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Electromagnetic Compatibility in the Tracker electronic system

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Abstract

This document has been written to clarify the Electromagnetic Compatibility of the Tracker electronics; it can be taken as an example for the electromagnetic compatibility of the all AMS02 experiment.

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1 General rules for the AMS02 Electromagnetic Compatibility

In this document, the metallic structure of AMS02 will be called "SHIELD". SHIELD will be connected to the International Space Station's electrical ground.

> **I – Each electrical ground, isolated from the others, MUST be connected to SHIELD in one single point. Indeed, SHIELD must be an equipotential surface.**
>
> **II – Connections between SHIELD and the electrical grounds MUST be at low impedance.**

2 Ground loop in the Tracker system – mathematical analysis

Fig. 1 and fig. 2 show two different configurations of the Tracker electronics, when one or two ladders (and TDR2 boards) are connected to their electronics; R278, R364 (from the TBS schematics) are not connected in fig. 2, to show that ground loops are generated also in that case. The drawings in fig. 1 and fig. 2 are focused on the problems caused from existing ground loops in an electronics' system, so that only the main components/boards, useful to this target, are reported.
SHIELD is represented with the blue coloured structure, while green arrows show different ways for the current, powering *ladder 1*, to come back to its source: the shielding of the cables connected to the ladders will act as a current wire, picking up the external electromagnetic field in the internal electrical system.
The following part will show the effect of an electromagnetic field in the particular case of a rectangular wire loop, with lengths L_1 and L_2.
We can suppose to inject a planar electromagnetic wave with:

1) $L_2 = \frac{\lambda_0}{2}[m]$, so that

2) $f_0 = \frac{c}{\lambda_0} = \frac{c}{2 \cdot L_2}\left[s^{-1}\right]$, where: $c = \frac{1}{\sqrt{\mu_0 \cdot \varepsilon_0}} \cong 3 \cdot 10^8 \left[m \cdot s^{-1}\right]$.

Considering the propagation of an electromagnetic wave in vacuum, assuming that the reflected wave $B_0^- = 0$, the equation describing the magnetic field of a planar electromagnetic wave is:

3) $B_z^+(x,t) = B_0^+ \cdot \cos\left(\frac{2\pi}{T_0} \cdot t - \frac{2\pi}{\lambda_0} \cdot x\right) \ [Tesla]$, where:

4) $T_0 = \frac{1}{f_0} \ \left[s^{-1}\right]$, 5) $B_0^+ = \frac{V_0^+}{c}$, where:

$V_0^+ = \text{electric field intensity} \ \left[V \cdot m^{-1}\right]$.

Fig. 3 shows the magnetic field waveform described from equation 3).
The blue coloured wave represents the magnetic field at the time $t_1 = 0$, while the grey one represent it at the time $t_2 = \frac{T_0}{2}$.

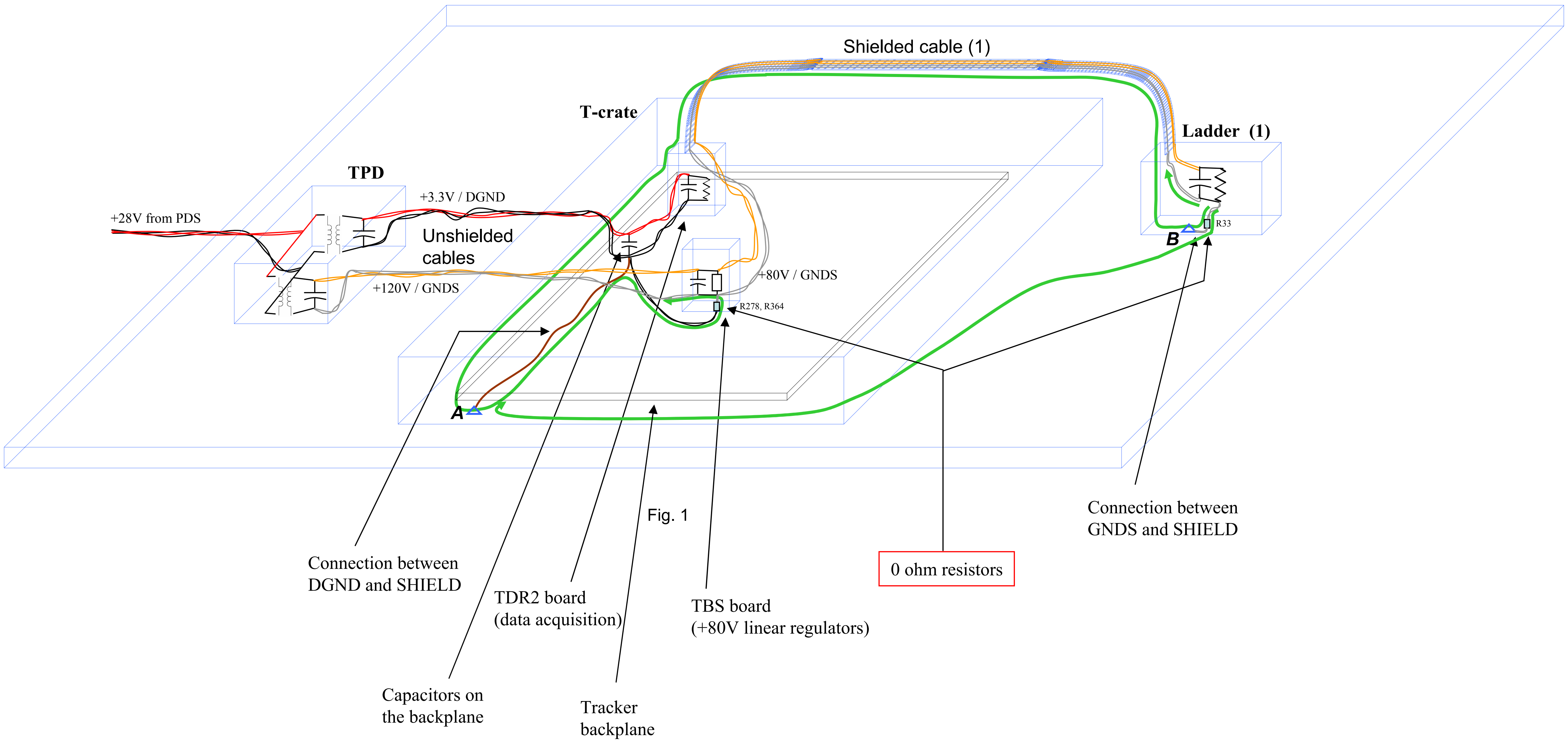
Shielded cable (1)
T-crate
Ladder (1)
TPD
+3.3V / DGND
+28V from PDS
Unshielded
cables
+120V / GNDS
+80V / GNDS
R278, R364
R33
A
B
Connection between
DGND and SHIELD
TDR2 board
(data acquisition)
TBS board
(+80V linear regulators)
0 ohm resistors
Connection between
GNDS and SHIELD
Capacitors on
the backplane
Tracker
backplane

Fig. 1

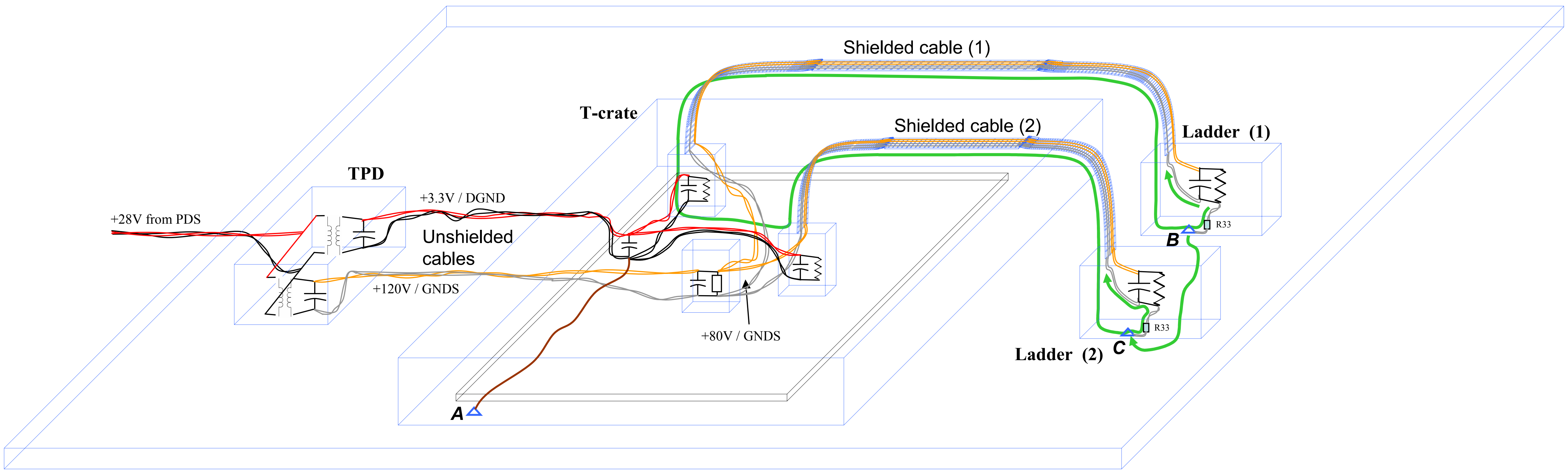
Shielded cable (1)
T-crate
Shielded cable (2)
Ladder (1)
TPD
+3.3V / DGND
+28V from PDS
Unshielded cables
R33
B
+120V / GNDS
R33
+80V / GNDS
C
Ladder (2)
A

Fig. 2

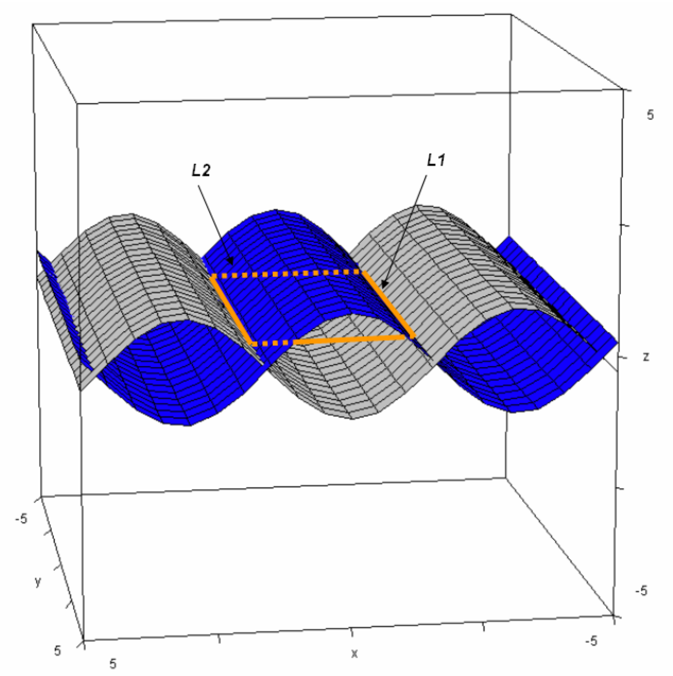

Fig. 3

It is possible to calculate the magnetic flux in the wire loop:

$$\Phi_B(t) = B_0^+ \cdot \int_{-\frac{L_2}{2}}^{\frac{L_2}{2}} dx \int_{-\frac{L_1}{2}}^{\frac{L_1}{2}} \cos\left(\frac{2\pi}{T_0}\cdot t - \frac{2\pi}{\lambda_0}\cdot x\right)\cdot dy \qquad \Rightarrow$$

$$\Phi_B(t) = L_1 \cdot B_0^+ \cdot \int_{-\frac{L_2}{2}}^{\frac{L_2}{2}} \cos\left(\frac{2\pi}{T_0}\cdot t - \frac{2\pi}{\lambda_0}\cdot x\right)\cdot dx \qquad \Rightarrow$$

$$\Phi_B(t) = L_1 \cdot B_0^+ \cdot \frac{\lambda_0}{2\pi}\cdot\left[\sin\left(\frac{2\pi}{\lambda_0}\cdot x - \frac{2\pi}{T_0}\cdot t\right)\right]_{-\frac{L_2}{2}}^{\frac{L_2}{2}} \qquad \Rightarrow$$

6) $\Phi_B(t) = L_1 \cdot B_0^+ \cdot \frac{\lambda_0}{\pi}\cdot \cos\left(\frac{2\pi}{T_0}\cdot t\right)$

From the Faraday-Neumann-Lenz law, the induced electromotive force is:

7) $emf = -\frac{d\Phi_B(t)}{dt}$.

Then, deriving equation 6):

$$\frac{d\Phi_B(t)}{dt} = -L_1 \cdot B_0^+ \cdot \frac{\lambda_0}{\pi}\cdot\frac{2\pi}{T_0}\cdot \sin\left(\frac{2\pi}{T_0}\cdot t\right) \qquad \Rightarrow$$

from 2) and 5):

$$\frac{d\Phi_B(t)}{dt} = -2 \cdot L_1 \cdot B_0^+ \cdot c \cdot \sin(2\pi \cdot f_0 \cdot t) \qquad \Rightarrow$$

from 4)

$$\frac{d\Phi_B(t)}{dt} = -2 \cdot L_1 \cdot V_0^+ \cdot \sin(2\pi \cdot f_0 \cdot t).$$

Then from 7):

8) $emf = 2 \cdot L_1 \cdot V_0^+ \cdot \sin(2\pi \cdot f_0 \cdot t)$

With all the simplifications made, equation 8) describes the electromotive force between point A and point B in fig. 1, and between point B and point C in fig. 2.

Table 1 shows the frequency and the intensity of the injected electric field in the RS03 test, to which the AMS02 experiment must be immune. ***Considering 1) and 2), it is possible to substitute one possible value of E (that is*** V_0^+***) in 8), showing impressive results.***

Table 1

Frequency / Range (f)	**Radiated Electric Field Level (E)**
14 kHz – 10 MHz	5 V/m
200 MHz – 8 GHz	60 V/m
8 GHz – 10 GHz	20 V/m
2.2 GHz	161 V/m
8.5 GHz	79 V/m
13.7 GHz – 15.2 GHz	250 V/m

3 Violation of the *II* general rule

Two planes (or parts of two planes) on a PCB will form a capacitor, with a capacitance usually named *parasitic capacitance*. In the Tracker electronics, SHIELD is always a plane or part of a plane of the PCBs, as well as the electrical grounds.

Violation of the *II* general rule might imply that the radio frequency current introduced in the unshielded wires between TPD and Tcrate will go to SHIELD through the parasitic capacitances on the PCBs instead of going through the wires connected to point A (fig. 1,2). Indeed, the radio frequency current will choose the lowest impedance way to go to the International Space Station electrical ground.

The capacitance between 2 plates can be calculated using the following formula:

$$9)\quad C = 8.85 \cdot \frac{k \cdot A}{d}\ [\mathrm{pF}], \qquad [1]$$

where:

k = relative dielectric constant of the material between the 2 plates
A = area of the plates in m²
d = distance between the 2 plates in m

The following formula can be used to calculate the inductance of a conducting wire:

$$10)\quad L = l \cdot \left(\ln\left(\frac{4 \cdot l}{d}\right) - 1 \right) \cdot 200 \cdot 10^{-9} [H] \qquad [1]$$

where:

L = inductance in H
l = length of the wire in metres
d = diameter of the wire in metres

4 Conclusions

DGND and GNDS in the Tracker electronics must be connected together at low impedance because it is needed for the ADCs on the TBS to work properly (that is the effect of R278, R364). Removing R278, R364 will not help on avoiding ground loops, because in case of having two or more ladders connected, ground loops will be generated through R33 in the hybrids' electronics; indeed, 6 ladders are powered by one single *isolated power source* in the TPD.

The solution to avoid ground loops is to disconnect R278, R364 from the TBS, disconnect R33 from each hybrid, and redesign the Tracker backplane.

Bibliography

[1] Clayton R. Paul. *Compatibilità elettromagnetica*, HOEPLI - *Introduction to Electromagnetic Compatibility,* WILEY.