High Voltage (HV) Testing For Today's EVs

Review of Technology and Requirements

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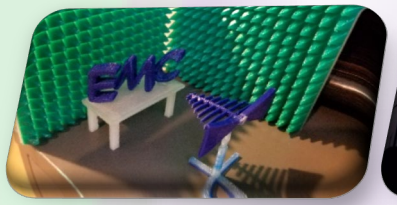
ABSOLUTE EMC



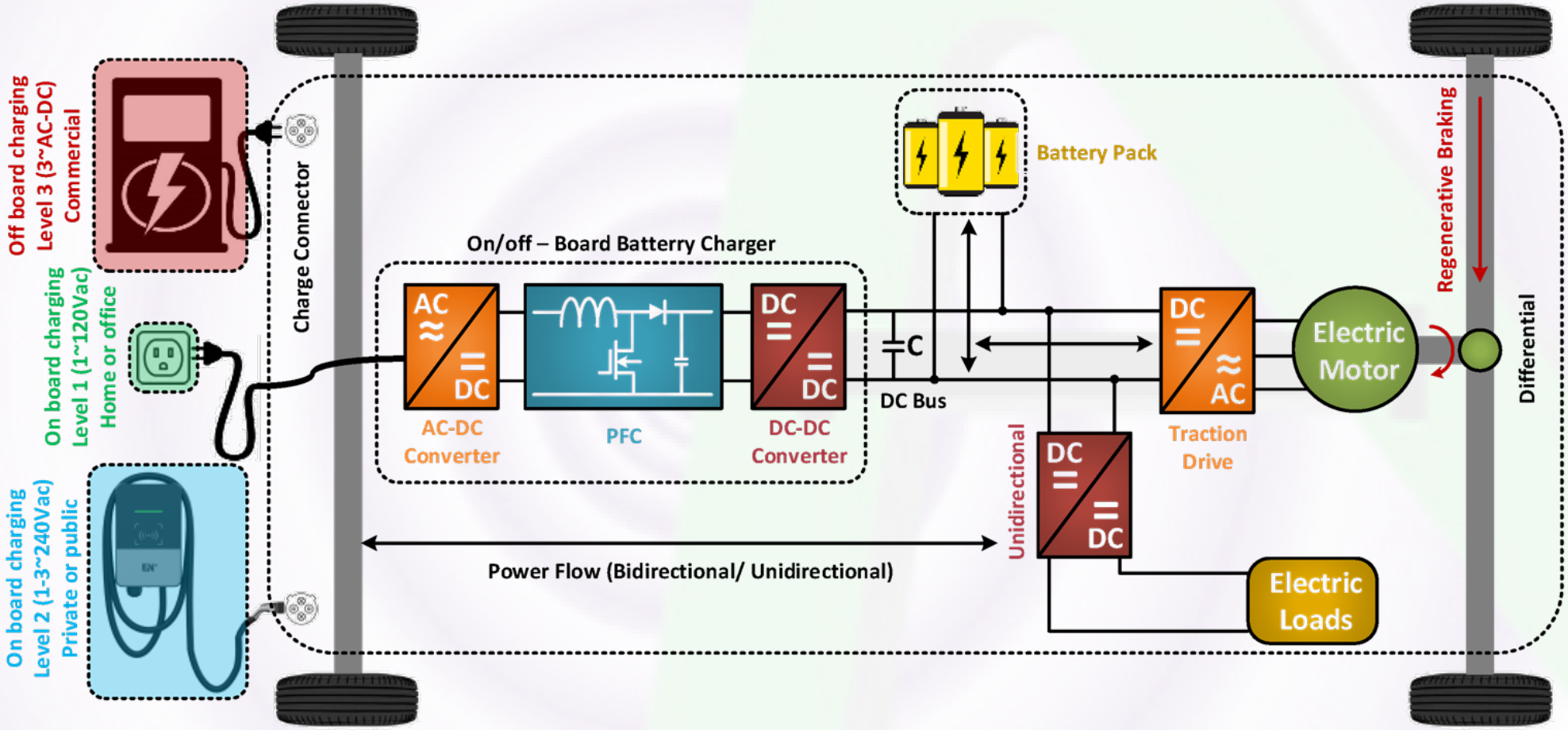
Contents

- Brief History of Test Standards and Development
- Market Awareness
- HV Testing with HV Supply

- Testing Beyond the HV Supply
  - How Ripple is coupled
  - Benefits and negatives

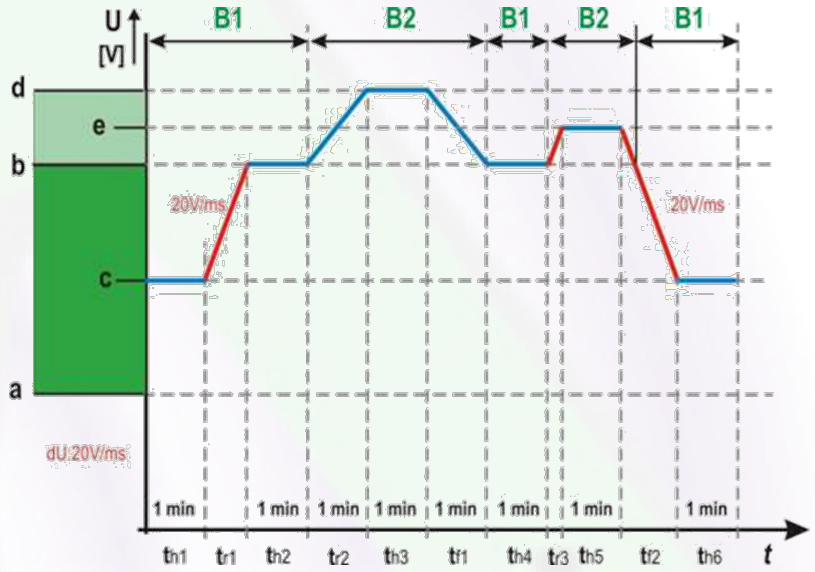
- Extended use for LV testing

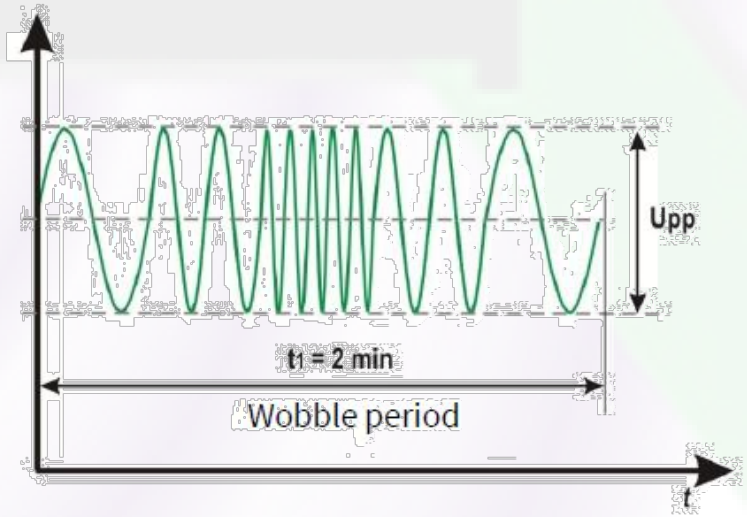
Complexity Made Simple



Standards

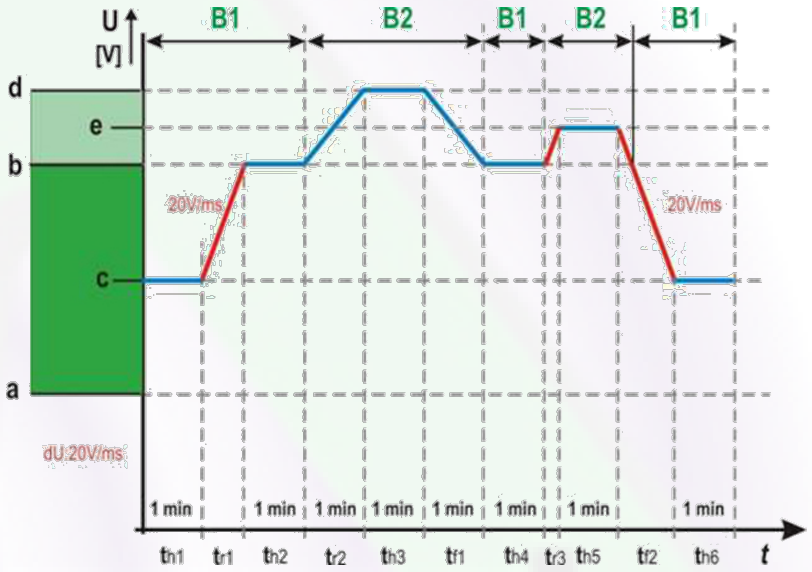
- LV123 Original HV EV standard
  - Created in 2009
  - Updated 2014
  - Updated Recently
- 2 basic test setups
  1. Voltage variation
     - “Not Fast” performed by programable PS
  2. Voltage Ripple
     - Fast above the capabilities of the PS
     - Ripple was first introduced at Hz-20 kHz
     - Current standards increased to 200 kHz
     - … 200 kHz and some going up to 300 kHz

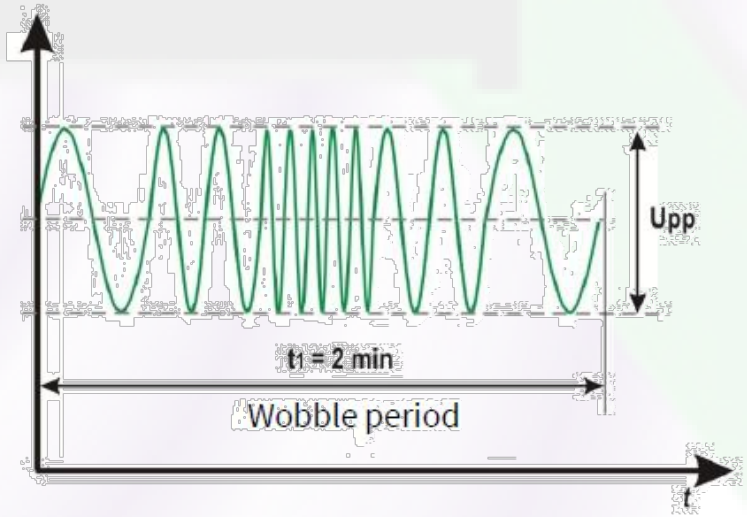




Current Standards

- ISO 21498
- ISO 7637-4
- VW 80300
- MBN 1123
- Nissan 28400N
- PSA B21 7112
- Stellantis CS.00245
- FORD FMC 1280
- ……





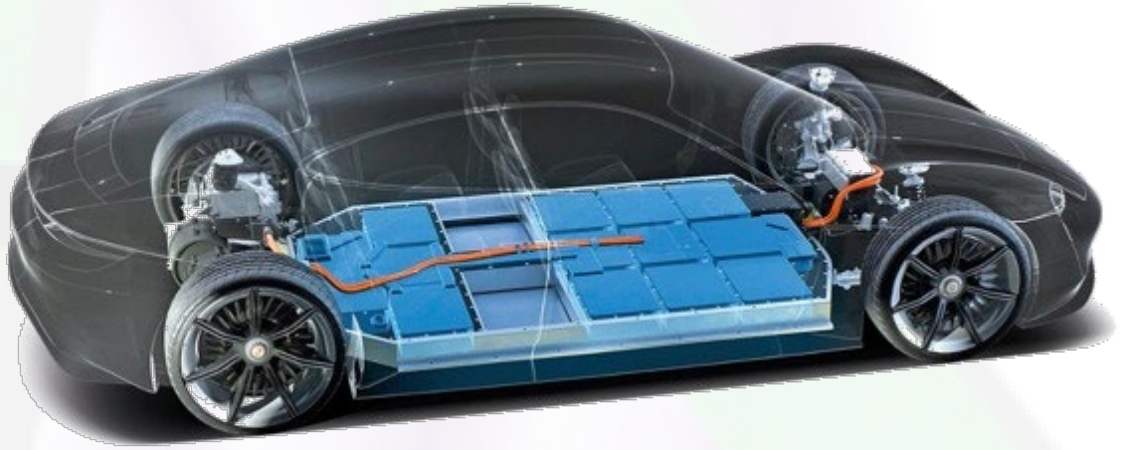
How to Size the System Voltage / Current

Market Trends

- DUT's Voltage and Current are Known?
- Where is the future going
- Today, systems 400V↗600V↗800V
- Proposed for 1200V↗ 1300V↗

  - Higher Voltage = more available power
  - Higher Voltage = less current
  - High Voltage = more safety concerns

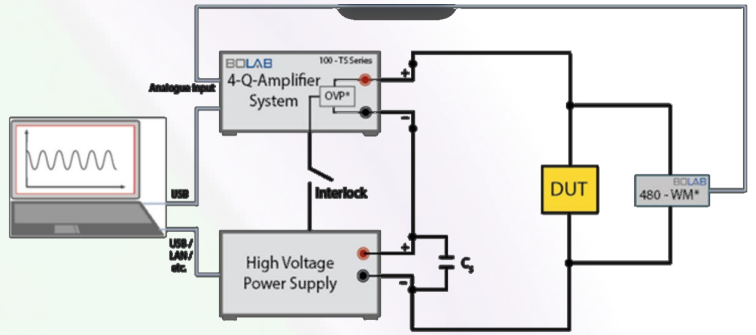
- How much current will a DUT need??



HV PS Features

- 500 V / 1000 V / 1500 V / 2000 V
- Building Blocks: 18 kW / 27 kW / 36 kW / 54 kW
- Modularly scalable up to 44 power supply modules,
  - serial / parallel / combined
  - Even modules of different power scalable
- Regenerative
- Voltage dynamics:
  - Voltage rise time 10% - 90%: <200 µs
  - Voltage fall time 90% - 10%: <200 µs

Power Supply Speed



- VW 80300 INCLUDING LOAD DUMP EXECUTION

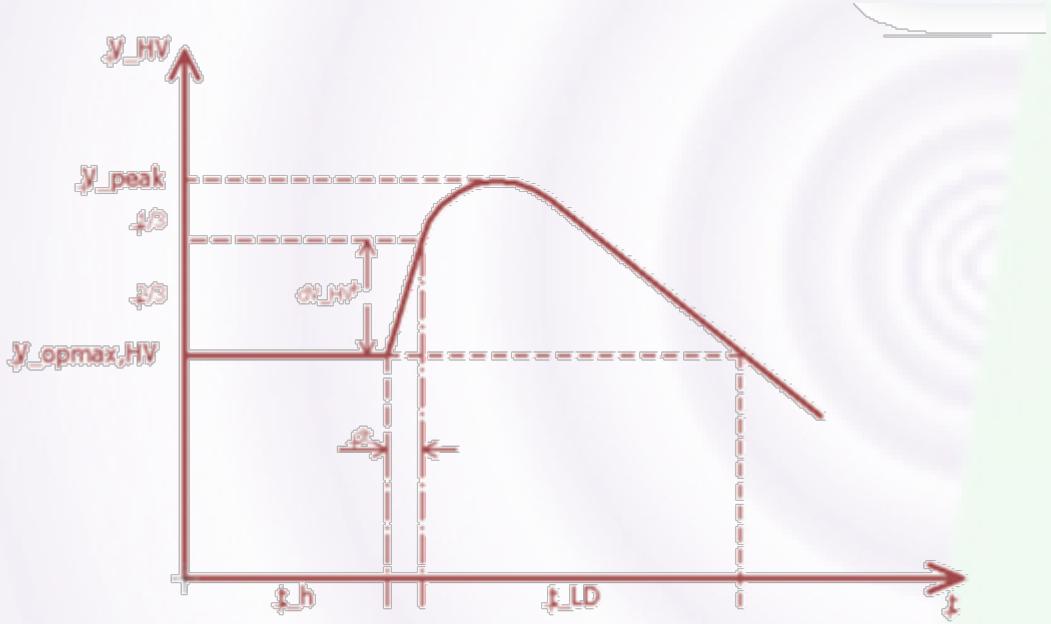


Figure 2: Voltage Curve to HV voltage limit

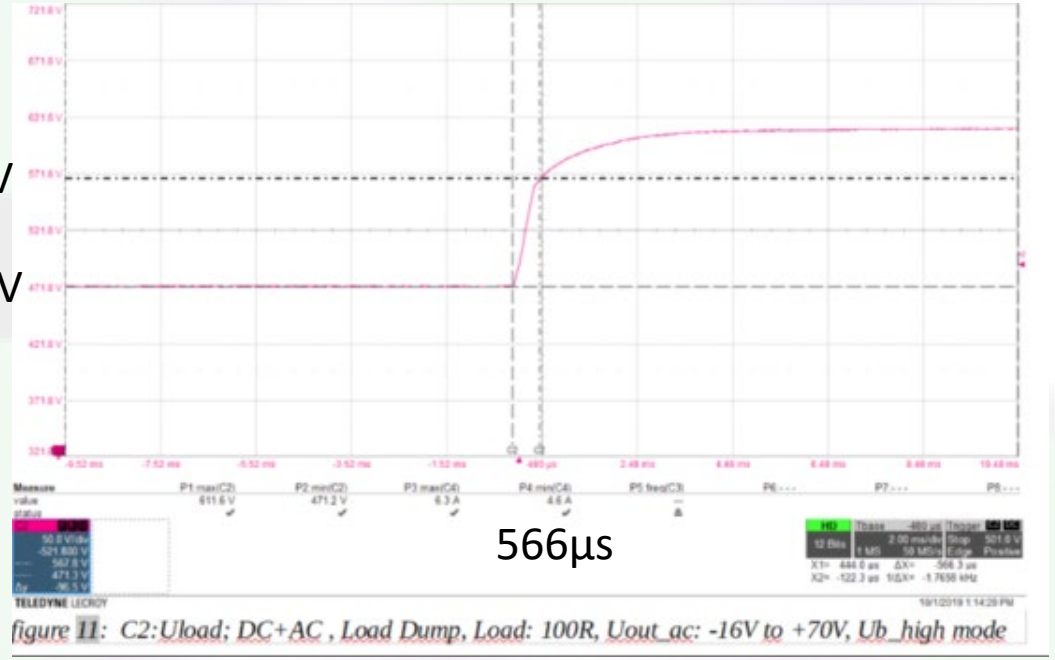
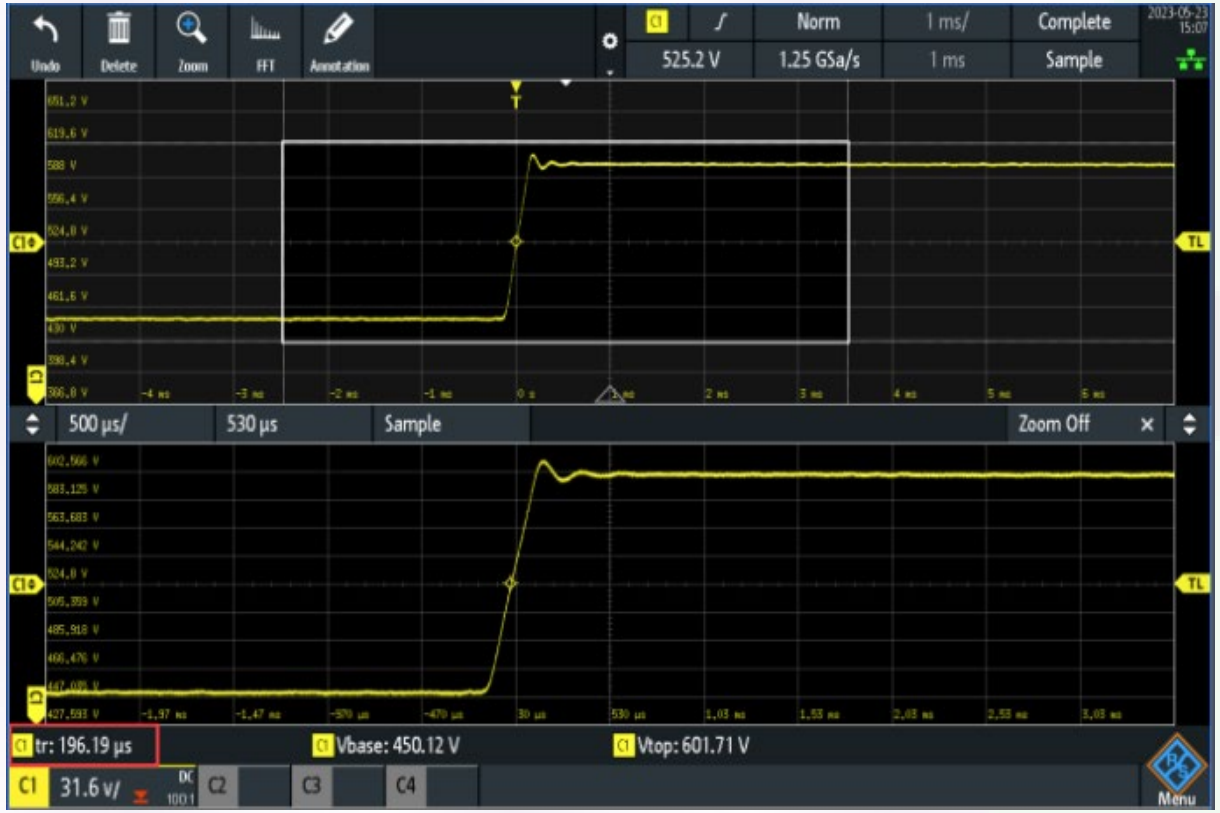


figure 11: C2:Uload; DC+AC , Load Dump, Load: 100R, Uout_ac: -16V to +70V, Ub_high mode

1ms PS are too slow

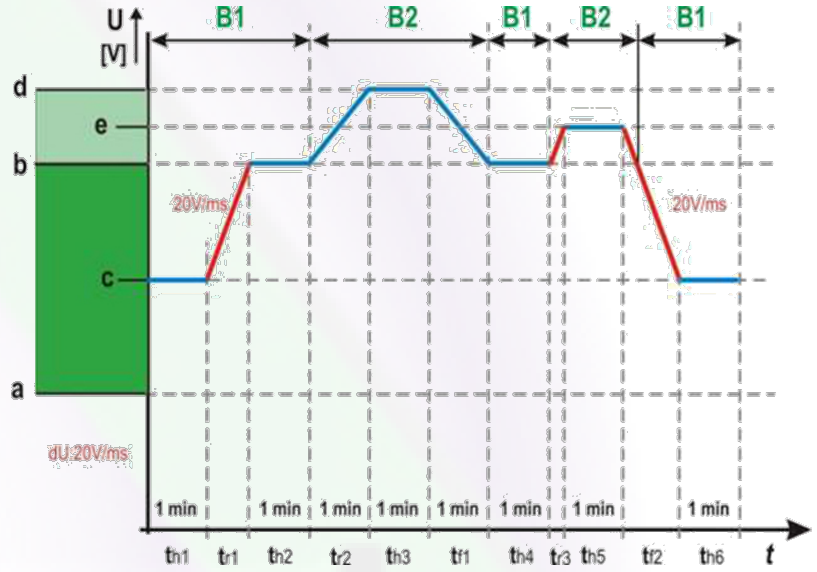
HV PS Features

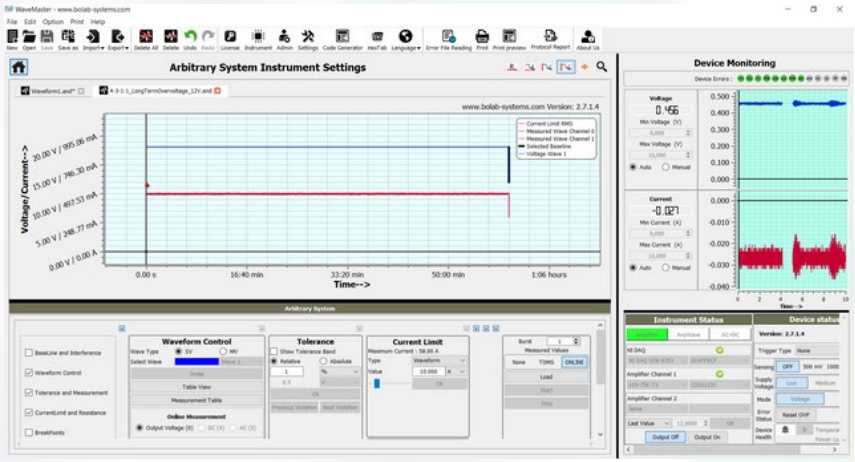
- Voltage dynamics:
  - Voltage rise time 10% - 90%: <250 µs
  - Voltage fall time 90% - 10%: <250 µs



Power Supply Control

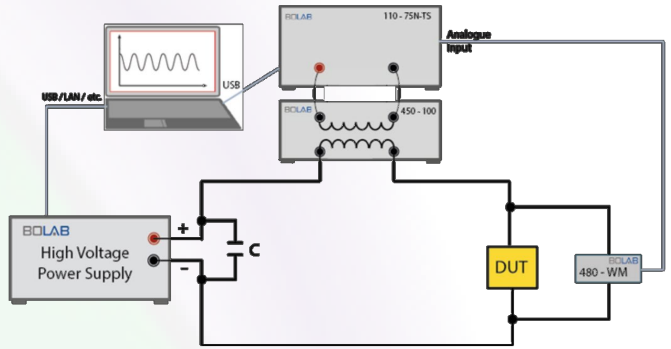
- Need Good Software and Hardware Control
- Some tests can run hours/days
- Standard ARB (Arbitrary Waveform Generator)
  - G-Samples run out of points in long tests
  - Requires the use of a system with an endless buffering system
    - No limitations
- Easy Software Interface, pre-programmed and user Generated tests

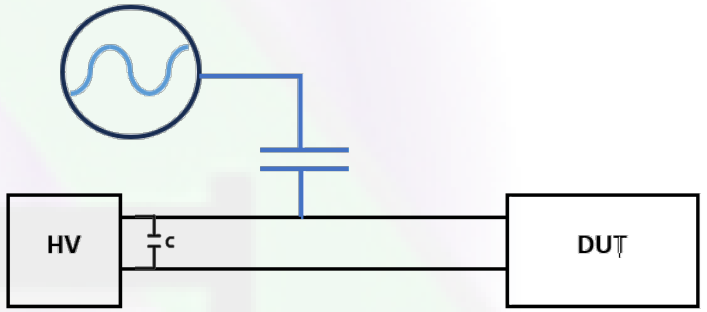


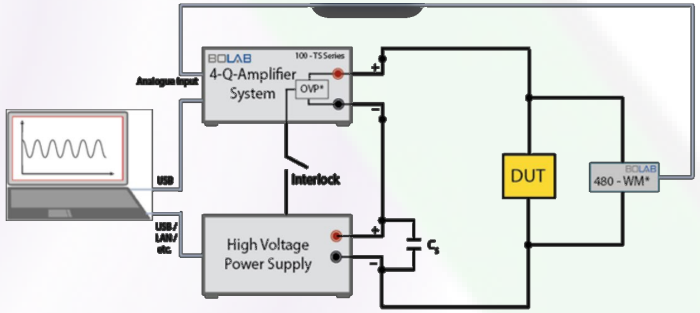


Tests Beyond the PS

- When test speed/frequency is faster
- Ripple tests
  - 20kHz, 150kHz, 200kHz, 300kHz, ….
- An amplifier is required
  - Bypass CAP needed
- Needs to be coupled to HV PS
  1. Transformer
  2. Capacitor
  3. 4 Quadrant Amplifier In-series



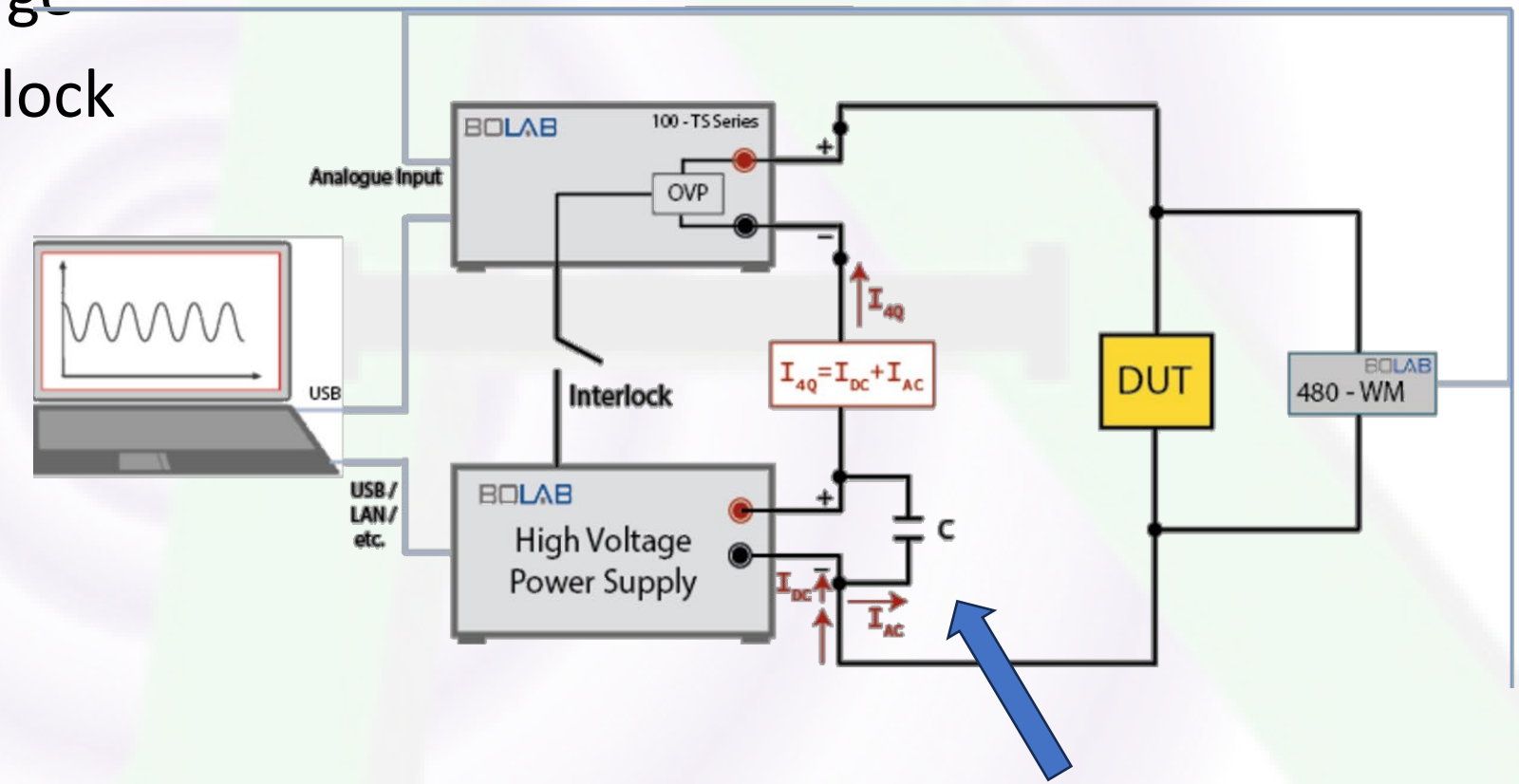




*WM: Measurement Unit for Closed Loop Regulation
*OVP: Over Voltage Protection

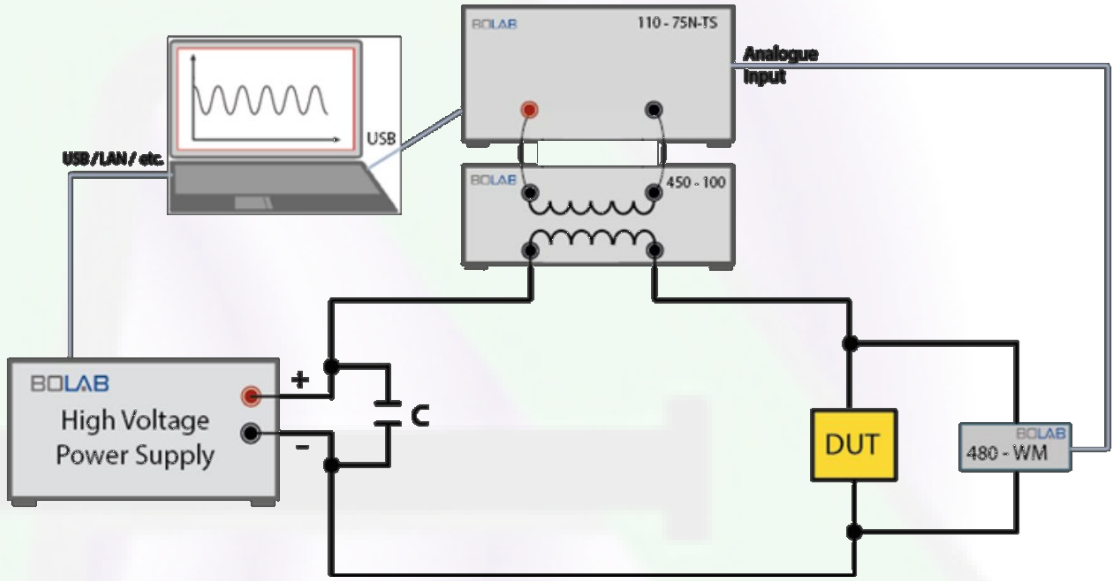
CAPACITOR BANK

- Active/passive discharge
- internal, external Interlock
- 10 mF
- Protections
  - Temperature
  - Over Current
  - Over Voltage

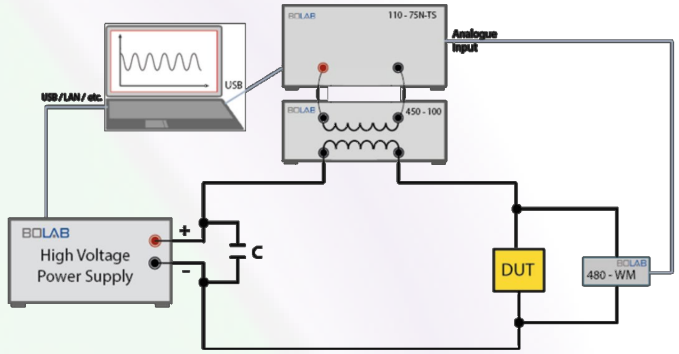


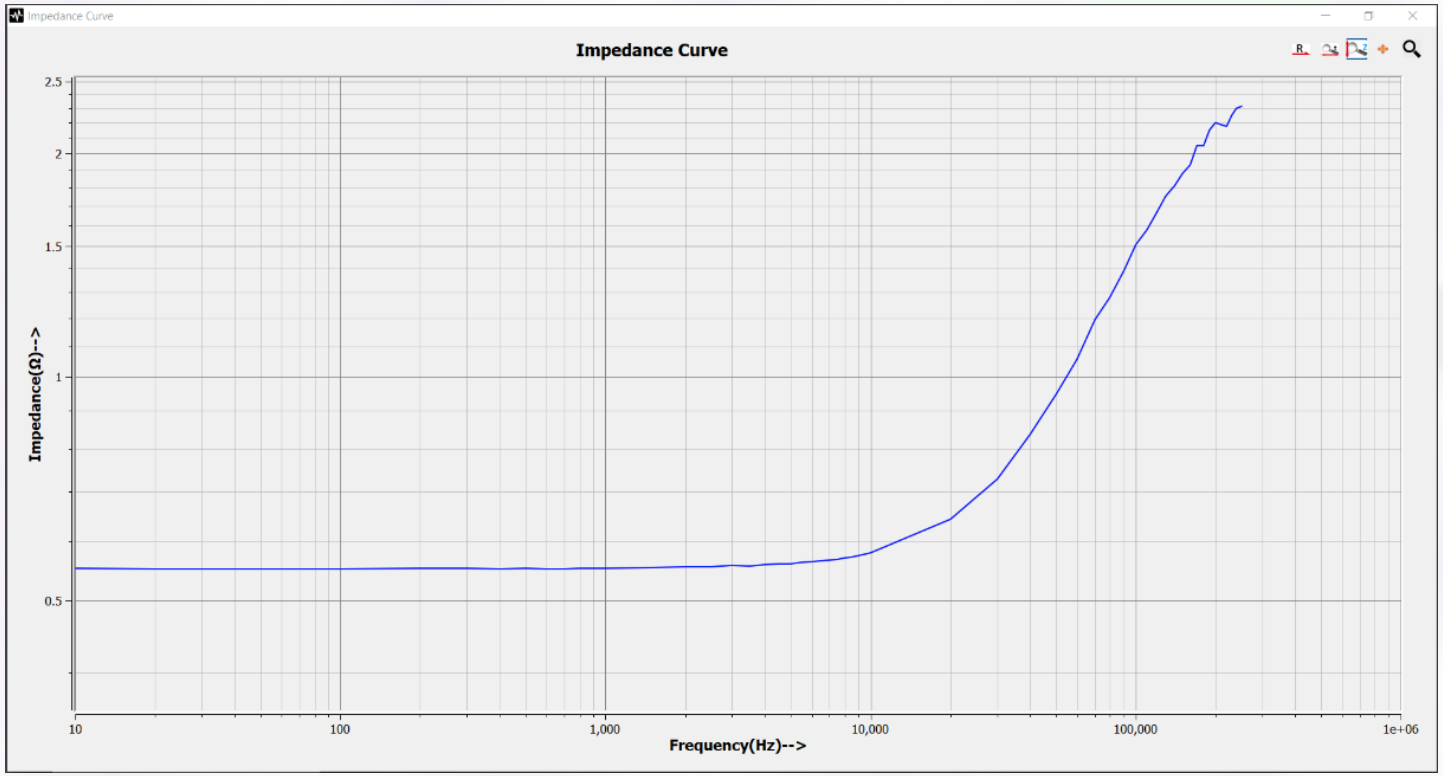
Transformer Coupling

- Historically, how testing was done
  - < 20 kHz
- Worked for earlier requirements



Transformer Coupling

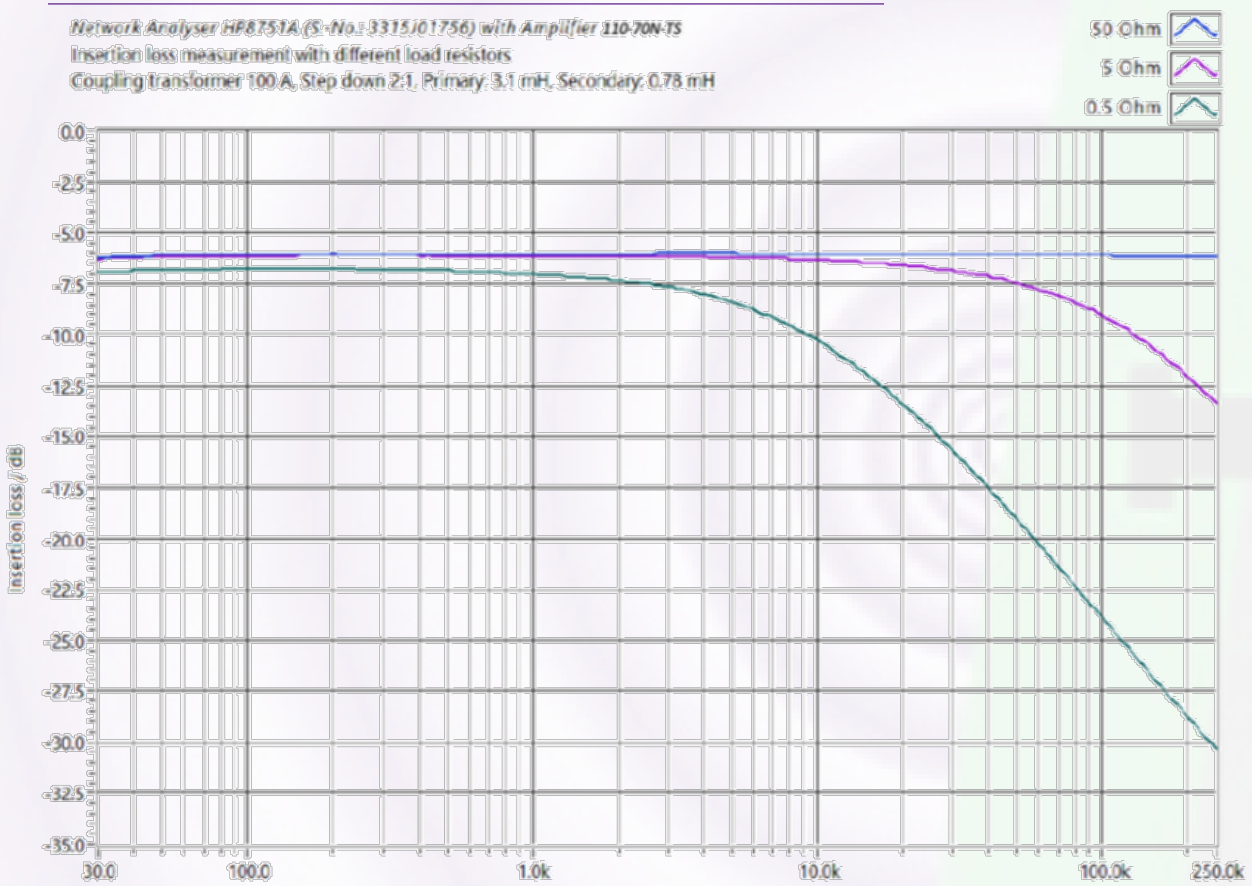




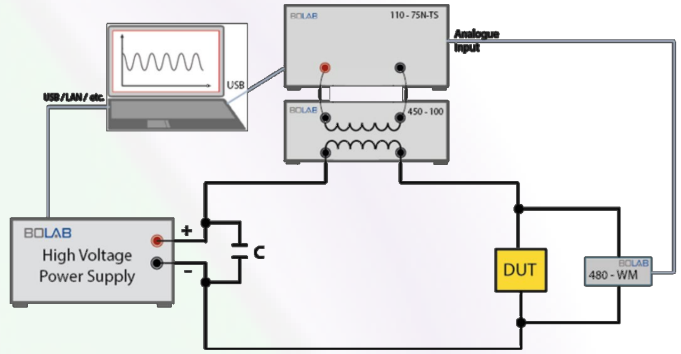
The behavior of an inductive impedance ZL

- With increasing frequency, the impedance of an inductive transformer is increasing exponentially
- Higher resistance of the coupling transformer causes significant voltage drop inside the transformer
- If voltage drops in the transformer, this voltage is missing at the DUT; it cannot be compensated as this voltage drop is dramatic

Transformer Coupling



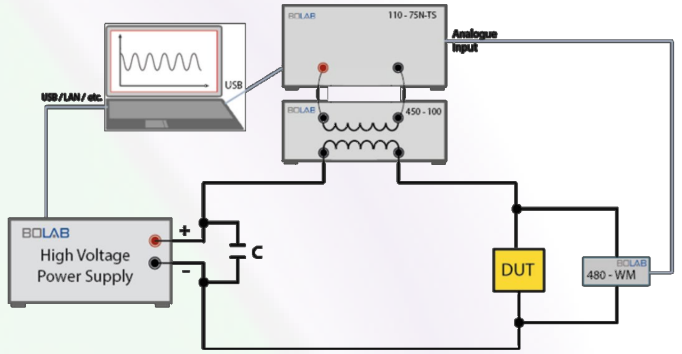
Graphic: Losses in transformers depending on current



Blue: With no or less current flow, a transformer solution can work quite properly.

Purple/Green: At higher frequencies and DUTs with high/current requirements, the losses are dramatic.

Transformer Coupling

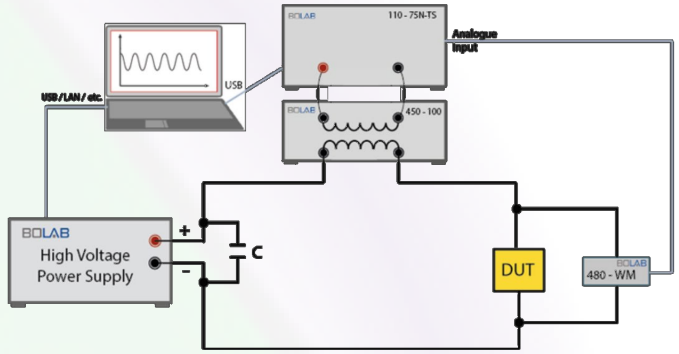


Workaround:

- Frequency ranges are divided up for using different transformers for the specific frequency ranges, e.g.

  a) 15 Hz ... 200 Hz: Ripple with power supply
  b) 200 Hz ... 1 kHz: CT 1
  c) 1 kHz ... 50 kHz: CT 2
  d) 50 kHz ... 150 kHz: CT 3

Transformer Coupling

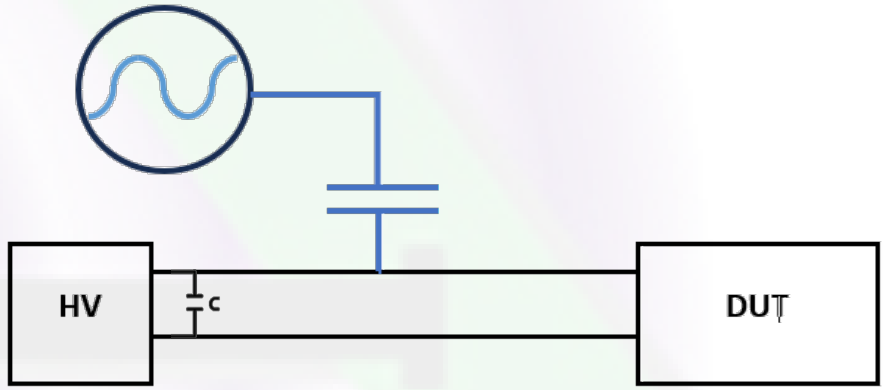


Disadvantages:

- AC signals only
  - Can not pass DC or low frequencies, saturation
- Low freq. >200 Hz must be done with HV PS
- Extended frequency range requires more Transformers
- Larger, higher current systems require more amp/transformers
- Not able to sweep from DC to 200kHz in one test

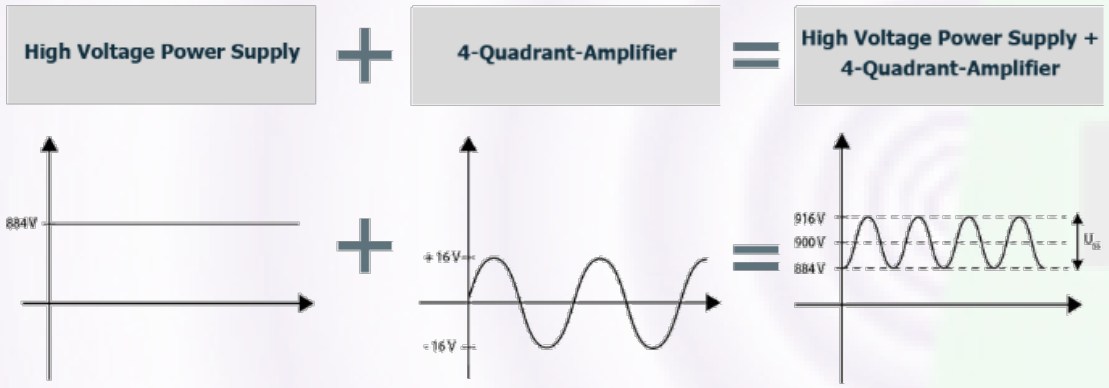
Capacitor Coupling

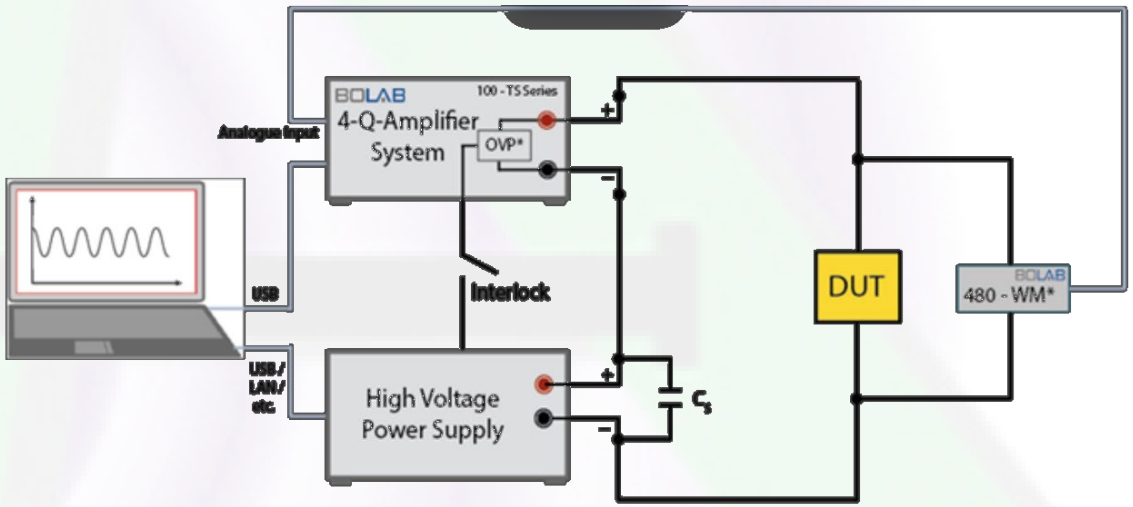
- Not used extensively
- Similar disadvantages as transformer:
  - AC signals only
  - Low freq. >200 Hz must be done with HV PS
  - Larger, higher current systems require more amp/CAP
  - Not able to sweep from DC to 200kHz in one test
  - Safety concerns



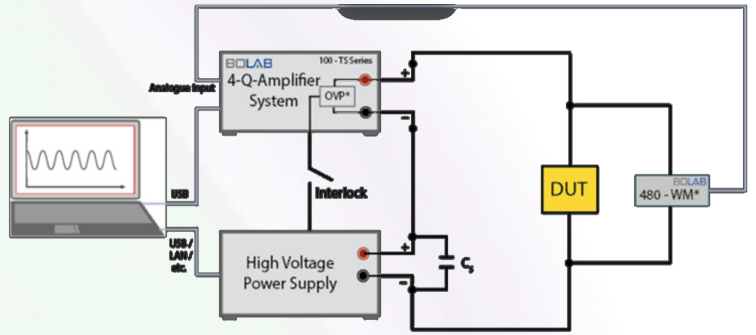
Amplifier in Series

- Amplifier is placed in series with HV PS



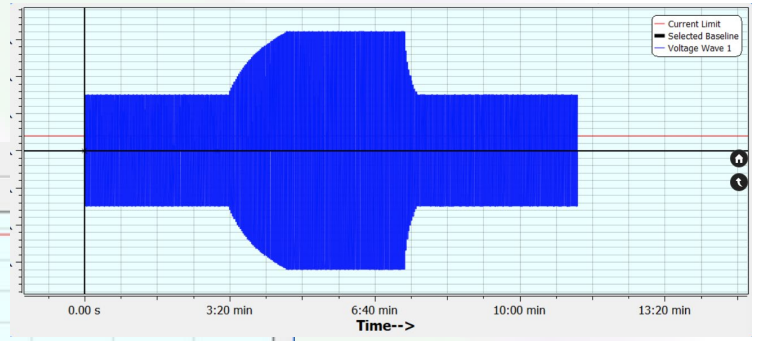


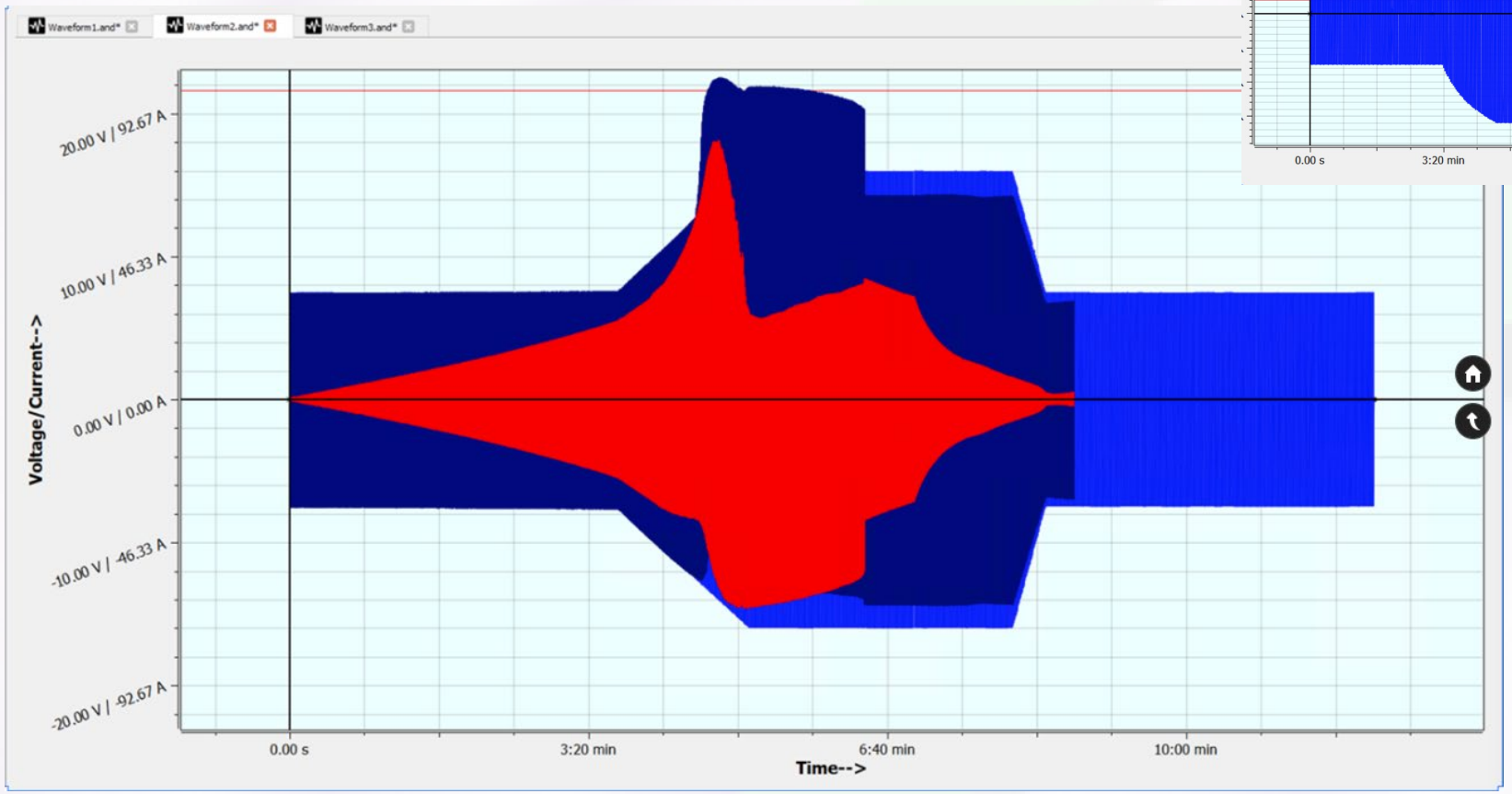
Amplifier in Series



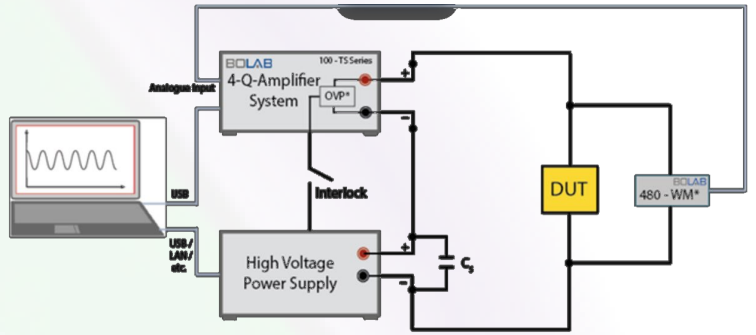
- Ripple tests without interruption from 15 Hz ... 200 kHz +
  - Continuous sweep
- Load Dump out of VW 80300, EHV-10 feasible Triangle, rectangle, trapeze, pulses, spikes can be performed easily
- Highest signal quality
- Prepared for upcoming changes in standards and new standards
- 4-Quadrant Amplifier system can be used for 12 V / 24 V / 48 V standard testing as well

Real Measurements





Amplifier in Series



Fast Load Dump

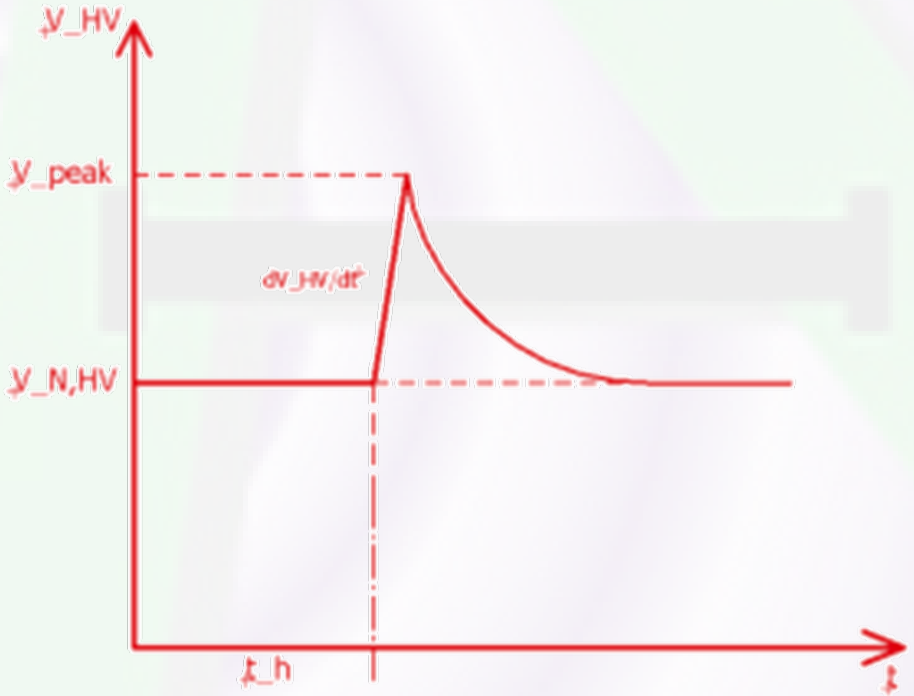
3000 V/ms (3 V/µs)

V_peak = V_N,HV + 20 V

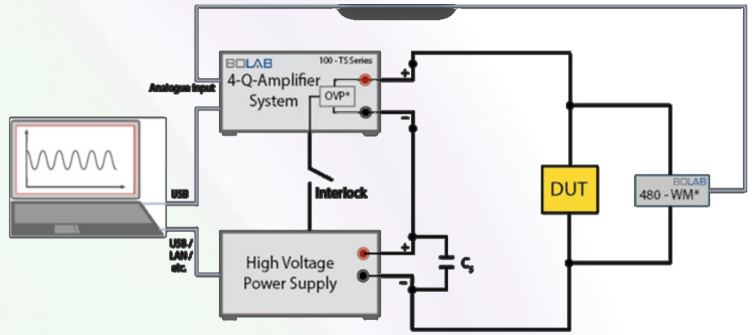
---> V_peak = 20 V / 7 µs

100TS: 20 V / 1 µs

- **is 7 times faster with best signal quality**



Amplifier in Series

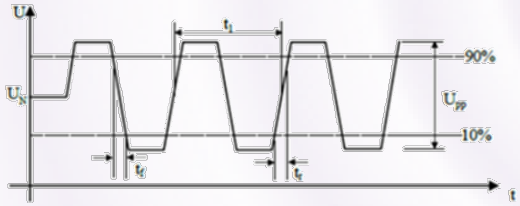


RECTANGLE SIGNALS (Nissan, MES, etc.)

BOLAB´s solution is flexible for generating all kinds of waveforms (not only sine interferences), also rectangle, respectively trapeze waveforms are feasible!

Table 16A Continuous Noise (Voltage Ripple) Requirements for High Voltage Components

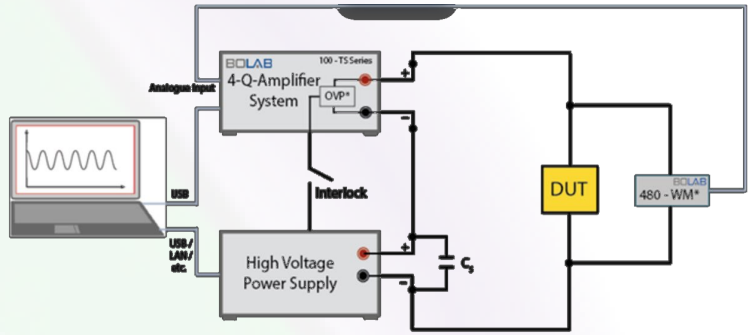
Frequency Range (kHz)	Step size	Test voltage Level 1	Test voltage Level 2	Dwell time	Test Coupling
1 – 30	1 kHz	5 V_{P-P}	25 V_{P-P}	2 s	HV + to HV –, HV + to GND and HV – to GND
30 – 300	10 kHz	2 V_{P-P}	4 V_{P-P}		



	1 - 300 kHz
t_1	3.3 - 1000 µs
t_r	< 1µs
t_f	< 1µs
U_{pp}	Test pulse voltage Refer to Table 16A
U_N	To define in EMC Test Plan

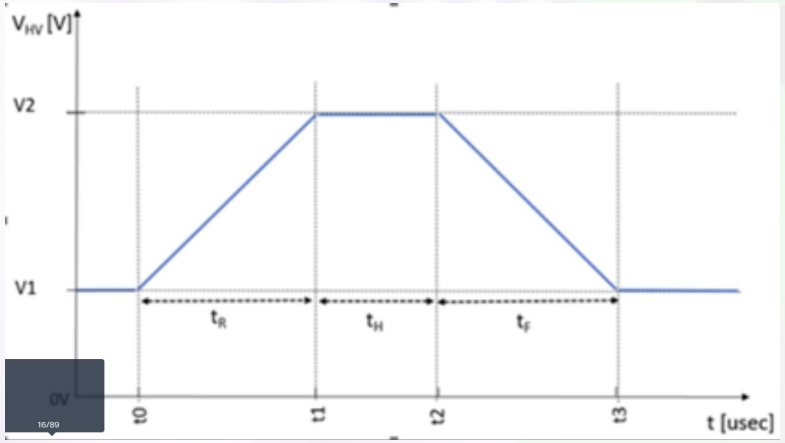
Fig. 16A Continuous Noise (Voltage Ripple) Test Waveform Requirements

Amplifier in Series



High Speed + HV transitions

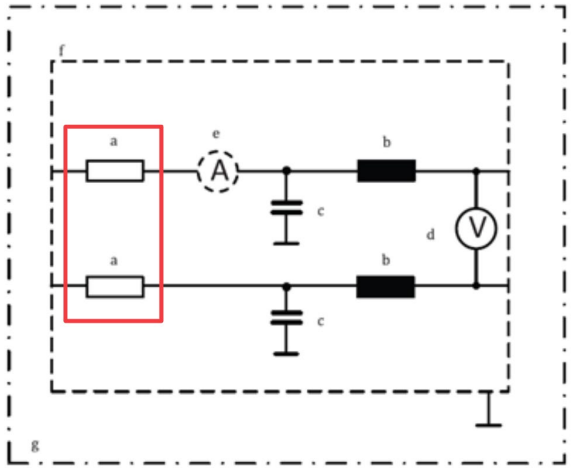
- **DC/DC Converters**
- Rising times up to 10uS and amplitudes 220V



#	V1 (V)	V2 (V)	Slew Rate (V/ms)	tR (us)	tH (us)	tF (us)
1	250	270	2000	10	30	10
2	250	300	2000	25	30	25
3	250	350	2000	50	30	50
4	250	470	2000	110	30	110
5	360	380	2000	10	60	10
6	360	400	2000	20	60	20
7	360	470	2000	55	60	55
8	360	500	2000	70	60	70
9	470	490	2000	10	100	10
10	470	510	2000	20	100	20
11	470	570	2000	50	100	50
12	250	275	1000	25	100	25
13	250	300	1000	50	100	50
14	250	350	1000	100	100	100
15	250	470	1000	220	100	220
16	360	380	1000	20	60	20
17	360	400	1000	40	60	40
18	360	470	1000	110	60	110
19	360	500	1000	140	60	140
20	470	490	1000	20	30	20
21	470	510	1000	40	30	40
22	470	570	1000	100	30	100

The Complete Package

- ISO 21498
  - 10Hz to 150kHz (200kHz)
  - Resistors Ri,HV: 10mΩ, 50mΩ, 100m Ω, or 200m Ω
  - In both + and return lines (other standards only +)



The Complete Package

- ISO 21498
  - 10Hz to 150kHz (200kHz)
  - Resistors Ri,HV: 10mΩ, 50mΩ, 100m Ω, or 200m Ω
  - Calibration over Freq (not just DC) while powered!

Table D.2 — Magnitude of artificial network impedance with $R_{i,HV}$ = 10 mΩ

	Impedance [Ω]		
Frequency [Hz]	Nominal	Lower tolerance	Upper tolerance
10	$2{,}30 \times 10^{-2}$	$2{,}10 \times 10^{-2}$	$2{,}50 \times 10^{-2}$
10^2	$2{,}30 \times 10^{-2}$	$2{,}10 \times 10^{-2}$	$2{,}51 \times 10^{-2}$
10^3	$2{,}62 \times 10^{-2}$	$2{,}39 \times 10^{-2}$	$3{,}02 \times 10^{-2}$
10^4	$1{,}28 \times 10^{-1}$	$1{,}15 \times 10^{-1}$	$1{,}72 \times 10^{-1}$
10^5	1,26	1,13	1,73
$1{,}5 \times 10^5$	1,88	1,70	2,70

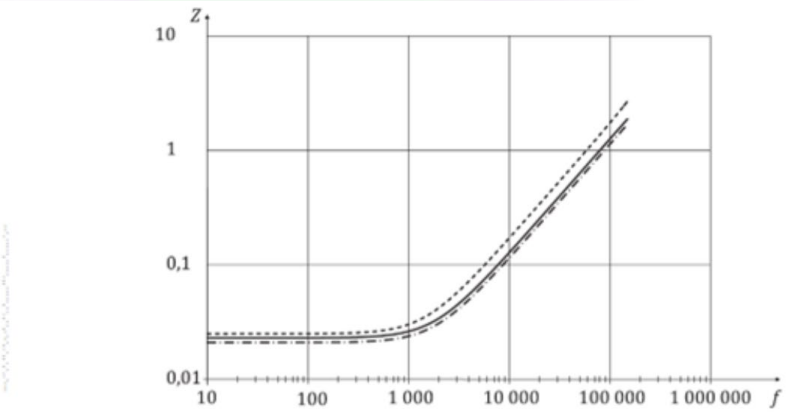
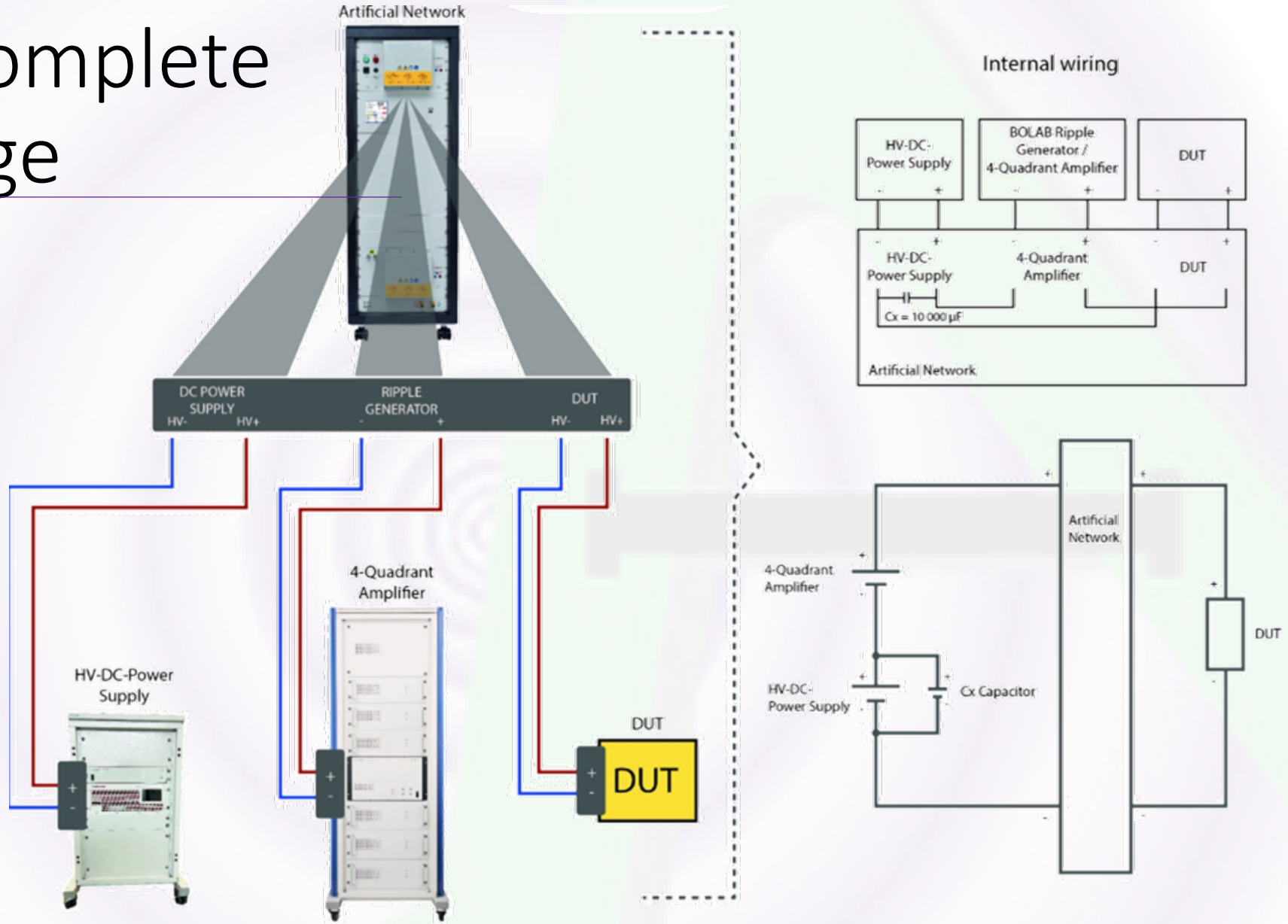


Figure D.2 — Characteristics of artificial network impedance with $R_{i,HV}$ = 10 mΩ

The Complete Package



Amplifier System

- **Modular**
- **Extendable**
- **Scalable**
- **Flexible**
- **Easy Service**

LV Testing with Same Amp

- ISO 7637-2,…
- 4-Quad Amp (same)
- Load Dump
- Fast Switch
- EFT/Micro-pulse
- Advanced Software Control
- Real-Time Measurement

Thank you

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