Electromagnetic bandgap (EBG) structure

For XENSIV™ BGT60LTR11AIP 60 GHz radar

About this document

Scope and purpose

Infineon's XENSIV™ BGT60LTR11AIP provides excellent antenna performance while simultaneously featuring a small size and low cost. This application note introduces the use of an electromagnetic band gap (EBG) design for 60 GHz radar sensors with integrated antennas in case of additional available space on the PCB. Using an EBG design can further improve isolation between the sensor package and PCB circuitry. As a consequence, the impact of the actual PCB layout and PCB size on the resulting radiation pattern will be reduced. The document first explains the impact of the PCB layout on the radiation characteristics and then introduces the EBG as a potential solution. Simulation and measurement results with the BGT60LTR11AIP radar sensor demonstrate and highlight the benefits of the designed EBG structure.

Intended audience

This document is intended for users who want to learn more about the EBG concept used on the BGT60LTR11AIP shield v3.1 [8] or who are looking for a solution to achieve consistent radiation performance with their custom BGT60LTR11AIP PCB design.

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1 Introduction

The general idea of integrating antennas into the radar sensor package is to provide a complete system with small physical dimensions which is easy to use and integrate into various applications. This is also supported by the no longer necessary design of external antennas and other radio frequency (RF) structures and the great flexibility in the choice of PCB laminate materials.

However, the impact of the carrier PCB on the radar sensor performance cannot be completely ignored. Important sensor properties like the shape of the radiation pattern, the maximum radiation gain, or the TX-RX isolation can be affected by the actual PCB design. Therefore, important system performance indicators like the sensor field of view (FoV), the maximum detection range or the signal-to-noise ratio (SNR) may differ between various PCB layouts.

Consequently, specified performance values might only be valid in combination with a particular PCB. This can require the performance of EM simulations of the complete system consisting of radar sensor and PCB to evaluate the performance when using a custom PCB design or even when just making modifications to an existing and tested PCB design. Nevertheless, Infineon's BGT60LTR11AIP in general has proven to have excellent antenna performance while featuring a small size and low cost on different PCB designs.

This document explains the interactions between sensor package and carrier PCB, focusing mainly on the radiation characteristics. The EBG concept is introduced as a potential solution to reduce the sensitivity of a radar sensor with integrated antennas toward the PCB design and to provide more consistent performance between various PCB layouts. The simulation and measurement results highlighting the benefits of the EBG design are based on the BGT60LTR11AIP [1]. Nevertheless, the EBG concept itself is not in general limited to a specific radar sensor or frequency. However, addressing different frequency bands will require the design of different EBG geometries.

2 PCB impact on radar sensors with integrated antennas

Many of Infineon’s 60 GHz radar sensors feature an antenna-in-package (AIP) configuration where the complete radio RF system consisting of silicon and antennas is integrated into a small package. This concept provides reduced sensor system size, facilitates the sensor integration into an application and does not demand RF knowledge to design external antennas and other RF structures.

However, in order to achieve optimum sensor performance, the impact of the PCB layout should be taken into consideration during the design. The next two sections will explain why there is a dependency between the AIP radar sensors and a carrier PCB and how this will impact the resulting radiation characteristics of the sensor system.

2.1 Isolation limitations between package and PCB

During the design of a radar sensor package with integrated antennas various design goals need to be considered. This includes for example package cost and size, antenna performance, TX-RX isolation and isolation of the RF signal toward the PCB. The final design will always be a trade-off between the different goals with a strong emphasis on cost-efficiency. The isolation between package and PCB is mainly defined by the sensor package design and can vary significantly between different products. In general, increasing the isolation between package and PCB will require a more complex package design concept (increased number of metal layers and via connections for shielding). The isolation between package and PCB for the RF signal is therefore finite. This means there will always be a portion of the RF signal interacting with the PCB structures. Coupling of the RF signal onto the PCB can happen either wirelessly or through the solder ball connections.

In some cases, the PCB area underneath the package is intentionally used as a GND plane or reflector for the package antennas. This will result in a strong coupling of the RF signal between package and PCB and special attention has to be paid to the PCB design guidelines of the specific sensor.

The package design of the BGT60LTR11AIP features a cost-efficient two-layer design with low height of the antennas above the PCB surface. Consequently, an increased coupling of the RF signal onto the PCB can be observed. This makes the BGT60LTR11AIP a suitable candidate to demonstrate the impact from the sensitivity toward the PCB and the potential benefit of including the EBG in the PCB design. Therefore, simulation and measurement results in this document are based on the BGT60LTR11AIP.

2.2 PCB impact on the radiation pattern

Interaction of the RF signal with the PCB can result in two different effects which have an impact on the overall antenna radiation pattern. A large part of the signal will be radiated by the TX antenna as intended with the designed radiation pattern. However, the resulting radiation pattern of the whole system will be formed by the superposition of the signal directly radiated from the antenna and all other signal portions, e.g., reflected or re-radiated from the PCB for all spatial angles. This means that reduced isolation between package and PCB will lead to more reflection and re-radiation from the PCB, and therefore can potentially cause more deviation to the initial radiation pattern of the pure package.

A schematic view of a radar sensor with integrated antennas assembled on a PCB is shown in Figure 1 in a side view. The PCB top layer includes a GND plane underneath and around the sensor package. The connection from the package to the PCB is made by several solder balls resulting in a specific height *h* between the antennas in the package and the PCB top layer GND plane. Typically, the height *h* is in the range of several hundred microns but varies for different radar sensors depending on the actual package design.

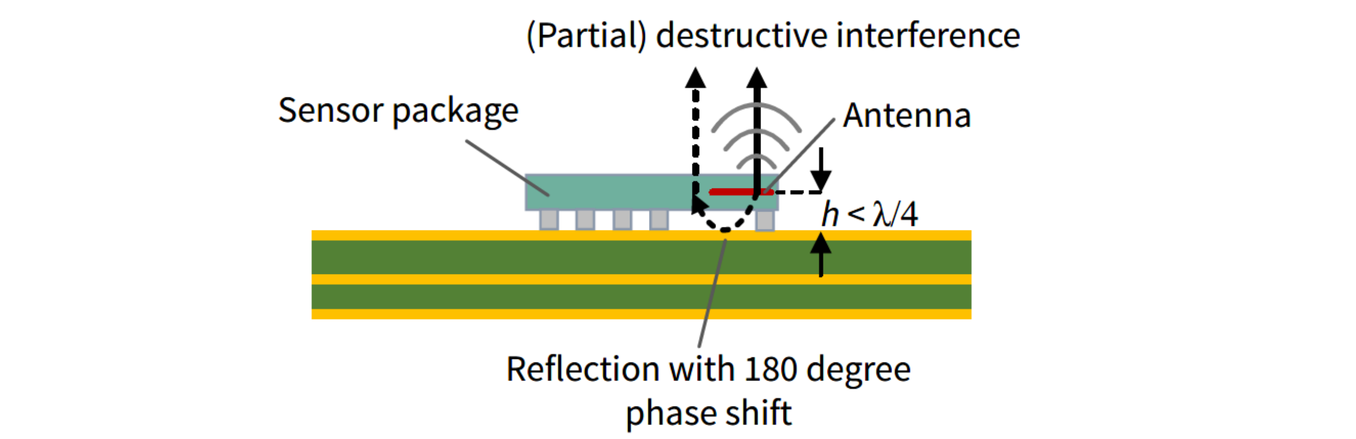

Figure 1 **Schematic view of a radar package on PCB**

For most sensors and applications, the intended main radiation direction providing the maximum gain is perpendicular to the sensor top surface (0 degrees in azimuth and elevation). This is indicated by the solid black arrow in Figure 1. As mentioned earlier, part of the RF TX signal will also couple onto the PCB due to the limited isolation. The metal surface on the PCB top layer works as a reflector for the RF signal, which will then be redirected upwards as indicated by the dashed arrows. A reflection on a conductive surface causes a 180 degrees change in phase of the reflected signal. The resulting antenna pattern in the far field is formed by the superposition of the signal initially radiated by the antenna and all reflections from the PCB with respect to the individual phase values. Depending on the individual phase values the different signal portions can sum up (partly) constructive or (partly) destructive. Destructive interference will reduce the radiated signal power in the particular direction which causes a reduced gain or directivity value in the corresponding radiation pattern. In the typical case with a GND plane on the PCB surface, the height *h* might be significantly smaller than the wavelength λ (λ = 5 mm at 60 GHz). Consequently, the 180 degrees phase shift caused by the reflection becomes dominant in the phase of the reflected signal, which causes partly destructive interference with the initially radiated signal. This results in reduced maximum gain in boresight and reduced maximum detection range of the sensor.

One option to address this effect is shown in Figure 2. The reflecting GND plane on the PCB top layer is removed around and underneath the sensor package. This increases the height *h* of the antenna and the first internal PCB GND plane, e.g., in layer 2. It needs to be highlighted that *h* is now partially filled with air and partially filled with the PCB laminate material, providing a specific relative permittivity. Therefore, the resulting effective electrical height h_{eff} is larger than the geometrical distance *h*.

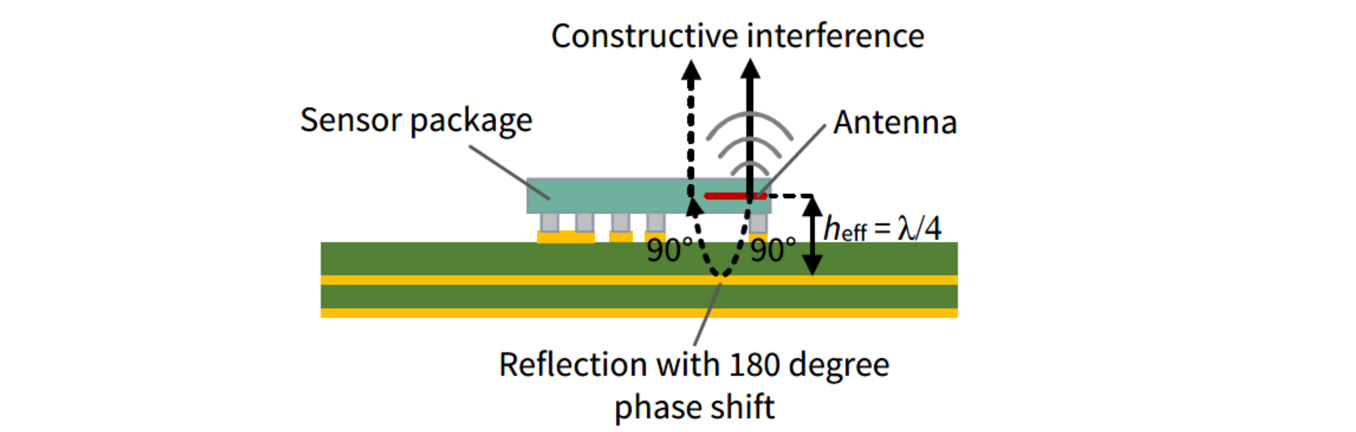

Figure 2 **Schematic view of a radar package on PCB with increased distance to the PCB GND plane**

If the distance h with respect to the relative permittivity of the substrate material is chosen to result in the effective electrical height h_{eff} being approximately a quarter of the wavelength λ the propagation from the antenna to the PCB GND plane will cause a change in the signal phase of 90 degrees. The same 90 degrees phase shift applies for the return path after the reflection. As mentioned previously, the reflection at the PCB GND plane additionally introduces 180 degrees of phase shift. In total, the introduced phase shift of the complete round trip (dashed arrows) gets compensated, leading to a mostly constructive interference with the initially radiated signal from the package antenna. This leads to an increased antenna gain in boresight.

This concept is implemented in the BGT60LTR11AIP shield v2.0 where no GND fill is used on the PCB top layer and the first laminate layer is intentionally made large to ensure a specific distance between the package antennas and the internal PCB GND plane on layer 2.

It is important to note that using this concept to optimize the antenna gain can require a custom PCB layer stack and knowledge of the dielectric properties of the substrate material at the RF frequency. As a result, the concept might not be applicable for all applications.

Besides the reflections from conductive PCB structures there is a second mechanism which can have a big impact on the shape of the resulting radiation pattern when significant coupling between the sensor package and PCB is present for the RF signal.

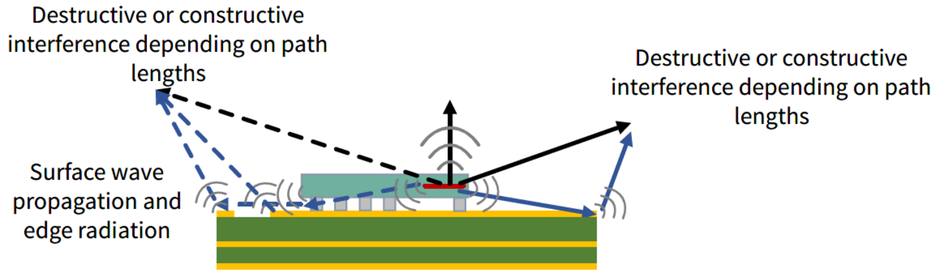

Figure 3 **Schematic view of surface wave propagation on PCB**

In addition to being reflected, an electromagnetic wave can also travel across the PCB surface. In the following this effect will be referred to as surface wave propagation. This can either happen by wireless coupling from package structures onto the PCB or through the solder ball connections. The wave travels on top of a surface metallization or the substrate material in all directions from the sensor package, as highlighted in Figure 3. The electromagnetic wave travels on the PCB surface until the PCB edge or any other discontinuity on the surface (e.g., lines, gaps and openings in a metallic structure or SMD footprints). This also means that a significant amount of the signal power can be present in PCB areas spaced apart from the radar sensor. Depending on the shape and size of each discontinuity a radiation of the signal can occur. Those re-radiated signals will then interfere with the initial antenna radiation forming the resulting antenna radiation pattern. Constructive or destructive interference will take place depending on the length of the individual transmission paths for initial and re-radiated signals for all spatial angles. This effect is indicated in Figure 3 for two different angles (solid and dashed arrows) where the initial radiation from the antenna is indicated in black while the surface wave propagation and re-radiated signals are marked in blue. The propagation of surface waves does not require a GND fill on the PCB top layer.

A typical PCB design includes not only the radar sensor itself but various other components and connections leading to a complex scenario of different metallic structures distributed all over the PCB surface. All of those edges can then be subject to re-radiation of signals fed by surface wave propagation. This leads to many different radiation sources on the PCB, which all contribute to the final radiation pattern of the whole system. Usually, this can cause strong deviations of the initial antenna radiation pattern for multiple angles. As a consequence, ripple and notches can be found in the resulting radiation pattern. It is important to understand that this is related to a strong dependency of the resulting antenna radiation pattern on a specific PCB design.

Any change in the PCB size in general or in the component placement or routing can have an impact on the final radiation pattern.

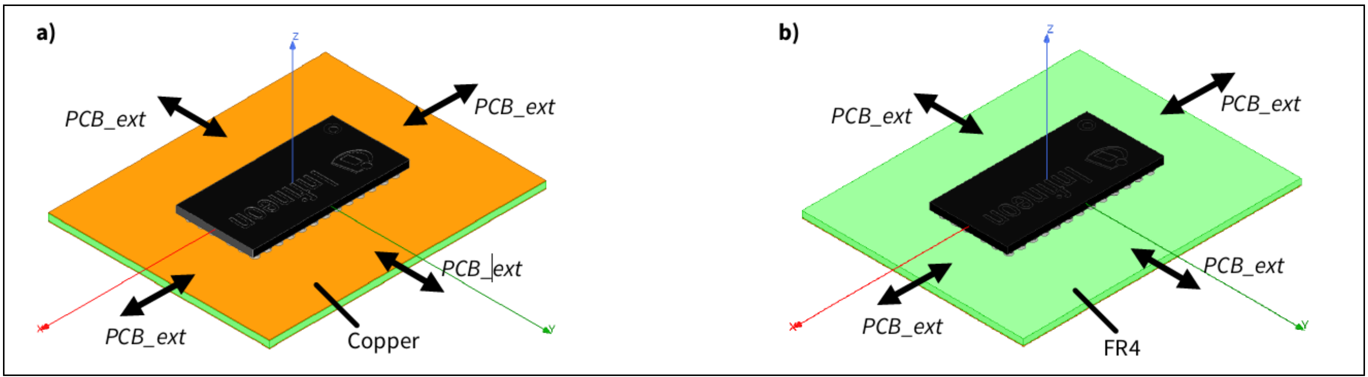

Figure 4 **BGT60LTR11AIP simulation model with a) GND plane on PCB top layer and b) without GND plane on PCB top layer**

Figure 4a) shows a very simple simulation model for the BGT60LTR11AIP to demonstrate the impact of the PCB size on the overall antenna pattern. The radar package is centered on a rectangular PCB with a continuous GND plane on the top layer. Besides the PCB edges, no other PCB discontinuities are present in this simulation. Figure 4b) includes a similar simulation model but without a GND plane on the PCB top layer. A GND plane is included on the bottom side of a 0.35 mm layer of FR4.

Figure 5 shows the simulated radiation patterns in E- and H-plane for the model with GND plane on the PCB top layer and with the PCB size being modified in the *x* and *y* dimensions. The starting size is 11.85 mm × 9.45 mm. All four edges are moved outward simultaneously by the parameter *PCB_ext*. Figure 6 presents the corresponding results for the second simulation model without GND plane on the top PCB layer.

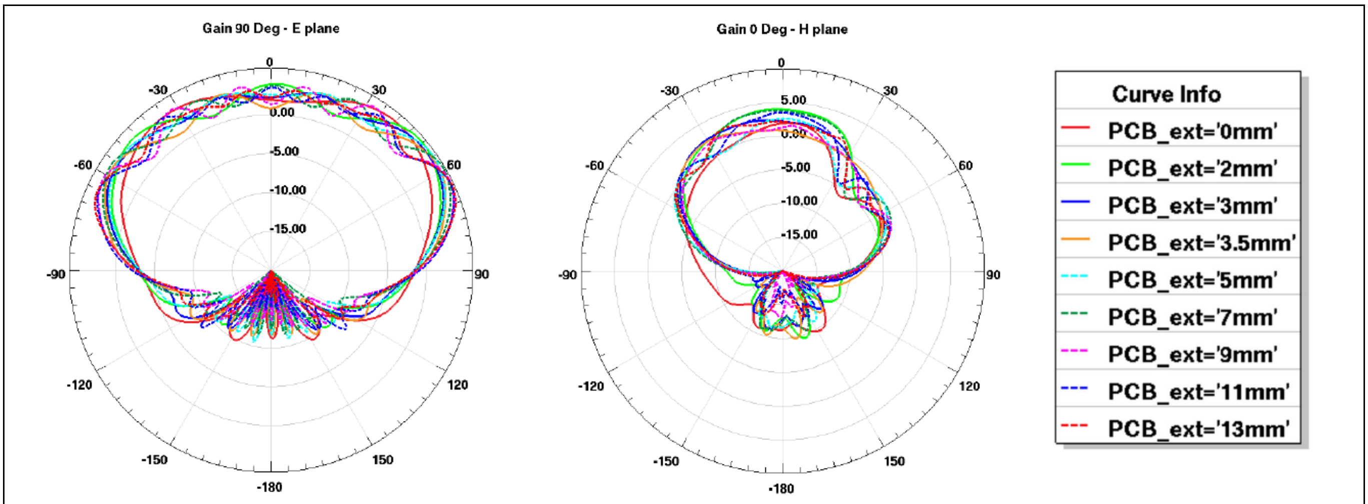

Figure 5 **Simulated TX radiation pattern in E- and H-plane for BGT60LTR11AIP placed on PCB with top layer GND plane and PCB size variation**

It becomes obvious for both simulation models that the PCB size and therefore, the position and distance of the PCB edges can cause a non-negligible impact on the shape of the antenna pattern in some cases. Additionally, also the impact of the distance between package antenna and first PCB GND plane for identical PCB size is clearly visible when comparing Figure 5 and Figure 6.

Achieving consistent performance typically requires strict adherence to the PCB design guidelines for a specific sensor or including the whole PCB design in an EM simulation to investigate the impact of surface wave propagation and edge radiation. Nevertheless, the simulations show suitable FoV and gain for many applications despite the variations in PCB size.

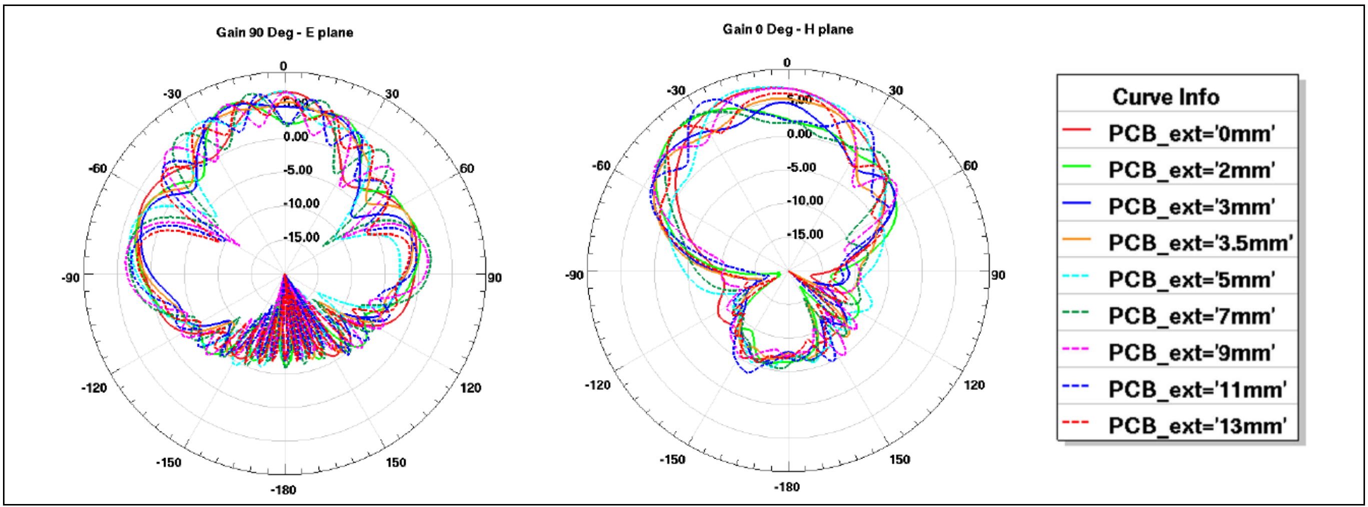

Figure 6 Simulated TX radiation pattern in E- and H-plane for BGT60LTR11AIP placed on PCB without top layer GND plane and PCB size variation

The two effects of reflections on the PCB and surface wave propagation on the PCB followed by re-radiation are both present at the same time. This means both mechanisms will interfere with each other and cannot be separated in measurement or simulations.

3 EBG concept

One possibility to address limited isolation between radar package and PCB can be found in the so-called EBG concept. The EBG is a periodic structure which is placed on the PCB around the sensor package. The goal is to reduce the impact from the actual PCB design on the antenna radiation pattern.

An EBG design has a specific operation bandwidth in which it shows the intended behavior. The bandwidth and operation frequency of the EBG are defined by the capacitance and inductance between neighboring EBG elements and, e.g., a PCB GND layer and are subject to the EBG design process.

Both mechanisms impacting the radiation pattern introduced in Section 2.2 can be addressed by the EBG concept due to its specific properties at the operating frequency. Inside the operating frequency band, the EBG shows a very high surface impedance for the RF signal. The reflection behavior of the EBG for electromagnetic waves with incidence close to 0 degrees is very similar to a continuous conducting surface, with one major difference. While the reflection on a continuous conducting surface introduces a phase shift of 180 degrees, there will be no additional phase shift introduced by the reflection at the EBG surface [2].

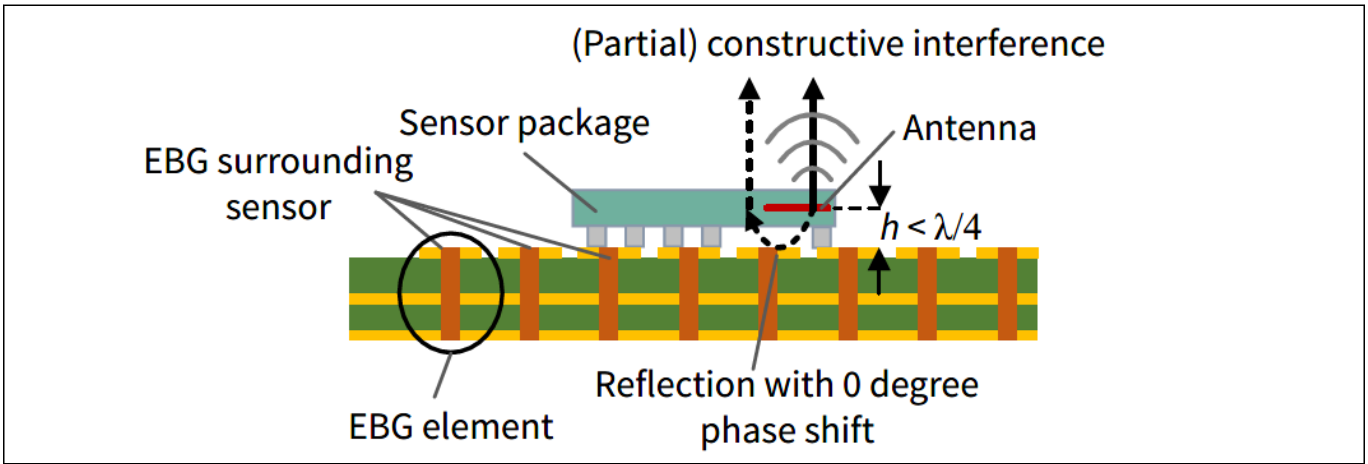

Figure 7 Schematic view of a radar package on PCB with EBG showing reflection behavior

The consequence of this effect can be explained with Figure 7. Instead of a GND plane on the top PCB layer several EBG elements are placed around the sensor package on the PCB. It is again assumed that the height *h* of the antennas in package above the PCB surface is significantly smaller than the wavelength λ. As a result, the phase change due to the propagation path of the reflected signal (dashed arrows) is minor. Together with the 0 degree phase shift introduced by the reflection on the EBG surface this leads to only small phase differences between the reflected signal and the initially radiated signal. As a consequence, the superposition of all signal contributions results in mainly constructive interference for the boresight radiation.

The second benefit of the EBG concept is highlighted in Figure 8. The high surface impedance of the EBG implementation strongly suppresses the propagation of surface currents and therefore surface wave propagation. Additionally, the EBG is also not re-radiating the RF signal. As a result, the RF signal coupling from the package onto the PCB is only limited to a small area around the sensor. The re-radiation of the RF signal from the package edges or any other PCB structures is strongly reduced.

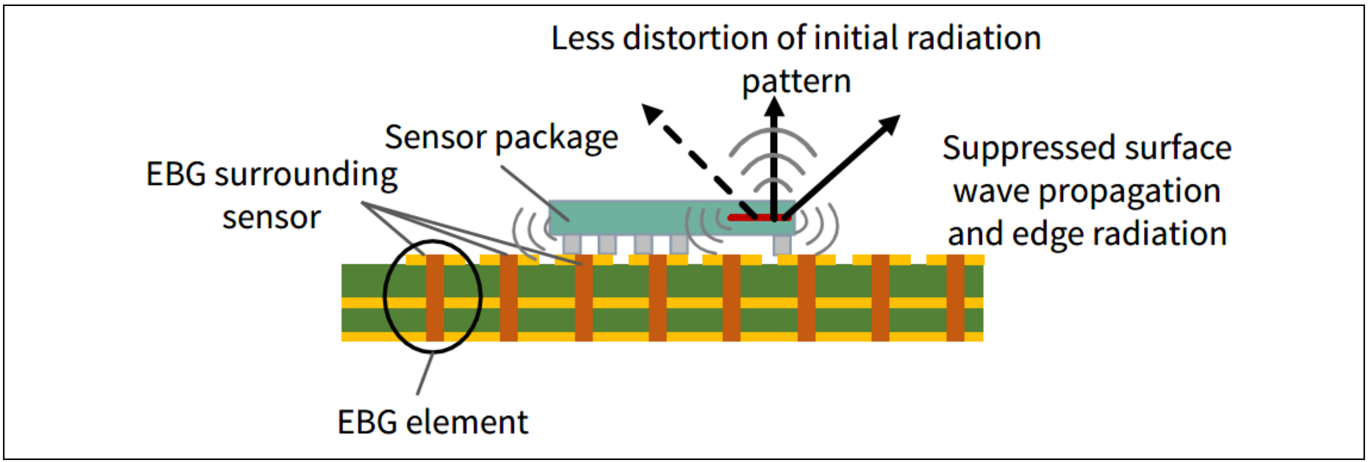

Figure 8 **Schematic view of a radar package on PCB with EBG showing suppression of surface wave propagation**

When using the EBG design on the PCB around the sensor package the radiation characteristic is significantly less deviated by re-radiation from the PCB and, in general, less dependent on the PCB shape, the PCB size and the PCB layout in areas not in direct proximity to the sensor. As long as the EBG structure stays untouched, changes in the PCB layout will not have a major impact on the radiation pattern. The EBG concept can also be used to get more consistent radiation performance on different custom PCB layouts.

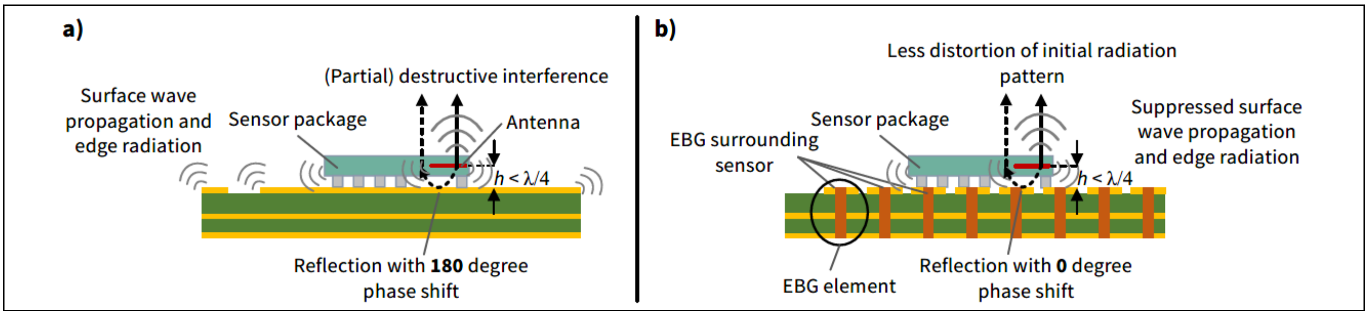

Figure 9 **Comparison of radar package on (a) PCB GND layer and (b) surrounded by EBG design**

The main benefits of the EBG concept in combination with radar sensors with integrated antennas are summarized again in Figure 9 as a comparison between the scenario of the sensor package being placed on a PCB GND plane and the placement of an EBG design around the sensor package. In many cases, the internal package layers provide reasonable shielding of the antennas toward the PCB area directly underneath the sensor. Therefore, the PCB area directly underneath the sensor package does not need to be filled with EBG elements but can be used for routing or can simply be filled with a GND metallization.

4 EBG design

After the introduction of the general EBG concept and its benefits this section is focused on the actual design of the EBG structure, especially for the use with the BGT60LTR11AIP.

4.1 General EBG design considerations

The EBG design is formed by several single EBG elements, in most cases placed on a uniform grid. The literature shows various design approaches using many different geometries at a wide range of operating frequencies. The main design objective is to provide the required inductance and capacity values with a given PCB layer stack to result in operation at the target frequency range. This can also require the use of multilayer designs.

It is typically recommended to keep the size or periodicity of the single elements significantly below the wavelength. A small single element size is also useful with respect to the size of the overall occupied PCB area. A single element placed next to the sensor will not show the desired effect. Only the combination of sufficient rows of single elements around the sensor provides the expected performance. Simulations have shown that at least three rows of single elements are required to show a significant impact.

It is important to highlight that the frequency behavior of a designed EBG structure will be dependent on the selected substrate material and most likely also on the layer stack (i.e., the thickness of the relevant layers). This means that one specific EBG design is only valid for a specific layer stack and the initial target frequency. All changes to the layer stack or the target frequency might require a modification or re-design of the EBG element structure.

4.2 60 GHz EBG design

In this section the developed EBG design for the operation together with the BGT60LTR11AIP will be presented. At 60 GHz the wavelength λ in free space equals 5 mm. The target frequency introduces some limitations and challenges to the EBG design. For cost-efficient manufacturing the widths of copper traces and slots, as well as the minimum via diameters, are limited. Additionally, all copper structures are subject to manufacturing tolerances, which can introduce a significant frequency shift at the target frequency band. Those requirements demand a design with low complexity to comply with the PCB design rules and to be robust toward tolerances.

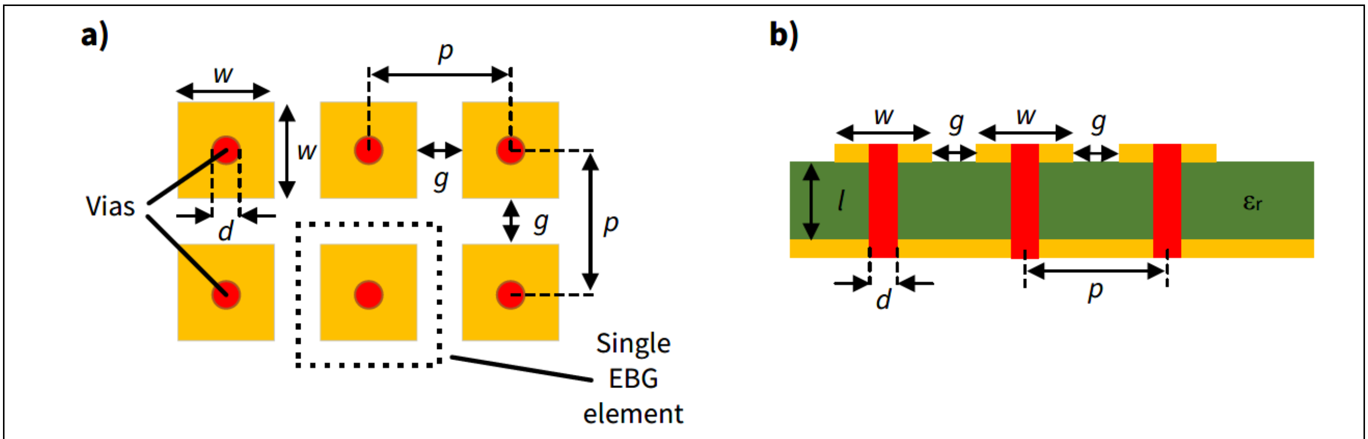

Figure 10 Grid of EBG elements with corresponding design parameters in a) top view and b) side view

The chosen EBG single-element design consists of a square patch of width w on the top layer and a continuous GND plane underneath in the second PCB layer. A via in the center of the patch provides a vertical connection to the GND plane in the second PCB layer. The single EBG elements are placed in a rectangular grid with the periodicity p. This results in a gap $g = p - w$ between two patches in the x and y direction. A drawing of the proposed EBG structure can be found in Figure 10 with all important design parameters. The corresponding design values for a FR4 PCB material are provided in Table 1. The thickness of the first laminate layer, and therefore the length of the via connection, is selected to be 0.35 mm. The square patch elements with the gap in between create a capacitance while the via connection to the GND plane in layer 2 provides an inductive component. Despite being designed for the sensor operating frequency there is no need to use RF PCB materials for the EBG design but knowledge of the relative permittivity value at the target frequency range is necessary.

Table 1 EBG design parameters for 60 GHz

w	p	g	d	l	ε_r
0.55 mm	0.85 mm	0.3 mm	0.2 mm	0.35 mm	4.4

For the chosen EBG geometry some design equations are proposed in [2], [3], and [4] which can be used for an approximation of the initial design parameters based on calculation of the equivalent capacitance *C* and inductance *L* for the target operating frequency f_0 of the EBG. Nevertheless, it is strongly recommended to use EM simulations for the design and verification process of any custom-designed EBG geometries. Fine tuning of the frequency behavior of this EBG geometry can be easily achieved by the width of the patches, the gap between the patches and in some cases the via diameter without needing to perform modifications to the PCB layer stack.

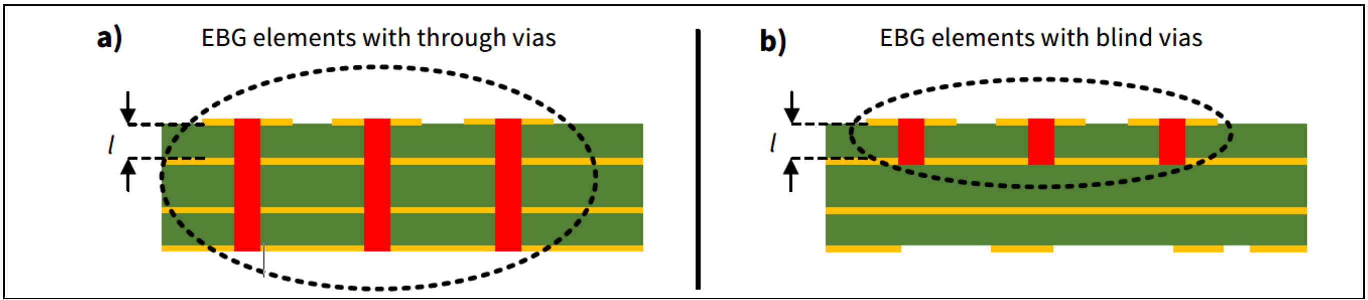

Figure 11 EBG elements with (a) through vias and (b) blind vias

The EBG design uses only the top PCB layer and a GND plane in the second PCB layer which is typically already part of most PCB designs. Additional layers underneath the GND plane can be used for other purposes and will not affect the EBG functionality. When using the most common through vias the dense via grid of the EBG can make the routing of other signals and connections in other layers underneath the EBG elements more complex. An option to reduce the routing complexity can be found in using blind vias connecting only the first two PCB layers, as shown in Figure 11. In this case there are no restrictions for the routing underneath the EBG. Note that the use of blind vias is not mandatory to integrate the EBG into a PCB design. Using blind vias will just make the general PCB layout less complex in some cases.

5 Demonstration of EBG design and functionality for BGT60LTR11AIP

After the introduction of the EBG concept and the EBG design for operation with the BGT60LTR11AIP this section will give some examples to demonstrate the benefits of the EBG for actual PCB designs. In order to provide a comprehensive investigation, simulation and measurement results will be presented. It is important to highlight that the designs presented in the following are of an exemplary nature to demonstrate the impact of the EBG concept in certain scenarios. This can also include preliminary or internal PCB design variants, which will differ from the current available variants. It is also worth mentioning that Infineon's BGT60LTR11AIP achieves an excellent antenna performance for a small size and low cost which has been demonstrated in various applications. In case of additional space on the PCB the performance can even be improved by using EBG structures.

5.1 EM simulation results

Using an electromagnetic (EM) simulation environment allows the testing of different scenarios to get a better understanding of the functionality and benefits of the EBG concept. All EM simulations were carried out with Ansys HFSS.

5.1.1 Impact of PCB size variations

In Section 2.2 it was explained how the PCB size and top layer configuration have an impact on the resulting radiation pattern. The following example demonstrates how the previously introduced EBG concept can be used to strongly reduce the impact of the PCB geometry on the radiation characteristics. Figure 12 shows a simplified simulation model similar to the ones presented in Figure 4. The area underneath and around the BGT60LTR11AIP package is filled with EBG elements. There are three EBG elements placed in each direction around the sensor package. As for the previous models the initial PCB size is 11.85 mm × 9.45 mm on a FR4 substrate with 0.35 mm thickness. In the simulation all four edges are again moved outward simultaneously by the parameter *PCB_ext*, while the number and positions of the EBG elements do not change.

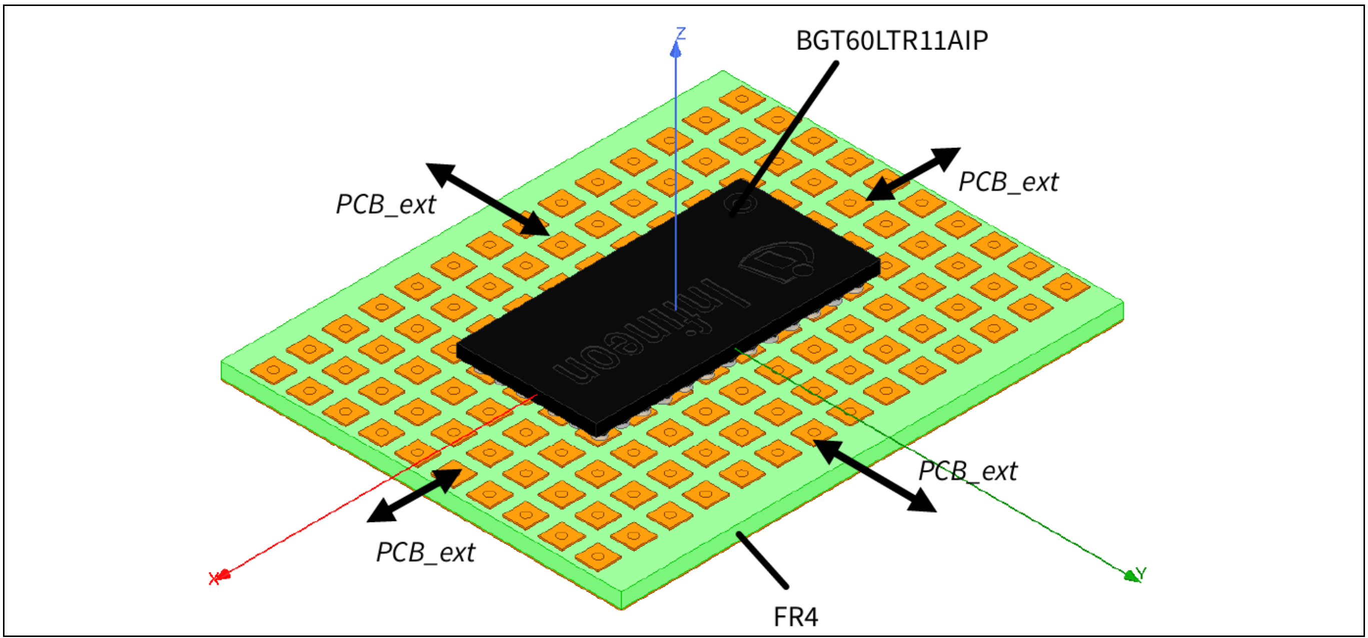

Figure 12 BGT60LTR11AIP simulation model including EBG structures

Figure 13 summarizes the simulated TX radiation pattern in E- and H-plane for various values of *PCB_ext*. Despite the variation of the PCB size all resulting radiation patterns are very similar in shape and absolute gain values. Comparing these results with the results presented in Figure 5 and Figure 6 it becomes obvious that including the EBG design significantly reduced the sensitivity of the radiation pattern toward the PCB dimensions. The use of only three EBG elements in every direction around the sensor with a relatively small size requirement is already sufficient to suppress most of the impact of PCB size variations. Using more EBG elements will strengthen this effect even further.

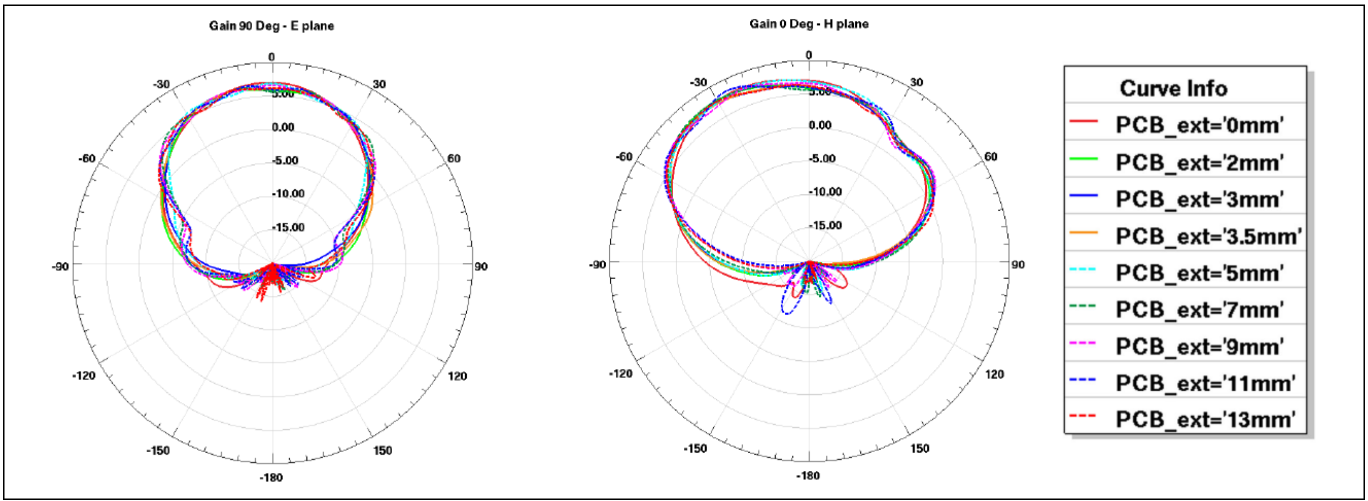

Figure 13 Simulated TX radiation pattern in E- and H-plane for BGT60LTR11AIP surrounded by EBG elements and PCB size variation

5.1.2 Radiation pattern of BGT60LTR11AIP M0 reference design

This example uses the XENSIV™ BGT60LTR11AIP SPI M0 reference board design in a preliminary version. The PCB size is 25 mm × 25.6 mm. In addition to the BGT60LTR11AIP the design includes several LDOs for power supply, an XMC™ microcontroller unit, level shifters and an oscillator as frequency reference. More details on the final version of the M0 reference board and its functionality can be found in the corresponding UG170807 user guide [5]. The initial PCB design can be seen in Figure 14a with the BGT60LTR11AIP position highlighted.

Figure 14b shows a modified layout version of the same design. The area around the radar sensor on the top PCB layer is filled with the previously designed EBG elements. The positions of some SMD resistors and capacitors had to be slightly altered to make room for sufficient EBG elements. The position of all other components stays the same between both variants. It has to be highlighted that despite the integration of the EBG elements the overall PCB size also did not change.

The simulated 3D TX radiation patterns for both PCB layouts at 61 GHz are presented in Figure 15a, and Figure 15b. For the initial design without EBG there is a significant effect from various PCB structures distorting the final radiation pattern. This results in several local minima and maxima but still provides a wide FoV. Additionally, the main radiation direction is slightly tilted. In contrast, the radiation pattern for the EBG layout looks smoother, with a boresight close to 0 degrees. The resulting FoV is also even further increased by the use of the EBG. This can also be seen in Figure 15c where E- and H-plane are shown together for the initial design (solid lines) and the modified variant with EBG (dashed lines). In this plot it can be seen that the maximum gain at boresight was also increased for the modified PCB with EBG.

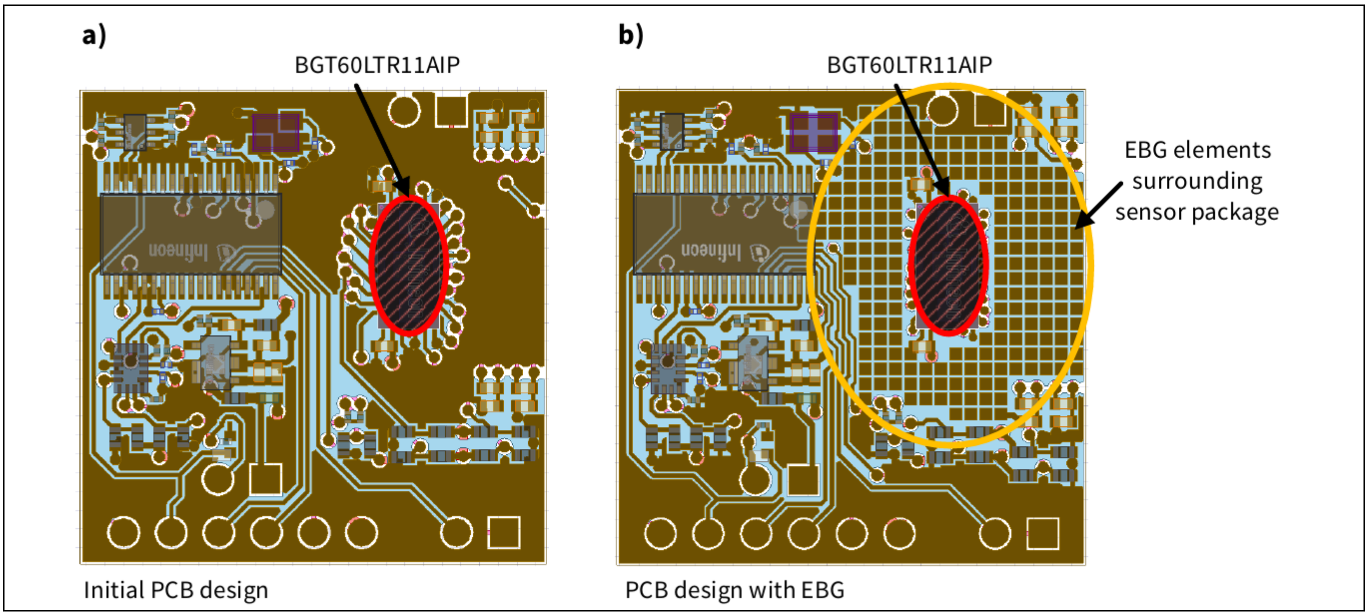

Figure 14 **Simulation model of M0 reference board PCB (a) initial design and (b) modified design including EBG**

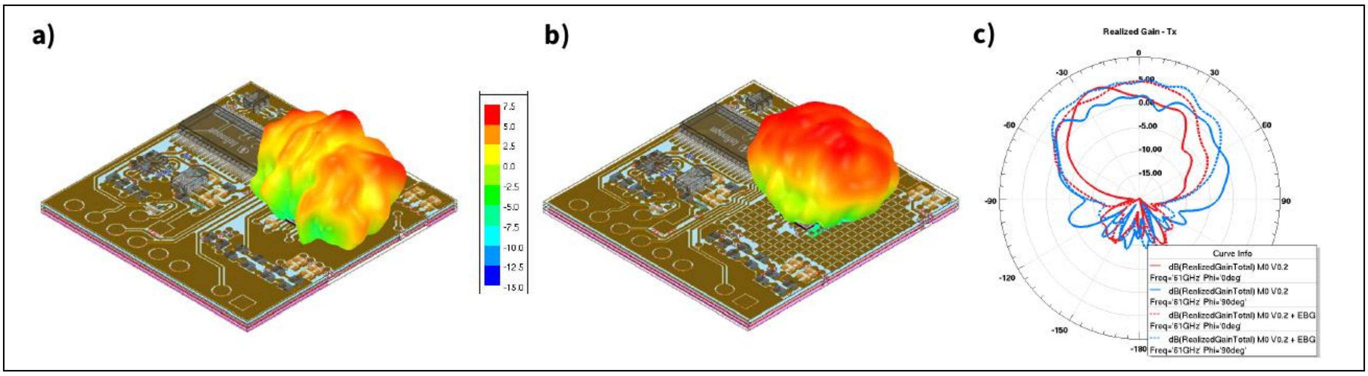

Figure 15 **Simulated TX radiation pattern (a) initial PCB without EBG, (b) modified PCB design with EBG and (c) comparison of both PCB designs in E- and H-plane**

This example demonstrates how a complex PCB design can benefit from the EBG concept and that the EBG concept could in fact be integrated in an existing PCB layout without increasing the PCB dimensions.

5.1.3 Reduced impact of MCU baseboard on BGT60LTR11AIP shield performance

It was explained and demonstrated in Section 2.2 that the PCB size can have an impact on the resulting radiation pattern. If the PCB carrying the radar sensor is very small, for example like the BGT60LTR11AIP shield v2.0, not only the PCB layout and size itself but also its surrounding becomes relevant. One use case of the BGT60LTR11AIP shields is SPI mode in combination with the Radar Baseboard MCU7 [6]. In this case the coupling of the RF signal from the package is not only limited to the shield PCB. There will also be additional coupling from the shield PCB onto the baseboard, where again various edges can cause re-radiation leading to further interference of the initial radiation pattern. As a result, the baseboard has an impact on the final radiation pattern and the radiation patterns for the scenario with and without the baseboard can show a difference. This will especially be the case when the initial carrier PCB is very small.

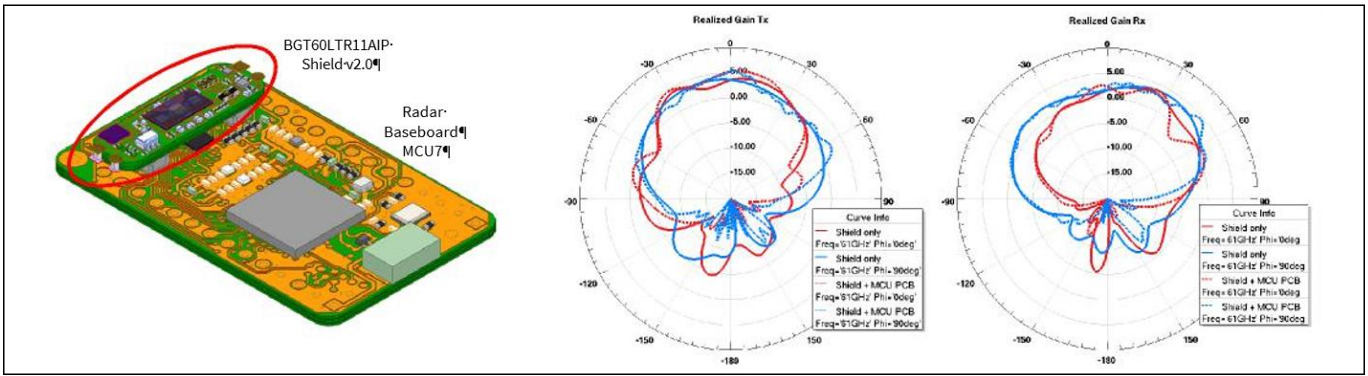

Figure 16 BGT60LTR11AIP shield v2.0 simulation model and simulated TX and RX radiation pattern

The impact of the baseboard on the radiation pattern is shown in Figure 16 based on a simulation with the BGT60LTR11AIP shield v2.0. The simulated radiation patterns for the TX and RX antennas are plotted for the case of the pure shield PCB (solid lines) and the shield PCB together with the baseboard PCB (dashed lines). In general, the patterns of both cases look similar, but variations of several dB can occur for certain angles. Overall, the BGT60LTR11AIP shield v2.0 radiation characteristic shows a wide FoV with and without the MCU baseboard.

Also in this scenario, the EBG concept can be used in order to decrease the impact of the Radar Baseboard MCU7. In Figure 17 on the left side a simulation model with a preliminary version of the BGT60LTR11AIP shield v3.0 together with the baseboard is shown. For v3.0 the layout of the shield PCB is modified to incorporate the EBG design. In this case this also results in an increased PCB size. The goal of including the EBG onto the shield is to better isolate the RF signal inside the package from the shield PCB. As an additional consequence, the coupling of the RF signal onto the baseboard will also be strongly reduced. This effect can be seen in Figure 17 where TX and RX radiation patterns in the E- and H-plane are plotted for the pure shield (solid lines) and the shield together with the baseboard (dashed lines). It can be clearly seen that the results for the scenarios with and without baseboard are nearly identical, demonstrating that the EBG design can help with achieving more consistent performance in different environments.

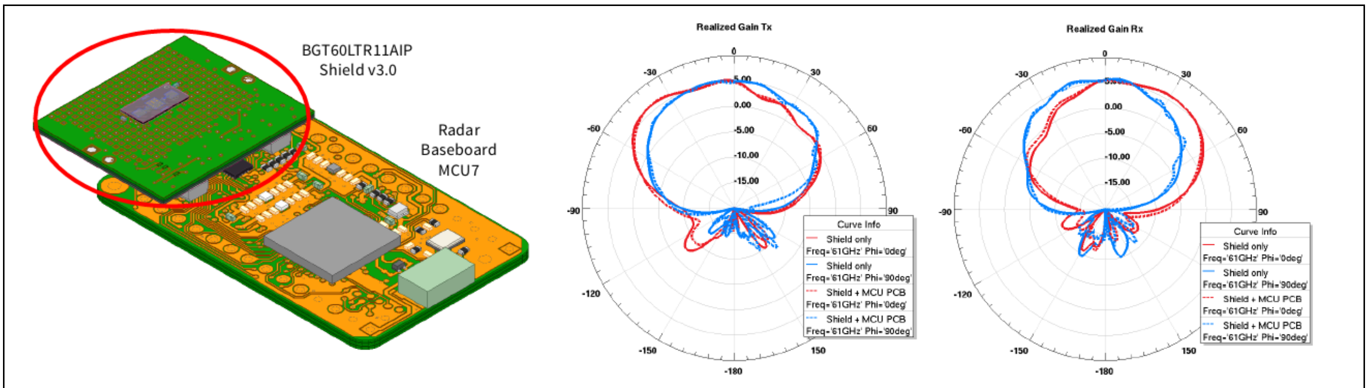

Figure 17 BGT60LTR11AIP shield v3.0 simulation model and simulated TX and RX radiation pattern

5.1.4 Investigation on number of EBG elements

The BGT60LTR11AIP shield starting from v3.0 includes the EBG design placed around the radar sensor on the PCB. Therefore, the PCB size is enlarged compared to v2.0. To ensure optimum performance and low sensitivity of the radiation pattern toward the surrounding environment as many EBG elements as possible are placed on the PCB in the available area around the sensor package. The design is shown in Figure 18a together with the simulated 3D radiation patterns for TX and RX. The design includes in total 259 EBG elements. As reference,

Figure 18d includes the same PCB layout but without any EBG elements together with the corresponding simulated radiation patterns. The effect of the EBG design is clearly visible. Without EBG the radiation patterns show side lobes and a reduced FoV.

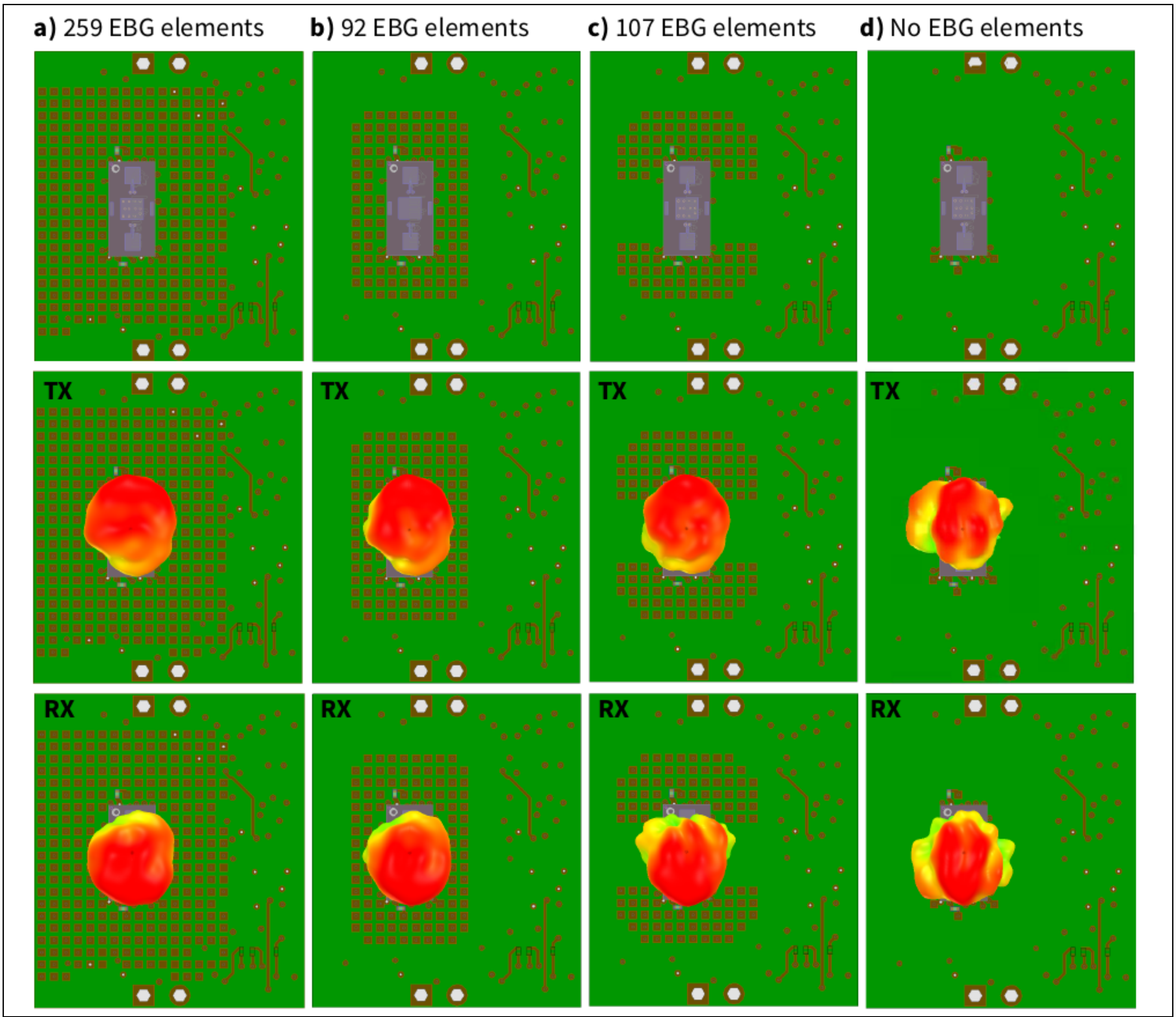

Figure 18 **BGT60LTR11AIP shield v3.0 with different numbers of EBG elements and simulated 3D TX and RX pattern**

However, in some applications the total available PCB area can be limited, which might require a reduction of the number of EBG elements around the sensor package. Therefore, two additional variants have been designed with significantly reduced numbers of EBG elements. Those designs are shown in Figure 18b and Figure 18c and feature different distributions of the EBG elements. The radiation patterns in the E- and H-plane for all four designs are summarized in Figure 19. Even with the strong reduction in the number of EBG elements (36% and 41% of the initial design) the general benefit of the EBG design is still present in terms of the wider FoV and the general shape without any side lobes. A drop in the maximum gain at 0 degrees can be observed in the TX pattern for the reduced element versions.

These results also demonstrate that in a scenario where there is only limited space available for EBG elements, placing EBG elements in only some areas can still be beneficial. EM simulations are recommended to analyze custom layouts and identify a suitable number and positioning of the EBG elements in case the recommendation of at least three elements in each direction around the sensor cannot be fulfilled.

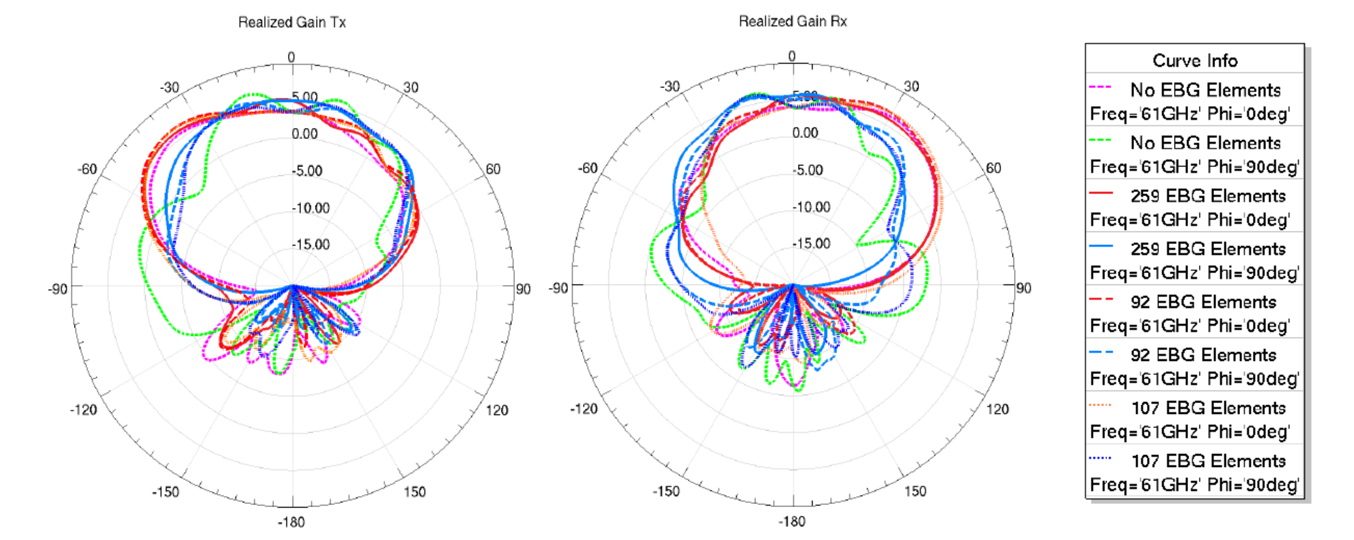

Figure 19 Simulated 2D radiation patterns for BGT60LTR11AIP shields v3.0 with different numbers of EBG elements

5.2 Measurement results

After the benefit of the EBG design with BGT60LTR11AIP has been shown in simulations this section will present the impact of the EBG design on two measurements, focusing on the FoV and the measured TX radiation pattern. The measurements are based on prototypes for the evaluation of the EBG design and the presented result values are not guaranteed performance specifications for any specific application.

5.2.1 FoV for ceiling-mounted applications

In this experiment the FoV of the radar sensor mounted at the ceiling will be investigated. For this purpose, the BGT60LTR1AIP M0 reference design in a preliminary version without and with EBG is utilized. The layout of this hardware has already been presented in Figure 14.

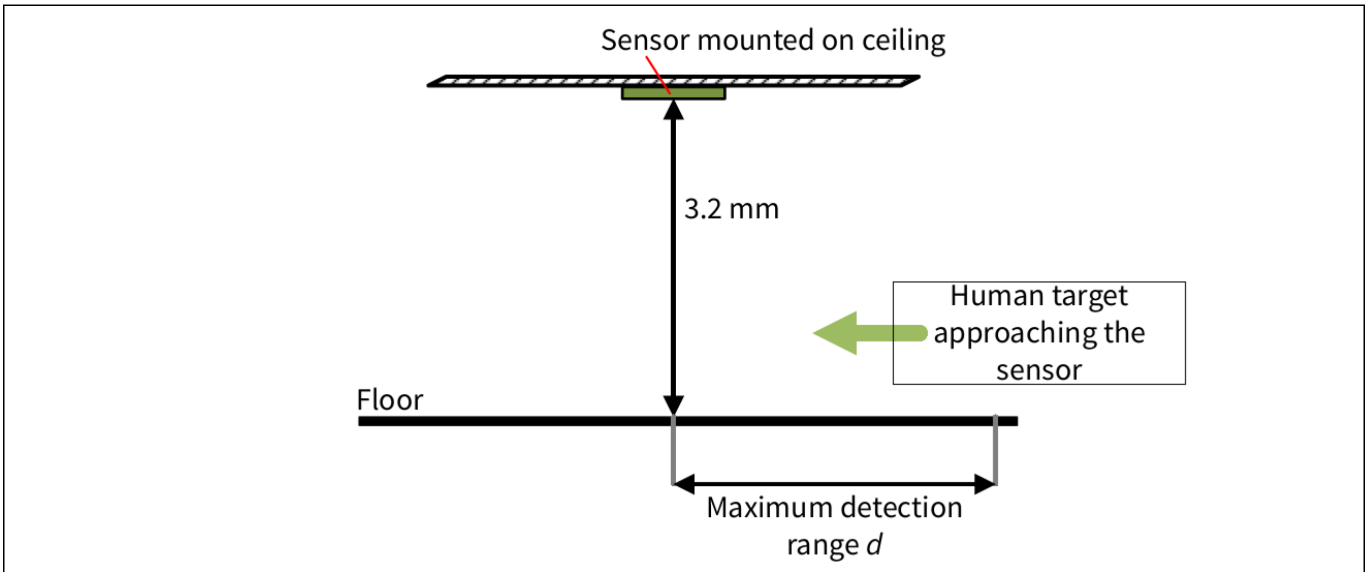

Figure 20 Measurement scenario for ceiling-mounted FoV

The measurement scenario is depicted in Figure 20. The radar sensor is mounted on the ceiling at approximately 3.2 m height, facing directly downwards. A person is approaching the center on the floor underneath the sensor from multiple angles and the maximum detection range d for each angle is noted. This measurement procedure is performed for both hardware variants.

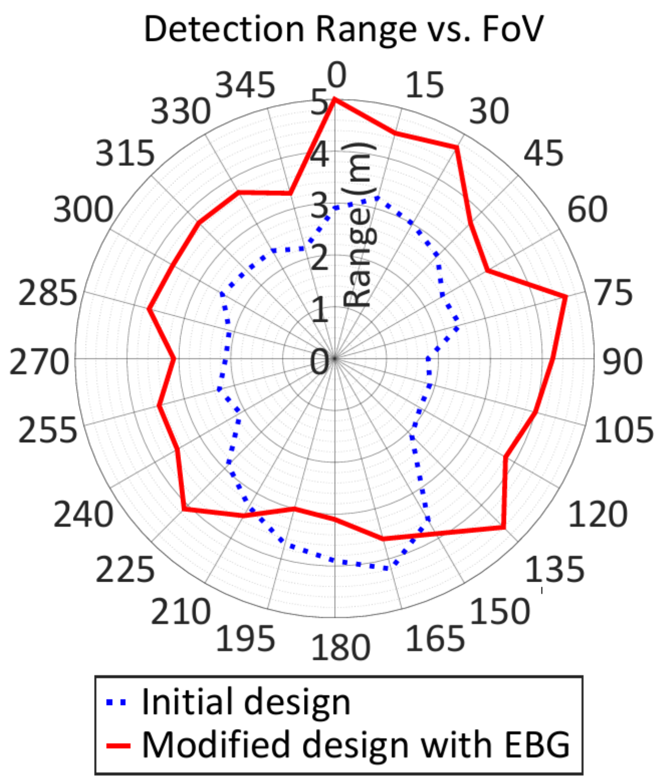

Figure 21 Measured detection range for different angular directions of both PCB variants

The resulting detection range versus the FoV pattern is plotted in Figure 21 for 15 degree steps, with the same algorithm being used for both hardware variants. As expected from the simulated radiation patterns, the resulting FoV in the surface-mounted scenario with the EBG included is in general significantly larger. Additionally, the FoV for the EBG variant is distributed more evenly around the center. For the initial design without EBG the field of view is narrower with a tilt toward 180 degrees. Nevertheless, even without EBG the excellent sensing performance has been demonstrated in multiple applications. The integration of the EBG concept can even further increase this performance.

5.2.2 Measured TX radiation pattern of BGT60LTR11AIP shields

In Section 5.1.3 two different BGT60LTR11AIP shield designs with and without the integration of the EBG design have been introduced together with simulation results of the TX and RX radiation patterns. While Section 5.1.3 was focused on the impact of the MCU baseboard, a difference in the shape of the radiation patterns for both shield variants was already visible in the simulation results. In this section the measured TX radiation pattern of the shield variant v2.0 without the EBG design and the v3.1 with EBG will be presented and compared. A top view of both shield designs is presented in Figure 22. More information on the current BGT60LTR11AIP shield version can be found in the corresponding user guides UG093524 [7] and UG133733 [8].

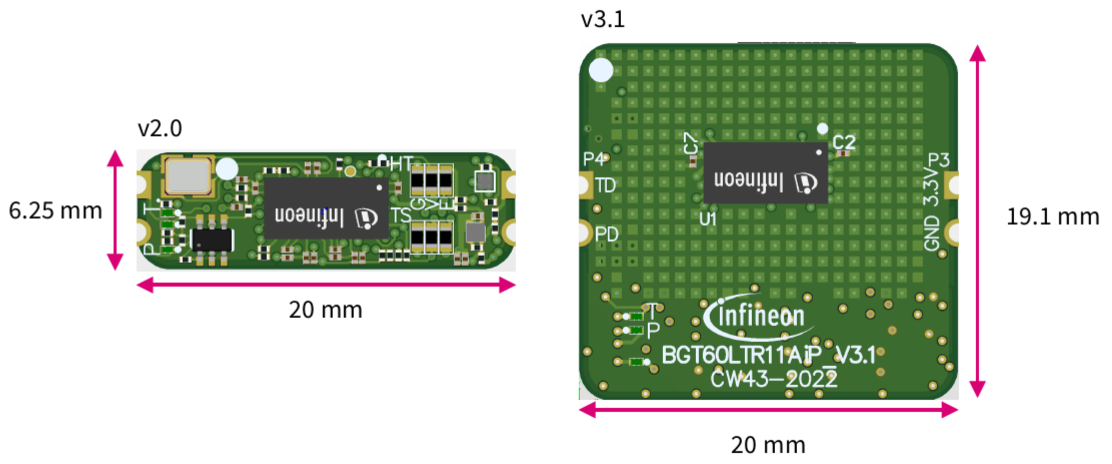

Figure 22 BGT60LTR11AIP shield v2.0 (left) and BGT60LTR11AIP shield v3.1 with EBG design (right)

The measurements were performed in an anechoic chamber with the BGT60LTR11AIP shields together with an MCU baseboard mounted on a gimbal with two perpendicular rotation axes. A reference antenna and a spectrum analyzer were used to measure the received TX power for different rotation angles in the E- and H-plane. Figure 23 shows the measured TX radiation pattern of both BGT60LTR11AIP shield versions in the H-plane. For each PCB variant three samples were measured. The behavior of the three samples is consistent. The v3.1 shield with the EBG design included already shows an increased FoV in the H-plane with the most improvement being visible in the angular range from 30 degrees to 60 degrees. Also, the maximum gain in boresight increases for the v3.1 shield.

Figure 24 shows the measured TX radiation patterns in the E-plane. In the E-plane the MCU baseboard introduces a dip in the radiation pattern at -15 degrees to -30 degrees for the v2.0 shield. This effect is removed with the v3.1 shield design and the integration of the EBG concept. This significantly increases the antenna beam width in the E-plane. The overall increased maximum gain for v3.1 is also visible in the E-plane pattern.

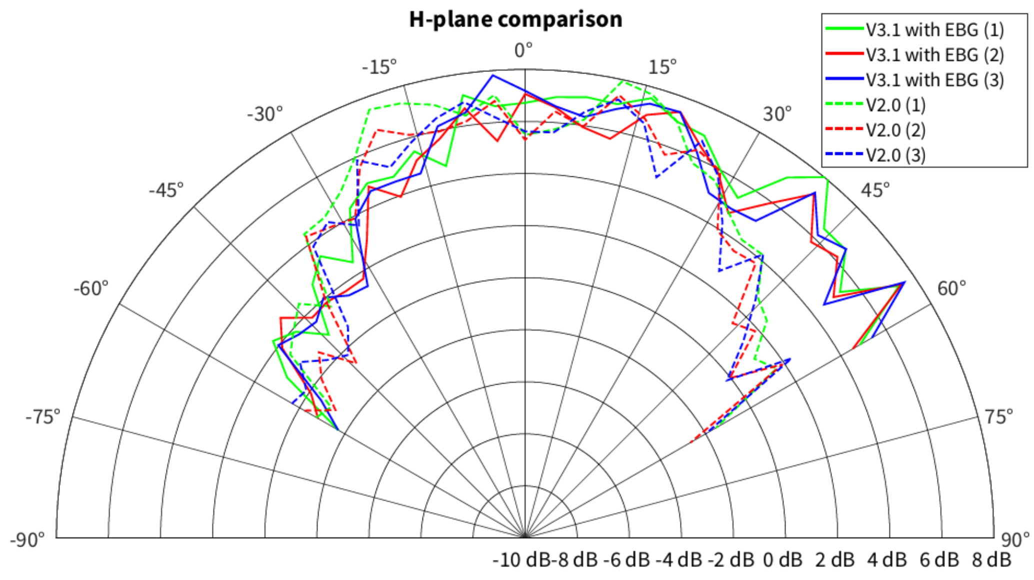

Figure 23 Measured TX radiation patterns in the H-plane for two different PCB variants

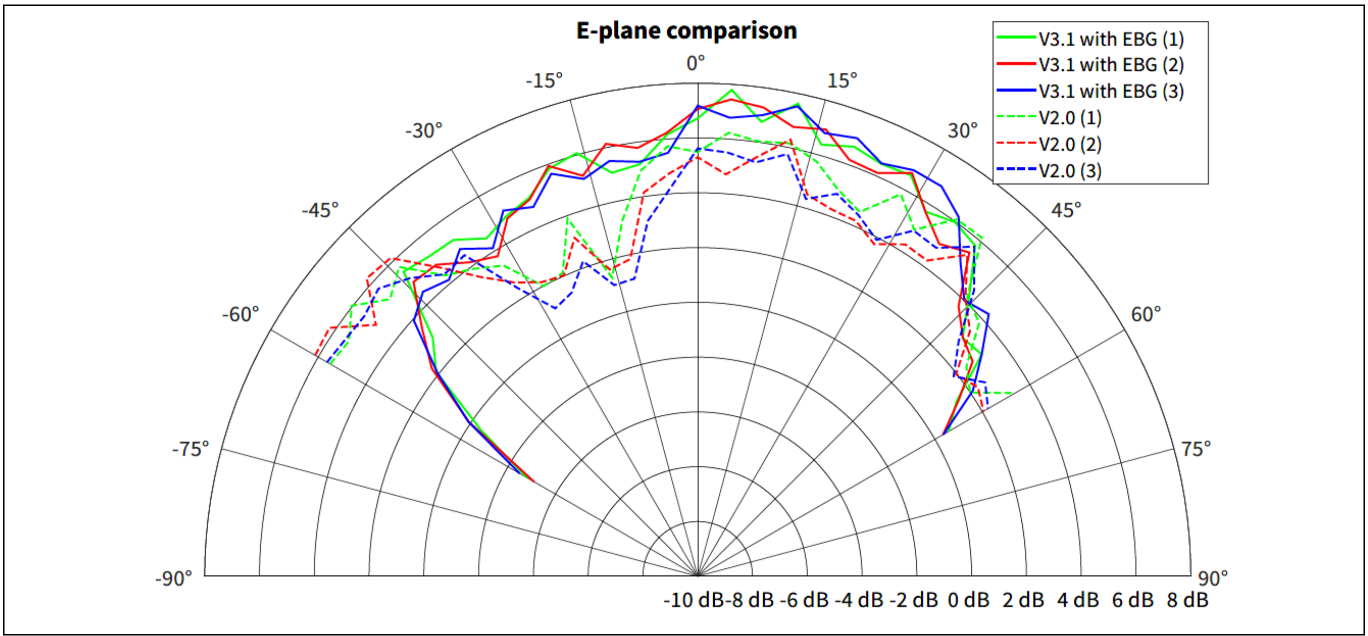

Figure 24 Measured TX radiation patterns in the H-plane for two different PCB variants

6 Summary and conclusion

Infineon’s BGT60LTR11AIP achieves an excellent antenna performance for a small size and low cost. In case of additional space on the PCB the performance can even be improved by EBG structures. Due to various design aspects, the isolation of the RF signal inside a package with integrated antennas toward the PCB will always be limited. A limited isolation toward the PCB will result in a dependency of the sensor radiation characteristic on the actual PCB layout, resulting in possible performance variations in combination with different PCBs.

The introduced EBG concept can address these effects by its specific electromagnetic properties in its operation frequency band. In order to achieve this a suitable EBG element design needs to be developed for every frequency band and PCB layer stack, considering also the PCB substrate material and thickness. Changes in the layer stack of an existing EBG design can require a re-design or modification of the EBG element geometry. At least three rows of EBG elements placed in every direction around the sensor package are recommended to take the most benefit from the EBG concept. Therefore, a certain additional space requirement should be considered with the use of the EBG concept. In the end this results in a trade-off between size requirements and reduced sensitivity toward the PCB provided by the EBG elements.

However, it is important to highlight that the EBG is not mandatory for use with any of Infineon’s radar sensors. Remarkable system performance has been demonstrated in various PCB designs without the use of the EBG concept. The EBG should just be considered as a potential option in case a strong negative impact of the PCB design is expected or has been investigated or as a solution to provide consistent performance on multiple PCB designs without performing EM simulations of the complete system.

All simulations and measurements in this document have been performed for the BGT60LTR11AIP. Due to its design this device can benefit significantly from the EBG design in some application scenarios. In general, the concept of the EBG is not limited to a specific radar sensor or operation frequency. Addressing a different frequency band will then require a re-design of the EBG geometry.

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