3D MEMS Air-core Inductor in a Very High Frequency Switched-Mode Power Converter

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Power supply on chip (PwrSoC) is the vision of miniaturized switched-mode power supplies with a monolithic integration of all active and passive components [1], [2]. Passive inducers are by far the most bulky and expensive parts in power supplies. Increasing operating frequency to very high frequency (VHF; 30–300 MHz) allows the usage of smaller inducers thus reducing the size of power supplies. Indeed, with the inductance of tens of nH [3], integrated air-core inducers are suitable for VHF power converters.

Last year we reported on the fabrication of a 3D MEMS air-core toroidal inductor. In the present work, we demonstrate its application in a power converter. The inducers are electrically characterized with small signal measurement, and tested in a VHF class E resonant boost converter.

Briefly, the MEMS inducer is designed with a silicon-embedded 3D construction consisting of through-Si vias (TSVs) arranged in a toroidal shape, suspended copper (Cu) windings, and Si fixtures [4]. The inducers are fabricated with a four-step 3D fabrication process (Fig. 1). These are (i) through-wafer deep reactive ion etching of TSVs, (ii) electroplating Cu TSVs and top and bottom Cu layers, (iii) spray coating of resist and wet etching, and (iv) removing Si core by isotropic ICP etching. The MEMS inducer is shown in Fig. 2a. The suspended windings are attached to the Si support die by five fixures.

Air-core and Si-core inducers are electrically characterized and compared using an impedance analyzer (Agilent 4294A). The frequency is between 1 to 110 MHz. The tested inducers have 20 turns, 1.5 mm outer radius, 0.75 mm inner radius, and 350 µm height. The inductances are 44.6 nH and 43.9 nH for the air-core and Si-core inducer, respectively. Air-core inducers have superior performance with higher quality factor (Q) of 13.3 at 33 MHz compared to Q of 9 at 20 MHz of Si-core inducers. With the complete removal of the Si core, the parasitic capacitance reduces three folds from 11.5 pF to 3.7 pF, thus allowing a higher Q at higher frequencies. A higher Q indicates that air-core inducers have lower power losses than Si-core inducers, and therefore achieve a higher power conversion efficiency.

To demonstrate the application of our fabricated inducer, a VHF Class E resonant converter is designed, simulated with LT-SPICE, and implemented using our MEMS inducer (L2) and a high-performance gallium nitride field-effect transistor as key components. The converter consists of a class E resonant inverter and a current-driven rectifier (Fig. 2b). The MEMS inducer is used as part of the resonant network in the inverter. It is glued onto the PCB by epoxy and the electrical connections are made by three gold wire bonds. The detailed working principle of the converter can be found in [5]. In brief, the converter is designed to operate at 33 MHz in zero voltage switching (ZVS) mode to reduce switching losses. The converter achieved an efficiency of 77% converting 8.4 VAC to 12.4 VDC and delivered 7.72 W to the load with a total loss of 2.32 W (Fig. 3). The simulated AC current in the MEMS inducer is 1 A RMS. The AC power loss in L2 is estimated via DC power loss using thermal measurement method. An increasing DC current is driven through L2 until the thermal images are match (Fig. 4). An AC power loss of 0.98 W is obtained.

At the MNE conference, we look forward to present in detail the applications of our air-core inducers in power supplies.