Interconnect RL Extraction at a Single Representative Frequency

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Outline

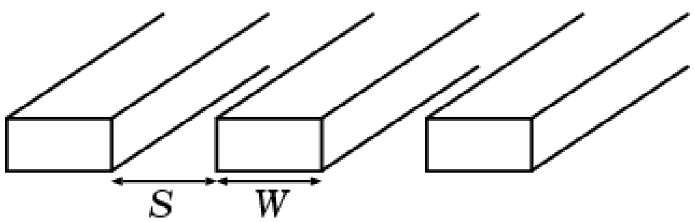
- Background and motivation
- Frequency dependence of interconnect characteristics
- Representative frequency based on transfer characteristics
- Experimental results
- Conclusion

Background & Motivation

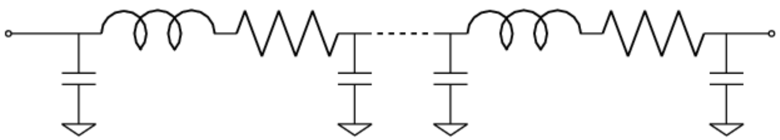
Interconnect design is a big problem in circuit design

One difficulty is frequency-dependency

On-chip wire



RLC ladder circuit



Frequency-dependent

Frequency-independent

<u>Which frequency should we use for extraction?</u>

Why frequency-independent model?

- Frequency-dependent models are already developed
  - Higher accuracy

However…

  - Higher cost for creating the model
  - Which frequency is important?

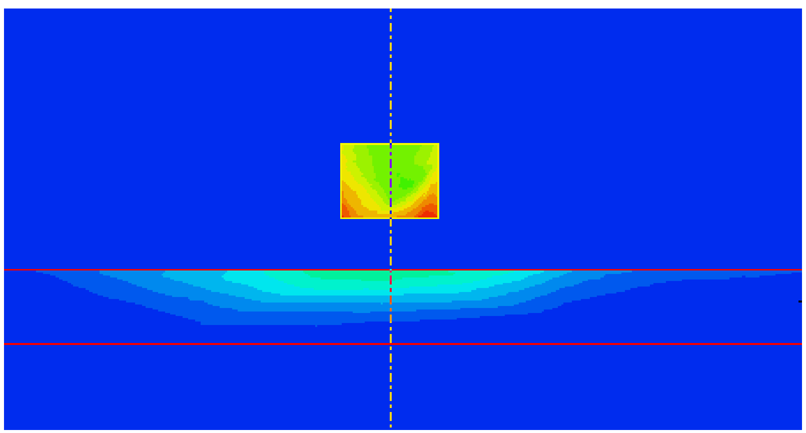
RLC ladder is useful in the early stage of design
To clarify the important frequency helps wire design

Outline

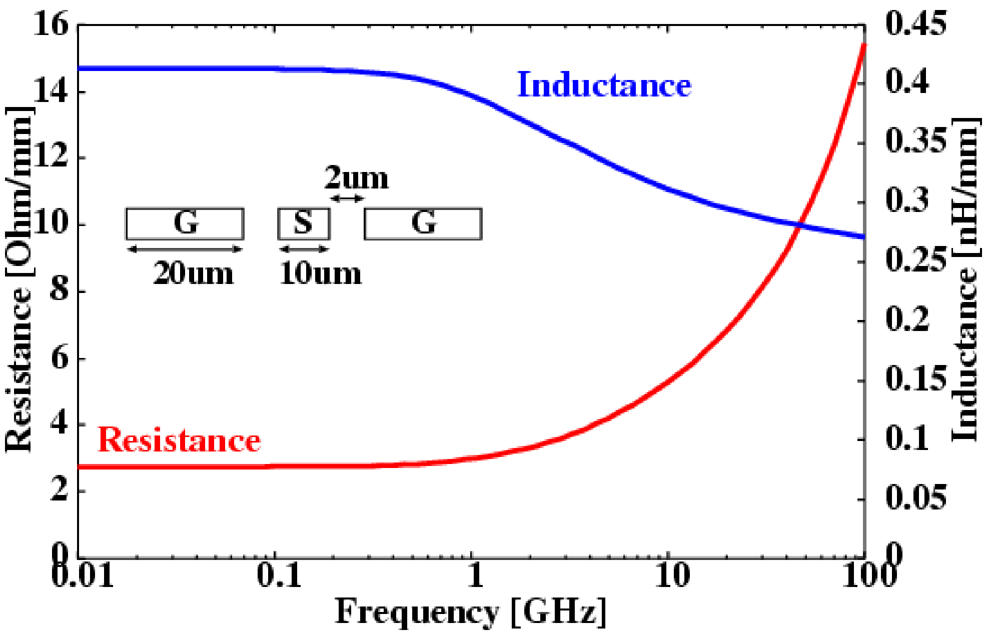
- Background and motivation
- Frequency dependence of interconnect characteristics
  - Problem description
  - Conventional methods
- Representative frequency based on transfer characteristics
- Experimental results
- Conclusion

Frequency-dependence of RL

- Skin-effect, return-current distribution
  - In high freq., R increases and L decreases
  - Frequency dependence of C is negligible

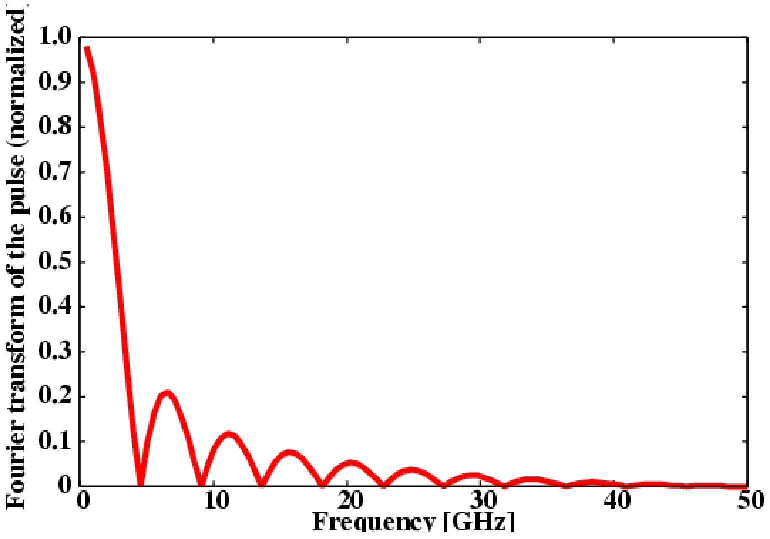


Current density of micro-strip line



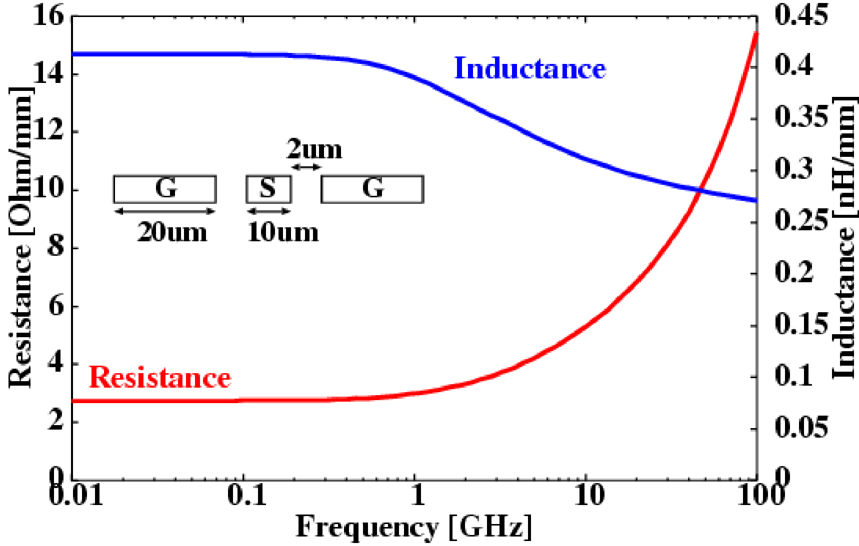
Problem of frequency-dependence

In digital circuits,
spectrum of pulse waveform widely spreads



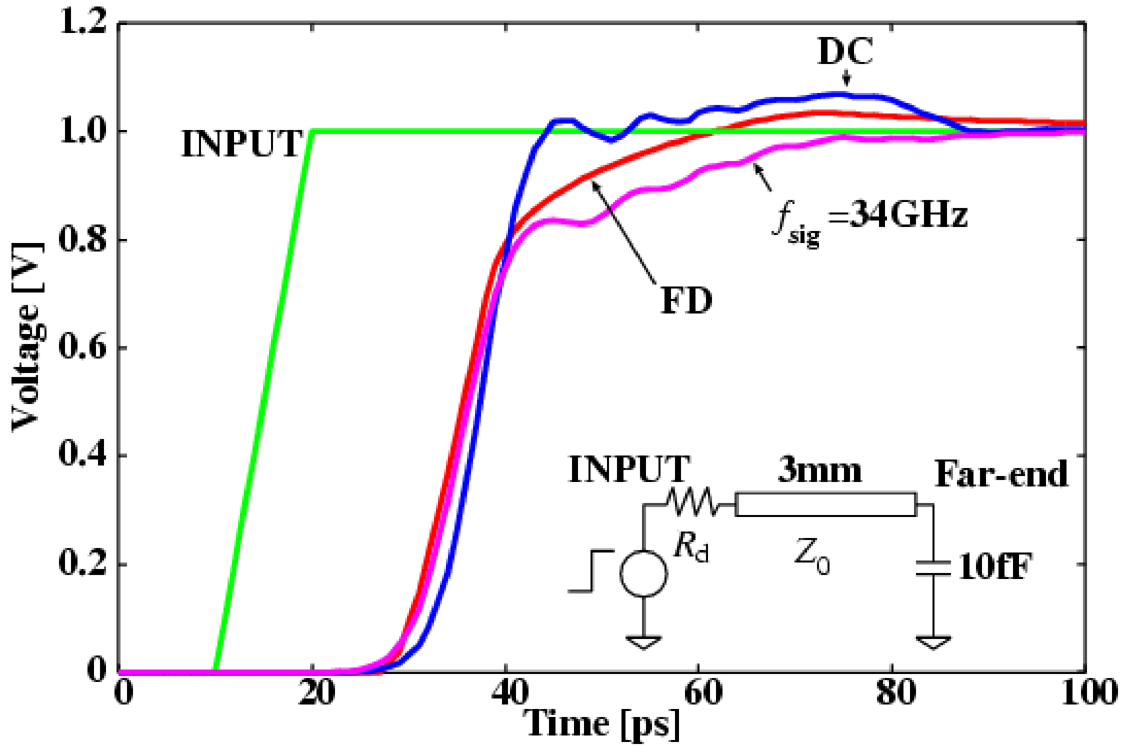
Which frequency component is important?

Frequency dependent model can consider all freq. Components

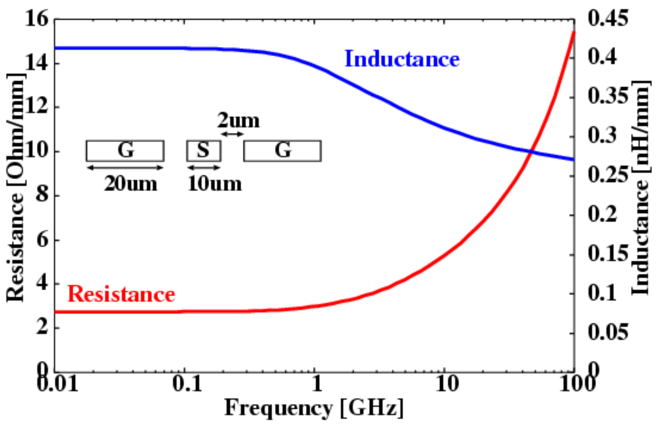


We have to cheese one frequency for freq.-independent model

Effects on waveform



FD:
Freq.-dependent model
(Golden model)



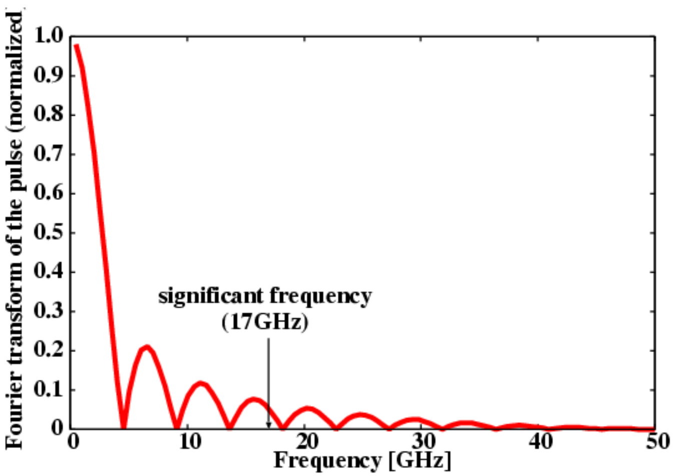
Extraction at

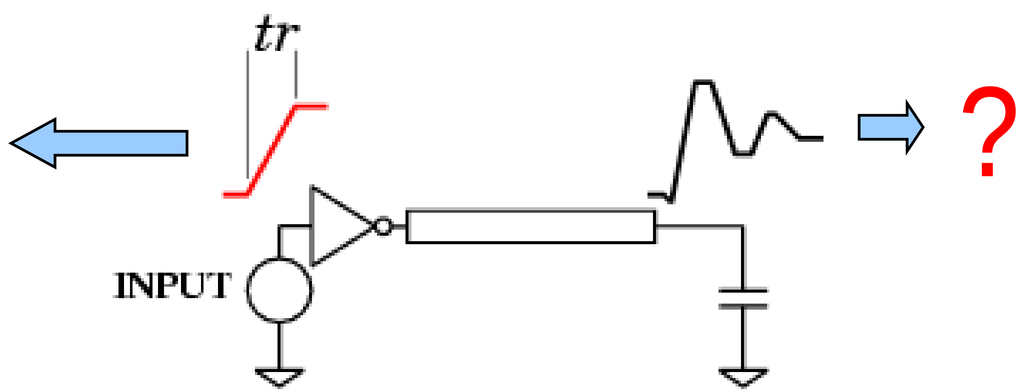
too low freq. overestimates delay and amplitude

too high freq. underestimates delay and amplitude

Conventional methods

- Extraction at DC.
- Determine from the shape of <u>input pulse</u> significant frequency (= 0.34/tr)





<u>Output waveform</u> is more important

Our idea: determine extraction frequency from the transfer characteristic of interconnect

Outline

- Background and motivation
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- Representative frequency based on transfer characteristics
  - Transfer characteristic of interconnect
  - Proposed method
- Experimental results
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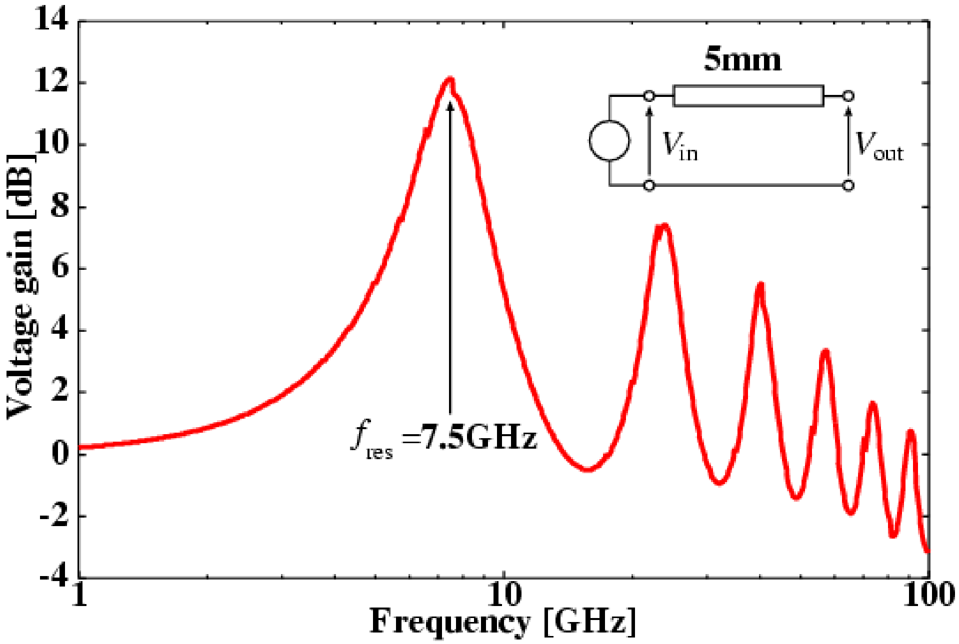
Transfer characteristic of transmission-line

Basic idea: the peak of transfer characteristics has strong effect on the waveform at the far-end

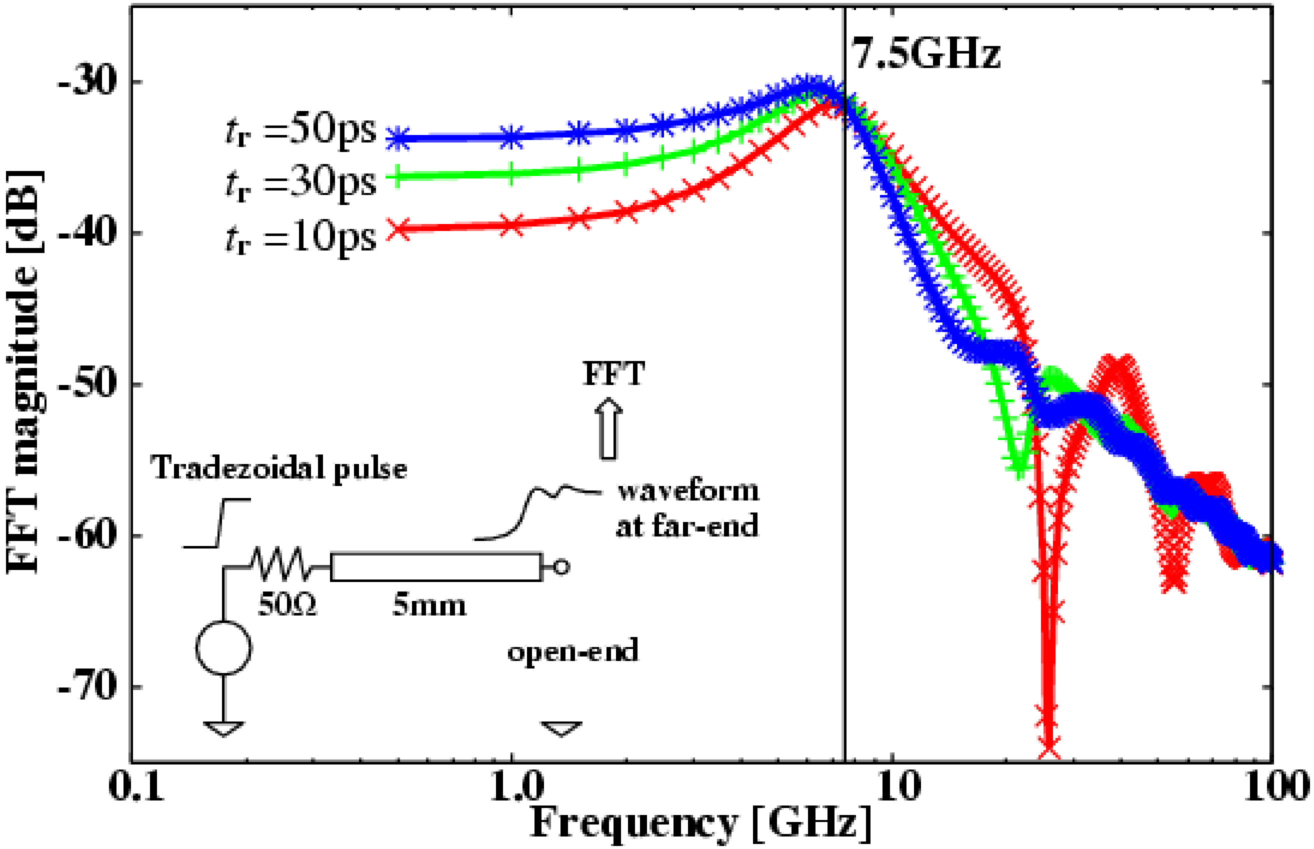


Transmission-lines have resonance frequencies

Ex. Open-ended line:
the frequency where $\lambda/4 =$ wire length

(Preliminary work is presented in ASP-DAC2004)

Spectrum at the far-end



Resonance frequency is a peak regardless of the rise time

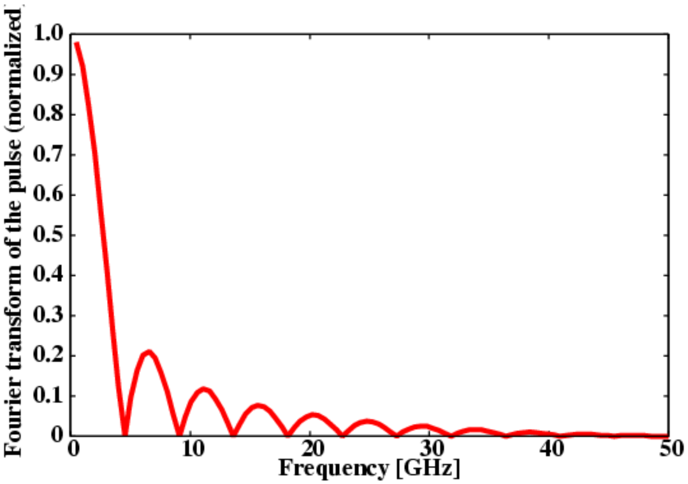
Relationship between the resonance freq. and the spectrum of input

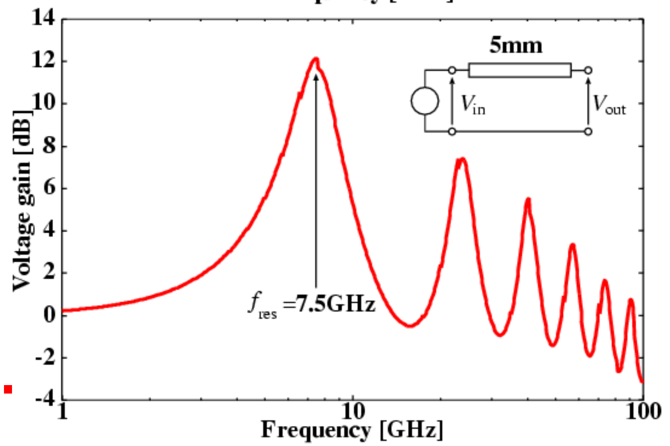
Spectrum of input pulse also affect the waveform

Resonance freq. >> significant freq.

Input at the resonance freq. is small

The importance of the resonance freq. is small



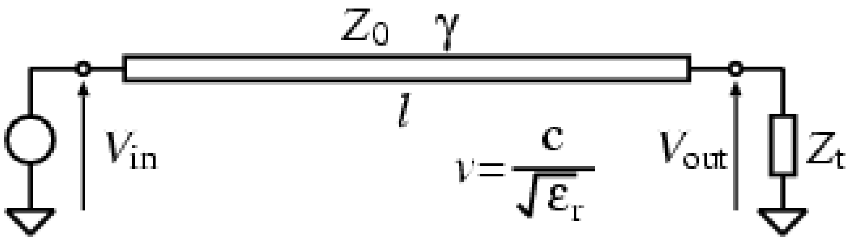


In the proposed method,
we use the significant freq.
as the upper limit of extraction freq.

Resonance frequency of uniform transmission-lines

- Resonance frequency is easily derived from transmission-line theory

$$\frac{V_{out}}{V_{in}} = \frac{1}{\cosh \gamma l + \frac{Z_0}{Z_t} \sinh \gamma l}$$



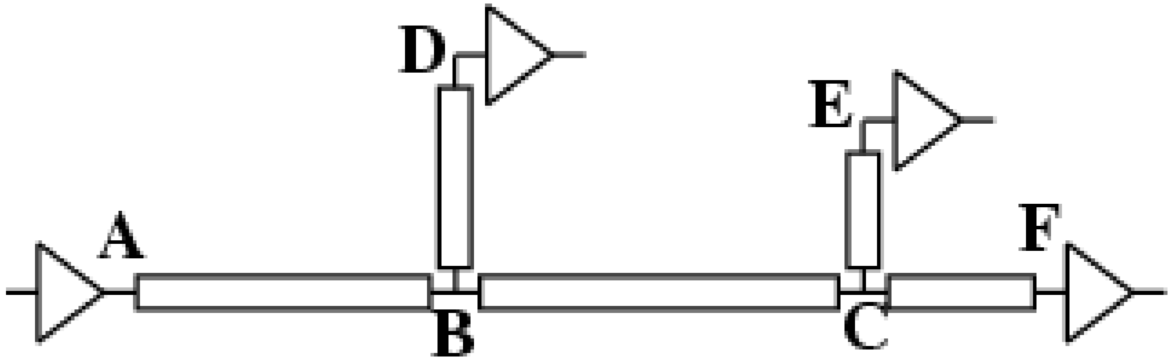
Z0: characteristic impedance
Zt: impedance of load

γ: propagation const.
l : wire length

How to treat non-uniform or branching wire?

Non-uniform / branching wire

- Divide the wire into uniform segments
- Determine the extraction frequency for each segment

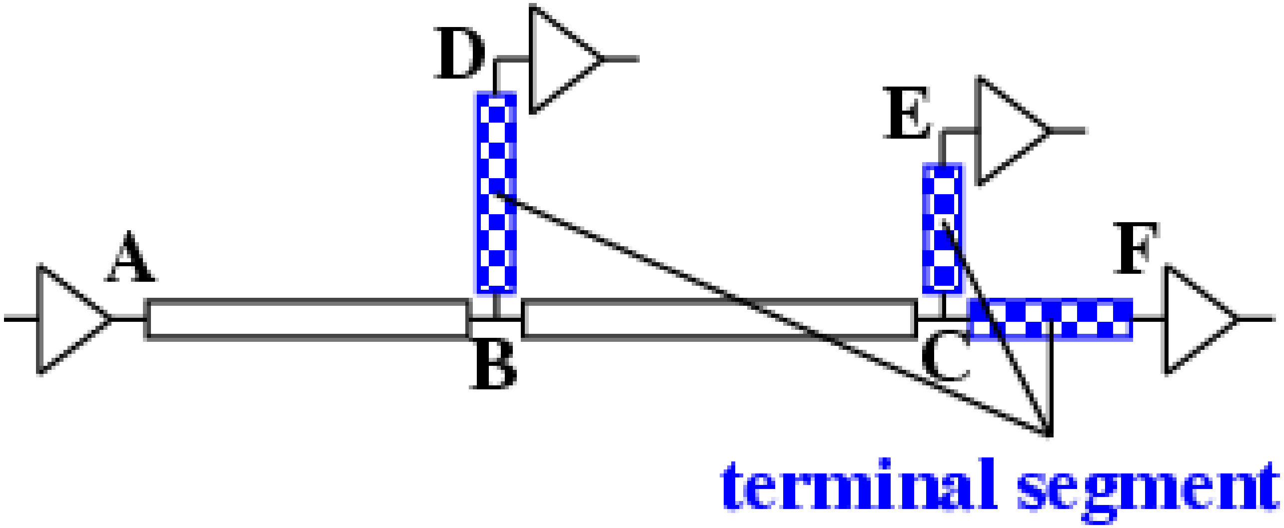


Load of A-B = parallel connection of the input impedance of B-C and B-D

Proposed method (1/3)

Step1. Determine the freq. for terminal segment

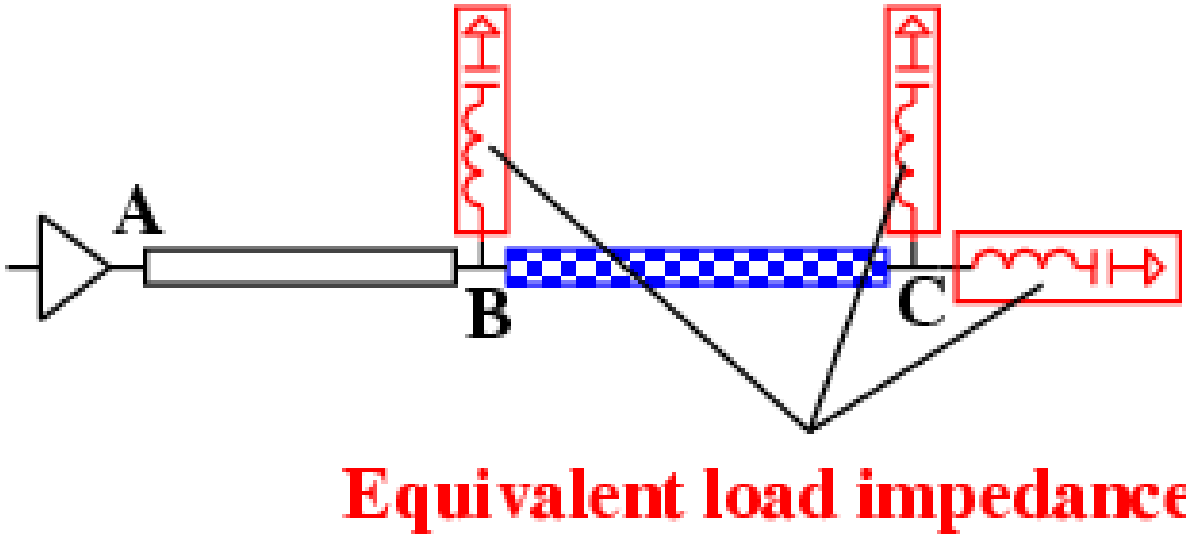
Input of gates is assumed to be open-end



Extraction freq. for B-D, C-E, C-F are determined

Proposed method (2/3)

Step2. Calculate the input impedance

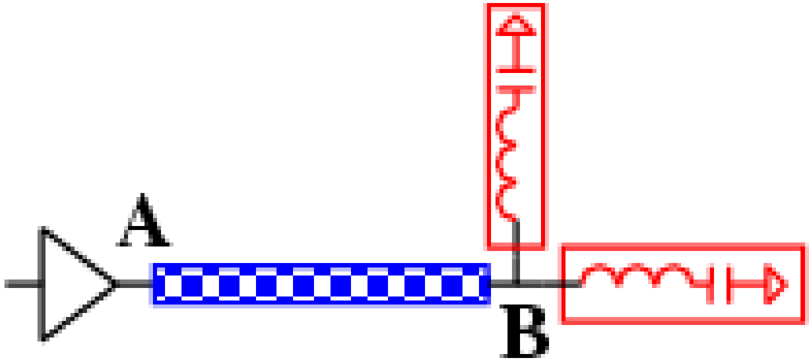


The load of B-C is determined

The extraction freq. of B-C can be determined

Proposed method (3/3)

Iterates Step1. and Step2.



Calculate the input impedance of B-C

- The load of A-B is determined
- The extraction frequency of A-B is determined

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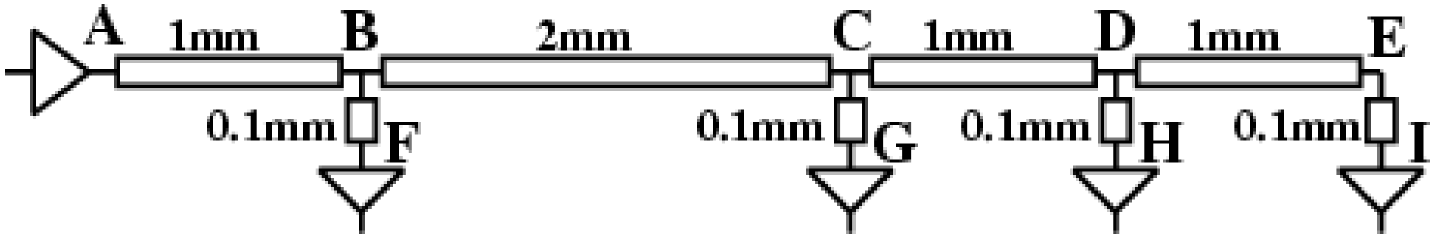
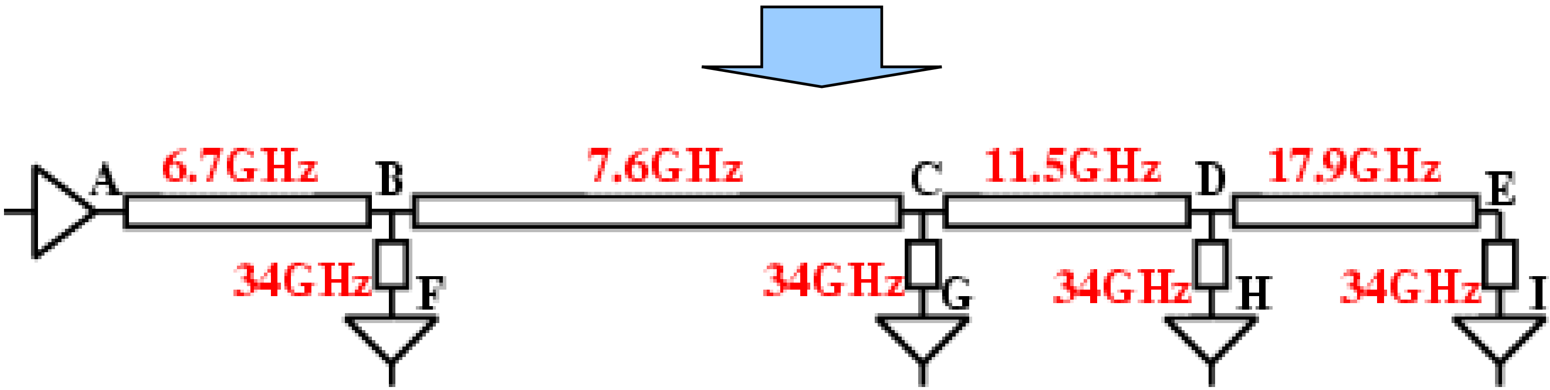
- Experimental results
  - Case study
  - Statistic of experimental results
- Conclusion

Case study: stub-bus



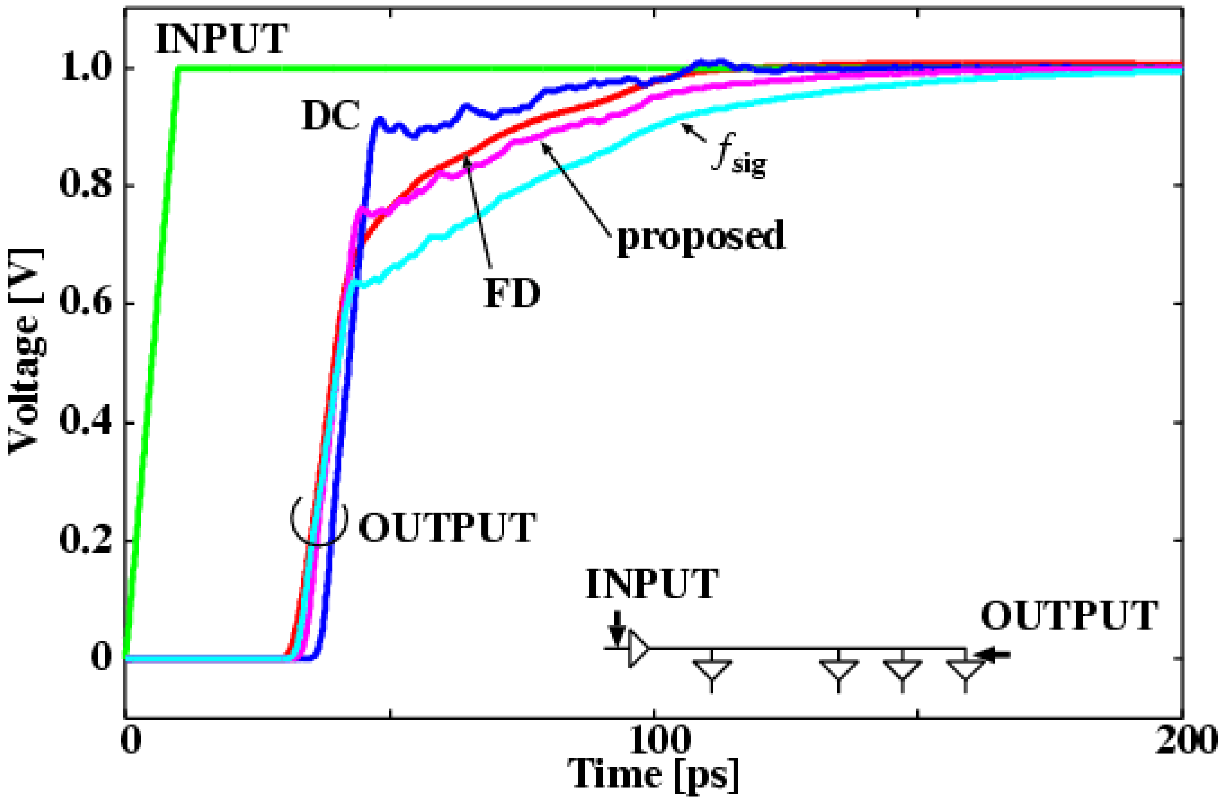
- 10μm wide interconnect (A-B-C-D-E) and 1μm wide stub
- transition time of input is 10ps



Extraction frequencies by the proposed method

Transition waveform

- Waveform at the terminal of a stub



Result of our method meets that of FD

Summary of overall experiments

- 43,199 nodes in 9,545 configurations are evaluated

Freq.	Delay		Transition time	
	Max. err.	>5%*	Max. err.	>5%*
DC	-88.1%	11.5%	-71.9%	27.8%
Proposed	-9.9%	5.4%	-9.8%	12.5%
Sig. Freq.	+110.0%	12.2%	+160.3%	35.2%

(*: ratio that the error is over 5%)

Proposed method achieve less than 10% error

Conclusion

- A representative frequency for RL extraction is proposed
- Determine the extraction frequency from the transfer characteristics
- The proposed method can handle non-uniform and branching wires
- The maximum error in delay and transition time is less than 10%