Integrated Circuits for MEMS - Design and Characterisation

G. Ebest, S. Buschnakowski, S. Heinz, F. Korndörfer, H. Zeun

The development of integrated circuits to drive micro actuators and the processing of micro sensor signals are the main topics in the research activities of the working group „Microsystem Electronics“ at the professorship of electronic devices (LEB) at the Chemnitz University of Technology. Our workgroup is an essential part of the Collaborative Research Centre No. 379.
The field of activity comprises the design of integrated high-voltage circuits for electro statically driven micro actuators, characterization and modelling of devices for high-voltage micro technologies, the design of low power and low noise integrated circuits for signal editing of micromechanical sensor arrays and electrical characterization of microsystems.

An example of integrated high-voltage circuits is the 48-channel micromirror switcher for a Hadamard-Transformation-Spectrometer. Each of the 48 micromirrors forms a capacitive load. The voltage-swing of every output stage amounts 20 volts up to 120 volts. The output voltages are stored in 48 sample-and-hold stages as low voltage signals. Data transfers take place in serial form. Figure 1 shows the circuit layout. The micromechanical components were assembled with a wafer bonding process.

Other developments are multi-channel high-voltage amplifiers to drive micro actuators. Their voltage-swings are about 300 volts, 500 volts and 850 volts high. Our working group develops two concepts of integrated high-voltage amplifiers. The first one is a pseudo-push-pull-amplifier with a high-voltage n-channel output stage for an electrical strength up to 850 V. The second one is a 350 V class D switching amplifier with pulse width modulation.

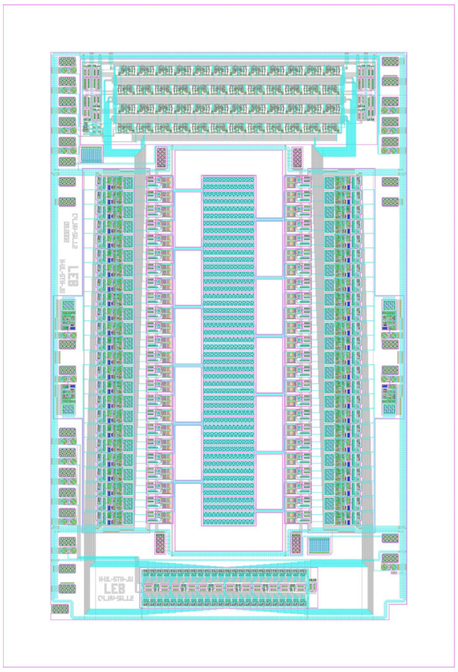

Figure 1: Layout of high-voltage 48-channel micromirror switcher

The fully integrated two-phase lock-in amplifier is an example of a low power and low noise circuit for signal conditioning of micromechanical sensorarrays (Figure 2). A lock-in amplifier is a signal recovery instrument that can be considered as sophisticated filter accepting some signal frequencies and rejecting others. Commercial lock-in amplifiers are very expensive and not suitable for portable instrumentation. For this reason we designed an integrated simplified lock-in amplifier in CMOS technology.

In our case the lock-in amplifier is used to detect the vibration frequency of resonant micromechanical structures. The electronics can be used for vibration monitoring systems in a frequency range from several Hertz up to 10 kHz. The movement of the resonant structure is detected capacitively.

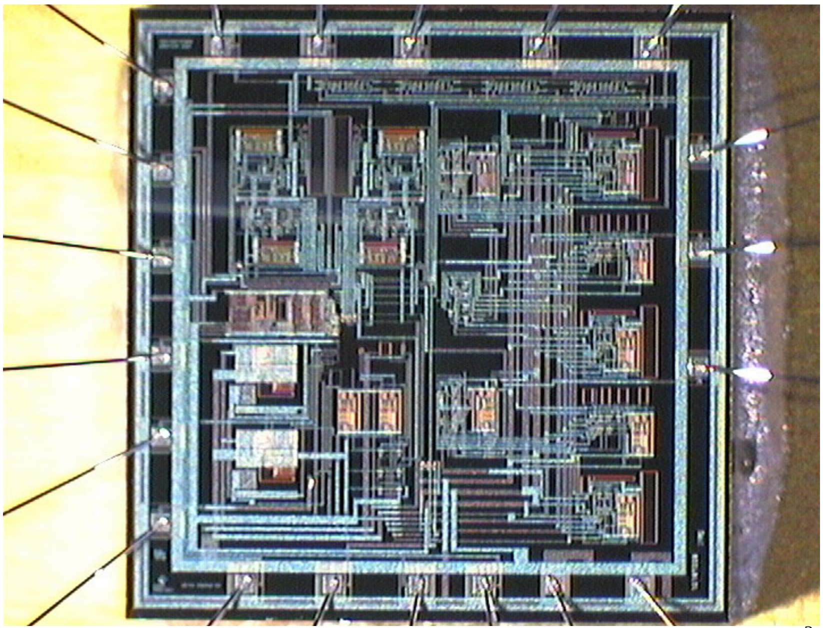

Figure 2: Chip photo of an integrated two-phase lock-in amplifier (area about 10 mm^2)

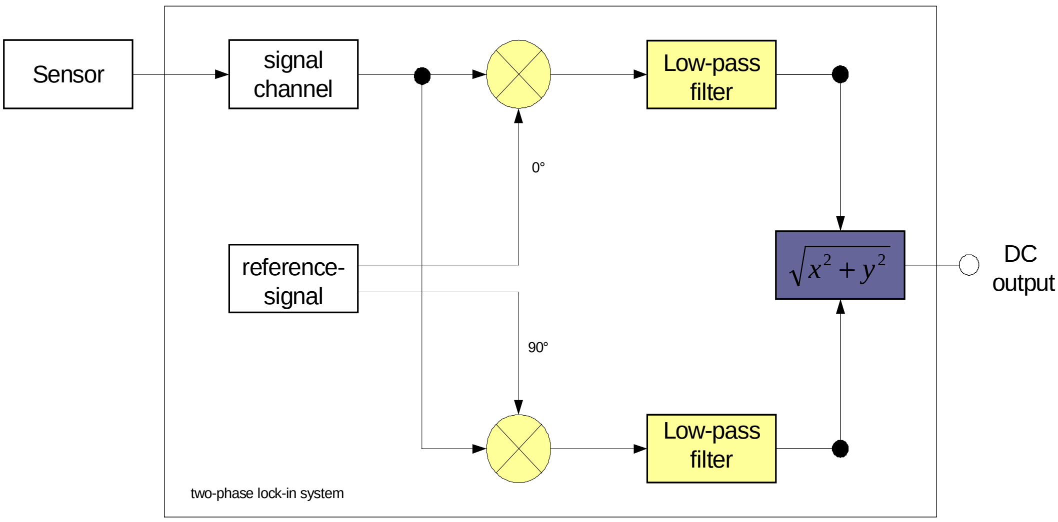

Figure 3: Simplified block diagram of a two-phase lock-in system

A two-phase lock-in amplifier consists of an input amplifier, a pair of phase-sensitive detectors, two low pass filters and a vector computer. The input amplifier pre-processes the signal buried in noise by amplifying it to a level suitable for the phase-sensitive detector. The phase-sensitive detector gives a selective rectification of the signal by means of a switching operation. The reference voltage and switches between A and B control the two-position switch electronically as the reference waveform changes polarity. This gives a systematic change of gain in the signal path between +1 and –1. The pair of phase sensitive detectors enables the simultaneous measurement of the in-phase and the quadrature components of a coherent signal.
A vector computer calculates the resultant (Figure 3). The electronic circuit is realized in switched capacitor (SC) technology. Such networks are composed by capacitors and operational amplifiers interconnected by an array of periodical operating switches (Figure 4). The main advantages of this

network technology are high precision monolithic fabrication of frequency selective devices and reduced chip area in comparison to continuous-time integrated circuits.
The two-phase look-in amplifier is designed in a 0.8 µm CMOS technology.

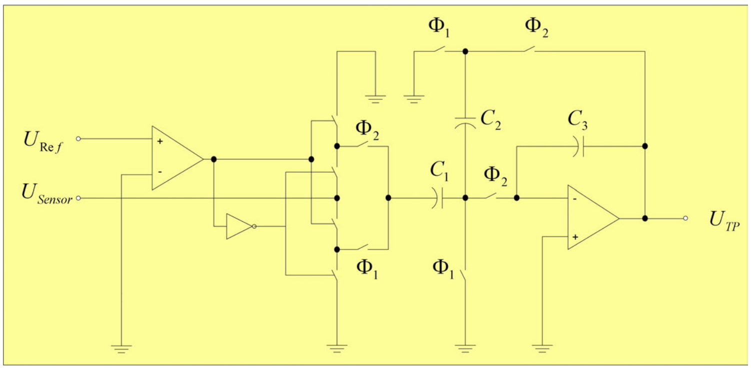

Figure 4: SC phase sensitive detector

Several device models for diodes, resistors, low voltage MOS-transistors and high voltage DMOS-transistors were generated. These model sets enable us to perform accurate circuit simulations and optimisations.
Currently we optimise a high speed switching amplifier stage to drive piezoelectric micro transducers for ultrasonic beam applications. The amplifier operates a ternary signal with the states –200 V, 0 V, +200 V where slew rates of about 20 kV/µs are required.
An ultrasonic beam that enters a sensor with eight elements causes eight sensor signals. Because one beam reaches every single sensor element at a different time, a time skew exists that is dependent on the entering angle. To form the sum of all signals a delay and summing circuit was developed. The circuit has a bandwidth of 10 MHz. It consists of summing stages and adjustable delay stages. The delay time that matches the time skew can be adjusted via a single voltage. Adjustable delay times between two signals range from 30 ns to more than 100 ns. The integrated circuit can be used to operate with different PVDF ultrasonic sensors.
The required chip size per signal is about 1 mm² in a 0.8 µm standard CMOS process. Four signal summations are included in one DIL 24 package. A summation of eight signals is possible by connecting two packages in series (Figure 5). It is possible to use identical circuits in sensors with 4, 8, 12, 16 … elements and get one output signal. Naked dies can be bonded to the board to decrease the application size of sensor systems with a large number of elements.

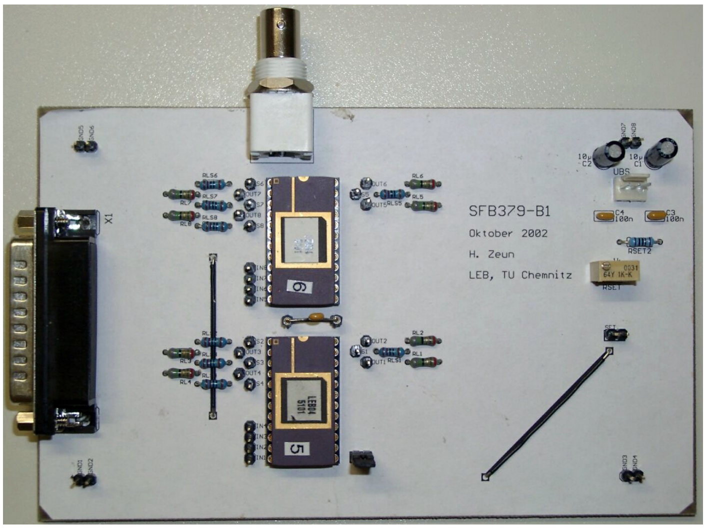

Figure 5:
8-Channel Delay and Summing Board