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Rzeczpospolita Polska

Unia Europejska
Europejski Fundusz Społeczny

Politechnika Śląska jako Centrum Nowoczesnego Kształcenia
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Digital Circuits Design

Faculty of Automatic Control, Electronics and Computer Science,
Informatics, Bachelor Degree

Lecture 11.

Transmission lines

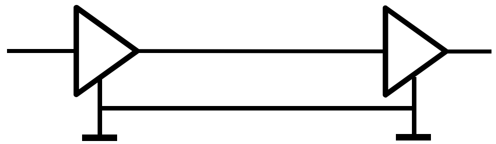
Ph.D. Eng. **Adam Opara**

Transmission lines

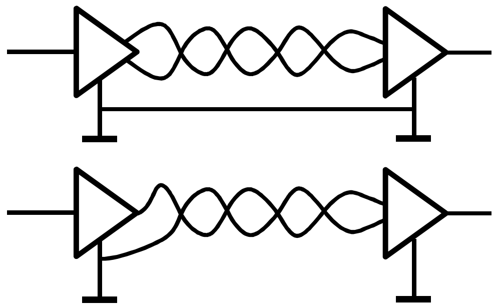
- What is it?
- Types
  - Microstrip lines
  - Impedance
  - Skin effect resistance
- Theory
- Parameters
- Impedance matching
- Bergeron's method
- EMC

Transmission lines

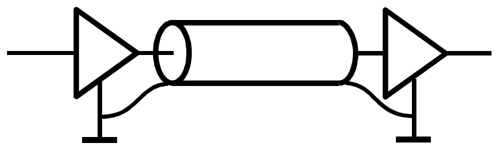
- Asymmetric



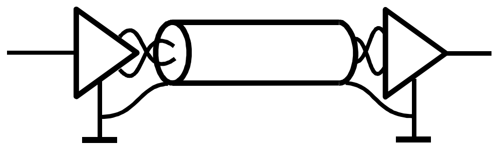
- Symmetric



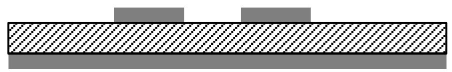
- Shielded asymmetric



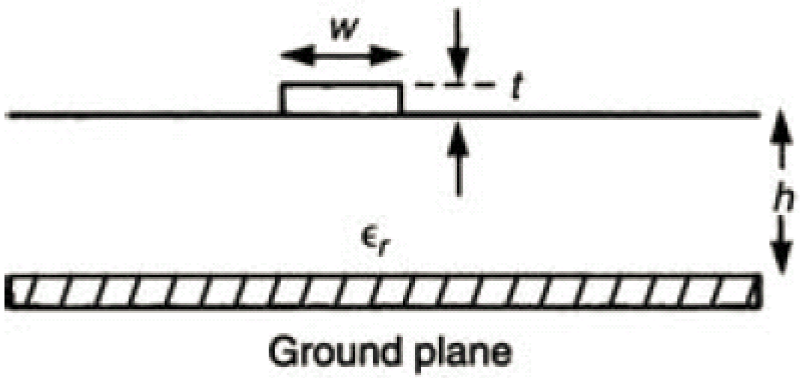
- Shielded symmetric

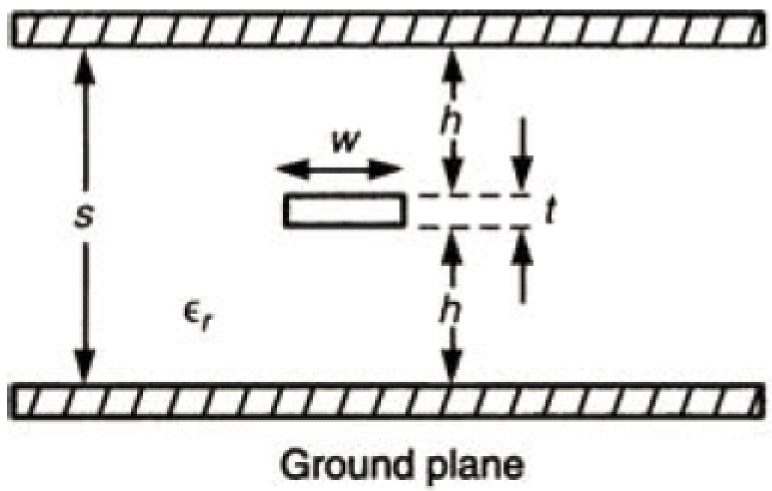


- Microstrip



Microstrip line





Microstrip line

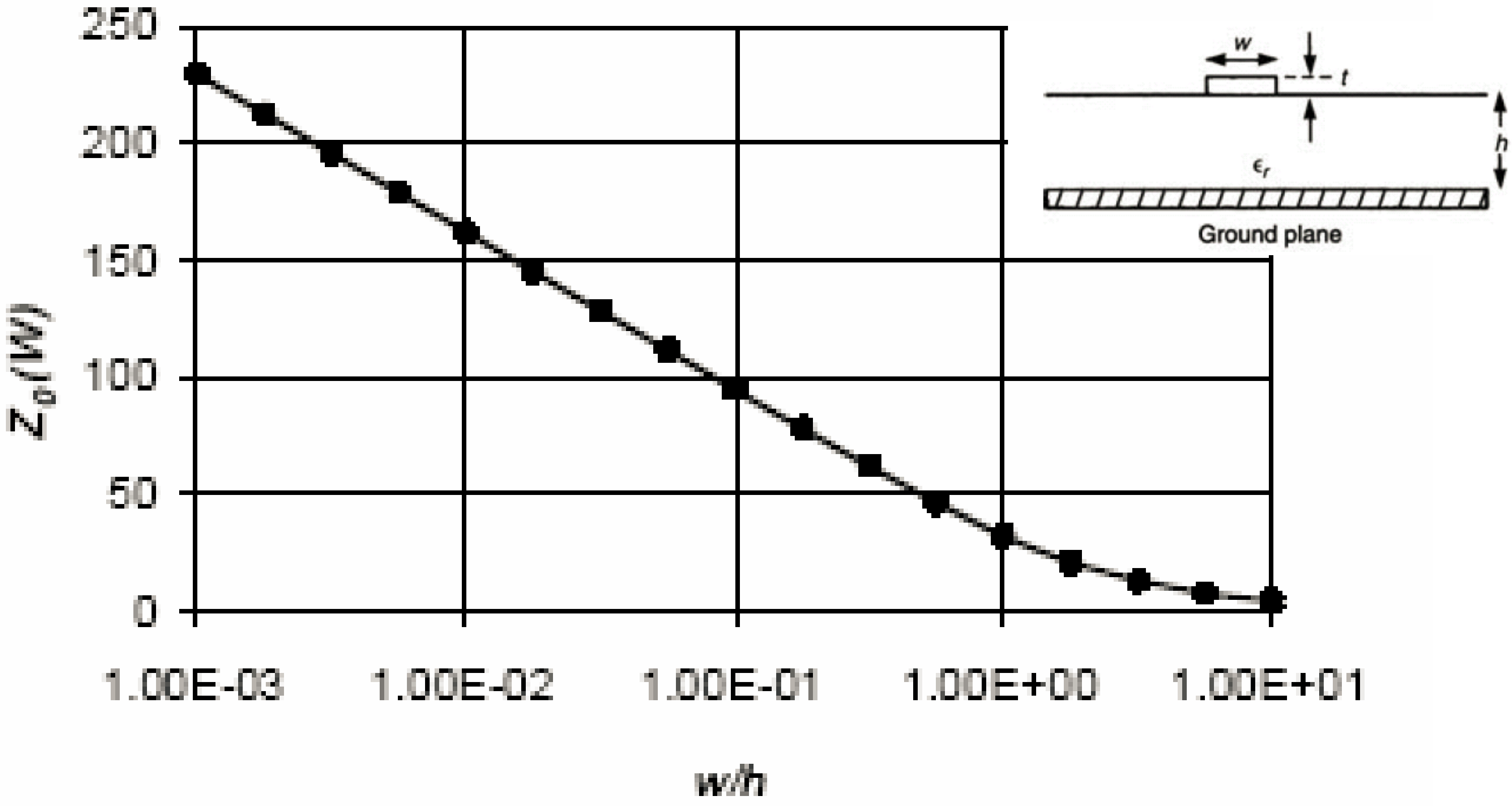
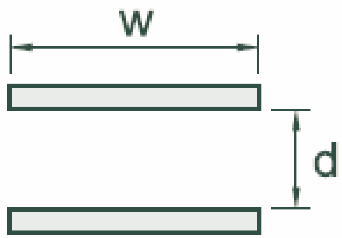


FIGURE 16.24 Impedance for different relative widths (substrate dielectric constant: 4.2).

Microstrip line



$$C = \epsilon \frac{w}{d}$$

$$G = \sigma \frac{w}{d}$$

$$L = \mu \frac{d}{w}$$

$$R = 2 \frac{R_s}{w}$$

Skin effect resistance $R_s = \sqrt{\dfrac{\pi f \mu_0}{\sigma}}$

Transmission lines - theory

- For rectangular pulses of edge rise/ fall time t_r significant components of frequency spectrum are in the $f_{max} < \frac{1}{\pi\, t_r}$

- For the highest significant frequency the transmission line should be electrically short

$$u = \frac{c}{\sqrt{\varepsilon_r}}$$

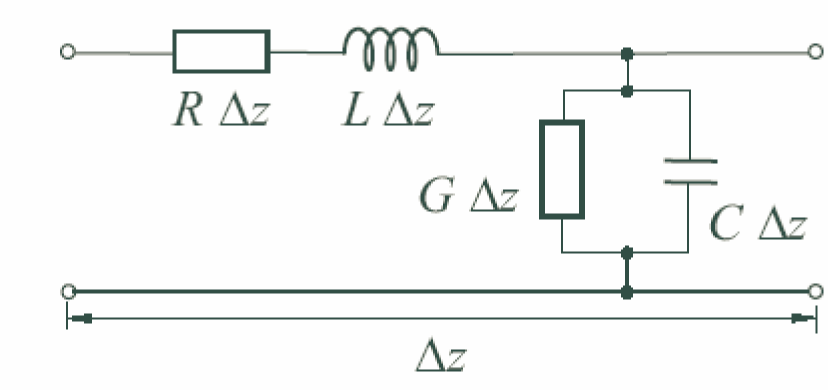
$$u \cdot t_p = l < 0.1\,\lambda = 0.1\,\frac{u}{f_{max}} = 0.1\,\pi\,u\,t_r$$

$$t_p < 0.314\,t_r$$

Transmission lines - theory

- Characteristic (surge) impedance:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \approx \sqrt{\frac{L}{C}} = R_0$$

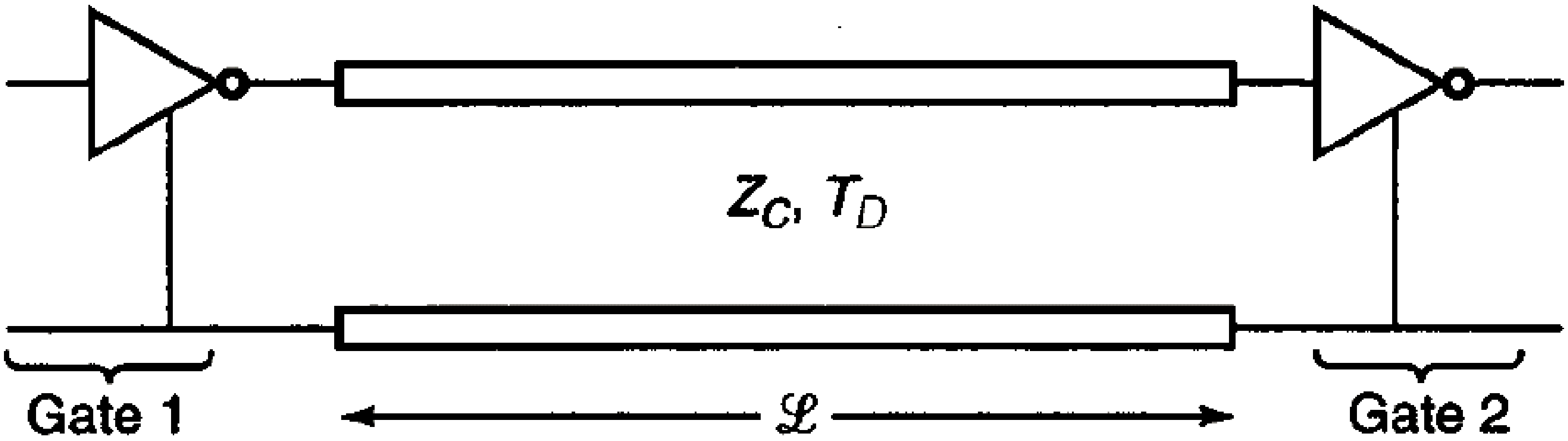


- $R_{in}, R_L \neq R_0$ → reflections
- Reflection coefficient $\Gamma_L = \frac{R_L - Z_0}{R_L + Z_0}$, $\Gamma \in \langle -1, 1 \rangle$
  - $\Gamma = -1$ short $R_L = 0$
  - $\Gamma = 1$ open $R_L = \infty$
  - $\Gamma = 0$ match $R_L = R_0$

Impedance matching

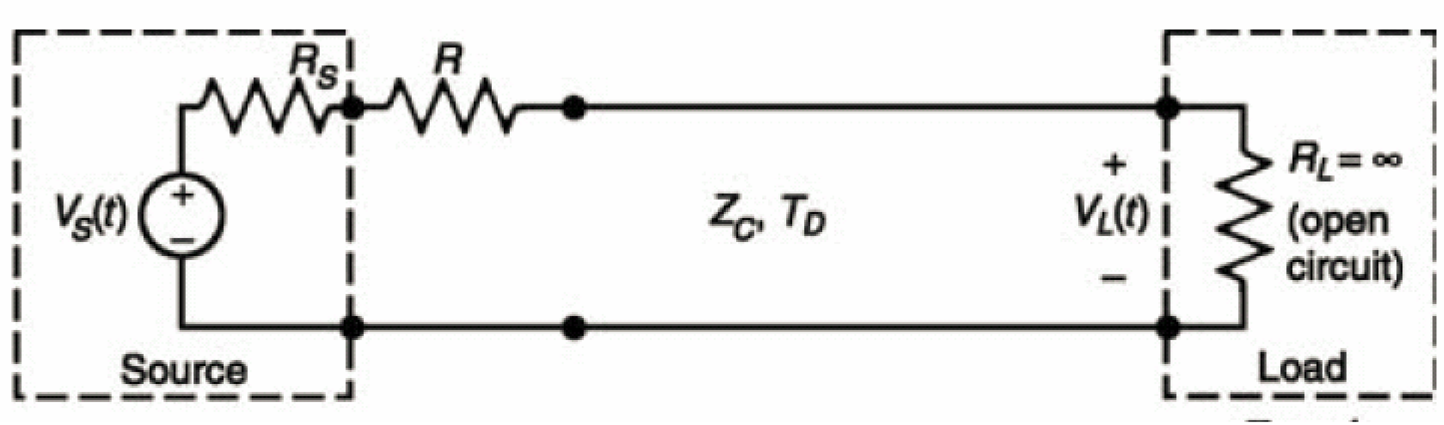
- Impedance matching is used in order to avoid reflections
- In digital systems, reflections may cause incorrect system operation and cause an EM field emission increase.
- In RF systems, getting the right level of matching is much more important than in digital circuits.
- The matching system should be a lossless system.

Impedance matching



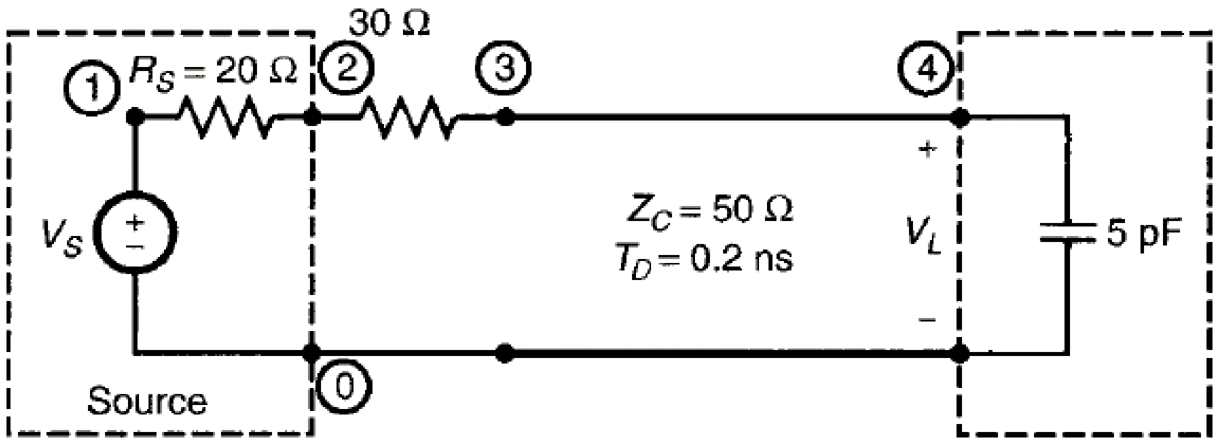
- In practice, we usually deal with a situation where the line is stimulated from a source with an impedance less than the characteristic impedance of the line, and the load is mainly of a capacitive nature.

Impedance matching



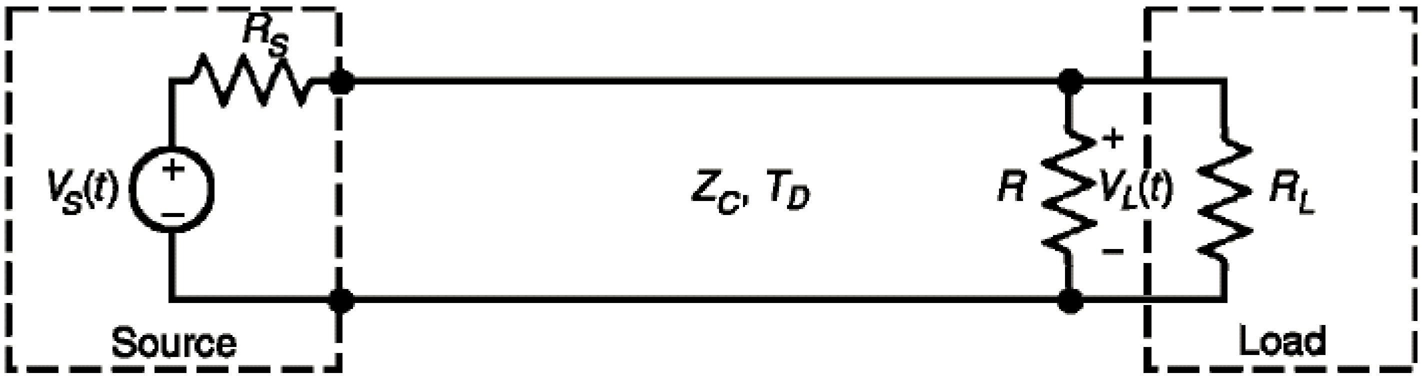
- Line input impedance matching

  Rs + R = Zo



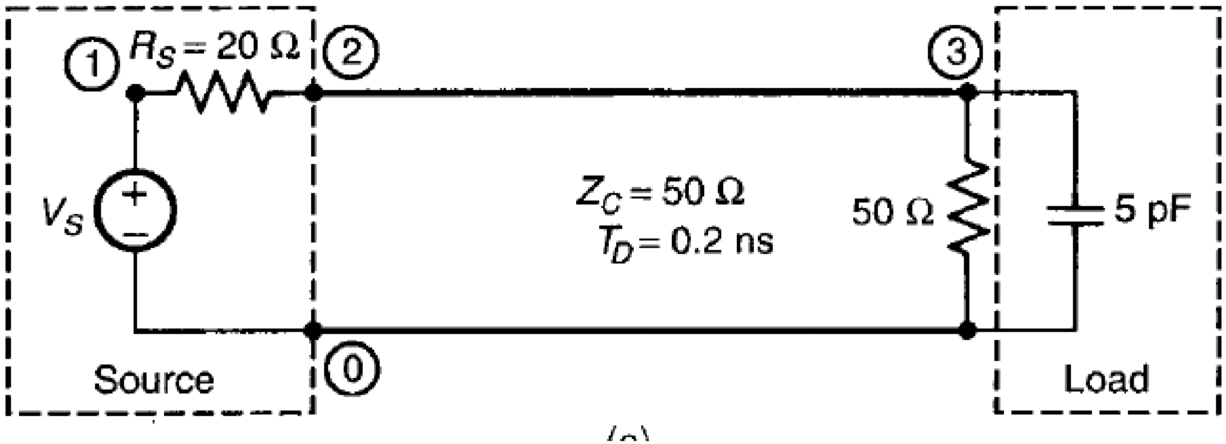
(a)

Impedance matching



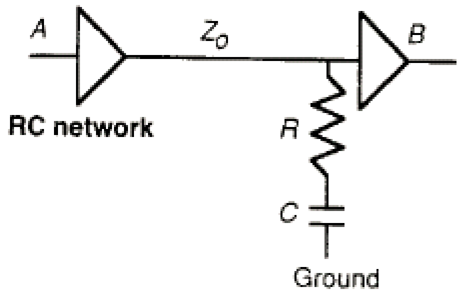
- Line output impedance matching

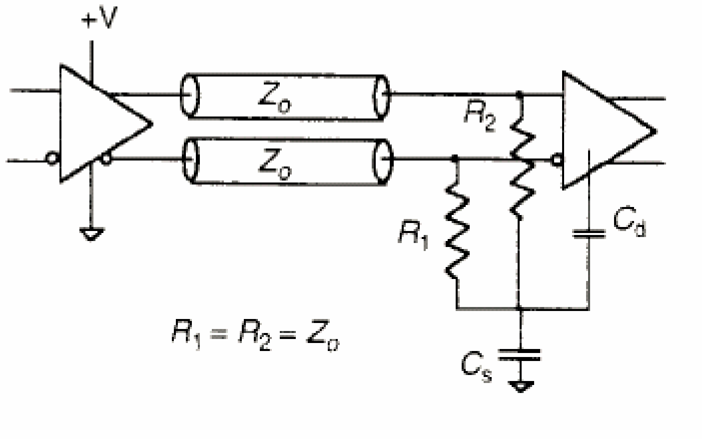
$R_L \,||\, R = Zo$



Impedance matching

Other methods





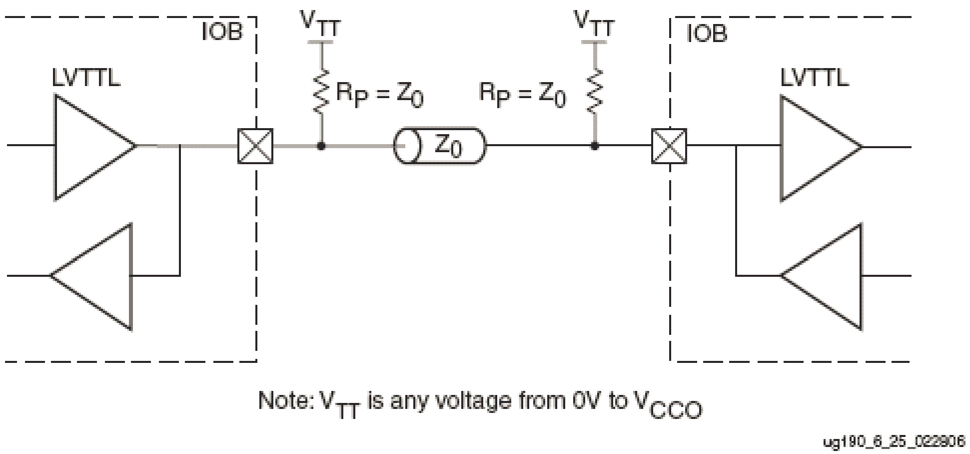


Figure 6-27: **LVTTL Bidirectional Termination**

Impedance matching

Other methods

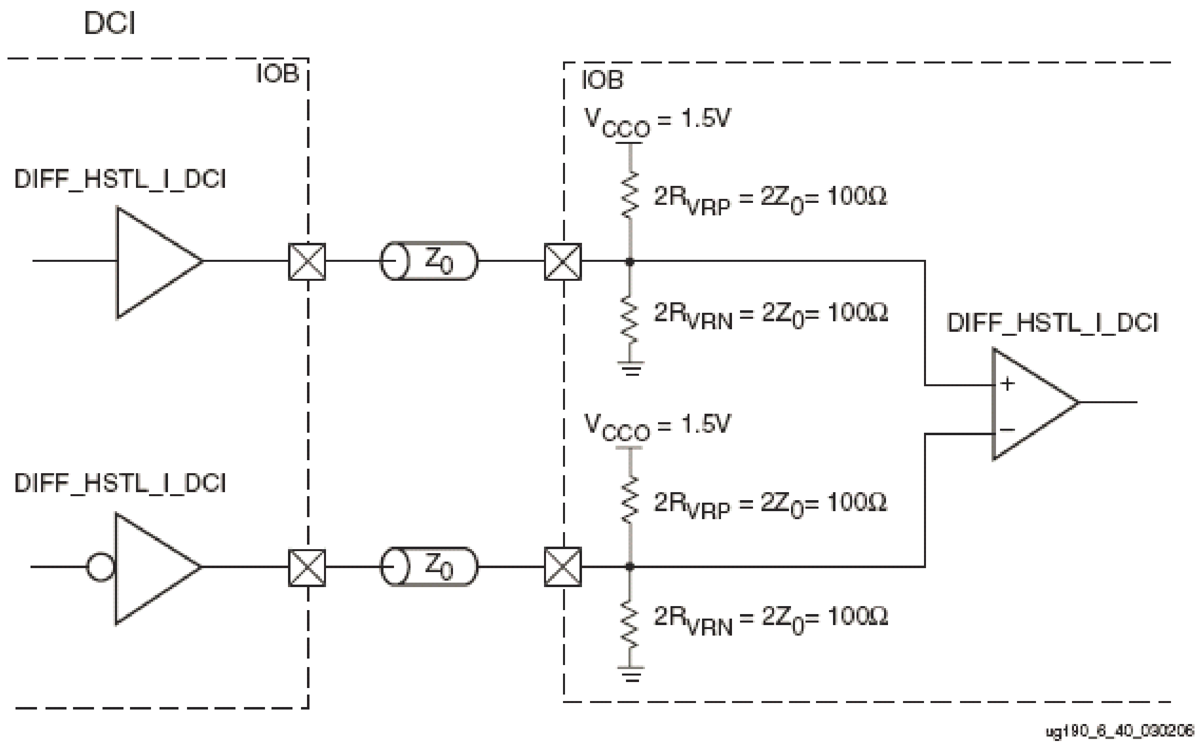
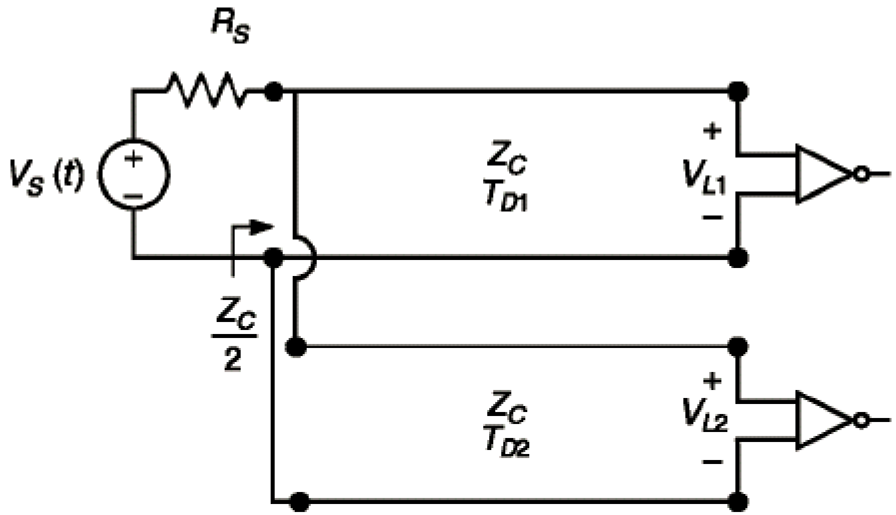


Figure 6-42: **Differential HSTL (1.5V) Class I DCI Unidirectional Termination**

Impedance matching

Other methods



Impedance matching

Other methods

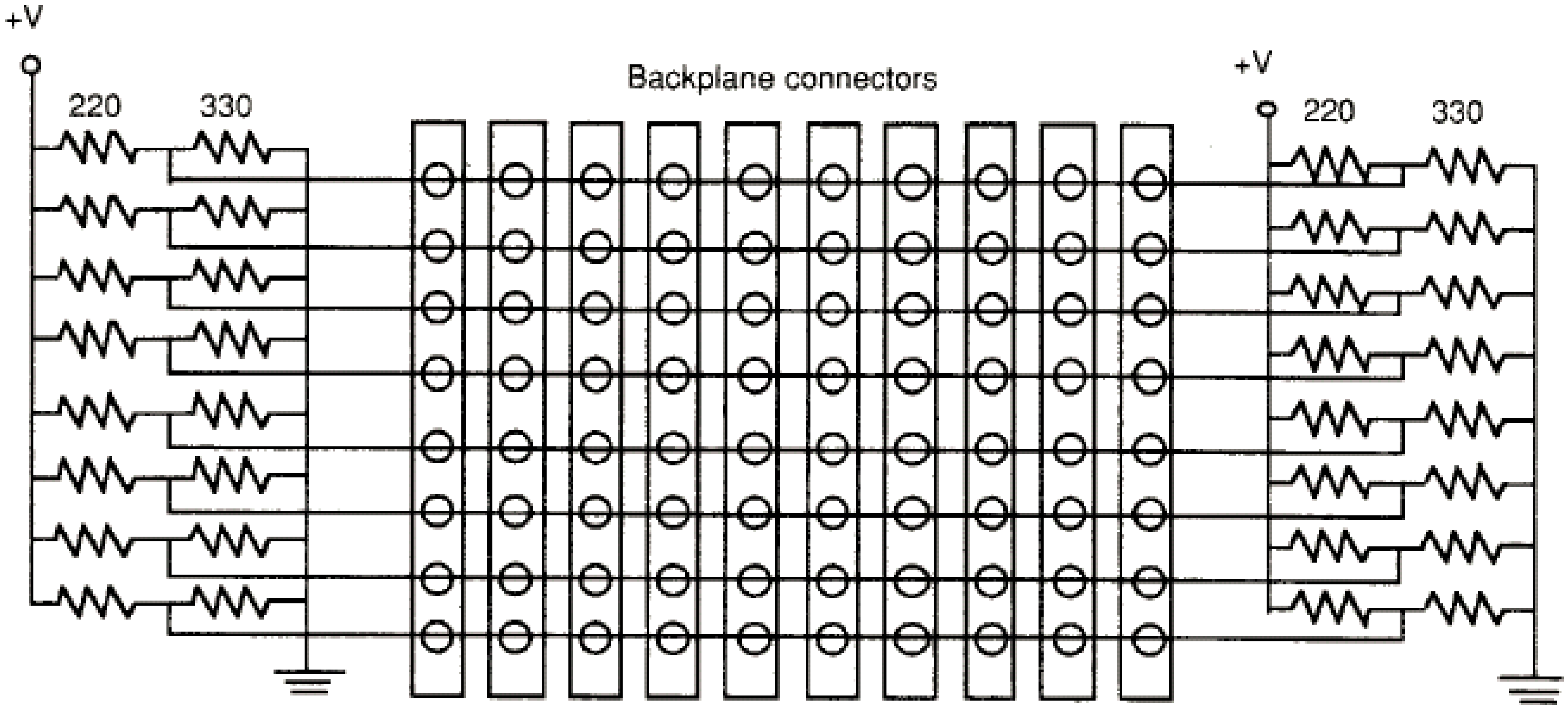


Figure 8.14 Backplane termination implementation.

Impedance matching

- Matching at the input does not eliminate the reflection from the end of the line. The problem is the different output impedance of the gates in the low and high state.
- Adaptation at the output causes the power consumption in a transient state and allows to obtain a lower voltage value than the input matching.
- For splited lines, good results can only be achieved by matching the input and output impedance at the same time.

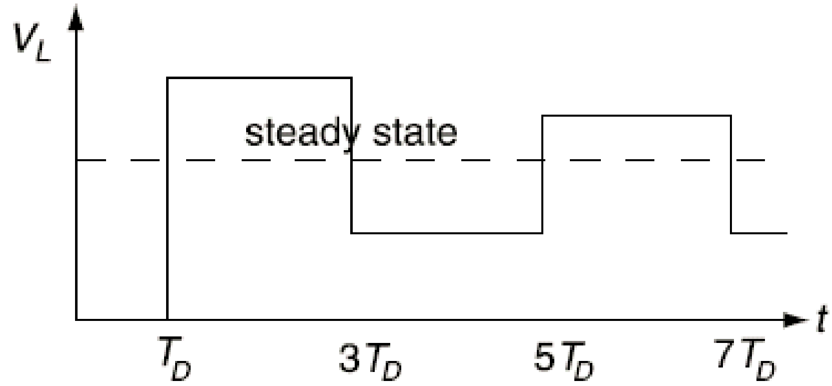
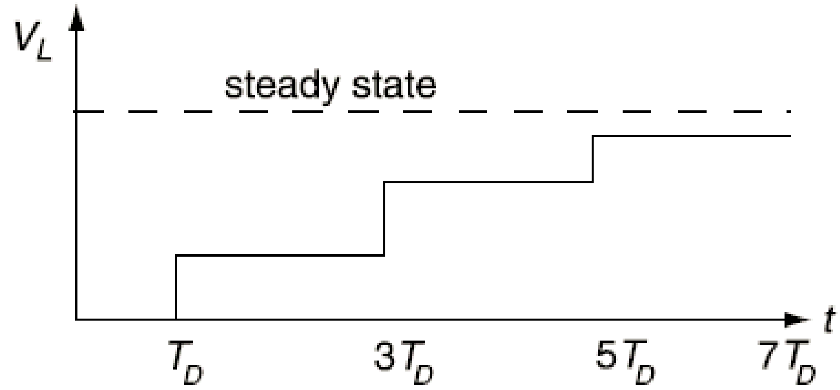
Transmission lines – theory continued

- Reflection coefficient (at output)

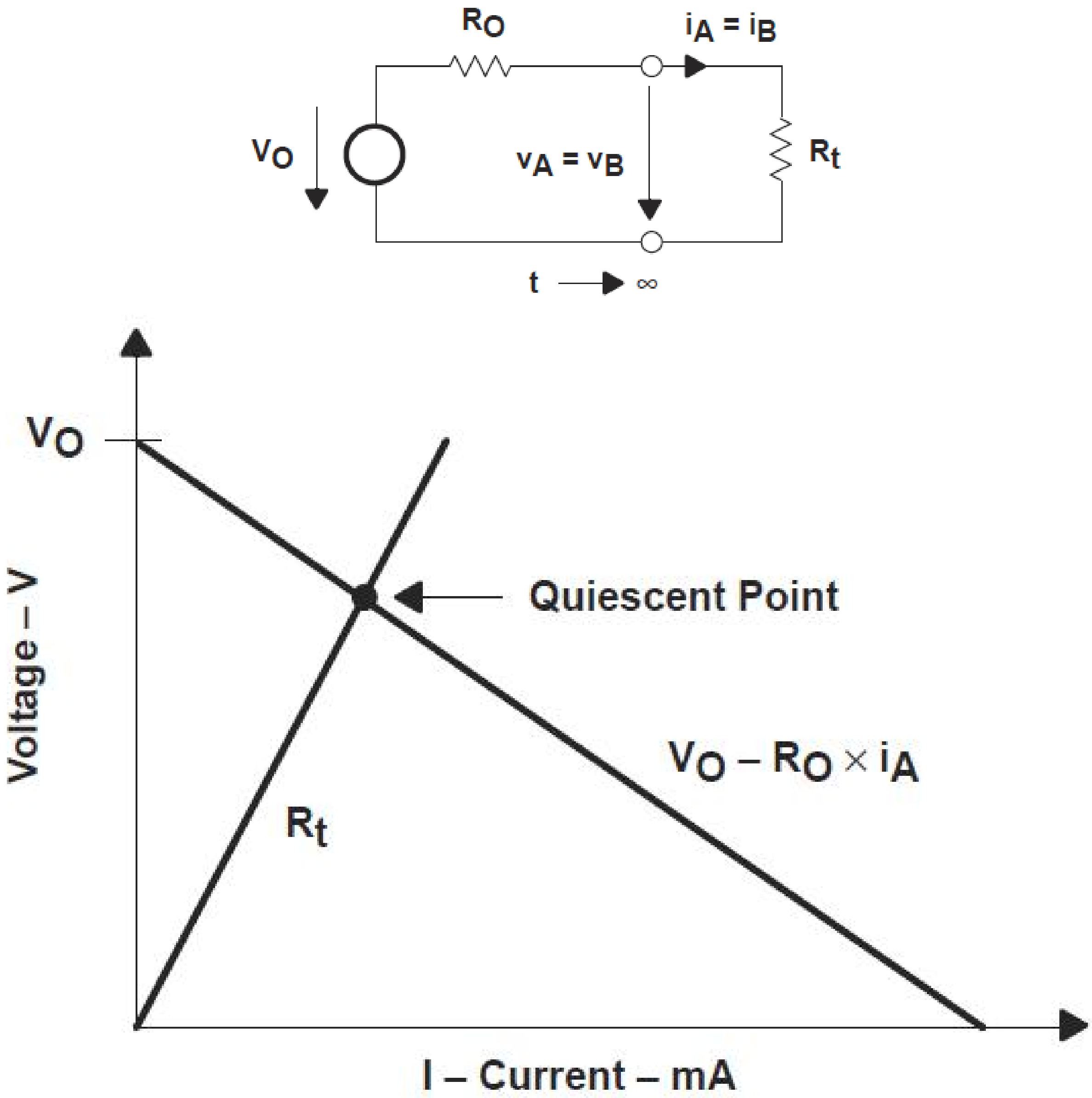
$$\Gamma_L = \frac{R_L - Z_0}{R_L + Z_0}$$

- $\Gamma \in \langle -1, 1 \rangle$
  - $\Gamma = -1$ short $R_L = 0$
  - $\Gamma = 1$ open $R_L = \infty$
  - $\Gamma = 0$ match $R_L = R_0$

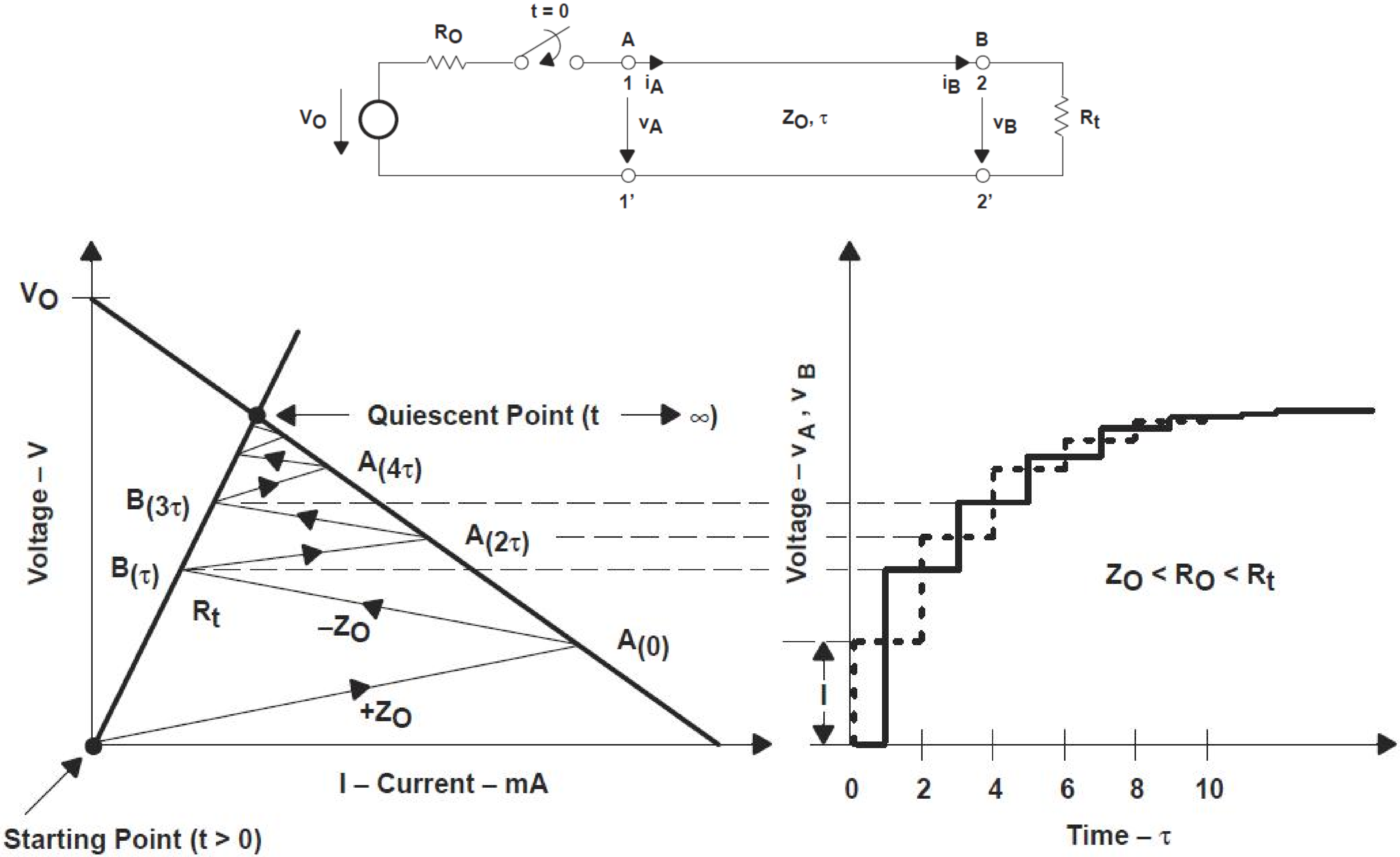
Transmission lines – theory

Γ_S	Γ_L	Load Voltage Waveform
$-$ $R_S < Z_C$	$+$ $R_L > Z_C$	
$+$ $R_S > Z_C$	$-$ $R_L < Z_C$	
$+$ $R_S > Z_C$	$+$ $R_L > Z_C$	
$-$ $R_S < Z_C$	$-$ $R_L < Z_C$	

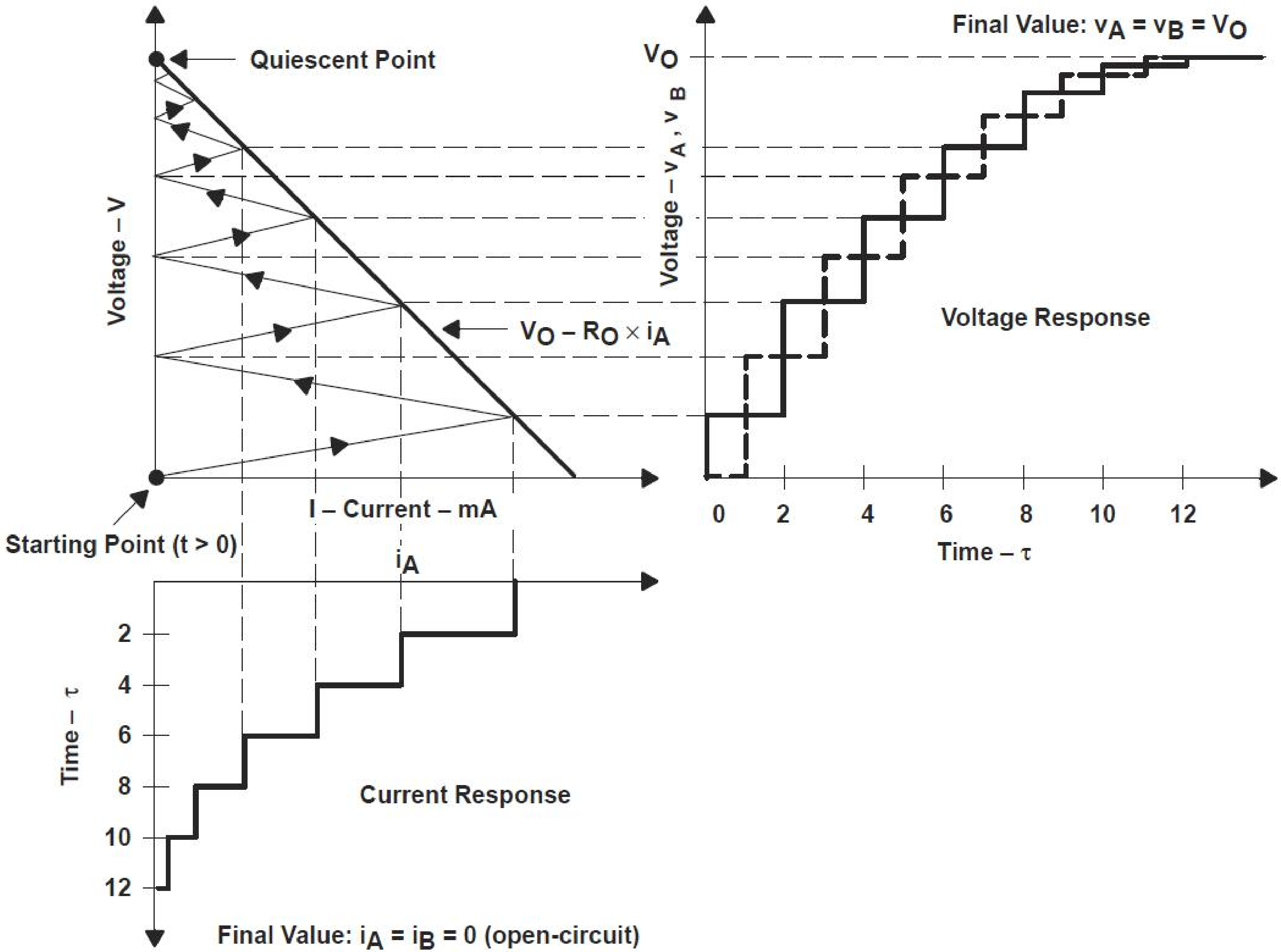
Line reflections – Bergeron method



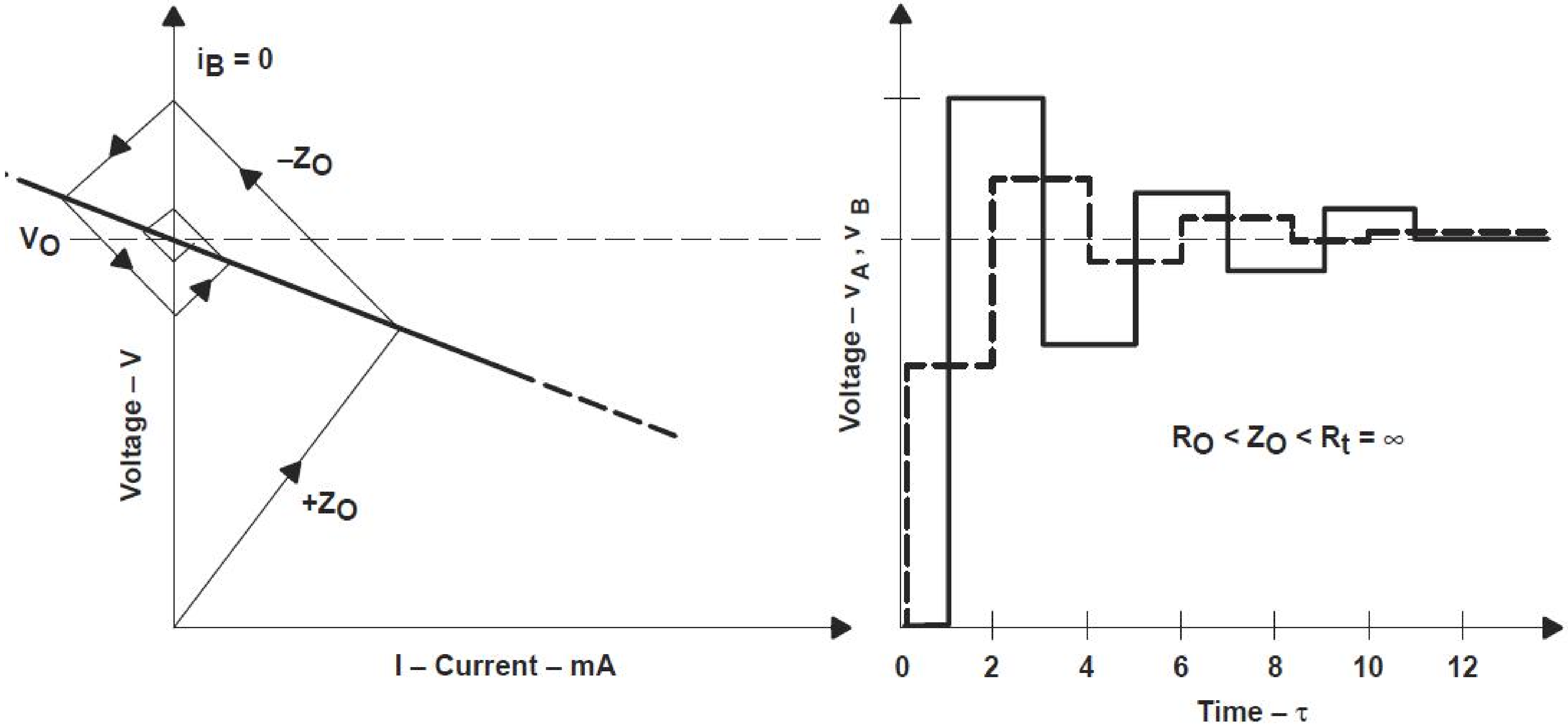
Line reflections – Bergeron method



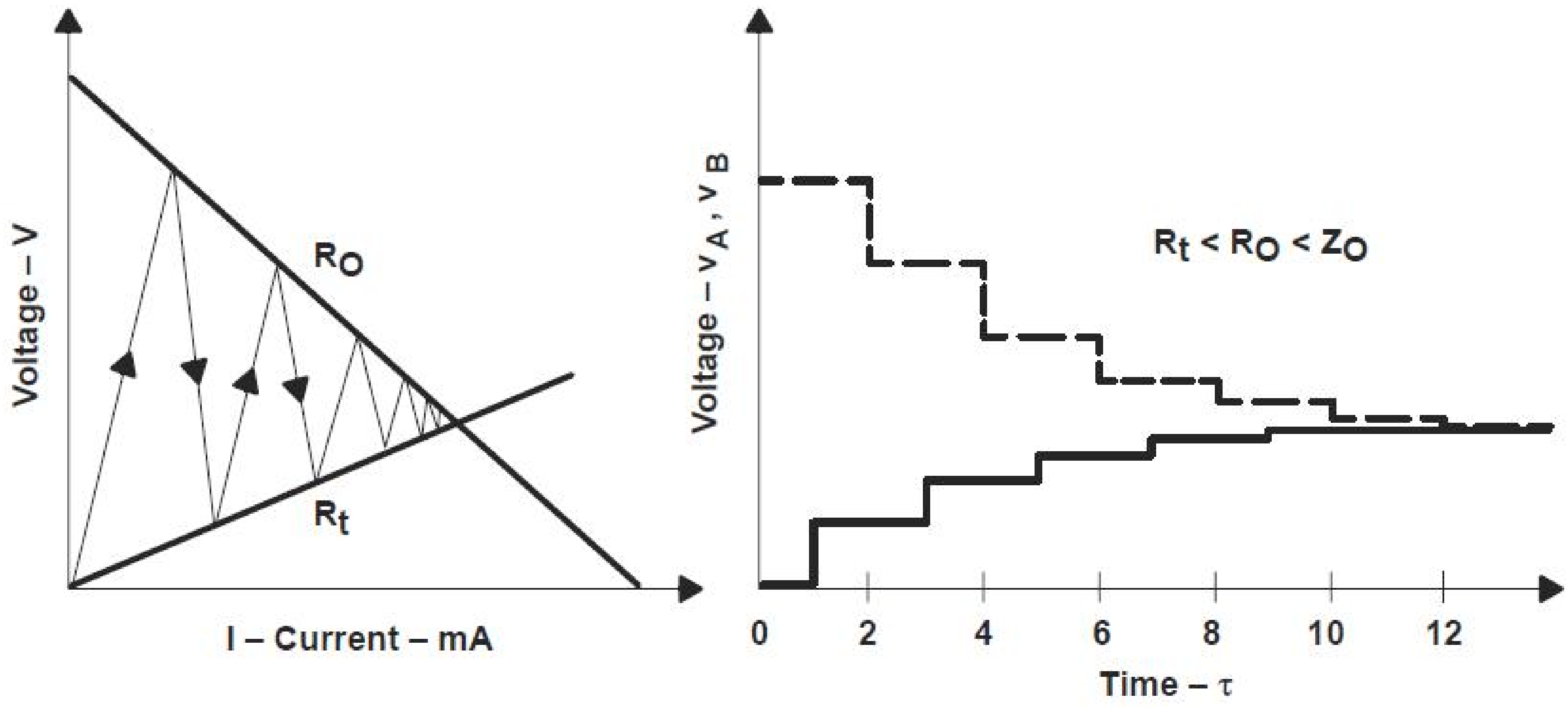
Line reflections – Bergeron method



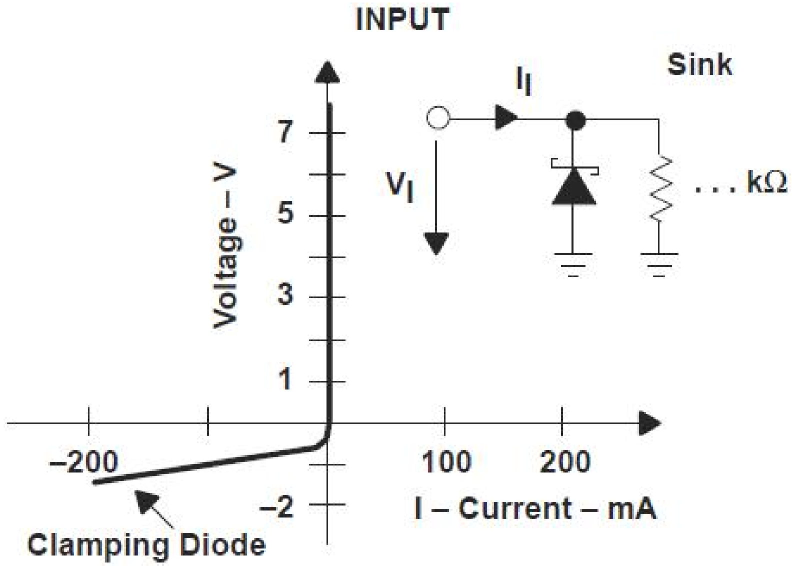
Line reflections – Bergeron method

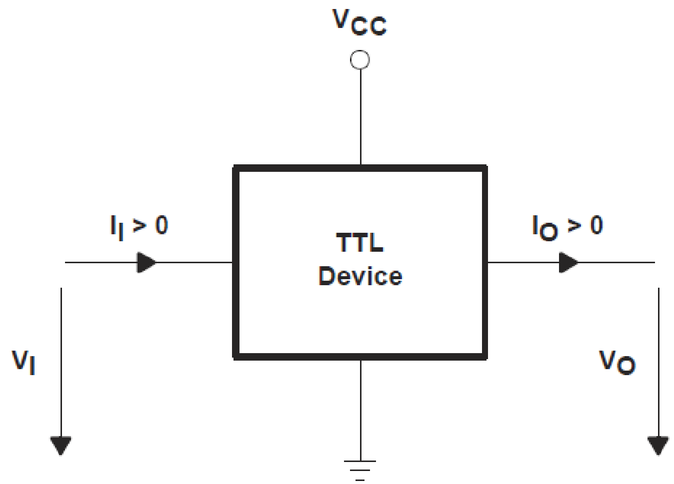


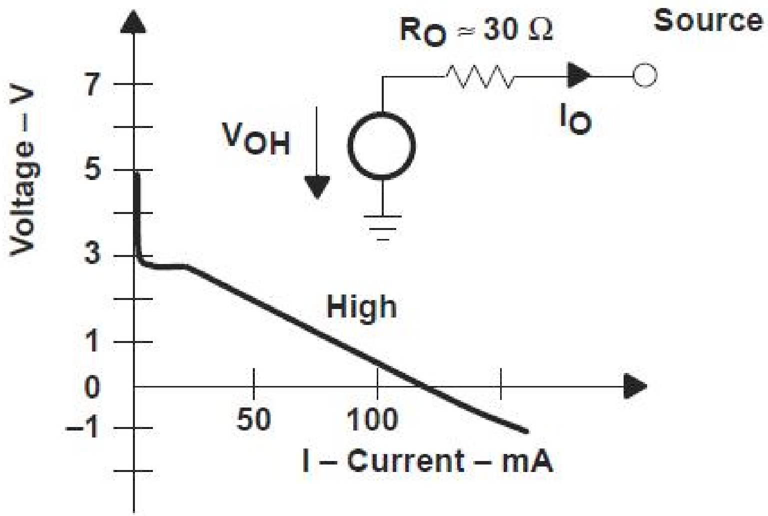
Line reflections – Bergeron method

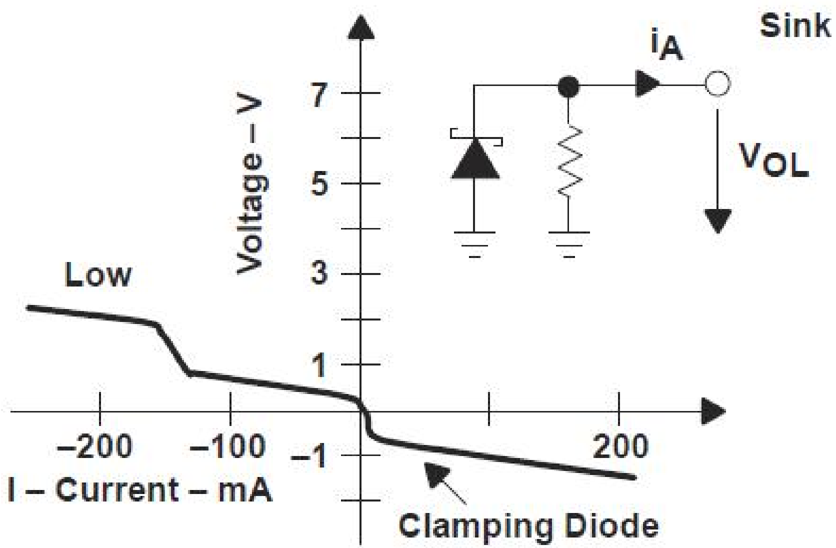


Line reflections – TTL gate



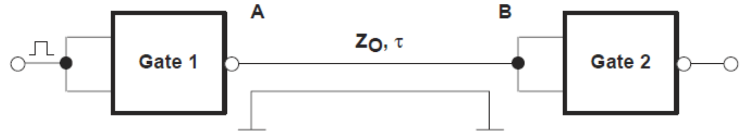


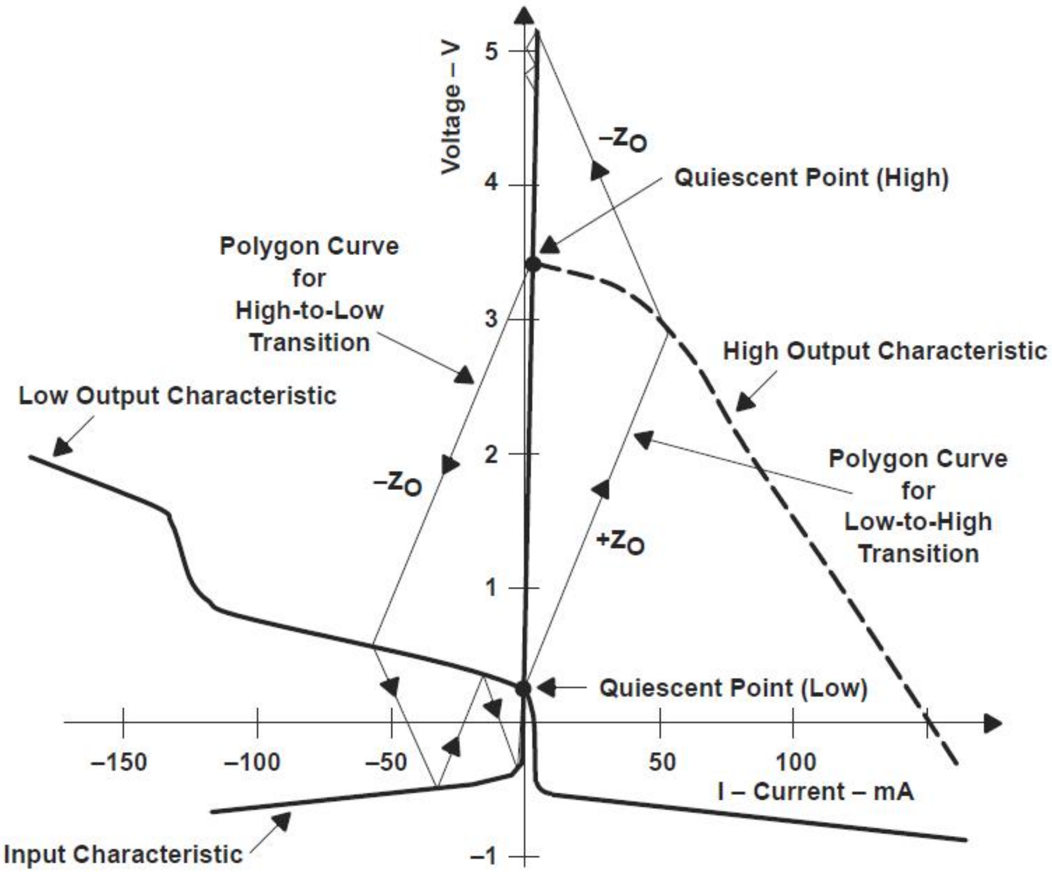


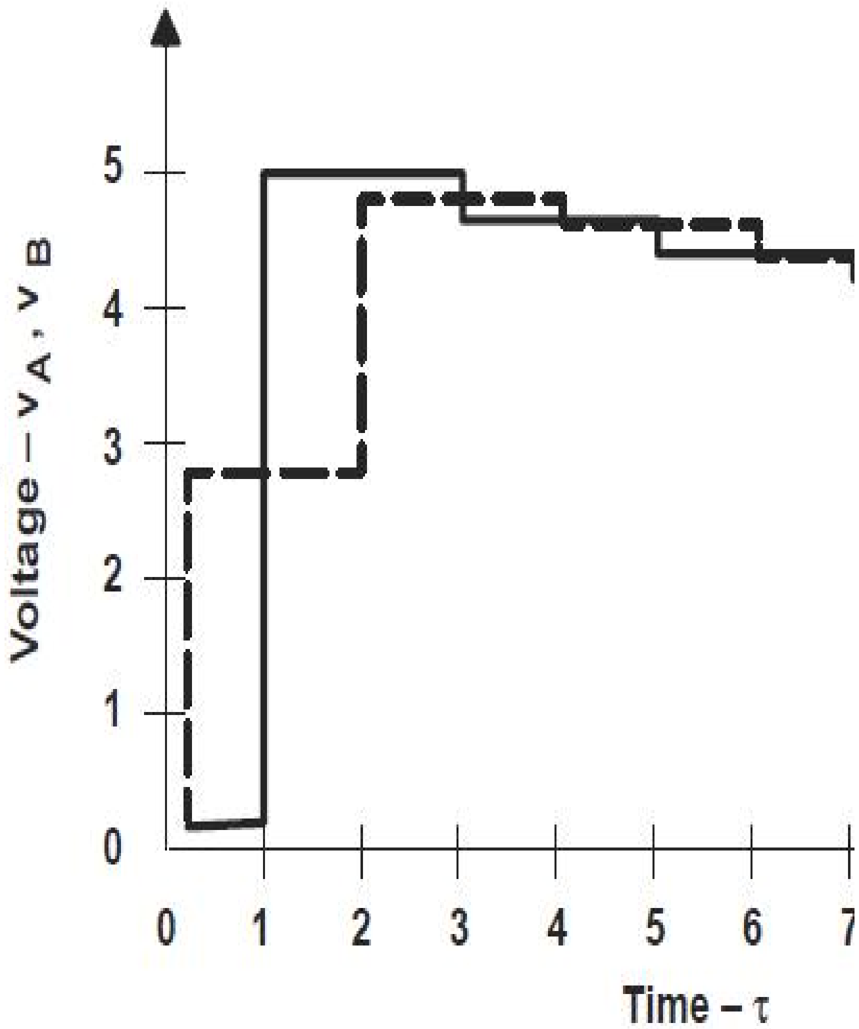


Line reflections – Bergeron method

- SN74AS00 TTL

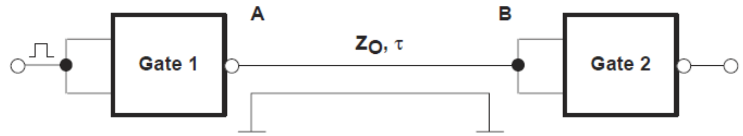


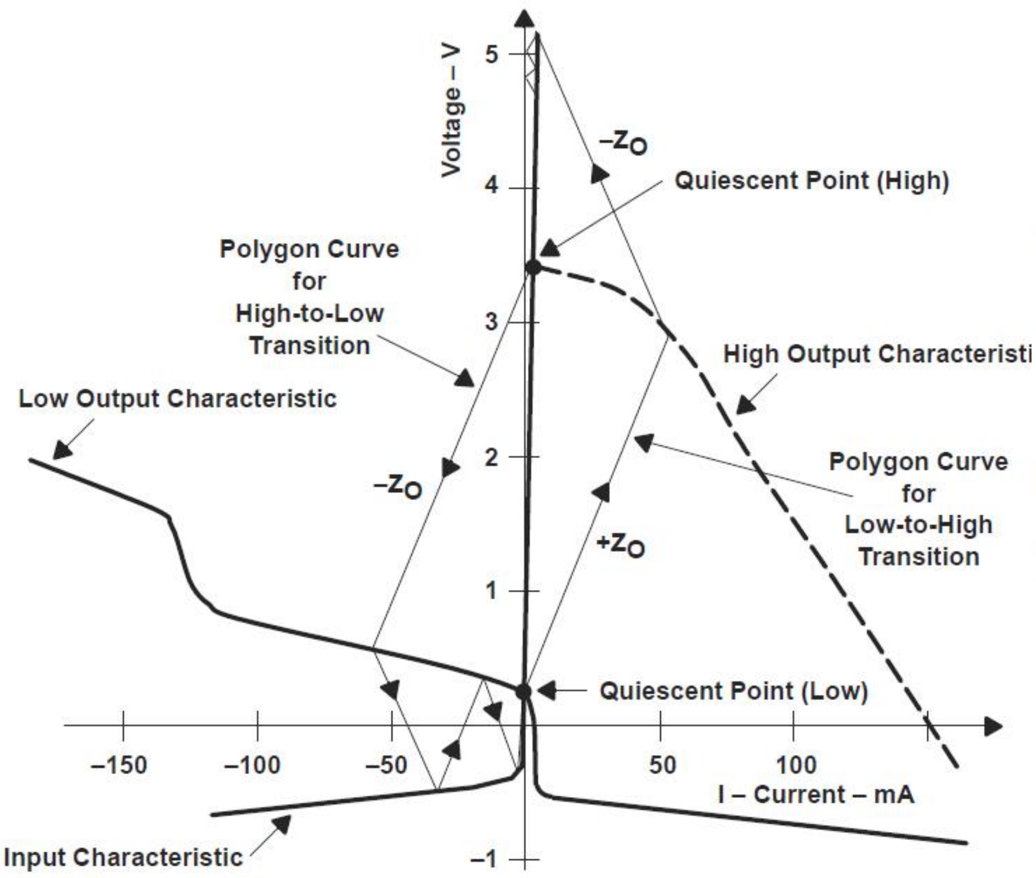


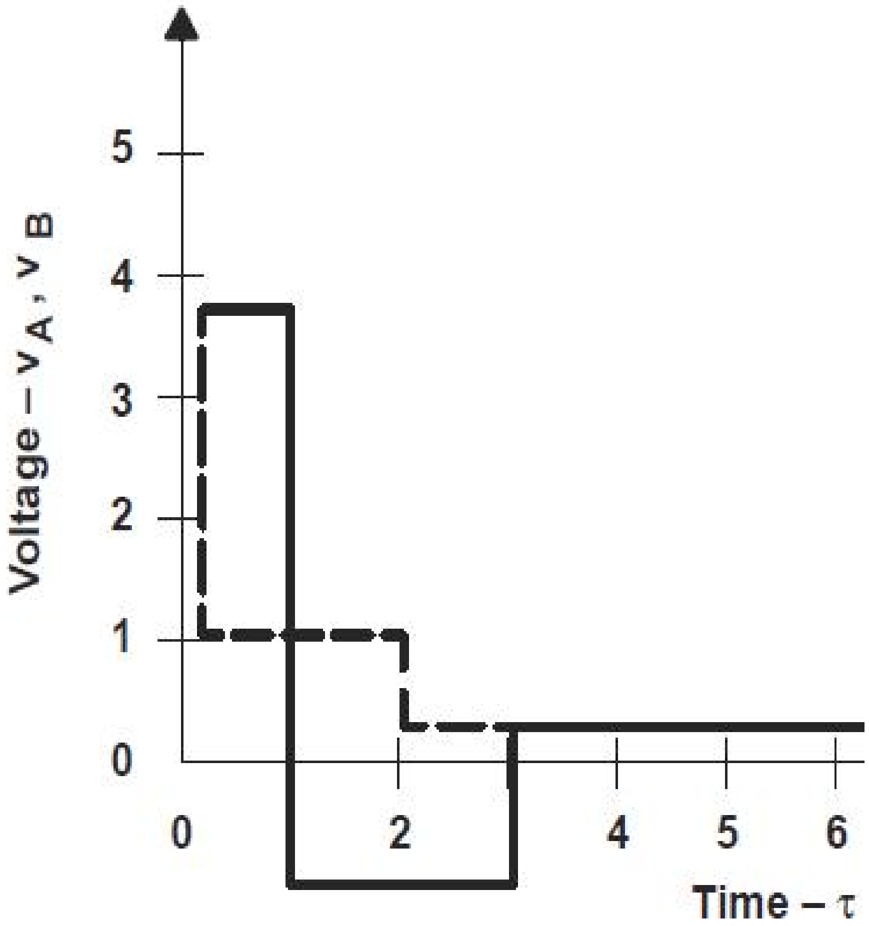


Line reflections – Bergeron method

- SN74AS00 TTL

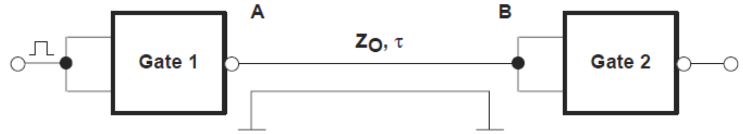


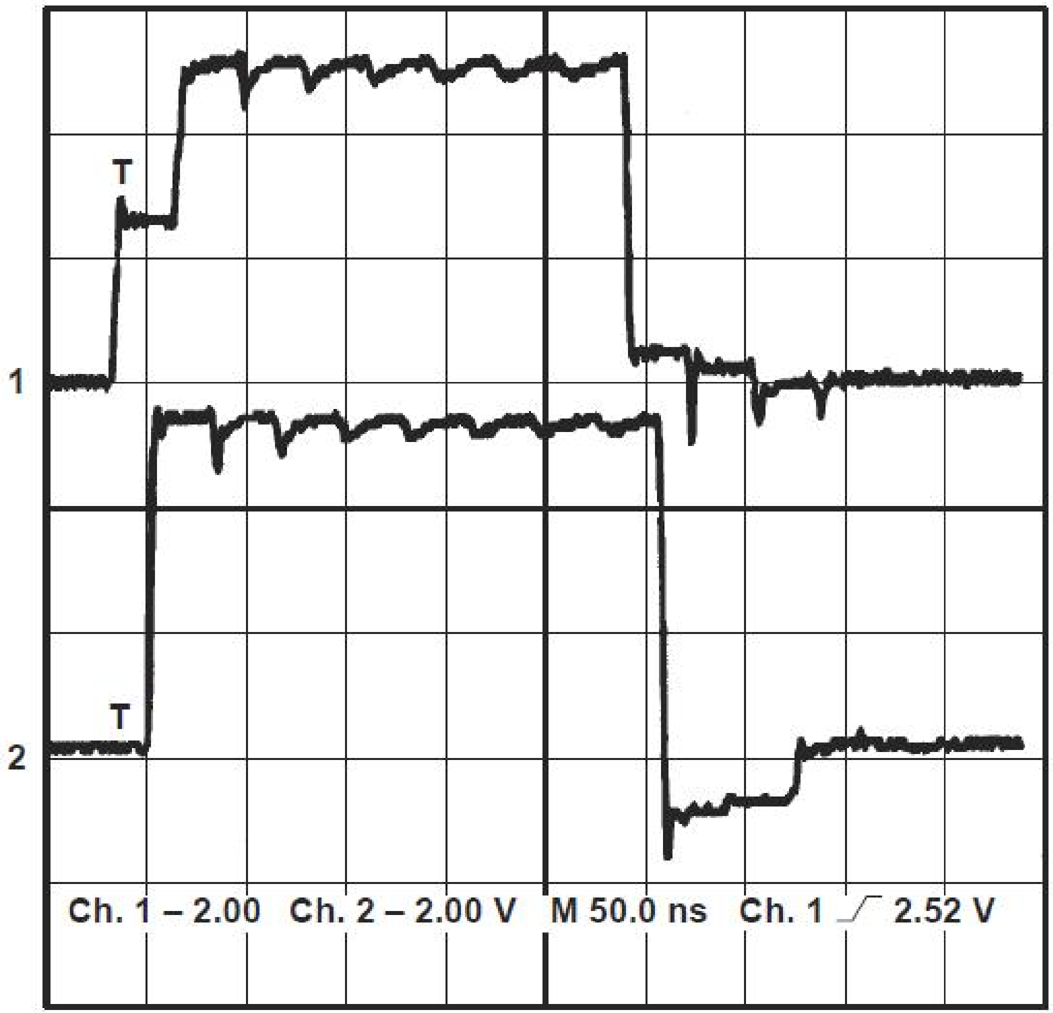




Line reflections – measurement

- SN74AS00 TTL





Measured Line Reflections (Line Length = 3 m, Z_O = 50 Ω)

Electromagnetic compatibility (EMC)

- The device is electromagnetically compatible if
  - do not cause interference with a level dangerous for other devices
  - do not disturb himself
  - works correctly in the presence of disturbances at a fixed level.
- Permissible levels of generated and received disturbances, at which the device should work correctly are included in the compatibility standards.
- Each device should undergo appropriate tests before being placed on the market.

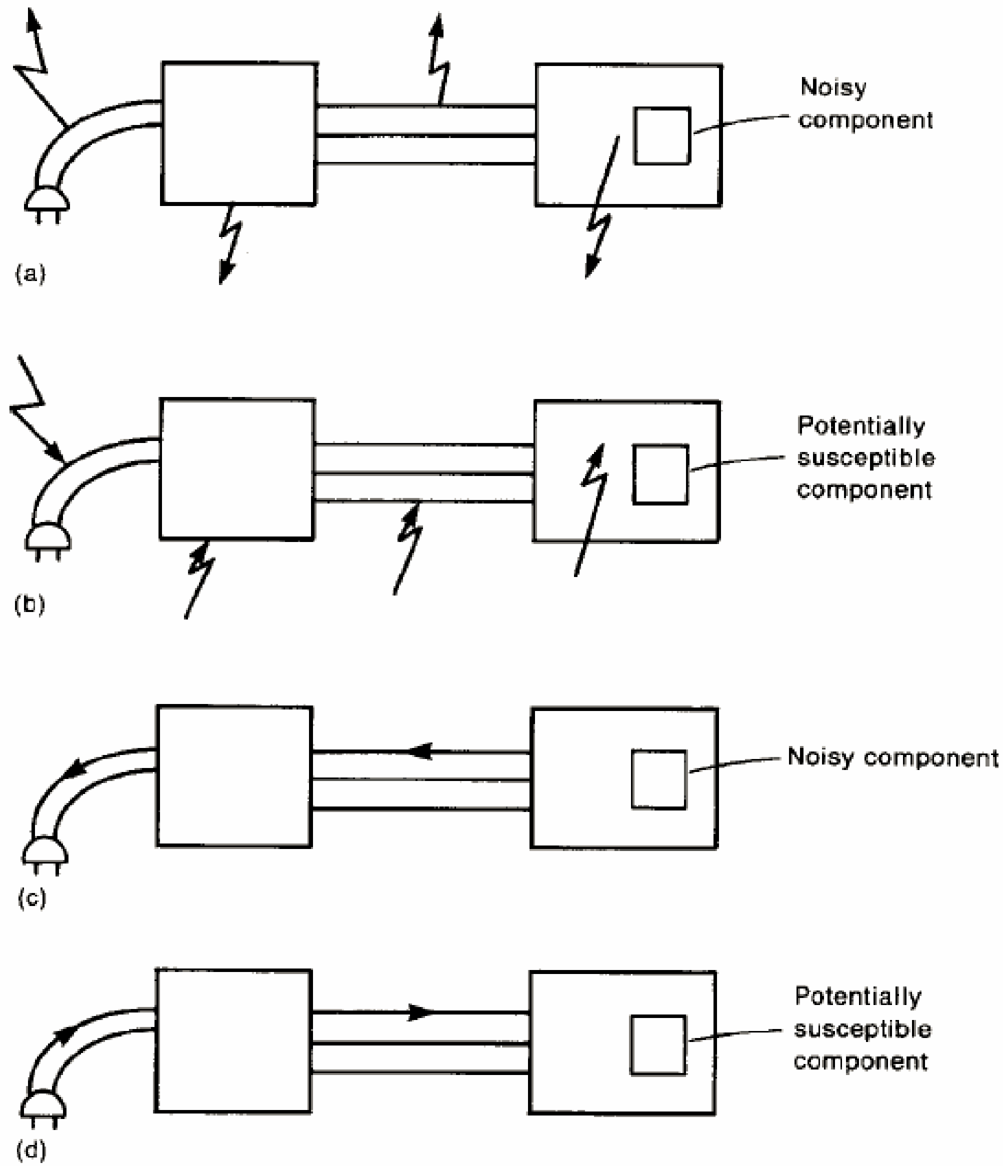
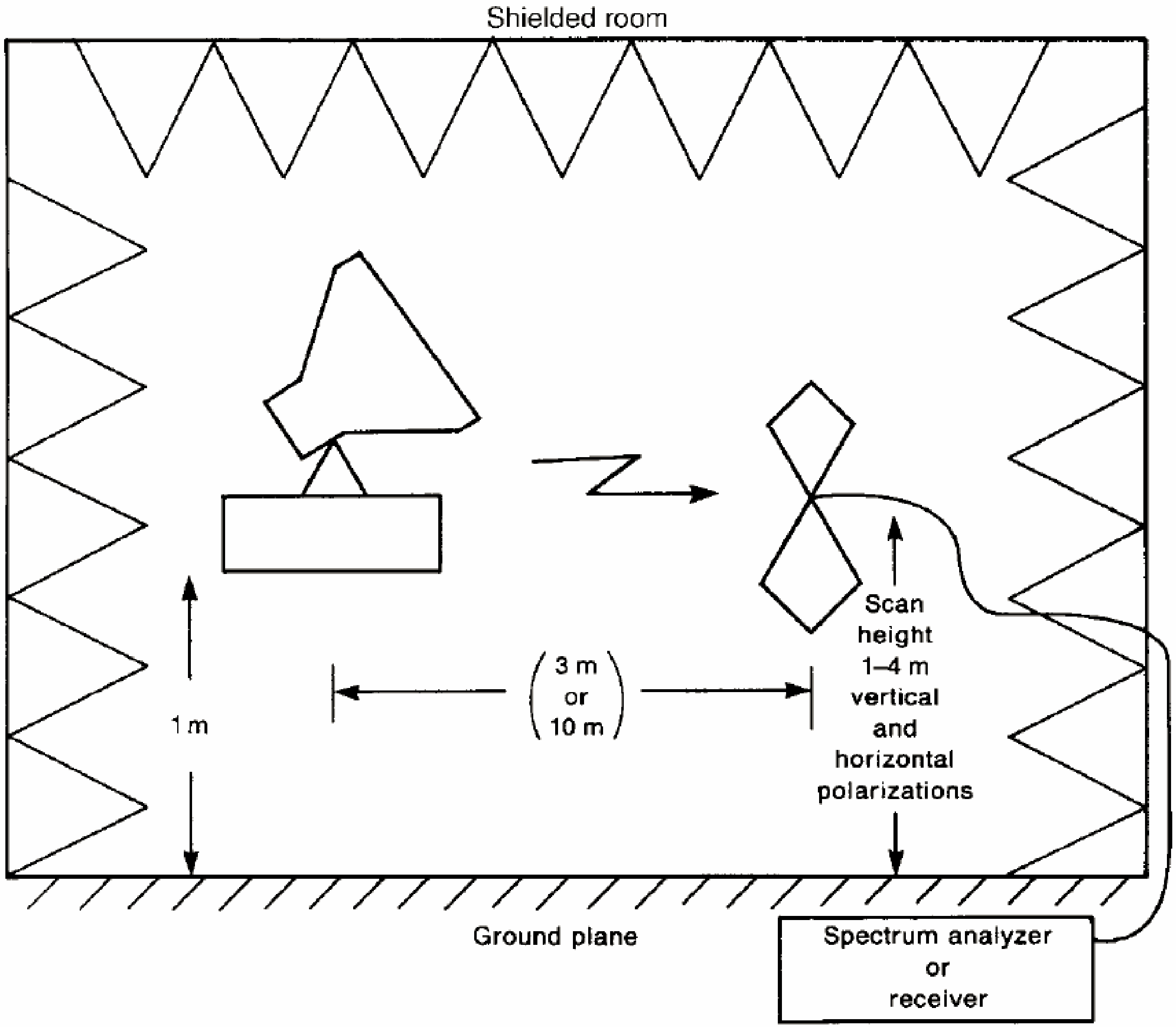
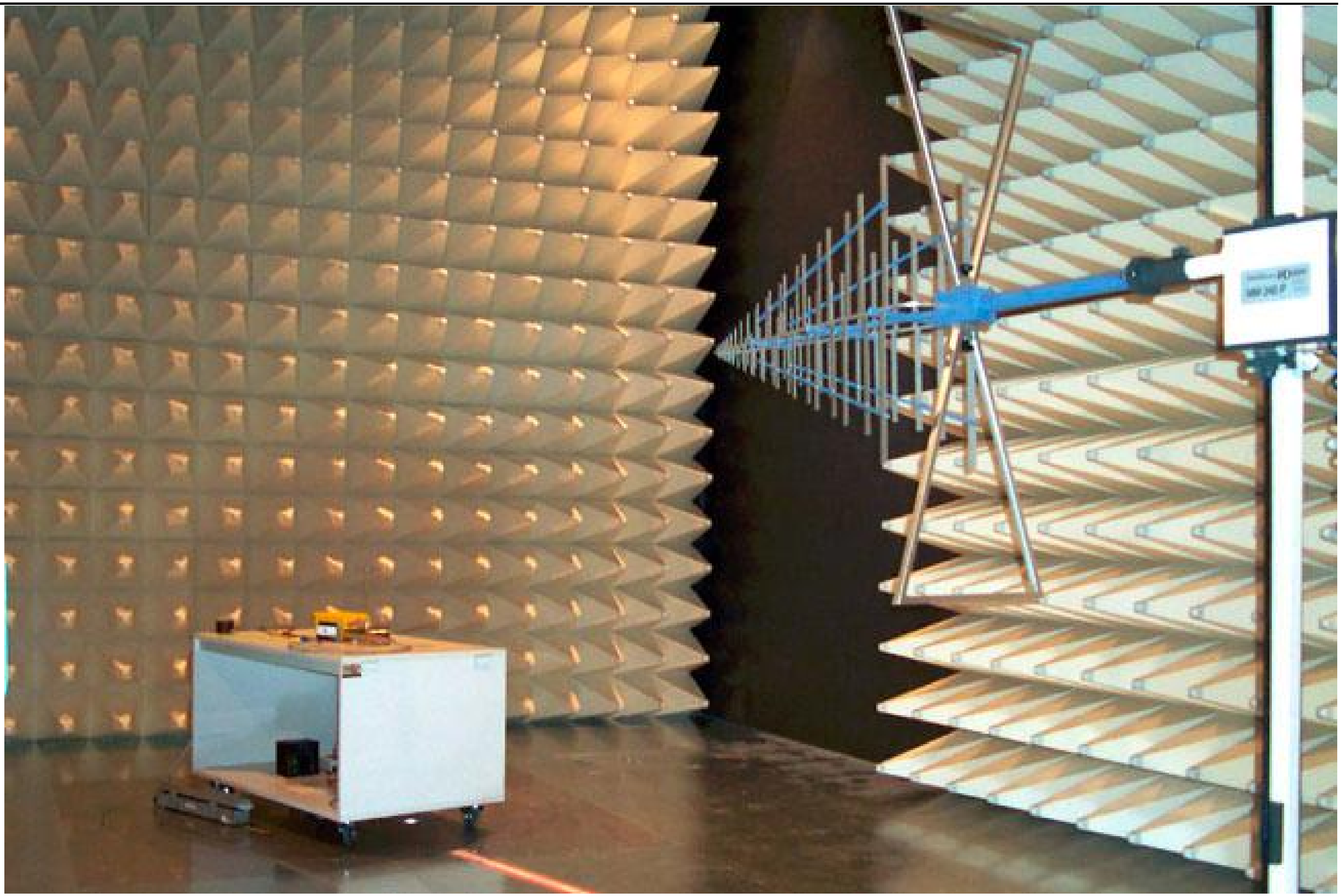


FIGURE 1.2 The four basic EMC subproblems: (a) radiated emissions; (b) radiated susceptibility; (c) conducted emissions; (d) conducted susceptibility.

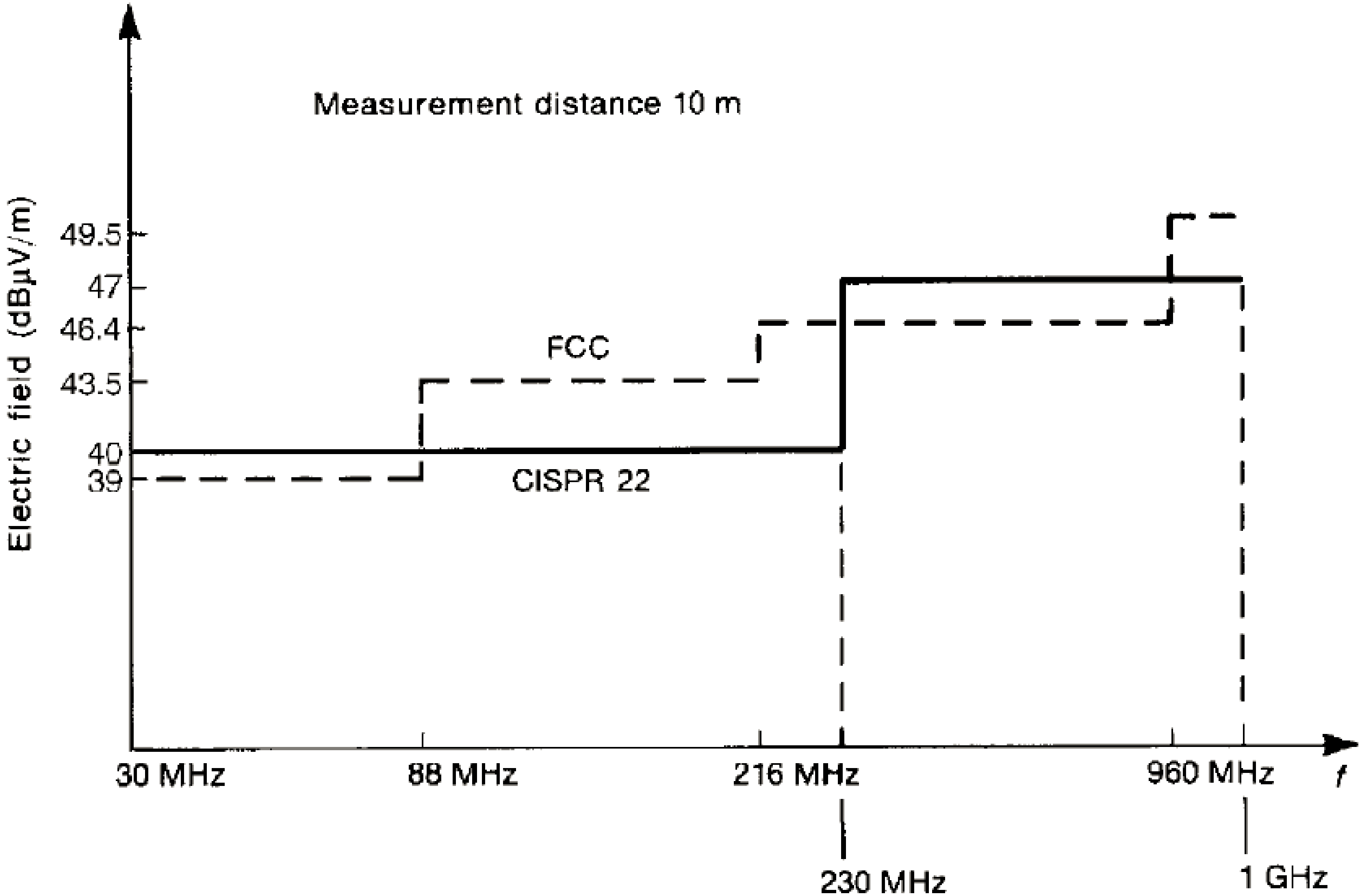
Electromagnetic compatibility



Electromagnetic compatibility

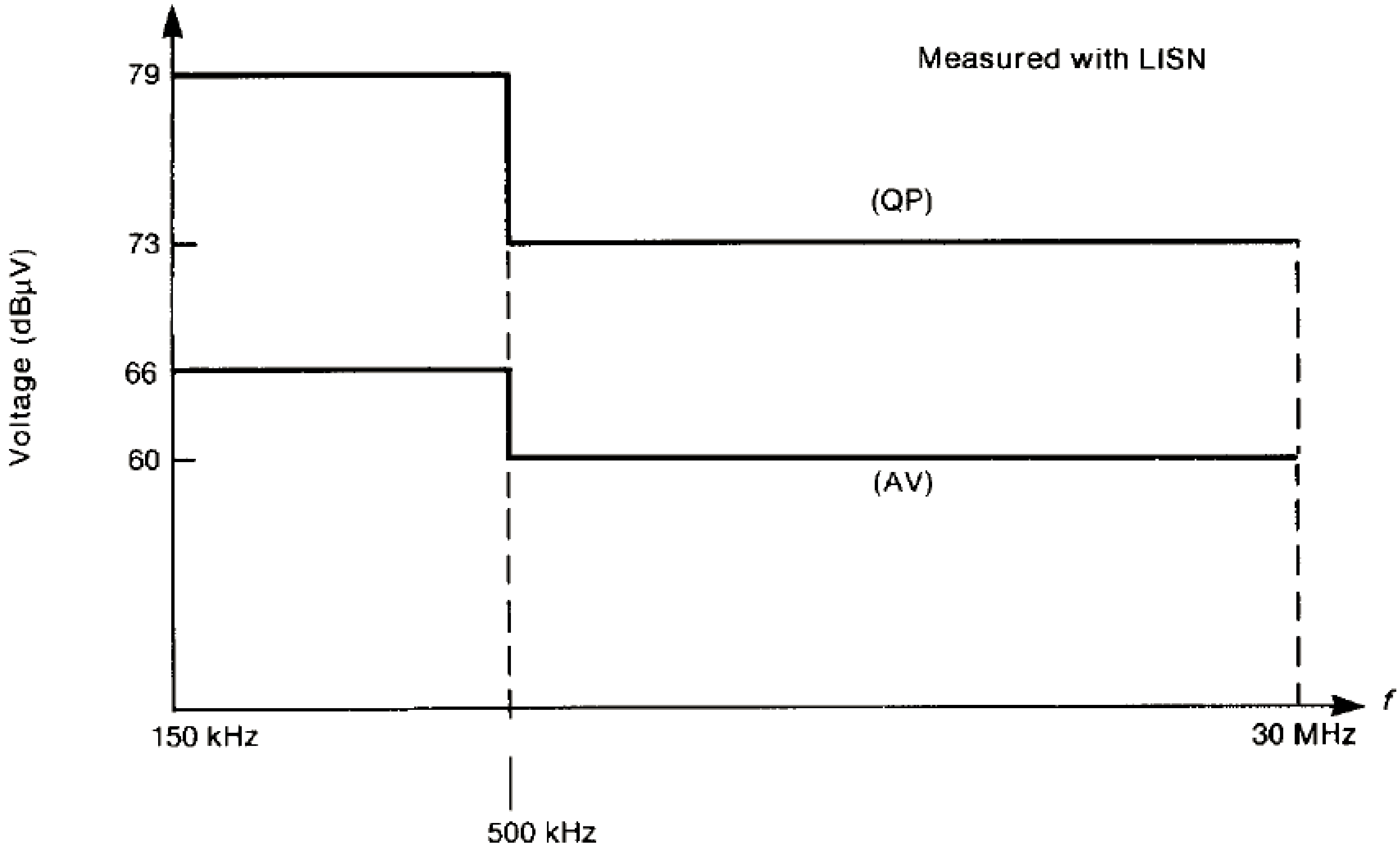


Max radiated emission (class A)



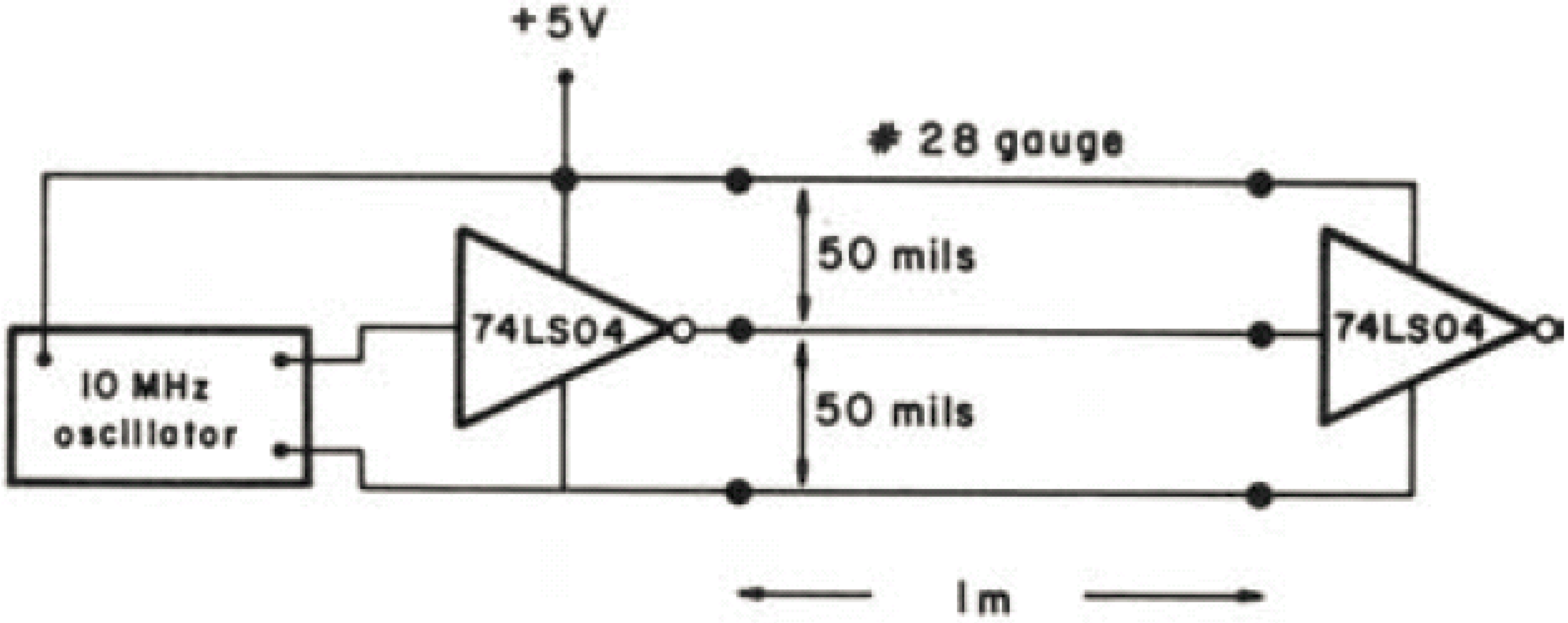
(b)

Max conducted emission (class A)

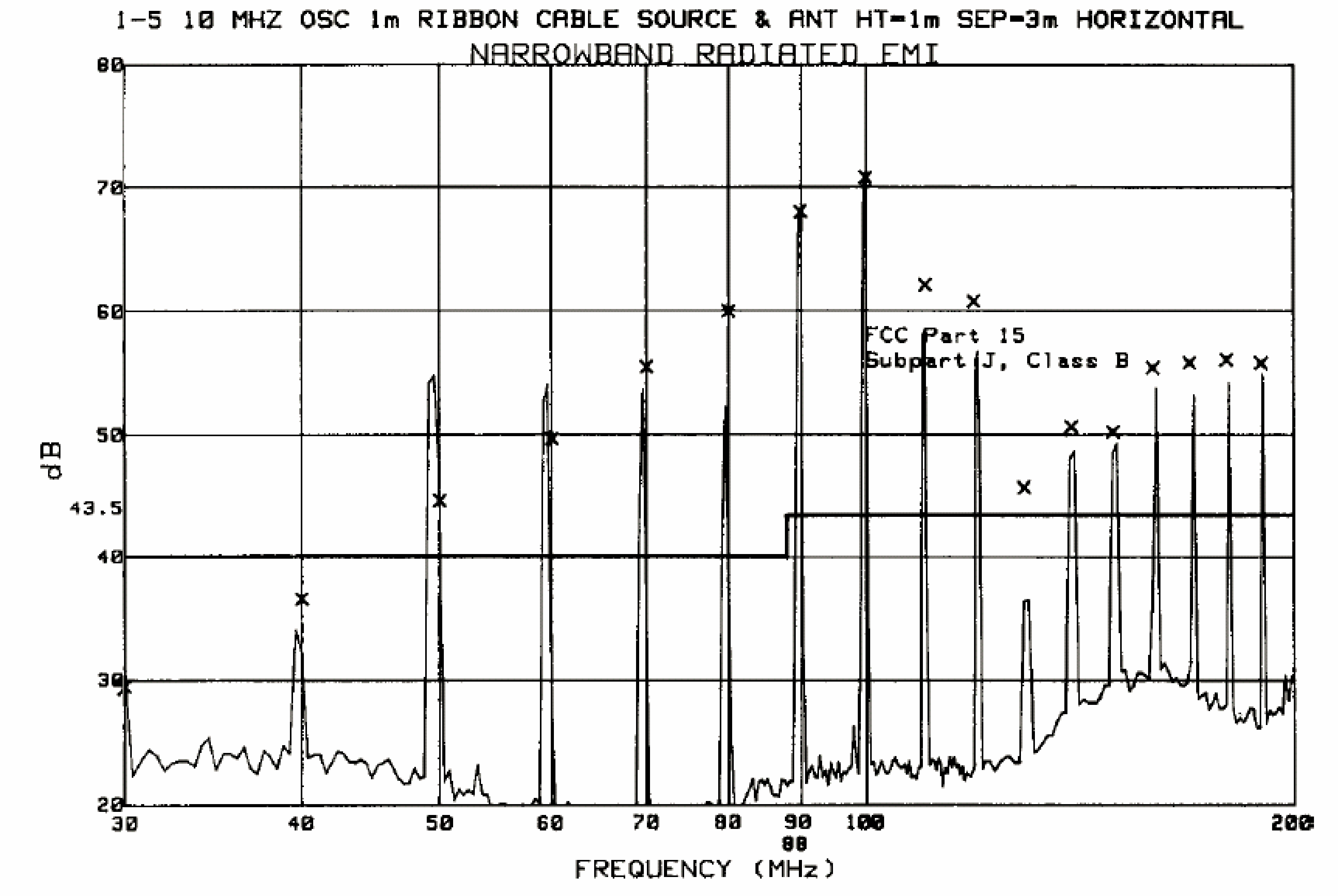


Electromagnetic compatibility

- Practical test:



Electromagnetic compatibility



Sources:

[1] Karlheinz Fleder *The Bergeron Method. A Graphic Method for Determining Line Reflections in Transient Phenomena*