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Avalanche Breakdown Transistors and the Open Circuit Transmission Line Technique for Nanosecond Electroporation

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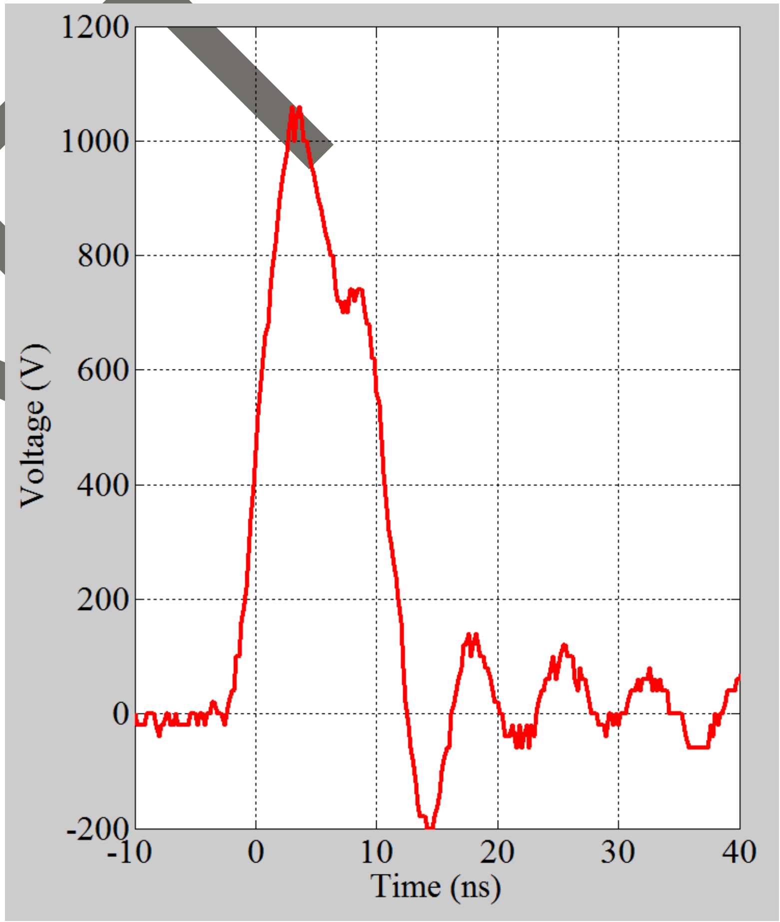
Introduction

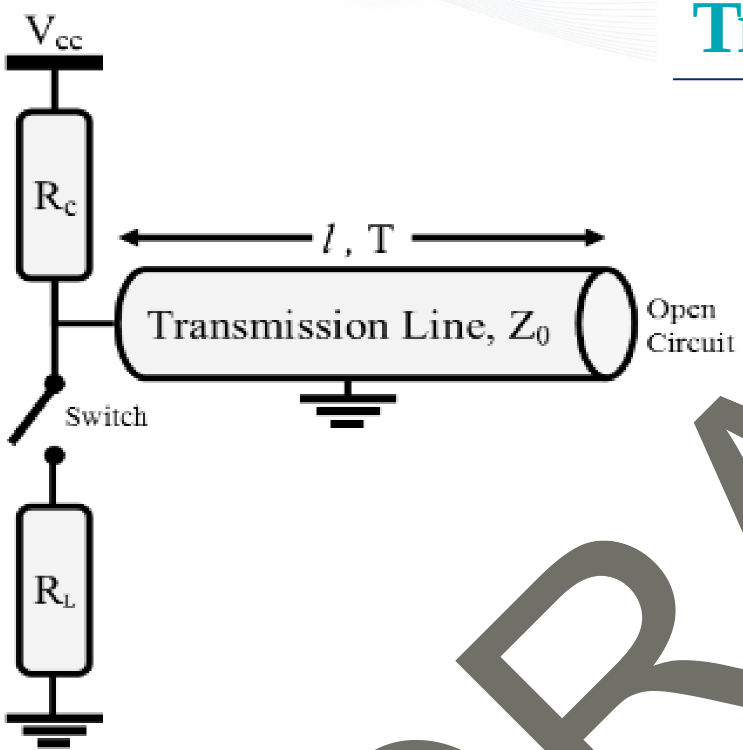
- Research focuses on medical applications of high voltage nanosecond electric field pulses, such as nano-electroporation in a cost effective manner.

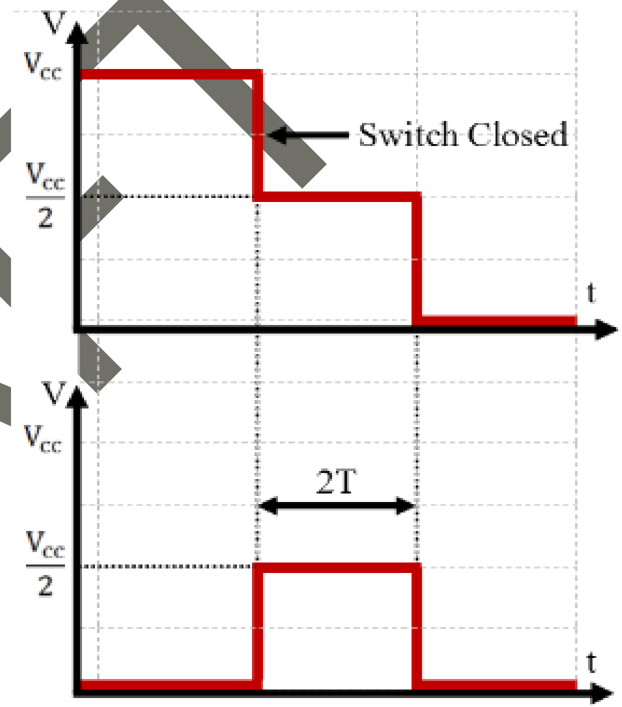
- Demonstrate a low-cost circuit design for the generation of high voltage symmetrical monopolar nanosecond pulses:
    - Rise times <2 ns
    - High voltage amplitude: 500 V+
    - Variable pulse widths
    - Controllable pulse repetition rate

- Achieved through an open circuit transmission line technique in conjunction with the stacking of low-cost avalanche transistors as a fast switching element.



Open Circuit Co-Axial Transmission Line Technique



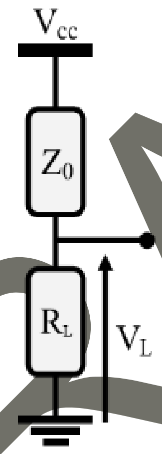


- Discharging of an open-ended delay line via a fast switching element
- Producing ‘flat-top’ rectangular pulse with steep fall times (< 2ns)
- Pulse width $= 2\text{T} = 2\frac{l\sqrt{\varepsilon_r}}{c}$
- Rise time determined by the switching element

Low Frequency Network Theory

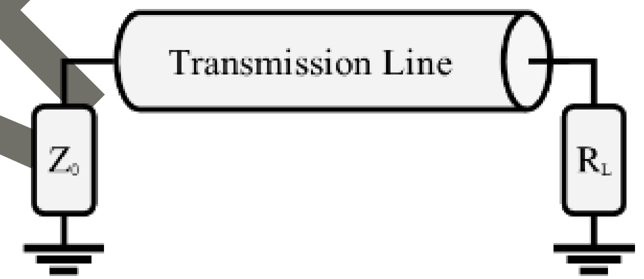
- Z_0 and R_L implements as a voltage divider.
- $V_L = \left(\frac{R_L}{R_L+Z_0}\right) V_{cc}$
- Maximum pulse amplitude at the load, V_{Lmax}, is half the voltage the transmission line is charged too

$$V_{Lmax} = \frac{V_{cc}}{2}$$
$$if\ R_L = Z_0$$



Transmission Line Theory

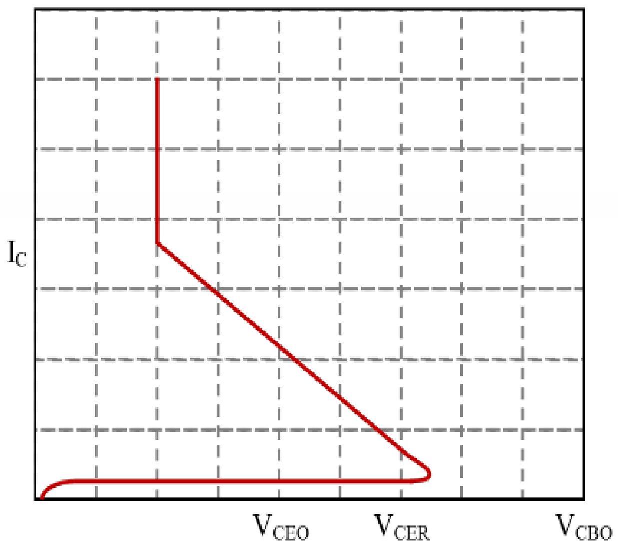
- Z_0 and R_L determines the reflection coefficient, Γ, and the pulse shape

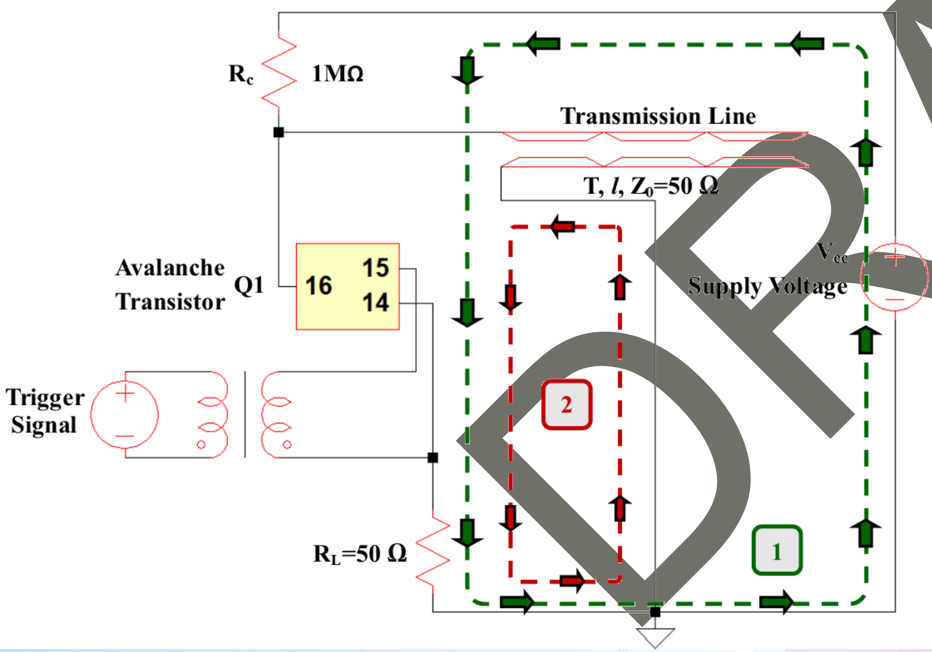


- Need a reflection coefficient of 0

$$\Gamma = \left(\frac{R_L - Z_0}{R_L + Z_0}\right)$$
$$\Gamma = 0, when\ R_L = Z_0$$

relationship between the characteristic impedance of the transmission line, Z_0 and the load, R_L is integral to the performance





Switching Element

- Avalanche Breakdown Transistor
- Provide reliable and repeatable highspeed switching of high voltages with rise times as low as 300 ps

i. Energy is stored in the co-axial transmission line via a small current flow loop (1).

ii. Trigger signal into lowest transistor Q1's base, switches Q1 'on'

iii. Energy stored in the transmission line will be released as a high current along loop (2)

iv. Producing a positive pulse on R_L

- Trigger signal determines the pulse repetition rate at the load, R_L

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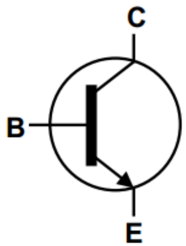
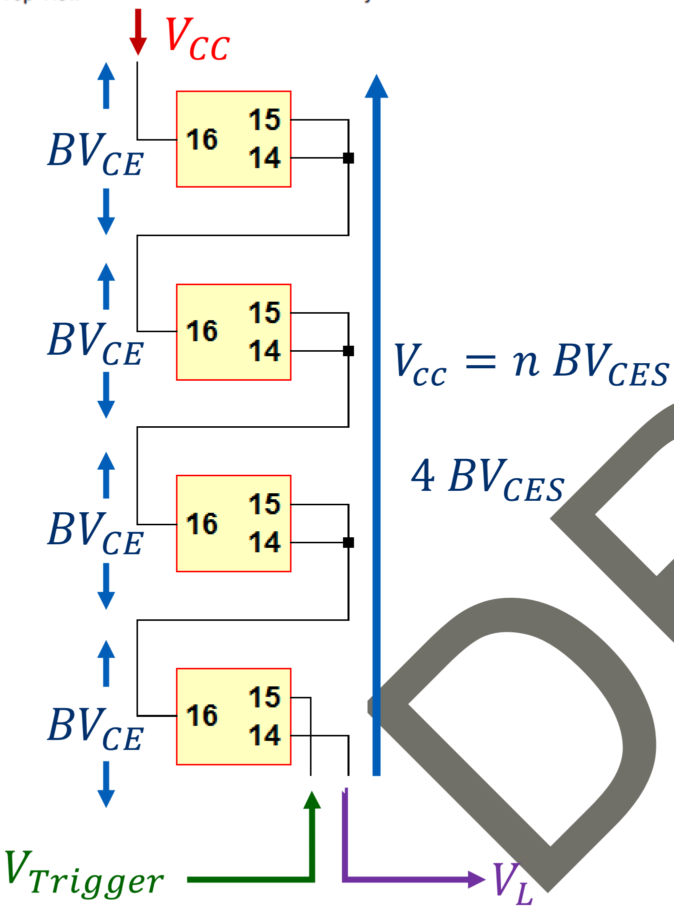
Top View



Device Symbol



Avalanche Breakdown Transistors

Limitation:

- Voltage supply is limited to the collector-emitter breakdown voltage, BV_{CE}

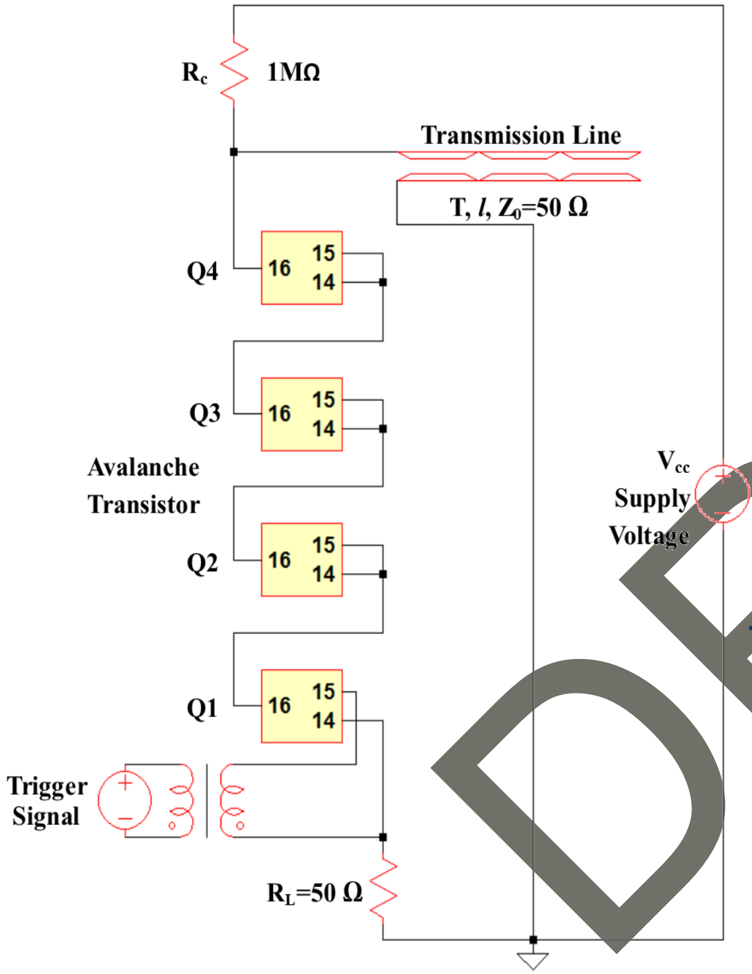
$$V_{CCmax} = n\ BV_{CES}$$

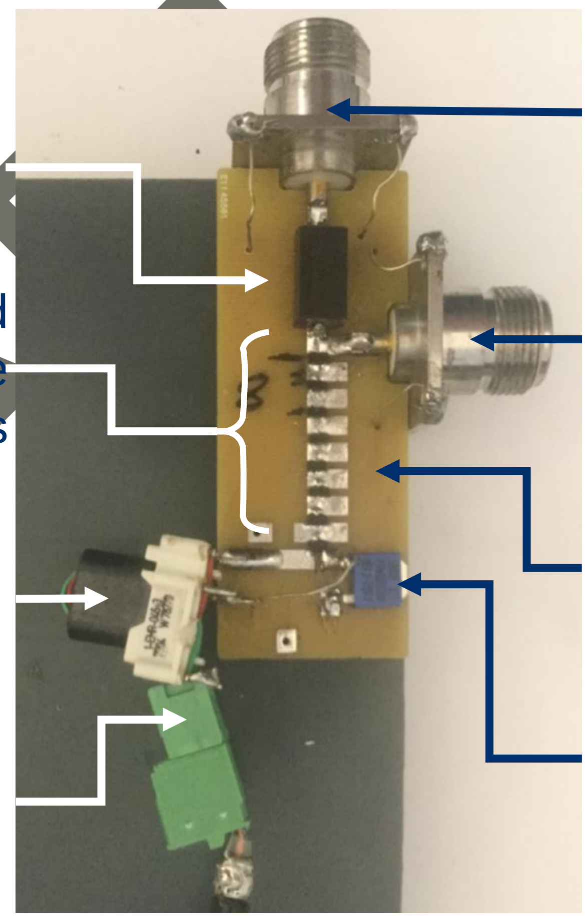
Solution:

- Stacking multiple avalanche transistors, n
- Operates like a single avalanche transistor
- Results in a proportionally higher pulse amplitude at the load

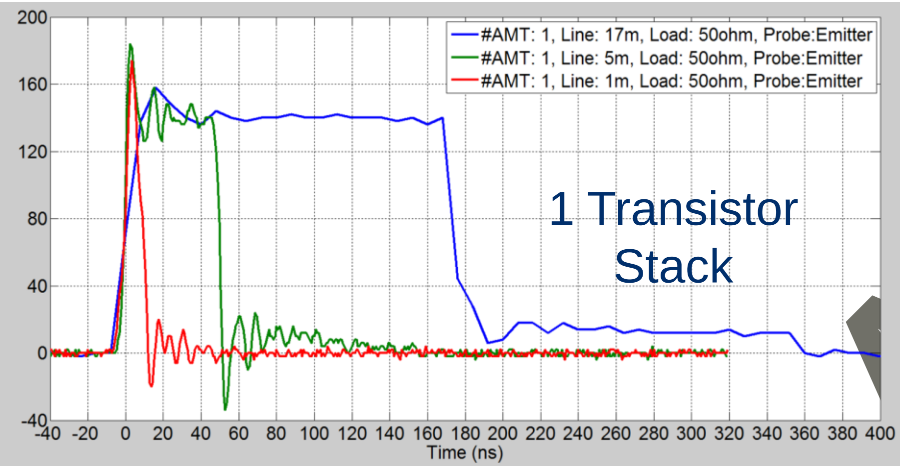
$$V_{Lmax} = n\frac{V_{cc}}{2} = n\frac{BV_{CE}}{2}$$

Circuit Design and Implementation





Result and Analysis

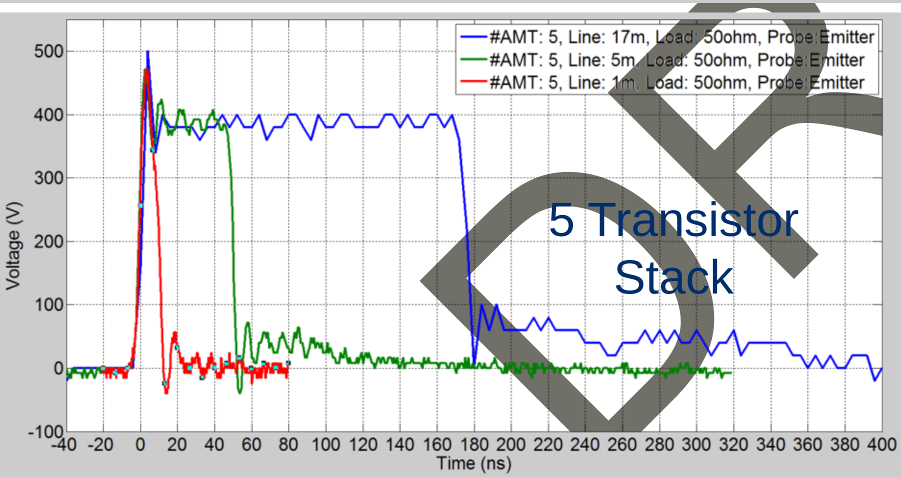


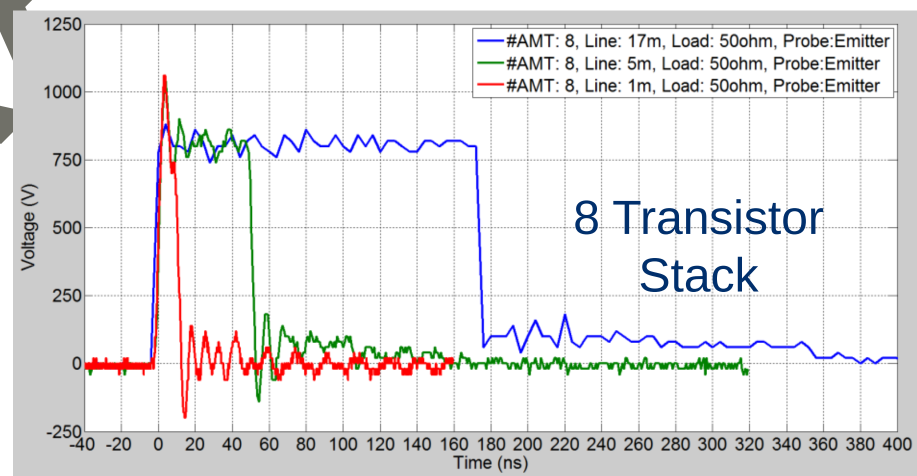
Pulse Width Result:

- Transmission lines of 1 m (10 ns), 5 m (50 ns) and 17 m (170 ns)
- Line length determines pulse width

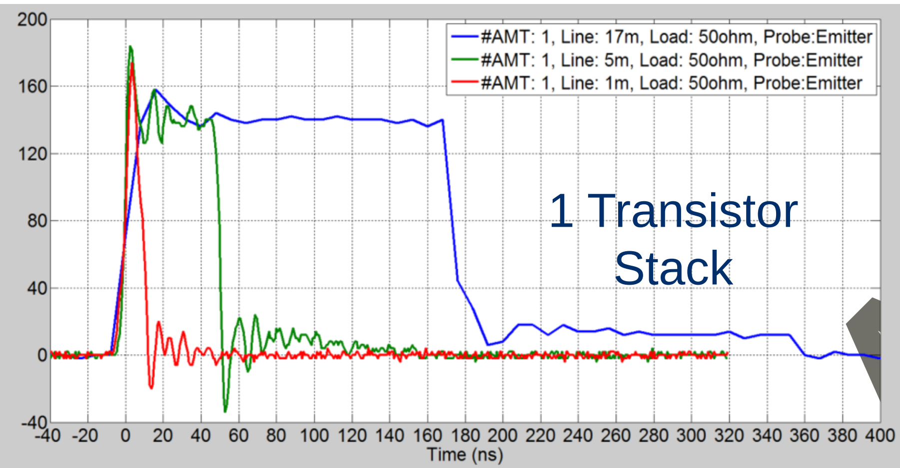
$$\text{Pulse width} = 2T = 2\frac{l\sqrt{\varepsilon_r}}{c}$$

- Rise times are the same





Result and Analysis

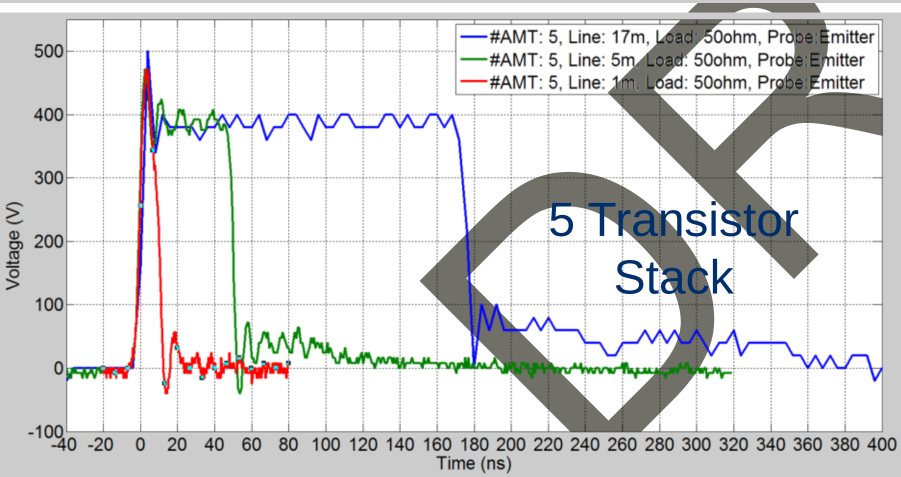


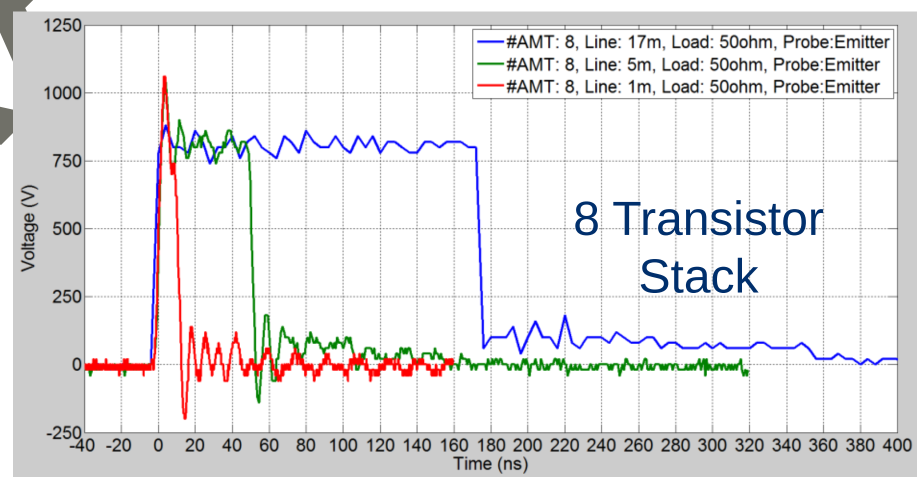
Stacking Transistors Result:

- Number of avalanche transistors stacked from a 1 to 8.
- Larger the number of transistors sack the higher the pulse amplitude.

$$V_{Lmax} = n\frac{V_{cc}}{2} = n\frac{BV_{CE}}{2}, \qquad V_{Lmax} \propto n$$

- Rise times are the same

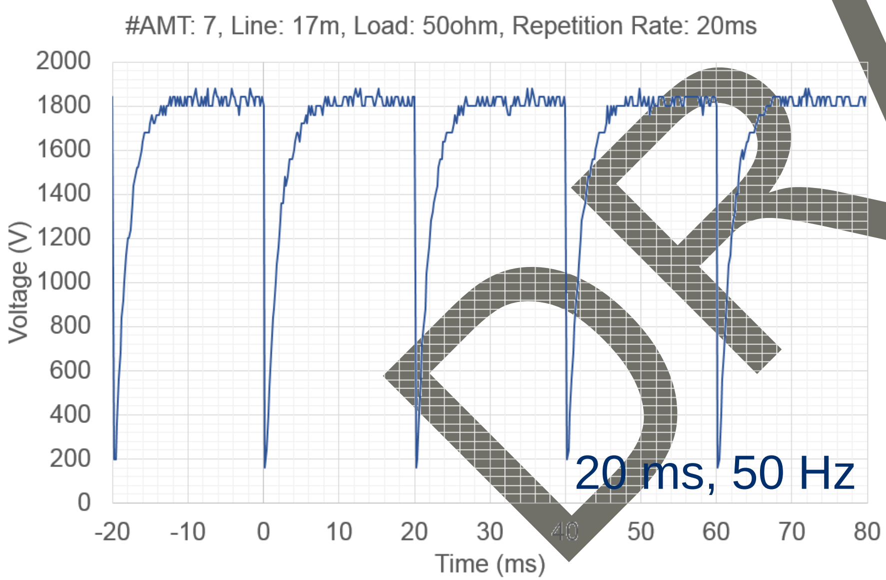


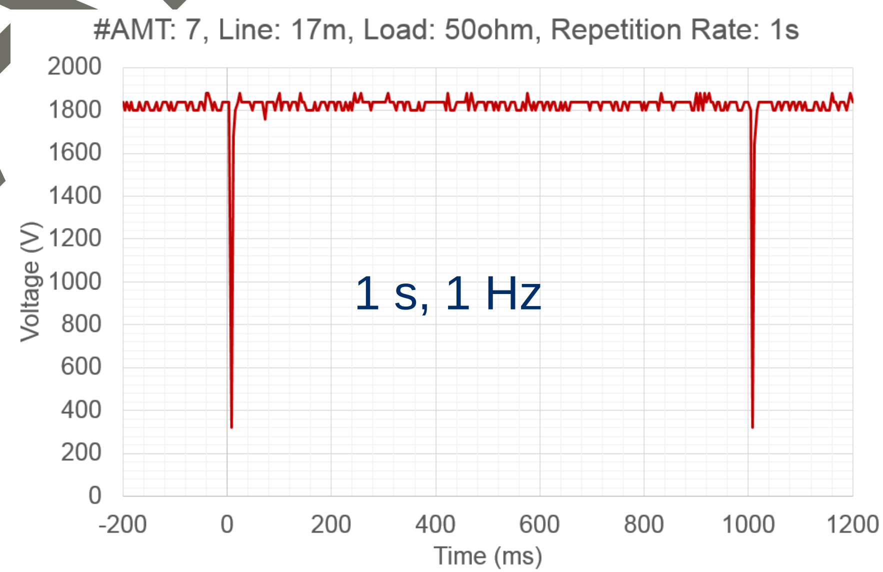


Result and Analysis

Repetition Rate Result:

- Repetition rate of the trigger signal determines the pulse repetition rate.
- Evidence as the charged line is discharged at these rate.
- Charge time of the line is dependent of the line length.
- Repletion rate is limited to transmission line time constant



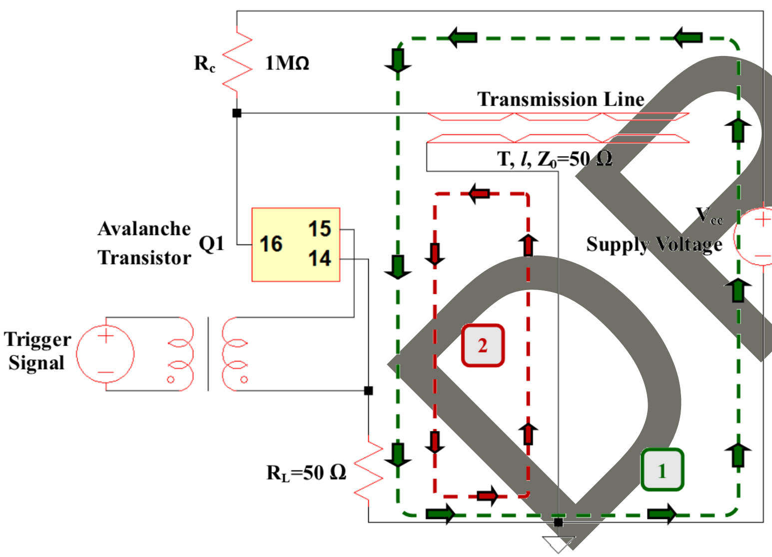


Result and Analysis

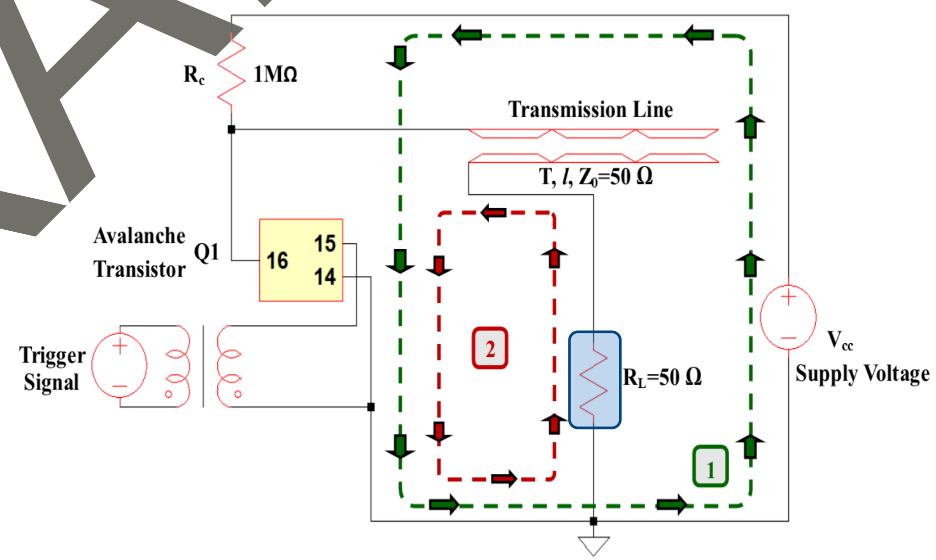
Adjust Pulse Polarity:

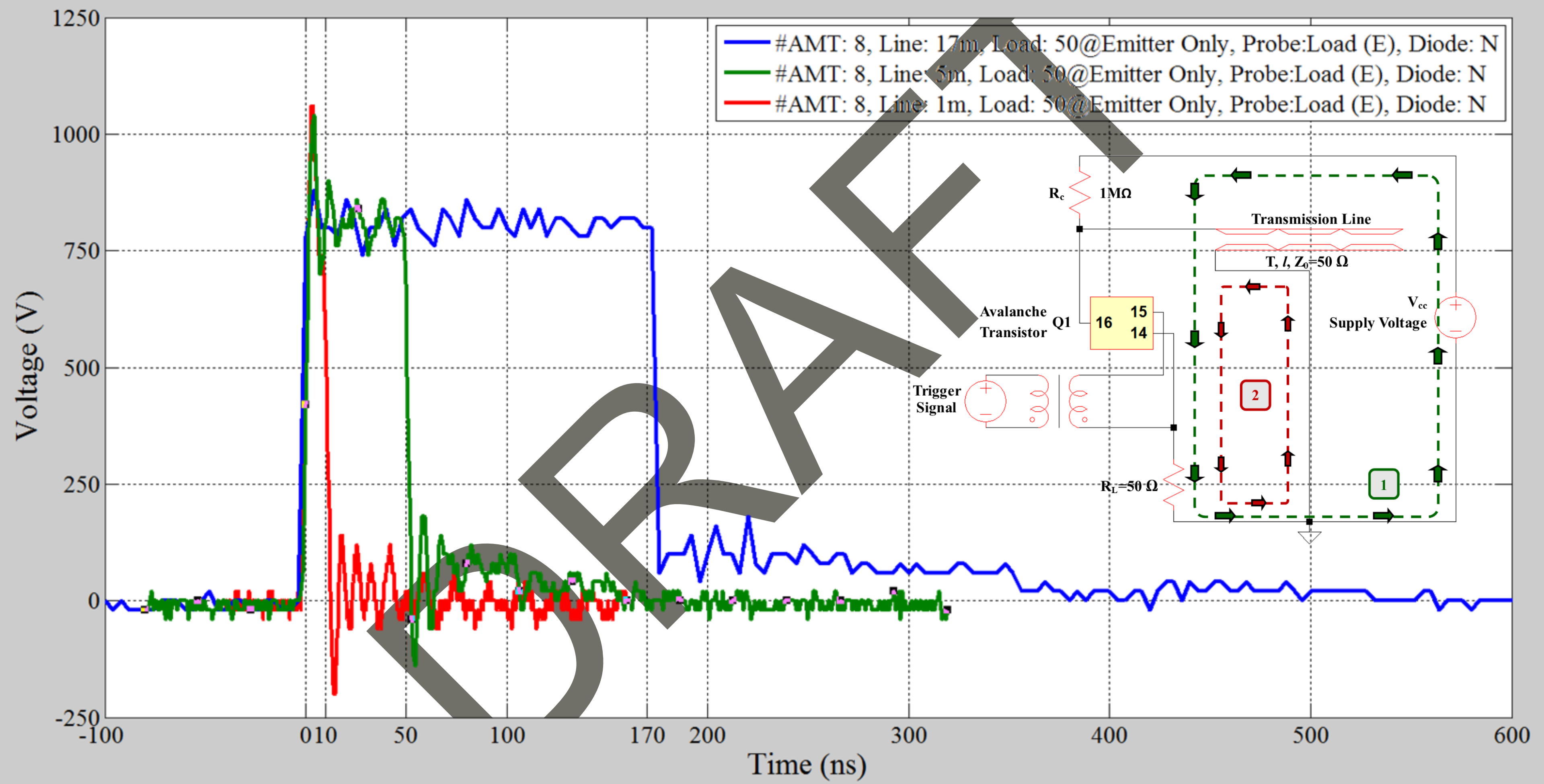
- Pulse polarity determined by location of the load within the circuit design.
- Take advantage of the current flow in loop (2).
- Charge time of the line is dependent of the line length.

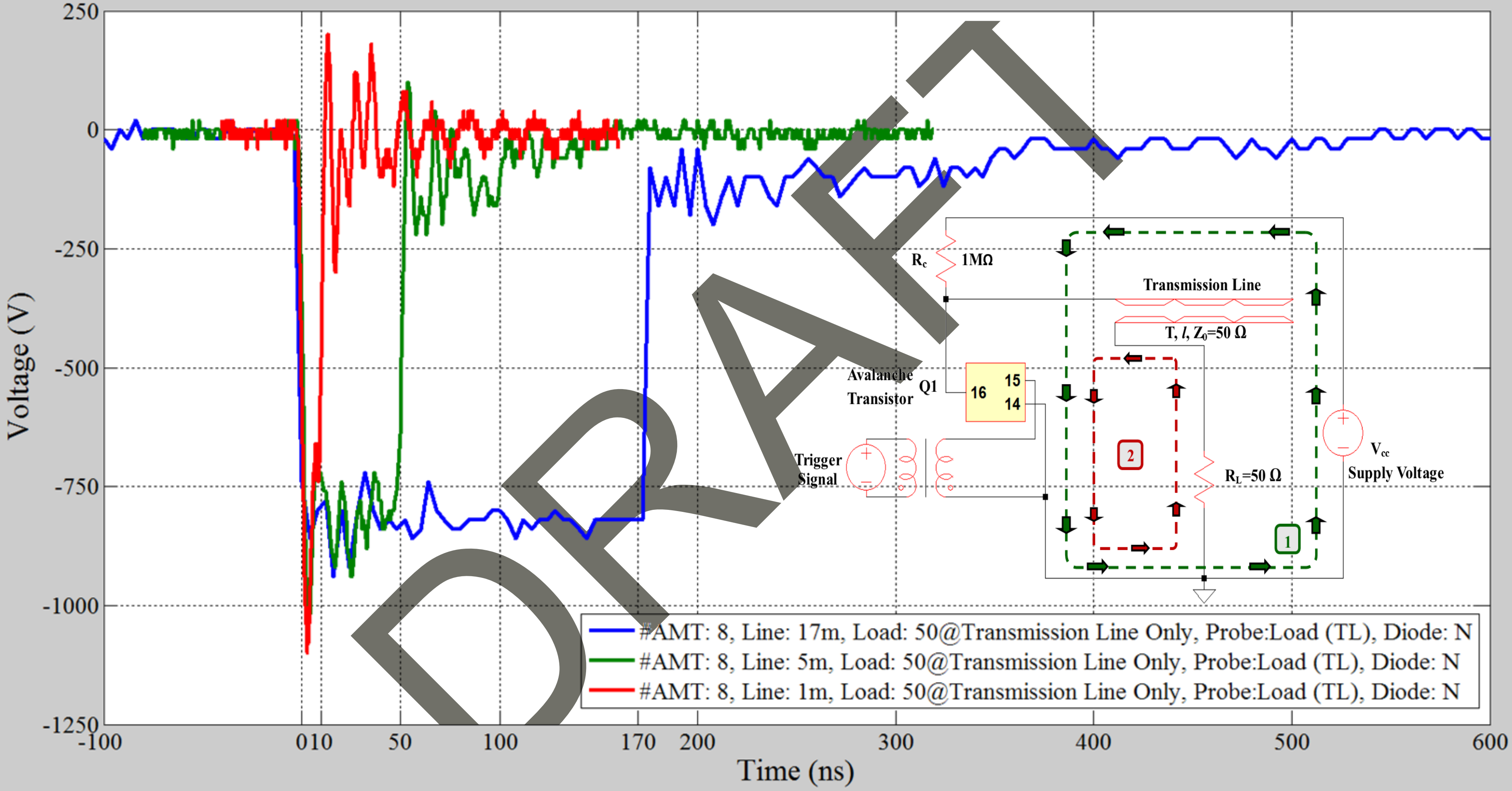
Positive Polarity Pulse



Negative Polarity Pulse




#AMT: 8, Line: 17m, Load: 50@Emitter Only, Probe:Load (E), Diode: N
#AMT: 8, Line: 5m, Load: 50@Emitter Only, Probe:Load (E), Diode: N
#AMT: 8, Line: 1m, Load: 50@Emitter Only, Probe:Load (E), Diode: N
Voltage (V)
Time (ns)
1250
1000
750
500
250
0
-250
-100
0
10
50
100
170
200
300
400
500
600
R_c
1MΩ
Transmission Line
T, l, Z_0=50 Ω
Avalanche Transistor
Q1
16
15
14
V_{cc}
Supply Voltage
Trigger Signal
R_L=50 Ω
1
2


250
0
-250
-500
-750
-1000
-1250
Voltage (V)
-100
0 10
50
100
170
200
300
400
500
600
Time (ns)
Rc
1MΩ
Transmission Line
T, l, Z0=50 Ω
Avalanche Transistor
Q1
16
15
14
Trigger Signal
RL=50 Ω
Vcc
Supply Voltage
2
1
#AMT: 8, Line: 17m, Load: 50@Transmission Line Only, Probe:Load (TL), Diode: N
#AMT: 8, Line: 5m, Load: 50@Transmission Line Only, Probe:Load (TL), Diode: N
#AMT: 8, Line: 1m, Load: 50@Transmission Line Only, Probe:Load (TL), Diode: N
DRAFT

Conclusion

- Pulse width determined by the transmission line length
- Relationship between the characteristic impedance of the transmission line, Z_0, and the load, R_L , determines the:
  - Pulse amplitudes
  - Secondary pulse or rebound of the primary pulse (Γ=0)
- The pulse repletion rate is the controller trigger signal repletion rate to Q1's base

Produce well-defined symmetrical bipolar nanosecond pulses require to support nanosecond electroporation and other biomedical applications in a cost-effective manner

Future/Related Work: A Bipolar Design in Development and gain Biological Effect

Acknowledge

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

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Thank You for Your Time

Questions