Chapter 10
From Prototype to Product

During the course of this book the full development of a MEMS magnetic field sensor prototype has been shown, providing some guidelines and highlighting critical points and potential pitfalls, as well as how to forecast or mitigate them. The feasibility of such a system based on multi-chip approach has been experimentally proven and the main steps, which represent the core of the design activity for a new product development, have been reported. Beside these ones, in an industry-related environment there are other standard development steps, including, for example, pads design, programming interface, biasing blocks, etc., in order to guarantee typical products specifications, such as ESD requirements, RFI immunity, etc., and to have high yield in production. All major steps needed will be mentioned in this chapter but they are not discussed in detail; however, some references are provided.

10.1 Towards Industrialization of MEMS Chip

As far as MEMS die is concerned, three major items are discussed:

- devices redesign;
- combination of several sensors in the same package;
- possible alternative working regimes for mechanical devices.

10.1.1 Devices Redesign: The Second Generation of Magnetometers

A second generation of devices is implemented with the same micromachining process, taking into account both obtained performance and the developed hardware to model correlation. Device architecture for *Z*-axis sensing element is the same as

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previous generation and only magnetometers with $N = 4$ and $N = 8$ are designed because of their better performance as far as area, cross sensitivity to acceleration (they have lighter masses), and noise are concerned. If the pressure is kept in the range where free molecular flow dominates (and this is the case for industrial standard packages), the presented theory about sensitivity still applies. The main improvements of second generation of devices are:

- Longer beam: $L_{2\text{nd gen}} = 1060\ \mu\text{m}$; increasing springs length has a direct impact on increasing the mechanical sensitivity.
- Lower resonance frequency right at the border of audio bandwidth: $f_{r,2\text{nd gen}} = 20\ \text{kHz}$;
- A lower package pressure (taking into account technological constraints), possibly on order of 0.5 mbar.

Referring to Eq. (3.42), the corresponding expected improvement in terms of sensitivity is given by:

$$\frac{\frac{\Delta C}{\Delta B}_{2\text{nd gen}}}{\frac{\Delta C}{\Delta B}_{1\text{st gen}}} = \frac{L_{2\text{nd gen}}}{L_{1\text{st gen}}} \cdot \frac{f_{r,1\text{st gen}}}{f_{r,2\text{nd gen}}} \cdot \frac{b_{\text{area},1\text{st gen}}}{b_{\text{area},2\text{nd gen}}} = \frac{1060\ \mu\text{m}}{868\ \mu\text{m}} \cdot \frac{28.3\ \text{kHz}}{20\ \text{kHz}} \cdot \frac{5.8\ \text{kg}/(\text{s}\,\text{m}^2)}{2.3\ \text{kg}/(\text{s}\,\text{m}^2)} = 4.36\,, \tag{10.1}$$

which corresponds to a better resolution in terms of minimum detectable magnetic field on equal current. Furthermore, the pumped current can now be reduced to save intrinsic power consumption and, in that case, the exact value should be trimmed to get a trade-off between resolution and power consumption. Figure 10.1 shows layouts of the second generation of devices.

10.1.2 Combination of Magnetometer with Other MEMS Sensors

Thanks to the developed theory and design methodology of mechanical devices, as reported in Chap. 3, an optimized magnetometer must be long but does not need to be large because its sensitivity is independent from the number of capacitive sensing cells. With such a form factor this device can fit in the same die where other MEMS sensors are integrated. A proposed possible solution is to combine it with a three-axis gyroscope, as shown in Fig. 10.2.

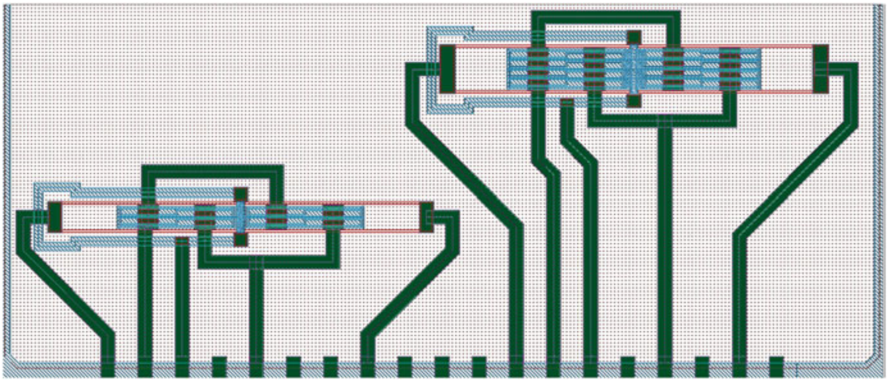

Fig. 10.1 Layout of the second generation of devices: beams length is extended to 1060 μm which is the maximum suspended dimension allowed to avoid buckling effects. Resonance frequency is fixed right at the border of audio bandwidth: 20 kHz. For $N = 4$ magnetometer, drawn spring width is $W_{s4,2\text{nd gen}} = 5.8$ μm and for $N = 8$ is $W_{s8,2\text{nd gen}} = 6.6$ μm

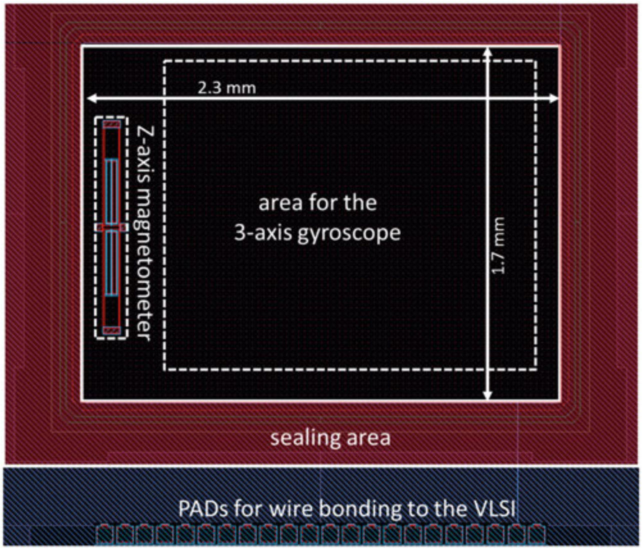

Fig. 10.2 Layout view of the Z-axis magnetometer inside a (2.3 mm × 1.7 mm) active area package. This high-aspect-ratio device can fit in a side of the same package of a three-axis gyroscope. A combination of this unit with a three-axis accelerometer results in a 7-DOF MEMS IMU that solves the problem of out-of-plane assembling of the Z-axis AMR magnetometer

10.1.3 Device Alternative Structures and Working Regimes

Device concept proposed in this manuscript is based on the excitation at resonance frequency of a main shuttle, to which capacitors are anchored, suspended by four springs (Fig. 3.7). At a later time, scientific research on MEMS magnetometer also investigated different architectures of devices and alternative operating modes; a comprehensive overview of these different implementations can be found in [1–3].

The choice among these different approaches may be done considering also product specifications on bandwidth and power consumption.

10.2 Towards Industrialization of ASIC Chip

In Chap. 9 ASIC design is presented, focusing on signal path. Towards the direction of a complete product, other blocks need to be implemented at ASIC level; a detailed discussion is not reported because they are blocks common to any sensor ASIC and they do not have a critical role in the development of a MEMS magnetometer. Among them, there are:

- Bandgap: providing with reference voltages for internal supplies, charge-pumps, and biasing of other blocks [4].
- Internal power supplies: typically generated with low dropout regulators (LDOs).
- ADC (as already discussed, in case of a digital output product). MEMS sensors applications typically require a maximum bandwidth of a few kHz and therefore sigma-delta modulators are extensively used [5].
- Design for testability: implementation of debugging features and the possibility to monitor internal nodes and references at one pad.
- Digital filtering and processing of signal.
- A digital part is also needed to control ASIC startup, calibration, and test features.
- ESD protections: particular attention is due to input pins where MEMS device is wire bonded to. Indeed these input nodes are critical for noise and parasitic capacitances. For ESD design, book [6] can be considered together with references which are there reported.

References

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