System integration of an Alphasat Propagation terminal

Diploma thesis

by

Gerald Faustmann

Institute for communication networks and satellite communications
at technical University Graz

Head of the Institute: Univ.-Prof.Dipl.-Ing. Dr. Otto KOUDELKA

Advisor: Univ.-Prof.Dipl.-Ing. Dr. Otto KOUDELKA

Supervisor: Univ.-Prof.Dipl.-Ing. Dr. Otto KOUDELKA (TU Graz)
Dr. David FERNANDEZ PRIM (JOANNEUM RESEARCH)

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Abstract

This thesis is based on the document "Signal chain of the 'Ka/Q Band Ground Propagation Terminals for the Alphasat TDP5 Scientific Experiment' written by Gerald Faustmann in May 2010 during a project with JOANNEUM RESEARCH.
The above mentioned document focuses on the preliminary design of a ground terminal for the simultaneous reception of two beacons, each in two orthogonal polarizations in Ka-and Q-band. These beacons shall be simultaneously received and the attenuation, scintillation and depolarisation of the two signals shall be measured and evaluated

The present document refines these data and the design documents created. The work conducted during this thesis is mainly deicated to the design, procurement, integration, and testing of the second down conversion stage. It is described in detail and the components used are depicted in detail. Additionally, of course, a preview of the antenna design and the outdoor unit, based on the data already available, is presented.

Zusammenfassung

Dieses Dokument basiert auf der Projektarbeit "Signal chain of the 'Ka/Q Band Ground Propagation Terminals for the Alphasat TDP5 Scientific Experiment'" von Gerald Faustmann datiert Mai 2010
Obige Arbeit war auf die Suche nach geeigneten Komponenten für die Alphasat Bodenstation ausgerichtet. Diese Bodenstation soll zwei Bakensignale im Ka-Band und Q-Band, jedes Band in zwei orthogonalen Polarisationen, empfangen und charakteristische Eigenschaften der Übertragung wie Dämpfung, Szintillation und Depolarisation messen.

Die vorliegende Arbeit beschäftigt sich nun mit der Feinauswahl der Komponenten und deren Zusammenbau. Der Fokus dieser Arbeit liegt dabei auf der zweiten Konversionsstufe, da die sog. „Outdoor unit" und die Antenne noch in der Planungs- und Designphase sind. Natürlich werden auch diese wesentlichen Teile des Terminals auf Basis der bereits vorliegenden Daten beschrieben.

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

……………………………   ………………………………………………..
Date   (signature)

Acknowledgement

This thesis is dedicated to my family, my girlfriend Ursula and my children Miriam and Luca, who had a hard time, while I was writing this thesis.

Many thanks go to JOANNEUM RESEARCH Forschungsgesellschaft mbH for the opportunity to write my Diploma thesis during the development phase of the ESA project 'Ka/Q Band Ground Propagation Terminals for the Alphasat TDP5 Scientific Experiment' .

Special thanks go therefore to the members of the Institute of applied Systems for their dedicated help and support. In particular I want to thank David Fernandez Prim, as the external advisor for his support.

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Schönhuber Michael
Diaz Alvarro
Flohberger Markus
Prechtl Thomas
Richter Maximilian

Gerald Faustmann

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LIST OF ACRONYMS

ACM	Adaptive coding and modulation
BPF	band pass filter
BW	bandwidth
COTS	commercial off-the-shelf
CPU	Central processing unit
EIRP	Effective isotropic radiated power
ESA	European Space Agency
FEC	Forward error correction
FFT	Fast Fourier Transformation
GPS	Global positioning system
HU	Height units
IF	Intermediate frequency
LAN	Local area network
LNA	Low noise amplifier
LNB	Low noise block
LO	Local oscillator
MEMS	Micro mechanical systems
MSPS	Megasamples per second
N	absolute noise power in W
N_0	noise density in W/Hz
NF	Noise Figure
NRE	Non recurring engineering
OMT	Orthogonal mode transducer
PLO	Phase locked oscillator
RF	Radio frequency
SMA	Sun miniature - A
SNR	Signal to noise ratio
TBC	To be confirmed
TBD	To be discussed
UPS	Uninterruptible power supply
XPD	cross - polar discrimination

1 Introduction and Motivation

This thesis covers the integration of the Alphasat propagation terminal also known as ‘the Terminal’. This project is launched by the European space agency and is divided into several stages.

From [Ref. 18.]:

“

- *Communications experiments: The main aim is to assess, over-the-air, the performance of links operating at Q/V band in conjunction with Interference and Fading Mitigation Techniques (noticeably ACM), in the perspective of deploying future high-capacity systems utilizing that band for the feeder-link (and lower frequency bands for the user-link.*

- *Scientific experiment: The main aim is to obtain additional Q/V-band propagation data that are indispensable for optimizing modern satellite systems design, and to assess the system-level impact of data coming from propagation measurements, databases and channel simulators,*

- *Technology experiment: to verify the in-flight performance of innovative hardware, with particular regard to devices based on Micro-Electro-Mechanical Systems (MEMS).*

“

In particular this thesis is concerned about the propagation effects in the atmosphere in Q - and Ka band. The Q/V band mentioned above is misleading because other experiments are also payload of the Alphasat satellite. but the propagation experiment is using 19.704 GHz for Ka-band and 39.402 for Q-band. Further details of the beacons are provided in section 2.1 on page 19.

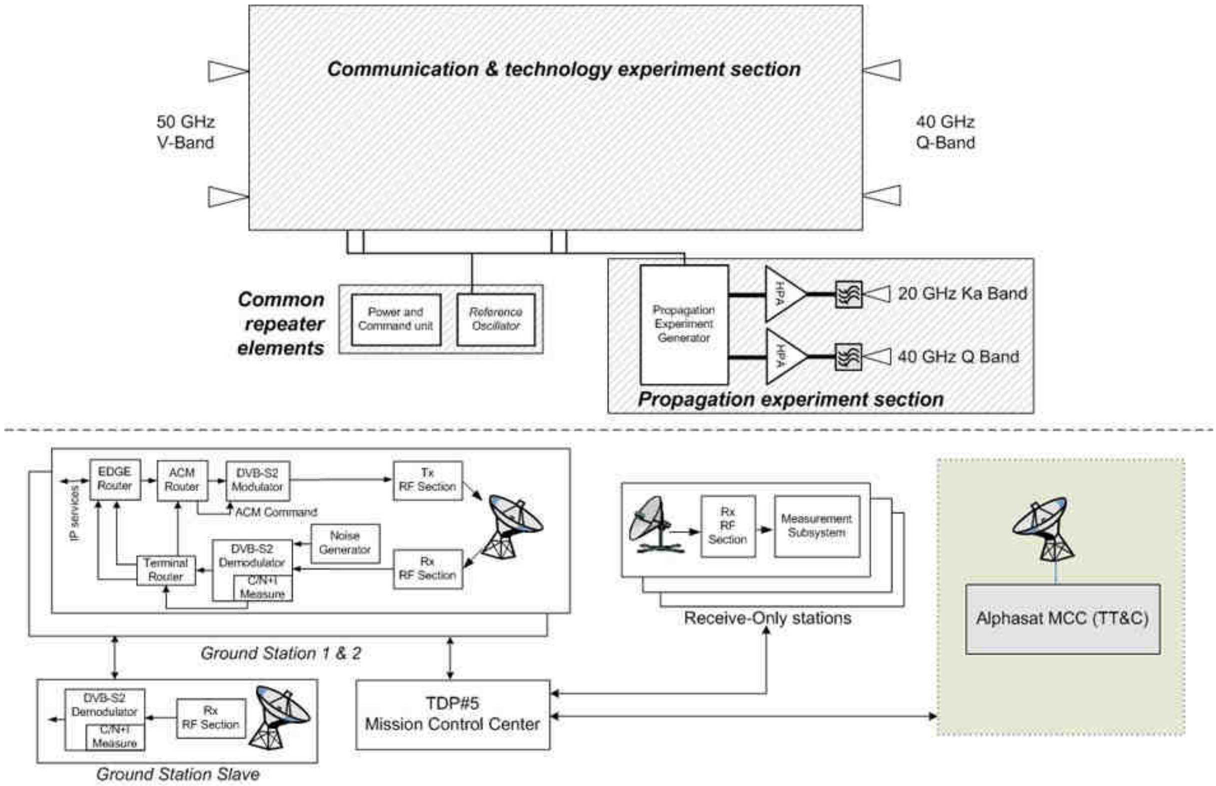

Figure 1-1 Overview Alphasat project [Ref. 18.]

In Figure 1-1, the structure of the experiment is shown. The development of the space segment is within the responsibility of the Italian RF company SPACE ENGINEERING located in Rome, while the ground communication and propagation experiments have been assigned to JOANNEUM RESEARCH.

This diploma thesis has been written during a project of the author with JOANNEUM RESEARCH to develop and integrate a prototype of a ground receiver terminal, based on COTS.

Preliminary work was done under a different contract, which was mainly the selection of potential components and suppliers. The paper, *"Signal chain of the 'Ka/Q Band Ground Propagation Terminals for the Alphasat TDP5 Scientific Experiment"* [Ref. 19.], therefore worked as a base document for this thesis.

During this thesis the above mentioned paper was critically reviewed as well as some redesign was applied in particular to the so called "outdoor unit" which consists of antenna and feed and the first down conversion unit.

2 General

The functional frame for the Terminal has been provided by ESA in the Statement of work [Ref. 3.]. Section 2.1 and 2.2 are summarizing the specifications and functional requirements with reference to the document above.

2.1 Beacon specification

2.1.1 Orbital characteristics

- Geosynchronous orbit with variable inclination not exceeding ±3 deg
- East-West Station Keeping Box Half-Width equal to 0.1 deg
- Compensation of inclination-induced yaw error;
- 3-axes control with 0.12 deg accuracy on each axis;
- Satellite repointing (up to 0.05°, TBC).

2.1.2 Beacon specifications

- Frequencies: Ka @ 19.704 and Q @ 39.402 GHz
- The polarization of the Q band beacon is 45° deg linear.
- The polarization of the Ka band beacon is linear vertical.
- EIRP of Q –band beacon > 26.5 dBW
- EIRP of Ka –band beacon > 19.5 dBW

2.1.3 Oscillator drift of space segment

TDP5-SSG-PER-0540 Q-Band Beacon Frequency stability:	± 5x10-7 over 24 h ± 5x10-7 over 30 days ± 5x10-7 over 3 years.

2.1.4 Phase Noise Oscillators

The beacon characteristics of the space segment are depicted in Table 2-1 The oscillators used to convert the RF to the IF1 frequency should not exceed these limits to avoid further contamination of the signal.

Q Band	Ka Band
-22 dBc/Hz at 10 Hz from carrier -42 dBc/Hz at 100 Hz from carrier -52 dBc/Hz at 1 kHz from carrier -62 dBc/Hz at 10 kHz from carrier -82 dBc/Hz at 100 kHz from carrier -82 dBc/Hz at 100 MHz from carrier	-30 dBc/Hz at 10 Hz from carrier -50 dBc/Hz at 100 Hz from carrier -60 dBc/Hz at 1 kHz from carrier -70 dBc/Hz at 10 kHz from carrier -90 dBc/Hz at 100 kHz from carrier -90 dBc/Hz at 100 MHz from carrier

Table 2-1 Space segment specifications of the two transmitted beacons

2.2 Functional Requirements

2.2.1 Environmental specification

- Air temperature
  Operational temperature: -40°C … +45°C
  Survival temperature: -50°C … +50°C

- Wind speed
  Operational up to 90 km/h
  Survival up to 140 km/h

- Relative humidity
  Operational humidity: 0% … 99%

2.2.2 Measured Parameters

- Total atmospheric attenuation, Atot [dB].
  Accuracy shall be 0.1 [dB] within a 0.1 ... 20 dB a range.

- Atmospheric noise temperature, Tsky [K].
  Accuracy shall be 1 K within the 10 ... 150 K range

- Atmospheric excess attenuation, Aexc [dB].
  Accuracy 0.1 [dB] within a 0 ... 20 dB a range.

- Atmospheric crosspolar discrimination, XPD [dB].
  Accuracy 0.3 [dB] within a 10 ... 30 dB a range.

- Scintillation standard deviation and frequency spectrum.

2.2.3 Receiver Specification

- The minimum required C/N shall be 5 dB
- Receiver noise temperature shall not exceed 400 K for Ka band
- Receiver noise temperature shall not exceed 600 K for Q band
- Receiver bandwidth shall be 1 KHz
- Receiver antenna XPD shall be higher than 35 dB
- The average terminal operational period shall be 99.99 % of the year during the nominal life period of the Alphasat TDP5 scientific experiment (3 years).

2.2.4 Antenna Specification

- *Receiver antenna half power beam width* Shall be lower than 0.7 deg at Ka band Shall be lower than 0.55 deg at Q band
- *Receiver antenna efficiency* Shall be higher than 60 %
- *Max antenna diameter* Shall be lower than 1.5 m (TBC)
- *Receiver antenna XPD* Shall be higher than 35 dB

2.2.5 Requirements for Pointing:

"*Antenna Pointing Deviation: S*hall be lower than 0.06 deg with 90 Km/h constant wind speed. "

For the prototype no pointing device is implemented, because the Q – band beacon will not be in orbit at the time of the outdoor testing campaign.

2.2.6 Requirements for De-icing and blower

"*Antenna de-icing/blower system:* Antenna surface shall be dry within 10 min from the switch on of the system (for icy conditions or air relative humidity > 90 %) or from the end of rainfall / snowfall event "

3 Design concept

The Terminal consists of three main units:

1. Antenna and Feed
2. First down conversion and signal conditioning stage
3. Second down conversion and signal conditioning stage

Additional devices are included in the Terminal but are only roughly described during this thesis. In particular:

4. Signal post processing
5. Web interface and remote control

After several design iterations the design depicted in Figure 3-1 has been chosen. (A larger view is depicted in ANNEX A Figure11-1)

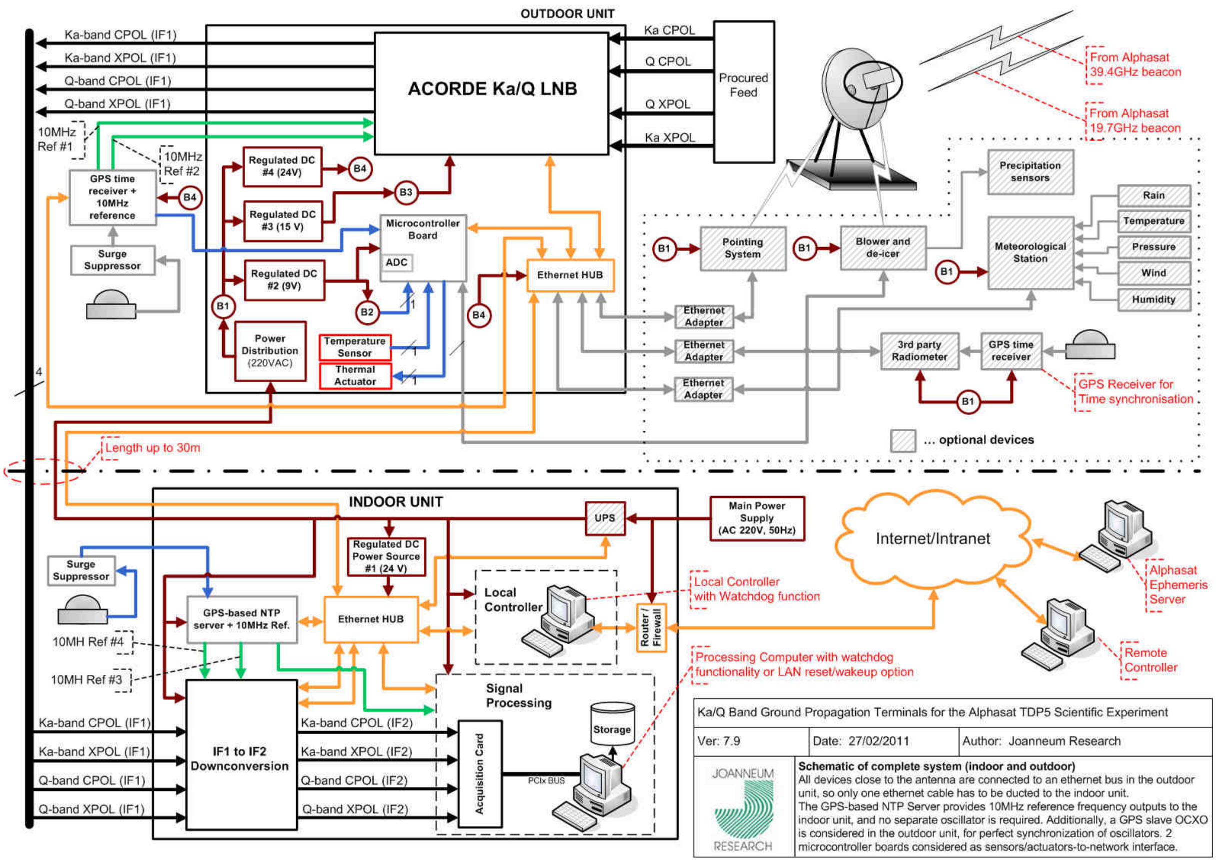

Figure 3-1 System design schematic

3.1 Description

The Terminal is based on a modular design allowing the control of optional devices like meteorological instruments or a radiometer.

The power to the Terminal shall be supplied from a 220V/50Hz source which could be optionally supported with an UPS.

The signal will be received by a dual band feed and reflector, where the development focus lies on the feed to provide the necessary XPD as specified in section 2.2.3 on page 20. The antenna has to provide four outputs as waveguide

The LNB will amplify and down convert each RF signal to an IF in the range of 1 GHz to allow a transmission over a commercial RF cable with acceptable losses. The first LNB will fix the noise figure following the Friis formula depicted in Equ. 1.

$$T_{Dev\_ref} = \sum_{n=1}^{N} \frac{T_n}{\prod_{i=1}^{n-1} G_i} \qquad \textbf{Equ. 1}$$

where:

N … Total number of components in signal chain
T_n … Noise temperature of the actual device
G_i … Gain of device i in signal chain
T_{Dev_ref} … Total system noise at reference point

The target for the LNB was therefore to get as much gain as possible with the lowest noise figure that could be achieved. For this the design team outsourced the development of the LNB to ACORDE Ltd. Details can be found in section 5.3 on page 30.

After the four signals of interest have been produced, they are transmitted to the indoor unit, where the incoming IF1 is further converted to an IF2 of currently 10.7 MHz which is then fed into a signal acquisition card, which samples the incoming IF signals and applies further processing. A scheme of this procedure is given in Figure 3-2.

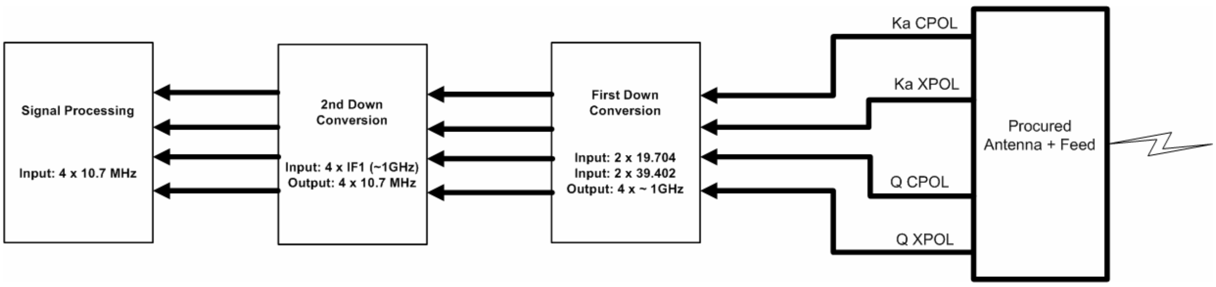

Figure 3-2 Stages of signal processing

After the signals have been processed the data is stored in a common storage. This storage can be accessed by the local control computer, which hosts the web interface and monitors auxiliary devices.

The data generated by the Terminal can be sent in periodic intervals to a remote computer, because it is meant to operate mainly unattended. This sending procedure is automatically launched by the local control computer, but the Terminal can be manually checked or data can be acquired by using the web-interface, which allows a privileged user to obtain data, and view the current status of the Terminal.

The internal communication within the Terminal is established by a local area network (LAN), basically consisting of two Ethernet hubs, one located in the outdoor unit and the other in the indoor unit.

Two microcontroller systems located in the indoor and outdoor unit are monitoring system relevant signals like temperature and voltages. These signals are also provided on the LAN and received by the local control computer which stores them time tagged to the common storage.

The common time base necessary for this is derived from a GPS based NTP server located in the indoor unit. Additionally this GPS receiver provides a 10 MHz reference signal to the signal acquisition card and the second down conversion stage.

Because it is necessary that all RF elements receive a coherent reference signal it is not recommended that the internal 10 MHz signal is also used for the outdoor unit via cabling, because the maximum cable length will be 30 m. Instead, a second GPS receiver is installed for the outdoor unit providing an additional reference signal.

4 Antenna and feed

The antenna and feed required for system reception are still under development, so only a brief overview of the intended design can be provided.

The antenna is meant to have a prime focus reflector, as depicted in Figure 4-1. Obviously this design has a few disadvantages:

- Shadowing of the reflector from the waveguides
- Further attenuation from waveguides
- More noise directly contributing to noise figure caused by additional attenuation.

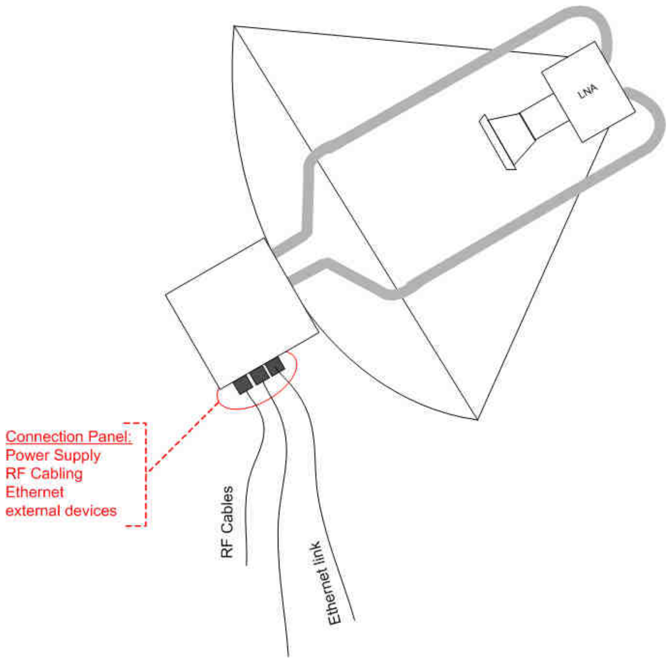

Figure 4-1 Prime focus antenna principle

5 Outdoor unit

The scheme depicted in Figure 5-1 shows the basic functionalities of the outdoor unit. These are:

- LNB for down-converting the RF signal
- System monitoring
- Internal LAN communication
- GPS slaved reference signal

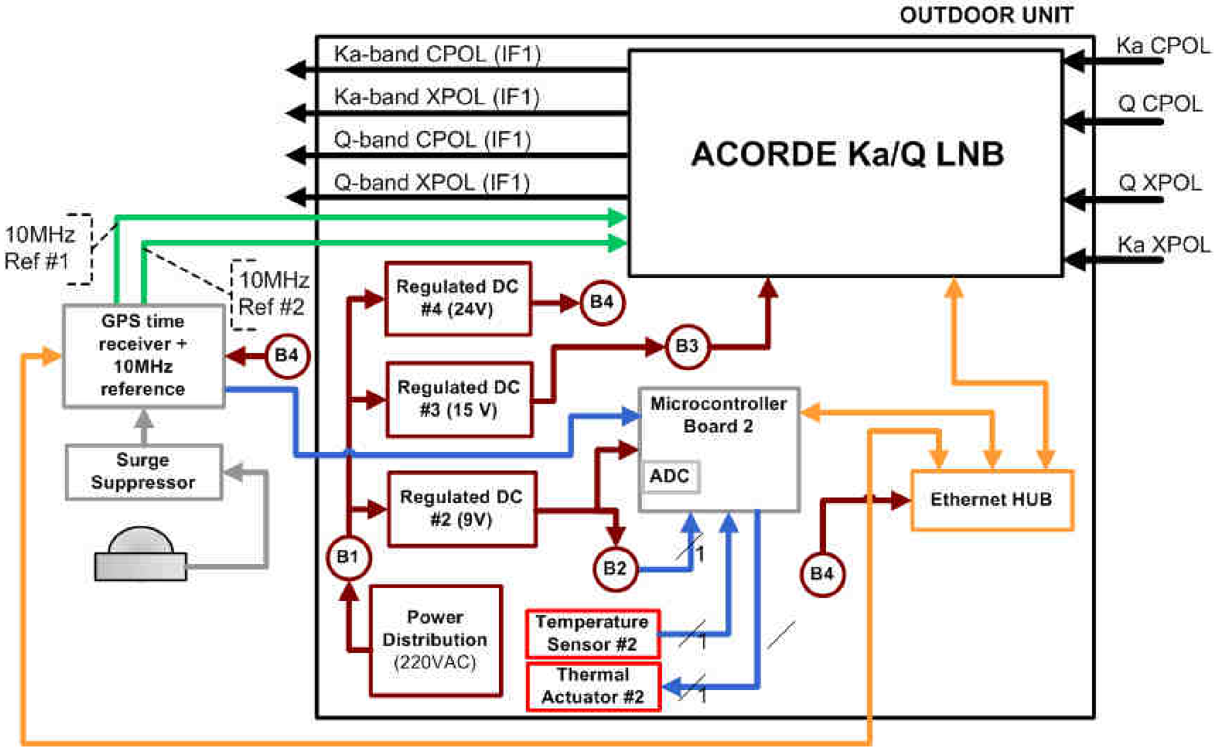

Figure 5-1 Outdoor unit schematic

The Outdoor unit will be located in a thermally isolated aluminium housing which stabilizes the temperature inside in a range of +/- 10°C.

5.1 Power supply:

The outdoor unit will be powered from a 220V power cord from indoors, which is UV – resistant and all connections will be waterproof at IP67 level. Within the unit, the power will be distributed to several regulated DC power supplies providing power to within the same

5.2 Signal transmission to indoor unit:

For signal transmission, four UV-resistant coaxial cables will be routed to the indoor unit. Again all connections are IP67 standard. A suitable cable type has already been identified which losses are lower than 10dB for a length of 30m.

5.3 First Downconversion stage

At the beginning of the project it was planned to develop the first down conversion unit by JOANNEUM RESEARCH itself. After finding out that no commercially available LNA or LNB in Q-band would fulfil the specifications without further customization (Which would significantly raise the costs of the equipment), the design team decided to completely outsource the development of the first down conversion stage to ACORDE Ltd. This resulted in higher costs for the first unit caused by NRE (non recurring engineering) for the initial development, but given the specification sent from ACORDE the price for the following units are able to compete in the market.

For the selection of ACORDE Ltd. as supplier, it was very important to the design team to find an experienced company located in Europe to allow eventually visits and meetings on site. Further the development of a solution from one hand is eventually cheaper than the customization of each subpart, as well as it is guaranteed that all subparts are harmonized to work together.
In Figure 5-2 and Figure 5-3 the preliminary designs of the two LNB - modules are depicted.

Note, that subharmonic mixers are used to reduce the complexity of the local oscillator circuits.

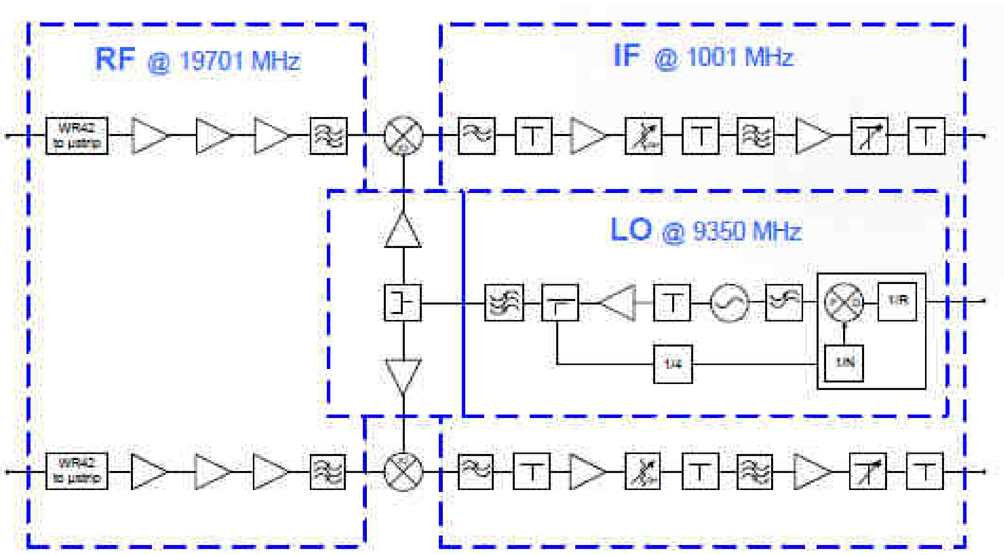

Figure 5-2 Ka-Band LNB basic block Diagram [Ref. 6]

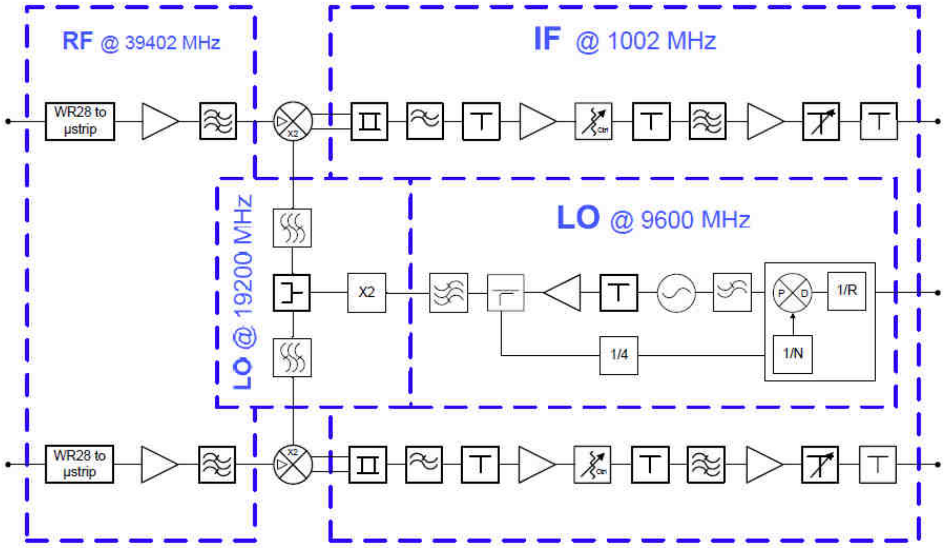

Figure 5-3 Q-Band LNB basic block Diagram [Ref. 6]

For both frequency bands, the incoming RF-signal is fed into a waveguide transition based on micro-strip technology. Then the signal is amplified and after filtering converted by a sub-harmonic mixer into the IF1 for each band. The lower sideband of the IF1 will be further amplified and sent to the output. In addition, temperature compensation is applied to avoid gain variations. This issue will be further discussed in section 5.3.1.

5.3.1 Thermal management

For attenuation measurements, it is required that the gain of the signal chain is independent of the environment temperature. Therefore, the LNB is located in a thermally stabilized housing, depicted in Figure 5-4, which stabilizes the temperature inside between +/- 10°C around a specific operational temperature which is still to be defined.

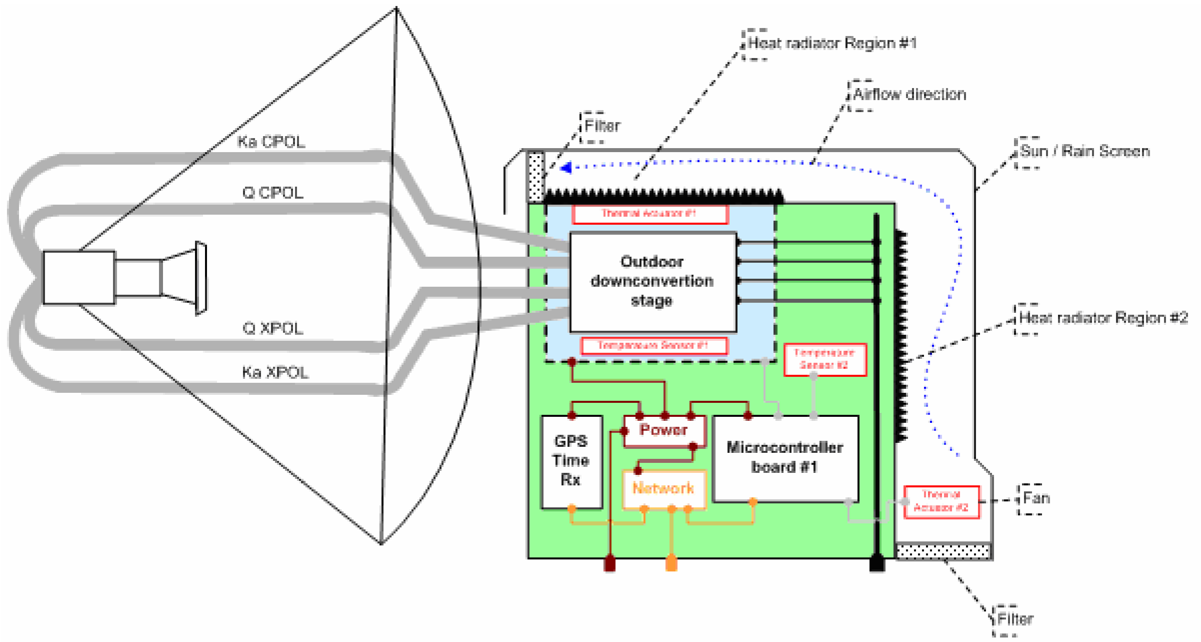

Figure 5-4 Thermal stabilization of the outdoor unit

Figure 5-5

Under these conditions the LNB operates with a gain stability of +/- 0.25 dB. This can be obtained by applying the following procedure to the conversion chain. In Figure 5-2 and Figure 5-3 we can see the preliminary design of the temperature stabilization. In general, it.is a thermally isolated housing. The outdoor unit requires heating and cooling and this can be achieved by using Peltier-elements. It is advisable to use an automatic temperature controller from the same supplier, because of the strong nonlinearity of the elements. The lifetime of these elements is limited.

For both bands the temperature compensation takes place after down conversion. The first step is to actively compensate gain variations by a microcontroller thermometer driving an analogue variable attenuator. The second attenuator is a passive one with an opposite temperature characteristic than the amplifiers. (cf. Figure 5-2 and Figure 5-3) on the previous pages.

5.3.2 RF input signal and IF frequency

In the tables below, the input frequencies as well as the interface used are listed:

Input	Type	Frequency (RF)
Ka – band co-polar	waveguide WR42	19701MHz
Ka – band cross-polar	waveguide WR42	19701MHz
Oscillator – reference – Ka	SMA	10MHz
Q – band co-polar	waveguide WR28	39402 MHz
Q – band cross-polar	waveguide WR28	39402 MHz
Oscillator – reference – Q	SMA	10 MHz

Table 5-1 Front LNB input connections

Output	Type	Frequency (IF1)
Ka – band co-polar	SMA	1001MHz
Ka – band cross-polar	SMA	1001MHz
Q – band co-polar	SMA	1002MHz
Q – band cross-polar	SMA	1002MHz

Table 5-2 Front LNB output connections

To simplify the down conversion, the IF1 of the two chains are not equal. By exploiting this possibility, the LO can be derived directly from the 10MHz reference and multiplication by factor two is sufficient. By doing this the complexity of generating a suitable LO is significantly reduced.

This variation in IF1 is allowed because in the second down conversion stage two programmable oscillators are used, which allow to independently compensate drifts or differences of $IF1_{Ka}$ and $IF1_{Q}$ in 1 kHz steps.

5.3.3 Total gain and noise characteristic

Two important figures of the LNB are the gain and the noise introduced. Preliminary information to this respect is given in Figure 5-6 and Table 5-3.

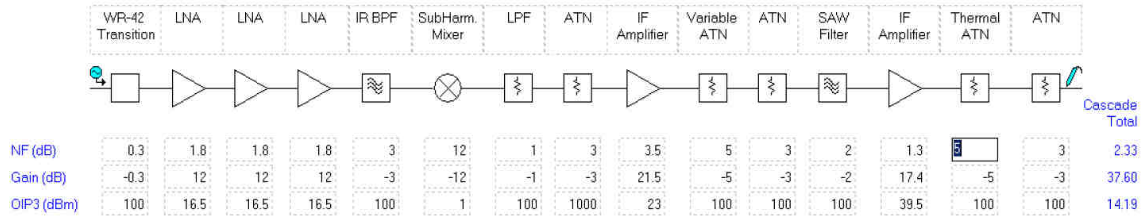

Figure 27: Preliminary Ka-band LNB design cascade calculations

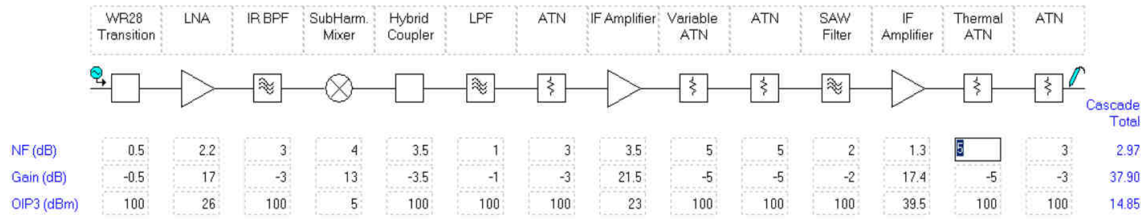

Figure 28: Preliminary Q-band LNB design cascade calculations

Figure 5-6 Preliminary chain calculations [Ref. 6]

MODULE	NF (dB)	Gain (dB)
Ka-band twin LNB chains	< 2.4	> 37
Q-band twin LNB chains	< 3	> 37

Table 5-3 LNB characteristics [Ref. 6]

The maximum gain that could be achieved is 60dB. To fix the noise figure a high gain is advisable even if the noise figure increases. For a detailed analysis of the link budget please refer to section 7.

5.3.4 Mechanical design of LNB

The LNB will be housed in an industrial standard case that is robust and can be mounted to a metal frame

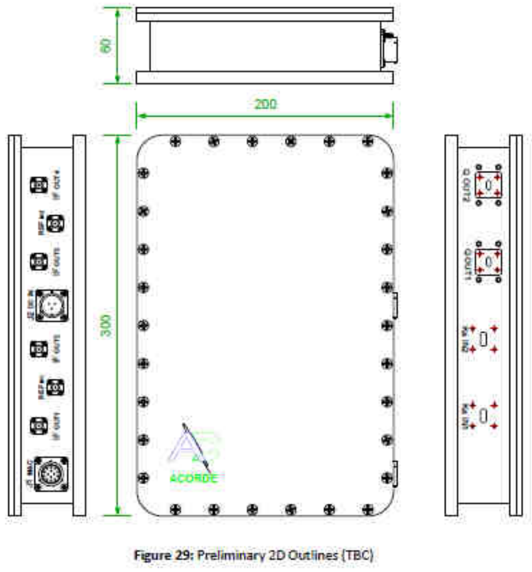

Figure 5-7 Preliminary mechanical design of LNB [Ref. 6]

5.4 GPS Receiver outdoor

For synchronous down conversion in both mixer stages a common reference is used. In this design a frequency of 10 MHz is chosen, because of the common availability. At the first place a single GPS receiver providing the reference signal has been taken into account, but at a later point the design team decided to use separate devices for indoor and outdoor devices to avoid possible phase variations by the coaxial cable that would be required to transmit the reference signal to the outdoor unit.

Therefore, a compact receiver with integrated sinus module is chosen. This device is rail mountable and compact. It is located in the housing of the outdoor unit so no real outdoor capability is required. As depicted in Figure 5-1 the device is powered by a 24 V power supply.

Figure 5-8 GPS 161 DHSx/HQ

The device is equipped with a serial port where a Windows PC could be connected using the included software “GPSMon32”. With this software, it is possible to define the communication parameters and most important the data telegram sent from the GPS receiver.

For this project, “NMEA” was chosen, because it delivers the position of the antenna and is the standard protocol for GPS applications.

5.4.1 Reference sine signal of 10 MHz

The GPS module includes an integrated sine generator. A detailed block diagram is depicted in Figure 5-9.

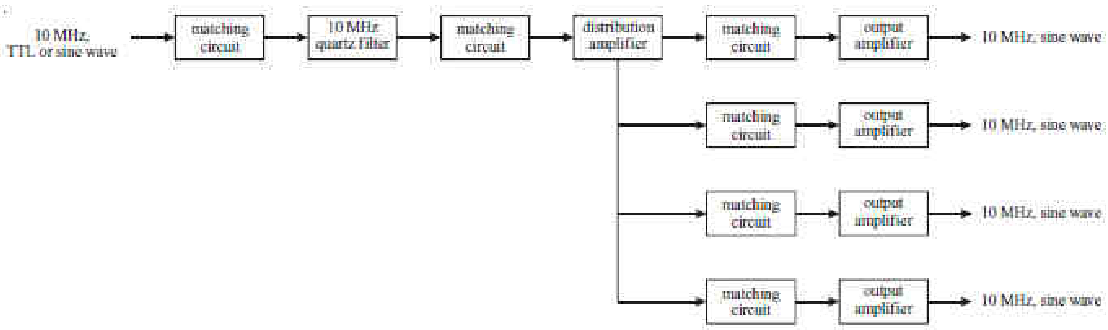

Figure 5-9 Sine wave former SD04 Block diagram [Ref. 8]

Meinberg offers several quality standards for oscillators. The selected quality option for the Terminal is “OCXO-HQ”. The theoretical characteristics are depicted in Table 5-4 O.

	TCXO	OCXO LQ	OCXO MQ	OCXO HQ	OCXO DHQ	Rubidium (only available for 3U models)
short term stability (τ = 1 sec)	$2 \cdot 10^{-9}$	$1 \cdot 10^{-9}$	$2 \cdot 10^{-10}$	$5 \cdot 10^{-12}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-11}$
accuracy of PPS (pulse per sec)	< ±250 nsec	< ±250 nsec	< ±100 nsec	< ±100 nsec	< ±100 nsec	< ±100 nsec
phase noise	1Hz -60dBc/Hz 10Hz -90dBc/Hz 100Hz -120dBc/Hz 1kHz -130dBc/Hz	1Hz -60dBc/Hz 10Hz -90dBc/Hz 100Hz -120dBc/Hz 1kHz -130dBc/Hz	1Hz -75dBc/Hz 10Hz -110dBc/Hz 100Hz -130dBc/Hz 1kHz -140dBc/Hz	1Hz < -85dBc/Hz 10Hz < -115dBc/Hz 100Hz < -130dBc/Hz 1kHz < -140dBc/Hz	1Hz < -80dBc/Hz 10Hz < -110dBc/Hz 100Hz < -125dBc/Hz 1kHz < -135dBc/Hz	1Hz -75dBc/Hz 10Hz -89dBc/Hz 100Hz -128dBc/Hz 1kHz -140dBc/Hz
accuracy free run, one day	$\pm 1 \cdot 10^{-7}$ ±1Hz (Note1)	$\pm 2 \cdot 10^{-8}$ ±0.2Hz (Note1)	$\pm 1.5 \cdot 10^{-9}$ ±15mHz (Note1)	$\pm 5 \cdot 10^{-10}$ ±5mHz (Note1)	$\pm 1 \cdot 10^{-10}$ ±1mHz (Note1)	$\pm 2 \cdot 10^{-11}$ ±0.2mHz (Note1)
accuracy free run, one year	$\pm 1 \cdot 10^{-6}$ ±10Hz (Note1)	$\pm 4 \cdot 10^{-7}$ ±4Hz (Note1)	$\pm 1 \cdot 10^{-7}$ ±1Hz (Note1)	$\pm 5 \cdot 10^{-8}$ ±0.5Hz (Note1)	$\pm 1 \cdot 10^{-8}$ ±0.1Hz (Note1)	$\pm 5 \cdot 10^{-10}$ ±5mHz (Note1)
accuracy GPS-synchronous, averaged 24h	$\pm 1 \cdot 10^{-11}$	$\pm 1 \cdot 10^{-11}$	$\pm 5 \cdot 10^{-12}$	$\pm 1 \cdot 10^{-12}$	$\pm 1 \cdot 10^{-12}$	$\pm 1 \cdot 10^{-12}$
accuracy of time free run, one day	± 4.3 msec	± 865 µs	± 65 µs	± 22 µs	± 4.5 µs	± 1.1 µs
accuracy of time free run, one year	± 16 s	± 6.3 s	± 1.6 s	± 788 ms	± 158 ms	± 8 ms
temperature dependant drift free run	$\pm 1 \cdot 10^{-6}$ (-20...70°C)	$\pm 2 \cdot 10^{-7}$ (0...60°C)	$\pm 5 \cdot 10^{-8}$ (-20...70°C)	$\pm 1 \cdot 10^{-8}$ (5...70°C)	$\pm 2 \cdot 10^{-10}$ (5...70°C)	$\pm 6 \cdot 10^{-10}$ (-25...70°C)

Note 1:
The accuracy in Hertz is based on the standard frequency of 10 MHz. For example: Accuracy of TCXO (free run one day) is $\pm 1 \cdot 10^{-7} \cdot$ 10MHz = ± 1 HZ

Table 5-4 Oscillator data of the GPS from HP [Ref. 8]

The following specifications have been provided from ACORDE, so that the LNB can fulfil the receiver requirements (Cf. section 2.1.4 on page 19)

Distance from carrier	Attenuation
100 Hz	-135 dBc/Hz
1 KHz	-145 dBc/Hz
10 KHz	-155 dBc/Hz

Table 5-5 Phase noise requirements for the LNB specified by ACORDE [Ref. 6]

In Figure 5-10 the measured phase noise provided by Meinberg is depicted. We can see that the specifications above are not totally met but the Alphasat beacon carries no information so the risk of masking any signal is practically not existent. Masking means that the spurious of the oscillator is already larger than a signal at this frequency.

A discussion with ACORDE Ltd. project members resulted in the conclusion that the reference is sufficient.

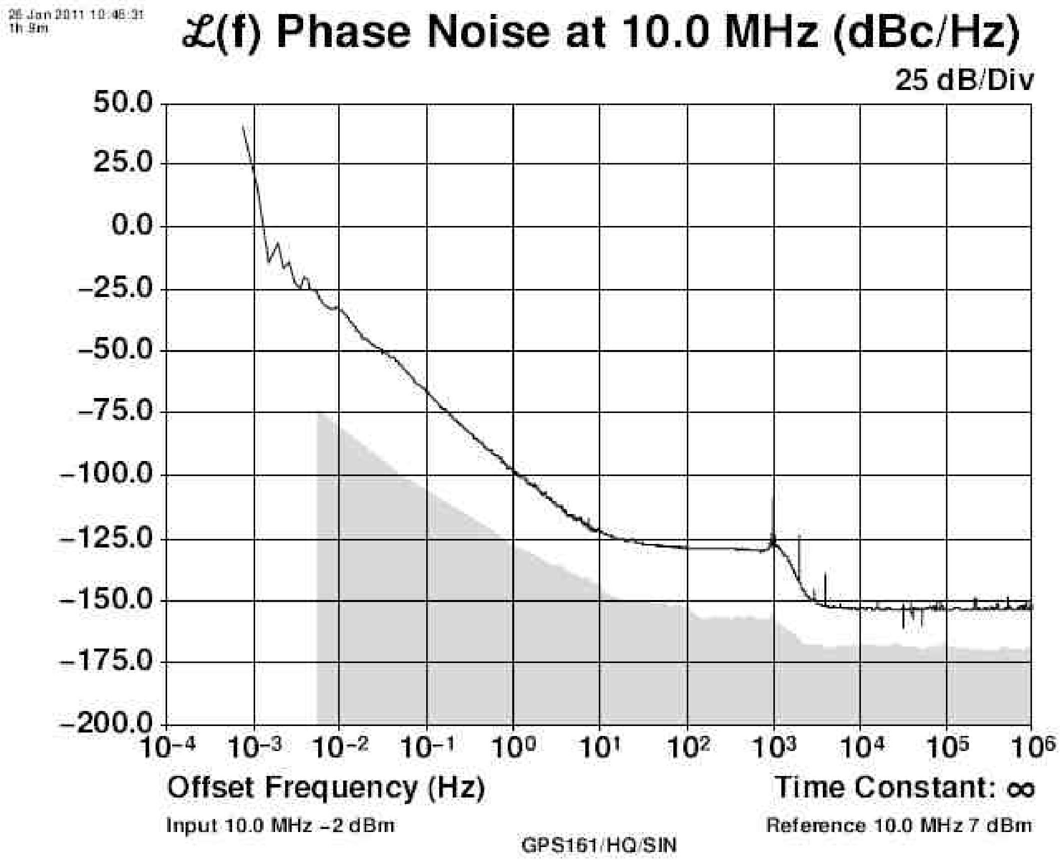

Figure 5-10 measured phase noise of Sinus module in GPS 161 [Ref. 7]

5.5 Microcontroller board

In the outdoor unit, at least one AVR Net IO micro controller board based on the ATMEGA 32 CPU will be installed [Ref. 12.]. This board will be used to monitor voltages and temperatures within the unit and provide alarms and warnings if necessary. In addition it controls the GPS receiver via serial interface to obtain the position of the antenna and eventually allow remote configuration. This is still under discussion because the receiver does not have a serial ASCII protocol, but a binary one.

For the outdoor unit is still under design, no further details can be provided at this stage of design. For a general functionality analysis, please refer to the indoor unit chapter 6.1.8

5.6 Ethernet bus

The communication to the indoor unit is fully based on an Ethernet link. Therefore an industrial hub will be installed to which all devices shall be connected. In case there is no LAN interface available in any of the components, a converter will be installed. The devices connected will be:

- The micro controller board
- The LNB
- Any other optional device like a pointing system, a radiometer or a meteorological station

All information sent to the LAN network will be recorded in the local control PC located in the indoor unit, and stored in the common database. Also all devices connected to the LAN interface will be accessible from the control program.

5.7 Mechanical design

The mechanical frame of the outdoor unit was still under design, at the time of writing. Therefore only a few characteristics can be discussed at this early stage. The unit should be light weight and therefore housed in a frame of aluminium profiles. The size of the LNB is already known and it will be the heaviest part too.

On one hand enough space must be available to allow proper ventilation, but on the other hand the size should be compact, because the unit shall be mounted to the back of the reflector of the antenna. The antenna and outdoor unit shall be balanced to ease positioning in case this option is installed.

6 Indoor unit

The indoor unit of the terminal as depicted in Figure 6-1 is responsible for the control of the Terminal as well as the housing of the data storage for the collected data. It is housed in an industrial 19” rack that allows robust mounting of all necessary devices.

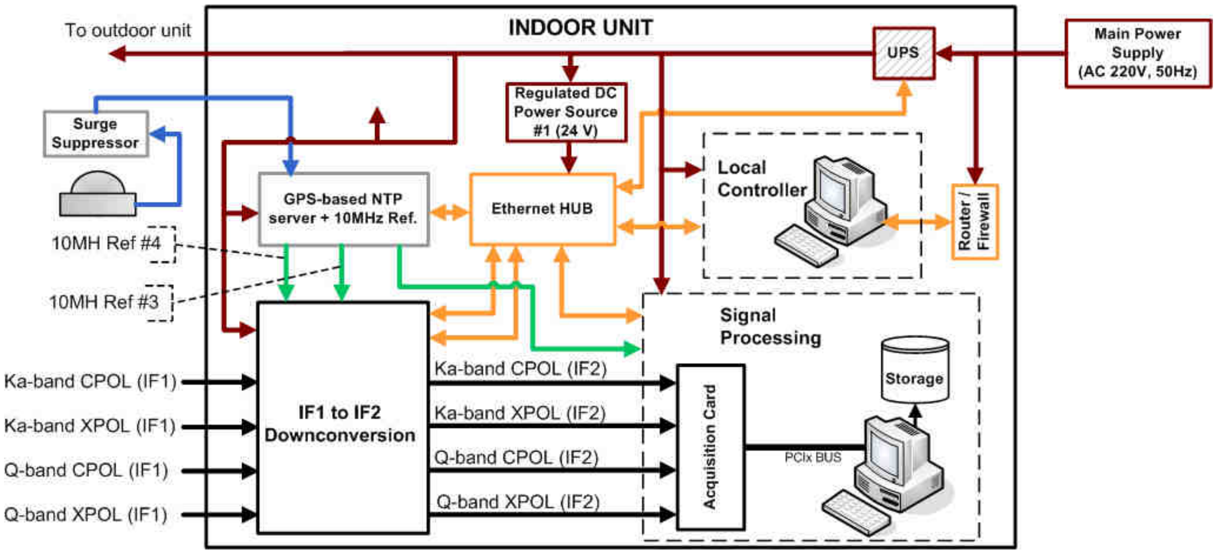

Figure 6-1 Indoor unit components

The signal arrives at the indoor unit already down converted to IF1 with very low power, due to the attenuation of the transmission cable and restrictions for pre-amplification in the outdoor unit LNB, but this issue will be further discussed in section 7 during the link budget analysis.
Another down conversion unit is installed to convert the IF1 to IF2, which is more suitable for the signal acquisition card. Again a GPS slaved reference oscillator is providing the 10 MHz signal for the down conversion. This GPS receiver also provides a NTP signal where the common time stamp of the system will be provided to the LAN-network.

A local control computer is installed, which is in charge of the control and monitoring of the Terminal.
The central communication point is the industrial standard Ethernet interface located in the rack. The Ethernet hub is powered from a 24 V standard power supply (15 W) and mounted on a DIN rail at the back of the 19” rack unit.

The power to the indoor unit is supplied from 220V/50 Hz mains.

6.1 Second Down conversion stage

The IF1 of approximately 1GHz cannot be directly fed into the signal processing unit. The acquisition card can be configured for a sampling rate of 160 MSPS or 180 MSPS. This allows according to the law of Shannon a maximum input frequency of less than 80 MHz or 90 MHz. In practice the IF2 has to be much lower to achieve a qualitatively good signal.

A market survey showed that in the frequency range of around 1 GHz a lot of devices are commercially available, because this band is already commercially used in GPS applications. Besides, a band pass-filter was chosen with a centre frequency of 10.7 MHz.
By selecting this specific filter, the IF2 is now fixed to 10.7 MHz too. An overview of the design of the conversion stage is depicted in Figure 6-2 on the next page.

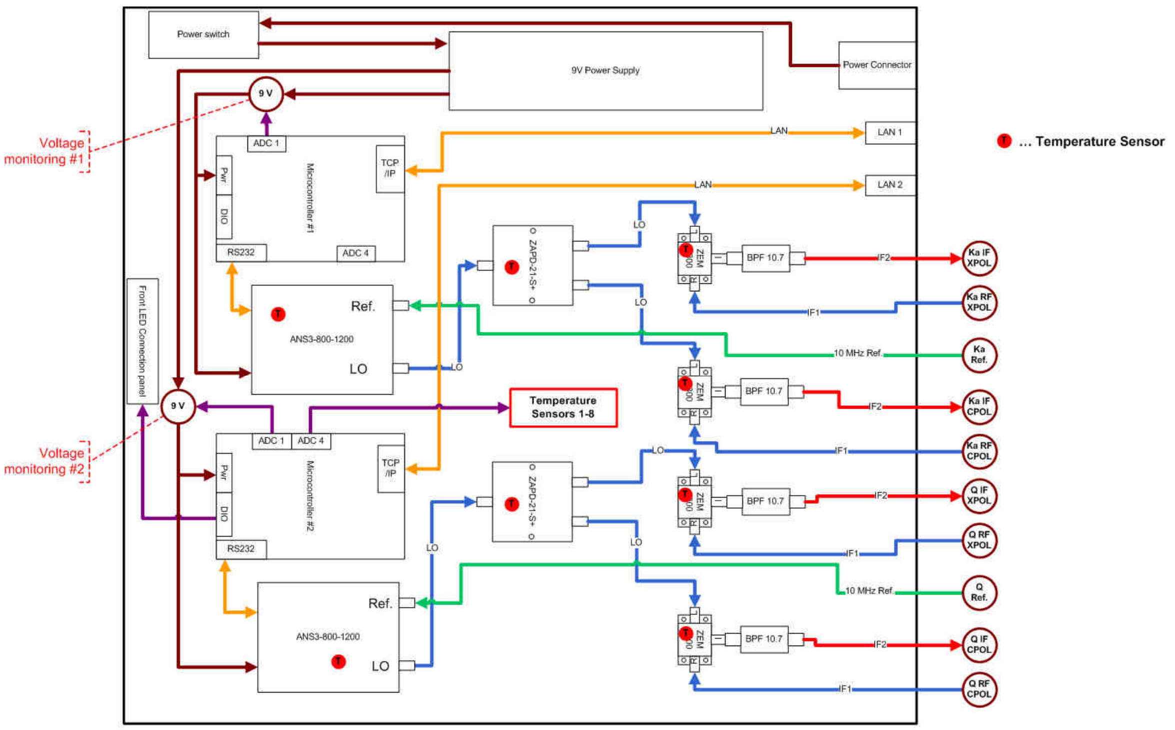

Figure 6-2 Simplified schematic of second down conversion stage

In Figure 6-2, all relevant signal paths are depicted. The legend below shows the meaning of each coloured line.

- … RF and LO signals
- … 10 MHz Reference signal
- … Power lines
- … Communication lines (LAN or serial)
- … Control and monitoring lines from µC

6.1.1 Description

The backside of the conversion unit is located on the right of Figure 6-2. A total number of ten SMA connectors is installed at this side for input and output purposes.

- 2 inputs for Q- and Ka-band Reference signal provided by GPS slaved oscillator
- 2 inputs for Q-band XPOL & CPOL at IF1
- 2 inputs for Ka-band XPOL & CPOL at IF1
- 2 outputs for Q-band XPOL & CPOL at IF2
- 2 outputs for Ka-band XPOL & CPOL at IF2

6.1.2 RF Design

Each of the four lines are identical except for the fact that the LO frequency may differ because of the different IF1 for Q- and Ka- band. Therfore, only one line will be described here as an example. In Figure 6-3, the electrical schematic of the down conversion is depicted.

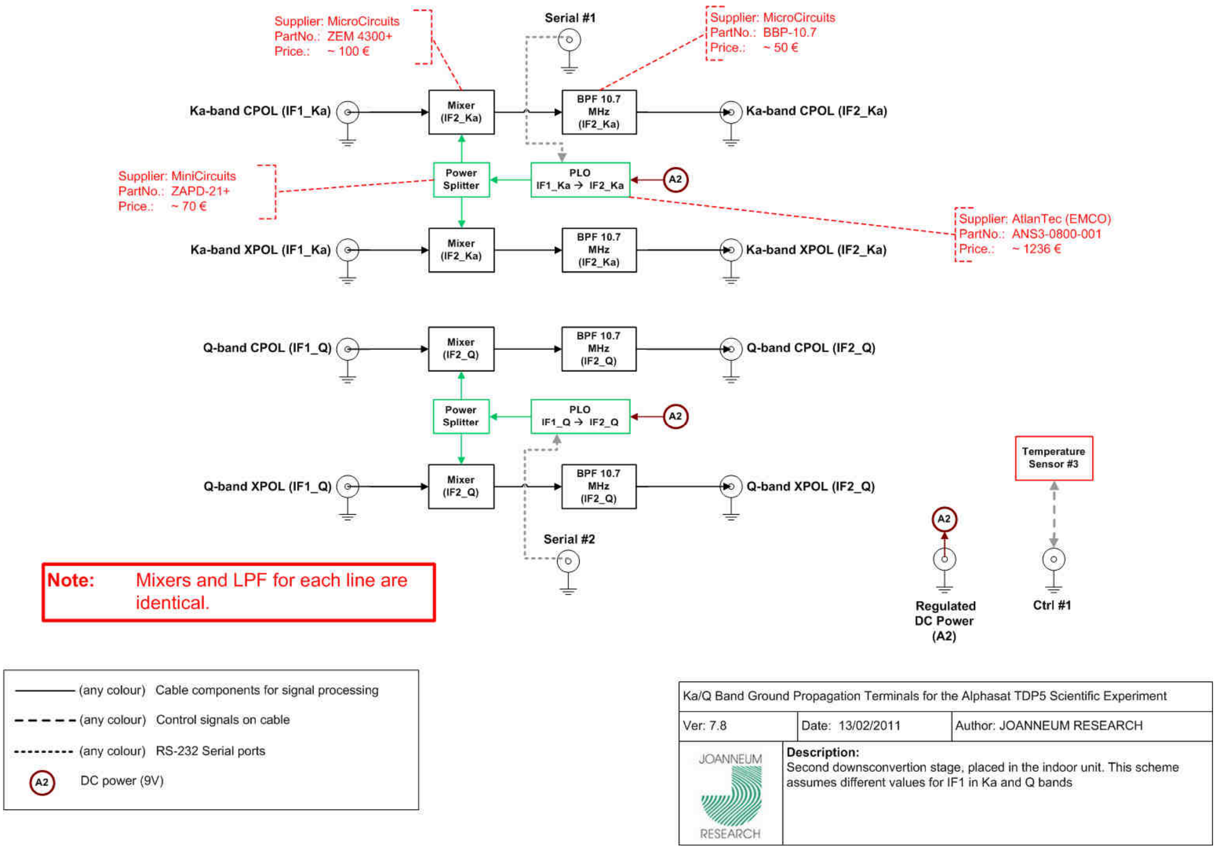

Figure 6-3 RF design of 2nd down conversion stage

To allow maximum flexibility, a programmable PLO was chosen to counteract any unexpected frequency drift of the beacon or if the IF 1 is not exactly 1 GHz. For independent treatment of Q- and Ka-band, two oscillators are foreseen. In fact it turned out that the first down conversion unit provides two different IF's at 1001 MHz for Ka-Band and 1002 MHz for Q-band. The devices used are listed in Figure 6-4 on the next page

Device	Supplier
Mixer ZEM 4300 +	Mini Circuits
Filter SBP10.7 +	Mini Circuits
Power divider ZAPD 21 +	Mini Circuits
Programmable PLO ANS3 - 800 - 1200	ATlantecRF

Figure 6-4 Device list of second down conversion unit

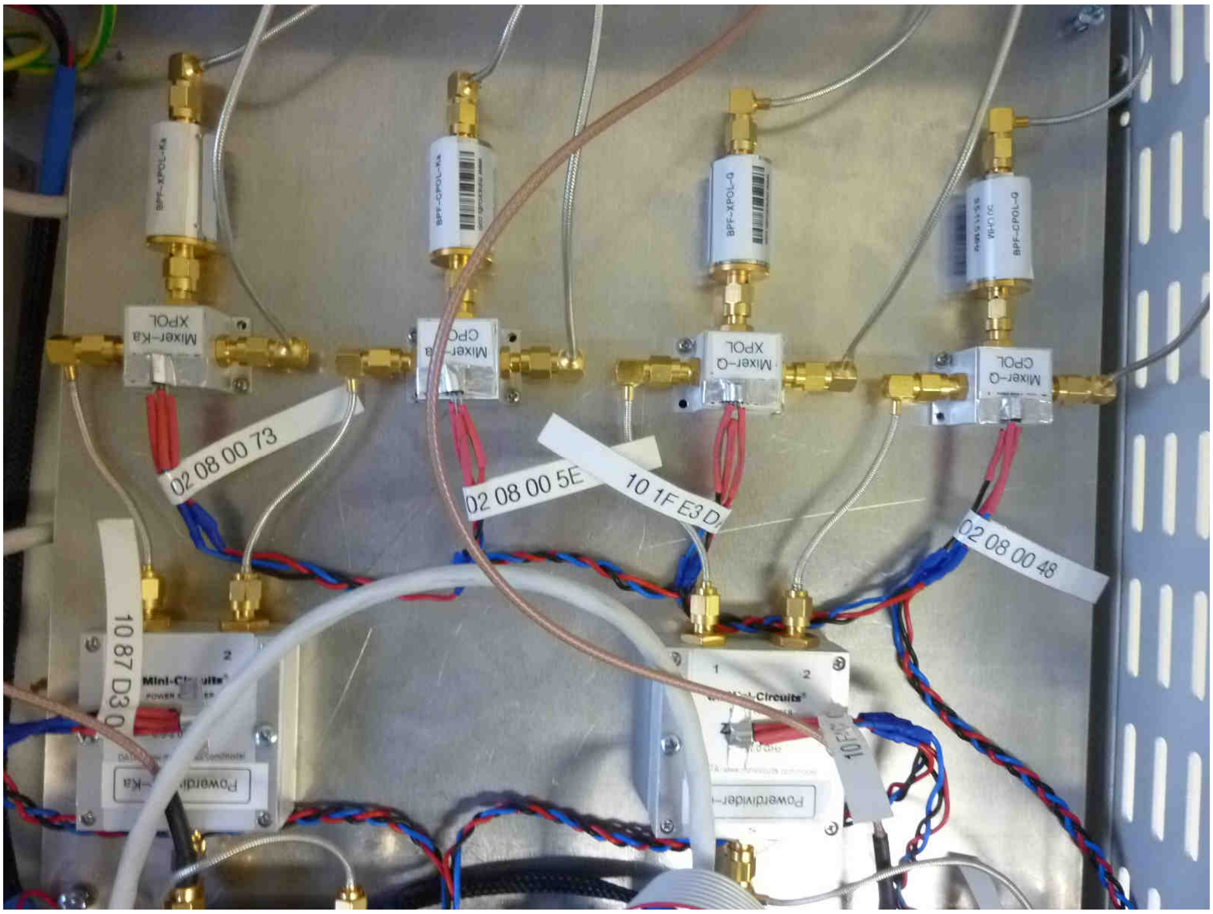

Figure 6-5 Mixers, power divider, pass band filter and attached temp. sensors

6.1.3 Mixing the signal

The down conversion is a totally passive procedure. In Figure 6-7 the scheme of the electrical circuits is depicted. Basically two signals are multiplied by using the logarithmic dependency of the diode current from the voltage. One can see that no additional power is required, except the reference signal and the signal to be converted.

Therefore it expects that sufficient signal power is available. Note that the signal power is limited by the compression point P@1dB to maintain a linear function of the mixer.

Due to the fact that this converter is totally passive and no amplifiers are installed, the compression point needs to be observed only for the mixer.

The compression point is defined as the input power level where the output power is 1 dB lower than linearly expected.

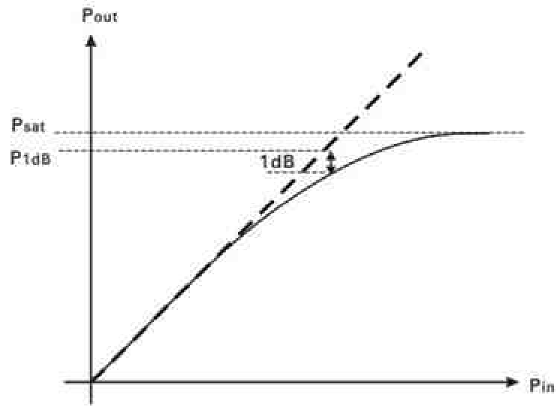

Figure 6-6 Definition of compression point

In Figure 6-7 the specifications of the mixer in use are depicted. The theoretical compression point is +1 dBm, but to obtain a linear behaviour the input signal needs to be significantly lower.

Electrical Specifications

FREQUENCY (MHz)		CONVERSION LOSS (dB)			LO-RF ISOLATION (dB)				LO-IF ISOLATION (dB)			
LO/RF	IF	Mid-Band		Total Range	L		U		L		U	
f_L-f_U		$\overline{X}$	σ	Max.	Typ.	Min.	Typ.	Min.	Typ.	Min.	Typ.	Min.
300-4300	DC-1000	6.65	0.06	9.5	40	20	30	17	15	8	15	8

1 dB COMP.: +1 dBm typ. L = low range [f_L to 10 f_L] U = upper range [10 f_L to f_U]

Electrical Schematic

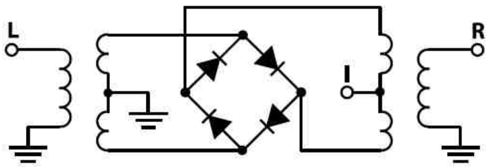

Figure 6-7 Mixer Minicircuits ZEM 4300+ Specifications [Ref. 10]

In Figure 6-8 on the next page the measured conversion loss is depicted.

Typical Performance Data

Frequency (MHz) RF	Frequency (MHz) LO	Conversion Loss (dB) LO +7dBm	Isolation L-R (dB) LO +7dBm	Isolation L-I (dB) LO +7dBm	VSWR RF Port (:1) LO +7dBm	VSWR LO Port (:1) LO +7dBm
300.00	400.00	7.36	51.34	31.66	5.75	4.40
414.29	514.29	6.29	64.83	33.69	3.35	2.89
528.57	428.57	5.08	49.72	36.96	2.55	2.65
757.14	657.14	4.96	41.17	38.13	1.71	2.19
1000.00	900.00	5.45	37.81	30.37	2.55	2.08
1214.29	1114.29	6.11	36.73	26.04	3.13	1.99
1442.86	1342.86	6.61	35.66	22.90	3.50	1.85
1671.43	1571.43	6.86	34.88	19.27	4.13	1.68
1900.00	1800.00	7.03	33.74	17.66	4.48	1.61
2000.00	1900.00	7.13	33.54	17.52	5.06	1.57
2128.57	2028.67	7.43	33.70	17.76	5.38	1.47
2471.43	2371.43	8.04	33.24	18.85	5.56	1.41
2700.00	2000.00	8.34	33.45	19.52	5.51	1.37
2814.29	2714.29	8.52	34.07	19.86	5.27	1.36
3000.00	2900.00	8.85	33.99	19.95	5.77	1.58
3157.14	3057.14	9.03	33.55	19.48	6.97	1.60
3500.00	3400.00	9.22	32.04	18.72	8.72	2.03
3728.57	3628.57	9.04	30.42	18.47	8.23	2.39
4000.00	3900.00	8.91	29.46	20.82	7.47	2.43
4300.00	4200.00	8.41	33.24	24.62	6.26	2.13

Table 6-1 Minicircuits Mixer ZEM 4300+ Performance data [Ref. 10]

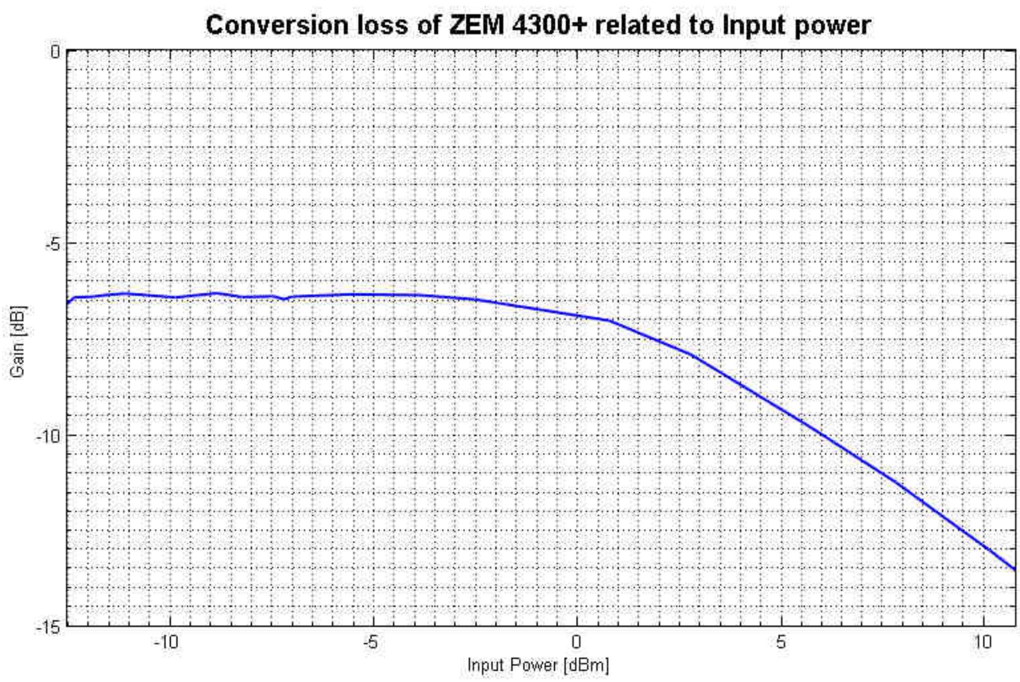

Figure 6-8 Measured conversion loss and compression point P@1dB

The measurement results depicted in Figure 6-8 in show that the typical performance of the mixer specified by the supplier is met (cf. Table 6-1 on page 46). The device is linear up to around - 2 dBm. The conversion loss is slightly higher than specified, but this is caused by additional losses from cabling and connections.

Mathematical background of signal mixing:

In a mixer basically two signals are multiplied

Signal 1 (RF): $A_1 \cos(\omega_1 t)$ **Equ. 2**

Signal 2 (LO): $A_2 \cos(\omega_2 t)$ **Equ. 3**

The signals above are multiplied as depicted in Equ. 1:

Output (IF): $A_1 \cos(\omega_1 t) A_2 \cos(\omega_2 t)$ **Equ. 4**

By applying the cosine theorem we can derive:

Output (IF): $\frac{A_1 A_2}{2}\left\{\cos\left[(\omega_1+\omega_2)t\right]+\cos\left[(\omega_1-\omega_2)t\right]\right\}$ **Equ. 5**

Equ. 5 shows that a mixer does not produce only one frequency, but an upper and lower side-band as depicted for example in Figure 6-9. For a down converter the lower frequency is the desired one and the upper one needs to be removed by filtering.

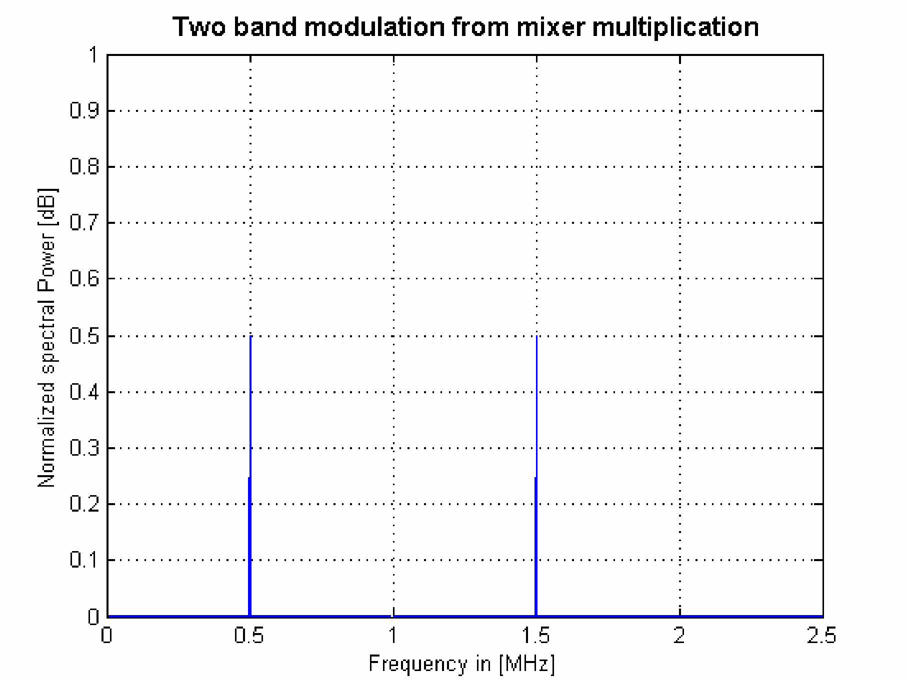

Figure 6-9 Spectral result for mixing of f1=1MHz and f2=0.5 MHz

As depicted in Figure 6-9 above, two frequencies will appear after mixing two signals. For the down converter we have the following input frequencies, already discussed in section 5.3.2 on page 33.

- For Q – band the IF 1 will be 1002 MHz
- For Ka – band the IF1 will be 1001 MHz

The oscillator used to provide the modulation frequency was chosen programmable and therefore the converter is very flexible in this case. To provide a IF2 at 10.7 MHz the following LO frequencies have to be programmed.

- For Q – band the LO will be 991.3 MHz
- For Ka – band the LO will be 990.3 MHz

Applying these LO frequencies all four input signals shall be converted to 10.7 MHz under normal operating conditions. This frequency has been chosen because it is commonly used and therefore filters are available at low prices.

6.1.4 Filtering:

In Figure 6-11 the specification of the selected filter is depicted. For the selection of the filter several considerations have been taken into account. Although the received signal is a single beacon carrying no information an therefore the bandwidth is almost zero it is necessary to provide sufficient bandwidth to cover e.g. the Doppler shift or a possible drift of the beacon from aging components in the space segment. Also the IF chosen must not be a multiple of 10 because the reference frequency in the Terminal is 10 MHz and it is unavoidable that this 10 MHz appear even after filtering and this could lead to a false tracking of the beacon.

Figure 6-10 Mini circuits SBP – 10.1+ + [Ref. 11]

Doppler shift:

$$\frac{f_0}{f_s} = \frac{c}{c + v_s} \qquad \textbf{Equ. 6}$$

$\frac{f_0}{f_s}$ … frequency factor

v_s … speed of the signal source

c … speed of light

The Doppler shift will only account for a few kHz so the bandwidth of the filter is far enough to cover this physical effect. Also the frequency drift of the space segment is easily covered by this filter.

.

CENTER FREQ. (MHz)	PASSBAND (MHz) I.L. 1.5 dB Max.	3dB BANDWIDTH (MHz) Typ.	STOPBANDS (I. loss > 20 dB) at MHz	STOPBANDS (I. loss > 35 dB) at MHz	VSWR (:1) Passband Max.	VSWR (:1) Stopband Typ.
10.7	9.5-11.5	8.9-12.7	7.5 & 15	0.6 & 50-1000	1.7	16

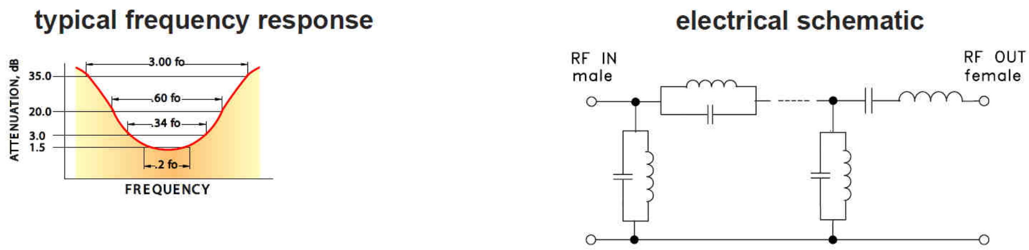

Figure 6-11 Minicircuits SBP – 10.7 + specifications [Ref. 11]

Another important consideration is to keep the bandwidth as small as possible to avoid too much noise transferred to the signal processing. Table 6-2, the performance data is depicted. It shows that the insertion loss is very low at the centre frequency and stays constant within the pass band, which further eases tracking of the beacon, although the signal processing unit applies a calibration over the observed band. The observed band is, of course, the band fixed by the filter, which is wide enough to accommodate the beacon affected with the expected Doppler effect shift

Typical Performance Data

Frequency (MHz)	Insertion Loss (dB) $\bar{x}$	Insertion Loss (dB) σ	Return Loss (dB)	Frequency (MHz)	Group Delay (nsec)
0.3	75.80	2.6	0.1	0.7	32.371
0.4	76.10	4.5	0.1	3.0	12.114
0.4	74.62	4.4	0.1	5.2	24.403
0.5	69.06	2.7	0.1	7.5	215.923
0.5	69.33	1.0	0.1	7.9	159.468
0.6	67.91	1.5	0.1	8.0	91.912
1.0	57.74	0.3	0.1	8.5	212.732
5.3	25.94	0.6	0.2	8.9	237.192
7.5	30.37	2.8	0.8	9.1	235.123
7.6	26.43	4.9	0.9	9.4	213.803
8.2	7.00	1.5	3.3	9.6	197.449
8.5	3.15	0.8	7.6	9.8	180.177
8.9	2.45	0.7	9.6	10.2	153.153
9.5	0.99	0.1	16.3	10.4	145.221
9.6	0.97	0.1	16.4	10.6	140.803
10.7	0.86	0.1	17.6	10.9	138.559
11.5	0.92	0.1	18.2	11.3	141.337
12.7	3.16	0.8	7.0	11.5	145.896
13.1	3.82	1.0	5.7	12.5	165.780
13.7	10.81	2.5	1.6	12.8	163.590
14.4	22.10	4.6	0.7	13.3	145.784
15.0	33.97	4.4	0.4	13.6	127.403
20.0	26.84	0.5	0.1	14.1	36.953
40.0	41.22	0.5	0.1	15.0	85.658
50.0	46.00	0.7	0.1	16.0	118.360
100.0	62.57	1.7	0.1	27.1	4.513
325.0	66.25	3.8	0.1	39.0	2.558
550.0	51.22	1.1	0.1	48.7	2.259
775.0	43.48	1.5	0.4	49.7	2.045
1000.0	41.66	1.9	0.4	50.7	2.283

Table 6-2 Minicircuits SBP – 10.7 + Performance data [Ref. 11]

6.1.5 Generation of the local oscillator frequency

As already discussed, the mixer requires a local frequency to shift the signal either to a higher or lower band.
For the Terminal the reference frequency is defined with 10 MHz. So the oscillator should be able to work with this frequency. As 10 MHz is very common, this was not a critical parameter.

Figure 6-12 ANS3 800 – 001 oscillator [Ref. 15]

More important characteristics taken into account for selecting a proper oscillator were:

- At the time the converter was assembled the final frequency of the IF1 provided from the outdoor unit was not defined, so the oscillator must not be fixed, but should be programmable via interface. In this case a serial RS232 interface is provides which can be accessed using a set o ASCII commands.

- The step size shall be as small as possible. A step size of 1 kHz is considered as sufficient.

- Because the Terminal is supposed to operate unattended for the life time of the TDP5 experiment the oscillator must provide an alarm in case lock is lost or if the reference frequency is lost by any reason.

- The phase noise should be lower than the expected phase noise of the received input signal in order not to mask the beacon.

- The oscillator needs to provide a frequency in the range of 1 GHz.

Model No	Freq. Range (MHz)	Freq. Steps (KHz)	Freq. Stability (ppm)	Int. Ref. Freq. (MHz)	Output Power typ. (dBm)	Harmonics (dBc)	Spurious (dBc)	Phase Noise			Current @+9V d.c. (mA) max.
								@1KHz (dBc/Hz)	@10KHz (dBc/Hz)	@100KHz (dBc/Hz)	
ANS3-0065-001	65-95	1.0	±1	5	+7	-35	-60	-67	-92.5	-115	300
ANS3-0120-001	120-160	1.0	±1	10	+7	-35	-60	-90	-96	-116	300
ANS3-0160-001	160-220	1.0	±1	10	+7	-35	-60	-90	-94	-117	300
ANS3-0220-001	220-350	1.0	±1	10	+7	-35	-60	-86	-90	-119	300
ANS3-0350-001	350-620	1.0	±1	10	+7	-35	-60	-73	-84	-108	300
ANS3-0500-001	500-800	1.0	±1	10	+7	-35	-60	-74	-80	-106.5	300
ANS3-0800-001	800-1200	1.0	±1	10	+7	-35	-60	-77	-80	-106	300
ANS3-1200-001	1200-2000	1.0	±1	10	+7	-35	-60	-73	-82	-105	300
ANS3-1750-001	1750-2500	1.0	±1	10	+7	-35	-60	-72	-82	-108	300
ANS3-2000-001	2000-3000	1.0	±1	10	+7	-35	-60	-73	-79	-101.5	300
ANS3-2400-001	2400-3400	1.0	±1	10	+7	-35	-60	-72	-78	-102	300
ANS3-3400-001	3400-3700	1.0	±1	10	+7	-35	-60	-70	-78	-109	300
ANS3-3700-001	3700-4200	1.0	±1	10	+7	-35	-60	-67	-75	-103	300
ANS3-5150-001	5150-5350	1.0	±1	10	+7	-35	-60	-67	-75	-103	300
ANS3-5470-001	5470-5875	1.0	±1	10	+7	-35	-60	-61	-71	-96	300

Table 6-3 ANS 3 Series specification [Ref. 15]

After an exhaustive market survey and from discussion with other developers the ANS3 series was from AtlanTecRF was identified as a suitable device. A table of available models is depicted in Table 6-3. Also a provider in Germany is available, which simplifies procurement compared to importing from outside the European Community.
As the frequency of the IF1 will be in the range of 1GHz the model ANS3-0800-001 was selected.

<u>Characteristics of the ANS3 – 0800 – 001:</u>

In Figure 6-14 and Figure 6-13 the oscillator is depicted showing available connections and interfaces. The label “NovaSource” is a bit confusing but actually the manual supplied from AtlanTecRF describes this device.

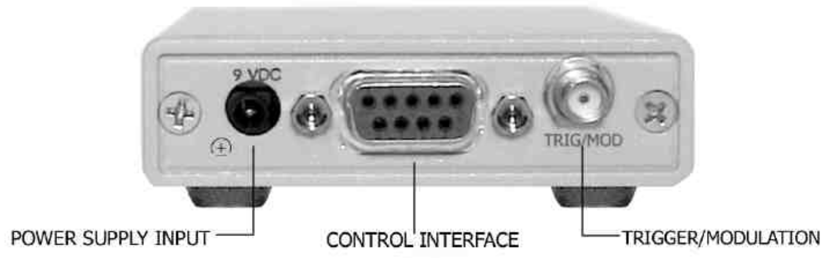

Figure 6-13 ANS3 – 800 – 001 rear panel [Ref. 14]

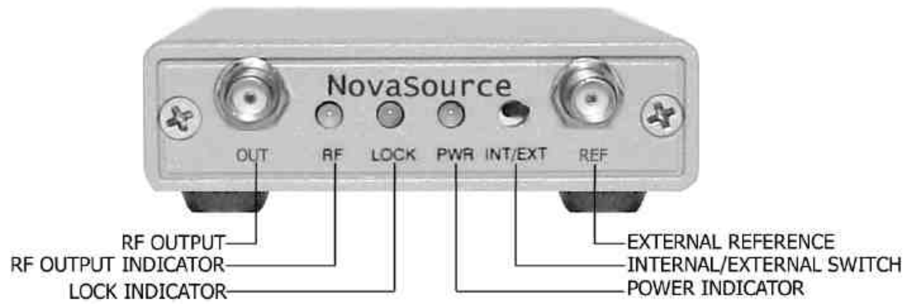

Figure 6-14 ANS3 – 800 – 001 front panel [Ref. 14]

The oscillator provides a serial interface with the following settings:

<u>Serial Parameters:</u>

- Baud Rate: 38400 bps
- Data bits: 8
- Parity: None
- Stop Bits: 1

From this interface the status of the oscillator can be acquired and additionally the status is displayed at the front panel. The device allows also the setting of attenuation.

6.1.6 Power division for local frequency

For each band a separate oscillator is foreseen. But each band has two lines, one for the co-polar signal branch and one for the cross-polar signal portion. Therefore the frequency provided by the oscillator described before needs to be divided to provide the LO-input for both mixers of each chain. The ZEM 4300 + mixer expects an LO power level of 7 dBm because all mixers refer to a certain power level in their characteristics. (cf. Figure 6-7 on page 18). Especially in terms of conversion loss, the power of the second signal is of course is important as one can see on page 47 in Equ. 5. The product of the two signal amplitudes results the amplitude of the mixed signal. The oscillator output was measured to be around 10dBm. The typical loss of the ZAPD – 21 + is depicted in Table 6-4. Based on these data, the divider was considered suitable for this purpose.

Figure 6-15 Mini circuits ZAPD - 21 + [Ref.20]

Typical Performance Data

Frequency (MHz)	Total Loss[1] (dB) S-1	Total Loss[1] (dB) S-2	Amplitude Unbalance (dB)	Isolation (dB)	Phase Unbalance (deg.)	VSWR S	VSWR 1	VSWR 2
500.00	3.17	3.14	0.03	21.12	0.45	1.31	1.16	1.17
525.00	3.18	3.15	0.03	22.44	0.48	1.27	1.13	1.14
575.00	3.12	3.10	0.02	25.62	0.50	1.18	1.07	1.08
625.00	3.14	3.12	0.02	29.70	0.53	1.10	1.02	1.03
675.00	3.14	3.11	0.03	33.67	0.60	1.03	1.04	1.02
750.00	3.08	3.05	0.03	30.96	0.61	1.08	1.11	1.09
825.00	3.22	3.19	0.03	27.43	0.73	1.17	1.17	1.15
900.00	3.18	3.15	0.03	25.73	0.77	1.24	1.21	1.19
1000.00	3.21	3.17	0.04	25.37	0.68	1.29	1.23	1.22
1200.00	3.17	3.14	0.03	30.28	0.92	1.21	1.15	1.16
1400.00	3.19	3.17	0.02	29.13	1.15	1.03	1.01	1.03
1600.00	3.23	3.19	0.04	24.08	1.27	1.16	1.10	1.08
1800.00	3.35	3.31	0.03	27.44	1.41	1.22	1.16	1.15
1900.00	3.33	3.30	0.03	35.87	1.42	1.19	1.18	1.17
2000.00	3.31	3.29	0.01	33.59	1.48	1.15	1.17	1.18

1. Total Loss = Insertion Loss + 3dB splitter loss.

Table 6-4 Mini circuits ZAPD-21 + Performance data [Ref. 11]

6.1.7 Power Supply

A standard commercial switched 9 V power supply is used with 150W maximum power. Although it is a bit over dimensioned this type was selected to provide enough power for eventual additional devices.

The power supply provides the power for:

- 2 ANS3 – 800 - 001 programmable oscillators 2,7 W each
- 2 AVR – NET – IO micro - controller 1W each

This results in a total power consumption of 8.82 W. In a second version of the Terminal this part could be replaced by a smaller and less powerful device to save space and lower the price.

6.1.8 Microcontroller AVR – NET – IO

The microcontroller board AVR -NET-IO based on the ATMega32 µC is used to control the programmable oscillator as well to monitor the temperature at 8 points within the down conversion stage. Because the board is only equipped with one single serial port, there are two boards installed to allow parallel control an monitoring of the two programmable oscillators. (E.g. lock status, change actual frequency) Besides the voltage at the PLO power input is periodically monitored. The board is connected to the local network and provides the acquired data to the control software running on the local control PC. Also the board is in charge of driving the front LED lights for displaying warning and alarm.

Figure 6-16 Microcontroller board AVR – NET – IO [Ref. 12]

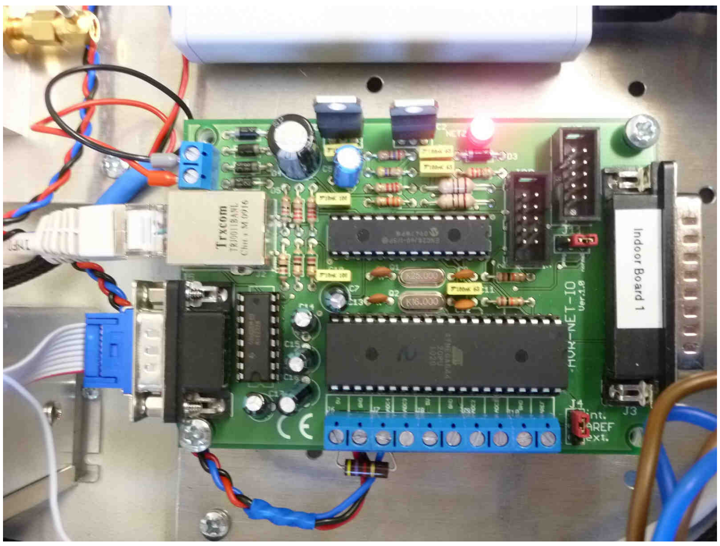

Figure 6-17 AVR Net IO in operation

6.1.9 Oscillator monitoring and control

The microcontroller board is interfaced to the oscillator with a flat cable using suitable 9 -pin sub-D connectors (male to female). The software of the board is configured as mentioned in section 6.1.5 on page 52. The board reads the oscillator status in periodic intervals or upon request from the user via web interface. In case the oscillator status is not normal an alarm will be sent to the control software running on the local control PC.

6.1.10 Temperature monitoring

Temperature is a critical factor in every electronic device. It influences the gain of amplifiers and adds noise to the signal. To detect existing hotspots in the down converter unit, eight temperature sensors of type Dallas DS1820 are installed to measure the temperature at several spots. In Figure 6-2, the positions of the temperature sensors are depicted and Figure 6-5 shows the actual installation.

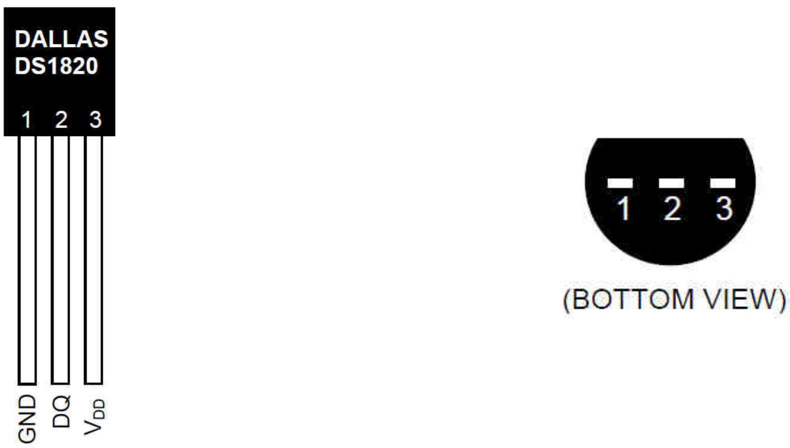

Figure 6-18 Dallas DS1820 precision thermometer TO92 housing [Ref. 13]

PIN DESCRIPTION

PIN		NAME	FUNCTION
TO-92	SO		
1	5	GND	Ground
2	4	DQ	Data Input/Output. Open-drain 1-Wire interface pin. Also provides power to the device when used in parasite power mode (see the *Powering the DS18S20* section.)
3	3	V_{DD}	Optional V_{DD}. V_{DD} must be grounded for operation in parasite power mode.
—	1, 2, 6, 7, 8	N.C.	No Connection

Table 6-5 Dallas DS1820 Pin description [Ref. 13]

A very convenient feature of this sensor is that it integrates its own micro processor which allows communication via a bus system (cf. Figure 6-19). This simplifies the cabling a lot, because there is no necessity to install sensor cables to each unit. In addition the sensor is able to derive its power directly from the data line, as depicted in Figure 6-20. The sensor is housed in a TO 92 case which allows direct contact with the flat side to the surface to be measured.

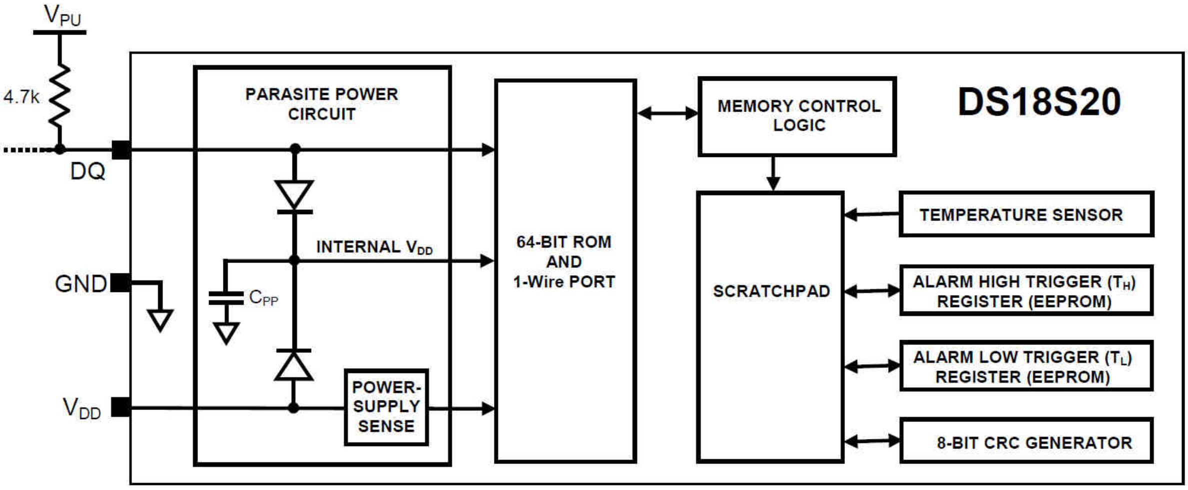

Figure 6-19 Dallas DS1820 precision thermometer block diagram [Ref. 13]

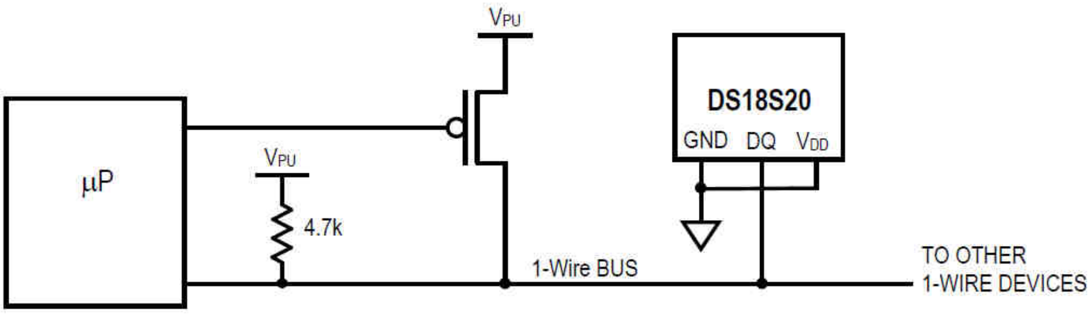

Figure 6-20 Dallas DS1820 one wire bus with parasite power [Ref. 13]

For more flexibility, the sensors are connected with three wires to alternatively use one wire bus provide external power to the sensors. During tests it was found that separate power is not required and the 1-wire system works well.

The sensors can be controlled over the bus by sending commands to the bus. Each sensor can be addressed by its unique 64-bit serial number.

6.1.11 Voltage monitoring

The micro controller board is equipped with one 4 channel ADC. One of the ADC channels is used to monitor the voltage provided from the power supply. Due to the limitation of the ADC to 5 V (full scale voltage) this cannot be achieved directly, but by installing the circuit depicted in Figure 6-21 the voltage can be divided. This allows the continuous monitoring of the voltage to detect fluctuations of the supply voltage. The measurement point is close to the PLO input power connector as depicted in Figure 6-22 to detect a cable break causing a power loss.

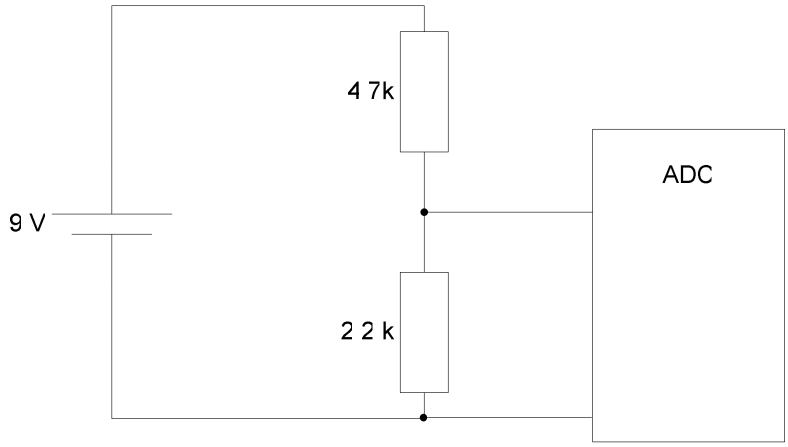

Figure 6-21 Measurement circuit for voltage monitoring

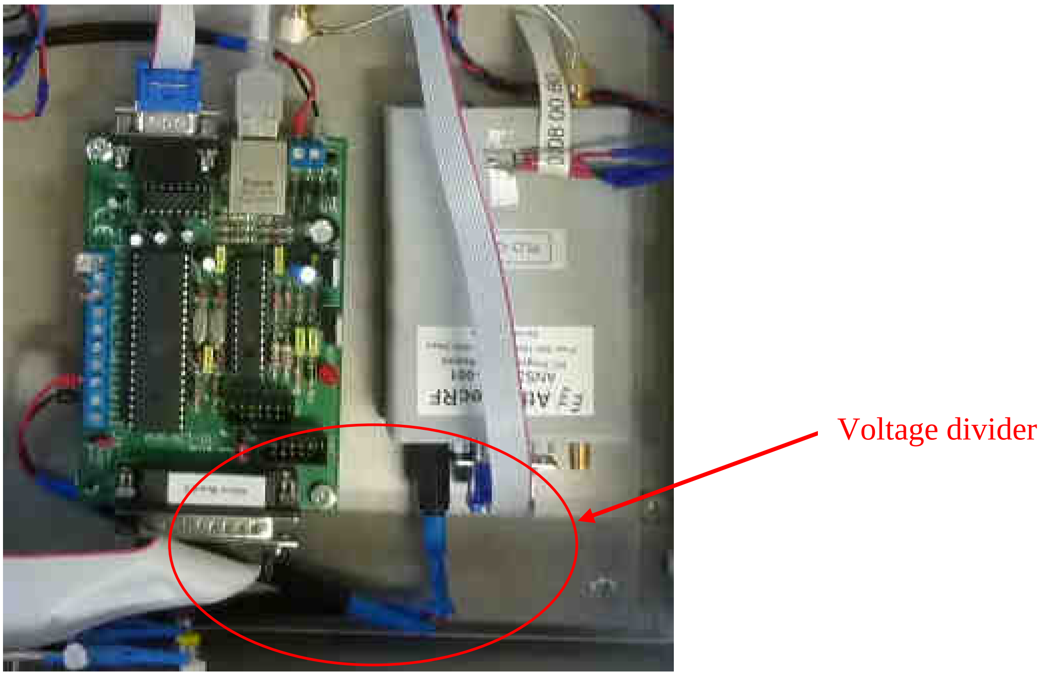

Figure 6-22 Measurement circuit for voltage monitoring

6.1.12 Communication to local control PC

Both microcontroller boards are equipped with an Ethernet interface and are connected to the hub located at the back of the Terminal. For this, two LAN couplings with RJ45 connectors are installed at the backplane of the conversion unit. Each of the microcontroller boards is connected to a RJ45 connector with a standard CAT TCP/IP patch cable. At the beginning of the design process, a switch inside the conversion unit was considered, but this would have required more space for the switch itself and additionally a second power supply would be necessary.

Both boards can be addressed through their IP address and are controlled from the local control PC. Any alarm, warning or information generated by the boards is acquired periodically.

6.2 Characteristics of down conversion

The gain characteristic of the down conversion unit is an important parameter for further development. To determine the gain characteristic of the conversion unit a RF signal is generated and fed in the RF input of the converter. The amplitude and frequency of this signal is of course known.

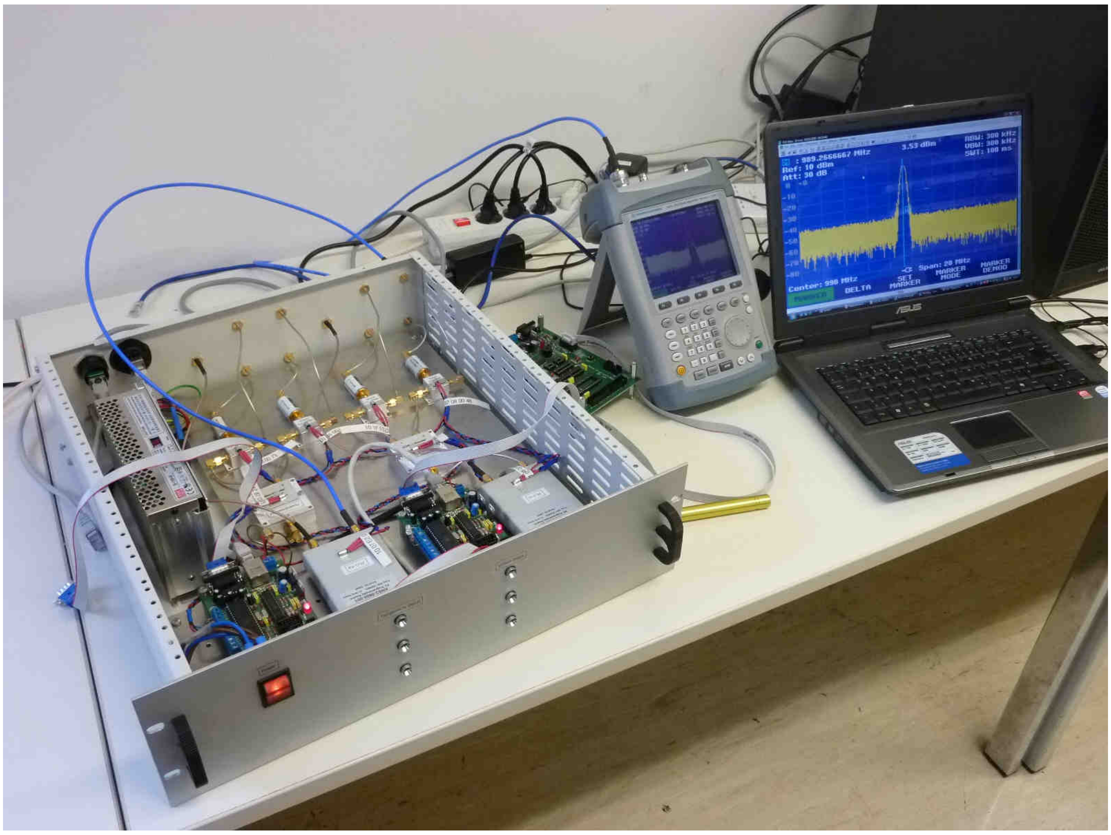

Figure 6-23 Measurement environment for gain characteristic of 2nd down conversion

The measurement environment is depicted in Figure 6-23. The measurement was such that one PLO was used to provide the RF signal as a signal generator. For simplification of the measurement the PLO was controlled over MATLAB serial interface allowing a sweep over the expected bandwidth of the converter. The measurement itself was done with a ROHDE & SCHWARZ FSH 3 spectrum analyser, also controlled by MATLAB serial interface. The data was recorded in MATLAB and stored in an Excel-file.

The procedure was to sweep the frequency of the RF in 10 kHz steps from 995 MHz to 1005 MHz resulting in an output frequency of the converter from 5.5 MHz to 15.7 MHZ.

The next pages depict the signals used for measurement. As a matter of space only the signals in standard operation mode can be shown.

Figure 6-24 and Figure 6-25 depict the beacon used as RF-input signal. The Ka-band signal was produced from the Q-band oscillator, the Q-band signal from the Ka-band signal. Therefore the beacon power is not equal.

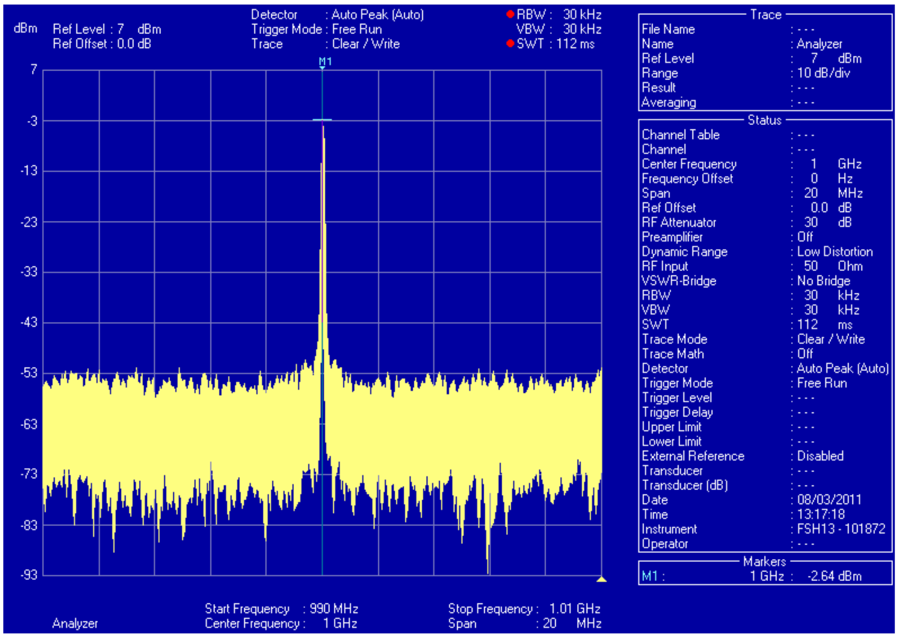

Figure 6-24 RF for Ka – band chain

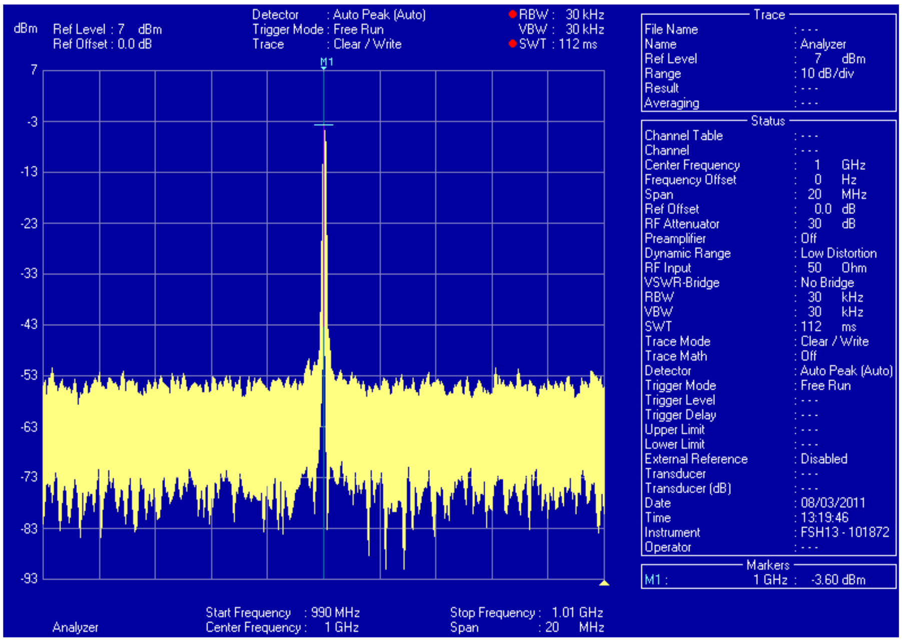

Figure 6-25 RF for Q – band chain

The input signal of the RF must not exceed -2 dBm to ensure the linearity of the mixer, which has a compression point of 1 dBm (cf. section 6.1.3 on page 45), but at this point the mixer is already nonlinear at the output. The oscillator has a maximum output of around 10 dBm but can be attenuated in 31 steps in minimum range of 25 dB. By experiment the ideal step was determined as “7” resulting in an output of around -3 dBm allowing operation of the mixer in linear conditions and having a rather high input signal, which is easier to detect and also providing more dynamic range. The LO signal for the Ka-band mixer is depicted in Figure 6-26 and for Q-band in Figure 6-27.

Of course the measurement of the LO power was performed after power division to determine the power fed into the mixer. A signal power that is lower than 7dBm results in higher conversion loss of the downconversion stage.

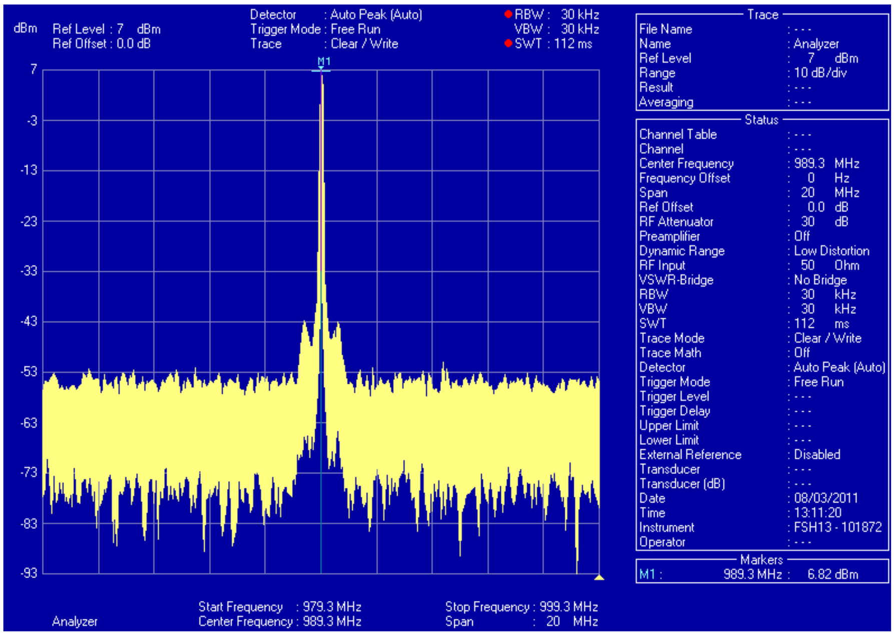

Figure 6-26 LO for Ka-band chain

For the Ka-band LO the power is around 6.82 dBm. It is indeed a little bit lower than the 7 dBm specified, but in an acceptable range as the conversion loss measured showed. The Q – band power is above 7.15 dBm and therefore even better than required.

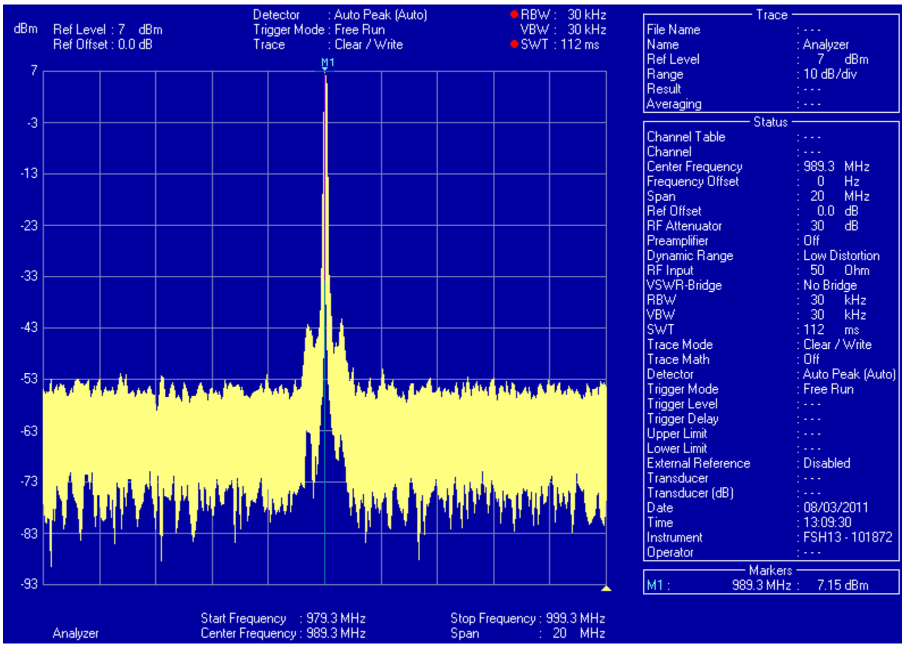

Figure 6-27 LO for Q-band chain

For the complete measurement, the RF power, injected to the converter, (995 MHz to 1005 MHz) was recorded for the observed band, to determine the stability of the LO output power. (Cf. Figure 6-28)

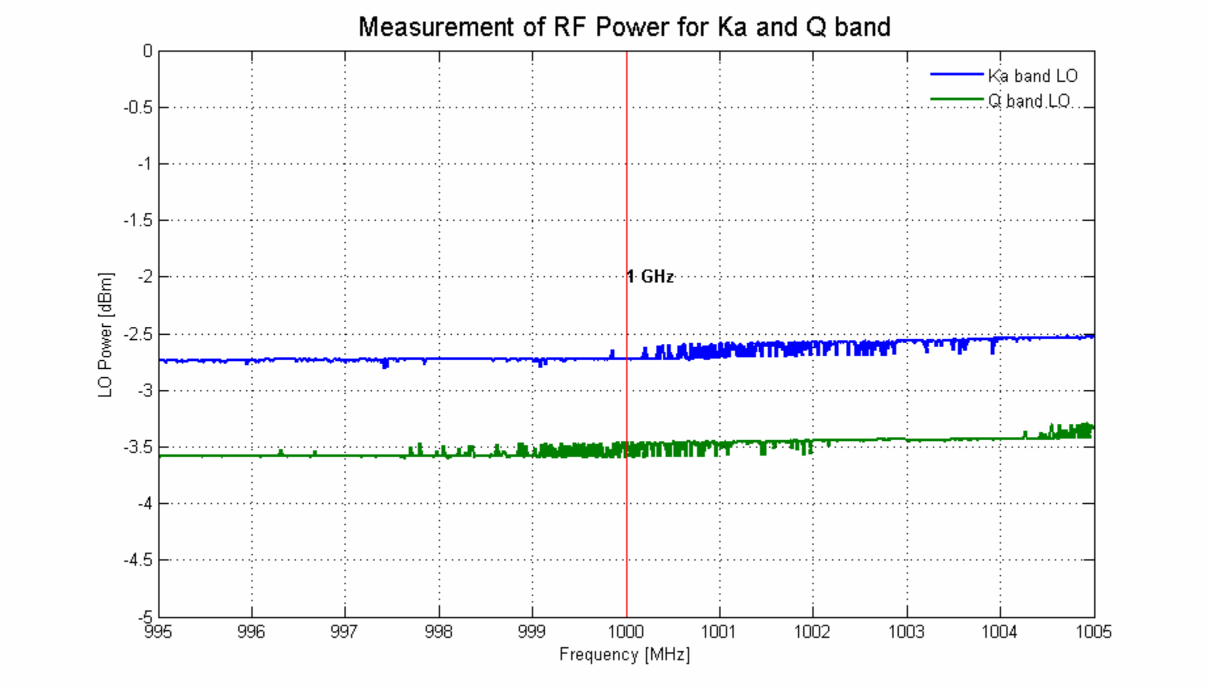

Figure 6-28 LO power measurement for 2nd down conversion characteristic

The measurement shows that the output power rises from -2.74 dBm to 2.54 dBm for Ka-band and from -3.58 dBm to -3.32 dBm when the out frequency is increased. Therefore for the calculation of the conversion loss the output power at the specific frequency was subtracted.

The total behaviour of each conversion line is depicted in Figure 6-29 on the next page. The red line marks the 10.7 MHz. The results of each line are almost identical and give satisfactory results. The loss in the observed range is around 7dB and is stable around the operating point.
In this measurement the conversion loss of the mixer, the insertion loss of the filters, and connection and cabling are included. This figure is important to further analyze the link budget, especially with respect to pre-amplification of the signal as well as further amplification to obtain a signal level that is high enough to give the best resolution at the data acquisition card located in the signal processing unit. The final characteristic of the down conversion is mainly based on the bandpass-filter at the end of conversion.

A detailed data table of the conversion characteristics and measurement results can be found in ANNEX A in section 13.1.

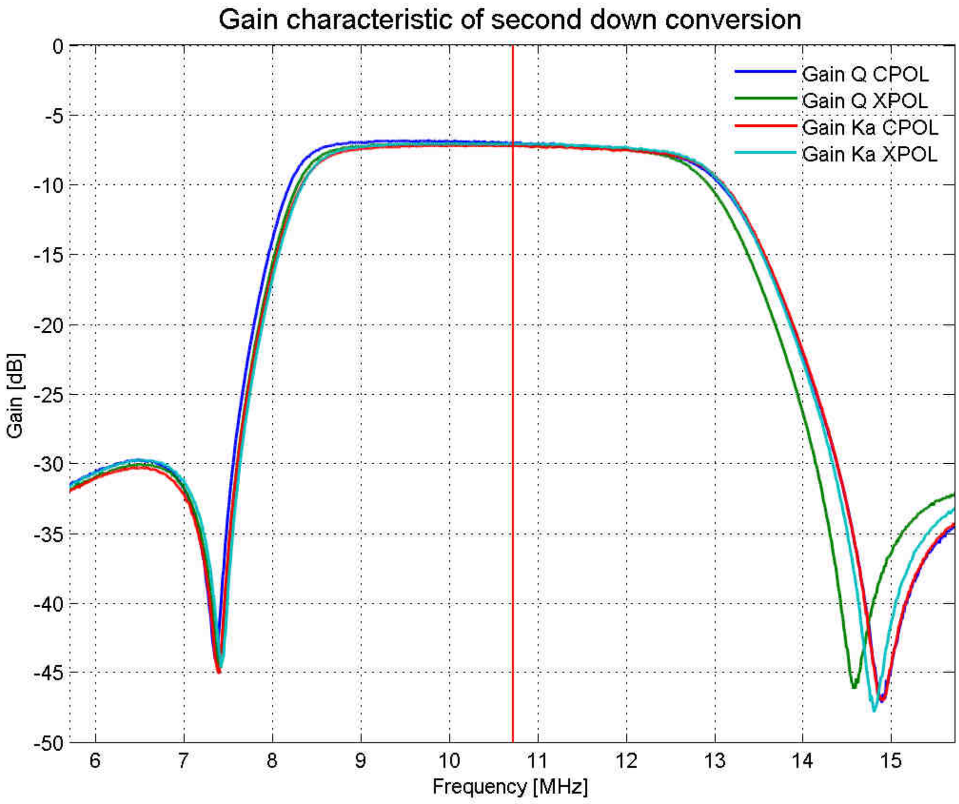

Figure 6-29 Measured gain characteristic of the second down conversion unit

6.2.1 Mechanical Design

Mechanically, the second down conversion unit is installed in a commercially available 19 inch rack with the dimensions 460 x 420 mm with 4 HU (1 HU is 44.45 mm or 1.75 inch).

Figure 6-30 housing for the 2nd down conversion unit

To allow easy assembling and operation during prototyping the RF parts (The filters, the mixers, the power dividers and the oscillators) are mounted on an L-shaped aluminium plate. This allows removing the RF section in one step without completely disassembling all units.

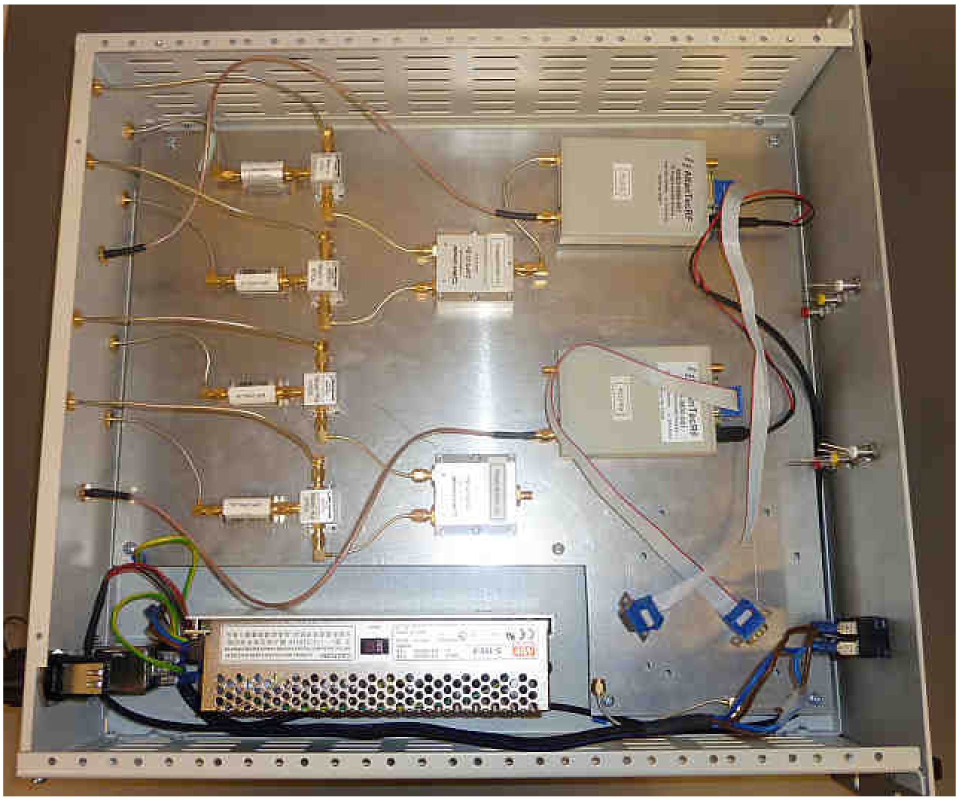

Figure 6-31 Aluminium plate with mounted RF devices of 2nd down conversion

The aluminium plate itself is fixed to the bottom of the box with several distance bolts. As on can see in Figure 6-31 the reason for the L-shape is to leave space for the power supply.

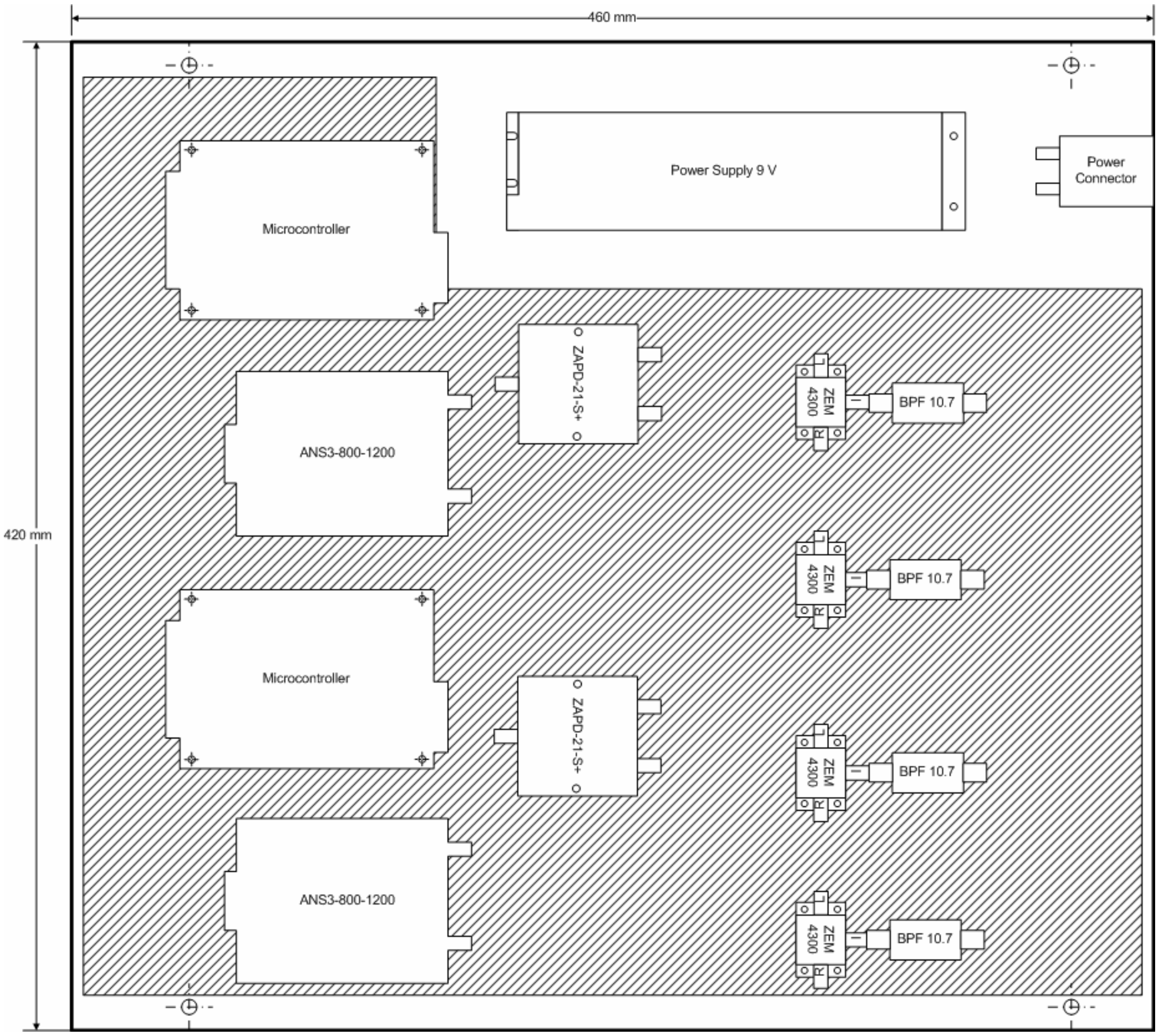

Figure 6-32 2nd downconversion box mechanical scheme

In addition, the two micro controller boards are also mounted on the aluminium plate. In a first design step, a solution with stacked boards was considered but not realized because enough space was available and there was a risk of producing a hotspot caused by the temperature generated from the two boards.

On the front panel the power switch and six LED's to indicate the unit status shall be located. In Figure 6-33, the mechanical specifications for metal works are depicted.

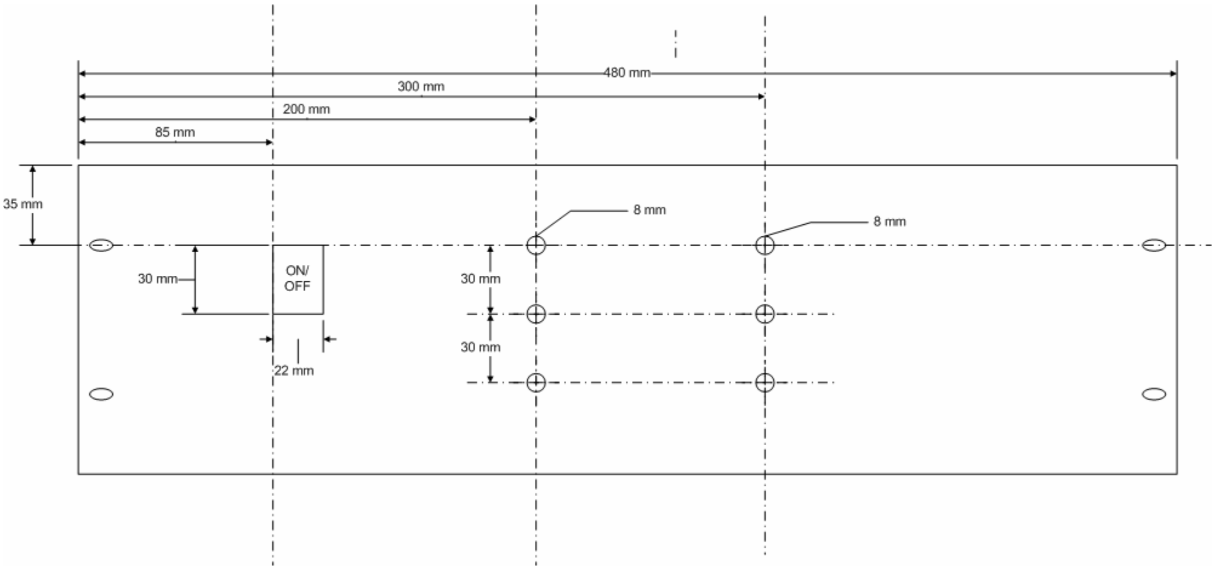

Figure 6-33 Front panel mechanical design for manufacturing

In Figure 6-34 below, the final front panel is depicted, with all elements mounted.

Figure 6-34 Integrated front panel of 2nd down conversion

Besides, the back panel needs holes for the SMA connectors and cut – outs for the power connector and for the two LAN – through the wall connectors required to connect the two micro processor boards located inside the conversion unit. In Figure 6-35 and Figure 6-36 the mechanical scheme and the finalized rear panel are depicted.

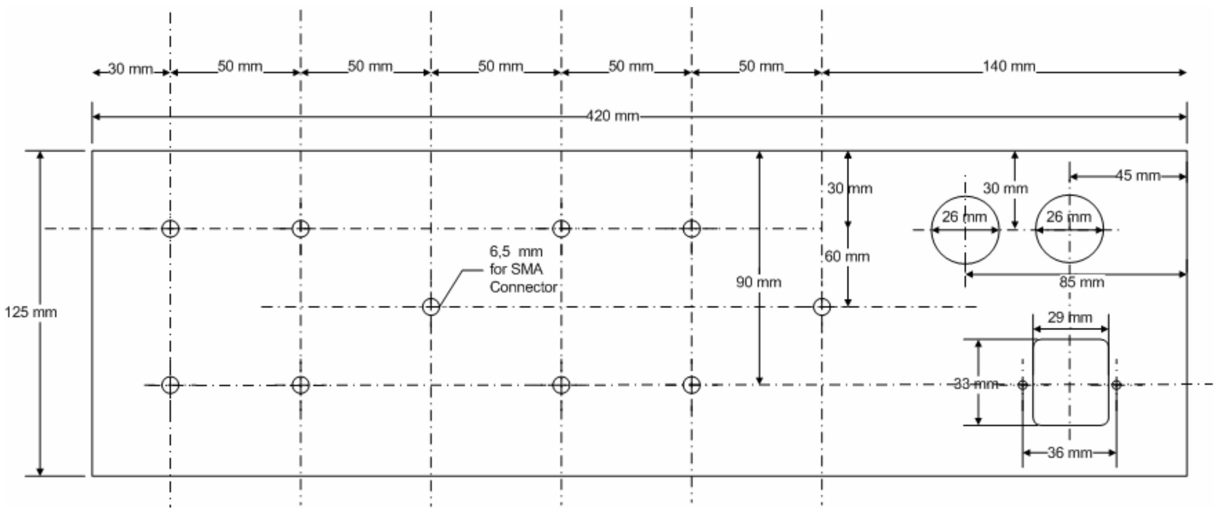

Figure 6-35 Rear panel mechanical design for manufacturing

Note that in Figure 6-36 only one Ethernet connector is integrated due to the fact that initially a master-slave system was foreseen.

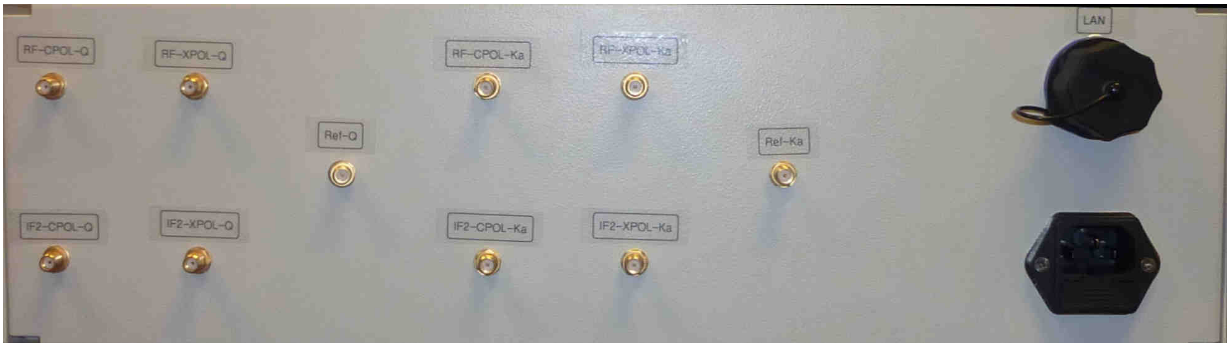

Figure 6-36 Integrated rear panel of 2nd down conversion

In Figure 6-37 on the next page the down conversion unit is depicted in operation. The front switch indicates that the system is powered on. Besides, two green LED's indicate that every monitored parameter is within limits. All RF-components are installed and mechanically fixed. The inter-component cabling is done and the system is in working condition. The red/blue wires fixed to the top of each RF-component are the bus cables for the temperature monitoring.

Figure 6-37 Integrated 2nd down conversion unit

6.3 GPS NTP Server

Figure 6-38 Meinberg LAN M300 [Ref. 16]

To provide a common time stamp for both computers in the Terminal, a NTP server is required. For the Terminal, the Meinberg M 300 from Meinberg Funkuhren GmbH depicted in Figure 6-38 was selected. It provides a GPS NTP time stamp and as secondary feature a high quality OCXO as described in section 5.4 is integrated generating the reference frequencies for the second down conversion and the signal processing unit.
The NTP server provides a LAN interface and can be accessed via the network. The device is uniquely identified in the network by its IP-address. With correct configuration of the router the device could be remotely accessed or via the local control computer..

6.4 Ethernet network

All communications within the indoor unit and also to the outdoor unit are done via Ethernet. In case a TCP/IP interface is not directly available, a converter is installed.
Of course, an industrial standard hub was chosen to provide safe and robust communication. This device can be mounted on standard DIN rail and allows powering from an external power supply. This power is supplied from a 24V power supply located at the back of the indoor unit rack. In addition, the power-supply can be used also to provide power to other devices.

Figure 6-39 Ethernet Hub Harting eCon 3080-A

Number of ports, Copper / Termination	8x 10/100Base-TX / RJ45 (Twisted Pair)
Input voltage / Termination	24 V DC / 3-pole pluggable screw contact
Permissible range	12 V to 30 V DC
Input current	approx. 150 mA (at 24 V DC)

Table 6-6 Technical specification of Harting eCon 3080-A

6.5 Local control computer

The local controller is a medium end industrial computer installed in a 19” rack mountable housing. There is no processor-consuming application meant to run on the local controller.

Only the following applications are installed:

- Terminal control
- Web interface

Therefore a computer with a dual core processor Intel Core2 Duo Mobile 667 T7200, 2 GHz and 2 GB of RAM was selected. The hard disk - space is 750GB. This is sufficient because the main storage will be located in the signal processing computer.

6.6 Signal Processing

The signal processing itself is not part of this thesis and is executed by TU Graz as a subcontractor of JOANNEUM RESEARCH. In this section, a short overview will be discussed, with special focus on the interfaces to the RF part of the Terminal.

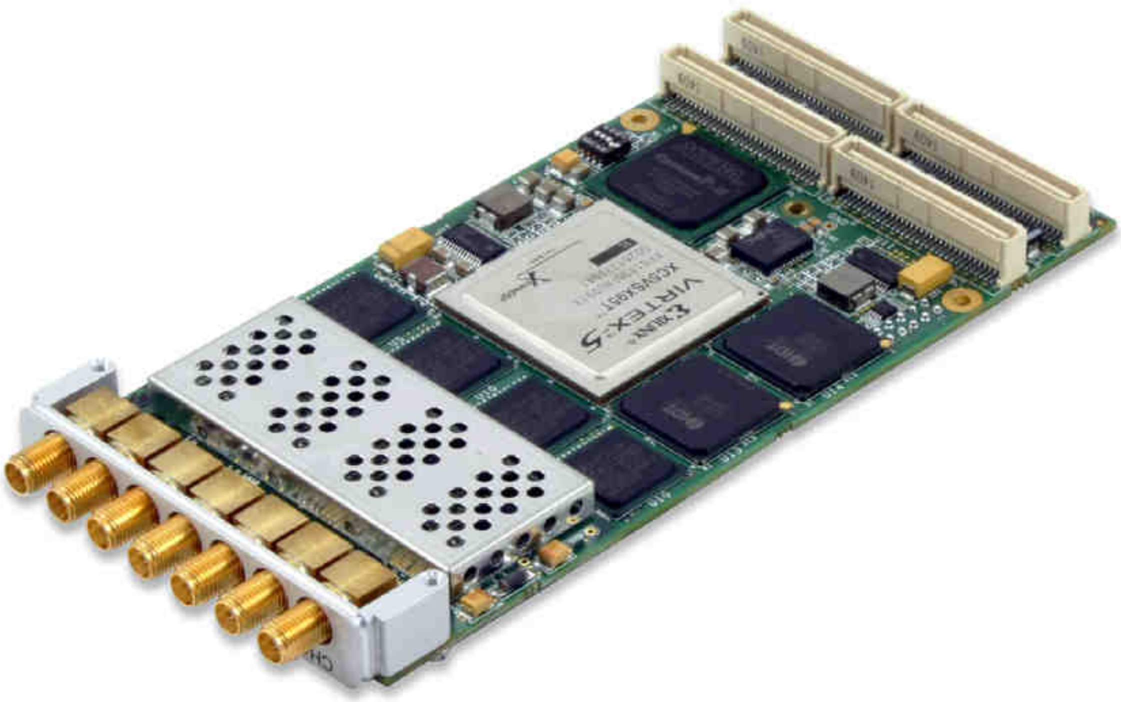

Figure 6-40 GE Fanuc ICS-1555 [Ref. 4]

The signal processing computer is a high end computer housing the common database storage. It further contains the signal acquisition card depicted above.
Specifications of the used FPGA card are depicted in Table 6-7 .

ICS-1555 Specifications

Table 1 - ICS-1555 Specifications[1]

Analog Output	
Number of Analog Input Channels:	4
Analog Connector Type:	SMA
Input impedance:	50 Ohm
Full Scale Input:	1.48 dBm (0.75Vpp) or 5dBm (1.125 Vpp) into 50 Ohms, software selectable
Input Signal Bandwidth:	2 MHz – 300 MHz
Max. Sampling Rate:	160 MSPS or 180 MSPS
Min. Sampling Rate:	1 MSPS
Internal Sample Clock Oscillator:	100 MHz at power-on; ≤100 MHz when using DDCs; ≤160 MHz or 180 MHz when bypassing DDCs
External Clock Reference:	10 MHz – 200 MHz
ADC Resolution:	16 bits
Sampling:	Rising edge of sample clock
External Clock:	LVTTL / Sinewave compatible, -3 dBm min. to +6 dBm max.
External trigger:	3.3V LVTTL/LVCMOS, 5 V tolerant, software selectable rising or falling edge
External Synchronization:	3.3V LVTTL/LVCMOS, 5 V tolerant, software selectable rising or falling edge
Signal-to-Noise Ratio (SNR):	72.9 dBFS @ *fin* 70 MHz @ 160 MSPS or better
SFDR:	84 dBc @ *fin* 70 MHz or better
Inter-channel Cross-talk:	<- 80 dB

Table 6-7 Sampling Card Specifications [Ref. 9]

The signal processing unit applies a decimal filtering of the incoming signal and tracks the beacon to determine frequency shift, attenuation and scintillation amongst other parameters.

6.7 The Terminal

In Figure 6-41 the rack including some core components is depicted. The signal processing computer is not installed, because it was still under development, regarding software, at the time of writing.

The black box at the top of the Terminal is the local control computer. Beneath the Meinberg 300 GPS receiver is located. At the bottom of the rack the downconversion unit can be seen.

The position of the components in the finalized design may change because the temperature distribution is not known in this stage of design

Figure 6-41 Terminal

7 Link budget analysis

The most important topic in the analysis of a satellite link is the link budget. The link budget is strongly dependent on the SNR of the received signal. In the Terminal designed during this thesis a single beacon per band is transmitted carrying no information. But for the next steps of system integration a close look to the satellite link from space segment to the signal processing is required to determine the required amplification

The criteria taken into account are:

- The received signal from space is very low powered and needs to be amplified as much as possible by avoiding additional noise.
- The input signal power for any component in the the signal path must be kept below the maximum input level to maintain linearity of operation. In the Terminal at the actual stage, these components are the mixers. (cf. section 6.1.3 on page 45)
- The signal acquisition card has two modes. It can be configured to 1.48 dBm or 5 dBm full-scale. The signal power under clear sky conditions should be close two either one of these values but must not exceed it.

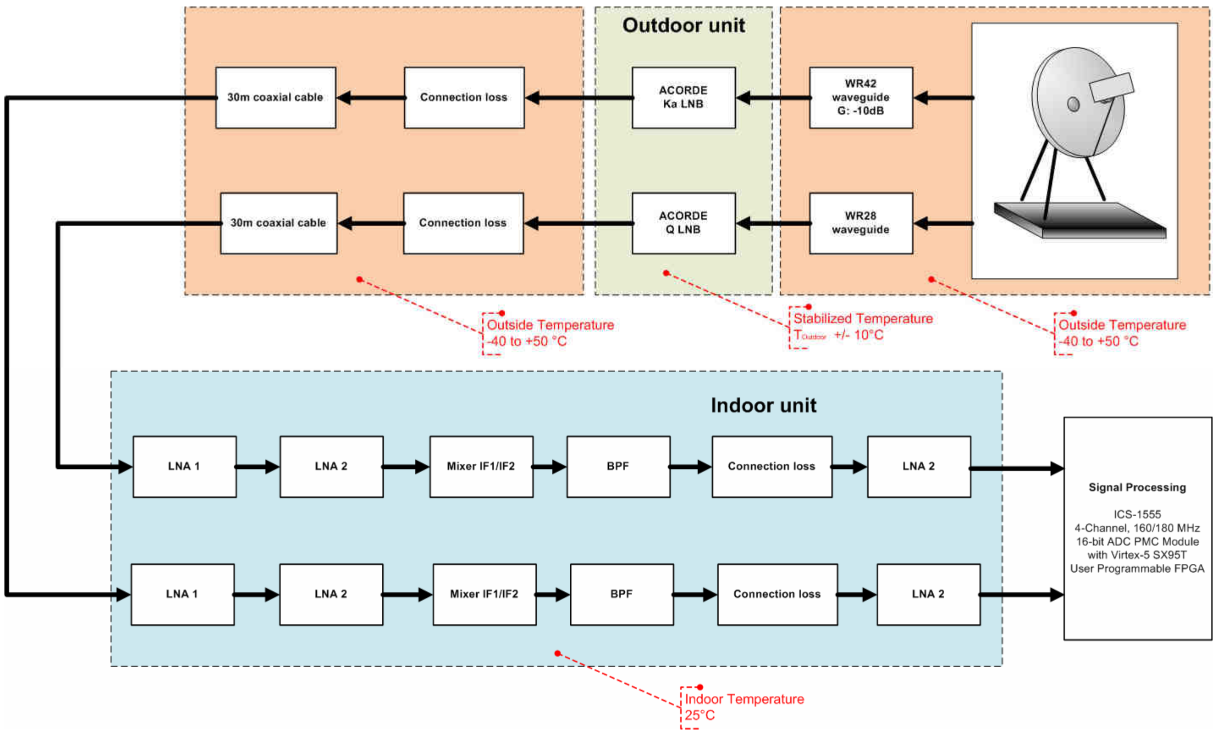

Figure 7-1 Detailed signal path

In Figure 7-1, the signal path is depicted, showing the detailed components. The different temperature conditions are also shown in different colours.

The EIRP of both beacons are:

Q-Band: 26.5 dBW
Ka-Band: 19.5 dBW

In Equ. 7 and Equ. 8, the calculation of free space loss is detailed.

Calculation of Free space loss:

$$l_{FS} = \left(\frac{4\pi \cdot r}{\lambda} \right)^2 \text{ [1]}$$ **Equ. 7**

$$L_{FS} = 10 \log \left(l_{FS} \right) \text{ [dB]}$$ **Equ. 8**

By estimating the diameter of the Alphasat orbit in 38200 km we get the following free space loss at the antenna:

Q-Band: 215.99 dB
Ka-Band: 209.97 dB

By applying these losses to the beacon power we receive -160.47 dBm for Ka-band and for Q-band we receive -159.49 dBm at the antenna.

Note that for clear sky conditions, the received signals for Ka-band and Q-band are almost equally powered to simplify comparison of losses.

During the following sections the degradation of the signal within the receiver will be analyzed. The first device is the antenna through which the signal enters the Terminal.

Antenna gain:

The parabolic reflector of a satellite antenna works as an amplifier because the signal received is focussed to the feed of the antenna. In case of a prime focus antenna, its effective gain is calculated as follows:

Effective antenna gain :

$$g = \eta_A \frac{4\pi A}{\lambda^2} \text{ [dBi]}$$ **Equ. 9**

g … effective antenna gain [dBi]
η_A … aperture efficiency [%]
λ … wave length [m]
A … aperture area [m²]

Half power beamwidth :

$$HPBW \approx 70 \frac{\lambda}{d} \text{ [°]}$$ **Equ. 10**

d … reflector diameter

By applying Equ. 9, we can depict Figure 7-2, which shows the relation between the antenna diameter and its gain and half power beamwidth of the antenna.

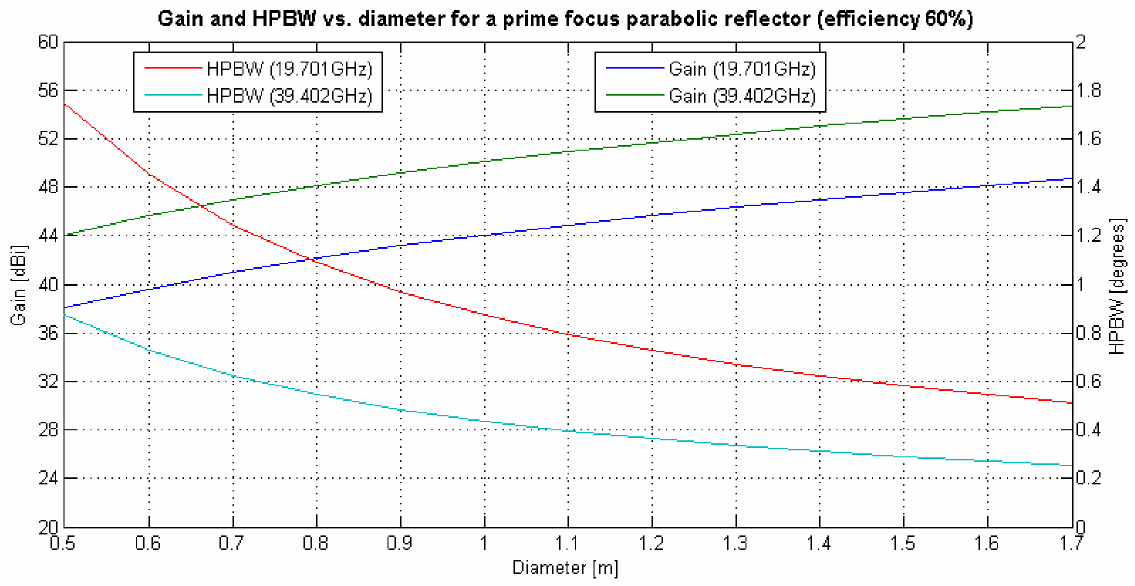

Figure 7-2 Gain and HPBW vs. diameter, assuming efficiency of 60% [Ref. 17]

The information given.to the design team from ESA about the antenna is that the diameter will be ~ 1.5 m and we also know the minimum efficiency of 60 % from the statement of work.

This results in an effective antenna gain of ~ 47.6 dB for Ka-band and ~ 53.6 dB for Q-band assuming a 1.5 m antenna.

For determining the system noise of the Terminal the following mathematical framework is applied (Equ. 11 to Equ. 17):

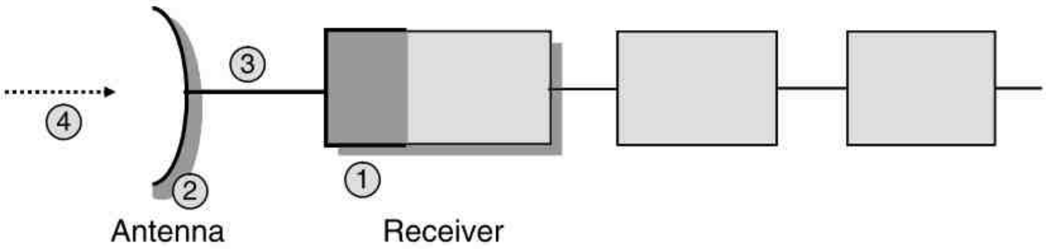

Figure 7-3 receiver front end noise contribution [Ref 1.]

1 … front end receiver
2 … receiver antenna
3 … connection elements between front end receiver and antenna
4 … noise entering from free space path

Thermal noise power:

$$N = 4 \cdot k \cdot T \cdot B \text{ [W]}$$ **Equ. 11**

k … Boltzmann constant
B … effective bandwidth
T … device temperature

Antenna Noise temperature:

$$T_A = \eta_A T_{Sky} + \frac{(1-\eta_A)\left(T_{Sky} + T_{Ground}\right)}{2} \text{[W]}$$ **Equ. 12**

T_{Sky} … sky temperature
T_{Ground} … ground temperature
T_A … antenna noise temperature

Calculation of the gain factor for active devices:

$$G = 10^{\frac{G_{dB}}{10}} \text{ [1]}$$ **Equ. 13**

Excess noise temperature for passive devices:

$$t_e = t_0 \left(10^{\frac{L}{10}} - 1 \right) \text{ [K]} \qquad \textbf{Equ. 14}$$

L … passive device losses [dB]

Calculation of noise temperature at the Reference point:

$$T_{Dev\_ref} = \frac{\text{device noise temperature}}{\text{accumulated gain at device input}} \qquad \textbf{Equ. 15}$$

$$T_{Dev\_ref} = \frac{T_{Dev}}{G_{prev}} \qquad \textbf{Equ. 16}$$

Total noise of the signal chain at the Reference point:

$$T_{Dev\_ref} = \sum_{n=1}^{N} \frac{T_n}{\prod_{i=1}^{n-1} G_i} \qquad \textbf{Equ. 17}$$

N … Total number of components in signal chain

In Table 7-1 and Table 7-2 the result of the link budget analysis is depicted based on the following assumptions:

- The gain of the front LNB is limited to 60 dB due to technical constraints, which is a realistic approach but not definitely fixed yet, especially the gain for Q band could significantly be lower.
- The noise of the front LNB is a realistic estimation based on the design paper and the presentation held from ACORDE Ltd.
- The waveguide losses are assumed for a length of around 2 m considering also flanges. But the final value can be determined only, when knowing the exact dimensions
- The loss of the feed is not taken into account in the calculation, because no information is available at the time of writing.
- The theoretical data for the LNA is taken from the supplier's data sheet.
- The sky temperature is assumed to be 15K
- The ground temperature is assumed to be 300K

<u>Other considerations:</u>

- A figure of merit is that the final output to the signal acquisition card should not exceed 5dBm because then the acquisition gets nonlinear.
- The compression point of the mixer is 1 dBm and must not be exceeded.
- All components shall be off-the-shelf components if possible.
- Q – and Ka – band components should be symmetric if possible

Device	Supplier	Type	nom. Gain [dB]	Insertion loss [dB]	P@1dB [dBm]	NF (dB)	T_N [K]	T_{NREF} [K]	NF_{REF} [dB]	acc. Gain [dB]	Signal-strength @ input [dBm]	Signal-strength @ output [dBm]
Antenna	ESA		53,60				72,00	72,00	0,96	0,00	-159,49	-105,89
Reference Point												
Waveguide	Flann MW [0,5dB/m]			0,9			69,08	69,08	1,72	-0,90	-105,89	-106,79
Front LNB	ACORDE		60,00		-3	3,5	365,42	449,57	4,82	59,10	-106,79	-46,79
Connection loss	SMA Connectors			0,2			13,90	0,00	4,82	58,90	-46,79	-46,99
Transmission cable	Krenn			10			2655,00	0,00	4,82	48,90	-46,99	-56,99
IF1 LNA 1	Mini circuits	ZKL-2+	30,79		16	3	293,60	0,00	4,82	79,69	-56,99	-26,20
IF1 LNA 2	Mini circuits	ZKL-2+	30,79		16	3	293,60	0,00	4,82	110,48	-26,20	4,59
Connection loss	SMA Connectors			0,2			13,90	0,00	4,82	110,28	4,59	4,39
IF1 Mixer	Mini circuits	ZEM 4300 +		7	0		1183,50	0,00	4,82	103,28	4,39	-2,61
IF1 BPF	Mini circuits	SBP-10.7		1			76,38	0,00	4,82	102,28	-2,61	-3,61
IF1 LNA	Mini circuits	ZFL-1000+	17,00		10	6	879,42	0,00	4,82	119,28	-3,61	13,39
System characteristics		Noise Figure [dB]: **4,82**			Noise Temp. [K]: **590,66**			Gain [dB]: **119,28**				

Table 7-1 Q-band link budget

Device	Supplier	Type	nom. Gain [dB]	Insertion loss [dB]	P@1dB [dBm]	NF (dB)	T_N [K]	T_{NREF} [K]	NF_{REF} [dB]	acc. Gain [dB]	Signal-strength @ input [dBm]	Signal-strength @ output [dBm]
Antenna	ESA		53,60				72,00	72,00	0,96	0,00	-159,49	-105,89
Reference Point												
Waveguide	Flann MW [0,5dB/m]			0,9			69,08	69,08	1,72	-0,90	-105,89	-106,79
Front LNB	ACORDE		60,00		-3	3,5	365,42	449,57	4,82	59,10	-106,79	-46,79
Connection loss	SMA Connectors			0,2			13,90	0,00	4,82	58,90	-46,79	-46,99
Transmission cable	Krenn			10			2655,00	0,00	4,82	48,90	-46,99	-56,99
IF1 LNA 1	Mini circuits	ZKL-2+	30,79		16	3	293,60	0,00	4,82	79,69	-56,99	-26,20
IF1 LNA 2	Mini circuits	ZKL-2+	30,79		16	3	293,60	0,00	4,82	110,48	-26,20	4,59
Connection loss	SMA Connectors			0,2			13,90	0,00	4,82	110,28	4,59	4,39
IF1 Mixer	Mini circuits	ZEM 4300 +		7	0		1183,50	0,00	4,82	103,28	4,39	-2,61
IF1 BPF	Mini circuits	SBP-10.7		1			76,38	0,00	4,82	102,28	-2,61	-3,61
IF1 LNA	Mini circuits	ZFL-1000+	17,00		10	6	879,42	0,00	4,82	119,28	-3,61	13,39
System characteristics		Noise Figure [dB]: **4,82**			Noise Temp. [K]: **590,66**			Gain [dB]: **119,28**				

Table 7-2 Ka-band link budget

Note, that the numbers in red mark critical values close or exceeding a limit.

7.1 Analysis of Link budget calculation

As already discussed in previous sections the amplification of the LNB is assumed to be 60 dB, although the final figure is not fixed at the time of writing.

The Link budget shows that after amplification through the LNB the signal power is still very low. Unfortunately no further amplification can be applied at this stage, because of the expected temperature changes in the outdoor unit.

After the losses introduced by the transmission cable the signal is amplified again. Due to size restrictions two cascaded amplifiers are used. For simplification of procurement two identical amplifiers are chosen. After this amplification is applied the important criterion is to stay below the compression point of the mixer. The figure for Ka-band is still below the critical point but very close to the limit determined through measurements of the mixer. For Q-band path, the limit is exceeded, but this is not considered as critical, because the finalized values of antenna gain and the exact free space loss are unknown. Therefore it makes no sense to adapt the amplification too exactly before prototyping.

In any case, if the measurements show, that the mixer is working nonlinear an attenuator can be installed before it. This is easier to implement and attenuators are available in various designs and specifications.

The conversion losses of the mixers reduce the signal power again. This is compensated by using amplifiers before feeding the signals into the signal processing unit.

With the actual parameters the signal power after this amplification is now exceeding the Full scale range of the signal acquisition card. Again, this is acceptable, considering that some parameters are only estimations. Besides, the attenuation of the Q-band beacon will be far higher than in Ka-band so in typical operation conditions the beacon will be within limits.

7.2 Noise figure:

Referring to the receiver specification on in section 2.2.3 on page 20 the receiver exceeds the noise temperature limit for Ka – band (400K) a little bit and fulfils it for Q –band (600K). Actually the noise figure of the receiver is fixed by the LNB assuming a gain above 40dB and we can realistically estimate that it will be close to 60dB. The final noise temperature is therefore strongly dependent on the noise figure of the LNB, which is not exactly known yet.

The biggest drawback in terms of noise is of course the prime focus design, which requires long waveguides to the front end of the Terminal adding additional noise, but the figures achieved with the components in use are satisfying.

8 Performance

Important figures of merit of the Terminal are the C/N ratio, measured at the signal acquisition card after digital decimation, and derived from it the dynamic range. The final C/N is strongly dependent on the effective bandwidth at the digital receiver of the signal processing unit.

The signal from the RF part is filtered as already discussed in an earlier section with a bandwidth of 2 MHz at an IF of 10.7 MHz. The digital receiver applies additional decimation to lower the sampling frequency according to Equ. 18.

Decimated sampling frequency:

$$f_{dec} = \frac{f_s}{D} \text{ [Hz]}$$ **Equ. 18**

f_{dec} … decimated sampling frequency

f_s … Sampling

D … Decimation rate

In Equ. 19, the calculation of the bandwidth is shown. Basically, it is related to the number of FFT points resulting in the bandwidth of one FFT bin. Of course the noise within this bandwidth is contributing to the peak power but it is now significantly lower with the initial bandwidth of 2 MHz.

Digital receiver BW:

$$B_{dec} = \frac{f_{dec}}{L_{FFT}} \text{ [Hz]}$$ **Equ. 19**

B_{dec} … digital receiver BW

L_{FFT} … Length of FFT

From these data we can derive the following parameters:

Carrier to noise ratio:

$$\frac{C}{N} = \frac{received\ Power}{Noise\ \mathrm{Power}}$$ **Equ. 20**

$$C = P_t g_R l_{FS} \quad \mathrm{[W]}$$ **Equ. 21**

g_R … gain factor of the receiver antenna
p_t … transmitted power from satellite (EIRP)
l_{FS} … Free space loss factor
N … Noise power

Carrier to noise density:

$$\frac{C}{N_0} = \frac{P_t\ g_R\ l_{FS}}{4kT} \quad \mathrm{[W/Hz]}$$ **Equ. 22**

Dynamic Range :

$$DR = \frac{C}{N} - DL \quad \mathrm{[dB]}$$ **Equ. 23**

DR … Dynamic Range
DL … Detection Level

For the exemplary calculation depicted in Table 8-1 and Table 8-2, the following conditions have been assumed:

- FFT Length of 8192
- Decimation rate of 4096
- Sampling rate of 30 MHz
- The detection level of the data acquisition card is 6 dB

The limitation to the digital receiver is the computational power of the signal processing PC. The more FFT computations per second the more complex gets the calculation. The requirement for the signal processing is that at least one sample per second is the minimum rate.

Noise power	5,04E-21	W	decimated sampling freq.	7,32E+03	Hz
System gain	8,47E+11	[1]	ffts per second	3,58	[1]
FFT Overlap	2,05E+03		Free space loss	209,97	dB
Window BW	1		Received Power after antenna	-142,87	dBW
FFT length	8192,00		system noise temperature	26,12	dBK
Decimation rate	4096,00		noise power density	-202,49	dBW/Hz
Antenna Temperature	72,00	K	noise power	-202,97	dBW
Detection level	6	dB	Freq. resolution per FFT Bin	0,89	Hz
Antenna gain	47,6	dB	C/N	60,10	dB
Receiver Noise figure	3,82	dB	C/No	59,62	dBHz
Receiver Bandwidth	0,89	Hz	Dynamic range	54,10	dB

Table 8-1 Ka-Band performance

Noise power	7,29E-21	W	decimated sampling freq.	7,32E+03	Hz
System gain	8,47E+11	[1]	ffts per second	3,58	[1]
FFT Overlap	2,05E+03		Free space loss	215,99	dB
Window BW	1		Received Power after antenna	-135,89	dBW
FFT length	8192,00		system noise temperature	27,71	dBK
Decimation rate	4096,00		noise power density	-200,89	dBW/Hz
Antenna Temperature	72,00	K	noise power	-201,37	dBW
Detection level	6	dB	Freq. resolution per FFT Bin	0,89	Hz
Antenna gain	53,6	dB	C/N	65,49	dB
Receiver Noise figure	4,82	dB	C/No	65,00	dBHz
Receiver Bandwidth	0,89	Hz	Dynamic range	59,49	dB

Table 8-2 Q-Band performance

With the configuration depicted above a frequency resolution of 0.89 Hz can be achieved for both bands. This results in an effective noise power of only -201.37 dBW for Q – band and -202.97 dBW for Ka – band.

Finally we get a C/N of 65.49 dB for Q – band and 60.10 dB for Ka – band. This is a result of the higher gain for Q – band, but this is for the moment a theoretical value and needs to be verified under real conditions.

9 Outlook and conclusion

The next steps during this project will be the finalizing of the outdoor unit and the antenna manufacturing. Once these devices are available, the final integration of the system will be completed.

Once everything is integrated the device will be tested in the lab and the theoretical data can be verified.

After the lab tests have been successfully completed, the Terminal will be installed on an experiment site. The prototype will be put under several months of test. For test purposes, existing satellites (transmitting at Ka-band) can be used. Unfortunately no satellite is in orbit that is transmitting in Q-band. Therefore this functionality cannot be tested under real conditions until the TDP5 payload at the Alphasat is transmitting..

The launch of the Alphasat space segment is scheduled to end of 2012. Therefore the Terminal needs to be ready for reproduction at beginning of 2012.

9.1 Conclusion

The Terminal is in good condition at the moment and the design of the critical component of the outdoor unit, the LNB, is already in progress. It should be possible to produce a small series of Terminals for interested experimenters that already showed interest.

Nobody can deny that future applications in civil and military communication will be more demanding in bandwidth and/or data rate. Obviously there is also a trend to wireless communication. The advantages are clear: Inexpensive and easy coverage of large regions. At the moment the existing bands are still sufficient but are getting more and more crowded, so additional bandwidth needs to be discovered.

Q/V bands could be the right decision but experiments will show its feasibility. Anyhow, the effort required to transmit in Q/V band can be determined by this experiment. Sooner or later it will be cost effective to use it when the existing bands are getting occupied.

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11 ANNEX A: Schemes

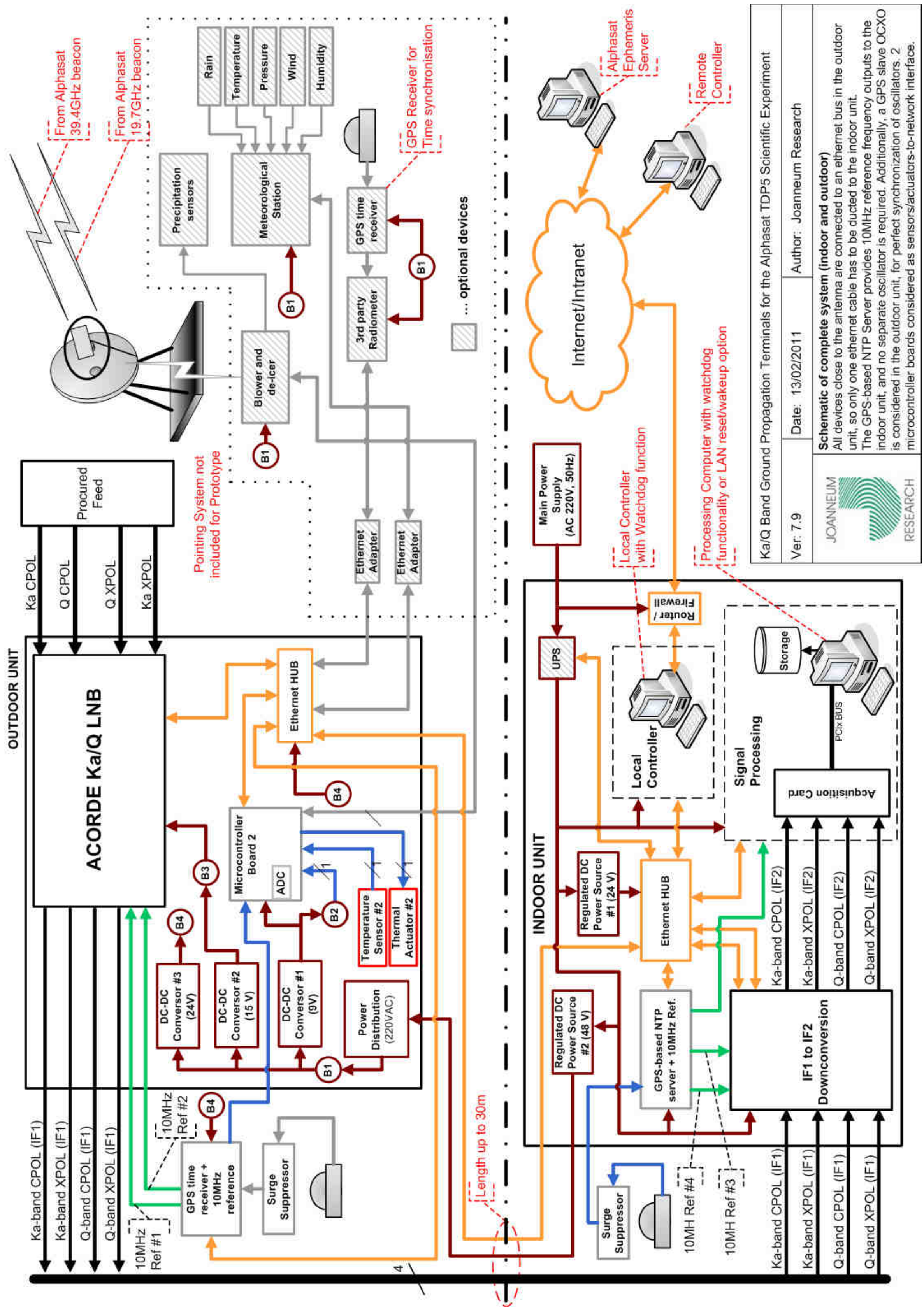

Figure11-1 System design schematic

12 ANNEX B: Specifications

12.1 ACORDE Ka/Q – band LNB Specification [Ref. 5]

RECEIVER SPECIFICATIONS

Ka-Band input frequency	19701 MHz
Q-Band input frequency	39402 MHz
Input impedance	50 Ohms
Input Ka-band VSWR	< 2:1
Input Q-band VSWR	< 2:1
Maximum input level without damage	- 10 dBm
Input stability	Unconditionally stable
IF Output frequency	1 GHz
Output impedance	50 Ohms
Output Ka-band VSWR	< 2.0:1
Output Power @ P1dB	+0 dBm
Spectrum inversion	None
Spurious	< -60 dBc @ POUT=0 dBm
Gain flatness over the whole bandwidth	± 0.05 dB BW=1MHz
Gain variation over temperature	± 0.25 dB over 20ºC variation range (*)
Ka-Band Noise figure	< 3.7 dB
Q-Band Noise figure	< 4.8 dB
Image Rejection	> 40 dB

LOCAL OSCILLATOR

Ka-Band output phase noise:

10 Hz	-30 dBc/Hz
100 Hz	-50 dBc/Hz
1 KHz	-60 dBc/Hz
10 KHz	-70 dBc/Hz
100 KHz	-90 dBc/Hz
1 MHz	-90 dBc/Hz

Q-Band output phase noise:

10 Hz	-22 dBc/Hz
100 Hz	-42 dBc/Hz
1 KHz	-52 dBc/Hz
10 KHz	-62 dBc/Hz
100 KHz	-82 dBc/Hz
1 MHz	-82 dBc/Hz

External reference frequency	10 MHz (exclusive input for each band)
Reference input level	0 dBm ± 3 dB
LO frequency stability	same as external reference

Minimum external reference to compliant typical phase noise:	
100 Hz	-135 dBc/Hz
1 KHz	-145 dBc/Hz
10 KHz	-155 dBc/Hz

POWER SUPPLY

DC input voltage	15VDC
Power consumption	25W typ. (TBC)

ENVIRONMENTAL SPECIFICATIONS

Storage temperature	-40 to +80ºC
Operating temperature	0 to +50ºC (*)
Relative humidity	up to 95%
Operating altitude	up to 3500 m

MECHANICAL SPECIFICATIONS

Dimensions	300 x 200 x 60 mm
Weight	1.5 Kg
Interfaces Ka-Band Rx inputs	2 x WR42 UG-595/U type
Q-Band Rx inputs	2 x WR28 UG-599/U type
IF L-Band outputs	4 x SMA(F)
10MHz reference inputs	2 x SMA(F)
Power supply	MS3112E12-14S
Monitoring & Control	MS3112E12-3S
Cooling system	None
Finish	White RAL 9003

12.2 Technical specifications GPS161DHS

- RECEIVER: 6 channel C/A code receiver with external antenna/converter unit
- ANTENNA: Antenna/converter unit with remote power supply
- ANTENNA INPUT: Antenna circuit dc-insulated; dielectric strength: 1000V
- TIME TO SYNCHRONIZATION: One minute with known receiver position and valid almanac , 12 minutes if invalid battery buffered memory
- BATTERY BACKUP: Storage of important GPS-system data in the internal RAM backed-up by lithium battery lifetime of battery 10 years min.
- SERIAL PORT: One asynchronous serial port COM0 (RS-232)
  Baud Rate: 300 up to 19200
  Framing: 7N2, 7E1, 7E2, 8N1, 8N2, 8E1
- STATUS INDICATION: Receiver status:
  Lock: the receiver was able to compute its position after power-up
  Fail: the receiver is asynchronous to the GPS-system
- POWER REQUIREMENTS: 19-72 VDC, e.g. 3.6 W
  DC-insulation: 1.5 kVDC
  Fuse: 500mA, slow blow
- DIMENSION: 105 mm x 125 mm x 104 mm (H x W x D)
- CONNECTORS: Coaxial BNC connector for antenna/converter unit
  Female nine-pole SUB-MIN-D-connector for RS232
- AMBIENT TEMPERATURE: 0 ... 50°C
- HUMIDITY: 85% max.

12.3 Specifications of programmable oscillator ANS3 – 800 -001

General Specifications (also see options)	
Output Frequency	65 MHz to 5875 MHz in ranges
Frequency Stability	+/-1ppm max. over 0+50C
Internal Ref. Aging	+/-1ppm max./year
Internal Ref. Accuracy	+/-1ppm @ +23 +/-2 deg.C
Internal Ref. Output	0 to +2dBm into 50 ohms
External Ref. Frequency	As Internal Reference
External Ref. Level	0.6-2.5 Vpp
External Ref. Impedance	600 ohms in parallel with 25pF
Reference Select	Miniature Toggle Switch
Output Power	+5dBm min, +7dBm typ.
Level Control Range	25dB min in 31 steps
Control Interface	Serial RS-232
Modulation Rate	1 KHz internal 50KHz max. external
Modulation Deviation	+/-1.25 MHz
Input Voltage	+8 to +12 V d.c. @ 300 mA
Operating Temperature	0+50C
Storage Temperature	-20+70C
Lock Time	2 to 6 msec. typ.
Status LED's (green)	RF On, Phase Lock, DC Applied
RF Output Connector	SMA female
Ref. Connector	SMA female
Trigger/Modulation Connector	SMA female
Input Power Connector	1.3 x 9.0mm centre positive jack
Data Connector	DB-9P
RF Output Modes	Continuous, Momentary & Toggled
Output Impedance	50 ohms
Size	90 x 70 x 19mm (excluding connectors)
Weight	170g
Housing	Aluminium with White Epoxy Paint

Figure12-1 ANS3 – 800 - 001 general specifications [Ref. 15]

13 ANNEX C: Measurement results

13.1 Measured system gain of 2nd down conversion stage

		CPOL Q		XPOL Q		CPOL Ka		XPOL Ka	
RF MHz	IF MHz	IF dBm	Gain dB	IF dBm	Gain dB	IF dBm	Gain dB	IF dBm	Gain dB
996	6,7	-33,56	-30,06	-33,77	-30,27	-33,26	-30,68	-32,69	-30,11
996,1	6,8	-33,9	-30,4	-34,12	-30,62	-33,49	-30,91	-32,9	-30,32
996,2	6,9	-34,5	-31	-34,62	-31,12	-34,11	-31,53	-33,35	-30,77
996,3	7	-35,4	-31,9	-35,47	-31,97	-34,8	-32,22	-34,15	-31,57
996,4	7,1	-37,2	-33,7	-36,8	-33,3	-36,42	-33,84	-35,29	-32,71
996,5	7,2	-40,2	-36,7	-39,14	-35,64	-38,5	-35,92	-37,3	-34,72
996,6	7,3	-44,8	-41,3	-43,41	-39,91	-42,56	-39,98	-40,8	-38,22
996,7	7,4	-44,2	-40,7	-47,82	-44,32	-46,5	-43,92	-46,95	-44,37
996,8	7,5	-36,3	-32,8	-39,58	-36,08	-38,7	-36,12	-41,1	-38,52
996,9	7,6	-30,85	-27,35	-33,33	-29,83	-32,69	-30,11	-34,03	-31,45
997	7,7	-26,6	-23,1	-28,74	-25,24	-28,2	-25,62	-29,18	-26,6
997,1	7,8	-23,11	-19,61	-24,98	-21,48	-24,5	-21,92	-25,33	-22,75
997,2	7,9	-20,02	-16,52	-21,85	-18,35	-21,5	-18,92	-22,09	-19,51
997,3	8	-17,38	-13,88	-19,05	-15,55	-18,8	-16,22	-19,22	-16,64
997,4	8,1	-15,18	-11,68	-16,69	-13,19	-16,46	-13,88	-16,82	-14,24
997,5	8,2	-13,52	-10,02	-14,82	-11,32	-14,61	-12,03	-14,72	-12,14
997,6	8,3	-12,36	-8,86	-13,36	-9,86	-13,22	-10,64	-13,15	-10,57
997,7	8,4	-11,53	-8,03	-12,35	-8,85	-12,1	-9,52	-11,96	-9,38
997,8	8,5	-11,16	-7,66	-11,67	-8,17	-11,4	-8,82	-11,23	-8,65
997,9	8,6	-10,93	-7,43	-11,32	-7,82	-10,97	-8,39	-10,65	-8,07
998	8,7	-10,77	-7,27	-11,1	-7,6	-10,67	-8,09	-10,39	-7,81
998,1	8,8	-10,75	-7,25	-10,92	-7,42	-10,51	-7,93	-10,27	-7,69
998,2	8,9	-10,62	-7,12	-10,92	-7,42	-10,37	-7,79	-10,14	-7,56
998,3	9	-10,62	-7,12	-10,8	-7,3	-10,3	-7,72	-10,02	-7,44
998,4	9,1	-10,62	-7,12	-10,78	-7,28	-10,24	-7,66	-10,1	-7,52
998,5	9,2	-10,61	-7,11	-10,78	-7,28	-10,24	-7,66	-10,04	-7,46
998,6	9,3	-10,49	-6,99	-10,78	-7,28	-10,2	-7,62	-10,03	-7,45
998,7	9,4	-10,48	-6,98	-10,78	-7,28	-10,12	-7,54	-10,03	-7,45
998,8	9,5	-10,49	-6,99	-10,77	-7,27	-10,11	-7,53	-10,03	-7,45
998,9	9,6	-10,47	-6,97	-10,66	-7,16	-10,11	-7,53	-10,03	-7,45
999	9,7	-10,48	-6,98	-10,64	-7,14	-10,11	-7,53	-9,95	-7,37
999,1	9,8	-10,48	-6,98	-10,64	-7,14	-10,11	-7,53	-9,95	-7,37
999,2	9,9	-10,47	-6,97	-10,64	-7,14	-10,11	-7,53	-9,93	-7,35
999,3	10	-10,5	-7	-10,64	-7,14	-10,05	-7,47	-9,92	-7,34
999,4	10,1	-10,56	-7,06	-10,64	-7,14	-10,11	-7,53	-9,93	-7,35
999,5	10,2	-10,56	-7,06	-10,64	-7,14	-10,13	-7,55	-9,94	-7,36
999,6	10,3	-10,55	-7,05	-10,63	-7,13	-10,13	-7,55	-9,92	-7,34
999,7	10,4	-10,55	-7,05	-10,65	-7,15	-10,13	-7,55	-9,92	-7,34
999,8	10,5	-10,55	-7,05	-10,63	-7,13	-10,13	-7,55	-9,93	-7,35
999,9	10,6	-10,58	-7,08	-10,64	-7,14	-10,13	-7,55	-9,94	-7,36

RF MHz	IF MHz	CPOL Q IF dBm	CPOL Q Gain dB	XPOL Q IF dBm	XPOL Q Gain dB	CPOL Ka IF dBm	CPOL Ka Gain dB	XPOL Ka IF dBm	XPOL Ka Gain dB
1000	10,7	-10,67	-7,17	-10,64	-7,14	-10,13	-7,55	-9,94	-7,36
1000,1	10,8	-10,66	-7,16	-10,7	-7,2	-10,13	-7,55	-9,97	-7,39
1000,2	10,9	-10,66	-7,16	-10,75	-7,25	-10,13	-7,55	-10	-7,42
1000,3	11	-10,66	-7,16	-10,75	-7,25	-10,13	-7,55	-10,01	-7,43
1000,4	11,1	-10,67	-7,17	-10,75	-7,25	-10,13	-7,55	-10,01	-7,43
1000,5	11,2	-10,7	-7,2	-10,75	-7,25	-10,105	-7,525	-10,01	-7,43
1000,6	11,3	-10,77	-7,27	-10,75	-7,25	-10,12	-7,54	-10,015	-7,435
1000,7	11,4	-10,77	-7,27	-10,75	-7,25	-10,1	-7,52	-10,03	-7,45
1000,8	11,5	-10,775	-7,275	-10,77	-7,27	-10,1	-7,52	-10,11	-7,53
1000,9	11,6	-10,89	-7,39	-10,87	-7,37	-10,1	-7,52	-10,11	-7,53
1001	11,7	-10,89	-7,39	-10,87	-7,37	-10,22	-7,64	-10,11	-7,53
1001,1	11,8	-10,88	-7,38	-10,87	-7,37	-10,22	-7,64	-10,12	-7,54
1001,2	11,9	-11	-7,5	-10,95	-7,45	-10,22	-7,64	-10,21	-7,63
1001,3	12	-11	-7,5	-10,98	-7,48	-10,22	-7,64	-10,21	-7,63
1001,4	12,1	-11,06	-7,56	-11,04	-7,54	-10,34	-7,76	-10,22	-7,64
1001,5	12,2	-11,13	-7,63	-11,13	-7,63	-10,34	-7,76	-10,32	-7,74
1001,6	12,3	-11,23	-7,73	-11,25	-7,75	-10,34	-7,76	-10,32	-7,74
1001,7	12,4	-11,31	-7,81	-11,39	-7,89	-10,46	-7,88	-10,42	-7,84
1001,8	12,5	-11,45	-7,95	-11,6	-8,1	-10,59	-8,01	-10,54	-7,96
1001,9	12,6	-11,66	-8,16	-11,83	-8,33	-10,72	-8,14	-10,67	-8,09
1002	12,7	-11,87	-8,37	-12,26	-8,76	-10,85	-8,27	-10,9	-8,32
1002,1	12,8	-12,24	-8,74	-12,78	-9,28	-11,2	-8,62	-11,25	-8,67
1002,2	12,9	-12,64	-9,14	-13,4	-9,9	-11,6	-9,02	-11,69	-9,11
1002,3	13	-13,23	-9,73	-14,23	-10,73	-12,12	-9,54	-12,26	-9,68
1002,4	13,1	-13,96	-10,46	-15,28	-11,78	-12,81	-10,23	-12,99	-10,41
1002,5	13,2	-14,76	-11,26	-16,36	-12,86	-13,65	-11,07	-13,93	-11,35
1002,6	13,3	-15,75	-12,25	-17,71	-14,21	-14,63	-12,05	-15	-12,42
1002,7	13,4	-16,9	-13,4	-19,13	-15,63	-15,85	-13,27	-16,21	-13,63
1002,8	13,5	-18,17	-14,67	-20,76	-17,26	-17,11	-14,53	-17,51	-14,93
1002,9	13,6	-19,59	-16,09	-22,37	-18,87	-18,52	-15,94	-19	-16,42
1003	13,7	-21,07	-17,57	-24,18	-20,68	-19,95	-17,37	-20,57	-17,99
1003,1	13,8	-22,63	-19,13	-26,08	-22,58	-21,62	-19,04	-22,23	-19,65
1003,2	13,9	-24,34	-20,84	-28,14	-24,64	-23,27	-20,69	-24,05	-21,47
1003,3	14	-26,07	-22,57	-30,42	-26,92	-25,05	-22,47	-25,88	-23,3
1003,4	14,1	-27,99	-24,49	-32,9	-29,4	-26,88	-24,3	-27,86	-25,28
1003,5	14,2	-29,97	-26,47	-35,75	-32,25	-28,9	-26,32	-30,07	-27,49
1003,6	14,3	-32,1	-28,6	-39,13	-35,63	-31,2	-28,62	-32,43	-29,85
1003,7	14,4	-34,47	-30,97	-43,29	-39,79	-33,55	-30,97	-35,2	-32,62
1003,8	14,5	-37,24	-33,74	-48,02	-44,52	-36,32	-33,74	-38,52	-35,94
1003,9	14,6	-40,48	-36,98	-48,8	-45,3	-39,57	-36,99	-42,53	-39,95
1004	14,7	-44,38	-40,88	-45,6	-42,1	-43,74	-41,16	-47,63	-45,05

13.2 Gain characteristic of second down conversion

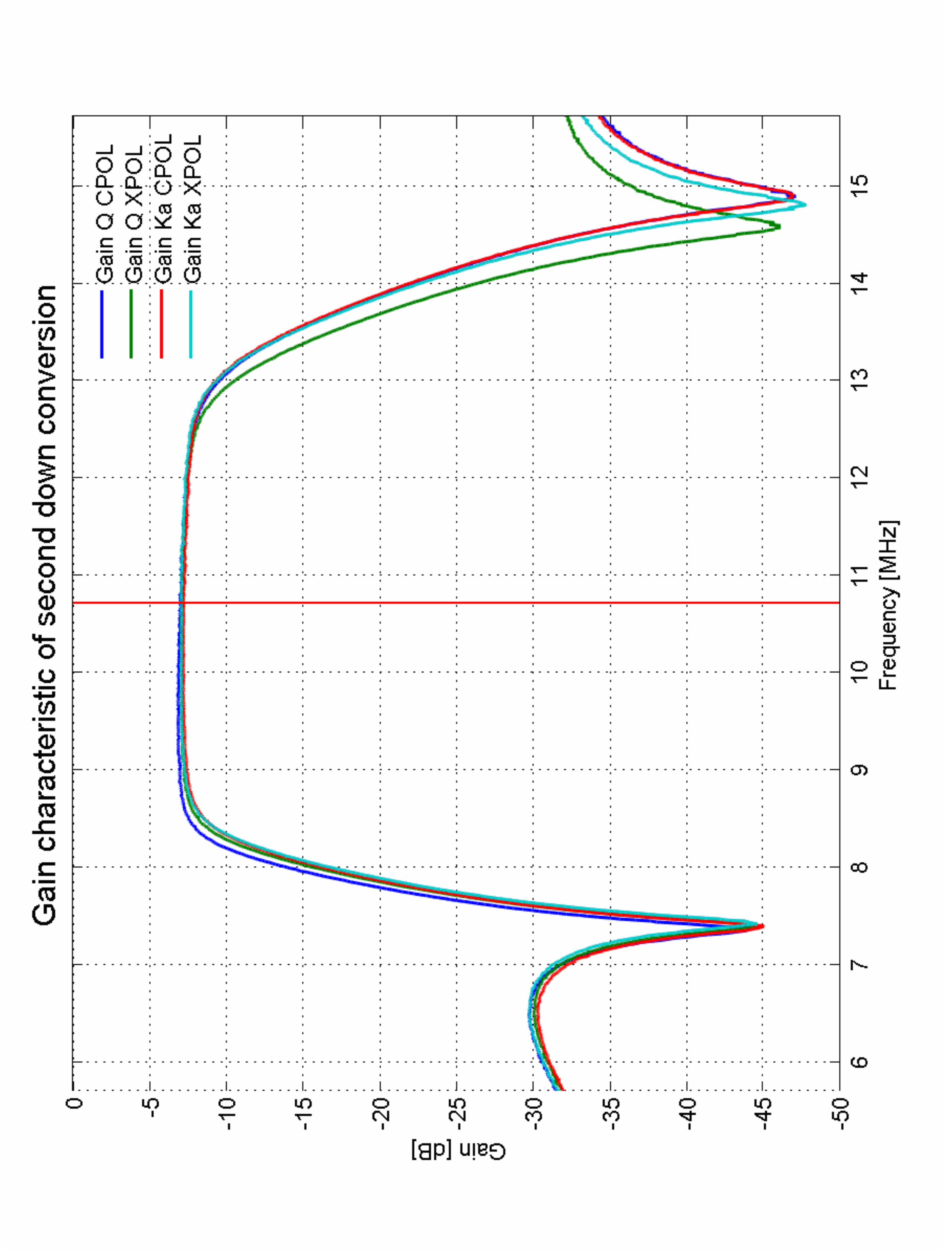

Table 13-1 2nd Down conversion gain characteristic larger image

13.3 Conversion loss of the ZEM 4300 + Mixer

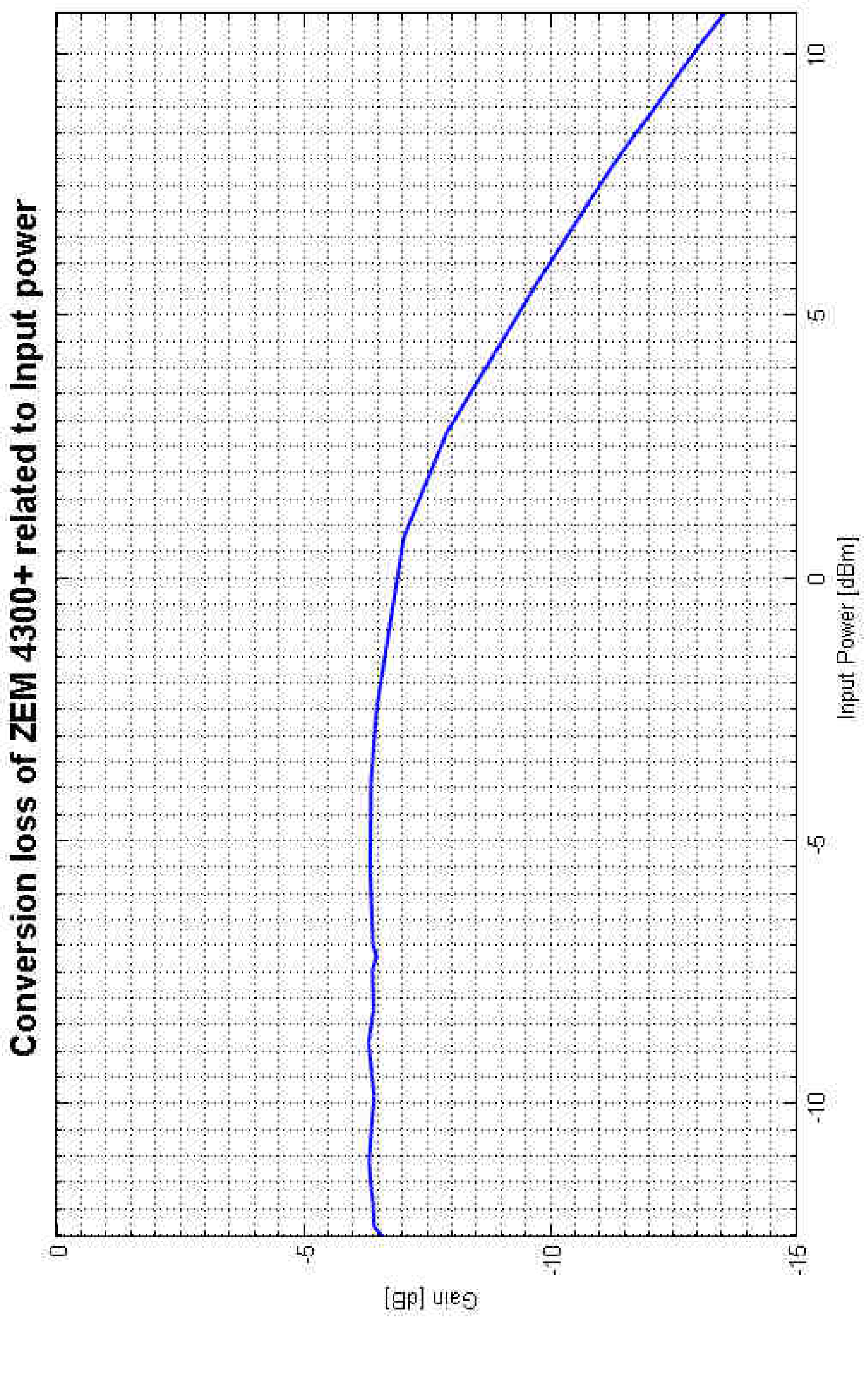

Figure13-1 larger image of mixer ZEM4300+ conversion loss

14 ANNEX D: Software scripts

14.1 MATLAB settings for automatic characterisation of 2nd Down conversion stage

```
% Title:    AlphasatRX Terminal down conversion
% Author:   Gerald Faustmann
% Date:     02/01/2011

% Description:
% This program automatically measures the gain characteristic of the 4
% signal chains. A manual recabling has to be executed by the operator

clc;
clear;
close;
delete(instrfindall);

%------------------------------------------------------------------------
% Serial port Settings for Oscillator:
%------------------------------------------------------------------------

PLO_port = 'COM1';
PLO_baudrate = 38400;
PLO_databits = 8;
PLO_terminator = 'CR';

%------------------------------------------------------------------------
% Serial port Settings for Oscillator:
%------------------------------------------------------------------------

FSH_port = 'COM4';
FSH_baudrate = 19200;
FSH_databits = 8;
FSH_terminator = 'CR';

%------------------------------------------------------------------------
% Measurement Settings
%------------------------------------------------------------------------

start_frequency = 995;
stop_frequency = 1005;
step_frequency = 0.01; % in MHz
LO_frequency = 989.3; %MHz
```