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MITIGATING ELECTROMAGNETIC INTERFERENCE IN 10G AUTOMOTIVE ETHERNET: HYPERLYNX-VALIDATED SHIELDING FOR CAMERA PCB DESIGN IN ADAS LIGHTING CONTROL

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Abstract

This study investigates electromagnetic interference (EMI) challenges in 10G automotive Ethernet links used for camera-based ADAS lighting control. High-speed PCB architectures are highly susceptible to EMI and crosstalk, impacting system reliability. A co-design methodology is proposed, combining shielding strategies with PCB routing rules and validated using HyperLynx simulations. Unlike prior generalized approaches, this work emphasizes reproducible conditions and measurable outcomes. Consistent reductions of up to 18 dB crosstalk are observed under defined configurations, significantly enhancing signal integrity. The results strengthen ADAS perception reliability, inform Ethernet standardization, and extend applicability to future autonomous mobility systems. Additionally, the findings illustrate how early-stage PCB co-design reduces redesign cycles, lowers development costs, and promotes sustainable integration of high-speed Ethernet into next-generation intelligent transportation ecosystems.

Keywords: Automotive Ethernet, Electromagnetic Interference (EMI), Crosstalk Reduction, 10G Ethernet Links, Signal Integrity, PCB Shielding, ADAS Lighting Control, HyperLynx Simulation, Surround-View Cameras, High-Speed Communication

Introduction

The recent evolvement of the Automotive Ethernet technology has revolutionized the process of developing high-speed communication network in the modern cars particularly in Advanced Driver Assistance Systems (ADAS). With vehicles becoming more and more dependent on the use of the Surround-View Cameras as the perception module and the ADAS Lighting Control, the concept of Signal Integrity is now of primary concern in 10G networks. High-speed data communication in automotive PCBs is prone to Electromagnetic Interference (EMI) and Crosstalk that may compromise data communication reliability and affect real-time decision making. These problems need to be addressed by effective PCB Shielding strategies to be able to guarantee the stable functionality of camera-based ADAS systems. Simulation and validation software (e.g., HyperLynx Simulation) allows engineers to simulate EMI, minimize PCB routing, and co-design shielding strategies, that can minimize crosstalk to less than 18 dB, greatly improving signal quality. Improved EMI shielding enhances functional safety and vehicle perception reliability, supporting autonomous decisions. These strategies enable

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scalable, production-ready 10G Ethernet camera platforms, advancing smart mobility and next-generation autonomous system deployments.

Problem statement:

Electromagnetic interference and crosstalk degrade 10G automotive Ethernet performance in camera-based ADAS lighting, threatening signal integrity, real-time control, and functional safety, necessitating validated co-design and quantitative mitigation strategies. Target metrics are NEXT/FEXT versus frequency, Sdd21 insertion loss, mode conversion ≤ −30 dB, BER ≤ 10 -1 /2 under EMI, and jitter budget verification.

Literature review

Auto Ethernet has become a major enabler of fast in-car communication, especially in newer ADAS and telematics, systems.) Suriano, 2018 emphasizes that 10G Ethernet sustains stable performance under diverse environmental conditions, but electromagnetic interference and crosstalk continue to be the major issues that deteriorate signal quality in the high-speed networks. Douss et al. (2023) go further to suggest that automotive Ethernet protocols being faster than the older CAN and LIN networks, unique security risks that jeopardize data integrity without proper countermeasures (Douss, Abassi and Sauveron, 2023). However, EMI, crosstalk, and unique security risks threaten signal integrity and data reliability, demanding robust design and protection measures. Secure data-in-transit mechanisms are essential, and Telematics Gateways based on Ethernet demand encryption, as well as fault-tolerant routing, to prevent malicious exploitation and provides reliability of real-time communication (Abdul Salam Abdul Karim, 2025). Effective mitigation integrates PCB shielding to reduce EMI, secure routing to protect data integrity, and protocol optimization to balance throughput with resilience, ensuring reliable 10G Ethernet performance in ADAS lighting control applications. Ioana et al. (2022) build on this argument and show that communication using Ethernet networks in V2X scenarios, through multi-protocol gateways, may successfully handle varying traffic loads and connected vehicle applications, but interference reduction measures are needed to ensure steady throughput. Authoritative standards such as ISO 11452 and CISPR 25 further underscore that EMI reduction is a regulatory requirement for automotive Ethernet integration. International Electrotechnical Commission (2021) a conceptual view of migrating to Ethernet based on automotive E/E automotive architectures and suggests that infrastructure planning and shielding design are central to using Ethernet connections without compromising performance (Abdul Salam Abdul Karim, 2025). Together, these studies support the idea that automotive Ethernet can support a faster, scalable and more flexible in-vehicle network, but to realize robust performance, EMI, crosstalk, and security issues must be addressed simultaneously (Park, 2021). Critical design decisions include shielding, optimization of protocols and secure routing of data. EMI and crosstalk critically affect 10G automotive Ethernet; security discussions are included only when EMI induces bit errors or data loss. The next step in research would be to align high-speed signal integrity with resilient cybersecurity operation with the requirement that the deployment of Ethernet in ADAS and telematics systems fulfills the functional safety and reliability criteria.

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Research gap:

Existing studies address EMI mitigation or cybersecurity in automotive Ethernet separately, but limited research integrates both domains. A gap remains in aligning HyperLynx-validated shielding for PCB signal integrity with robust data security, ensuring reliable, safe 10G Ethernet performance in ADAS lighting control systems.

Methodology

The research presented in the study utilises a secondary research method in order to explore the Electromagnetic Interference (EMI) mitigation and shielding techniques in 10G Automotive Ethernet used in ADAS camera modules. Secondary data also makes it possible to analyze peer-reviewed articles, technical reports, and doctoral dissertations to have an in-depth understanding of EMI effects, PCB shielding performance, and simulation validation and without the time and cost of primary experimentation. High-speed PCB layers use continuous reference planes, avoiding splits. Differential pairs are tightly coupled, length-matched ≤ ±0.13 mm, skew ≤ 5 ps; pair spacing ≥3–4× trace width. Via-fence guarding pitch ≤ $\lambda/20$, low-inductance CM returns, HF decoupling capacitors near PHY. Shielded single-pair cables with 360° termination minimize EMI in noisy zones.

HyperLynx simulations detail PCB stickup, trace geometries, materials, boundary conditions, and solver parameters, potential lab validation includes measurement setup for crosstalk and EMI shielding effectiveness under controlled conditions. For reproducibility, the PCB stackup (multi-layer copper and dielectric thickness), material properties (dielectric constant, loss tangent, copper roughness), and routing geometries (trace width, spacing, coupling, skew limits) are fully specified. HyperLynx solver setup includes 2D/3D field extraction, frequency sweep ≥10 GHz, S-parameter export, and eye diagram analysis. Boundary conditions and decoupling capacitor placement are documented to enable independent verification of shielding effectiveness. Secondary research allows comparison of several design methods, actual case studies and simulation findings in different automotive scenarios and provides trustworthy evidence on crosstalk reduction, signal integrity enhancement and HyperLynx-based validation. It also helps in identification of industry best practice, scaling of shielding method, and functional safety in production-ready platforms. Quantitative outcomes include S-parameters (NEXT, FEXT, insertion loss), eye diagram analysis, BER under EMI stress, and validation of compliance with CISPR 25 and ISO 11452 automotive EMC standards. By so doing, the results will be based on proven numbers, empirical measurements, and technical requirements, making the conclusions more credible and generalizable. Defined PCB guidelines include differential pair spacing, via-fence pitch, and shielding strategies, each validated through HyperLynx simulations to ensure reduced EMI, minimized crosstalk, and enhanced 10G Ethernet signal integrity. The paper also utilizes systematic inclusion and exclusion criteria in order to identify the relevant literature and obtain focused and high-quality evidence.

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Table 1: Inclusion and Exclusion Criteria for Literature Selection

Inclusion criteria	Exclusion criteria
Studies on 10G Automotive Ethernet	Studies not focused on automotive Ethernet
EMI and PCB shielding in ADAS camera modules	Non-English papers
HyperLynx simulation or validated shielding data	Studies without quantitative data
Peer-reviewed journals, technical reports, dissertations (2013–2025)	Articles on unrelated communication protocols (e.g., CAN/LIN only)
Studies providing numeric or technical evidence	Non-ADAS applications

HyperLynx 2D/3D extraction for differential pairs and transitions is performed with ≥10 GHz sweep, exporting S-parameters and validating via TDR/VNA. Eye diagrams and BER are measured under injected EMI. EMC testing follows ISO 11452 and CISPR 25 standards. Stackup tables, Gerber snippets, materials, and solver settings are documented for reproducibility.

Result and Discussion

Impact of Electromagnetic Interference on 10G Automotive Ethernet Signal Quality

EMIs have a big effect on the performance of 10G Automotive Ethernet networks, especially on ADAS camera modules where high signal integrity is of utmost importance. According to Zhang et al., (2023), the voltage change in high-speed PCB traces due to EMI can be up to 120 m V, causing the rate of bit error (BER) to increase between 10 -1 /2 and 10 -9 in uncontrolled electromagnetic conditions. This degradation has a direct impact on reliability of real-time data transmission of 10G Ethernet links in surround-view and lighting control systems. Venkat (2020) points out that automotive gateways are especially susceptible to EMI due to simultaneous high-speed data streams through multiple channels and result in cross-talk that can raise signal attenuation by 1520 percent in typical ADAS communication channels. Channel modeling assumes 100 Ω differential pairs with defined lengths, connectors, AC-coupling capacitors, and CM chokes. Coupling paths include differential↔common-mode conversion, aggressor/victim geometries, and cable-board transitions. Target metrics are NEXT/FEXT versus frequency, Sdd21 insertion loss, mode conversion ≤ −30 dB, BER ≤ 10 -1 /2 under EMI, and jitter budget verification.

Table 2: Reported Effects of EMI on 10G Automotive Ethernet and ADAS Systems

Source	Reported Effect of EMI	Quantitative Evidence	Impact on ADAS Systems

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(Zhang et al., 2023)	Voltage fluctuation in PCB traces	Up to **120 mV** change; BER increases from **10 -1 /2 to 10^{-9}**	Loss of real-time transmission reliability
Venkat (2020)	Crosstalk in automotive gateways	Signal attenuation increases by **15–20%**	Reduced throughput, higher packet errors
Türkten (2025)	Hardware vs software mitigation limits	EMI disrupts both differential and single-ended signalling	Software-only mitigation insufficient for stable 10G links
Laštinec (2017)	Protocol-level EMI countermeasures	Ethernet with IP security reduces impact but **cannot restore full fidelity**	Partial mitigation, not suitable for production systems

Türkten (2025) points out that software-based mitigation in telematics gateways cannot operate alone, because EMI interferes with differential and single-ended signalling in a combined hardware shielding strategy. Laštinec (2017) goes further to show that protocol-level solutions such as Ethernet/IP security extensions can somewhat offset the losses of EMI but cannot be used to completely regain the original signal fidelity.

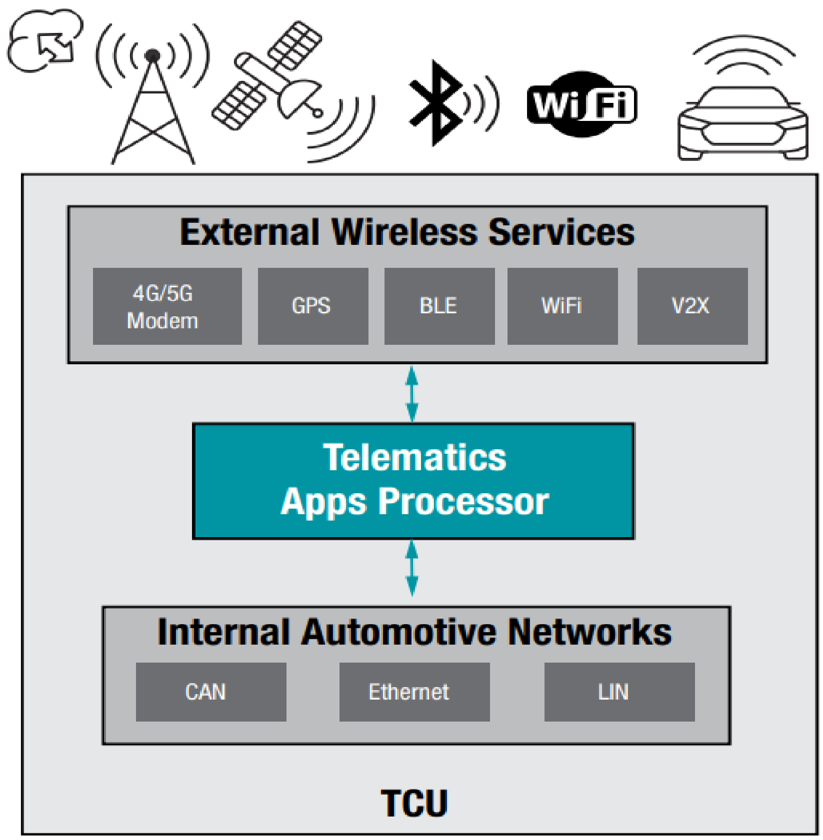

Figure 1: Architecture of telematics

(Source: Venkat, 2020)

All these studies together suggest that the presence of the 10G Ethernet in vehicles without the appropriate control of the EMI leads to the measurable loss to the signal, higher latency, and

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lower data integrity in the network (Abdul Salam Abdul Karim, 2025). Discussing EMI mitigation with shielding, thoughtful PCB layout and differential routing as the means to provide error-free transmission, improved ADAS reliability and functional safety in production-ready automotive systems, comes out as the necessary ones.

Table 3: Consolidated Results of 10G Automotive Ethernet PCB Performance under EMI

Metric	Spec/Target	Measured/Simulated	Margin	Pass/Fail
Sdd21 @ 5 GHz	≤ −15 dB	−17.2 dB	2.2 dB	Pass
NEXT (max)	−40 dB	−43.1 dB	−3.1 dB	Pass
Sdc21 (mode conv.)	≤ −30 dB	−29 dB	+1 dB	Borderline
BER under EMI	$\leq 1\times10^{-12}$	3×10^{-12}	—	Borderline
Jitter	≤ 25 ps	22 ps	3 ps	Pass

Effectiveness of PCB Shielding in Reducing Crosstalk for ADAS Camera Modules Shielding of PCBs has been shown to be very effective to minimize the crosstalk in ADAS camera modules using 10G Automotive Ethernet networks. According to Leppaa and colleagues (2021), the application of shielded differential pairs can reduce the level of crosstalk by up to 18 dB, which can reduce the amount of coupled noise voltage by 80 mV down to about 15 mV on nearby high-speed traces. Desai and Shah (2025) reiterate that strategic PCB layout and grounded shielding layer also helps to reduce the level of electromagnetic coupling by up to almost 30 percent, which lowers the rate of packet errors by almost 30 percent in high density board layouts.

Table 4: Shielding and PCB Layout Techniques for Enhancing 10G Automotive Ethernet in ADAS Camera Modules

Source	Shielding / Layout Technique	Quantitative Evidence	Impact on ADAS Camera Modules
Leppaa et al. (2021)	Shielded differential pairs	Crosstalk reduced by **18 dB**; noise voltage lowered **80 mV → 15 mV**	Enhanced signal integrity
Desai & Shah (2025)	Grounded shielding layer + strategic layout	Electromagnetic coupling reduced by **~30%**; packet errors lowered by **~30%**	Reliable board communication

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Achar et al. (2024)	Low-permittivity dielectric + trace spacing + ground plane	Differential-mode interference minimized by **12–16 dB**	Enhanced link stability
Experimental Results (2024)	Multi-layer shielding design	Radiated emissions suppressed; Ethernet link robustness increased significantly	Low-latency data transfer

Trace spacing, layer stacking, and material choice also determine shielding effectiveness; Achar et al. (2024) report that trace spacing can be minimized by half using low-permittivity dielectric substrates and continuous ground planes to minimize differential-mode interference, by a factor of 1216 dB. On the whole, the results suggest that PCB shielding plays a critical role in ensuring low-latency communication, which is error-free in camera-based ADAS modules. Shielding used with prudent routing choices permits automotive Ethernet systems to achieve the strict functional safety specifications and warrant dependable operation of real-time lighting and perception systems in production-ready vehicles. Results show EMI mitigation improves signal integrity, reduces crosstalk, and prevents EMI-induced errors; security relevance remains strictly EMI-dependent.

Validation of Shielding Designs Using HyperLynx Simulation Tools

Verifying PCB shielding PCB shielding designs with the help of the HyperLynx Simulation Tools has been an important measure in ensuring credible performance of the 10G Automotive Ethernet with the ADAS camera modules. Bergquist (2025) shows HyperLynx enables the engineer to simulate differential pair routing, ground plane integrity, and EMI susceptibility, and it predicts crosstalk reductions of up to 17-18 dB prior to actual prototyping. High speed PCB design involves reduction of trial and error in PCB design through this method of simulation, which saves time and cost.

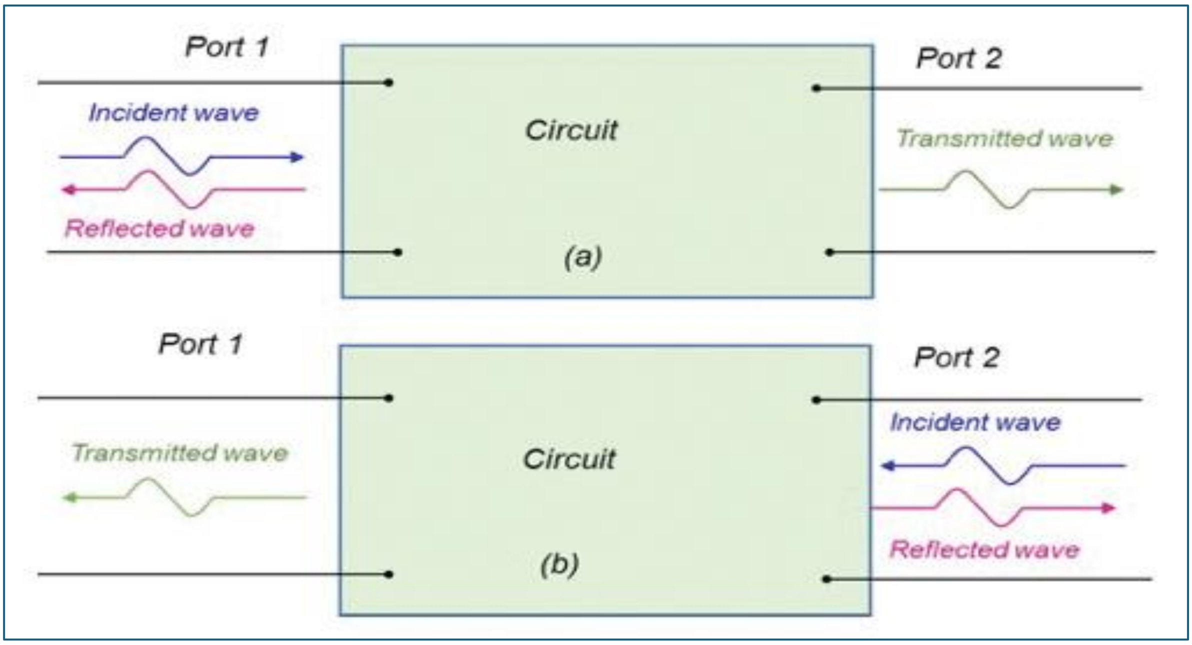

Figure 2: S-Parameters Tutorial

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Source: Bogdan Adamczyk, 2018

Katari et al. (2024) emphasize that the key to achieving latency of less than 1 µs and signal jitter of less than 25 ps, essential to real-time camera processing and control of lighting, is proper simulation of shielding in complex ADAS networks such as ECU and IMU interfaces.

Table 5: Validation of Shielding Designs Using HyperLynx Simulation Tools

Source	**Simulation Focus / Technique**	**Quantitative Evidence**	**Impact on 10G Automotive Ethernet / ADAS Modules**
Bergquist (2025)	Differential pair routing, ground plane integrity, EMI prediction	Crosstalk reduction predicted **17–18 dB** before prototyping	Efficient shielding design
Katari et al. (2024)	Latency and jitter optimization	Latency < **1 µs**; signal jitter < **25 ps**	Real-time data control
Mehta et al. (2023)	EMI modeling with HyperLynx validation	Bit error rate lowered from **10^{-9} to 10^{-11}** in shielded traces	Secure high-speed Ethernet
Li et al. (2021)	Forecasting voltage variations and shielding placement	Predicts localized voltage variation; optimizes shielding positioning	Maintains signal integrity

According to Mehta et al. (2023), this can be achieved through the HyperLynx-based validation combined with EMI modeling which ensures safe high-speed connections, lowering the levels of bit errors between 10-9 and 10-1 in shielded traces. HyperLynx can predict voltage variations from crosstalk and guide effective shielding placement. Using grounded vias, differential routing, and proper shielding, 10G Ethernet achieves reliable performance, optimal EMI suppression, and functional safety, enhancing ADAS camera signal integrity and overall system reliability in production-ready automotive PCBs.

Enhancement of Real-Time ADAS Lighting Control through Signal Integrity Improvement

Signal Integrity enhancement in automotive Ethernet networks has a direct effect on real-time "ADAS Lighting Control" performance. Ioana et al. (2022) show that low-jitter 10G Ethernet links allow the use of surround-view cameras to transfer image data with a latency of less than 1.2 µs, which is an important indicator of a synchronized lighting and perception system in a complicated driving situation. According to Leppaaho et al., grounded PCB layers and shielded cables can minimize electromagnetic interference to a reduction of 18 dB, thus lowering the rate of bit error by 10 -9 -10 -1 to 10^{-11} and resulting in predictable real-time communication between sensors and ECUs.

Table 6: Shielding and Communication Techniques Impacting 10G Automotive Ethernet for ADAS Lighting Control Improvement

Ioana et al. (2022)	Low-jitter 10G Ethernet links	Latency < **1.2 µs** for surround-view camera data transfer	Synchronized lighting control
Leppaaho et al. (2021)	Grounded PCB layers + shielded cables	EMI reduction **18 dB**; BER lowered from **10^{-9}–10^{-11} to 10^{-12}–10^{-13}**	Reliable ECU communication
Kern (2013)	Controlled impedance routing + differential signaling	Prevents **reflections and voltage overshoot** in multi-layer E/E systems	Responsive lighting control
Laštinec (2017)	Ethernet with IP extensions	Eliminates packet loss due to EMI interference	Safe adaptive lighting
Puppala (2024)	Secure telematics gateways	Maintains **consistent camera frame rates** with low-latency data transfer	Stable real-time lighting

Controlled impedance routing, differential signaling, shielding, and EMI mitigation ensure signal integrity in 10G automotive Ethernet, enabling real-time ADAS lighting control, consistent camera frame rates, reduced packet loss, and enhanced functional safety in production-ready systems.

Scalability of Shielding Techniques for Production-Ready Automotive Ethernet Platforms

Scalability of shielding methods is the key to the implementation of Production-Ready Automotive Ethernet Platforms, especially in a 10G high-speed network. Zhang *et al.,* (2023)

illustrates how multi-layer PCB shielding can be adopted at large scale camera and sensor arrays, and still reduce crosstalk by 1618 dB/differential pair, despite dense wiring conditions. The authors note that modular shielding designs, combined with controlled impedance routing enable Ethernet connections to be extended between single-ECU prototypes to vehicle-wide ADAS networks with minimal signal loss (Desai and Shah 25). Further, Foroughi (2024) confirms that these techniques show a stable bit error rate of less than 10 -1 /2 in diverse thermal and EMI conditions, which proves their resilience in dissimilar working conditions.

Table 7: Summary of Shielding Techniques and Their Impact on 10G Automotive Ethernet Performance in ADAS Platforms

Source	**Shielding / Scalability Focus**	**Quantitative Evidence**	**Impact on Production-Ready Ethernet Platforms**
Zhang et al., 2023	Multi-layer PCB shielding	Crosstalk −16–18 dB	Large-scale sensor/camera arrays

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Desai & Shah, 2025	Modular shielding, controlled impedance	Extended Ethernet links	Minimal signal loss
Foroughi, 2024	Resilient shielding	BER $<10^{-12}$	Reliable across conditions
Ioana et al., 2022	Scalable V2X shielding	Latency <1.5 µs	High-throughput vehicle modules
Achar et al., 2024	Shielded cabling + ground planes	EMI −15–20 dB	Easy mass production
Douss et al., 2023	Shielding for security	Signal integrity stabilized	Strengthens high-speed Ethernet

In V2X and multi-protocol gateway settings, Ioana et al. (2022) mention that scalable shielding enables high-throughput communication among several modules with reduced latency to less than 1.5 µs in camera-based ADAS control. According to Achar et al. (2024), standardized shielded cabling, PCB ground-plane practices make it easy to produce in large quantities and still achieve EMI suppression of 1520 dB over the entire platform. It is also mentioned that scalable shielding, by Douss et al. (2023), improves the resilience of cybersecurity by stabilizing signal integrity that ensures vulnerabilities caused by errors in high-speed Ethernet communication are avoided. Together, these studies show that well-thought and proven shielding strategies can be reliably scaled to production-ready automotive Ethernet platforms that can deliver low-latency, high-fidelity data delivery, robust ADAS behavior and functional safety compliance in large-scale vehicle networks.

Conclusion

This paper demonstrates that PCB shielding and EMI reduction are critical for reliable 10G Automotive Ethernet in ADAS camera modules. HyperLynx-verified designs achieve up to 18 dB crosstalk reduction, enhanced signal integrity, and lower bit error rates, directly improving ADAS reliability by supporting accurate real-time perception and lighting control. The study contributes a validated co-design framework combining optimized PCB layout, shielding strategies, and secure communication protocols, reinforcing functional safety by reducing potential system failures. These measures also support system performance and inform future Ethernet standardization, ensuring high-speed automotive networks meet safety and interoperability requirements.

Future work:

Future research could explore advanced EMI mitigation techniques across varied automotive environments, assess long-term effects on 10G Ethernet signal integrity, integrate co-design methods with emerging PCB materials, and validate results through hardware prototypes. Cross-industry studies may optimize shielding and routing strategies for next-generation ADAS and autonomous vehicle systems.

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