# Metacapacitors™

Next-generation electric power converters

<table>
<thead>
<tr>
<th>What</th>
<th>Why</th>
<th>How</th>
<th>What for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Better DC-DC converters</td>
<td>Cheaper</td>
<td>Switched capacitor circuit topologies</td>
<td>LED lighting drivers</td>
</tr>
<tr>
<td></td>
<td>Smaller</td>
<td>Novel high-frequency, low-loss capacitors</td>
<td>PV power conversion</td>
</tr>
<tr>
<td></td>
<td>More efficient</td>
<td>Scalable continuous printed fabrication</td>
<td>Mobile devices</td>
</tr>
<tr>
<td></td>
<td>Longer lasting</td>
<td>No transformers or electrolytics</td>
<td>Power supplies</td>
</tr>
</tbody>
</table>

Our multidisciplinary team combines enabling technology and expertise:

- Self-assembling nanoparticle dielectrics
- Scalable capacitor printing technologies
- Novel device integration
- Analog power circuits and IC design

O’Brien (CUNY)  
Steingart (Princeton)  
Leland (CUNY)  
Kymissis (Columbia)  
Sanders (Berkeley)  
Kinget (Columbia)
Metacapacitors™
Switched capacitor power conversion: Simplified concept

- A capacitor is a component that stores electricity, like a battery.
- Our circuits repeatedly charge a set of capacitors, reconfigure them electronically, and then discharge them to convert electric voltage and current, millions of times per second.
- No electrolytics or expensive magnetics required for DC-DC conversion.
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Switched capacitor advantages over switched mode power supplies

- DC-DC power train is only switches and capacitors, no transformers or inductors
- Smaller switches and capacitors only handle a fraction of the input voltage or total current
- Higher switching frequencies allow for higher power densities, efficiencies of 95% or greater

**Vision:** A two-component power converter
- Passives printed on cheap flex substrate
- Single power IC for switching, control
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Printable nanoparticle dielectric for high frequency capacitors

- High frequency performance with low loss—single crystal nanoparticles exhibit no ferroelectric hysteresis
- Nanoparticle dielectric inks are readily printable and are compatible with spin coat deposition
- Synthesized below 100°C, No HTCC/LTCC required
- BaTiO₃ and (Ba, Sr)TiO₃ nanoparticles, size controllable from 5-100 nm
- No rare earth materials

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Printed multilayer capacitors for power conversion

- Purely additive, roll-to-roll compatible spray-coat or gravure deposition
- All processing below 200 °C
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Printed multilayer capacitors high-frequency performance

Wide-area spray-printed multilayer capacitor

Mean Capacitance with Increase in Layers

Dissipation Factor of 6-layer Devices

Each line represents the loss characteristics of a single multilayer capacitor
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Printed capacitors in high-frequency power circuits

Voltage regulation is comparable to standard MLCCs in an off-the-shelf 1 MHz charge-pump LED driver

All-flex 1 MHz charge pump LED driver
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Custom switched-capacitor power IC designs

- Stackable 2:1 DC-DC converter step-down IC
- Implemented in Texas Instruments’ ABCD5HV process, maximum 120 V on-chip
- As shown operating 2 ICs in stacked configuration at 2.2 MHz, 15 W, 4:1 step-down converter (160 V to 40 V)
Metacapacitors™
Next-generation power IC with integrated PFC

- Full off-line LED driver chip currently in progress
- Target specs: 15 W, PFC > 0.99, efficiency at full load > 90%, dimming to 5% with efficiency > 50%, galvanic isolation between input and output
# Metacapacitors™

Technology is highly cost-competitive

<table>
<thead>
<tr>
<th>Capacitor type</th>
<th>Energy density per area ($\mu$J/mm²)</th>
<th>Energy density per volume ($\mu$J/mm³)</th>
<th>$f_{\text{max}}$ (MHz)</th>
<th>Power density per area (W/mm²)</th>
<th>Power density per volume (W/mm³)</th>
<th>Footprint area, 10 $\mu$F @ 50 V (mm²)</th>
<th>Cost, 10 x 1 $\mu$F @ 50 V</th>
<th>Operating lifetime</th>
<th>Package form factor</th>
<th>Suitable for 15 W LED driver in 1 cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metacapacitors (projected)</td>
<td>12.5</td>
<td>625</td>
<td>10</td>
<td>125</td>
<td>6260</td>
<td>1000</td>
<td>$0.50</td>
<td>Infinite</td>
<td>PSiP/PwrSOC</td>
<td>Yes</td>
</tr>
<tr>
<td>Deep trench</td>
<td>21.1</td>
<td>469</td>
<td>10</td>
<td>211</td>
<td>4690</td>
<td>154</td>
<td>&gt;$7.00 (lower bound)</td>
<td>Infinite</td>
<td>PwrSOC</td>
<td>Yes</td>
</tr>
<tr>
<td>X7R MLCC</td>
<td>252</td>
<td>126</td>
<td>2</td>
<td>504</td>
<td>252</td>
<td>49.6</td>
<td>$2.00</td>
<td>Infinite</td>
<td>PSiP</td>
<td>Yes</td>
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<tr>
<td>Metallized polymer film</td>
<td>28.5</td>
<td>6.3</td>
<td>2</td>
<td>57</td>
<td>12.7</td>
<td>438</td>
<td>$6.60</td>
<td>Infinite</td>
<td>Non-integrated</td>
<td>No</td>
</tr>
<tr>
<td>Tantalum electrolytic</td>
<td>65</td>
<td>26</td>
<td>0.03</td>
<td>2</td>
<td>0.8</td>
<td>192</td>
<td>$5.30</td>
<td>50k hours</td>
<td>Non-integrated</td>
<td>No</td>
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<tr>
<td>Aluminum electrolytic</td>
<td>139</td>
<td>26</td>
<td>0.03</td>
<td>4.2</td>
<td>0.8</td>
<td>90</td>
<td>$0.68</td>
<td>10k-25k hours</td>
<td>Non-integrated</td>
<td>No</td>
</tr>
</tbody>
</table>
The Metacapacitors Team

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Interested in partnering? Email info@metacapacitors.com