Boolean Gate Network Exploration: Chaos?

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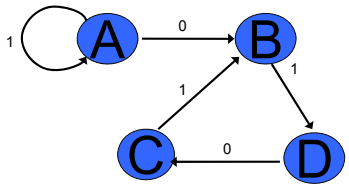
Boolean Networks

• A Boolean network model is a directed graph (network) whose nodes represent the elements of a system, edges represent relationships between elements, and every node is characterized by a binary state

• Originally proposed as models of gene regulatory networks, but ubiquitous in complex natural systems



Example Boolean Network
Each node has a binary state(1 or 0) and is connected with directed edges to some other nodes. Each node has a Boolean function mapping its inputs to outputs.

α	β	B
0	0	1
0	1	1
1	0	1
1	1	0

Example Boolean function (NAND) for node B, maps inputs to distinct output state.

Experimental Implementation: Asynchronous Electronic Gate Networks

• Set of connected electronic gates (NOT,NAND, etc) create physical Boolean Networks
• Exhibit **Chaotic** and extremely **wide-band behavior**
• Built several circuits with the Micrel SY58051U AnyGate chip, with switching time of ~100 picoseconds (~10 GHz)

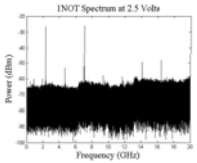
Promising Applications:

• Small cheap chaotic RF sources
• Chaotically modulate (encrypt) a secret transmission
• Self-Synchronize with other networks
• Undetectable electromagnetic sensors

Circuit Characterization

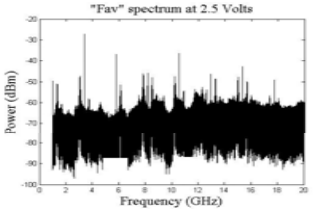
• Built several networks and generated spectrograms
• Used gate supply voltage as bifurcation parameter

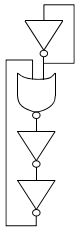
1NOT

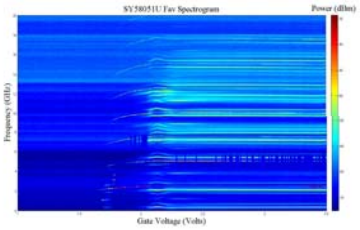


• 1NOT shows fundamental switching frequency ~2.4 GHz with harmonics to ~16.5 GHz
• 1NOT does not operate chaotically

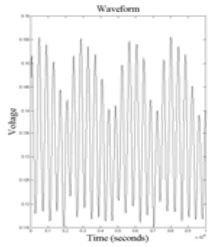
NOT-NAND-2NOT "Fav"

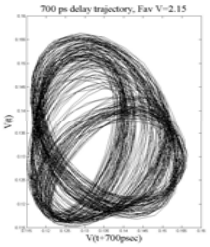






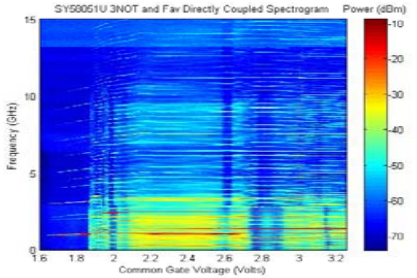
• "Fav" circuit shows more populated spectrum, but not chaotic
• Turns on with Hopf bifurcation
• Frequency levels with gate voltage at 2.15V

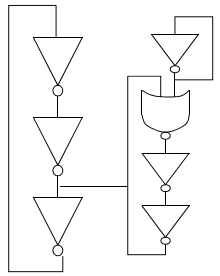




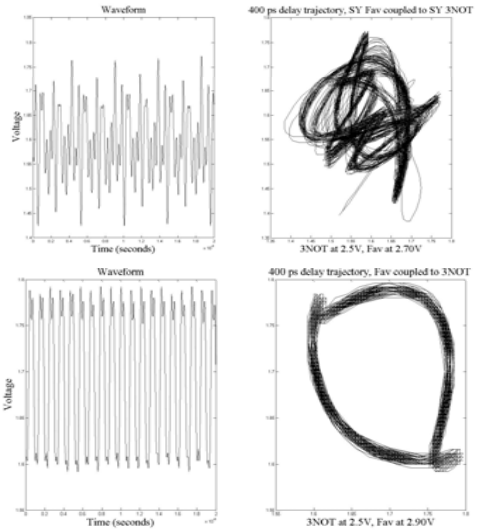
Coupled Networks

• Connected the 3NOT loop and the "Fav" together
• Spectrum shows broadband behavior from DC~4GHz





Selected Waveforms and Return Maps



Conclusions/Further Questions:

• **Broadband** and **possibly chaotic** behavior seen from coupled networks, but not from simple individual networks
• Characterized several networks at a variety of gate voltages in both frequency and time domain
• Why not even broader spectrum ?
• How does the circuit board and micro-strip layout affect the behavior ?
• Frequency levels with gate voltage at 2.15V, why ?
• Board and chip parasitics vs. chip switching speed ?