CHOSeN

Project Report

DELIVERABLE NO	**D4.4.2**
DELIVERABLE TITLE	**Field trials and assessment for aeronautic application**
AUTHOR	Jirka Klaue (EADS) Javier Garcia-Jimenez (EADS) Dominik Samson (EADS) Alexandros Elefsionitis (EADS)
DISCLOSURE LEVEL	**Public**
VERSION	Final

SEVENTH FRAMEWORK PROGRAMME

TABLE OF CONTENTS

1 Introduction

This documents describes the performance evaluations and field trials of the CHOSeN components and systems. Theses tests were performed in order to assess the usefulness of the CHOSeN components for the aeronautic use cases. The tests were focused on the energy availability versus the energy consumption of the CHOSeN devices. That was done because the key feature required for the aeronautic use cases is the long-term autonomous operation of the wireless sensor nodes. That's why the use of an energy-harvesting device together with the CHOSeN nodes was thoroughly tested and assessed.

The aeronautic system prototype architecture is described shortly in section 2, the performance evaluation and flight tests in section 3 and the conclusions are drawn in section 4.

2 Aeronautic system prototype architecture

The aeronautic prototype is built on an A320 door surrounding structure part. A wireless node is fixed on the inside on that structure. It is connected to a power management [2] platform with a thermo harvester [1]. The harvester-powered node on the structure element is accompanied by battery-driven nodes, which can be distributed freely. One gateway node is used in order to discover the wireless nodes, configure their parameters like measurement interval, thresholds and transmission intervals as well as to collect the measurement data from the wireless nodes. The gateway node is connected to a Laptop via Ethernet, which is used for the application control and display software.

3 Application demonstration scenario and experimental results

Three tests and validation campaigns were performed in order to assess the CHOSeN nodes regarding usefulness for the aeronautic application scenario [3]. Firstly, the performance of the wake-up receiver is measured, secondly, the energy output of the harvester is measured in flight test, and thirdly, the overall application performance is assessed in a laboratory setup.

3.1 Performance evaluation

For the evaluation of the wake-up receiver (WUR) performance a test-bed was built, which enables the measurement of the key factors BER regarding the channel characteristics and wake-up delay regarding the various parameters of the WUR. Figure 1 shows the test-bed setup, with the CHOSeN FPGA transceiver platform (10), an EFM32 development kit (1) with the WUR (4) and a variable channel emulator (7).

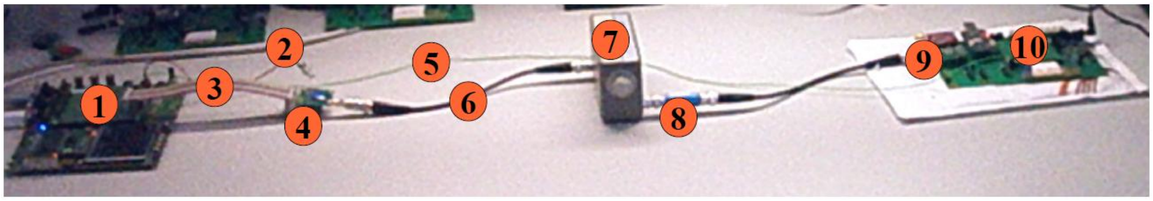

Figure 1: Performance evaluation test-bed for wake-up receiver

An important measure is the wake-up delay regarding the channel conditions and the WUR parameters. Figure 2 shows a screenshot from the oscilloscope with the delay between the received wake-up pattern and the wake-up interrupt for the sensor node. In this case the delay is 29.2 ms.

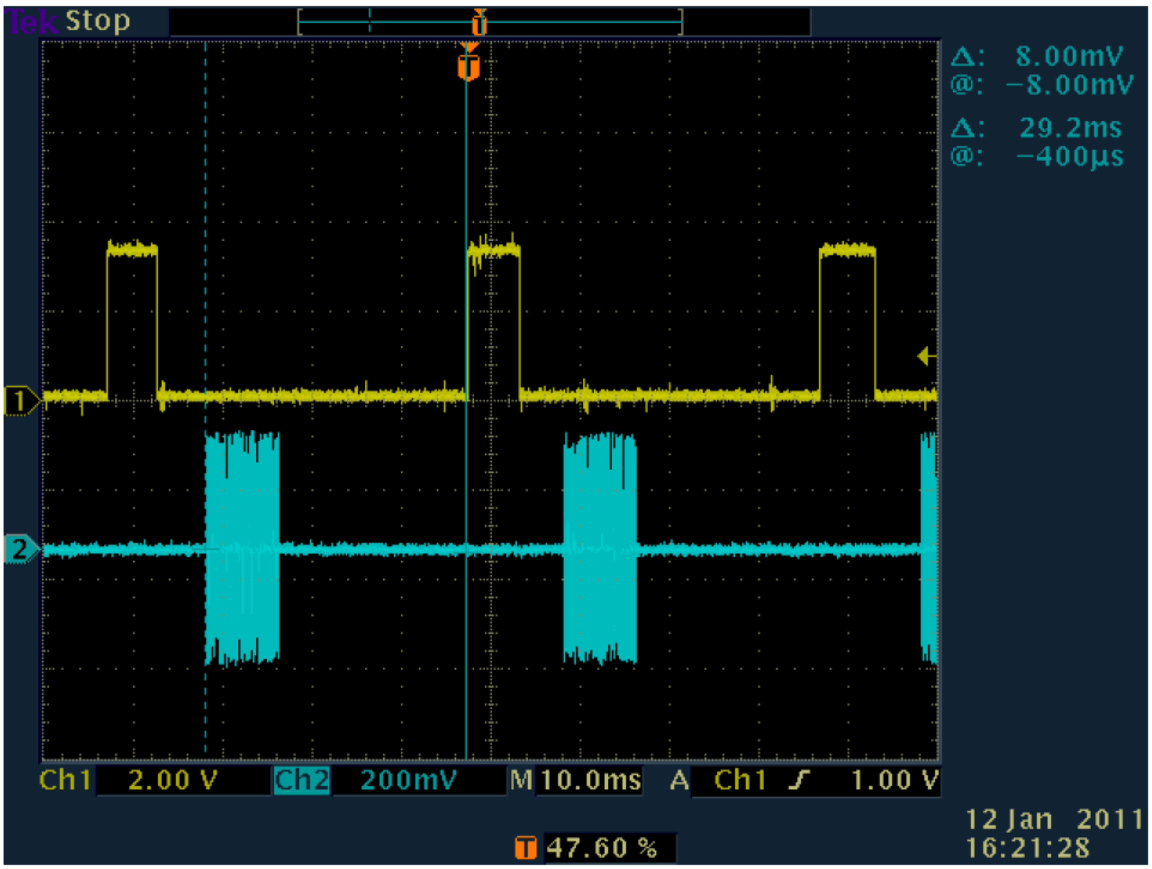

Figure 2: Screenshot from measurement of wake-up receiver delay

The wake-up delay for different channel damping and WUR parameters is shown in Figure 3. The delay is always between 20 and 30 ms.

Damping	Correlation Time	Threshold	Interrupt Latency
47	300	15	**21,6**
40	300	15	**27,8**
33	300	24	**28,8**
30	300	24	**30,8**
47	700	15	**20,6**
40	700	15	**27,4**
47	700	24	**25**
40	700	24	**29,2**

Figure 3: Wake-up delay for different WUR configurations

The other important key figure is the BER of the wake-up receiver regarding the channel attenuation and the WUR configuration. A high BER would render the WUR useless, since a reliable wake-up of the sensor node wouldn't be possible. Figure 4 shows the BER measurements for different channel attenuations and all possible WUR parameter combinations and Figure 5 shows the resulting packet error rate (PER) graphically. The PER determines if the wake-up signal will be reliable for a certain channel condition.

CORR	0x98	0x8F	0x18	0x0F	
	Packet Error Rate – PER at WUR Configuration:				
damping in dB Theoretical	700 / 24	700 / 15	300 / 24	300 / 15	Real damping in dB
40	0,00000000	0,00000000	0,00000000	0,00000000	41,4
41	-	-	-	-	-
42	0,00000000	0,00000000	0,00000000	0,00000000	42,8
43	0,00000000	0,00000000	0,00000000	0,00000000	44,4
44	-	-	-	-	-
45	0,00000000	0,00000000	0,00000000	0,00000000	45,8
46	0,00000000	0,00000000	0,00000000	0,00000000	47,6
47	-	-	-	-	-
48	0,00000000	0,00000000	0,00515100	0,00000000	48,8
49	0,00000000	0,00000000	0,99965600	0,00000000	50,6
50	0,00000000	0,00000000	1,00000000	0,00000000	51
51	-	-	-	-	-
52	0,00008350	0,00000000	0,99900000	0,15465600	53,8
53	0,69690900	0,00000350	0,80500000	0,23857800	54,4
54	-	-	-	-	-
55	0,99539700	0,16407200	1,00000000	0,99051400	56,8
56	1,00000000	0,73853300	1,00000000	0,99984400	57,6
57	-	-	-	-	-
58	1,00000000	0,76221600	1,00000000	0,99984600	59,8
59	1,00000000	0,75600000	1,00000000	0,99600000	60,6
60	1,00000000	0,77301200	1,00000000	0,99600000	61
61	-	-	-	-	-
62	1,00000000	0,99987300	1,00000000	1,00000000	63,8
63	1,00000000	0,89546600	1,00000000	0,98900000	64,4
64	-	-	-	-	-
65	1,00000000	0,99999900	1,00000000	0,99200000	66,8
66	1,00000000	0,99999900	1,00000000	1,00000000	67,6
67	-	-	-	-	-
68	1,00000000	0,99981100	1,00000000	1,00000000	69,8
69	1,00000000	1,00000000	1,00000000	1,00000000	70,6
WUR used	Blue	Blue	Red	Blue	

Figure 4: BER of wake-up receivers for different parameters

	700 / 24 B	700 / 15 C	300 / 24 D	300 / 15 E
CORR Reg	0x98	0x8F	0x18	0x0F

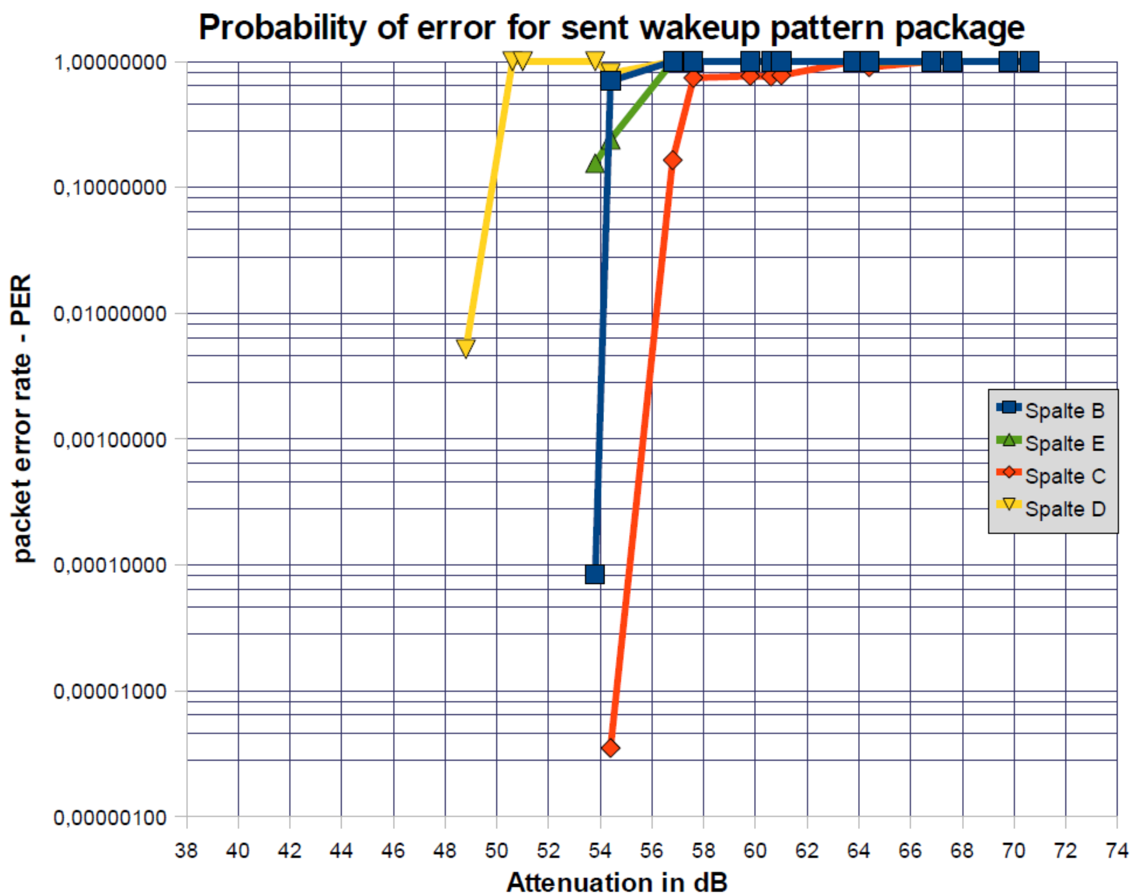

Figure 5: Packet error rate of WUR

According to the aircraft channel measurements performed in CHOSeN, the reliable wake-up distance will be around 10 m, which is well within the limits of the application requirements. Also, an wake-up delay of less than 30 ms fulfills the aeronautic application requirements.

3.2 Flight tests

Another important factor for the success of wireless sensors for structural health monitoring is the autonomous operation (without the need for battery exchange). That's why the performance of the energy harvester (it's power output during flights) was measured. For that purpose several flight test campaigns were performed with the energy harvester device, which is used for the CHOSeN demonstration. The energy output was recorded for each flight in order to know if there is enough energy available for the operation of the CHOSeN wireless nodes. Figure 6 shows the installation of the harvester in the aircraft for the flight test campaigns.

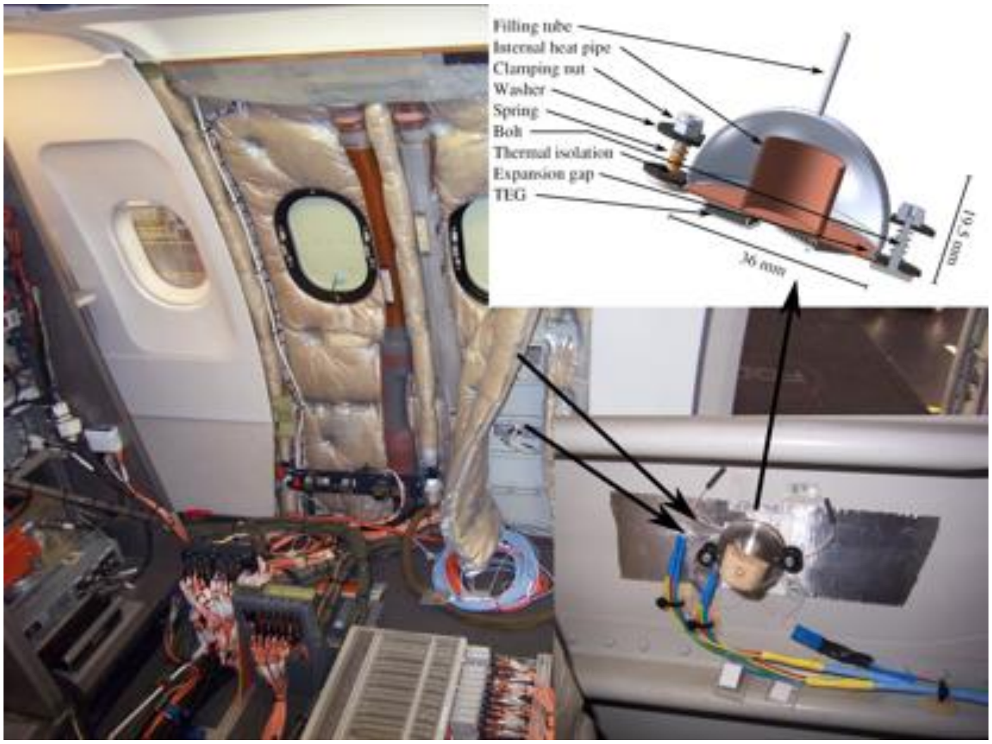

Figure 6: Flight test installation of harvester device

In Figure 7 the energy output of the harvester is shown for an exemplary flight with a start, cruising and landing phase. It was 20 and 23J for the two installed devices. Another power profile is shown Figure 8, where the aircraft followed a more complicated flight profile. The generated energy was also in the range of 20 to 25J here.

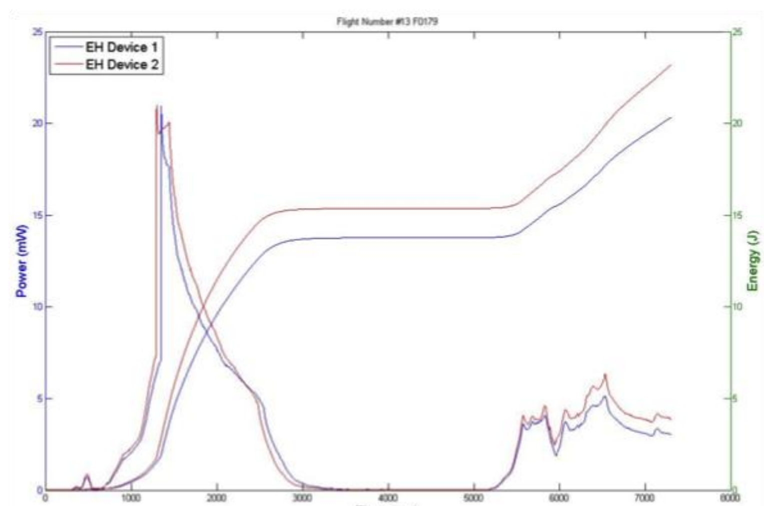

Figure 7: Exemplary power output for one flight (start, cruise, landing)

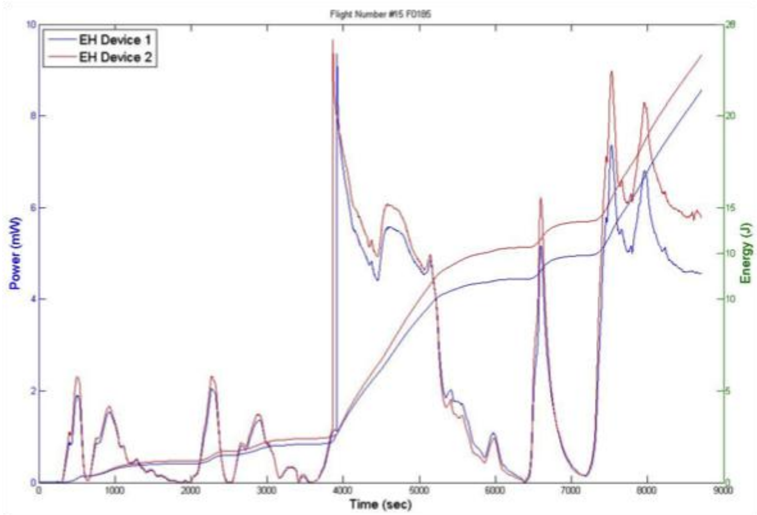

Figure 8: Exemplary power output for another flight profile

The following table shows the energy output of the two installed harvester devices for all flight test campaigns. As can be seen, the generated energy was between 10 and 50J or 2.8 and 13.9 mWh.

##	Date	Max Altitude (ft)	Min Temp(°C)	ΔT (°C)	EH Device1 (J)	Energy_2 (J)
1	20.05.11	35343.88	-33.26	51.50	18.49	19.27
2	23.05.11	39651.74	-45.79	69.05	18.08	19.04
3	24.05.11	39139.80	-31.38	50.56	12.19	12.93
4	09.08.11	33743.79	-24.42	48.84	16.19	31.86
6	12.08.11	40763.80	-38.18	69.23	10.50	21.10
9	24.08.11	33788.10	-17.43	45.31	10.35	12.35
10	25.08.11	40136.89	-41.29	74.24	27.77	30.78
13	29.08.11	40251.30	-33.99	59.41	20.32	23.17
15	13.09.11	41605.47	-30.71	64.56	18.65	21.39
16	15.09.11	40604.96	-37.43	69.18	18.59	21.32
18	16.09.11	34567.72	-24.36	56.61	16.93	18.46
19	17.09.11	39076.80	-32.56	56.44	19.31	21.29
20	18.09.11	35226.05	-19.30	37.48	10.98	12.31
21	20.09.11	39929.40	-30.31	64.17	46.22	51.68
22	21.09.11	40889.00	-40.63	69.43	20.85	22.94
23	22.09.11	39214.00	-30.81	56.79	15.90	18.14

3.3 Application tests

In order to test the application performance regarding the energy limits and wake-up receiver performance a complete prototype was built including the harvester and power management modules. The set-up of the prototype can be seen in Figure 9.

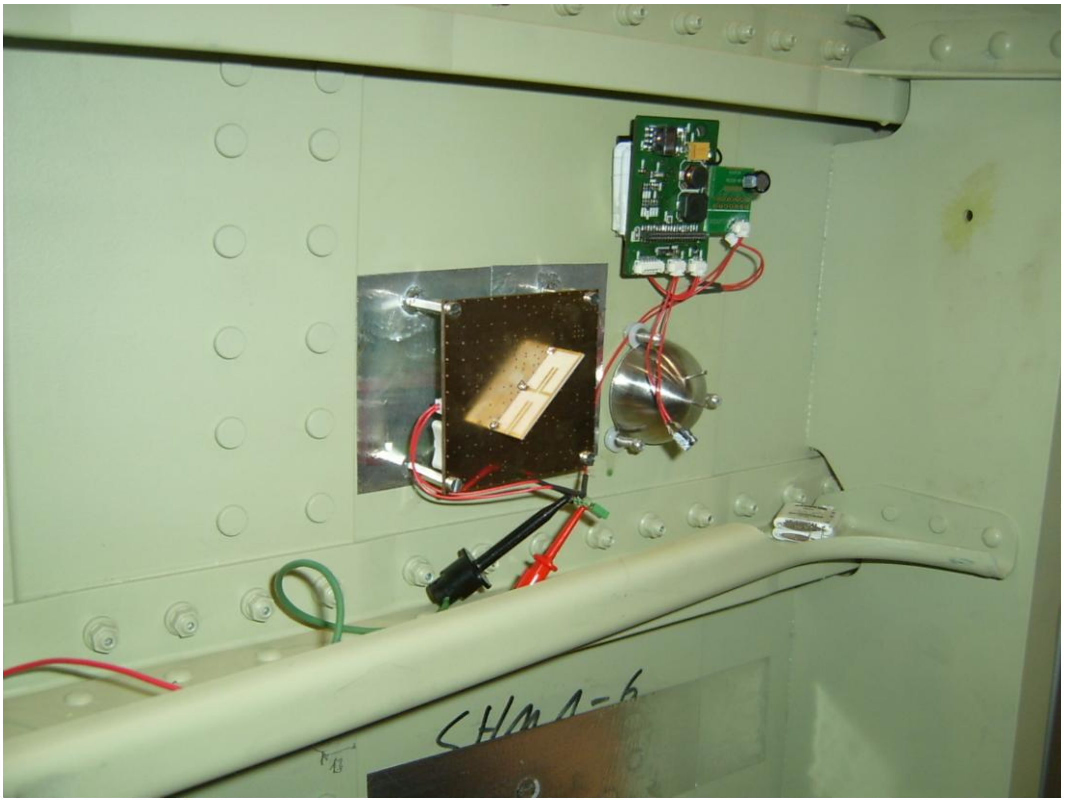

Figure 9: Test setup of aeronautic application demonstrator

With this prototype, using the aeronautic hardware and software components and architecture described in D4.1.2 [4] and D4.3.2 [5], final assessments were done. The power consumption of the CHOSeN node was within the limits of the energy generated by the harvester and stored in the power management. Also, the communication range and performance was within the application requirements.

4 Conclusions

Performance evaluations of the wake-up receiver under realistic channel conditions were done and resulted in a measured wake-up delay of 20-30 ms and a reliable wake-up range of 10m. The flight test campaign of the energy harvester showed a generated power per flight and harvester device from 3 to 13 mWh, which proved to be enough for the ultra-low power wireless sensor node developed in CHOSeN using the defined aeronautic application scenario. The final assembled prototype was tested with the harvester and the required measurements of the aeronautic use cases were performed.

The result of the field trials and assessments is that the CHOSeN wireless sensor platform fulfills the requirements of the aeronautic application.

References

[1] D. Samson, M. Kluge, Th. Becker, U. Schmid, Optimization of a Heat Storage Device for an Aircraft Specific Thermoelectric Power Generator, Proceedings of the ECT 2010, p. 115-119, 22-24 September 2010, Como, Italy.

[2] M. Kluge, D. Samson, T. Becker, A. Gavrikov, B. Bennemann, J. Nurnus, Efficient Power Management for Energy Aware, Selfsufficient Wireless Sensors in Aeronautical Applications, PowerMEMS 2010, technical digest poster sessions, pages 81f., 1-3 December 2010, Leuven, Belgium.

[3] CHOSeN Deliverable D1.4, "Description of the aeronautic demonstrator", http://chosen.eu

[4] CHOSeN Deliverable D4.1.2, "Demonstrator HW setup for aeronautic application", http://chosen.eu

[5] CHOSeN Deliverable D4.3.2, "Demonstrator protocols and application SW for aeronautic application", http://chosen.eu