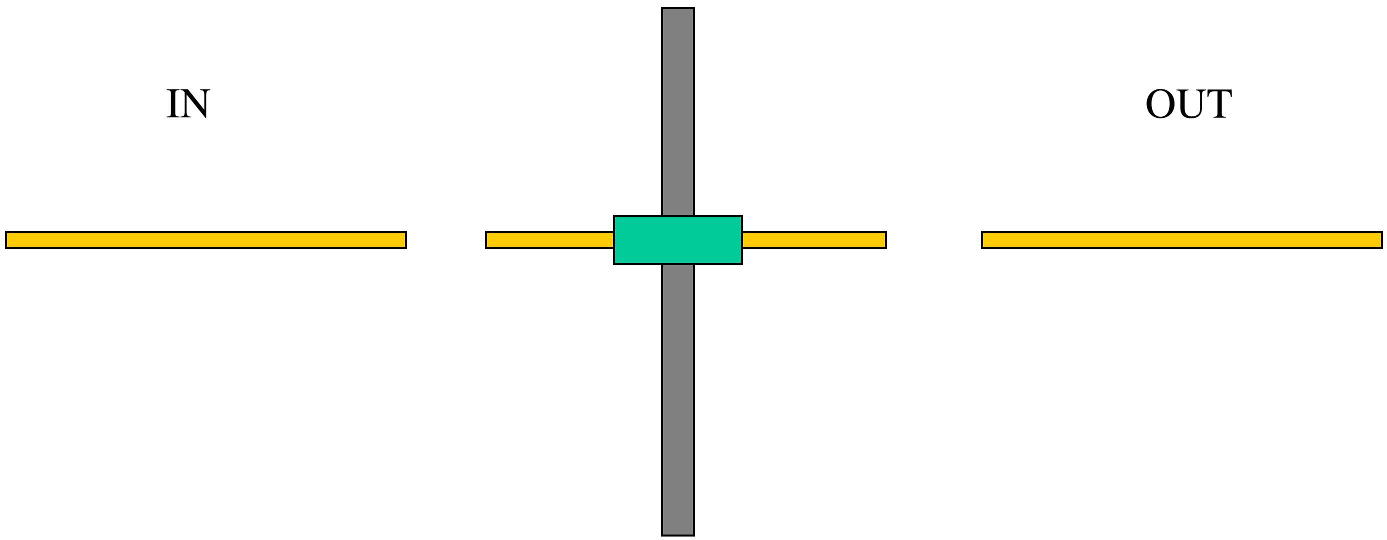


cable$_{in}$:
very flexible
(1.5m)

cable$_{feed}$:
gas tight, not too thick
(0.5-1m)

cable$_{out}$:
As reliable as possible.
(2.5-4m)

and for each set two options

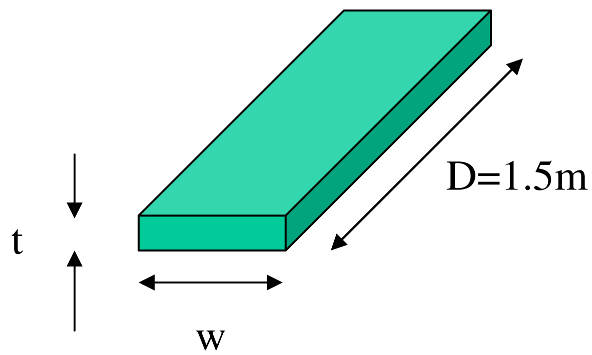
option1: impedance matched (Derek)

option2: low capacitance (Diego)

impedance matched option (1)

impedance matched option (in)

Problem: Signal is dumped due to resistive losses as $\exp(-R/2Z_c)$. Assuming $Z_c=50\Omega$, and 20% loss:



For a copper trace (rho_{DC}=1.7e-6, --no skin effect at the frequencies of interest, no dielectric losses)

$\boxed{R<22\Omega}$

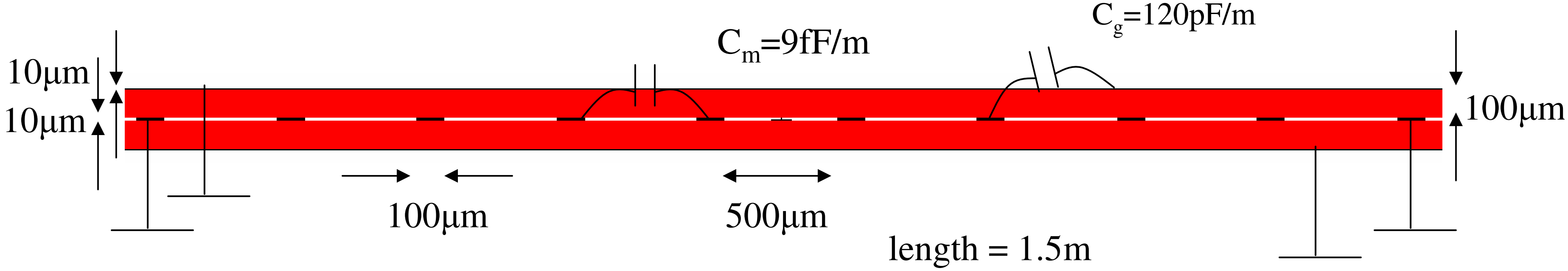
For a length of 1.5m:

$\boxed{t \times w > 30\ \mu m \times 30\ \mu m}$

That is not too bad, but consider that a 5µm-thick trace requires of at least 200µm width.
For that, in order to get 50Ω with polyimide (in strip-line), a thickness of around 200µm is needed. Actually I have aborted this design because it looks unreasonable. If you still think it can be reasonable, I will give final values for the 5µm x 100µm trace (200µm polyimide thickness is an estimate)

It looks more reasonable to chose a 10µm-thick trace (used before by D_o, for instance), 100µm width and look for the thickness that matches impedance in polyimide. This is the option I have chosen.

impedance matched option (in)



Z_c=**50Ω**

x-talk fraction (intra-cable)~ ½ C_m /C_g**<<1/250**

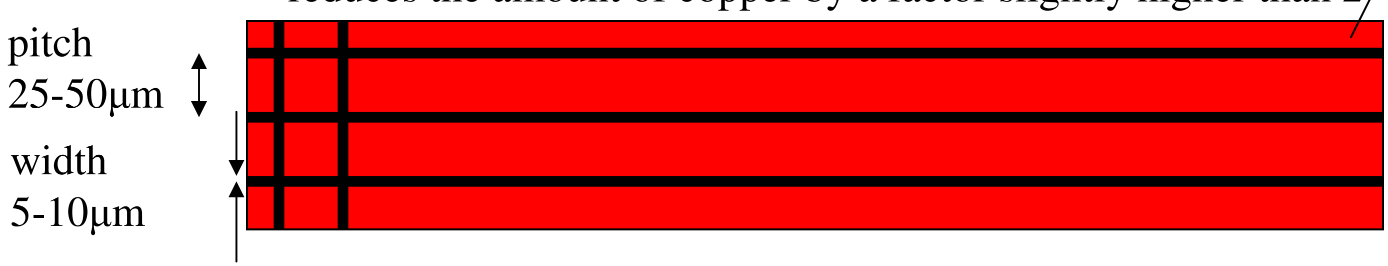
x-talk fraction (inter-cable)=**0**

losses ~**20%**

C_g</C_{SiPM} ~ **5**

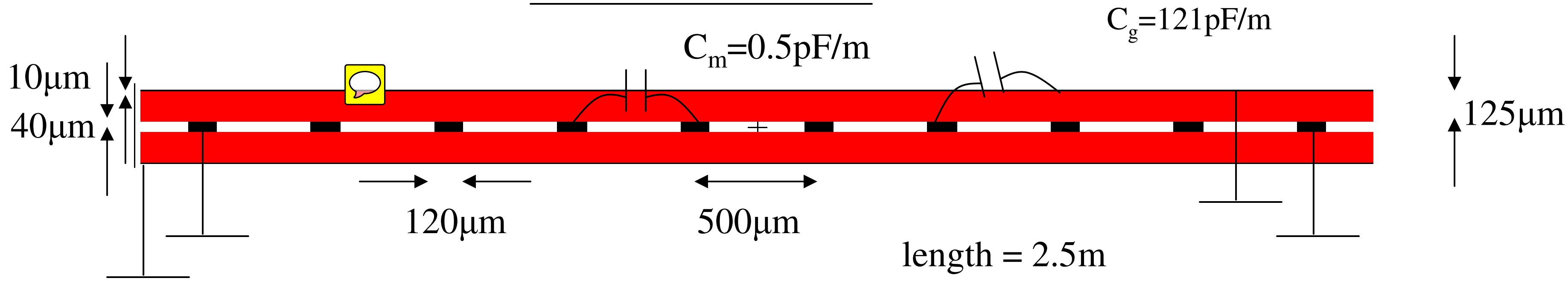
for higher flexibility, a square pattern as a ground mesh might be ok, with pitch much smaller than strip-to-ground distance, not to change Z_c (otherwise it requires 3D-simuls). For instance:

reduces the amount of copper by a factor slightly higher than 2



if possible with a mesh-pitch in sub-multiples of the connector pitch. **Lines along the strip should be disaligned with respect to signal traces** to allow for higher flexibility

impedance matched option (out)



Z_c=**50Ω**

x-talk fraction (intra-cable)~ ½ C_m /C_g~1/2 x **1/250**

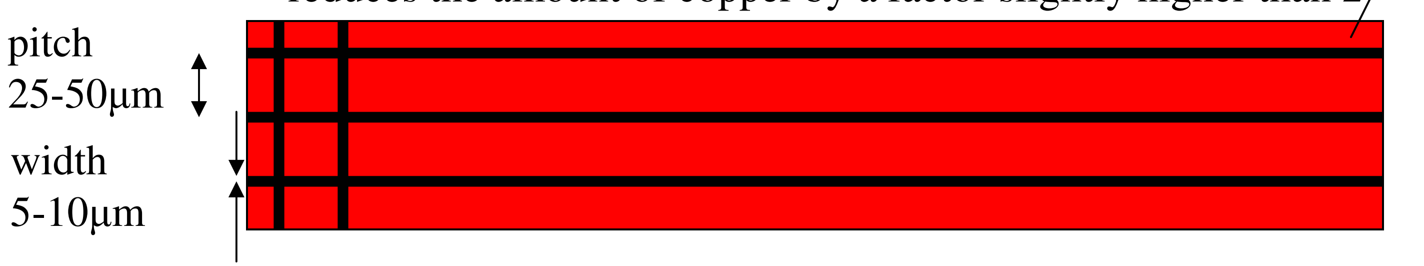
x-talk fraction (inter-cable)=**0**

losses <**10%**

C_g/C_{SiPM} ~ **9**

for higher flexibility, a square pattern as a ground mesh might be ok, with pitch much smaller than strip-to-ground distance, not to change Z_c (otherwise it requires 3D-simuls). For instance:

reduces the amount of copper by a factor slightly higher than 2

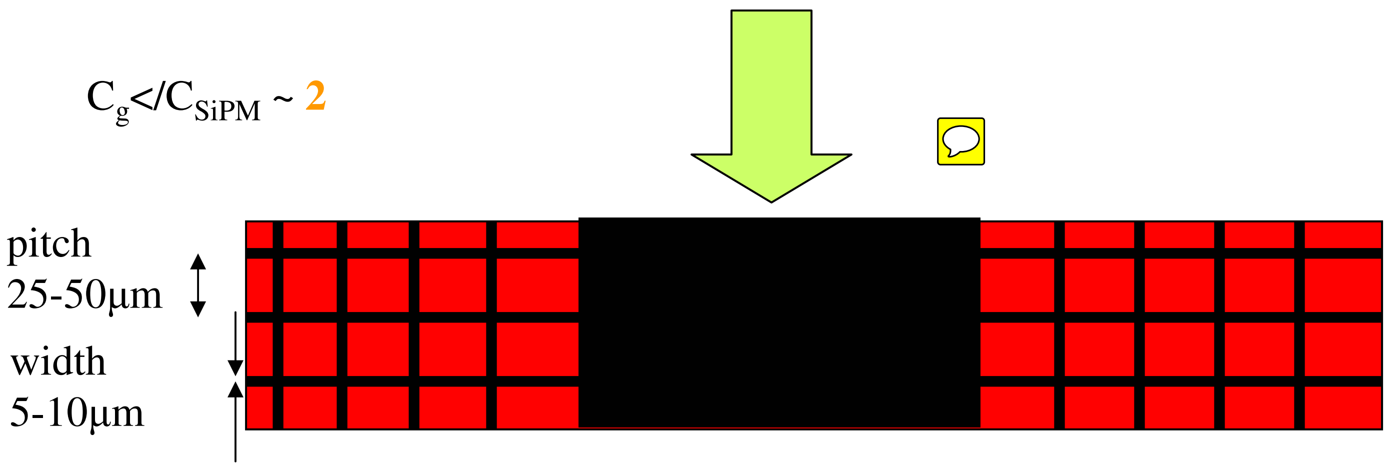


if possible with a mesh-pitch in sub-multiples of the connector pitch. **Lines along the strip should be disaligned with respect to signal traces** to allow for higher flexibility

impedance matched option (feed-through)

same as the outer region but use solid copper in
the feed-through region for ensuring no problems
with gas tightness

$C_g < / C_{SiPM} \sim$ **2**



In total, a 4m long cable will have a capacitance x16 higher than the SiPM, ~0.6nF.

I think we should keep cables at the input of amplifier as short as possible as a rule. 4m total length seems sufficient

variations of the impedance-matched option one might try

• Reduce the copper thickness to 5µm, increase the strip to 100µm and accept a roughly doubled cable thickness and higher x-talk.

• This configuration, in the way proposed, is analogous to a directional coupler. Indeed, in a directional coupler, when properly terminated at the source side there is no cross-talk at the far-end (Although cross-talk is very small here anyhow), So one should consider using a 50ohm smd resistor in parallel with the SiPM output on the dice-board. Signal will be reduced by a factor x2 in such a case (needs to be tested). Perhaps not needed, it is certainly very elegant. This resistor will also reduce noise pickup.

notes, important for the design

• Impedance will be broken at the connectors. In view of the signal rise-time (1ns at best), any connection smaller than 5cm should have no effect in signal propagation. In practice, the impedance-broken region will extend to a region larger than the connector itself, and should be kept strictly below this number (5cm). For this option (impedance matching) we should aim at HF connectors prepared for at least one ground plane.

• Related to that, having ground strips every 9th strip, will help avoiding ground-breaks at the connectors (useful in the next approach). **It is important to connect these ground strips with vias to the upper and lower ground planes**. This can be done at the cable heads.

• One should design the power lines well separated from the signal lines, and with proper dimensions for reducing voltage drops and power dissipation. This is expected to be a simple technical matter [?].

• It might be convenient to work in micro-strip (easier/cheaper to manufacture) although then, the impedance will change by proximity of nearby cables. Should we try it anyhow?

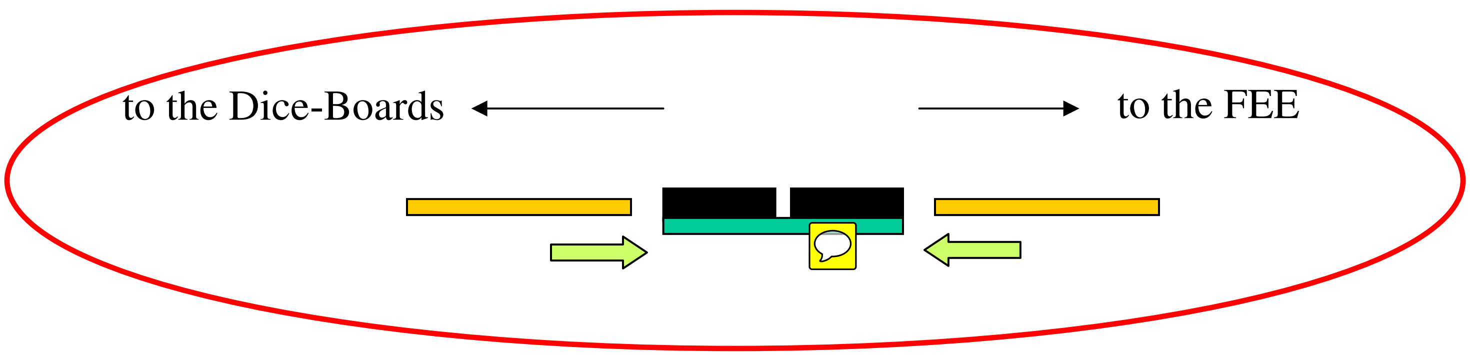
connectors

• Use HF connectors if they provide a convenient way of ensuring ground continuity.

• Since in these cables the upper and lower planes must be joined with vias, I think ground continuity and impedance mismatch can be kept reasonable at the connector even if it is not a HF-standard.

• In case of strong radiopurity arguments, the most radiopure connector should be chosen.

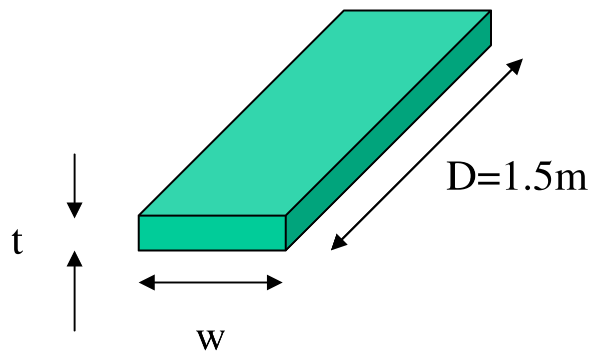
• For present design, at the feedthrough, chose back-to-back on-board connectors.



low capacitance option (2)

low capacitance option (in)

It is difficult with present constraints. Why?. The main problem are the minimum dimensions of the trace.



$R<22\Omega$

$t \times w > 30\ \mu m \times 30\ \mu m$

Solutions: reducing the trace to a 30 µm x 30 µm square and reducing the ground plane to a mesh allows for a reduction of the coupling to ground of around ~x2.5 (not much) as compared to option 1 (impedance matched). It increases the intracable x-talk. This can be kept at a reasonable 1/40 level, but the intercable x-talk will be very large. Decreasing the inter-cable x-talk to some level around 1/40 will increase the coupling to ground within a factor of less than 2 of option 1.

If one could make the cable-inside much thicker than 150micron (even 300micron), and allows for a thicker trace it is possible to reduce the coupling to ground by a factor around x3 and reasonably respecting the x-talk constraints.

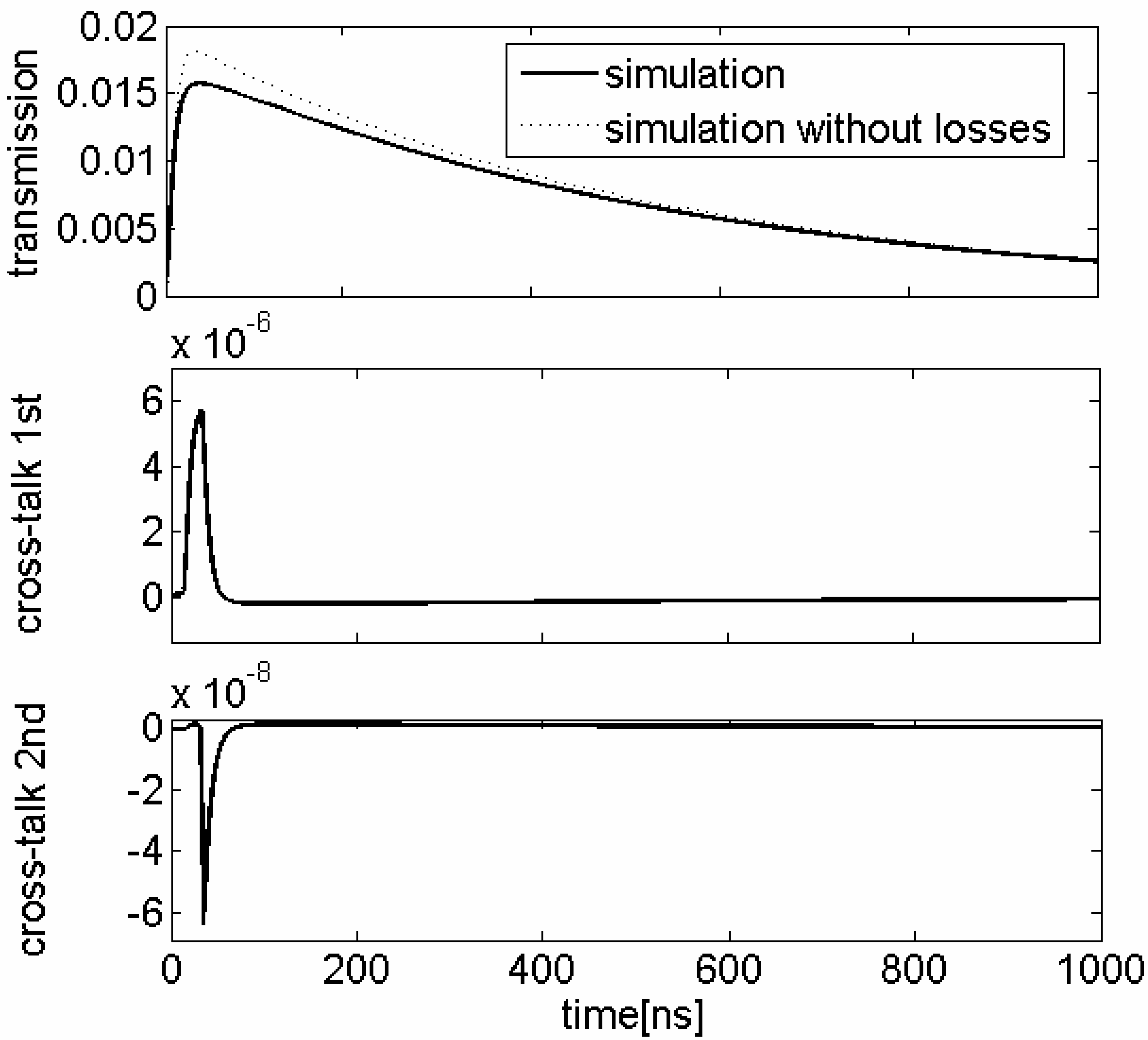
low capacitance option (in)

Conclusion: in view of resistive losses, that determine the minimum area of the trace,
in view of the trace pitch, that is fixed.
in view of the proximity of nearby cables

I find no way to meaningfully reduce the capacitance (say, by more than a factor x2 lower than the impedance-matched option). I see at the moment no way to improve, unless the above conditions are relaxed. That means:

smaller cable lengths inside
larger connector pitch
thicker cables
clearance between cables

SiPM signal injected at the beginning of the inner cable and read with current FEE after 1.5m



SiPM signal injected at the beginning of the outer cable and read with current FEE after 2.5m