

A High-Isolation Dual-Band Base Station Antenna Design for Full Duplex Technologies

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Abstract—Full duplex schemes technologies have considerable potential to improve the performance of future generations of mobile communication systems. While promising, these technologies face several challenges, particularly self- and cross-link-interference. This paper addresses the self-interference issue, which can severely impact the performance of full duplex systems. A novel dual-band antenna architecture tailored for full duplex systems is presented alongside the design of two shielding structures and their performance are evaluated in electromagnetic simulation software. The simulation results indicate that the isolation between a transmit beam and a receive radio branch can reach more than 80 dB over a support of 500 MHz for different beam steering directions.

Index Terms—5G Advanced, 6G, full duplex, antennas

I. INTRODUCTION

The evolution of 5G new radio (NR) aims to enhance network performance, boost energy efficiency, and introduce features beneficial to mobile network operators [1], [2]. As part of these advancements, the 3rd Generation Partnership Project (3GPP) initiated efforts for Release 18 in June 2021, highlighting opportunities for improved network capacity and flexibility [3], [4]. A study item was devoted to the investigation of evolved duplex schemes, specifically the non-overlapping sub-band full duplex [5], focusing on the improvement of uplink performance and reduction of communication latency. However, implementation challenges arise due to cross-link interference and self-interference from out-of-band downlink transmissions, particularly in high-power wide-area coverage scenarios [6]. Several studies have investigated the system-level aspects of the non-overlapping sub-band full duplex scheme [5], [7]–[10] and, overall, base stations (BS) in the millimeter-wave frequency range with mid-range power levels, e.g., 30 dBm, seem to manage these interference issues effectively. While various residual self-interference cancellation (RSIC) strategies exist, propagation-domain techniques, which are related to passive antenna array module designs, prove most effective in reducing interference [11], [12].

Current antenna designs for massive MIMO full duplex systems focus predominantly on single-band solutions, leaving a considerable amount of physical space unused between the shielding structures [6], [9], [10]. To address this and to engage in the preference of mobile network operators for multi-band solutions, this paper introduces a novel dual-band antenna design for full duplex. The main contributions of this paper are: (i) the presentation and simulation-based evaluation of a new dual-band antenna architecture for full duplex systems, and (ii) a comparative analysis of two shielding structures, with simulation results indicating more than 80 dB of isolation over a 500 MHz support for various beam steering directions.

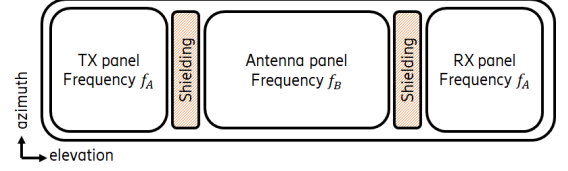


Fig. 1: Architecture of the passive antenna array module of the proposed active antenna system. The f_A -band antenna panels operate in evolved duplex mode, while the f_B -band panel in conventional duplex mode.

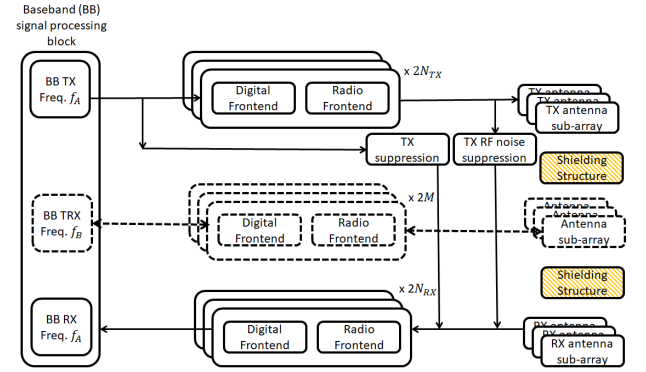


Fig. 2: Active antenna system architecture outlining the integration of the passive antenna array module with the frontend and baseband signal processing modules.

The paper structure is as follows: Section II discusses the proposed architecture, hardware prerequisites, and mutual coupling mechanisms. Section III studies the shielding structures, followed by an assessment of antenna far-field and isolation performance in Section IV.

II. ACTIVE ANTENNA SYSTEM ARCHITECTURE

The architecture of active antenna systems (AAS) depends on where their functional split lies [13]. In the proposed AAS architecture, Split 6 including Layer 1 functionalities is considered without any loss of generality. In this case, the AAS comprises a passive antenna array module, an integrated radio unit, and a baseband signal processing unit [13].

The proposed passive antenna array design with dual-polarized radiator elements is illustrated in the diagram of Figure 1. This dual-band design comprises three antenna panels, in which those at the left and right side operate at the same frequency band f_A and that in the middle at a different frequency band f_B . Shielding structures are implemented

between each antenna panel to reduce mutual coupling. If these structures provide enough decoupling, then the f_A -band panels would enable separate transmit (TX) and receive (RX) with enough passive self-interference suppression, which is essential for evolved duplex schemes. In this case, the f_B band panel would implement an independent antenna system using conventional duplex schemes, such as time division duplex (TDD) and frequency division duplex (FDD). This is advantageous compared to single-band solutions as it simplifies the antenna deployment for mobile network operators.

The general architecture of the integrated radio and baseband signal processing units is depicted in the diagram of Figure 2. The TX and RX antenna panels are respectively partitioned into N_{TX} and N_{RX} sub-arrays of dual-polarized radiator elements. Each sub-array is linked to two front-end branches, one per polarization, which requires $2(N_{TX} + N_{RX})$ front-end branches. Likewise, the f_B -band panel is split into M sub-arrays and connected to M front-end branches. Each front-end unit is then connected to the corresponding baseband transceiver module. To further attenuate the RSIC that leak into the RX panel, it is usual to implement further stages of transmit-signal cancellation in both analog and digital domains [11], [12].

A. Hardware Requirements

The gains of evolved duplex schemes can only be realized if strict hardware requirements are satisfied. For instance, the paper [6] presents an RSIC breakdown for base station classes with different TX power levels. In any case, a combination of passive antenna isolation, frequency-domain filtering, beam nulling, and digital interference cancellation is required to achieve the needed RSIC level [12]. In this work, two definitions for isolation are considered. Let TRP_{SA} , TRP_P , $P_{SA,RX}$ denote respectively the total radiated power by a single TX sub-array, by the whole TX panel, and the received power at the RX branch of interest. The following isolation metrics are thus defined:

- 1) Sub-array-to-sub-array isolation [dB] = $TRP_{SA} - P_{SA,RX}$
- 2) Panel-to-sub-array isolation [dB] = $TRP_P - P_{SA,RX}$

RSIC levels have been reported to reach 125 dBc considering 65 dB of passive antenna panel-to-subarray isolation over 500 MHz [6]. While this isolation value is reasonable in practice, more sophisticated antenna designs can further increase the passive isolation term and relax the RSIC breakdown requirements on other components. Therefore, the design target is to maximize the isolation between the f_A -band panels over 500 MHz bandwidth at least.

B. Mutual Coupling Mechanisms

It is fundamental to identify what are the main coupling mechanisms enabling the TX-RX power leakage in order to isolate the TX and RX panels. Typically, mutual coupling in antenna arrays occurs because of physical phenomena such as surface waves, near-field and far-field coupling [14]. Surface waves propagate along the interface between two media, e.g., air and ground, and become more critical in the presence of dielectric substrates. Near-field coupling occurs when the RX is located within the reactive near-field region of the TX and are manifested in the form of space waves. Finally, far-field

coupling refers to the scattering and reflections that occur in the far-field region. These are usually caused by metallic structures placed nearby the antenna.

Surface waves and near-field coupling are the main leakage mechanisms in the considered antenna design. Surface waves will propagate from the TX panel through the common ground structure and reach the RX panel. Furthermore, the radiated fields can be guided by the radome and eventually leak into the RX panel. A particular challenge in this design is that any structure in the vicinity of the TX might scatter the radiated energy from the TX towards the RX. Although far-field coupling might occur in practice, its contribution to self-interference is less important than the other mechanisms. Furthermore, advanced beam nulling schemes can mitigate these undesired contributions [6]. In the next section, examples of shielding structures that significantly reduce the mutual coupling by addressing these mechanisms are provided.

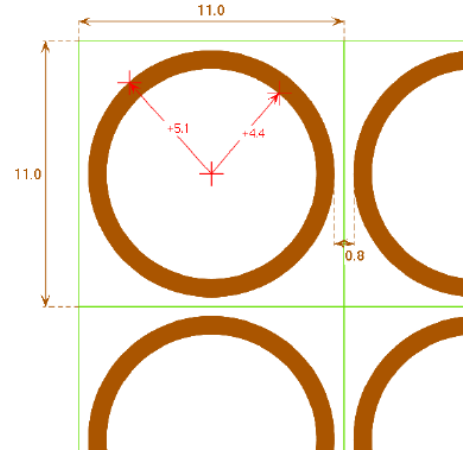


Fig. 3: Dimensions of the metamaterial-based wall unit cell in millimeters.

III. SHIELDING STRUCTURES

Shielding structures are necessary to increase the isolation between the antenna panels. The shielding structures discussed in this section are designed to further decouple the f_A -band panels. These panels will certainly interact with the f_B -band in between, but this is not much problematic as long as f_A and f_B are sufficiently far apart. Two shielding structures are presented in this section considering $f_A = 7$ GHz and $f_B = 3.5$ GHz. Simulations based on a finite-difference time-domain electromagnetic solver were performed to optimize the parameters of the shielding structures targeting the maximization of the worst sub-array-to-sub-array isolation over a bandwidth of 500 MHz centered at 7 GHz.

To reduce the runtime of the optimization procedure, a single 4×1 sub-array of dual-polarized dipole radiators with $0.7\lambda_A$ inter-element spacing was considered at both TX and RX sides, where λ_A denotes the free space wavelength at 7 GHz. In between these sub-arrays, an array of 8×3 dual-polarized dipole radiators at 3.5 GHz was implemented, as shown in Figure 4. The horizontal and vertical inter-element spacing in this array are $0.5\lambda_B$ and $0.7\lambda_B$, respectively, where

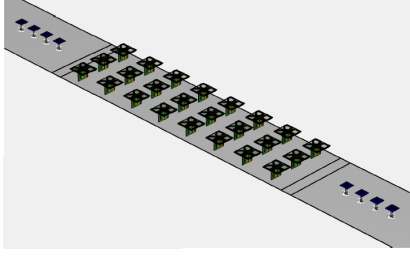


Fig. 4: Baseline sub-array-to-sub-array antenna setup for shielding structure optimization. The 7-GHz sub-arrays are located at the array extremities and the 3.5-GHz array in between.

λ_B denotes the free space wavelength at 3.5 GHz. Furthermore, a 2.5 mm-thick radome structure with relative electrical permittivity $\epsilon_r = 2.85$ and loss tangent $\tan \delta = 0.0055$ has been considered in all simulations.

A. Metamaterial-Based Wall

A metamaterial-based absorber fabricated on FR4 substrate is implemented to achieve the target isolation between TX-RX at 7 GHz. Each unit cell of this absorber consists of two-sided ring resonators that couple to each other, producing a stop-band filter effect at the target frequency band of 7 GHz. The dimensions of the ring resonator unit cell were optimized to maximize the sub-array-to-sub-array isolation in the presence of a radome and the 3.5-GHz array. The dimensions of the optimized unit cell are shown in Figure 3. The thickness of the FR4 substrate is 1.6 mm, the relative electrical permittivity is $\epsilon_r = 4.4$, and the loss tangent is $\tan \delta = 0.02$.

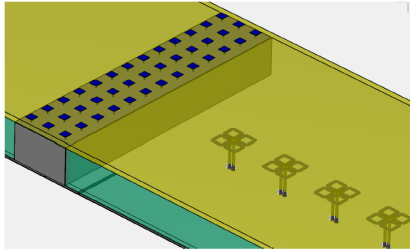


Fig. 5: 7-GHz antenna sub-array next to the EBG-based wall. The EBG mushrooms are implemented on the elevated metal wall and within the radome.

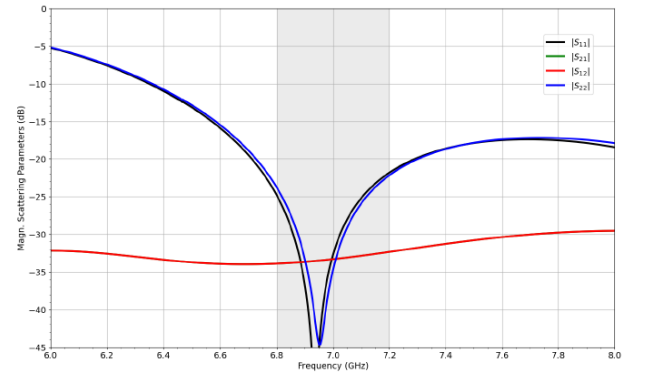
B. Electronic Band Gap-Based Wall

Electronic bandgap structures (EBG) have been demonstrated to effectively reject microwave signals at their designated bandgap frequencies [14]. In the proposed solution, elevated metal walls between the reflector and radome are built, and EBG unit cells are implemented, as illustrated in Figure 5. The employed EBG structure is of a basic mushroom type, utilizing the radome as its dielectric medium. The dimensions of mushroom unit cell were optimized to maximize the sub-array-to-sub-array isolation targeting a band rejection at 7 GHz in the presence of a radome and the 3.5-GHz array. The elevated metal walls serve to multiple purposes: they not only suppress unwanted coupling between sub-arrays but also offer mechanical support and establish a common ground for the EBG.

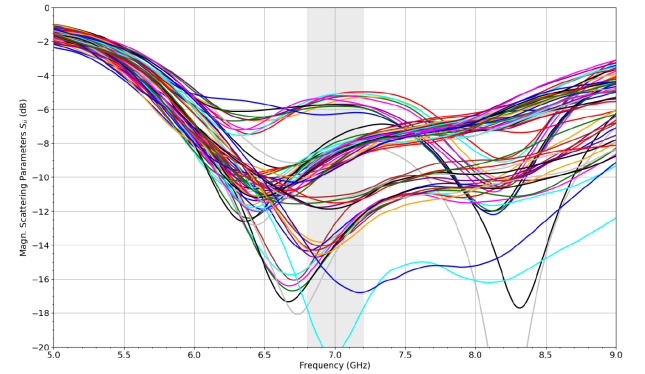
IV. FULL TRANSMIT PANEL SIMULATION RESULTS

The antenna concept is now evaluated considering the shielding structures and an 8×8 array at the TX side. A single sub-array is considered at RX to save simulation runtime. This setup represents the practical scenario where the whole TX aperture interferes with individual RX branches. The TX part of the 7-GHz system comprises an array of 8×8 elements, which corresponds to an 2×4 array of 4×1 sub-arrays. The horizontal and vertical inter-element spacings are $0.5\lambda_A$ and $0.7\lambda_A$, respectively.

It is important to discuss the impedance matching of the antenna arrays before presenting the isolation results. The reflection coefficients and the isolation of the considered 7-GHz dual-polarized radiator are shown in Figure 6a. The radiator is matched to 50Ω and it is simulated in an isolated setup. In array configurations, the tight arrangement of the antenna elements causes strong mutual coupling and affects the impedance matching at the input of each element. In this case, the active reflection coefficient of each antenna element in the TX array is shown in Figure 6b. The presence of the shielding structures influences mostly the matching of the nearby radiators. However, the effect of the shielding structure on these nearby radiators is not significant when all the radiators are excited.



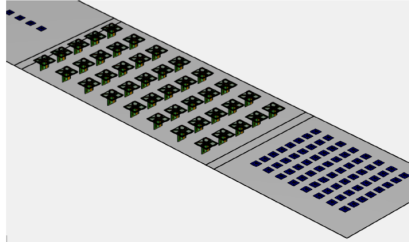
(a) S-parameters magnitude of isolated 7-GHz radiator.



(b) Active reflection coefficient magnitude of the 8×8 TX radiators.

Fig. 6: Reflection coefficient of the antenna elements in isolated and array conditions.

The panel-to-sub-array isolation performance is now discussed in terms of the simulated S parameters. The S parameter curves are calculated for both co- and cross-polarized port

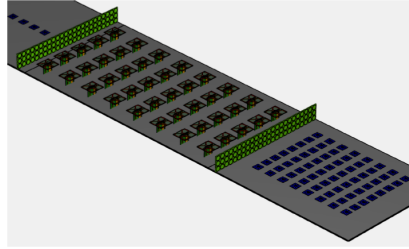


(a) Antenna model.

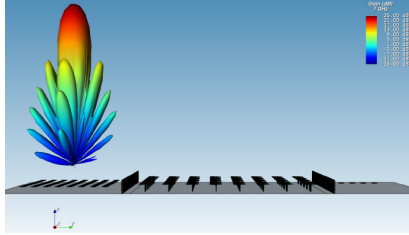


(b) Far-field gain pattern.

Fig. 7: Baseline dual-band antenna array. The 7-GHz TX system comprises an 8×8 arrays and the 3.5-GHz system includes an 8×5 array.



(a) Antenna model.

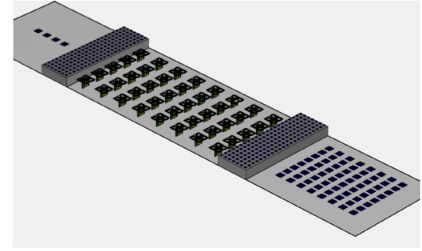


(b) Far-field gain pattern.

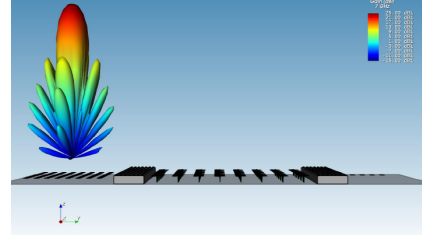
Fig. 8: Antenna concept with full TX panel and metamaterial-based walls.

pairs, and the TX beam is electronically steered towards the RX in order to evaluate the shielding stability over different steering directions θ_0 . Figure 7a shows the baseline model and Figures 7b and 10 its far-field gain pattern and coupling magnitude curves, respectively. The peak gain of the transmit beam at boresight is 25 dBi, in which 18 dB is due to the array factor, and 7 dBi refers to the radiator gain. The worst isolation level for both cross- and co-polarized ports within the frequency bandwidth of interest is 67 dB. Such an isolation is already relatively large and it is likely due to the presence of the 3.5-GHz array. The energy leaked from the TX panel is scattered by this low mid-band array, and the isolation is improved.

The metamaterial-based model is illustrated in Figure 8a, and its gain and coupling performance are respectively reported in Figures 8b and 11. The peak gain does not significantly change compared to the baseline, while the sidelobes



(a) Antenna model.



(b) Far-field gain pattern.

Fig. 9: Antenna concept with full TX panel and EBG-based walls.

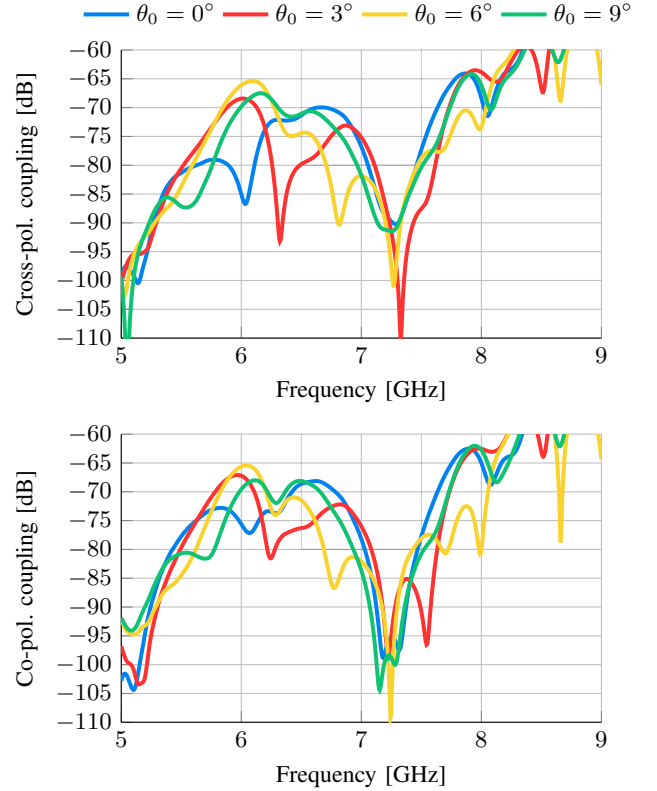


Fig. 10: Coupling curves for both cross- and co-polarized ports in the baseline configuration and various TX beam directions θ_0 . The hashed region denotes the isolation requirements.

pointing to the RX are suppressed. The worst isolation is 78 dB for the cross-polarized case and 81 dB for the co-polarized case. Finally, the EBG-based model is presented in Figure 9a and the corresponding simulation results in Figures 9b and 12. As in the metamaterial-based model, the peak gain does not vary and the gain of the sidelobe pointing to the RX is reduced.

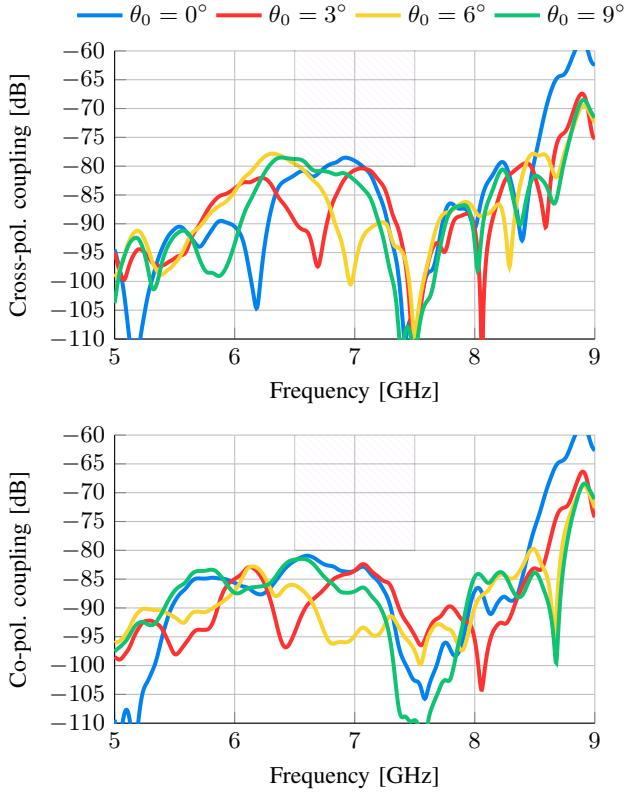


Fig. 11: Coupling curves for both cross- and co-polarized ports in the metamaterial-based shielding wall configuration and various TX beam directions θ_0 . The hashed region denotes the isolation requirements.

Unlike the metamaterial-based model, the isolation for all beam steering directions and both polarization setups is below 80 dB over more than 500 MHz of bandwidth. Specifically, the worst isolation within the bandwidth of interest is 85 dB in the co-polarized case, and 87 dB in the cross-polarized case.

V. CONCLUSION

This paper introduced a novel dual-band antenna architecture that provides more than 80 dB of panel-to-sub-array isolation in different beam directions over 500 MHz of bandwidth centered at 7 GHz. This allows for the relaxation of requirements in analog- and digital-domain RSIC, which is essential for evolved duplex schemes in mobile networks beyond 5G. Although the proposed EBG-based shielding solution provides large isolation over a broad bandwidth, its fabrication might be expensive. While the proposed metamaterial-based solution offers poorer isolation performance, it is based on simpler materials and its fabrication is more straightforward.

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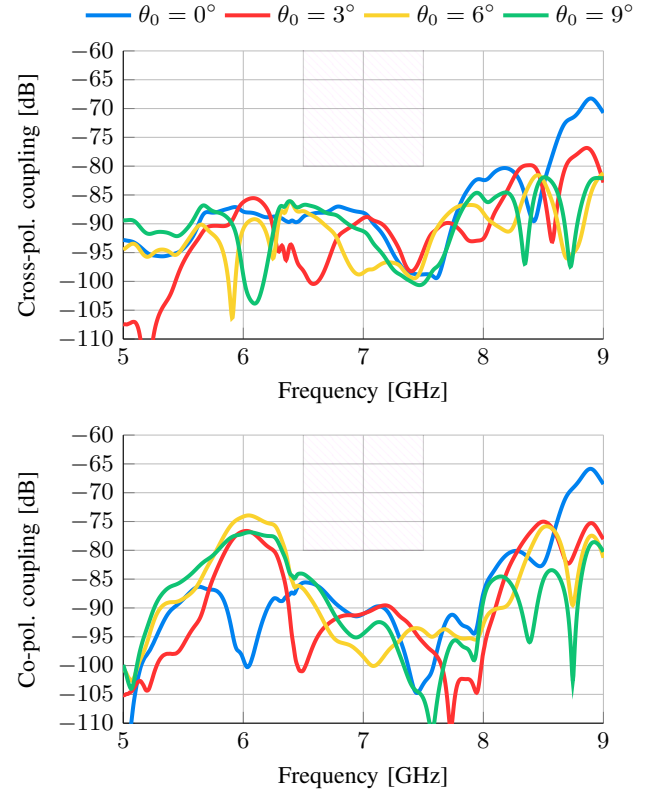


Fig. 12: Coupling curves for both cross- and co-polarized ports in the EBG-based shielding walls configuration and various TX beam directions θ_0 . The hashed region denotes the isolation requirements.

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