
Software controlled
high speed photography
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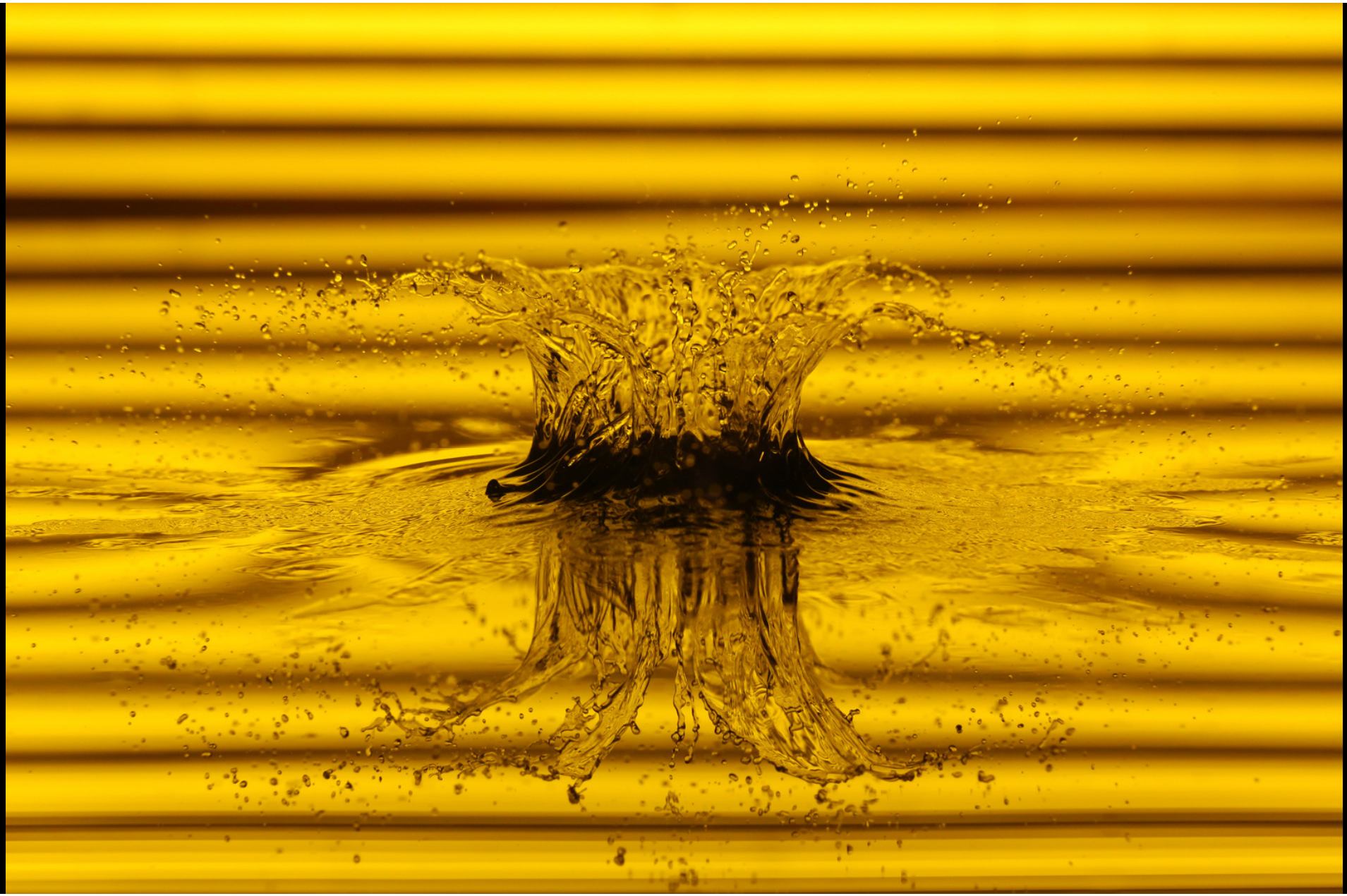
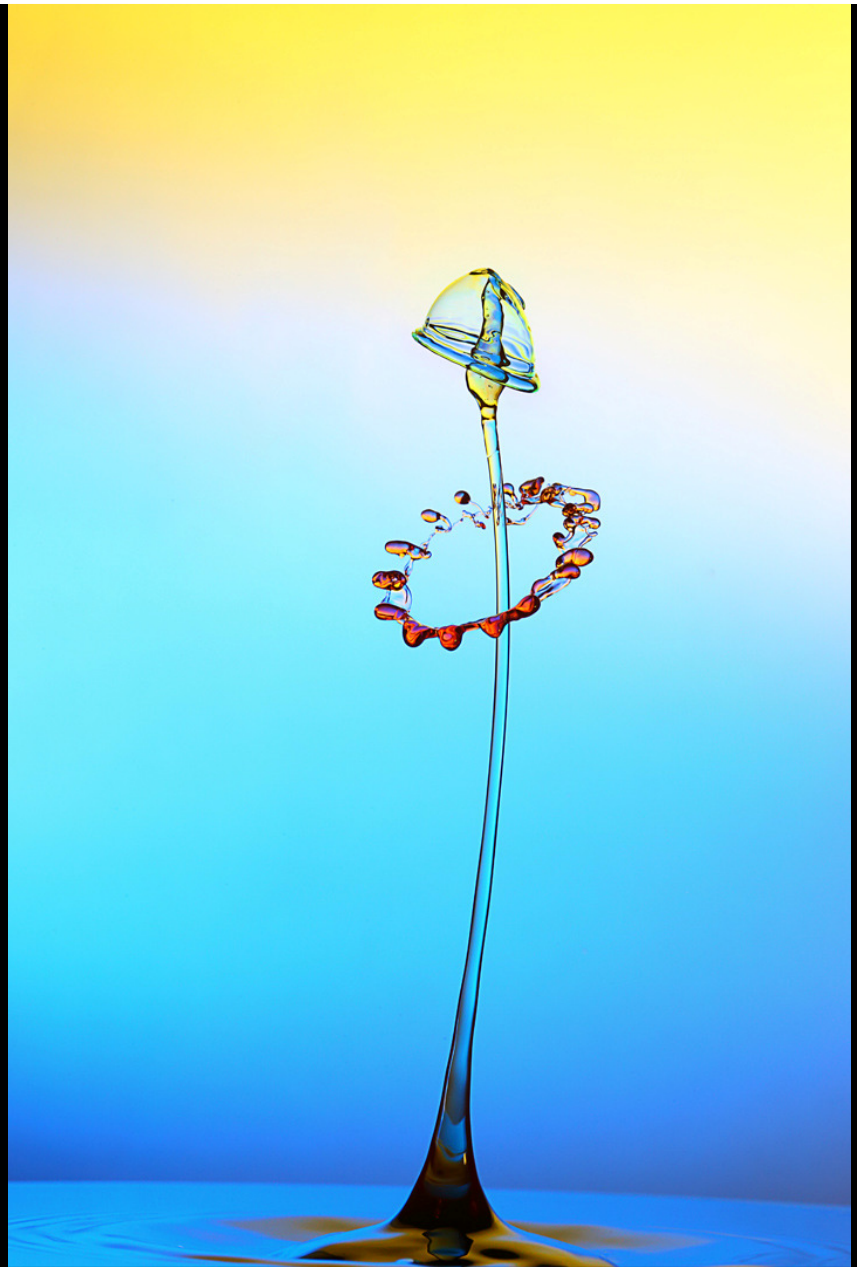
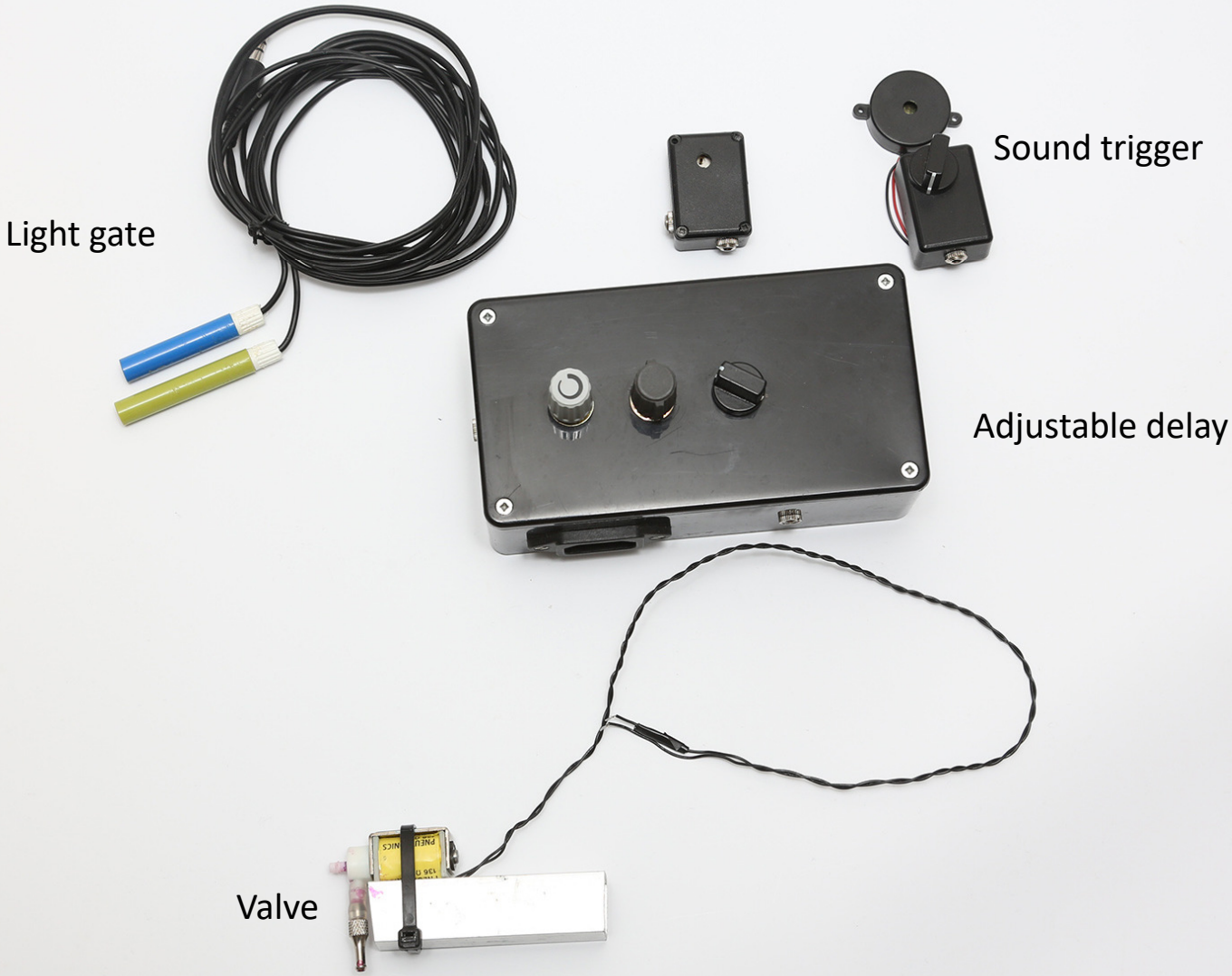




How to take such pictures?

- Exposure time as short as 40 µs
- Exposure time ≠ shutter time
- Dark scene
- Open shutter (for e.g. 1/10 sec)
- Synchronize events (drops, bullets, …)
- Fire flash(es)
- Exposure time = flash duration

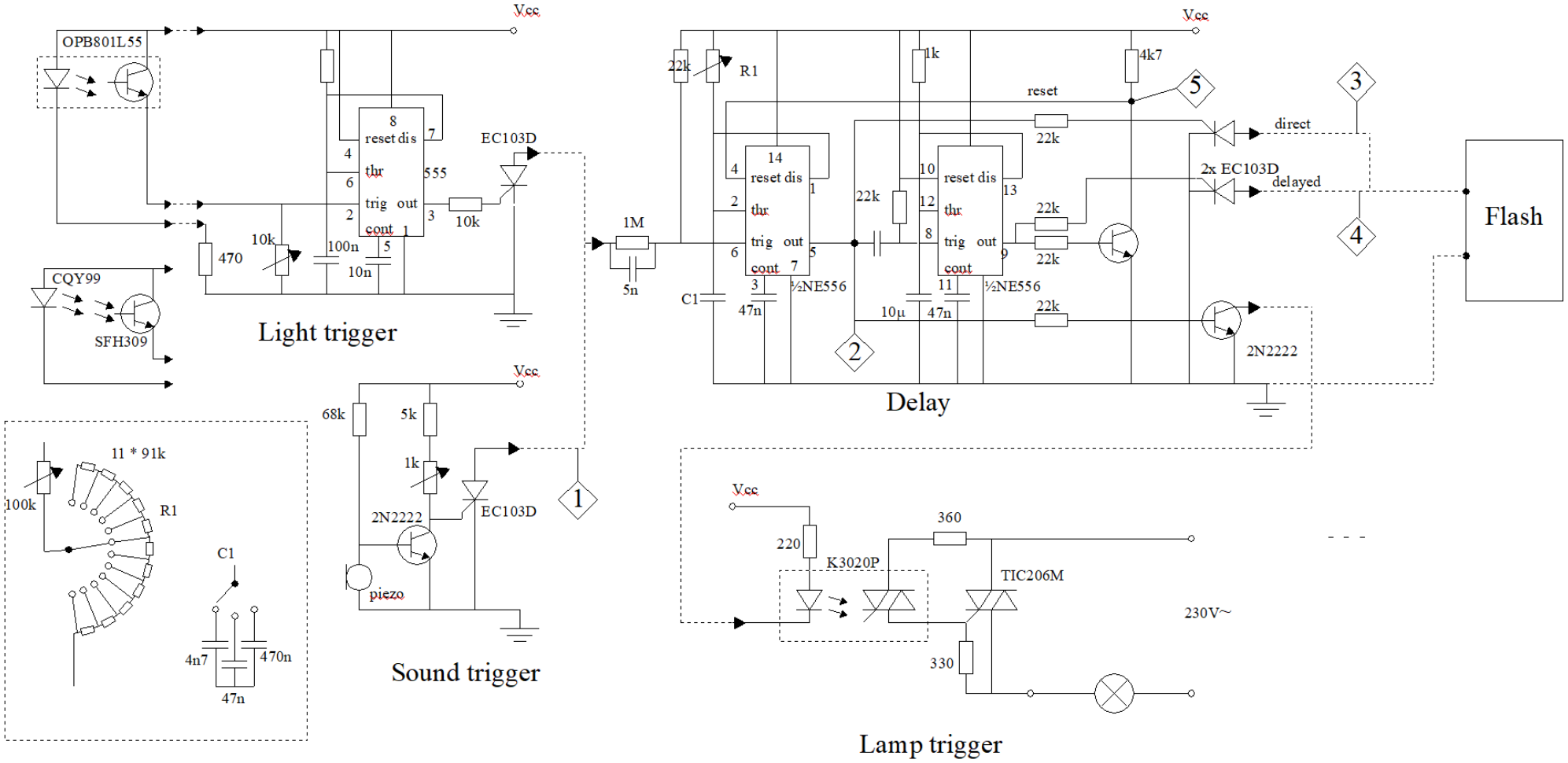
2005: Analog equipment



Analog equipment

Analog equipment

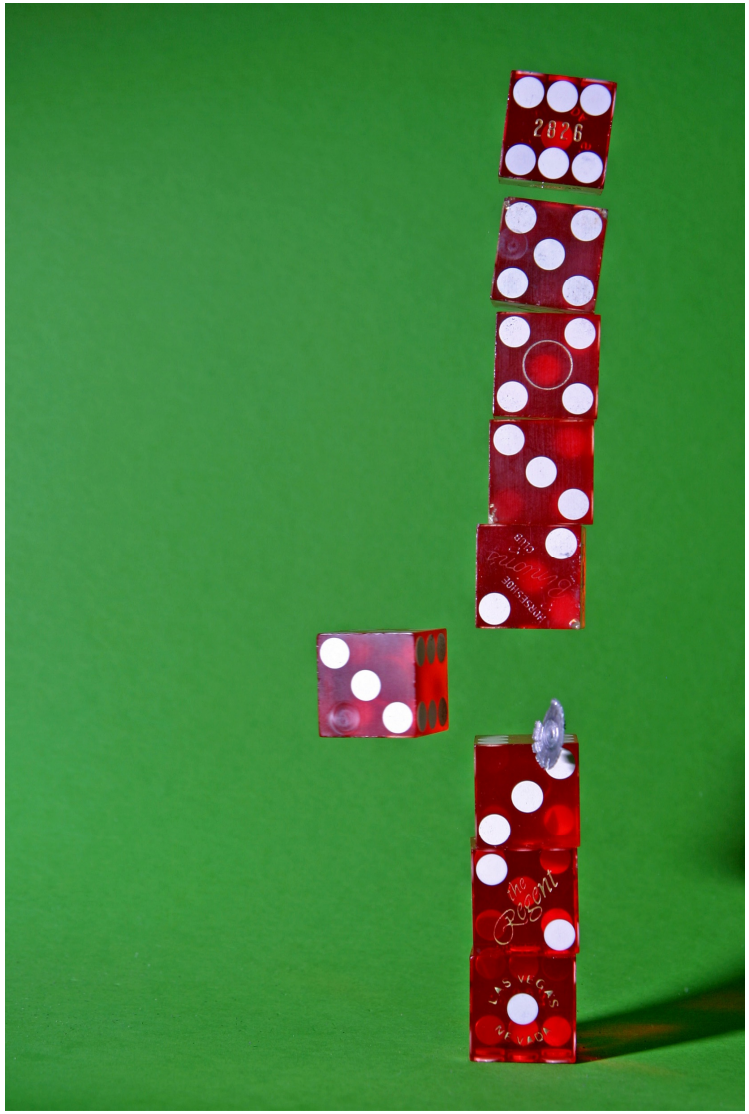
- Original analog timer, 500 µs .. 0.5 sec



Draw-backs of analog equipment

- Precision
- Reproducability
- Pellet iso bullet
- One input, one output event
  - Optical, audio input
  - Flash output
  - No shutter control, no valves
- Need event before input
  - Valve before gun

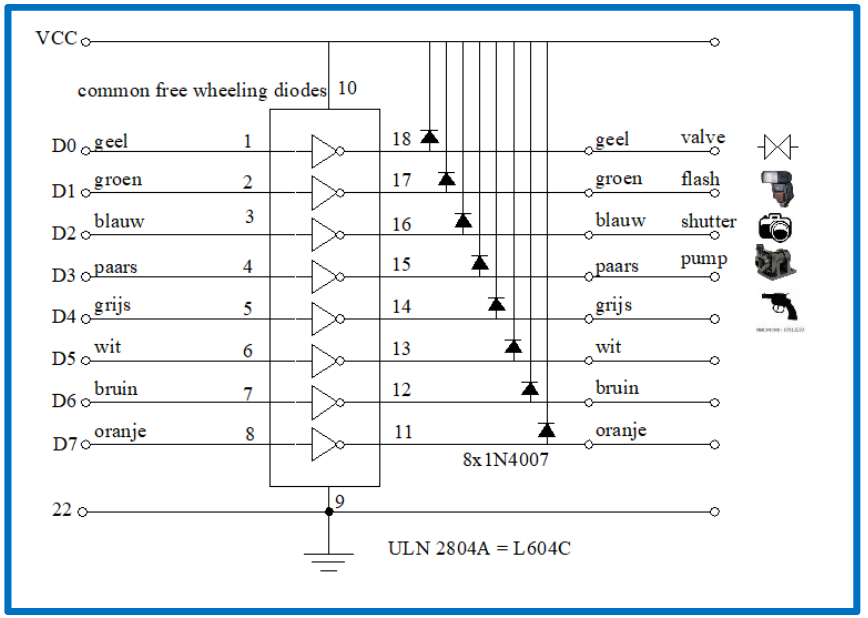
- Go digital!



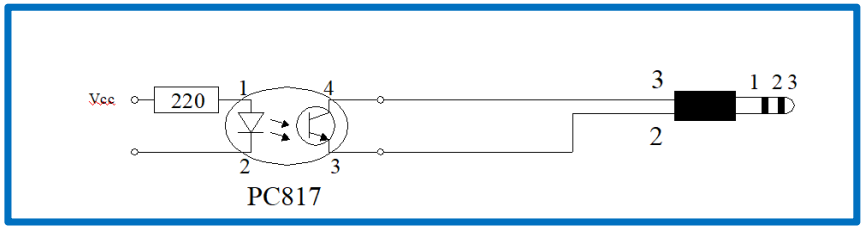
Digital equipment

- Laptop with parallel(!) port

- Open collector driver



- Opto coupler to insulate sensitive devices (like camera!)



- Wiring to
  - Flashes
  - Camera
  - Valves
  - Pump
  - Gun

Software

- Redhat 9, single user, no network
  - Minimal latency
- Running as root (sbit) to get access to parallel port
- Control parallel port through MMIO: 1 µs resolution
  - **void outb(unsigned char *value*, unsigned short int *port*);** // port = 0x378
- Language to specify events and actions
- Implement through Front (*http://front.sourceforge.net*)

Software

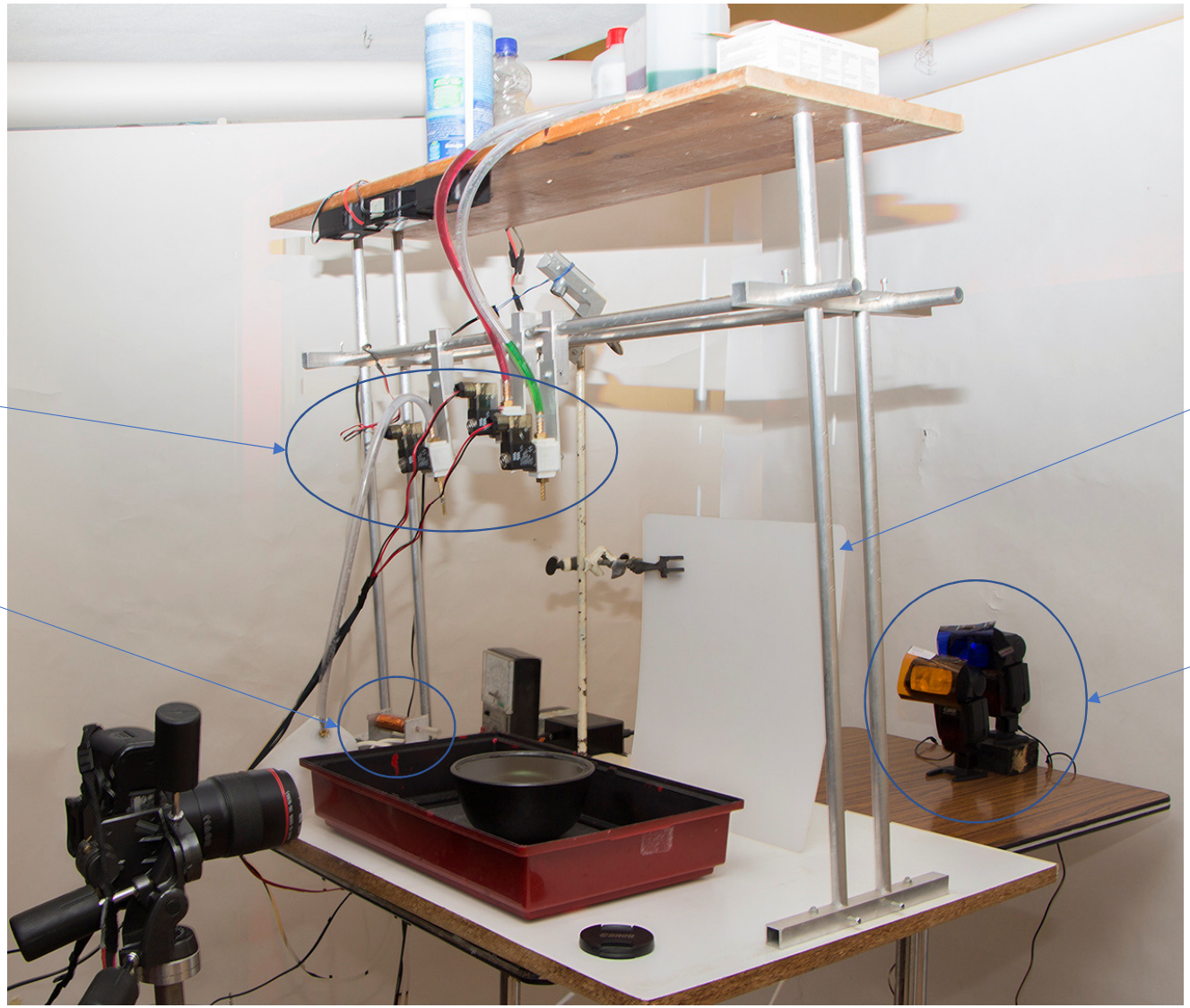
Drop control code

```
port valve
port flash
port shutter
port pump
port gun

event pump    action pump      duration 700 ms  start

event drop1   action valve     duration 55 ms   100 ms after pump

event drop2   action valve     duration 45 ms   134 ms after drop1

event camera  action shutter   duration 500 ms  350 ms after drop1

event light   action flash     duration 10 ms   150 ms after camera

event shoot   action gun       duration 7 ms    124 ms after camera
```

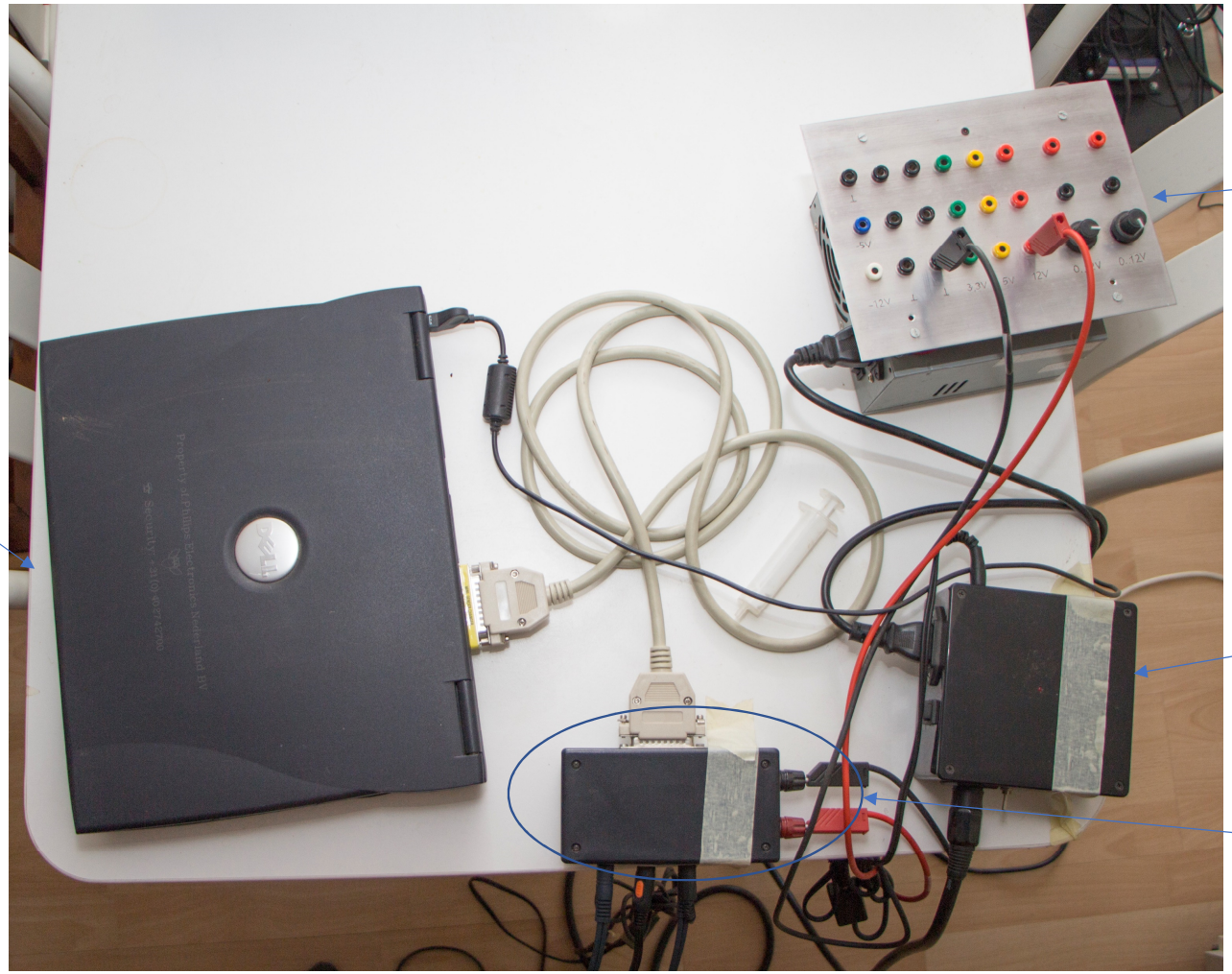
Drop grammar in Front

```
events ::= ports  : { Port  }
           events : { Event } ;

Port  ::= "port" SP id : DEFINING Ident  NAMESPACE PORT NL
          value : Int = 0  ;

Event ::= "event"  SP id : DEFINING Ident NAMESPACE EVENT SP
          "action" SP
          port     : APPLIED Port NAME Ident SP
          duration : [ "duration" SP Time SP ]
          < StartEvent ::= "start"
          | InputEvent ::= "input"
          | TimedEvent ::= t : Time SP "after" SP pred : APPLIED Event NAME Ident
          > NL
          ticks  : clock_ticks = 0    %% time at which the event should happen
          action : Action = NULL      %% Action to be executed
          arg    : Int = 0            %% Argument to action
          passed : clock_ticks = -1   %% time at which the event happened
          ;

Time ::=  t : Int SP
          unit : TimeUnit  ;

TimeUnit ::= < u_time ::= "us"
             | m_time ::= "ms"
             | s_time ::= "s"
             > ;
```

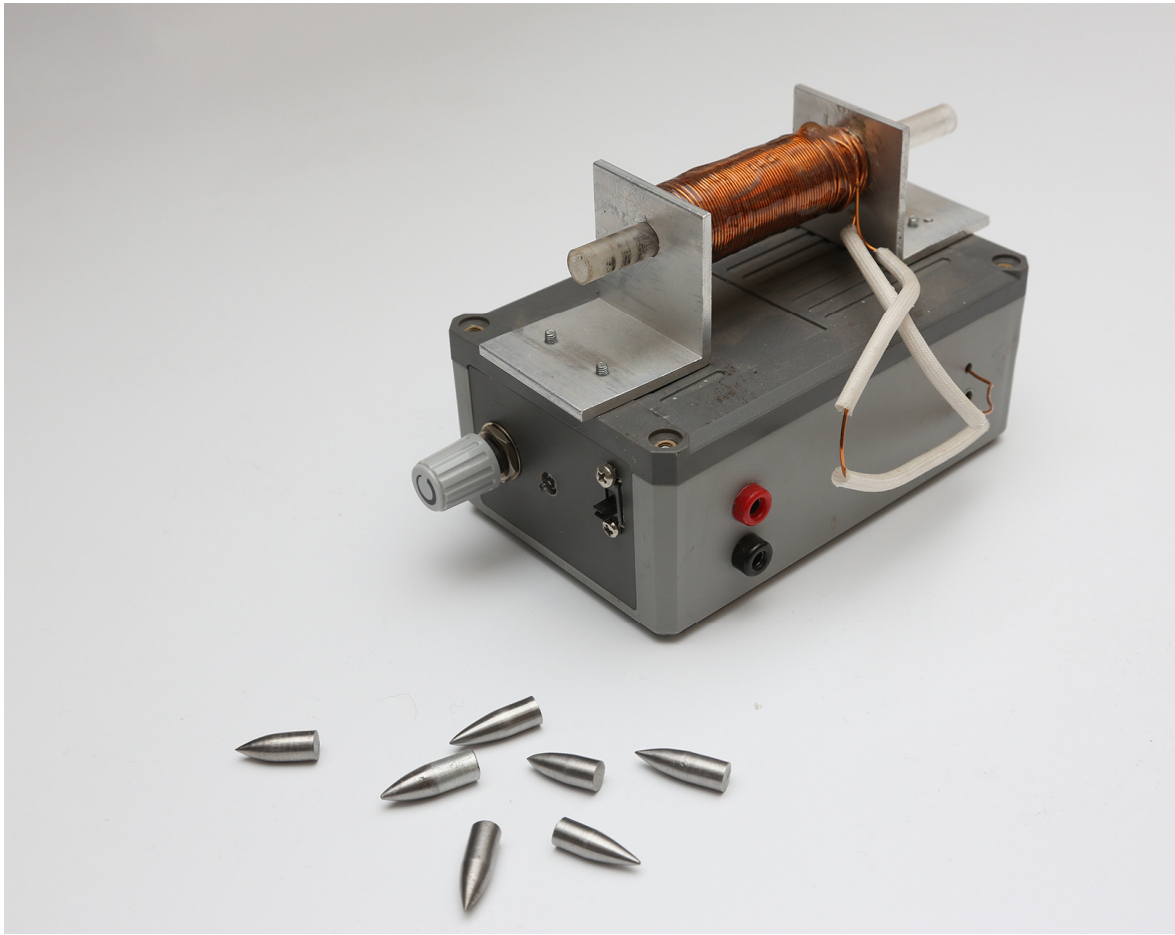
Setup



Setup



Coil gun



- Charge capacitor (~1mF) to 200-300V
- Dozens of Joules (½ CV^2 : lethal!)
- Short-circuit over big coil
- Strong induction peak
- Pull steel bullet through coil
- Timing very precise
- Control bullet speed by pulse duration

- How to switch 300V and 100A within microseconds?
- IGBT (used in induction cooktop)

International
IOR Rectifier

PD -95185

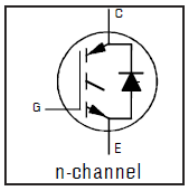
IRG4PC50UDPbF

INSULATED GATE BIPOLAR TRANSISTOR WITH ULTRAFAST SOFT RECOVERY DIODE

UltraFast CoPack IGBT

Features

- UltraFast: Optimized for high operating frequencies 8-40 kHz in hard switching, >200 kHz in resonant mode
- Generation 4 IGBT design provides tighter parameter distribution and higher efficiency than Generation 3
- IGBT co-packaged with HEXFRED™ ultrafast, ultra-soft-recovery anti-parallel diodes for use in bridge configurations
- Industry standard TO-247AC package
- Lead-Free



n-channel

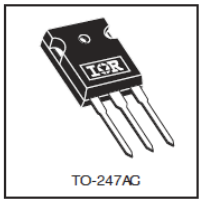
V_{CES} = 600V

$V_{CE(on)\ typ.}$ = 1.65V

@V_{GE} = 15V, I_C = 27A

Benefits

- Generation 4 IGBT's offer highest efficiencies available
- IGBT's optimized for specific application conditions
- HEXFRED diodes optimized for performance with IGBT's. Minimized recovery characteristics require less/no snubbing
- Designed to be a "drop-in" replacement for equivalent industry-standard Generation 3 IR IGBT's


TO-247AC

Absolute Maximum Ratings

	Parameter	Max.	Units
V_{CES}	Collector-to-Emitter Voltage	600	V
I_C @ T_C = 25°C	Continuous Collector Current	55	A
I_C @ T_C = 100°C	Continuous Collector Current	27	
I_{CM}	Pulsed Collector Current ①	220	
I_{LM}	Clamped Inductive Load Current ②	220	
I_F @ T_C = 100°C	Diode Continuous Forward Current	25	
I_{FM}	Diode Maximum Forward Current	220	
V_{GE}	Gate-to-Emitter Voltage	± 20	V
P_D @ T_C = 25°C	Maximum Power Dissipation	200	W
P_D @ T_C = 100°C	Maximum Power Dissipation	78	
T_J T_{STG}	Operating Junction and Storage Temperature Range	-55 to +150	°C
	Soldering Temperature, for 10 sec.	300 (0.063 in. (1.6mm) from case)	
	Mounting Torque, 6-32 or M3 Screw.	10 lbf•in (1.1 N•m)	

Thermal Resistance

	Parameter	Min.	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case - IGBT	------	------	0.64	°C/W
$R_{\theta JC}$	Junction-to-Case - Diode	------	------	0.83	
$R_{\theta CS}$	Case-to-Sink, flat, greased surface	------	0.24	------	
$R_{\theta JA}$	Junction-to-Ambient, typical socket mount	-----	-----	40	
Wt	Weight	------	6 (0.21)	------	g (oz)

IGBT

Absolute Maximum Ratings

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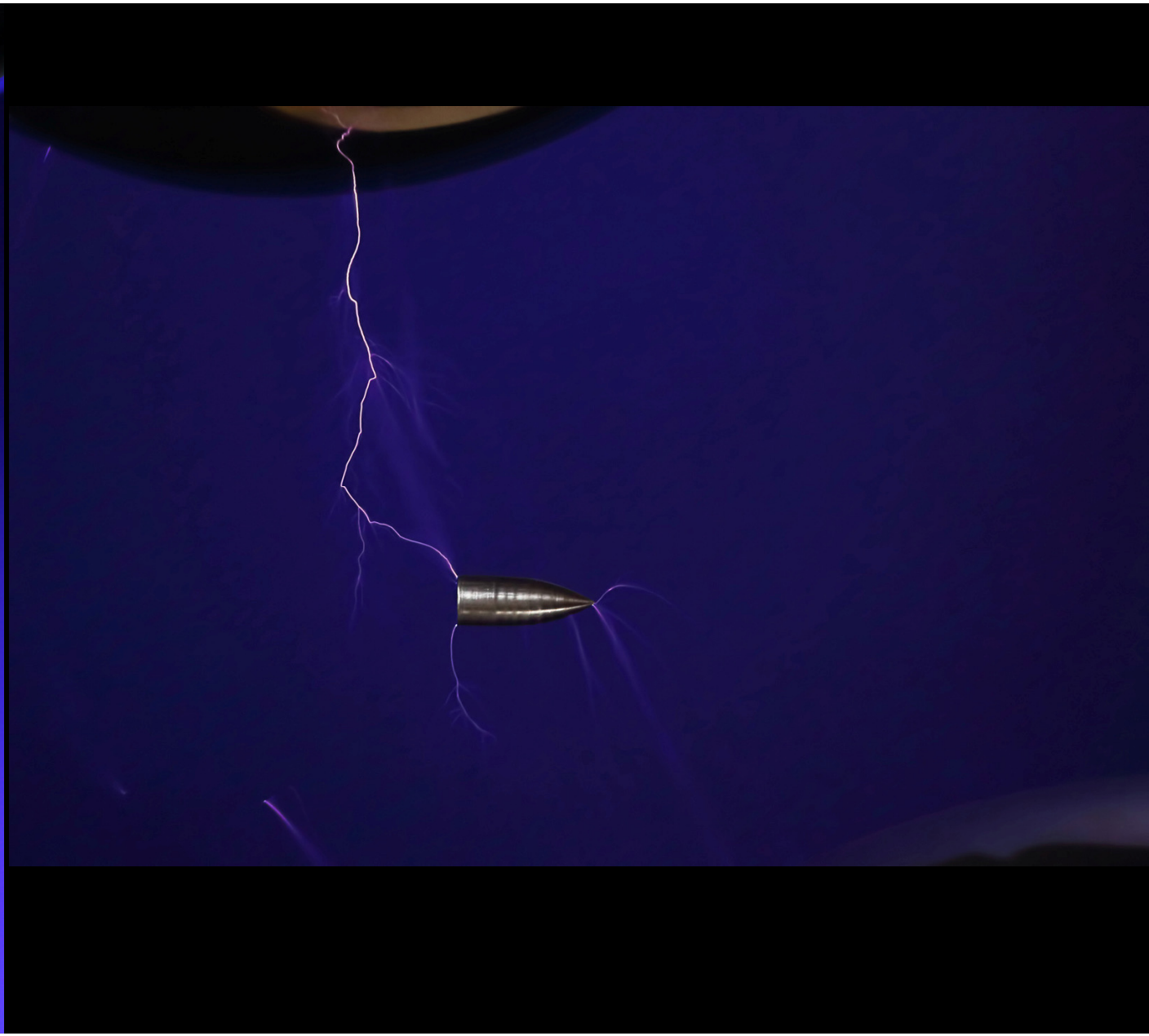
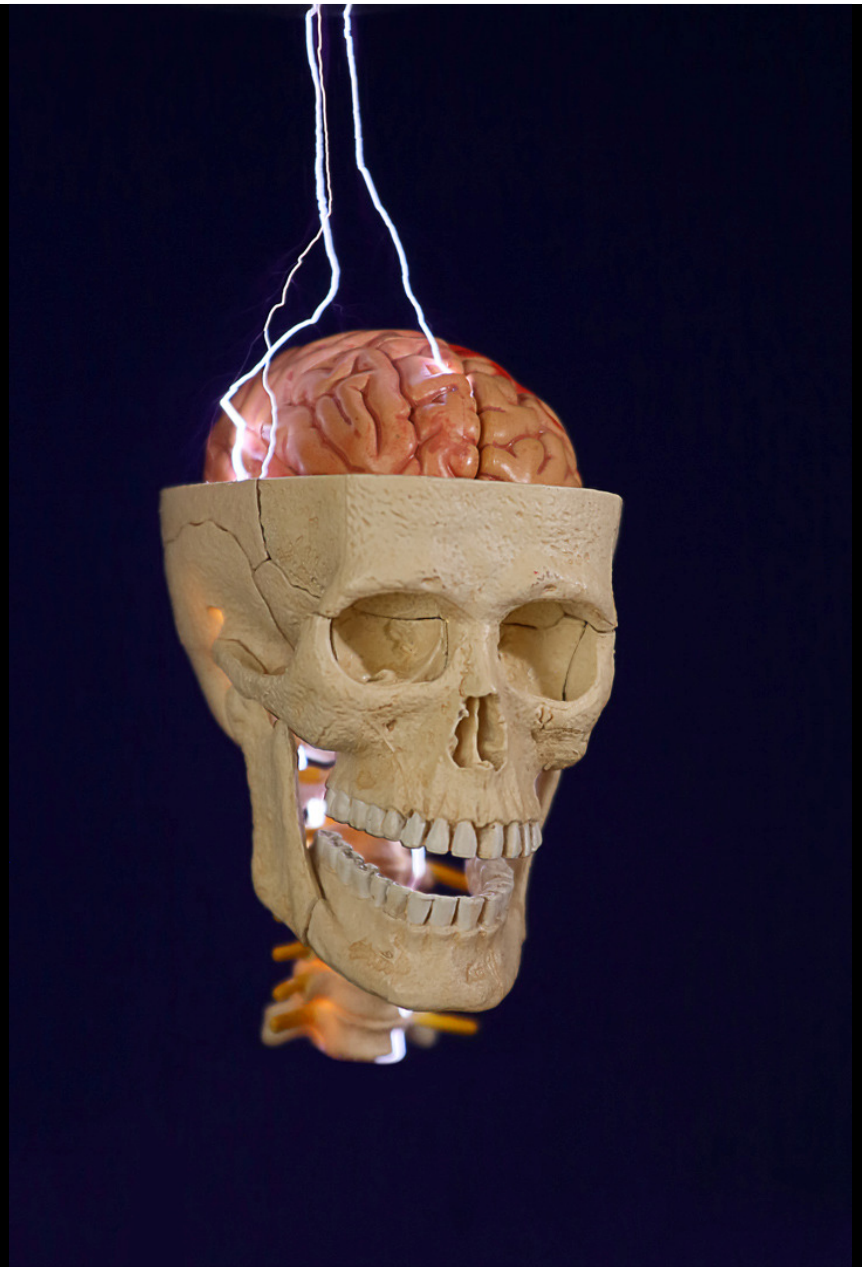
Switching Characteristics @ T_J = 25°C (unless otherwise specified)

	Parameter	Min.	Typ.	Max.	Units	Conditions
Q_g	Total Gate Charge (turn-on)	----	180	270	nC	I_C = 27A
Q_{ge}	Gate - Emitter Charge (turn-on)	----	25	38		V_{CC} = 400V See Fig. 8
Q_{gc}	Gate - Collector Charge (turn-on)	----	61	90		V_{GE} = 15V
$t_{d(on)}$	Turn-On Delay Time	----	32	----	ns	
t_r	Rise Time	----	20	----		T_J = 25°C
$t_{d(off)}$	Turn-Off Delay Time	----	170	260		I_C = 27A, V_{CC} = 480V
t_f	Fall Time	----	88	130		V_{GE} = 15V, R_G = 5.0Ω

High voltage


Made in France





Thank you!