ELECTROMAGNETIC INTERFERENCE

and

ELECTROMAGNETIC COMPATIBILITY

for

COLLISION PREVENTION SYSTEMS (CPS)

(I.E., WORK PACKAGE (9)

INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA

REV 4

EMI and EMC Report Acceptance			
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i. INDUSTRY ACCEPTANCE

Technical Specification Guideline Review Report Acceptance			
Name	Signature	Organisation	Date

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1. Purpose of this document

This document provides insights into EMI and EMC as applicable to Collision Prevention Systems for Trackless Mobile Machines (TMM) in the SA Mining Industry (SAMI).

2. Definitions and abbreviations

The following definitions and abbreviations will be used to create a common approach for all deliverables: (Note: The rationale for some of the terms and definitions is set out in the Specification Guideline Review Report)

Term/abbreviation	Description
CMS	Collision Management System – The overall combination of preventative controls, mitigation, recovery and supporting controls implemented by a mine site to prevent TMM collisions.
CPS	Collision Prevention System: The product system that complies with the regulatory (8.10.1 and 8.10.2) and user requirements.
ECA	Electronic Communications Act 36 of 2005.
EMI	Electromagnetic interference (EMI) is a phenomenon that may occur when an electronic device is exposed to an electromagnetic (EM) field.
Emissions	Radio energy that is emitted from a device.
EMC	Electromagnetic Compatibility, also known as EMC, is the interaction of electrical and electronic equipment with its electromagnetic environment, and with other equipment. All electronic devices have the potential to emit electromagnetic fields.
Frequency band	An interval of the frequency spectrum, delimited by a lower and an upper frequency.
Frequency spectrum management	The allocation of frequency bands to specific applications.
Functional Specification	Specifications that define the function, duty or role of the product. Functional specifications define the task or desired result by focusing on what is to be achieved rather than how it is to be done.
ICASA	Independent Communications Authority of South Africa.
Immunity	A device is immune to emissions from another device.
SAMI	South African Mining Industry.
Significant risk (of collision)	The reasonable possibility of a TMM collision **given** all the controls that a mine has put in place to prevent a TMM collision.

Technical specification	Specifications that define the technical and physical characteristics and/or measurements of a product, such as physical aspects (e.g. dimensions, colour, and surface finish), design details, material properties, energy requirements, processes, maintenance requirements and operational requirements.
TMM	Trackless Mobile Machine. (Machine, vehicle, etc.)
TMM COP	Guideline for the compilation of a Mandatory Code of Practice for Trackless Mobile Machines.
TMM OEM	Original Equipment Manufacturer of TMMs. Original Equipment Manufacturer of a TMM may be the organisation which originally supplied, or last rebuilt or modified the TMM or the supplier per section 21 of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996)

3. Context of this document

The document is one of the deliverables of Work Package 9 of the CAS Readiness Phase work of the *INDUSTRY ALIGNMENT ON TMM REGULATIONS; SPECIAL PROJECT OF THE MINERALS COUNCIL SOUTH AFRICA.*

4. Executive Summary

The detail report highlights that EMI is currently affecting CPS technology maturity (specifically underground) and as a result a trial-and-error approach is followed by suppliers on specific mines, resulting in costly repetition of testing and associated time delays. Such an approach must be avoided in the accelerated development initiative.

Section 21 of the MHSA Act 29 of 1996 requires a supplier of a product to the mining industry to ensure

*"that the article supplied is **safe and without risk to health and safety** when used **properly"**;*
It follows that all suppliers of CPS related articles must perform a comprehensive risk assessment of amongst others the effect of EMI, both of the correct functioning of the "article" or the effect that the functioning of the "article" may have on other "victim" systems. The risk associated with EMI of either the **detection element** or the **V2X communication element** can result in false, ineffective warnings or not giving effective warnings when a potential collision is imminent. It may also result in unnecessary automatic stops, significantly impacting production.

EMI is not only limited in risk directly related to CPS but can also have devastating effects on other radio frequency-based systems used on a mine, not the least of which are central blasting and other safety related systems.

EMI and EMC also have an impact on **interoperability** of CPSs supplied by different suppliers. This is specifically addressed in the interoperability analysis that also forms part of the deliverables of WP 9.

EMC therefore must be addressed in conjunction with interoperability.

While the SANS 13766 as the EMC standard will be specified for CPS products, or the newer ISO 13766-1:2018 (Part 1), it is important to note the **recent** work done internationally with regards to the **functional safety** of automatic protection (safety) systems. This work is included in part 2 of ISO 13766:2018. The Global Mining Guidelines Group (GMG) recommends ISO 13766:2018 (Part 1 and 2) compliance for the mining industry.

5. Conclusions

With respect to EMI and EMC it can be concluded that:

1. EMC is a key technical performance criterion for effective CPS products.
2. EMI has an impact on interoperability that must be considered.
3. Current CMS products seems to have EMI challenges.
4. ICASA Type Approval is not sufficient to guarantee EMC if the recommended EMC test methods are not conducted as part of the Type Approval.
5. EMI and EMC are mature fields of technology development, with local and international standards that are mature.
6. EMC is an execution challenge rather that a technical challenge.
7. EMC is a much wider aspect for the mining industry than just CPS and it should be addressed holistically.
8. Frequency spectrum management is a key enabling solution for CPS EMC. It must be resolved before the functional and technical requirements can be finalised.
9. If EMC testing is required for every CPS – TMM combination it will have significant cost and schedule impact (This will be addressed in detail in the CPS Test Facility and Testing setups Report.

6. Recommendations

Based on a detailed review of the South African legislation, international approaches and the specifics of the standards required, the following recommendations are made for the SAMI to adopt as minimum requirements for CPSs:

1. **ICASA Type Approval** must be obtained for any radio-based CPS, even for the case of underground mining equipment.
2. Adoption of a **frequency spectrum management plan,** either as part of the TMM COP or a mine standard, as appropriate.
3. Adoption of **SANS 13766** (or the newer ISO 13766-1:2018) to ensure EMC of all earth-moving machinery and other TMMs operating on mine sites for the 30 MHz to 1 GHz frequency range (see note 1)
4. For cases where the intended operating frequency band is above 1 GHz, the limit of disturbance for emissions be extended at the same level (peak, quasi-peak, or

average, as applicable) from 1GHz to the frequency of interest, to cover an extended range of sensor applications and V2X communications. Measurement equipment at frequency ranges above 1 GHz shall be as specified in **SANS 216-1-4 (CISPR 16-1-4)**.

5. For cases where **intended operating frequencies fall outside of the designated** test methods of the recommended standards, an **experienced engineer with a background in EMC** standards and test methods must be consulted to ascertain compatibility. (an experienced EMC engineer may recommend SANS 61000-4-4 (IEC 61000-4-4) testing to establish immunity to electrical fast transients/bursts, if deemed applicable).
6. EMC testing must be conducted by an **accredited test laboratory** (accredited by SANAS in accordance with SANS 17025 (ISO/IEC 17025)).
7. Further and specific work must be done with respect to functional safety, its relevance and implications for CPS products.
8. The Minerals Council as the CPS development facilitator must initiate the **frequency spectrum management plan development** soonest.

Except for items 2, 7 and 8 of the recommendations as listed above all other recommendations will be integrated into the CPS Functional and Technical Performance requirements for CPS products.

As for item 2: The adoption of a **frequency spectrum management plan** as part of the TMM COP or mine standard (as appropriate): the development of such a frequency spectrum management plan must be dealt with holistically (including the CPS perspective) since it has a much wider operational scope that will require **expert** input and employer's alignment.

The Frequency spectrum allocated to the development of CPS products is a key requirement for the finalisation of the CPS functional and technical performance specification.

Some of the considerations and questions to be answered are:

- What are the typical frequencies used in the SAMI and how is it currently managed?
- Should SAMI adopt an industry wide plan? How does SAMI anticipate the future of WiFi and future 5G developments in mines (both surface and underground)? How will that affect CPS frequency management?
- Can the choice of frequency bands be impacted by the future (ISO/ICMM) developments?
- Are there existing frequency bands that can be used for CPS and that will eliminate/minimise frequency interferences?
- How does the choice of CPS frequency bands impact interoperability?
- Which bands should be used? Which technical aspects influence this recommendation? Will the same bands be sufficient for all mining methods and types (ie. for UG and Surface)?

- Do the recommendations of EMI and EMC for CPS in the SAMI, form part of the current ICASA Radio Frequency Spectrum Management plan? If not, what can be done instead? Can the recommendations be added to the plan?
- Are there off-the-shelf components available in the frequency bands that will be chosen? (What are the implications for the project if not)
- How best must the impact of ferritic /iron content in the ore body impact on EMF?
- How best to eliminate the impact of conductive elements along the roadways, such as cables and metal pipes?
- Are there alternative methods of EMC testing other than complete TMMs?

7. Background

TMM regulations for the SAMI were promulgated in 2015. Some of the clauses related to diesel powered TMMs were suspended as a result of non-availability of technology to provide the functionality that is required to auto slowdown and stop the TMMs. A CPS is a Product System that is complex, comprising of multiple elements (sub systems), some comprising components are still in technology development. Furthermore, the range of TMM types, brands and models in the mining industry is vast. This adds to the complexity and the challenge faced by the SAMI.

In 2019, the MRAC of the MHSC (the committee responsible for facilitation of the TMM regulations) assembled a task team made up of experts to advise it on the readiness of technology with a view to uplift the suspended clauses of the TMM regulations.

The task team concluded that the technology is not yet ready and that a few, but significant technology challenges are still to be overcome. EMI and EMC were one of the aspects highlighted. The Minerals Council South Africa initiated a project to facilitate the technology development of the CPS technology and the associated ecosystem (Life Cycle System).

The Minerals Council contracted SECDI that has assembled a project team to assist the Minerals Council with specific work packages.

8. Detail EMI and EMC Report

Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) are key to the proper function of Collision Prevention Systems in the South African Mining Industry. This report discusses the fundamentals of EMI and EMC and it addresses the current requirements and industry best practices in both the South African and the international mining industry.

Electromagnetic (EM) waves propagate through the air or along wires. EMI occurs when electromagnetic energy from one piece of equipment (the source) interferes with the proper operation of another piece of equipment (the victim) [1]. EMC is achieved when [2]:

- Electronic products do not interfere with their environments (emissions)
- The environments do not upset the operation of electronic products (immunity)

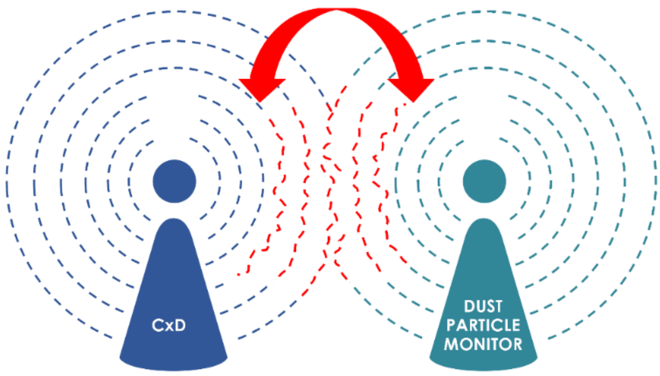

Figure 1 – Compatibility is achieved if the CPS or Dust Particle monitor does not interfere with the proper operation of each other.

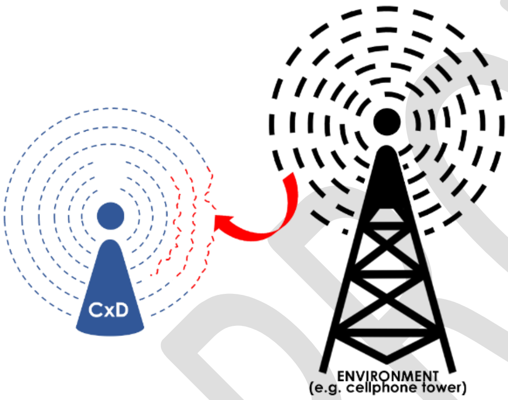

Figure 2 – Immunity of the CxD is achieved if other equipment in the environment (cell phone tower) do not upset the operation of the CxD

EM energy can be propagated within and between systems, with energy being transferred from source to receiver (known as the victim). Energy transmission can be via [2]:

- Conductive materials (such as metal wires, steel infrastructure, metal pipes/conduits or rock with metallic content), known as **conducted emissions.**
- Via non-conductive materials (such as through the air), known as **radiated emissions.**

Electronic products may be susceptible to either conducted or radiated emissions, or possibly both. **Both** susceptibility pathways are of relevance to collision prevention systems (CPS), because:

- A CPS typically requires antennas and receivers to determine where pedestrians or Trackless Mobile Machines (TMMs) are in relation to its host (**sensor technology**). A CPS must also communicate with other machines and pedestrians, **effectively** warning of its presence and actions to be taken (**V2X communication**). Other sources of EM energy (such as Wi-Fi routers, dust particle monitors, etc.) may thus interfere with the proper operation of the CPS. The CPS may also interfere with the proper operation of other safety critical systems (such as gas leak detection, electronic detonators, etc.).

- A CPS typically requires power from the TMM host and may be susceptible to transmitted EM interference, power dips, etc.
- Electrostatic discharge is also relevant for EMC and part of EMC testing. This is especially important for coal mining applications.

Anecdotal evidence in the South African Mining Industry (SAMI) suggest that EMI and EMC are limiting the performance and influencing the proper operation of CPS.

What has Been Done?

Local provisions for EMI and EMC are defined in Section 35 (1) of the Electronic Communications Act (ECA) [3] and stipulates that:

No person may use, supply, sell, offer for sale or lease or hire any type of electronic communications equipment or electronic communications facility, including radio apparatus, used or to be used in connection with the provision of electronic communications, unless such equipment, electronic communications facility or radio apparatus has, subject to subsection (2), been approved by the Authority.

The ECA thus requires Type Approval. Type Approval is a process by which equipment or a device or system is authorized by the Independent Communications Authority of South Africa (ICASA) to be used in South Africa or imported into South Africa and involves verification of the equipment's compliance with the applicable standards and other regulatory requirements. One of the aims of the Electronic Communications Act, and hence of ICASA Type Approval, is to prevent 'harmful interference' that may interrupt electronic communication [3]. This is typically limited to:

- Ensuring that a device only operates within its designated band.
- That the power emitted within the designated band is below the regulated maximum.
- That the device does not emit harmonic out-of-band effects that may influence the operation of other devices within those harmonic bands.
- That the enclosures are properly designed.

ICASA determines and publishes in the Government Gazette the recognized technical standards with which equipment must conform in order to be eligible for Type Approval. These standards are based on the standards prepared by recognized international, regional and national standards-making bodies and include minimum requirements for meeting the Type Approval. The applicable technical standards are found in the Technical Regulations [4] as defined in the Type Approval Regulations [5].

Non-type approved or non-exempt equipment, therefore, will not be allowed for use in the country and such equipment will be sealed and/or seized.

Type Approval is done by Accredited Test Laboratories (ATL). ATL means any laboratory accredited by its own national accreditation body and/or other recognized accreditation body in terms of ISO/IEC 17025 requirements. Type Approval includes testing of EMC, both for emission and immunity measurements, if specified.

The Technical Regulations [4] include the technical standards given in the table below[1]:

Table 1 – Technical standards specified[1] in the Technical Regulations [4]

Equipment classification	Emissions standard	Immunity standard
Generic standards		
Light-industrial products	SANS 61000-6-3	SANS 61000-6-1
Industrial environments	SANS 61000-6-4	SANS 61000-6-2
Non-telecommunication EMC standards		
Industrial, Scientific and Medical (ISM) equipment, excluding telecommunications equipment operating in the ISM bands mandated by ITU-R	SANS 211	SANS 224
Vehicles, boats and internal combustion engine-driven devices	SANS 212	Nil

Chapter 8 of the Mine Health and Safety Act 29 of 1996 (MHSA) [6] deals with machinery and equipment, with clause 8.10 dealing specifically with trackless mobile machinery. Clauses 8.10.1 and 8.10.2 regulate the CPS requirements but make no mention of EMI or EMC. As a result, there are no specific legal requirements (other than Type Approval discussed above) directly pertaining to the EMC of CPS. However, other sections of the MHSA do address EMI and EMC considerations. EMI and EMC also feature prominently in the Guideline for the compilation of a mandatory code of practice for TMMs (TMM COP) [7]. The Safety in Mines Research Advisory Committee (SIMRAC) also funded a project with relevance to EMI and EMC in mines [8].

Clause 8.10.19 of the MHSA deals with remotely operated TMMs. The requirements of clause 8.10.19 specifically address the EMI and EMC requirements for remotely operated machines. This thus provides an example of a best practice that can be adopted by the South African Mining Industry (SAMI). Clause 8.10.19 specifies the following [6]:

> The *employer* must take *reasonably practicable* measures to ensure that remote control devices for trackless mobile machines using a wireless remote-control device comply with:
> SANS 61000-4-2 (IEC 61000-4-2) Electrostatic immunity discharge test;
> SANS 61000-4-3 (IEC 61000-4-3) Radiated, radio frequency, electromagnetic field immunity test;

[1] This is a summary of relevant standards and should not be considered a complete or comprehensive list

SANS 61000-4-4 (IEC 61000-4-4) Electrical fast transient/burst immunity test; SANS 61000-4-5 (IEC 61000-4-5) Surge immunity test; SANS 61000-4-6 (IEC 61000-4-6) Immunity to conducted disturbances, induced by radio-frequency fields; SANS 61000-4-8 (IEC 61000-4-8) Power frequency magnetic field immunity test; and SANS 61000-4-11 (IEC 61000-4-11) Voltage dips, short interruptions and voltage variations immunity test.

It is thus clear that the SANS 61000-4-X family of standards are already referenced in the MHSA, although not specifically for CPS.

The TMM COP [7] also makes provision for EMI and EMC considerations. Two items with relevance to EMI and EMC are:

As part of the risk management guidelines (Section 7 of Part C), all relevant information such as manufacturer's specifications, design criteria and performance figures for all relevant types of TMMs must be obtained by the employer from the TMM OEMs. This may include EM emission, susceptibility and compatibility information.

Section 8 of Part C sets out how the identified significant risk should be addressed. This includes the keeping of an updated TMM design and specification register. Currently, EMI and EMC specifics are not included in the prescribed information, but it is feasible to update the TMM COP to include EMI and EMC relevant information.

The SIMRAC project GEN109 [8] provided recommendations for a detailed programme of development for remote control systems in underground mining equipment. Although this project was conducted in 1994 and its focus was on remote controlled machinery, the recommendations pertaining to wireless equipment remain valid today. The project pointed out that the propagation of radio waves is unstable. The propagation depends on:

- Wavelength
- Cross-section of mining development or face
- Kind of rock and coal and moisture contents
- Rock/coal stress
- Conductive structures along propagation path

Furthermore, the project pointed out that there are **serious implications for the functional operation** of wireless systems [8]:

- The EM field near a machine chassis is unstable. Even a loose bolt on a machine in the immediate vicinity of the receiver antenna may be a source of interference and a cause of signal dropouts.
- Cross activation between different, independent systems is possible. **Cross activation** is defined as the response of a radio-controlled machine to a radio signal not directed to that machine

A key recommendation in the project is that using **separate frequency channels** in the same work area is essential to prevent interference [8]. This is known as **frequency spectrum management**.

International EMI and EMC activity

'Proximity detection systems' (PDS) are required on continuous mining machines (CMs) in underground coal mines in the United States [9]. These systems are intended to prevent miners from being crushed, struck or pinned by CMs. These systems are based on the principle of magnetic flux density and generates magnetic wave signals at frequencies between 10 and 120kHz. A device worn by the miner measures magnetic flux density and wirelessly transmits this measurement back to a controller on the CM, typically at a frequency between 400MHz and 2.5GHz. These measurements are used to determine the distance between the CM and the miner, triggering different alarms and actions as deemed necessary.

Coal miners are also required to wear personal dust monitors to measure the exposure of a miner to respirable mine dust. The Mine Health and Safety Administration confirmed reports of cases where the personal dust monitors were causing interference with the PDS. The interference influenced the function of the PDS, with the PDS incorrectly determining the location of a miner [9].

Noll, Matetic [9] investigated the possibility of interference between the personal dust monitor and the PDS and found that:

- The personal dust monitor interfered with the function of the PDS three out of four times when the personal dust monitor was 7cm away from the PDS device worn by the miner.
- This result was confirmed with multiple different personal dust monitors and hence the performance was consistent for different instruments.
- The personal dust monitor conformed to the requirements of the military standard MIL-STD-461E RE101.
- The EMI between the personal dust monitor and the PDS device was negligible when the distance between the two instruments was increased to 15cm.

Several other devices commonly used in underground coal mines were also tested with the PDS, including several multi-gas analysers, laser distance finders and a personal air sampling pump. Intermittent interference between one of the laser distance finders and the PDS was also noted.

Due to the increased presence of radio-based systems in coal mines in the United States, the Office of Mine Safety and Health conducted a project to identify available practices, standards and resources that can be adopted by the Mine Health and Safety Administration to reduce the potential for EMI [1].

The project made the following recommendations [1]:

- To adopt CISPR 11 emission requirements for most situations and to use the MIL-STD-461 requirements for special situations.

- Immunity standards must be used to measure intentionally generated fields at representative separations (this is between potential sources of interference, in this case the distance between the cap lamp and the dust particle monitor).
- The development of a frequency management plan at mine sites. Such a management plan will assist radio-based devices to operate in a compatible manner with each other. Key to establishing a frequency management plan is the sourcing of the right personnel. An experienced engineer with a background in EMC standards and test methods is required.

Komatsu [10] has noted the importance of EMC. According to [10], compliance with EN 13309 and ISO 13766 is required in the European Union. Komatsu constructed an EMC test laboratory (anechoic chamber) that can accommodate large TMMs (floor space of 25m x 20m, access door of 8m x 8m) [10]. The facility can be used to test interference, susceptibility and electrostatic discharge. The EN 13309 and ISO 13766 standards have since been harmonized as ISO 13766-1 (general requirements, similar to the original ISO 13766) and ISO 13766-2 (additional requirements for functional safety). The Global Mining Guidelines Group (GMG[2]) also recommends compliance to ISO 13766-1 [11].

Functional safety is an increasingly relevant and important consideration for safety systems where software is used in safety-critical product development — such as automobiles, planes, and earth moving equipment. The software developed in these systems needs to be safe, secure, and reliable. Specific safety standards have been designed for embedded software systems development for several industries.

These standards aim to eliminate risk (physical injury or damage to overall health of people) and is important because lives and reputations are at stake.

Functional safety is part of the overall safety of a system or piece of equipment that depends on **automatic** protection. This automatic protection system needs to respond correctly to its inputs. It should have **predictable** responses to failure (this is also required for the CPS requirements in the MHSA). This includes human errors, hardware failures, and operational/environmental stress. Safety standards are designed to ensure exactly this, however they often come with complex requirements for software developers.

IEC 61508 the umbrella safety standard for functional safety covers electric, electronic, and programmable electronic safety-related systems. This standard ensures risk reduction through Safety Integrity Levels (SILs 1–4). The GMG has provided functional safety guidelines that have been adopted by the ICMM.

Reference to several EMI and EMC technical specifications and standards have been made throughout this report. Appendix A lists the standards mentioned in this report and their application areas.

[2] GMG members at the time of writing include Caterpillar, Epiroc and Komatsu (as leadership members) and Hexagon, Hitachi, Liebherr, Volvo and Wabtec (as general members), amongst others.

9. References

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[11] Global Mining Guidelines Group. GMG RECOMMENDED PRACTICES FOR BATTERY ELECTRIC VEHICLES IN UNDERGROUND MINING – 2nd Edition. 2018 2 July 2021]; Available from: https://gmggroup.org/wp-content/uploads/2018/11/20180621_UG_Mining_BEV_GMG-WG-v02-r01.pdf.

Appendix A – Standards that address EMI and EMC

Standard	Description
CISPR 11 (adopted as SANS 211)	Applies to industrial, scientific and medical electrical equipment operating in the frequency range 0 Hz to 400 GHz and to domestic and similar appliances designed to generate and/or use locally radio-frequency energy. This standard covers emission requirements related to radio-frequency (RF) disturbances in the frequency range of 9kHz to 400GHz. Measurements need only be performed in frequency ranges where limits are specified.
CISPR 12 (adopted as SANS 212)	Intention is to protect the radio environment outside a vehicle. It is intended for radio receivers in the residential environment in the frequency range of 30MHz to 1000MHz.
CISPR 24 (withdrawn by the IEC, but still adopted as SANS 224)	The object of this publication is to establish requirements that will provide an adequate level of intrinsic immunity so that the equipment will operate as intended in its environment. Procedures are defined for the measurement of ITE and limits are specified which are developed for ITE within the frequency range from 0Hz to 400GHz
CISPR 25 (adopted as SANS 225)	Contains limits and procedures for the measurement of radio disturbances in the frequency range of 150kHz to 2500MHz. The standard applies to any electronic/electrical component intended for use in vehicles, trailers and devices. The limits are intended to provide protection for receivers installed in a vehicle from disturbances produced by components/modules in the same vehicle. Only a complete vehicle test can be used to determine the component compatibility with respect to a vehicle's limit
IEC 61000-4-2 (adopted as SANS 61000-4-2)	Relates to the immunity requirements and test methods for electrical and electronic equipment subjected to static electricity discharges, from operators directly, and from personnel to adjacent objects.
IEC 61000-4-3 (adopted as SANS 61000-4-3)	Applicable to the immunity requirements of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures. The test method describes a consistent method to assess the immunity of an equipment or system against RF electromagnetic fields from RF sources not in close proximity to the equipment under testing.
IEC61000-4-4 (adopted as SANS 61000-4-2)	The object of this standard is to establish a common and reproducible reference in order to evaluate the immunity of electrical and electronic equipment when subjected to electrical fast transient/bursts on supply, signal, control and earth ports.
IEC61000-4-5 (adopted as SANS 61000-4-5)	Relates to the immunity requirements, test methods, and range of recommended test levels for equipment with regard to unidirectional surges caused by over-voltages from switching and lightning transients.
IEC 61000-4-6 (adopted as SANS 61000-4-6)	Relates to the conducted immunity requirements of electrical and electronic equipment to electromagnetic disturbances coming from intended radiofrequency (RF) transmitters in the frequency range 150kHz up to 80MHz.
IEC 61000-4-8 (adopted as SANS 61000-4-8)	Relates to the immunity requirements of equipment, only under operational conditions, to magnetic disturbances at power frequencies 50Hz and 60Hz.
IEC 61000-4-11 (adopted as SANS 61000-4-11)	Defines the immunity test methods and range of preferred test levels for electrical and electronic equipment connected to low-voltage power supply networks for voltage dips, short interruptions, and voltage variations. This document applies to electrical and electronic equipment having a rated input current not exceeding 16 A per phase, for connection to 50 Hz or 60 Hz AC networks
IEC 61000-6-1 (adopted as SANS 61000-6-1)	EMC immunity requirements applied to electrical and electronic equipment intended for use in residential, commercial, public and light-industrial locations. Immunity requirements in the frequency range 0 Hz to 400 GHz are covered.
IEC 61000-6-2 (adopted as SANS 61000-6-1)	Apparatus intended for use in industrial environment, for which no dedicated product or product-family immunity standard exists but excluding radio transmitters.
IEC 61000-6-3 (adopted as SANS 61000-6-1)	A generic EMC emission standard applicable only if no relevant dedicated product or product family EMC emission standard has been published. This part of IEC 61000 for emission requirements applies to electrical and electronic equipment intended for use at residential locations.

Standard	Description
IEC 61000-6-4 (adopted as SANS 61000-6-1)	Applies to electrical and electronic equipment intended for use within the environment existing at industrial locations. The environments encompassed by this document cover both indoor and outdoor locations. Emission requirements in the frequency range 9kHz to 400GHz are covered
ISO 13766 (adopted as SANS 13766)	Provides test methods and acceptance criteria for the evaluation of the electromagnetic compatibility of earth-moving machinery. It covers broadband and narrowband electromagnetic interference; electromagnetic field immunity test; broadband and narrowband interference of electrical/electronic subassemblies; electromagnetic field immunity test of electrical/electronic subassemblies; electrostatic discharge; conducted transients. It is stricter with lower reference limits for emissions and increased reference limits for immunity. ISO 13766:2006 was withdrawn and replaced by ISO 13766-1:2018 and ISO 13766-2:2018 when ISO 13766 was harmonized with EN 13309, but it is still the current SANS 13766 standard.
MIL-STD-461	Establishes interface and associated verification requirements for the control of the electromagnetic interference (EMI) emission and susceptibility characteristic of electronic, electrical and electromechanical equipment and their subsystems.