TRANSIENT SURGE FILTERING

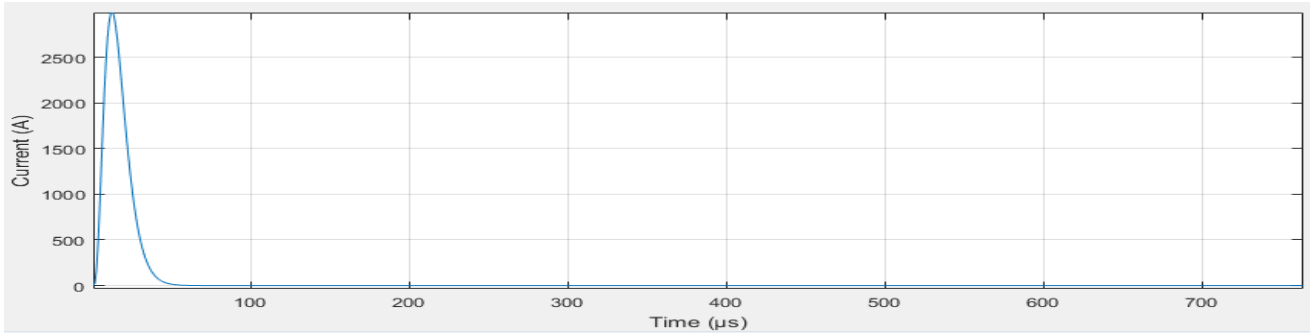
USE OF LOW PASS FILTERING IN SURGE PROTECTION

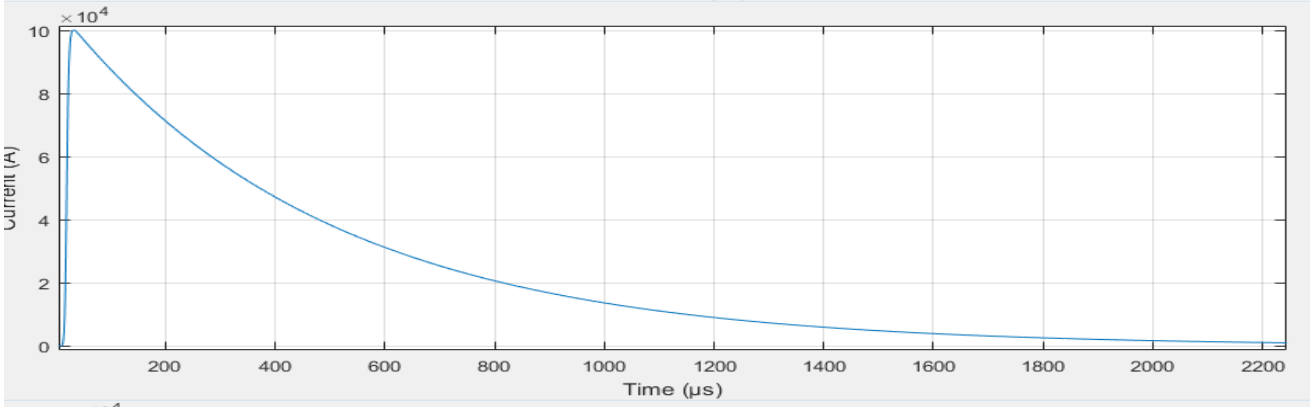
AGENDA

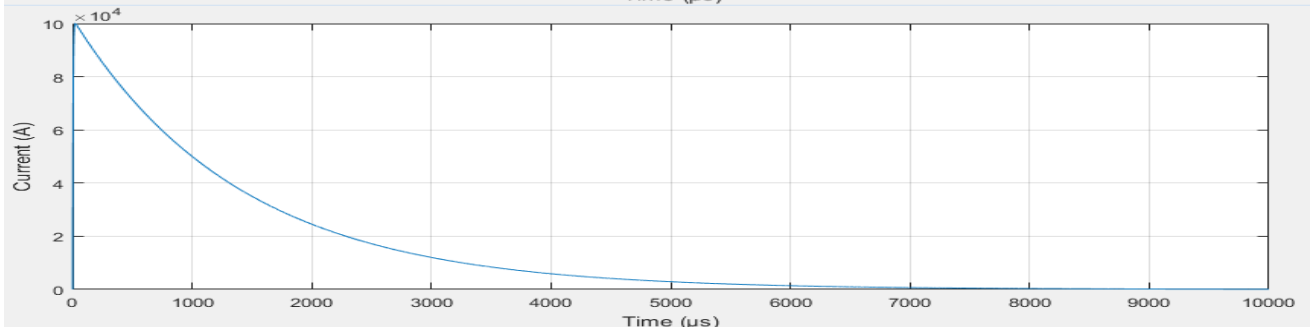
- Classification of Impulses & Surges
- Traditional MOV/Crowbar Protection vs. Filtering
- Concepts Behind Surge Filtering
- Summary

Classifications of Surge Impulses

- Waveshape
  - t_{front}, t_{tail}
- Magnitude
  - i_{pk}
- Charge
  - Q
- I^2t
  - kJ/Ω



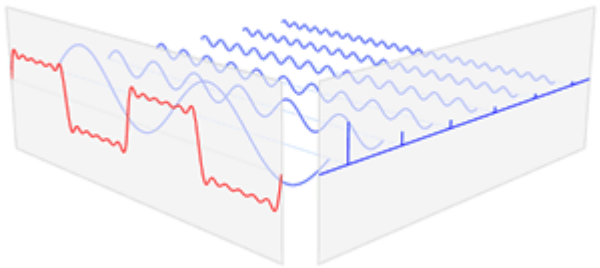


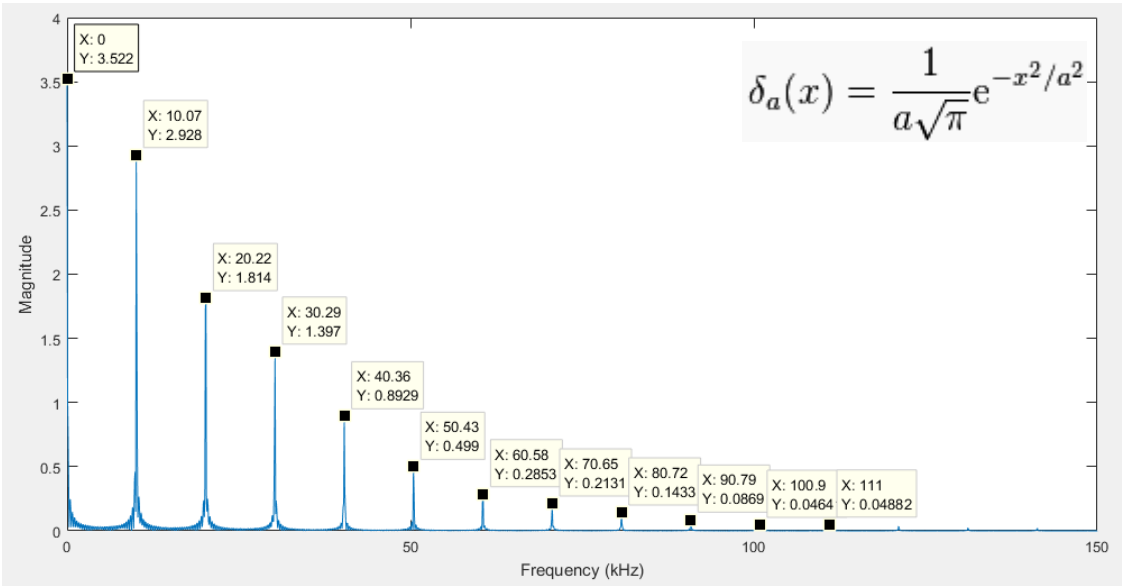


Classification of Surge Impulses (cont.)

- Frequency
  - Harmonics
    - Sum of Dirac delta functions
  - Bandwidth
  - Magnitude

$$\hat{f}(\xi) = \delta(0) + \delta(10E3) + \delta(20E3) + \ldots + \delta(100E3)$$

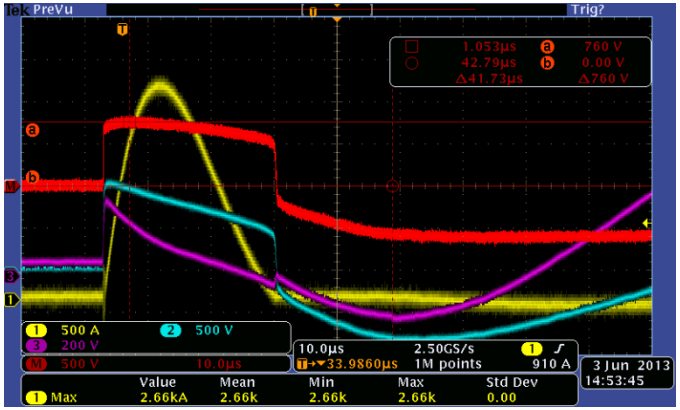


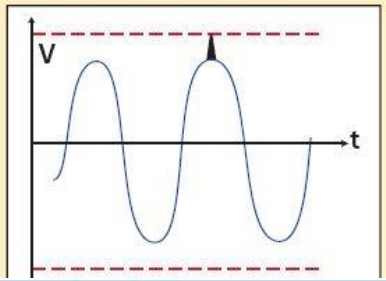


All transients are signals and can be analyzed by the Fourier Transform

Traditional Surge Protection Design

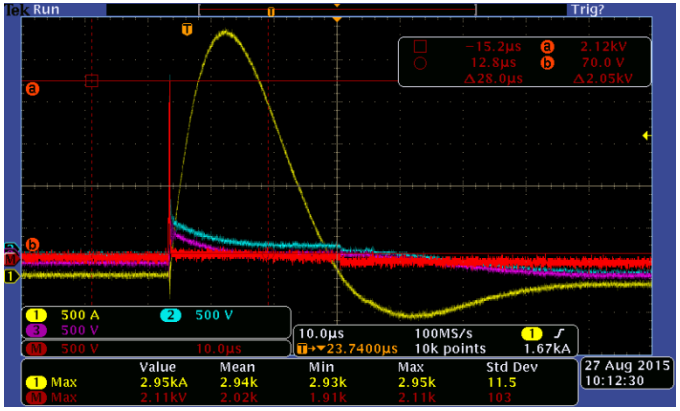
- Metal Oxide Varistors (voltage limiting devices)

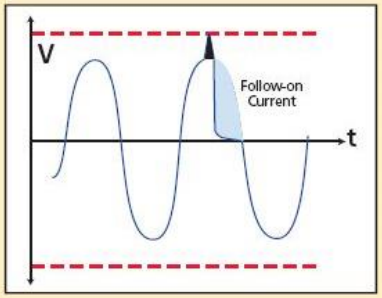


Type	Typical Response
Voltage Limiting type SPD*	

Type Typical Response

- Crowbar (GDT/Sparkgap type devices)

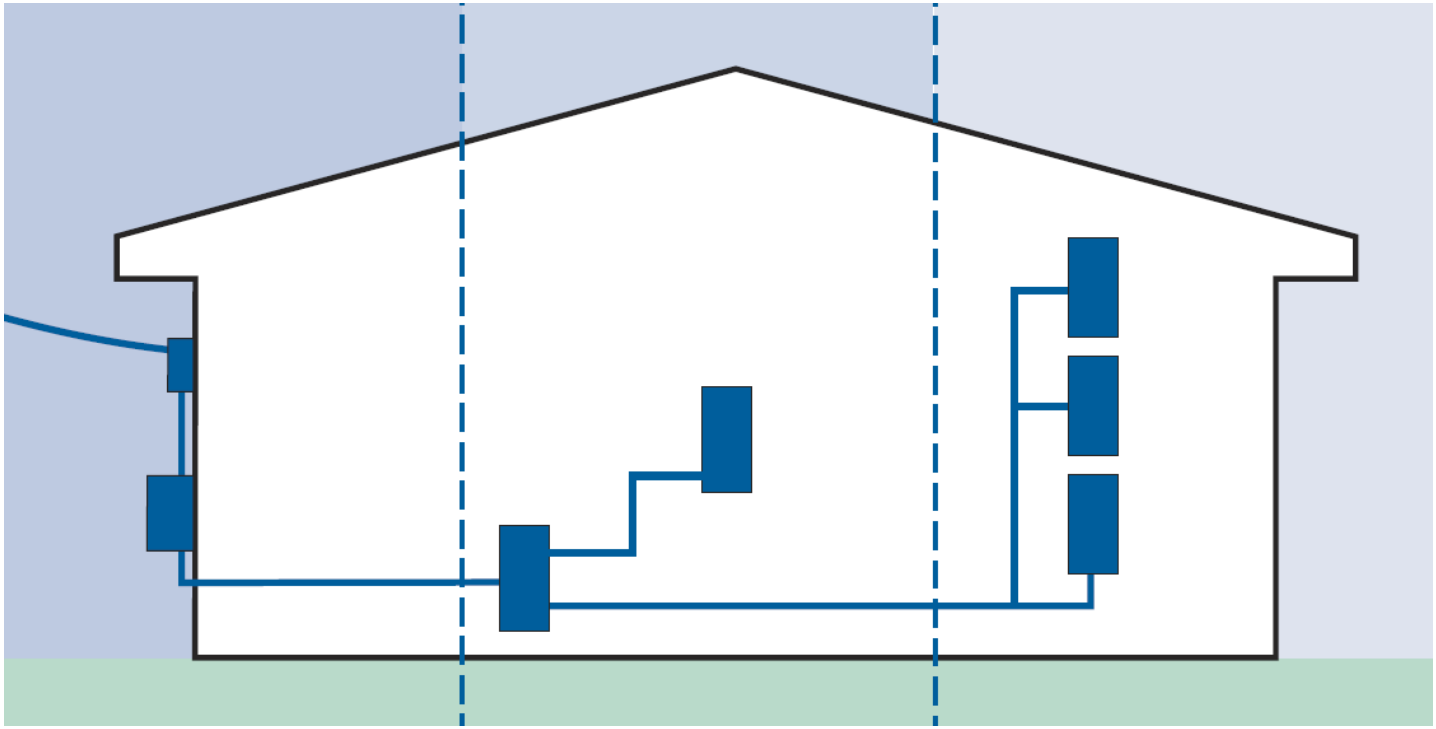


Voltage Switching type SPD*	

Voltage limiting and switching are the main components for protection

Traditional Surge Protection Design

- Cascading protection
  - SPDs at the service entrance are higher rated (higher let-through)
  - SPDs at the sub-panels are lower rated (lower let-through)

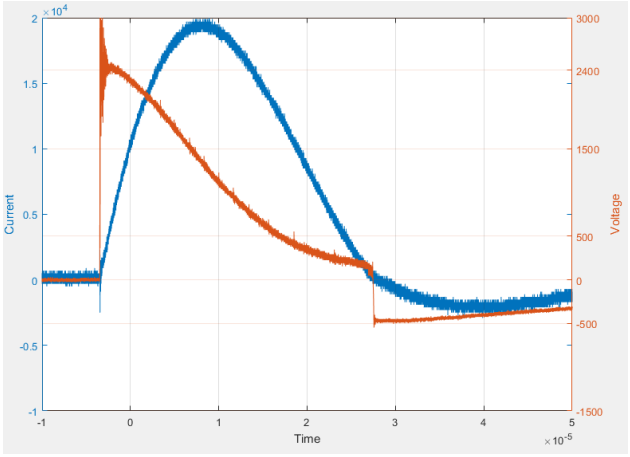


Cascading protection limits the voltage from transients in stages

Cascading Stage Limiting

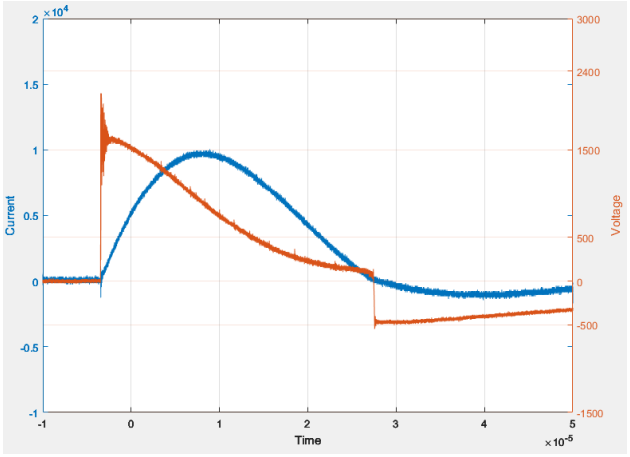
Stage 1 (2400V)

Type 1 (UL1449)
20kA 8/20µs | 2400V



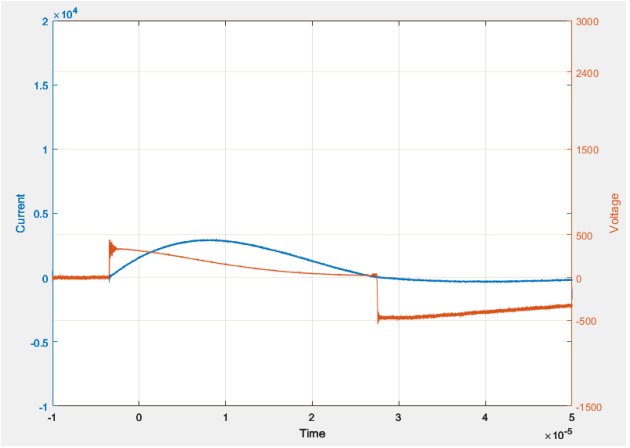
Stage 2 (1600V)

Type 1/Type 2 (UL 1449)
10kA 8/20µs | 1600V



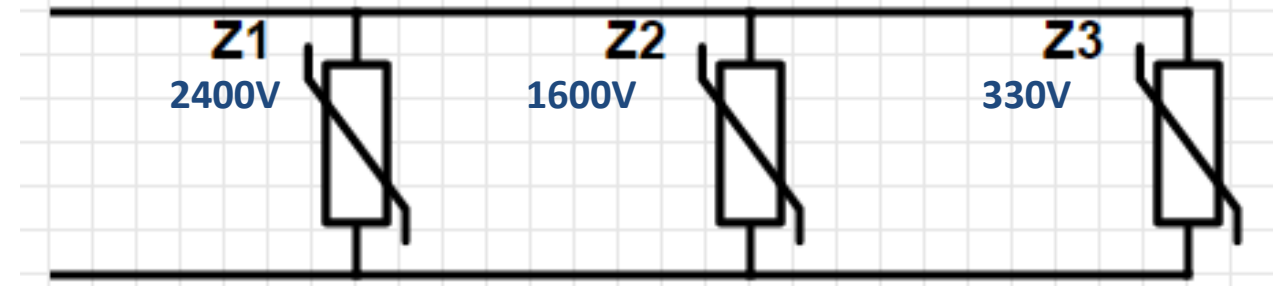
Stage 3 (330V)

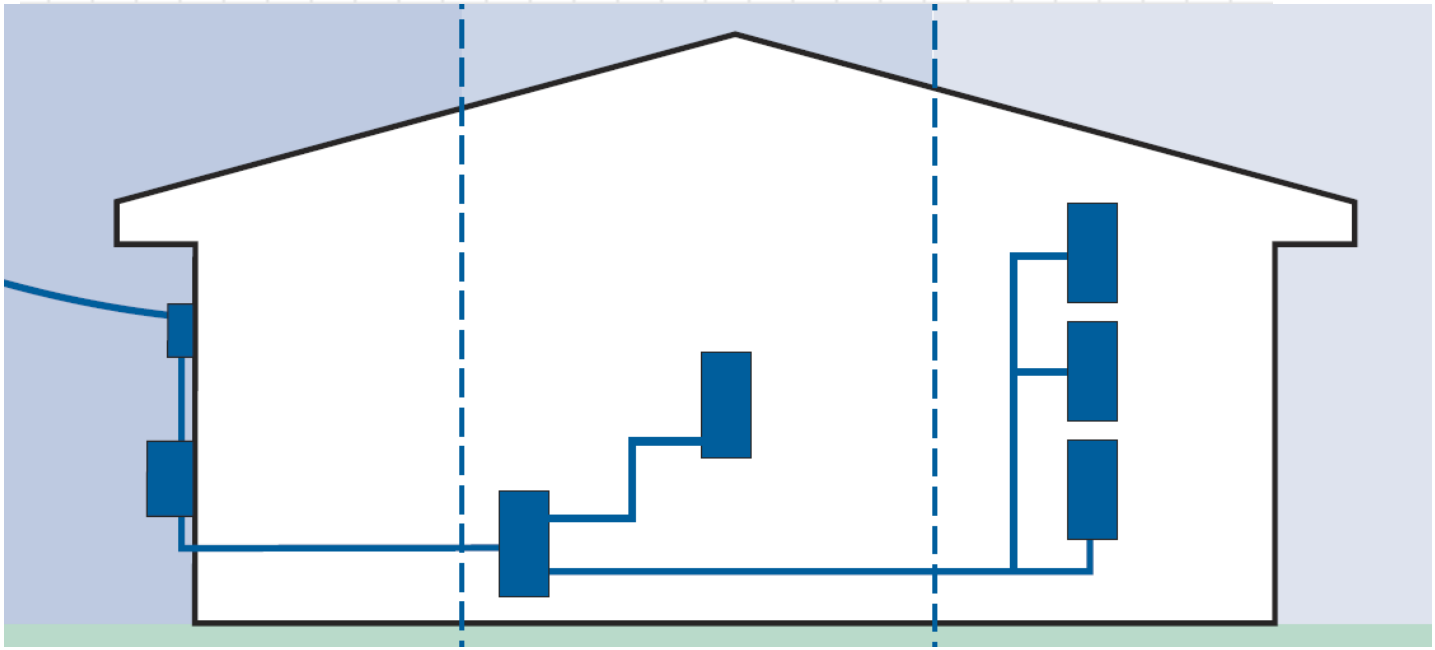
Type 2/Type 4CA (UL 1449)
3kA 8/20µs | 330V



Each stage diverts more energy and keeps the end voltage low

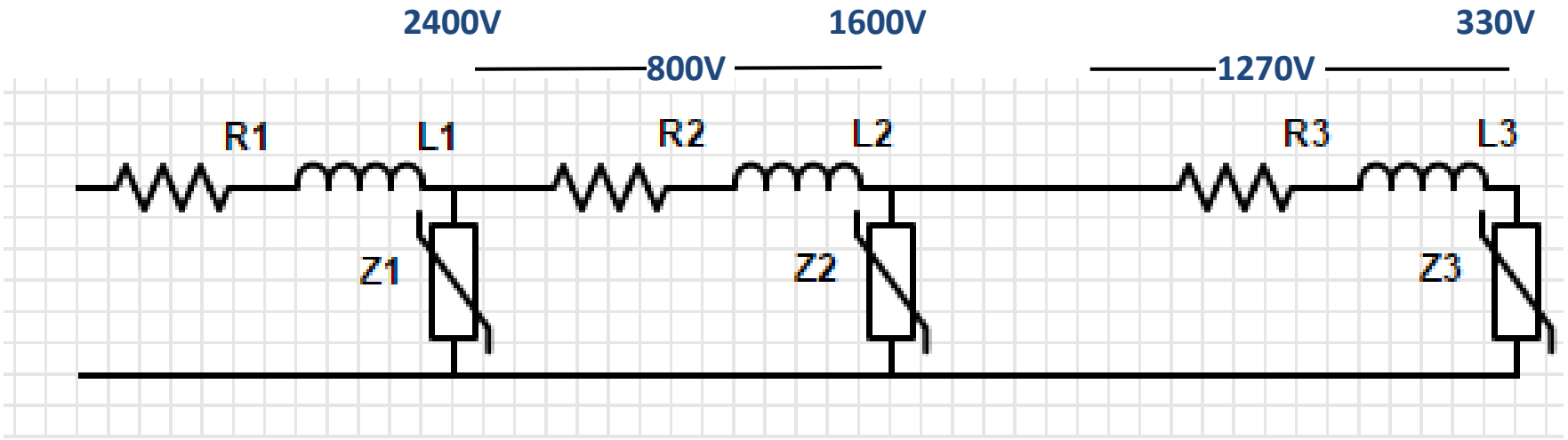
Different Voltages on Parallel Lines

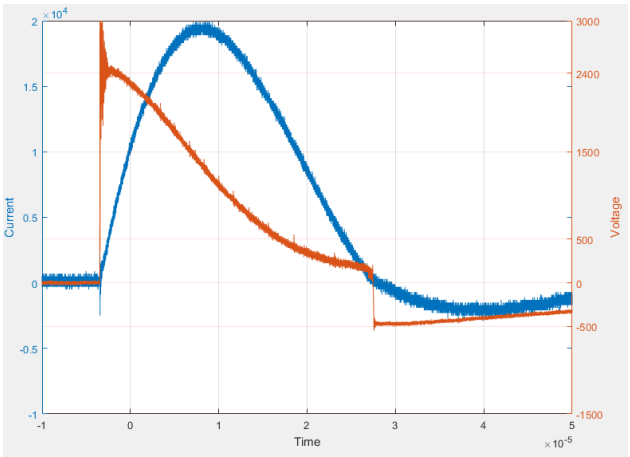


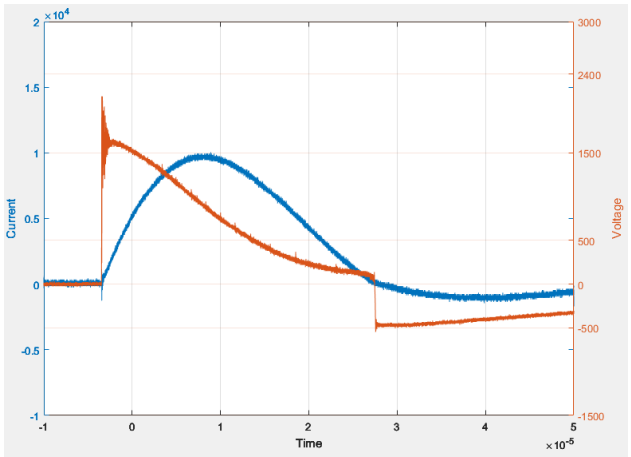


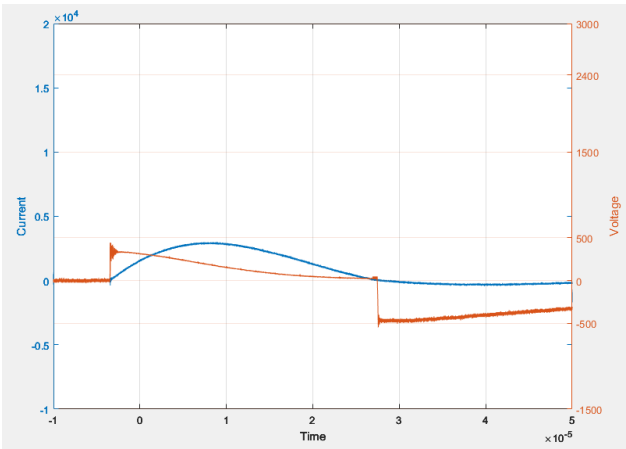
Voltages in parallel are the same, additional voltage drop exists

Voltage Must be Dropped Across the Wiring







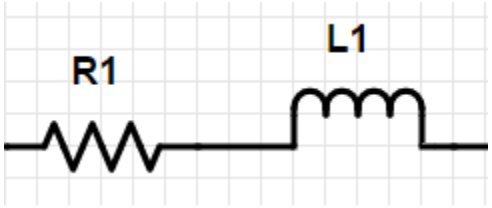


Wiring impedance can be used to isolate staged protection

Voltage Drop Across Wiring

- Theoretically: 4mm² (12AWG) wire is $\approx {}^{4m\Omega}/_{m}$ and ${}^{1\mu H}/_{m}$

$$V = i \cdot R + L\frac{di}{dt}$$



Large loss due to inductance

- Given a 3kA 8/20µs impulse

$$V = 3000A \cdot {}^{4m\Omega}/_{m} + {}^{1\mu H}/_{m}\frac{3000A}{8 \cdot 10^{-6}s}$$
$$V = 3 + 375$$
$$V = 378\,{}^{V}/_{m}$$

- Gets lower with larger wire

		6 AWG		4 AWG		2 AWG	
		(V/ft)	(V/cm)	(V/ft)	(V/cm)	(V/ft)	(V/cm)
3	kA	152.40	5.00	94.45	3.10	83.61	2.74
10	kA	441.16	14.47	385.00	12.63	340.65	11.18
40	kA	?	?	1579.35	51.82	1254.19	41.15

Wiring might be sufficient to mitigate this problem

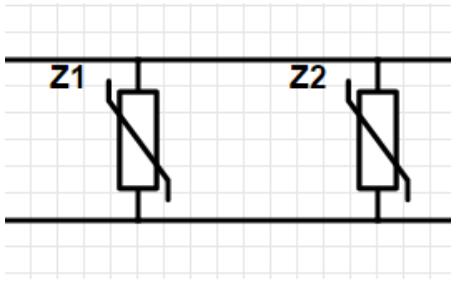
When Wiring is Short with Minimum Losses (1/2)

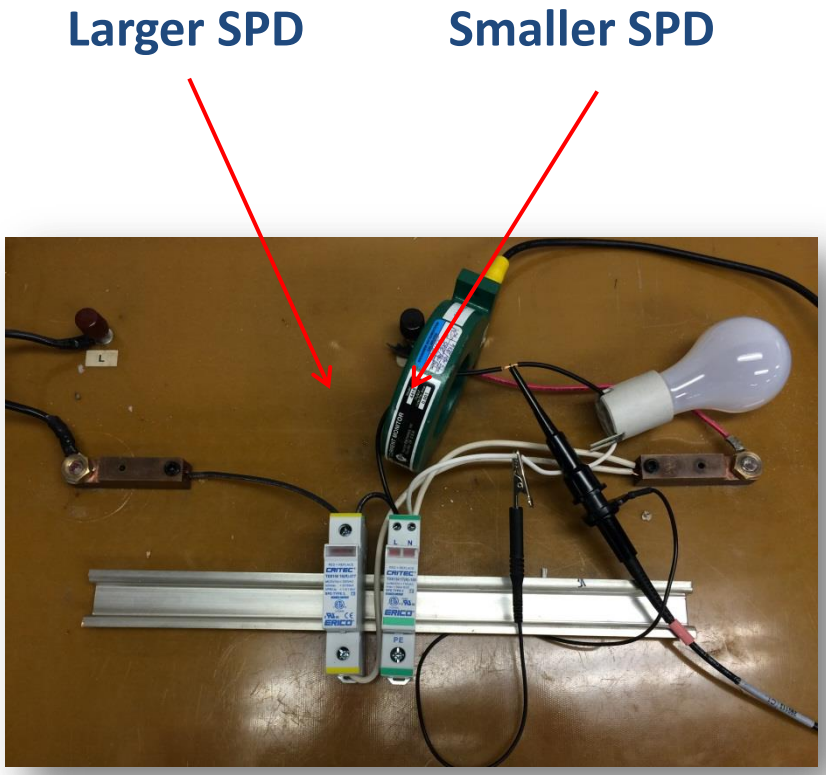
Smaller SPD clamps first

Since the lower rated MOVs are more sensitive they will begin clamping the voltage first

Larger SPD only when threshold is exceeded

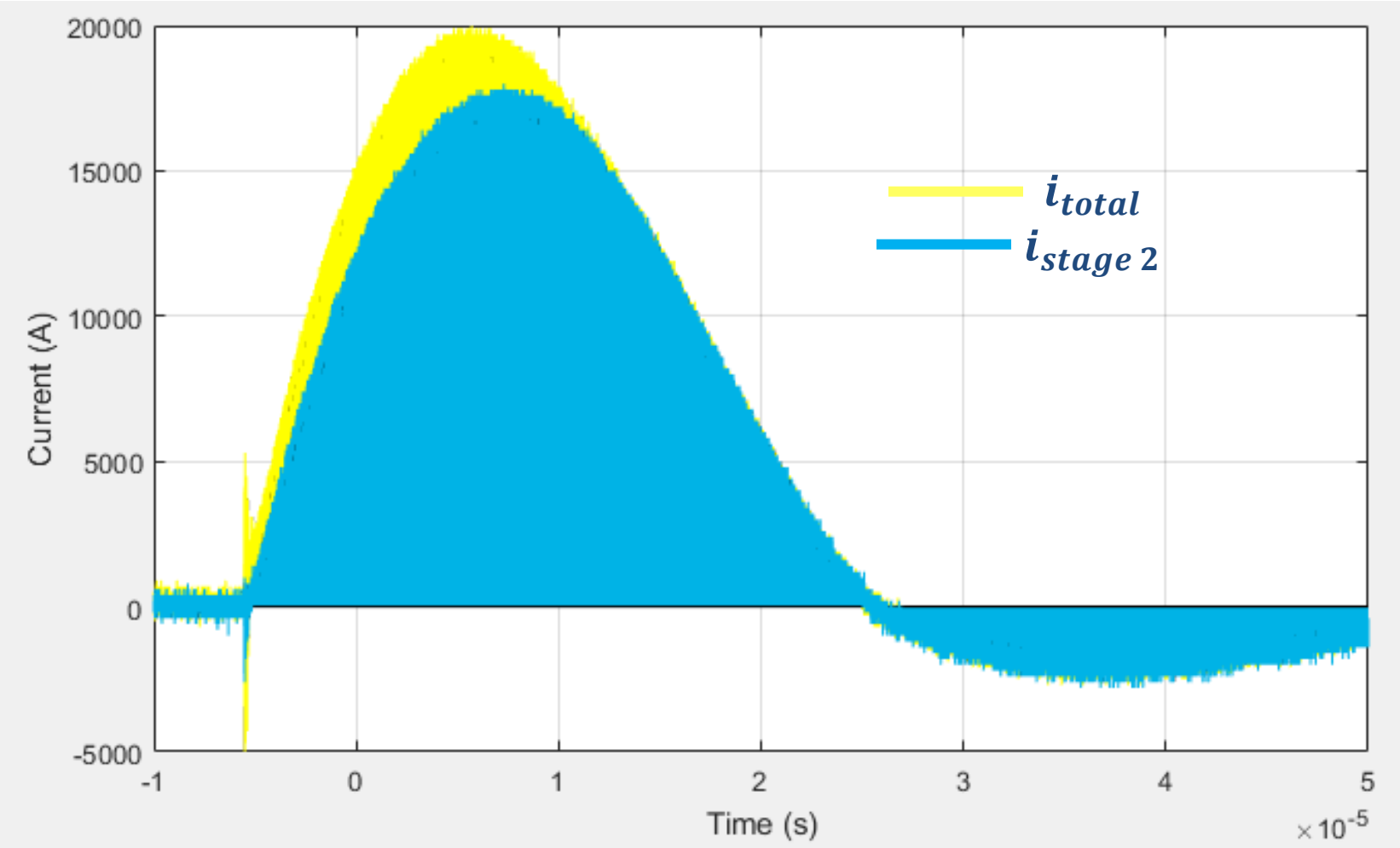
The larger SPD will only turn on if the smaller SPDs clamping voltage goes above the turn-on voltage of the larger SPD





Current initially goes through the smaller SPD until larger turns on

When Wiring is Short with Minimum Losses (2/2)

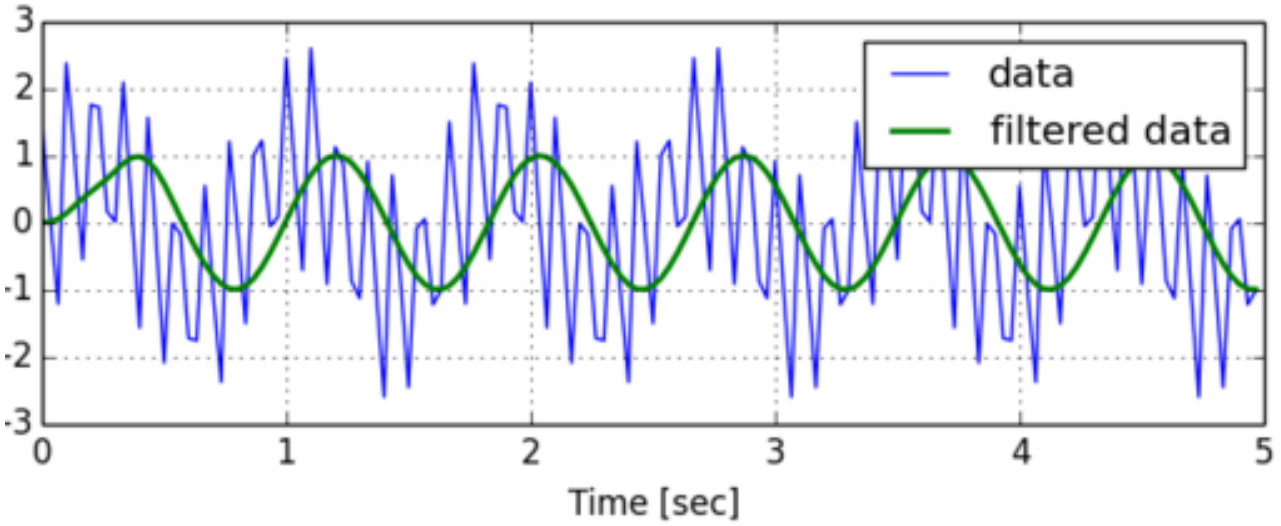


The lower rated device absorbs most of the impulse

What is a Low Pass Filter?

Low-Pass Filter

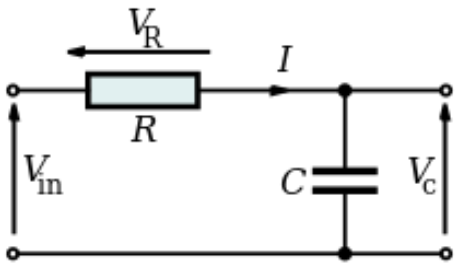
- **Low**er frequencies **Pass** while higher frequencies are attenuated



Low Frequency Signals Pass!

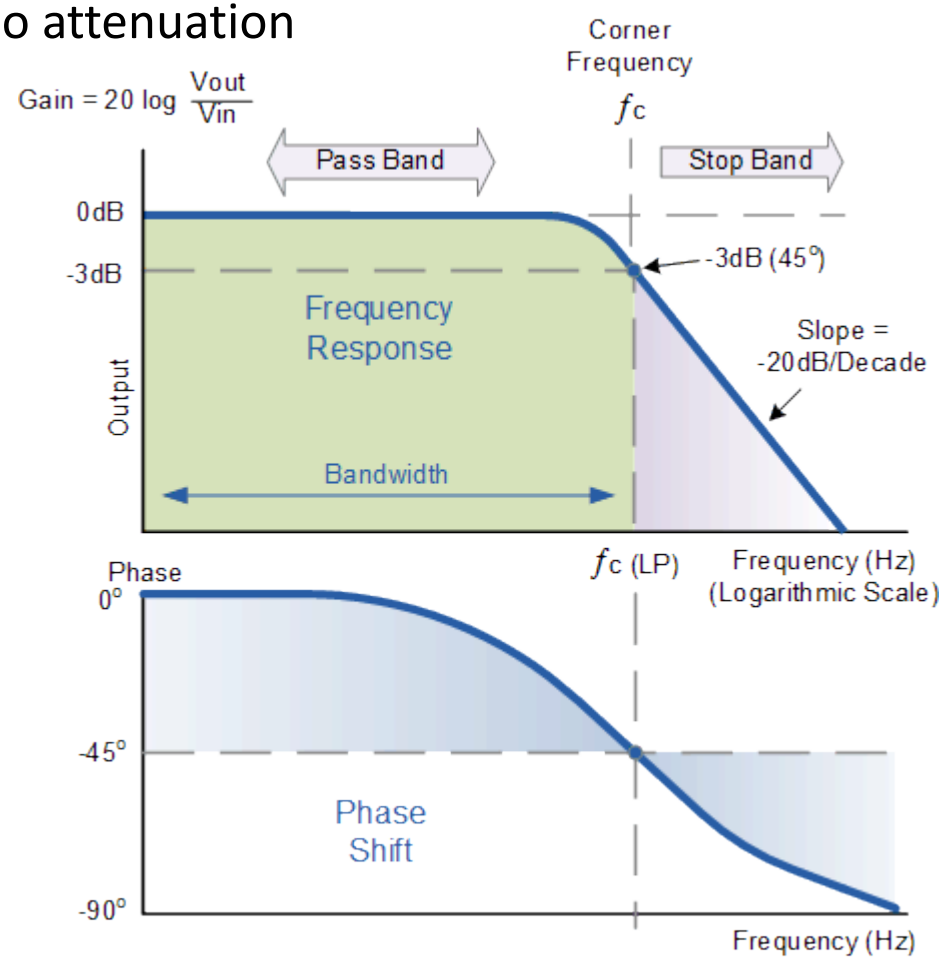
Low Pass Filters

- Low frequency signals experience no attenuation
- High frequency signals experience large amounts of attenuation



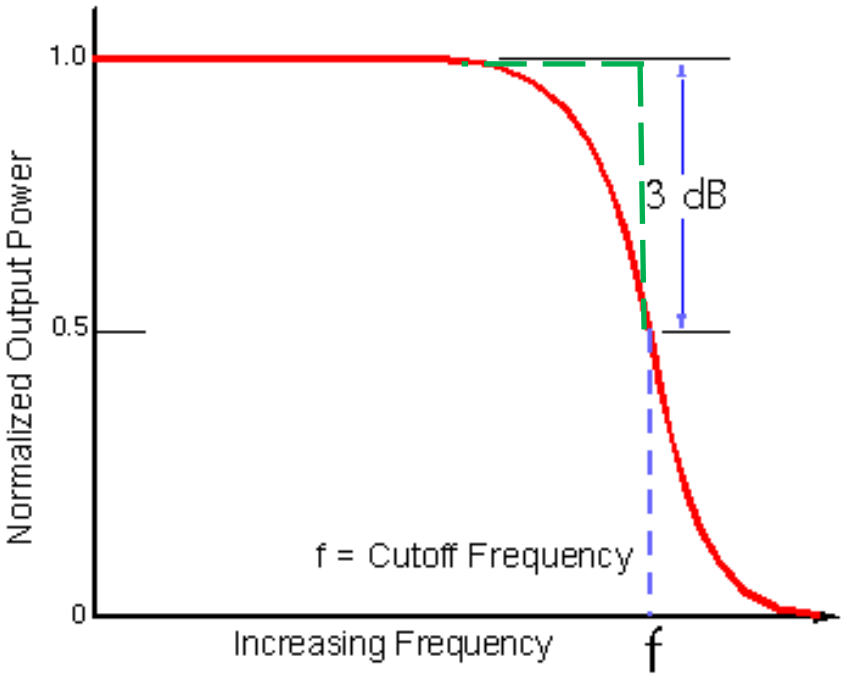
$$H(s) = \frac{1}{1 + RCs}$$

Where s = jω



Characterizing a Filter

- At higher frequencies, Vout is multiplied by something smaller than “1”.
- 3 dB Point – “cutoff frequency” this is the frequency where the filter cuts off of the output power (half-power point)
- 100 kHz Gain – a benchmark frequency used to compare filtering at a high frequency



Higher Frequencies are attenuated!

100kHz Benchmark

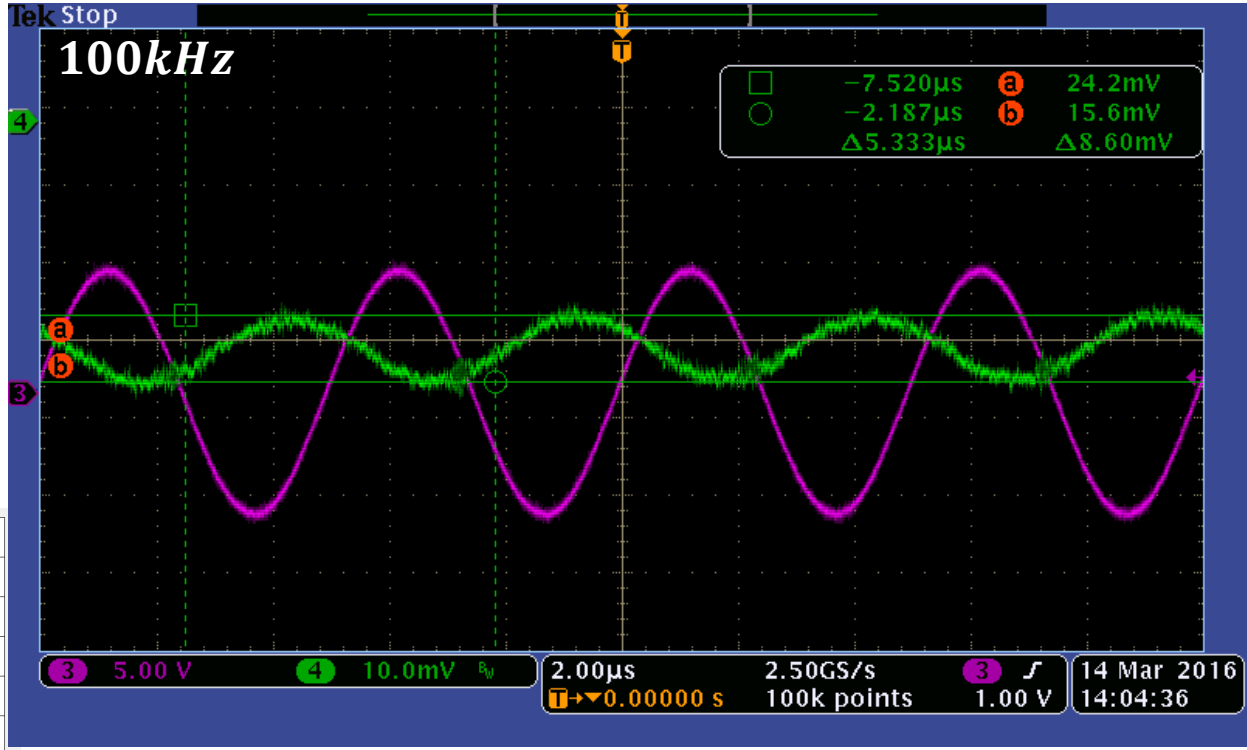
- Filter input = 15.8Vpp
- Filter output = 8.6mVpp

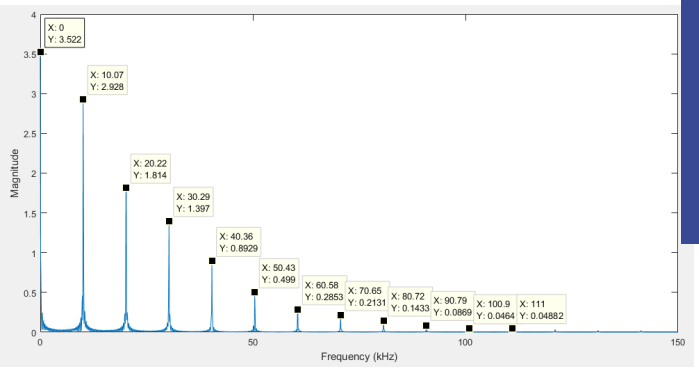
$$= 20 \log_{10}\left(\frac{V2}{V1}\right)$$

= 20 * Log(0.0086/15.8)

= 20 * Log(0.0005)

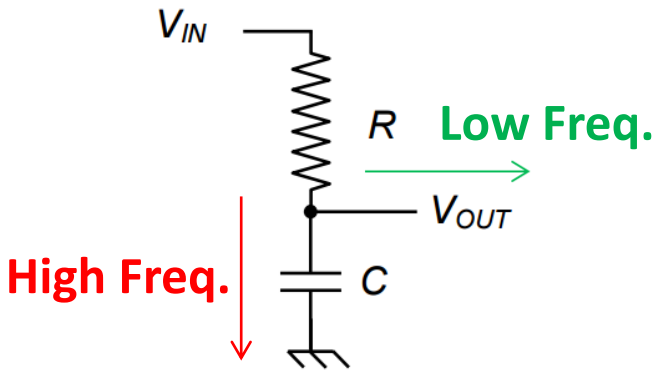
= -65.28 dB



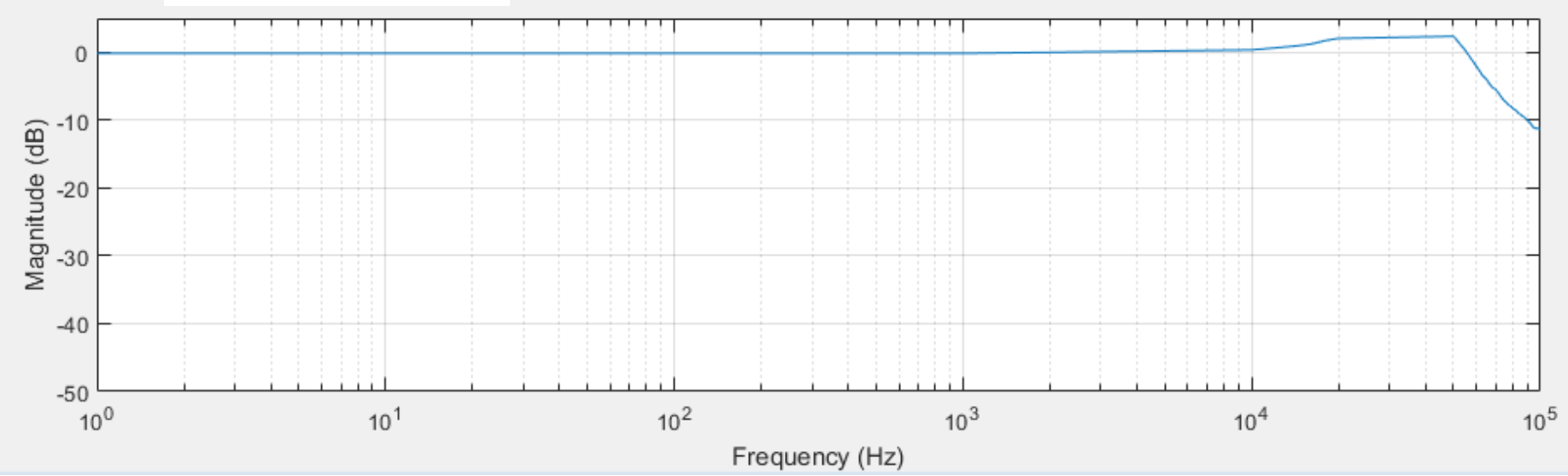


Industry rule of thumb is for −45db at 100kHz

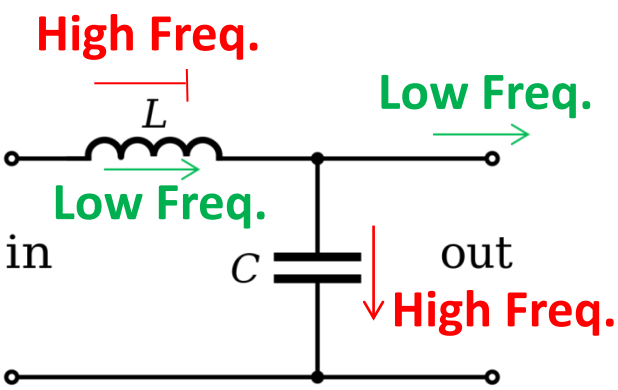
RC Filter

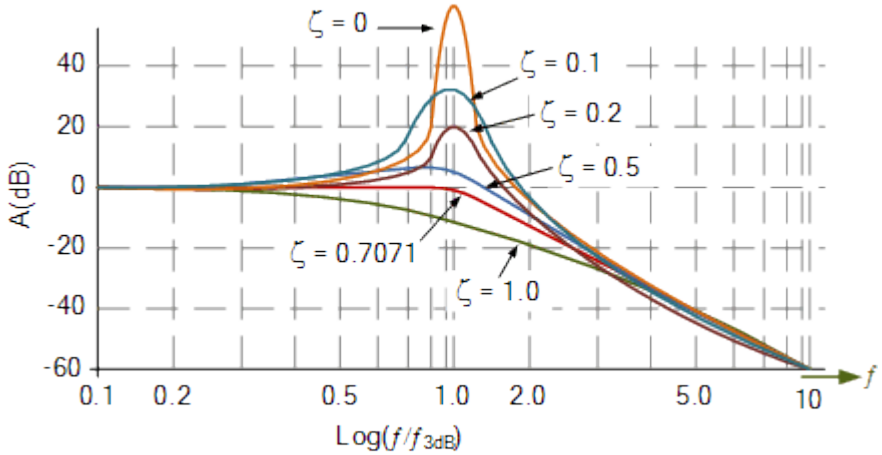


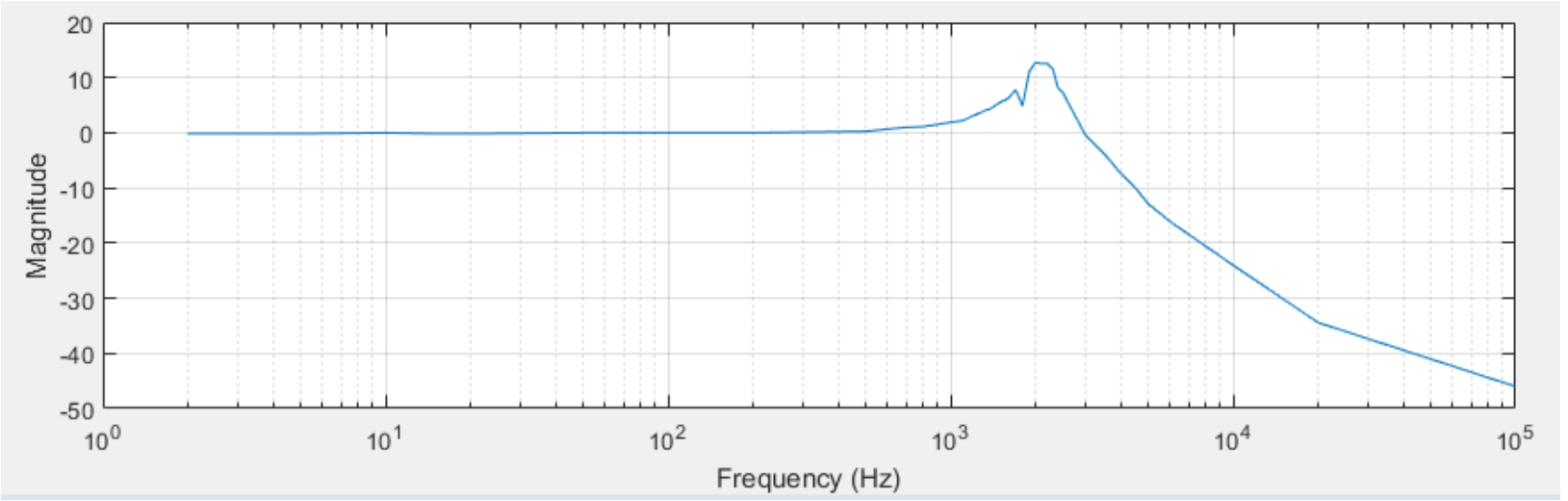
$$Z_C = \frac{1}{j\omega C}$$



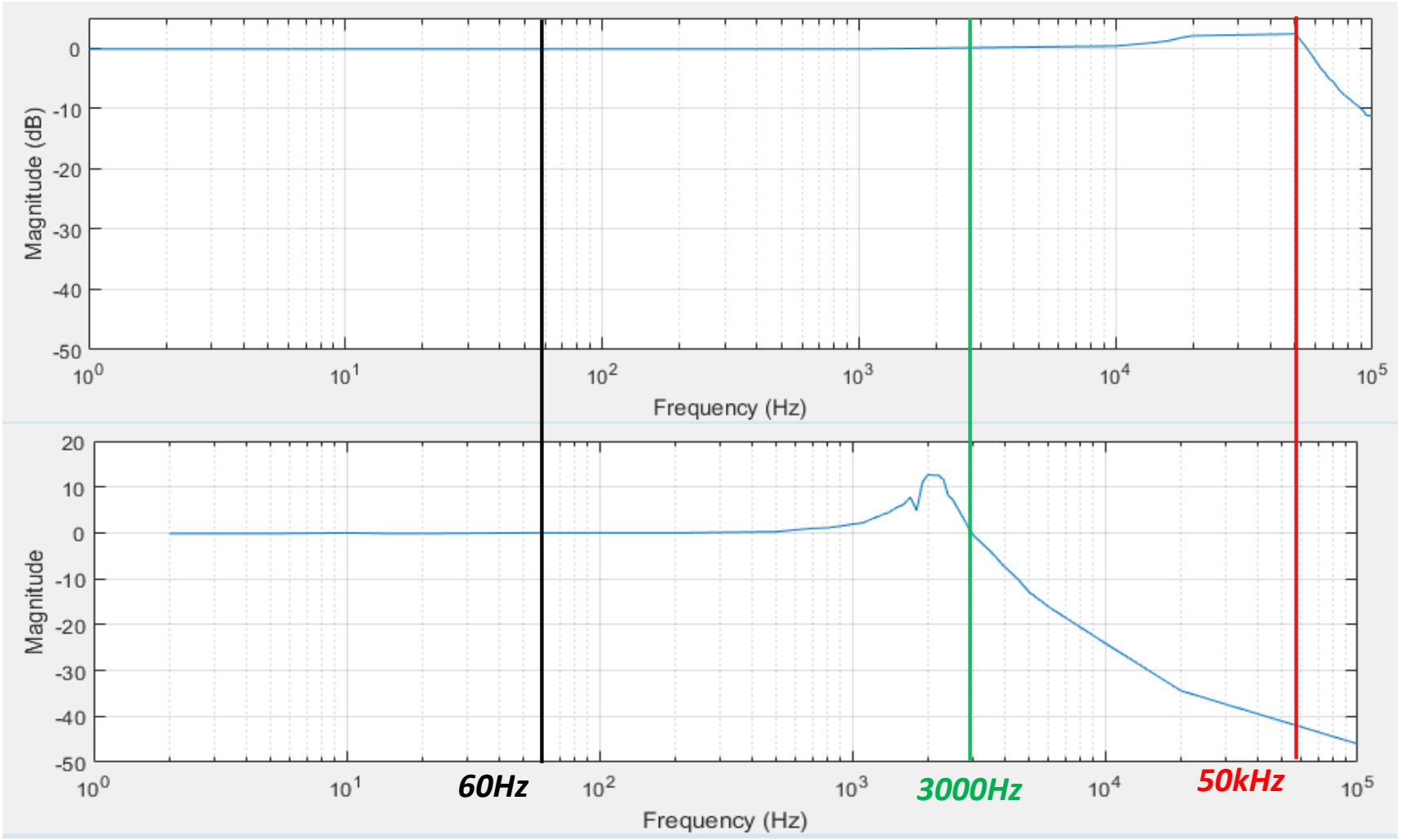
LC Filter


High Freq.
L
Low Freq.
Low Freq.
in
C
out
High Freq.

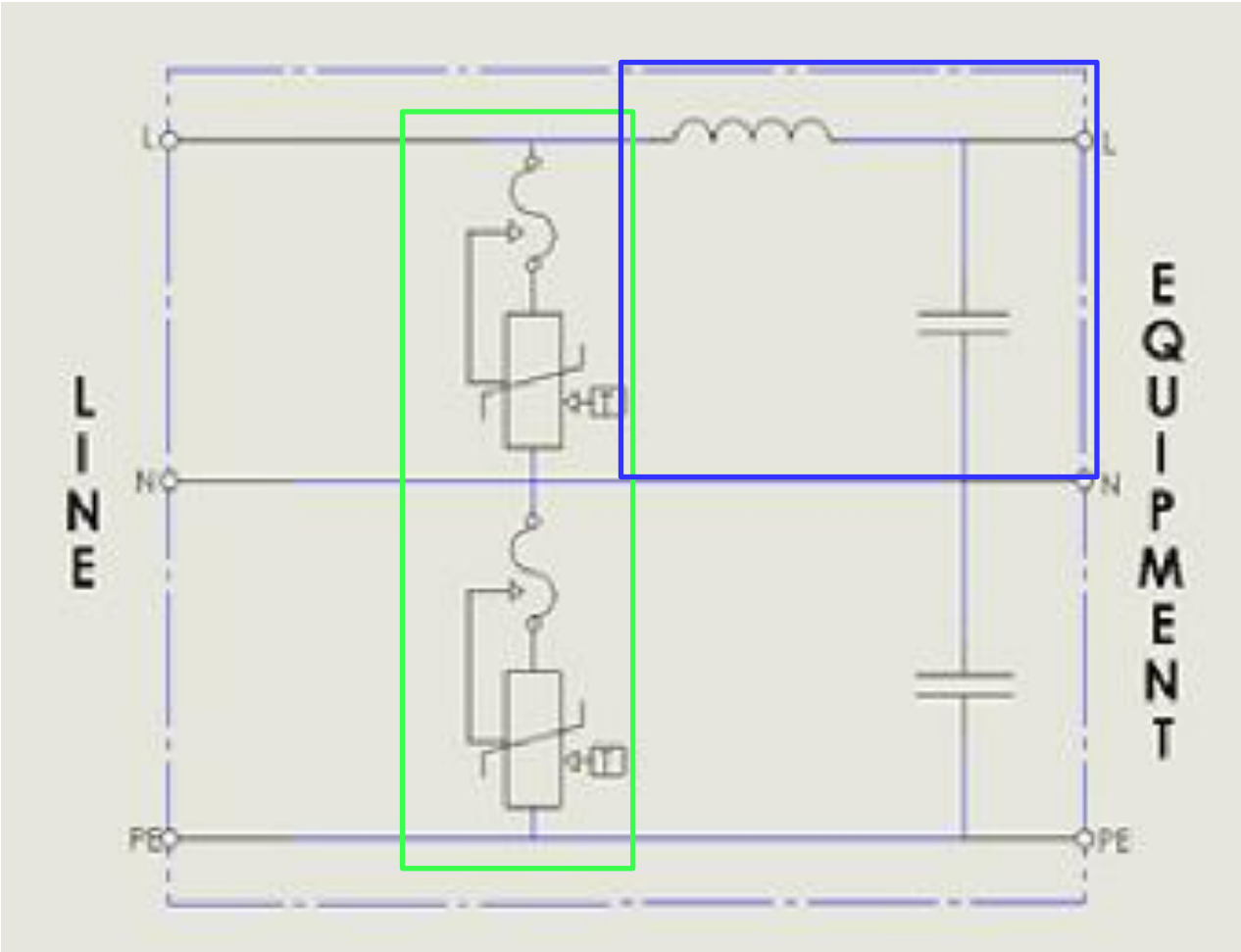

ζ = 0
ζ = 0.1
ζ = 0.2
ζ = 0.5
ζ = 0.7071
ζ = 1.0
A(dB)
40
20
0
-20
-40
-60
0.1
0.2
0.5
1.0
2.0
5.0
10
f
Log(f/f3dB)


Magnitude
20
10
0
-10
-20
-30
-40
-50
10^0
10^1
10^2
10^3
10^4
10^5
Frequency (Hz)

Comparing: RC vs LC



Combining these Functions

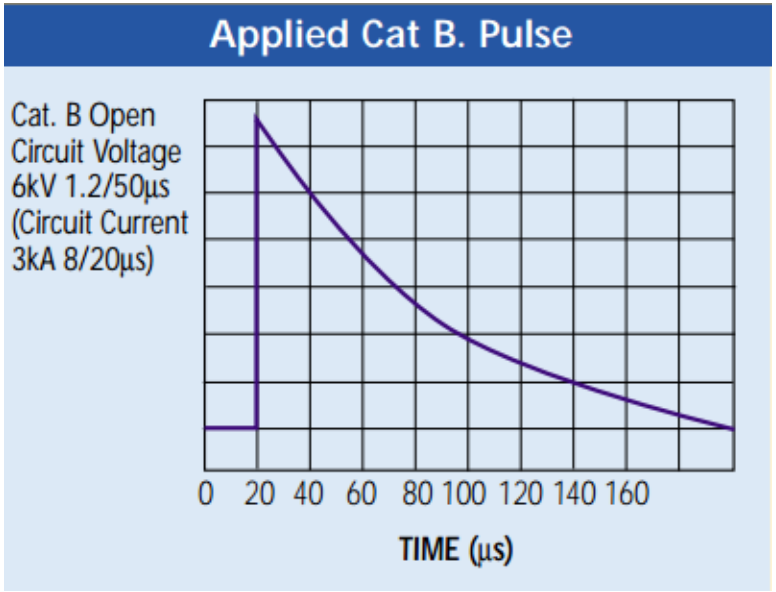


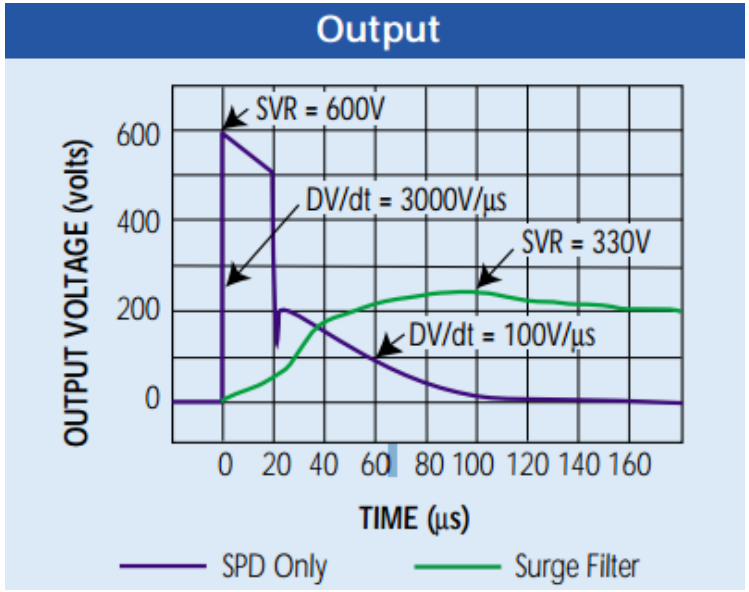
Low-Pass between LINE and NEUTRAL

Traditional Surge Protective Device (MOV, GDT…)

Combining these Functions

- Clamps transient voltage
- Slows the rate of voltage rise
- Attenuates small signal RFI/EMI noise problems



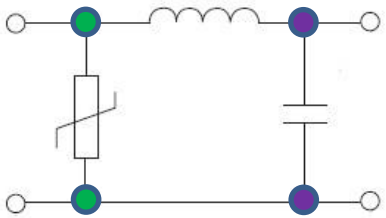


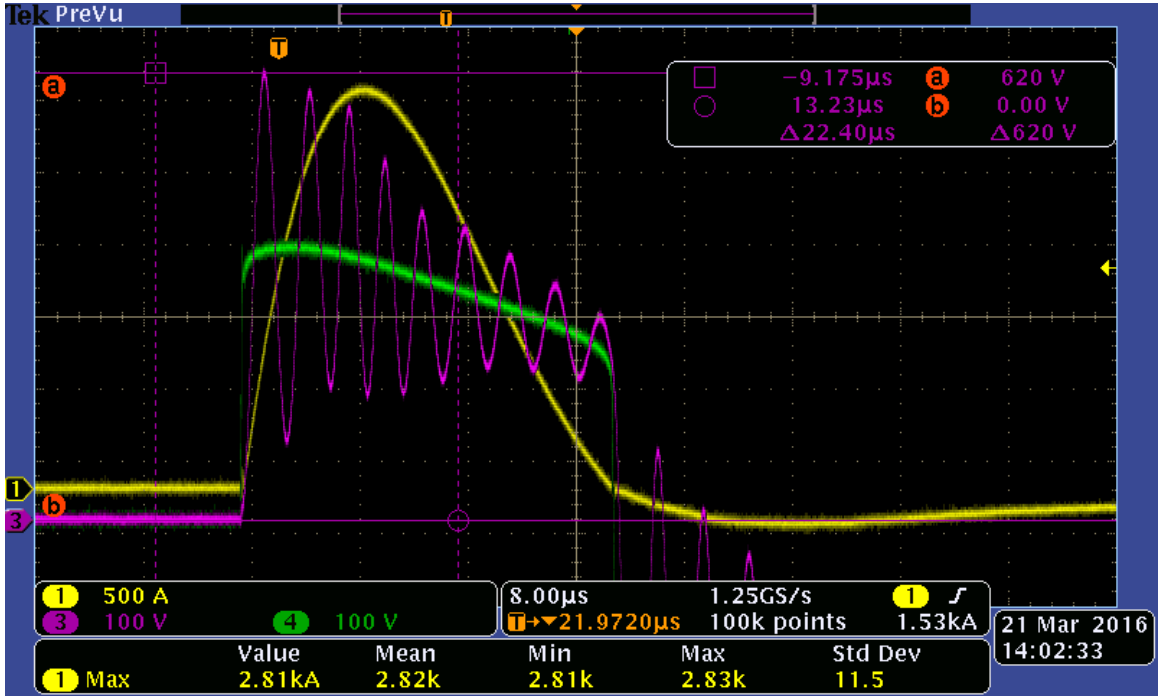
Surge Filter reduces let-through voltage!

Value Choices for inductor & capacitor

Filter – Negligible improvement but badly ringing

- 3kA 8/20us
- Green SPD output
  - 378Vpk
- Purple filter output
  - 620Vpk





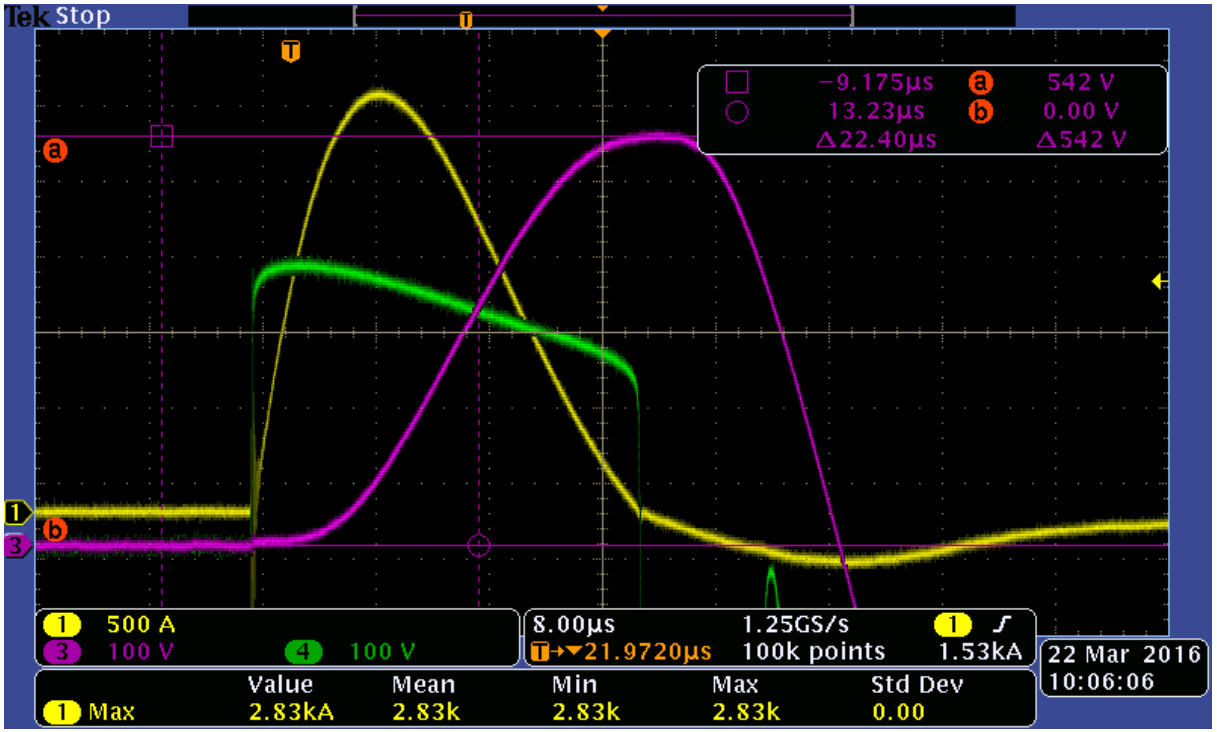
- No improvement over MOV only
- Harmful ringing of the LC filter actual makes the results worse

Filter ringing worsens results!

Value Choices for inductor & capacitor

Filter – Bad

- 3kA 8/20us
- Green SPD output
  - 370Vpk
- Purple filter output
  - 542Vpk



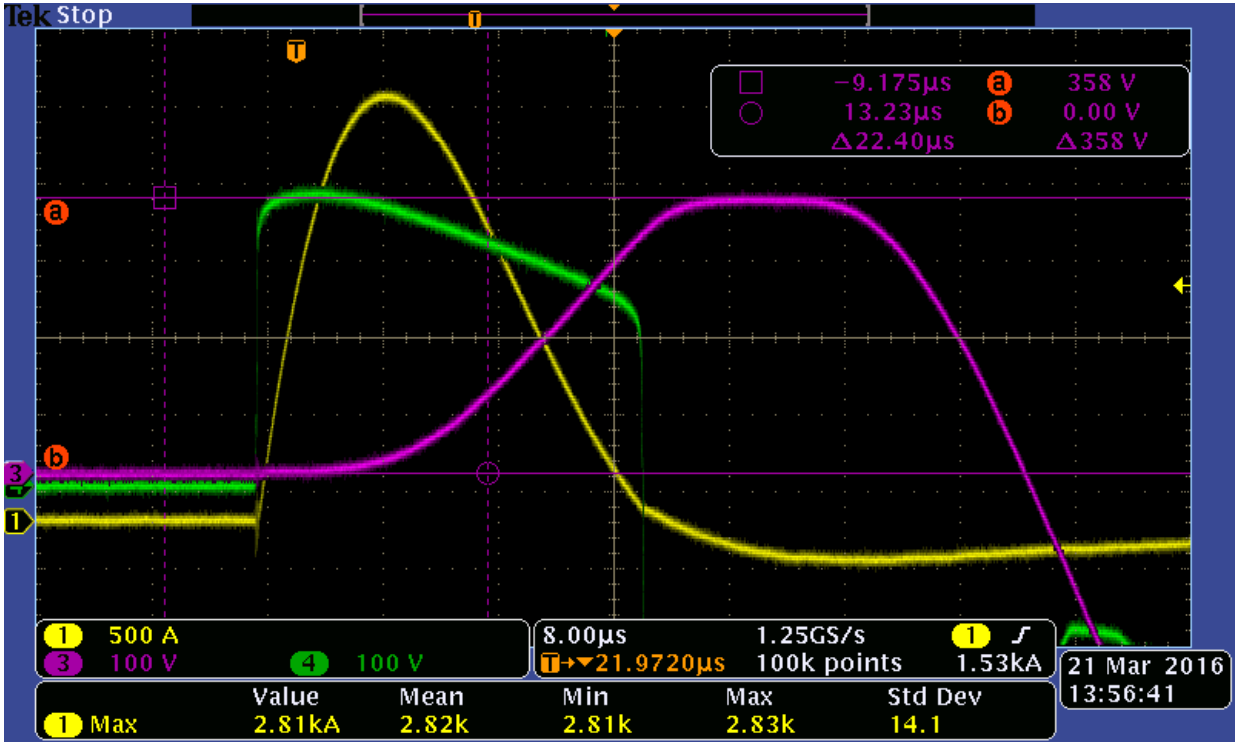
- Filter starts to improve the dV/dt
- The output voltage is still climbing even after MOV voltage has dropped.
- Once the inductor current reaches zero the output voltage peaks

Voltage continues to rise after MOV drops

Value Choices for inductor & capacitor

Filter – Good not Great

- 3kA 8/20us
- Green SPD output
  - 378Vpk
- Purple filter output
  - 358Vpk



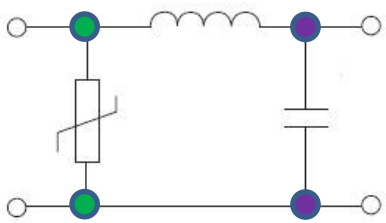
- Filter starts to improve the dV/dt
- The output voltage is still climbing even after MOV voltage has dropped.
- Once the inductor current reaches zero the output voltage peaks

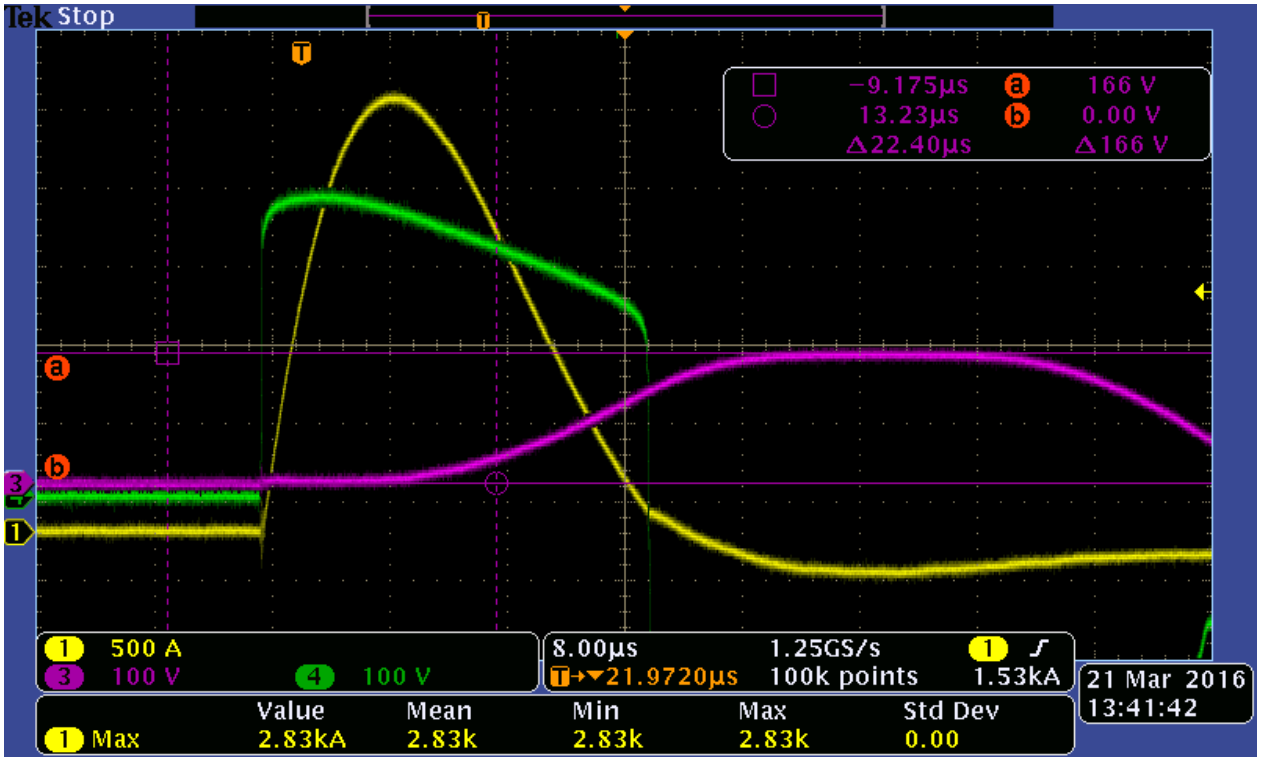
What is the point?

Value Choices for inductor & capacitor

Filter – Great Filter

- 3kA 8/20µs
- Green SPD output
  - 382Vpk
- Purple filter output
  - 166Vpk



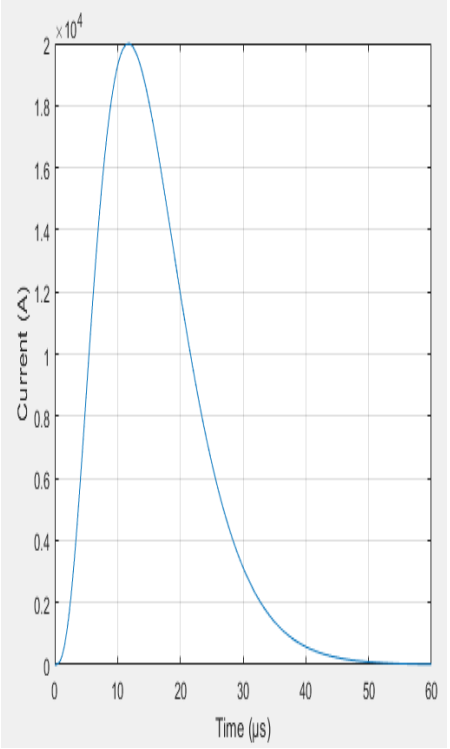


- Filter significantly reduced the dV/dt
- Filter output is less than the MOV alone

Filter reduces the output!

Cascading Stage Testing w/ TSF

Input Impulse



Stage 1

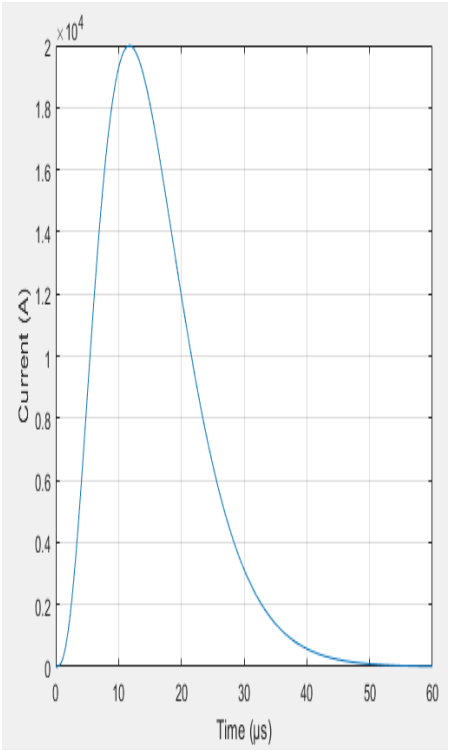
Type 1CA (UL1449)
20kA 8/20µs

Stage 2

Type 1/Type 2 (UL 1449)
10kA 8/20µs | 1600V

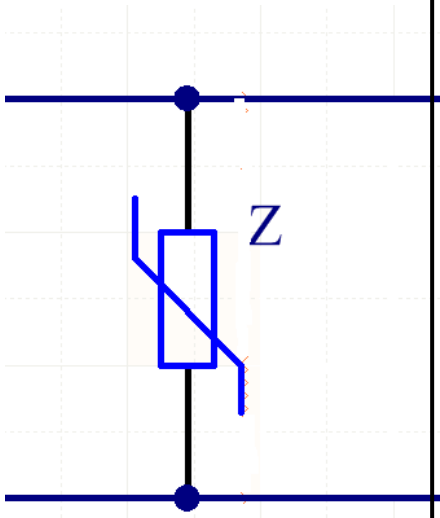
Cascading Stage Testing w/ TSF

Input Impulse



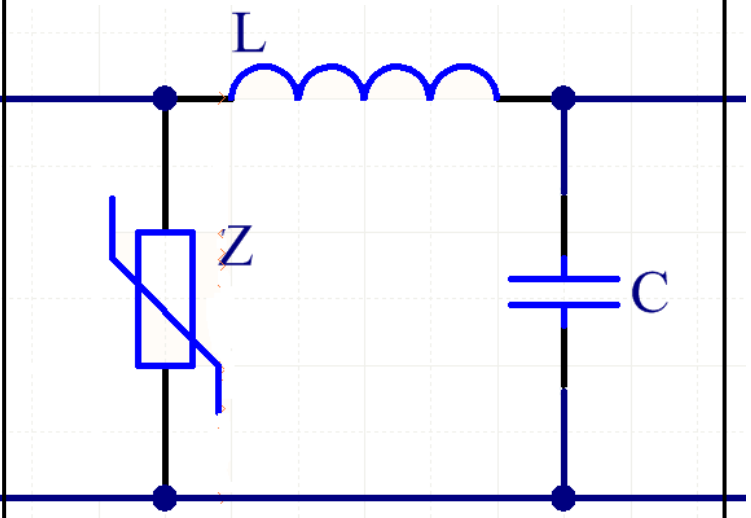
Stage 1

Type 1CA (UL1449)
20kA 8/20µs

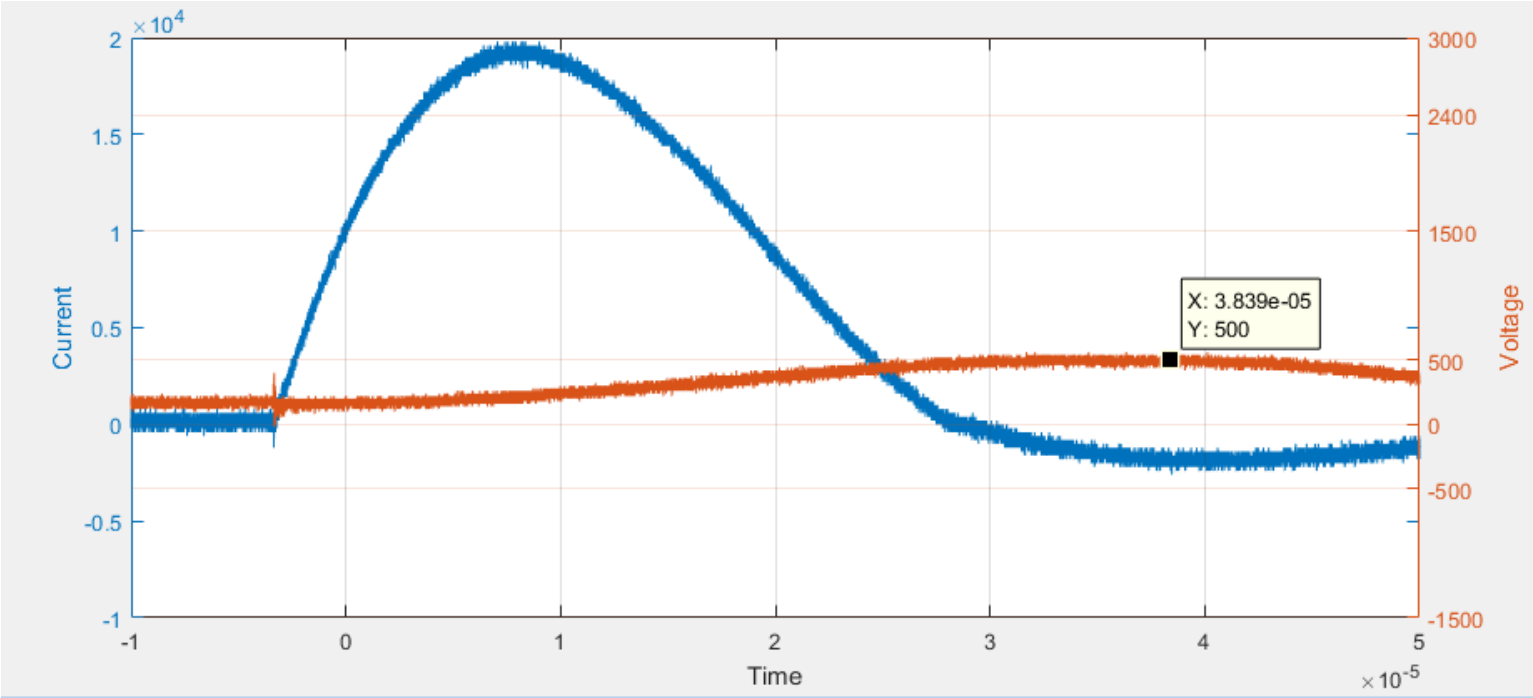


Stage 2

Type 1/Type 2 (UL 1449)
10kA 8/20µs | 1600V



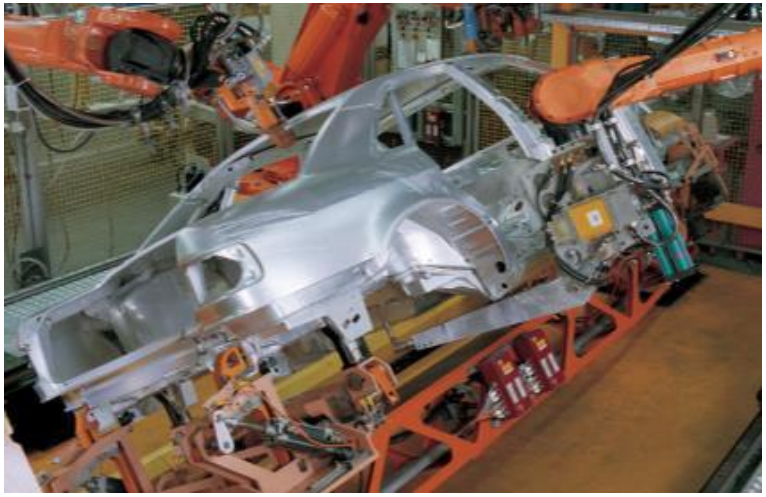
Cascading Stage Testing w/ TSF



Each stage diverts more energy and keeps the end voltage low

Many industries demand high performance protection

- Process Control
- SCADA and Telemetry
- Panel Shops / SI's
- OEMs
- Automotive
- Petrochem
- Telecom Power
- Lighting Control
- Water & Wastewater Treatment
- Medical Equipment
- Semiconductor Equipment

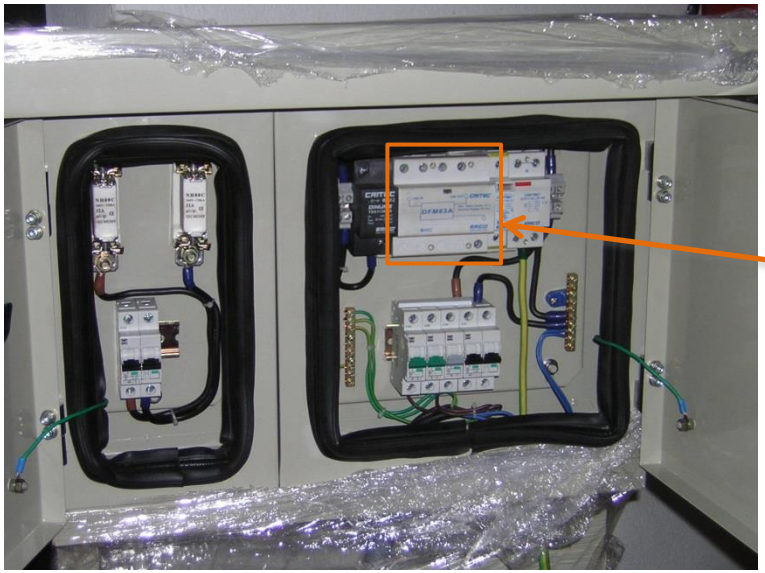


Many Applications…

Application: BTS Sites

Mobile Telecom Enclosure

- Standalone type BTS sites
- No shelters – trending upward
  - Small IP66 enclosure where they can fit all electrical switchgear equipment.



Example Application: Telecom BTS Sites

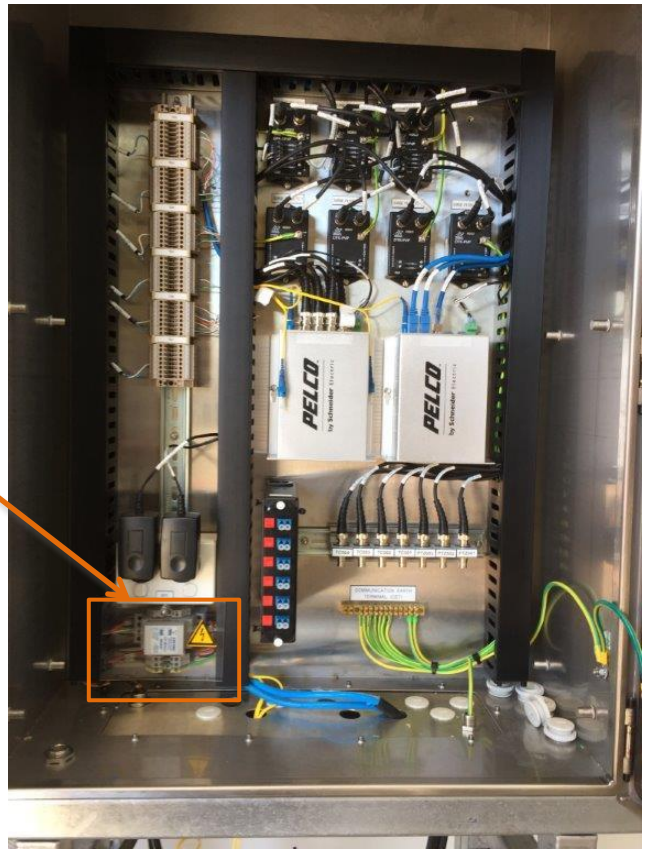
Application: Communication System at a LNG Extraction Facility

Telecommunications cabinets (Fiber nodes, telephones, CCTV)

Fiber Optic

Surge Filter
(240VAC - 6A)

CCTV



Example Application: Resource Extraction Telecom Cabinets

Application: Public Transit Pass

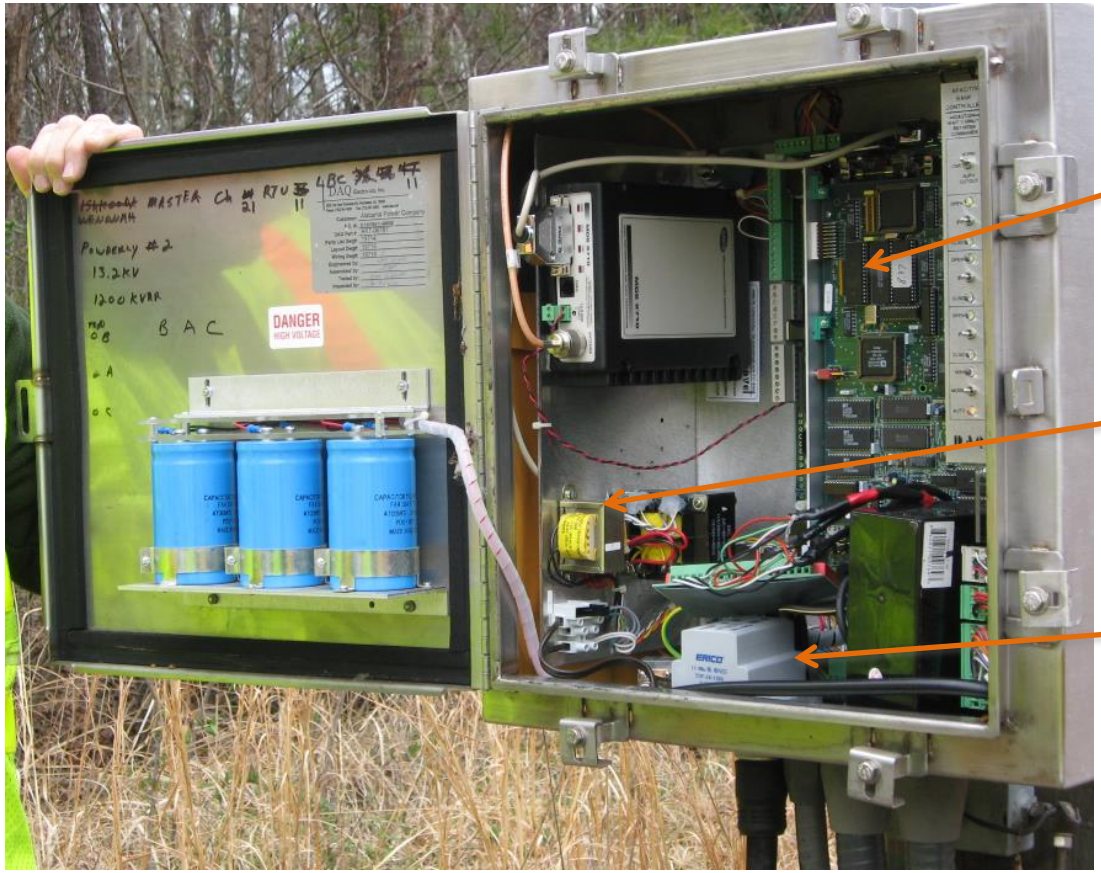
Fast Pass Reader for railway / subway stations

Fast Pass Reader

Example Application: Railway Pass Readers

Application: SCADA

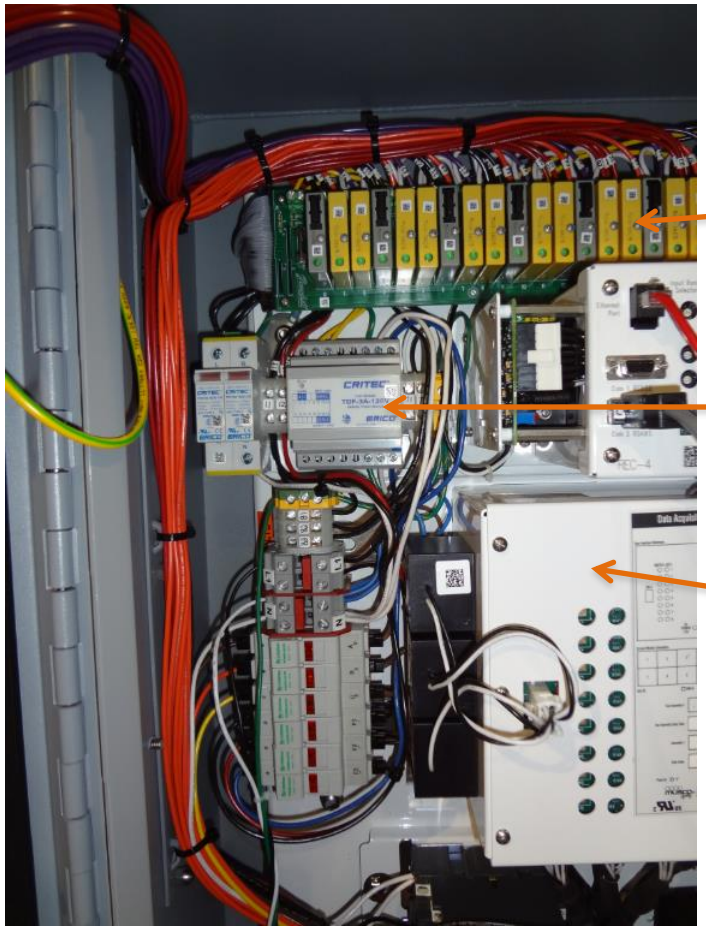
Remote Terminal Unit (RTU) used to take sections of the grid offline



Example Application: RTU

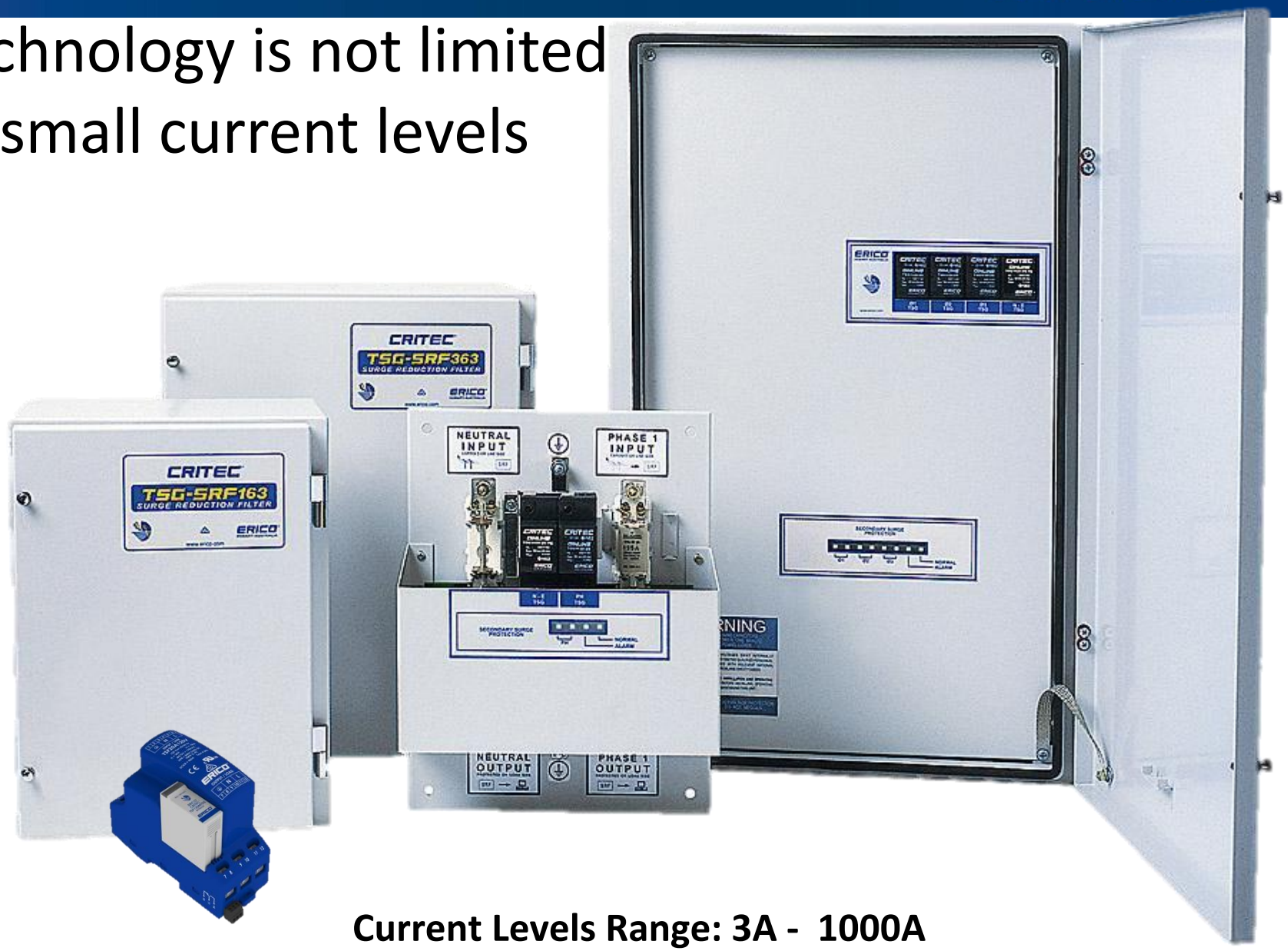
Application: Lighting Control

Lighting Control Panel



Example Application: Control Panel

Technology is not limited to small current levels

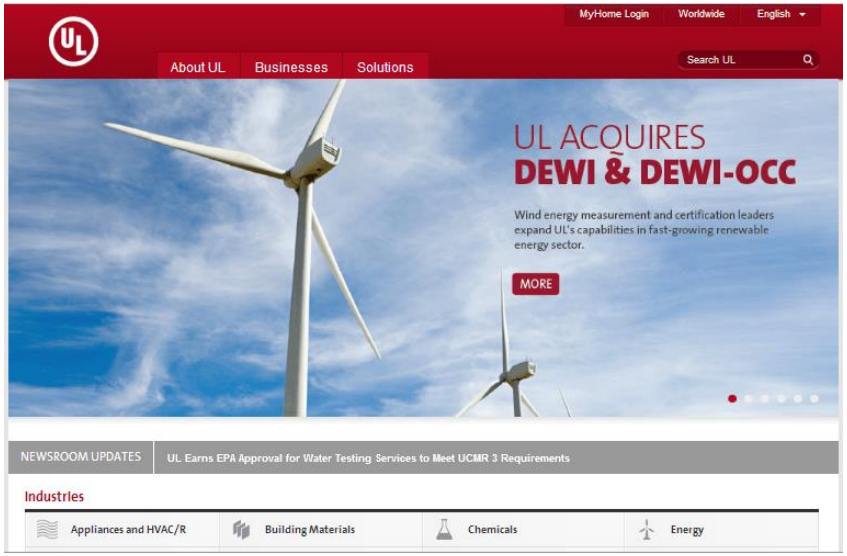


Current Levels Range: 3A - 1000A

What is a Surge Filter?

Relevant Standards for Surge Filters

- UL 1449 4th Edition – Standard for Surge Protective Devices
- UL 1283 – Standard for Electromagnetic Interference Filters
- IEC 61643-11 – Standard for Low-voltage Surge Protective Devices



RELEVANT STANDARDS!

QUESTIONS?

GREG.MARTINJAK@PENTAIR.COM

CHRISTIAN.BARCEY@PENTAIR.COM