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A FLUSH MOUNT PACKAGING CONCEPT FOR A MEMS MICROPHONE ARRAY FOR AERO-ACOUSTIC MEASUREMENTS

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Abstract: This paper presents a new approach to package a MEMS microphone for flight tests on airplanes for noise measurements. The package consists of a conventional thinned printed circuit board (PCB) with a cavity, in which the sensor chip is attached. The electrical connections are done with very shallow wire-bonds and the cavity is then sealed with a soft silicone gel. First a brief introduction on the measurement of noise in flight tests is given, followed by the measurement scenario addressed in this paper. The most common packaging approach for MEMS microphones is explained and a new concept for thinner and smaller sensor systems is presented, followed by testing procedures.

Key words: bare-die-integration, MEMS-microphone-array; aero-acoustic-measurements; flight-test.

1 INTRODUCTION

There is a social need to reduce the emissions of airplanes, both to reduce the global CO_2 exhaust and meet the desire of silent airplanes. Residents of airports, ground staff as well as passengers and flight crews benefit from the reduction of noise in aircraft. By decreasing noise emission limit values for airports, for instance the International Civil Aviation Organization (ICAO) increases the pressure on aircraft manufacturers [1]. By the instrument of noise certification, the ICAO aims to ensure that the latest available noise reduction technology is incorporated into aircraft design. The aircraft, engine and nacelle manufacturers need to consider the noise in the construction of future airplane generations. Also, the certification process for new airplane types and the planning of new airports require a precise knowledge of the sound emitted in starting, landing and cruise conditions. During take-off and at cruise condition, when the engines run near full load, the major impact to noise is contributed by the fan and jet. While at landing, when the low-pressure shaft is running at 50-60% of the maximum speed, also the sound of turbine, combustion chamber and compressor are an issue [2]. To be able to measure, locate and distinguish these different sources of noise,

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extensive research programs have been carried out. For example, the LINFaN project [3], in which Airbus and Rolls-Royce have jointly investigated the acoustic impact of supersonic jet noise on the rear fuselage of an A340 equipped with Trent 500 engines. Here an array arranged of 76 B&K microphones attached on the fuselage is used to detect the sources of so-called broadband shock-associated noise. Common to the microphones used in the flight tests described in the publications above are quite bulky cases. The thickness is usually in a range of several millimetres and they need to be covered with specially designed plastic gloves, to limit the interaction with the boundary-layer on the fuselage, they are attached to. The size of the microphones and these gloves limit the spacial resolution of the array, depending on the center to center distance of the gloves.
A new approach to significantly reduce the size of microphones in flight tests, is the implementation of much smaller MEMS microphones. The MEMS microphones available are designed for consumer electronics and have a too low acoustic overload point, of around 135 dB SPL, for flight tests, where values up to 175 dB SPL are measured. There have been several academic projects, in which custom MEMS microphones for flight tests have been build. A summary is given in the publications by Reagan [4] and Williams [5]. Unfortunately, these sensors are not available on the open market. The author of this paper has presented an approach of a custom MEMS microphone for flight tests, combined with a packaging approach using through silicon vias (TSVs) [6]. As this approach is combined with a high effort in the fabrication of the MEMS chip and the packaging of the chip, we present a concept that allows the flush mounted integration of the custom MEMS microphone described in [7] into a conventional printed circuit board (PCB).

2 MEASUREMENT SCENARIOS

The measurement scenario addressed in this paper is well described in [3]. Aim is the localization and measurement of sound sources generated by the jet of the engine. The broadband shock-associated noise (BBSAN) is a phenomenon generated by the mixing of the primary (fan) and secondary (core) jets. The fan jet is supersonic and the mixing with the slower air results in shock cells, which are located behind the engine. To reduce the noise, a better understand of this BBSAN is necessary in general, also a sound insulation inside the fuselage hull can reduce the impact on the noise level inside the cabin. To keep the weight of the insulation low, the exact position of the impact and the sound pressure level and frequency range are of interest. The localisation of the sound sources can be done in the post processing, via beamforming. This is a process where at a specific frequency, by knowing the distances between several sensors of an array and the speed of sound, the array can be directed to a point in space, with shifting the phase of each microphone respectively to their distance to the point of interest. An array used for measurements of BBSAN is shown in Figure 1.

Figure 1: Arrangement of microphones for the measurement of noise from the jet of the engine (Source Airbus)

3 MEMS MICROPHONE PACKAGING

Most of the commercially available MEMS microphones have a package consisting of a thinned PCB to which the sensor chip is attached and wire-bonded, and a metal lid to encapsulate the chip and wires. The sound inlet is usually a hole in the PCB directly under the membrane of the chip, this way the volume of the back-chamber volume above the membrane is maximized, resulting in good a signal to noise ratio. This package can be built with standard MEMS packaging technologies. An example package of the manufacturer Vesper with a piezoelectric MEMS microphone with a sliced diaphragm is shown in Figure 2.

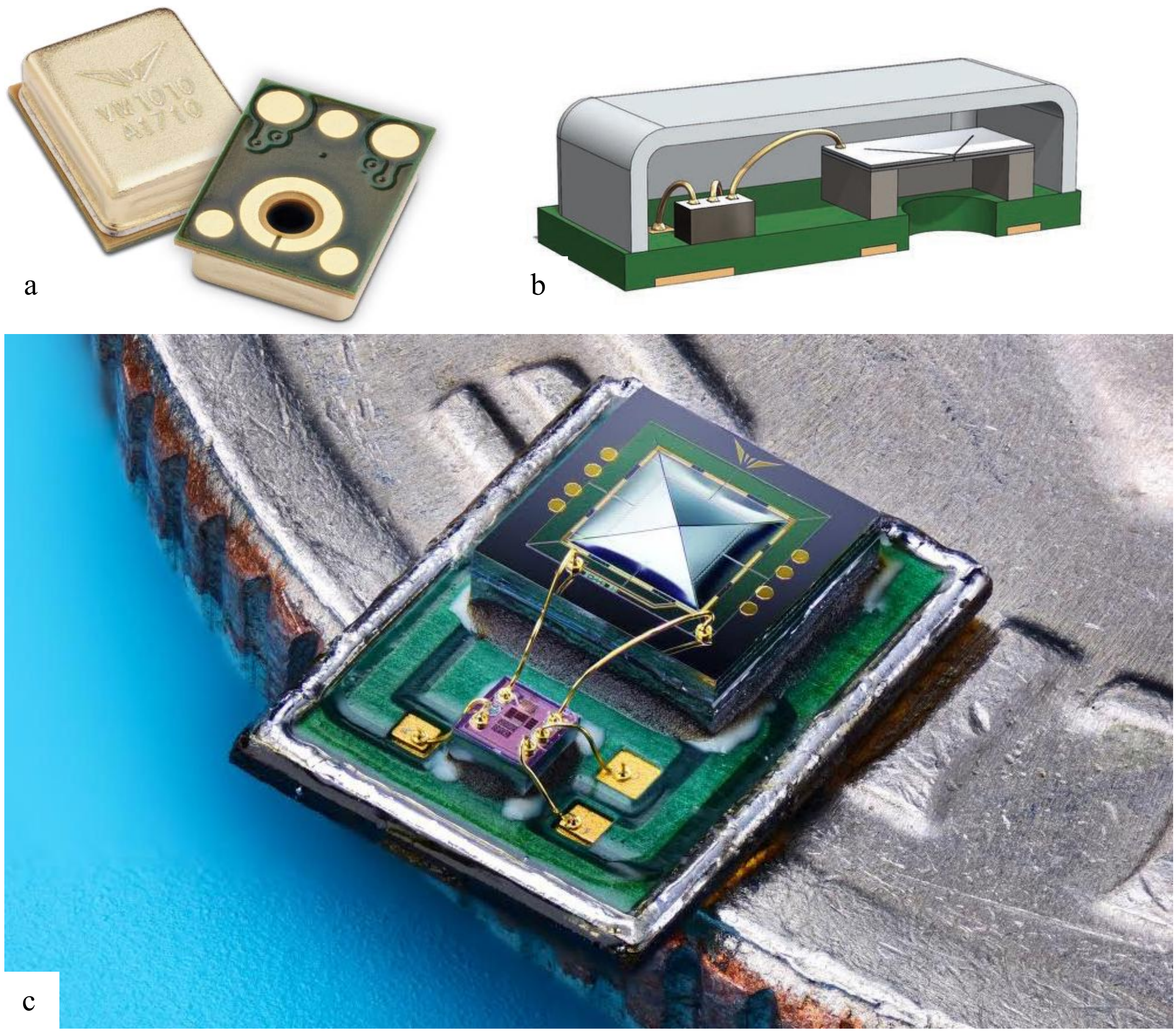

Figure 2: Conventional MEMS packaging a) top/bottom view of a package by Vesper [8] b) cross sectional view with sensor chip, ASIC and wire-bonds [9] c) opened Vesper MEMS microphone [9]

This packaging design with a size of 3.76mm x 2.95mm x 1.3mm (Vesper) is sufficiently small for consumer electronics. To make this type of packages suitable for flight tests, it needs to be assembled with surface mount technology to another PCB, which leads to an overall thickness larger than 2mm. Ahlefeldt et al. [10] demonstrated in their publication an array built of MEMS sensors from Knowles with a total thickness of 1.55mm.

4 NEW PACKGING APPROACH FOR FLIGHT TESTS

The new package presented in this paper and shown in Figure 3, aims to combine a very low total thickness of less than 1 mm with a low topology surface and a diaphragm, which is directly exposed to the incoming pressure waves. The package is based on a PCB built of one thinned FR4 core with a thickness of 360µm and a prepreg with a milling groove, the later place for the sensor chip, which get laminated together. This fabrication allows the forming of a cavity in the PCB with lading pads for wire-bonds on the bottom. The sensor chips get attached with silicone glue to the bottom of the cavity. The wedge-wedge wire-bonds with 25µm thick Aluminum wire then get bonded from the lading pads inside the cavity to the lading pads on the chips, allowing a precise control of the loop, leaving only very little topography above the surface of the chip. The rest of the cavity is then filled with a very soft silicone gel. For electrical connection to the data acquisition system, a ZIF-connector is soldered on at one edge of the PCB and the remaining cavities are filled with silicone gel as well. The overall thickness of the device will be in the range of 0.6mm. The attachment to the airplane for the flight test is done with Aluminum tape.

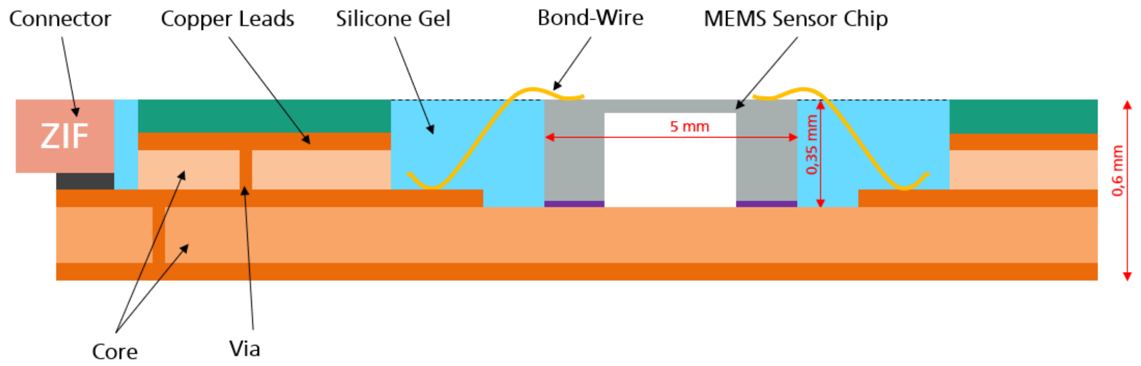

Figure 3: Cross section view of the presented package

5 TESTING

The fabricated samples need then to be measured regarding their final dimension and their response to lower temperatures, as the ambient temperature in flight tests drop down to -65°C. Firstly, the thickness and surface topology is measured with an optical profilometer and then the samples are exposed to temperatures down to -70°C. The shift of the electrically offset of the sensors allows to compensate the measured values of the flight test regarding the temperature influence. Secondly, the response of the samples to sound generated in a standing wave tube is measured. The so acquired frequency and dynamic range are needed to compare the device under test microphones to reference microphones in the test flight.

6 EXPECTED RESULTS

The evaluation of the packaged microphone sensors is expected to show a smooth surface of a package with a constant thickness of about 0.6mm. The loops of the wire-bonds will stand out of the silicone gel by the height of 30-40µm. The preliminary comparison of the built MEMS microphone with a GRAS BP40 reference microphone (shown in Figure 4), shows a lack of sensitivity of about 20dBV to the reference. This measurement was done with a conventional package, with the presented new approach the sensitivity will exceed the values in the diagram, as the membrane is directly exposed to the ambient.

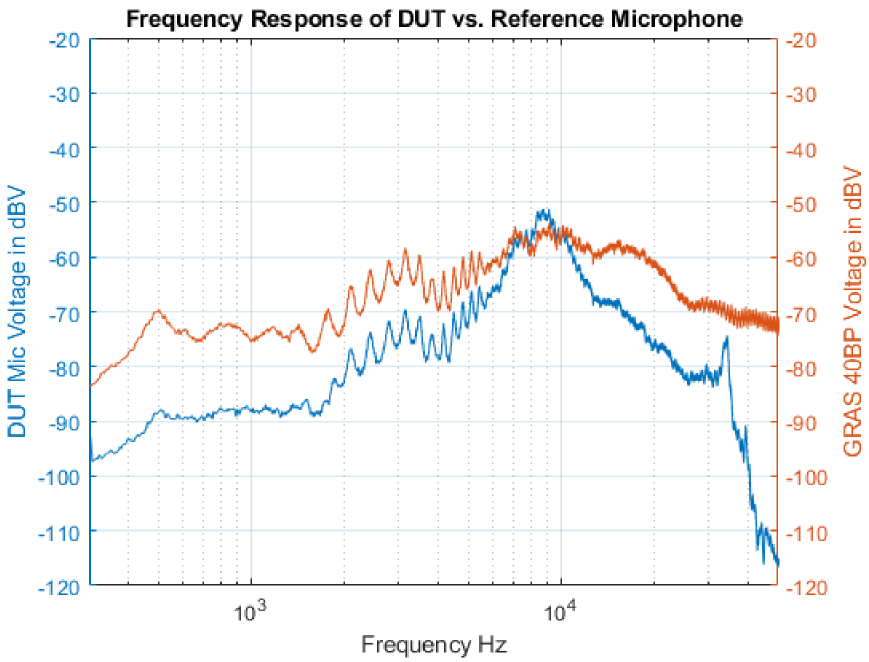

Figure 4: Comparison of the frequency response of a packaged MEMS microphone with a GRAS reference microphone

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