Lighting Controls

Radio technology in lighting applications

At a glance

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1. About this document

Wired connections and wireless connections differ in one central point:
Wired connections are static and do not change. Wireless connections, on the contrary, are dynamic. By changing the external circumstances, they can change or be disturbed.

The following conditions can influence and disrupt wireless connections:

_ Change of the radio connections used in parallel in the same frequency band (e.g. due to new additional WLAN)
_ Utilization of the radio connections at different times (e.g. higher WLAN utilization during video conferences than at times when small amounts of data are transmitted)
_ Change in spatial conditions

The following text provides explanations and information on radio technology, on possible influencing factors and on avoiding or reducing the resulting changes or interference.

Basics of electromagnetic waves

2. Basics of electromagnetic waves

Many examples of electromagnetic waves can be found in technology and everyday life:

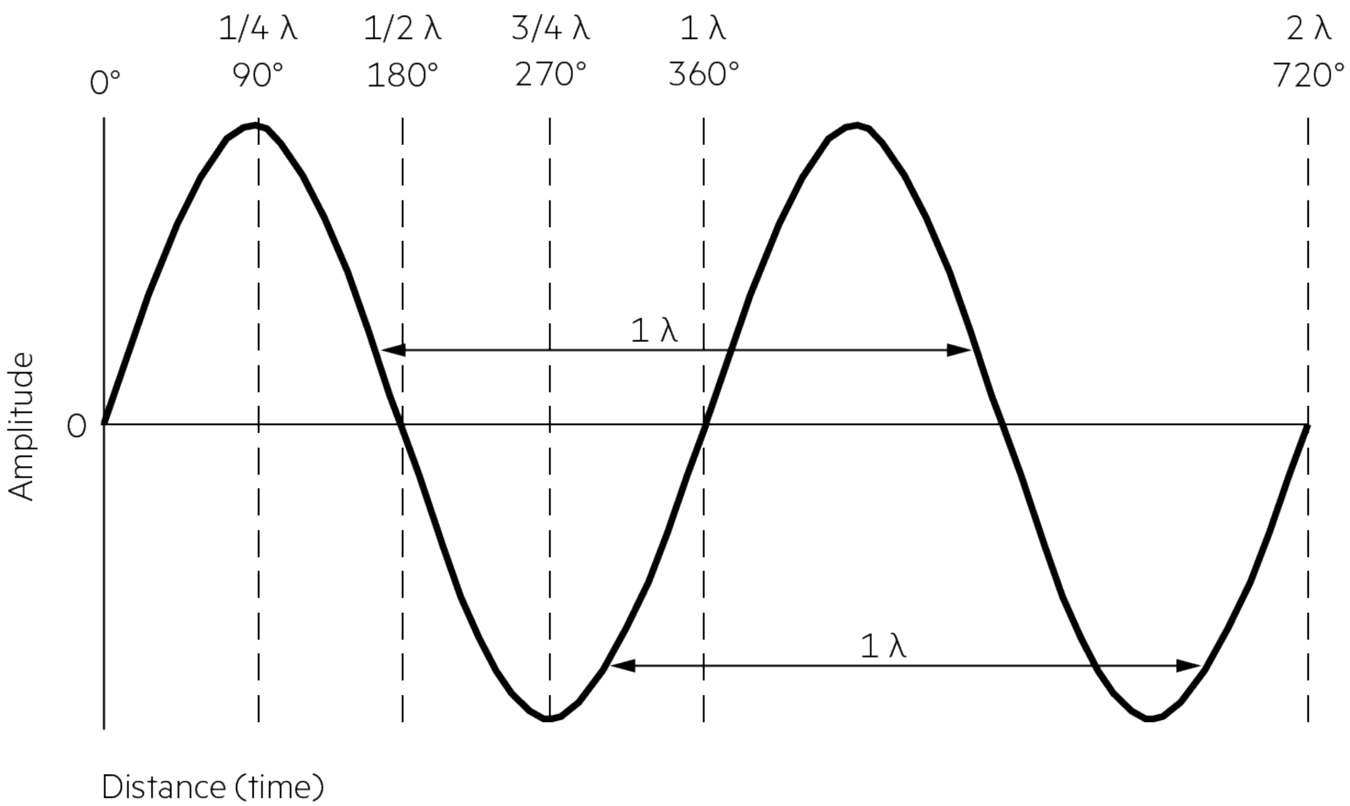
- Radio waves
- Microwaves
- Thermal radiation
- Light
- X-rays
- Gamma radiation

Electromagnetic waves are vibrations from coupled electric and magnetic fields.
Under ideal conditions, electromagnetic waves propagate spherically in space at the speed of light. Different electromagnetic waves can be differentiated based on their frequency.

The following formula shows the relationship between wavelength, frequency and speed of light:

$c = f * \lambda$ --> $\lambda = c / f$

Explanation:
λ = wavelength [m], c = speed of light (approx. 300,000,000 m/s), f = transmission frequency [Hz]



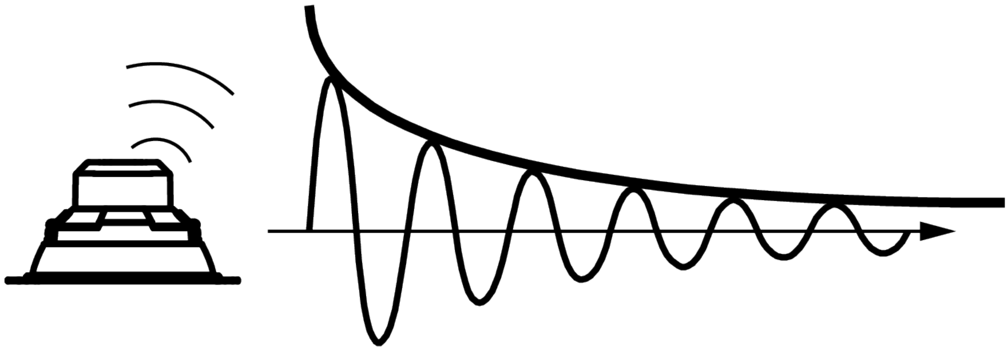
Radio waves and their propagation

3. Radio waves and their propagation

Radio waves are electromagnetic waves that move in the low frequency range. They are used to transfer information.

In free space, radio waves propagate spherically. The signal strength decreases quadratically with distance. From a certain distance on, the signal is so weak that it can no longer be received without errors or is masked by the surrounding noise.

The following graphic shows how the signal strength decreases with distance.



4. Coexistence of different radio systems

Different frequency bands are subject to regional restrictions. The only frequency band that is freely available worldwide is the 2.4 GHz frequency band.

It is used for a variety of different applications such as:

_ WLAN

_ Bluetooth® wireless technology

_ Thread

_ ZigBee

_ etc.

By using the same frequency band all these applications can influence each other. Various methods have been developed to make sure that these technologies can be used in parallel and without interference. The right channel selection in WLAN, for example, can guarantee a problem-free parallel operation.

CAUTION!

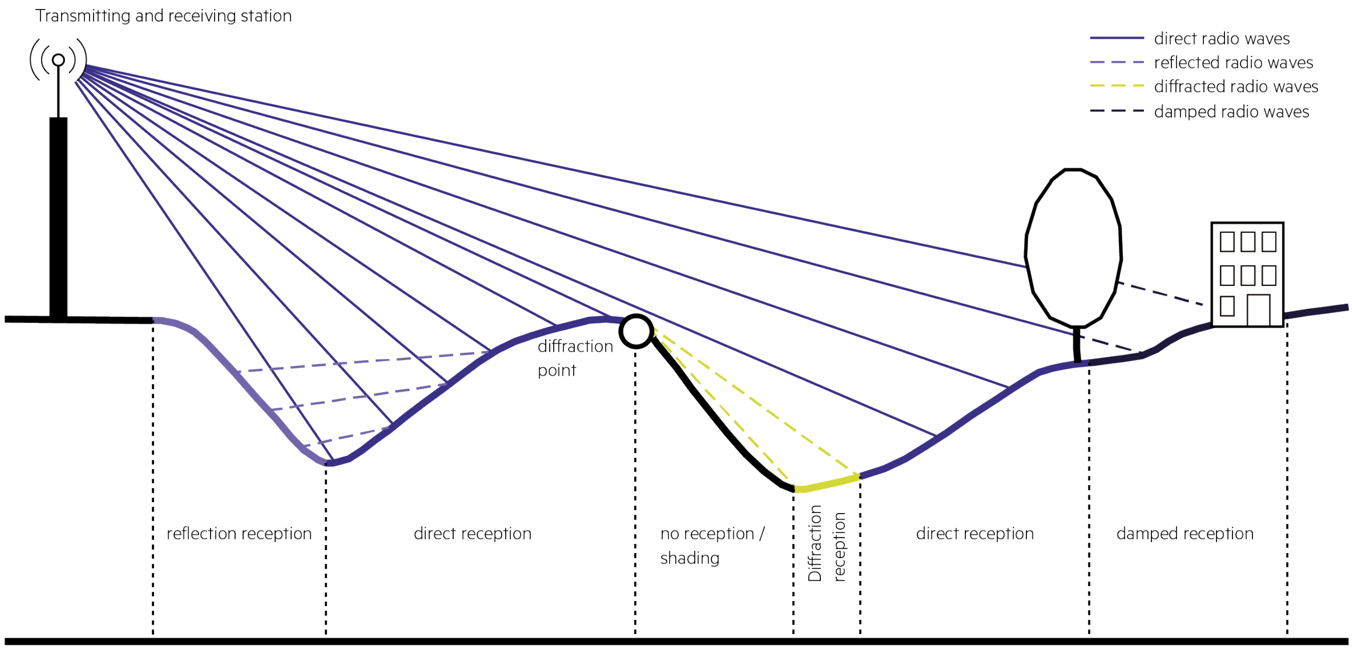
_ WLAN, Bluetooth® wireless technology, THREAD etc. all use the same frequency band and can influence and interfere with one another.

_ Depending on the load, a WLAN can interfere with other applications more or less.

_ An analysis of the occupancy in the frequency band before installation over a longer period of time is necessary in order to make the right channel selection (occupancy is dynamic and can change at any time!).

5. Factors influencing radio waves

The following graphic illustrates the different possible influencing factors on radio waves in an open field. In closed rooms, possible interferences even occur in a superimposed form and are not able to be descriptively illustrated in a graphic any more.



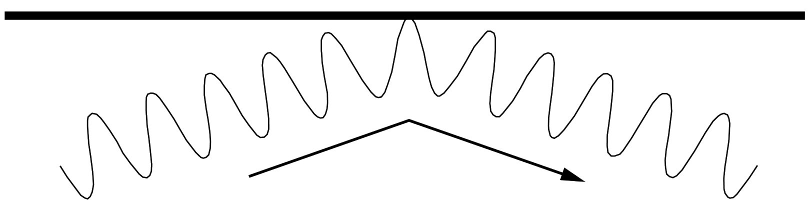
The graphic shows the sending and receiving station of the signal (top left) and various influencing factors that can occur depending on the location of the receiving station:

_ Reflection
_ Interference
_ Diffraction
_ Shadowing
_ Damping

The influencing factors mentioned are described in more detail in the following chapters.

5.1. Reflection

Radio waves that hit metal surfaces are reflected by them.



Factors influencing radio waves

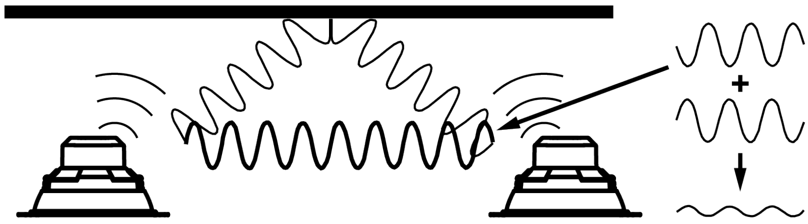
Reflections from radio waves can have advantages but also disadvantages.

_ In rooms, reflections are often advantageous because they allow every corner in a room to be reached, even if there is no direct line of sight between sender and receiver (in rooms with L-shape for example).

_ However, reflections can also cause interference, see next chapter.

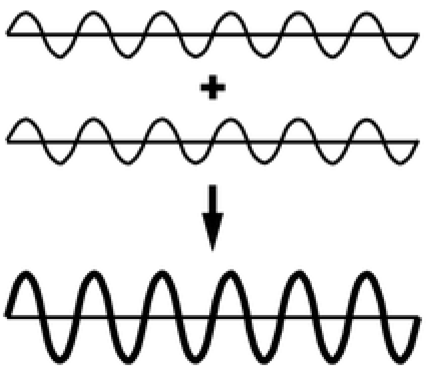
5.2. Interference

If different radio waves overlap, this is called interference.
Reflections can cause interference. Due to different signal transit times, the radio waves can either add or subtract each other when they are superimposed.



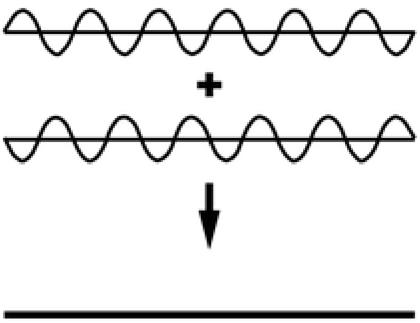
The graphic above shows how radio waves arrive at the receiver in two forms, directly and reflected.
The reflected radio waves have a different transit time than those that arrive directly. Depending on local conditions, this can lead to extremes like the doubling of the signal strength or the complete cancellation of the signal.

Doubling of the signal strength



Factors influencing radio waves

Cancellation of the signal



5.3. Diffraction and shadowing

When radio waves hit an obstacle, the radio waves are diffracted.

How and how strongly the radio waves are diffracted, depends on the following factors:

_ The frequency of the radio wave: The higher the frequency, the lower the diffraction angle and vice versa.

_ The size of the obstacle or the passage between obstacles: See graphics below.

Diffraction has both positive and negative effects on the propagation of radio waves:

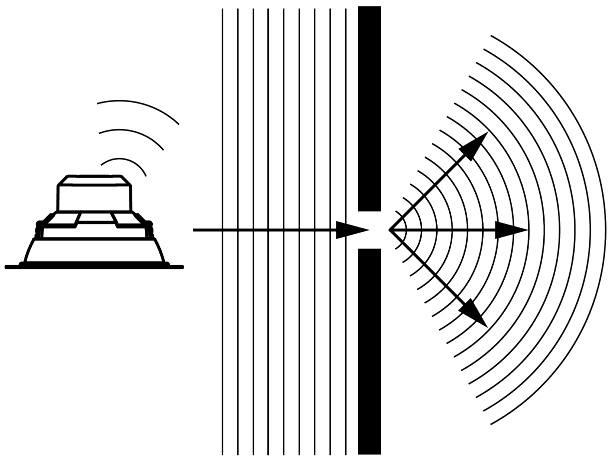
_ **Positive**: Because of diffraction, radio waves can reach areas that don't have a line of sight between sender and receiver (because of the obstacle).

_ **Negative**: There are areas behind the obstacle in which shadowing occurs.
Shadowing refers to areas in which radio waves cannot propagate due to the spatial conditions. In such areas there is no or only poor reception.
The type and size of the shadowing depends on the diffraction of the radio waves.

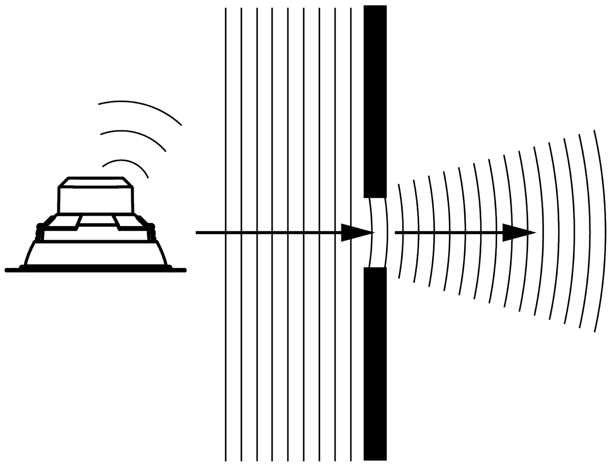
The following graphics illustrate diffraction and shadowing for different obstacles:

Factors influencing radio waves

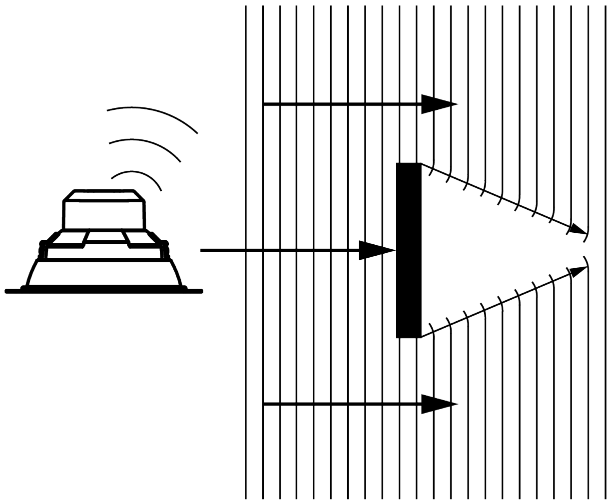
Diffraction and shadowing behind obstacles with a narrow passage



Diffraction and shadowing behind obstacles with a wider passage



Diffraction and shadowing behind surface area obstacles



Factors influencing radio waves

CAUTION!

In addition to the spatial conditions on site, the construction of the luminaire itself can lead to shadowing and deteriorate the propagation of radio waves:

If the radio connection between individual luminaires in the room is poor, the following measures can be useful:

- Change of position of the luminaire
- Adding more luminaires
- Adding a basicDIM wireless module, which only functions as a bridge

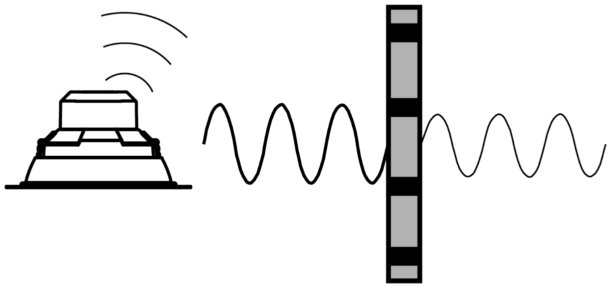
Factors influencing radio waves

5.4. Damping

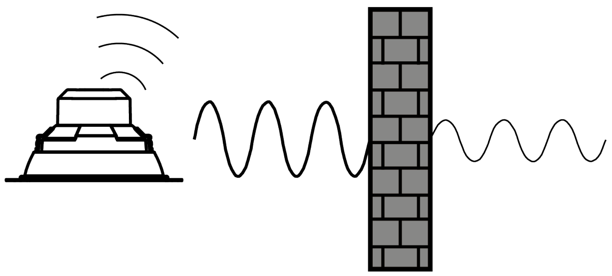
Radio waves can travel through solid materials. However, compared to air transmission, there is greater damping of the radio waves.
This effect must be taken into account when designing a luminaire and placing it in the application.

The following graphics show materials with different levels of penetration:

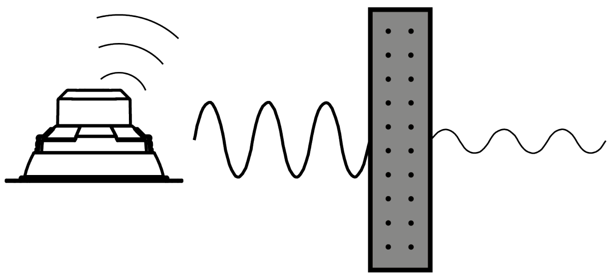
Wood / plasterboard: weak damping => very good penetration



Bricks / Masonry: medium damping => medium penetration

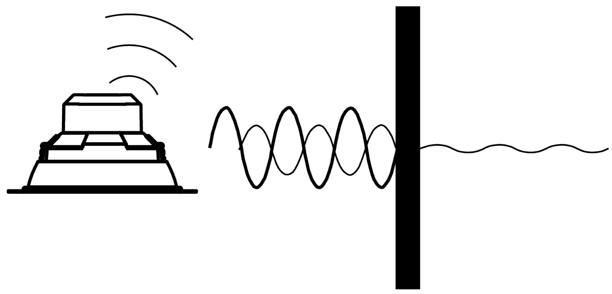


Reinforced concrete: strong damping => poor penetration



Factors influencing radio waves

Metal surface: very strong damping => very poor penetration

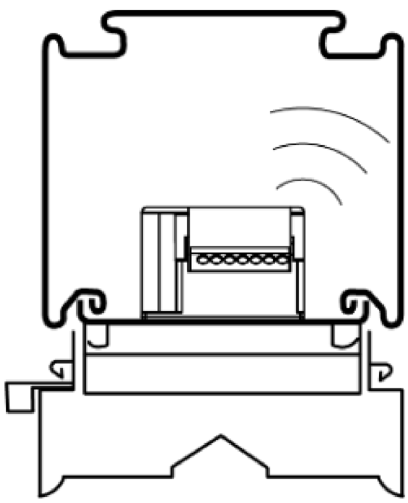


NOTICE

Metal is an extreme example as it does not allow radio waves to pass through or only with great difficulty.
If a radio transmitter is completely surrounded by metal, it acts like a Faraday cage from which no radio waves at all can escape.

This must be taken into account when designing a luminaire with radio technology!
Make sure that the radio module is never completely surrounded by metal!

The following graphic shows a luminaire that is unfavorably constructed.
The thick lines represent the sheet metal parts of the luminaire. The radio module is completely surrounded by sheet metal parts which leads to a drastic reduction in the signal strength.



In an application, the weakening effects of the luminaire and of the room complement each other.
If the signal is already weakened because of the construction of the luminaire, an additional loss of signal strength because of walls, ceilings or windows can reduce the signal strength to such an extent that communication is no longer possible!

Factors influencing radio waves

NOTICE

Sometimes the weakening effect of metals is not obvious.
Tinted windows, for example, are often vaporized with metal and also lead to this effect.

5.5. Fresnel zone

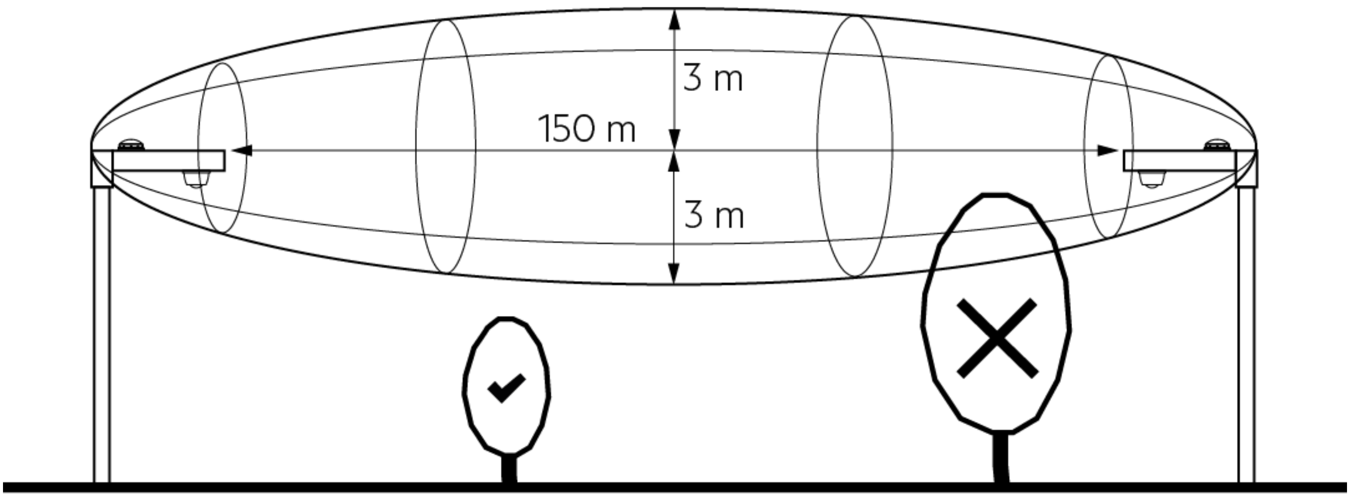
Radio waves can be affected by obstacles. What is critical are not only those obstacles that are in the direct line of sight between the transmitting and receiving antenna, but also those that are above, below and to the side of this line. The distance above, below and to the side changes with the distance to the antennas. The overall result is an ellipsoidal (Zeppelin-shaped) area in which obstacles can impair the radio connection. This area is called the Fresnel zone.

NOTICE

The following points must be considered in connection with the Fresnel zone:

_ When dealing with obstacles, it is crucial that not only the direct connection between the transmitting and receiving antenna is free of obstacles, but the entire Fresnel zone.
_ For outdoor applications with larger distances, the antennas must be placed high enough (so high that the Fresnel zone at its lowest point does not touch the ground).

The graphic below shows the dimensions of the Fresnel zone for a distance of 150 meters between the antennas.
For this value the maximal radial expansion of the Fresnel zone is 3 meters (3 meters above, below and to every side of the direct line of sight). There are various internet tools and sites to calculate this value.



Range of radio waves

6. Range of radio waves

The range of radio waves depends on many factors and is difficult to predict!
The influencing factors include:

_ Antenna

_ Transmission power of the radio module

_ Luminaire design

_ Spatial conditions

Larger ranges can only be reached with a combination of optimal luminaire design and appropriate installation.

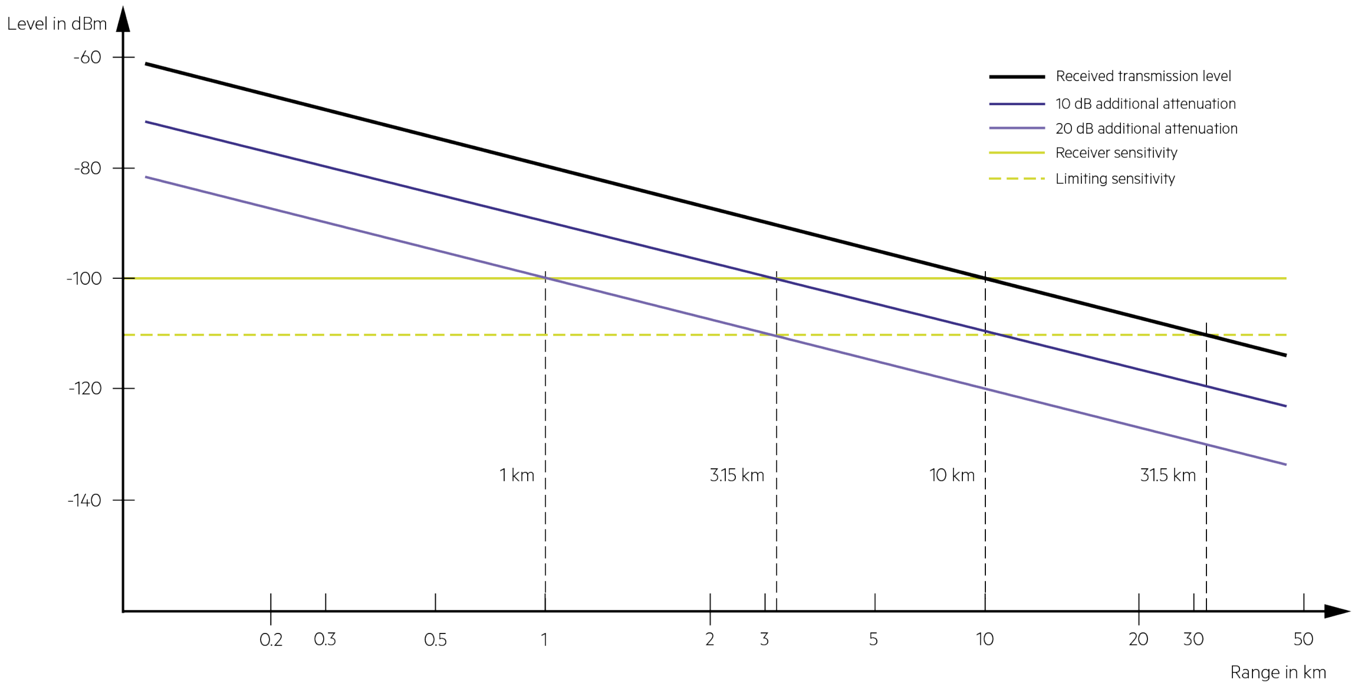
The following graphic illustrates the relationship between transmission level and range and how a less than optimal luminaire design has a direct effect on the range!

CAUTION!

This following graphic and the distance information it contains do NOT apply to the 2.4 GHz frequency band, but to radio waves with:

_ 1 MHz

_ 100 mW transmission power



Range of radio waves

The black line shows the received transmission level over increasing distances (logarithmic). In this representation, the level decreases linearly over distance.
With a receiver sensitivity of -100 dB, this results in a range of 10 km. This represents the optimum (radio module in the free field without disturbing influences).
In comparison, the other two lines show the transmission level with an additional attenuation of 10 dB and 20 dB. At 10 dB attenuation the range is reduced from 10 km to 3.15 km, at 20 dB attenuation the range is reduced to 1 km.

⚠ CAUTION!

By attenuating the transmission level, the range of the radio signal is significantly reduced:

_ -10 dB in level means only a third of the maximum range.

_ -20 dB in level means only a tenth of the maximum range.

7. Installation of the radio components in the luminaire

In order to be able to ensure trouble-free operation of the luminaire, it is necessary to place the radio components in the luminaire in order to influence the transmission power of the antenna as little as possible. This is especially applies when it comes to metal luminaires as metal reflects the radio waves and also shields them very well.

The following points can affect the signal quality and must therefore be avoided:

- Enclosing the radio components with metal (which would result in a Faraday cage)
- Insufficient distance between antenna and metal parts of the luminaire
- Shadowing the radio signal by metal parts of the luminaire

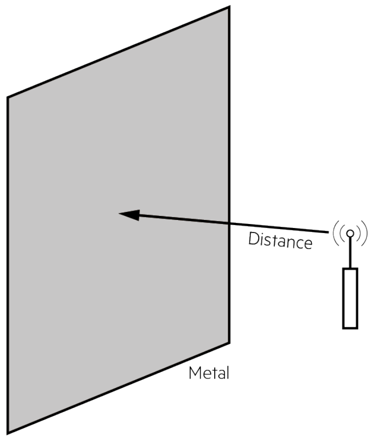
For wireless components from Tridonic, information about the position of the antenna can be found in the data sheet.

Influence of metal parts on the antenna

8. Influence of metal parts on the antenna

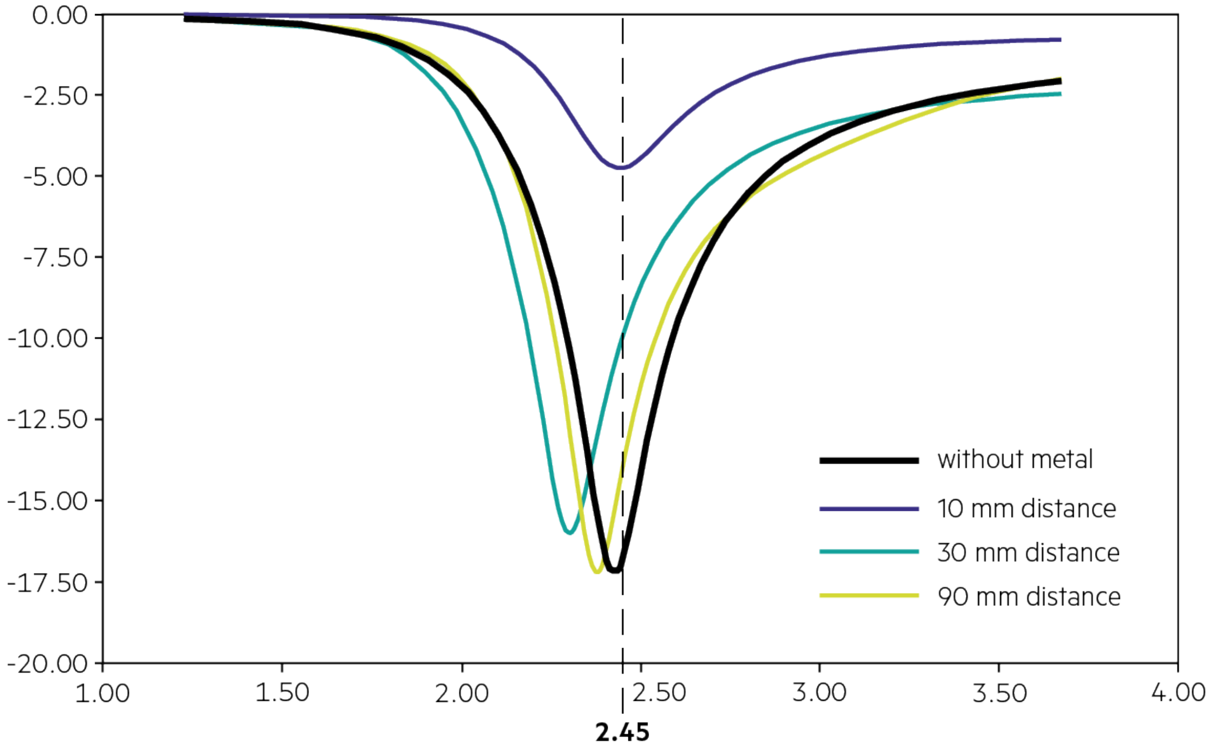
Metal parts close to the antenna change the antenna's resonance and the radio waves are reflected.
In order to keep this influence as low as possible, the distance between the antenna and metal parts of the luminaire should be as large as possible. A distance larger than λ / 4 is optimal (λ is the wavelength of the radio waves). At 2.44 GHz (the middle frequency in the 2.4 GHz frequency band), the wavelength is 12.28 cm. In this case, the distance should be at least 3.07 cm.

The following figures show a simulation that illustrates the influence of metal on the antenna. What was simulated was the attenuation of the antenna when it was positioned at different distances from a metal plate.



The black curve in the following graphic shows the attenuation of the antenna without metal in the vicinity. This curve represents the optimal starting situation.
In comparison, the other curves show the values for different distances to the metal plate. It can be clearly seen how the resonance of the antenna changes with metal in the antenna environment at 2.45 GHz. A decrease is already visible at a distance of 90 mm.

Influence of metal parts on the antenna

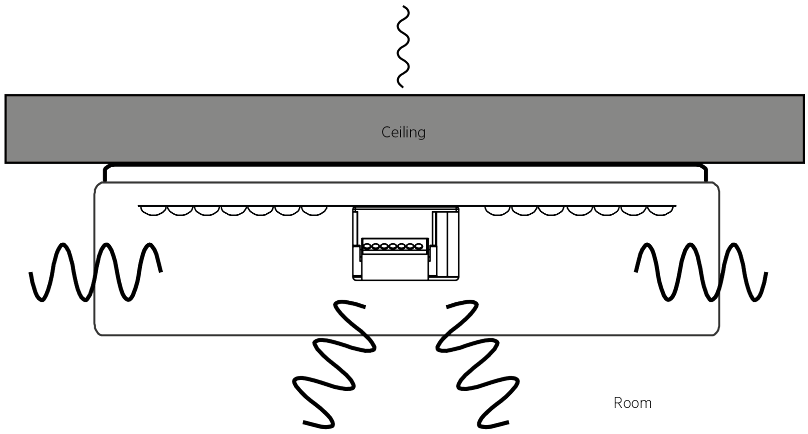


Metal dampening and shadowing

9. Metal dampening and shadowing

Radio modules must be installed in luminaires in such a way that the attenuation and shadowing of the radio waves in the room is as low as possible. The attenuation and shadowing is different depending on the construction, design and mounting of the luminaire.

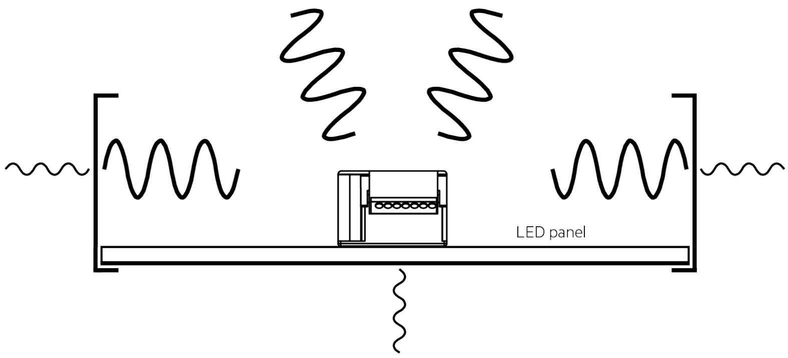
The following graphic shows how a radio module should be installed ideally:
The antenna can transmit through the plastic diffuser into the room without hindrance, the propagation of radio waves into the ceiling is weakened by the metal base of the luminaire.



If the radio module is installed between metal parts and the ceiling, the radiation of the antenna into the room is hindered by the metal. Such a structure would be very unfavorable in terms of radio transmission.

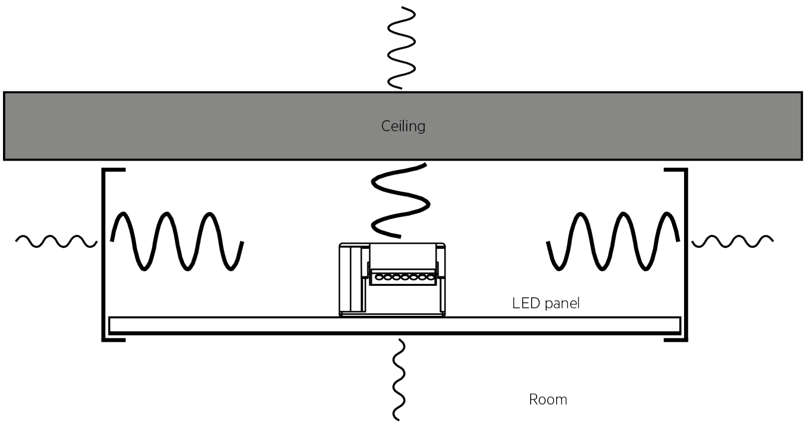
In the laboratory, such a structure can still deliver good measurement results since the luminaire is open at the top. In the real environment, however, the luminaire could be installed on a reinforced concrete or metal ceiling and become a Faraday cage, which hardly allows radio waves to penetrate to the outside.

Laboratory conditions:

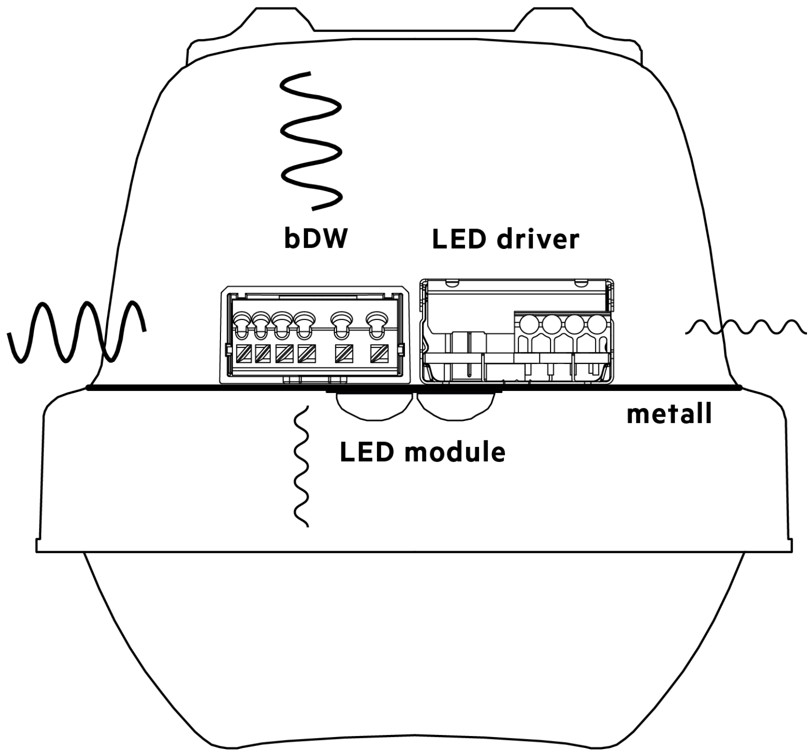


Metal dampening and shadowing

Installation situation:



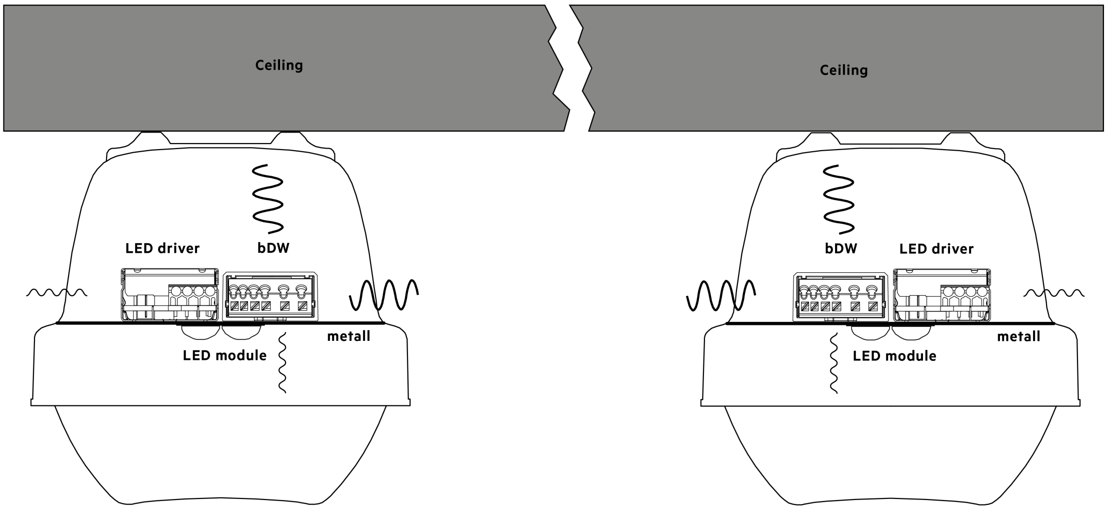
Komponenten in der Leuchte, insbesondere solche aus Metal, können Funksignale erheblich beeinflussen. Dies kann dazu führen, dass die Signalstärke je nach Richtung variiert.
Das folgende Beispielbild verdeutlicht dies. Das Funksignal wird nach unten durch eine dort angebrachte Metallplatte und seitlich durch einen dort befindlichen Treiber gedämpft. Die Signalstärke ist in diesen Richtungen schwächer.



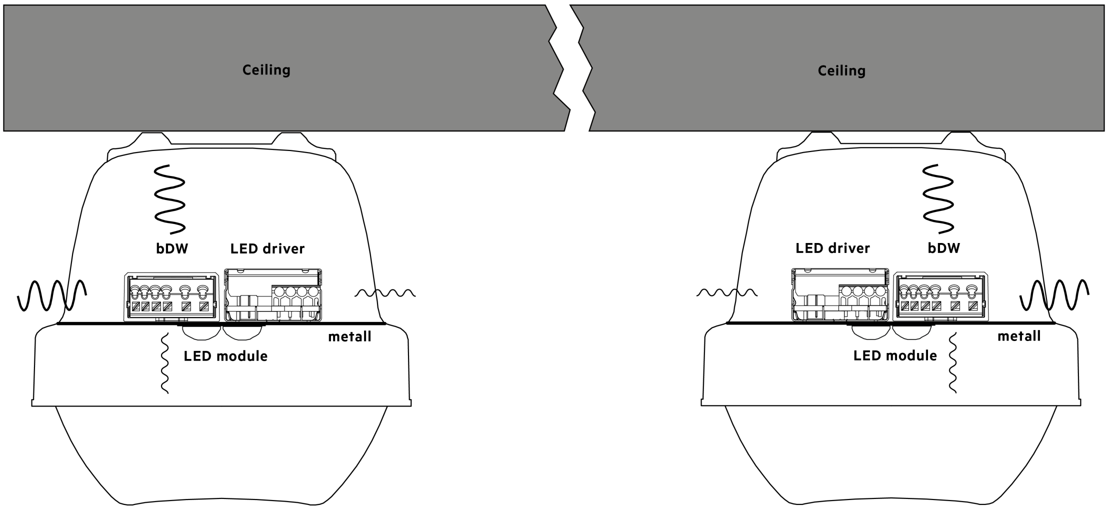
Depending on the orientation of the luminaire, this results in signal strengths and ranges that vary in quality:

Metal dampening and shadowing

Arrangement of luminaires with good range:



Arrangement of luminaires with reduced range:



10. Structural measures for radio-compatible metal luminaires

Metal luminaires can be built radio-compatible by use of rectangular cutouts in the metal frame of the luminaire. This gives the radio waves an exit path from the luminaire.

The size of the cutouts is based on the frequency and wavelength of the radio waves. Radio modules that use the 2.4 GHz frequency band have a wavelength of 12.28 cm. The length of the cutouts should be half of that which is 6.24 cm. The width of the cutouts is variable and is typically around 1 cm.

⚠ CAUTION!

Untested luminaires can lead to significant problems!
Before finally using a radio-compatible metal luminaire, the following measures must be taken:

_ The combination of radio model and cutouts in the metal frame must be tested for signal quality and range!

_ Each time the cutouts or the position of the radio module is changed, the luminaire must be tested again!

Measurement of the signal quality

11. Measurement of the signal quality

In order to obtain a reliable statement about the signal quality of the respective luminaire, it is advisable to measure the luminaire professionally.

The signal quality can be estimated by performing two measurements via the app (one with the radio module inside the luminaire and one with the radio module outside the luminaire) and then comparing the results.

The normal signal strength of an open radio module is around -40 dBm. The lower limit is around -90 dBm. Communication is no longer possible with an even lower value.

Signal quality	Level in dBm
Well	> -50 dBm
Medium	-65 dBm to- -50 dBm
Bad	< -65 dBM

⚠ CAUTION!

By attenuating the transmission level (in this case by the luminaire itself) there is a significant reduction in the range of the radio signal:

_ -3 dB corresponds to halving the signal strength.

_ -10 dB corresponds to a tenth of the original signal strength.

The final installation situation must also be taken into account!
Reinforced concrete and metal ceilings can cause significant problems!

12. Signal range test with basicDIM wireless

NOTICE

This chapter describes how to carry out a signal range test with the basicDIM Wireless from Tridonic. The description is specific for this device and cannot be transferred to other devices of a similar type.

Testing the signal range is essential to obtain information about the quality of the luminaire.

Tests should be done:

_ From luminaire to luminaire

_ From mobile device to luminaire

_ From different angles, directions and distances

_ At every stage of the luminaire development

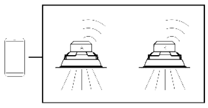
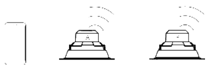
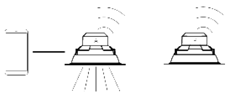
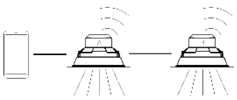
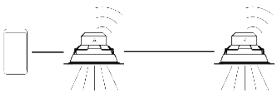
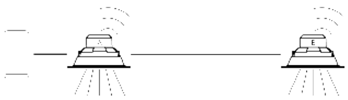
Signal range test with basicDIM wireless

⚠ CAUTION!

For the test it is important that the basicDIM wireless modules and drivers are in the same exact position as in the later installation and are not installed at a different point in the luminaire!
Changes in position change the test result and make a new test necessary (signal strength and range)!

Signal range test with basicDIM wireless

Two sample luminaires A and B with integrated basicDIM wireless are required for this test .
Proceed as follows:

1	 Set up a basicDIM wireless test network with these two sample luminaires.
2	 Disconnect both sample luminaires from mains.
3	 Switch on sample luminaire A again and wait until the basicDIM wireless app connects to it.
4	 Switch on sample luminaire B again.
5	 Move sample luminaire B away from sample luminaire A and leave the mobile device with the basicDIM wireless app with sample luminaire A.
6	 Keep pressing "All luminaires" in the basicDIM wireless app while continuously moving sample luminaire B away from sample luminaire A.
7	 Continue with that until sample luminaire B stops responding. => The distance at which this happens is the maximum range.

Influence of the spatial conditions on the luminaire

13. Influence of the spatial conditions on the luminaire

In addition to the construction of a luminaire, the conditions on site are also essential for the trouble-free operation of the luminaire. A luminaire that works in the laboratory is not a guarantee for a functioning system on site.
The following on-site conditions must be taken into account:

_ Ceiling

_ Materials in the walls

_ Windows and panes

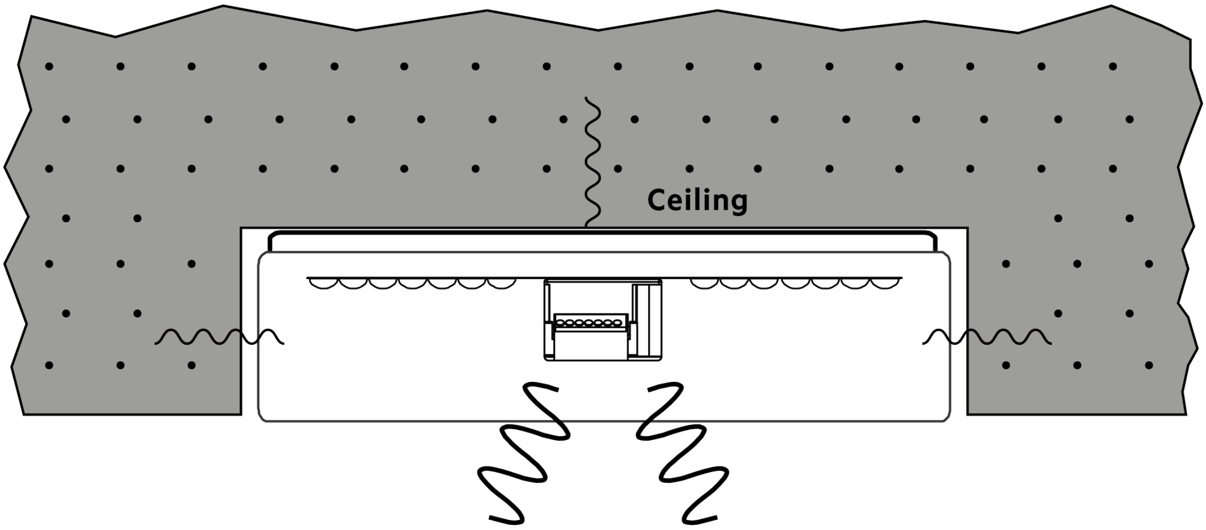
_ Other radio systems available on site

13.1. Ceiling

The influence of ceilings differs depending on the application. Attention must be paid to suspended metal ceilings and reinforced concrete ceilings. Luminaires that are free of metal only in direction of the ceiling act like a Faraday cage when they are mounted on reinforced concrete or metal ceilings.

If luminaires are recessed in reinforced concrete or metal ceilings, it must be ensured that the antenna of the luminaire's radio module is not completely enclosed on the side, but extends slightly above the ceiling.

If this is not the case, the radio signal is very strongly attenuated to the sides. The graphic below illustrates this.



13.2. Materials in the walls

Fine-meshed metal texture in the walls suppresses communication. It is advisable to check this in advance, especially in older buildings where it is not exactly known which materials were used in the walls.

Influence of the spatial conditions on the luminaire

13.3. Windows and panes

In the case of windows and panes with sun protection, it should be noted that these are often coated with metal. Such windows and panes can severely attenuate the radio signal.

13.4. Other radio systems available on site

Before installing a radio-controlled lighting solution, it makes sense to check the conditions on site with regard to other radio systems. In the 2.4 GHz frequency band in particular, correct channel selection must ensure that the systems do not interfere too much. Here it makes sense to observe the conditions on site over a longer period of time with a suitable analysis tool (e.g. with the analysis software "Metageek").
Radio systems are dynamic systems that can change at any time. Increased traffic in one radio system can lead to reduced data transmission in another radio system if both systems are on the same or overlapping channels.

NOTICE

Example for the mutual interference between two systems:
If a video conference is started via WLAN, the data throughput and the load on this channel increases. Systems that previously worked perfectly in parallel on the same channel may no longer work properly for the duration of the video conference!

13.5. Floor plan of the building

Well-functioning networks have a circular structure with few hops.

The following aspects must be considered:

_ Avoid long corridors

_ Keep the distance between luminaires as short as possible (less than the maximum range of a luminaire)

CAUTION!

Emergency applications require special attention because the distances between the luminaires can be quite large here.

13.6. "Island problem"

Unfavorable building layouts can lead to "island problems". An "island problem" occurs if a single network is divided into multiple non-contacting networks due to the physical nature of the building.

"Island problems" must be solved, otherwise the network will never function properly.
The following actions can be taken to fix the "island problem".

_ Use of repeaters

_ Split network into smaller individual networks

Influence of the spatial conditions on the luminaire

_ Keep the distance between the luminaires as short as possible (less than the maximum range of a luminaires)

14. Explanations of used terms and abbreviations

_ Bluetooth® wireless technology:
Bluetooth® wireless technology is an industry standard for data transmission between devices over short distances using radio technology. The name "Bluetooth" is derived from the Danish King Harald Bluetooth, who united warring parts of Norway and Denmark. Homepage: https://www.bluetooth.com/

_ Thread:
Thread is an IPv6-based, low-power mesh networking technology for IoT products, intended to be secure and future-proof.
Homepage: https://www.threadgroup.org/

_ WLAN:
WLAN (short for Wireless Local Area Network) is a wireless computer network that links two or more devices using wireless communication to form a local area network within a limited area such as a home, school, computer laboratory, campus, or office building.

_ ZigBee:
ZigBee is a specification for wireless networks with low data traffic such as home automation, sensor networks, lighting technology. This allows devices to communicate with each other.
Homepage: https://zigbeealliance.org/