

# **Time-Domain Analysis of Transmission Line Circuits**

(Part 5)

**Dr. José Ernesto Rayas Sánchez**

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## Outline

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- Basic concepts on Bergeron diagrams
- Bergeron diagrams for TLs with linear terminations
- Alternative notation for Bergeron diagrams
- Examples using the alternative notation
- Bergeron diagrams for TLs with nonlinear loads
- Bergeron diagrams for TLs with non ideal drivers
- Bergeron diagrams with fully nonlinear terminations

## Bergeron Diagrams

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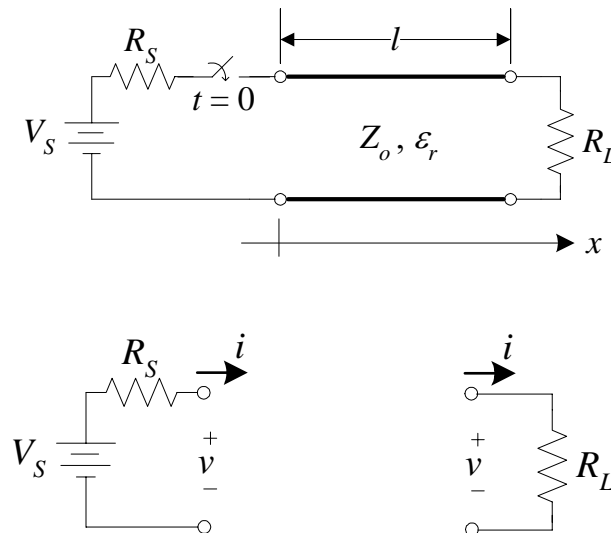
- It is a technique for calculating transient waveforms on transmission line circuits
- As in the lattice diagrams, it is restricted to lossless transmission lines
- It allows to easily calculate the transient voltages and currents at the input of the line and at the load (intermediate points can not be directly calculated)
- It can be applied to TLs with nonlinear sources and loads (as oppose to lattice diagrams)
- It is based on the  $i$ - $v$  characteristics of the driver, the transmission line and the load

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## Bergeron Diag. for a TL with Resistive Term.

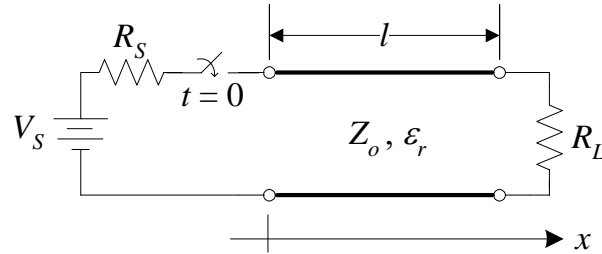
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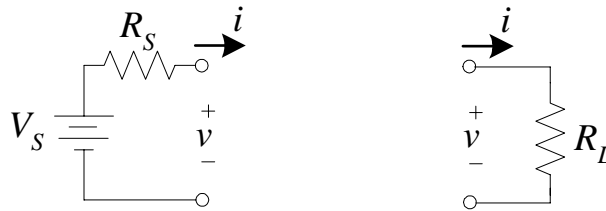
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## Bergeron Diag. for a TL with Resistive Term.



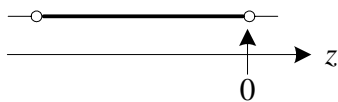
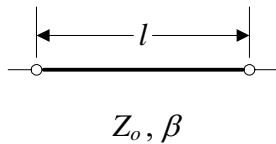
at steady-state...



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## $i$ - $v$ Characteristics of a Lossless TL



Frequency domain:

$$V(z) = V_o^+ e^{-j\beta z} + V_o^- e^{+j\beta z}$$

$$I(z) = I_o^+ e^{-j\beta z} + I_o^- e^{+j\beta z}$$

$$I(z) = \frac{1}{Z_o} (V_o^+ e^{-j\beta z} - V_o^- e^{+j\beta z})$$

Time domain:

$$v(z,t) = |V_o^+| \cos(\omega t - \beta z + \phi^+) + |V_o^-| \cos(\omega t + \beta z + \phi^-)$$

$$v(z,t) = v^+(z,t) + v^-(z,t)$$

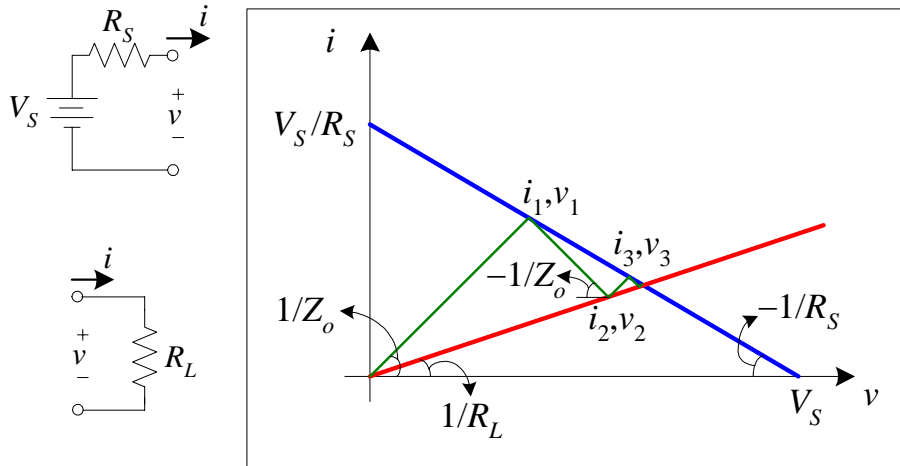
$$i(z,t) = \frac{1}{Z_o} (v^+(z,t) - v^-(z,t)) \quad i(z,t) = i^+(z,t) + i^-(z,t)$$

$$i^+(z,t) = \frac{v^+(z,t)}{Z_o} \quad i^-(z,t) = \frac{-v^-(z,t)}{Z_o}$$

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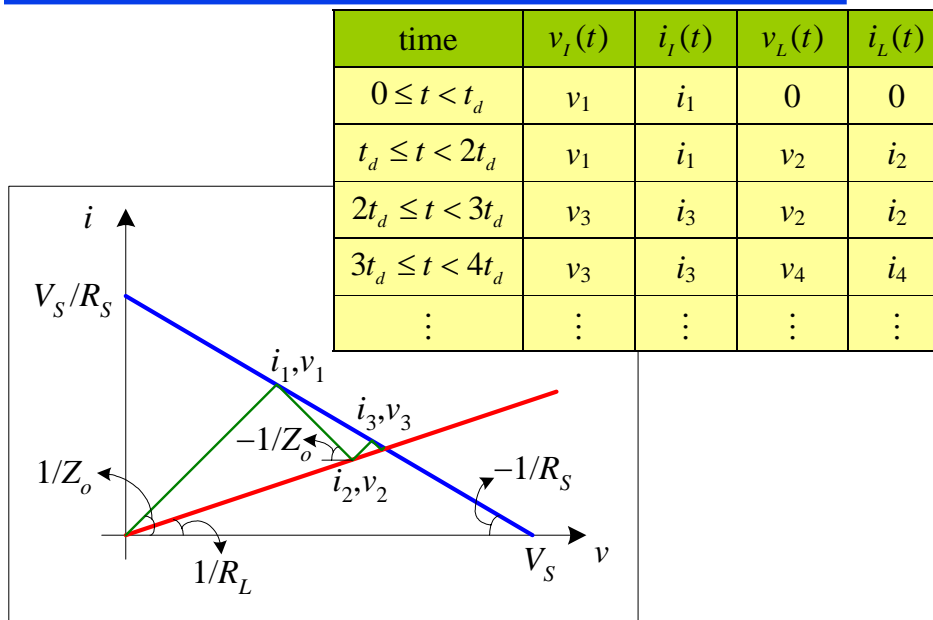
## Bergeron Diag. for a TL with Resistive Term.



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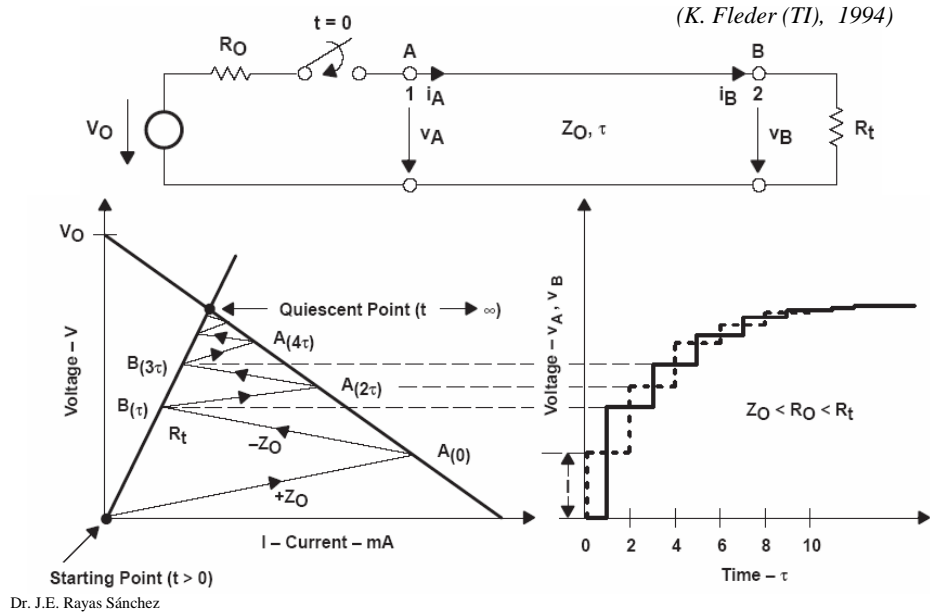
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## Bergeron Diag. for a TL with Resistive Term.



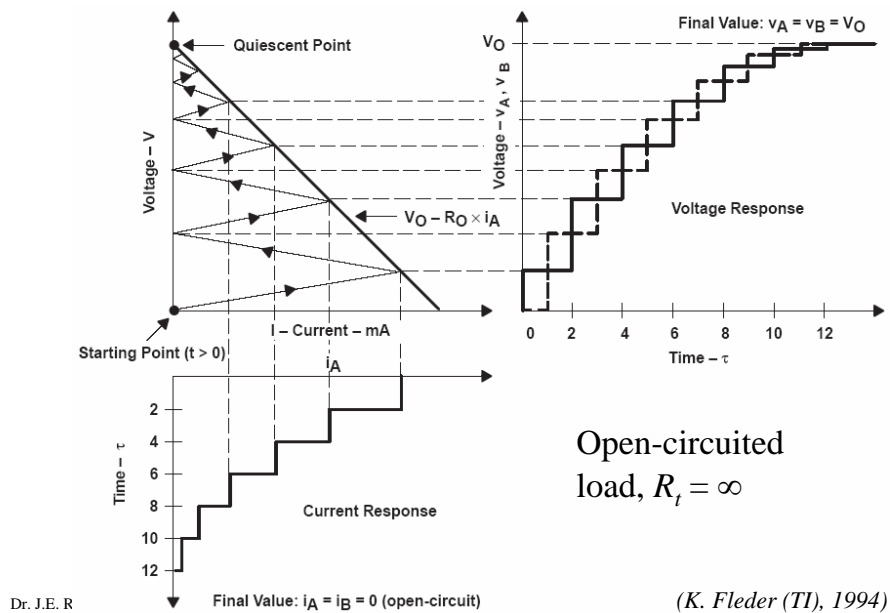
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## Alternative Notation for Bergeron Diagrams



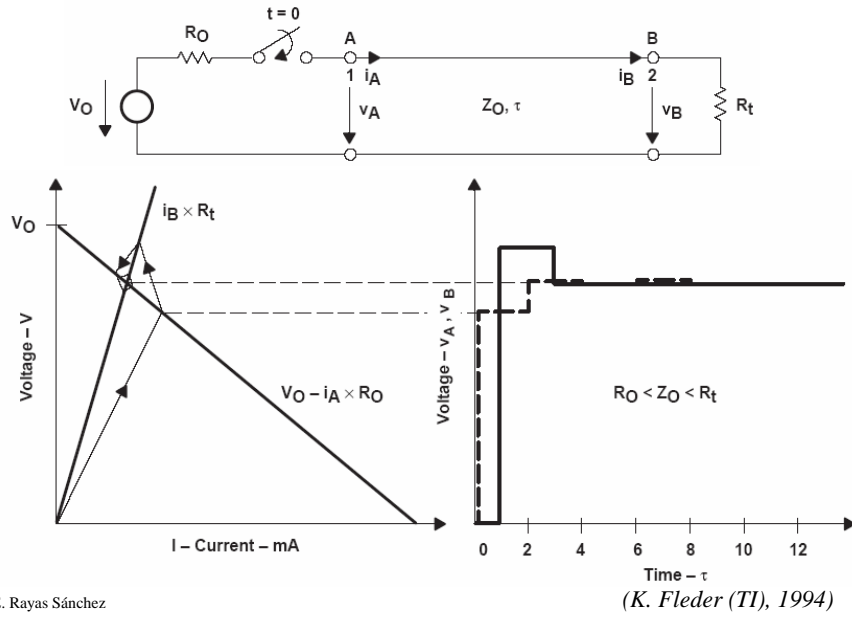
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## Alternative Notation - Example 2

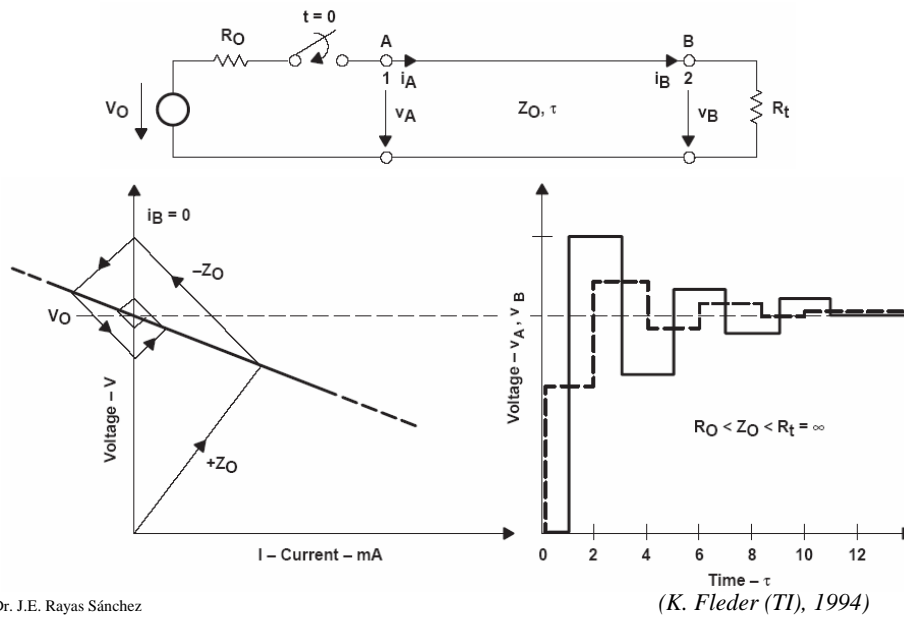


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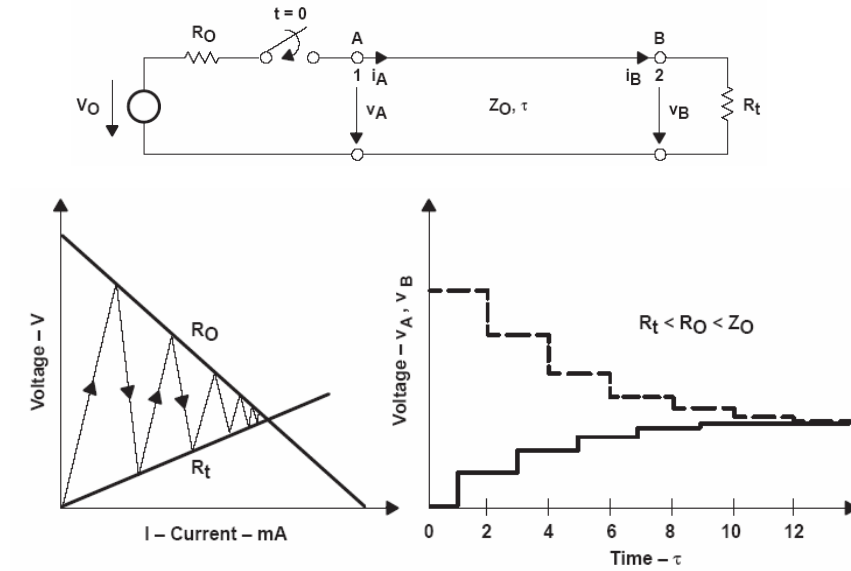
### Alternative Notation - Example 3



### Alternative Notation - Example 4



## Alternative Notation - Example 5

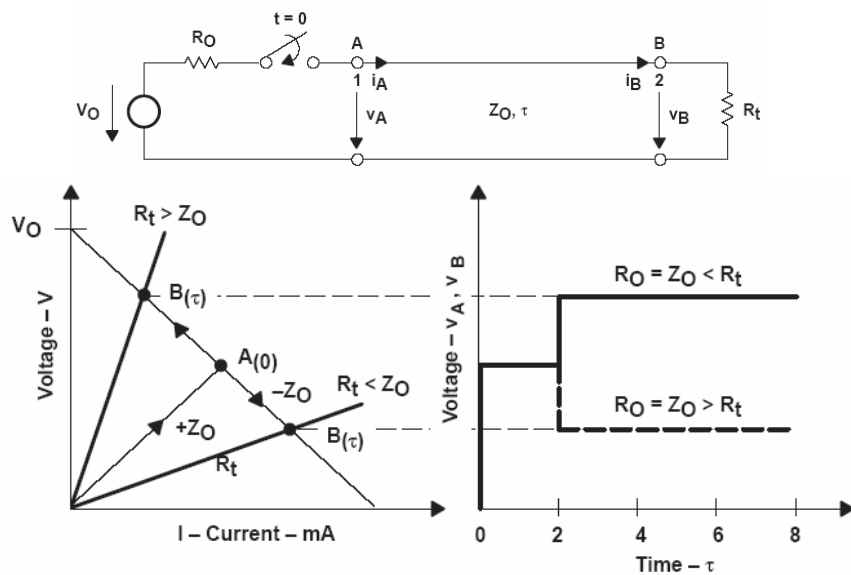


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(K. Fleder (TI), 1994)

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## Alternative Notation – Ex. 6 (Source Matched)

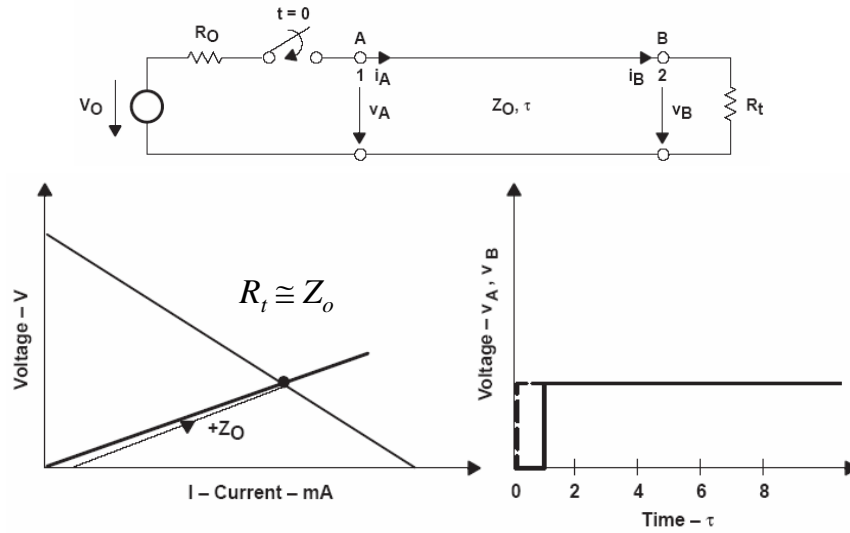


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(K. Fleder (TI), 1994)

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## Alternative Notation – Ex. 6 (Load Matched)

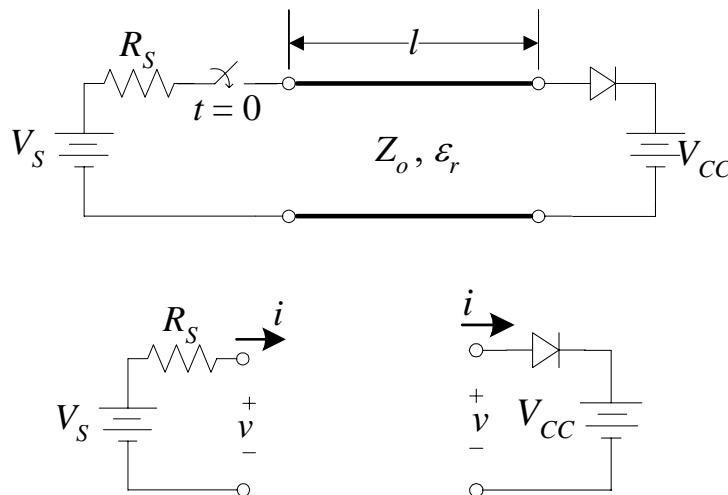


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(K. Fleder (TI), 1994)

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## Bergeron Diag. for a TL with Diode Termination

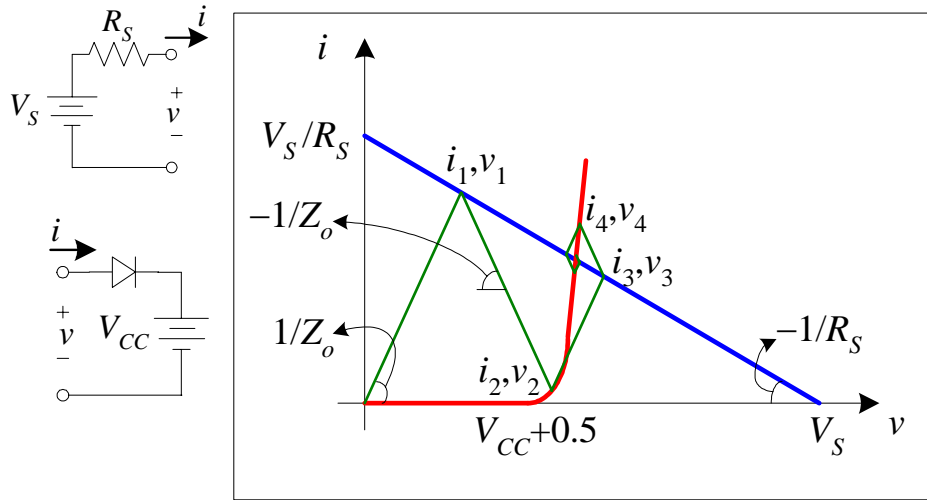


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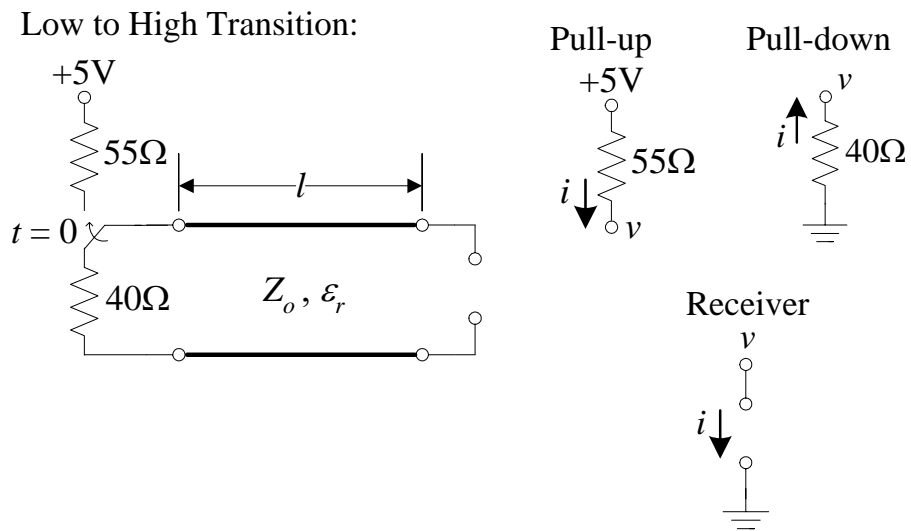
## Bergeron Diag. for a TL with Diode Termination



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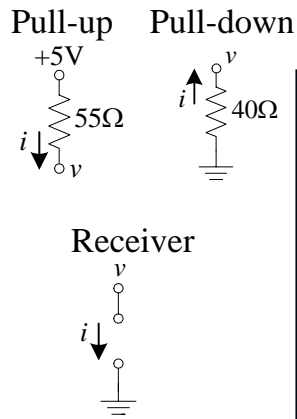
## Bergeron Diag. for a TL with Non-ideal Driver



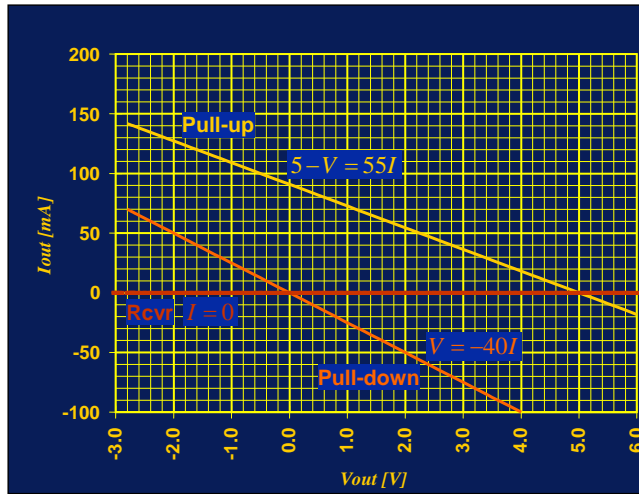
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## Bergeron Diag. for a TL with Non-ideal Driver



(H. Heck, 2002)

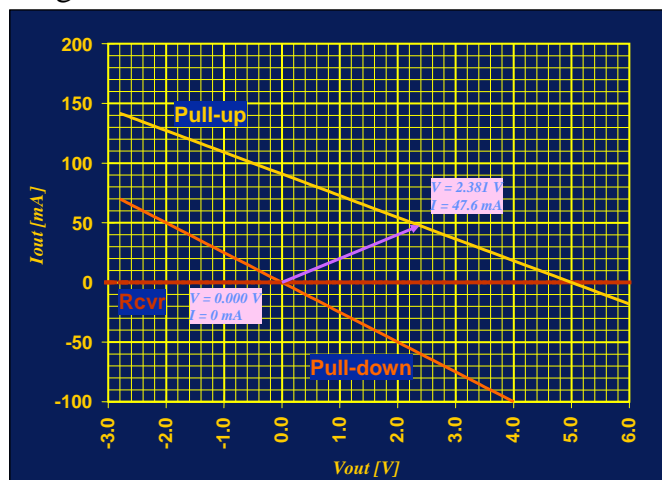


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## Bergeron Diag. for a TL with Non-ideal Driver

Low to High Transition:



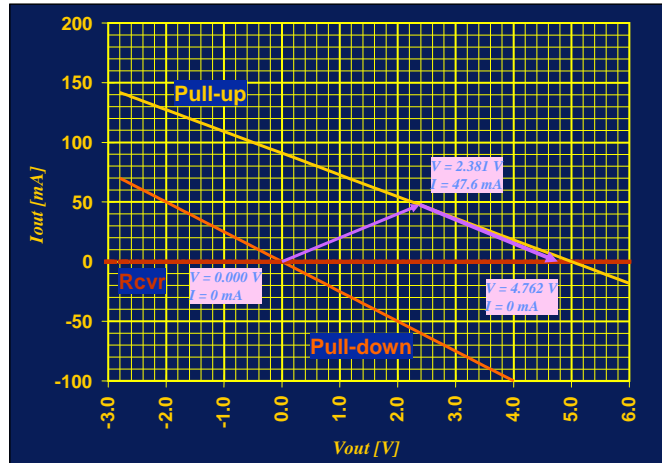
(H. Heck, 2002)

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## Bergeron Diag. for a TL with Non-ideal Driver

Low to High Transition:



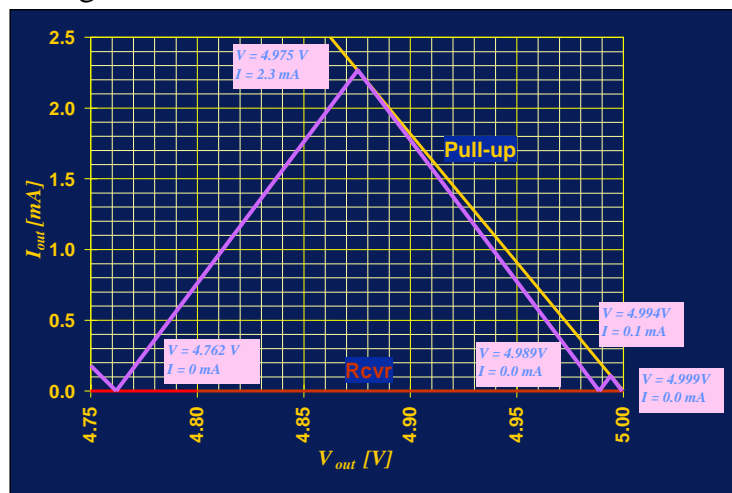
(H. Heck, 2002)

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## Bergeron Diag. for a TL with Non-ideal Driver

Low to High Transition:



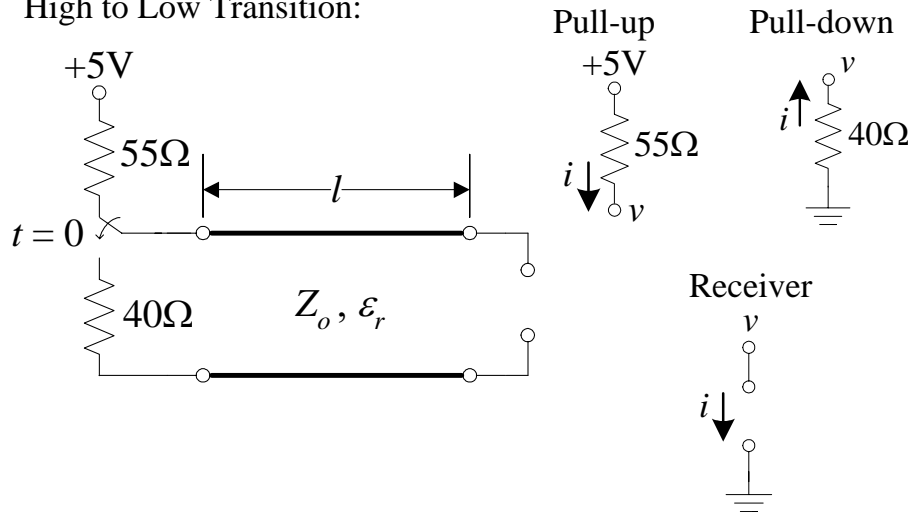
(H. Heck, 2002)

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## Bergeron Diag. for a TL with Non-ideal Driver

High to Low Transition:

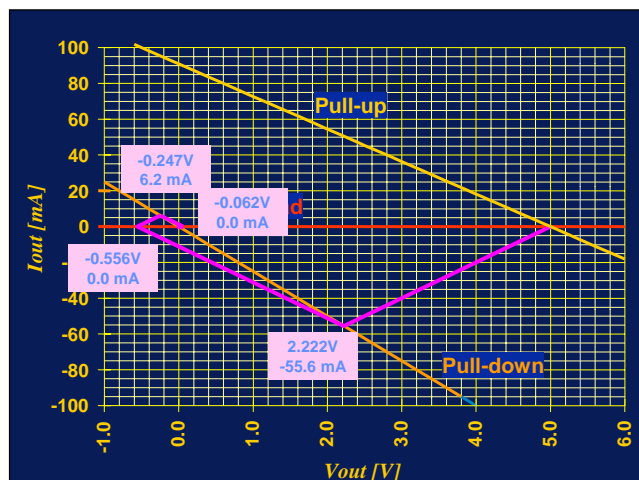


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## Bergeron Diag. for a TL with Non-ideal Driver

High to Low Transition:



(H. Heck, 2002)

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## Bergeron Diag. for TLs with Non-linear Devices

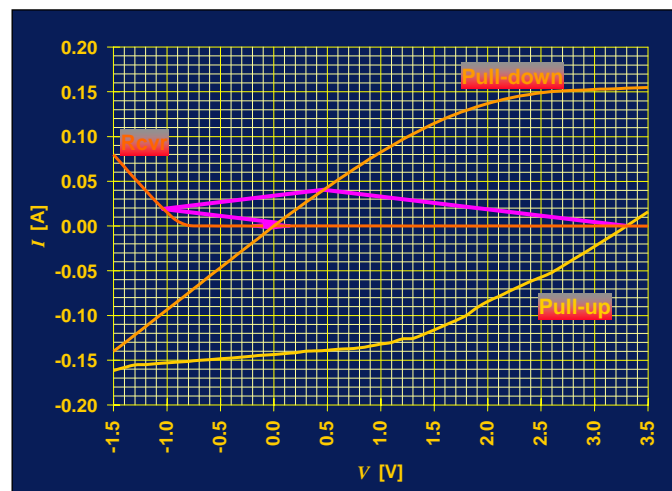


(H. Heck, 2002)

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## Bergeron Diag. for TLs with Non-linear Devices

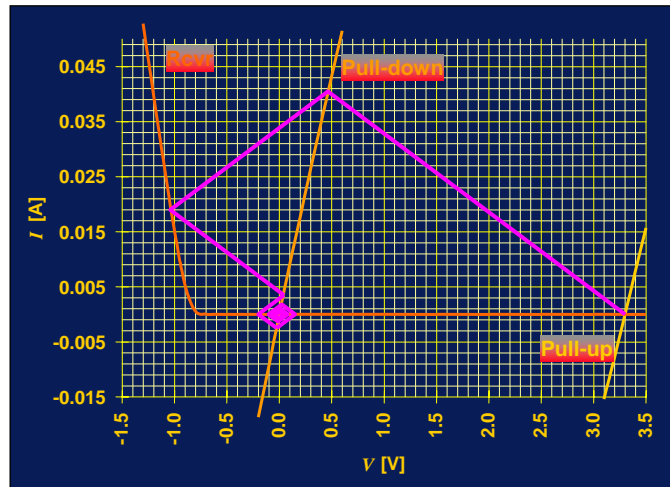


(H. Heck, 2002)

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## Bergeron Diag. for TLs with Non-linear Devices

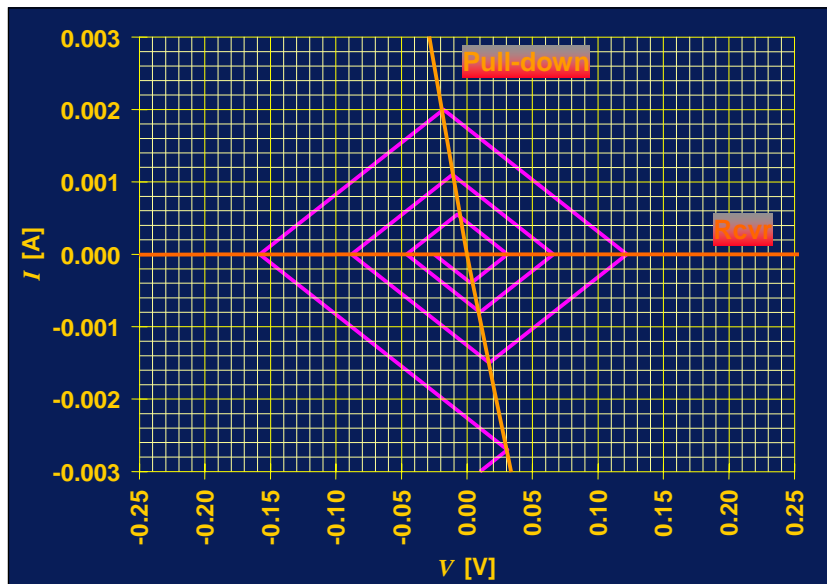


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(H. Heck, 2002)

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## Bergeron Diag. for TLs with Non-linear Devices



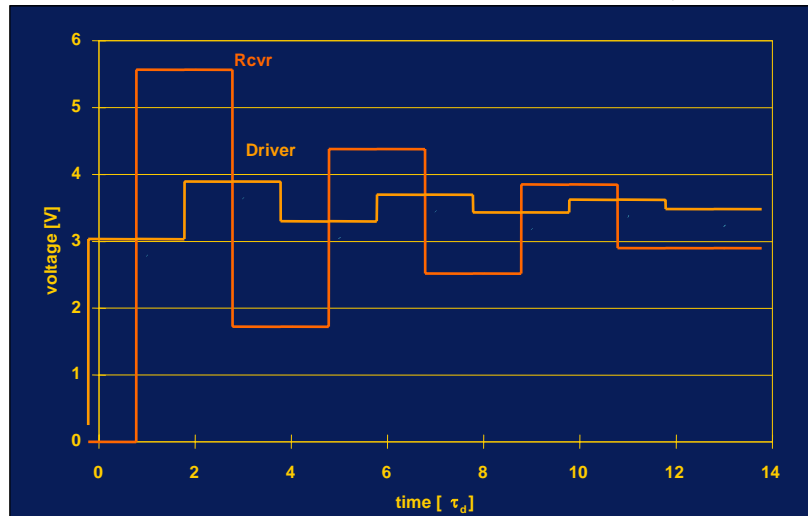
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## Bergeron Diag. for TLs with Non-linear Devices

Example: PowerPC 604E

(H. Heck, 2002)



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