# Design and implementation of a C-Band transceiver for the South African Synthetic Aperture Radar (SASAR II) project

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A project report submitted to the Department of Electrical Engineering, University of Cape Town, in fulfilment of the requirements for the degree of Bachelor of Science in Engineering.

Cape Town, October 2005

# Declaration

I declare that this report is my own, unaided work. It is being submitted for the degree of Bachelor of Science in Engineering in the University of Cape Town. It has not been submitted before for any degree or examination in any other university.

Signature of Author ..............................................................

Cape Town

18 October 2005

# Abstract

This report focuses on the design and implementation of a C-band transceiver for the South African Synthetic Aperture Radar (SASAR II) project. The transceiver transmits and receives a chirp signal at a frequency of 5300 MHz and is designed to replace the existing X-band RF stage and interface with the existing system at an intermediate frequency of 1300 MHz.

A 3W power amplifier was supplied for the transmitter power stage, which required a new power supply unit (PSU) to be designed and built. The completed power supply provided output voltages 5V, 10V, 15V, -15V and ground and could supply up to 2A of current.

The frequency distribution unit (FDU) was modified to produce two identical 4000 MHz local oscillator signals at 10 dBm for the up and down-conversion of the signal in the transmitter and receiver.

The power levels in the transmitter were tracked through each component and it was found that the C-band transmitter could interface with the existing system. A budget analysis of the C-band receiver compared favourably with the existing system budget with respect to signal and noise levels.

The transceiver was then designed and simulated using *SystemView* by Elanix. Given a 100 MHz chirp signal at 158 MHz the transceiver was able to up-convert the signal to 5300 MHz and then down-convert a received signal to 158 MHz. Filtering requirements were met in the simulation.

Components for the C-band transceiver were selected, however, the system was not constructed due to time constraints.

For my family

# Acknowledgements

I would like to thank my supervisor, Professor Inggs, for all the guidance that he has given me over the entire duration of the project.

I would also like to thank Georgie George who's office door was always open when I was having problems and was also a great aid in the testing phase of the project.

A very big thank you must also go to my parents for proof reading this project report.

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# List of Symbols

B— RF bandwidth [Hz]

K— Kelvin

N— Noise signal

$T_o$— 290K

$T_e$— Equivalent temperature

S— signal

F— Noise figure

G— Gain

k— Boltzmann's constant ( $= 1.38 \times 10^{-23}$)

$V_o$— Output voltage

R— Resistance

# Nomenclature

**ADC**—Analogue to Digital Converter.

**AWG**—ArbitraryWaveform Generator.

**Baseband**—The range of frequencies occupied by the signal before modulation or after demodulation close to dc.

**BIT**—Built in Test.

**C-band**—Frequency range from 4 GHz to 8 GHz

**Chirp**—A pulse modulation method used for pulse compression. The frequency of each pulse is increased or decreased at a constant rate throughout the length of the pulse.

**Coherence**—A continuity or consistency in the phases of successive radar pulses.

**DAC**—Digital to Analogue Converter.

**DPG**—Digital Pulse Generator.

**DSU**—Data Strorage Unit.

**FDU**—Frequency Distribution Unit.

**GPS**—Global Positioning System.

**I**—In-phase.

**IF**—Intermediate Frequency.

**L-band**—Frequency range from 1 GHz to 2 GHz

**LNA**—Low Noise Amplier

**LO**—Local Oscillator.

**MCG**— Manual Gain Control

**NAV**—Navigation Unit.

**Q**—Quadrature.

**Radar**—Radio Detection and Ranging.

**Range**—The radial distance from a radar to a target.

**RCU**—Radar Controller Unit.

**RDU**—Radar Digital Unit.

**RF**—Radio Frequency.

**RFU**—Radio Frequency Unit.

**RRSG**—Radar Remote Sensing Group (UCT).

**SASAR II**—South African Synthetic Aperture Radar.

**STC**— Sensitivity Time Control

**Synthetic Aperture Radar (SAR)**—A signal-processing technique for improving the azimuth resolution beyond the beamwidth of the physical antenna actually used in the radar system. This is done by synthesizing the equivalent of a very long sidelooking array antenna.

**Target**—Any reflecting object which interferes with the transmitted wave and reflects part of its energy.

**X-band**—Frequency range from 8 GHz to 12 GHz.

# Chapter 1

# Introduction

## 1.1 Project Background

This project report describes the design, implementation and testing of a C-Band (6cm) transceiver for the South African Synthetic Aperture Radar (SASARII) project.

The SASAR II Imaging Radar System is currently an X-band system which operates at 9.3 GHz. The system is used to acquire high resolution images of the surface of the earth from a moving platform such as an airplane or a satellite.

The system is based on SAR (Synthetic Aperture Radar) theory and uses radar pulses to illuminate a target area and gather information, in order to construct an image of that area. The benefit of such a system is that it is able to perform regardless of the weather conditions or the time of day.

The SASAR II system is made up of various sub-systems. Each of the separate sub-systems was designed and built as part of masters dissertations and completed in 2004.

Each sub-system is responsible for a specific task. The SASAR II system is divided into about eight sub-systems as illustrated below in Figure 1.1, modified from the diagram on the SASAR II website [7].
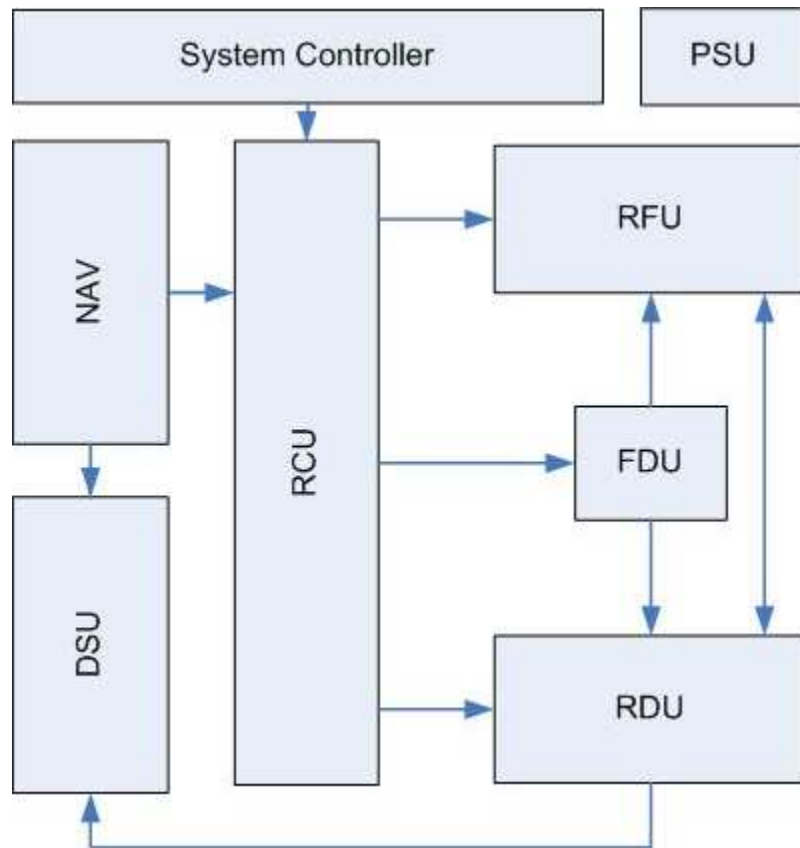
Figure 1.1: Block diagram of the SASAR II system showing the interfaces between different systems

The project will mainly focus on the re-design of a Radio Frequency Unit (RFU), which consists of the transmitter and the receiver components, as well as the antenna as shown in Figure 1.2.
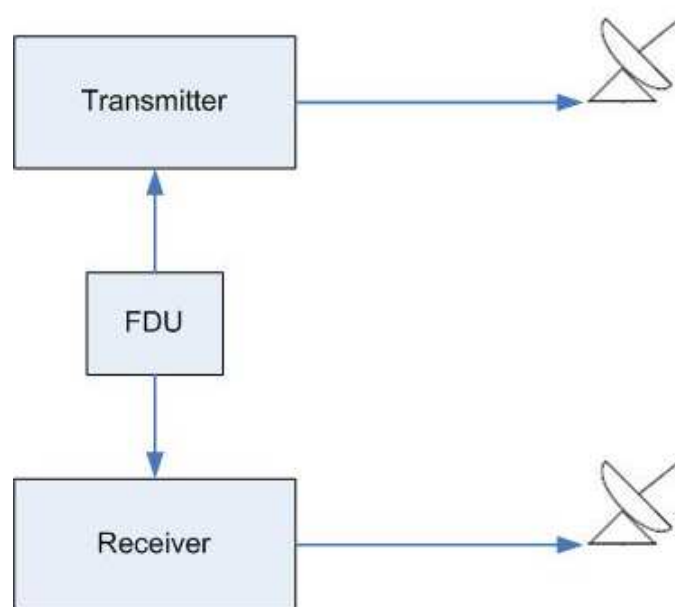


Figure 1.2: Block diagram of the RFU

The new RFU, which will operate at 5.3 GHz, will make use of several existing signals from the Frequency Distribution Unit (FDU), which is responsible for providing the clock and local oscillator signals.

The material presented in this report was gathered from various books, the Internet, final year thesis projects of previous students and various or knowledgeable people involved in the project.

## 1.2  User Requirements

The following user requirements were specified for the C-band transceiver:

- The transmitted and received carrier frequency will be 5300 MHz (C-band).

- The bandwidth of the chirp signal is 100 MHz

- The input to the system will be at 1300 MHz.

- The 1300 MHz signal must be obtained from the L-band stage of the existing transceiver.

- The receiver intermediate frequency will be 1300 MHz.

- The power level in the receiver must be compatible with the existing receiver.

- Transceiver signal levels must be consistent with the SASAR II system budget.

- The 3W Tellumat power amplifier supplied must be used in the C-band power stage.

- All signals must be filtered. Spurious signals must be must be eliminated on transmission and the receiver must be protected from other frequency emissions.

- The power supply must be compatible with the existing SASAR II power supply

- The receiver must have a reasonable level of BIT (built in test) and also be compatible with the SASAR II control processor.

## 1.3  Plan of Development

This project report is arranged in the following structure:

**Chapter 2: Background Information**

This chapter provides background information on the sub-systems, which will be used in the design of the C-band transceiver. Since the C-band transceiver is replacing the existing X-band transceiver, it is necessary to investigate various aspects of these sub-systems to make the new transceiver as compatible as possible. The sub-systems under investigation

include the power supply unit (PSU), the frequency distribution unit (FDU) as well as the existing transmitter and receiver. The PSU is investigated to determine which voltages it can provide to the system and to determine any modifications that need to be made, based on the requirements of any new components. The FDU is investigated to determine how it can be modified to supply the local oscillator signal of 4000 MHz. The existing transmitter and receiver are studied to determine the correct power levels for the interfaces between the existing L-band section and the new C-band section on the transmitter side, as well as the new C-band to L-band interface on the receiver side. A thorough understanding of the existing systems is necessary for constructing the simulations for the transceiver.

**Chapter 3: Concept Study**

This chapter defines the problem which will be examined in this report. The design of the C-band transceiver is based on the user requirements, the existing SASAR II system architecture, time available for this project and the cost of available components. The objectives of this chapter are to take the user requirements and then show how we plan to accomplish those requirements. The concept study discusses the requirements for each sub-system, the system architecture requirements and finally the hardware suppliers. A summary is then given at the end of the chapter.

**Chapter 4: Design of the C-band Transceiver**

The knowledge gained from the concept study is used to complete a full simulation of the transmitter. The chapter begins with a block diagram approach and identifies critical levels which have to be achieved for the system to function with maximum efficiency. A mask is identified for the output signal, which gives constraints on the type of mixers and filters that can be used, as well as the total gain of the system. Once all the constraints have been identified, real components are selected and their properties are simulated in the RF simulator *SystemView* by Elanix. The simulated C-band transmitter is then combined with a simulated version of the existing transmitter, and the performance is monitored to achieve total compatibility, as well as consistency with respect to the gain and noise figure.

As with the transmitter, the receiver is designed by taking block diagrams and establishing the various constraints, based on the user requirements and required power levels of the system. Once again real components are chosen, which will achieve total compatibility with the existing system, and they are simulated with the same software. A budget analysis is drawn up so that the performance can be monitored to ensure that the final product meets the correct specifications. A brief summary ends the chapter.

**Chapter 5: Construction**

The construction chapter describes the modifications to the PSU and the FDU.

**Chapter 6: Testing**

The penultimate chapter describes the testing of the simulations to prove that, given a chirp signal on the input, the output is indeed consistent with the user requirements and is compatible with the system. The 3W Tellumat power amplifier and the modifications that

were made to the FDU and the PSU for the 3W Tellumat amplifier are thoroughly tested for performance

**Chapter 7: Conclusions and recommendations**

The final chapter deals with recommendations for any future work on the project

## 1.4   Scope and Limitations

This project report describes the design and implementation of a C-band transceiver for the SASAR II system. Testing was done under the supervision of Georgie George at UCT.

The system has not been constructed due to the long delivery times of the components and time constraints on the project. However, thorough simulations have been done on the proposed system based on the real components chosen.

Detailed descriptions on the other SASAR II sub-systems are beyond the scope of this project. All information on the various other sub-systems is available in the thesis projects of previous students.

# Chapter 2

# Background Information

The transceiver is essentially divided into three main parts. The transmitter is responsible for taking the low-power, baseband signal, which is a 100 MHz chirp waveform from the existing system, and converting it into a high power RF signal. The receiver will receive any pulses from the transmitter, which have been reflected by a target and convert them down to a workable intermediate frequency where they can be processed by one of the other sub-systems. The antenna is responsible for the transmission and receiving of signals. A duplexer is implemented to enable the same antenna to be used to transmit and to receive. This study does not however implement a duplexer, mainly due to time constraints. The system will therefore be designed on the basis that there are two separate horn antennas, one on the transmitter and one on the receiver.

It has been decided that the design should be followed from the previous X-band transceiver. This course of action allows for maximum compatibility with the existing system as per the user requirements.

The transceiver relies heavily on other sub-systems. The most notable of these are the PSU and the FDU.

## 2.1 The PSU (Power Supply Unit)

The PSU is responsible for supplying the components of every sub-system with power at the correct voltage levels. It is important for the PSU to maintain stable voltages as this affects the performance of the system.

The following information was obtained, after an investigation into the existing PSU:

- The PSU is built inside an old UPS. The 230V (AC) mains voltage is fed into the back of the unit and the various output voltages are made available on the front panel.

- There are three main components in the system. First there is the transformer stage, which branches into a pre-purchased power supply and into a voltage regulation

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panel. The voltage regulation panel consists of a series of adjustable voltage regulators (LM317), which tap off independently form the 12V output of the pre-purchased power supply and are then set to regulate a specific output voltage by selecting a suitable resistor.
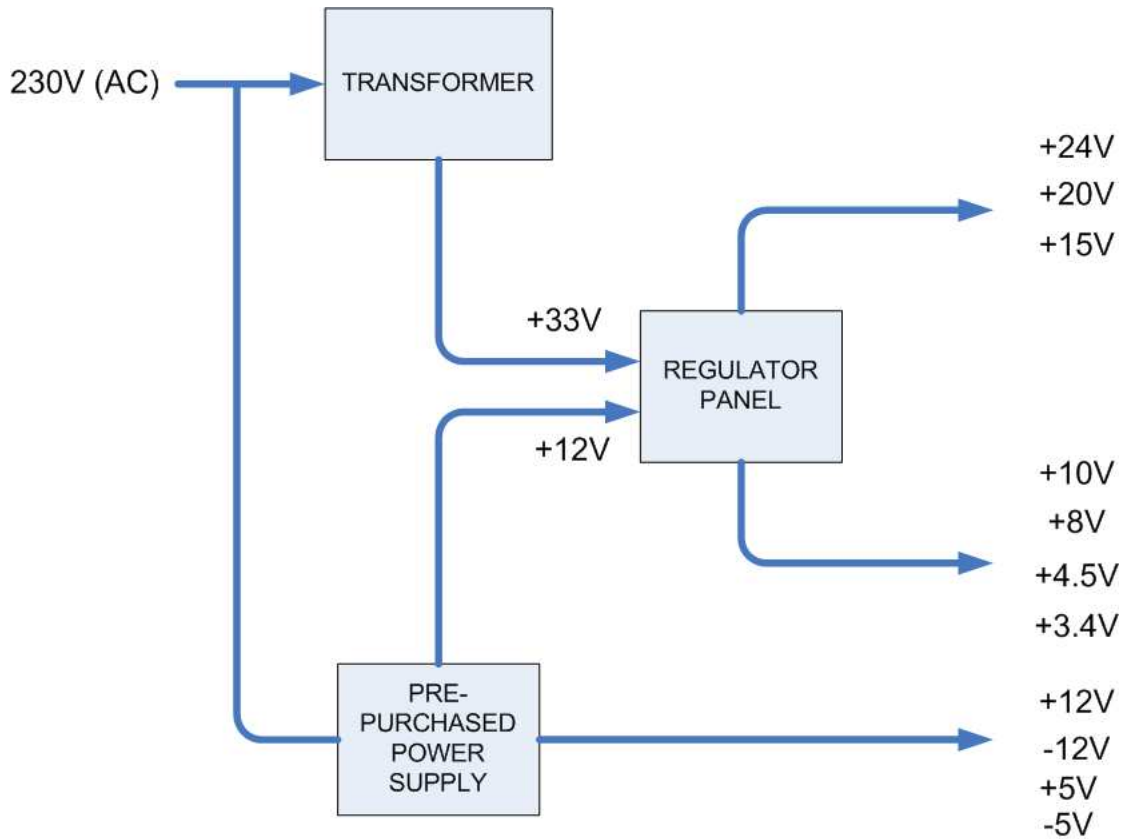


Figure 2.1: A block diagram of the PSU showing the available output voltages

As can be seen in Figure 2.1 the output voltages available are 24,20,15,$\pm$12,10,8, $\pm$5,4.5 & 3.4 volts.

The PSU is very stable and has a very low frequency ripple. Voltage ripple is also within 10%.

## 2.2   The FDU (Frequency Distribution Unit)

The FDU produces all the local oscillator signals for the mixers in the transceiver. A 10 MHz stable oscillator is used to generate all the required local oscillator signals at 158 MHz (IF 1), 1142 MHz (IF 2) and at 4000 MHz (multiplied by 2 for 8000 MHz in the X-band receiver).[1]

The FDU also provides clocking signals to the ADC and DAC in the digital unit. They are, however, irrelevant in this study.

A block diagram in Figure 2.2 below shows the architecture of the FDU with the required output frequency.
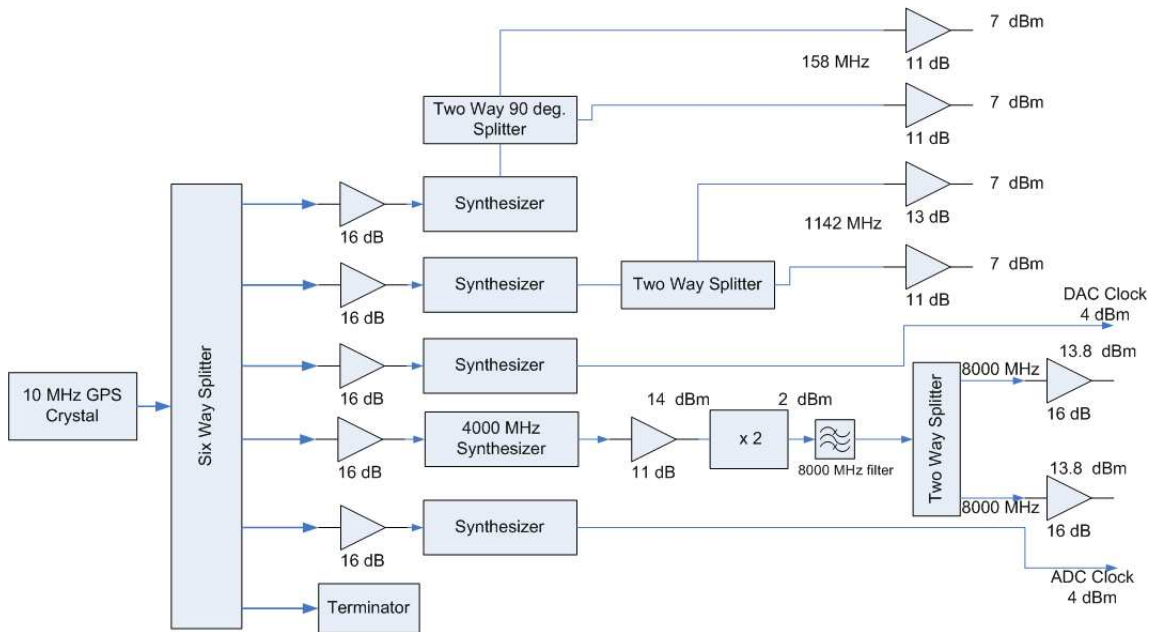


Figure 2.2: Block diagram of the FDU

We will only be interested in the 4000 MHz signal for this project. The 4000 MHz signal will be split so that the local oscillator signal is the same for the transmitter and the receiver.

## 2.3 The Existing Transmitter

Figure 2.3 below shows the L-band stage of the SASAR II system, which will be the input for the 5300 MHz transceiver.

The inputs I and Q come from a PC card. They are mixed with a 158 MHz oscillator and the two signals are added together, filtered and then mixed with a 1142 MHz local oscillator signal before being filtered to give the required 1300 MHz signal.[1]
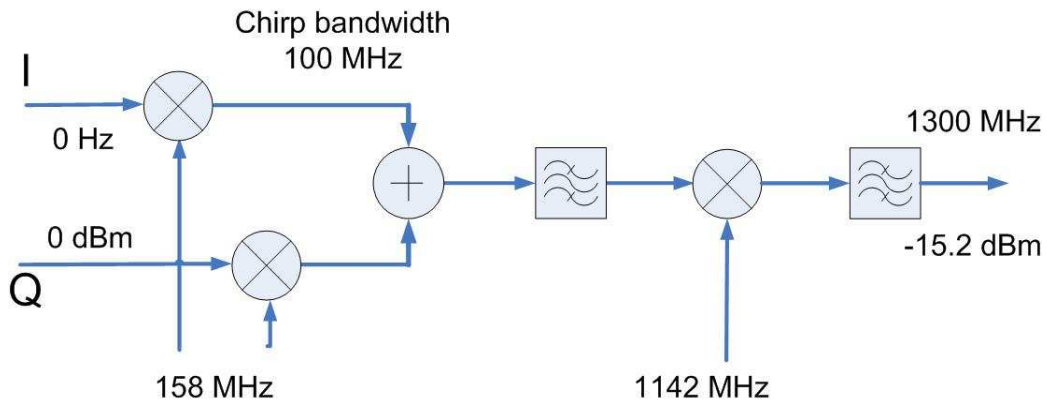
Figure 2.3: Diagram of the existing 1300 MHz (L-band) transmitter

## 2.4 The Existing Receiver

The C-Band receiver will interface with the existing L-band receiver at 1300 MHz as shown in Figure 2.4.
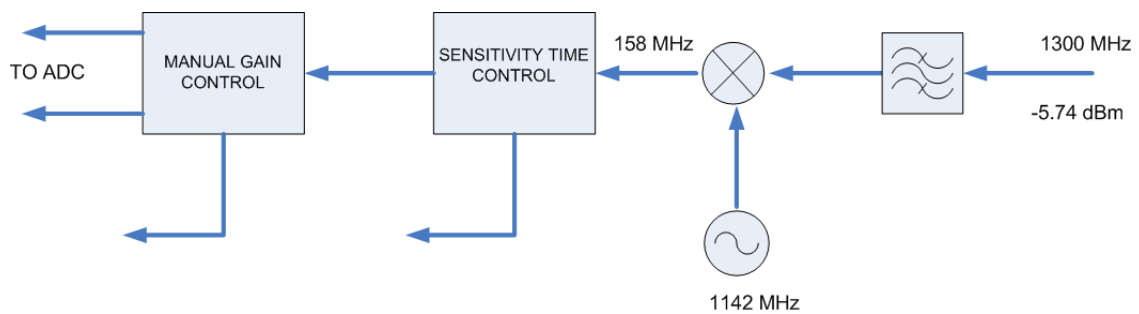


Figure 2.4: Diagram of the L-band Receiver

The STC block represents a variable gain, which changes with time. This enables the system to maintain a constant power level over the time at which the echo pulse is received.

The MGC is used when the system is operating over different targets. If the targets are small or distributed and expected to return low levels then the MGC is switched to boost the gain, which in turn improves the noise figure. If the targets are large then the MGC is switched to limit the received signal and avoid driving the receiver into compression.[3]

## 2.5 The 3W Tellumat Power Amplifier

The transmitter must use the custom 3W Tellumat amplifier in the power stage, as specified in the user requirements.

There are seven connections in addition to the input and output of the power amplifier.

Four of the seven connections are voltage inputs and three are control signals. The diagram in Figure 2.5 shows the pin connections for the 3W amplifier.
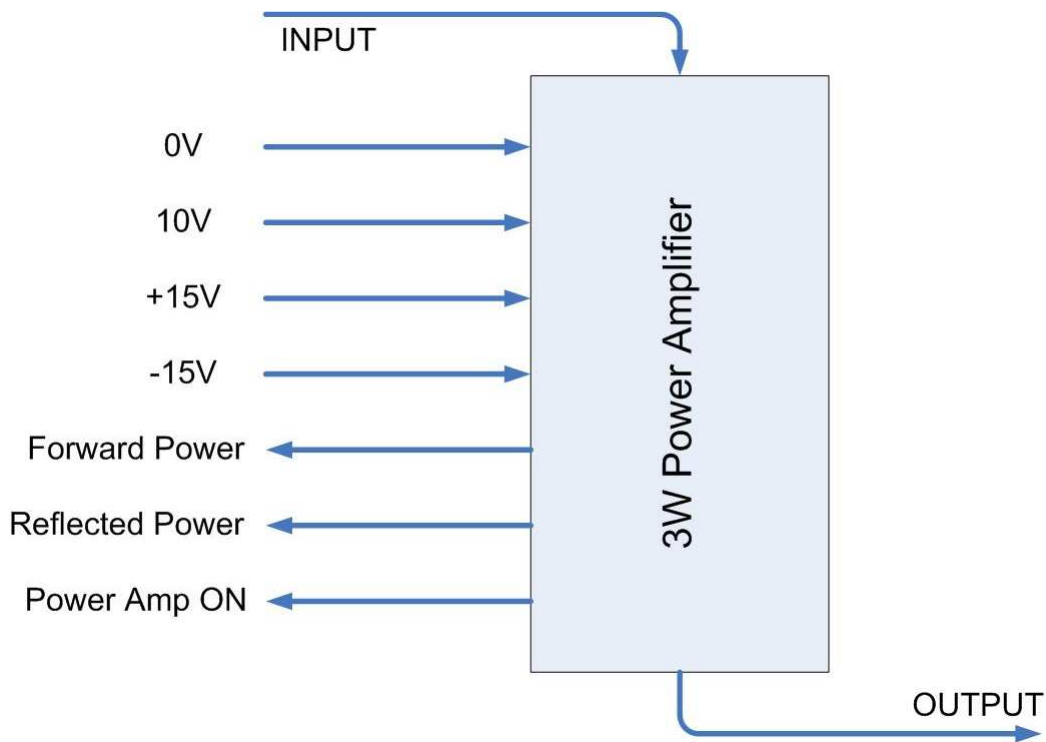
Figure 2.5: Diagram of the custom 3W Tellumat amplifier

The following was determined by the investigation:

- The +15 and -15 volt supplies are bias voltages.

- The 10V supply draws between 1.5 and 1.6 amperes and is the main power requirement of the amplifier.

- *Forward power* and *reflected power* output a voltage which is directly proportional to the actual forward and reflected power in the amplifier. These two pins will be used to monitor the forward and reverse power on the front panel of the SASAR II package.

- *Power Amp ON* requires a 5V signal to turn the power amplifier on.

# Chapter 3

# Concept Study

This chapter defines the problem which will be examined in this report. The design of the C-Band transceiver is based on the user requirements, the existing SASAR II system architecture, time available for this project and cost of available components.

## 3.1 Requirements Analysis

The following conclusions were drawn, based on the user requirements of the C-band transceiver:

- *The transmitted and received carrier frequency will be 5300 MHz (C-band):* The existing system uses a 9300 MHz (X-band) transceiver. A new transceiver will have to be built utilising components which operate in the 5300 MHz range. Since most RF components are made specifically to operate within a certain frequency band, it is unlikely that any of the components could be reused in the C-band transceiver. New components would have to be selected and ordered, which would include filters, mixers and amplifiers.

- *The bandwidth of the chirp signal is 100 MHz:* Since the 5300 MHz transceiver will form a new sub-system, the 100 MHz signal will come in at the existing L-band part of the system. The operating frequencies for the components must therefore be in the range of at least 5200 MHz to 5400 MHz if 5300 MHz is the centre frequency to accommodate this bandwidth.

- *The input to the system will be at 1300 MHz:* This means that the output of the existing L-band stage will be the input of the new C-band stage. The power level at which the 1300 MHz inputs into the new transceiver must compatible to ensure that the system does not overload.

- *The receiver intermediate frequency will be 1300 MHz:* It is easier to process the received information at a lower frequency than at the received 5300 MHz. So the

signal is down-converted to 1300 MHz, where it becomes easier to perform proper filtering and other processing on the signal. The 5300 MHz signal must be mixed with a 4000 MHz local oscillator signal to achieve this. The same 4000 MHz oscillator signal from the transmitter must be used to ensure coherency

- *The power level in the receiver must be compatible with the existing receiver:* The level at which the C-band receiver outputs the received signal must be compatible with the existing system. This will ensure that it interfaces at the correct levels to the other sub-systems and that they all operate at their designed levels.

- *The 3W Tellumat power amplifier supplied must be used in the C-band power stage:* In order for the power amplifier to operate at the highest efficiency, the 5300 MHz signal level must be at the correct level before it is input into the amplifier. Therefore the 5300 MHz signal may have to be adjusted by a pre-amplifier after the mixing stage. According to the data sheet for the 3W amplifier, the best operating conditions are when the input signal is between -10 dBm and 0 dBm.

- *All signals must be filtered. Spurious signals must be must be eliminated on transmission and the receiver must be protected from other frequency emissions:* Unwanted harmonics from the mixing stages must be removed as well as other unwanted frequency components which are received by the receiver. This is to ensure that no additional frequency components are transmitted other than those required, and that no other additional received frequency components distort the signal. Unwanted signals on the transmitter side will be generated by the mixers as inter-modulation products. Unwanted signals on the receiver will be caused by other transmissions on different carrier frequencies.

- *The power supply must be compatible with the existing SASAR II power supply: the existing PSU must be able to supply the 5300 MHz transceiver.* Any additional required voltages should be tapped from the existing PSU. Currently the only required voltage not available from the PSU is -15V. A suitable circuit will have to be designed and implemented to convert one of the available voltages to -15V. Any other components which have not been purchased should be selected based on the available outputs from the PSU.

- *The receiver must have a reasonable level of BIT (built in test) and also be compatible with the SASAR II control processor:* this will be the manner that it is proved that the system does what it was designed to do without actually having to take it out of the laboratory.

## 3.2  C-Band Transceiver Architecture Concept Study

### 3.2.1  The C-Band Transmitter

The input of the C-band transmitter will be the 1300 MHz signal from the L-band stage of the existing transmitter. The mixer will take in a local oscillator signal at 4000 MHz, at the required power level from the FDU.

Since most mixers required between 7 dBm and 10 dBm of power on the local oscillator it was decided that the FDU should deliver the 4000 MHz signal at 10 dBm.

The L-band transmitter outputs the 1300 MHz signal at -15.2 dBm. This signal must then be mixed up to a 5300 MHz signal. In order for the power amplifier to operate at maximum efficiency the input power to the amplifier must be between -10 dBm and 0 dBm. The power amplifier will therefore be driven with an input power of 0 dBm. This means that a pre-amplifier is required between the mixing stage and the power amplifier. It may be necessary to put more gain into the circuit than is required, since the range of available gains is limited by the manufacturer. Barrel attenuators will then be used to bring the signal down to the correct level.

There are also requirements on the output signal. Filters must be inserted to ensure that no unwanted signals are transmitted. A filter will therefore be placed after the mixer to eliminate any intermodulation products and a filter will also be placed at the output to ensure that the output signal does not trespass outside of the allocated band.

The filters must only allow the 100 MHz signal band to pass above 10 dB below the carrier.

### 3.2.2  The Frequency Distribution Unit

The FDU will supply the local oscillator signals for the C-band transceiver. The FDU is currently modified to provide an 8000 MHz local oscillator signal to the X-band transceiver. Since this is done by taking a 4000 MHz signal, multiplying it by two and then splitting it into two 8000 MHz signals for the transmitter and receiver, it is only necessary to remove the "multiply by two stage". Once the "multiply by two" stage has been removed, the 4000 MHz signal can be split into two signals for the transmitter and the receiver.

Fortunately the splitter that has been used for the 8000 MHz signal can operate over a frequency range 3500 to 9000 MHz. It is therefore unnecessary to replace this component and the FDU can be successfully modified simply by removing the multiplier and replacing the amplifiers on the output of the splitter.

As discussed previously, the amplifiers on the output of the splitter must have sufficient gain to ensure that the 4000 MHz signals drive the mixers at least at 10 dBm.

### 3.2.3   The C-band Receiver

The C-band receiver receives a 5300 MHz signal, which has been transmitted by the C-band transmitter and reflected off a target. In this project it is assumed that the received signal will be -50 dB.

A filter will be placed at the receiving end to eliminate all unwanted frequency bands. This means that there is a narrow filter requirement.

The signal is amplified before the mixing stage. This amplifier must have a low noise figure as it will contribute the most to the total noise figure of the receiver.

The 5300 MHz signal will then be mixed down to a 1300 MHz intermediate frequency. The 1300 MHz signal is then fed into the existing receiver for sampling and processing. It is therefore necessary that the budget of the C-band receiver correspond closely to that of the X-band receiver to ensure maximum compatibility. Total noise figure, gain and signal strength should therefore correspond to the existing system budget in order to fulfil the user requirements.

### 3.2.4   The Power Supply Unit

The power supply unit will supply power to all the components in the transceiver. Since the power supply will need to be modified for the custom 3W Tellumat amplifier, it was decided that a separate power supply should be built for it.

The 3W amplifier requires a very stable, linear supply with a low frequency and voltage ripple. The power supply must therefore be a linear DC supply. A switch mode power supply cannot be implemented due to the high noise and ripple.

The 3W amplifier requires voltages of +15V, -15V, +10V, +5V and ground. The total current requirement is in the region of 2A.

It was decided that a 220V to 30V transformer be used to step down the 220V AC mains voltage to 30V. A bridge rectifier circuit would then be used to convert the 30V AC to just over 20V DC and voltage regulators placed in the circuit to tap of our required voltages.

## 3.3   Hardware Supplier Concept Study

Although the assembly of the C-band transceiver is beyond the scope of the project, it was still necessary to select real components for the sake of running simulations and performing various other calculations. Several company's websites were consulted and components selected based on cost and the user requirements. In the end it was decided that the components should come from three companies. Minicircuits was chosen as the supplier of the mixers and amplifiers; Miteq was the supplier of the LNA and K&L was used for the custom filters.

The component for the modification of the FDU was sourced from *Hittite Microwave Corporation*, which provided a packaged DC to 6 GHz amplifier.

## 3.4 Conclusions

The user requirements and the system architecture were analysed and the specifications for the design of the C-band transceiver were obtained. These specifications were used to form the basis of the designs and to choose manufacturers for the components.

The user requirements will be satisfied by following the design specifications obtained in this concept study.

# Chapter 4

# Design of the C-band Transceiver

This chapter describes the design of the C-band transceiver for the SASAR II system. The technical specifications of the various components incorporated in the system are not given and readers should consult the appendices of this document or the CD provided with this project report for data sheets to familiarise themselves with these components.

A transceiver was designed, which consisted of a transmitter, a receiver, modified FDU and a PSU. The process begins with block diagrams of the system and then evolves into simple circuit diagrams and simulations. A summary is then given on the outcomes of the design process.

## 4.1   Design of the C-band Transmitter

In the previous chapter we discussed the requirements for the C-band transmitter and the design parameters and specifications which were required. A brief summary of the main points is given below:

- The input is the 1300 MHz signal from the existing L-Band stage.

- The input power of the 1300 MHz signal is at -15.2 dBm.

- The input signal at 5300 MHz to the 3W power amplifier is to be at 0 dBm.

- All spurious signals must be filtered out.

The architecture of the transmitter for the SASAR II system is described by the block diagram below in Figure 4.1.
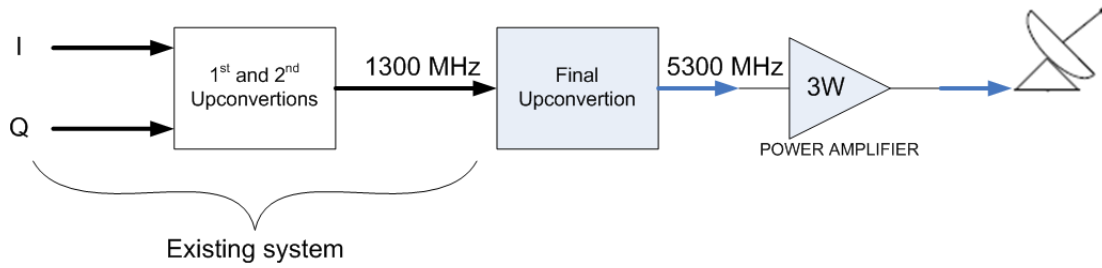
Figure 4.1: Block diagram of the transmitter of the SASAR II system

The goals of the C-band transmitter are to take the 1300 MHz signal from the existing L-band stage, mix it up to an RF frequency of 5300 MHz, amplify the signal sufficiently using the provided 3W Tellumat amplifier and transmit the signal via a horn antenna.

The design process of the existing system was followed to ensure maximum compatibility, therefore the C-band transceiver has been designed similar to the X-band transceiver. Layout of the following chapter also closely corresponds to that of the master's dissertations, in which X-band systems are described. Figure 4.2 below shows the circuit diagram of the C-band transmitter RF stage.
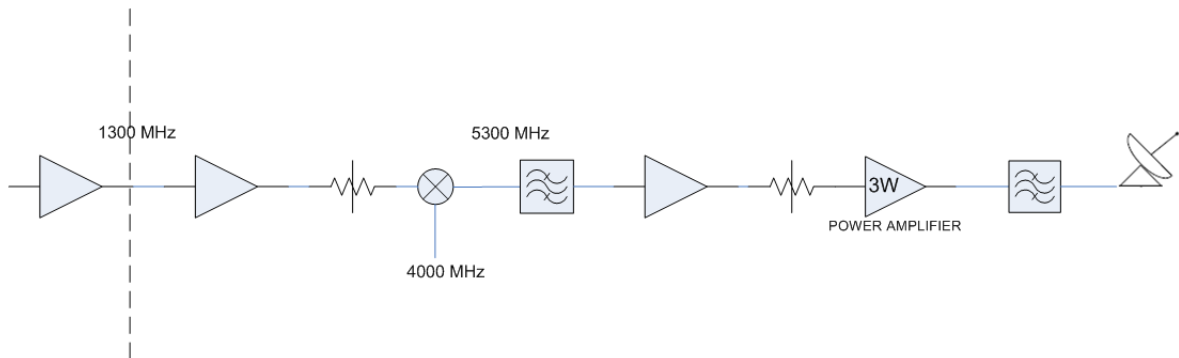


Figure 4.2: Circuit diagram of the C-band RF stage

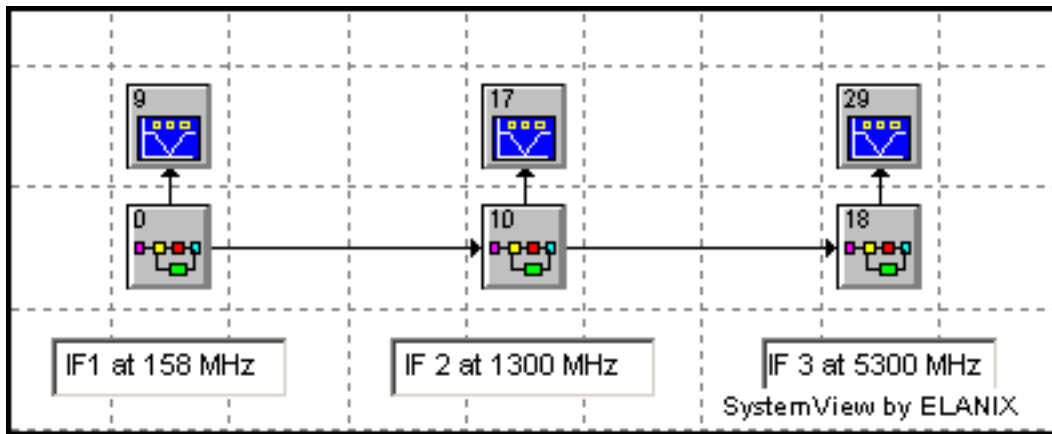The corresponding *SystemView* token diagram is also shown in Figure 4.3.

Figure 4.3: Token diagram of the SystemView simulation of the transmitter

The first two tokens, 0 and 10, represent the existing system. Figure 4.4 and Figure 4.5 represent the simulated IF 1 and IF 2 stages. The information for these tokens was gathered from the thesis reports of Darren Coetzer and Ajmal Mohungoo [1,3].
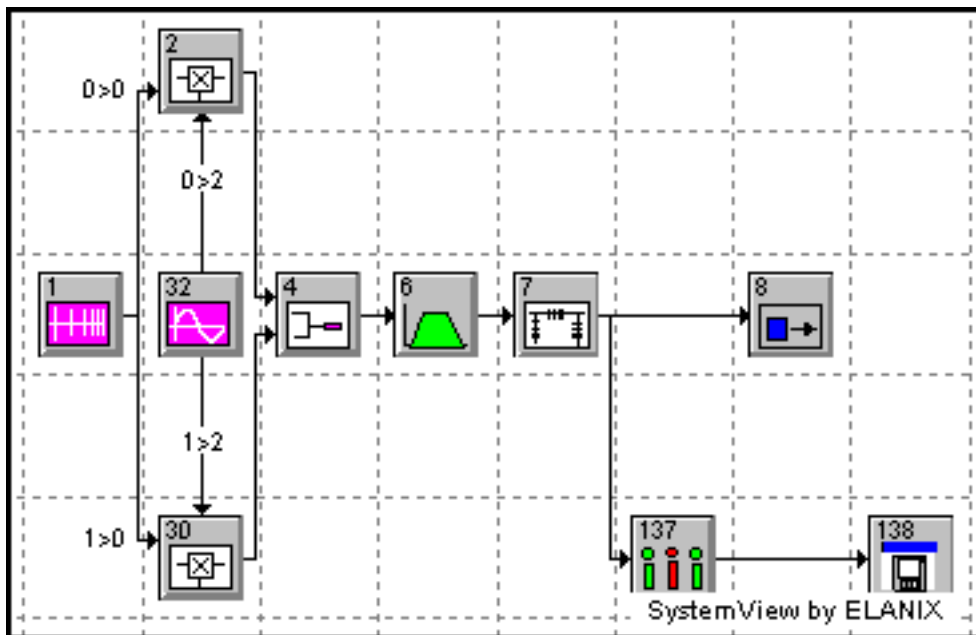


Figure 4.4: Simulation of IF 1 stage at 158 MHz

| Token No. | Type | Manufacturer | Part No. |
|---|---|---|---|
| 2 | Mixer | Minicircuits | ZFM-3 |
| 30 | Mixer | Minicircuits | ZFM-3 |
| 4 | Splitter/Combine | Minicircuits | ZMSCQ-2-180 |
| 6,7 | Filter | Lorch | Custom |

Table 4.1: Components for IF 1
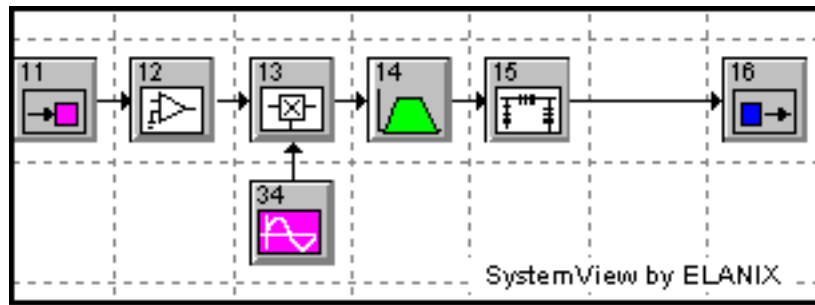
Figure 4.5: Simulation of IF 2 stage at 1300 MHz

| Token No. | Type | Manufacturer | Part No. |
|-----------|------|--------------|----------|
| 12 | Amplifier | | |
| 13 | Mixer | Miteq | IR0102LC1C |
| 14,15 | Filter | Lorch | Custom |

Table 4.2: Components of IF 2

Token 18 represents the final RF stage at 5300 MHz and is shown in Figure 4.6 below. All the components are real components selected from various component manufacturers. Full data sheets regarding these components can be found in Appendix D, however a summary is given in Table 4.6.
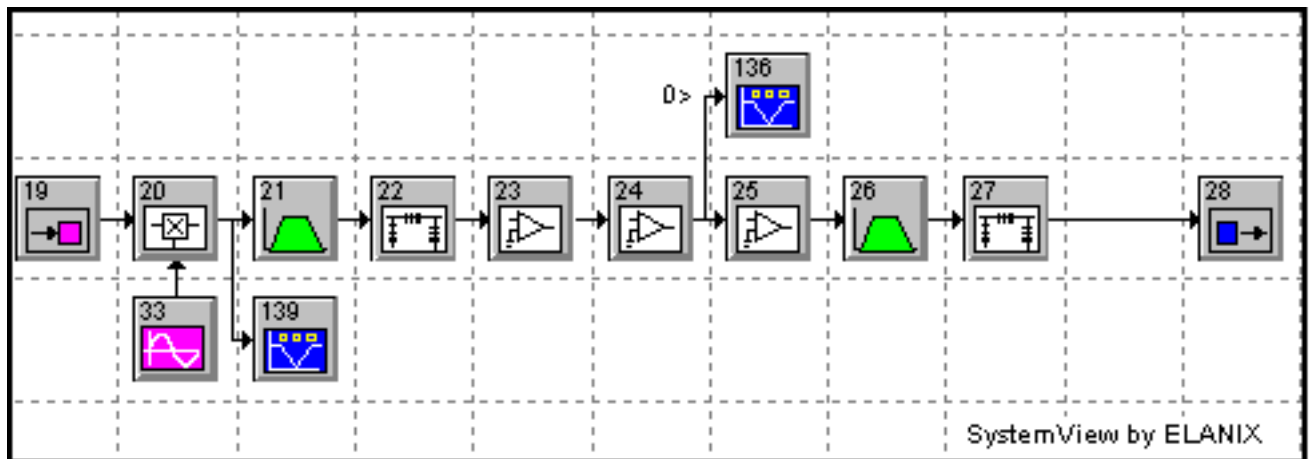


Figure 4.6: Simulation of the RF stage at 5300 MHz

## 4.1.1   Mixers and Filters

A mixer is a three port device which is used to translate a signal either up or down in frequency. It achieves this translation in frequency by combining an RF signal with a local oscillator (LO) signal in a nonlinear or time-varying element such as a diode or a transistor. These nonlinear components generate harmonics and other products of the two

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input frequencies so the outputs can be represented by the formula *mLO±nRF,* where *m* and *n* are integers or zero. These terms are called harmonic intermodulation products with the sum of *m* and *n* giving the order. There are several types of mixers available, the most common being:

- Unbalanced

- Single balanced

- Double balanced

- Image rejection

The important attributes to look at when selecting a mixer include:

- The input power levels of the RF and LO signals

- The conversion loss of the mixer

- The isolation between the different ports

- The operating frequencies of the mixer for both the RF and LO as well as the IF.

In order to up-convert the 1300 MHz signal to 5300 MHz, the 1300 MHz signal is required to be mixed with the local oscillator signal of 4000 MHz. Since only the upper-side band at *LO + RF* is required, all the other products must be filtered out [1,6].
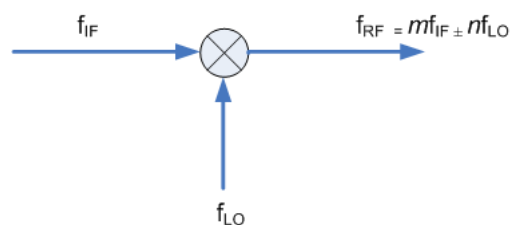


Figure 4.7: Up-conversion in a mixer

The harmonic intermodulation products from the mixer are shown in Figure 4.8, which is the output from token 139. Figure 4.9 shows a simplified version with the signal level of each product.
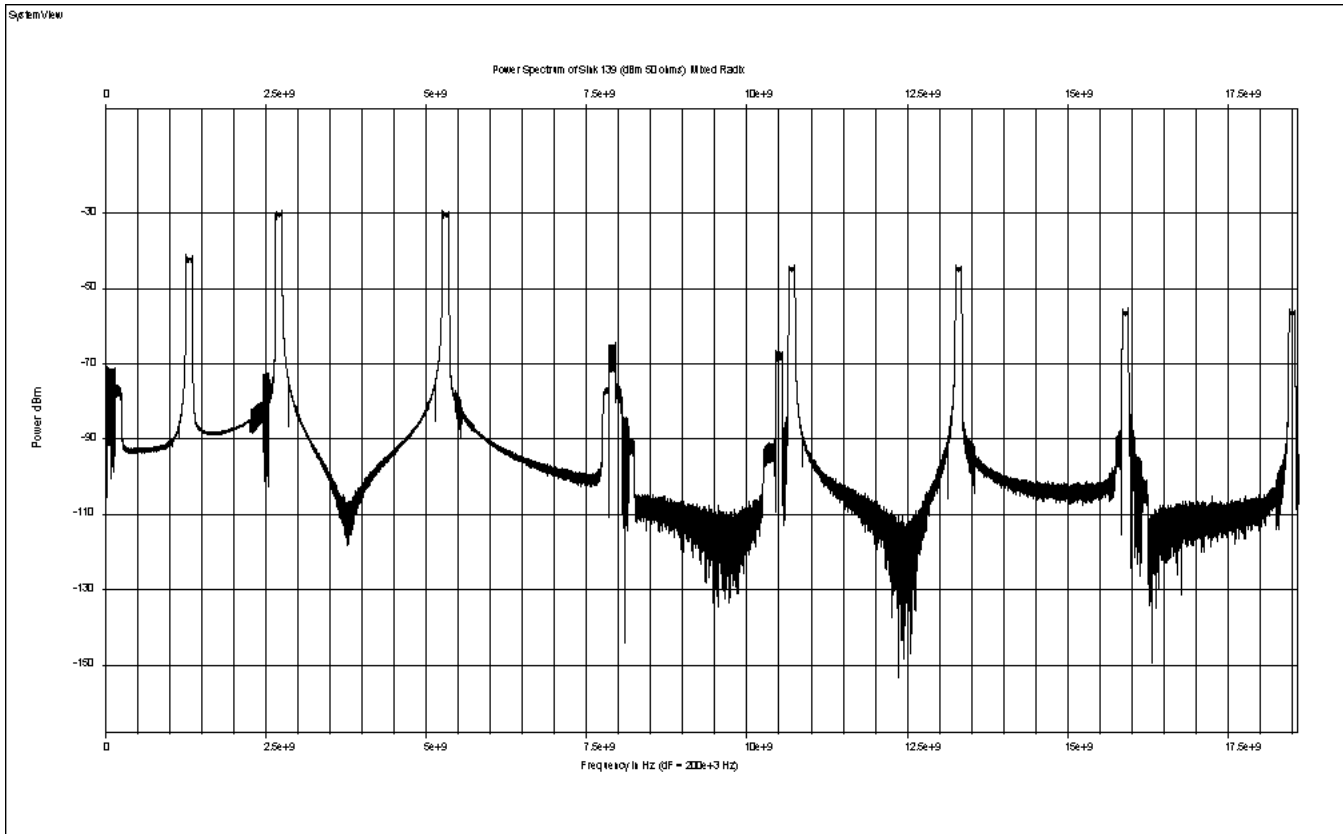
Figure 4.8: Intermodulation products on the output of the *Minicircuits* ZX05-C60LH mixer

| n | m | nLO + mIF | nLO - mIF | Order |
|---|---|-----------|-----------|-------|
| 0 | 1 | 1300 | -1300 | 1 |
| 1 | 0 | 4000 | 4000 | 1 |
| 1 | 1 | 5300 | 2700 | 2 |
| 2 | 2 | 10600 | 5400 | 4 |
| 3 | 3 | 15900 | 8100 | 6 |
| 1 | 3 | 7900 | 100 | 4 |
| 3 | 1 | 13300 | 10700 | 4 |
| 3 | 5 | 18500 | 5500 | 8 |

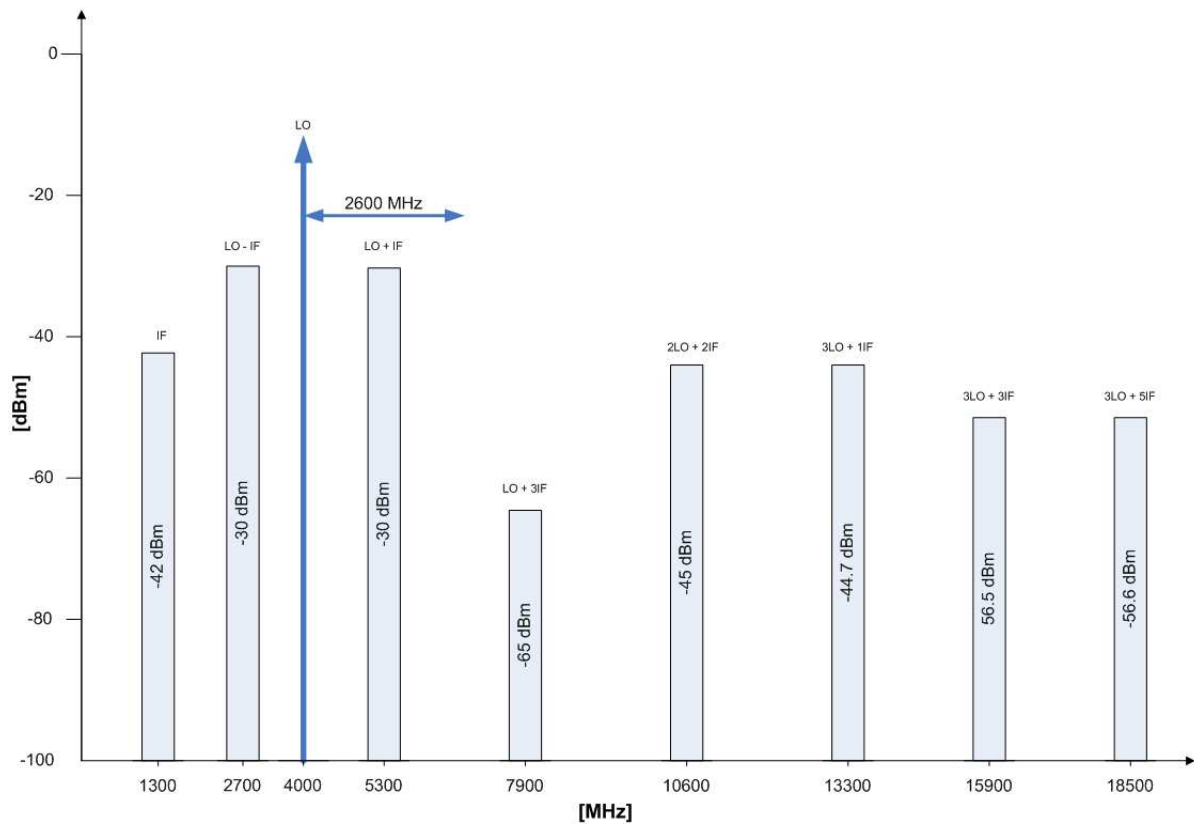Table 4.3: Mixer output with LO = 4000 MHz and IF = 1300 MHz

Figure 4.9: Signal level of harmonic intermodulation products

As can be seen the filtering requirements are not very critical. Therefore, it was decided to use a 5th order Butterworth filter. After filtering only the 5300 MHz signal should remain, which will then be sent to the power amplifying stage.

## 4.1.2   Power Levels

Now that the transmitter has been designed, it is necessary to track the power levels through the system to ensure that all the components meet there input power specifications. The input power requirements of the 3W Tellumat amplifier are of particular interest.

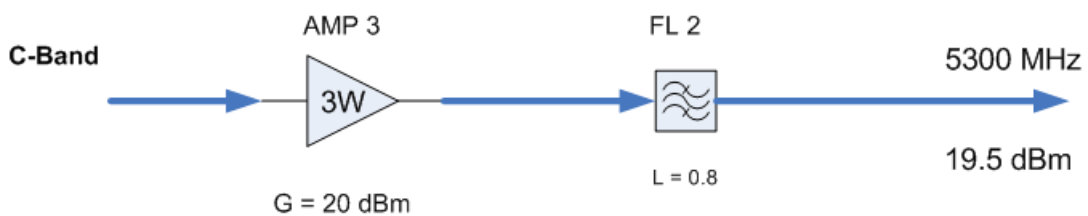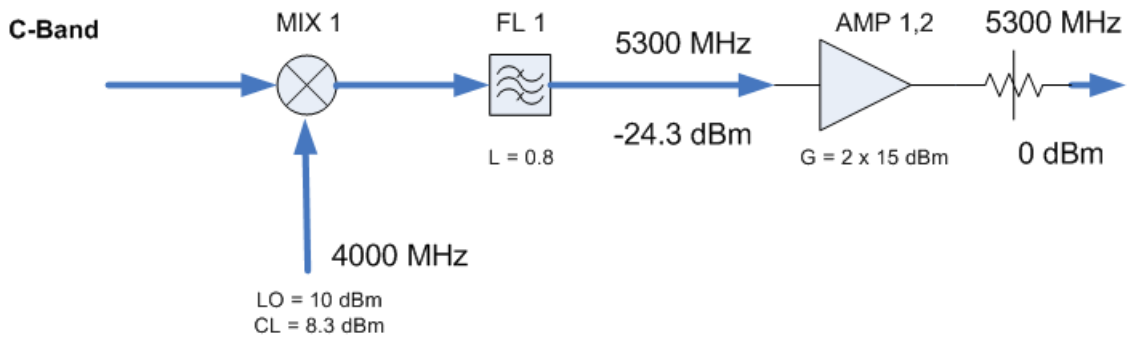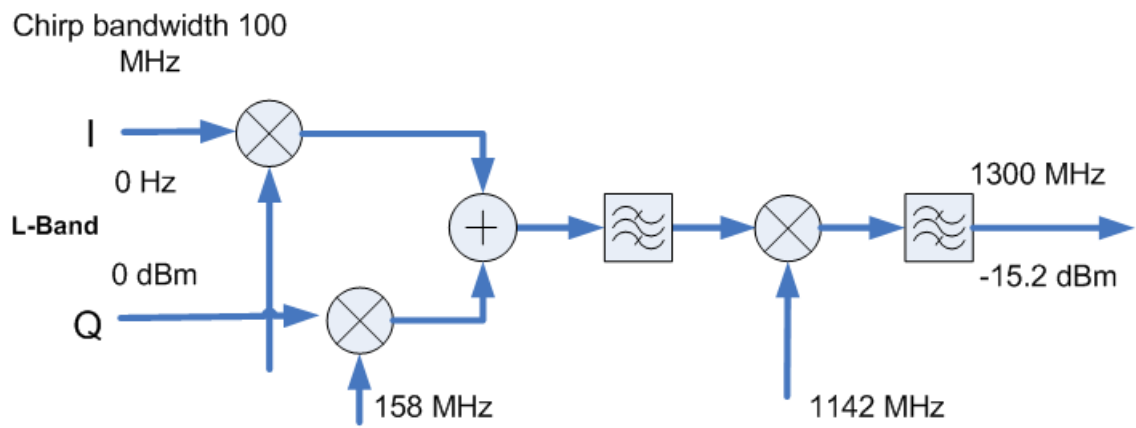Figure 4.10 shows the power levels at various stages of the transmitter.

Figure 4.10: Power levels in the transmitter

It must be noted that the values of the components were taken from the manufacturer's data sheets and are worst case estimates. Losses from cables are also not taken into account. Barrel attenuators have been inserted in the design to enable the signal to be padded down to the desired level once the components have been tested [1].

Since the 3W power amplifier requires a 0 dBm input signal level, two 15 dBm amplifiers have been cascaded and added to the output in order to bring the signal level from -24.3 dBm up to 0 dBm. A barrel attenuator is also inserted to fine tune the signal to its correct level.

## 4.2    Design of the C-band Receiver

In the previous chapter the requirements for the C-band transmitter and the design parameters and specifications which were required were discussed. A brief summary of the main points is given below:

- Receive a 5300 MHz signal.

- Budget must be consistent with the existing SASAR II budget.

- All unwanted frequency bands must be filtered out.

The architecture of the receiver for the SASAR II system is described by the block diagram below in Figure 4.11.
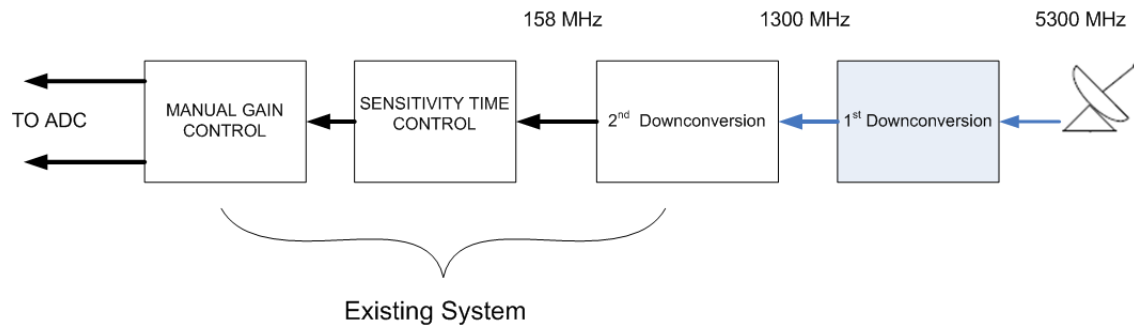


Figure 4.11: Block diagram of the receiver

The goal of the receiver is to receive the pulses that have been reflected off of distant targets at 5300 MHz and then to down convert the signal to intermediate frequencies at 1300 MHz and at 158 MHz. The C-band receiver must interface with the existing receiver at 1300 MHz and at the correct signal level.

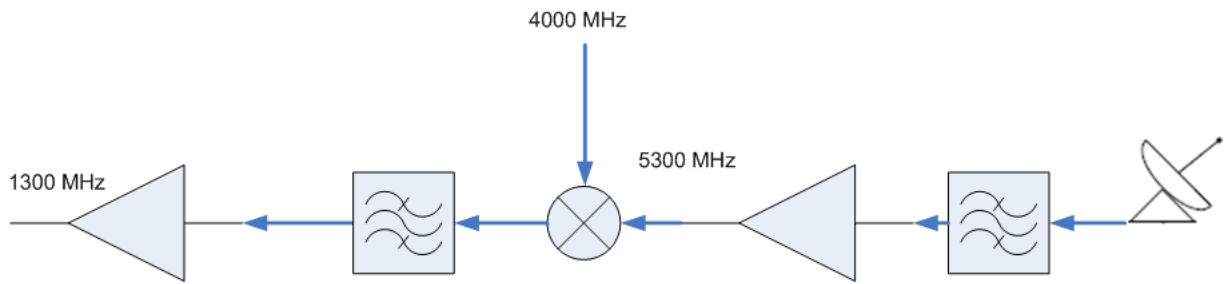Figure 4.12 below shows the circuit of the C-band receiver.

Figure 4.12: Circuit diagram of the C-band receiver

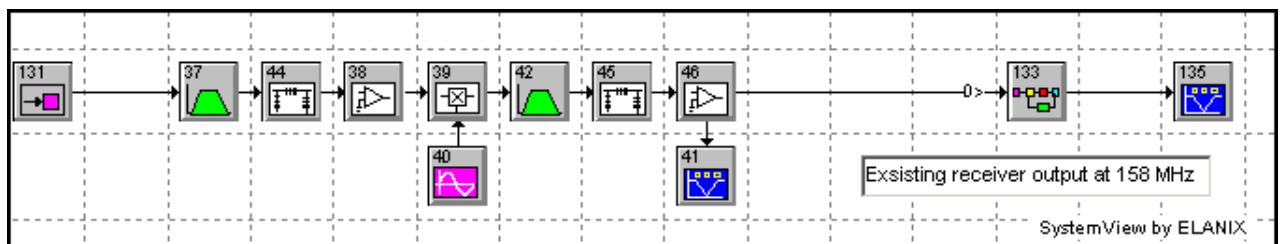The corresponding *SystemView* token diagram is also shown in Figure 4.13.



Figure 4.13: Token diagram of the receiver

## 4.2.1 Noise

Noise is critical in the receiver design, as it limits the smallest detectable signal. There are two types of noise in the receiver:

- Noise received by the antenna (at 290K).

- Noise generated by the components of the receiver.

The noise received by the antenna is given by the equation [6, pg 77]:

$$N = kT_0B \tag{4.1}$$

Since the design of the existing X-band receiver is followed, the bandwidth at the front end of the receiver will be 200 MHz. Therefore, the received noise power will be:

$$N = 1.38 \times 10^{-23} \times 290 \times 200 \times 10^6 [W] \tag{4.2}$$

$$N = -90.97 [dBm] \tag{4.3}$$

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The noise must be tracked through each stage of the receiver so that the signal to noise ration can be calculated at the output.

One way of doing this is to use the noise figure of each component. The noise figure is defined as the measure of degradation in the signal to noise ratio between the input and the output of the component and is given by [6, pg89]:

$$F = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}} \tag{4.4}$$

The noise that is input into the receiver is given by the equation:

$$N_i = kT_oB \tag{4.5}$$

B representing the bandwidth of the noise.

The noise that is then added by the receiver can be represented as by an equivalent noise temperature

There is a relationship between the noise figure and the equivalent noise temperature of a component, which is given by [6, pg 91]:

$$F = 1 + \frac{T_e}{T_o} \tag{4.6}$$

Ni = kToB    →    G, F, B,Te    →    No = (Ni + kTeB)G

Figure 4.14: Diagram of total noise signal

As can be seen from Figure 4.14, the total noise signal in the receiver is equal to the sum of the input noise and the noise generated by the components of the system. Note that the noise from the input is amplified through each gain stage.

The total noise signal is therefore given by the equation [6, pg 91]:

$$N_o = (N_i + kT_oB)G \tag{4.7}$$

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The receiver consists of several components and each has it's own properties with respect to gain, noise figure and bandwidth. The overall noise figure of the system is therefore given by the cascade noise figure equation [6, pg 93]:

$$F = F1 + \frac{F2 - 1}{G1} + \frac{F3 - 1}{G1.G2} + ... + \frac{F_n - 1}{G1.G2....G_{n-1}} \tag{4.8}$$

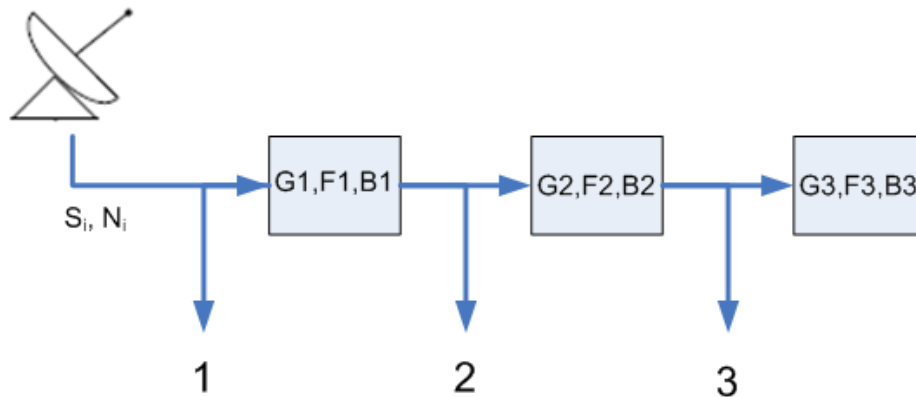Figure 4.15 shows how the various components are represented in a cascaded system



Figure 4.15: Block diagram of a cascaded system

## 4.2.2 RF Filter

The received signal that has been reflected off of the target will be low in power. Having taken attenuation of the transmitted signal as well as the gain of the receiver antenna into account, the received pulse will be represented as being at a level of -50 dBm.

The goal of the RF filter is to prevent all the signals from outside the passband from entering the receiver and to limit the input of noise. A 5th order Butterworth filter with a bandwidth of 200 MHz, which is consistent with the existing receiver, is used.

## 4.2.3 The Low Noise Amplifier (LNA)

As can be seem by equation 4.8, the first component contributes the most to the overall system noise figure. It is very important that the RF amplifier at the input of the receiver has a high gain but a low noise figure. The *Miteq* AFS3-04000800-10-HE-4 low noise amplifier was therefore selected. The LNA has a gain of 30 dB and a noise figure of 1dB.

## 4.2.4 Mixer

The mixer in the C-band receiver is used to convert the high frequency RF signal at 5300 MHz down to an intermediate frequency at 1300 MHz.
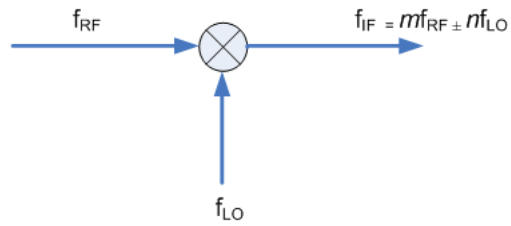
Figure 4.16: Down-conversion in a mixer

In the case of the receiver, the desired signal will be given by RF-LO. The image band as well as other unwanted harmonic products must be removed by filtering the output.

The harmonic intermodulation products that need to be filtered out can be seen in Figure 4.17.

| n | m | nRF+mLO | nRF-LO | Order |
|---|---|---------|--------|-------|
| 0 | 1 | 4000 | -4000 | 1 |
| 1 | 0 | 5300 | 5300 | 1 |
| 1 | 1 | 9300 | 1300 | 2 |
| 2 | 1 | 14600 | 6600 | 3 |
| 1 | 3 | 17300 | -6700 | 4 |
| 0 | 3 | 12000 | -12000 | 3 |

Table 4.4: Mixer output with RF = 5300 MHz and L0 = 4000 MHz
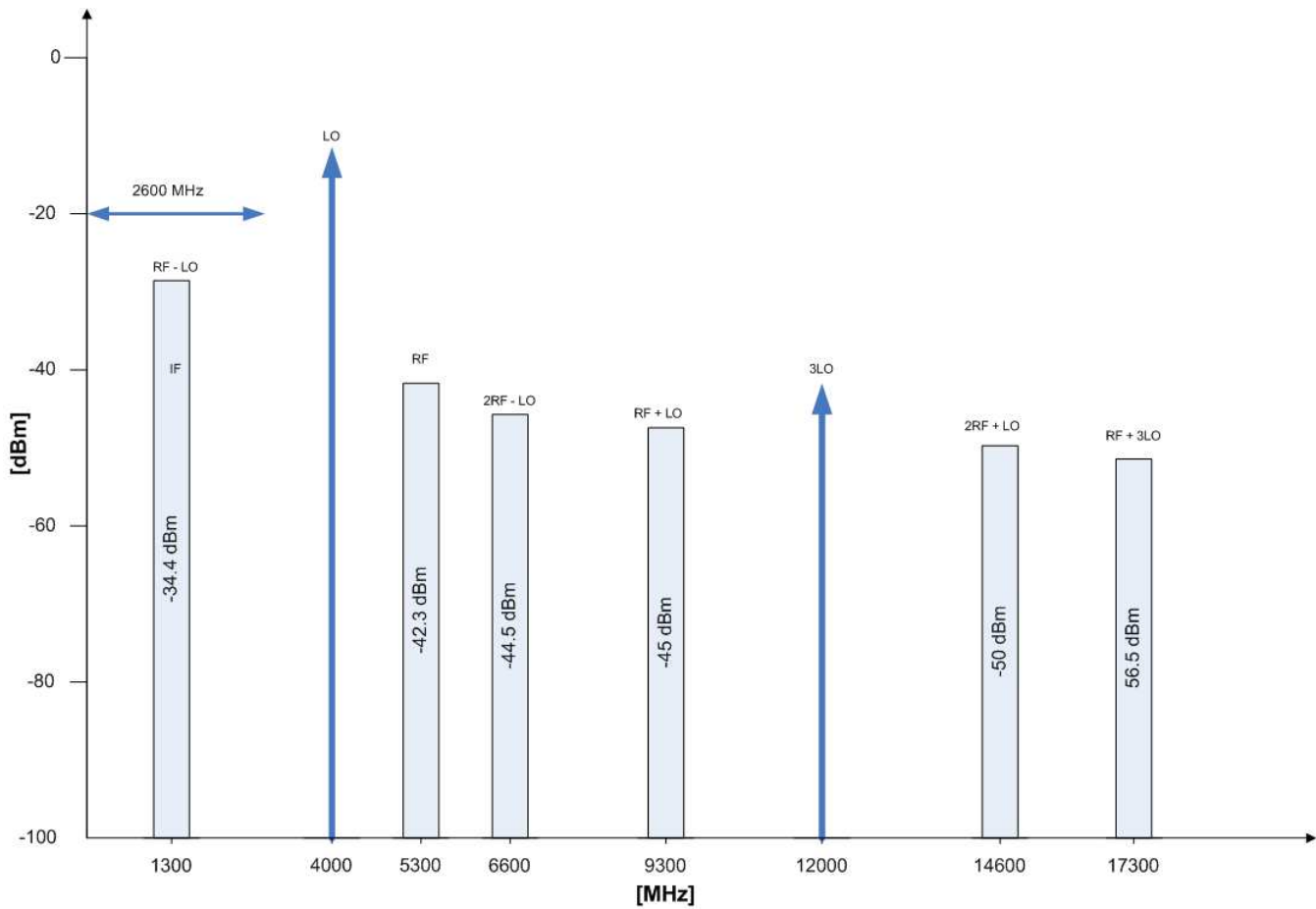
Figure 4.17: Harmonic intermodulation products in the C-band receiver

### 4.2.5 IF Filter

The IF filter is also chosen to be a 5th order Butterworth, however the bandwidth is reduced from the 200 MHz of the input filter to 100 MHz, which is the user requirement. Filtering does not present any problem, since the harmonic products are spaced far apart from the wanted signal.

### 4.2.6 Budget Analysis

Now that the C-band receiver has been designed, it is necessary to track the signal levels through each stage of the receiver in order to determine whether the C-band stage will interface correctly with the existing L-band stage. Unlike the transmitter, the receiver is very sensitive to noise and it is important to track this noise through the system in order to ensure that the total noise figure is comparable to the designed noise level of the existing receiver.

The level of the noise can be calculated after each component using equations 4.5 and 4.7. The noise figure of each component, the gain, as well as its operating bandwidth, must be known.

The table 4.5 shows the results of the budget analysis. The calculated noise figure was 2.025 dB and the noise signal was -44.9 dBm. Both these values are comparable to the budget analysis of the existing receiver.

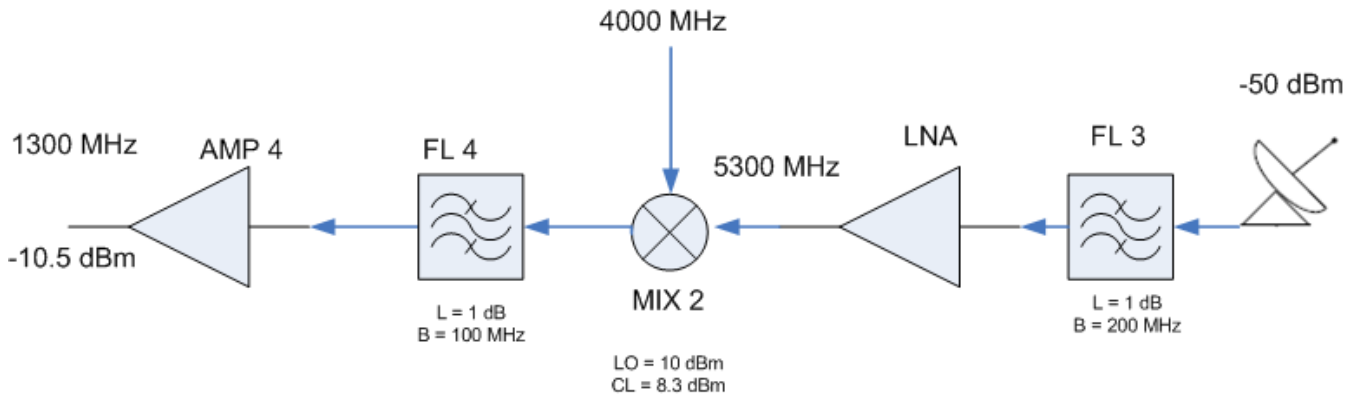Figure 4.18 shows the final receiver design with component designations and input/output power levels.



Figure 4.18: Final design of the receiver

| Components | Input | FL 3 | LNA | MIX 2 | FL 4 | AMP 4 |
|---|---|---|---|---|---|---|
| Stage No. | 1 | 2 | 3 | 4 | 5 | 6 |
| Bandwidth [MHz] | | 200 | 2000 | 1600 | 100 | 500 |
| Gain [dB] | | -1 | 30 | -8.5 | -1 | 20 |
| Cumulative Gain [dB] | | -1 | 29 | 20.5 | 19.5 | 39.5 |
| Noise Figure [dB] | | 1 | 1 | 6 | 1 | 1.5 |
| Signal [dBm] | -50 | -51 | -21 | -29.5 | -30.5 | -10.5 |
| Noise [dBm] | 90.97 | 90.97 | -55.42 | -63.89 | -64.89 | -44.88 |
| 1dB gain Comp. | | | 0 | 1 | | 8 |
| Cum. Noise Figure [dB] | | | 2 | 2.01 | 2.02 | 2.025 |
| | | | | | | |
| | | | | | | |

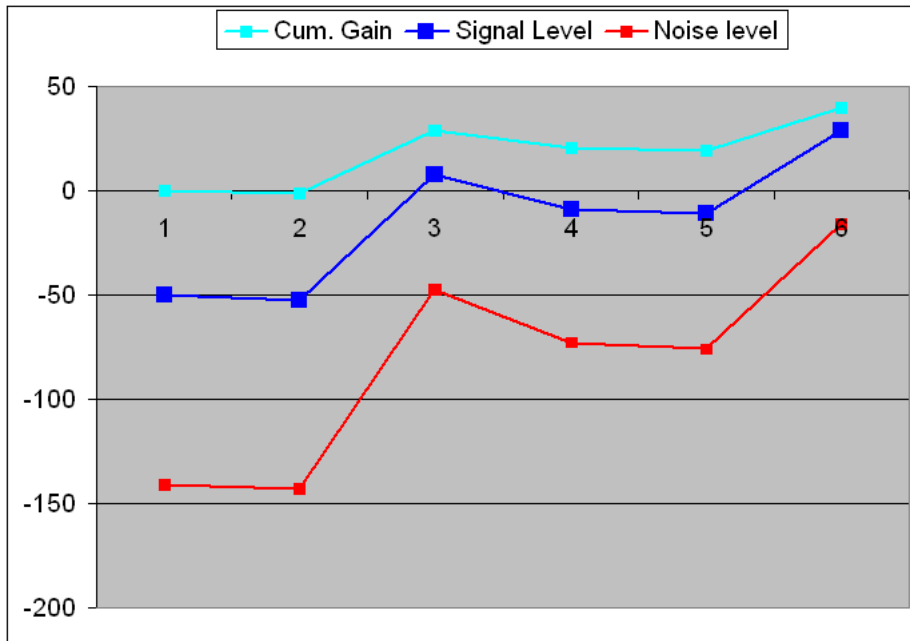Table 4.5: Budget analysis of the C-band receiver

Figure 4.19: Receiver Level diagram of signal and noise

The data in Table 4.5 was used to plot the curves of signal, noise and accumulated gain on the receiver level diagram in Figure 4.19. This tracks the levels of signal and noise up to the input of the existing L-Band stage of the receiver.

The budget analysis for the existing receiver can be seen in [3, Table 4.1] for comparison.

## 4.3   Summary

A block diagram of the transmitter was made and a circuit for the C-band, RF stage was designed. The design was then used to create a simulation using *SystemView* simulation software by *Elanix*. The simulation was then used to choose the hardware for the RF stage. Some mixer and filter theory then lead into analysis of the mixer harmonic inter-modulation products and filter requirements. The filter was not deemed as critical and its bandwidth was set to 200 MHz. The bandwidth on the filter at the output was then set to be 100 MHz, to limit the output signal to the specified frequency band.

Once the transmitter circuit had been realised, a power budget was drawn up which introduced the need for amplification before the input of the power amplifier stage. Table 4.6 summarises the components used in the C-band transmitter. Figure 4.10 can be referred to for component name designation.

| Token No. | Component name | Type | Manufacturer | Part No. |
|-----------|----------------|------|--------------|----------|
| 20 | MIX 1 | Mixer | Minicircuits | ZX05-C60LH |
| 21, 22 | FL 1 | Filter | K&L | Custom |
| 23, 24 | AMP 1, 2 | Amplifier | Minicircuits | ZX60-5916M |
| 25 | AMP 3 | Power Amp | Tellumat | Custom |
| 26, 27 | FL 2 | Filter | K&L | Custom |

Table 4.6: Components used in the C-band transmitter

The chapter also described the design of the C-band receiver. The same procedure was followed that was used for transmitter design. The signal and noise level were tracked up to the input of the existing receiver and a receiver level diagram was created.

The bandwidth of the filter at the input end of the receiver was designed to be 200 MHz, as in the previous receiver, and then the IF filter was set to 100 MHz to fulfil the user requirement.

The budget analysis showed that the total noise figure for the C-band receiver was 2.025 dB, which compared closely to the 2.1 dB noise figure at the same stage of the existing set-up.

The signal level was -10.5 dBm, which was compared to a -5.74 dBm level. The noise level was -44.9 dBm, which was compared to a level of -44.5 dBm. The budget of the C-band, therefore, closely resembled the budget of the X-band receiver ensuring a good compatibility with the existing system.

Table 4.7 summarises the components used in the C-band receiver. Figure 4.18 can be referred to for the component name designation.

| Token No. | Component name | Type | Manufacturer | Part No. |
|-----------|----------------|------|--------------|----------|
| 37, 44 | FL 3 | Filter | K&L | Custom |
| 38 | LNA | Amplifier | Miteq | AFS3-04000800-10-HE-4 |
| 39 | MIX 2 | Mixer | Minicircuits | ZX05-C60LH |
| 42, 45 | FL 4 | Filter | K&L | Custom |
| 46 | AMP 4 | Amplifier | Minicircuits | ZEL-1217LN |

Table 4.7: Components used in the C-band receiver

# Chapter 5

# Construction

## 5.1 Modification of the FDU

In the previous chapter the requirements for the FDU and the modifications that needed to be made to the FDU in order for it to become compatible with the C-band transceiver were discussed. A brief summary of the main points is given below:

- The multiplier would be removed

- The 4000 MHz signal would be split into two identical signals by using the existing ZFSC-2-9-G splitter by Minicircuits.

- New amplifiers would be placed at the output of the splitter to increase the signals to 10 dBm.

Figure 5.1 below shows the existing FDU setup with the multiply by two stage.
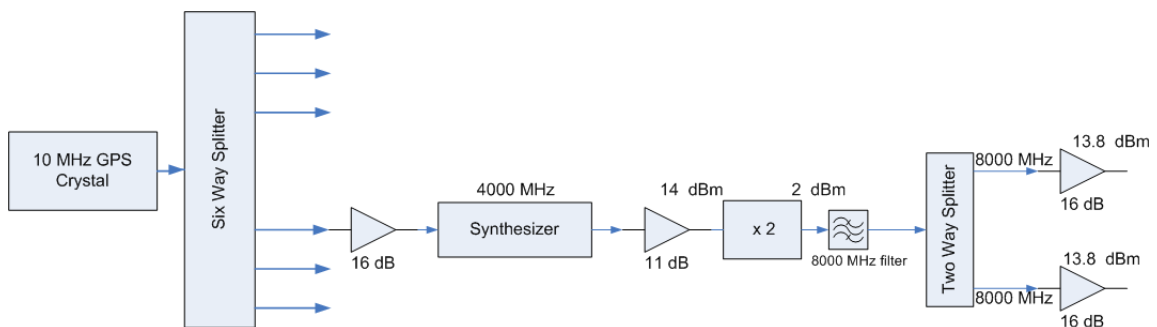


Figure 5.1: Diagram of the existing FDU

Once the "multiply by two" stage has been removed the 4000 MHz signal is amplified by the *Hittite* HMC311LP3 amplifier and fed into the splitter. Since the losses in the circuit are less, due to the absence of the "multiply by two" and the 8000 MHz filter, the gain from the HMC311LP3 should be sufficiently large so that the split signal is at the required

level of 10 dB. Figure 5.2 below shows how the two 4000 MHz signals are obtained from a modified FDU.
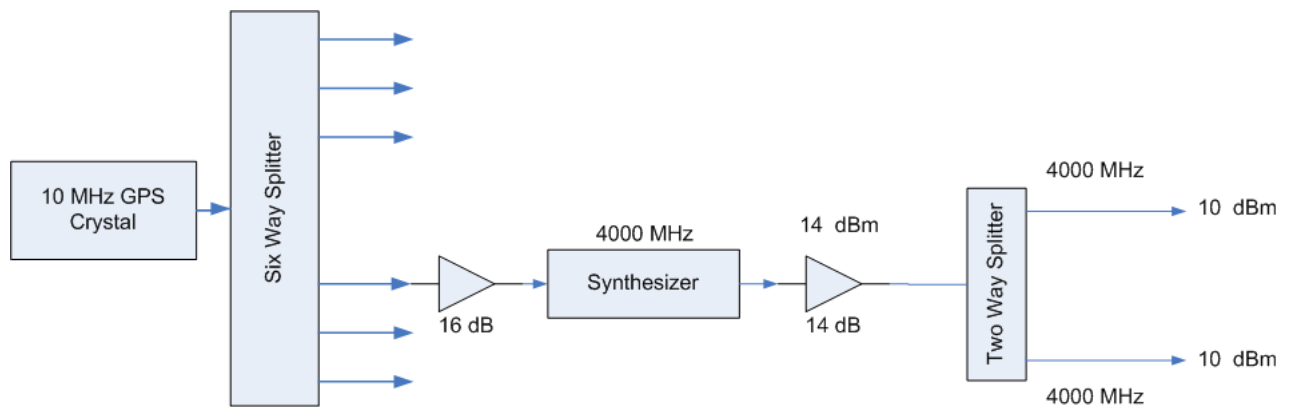


Figure 5.2: Diagram of the FDU modified for the C-band transceiver

The two 4000 MHz signals can be fed into the local oscillator terminals of the mixers for the transmitter and the receiver. This ensures coherency between the transmitter and the receiver.

The only problem that occurred during the design was that the Hittite amplifier required a 7V supply. Since this supply was not available from the PSU, it was decided to use a 5V supply. We would therefore expect the gain to be less and the signal level going into the mixer slightly lower than the designed level.

Figure 5.3 shows a picture of the modified FDU. All connections are SMA female. The synthesiser has a chip inside the casing that has to be programmed with the correct register values before it can generate the correct signal. This is done by a serial connection to a PC via the programming port in the figure.
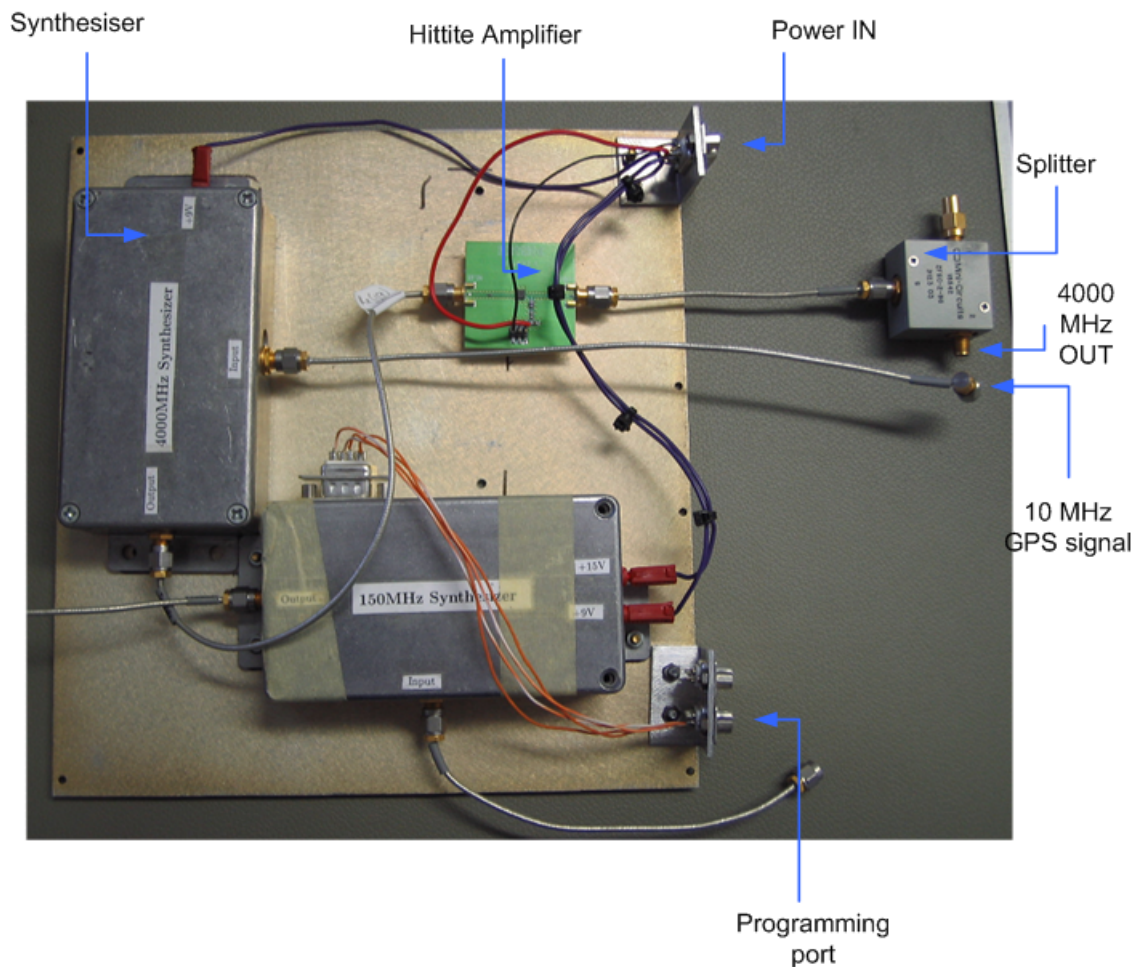
Figure 5.3: Image of the modified FDU

## 5.2 Design of a new PSU

In the previous chapter the requirements for the PSU and the modifications that needed to be made to the PSU in order for it to become compatible with the C-band transceiver were discussed. A brief summary of the main points is given below:

- A separate PSU would be built for the 3W Tellumat Amplifier

- The required voltages would be +15V, -15V, +10V, +5V and ground.

- The power supply would have to supply up to 2A of current.

- The supply would be a linear DC supply, use a transformer to step down the mains voltage and voltage regulators to provide the required voltages.

Figure 5.4 below shows the design of the power supply. The LM350 was chosen because it was an adjustable 3A voltage regulator which could be set by choosing resistors R1 and R2 by the formula:

$$Vo = 1.25(1 + \frac{R1}{R2}) + 50 \times 10^{-6} \times R1 \tag{5.1}$$

The LM350 is therefore used to set the required 15V and 10V. Since the LM350 is rated at 3A it is easily able to handle the high current requirement of the power supply.

We chose R2 = 220 Ohms for the 15V regulator . Therefore R1 becomes:

$$15 = 1.25(1 + \frac{R1}{220}) + 50 \times 10^{-6} \times R1 \tag{5.2}$$

Therefore,

$$R1 = 2398\Omega$$

R1 is split according to Figure 5.5 into a $2200\Omega$ resistor and $1000\Omega$ potentiometer.

We chose R2 = 220 Ohms for the 10V regulator. Therefore R1 becomes:

$$10 = 1.25(1 + \frac{R1}{220}) + 50 \times 10^{-6} \times R1 \tag{5.3}$$

Therefore,

$$R1 = 1526\Omega$$

R1 is split according to Figure 5.5 into a $1200\Omega$ resistor and $1000\Omega$ potentiometer.
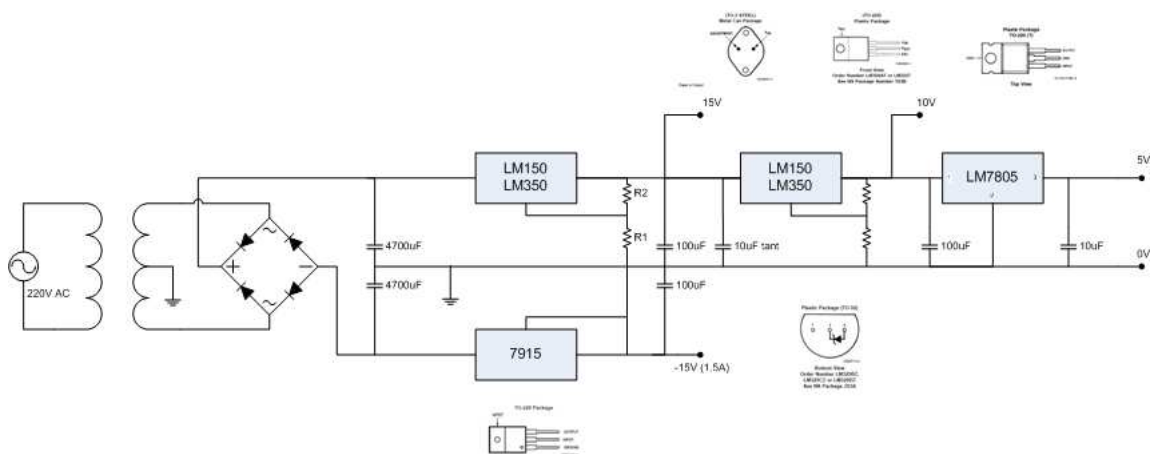


Figure 5.4: Diagram of the PSU for the 3W Tellumat Amplifier

All the voltage regulators were insulated and mounted on a heatsink. An extraction fan was mounted inside the casing to allow for the rapid cooling of the components.

In order to ensure that the correct voltage levels were obtained, a trimming potentiometer was inserted in conjunction with a fixed resistor as part of R1.

As shown in Figure 5.5 below the total R1 is calculated and then the total resistance is divided into parts of 80% and 30%. This allows the trimming potentiometer to adjust the output voltage by a small amount until the desired output voltage is achieved. The advantage of using this method over a single potentiometer at R1 is that it reduces the sensitivity of the potentiometer and allows for more accurate trimming.
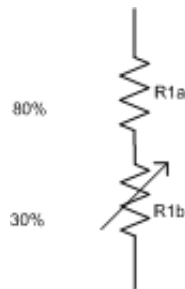


Figure 5.5: Diagram of R1 with trimming potentiometer

Figure 5.6 shows the completed power supply unit for the 3W Tellumat amplifier. The output voltages are made available via a female D connector on the exterior of the casing. The input is the 220V mains at the rear of the casing. The power can be turned on by a switch on the back of the casing and is indicated by a green LED on the front panel.
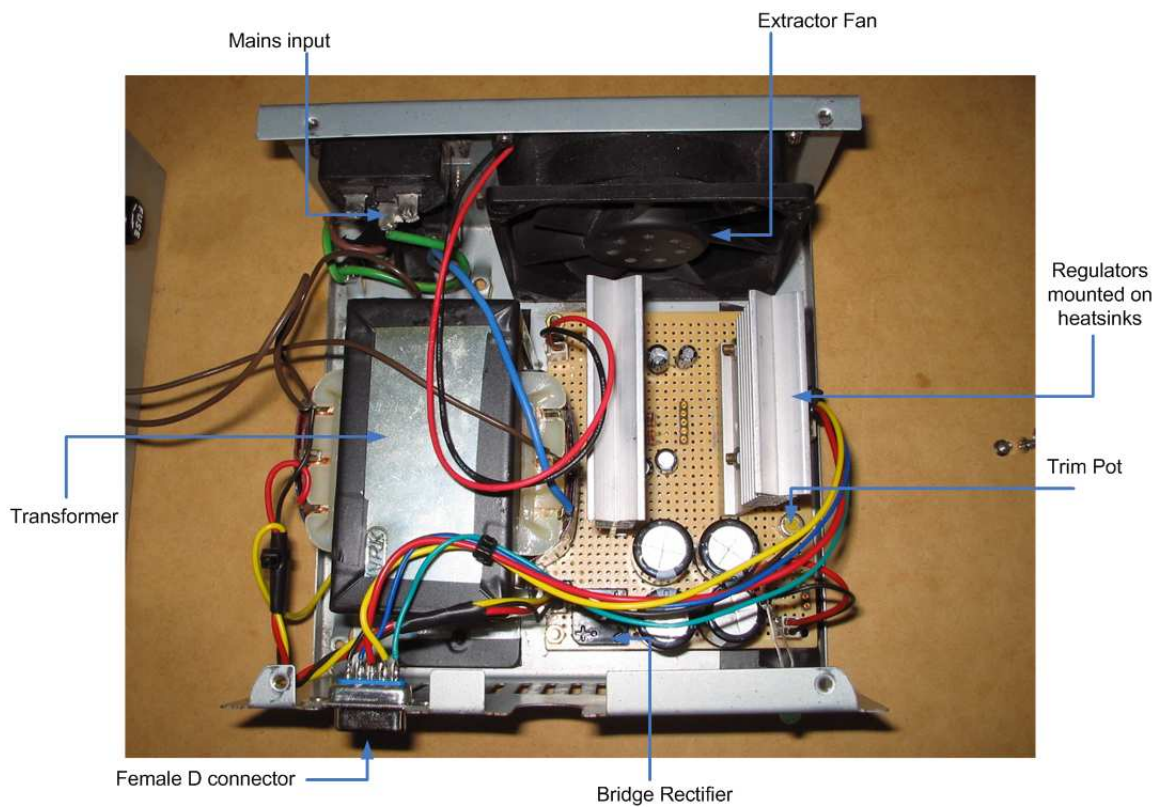
Figure 5.6: The completed power supply for the 3W Tellumat amplifier.

The inrush current was found to be quite high due to the large capacitance at the input of the regulator, therefore, a slow blow fuse was installed on the primary side of the transformer so that the inrush current would not cause the fuse to blow, when the unit was switched on. Any other fault in the circuit, however, would mean that the fuse would blow and the circuit would turn off.

# Chapter 6

# Tests and Results

## 6.1 Introduction

The testing chapter deals with the testing of the following:

1. The modified FDU

2. The PSU for the 3W Tellumat Amplifier

3. The 3W Tellumat Amplifier

4. The SystemView design simulations

Testing is performed on these various sections in order to verify their design.

The following equipment was used during the testing phase:

| Equipment | Model |
|---|---|
| Spectrum Analyser | Agilent 9kHz - 26.5 GHz E4470B |
| Sweep Oscillator | HP 8350B |
| Digital Multimeter | Escort EDM-2116 |
| Digital Oscilloscope | Agilent 60MHz 54621A |
| S-Parameter Test Set | HP 8743B |
| Network Analyser | HP 8410 |
| Arbitrary Waveform Generator (AWG) | HP 33120A |
| Power Meter | HP 435A ( 1% of Full Scale) |

Table 6.1: Table of test equipment

## 6.2 Modified FDU Testing

**Equipment Required**

Spectrum Analyser, AWG and PC

**Equipment Setup**

The test equipment was set up as shown in the block diagram in Figure 6.1. A photograph of the lab set up can be seen in Figure 6.2.
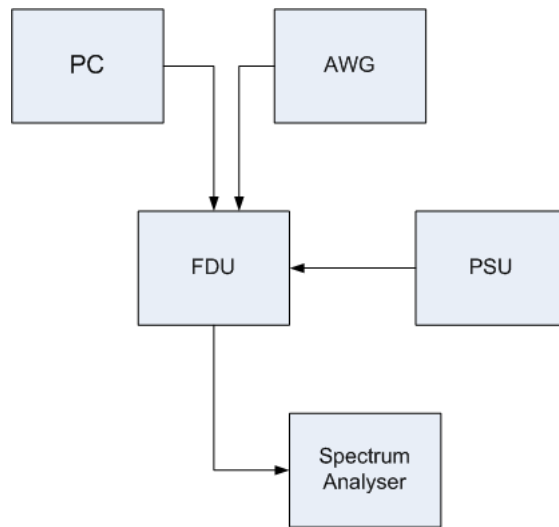


Figure 6.1: Block diagram of PSU test set up
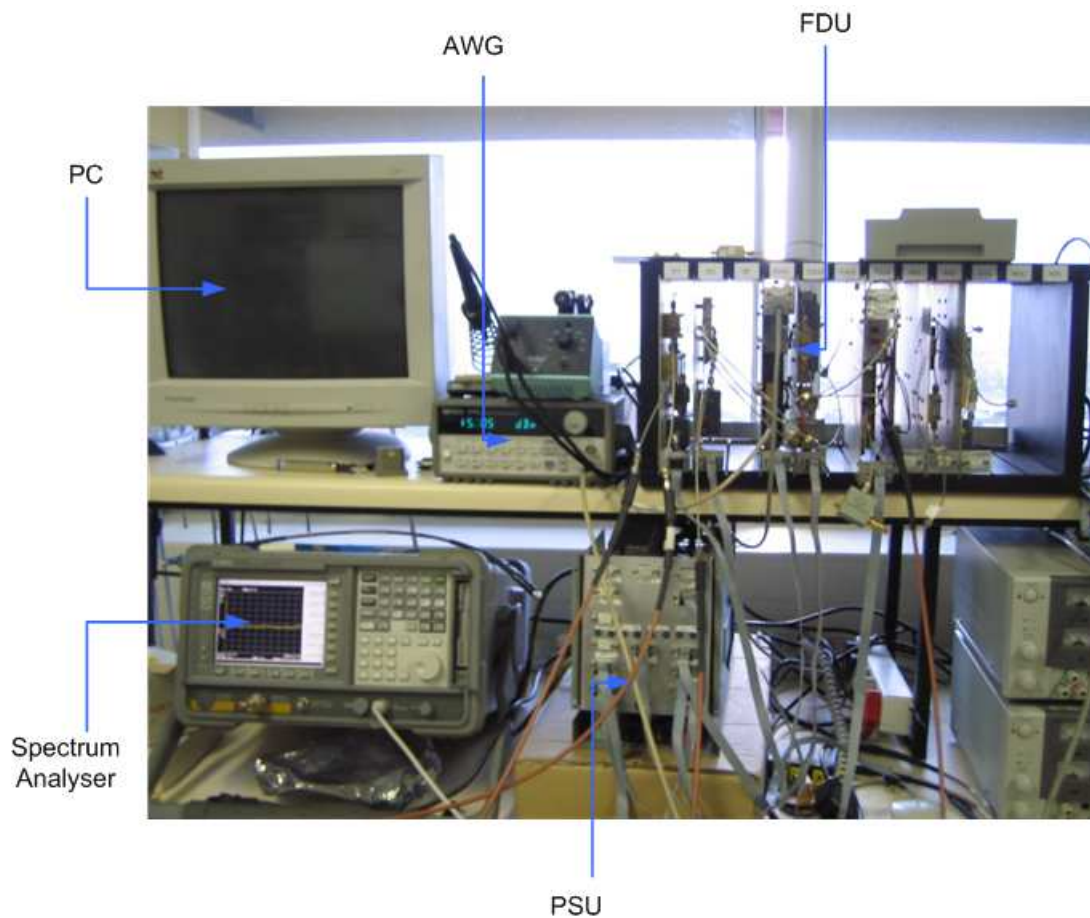


Figure 6.2: Photograph of the lab with FDU test set up

**Testing Procedure**

A 10 MHz stable oscillator signal from the back of the AWG unit is connected to the input of the 4000 MHz synthesiser via a coaxial test cable. The power is turned on and the 4000 MHz synthesiser registers are then programmed from the PC.

The output of the 4000 MHz synthesiser is connected via a coaxial test cable to the spectrum analyser. The frequency and power level is recorded as well as other harmonics present. The *Hittite* amplifier is connected to the output of the 4000 MHz synthesiser and the output of the amplifier is then connected to the spectrum analyser. Once again the frequency and power level is recorded and other harmonics present are also recorded. The splitter is then connected to the output of the amplifier and the spectrum analyser is connected to each of the splitter outputs in turn with a 50 Ohm terminator being placed at the unconnected output. Frequency and power levels are recorded for each of the two splitter outputs.

**Test Results**

The results of the FDU testing procedure can be seen in Table 6.2. Stage designations can be seen in Figure 6.3.
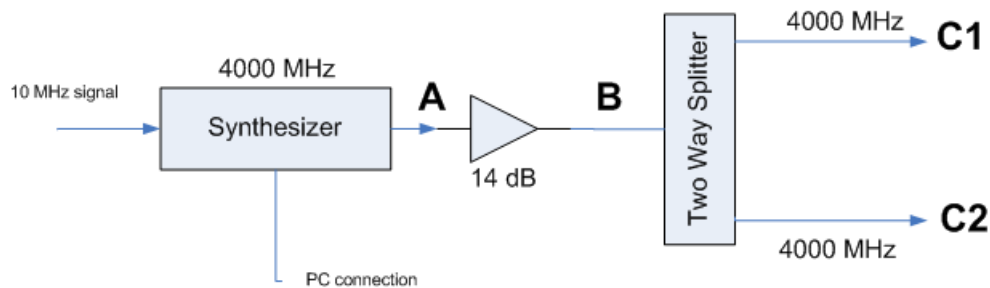


Figure 6.3: FDU test stages

| Stage | Frequency [MHz] | Output [dBm] | Expected output [dBm] |
|-------|-----------------|--------------|-----------------------|
| A | 4000 | 2.836 | 3.08 |
| B | 4000 | 13.39 | 17 |
| C1 | 4000 | 10 | 10 |
| C2 | 4000 | 10.2 | 10 |

Table 6.2: Results of FDU test

It was expected that the output of stage B would be less than a 14 dB gain, since the amplifier was only given a 5V supply instead of 7V.

Spectrum analyser plots of the outputs can be seen in Appendix A.

**Harmonics**

Figures 6.4 and 6.5 show the levels of the harmonics present at stage A and stage B (before and after amplification). These harmonics came from the synthesiser and were then amplified in stage B. It is believed, however, that they will have no effect since the closest harmonic is nearly 30 dBm below the 4000 MHz signal.
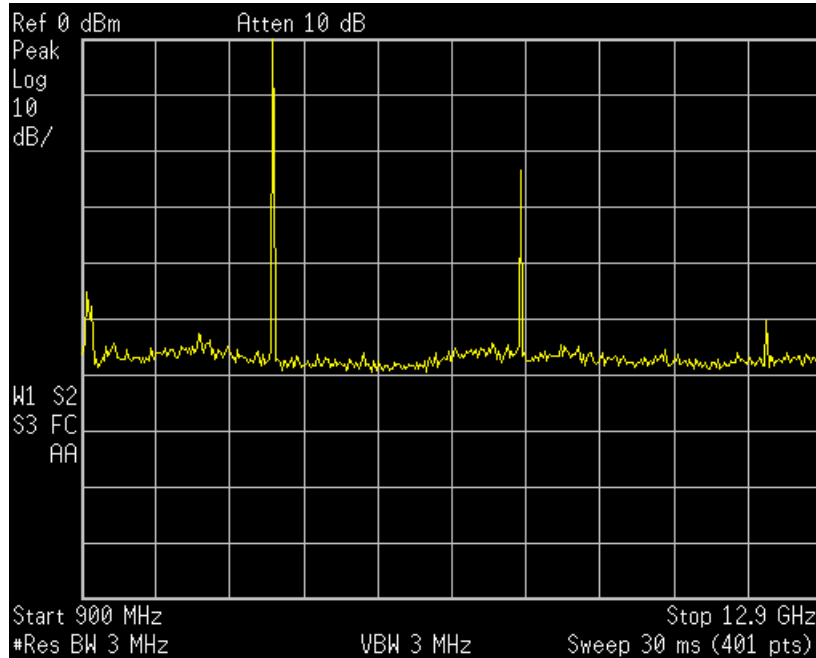


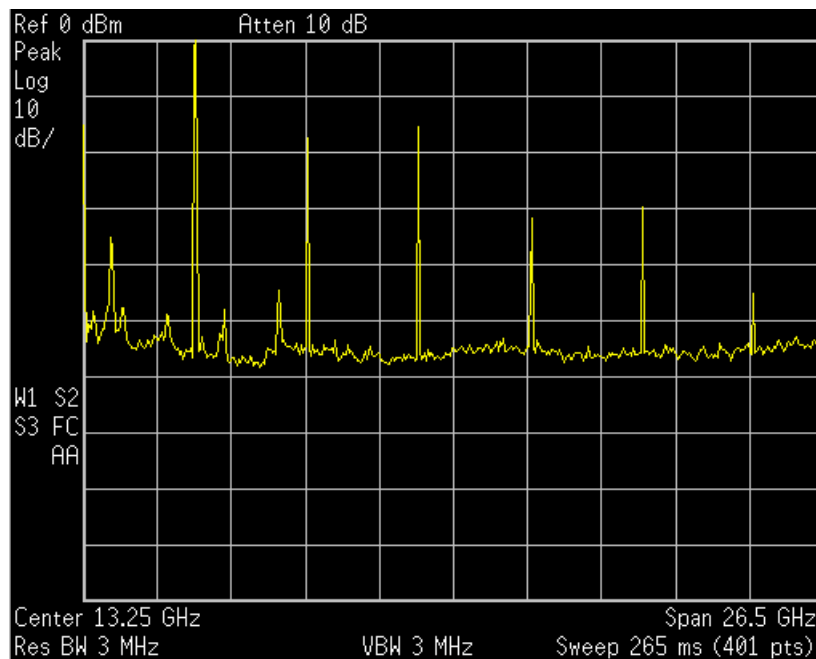Figure 6.4: Harmonics in stage A before amplification



Figure 6.5: Harmonics in stage B after amplification

Table 6.3 shows the power levels of the harmonics after amplification.

| Frequency [MHz] | Power Level [dBm] |
| --- | --- |
| 990 | -35.1 |
| 3000 | -49.8 |
| 4000 | 13.6 |
| 5000 | -47.8 |
| 7000 | -45.7 |
| 8000 | -17.3 |
| 12000 | -15.5 |
| 16000 | -31.9 |
| 20000 | -29.5 |
| 24000 | -45.3 |

Table 6.3: Power levels of harmonics from the 4000 MHz synthesiser

**Signal**

The 4000 MHz had two side lobes at 3990 MHz and 4010 MHz caused by leakage of the 10 MHz stable oscillator signal. Figure 6.6 shows the 4000 MHz signal with the side lobes before amplification and Figure 6.7 shows the 10 MHz leakage signal.
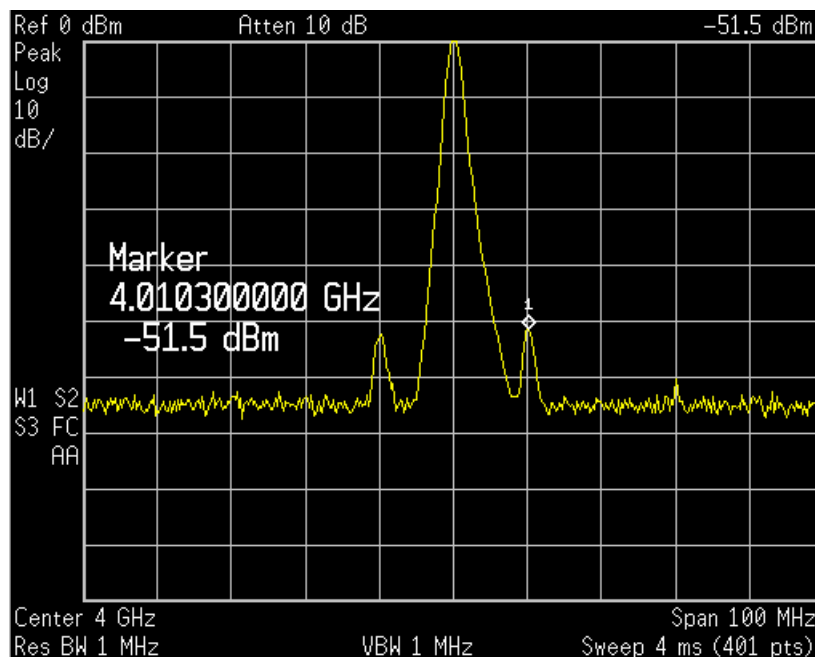


Figure 6.6: 4000 MHz oscillator signal with side lobes
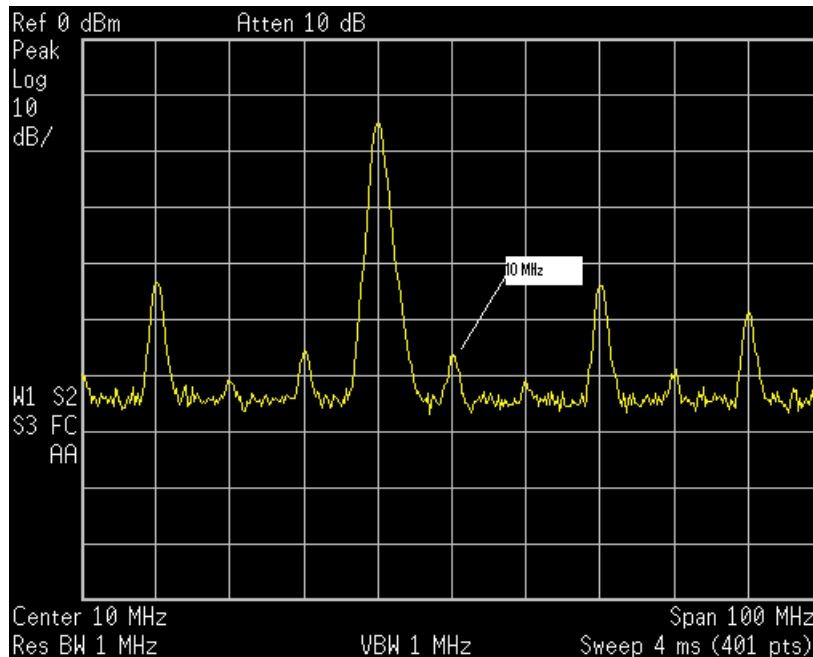
Figure 6.7: 10 MHz leakage signal

Since these side lobes are more than 60 dBm below the 4000 MHz, they can be ignored.

## 6.3   PSU for the 3W Amplifier testing

**Equipment Required**

Digital Multimeter, Digital Oscilloscope, $10\Omega$/ 10W power resistor.

**Equipment Setup**

The test was set up as in the block diagram in Figure 6.8. The outputs of the female D-connector can be seen in Figure 6.9.
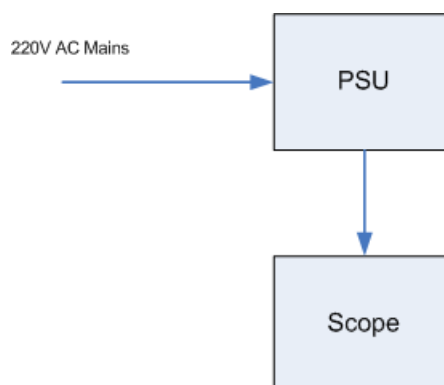


Figure 6.8: Block diagram of PSU test set up

Front View
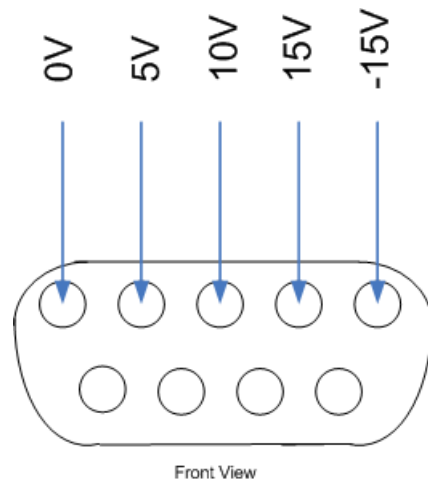
Figure 6.9: Outputs of PSU

**Testing Procedure**
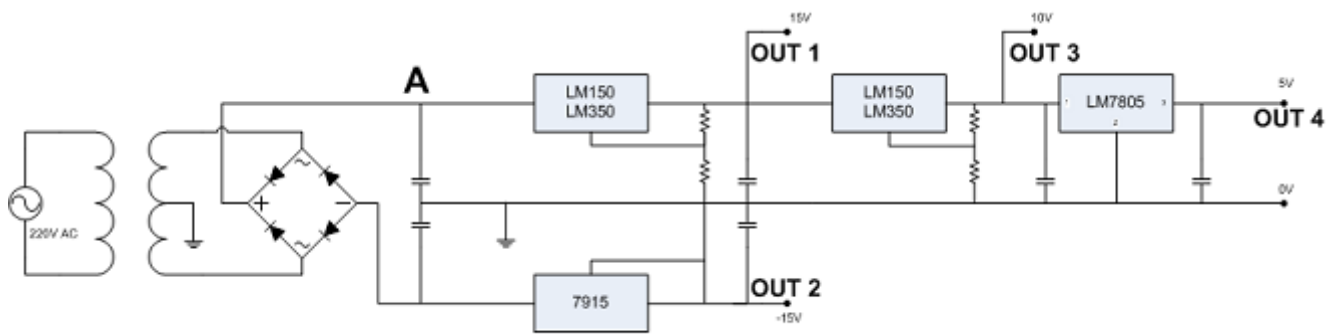


Figure 6.10: PSU circuit

The PSU was plugged into the mains and the unit was switched on. No load was put on the output and the scope probe was placed at point A as shown in Figure 6.10. The unregulated voltage was captured with the scope. The scope probe was then placed at points OUT1, OUT2, OUT3 and OUT4 and the voltages were captured.

A $10\Omega$/ 10W resistor was then connected between the 10V output and ground. The digital multimeter was set to measure the current and the leads were placed in series with the load. Figure shows the PSU with the load on the output.
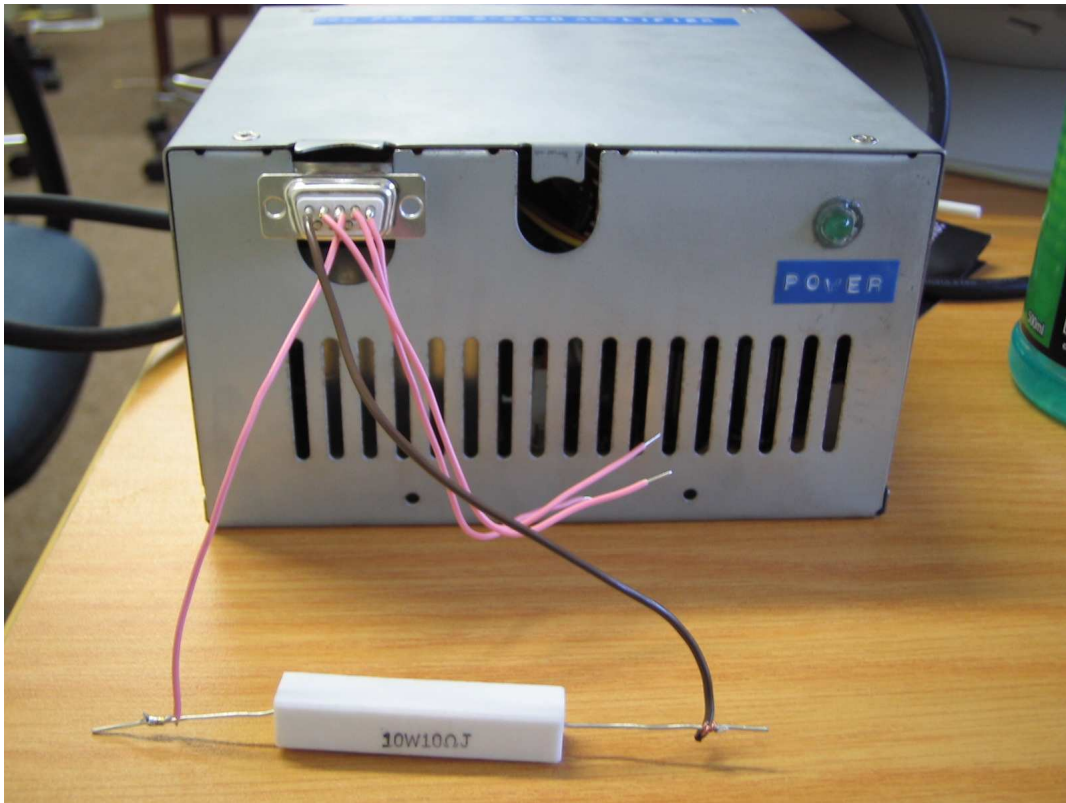
Figure 6.11: PSU with load on the output

The load was kept in place and the voltages at OUT1, OUT2, OUT3 and OUT4 were captured.

**Test Results**

The unregulated input voltage at point A can be seen in Figure 6.12. Closer inspection of this waveform in Figure 6.13 shows that the input voltage is about 21.5V and that there is about 650mV of ripple.
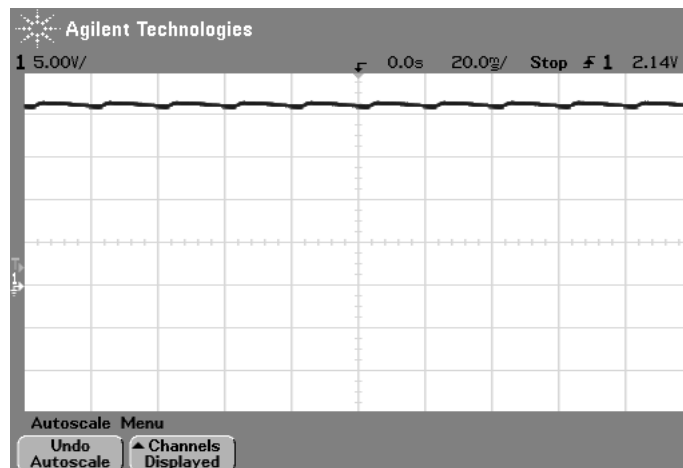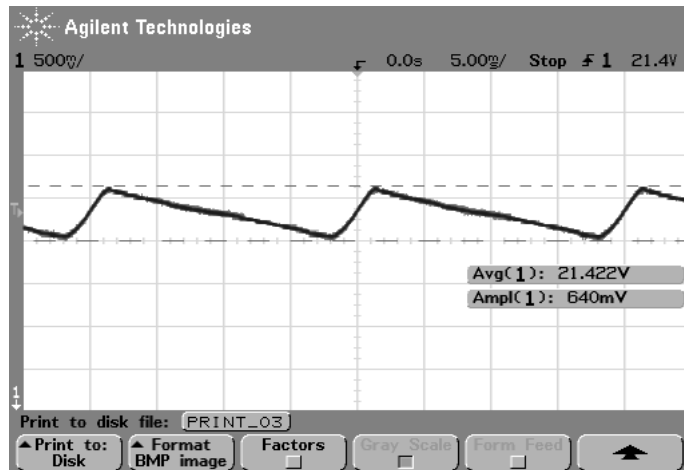


Figure 6.12: Unregulated input voltage

Figure 6.13: Close up of input voltage

The output voltages with no load can be seen in Table 6.4 and the output voltages under load can be seen in Table 6.5.

| Stage | Measured Voltage [V] | Expected [V] |
| --- | --- | --- |
| OUT1 | 15.039 | 15 |
| OUT2 | -15.067 | -15 |
| OUT3 | 10.705 | 10 |
| OUT4 | 5.096 | 5 |

Table 6.4: Output voltages of the PSU at no load

| Stage | Measured Voltage [V] | Expected [V] |
| --- | --- | --- |
| OUT1 | 15.039 | 15 |
| OUT2 | -15.158 | -15 |
| OUT3 | 10.579 | 10 |
| OUT4 | 5 | 5 |

Table 6.5: Output voltages of the PSU under load

Figures on the captured voltages under load and no load can be seen in Appendix 6.

**Output ripple**

Closer inspection of the 10V output voltage under load and no load showed the amount of ripple on the output. Results are shown in Table 6.6. Output ripple is within 0.5% under no load and within 0.2% under load on the 10V output.
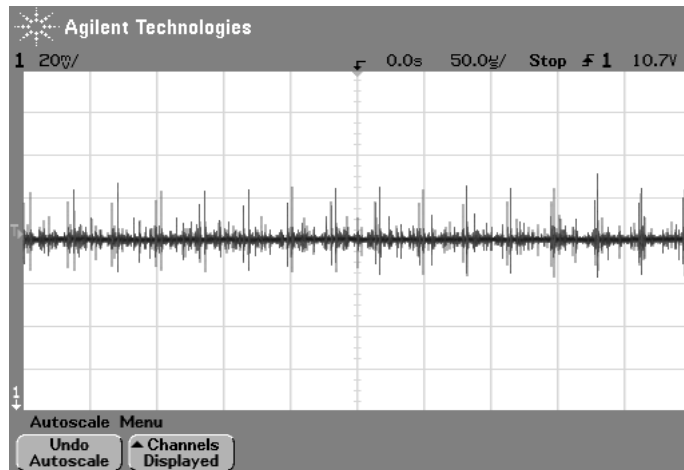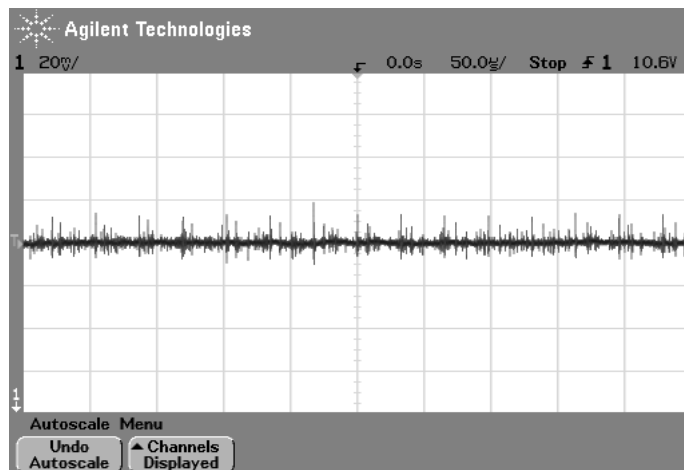
Figure 6.14: 10V no load ripple



Figure 6.15: 10V load ripple

| State | Measured [mV] | Expected [mV] | % |
|-------|---------------|---------------|------|
| No load | 40 | 50 | 0.4 |
| loaded | 15 | 50 | 0.15 |

Table 6.6: 10V output ripple

# 6.4   3W Tellumat Amplifier Testing

## 6.4.1   S-Parameters Test

**Equipment Required**

Network analyser, S-Parameter test set, Sweep Oscillator

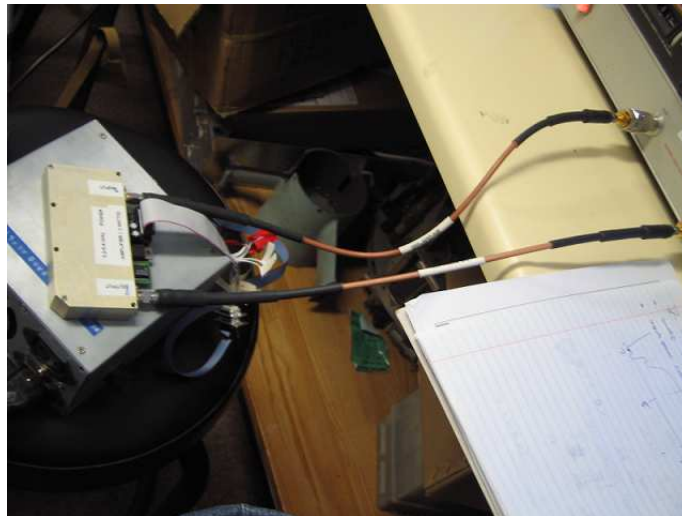**Equipment Setup**



Figure 6.16: Test setup for the 3W amplifier



Figure 6.17: Connection to the S-Parameter test set

**Testing Procedure**

The network analyser was switched on and left to warm up for about thirty minutes. The PSU that was built for the amplifier was plugged into the mains and the amplifier was plugged into the female D-connector on the front panel. The sweep oscillator was set to sweep from 2GHz to 7GHz. A coaxial test cable was connected from port 1 of the S-Parameter test set to the input of the amplifier. The reference line was set up on the

rectangular display of the network analyser. S11 was selected on the test set and the return loss was plotted for the input of the amplifier. The same procedure was then repeated for the output of the amplifier with S22 selected on the test set.

The input of the amplifier was left connected to port 1 of the test set and the output of the amplifier was connected to port 2 as shown in Figure 6.17. S12 was selected and the results were plotted. S21 was then selected and the results plotted.

**Test Results**

The reference voltage was set to about half way as shown in Figure 6.18. The S11 into the amplifier was measured and is shown in Figure 6.19. The result is expected since we expect the input to see $50\Omega$ termination and not reflect any signal back. As can be seen the reflected signal is 25 dB lower. Similar results were obtained for the output port on S22.
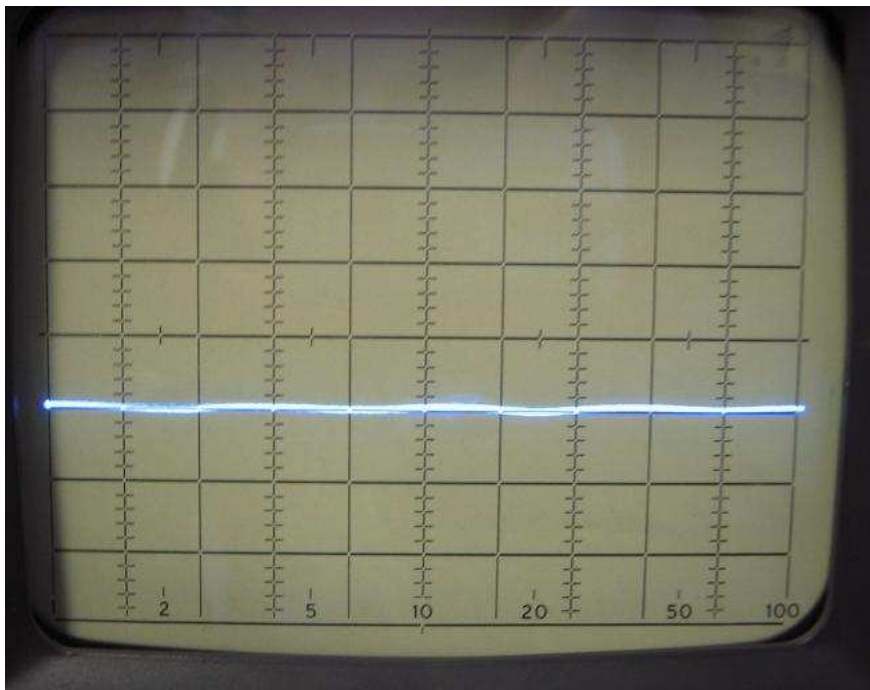


Figure 6.18: Reference line

The S12 plot showed only noise. This was expected because the amplifier is a unidirectional device and only allows signal to travel in the forward direction.

The S21 plot in Figure 6.20 showed the amplifier to have a flat response over the passband. One can also observe that the gain of the amplifier is 20 dB. Figure 6.21 shows an Excel graph of the S21 parameter. The data was captured in steps of 100MHz.
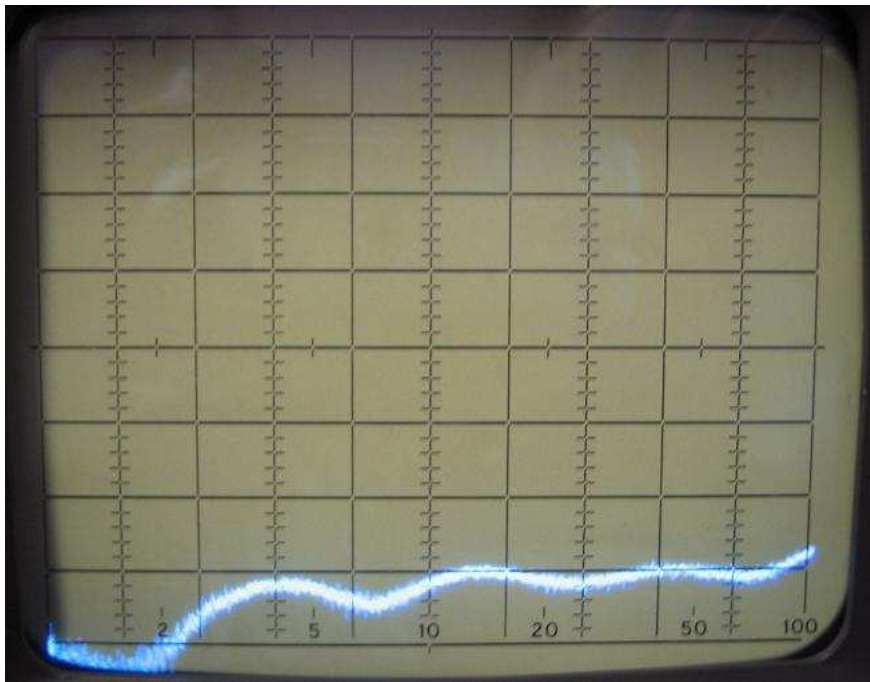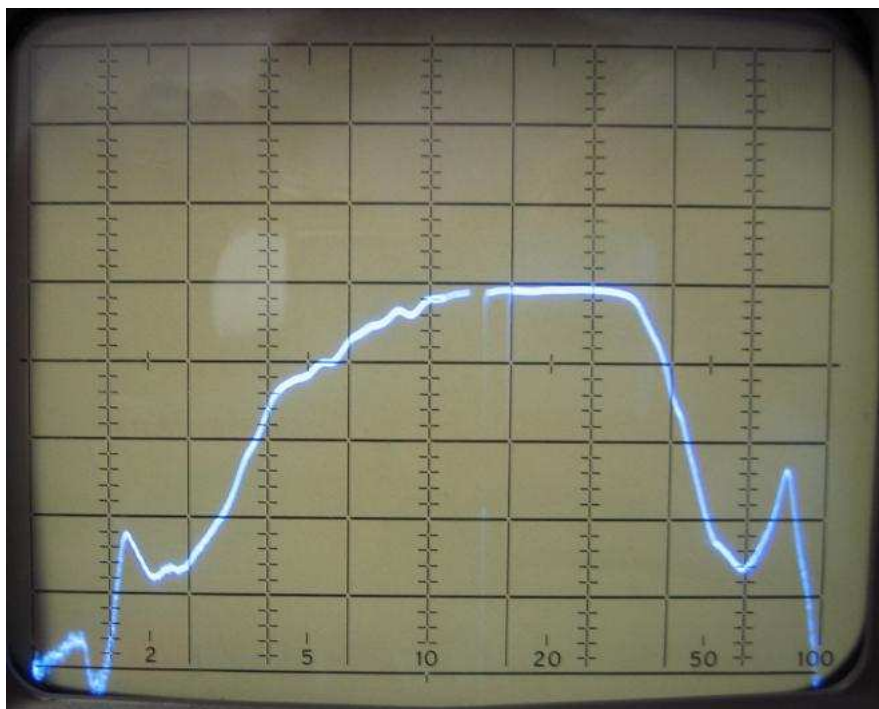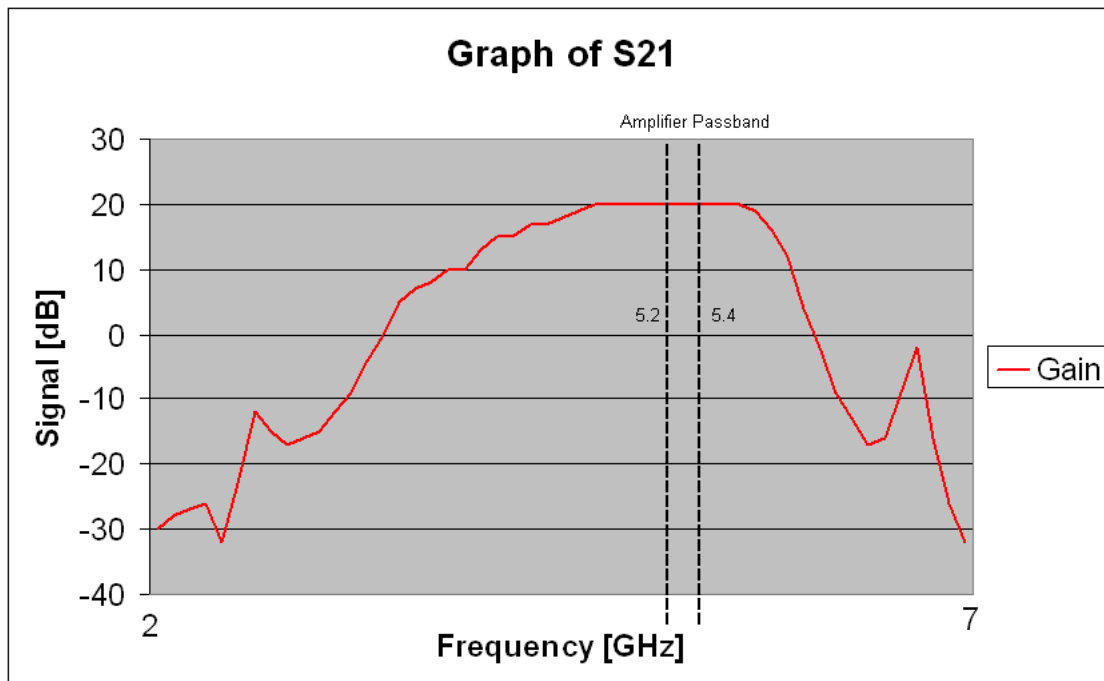
Figure 6.19: Return loss S11



Figure 6.20: S21

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Figure 6.21: Excel representation of the S21 parameter

## 6.4.2 Pin vs Pout Test

**Equipment Required**

Sweep oscillator, Power meter, attenuators, digital multimeter
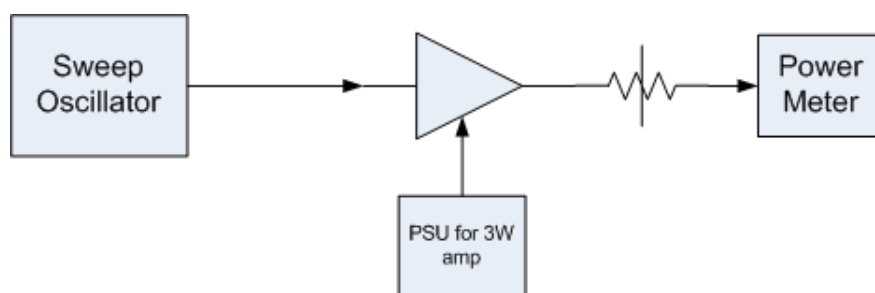
**Equipment Setup**



Figure 6.22: Setup of the Pin vs. Pout test

**Testing Procedure**

The equipment is set up according to the block diagram in Figure 6.22. The sweep oscillator is set to output a continuous signal of 5300 MHz. The power meter is calibrated and connected to the output of the amplifier. A 30 dB attenuator is placed on the output of the amplifier to pad down the output signal before going into the power meter. The digital

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multimeter is set to measure voltage and is connected between the *forward power pin* on the amplifier and ground. The system is switched on and allowed to settle for five minutes before any readings are taken.

The input signal from the sweep oscillator is checked with the power meter to ensure that it is at the correct level. The power of the input signal is then varied from -8 dBm to 4dBm and the output power is captured off the power meter. The voltage off the forward power pin is also recorded.

**Test Results**

As can be seen from Table 6.7 and Figure 6.23 the 1dB gain compression point of the 3W power amplifier is 33 dBm.

| Input Power [mW] | Input Power [dBm] | Output Power [mW] | Output Power [dBm] |
|------------------|-------------------|-------------------|--------------------|
| 0.150 | -8.24 | 0.795 | 29.00367129 |
| 0.165 | -7.83 | 0.915 | 29.61421094 |
| 0.185 | -7.33 | 0.99 | 29.95635195 |
| 0.205 | -6.88 | 1.08 | 30.33423755 |
| 0.230 | -6.38 | 1.23 | 30.89905111 |
| 0.260 | -5.85 | 1.38 | 31.39879086 |
| 0.290 | -5.38 | 1.53 | 31.84691431 |
| 0.325 | -4.88 | 1.71 | 32.3299611 |
| 0.355 | -4.50 | 1.89 | 32.76461804 |
| 0.405 | -3.93 | 2.04 | 33.09630167 |
| 0.455 | -3.42 | 2.19 | 33.40444115 |
| 0.515 | -2.88 | 2.295 | 33.6078269 |
| 0.580 | -2.37 | 2.355 | 33.71990911 |
| 0.650 | -1.87 | 2.4 | 33.80211242 |
| 0.735 | -1.34 | 2.43 | 33.85606274 |
| 0.850 | -0.71 | 2.46 | 33.90935107 |
| 0.950 | -0.22 | 2.475 | 33.93575203 |
| 1.275 | 1.06 | 2.475 | 33.93575203 |
| 1.470 | 1.67 | 2.475 | 33.93575203 |

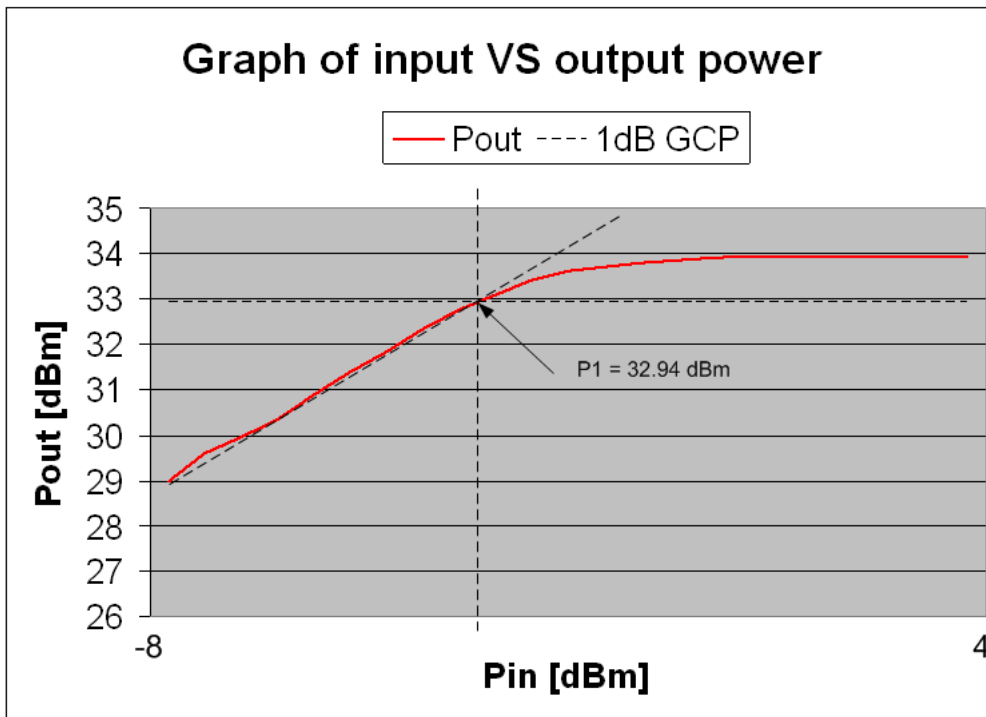Table 6.7: Results of Pin vs. Pout

Figure 6.23: Graph of Pin vs. Pout

The voltage on the forward power pin was linearly proportional to the actual measured forward power as can be seen from Figure 6.24. The voltage readings for the forward power were heavily influenced by the temperature of the amplifier. The dotted line shows the ideal linear relationship.
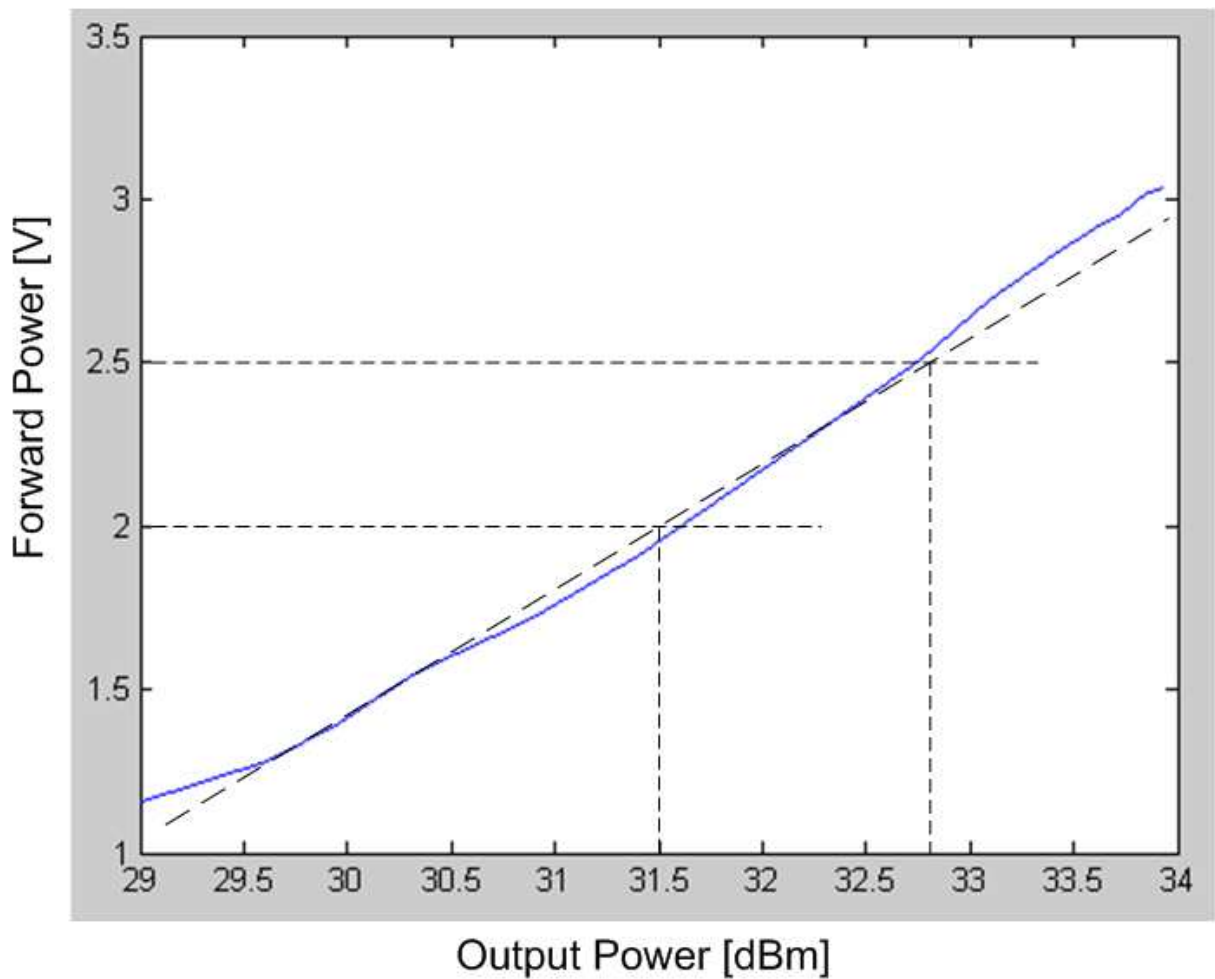
Figure 6.24: Graph of output power vs. forward power voltage

## 6.5  SystemView Simulations Testing

**Equipment Required**

PC with SystemView software

**Testing Procedure**

Graphical sinks were placed at the outputs of each stage and the power spectrum into $50\Omega$ was calculated from each sink to give the frequency plots of the 1300 MHz and 5300 MHz for the transmitter and the receiver as well as the 158 MHz output signal. .

**Test Results**

Table 6.8 shows the results of the simulations. Plots of the power spectrum can be seen in Appendix C.

| Sink No. | Tx/Rx | Frequency [MHz] | Expected level [dBm] | SystemView level [dBm] |
|----------|-------|-----------------|---------------------|------------------------|
| 17 | Tx | 1300 | -15.2 | -22 |
| 136 | Tx | 5300 | 0 | -6.5 |
| 29 | Tx | 5300 | 19.5 | 12.5 |
| 140 | Rx | 5300 | -50 | -50 |
| 41 | Rx | 1300 | -10.5 | -17.6 |
| 135 | Rx | 158 | 37 | 23.5 |

Table 6.8: Results of the SystemView simulation

The levels all appeared to be 7 dBm lower than the expected values. A possible explanation for this could be that the peak signal power is given in SystemView rather than the power integrated over the entire band.

## 6.6 Summary

The tests performed in this chapter are to verify the design of the C-band transceiver and the modifications of the other sub-systems.

Tests were performed on the FDU, the 3W Tellumat Amplifier and its power supply as well as the *SystemView* simulations. Tables 6.9 to 6.12 summarize the results of this chapter.

| Stage | Frequency [MHz] | Measured [dBm] | Expected [dBm] |
|-------|-----------------|----------------|----------------|
| C1 | 4000 | 10 | 10 |
| C2 | 4000 | 10.2 | 10 |

Table 6.9: Results of FDU test

| Stage | No load [V] | Expected [V] | Loaded [V] | Expected [V] |
|-------|-------------|--------------|------------|--------------|
| OUT1 | 15.039 | 15 | 15.039 | 15 |
| OUT2 | -15.067 | -15 | -15.158 | -15 |
| OUT3 | 10.705 | 10 | 10.579 | 10 |
| OUT4 | 5.096 | 5 | 5 | 5 |

Table 6.10: Results of the PSU test

| | Gain [dB] | 1 dB gain compression point [dBm] |
|--|-----------|-----------------------------------|
| 3W Amplifier | 20 | 33 |

Table 6.11: Results of amplifier test

| Sink No. | Tx/Rx | Frequency [MHz] | Expected level [dBm] | SystemView level [dBm] |
|----------|-------|-----------------|----------------------|------------------------|
| 17 | Tx | 1300 | -15.2 | -22 |
| 136 | Tx | 5300 | 0 | -6.5 |
| 29 | Tx | 5300 | 19.5 | 12.5 |
| 140 | Rx | 5300 | -50 | -50 |
| 41 | Rx | 1300 | -10.5 | -17.6 |
| 135 | Rx | 158 | 37 | 23.5 |

Table 6.12: Results of the SystemView simulation

# Chapter 7

# Conclusions and Recommendations

## 7.1 Conclusions

Based on the findings of this project report, the following conclusions can be drawn:

- The FDU could be modified to output two identical 4000 MHz local oscillator signals at 10 dBm.

- There are harmonics present in the 4000 MHz local oscillator signal caused by products in the synthesizer.

- The C-band transmitter can interface with the existing L-band transmitter at 1300 MHz at a level of -15.2 dBm

- The filters on both the C-band transmitter and receiver are sufficient to allow the 100 MHz chirp signal through the system but eliminate any unwanted signals.

- The budget for the C-band receiver is comparable to the existing system budget, allowing the C-band receiver to be compatible with the existing system. The noise figure of the C-band receiver was calculated to be 2.025dB.

- The C-band receiver can down-convert the 5300 MHz RF signal to an IF of 1300 MHz.

- A power supply unit has been constructed for the 3W Tellumat amplifier and the amplifier has been tested to show that it can be used in the C-band transmitter power stage. The gain of the amplifier was 20 dB and had an 1 dB gain compression point of 33 dBm.

- The transceiver was simulated successfully in *SystemView* and the simulated results enabled real components to be selected.

## 7.2   Recommendations for Future Work

Based on the conclusions and the experience gained from the project, the following recommendations can be made:

- The system should be constructed from the components that have been selected and tested to verify the design.

- A filter should be added to the 4000 MHz local oscillator signal to eliminate all the unwanted harmonics.

- The data that has been collected on the relationship between the forward power and the *forward power output voltage* pin on the amplifier should be used to construct a meter to display the forward power on the front of the C-band transceiver case.

- A duplexer should be implemented to allow for the same antenna to transmit and receive.

# Appendix A

# Spectrum Analyser plots of the FDU output
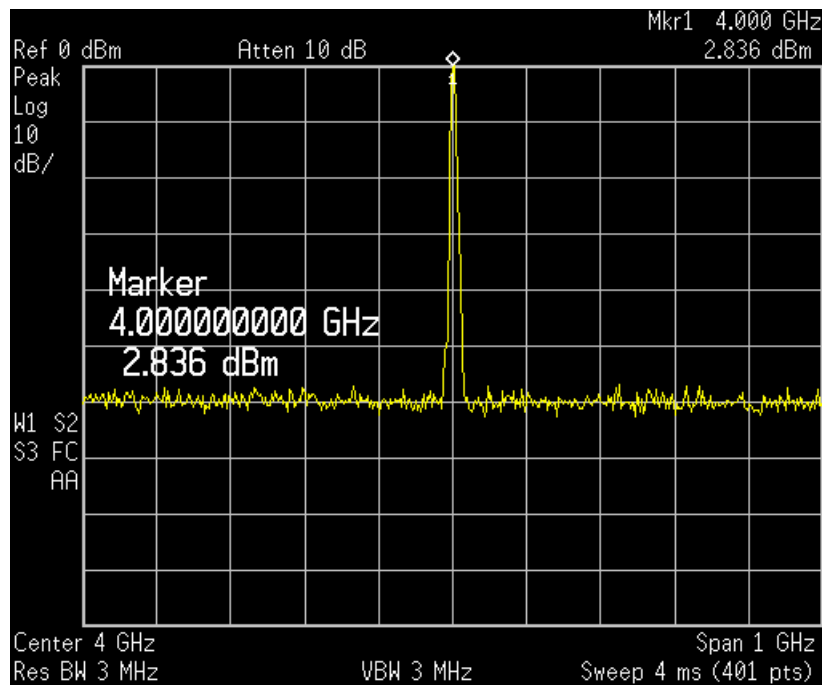


Figure A.1: Output of 4000 MHz synthesiser
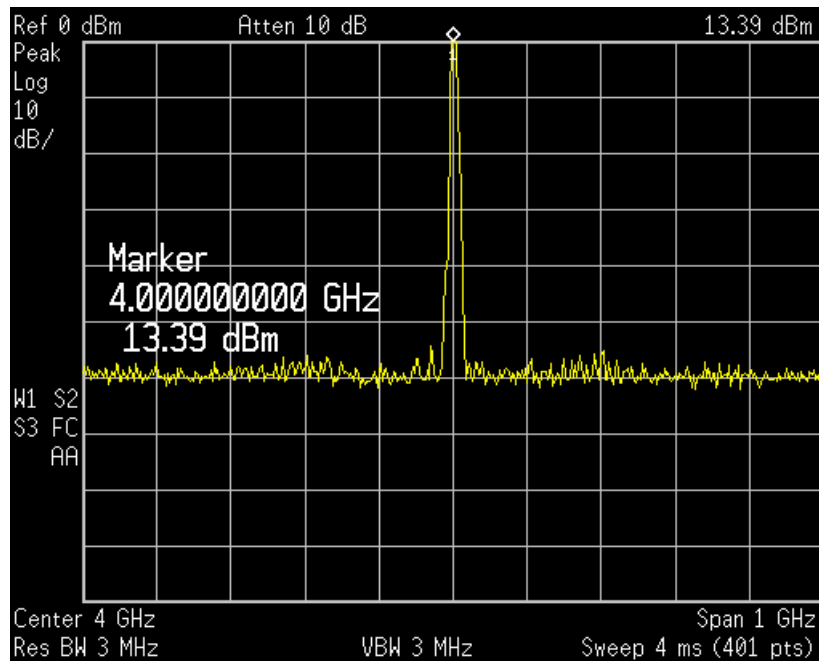
Figure A.2: 4000 MHz output from amplifier
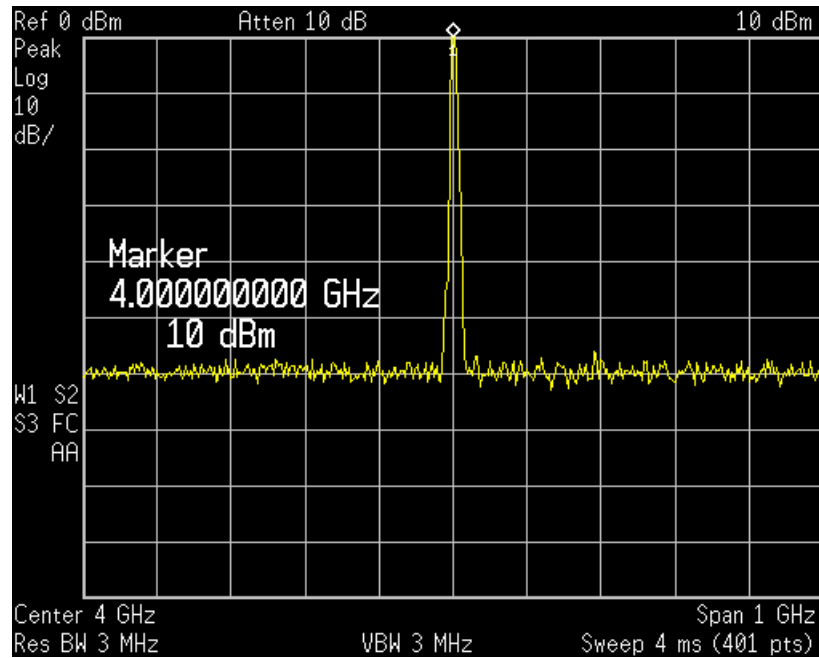


Figure A.3: 4000 MHz output from splitter 1
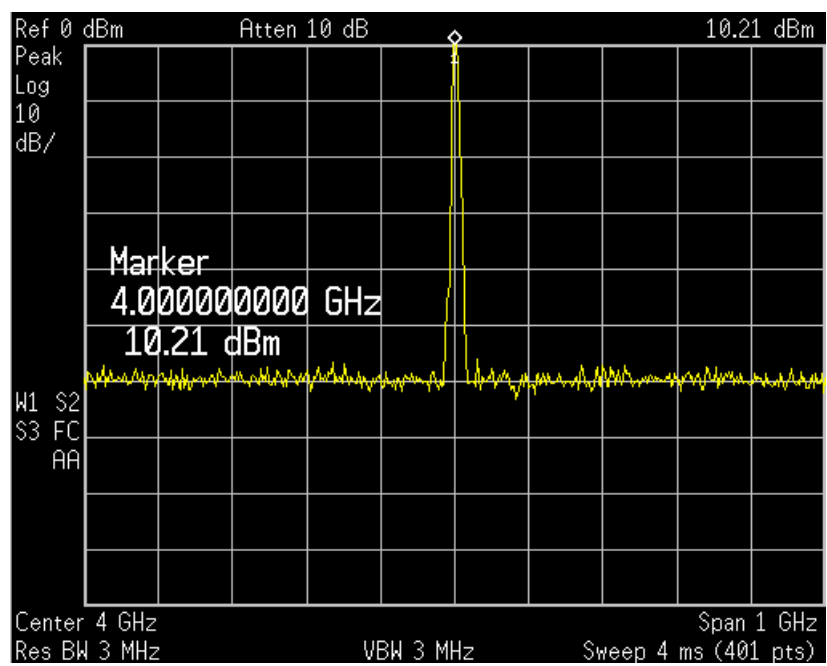
Figure A.4: 4000 MHz output from splitter 2

# Appendix B

# 3W amplifier PSU output voltages
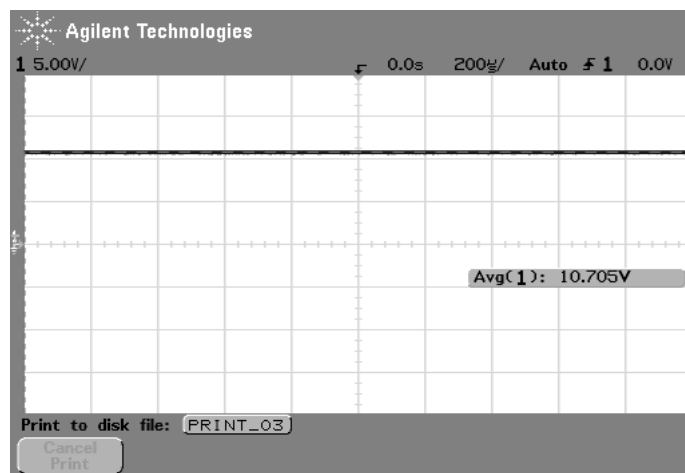


Figure B.1: 10V no load
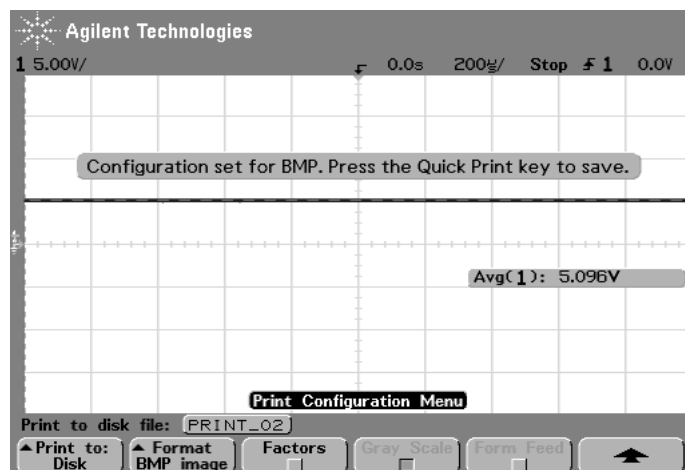


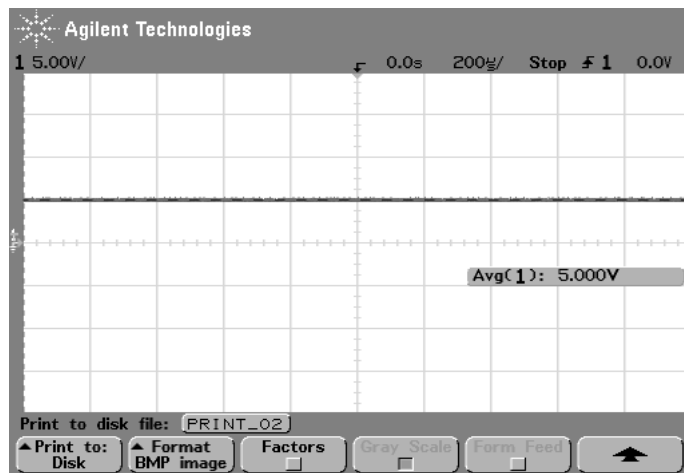Figure B.2: 5V no load
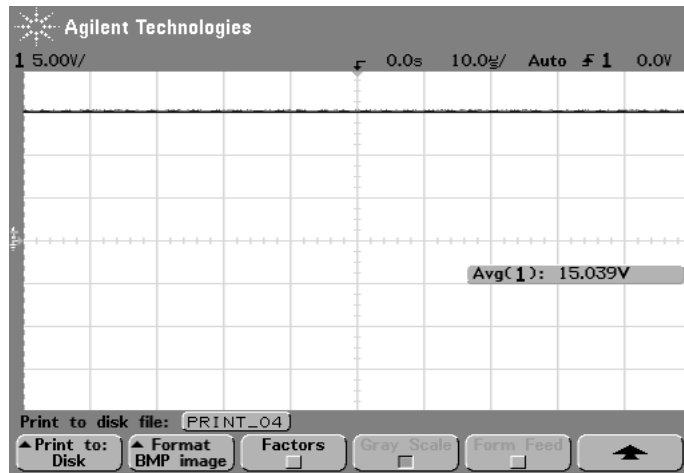
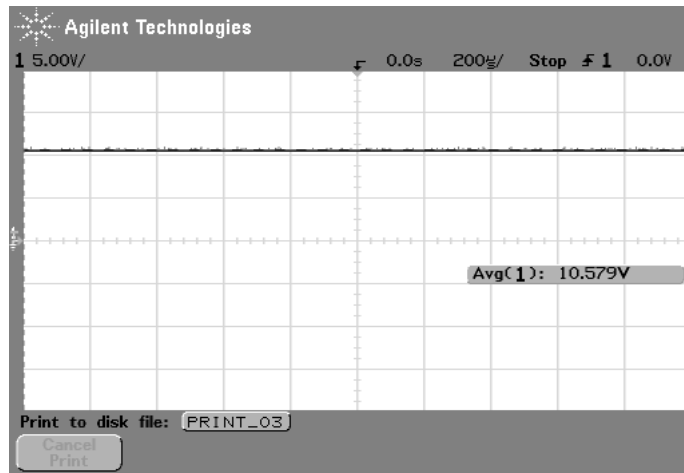Figure B.3: 15V no load
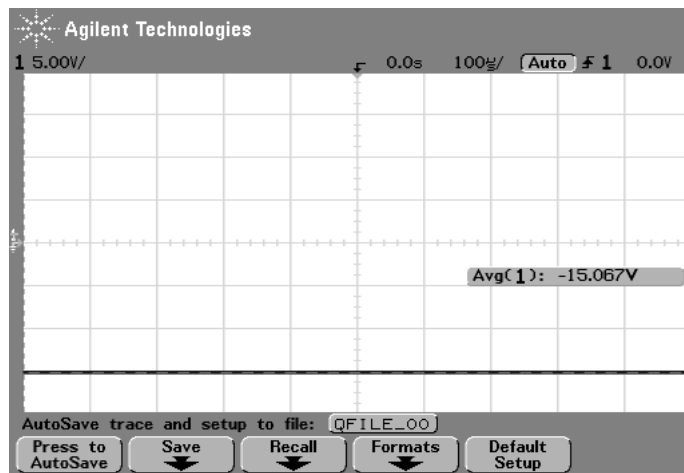


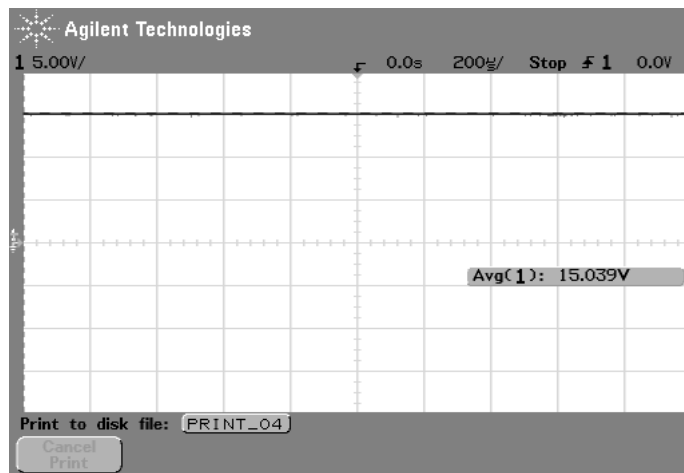Figure B.4: -15V no load
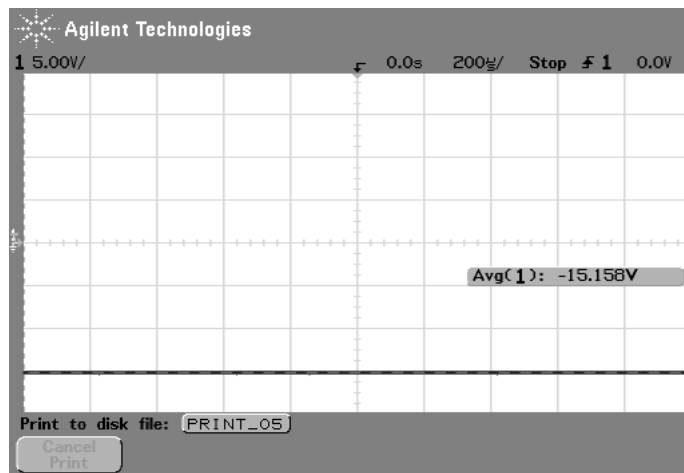


Figure B.5: 5V load

Figure B.6: 10V load



Figure B.7: 15V load



Figure B.8: -15V load

# Appendix C

# SystemView Power Spectrum Plots
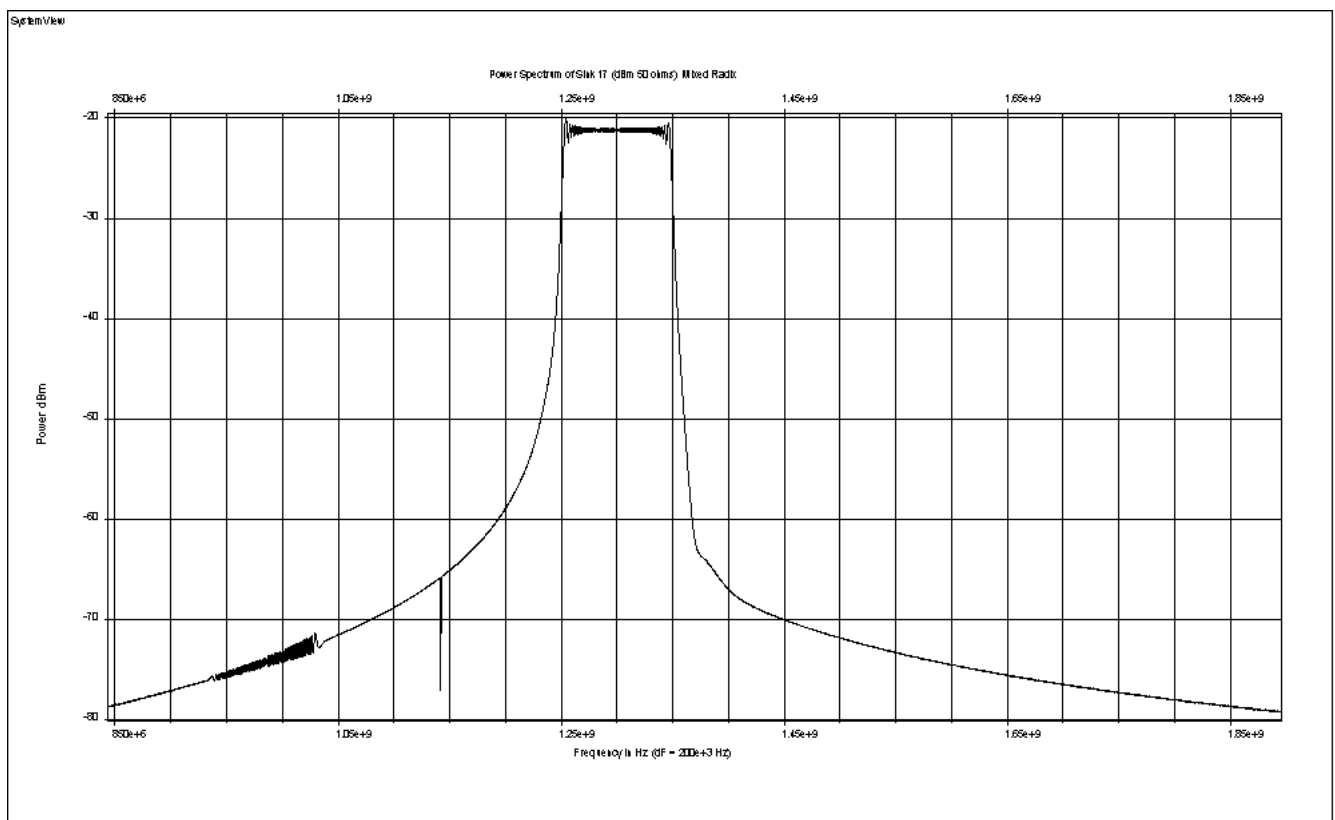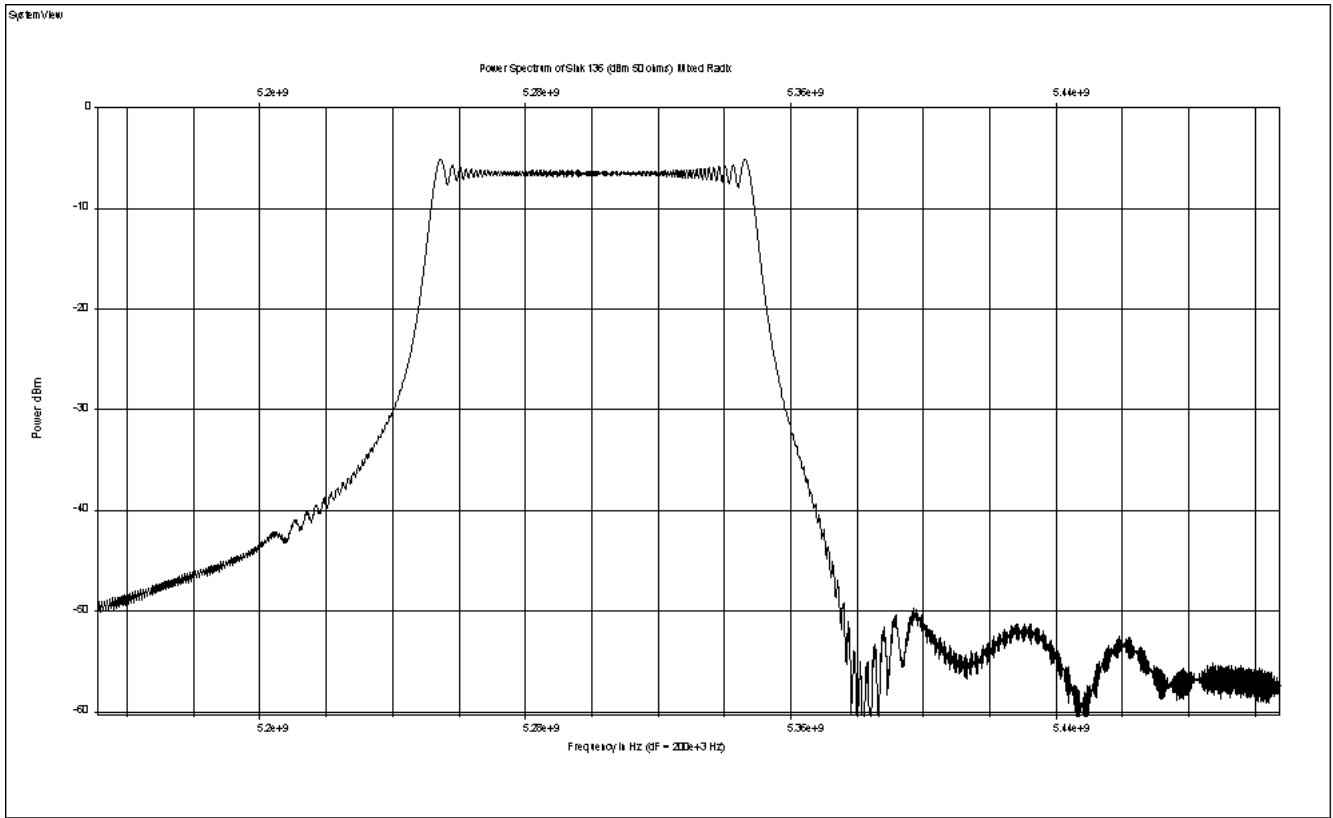


Figure C.1: Transmitter signal of 1300 MHz

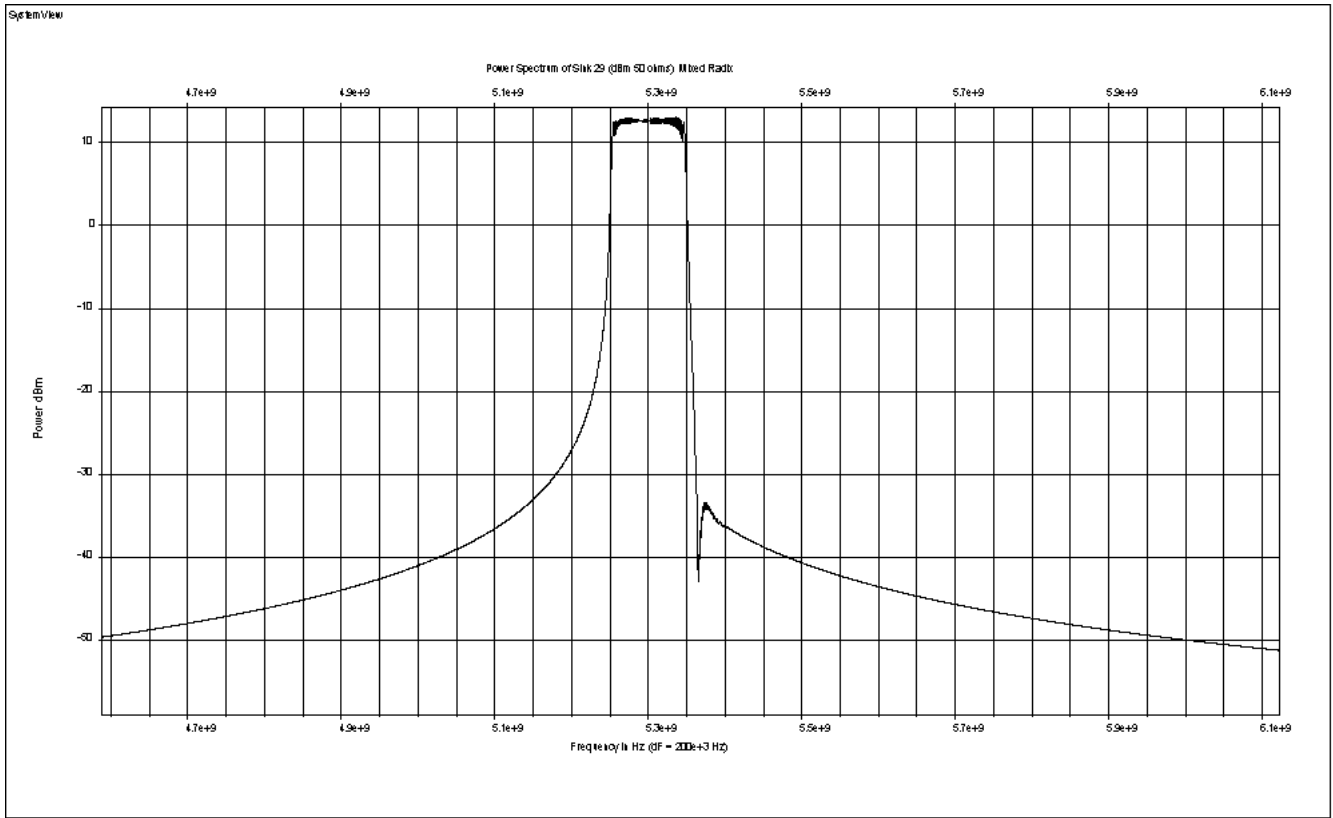Figure C.2: Transmitter signal at 5300 MHz going into the power amplifier

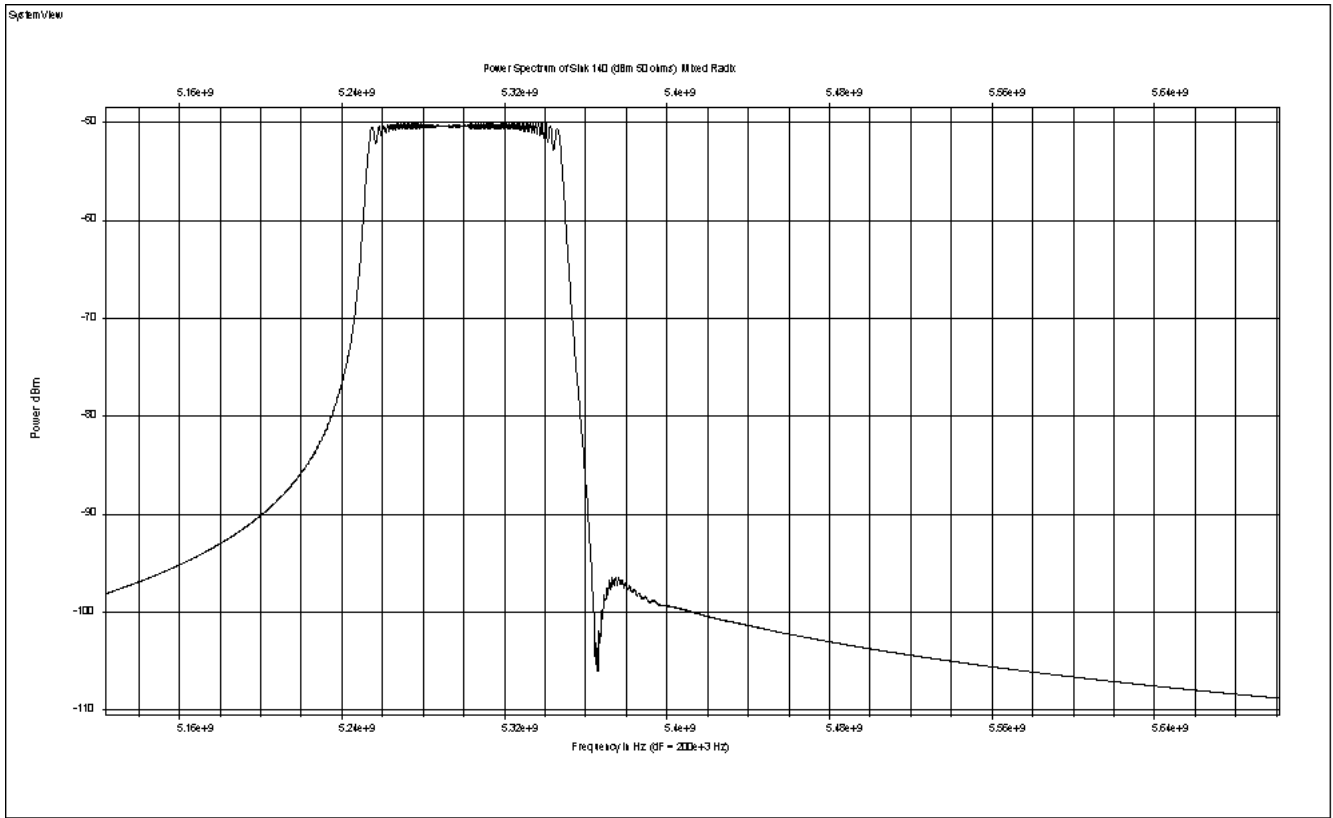Figure C.3: Transmitter signal of 5300 MHz
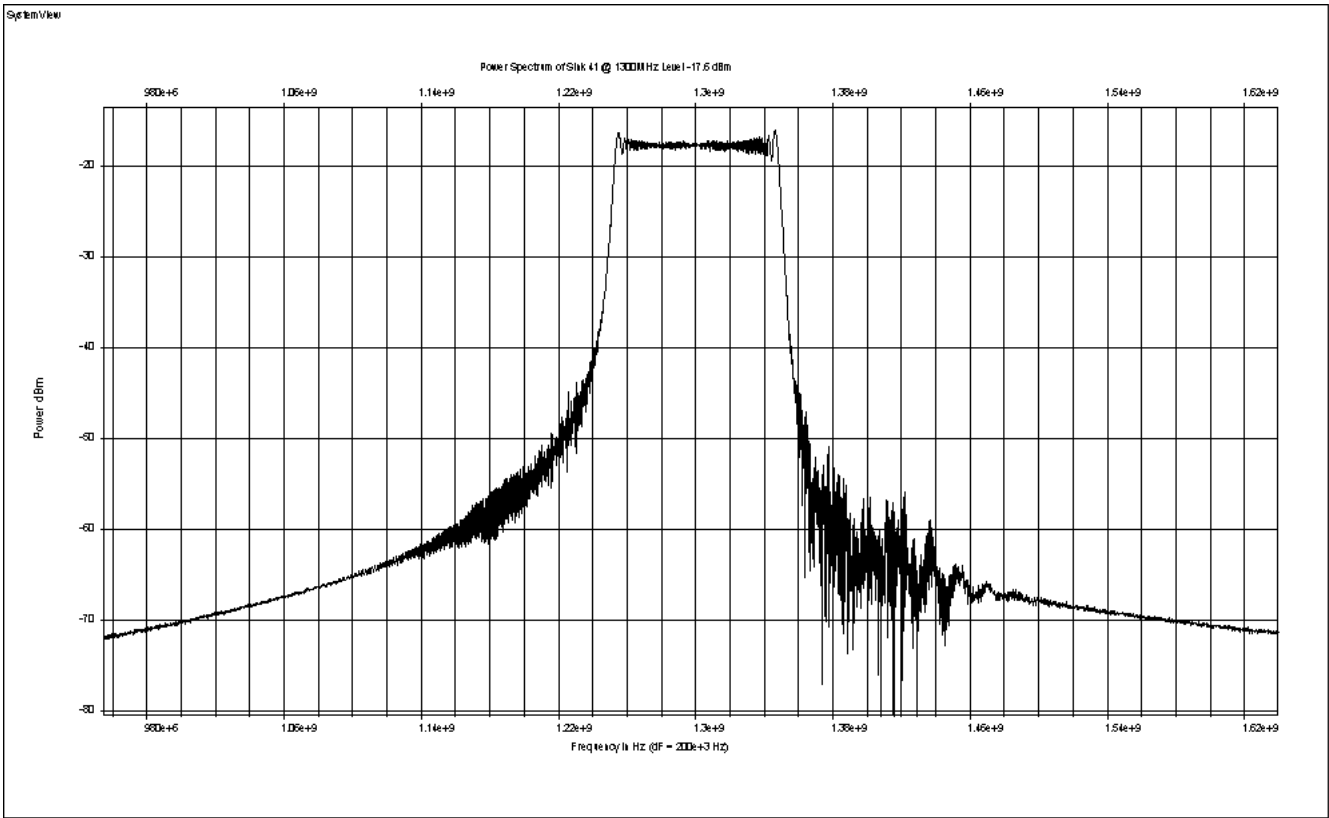
Figure C.4: Receiver signal of 5300 MHz
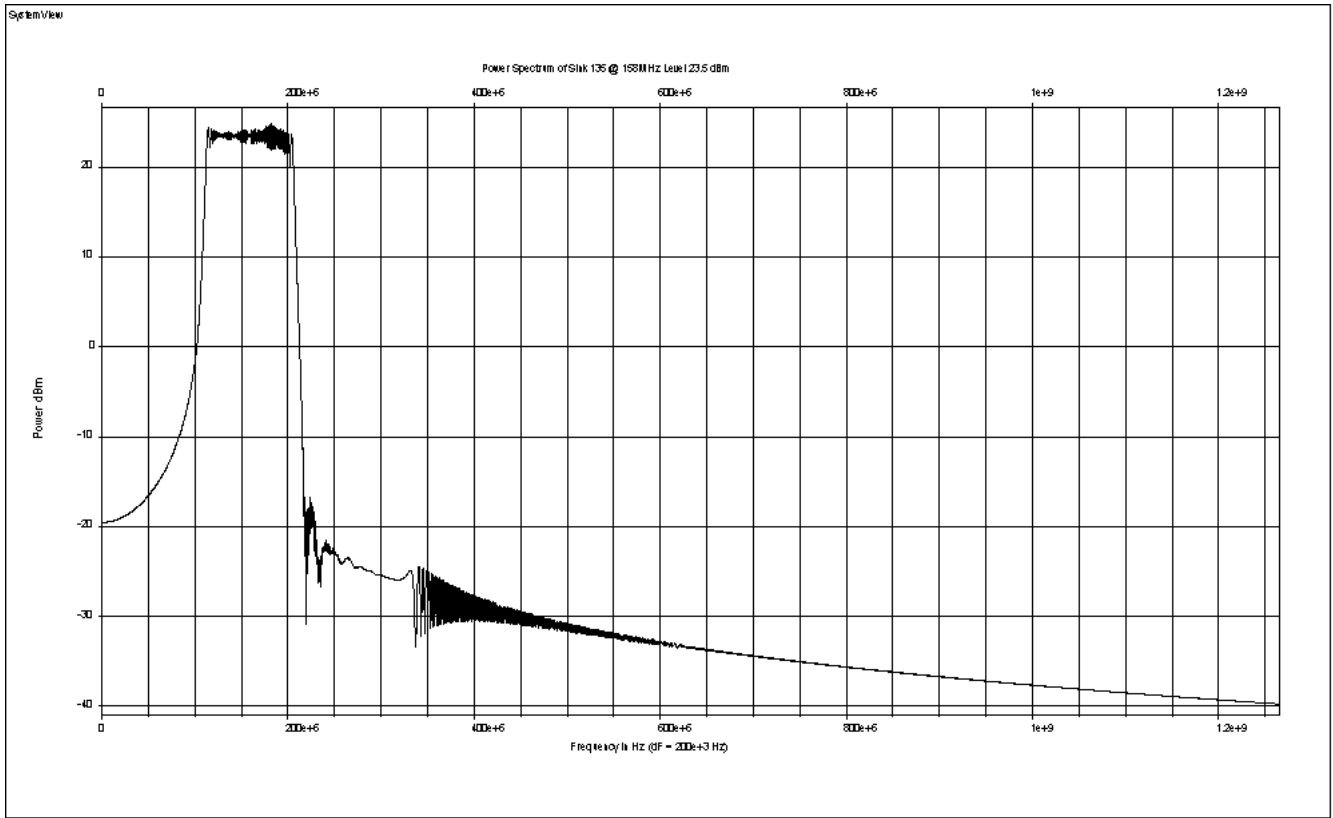
Figure C.5: Receiver signal of 1300 MHz

Figure C.6: Transmitter signal of 1300 MHz

# Appendix D

# Contents of the CD

The CD at the back of this project report contains the following directories:

- **2004 Dissertations:** contains the previous research material on the SASAR II system.

- **FDU Datasheets:** contains the datasheets of the components used in the modification of the FDU.

- **PSU Datasheets:** contains the datasheets of the components used in the construction of the PSU for the 3W amplifier.

- **SystemView Simulations:** contains the token file for the simulation that was run on *SystemView.*

- **Tests:** Contains all the plots from the spectrum analyser, network analyser, digital oscilloscope and *SystemView* .

- **Transceiver Datasheets:** Contains the datasheets for the components selected for the C-band transceiver.

- **Visio:** Contains all the block diagrams that were made using this software.

- **Thesis:** Contains a soft copy of this thesis in Lyx format and in PDF format.

The CD also contains the prestudy and the requirements review, which were completed at an earlier time in the project.

# Bibliography

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[8] S. Schrire. *EEE371W Course Notes*. 2004.

[9] J. M. Webster. The development of a radar digital unit for the sasarii project. Master's thesis, Department of Electrical Engineering, 2004.