Conductor Modelling
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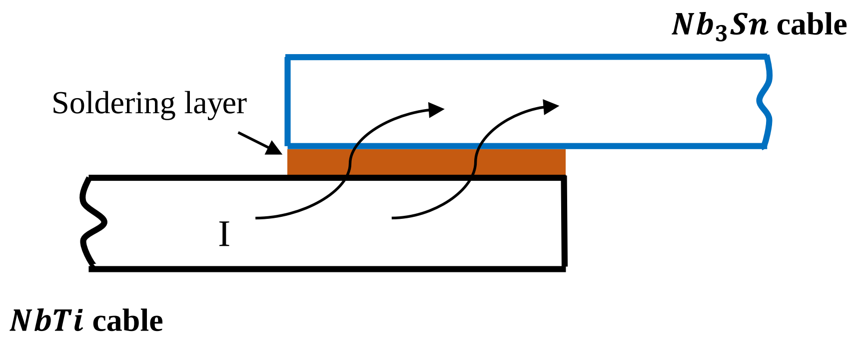
Model

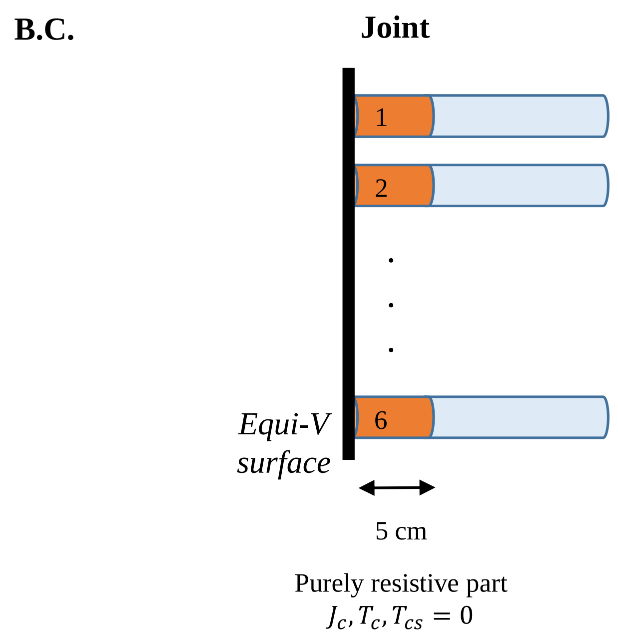
Framework: Cable + Connection joints.

Joint: a splice between a $NbTi$ and a Nb_3Sn cable (magnet leads), with soldering material as physical connection.

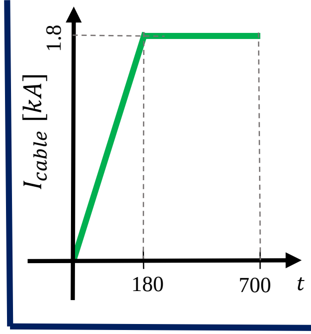
Real system

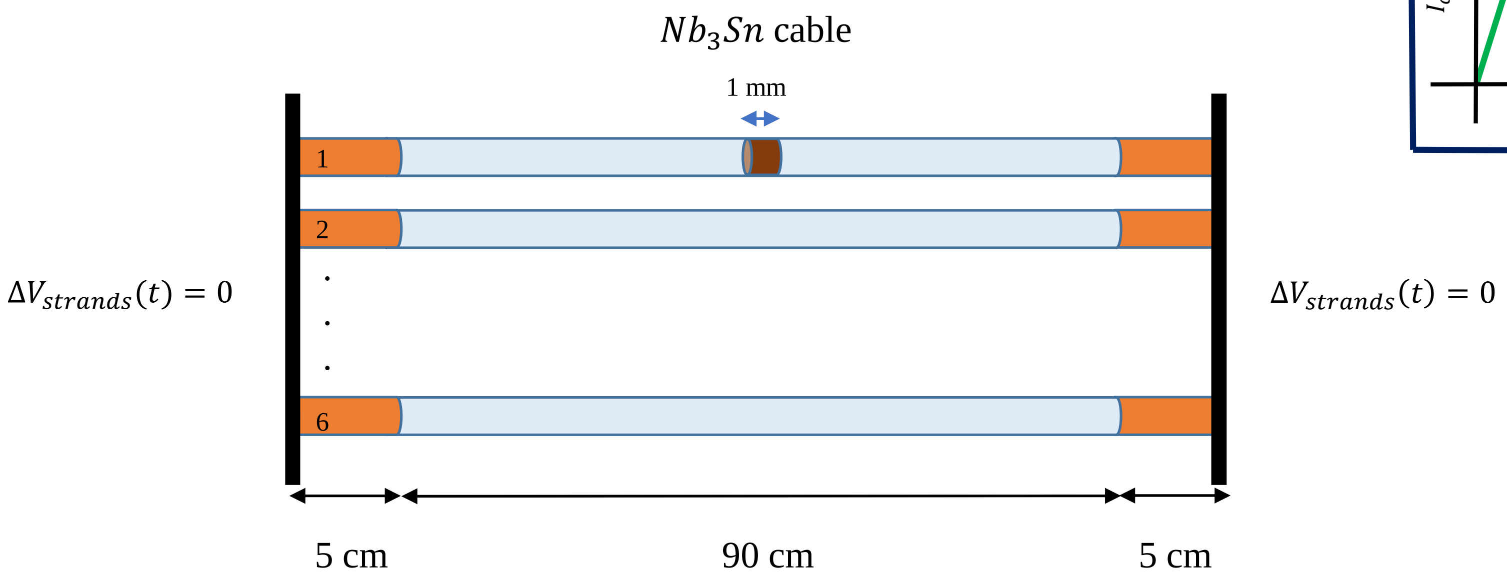


Model



Model & Assumptions





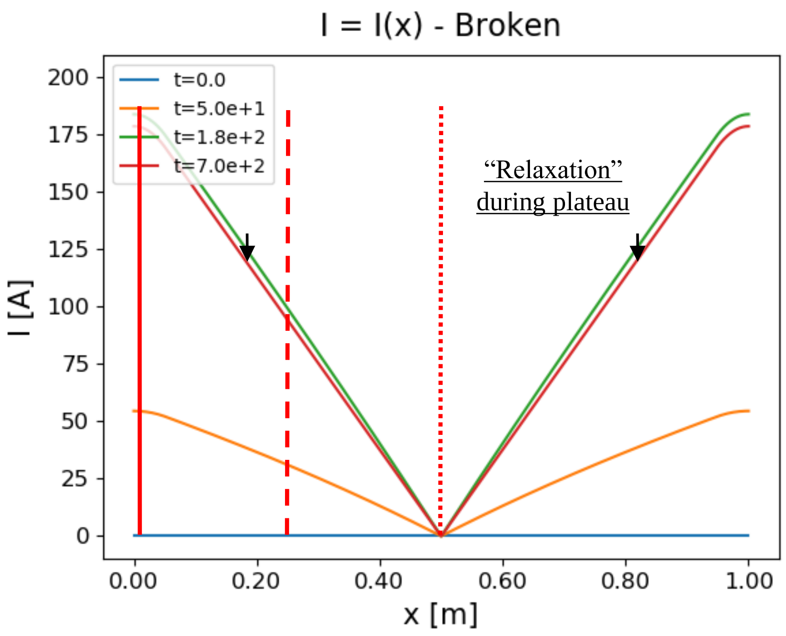
Assumptions

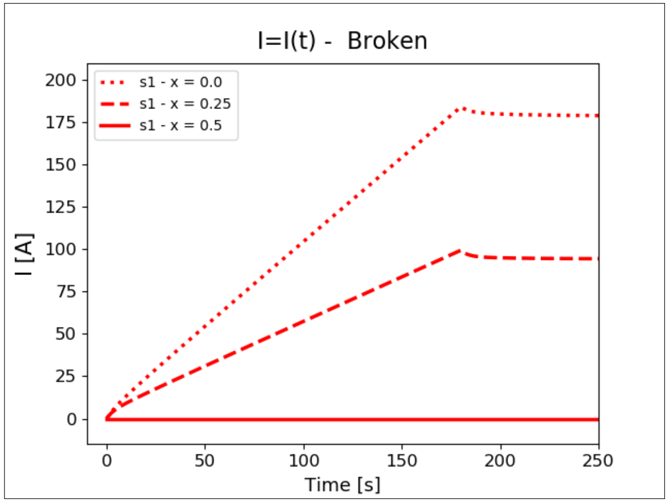
- Zero-voltage difference among strands in the *NbTi* cable *before the joint* (equi-V condition).

- Current is forced to be transferred from $NbTi$ to Nb_3Sn strands through the *Cu barrier* of the strands themselves and the *soldering layer*. We define a *purely resistive*, 5-cm *region*, where superconducting properties (J_c, T_c, T_{cs}) are set to zero, and such that $R_{joint} = 1\ n\Omega$.

Results

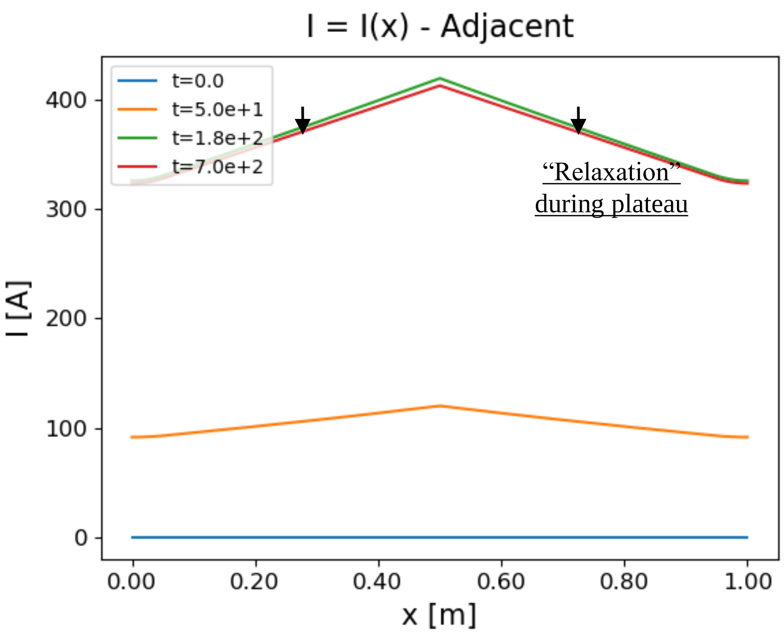
As reference, we start with: $R_{joint} = 1\ n\Omega \quad \Leftrightarrow \quad R_{joint,40\ strands} \approx 7\ n\Omega$

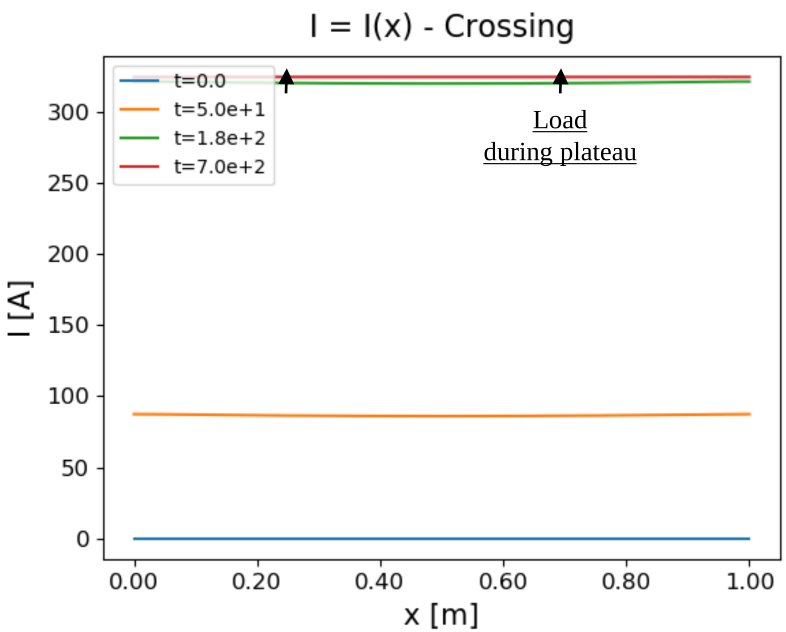


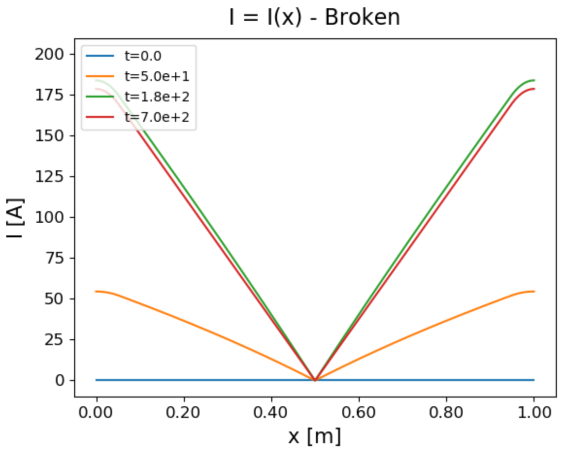


- V-shape profile evolution with boundary value ~180 A (intermediate)
- Relaxation during plateau

Results



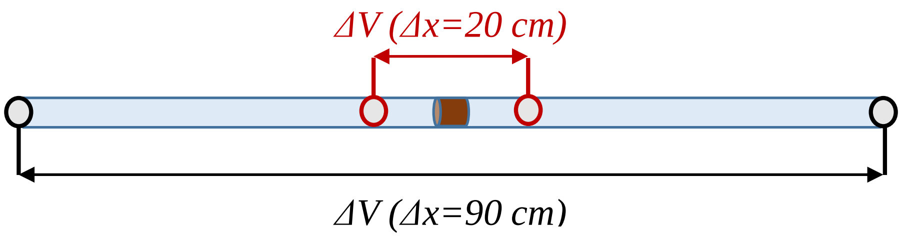




- Adjacent strands: current in *s1* has a smoother profile with respect to the case of imposed equal current distribution at the boundaries (see past presentations).

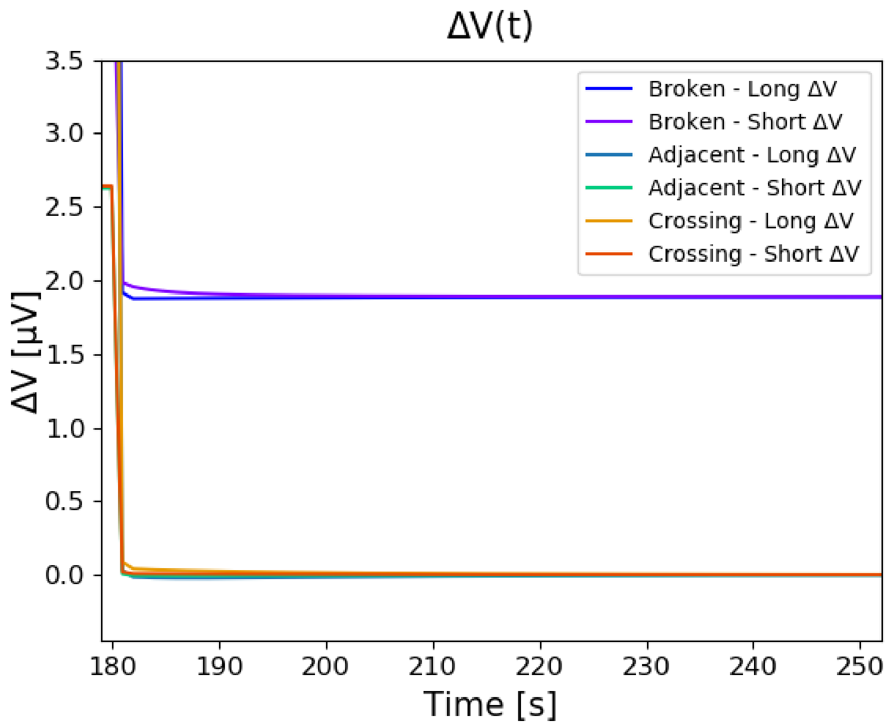
- Crossing strands: profile goes above 300 A, a sign that they contribute to the current distribution

Results



ΔV → "Long"

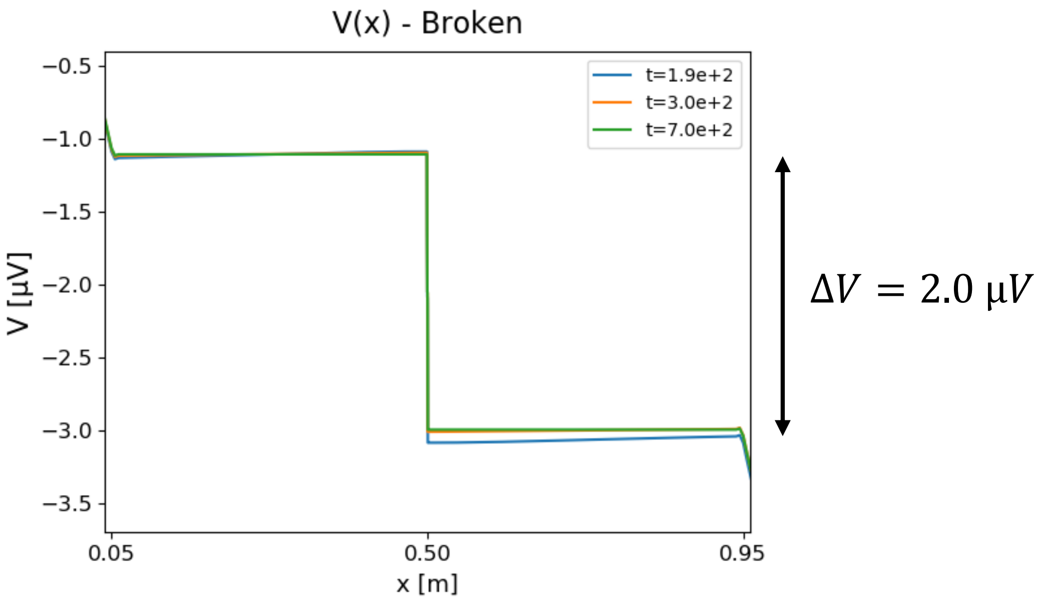
ΔV → "Short"



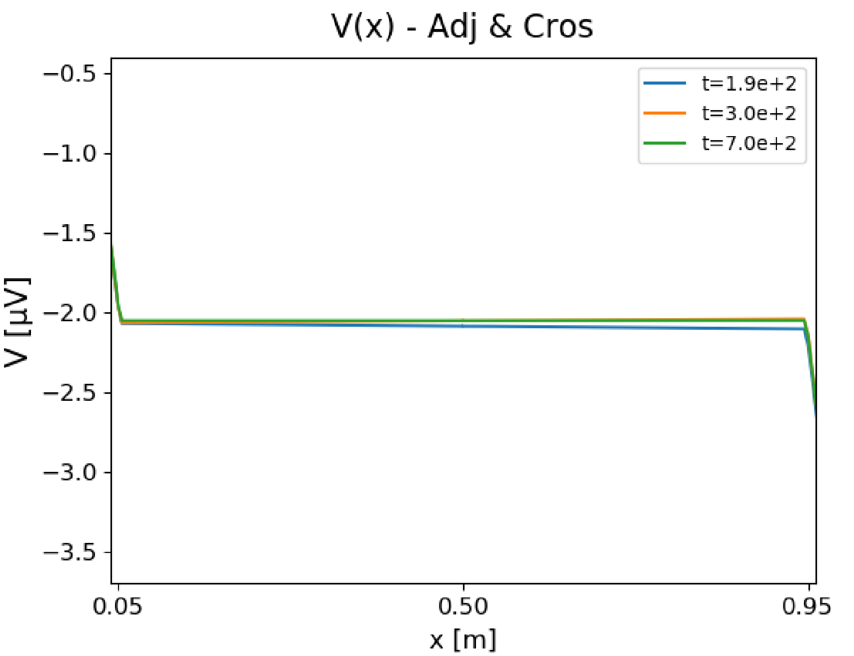
- Broken strand remains the only to experience a relevant *ΔV (few μV)* along its length
- Adjacent strands are still the only to see *ΔV<0*, due to relaxation (current reduction) during plateau
- Crossing strands have *ΔV>0*, more relevant than with 40 strands (here we have only 3 crossing strands)

Results

An insight: voltage profile in space



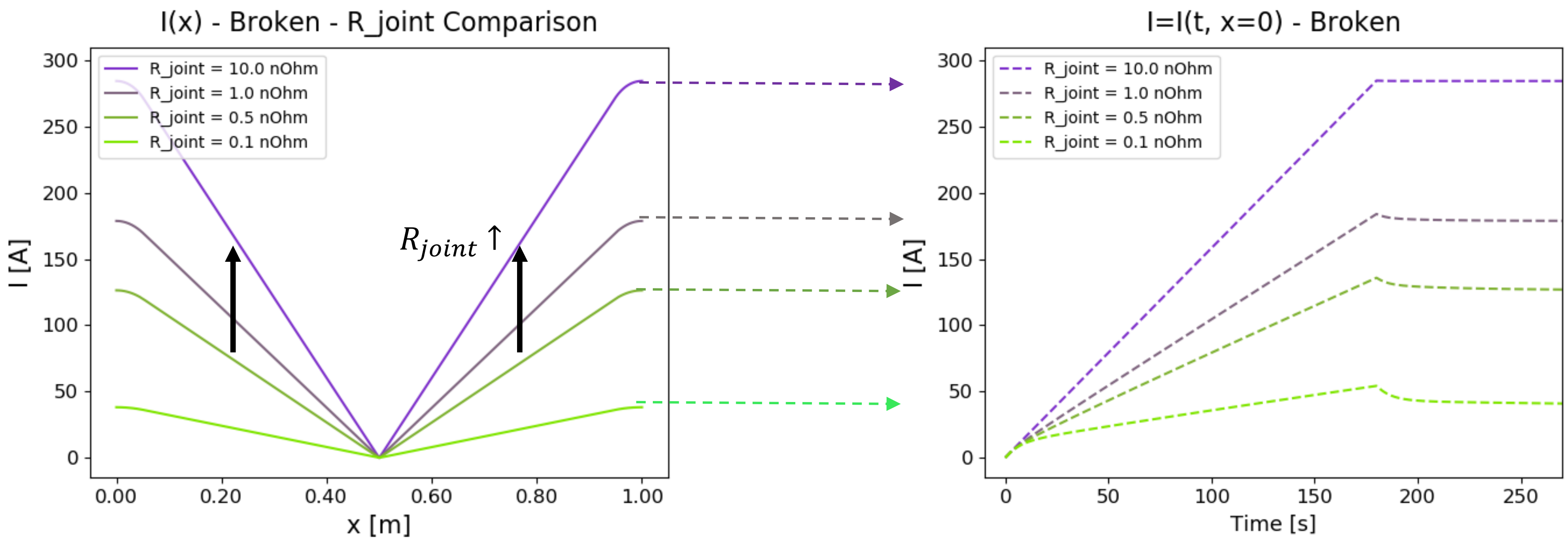
- *V variation is a step-like function* → no much different signals from farther and closer V taps.



- (Almost) flat profile in adjacent and crossing strands; still, evolution during plateau takes place

Parametric studies – Joint Resistance

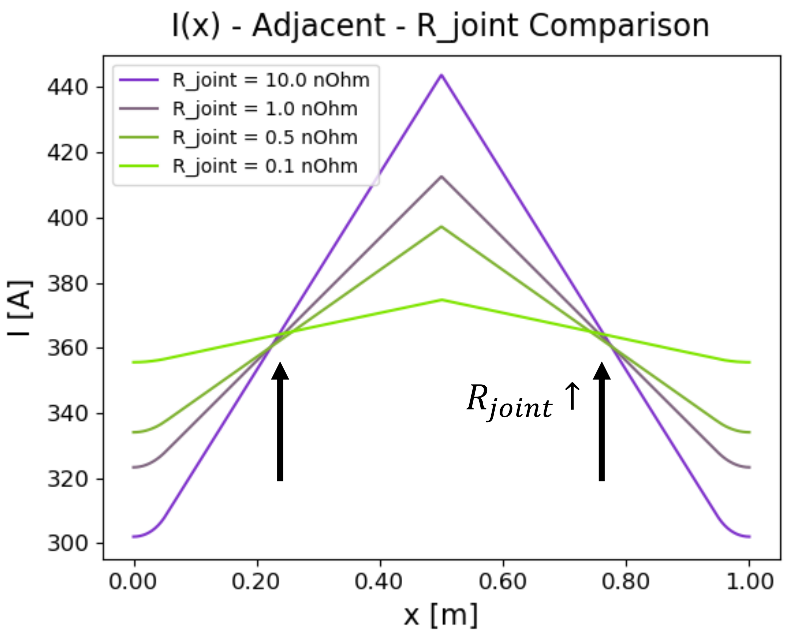
We propose here a comparison for Currents R_{joint} = 0.1, 0.5, 1.0, 10.0 nΩ

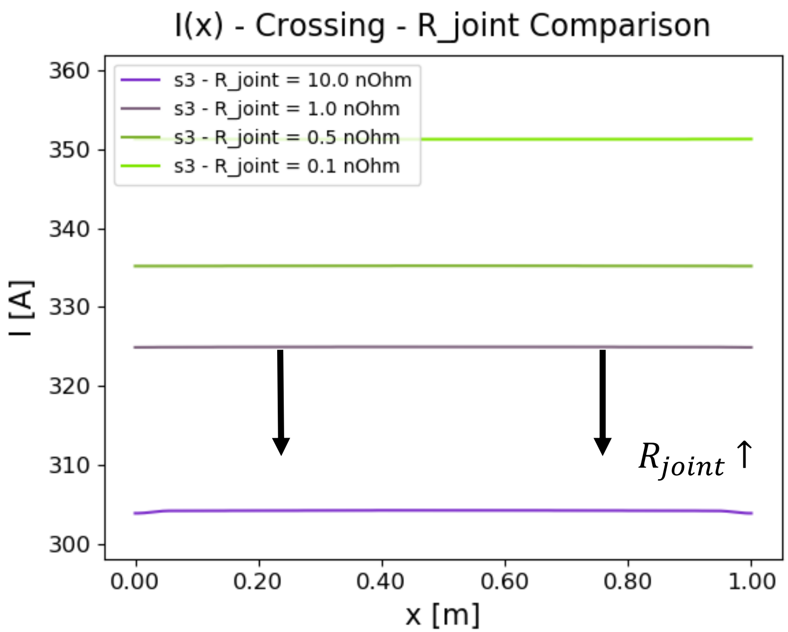


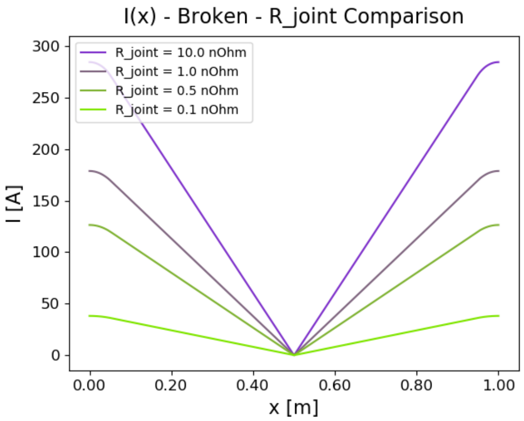
- As R_{joint} ↑, current at the boundaries gets closer to an equal distribution → *I(x)* profile gets steeper
- As R_{joint} ↑, the time constant of the system decreases (τ ≈ L/R) → Evolution at ramp end is faster

Parametric studies – Joint Resistance

We propose here a comparison of Currents for R_{joint} = 0.1, 0.5, 1.0, 10.0 nΩ



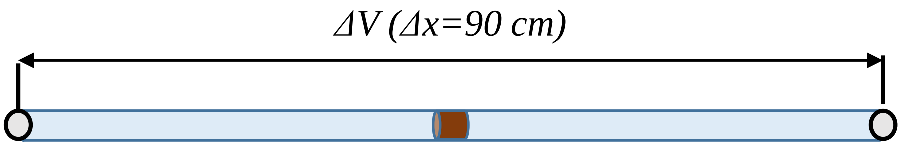


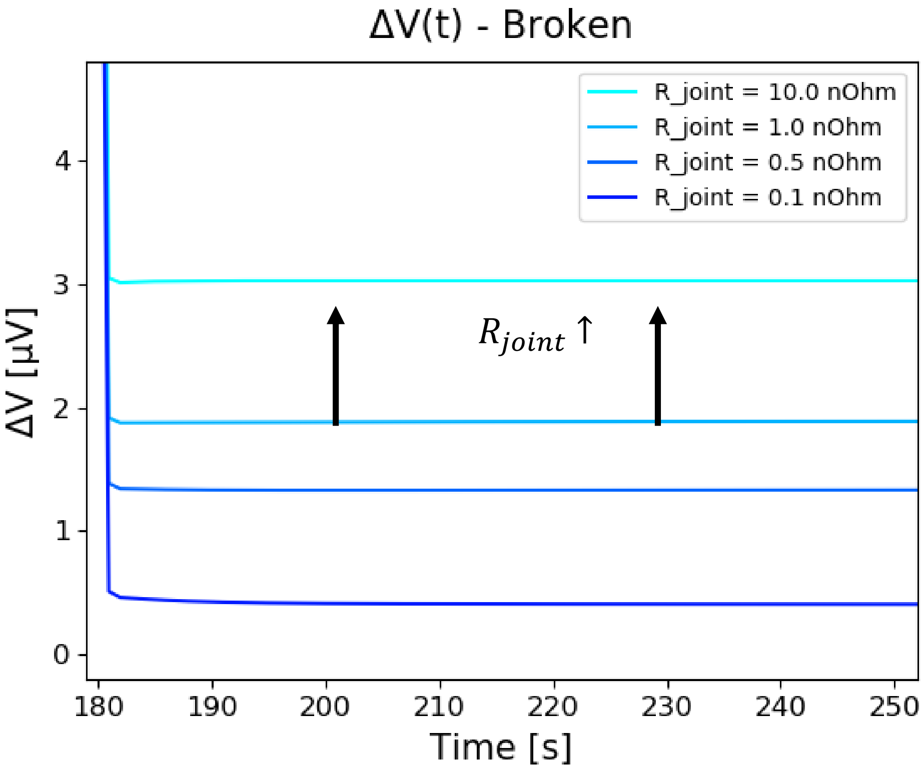


- As R_{joint} ↑, *I(x)* is steeper in the adjacent strands; *less sharing to the crossing strands*, as well.
- $\boldsymbol{R_{joint}}$ ↑ **implies a** general **worse behaviour.**

Parametric studies – Joint Resistance

We propose here a comparison of Voltages for R_{joint} = 0.1, 0.5, 1.0, 10.0 nΩ

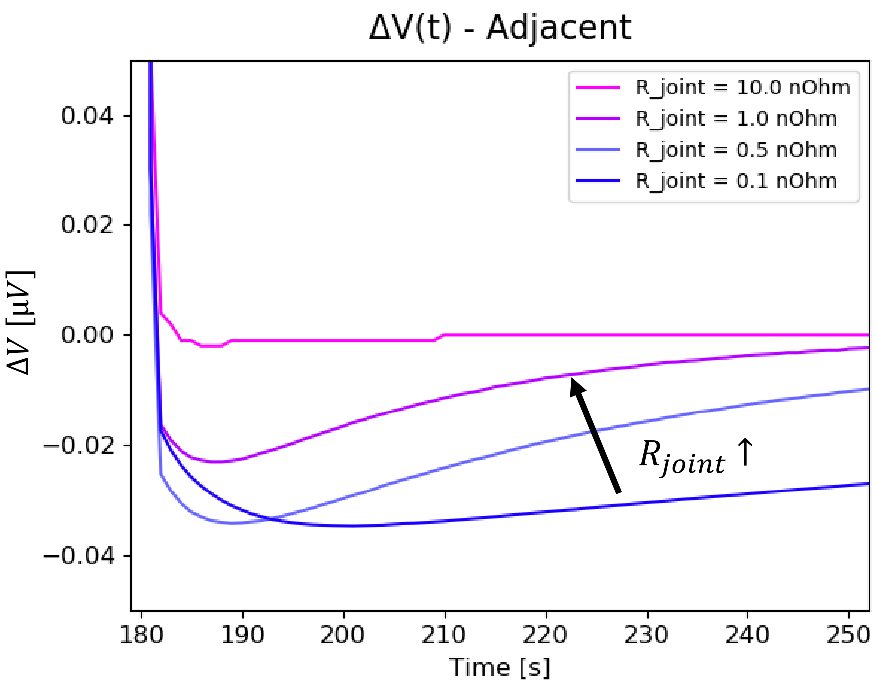




- As R_{joint} ↑, *I(x)* profiles are steeper → higher current transfer to adjacent strands → higher *ΔVs*

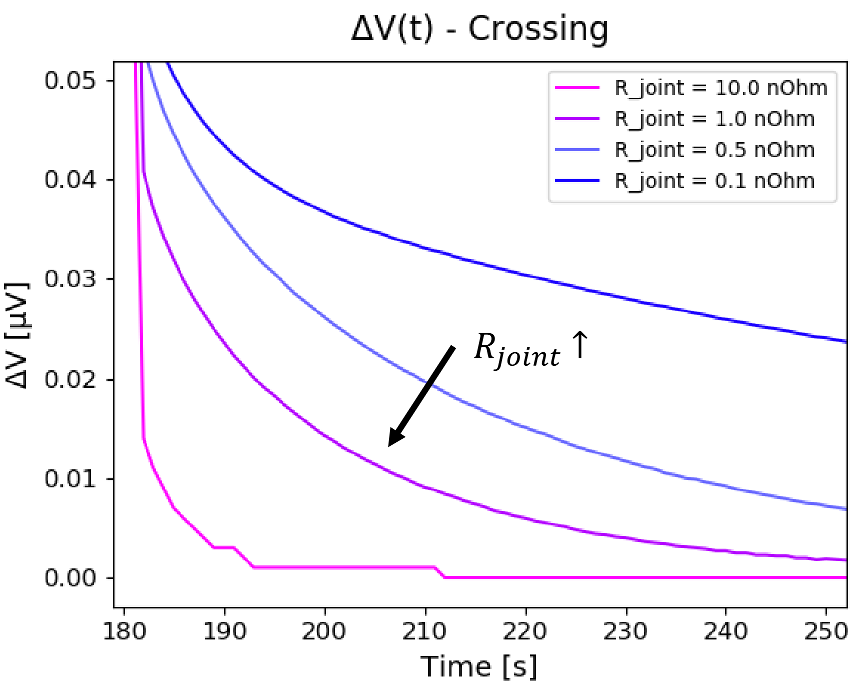
Parametric studies – Joint Resistance

We propose here a comparison of Voltages for R_{joint} = 0.1, 0.5, 1.0, 10.0 nΩ



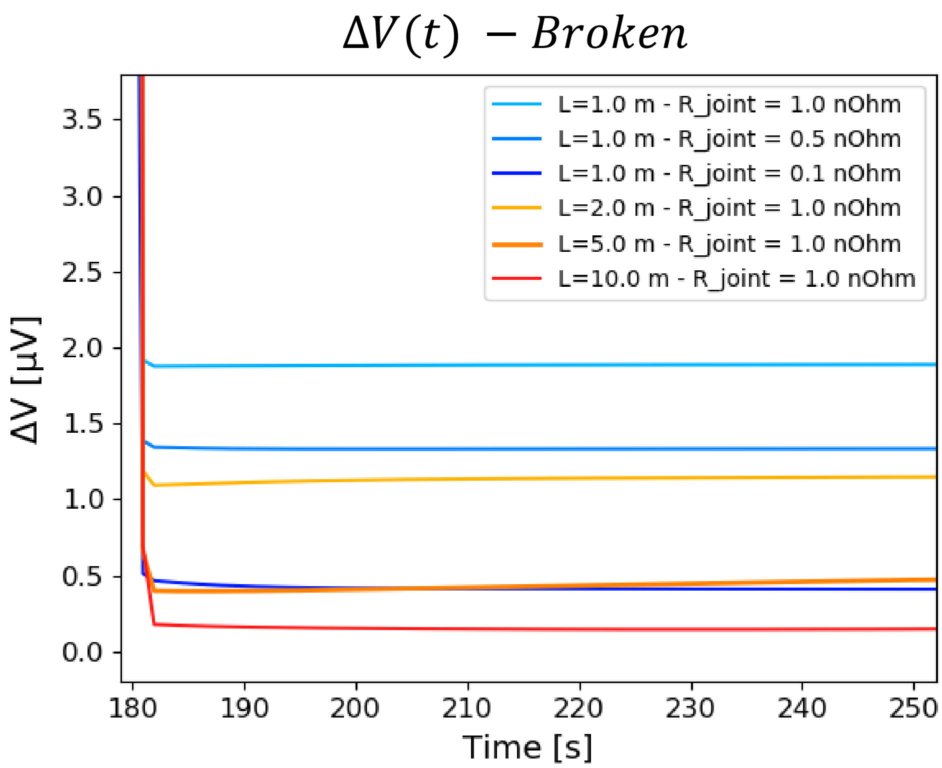
- As R_{joint} ↑, lesser inductive effect → *lesser decay* on adjacent strands at ramp end → lesser *ΔVs*

- As R_{joint} ↑, *shorter τs*



Parametric studies – System Length

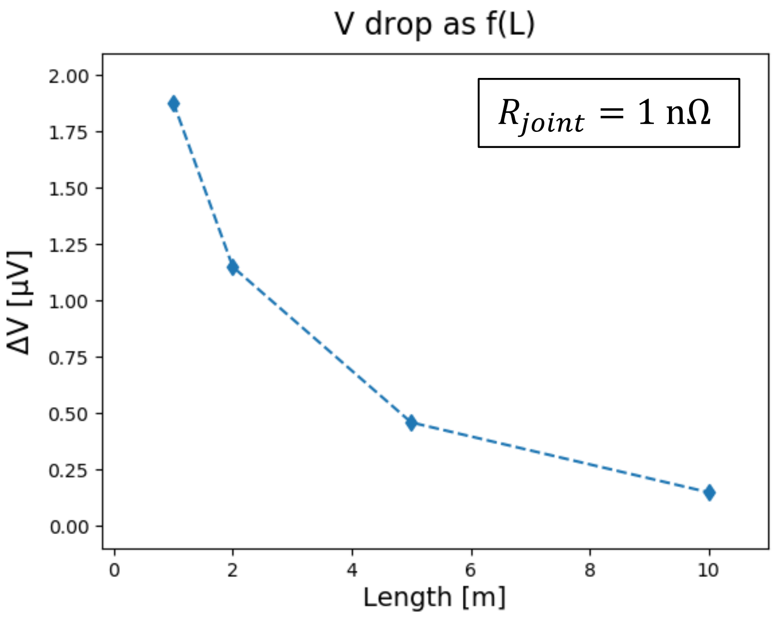
We propose here a comparison of Voltages for a R_{joint} = 1.0 nΩ & L =1.0, 2.0, 5.0, 10.0 m



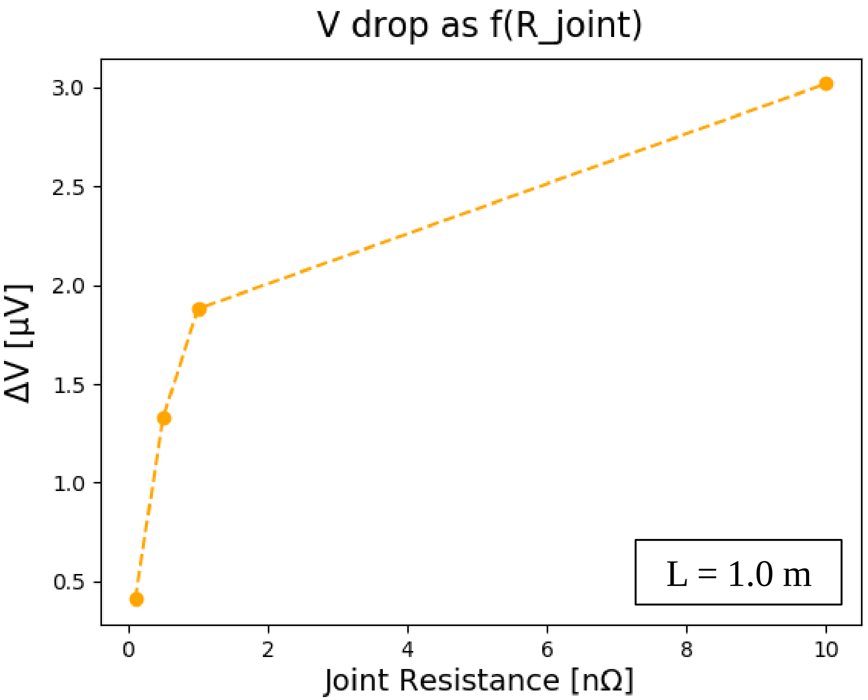
- At a given R_{joint}, increasing the domain length means lowering *ΔV* across the breakage
- One may think about an 'equivalence' between different combinations of L & R_{joint}.
  For example, here, *L=5.0 m & R_j=1 nΩ* ⇔ *L=1.0 m & R_j=0.1 nΩ*

Correlations

A few correlations may be noted:



- *Inverse proportion* between *L* and *V drop* across breakage



- *"Saturation"* of V drop above a given R_{joint} → uniform current distribution at the boundaries

Conclusion

- A high joint resistance, R_{joint}, behaves as a strong voltage “pump”, forcing the current to flow into the broken strand. As a result, I profiles are steeper both in the broken and adjacent strands, putting system stability at a higher risk (since the adjacent strands take all the current from the broken strand).

→ *Low R joints are better*

- Viceversa, as R_{joint} decreases, boundaries go towards an *equi-V* condition: the broken strand is left with a lower current. The rest of the cable current is uniformly distributed among all non-broken strands (adjacent + crossing).

- Increasing the cable length L is equivalent to decreasing R_{joint} → a 10^3 long cable would converge towards an even better *equi-V* condition, with all crossing strands taking part in the current distribution process.

Next steps

- Parametric study on R_a vs R_c influence on the current distribution process (6-strand model)

- Go up to 40 strands and longer domains (10 → 100 m)