ACASIAS

Specifications for the smart active panel

Deliverable 3.1

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30/01/2017
V1

Grant Agreement number:	723167
Project acronym:	ACASIAS
Project title:	Advanced Concepts for Aero-Structures with Integrated Antennas and Sensors
Funding scheme:	RIA
Start date of the project:	01/06/2017
Duration:	36 months
Project coordinator (organisation):	Harmen Schippers (NLR)
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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723167

DOCUMENT INFORMATION

Document Name	D3.1 Specifications for the smart active panel
Document reference	ACASIAS_D3.1_Specifications_Smart_Active_Panel_DLR_180130_v1.docx
Version	1
Version Date	30/01/2017
Author	WP3 contributors
Security	

APPROVALS

	Name	Company	Date	Visa
Coordinator	H. Schippers	NLR	30/01/2018	
WP/Task Leader	S. Algermissen	DLR	30/01/2018	
Other (Quality M., AB)	A. Hoque	L-UP	23/01/2018	

DOCUMENTS HISTORY

Version	Date	Modification	Authors
01	30.10.2017	Initial version	Algermissen
0.1	15.11.2017	Input from Invent	S. Steeger
0.2	17.11.2017	Input from Invent	S. Steeger
02	21.11.2017	Merge and addition	Algermissen
1	27.11.2017	Correction	Algermissen, Misol

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DISTRIBUTION LIST

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1. Introduction

Work package 3 integrates a smart layer of sensors and actuators into a fibre reinforced plastic structure to set up an active panel. By means of a smart controller this panel is able to increase its sound transmission loss. The controller is synthesized to specific counter rotating open rotor (CROR) noise. Due to the preliminary actuator experiments conducted by the DLR, the target structure of this work package has changed from a fuselage to a lining structure. The lining panel which is located between the fuselage and the passenger has a smaller stiffness and usually a larger thickness than fuselage panels. Due to that, smaller and lighter actuators can be used and the integration process could be realizable. As an additional feature the actuators in the lining can be used as passenger announcement system to replace the loudspeakers in the passenger service units (PSU). Nevertheless, active linings can even be used for retrofitting in older aircraft types.

In this document a preliminary design is proposed. It consists of hard constraints concerning the maximum size of the panel which is limited by the acoustic test facility of the DLR and the manufacturing capabilities of Invent. Apart from that, this document gives an overview about possible materials and designs for the panel as well as a choice of actuators and sensors for the active system including the wiring.

2. Dimensions and materials of the lining structure according to manufacturing and testing constraints

The experimental setup will be placed in the Acoustic Transmission Loss Test Facility (ATB) of the DLR in Braunschweig. The ATB consists of a reverberation and a semi-anechoic room which are connected by a square opening where test objects are mounted. A mounting frame for test samples 1690 mm x 1300 mm (width x height) is available. For a realistic setup, a part of an A350-like fuselage structure can be provided by DLR, see Figure 1. It includes stringers, frames and two windows. Mounting points for the lining panels and insulation bags are part of the structure. Therefore, the dimensions of the lining panel are limited to the following:

Description	Value	Remark
Width	1690 mm	
Height	1300 mm	
Radius	~2980 mm	
Thickness	8 mm < d < 20 mm	

Table 1: Dimensions

The lining panel will have a sandwich design with honeycomb or foam core and glass or carbon fibre panels.
Insulation material is for example according to Airbus Standard ABS 5429 and cascading specification AIMS04-18-004A. As the insulation material contains antimony pentoxide (CAS85535-84-8) (high issue EHS) it is recommended to select alternative equivalent material for test purposes where assembly and disassembly activity are needed on the test panels.
Alternatives are insulations from „M. Bricolage" or local hardware store insulation materials sealed in PE bags.

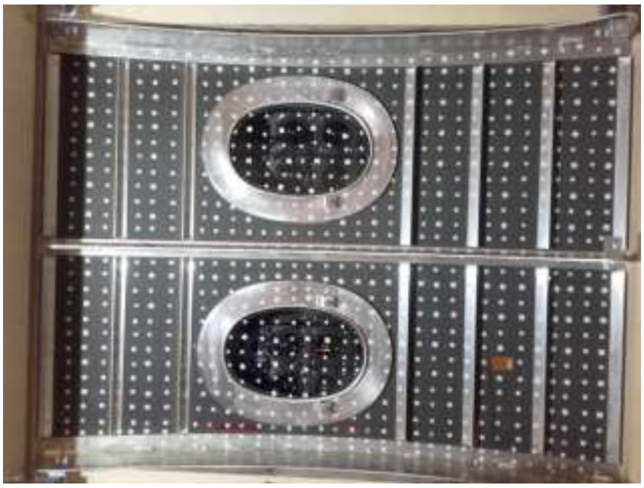

Figure 1: A350-like fuselage panel

3. Class of suitable actuators for the integration in fibre reinforced plastics

According to deliverable D1.1 the actuators have to fulfil the following requirements:

Mass of actuators: 4-60 g
Size of actuators: Max. base size=50x50 mm^2

Based on the document ACA0071 – "Actuator performance comparison" it would be advisable to use exciters as their performance is better. Nevertheless piezo patch actuator could be implemented, if the integration level needs to be higher or if the higher frequency range is not being covered by the exciters. A market survey of existing exciters that fulfil the dimension and mass requirements is completed. Candidate actuators are listed in Table 2. The results of a market survey of piezo transducers (perform both as sensor and as actuator) are shown in Table 3. Although there are standard piezo transducers with defined dimensions, they can be adapted and produced in every size, if required.
The number of actuators and their placement depends upon the result of the simulations with the active panel. Since these results are available at a later stage of the project, the number of actuators N_{act} can only be estimated by experience to $1 < N_{act} < 6$.

For maintenance two concepts are considered. On failure of single actuators, the repair could be on:

- Actuator level -> change of faulty actuator -> enable detachable connection of actuators.
- Lining level -> exchange entire lining with faulty actuator.

The connection between the wiring and the actuators depends upon the maintenance concept. When an actuator replacement is considered a connector has to be set between the wiring and the actuator. Otherwise, the connection can be realized via the solder pads on the actuator.
The given temperature range is important and limiting for the manufacturing process.

Manufacturer	**Model**	**Picture**	**Power** in W	**Weight** in g	**Dimensions** in mm (W x L x H)	**Tempe-rature range** in °C
Visaton www.visaton.de	EX30		10	40	30 x 30 x 17	-25 to 70
	EX45		10	60	46 x 46 x 17	-25 to 70
Dayton www.daytonaudio.com	BCE-1		3	23	21.8 x 17.8 x 7.5	unknown
	DAEX9CT-4		0.5	14	Ø20.9 x 8.5	unknown
	DAEX13CT-4		3	23	Ø26.3 x 9.5	unknown
	DAEX19CT-4		5	23	Ø33 x 13	unknown
Tectonic www.tectonicelements.com	TEAX19C01-4/LP		1	14.1	Ø30 x 6.3	-20 to 55
	TEAX09C005-8		0.5	3.2	26 x 13 x 6.5	-20 to 55

Table 2: Market survey of exciters

Manufacturer	**Model**	**Picture**	**Power** in W	**Weight** in g	**Dimen sions** in mm (W x L x H)	**Tempe-rature range** in °C
PI Ceramic GmbH www.piceramic.de	P-876.A11		-	2.1	61 x 35 x 0.4	-20 to 150
	P-876.A12		-	3.5	61 x 35 x 0.5	-20 to 150
	P-876.A15		-	7.2	61 x 35 x 0.8	-20 to 150

Table 3: Market survey of piezo transducers

4. Class of suitable sensors for the integration in fibre reinforced plastics

According to deliverable D1.1 the sensors have to fulfil the following requirements:

Mass of sensors: 1-20 g
Size of sensors: Max. base size=20x20 mm²

The type of sensor that is appropriate for this kind of active noise reduction is an accelerometer. The required direction of measurement is normal to the surface where the accelerometer is mounted. Practical experience shows that a measurement range up to 40 g = 392.4 m/s² is sufficient for this application. Since the bandwidth of the active system is currently limited to app. 500 Hz, the accelerometer bandwidth is chosen accordingly.

Manufacturer	**Model**	**Measurement range** in g	**Bandwidth** in kHz	**Output type**	**Tempe-rature range** in °C
Analog Devices www.analog.com	ADIS16223	70	14.25	SPI	-40 to 125
	ADIS16227	70	14.25	SPI	-40 to 125
	ADXL001	70	22	Analog	-40 to 125
	ADXL1001	100	11	Analog	-40 to 125
	ADXL1002	50	11	Analog	-40 to 125
	ADXL356	40	1.5	Analog	-40 to 125
	ADXL357	40	1	SPI	-40 to 125
	ADXL372	200	3.2	I²C, SPI	-40 to 105
	ADXL375	200	1.6	I²C, SPI	-40 to 85
	ADXL377	200	1.6	Analog	-40 to 85
STMicroelectronics www.st.com	AIS1120SX	120	1.6	Digital	-40 to 105
	AIS2120SX	120	1.6	Digital	-40 to 105
	H3LIS200DL	100	0.5	Digital	-40 to 85
	H3LIS331DL	100	0.5	Digital	-40 to 85

Table 4: Market survey of MEMS accelerometers

Common laboratory accelerometers are not taken into account since the prices for the sensors and the cabling are much too high for a serious production. A cheaper alternative can be found in micro-electro-mechanical systems (MEMS). A market survey of available MEMS accelerometers that fulfil the given requirements is given in Table 4.

The number of sensors and their placement depends upon the result of the simulations with the active panel. Since these results are available at a later stage of the project, the number of sensors N_{sens} can only be estimated by experience to $4 < N_{sens} < 10$.

The MEMS accelerometers are placed and connected on a printed circuit board (PCB). This PCB has solder pads that have to be connected to the wiring.
The maintenance concept for the sensors has to be the same for the actuators.
Like the actuators, the sensors can be directly integrated or by the use of an insert. Finally, the sensor or the insert are attached to the structure by an adhesive.

5. Requirements for the wiring of the smart layer

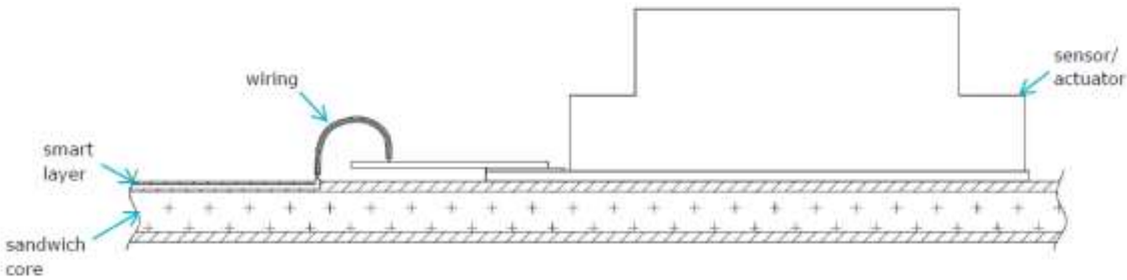

Figure 2: Sensor/actuator connected to the smart layer with an integrated wiring

The wiring of the sensors and actuators can be achieved either by integrating the wiring into the smart layer or by connecting the component externally. The factors to be considered while choosing one of the options are: type and quantity of sensor/actor, level of integration and replaceability. As an example, if a single exciter is used, it would be reasonable to connect it externally, in order not to increase the complexity and costs of the inner lining network. But if several actuators are used, the only reasonable possibility for their fixation would be the integration into the smart layer along with the wiring. In both cases a study should be conducted to determine the fatigue effect and limit. Figures 2 and 3 show both wiring concepts. Figure 4 includes examples of those.

As described in Chapter 3 and 4 the fixation of exciters and accelerometers can be achieved with adhesives. Nevertheless, for a more secure fixation the use of screw would be recommended. As the inner lining panel is likely to consist of a sandwich structure, its stiffness has to be increased locally. For this purpose, three main possibilities exist: inserts, filling mass or precured hard points in the structural sandwich core.

Figure 5 shows the fixation using inserts. Taking into account the size limitations for the sensors and actuators, the space between the screws might not be big enough for the implementation of multiple inserts. It could be possible to use a single insert, where various screws could be fixed.

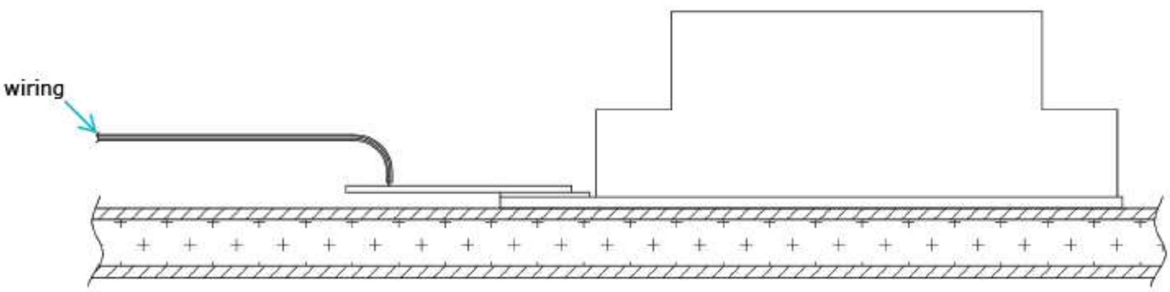

Figure 3: Sensor/actuator connected to external wiring

Figure 4: Wiring and piezo transducer integrated in smart layer (left) and piezo transducers with external wiring (right)

Another possibility is to use a hardpoint which is a locally integrated solid composite block in the sandwich panel. This measure would increase the weight of the panel, but it would be sufficiently stiff for the fixation of screws and load introduction of exciters into the pane. Figure 6 shows this possibility.

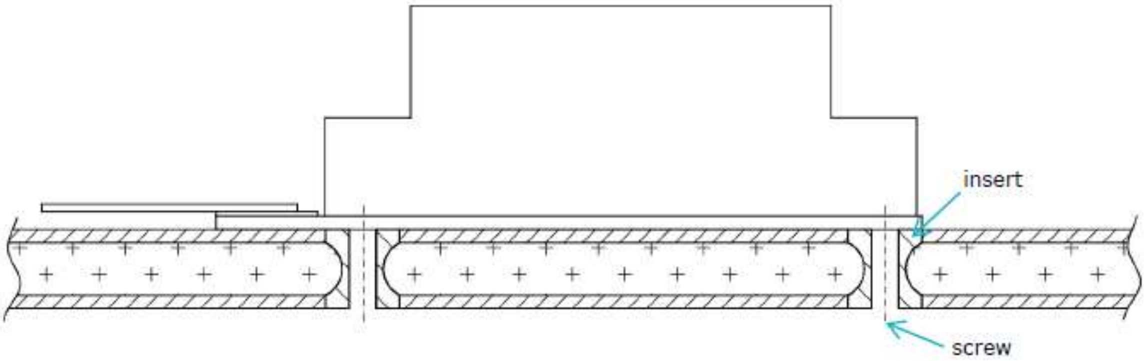

Figure 5: Fixation of a sensor/actuator using inserts

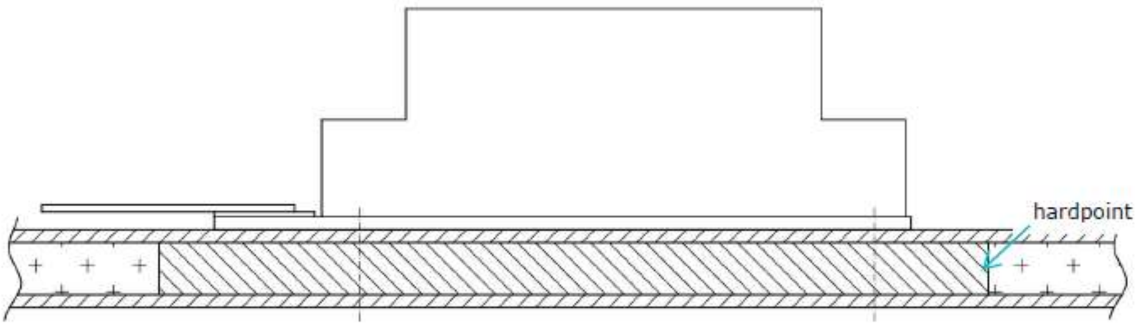

Figure 6: Fixation of a sensor/actuator using a hardpoint

In order to maintain the panel lightweight, the sandwich panel could be filled with potting mass. This later, when solidified, stiffens the panel locally and enables the fixation of screws to it. In Figure 7 an example of this measure is shown.

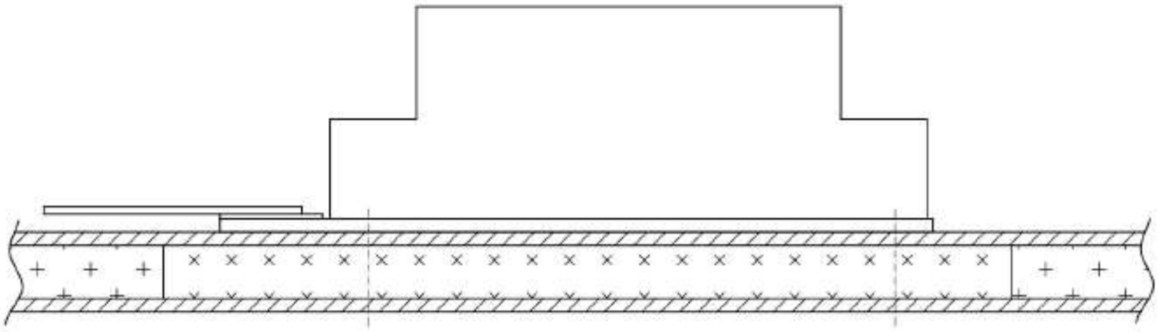

Figure 7: Fixation of a sensor/actuator using a filling mass

The voltage and current requirements for the exciters can be roughly estimated with the power and the impedance of the actuators. With P=UI and R=U/I, where P is the power, U the voltage, I the current and R the impedance gives:

$$U_{max} = \sqrt{PR}$$
$$I_{max} = \sqrt{\frac{P}{R}}$$

The maximum power of all actuators in Table 2 is 10 W while their impedance ranges from 4-8 Ohm. Including a safety factor of two leads to the following rounded maximum values:

$$U_{max} = 20\,V$$
$$I_{max} = 3.5\,A$$

The type of current is AC since the controller drives the actuators up to app. 1 kHz.

The wiring of the sensors is less demanding than for the actuators with respect to the operating currents. Here, the disturbance rejection and thus the routing of the wires are of high importance. Actuator and sensor wires have to be routed on different paths to avoid crosstalk. The accelerometers in Table 4 the maximum values with a safety factor of two are:

$$U_{max} = 10\,V$$
$$I_{max} = 100\,mA$$

In contrast to the actuators, the sensors are equipped with different interfaces. All listed accelerometers have one of these three types:

- Analog interface;
- Serial peripheral interface (SPI);
- Inter-Integrated Circuit (I^2C).

Therefore, the chosen sensor type has a large influence on the wiring of the smart layer. The following list summarizes the number and type of lines that need to be routed to each sensor:

- Analog (3 wire)
    - VS – Supply
    - GND – Ground
    - OUT - Data
- SPI (6 wire)
    - VS – Supply
    - GND – Ground
    - CS – Chip select
    - SCLK – Serial clock
    - MOSI – Master Output, Slave Input
    - MISO – Master Input, Slave Output
- I²C (4 wire)
    - VS – Supply
    - GND – Ground
    - SDA – Serial data
    - SCL – Serial clock

The sensor networks for the three variants look quite different. Depending on the line, a bus or a star topology is needed to connect all sensors. In Table 5 the different topologies are listed as a function of the interface type.

Interface	**Bus topology**	**Star topology**
Analog	VS, GND	DATA
SPI	VS, GND, MOSI, MISO, SCLK	CS
I²C	VS, GND, SCL, SDA	-

Table 5: Topology types

Figures 8-10 show three examples for the realization of a sensor network for each interface type with one master and three sensors.

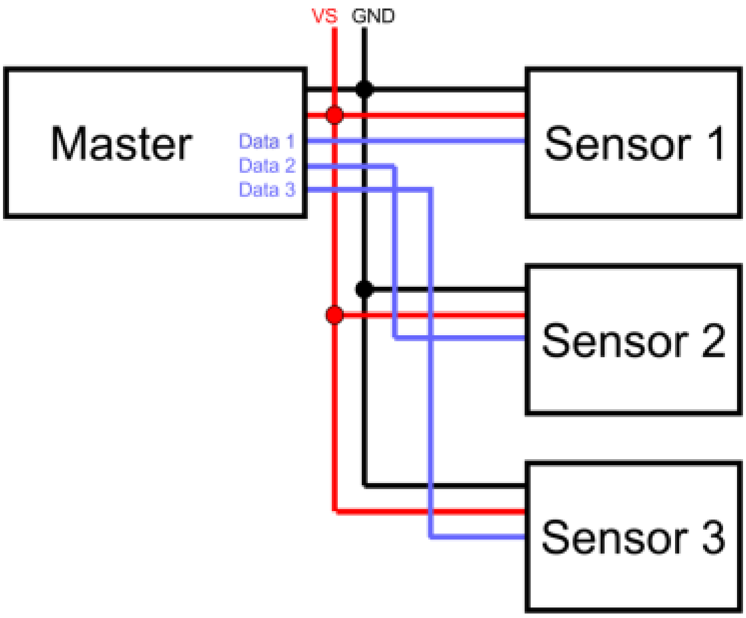

Figure 8: Three analog sensors network

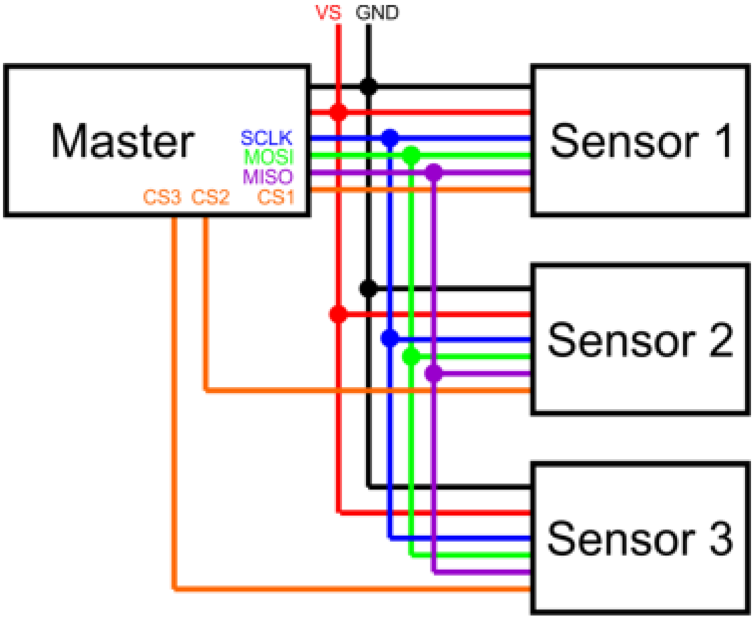

Figure 9: Three SPI sensors network

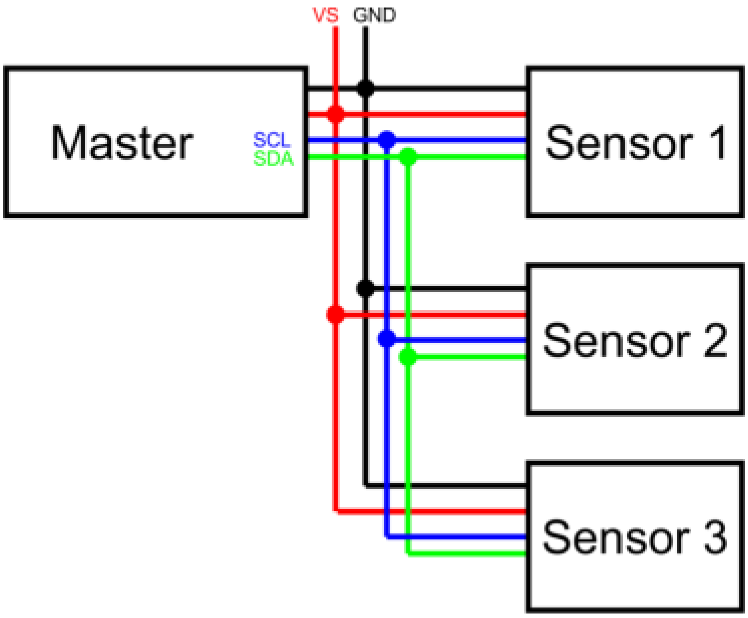

Figure 10: Three I²C sensors network

For electromagnetic compatibility (EMC) issues the data lines in the smart layer can be shielded. Two variants for shielding are considered:

- lightweight cross-hatch shield for low noise, low sensitivity applications
- solid shield, with edge stitching vias, for high(er) noise, high(er) sensitivity applications

Wire samples are shown in Figure 11.

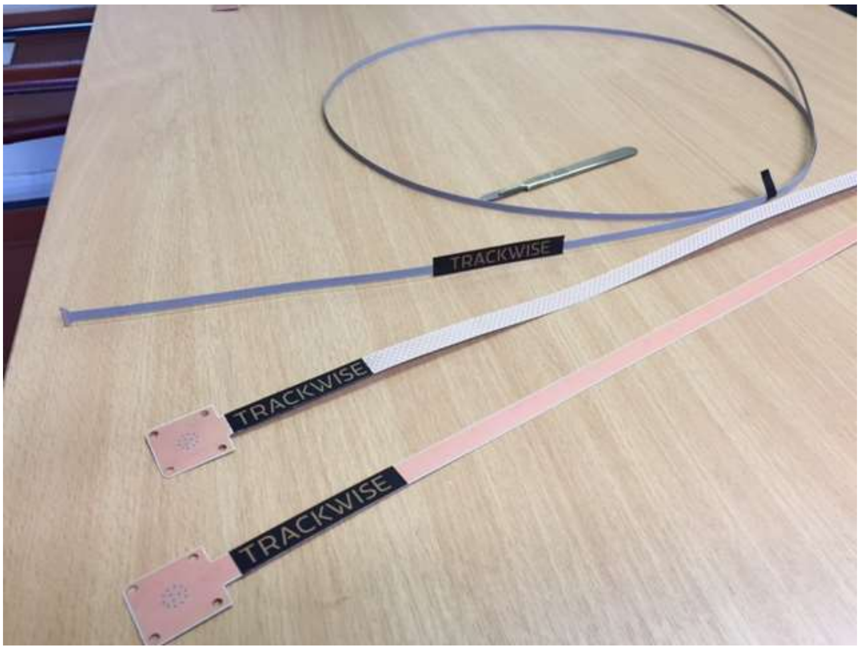

Figure 11: Solid shielding (lower wire) and cross-hatched shielding (mid wire)

In the smart lining power lines for supplying the components and data lines have to be routed. The exciters need current up to 3.5 A. In Figure 12 a sample for parallel routing of power and power tracks is shown.

Figure 12: Data and power tracks on a single PCB

The external electrical connection of the smart lining to the aircraft is realized with connectors that are contacted with the smart layer. In Figure 13 left is shown how the smart layer is split into single wires while a hot meld mould (black) provides strain relief and seals up the interface. One or more of these layers are fed into a single connector, see Figure 13 right. The single wires are crimped for contact.

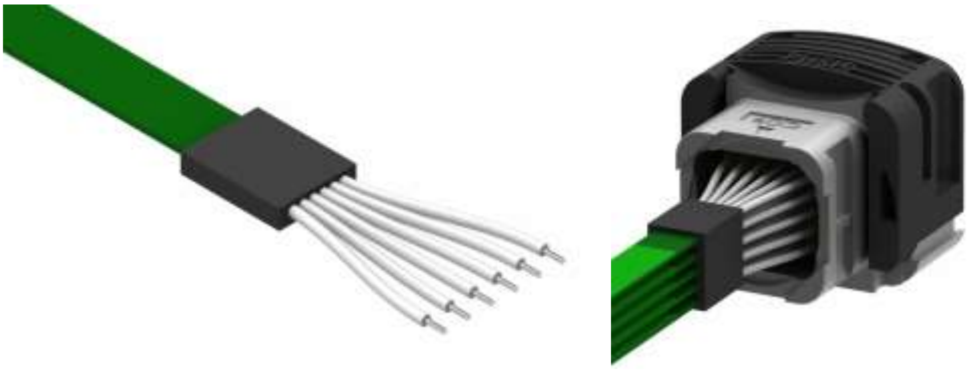

Figure 13: Connection of smart layer and connector

6. Simplified CAD model of the panel based on the previous definitions

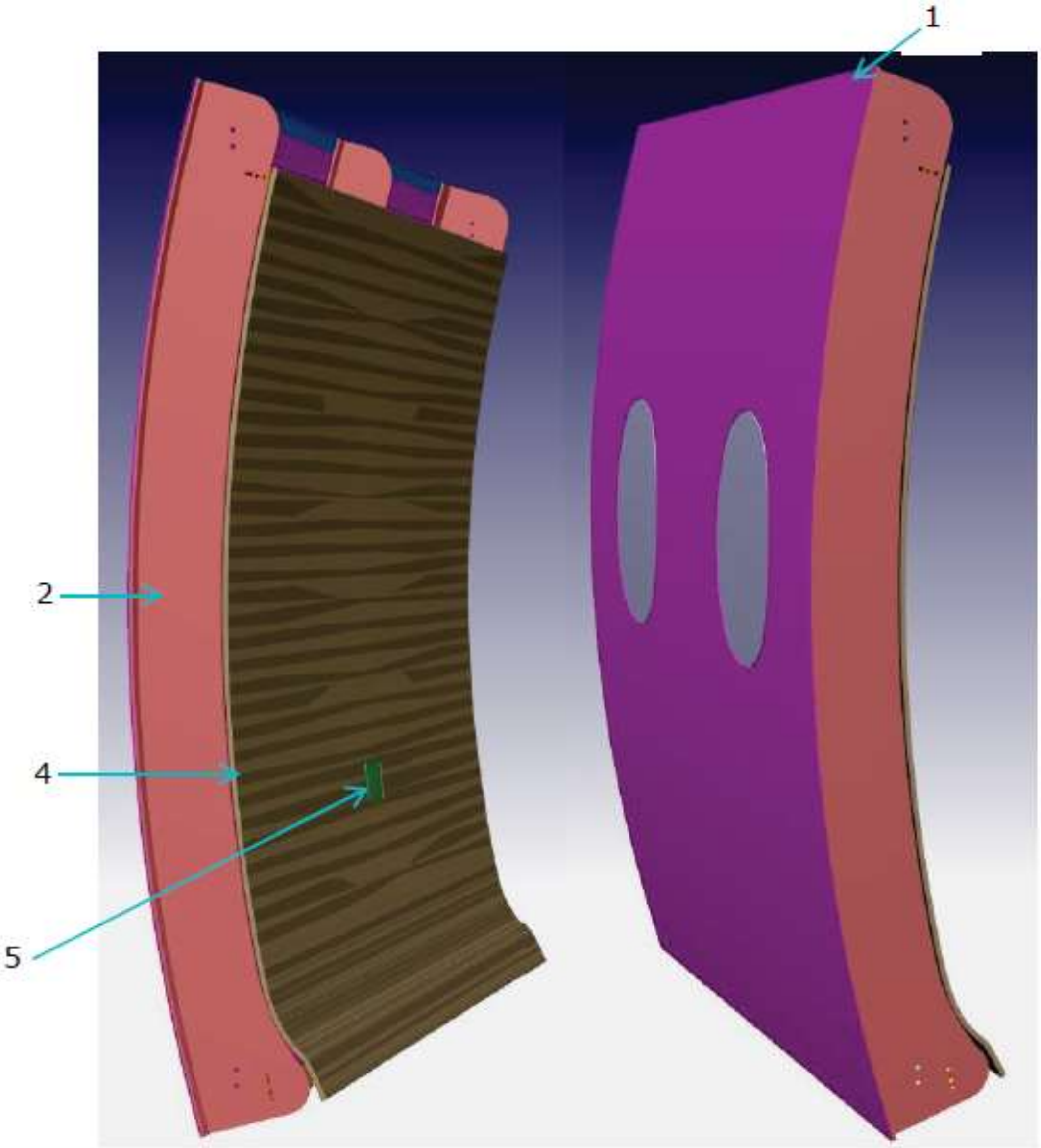

Figure 14: Side view of the fuselage panel

A simplified CAD model based on the existing fuselage panel from DLR and the mentioned definitions was designed. The following figures show the CAD model and its components. The fuselage consists of an external panel (1), inner vertical ribs (2), inner horizontal ribs (3), inner lining (4) and sensor/actuator (5) connected with a smart layer.

The position of this last component is here only shown as an example. The actual type, quantity and position of the sensor/actuators are yet to be defined. The connectors used for lining fixation to the structure are Airbus Standard parts (ABS) reflecting state of the art lining fixation. Further development on such connectors for active linings could be subject of ACASIAS as well.

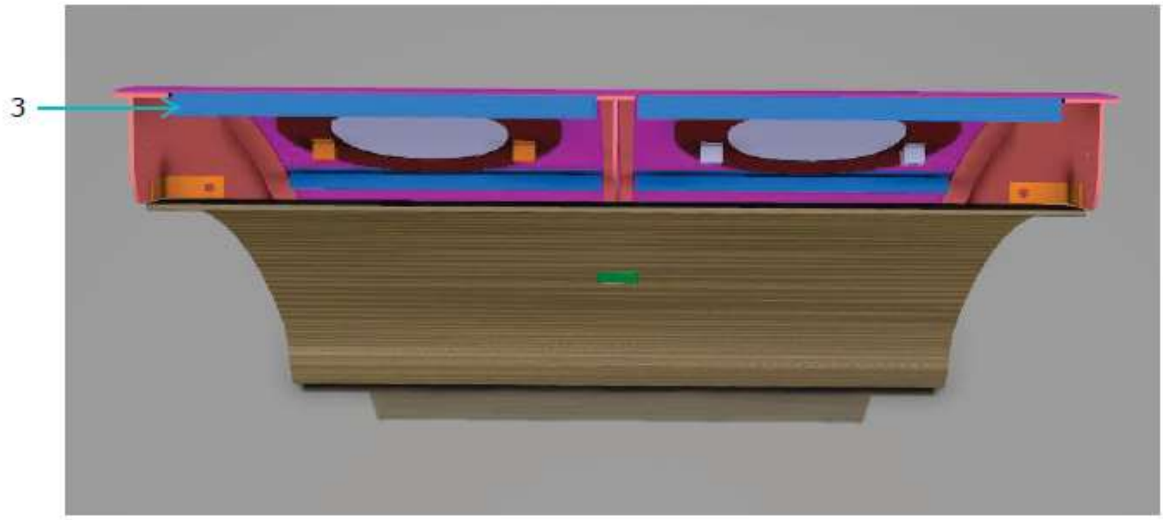

Figure 15: Front view of the fuselage panel

Different models are provided in CATIA Format: a lining with and without windows.

For the preliminary design this is made available to the partners and on EMDESK:

- 300385-01-01-MOD-01 Fuselage Panel.CATPart;
- 300385-01-02-MOD-02 Active Lining –window.CATPart;
- 300385-01-01-MOD-02 Active Lining - no window.CATPart;
- 300385-01-01-MOD-00 Assy w_o window.CATProduct;
- 300385-01-02-MOD-00 Assy w window.CATProduct.