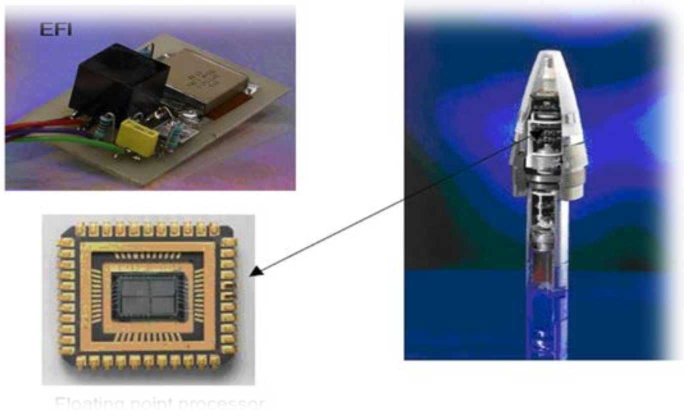
MCEFI DEVELOPMENT AT TNO

Fuse Conference 2015 | Gert Scholtes, Wim Prinse and Marco v.d. Lans

TNO innovation for life

OVERVIEW

- Introduction
- Why an EFI initiator
- Optimization of EFI system
- McEFI Research & development and testing
- Best option: McEFI
- Summary



TNO CURRENT/FUTURE RESEARCH

TRENDS THAT HAVE OUR ATTENTION

WHY AN EFI SYSTEM

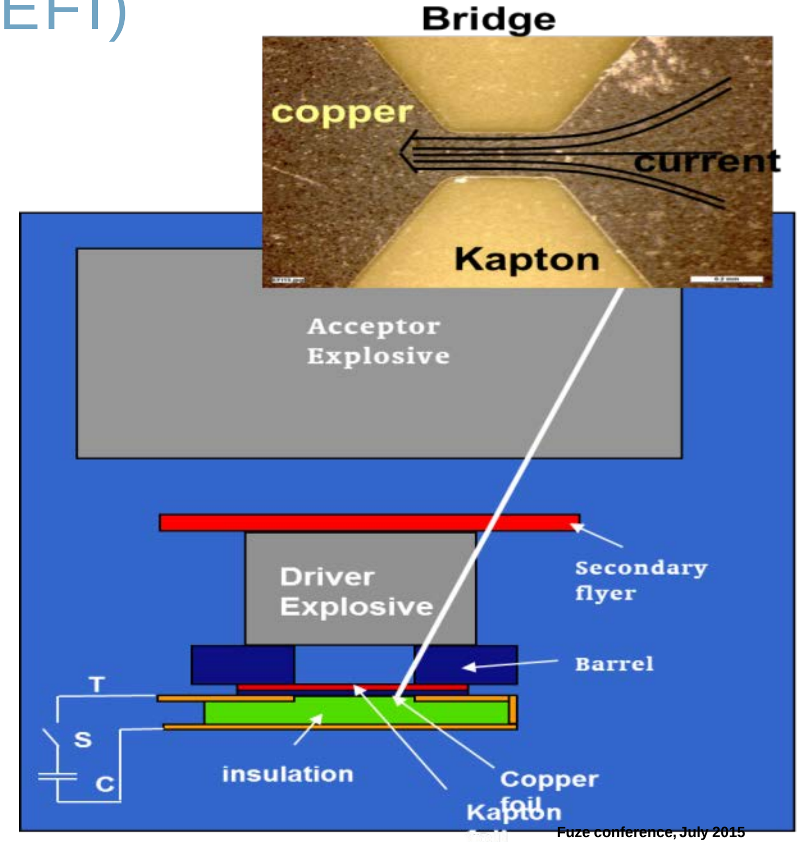
- An EFI is intrinsically safer than standard initiators (no primary explosive); in-line with booster-main charge
- More reliable (So, no UXO's), conventional ignitors 5-10% duds
- Functionality can be tested non-destructive
- Works much faster < microseconds i.s.o. milliseconds scale
- Is compliant with new STANAG (4560) NATO defence regulations
- Not sensitive to Electro-Static Discharge (ESD)
- New opportunities (smart munitions for reduction of collateral damage; p.s.: Energy needed ~100mJ, CR2032 battery: >2000 times more energy)

- Current disadvantage: Price in range of $1000, size; too expensive and too large for most applications

- Future: Micro Chip EFI (McEFI) → inexpensive; few dozens of $, microchip based technology

EXPLODING FOIL INITIATOR (EFI) (WITH SECONDARY FLYER)

- Important components:
- High Voltage unit
- Switch
- Capacitor
- Bridge/transmission line
- Logic and other components and automatic production line



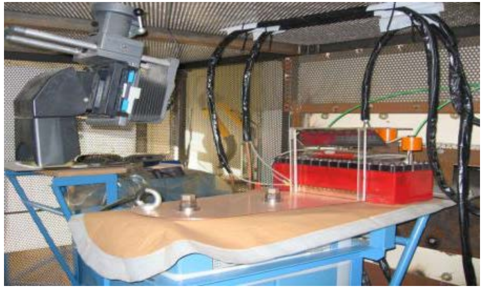
OPTIMIZATION OF EFI

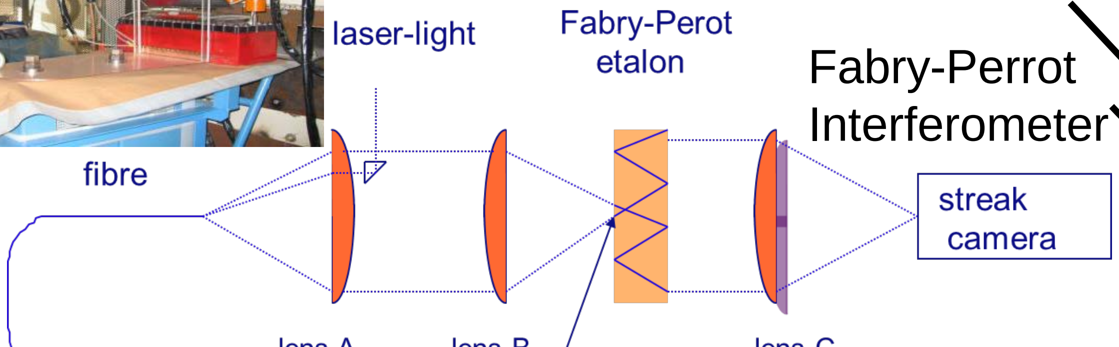
- State of the art facilities

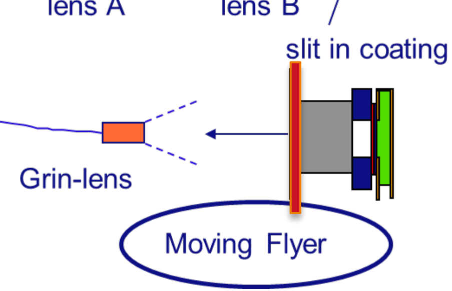
- Important design aspects
  - Energy use and materials of bridge
  - Shock impedance and effective flyer
  - Lorentz force in EFI systems
  - LRC circuit optimization

- Micro-chip technology favourite

SHOCK INITIATION RESEARCH AT TNO: MEGA AMPERE PULSAR AND FLYER IMPACT



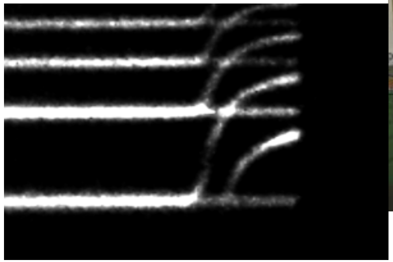




~4 feet

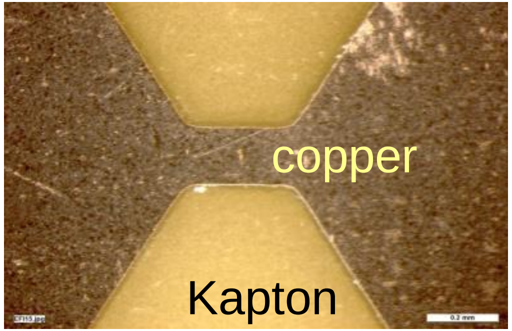
Wim Prinse

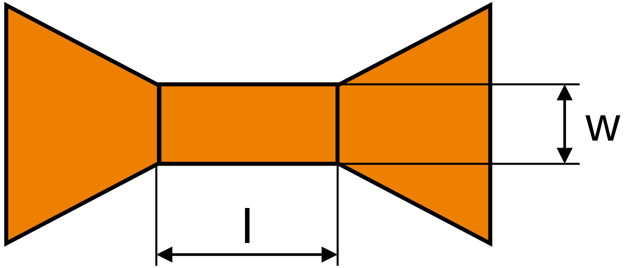
Fabry-Perrot Interferometer

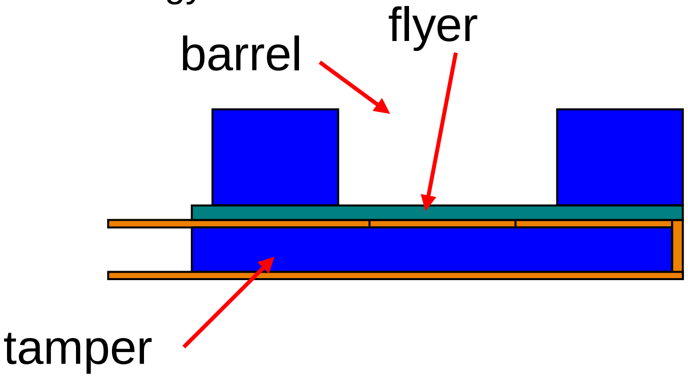


EXPLODING FOIL/BRIDGE; IMPORTANT DESIGN ASPECTS

- Dimension of the foil (length, width, thickness, shape, material)
  - More material and certain amount of Energy → lower temperature → lower maximum flyer velocity
  - 0.12J → max. temperature copper ~100,000 K, aluminium ~150,000 K
- Tamper material: Shock impedance of the tamper higher: more energy deposited in exploding bridge
- Thickness/size ratio and material of the flyer (next sheet)
- Length and width of the barrel





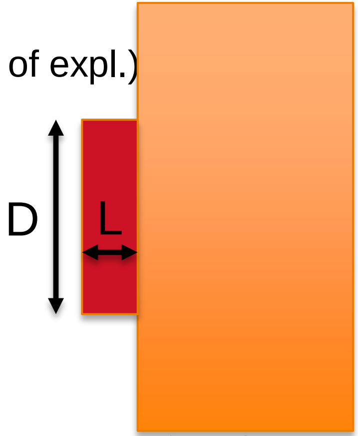


RATIO OF THICKNESS AND SIZE OF FLYER

- Shock criteria: Critical Energy fluence in to explosive [1]): $E = P\, u_p\, \tau$ with P= pressure, Up Part. Velocity and τ the time.
  Shock attenuation due to release wave from back of the plate or from periphery, so:

$$E = \int P \cdot u_{p,x} \cdot dt$$

- For flyer plate time of thickness L and W_p the shock velocity in the plate: $\tau_1 = 2L / w_p$
- For a Rod with diameter D: time $\tau_2 = D/6c_e$ [2]) with c_e = sound speed in shocked Explosive
- With shock Hugoniot of explosive **$Us = Co + Su_p$** we get: (Co sound vel., S parameter of expl.)
- Optimum thickness/size ratio $\tau_1 = \tau_2$: $L / D = wp / \{4ce\ (2 + Co / Su_p)\}$ [3])



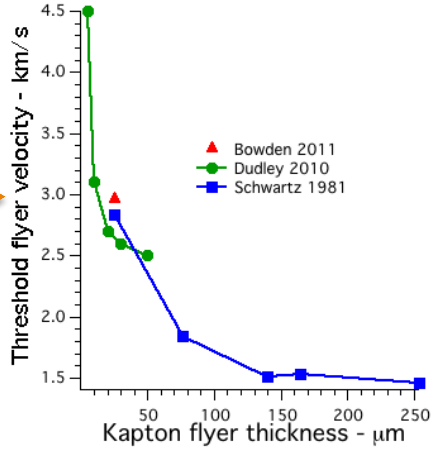
- [1])Walker, F. E., and R. J. Wasley, R. J.,"Critical Energy for Shock Initiation of 1428 Heterogeneous Explosives", Explosivstoffe Vol.17 (1), pp. 913, 1969
- [2])James, H. R., "Critical Energy Criterion for the Shock Initiation of Explosives by Projectile Impact", *Propellants Explos., Pyrotech.* Vol. 13, pp. 3541, 1988.
- [3]) Peter J. Haskins and Malcolm D. Cook, "A Modified Criterion for the Prediction of Shock Initiation Thresholds for FlyerPlate and Rod Impacts", 14th int. Detsymp 2010, p1421

RATIO L/D (CONT'D) AND LENGTH OF BARREL

- A certain flyer size results in an optimum thickness of the flyer.

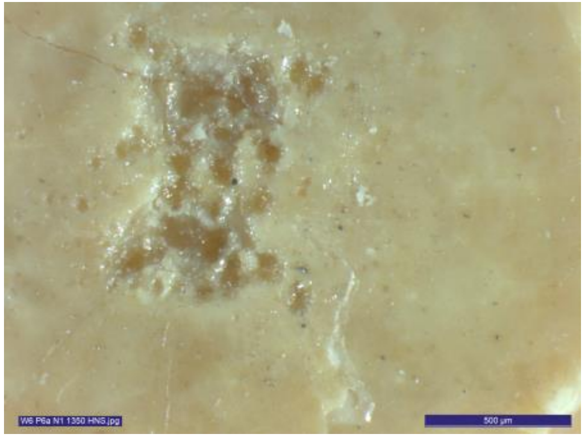
- **Example:** Diameter = 300 µ → optimized thickness L_{opt} = ~26 µ
  - Diameter = 350 µ → L_{opt} = ~31 µ
  - Diameter = 400 µ → L_{opt} = ~35 µ

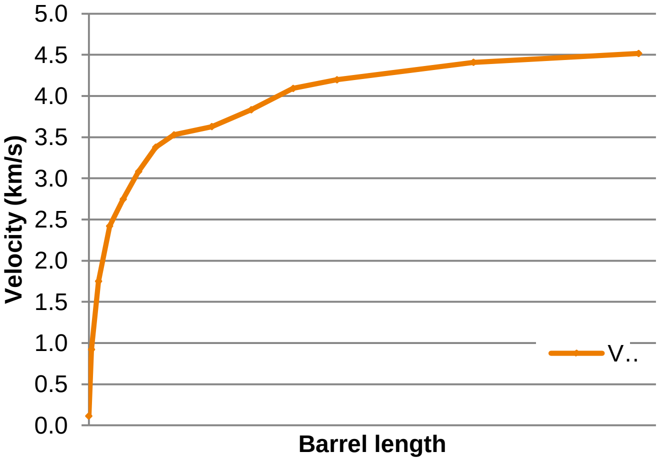
- However, a thin flyer needs more velocity!



LENGTH OF BARREL

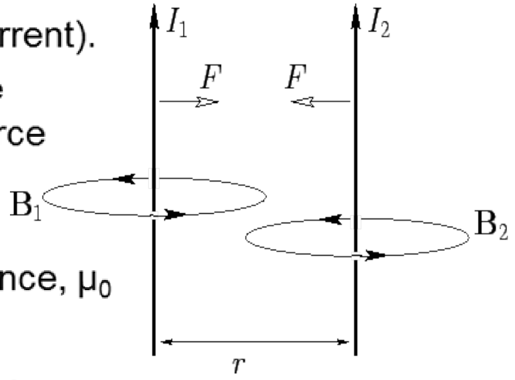
- Important: Maximum velocity but also integrity of flyer before impact on explosive pellet.
- Maximum barrel length depends strongly on LRC-system and flyer-thickness/integrity





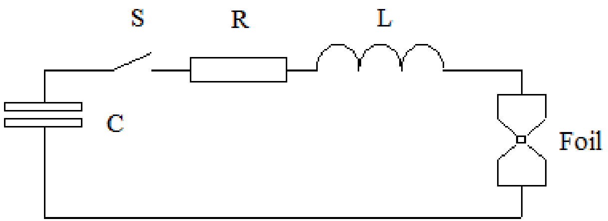
FORCES BETWEEN TRANSMISSION LINES

- Based on the law of Ampère, a current will produce a magnetic field around the electric current of the transmission line proportional to the amount of current
- The Lorentz law, is a law describing the force on a moving electric charge (current).
- So both transmission line produce a magnetic field resulting in an acting force between the two lines (parallel current: attracting force, opposite: repelling force

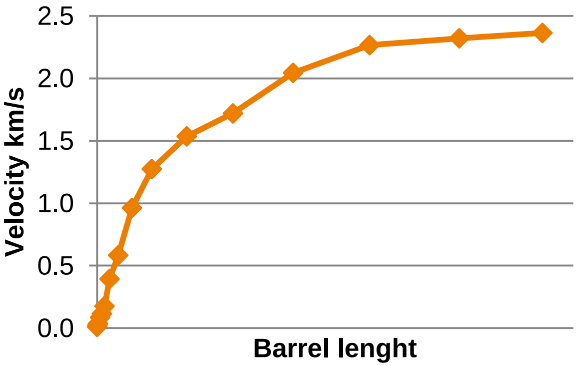


- $F = \frac{\mu_0 I_1 I_2 \text{ le}}{2\pi r}$ with F the force in Newton, I_1 and I_2 the currents, r the distance, μ_0 the value of $4\pi \ 10^{-7}$ and *le* the length of the part of the transmission line
- Mega ampere pulsar: (large system: transmission line 2x2 cm, I_{max} = 500,000 Amp. 40 μ distance: (first order estimate no integral over distance and current).
- F = 10 10^6 N and acceleration ~231 10^9 m/s^2 → 23100 m/s Relevant for flyer velocity
- EFI: I_{max} =4000 Amp. , ~300 microns. F = 9.6 N, accell. = 4 10^6 m/s^2 → 100ns → 0.4 m/s : → Not relevant for flyer velocity

OPTIMIZED CIRCUIT



- Electronic circuit of EFI
- wherein L and R are substantially parasitic in nature → as low as possible
  - Loop in circuit
  - Impedance of switch, transmission lines.



Non-optimized circuit

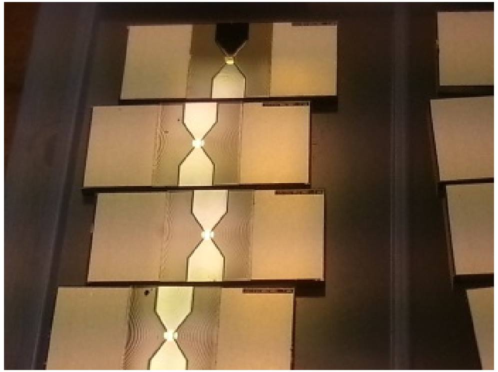
Optimized circuit

MICRO CHIP TECHNOLOGY

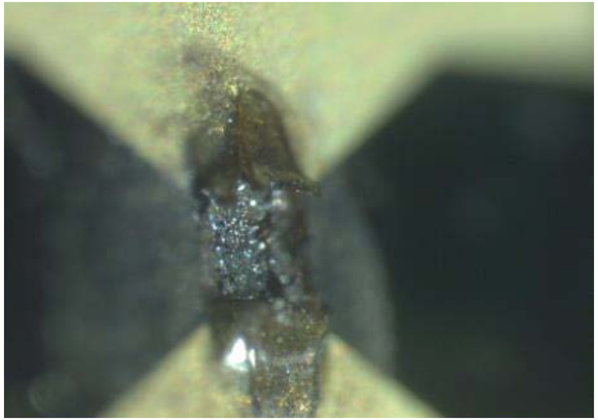
- The next important factor in the production:
  - Inexpensive technology/production step
  - Mature technology is preferable
  - Suitable for small parts thin layers
  - Clean, precise and reproducible
  - Not to far from TNO and
  - Not to many process steps at different company's/laboratories

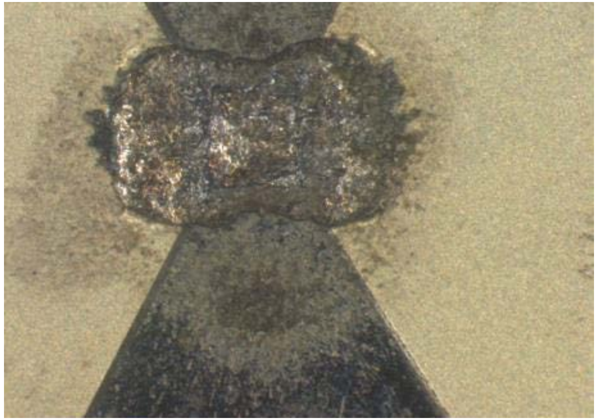
- Micro-chip technology is favourable:
  - Mature and cheap in large quantities (in production of about 50 wafers ~ $1 - $2 per die)
  - Clean (clean room)
  - Precise, reproducible and extremely suitable for small components
  - TU Delft chip production/development department close to TNO Rijswijk

EXAMPLE OF BRIDGE PRODUCTION AND TESTING



Bridges

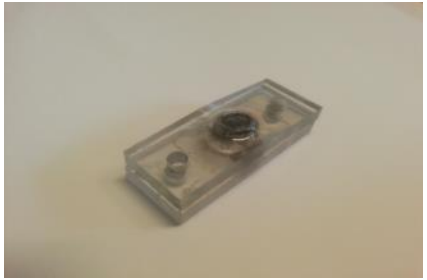




Exploded bridges

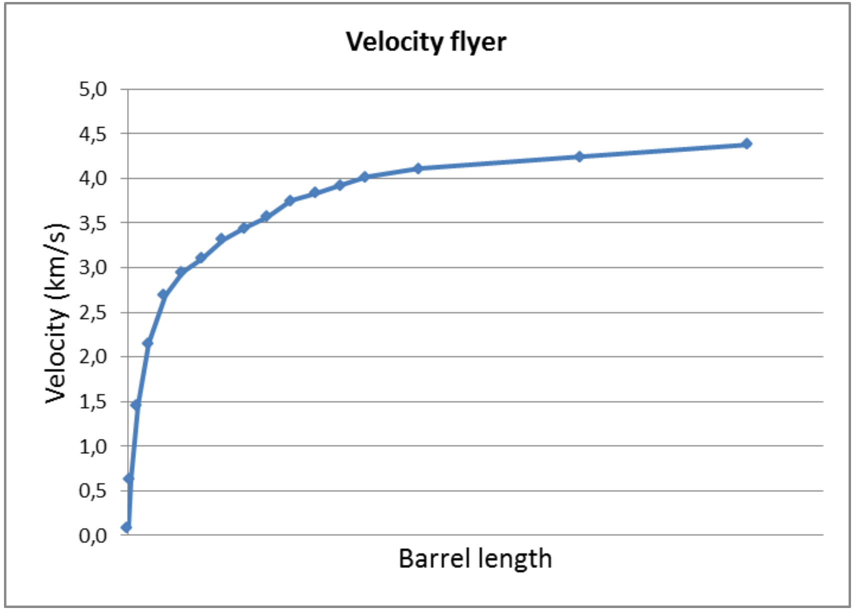
MICRO CHIP EFI DEVELOPMENT/TESTING

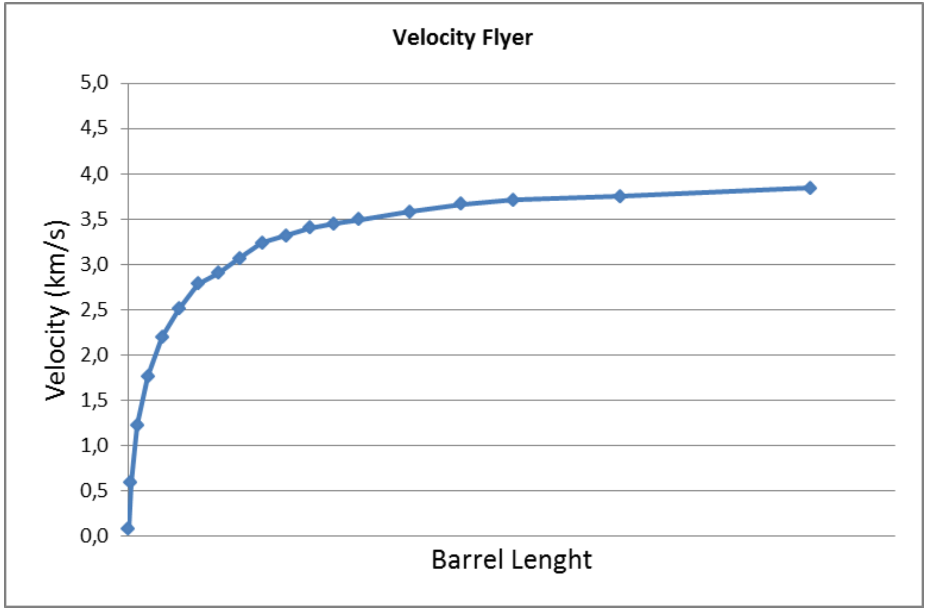
- Bridges design:
  - Variation of size, thickness of bridge
  - Variation of flyer thickness
  - Variation in voltage
- Measuring velocity and testing with HNS
- Many test series



Wafer	Bridge	Voltage			
		1350	1250	1150	1050
W6	N1	+	-	-	-
W6	N2		+	-	-
W6	N3	+	+	+	-
W6	N4	+	-	-	-
W6	N5	+	+	-	-
W3	N1	+	-	-	-
W3	N2		+	-	-
W3	N3	-	-	-	-
W3	N4	-	-	-	-
W4	N1	+	+	-	-
W4	N2	+	-	-	-
W4	N3	+	-	-	-
W4	N4	+	-	-	-
W4	N5	+	-	-	-

RESULTS TESTING





Velocity at 1200 V

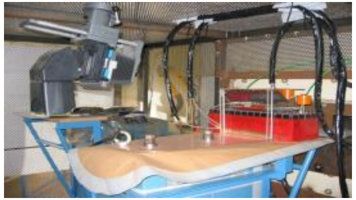
Velocity at 1000 V

TNO EXPERIENCE ON EXPLOSIVE FOIL INITIATORS

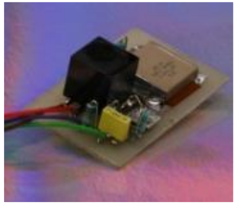
- Mega Ampere Pulsar for characterisation of explosives
  - ~Mega Ampere at 30,000 - 40,000 Volts
  - Flyers up to 25 mm, up to 1 mm thick

- Mini EFI system with
  - Solid state switch ~1400 Volts
  - Components of the shelf

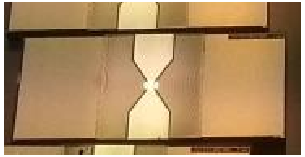
- Current McEFI development
  - ~1000 Volt
  - Chip technology → <1$
  - Ready in 2017



MAP

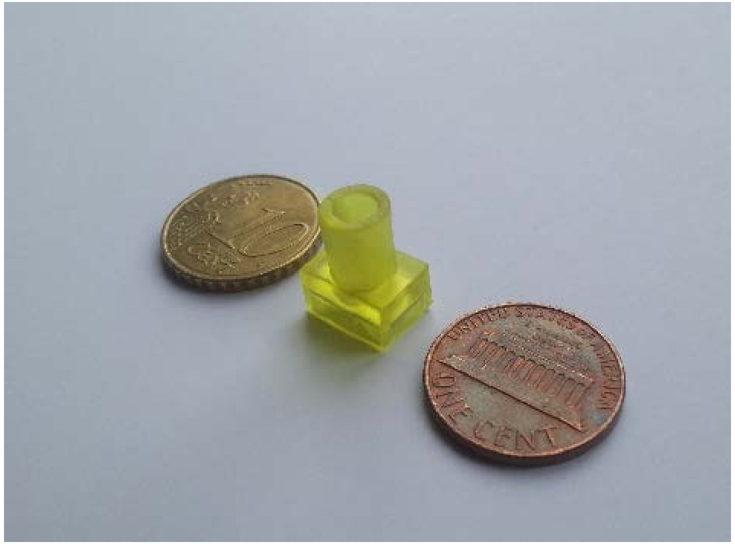


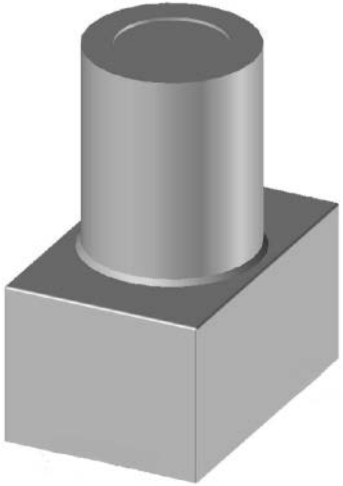
Mini EFI



McEFI

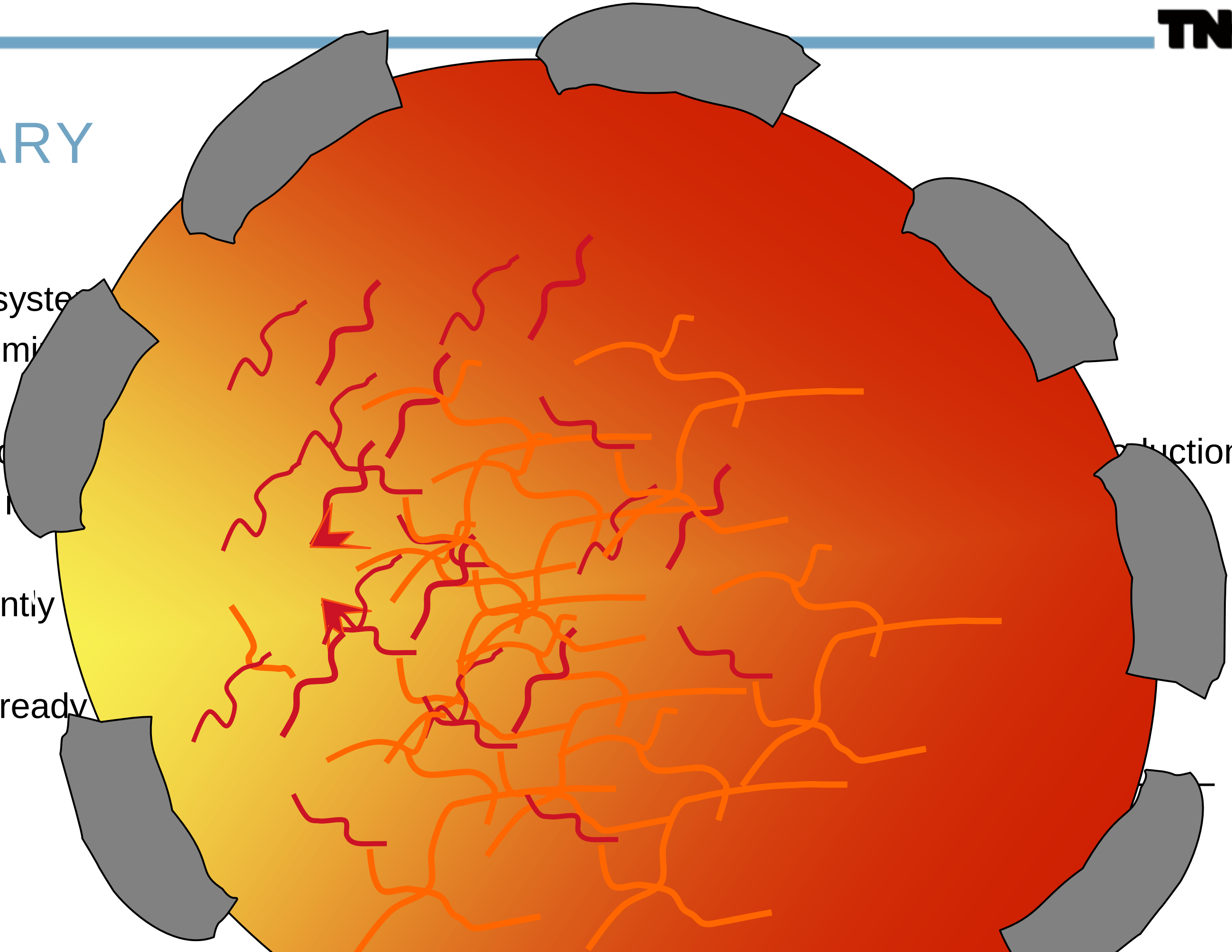
MCEFI PACKAGE

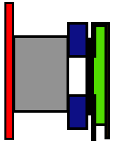




SUMMARY

- Current EFI syste
- Need for optimi
- Chip technolo ...uction method
- Optimization r
- TNO is currently
- 2017 McEFI ready





- Offices
- Agencies

THANK YOU FOR YOUR ATTENTION