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Shielded CCTV system with FO comunications for EMC tests

A Master's Thesis

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by

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MASTER IN ELECTRONIC ENGINEERING

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Title of the thesis: Shielded CCTV system with FO comunications for EMC tests

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Abstract

All electric and electronic devices are required to do electromagnetic compatibility (EMC) tests to be sold anywhere in the world. During EMC tests it is required to monitor the equipment under test. An equipment may be monitored in several ways, but one of them is with video and audio monitoring. The main goal for this thesis is to obtain a functional and low cost usable video and audio monitoring system to be used during radiated immunity EMC tests.

This thesis consists on the research, the assembly and the validation, both functional and from the EMC point of view, of a monitoring system with real time video and audio communication with a PC, being the main features of such system, fiber optic communication, independence from the mains and good EMC performance.

Different systems will be assembled and validated in order to choose the best option available. Once the system has been chosen a further validation in more demanding conditions will be performed and upgrades will be proposed to improve the system performance in EMC environment.

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I would also like to thank the Electromagnetic Compatibility Group (GCEM) from the Department of Electronic Engineering at the Universitat Politècnica de Catalunya (UPC) because without his support this thesis would not have been possible.

Finally my sincere gratitude to my family, especially my mother, for their help and assistance in the completion of this thesis.

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1. Introduction

The objective of this thesis is to develop a system for the Electromagnetic Compatibility Group (GCEM) from the Department of Electronic Engineering at the Universitat Politècnica de Catalunya (UPC) capable of monitoring the interior of the anechoic chamber found in the GCEM laboratory during radiated immunity tests.

1.1. Statement of purpose

All electrical and electronic equipment influence each other when interconnected or placed together, being so, anywhere in the world some sort of EMC tests are required. Part of those tests are called radiated immunity tests, where the susceptibility against radiated electromagnetic interferences of the equipment under test (EUT) is validated. Monitoring is needed to validate the correct performance of the equipment in this kind of tests, there are several ways to monitor an equipment, and one of them is with video and audio surveillance, which is very useful when the equipment may exhibit different observable behaviour, such as non-intended mechanical movement, display issues, audible noises or other non-desired behaviour.

A system capable to provide such function and capable to withstand the harsh conditions required during radiated immunity tests is the main objective of this thesis.

The system provided to GCEM group will be validated in his laboratory alongside the current equipment available. Radiated immunity tests with different setups and parameters will be performed to the system to evaluate and determine their level of robustness for EMC testing.

1.2. System requirements

GCEM group proposes a system with the following requirements to be used during radiated immunity tests:

- Video and audio capture to monitor the inside of the anechoic chamber.
- Optical fiber connection for sending the multimedia signal to a PC located outside the chamber.
- Detachable from the mains with a minimum autonomy of 4 hours.
- Immunity against electric field at maximum levels capabilities of GCEM lab (up to 100 V/m).
- Low cost and multipurpose system.

Optional features which would be considered as positive additions to the system are:

- Shielded system to grant larger immunity against radiated electromagnetic interferences.
- Usable during radiated emissions tests.
- Zoom and focus settings adjustable from the PC.
- Small size.

1.3. Methodology

Based on the System requirements, the following project development methods have been used during the different steps of the project

- Analysis of the current monitoring system of the GCEM laboratory and possible alternatives.
- Study of the system approach to assess the best suitable approach to the system taking into account project objectives and limitations such as time, complexity or cost.
- Design and integration of the system proposed.
- Functional validation to grant the fulfilment of all the system requirements not related with EC performance.
- EMC validation with different immunity and emission tests to evaluate the initial specifications of the system
- Improvements and upgrades to improve the specifications of the system

1.4. Work plan with tasks

In this section a detailed work plan with tasks, duration and dates is proposed. Table 1 contains the initial schedule proposed for the project which was supposed to finish on the ordinary deadline for the Master Thesis. In the Figure 1 can also be seen the Gantt diagram according the work plan detailed in Table 1.

Table 1. Initial work plan

ID	Task Name	Duration	Start	Finish	Predecessors
1	**TFM**	**114 days**	**Mon 11/02/19**	**Fri 19/07/19**	
2	Project Matriculation	0 days	Mon 11/02/19	Mon 11/02/19	
3	Project definition	5 days	Mon 11/02/19	Fri 15/02/19	2
4	Market research	10 days	Mon 18/02/19	Fri 01/03/19	3
5	Possible approaches	15 days	Mon 04/03/19	Fri 22/03/19	4
6	Approach decision	0 days	Fri 22/03/19	Fri 22/03/19	5
7	System design investigation	10 days	Mon 25/03/19	Fri 05/04/19	6
8	Device and component selection	5 days	Mon 08/04/19	Fri 12/04/19	7
9	Buy all the hardware	1 day	Mon 15/04/19	Mon 15/04/19	8
10	All the hardware obtained	0 days	Mon 15/04/19	Mon 15/04/19	9
11	First approach and testing	10 days	Tue 16/04/19	Mon 29/04/19	10
12	System integration	4 days	Tue 30/04/19	Fri 03/05/19	11
13	System validation	5 days	Mon 06/05/19	Fri 10/05/19	12
14	System validated and functional at ambient conditions	0 days	Fri 10/05/19	Fri 10/05/19	13,12
15	**EMC testing**	**17 days**	**Mon 13/05/19**	**Tue 04/06/19**	

16	EMC domestic, industrial and railway setup	5 days	Mon 13/05/19	Fri 17/05/19	14
17	EMC automotive setup	2 days	Mon 20/05/19	Tue 21/05/19	16
18	Specification worst case scenario obtained	0 days	Tue 21/05/19	Tue 21/05/19	16,17
19	Improvements and upgrades	10 days	Wed 22/05/19	Tue 04/06/19	18
20	Conclusions	10 days	Wed 05/06/19	Tue 18/06/19	15,19
21	Evaluation board	0 days	Fri 21/06/19	Fri 21/06/19	
22	Documentation	109 days	Mon 18/02/19	Thu 18/07/19	3
23	Upload thesis	0 days	Fri 19/07/19	Fri 19/07/19	22,20
24	End of the project	0 days	Fri 19/07/19	Fri 19/07/19	23

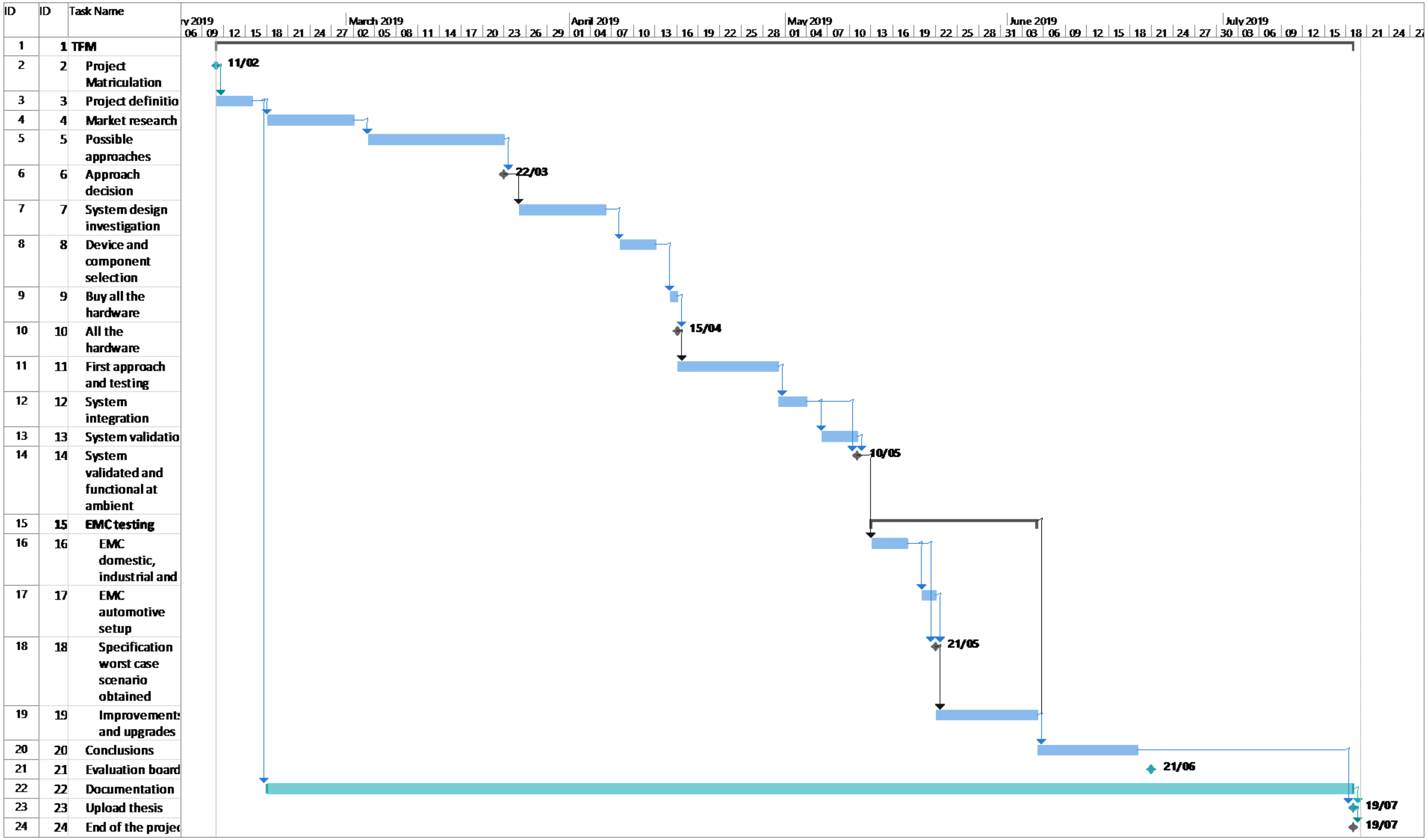

Figure 1. Gantt diagram for the initial schedule

1.5. Deviations from the initial plan

In this section the deviations occurred during the project are defined, and the real Work Plan and Gantt Diagram for the project are presented.

The main deviation from the initial plan was a change in the approach to the project, this topic is covered in further detail in sections 4 and 5. This caused a delay in several tasks and lead to the extension on the deadline of the thesis.

The real work plan and Gantt diagrams for the project can be seen below.

Table 2. Real Work plan

ID	Task Name	Duration	Start	Finish	Predecessors
1	**TFM**	**177 days**	**Mon 11/02/19**	**Wed 16/10/19**	
2	Project Matriculation	0 days	Mon 11/02/19	Mon 11/02/19	
3	Project definition	5 days	Mon 11/02/19	Fri 15/02/19	2
4	Market research	10 days	Mon 18/02/19	Fri 01/03/19	3
5	Possible approaches	15 days	Mon 04/03/19	Fri 22/03/19	4
6	Approach decision - USB approach	0 days	Fri 22/03/19	Fri 22/03/19	5
7	System design investigation	8 days	Mon 25/03/19	Wed 03/04/19	6
8	Device and component selection	5 days	Thu 04/04/19	Wed 10/04/19	7
9	Partially buy the hardware	1 day	Thu 11/04/19	Thu 11/04/19	8
10	Hardware obtained	0 days	Thu 11/04/19	Thu 11/04/19	9
11	First approach and USB protocol testing	8 days	Fri 12/04/19	Tue 23/04/19	10
12	USB protocol investigation. FO conversion	8 days	Wed 24/04/19	Fri 03/05/19	11
13	Feasibility analysis. USB protocol issues	8 days	Mon 06/05/19	Wed 15/05/19	12
14	Change approach decision	0 days	Wed 15/05/19	Wed 15/05/19	13
15	Market research	5 days	Thu 16/05/19	Wed 22/05/19	14
16	Possible approaches	5 days	Thu 23/05/19	Wed 29/05/19	15
17	Approach decision - Ethernet approach	0 days	Wed 29/05/19	Wed 29/05/19	16,14,15
18	System design investigation	8 days	Thu 30/05/19	Mon 10/06/19	17
19	Device and component selection	5 days	Tue 11/06/19	Mon 17/06/19	18
20	Buy all the hardware	2 days	Tue 18/06/19	Wed 19/06/19	19
21	All the hardware obtained	0 days	Wed 19/06/19	Wed 19/06/19	20
22	First approach and testing	5 days	Thu 20/06/19	Wed 26/06/19	21

23	System integration	5 days	Thu 27/06/19	Wed 03/07/19	22
24	System validation	5 days	Thu 04/07/19	Wed 10/07/19	23
25	System validated and functional at ambient conditions	0 days	Wed 10/07/19	Wed 10/07/19	23,24
26	**EMC testing**	**12 days**	**Thu 11/07/19**	**Fri 26/07/19**	
27	EMC domestic, industrial and railway setup	5 days	Thu 11/07/19	Wed 17/07/19	25
28	EMC automotive setup	2 days	Thu 18/07/19	Fri 19/07/19	27
29	Specification worst case scenario obtained	0 days	Fri 19/07/19	Fri 19/07/19	27,28
30	Improvements and upgrades	5 days	Mon 22/07/19	Fri 26/07/19	29
31	Conclusions	10 days	Fri 06/09/19	Thu 19/09/19	26,30
32	Evaluation board	0 days	Thu 19/09/19	Thu 19/09/19	
33	Documentation	172 days	Mon 18/02/19	Tue 15/10/19	3
34	Upload thesis	0 days	Wed 16/10/19	Wed 16/10/19	33,31
35	End of the project	0 days	Wed 16/10/19	Wed 16/10/19	34

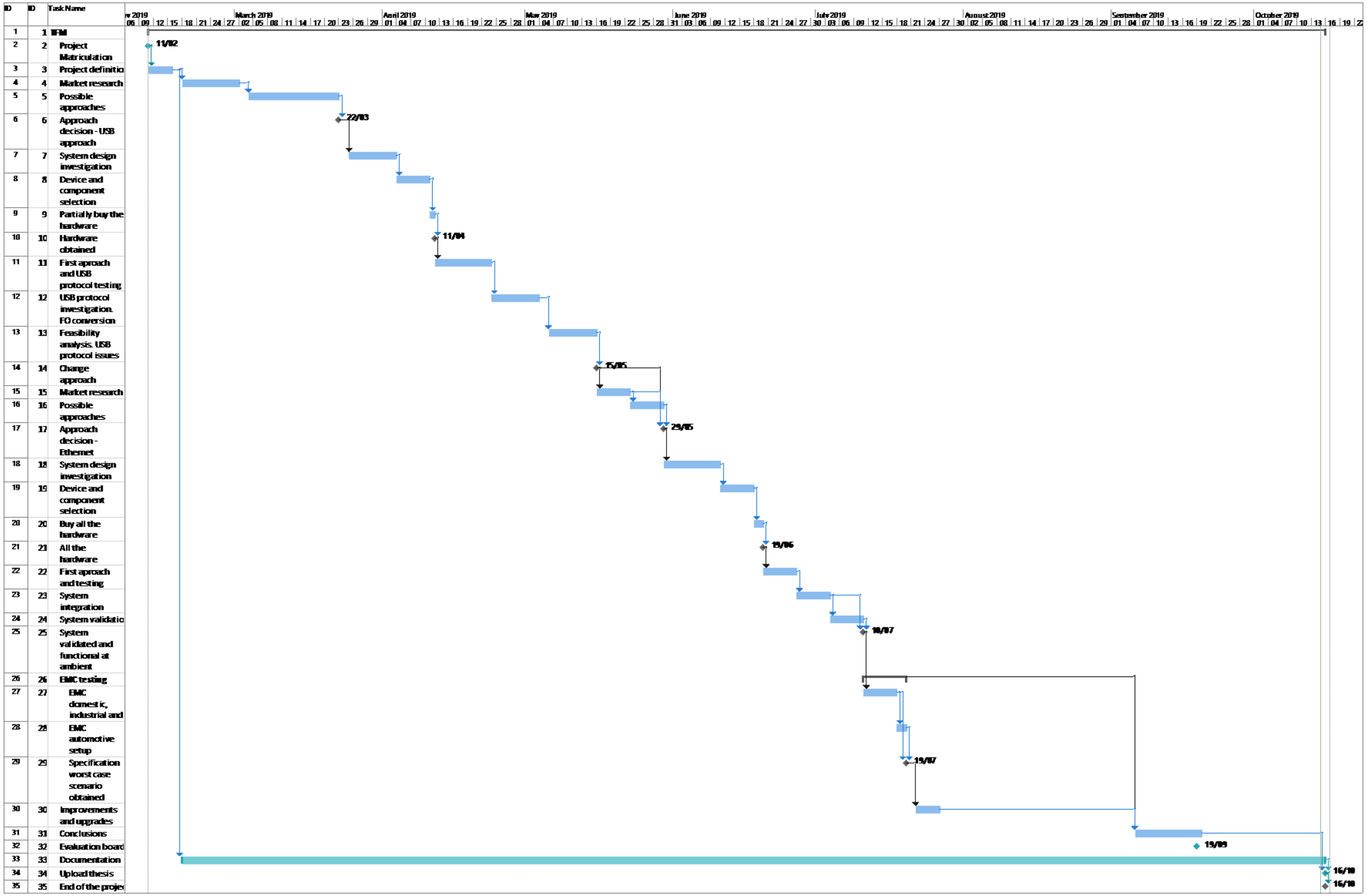

Figure 2. Real Gantt diagram

2. State of the art in EMC

All electric devices or installations influence each other when interconnected or are close to each other. The purpose of the electromagnetic compatibility (EMC) is the study of the unintentional generation, propagation and reception of electromagnetic interferences and to keep all this effects under reasonable limits.

Compliance with EMC legislation is required by national laws and demanded by industries and costumers.

For instance, the CE marking is mandatory on many products of the European Economic Area (EEA). This mark implies that the products holding it have been assessed to meet high safety, health and environmental protection requirements.

The CE marking is the manufacturer's declaration that the product meets the requirements of the applicable European Directives. The CE mark logo can be seen in the Figure 3.

Figure 3. CE mark logo [1]

For the EMC field, this means that electronic and electrical equipment have a Declaration of Conformity (DoC) where there is a presumption of compliance with the EMC standards. For radiated immunity tests, this means that the equipment can withstand a level of 3 V/m for a domestic environment and 10 V/m for industrial one.

The EMC Directive 2014/30/EU is a European Directive which ensures that electrical and electronic equipment does not generate, or is not affected by, electromagnetic disturbance. The EMC Directive limits electromagnetic emissions from equipment in order to ensure that, when used as intended, such equipment does not disturb radio and telecommunication, as well as other equipment. The directive also specifies the immunity required of such equipment to electromagnetic interferences and seeks to ensure that this equipment is not disturbed by radio emissions.

This is summarized in the essential requirements referred to Article 5 of the EMC Directive:

“Equipment shall be so designed and manufactured, having regard to the state of the art, as to ensure that:

a) The electromagnetic disturbance generated does not exceed the level above which radio and telecommunications equipment or other equipment cannot operate as intended;

b) It has a level of immunity to the electromagnetic disturbance to be expected in its intended use which allows it to operate without unacceptable degradation of its intended use.”

2.1. Brief introduction to EMC concepts

In this section are summarized some of the main EMC concepts for a better understanding of the project.

2.1.1. Electromagnetic Interferences

Electromagnetic Interferences (EMI) are disturbances that may degrade the performance of electrical components or circuits. Can be divided into two different kinds, radiated interferences and conducted interferences.

Radiated electromagnetic interferences are propagated through the air, on the other hand conducted electromagnetic interferences are propagated through cables.

2.1.2. EMC test site

In EMC disturbances generation tests, radiated and conducted emissions of the EUT are measured to verify that products cannot produce harmful EMI that may interfere and degrade the performance of other electric or electronic systems.

On the other hand, in EMC immunity tests, radiated and conducted EMI are applied to the EUT in a wide range of frequencies to see if there is a degradation in the performance of the equipment.

EMC tests are performed in a wide variety of rooms, such as faraday, reverberant… but for radiated tests, rooms called anechoic or semi-anechoic chambers are used.

An anechoic chamber is designed to block electromagnetic interferences coming from outside the chamber, and completely absorb any kind of reflections produced inside. This rooms are completely surrounded by electromagnetic absorbing material which transform electromagnetic energy in to heat, absorbing and reducing reflections.

The objective is to provide a controlled environment to perform EMC tests.

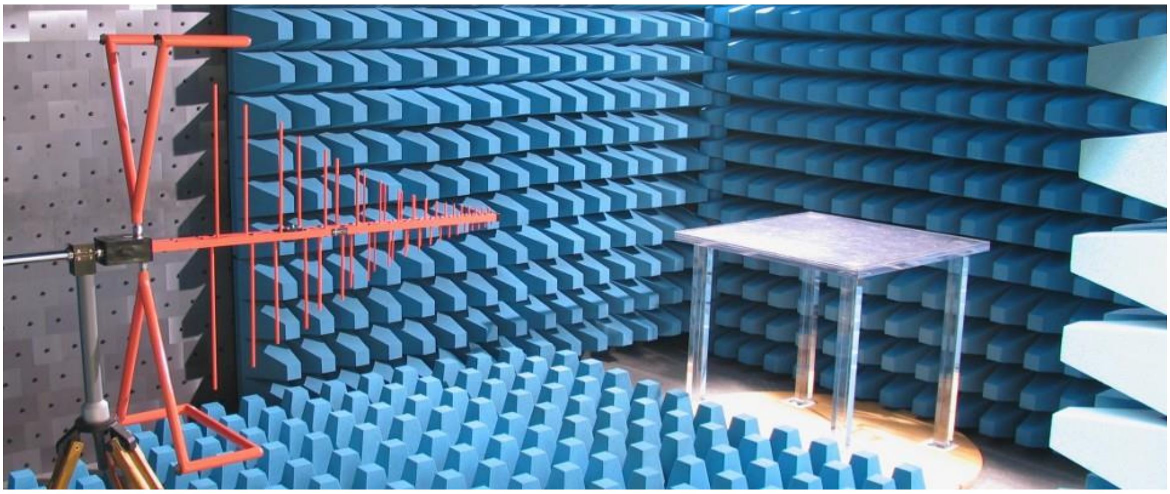

Figure 4. Anechoic chamber in GCEM group

2.2. <u>EMC radiated tests</u>

After the introduction done in section 2.1, can be seen that there is a wide range of EMC tests, but for the purpose of the validation of the system developed on this thesis, the tests will be focused on radiated immunity, being radiated emissions left as optional. This information is summarized in the Table 3 below.

Table 3. EMC tests proposed for the system validation

	Immunity	Emissions
Radiated	Project Goal	Optional

The criteria is explained in the sections below.

2.2.1. Radiated immunity tests

In EMC radiated immunity testing electric field is radiated at a wide range of frequencies to test the performance and the degradation of the EUT.

To generate the requested electric field levels in the standards the main elements of the setup are a signal generator, a Radio Frequency (RF) amplifier and an antenna.

For some environments as domestic, residential, industrial or railway is required to create a uniform electric field pane where the EUT will be placed. This can be seen in the Figure 5, where a 16 point uniform field is created previously to testing according to standard EN 61000-4-3.

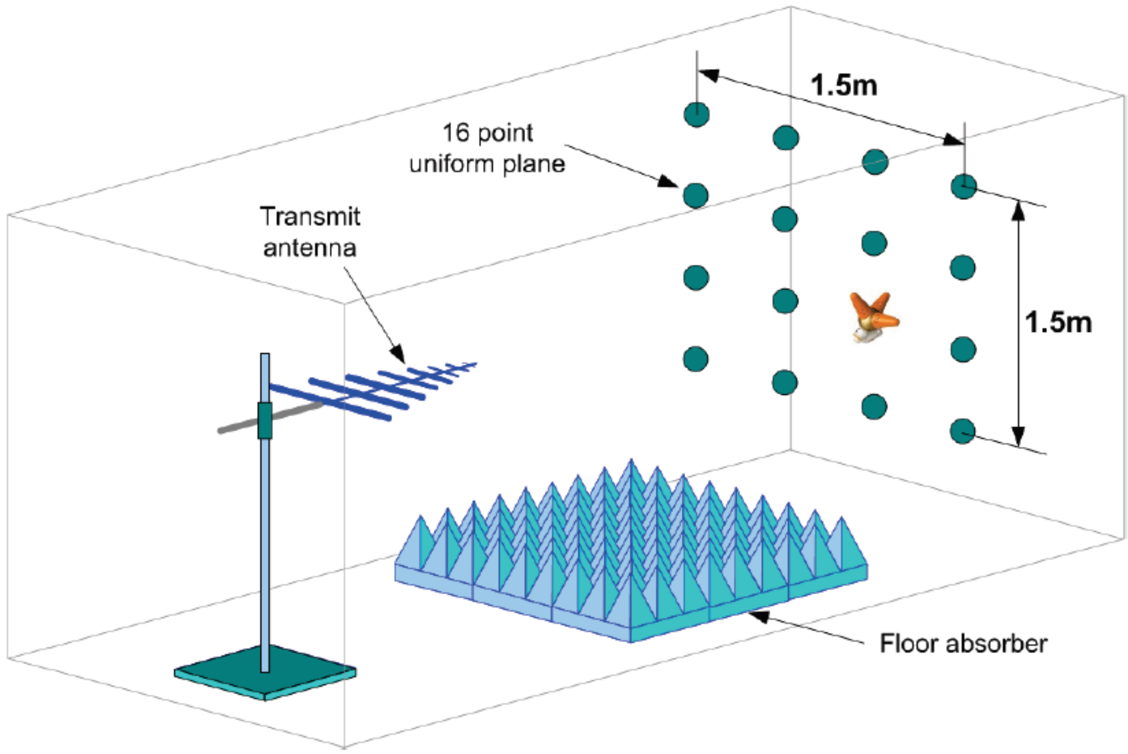

Figure 5. Immunity test setup [1]

For Automotive electronic components setups the electric field is only defined at one point and levels have much greater values. Furthermore, the setups requires a ground plane and other reflective floor surfaces located in the test area.

During radiated immunity tests, important levels of electric field is being radiated inside the anechoic chamber, the EUT requires to be monitored to be able to evaluate if a degeneration in the performance of the equipment has occurred during the test. This monitoring can be done in several ways, through electronic instrumentation, measuring current consumptions or electric signals, through communication protocols or with video and audio monitoring of the equipment, which is the main purpose of this equipment.

Video and audio monitoring of the EUT during radiated immunity tests is very useful as it allows to evaluate degenerations in the performance of the equipment with mechanical movement, displays that provides information, visual indicators such as LEDs, speakers, and others.

2.2.1.1. System validation scope for radiated immunity tests

There are several types of radiated immunity tests that differ in the test setups, parameters applied and others conditions, this tests are performed in the daily work of the GCEM group, for that reason it is decided to evaluate the system in those tests.

In Table 4 below are defined the main test scope for the validation of the system proposed.

Table 4. Radiated immunity tests

Scenario	Electric Field	Setup	Legislation
Domestic	3 V/m	EN 61000-4-3	EN 61000-6-1
Industrial	10 V/m	EN 61000-4-3	EN 61000-6-2
Railway	20 V/m (maximum)	EN 61000-4-3	EN 50121-3-2
Automotive	30 V/m (minimum)	ISO 11452-2	UNECE REGULATIONS nº10

2.2.2. Radiated emissions tests

In EMC emissions tests, radiated and conducted emissions are measured to verify that products cannot produce harmful EMI that may interfere and degrade the performance of other electric or electronic systems.

For radiated EMC emissions testing, the Equipment Under test (EUT) is placed inside the anechoic chamber operating in the mode that generates the most EMI possible. At a certain distance specified in the standards the antenna receives the EMI being generated and the levels must be below the ones specified in the standard applied.

In the Figure 6 can be seen a conceptual example of a simple setup for radiated emissions tests.

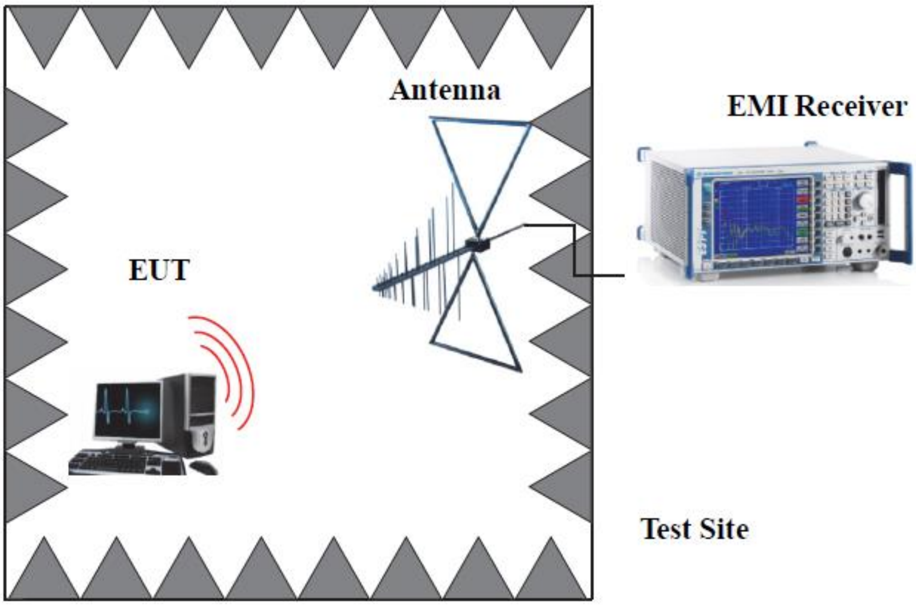

Figure 6. EMC emissions setup [1]

During radiated emissions tests, video and audio monitoring from the EUT doesn't provide so much information as it does in immunity tests, because for emissions tests, the equipment is turned on, it is set in the desired operating mode and then the test is performed. It is not required to real time monitor the equipment during this process, although having a video and audio monitoring system during the emissions test, could allow to check (if the equipment has some sort of visual indicators) that the operating mode of the EUT is the one expected, which could be a useable feature.

Although having a system which is emitting EMI in its own, it's not the best option when other equipment is being tested. For this reason, the validation of the system in radiated emissions is left as a positive addition but considered as optional.

2.3. Video and audio monitoring equipment for radiated immunity tests

As has been explained in section 2.2, during radiated immunity tests it is necessary to validate the functionality and performance of the EUT, one way to perform this validation is through video and audio monitoring, this is especially useful when mechanical parts, visual indicators, displays or audible noises are involved in the performance of the EUT.

2.3.1. Current GCEM laboratory equipment for video monitoring

The current monitoring equipment for radiated immunity tests at GCEM laboratory consists in an analogic shielded camera with very good video features, but completely manual, which transmits only analog video signal through BNC coaxial cable into a computer with a USB acquisition device. In addition to that the analogic camera is supplied with a mains power cable.

Although this camera provides good video quality and performance in higher frequencies due to the shielding, it has some inconveniences such as very long cables where the electric field can couple, which produces degradations in the video signal. Below are summarized the benefits and the drawbacks.

Benefits:

- Very good quality
- Good performance in high frequencies

Drawbacks

- Bad performance in low frequencies due to the long supply and signal cables
- No audio
- Big size
- Manual adjust of the zoom and focus

2.3.2. Alternatives to current equipment

The alternative proposed would be a system with fiber optic communication and powered with batteries to prevent long cables from power supply or multimedia signal and improve the performance from an EMC point of view.

In addition a system with audio signal is required, and automatic control of the zoom and focus would be positive additions to the system.

In the sections below are exposed different options available to the system proposed

2.3.2.1. Specialized EMC equipment

Due to the need for a video system with optical fiber communications to improve the performance, the GCEM group contacted specialized EMC equipment vendors. Below are summarized the benefits and the drawbacks.

Benefits:

- Very good quality
- Very good EMC performance

Drawbacks

- Very expensive equipment
- No audio

The details of this product can be seen in the Appendix II.

Specialized EMC equipment despite the fact to have very good specifications and performance is also very expensive. The EMC equipment market is a very closed because vendors know that his equipment is going to be used in EMC laboratories, so the price tends to be very high because the demand is low.

2.3.2.2. Modular EMC system

A modular system composed by commercial equipment integrated together into a system to meet the requirements proposed for the GCEM group specified in section 1, which are a video and audio monitoring system with fiber optics connection to a PC, and capable to operate without mains connection with high radiated immunity. Below are summarized the benefits and the drawbacks.

Benefits:

- Very interchangeable and upgradable equipment
- Inexpensive

Drawbacks

- Regular EMC performance for domestic/industrial equipment

An EMC modular system would have to be tested to validate the real specifications of the system, and most likely upgrades will have to be proposed to improve the EMC performance.

3. Project approach and proposed options

During section 2.3 video and audio monitoring systems for radiated immunity tests have been discussed, and the actual equipment used in the GCEM group and alternatives to that equipment have been exposed. In this section the project approach is confirmed and different options for the chosen approach are proposed.

3.1. Approach decision

In sections 2.3.2.1 and 2.3.2.2 both specialized and modular domestic/industrial equipment have been reviewed as possible systems which could meet the requirements proposed for the GCEM group in section 1.

It is concluded to develop for the GCEM group a modular EMC equipment based on domestic/industrial devices that can be integrated to perform the task demanded.

To validate the requirements proposed, functional and EMC radiated immunity testing will be required. With a functional system and the initial EMC specifications, a review of the system can be done and upgrades and improvements proposed.

3.2. Modular design options

In section 3.1 has been decided a modular system for the monitoring equipment needed for the GCEM group. The purpose to use a modular design is that allows to divide the full operation of the system into individual tasks which are simpler to perform. A very intuitive design can be seen in Figure 7, the main three modules proposed for the system are:

- Video and audio acquisition, camera
- Fiber optic conversion.
- Power supply.

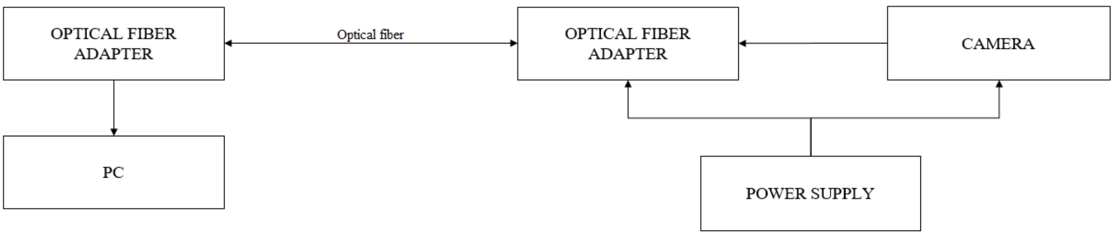

Figure 7. Main system modules

In this section an overview for different options available for the main three modules proposed based on domestic/industrial devices are balanced. In the following sections can be found a description of each module alongside the different options.

3.2.1. Camera system

The camera system must include real time video and audio capture, and as a positive feature have zoom and focus options. Has to be able to send the video and audio signal to a computer with some kind of communication protocol which can be later transformed into an optical signal to use with fiber optics.

Different options have been taken into account, can be seen in the following sections.

3.2.1.1. CCD sensor and camera design

In this option the fully design of the camera system with all the features using a CCD or CMOS sensor is balanced.

Benefits:

- Inexpensive
- Good control of the design
- Customizable
- Sony CCD sensors

Drawbacks:

- Time expensive
- Implementation of video and audio hardware, complex design
- Lack of information and availability the circuits
- Analogic output

3.2.1.2. Camera module

In this case is proposed to use an existing camera module in conjunction with some kind of device such as microcontroller.

Benefits

- No need of video hardware
- Less time inverted in the design part
- Small size

Drawbacks:

- Time expensive
- Difficult to find video and audio in the same module, would lead to mixing of two signals
- Zoom and focus features fixed or no easy to find
- Usually analogic output of the modules

3.2.1.3. Webcam

A Webcam offers a video and audio system together, plus uses a USB communication protocol which uses only two signals for data and is powered at 5V.

Benefits:

- No need of video and audio hardware
- No time inverted in the design part
- Small size
- USB power and communication

- Easy to replace as is based in USB protocol

Drawbacks:

- Lack of USB over fiber optics converters

3.2.1.4. IP camera

An IP surveillance camera offers video and audio monitoring with Ethernet protocol connection, which is very common in fiber optics communication.

Benefits:

- No need of video and audio hardware
- No time inverted in the design part
- Ethernet protocol easy to send over fiber optics
- Small/medium size
- Easy to replace as is based in Ethernet protocol

Drawbacks:

- Power usually at 12 V
- Limited options for Video and audio with Ethernet port

3.2.2. Optical communication

The communication from the camera to the PC needs to be done in optical fiber as is a requirement for the system, the optical fiber improves the system immunity against EMI. This module must be capable of converting whichever signal is coming from the camera module and be able to send it through optical fiber communication to a PC. The protocol used for the camera system greatly affects the optical conversion system.

3.2.2.1. Analogue video converter

For the case that an analogic camera is used for the camera module it would require an analogue converter to optical fiber.

Benefits:

- Could be hand designed
- Literature available

Drawbacks:

- Separate video and audio signals management
- Expensive commercial converters
- Analogic signals have worse performance in EMC

3.2.2.2. USB converter

If USB protocol communication for the camera module, a USB to optical fiber converter would be required for the transmission of the signal from the system to the PC.

Benefits:

- Many options to work with in the camera section
- Could be hand designed (feasibility analysis)
- Video and audio signals mixed together
- Power at USB levels
- Usable beyond the sole purpose of the system (other EUT with Ethernet connection)

Drawbacks:

- Difficult to find commercially available
- Expensive
- Lack of standard for USB over fiber optics

3.2.2.3. Ethernet converter

If an IP camera with Ethernet protocol communication is used, an Ethernet to optical fiber converter would be required for the transmission of the signal from the system to the PC.

Benefits:

- Commercially available due to Ethernet over fiber is wide spread
- Medium price
- Video and audio signals mixed together
- Usable beyond the sole purpose of the system (other EUT with Ethernet connection)

Drawbacks:

- Difficult to hand design
- Hard to find powered at 5 V

3.2.3. Power supply

The power supply module must provide energy to the system, namely the camera and the optical conversion modules. With the requirement proposed that the system must be detachable from the mains, three different implementations for this module are possible.

3.2.3.1. Battery

The system is only powered with a battery without possibility for mains connection when operating, this solution has a lot of dependence on the battery life time. In the Figure 8 below can be seen a simple diagram of the system setup.

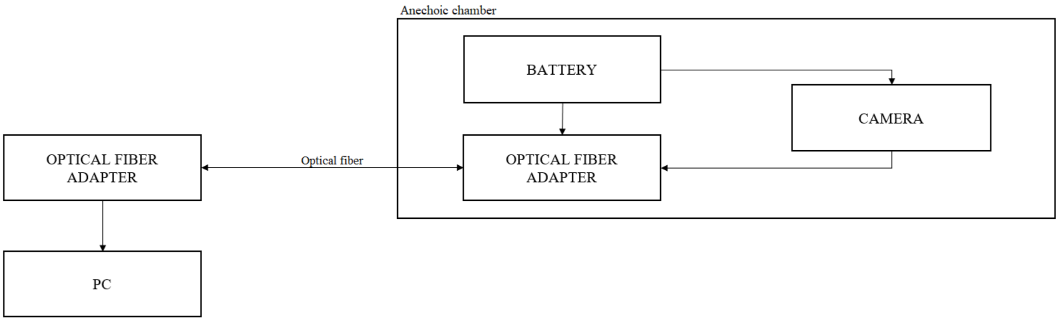

Figure 8. System powered with battery

Benefits:

- Possibility to have an integrated battery and camera module
- Batteries with big capacity in small package
- Wide commercial availability

Problems:

- Maximum life time of the battery will limit the test
- Charge the battery after the test (time expensive)

3.2.3.2. Battery and power from mains

The system is powered with a battery but can also be connected to the mains when operating if needed. In the Figure 9 below can be seen a simple diagram of the system setup.

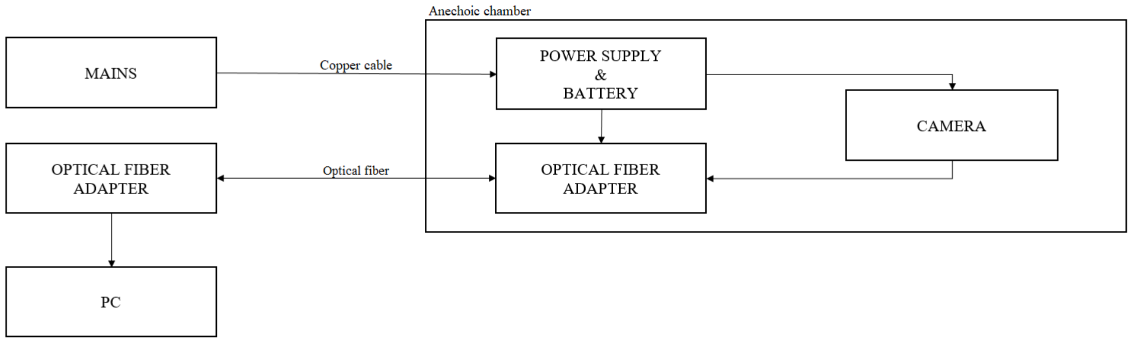

Figure 9. System powered from the mains and battery

This solution would require the use of filters for the mains connection, and circuitry to allow to charge the battery when operating, although most modern batteries have this feature integrated.

Benefits:

- No mains connection, when need it
- Batteries with big capacity in small package
- Not a strict dependence on the life time of the battery
- Wide commercial availability

Drawbacks

- Filtering and protection of the mains power if needed

3.2.3.3. Power through optic communication

This technology is called Power over Fiber (PoF), in this option optical power is transmitted through the optical fiber cables. Power and data are transmitted through the optical fiber communications, this solution provides much better immunity with zero dependence from battery life time. In the Figure 10 below can be seen a simple diagram of the system setup.

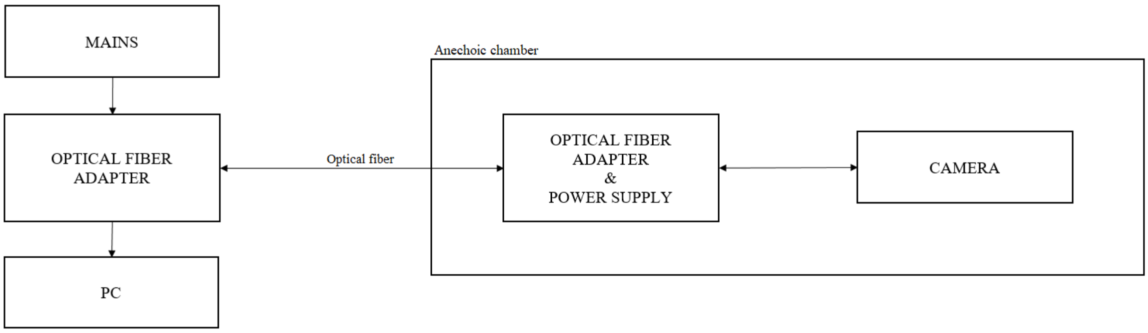

Figure 10. System powered from optical fibber

Benefits:

- Maximum immunity against EMI
- Power and data only in fiber cables

Drawbacks:

- Very new technology, few documentation and commercial solutions available
- Camera and communications system will draw a significant amount of power, difficult to provide through optical fiber

3.3. Modular approach conclusions

Taking into account the different options proposed for the modular system, the benefits and drawbacks of each options are balanced, and it is decided to approach the project by analysing two options

The first option will be a USB camera with a USB converter to optical fiber, all powered with a battery capable to charge when operating. The main reason is that USB cameras have very good specifications and lots of functionalities (zoom, focus…) and the output signal contains video and audio already mixed and synchronized. In addition USB devices are very widespread and the prices are very competitive, also there is room for handmade design. Another reason is that all the system could be powered with USB power levels, which would reduce the size of the system considerably. This kind of system would fulfill all the requirements regarding functionality of the ones proposed for the GCEM group, being the radiated immunity the only one left to validate with EMC tests.

The second option will be an IP camera with Ethernet connection and an Ethernet converter to optical fiber, all powered with a battery capable to charge when operating. The main reason is that Ethernet protocol conversion over optical fiber is very widespread. IP cameras with all the requirements proposed are not so common as USB ones, but also provide video and audio already mixed and synchronized which is the most important, plus can also be powered at 5 V as for the USB case, so the power supply module can be the same for both options. This kind of system would also fulfill the mandatory requirements regarding functionality of the ones proposed for the GCEM group, being the radiated immunity the only one left to validate with EMC tests.

In the next sections both options are further analysed and investigated to decide which one will be the best option for the system, taking into account the project limitations, which are mainly time and cost.

4. Initial approach to the project - USB protocol

In this section is discussed the first approach to the project based on a USB camera and sending the signal over FO.

4.1. Initial System proposal

After the initial research and taking into account the available options it was decided to approach the project in the following way:

- USB camera
- Design an Optical fiber converter for USB protocol
- Power bank for supply only with battery

The features of this system were that USB cameras have very good specifications with video, audio, zoom and focus features (depending on the model), with the benefits of small size and low cost products.

In addition, the USB protocol is powered at 5 V which was perfect to use in conjunction with a power bank, which provides a high capacity battery also in small size and low cost, although the biggest benefit would be that the camera and the power supply modules are easily interchangeable as the USB protocol is very wide spread.

The design part would consist on the fully design of the USB to the optical fiber converter, so an understanding of how the USB protocol works and which speeds uses is needed.

4.2. Device selection for USB approach

Taking into account the system proposal defined in section 4.1, the device selection for each module can be found below.

It is important when researching electronic equipment to be used for EMC tests, to search the documentation of the product to see which directives and standards is compliant with, as allows an initial approximation of which levels of EMC performance will provide.

4.2.1. USB camera

For the USB camera a Logitech would be a good solution. There is a wide options of webcams available from Logitech, which would be useful in case of replacing or upgrading a camera. For this project a good option would be the model “Logitech HD Pro C920”, as it has the following features:

- Good price/quality ratio
- Small size
- USB powered
- Full HD video recording
- Auto Focus
- Stereo microphone
- Automatic low-light correction
- USB 2.0
- H.264 video compression
- Logitech webcam software
- DoC with EMC legislation

Figure 11. Logitech HD Pro C920 [6]

The main advantage of using USB cameras is that can be replaced very easily.

The CE compliance for the Logitech HD Pro C920 can be proved by means of the DoC [7].

Having this information is helpful because allows to know which tests EMC tests have been conducted to the product.

4.2.2. Optical conversion

For the conversion to optical fiber communication, according to section 4.1 it is decided to do a tailor made design capable of sending the USB protocol over optical fiber. See Appendix VI further details on this topic.

4.2.3. Power supply

Being the USB protocol the main pillar of this approach the best option to follow with the small size and low cost idea is to supply the system with only a battery, being a power bank the best solution possible because is already designed with USB interface in mind, and has its own smart charge hardware handling the different modes of the battery.

In order to select the specific model, the consumption and the wanted autonomy of the system has to be known. As the consumption for the optical conversion module was not clear yet, the final model for the power supply was left unchosen until the optical conversion module was finished.

4.3. Feasibility study

After the research and initial testing with the USB protocol and hardware, although the USB approach provided several benefits, there were also some drawbacks. A feasibility study has to be conducted to validate the approach to the project.

4.3.1. Project description and goal

As defined in section 1 the project consists in a functional CCTV system, with video and audio real time transmission to a PC through fiber optical communications. The system is intended to be used during EMC tests of other equipment, so it has to be tested itself in EMC conditions.

Once the system is functional and has been tested in EMC conditions, it can be further improved.

The project is first based on the USB protocol, being both the camera and the power supply modules USB based devices. The optical fiber conversion is planned to be handmade designed

4.3.2. Benefits and drawbacks

The benefits for this system approach are:

- System powered at USB levels
- Good performance equipment
- Easily interchangeable
- Low cost products
- Digital signal

On the other hand, the drawbacks are:

- USB to optical conversion complex
- Time expensive (design part)
- Possibility of not validating the system in EMC conditions due to the delay and time constrains of the project

4.3.3. Timeline

Due to the complexity of converting the USB signals to optical fiber, the time needed for the design and the design validation of the converter would have interfered with the scheduled proposed in the section 1.4, mainly with the full system validation in EMC conditions.

The approach for the project has to permit the validation of the system in EMC conditions and evaluate the system performance.

4.3.4. Alternatives

As an alternative on the design of the USB to optical fiber conversion, there are mainly two proposals:

- Commercial USB to optical fiber converter
- Change the approach to the project and use Ethernet protocol for the camera system

4.3.5. Conclusion

Due to the deviations that would have occurred in the work plan proposed, mainly in the timing of the tasks, caused by the complex design of a USB optical fiber converter, it is decided to change the approach of the project.

The first option would be the search for a commercial USB optical fiber converter, yet this technology is not wide spread commercially, and can't not be found easily. Specialized vendors sell this kind of convertors but there are mainly two inconveniences, high prices and potential issues with some USB devices.

The second proposal is to change the approach for the project and use Ethernet based devices. The benefit of this approach is that Ethernet conversion to fiber optics is much more wide spread because has a lot of uses outside the EMC field, but it has also some drawbacks.

After pondering on both alternatives is decided to change the approach to Ethernet protocol, due to the fact that will allow a functional prototype to be validated. Further information on this can be found in section 5

5. Final approach to the project – Ethernet protocol

In this section is discussed the second approach to the project after the feasibility analysis conducted in section 4.3. The system will be based on a camera that will use the Ethernet protocol to send the signal over optical fiber to the PC.

5.1. System proposal

After the USB approach research and taking into account the conclusions reached in the Feasibility study made in section 4.3, it is decided to approach the project in the following way:

- IP camera with Ethernet connection and powered at 5V.
- Ethernet to Optical fiber converter compatible with IP camera specifications and powered at 5V
- Power supply consisting in a power bank capable of supply both modules during a useful time for EMC tests.

The benefits of this system are that by choosing the right compatible products, a functional good performance and low cost system can be obtained.

Due to time limitations it is decided to assemble a modular system based on commercial available products, in order to be able to achieve the project goal to have a functional system for EMC tests.

5.2. Devices selection for Ethernet approach

In this section after the market research done in section 3, a review for the systems that will be under test is done.

5.2.1. IP Cameras

One of the virtues of using a standard protocol devices such as Ethernet, is that the system is easily interchangeable. Different cameras are proposed to determine which has better performance and features.

In the following sections the IP cameras with Ethernet connection that will be used are shown.

5.2.1.1. D-Link DCS-932L

The DCS-932L is a surveillance Ethernet camera for interior use, it has built-in night vision which allows vision in low light situations, and sound and motion detection.

Figure 12. DCS-932L [8]

The main features of this option are:

- Powered at 5V and 1A through a power jack.
- RJ45 Ethernet port
- Good video quality
- Sound detection at programmable threshold.

This Ethernet camera allows seeing the video feedback through two different ways, while being connected in the same subnetwork, can be seen through a direct connection to the IP direction with an internet browser and through the Website of D-link. The setup and connection is explained in further details in Appendix III.

The DoC for the D-Link DCS-932L can be found in the bibliographic reference [9].

5.2.1.2. Sricam SP020

The Sricam SP020 is an Ethernet camera similar to DCS-932L but with a different form factor. Main differences are that has two-way audio and 360º of movement thanks to the head rotation.

Figure 13. SP020 camera [10]

The main features of this option are:

- Powered at 5V and 1A through a micro USB.
- RJ45 Ethernet port
- Good video quality
- Two-way Sound detection.
- 360º of movement.

This Ethernet camera allows seeing the video feedback only by being connected to the same subnetwork and downloading an application provided by Sricam, which allows the movement of the head and some other features useful when dealing with more cameras.

Certifications for the SP020 camera can be found in the bibliographic reference [11].

5.2.1.3. Raspberry Pi 3B & Pi Camera Module V2

The Raspberry Pi 3B is a well-known single-board computer with a lot of connectivity and a small form factor. This device is useful for a wide range of projects, and allows a very detailed control and customization of how the video obtained through the camera is sent through the Ethernet port.

Figure 14. Raspberry Pi 3B [12]

The Camera Module is a very popular option for security applications, can be used to take high-definition video and photographs, it works with all models of Raspberry Pi 1, 2 and 3. It attaches via a ribbon cable to the CSI port of the Raspberry port.

The DoC for the Raspberry Pi 3B can be found in the bibliographic reference [13].

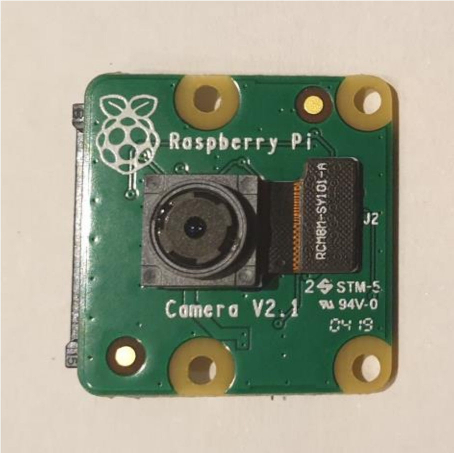

Figure 15. Camera Module V2

By using the Raspberry Pi 3B alongside with the Camera Module V2 of Raspberry, an Ethernet camera is obtained. The main features are:

- Powered at 5V and 1A through a micro USB.
- RJ45 Ethernet port
- Good video quality
- No sound
- Compact design

This system needs a previous configuration in order to work as an Ethernet camera. By downloading a software called VLC and using a code, the Raspberry behaves as an Ethernet camera. This is explained in further detail in Appendix IV.

The DoC for the camera module V2 can be found in the bibliographic reference [14].

5.2.1.4. Raspberry Pi Zero W & Pi Noir Camera V2

The Raspberry Pi Zero W is similar to the Raspberry Pi 3B but the hardware is less powerful, has less connectivity and is smaller in size. As the Raspberry Pi 3B, this Raspberry is useful for a wide range of projects, and allows a very detailed control and customization of how the video obtained through the camera is sent through the Ethernet port.

Figure 16. Raspberry Pi Zero W [12]

The DoC for the Raspberry Pi Zero W can be found in the bibliographic reference [15].

The Pi Noir Camera Module has the same features as the Camera Module V2 with one difference: it does not employ an infrared filter, this provides ability to see in the dark with infrared lighting. It attaches via a ribbon cable to the CSI port of the Raspberry port.

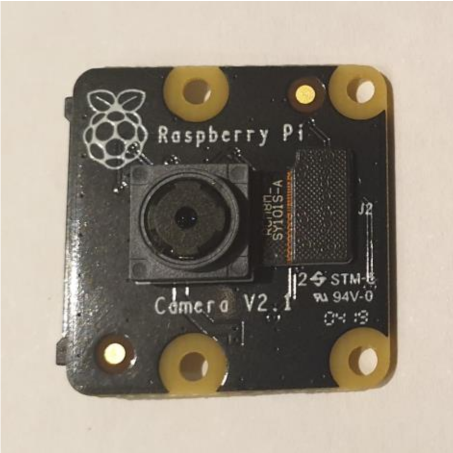

Figure 17. Pi Noir Camera V2

The DoC of the Raspberry Pi Noir Camera 2 is shared with the Raspberry Pi Camera 2.

Due to the small size of the Raspberry Pi Zero W there is a tradeoff between size and connectivity. In this case the Ethernet port is not added to the board, so for a Ethernet connection the Plugable USB 2.0 OTG Micro-USB to 10/100 Network Adapter is used in this system.

Figure 18. Micro USB to Ethernet adapter [16]

The DoC for the adapter is not found online, although it carries the CE mark.

By using the Raspberry Pi Zero W alongside with the Pi Noir Camera V2 of Raspberry and a Micro USB Ethernet adapter, an Ethernet camera is obtained. The main features are:

- Powered at 5V and 1A through a micro USB.
- RJ45 Ethernet port
- Good video quality
- No sound
- Extra device for connectivity
- Very Compact design

As for the previous Raspberry system, this one needs a previous configuration in order to work as an Ethernet camera. By downloading a software called VLC and using a code, the Raspberry behaves as an Ethernet camera. This is explained in further detail in Appendix IV.

5.2.2. Optical fibber converter

The 10Gtek A7S2 is a Gigabit Ethernet Media Converter which allows the easy conversion of Ethernet networks to optical fibber. The converter has a built-in SMF (Single-Mode optical Fiber) Dual SC (Square Connector) transceiver port for the optic fiber connection and the typical RJ45 port for the Ethernet cable.

The Fiber Data Rate of the converter is 1.25GB/s and uses a wavelength of 1310 nm. It allowns to extend a network to a distance of around 20 Km, although for the scenario where it will be used, the distance covered in optical fibber will be around 10 meters.

By connecting the converter to any of the cameras with an Ethernet cable throught the RJ45 ports, the video can be sent through the optical fibber from inside the anechoic chamber to the outside, where another 10Gtek A7S2 is used to convert the optical fibber signal to an Ethernet connection.

Figure 19. Ethernet to Optical Fiber converter

The main features of 10Gtek A7S2 Gigabit Ethernet Media Converter are:

- Powered at 5V and 1A through a power jack
- RJ45 Ethernet port
- Dual SC SMF Fiber connector
- Support Gigabit Ethernet
- Fiber Data rate of 1.25 Gb/s
- Wavelength of 1310 nm
- Compact design

Certifications for the Ethernet to Optical Fiber adapter can be found in the bibliographic reference [17].

The optic fiber used is a 10 meter length SMF SC to SC cable. The SC connector is broadly used for data connections. The 9/125µm cables use the same wavelength as the converter (between 1310 and 1510 nm) and the minimum curvature radius allowed is 5 cm.

Some other features are that the SC connectors are APC (Angled Physical Contact, polished at 8 degree angle) and are rated OS1 (Indoor use). For further details on the specifications of the optical fiber used see bibliographic reference [19].

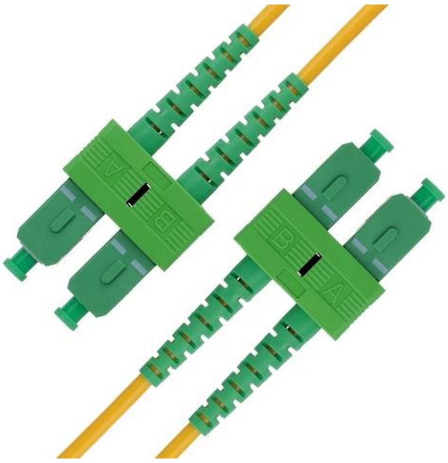

Figure 20. Optical Fibber SC to SC [18]

5.2.3. Power supply

Prior to the selection of the power supply module, a power balance was done for the system proposed to be able to choose the adequate product which must provide enough lifetime to the system, see section 5.2.3.1 for further information on this topic.

The Anker PowerCore 13000 is a compact high capacity battery. It has two USB ports capable to supply 5 V and 3 A, and a capacity of 13000 mAh. The two ports allow to supply both the fiber optic converter and any of the cameras.

Figure 21. Anker PowerCore 13000 [20]

The main features of are:

- Output of 5V and 3A
- Two USB ports
- Compact design

- High capacity

The DoC for the Anker PowerCore 13000 can be found in the bibliographic reference [21].

5.2.3.1. Ethernet power balance

In this section, a power balance for an Ethernet camera setup is analysed. A worst-case scenario is contemplated in order to be sure that the battery can supply enough power to the system

The setup consists of:

- Ethernet Camera
- Ethernet to optical fiber media converter

5.2.3.1.1. Consumption

Both the camera and the Media converter use the alimentation: 5 V DC 1 A.

Ethernet camera electrical characteristics:

$$V_{out} = 5\ V \quad [1]$$

$$I_{out_{max}} = 1\ A \quad [2]$$

$$W_{out_{max}} = V_{out} \cdot I_{out_{max}} = 5 \cdot 1 = 5\ W \quad [3]$$

Ethernet to optical fiber media converter

$$V_{out} = 5\ V \quad [4]$$

$$I_{out_{max}} = 1\ A \quad [5]$$

$$W_{out_{max}} = V_{out} \cdot I_{out_{max}} = 5 \cdot 1 = 5\ W \quad [6]$$

5.2.3.1.2. Electric charge calculation

Taking into account the electrical characteristics of the setup, and adding a safety factor to the calculations, the electric charge needed to supply the device for a specified time can be calculated.

Being the electric charge 'Q', the discharge time 'DT', and the electric consumption of the system 'EC_T', the electric charge can be calculated:

$$Q = EC_T \cdot DT \quad [7]$$

$$EC_T = EC_1 + EC_2 = 1 + 1 = 2\ A = 2.000\ mA \quad [8]$$

Two discharges times are contemplated.

In the case of a discharge time of 9 hours, in this case the electric charge is:

$$Q_{9h} = EC_T \cdot DT = 2.000 \cdot 9 = 18.000\ mAh \quad [9]$$

Adding a safety factor 'SF' of 20% in order to be cautious in the calculations, the corrected electric charge is:

$$Q_{9h_c} = Q_{9h} \cdot SF = 18.000 \cdot 1{,}2 = 21.600\, mAh \quad \textbf{[10]}$$

In the case of a discharge time of 4 hours, the electric charge is:

$$Q_{4h} = EC \cdot DT = 2.000 \cdot 4 = 8.000\, mAh \quad \textbf{[11]}$$

Adding a safety factor 'SF' of 20% in order to be cautious in the calculations, the corrected electric charge 'Qc' is:

$$Q_{4h_c} = Q_{4h} \cdot SF = 8.000 \cdot 1{,}2 = 9.600\, mAh \quad \textbf{[12]}$$

In conclusion, with the worst case conditions which means full power consumption all the time and with a safety factor of 20%, the values obtained are easy achievable for regular power banks.

5.3. Feasibility study

After the system proposal with the Ethernet protocol as the main pillar of this approach and the device selection done, a feasibility study has to be conducted to validate the approach to the project.

5.3.1. Project description and goal

As defined in section 1, the project consists in a functional CCTV system, with video and audio real time transmission to a PC through fiber optical communications. The system is intended to be used during EMC tests of other equipment, so it has to be tested itself in EMC conditions.

Once the system is functional and has been tested in EMC conditions, it can be further improved.

The project will be based on two ideas, the camera will use Ethernet protocol for sending the video and audio signals over fiber optics with a converter, and the voltage supply for the modules must be 5V.

5.3.2. Benefits and drawbacks

The benefits for this system approach are:

- System powered at USB levels
- Good performance equipment
- Interchangeable modules
- Compatibility between modules
- Low cost products
- Digital signal
- Ethernet to optical fiber adapters widely available
- Time consumption acceptable
- The timing allows EMC validation

On the other hand, the drawbacks are:

- Limited availability of IP cameras with all the characteristics needed:
  - Ethernet port
  - Powered at 5V
  - Good quality Video and audio
- Not very customizable design

5.3.3. Timeline

With the new Ethernet approach and all the modules being compatible with each other, the work plan proposed in section 1.4, can now be completed taking into account some delay due to the initial approach, this delay can be seen in the section 1.5 where the deviation of the initial work plan is contemplated.

5.3.4. Conclusion

With the adequate device selection done in section 5.2, which grants compatibility of all the modules, and the timing and schedule corrected, allowing to have a functional validation tested in EMC conditions, this option is feasible and it is decided to continue the project with this approach.

With the conclusion of the feasibility studio being positive, all the hardware was bought to begin with the integration and functional validation.

6. Systems under test

In this section an overview of the integration, validation and setup conditions for the systems that will do EMC tests is defined.

All the systems related with the final approach will be validated in the same operating mode which has been called Operating Mode 1. The details can be seen in the Table 5 below.

Table 5. Operation Mode details

Operation Mode 1	System powered, internet connection and real time video and audio visualization from the PC.

In all the setups for the system under tests, a router and a PC will be used as a part of the equipment required for the video and audio monitoring. This devices are part of the current equipment of the GCEM group and are used during the daily work of the laboratory

6.1. System 1: DCS-932L

The System 1, from now one called DCS-932L system, will be integrated by the following modules:

- Camera module: D-Link DCS-932L
- Fiber optics conversion module: 10Gtek A7S2 Gigabit Ethernet Media Converter
- Power Supply module: Anker Power Core 13000

The setup used for the validation of the DCS-932L system is depicted in Figure 22 below.

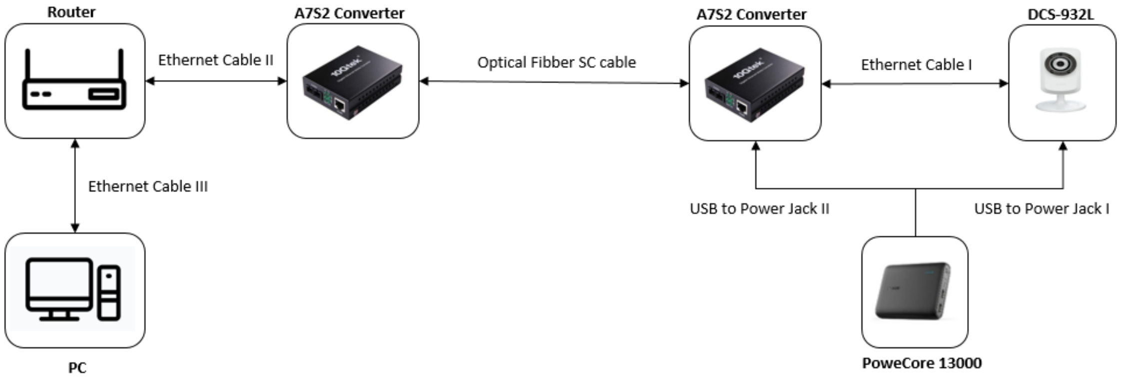

Figure 22. Diagram of the setup for DCS-932L system validation

In the Figure 23 below can be seen a picture of the physical implementation of the system.

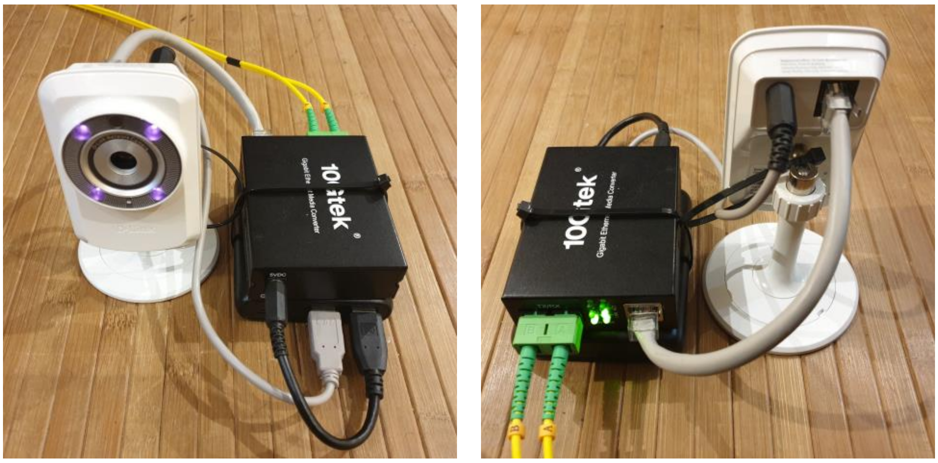

Figure 23. Physical implementation of the DCS-932L system (front & back view)

Due to the high importance of the cable due to the coupling during EMC testing, the cables types and lengths used for the validation are defined in the Table 6 below.

Table 6. Setup for DCS-932L system

Cable name	Length (from top to bottom)
USB to Power Jack I	17.5 cm
USB to Power Jack II	31.5 cm
Ethernet Cable I	19.5 cm
Ethernet Cable II	NA*
Ethernet Cable III	NA*
Optical Fiber SC cable	10 m
NA*: Not Applicable, any length required.	

The validation has to be performed under Operation Mode 1 requirements.

6.2. <u>System 2: SP020</u>

The System 2, from now one called SP020 system, will be integrated by the following modules:

- Camera module: Sricam SP020
- Fiber optics conversion module: 10Gtek A7S2 Gigabit Ethernet Media Converter
- Power Supply module: Anker Power Core 13000

The setup used for the validation of the SP020 system is depicted in Figure 24 below.

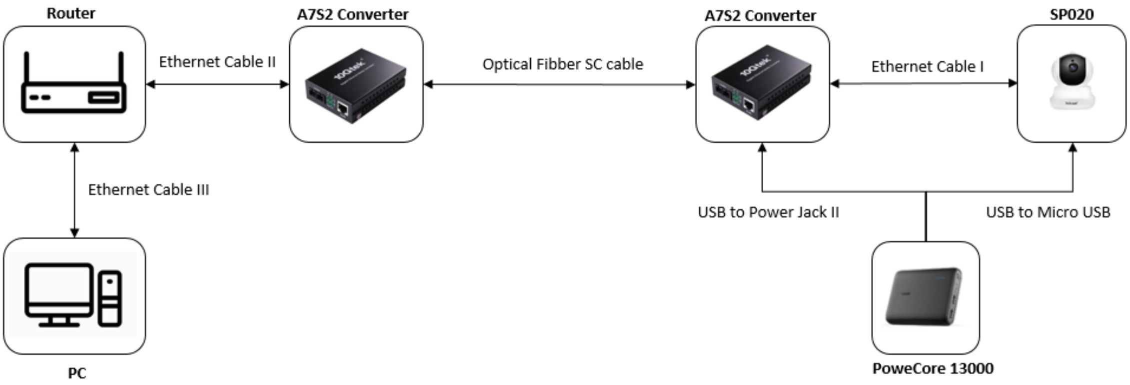

Figure 24. Setup for SP020 system validation

In the Figure 25 below can be seen a picture of the physical implementation of the system.

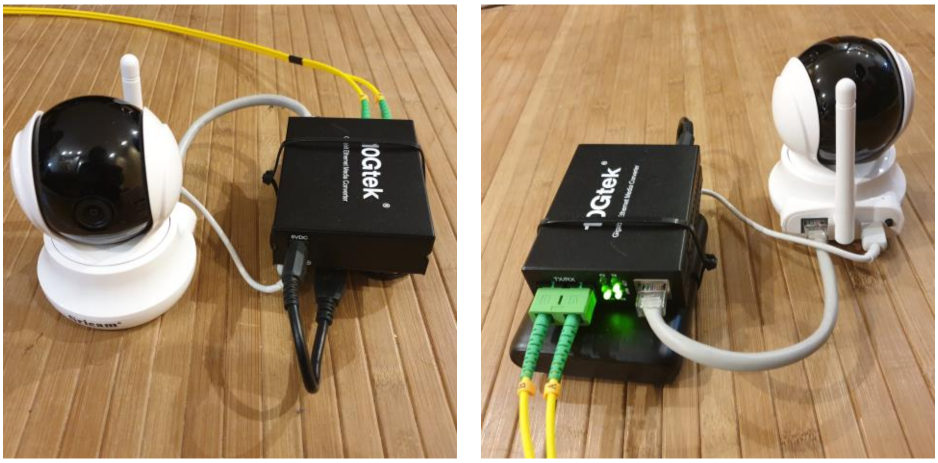

Figure 25. Physical implementation of the SP020 system (front & back view)

Due to the high importance of the cable due to the coupling during EMC testing, the cables types and lengths used for the validation are defined in the Table 7 below.

Table 7. Cables for SP020 system

Cable name	Length (from top to bottom)
USB to Micro USB	19 cm
USB to Power Jack I	17.5 cm
Ethernet Cable I	19.5 cm
Ethernet Cable II	NA*
Ethernet Cable III	NA*
Optical Fiber SC cable	10 m
NA*: Not Applicable, any length required.	

The validation has to be performed under Operation Mode 1 requirements.

6.3. System 3: Pi3B

The System 3, from now one called Pi3B system, will be integrated by the following modules:

- Camera module: Raspberry Pi 3B & Pi camera 2
- Fiber optics conversion module: 10Gtek A7S2 Gigabit Ethernet Media Converter
- Power Supply module: Anker Power Core 13000

The setup used for the validation of the Pi3B system is depicted in Figure 26 below.

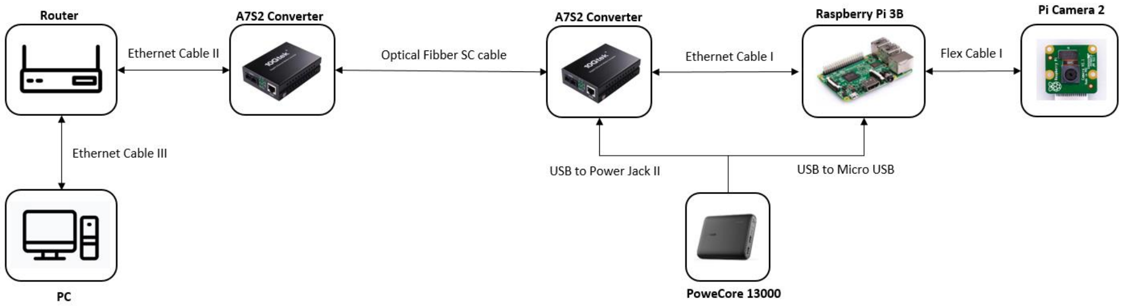

Figure 26. Setup for Pi3B system validation

In the Figure 27Figure 25 below can be seen a picture of the physical implementation of the system.

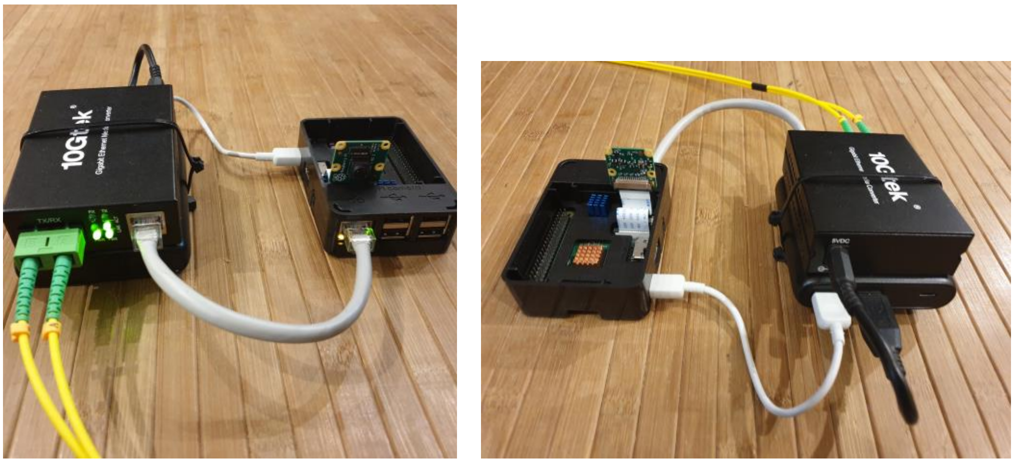

Figure 27. Physical implementation of the Pi3B system (front & back view)

Due to the high importance of the cable due to the coupling during EMC testing, the cables types and lengths used for the validation are defined in the Table 8 below.

Table 8. Cables for Pi3B system

Cable name	Length (from top to bottom)
USB to Micro USB	19 cm
USB to Power Jack I	17.5 cm
Flex Cable I	5 cm
Ethernet Cable I	19.5 cm
Ethernet Cable II	NA*
Ethernet Cable III	NA*
Optical Fiber SC cable	10 m
NA*: Not Applicable, any length required.	

The validation has to be performed under Operation Mode 1 requirements.

6.4. System 4: PiZero

The System 4, from now one called PiZero system, will be integrated by the following modules:

- Camera module: Raspberry Pi Zero W & Pi Noir camera 2
- Fiber optics conversion module: 10Gtek A7S2 Gigabit Ethernet Media Converter
- Power Supply module: Anker Power Core 13000

The setup used for the validation of the PiZero system is depicted in Figure 54 below.

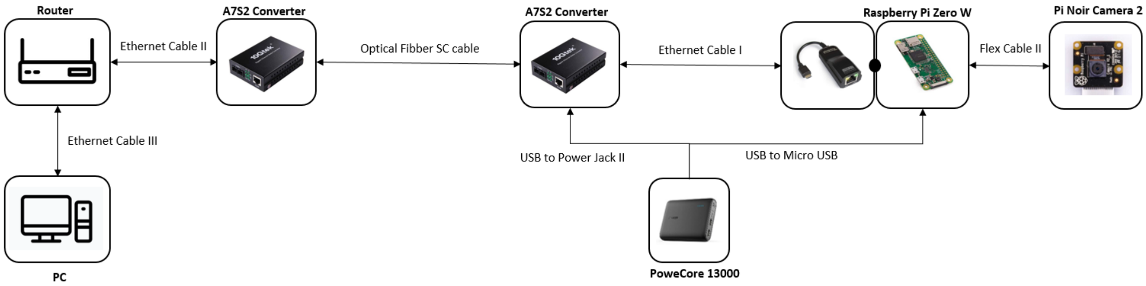

Figure 28. Setup for PiZero system validation

In the Figure 29Figure 27Figure 25 below can be seen a picture of the physical implementation of the system

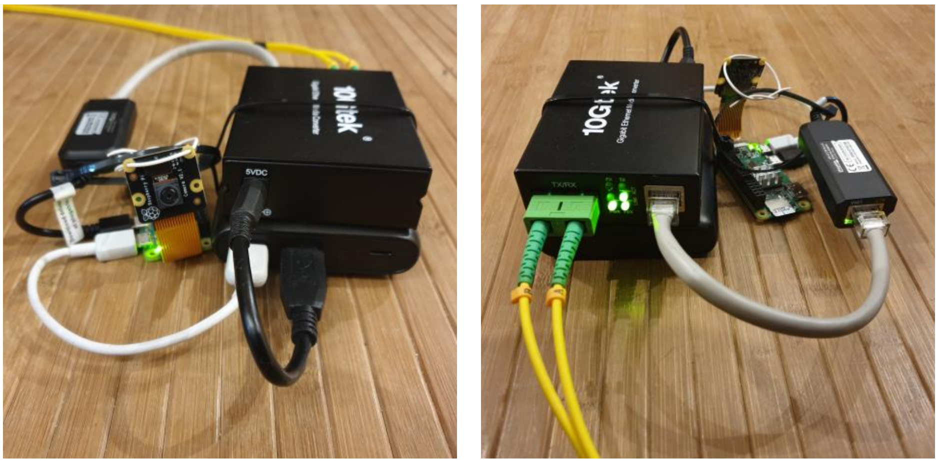

Figure 29. Physical implementation of the PiZero system (front & back view)

Due to the high importance of the cable due to the coupling during EMC testing, the cables types and lengths used for the validation are defined in the Table 9 below.

Table 9. Cables for PiZero system

Cable name	Length (from top to bottom)
USB to Micro USB	19 cm
USB to Power Jack I	17.5 cm
Flex Cable II	4 cm
Ethernet Cable I	19.5 cm
Ethernet Cable II	NA*
Ethernet Cable III	NA*
Optical Fiber SC cable	10 m
NA*: Not Applicable, any length required.	

The validation has to be performed under Operation Mode 1 requirements.

7. Results

In this section all the results of the validations for the systems proposed in section 6 are detailed and explained.

The results are divided into three sections, a functional validation under nominal conditions to see if the systems work properly, radiated immunity tests, which is the main core of this section, to test how much electric field and at which frequencies the systems can withstand, and finally radiated emissions to check which emission levels are being radiated from the systems and whether or not could be used in radiated emission tests.

The structure of the testing performed can be seen below:

- Functional validation under nominal conditions
- Radiated Immunity. Setup according to EN 61000-4-3
  - Levels of residential environment, according to EN 61000-6-1
  - Levels of industrial environment, according EN 61000-6-2
  - Levels of railway rolling stock environment, according to EN 50121-3-2
- Radiated immunity. Setup according to ISO 11452-2
  - Levels of automotive environment, according to UNECE REGULATIONS nº10
- Radiated emissions. Setup according to EN 55016-2-3
  - Limits of residential environment, according to EN 61000-6-3

7.1. Initial Functional tests

A functional validation under nominal conditions without any kind of stress applied to the system is required prior to the EMC validation for two purposes, discard any non-functional systems, which could be caused for setup problems or incompatibility of the modules, and check compatibility on site of the equipment with the GCEM equipment and network.

The purpose of this tests are to ensure that the systems are working properly with the setups defined in section 6 under nominal conditions when no external perturbations are applied and with the requirements defined Operation Mode 1 (see Table 5).

The summary of the results obtained are defined in Table 10.

Table 10. Initial functional validation results

System	Operation Mode	Result	Comments
DCS-932L	1	Functional	
SP020	1	Functional	Sricam software required
Pi3B	1	Functional	Only video, no audio
PiZero	1	Functional	Only video, no audio

All the systems are functional, so the EMC immunity and emission tests can be performed.

7.2. Radiated immunity tests results

In EMC radiated immunity testing, electric field is radiated at a wide range of frequencies to validate the performance and the degradation of the systems in such conditions.

The basic setup used for radiated immunity tests defined in standard EN61000-4-3 is depicted below in Figure 30.

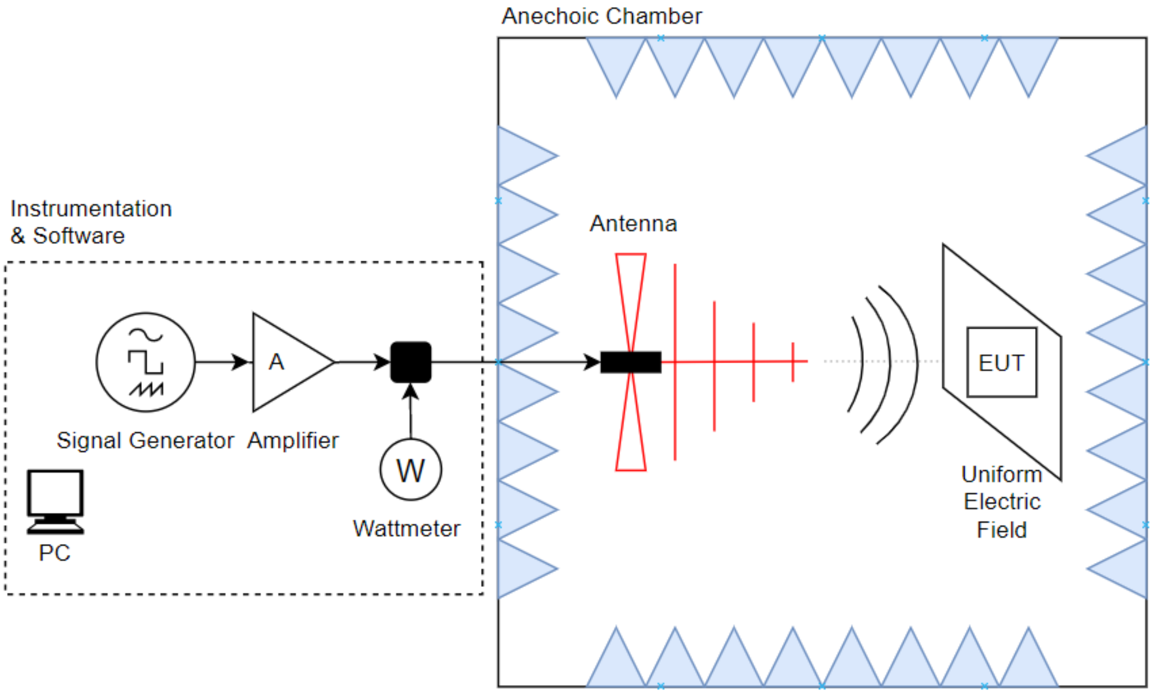

Figure 30. Basic laboratory setup for radiated immunity tests

For automotive environment the uniform field area is not used and the setup used will be according to ISO 11452-2 which is the basic standard for components immunity in the automotive sector.

The EMC radiated immunity tests are performed to the four systems proposed in section 6, to verify the real specifications of each system.

Radiated immunity tests results are obtained by setting the systems in Operating Mode 1 (see Table 37), applying the test conditions and observing the function and performance of the real time video and audio sent from the systems to the computer. If degradations are observed are written in the test reports.

In order to help in the evaluation of the performance of the real time video and audio of the systems, passive devices based on mechanical movement, such as pendulums and a metronome will be used simulating to be a real EUT.

The following criteria will be used to grade the system performance during the test.

Table 11. Test criteria

Criteria	Definition
A	System behaved as expected
B	Malfunction, the system recovers itself
C	Malfunction, the system recovers with user help

Due to the monitoring system will always have to be facing the EUT, the systems will be tested in the orientation required for the monitoring.

In the following sections can be found the results for the radiated immunity tests in the two setups that tests have been performed:

- Domestic, Industrial and Railway environments
- Automotive environment

7.2.1. Radiated immunity for domestic, industrial and railway environment

The setup used for domestic, industrial and railway environments EN 61000-4-3, is widely used as it includes a wide range of electronic and electrical devices.

With this setup, by applying a uniform electric field area of 20 V/m, the domestic, industrial and railway radiated immunity environments are being validated, because 20 V/m is the maximum electric field requested by any of these standards. In any case with this setup it's not possible to increase the level of electric field for the whole frequency range using the current equipment at the GCEM laboratory. Tests are performed from 80 MHz to 1 GHz in vertical and horizontal polarizations of the antenna.

7.2.1.1. System placement in the uniform electric field plane

All the systems will be tested in this location to evaluate the one with better performance under the perturbation of the electric field.

7.2.1.1.1. DCS-932L

The DCS-932L system is the first to be tested. The setup and conditions for the system are the ones defined in Section 6.1.

In the figures below can be seen the actual in site setup for the DCS-932L system in the uniform field area location.

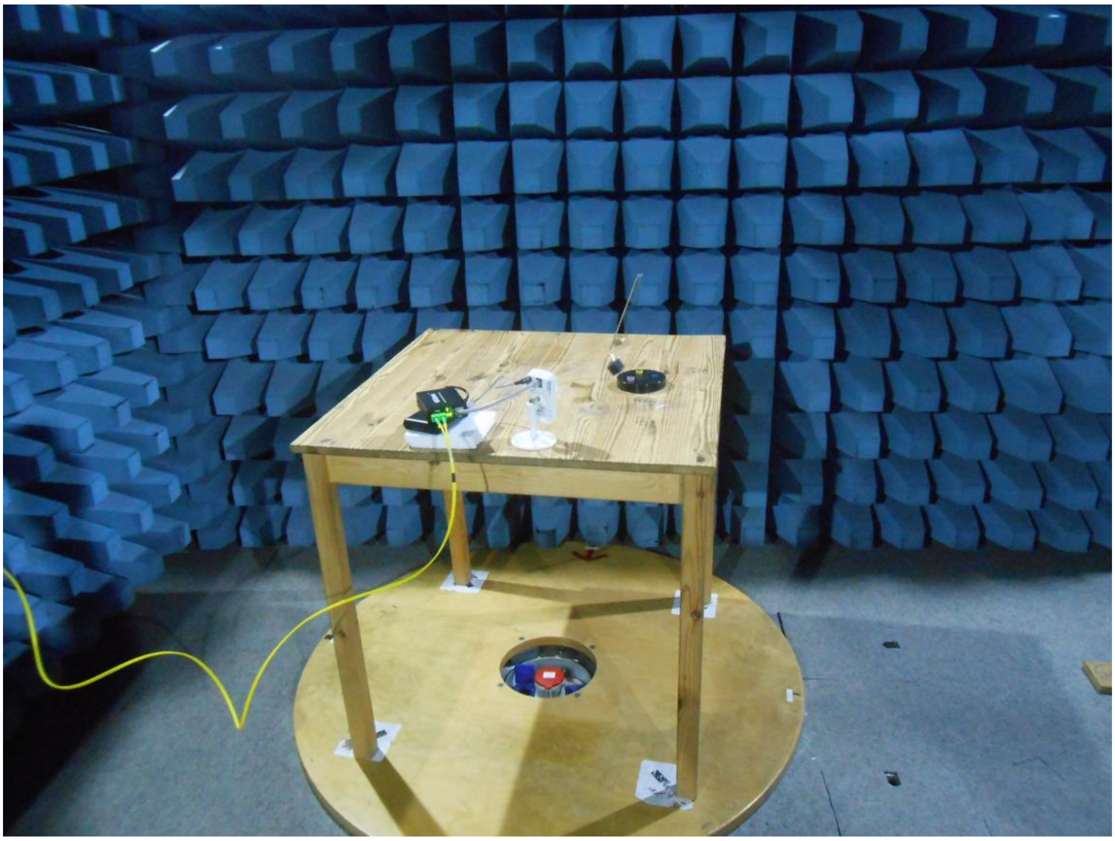

Figure 31. DCS-932L in Calibration Plane position (I)

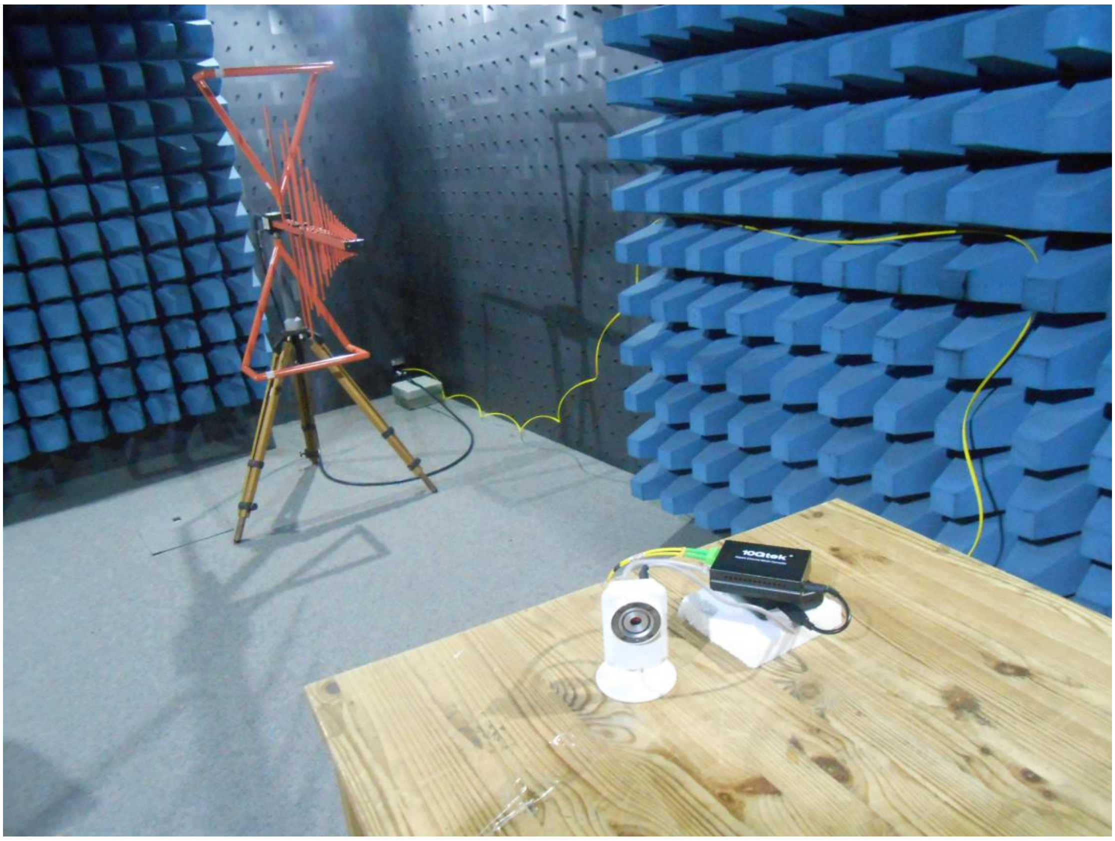

Figure 32. DCS-932L in Calibration Plane position (II)

The report obtained and the pictures for the setup used can be found below.

Table 12. DCS-932L camera report I

Parameters		
Electric Field	20 V/m	
Frequency Range	80 MHz – 1 GHz	
Frequency Increment	1%	
Modulation	AM 80% (1 kHz)	
Dwell Time	1 s	
Position	Calibration plane	
Results		
Test Antenna Polarization	Vertical	Good performance during the test, no appreciable downgrades in the functionality of the system. No disconnection or any kind of reset.
	Horizontal	Good performance during the test, no appreciable downgrades in the functionality of the system. No disconnection or any kind of reset.
Comments		
Good performance through the test.		

The performance for the DCS-930L system has been good through all the frequency range, any downgrade have been observed with the electric field applied. The test for this system is considered A criteria according to Table 11.

7.2.1.1.2. SP020

The SP020 system is the next to be tested, the setup and conditions for the system are the ones defined in Section 6.2.

In the figures below can be seen the actual in site setup for the SP020 system in the calibration plane location.

Figure 33. SP020 in Calibration Plane position (I)

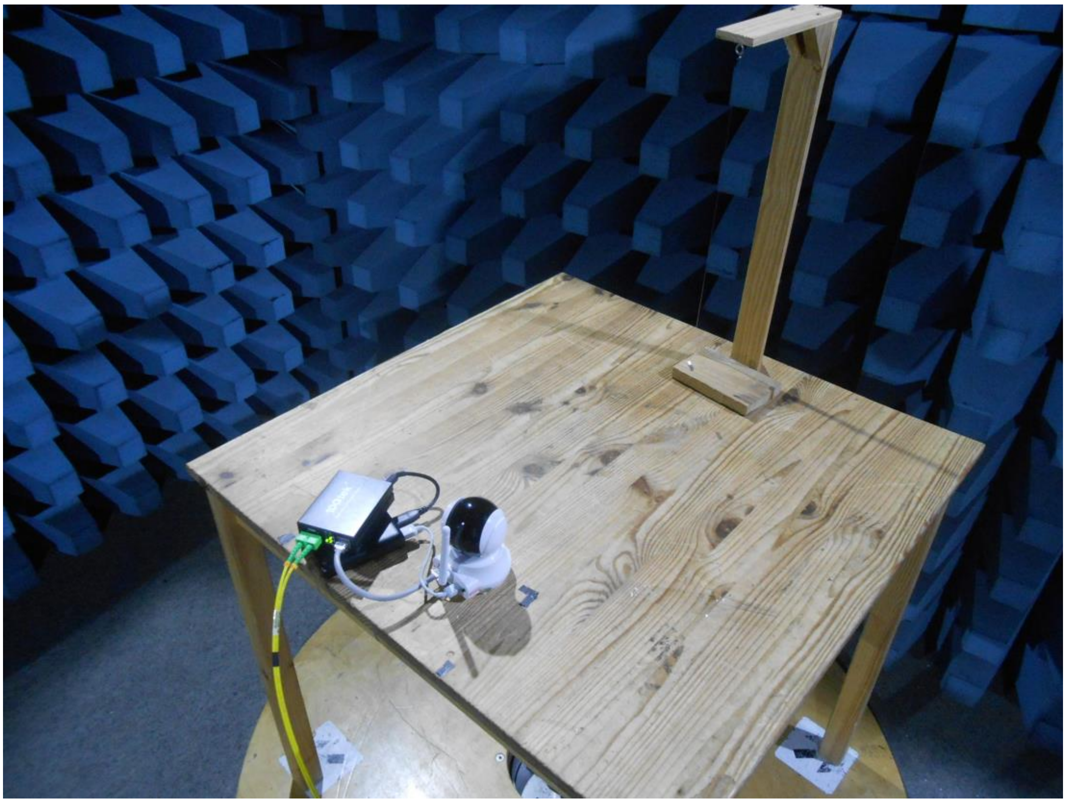

Figure 34. SP020 in Calibration Plane position (II)

The report obtained and the pictures for the actual setup used are found below.

Table 13. SP020 camera report

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>20 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>80 MHz – 1 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration plane</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test Antenna Polarization</td><td>Vertical</td><td>At 122 MHz a downgrade in the Frames per Second related to the Electric Field applied is observed, it recovers itself.
No unintentional rotation of the motors.
No disconnection or any kind of reset.</td></tr>
<tr><td>Horizontal</td><td>Good performance during the test, no appreciable downgrades in the functionality of the system.
No unintentional rotation of the motors.
No disconnection or any kind of reset.</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">Requires special software from Sricam to visualize the video and audio, apply zoom and to maneuver the rotary motors.</td></tr>
</table>

The performance for the SP020 system has been good except at 122 MHz with vertical polarization where a downgrade in the Frames per Second has occurred. Due to the system has recovered itself without the user intervention this test is considered as B criteria according to Table 11.

7.2.1.1.3. Pi3B

The Pi3B system is the third to be tested, the setup and conditions for the system are the ones defined in Section 6.3.

In the figures below can be seen the actual in site setup for the Pi3B system in the calibration plane location.

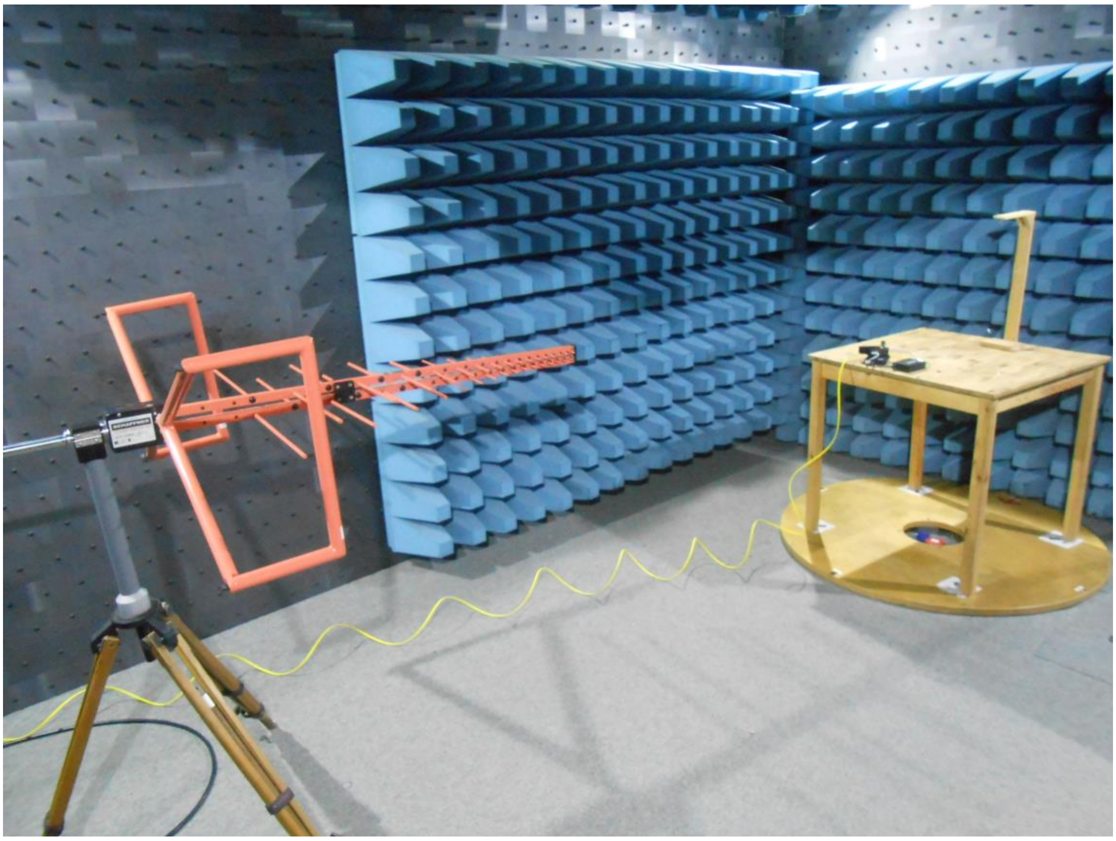

Figure 35. Raspberry Pi 3B in Calibration Plane position (I)

Figure 36. Raspberry Pi 3B in Calibration Plane position (II)

The report obtained and the pictures for the actual setup used are found below.

Table 14. Raspberry Pi 3B camera report

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>20 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>80 MHz – 1 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration plane</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test
Antenna
Polarization</td><td>Vertical</td><td>From 925 MHz to 952 MHz purple horizontal lines appear in the video.
At 953 MHz the horizontal purple lines are increased and different tonalities of colour appear in the image. The video retransmission is eventually lost. But is recovered when the electric field is turned off.
From 954 MHz to 960 MHz purple horizontal appear in the video.
In the other range of frequencies good performance during the test.
No permanent disconnection. No reset.</td></tr>
<tr><td>Horizontal</td><td>Good performance during the test, no appreciable downgrades in the functionality of the system.
No disconnection or any kind of reset.</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">Only video monitoring.</td></tr>
</table>

The performance for the Pi3B system has been good until the higher part of the frequency range around 900 MHz where clearly there is a degeneration in the video signal performance of the equipment, directly related to the electric field applied. The video signal was eventually lost, although the system recovers itself when removing the electric field. Due to this factors the test for this system is considered as B criteria according to Table 11.

7.2.1.1.4. PiZero

The PiZero system is the last to be tested, the setup and conditions for the system are the ones defined in Section 6.4.

In the figures below can be seen the actual in site setup for the PiZero system in the calibration plane location.

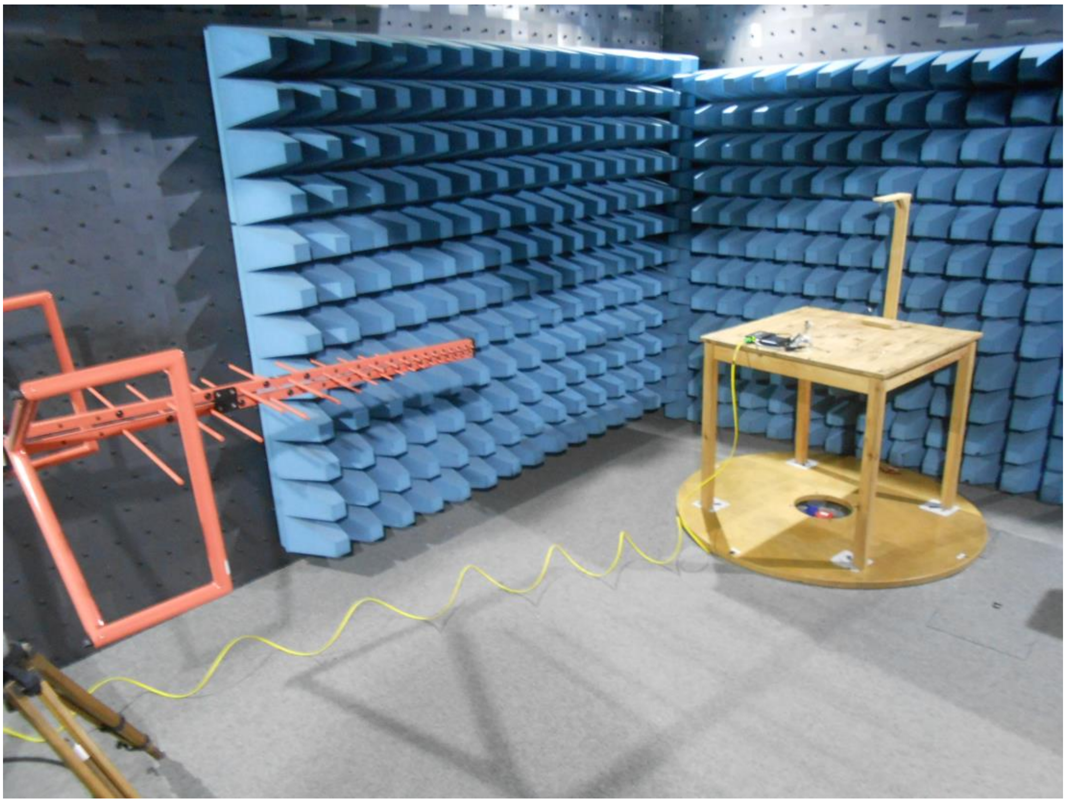

Figure 37. Raspberry Pi Zero in Calibration Plane position (I)

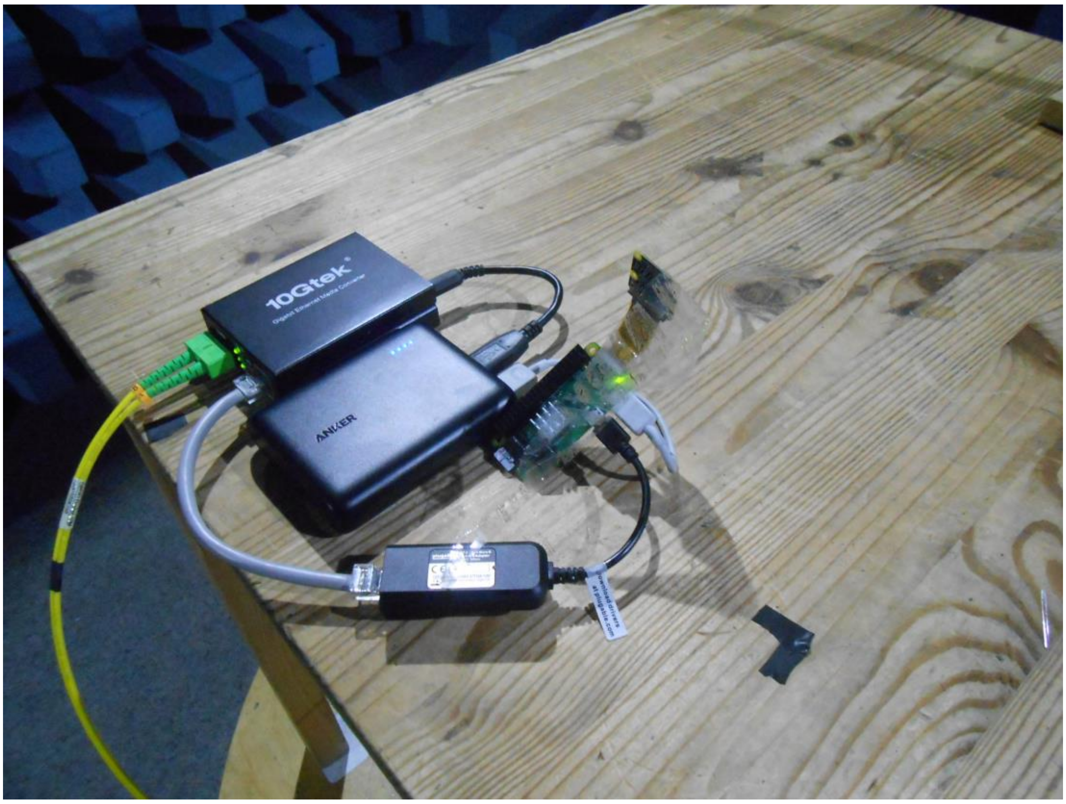

Figure 38. Raspberry Pi Zero in Calibration Plane position (II)

The report obtained and the pictures for the actual setup used are found below.

Table 15. Raspberry Pi Zero IR camera report

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>20 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>80 MHz – 1 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration plane</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test
Antenna
Polarization</td><td>Vertical</td><td>Not performed</td></tr>
<tr><td>Horizontal</td><td>From 179 to 312 MHz, the video is frozen and the camera does not recover functionality by its own, even when the electric field is removed. The user has to perform a hard reset by removing the power from the modules and connecting the software again from the PC.
At 573 MHz the video is frozen, when the electric field is removed, the user has to reconnect the software from the PC to regain the video signal. The system has recovered by its own.
Both phenomena continues to happen at higher frequencies, so the test is finished at 600 MHz.</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">Do to the bad performance in Horizontal polarization the immunity test is stopped before the 1 GHz and is not done in vertical polarization because the immunity of this system is very low and this option has been discarded.
Only video monitoring.</td></tr>
</table>

For this system can be seen that there is an important degeneration of the performance of the equipment directly related to the electric field applied. Several disconnections occurred and the system did not recover itself, the reason behind this bad performance could be either that the Raspberry Pi Zero has limited EMC immunity resistance, or that the extra device used, the USB Ethernet adapter is very susceptible to EMI.

Due to the factors discussed above the test for this system is considered as C criteria according to Table 11, because requires user intervention to recover.

7.2.1.1.5. Summary of results in the uniformity electric field plane

With all the tests reports obtained a review of the performance of each system is done. A summary with the test criteria's of each system can be found in Table 16 below.

Table 16. Summary of test criteria results for domestic, industrial and railway setup EN 61000-4-3.

		TEST CRITERIA
SYSTEM	DCS-932L	A
	SP020	B
	Pi3B	B
	PiZero	C

The system with best radiated immunity and performance of all the alternatives has been the DCS-932L. With the results obtained, the system would fulfill the requirements specified for radiated immunity in standards EN 61000-6-1, EN 61000-6-2 and EN 50121-3-2 in the frequency range applied.

The specifications for the DCS-932L system obtained during the tests are:

- Radiated immunity of 20 V/m up to 1 GHz
- Battery lifetime of 8 hours

With the good performance, it is decided be tested in the automotive setup with a higher frequency range and electric field. This can be seen in section 7.2.2.

Due to the system is intended for the monitoring of the chamber while other devices are being tested, different locations inside the anechoic chamber are proposed, to further test the device, this can be seen in section 7.2.1.2. The location has an important impact in EMC testing due to the electric field can vary significantly depending on the location.

7.2.1.2. System placement in locations A, B and C

The only system tested in locations A, B and C is the DCS-932L system due to it is the one with best performance and A criteria in the calibration plane.

In the uniform electric field plane the monitoring system would provide a close view of the EUT, especially useful in the case of the EUT has visual indicators such as LEDs, display, small mechanical movements…

Locations A, B and C, are other positions located at 1 meter distance from the calibration plane and provide a more global view, useful in the case of equipment with mechanical movement, audible noises and others.

Below can be seen a figure with the actual anechoic chamber of the GCEM group and the different locations proposed for the monitoring system to be during other tests.

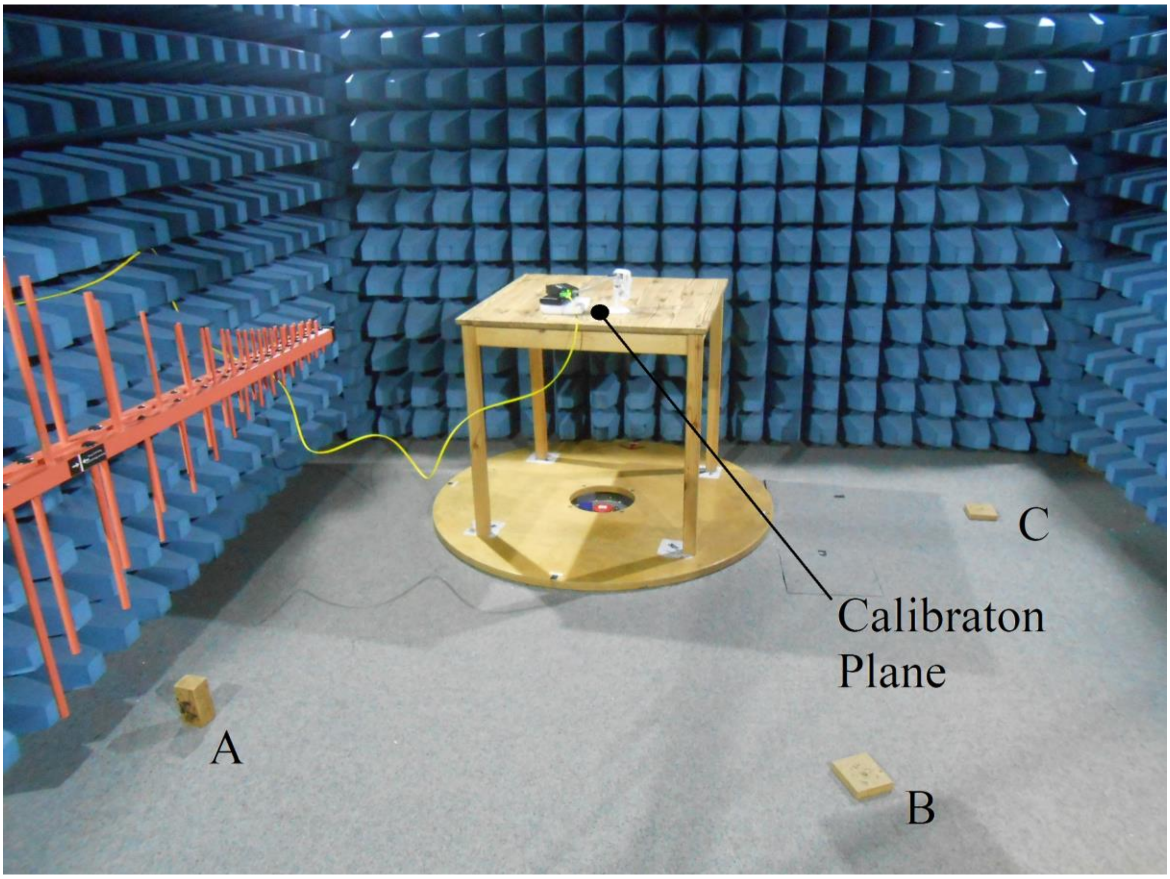

Figure 39. Immunity testing locations

The DCS-932L system is tested with the setup and conditions defined in Section 6.1. Foam blocks are used to level up the system with the intended EUT location and high.

First location to be tested is location A. In the figures below can be seen the actual in site setup for the DCS-932L system in the location A.

Figure 40. DCS-932L in A position (I)

Figure 41. DCS-932L in A position (II)

Good performance through all the frequency range, any downgrade have been observed with the electric field applied. The test for this system is considered A criteria according to Table 11.

Next location to be tested is location B. In the figures below can be seen the actual in site setup for the DCS-932L system in the location B.

Figure 42. DCS-932L in B position (I)

Figure 43 DCS-932L in B position (II)

Good performance through all the frequency range, any downgrade have been observed with the electric field applied. The test for this system is considered A criteria according to Table 11.

Last location to be tested is location C. In the figures below can be seen the actual in site setup for the DCS-932L system in the location V.

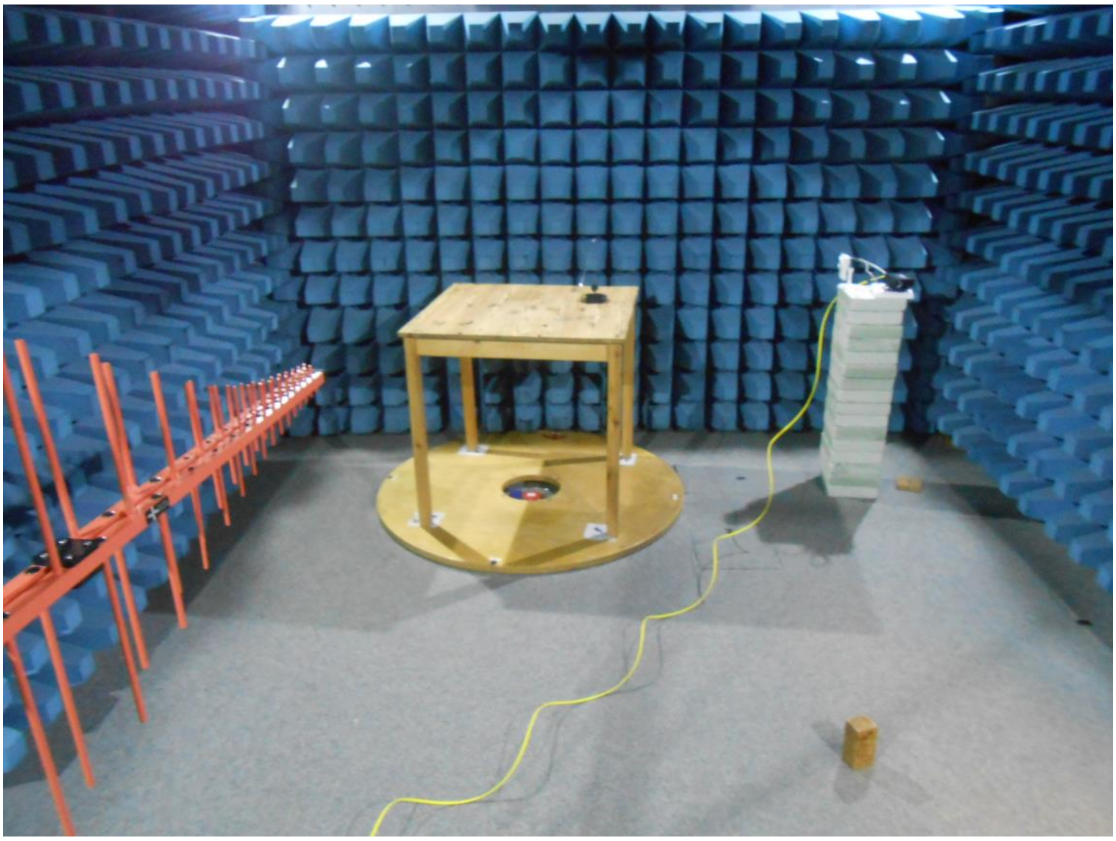

Figure 44. DCS-932L in C position (I)

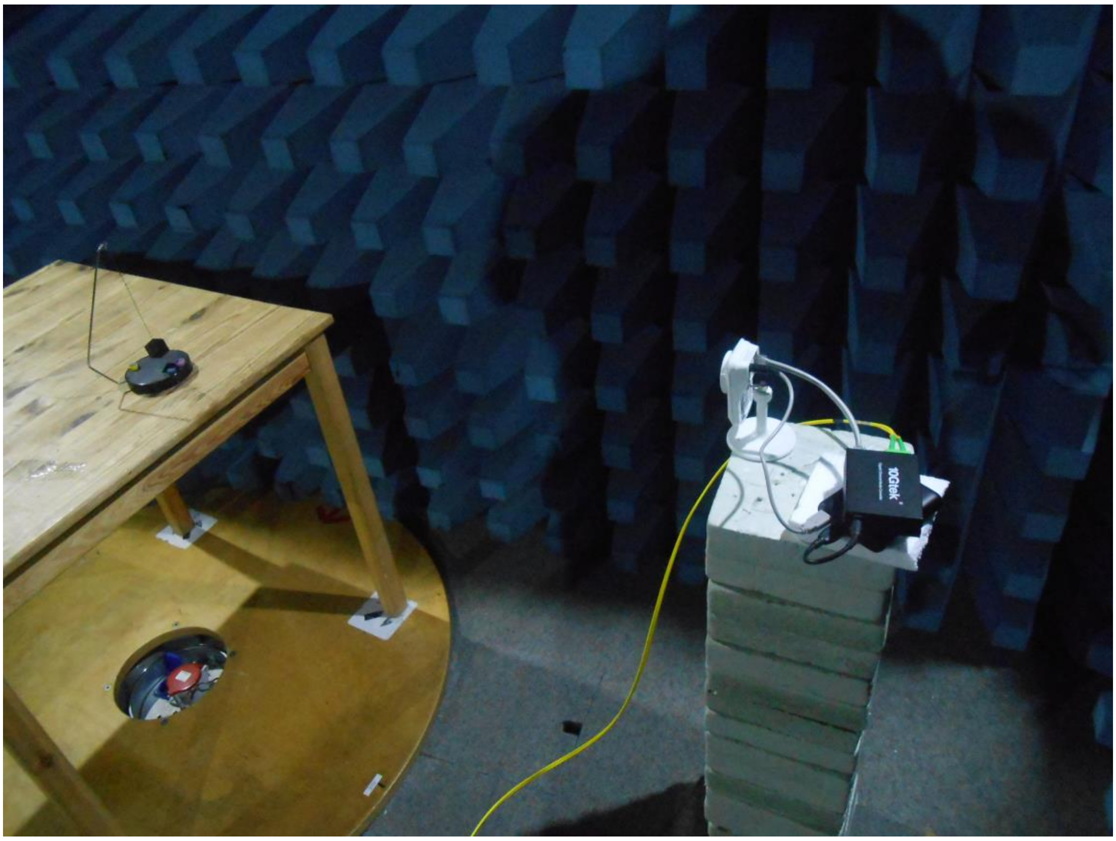

Figure 45. DCS-932L in C position (II)

Good performance through all the frequency range, any downgrade have been observed with the electric field applied. The test for this system is considered A criteria according to Table 11.

The report for all locations can be seen in the table below.

Table 17. DCS-932L camera report IV

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>20 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>80 MHz – 1 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>A, B and C</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test
Antenna
Polarization</td><td>Vertical</td><td>Good performance during the test, no appreciable downgrades in the functionality of the system.
No disconnection or any kind of reset.</td></tr>
<tr><td>Horizontal</td><td>Good performance during the test, no appreciable downgrades in the functionality of the system.
No disconnection or any kind of reset.</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">Good performance through the test.</td></tr>
</table>

The performance for the DCS-930L system has been good in all the locations proposed and in all the frequency range, no downgrade has been observed with the electric field applied.

The system has behaved very well and hasn't showed any sign of degradation in the performance, so in the other positions proposed the system also withstands the test parameters required in radiated immunity standards EN 61000-6-1, EN 61000-6-2 and EN 50121-3-2 in the frequency range applied.

7.2.1.3. Conclusions on radiated immunity for domestic, industrial and railway environment

With all the tests reports obtained a full summary with the test criteria's of each system including the locations can be found in Table 18 below.

Table 18. Summary of test criteria results for domestic/industrial and railway setup

		TEST CRITERIA			
		Calibration Plane	Location A	Location B	Location C
SYSTEM	DCS-932L	A	A	A	A
	SP020	B	-	-	-
	Pi3B	B	-	-	-
	PiZero	C	-	-	-

As can be seen the best performing system is the DCS-932L which also behaves well in the alternative locations proposed. The system would fulfill the requirements specified for radiated immunity in standards EN 61000-6-1, EN 61000-6-2 and EN 50121-3-2 in the frequency range applied.

The system is not tested in a higher range of frequencies, because it will be tested in the automotive setup in section 7.2.2, and there more electric field and higher frequencies will be applied. Besides the laboratory availability is limited due normal work performed, so is decided to do further tests in the automotive setup.

The final specifications for the DCS-932L system obtained during the tests are:

- Radiated immunity of 20 V/m up to 1 GHz
    - Both in the uniform electric field plane and in different locations
- Battery lifetime of 8 hours

7.2.2. Radiated immunity for automotive environment

In the automotive components setup defined for electrical disturbances according ISO 11452-2, metallic ground planes are placed and connected to metallic floor of semi-anechoic chamber by sheets of copper.

For automotive electronic components setup the electric field is only defined at one point with only 1 meter distance to the antenna, which allows to have much greater values.

The only system under test will be the DCS-932L, and this time, as explained in section 7.2.1.3, the frequency range will be increased, up to 3 GHz.

7.2.2.1. Test according to UNECE REGULATIONS nº10 from 80 MHz to 1 GHz

EMC immunity tests performed at a frequency range from 80 MHz to 1 GHz with levels of 30 V/m according UNECE REGULATIONS nº10.

As before, the DCS-932L system setup and conditions are the ones defined in Section 6.1. In the figures below can be seen the actual in site automotive setup for the DCS-932L system in the electric field measurement point.

Figure 46. DCS-932L automotive setup from 80 MHz to 1 GHz (I)

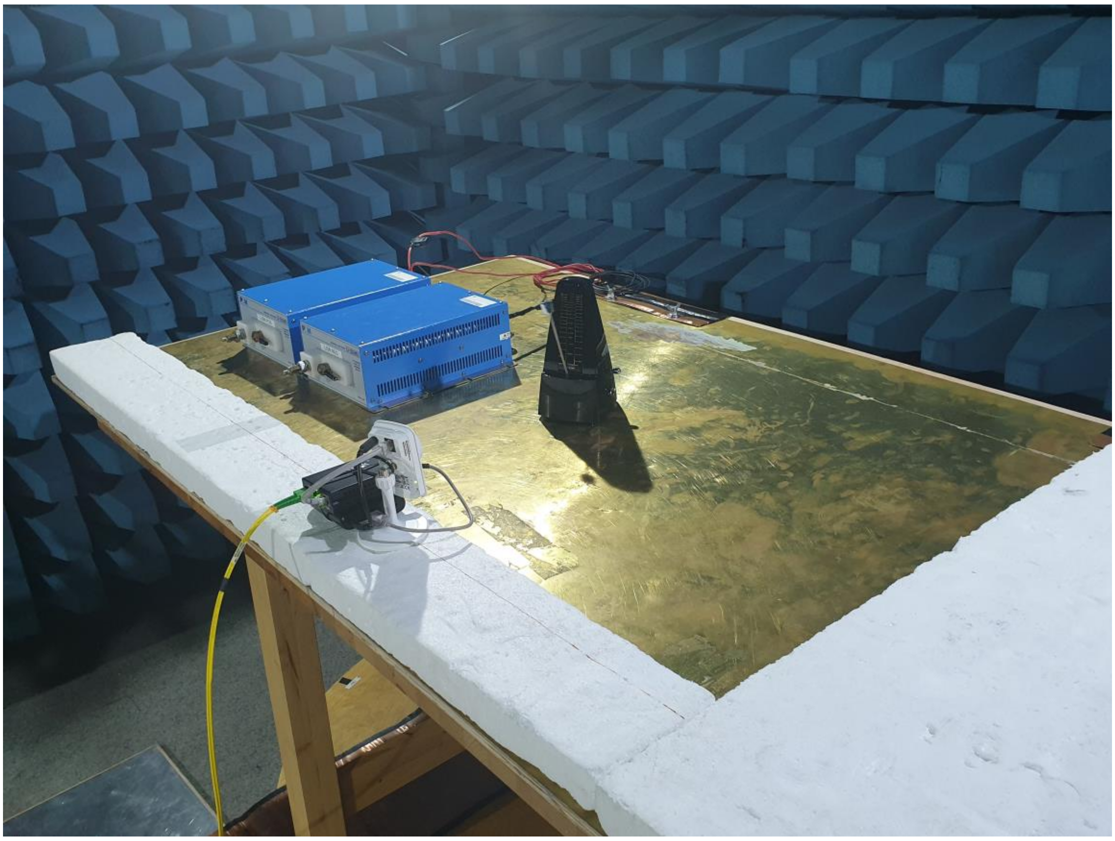

Figure 47. DCS-932L automotive setup from 80 MHz to 1 GHz (II)

The system is tested with an electric field of 30 V/m. The report can be seen below.

Table 19. DCS-932L camera report V.

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>30 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>80 MHz – 1 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration point</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test Antenna Polarization</td><td>Vertical</td><td>A downgrade in the Frames per Second of the camera has been seen around the frequencies detailed below. When removing the electric field the video recovers normal performance.
- 728 MHz
- 773 MHz</td></tr>
<tr><td>Horizontal</td><td>In UNECE REGULATIONS nº10 automotive EMC testing, horizontal polarization is not required.</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">As an improvement, it is decided to put two ferrites from Wurth Electronics model 742715W3 in the Ethernet cable to check if the radiated immunity is improved.</td></tr>
<tr><th colspan="3">Results with ferrites</th></tr>
<tr><td rowspan="2">Test Antenna Polarization</td><td>Vertical</td><td>Good performance during the test, no appreciable downgrades in the functionality of the system.
No disconnection or any kind of reset.</td></tr>
<tr><td>Horizontal</td><td>In UNECE REGULATIONS nº10 automotive EMC testing, horizontal polarization is not required.</td></tr>
<tr><th colspan="3">Comments with ferrites</th></tr>
<tr><td colspan="3">With ferrites the system has behaved well with the parameters applied.</td></tr>
</table>

Ferrites are very used in the EMC field, both in immunity and emissions, as help dissipate radiofrequency. From the EMC point of view, the Ethernet cable is being divided by the ferrites, making it more immune to certain frequencies.

Without the ferrites there is a downgrade in the video signal around 728 and 773 MHz, the test criteria would be B, because the system recovers normal operation itself. But with the ferrites applied the performance of the system has been good through all the frequency, no downgrades have been observed with the electric field applied. The test is considered A criteria according to Table 11.

Using ferrites in the system is one of the improvements detailed in section 7.5.

7.2.2.2. Test according to UNECE REGULATIONS nº10 from 1 GHz to 3 GHz

EMC immunity tests performed at a frequency range from 1 GHz to 3 GHz with levels according UNECE REGULATIONS nº10.

As before, the DCS-932L system setup and conditions are the ones defined in Section 6.1.

The system is tested with an electric field of 30 V/m. In the figure below can be seen the actual in site automotive setup for the DCS-932L system in the calibration point location.

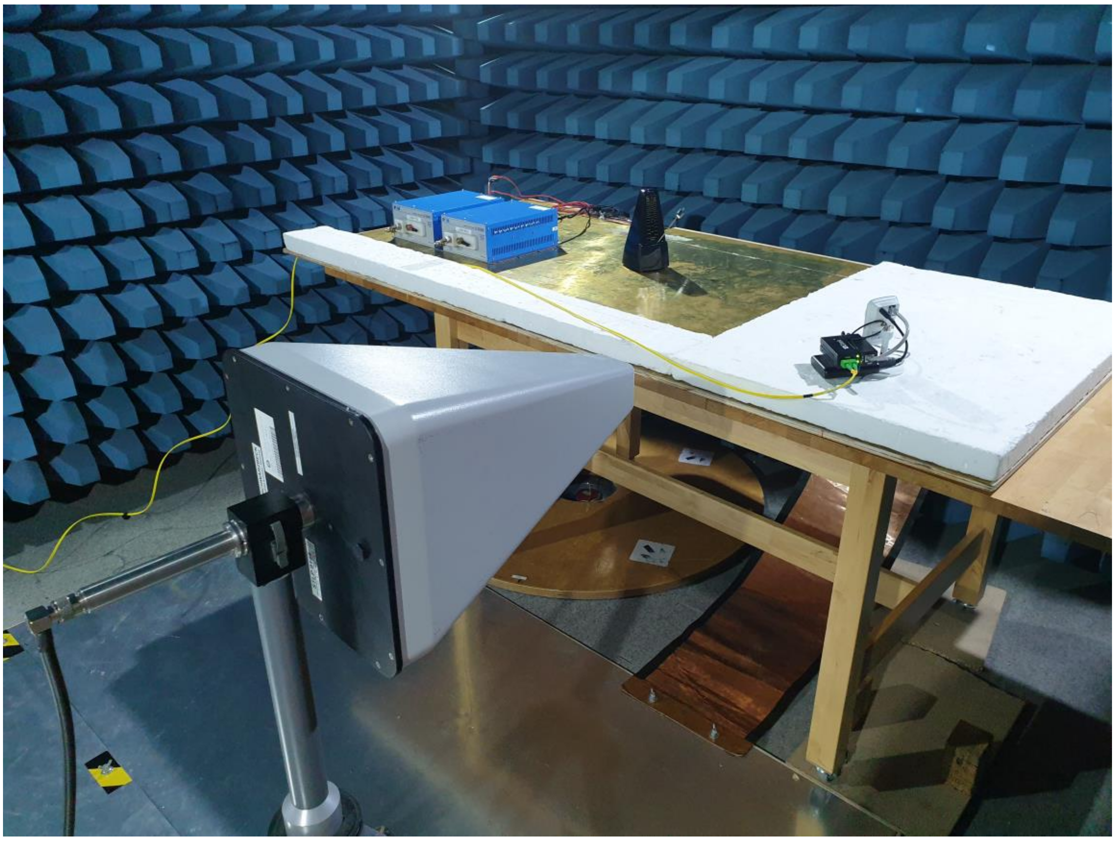

Figure 48. DCS-932L automotive setup from 1 GHz to 3 GHz (I)

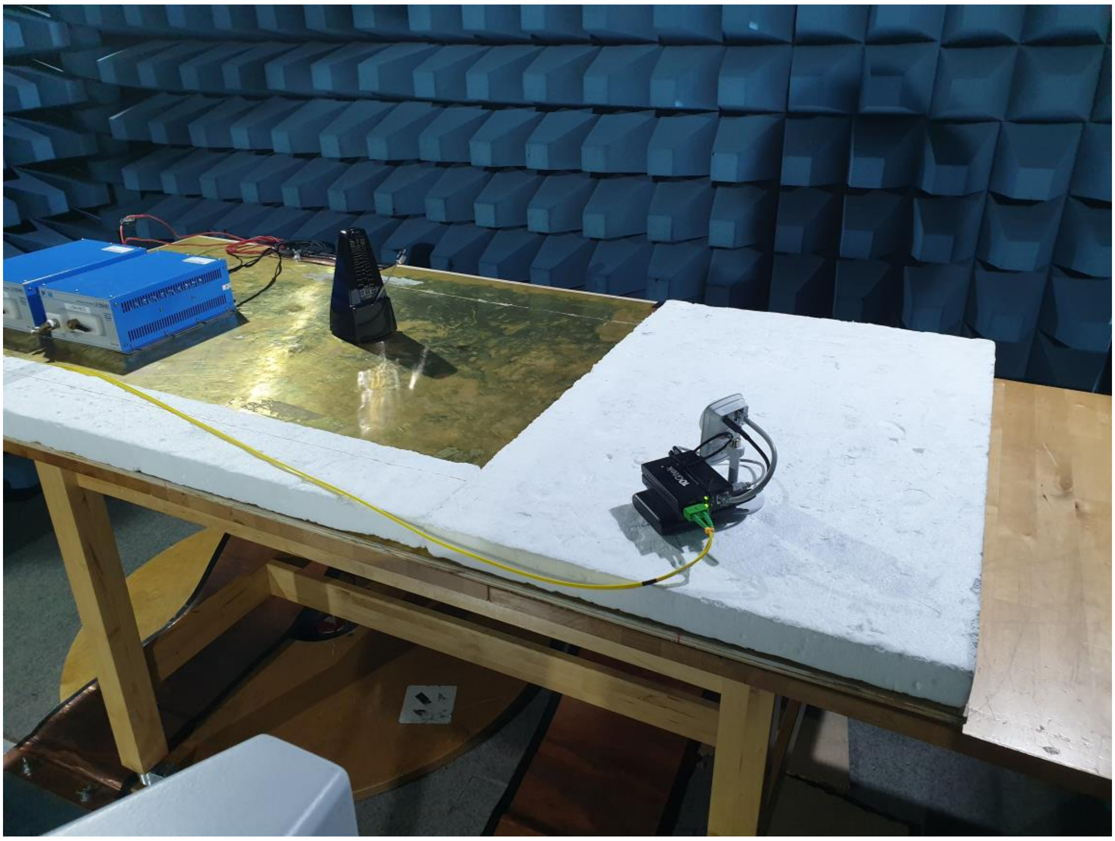

Figure 49. DCS-932L automotive setup from 1 GHz to 3 GHz (II)

The reports obtained and the pictures for the actual setup used are found below.

Table 20. DCS-932L camera report VII

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>30 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>1 GHz – 3 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration point</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test Antenna Polarization</td><td>Vertical</td><td>Drop in the Frames per Second and eventually a complete freeze of the video from 1.12 GHz to 1.18GHz. When removing the electric field the system recovers itself.</td></tr>
<tr><td>Horizontal</td><td>In UNECE REGULATIONS nº10 automotive EMC testing, horizontal polarization is not required.</td></tr>
</table>

Comments
At this higher frequencies, the ferrites in the cables no longer improve the immunity of the system due to the radiation efficiency.

With an electric field of 30 V/m the system showed a small degeneration in the performance from 1.12 GHz to 1.18 GHz, due to it recovers itself when removing the electric field the test would be considered as a B criteria according to Table 11.

7.2.2.3. Tests at higher electric field levels

In this section higher electric field values than the ones defined in UNECE REGULATIONS nº10 are applied. This higher electric filed values are usually demanded by the automotive industry to meet manufacturer requirements in order to have more guaranties when integrating automotive equipment.

The system is now tested with an electric field of 40 V/m in the frequency range of 80 MHz to 1 GHz with the ferrites applied in section 7.2.2.1 still attached to the Ethernet cable.

The setup is the same that the one defined in Figure 46 and Figure 47. The report can be found below.

Table 21. DCS-932L camera report VI.

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>40 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>80 MHz – 1 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80% (1 kHz)</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration point</td></tr>
<tr><th colspan="3">Results with ferrites</th></tr>
<tr><td rowspan="2">Test Antenna Polarization</td><td>Vertical</td><td>A downgrade in the Frames per Second of the camera has been seen around 700 MHz. When removing the electric field the video recovers normal performance.
No disconnection or any kind of reset.</td></tr>
<tr><td>Horizontal</td><td>Not performed.</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">The phenomena that originally happened at 30 V/m has been displaced to 40 V/m due to the addition of the ferrites in the Ethernet cable.</td></tr>
</table>

The system had a downgrade in the video signal only at 700 MHz, the performance for all the other frequency range has been good. The test for is considered B criteria according to Table 11, although most likely using a shorter Ethernet cable specially made for this system and using ferrites, would result in no downgrade of the video signal.

It is decided to test the system at 90 V/m in the frequency range of 80 MHz to 1 GHz, which is the maximum electric field that can be generated in the GCEM laboratory with the equipment available. In the figure below can be seen the actual in site automotive setup for the DCS-932L system.

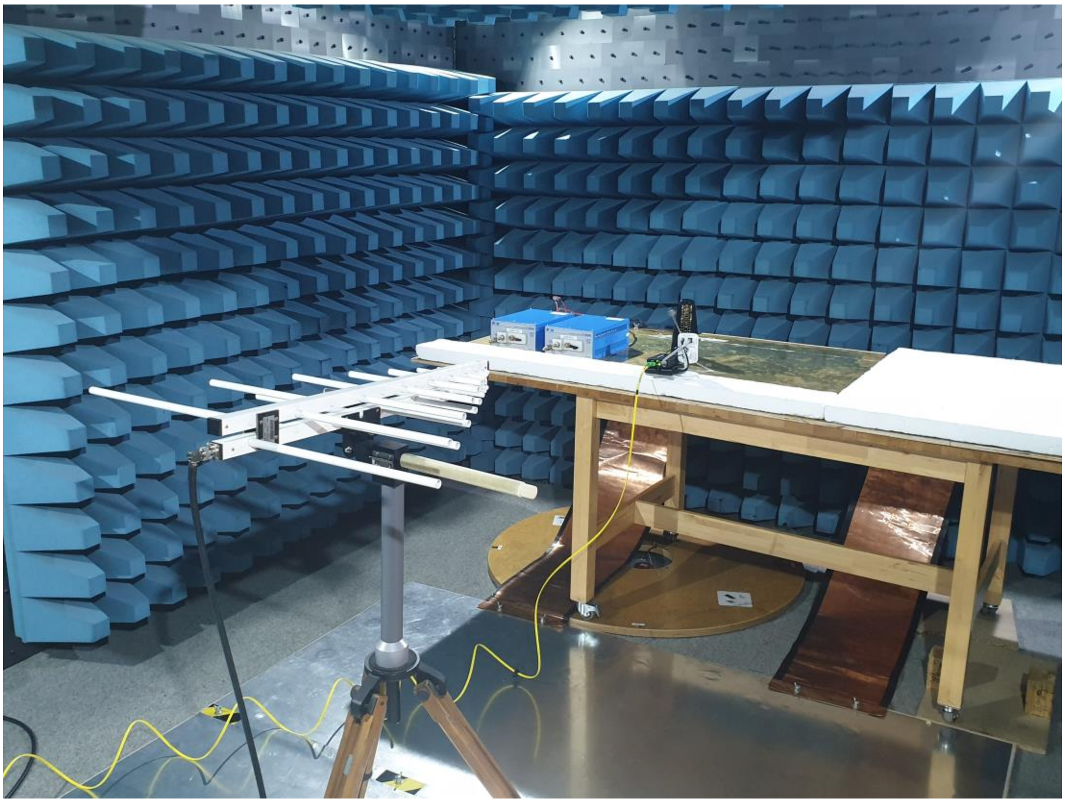

Figure 50. DCS-932L automotive setup from 80 MHz to 1 GHz for higher field levels

The report can be found below.

Table 22. DCS-932L camera report VII

Parameters	
Electric Field	90 V/m
Frequency Range	80 MHz – 1 GHz
Frequency Increment	1%
Modulation	AM 80% (1 kHz)
Dwell Time	1 s
Position	Calibration plane

<table>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test
Antenna
Polarization</td><td>Vertical</td><td>The following degradations in the frequency specified have been detected:
Drop in the Frames per Second and eventually a complete freeze of the video at 574 MHz. When removing the electric field the system recovers itself.
Slight drop in the Frames per Second at 647 MHz. When removing the electric field the system recovers itself.
Drop in the Frames per Second and eventually a complete freeze of the video at the frequencies specified below. When removing the electric field the system recovers itself.
- 673 MHz,
- 700 MHz,
- 729 MHz and
- 759 MHz
Slight drop in the Frames per Second at 805 MHz. When removing the electric field the system recovers itself.
Drop in the Frames per Second and eventually a complete freeze of the video at 821 MHz. When removing the electric field the system recovers itself.</td></tr>
<tr><td>Horizontal</td><td>Not Performed</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">Due to the big degeneration in the performance of the system, the test is not repeated with ferrites.</td></tr>
</table>

At 90 V/m the performance of the system is severely affected from 574 MHz to 821 MHz. The immunity could be improved by using specific cables designed for this setup minimizing the distance from the connections, introducing RF filters, shielding the cables, or using ferrites to dissipate radiofrequency. The test for is considered B criteria according to Table 11.

Additionally is also decided to test the system with an electric field of 40 V/m in the frequency range of 1 GHz to 3 GHz

In the figure below can be seen the automotive setup for the DCS-932L system in the calibration point location for frequencies above 1 GHz.

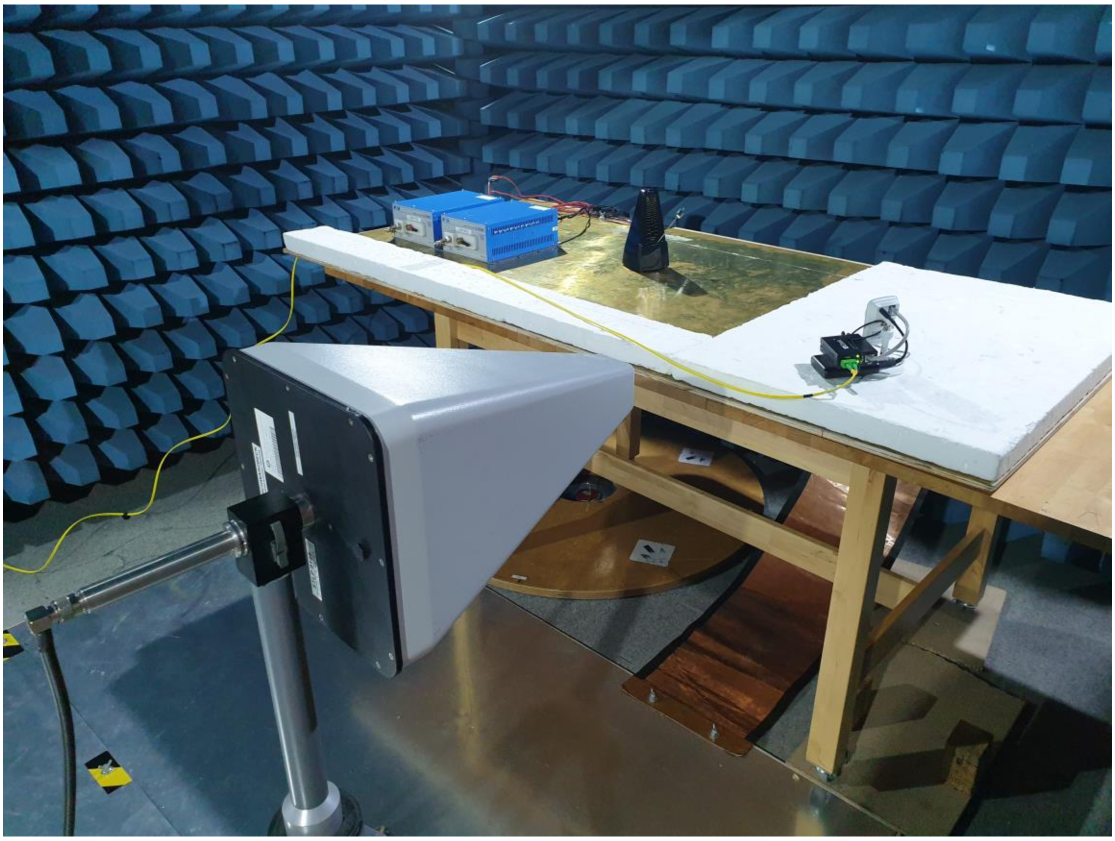

Figure 51. DCS-932L automotive setup from 1 GHz to 3 GHz (I)

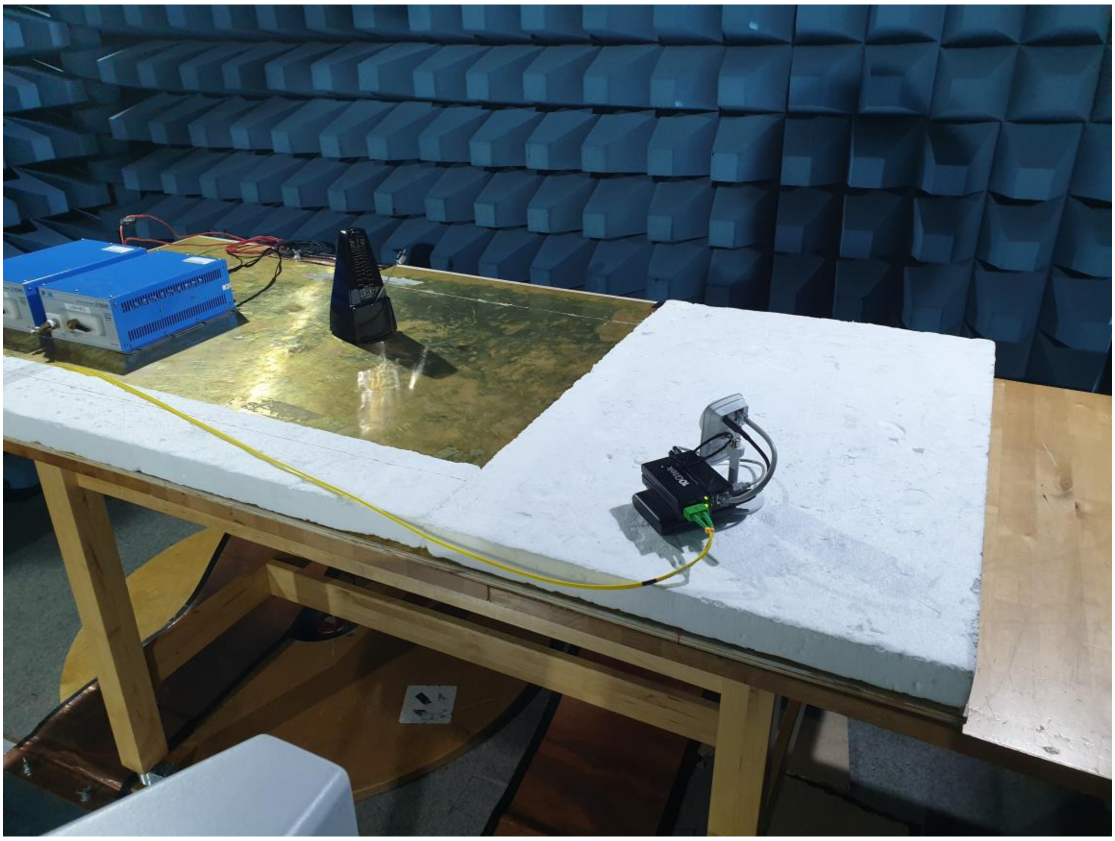

Figure 52. DCS-932L automotive setup from 1 GHz to 3 GHz (II)

The report can be found below.

Table 23. DCS-932L camera report VIII

<table>
<tr><th colspan="3">Parameters</th></tr>
<tr><td colspan="2">Electric Field</td><td>40 V/m</td></tr>
<tr><td colspan="2">Frequency Range</td><td>1 GHz – 3 GHz</td></tr>
<tr><td colspan="2">Frequency Increment</td><td>1%</td></tr>
<tr><td colspan="2">Modulation</td><td>AM 80%</td></tr>
<tr><td colspan="2">Dwell Time</td><td>1 s</td></tr>
<tr><td colspan="2">Position</td><td>Calibration point</td></tr>
<tr><th colspan="3">Results</th></tr>
<tr><td rowspan="2">Test Antenna
Polarization</td><td>Vertical</td><td>Drop in the Frames per Second and eventually a complete freeze of the video from 1.05 GHz to 1.18 GHz.
In the most part of this range when removing the electric field the system recovers itself, but at the frequency 1.12 GHz the system has not recovered itself, and a manual reset done by the user has been done. A first analysis shows that the Ethernet to optical fiber converter module was not regaining connection by itself.</td></tr>
<tr><td>Horizontal</td><td>Not performed</td></tr>
<tr><th colspan="3">Comments</th></tr>
<tr><td colspan="3">Due to the degeneration observed in the performance of the system is decided to not test the system with a bigger electrical field.</td></tr>
</table>

With an electric field of 40 V/m for frequencies above 1 GHz the system showed a significant degeneration in the performance, due to it doesn't recover itself when removing the electric field the test would be considered as a C criteria according to Table 11.

To improve the immunity in higher frequencies the system could be shielded, because at higher frequencies the signal couples at the copper tracks of the modules instead of the connections cables.

7.2.2.4. Conclusions on radiated immunity for automotive environment

With all the tests reports for the automotive obtained a review of the performance is done. A summary with the test criteria's of each test can be found in Table 24 below.

Table 24. Summary of test criteria results for automotive setup

		TEST CRITERIA				
		80 MHz – 1 GHz			1 GHz to 3 GHz A	
		30 V/m	40 V/m	90 V/m	30 V/m	40 V/m
SYSTEM	DCS-932L	A	B	B	B	C

The system has behaved quite well in the automotive environment withstanding at least 30 V/m and even more depending the circumstances, so can be used for radiated immunity according to UNECE REGULATIONS nº10 in the frequency range tested

The final specifications for the DCS-932L system obtained during the tests are:

- Radiated immunity of 30 V/m up to 1 GHz
- Usable with a downgrade of the frames per second for radiated immunity of 40 V/m up to 1 GHz
- Usable with a downgrade of the frames per second for radiated immunity of 30 V/m up to 3 GHz
- Battery lifetime of 8 hours

To improve the system immunity in the frequency range from 30 MHz to 1 GHz, the connections cables for the system must be done shorter, by specially using connection cables designed for minimizing the length. Also apply ferrites and some filtering stage.

To improve the system immunity in the frequency range from 1 GHz to 3 GHz, the system could be shielded, because at this higher frequencies the copper tracks of printed circuit board are the main path for coupling disturbances.

7.3. Emission tests results

Although it is not part of the main scope of the project, it is decided to do EMC radiated emission test to all the systems, to see the behaviour of the equipment and check if it would be feasible to use one of the systems for monitoring radiated emissions tests.

In EMC emissions tests, the EUT must be tested in the worst operating mode for emissions of the equipment, as initially this mode is not known, all the operating modes are tested. Monitoring the equipment can be useful if the equipment has some indicator such as LEGs or a display, and the operating mode of the device is indicated, in that case could be useful to assure that the equipment is in the corresponding mode.

Radiated emissions in the domestic environment.0 will be measured for the four systems proposed in section 6 while in Operating Mode 1 (see Table 37), because that would be the normal operation mode of the systems if are used in emission tests.

This will allow the comparison with the immunity results and verify if any system produces low levels of emissions and can be usable during radiated emissions tests.

The setup used consists in an antenna placed at 3 meters from the equipment, see a schematic setup in Figure 53 below.

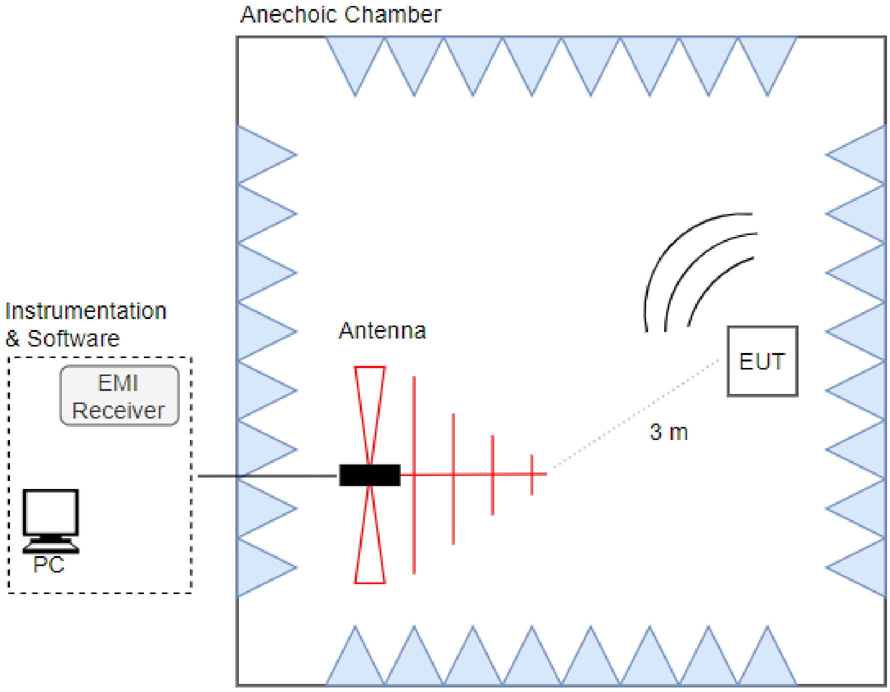

Figure 53. Schematic setup for radiated emissions tests

All the emission data results are read with a peak detector, one of the standardized detectors defined in the standards, the limits shown in the figures are for Class B products, which means that are intended for residential use, Class B limits tend to be stricter than Class A (industrial).

7.3.1. Emissions from 30MHz to 1GHz

The first section of EMC emissions test is performed to all the systems to see which kind of emissions levels have with the same setup conditions. All the measurements performed are done with a peak detector, although limits are for Quasi-Peak. The first frequency sweep will be done for a range from 30 MHz to 1 GHz with the domestic/industrial and railway setup according EN 55016-2-3 and applying the residential limits according to EN 61000-6-3..

7.3.1.1. Ambient noise measurement

An ambient noise of the anechoic chamber is made without the systems under evaluation turned on inside, to know which levels of ambient noise emissions are present during the test.

The environmental measurements have to be preferably below 20 dB, but mandatory 6 dB lower than the limits established in EN 61000-6-3.

The environmental measurement with horizontal polarization of the anechoic chamber can be seen in the figure below in which the video monitoring system developed are not used.

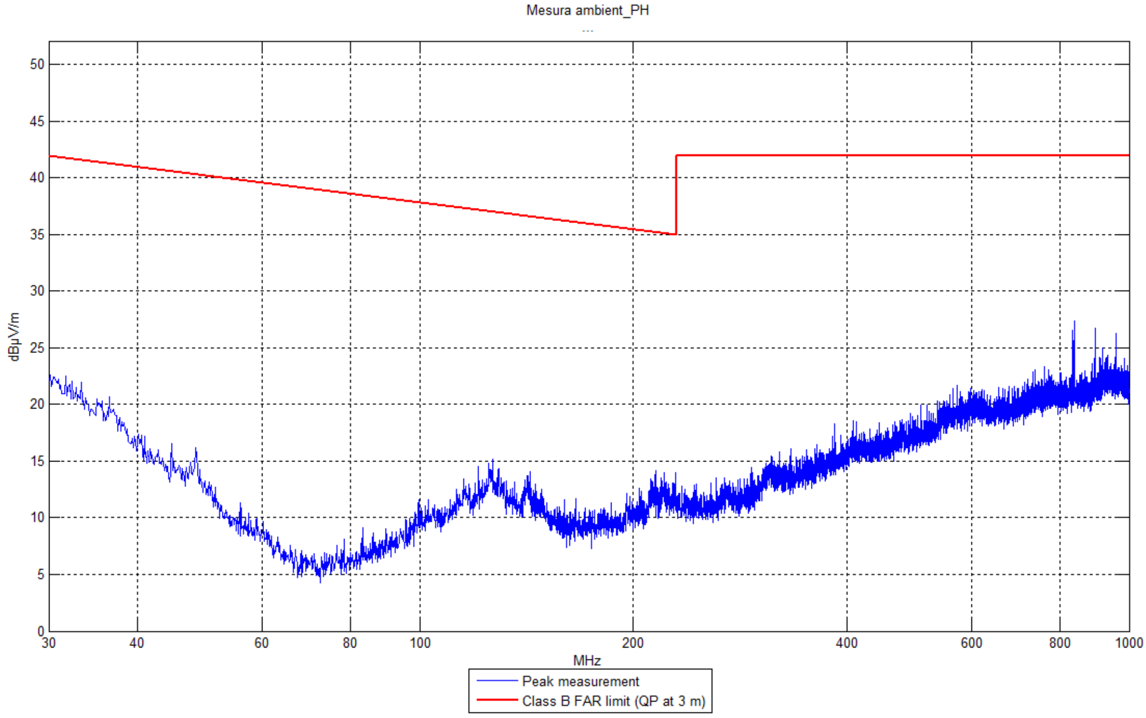

Figure 54. Ambient noise 30MHz to 1GHz HP

The ambient noise measurement with vertical polarization of the anechoic chamber can be seen in the figure below.

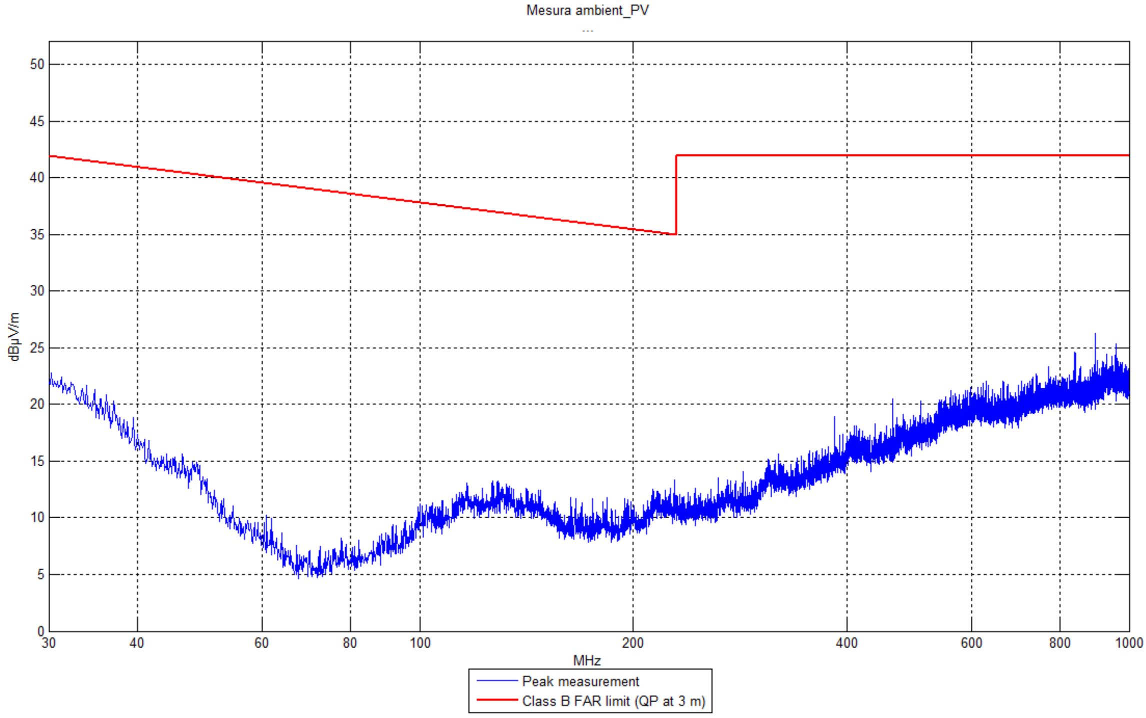

Figure 55. Ambient noise 30MHz to 1GHz VP

As can be seen the levels of EMI are very low and below the specified range and security margin, so the tests can start.

7.3.1.2. DCS-932L

While in Operating Mode 1 and with the conditions and setup defined in Section 6.1, the emissions generated by the system DCS-932L are obtained.

The DCS-932L system measurement with horizontal polarization can be seen in the figure below.

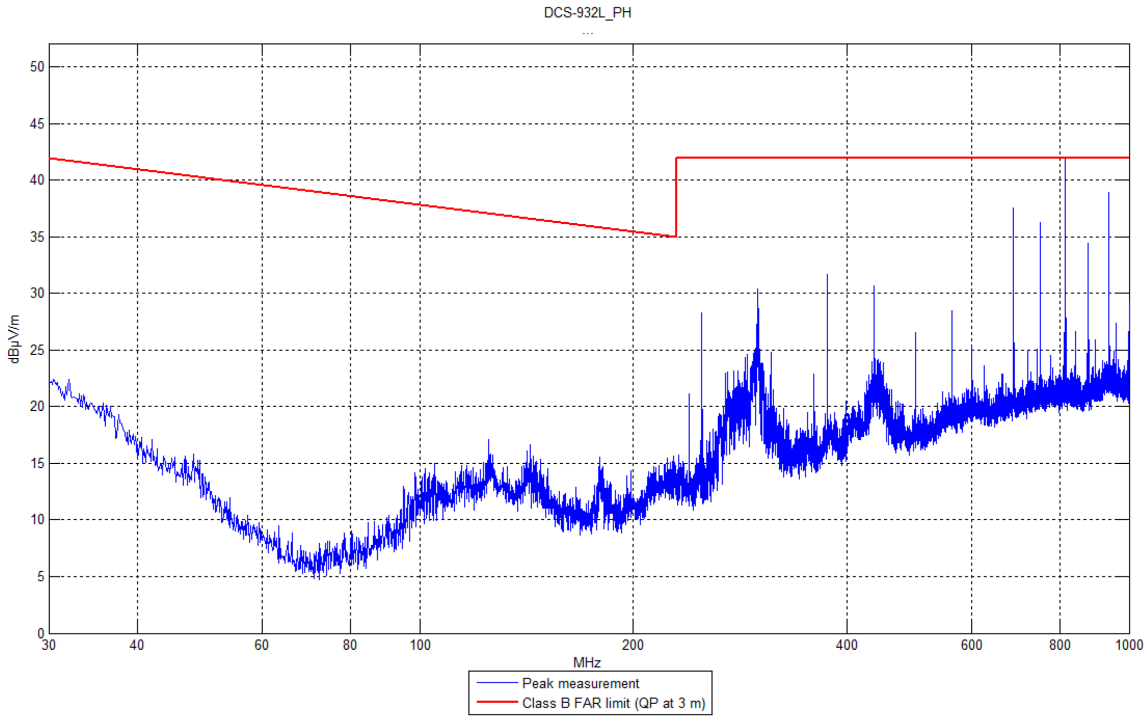

Figure 56. DCS-932L emissions Horizontal Pol.

As can be seen in the lower frequencies from 30 MHz to around 200 MHz the measurement as almost the same to the ambient noise one, this is mainly due to that there are no long cables that can radiate in those frequencies. As can be seen in the Appendix I, there is an inversely proportional relation between longitude and frequency, so long cables mean radiations in low frequencies while short cables mean radiation in high frequencies.

In higher frequencies, from 200 MHz to 1 GHz there is a significant difference from the environmental measurement, this is mainly that at this range, the cables used for the connections between the different modules start to radiate. Apart from the fact that the devices themselves or the traces of the printed circuit boards can also generate radiation at higher frequencies.

The Ethernet cable used for this setup according to Table 6 has a length of 19.5 cm, the wavelength at which this length behaves as a perfect antenna is:

$$\lambda = \lambda_{PA} \cdot 4 = 19.5 \cdot 10^{-2} \cdot 4 = 0.78\, m \qquad [13]$$

$$C \approx 3 \cdot 10^{8}\, {}^{m}/_{s} \qquad [14]$$

$$F_{PA} = \frac{C}{\lambda} = \frac{3 \cdot 10^{8}}{0.78} \approx 384\, MHz \qquad [15]$$

As can be seen in equation [13] the Ethernet cable behaves as a perfect antenna around 384 MHz, and in the Figure 56 there is a wide EMI reading near that frequency.

To solve this shorter connection cables must be used for the connections. As has been done in radiated immunity, adding ferrites also improves the performance in emissions.

By adding the same ferrites than in immunity (Wurth Electronics model 742715W3) to avoid cable radiation, the DCS-932L system measurement with horizontal polarization and ferrites can be seen in the figure below.

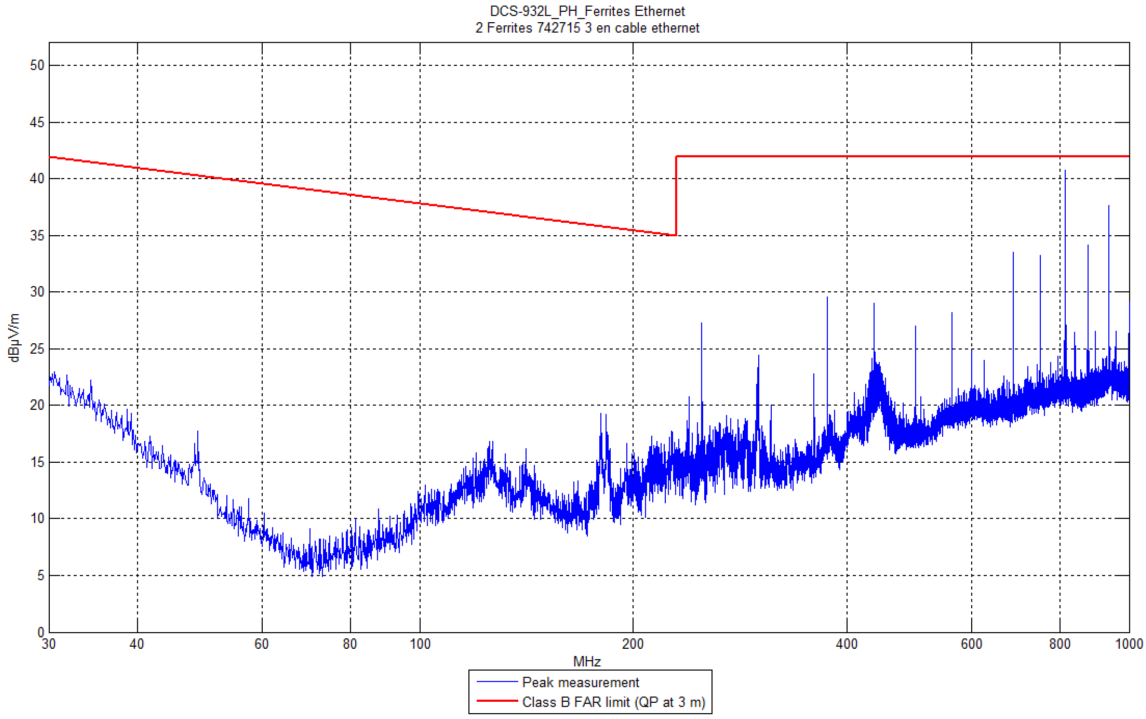

Figure 57. DCS-932L emissions Horizontal Pol. with ferrites

As can be seen in the figure below, by adding ferrites to the Ethernet cable now there is much less radiation around the 350 MHz area. Is worth noticing than in immunity a degradation of the video signal occurred near 700 MHz, by adding the ferrites the degradation did not occurred until the electric field has increased, This makes sense because as can be seen the peak around 700 MHz has been reduced by the addition of the ferrites.

The next step is the DCS-932L system measurement with vertical polarization which can be seen in the figure below.

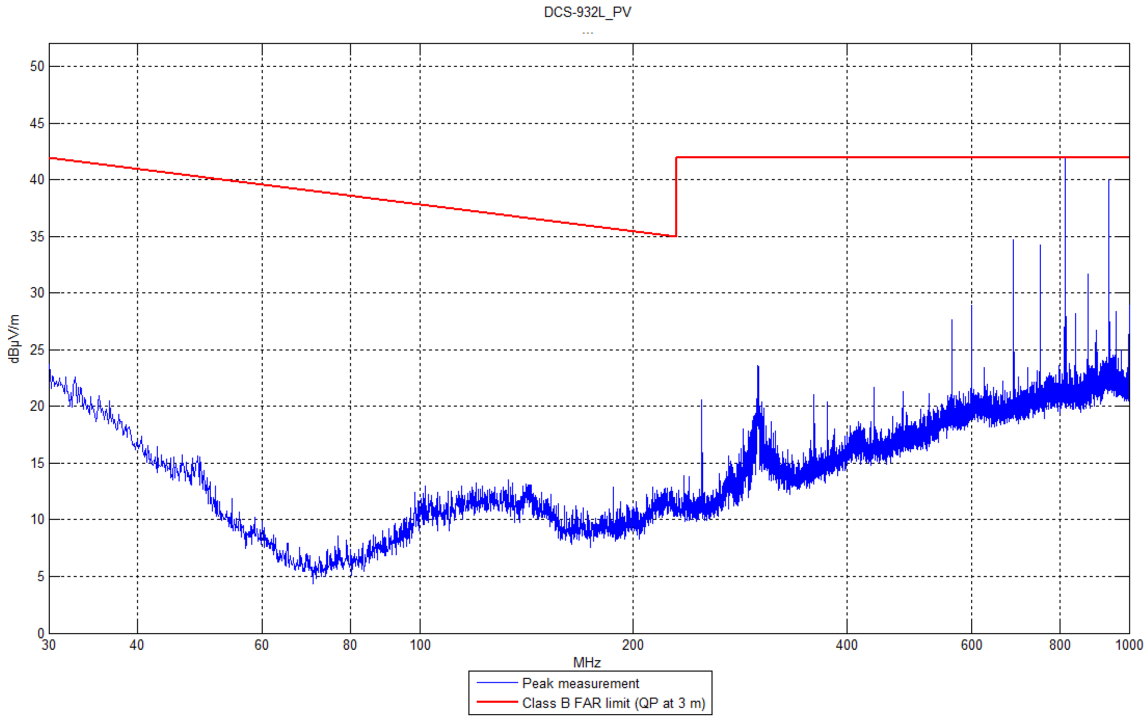

Figure 58. DCS-932L emissions Vertical Pol.

In vertical polarization there is a cleaner frequency spectrum, but there are still some large peaks in the higher frequencies.

As a conclusion, an EMC equipment emitting this kind of EMI can’t be placed inside the anechoic camera when doing EMC emissions tests, the reason is that there are large peaks the may distort the real equipment under test.

A valid option would be use the DCS-932L system for low frequencies EMC emission tests up to 200 MHz, as can be seen the measured levels are so close to ambient noise case.

7.3.1.3. SP020

While Operation Mode 1, with the conditions and setup defined in Section 6.2, the emissions coming from the system SP020 are read.

The SP020 system measurement with horizontal polarization can be seen in the figure below.

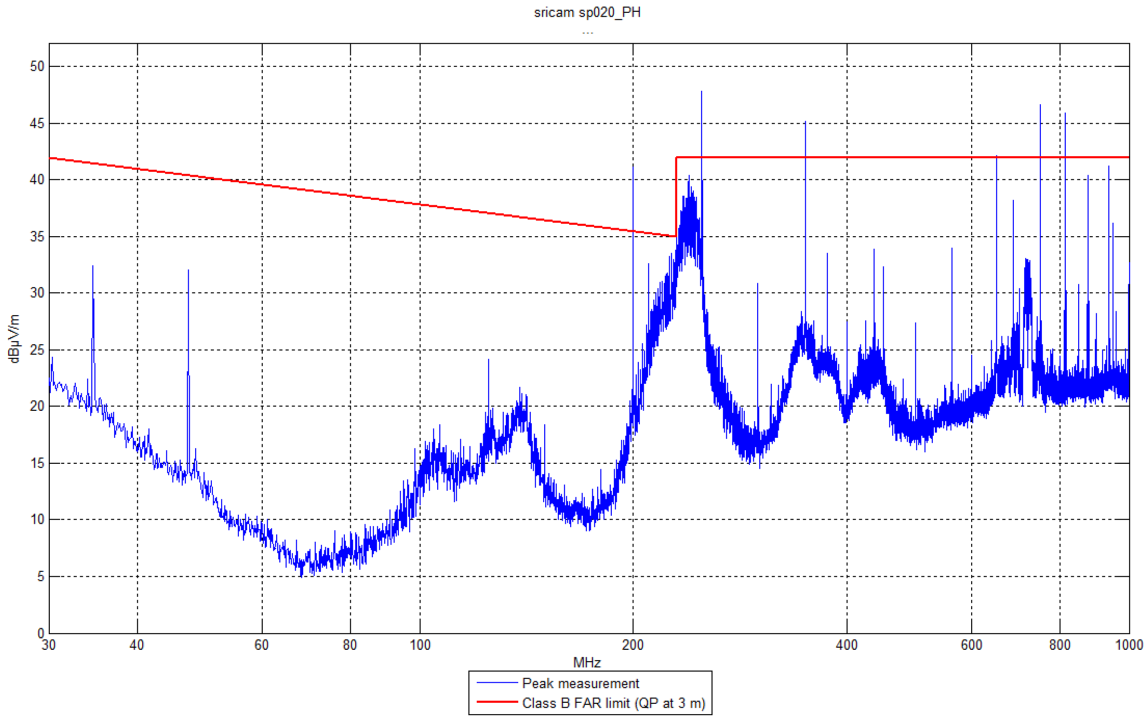

Figure 59. SP020 emissions Horizontal Pol.

In this case the measurement is quite worse than the last time, even at low frequencies there are narrow peaks, and it gets worse higher in frequency with a lot of EMI during all the frequency range.

The SP020 system measurement with vertical polarization can be seen in the figure below.

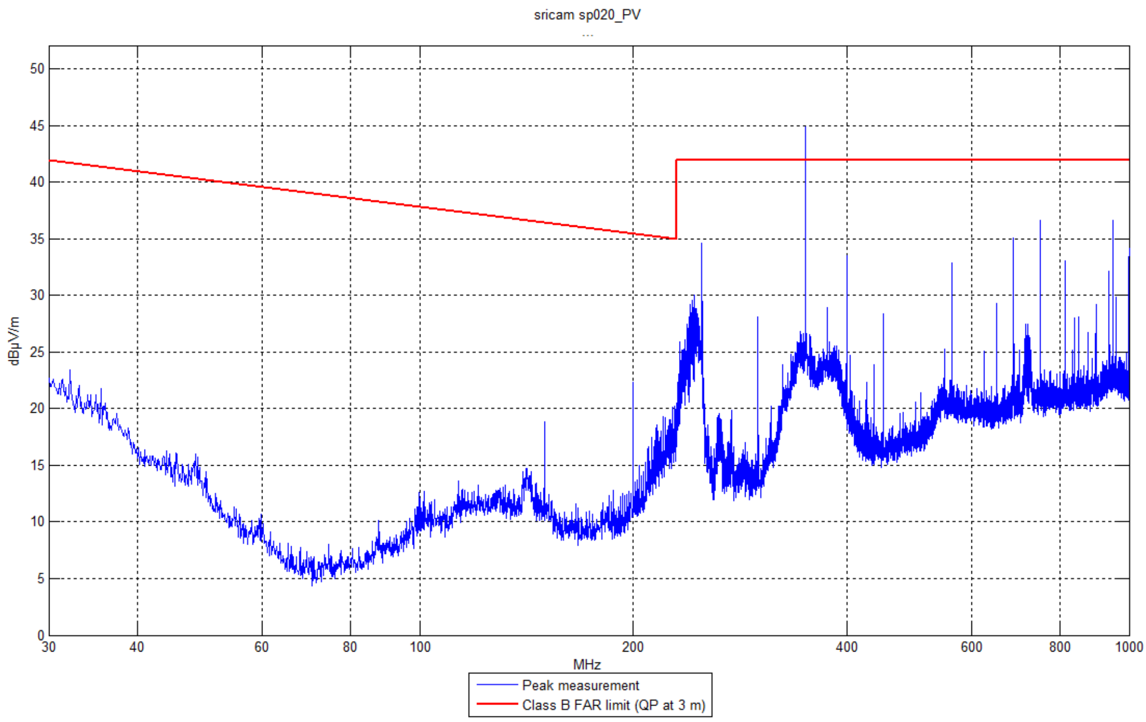

Figure 60. SP020 emissions Vertical Pol.

With vertical polarization the EMI are smaller in lower frequencies but in higher frequencies although better than in horizontal polarization is quite bad when comparing with the DCS-932L system.

A first conclusion is that meanwhile D-Link had the DoC for the camera available where it declared conformity with the RED, as can be seen in Table 32, on Sricam this information was not available.

As a conclusion, even more than for the DCS-932L system, an EMC equipment emitting this kind of EMI can't be placed inside the anechoic camera when doing EMC emissions tests whatever the frequency of interest.

7.3.1.4. Pi3B

While Operation Mode 1, with the conditions and setup defined in section 6.3, the emissions coming from the system Pi3B are read.

The Pi3B system measurement with horizontal polarization can be seen in the figure below.

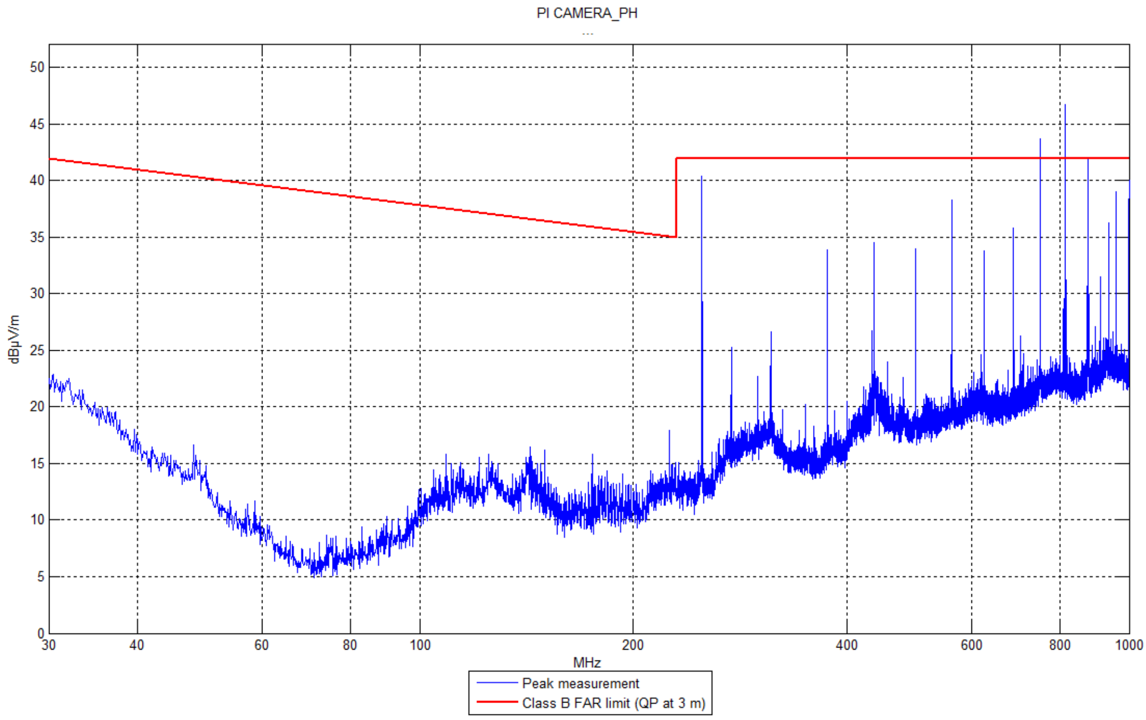

Figure 61. RbPi 3B emissions Horizontal Pol.

The behaviour is very much the same than for the DCS-932L system, clear in low frequencies but a lot of EMI in higher frequencies. This time there are peaks over Class B FAR limit.

The Pi3B system measurement with vertical polarization can be seen in the figure below.

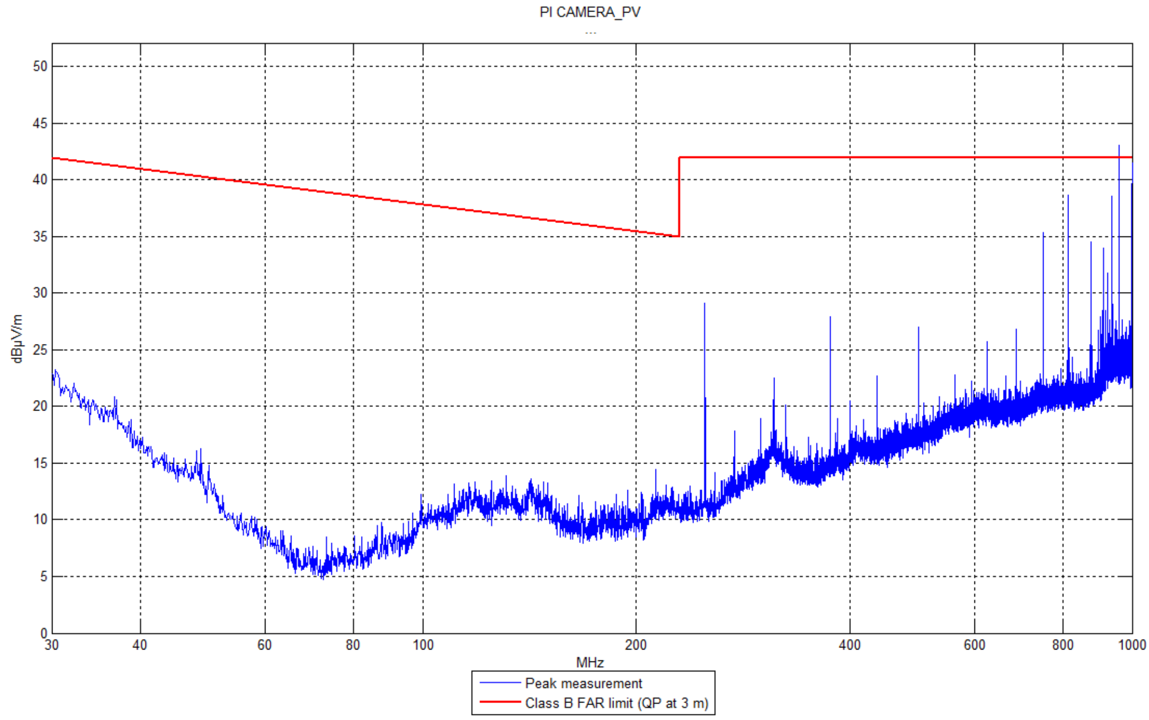

Figure 62. RbPi 3B emissions Vertical Pol.

Again similar results than for the DCS-932L, lower frequencies almost the same as the environmental, and some peaks in the higher frequencies.

The conclusion is the same than for the last two systems a system with this levels can't be present during the testing of other equipment.

7.3.1.5. PiZero

While Operation Mode 1, with the conditions and setup defined section 6.4, the emissions coming from the system PiZero are read.

The PiZero system measurement with horizontal polarization can be seen in the figure below.

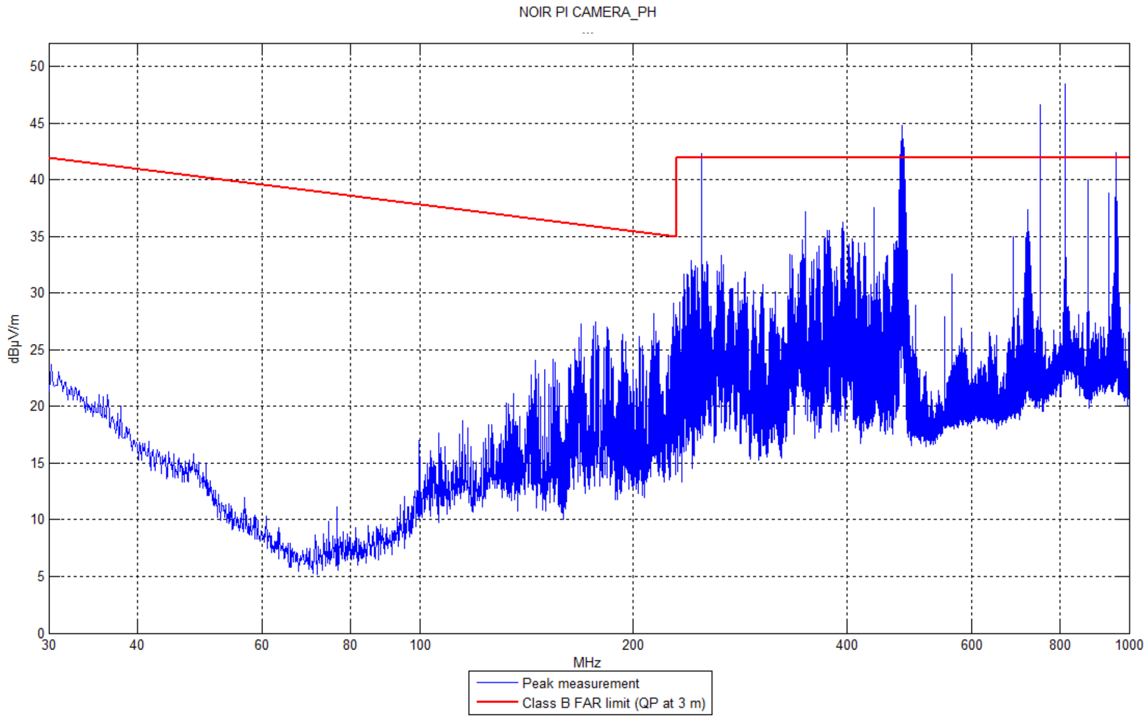

Figure 63. RbPi Zero emissions Horizontal Pol.

By far the worst measurement so far, with a lot of EMI even at 100 MHz. This system has an additional piece which is the Ethernet to Micro USB adapter, and maybe due to the small size some filtering stages are omitted resulting in a worse emission reading.

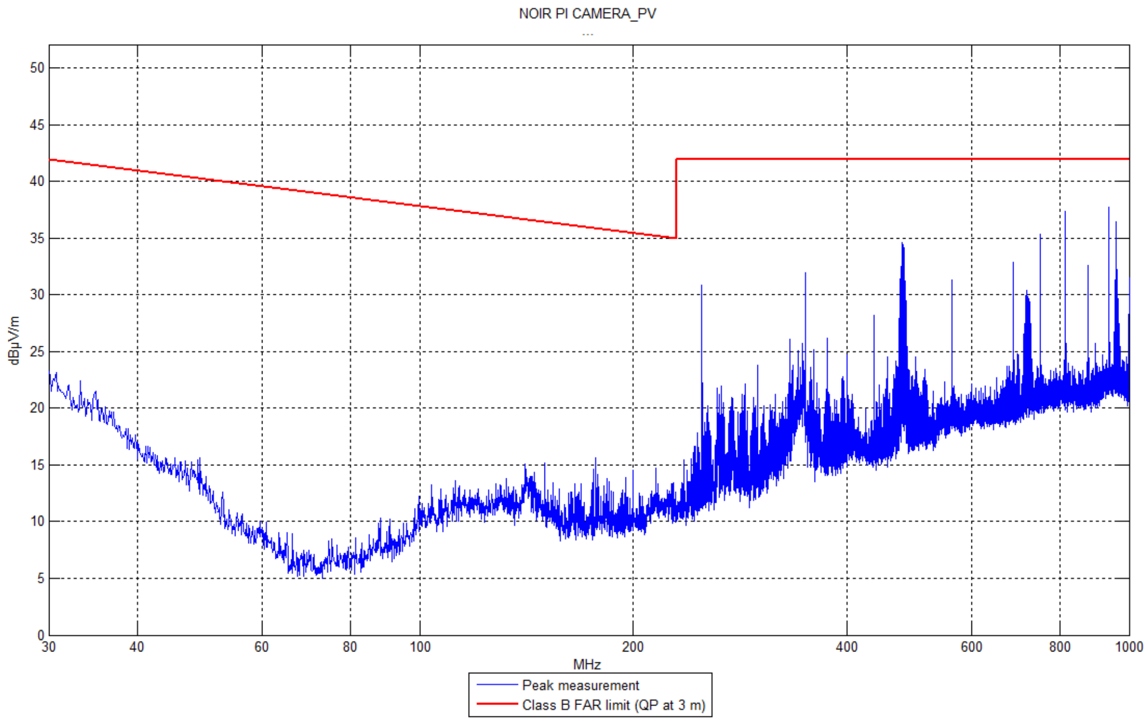

Figure 64. RbPi Zero emissions Vertical Pol.

Similar behaviour than seen previously, with consistent noise in higher frequencies. The conclusion is the same than for all the other systems, a system with this levels can't be present during the testing of other equipment.

7.3.1.6. Conclusions on radiated immunity tests results from 30 MHz to 1 GHz

With the radiated emissions obtained for a range from 30 MHz to 1 GHz for all the systems proposed, the system with best levels of radiated emissions was, as for the case of radiated immunity, the DCS-932L. This makes sense because the mechanisms involved in the emissions and immunity are the same.

In any case though, the emissions levels are very high and could not be used during a radiated emissions test because are very close to the limits. Only could be used if the frequency range would be up to 200 MHz.

The final specifications for the DCS-932L system obtained during the tests are:

- Usable in radiated emissions tests up to 200 MHz

7.3.2. Emissions from 1GHz to 3GHz

In this section high frequency EMC emissions tests are performed to the DCS-932L system as has proven to be the best system both in emissions and immunity, the frequency sweep will be done for a range from 1 GHz to 3 GHz with the domestic/industrial and railway setup. The measurements are done with a peak and average detectors, the limits are also for this two detectors according to EN 61000-6-3.

The setup is the same than the one defined in Figure 53, but with a high frequency antenna. For this high frequency range the only polarization will be horizontal to have an idea of the behaviour of the system.

7.3.2.1. Ambient noise measurement (HF)

As before, the first step consists in an environmental measurement to detect the signals present in the anechoic chamber.

The ambient noise measurement with horizontal polarization of the anechoic chamber at a frequency range between 1GHz and 3 GHz can be seen in the figure below

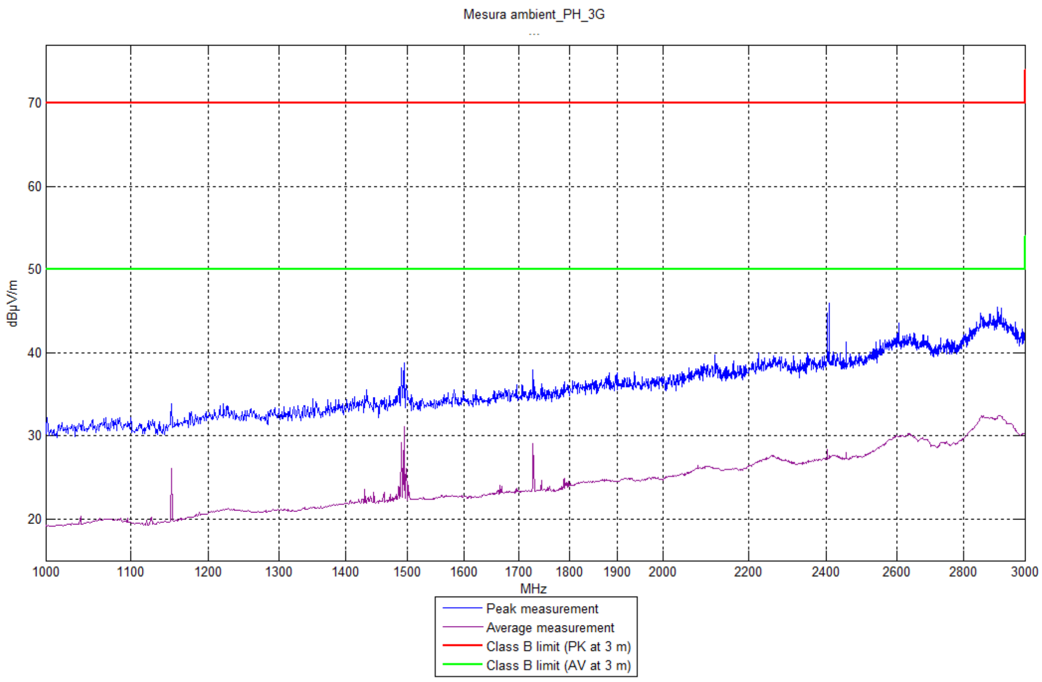

Figure 65. Ambient noise 1GHz to 3GHz Horizontal Pol

This time there are some signals with a small amplitude that are coupling to the equipment of the laboratory. As are very below the respective limits, this signals are considered as part of the ambient noise.

7.3.2.2. DCS-932L

As in the low frequency emission test, while in Operating Mode 1 and with the conditions and setup defined in Section 6.1, the emissions generated by the system DCS-932L are read.

The DCS-932L system high frequency measurement with horizontal polarization can be seen in the figure below.

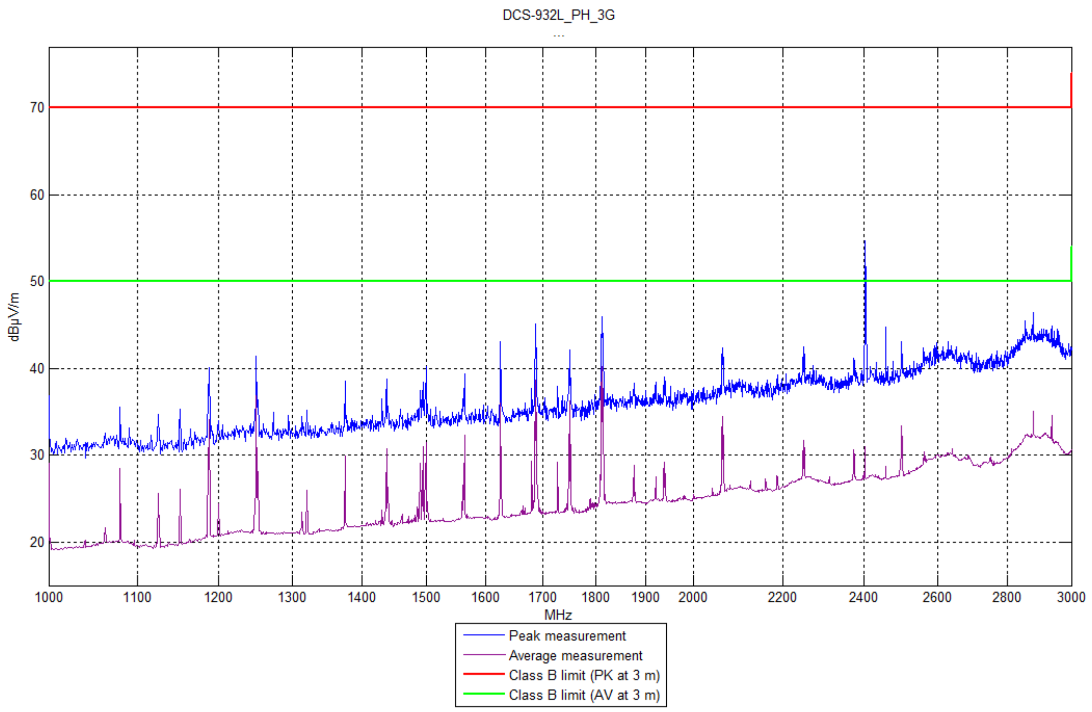

Figure 66. DCS-932L emissions Horizontal Pol.

Some narrow peaks can be seen through all the frequency range, but the levels are 15-20 dB below the Peak limit and only 10-15 dB below Average limit.

It is decided to put a two ferrites 742715 3 in the Ethernet cable to avoid cable radiation and see if the system improves the performance. The DCS-932L system high frequency measurement with horizontal polarization and ferrites can be seen in the figure below.

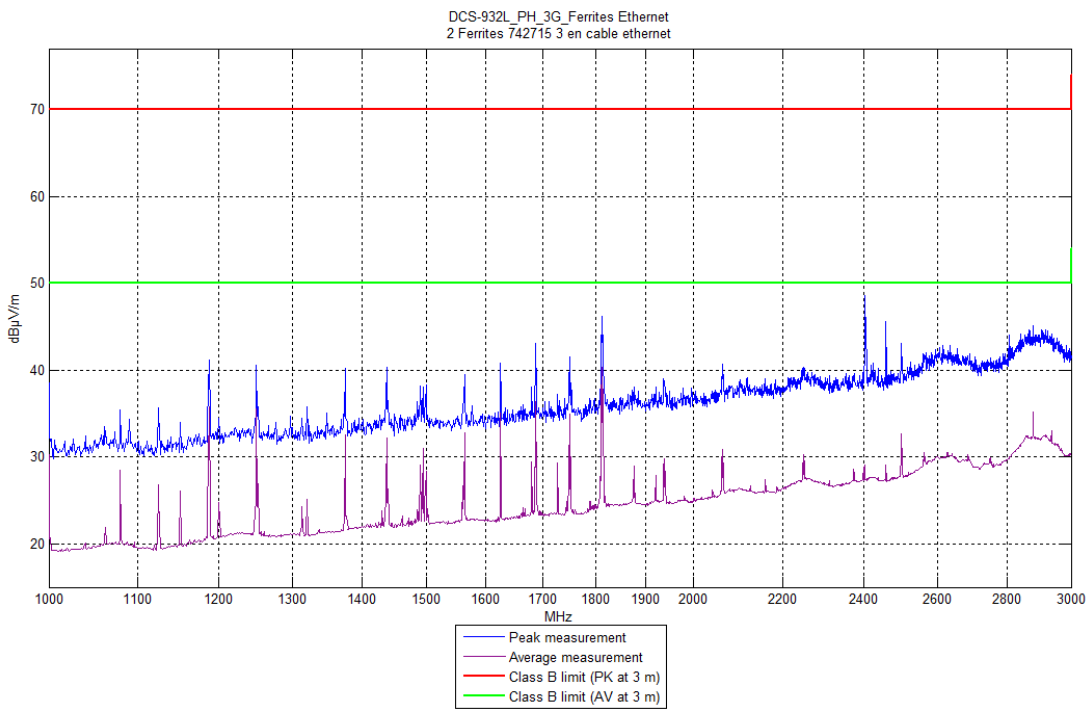

Figure 67. DCS-932L emissions Horizontal Pol. with ferrites

Unlike the last time, now the ferrites almost doesn't make any improvement, this is mainly that at this higher frequencies the source of radiation is not the connection cables between the modules, but the copper tracks of the PCBs inside the modules.

7.3.2.3. Conclusion on radiated immunity tests results from 1 GHz to 3 GHz

With the radiated emissions obtained for a range from 1 GHz to 3 GHz for the system, can be seen that although the emission are quite below the limits specified and it would be acceptable according environmental levels according the standards, is not very neat to add this noise to another EUT emission test, due to the fact that there are some high narrow bands during all the frequency range. In any case, the equipment would be usable if needed.

The final specifications for the DCS-932L system obtained during the tests are:

- Usable with restrictions in radiated emissions tests from 1 GHz to 3 GHz

7.4. Final specifications and discussion of the results

After finishing both radiated immunity and emissions, it is clear that system with better performance has been the DCS-932L, and is the one that will be provided to the GCEM group.

The final review of the system with the specifications obtained can be found below:

Table 25. Final specifications

Data transmission	Fiber Optics
Power supply	Battery. Lifetime of 8 hours.
Features	Video and Audio monitoring
	Zoom
	Small size
	Low cost
	Compatible with video recognition software*
Radiated immunity	Immunity against electric field of 30 V/m up to 1 GHz
	Usable with a downgrade of the frames per second for radiated immunity of 40 V/m up to 1 GHz
	Usable with a downgrade of the frames per second for radiated immunity of 30 V/m up to 3 GHz
Radiated emissions	Usable in radiated emissions tests up to 200 MHz
	Usable with restrictions in radiated emissions tests from 1 GHz to 3 GHz

* The system has proven compatible with the video recognition software currently being developed by the GCEM group

All the main system requirements are fulfilled except the radiated immunity of 100 V/m. With the current state of the system, the validation has demonstrated that the system would fulfill the requirements specified for radiated immunity in standards EN 61000-6-1, EN 61000-6-2 and EN 50121-3-2 and UNECE REGULATIONS nº 10, in the frequency range applied.

As a future modifications that would improve the system performance the following modifications are proposed.

- Minimize length of the connection cables
- Add Ferrites
- Mid-board for interconnection of the modules with filtering steps
- Shielding for the system

Minimize the length of the connection cables would allow to widely improve the immunity of the system in the range from 80 MHz to 1 GHz, as in this frequency range the length of the cables has a major impact.

Adding ferrites would improve the overall immunity and emissions of the system, as has been already proven.

By the use of a mid-board with a filtering steps (which also minimizes the length of the connection cables), the performance will greatly improve in the range from 80 MHz to 1 GHz and even at higher frequencies.

Shielding the system will be the measurement most effective for higher frequencies, because at that range is the only modification that can be done to improve the immunity.

7.5. Improvements applied and future upgrades

Balancing the available options, it is decided to apply the following modifications to the system.

- Minimize length of the connection cables
- Add Ferrites to the Ethernet cable

With this modifications the system will be very much improved, special in the range from 80 MHz to 1 GHz. There has not been available time to further test the system with the new modifications, but will be left to be tested during the normal work of the GCEM group.

The other two modifications are left as future improvements of the system, as the current state of the system is good enough to be used during the most part of EMC immunity tests performed in the GCEM group.

- Mid-board for interconnection of the modules with filtering steps
- Shielding for the system

A possible mid board schematic is proposed for the two power supply connections in the figure below.

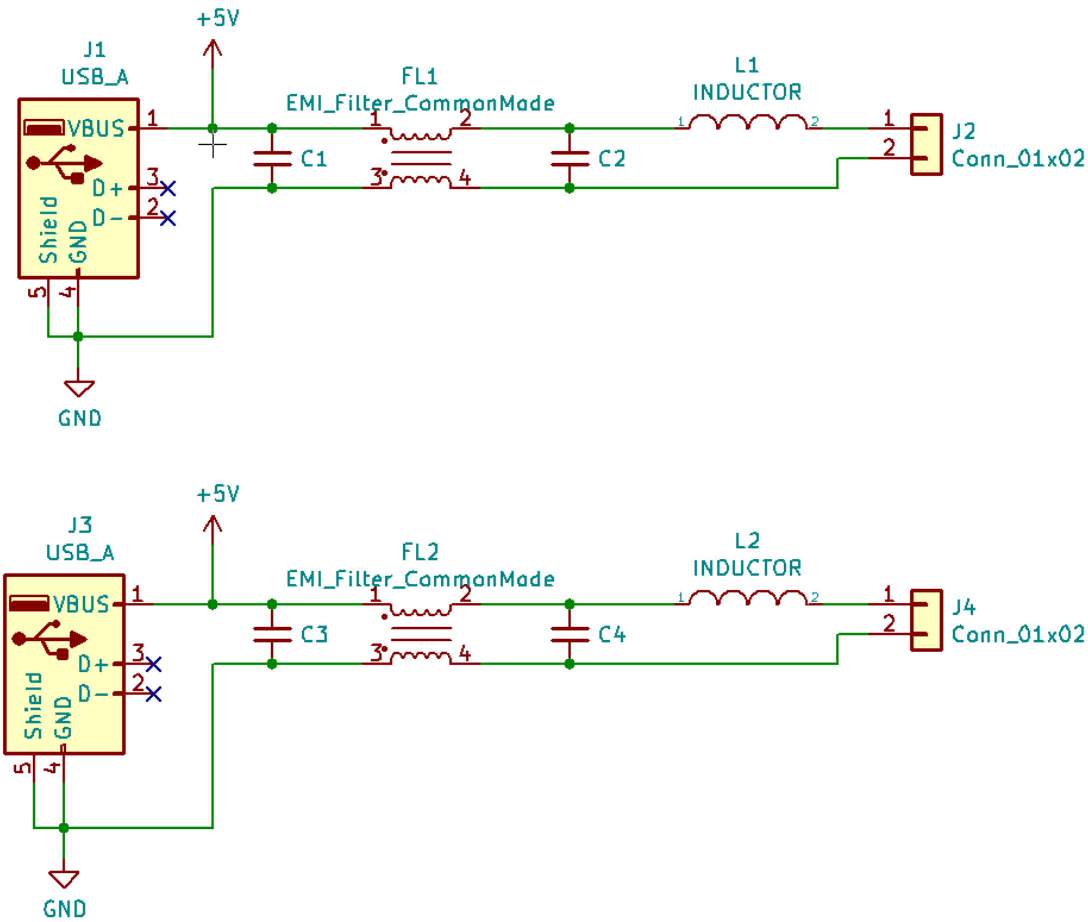

Figure 68. Mid board schematic

Shielding the system is left as an improvement for two reasons, there has not been time for the physical implementation of the shielding, and the current performance of the system has proven to be good enough during a wide range of low to medium high frequencies, and would be usable in almost all the setups that the GCEM group currently is working with. In addition the actual equipment of the laboratory, is especially good at higher frequencies because despite the fact that has long cables, in higher frequencies, being shielded behaves very well for immunity testing.. This makes both systems complementary.

8. Budget

In this section the costs for the project are detailed and a short financial analysis is performed to assess the economic viability of the project.

8.1. Project Costs

The cost for the project taking into account all the systems that have been tested can be seen in the Table 26 below.

Table 26. Cost for the systems under test

Item	Product name	Quantity [u]	Unitary Price [€/u]	Price [€]
	Equipment			
1	D-Link DCS-932L	1	41,31	41,31
2	Sricam SP020	1	29,99	29,99
3	Raspberry Pi 3B	1	36	36
4	Camera Module V2	1	32,64	32,64
5	Raspberry Pi Zero W	1	25,9	25,9
6	Pi Noir Camera V2	1	29,99	29,99
7	Plugable USB 2.0 OTG Micro-USB to 10/100 Network Adapter	1	13,95	13,95
8	10Gtek A7S2 is a Gigabit Ethernet Media Converter [Pack x2]	1	66,99	66,99
9	Anker PowerCore 13000	1	26,99	26,99
10	Ferrites 742715 3	2	1	2
	Subtotal			303,76
	Connectors			
11	USB power cable	2	5,34	10,68
12	USB to Micro USB cable	1	5,34	5,34
13	Power Jack connector	2	1,1	2,2
14	Ethernet cable	1	4	4
15	10 m Optical Fibber SC to SC cable	1	19,99	19,99
16	Pi camera flex cable	1	7,09	7,09
	Subtotal			49,3
	Total			**353,06 €**

It is also attached in Table 27 below the individual cost for the system chosen to provide to the GCEM group.

Table 27. Cost for the monitoring system chosen

Item	Product name	Quantity [u]	Unitary Price [€/u]	Price [€]
	Equipment			
1	D-Link DCS-932L	1	41,31	41,31
2	10Gtek A7S2 is a Gigabit Ethernet Media Converter [Pack x2]	1	66,99	66,99
3	Anker PowerCore 13000	1	26,99	26,99
	Subtotal			135,29
	Connectors			
4	USB power cable	2	5,34	10,68
5	Power Jack connector	2	1,1	2,2
6	Ethernet cable	1	4	4
7	10 m Optical Fibber SC to SC cable	1	19,99	19,99
	Subtotal			36,87
	Total			**172,16 €**

8.2. Financial viability analysis

This analysis is performed to assess the economic viability of the project. After sections 4 and 5, when the approach to the project was clear, the budget detailed in Table 26 was presented to the GCEM laboratory in order to obtain the equipment needed for the video and audio monitoring system demanded by the group.

Some of the equipment detailed in Table 26 was already available for the project author or the GCEM group, so for the evaluation of the EMC performance of such equipment was not needed to be bought, in case to be found that this equipment was the better option available, would have been bought for the final system provided to the GCEM laboratory.

The budget was appraised, by the approval of the budget four functional monitoring system with fiber optics communications would be obtained, only pending for the EMC tests validation.

Besides the monitoring systems, other benefits such as an Ethernet to optical fiber converter, which could be used to provide other EUTs with Ethernet ports internet connection through optical fiber.

The only drawback would be that without an EMC validation the immunity against electric field of the systems in not known, except the information provided by the EMC legislation of the products that offers very few guaranties beyond domestic/industrial levels.

Taking into account the relatively low cost of the equipment's and that some of it was already available it was decided to proceed with the purchase. The EMC performance of the equipment's had to be tested, but could be improved with optional upgrades if needed, once the specifications of the systems were clear.

9. Conclusions and future development

This project aimed to develop a system for the GCEM group that met the requirements and specifications proposed in section 1.2, with video and audio monitoring, to be of use during the daily work of the laboratory. The system shall work with, or in substitution of the current monitoring equipment at the GCEM laboratory.

Possible alternatives such as specialized EMC equipment and a modular domestic/industrial system were reviewed. By analysing both options it was concluded that specialized EMC market prices are very high because all clients tend to be laboratories, although the specifications are good and well known for such equipment, it was concluded that the construction of a system based on a modular design with domestic/industrial equipment with the option to improve the EMC performance by using fiber optics and short cables, was the most appealing choice.

Choose the right approach to the project was by far one of the most challenging parts of the project, as it involved several factors that needed to be taken into account, being the time the most restrictive one.

A significant amount of time was invested in trying to find a solution to a system based on the USB protocol, the main issue was that USB over fiber optics is not a well-established technology and lacks a defined standard. The initial approach was to make a design that could manage to send USB signal over fiber optics, but some technical drawbacks such as the lack of information available, the high speeds of the bus and lack of availability of the optical components finally lead to use a system based on Ethernet protocol, which has a more well-established conversion to optical fiber, as is used in several applications.

In both cases, being the main goal of the project to obtain a functional system, which had to be tested in radiated immunity tests in order to validate the specifications of the system, this severely restricted any option of self-design for any of the modules, because the implementation of such task would require most likely its own project.

With the protocol for the system clear, the other variables taken into consideration for the full system were compatibility, cost, performance and size. Finding equipment which was compatible with each other and met the systems requirements also restricted the options available.

One of the advantages of base the system in a protocol such as Ethernet, is that all the modules are highly interchangeable. This means that if a module fails can be replaced easily with another similar module, or even upgraded.

When dealing with combined equipment (as in the case of this project), the individual EMC performance of the modules has a big importance in the overall system, one useful criteria for a preliminary selection is the EMC legislation available on each equipment.

The most interesting part of this project has been the EMC validation of the systems, because a first-hand experience on how EMC tests are conducted has been obtained. Both immunity and emissions tests have been performed to a variety of systems, which has allowed to determine the best option available. Very important concepts for the EMC field have also been obtained during the validations, such as radiation efficiency, EMI radiation and coupling, far field and near field concepts, the normative for domestic, industrial, railway and automotive setups, and the radiated immunity standards used in each of the previous environments.

Radiated immunity testing was the main focus of this project and a wide range of tests with very different parameters have been applied. This has allowed to obtain the main specifications of the system. The system has fulfilled almost all the requirements proposed in section 1.2, is a video and audio monitoring system, sends the data through fiber optics and is supplied with a battery, which allows to dispense of long copper cables. But for the 100 V/m of immunity proposed, the system has reached a maximum of 40 V/m of immunity.

In any case, the system has been validated with the setup EN 61000-4-3 for radiated immunity in the domestic (EN 61000-6-1), industrial (EN 61000-6-2) and railway (EN 50121-3-2) environments. And with the setup ISO 11452-2 for radiated immunity in the automotive sector (UNECE REGULATIONS nº10).

In addition several optional requirements have also been fulfilled, such as that could be used in emission tests if needed (under the right circumstances), the zoom can be controlled remotely, and the system has a small size and low cost. The full list of specification can be seen in section 7.4.

One important lesson that has been observed, is that for a monitoring system intended for EMC tests, a lot of setup and standards are required to validate the system, because the monitoring system has to withstand the conditions required in the maximum standards possible. This makes that a validation for such system is far more complex and long that other equipment.

Several updates have been proposed to the system to enhance the performance under the EMC point of view, can be seen detailed in section 7.5. It has been decided to apply only two upgrades to the system while leaving the other two as optional. The cables lengths from the interconnection of the modules has been reduced to a minimum and ferrites have been added to the cables, to dissipate extra radiofrequency. This has allowed to improve the system although the real specifications with this improvements have not been obtained due to time constrictions.

The improved system will be used in the daily work laboratory for a wide range of tests especially in for the domestic, industrial and railway environments where the system developed has proven to be more effective.

It is left as a proposal for future improvements, the shielding of the system, the reason is that the current state of the equipment is good enough especially in domestic/industrial and railway, where the electric field is more limited than in the automotive sector, and currently can withstand the maximum values. Shielding the system will improve the performance of the equipment in high frequencies, but the current equipment of the GCEM group is a shielded camera, that although does not perform great in lower frequencies, it does in higher ones. So the performance of both equipment’s is complementary, and would allow to obtain a good synergy by the combined use of both.

Is also left as proposal a mid-board for the interconnection of the modules. This would make the same function as the minimized cables, with the addition that a filtering step can be introduced, but again, being the performance quite adequate, is not implemented.

In addition, the software being developed by the GCEM group has proven to be compatible with the system, and also with an IP camera setup, which could be great for future developments.

In conclusion this project has developed and provided to the GCEM group a system that meets the main requirements proposed. Is left with future improvements and upgrades for further enhance the performance of the system. This project could also help to lay the basis for future projects, such as the physical implementation of filters for USB and Ethernet connections, the design and the prototyping of one of the modules, such as the Ethernet converter, or perhaps the design and prototyping of a USB to fiber optics converter.

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Appendix I: EMI disturbances

Radiated Interferences

Radiated Interferences are propagated through the air, in the generation and propagation of radiated electromagnetic interferences three elements intervene:

- Interference source
- Coupling of the interference
- Radiating element

In the Figure 69 can be seen a typical example of a radiated interference, where an interference source from inside a computer such as a clock signal, is coupled to the mother board and to the mouse controller, and the is being radiated to the air through the mouse cable.

In a similar way, instead of a radiated interference being generated from inside the PC, an external radiated interference can get coupled into the mouse cable, and from then into the motherboard.

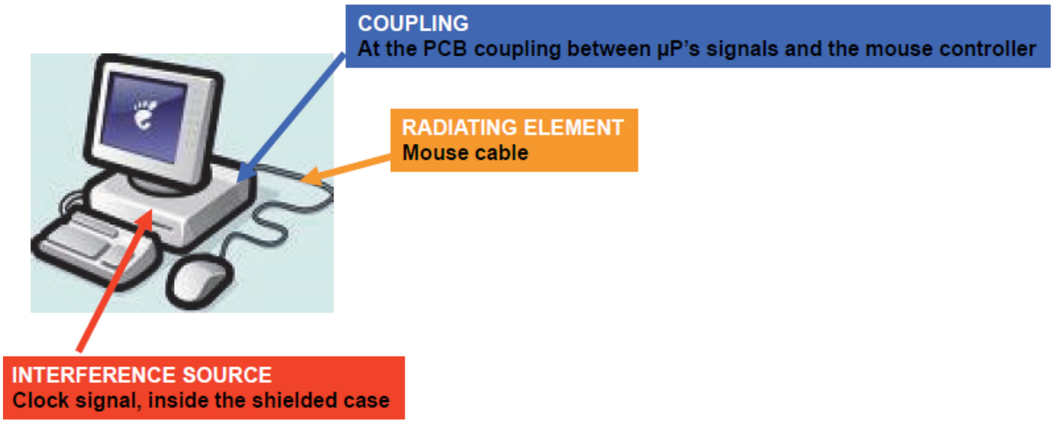

Figure 69. EMI generation and propagation [1]

A very important concept regarding the efficiency of radiated interferences is introduced below.

Radiation efficiency

A very important concept in EMC is radiation efficiency, as it effects in both the generation and in the reception of EMI or any kind of signal being radiated in general.

The first concept is that any conductor of any length behave as an antenna, as a result of that from a very long conductors to a very short one, all are subject to emit or receive signals.

In Table 28 can be seen a relation between different possible frequency signals, with which length of conductor can be radiated from (perfectly or efficiently) and examples of radiation sources.

Table 28. Radiation efficiency

Frequency (f)	Wavelength (λ)	Perfect antenna (λ/4)	Efficient antenna (λ/20)	Possible radiation sources
50 Hz	6.000 km	1.000 km	200 km	Power grid Telephone line
3 kHz	100 km	25 km	5 km	Power grid Telephone line
30 kHz	10 km	2,5 km	500 m	Power grid Telephone line Control installations Ethernet network
300 kHz	1 km	250 m	50 m	Control installations Ethernet network
3 MHz	100 m	25 m	5 m	Control installations Ethernet network External equipment cables
30 MHz	10 m	2,5 m	50 cm	External equipment cables
300 MHz	1 m	25 cm	5 cm	External equipment cables Internal cables, wires PCB
3 GHz	10 cm	2,5 cm	5 mm	Internal cables, wires PCB
30 GHz	1 cm	2,5 mm	500 µm	Internal cables, wires PCB Components
300 GHz	1 mm	250 µm	50 µm	Components

A perfect antenna is the length in which a given frequency can be better emitted or received, that length happen to be λ/4, but usually an efficient antenna is considered to be of a length of λ/20, which implies that for a given frequency there is a wide range of lengths that can emit or receive that given signal.

Conducted Interferences

The main difference between conducted and the radiated interferences is that as radiated interferences are propagated through the air, conducted interferences are propagated through cables.

In Figure 70 can be seen a typical example where interferences are getting coupled and propagated to power lines.

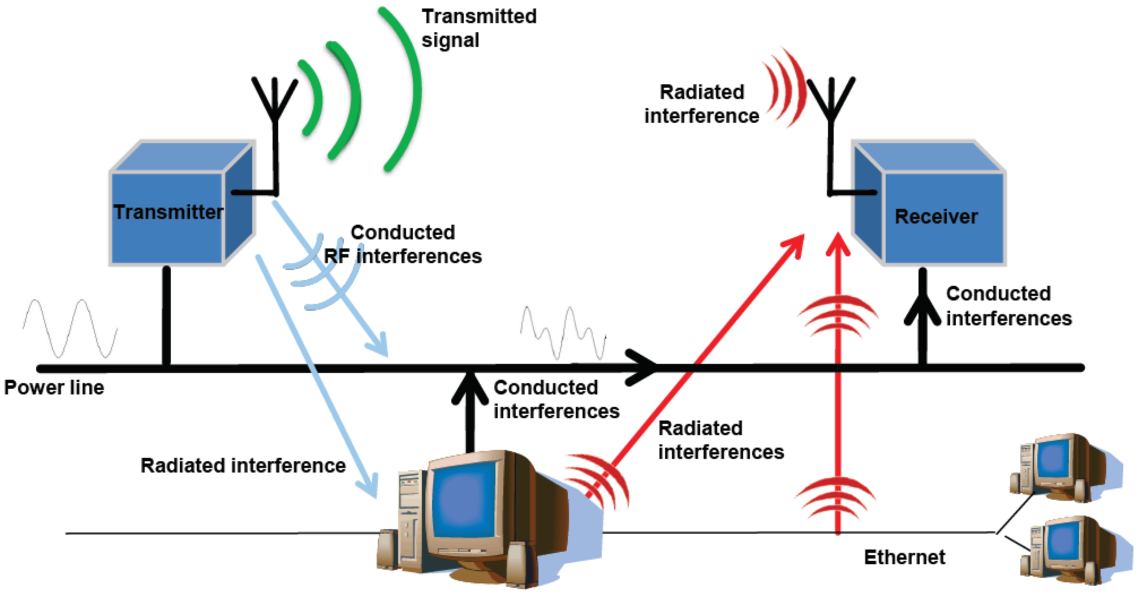

Figure 70. Difference between conducted and radiated interferences [1]

Common antennas for EMC tests

An antenna is an interface between signals being propagated through air and electric currents propagating through metal conductors. Antennas van be used both as a transmitters and receivers and have different polarizations depending of the antenna type, usually vertical or horizontal.

Taking into account Table 28. Radiation efficiency, EMC antennas are designed to be efficient in a wide range of frequencies, the main types used for EMC tests can be seen in the Figure 71 found below.

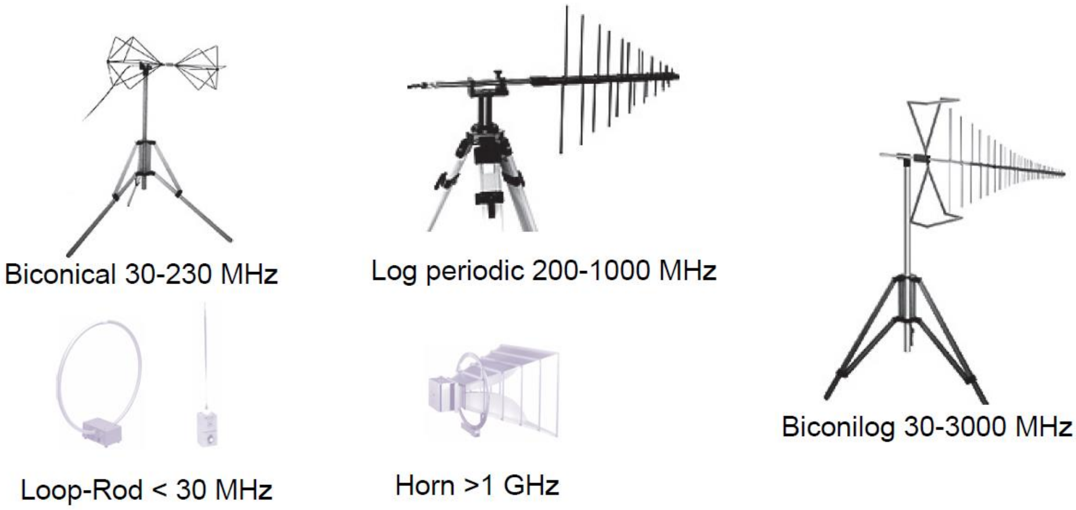

Figure 71. Broadband antennas [1]

Appendix II: Specialized EMC equipment

In this section can be seen an example of a real EMC specialized equipment with the real specifications and prices.

Cam8 + Con4Eco

1. Shielded CCTV System 1xCam8 + Con4eco						*Discounted Price*
Total		*1. Shielded CCTV System 1xCam8 + Con4eco*		*7.184,00 €*	*0%*	*7.184,00 €*
				Detailed Calculation		
Qty.		*Item*	*List price*	*Total*	*Disc.*	*Discounted*
		Camera				
1	**Cam80P36**	**EMC shielded SD Camera** **36**X zoom, 200V/m - **36x optical zoom** - 200V/m up to 40GHz - compliant to CISPR 25, Class 5 -20db, 150kHz – 4GHz - Dimensions : Ø100 x 190 mm - minimum illumination : 0.6 lx - minimum object distance (MOD) : 320Mm (Wide end) to 1500mm (Tele end) - remote controlled zoom, focus (auto focus) **Option**	2.400,00 €	2.400,00 €	0%	2.400,00 €
0	**Cam50x12**	**EMC shielded compact Camera** 12Xzoom, 200V/m - Small size 60x88x90 mm³ - local manual operation of zoom/focus - remote control of zoom/focus/PT - 12x optical zoom - 200 V/m up to 18GHz - Emission: CISPR25, 3rd edit. -10dB - auto focus - Minimum distance 290mm **Options** **x = P** : PAL System (for mains 50Hz) **x = N** : NTSC System ((for mains 60Hz)	2.200,00 €	- €	0%	0,00 €
		Power Supply				
1	**PSM24_230V**	***Mains Unit* 230 V** for Camera with Pan/Tilt or Audio system with ASAT Incl. Power supply cable set **Options**	950,00 €	950,00 €	0%	950,00 €
0	**PSB23_230V**	***Battery Pack* Charge 230 V** for Camera with Pan/Tilt or Audio system with ASAT Incl. Power supply cable set and Charger **cable length 10m**	950,00 €	- €	0%	0,00 €
		Pan / Tilt Option				
1	**PT81**	- for SD Cameras Cam8 - Tilt +80°/-90°, Pan ±135°	1.080,00 €	1.080,00 €	0%	1.080,00 €
		Mounting on Tripod				
1	**TR02**	**Camera Tripod (Wood) with P/T** For camera with Pant/tilt - Typ Report 2012 - adjustment of pan and tilt - Height : 8-115cm - Max load : 15kg - incl. Adaptorplate	265,00 €	265,00 €	0%	265,00 €

Cam8 + Con4Eco

		Fibre optic cables / Patches				
1	**FOC15D12-ST/FSMA**	fibre optic cable duplex, 15m, 50/125 µm glass fibre (ST-FSMA) Camera <=> AP	135,00 €	135,00 €	0%	135,00 €
1	**FOC05D12-ST/FSMA**	fibre optic cable duplex, 5m, 50/125 µm glass fibre (ST-ST) Camera <=> Controller	112,00 €	112,00 €	0%	112,00 €
2	**FOPat FSMA**	1 fibre optic patch (feed through), connections : **FSMA**	21,00 €	42,00 €	0%	42,00 €
		Controller				
1	**Con4Eco1**	**Controller for SD camera (single)** Desk housing * economic controller for SD System - Manual control of zoom, focus, pan/tilt - desk housing 2HE - Fibre optic converters for video - Mains :100 – 230VAC	2.200,00 €	2.200,00 €	0%	2.200,00 €
2. Monitor				625,00 €		625,00 €

Qty.		*Item*	*List price*	*Total*	*Disc.*	*Discounted*
1	Mon_PC_27	**PC-Monitor 27"** e.g. LG or Samsung	450,00 €	450,00 €	0%	450,00 €
1	Converter AV2HDMI	**Converter AV2HDMI**	115,00 €	115,00 €	0%	115,00 €
1	BNC Cable 3m	**Controller to Converter**	30,00 €	30,00 €	0%	30,00 €
1	HDMI cable 3m	**Converter to Monitor**	30,00 €	30,00 €	0%	30,00 €

Summary

1. Shielded CCTV System 1xCam8 + Con4eco	**7.184,00 €**
2. Monitor	**625,00 €**
in total :	**7.809,00 €**

Appendix III: IP Ethernet camera - D-Link DCS-932L connection

In order to be able to connect to any IP camera, both the computer and the camera must be in the same subnetwork.

A subnetwork is a logical subdivision of an IP network. An IPv4 address consists of 32 bits, a subnetwork shares some high-order bits from the host as part of the new IP address while the low-order bits are different, see Table 29.

Table 29. Example of a subnetwork

IP address	Number (Dot-decimal notation)
Host	192.168.1.1
Subnetwork	192.168.1.120

First connection to D-Link DCS-932L in GCEM laboratory

With both the computer and the camera connected at the same router, during the first connection or after a hard reset for restoring all the initial configuration, the IP address of the camera will be the one defined below.

- Original IP address for D-Link DCS-932L: 192.168.0.20

In a domestic network, the IP of the camera would be automatically setup to a subnetwork of the Host, but in the GCEM laboratory the IPs of the network are manually assigned to avoid conflicts between different equipment's, and the camera retains the default IP address detailed above.

In order to change the IP of the camera to a one suitable for the GCEM laboratory the IP of the computer must be momentary changed to subnetwork of that IP in order to access the camera.

In order to change the IP of the computer, one must go to "Panel de Control", the into "Redes e Internet" and "Conexiones de Red", find below the link to the previous configuration screen.

- Panel de control\Redes e Internet\Conexiones de red

Following the steps that can be seen in the figure below, the PC can be setup in the same subnetwork than the camera.

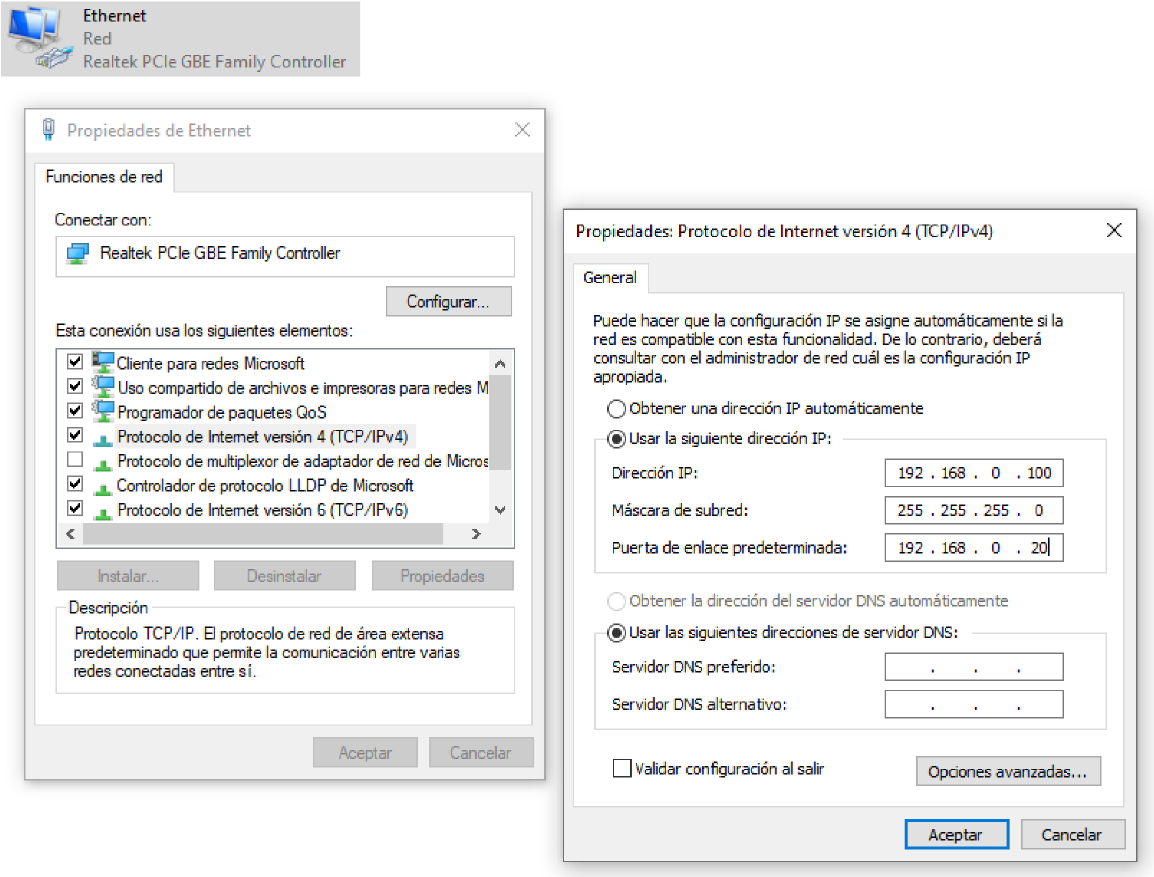

Figure 72. PC IP change

Once both the camera and the computer are in the same subnetwork, by using a web browser such as Internet Explorer (which tends to work better than others browser for this function), inserting the IP address of the camera in the browser allows to directly connect to it.

Once the computer is connected a user and a password is requested, these can be found in the datasheet of the camera which have default values, but are detailed below:

- Admin name. User
- Password: (Blank)

Once inside the firmware, the video can be seen in the home page, and all the configuration of the camera such video quality, format, audio threshold and Network configuration s can be set. In the latter a fix IP address must be set to be able to work in the network of the laboratory, by checking other devices that share the network in the laboratory, the camera can be set to the following IUP address:

Table 30. D-LINK DCS-932L IP address for GCEM laboratory

IP address	Number (Dot-decimal notation)
DCS-932L	192.168.1.101

Once this configuration is saved the IP of the computer can be set back to normal, and by introducing the IP in Table 30 in the browser, camera can be accessed by the PC or any device in the network.

Appendix IV: Raspberry PI as an IP camera

In order to use a Raspberry Pi board as an IP Ethernet camera, the Raspberry PI must have a camera port which allows the connection of the camera to the board. In addition the Raspberry Pi must have installed Raspbian, which is a Debian-based computer operating system for Raspberry Pi.

Once the OS has been installed, the Raspberry PI must be configured to be able to use the camera. By opening a terminal and typing the code [1], the Raspberry configuration screen is opened, here the camera can be enabled.

Sudo raspi-config [1]

The software that will be used to convert the Raspberry Pi into an Ethernet camera is called VLC media player. Commonly known as VLC, this software is a free and open-source cross-platform media player and streaming server. By opening a terminal and typing the code [2] the software VLC media player will be installed in the Raspberry PI.

Sudo apt-get install vlc [2]

With VLC installed you are able to stream video and data to another device as long as both devices have VLC installed and are connected in the same subnetwork.

Although for this project the Wi-Fi is disabled, the following method would also work for a Wi-Fi connection instead of the Ethernet connection that has been used.

The next step is find out the IP address of the Raspberry PI, there are several ways to find out the IP address of a Raspberry PI, the easies one is to type in the terminal the code [3], this automatically reveals the IP address of the Raspberry PI. Alternatively typing the code [4] reveals much more information about the connections of the board.

hostname -I [3]

ifconfig [4]

To stream the data the command "*raspivid*" will be used, which is the command line tool for capturing video with the camera module. First some basic configuration is done such as establishing the width, height and frames per second of the video, and then with the help of VLC, on the port that the user wants the Raspberry Pi will be streaming the video obtained with the camera with the format previously specified, using http and with the file type h264. So by opening a terminal and typing the code [5] the video from the camera is sent to the port 8160.

raspivid -o - -t 0 -hf -w 800 -h 400 -fps 24 |cvlc -vvv stream:///dev/stdin --sout '#standard{access=http,mux=ts,dst=:8160}' :demux=h264 [5]

Now, from another computer connected in the same subnetwork and with VLC installed, the only thing that needs to be done is use the option "open a network" that VLC provides. Here the IP address from the Raspberry Pi (E.g.: 192.168.1.25) and the port where the video is being streamed have to be inserted in the following format "http://192.168.1.25:8160".

With this simple steps the Raspberry Pi has been turned into an IP Ethernet Camera as is using the Ethernet port of the board to stream the video. In order to power up the Raspberry PI and stream the video directly without any kind of user interaction, the method to modify the ".bashrc" file has been choose.

By opening a terminal and typing the code [6] the file is opened, now in the last line, two code lines must be added, first the code [7] and then the code [5] but preceded by "sudo", see code [8]. Finally save the file and exit.

sudo nano /home/pi/.bashrc	[6]
echo Running at boot	[7]
sudo *raspivid -o - -t 0 -hf -w 800 -h 400 -fps 24 |cvlc -vvv stream:///dev/stdin --sout '#standard{access=http,mux=ts,dst=:8160}' :demux=h264*	[8]

Before restarting the Raspberry PI one last thing is recommended, using again the code [1], in the boot options, select "boot on console", this turns off the GUI and starts the OS in a console, this allows to save energy as the display will not be used.

With this steps, any time that the Raspberry PI is powered up, it automatically starts to send the video to the IP address of the board and to the port that has been established. By using any computer with VLC installed the video output of the camera can be seen.

If this would have to be used in the GCEM laboratory the domestic a static IP in the same subnetwork should be used for the Raspberry Pi, as has been done in Appendix III.

Appendix V: EMC legislation of the equipment

In this appendix are summarized all the EMC legislation found on the equipment researched for the systems.

Logitech HD Pro C920 C

Being Logitech a very well-known company and supplier of electronic equipment, in the DoC of the Logitech HD Pro C920 can be found the information stated in Table 31 regarding EMC legislation.

Table 31. EMC legislation for Logitech HD Pro C920

The product conforms with the essential requirements and provisions of: • Electromagnetic Compatibility Directive (EMC) 2014/30/EU of 26 February 2014 • The following standards and/or other normative documents:	
EMC	
EN 55032:2012/AC:2013 : Class B : Information technology equipment - Radio disturbance characteristic	
EN 55024:2010 : Information technology equipment - Immunity characteristics	
ESD	EN 61000-4-2: 2009
RS	EN 61000-4-3: 2006+A1:2008+A2:2010
EFTB*	EN 61000-4-4: 2012
Surge*	EN 61000-4-5: 2014
Conducted RF*	EN 61000-4-6: 2014
Magnetic Field*	EN 61000-4-8: 2010
Dip & Interrupt*	EN 61000-4-11: 2004
*: Standard not applicable to the device	
For Information: On the basis of this declaration, this product carries the CE mark, which was first affixed in 2012	

D-Link DCS-932L

D-Link is a well-known company and supplier of electronic equipment, in the DoC of the D-Link DCS-932L can be found the information stated in Table 32 regarding EMC legislation.

Table 32. EMC legislation for D-Link DCS-932L

DCS-932L is in compliance with the essential requirements and other relevant provisions of the directives 1999/5/EC (R&TTE).

For the evaluation of the compliance with these directives, the following standards are applied:
EMC
EN 301 489-1 V1.9.2
EN 301 489-1 V1.9.2
EN 55022: 2010+AC:2011, Class B
EN 61000-3-2: 2006+A2: 2009
EN 61000-3-3: 2008
EN 55024: 2010
For Information: This product carries the CE mark.

Raspberry Pi 3B

Raspberry Pi foundation is a charitable Organization founded to promote the study of computer science, like so is very transparent with the legislation of its products.

In the DoC of the Raspberry Pi 3B can be found the information stated in Table 33 regarding EMC legislation.

Table 33. EMC legislation for Raspberry Pi 3B

Raspberry Pi 3 Model B is in conformity with the essential requirements and other relevant requirements of the Radio Equipment Directive 2014/53/EU. The product is in conformity with the following standards and7or normative documents:
EMC (Art. 3(1)(b))
EN55032:2012
EN55024:2010 With reference to:
EN301489-1V1.9.2
EN301489-17V2.2.1
For Information: This product carries the CE mark.

Raspberry Pi Camera 2 & Pi Noir Camera

In the DoC of the Raspberry Pi Camera 2 can be found the information stated in Table 34 regarding EMC legislation.

Table 34. EMC legislation for Raspberry Pi Camera 2

Raspberry Pi Camera 2 is in conformity with the following applicable community harmonised legislation: Electromagnetic Compatibility Directive (EMC) 2014/30/EU The following harmonised standards have been used to demonstrate conformity to the standard:
EMC
55032:2012 Class B
EN55024:2010
EN61000-3-2:2014
EN61000-3-3:2013
For Information: This product carries the CE mark.

Raspberry Pi Zero W

In the Raspberry Pi Zero W DoC can be found the information stated in Table 35 regarding EMC legislation.

Table 35. EMC legislation for Raspberry Pi Zero W

Raspberry Pi Zero W is in conformity with the essential requirements and other relevant requirements of the Radio Equipment Directive 2014/53/EU. The product is in conformity with the following standards and or normative documents:
EMC (Art. 3(1)(b))
EN55032:2012
EN55024:2010 With reference to:
EN301489-1V1.9.2
EN301489-17V2.2.1
For Information: This product carries the CE mark.

10Gtek A7S2 Gigabit Ethernet Media Converter

A7S2 Gigabit Ethernet Media Converter carries the CE mark, and according to the certification the information regarding the EMC legislation can be found in Table 36 below.

Table 36. EMC legislation for A7S2 Gigabit Ethernet Media Converter

The optical transceivers are in conformity with the Directive 2014/30/EU. The product is in conformity with the following standards and or normative documents:

EMC
EN55032: 2015
EN61000-3-2: 2014
EN61000-3-3: 2013
EN55024: 2010+A1: 2015
For Information: This product carries the CE mark.

Anker PowerCore 13000

Anker is a well-known company and supplier of electronic equipment, in the DoC of the Anker PowerCore 13000 can be found the information stated in Table 37Table 32 regarding EMC legislation.

Table 37. EMC legislation for Anker PowerCore 13000

The above referenced product complies with the following recognized directive and standards, applicable in part or in whole: • 2014/30/EU
EMC
EN 55032:2015
EN 55024:2010+A1:2015
For Information: This product carries the CE mark.

Appendix VI: USB analysis

In this appendix a further detail on the USB investigation and the optical conversion for the USB protocol is further detailed.

USB protocol

In the following sections the USB protocol is analysed to better understand how to send the USB protocol over fiber optics.

Pinout

The standard USB connector (USB type A) has the following signals defined in Table 38.

Table 38. USB pinout and signals

Contact Number	Signal Name	Description	Typical cable colour
1	V_{BUS} / V_{CC}	+ 5 V	Red
2	D-	Data -	White/Grey
3	D+	Data +	Green
4	GND	Ground	Black

In the Figure 73 can be seen a diagram of a USB male and female type A connector.

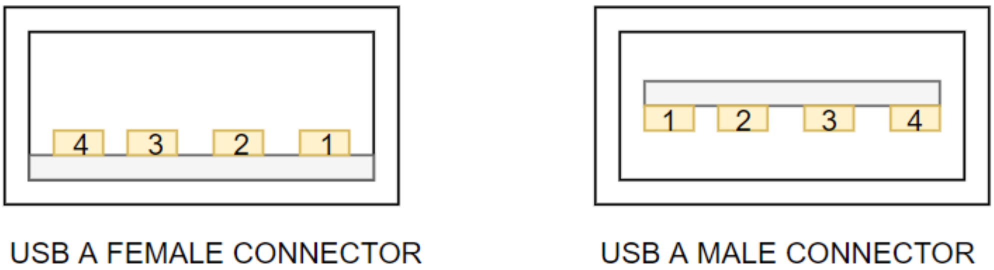

Figure 73. USB type A pinout

USB versions

Now a days there are three versions of the USB protocol, the main characteristics are explained below.

USB 1.0

Released in 1996 USB 1.0 specifies two data rates, 1.5 Mbit/s for Low Bandwidth or Low Speed and 12 Mbit/s for Full Speed.

USB 2.0

Released in 2000 besides the two speeds of USB 1.0, it was added a higher data rate of 480 Mbit/s named High Speed.

USB 3.0

Released in 2008 USB 3.0 adds a Super Speed mode, with associated backward compatible plugs, receptacles, and cables. Super Speed plugs and receptacles are identified with a distinct blue inserts in standard format receptacles.

The Super Speed bus provides for a transfer mode at a nominal rate of 5.0 Gbit/s, in addition to the three existing transfer modes.

Electrical specifications

The electric specifications depend on the speed of the USB.

Low-speed and Full-speed

Low Speed (LS) and Full Speed (FS) modes use a single data pair, labelled D+ and D−, in half-duplex. Transmitted signal levels are 0.0–0.3 V for logical low, and 2.8–3.6 V for logical high level. The signal lines are not terminated.

Half Duplex

A half-duplex (HDX) system provides communication in both directions, but only one direction at a time (not simultaneously). Typically, once a party begins receiving a signal, it must wait for the transmitter to stop transmitting, before replying.

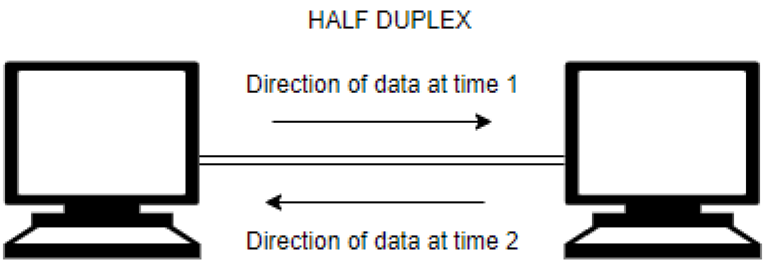

Figure 74. Example of Half Duplex communication

High-speed

High-speed (HS) mode uses the same wire pair, but with different electrical conventions. Lower signal voltages of −10 to 10 mV for low and 360 to 440 mV for logical high level, and termination of 45 Ω to ground or 90 Ω differential to match the data cable impedance.

Super Speed

SuperSpeed (SS) adds two additional pairs of shielded twisted wire (and new, mostly compatible expanded connectors). These are dedicated to full-duplex Super Speed operation. The half-duplex lines are still used for configuration.

Technical aspects for Low and Full Speed

Due to speed limitations, the Low and Full Speed are the best speeds to implement to the system.

Voltage levels

A differential ‘1’ is transmitted by pulling D+ over 2.8V with a 15K ohm resistor pulled to ground and D- under 0.3V with a 1.5K ohm resistor pulled to 3.6V.

A differential ‘0’ on the other hand is a D- greater than 2.8V and a D+ less than 0.3V with the same appropriate pull down/up resistors.

Low-speed and full-speed:

- VOD: 0.0V to 0.3 V
- VOH: 2.8V to 3.6 V

Transceivers

At each end of the data link between host and device is a transceiver circuit. The transceivers are similar, differing mainly in the associated resistors.

Speed identification

At the device end of the link a 1.5 KΩ resistor pulls one of the lines up to a 3.3 V supply derived from VBUS. This is on D- for a low speed device, and on D+ for a full speed device. (A high speed device will initially present itself as a full speed device with the pull-up resistor on D+.) The host can determine the required speed by observing which line is pulled high.

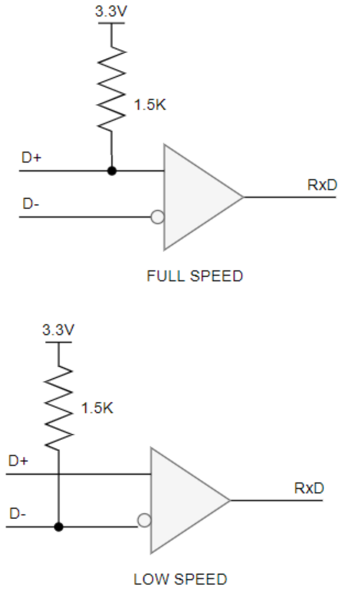

Figure 75. Speed identification

<u>Conversion to optical fiber</u>

Transfer of information in the form of light propagating within an optical fiber requires the successful implementation of an optical fiber communication system.

It is essential that all the components within the transmission system are compatible so that their individual performances, enhance rather than degrade the overall system performance.

The principal components of a general optical fiber communication system for either digital or analog transmission are shown in the system block schematic below.

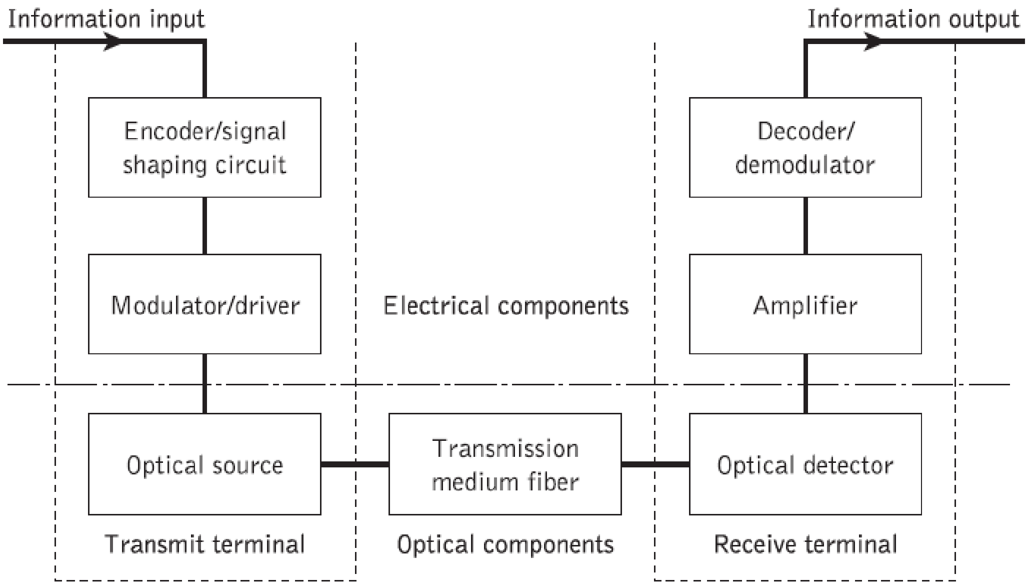

Figure 76. Fiber Optic system [2]

For the conversion from USB to optical fiber some things must be taken into account. As the data signals from the USB are bidirectional and the optical fiber signals require a transmit terminal and a receive terminal, each data line, would need one transmit and one receive terminal. As there are two data lines, in total it should be 4 lines of optical fiber.

Two circuits must be analysed, the transmitter and the receiver.

Digital transmitter

Two different transmitters are analysed.

LED circuits

The operation of the LED for binary digital transmission requires the switching on and off of a current in the range of several tens to several hundreds of mA. This must be performed at high speed in response to logic voltage levels at the driving circuit input.

A common method of achieving this current switching operation for an LED is shown below.

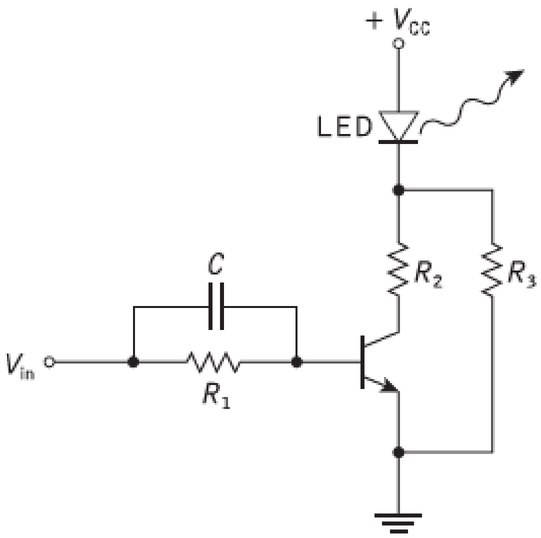

Figure 77. A simple drive circuit for binary digital transmission [2]

Increased switching speed may be obtained from a LED by the use of a low-impedance driving circuit. This may be achieved with the emitter follower driver circuit shown in the next figure. The use of this configuration with a compensating matching network provides fast direct modulation of LEDs with relatively low drive power. A circuit, with optimum values for the matching network, is capable of giving optical rise times of 2.5 ns for LEDs with capacitance of 180 pF, thus allowing 100 Mbit/s.

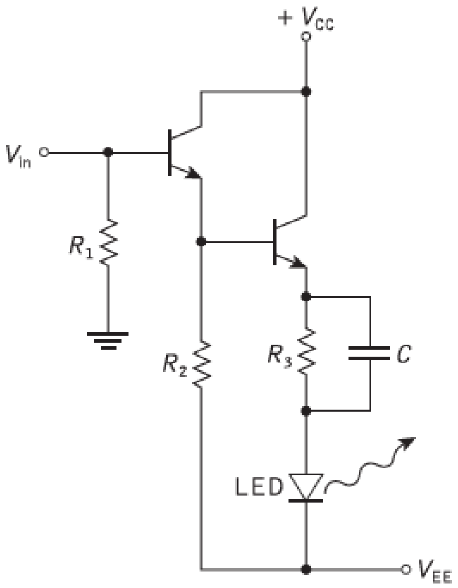

Figure 78. Drive circuit with compensating matching network [2]

Laser circuits

A number of configurations described for use as LED drive circuits for both digital and analog transmission may be adapted for injection laser applications with only minor changes. The laser, being a threshold device, has somewhat different drive current requirements from the LED. When digital transmission is considered, the laser is usually given a substantial applied bias.

A simple laser drive circuit for digital transmission is shown below.

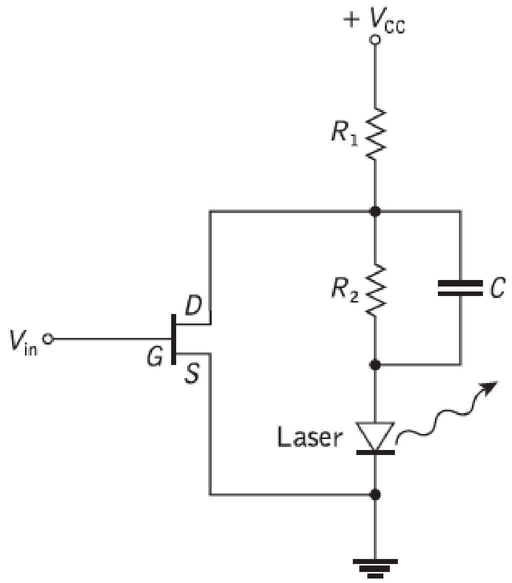

Figure 79. Shunt drive circuit for use with an injection laser [2]

This circuit is a shunt driver utilizing a field effect transistor (FET) to provide high-speed laser operation. Sufficient voltage is maintained in series with the laser using the resistor R2 and the compensating capacitor C such that the FET is biased into its active region. For a particular input voltage Vin a specific amount of the total current flowing through R1 is diverted around the laser leaving the balance of the current to flow through R2 and provide the off state for the device. Using stable gallium arsenide MESFETs the circuit shown in the figure above has modulated lasers at rates in excess of 1 Gbit/s.

Optical receiver circuit

A block schematic of an optical fiber receiver is shown in Figure below.

Figure 80. Block schematic showing the major elements of an optical fiber receiver [2]

Following the linear conversion of the received optical signal into an electric current at the detector, it is amplified to obtain a suitable signal level. Initial amplification is performed in the preamplifier circuit where it is essential that additional noise is kept to a minimum in order to avoid corruption of the received signal. As noise sources within the preamplifier may be dominant, its configuration and design are major factors in determining the receiver sensitivity.

The main amplifier provides additional low-noise amplification of the signal to give an increased signal level for the following circuits

Fiber Optics transmitters and receivers

For the optical transmitters and receivers a specific market research was done to find the availability of the optical components needed for the design of the USB converter. The best option turned to be Broadcom products, which are very well known and reliable brand for optical components.

Broadcom (bibliographic reference [4]) is the world's leading provider of fiber optic transmitters, receivers, and transceivers. Designed to operate in environments requiring reliable data transmission where the highest electrical isolation and EMI immunity are needed, applications include:

- Factory automation at Fast Ethernet speeds
- Home networking
- Industrial automation application
- Factory automation
- Industrial networking and fieldbuses
- Audio visual links and datalinks
- In-car entertainment

USB conversion to optical communication

In this section the different options for sending USB signals over optical fiber are analysed.

Directly conversion

As seen before, due to the nature of the fiber optics communication, it works with a transmitter (TX) and a receiver (RX), due to the USB protocol being Half-Duplex as has been explained before, an electrical preparation of the USB signal is needed.

So a direct conversion to fiber optics of both data lines as depicted in configuration depicted in Figure 81 would not be feasible.

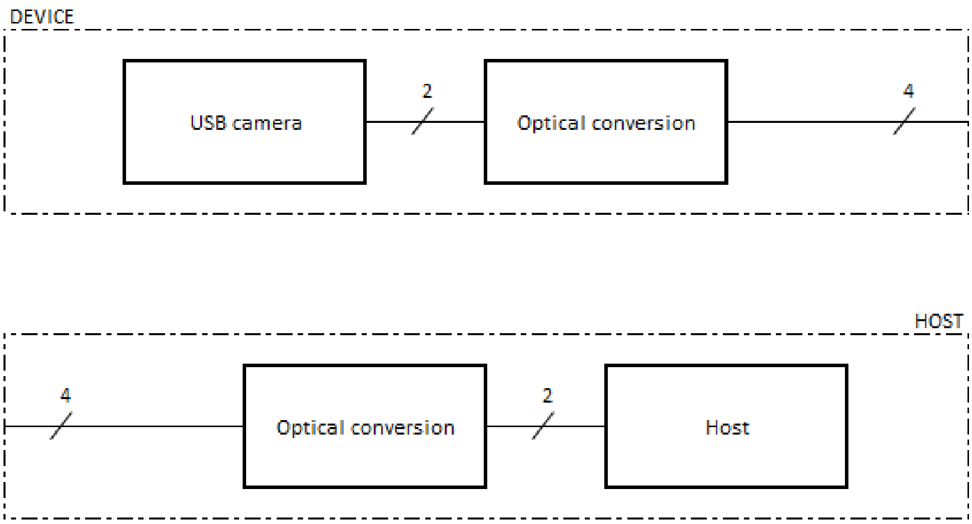

Figure 81. Direct conversion of USB data signal to optical fiber

USB to UART Bridge

By converting the USB data signals to serial, the conversion top optical fiber is reduced by half, as now there is only one line that will act as a Transmitter and one line that will act a Receiver. This configuration can be seen in the Figure 82below.

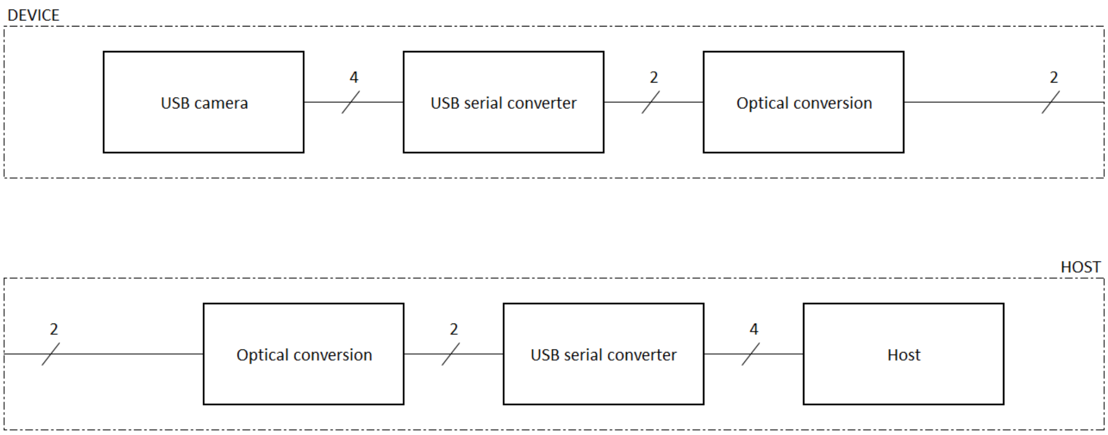

Figure 82 USB serial conversion

There are several Integrated Circuits (IC) that perform this function, for example the CP2102 from Silicon Labs.

Yet this approach doesn't work due to that the USB peripheral are detected as a COM serial port, and it can't be used as a Host for the camera.

USB interface and Microcontroller/FPGA

The idea of this approach is to use a microcontroller or a FPGA to reduce the complexity of the link of the optical conversion with the transceiver. The transceivers to be used would be the same than in the previous section.

In the Figure 83 can be seen a block diagram with this configuration.

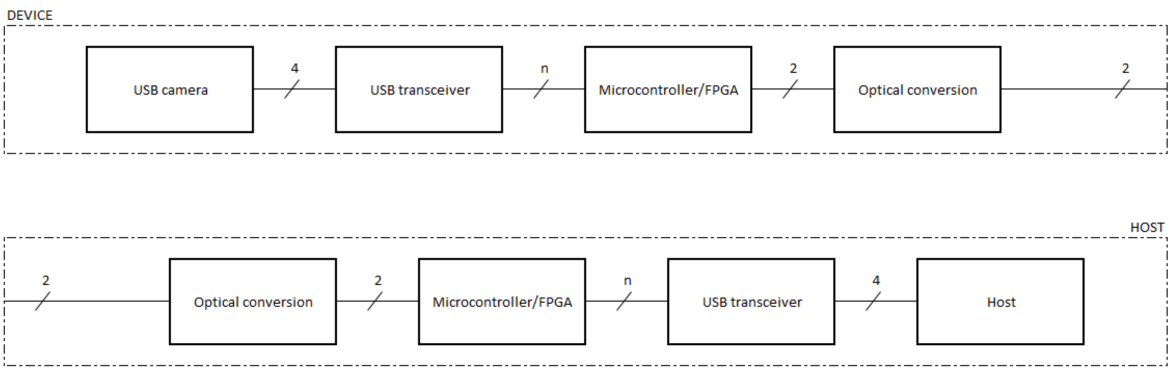

Figure 83. Conversion with transceiver and Microcontroller/FPGA

A USB transceiver is usually a chip that implements the hardware parts of the USB protocol for an end device. Nowadays dedicated chips for this are not used much because USB peripherals are built into microcontrollers. So the configuration would be reduced as can be seen in Figure 84.

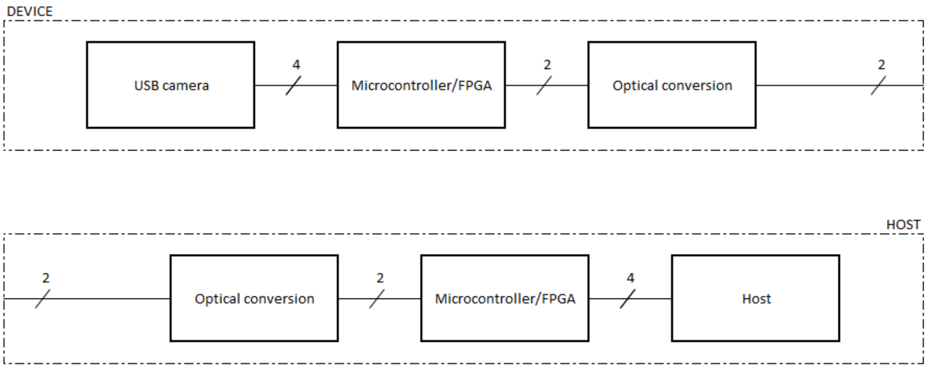

Figure 84. Conversion with Microcontroller/FPGA

Although this option would be feasible, it would require a lot of designing time to produce a functional optical converter. In the following sections can be seen available microcontrollers and FPGAs.

Microcontrollers

For the microcontroller option a PIC microcontroller of Microchip would be good options, for example:

- PIC18F45K50
- PIC18F4550
- PIC 18F2455
- PIC 18F2550
- PIC 18F4455
- PIC 16F1455

FPGA

A good option would be Altera Cyclone III FPGA, as is a low power, high functionality and low cost FPGA.

Other such as be Altera Cyclone I or Alter Cyclone II could be also used.

Glossary

Acronyms

APC: Angled Physical Contact.......44, 104

CCTV: Closed-Circuit television (Video Surveillance).......35, 46

DoC: Declaration of Conformity.......passim

E.g.: For example.......113

EMC: Electromagnetic Compatibility.......passim

EMI: Electromagnetic Interferences.......passim

EUT: Equipment Under Test.......passim

GUI: Graphical User Interface.......114

IC: Integrated Circuits.......126

OS: Operating System.......113, 114

PoF: Power over Fiber.......32

RF: Radio Frequency.......23

SC: Square Connector.......43, 44

SMF: Single-Mode optical fiber.......43, 44