

SACCADOMETER

Eye surface irradiance - report

version 1

About the Document

Terms and methods applied in conducting the Saccadometer IR Irradiance examination (ORS – Report), are based on the NASA document, outlining the basic principles of radiometry, which underlies the proper use of NASA Optical Radiation Safety Calculator available at:

<< http://vision.arc.nasa.gov/personnel/jbm/home/vislab/exps/java/safe_txt.html >>

The Report presents two approaches to the estimation of IR – Irradiance of the critical EYE surfaces, (Corneal Irradiance and Retinal Irradiance), namely the calculation based on the known sensor geometry and the IR Source Data, as well as the direct measurement of the IR Irradiance of the surface, located at the same distance as the EYE cornea (10mm).

The Eye IR – Irradiance, describes the total IR power falling on a surface of the eye and is expressed in power units per unit area, in this case the milliwatts per centimetre squared.

Infra-Red Irradiance calculated values based on the IR Source Manufacturer Data

Saccadometer uses the GaAs Infra Red Emitters SFH420 in the SMT (Topped) Package manufactured by Osram Germany.

Relevant Parameters

1. Wave length at peak emission (If = 100mA, pulse duration 20ms), equals 950nm
2. Radiant Intensity (Ie) mW/sr in Axial Direction, at solid angle equal 0.01 sr, driving current 100mA and pulse duration 20ms is equal 2.5 mW/sr
3. Half angle ± 60 deg
4. Radiation characteristic for 0 deg = 1, 10 deg = 0.97, 20 deg= 0.95, 30 deg = 0.88

Irradiance Calculation

Radiant Intensity specified by the manufacturer, is related to the solid angle of one steradian (1sr). Solid Angle of 1 sr corresponds to the Cone Angle equal 32.8 deg (0.57 rad)¹. The attenuation of the source radiation across the cone angle of 33 deg can be approximated by the arithmetic average of the 10 deg step values given in p.4. Average Radiant Intensity inside the Cone Angle of 32.8 deg is equal

$$\frac{0.97+0.95+0.88}{3}=0.93$$

The minimum possible distance between the Saccadometer IR Source and the EYE surface (cornea) is equal 10mm. From the distance H = 10mm, the IR Source with Radiant Intensity (Ie) expressed in mW per 1 sr, which corresponds to the cone angle 32.8 deg., irradiates the circular area with the radius

$$R = H \times \tan(32.8 \text{ deg}) = 10 \times 0.649 = 6.5 \text{ mm}$$

1 Illumination Engineering, Joseph B. Murdoch, 1985 Macmillan Pub. Comp. (page 29)

The area of the irradiated surface

$$S = \Pi \times R^2 = \Pi \times 42.25 \text{ mm}^2 = \Pi \times 0,4225 \text{ cm}^2 = 1.33 \text{ cm}^2 \quad .$$

The average Radiant Intensity (I_a) across the 32.8 deg. cone is equal the value given in p.2 times (0.93)

$$I_a = I_e \times 0.93 = 2.5 \frac{\text{mW}}{\text{sr}} \times 0.93 = 2.3 \frac{\text{mW}}{\text{sr}} \quad .$$

According the manufacturer data given in p.2, the value of (I_a) was calculated for the IR Source driving current equal 100mA. The Radiant Intensity of the SFH420 IR Source depends linearly from the value of its driving current. The maximum possible driving current in the Saccadometer is equal 10mA and usually during the real use on patients, has lower values (refer to measurements). The maximum Radiant Intensity of the Saccadometer IR Source is equal:

$$\text{maximum } I_a = \frac{I_a}{10} = \frac{2.3}{10} = 0.23 \frac{\text{mW}}{\text{sr}} \quad .$$

The IRRADIANCE (I_r) equals the total IR power in (mW) falling on the given surface in (cm^2). The total power radiated from the single IR Source into the solid angle of 1 sr, falls on the surface being the bottom – base of the cone with the angle 32.8 deg. The area of the irradiated surface located 10mm apart from the IR Source is equal 1.33cm^2 , thus the

$$I_r = \frac{0.23 \text{ mW}}{1.33 \text{ cm}^2} = 0.173 \frac{\text{mW}}{\text{cm}^2} \quad .$$

In the Saccadometer, each EYE is illuminated by two, simultaneously active IR Sources, having the half angle equal ± 60 deg, ref p.3. The distance between the illuminators is equal 7mm, what results in the overlap of the areas irradiated by the single IR Sources. The maximum Irradiation (I_{rm}) takes place in the center between the two illuminators and equals

$$I_{rm} = 2 \times 0.173 = 0.35 \frac{\text{mW}}{\text{cm}^2} \quad .$$

The calculated maximum instantaneous Irradiance of the Corneal Surface is equal

$$0.35 \frac{\text{mW}}{\text{cm}^2} \quad .$$

Due to driving the IR Sources with the square wave current, with the 50% duty cycle, thus the average Irradiance (I_{ra}) of the Corneal Surface equals

$$I_{ra} = \frac{0.35}{2} = 0.173 \frac{mW}{cm^2} .$$

The Threshold Limit Value (TLV), according the NASA Standards, for the chronic IR Corneal Irradiance is equal

$$10 \frac{mW}{cm^2} .$$

The Calculated Safety Factor is

$$\frac{10}{0.35} = 28 .$$

The Retinal Irradiance

To calculate the Retinal Irradiance it is necessary to define two parameters, namely the total amount of IR power entering the EYE and the Area of the illuminated surface on the Retina.

The amount of IR can be calculated as the product of the Corneal Irradiance times the Effective Pupil Area (EPA). Not constricted pupil is assumed to have diameter 7 mm, thus the effective pupil area is equal

$$EPA = \Pi \times (0.35cm)^2 = \Pi \times 0.1225 cm^2 = 0.38 cm^2 .$$

The maximum value of the Corneal Irradiance (equal $0.35 mW / cm^2$), when multiplied by the EPA, gives the IR power entering the inside of the EYE

$$IR[mW] = 0.35 \frac{mW}{cm^2} \times 0.38 cm^2 = 0.13 mW .$$

The area illuminated on the retina is equal the size of the IR Source imaged on the retina. The image of the IR Source, subtends the same angle from the posterior nodal point (eye optical system), as the IR Source does from the anterior nodal point. In this case the diameter of the output lens of the IR Source, can be treated as the dimension (size) of the IR Source (SFH420), which is equal 2.5 mm. The IR Source is placed closer to the EYE optical system (anterior distance equals 7 mm), then the image projected on the retina (posterior distance

equals 18 mm). Thus the Source Image on the retina will be magnified by the ratio of posterior and anterior distances

$$\frac{18 \text{ mm}}{7 \text{ mm}} = 2.6 \quad .$$

The area of the of the illuminated retina, will be equal the area occupied by the IR Source image ($\pi \times 1.25 \text{ squared}$) $\times 2.6 = 0.13 \text{ cm}^2$

$$\Pi \times (1.25 \text{ mm})^2 \times 2.6 = \Pi \times (0.125 \text{ cm})^2 \times 2.6 = 0.13 \text{ cm}^2 \quad .$$

The Retinal Irradiance is equal the ratio of the total IR power entering the eye (0.35 mW) and the IR irradiated Area on the retina (0.13 cm^2), thus

$$I_r \left[\frac{\text{mW}}{\text{cm}^2} \right] = \frac{0.35 \text{ mW}}{0.13 \text{ cm}^2} = 2.7 \frac{\text{mW}}{\text{cm}^2} \quad .$$

The above calculations were carried assuming the worst case when the optical axis of the EYE coincide with the optical axis of the IR Sources, what is not true for the considered case. The optical axis when the EYE is looking forward, is off-set by 10 mm from the axis of the IR Sources. The half angle of the IR Sources is equal ± 60 deg, thus when turning the EYE toward the IR Sources, we can assume that only the fraction (estimated to be the half) of the calculated IR Power can enter the eye, what reduces also the value of the calculated Retinal Irradiance.

The Maximum Permissible Exposure (MPE) for the IR Retinal Irradiance is equal

$$100 \frac{\text{mW}}{\text{cm}^2} \quad (\text{Silney 1973}).$$

The actual calculated value in Saccadometer is equal $2.7 \text{ mW} / \text{cm}^2$.

$$2.7 \frac{\text{mW}}{\text{cm}^2} \quad .$$

The Safety Factor for the Retinal Irradiance, caused by the Saccadometer IR Sources is equal

$$\frac{100}{2.7} = 37 \quad .$$

Infra Red Irradiance MEASURED Values

Measurement instruments

The measuring setup was built using the following instruments:

- Si-Photodiode for the IR precision photometry Type S1337-66BR Hamamatsu, Japan, active area size 5.8 mm x 5.8 mm, Effective active area 0.33 cm², Photosensitivity S (mA/mW) for the GaAs LED 930 nm equals 0.6 mA/mW,
- Custom designed Current Mirror, converting the Photo Current into Voltage,
- Custom designed mini optical bench, allowing the precise XYZ positioning of the Photometry Device in relation to the EYE movement transducer assembly. The transducer was mounted at the 10 mm distance from the light sensitive surface of the Photometry Device, which is equal the minimum possible distance between the sensor and the EYE surface,
- Oscilloscope, Tektronix 2225 allowing to display and measure the output signal from the Photometry Device.
- Multimeter, Hewlett-Packard 3478A allowing to measure and trim the conversion ratio (gain) of the Photo Current into Voltage converter,
- Power Supply, TRIO PR-630,
- Standard Weston CELL, Type 1268, H.Tinsley, UK allowing to check the correctness of the Multimeter and Oscilloscope calibration (1.01859 Abs. Volts at 20 deg. Celsius).

Photometry Device

The Photometry Device is based on the reverse polarized Si – Photodiode, connected to the inverting input of the OP amplifier AD 429 (Analog Devices). The non-inverting amplifier input was connected to the virtual ground (half of the supply voltage buffered by the same amplifier type). The 1 kOhm feed-back resistor, connecting the inverting input with the amplifier output, provided the photocurrent conversion into the voltage, with the ratio equal 1 mA into 1 Volt. (the ONE miliVolt of the amplifier output voltage, corresponds to ONE microAmpere of the diode photocurrent).

The Saccadometer IR Sources are driven with the 50% duty cycle, thus the output voltage of the Photometry Device is the square wave, which amplitude relates directly proportional to the IR power falling on the photodiode surface.

The IR power P (mW) illuminating the photo sensor can be calculated based on the known Photodiode Sensitivity S (mA / mW) and the actual value of the photocurrent I (mA)

$$P[mW] = \frac{I[mA]}{S[\frac{mA}{mW}]} \cdot$$

Replacing the Photocurrent with the measured output voltage of the Photocurrent Mirror Circuit (1 V corresponds to 1 mA).

$$P[mW] = \frac{U[V]}{S[\frac{mA}{mW}]} ; \text{where } S = 0.6 \text{ mA (manufacturer data)} \cdot$$

$$P[mW] = \frac{U[V]}{0.6[\frac{mA}{mW}]} \cdot$$

The Irradiance (Ie) (mW/cm²) of the photo detector surface, can be calculated based on the known Effective photo-sensitive area of the photo detector A (cm²) and the measured value of the IR power

$$Ie[\frac{mW}{cm^2}] = \frac{P[mW]}{A[cm^2]} ; \text{where } A = 0.33 \text{ cm}^2 \text{ (manufacturer data)} \cdot$$

Thus the Irradiance of the Equivalent EYE Surface (the cornea), can be identified based on the measured voltage

$$Ie[\frac{mW}{cm^2}] = \frac{U[V]}{0.33} = 5 \times U[V] \cdot$$

Measured Amplitudes of the Square Wave Output Voltage

First, immediately after the Saccadometer Power ON, the square wave amplitude was equal 100 mV and after 2 seconds the amplitude falls down to 30 mV.

After the Power ON the Saccadometer control system switches on the higher current than it is required for running the measurement. It forces the thermal transient processes in the IR Illuminators and shortens the time of Saccadometer to become ready for measurements.

Due to its short duration (2 s) as compared with the duration of the whole test (10 minutes), its effect on the chronic IR corneal Irradiance is negligible.

Thus the value of the chronic Corneal IR Irradiance is equal

$$5 \times \frac{30}{1000} = \mathbf{0.15} \frac{mW}{cm^2} .$$

The above value is the maximum instantaneous irradiance amplitude. Due to the 50% duty cycle of the current driving the Saccadometers IR Sources, the average irradiance is only

$$0.075 \frac{mW}{cm^2} .$$

The Threshold Limit Value for the chronic IR Corneal Irradiance according the NASA Standards is

$$\mathbf{10} \frac{mW}{cm^2} .$$

Thus, the **Safety Factor** of the Saccadometer Corneal Irradiance equals

$$\frac{\mathbf{10}}{\mathbf{0.15}} = \mathbf{67} .$$

Comparison of the Calculated and Measured Corneal Irradiance Safety Factors

The **Measured** Safety Factor value – 28 – is 2.4 times higher than the **Calculated** Safety Factor – 67.

The Retinal Irradiance is calculated based on the Corneal Irradiance, thus the same ratio (2.4 times) can be expected for the Safety Factors of the retinal Irradiance.

The possible explanation for the higher Safety Factor, achieved by the Irradiance measurement can be, that the amplitude of the IR Source driving current, utilized for Irradiance calculation, was assumed to take the maximum value of the current adjustment range. The Saccadometer control system, automatically adjusts the Intensity of the eye IR Illumination, to get the constant values of eye surface irradiance and made it independent from the distance from which the IR Sources illuminate the eye surface.

Cross Check with the results of the NASA Optical Radiation Safety Calculator

Input data:

Detector Diameter: 6.54 mm

The Hamamatsu Si-Photodiode has the rectangular area 5.8 mm x 5.8 mm = 33.64 mm². The equivalent detector diameter is equal 6.54 mm

Wavelength of the IR Source: 950 nm

Width of the source image at the pupil: 7 mm

The entire eye cavity is directly illuminated by the IR Source. Half angle ±60 deg equivalent cone base, from the distance of 10mm has larger diameter as the natural pupil diameter (7mm)

Height of the source image at the pupil: 7 mm

The reason as above

Diameter of the viewed source image: 2.5 mm

It is the case of the free viewing of the IR Source.

Viewing distance of the source image: 10 mm

The reason as above.

Detector Power: 50 microWatts

$$P[mW] = \frac{U[V]}{0.6 \left[\frac{mA}{mW} \right]}, \text{ for } U = 30 mV, P = 0.05 mW$$

Results of NASA calculator

Effective Detector Area = 033593 cm²

Source Diameter is 0.25000 radians

Source Subtends 0.04908739 steradians

Corneal Irradiance is 0.149 mW/cm²

Retinal Irradiance is 0.000503 W/cm², (0.530 mW/cm²)

Retinal Radiance is 0.0030 W / cm² / sr, (3 mW/cm²/sr)

TLV for Retinal Thermal Injury is 11.2468 W/cm²/sr

Actual Value is 0.000959

PASS – Safety Factor is 11729.3857

TLV for Chronic IR Corneal Irradiance is 10 mW/cm²

Actual Value is 0.149 mW/cm²

PASS – Safety Factor is 67.19

TLV for Chronic IR Retinal Radiance is 2.4000 W/cm²/sr

Actual Value is 0.0030 W/cm²/sr

PASS – Safety Factor is 791.51020

MPE (Sloney 1973) for IR Retinal Irradiance is 100 mW/cm²

Actual Value is 0.503 mW/cm²

PASS – Safety Factor is 198.85521

MPE (ANSI Z-136) for IR Retinal Radiance is 632.456 mW/cm²/sr

Actual Value is 3.03 mW/cm²/sr

PASS – Safety Factor is 208.73135