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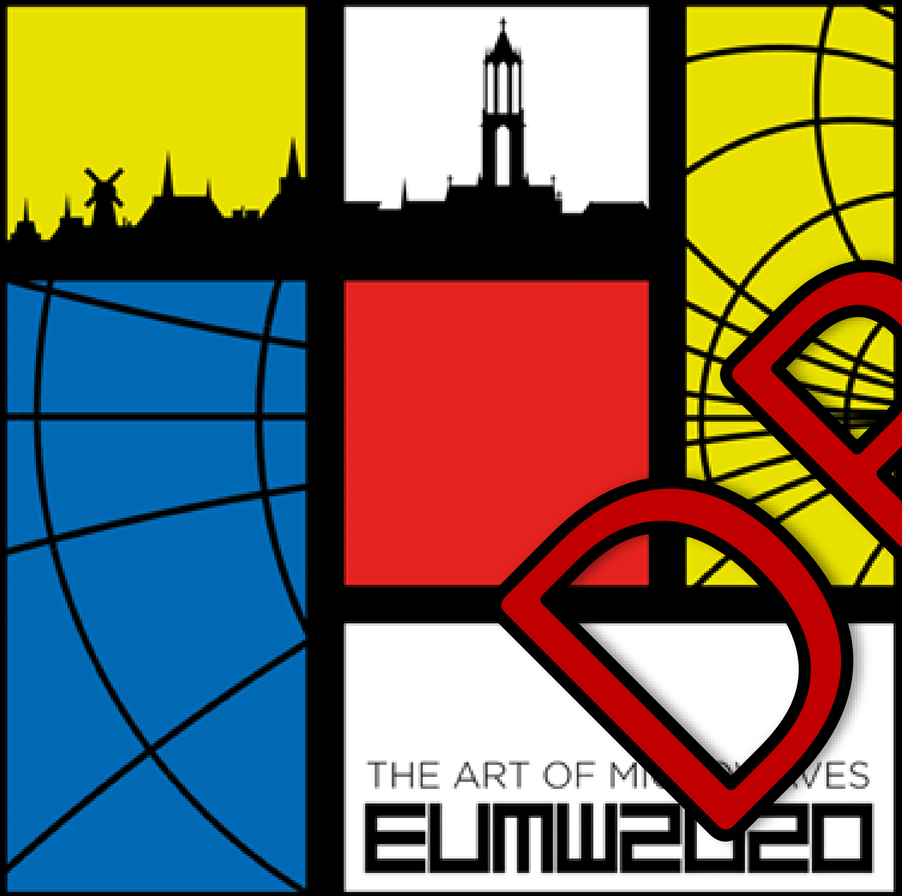
Generating Bipolar Nanosecond Pulsed Electric Field using Open Circuit Transmission Line Technique and Avalanche Transistors

EuMC52-3



Ilan Wyn Davies[1] and Christopher P. Hancock[2]
[1]MMSRG, Bangor University, Wales, UK
[2]Creo Medical Ltd, Chepstow, Wales, UK
[1]eeu25b@bangor.ac.uk

PRIFYSGOL BANGOR UNIVERSITY

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Author Introduction

Ilan Wyn Davies, MEng
Ph.D. Student / Student Microwave Engineer,
Bangor University / Creo Medical Ltd

Ilan's work is concentrated on the development of high voltage nanosecond pulses for electroporation applications. Raised in the heart of Snowdonia he completed his MEng degree in electronic engineering from Bangor University in 2017, where he is also undertaking his PhD at the Medical Microwave Systems Research Group.

PRIFYSGOL BANGOR UNIVERSITY

Prof Chris Hancock
Professor in Microwave Medical Devices / Chief Technical Officer
Bangor University / Creo Medical

Chris is the founder of Creo Medical with over 20 years' of experience in medical device development. He holds a personal Chair in the Medical Microwave Systems Research Group at Bangor University. Chris is a Fellow of the Institute of Physics, a Chartered Physicist, Fellow of the Institute of Engineering and Technology, a Chartered Engineer and a Senior Member of the IEEE.

Chris is a named inventor and lead author on over 500 patents/patent applications and international journal publications.

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- Theory of Operation
- Open Circuit Co-Axial Transmission Line Technique
- Avalanche Transistors Technique
- Monopolar nsPEF
- Bipolar nsPEF
- Conclusion
- Future Work
- Acknowledgments

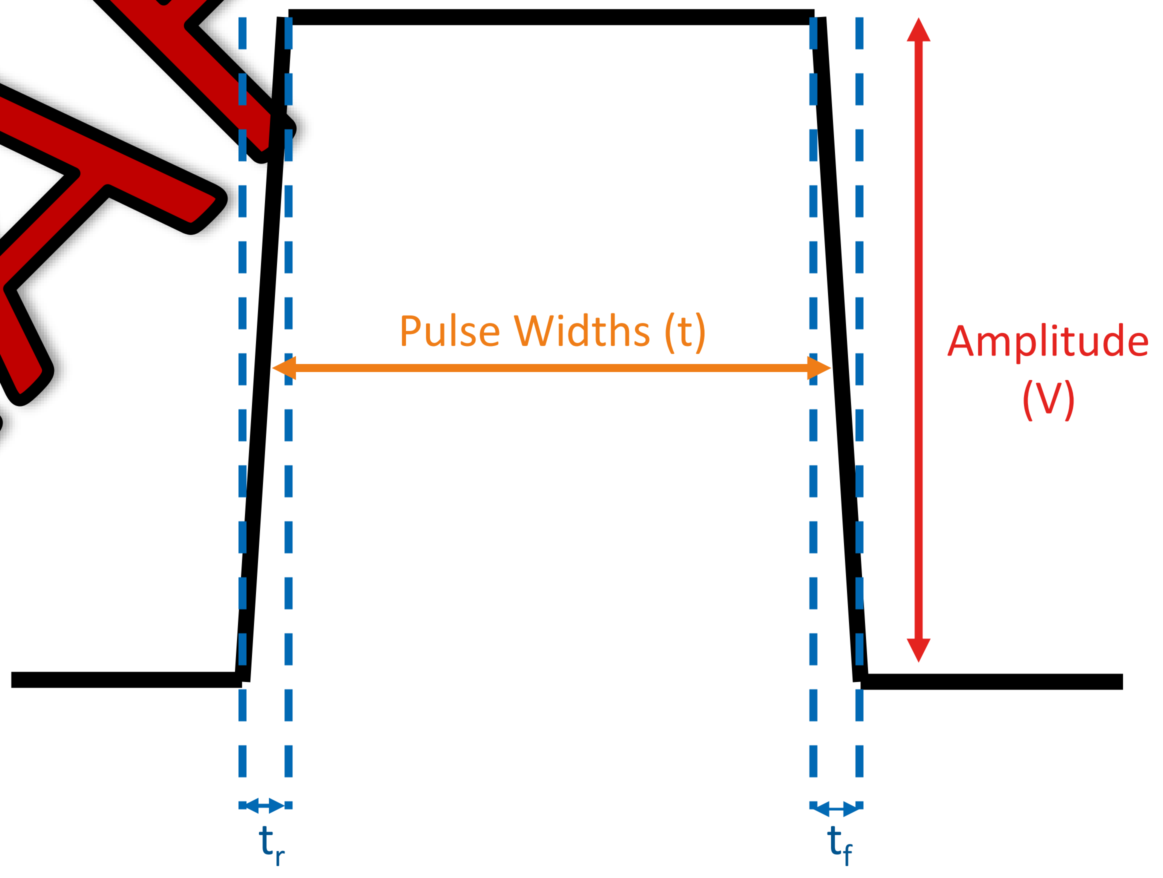
DRAFT

Research Introduction

- Development of nanosecond pulse electric fields (nsPEFs) generators
- Application on biological cells and tissues for cancer stem cells treatment
- Effects include increased plasma permeability of the cell membrane, calcium (Ca++) release, ion channel activation and apoptosis induction.
- Part of a European Union's Horizon 2020 funded project, SUMCASTEC http://www.sumcastec.eu/
- Continuation of published work: https://doi.org/10.1017/S1759078719000576

Theory of Operation

- **Objective: Produce nanosecond pulsed electric field (nsPEFs)**
  - Pulse Widths: 10 ns – 100 ns
  - Amplitude: 500 V+
  - Repetition: Rate 1 – 50 Hz
  - Transition times (t_r and t_f): < 2 ns



Theory of Operation

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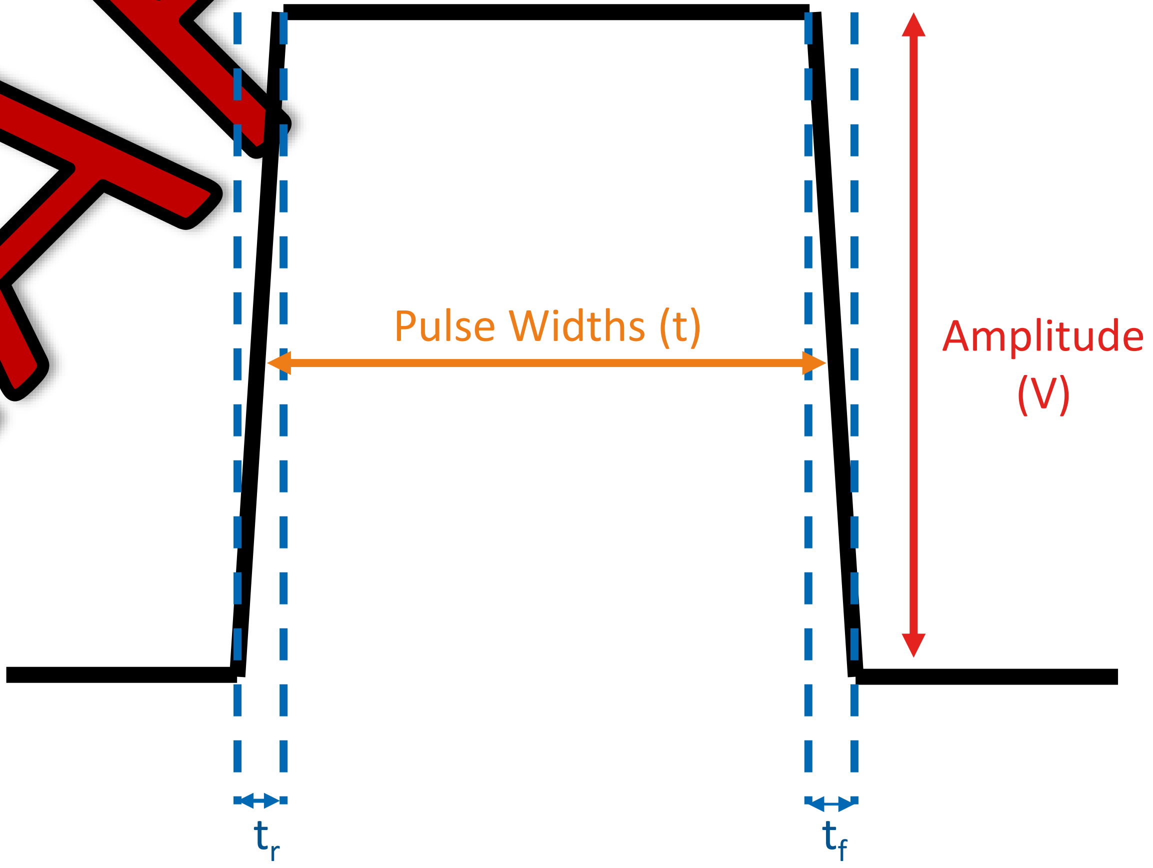
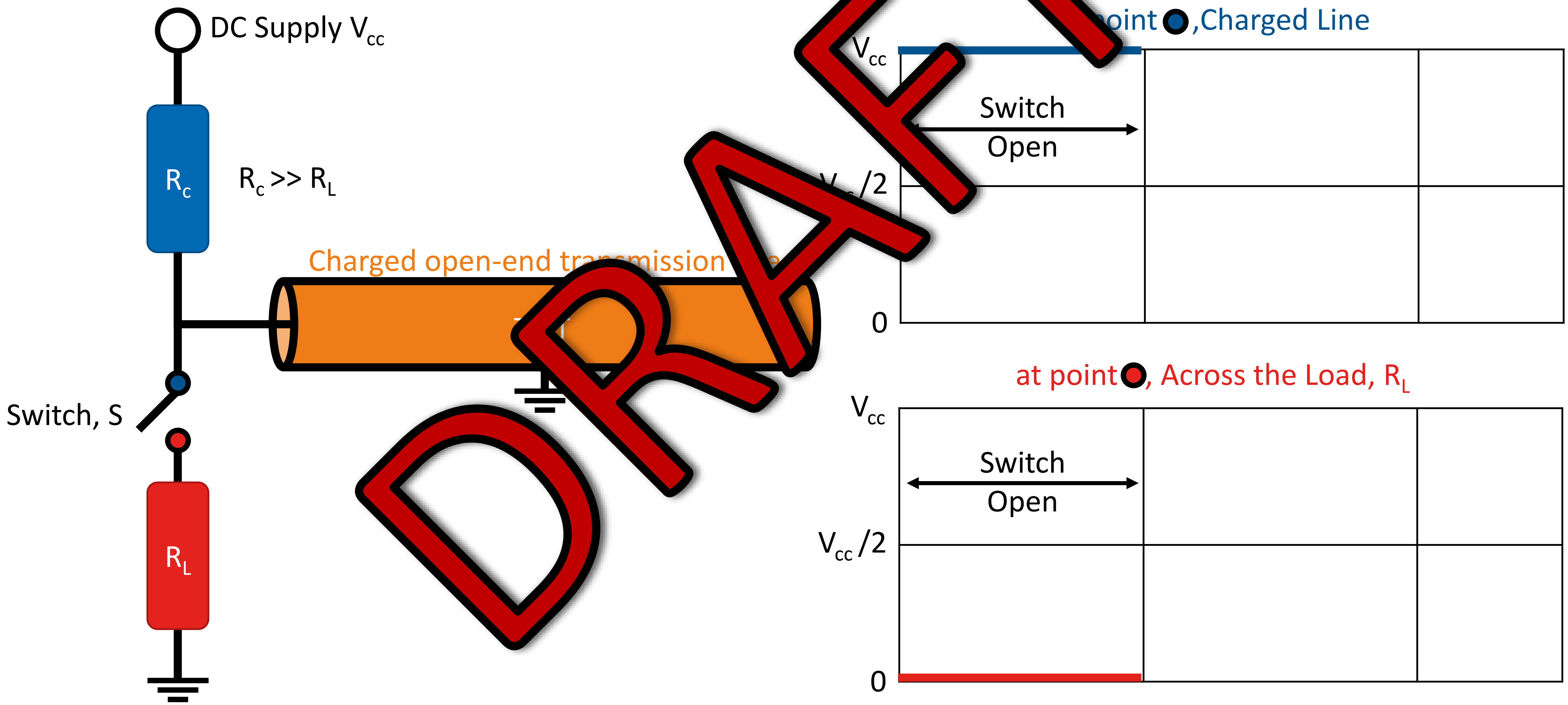
  - Pulse Widths: 10 ns – 100 ns
  - Amplitude: 500 V+
  - Repetition: Rate 1 – 50 Hz
  - Transition times (t_r and t_f): < 2 ns
- Combination of technologies:
  - Transmission Line Technique
  - Avalanche Transistors Technique



Open Circuit Co-Axial Transmission Line Technique



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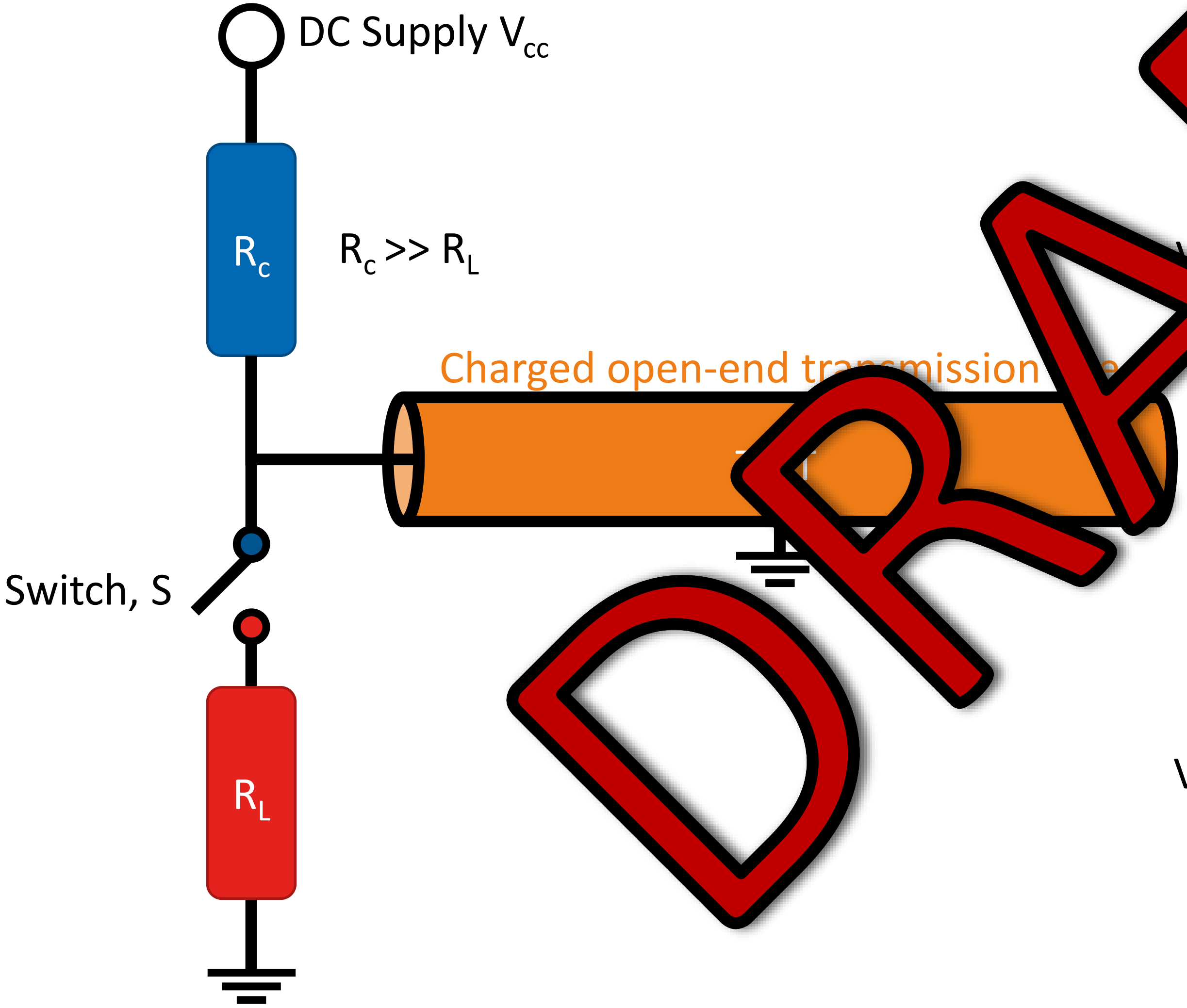

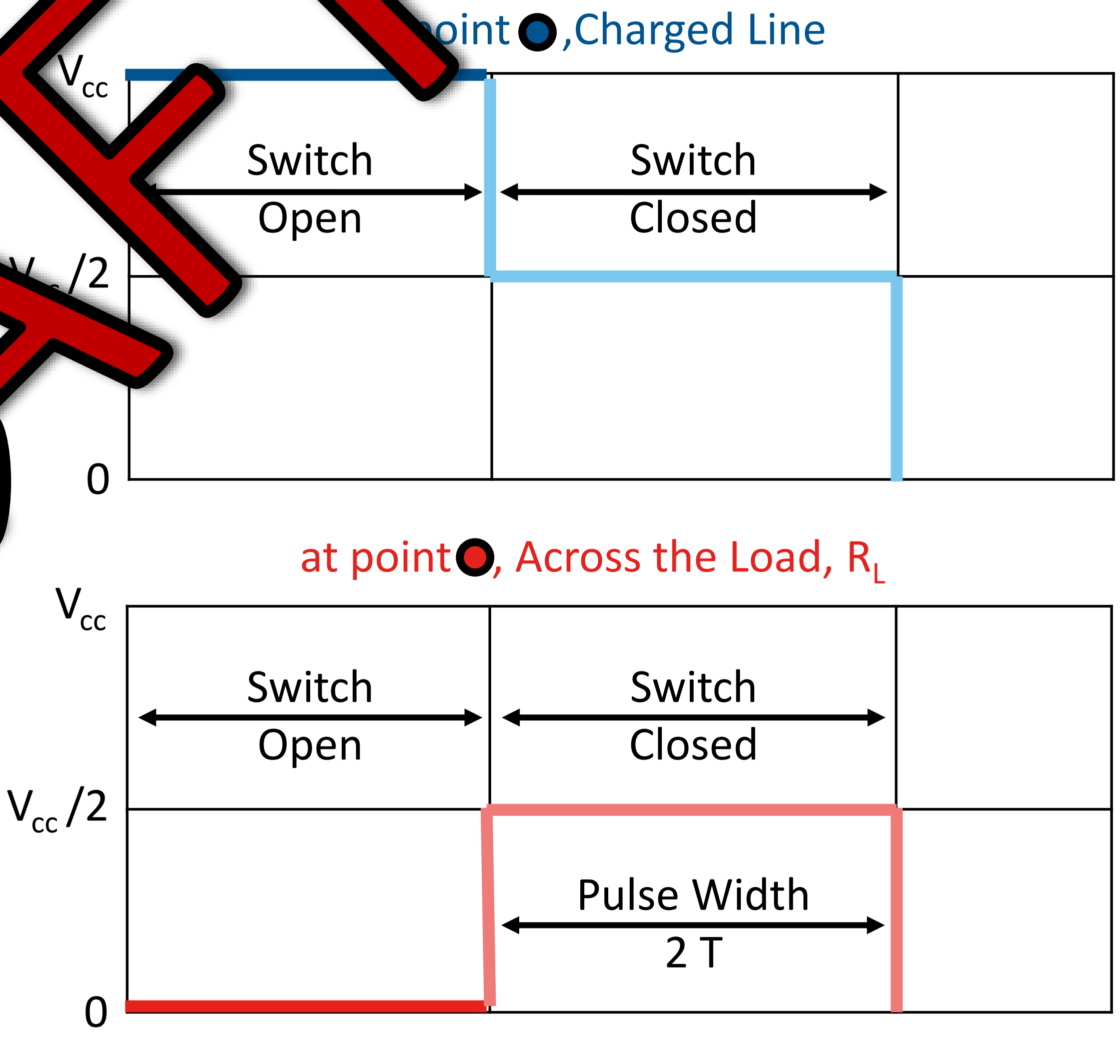

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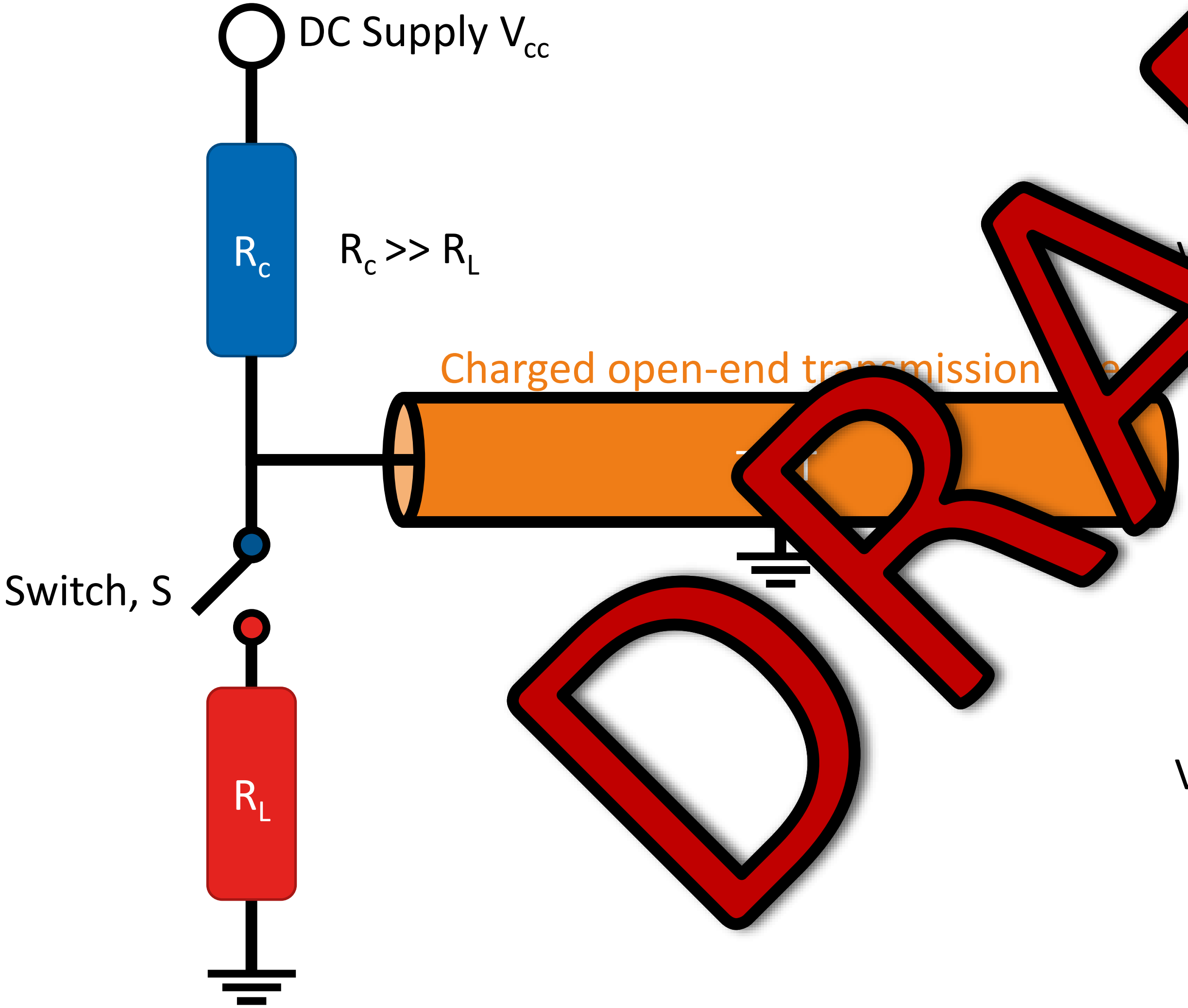

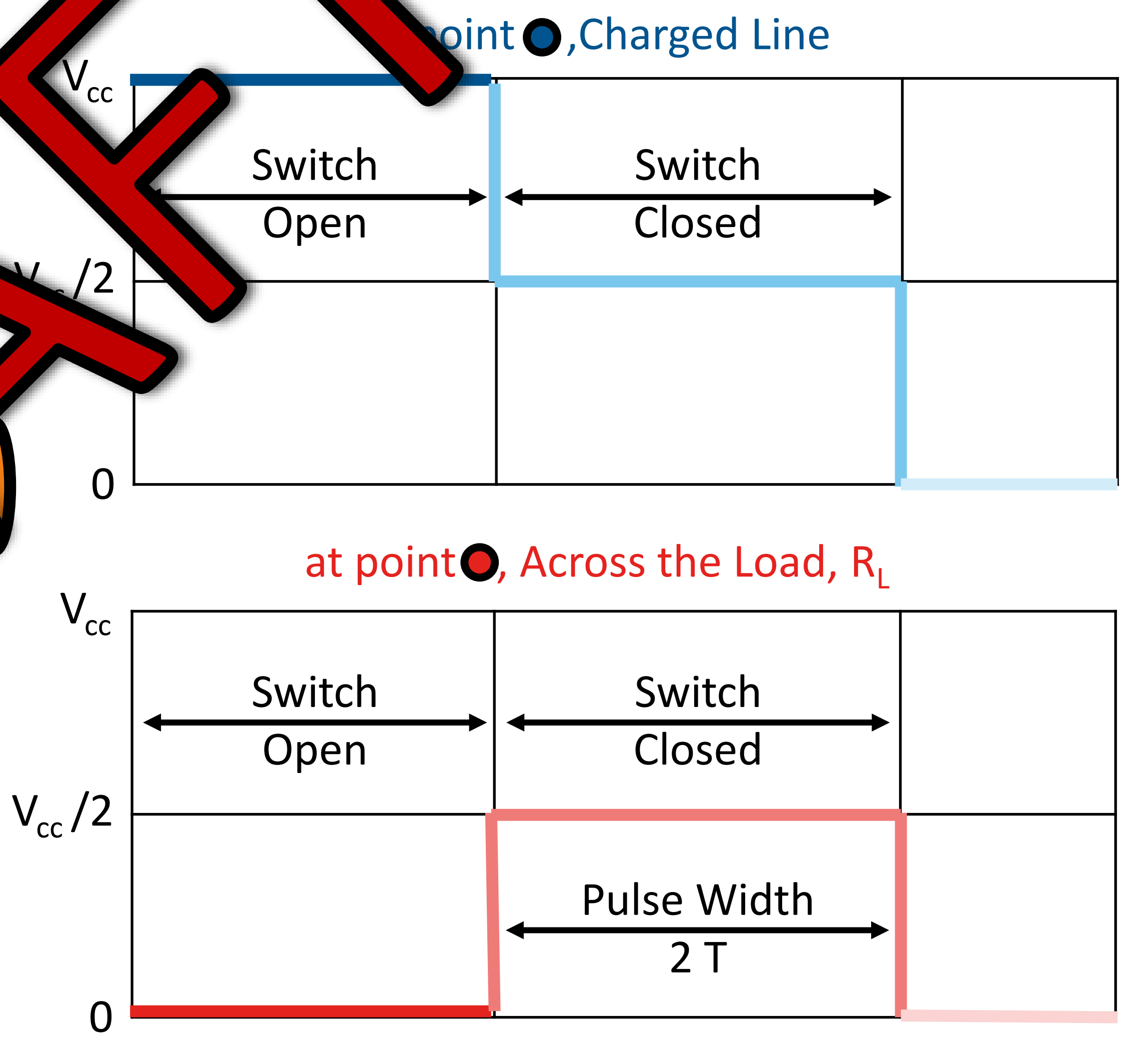

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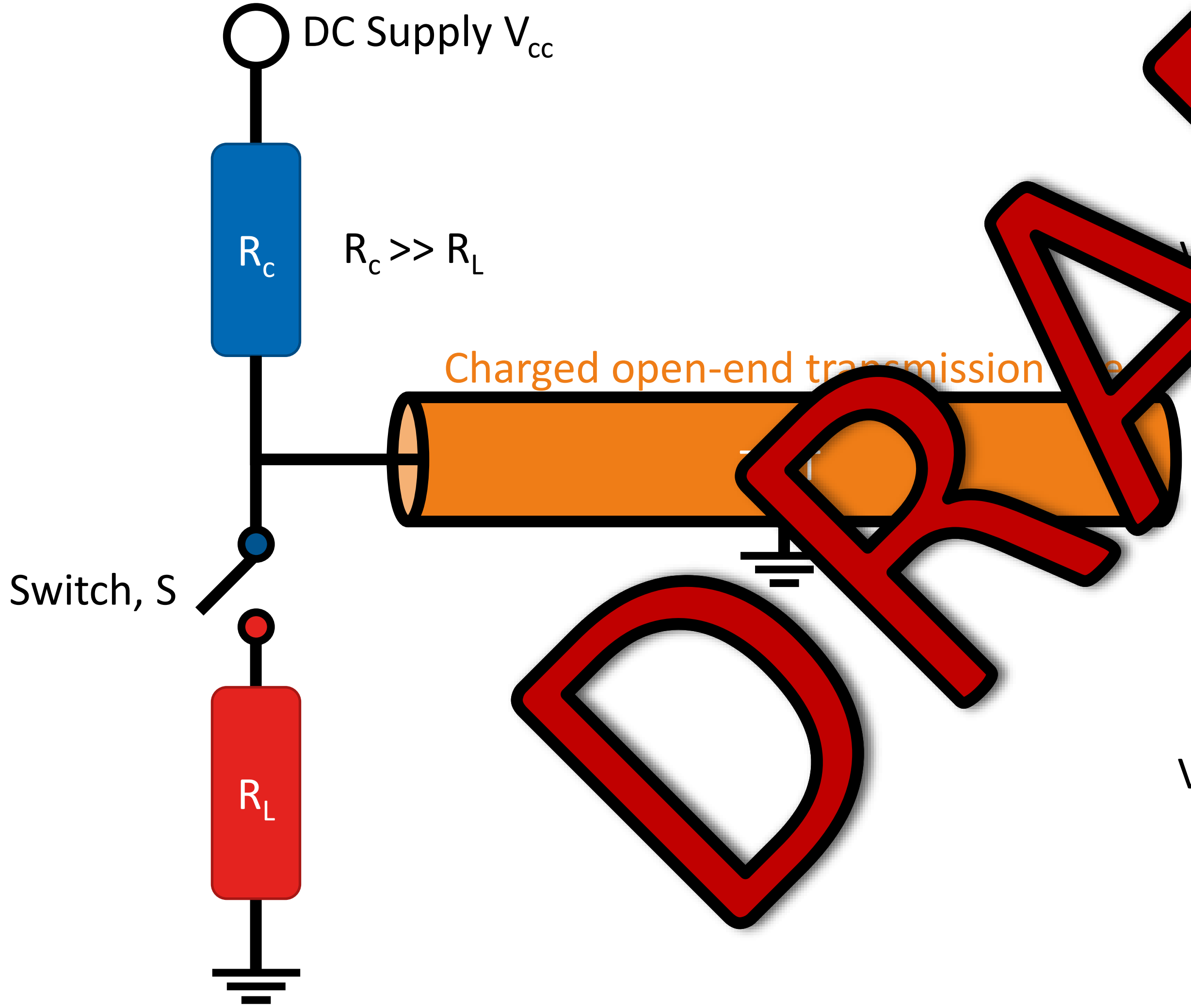
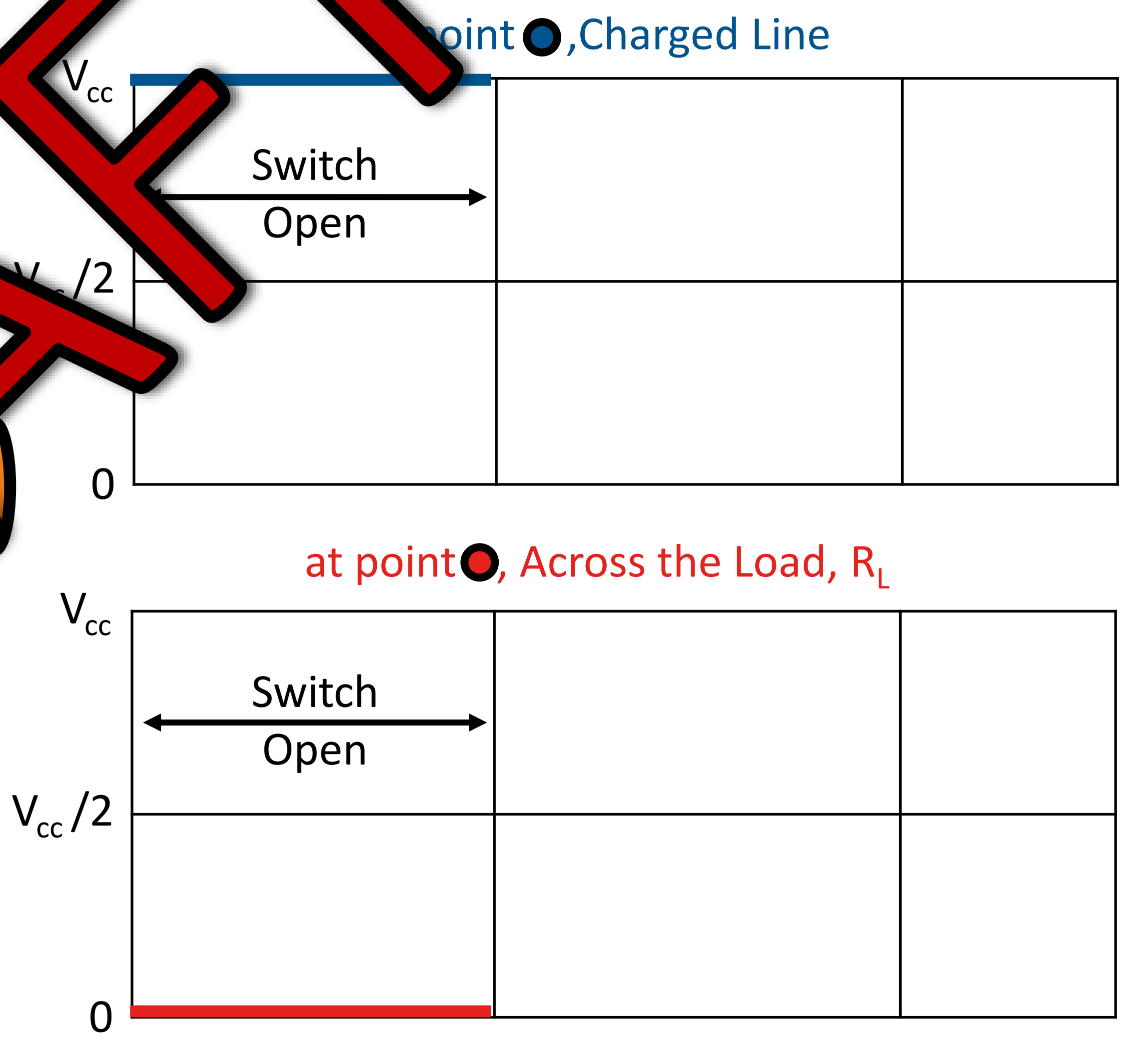
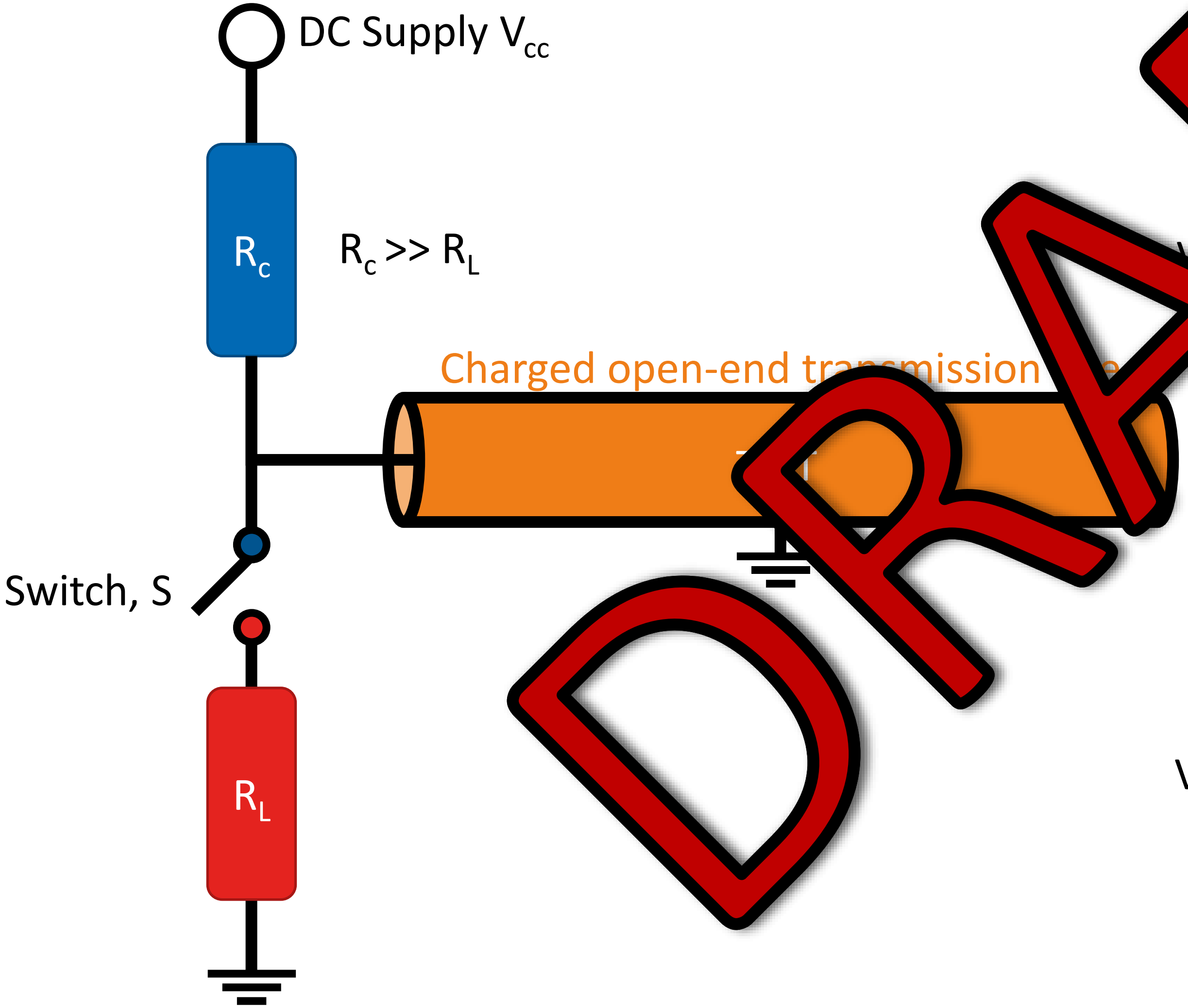
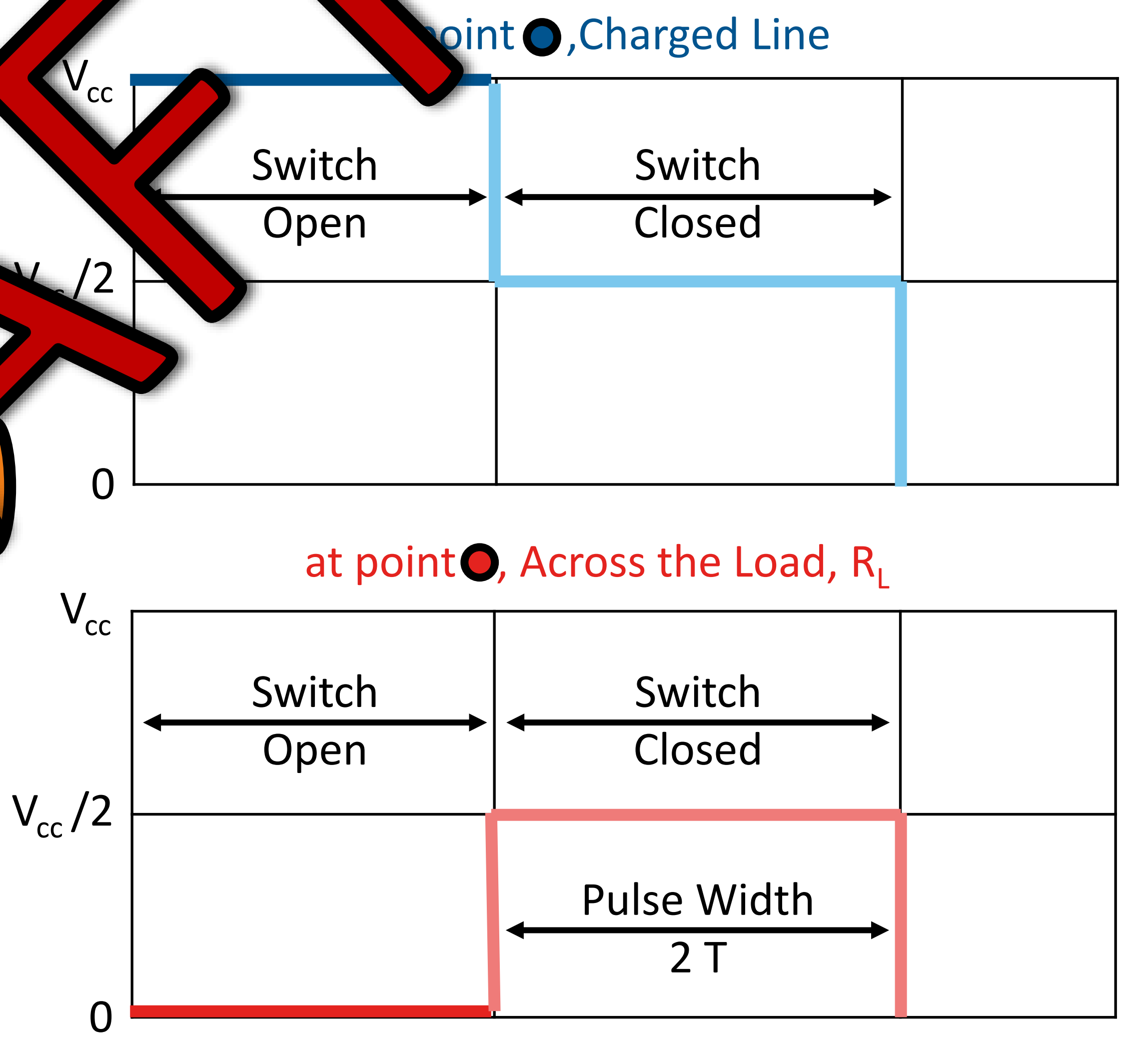


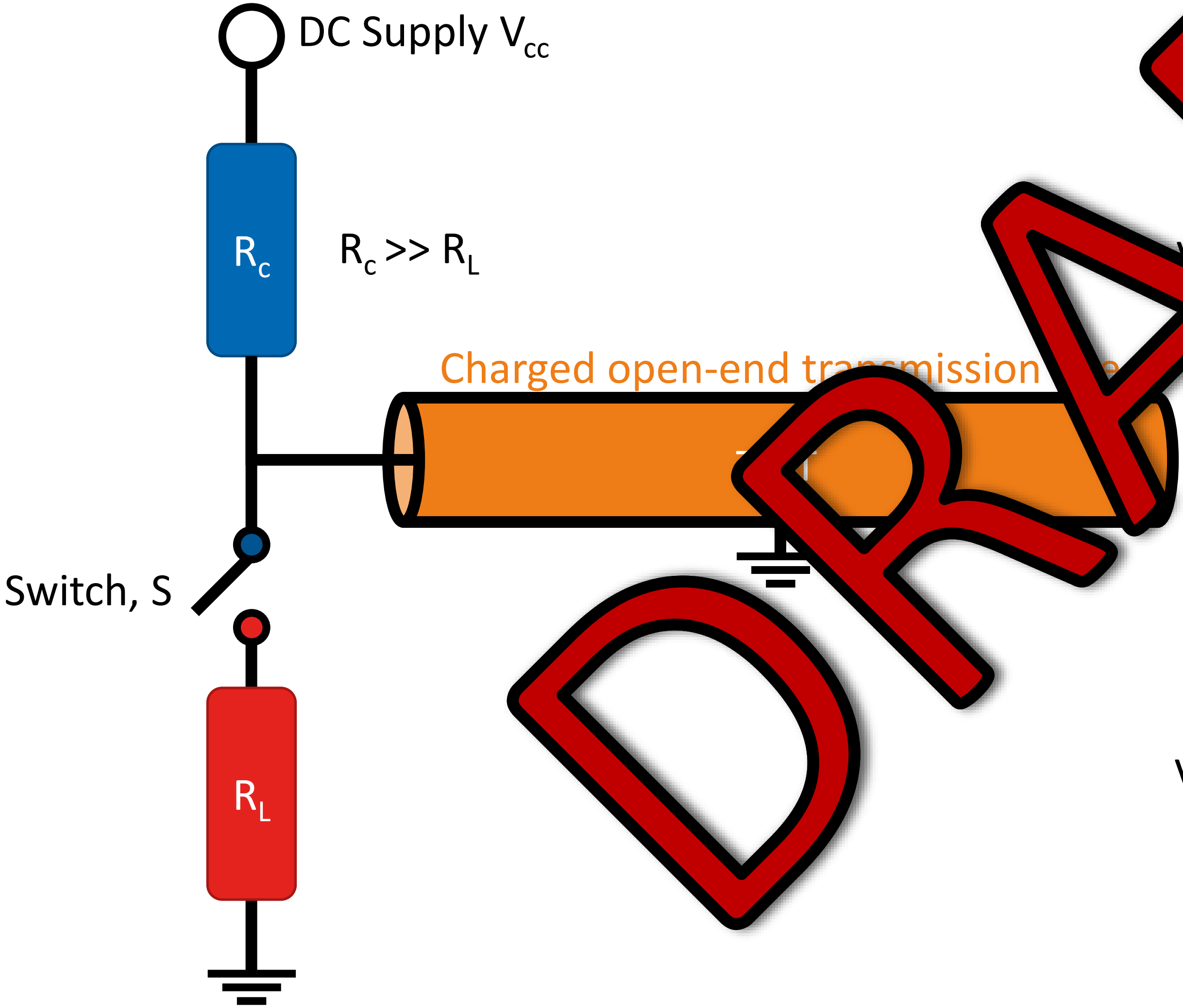


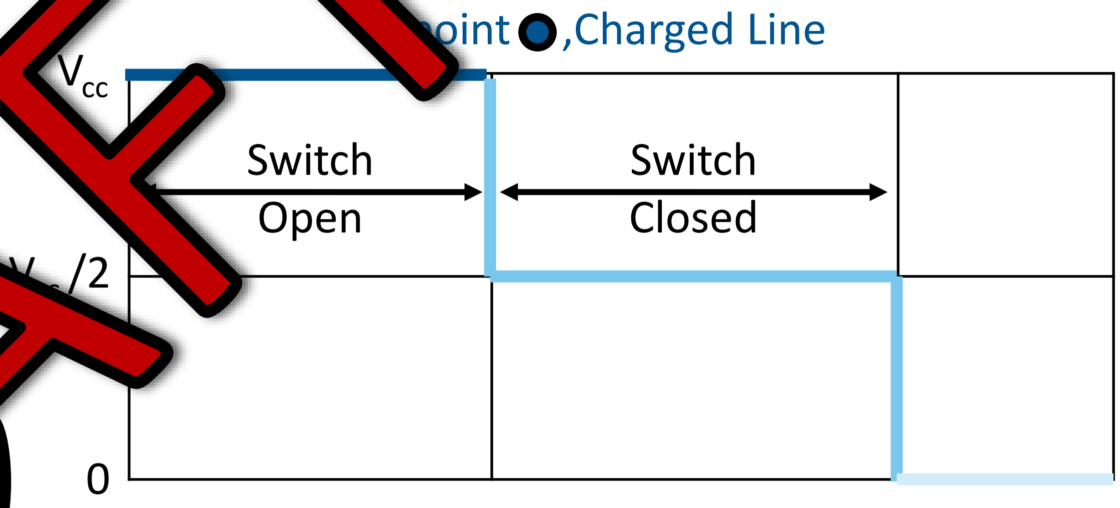
Open Circuit Co-Axial Transmission Line Technique

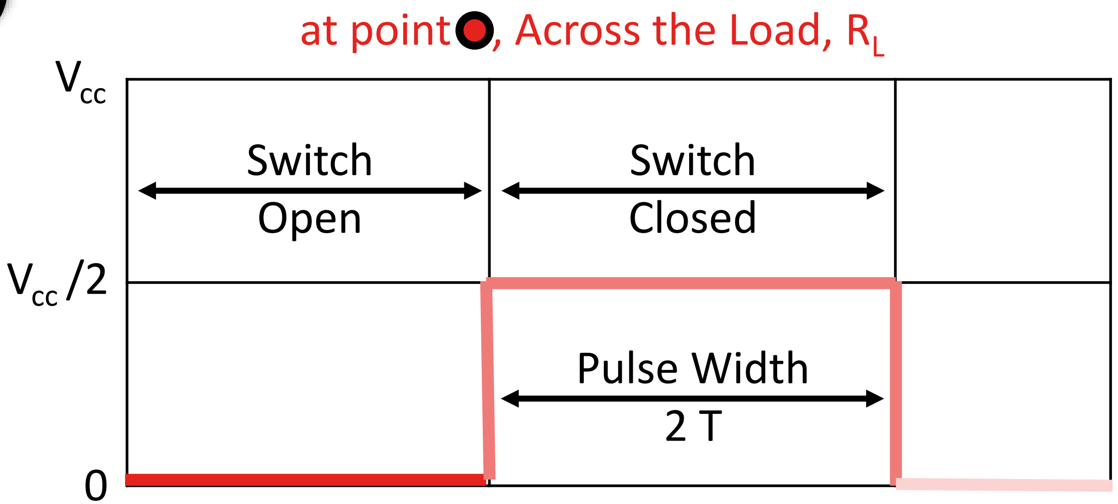




Open Circuit Co-Axial Transmission Line Technique







Open Circuit Co-Axial Transmission Line Technique

- **Essential Parameters**
  - $R_c >> R_L$
  - $Z_0 = R_L$
  - Pulse width ~2T
  - Switching element determines rise-time

$$T = \frac{\frac{l}{c}}{\sqrt{\varepsilon_r}}$$

l = transmission line length (m)
c = speed of light, 3×10^8 m/s
ε_r = dielectric constant of transmission line

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- Reliance on:
  - $Z_0 = R_L$ for
    - Minimal reflection
    - Maximum Amplitude

$$\Gamma = \frac{(R_L - Z_O)}{(R_L + Z_O)}$$

$$V_L = \frac{R_L}{(R_L + Z_O)} V_{CC}$$

Γ = Reflection coefficient
Z_0 = Transmission line impedance
R_L = Load impedance
V_L = Pulse amplitude
V_{CC} = DC Supply Voltage

Open Circuit Co-Axial Transmission Line Technique

- Reliance on:
  - If $Z_0 = R_L = 50$

$$\Gamma = \frac{(R_L - Z_O)}{(R_L + Z_O)} = \frac{(50-50)}{(50+50)} = \frac{(0)}{(100)} = 0$$

$$V_L = \frac{R_L}{(R_L + Z_O)} V_{CC} = \frac{R_L}{(R_L + Z_O)} V_{CC} = \frac{50}{(50+50)} V_{CC} = \frac{V_{CC}}{2}$$

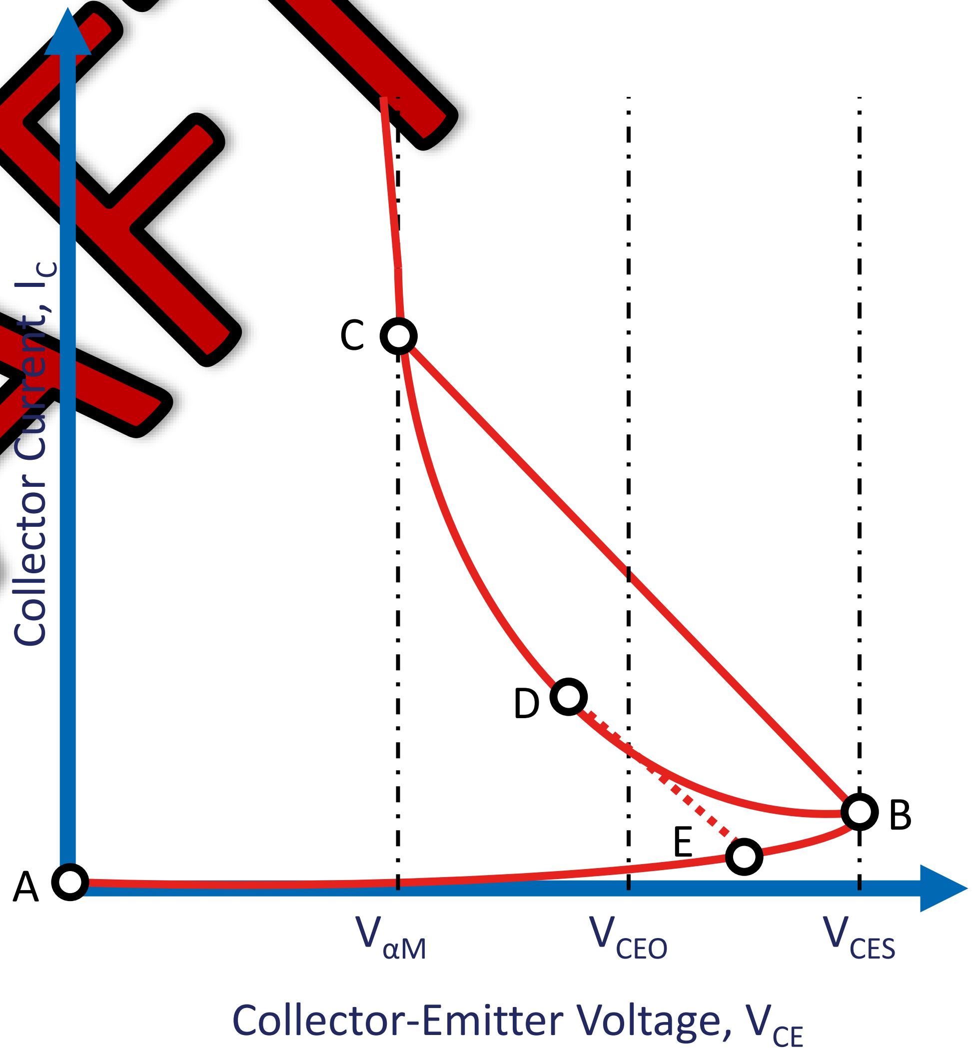
Γ= Reflection coefficient
Z_0 = Transmission line impedance
R_L = Load impedance
V_L = Pulse amplitude
V_{CC} = DC Supply Voltage

Avalanche Transistors Technique

- Used as a fast-switching element
- Transistors avalanche region lies between V_{CES} and V_{CEO}

- V_{cc} exceeds V_{CES} the transistor permanently breaks down
- V_{cc} is limited to avalanche transistors V_{CES}

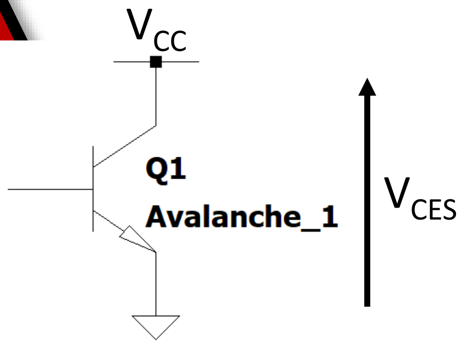
- $V_L = \sim V_{CES} / 2$



Avalanche Transistors Technique

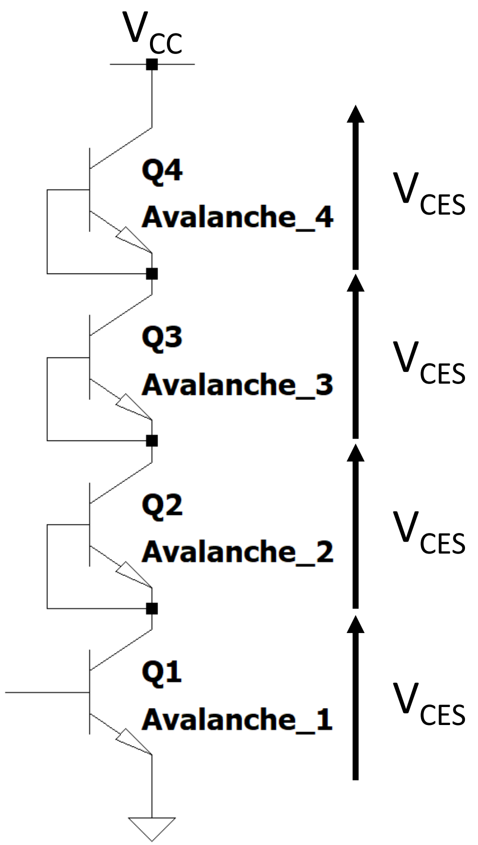
- Over come the pulse amplitude limitation of $V_L = \sim V_{CES} / 2$
- By Stacking avalanche transistors in series.
- $Vcc = \sim n\, V_{CES}$
- $V_L = \sim \frac{n\, V_{CES}}{2}$

n = number of avalanche transistor stacked



$V_{CC} = V_{CES}$

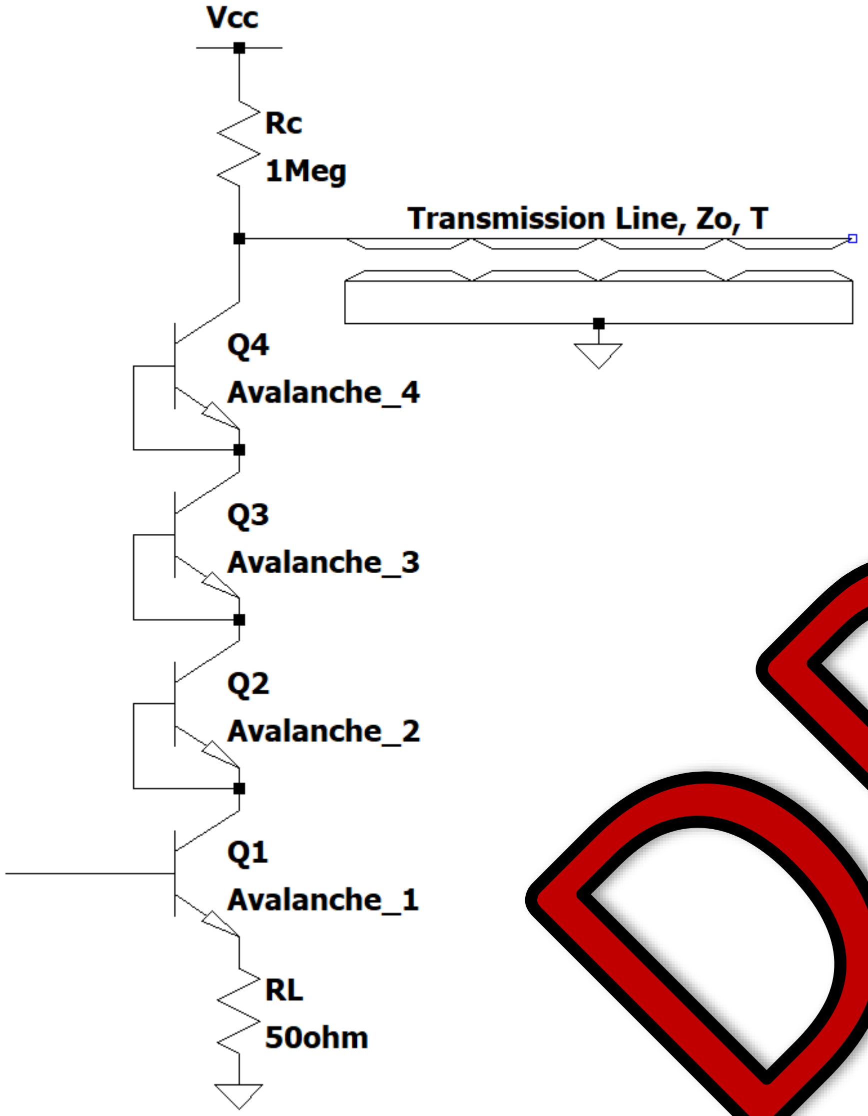
$V_L = \frac{V_{CES}}{2}$



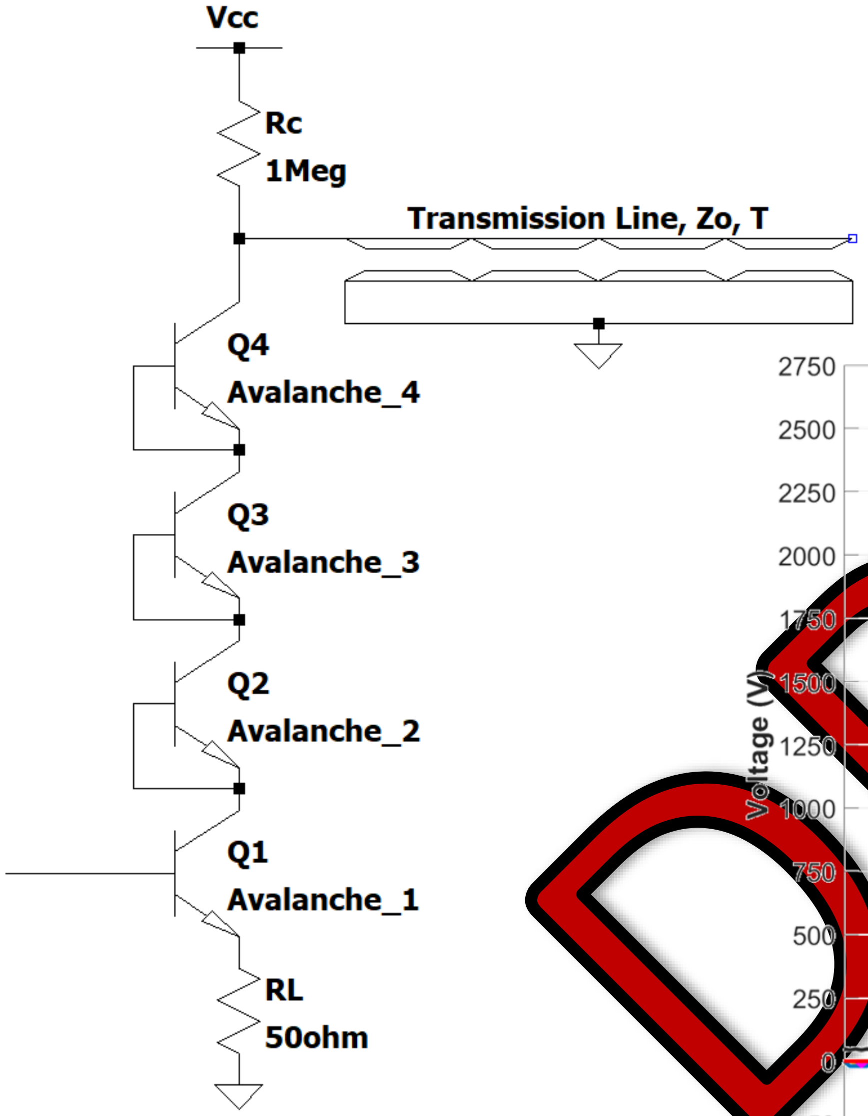
$V_{CC} = 4\ V_{CES}$

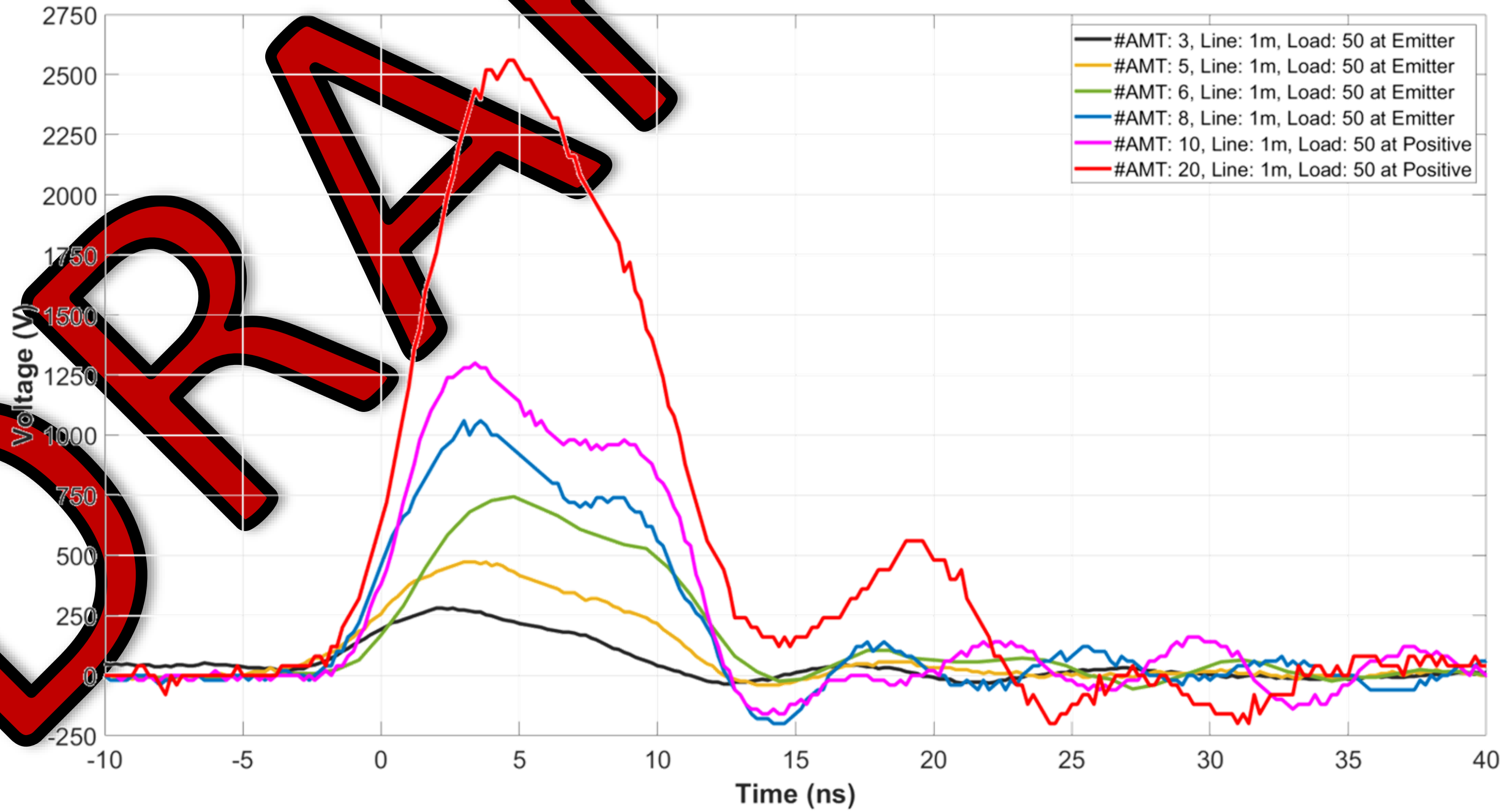
$V_L = \frac{4\ V_{CES}}{2}$

Monopolar nsPEF – Positive

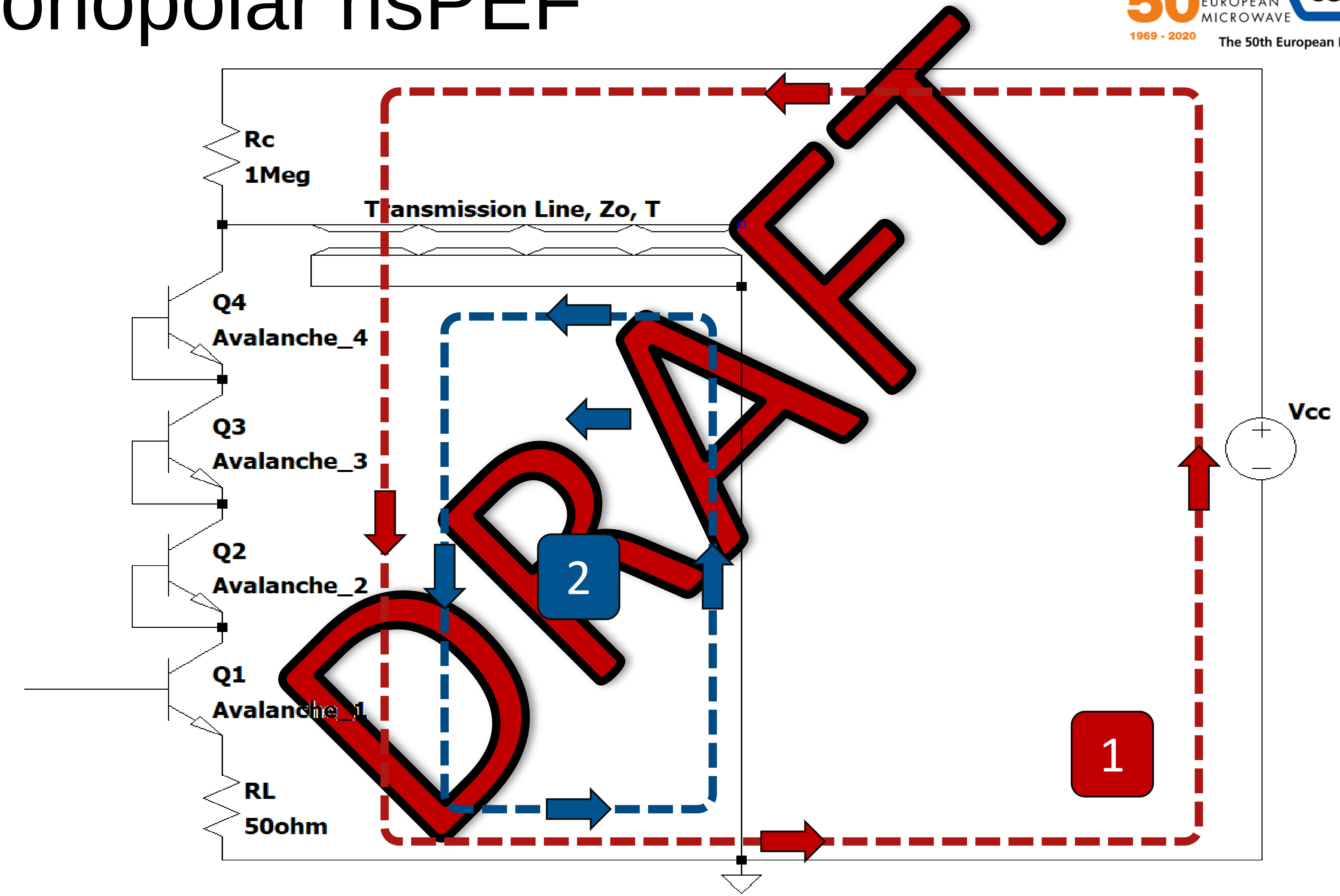


Monopolar nsPEF – Positive

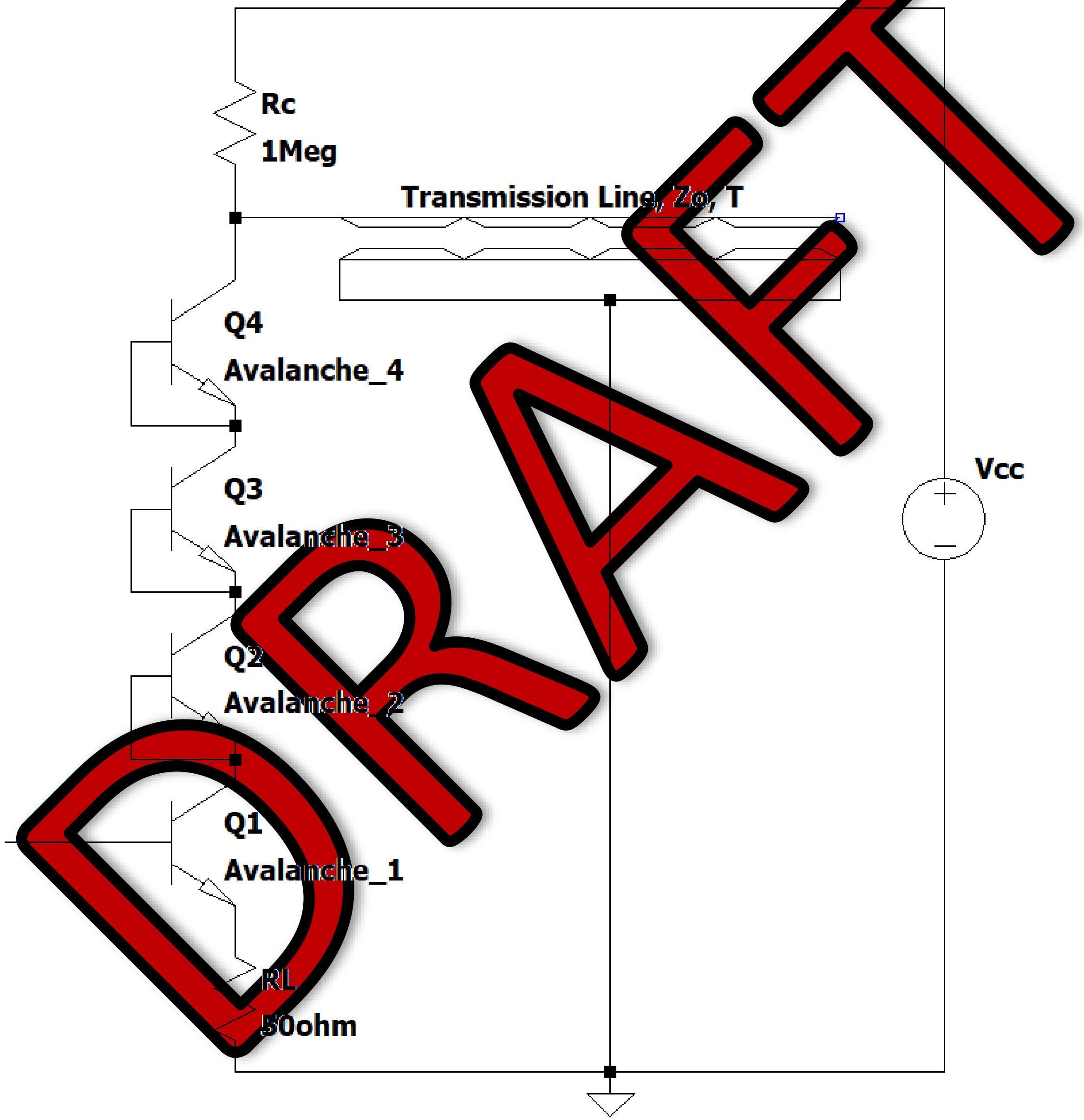




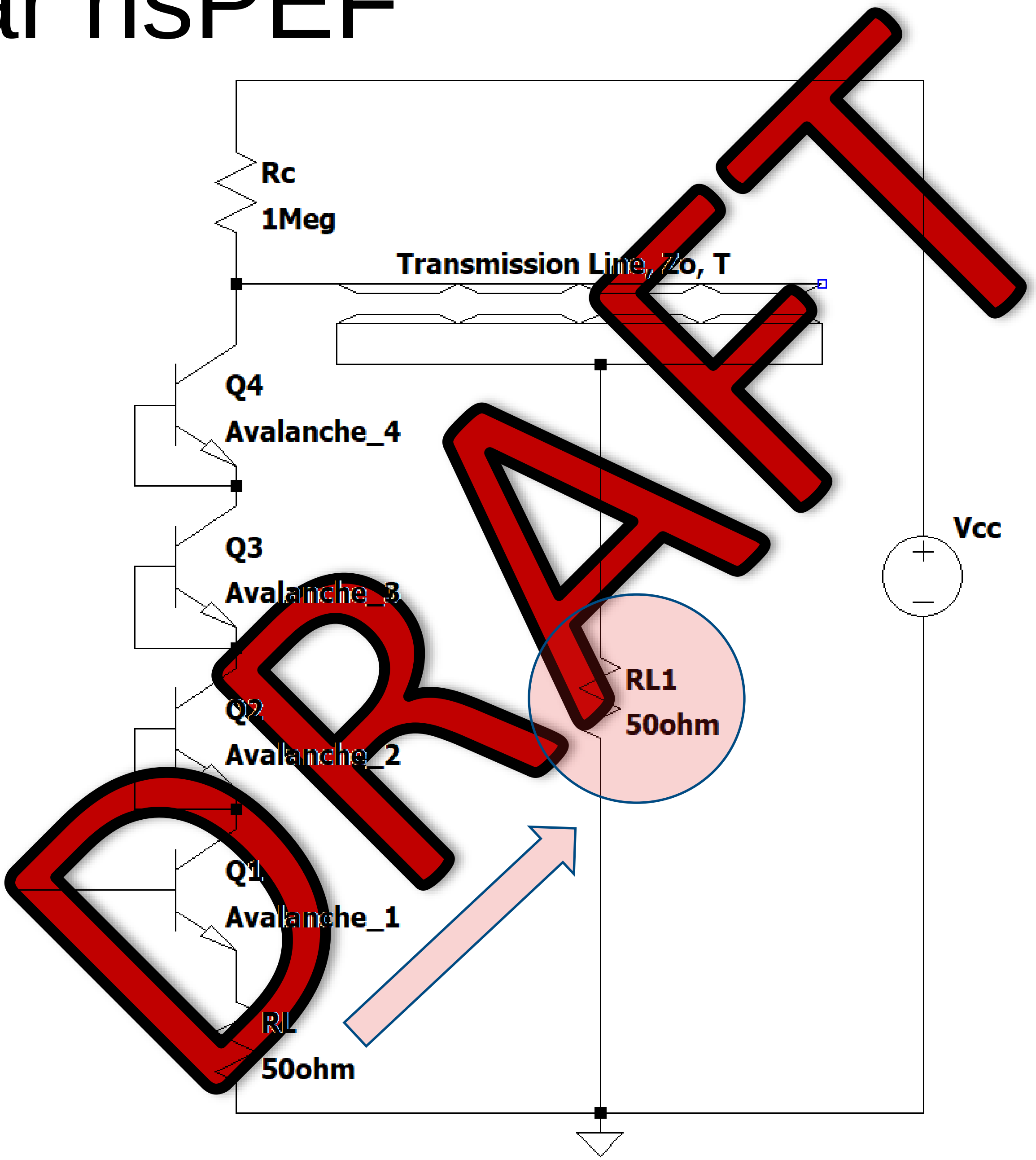
Monopolar nsPEF



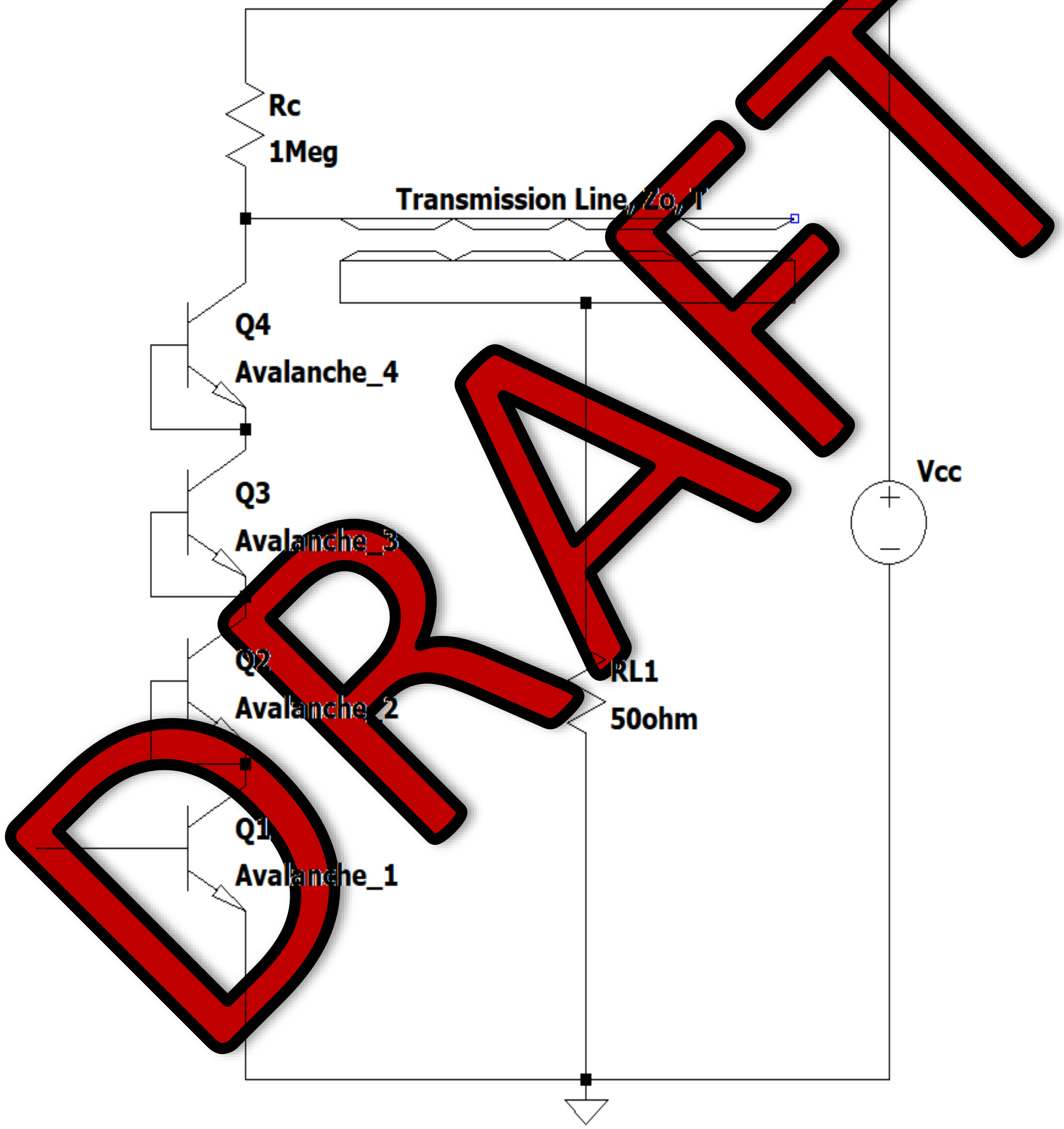
Monopolar nsPEF



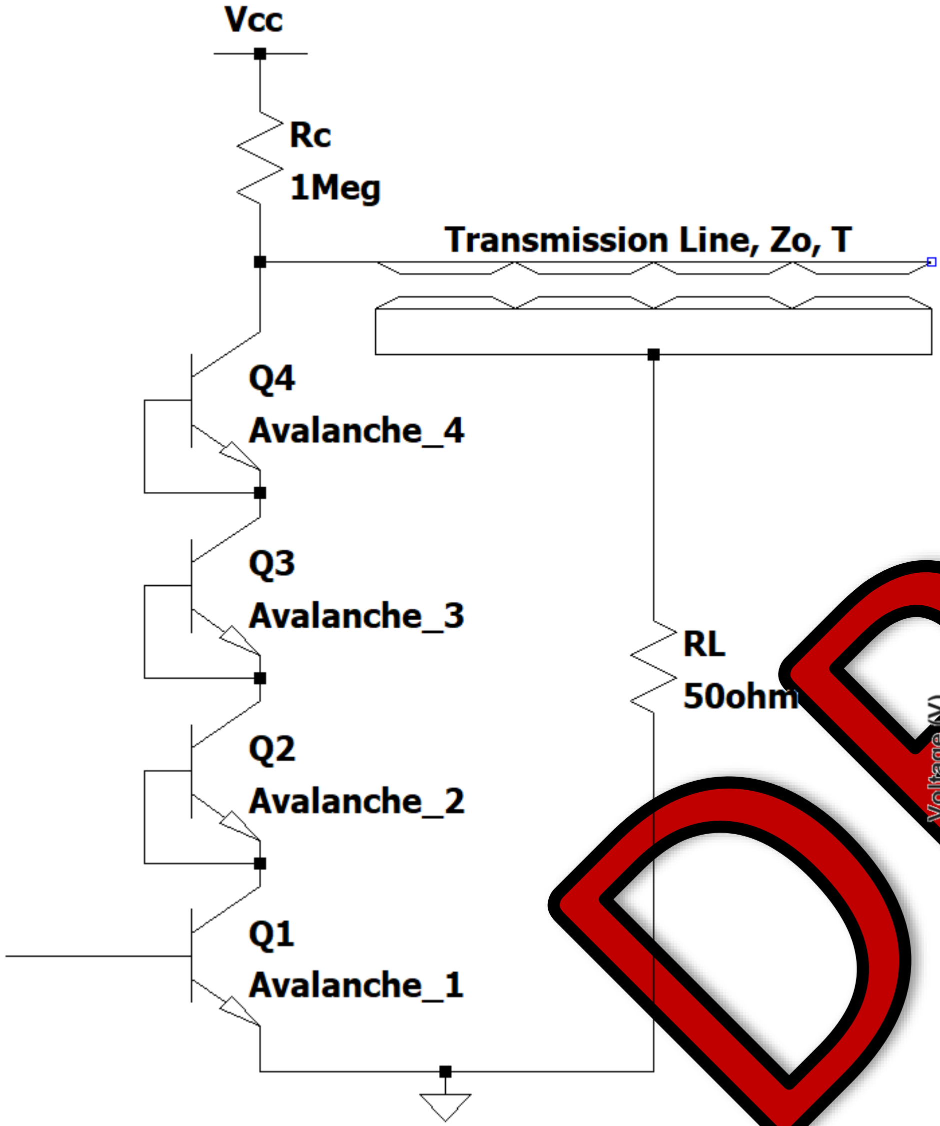
Monopolar nsPEF

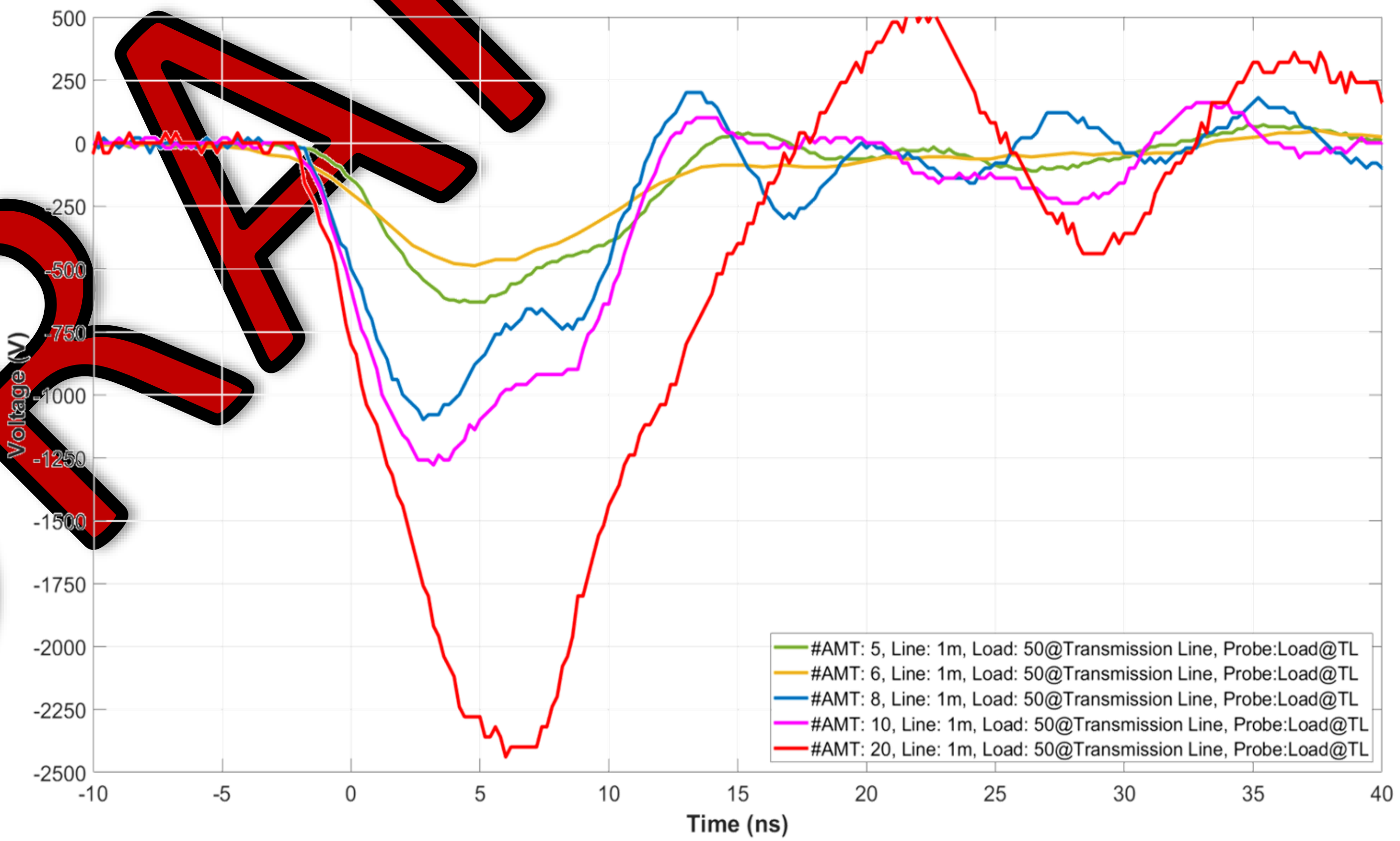


Monopolar nsPEF

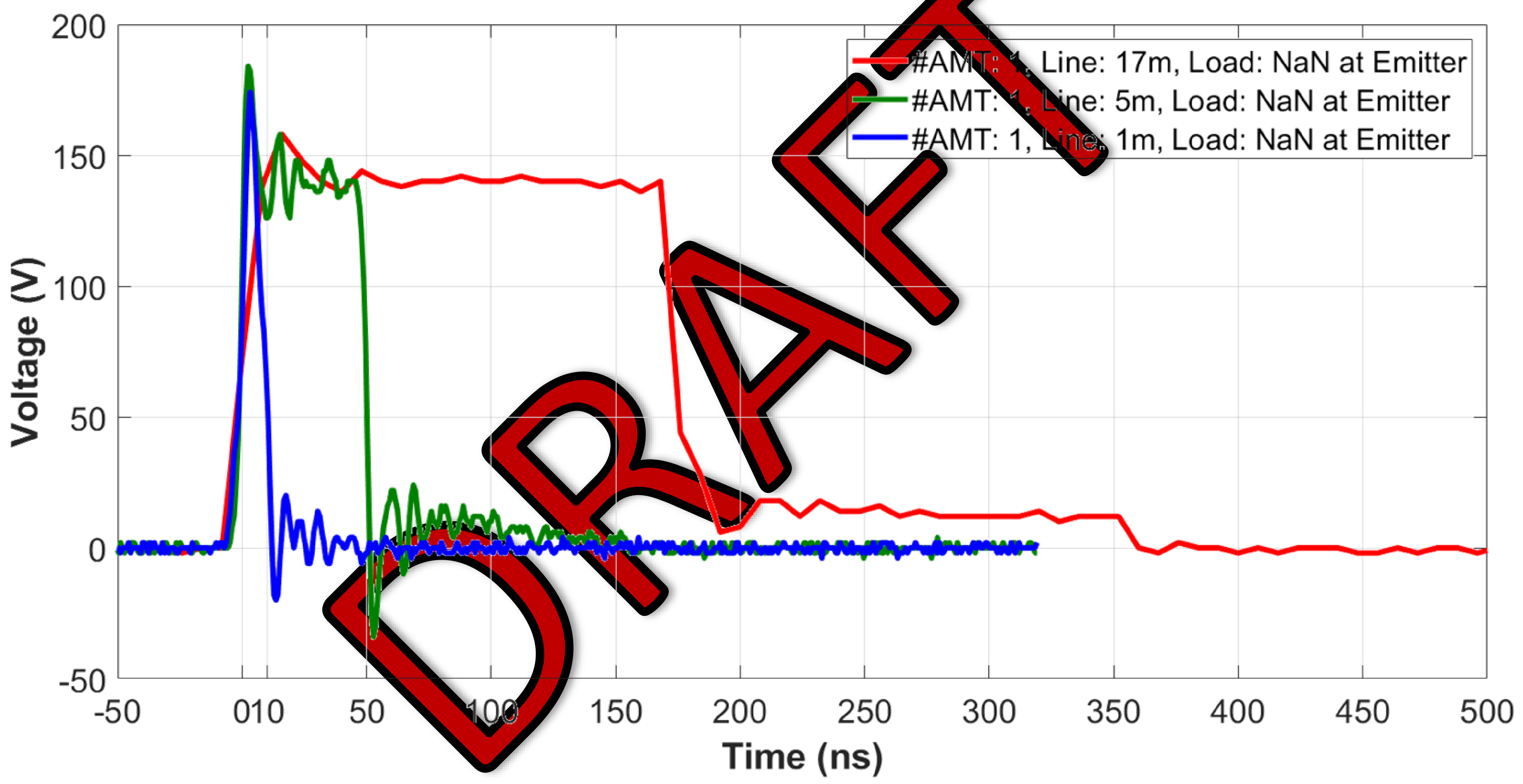


Monopolar nsPEF – Negative

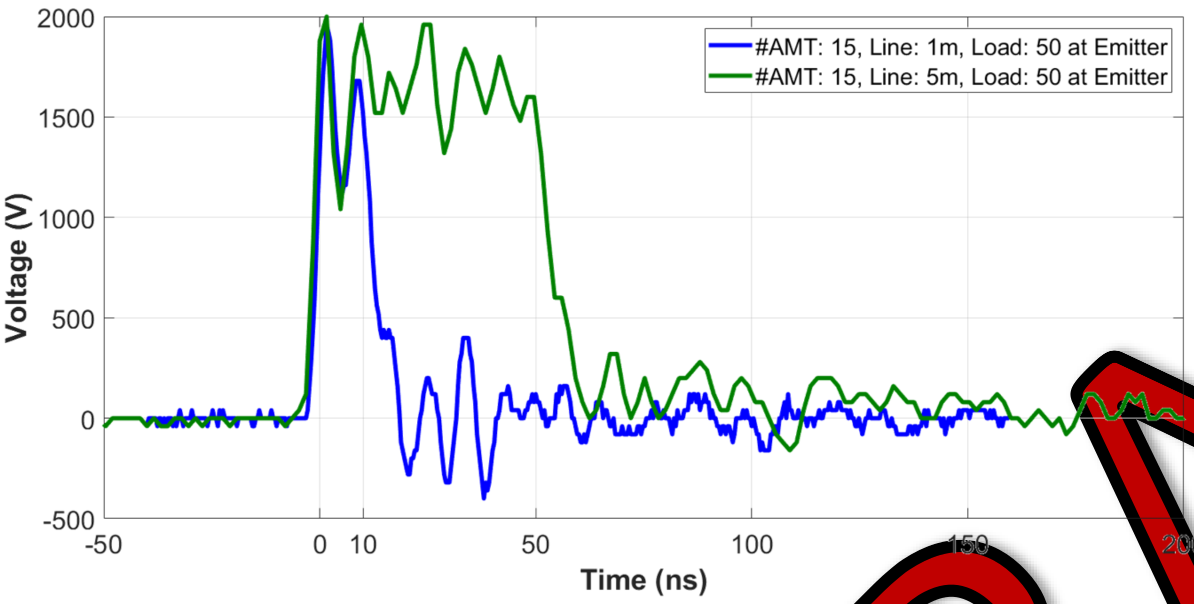


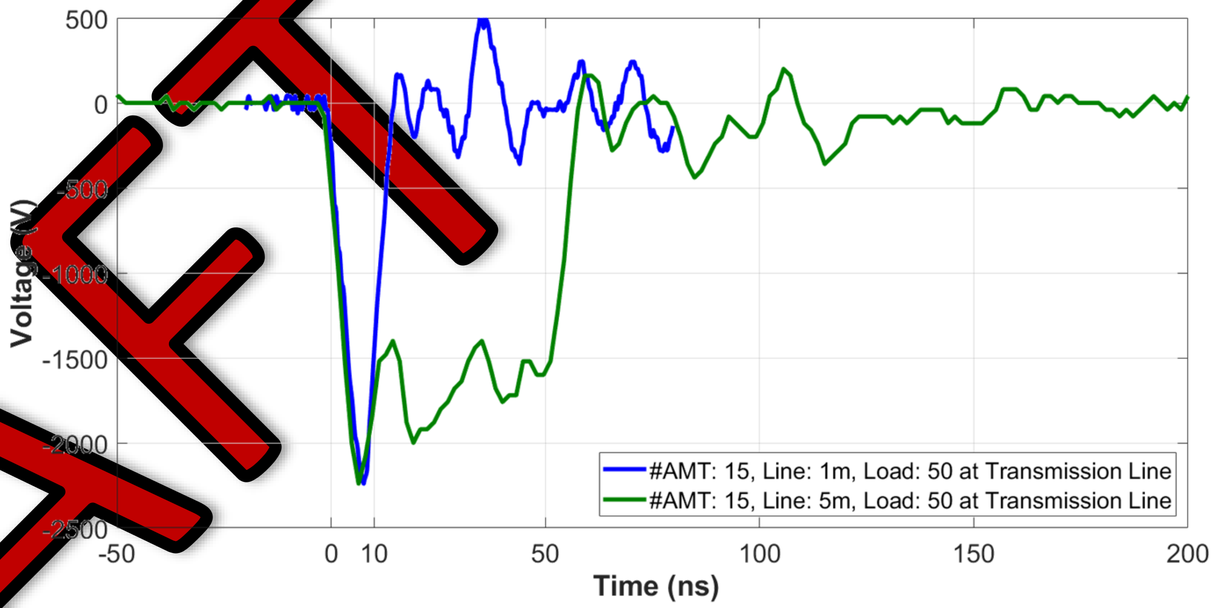


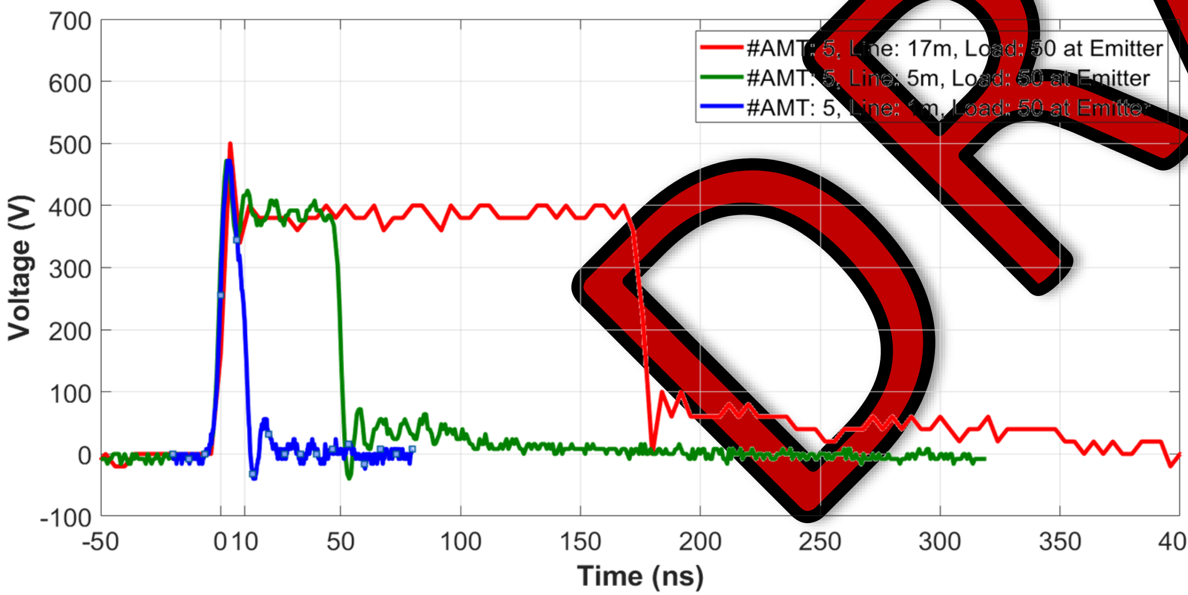
Monopolar nsPEF – Pulse Parameters

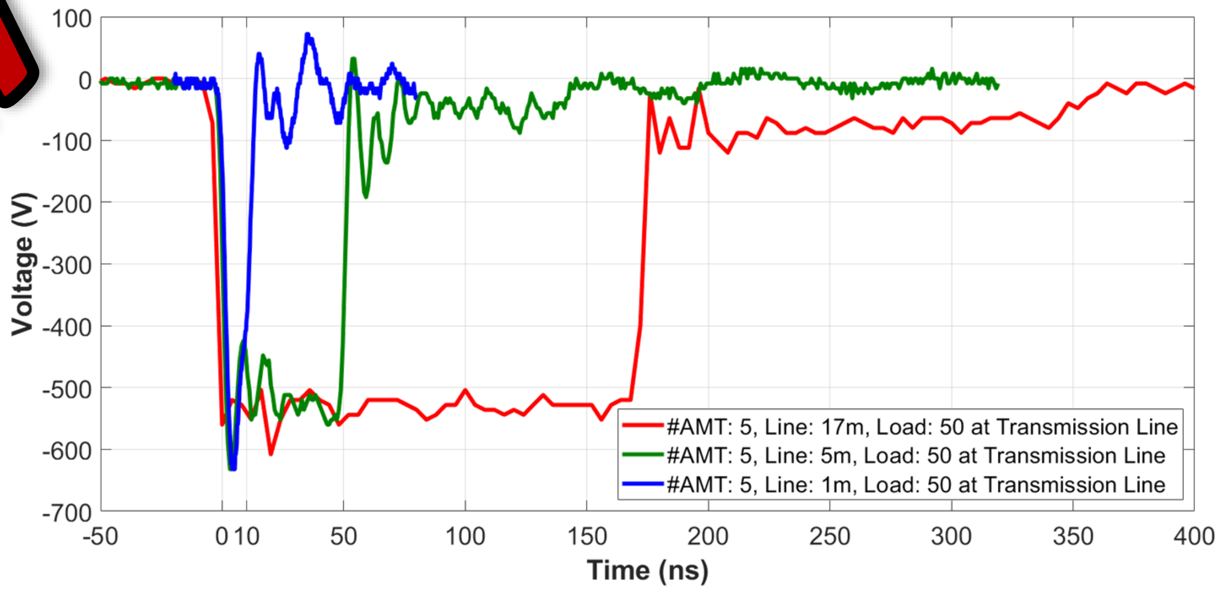


Monopolar nsPEF – Pulse Parameters









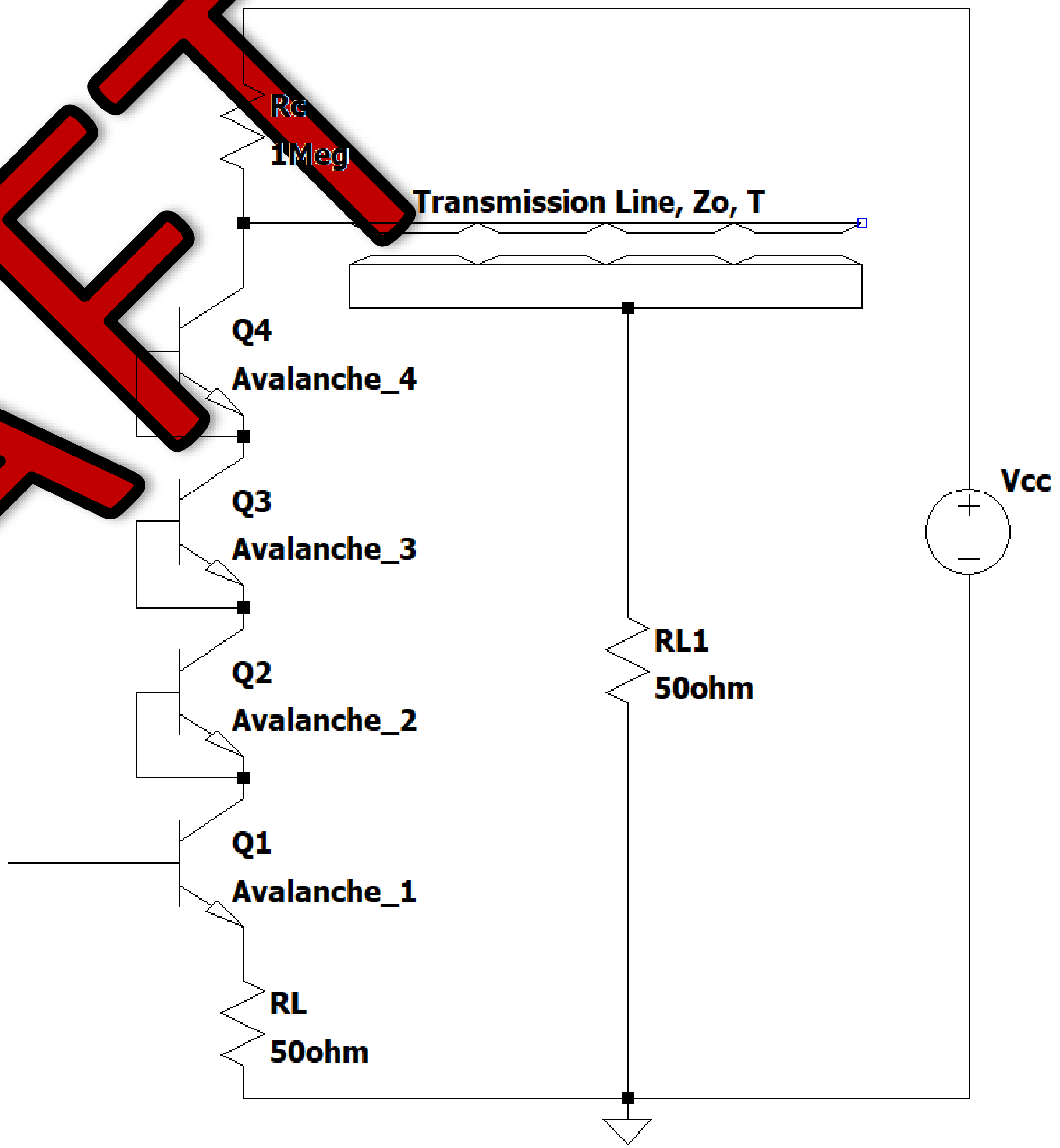
Bipolar nsPEF

- Can we generate a bipolar negative and positive pulse?

YES

- Can we calculate the amplitude and reflection coefficient for optimum efficient symmetrical pulse?

YES



Bipolar nsPEF

- Total Load R, $R_T = R_L + R_{L1}$

  $\therefore Z_O = R_T = R_L + R_{L1}$

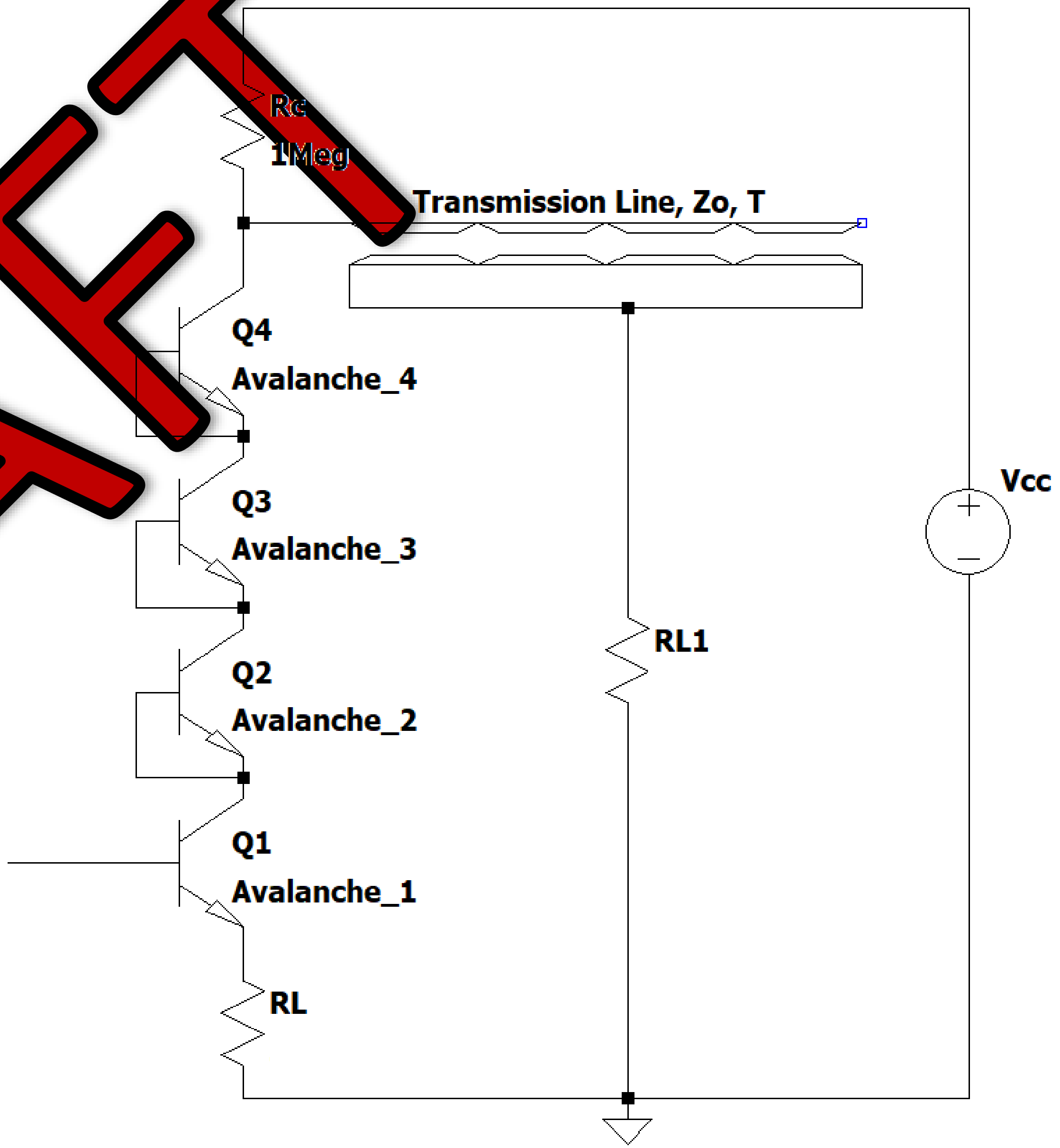
- Reflection Coefficient, Γ:

$$\Gamma = \frac{(R_T - Z_O)}{(R_T + Z_O)} = \frac{((R_L + R_{L1}) - Z_O)}{((R_L + R_{L1}) + Z_O)}$$

- Pulse amplitude, V_L

Total amplitude (peak-to-peak)

$$V_{LT} = \frac{R_T}{(R_T + Z_O)} V_{CC}$$



Bipolar nsPEF

- Pulse amplitude, V_L

Total amplitude (peak-to-peak)

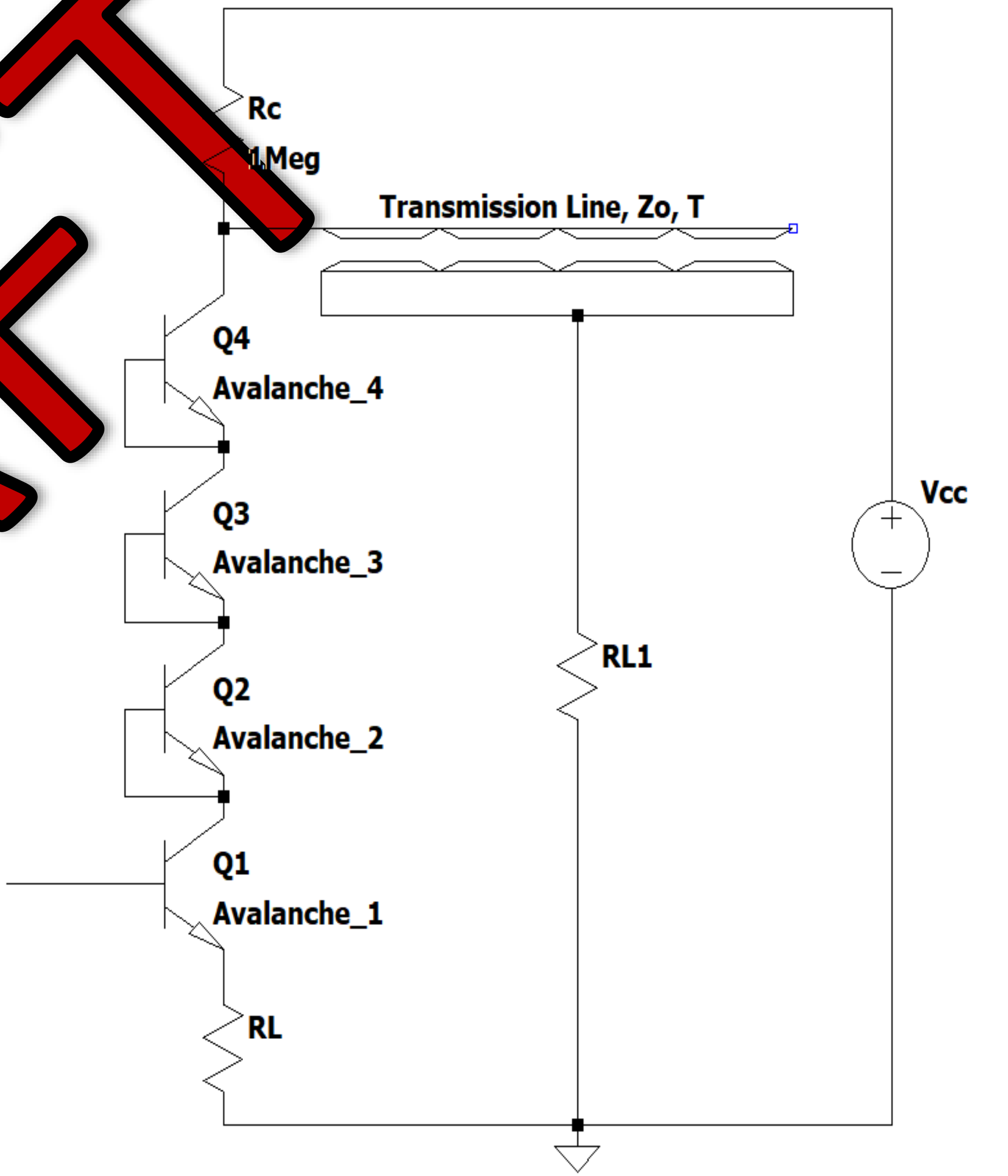
$$V_{LT} = \frac{R_T}{(R_T + Z_O)} V_{CC} = V_{RL} + V_{RL1}$$

Positive nsPEF Amplitude across RL

$$V_{RL} = \frac{R_{L1}}{(R_T + Z_O)} V_{CC}$$

Negative nsPEF Amplitude across RL1

$$V_{RL1} = \frac{R_L}{(R_T + Z_O)} V_{CC}$$



Bipolar nsPEF

Example:

$Z_O = 50,\ R_L = R_{L1} = 25,\ \therefore R_T = 50$

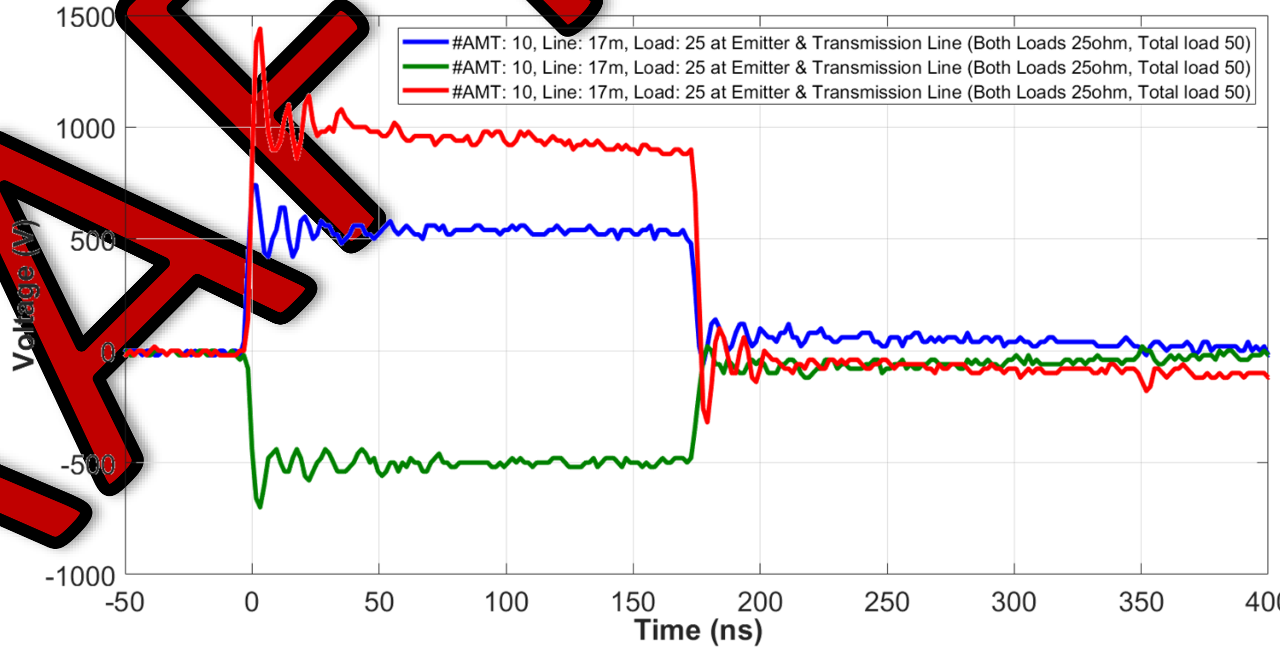
$$\Gamma = \frac{(R_T - Z_O)}{(R_T + Z_O)} = \frac{((R_L + R_{L1}) - Z_O)}{((R_L + R_{L1}) + Z_O)}$$

$$\Gamma = \frac{(50 - 50)}{(50 + 50)} = \frac{((25 + 25) - 50)}{((25 + 25) + 50)} = 0$$

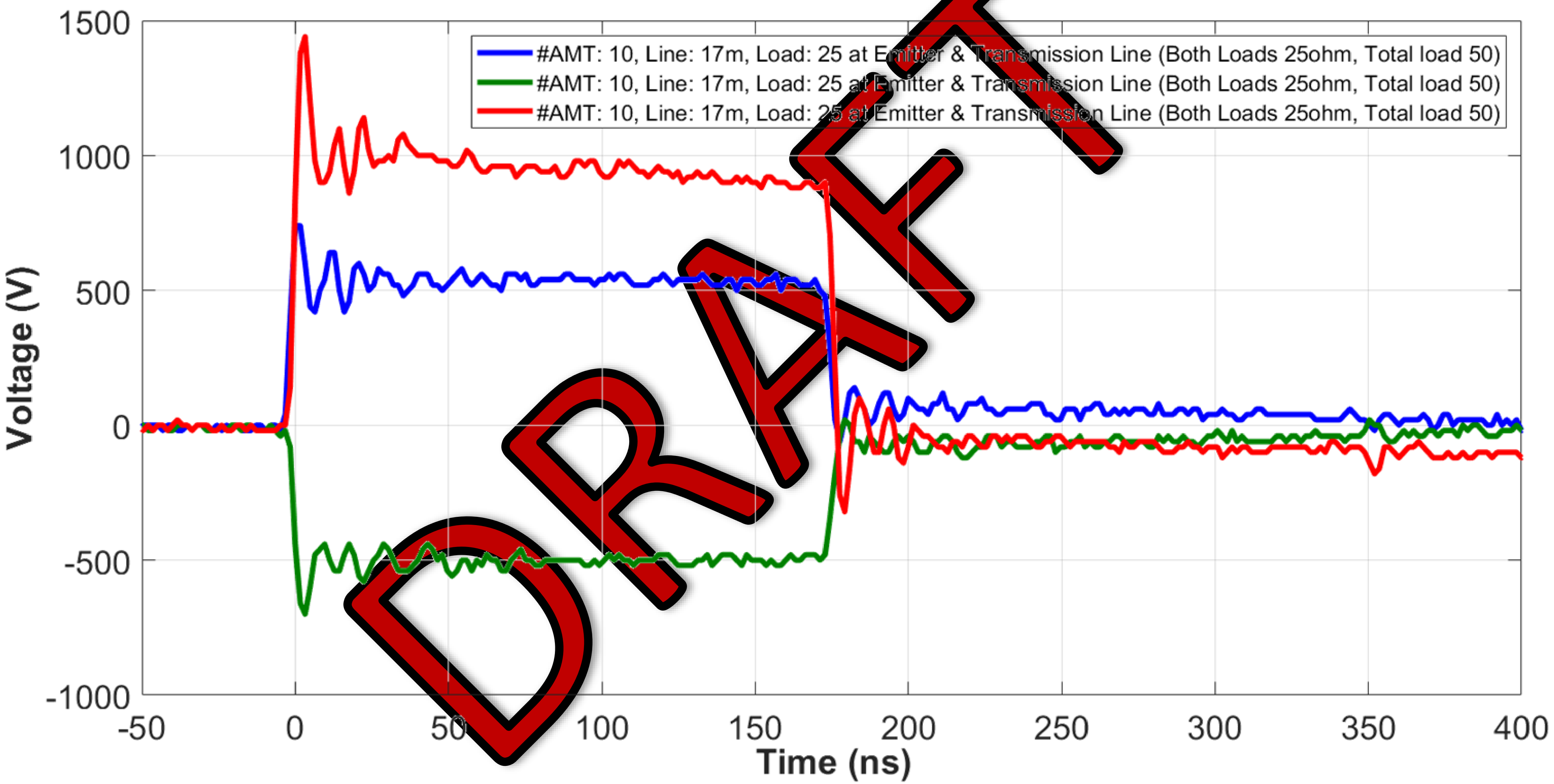
$$V_{LT} = \frac{R_T}{(R_T + Z_O)} V_{CC} = V_{RL} + V_{RL1} = \frac{50}{(50 + 50)} V_{CC}$$

$$V_{RL} = \frac{R_{L1}}{(R_T + Z_O)} V_{CC} = \frac{25}{(25 + 50)} V_{CC}$$

$$V_{RL1} = \frac{R_L}{(R_T + Z_O)} V_{CC} = \frac{25}{(25 + 50)} V_{CC}$$



Bipolar nsPEF



Conclusion

- Pulse width determined by the transmission line length
- Relationship between the characteristic impedance of the transmission line, Z0, and the load, RL , determines the:
  - Pulse amplitudes
  - Secondary pulse or rebound of the primary pulse (Γ=0)
- Produce well-defined symmetrical bipolar nanosecond pulses require to support nanosecond electroporation and other biomedical applications in a cost-effective manner

Future Work

- Investigate delay method
- Gain biological effect
- Transmission Line and strip line adaptation

Acknowledgments

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- Any IP that comes from this work is owned by Creo Medical Group PLC.

Thank you for your attention

eeu25b@bangor.ac.uk