Optical Link Budget

SteamVR™ Tracking

Introduction

The SteamVR™ Tracking system base stations emit 830 nm infrared (IR) light as reference signals used for calculating the position of tracked objects, and for optical synchronization between base stations. The IR light source is different for the synchronization blink signal than for the X or Y laser sweep signals. In the case of the synchronization blink signal, the IR light source is an array of LEDs, whereas the sources of the laser sweep signals are laser diodes. The operating range of the SteamVR™ Tracking system is directly related to the luminous intensity of these IR light sources. International standards specify an upper limit on the luminous intensity of both laser and lamp sources of light, for human eye safety reasons. Although the luminous intensity of the IR light sources could be increased up to the eye safety limits, extending the operating range, the current system operates with a fixed 5 meter range. The laser light sources in the base stations are capable of producing greater luminous intensity than the LED array, so the base station range is limited by the luminous intensity of the IR LEDs generating the synchronization blink signal.

The IR light generated by the base station LED array passes through the IR transmissive front cover of the base station, and through the IR transmissive material of the tracked object enclosure before arriving at a sensor in the tracked object. Both the base station front cover and the IR transmissive material of the tracked object contribute to the loss of some amount of the IR light. The magnitude of the loss depends on the optical properties of the materials as well as the paths the light takes through those materials.

After passing through the tracked object enclosure material, the light strikes the sensor photodiode. In order for the sensor to properly receive the reference signal, the photodiode must generate a large enough modulated current signal when the sensor is irradiated. The magnitude of the modulated current signal depends on the spectral sensitivity of the photodiode, as well as the modulated irradiance of the photodiode. The irradiance of the photodiode is dependent on the normal angle of the sensitive area of the photodiode relative to the direction of the IR light source. As the angle between the normal vector of the sensitive area of the photodiode and the direction of the IR light source increases, less radiant flux from the light source strikes the photodiode sensitive area.

When designing a trackable object, it is important to understand the optical link budget and how to minimize losses in the optical path. Reducing loss in the optical path directly contributes to increased operating range of the SteamVR™ Tracking system.

Base Station Luminous Intensity

The luminous intensity of the LED array is not uniform with respect to the angle from the normal vector of the array. The nonuniformity is a factor of the directional characteristics of the LEDs, as well as their relative positions and orientations in the array. The LED array of a typical base station produces between 5.2 W/sr and 6.6 W/sr of peak radiant intensity, at angles between 0° and 60°. The light then passes through the front cover material of the base station, where a certain amount of the light is attenuated. The amount of light attenuated is dependent on the optical properties of the front cover material, the incident angle of the light, and the material thickness. Typically, the cover material attenuates between 7.5 % and 21 % of the light when the angle of incidence is between 0° and 60°. The typical luminous intensity of the base station is the product of the LED array luminous intensity and the attenuation by the front cover, and is between 4.1 W/sr and 6.1 W/sr for angles between 0° and 60° relative to the normal.

Tracked Object Irradiance

The tracked object typically requires current modulation greater than 370 nA from the photodiode to reliably receive the reference signal. With a typical spectral sensitivity of 0.62 A/W, the radiant flux striking the sensitive area of the photodiode must be greater than 600 nW to generate at least 370 nA. The sensitive area of the photodiode is 7E-6 m^2, therefore the peak irradiance striking the photodiode must be greater than 0.086 W/m^2. As the angle between the normal vector of the sensitive area of the photodiode and the light source increases, the flux striking the sensitive area decreases. The relationship is given by the secant of the angle times the surface area. At 60°, twice the peak irradiance is required in order to maintain the same radiant flux. For this reason, it is desirable to minimize the angle between the photodiode normal vectors in a tracked object and the base station, as this increases the operating range of the tracked object.

Similarly to the base station, the sensors of the tracked object have an IR transmissive material in front of them that attenuates some of the incoming light. Again the attenuation is not constant with respect to the incident angle, and depends on the optical properties and thickness of the material. Additionally, the aperture of the opening for the sensor, and whether or not the cover material causes scattering of the light will impact the attenuation. Typical attenuation for the cover material is between 8 % and 65 % between incident angles of 0° and 60°. The typical minimum peak irradiance for a sensor to receive a reference signal is the product of the minimum peak irradiance required by the sensor and the attenuation by the object cover material. Therefore, the peak irradiance of the tracked object needs to be between 0.094 W/m^2 and 0.492 W/m^2 for incident angles of light between 0° and 60° striking the sensors.

Optical Link Budget

The typical luminous intensity of the base station and the typical irradiance requirements of the tracked object sensors, along with the operational distance make up the optical link budget. To calculate the irradiance 5 m from the base station, we simply need to convert from steradians to square meters. The typical peak irradiance 5 m from a base station is between 0.164 W/m^2 and 0.244 W/m^2 at angles between 0° and 60° from the normal vector of the front cover of the base station. This irradiance is sufficient for a tracked object sensor pointing directly towards the base station, but if the sensor normal points 60° away from the base station, there is insufficient flux to generate a large enough current at the photodiode for the reference signal to be detected by the tracked object sensor.

Thankfully, the synchronization blink need not be observed by all sensors to communicate to the tracked object, and at 5 meters there are typically enough sensors with low enough angles relative to the base station to reliably detect the synchronization blink. For the laser sweeps, the luminous intensity of the laser is set higher than that of the LED array, so that the laser can reliably be detected at sensor angles up to 60°, 5 meters from the base station and at an angle of 60° from the normal vector of the front cover of the base station.