List of technological options

Cable configuration
• 10x4 log stacking
• 10x4 classic stacking
• round configurations 3-5 mm diameter
• MCBXF
• ...

Impregnation
• MY 750
• CTD701X
• Wax
• Stycast
• PU
• ...

Former material
• Aluminum
• GRP
• 3D charged resin
• ...
List of cable configurations
Using NbTi strands (0.825 mm / 0.480 mm)

- Highest packing factor (~80%)
- Lower current supply
- More difficult to arrange

- Lower packing factor (~60%)
- Higher current supply
- Lower inductance
Technological choice

Strategy

Small box program
• quickly select best candidate(s) for impregnation using a short linear sample of cable

Subscale program in 3 phases
• phase 1: select best candidate(s) for cable configuration using winding tests on 3D formers
• phase 2: wind and impregnates 1 (or 2 ?) candidates on real formers:
  • Aluminum
  • GRP
• phase 3: power and test subscale magnets

Objective at the end: select the technologies that will be used on the demonstrator.
Small box program

**Principle**
- Stack a configuration of cable
  - log stacking
  - classical stacking
  - with fiber
  - round multiwired
- Impregnate
- Slice and visual inspection
- Thermal cycles (77K)

We can check:
- first packing test
- filling / wettability of impregnation
- effect of temperature
- compatibility with former material (Al. /GRP)

<table>
<thead>
<tr>
<th>#</th>
<th>Cable configuration</th>
<th>Channel [mm]</th>
<th>Material</th>
<th>Impregnation</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB1</td>
<td>log stacking (40)</td>
<td>10.03 x 3.50</td>
<td>Aluminum</td>
<td>MY 750</td>
<td>Parts ready</td>
</tr>
<tr>
<td>SB2</td>
<td>classic stacking (40)</td>
<td>9.56 x 3.88</td>
<td>Aluminum</td>
<td>MY 750</td>
<td>Drawing ready</td>
</tr>
<tr>
<td>SB3</td>
<td>log stacking (40)</td>
<td>10.03 x 3.50</td>
<td>Aluminum</td>
<td>Wax</td>
<td>Parts ready</td>
</tr>
<tr>
<td>SB4</td>
<td>classic stacking (40)</td>
<td>9.56 x 3.88</td>
<td>Aluminum</td>
<td>Wax</td>
<td>Drawing ready</td>
</tr>
<tr>
<td>SB5</td>
<td>log stacking (40)</td>
<td>10.03 x 3.50</td>
<td>Aluminum</td>
<td>CTD701x</td>
<td>Drawing ready</td>
</tr>
<tr>
<td>SB6</td>
<td>classic stacking (40)</td>
<td>9.56 x 3.88</td>
<td>Aluminum</td>
<td>CTD701x</td>
<td>Drawing ready</td>
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<tr>
<td>SB7</td>
<td>log stacking (40)</td>
<td>10.03 x 3.50</td>
<td>GRP</td>
<td>Stycast</td>
<td>Drawing ready</td>
</tr>
<tr>
<td>SB8</td>
<td>classic stacking (40)</td>
<td>9.56 x 3.88</td>
<td>GRP</td>
<td>Stycast</td>
<td>Drawing ready</td>
</tr>
<tr>
<td>SB9</td>
<td>log stacking + fiber (40)</td>
<td>7.77 x 2.73</td>
<td>Aluminum</td>
<td>MY 750</td>
<td>Design</td>
</tr>
<tr>
<td>SB10</td>
<td>classic stacking + fiber (40)</td>
<td>7.40 x 3.02</td>
<td>Aluminum</td>
<td>MY 750</td>
<td>Design</td>
</tr>
<tr>
<td>SB11</td>
<td>log stacking + fiber (40)</td>
<td>7.77 x 2.73</td>
<td>Aluminum</td>
<td>Wax</td>
<td>Design</td>
</tr>
<tr>
<td>SB12</td>
<td>classic stacking + fiber (40)</td>
<td>7.40 x 3.02</td>
<td>Aluminum</td>
<td>Wax</td>
<td>Design</td>
</tr>
<tr>
<td>SB13</td>
<td>log stacking + fiber (40)</td>
<td>7.77 x 2.73</td>
<td>Aluminum</td>
<td>CTD701x</td>
<td>Design</td>
</tr>
<tr>
<td>SB14</td>
<td>classic stacking + fiber (40)</td>
<td>7.40 x 3.02</td>
<td>Aluminum</td>
<td>CTD701x</td>
<td>Design</td>
</tr>
<tr>
<td>SB15</td>
<td>log stacking + fiber (40)</td>
<td>7.77 x 2.73</td>
<td>GRP</td>
<td>Stycast</td>
<td>Design</td>
</tr>
<tr>
<td>SB16</td>
<td>classic stacking + fiber (40)</td>
<td>7.40 x 3.02</td>
<td>GRP</td>
<td>Stycast</td>
<td>Design</td>
</tr>
<tr>
<td>SB??</td>
<td>round cable</td>
<td>tbd</td>
<td>Alu/GRP</td>
<td>tbd</td>
<td>tbd</td>
</tr>
</tbody>
</table>
Difficulties to stack the 40 wires in a log configuration:

- They naturally go 3 per row as they have the space for it
- 3D print a guide cap on both sides
Small box program

Chisel B

chisel stacking B
Round cables

- **Option 1:** small ropes with non insulated 0.480 mm strand
- **Option 2:** big rope with insulated 0.875 mm strand
Subscale program

- **phase 1**: select best candidates for cable configuration using winding tests on 3D printed formers
  - single layer
  - similar bend radii as demonstrator
  - outside diameter less than 200 mm
- **phase 2**: wind and impregnates 1 (or 2 ?) candidates on formers with demonstrator diameters
  - double layers
  - same diameters as demonstrator
  - 2 different materials: Aluminum and GRP
- **phase 3**: power and test subscale magnets
Subscale program

- **phase 1:** select best candidates for cable configuration using winding tests on 3D printed formers
  - single layer
  - similar bend radii as demonstrator
  - outside diameter less then 200 mm
- **phase 2:** wind and impregnates 1 (or 2 ?) candidates on formers with demonstrator diameters
  - Aluminum
  - GRP
- **phase 3:** power and test subscale magnets

<table>
<thead>
<tr>
<th>#</th>
<th>Material</th>
<th>Aperture</th>
<th>Length</th>
<th>Layer</th>
<th>Turn</th>
<th>Channel</th>
<th>Min rib thick.</th>
<th>Cond. length</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub1</td>
<td>Accura 25</td>
<td>&lt; 200 mm</td>
<td>??</td>
<td>1</td>
<td>4</td>
<td>Rectangle (log: 10.573 x 3.664 mm)</td>
<td>2 mm</td>
<td>??</td>
<td>Design</td>
</tr>
<tr>
<td>Sub2</td>
<td>Accura 25</td>
<td>&lt; 200 mm</td>
<td>??</td>
<td>1</td>
<td>4</td>
<td>Round (4 mm)</td>
<td>2 mm</td>
<td>??</td>
<td>Design</td>
</tr>
<tr>
<td>Sub3</td>
<td>Accura 25</td>
<td>&lt; 200 mm</td>
<td>??</td>
<td>1</td>
<td>4</td>
<td>Round double (8 x 4 mm)</td>
<td>2 mm</td>
<td>??</td>
<td>Design</td>
</tr>
<tr>
<td>Sub4</td>
<td>Aluminum</td>
<td>236 mm</td>
<td>??</td>
<td>2</td>
<td>4</td>
<td>Best option</td>
<td>??</td>
<td>??</td>
<td>Design</td>
</tr>
<tr>
<td>Sub5</td>
<td>GRP</td>
<td>236 mm</td>
<td>??</td>
<td>2</td>
<td>4</td>
<td>Best option</td>
<td>??</td>
<td>??</td>
<td>Design</td>
</tr>
</tbody>
</table>
Resistive CCT program

**Principle:** Build/test mini resistive CCTs with a single copper wire and 3D printed parts

- Test and measure a **straight** dipole.
- Test and measure the exact same design but **curved**.
- Test the assembly of a 3D printed former made of **2 parts**.

**Perspective:** validate fine tunings on the coil design

**Measuring**
Development of magnetic sensors toward the curved demonstrator:

- stretch wire for the straight one
- bowed wire for the curved one
- Hall probes arrays
- ...

**Powering**
Pulses of a dozen ms at few kA

- CLIC unit power supply
- Expecting ~0.12 T at 2 kA

Coil designs by G. Kirby
## Resistive CCT program

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Material</th>
<th>Aperture</th>
<th>Length</th>
<th>Layer</th>
<th>Turn</th>
<th>Channel</th>
<th>Min rib thick.</th>
<th>Conductor</th>
<th>Cond. length</th>
<th>Inductance</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>R1</td>
<td>Dipole</td>
<td>Accura 25</td>
<td>80 mm</td>
<td>250 mm</td>
<td>2</td>
<td>6</td>
<td>2.2 x 2.2 mm</td>
<td>3.8 mm</td>
<td>2.1 mm Cu</td>
<td>4.16 m</td>
<td>0.009 mH</td>
<td>Printed</td>
</tr>
<tr>
<td>R2</td>
<td>Dipole 2 parts</td>
<td>Accura 25</td>
<td>80 mm</td>
<td>450 mm</td>
<td>2</td>
<td>23</td>
<td>2.2 x 2.2 mm</td>
<td>3.8 mm</td>
<td>2.1 mm Cu</td>
<td>25.3 m</td>
<td>0.133 mH</td>
<td>Drawing</td>
</tr>
<tr>
<td>R3</td>
<td>Dipole Curved</td>
<td>Accura 25</td>
<td>80 mm</td>
<td>458 mm</td>
<td>2</td>
<td>23</td>
<td>2.2 x 2.2 mm</td>
<td>2.0 mm</td>
<td>2.1 mm Cu</td>
<td>25.3 m</td>
<td>0.133 mH</td>
<td>Design</td>
</tr>
</tbody>
</table>

### Powering table - CLIC unit power supply
- 10, 20, 30, 40, 50 mF
- 100 – 1000 V (100 V steps)

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Inductance</th>
<th>Capacitance</th>
<th>Voltage</th>
<th>Current</th>
<th>Pulse time</th>
<th>Temperature raise</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Dipole</td>
<td>0.009 mH (20 mΩ)</td>
<td>10 mF</td>
<td>100 V</td>
<td>3.3 kA</td>
<td>0.9 ms</td>
<td>2.6 K</td>
<td>Very short</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 mF</td>
<td>100 V</td>
<td>4.7 kA</td>
<td>1.3 ms</td>
<td>7.3 K</td>
<td></td>
<td>Longer but current is getting high, We need lower voltage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 mF</td>
<td>50 V</td>
<td>3.7 kA</td>
<td>2.1 ms</td>
<td>7.2 K</td>
<td></td>
<td>Good direction, higher C and lower V</td>
</tr>
<tr>
<td>R2</td>
<td>Dipole 2 parts</td>
<td>0.150 mH (140 mΩ)</td>
<td>50 mF</td>
<td>100 V</td>
<td>1.8 kA</td>
<td>8.6 ms</td>
<td>7.1 K</td>
<td>Good</td>
</tr>
<tr>
<td>R3</td>
<td></td>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>3.7 kA</td>
<td>8.6 ms</td>
<td>28.4 K</td>
<td>Current is getting high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100 mF</td>
<td>100 V</td>
<td>2.6 kA</td>
<td>12.2 ms</td>
<td>20.1 K</td>
<td>Good</td>
</tr>
</tbody>
</table>
## Resistive CCT program

<table>
<thead>
<tr>
<th>Inductance</th>
<th># turns</th>
<th>Length</th>
<th>Diameter</th>
<th>Length of wire</th>
<th>Wire diameter</th>
<th>Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.201 mF</td>
<td>101</td>
<td>500 mm</td>
<td>100 mm</td>
<td>31.7 m</td>
<td>5 mm</td>
<td>30 mΩ</td>
</tr>
</tbody>
</table>

### Room Temperature

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Inductance</th>
<th>Capacitance</th>
<th>Voltage</th>
<th>Current</th>
<th>Pulse time</th>
<th>Temperature raise</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1 + L</td>
<td>Dipole + Solenoid</td>
<td>0.210 mH (50 mΩ)</td>
<td>50 mF</td>
<td>100 V</td>
<td>1.5 kA</td>
<td>10.2 ms</td>
<td>6 K</td>
<td>0.2 K 30 V in coil / 45 V in solenoid / 25 V left</td>
</tr>
<tr>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>3.1 kA</td>
<td>10.2 ms</td>
<td>24 K</td>
<td>0.6 K</td>
<td>93 V in coil / 62 V in solenoid / 45 V left</td>
<td></td>
</tr>
<tr>
<td>R2/R3</td>
<td>Dipole 2 parts + Solenoid</td>
<td>0.342 mH (170 mΩ)</td>
<td>50 mF</td>
<td>100 V</td>
<td>1.8 kA</td>
<td>13.0 ms</td>
<td>4.7 K</td>
<td>0.1 K 14.8 V only lost in resistance</td>
</tr>
<tr>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>2.4 kA</td>
<td>13.0 ms</td>
<td>18.8 K</td>
<td>0.5 K</td>
<td>19.7 V only lost in resistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 mF</td>
<td>300 V</td>
<td>3.6 kA</td>
<td>13.0 ms</td>
<td>42.3 K</td>
<td>1.1 K</td>
<td>29.5 V only lost in resistance</td>
<td></td>
</tr>
</tbody>
</table>

### 77 K

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Inductance</th>
<th>Capacitance</th>
<th>Voltage</th>
<th>Current</th>
<th>Pulse time</th>
<th>Temperature raise</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1 + L</td>
<td>Dipole + Solenoid</td>
<td>0.210 mH (2.5 mΩ)</td>
<td>50 mF</td>
<td>100 V</td>
<td>1.5 kA</td>
<td>10.2 ms</td>
<td>0.6 K</td>
<td>0.02 K 3.8 V only lost in resistance</td>
</tr>
<tr>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>3.1 kA</td>
<td>10.2 ms</td>
<td>2.4 K</td>
<td>0.06 K</td>
<td>7.8 V only lost in resistance</td>
<td></td>
</tr>
<tr>
<td>R2/R3</td>
<td>Dipole 2 parts + Solenoid</td>
<td>0.342 mH (8.2 mΩ)</td>
<td>50 mF</td>
<td>100 V</td>
<td>1.8 kA</td>
<td>13.0 ms</td>
<td>0.5 K</td>
<td>0.01 K 14.8 V only lost in resistance</td>
</tr>
<tr>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>2.4 kA</td>
<td>13.0 ms</td>
<td>1.9 K</td>
<td>0.05 K</td>
<td>19.7 V only lost in resistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50 mF</td>
<td>300 V</td>
<td>3.6 kA</td>
<td>13.0 ms</td>
<td>4.2 K</td>
<td>0.11 K</td>
<td>29.5 V only lost in resistance</td>
<td></td>
</tr>
</tbody>
</table>
## Resistive CCT program

### Powering table - CLIC unit power supply
- 10, 20, 30, 40, 50 mF
- 100 – 1000 V (100 V steps) or below (manually triggered)

<table>
<thead>
<tr>
<th>#</th>
<th>Type</th>
<th>Inductance</th>
<th>Capacitance</th>
<th>Voltage</th>
<th>Current</th>
<th>Pulse time</th>
<th>Temperature raise</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>Dipole</td>
<td>0.009 mH (0.09 Ω)</td>
<td>10 mF</td>
<td>100 V</td>
<td>3.3 kA</td>
<td>0.9 ms</td>
<td>2.6 K</td>
<td>Very short</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20 mF</td>
<td>100 V</td>
<td>4.7 kA</td>
<td>1.3 ms</td>
<td>7.3 K</td>
<td>Longer but current is getting high, We need lower voltage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 mF</td>
<td>100 V</td>
<td>3.7 kA</td>
<td>2.1 ms</td>
<td>7.2 K</td>
<td>Good direction, higher C and lower V</td>
</tr>
<tr>
<td>R2</td>
<td>Dipole 2 parts</td>
<td>0.150 mH (0.60 Ω)</td>
<td>50 mF</td>
<td>100 V</td>
<td>1.8 kA</td>
<td>8.6 ms</td>
<td>7.1 K</td>
<td>Good</td>
</tr>
<tr>
<td>R3</td>
<td></td>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>3.7 kA</td>
<td>8.6 ms</td>
<td>28.4 K</td>
<td>Current is getting high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100 mF</td>
<td>100 V</td>
<td>2.6 kA</td>
<td>12.2 ms</td>
<td>20.1 K</td>
<td>Good</td>
</tr>
<tr>
<td>R  + L</td>
<td>Dipole + extra solenoid</td>
<td>0.150 mH</td>
<td>50 mF</td>
<td>150 V</td>
<td>2.7 kA</td>
<td>8.6 ms</td>
<td>16.0 K</td>
<td>R1 + a 0.150 mf solenoid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 mF</td>
<td>200 V</td>
<td>2.6 kA</td>
<td>12.2 ms</td>
<td>20.1 K</td>
<td>R2 + a 0.150 mf solenoid</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inductance</th>
<th># turns</th>
<th>Length of wire</th>
<th>Wire diameter</th>
<th>Resistance</th>
<th>Temperature raise</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.150 mF</td>
<td>40</td>
<td>12.2 m</td>
<td>1 mm</td>
<td>0.26 Ω</td>
<td>255 K</td>
<td>Ouch !! (75 V, 1.4 kA, 63 K)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.5 mm</td>
<td>1.05 Ω</td>
<td>4084 K</td>
<td>Ouch !! (75 V, 1.4 kA, 1021 K)</td>
</tr>
<tr>
<td>0.300 mF</td>
<td>55</td>
<td>17.3 m</td>
<td>1 mm</td>
<td>0.37 Ω</td>
<td>320 K</td>
<td>Ouch !! (75 V, 968 A, 45 K)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.5 mm</td>
<td>1.48 Ω</td>
<td>5134 K</td>
<td>Ouch !! (75 V, 968 A, 722 K)</td>
</tr>
</tbody>
</table>
Resistive CCT program

Short Straight Dipole – R1

Magnet design
J.S. Rigaud & A. Haziot

3D printing
R. Gavaggio

Winding
F.O. Pincot & A. Haziot
Resistive CCT program

Short Straight Dipole – R1

- Total length: 250 mm
- Former outer diameter: 119.2 mm
- Inner coil inner radius: 45 mm
- Inner coil spar: 5 mm
- Outer coil inner radius: 57.5 mm
- Outer coil spar thickness: 5 mm
- Channel size (wide, deep): 2.2 mm, 2.2 mm
- Pitch: 4.0 mm
- Min wall thickness: 3.8 mm
- Layers: 2
- Distance between layers: 12.5 mm
- Min bend curvature: 11.9 mm (at current lead exit)
- Wire length: 4.16 m
- Wire dia: 2.1 mm
- Inductance: 0.009 mH
- Peak dipole field: 0.0025 T (25 gauss) at 40 A
  : 0.12 T at 2 kA
Resistive CCT program

Short Straight Dipole – R1

- Total length: 250 mm
- Former outer diameter: 119.2 mm
- Inner coil inner radius: 45 mm
- Inner coil spar: 5 mm
- Outer coil inner radius: 57.5 mm
- Outer coil spar thickness: 5 mm
- Channel size (wide, deep): 2.2 mm, 2.2 mm
- Pitch: 4.0 mm
- Min wall thickness: 3.8 mm
- Layers: 2
- Distance between layers: 12.5 mm
- Min bend curvature: 11.9 mm (at current lead exit)
- Wire length: 4.16 m
- Wire dia: 2.1 mm
- Inductance: 0.009 mH
- Peak dipole field: 0.0025 T (25 gauss) at 40A
  : 0.12 T at 2kA
Resistive CCT program

Long Straight Dipole – R2

- Total length: 450 mm
- Former outer diameter: 119.2 mm
- Inner coil inner radius: 45 mm
- Inner coil spar: 5 mm
- Outer coil inner radius: 57.5
- Outer coil spar thickness: 5 mm
- Channel size (wide, deep): 2.2mm, 2.2mm
- Pitch: 4.0 mm
- Min wall thickness: 3.8 mm
- Layers: 2
- Distance between layers: 12.5 mm
- Min bend curvature: 11.9 mm (at current lead exit)
- Wire length: 25.3 m
- Wire dia: 2.1 mm
- Inductance: 0.133 mH
- Peak dipole field: 0.009 T (90 gauss) at 40A
Resistive CCT program

Long Curved Dipole – R3

- Total length: 458 mm
- Bending radius: 250 mm
- Bending angle: 105 deg
- Former outer diameter: 119.2 mm
- Inner coil inner radius: 45mm
- Inner coil spar: 5 mm
- Outer coil inner radius: 57.5
- Outer coil spar thickness: 5 mm
- Channel size (wide, deep): 2.2mm, 2.2mm
- Pitch: 4.0 mm
- Min wall thickness: 3.8 mm
- Layers: 2
- Distance between layers: 12.5 mm
- Min bend curvature: 11.9 mm (at current lead exit)
- Wire length: 28.2 m
- Wire dia: 2.1 mm
- Inductance: 0.150 mH
- Peak dipole field: 0.008 T (80 gauss) at 40A