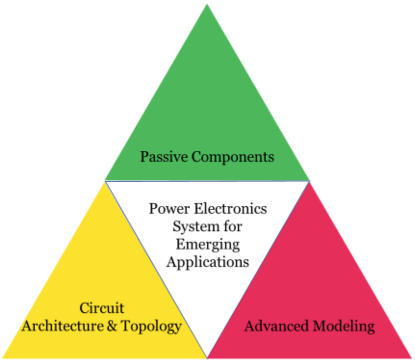
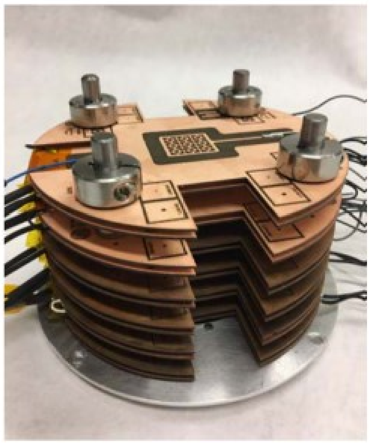
Past Research

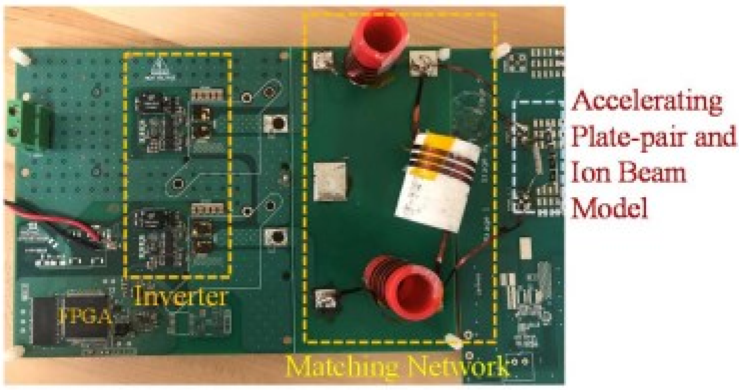
My research interests is power electronics for emerging future applications, including compact RF power for wireless power transfer, ion-beam accelerator and fusion. To achieve this, we need advanced modeling techniques for power electronics systems, design and utilization of passive components and high-level design of circuit architectures. In the future, I would like to keep delving into these aspects of power electronics. Some Example Projects are summarized as follows.

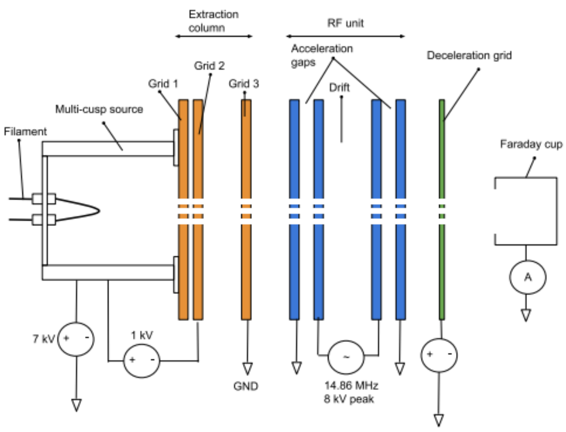


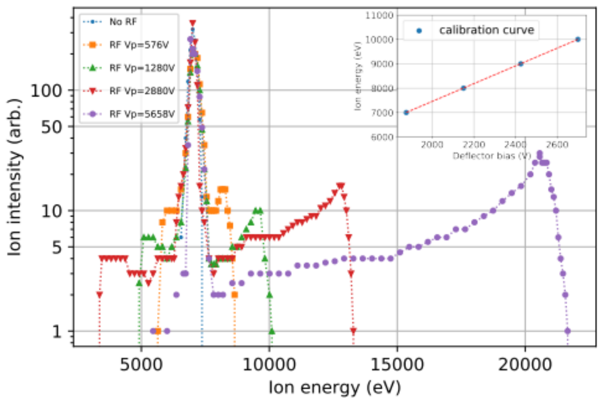
Compact RF Power Amplifier for Low-cost Compact Ion-Beam Accelerator

Ion-beam accelerator is widely used in medical, military and scientific research. Past ion-beam accelerators for these applications are bulky and expensive. Power electronics can be a key enabler for a novel compact ion-beam accelerator. We have recently reported on the development of multi-beam RF accelerators that we assemble from low cost wafers.6,7 RF acceleration structures and electrostatic quadrupole (ESQ) focusing elements are formed on printed circuit boards (PCB) and silicon wafers with 10 cm diameter using standard microfabrication techniques.8 In our prior work, 0.1 mA Ar+ ions were extracted through an array of 3×3 beamlets and we have demonstrated beam acceleration at an energy gain of 2.6 keV per acceleration gap.6 In this article, we report on our recent effort in scaling up the beam power by using 120 beamlets with improved energy gain per RF acceleration gap. These advances pave the path towards ion currents >1 mA and ion energies >100 keV in a compact, low cost setup for applications in material processing and manufacturing [1-10].



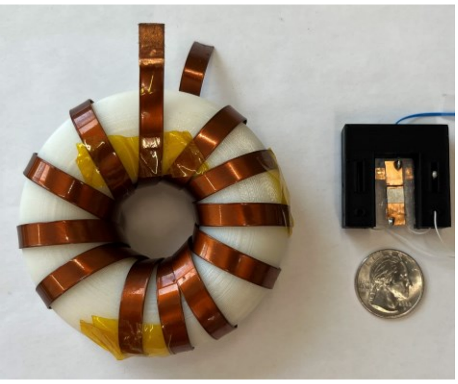


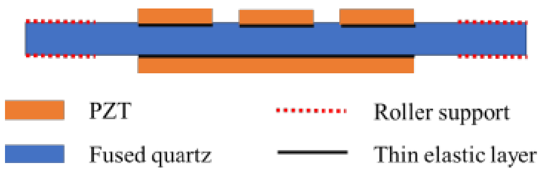




Piezoelectric Material: Exploration of Mechanical Field for Energy Storage and Power Conversion

With high power density and quality factor, piezoelectrics have emerged as a promising alternative to replace magnetics. However, piezoelectrics have mostly been explored in the context of dc-dc converter with off-the-shelf piezoelectrics. This paper presents a novel piezoelectric transformer (PT), which is suitable for power amplifier and can easily scale for different conversion ratios. The proposed PT is vertically stacked, with a quartz in the middle for mechanical coupling. Primary and secondary sides of the PT are mounted on two sides of the quartz which eases the scaling for the transformer ratio. A prototype PT is built and tested to verify the proposed structure, with conductive traces additively manufactured using silver paste for high conductivity and rapid prototyping. Finally, the equivalent circuit of PT is modeled and analyzed which agrees both with COMSOL simulation and experimental results. Our prototype has only has the potential of improving power density by eliminating air-core inductor which is conventionally used in high-frequency power amplifier [11-13].

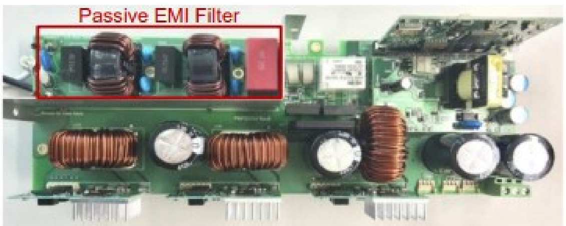




Past research has explored different topologies and control strategies for dc-dc converters which only use a single piezoelectric resonator as the main energy-storage component. However, such converters exhibit relatively low efficiency when the voltage conversion ratio varies from its nominal value. This digest proposes a new merged switched-capacitor piezoelectric-resonator based dc-dc converter which can achieve high and flat efficiency across a wide voltage conversion ratio. In this converter, the switched capacitor and the piezoelectric resonator are combined to form a multi-level structure and controlled in a manner to achieve high efficiency across a wide voltage conversion ratio. The proposed topology and control strategy enables the switched capacitor to be soft-charged by the current from the piezoelectric resonator and achieves zero-voltage-switching (ZVS) for all its switches [14].

Active EMI Filter for High-Power Offline Applications

Electric vehicles have no doubt switched from being a buzz word into reality. On-Board Charger (OBC) power density is not only limited by main power stage, but also by EMI filter. [15] presents an integrated active EMI filter (AEF) solution that mitigates conducted common-mode (CM) emissions and improves power density in kilowatt-scale off-line power supplies. The proposed AEF solution comprises an integrated circuit (IC) that senses high-frequency CM noise from the power lines using a set of Y-rated capacitors, while rejecting line-frequency and differential-mode components. The IC processes the sensed CM noise and injects a cancelling current back into the power lines through another Y-rated capacitor, hence presenting a very low impedance to CM noise and emulating a much larger capacitance that allows choke inductance to be reduced. A damping network external to the IC is placed in the injection path to stabilize the closed-loop system. Analytical formulations are presented to evaluate the performance and stability of the proposed AEF. The AEF is experimentally validated with a totem-pole power factor correction converter. It is shown to provide up to 25 dB reduction in CM noise, which enables the chokes of the EMI filter to be reduced in size by 55% while maintaining similar EMI performance.



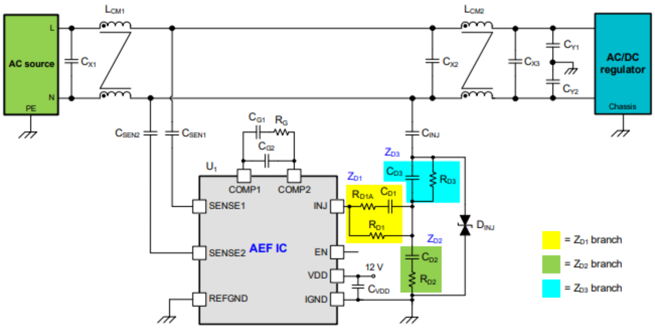


Fig. 3. Typical application diagram for the proposed AEF solution in single-phase AC systems.

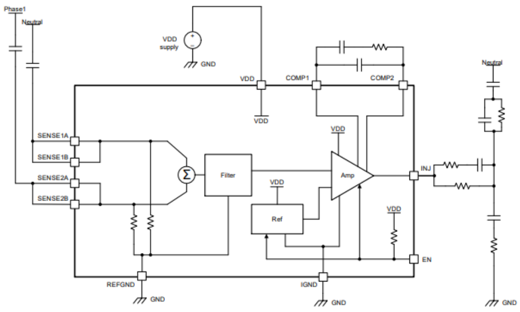
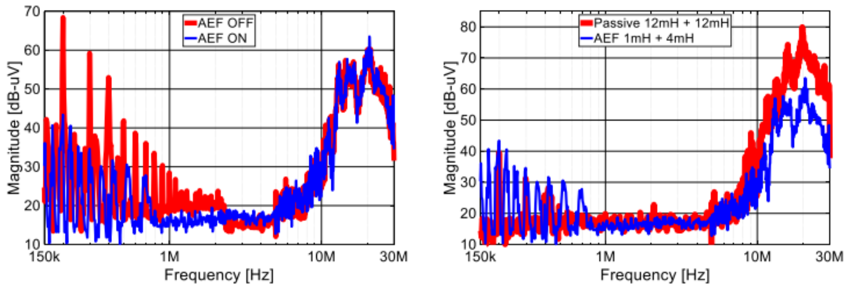
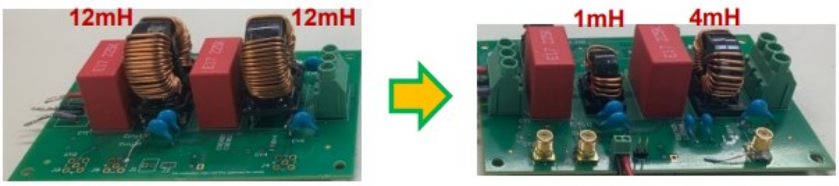


Fig. 4. Internal block diagram of the proposed AEF solution.



(a) (b)

Fig. 7. AEF performance: (a) OFF vs. ON with the same filter, and (b) small-choke AEF compared with large-choke passive filter.



Other Projects

I also worked on wireless power transfer, both capacitive [16-18] and inductive [19], and active power decoupling [20]. Some are enabled by the technology I developed during the ion-beam accelerator project.

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