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**Systems' Approach to Analog and Digital Signals in  
Automotive Control Modules**

**Bachelor's Thesis**

**directed by Dr. Nicolau Cañellas Alberich and Miguel Fisac  
Fuentes**

**Bachelor's Degree in Industrial Electronics and Automation  
Engineering**



UNIVERSITAT ROVIRA I VIRGILI

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## **Acknowledgement**

Firstly, I want to thank the Universitat Rovira i Virgili and Lear Corporation for giving me the opportunity to do this Bachelor's Thesis, which culminates my training as an electronics engineer.

The realization of this work has helped me to delve into topics developed during the Bachelor's Degree in Industrial Electronics and Automation Engineering, specifically in the specialty of Digital Electronics, being able to take all this to an environment within the automotive sector.

The strengths that I thought I would lack have appeared from places I did not expect. I want to thank my family, especially my mother and sister, who have made it possible for me to be writing this document. They have always supported me in the most difficult moments of the process and have always been there putting on a good face and providing me with nice words.

On the other hand, I cannot fail to thank my tutors, Dr. Nicolau Cañellas Alberich and Miguel Fisac Fuentes, for their constant patience and help throughout this Thesis. Also, thanks to David Alcon Leno and Jorge Borroy, who gave me the opportunity to join the company, where I have developed the Thesis and where I continue to work.

I would also like to thank all the professors that I have had in the Bachelor because each one has given me something very positive that I value very much. Not only the teachings of each one, but what really matters is their behavior and how they have taught us.

Finally, a special thanks to the people of Lear Corporation, Pablo Guzman Miro, Ivan Fernandez Lopez, and all the SW and SYS staff who have helped me obtain all the knowledge I needed to carry out this Thesis, always responding with a good face to my many questions and concerns.

Thanks to all those people who have crossed my path throughout the Bachelor's Degree and who have given me something valuable. Thank you for being there and for letting me be who I am.

## Resum

Aquesta Tesi neix de la necessitat de desenvolupar una validació de Senyals HW per a BCMs que s'estan fabricant per a vehicles de JLR.

Inclou una descripció dels cinc passos realitzats a l'hora de desenvolupar un Projecte d'Enginyeria des del punt de vista dels Sistemes: Obtenció i Gestió de Requeriments de Client, Especificació i Anàlisi de Requeriments del Sistema, Disseny Arquitectònic del Sistema, Proves d'Integració del Sistema i, finalment, Validació del Sistema.

Aquest projecte m'ha donat l'oportunitat de treballar en tres aspectes diferents d'un Enginyer de Sistemes: Requeriments, Arquitectura i Validació. Amb aquest desenvolupament, s'espera que les plaques comencin a produir-se l'estiu del 2023.

**Paraules Claus:** Sistemes, Automoció, Validació.

## Resumen

Esta Tesis nace de la necesidad de desarrollar una validación de Señales HW para las BCMs que se están fabricando para vehículos de JLR.

Incluye una descripción de los cinco pasos que se toman al desarrollar un Proyecto de Ingeniería desde el punto de vista de los Sistemas: Obtención y Gestión de Requerimientos de Cliente, Especificación y Análisis de los Requerimientos del Sistema, Diseño Arquitectónico del Sistema, Pruebas de Integración del Sistema y, finalmente, Validación del Sistema.

Este Proyecto me ha dado la oportunidad de trabajar en tres aspectos diferentes de un Ingeniero de Sistemas: Requerimientos, Arquitectura y Validación. Con este Desarrollo, se espera que las placas comiencen a producirse en el verano de 2023.

**Palabras Clave:** Sistemas, Automoción, Validación.

## Abstract

This Thesis is born from the need to develop a validation of HW Signals for BCMs that are being manufactured for JLR vehicles.

It includes a description of the five steps taken when developing an Engineering Project from a Systems' point of view: Stakeholder Requirements Elicitation & Management, System Requirements Specification & Analysis, System Architectural Design, System Integration Testing, and finally, System Testing.

This project has given me the opportunity to work in three different aspects of a System Engineer: Requirements, Architecture and Validation. With this development, boards are expected to start production in the Summer of 2023.

**Keywords:** Systems, Automotive, Validation.

## **Prelude**

This Thesis has been developed within the framework of a Work Contract at Lear Corporation in Valls, Spain, in conjunction with the Engineering Systems Department. It is part of an ongoing engineering project, which consists in designing and developing two Body Control Modules (BCMs) for Jaguar Land Rover vehicles.

Although I will describe different components of the BCMS throughout this Thesis, its focus is going to be the approach of Analog and Digital Signals from a systems' approach, which includes requirements, architecture, and validation of said signals.

Given that the development of the Thesis has been carried out entirely in the facilities of Lear Corporation Valls, all the information that supports the realization of itself, both technical and theoretical, as well as the technological solutions and results, are owned by Lear Corporation and remain under the protection of the relevant confidentiality agreement. That is why there will coexist a public version and another confidential part of this document.

So that this fact does not condition the comprehensibility of the public version of the present, it has been decided to keep the body of the wording identical in both versions, transferring to the Annexes section all the documents and data subject to confidentiality.

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## 1 Introduction

This Bachelor's Thesis is born from the needs of designing a proper validation for Analog and Digital Signals for the BCMs that are being manufactured for JLR vehicles.

In the development of the Thesis, knowledge acquired throughout the engineering Bachelor's Degree in Industrial Electronics and Automation Engineering was put into practice. In addition, due to the specific character within an electronic environment as specific as the Systems Department in the automotive sector, the digital aspect stands out.

In particular, the knowledge acquired in subjects such as Digital Electronics and Power Electronics is applied, combined with what is learned through the professional experience provided by working in an industrial environment such as the automotive industry, and working with a customer like Jaguar Land Rover.

Due to project timing issues, physical tests were only possible with prototype HW boards and delta SW versions, which leads to limited results being obtained.

### 1.1 Objectives

The main objectives sought within this Thesis are the following:

- Description of BCM behavior, including HW and SW points of view.
- Creation and revision of System Requirements for BCM signals, following client specifications.
- Implementation of Analog and Digital Signals strategy for validation.
- Development of strategies for protecting BCMs' digital outputs against short circuits.

### 1.2 Scope

This Thesis arises in the context that analog and digital signals in industrial applications need to be validated to verify that their behavior is as expected by customer, SW, and HW. In addition, digital outputs also must have some type of protection measure in order to avoid damage due to fault conditions, such as a short circuit or an over current, either of which can damage the device driving the signal.

In industrial control environments, there are many signals that need to be transmitted from one machine to another, to signal faults, or to initiate the next operating stage. These signals are often driven by PLCs or other digital controllers, which may have the ability to drive small resistive, capacitive, or inductive loads over a long cable run. They may not have the ability to withstand a fault and continue to operate normally.

### 1.3 Lear Corporation

Lear Corporation was founded in 1917 in Detroit, Michigan as American Metal Products where, at the time, was engaged in manufacturing supplies for the automobile and aircraft industries.



Figure 1. Lear Corporation Logo.

Currently, it manufactures automotive electrical systems and automotive seating. With its headquarters in Southfield, Michigan (USA), it currently counts with 251 facilities in 38 different countries, with a total of over 170,000 employees globally and #179 in the Fortune 500, supplying more than 300 different car brands.

This Thesis was developed in Lear Valls Site, which was established in 1970. With over 990 employees, it is the headquarters of the E-Systems division of the company, with an Engineering Center and an ELM Plant. Its facilities, of 64.054 m<sup>2</sup>, consist of 4 buildings for production and 1 for services. Their activity focuses on central functions (such as purchasing, finance, legal...), HR, Engineering, Test Lab, Manufacturing, Show Room, Innovation, and a Business Center. In 2020, it had \$207.5K in sales, having BMW, Renault, Ford, Jaguar Land Rover, and Volvo as main clients.



Figure 2. Lear Valls Site Products.

My work, which includes this Thesis, has been developed in the Electronic Module section of the company, specifically the Core Electronics System Department, as a System Requirement and System Test Engineer.

## 1.4 JLR Project



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**Abstract:** Brief description of the Lear Engineering Project this Thesis applies to.

## 2 System Approach

As said, this Thesis will mainly focus on the System's approach to the development of Analog and Digital Signals for the BCMs being designed for JLR vehicles.

Being one of the top companies when it comes to the automotive industry, Lear has a process, called LPMP (Program Management Process), which is followed by all E-Systems projects to ensure that all customer specifications are met, and that everything is done to maximize benefits and minimize issues.

### 2.1 Stakeholder Requirements



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**Abstract:** Stakeholder Requirements Process is to gather and manage stakeholder requirements throughout the life of the product/project, as well as establishing stakeholder requirements baselines that serve as the basis for defining the system requirements.

This process consists of three different steps:

- Defining & Reviewing the Requirement Management Strategy
- Obtaining & Analyzing Stakeholder Requirements
- Releasing Stakeholder Requirements

## 2.2 System Requirements



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**Abstract:** System Requirements Process is to define and analyze the system requirements based on the stakeholder requirements that will be the basis for the design and verification of the system.

This process consists of three different steps:

- Specifying System Requirements
- Analyzing System Requirements
- Releasing System Requirements

## 2.3 System Architecture



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**Abstract:** The System Architectural Design Process defines a System Architecture that satisfies the System Requirements and describes the elements and their interactions via the interfaces.

This process consists of three different steps:

- Designing & Documenting the System Architecture
- Allocating System Requirements to System Elements
- Verifying & Releasing the Architectural Design

## 2.4 System Integration



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**Abstract:** The System Integration Process consists of assembling a system that is consistent with its architectural design. In this process, system elements are combined to form complete or partial system configurations in order to create the product specified in the system requirements.

This process consists of three different steps:

- Defining, Planning & Reviewing the System Integration Test Strategy
- Defining & Reviewing the Test Specifications
- Defining & Performing the System Integration Test

## 2.5 System Test



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**Abstract:** System Testing ensures that the implementation of each System Requirement is tested for compliance, the System meets the customer expectations and that it is ready for delivery.

This process consists of five different steps:

- Defining, Planning & Reviewing the System Test and Regression Strategy
- Preparing the System Test Environments & Set-Ups
- Defining & Reviewing the System Test Specifications
- Planning and Performing the System Test Execution
- Evaluating & Reporting the System Test Results

### 3 Case Study



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**Abstract:** For a better understanding of the System Approach taken part in the JLR Project, in this section the whole process is applied to some of the requirements created. This way, the whole process will be visible from start to finish regarding different requirements or signal types.

The process includes the five main steps defined previously:

- Stakeholder Requirements
- System Requirements
- System Architecture
- System Integration
- System Test

## 4 Project Development

For the correct development of the Systems' Approach, and this Thesis, a series of materials were needed, both HW and SW. In this Section, all the materials used are described and explained, with the hope to make this Thesis and its contents more understandable.

### 4.1 Hardware

#### 4.1.1 Body Control Module Boards

The Body Control Module boards, or BCMs, oversee managing all the loads inside the vehicle related to bodywork and comfort. In this context, they manage the doors, windows, interior and exterior lighting, and electronic devices related to the vehicle's performance, such as the radio or electronic sensors.

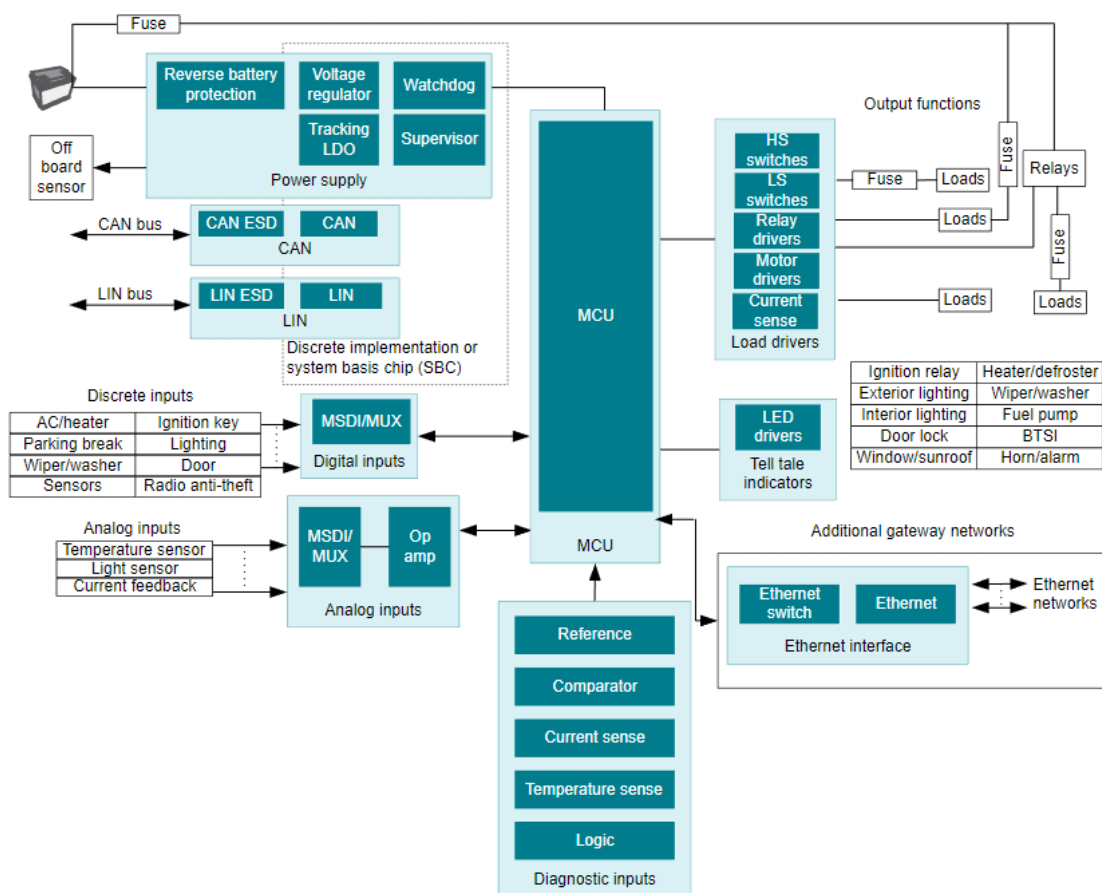


Figure 3. Block diagram of a BCM with Gateway.

In the Figure shown above, the basic architecture of a BCM board can be seen. It includes analog and digital signals, and CAN, LIN and Ethernet communications, which allow the board to communicate with other electronic modules of the vehicle. It also includes limp home functionality, high-side switches, and a gateway.

More information on this diagram can be found in [2], which leads to the manufacturer's website, Texas Instruments.

#### 4.1.1.1 JLR's BCMs



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**Abstract:** This Section describes the BCM boards that are being developed by Lear for JLR vehicles. It includes a list of characteristics and pictures.

#### 4.1.2 Panel of Loads

A Panel of Loads (PoL) is physical equipment that simulates vehicle loads (switches, sensors, bulbs, motors, etc...) used for HW, SW and SYS Validations.



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**Abstract:** This Section describes the Panel of Loads that are being used by Lear to validate the System Requirements. It includes a list of characteristics and pictures.

#### 4.1.3 Autotester



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**Abstract:** Autotester is a National Instruments based tool programmed with LabVIEW and designed to execute automatic test cases and perform a fully automated validation.

## 4.2 Software

### 4.2.1 DOORS NG

DOORS Next Generation is the standard Requirement Management tool for all E-System projects in Lear. All requirements received from the customer shall be stored and handled in DOORS NG. The relevant Systems, Software, Hardware, Mechanics, etc. requirements shall be handled and stored in DOORS NG as well.



Figure 4. IMB DOORS NG Logo.

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**Abstract:** This Section describes how DOORS NG is used in Lear to develop, analyze and implement Stakeholder and System Requirements.

#### 4.2.2 Enterprise Architect

Sparx System Enterprise Architect is a visual modelling and design tool based on the OMG URL. The platform supports the design and construction of software systems, modelling business processes, and modelling industry-based domains. It is used by businesses and organizations not only to model the architecture of their systems, but to process the implementation of these models across the full application development life-cycle.



Figure 5. Enterprise Architect Logo.

In Lear, Enterprise Architect is used to develop Software, Hardware, and Systems Architectural Diagrams.

#### 4.2.3 PySTA

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**Abstract:** PySTA is a set of python libraries for implementing Test Cases that works as a front-end for the System Test Autotester.

#### 4.2.4 Lauterbach Trace32

Lauterbach is the world's largest producer of complete, modular and upgradeable microprocessor development tools with experience in making world-class debuggers and real-time trace since 1979.

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**Abstract:** This Section describes how Trace32 and Lauterbach are used in the JLR Project.

This Section is also followed by the description of three Lear Internal Programs that are used for the following purpose:

- Managing requirements to be tested
- Import Test Cases or Protocols to be tested
- Gathering results automatically and generate reports to be delivered to customer

#### 4.2.5 JIRA

JIRA is a change control tool that is used for the development of Engineering Projects in Lear. IT offers an intuitive environment for issue and project tracking for development teams.



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**Abstract:** This Section describes how Lear uses JIRA to improve their task and issue management.

#### 4.3 Roles



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**Abstract:** This Section describes the different roles that are present during the development of an Engineering Project in Lear, focusing mostly on the roles applicable to System Engineering.

## 5 Conclusions

The main goal of this Thesis was to complete a full System Approach for the JLR Project, including aspects of all the system areas: requirements, architecture and validation.

### 5.1 Test Coverage



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**Abstract:** This Section contains the final coverage of the tests executed during the JLR Project and, hence, this Thesis.

### 5.2 Future Possibilities



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**Abstract:** This Section contains a list of future possibilities to be approached for the JLR Project. These possibilities depend on time and information obtained.

### 5.3 Economic Conclusions

Developing an Automotive Engineering Project is not a cheap thing to do, but during the development of this Thesis, I found some points that could reduce the economic impact while using the Systems' Approach:

- **Closer Approach with Customer:** As every release of requirements or validation is sent to Customer, this makes it easier to prevent big mistakes, or to have big errors during a long period of time. It also betters communication and understanding between Lear and the Customers.
- **Possibility of Validating Remotely:** With the Autotester, it is possible for the System Test Engineer to validate TCs without being present in the lab. This allows big flexibility, as tests can be launched from home, another Lear Building or Site, or even from the Engineer's personal desk.
- **Programming Reduction Time:** With the optimization of Lear internal libraries and/or each System Test Engineer's coding skills, coding time can be reduced to a minimum by, for example, using document parsers or dictionaries.

## **5.4 Personal Conclusions**

On a personal level, I am very happy to have had the opportunity to develop this Thesis in a company with as much prestige as Lear Corporation.

Not only has this project given me the opportunity to work in three different system sectors (requirements, architecture, and validation), but it also helped me to understand the whole operation behind an Automation Engineering Project. Not only this, but I managed to do it in my first year in the company, which accelerated my learning process very much.

Although I am not completely satisfied with the development of this project, I am still very content with all the work put into not only this Thesis, but the JLR Engineering Project.

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This bibliography includes the bibliographical references of the resources shown in this document, but it is worth saying that, for the development of this Thesis, an infinite number of documents, articles, classes, videos, and files of all kinds have been used with information regarding the aspects that have been described.

Much of this documentation comes from Lear's internal documentation on the BCM boards and the JLR Project, which is why its documents can't be listed as references.

## Appendix 1 - Acronyms

This chapter lists the definitions of the symbols and abbreviations used in this document.

<b>ASIL</b>	<b>A</b> utomotive <b>S</b> afety <b>I</b> ntegrity <b>L</b> evel
<b>BCM(s)</b>	<b>B</b> ody <b>C</b> ontrol <b>M</b> odule(s)
<b>CAN</b>	<b>C</b> ontroller <b>A</b> rea <b>N</b> etwork
<b>CUS</b>	<b>C</b> ustomer
<b>DOORS NG</b>	<b>D</b> ynamic <b>O</b> bject- <b>O</b> riented <b>R</b> equirements <b>S</b> ystem <b>N</b> ext <b>G</b> eneration
<b>DTC(s)</b>	<b>D</b> iagnostic <b>T</b> rouble <b>C</b> ode(s)
<b>E-Systems</b>	<b>E</b> lectronic <b>S</b> ystems
<b>ELM</b>	<b>E</b> lectromechanical
<b>EPL</b>	<b>E</b> ngineering <b>P</b> roject <b>L</b> ead
<b>HITS</b>	<b>H</b> ardware <b>I</b> nterface <b>T</b> echnical <b>S</b> pecification
<b>HW</b>	<b>H</b> ardware
<b>JLR</b>	<b>J</b> aguar <b>L</b> and <b>R</b> over
<b>LAB</b>	<b>L</b> aboratory
<b>LIN</b>	<b>L</b> ocal <b>I</b> nterconnect <b>N</b> etwork
<b>MEC</b>	<b>M</b> echanical
<b>OPC(s)</b>	<b>O</b> utput(s) <b>P</b> rotection <b>C</b> ontrol
<b>PCB</b>	<b>P</b> rinted <b>C</b> ircuit <b>B</b> oard
<b>PCR</b>	<b>P</b> roduct <b>C</b> hange <b>R</b> equest
<b>PLCC(s)</b>	<b>P</b> lastic <b>L</b> ead <b>C</b> hip <b>C</b> arrier(s)
<b>PM</b>	<b>P</b> roduct <b>M</b> anagement
<b>RE</b>	<b>R</b> equirements <b>E</b> ngineering
<b>RMP</b>	<b>R</b> equirements <b>M</b> anagement <b>P</b> lan
<b>RTE</b>	<b>R</b> elease <b>T</b> rain <b>E</b> ngineer
<b>SH</b>	<b>S</b> takeholder
<b>SOP</b>	<b>S</b> tart <b>O</b> f <b>P</b> roductions
<b>SW</b>	<b>S</b> oftware
<b>SYS</b>	<b>S</b> ystems

## Appendix 2 – DOORS NG Workflow



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**Abstract:** This Appendix contains information regarding the Workflow that has to be followed when working on Requirements in the DOORS NG Platform.

## Appendix 3 – Stakeholder Requirements



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**Abstract:** This Appendix contains a list of Stakeholder Requirements provided by JLR for Lear to develop Stakeholder Requirements.

## Appendix 4 – System Requirements



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**Abstract:** This Appendix contains a list of the System Requirements developed for the JLR Project, both for Input & Output Monitoring and OPCs.

## Appendix 5 – System Architecture



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**Abstract:** This Appendix contains a list of the System Architecture Designs developed for the JLR Project, both for Input & Output Monitoring and OPCs.

## Appendix 6 – System Integration for IO Monitoring



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**Abstract:** This Appendix contains all the code files that were developed during System Integration of Input & Output Signal Monitoring, plus any additional libraries or parsers that were necessary for their use.

## Appendix 7 – System Integration for Output Protection Control



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**Abstract:** This Appendix contains all the code files that were developed during System Integration of Output Protection Control.

## Appendix 8 – System Test Set-Ups & Tools



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**Abstract:** This Appendix contains lists and diagrams regarding the set-ups available for System Testing in the JLR Project.

## Appendix 9 – System Test Results



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**Abstract:** This Appendix contains the results of the Validation of the requirements developed in the JLR Projects.