Using DC-DC Converters at the HL-LHC

- The upgrade of front-end systems at the HL-LHC will result in an increase of the required power, which forces the development of new, more efficient power sources.
- The DC-DC converters bring an efficient low voltage and high current regulation technique for front-end systems.
- The DC-DC converters help to reduce the power losses in the cabling infrastructure, hence reducing the material overhead and the cooling needs.

Low Noise DC-DC Converters

- Low noise plug-in converter module based on Linear Technology LTC6005 controller.

DC-DC Modules Contribution to Material Budget

The material content of a converter module is split in PCB material, main coil copper and plastic, shield copper and plastic, and passive components.

- **PCB**: 28.4 mm X 13.5 mm FR4, 2 layers of 35% thick copper, copper coverage = 85%.
- **Main Coil**: 220 mm long copper wire, 380 μm diameter.
- **Shield**: 17 mm X 11.9 mm X 9 mm, 0.5 mm thick PE box, 35 μm copper coated.
- **Passives**: SMD ceramic capacitors (2 of size 1210, 1 of size 0805, 3 of size 0402).

The material contribution of the 12 converters of a stave is weighted with the overall stave area, resulting in equivalent material thicknesses, on which the fraction of radiation length is estimated.

DC-DC Mass Reduction Strategies

<table>
<thead>
<tr>
<th>Reference DC-DC construction:</th>
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<tr>
<td><em>%Xo(DC/DC) = 0.12%</em></td>
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<tr>
<td><em>%Xo(MOD) = 0.53%</em></td>
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<tr>
<td>DC/DC contribution to stave radiation length: 0.12(0.53 + 0.12) * 100 = 18.5%.</td>
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The material is mainly shared equally between the PCB, the coil, the shield and the passive components. The contribution of the ASIC is negligible.

### Capacitors

The ceramic capacitors contribute in one third of the reference converter material budget.

At expense of slightly higher emitted noise (few dB only), the size reduction of the 1206 and 1210 ceramic capacitors with 0805 sizes allows to decrease their equivalent fraction of radiation length from %Xo = 0.039 down to %Xo = 0.016.

More recently, silicon bulk capacitances are now available on the market. The replacement of the ceramic capacitors with those would allow achieving a %Xo = 0.005 only.

### PCB

The reference design assumes a double layer circuit 600 μm thick with 35 μm copper cladding on both sides, resulting in a %Xo = 0.031. A thickness reduction down to 300 μm with a copper cladding of 17 μm instead would result in a %Xo = 0.0156, and a further thickness decrease down to 100 μm would allow reaching a %Xo = 0.0107. Replacing the FR4 with Kapton would bring a further reduction on this front too.

### Summary Chart

**Conclusion**

A low noise DC-DC converter design has been used for a mass reduction exercise, applied to the staves design of the ATLAS upgraded tracker. At expense of small increase of noise and thermal losses, the material budget contribution of the DC-DC converters can be divided by two using ECCA wire for the main coil, smaller passives and a thinner printed circuit board. The use of bare aluminum for the shield or for the PCB clad does not bring any significant improvement of the overall fraction of radiation length contributed by the DC/DCs on the stave.

A compromise configuration (ECCA wire, small capacitors and thin copper PCB) combined with 10 μm copper coated PE shield boxes would result in a fraction of radiation length of 0.056% equivalent to 10% of the modules mass. Ultimately, silicon capacitors combined with a PCB thinned down to 100 μm of FR4 would result in a fraction of radiation length of 0.032% only.