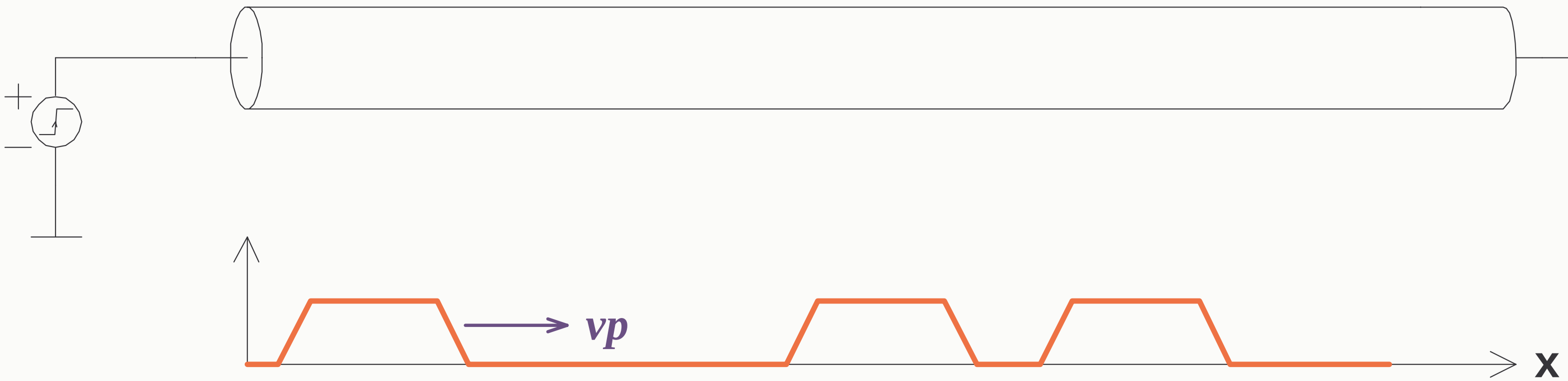
Basics/Session Overview

- Relationship time and distance
  - Signal propagation delay and propagation velocity
- Lumped systems versus distributed systems
- Mutual capacitance
- Capacitive crosstalk
- Mutual inductance
- Inductive crosstalk

Basics/Time and Distance

- Electrical signals in conductors propagate at a finite velocity (propagation velocity)
- Propagation velocity *vp* dependent on surrounding medium
- Propagation delay *Td* (per unit length) is the inverse of *vp*



Basics/Time and Distance

Propagation velocity $vp = \frac{c}{\sqrt{\varepsilon r}}$

remember: $c = \frac{1}{\sqrt{\varepsilon 0 \cdot \mu 0}}$

Propagation delay $Td = vp^{-1}$

Note:

•Propagation delay increases with the square root of the dielectric constant

•Equations assume that conductor is surrounded by homogenuous medium *(if not, determine effective εr)*

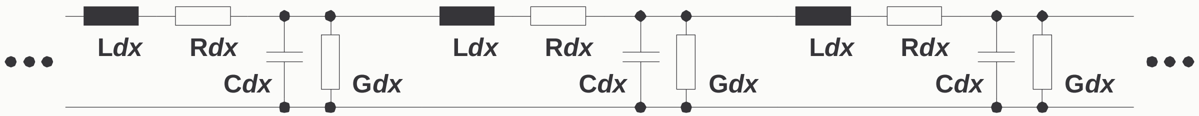
•Manufacturers of coax cable often use foamed or ribbed material

•Dielectric constant εr=f(T,f…)

Insulating Material	Permittivity εr	Propagation velocity vp
Air	1	300 mm/ns
Teflon	2	212 mm/ns
Polyimide	3	173 mm/ns
Silicon dioxide	3.9	152 mm/ns
FR4 (outer trace)	2.8-4.5	141…179 mm/ns
FR4 (inner trace)	4.5	141 mm/ns
Alumina (ceramic)	10	95 mm/ns
Silicon	11.7	88 mm/ns

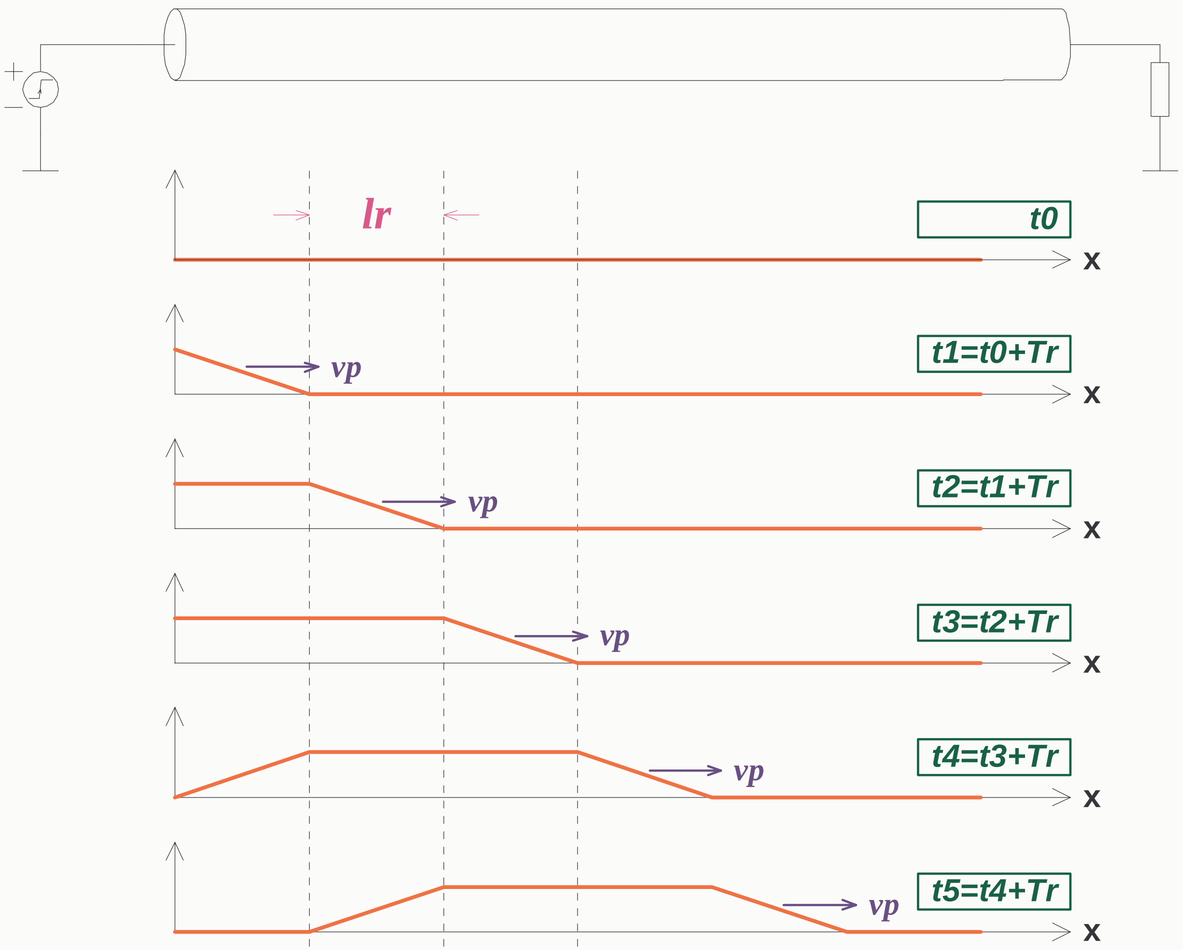
Signals on outer-layer PCB traces propagate faster than those on inner-layer PCB traces!

Basics/Time and Distance



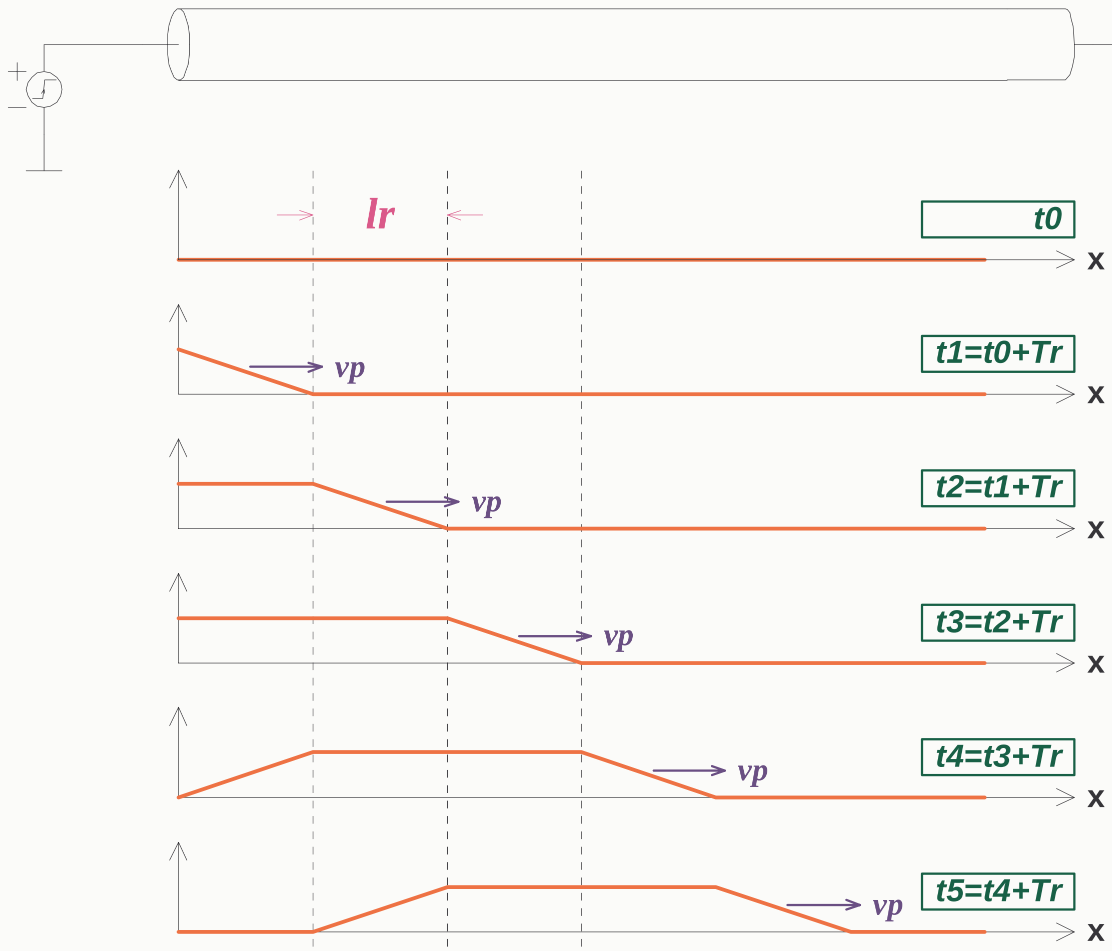
- Often: Circuit elements of a component are **distributed** along its length and not **lumped** in a single position
- The behaviour of distributed systems cannot be described by ordinary differential equations (analysis requires partial differential equations)
- **Question:**
  How small physically does a system need to be so that we can look at it as a lumped system?
- **Answer:**
  If the system is much smaller than the effective length of the fastest electric feature in the signal.

Basics/Time and Distance



- Series of snapshots of the electric potential along a trace.
- Potential v(x) is not uniform at all points
  ⇨ Distributed System
- For systems physically small enough for all points to react together: The voltage v(x) is uniform at all points
  ⇨ Lumped System

Basics/Time and Distance



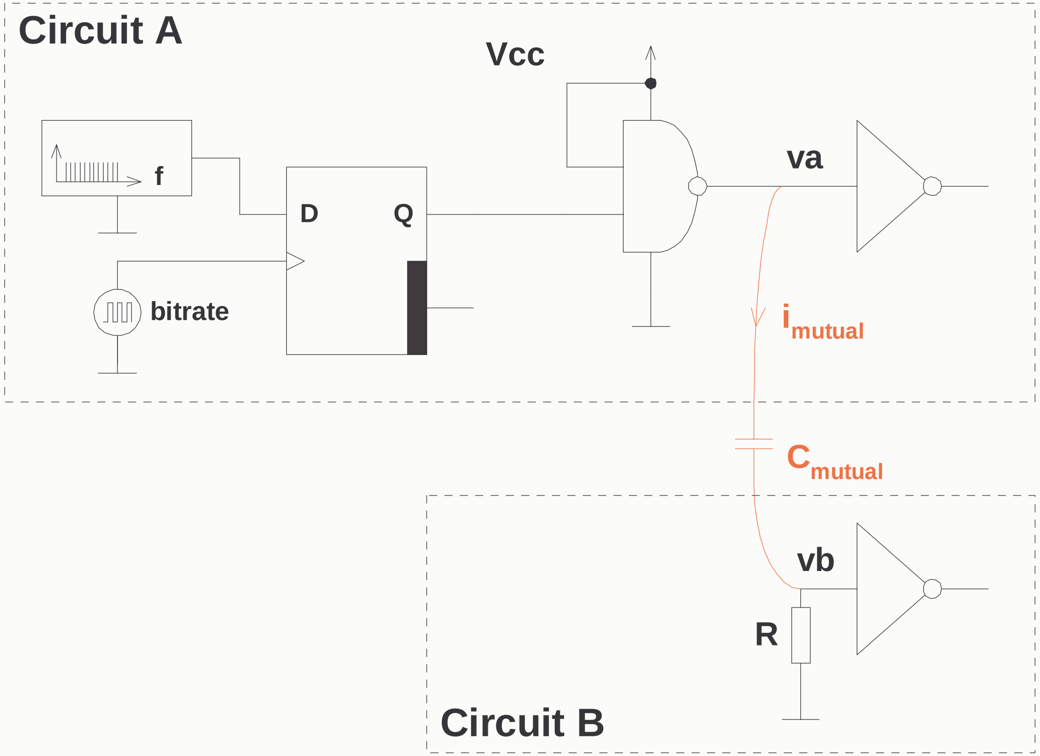
Effective length of rising edge

$$lr = Tr \cdot vp$$

- if l < lr/6

⇨ System behaves mostly in a lumped fashion

Crosstalk/Mutual Capacitance

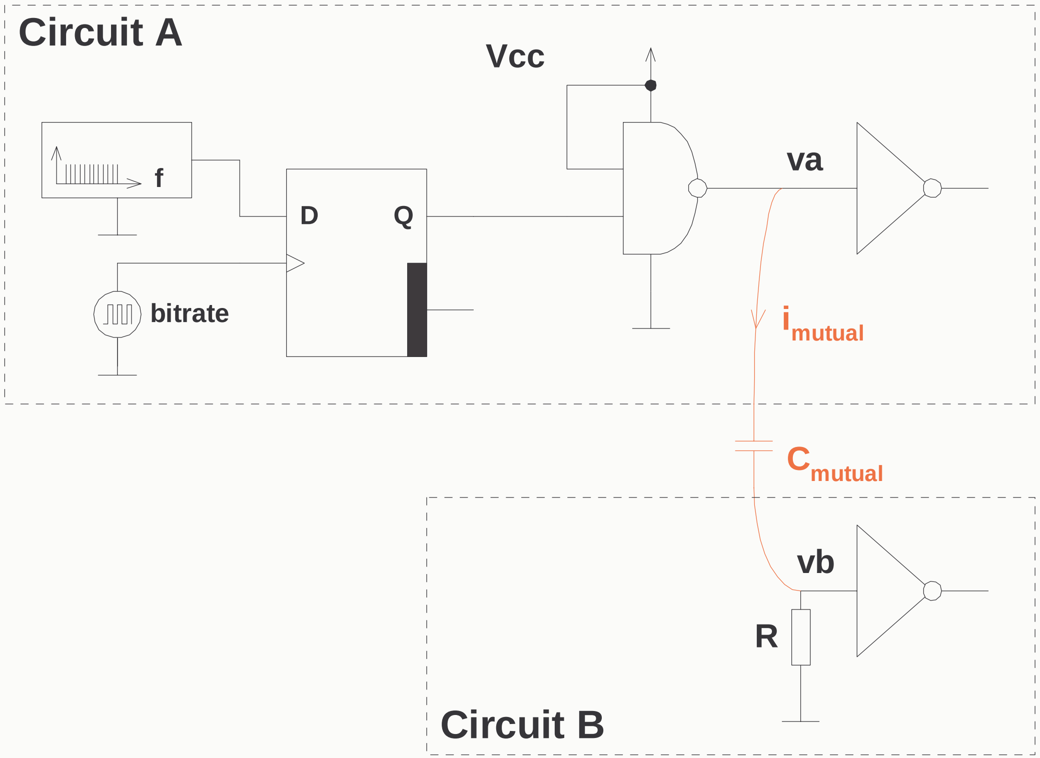


- Wherever there is two circuit nodes, there is **mutual capacitance**.
- Circuits interact electrically
- Coefficient of electrical interaction due to electric fields is called their **mutual capacitance**.

$$\{C_{mutual}\} = F = \frac{As}{V}$$

$$C_{mutual} \propto \frac{1}{distance}$$

Crosstalk/Mutual Capacitance



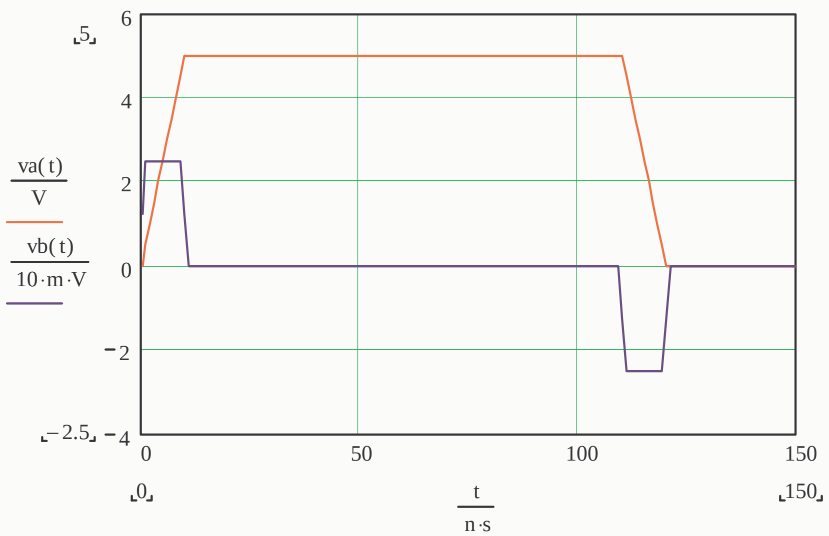
- Estimation of crosstalk. Assumptions:
  - Capacitor C_{mutual} doesn't load circuit A significantly
  - Coupled signal voltage (vb) is small compared to signal voltage (va)
  - Impedance of C_{mutual} is large compared to impedance to ground of circuit B
- Crosstalk is expressed as a fraction of the driving voltage
- Crosstalk is inversely proportional to rise time Tr

$$i_{mutual} = C_{mutual}\, {dva}/{dt} = C_{mutual} \frac{\Delta Va}{Tr}$$

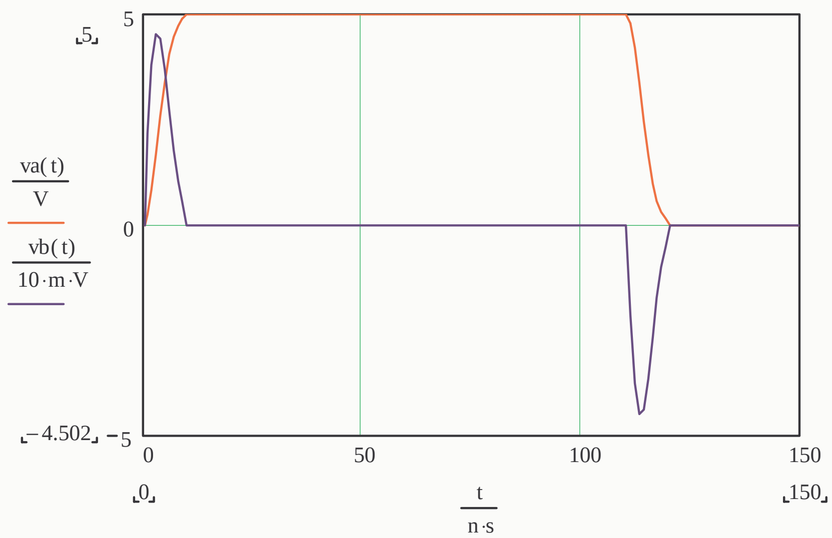
$$Crosstalk = \frac{\Delta Vb}{\Delta Va} = \frac{R \cdot i_{mutual}}{\Delta Va} = \frac{R \cdot C_{mutual}}{Tr}$$

Crosstalk/Mutual Capacitance/Example

Linear Pulse



Gaussian Pulse



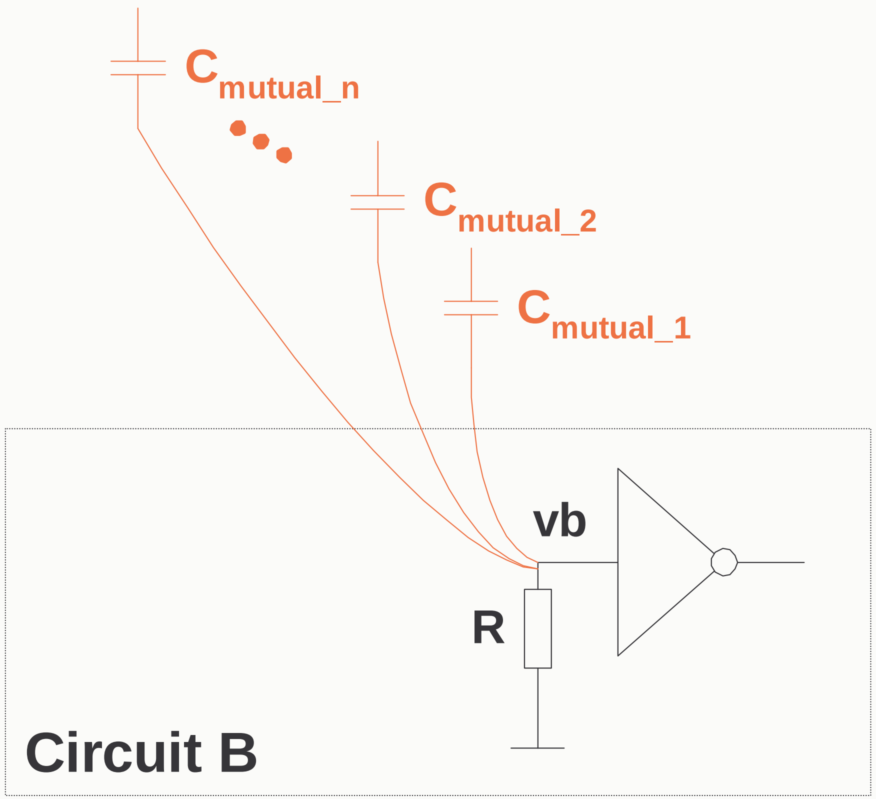
Example Parameter:

- Vcc=5V
- Tr=10ns
- Cmutual=0.5pF
- R=100Ω

$$Crosstalk = \frac{R \cdot C_{mutual}}{Tr} = 0.5\%$$

Accuracy of crosstalk estimation depends strongly on pulse shape!

Crosstalk/Mutual Capacitance



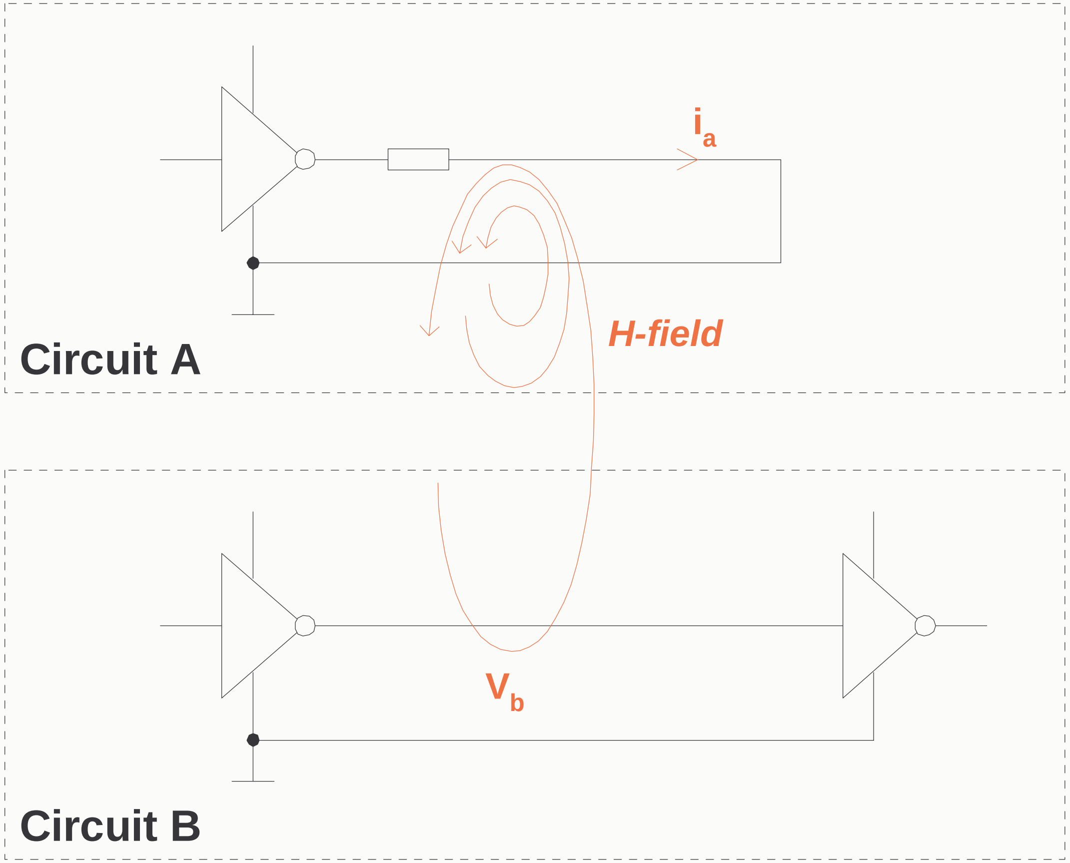
Estimation of the effect of multiple interfering sources

- Estimate the mutual capacitances separately
- Sum the fractional crosstalk figures

$$Crosstalk_{total} = \sum_{n} Crosstalk_{n}$$

Conservative estimation!

Crosstalk/Mutual Inductance



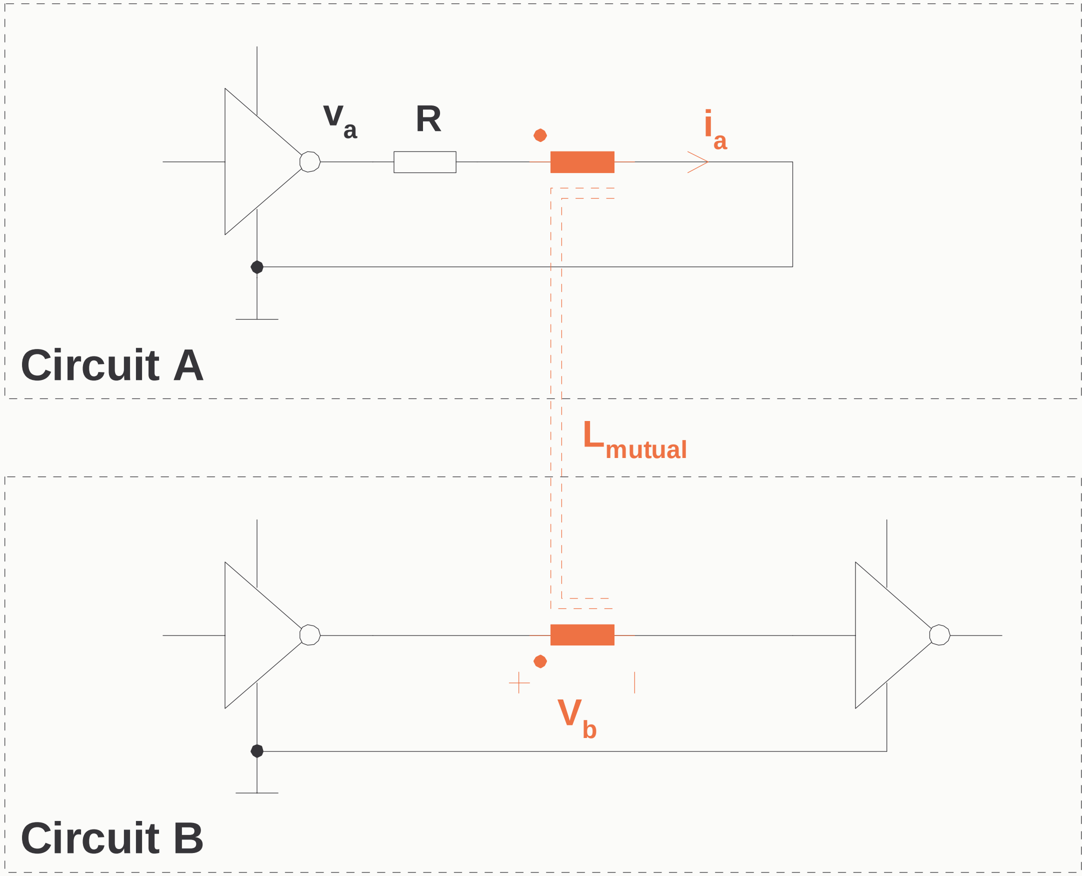
- Wherever there is two current loops, there is **mutual inductance**.
- Circuits interact electrically
- Coefficient of electrical interaction due to magnetic fields is called their **mutual inductance**.

- Magnetic field is a vector quantity:
  - Sensitivity to loop orientation (induced noise voltage reverses polarity)
  - If loop B is in parallel to H-field, no noise coupling

$$\{L_{mutual}\} = H = \frac{Vs}{A}$$

$$L_{mutual} \propto \frac{1}{distance^n} \quad \text{with} \quad n = 2..3$$

Crosstalk/Mutual Inductance



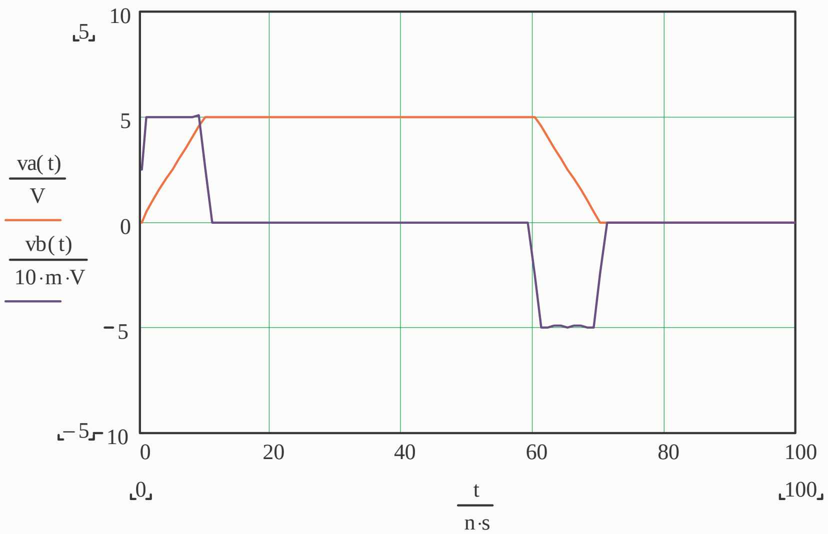
- Estimation of crosstalk. Assumptions:
  - Inductor L_{mutual} doesn't load circuit A significantly
  - Coupled signal current i_b is much smaller than signal current i_a
  - Secondary impedance of L_{mutual} is small compared to impedance to ground of circuit B
- Crosstalk is expressed as a fraction of the driving voltage
- Crosstalk is inversely proportional to rise time Tr
- Assess multiple interfering sources separately. Sum the fractional crosstalks.

$$v_b = L_{mutual} \, {di_a}/{dt} = L_{mutual} \frac{1}{R} \, {dv_a}/{dt} = \frac{L_{mutual} \cdot \Delta V_a}{R \cdot Tr}$$

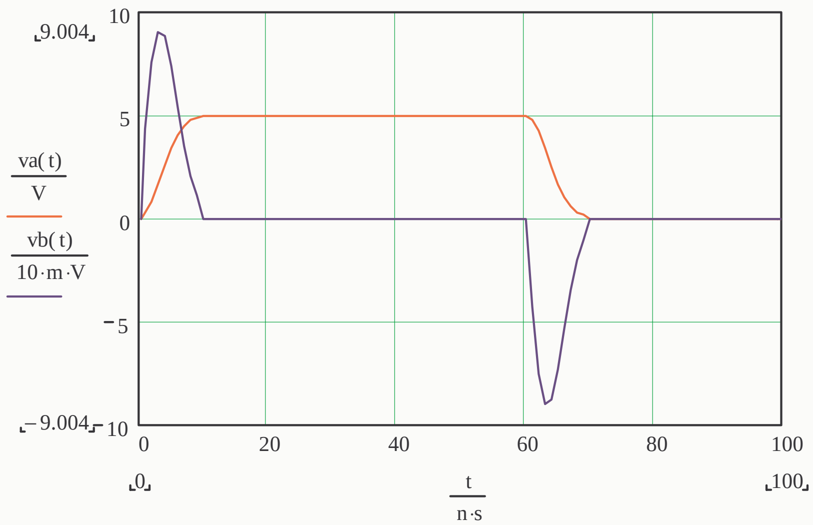
$$Crosstalk = \frac{\Delta Vb}{\Delta Va} = \frac{L_{mutual}}{R \cdot Tr}$$

Crosstalk/Mutual Inductance/Example

Linear Pulse



Gaussian Pulse



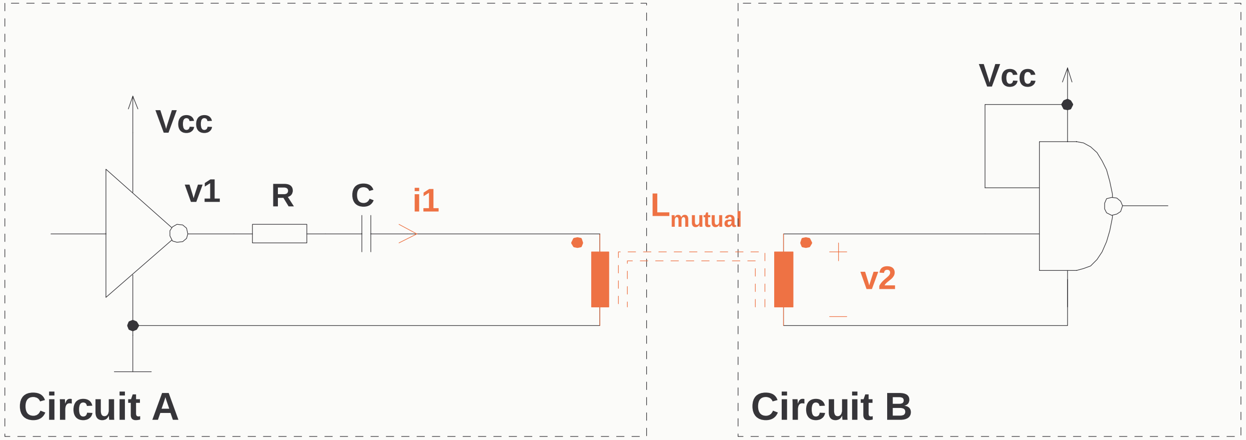
Example Parameter:

- Vcc=5V
- Tr=10ns
- Lmutual=5nH
- R=50Ω

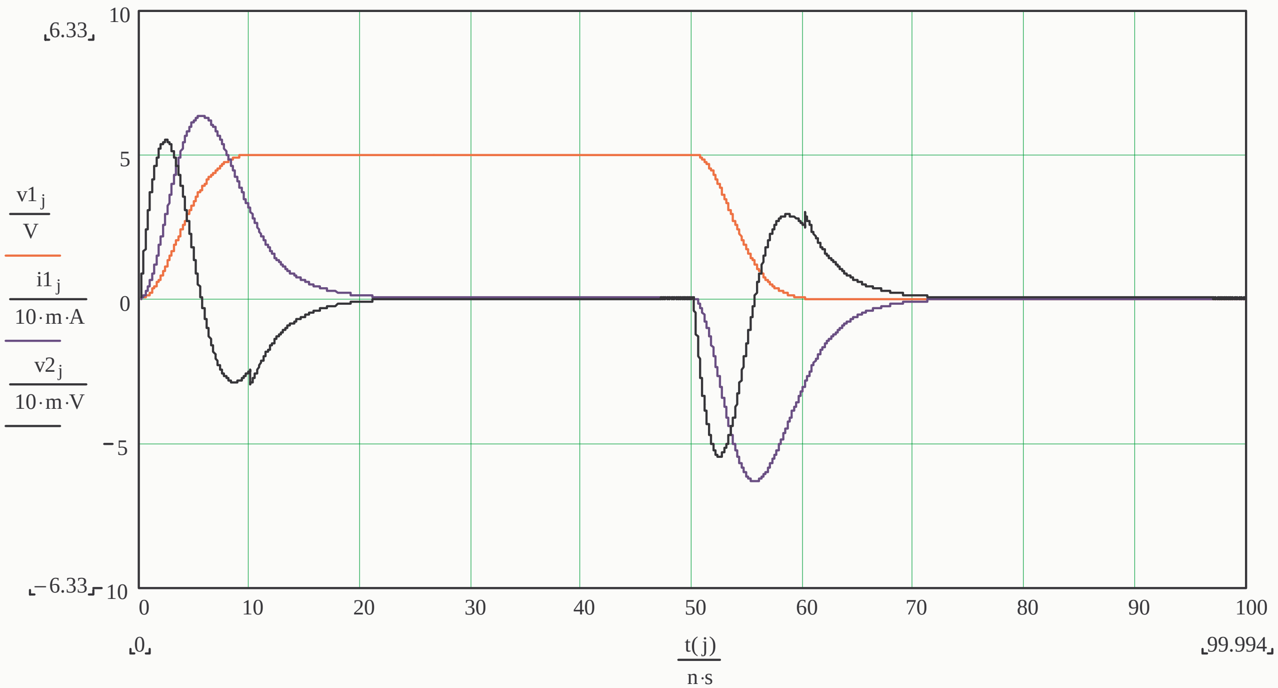
$$Crosstalk_{est} = \frac{L_{mutual}}{R \cdot Tr} = 1\%$$

Accuracy of crosstalk estimation depends strongly on pulse shape!

Crosstalk/Mutual Inductance



Example Parameter:
- •Vcc=5V
- •Tr=10ns
- •Lmutual=3nH
- •C=100pF
- •R=30Ω

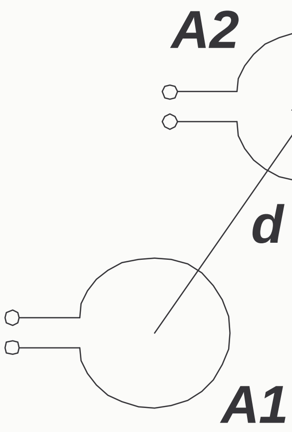


$$Crosstalk_{est} = \frac{L_{mutual}}{R \cdot Tr} = 1\%$$

Note:
- •Estimation of crosstalk is based on linear approximation
- •Use with care!
- •Higher order linear or non-linear situations: Analyse numerically! (Spice, Mathcad)

Crosstalk/Mutual Inductance/Estimations

Estimation of mutual inductance L_{mutual} :

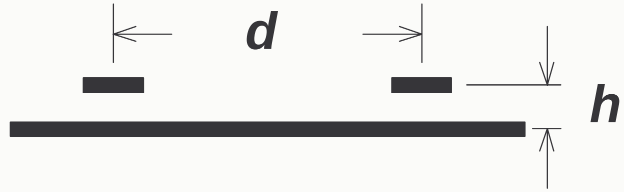


$$L_{mutual} \approx 200 \frac{nH}{meter} \cdot \frac{A1 \cdot A2}{d^3}$$

valid for $d > \sqrt{A1}$ and $d > \sqrt{A2}$

Note:

•Mutual Inductance for well separated loops



$$L_{mutual} \approx L_{individual} \cdot \frac{1}{1 + \left(d/h \right)^2}$$

Note:

•Mutual Inductance for transmission lines

•good estimation for stripline, microstrips, and twisted pair

Crosstalk/Capacitive vs Inductive Crosstalk

- In today's high speed digital designs **inductive crosstalk is typically a more serious problem than capacitive crosstalk**. Multiple reasons:
  - shrinking circuit dimensions
  - low-impedance gate/driver output stages. Small/Uncontrolled Tr and Tf
  - transmission lines directly driven by silicon without driver-side termination
  - inadequate grounding
    - » insufficient or sectioned ground planes in PCB
    - » not enough ground pins in high pin-count connectors
    - » ground loops

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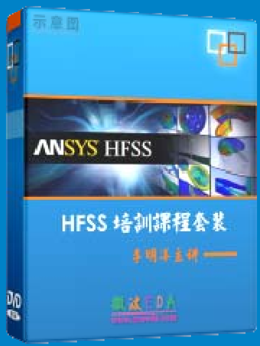

该套课程套装包含了本站全部 HFSS 培训课程，是迄今国内最全面、最专业的 HFSS 培训教程套装，可以帮助您从零开始，全面深入学习 HFSS 的各项功能和在多个方面的工程应用。购买套装，更可超值赠送 3 个月免费学习答疑，随时解答您学习过程中遇到的棘手问题，让您的 HFSS 学习更加轻松顺畅…

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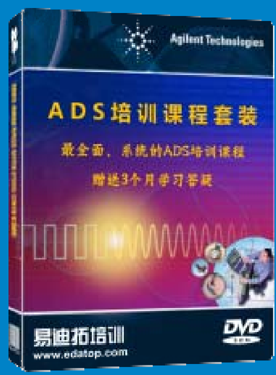

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※ 成立于 2004 年，10 多年丰富的行业经验，

※ 一直致力并专注于微波射频和天线设计工程师的培养，更了解该行业对人才的要求

※ 经验丰富的一线资深工程师讲授，结合实际工程案例，直观、实用、易学

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