used is the candela (cd), lumens per steradian. Some LED devices have sufficient light output to be readable in daylight conditions, when filtered by the correct night vision goggle/daylight viewing (NVG/DV) filter. Based on the design requirement for panels or status lights, it may be practical to use white LEDs in lieu of green LEDs to achieve the right color selection within the crew station. Typically, NVIS Green A is the required chromaticity selection and achieving this color using green LEDs can be difficult. Using white LEDs and filtering them to the NVIS Green A color has been found to be more practical. An alternate to using white LEDs for meeting this requirement is the use of other non-saturated green LEDs (lime-yellow or lime-green) that are not impacted by the transmission loss like pure green LEDs. If using phosphor converted white LEDs, you must consider the spectral distribution which is typical for this color design since most filters are still designed around a typical incandescent spectral distribution (see Figure 1). For example, a white LED will have a peak of spectral energy in the "blue" wavelength around 450nm and then a broader emission from the yellow phosphor peaking around the 550nm range (see Figure 6 for a cool White with a 5500°K color temperature. The blue and red lines defines the detection range of the human eye). This type of LED may be a good application for NVIS Green filters, but with the lack of radiometric energy in the longer wavelength would make them a poor candidate for NVIS Red filters.

3.3.2.2 Size of Lamp

Military grade LED lamps use a T0-46 hermetic package. NVG military grade LED panel mount lamps are available with an NVG filter incorporated as an integral part of the panel mount sleeve.

Plastic encapsulated LED lamps are available in T-1 3/4, T-1 and subminiature packages. Plastic light bars, typically used as anunciators, come in illuminated area sizes ranging from 0.10 inch x 0.20 inch to 0.4 inch x 0.80 inch.

3.3.2.3 Power Dissipation

LED lamps are current operated devices, and a current limiting resistor is required (see Figure 5). The value of the current limiting resistor may be determined from Equation 3. Maximum DC drive currents range between 30 and 50 mA, with a typical forward voltage drop of 2.2 V for red and amber colors while Green, Blue and White LED's are around 3V. LED lamps may also be pulse driven (strobed) with typical power dissipations in the range of 0.090 to 0.140 mW.

$$R(Limiter) = \frac{V_{CC} - \left(V_{SAT} + V_F(LED)\right)}{I_F(LED)} \quad \text{(Eq. 3)}$$

R = Resistance

V_{CC} = Source Voltage

V_{SAT} = Voltage through Driver Transistor

V_F = Forward Voltage Drop of LED

I_F = Current through LED

3.3.2.4 Thermal Considerations

The light output and operating life of LED lamps are functions of the LED junction temperature. As the LED junction temperature is increased due to a high thermal resistance, the light output and operating life decrease accordingly. LED light output decreases approximately 1.5% per 1 °C increase in junction temperature. Also, mean time between failure (MTBF) decreases by a factor of 2 for each 20 °C increase in junction temperature. Therefore, it is desirable to design the LED mounting configuration with as low a thermal resistance to ambient as possible to keep the LED junction temperature as low as possible. This will help to assure sufficient light output and expected operating life performance.

The ambient operating temperature range is dependent upon the type of LED lamp (see Table 3). Any LED lamp may be operated at its specified operating temperature limit without significant undue degradation, but will degrade more at higher temperatures. Design consideration should take into account the degradation of LED's at higher temperatures.

Table 3 - Typical operating temperature ranges for LED devices

Type of LED Lamp	Operating Temperature Range
Military Grade Lamps	-55 to +72 °C
Plastic Lamps	-40 to +72 °C
Plastic Light Bars	-40 to +72 °C

3.3.2.5 Dimming

Dimming of a DC driven LED lamp is accomplished by reducing the forward drive current. Dimming of a strobed LED lamp at a fixed refresh rate is accomplished by pulse width modulation (PWM) of the on time pulse. When PWM is used, the light output of an LED varies directly with the proportioned on time pulse; that is, 50% on time appears as 50% brightness, 10% on time appears as 10% brightness.

4. RELIABILITY TESTING

4.1 Incandescent Lamps

Incandescent lamps are generally tested per MIL-HDBK-310 and MIL-STD-810. Lower voltage lamps are typically selected for their resistance to mechanical shock and vibration.

4.2 Electroluminescent Lamps

Electroluminescent lamps are typically tested to the requirements specified in a source control drawing. The critical part of the construction of an EL lamp is the moisture seal.

4.3 Light Emitting Diodes

LED lamps are tested per MIL-D-87157, test procedures per MIL-STD-750. The detail drawing for a specific LED lamp specifies which tests are relevant. Military grade hermetic LED lamps are tested per MIL-PRF-19500, test procedures per MIL-STD-750. A source control drawing may also be used to specify reliability screening requirements for an LED lamp.

5. PHOTOMETRIC CONSIDERATIONS

Care must be taken in making light output and color measurements of NVG filtered light sources. The measurement method, equipment used and set-up, electrical operating conditions, ambient lighting, temperature and other pertinent parameters must be defined and recorded to assure accuracy and repeatability.

5.1 Light Output Measurement

Light output should be measured using a calibrated photometer or spectroradiometer. The measurements are typically luminous sterance in either footlamberts (fL) or candelas per square meter (cd/m^2). The area used in making a luminous sterance measurement must be precisely defined in order to assure accuracy and repeatability.

5.2 Color Measurement

Color measurements are typically done with a calibrated photometer or spectroradiometer. Incandescent and EL light sources are considered non-saturated light sources. Their colors are specified as u' and v' coordinates in the 1976 Uniform Color Space. The majority of LEDs are saturated color light sources and their colors can be specified in terms of dominant wavelength (λ_d) along with the CIE coordinates. However, with the expanded use of non-saturated LED's (like the expanded use of White LED's), the use of u' and v' coordinates should still apply for color measurements. Make sure that all color measurements are taken at the correct luminance level as defined in MIL-L-85762A for the appropriate chromaticity selection. This applies more to incandescent filtered light sources since EL and LED's do not shift in terms of chromaticity over different photopic levels.

PREPARED BY SAE SUBCOMMITTEE A-20A/C, CREW STATION & INTERIOR LIGHTING OF COMMITTEE A-20, AIRCRAFT LIGHTING

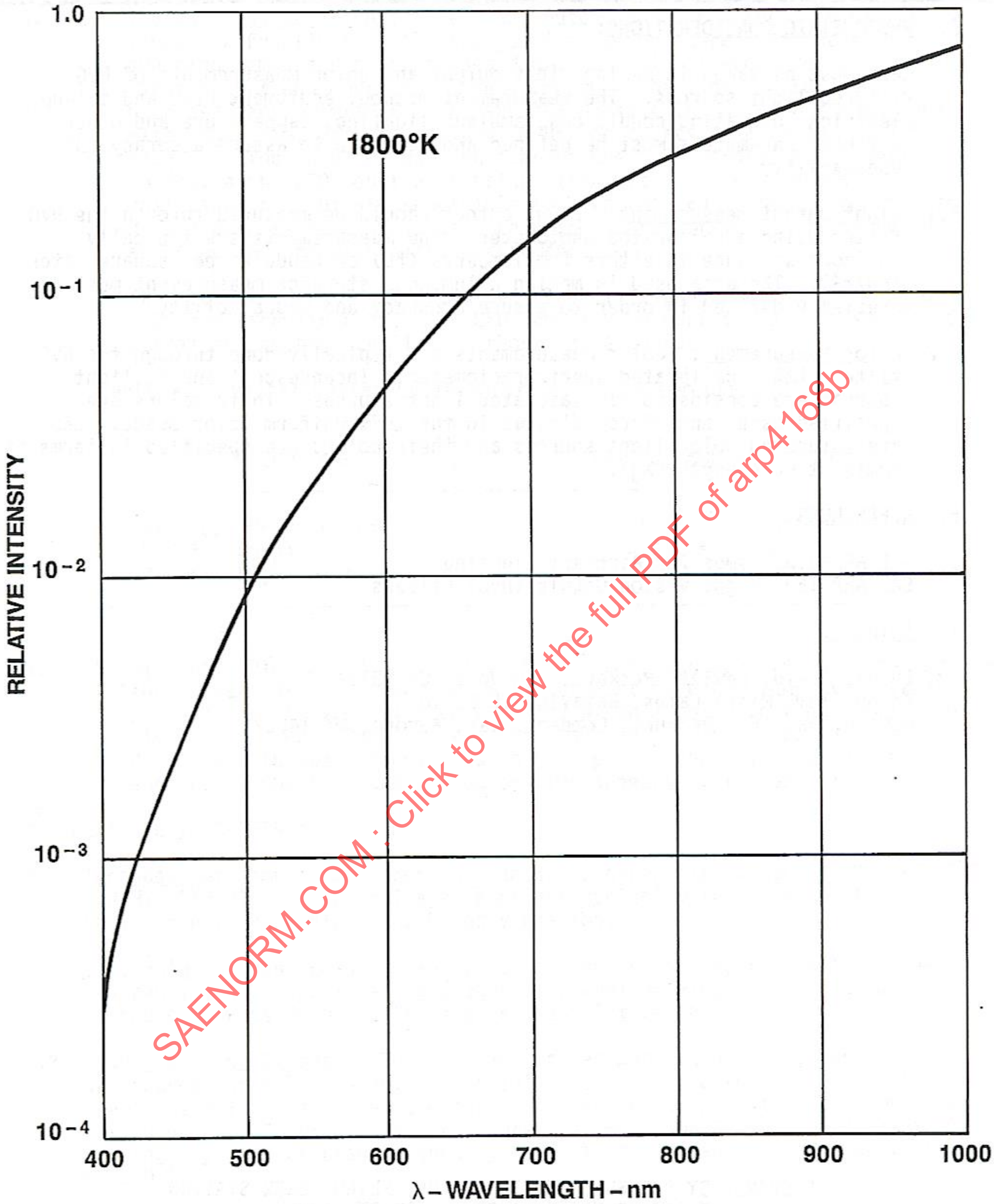

Figure 1 - Typical radiated spectrum of an incandescent lamp

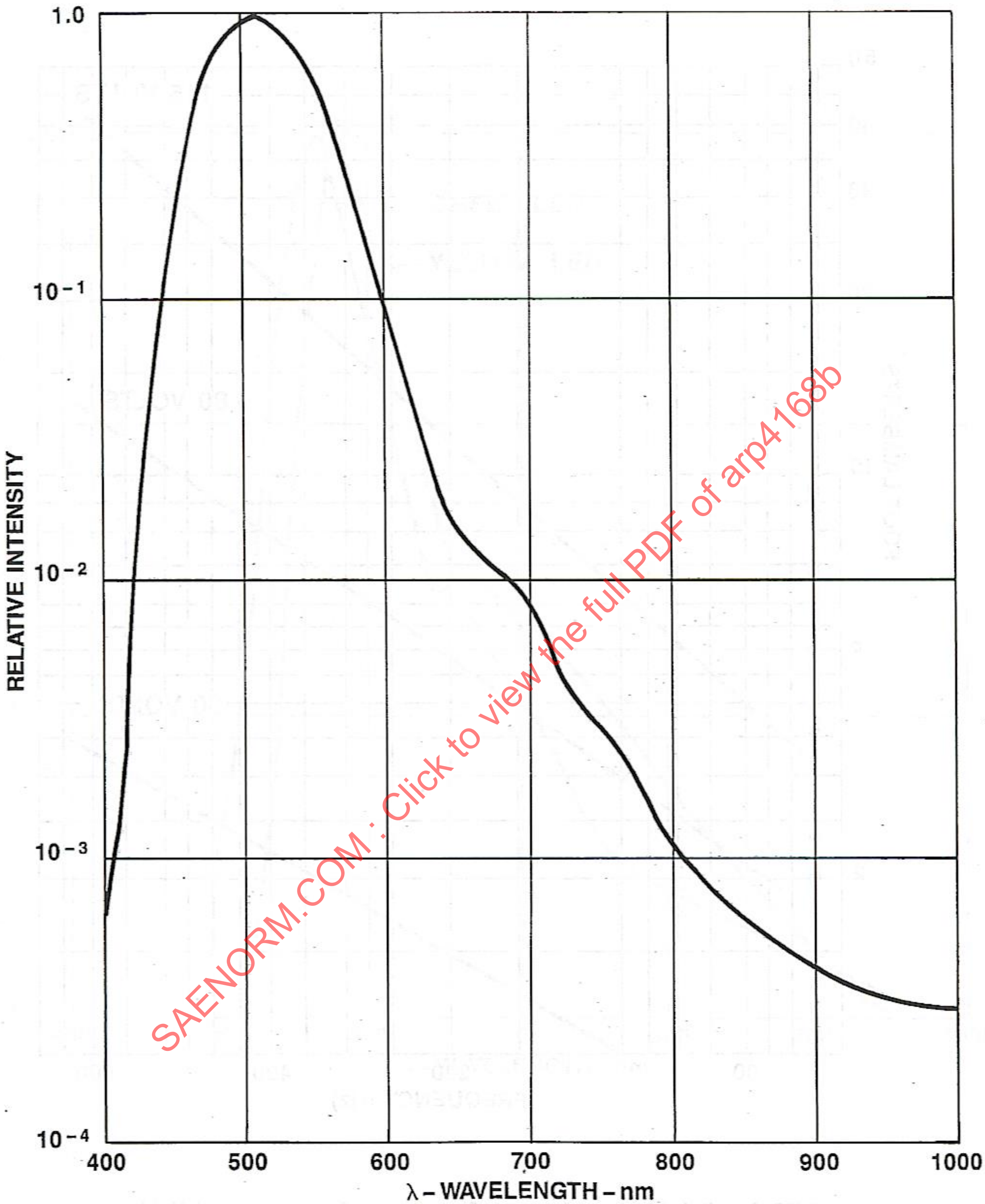

Figure 2 - Typical radiated spectrum of a blue-green AC EL lamp

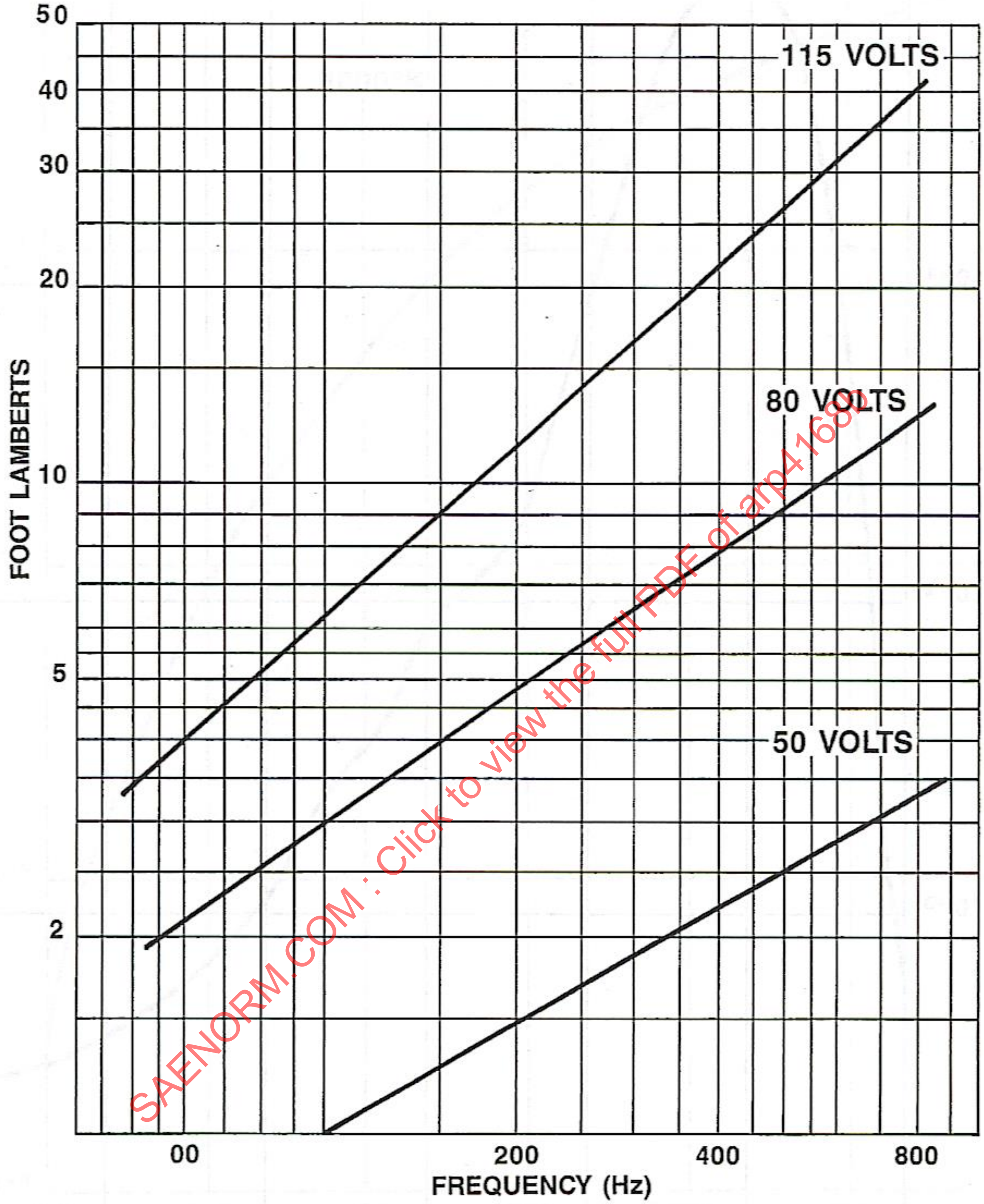

Figure 3 - Brightness of an AC EL lamp vs frequency and voltage