Raytec White-Paper

Lighting Theory

Light is fundamental to CCTV. Without light no images are possible as it is light that makes the world visible both to the human eye and to the CCTV camera.

What is Light?

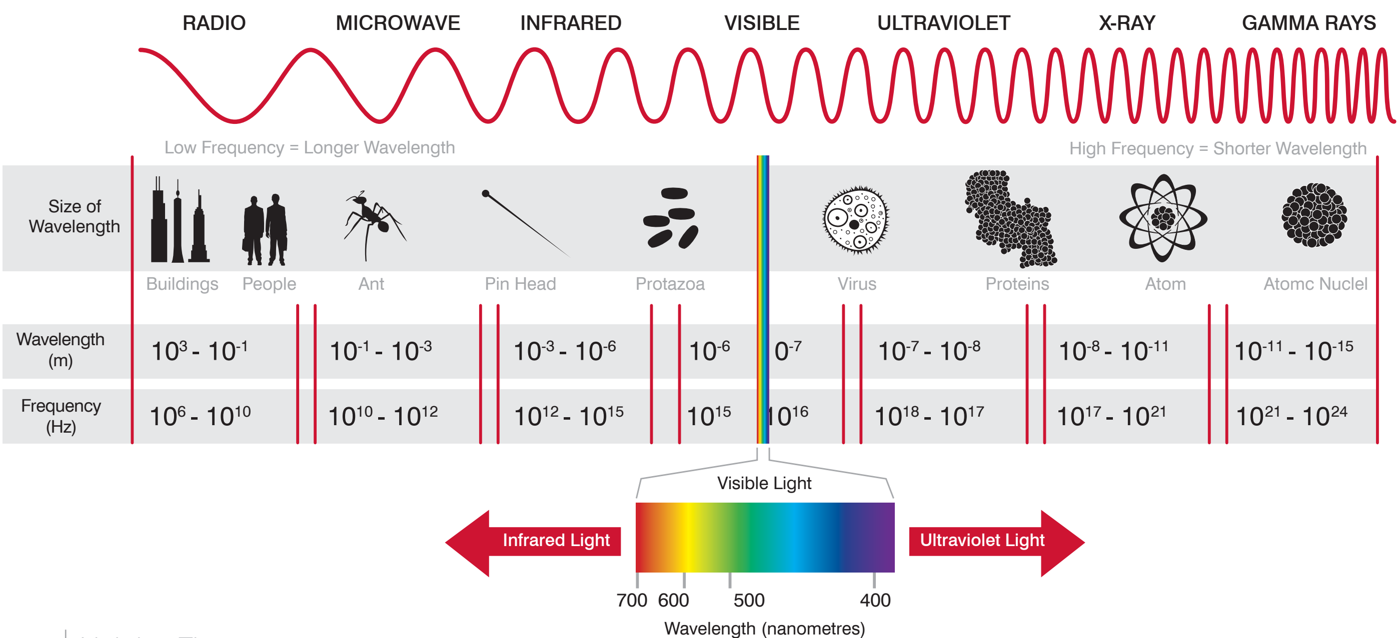
The performance of any CCTV system depends not only on the essential components of camera and lens, but also relies totally on the quantity, quality, and distribution of available light. Light determines whether a subject can be viewed at all, at what distances, and the quality and direction of the light controls the appearance of the subject.

The electromagnetic spectrum ranges from radio waves (long wavelengths) to gamma rays (short wavelengths). Light is the part of the electromagnetic spectrum that is visible to the human eye. The wavelength of light governs the colour and type of light and only a very narrow range of wavelengths is visible to the human eye from approximately 400 nanometres (violet) to 700 nanometres (red). This band is known as visible light.

Other wavelengths, especially near Infra-Red and ultraviolet are sometimes referred to as light when visibility to humans is not the main criteria (such as lighting for cameras). Most CCTV cameras can detect light beyond the range of the human eye allowing them to be used not only with White-Light but also with Infra-Red (typically cameras can see Infra-Red in the range of 715-950nm – longer wavelengths of IR up to 1,100nm require specialist cameras) for night-time surveillance.

Light travels at an amazing speed of 300,000,000m per second from a source such as the sun, an electric lamp or an Infra-Red lamp. Light travels in straight lines and causes shadowing where it is blocked.

Pro Tip *A nanometre is a billionth of a metre and can be written as 0.000,000,001m or as 10^{-9}m*



The behaviour of light varies according to the material or surface it strikes. As it reaches a surface light is reflected, diffused, absorbed, or more commonly, is subject to a mixture of these effects. Most surfaces reflect some element of light. Generally, the paler the surface, the more light it reflects (the surface actually appears pale because it reflects more light). Black surfaces absorb visible light, (so they look black because they reflect very little light) while white surfaces reflect almost all visible light. Infra-Red is not always reflected in the same way as visible light. It is the material composition of an object that affects both the levels of reflectance and which wavelengths of light are reflected.

Demonstration that Reflectance depends on the Material

Consider the two images above. The image on the left, illuminated by White-Light shows both people to be wearing black clothing. However, the image on the right, illuminated by Infra-Red makes it appear that one person is wearing light coloured clothing and the other is wearing dark coloured clothing.

Although both items of clothing appear black under White-Light illumination (because they absorb the light) one of the items reflects large amounts of IR and appears white under IR lighting conditions.

What is colour?

Wavelengths of light visible to the human eye are interpreted by the brain as colours from 400nm (violet) to 700nm (red). Between these wavelengths are the other colours - indigo, blue, cyan, green, yellow and orange. When visible White-Light is split into its component parts by a prism, or in a rainbow, these are the colours visible. When these wavelengths (from 400nm to 700nm) are seen together they appear as White-Light.

Before the 17th century it was believed that colour existed in objects, irrespective of the light by which they were seen. It was Isaac Newton who proved that light itself is the real source of all colours.

A green leaf looks green because it reflects green wavelengths present in White-Light. You can see this yourself by examining a green object under a red light: As the lighting contains no green, the object will appear black. To take a more familiar example, when you buy a coloured item of clothing you often take this to the door or window to check how it looks in daylight. This is because you know that incandescent interior lighting, although white, contains a slightly different mixture of wavelengths from the light outside, and consequently alters the apparent colour of the garment. The exact same can be said in CCTV terms. The colour output of an illuminator effects the colour seen by the camera and on the CCTV monitor. For example, low pressure sodium street lighting produces a yellowish light, distorting colour images on CCTV systems. Achieving accurate colour CCTV images is a challenge and a skill. To provide true colour images at night, either with the human eye or a CCTV camera, White-Light illuminators should provide illumination matched to the visible spectrum of the human eye.

Coloured objects reflect light selectively. They reflect only the wavelengths (i.e. colours) that you see and absorb the rest. A red flower, for instance, contains pigment molecules that absorb all the wavelengths in white light other than red. So that red is the only colour it reflects.

At shorter wavelengths than the visible spectrum we find ultraviolet light (UV). UV burns the skin, causing tanning, and is therefore unsafe for surveillance. At longer wavelengths than the visible spectrum we find Infra-Red (IR).

Pro-Tip There is no colour in objects, light is the source of all colour. Therefore, to get accurate CCTV images at night white-light exactly matching the visible spectrum delivers the best quality results

Demonstration –
The Importance of Colour Output

Take a look at the two images above. Both show the same stretch of perimeter fence line. The image on the left is illuminated by sodium lighting, so everything appears very yellow, the grass doesn't look a natural colour and some detail is lost in the fencing. Crucially the area between the fence and the wall is hard to see.

The image on the right is illuminated by a RAYLUX LED illuminator producing "White-Light" that is much more closely matched to the human eye's expectations and achieves far more accurate, lifelike and detailed results.

What is Infra-Red light?

Infra-Red light is electromagnetic radiation with a wavelength longer than that of visible light. It is a light that the human eye can't see but the monochrome or day/night CCTV camera can. Near Infra-Red light has a wavelength between 750 and 1,100nm, just beyond the visible spectrum. It is this near Infra-Red that is used for CCTV purposes.

As Infra-Red contains none of the colours visible to humans it cannot be used with colour cameras. To see Infra-Red monochrome, or day-night cameras, are needed. CCTV cameras using Infra-Red always provide monochrome images.

Applications that require covert surveillance, or applications where even low levels of overt (visible) lighting must be avoided for reasons of light pollution, are ideal for Infra-Red light. Infra-Red light can also be used to achieve longer illumination distances than visible light.

Infra-Red light is no more harmful to the eye than visible light. In fact there is more Infra-Red energy in daylight than there is visible light energy. However, the blink reflex protects the eye from overexposure to White-Light whereas pure IR goes undetected by the eye.

Pro-Tip Our eyes cope with Infra-Red every day. The sun emits more Infra-Red than it does visible light. When directly overhead, sunlight provides an irradiance of around 1 kilowatt per square metre at sea level. Of this energy around 53% is IR, 44% is visible light and 3% is ultraviolet.

Infra-Red Illuminators vs Thermal Imaging

Infra-Red illuminators, which throw IR light onto a scene and can be viewed with monochrome or day/night cameras, should not be confused with thermal imaging which detect Infra-Red radiation (heat) and create images based on differences in surface temperature producing false colours from these temperatures to create an artificial image.

Infra-Red light can be felt as 'heat'. Most objects emit thermal radiation as Infra-Red energy naturally and the heat felt from the sun on the human skin is predominantly Infra-Red energy.

Demonstration – Active IR vs Thermal IR

The image on the left shows a person under Active IR and the image on the right shows a person under Thermal IR. Infra-Red illuminators 'project' light onto a scene and are 'Active IR'. Thermal cameras detect Infra-Red radiation (heat) existing in the scene and are 'Passive IR'. They produce very different results for different applications.

See section 2, 'comparing specifications', for a full comparison of Active Infra Red systems and Thermal Imaging.

Infra-Red or White-Light

The first decision facing CCTV professionals is choosing whether colour or monochrome images are preferred at night. Often the end user would prefer colour images because that matches their experiences with their eyes during the day but care must be given to provide true colour with a white-light illuminator providing light output that matches the visible spectrum. For example, many installers will be familiar with the yellow light provided by low pressure sodium street lighting. Using incorrect White-Light as opposed to colour optimised White-Light can actually damage the performance of a CCTV system leading to inaccurate colour rendition. A camera is only as good as the light available.

As the human eye can see White-Light, it can also be used for deterrent purposes, flashed on activation by an intruder. Infra-Red by nature is invisible to humans, so cannot be used to warn intruders they are under surveillance. Fundamentally there is a decision to be made whether the purpose of the light is to illuminate an area for people or flashed on activation in order to prevent crime, in which case White-Light is needed, or whether the purpose of the lighting is covert surveillance in order to capture criminals in action, in which case Infra-Red should be the preferred option.

Where White-Light would be too intrusive (especially given recent legislation on light pollution) or where covert surveillance is required, Infra-Red should be the method of illumination. Infra-Red lighting can also illuminate longer distances than comparable size White-Light illuminators.

Raytec provide Infra-Red illumination in two standard wavelengths, 850nm and 940nm. 850nm is semi-covert and delivers the best images because CCTV cameras are all more sensitive to 850nm than 940nm. 940nm Infra-Red delivers covert lighting but distances drop by up to 40% compared to 850nm illuminators (the actual power output of 850nm and 940nm illuminators is similar but the distance reduction is due to a decrease in camera sensitivity at 940nm). Focus shift between day and night is also more problematic when using 940nm Infra-Red.

Advantages of White-Light

Full Colour CCTV Images

Can provide lighting for People

Can be used as a Deterrent

Can provide multipurpose lighting

Easier to align

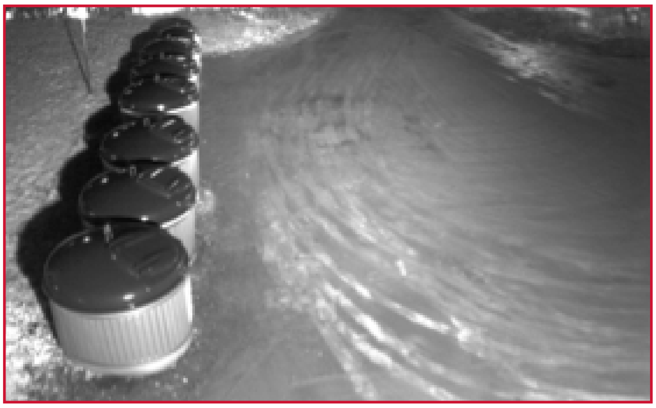
Advantages of Infra-Red

Longer Illumination Distances

Covert Surveillance

Zero Light Pollution

Demonstration of Infra-Red Images



Demonstration of White-Light Images

The key question in choosing Infra-Red or White-Light is defining the purpose of the lighting system.

Discreet or Covert Surveillance
No Light Pollution
Longer Distances
Monochrome images

Infra-Red

Illuminate the area for people
Visible lighting deterrent
Multi-purpose lighting
Full colour images

White-Light

Brightness and Glare

Brightness is an observer's perception of illuminance from a given target and is therefore highly subjective. Its value is different in darkness to that in daylight. For example, the light from car headlights appear to be brighter at night than during daytime: Because the ambient light level is lower there is greater contrast between peak and minimum light levels so the perception of brightness is higher.

Glare is the result of excessive contrasts between bright and dark areas within the field of vision. It is a particular problem for road safety at night when contrasting bright and dark areas make it difficult for the human eye (and CCTV cameras) to adjust to changes in brightness. Such high contrasts cause problems for the human eye in three ways:

Discomfort Glare: The brightness brings a sensation of light pain and discomfort, such as looking at a light bulb.

Disability Glare: The eye becomes less able to discern detail in the vicinity of peak light. It includes drivers being blinded by oncoming traffic at night and causes a reduction in sight capabilities.

Blinding Glare: Strong light, such as that from the sun, is completely blinding and leaves temporary vision deficiencies.

Humans wear sunglass to reduce glare while polarizing filters are used by CCTV professionals to reduce glare by reflected light.

Pro-Tip When there are exceptionally bright areas within the field of view a CCTV camera struggles to produce good images. By adding lighting to the scene the level of the ambient light increases, becomes closer to the peak light levels (glare) and the camera can produce higher quality images.

Demonstration of Glare

In both the above images the subject is holding a flashlight. In the scene without Infra-Red the flashlight causes glare in the scene because of the wide range in lighting levels between the flashlight and the ambient light level.

When Infra-Red light is added (the second image) the gap between minimum and maximum lights levels in the scene is reduced and the flashlight causes no glare. Glare is a perceptual concept created by variances in light levels within a scene.

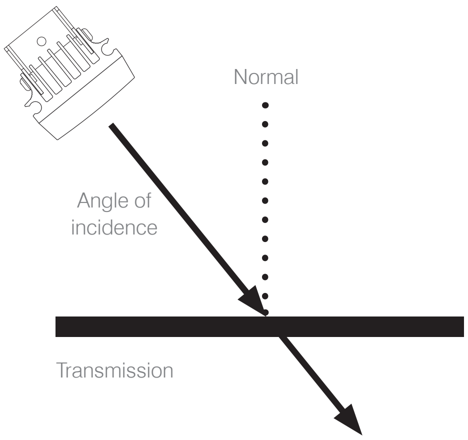
Light and Surface

To control lighting, you must understand how light changes in quality and direction when it meets a surface. The three main effects are transmission, reflection and absorption. Often light is affected by a combination of these effects and all influence the quality of CCTV lighting.

Pro-Tip When light hits most objects it is affected by a combination of diffusion, reflection and absorption.

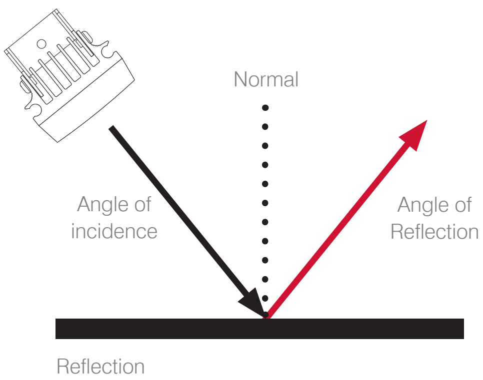
Transmission

A transmitting material passes light through it. The direction of the light can be changed as it passes through an object which is known as diffusion. Typical items with high transmission include air, glass and water.



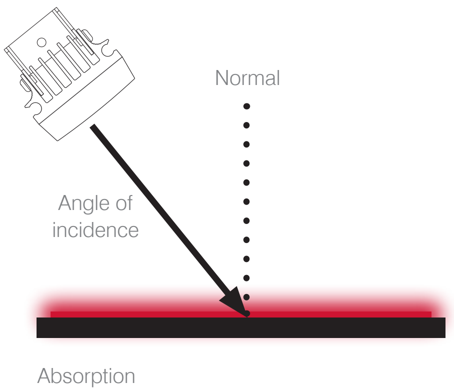
Reflection

When light hits a surface it can bounce back as reflection. The quality of the surface impacts the type of reflection. Highly textured surfaces scatter light due to tiny irregularities in the surface material whilst flat surfaces such as a mirror provide a more focussed reflection. All objects reflect light to some degree. When lighting scenes or objects it is principally the reflected light which is of interest. For a fuller description of reflection see page 10.



Absorption

Surfaces typically absorb some of the incident light. Coloured surfaces absorb some light and reflect the remainder – which is why they appear a particular colour. A black surface absorbs most of the incident light falling on it. The light energy is usually turned into heat, so dark materials heat up easily. For example, wearing a black t-shirt on a bright sunny day will generate extra warmth for the wearer.



Reflection

In lighting a scene to create high quality images, it is the quantity, quality and direction of the reflected light that is most important.

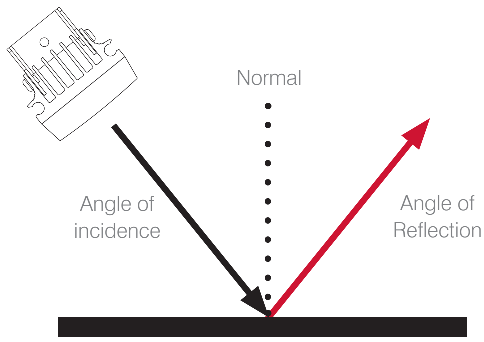
Pro-Tip It is important to remember that neither the human eye, nor a camera, use the ambient light on a scene as detected by a light metre. Both rely on the amount of light reflected from objects within the scene back to the eye or the camera lens.

Types of Reflection

There are two main types or reflection, specular and diffuse, although a third, retro-reflection is important in the field of number plate capture. All three types of reflection have different requirements for the positioning of a camera to make use of the light projected onto a scene.

Specular

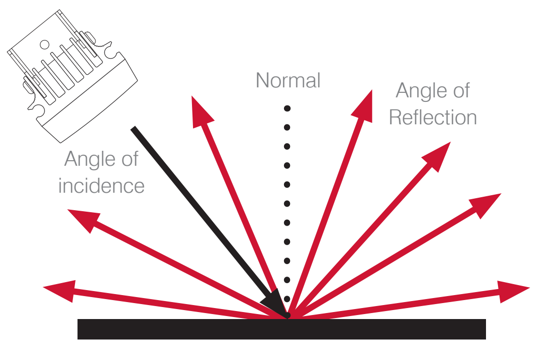
If a surface is completely smooth it reflects light as a mirror and is said to be of specular reflectance. With specular surfaces the angle of incidence is equal to the angle of reflectance.



Diffuse

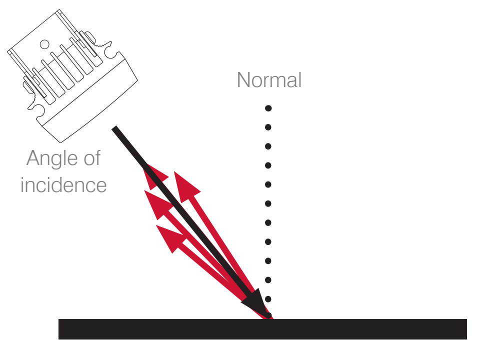
Diffuse reflection surfaces bounce light in all directions due to tiny irregularities in the reflective surface. For example a grained surface will bounce light in different directions.

A diffuse reflective surface can scatter light in all directions in equal proportions. This particular form of diffuse reflection is known as Lambertian reflectance. Most objects predominantly reflect light in this way.



Retro-Reflection

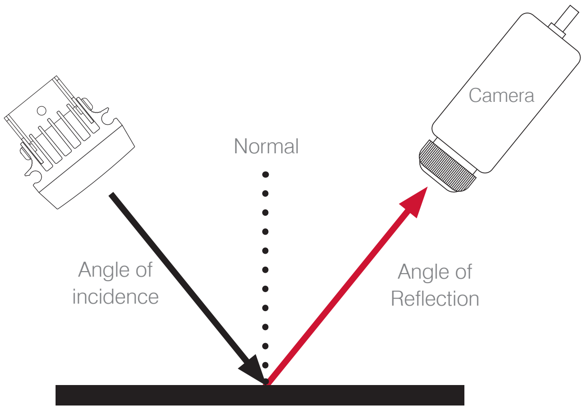
Retro-reflective surfaces bounce light back in the direction it came from. Traffic Signs and Vehicle license plates have retro-reflective surfaces. Retro-reflection is not a natural phenomenon but may be created by the development of specially designed man made materials



Ideal Camera Locations

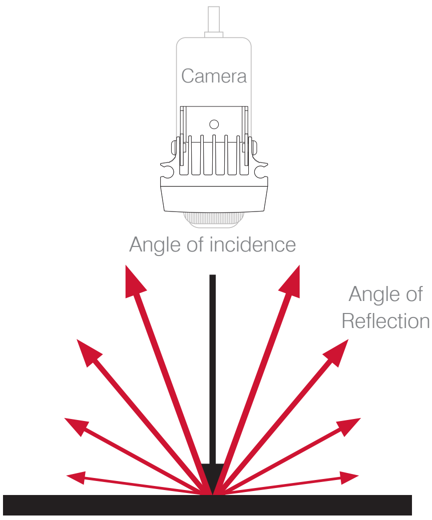
Specular

Specular reflection is not very common and is only seen on more unusual applications such as illuminating non-reflective license plates.



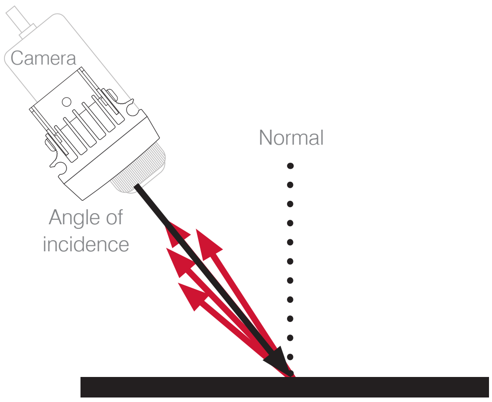
Diffuse

Diffused surfaces will reflect light in all directions but the reflection tends to be stronger when the light hits the object square, and reflects square. For this reason we typically recommend the camera is fitted beside the illuminators looking straight to the target. This also avoids the camera seeing any shadows on the scene



Retro-Reflection

Camera location is critical for retro reflective materials since the vast majority of reflected light returns to the source. With LPR set-ups the camera must be positioned at the side of the road, and the illuminator must be positioned with the camera.



Pro-Tip The position of a camera, relative to the position of an illuminator changes dramatically depending on the reflective properties of the target surface.

Typical Reflectance Levels

Reflectivity is a measure of the reflected power compared to incident power and objects reflect light to different intensities. The remaining energy not reflected is either transmitted through the object or is absorbed and converted to heat. Low reflectivity objects absorb a lot of energy – hence why bricks feel warm in sunlight. The photographic industry claims that the average object reflects approximately 20% of visible light. The table opposite shows some everyday objects and their level of reflectivity.

It is important to remember that neither the human eye, or a camera, use the ambient light on a scene as detected by a light metre. Both rely on the amount of light reflected from objects within the scene back to the eye or the camera lens.

There is a fundamental difference in designing light for CCTV or for people. White-Light designers attempt to provide a given light level on scene, for example 7 lux. But they design with the premise that the person using that light will be on the scene, with the light. CCTV is unique in that the light to be used is collected at the camera sensor, potentially a long distance from the scene, and relies more on reflected light.

Material	White-Light reflectance % at 6500k	Infra-Red reflectance % at 850nm
Brick	5	7
Concrete	6	5
Turf	3	10
Wood	30	40
Aluminium	75	65
Polyester black	1	25
Cotton black	1	30
Cotton white	40	30
Nylon black	1	10
Leaves	3	30

Demonstration - The Importance of Reflectance

Large range of Reflectance Levels

More Consistent Reflectance Levels

The image on the left shows a scene with bright areas and dark areas. That is because objects within the scene have large variances in their reflective properties. The Water simply bounces the light over it, not back to the camera, and appears dark; the trees have a good reflectance level and the sky can obviously reflect no light as the light strikes no object from which it can reflect. The image on the right shows an internal scene with a largely homogenous level of illumination due to consistent reflectance levels throughout the scene.

Using the Inverse Square Law

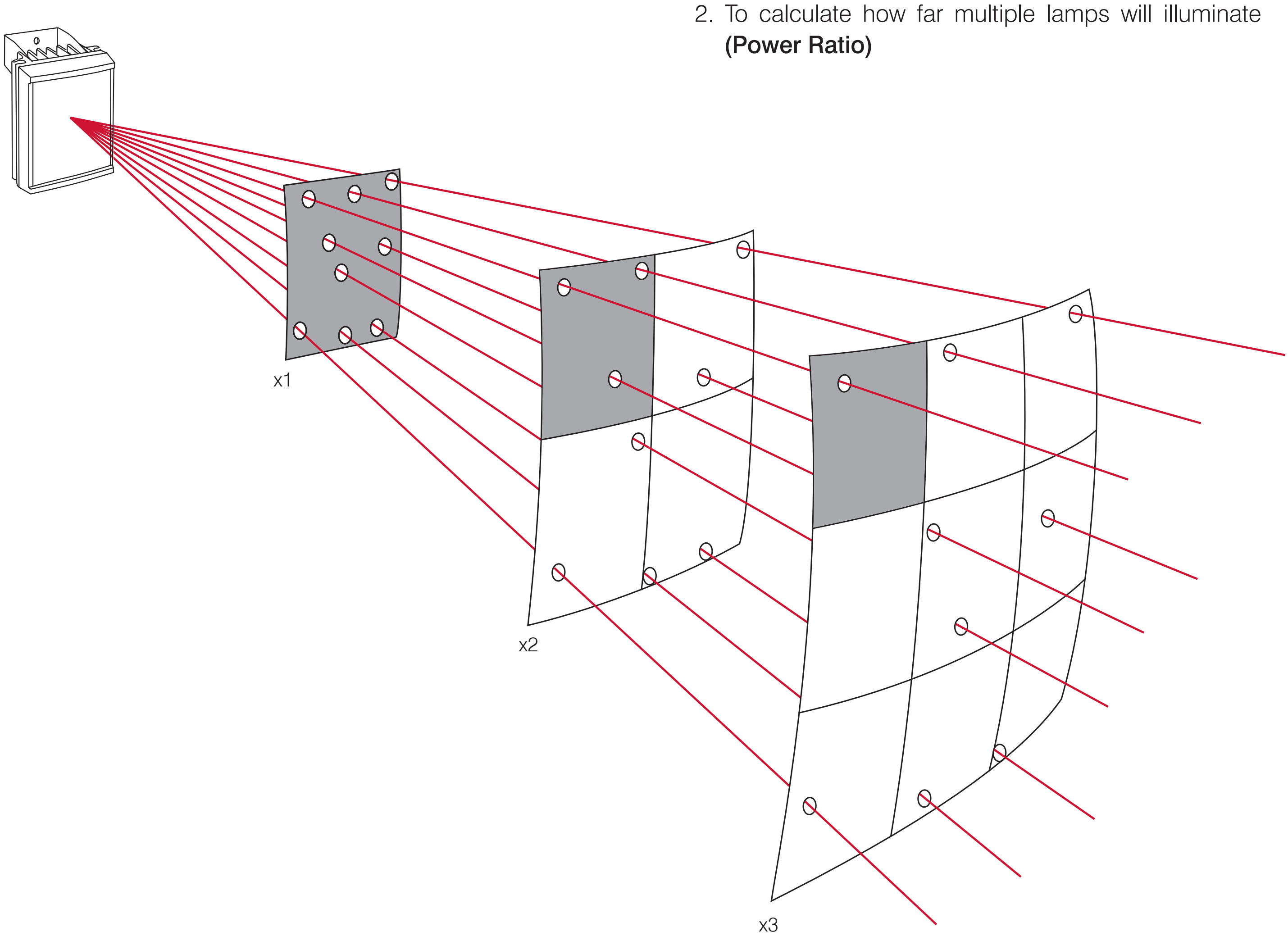
Light obeys the inverse square law so to fully understand the way that light travels, and the resultant impact on CCTV systems, some understanding of the inverse square law is required.

The inverse square law in relation to lighting states that the intensity of a diverging light source is inversely proportional to the square of the distance from that source.

As light travels away from a point source it spreads both vertically and horizontally and therefore intensity decreases – not as a linear function, but as a square function. This means that if light travels double the distance, there will not be ½ power intensity (which would be a linear law) but there will be a ¼ of the original power intensity (a square law).

There are two ways that lighting designers can use the inverse square law to help design a lighting system.

1. To calculate the number of illuminators required to illuminate a certain distance **(Distance Ratio)**
2. To calculate how far multiple lamps will illuminate **(Power Ratio)**



Calculators

Distance Calculator

Given the distance achieved by one illuminator designers can calculate how many illuminators are required to achieve a different distance

- To work out simple distances such as x2 distance, x3 distance it is simply a matter of squaring the distance multiplier.

Practical Examples
To achieve double (x2) the distance =
4 x the original power is required (2^2)

To achieve triple (x3) the distance =
9 x the original power is required (3^2)

- This same equation, squaring the distance multiplier, can also be used to see how many illuminators are required for a given target distance.

Practical Examples
If the target is 180m, and 1 illuminator covers 100m then
4 illuminators are needed $(180/100)^2$€ =1.82^2 = 3.24

If the target is 500m and 1 illuminator covers 300m then
3 illuminators are needed $(500/300)^2$ = 1.662^2 = 2.77

In simple terms:
Ratio of Distance is a square function

As a visual cue think of:

Distance^2

Pro-Tip The inverse square law applies to both Infra-Red and White-Light in the same way.

Power Calculator

To work out how far multiple lamps go simply find the square route of the number of required illuminators then multiply that number by the achievable distance of 1 illuminator.

Practical example:
How far will 6x RM200-AI-10's cover?

Square route of 6 is 2.45.
6 x RM200-AI-10's will cover 2.45 times the distance of 1 x RM200-AI-10
2.45 x 300 (the distance of 1 illuminator) = 735 mtrs

Installation Example:
Using the Eco-Logic setting on Raytec illuminators.

The Eco-Logic setting allows Raytec illuminators to operate at 50% of their normal power to deliver increased electrical savings and increases the power to 100% only upon an event "trigger"

When the illuminator is operating in eco-logic setting, at 50% of power, it will still achieve 71% of the illumination distance possible with 100% power (the square root of 0.5 = 0.71)

Installation Example:
What happens if the power setting on an illuminator is changed to 80% of maximum?

When the illuminator is operating at 80% of power it will still achieve 89% of the illumination distance possible with 100% power (the square root of 0.8 = 0.89)

In simple terms:
Ratio of Power is a square root function

As a visual cue think of:

$\sqrt{\text{Power}}$

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for Any Application

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