Rosenberger

RoProxCon® – Rosenberger Proximity Connector

Influence of the Material on Contactless Data Transmission

WHITEPAPER

Introduction

Modern industrial production plants have increasingly complex and elaborate components and systems. Their networking and control are of central importance. Countless sensors on machine tools, assembly machines and handling systems continuously record data which needs to be sent reliably to IT systems or the cloud for processing in real time.

The individual system components are usually connected by electromechanical systems. However, cables and connectors are exposed to considerable stress in industrial environments and can be damaged or even fail, which would bring the system to a standstill. If conventional electromechanical connectors reach their limits – for example due to rotating components or limited service life – contactless connection systems, such as RoProxCon® which transmit data via short-range radio come into consideration.

In order to make contactless data and energy transmission as reliable as possible, material and environmental influences on the antenna unit must be minimized. This is done by designing the so-called radome. This is the part of the enclosure that protects the antenna from external influences but at the same time must be as transparent as possible for the radio waves.

In the following whitepaper, the physical background of radio wave transmission is examined and – based on this – recommendations for the design of the radome are given, particularly with regard to the influences of the material and dimensions.

Content

01 Contactless Connection System RoProxCon®

RoProxCon® is a non-contact connection system that transmits data and power over short distances by radio in the mmW range (millimeter waves). This allows design-related air gaps to be bridged without electromechanical contact. The advantages are obvious: maximum mechanical flexibility is achieved as well as high immunity to environmental influences and absolute freedom from wear which minimizes maintenance costs. RoProxCon® is therefore a reliable and efficient connection solution, particularly in demanding industrial environments.

Transmitting data

RoProxCon® is characterized by high data rates. The SoM (System-on-Module) can transmit up to 3.125 Gbit per second. This requires high bandwidths, such as those available in the mmW range. A high-frequency band in this wavelength range is 60 GHz, allowing bandwidths of up to 7 GHz and is therefore suitable for transmitting high data rates.

Details are defined in the European standard ETSI EN 305 550.

The RoProxCon® radio module is based on the ST60 from STMicroelectronics which operates at a carrier frequency of around 60 GHz. Together with the unique antenna unit developed by Rosenberger, a full-duplex transmission allows data to be transmitted simultaneously in both directions. This also ensures error-free data transmission even with different axial, radial or angular misalignment. The antenna unit from Rosenberger even allows data transmission during continuous rotation – another unique selling point that opens up even more application possibilities.

Transmitting power

In principle, there are two possible mechanisms for the contactless transmission of electrical power: coupling via the electric field or via the magnetic field. This is referred to as capacitive or inductive coupling.

RoProxCon® uses inductive coupling where an alternating magnetic field with a frequency of around 200 kHz is generated. The high efficiency power electronics developed by Rosenberger for this purpose have few electronic components so there is little heat dissipation and losses are minimal. With the RoProxCon® "Hybrid" product, powers of up to 30 W can be transmitted.

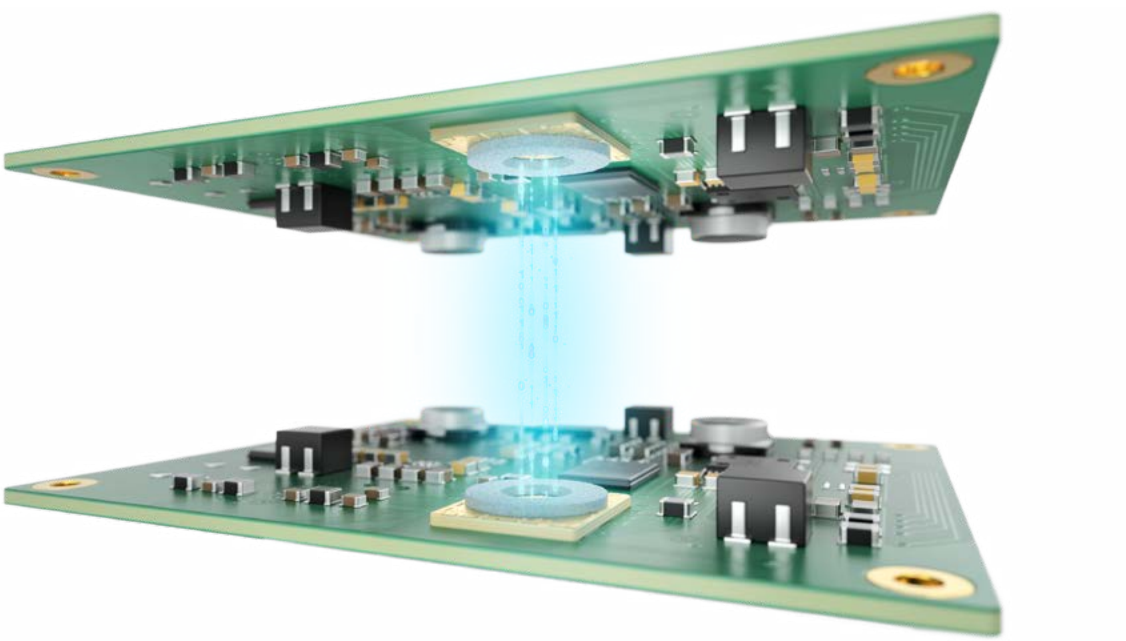

Figure 1: Data transmission with the SoM (System-on-Module)

Products and features

Product	SoM (System-on-Module)	Data	Hybrid
			
Data rate	up to 3.125 Gbit/s	up to 1 Gbit/s (Gigabit Ethernet)	up to 1 Gbit/s (Gigabit Ethernet)
Distance	up to 20 mm	up to 10 mm	up to 5 mm
Transmission	Data	Data	Data and power
Output	–	–	30 W
Misalignment	±2 mm	±2 mm	±2 mm
Rotation	0–360°	0–360°	0–360°
Advantage	Customized solutions easy to implement	Easy to integrate	Transmits data and power

02 Physical Background

Interference

Constructive and destructive interference occur when waves are superimposed.

If two or more electromagnetic waves of the same direction meet in phase this leads to a greater amplitude of the resulting wave, as the crests and troughs add up (Figure 2). Waves in phase are either not offset or offset by a multiple of the wavelength λ.
This is referred to as constructive interference.

If two or more electromagnetic waves of the same direction meet in opposite phase this leads to a lower amplitude of the resulting wave, or even to its extinction, as the crests and troughs subtract or cancel out completely (Figure 3). Waves in opposite phase are offset by a multiple of half the wavelength λ/2.
In this case, we speak of destructive interference.

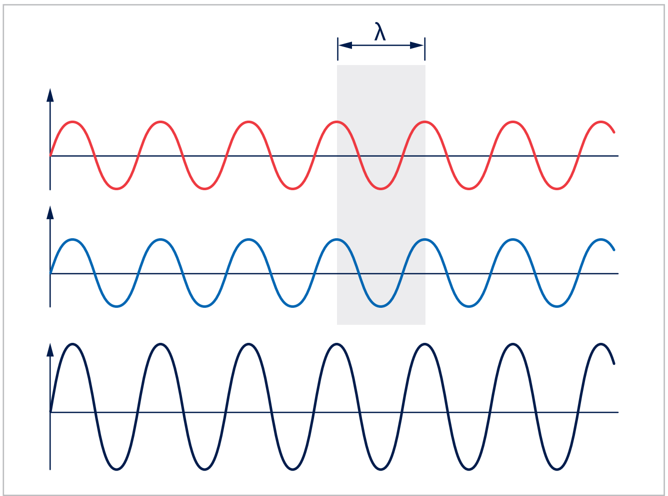

Figure 2: Amplified resulting wave (bottom) with constructive interference of two waves with phase difference λ

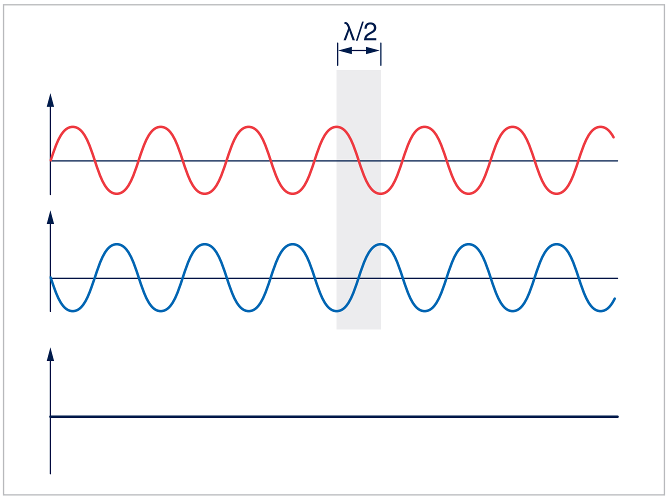

Figure 3: Canceled resulting wave (bottom) with destructive interference of two waves with phase difference λ/2

When electromagnetic waves impinge on a boundary surface between two dielectrically different materials (discontinuity), the incoming wave is partially reflected with a phase shift. This can result in interference. The amount of the reflected wave and its phase shift also depends on the dielectric properties of the two materials and the structure of the boundary surface.

Dielectric properties and characteristics

In principle, electromagnetic waves can be transmitted through a variety of materials, but these must be neither electrically conductive or magnetic. Such electrically insulating materials are also known as dielectrics. In technology, plastics as well as glass or ceramic materials are mainly used for this purpose.

The high-frequency electromagnetic waves emitted by the antenna in RoProxCon® must be transmitted through the material of the radome. There, these electromagnetic waves are partially reflected at the boundary surface and the transmitted components are attenuated (Figure 4).
If a radome material thickness of half a wavelength (λ/2) is selected the partial reflections interfere destructively and the partial transmissions constructively. This makes the radome almost transparent to the electromagnetic waves.

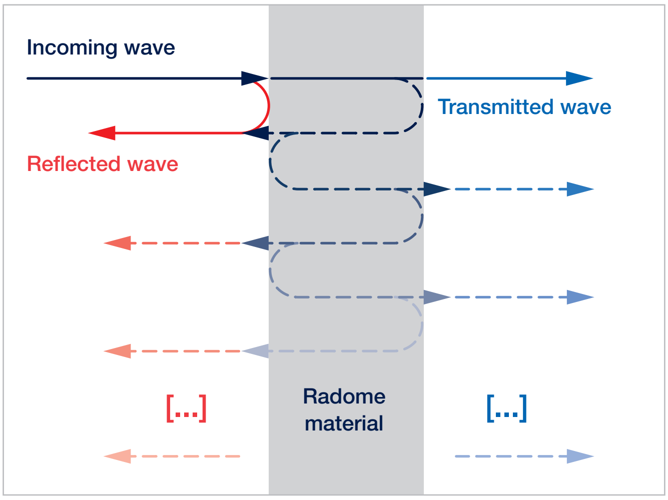

Figure 4: Proportions of the wave after impact on boundary surfaces

Knowledge and consideration of the physical properties of a material is essential for the design of discontinuities. It is a matter of estimating how well the material can store electrical charges and how it can influence the electric field compared to a vacuum. The electromagnetic material properties are identified by the relative permittivity ε_r (or: dielectric constant) and the loss factor tanδ (δ: loss angle).

The relative permittivity is a material-dependent parameter and indicates the ratio of the permittivity of the material to that of the vacuum. The relative permittivity of the material – in this case the material of the radome – provides information about the reflection of electromagnetic waves at the boundary surface to the air.

The loss factor, on the other hand, is focused on absorption losses due to the conversion into heat in the dielectric through which an electromagnetic wave is attenuated.

Together, relative permittivity and loss factor provide information about the efficiency of the propagation of electromagnetic waves in the material.

The lower the relative permittivity and the loss factor (Table 1), the lower the influence of the material on the propagation of the electromagnetic wave.

Material	Relative permittivity ε_r	Loss factor tanδ
Vacuum	1.0	0
Air	1.0006	0
Glass	6–8	0.002
Ceramics	9	0.002–0.006
Plastics	2–4	0.001–0.03

Table 1: Dielectric characteristics of selected materials

Effects on transmission

Figure 5 illustrates the influences of relative permittivity ε_r (negative y-axis, on the right in the figure) and material thickness (negative x-axis, on the front in the figure) on the transparency for electromagnetic waves (negative z-axis, on the left in the figure). The loss factor tanδ due to absorption is also taken into account (descending line at the back or curves in the negative x-direction to higher material thicknesses). The dark blue areas of the colored surface are desirable, the lighter incisions should be avoided.

If the material thickness corresponds to an integer multiple of half the wavelength (λ/2), the material is almost transparent for the intended carrier frequency of 60 GHz; in Figure 5, this takes us into the area of the dark blue wave crests.

At a carrier frequency of 60 GHz, the wavelength λ_0 is 5 mm in air and correspondingly shorter in the dielectric depending on the relative permittivity. In an exemplary dielectric with a relative permittivity $\varepsilon_r = 3$ (average relative permittivity of plastics), half the wavelength $\lambda_r/2$ is around 1.4 mm.

$$\frac{\lambda_r}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon_r}} = \frac{5}{2\sqrt{3}}\ \text{mm} \approx 1.4\ \text{mm}$$

The values of the exemplary calculation are shown in the point marked in red.

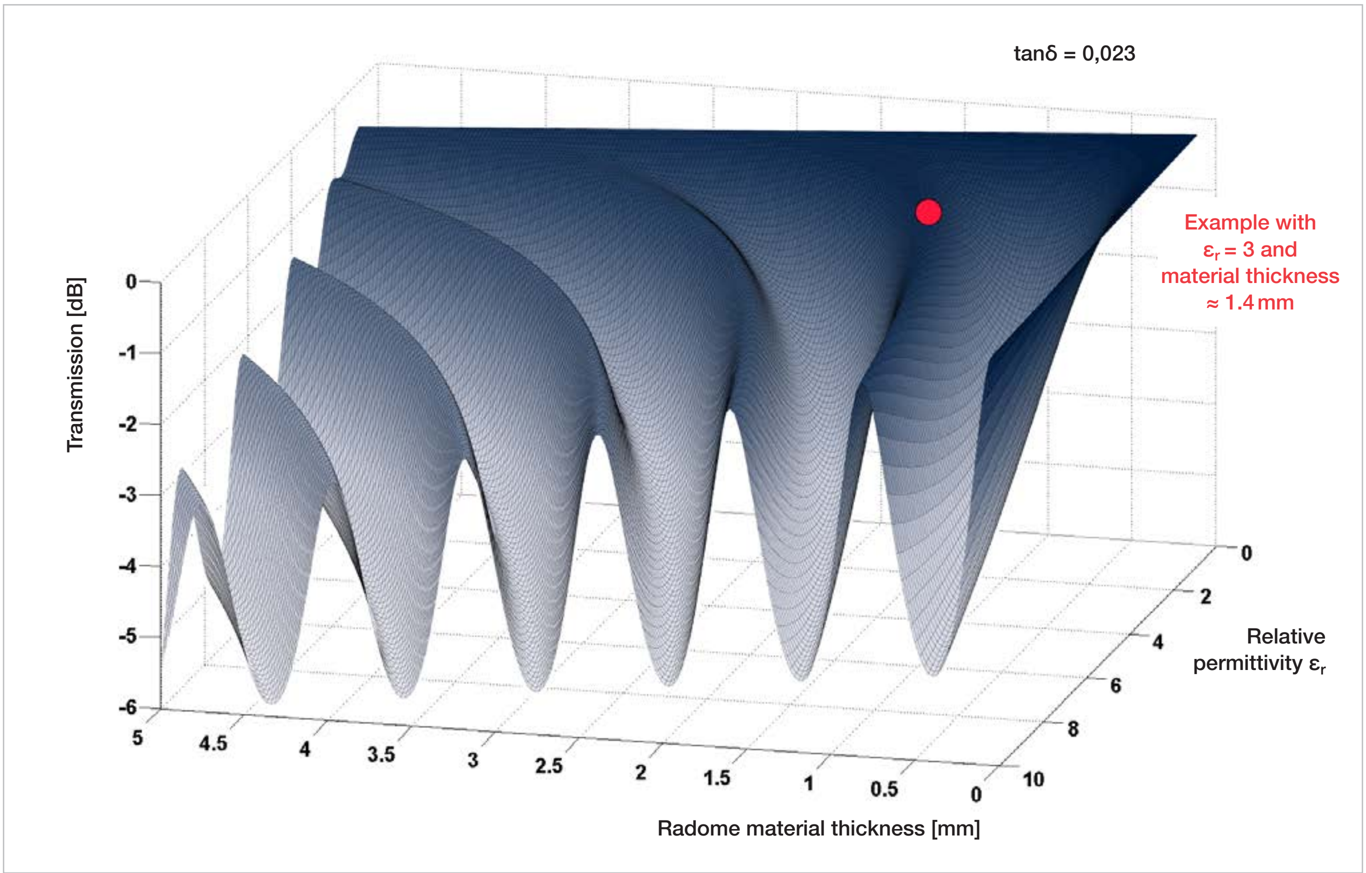

Figure 5: Combination of the influences of relative permittivity ε_r, loss factor tanδ and material thickness on the transmission of electromagnetic waves

Note that the destructive interference effects and therefore the losses in transmission due to an incorrectly designed material thickness, outweigh the selection of a material with high dielectric losses. Figure 5 shows this correlation: The effect of the dielectric loss factor (here tanδ = 0.023) is shown by the continuous drop in the curve towards the higher material thicknesses of the radome. However, this drop is significantly lower than the effects of the interference effect when the wrong material thickness is selected which leads to the lossy wave troughs.

Figure 6 illustrates the same relationships as Figure 5 but reduced to a view from above. In contrast to Figure 5, the x and y axes are referenced to a coordinate origin at the bottom left.

Here too, the dark blue areas with minimal losses in the transmission of the waves are desirable while the lighter areas should be avoided.

The values of the exemplary calculation are shown in the point marked in red.

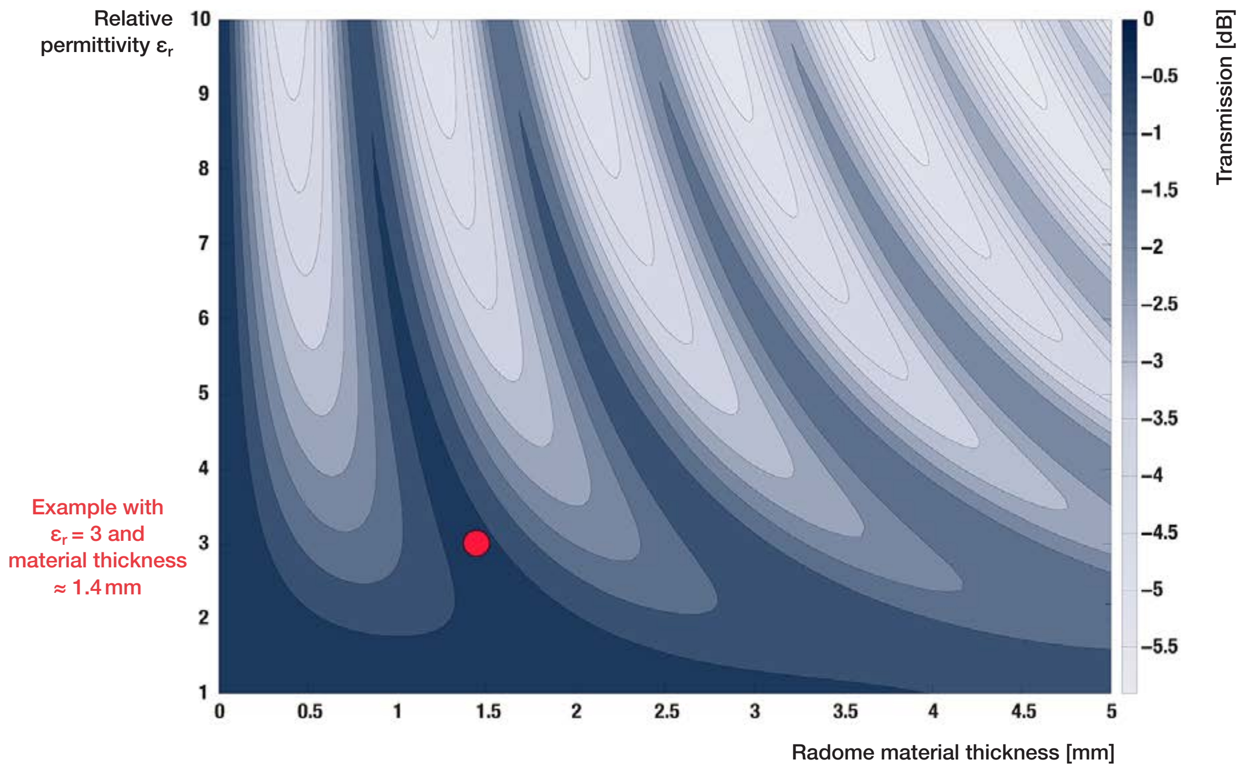

Figure 6: Combination of the influences of relative permittivity ε_r and material thickness on the transmission of electromagnetic waves at loss factor $\tan\delta = 0.023$ in plan view

03 Recommendations for the Design of the Radome

Material

In principle, electromagnetic waves cannot be transmitted through electrically conductive or magnetic materials.

Recommendation

Avoid electrically conductive or magnetic materials. All metallic materials are therefore to be excluded.

The structure of the boundary surface influences the reflective behavior of a material surface.

Recommendation

Avoid surface structures, provide only smooth surfaces for the radome.

The lower the relative permittivity, the lower the proportion of the reflected wave.

Recommendation

Only consider materials where their relative permittivity and loss factor are known.

Select materials for the radome with the lowest possible permittivity.

Ideally, the relative permittivity of the material for the radome should be as close as possible to the value 1, as it also has a value of around 1 in air at which electromagnetic waves are transmitted with no interference.

Recommendation

Materials with a relative permittivity close to 1 are generally porous and have air inclusions which have a negative impact on both strength and dielectric properties (due to additional boundary surfaces in the material). They are therefore unsuitable as a material for the radome in an industrial environment.

Select materials that are as homogeneous as possible, ideally without air or other material inclusions.

In industrial environments, most useful are non-flammable, easily machinable and mechanically and thermally stable materials with good dielectric properties.

Recommendation

Plastics are the preferred material for the radome. Table 2 shows typical types of plastic that are particularly suitable.

Material	**Relative permittivity ε_r**	**Loss factor tanδ**	**Optimum material thickness [mm]**
Polyamid PA 6.6	3.2	0.01	1.40
Polybutylen-terephthalat PBT	3.4	0.02	1.36
Polyoxymethylen POM	2.9	0.03	1.47

Table 2: Dielectric parameters and optimum material thickness of the radome for recommended plastics

Dimensions

The material thickness of the radome plays a decisive role in the propagation of electromagnetic waves in the mmW range.

Recommendation

Ensure that the material thickness corresponds to an integer multiple of half the wavelength (λ/2). This means that the material is almost transparent for the intended carrier frequency of 60 GHz and the transmission losses are low.
In the example with $\varepsilon_r = 3$ (Figures 5 and 6), half the wavelength is calculated in the radome:

$$\frac{\lambda_r}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon_r}} = \frac{5}{2\sqrt{3}} \text{ mm} \approx 1.4 \text{ mm}$$

The maximum permissible distance between the two antennas for the SoM (System-on-Module) is 20 mm.

Recommendation

Observe the maximum permissible distances (Figure 7). Between the antennas consider twice the distance from the antenna to the radome **A**, twice the material thickness of the radome **B** and the width of the air gap **C**.

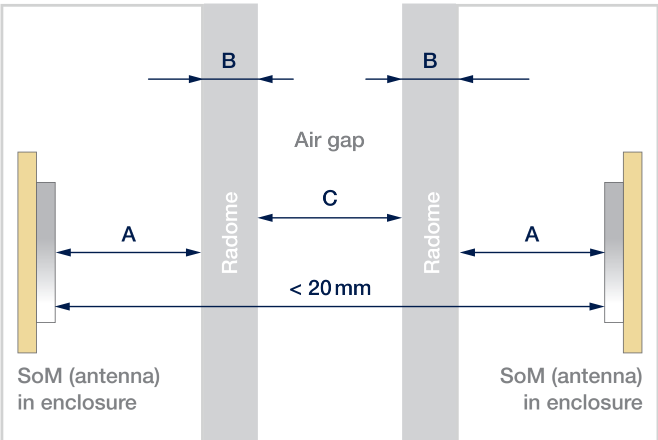

Figure 7: Distances for transmission via an air gap

The SoM (System-on-Module) tolerates misalignment between the opposing antenna units.

Recommendation

When positioning, do not exceed the maximum permissible values for the offset of ±2 mm and the inclination of 3°.

Contaminations

Industrial systems face a variety of challenges, such as extreme temperatures, contamination in the air gap from dust, particles or metal chips as well as moisture or lubricants. Deposits of low thickness on the enclosure and radome are not critical, but it still makes sense to check the ambient conditions and their contamination.

Recommendation

Design the housing to be dust-tight in accordance with protection class IP6X.

Provide access for cleaning both radomes.

04 Summary

When integrating the RoProxCon® SoM (System-on-Module) into your specific system, the design of the radome – i.e. the part of the enclosure through which the radio waves are transmitted – determines the efficiency of the contactless connection.

It is very important to consider the dielectric properties of the projected material and the interaction of all material influences. The design of all dimensions, in particular the material thickness, also has a direct impact on the transmission of electromagnetic waves.

Use our support especially for design questions about RoProxCon®. We will be happy to advise you!

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