BGT60LTR11AIP radome design guide

XENSIV™ 60 GHz radar sensor

About this document

Scope and purpose

This application note provides a guideline on how to design radomes for the Infineon's XENSIV™ 60 GHz radar BGT60LTR11AIP. General recommendation on the selection of the radome material as well as the proper values for the radome thickness and radome distance are given. Additionally, the effect of deviations from the recommended values are presented to emphasize the importance of a diligent radome design.

Intended audience

The intended audience for this document are design engineers, technicians, and developers of electronic systems, planning to use the XENSIV™ BGT60LTR11AIP in combination with a cover or radome placed in front of the sensor. The information provided in this application note is not only limited to BGT60LTR11AIP and can be also applied to other radar sensors.

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1 General considerations on radome design and PCB layout

A radome is a radar sensor enclosure or cover to protect the sensor or hide it from the product outlook, however, the radome will impact on the radar performance reducing the signal strength of the detected radar targets. The objective of this document is to provide some guidelines for the radome design taking the BGT60LTR11AiP sensor as an example in order to ensure the expected performance of the radar system. For further information, it is recommended to read the general whitepaper about radome design [1]. There are two different frequency bands for the sensor at 60 GHz and 61 GHz. This will lead to small difference in the wavelength ($\lambda_{60\text{GHz}}$= 5 mm and $\lambda_{61\text{GHz}} \approx$ 4.92 mm) and the wavelength related radome geometry and positioning.

1.1 Material considerations

- The dielectric properties of the radome material (dielectric losses and relative permittivity value) at the operating frequency range are important to be considered. They should be measured at the operating frequency first if no data is available.

- **Recommended: plastics** like Teflon, Plexiglas, polycarbonate or ABS.

- **Avoid: metals** – solid metals, but even thin foils like aluminum foil will hinder radar operation through them. Some paint colors contain tiny metal particles which greatly reduce radar signal strength as well.

- **Avoid: dielectrics that are not listed above**. For example, some dielectrics are lossy and absorb radar radiation. A list of materials and their losses at a frequency of 60 GHz can be found in Table 2 of the whitepaper [1]. For example, even a thin layer of water on the surface will drastically attenuate radar signals. Other examples of materials to avoid are dielectrics with high electrical permittivity (e.g., the ceramic zirconia) which reflect most of the radar radiation instead of letting it pass through.

1.2 Mechanical considerations

- The distance between the BGT60LTR11AIP and the radome should be half the free-space wavelength (λ/2 ≈ 2.46 mm at 61 GHz and λ/2 ≈ 2.5 mm at 60 GHz) or multiples of that, see Figure 1a – for lower distances, refer to the whitepaper [1]. More details on the correct choice of the radome distance can also be found in section 2.

- Placing any components in close proximity of the antenna(s) should be avoided. This includes dielectric materials like the radome. Components placed in the antenna near-field will not only block parts of the radiation but also affect important antenna characteristics like the antenna impedance. As a consequence, the antenna matching will also be affected. This can lead to a reduced power radiated by the antenna which again will reduce the detection range. If placement of the radome in the antenna near-field cannot be avoided, the effect on the antenna performance is required to be investigated in individual EM simulations or measurements.

- Field of View (FoV): The placement and orientation of the radar sensor can be used to adjust the field of view according to the application and environment. For example, in Figure 1b, a simple tilting of the sensor towards the floor shapes the FoV in a manner that a fan at the ceiling will no longer be detected. For more details on how to shape the FoV for example with lenses, refer to the whitepaper [1].

- The radome should be formed by an isotropic homogeneous material and provide smooth surfaces. Avoid holes, drills or other modifications on the radome in the field of view of the radar.

- Vibrations: Mount the whole radar system rigidly so there are no vibrations. Avoid vibrations between the radome and the radar antennas at all costs!
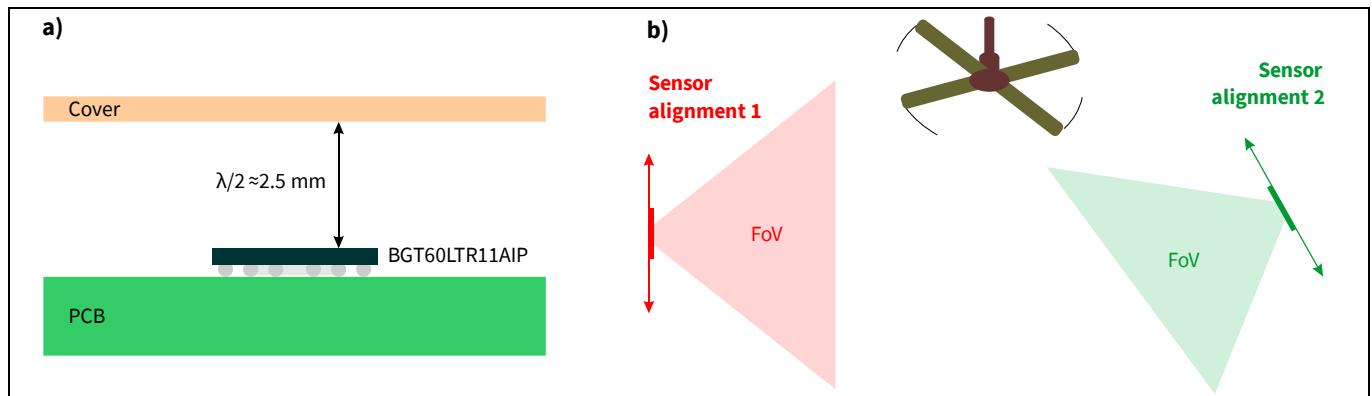
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Figure 1   **Spacing between BGT60LTR11AIP and radome (a) and tilting a sensor to avoid detection of unwanted targets (b)**

1.3 Electrical considerations

- For the antennas in the BGT60LTR11AIP to function as designed, the sensor needs a strong connection to a grounded copper plane. The PCB with the grounded copper plane should extend at least λ ($\lambda \approx 4.92$ mm at 61 GHz and $\lambda \approx 5$ mm at 60 GHz) in all directions around the BGT60LTR11AIP. Place as few components as possible in this area, e.g., the de-coupling capacitors for the supply of the radar sensor. These components should have heights that are smaller than the package height of the BGT60LTR11AIP (≈ 0.6 mm), as shown in Figure 2a and Figure 2b.

- It is recommended to place all components besides the de-coupling capacitors on the backside of the PCB. In case not all components can be placed on the backside this should be considered in particular for all taller (i.e., more than 0.6 mm in height) components. If necessary, some of the smaller components can be placed on top side of the PCB with a much distance as possible from the BGT60LTR11AIP so that they cannot interfere with the antenna radiation (Figure 2b).

- In the case of a metallic casing, the cover has to be replaced with plastic at the position of the sensor. If the smallest cover distance of half the wavelength in air is chosen the plastic should extend at least λ ($\lambda \approx 4.92$ mm at 61 GHz) around the sensor in all directions, as shown in Figure 2c and Figure 2d.

1.4 PCB layout

- It is strongly recommended to follow the PCB layout of the reference design as close as possible in order to achieve reliable performance. Modifications of the layout in proximity of the sensor can affect the radiation performance and lead to a decrease in gain or a tilt of the radiation pattern.
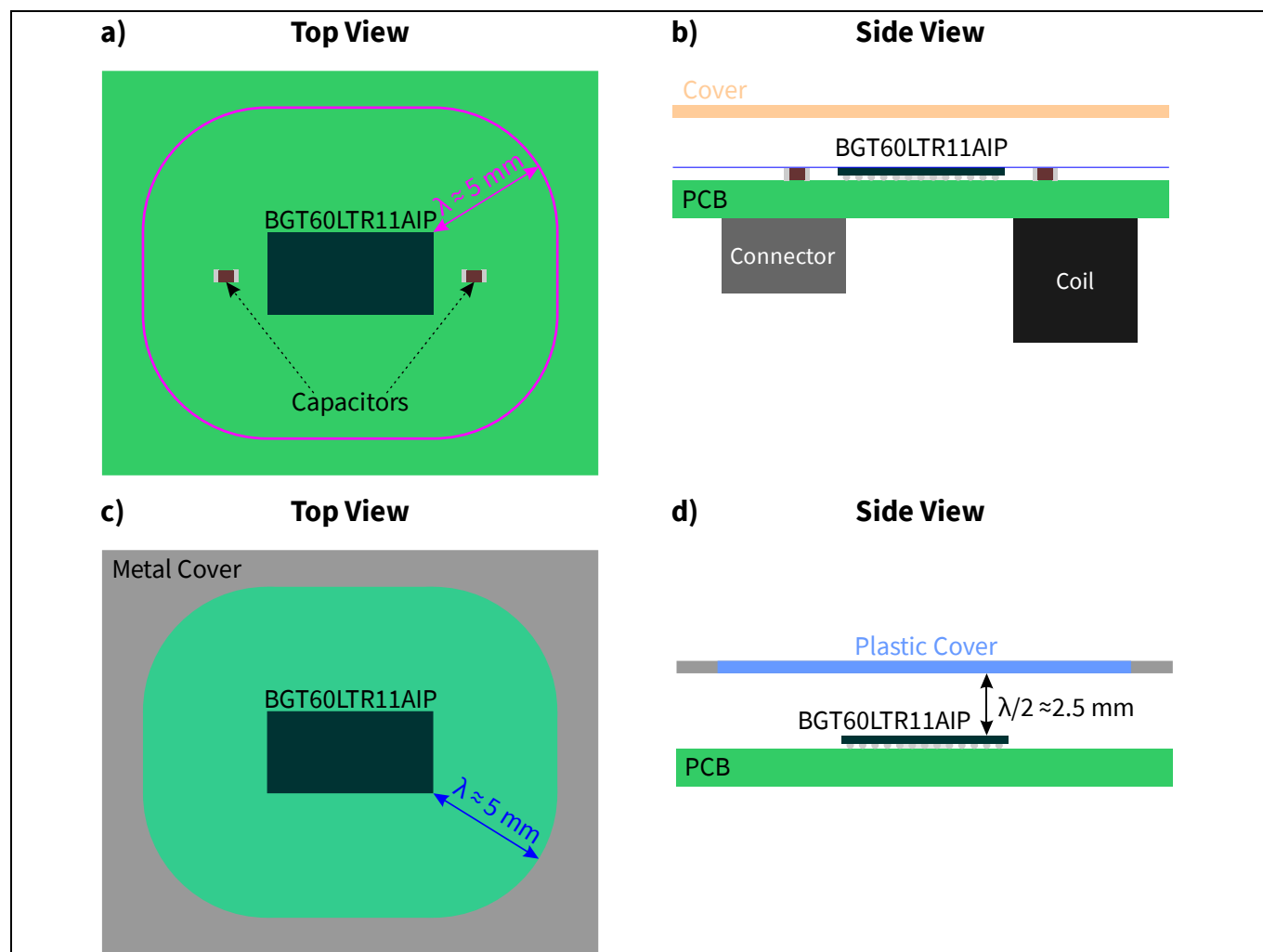
Figure 2   **Minimum PCB size (with grounded copper) around BGT60LTR11AIP (a), component placement near the sensor (b), and restrictions with metal casings (c) and (d) for 60 GHz**

2 Radome thickness and radome distance

In this section the effect of a radome on a radar sensor is investigated in more detail. Based on this analysis recommended design values for the radome thickness and radome distance are provided.

2.1 General radome setup, impact, and design

The basic radome setup is displayed in Figure 3a. The change in the relative permittivity value ε_r on the surface between air and radome causes the radar signal to be partially reflected when entering and also when exiting the radome. The magnitude of the reflection coefficients $|r|$ rises with an increasing relative permittivity value of the radome material. As a result, parts of the signal will be reflected multiple times inside the radome travelling back and forth with only a portion of the signal being able to leave the radome at each side. The portions of the signal which leave the radome travelling back to the radar sensor are again partially reflected back from the sensor antenna structures and the PCB.

The desired transmit signal after the radome, is formed by the superposition of all individual multipath signal portions. Maximum transmission through the radome is achieved when all of these signals sum up in phase. To fully include all of these effects, the distance from the radome to the BGT60LTR11AIP and the thickness of the radome need to be investigated and evaluated together.

The recommended values are:

- The ideal thickness of the radome d_2 being integer multiples of half of the wavelength inside the radome material λ_{radome} but as thin as possible: $d_2 = m_2 \cdot \frac{\lambda_{\text{radome}}}{2} = m_2 \cdot \frac{\lambda}{2n_2}$

- The ideal distance of the radome in front of the sensor d_1 being integer multiples of half of the wavelength in free-space λ but as far as possible: $d_1 = m_1 \cdot \frac{\lambda}{2}$

This provides the reflected signals to be offset by multiples of the wavelength or 2π towards the signal travelling directly through the radome.

A detailed analysis of the radome impact taking all effects into account requires electromagnetic (EM) simulations of the whole setup including sensor and radome. This becomes especially important in cases where the ideal values for radome thickness and distance cannot be met. An alternative approach to estimate the influence of the radome on the transmission behavior will be introduced in the next section.
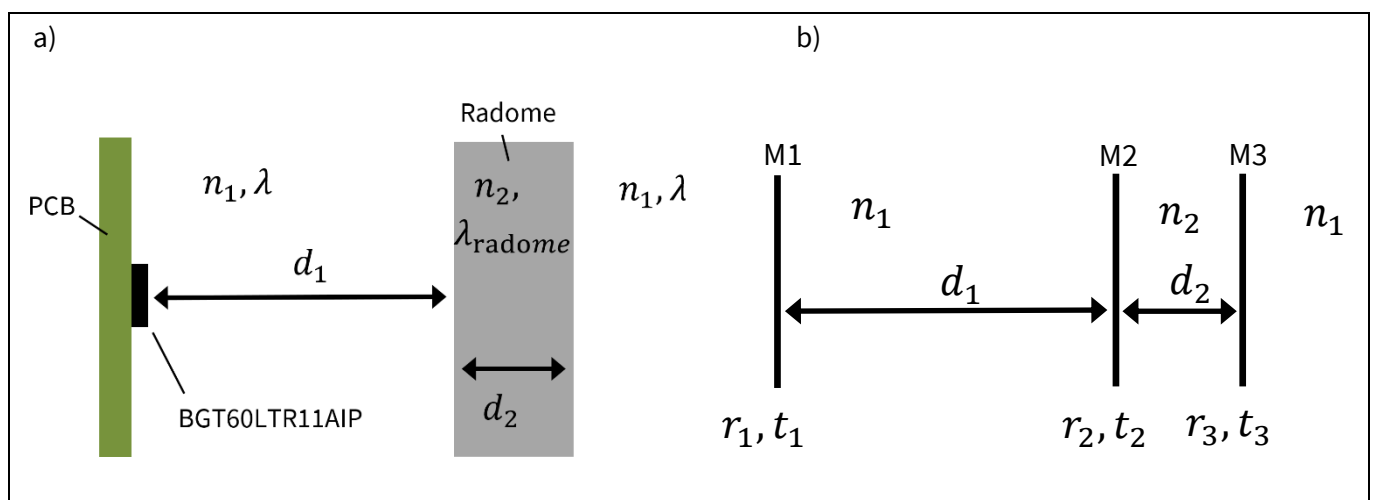

Figure 3 Radome placed in front of radar sensor with important design parameters (a) and corresponding Fabry Perot model (b)

Where d_1 is the radome distance, d_2 is the radome thickness, n_1 is the refractive index of air, n_2 is the refractive index of the radome material, r_1 & t_1 are the reflection and transmission coefficients at the sensor, r_2 & t_2 are the reflection and transmission coefficients at the interface from air into the radome, r_3 & t_3 are the reflection and transmission coefficients at the interface from the radome into air and M1, M2 & M3 are the three partly transparent mirrors.

2.2 Fabry Perot model

An analogy to describe a radome setup can be found in the Fabry Perot resonator which is typically used in the optical domain. The general Fabry Perot theory describes the transmission and reflections of a signal passing through a pair of partly transparent mirrors. The radome itself can be seen as such a two-mirror system. The model can be extended to a three-mirror scenario in order also to consider the antenna structures as an additional mirror for the signals being reflect backwards from the radome. Figure 3a shows the scenario of a radome placed in front of the radar sensor with the most relevant parameters. The corresponding three mirror (M1, M2 & M3) Fabry Perot configuration is presented in Figure 3b.

- The transmission T of a three mirror Fabry Perot system can be calculated by:

$$T = \frac{t_1^2 t_2^2 t_3^2}{D}$$

with:

$$D = 1 + (r_1 r_2)^2 + (r_2 r_3)^2 + (r_1 r_3)^2 + 2r_1 r_2 (1 + r_3^2) \cos \varphi_1 + 2r_2 r_3 (1 + r_1^2) \cos \varphi_2 + 2r_1 r_3 \cos(\varphi_1 + \varphi_2)$$
$$+ 2r_1 r_2^2 r_3 r_3 \cos(\varphi_1 - \varphi_2)$$

and:

$$\varphi_1 = 4\pi \frac{f}{c} d_1, \ \varphi_2 = 4\pi \frac{f}{c} d_2 n_2, \ t_{2/3} = \sqrt{1 - r_{2/3}^2}, \ r_2 = \frac{n_1 - n_2}{n_1 + n_2} \text{ and } r_3 = \frac{n_2 - n_1}{n_2 + n_1}.$$

- The transmission coefficients $t_{2/3}$ and reflection coefficients $r_{2/3}$ are dependent on the refractive index of the radome material $n_2 = \sqrt{\varepsilon_{r,\text{radome}}}$ with the refractive index for the free-space environment of $n_1 = 1$. The radome distance is expressed as d_1 and the radome thickness as d_2.
- The reflection and transmission coefficient (r_1 & t_1) are not clearly defined in this model and can be used as scaling factors to match the results with simulations or measurements. For optimal performance the transmission T should be maximized at the operating frequency f by proper choice of the radome thickness, distance and material. More background on the three mirror Fabry Perot theory can be found in [2].

It is important to note that this equation provides only an approximation of the transmission behavior and also does not consider any near-field effects. It is also not suitable to calculate absolute values for the transmission. Besides, the equation is only valid for a limited field of view in which the direction of propagation can be approximated as being perpendicular to the radome face when using a planar radome. For a larger FoV the equations are only valid for a curved radome with the antenna placed in the center. This ensures that the radome thickness and distance are constant for all angles.

Nevertheless, a rough first estimation of a chosen setup can be performed with the Fabry Perot equation without complex and time-consuming EM simulations as well as a comparison of the effects of different design parameters.

3 Impact of non-ideal radome design values

After providing the values for the ideal radome thickness and radome distance it is worth to investigate the impact of deviations from these recommended values. With the previously presented Fabry Perot calculation the effect of a non-ideal radome design can be demonstrated. Therefore, the radome thickness (d_2) and relative permittivity ($\varepsilon_{r,\text{radome}}$) will be altered with the transmission magnitude plotted over various radome distances (d_1) between 1 mm and 10 mm.

3.1 Impact of the radome distance

Four different radome thicknesses ($d_2 = \lambda_{\text{radome}}/2, \lambda_{\text{radome}}/4, \lambda_{\text{radome}}/8, \lambda_{\text{radome}}/16$) are investigated, specified with respect to the wavelength inside the radome material at 61 GHz, (i.e., $\lambda_{\text{radome}} = 2.92$ mm with $\varepsilon_{r,\text{radome}} = 2.84$). The results are presented in Figure 4.

- For the ideal thickness of half the wavelength ($d_2 = \lambda_{\text{radome}}/2$) in the radome material, the Fabry Perot calculation shows a constant transmission behavior over different radome distances (d_1). If other thicknesses are chosen, a variation of the transmission magnitude becomes visible for a variation of the radome distance d_1. This leads to local maxima and minima of the transmission with the maxima located close to the previously specified optimal distances of half the free-space wavelength or multiples ($d_1 = m_1 \cdot \frac{\lambda}{2}$). Nevertheless, the exact position of the maxima changes with thickness variations.

- The variation of the transmission magnitude with respect to the radome distance becomes maximal for a radome thickness equal to a quarter of the wavelength ($d_2 = \lambda_{\text{radome}}/4$) inside the radome material. For this value, the transmission magnitude becomes strongly sensitive towards the radome distance (d_1). This means that a change in the radome distance causes strong variations in the amplitude of the transmission through the radome. It can be seen that minima and maxima of the transmission amplitude occur periodically. In such a configuration it is still possible to find appropriate values for the radome distance which provide strong transmission of the signal. Attention must be paid to avoid distances corresponding to a minimum in the transmission magnitude leading to a significant decrease in signal range and a reduced detection range.

The effect of the radome thickness in combination with the radome distances has also been confirmed in EM simulations and measurements. In both, simulations and measurements, the optimum thickness of half the wavelength ($d_2 = \lambda_{\text{radome}}/2$) in the radome material still results in a variation of the transmission magnitude over the radome distance. This is mostly due to the fact that the simulations and measurements feature a planar cover with the full signal propagation and not only a single signal path perpendicular to the cover as with the Fabry Perot theory. EM simulations can be used in this case to identify the optimum positioning of the radome.
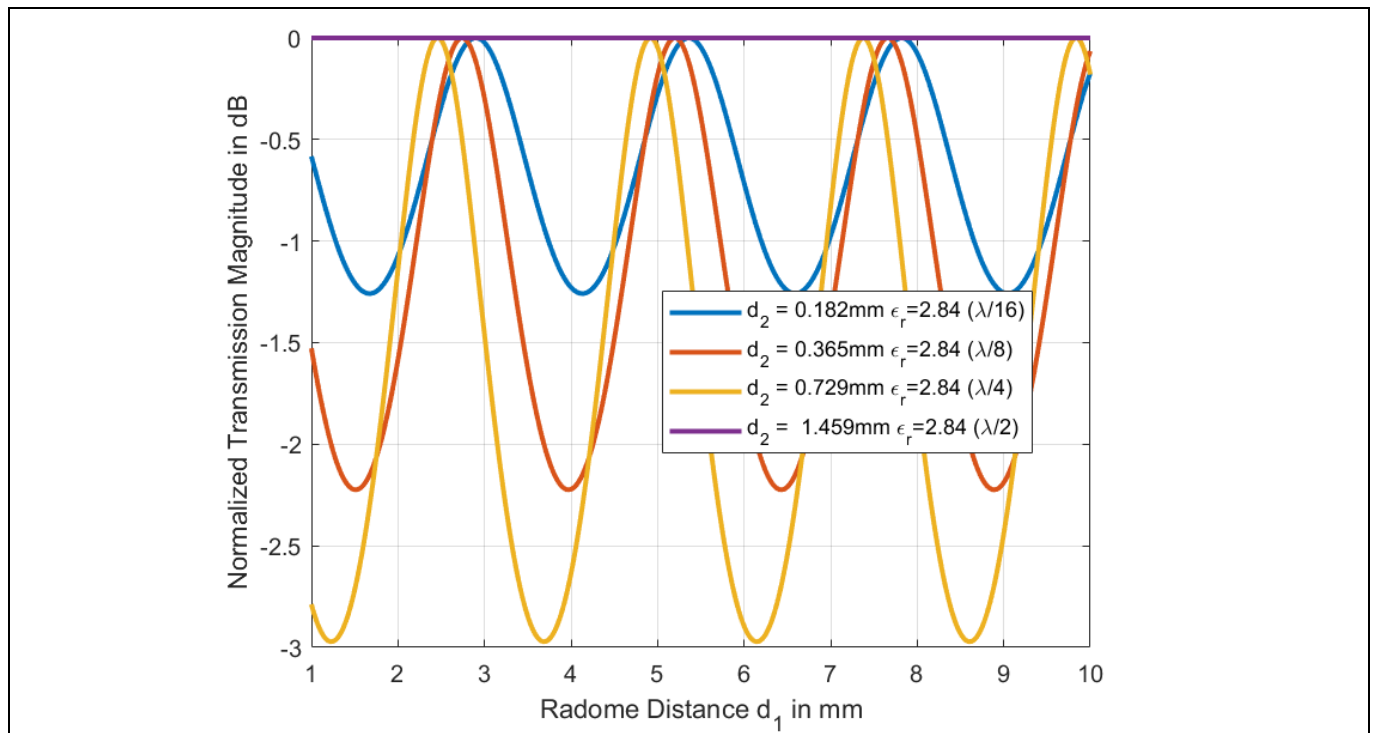
Figure 4   Calculated transmission magnitude according to the Fabry Pero model for four different radome thicknesses ($\lambda_{\mathrm{radome}}$/2, $\lambda_{\mathrm{radome}}$/4, $\lambda_{\mathrm{radome}}$/8 and $\lambda_{\mathrm{radome}}$/16) at 61 GHz

3.2   Impact of radome's relative permittivity ($\varepsilon_{r,\mathrm{radome}}$)

The relative permittivity of the radome material affects the transmission behavior in two different ways:

- Additionally, a change in the relative permittivity of the radome material also results in a change of the reflection coefficient at the radome surface. An increase in the relative permittivity increases the magnitude of the reflection coefficient. If the magnitude of the reflection coefficients increases, the impact of those signals which are reflected multiple times in the setup becomes more dominant compared to the signals travelling straight through the radome. As a consequence, the effects of the radome thickness and distance become more significant and also a general decrease in transmission magnitude occurs. Figure 5 shows the resulting transmission of the Fabry Perot calculations for different relative permittivity values ($\varepsilon_{r,\mathrm{radome}}$). The radome thickness was adapted to the change in the permittivity value in order to result in a thickness of $d_2 = \lambda_{\mathrm{radome}}/4$.

- An increase in the relative permittivity $\varepsilon_{r,\mathrm{radome}}$ decreases the transmission magnitude for all radome distances. This means that even if the optimum values for radome thickness and distance are selected a higher permittivity value will worsen the transmission behavior. The position of the minima and maxima are not affected by the permittivity if the thickness is adapted accordingly. The effect of the permittivity reduces when the thickness is closer to the ideal thickness. By choosing the ideal radome thickness the effect of the permittivity can be minimized.

Therefore, the use of radome materials with lower relative permittivity values is recommended. The closer the permittivity value is to 1, the value for free-space, the less reflections will occur at the radome interfaces. If possible, values above 3 should be avoided.
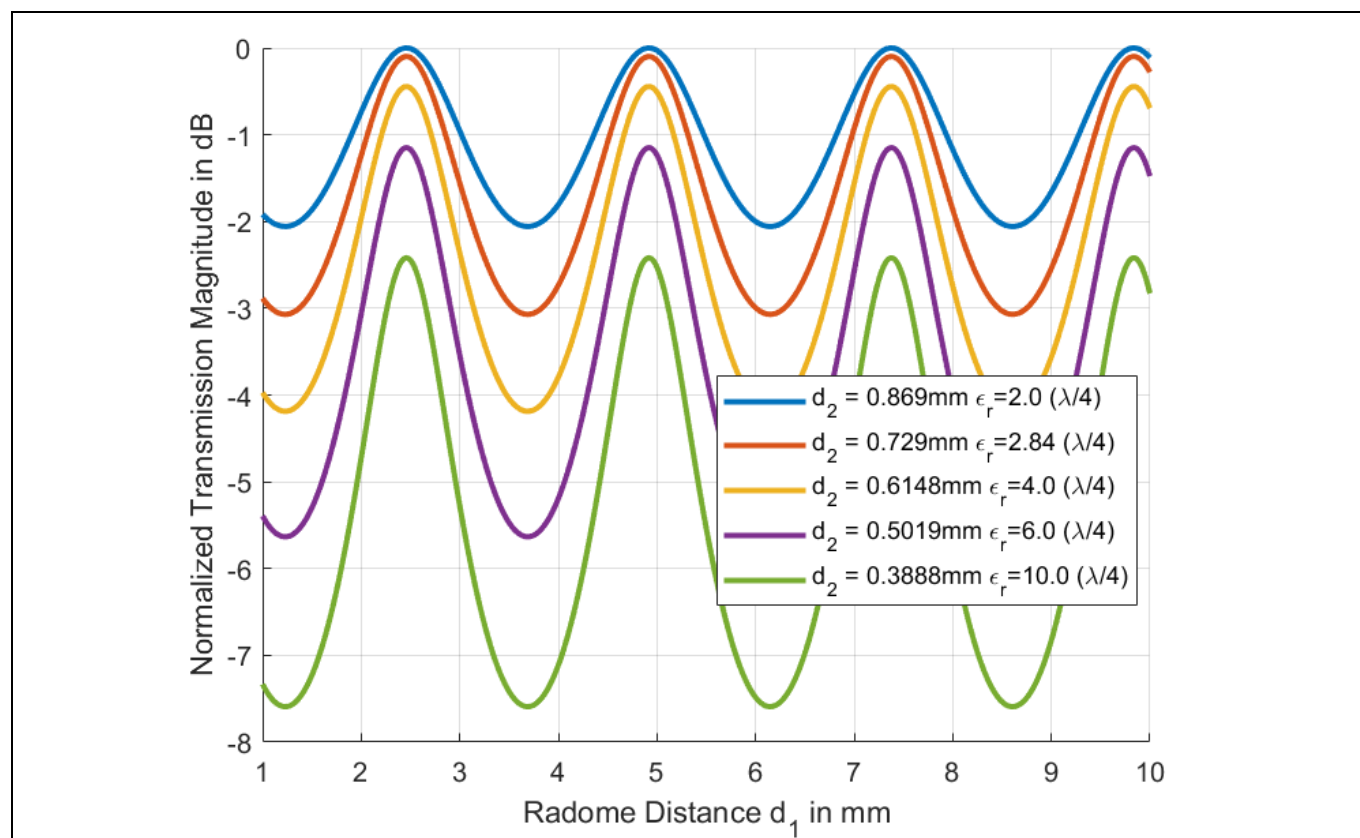
Figure 5 Calculated transmission magnitude according to the Fabry Pero model for different relative permittivity values (ε_r) at 61 GHz all normalized on the maximum value for a thickness (d_2) of 0.869 mm

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4 Examples

Table 1 provides the values of the wavelength inside the material at 61 GHz for different dielectric materials from [1] and the resulting recommended radome thickness. This overview emphasizes how strongly the wavelength inside the material and therefore, the recommended radome thickness depends on the relative permittivity and consequently can vary for different materials.

Table 1   Recommended radome thickness for various materials from [1] at 61 GHz

Material	Relative Permittivity ε_r (Measured in Infineon Lab according to [1])	Wavelength inside material (at 61 GHz) : $\lambda_{\text{radome}} = \dfrac{c_0}{f\sqrt{\varepsilon_r}}$	Recommended thickness (at 61 GHz): $d_2 = m_2 \cdot \dfrac{\lambda_{\text{radome}}}{2}$	Recommended distance (at 61 GHz): $d_1 = m_1 \cdot \dfrac{\lambda}{2}$
Poron	1.6	3.88 mm	$m_2 \cdot 1.94$ mm	$m_1 \cdot 2.46$ mm
Teflon (PTFE)	2	3.48 mm	$m_2 \cdot 1.74$ mm	$m_1 \cdot 2.46$ mm
Plexi glass	2.2	3.31 mm	$m_2 \cdot 1.66$ mm	$m_1 \cdot 2.46$ mm
Polycarbonate	2.6	3.05 mm	$m_2 \cdot 1.52$ mm	$m_1 \cdot 2.46$ mm
ABS	2.9	2.89 mm	$m_2 \cdot 1.44$ mm	$m_1 \cdot 2.46$ mm
Polyamide-nylon	3	2.84 mm	$m_2 \cdot 1.42$ mm	$m_1 \cdot 2.46$ mm
HPFS glass	3.8	2.52 mm	$m_2 \cdot 1.26$ mm	$m_1 \cdot 2.46$ mm
Gorilla glass	≈7	1.86 mm	$m_2 \cdot 0.93$ mm	$m_1 \cdot 2.46$ mm

Where f is the operating frequency, c_0 is the speed of light in free-space and λ is the free-space wavelength.

5 Summary

As conclusion, the main guidelines for the radome design are summed up in this section:

- Ideal radome distance from the BGT60LTR11AIP MMIC: $d_1 = m_1 \cdot \frac{\lambda}{2}$, but as far as possible.
- Ideal radome thickness: $d_2 = m_2 \cdot \frac{\lambda_{\text{radome}}}{2}$, but as thin as possible.
- Prefer low loss dielectric materials for radome design.
- Prefer materials with low relative permittivity ε_r for radome design.
- Do not place the radome in the antenna near field.

References

[1]   Infineon Technologies AG. Radar wave propagation through materials. White Paper, 2020.

[2]   Sake J. Hogeveen and Herman van de Stadt, Fabry-Perot interferometers with three mirrors, Appl. Opt. 25, 4181-4184, 1986.

Revision history

Document revision	Date	Description of changes
1.00	2020-10-20	Initial version
1.10	2021-07-15	Added sections 2-5
1.20	2023-02-14	Miscellaneous document cleanup updates