1 Publishable summary

1.1 Introduction

In today's green aircraft technology development active flow control techniques are used to reduce noise, CO_x/ NO_x emission and fuel consumption. MEMS based piezoelectric actuators for active flow control have strong requirements with respect to the actuation voltage level and the capacitive load which has to be controlled. Commercial high voltage amplifier components are mostly large and heavy or can only drive moderate capacitive loads. This work has been carried out within the 7th Framework program of the JTI Clean Sky. An integrated high-voltage circuit (HV-ASIC) consisting of six high-voltage amplifier stages together with integrated electronics for temperature monitoring and phase shift control has been developed and characterized.

1.2 Design Approach and Implementation

The focus of this development was the demonstration of the actuation of micro-pulsed jet actuator (µPJA) elements by integrated high voltage amplifier stages. An output stage design based on high-voltage PMOS and DMOS devices has been implemented in a 1 µm technology- XDH10 of XFAB foundry AG. Each output stage is able to drive capacitive loads up to 100 nF at a level of 300 V with an operation frequency of 500 Hz or 2.5 nF with 20 kHz, respectively. In order to reduce the maximum peak current a phase shift circuitry has been implemented whereas the output signal of each HV stage can be shifted by 60 °. In a first iteration three different HV output stage topologies have been designed, simulated, fabricated and measured on a test chip in order to judge the performance of these output stages. The best approach could be identified with the PMOS/ DMOS output stage (Figure 1).

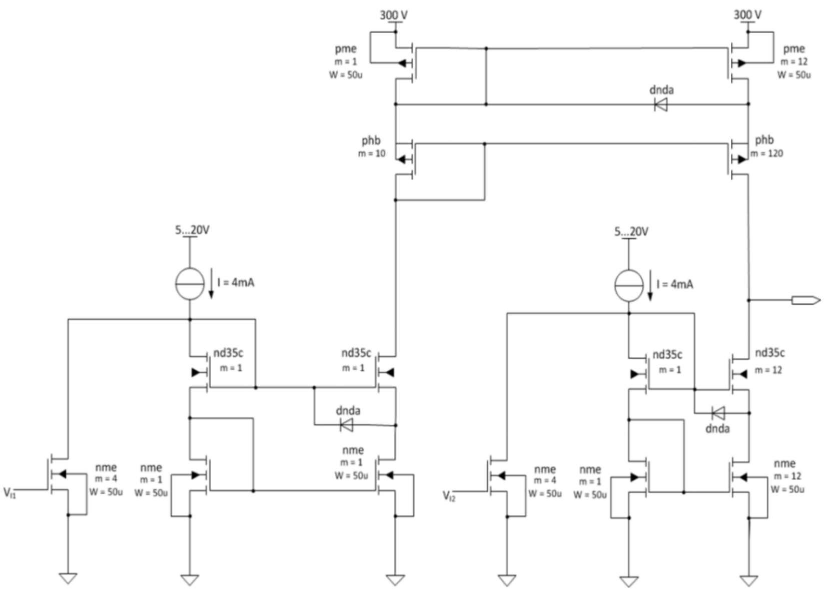


Figure 1: High voltage output stage - PMOS/ DMOS based with additional control stage

The evaluation has been carried out using CoB (Chip on Board) assemblies of two different carrier materials (FR4/ Aluminum Figure 2 b).

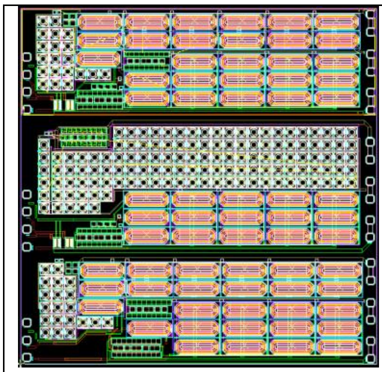
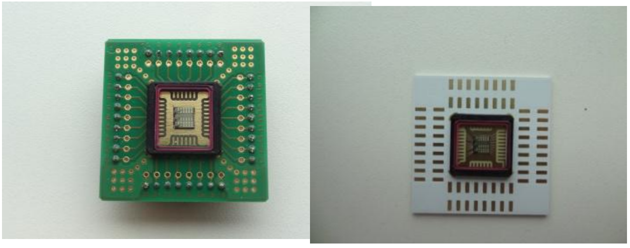


Figure 2: a) Test Chip layout



b) FR4/ Al CoB

Based on the results of the test chip a final HV ASIC could be developed and fabricated. The methodology of this HV ASIC design follows the ideas of:

- Accessibility to each relevant subcircuit in order to enable a single characterization
- Decoupling of subsystem functionalities by turn_off features in order to ensure full system functionality even in case of single malfunctions which may be fixed by external circuitries.
- Each HV stage can be powered separately and can drive a maximum load of 100 nF parallel to 50 kΩ.
- Energy saving/ Power management by phase shift unit
- HV operation emergency stop in case of excessive heating by integrated temperature control with automatic turn_off
- Simulations were done with respect to save start-up, technology tolerances, temperature range and functionalities (e.g. Figure 3, Figure 4).

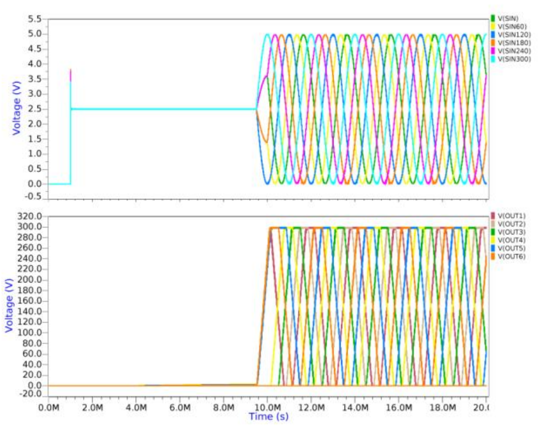


Figure 3: Simulation results HV stage-low voltage control signal inputs and high voltage output signals

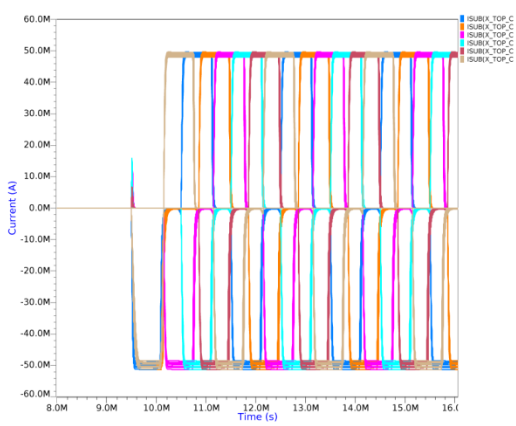


Figure 4: simulation results of output charge/ discharge currents

Figure 5 shows the block diagram of the HV ASIC system.

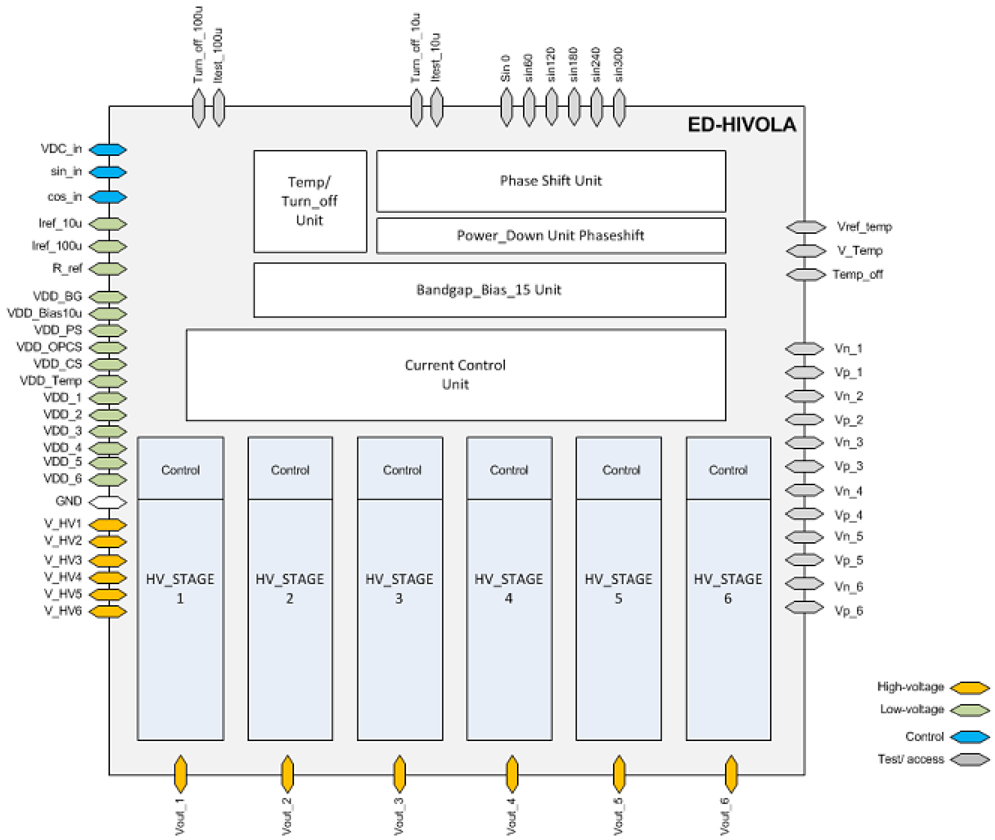


Figure 5: Block diagram- HV ASIC System

1.3 Results

The mock-up panel consists of three basic modules whereas the HV ASIC module and the actuator module are the main elements. The third module is designed to provide a useful common 230 V AC/ 24 V DC and 24 V DC/ HV DC conversion for easy use and demonstration by SFWA partners. In a final aircraft implementation it may be easy to be replaced by an optimized solution with respect to the board voltage supply capabilities.

Figure 6: HV ASIC dies

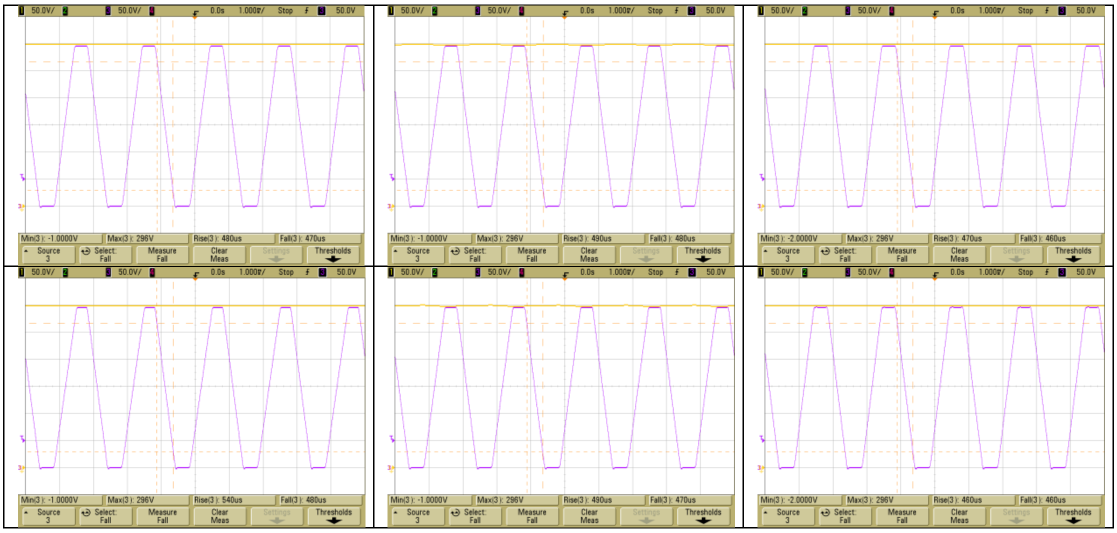
Figure 7: Mock-up Panel – electronic assembly

Table 1 shows exemplary the results of all six HV output stages with applied full load of 100nF with 300 V/ 500 Hz and Table 2 the related output signals.

Table 1: Summary of all HV stage output signals

HV_Amp	Min [V]	Max [V]	t_rise 90% [s]	t_fall90% [s]	V_Temp [V]	delta T [°C]
Out_1	0	296	480	470	1,47	33,8
Out_2	0	296	490	480	1,46	35
Out_3	0	296	470	460	1,44	39,4
Out_4	0	296	540	480	1,49	29
Out_5	0	296	490	470	1,48	31
Out_6	0	296	460	460	1,48	32

Table 2: Output signals of HV stages 1-6



1.4 Summary

An integrated high voltage circuit has been developed in order to drive high capacitive loads up to 600 nF and enable operation voltages up to 300 V. Due to the reduction of space, weight and power consumption this solution enables active flow control by MEMS based piezoelectric actuators for aircraft applications.