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List of Abbreviations

ADC	Analog-to-Digital Converter
COTS	Commercial Off The Shelf
DAC	Digital-to-Analog Converter
FE	Front-End
FPGA	Field Programmable Gate Array
LNA	Low Noise Amplifiers
RX	Receiver
SAR	Synthetic Aperture Radar
SDR	Software-Defined Radio
SWA	Size, Weight and Absorption
TX	TRANSMITTER
UAV	Unmanned Aerial Vehicle
USRP	Universal Software Radio Peripheral
VSWR	Voltage Standing Wave Ratio

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1 Summary

The present report describes architecture and design of the low-frequency, multi-mode, radar to be installed on board of light UAV, envisaged for FLY-RADAR project.

The radar system will have two operative modes, working as side-looking SAR and nadir-looking sounder, with two central frequencies in the P-band and VHF band respectively.

In SAR mode, the radar will allow acquisition of full polarised (HH, HV, VH and VV) images, while in sounder mode only one polarisation will be used for producing radargrams.

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2 Architecture

The foreseen architecture of the radar is shown in Figure 1, where three main blocks can be identified:

Electronic system, that is devoted to:

- generate signals to be transmitted;
- generate all trigger signals for radar synchronization;
- acquire signals received by the radar.

Antenna front-end that is devoted to:

- perform TX/RX switch;
- amplify transmitted signals;
- amplify received signals (low-noise).

Antenna, that will be different for the two radar operative modes.

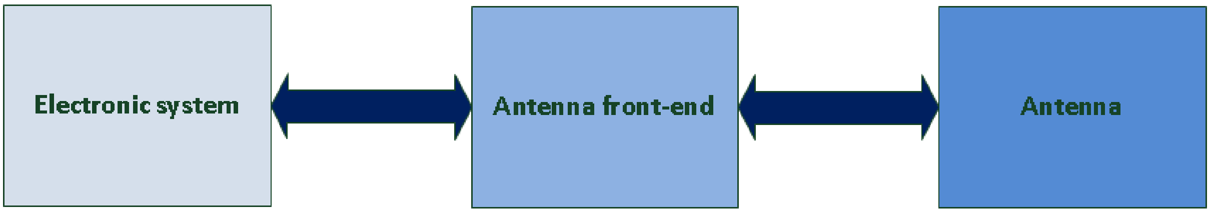

Figure 1 – Radar architecture

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3 Radar design

The limitations of oversize and overweight of the majority of airborne radar systems can be faced by exploring the potential of the software-defined radio (SDR) technology to provide flexible, cost-effective and low-weight radar prototypes.

The origin of the software-defined radio technology is related with the military field in the 1970s. Later on in the 1990s, some projects started with the purpose of developing a software programmable radio systems, operating in the band between 2 MHz and 2 GHz. This can be considered as the base of the SDR technology.

In summary, SDR can be understood as a reconfigurable radio system which substitutes the hardware components such as mixers, filters and modulators into software components by using computing embedded systems. The basic SDR systems are composed by an embedded system with a field programmable gate array (FPGA) interface with a digital-to-analog and analog-to-digital conversion (DAC and ADC, respectively) both adapted to a radio frequency trans-receiver system.

The advantages presented by the SDR technology suits perfectly with the oversize and overweight drawbacks of a traditional radar system. In this manner the term software-defined radar has showed up in the picture as a novel paradigm, which gives a more versatile solution by implementing the fundamental radar operations such as signal generation, filtering and up-and-down conversion via software. Despite of the synchronisation issues given by the digital nature that the SDR technology can have, undoubtedly the software domain provides advantages such as

- the possibility to create multipurpose radar,
- the possibility to reuse the same hardware,
- an easier implementation of advanced signal processing algorithms,
- a faster development and a cost-effective solution.

In the last decade, many scientists and researchers are focusing their attention in SDRadar systems and their applications in different test beds considering the Universal Software Radio Peripheral (USRP) as the hardware base and GNU Radio, an open-source software-defined project, as a software tool to implement very sophisticated, cost-effective radar applications.

In the following paragraphs main guidelines for design of each radar subsystems are described, following architecture shown in Figure 1.

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3.1 Electronic system design

The design relays on Ettus ReseachTM products, that offers a wide range of SDR solutions combining ease of use and a robust open-source software community.

The selected model is the E320, which layout is shown in Figure 2, while its main specifications are reported in Table 1.

The USRP E320 brings performance to embedded software defined radios by significantly improving FPGA resources as well as streaming, synchronization, integration, fault-recovery, and remote management capability. The board uses the flexible 2×2 MIMO AD9361 transceiver from Analog Devices, which covers frequencies from 70 MHz – 6 GHz and provides up to 56 MHz of instantaneous bandwidth.

The USRP E320 is available in 3U board-only and fully enclosed of compact size.

The open-source USRP Hardware Driver (UHD) API and RF Network-on-Chip (RFNoC) FPGA development framework reduces software development effort and integrate with a variety of industry-standard tools such as GNU Radio.

The baseband processor uses the Xilinx Zynq-7045 SoC to deliver a powerful user-programmable FPGA for real-time and low-latency processing, and a dual-core ARM CPU for stand-alone operation. Users can deploy applications directly on to the preinstalled embedded Linux operating system or stream samples to a host computer using high-speed interfaces such as 1 Gigabit Ethernet, 10 Gigabit Ethernet, and Aurora.

The USRP E320 has a flexible synchronization architecture with support for traditional SDR synchronization methods such as clock reference, PPS time reference, and GPSDO.

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Figure 2 – Ettus™ E320 layout

Specification	Typical	Unit
RF Performance[2]		
IIP3 (at typical NF)	-20	dBm
Power Output	> 10	dBm
Receive Noise Figure	< 8	dB
Conversion Performance and Clocks[2]		
ADC Sample Rate (Max.)	61.44	MS/s
ADC Resolution	12	bits
DAC Sample Rate (Max.)	61.44	MS/s
DAC Resolution	12	bits
Host Sample Rate (16b)	61.44	MS/s
GPSDO Frequency Stability Unlocked[3]	0.1	ppm
GPSDO PPS Accuracy to UTC[3]	< 8	ns
GPSDO Holdover Stability[3]	< +/-50 3 25	µs hours °C
Power		
DC Input	10 – 14, 3	V, A
Power Consumption (Max.)	30	W

Specification	Typical	Unit
Temperature		
Operating	0 – 45	°C
Non-Operating	-40 – 85	°C
Humidity (Non-Condensing)		
Operating	10 – 90	%
Non-Operating	5 – 95	%
Shock and Vibration		
Operating Mechanical Shock (Tested in accordance with IEC 60068-2-27. Meets MIL-PRF-28800F Class 2 limits.)	30 half-sine 11	g peak ms pulse
Operating Random Vibration (Tested in accordance with IEC 60068-2-64.)	5 – 500 0.3	Hz g rms
Non-Operating Random Vibration (Tested in accordance with IEC 60068-2-64. Non-operating test profile exceeds the require-ments of MIL-PRF-28800F, Class 3.)	5 – 500 2.4	Hz g rms
Altitude		
Operating	2000	m

Table 1 - EttusTM E320 main specifications

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3.2 Antenna front-end

Antenna front-end will be developed directly by CORISTA using COTS components.

The foreseen architecture is shown in Figure 3 and it includes:

- no. 2 power amplifiers with 1 W of maximum output power;
- no. 2 of high speed switches;
- no 2 of low noise amplifiers with limiters.

In SAR mode, the needed isolation between polarisations is achieved by the use of two antennas.

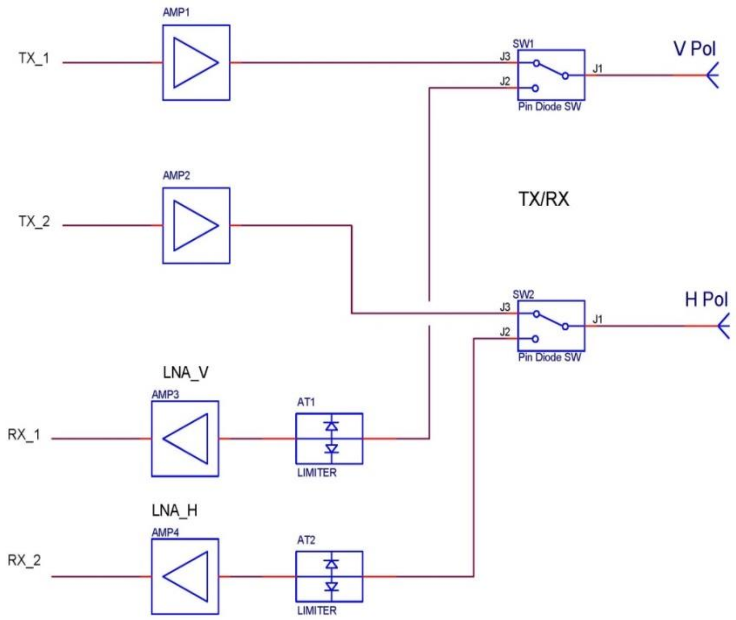

Figure 3 – Antenna front-end architecture

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3.3 Antennas

For SAR mode, Yagi Uda antenna has been selected. Figure 4 shows antenna mechanical design for a central frequency of 435 MHz.

Antenna patterns are shown in Figure 5, from which it is possible to estimate 3dB apertures of 66° and 110° along elevation and azimuth direction respectively. The estimated directivity is 6.5 dB.

Antenna impedance is shown in Figure 6, from which a matching input resistance of 180 Ω can be derived. Antenna VSWR is shown in Figure **7**, from which a bandwidth of 63 MHz can be estimated, in the range 415-478 MHz.

For SAR mode two antennas are needed for transmitting and receiving H and V polarisations. The two antennas should be positioned perpendicularly one with respect the other, and pointing with an off-nadir angle of about 60°-65°. Antenna positioning on drone is shown in Figure 8.

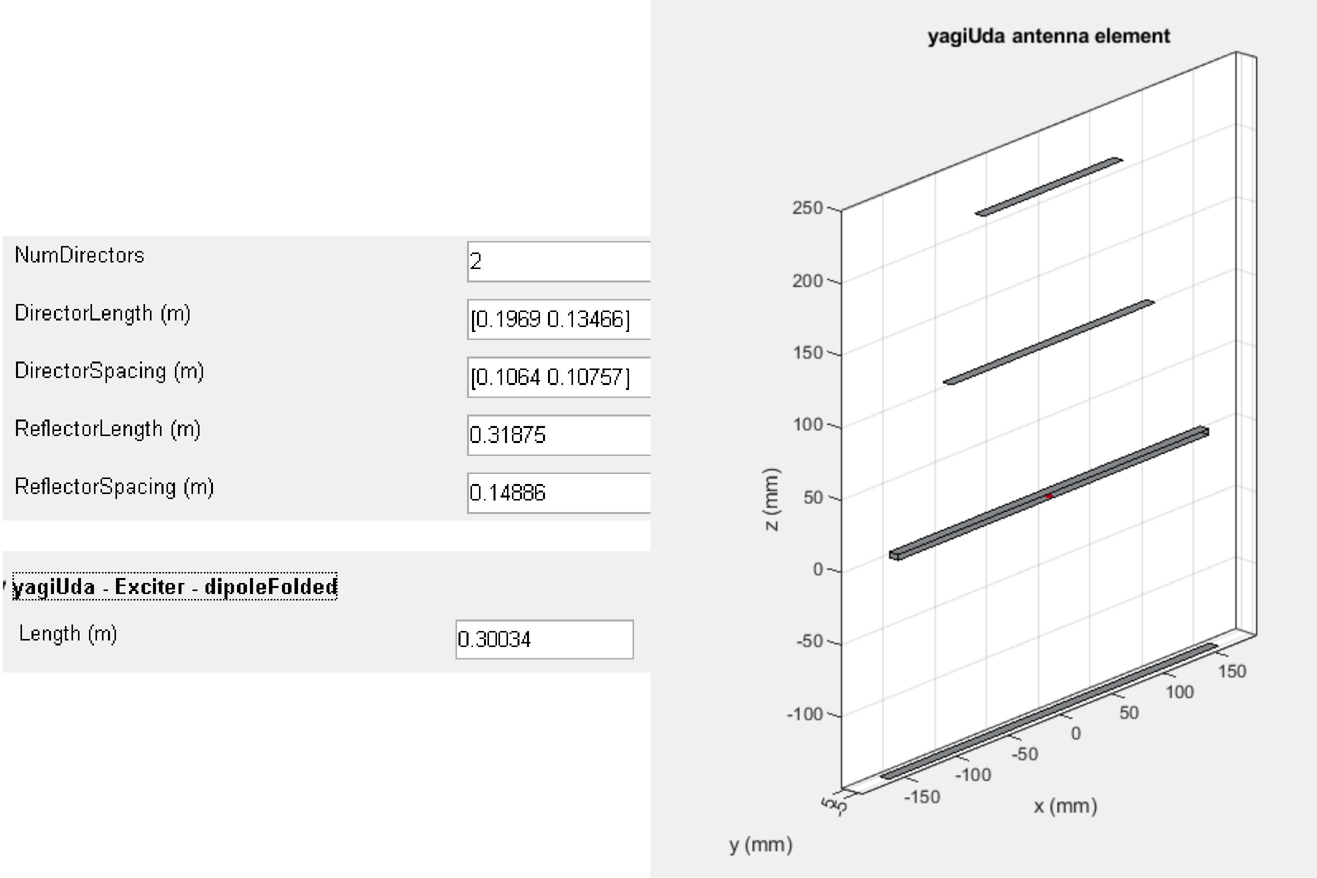

Figure 4 – SAR mode: antenna mechanical design

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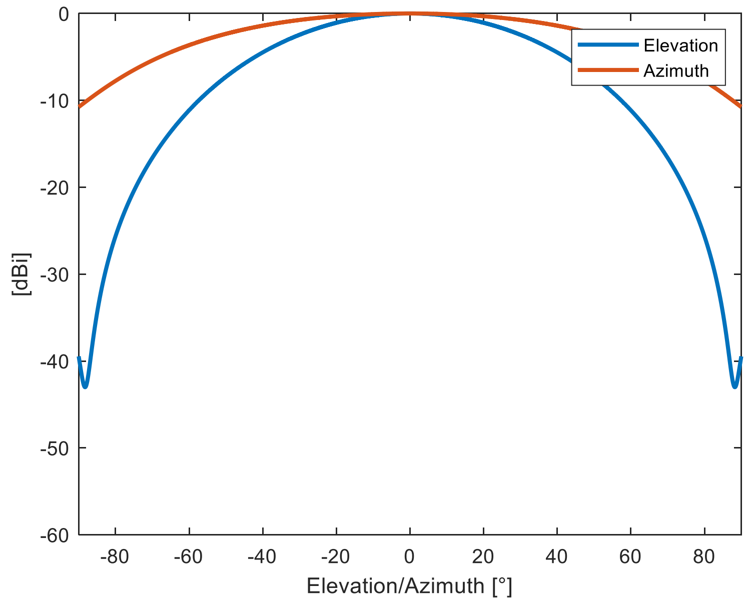

Figure 5 – SAR mode: estimated antenna patterns

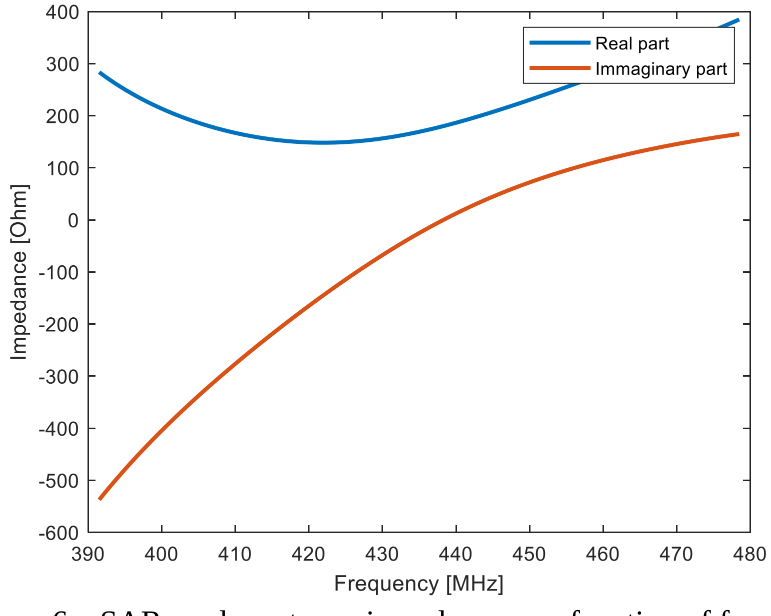

Figure 6 – SAR mode: antenna impedance as a function of frequency

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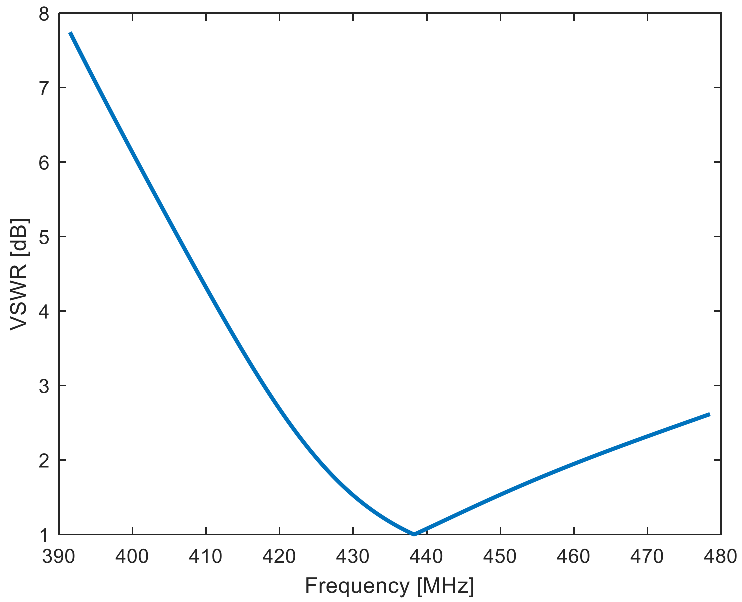

Figure 7 – SAR mode: antenna VSWR as a function of frequency

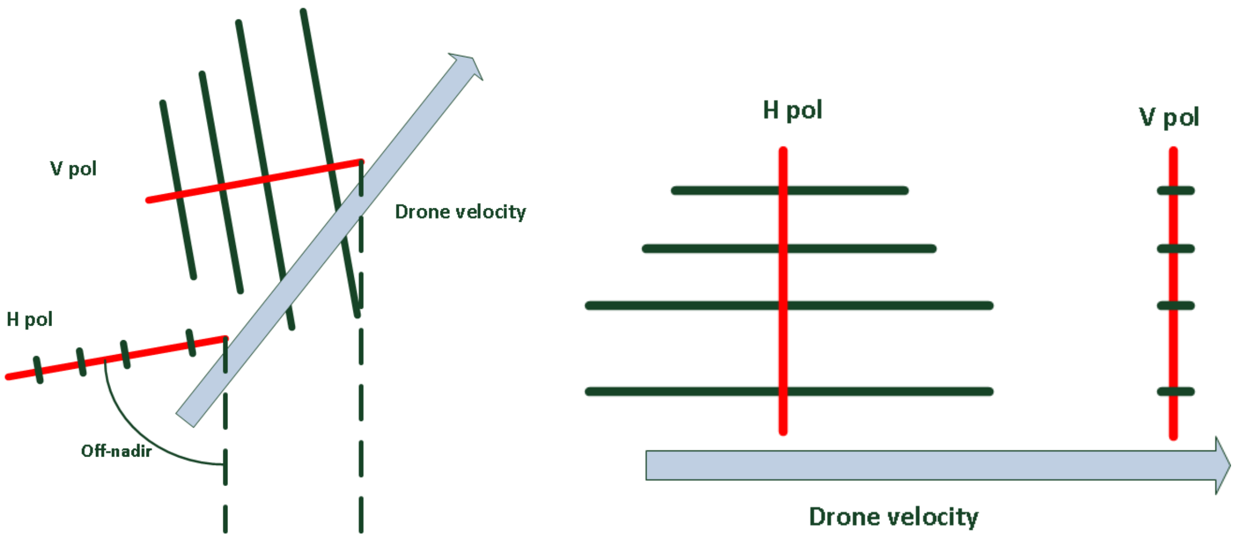

Figure 8 – SAR mode: antenna positioning on drone

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For SOUNDER mode, a folded dipole antenna has been selected. Figure 9 shows antenna mechanical design for a central frequency of 80 MHz.

Antenna patterns are shown in Figure 10, from which it is possible to estimate 3dB apertures of 77° along elevation direction, while along azimuth direction is isotropic. The estimated directivity is 2 dB.

Antenna impedance is shown in Figure 11, from which a matching input resistance of 280 Ω can be derived. Antenna VSWR is shown in Figure 12, from which a bandwidth of 16 MHz can be estimated, in the range 72-88 MHz.

For SOUNDER mode only one antenna is foreseen, that should be positioned perpendicularly to the drone velocity direction, as shown in Figure 13.

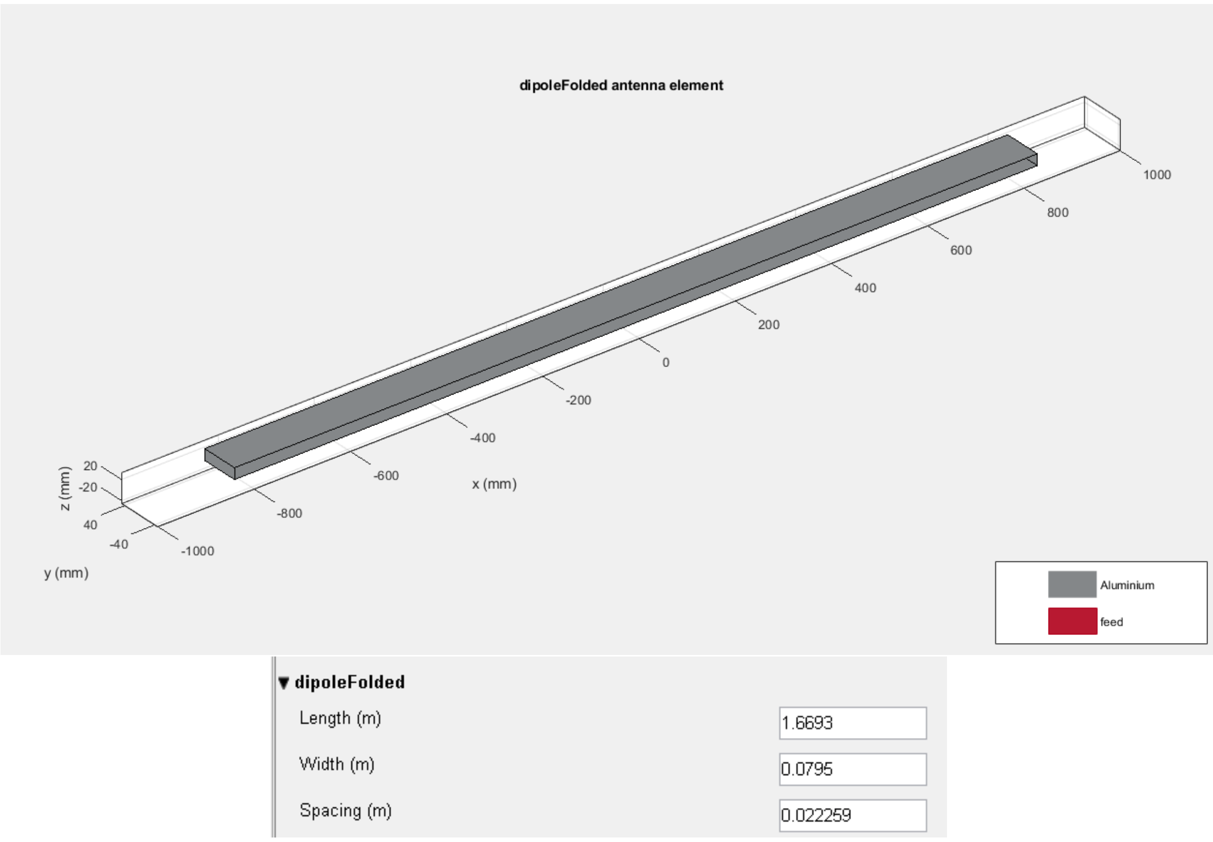

Figure 9 – SOUNDER mode: antenna mechanical design

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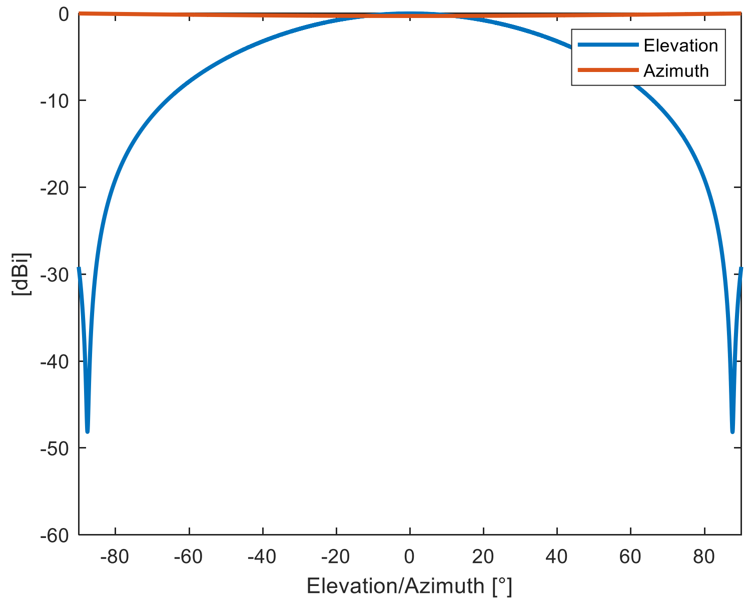

Figure 10 – SOUNDER mode: estimated antenna patterns

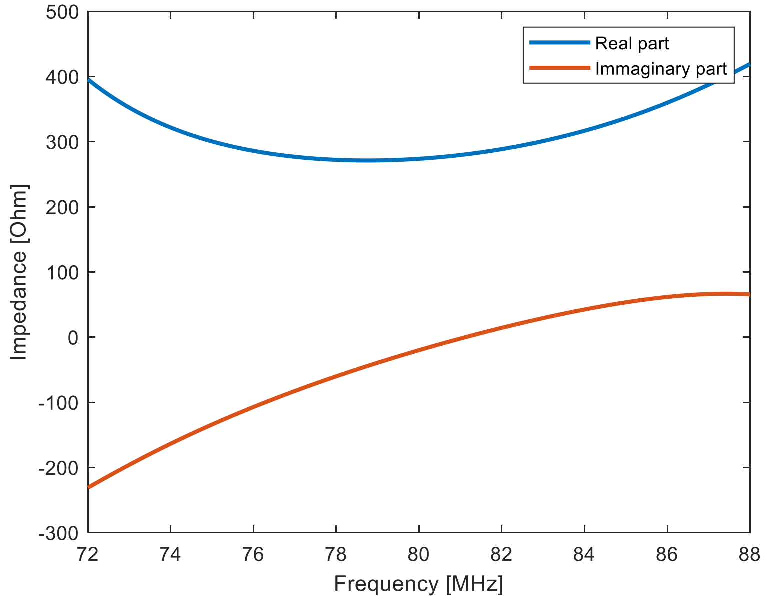

Figure 11 – SOUNDER mode: antenna impedance as a function of frequency

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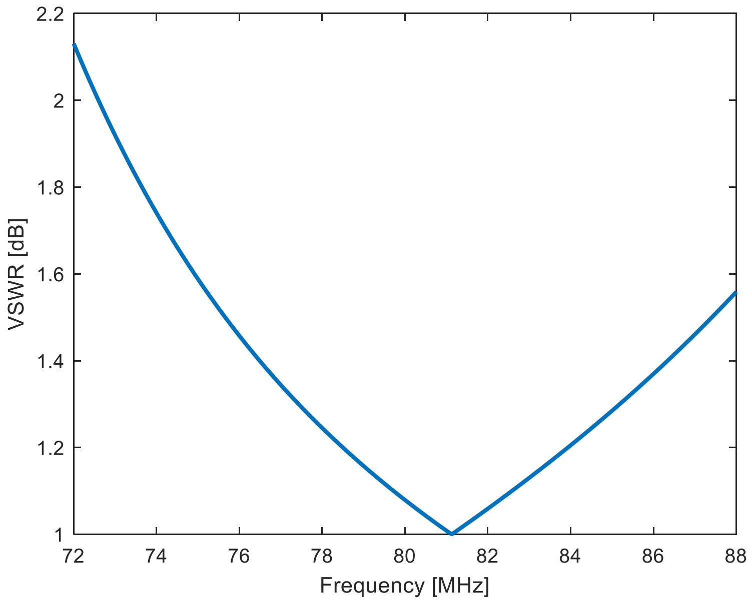

Figure 12 – SOUNDER mode: antenna VSWR as a function of frequency

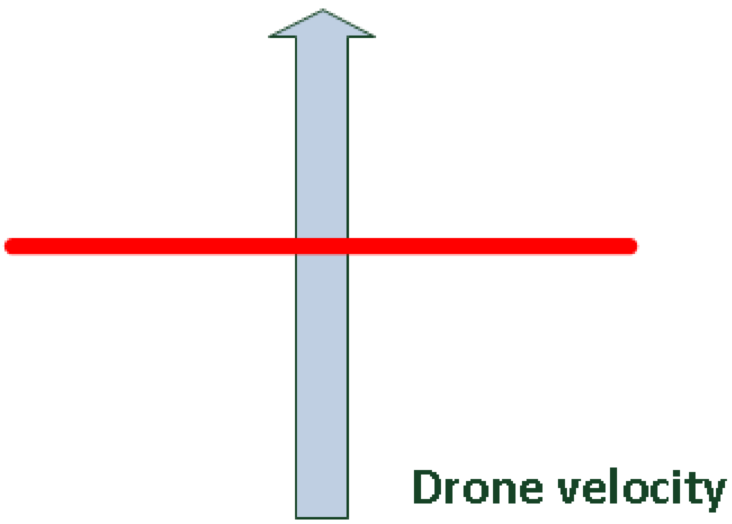

Figure 13 – SOUNDER mode: antenna positioning on drone

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3.4 Size, weight and power budget

SWA budget for the whole radar system is reported in Table 2.

	Size [mm]	Weight [kg]	Absorption [W]
Electronic system	175x106x38	0.86	30
Antenna FE	160x100x30	0.3	5
Antenna SAR (each)	300x400x10	0.3	
Antenna SOUNDER	1700x80x40	0.3	
Harness		0.6	

Table 2 – SWA budget for radar

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4 Conclusion

The present report describes architecture and design of the low-frequency, multi-mode radar system.

Design has been driven by the need to have flexible and light instruments. Signal generation as well as radar synchronisation and data acquisition relays on SDR technology.

Estimated radar size, weight (< 3 kg) and absorption (< 40 W) allow installation on light drones as envisaged for FLY-RADAR project.

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