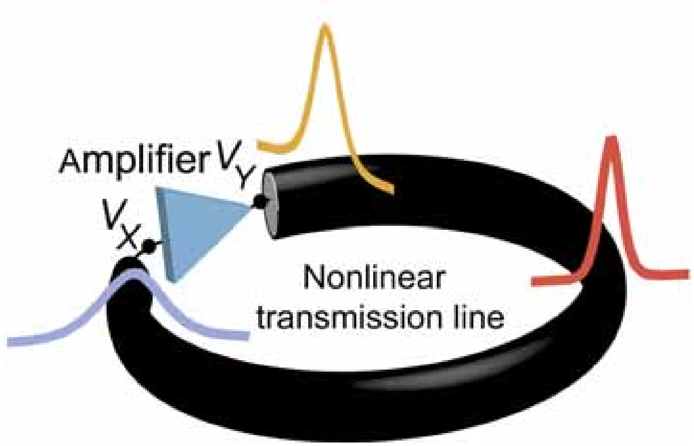
Soliton Electronics



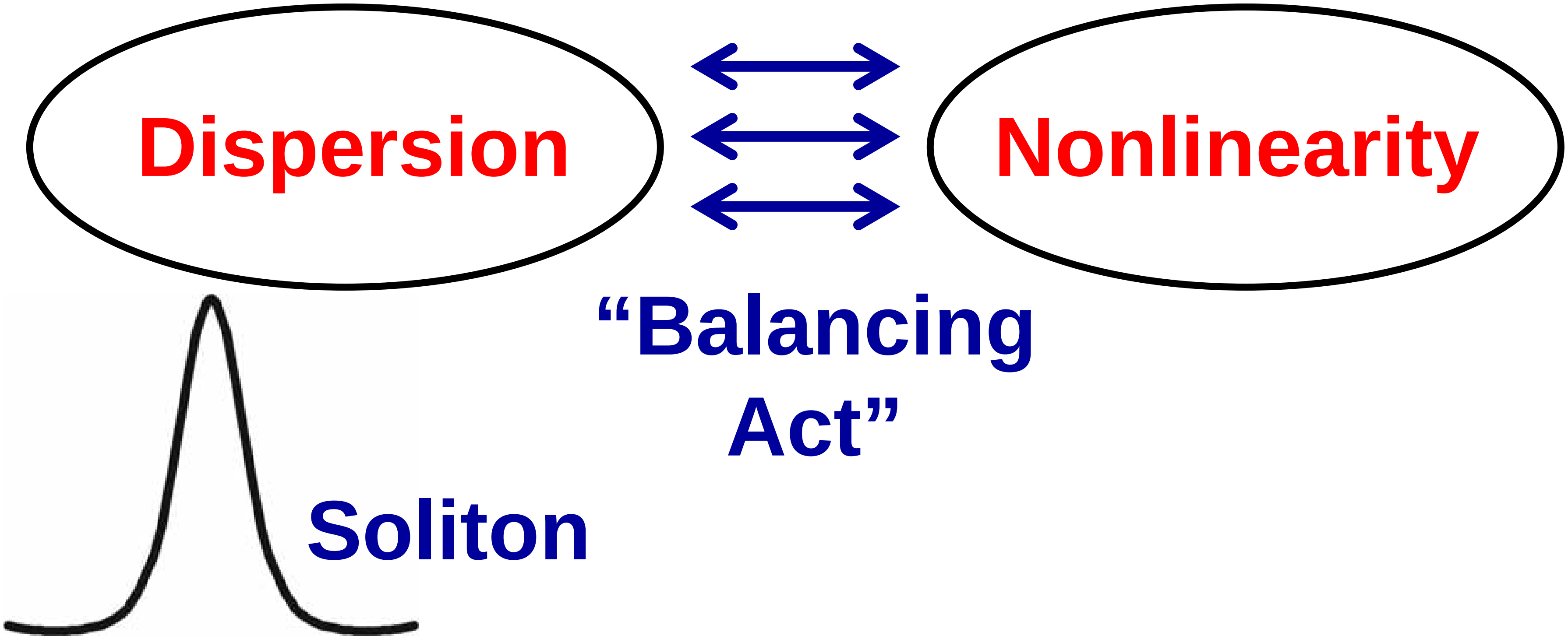
David Ricketts, Xiaofeng Li, & Donhee Ham

Harvard University

Today's speaker ––– Xiaofeng Li

Solitons: Review

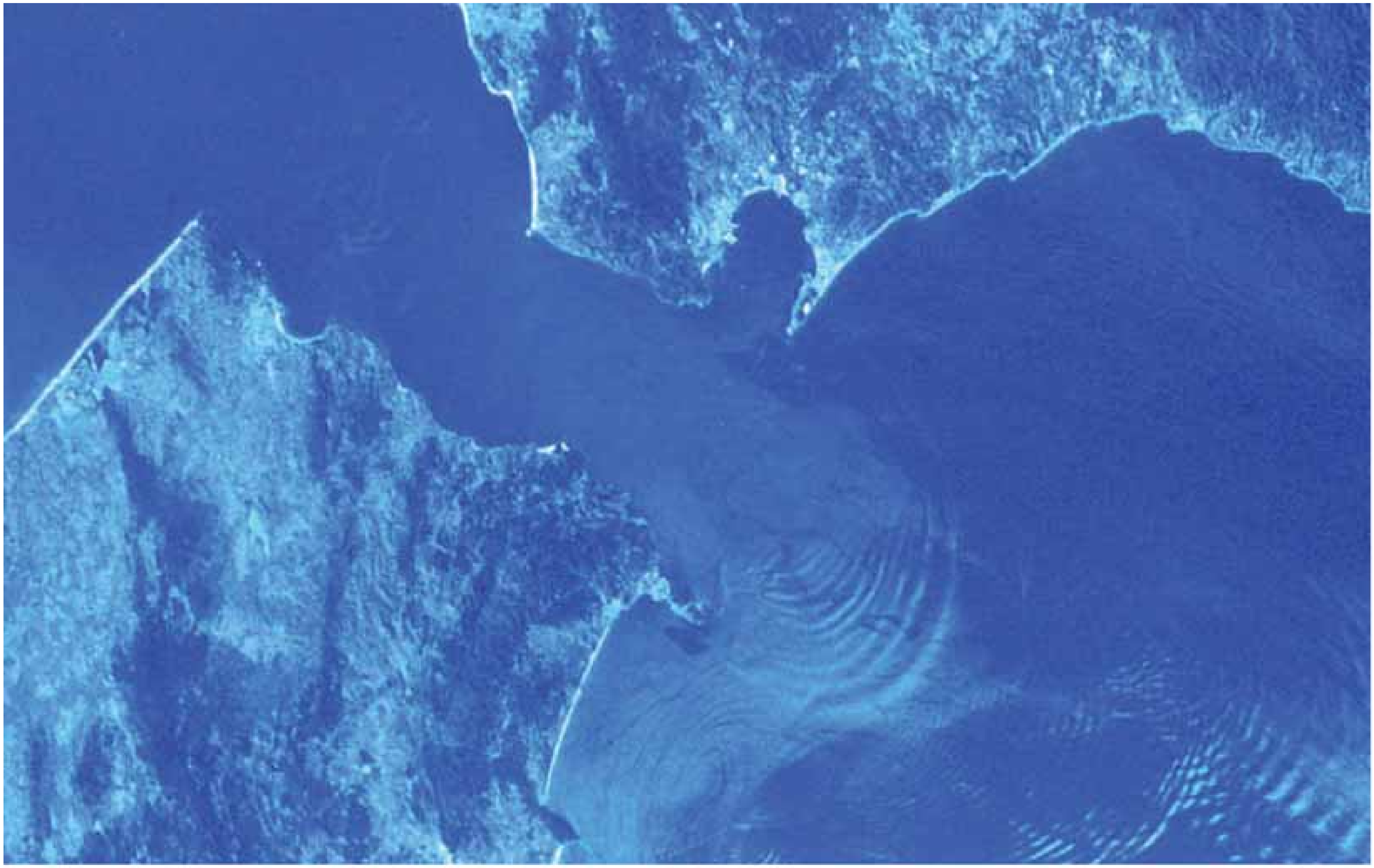
Solitons: Review (1)



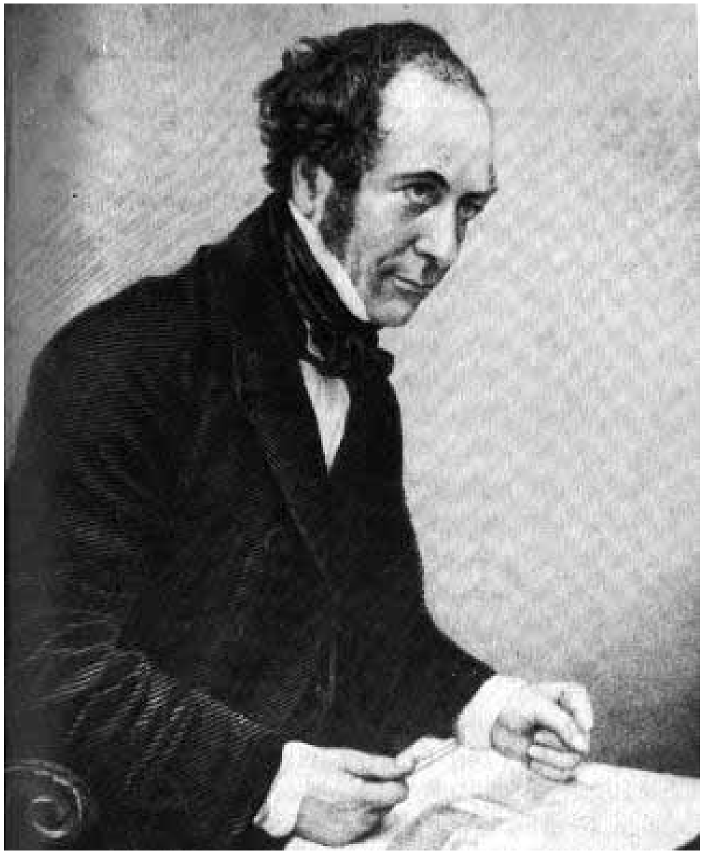
- Shape maintenance (if loss = 0)
- Pulse state maintenance (if loss>0)
- Unique collision & propagation

Solitons: Review (2)

Solitons: Review (3)



Solitons: Review (4)



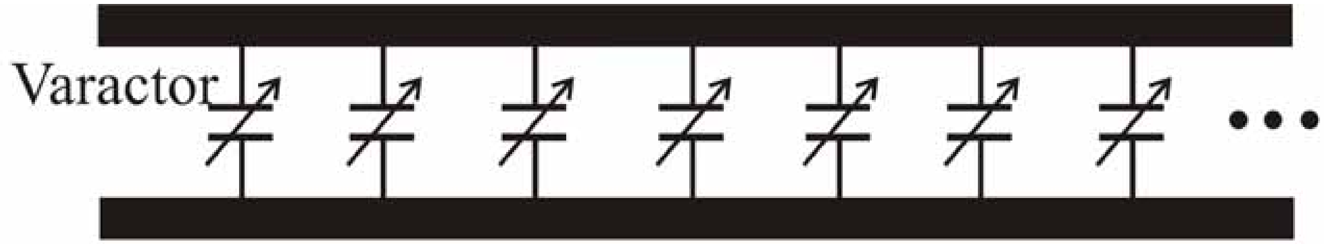
Scott Russell

Solitons: Review (5)

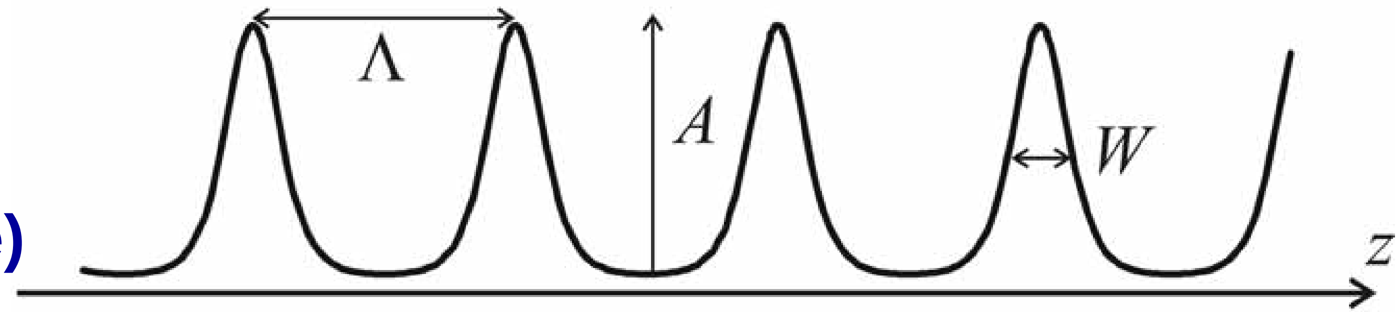
- Water **(Russell)**
- Mechanical lattice **(Fermi)**
- Plasma **(Zabusky & Kruskal)**
- Optical fiber **(Haus, Gordon)**
- Magnetic films, superconductors, etc.

Electrical Solitons: Review (1)

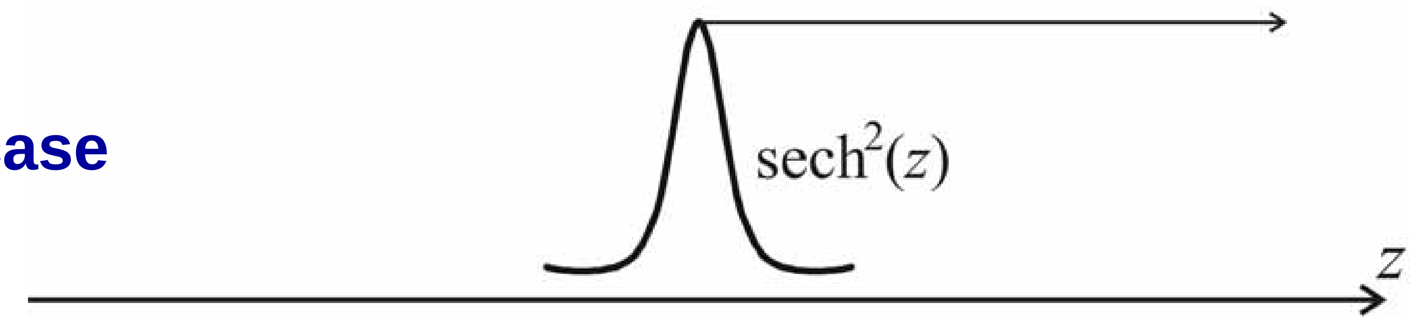
Nonlinear Transmission Line (NLTL)



Soliton pulse train (Cnoidal wave)

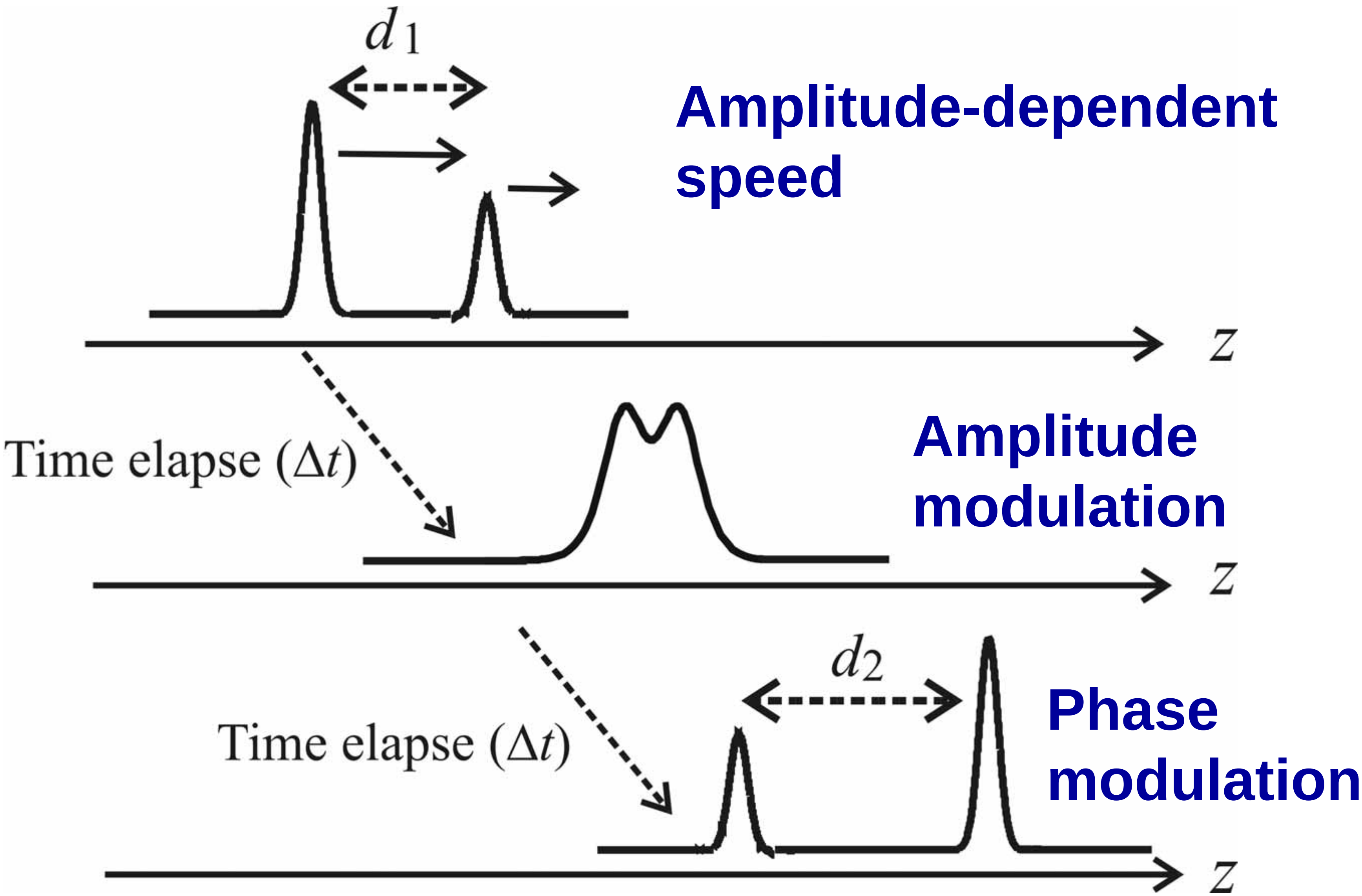


Mono pulse case

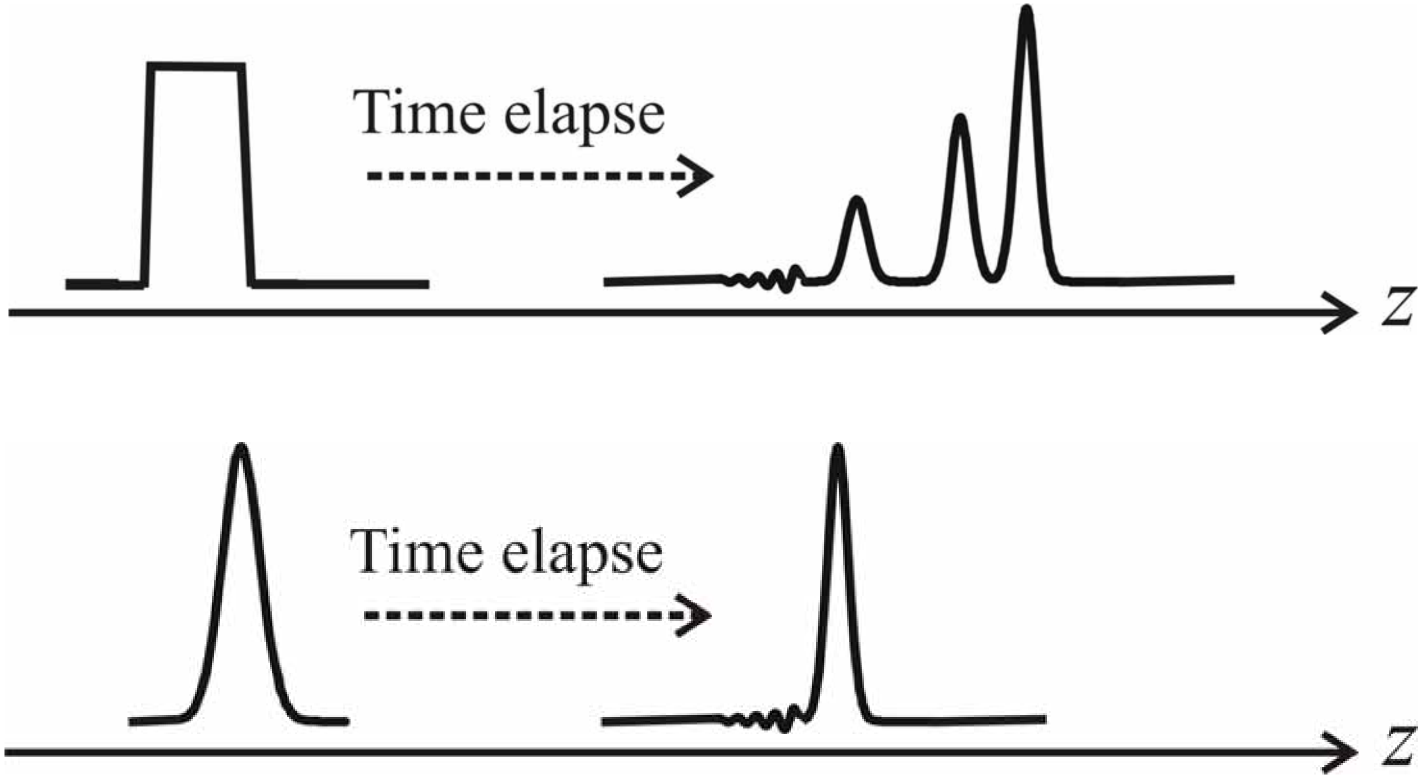


Rodwell *et al*, *Proc. IEEE*, 1994. (Review article)

Electrical Solitons: Review (2)



Electrical Solitons: Review (3)

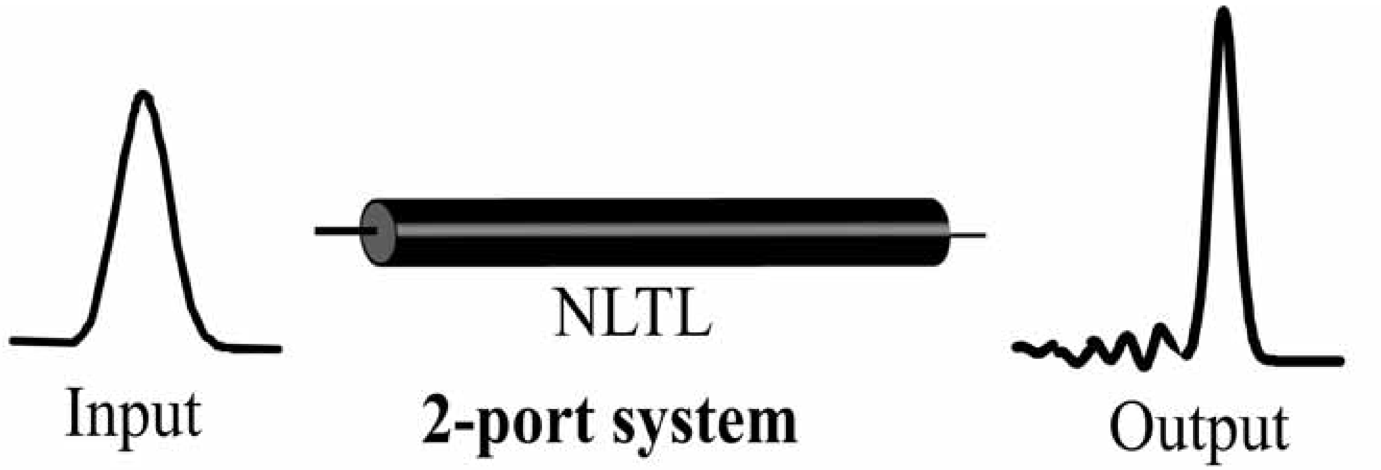


- **Transient, soliton-forming process**
- **2-port applications (Pulse sharpening)**

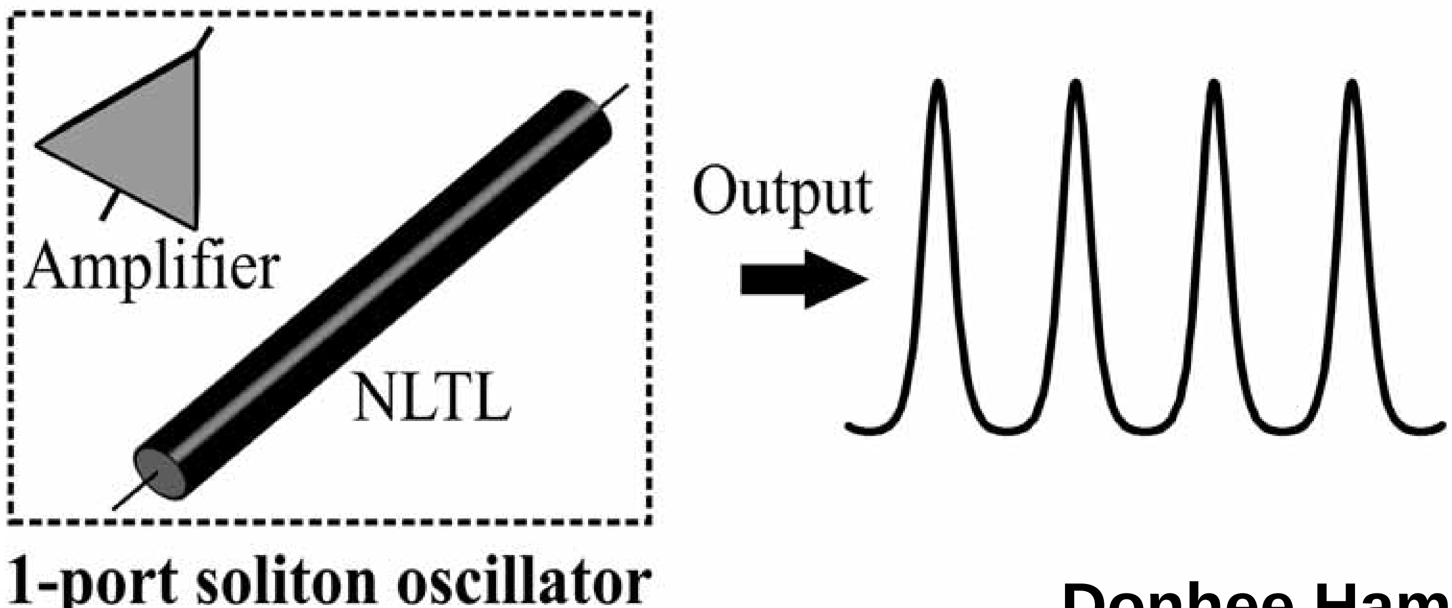
Rodwell *et al*, *Proc. IEEE*, 1994. (Review article)
Van der Weide, *APL*, 1994.

Problem Statement

Past
46 years



Can we build a soliton oscillator ?



Donhee Ham

Electrical Soliton Oscillator

- **Original articles (05-07):** ***IEEE T-MTT, IEEE ISSCC, & IEEE JSSC***
- **Invited articles:** ***IEEE CICC*, *IEEE LEOS*, *IEEE RFIC, IEEE Communications Magazine, & McGraw-Hill 2008 Yearbook of Science & Technology***

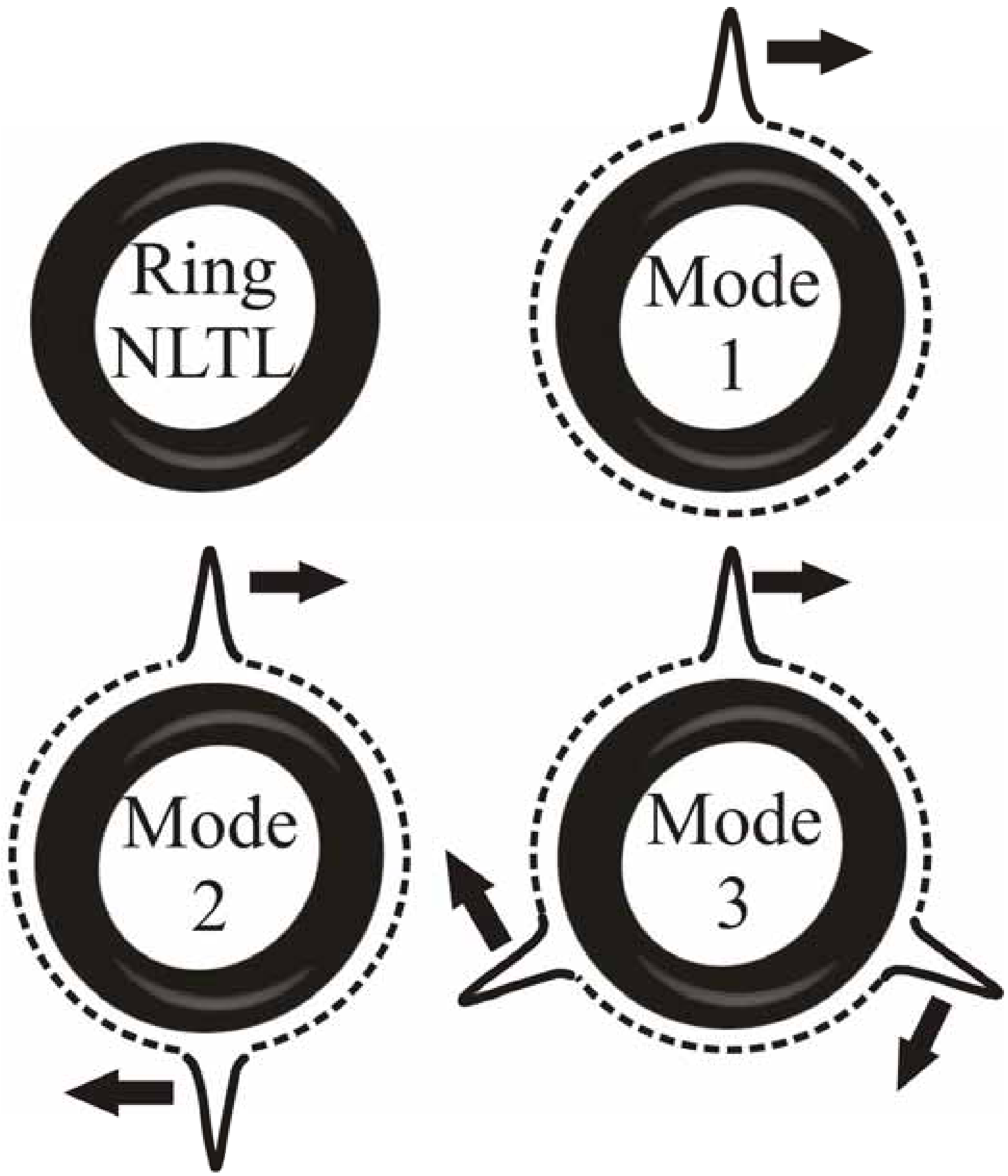
***Nature* 2006**

DEVICE PHYSICS

Electrical solitons come of age

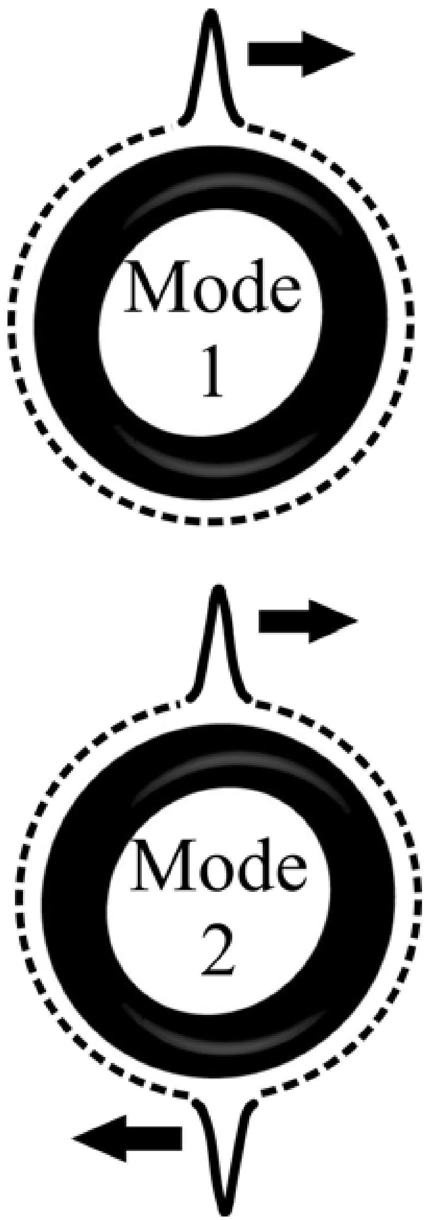
Thomas H. Lee

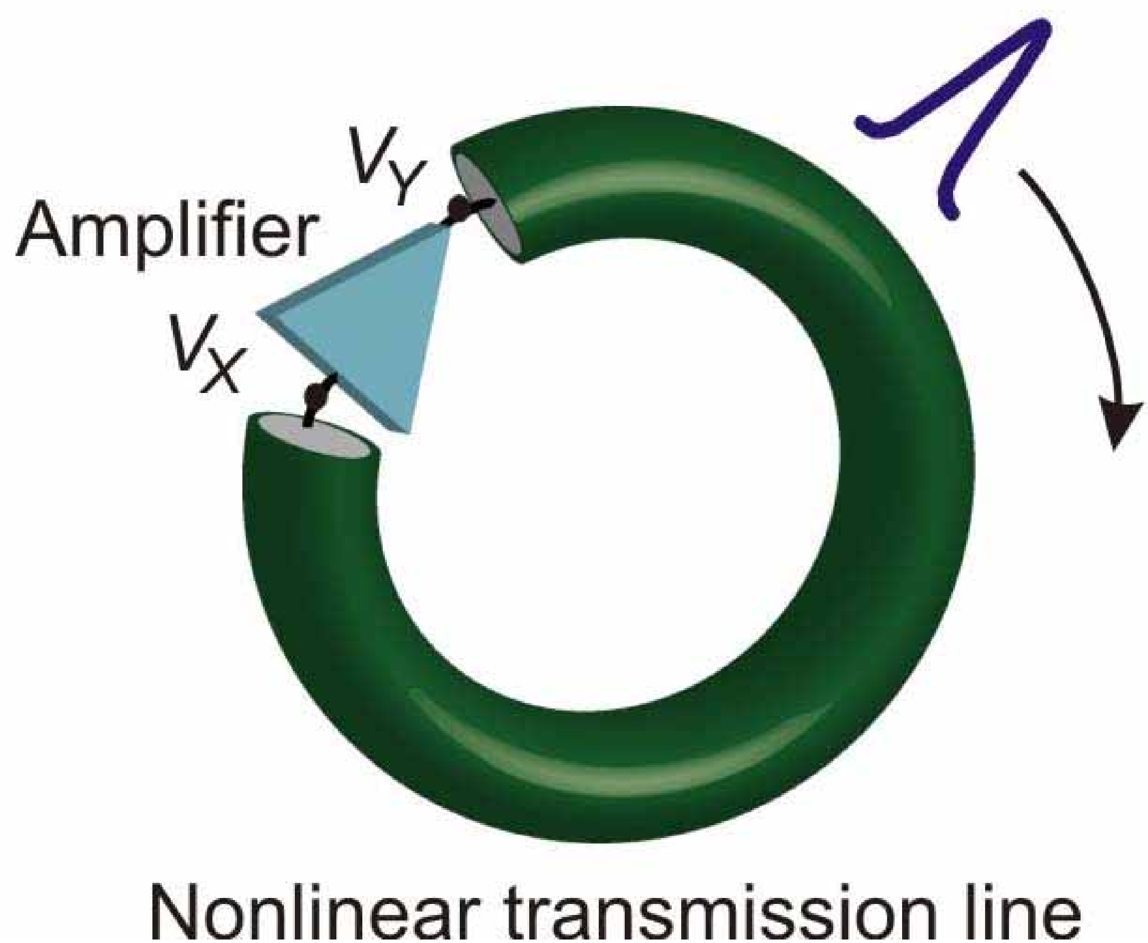
Ring NLTL



Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

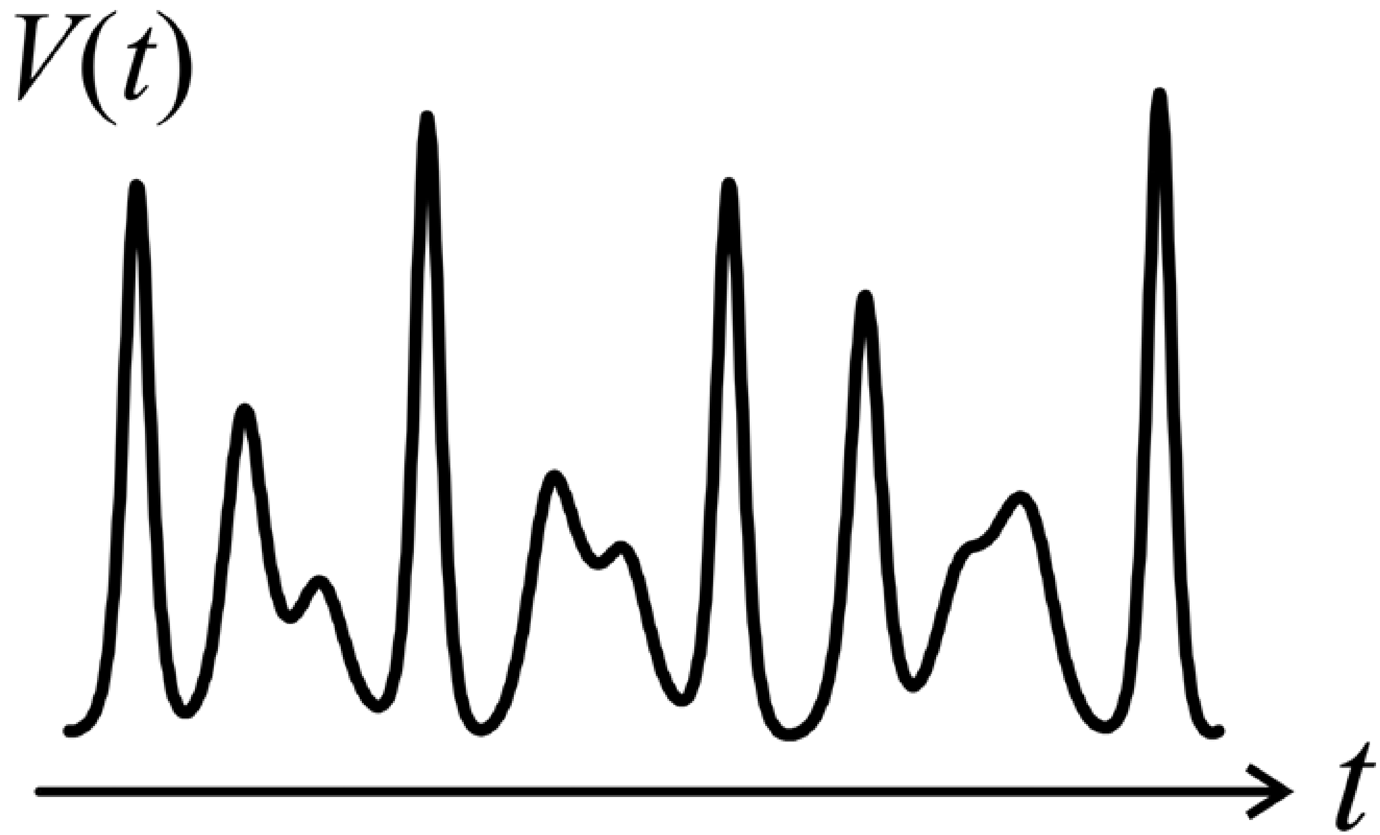
Soliton Oscillator Topology





Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Oscillation Instability Problem

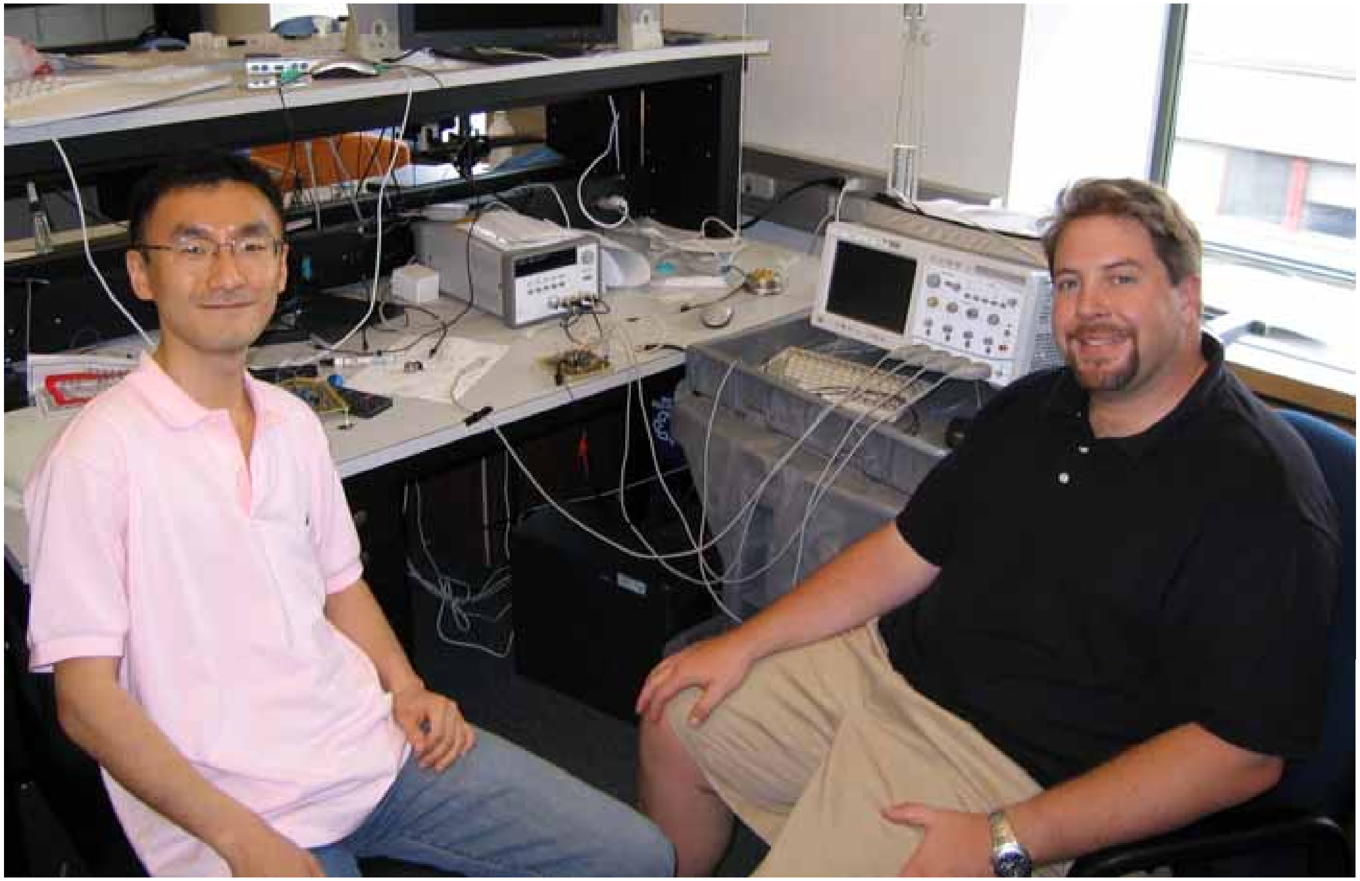


Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

The Soliton Oscillator Team

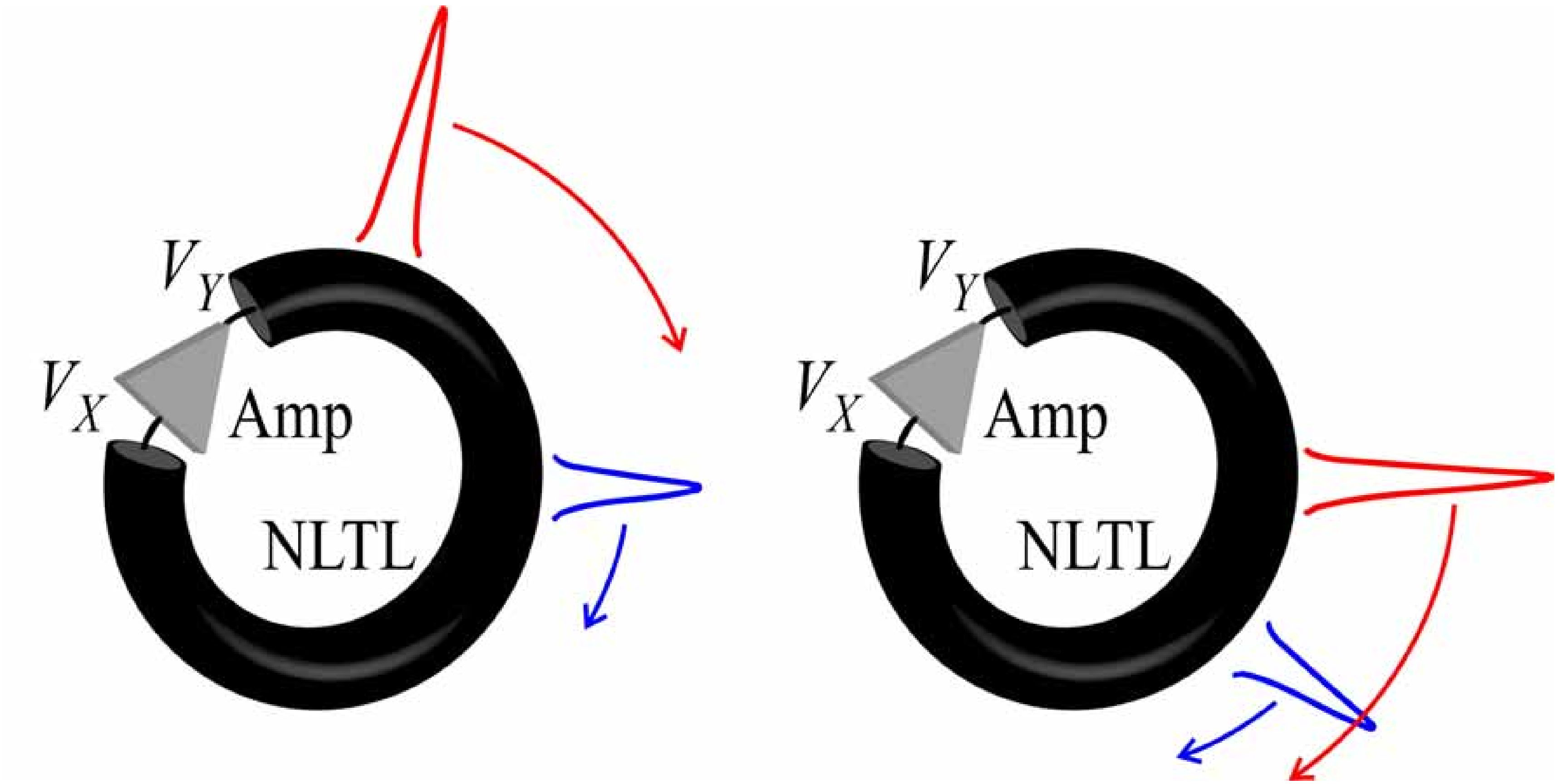
David Ricketts

Xiaofeng Li



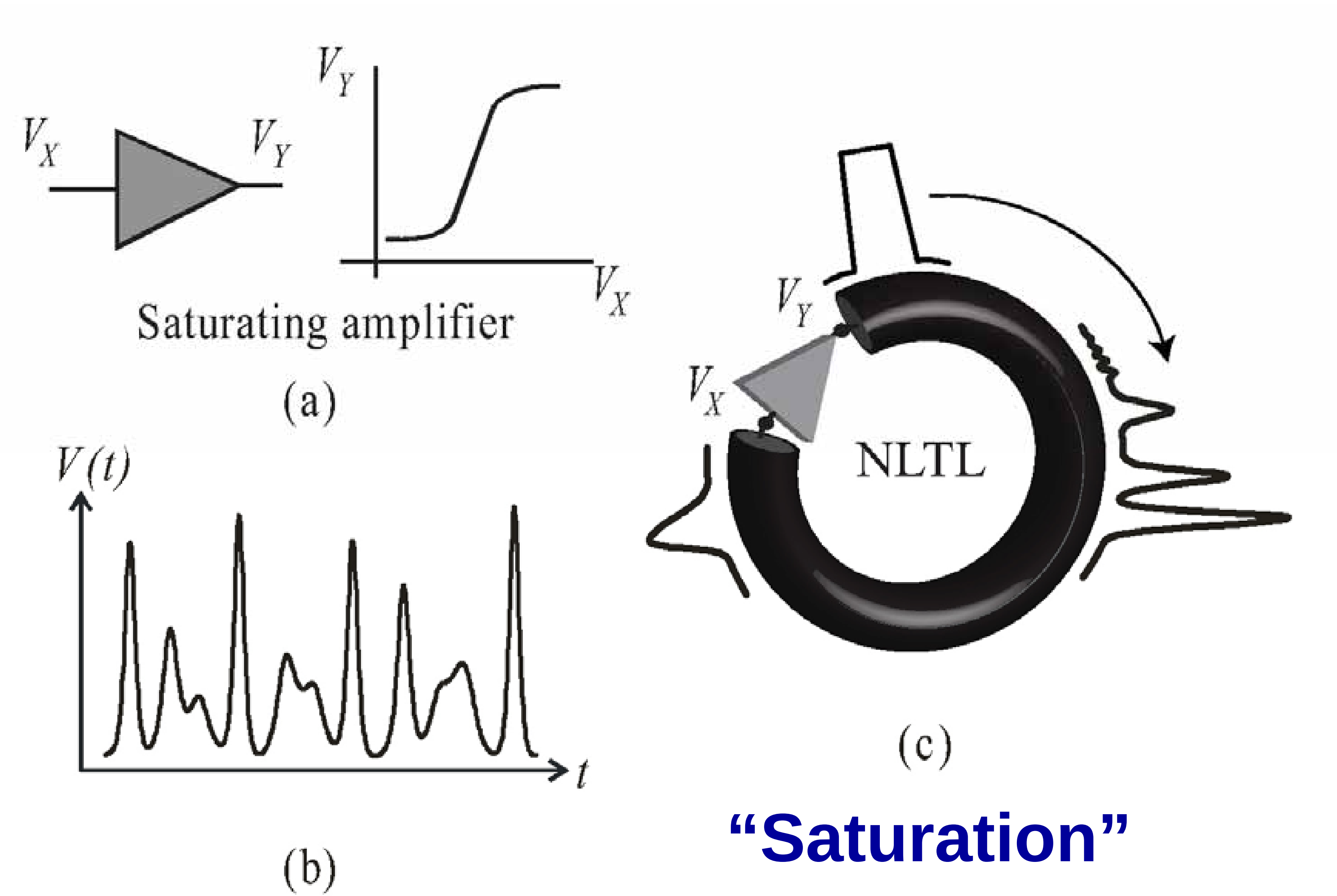
Sine Qua Non of Oscillation Instability

“Soliton Collisions”



Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

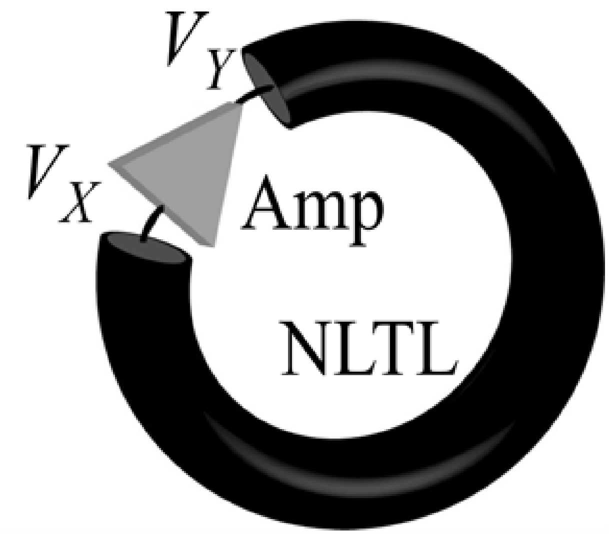
Detailed Instability Mechanisms (1)

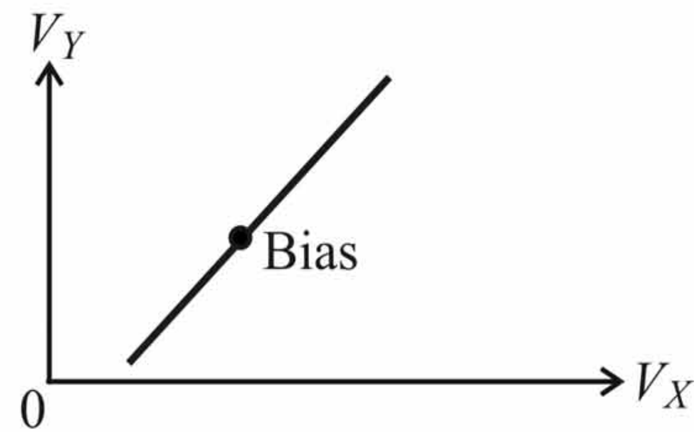


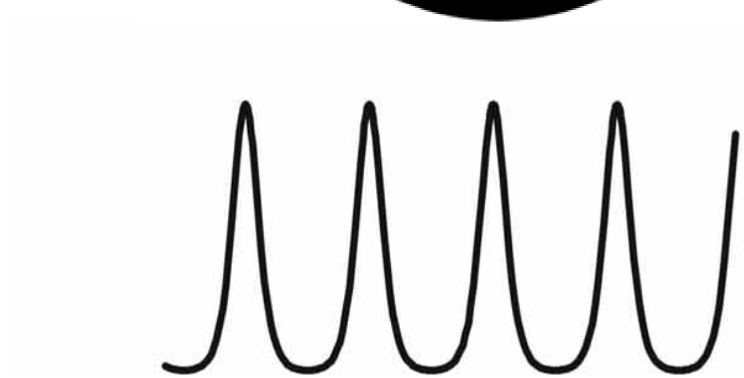
“Saturation”

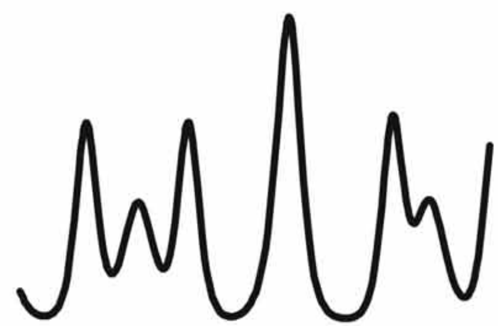
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Detailed Instability Mechanisms (2)





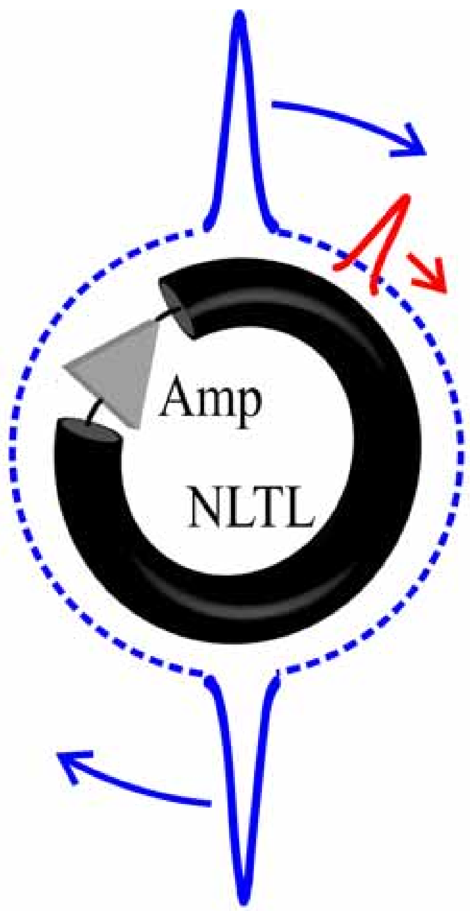




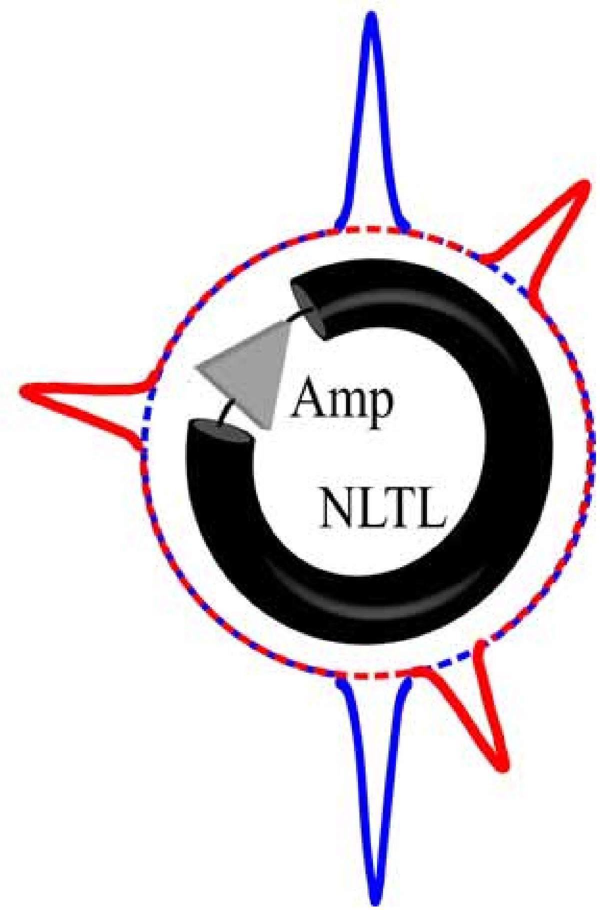
G. J. Ballantyne, PhD dissertation, U. Canterbury, 1994.

Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Detailed Instability Mechanisms (3)



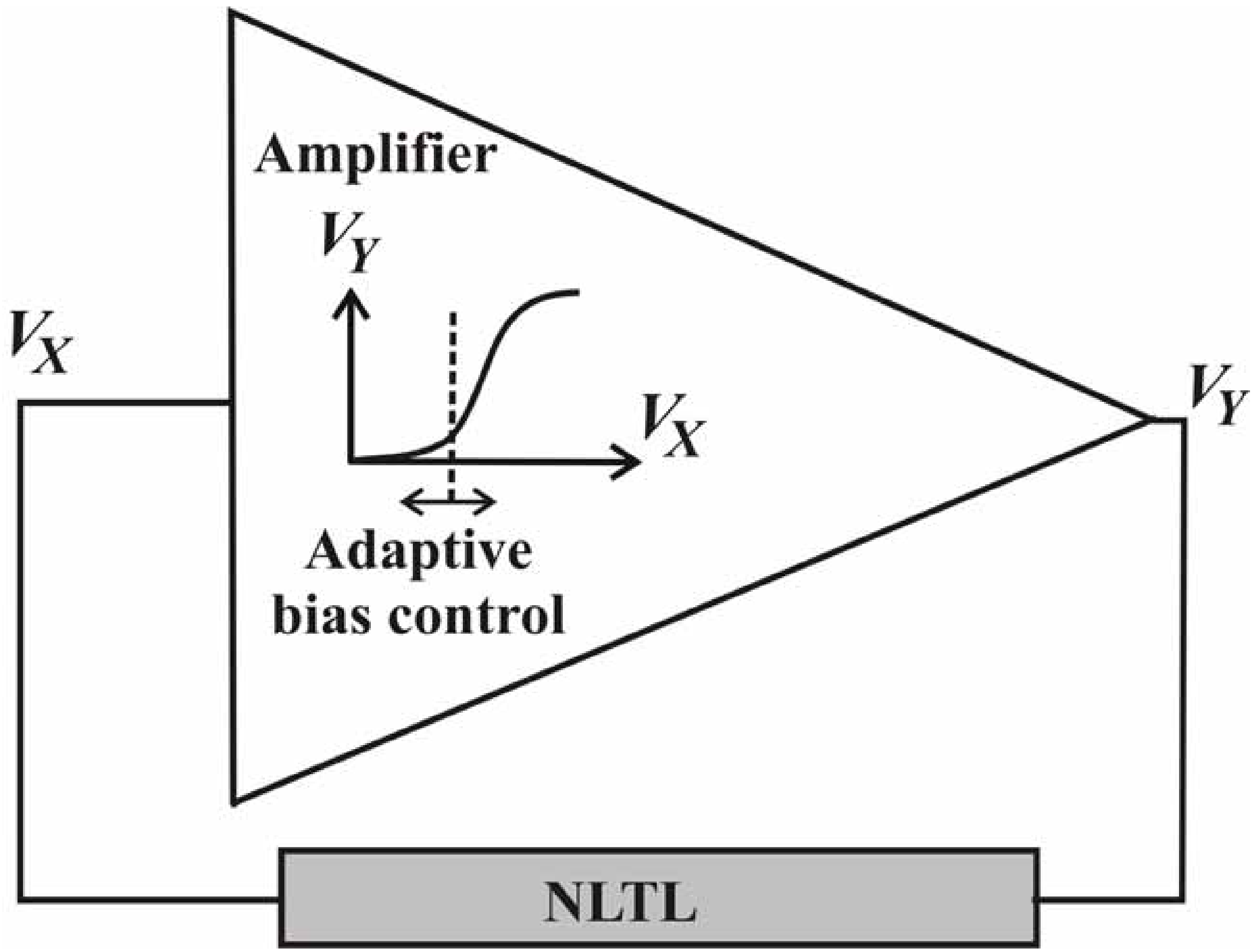
"Perturbations"



"Multi modes"

Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

"*Taming the Unruly Solitons*"



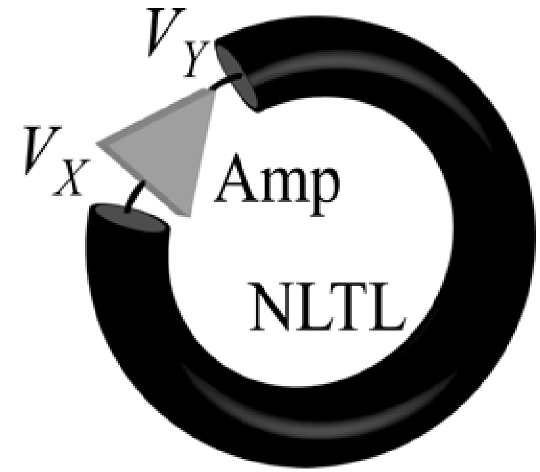
Saturation reduction

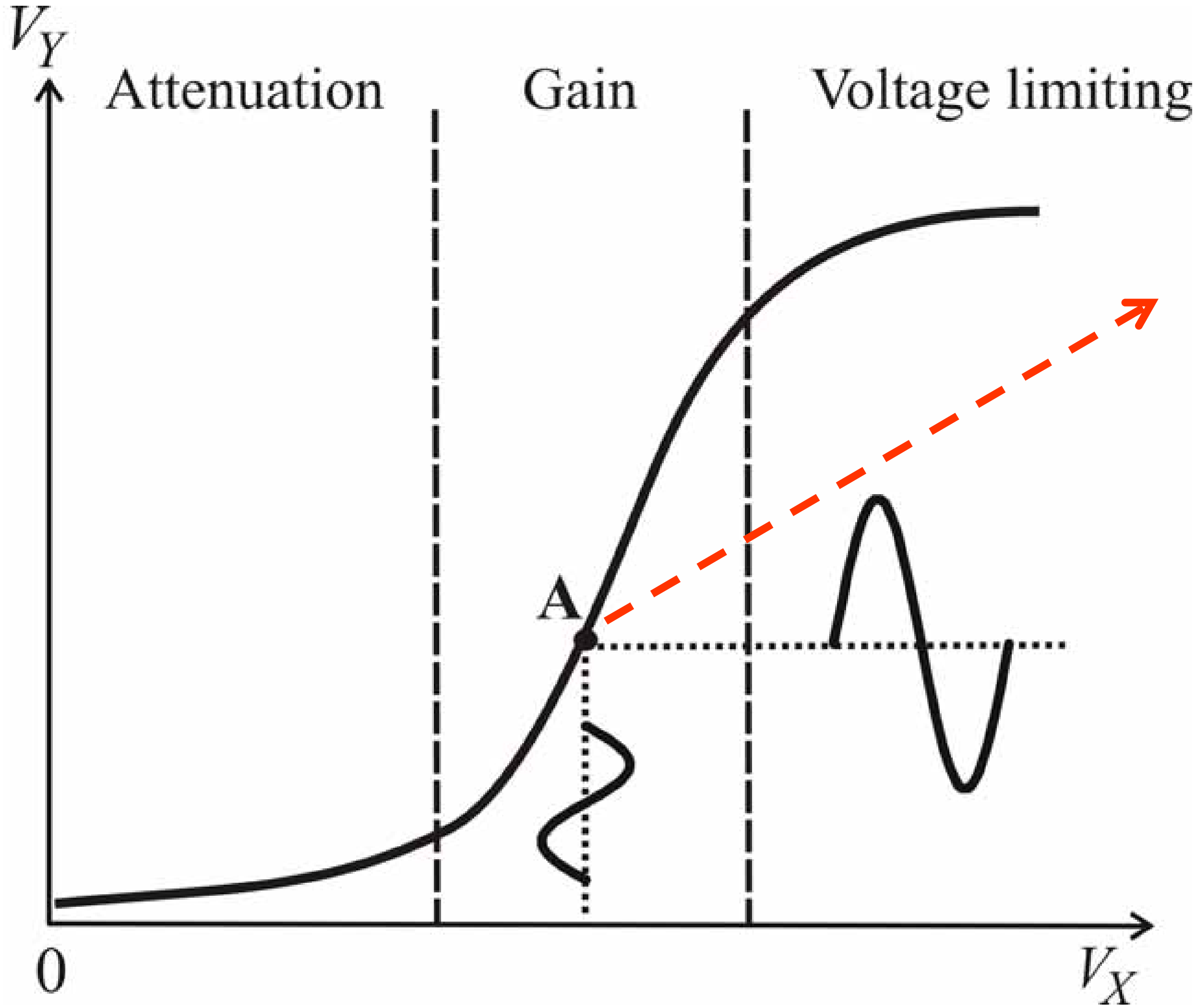
Perturbation rejection

Single mode selection

Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Operating Principle (1)

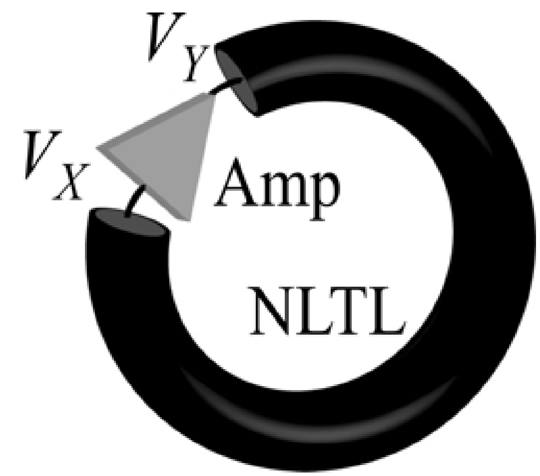




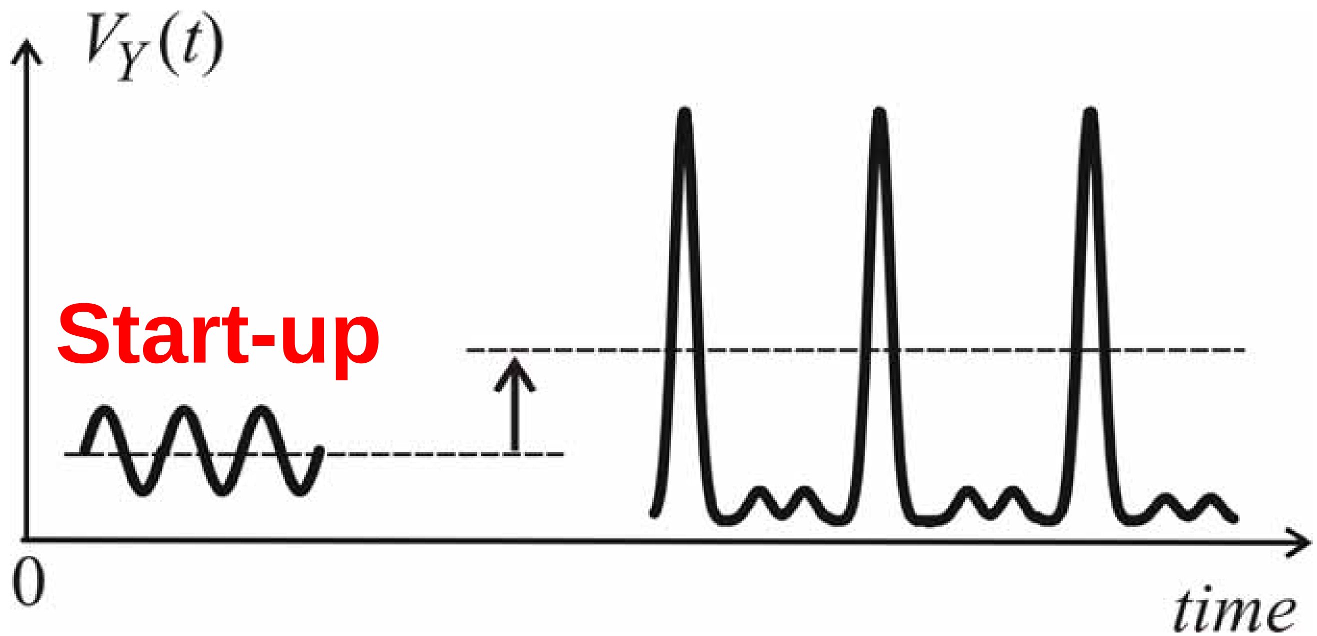
Initial start-up bias

Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Operating Principle (2)

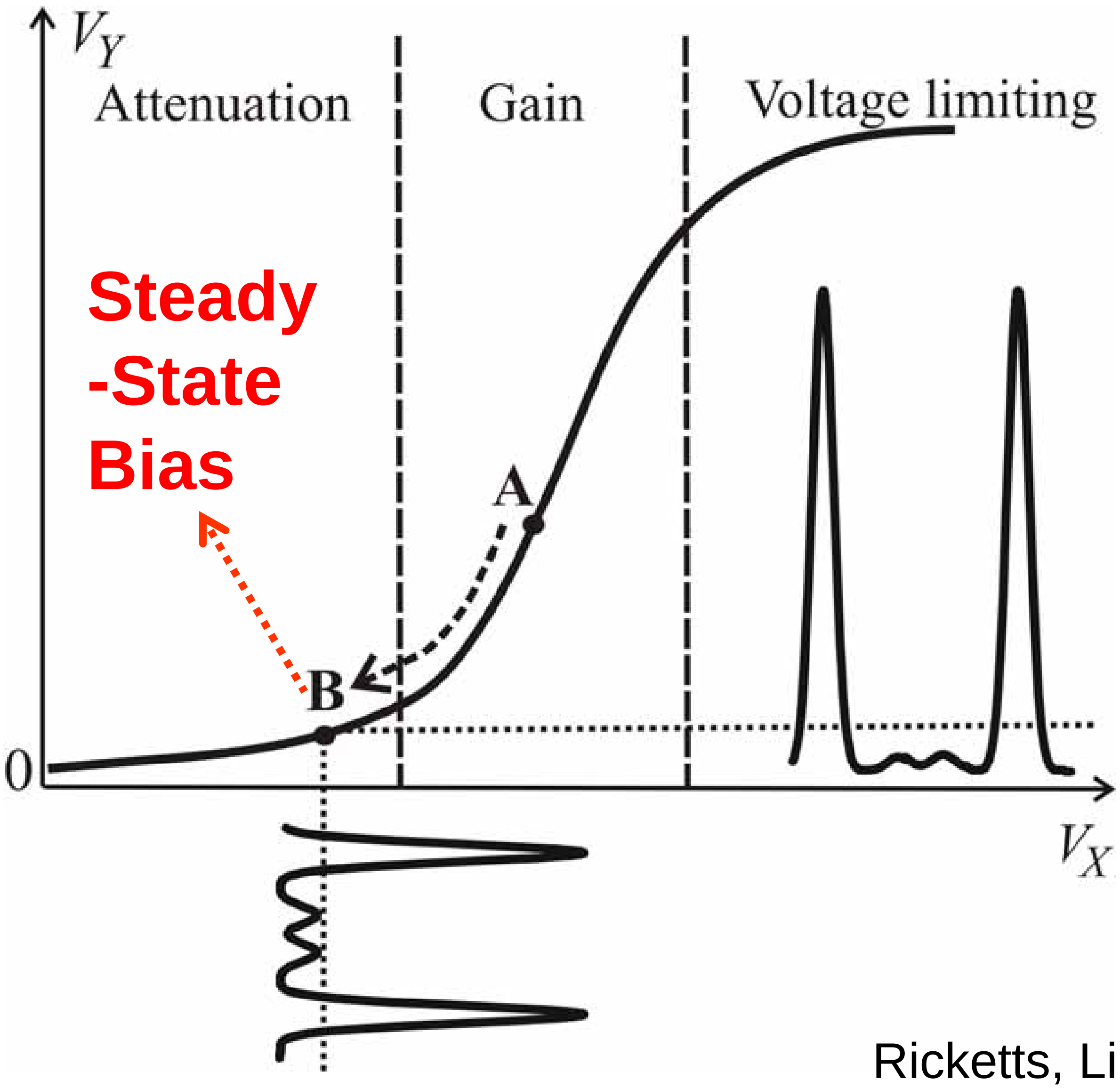


Start-up transient: *dc* component

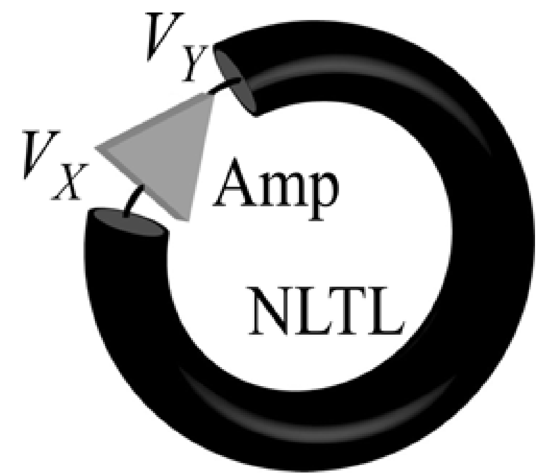


Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Operating Principle (3)



Steady -State Bias



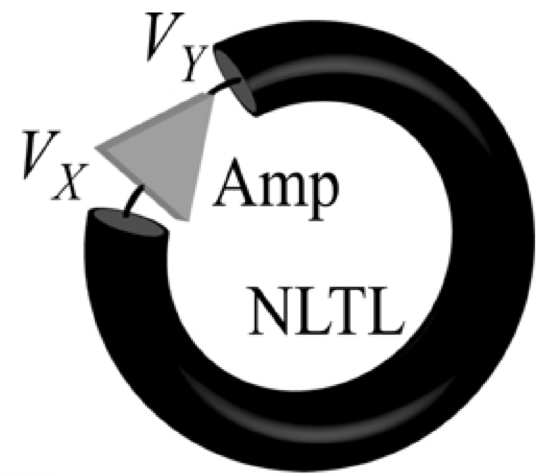
Saturation reduction

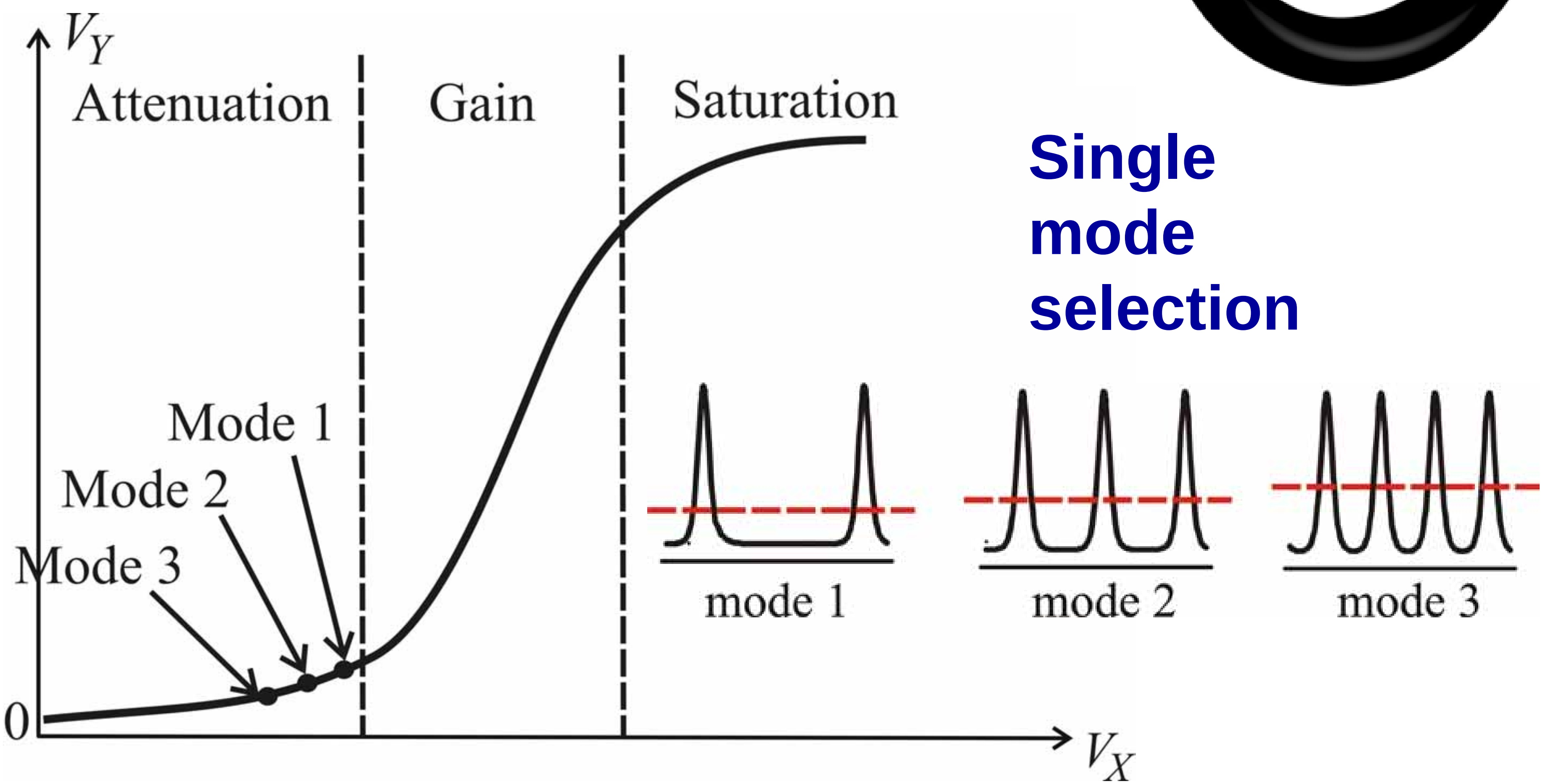
Perturbation rejection

“Saturable Absorption”

Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Operating Principle (4)

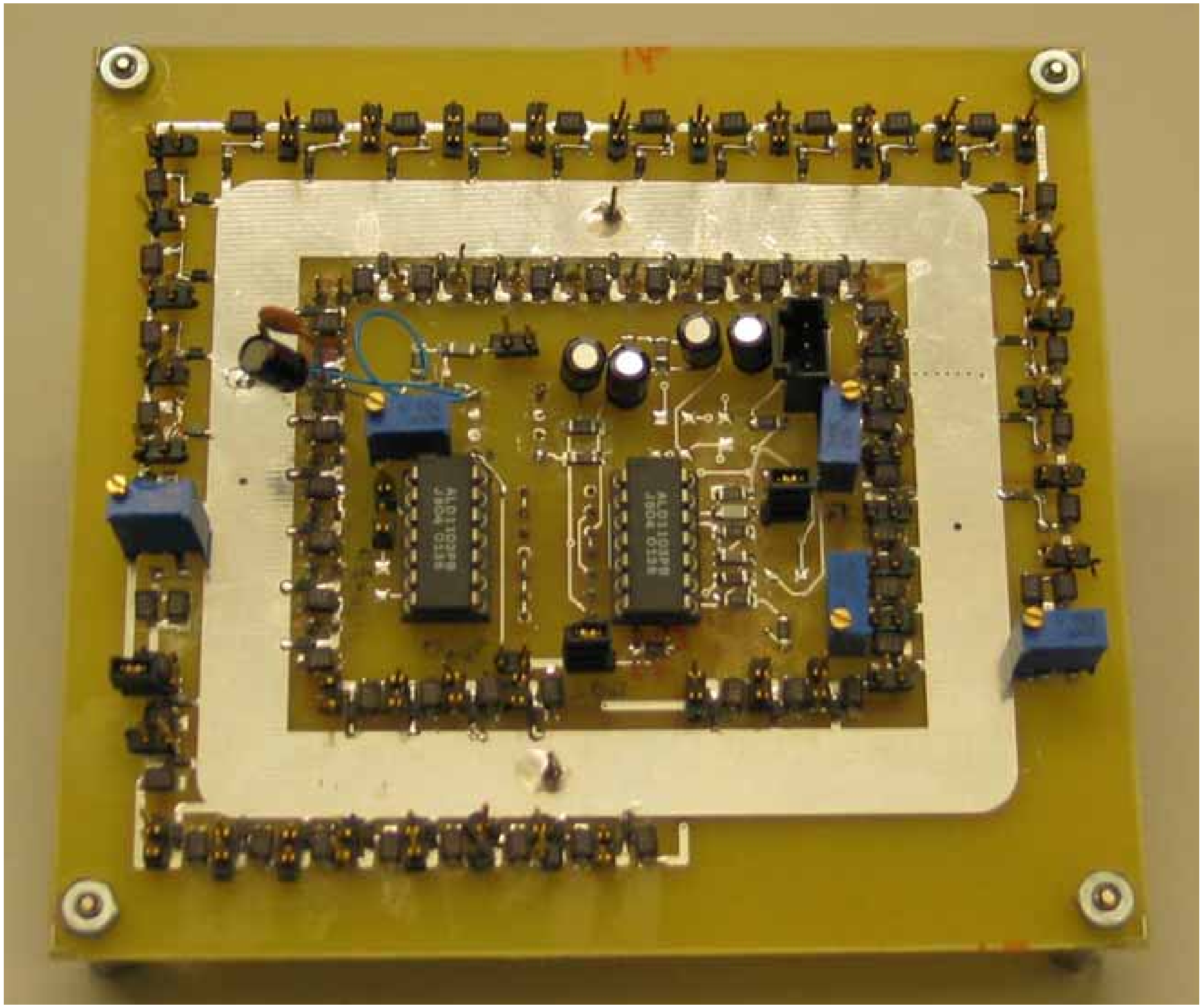




Single mode selection

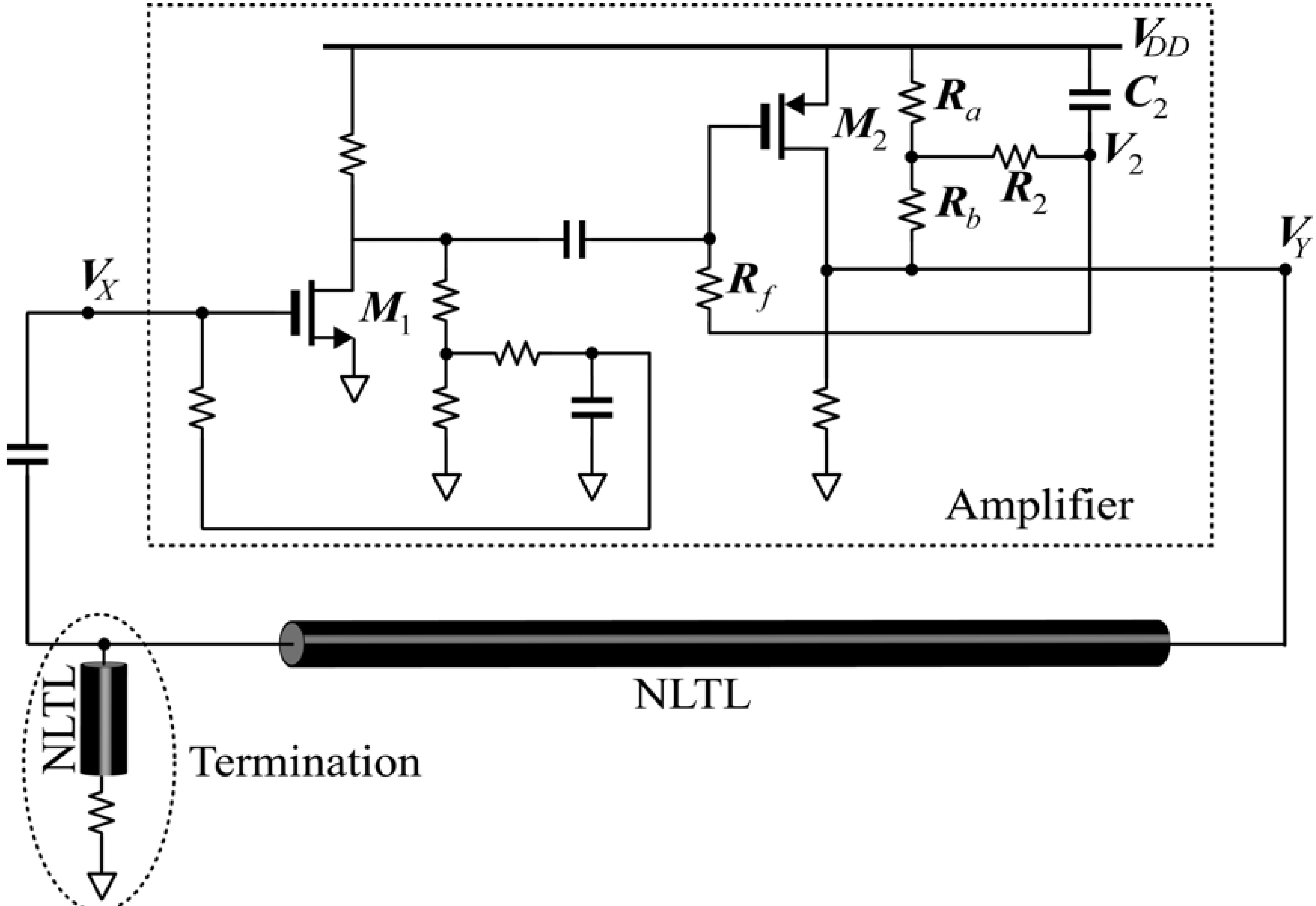
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

1st Prototype



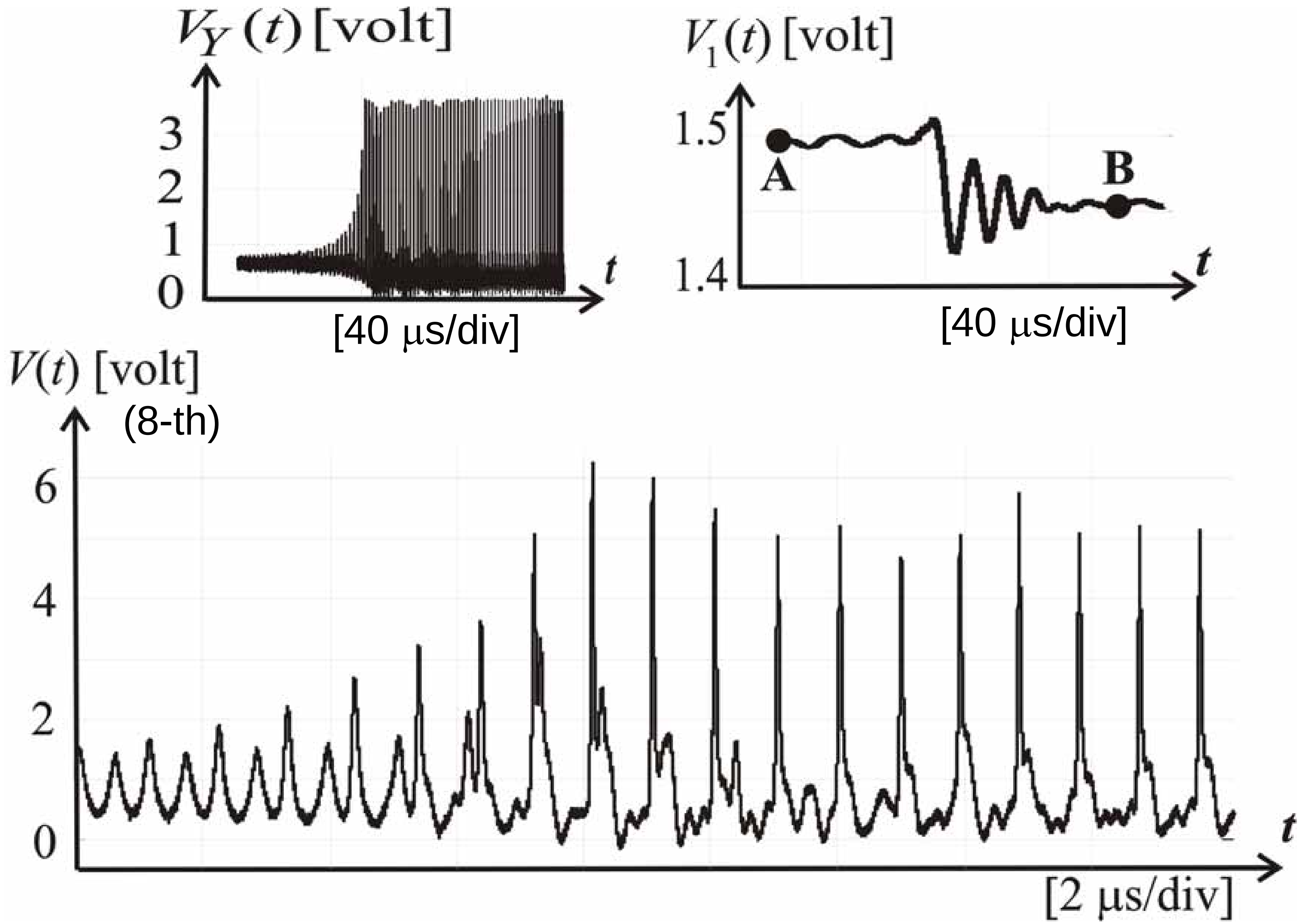
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

1st Prototype: Schematic



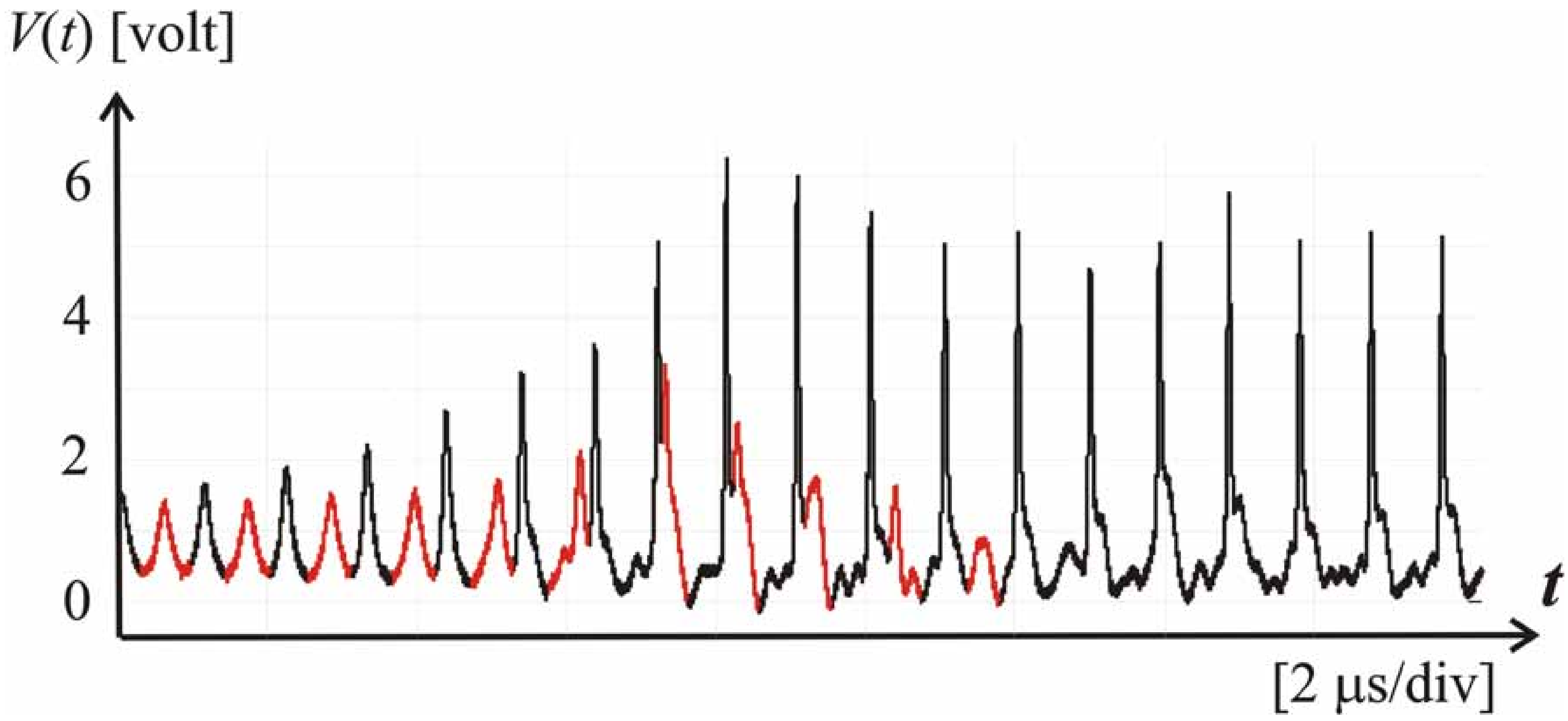
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

1st Prototype: Startup Dynamics



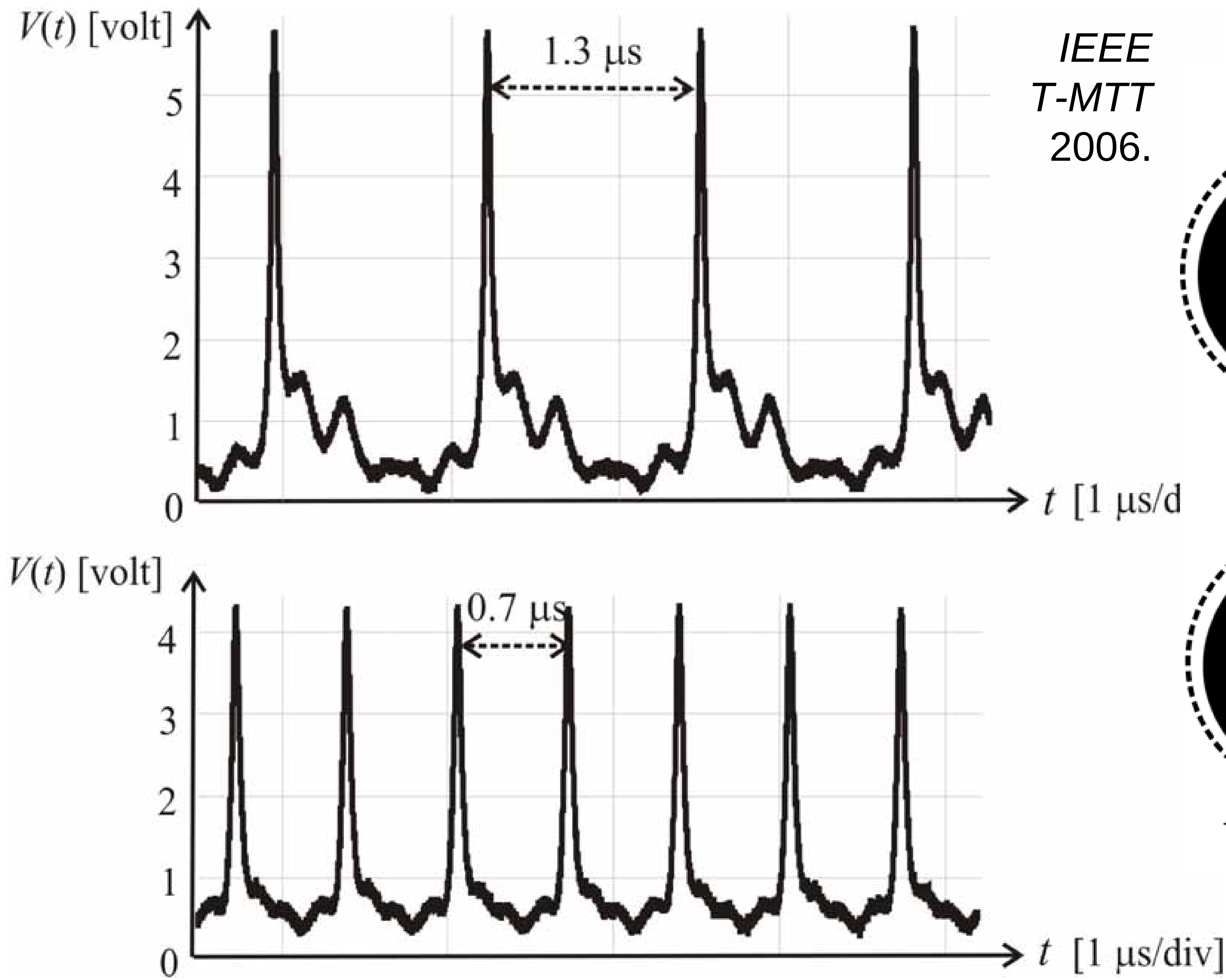
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

1st Prototype: Startup Dynamics

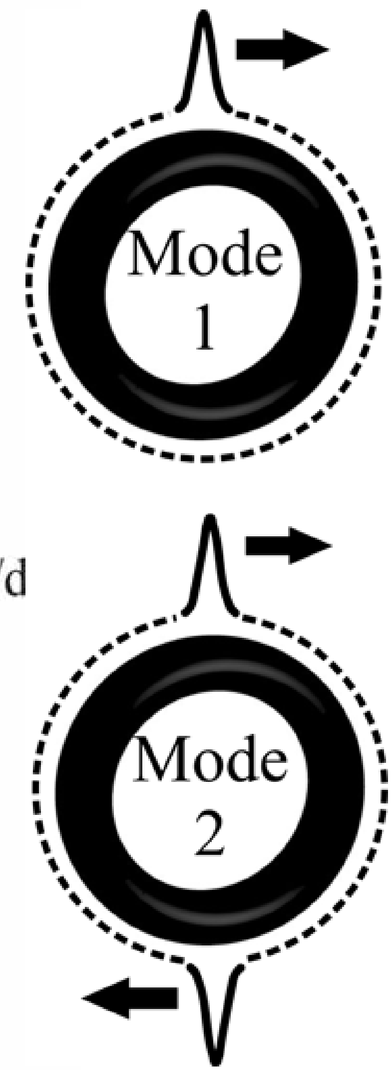


Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

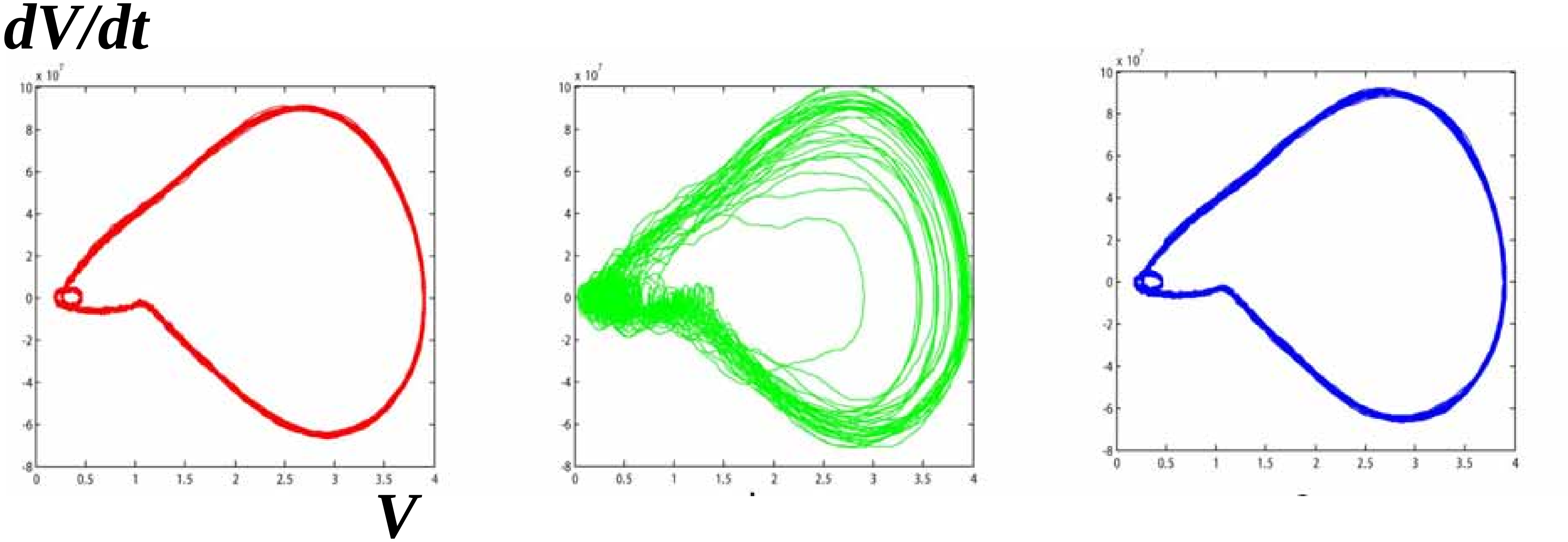
1st Prototype: Steady-State Oscillation



IEEE T-MTT 2006.



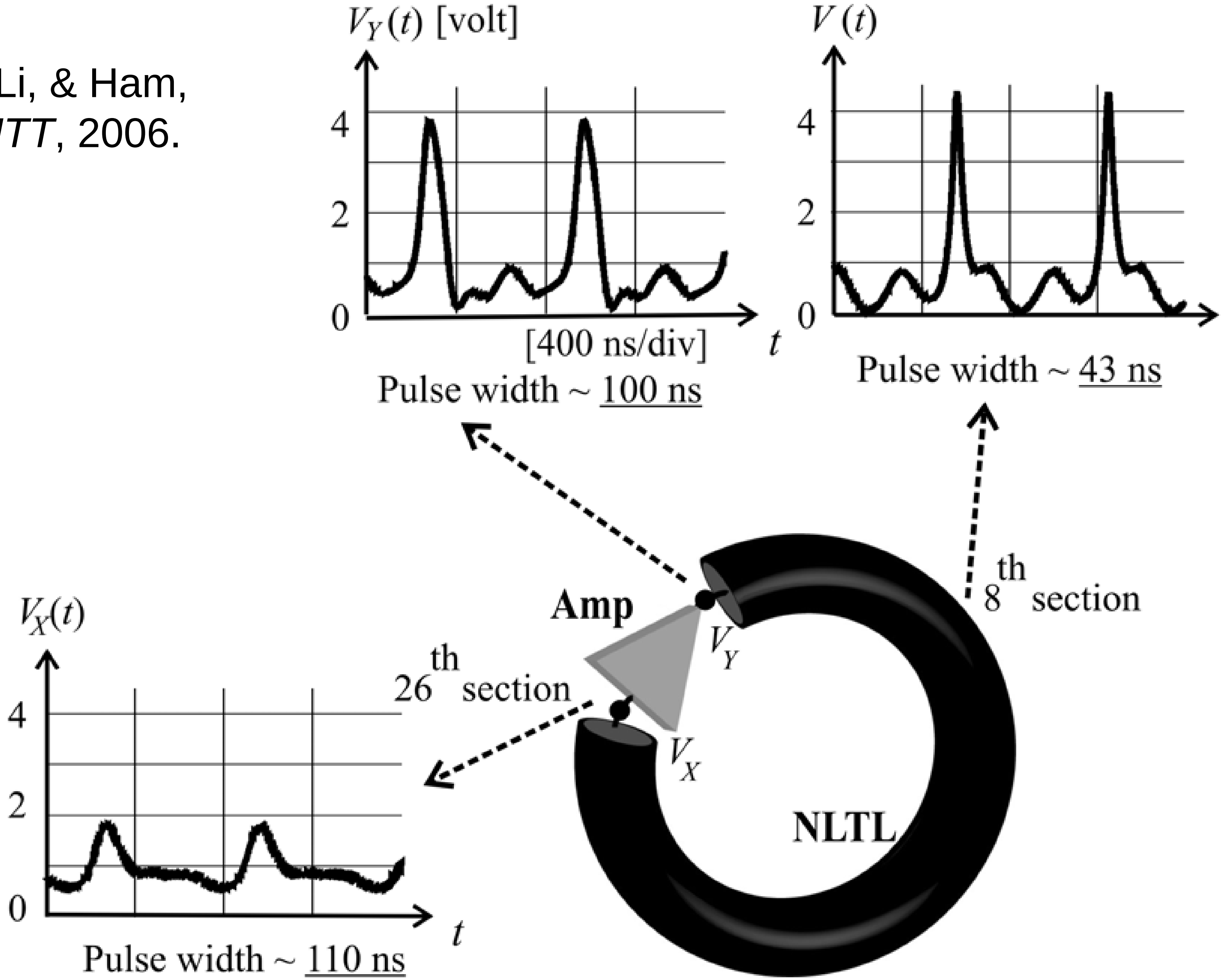
1st Prototype: Limit Cycle



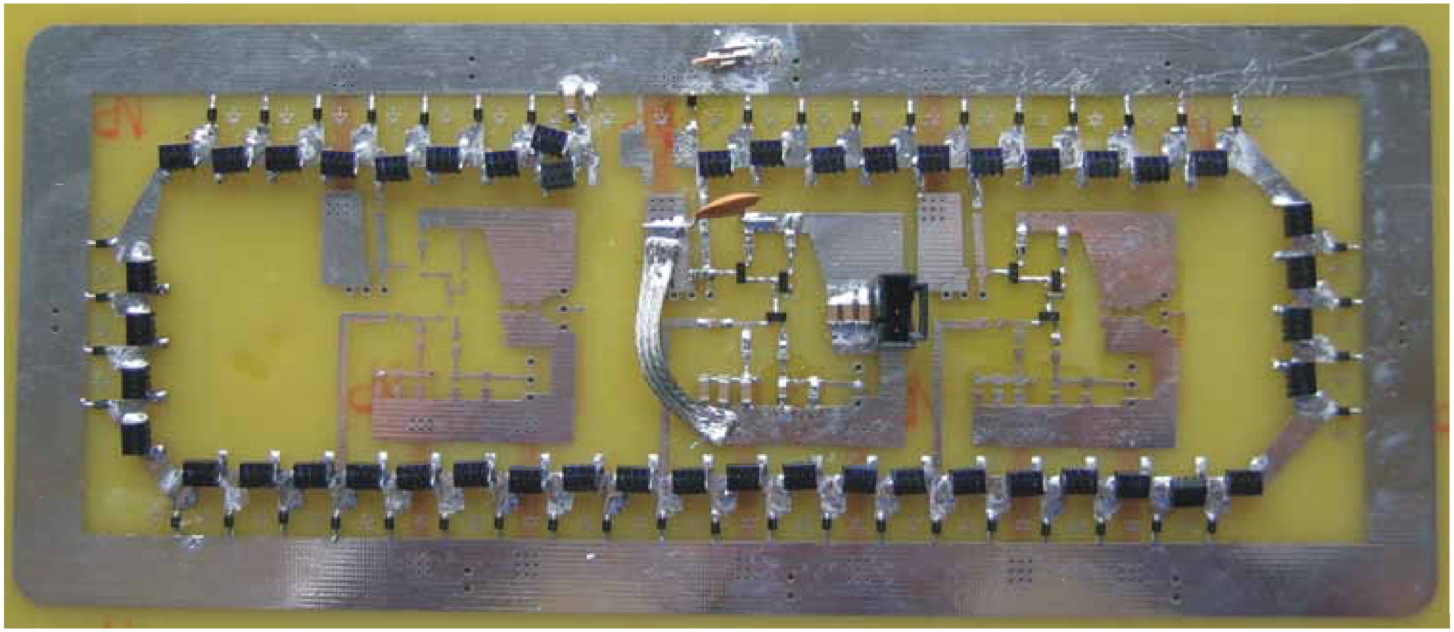
Ricketts, Li, Sun, Woo, & Ham
IEEE JSSC 2007

1st Prototype: Spatial Dynamics

Ricketts, Li, & Ham,
IEEE T-MTT, 2006.

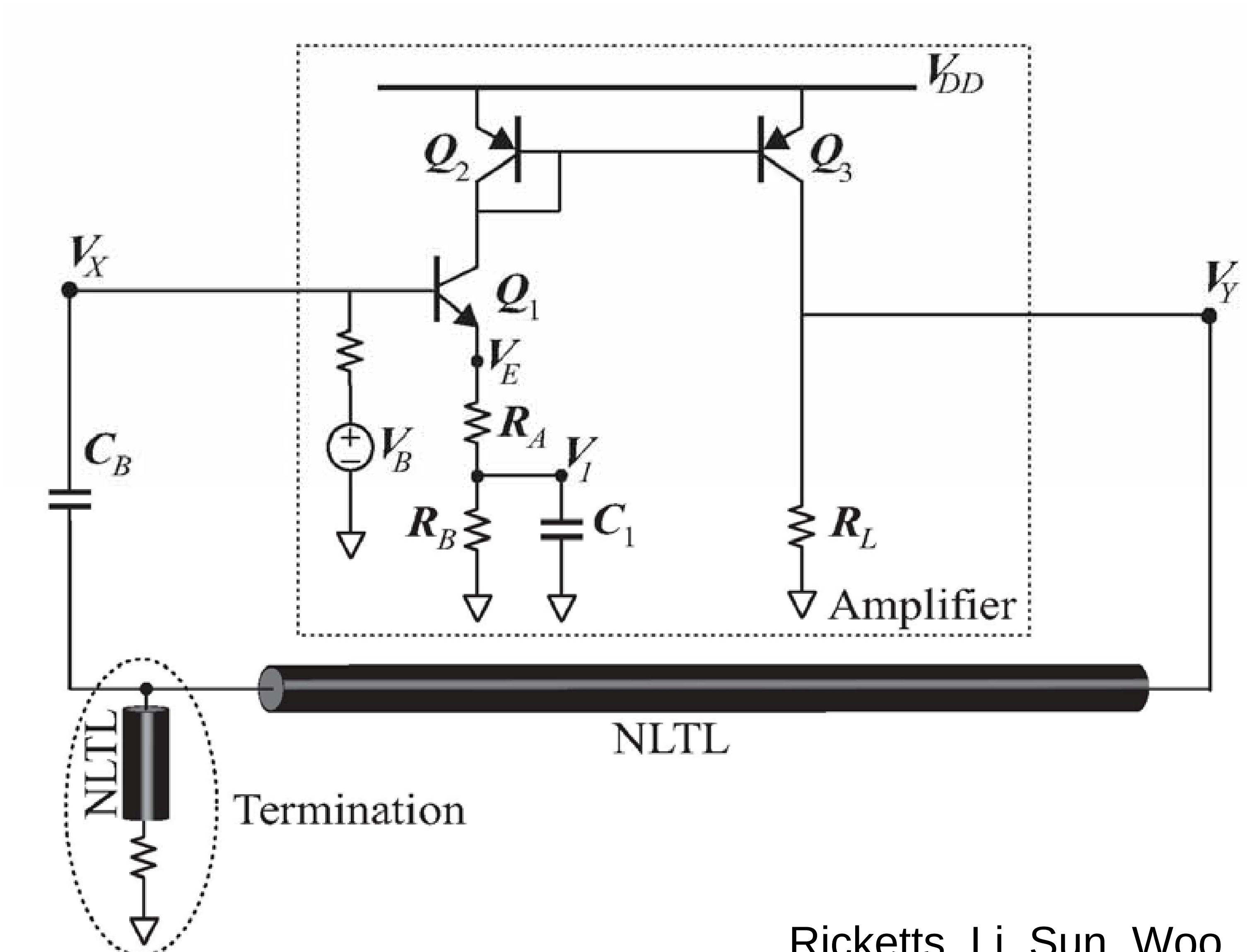


2nd Prototype



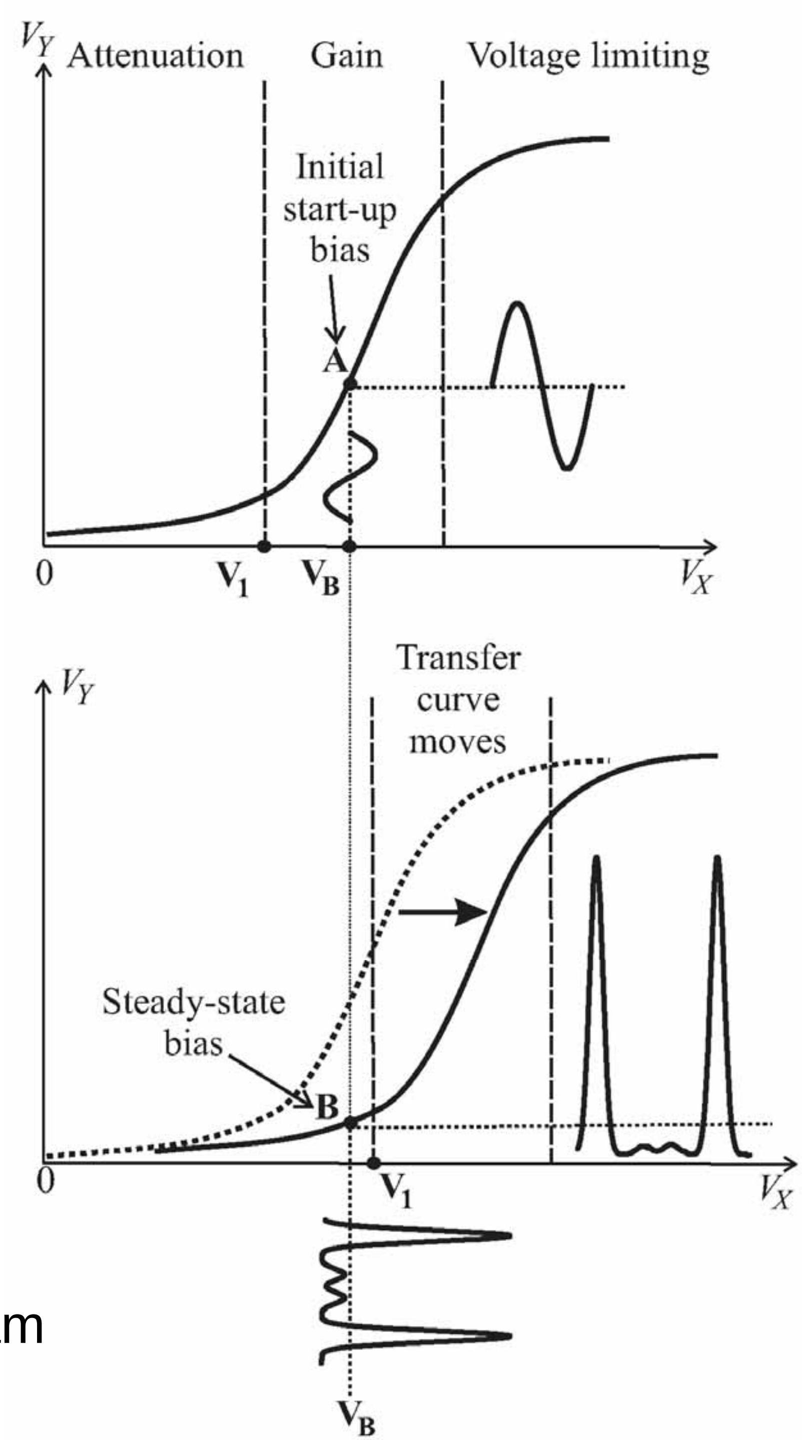
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

2nd Prototype: Schematic



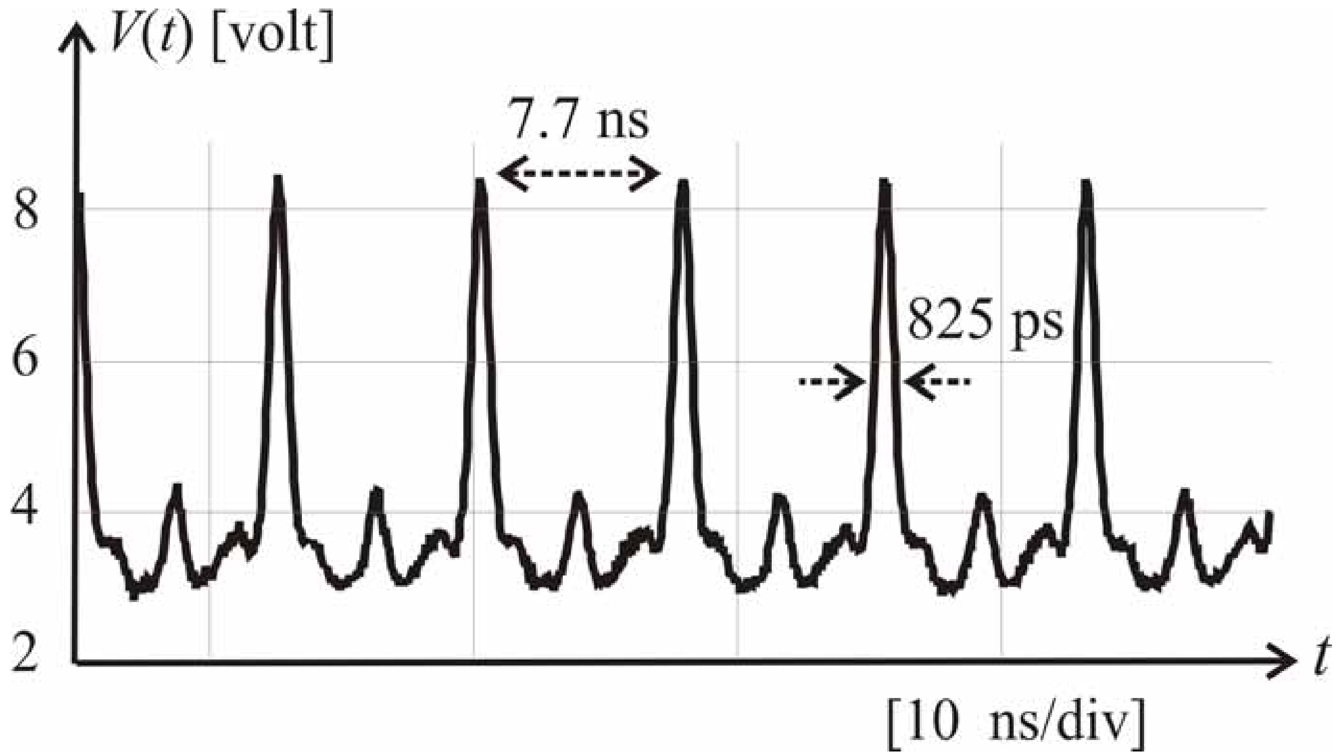
Ricketts, Li, Sun, Woo, & Ham
IEEE JSSC 2007

2nd Prototype : Operation



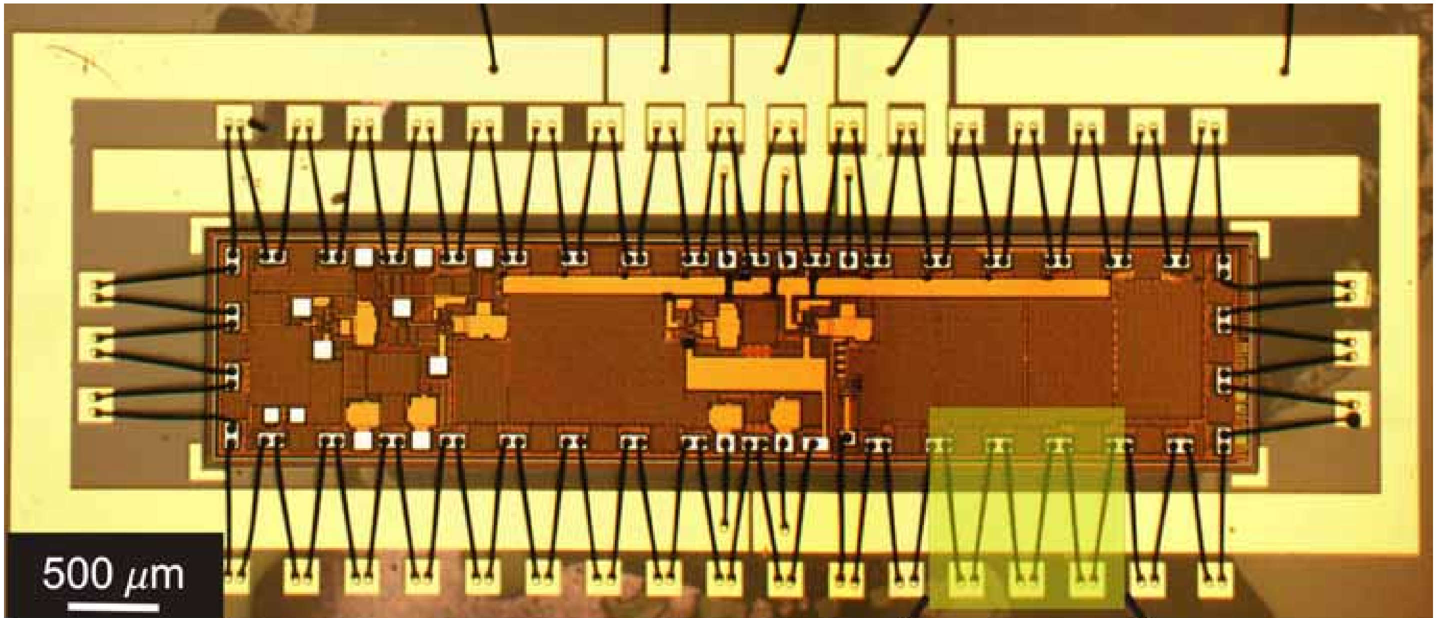
Ricketts, Li, Sun, Woo, & Ham
IEEE JSSC 2007

2^{nd} Prototype: Steady-State Oscillation



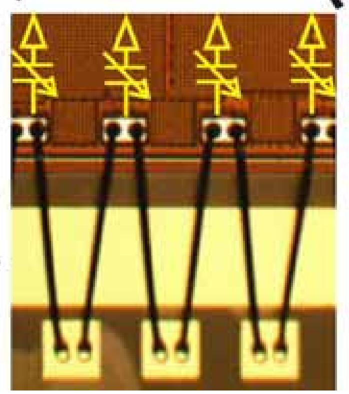
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

3rd CMOS Prototype



Prototype
7.5mm x 2.7mm

Bondwire Inductors

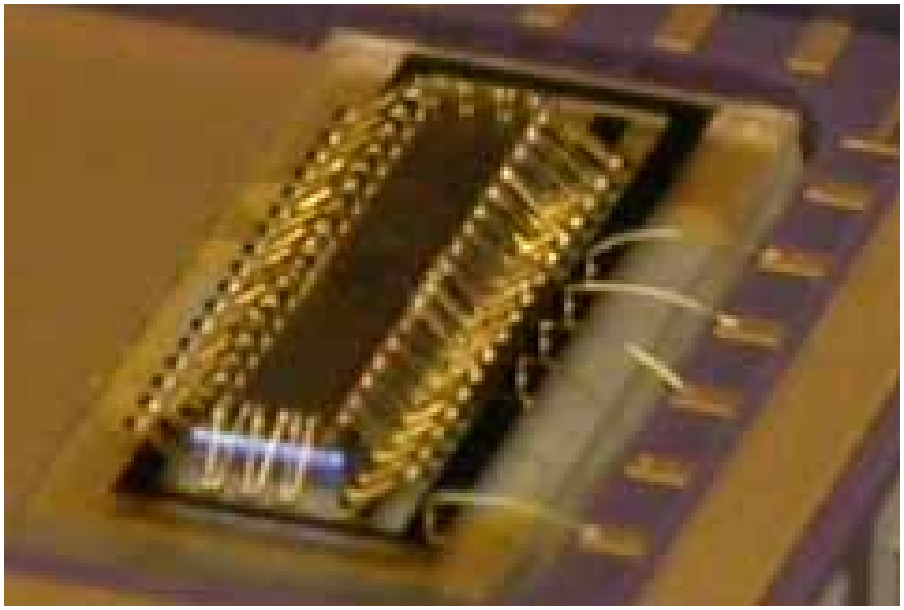


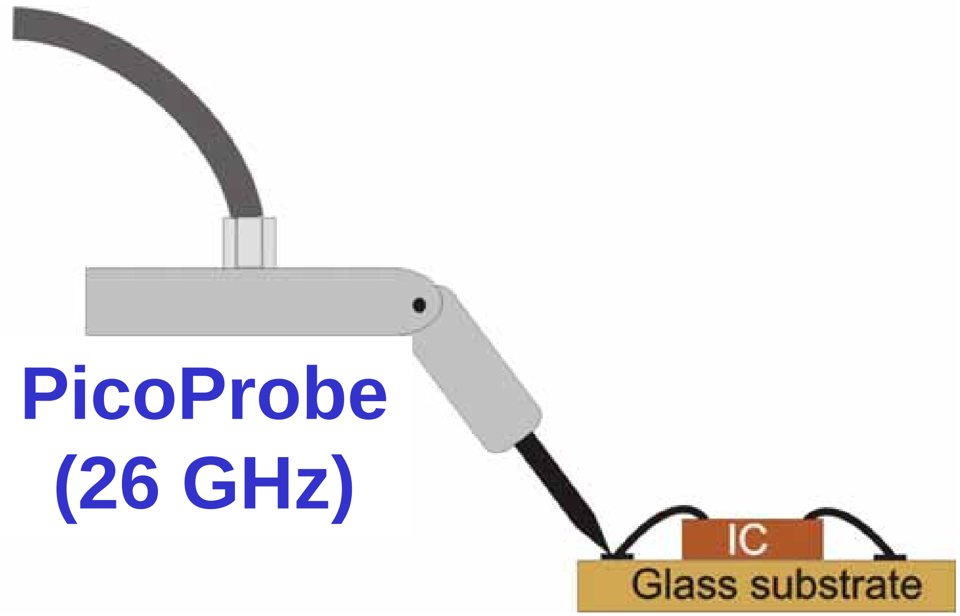
Varactors

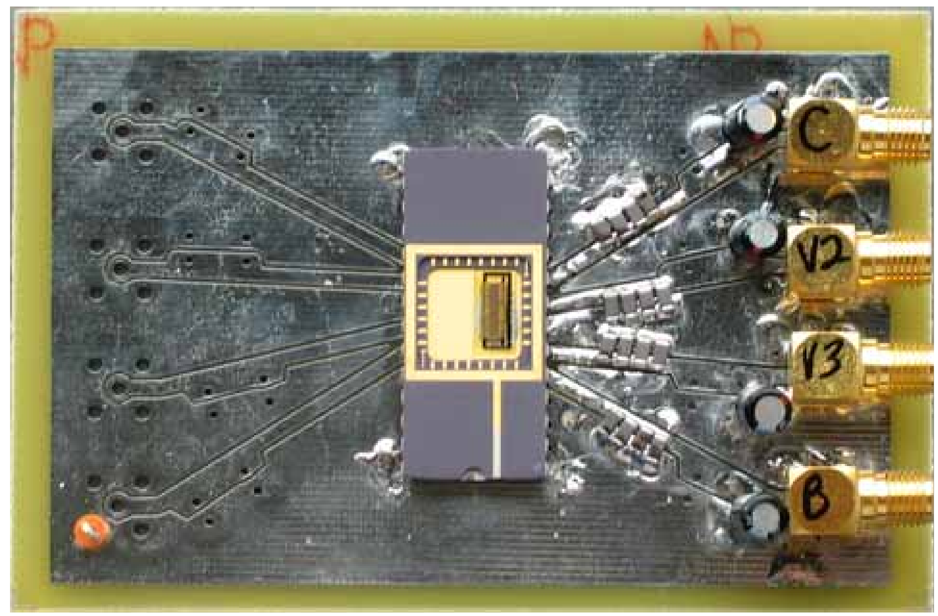
Ricketts & Ham, *IEEE ISSCC*, 2006.

3^{rd} CMOS Prototype

To Oscilloscope
(<7 GHz)

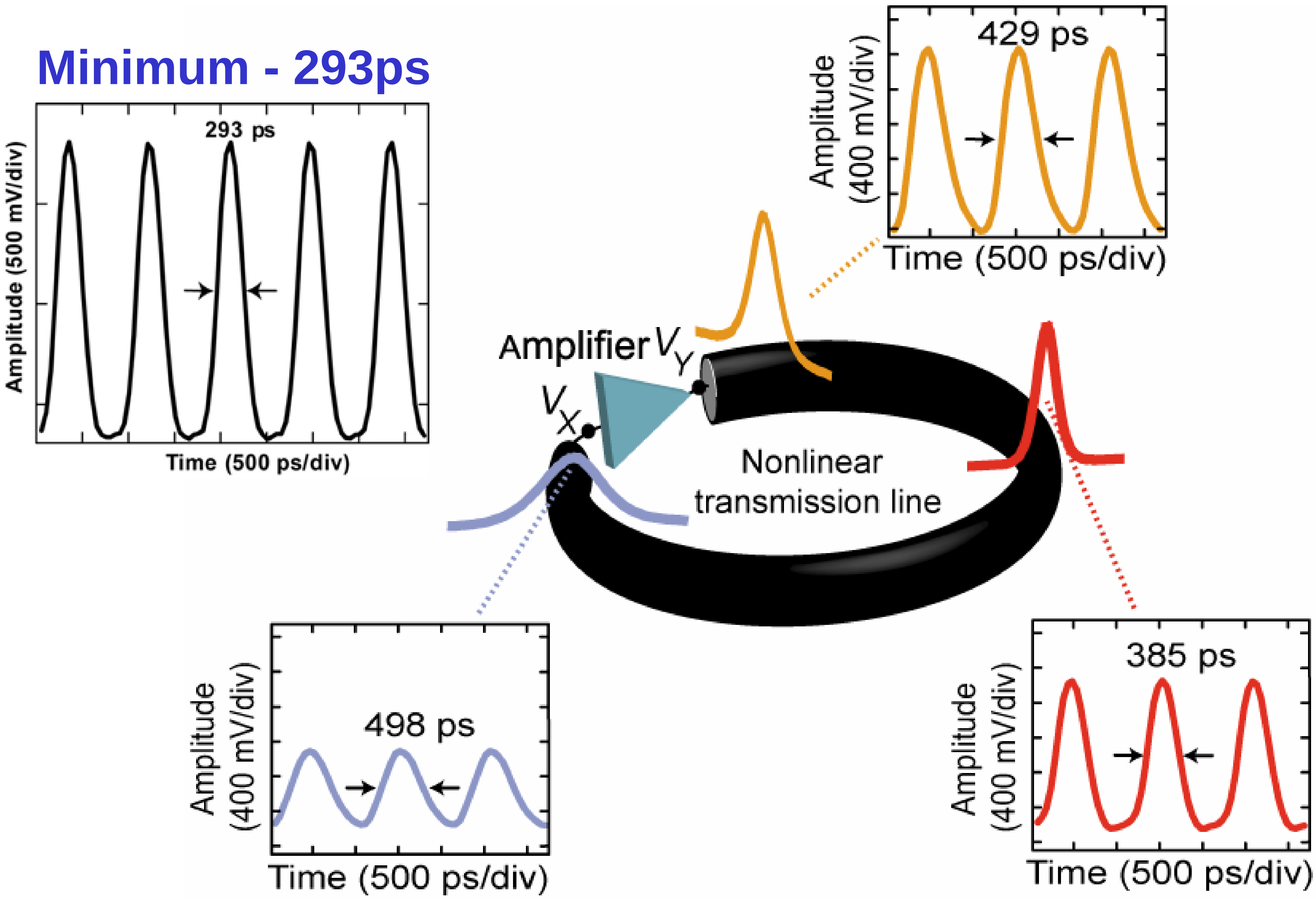






Ricketts & Ham, *IEEE ISSCC*, 2006.

3rd CMOS Prototype



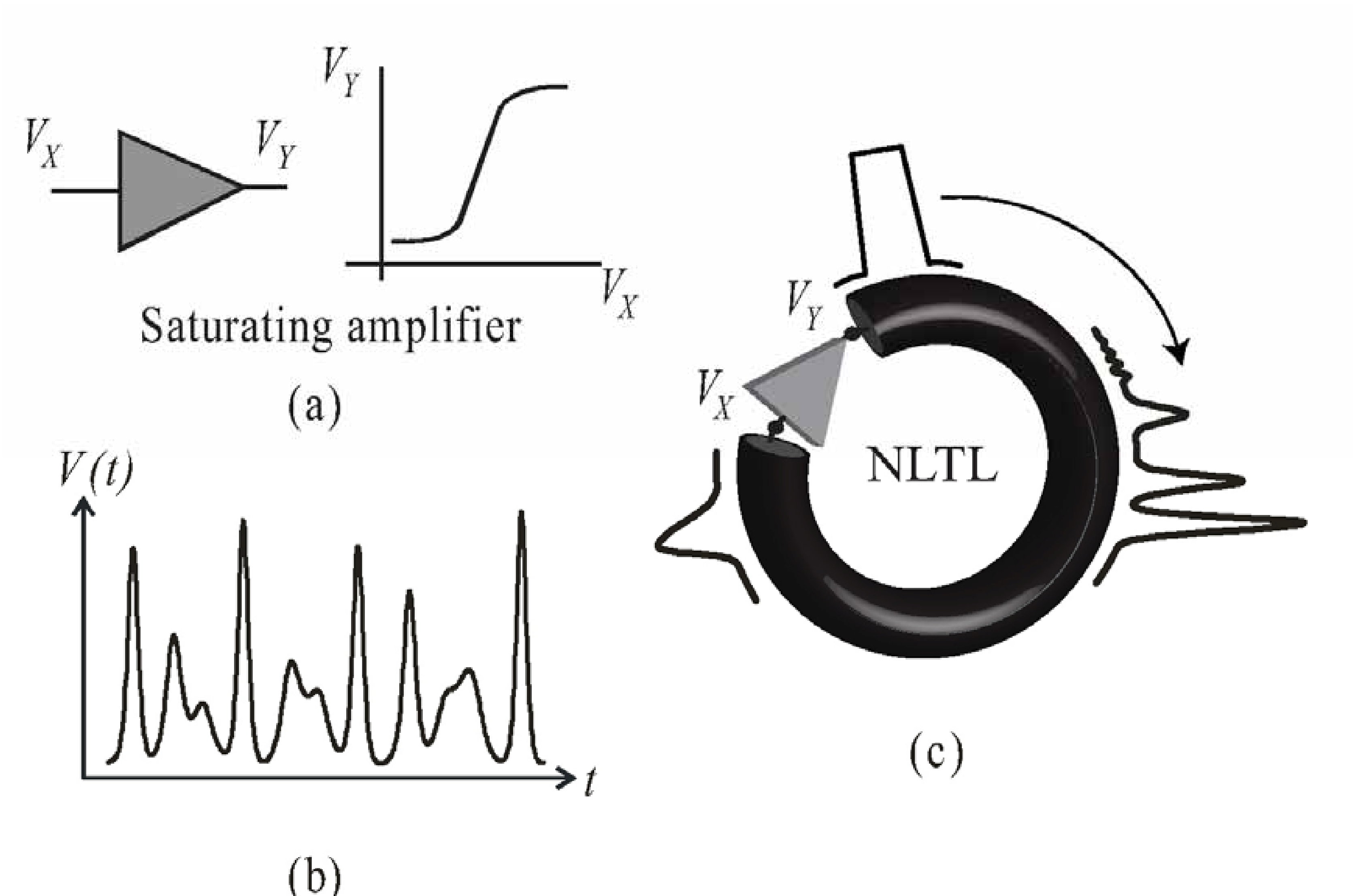
Ricketts & Ham, *IEEE ISSCC*, 2006.

Electrical Soliton Oscillator

- Chaotic Operation -

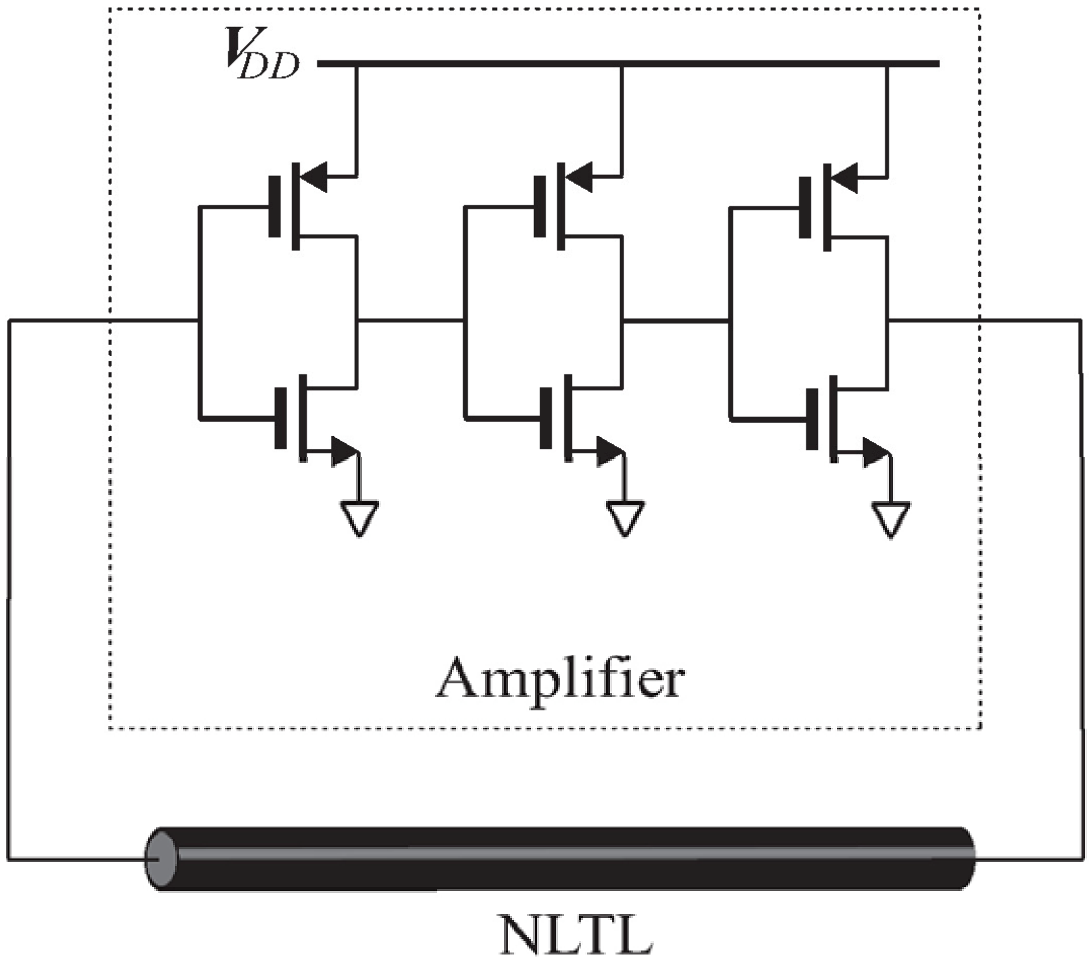
- **Original articles:** ***IEEE JSSC***
- **Invited articles:** ***IEEE Communications Magazine***

Let's Revisit the Case with a Saturating Amplifier.



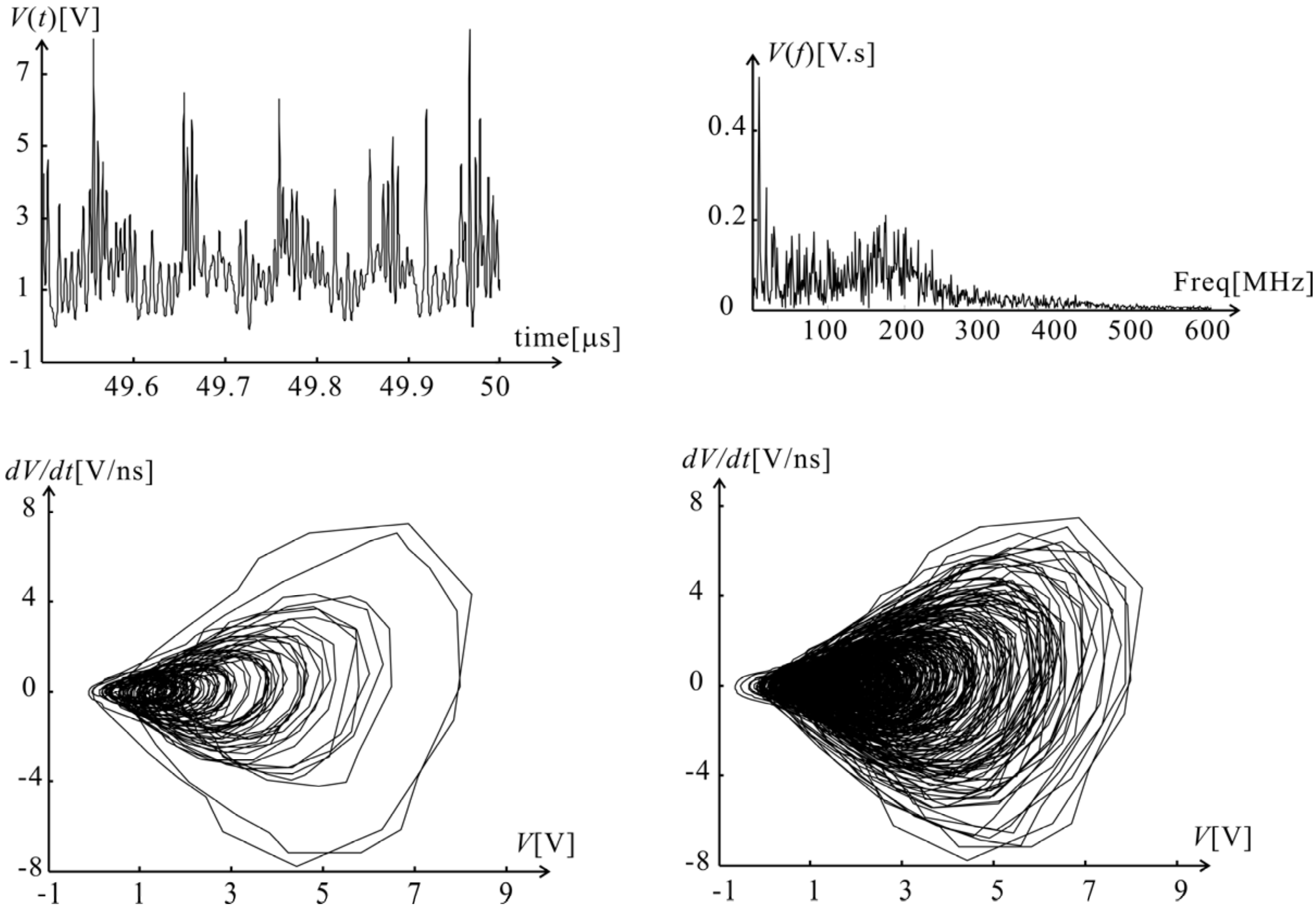
Ricketts, Li, & Ham, *IEEE T-MTT*, 2006.

Simple Chaotic Soliton Oscillator



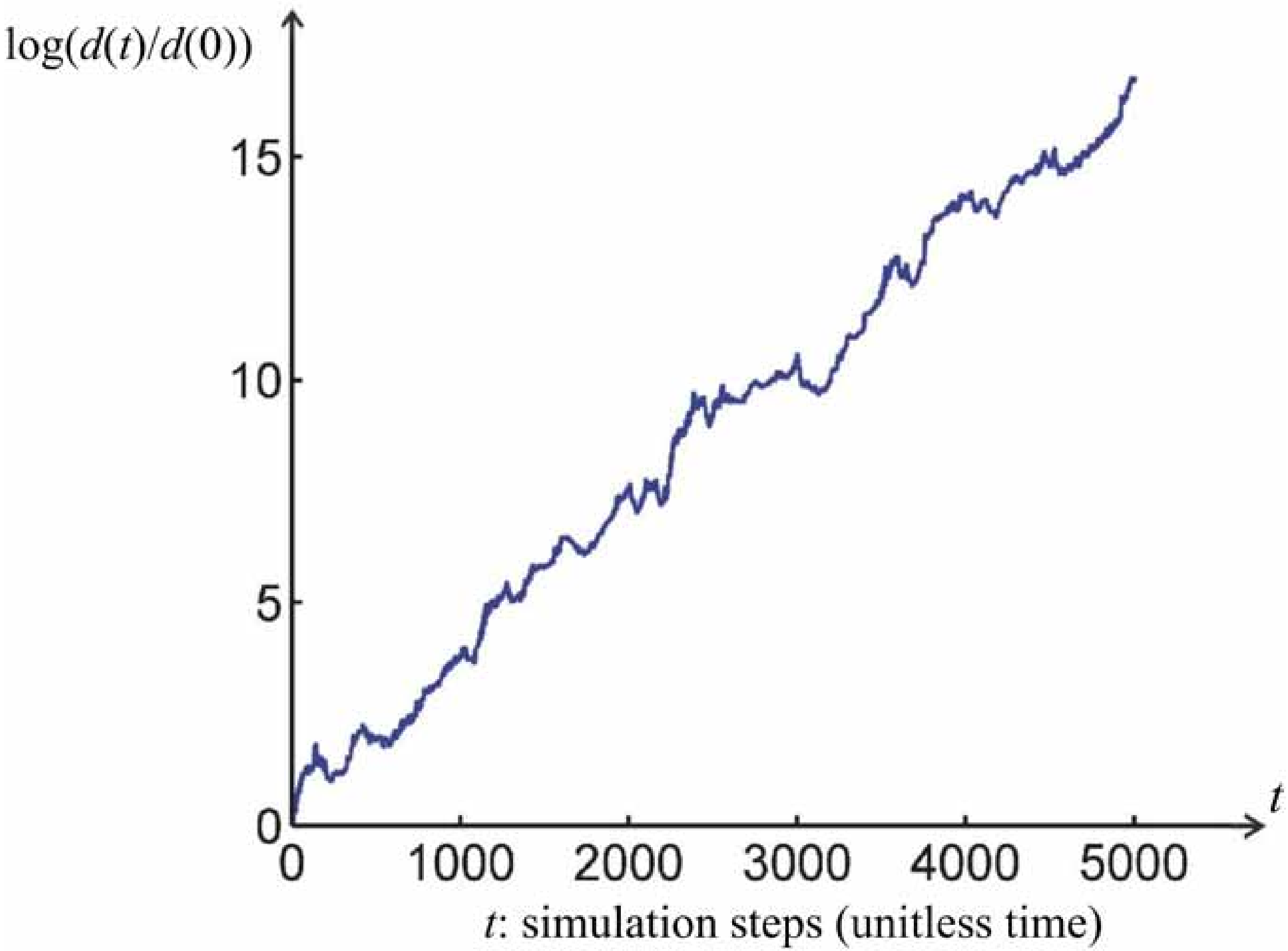
Ricketts, Li, Sun, Woo, & Ham
IEEE JSSC 2007

Chaotic Oscillation



Ricketts, Li, Sun, Woo, & Ham
IEEE JSSC 2007

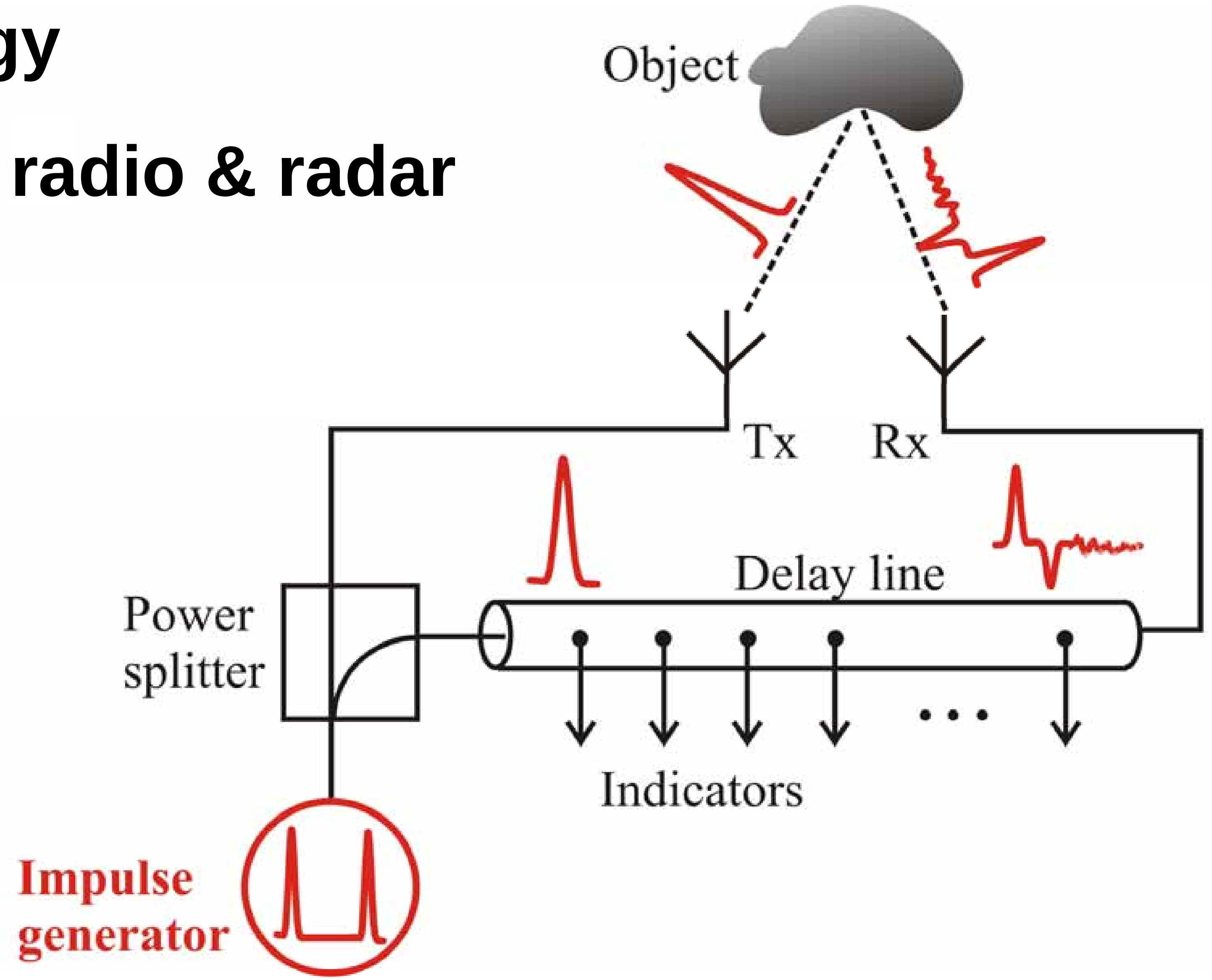
Lyapunov Analysis



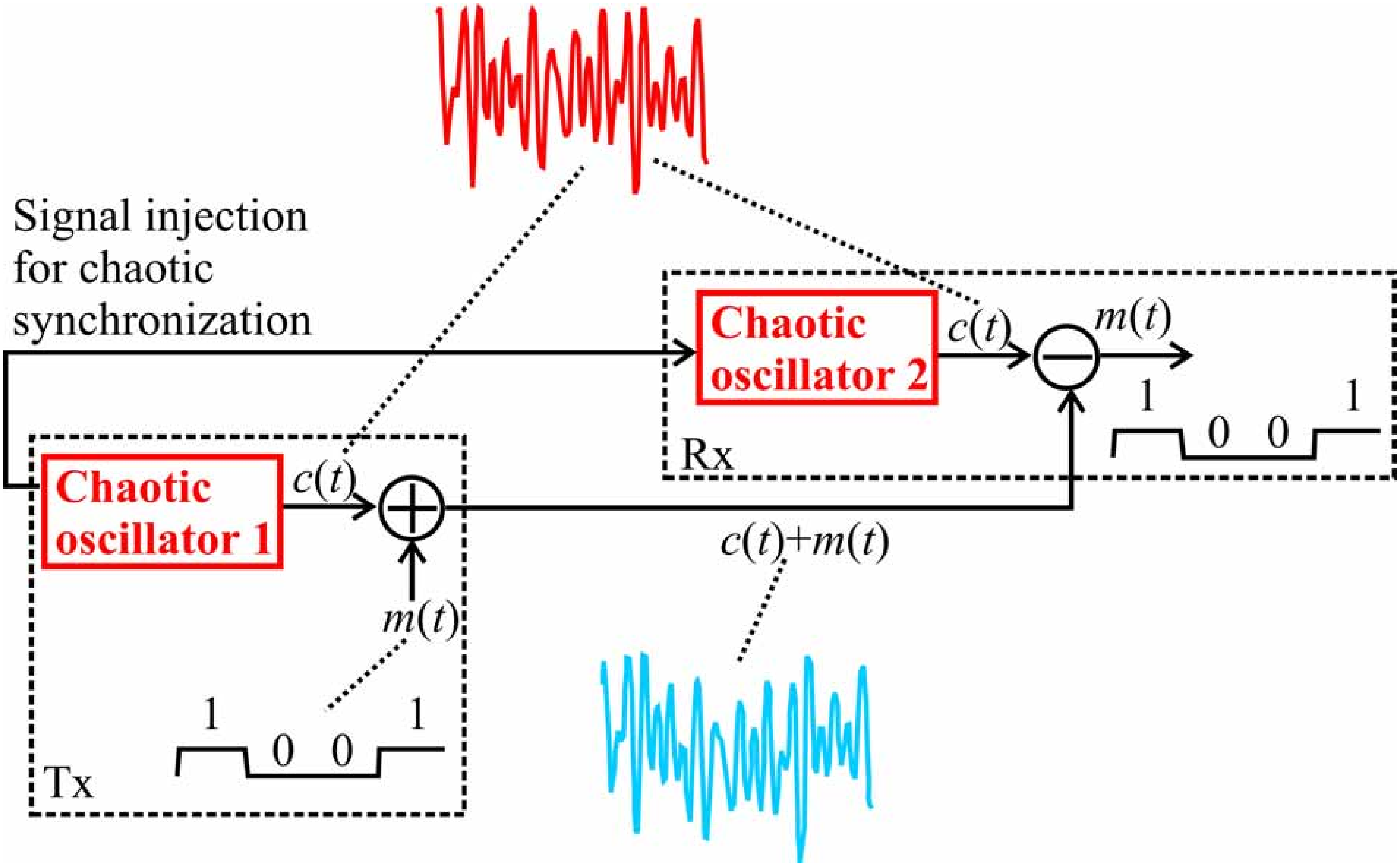
Ricketts, Li, Sun, Woo, & Ham
IEEE JSSC 2007

Applications

- **Ultra-fast time-domain metrology**
- **Impulse radio & radar ("X"WB)**



Chaotic Communication



Acknowledgement

- ***MIT*****:** Charles G. Sodini & Kevin Kyungbum Ryu
- ***Analog Devices*****:** Larry Devito & Rick Sullivan
- ***U. Canterbury*****:** Gary Ballantyne & Desmond Taylor
- ***Harvard*****:** Matt DePetro, Ali Belabbas, & Roger Brockett
- ***Stanford*****:** Thomas H. Lee