Modeling, simulation and experiments for EFI design and characterization

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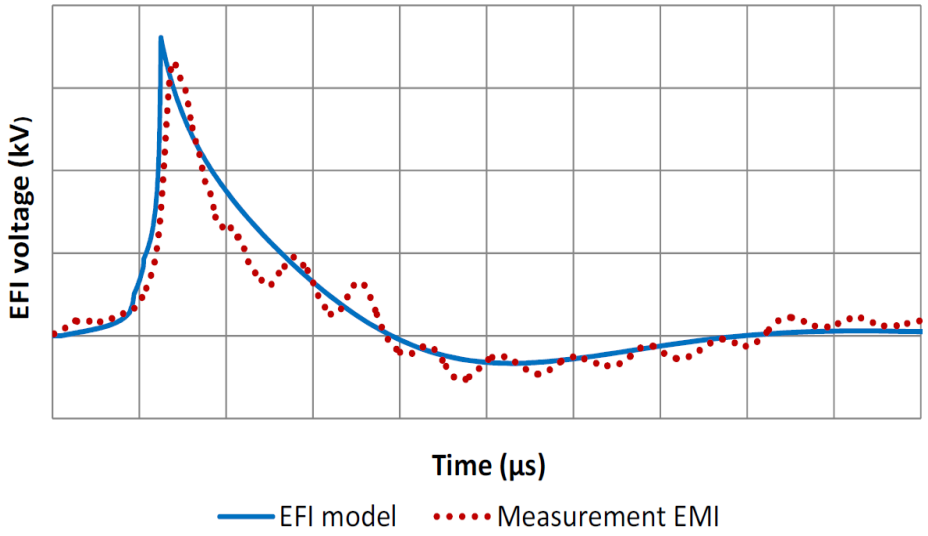
Modeling, simulation and experiments for EFI design and characterization: Content of presentation

- Motivation for EFI activities at EMI
- EFI modeling and simulation
- Experimental validation of model
- Reliability and safety analysis
- Conclusion



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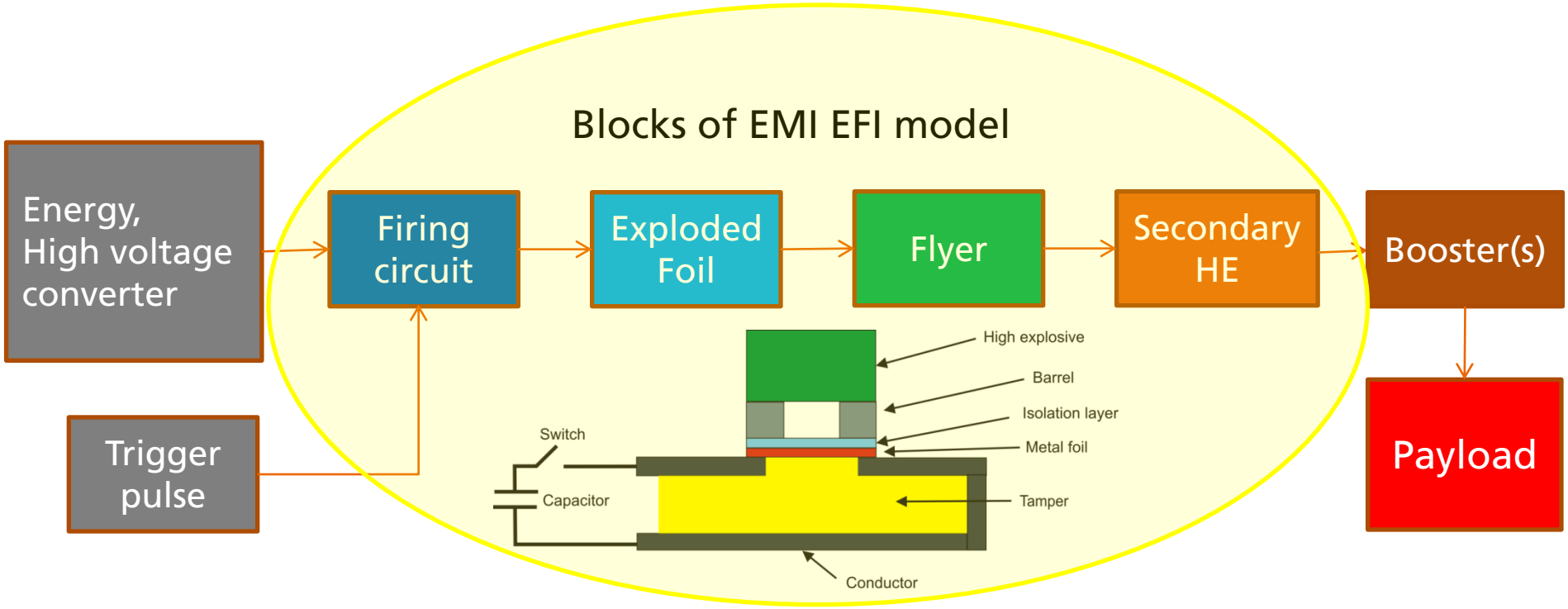
Motivation: Objectives to modeling EFIs

- Consideration of all important fuze components and physical principles
- Description of relevant physical processes using approximations with sufficient accuracy
  - No complex numerical simulation needed
- Determination of safety related requirements
  - Allocation of relevant parameters for HE initiation
  - Evaluation of sources of disturbance
  - Formulation of no-fire and all-fire criteria
- Design optimization for development of fuzes
- Predictions respective measuring methods

➔ Reduction of time and costs for **realization** and **qualification**

Motivation: Complexity of fuzing system



➔ Model includes behavior of blocks and their interactions

- Voltage, current rising, bridge resistance, material properties, barrel geometry, chemical characteristics (explosive)…

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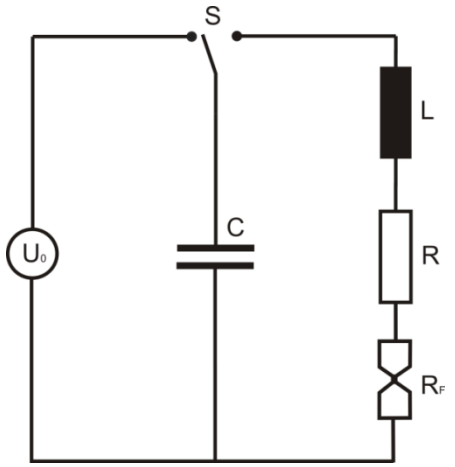
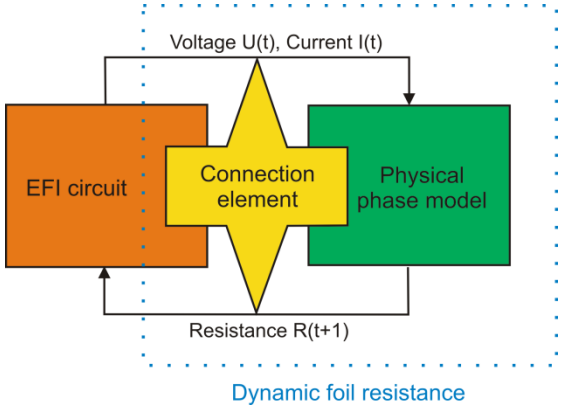
EFI modeling and simulation: Foil explosion in the firing circuit

- Energy from firing capacitor
- Conductors and contacts: Ohmic losses and inductances
- High voltage switch
  - Switching time and on- / off- resistance
- Parasitic effects (of measuring equipment)
- Simulation of firing circuit from closing of switch until foil explosion (control loop)
- Calculation of dynamic foil resistance R_F for every time step
- Resistance depends on EFI geometry, material data and coupled bridge energy as a function of phase state





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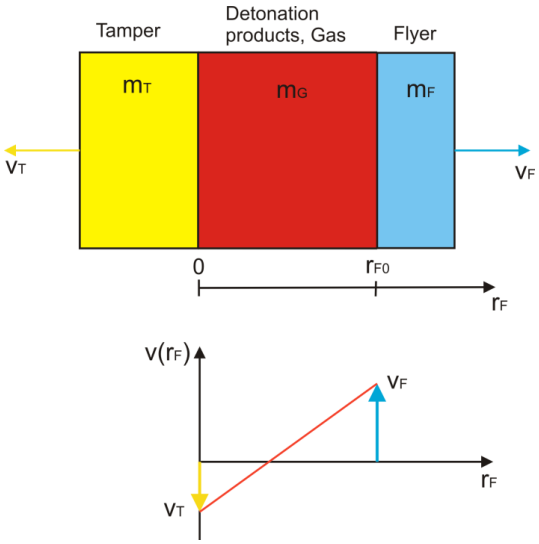
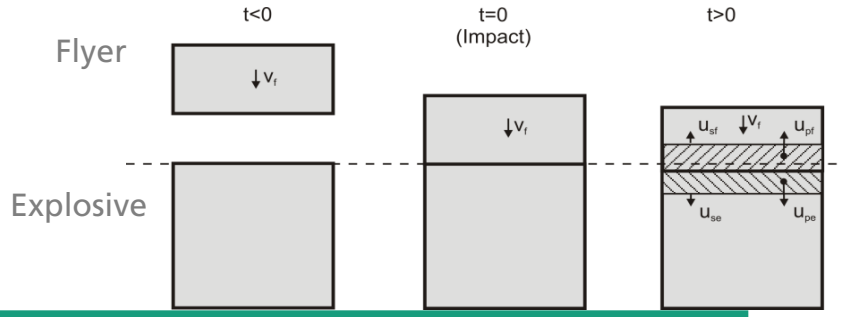
EFI modeling and simulation: Flyer acceleration and impact

- Time-dependent Gurney model (sandwich configuration)
  - Conversion of explosive energy into internal gas energy
  - Assumes linear increase of velocity of gas, tamper and flyer
- Flyer velocity depends on released explosion energy
- Flyer velocity is a function of barrel length



- Estimation of HE initiation by common criterion*
  - $P_e^x \cdot t_p \geq c$
  - Literature data for *x* and *c* available
  - Pressure P_e und pulse duration t_p calculated by planar impact**



*based on Walker-Wasley and Schwarz
** based on Hugoniot

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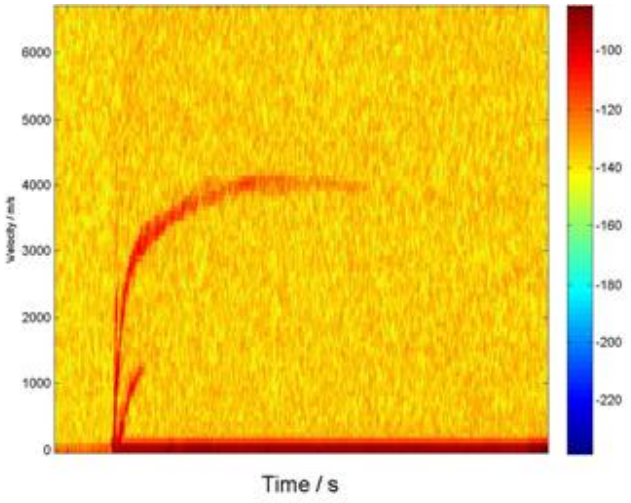
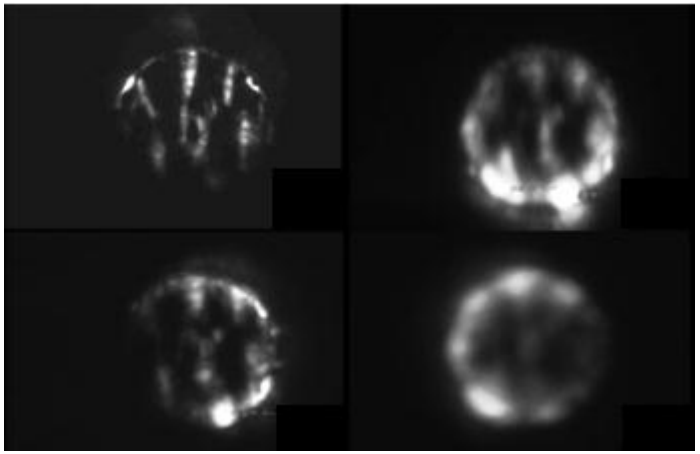
Experimental validation: Measurement equipment used at EMI

- Differential voltage measurement
- Rogowski coil for current measurement
- Photonic Doppler Velocimetry (PDV)
  - Flyer velocity is the most important information for characterizing EFI
    - Initiation criteria
    - Efficiency of energy coupling
- Characteristics of flyer shape by high-speed microscope
  - Flyer intact or torn?
  - Flyer planar or bent/curved?
  - Synchronization with PDV possible





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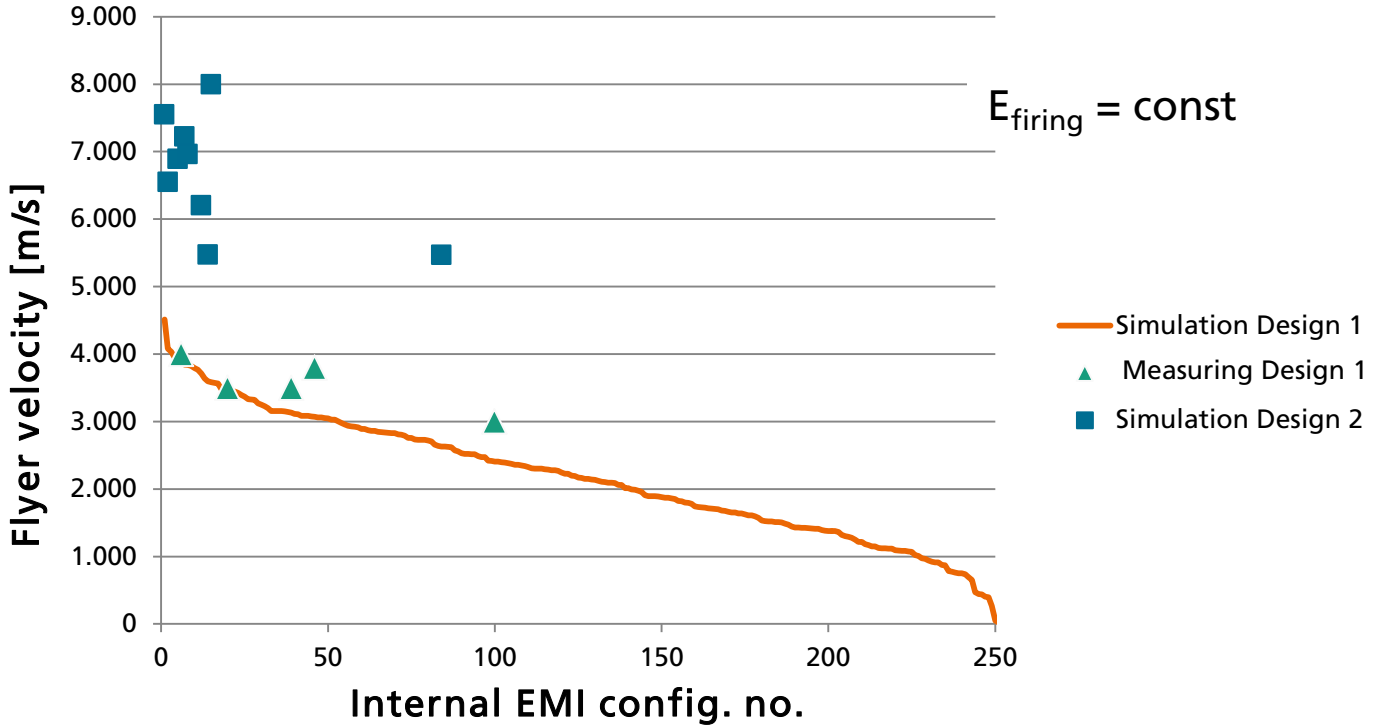
Experimental validation: Simulation of EFI designs



- Experimental validation performed at EMI show good agreement between simulation and experiments
- Design verification
  - Design 1: Limited capabilities
  - Design 2: Higher flyer velocities achieved for the same firing energy

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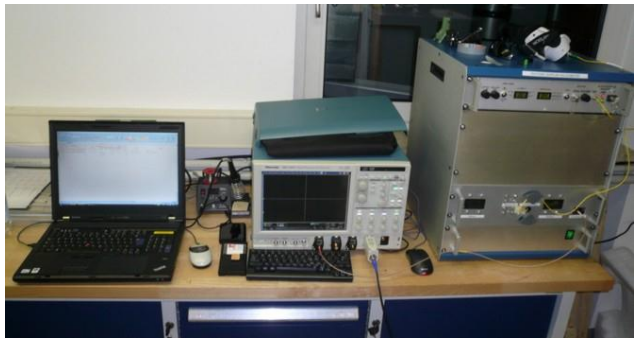
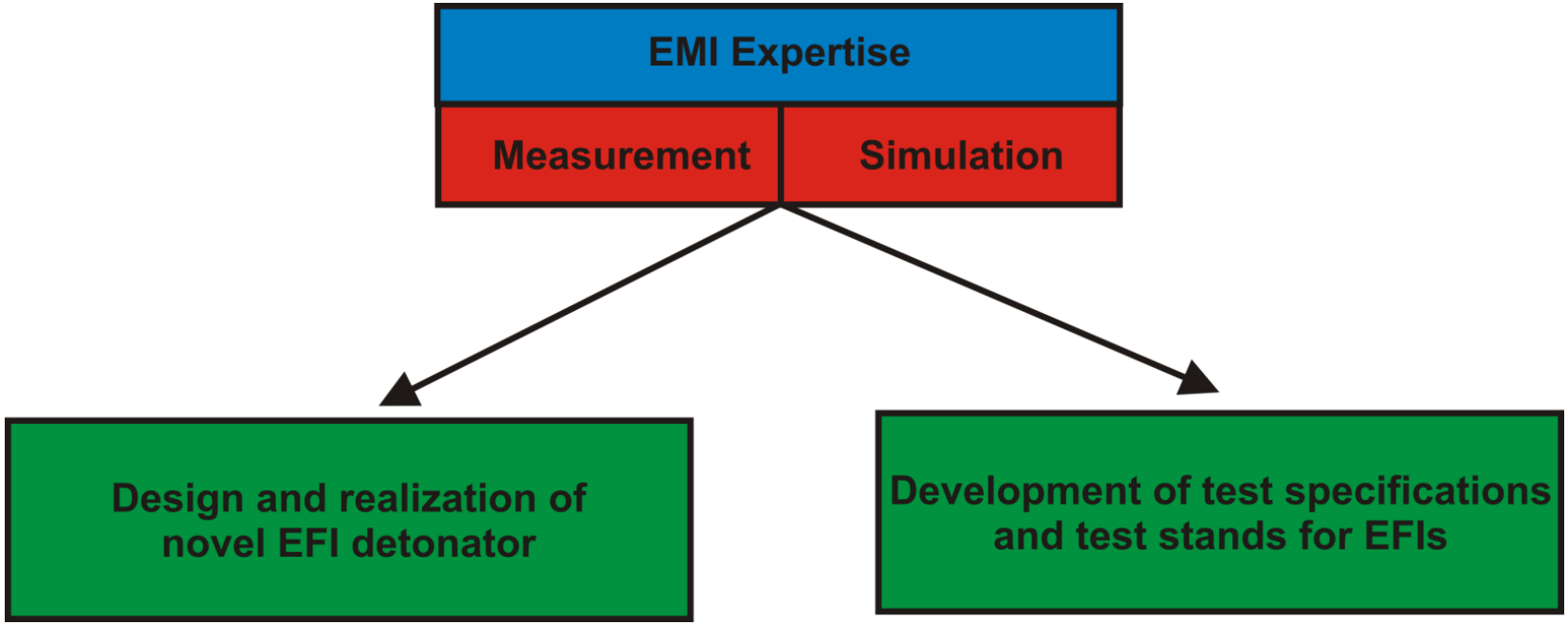
Reliability and safety analysis: Complementary strategy

Bridge structure

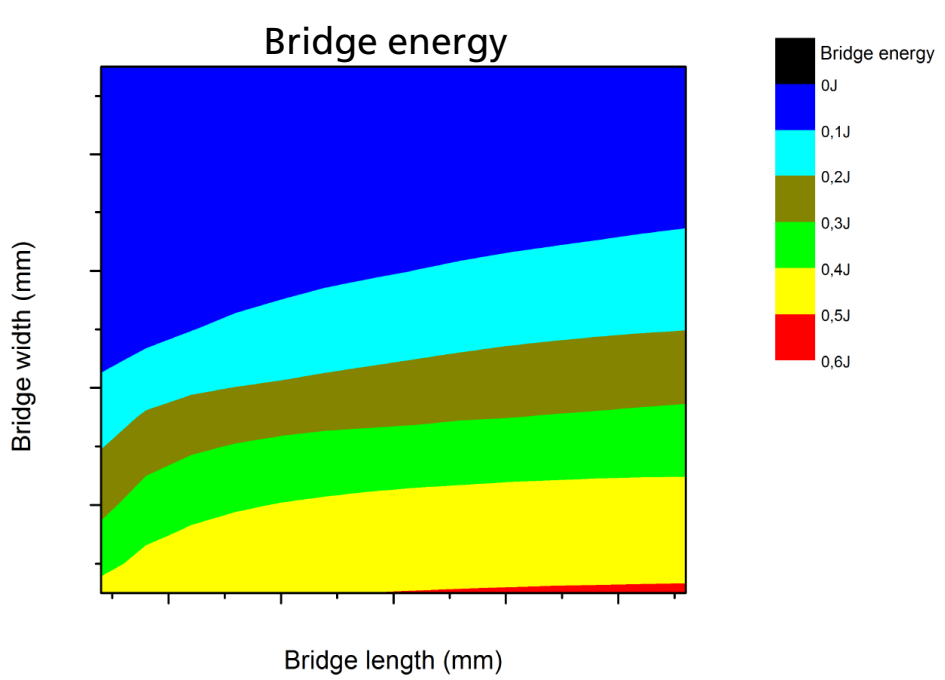
Two EMI strategies

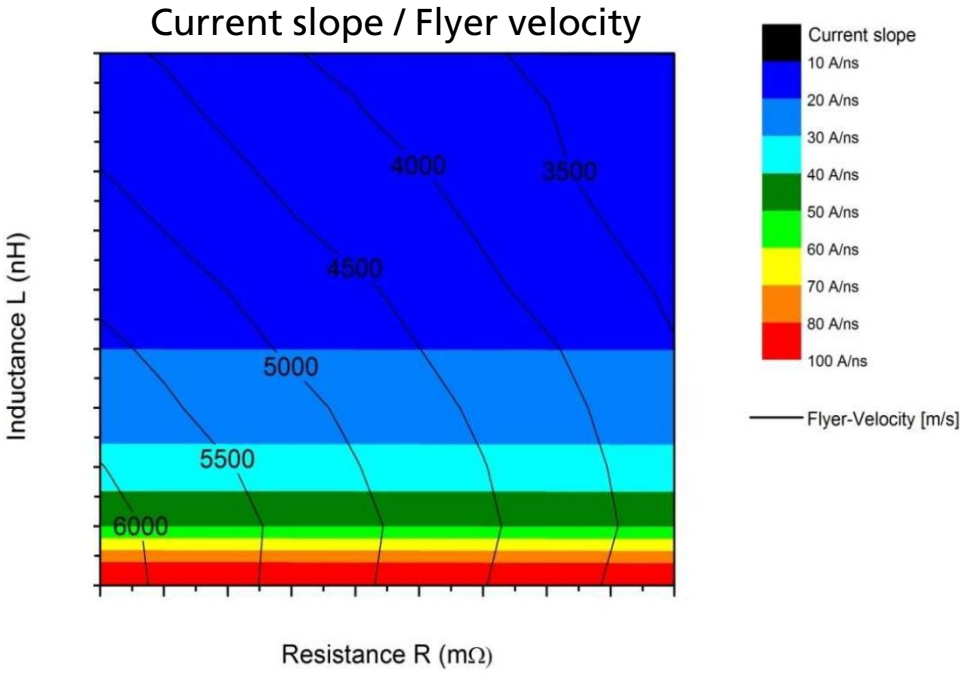


PDV



Reliability and safety analysis: Systematic design optimization





Parameter analysis provides values for reliable and safe EFI operation with respect to e.g.,

➔ energy coupling in foil/bridge

➔ kinetic behavior of flyer

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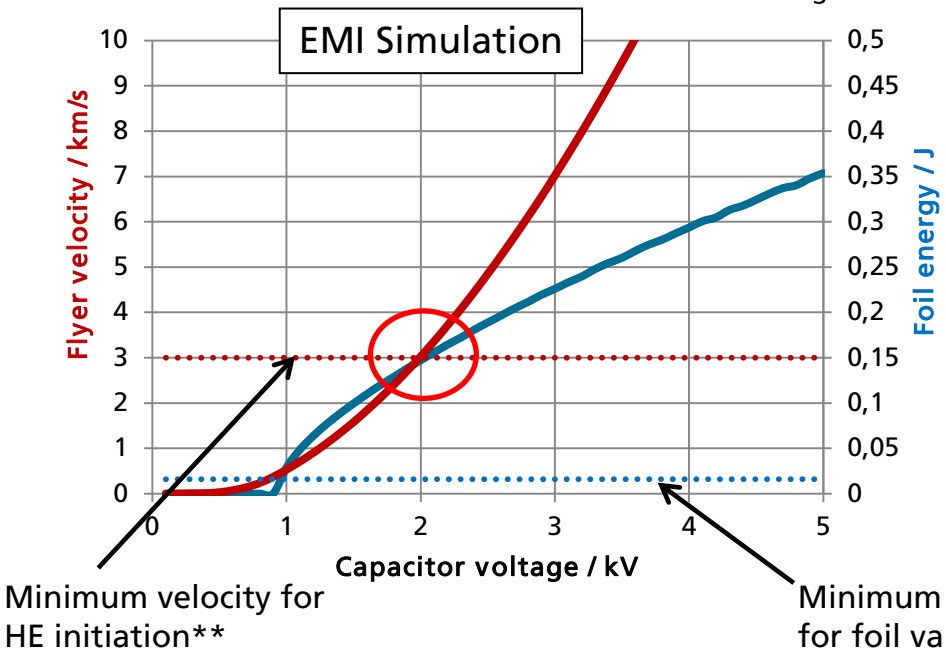
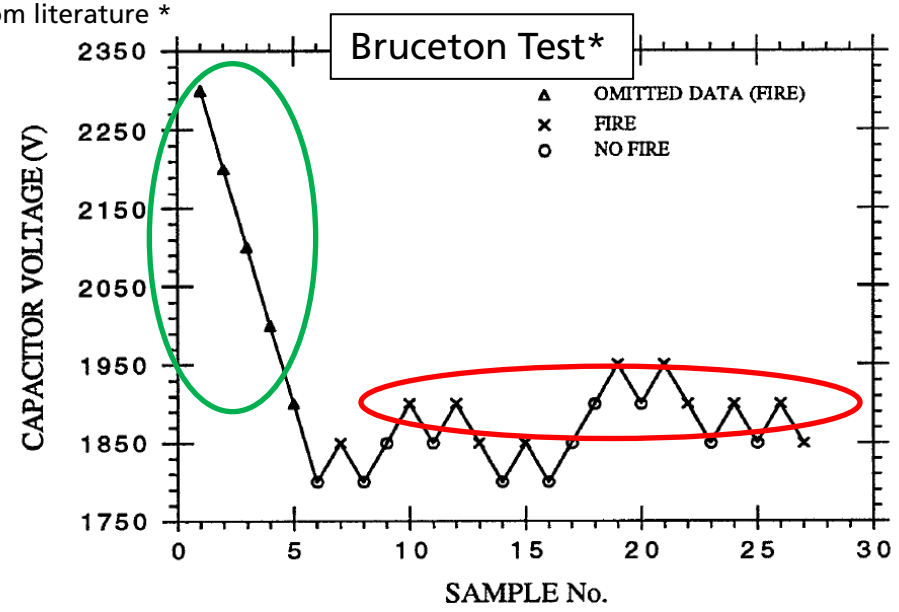
Reliability and safety analysis: EFI model as tool for characterization

EFI configuration from literature *





For a specific EFI design safety critical parameters are determined

➔ Simulation in good agreement with literature ($U_{Initiation}$ = 2kV vs. $U_{Firing^{50\%}}$ =1.86kV)

Application of EMI model:

Reduction of time and effort for fuze qualification through efficient use of samples

Verification of all-fire and no-fire criteria, creation of new safety requirements concerning EFI in undefined states after foil vaporization

*Nappert, L., *AN EXPLODING FOIL INITIATOR SYSTEM*. 1996, Defense Research and Development Canada

** Empirical data from literature

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Conclusion

Fraunhofer Ernst-Mach-Institute has a efficient development and characterization platform for EFI detonators

- Fuze modeling
  - No fitting parameters (only physical data) required
  - Highly efficient in time
  - Already validated with experiments and literature data
  - Expansion to extensive numerical simulation feasible
- High-performance diagnostics for determination of all relevant parameters
  - Velocity profile, flyer geometry
  - Electrical characteristics
- Two EMI strategies
  1. Realization and optimization of EFI design
  2. Generation of test specifications for EFI characterization and qualification
  - Dimensioning of test stands and measurement instrumentation (development and qualification)

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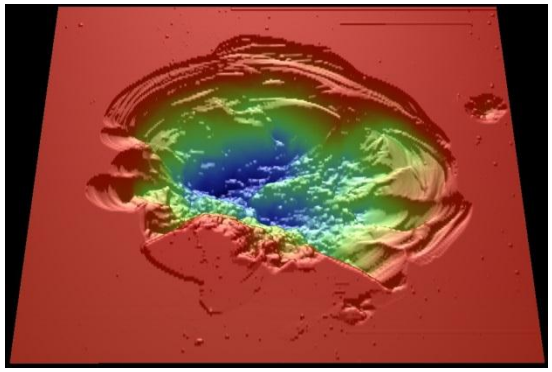

Impact crater of EFI flyer on glass substrate

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