WideBand Voltage Sensors For The Modern Substation

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Acknowledgements: Erik Sperling, Florian Gegier

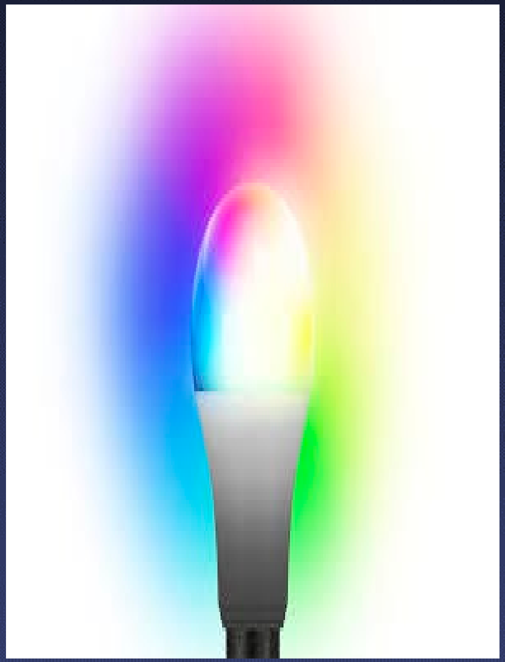
Presentation Outline

- Introduction
- Impacts To The High Voltage Equipment In A Network
- Types Of Instrument Transformers For Voltage Measurement
- Theoretical Aspects of RC-Dividers
- Frequency Response Behavior Of RC-Dividers
- Conclusions

Introduction

Generation

Consumer / Industrial



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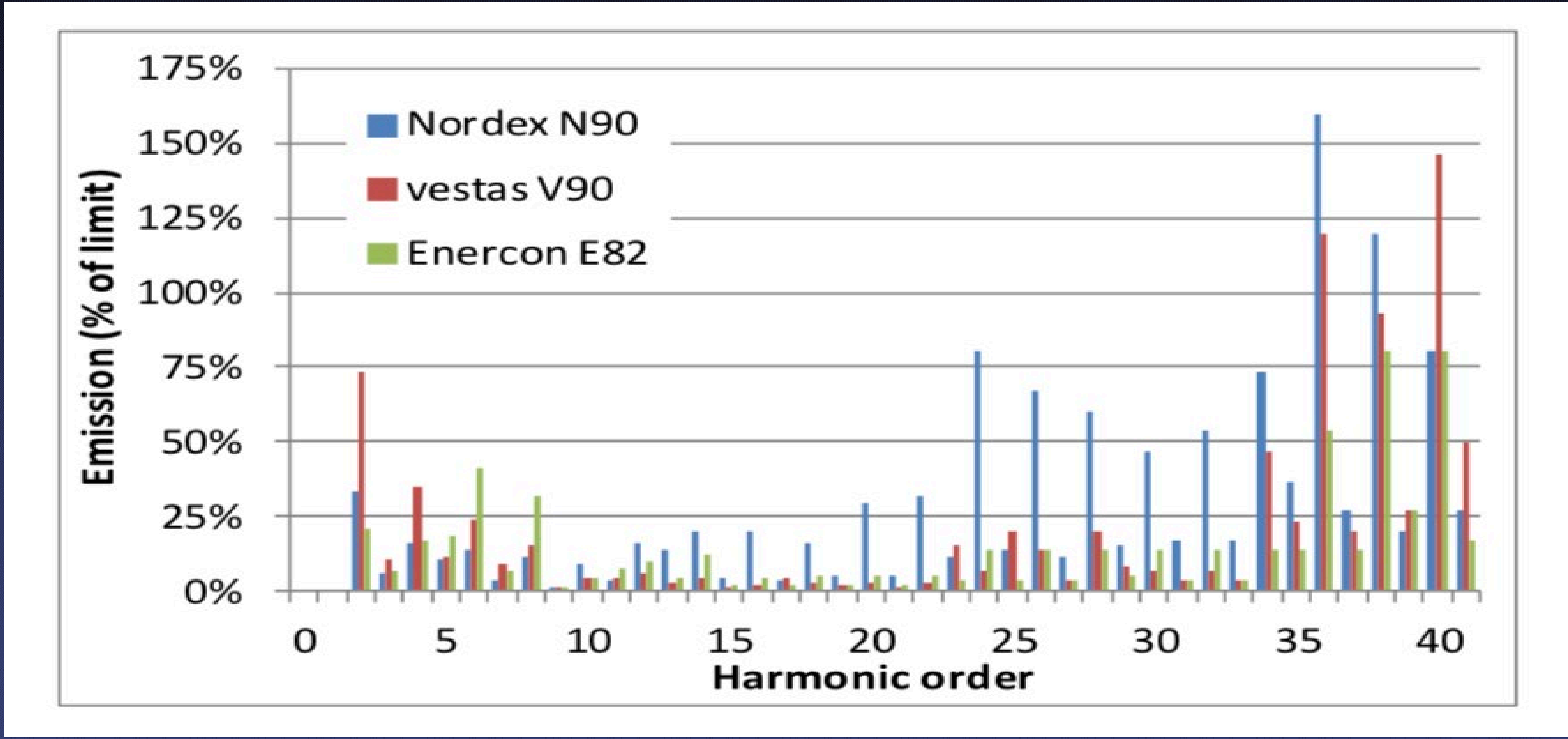
Harmonic Emissions – Per IEEE 519 Limits



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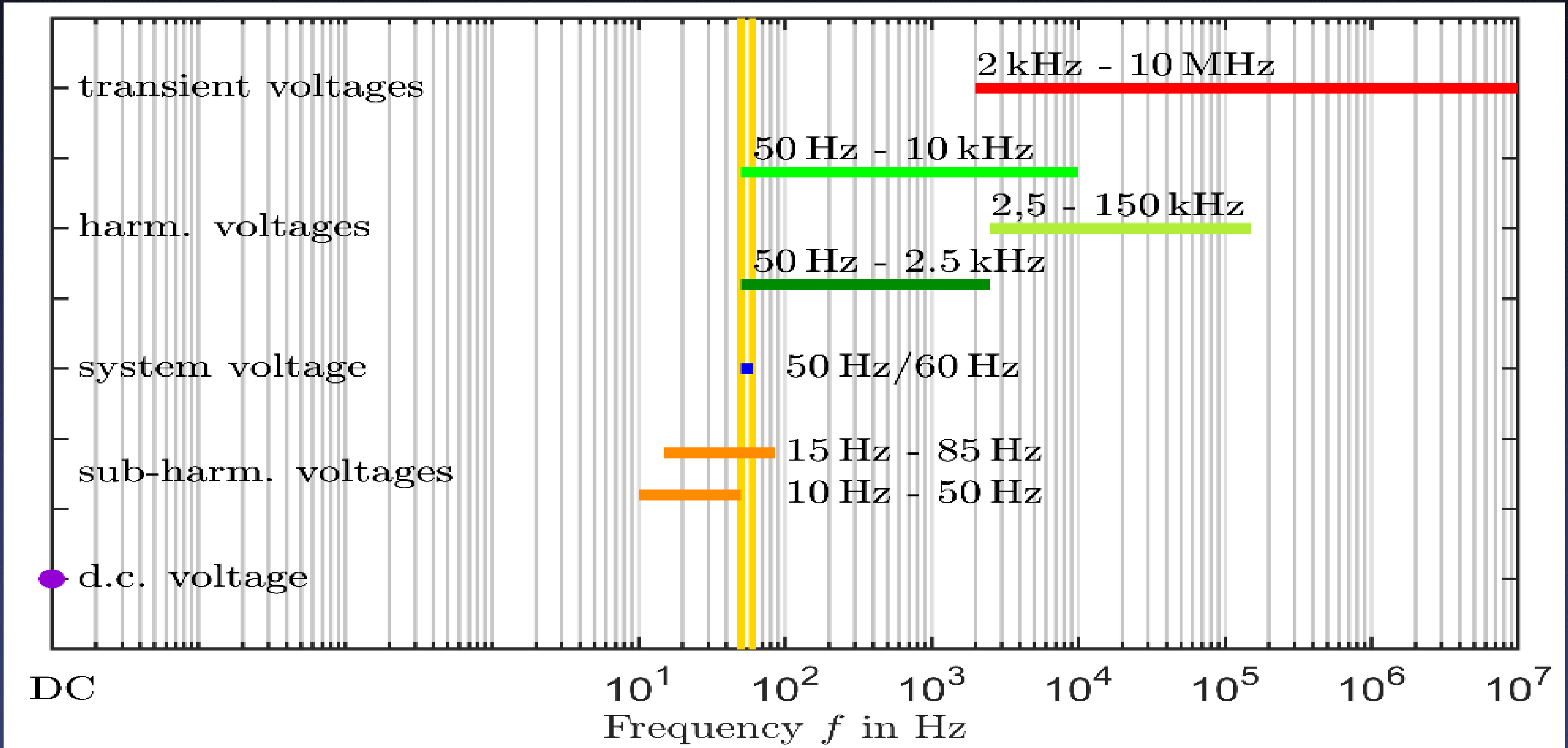
Other Emission Sources

Equipment	Voltage dips	Voltage swells	Harmonics	Interharmonics	Subharmonics	Supraharmonics	Slow voltage variations	Fast voltage variations	Transients	Voltage unbalance	Frequency variations	DC components
PV inverters	X											
Production units	X										X	
Active converters	X	X	X	X	X	X	X	X	X	X	X	X
LED lamps				X				X				
Power line communication						X			X			
Transformers						X			X			
Rotating machines						X			X			
Cable insulation						X						
Instrument transformers						X						
Three-phase converters										X		

Frequency Content



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Impacts To The High Voltage Equipment In A Network

- Increasing of power losses within the network
- Increasing electric stresses within the HV insulation system (permanently as well as transient)
- Thermal stresses within the connected equipment due to harmonic currents
- Increasing sound noise emission (transformers, coils, capacitors, etc.)
- Incorrect control of equipment
- Faulty activation of protection equipment (old protection system)
- Forced aging of high voltage equipment

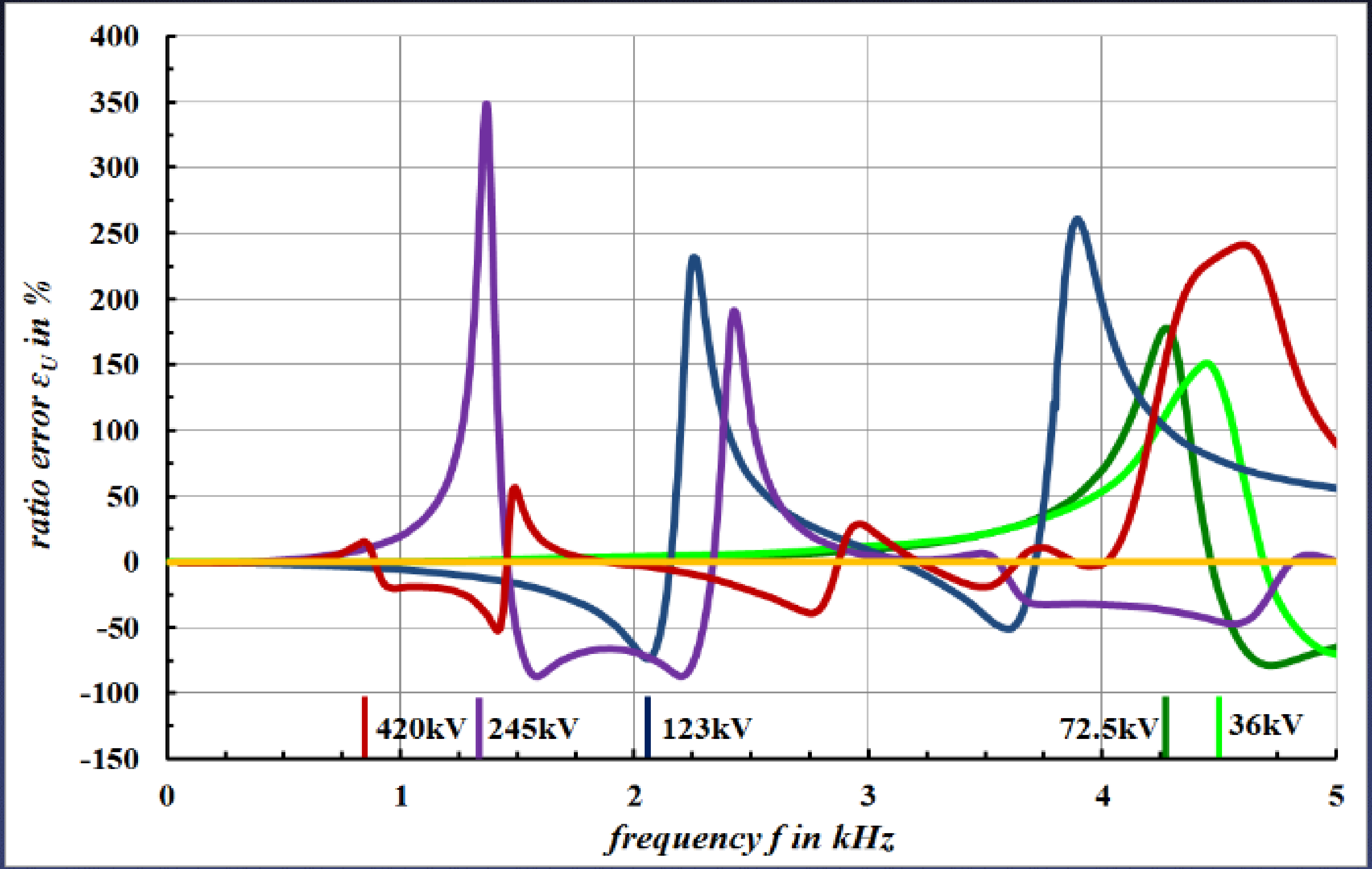
Types Of Instrument Transformers For Voltage Measurement

- Potential Transformer (PT)
    - Magnetically Coupled
    - Most Frequently Used

- Capacitive Coupled Voltage Transformer (CCVT)
    - As the name suggests capacitive coupling
    - Mature technology, but less frequently used

- Optically Coupled Voltage Transformer
    - Uses Faraday effect.
    - In Development.

Frequency Response – Magnitude Accuracy



Legend

36kV-VT(light green)

72.5kV-VT(dark green)

123kV-VT(blue)

245kV-VT(purple)

420kV-CTVT(red)

420kV-RC-divider (yellow)

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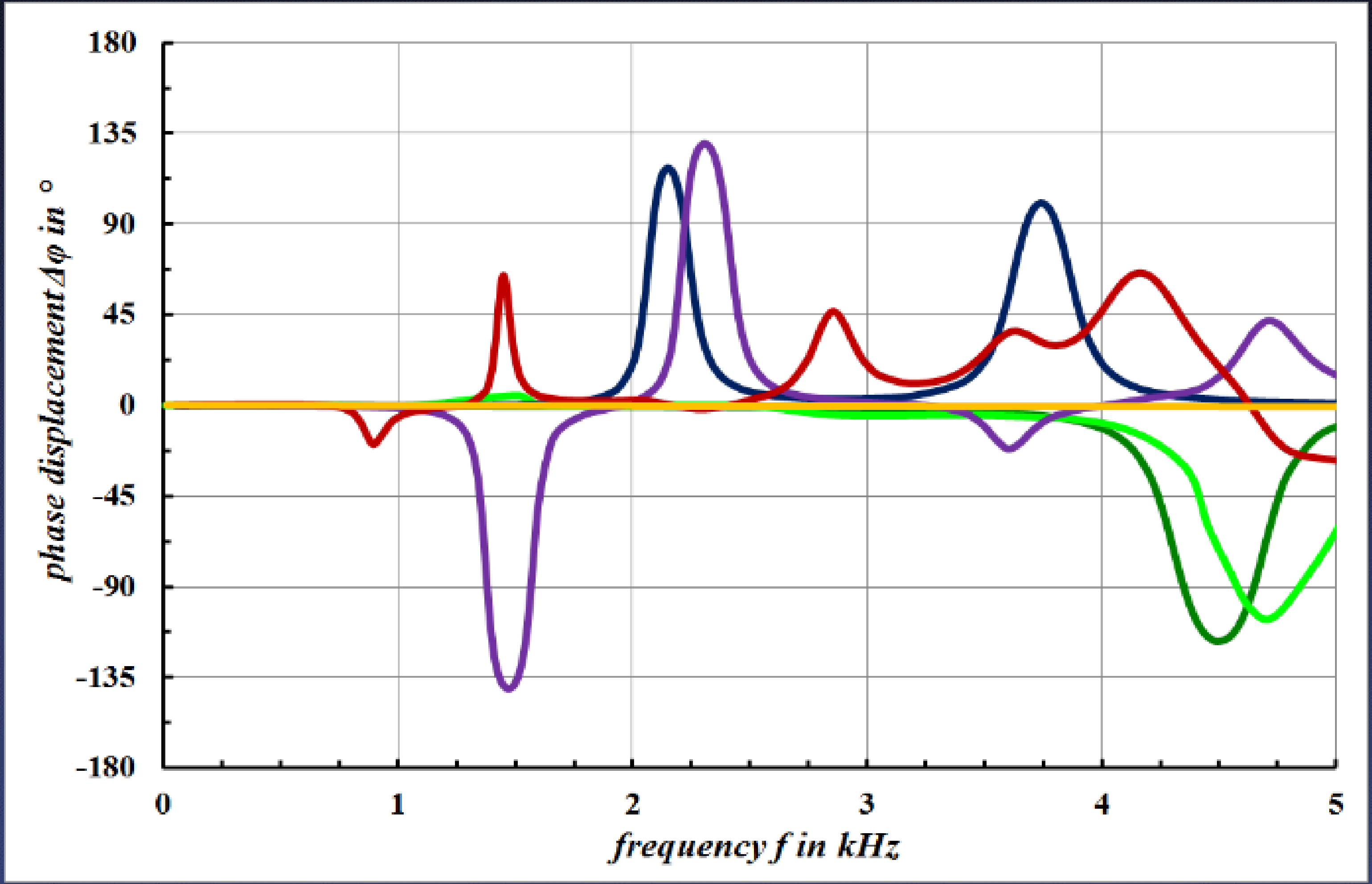
Frequency Response – Phase Shift Error



Legend

36kV-VT(light green)

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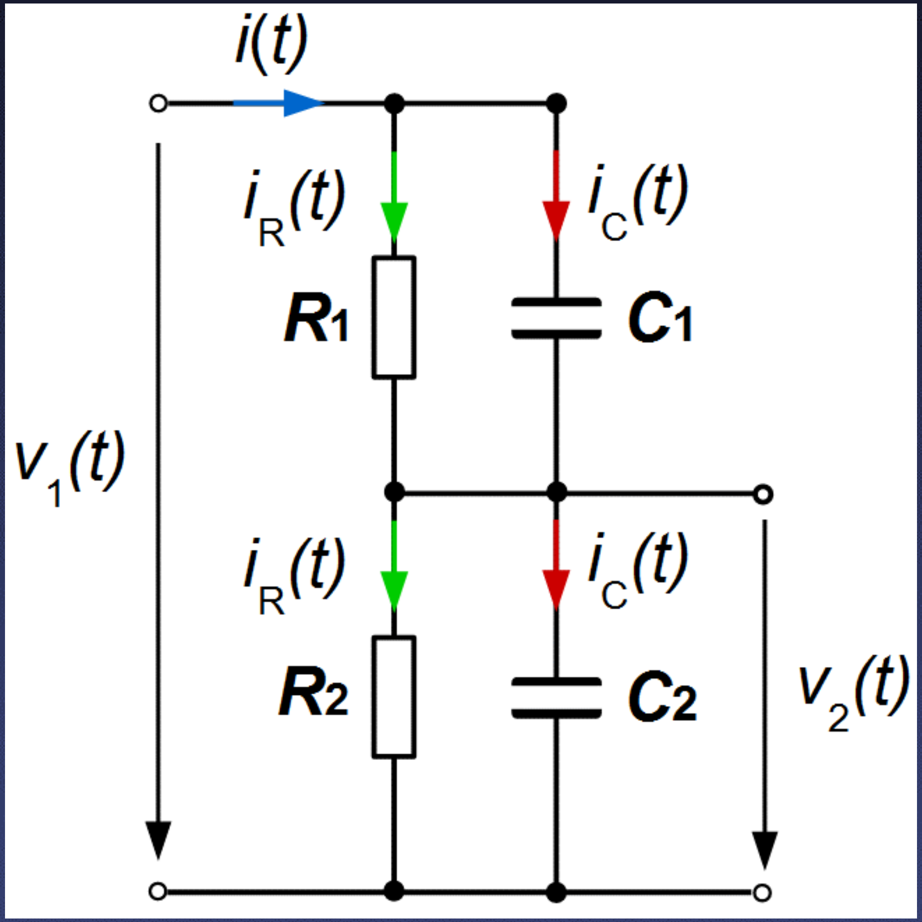
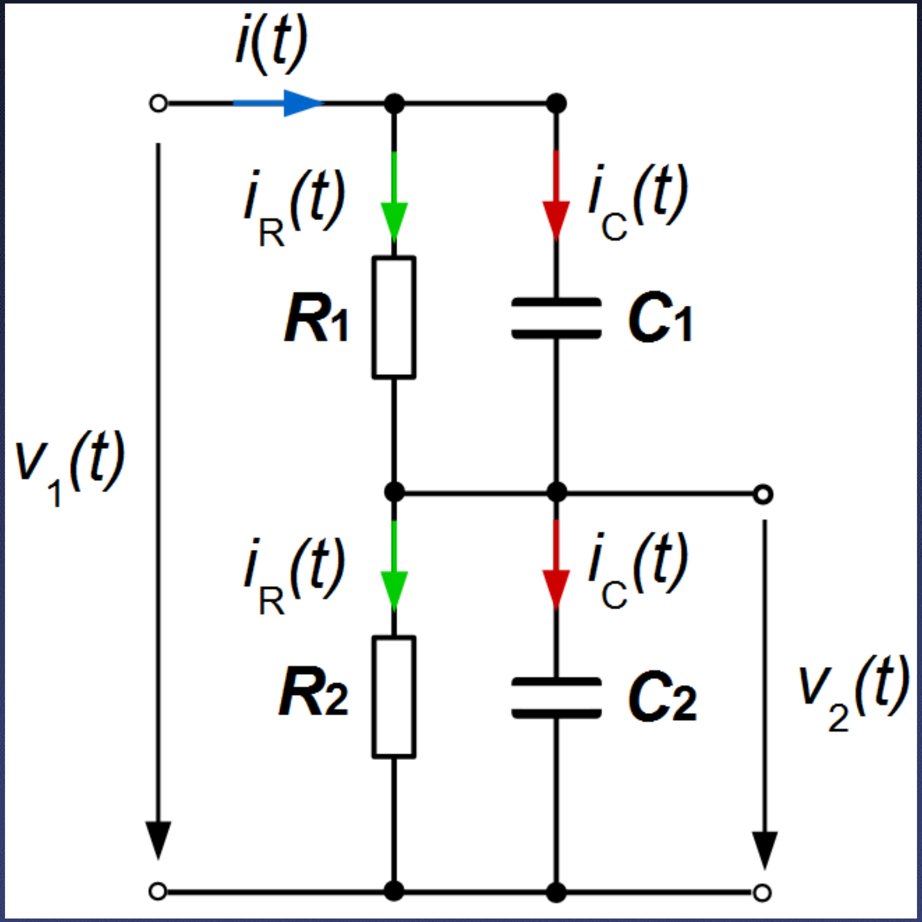
Theoretical Aspects Of RC-Dividers



V_1: Primary voltage
V_2: Secondary voltage
C_1: Primary capacitance
R_1: Primary resistance
C_2: Secondary capacitance
R_2: Secondary resistance
i_C: Capacitive current
i_R: Resistive current

Theoretical Aspects Of RC-Dividers

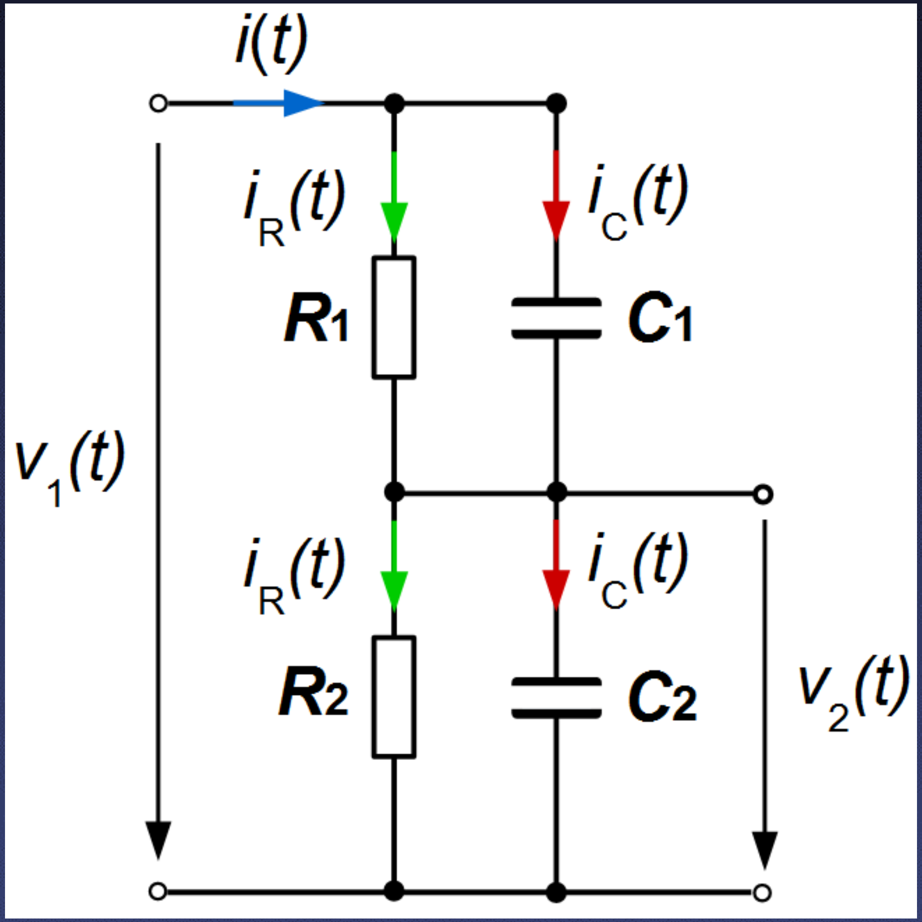


$$\underline{Z}_1 = \frac{R_1}{1 + j\omega C_1 R_1}$$

$$\underline{Z}_2 = \frac{R_2}{1 + j\omega C_2 R_2}$$

$$\underline{Z}_{\text{total}} = \frac{R_1}{1 + j\omega C_1 R_1} + \frac{R_2}{1 + j\omega C_2 R_2}$$

Theoretical Aspects Of RC-Dividers



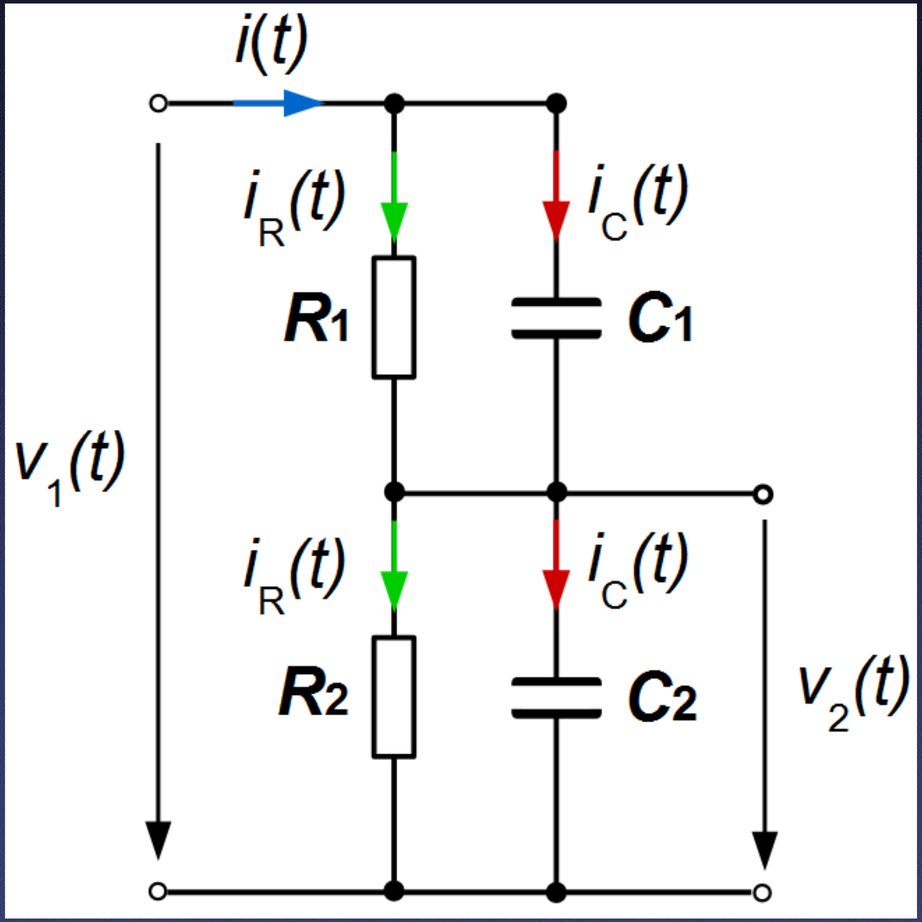
$$\underline{k}_{\mathrm{C}}(j\omega) = \frac{C_1}{C_1 + C_2 \cdot \frac{(1 + 1/(j\omega C_2 R_2))}{(1 + 1/(j\omega C_1 R_1))}}$$

$$\underline{k}_{\mathrm{R}}(j\omega) = \frac{R_2}{R_2 + R_1 \cdot \frac{(1 + j\omega C_2 R_2)}{(1 + j\omega C_1 R_1)}}$$

$$f \to \infty \qquad \frac{Z_2}{Z_{\text{total}}} = \frac{C_1}{C_1 + C_2}$$

$$f \to 0 \qquad \frac{Z_2}{Z_{\text{total}}} = \frac{R_2}{R_2 + R_1}$$

Theoretical Aspects Of RC-Dividers



$$\tau_1 = \tau_2 \;\rightarrow\; R_1 \cdot C_1 = R_2 \cdot C_2$$

1. $\tau_1 > \tau_2$, undercompensated
2. $\tau_1 = \tau_2$, compensated
3. $\tau_1 < \tau_2$, overcompensated

In case 2, the secondary voltage follows the primary voltage with a fixed time delay:

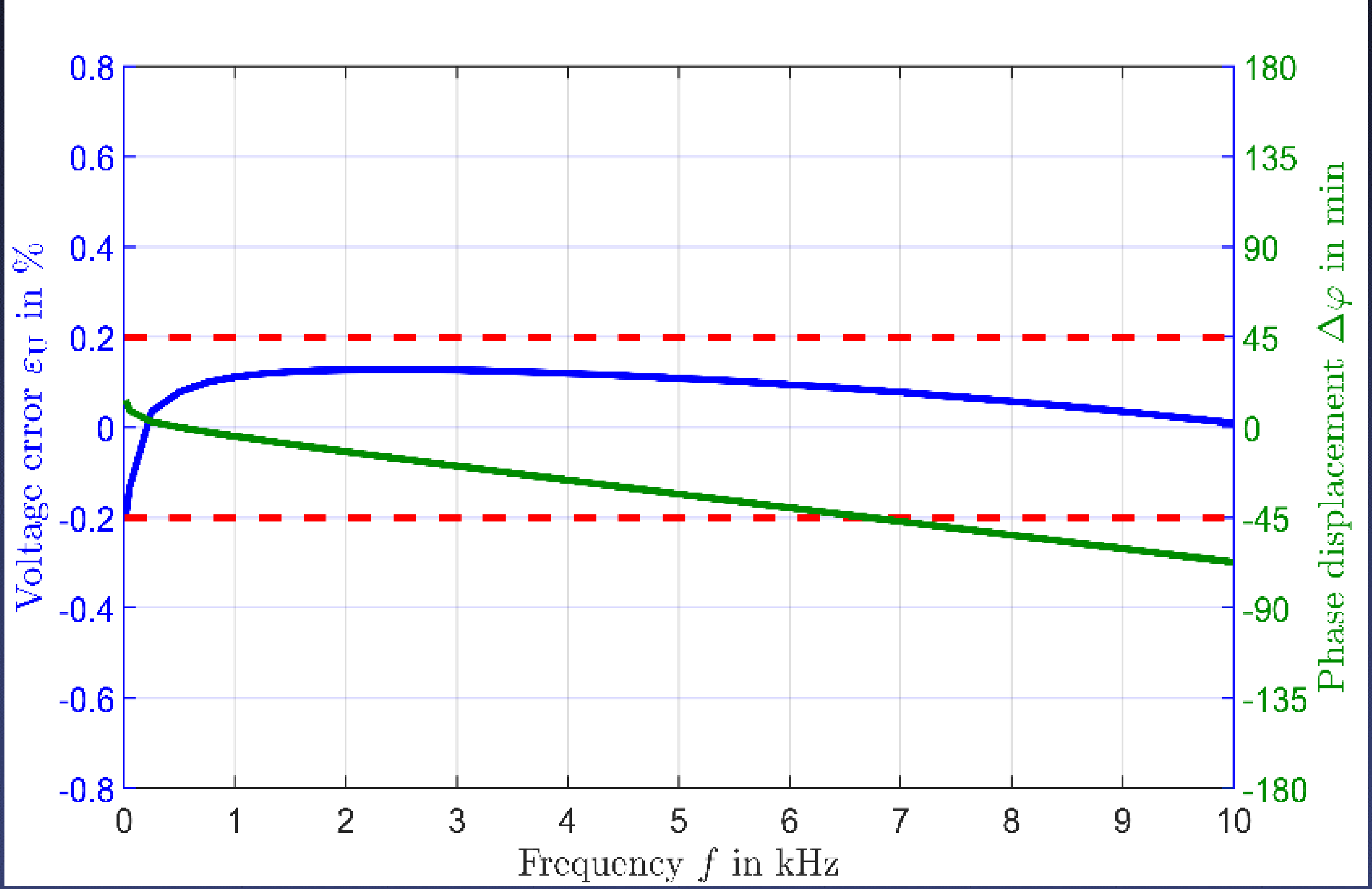
$$T_a = 2.2 \cdot \tau_1 = 2.2 \cdot \tau_2$$

Frequency Response Behavior Of RC-dividers

- For a variety of reasons, it is not possible to perfectly match the primary and secondary components, therefore:
  - $\tau_1 \neq \tau_2 \;\rightarrow\; R_1 \cdot C_1 \neq R_2 \cdot C_2$

- Frequency-dependent error formulas may be derived.

Frequency Response Behavior Of RC-dividers



Legend

Type: AIS RC-divider

Voltage accuracy – blue

Phase displacement – green

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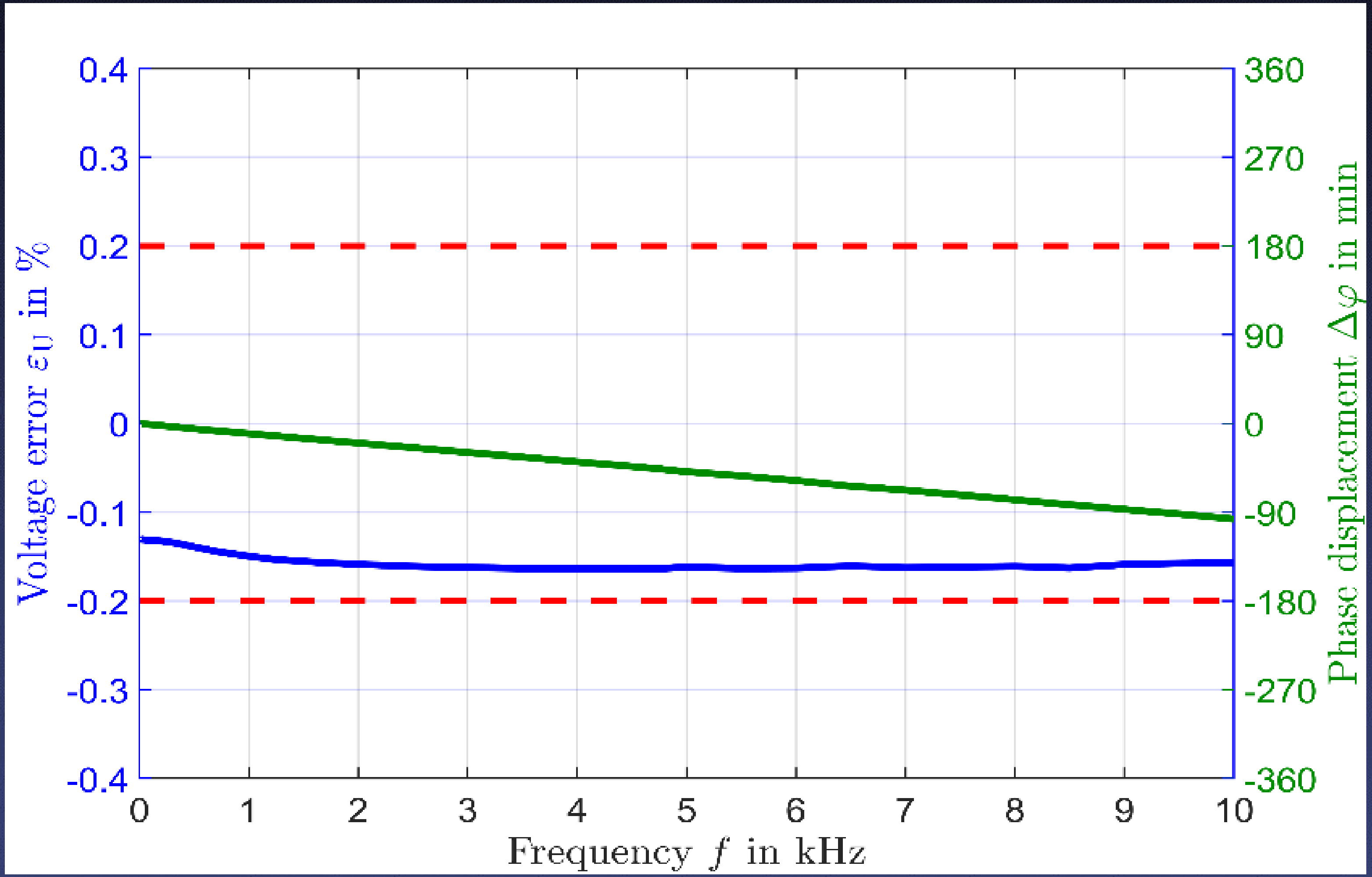
Frequency Response Behavior Of RC-dividers



Legend

Type: GIS RC-divider

Voltage accuracy – blue

Phase displacement – green

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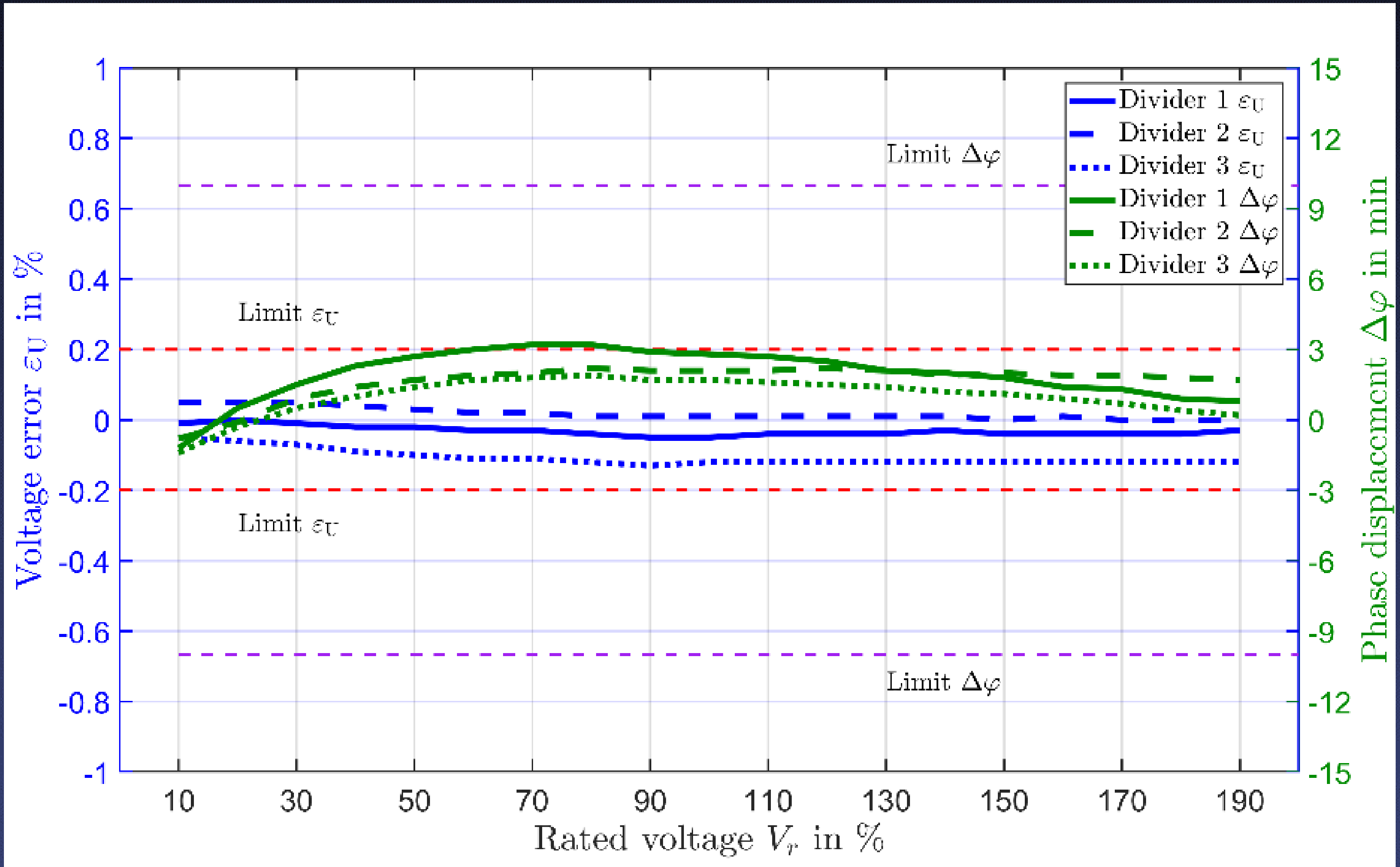
Frequency Response Behavior Of RC-dividers



Legend

Voltage accuracy – blue

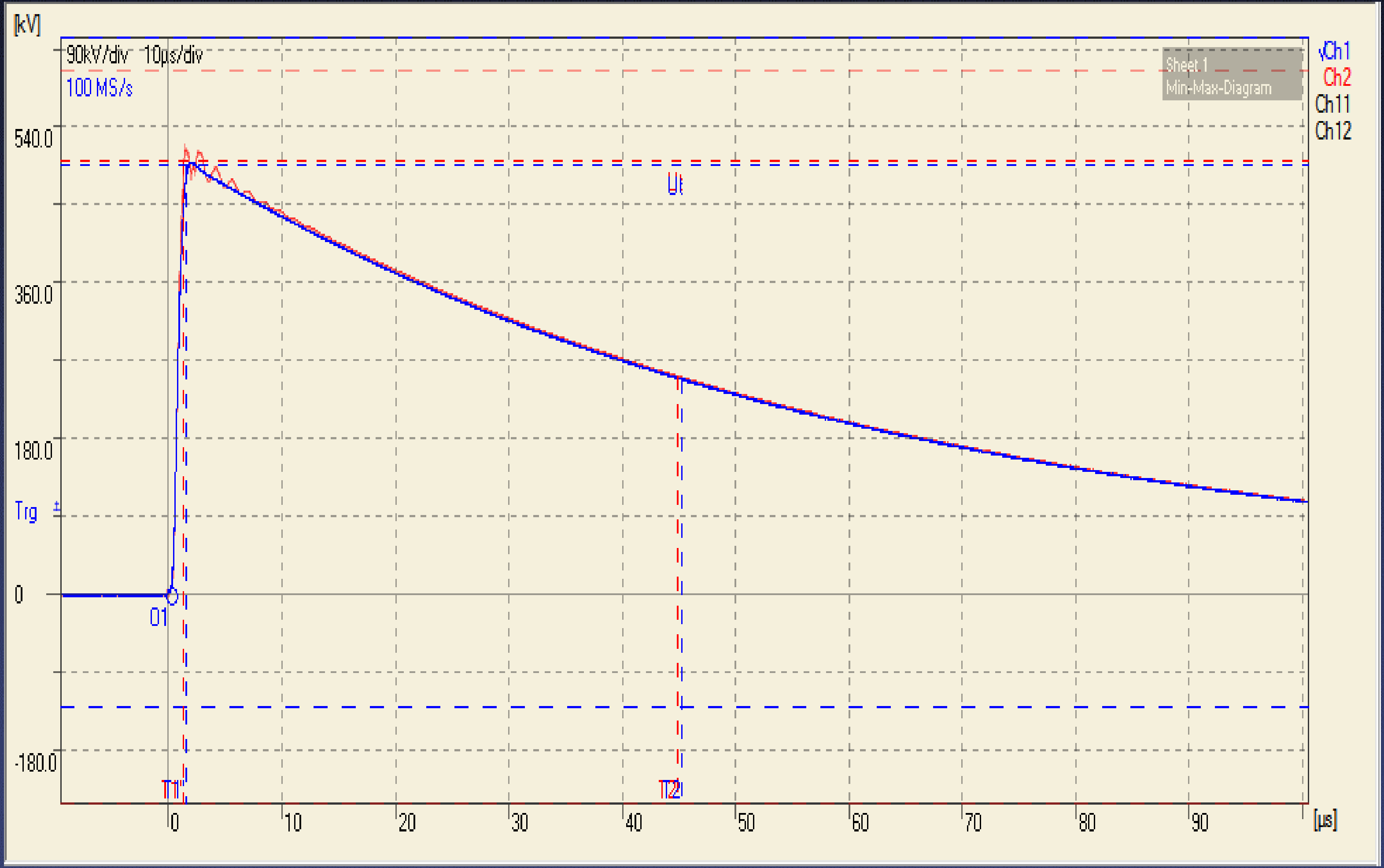
Phase displacement – green

IEC Accuracy Class 0.2

Voltage – Red

Phase displacement – Purple

Frequency Response Behavior Of RC-dividers



Legend

Type: GIS RC-divider

Input Signal: Impulse

Reference – Blue

Measured – Red

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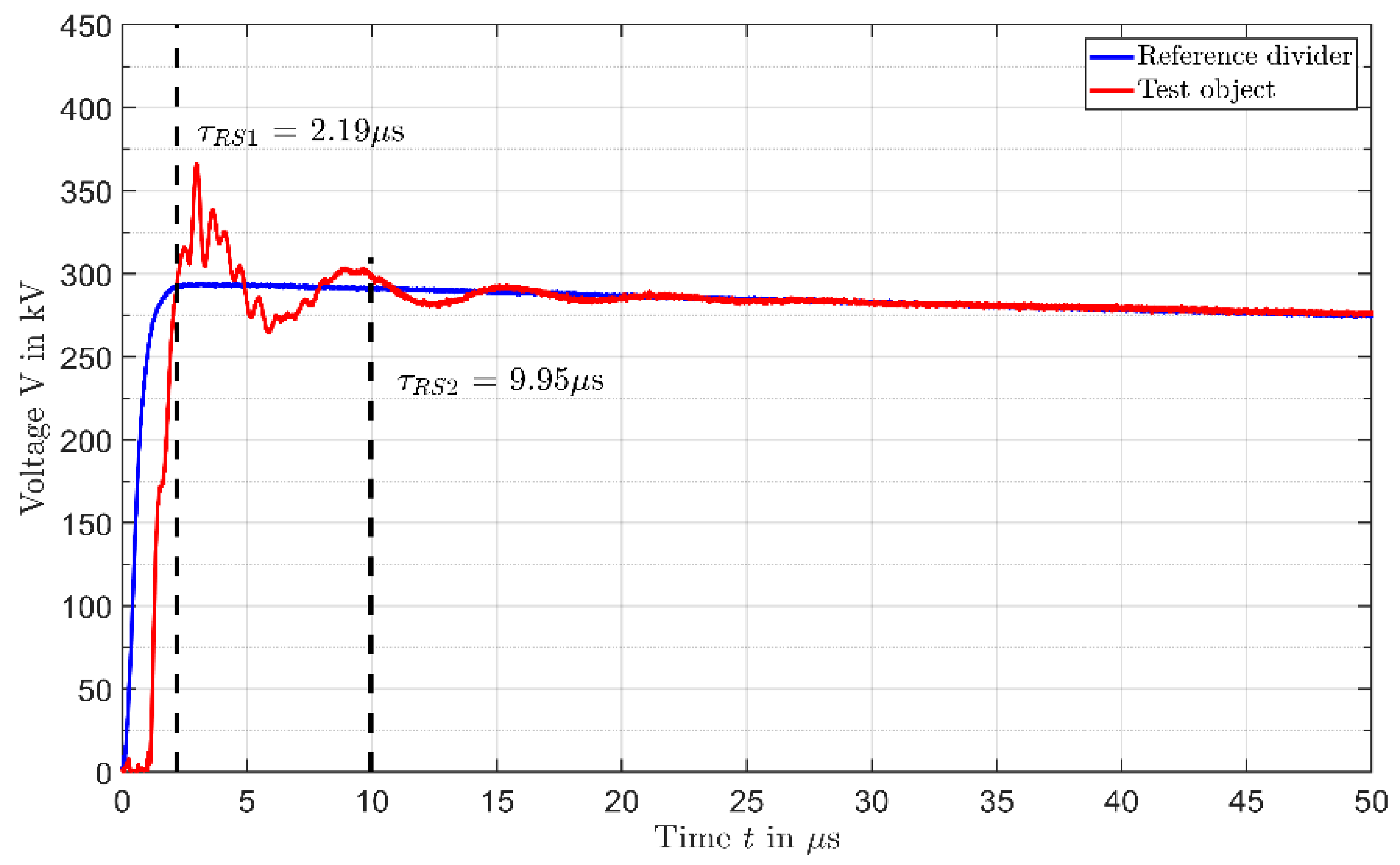
Frequency Response Behavior Of RC-dividers



Legend

Type: AIS RC-divider

Input Signal: Step Response

Reference – Blue

Measured – Red

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Conclusions

- The grid is becoming a "more noisy" place.
- Traditional measurement transformers may lack the bandwidth to accurately observe phenomenon on the grid.
- There are new types of measurement transformers which provide adequate frequency response with low measurement error.

- Final thought – present standards may not have accuracy classes which cover all of the necessary functions in the modern grid: revenue metering, protection, power quality measurement, etc.

Questions?

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PRESCRIPTIONS FOR THE POWER GRID IN THE DIGITAL AGE

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