STUDENTS' SPACE ASSOCIATION

THE FACULTY OF POWER AND AERONAUTICAL ENGINEERING

WARSAW UNIVERSITY OF TECHNOLOGY

CRITICAL DESIGN REVIEW

Communication System and Ground Station

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Abbreviated terms

ADCS	Attitude Determination and Control System
COMM	Communication subsystem
DT	Deployment Team
EM	Engineering Model
EPS	Electrical Power System
ESA	European Space Agency
FM	Flight Model
GS	Ground Station
LEO	Low Earth Orbit
MA	Mission Analysis
MDR	Mission Definition Review
PDR	Preliminary Design Review
SC	Spacecraft
SKA	Studenckie Koło Astronautyczne (Students' Space Association)
SSO	Sun-Synchronous Orbit
SW	Software
TBC	To Be Continued
TBD	To Be Defined
WUT	Warsaw University of Technology

1 INTRODUCTION

1.1 DOCUMENTATION STRUCTURE

Chapter 2 describes the Communication Module

Chapter 3 contains description of ANT module.

Chapter 4 is related to Ground Station equipment.

Chapter 5 provides description and calculation of Radio Link Budget.

Chapter 6 lists communication scenarios.

Chapter 7 is devoted to testing philosophy, procedures and plans.

1.2 PROJECT DOCUMENTATION STRUCTURE

See §1.3 in [PW-Sat2-C-00.00-Overview-CDR].

1.3 REFERENCE DOCUMENTS

[1] ISIS Space, „ISIS UHF downlink / VHF uplink Full Duplex Transceiver,” [Online]. Available: http://www.cubesatshop.com/product/isis-uhf-downlink-vhf-uplink-full-duplex-transceiver/.

[2] ISIS, „ICD for the TRXVU - Documentation”.

[3] „Tabela przeznaczeń częstotliwości UKE”.

[4] „Dokumentacja układu RFMD2081,” [Online]. Available: http://www.farnell.com/datasheets/1699519.pdf.

[5] „Dokumentacja układu C/A AD5340,” [Online]. Available: http://www.analog.com/static/imported-files/data_sheets/AD5330_5331_5340_5341.pdf.

[6] „Dokumentacja płytki Altera DE0,” [Online]. Available: http://www.ee.ic.ac.uk/pcheung/teaching/ee2_digital/DE0_User_manual.pdf.

[7] „Dokumentacja wzmacniacza operacyjnego AD8544R,” [Online]. Available: http://www.analog.com/static/imported-files/data_sheets/AD8541_8542_8544.pdf.

[8] „Dokument opisujący anteny ISIS,” [Online]. Available: http://www.cubesatshop.com/.

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[10] Altera, „PowerPlay Early Power Estimator Download for Cyclone III Devices,” [Online]. Available: http://www.altera.com/support/devices/estimator/pow-powerplay.jsp.

[11] J. Cichocki, Materiały do przedmiotu "Miernictwo Radioelektroniczne", EiTI PW, 2014.

[12] K. Kurek, Materiały do przedmiotu "Łączność Satelitarna", EiTI PW, 2014.

1.4 DOCUMENT CONTRIBUTORS

This document and any results described were prepared solely by PW-Sat2 project team members.

2 COMMUNICATION MODULE OVERVIEW

2.1 INTRODUCTION

The UHF downlink and VHF uplink communications module is responsible for receiving commands, sending telemetry and payload data. It has been decided to buy an existing communications module along with an antenna module. ISIS UHF downlink / VHF uplink Full Duplex Transceiver have been chosen. The technical specification of the communications module is obtained from the manufacturer’s website [1]. The transceiver module is presented on the image below.

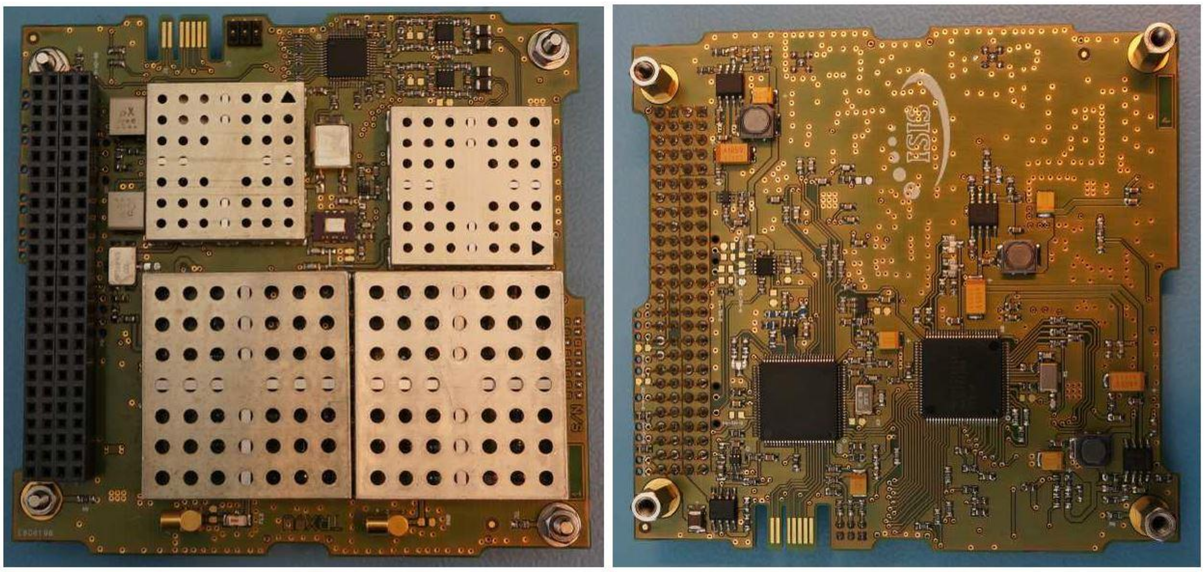


Figure 2-1 Photo of ISIS UHF downlink / VHF uplink Full Duplex Transceiver PCB.

2.2 BASIC PARAMETERS

Most important parameters of chosen communication module are shown in Table 2-1 from [1].

Table 2-1 Parameters of ISIS UHF downlink / VHF uplink Full Duplex Transceiver

Technical parameters of an UHF transmitter	
RF output power	500 mW (27 dBm)
Bitrate	9600 bps (max)
Modulation type	BPSK
Link layer protocol	AX.25
Technical parameters of a VHF receiver	
Sensitivity	- 98 dBm (@ BER = 1e-5)

Data rate	1200 bit/s
Modulation type	AFSK
Link layer protocol	On-board AX.25 command decoding
Frequency deviation	3.5 kHz
Power consumption	
Supply voltage	6. – 20 VDC
While transmitting and receiving (V_{sup} = 8 V)	Max. 4800 mW
While receiving (V_{sup} = 8 V)	Max. 480 mW

The module will be prepared to transmit/receive on frequencies from PW-Sat(1) satellite:

- 145.900 MHz (VHF Uplink)
- 435.020 MHz (UHF Downlink)

Uplink and downlink frequencies was swapped in comparison to Phase A documentation. This action was performed due to known RF interferences with military radar bands in Poland.

2.3 MODULE BLOCK DIAGRAM

Transceiver can be divided into 4 basic parts: receiver, transmitter, and data processing block. Both receiver and transmitter are double heterodyne devices and their frequencies will be configured by ISIS. Shared data processing block is responsible for processing input/output data so that it'll be ready to write/read from I2C. Block diagram of the module is shown below.

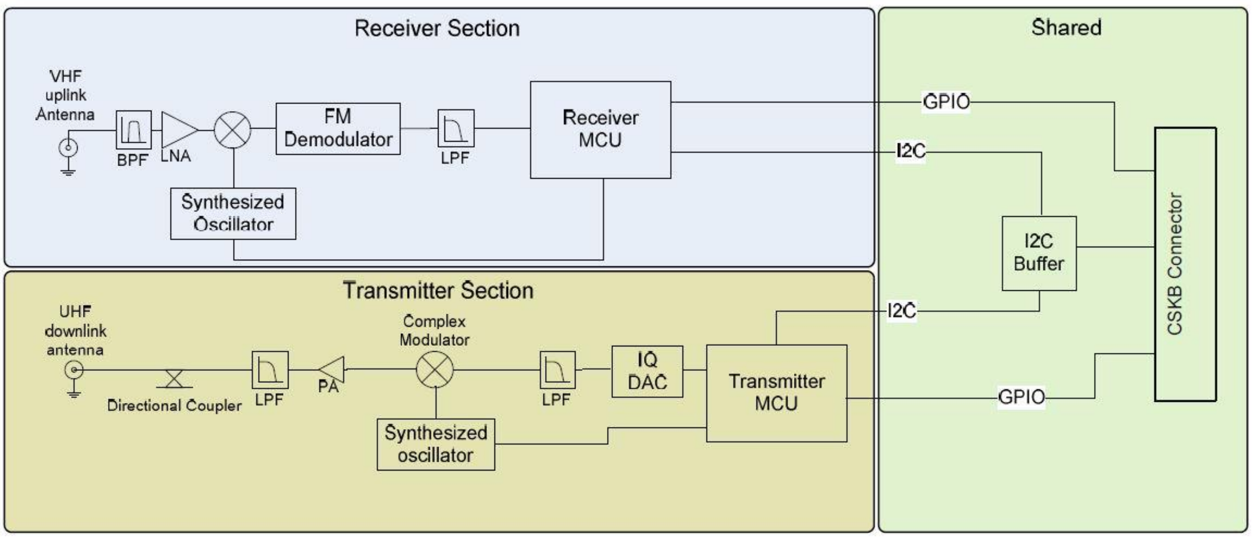


Figure 2-2 Functional block diagram of of ISIS UHF downlink / VHF uplink Full Duplex Transceiver.

2.4 INPUT/OUTPUT INTERFACES

The module will be connected to PC-104 stack connector on appropriate pins handling I2C, power supply and additional features described in [2]. Configuration of device electronics and calibration with the antennas is made by ISIS.

Communication module is designed to communicate with OBC or EPS (in emergency mode) via I2C.

The module will be connected to antennas via MMCX connectors. Impedance of connectors and lines is 50 Ω. Cables with proper length and properties will be used.

Table 2-2 and Figure 2-3 show how to identify the different electrical interface on the board.

Table 2-2 TRxVU External Interfaces

Source-destination	Conn	Signal	Comments
Antenna System	J4	RX–VHF Receiver input	MMCX
Antenna System	J3	TX–UHF Transmitter output	MMCX
System Bus	H1and H2	CubeSatKitBus	PC104

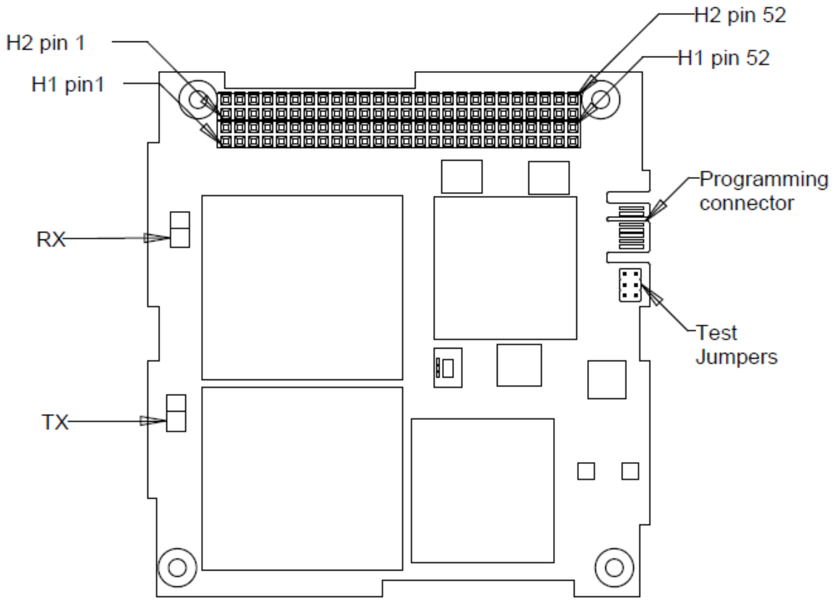


Figure 2-3 TRxVU external interfaces (top view)

2.4.1 VHF RECEIVER INPUT

Figure 2-4 shows the VHF receiver input schematic to provide an indication of the internal structure.

The connector used to connect to a VHF antenna is an MMCX right-angle plug, oriented towards the CSKB connector. The connector identifier is J4. Connector pin-out can be seen in Table 2-3.

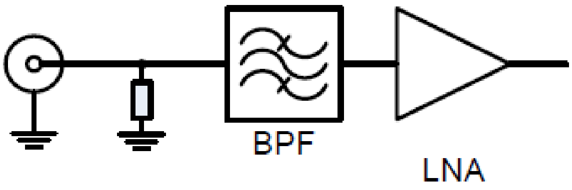


Figure 2-4 VHF Receiver input interface schematic

Table 2-3 RX - VHF receiver input connector pin out

Center pin	RF input	50 Ω RF input
Cladding	GND	RF ground (common with power ground)

Table 2-4 VHF Receiver input electrical characteristics

Parameter	**Value**	**Notes**
RX frequency	145.900 MHz	
Baud rate	1200 bit/s	
IF bandwidth	30 kHz	
Modulation scheme	FM	
Receiver type	Double conversion super-heterodyne	
First Intermediate Frequency	45 MHz	
Second Intermediate Frequency	455 kHz	
Local oscillator frequency	Receive frequency –45 MHz	
Receiver sensitivity	-98 dBm	Bit Error Rate= 1e-5
Maximum input level	0 dBm	Absolute Maximum
VSWR	< 1:1.3	
DC Resistance to GND	< 1 Ω	

2.4.2 UHF TRANSMITTER OUTPUT

Figure 2-5 shows the UHF receiver output schematic to provide an indication of the internal structure. The connector used to connect to a UHF antenna, is an MMCX right-angle plug, oriented towards the CSKB connector. The connector identifier is J3. Connector pin-out can be seen in Table 2-5.

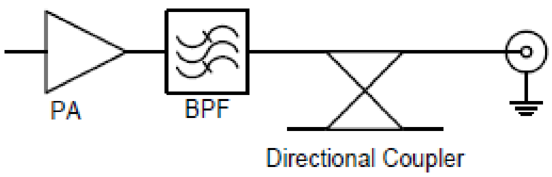


Figure 2-5 UHF Transmitter output interface schematic

Table 2-5 TX - UHF transmitter output connector pin out

Center pin	RF out	50 Ω RF output
Cladding	GND	RF ground (common with power ground)

Table 2-6 shows the electrical characteristics of the receiver.

Table 2-6 UHF Transmitter output electrical characteristics

Parameter	Value	Notes
TX frequency range:	435.020 MHz	
Peak output power	27 dBm	Maximum value
VSWR	< 1:1.3	With ISIS ants module
Spurious suppression:	> 50 dBc	
DC Resistance to GND	< 1 Ω	

2.4.3 CUBESAT KIT BUS INTERFACE

The pin-out of the stack connector and the definition of the channels are explained in the following figures and tables.

Figure 2-6 CSKB connector pin-out.

Table 2-7 CSKB connector pin-out.

CSKB Pin	ISIS TRxVU	Signal Description	Voltage range
H1-41	I2C SDA	I2Cdata Signac	0-3.3 V
H1-43	I2C SCL	I2C clock signal	0-3.3 V
H2-29	GND	Ground	
H2-30	GND	Ground	
H2-32	GND	Ground	
H2-45	BAT_BUS	Battery bus	6.0-20 V
H2-46	BAT_BUS	Battery bus	6.0-20 V

2.5 RF INTERFACE

This section describes the uplink and downlink modulation and protocol parameters.

2.5.1 DOWNLINK

The downlink modulation and protocol parameters are summarized in Table 2-8.

Table 2-8 Downlink modulation and protocol parameters

Parameter	Value	Notes
Modulation	BPSK	
Pulse shaping	Raised Cosine	
Roll-off factor	1.0	

Scrambling polynomial	1 + X12 + X17	G3RUH scrambling
Protocol	AX.25connectionless	Only UI frames supported
Maximum frame payload size	235	Default value. Specified in option sheet

2.5.2 UPLINK

The downlink modulation and protocol parameters are summarized in Table 2-9.

Table 2-9 Uplink modulation and protocol parameters

Parameter	Value	Notes
Modulation	AFSK	
Frequency deviation	3 kHz	
Baudrate	1200bps	
Scrambling polynomial	None	
Protocol	AX.25	
Maximum frame payload size	200	Default value. Specified in option sheet

3 ANTENNA MODULE OVERVIEW

Transceiver will be connected to suitable antenna system from ISIS. Due to the fact, that for selected frequencies antennas lengths exceed satellite dimensions, deployable antenna system was chosen.

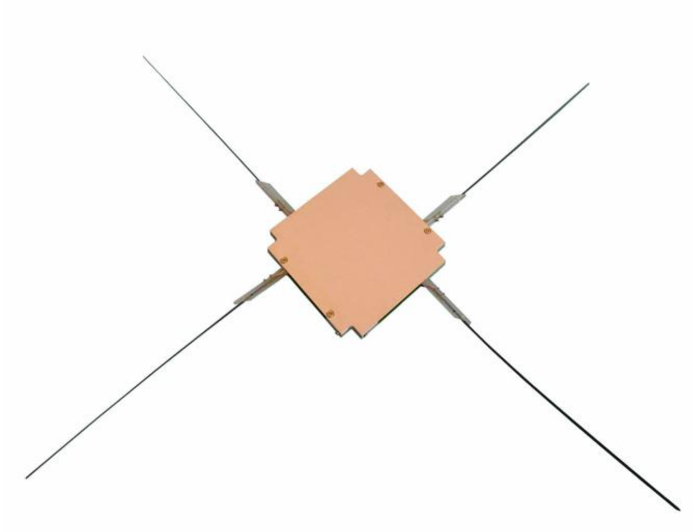


Figure 3-1 ISIS Deployable Antenna System

Deployment of antenna module is implemented using special wires that are burned out by DC current in few seconds and release deployment mechanism. The whole antenna deployment system is one of critical ones, so its sub-systems are duplicated – including communication lines and burn-out wires. According to this, it has two addresses and if there's no confirmation after first try of revealing the antennas, there's a possibility of connecting to the module via another address. Some basic parameters of Antenna module are show in Table 3-1.

Table 3-1 Parameters of deployment system

Antenna module configuration	
Bus	I2C Dual Bus
Primary/secondary I^2C address	0x31 / 0x32
Connectors type	MMCX
Supply voltage	5 VDC
Antenna gain	0 dBi

3.1 TRANSMITTER/RECEIVER ANTENNA CONFIGURATION

Selected mechanical configuration for antennas is shown in Figure 3-2.

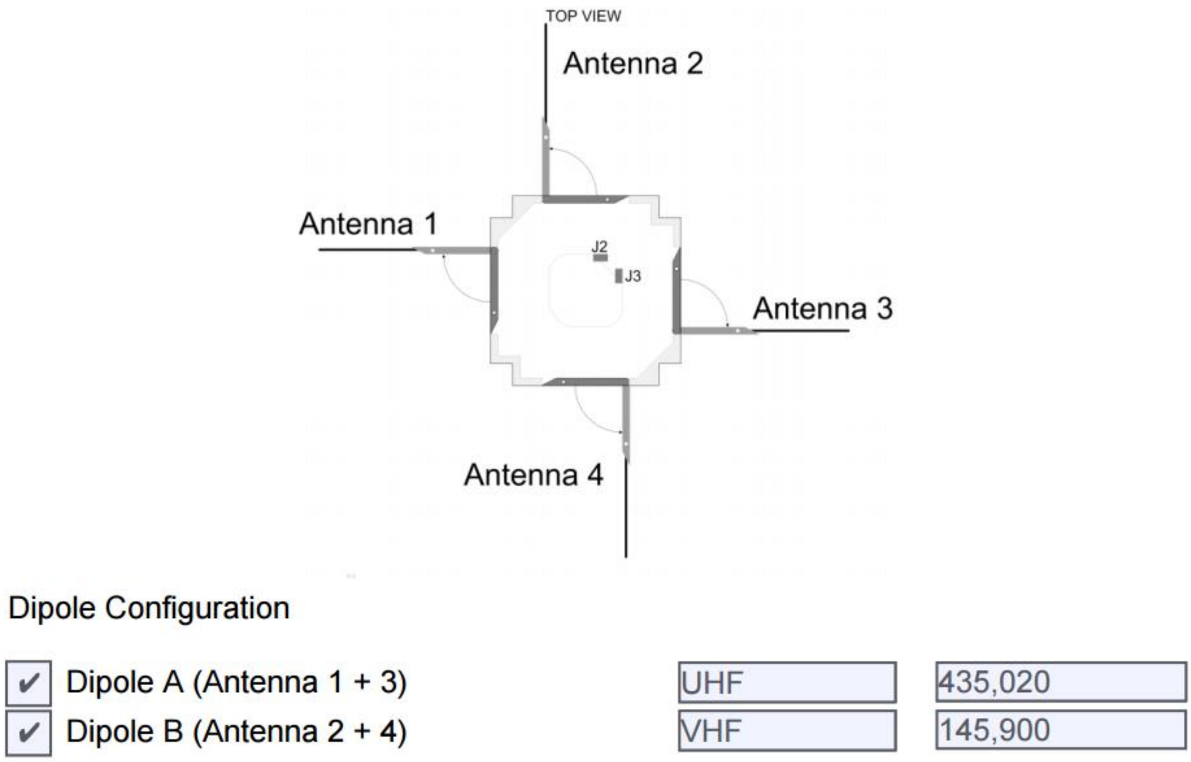


Figure 3-2 ISIS Deployable Antenna System configuration

3.2 RADIATION CHARACTERISTIC SIMULATIONS

- Charakterystyka bez żagla
- Charakterystyka z otwartym żaglem

4 GROUND STATION OVERVIEW

4.1 MAIN GROUND STATION IN WARSAW

Main base station that will be used to communicate with PW-SAT2 will be placed in the Faculty of Electronics and Information Technology, ul. Nowowiejska 15/19, 00-665 Warszawa.

4.2 EQUIPMENT

The station is equipped with transceiver ICOM IC-910H, computer, system to rotation antennas and TNC to digis modes. Using the experience of BRITE team, we decided to use cross Yagi-Uda antennas – Tonna 20818 (2 x 9 elements) for VHF and Tonna 20938 (2 x 19 elements) for UHF. Antennas will be used with symmetrical splitters from Tonna. This will decrease in the radio signal associated with the rotating PW-Sat2. To eliminate interferences and to amplify the satellite signal has been low noise amplifier added – SSB LNA-70.

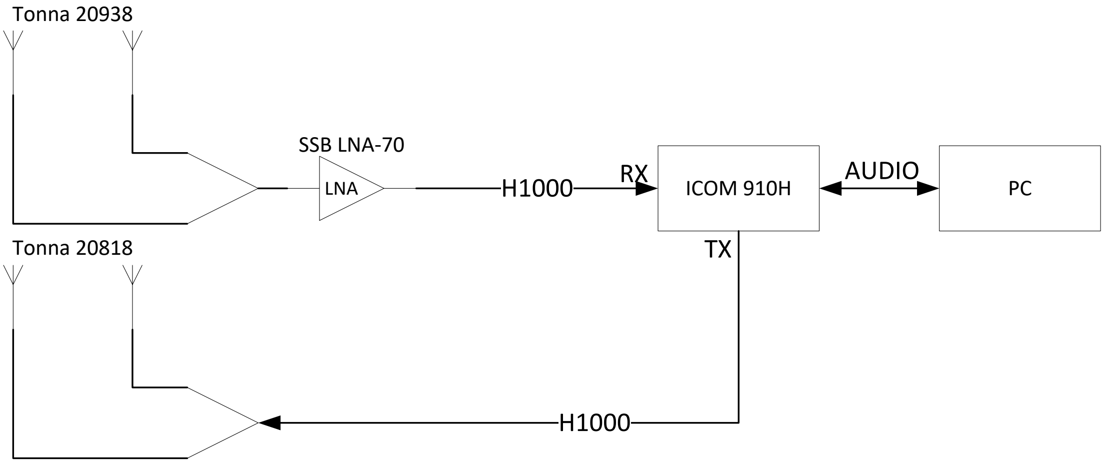
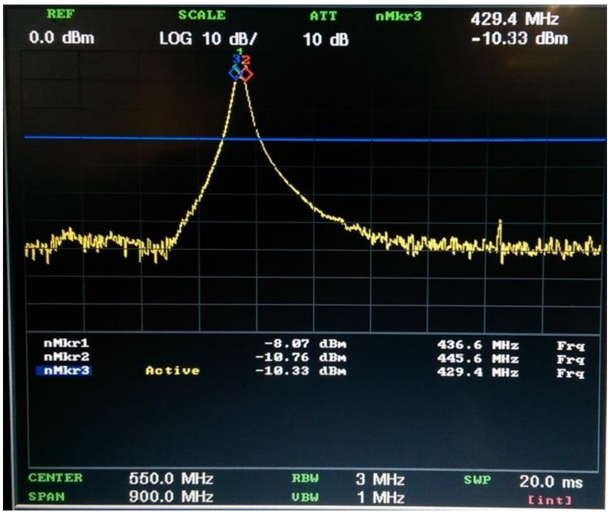


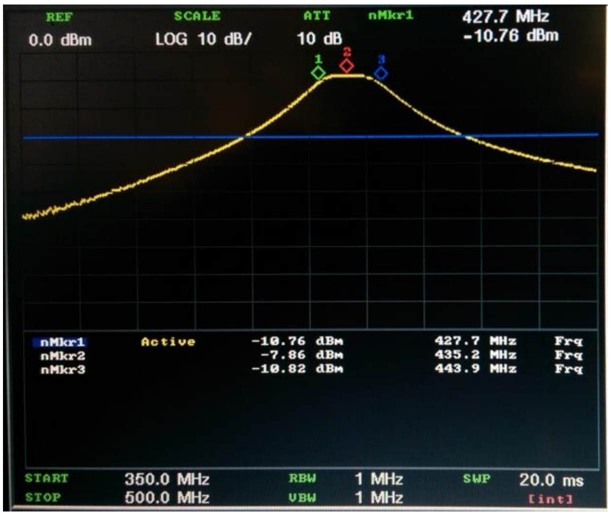
Figure 4-1 GS block schematic

4.2.1 LNA MEASUREMENTS

Below are presented the results of measurements of the amplifier, which will be used in the RX path (435.02 MHz). The declared value of the gain - 20dB, it had been fulfilled.

To work properly, the device must be supplied with DC 12V





4.3 EXPECTED PARAMETERS

It is expected that following parameters of GS will be obtained:

Table 4-1 GS parameters

Description	Value
Frequency (Receiver / Transmitter)	435.020 / 145.900 MHz
Transmitter antenna gain	14.8 dBi
LNA gain	21 dB
Additional losses	20 dB
Transmitter RF power supply	50 dBm

5 RADIO LINK POWER BUDGET

In order to validate the communication link budget will be calculated in both uplink and downlink. Received powers as well as BER will be calculated.

5.1 UPLINK

Description	Comment	Value
Transmit power	ICOM-910H at 145.9 MHz – 100 W = 50 dBm	50 dBm
Matching loss	VSWR = 1.5	0.2 dB
Splitter	split equally on two cross-polarized antennas	3 dB
TX Antenna gain	Tonna 20818 (2 x 9 elements)	13.15 dBi
Atmospheric loss	Based on ITU-R P.676-11; 50 km atmosphere	1.5 dB
Polarization loss	maximum deflection: 45°	3 dB
Free Space Loss	d = 1600 km (15° above horizon); f = 145.9 MHz	140 dB
RX Antenna gain		0 dBi
Matching loss	VSWR < 1.2	0.1 dB
Balun loss	As measured by manufacturer	4 dB
SUM	Input power at COMM module	**-88.65 dBm**
RX sensitivity	for BER=1e-5	**-98 dBm**
Margin		**9 dB**

For uplink, there is 9 dB margin. The margin will likely to drop when satellite is not in correct orientation due to radiation pattern of receiving antenna. RX antenna gain will vary from -10 to 0 dB (with one drop up to -20 dB), so effort should be made to increase this margin.

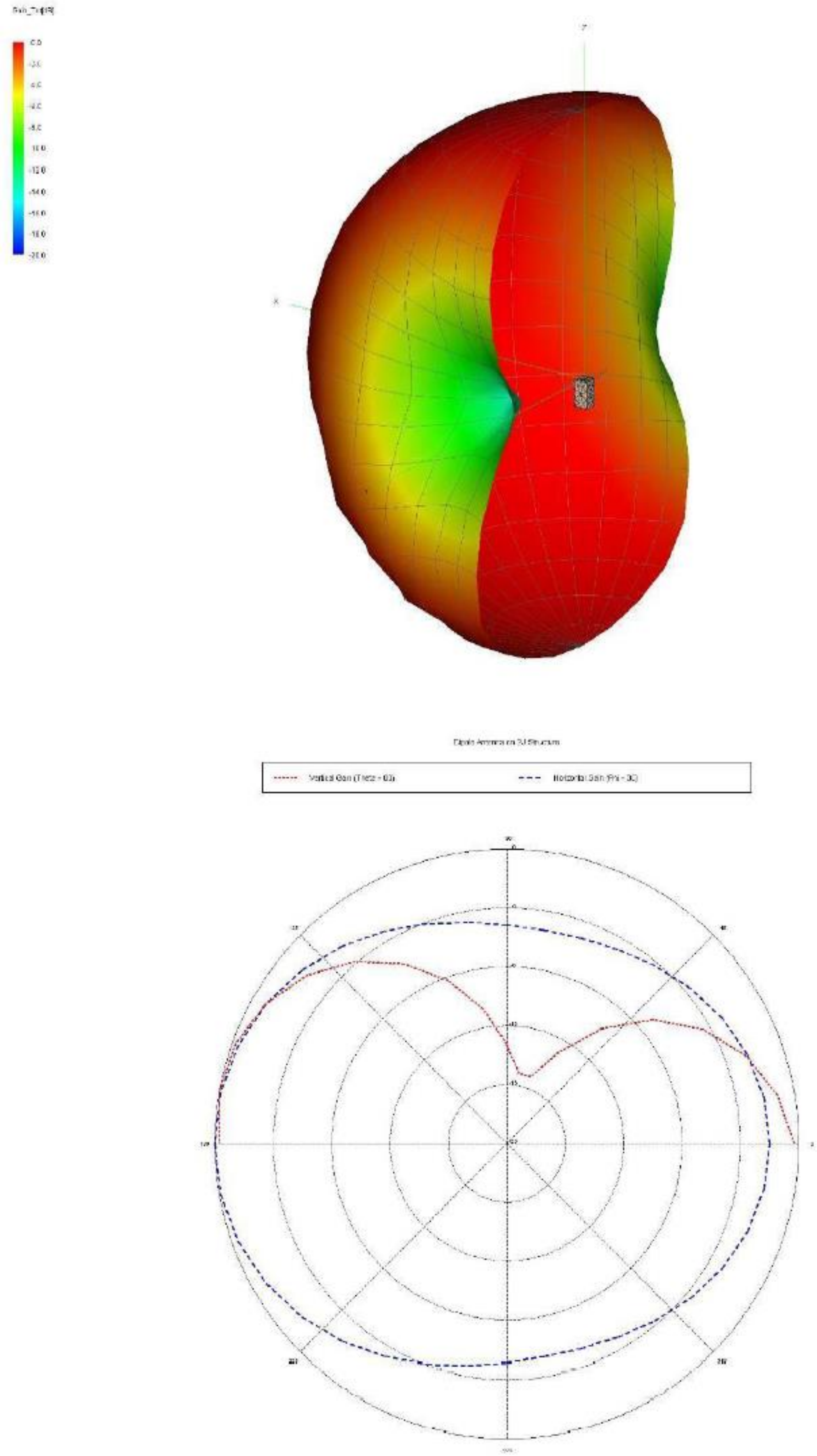


Figure 5-1 RX antenna radiation pattern

5.2 Downlink

For downlink, Eb/N0 parameter will be calculated. Ground station is made by PW-Sat2 team, therefore we don't have input power requirements.

5.2.1 Received power

Description	Comment	Value
Transmit power	As measured by manufacturer	27.8 dBm
Matching loss	VSWR = 1.2	0.1 dB
Balun loss	As measured by manufacturer	4 dB
TX Antenna gain		-6 dBi
Atmospheric loss	Based on ITU-R P.676-11; 50 km atmosphere	1.5 dB
Polarization loss	maximum deflection: 45°	3 dB
Free Space Loss	d = 1600 km (15° above horizon); f = 435.02 MHz	150 dB
RX Antenna gain	Tonna 20938 (2 x 19 elements)	16 dBi
Matching loss	VSWR < 1.5	0.2 dB
Splitter		3 dB
SUM	Input power at LNA port	**-126 dBm**

5.2.2 Equivalent noise temperature of system

In receiver system, there is LNA next to the antenna, next connected to GS radio.

Description	Comment	Value
Antenna noise temperature	At normal conditions; measured	300 K
LNA noise figure	From datasheet	0.35 dB
LNA noise temperature		24 K
LNA gain	As measured	20 dB
Radio sensitivity	Declared by manufacturer	0.11 μV ⇒ -126 dBm
Radio bandwidth	on SSB mode	4200 Hz

Radio noise temperature		4172 K
LNA + radio noise temperature	Radio/LNA gain + LNA temp.	66 K
Antenna + LNA + radio noise temperature		366 K

Equivalent noise temperature of receiving system is 366 K.

5.2.3 Eb/N0

Noise floor was calculated, assuming 4200 Hz bandwidth on SSB mode:

$$N = k \cdot T \cdot B = -166\ dBm$$

Carrier-to-noise:

$$C/N = 40\ dB$$

Channel bitrate = 2400 bit/s.

Therefore:

$$Eb/N0 = C/N \cdot \frac{B}{bitrate} = 37\ dB$$

For BPSK modulation required Eb/N0 is about 15 dB.

Margin of Eb/N0 = 12 dB.

For receiving, there is very sufficient margin of safety.

6 Communication Scenarios And Data Format

Selected communication system is using AX.25 data link layer protocol designed for use by amateur radio operators. It is used extensively on amateur packet radio networks.

To transmit satellite-specific information, additional data structures will be designed. This data bytes structures are automatically put into AX.25 frames.

6.1 Down-link data

6.1.1 Data storage

All experiments data are stored in non-volatile FLASH memory connected via SPI bus to OBC.

Storage is made with yaffs file system, providing abstraction layer of files in memory.

Each file is data from experiment or HK data (e.g. SunS experiment).

6.1.2 Radio frame

Maximum allowed payload to be send via AX.25 frame is 235 bytes, therefore is is necessary to provide mechanism to split experiment data into frames, which can be send to GS, as well as later discarded/retransmitted.

6.1.3 Frame format

PW-Sat2 frame was derived from CCSDS space packet protocol.

Each file inside memory will be assigned unique APID (application ID), and within the file each 235-byte block will be assigned unique SEQ (Sequence counter). This leads to assumption that each 235-byte block in memory will be addressable and accessible from GS.

APID and SEQ will be added to each frame transmitted via radiolink to make identification and merging possible on ground:

header		data
APID	SEQ	
6 bits	*18 bits*	*1856 bits*

6.1.4 Data storage limit

Each FLASH bank is 16 MB. At this stage is it sure that on PLD board there will be no more than 8 memory banks. This leads to value of 128 MB accessible memory from OBC. Therfore, there is a limit of 571139 blocks in memory, which is ~ 2^19.

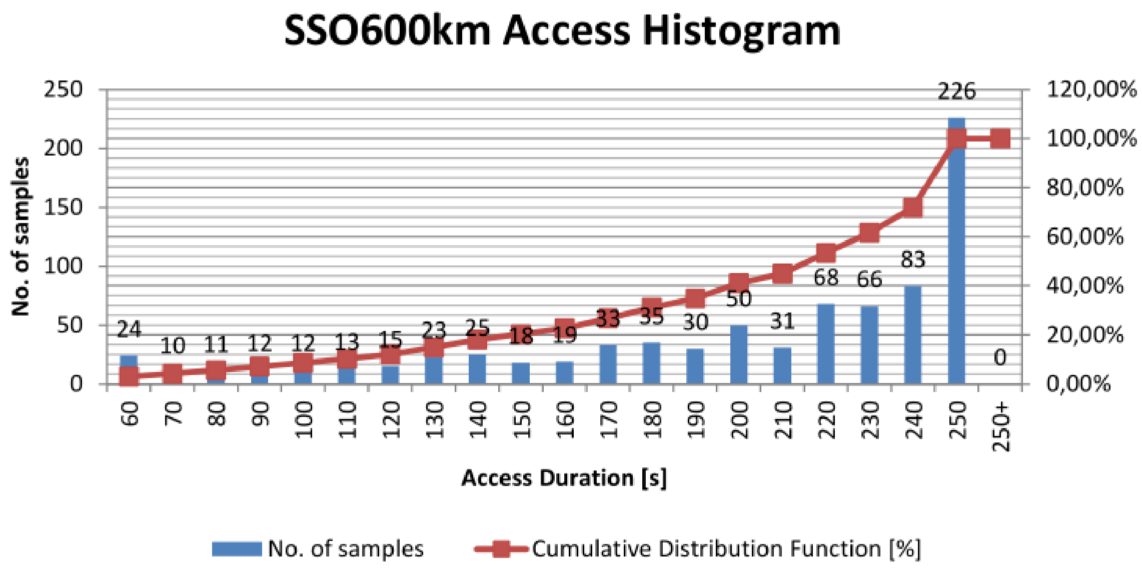


Figure 6-1 Communication window histogram [PW-Sat2-B-00.01-MA-PDR]

Communication window histogram is depicted above (Location: Warsaw 130 m a.s.l, Minimum elevation angle for satellite visibility: 30°, Omni-directional antenna).

Assuming longest communication session to be ~4 minutes and data rate of about 9600 bit/s and overhead of ~10% (AX.25) is was calculated that amount of data which could be send within one window is TBD kB.

6.1.5 APID and SEQ bit-lengths

Is is assumed that number of files will be less than 64 - so the number of 6 bits for APID was fixed.

The length of SEQ is just filling remaining bytes. 10 bits would be to less for one file (245 kB limit), so the value of 18 bits was chosen.

6.1.6 Data access

With this kind of block numbering GS can access every block in OBC memory to be transmitted.

Each block in memory will have its unique pair of (APID, SEQ) - so even in case of packet loss during transmission GS can ask OBC to re-send particular block.

6.1.7 File storage

Inside files on FLASH memory data from measurement channels has to be stored.

It was proposed to hold each values in each block as (key, value) pairs:

id	value	id	value	id	value	...

This will induce very large overhead, but it is considered as most reliable and easy to code solution.

Each measurement channel ID will be unique number, meaning one telemetry channel in the whole satellite.

Most probably ID will be two bytes long, because it is thought that there will be more that 255 channels.

But, if many data channels could be merged into one ID (e.g. 3 gyro axis send with 1 byte ID and 3*n bytes value) changing to 8 bit ID could be considered.

Telemetry message and beacon are continuously transmitted, the data refreshed every 2 minutes. The interval between successive frames will not be longer than 30 seconds.

6.2 UP-LINK DATA FORMAT

6.2.1 TELECOMMAND

It is proposed to add following telecommands:

“Send data”

- Parameters: first and last block to be send (block range)
- Reponse: ACK + following blocks from memory.

With this telecommand GS can automatically ask for particular block in case of packet loss (due to e.g. random noise).

TBD

7 TESTING

For testing transmitter functionality schematic from Figure 7-1 is going to be used.

The transmitter will be tested by measuring the generated power in two ways:

- With antenna. It will be measured power received by the reference antenna on the known distance.
- Without antenna. Power is measured directly at the output of the transmitter

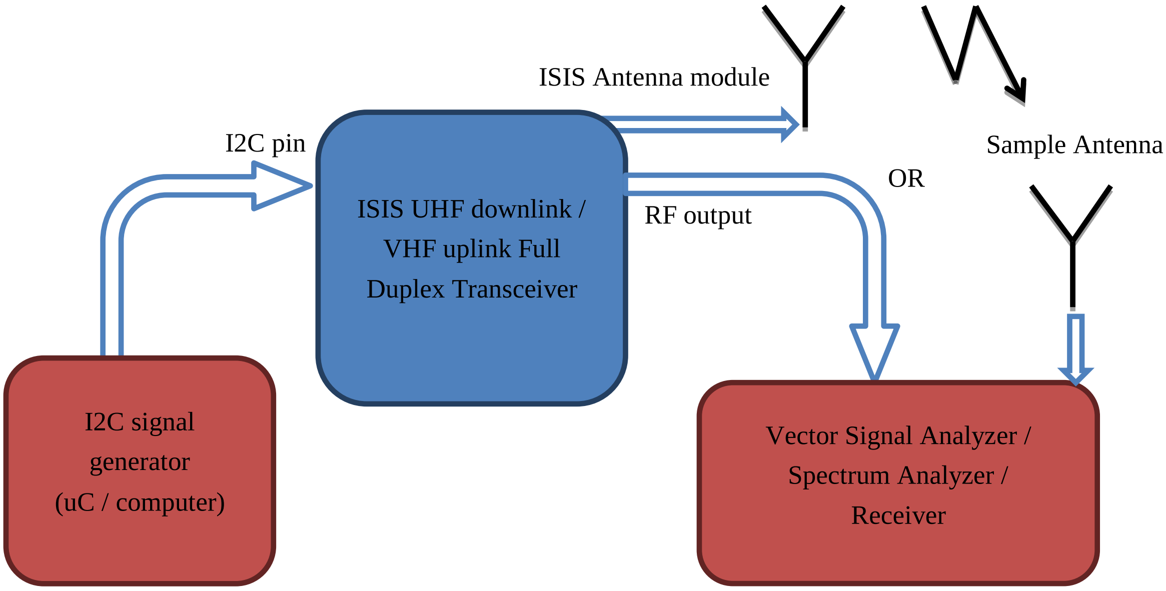


Figure 7-1 Measurement schematic for transmitter tests

7.1 RECEIVER MODULE TESTS

For testing receiver functionality schematic from Figure 7-2 is going to be used.

Receiver tests will be carried out:

- Sensitivity test. Carried out using an external generator, which will supply a signal directly to the input of the receiver.
- Selectivity test. Test carried out by the administration of signals of other frequencies on the input of the receiver. It will be checked saturation receiver on mirrors frequencies.

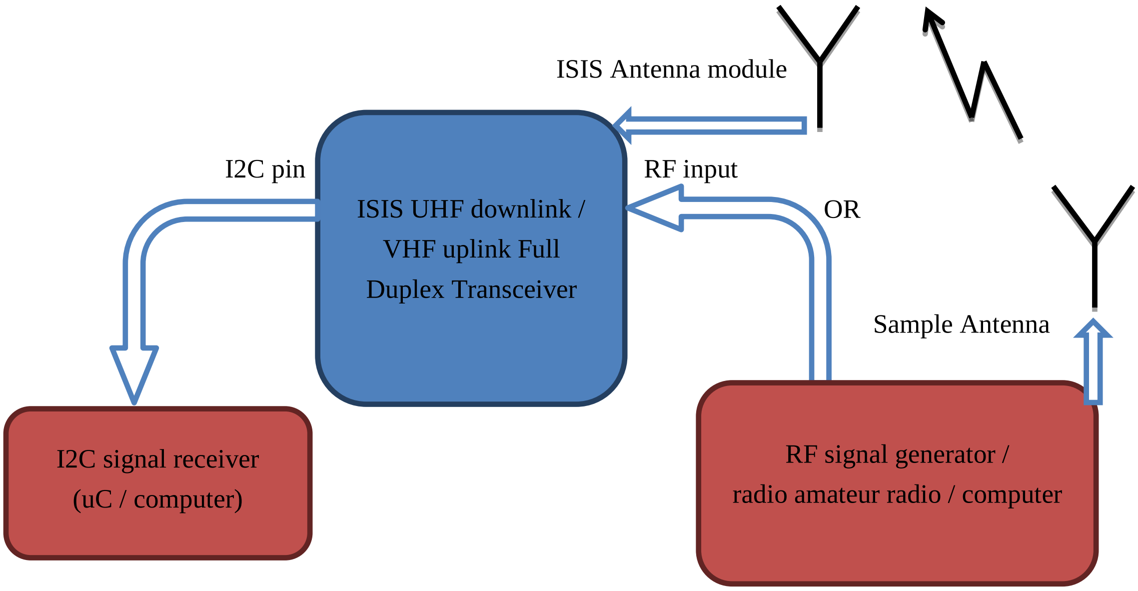


Figure 7-2 Measurement schematic for receiver tests.

7.2 ANTENNA MODULE TESTS

Due to the security module antenna will be conducted test opening aerials, and VSWR test. Directionality and dependence on the sail will be checked using simulation programs.

7.2.1 SIMULATIONS

Without sail (dipole antenna only):

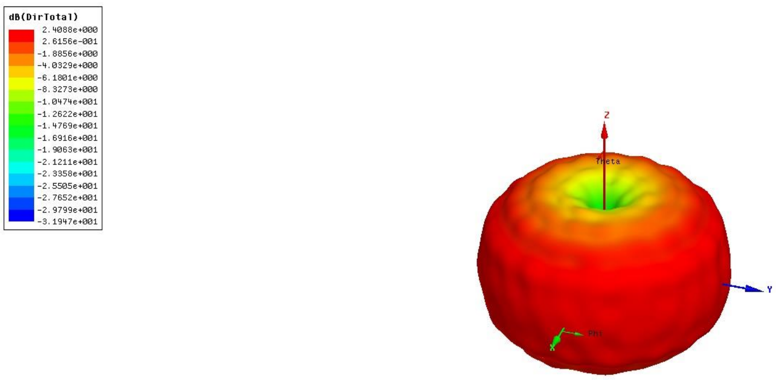


Figure 7-3 Simulations results for case without sail

With open sail:

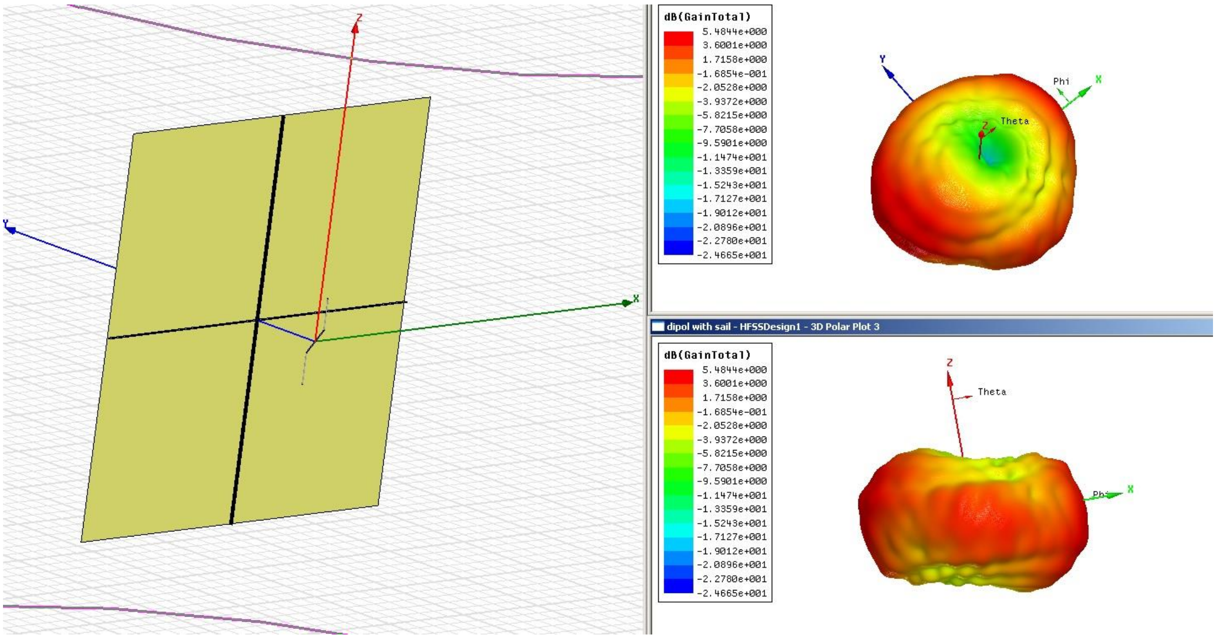


Figure 7-4 Simulations results for case with open sail

Simulations have shown that such a thin sail and its frame is not significantly affected on antenna characteristic.