Master’s Thesis

Master´s degree in Telecommunications Engineering

Antenna validation Laboratory Startup

Andoni Amurrio González

UAB Tutor: José Lopez Vicario

Telecommunications and Systems Engineering Dept.
Signal Theory and Communications

Escola Tècnica Superior d’Enginyeria (ETSE)
Universitat Autònoma de Barcelona (UAB)

Supervisor: Alberto Gil Ferras

Antenna Projects
SEA/EE-52
SEAT S.A.

July 2016

UAB

El sotasignant, *Nom del Professor*, Professor de l'Escola Tècnica Superior d'Enginyeria (ETSE) de la Universitat Autònoma de Barcelona (UAB),

CERTIFICA:

Que el projecte presentat en aquesta memòria de Treball Final de Master ha estat realitzat sota la seva direcció per l'alumne *Andoni Amurrio*.

I, perquè consti a tots els efectes, signa el present certificat.

Bellaterra, *data_de_sol.licitud_de_lectura*.

Signatura: *Nom del director del projecte*

Resum:

La validació dels components de qualsevol projecte es fonamental per garantir el compliment dels requisits establerts. Actualment dins de SEAT S.A. es el proveïdor que realitza aquesta validació, sense que un cop adquirits els components, es torni a comprovar que es compleixen les especificacions. L'objectiu d'aquest projecte es posar en marxa en el Centre Tècnic de SEAT un laboratori que realitzi la validació dels components dels sistemes d'antenes, realitzant una sèrie de muntatges i mesures gracies a les quals es pot verificar el seu correcte funcionament. Per això s'haurà de fer un minuciós estudi tan dels procediments estandarditzats en el consorci de Volkswagen com de les diferents alternatives existents, pel que es refereix a instrumentació, desenvolupament de mesures... Com a complement al projecte, es treballarà amb una font d'alimentació portàtil de estil Phantom per alimentar les antenes, de manera que es pugui portar la validació de components en un entorn real com son les proves de conducció. Començant d'un disseny electrònic basic, s'implementarà aquest generador que permetrà proveir a la antena de senyal continua i analitzar la senyal de RF necessària segons la aplicació.

Resumen:

La validación de los componentes de cualquier proyecto es fundamental para garantizar el cumplimiento de los requerimientos establecidos. Actualmente dentro de SEAT S.A es el proveedor quien realiza esta validación, sin que una vez adquiridos los componentes se vuelva a comprobar que se cumplen con las especificaciones. El objetivo de este proyecto es poner en marcha en el Centro Técnico SEAT un laboratorio que realice la validación de los componentes de los sistemas de antenas, realizando una serie de montajes y medidas gracias a los cuales se pueda verificar el correcto funcionamiento de los mismos. Para ello deberá hacerse un minucioso estudio tanto de los procedimientos estandarizados en el consorcio Volkswagen como de las diferentes alternativas existentes, en lo que se refiere a instrumentación, desarrollo de medidas...Como complemento al proyecto se va a trabajar en una fuente de alimentación portátil tipo Phantom para la alimentación de las antenas, de forma que se pueda llevar la validación de los componentes a un entorno real como son las pruebas de conducción. Partiendo de un diseño electrónico básico se implementará este generador que permitirá proveer a la antena de señal continua y analizar la señal RF necesaria según la aplicación.

Summary:

In any project, component validation is essential in order to guarantee the fulfillment of the specified requirements. Nowadays in SEAT S.A, it is the component provider who makes this validation, without checking they fulfill the requirements anymore once obtained. The objective of this project is to startup a laboratory that can perform component validation of antenna systems at Centro Tecnico SEAT, performing some setups and measurements that will allow verifying the well-functioning of them. To do so, a very deep study about Volkswagen´s internal regulations will have to be carried out, as well as about the different existing alternatives, regarding to instrumentation, measurement procedures... As a complement for this project, works will be undertaken to develop a Phantom power supply for antenna feeding, so that validation can be taken to real environments like drive tests. It will be implemented from a simple electronic design, and it will allow feeding antennas both with DC and RF signals through a single coaxial, so that signals can be analyzed depending on the application.

INDEX OF CONTENTS

1. Introduction

This first section is oriented to give key information about this project, called "Antenna validation laboratory start-up". To do so, the main reasons to justify the development of the project that aims to go a step forward in validation tasks will be given. Then, the objectives set will be explained, divided in some secondary objectives that will make possible to obtain the main one. Finally, a brief explanation about how this project´s memory is organized will be presented, so that a clear overview of the structure of this document can be made.

1.1.Motivation

Component validation is an essential part in any project. Big companies save a lot of money just adding to their workflow a validation stage, at which every component undergoes real case situations that will check if they fulfill all the requirements that have been set before. If they do, they just have to be implemented and wait till every single component is ready for the start of production, but if they don´t, an iterative path has to be set in order to get the optimum response expected from that component.

Normally, components are obtained through external suppliers that are dedicated to that certain product, so that already gives the security of having a high level component. SEAT SA works in that way, and in addition, a complete set of regulations and requirements is previously given to suppliers. They receive all the information about different regulations and requirements, as well as concrete indications about how validation tests have to be made. When the component is delivered, a full validation report is attached, so that it can be checked in SEAT. These documents are checked and stored where it belongs, not to be read again as long as everything works properly.

Since impedance adapters for different car models are fabricated by different suppliers, these reports have very different formats; each one use their own result presentation templates, instrumentation and even the scales used are different from one to another… All this makes very difficult identifying possible errors at components when they are received at SEAT. Having an own validation laboratory helps to standardize this process, and instead of depending on the supplier´s reports, SEAT´s own reports are the referent ones. Supplier´s reports will only be checked in case of mismatching of the results. Furthermore, this laboratory gives the chance of making deeper tests that the ones performed by suppliers, which normally are more basic and don´t include many probes that should be done.

The main purpose for starting up this laboratory is to give a step forward in development tasks, having a better control over it, so that SEAT is not limited to management tasks. This will bring SEAT to its consortium partners´ level, Volkswagen, Audi and Skoda, who already have an antenna validation laboratory.

1.2.Objectives

As said before, a main objective has been defined for this project: to start-up a validation laboratory in SEAT SA. This is a very big and ambitious objective, since validation is a wide ambit at which many different kind of tests can be made, so different paths have to be taken. The first step to take is going to be setting a laboratory where Impedance adapters, impedance adapter for on board antennas, can be tested and validated or rejected. Then, further procedures will have to be considered, such as on board validation at real environments.

In order to get the main objective, some secondary objectives have been defined. First, a deep study about Volkswagen´s internal regulations will have to be done. Thanks to this study, a perfect *know how* will outcome; a set of reports that will clearly specify all the procedures and settings for validation. This will help future workers in this laboratory to understand easily everything they need to work in it. Another secondary objective will be choosing and installing all the instrumentation according to the requirements for the laboratory. The proper settings of this equipment will have to be added to the previously mentioned set of reports. Evaluating the automation of the procedure of validation will be also a secondary objective; it will be very important to optimize the validation tasks so that the least time is spent in obtaining the accurate expected results. However, developing a wide test bench will be prioritized over automation, which can be let to future work lines in case timing doesn´t allow to work on it. Finally, a Phantom power supply will be developed to make possible validation at real environment, as a next step of the validation stage.

The following pictures summarize the objectives for this project.

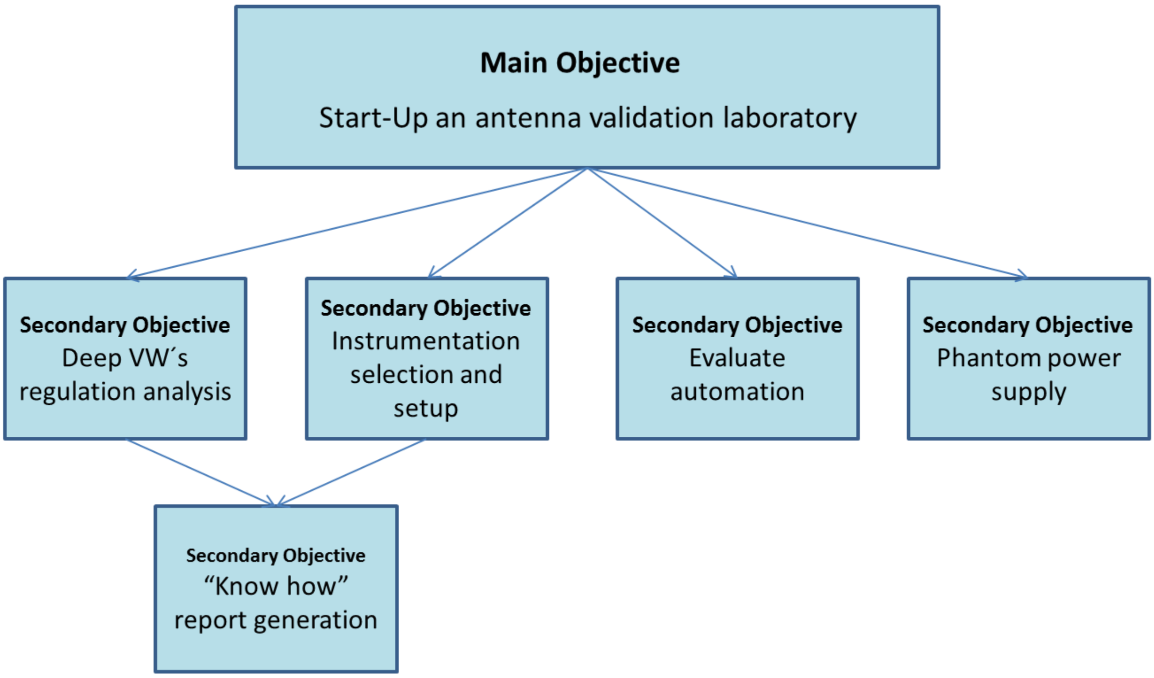


Figure 1: Objectives tree

1.3.Memory organization

Here comes a brief explanation of how this project´s memory is organized. First comes this introduction chapter, at which the motivation and justification of this project is explained, and then the main objectives are stated. Then, a State of art chapter explains the context of everything around this project; antenna systems, the company this project is made for, and some mentions to the functions that antennas make possible to perform.

The third chapter makes an overview about the Impedance adapter, which will be the main Device under test of this validation laboratory. The requirements this component must fulfill are explained, according to Volkswagen´s internal regulations.

After that the laboratory Deployment is deeply explained in chapter 4. A timing for the project will be shown, and then a wide explanations about the material resources that will be used along the project. Then the procedures for measuring different parameters are explained, in order to obtain the minimum values mentioned in the requirements.

Chapter 5 will show the results obtained when measuring a full set of devices, presented in a model document developed for this issue. The design of the Phantom Power Supply is explained in chapter 6. After a brief introduction justifying the development of this

Device, the design has been divided in high level and low level design, in order to show how this power source has been developed out of raw ideas. In chapter 7 an econòmic summary has been carried out, in order to show how much a project of this size can cost in econòmic terms.

Finally, the conclusions for this project are summarized. Here the project´s maturity level reached is explained, and future steps and considerations are stated so that this project doesn´t finish with the presentation of this work.

2. State of Art & Context

This chapter has the objective of giving an overview about this project, so that next chapters are well placed in context. First, a brief introduction about antenna technologies is given, as well as a summarized list of different services that can be offered on board. Then, the project is located in its business area, giving some notes about SEAT that allows the reader knowing where this project is held, from a high company level to the certain department where it is developed.

2.1. Antennas and on board antenna-systems

The need of connecting two devices in order to transmit information, either unidirectionally or bidirectionally, makes the use of antennas compulsory. Even though they are liable to interferences or security vulnerabilities, they are really useful in moving environments where wiring is not a suitable option. According to the Institute of Electrical and Electronics Engineers (IEEE) at the Standard Definitions of Terms for Antennas, antennas are the part of transmitting or receiving system that are designed to radiate or to receive electromagnetic waves, being transitional structure between transmission lines and the free space [2]. They are designed to make this conversion in the most efficient way, taking into account that their geometry and dimensions are directly related with the wavelength λ (let's remember that the wavelength of a wave is related with the light´s propagation speed at a certain medium). The following picture shows the electromagnetic spectrum, highlighting the frequencies at which most antennas work.

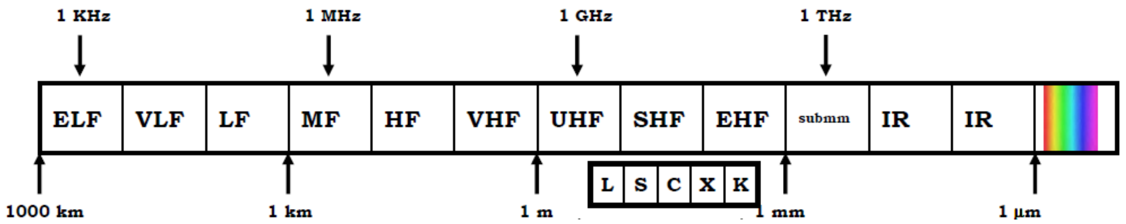


Figure 2: Electromagnetic Spectrum.
Source: Module 9.2.3 ELTICA

There are many different kind of antennas, depending on their geometry, feeding… those antennas that need a power supply in order to work properly are called active antennas, while those that do not need that feeding are called passive. Regarding to their geometry four different kind of antennas should be mentioned:

- Wire antennas: Those antennas radiating fields generated by currents through a conductor wire. According to the antenna theory, it is demonstrated that the best performance is obtained by using a length slightly shorter than $\lambda/4$. At lower frequencies, since the wavelength could be to large to implement a wired antenna, their length is usually reduced assuming a reduction of efficiency.

  The most known wired antennas are dipoles, loops, helices…

Figure 3: Wire antenna for on board radio reception
Source: SEAT Ibiza 2012 project

- Aperture antennas: Radiated fields are generated by a field distribution supported in an aperture antenna, so this radiation is tightly related with the geometry of this aperture. They allow very long distance communications; the most common aperture antennas are parabolic reflectors. Also horns, open waveguides and slots are considered aperture antennas.

Figure 4: On board parabolic antenna
Source: Module 9.2.3 ELTICA

- Printed and microstrip antennas: They are printed antennas over a dielectric substrate, being this substrate placed in a ground plane. The shape of this printed antenna can be any, even though normally they have square-like forms. Normally, due to their small size and because of being placed over a loosy dielectric substrate, their efficiency is lower compared with other antennas.

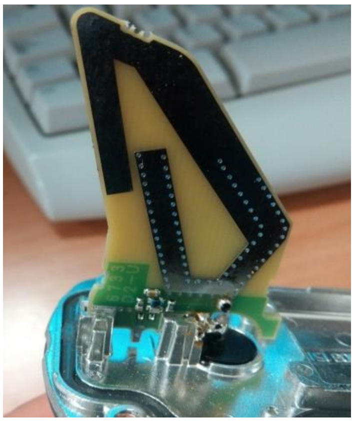


Figure 5: "Shark fin" antenna for mobile communications on board
Source: Andoni Amurrio & Julio Arellano PAWS Practica 3

- Array antennas: These antennas are used when some radiation characteristics cannot be obtained just by means of a single antenna, so two or more antennas are combined. The Yagi-Uda antenna is one of the most seen array antenna. This kind of antennas, due to their bandwidth, are normally used for radiation patterns validation.

Figure 6: Array antenna

- Integrated antennas: Sometimes antennas must be integrated in the physical design of the system, due to esthetic constrains or just to protect them from external influences (robs forces…). This brings many disadvantages at design phases, since an antenna designed to be integrated in a certain place will not be used anywhere else. In automotive sectors these antennas are very used, since they can be hidden all over the vehicle.

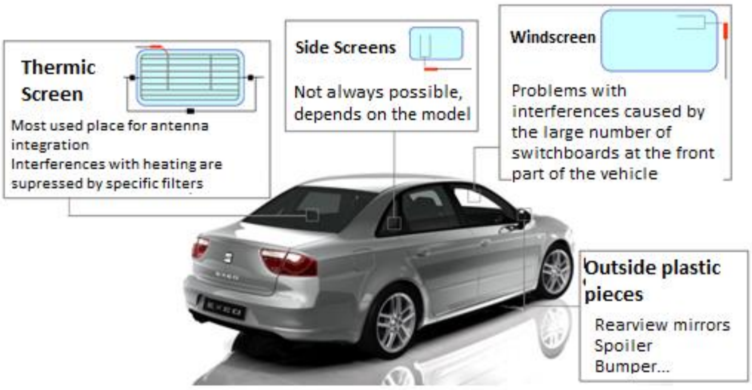


Figure 7: Integrated antennas
Source: Module 9.2.3 ELTICA

2.2.On board Services

In this section some of the most important services that can be offered on board are explained. This will make easier to understand why these specific tests that will be shown later are performed.

- Radio

  This is the most common service provided in almost any vehicle. At this point, it is necessary to make a clear division; AM and FM. In Spain AM radio is not used so much, since it has poor quality compared with FM. This is because of the frequency band of these two radio services. AM band goes approximately from 150KHz to 6.2MHz, and as said before, low frequency waves have long wavelengths. In this case, 100m antennas would be needed to obtain the best reception, which is impossible for vehicles. However, in the United States it is more usual to find AM users, because thanks to this long wavelength the same signal can be received much far away than FM, so it is a good choice for those who travel huge distances all over the country. FM reception is much easier since the antennas needed should be 70cm long, which is more viable for vehicles, as it has been shown in previous images.[5]

A special radio service becoming more and more popular is DAB, Digital Audio Broadcasting. Thanks to newly developed transmission-reception and compressing techniques, a great reception quality is obtained even for moving receptors. It gives the advantage of broadcasting a program always in the same channel without re-tuning, so apart from the improvement for users, it frees a lot of space in the radioelectric spectrum.

- DTV

Digital Television; images and sound are coded in binary in order to transmit and receive with high quality. This service is not very common nowadays, but it is becoming more and more as time passes by. Antennas for this service are much smaller (since frequencies go upper in the spectrum), and it is common to use more than one so that multipath and Doppler Effect are avoided.

- Navigation

This is one of the most important step forward in telecommunications for vehicles. The Global Navigation Satellite System (GNSS) includes the American GPS, European Galileo and the Soviet-Russian Glonass, and more emerging powers are adding their own systems, such as China and India. This makes the frequency band definition a bit difficult, but the most commonly used ones will be those at 1500MHz-1600MHz.

Circular polarization is used in this system. This is because in cities, where navigation systems are commonly used, buildings may cause bumpings, so each of them provoke changes in the rotation of the wave that will let the receiver know whether the signal received is a direct wave or a bounced one. This ceramic square is a navigation signal received (the other is shark fin for phone services).

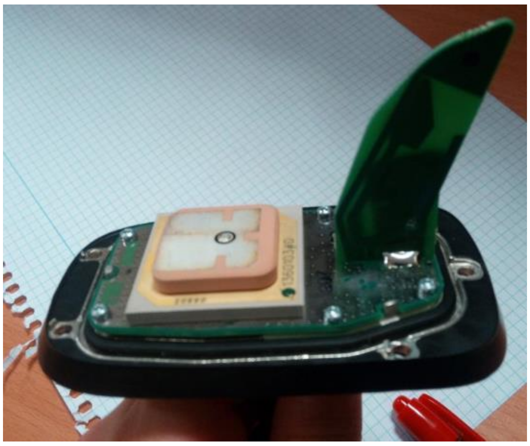


Figure 8: On board navigation antenna
Source: Andoni Amurrio & Julio Arellano PAWS Practica 3

- Wi-Fi

  This is a newly integrated service for vehicles. It is used to connect users to the vehicle as well as the vehicle itself to the infrastructure, so more than one antenna is needed. However, since Wi-Fi signals are at 2.4GHz and 5GHz, antennas are very small and can be placed easily.

Figure 9:Wi-Fi antenna for vehicles
Source: Source: Andoni Amurrio & Julio Arellano PAWS Practica 3

- Phone

  Phone services are essential for vehicles´ connectivity. Many antennas for this service must be integrated, since apart from GSM bands, Long Term Evolution (LTE) or 4G services are more and more used with time and the demand is growing up to four phone antennas in every single car.

2.3. VOLKSWAGEN group

SEAT S.A. is part of Volkswagen group, one of the leading car manufacturer of the world and first one in Europe. This consortium is formed by 12 companies from 7 European countries: Volkswagen, Audi, SEAT, SKODA, Bentley, Bugatti, Lamborghini, Porche, Ducati, Volkswagen Commercial vehicles, Scania and MAN. This picture shows the year every company that nowadays form the VW group joined it.

Figure 10: Companies composing VW group
Source: Volkswagen AG 2013

Each of these brands works on their own inside the car market, although all of them share the strategy towards common objectives. Nowadays, 99 production factories distributed in 18 countries in Europe and 9 in Asia, Africa and America form the VW group.

The main interest for this project is the internal regulation of Volkswagen group. A huge set of documents regarding different areas needs to be analyzed in order to fulfill all requirements respecting these regulations. This is a list of the most used documents during this entire project:

- **TL-82133**: Functional requirements for on-board antennas. The most used document, helped to orientation. In next chapters some of the requirements of this document have been gathered.
- **TL-81000**: EMC, Electromagnetic compatibility. Regulations about configuration of devices and setups so that any undesired radiation can affect to proper functioning of systems.
- **VW-99000**: Global requirements for services regarding to component development.

- **VW-80000**: Electric and electronic components in vehicles; general specifications, test conditions and tests.

2.4. SEAT

SEAT (Sociedad Española de Automoviles de Turismo) was founded in 1950 by the Spanish government´s National Industry Institute. Headquartered in Martorell (Catalunya), it´s divided in three main factories; El Prat de Llobregat, Zona Franca and Martorell. However, the production of different vehicles is divided all over Europe, as the following picture shows:

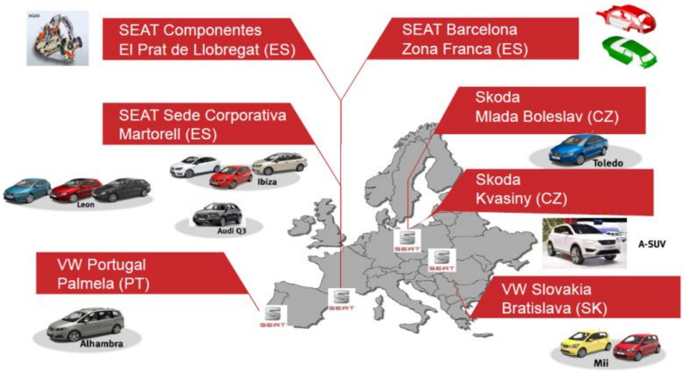


Figure 11: Europe locations where SEAT cars are produced
Source: Volkswagen AG 2013

SEAT is the only car company in Spain able to design, develop, produce and commercialize their vehicles. Nowadays there are more than 14.000 people working for SEAT, and the invoicing in 2014 has been 7.500 million €.

The following picture shows the internal structure of SEAT, divided in 7 areas:

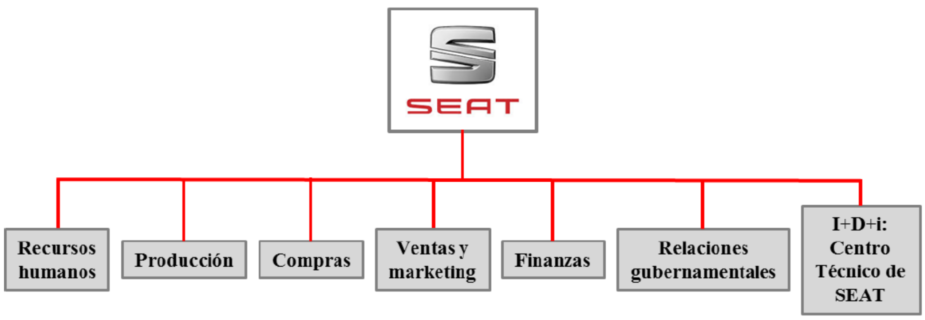


Figure 12: SEAT flowchart
Source: intranet SEAT

Centro Tecnico SEAT is where all the research and development is performed, provided with all the infrastructure and resources needed to fully develop a new car. Here work more than 1000 highly qualified people from all over the world, with a great future vision that allows creating a new car out of just an idea. Following a similar structure in all the departments, CTS SEAT is divided in 9 sections.

This project is located within the work at Electric Development (EE, from Entwicklung Elektrik/Elektronik in german). Inside the EE group, which is really big, EE-52 is leading this project, since everything related to antennas is managed by this department.

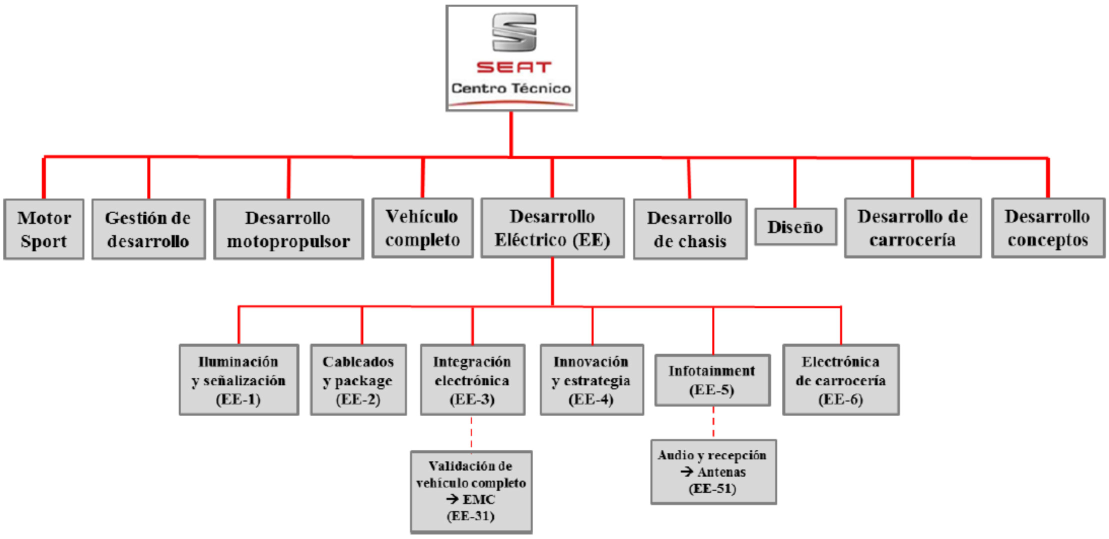


Figure 13: Centro Tecnico SEAT
Source: Intranet SEAT

Here is a brief summary of the groups that form Electronic Development at Centro Técnico SEAT:

- **EE – 1: Lighting and Signposting:** Management, control and execution of all the vehicle´s lighting system development.

- **EE – 2: Wiring and package:** Management, execution and control of the car´s wiring system, ensuring all functionalities work properly and safely. Wire bundles´ paths must be designed following the quality, cost and timing objectives.

- **EE – 3: Electronic integration:** Management of all activities related with control and documentation for electronic development.
    - **EE – 31: Complete vehicle: EMC** (Electromagnetic Compatibility): Many people from this group have helped in this project, contributing with their

experience in electromagnetic issues, like the election of an appropriate shield box for the validation laboratory.

- **EE – 5: Connected car & Infotainment:** Management, execution and control of audio, phone, navigation and entertainment electronic system development, making sure all security issues are respected. It is essential to accomplish economic, timing and quality objectives.

    - **EE-51: Entry main units y ABT & ITC**
    - **EE-52 STD/HIGH main units, Antennas and Sound:** The antennas department, at which this project and all projects regarding to antenna systems are held, has been newly moved to EE-52.
    - **EE-53: Infotainment functions**
    - **EE-54: HMI & Infotainment pre-development**
    - **EE-55: Connected car**

- **EE-6: Bodywork electronic:** Management, execution and control of the development of components for instrumentation, air-conditioning and switching, ensuring their security and quality. Quality, cost and timing objectives must be respected.

2.5. Infotainment

As said before, antenna projects (including validation of antenna systems) is part of the Infotainmet department at SEAT. But, what is infotainment? It is a newly created word, coming from mixing Information and Entertainment. Infotainment is the system that covers all the functions that provides drivers and passengers with entertainment (music, video and connectivity) and information/communication (navigation, telephony and internet) independent to the driving.

An infotainment system is composed by the following elements:

- Infotainment Main Unit (MU): It is the main switchboard that performs the main functions of the system, could be some kind of a brain of the full system. Interacts with user´s input/outputs and peripherals that include user´s functions, and has self-diagnosis capability as well as peripheral’s diagnosis. The HMI (Human Machine Interface) is integrated in the MU.
- Peripherals: They are external switchboards that include functions that the MU does not. These functions can be indispensable, joysticks and displays for instance or optional, like Bluetooth switchboards or DAB/SDARS systems (which would require antennas). It is usual that when an optional function gets extended in the market, it eventually gets integrated in the MU.
- User´s input/outputs: These devices allow the communication between users and the system by selecting an available function. Inputs can be tactile displays or buttons and voice recognizing microphones, while outputs can be displayed or by means of speakers.

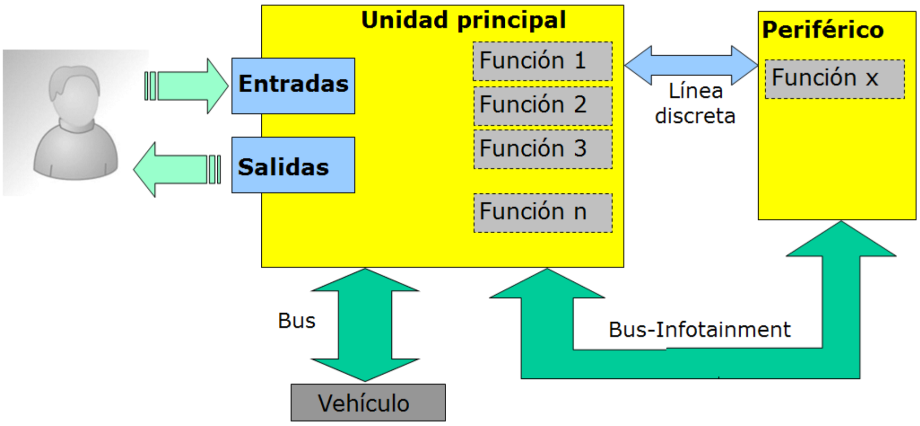


Figure 14: Infotainment block diagram
Source: ELTICA MEE9

Regarding to the **functions**, here is a brief list of the main ones that any Infotainment system includes:

- **Broadcast services reception**: Audio services; AM, FM, DAB, America´s Satellite Digital Audio Radio Service SDARS… and video services; analog TV and Europe´s DVB, DMB… For every single service, an antenna system is required, which include the antenna and its amplifier, all the wiring and the tuner.

- **Media reproduction**: Decodification and reproduction of different media formats obtained from many diverse supports: Cassete, CD/DVD/BlueRay readers, USB ports, SD card readers…
- **Telephone and connectivity**: Exterior communication integrated on board. Includes more mobile services further than phone connection, such as internet access or online services. The mobile phone is integrated in the car, so that it becomes an interface between users and the exterior. Includes the European Union´s project "e-Call".
- **Navigation**: Guiding system, from a known place to a pre-selected destination, using vision and acoustic indications. Includes new functionalities like dynamic and/or predictive navigation.
- **Sound**: It´s the system responsible of the electrical signal processing so that it can be adapted to the vehicle´s environment and turned into acoustic signals.
- **HMI**: Human Machine Interface. Its main objective is to present the users all the functions available in a clear and esthetic way.
- **Information/Vehicle adjusts**: The information is referred to the well-functioning parameters of the car, throwing warnings in case of anomalies. Using the MU´s display and buttons, drivers can adjust some parameters regarding to driving comfort.
- **Voice recognition**: Nowadays, almost any function mentioned in this list can be controlled through voice commands.

It can be easily seen that most of these functions need one or more antennas to work, making obvious the need of having good quality antenna systems.

3. Device under test & Requirements

This chapter is going to present a deep analysis of the device under test in this validation laboratory. The impedance adapter will be described, showing some specific configurations that will allow the reader to view a real use case of the device. Then, after studying and analyzing Volkswagen´s internal regulations, which are more than many documents regarding many aspects, a summary of the requirements the impedance adapters must fulfill will be presented. This will help to understand the next chapter, which will describe the procedure to measure all the different parameters that will determine the validity of the device.

3.1. Impedance adapter

As said before, the main objective of this project is to start up an antenna validation laboratory at SEAT. This validation laboratory will perform different tests that will be explained later; these tests will be carried out over this device: the Impedance adapter.

This component, provided and previously validated by different suppliers depending on the car model, will have to be validated in this laboratory before being placed anywhere, once Wolkswagen internal regulations are fulfilled is verified.

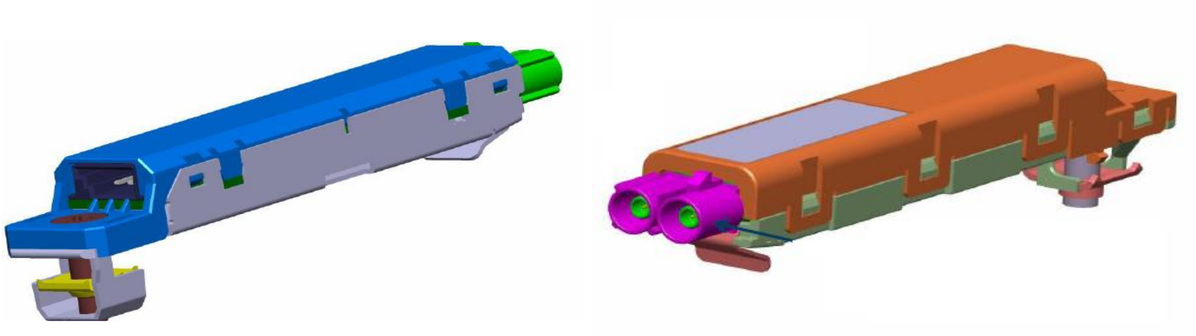


Figure 15: Impedance adapters´physical design
Source: LAH 8V0.035.C

The main function of this device is to make the impedance matching between the antenna and the rest of the antenna system (cables and tuner) that performs the signal processing, so that this transmission/reception is optimum. There are some filtering stages at which different input signal are splitted in order to be received separately. In some cases, there may be some amplifying stages depending on the needs of the signal.

Picture 13 shows two *FAKRA (*SMB connector with specific coding, depending on the service provided) connectors, green and pink; depending on the frequencies the device is dedicated for, there may be one or two ports to split the signal obtained from the antenna and drive it to the radio (or switchboard for signal processing). The input port, a 3 pin MQS connector, is connected to the antenna, which can be located in many places of the car, as it has been explained in previous chapters. It is composed by three pins (1, 2 and 3) and they have different uses. Here is an example of the different antennas and impedance adapters that can be configured in a car:

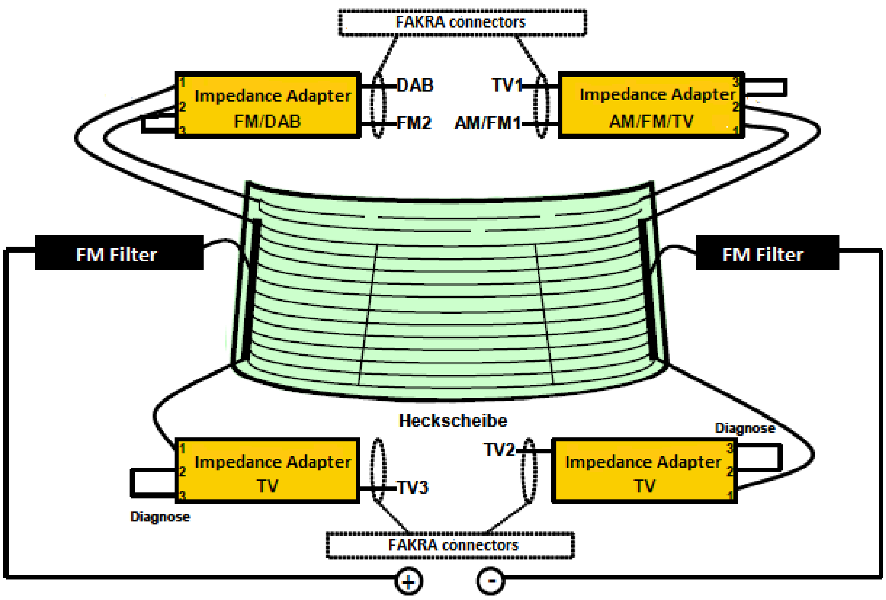


Figure 16: Specific impedance adapters' configuration
Source: Audi A1 2015 project

This configuration combines both variations *of Impedance adapters* mentioned before; some of them receive two different services (i.e. FM and DAB) from the antennas placed in the rear screen, while others receive just one (i.e. TV).

The two IWs at the bottom of the picture show a shortcut between pins 2 and 3. This configuration is commonly used, and during validation tests it will be a very important factor to consider. This shortcut regards to the Diagnosis function, and it is used to check if the component is correctly connected to the whole system; if this shortcut is not detected, that would mean that there is some kind of error at connecting the device.

Regarding to the FM filters, they allow connecting antennas through the thermic screen. If they were not, high frequency signal would spread through the wiring of the antennas and the whole car would radiate as an antenna. Thanks to this filter, that RF component perceives a very high impedance at that point, so only the DC component that feeds antennas propagates through the wires.

These devices are fed by a special feeding technique called “Phantom”, which will be deeper explained later in this memory. This feeding allows transmitting DC and RF signals through the same coaxial.

This is an inside view of the highlated impedance adapter in the previous picture, which works for AM, FM and TV services. It shows the different splitting, filtering and amplifying stages:

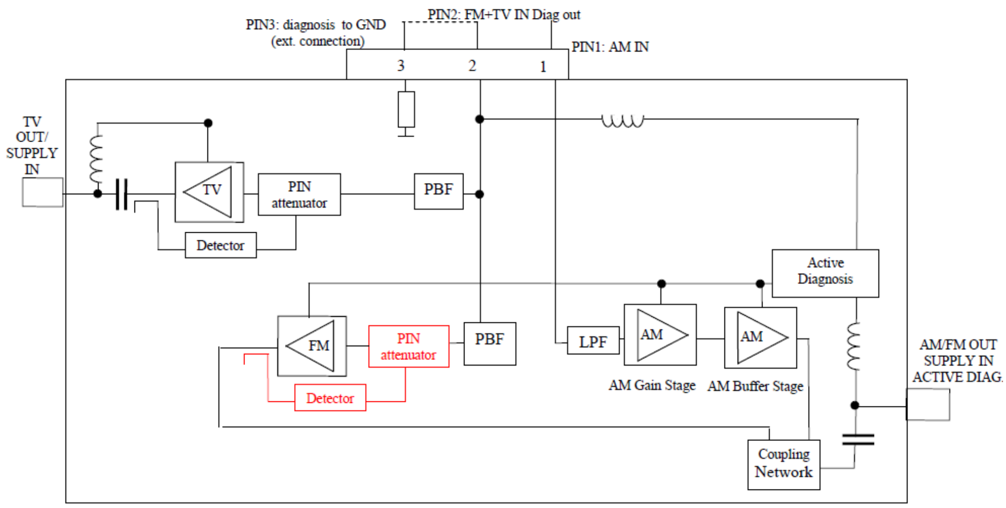


Figure 17: Inside view of an impedance adapter
Source: LAH 8V0.035.C

3.2. Requirements and regulations

In this section the electrical requirements *Impedance adapters* must fulfill are presented. As mentioned before, all this information is gathered thanks to the deep study of Volkswagen´s regulation, collected from many documents and reports like the ones mentioned before [6]. In order to have a clear overview of them, and taking into account the different frequencies at which they can work at, this section will be divided into different services; radio reception and TV reception.

The following chart shows the relation of frequencies and services, the same way they will be mentioned all over this memory. Since some of these frequency bands are out of the boundaries of interest for the company, they will not be mentioned any more apart from this table.

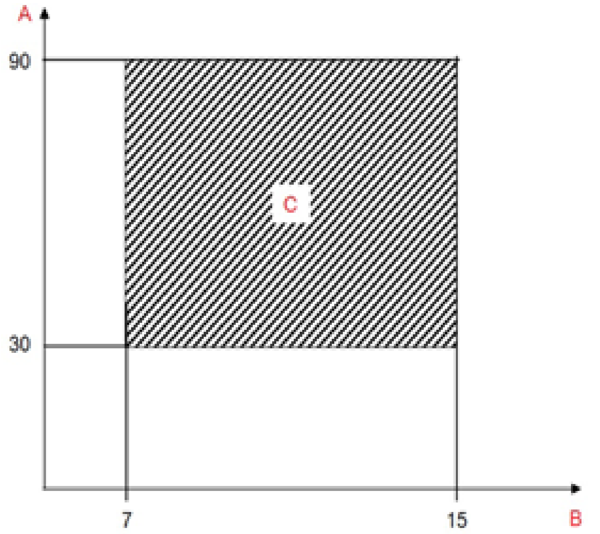
Symbol	Frequency (MHz)	Band
F_0	0.15 to 0.285	LF
F_1	0.52 to 1.71	MF
F_2	5.95 to 6.2	HF
F_3	76.0 to 90	FM Japan
F_4	87.0 to 108.0	FM RDW
F_5	174.0 to 240.0	DAB III band
F_6	1452.0 to 1492.0	DAB L band
F_w	162.4	USA Meteorological band
F_7	47.0 to 68.0	TV, band I Europe
F_8	90.0 to 108.0	TV, band II Japan, channels 1 to 3
F_9	174.0 to 230.0	TV, band III Europe/ 4 to 12 channels Japan
F_{10}	462.0 to 862.0	TV, bands IV and V Europe / 13 to 62 channels Japan
F_{GPS}	1574.397 to 1576.443	GPS
F_{SDARS}	2320.00 to 2345.00	SDARS

3.2.1. Radio Reception

- Amplifier-train current consuption

First of all, in order to ensure the Diagnosis function of the device, the electrical behavior must be tightly controlled. Therefore, some feed voltage ranges have been set, as well as a current consumption range that should be satisfied.

So, this pictures show the relationship between the feed voltage (B) and the current consumption (A), for AM/FM and DAB. The areas in shadows are the “permited” values of this relationship:



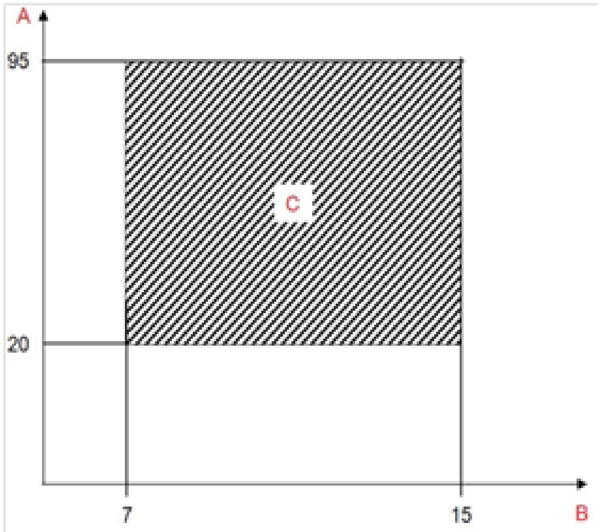


Figure 18: Current consuption and voltage relationships. Left: AM/FM Right: DAB
Source: TL 82133

- Amplification Measurement

The frequency response is a very important parameter to verify in these devices. To do so, the forward gain is measured. The S21 parameter, expressed in dBs, must stay at a certain range, which will vary depending on the operating frequency:

Band	Frequency range (MHz)	S_{21} (dB)	S_{11} (dB)<	S_{22}(dB)<
AM	f_0 0.15-0.285	-12 – -8	-10	-10
	f1 0.52-1.71			
	f2 5.95-6.2			
FM	f_3 76-90 (FM Japan)	3.5 – 5.5	-10	-10
	f_4 87-108 (FM RDW)			
DAB	f_5 174-240 (III Band)	12 - 20	-10	-8
	f_6 1452-1492 (L Band)	12 – 18	-10	-8

- Intermodulation products

In this section the strong signal requirements are presented. Considering that input signals are formed by many frequency components, the intermodulation products become very important parameters in circuits; they help to characterize the non-linearity of a receiver.
[1]Let´s consider an input signal formed by two pure tones at ω_1 and ω_2 (where f_1 and f_2 are near each other) and equals in amplitude (A). It could be expressed as follows:

$$(1)\ X(t) = A \cdot \cos(\omega_1 \cdot t) + A \cdot \cos(\omega_2 \cdot t)$$

The following equation shows the output expression of the RF receiver:

$$(2)\ y = f(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + \ldots$$

Where:

$$a_0 = f(0)\ ;\quad a_1 = \left.\frac{df(x)}{dx}\right|_{x=0}\quad ;\quad a_2 = \left.\frac{1}{2!}\frac{d^2f(x)}{dx^2}\right|_{x=0}\quad \ldots\quad a_n = \left.\frac{1}{n!}\frac{d^nf(x)}{dx^n}\right|_{x=0}$$

So, introducing (1) in (2), the overall output function would be:

$$y = f(x)$$
$$= a_0 + a_1 \cdot [A \cdot \cos(\omega_1 \cdot t) + A \cdot \cos(\omega_2 \cdot t)] + a_2 \cdot [A \cdot \cos(\omega_1 \cdot t) + A \cdot \cos(\omega_2 \cdot t)]^2 + a_3 \cdot [A \cdot \cos(\omega_1 \cdot t) + A \cdot \cos(\omega_2 \cdot t)]^3 + \cdots$$

$$= b_0 + b_1 \cdot (cos\omega_1 t + cos\omega_2 t) + b_2 \cdot (cos2\omega_1 t + cos2\omega_2 t) + b_{11} \cdot [\cos(\omega_1 + \omega_2)\, t + \cos(\omega_1 - \omega_2)\, t] + b_3 \cdot (cos3\omega_1 t + cos3\omega_2 t) + b_{12} \cdot [\cos(2\omega_1 + \omega_2)\, t + \cos(2\omega_1 - \omega_2)\, t + \cos(\omega_1 + 2\omega_2)\, t + \cos(\omega_1 - 2\omega_2)\, t] + \cdots$$

It is easy to appreciate that many frequency components appear in this expression; these are intermodulation products. The higher their order is, the smaller will be their effect in the receiver because of the progressive reduction of a_n constants. Second order IMs are those at

$\omega_1 \pm \omega_2$. Therefore, their contribution is not always in the boundaries of interest of on board systems. However, third order intermodulation products are going to be crucial, since they will appear at frequencies near the operational band of the receiver, as the following picture shows:

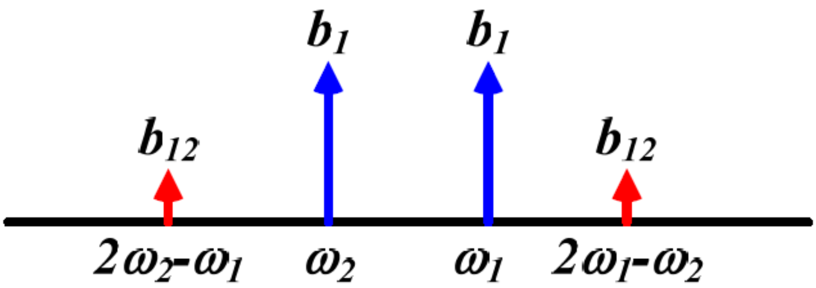


Figure 19: 3rd order intermodulation products
Source: Universidad Técnica Federico Santa Maria

It will be essential to avoid these effects, and in case they appear, some maximum levels have been set in order to ensure the correct function of the system.
In this table the IM3´s maximum values have been collected for the different radio reception services:

Band		**U_{in}* (dBµV)**	**IM3 (dB)>**
AM	-	120 >	50
FM	-	85 >	75
	-	$85 \leq U_{in} \leq 120$	60
DAB	III Band	85 >	70
	L Band	80 >	70

*U_{in} is the level of the input signals, those generated by signal generators.

A particular case of these intermodulation products is the intrusion of frequency components generated by FM channels in AM bands. When this happens, validation tests must ensure that this signal´s power is not higher than **20 dBµV.**

- Noise Factor

In RF, the signal to noise ratio shows the relationship between the pure signal and its noise. The noise factor (NF) is the cause of the degradation of this parameter, so a low value of the NF means a good performance of a device.[3]
The following picture shows some examples of different phenomenon and the noise they generate, expressing the noise factor F_a (dB) and the noise temperature T_a (K), at different frequencies. Once the noise temperature is obtained, it is easy to determine the power of the noise:

$$N_a = kT_a B \mu_r$$

where k is Boltzman´s constant (1,38·10−23 J/K), B is the noise´s bandwidth and μ_r is the antenna´s ohmnic losses efficiency.

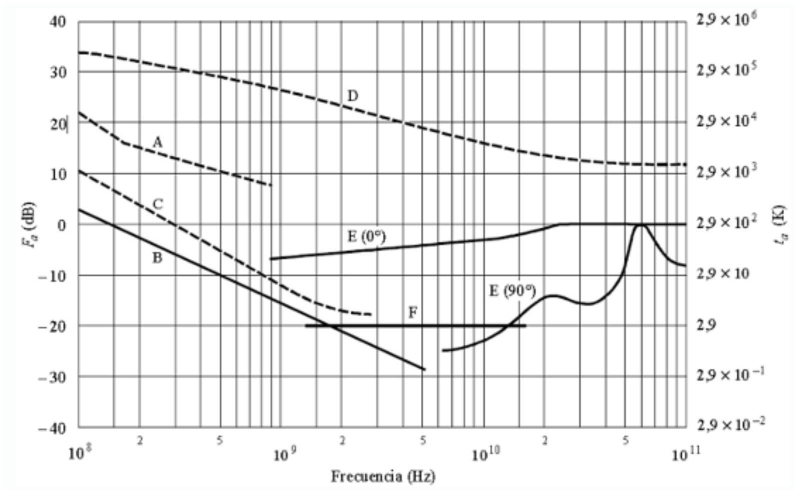


Figure 20: Noise figure for different noise sources

In the picture above *A* is for the artificial noise at a commercial zone; *B* and *C* are galactic noise; *D* is the noise generated by the sun; and finally *E* is the noise all over the sky, provoked by oxygen and water vapor.
These are the maximum noise factor values admitted when validating a device for radio reception frequencies.

Frequency Band	**F (dB)**
f_3 , f_4	< 3

f_5 , f_6	< 1.5

- Noise Level

The sensibility of an antenna system is tightly related with the internal noise of the antenna, such as the noise generated by amplifiers and many other components, but also external noise sources have a big impact on it. This external noise sources can be natural or artificial; engines and electromechanic generators, switches… are examples of external and artificial noise sources, normally at low frequencies. Natural noise sources are atmospheric phenomenon that may cause interferences in radio communications; the sun is a big white noise generator that affects to satellite links.

Frequency Band	**U_a (dBμV)**
f_0	$\leq$ -12 + G
f_1, f_2	$\leq$ -14 + G
f_3, f_4	$\leq$ -7.5 + G

This table shows the maximum level of the noise that cannot be exceeded in any case. The forward gain of the device under test has to be considered during the tests; the value G shown in the table refers to the S21 parameter and it has to be added to the measurement obtained in the spectrum analyzer.

3.2.2. TV reception

- Amplifier-train current consuption

TV reception amplifiers also need to have their current consumption controlled, so that it remains at certain values when fed at 7V-15V. As said before, being out of this consumption window will be considered a malfunctioning device.

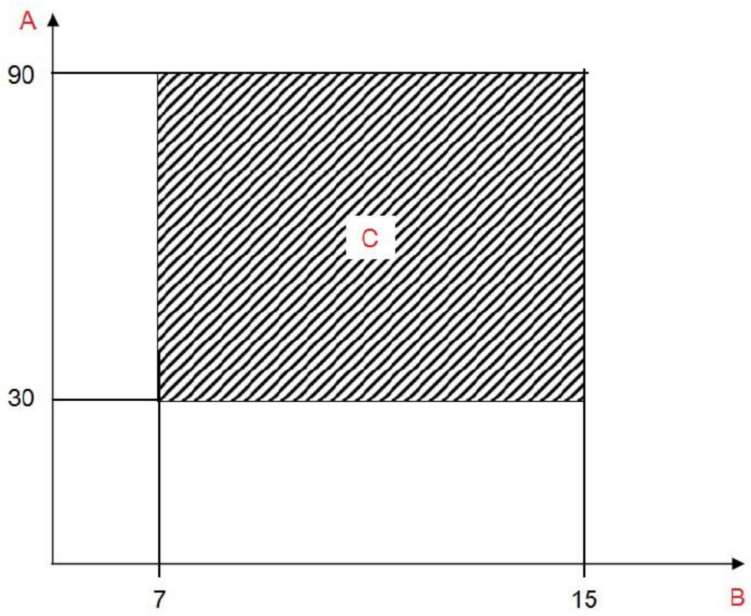


Figure 21: Current consuption and voltage relationships for TV

- Amplification Measurement

TV reception impedance adapters must fulfill some amplification requirements, regarding to the S21 parameter. They are shown in the following table.

Band	Frequency range (MHz)	S_{21} (dB)	S_{11} (dB)<	S_{22} (dB)<
TV	f_7 47-68 (I Band Europe)	12 – 22	-10	-8
	f_8 90-108 (II Band Japan)	12 – 15	-10	-8
	f_9 174-230 (III Band Europe)	12 – 15	-10	-8
	f_{10} 462-862 (IV and V Band Europe)	8 – 14	-10	-8

- Intermodulation products

Third order intermodulation products must be measured, so that their effect at reception is negligible can be verified.

Here are the maximum values these intermodulation products can reach at TV services frequencies:

Band	**U_{in} (dBµV)**	**IM3 (dB)>**
TV	85 >	75
	$85 \leq U_{in} \leq 120$	60

- Noise Factor

Previous explanations for noise´s effects can be applied to TV reception, so maximum noise factor values also have to be set:

Frequency Range	**F (dB)**
f_7, f_8, f_9, f_{10}	< 4.2

- Noise Level

When evaluating an antenna system´s sensibility, noise is an important factor to take into account. It has to be lower than some values that ensure communications will not be in risk at any case. For TV reception, those values are the following:

Frequency Band	**U_a (dBµV)**
f_7, f_8, f_9, f_{10}	≤ -12 + G*

In this case, the inside amplifier´s gain also has to be taken into account, so for any noise level measurement it must not be over -12dBµV plus the S_{21} parameter, which has been measured at previous amplification tests.

4. Laboratory Deployment

This chapter contains all the information regarding to the deployment of the validation laboratory at SEAT. The first step is to establish a timing, taking into account all the different tasks to perform, as well as their duration. Then, the material resources needed are descried, in order to have a clear view of each one´s role in the mountings. Finally, the main tests to be done are explained, going deep into details concerning the setup of all components that will be used.

4.1. Timing

In this section the main stages of the start-up of the laboratory are going to be explained. To do so, an overview timetable has been set, so that all tasks are ordered and an appropriate time can be dedicated to all of them. Of course, this timing will not be strict and it will be open to modifications during the passing of the project.

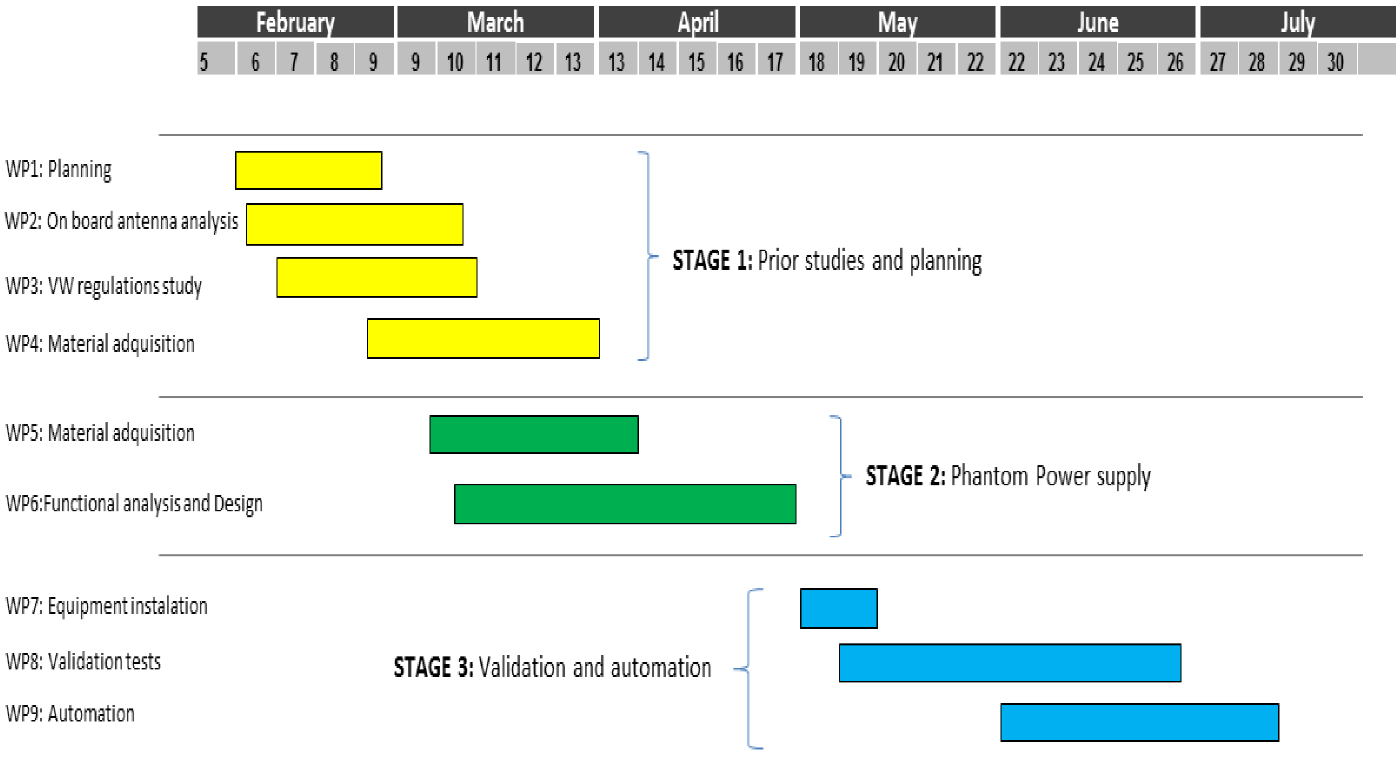


Figure 22: Project timing

As this picture shows, this project has been divided in three main stages: Prior studies and planning, phantom power supply and validation and automation. Every stage is going to be deeper explained in these lines.

- STAGE 1:

  The first stage corresponds to all the previous work that has to be done. It has been divided in four different work packages (WP):

  - WP 1: Planning: The very first task of this project. More than three weeks are dedicated to plan all the work packages and the tasks that compose them. First of all, the state of art has to be analyzed, regarding to components and equipment needed. This will help to work in the proper direction from the beginning. As an output from this work package, the timing shown in the previous image should be highlighted.
  - WP 2: On board antenna analysis: This work package is crucial for the project. Even though most antenna basics are clear for any telecommunications engineer, their application in automotive needs a deep study to understand technical concepts specific in this field.
  - WP 3: VW regulations study. As this project aims to start up a laboratory that validates Volkswagen´s components, it is important to know exactly what the internal regulations say about them. Since there are lots of regulation documents, this work package is intended to make an overall view of them all. A summarized regulations report should be an outcome from this task, so that it can be consulted when needed.
  - WP 4: Material acquisition: This work package is going to be the most important one at this stage. First, after analyzing all the material resources needed, a deep study of components and equipment has to be done. At this time, it will be necessary to arrange many meetings with different equipment supplier´s sales agents, so that they can make different offers. At this point, the

most suitable offers will be evaluated according to the previous studies done. By the end of this work package, all components for the laboratory must be ordered, in order to start measuring in next stages.

- STAGE 2:

The second stage corresponds to the development of the Phantom Power Supply, which will be described completely in chapter 6.

  - WP5: Material acquisition: This stage´s material acquisition is going to be much easier than in the previous one, since the electronic design just needs a few components which can be found in any laboratory dedicated to this issue.

  - WP 6: Functional analysis and design: Starting from a set of requirements this power source needs to fulfill, the most suitable electronic design will be done. This process will be some kind of a loop until the best performance is obtained.

It is not by chance the fact of placing this stage in the middle of the planning. It responds to a prevision made in the first stage that takes into account that it will take long to obtain the totality of material resources. This way, nonstop working is achieved all over the project.

- STAGE 3:

Final stage, at which the laboratory will be completely set up and measurements will be carried out.

  - WP 7: Equipment installation: This stage begins with obtaining all the equipment ordered at the first one. A suitable place has to be reserved, since normally they are big size devices and this laboratory requires its own operating space. After that, the proper configuration and/or calibration of all the systems is very important to obtain good results.

  - WP 8: Validation tests: The main objective of this project. A set of Impedance adapters will be chosen and measured at a time. Every measurement procedure includes the elaboration of a report, which will contain the results obtained. All the set-up and the specific procedures will be explained in the following section.

- WP 9: Automation: Once the measuring procedure is standardized and optimized, automation works will begin. To do so, all the equipment that can be automated will have to be connected to a computer, and with the use of programming software, an executable program will be developed to make the measurements the most automatic as possible.

After making the project´s schedule, it is time to begin to start up the validation laboratory. In this section, the components and devices previously chosen will be explained, mentioning their most important features. Then, the different set ups will be shown, depending on the test to be performed (direct current gain, noise…). The specific configurations of the devices will be shown, as well as a deep explanation of the measurement procedure.

4.2. Material resources

As said before, many meetings were arranged with different supplier sales agents. Of course, their first offers were best-in-class devices, too good for the requirements of this project, which are simpler. The tradeoff between the equipment´s features on one hand, and the project´s requirements and the budget on the other had to be always considered.

- Network Analyzer

  This device will provide reliable S-parameter measurements, either in logarithmic scale or in a Smith´s card. Here are some of its features:

Agilent E5062A	
Frequency range	300 KHz – 3 GHz

RF connections	Type-N, female; 50 Ω or 75 Ω
Dynamic Range	95 – 120 dB (depending on IF bandwidth)
Other connections	BNC-female (for triggering and reference signaling), VGA, USB, LAN, GPIB, Parallel port, Line Power.

For this laboratory, taking into account that most of the times SMA connections will be used, it will be necessary to acquire a SMA calibration KIT, so that the most accurate calibration can be made.

- Spectrum Analyzer

This device measures the magnitude of an input signal versus the frequency. It will be used to determine desired and undesired signals´ levels.

R&S FSV7 Signal and Spectrum Analyzer	
Frequency range	10Hz to 7 GHz
Bandwidth	28 MHz
Measurement Uncertainty	0.4 dB
Displayed Average Noise	-148 dBm
RF connections	Type-N, female; 50 Ω or 75 Ω

- Signal Generator

Microwave signal generators will be used to simulate input signals received by on board antenna systems. A reference oscillator will be added to their composition in order to improve spectral purity.

R&S SMB100A RF and Microwave Signal Generator	
Frequency range	9 KHz to 2.2 GHz
Frequency error	$< 1 \times 10^{-7}$
Signal Level	9 kHz ≤ f < 100 kHz –145 dBm to +8 dBm 100 kHz ≤ f < 300 kHz –145 dBm to +13dBm 300 kHz ≤ f < 1 MHz –145 dBm to +18 dBm 1 MHz ≤ f ≤ 6 GHz –145 dBm to +30 dBm
RF connections	Type-N, female; 50 Ω or 75 Ω
Other connections	BNC-female (for triggering and reference signaling), VGA, USB, LAN, GPIB, Parallel port, Line Power

- Shield Box

This box is a great shielding solution to make RF measurements in a properly isolated environment. It will be needed to attenuate a wide frequency range and at a high level. Moreover, its size will be crucial since apart from de DUT, more components will have to be placed in it, as it will be later shown.

HS High performance EMI / RF shielded boxes	
Frequency range	1 KHz to 10 GHz
Attenuation	Up to 120 dB (shown in next picture)
Size	600 x 400 x 400 mm (outside size, inside size slightly inferior)
Inputs	SMAx10 RF connections, LAN, USBx2, VGA.

In this graph the attenuation has been plotted versus the frequency. It is easy to see that more than 100 dB can be attenuated in the range of interest (50 KHz to 2.4 GHz aprox).

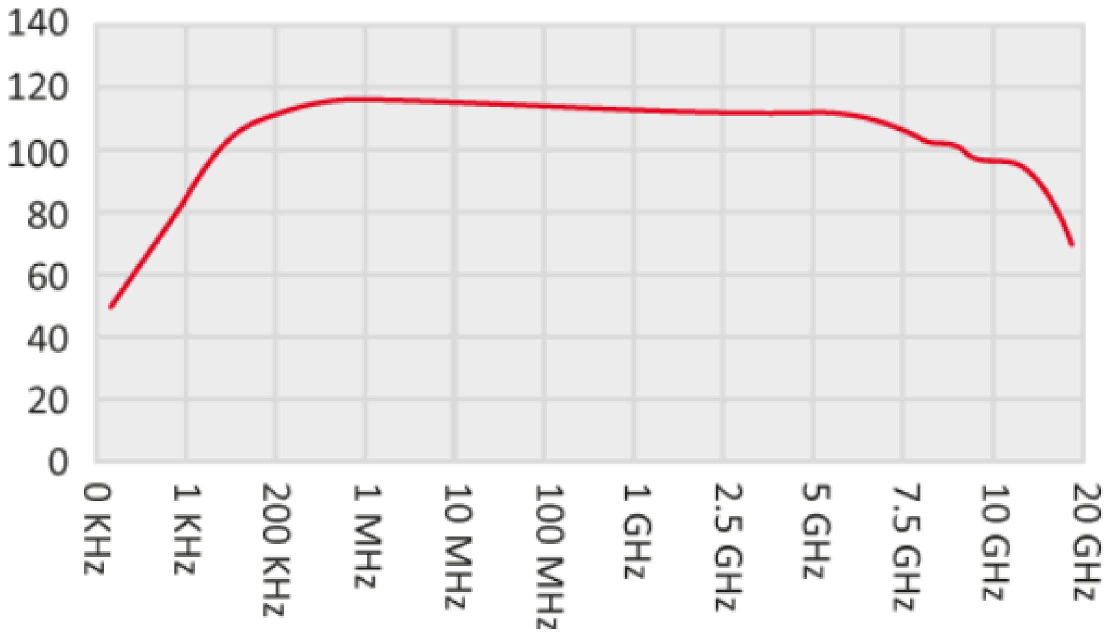


Figure 23: Shield Box´s attenuation graph
Source: Holland Shielding

- Power supply

A DC power supply is needed to feed the DUT when it is being measured. When choosing it, it was highly appreciated the capability of being programmable (via software), towards a near future when the automation of the procedure is developed. It will give the possibility of programming different voltages versus time; validation tests require analyzing the behavior of the DUT at different feeding values.

R&S HMC Power Supply	
Number of channels	3
Range	0V to 32V / 3A

Resolution	1mV/0.1mA
Other connections	USB stick connector, LAN

- Multimeter

The digital will be always connected to the DUT, in order to control the voltage at different points as well as the current consumption. This device is programmable to, so different values will be recorded for future analysis purposes.

R&S HMC8012 Digital Multimeter	
Measurement range	DC to 100KHz
Resolution	1 µV, 100 nA, 1 mΩ, 1 pF, 1 Hz, 0.1 °C/F
Accuracy	0.015%

- BiasTee

This component will allow the DUT to be fed through a single coaxial cable. It is a three point network; one corresponds to the DC (low frequency) signal that sets the bias, the other one will transport the RF (high frequency) signal and the combined port is connected to the device.

Coaxial Bias-Tee ZFBT-4R2GW+	
Frequency range	0.1 to 4200 MHz
Insertion loss	0.6 dB
Isolation	40 dB

This picture represents the ideal view of a Bias-Tee: a capacitor that blocks DC bias and only allows AC signal through in one port and an inductor allowing DC signal through and blocks AC. Of course, this is a simple version and wideband Bias-Tees require more complexity.

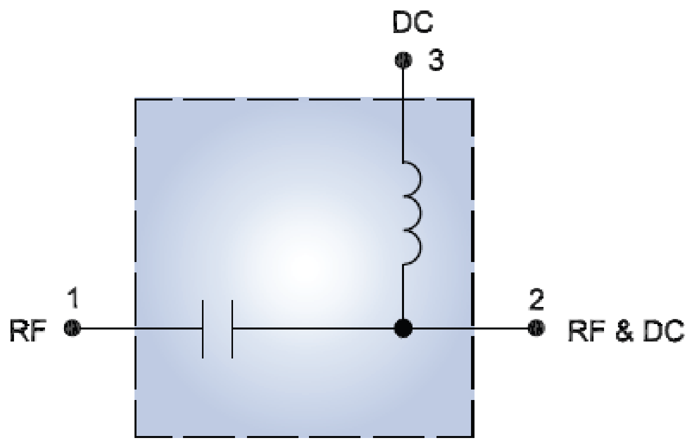


Figure 24: BiasTee´s simlified inside view
Source: MiniCircuits.com

- Other resources
  - High pass filter (MiniCircuits):

    SMA connector filter that will block low frequency signals with low attenuation in pass band.
  - Low pass filter (MiniCircuits):

    SMA connector filter that will block high frequency signals with low attenuation in pass band.
  - Power splitter/combiner (MiniCircuits)

    Mixer that will emulate a two signal input. It is important to choose the right one, which will be that which remains its performance (which should be good in terms of attenuation and return losses) at a wide frequency range.
  - 3 dB attenuator (MiniCircuits):

    Specific tests will require attenuating input signals to half of their power. The operation range will have to be checked, more than one should be acquired to cover all the frequencies under test.
  - 50Ω loads (MiniCircuits):

When working with networks composed of more than 2 ports, sometimes some of them will have to be closed and adapted with this SMA termination.

- Coaxial cables (MiniCircuits):

  Since validation tests require high precision equipment, coaxial cables should also have outstanding performance, that way their drought effects will be avoided. This picture shows the shielding of a high performance 50Ω coaxial cable:

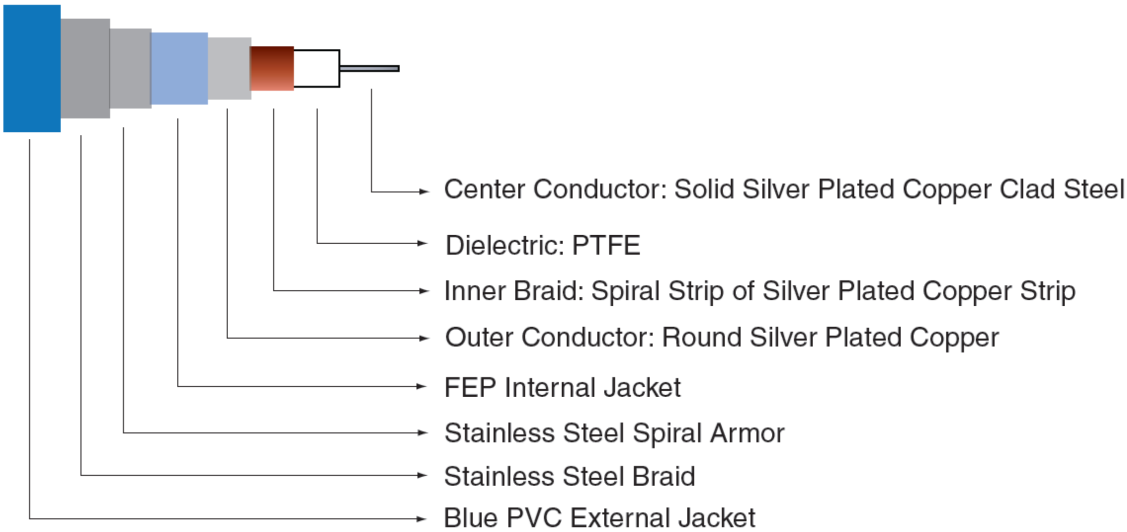


Figure 25: Coaxial cable Shielding
Source: rsonline.es

- SMA-SMB connector (MiniCircuits):

  As explained before, fakra connectors have a SMB termination that needs to be adapted to be joined to a SMA cable, which are going to be the most used cables. Low attenuation and losses connectors must be chosen.

- NI LabVIEW:

  Laboratory Virtual Instrumentation Engineering Workbench is a development environment and system design platform using visual programming language. It is recommended for hardware systems as well as test, control and design software, since it improves the productivity. It uses G programming language, meaning it is a Graphic programming system.[4]

  It was created in 1976 by National Instruments, and it was released to work over MAC machines in 1986. Nowadays, it is available for Windows, UNIX, OS X and GNU/Linux platforms. Its latest version is LabVIEW 2015.

Figure 26: National Instruments´LabVIEW logo
Source: National Instruments

- Instrument Drivers:

  During the automation process, it is going to be necessary to use different drivers in order to control every single device. These drivers are normally supplied by the equipment provider, but also can be obtained through the automation software companies.

  For this project, since not all the devices are from the same provider, different drivers will have to be used. However, the Application programming interface (API) used supports both providers´ equipment; so Virtual Instrument Software Architecture (VISA) 5.0 version will be installed and used for communication between devices and computer. This standard includes specifications for communications over GPIB, VXI, USB and LAN. Due to the facility of working with TCP/IP protocols Telecommunications Engineers have, all communications have been chosen to be over Ethernet.

4.3. Setup

This section is going to gather most of the validation tests that are going to be performed in this laboratory. For all of them the same structure is going to be followed; the test to be done is going to be presented, then the equipment setup will be shown and the material needed will be listed.

These tests will validate the requirements explained in section 3 at Requirements and regulations:

4.3.1. Amplification measurement:

This test has the objective of measuring the forward gain of the device under test, expressed in decibels by the S21 parameter. This analysis will be will be carried out for the frequency range from F_0 to F_{GPS}.

The following picture shows the setup of the instrumentation for the measurement. Notice that there is a red box containing two components, which are a Capacitor and a 50Ω load. These parameters only will have to be considered at certain frequencies (F_0, F_1 and F_2), corresponding to AM channels; they model a dummy antenna considering some effects that may appear at AM frequencies.

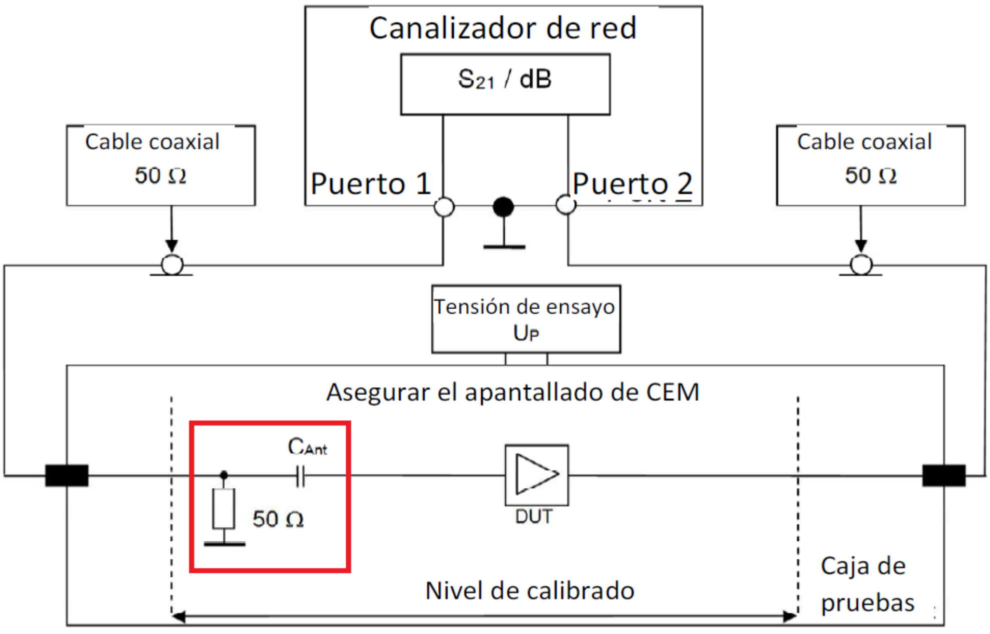


Figure 27:Amplification measurement setup
Source: TL82133

The capacitor C_{Ant} will vary depending on where the antenna is placed: it could be a 6.8pF capacitance if it is a conventional roof antenna; 56pF if it is in the side screen and 150pF if it is in the front screen.

Material needed:

- Network Analyzer
- Shield Box
- Power supply
- 50Ω coaxial cables

- Capacitors and 50 Ω loads

4.3.2. Intermodulation Products

In this section the strong signal analysis is going to be explained. First of all the intermodulation products (IP) will be analyzed and later the FM-->AM intrusion will be evaluated.

The procedure for this analysis is very simple. Two tones (equals in magnitude) are mixed; they should be near in frequency so that their IPs appear at the interest frequency range. The signal analyzer will show both tones and the intermodulation products, which will be marked and evaluated. This picture shows the block diagram of the setup that will be used to make these tests.

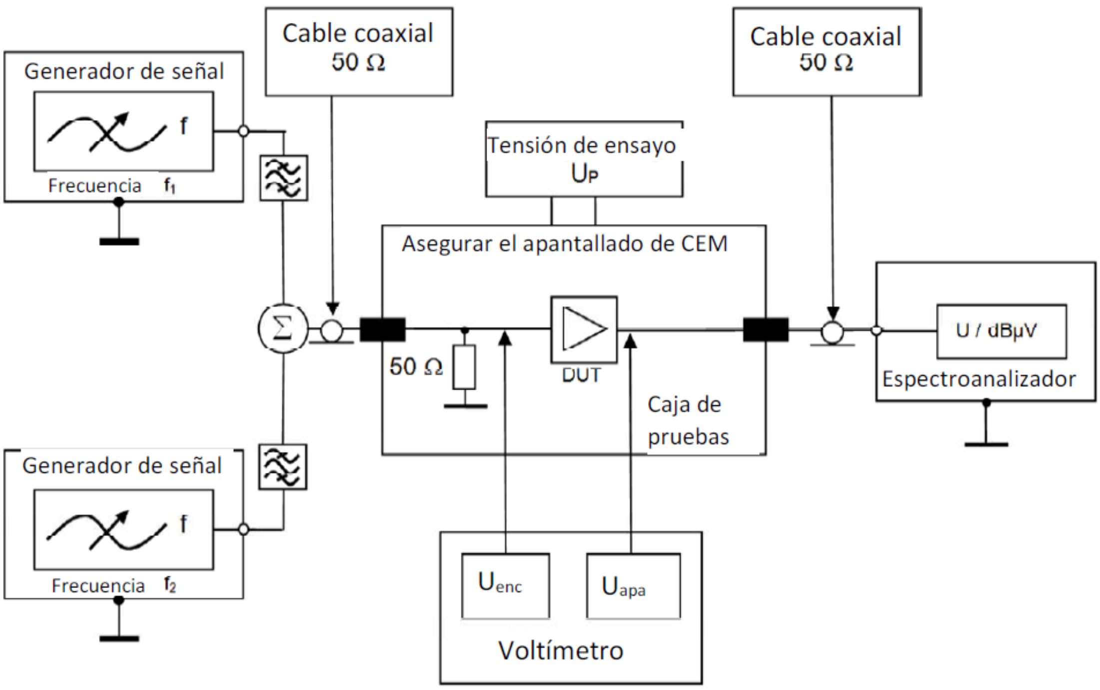


Figure 28:Strong signal measurement setup
Source: TL82133

Normally, 2nd order IPs are out of the interest band and 3rd order ones appear near the input signals, but in this tests both of them will be evaluated, as well as N^{th} harmonics. The following chart shows the frequencies at which this evaluation is going to be made.

	f1 (MHz)	f2 (MHz)
AM	600KHz	700KHz
	700KHz	800KHz
FM	88	89
	97	98
	107	108
	162	163
DAB	174	175
	207	208
	239	240
	1452	1453
	1472	1473
	1491	1492
TV	56	57
	210	211
	470	471
	610	611
	810	811
IM2	f1 + f2, f1 - f2	
IM3	2f1 - f2, 2f2 - f1, 2f1 + f2, 2f2 + f1	
N^{th} Harmonic	2f1, 2f2, 3f1, 3f2, 4f1	

Material needed:

- Signal Generator x2
- Voltmeter
- Spectrum Analyzer
- Power supply
- 50Ω coaxial cables
- Shield box
- Filters
- Signal mixer

As said before, an special case of intermodulation products is going to be analyzed: the FM-->AM intrusion. Two FM-transmitters f1 and f2 can have their difference |f1-f2| falling inside an AM-band, causing undesired interferences in an AM channel. This test aims to evaluate this intrusion, and some limits that should not be reached are established in the requirements section.

This setup has been chosen for the measurement; in this case both AM and FM inputs come through the same pin, but it could be they came through pins 1 and 2 of the DUT respectively. The spectrum analyzer will have to be configured as follows:

RBW	VBW	Range	Reference level
10 kHz	100 Hz	800 kHz	50 dBμV

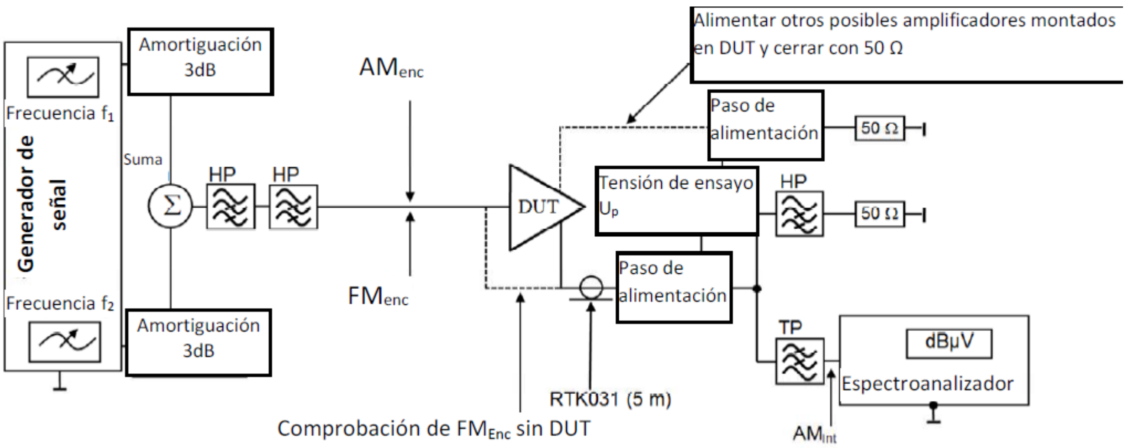


Figure 29: FM to AM intrusion measurement setup
Source: TL82133

These are the frequencies that will be analyzed to determine de FM-->AM intrusion:

f1 (MHz)	f2 (MHz)			
88	88.6	88.9	89.2	89.6
98	98.6	98.9	99.2	99.6

108	107.4	107.1	106.8	106.4

Material needed:

- Signal generator
- 3dB attenuator x2
- Signal mixer
- Filters
- Bias Tee
- Spectrum analyzer
- 50Ω coaxial cables
- 50Ω loads

4.3.3. Noise factor measurement

It has been said before that Noise Factor is the parameter that degrades signal to noise ratio (SNR). This setup is going to be used to measure it.

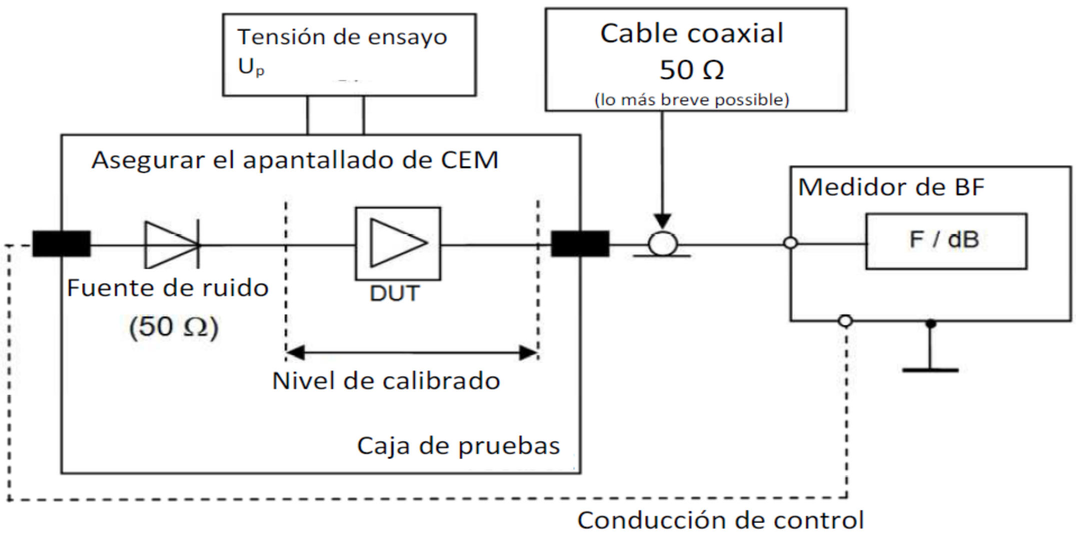


Figure 30: Noise factor measurement setup
Source: TL82133

Material needed:

- Spectrum analyzer
- Shield box

- Power supply
- 50Ω coaxial cable (short)

4.3.4. Noise level measurement

Noise level is calculated with a receiver that produces a very low noise compared to the signal that will be measured.

The following chart shows the frequencies that will be analyzed, as well as the resolution bandwidth that will have to be set at the measurement receiver.

Function	FM: f_3, f_4					AM: f_0, f_1, f_2		
Frequency (MHz)	76.1	88.1	94.1	100.1	107.9	0.161	1.053	6.0
Resolution Bandwidth (kHz)	120					9		
Function	TV: f_7, f_8			TV: f_9			TV: f_{10}		
Frequency (MHz)	47	70	108	174	200	230	470	650	860
Resolution Bandwidth (kHz)	120								

This is the setup for measuring noise level using the instrumentation of the laboratory.

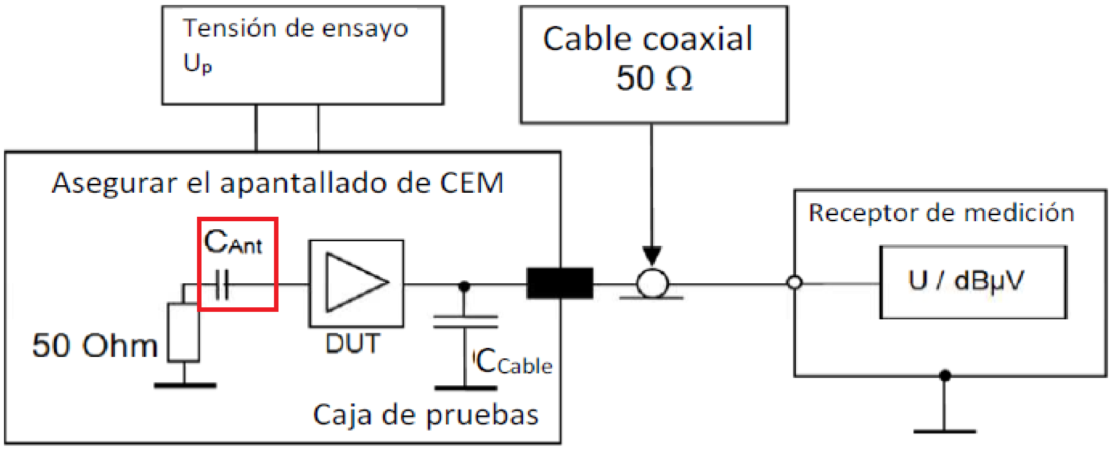


Figure 31: Noise level measurement setup
Source: TL82133

In this case, as seen before, it will be also very important to consider the capacitance of the antenna depending on where it is placed when measuring the noise at AM channels.

Material needed:

- Spectrum Analyzer
- Shield Box
- 50Ω coaxial cable
- Power supply

5. Measurements

This chapter is going to show a full set of Impedance adapters measured in the validation laboratory, following all the procedures explained in previous chapters. These impedance adapters are part of the SEAT Leon project, and with the results obtained and shown here, the validity of these components will be checked.

Figure 32: Impedance adapter set for SEAT Leon

The picture above shows the three Impedance adapters that are going to be analyzed; the first one corresponds to the FM1 and AM signals, the second one is for the FM2 signal and the last one corresponds to FM2 and DAB signals. As it can be seen, FM signal is redundant for on board systems, in order to avoid undesirable effects provoked by multipath and other bouncings.

For most cases, the instrumentation setup is not going to be shown in any chart, because most screenshots gather all the information regarding to these parameters, and the rest of the procedure has been deeply explained in previous chapters.

5.1. FM1 / AM

As said before, the amplifier-train´s current consumption has to be controlled in order to verify it remains in its correct bounds. The following table shows these current values. Two cases have been analyzed; the normal use case and the diagnosis mode. Let´s remember that pins 2 and 3 of many Impedance adapters are shortcut so that their proper connection is verified. When this shortcut opens, which would mean that some connection has not been done, current consumption goes down, as it is clearly observed here.

Feeding voltage (V)	Normal mode (mA)	Diagnosis mode (mA)
7.5	57.6	18.9
8.5	66.6	21.7
9	71.2	23.0

- Amplification measurement
    - AM measurement

These screenshots show the amplification measurements at AM band. First, this is the Gain, S21:

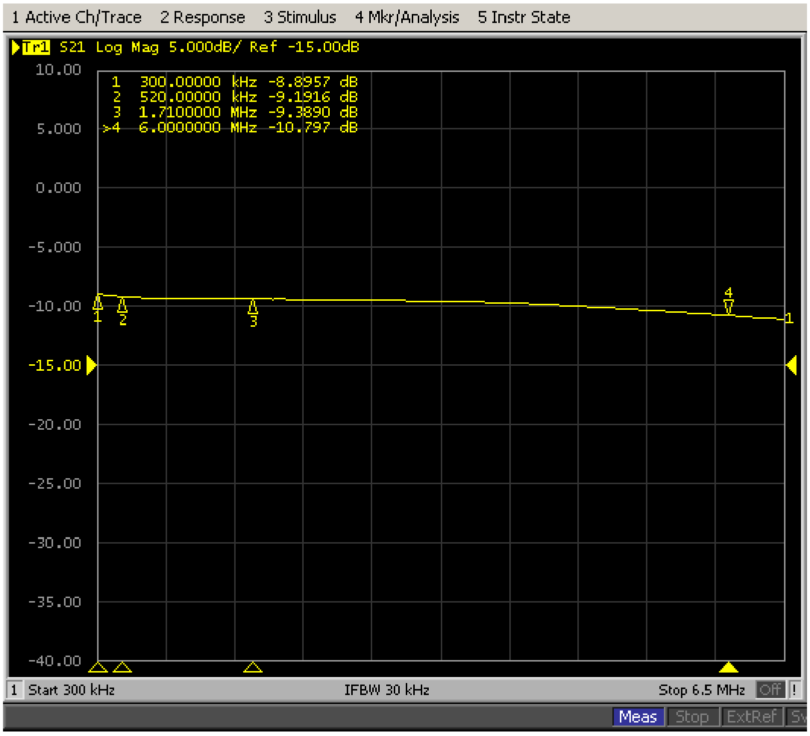


Figure 33: S21 trace (AM)

Then, the output losses coefficient, S22:

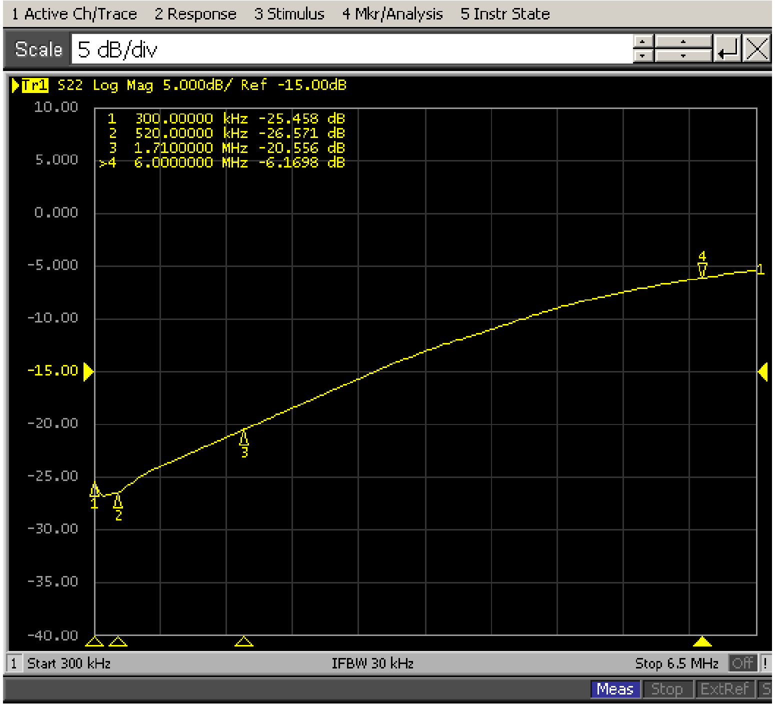


Figure 34: S22 trace (AM)

This table summarizes the amplification measurements in AM, in order to check the validity of the DUT in this test.

Parameter	Value	Valid
S21	< -10dB	YES
S22	> 3.5dB < 5.5dB	YES

- FM measurement

The following pictures are captions from the network analyzer. First, the input return loses coefficient is shown, S11:

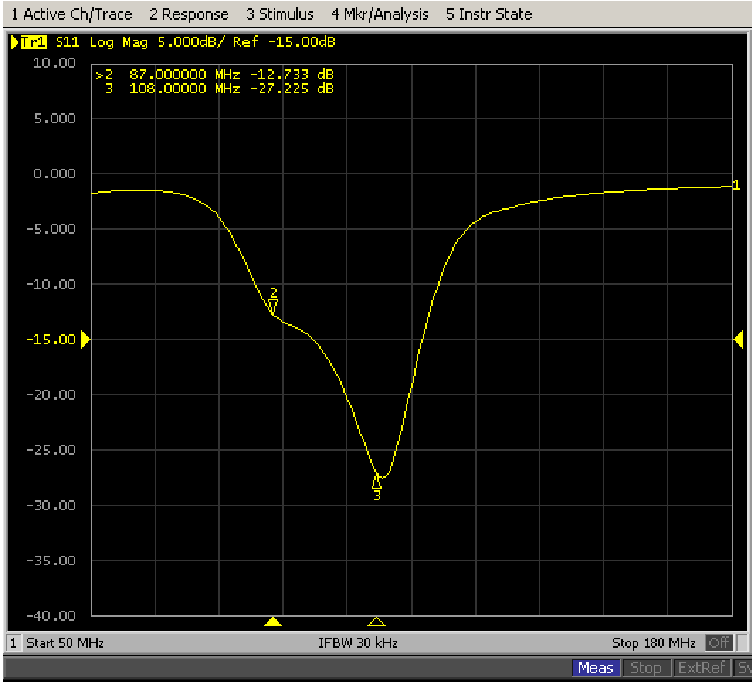


Figure 35: S11 trace (FM1)

Then the Gain (S21):

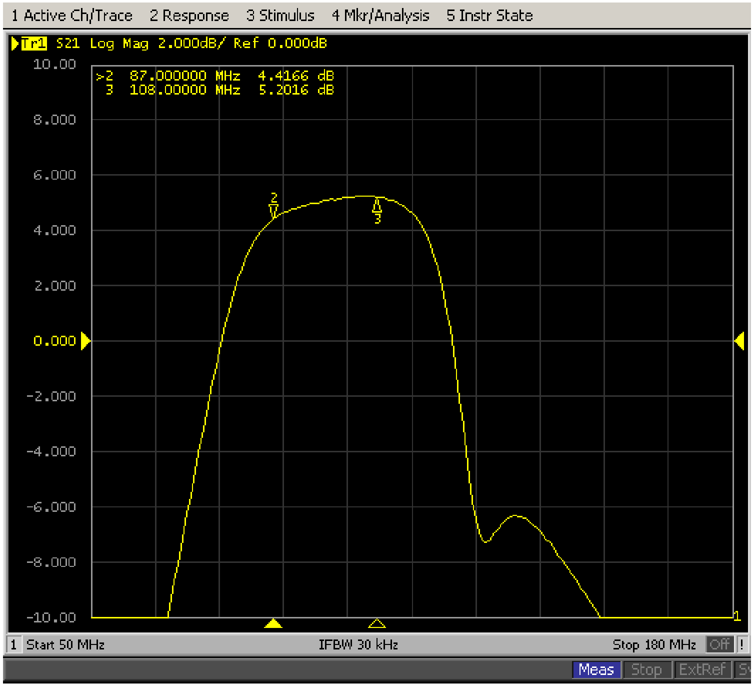


Figure 36:S21 trace (FM1)

And finally the output return loses (S22):

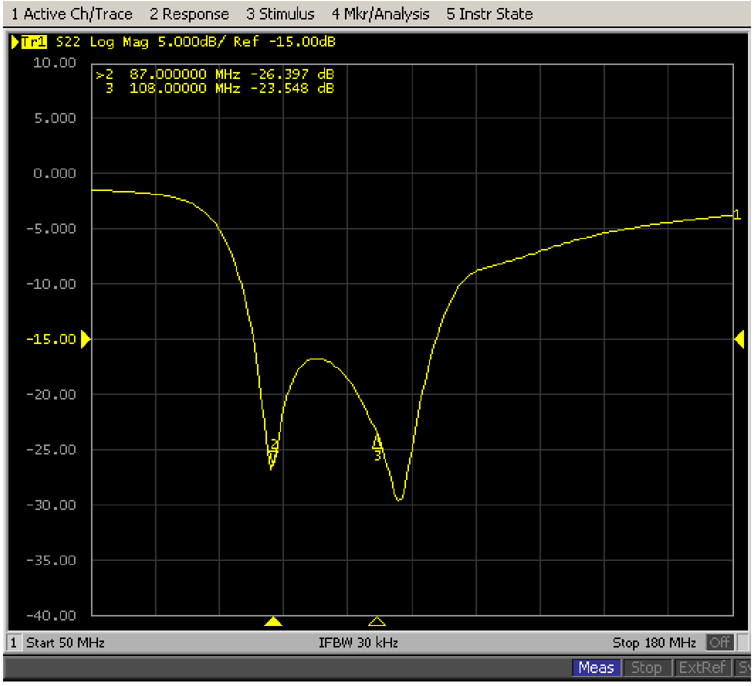


Figure 37: S22 trace (FM1)

Summary of amplification measurements at FM band:

Parameter	Value	Valid
S11	< -10dB	YES
S21	> 3.5dB < 5.5dB	YES
S22	< -10dB	YES

- Intermodulation products (IM3)

In this section intermodulation products are going to be analyzed, dividing the section in two services; AM and FM. Since both services are transmitted by the same port, the FM intrusion in AM bands will be analyzed too.

- AM measurement

First the AM analysis is going to be made, in order to measure the effect of third order intermodulation products.

As shown in previous chapters, two frequency bands are going to be analyzed. First, F_1=600KHz and F_2=700KHz, here is a caption of the spectrum analyzer:

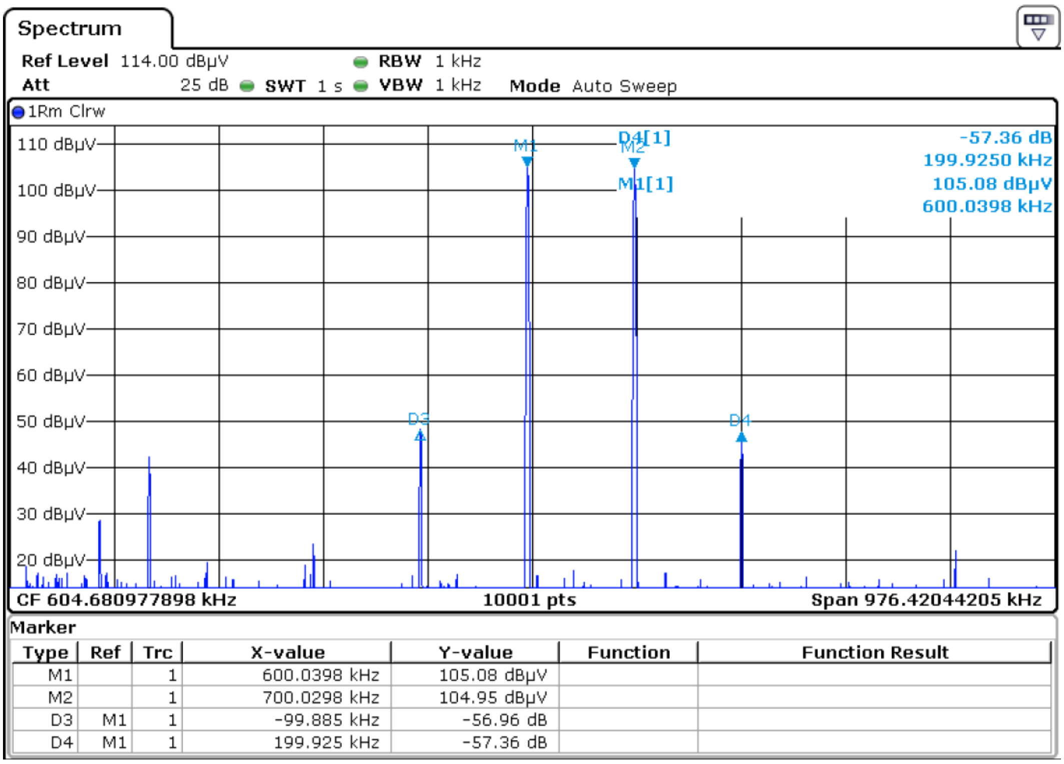


Figure 38: IM3 @ 600-700KHz trace (AM)

The second caption corresponds to the third order intermodulation products measurement, where F_1=700KHz and F_2=800KHz:

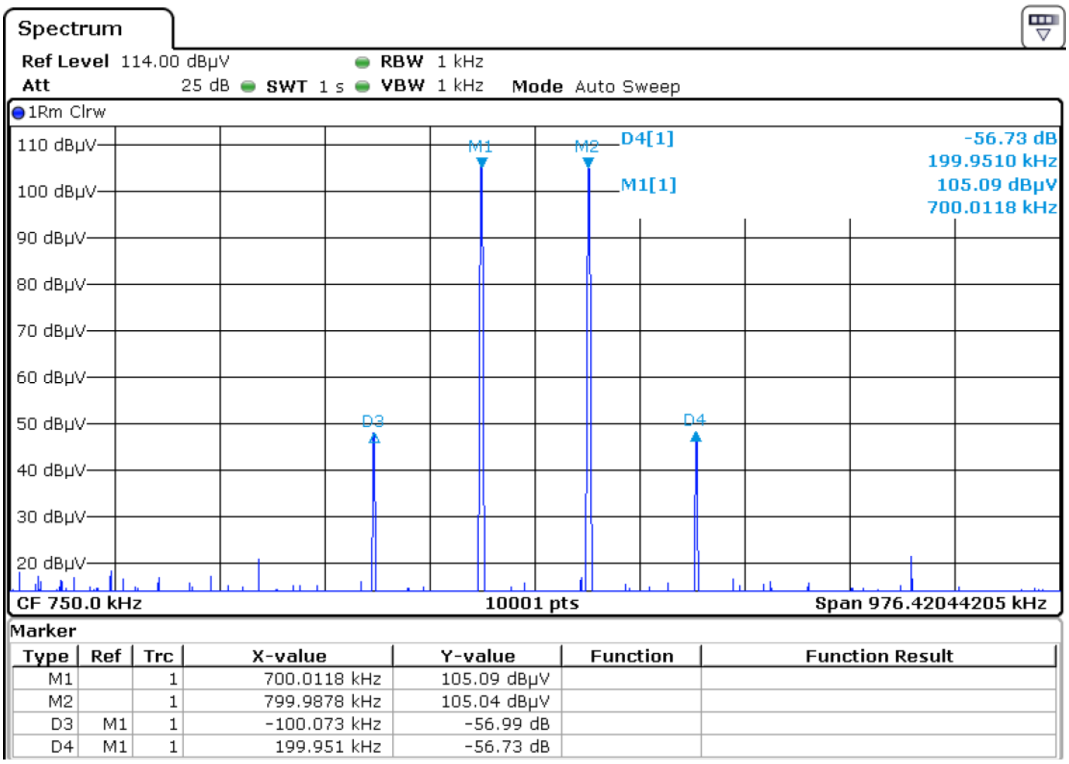


Figure 39: IM3 @ 700-800KHz trace (AM)

Here is the summary of the intermodulation products measurement for AM:

F_1-F_2	IM product level	Valid
600KHz-700KHz	-56.96dB / -57.36dB	YES
700KHz-800MHz	-56.99 / -56.73	YES

- FM measurement

Now the FM analysis is going to be performed for the FM1 operating band.

The same way as before, here are the captions from the spectrum analyzer regarding the third order intermodulation products (IM3).

First caption, where F_1 = 88MHz:

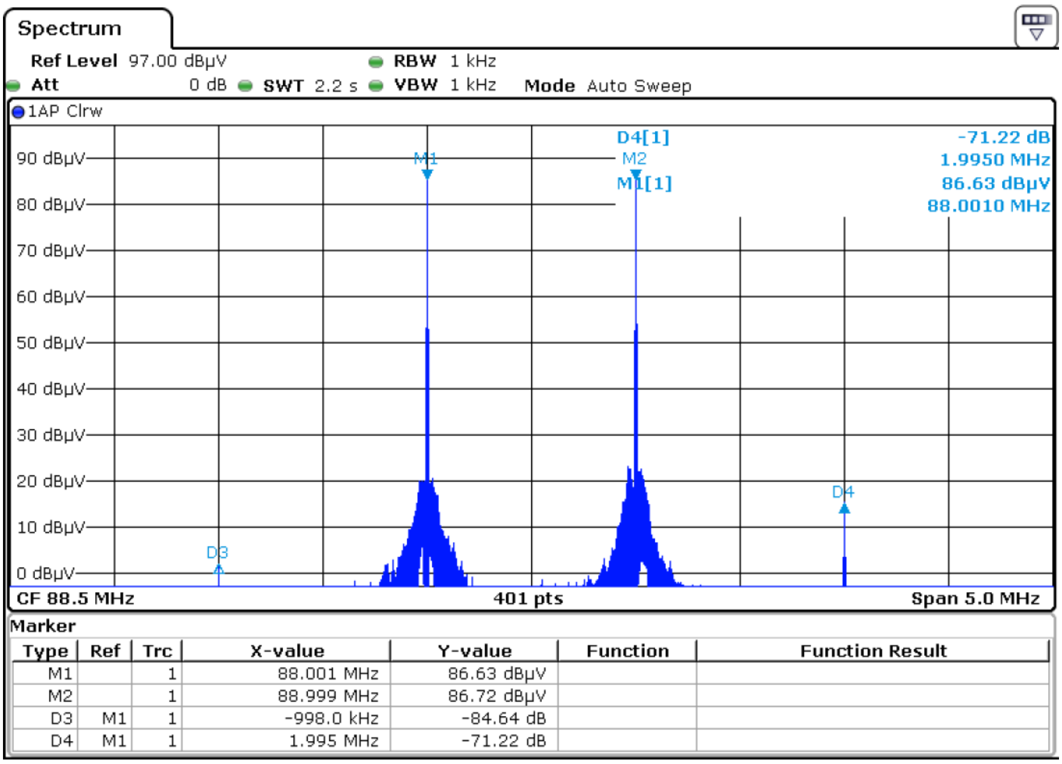


Figure 40: IM3 @ 88-89MHz trace (FM1)

Second caption, where F_1 = 97MHz:

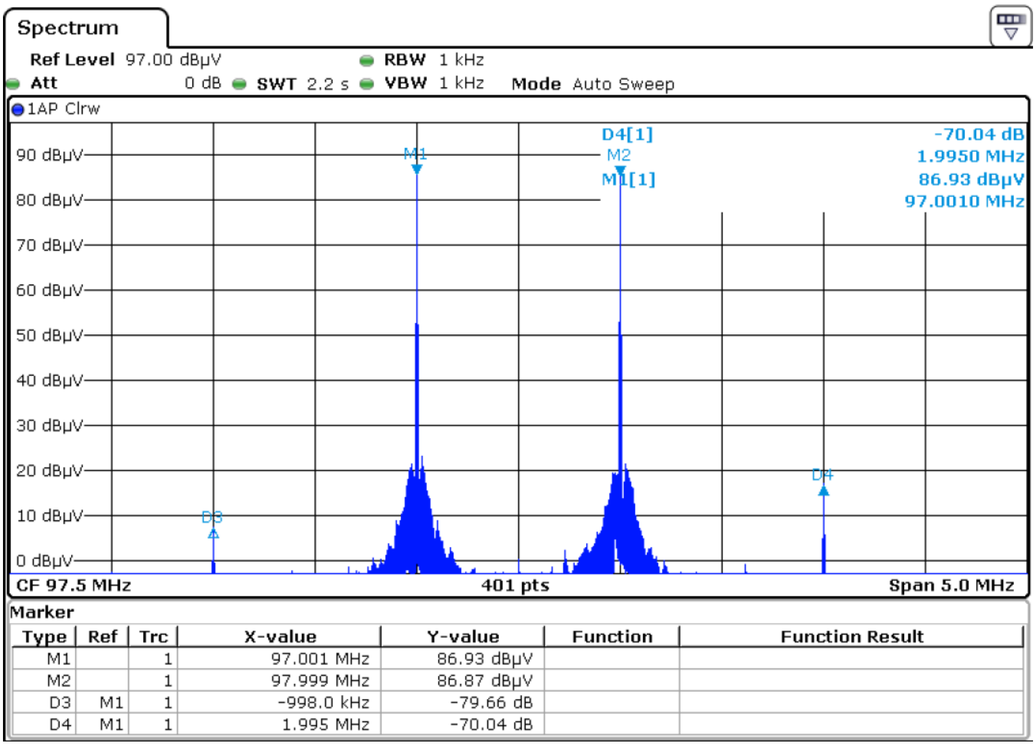


Figure 41:IM3 @ 97-98MHz

Next caption, where F_1 = 107MHz:

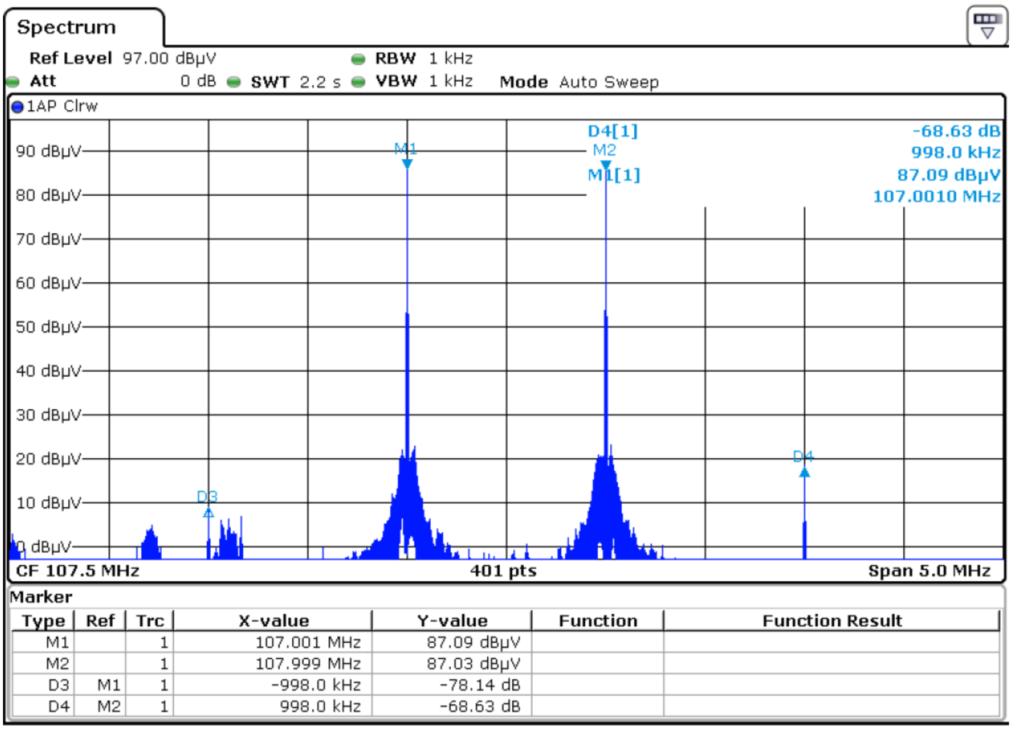


Figure 42: IM3 @ 107-108MHz

Last caption, where F_1 = 162MHz:

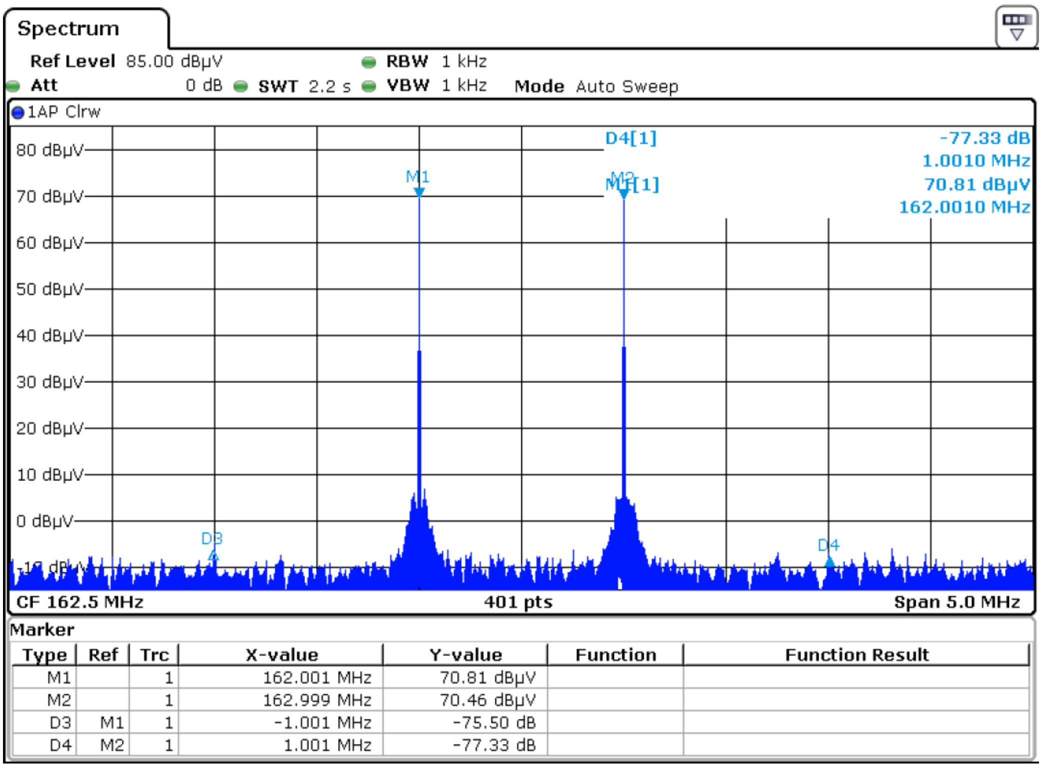


Figure 43:IM3 @ 162-163MHz

Summary for intermodulation products analysis:

F_1-F_2	IM product level	Valid
88MHz-89MHz	-88.64dB / -71.22dB	YES
97MHz-98MHz	-79.66dB / -70.07dB	YES
107MHz-108MHz	-78.14dB / -68.63dB	YES
162MHz-163MHz	-75.5dB / -77.33dB	YES

- FM to AM intrusion

In this section the FM to AM intrusion is going to be analyzed, following the instructions from chapter 4. As it is shown in this chapter, there will be three reference frequencies for F_1 and small frequency deviations for F_2:

First, F_1 = 88MHz, and F_2= 88.6MHz, 88.9MHz, 89.2MHz and 89.6MHz. Here are the results:

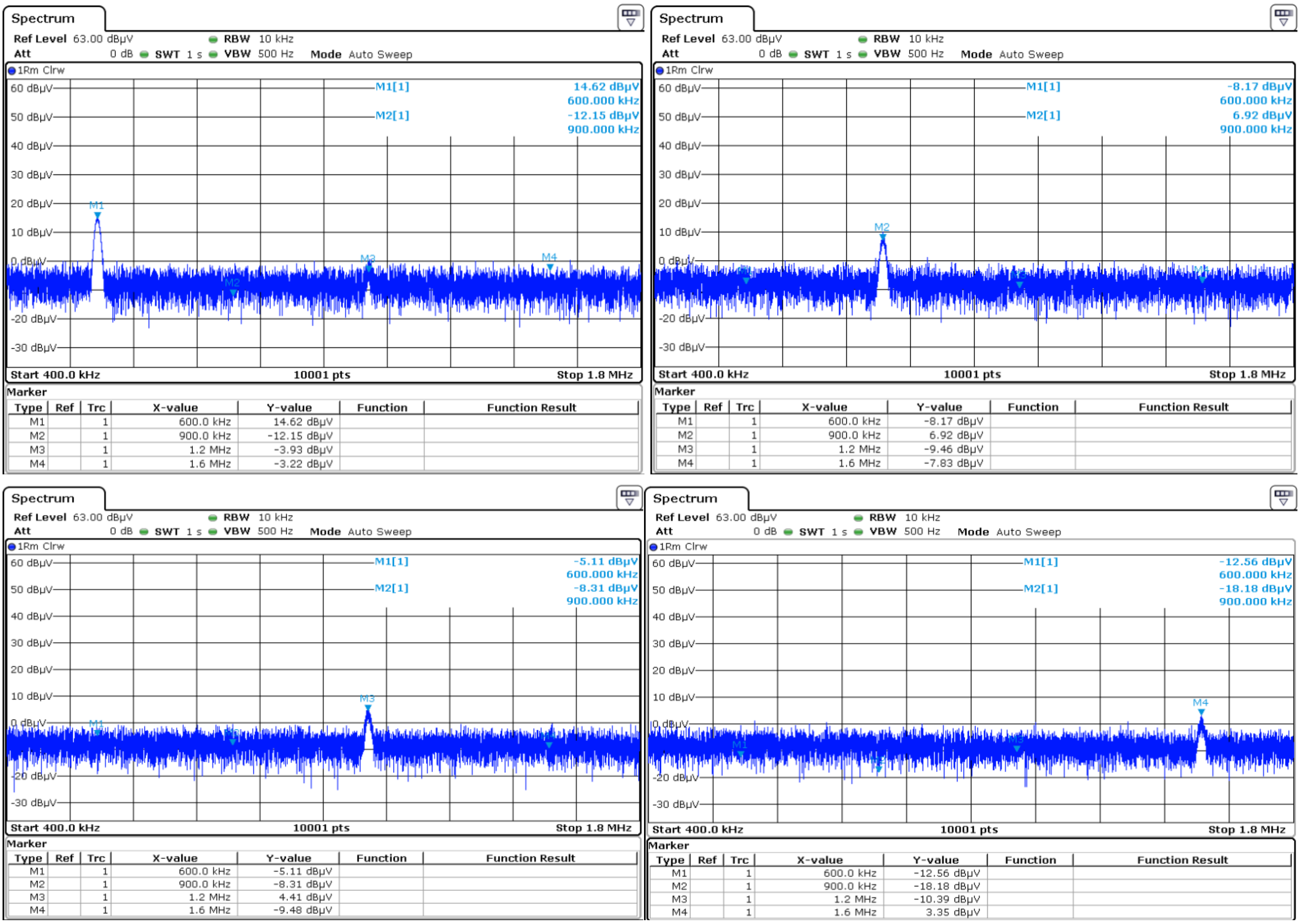


Figure 44: FM to AM intrusion @ 88MHz

This table summarizes the previous images ´values:

F_1=88MHz	Intrusion level (dBµV)	Valid
F_2=88.6MHz	14.62	YES
F_2=88.9MHz	6.92	YES
F_2=89.2MHz	4.41	YES
F_2=89.6MHz	3.35	YES

Then, F_1 = 98MHz and F_2= 98.6MHz, 98.9MHz, 99.2MHz and 99.6MHz. Here are the results.

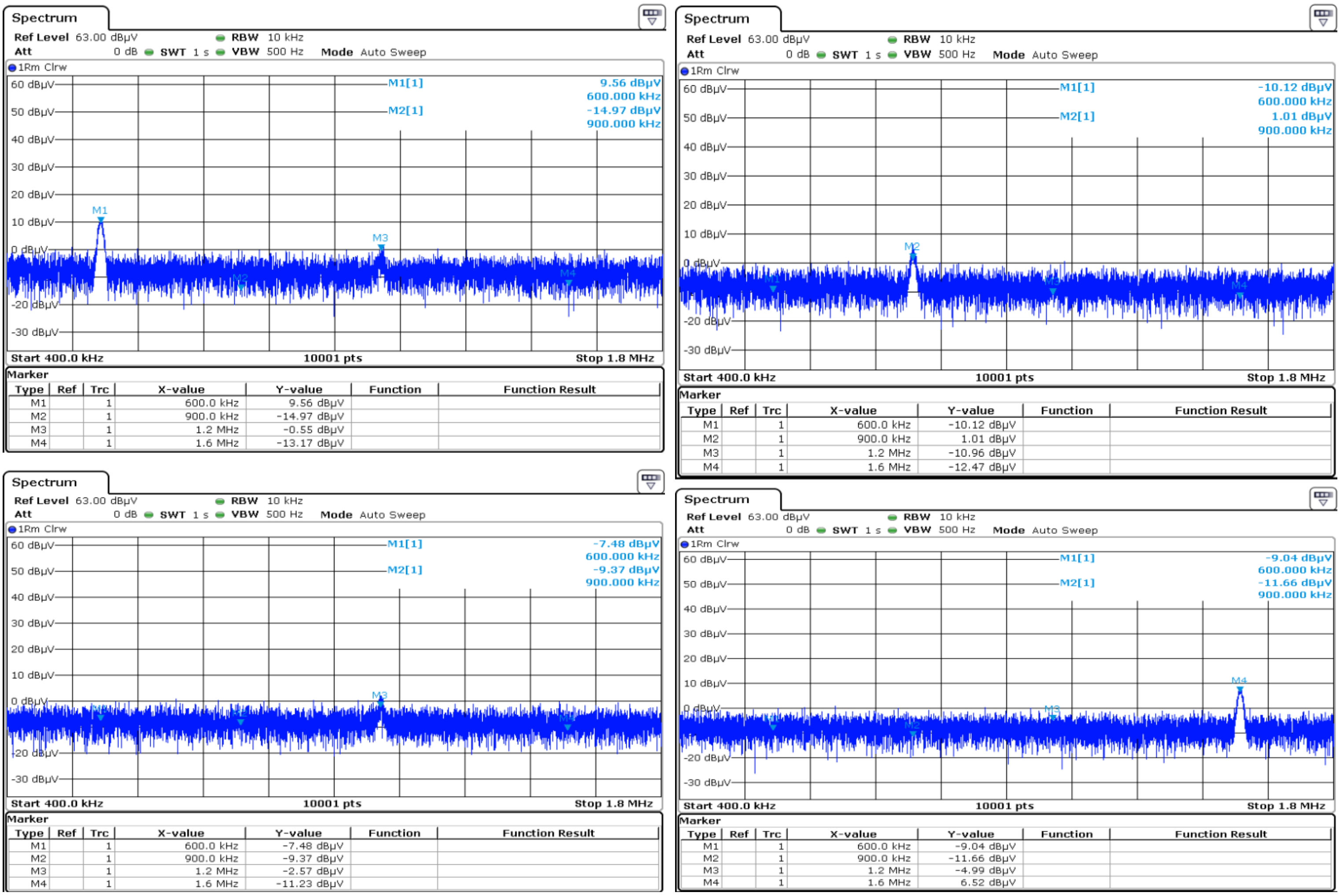


Figure 45: FM to AM @ 98MHz

Summarizing these graphs´ values:

F_1=98MHz	Intrusion level (dBµV)	Valid
F_2=98.6MHz	9.56	YES
F_2=98.9MHz	1.01	YES
F_2=99.2MHz	-2.57	YES
F_2=99.6MHz	6.52	YES

And finally, F_1 = 108MHz and F_2= 107.4MHz, 107.1MHz, 106.8MHz and 106.4MHz. These are the results.

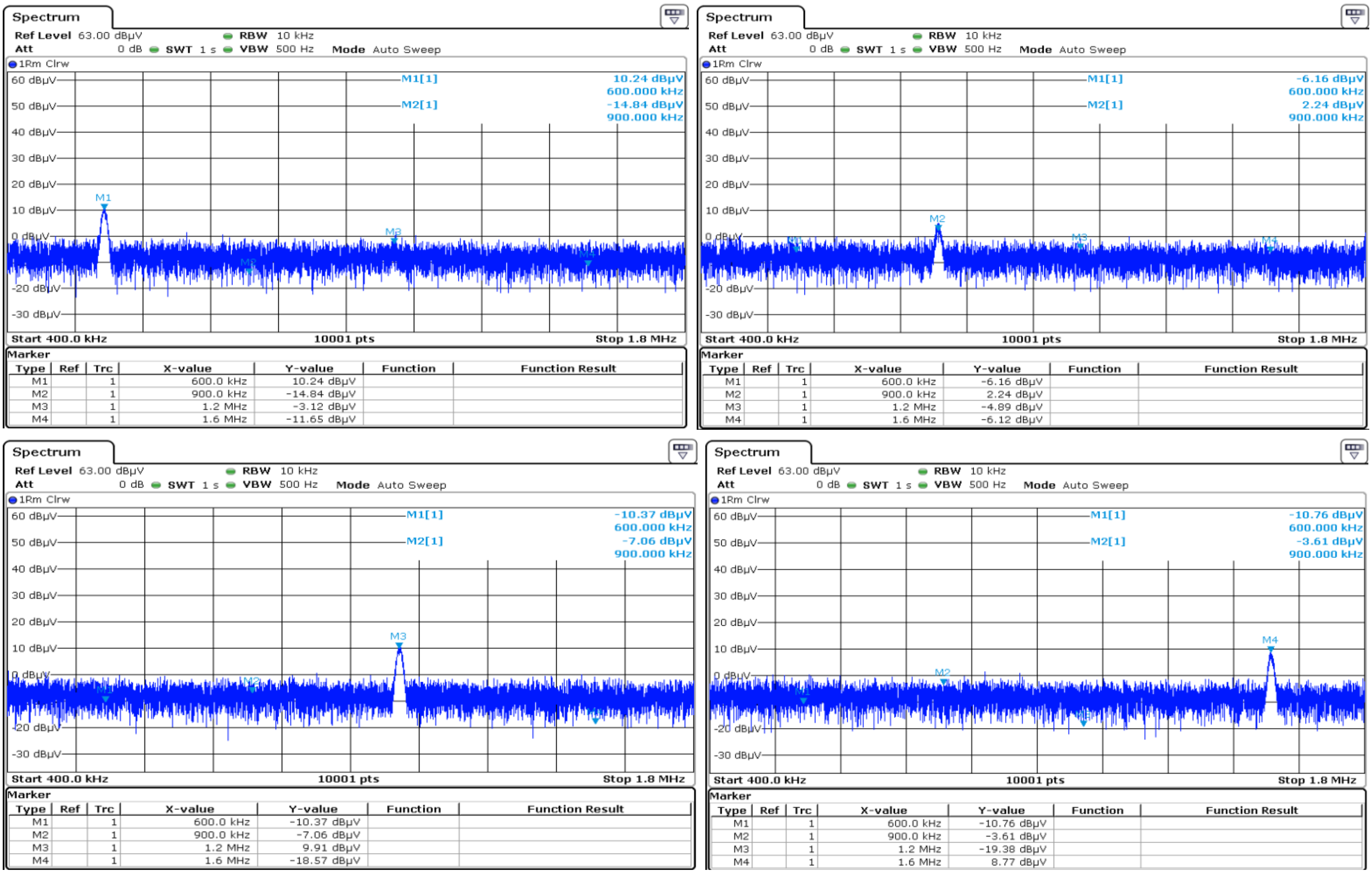


Figure 46:FM to AM intrusion @ 108MHz

Summary of the intrusion values:

F_1=108MHz	Intrusion level (dBµV)	Valid
F_2=107.4MHz	10.24	YES
F_2=107.1MHz	2.24	YES
F_2=106.8MHz	9.91	YES
F_2=106.4MHz	8.77	YES

5.2. FM2

This impedance adapter is dedicated just to FM reception, but it is independent from the previously shown one (FM1). This helps to cancel multipath and other undesirable effects. First, current consumptions have to be checked, both in normal and diagnosis modes.

Feeding voltage (V)	Normal mode (mA)	Diagnosis mode (mA)
7.5	34.6	16.7
8.5	40.6	19.5
9	46.8	22.3

- Amplification measurement

These are screenshots from the network analyzer; the frequencies of interest have been bounded with markers in order to check that requirements are fulfilled.

First, here is the input reflection loses coefficient, S11:

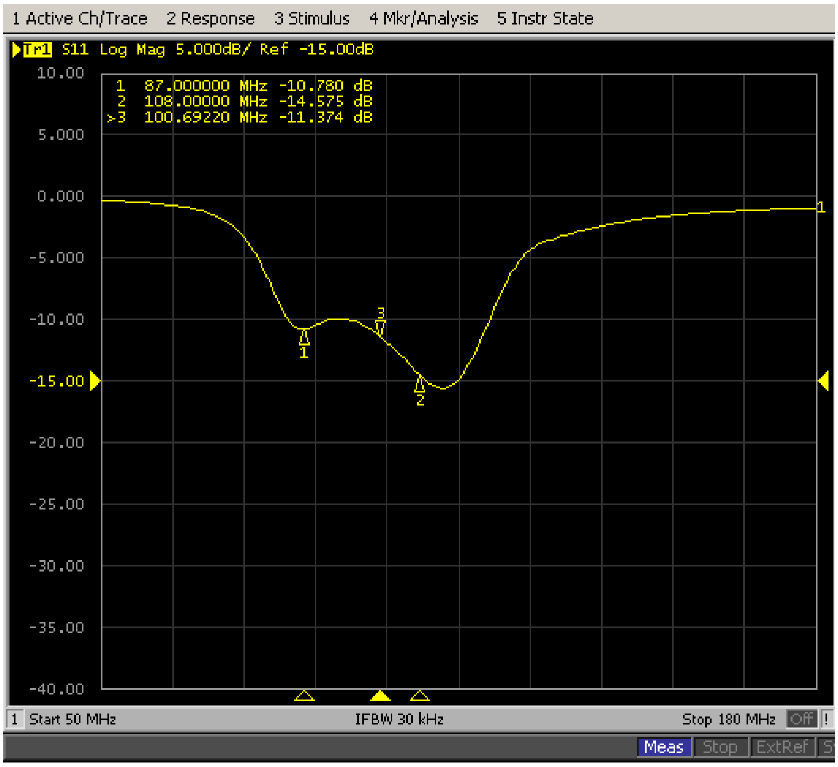


Figure 47: S11 trace (FM2)

After that, the Gain (S21):

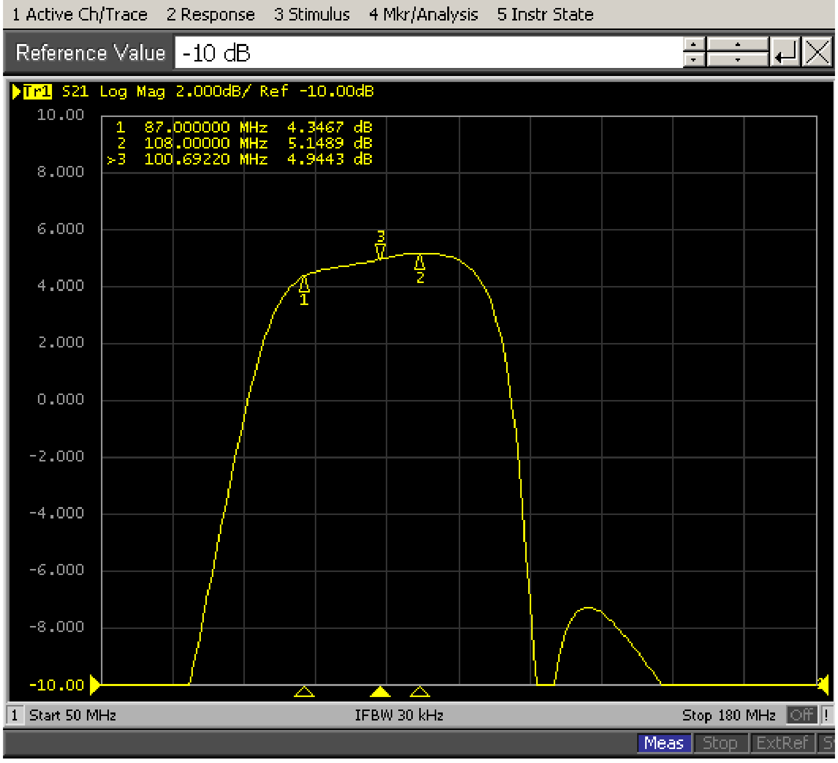


Figure 48: S21 trace (FM2)

And finally the output return loses, S22:

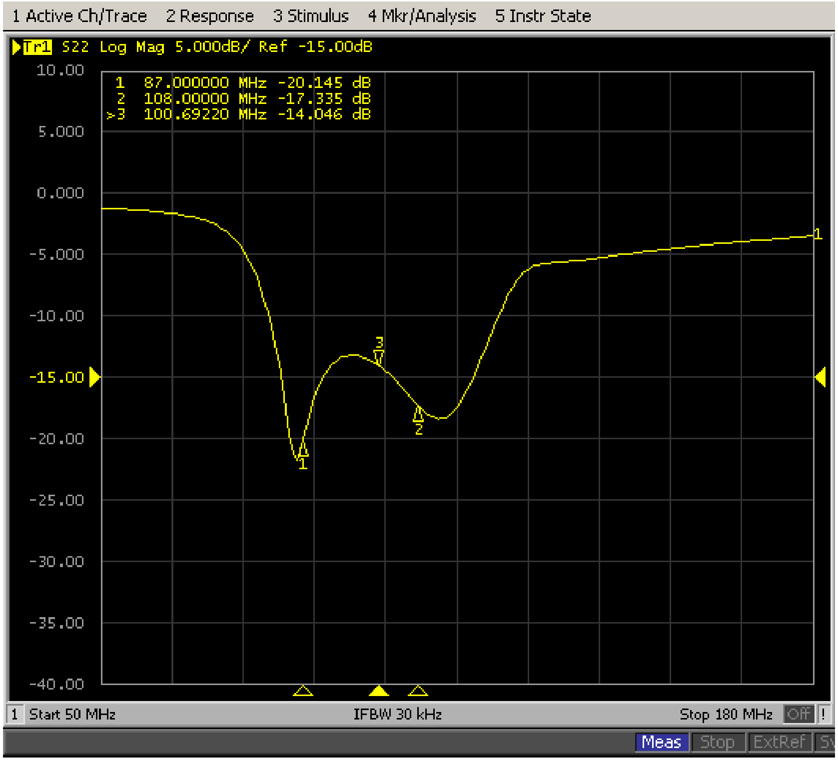


Figure 49: S22 trace (FM2)

Summary of amplification measurements at FM band (second input):

Parameter	**Value (dB)**	**Valid**
S11	11.37	YES
S21	4.94	YES
S22	14.04	YES

- Intermodulation products

Following the procedure of chapter 4, intermodulation products have been measured. Here is the first caption, where F_1=88MHz. Let´s remember that in all the cases for analyzing intermodulation products, F_2=F_1+1MHz (Chapter 4).

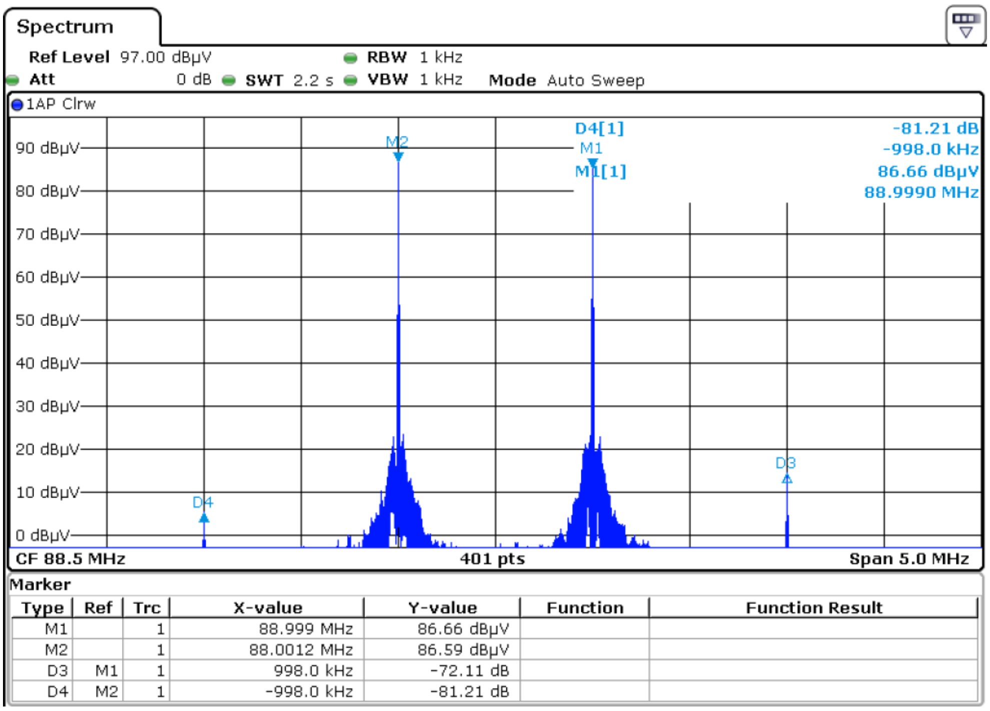


Figure 50**:** *IM3 @ 88-89MHz trace (FM2)*

Next caption, where F_1=97MHz:

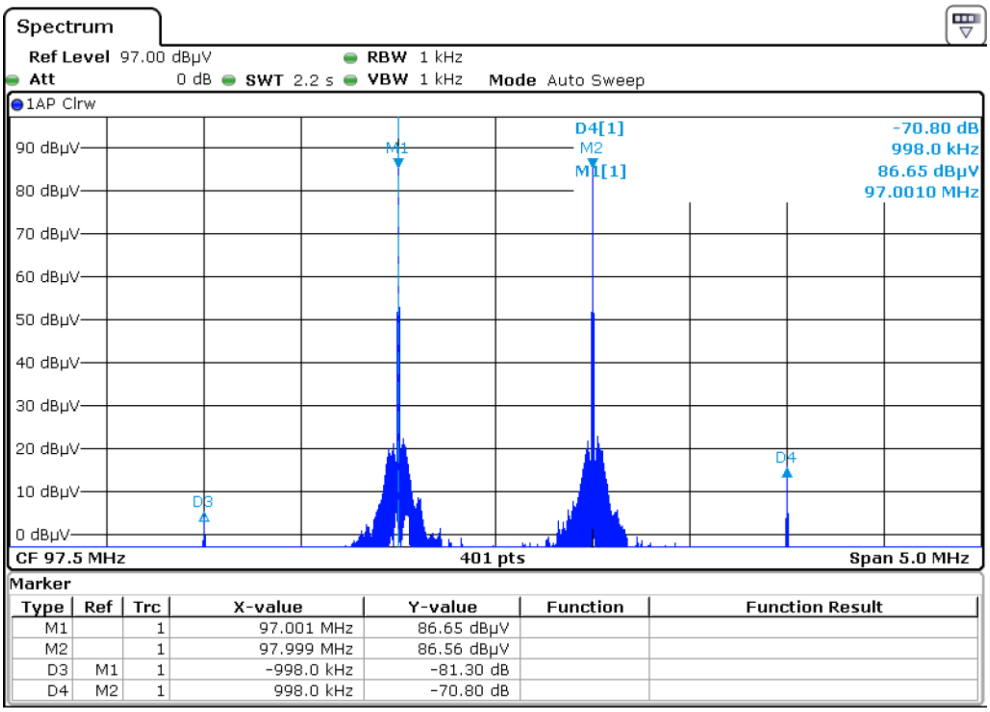


Figure 51: IM3 @ 97-98MHz trace (FM2)

Third caption, where F_1=107MHz:

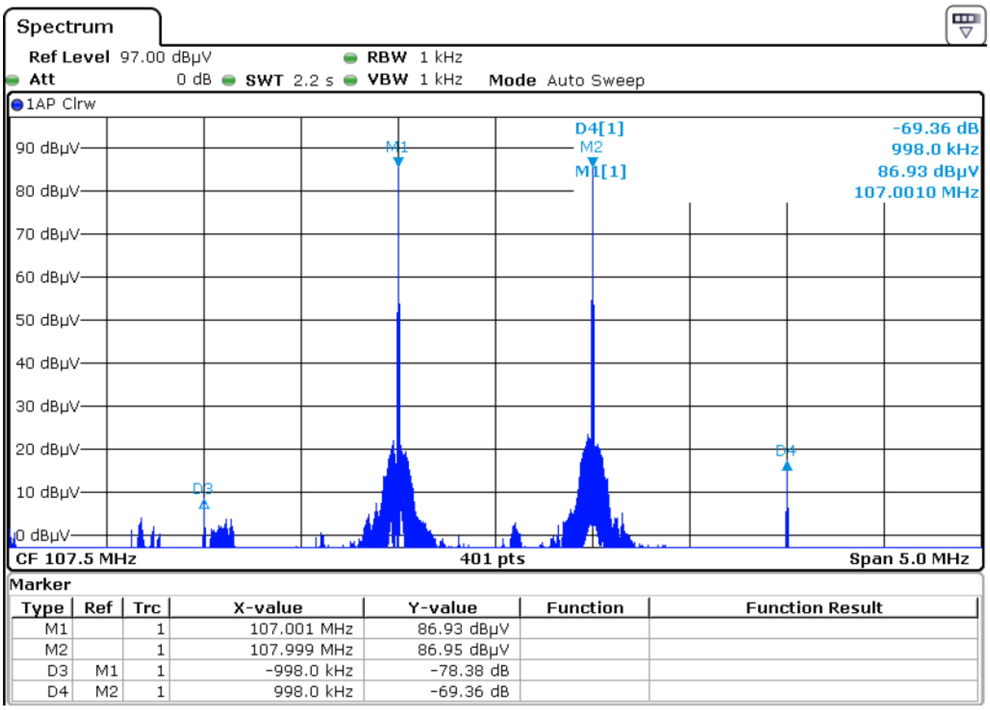


Figure 52: IM3 @ 107-108MHz (FM2)

And last caption, where F_1=162MHz:

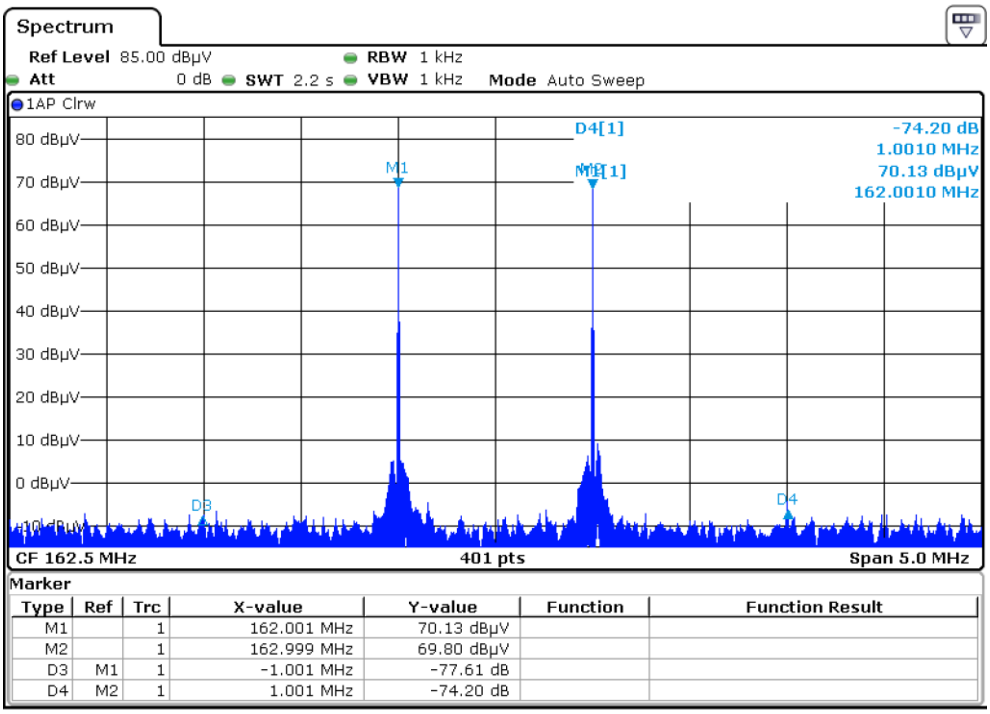


Figure 53: IM3 @ 162-163MHz (FM2)

Here is a summary for the intermodulation products:

F_1-F_2	IM product level	Valid
88MHz-89MHz	-72.11dB / 81.21dB	YES
97MHz-98MHz	-81.30dB / 70.80dB	YES
107MHz-108MHz	-78.38dB / -69.36dB	YES
162MHz-163MHz	-77.61dB / -74.20dB	YES

5.3. FM2 / DAB

This impedance adapter works for the second FM input and also for DAB channels. In this case, there are two output pins because of the difference in frequency between the two services. The same way as before, current consumption is analyzed for normal and diagnosis modes:

Feeding voltage (V)	Normal mode (mA)	Diagnosis mode (mA)
7.5	40.1	18.8
8.5	46.5	21.4
9	52.9	24.2

- Amplification measurement
    - FM measurement

To check the amplification parameters fulfill the requirements, here are some captions from the network analyzer.

First, the input return loses coefficient, S11:

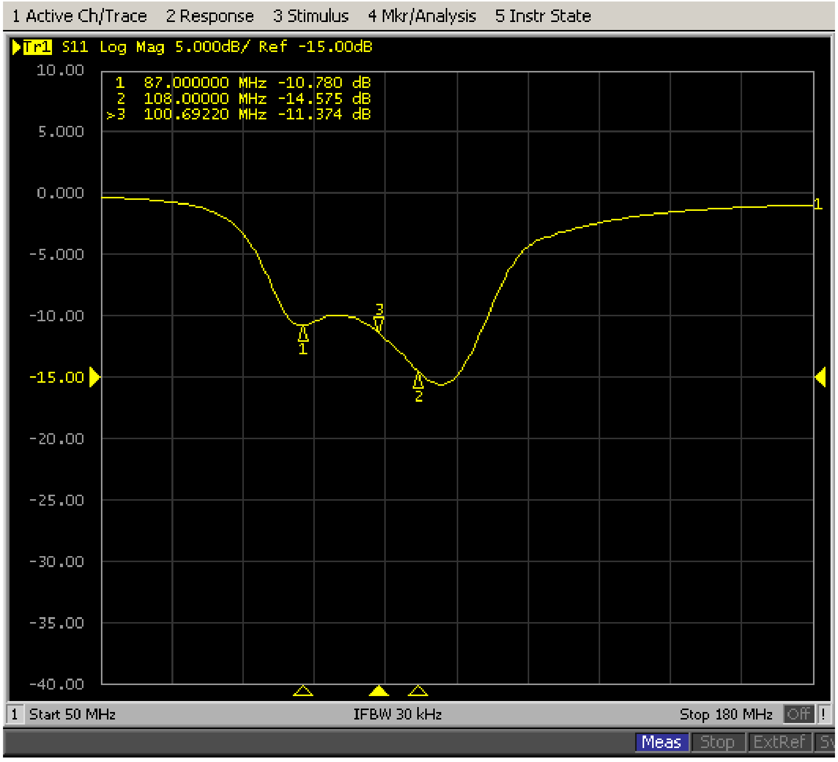


Figure 54: S11 trace (FM2)

Then the Gain, S21:

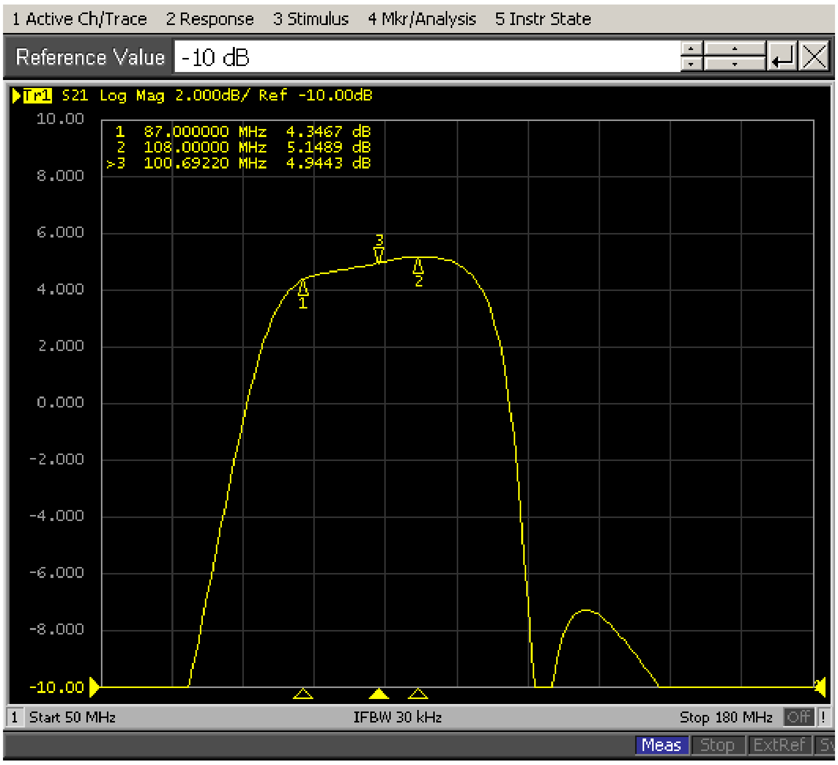


Figure 55: S21 trace (FM2)

And finally the output return loses, S22:

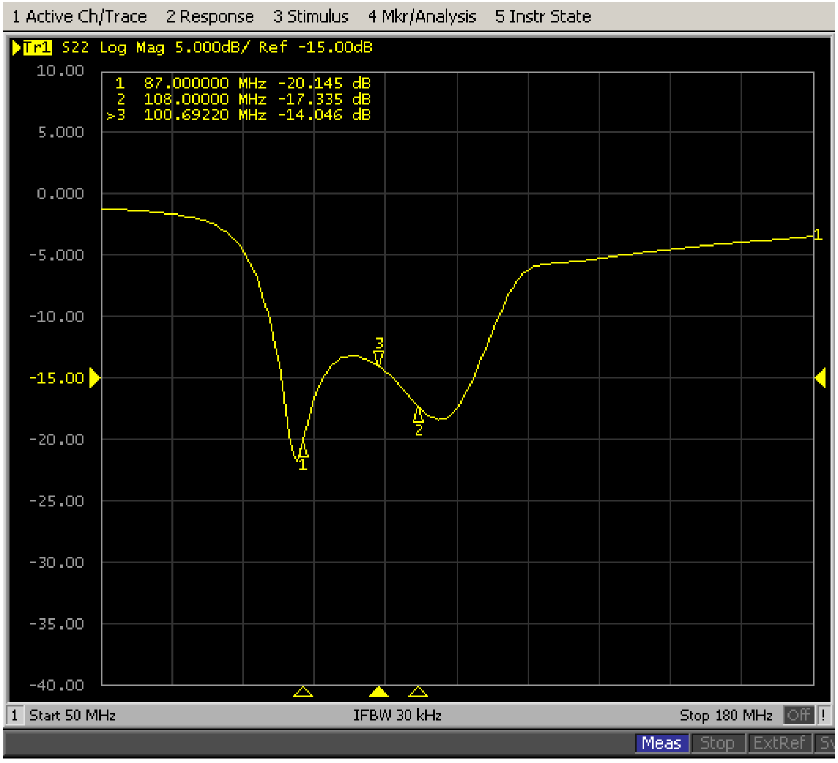


Figure 56: S22 trace (FM2)

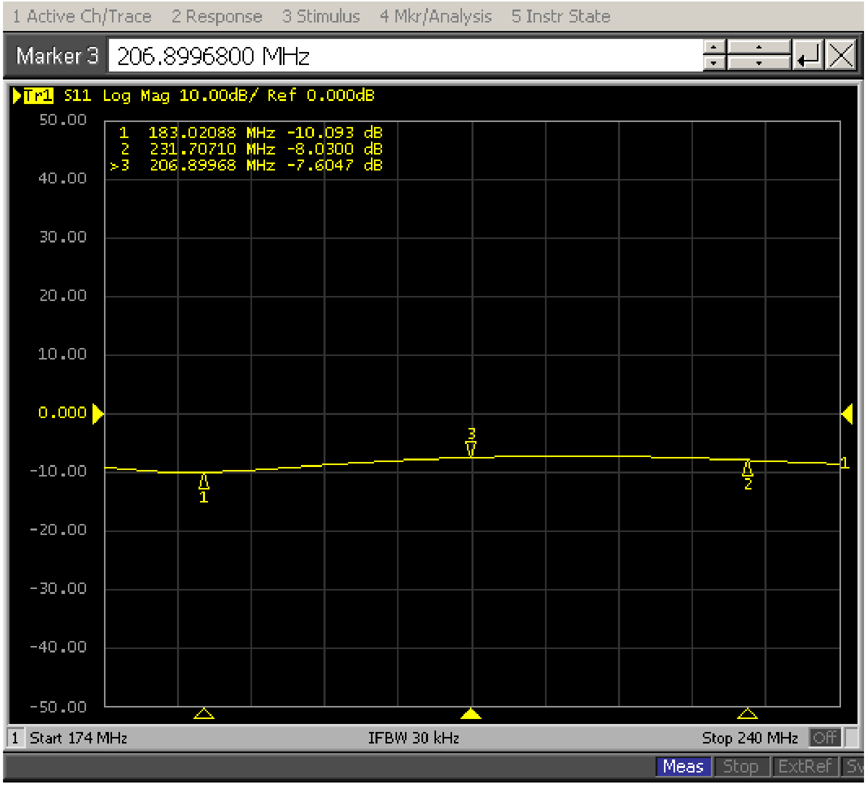
Summary of amplification measurements at FM band (second input):

Parameter	Value	Valid
S11	-11.37dB	YES
S21	5.14dB	YES
S22	-14.04dB	YES

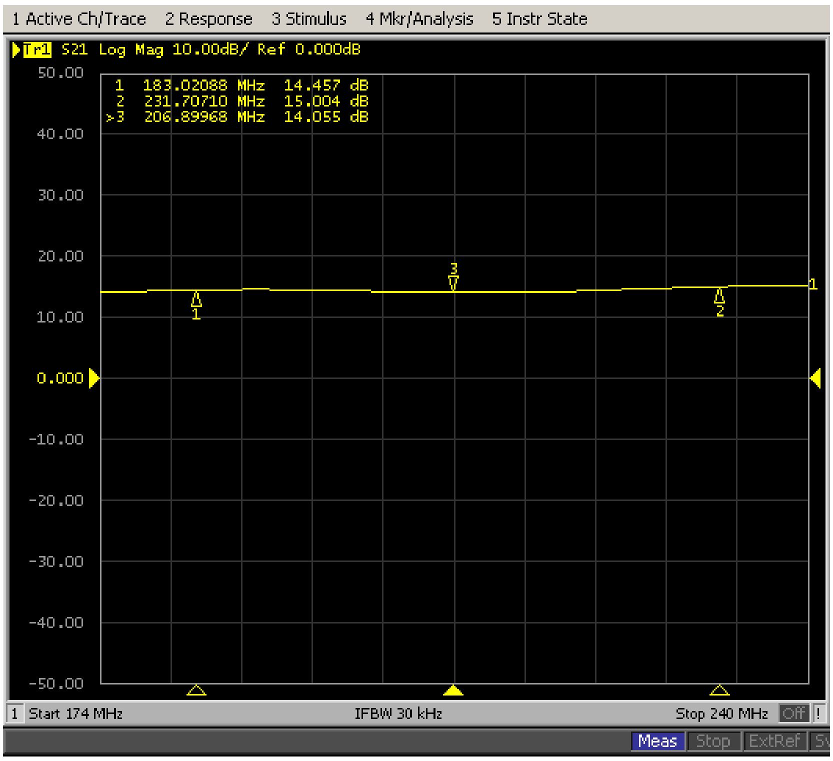
- DAB measurement

Here the amplification measurement is going to be performed for DAB service. As shown before, DAB services are divided in two different frequency bands, III Band and L Band.

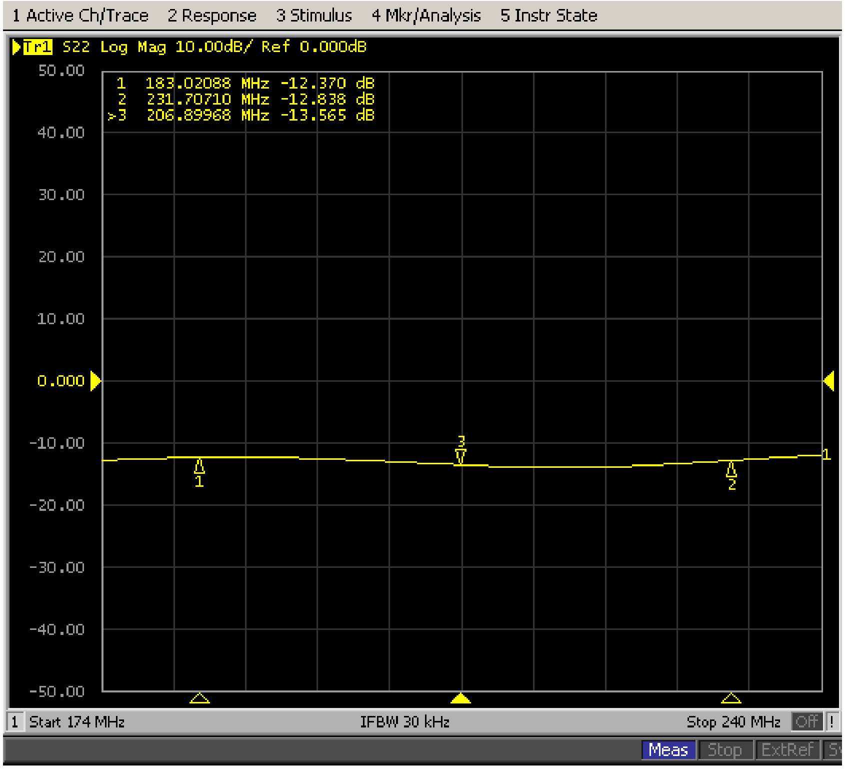
First, measurements for III Band are going to be presented. This first picture shows the input return loss coefficient, S11:



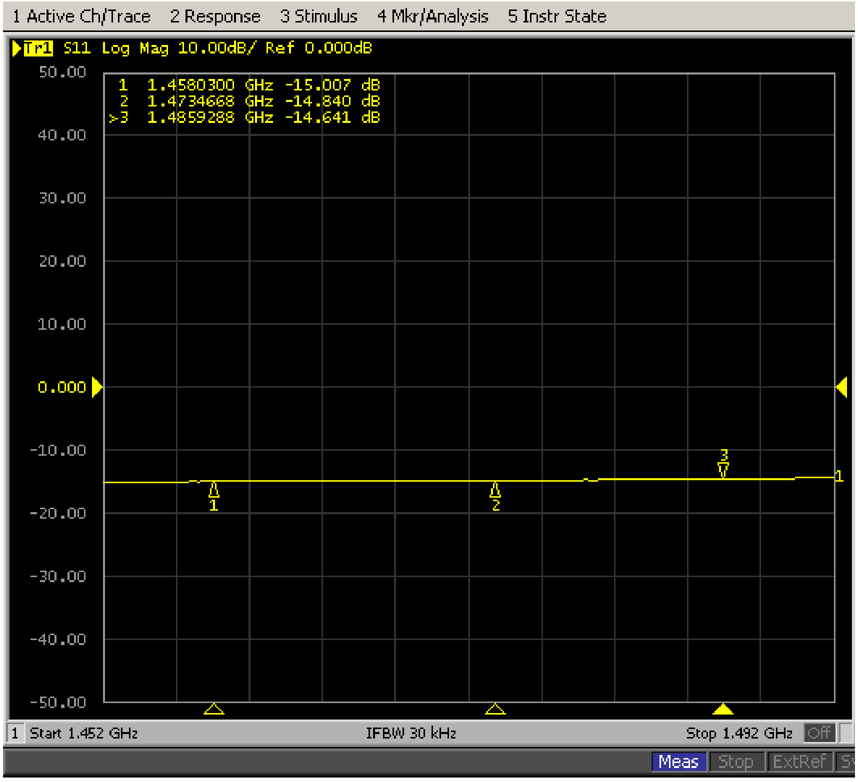
Next picture shows the Gain, S21:



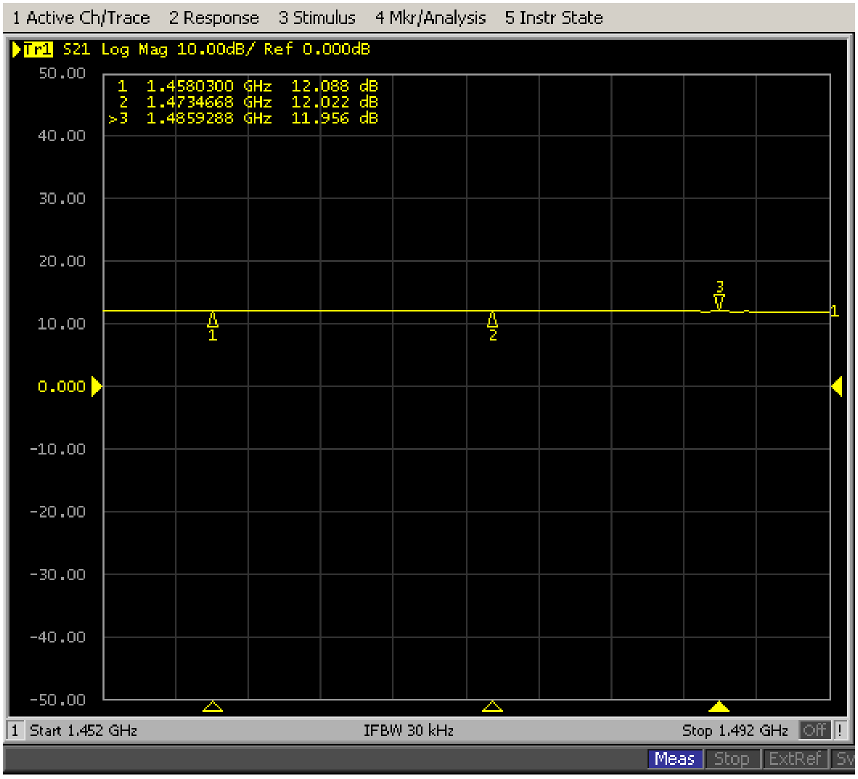
Finally, the output return loss coefficient, S22:



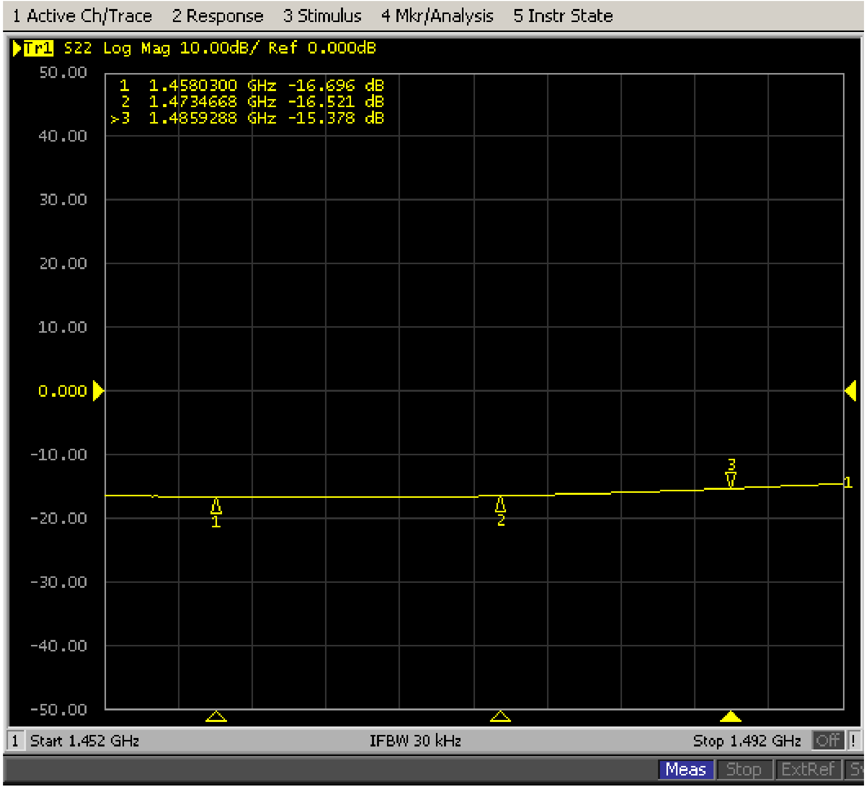
Now measurements regarding to L Band are shown, following the same order as before. First, input return loses, S11:



Then the Gain, S21:



Finally output return loses, S22:



Here is a summary of the amplification measurements regarding to DAB services:

DAB Band	Parameter	Value	Valid
III	S11	-7.6	YES
	S21	14.05	YES
	S22	-13.56	YES
L	S11	-14.64	YES
	S21	11.95	YES
	S22	-15.37	YES

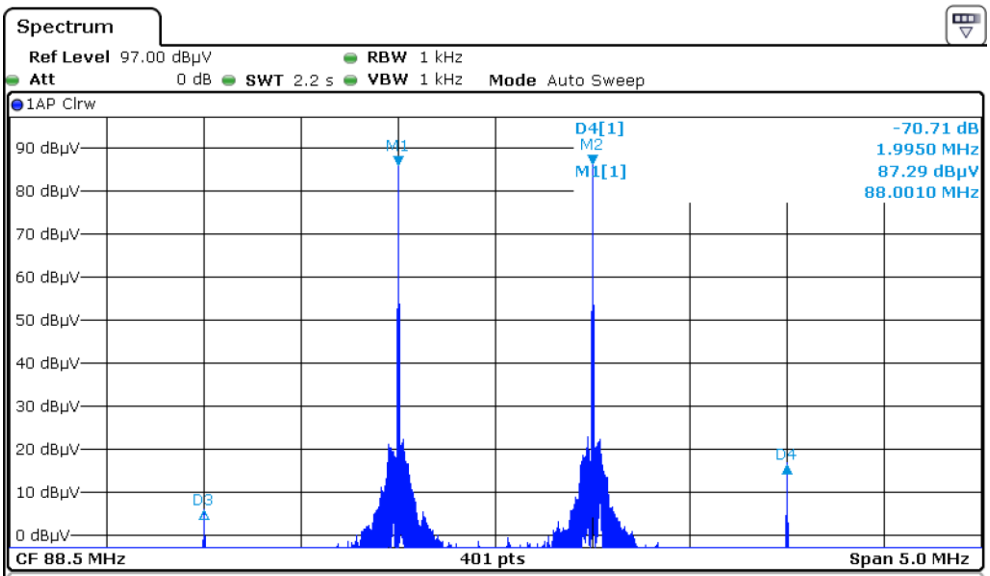
- Intermodulation products:

Now the strong signal analysis is going to be performed for this impedance adapter. As always, the two different services are analyzed separately:

  - FM measurement

Here are the results for the third order intermodulation products in FM band:

First caption, where F_1=88MHz:



Type	Ref	Trc	X-value	Y-value	Function	Function Result
M1		1	88.001 MHz	87.29 dBµV		
M2		1	88.999 MHz	87.35 dBµV		
D3	M1	1	-998.0 kHz	-81.35 dB		
D4	M1	1	1.995 MHz	-70.71 dB		

Figure 57: IM3 @ 88-89MHz (FM2)

Second caption, where F_1=97MHz:

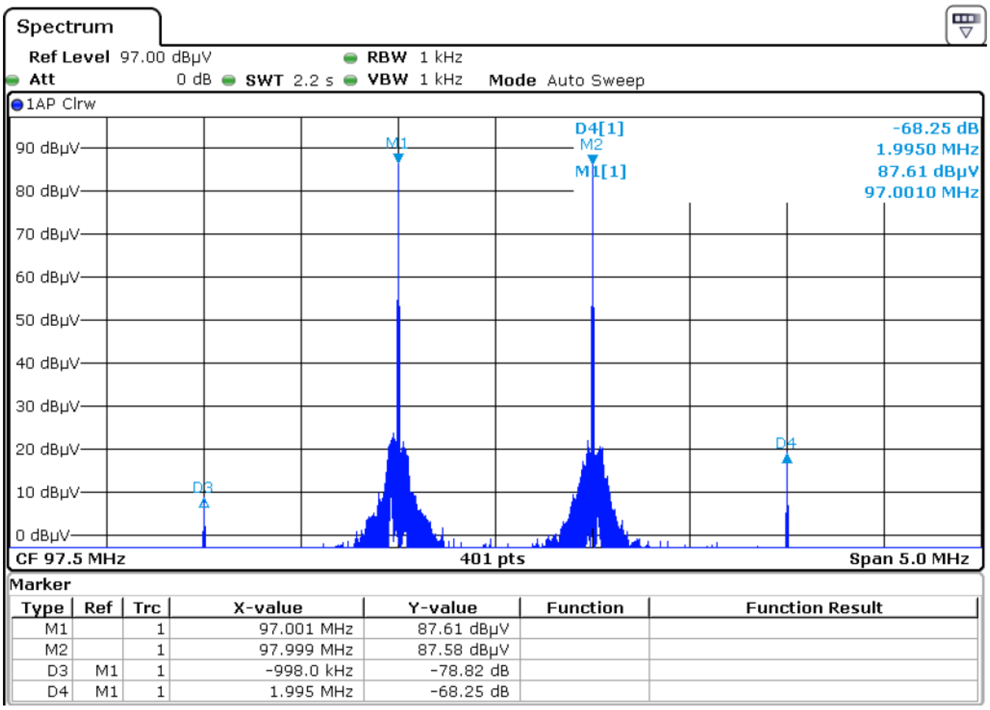


Figure 58: IM2 @ 97-98MHz (FM2)

Third caption, where F_1=107MHz:

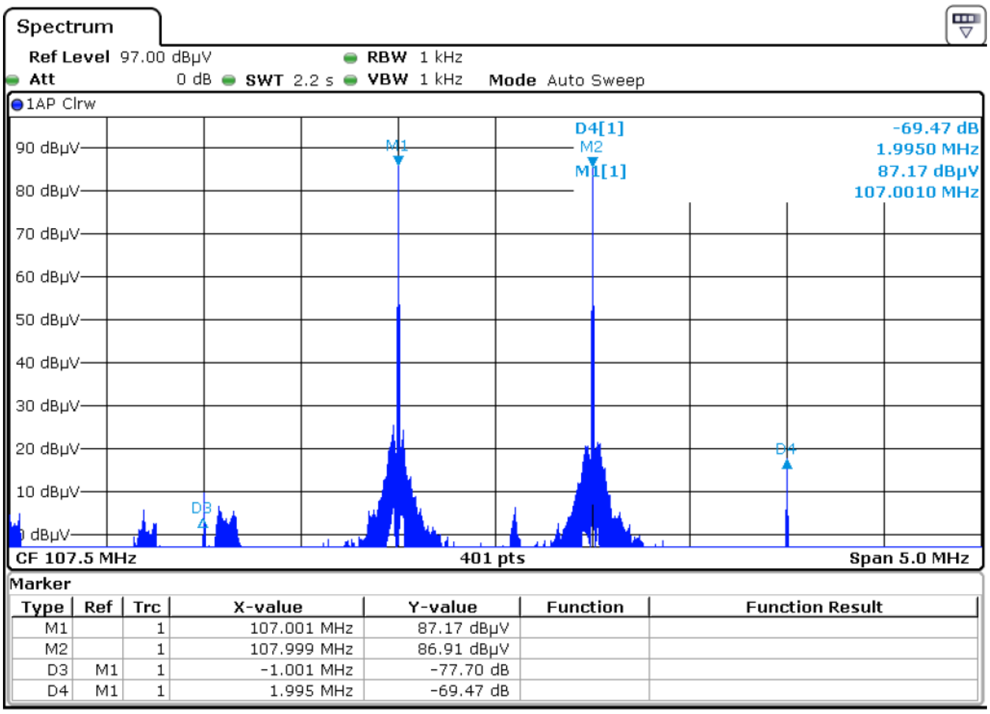


Figure 59: IM3 @ 107-108MHz (FM2)

Last caption, where F_1=162MHz:

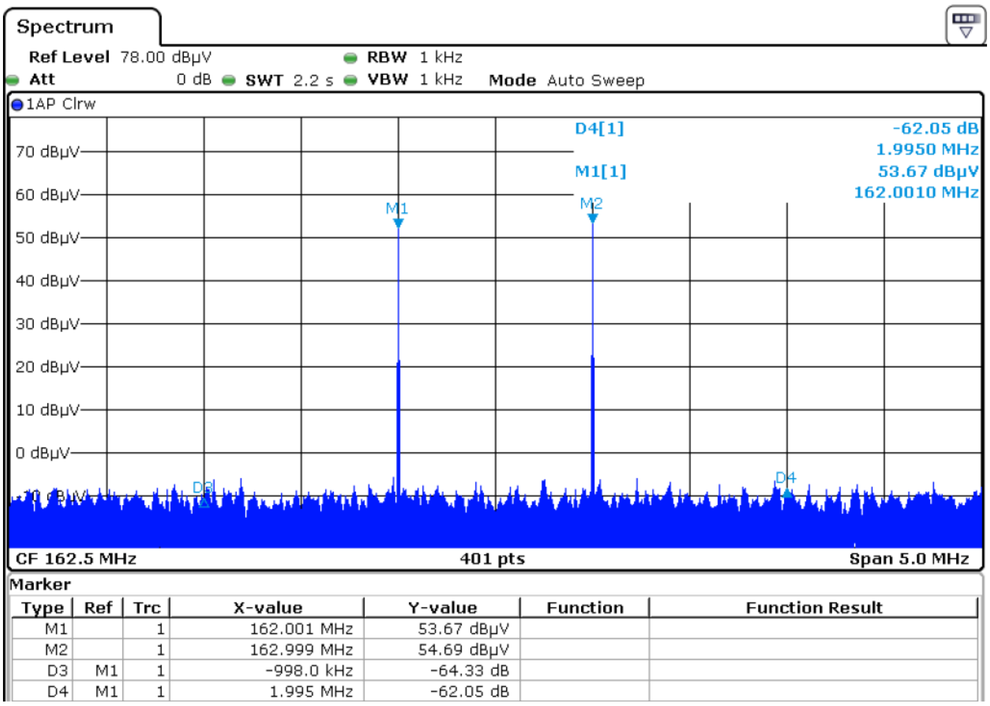


Figure 60:IM3 @ 162-163MHz

This table is a summary for the third order intermodulation products in FM:

F_1-F_2	IM product level	Valid
88MHz-89MHz	-81.35dB / -70.71dB	YES
97MHz-98MHz	-78.82dB / -68.25dB	YES
107MHz-108MHz	-77.7dB / -69.47dB	YES
162MHz-163MHz	-64.33dB / -62.05dB	YES

- DAB measurement:

Here are the results from the strong signal analysis in DAB band. There are a few more frequencies to analyze, since there are two bands for this service.

First caption, where F_1=174MHz:

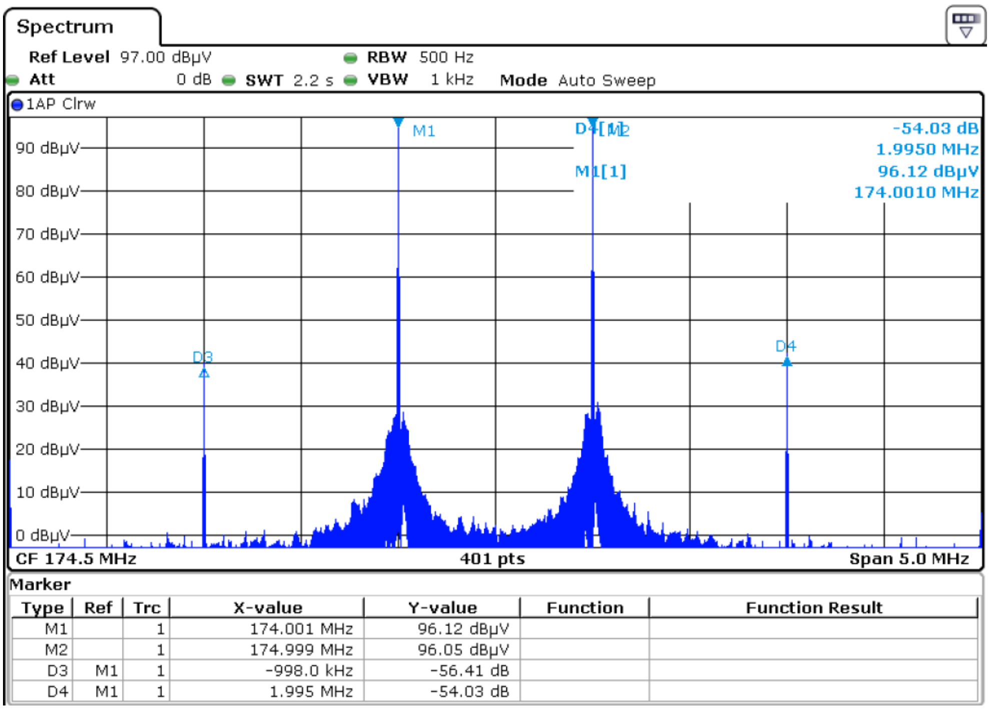


Figure 61: IM3 @ 174-175MHz (DAB)

Second caption, where F_1=207MHz:

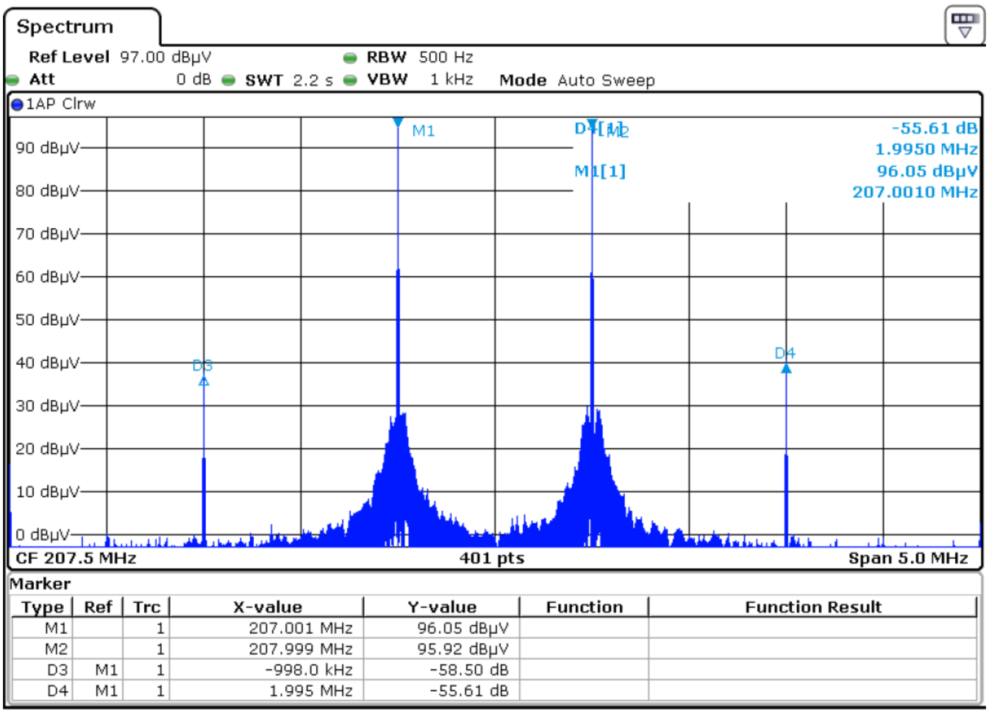


Figure 62: IM3 @ 207-208MHz (DAB)

Third caption, where F_1=239MHz:

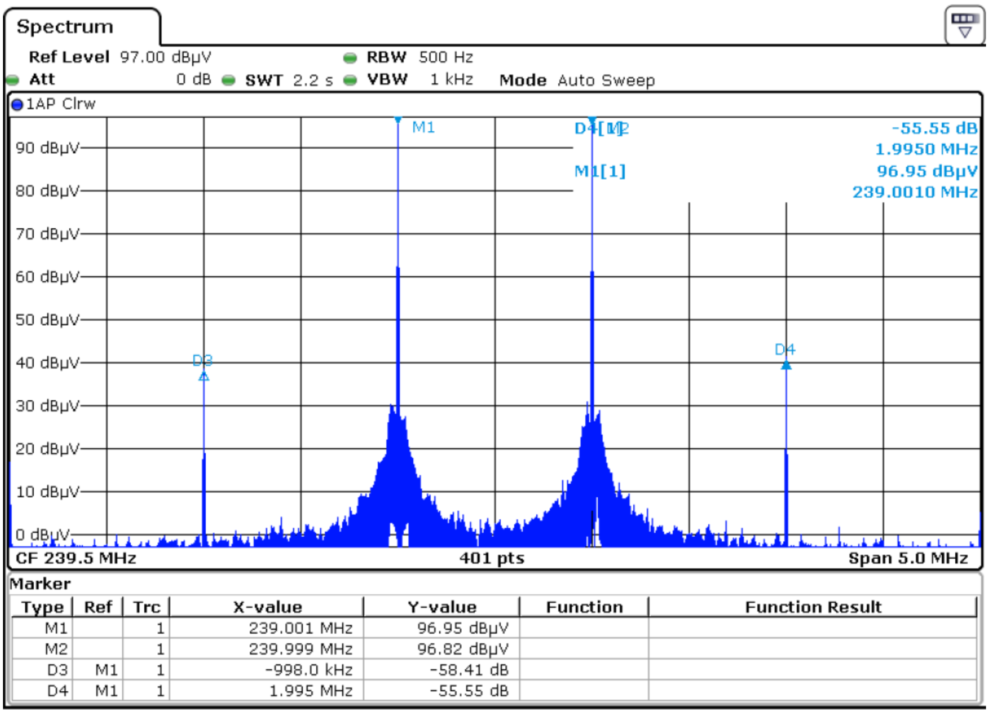


Figure 63: IM3 @ 239-240MHz (DAB)

Fourth caption, where F_1=1452MHz:

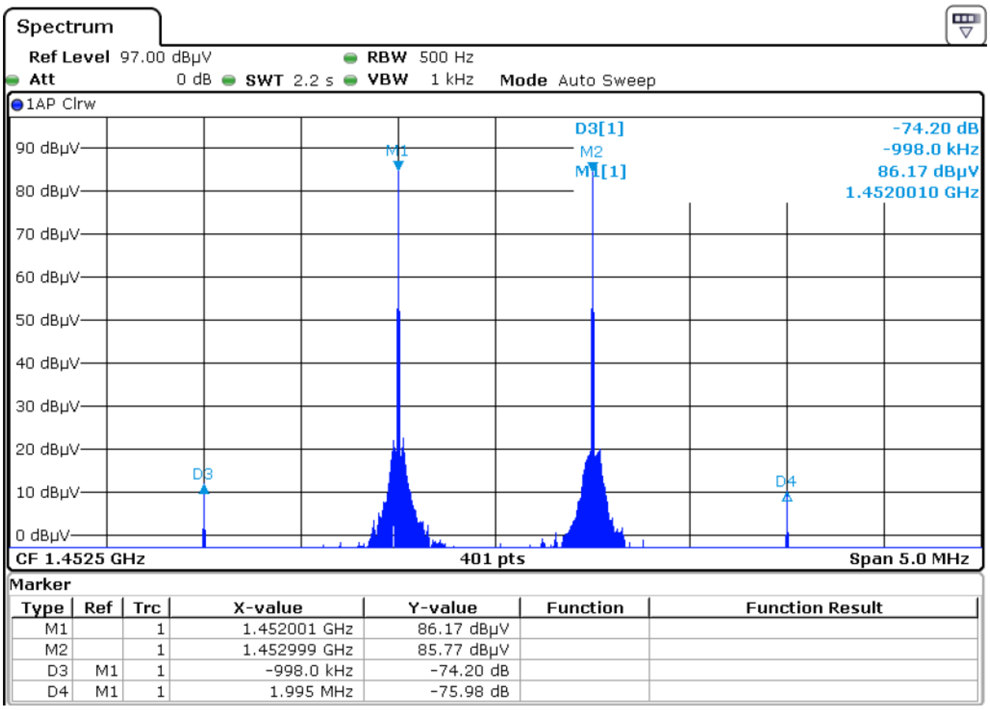


Figure 64: IM3 @ 1452-1453MHz (DAB)

Fifth caption, where F_1=1472MHz:

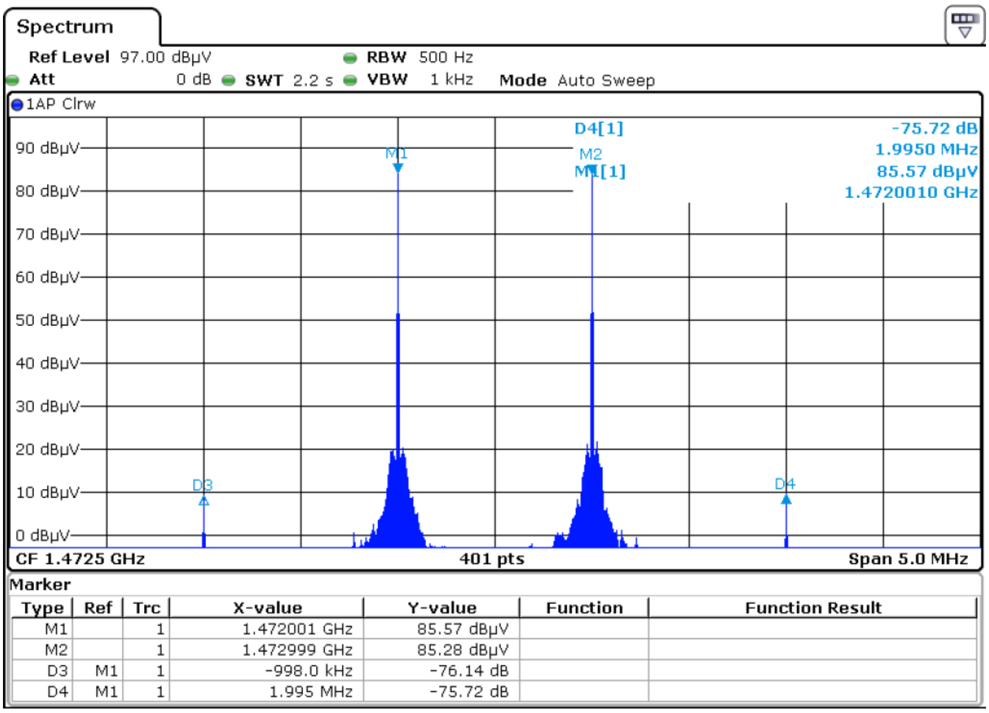


Figure 65: IM3 @ 1472-1473MHz (DAB)

Sixth caption, where F_1=1491MHz:

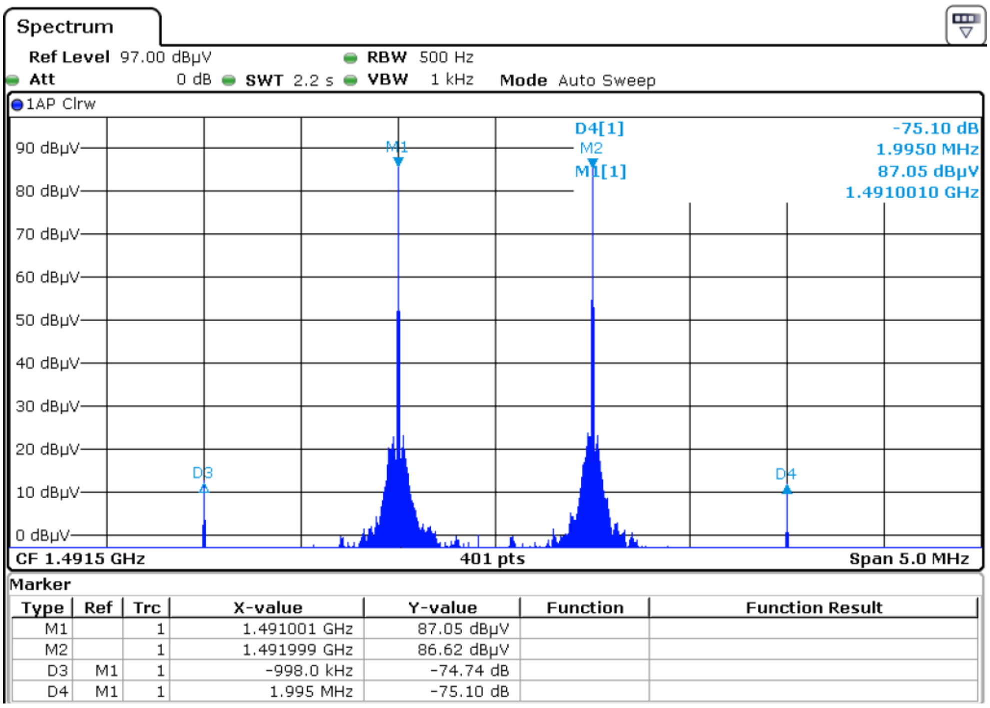


Figure 66: IM3 @ 1491-1492MHz (DAB)

In this table the results from the intermodulation product measurement have been collected:

F_1-F_2	IM product level	Valid
174MHz-175MHz	-56.41dB / -54.03dB	YES
207MHz-208MHz	-58.50dB / -55.61dB	YES
239MHz-240MHz	-58.41dB / -55.55dB	YES
1452MHz-1453MHz	-74.2dB / -75.98dB	YES
1472MHz-1473MHz	-76.14dB / -75.72dB	YES
1491MHz-1492MHz	-74.74dB / 75.10dB	YES

6. Phantom Power Supply

This chapter describes the full process of the design of the Phantom power source. After a brief introduction in which the power supplier´s necessity is justified, the design process is explained. This process will be divided in two sections, high level design and low level design. Finally a list of the material needed to develop this system is shown.

6.1. Introduction

At the very beginning of this memory, antennas have been classified in two groups, depending on whether they need DC feeding or not. Antennas placed in vehicles, those that are going to be validated in this laboratory, are active antennas because they need external power supply for operating. This feeding is commonly used when designing reduced-size antennas as well as those that operate at specific (and reduced) frequency ranges.

To supply this DC voltage (in most cases 8.5V) a specific technique is used: phantom power supply. This makes possible to feed antennas with both the DC supply needed to work properly but also with the Radio Frequency signal that has to be transmitted using a single cable. Of course, if antennas are receiving rather than transmitting (most common case in on-board antennas), it is also possible to drive incoming signals to the receivers through this unique coaxial cable. Thanks to this, it is possible to monitor input signals with a portable spectrum analyzer while it´s being fed.

Since this project is aimed to start up a full antenna validation laboratory, in this section a key element for antenna validation is going to be developed. The design and implementation of this portable power source will allow feeding antennas using the previously explained Phantom power during drive tests. Nowadays, very poor solutions could make this possible: sometimes the 12V supplied by the car´s battery were used to feed antennas, with all noises and undesirable effects this could carry. Some other times, antennas under test were fed using 8.5V that came from the car´s radio, making the tests tightly dependent of having a (well-functioning) radio during all tests, which was not always possible. Even though these solutions allowed making punctual tests, they were not really effective to test the validity of antenna systems and their components, that´s why the necessity of this power source is great. Testing antennas in real environment with this new device is a very big step forward in component validation.

6.2.Design

6.2.1. High level design

To begin with the design of the Phantom power supply, some requirements have been established. They have been listed here, and the best configuration has to be chosen in order to fulfill all of them.

- It has to be a portable box, not bigger than 300x300 mm.
- As specified before, it has to be a three port device: RF port, DC port and RF+DC port.
- Input voltage and current consumption have to be monitored.
- Input voltage has to be adjustable, in a range from 5V to 20V. This may allow testing antennas´ behavior at different input values.
- The device´s maximum autonomy must be guaranteed.
- Electromagnetic compatibility has to be checked. Colleagues from EE-31department, who are specialized in electromagnetic compatibility tests, will help to that.

The following picture shows the external view of the Phantom power supply box, containing the most important facts required.

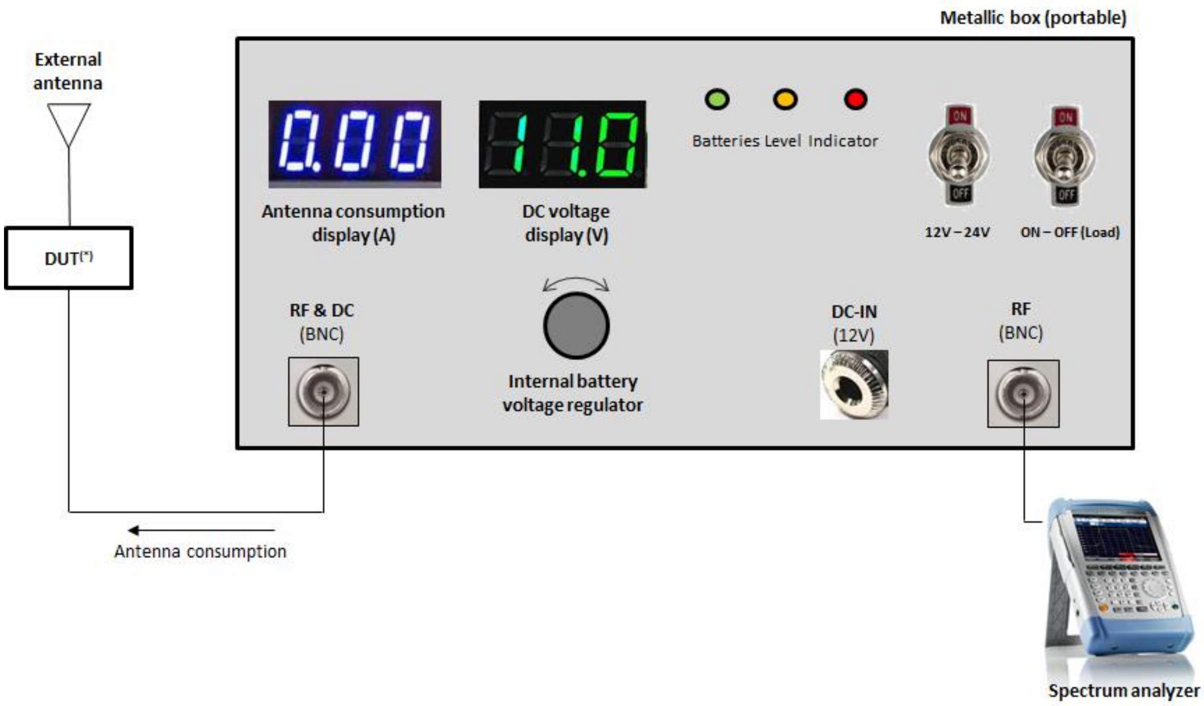


Figure 67: Phantom power supply external view

In the following lines how these requirements are going to be fulfilled is going to be explained.

First, regarding to the connectors, some decisions have to be made. First, RF BNC connectors have been chosen because they are one of the most commonly used coaxial cables. So, two BNC female bushing connectors have to be placed in the box for ports RF&DC and RF. The DC input port is a connector that allows plugging in the Phantom power source to the car power supply. This decision will be deeper justified when talking about the autonomy of the device. It is important to notice that having a “Jack” connector for reloading allows the possibility of having diverse ways of loading: one of them would be the car´s 12V supply and the other, using the appropriate transformers, the electric network´s 220 Vac.

Figure 68: Car´s power supply (12V) connection
Source: shoptronica.com

As it can be seen in the external view of the power source, two input operating modes have been set; one of them at 12V, and the other one at 24V. The explanation for this is clear: even though the requirements state that input voltage should be from 5V to 20V, normal and most common tests are performed feeding antennas at 8.5V. Having a 24V power source would make current consumption too big when 8.5V are needed (which is most of the time). So, instead of designing a voltage regulator for such a big voltage range, this range has been divided into two, so that circuits don´t overheat when operating at 8.5V thanks to the 12V input operating mode. Only when antennas need to be fed with higher voltages than 10V the 24V input operating mode will be selected. (No se si se entiende).

Furthermore, choosing 12V and 24V operating modes is not by chance. The requirement of the autonomy is very important for this device, and combined with the requirement of the adjustability of the feeding voltage, few options remain viable. After studying different options, choosing two 12V internal batteries is the most suitable one, because of many reasons:

- The voltage regulator needs to be fed with at least 2V plus the desired output voltage. If there is a test at which antennas need to be fed at 15V (as stated in the voltage range requirement), 18V are needed to supply the circuit. Batteries' nominal values are 6V, 12V and 24V, so 12V+6V, 12V+12V or 24V batteries are the remaining options.
- The size is a constraint, so 24V are too big to put inside the box.
- To satisfy the autonomy requirement, it is obvious that batteries will have to be reloaded after being used, and substituting them every time they have to be reloaded is not an option. Taking into account that this device will be used during drive tests, it is not a bad idea to consider designing it so that it can be reloaded using the car´s supply. Since the car´s supply is 12V, it makes sense that 12V batteries can be reloaded like that, so the 12V+12V internal battery supply results to be the most suitable option. However, it will be possible to reload them connecting the DC port to the electric network, but some voltage transformers will have to be used.

6.2.2. Low level design

Now a deep analysis of all the parts that help fulfilling the requirements and explained in the previous chapter is going to be made. First, an inside view of the box will be presented, so that these different parts can be easily identified, and then each of these modules will be shown, explaining and justifying the design process.

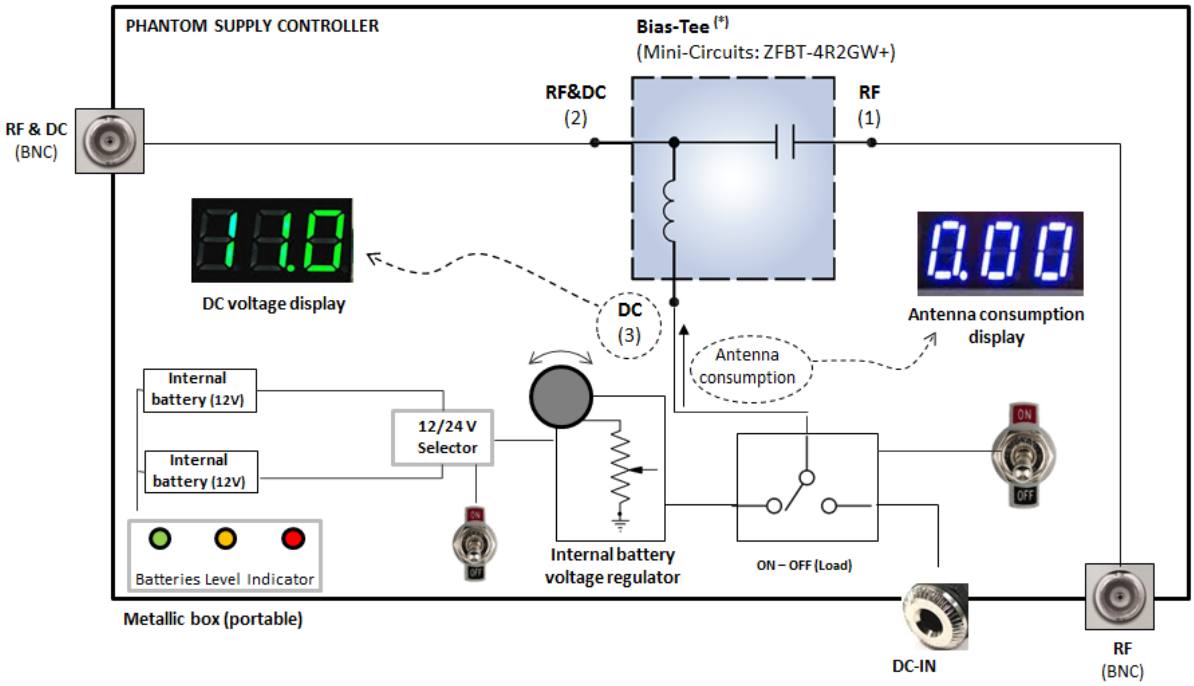


Figure 69: Phantom power supply inside view

These are the different modules that have been designed for the Phantom power source:

- Internal battery voltage regulator

This is one of the most important components of this power supply. It makes possible to obtain different voltages to feed antennas under test, regulating it with a simple knob. To do so, just a few components are needed: the most important one is the LM317 voltage regulator that can supply an output voltage from 1.2V to 37V. Two resistors have to be added in order to get the voltage divisor; one of them fixed (R_1) and the other one a 5K potentiometer (R_2), so that output voltage can be regulated.

This is the expression that gives the output voltage as a function of the previously mentioned resistors:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{adj}R_2$$

In this equation, V_{ref} is a constant value that the component fixes at 1.25V, the same as I_{adj}, which is controlled by the LM317 and kept under 100µA.

To protect the voltage regulator from input short-circuits, a diode is placed between input and output pins.

As this power source will be used to feed antennas that have to be accurately validated, noises and undesired effects have to be controlled. Ripple, which is an undesirable effect likely to appear, will be avoided by adding some input capacitance. To ensure output stability another capacitance has been placed at this point.

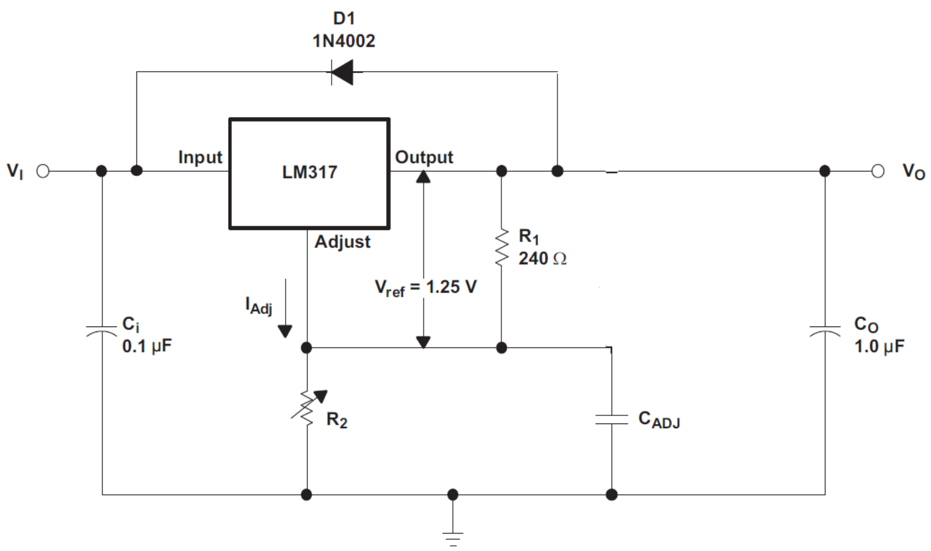


Figure 70: Voltaje regulator design
Source: onsemi.com

- 12V – 24V and ON – OFF (Load) states selectors

Now two selectors are going to be designed. They share some aspects in common, so their circuitry will be the same for both.

First of all, let's start with the 12V – 24V input operating modes. As said before, 12V operating mode will be selected when antennas need to be fed with voltages under 10V, which will be most of the times. 24V operating mode will be selected when higher voltages are needed. It has also been said before that two 12V batteries will be used.

It is obvious that when the 12V mode is desired, both batteries will have to be connected in parallel so that the supplied voltage is 12V, and connected in series when the 24V mode is selected. On the other hand, when batteries need to be reloaded they will have to be connected in parallel and never, under any circumstance, in series. Connecting a 24V source to the car´s 12V battery could seriously damage it.

Taking all this into account, this relay based circuit has been designed.

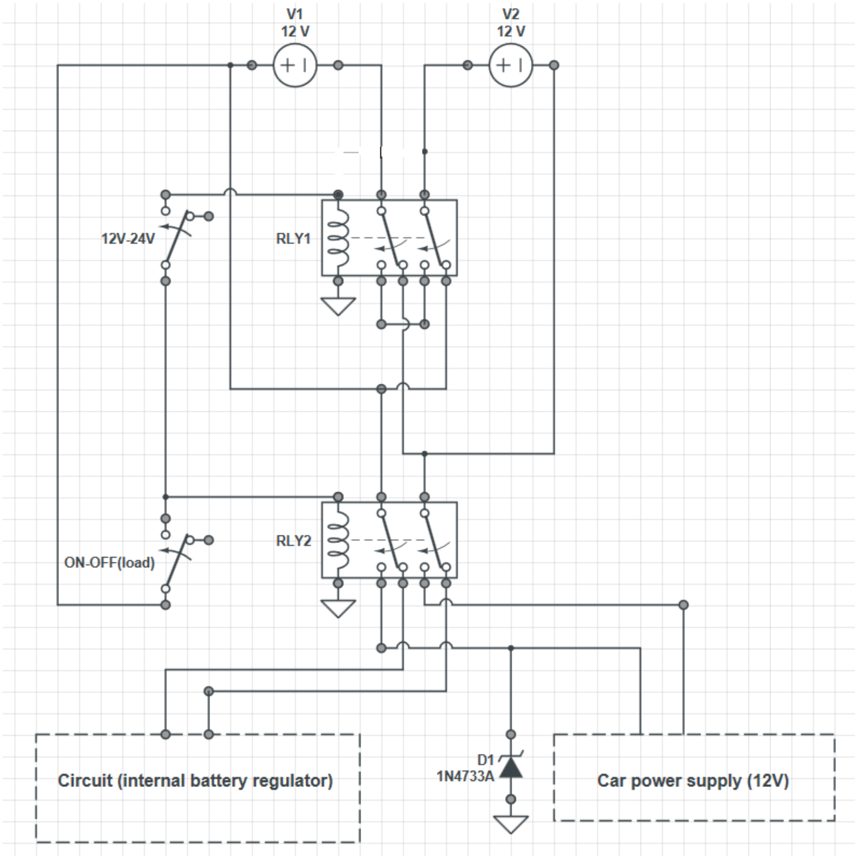


Figure 71: Schematic for ON-OFF and 12V-24V selectors

The combination of R1 and R2 relays makes possible commuting from different states depending on the application. These are the main features of this circuit:

- R1 relay´s default state connects batteries in parallel. When switch 2 feeds the coil and commutation happens 24V are supplied at the output port, by connecting batteries in series.
- R2 relay´s default state is to connect the rest of the circuit to the batteries, and when switch 1 allows the commutation the circuit is isolated and shut down. Only at this point batteries can be reloaded.
- As the circuit´s schematic shows, switches that feed both relays are connected in series. This is to avoid the possibility of having switch one off (circuit off or reload state) and switch 2 on (batteries in series, supplying 24V), which could damage the circuitry if connected to a 12V power supply.

➢ Finally, a 12V Zener diode has been placed in parallel with the battery reload path, so that when 12V are exceeded current is directed to ground.

- Batteries level indicator

  A very simple circuit has been designed in order to control the batteries´ charge level at every moment. Just a few simple components are needed, resistors, LEDs and two low power operational amplifiers.

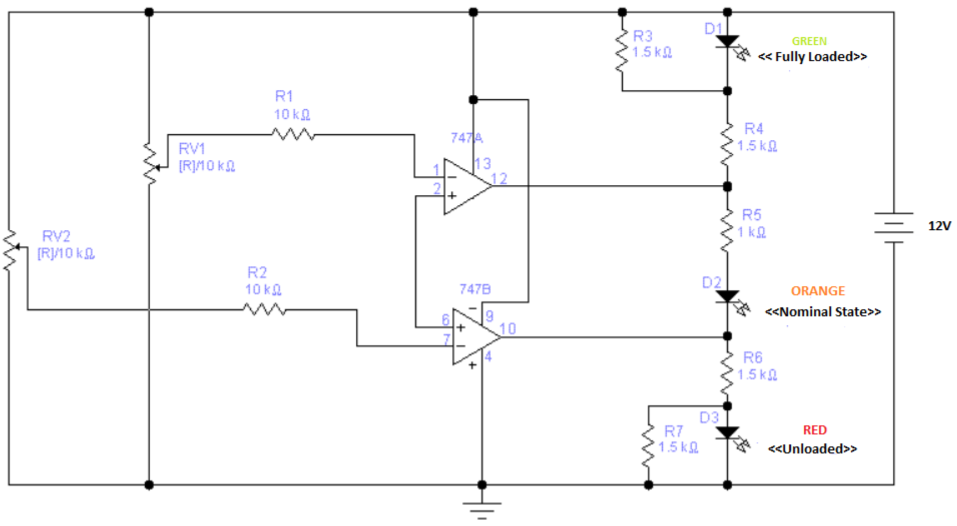


Figure 72: Battery level indicator design
Source: neoteo.com

By regulating RV1 and RV2 voltages can be set so that LEDs turn on at different ranges. Green LED will turn on when batteries are equal or higher than 12V, the orange one when batteries are between 10V and 12V and the red LED will turn on when batteries´ level is lower than 10V.

6.3.Material

Here is a list of the material that has been used to design and implement the Phantom power supply:

- Metal box (300x200x100 mm aprox.)
- BiasTee ZFBT-4R2GW+
- 12V Battery x2

- Potentiometer
- Ammeter Display
- Voltmeter display
- Coaxial pieces
- Circuit board
- Relay x2
- Switch x2
- Light Emitting Diode x3
- Resistors
- Capacitors

7. Economic Summary

This section aims to gather all the information regarding to the economic planning. This is a very important part of the project, because normally the economic viability is what usually marks the roadmap of any project. First, the main tasks mentioned in the planning section will be shown. This time an approximation of the cost in time will be made, so that when the work team is presented, a calculation of the human resources cost can be made. Then, the material resources will be shown classified in three types, and their cost will be calculated. Finally the overall economic summary will have to be analyzed and compared with the initial budget of the project.

7.1. Tasks duration

- Stage 1: Prior studies and planning
  - WP1 Planning: Duration -> 2 weeks
  - WP2 On board antenna analysis: Duration -> 1.5 weeks
  - WP3 VW regulations study: Duration -> 2 weeks
  - WP4 Material acquisition: Duration -> 2.5 weeks
- Stage 2: Phantom Power Supply
  - WP5 Material acquisition: Duration -> 1.5 weeks
  - WP6 Functional analysis and design: Duration -> 6.5 weeks
- Stage 3
  - WP7 Equipment installation: Duration -> 1.5 weeks
  - WP8 Validation tests: Duration -> 5 weeks
  - WP9 Automation: Duration -> 3.5 weeks

7.2. Work Team

In this project two telecommunication engineers have taken part, a senior telecommunication engineer and a junior telecommunication engineer.

Code	Name	Cargo	Cost (€/hour)
PD	Alberto Gil	Project Director	15
JD	Andoni Amurrio	Junior developer	6

Alberto Gil is a Telecommunication engineer who has worked at SEAT for more than ten years, leading projects from many sections such as radio development and more recently antenna projects for SEAT and AUDI. Even though he will not take part in the main development works, his wide experience will be essential for technical decisions, and he will help and orientate the junior developer when needed.

Andoni Amurrio is a junior telecommunication engineer whose experience at big companies and projects is limited, but his excellent academic background will allow him to develop the project to a good maturity level.

7.3.Human resources budget calculation

The following charts summarize the cost of the nine work packages of this project, regarding to human resources. To make it easy to understand, eight our work days have to be considered, five days a week from Monday to Friday, so that a whole week is composed by 40 ours. Regarding to the unitary price per day, the following estimation has been made: project director will take part in 25% of the hours dedicated to the work package, while the junior developer will carry out the 75% of the hours. The column "Distribution" will show how the workload has been divided in every work package.

Work Package	Duration (days)	Unitary price (€/day)	Distribution 75%-25% (Days)	Amount (€)
STAGE1				
WP1	10	48 JD 120 PD	7.5 JD 2.5 PD	360 JD 300 PD
WP2	8.5	48 JD 120 PD	6.375 JD 2.125 PD	306 JD 255 PD
WP3	10	48 JD	7.5 JD	360 JD

		120 PD	2.5 PD	300 PD
WP4	13.5	48 JD 120 PD	10.125 JD 3.375 PD	486 JD 405 PD
STAGE 2				
WP5	8.5	48 JD 120 PD	6.375 JD 2.125 PD	306 JD 255 PD
WP6	33.5	48 JD 120 PD	25.125 JD 8.375 PD	1206 JD 1005 PD
STAGE 3				
WP7	8.5	48 JD 120 PD	6.375 JD 2.125 PD	306 JD 255 PD
WP8	25	48 JD 120 PD	18.75 JD 6.25 PD	900 JD 750 PD
WP9	18.5	48 JD 120 PD	13.875 JD 4.625 PD	666 JD 555 PD

- Human resources summary

TOTAL	4896 JD 4080 PD
	8976
Incidentals (5%)	448.8
VAT (18%)	1436.16
TOTAL HUMAN RESOURCES	**10.860,96 €**

The total budget dedicated to human resources is **10.860,96 Euros**.

7.4. Material resources

Now the economic plan for the material resources is going to be presented. As said before, these resources will be divided in three categories: acquired material, depreciable material and consumable material.

7.4.1. Acquired material:

This is a list of all the material acquired for this project. As in previous chapters where and how this material has been used has been explained, this list will gather all the components for both parts of the project, validation tests and phantom power supply.

Component	**Model**	**Quantity**	**Prize (€)**
Network Analyzer	Agilent E5062A	1	32.020
Spectrum Analyzer	R&S FSV7	1	25.861
Signal Generator	R&S SMB 100A	2	16.962
Shielded Box	Holland Shielding high performance	1	21.406,25
Power Supply	R&S HMC8043	1	948
Digital Multimetre	R&S HMB8012	1	658
High Pass Filter	SHP-50+	3	136.08
Low Pass Filter	SLP-2.5+	1	44.19
Power Splitter/Combiner	ZFSC-2-2-S+	2	132.64
Power Splitter/Combiner	ZFSC-2-2500-S+	1	87.28
3dB Attenuator	SF-BM-3+	2	46.46
50Ω Load	ANNE-50+	3	34.77
BiasTee	ZFBT-4R2GW	1	82.94
12V Battery	Panasonic 12V 1.3Ah	2	2x 29.31

Potentiometer	Hilo. Bob. 1W 5K	1	12.13
Ammeter Display	5-40V 20A	1	49.47
Voltmeter display	8-40Vdc	1	78.49
Piece of Coaxial	300mm	2	16.95
SMA-SMB transition	SMA-BNC 50Ω	1	8.62
Board for circuitry	RE200-LF	1	4.46
Relay	DPDT 12Vdc	4	4x 4.85
Switch	C135ALAAF 16A 250V	2	2x 1.57
Total			**108.687,84 €**

7.4.2. Depreciable Material

The following material listed has been used for this project, but it could be found in the department´s laboratory, so this section will only consider the equivalent price for the time these resources have been used.

Component	**Price/unit (€)**	**Amortization term**	**Cost (€/month)**	**Total Cost**
Portable Computer	1300	40 month	32.5	162.5
Labview 2013	1500	2 years	62.5	312.5
Microsoft Office	420	2 years	35	175
Total				**650€**

7.4.3. Consumable Material

This is the material once has been used no one will be able to use it again.

Description	Cost (€)
Paper	100
Others*	200
Total	**300**

* “Others” mean small electronic components such as resistors, capacitors, wires, stain for welding…

- Material resources summary

Concept	Cost (€)
Acquired Material	108.687,84
Amortizable Material	650
Fungible Material	300
Total	109637.84
Incidentals (5%)	5481.892
VAT (18%)	17542.0544
Total Material Resources	**132.661,7874**

The budget devoted to material resources is **132.661,7874 Euros.**

7.5.Final budget calculation

This is the summarized calculation for this project´s budget. As seen before, a 5% contingency fund has been considered for both human and material resources. Value Added Tax (V.A.T) is the Spanish I.V.A (Impuesto sobre el Valor Añadido) and nowadays it is considered to be 18%.

Concept	Total Price (€)
Total Human Resources	**10.860,96**
Total Material Resources	**132.661,7874**
TOTAL (V.A.T included)	**143.522,7474**

The total budget for this project is **143.522,7474 Euros.**

8. Conclusion

In this final chapter the maturity of the project will be analyzed, in order to determine whether objectives have been completed or not. Then some further validation measurements are proposed for future steps in this long project.

8.1.Maturity of the project

The antenna validation laboratory project for SEAT´s Infotainment department is supposed to be a two year lasting project that will include many fields of validation (laboratory and/or field tests). The aim of this master thesis is to start-up this laboratory, from planning and management tasks to deploying a set of tests that can determine the validity of the devices under test.

Given all this, it can be said that the objectives of this project have been fulfilled; SEAT has now a fully equipped and operative laboratory at which validation tests can be made to different components, as it can be checked at chapter 5 where a complete set of impedance adapters have been tested and validated. First steps in automation have also been given, interconnecting all devices in a private network that later will allow to create a full executable for validation tests. Finally, a wide set of documents has been created so that anyone new at this laboratory can start working easily, knowing all the requirements and the regulations of the company.

Regarding to the Phantom power supply, all circuits explained at the low level design chapter have been implemented so that their behavior can be analyzed and corrected if needed. The whole system has been integrated in a circuit board and all the requirements have been achieved.

It is also true that at the beginning of the project, when planning tasks where being performed, some unpredictable events where not taken into account. The most important one, which provoked really serious delays on the development of the project, was the "economic" fusion between Centro Tecnico SEAT and SEAT itself. It seems that until now economic issues were managed separately from the rest of the company. During 2 full months, while the economic management tasks where being held to perform this fusion, there was a freezing in purchases in order to complete these tasks. These two months were just at the beginning of this project, so it supposed a big problem for material acquisition. It is probable that if this hadn´t happened the maturity of the project was much higher than the one nowadays is. Furthermore, these delays provoked that the timing shown in chapter 4 couldn´t be strictly followed at all its stages. However, there has not been a moment without work during the whole project; just some tasks planned for a certain date were moved into others to fit the schedules. Anyway, and as said before, the main objectives have been fulfilled and the remaining tasks have been documented in the future steps section so that they can be performed in an early future.

8.2. Future steps

8.2.1. Automation

It has been said that first steps in validation have been given. Connecting all devices to the same network and work at the same time with all of them is considered one of the most difficult tasks, and since it´s already done, it is time to start programming the automation process. The future aim for this project is to create an executable program, user friendly and efficient, that allows making validation tests by "just one click". By means of Labview, this program will select the frequency band of the device under test, and will select the different specific parameters the instrumentation needs. Then, once the results are obtained as explained in previous chapters, a document will outcome when the whole process is over, and it will automatically say whether the validation has been successful or not.

8.2.2. Further validation measurements

For the first stages of this project, only some of the validation tests that can be performed have been considered (those shown in previous chapters), in order to make an initial approach. Newer technologies are carring new developments in terms of antenna systems, that of course need their validation. These new services are already being studied and some requirements are being set nowadays. Here are some examples of these new works:

- C2X :

Car to X (where X can be Car, Infrastructure…) is a newborn technology that is coming strong nowadays. This technology allows connecting cars between them, as well as to the infrastructure around them, such as traffic lights, movement sensors… using wireless systems. These systems, of course, will need antennas that can perform real time processing, so these smart antennas must be implemented and therefore validated. It will not be as "easy" as validating radio antennas, since they include software and data transmission that requires specific testing.

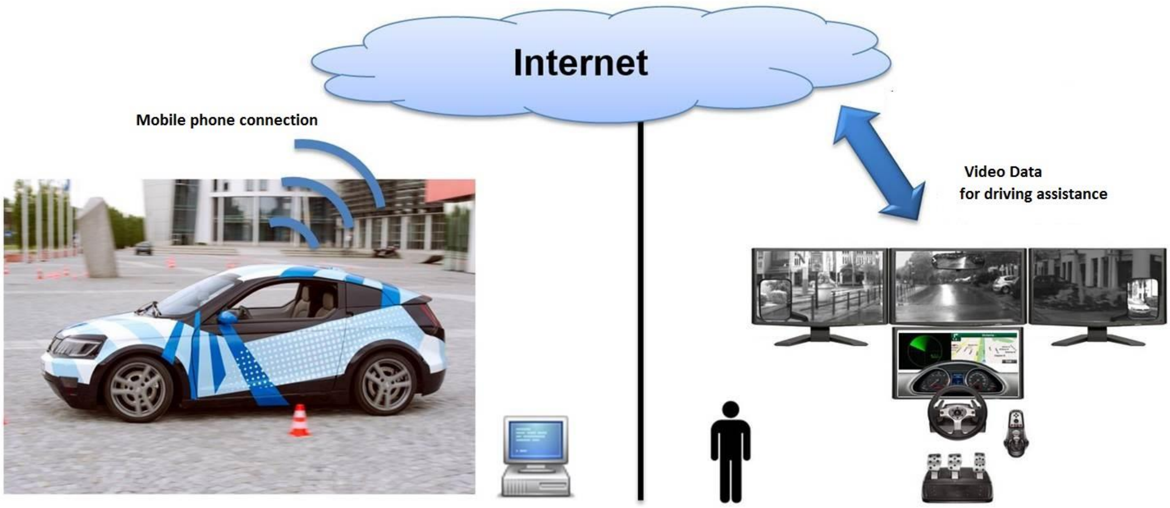


Figure 73: C2X implementation example
Source: ATZ, M. Lienkamp, TU München Teleoperated driving

- Navigation antenna systems validation:

Navigation systems are a vital part of the vehicle´s communication system, as one of the main functions of an Infotainment system. However, due to the company´s politic, antennas for navigation systems will not be validated at very first stages. Here are some of the requirements that are being evaluated for navigation systems validation.

- Amplifier-train current consumption

A consumption window is going to be established; for an input feeding voltage of 5V (with a ±5V tolerance), current through the device should be maintained between 15mA and 40mA.

- Adaptation

Return losses at the low noise amplifier´s output will be measured. They should not exceed 10dB. An adequate calibration of all connectors and feeding lines will be very important.

- Decoupling

The decoupling between GPS and phone services will have to be ensured, so that interferences can be avoided. Using short coaxial cables (shorter than 200mm if possible), S_{21} will be measured at the GPS receiver impedance adapter, and the decoupling will be considered $-S_{21}$.

Two frequency ranges will be measured to check the GPS-Phone decoupling:

- 800 MHz ≤ f ≤ 1000 MHz: -S21 < -45dB
- 1700 MHz ≤ f ≤ 2200 MHz: -S21 < -40dB

- Other specifications

The same way different parameters are measured in other services, navigation system components also must fulfill some specifications; most important ones have been listed below:

- Noise factor cannot exceed 1.5dB
- LNA´s gain will be typically 30dB (±3dB)
- 3dB Bandwidth won´t be greater than 20MHz
- Out of band attenuation will be 25dB at F_{GPS} ±50MHz
- Polarization will be right handed circular

8.2.3. Phantom power supply

All the circuitry has been implemented in a circuit board in order to test it in real use. As its behavior fulfilled all the requirements of functionality, the next step is to provide a PCB manufacturer a design file of all this circuitry. Using the appropriate software, a deep description of the circuit´s features (dimensions, ground planes, certain position of some components...) must be given, in order to get a printed circuit board that can be implemented in the box. Once it´s ready, buttons, displays and other elements that must be in the control pad of the box will be placed, completing the final prototype.

The last step will be to check the electromagnetic compatibility (colleagues from EE-31 will have to help on measuring EM emissions don´t affect anywhere) and make some noise measurements so that perfect functioning is ensured. Then it´s just a matter of getting into a car and test the power supply with real environment conditions.

9. Bibliography & References

BIBLIOGRAPHY

- C.A. Balanis, *Antenna Theory: Analysis and Design*, Wiley-Inrescience, New Jersey, 3rd edition, 2005
- A. Cardama, Ll. Jofre, J.M. Rius, J. Romeu, S. Blanch, M. Ferrando, *Antenas*, Edicions UPC, Barcelona, 2da edición 2002.
- V. Rabinovich, N. Alexandrov, B. Alkhateeb, *Automotive Antenna design and Applications*, CRC Press, 2010.
- C. Rauscher, *Fundamentos del Análisis de Espectro*, Rohde&Schwarz, 2003.

REFERENCES

- [1] ITU-R www.itu.int/ITU-R SM1446 *Definición y medición de los productos de intermodulación en transmisores que utilizan técnicas de modulación de frecuencia, de fase o compleja*. (04/2000)
- [2] IEEE *Standard Definitions of Terms for Antennas*, IEEE Std 145-1993, IEE, 1993
- [3] Agilent *Fundamentals of RF and Microwave Noise Figure Measurements*, Application Note 57-1
- [4] National Instruments´ "*LabView Training Days*"
- [5] A. Amurrio, J. C. Arellano, *PRÁCTICA 3: BENCHMARKING DE UNA ANTENA DE TELEFONÍA PARA AUTOMOCIÓN*, Plannar Antennas for Wireless Systems, UAB, 2015.
- [6] Volkswagen´s Internal regulation documents [CONFIDENTIAL]
    - TL-81000: *Compatibilidad electromagnética (CEM) de componentes electrónicos de vehículos*
    - TL-82133: *Functional requirements for on-board antennas*.
    - VW-99000: *Requisitos globales para la prestación de servicios en el contexto del desarrollo de componentes*
    - VW-80000: *Electric and Electronic Components in Motor Vehicles up to 3,5 t: General Requirements, Test Conditions and Tests*