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Designing Audible Safety with Acoustic Vehicle Alerting System for Commercial Vehicles

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Abstract: Electric and hybrid vehicles, known for their environmental benefits, also present a unique challenge because of their quiet operation. In urban settings, this lack of noise increases the potential for accidents with pedestrians who rely heavily on auditory cues. In response to this concern, Acoustic Vehicle Alerting Systems (AVAS) have been introduced and many countries, including the US and EU, have mandated the installation of Acoustic Vehicle Alerting Systems. These systems produce sounds to alert pedestrians of an approaching vehicle by increasing the audibility of electric and hybrid vehicles to ensure pedestrian safety [1]. In this paper, we dive deep into designing an effective AVAS for commercial vehicles, such as trucks and buses. Any AVAS must conform the international regulations such as the ECE-R138 regulation by the United Nations Economic Commission for Europe (UNECE) and FMVSS 141 by the National Highway Traffic Safety Administration (NHTSA), so our design adheres to guidelines set by key global bodies. This endeavour was supported by The Scientific and Technological Research Council of Türkiye. Our AVAS not only offers a variety of sound options but also includes self-diagnostic features to ensure its consistent performance. An integral part of our study was the utilization of an ASIL-B functional safety-compliant embedded MCU system to generate and manipulate psychoacoustic sounds. The regulations regarding the acoustic characteristics of AVAS sounds, such as minimum sound level, frequency spectrum, and frequency shift, have been instrumental in improving awareness of the AVAS sounds of quiet vehicles[2]. The ultimate aim is to showcase a versatile, compliant, and efficient AVAS, beneficial for the future landscape of electric and hybrid commercial vehicles.
Keywords: Acoustic Vehicle Alerting System, Pedestrian Safety, Electrical Vehicles, Sound Design, Sound Manipulation with MCUs

I. INTRODUCTION

In today's rapidly evolving automotive industry, there has been a considerable shift towards electric and hybrid vehicles due to their environmental benefits and usage of electric and hybrid vehicles is steadily increasing worldwide. However, the quiet operation of these vehicles has presented a significant challenge in terms of pedestrian safety.[1] To address this challenge, many countries have required the installation of Acoustic Vehicle Alerting Systems in electric and hybrid vehicles. The goal of AVAS is to generate a psychoacoustic sound that attires the attention of pedestrians while electric and hybrid vehicles are travelling at low speeds (20km/h and below).[2] Therefore, the design of an effective AVAS for commercial vehicles, such as trucks and buses, plays a crucial role in ensuring pedestrian safety. AVAS designs must comply with international regulations such as the ECE-R138 regulation by the United Nations Economic Commission for Europe and FMVSS 141 by the National Highway Traffic Safety Administration. The acoustic characteristics of AVAS sounds, including minimum sound level, frequency spectrum, and frequency shift, are specified in these regulations to ensure their effectiveness [3].

The term AVAS was first introduced in a press release by a Japanese automotive company in 2010, announcing a system that audibly alerts of approaching electric and hybrid vehicles. In the same year, the American Council of the Blind issued a press release stating that visually impaired individuals are at significant risk due to the quiet operation of electric and hybrid vehicles, emphasizing the need for regulatory measures. These regulations included requirements regarding the acoustic characteristics of AVAS sounds, such as the minimum sound level, frequency spectrum, and frequency shift of the sounds [3]. To improve awareness of the AVAS sounds of quiet vehicles, various studies have been conducted internationally. One such study conducted by Pilskow et al focused on a sound detection experiment involving AVAS sounds of quiet vehicles and blind and visually impaired participants. The study conducted by Pilskow et al aimed to examine how blind and visually impaired participants detected the AVAS sounds of quiet vehicles compared to traditional internal combustion engine vehicles travelling at slow speeds.

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The results of the study revealed that blind participants were able to detect hybrid electric vehicles at a shorter distance and with less time to avoid a collision compared to traditional ICE vehicles. The findings of Pilskow et al's study highlight the importance of designing effective AVAS systems for commercial vehicles to ensure the safety of pedestrians, particularly those with visual impairments.

AVAS comprises various components, including speakers, horns, and other sound-producing devices. While some AVAS systems activate automatically when the vehicle is in motion, others can be manually activated by the driver. Additionally, some systems integrate with the existing sound system of a vehicle or are available as aftermarket accessories. As electric and hybrid vehicles become more prevalent on the roads, the implementation of effective Acoustic Vehicle Alerting Systems becomes crucial in ensuring the safety of pedestrians, especially those with visual impairments. The incorporation of AVAS in commercial vehicles is a response to the increased prevalence of electric and hybrid vehicles on the roads.

The design and product presented in this study can be characterized as a unique AVAS system with an innovative ventilation system, a design compliant with UNECE R138 and UNECE R10 regulations and sealed according to IP standards for waterproofing and dust resistance. The designed system is a product that can be mounted on all kinds of commercial vehicles. The subsequent sections of this study share the R&D stages of the design and discuss the significant challenges encountered during the process and how they were overcome.

II. MATERIALS AND METHODS

A. Regulations

To meet the regulatory requirements set by various countries, including the US and EU, regarding AVAS sounds, the design of the acoustic vehicle alerting system incorporated compliance with UNECE R138 and UNECE R10 regulations. Two regulations directly cover AVAS. These are the ECE-R138 regulation introduced by the United Nations in 2017 and the FMVSS - 141 regulations introduced by the United States Department of Transportation in 2018. While designing the psychoacoustic sound for AVAS systems, the minimum sound level, frequency spectrum, and frequency shift requirements specified by these regulations were taken into consideration [1]. For designing the system, component selection and design are carried out in accordance with AEC-Q100, AEC-Q200 and ASIL-B standards to comply UNECE R10 regulation.

The regulation, that AVAS's sound is subject to, is R138. Its purpose is to protect vulnerable people on the road (children, cyclists, elderly, visually impaired and potentially distracted pedestrians) from the danger posed by silent electric and hybrid vehicles with audible warnings.

In this context, in the relevant regulation, the minimum sound levels that AVAS should emit are defined by dB(A), which is the sound pressure level that the human ear will hear, used in sound pressure level measurement in accordance with international standards.[2]

TABLE I
TABLE OF MINIMUM SOUND LEVELS THAT AVAS MUST EMIT, ACCORDING TO REGULATION R138.

Frequency (Hz)		Constant Speed (10 km/h)	Constant Speed (20 km/h)	Reverse
Column 1	Column 2	Column 3	Column 4	Column 5
Total		50	56	47
1/3 Octave Band	160	45	50	
	200	44	49	
	250	43	48	
	315	44	49	
	400	45	50	
	500	45	50	
	630	46	51	
	800	46	51	
	1.000	46	51	
	1.250	46	51	

	1.600	44	49	
	2.000	42	47	
	2.500	39	44	
	3.150	36	41	
	4.000	34	39	
	5.000	31	36	

The relevant measurements must be performed with the AVAS installed in the vehicle. The background noise in dB(A) must be recorded for 10 seconds and the difference between the maximum and minimum values must be less than or equal to 2 dB(A). The system measurement can be performed with the vehicle in motion or stationary. If the vehicle is measured in a stationary controlled environment, the relevant measurement is performed by simulating the vehicle speed via the CANBus communication protocol. As shown in Figure 2.2.1 and Figure 2.2.2, microphones are placed on the PP' line with a distance of 4 meters between them. The PP' line should be perpendicular to the CC' line, which is the vehicle route line. The microphones shall be placed 1.2 meters above the ground and perpendicular to the CC' line.

The test methods for the relevant regulation are listed below;

Method (A): Measured outdoors while the vehicle is in motion.

Method (B) and Method (D): Measured with the vehicle stationary in the outdoor and indoor environment.

Method (C): Measured indoors with the vehicle in motion.

Method (E): Measured indoors when the AVAS is not mounted on the vehicle.

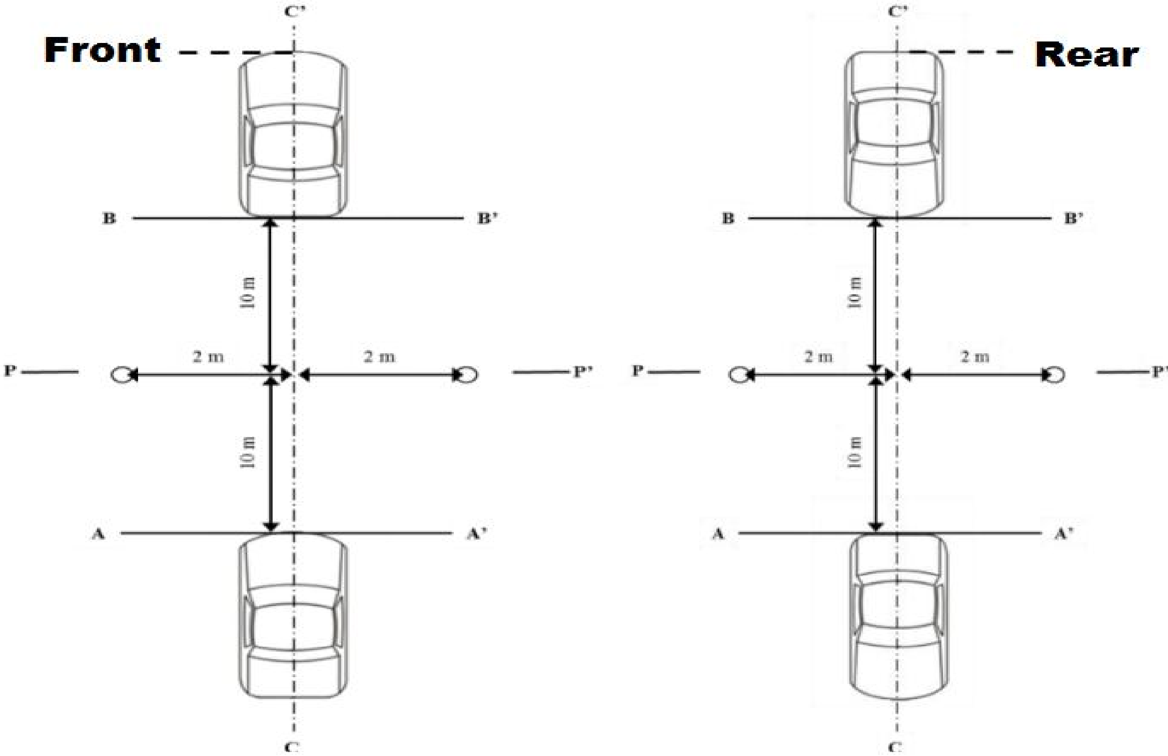

Fig. 1 Microphone and Vehicle Distances for Outdoor Measurement

According to Method (A), in the measurements to be taken in forward and reverse motion, the vehicle must maintain a constant speed for at least 5 seconds, and measurements must be taken separately at speeds of 10 km/h and 20 km/h. According to Method (B) and Method (D), in the test setup to be simulated over the CANBus communication line in the indoor environment, the vehicle shall be measured according to the required criteria while the vehicle is moving. When measurements are to be taken at different speeds while the vehicle is moving or stationary, measurements should be taken with an acceleration of 5 km/h between 5 km/h and 20 km/h.

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According to Method (E), when the AVAS is to be measured without being mounted on the vehicle, the AVAS and microphone should be at the same height and facing each other, with a distance of 1 meter between them. For indoor measurements, if an anechoic chamber is not used, the background noise level should be measured in the same way as for outdoor measurements. Where the background noise level is not less than 2 dB, the background noise should be subtracted from the measured values in the relevant frequency bands. If the difference between dB(A) test and dB(A) background is less than 3 dB(A), the measurement is invalid. If more than 3 dB(A), the correlation and correction values specified in Table 2 are applied to the measured values.

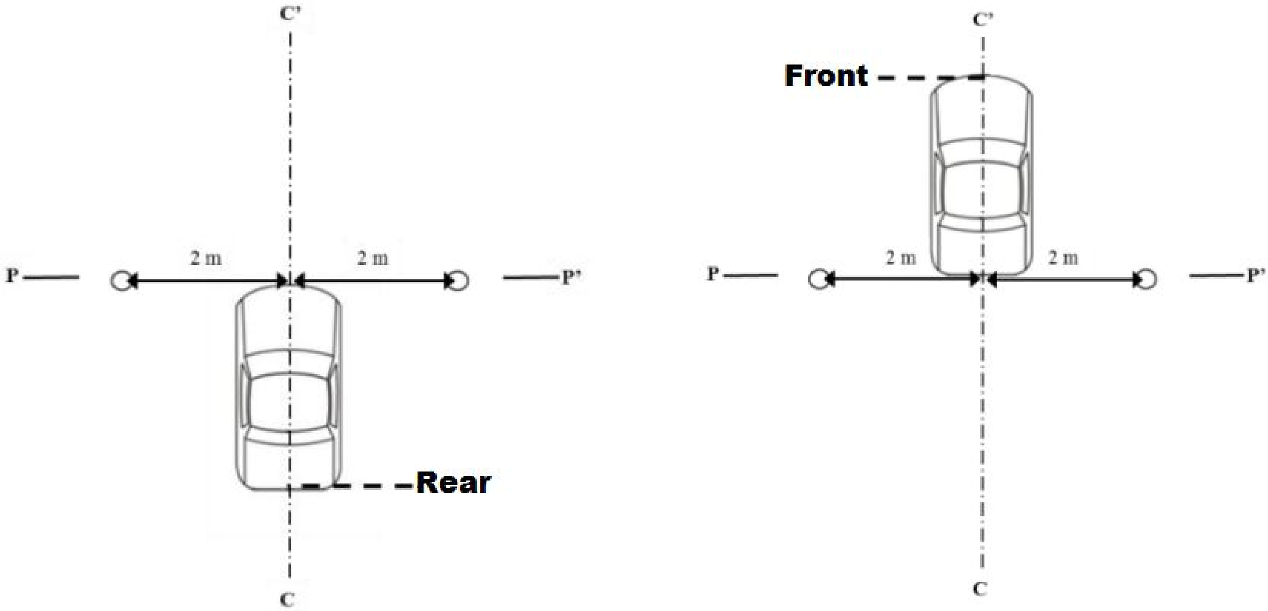

Fig. 2 Microphone and Vehicle Distances for Controlled Ambient Measurement

TABLE II
TABLE OF BACKGROUND NOISE CORRECTION FOR AVAS MEASUREMENT ACCORDING TO REGULATION R138.

Correction of Background Noise		
L_{eq}(A) difference btw max and min background noise (dB(A))	$\Delta L = L_{test} - L_{background}$ (dB(A))	Correction Value (dB(A))
-	$\Delta L \geq 10$	No Correction
≤ 2	$8 \leq \Delta L < 10$	0.5
	$6 \leq \Delta L < 8$	1.0
	$4{,}5 \leq \Delta L < 6$	1.5
	$3 \leq \Delta L < 4.5$	2.5
	$\Delta L < 3$	Invalid Measurement

As our AVAS system will be an OEM design, it can be integrated into commercial vehicles during the assembly process or aftermarket installation. Therefore, it is crucial to ensure that the AVAS system meets the regulations and standards set forth by UNECE R138. So sound level needed to be adjustable in order to comply with the minimum and maximum sound level requirements outlined in UNECE R138.

The measurement methods for the acoustic characteristics of AVAS, as outlined in the relevant regulation, are crucial to ensure accurate and reliable results.

III. TESTS AND RESULTS

During the design of the system, existing products in the market were initially analyzed. Concurrently, solutions offered by semiconductor component manufacturers (MCU, MPU, Amplifiers, Various Integrated Circuits) were explored. The study involved a design based on sound processing.

The proposed system is one that meets all the requirements expected from an AVAS (Acoustic Vehicle Alerting System) comparable to its market equivalents (Fig.3). It is anticipated that the system can operate across all voltage ranges actively used in the automotive sector. The components of the developed AVAS system must comply with automotive regulations. In this context, the microcontroller used in the control unit supports ASIL-B level under the ISO 26262 Functional Safety standard, aligning with automotive sector standards, while other components are determined at the AEC-Q100 level. Preliminary studies have been conducted for the sound amplifier block to achieve the sound levels required by regulation, selecting a Class D sound amplifier and suitable speaker to meet these requirements. Due to Commercial Confidentiality, details of the used components cannot be shared. AVAS sounds are identified as variable and stimulating wideband electronic sounds, primarily in the frequency range where the human ear is most sensitive, along with engine sounds (Denjean et al., 2021). Although this sound is essentially a psychoacoustic one within human perceptible levels, it is produced by combining ten sinusoidal components, each separated by an octave, and is referred to in literature as the Shepard tone (Roger, 1964). The sound synthesis in an infinite loop is conducted based on vehicle speed and gear data received from the vehicle's CANBus, producing AVAS sounds according to the vehicle's acceleration and deceleration from 0 to 20 km/h. To create a sensation of acceleration and deceleration, a frequency shift method (Fig.4) has been determined by keeping the playback duration constant and reducing the number of samples. This study increases the perceived sound frequency in relation to vehicle speed, creating a sensation of acceleration. The frequency shift requirement from regulation mandates has also been implemented with this method. After the research, design and prototyping following results are obtained (Table III and IV).

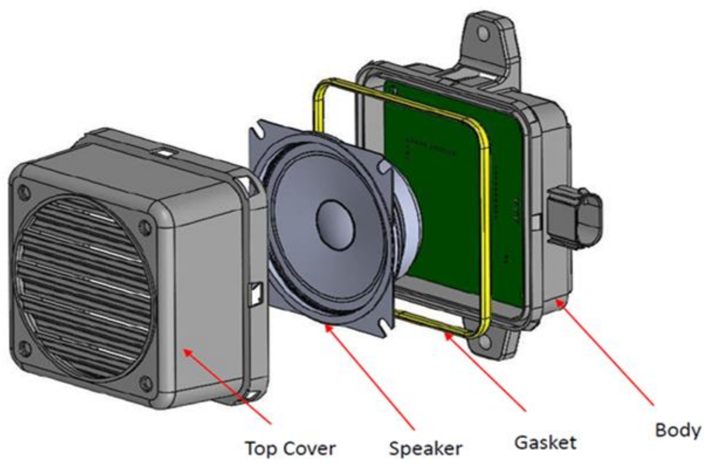

Fig. 3 Mechanical and Electronic system integration

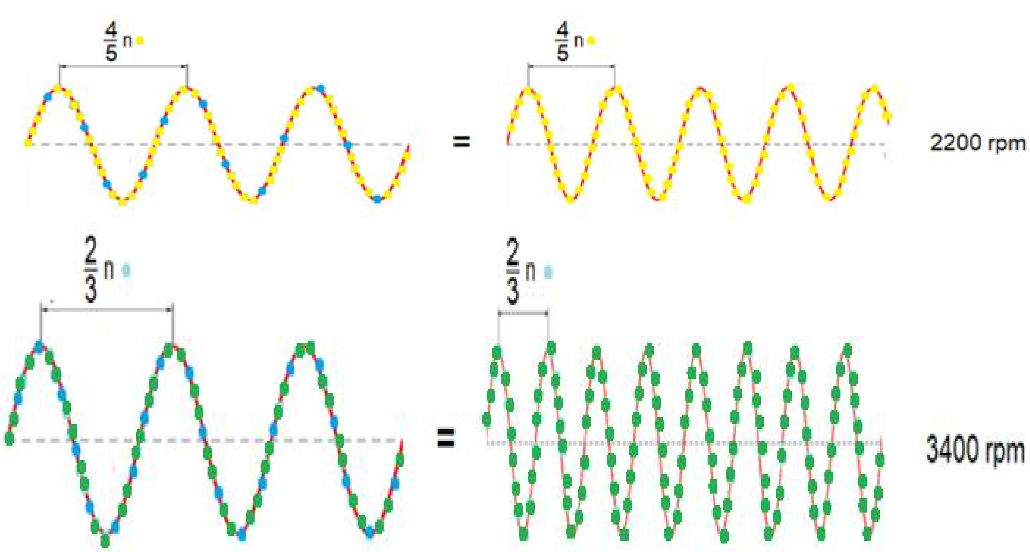

Fig. 4 Frequency shifting method

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TABLE IIII
MEASUREMENT RESULTS NO 1. ACCORDING TO REGULATION R138.

		Test Results at Target Speeds			
		5 km/h (Reference)	10 km/h	15 km/h	20 km/h
Reported Speed	km/h	5,0	10,0	15,0	20,0
Frequency, f_{speed}, Left Side	Hz	813	888	938	938
Frequency, f_{speed}, Right Side	Hz	813	888	938	938
Frequency Shift, Left Side	%	n.a.	1,8	1,5	1,0
Frequency Shift, Right Side	%	n.a.	1,8	1,5	1,0
Frequency Shift Criteria	> 0.8% / km/h		Pass	Pass	Pass
Frequency Shift Test Method:	Method (B)				

TABLE IV
MEASUREMENT RESULTS NO 2. ACCORDING TO REGULATION R138.

Frequency in Hz		Test Type		
		Constant Speed		Reversing
		10 km/h $L_{crs\ 10}$	20 km/h $L_{crs\ 20}$	6 km/h $L_{reverse}$
Final Sound Pressure Level dB(A)		68	69	69
1/3rd Octave Bands (Hz)	160	33	34	
	200	33	35	
	250	32	36	
	315	34	39	
	400	38	44	
	500	42	45	
	630	64	46	
	800	62	57	
	1000	59	64	
	1250	58	65	
	1600	58	56	
	2000	63	62	
	2500	58	64	
	3150	46	45	
	4000	39	39	
	5000	38	38	

IV. CONCLUSION

In the first step, the sound levels generated at frequency values within the 1/3 octave band, a basic requirement of the developed AVAS (Acoustic Vehicle Alerting System) regulations, were measured by an accredited testing organization. According to the test results, the values marked in green in the table below have been assessed as compliant. The AVAS regulation requires that sound levels at two consecutive frequencies in the 1/3 octave band meet sufficient conditions. Our AVAS product meets this criterion at seven different sound frequencies. In the second step, to fulfill the basic regulatory requirements of the developed AVAS system for frequency shifting, the central sound frequency at various speeds was measured, and frequency shift ratios were calculated. Our AVAS product meets the UN ECE R138 regulation requirements by adhering to these frequency shift ratios. This study discusses and analyzes the sound regulation and design phases of the AVAS system developed for commercial vehicles in compliance with international regulations.

It is anticipated that the presented AVAS, with its stated advantages, will significantly contribute to the national automotive industry.

V. ACKNOWLEDGMENTS

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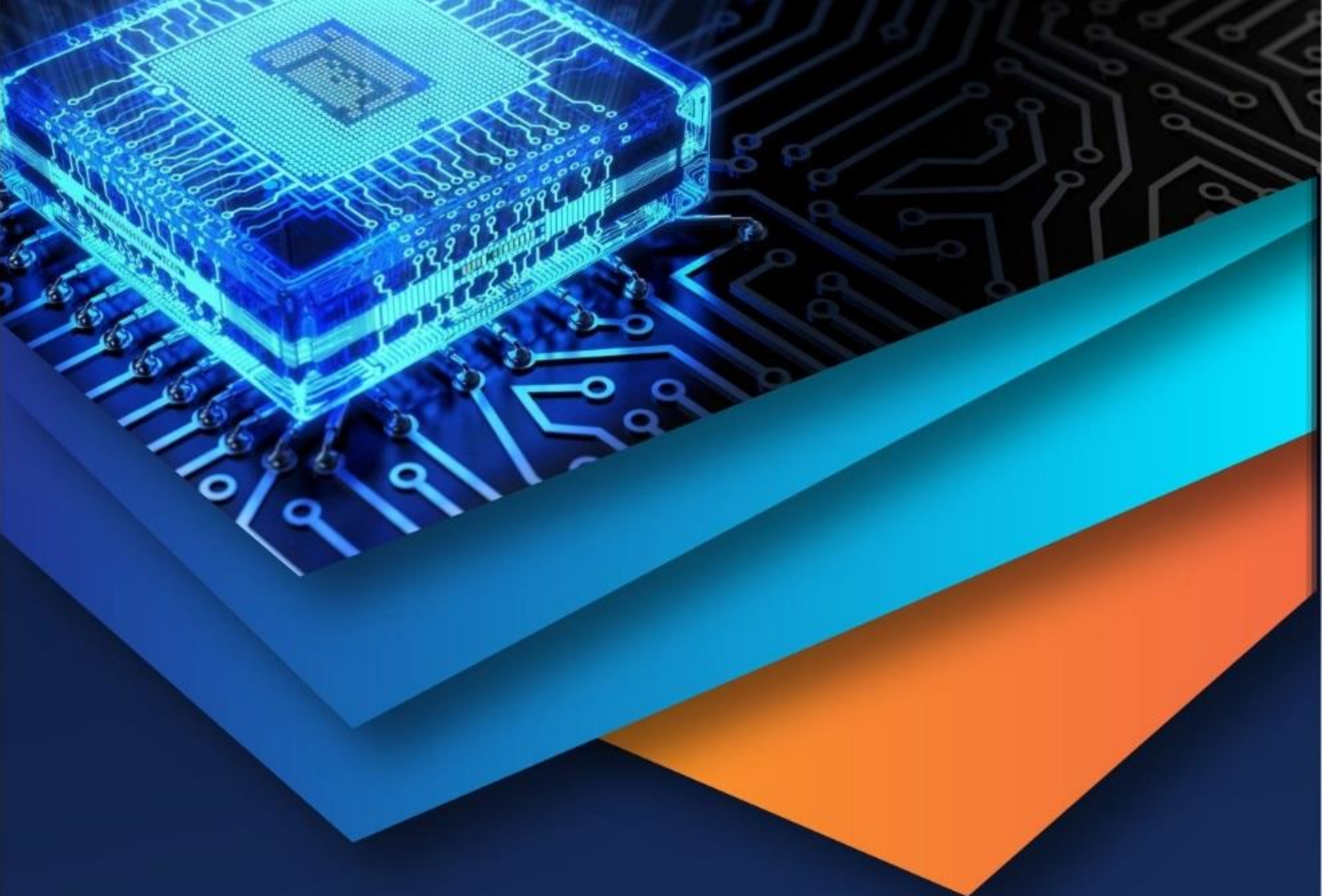

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