Introducing ELFIAC – Completely new actuator technology

Flexible and compliant - unlike piezo
Cost-efficient
Thin and adaptable, can be manufactured in almost any size and shape, flat or curved
Excellent low-frequency performance and high actuation displacement
Lead-free and biocompatible
Elastomeric Film Actuator (ELFIAC): A flexible, universal actuator solution for today’s and tomorrow’s diverse applications

ABSTRACT

Today, piezo actuators are found in a great number of applications. Optical system auto-focusing, positioning, haptics, pumps, valves, vibration sources, vibration control, motors, printers, image stabilization, manipulators, and many more use piezo actuators as part of their function.

A solid-state form factor has often been an advantage of using piezos over other actuators or motors. However, the technology has also a number of shortcomings: fairly small actuation displacement compared to the actuator thickness, and the relatively high thickness of piezo actuators when used in small devices. Also, most piezo actuators contain lead, which is a toxic material, often preferred to be avoided in consumer devices.

In this document, we present a totally new type of actuator: Elastomeric Film Actuator (ELFIAC) which has been specifically designed to address the limitations of piezo technology. ELFIAC can also be used to enable a whole new range of applications, especially in areas where actuator flexibility is an advantage.

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1. Overview of ELFIAC Structure

ELFIAC is a flexible actuator composed of insulated electrode films separated by silicone elastomer spacers, or pillars, that act like miniature springs (Figure 1). A high voltage, but very low current, signal is driven to every other electrode while the other electrodes are kept at ground level. This causes the system to compress due to electrostatic attraction between electrodes on consecutive film layers. The basic operating principle is therefore simple and robust. The system can also be used to sense pressure. Typical ELFIAC operating voltage starts from a couple of hundred volts.

THIS NEW TECHNOLOGY IS ENABLED BY FOUR RECENT TECHNICAL DEVELOPMENTS:

- The now excellent mechanical properties of liquid silicone rubber from which the elastomer pillars are made.
- Various micromachining technologies have matured to a level that allows consistent manufacturing of microstructures (such as the micropillars used in ELFIAC).
- The availability of compact high voltage electronics, of which an example solution suitable for consumer electronics is introduced in this document in Section 4.
- Manufacturing methods of flexible electrodes and insulating coatings, especially with roll-to-roll techniques, have matured.

The simple overall structure of ELFIAC lends itself to a great variety of different shapes and configurations. The actuation layers in ELFIAC can also be stacked into multiple layers, which allows its displacement to be multiplied to suit various applications. In some mechanically demanding applications, an external cover can be placed around ELFIAC to provide required the robustness. The thickness of the whole ELFIAC stack can be varied from fractions of a millimeter to several millimeters, wherein actuation displacement is up to 20 % of the overall stack thickness. ELFIAC can take any planar (2D) shape. These can then be formed to follow more complex shapes, therefore providing actuation over for example curved surfaces.

In addition to its high relative displacement compared to piezos, ELFIAC has an excellent low frequency performance down to DC. However ELFIAC is unsuited to high frequency operation, such as ultrasound or high audio frequencies. Unlike lead-containing piezo components, ELFIAC is constructed from proven, tested and environmentally-friendly materials such as conductive inks or thin metals coatings, polymer films and bio-compatible silicones. ELFIAC is proprietary technology of Senseg, and is developed and manufactured by Senseg. ELFIAC is protected by several pending and allowed patents.

Figure 1. A diagram of an example ELFIAC structure. The system is composed of insulated electrodes that have micropillars as separating springs. The electrodes are stacked in an alternating pattern of ground and driven electrodes.
2. Present and Future Applications

Three core properties of ELFIAC - extreme flexibility, thin structure, and highly-scalable size and shape - open the door to a whole new range of applications for this actuator technology. Each of these properties is elaborated below with example applications and artistic concept illustrations:

A. Mechanically ELFIAC is composed mainly of thin polymer films that make it highly flexible and compliant. Possible applications of this include:

• Smart clothing, VR and AR gloves and other close-to-body apparel, gaming and car seats, robotic skin, various toys.

B. ELFIAC is designed to be manufactured at thicknesses from millimeters down to fractions of a millimeter and to provide large compression (up to 20%) compared to its thickness. Possible applications of this include:

• Various haptic applications – e.g. in conjunction with soft surfaces or as an actuator for a screen that has been arranged to be moved within a suitably elastic gasket. It can also be used in various mechanical manipulators, micro and small pumps, and adjustment devices requiring a thin form factor.
C. Unprecedented freedom of form factor: Practically any 2D film shape and size can be realized. This includes very large areas (up to square meters). ELFIAC can also easily bend over curved surfaces and follow complicated shapes. Possible applications of this include:

- Actuation of various game controller devices with curved surfaces, as well as professional control systems, such as industrial panels or flight controls, and automotive controls including steering wheel. It is also possible to provide localized feedback, such as the individual actuation of finger locations on a game controller. Actuation of large surfaces such as interactive meeting room screens, industrial conveyor belts and solar panel dust removal through vibration is also possible.

In addition to its compliant properties, a further factor enabling various applications for ELFIAC, is that its performance properties can be tuned to suit a great variety of purposes. For example, the optimal operating frequency range can be adapted to customer needs by varying the properties of the micropillar structures. However, a high frequency range (e.g. above 500 Hz) is naturally better-suited for other types of actuators.
Heavier loads can be handled by varying the properties of the micropillars and also by increasing the active area of the actuator. Naturally, the electrical driving capabilities, and the driving current in particular, also need to scale as ELFIAC’s active area increases; the capacitive load of the system increases as a consequence of increased actuator area. For a fixed capacitive load, ELFIAC can be optimized to provide a large displacement for light mechanical loads, or smaller displacement for heavier loads. Naturally, the ELFIAC actuators can be arranged into various row or matrix patterns to provide multi-location actuation.

Several layers can be stacked to obtain more displacement, or as enabled by ELFIAC’s flexibility, it can for example be wrapped around a cylindrical object several times to provide a multilayer structure. It is noteworthy that force and displacement are in general dependent variables - i.e. most piezo actuators can generate large forces but provide only small displacement. ELFIAC addresses this trade-off favorably for many applications by providing larger displacements at lower force.

For haptic applications, the ability to provide large displacement is generally essential to obtain the best user experiences. The most pleasant haptic sensations are produced at a fairly low (20 to 80 Hz) frequency range. Human haptic perception strongly depends on the vibration displacement as a function of frequency; low frequency vibrations generally require much higher displacement to reach sensations comparable to high frequency vibrations (See Figure 3). This is somewhat analogous to the more well known human auditory perception. ELFIACs, which can readily provide high displacement also at low frequencies, are well-suited for providing the best haptic experience.

**Figure 3.** Human haptic perception of vibratory signals as a function of frequency. The blue line indicates just noticeable vibration, while the red line indicates the approximate limit of vibration displacement where the effect may become unpleasant.
3. Regulatory Compliance and Operating Conditions

ELFIAC is naturally ROHS compliant and safe to use. It meets all relevant safety regulations, including IEC60950. The system comprises multiple layers of electrical safety, all of which would provide a sufficient level of safety alone.

ELFIAC SAFETY

1) The energy contained in a charged ELFIAC is low, being notably less than in a typical equivalent area piezo actuator.

2) ELFIAC structure is such that all parts that could be exposed in case of severe mechanical damage to a device cover are at electrical ground level, and do not pose a shock hazard.

3) Senseg’s solution firmware continuously monitors generated current and voltage waveforms and interrupts the signal in potentially hazardous situations.

The complete ELFIAC system, including the electrical driver, meets all relevant EMC norms.

ELFIAC has high durability and a long lifespan. While the silicone pillars, which are the key functional components of the ELFIAC, are used in a unique way within ELFIAC, the mechanical compression durability of silicone structures has been extensively studied in conjunction with electroactive polymers. Typically, durability of up to tens of millions of compression cycles has been shown\(^1\),\(^2\), and the breakage mechanics are often due to weaknesses of other structures within electroactive polymers devices. These structures are different and much more resilient in ELFIAC. A large temperature range is a well-known benefit of liquid silicone rubbers, and ELFIAC is capable of operating under a wide range of environmental conditions:

- Wide functional temperature range: typically -40 to +90 C
- Can be operated in normal electronics humidity ranges.
- Special hermetically sealed ELFIAC variants can be operated even under water.
- Remains fully-operational throughout hundreds of millions of operating cycles.

While special silicones can be used to extend the operating temperature range even further, normal silicone materials may age prematurely if extensively stressed at over +100 C temperatures.
4. Senseg SiP and Reference Design

One of the factors limiting the adoption of technologies requiring high voltage in consumer electronics has been the availability of suitable driver solutions. While various high voltage drivers are available, they are often intended for high power and high current applications. In addition, these drivers tend to be bulky, expensive, and often lack accurate signal control and monitoring capabilities.

Senseg has developed a uniquely compact and accurately controlled high voltage driver for the low current demand use of ELFIAC. The solution is suitable for a wide range of consumer applications. At the heart of this solution is Senseg’s proprietary S220 system-in-package (SiP) chip, which also powers the ELFIAC demonstration kit. It uses fly-back topology to generate a high voltage from a typical single cell 3.7-volt battery. With the use of externals, the maximum output voltage can be set to anything from a few hundred volts up to 2.5 kV. The solution is intended and sized for consumer applications. Senseg is committed to providing other driver solutions intended for automotive and larger industrial applications in the near future.

S220 SIP MAIN FEATURES:

- Supply voltage range from 2.5 to 5.5 V
- Fly-back boost converter with programmable slew rate
- The STM32F031x6 with 16 Kbytes Flash integrated
- 60 V switching MOSFET integrated
- Programmable peak current limit up to 3.2 A
- Programmable overvoltage threshold
- Programmable zero energy detector threshold
- Programmable LDO with 0.08 A capability for the STM32F031x6 supply
- 1.8 V LDO with 0.08 A capability for the STM32F031x6 supply
- 1x and 6x buffers for sensing HV output
- Output current measurement
- RDS (on) of the power switch 0.15 Ω
- Efficiency of the fly-back up to 83%
- 5.5 V push/pull output to drive the discharging circuit
- Overvoltage and overcurrent protection
- Overtemperature protection
- NTC protection for fly-back transformer
- Package VFQFPN 5x6 mm 44 leads 0.4 mm pitch
- I2C control
- Operating junction temperature: from -25 °C to +125 °C
The S220 SiP is used as part of Senseg's reference circuit whose topology is described as shown in the block diagram below. The actual reference design is shown in Figure 4. Please note that the reference design can be customized to customer purposes.

**SENSEG REFERENCE DESIGN BLOCK DIAGRAM**

![SENSEG REFERENCE DESIGN BLOCK DIAGRAM](image)

**POWER CONSUMPTION OF A 1.2 KV DRIVER**

The power consumption of the system is low, and the key numbers for an exemplary 1.2 kV driver version are shown below. If the ELFIAC system would be used for providing haptic feedback in a mobile phone use case, it would typically use less than 1% of the mobile phone battery capacity per day, even in a demanding real-world use case.

<table>
<thead>
<tr>
<th>State</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off state</td>
<td>$I_{OFF} = 1 \mu A$</td>
</tr>
<tr>
<td>Idle state</td>
<td>$I_{IDLE} = 1.3 mA$</td>
</tr>
<tr>
<td>Active state</td>
<td>$I_{ACTIVE} = 31 mA (1 kV / 100Hz)$</td>
</tr>
<tr>
<td>Max current</td>
<td>$I_{MAX} = 800 mA (0.5 ms t-window)$</td>
</tr>
<tr>
<td>Converter efficiency</td>
<td>Typically 25-27%</td>
</tr>
</tbody>
</table>
5. About OFILM and Senseg

OFILM Tech Co., Ltd. formally began to operate in August 2002 and listed in Shenzhen Stock Exchange in August 2010 with stock code 002456. The main products of OFILM are TP, CCM, FPM etc., as well as developing in Smart City and Smart Car fields. We are a multi-national enterprise with branches in China, the United States, Japan, Germany, Finland, Holland and Israel.

Senseg is the leading innovator and provider of next generation user experiences and various solutions involving electrostatic forces. Senseg technology delivers sophisticated tactile sensations to your fingertips on touch interface devices. Senseg Oy is a Finnish company and a subsidiary of OFILM. Senseg is operating as an advanced R&D unit of its parent company.

To inquire about the suitability of ELFIAC for your application, or to get your hands on a demonstrator kit contact:

info@senseg.com

6. References
