Ring Oscillator Simulation

ELEC 654 – Advanced Simulation of Electronic Circuits

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I. Introduction

- A ring oscillator comprises of an odd number of CMOS inverters. The output of each inverter is used as input for the next one. The last output is feedback to the first inverter. Because of the delay time of each stage the whole circuit spontaneously starts oscillating at a certain frequency. The frequency f depends on the number of stages n and the delay time of the inverters τ as follows. [1]

$$f = \frac{1}{2n\tau}$$

II. Details

- A real ring oscillator only requires power to operate. Above a certain threshold voltage, oscillations begin spontaneously. To increase the frequency of oscillation, two methods are commonly used. Firstly, the applied voltage may be increased. This increases both the frequency of the oscillation and the current consumed. The maximum permissible voltage applied to the circuits limits the speed of a given oscillator. Secondly, making the ring from a smaller number of inverters results in a higher frequency of oscillation given a certain power consumption. [2]

III. Operation

- To understand the operation of a ring oscillator, one must first understand gate delay. In a physical device, no gate can switch instantaneously. In a device fabricated with MOSFETs, for example, the gate capacitance must be charged before current can flow between the source and the drain. Thus, the output of every inverter in a ring oscillator changes a finite amount of time after the input has changed. From here, it can be easily seen that adding more inverters to the chain increases the total gate delay, reducing the frequency of oscillation. [2]

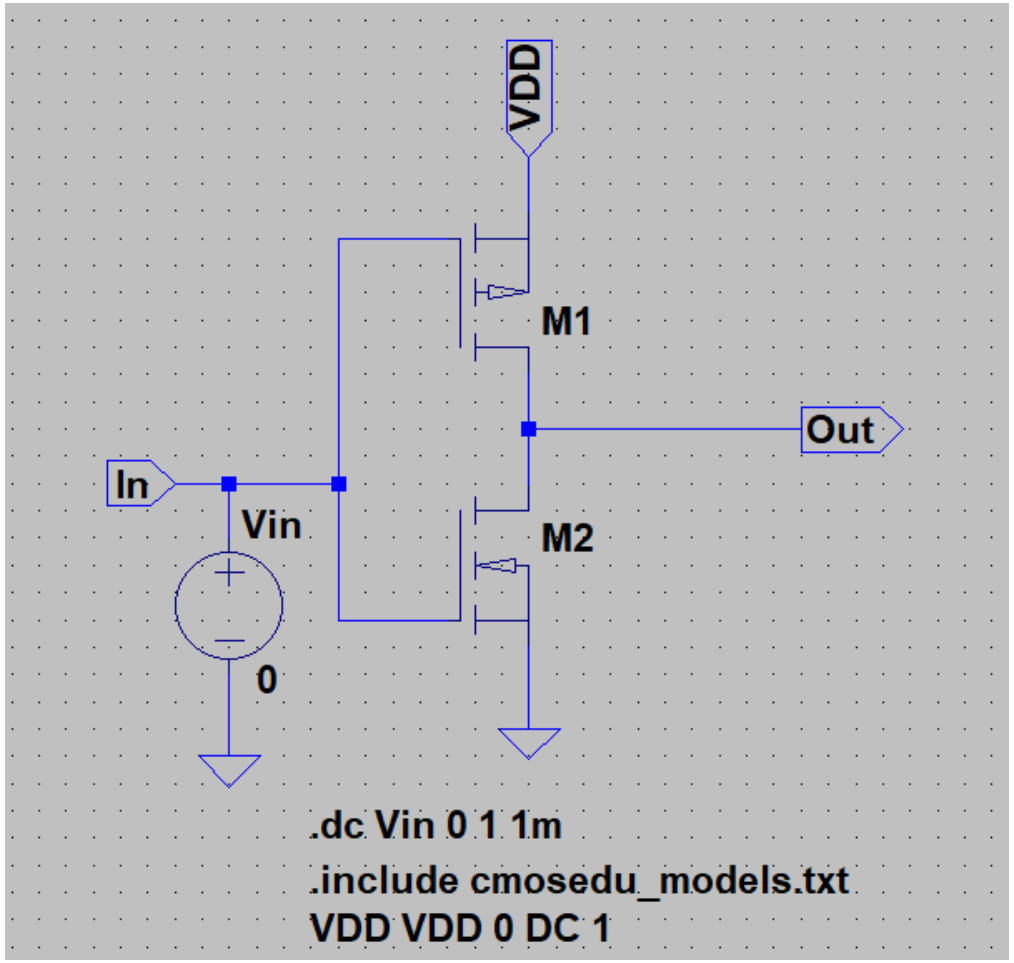
IV. Jitter

- Period of ring oscillator vibrates in a random manner T=T+T' where T' is a random value. In high-quality circuits, the range of T' is relatively small compared to T. This variation in oscillator period is called jitter. Local temperature effects cause the period of a ring oscillator to wander above and below the long-term average period. When the local silicon is cold, the propagation delay is slightly shorter, causing the ring oscillator to run at a slightly higher frequency, which eventually raises the local temperature. When the local silicon is hot, the propagation delay is slightly longer, causing the ring oscillator to run at a slightly lower frequency, which eventually lowers the local temperature. [2]

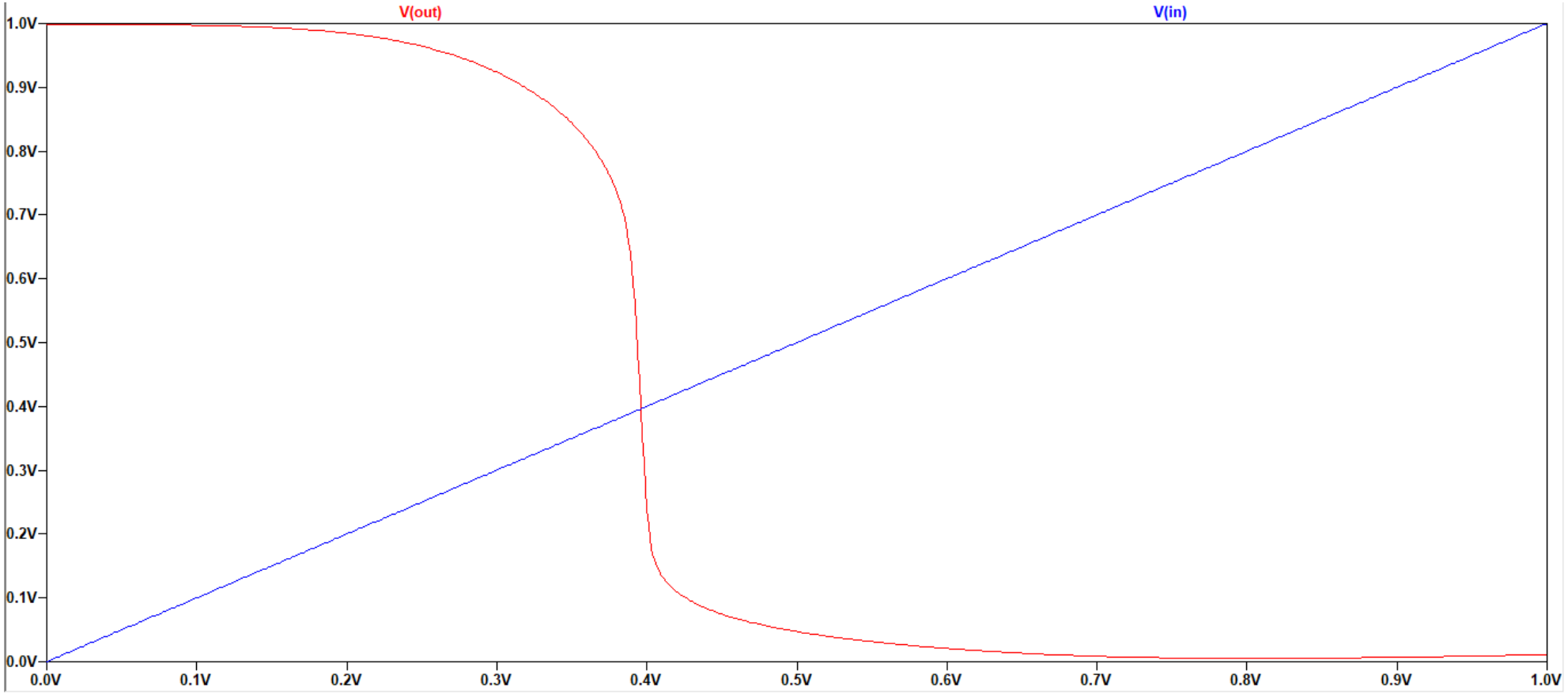
V. Applications

- The **voltage-controlled oscillator (VCO)** in most **phase-locked loops (PLL)** is built from a ring oscillator.
- Jitter of ring oscillators is commonly used in **hardware random number generator**s.
- Many wafers include a ring oscillator as part of the **scribe line test structure**s. They are used during wafer testing to measure the effects of manufacturing **process variation**s.
- Ring oscillators can also be **used to measure the effects of voltage and temperature** on a chip. [2]

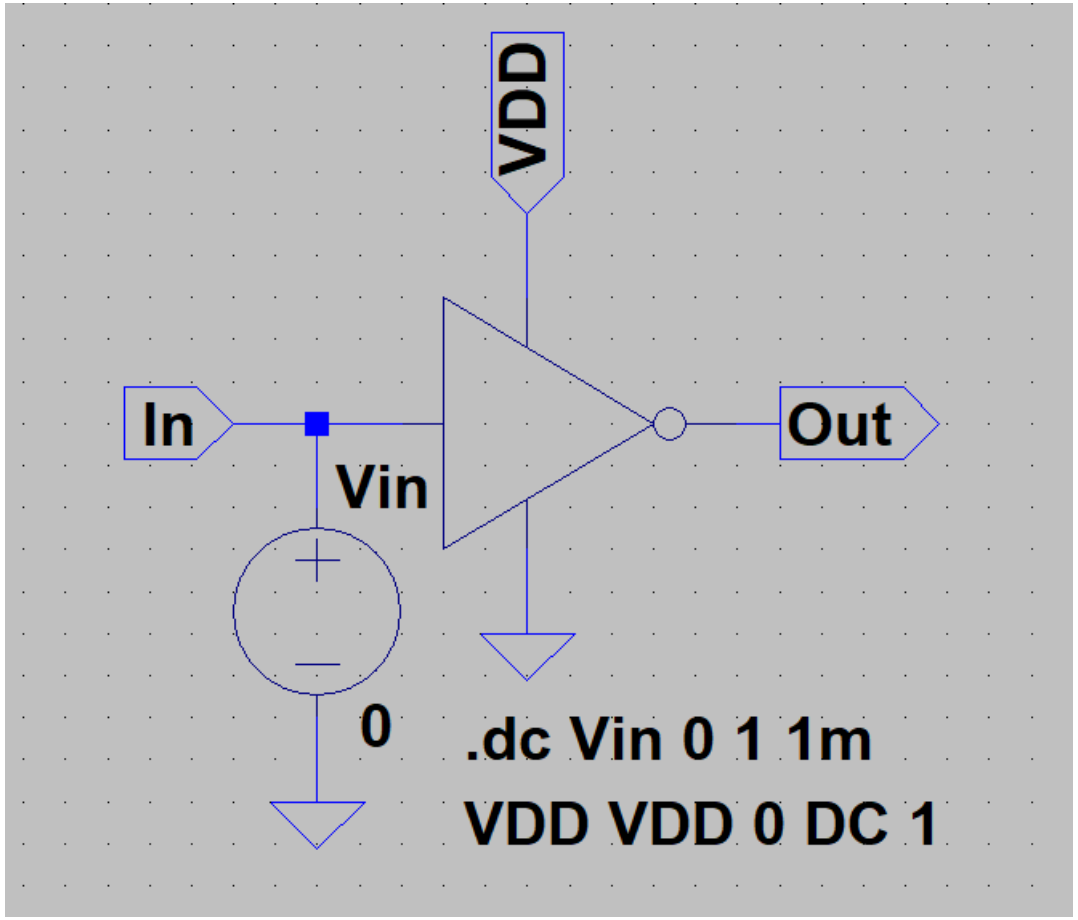
VI. Simulation on LTspice



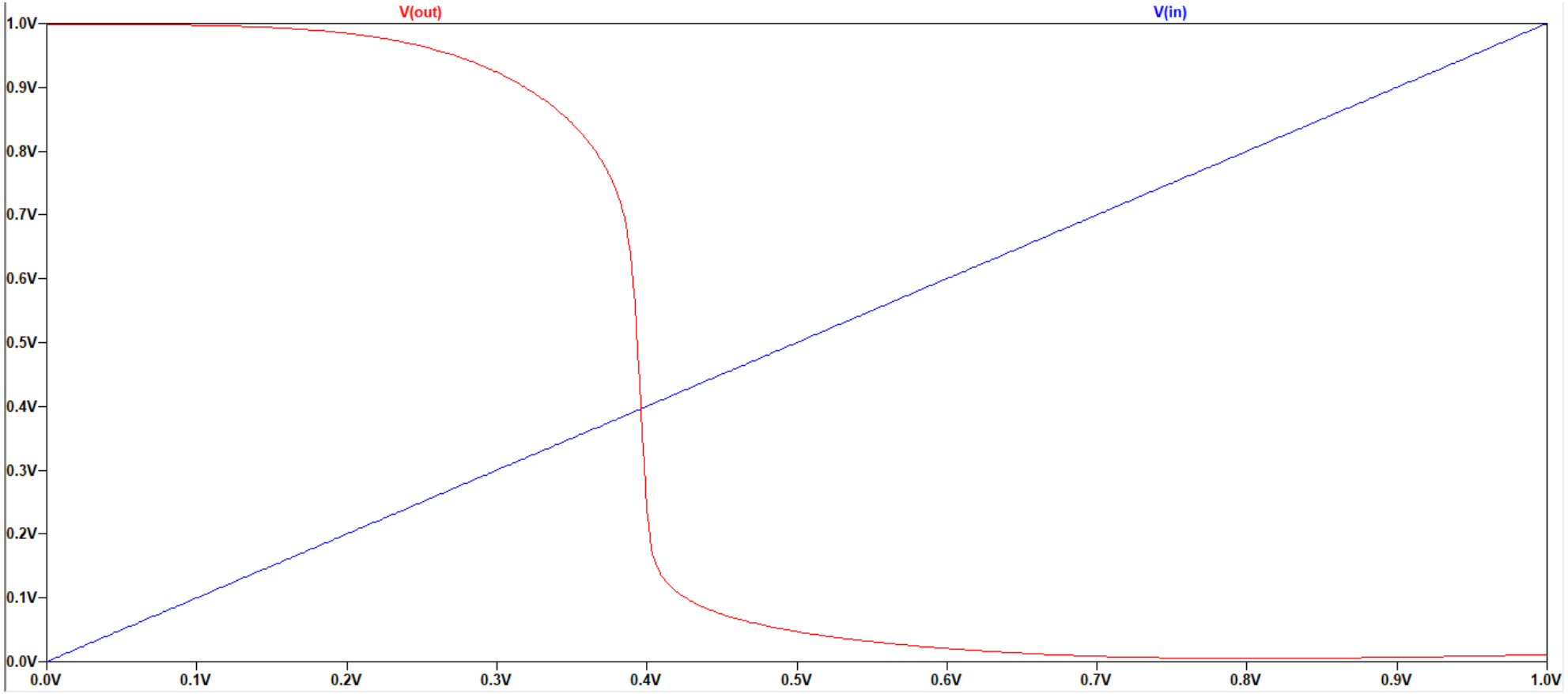
VI. Simulation on LTspice



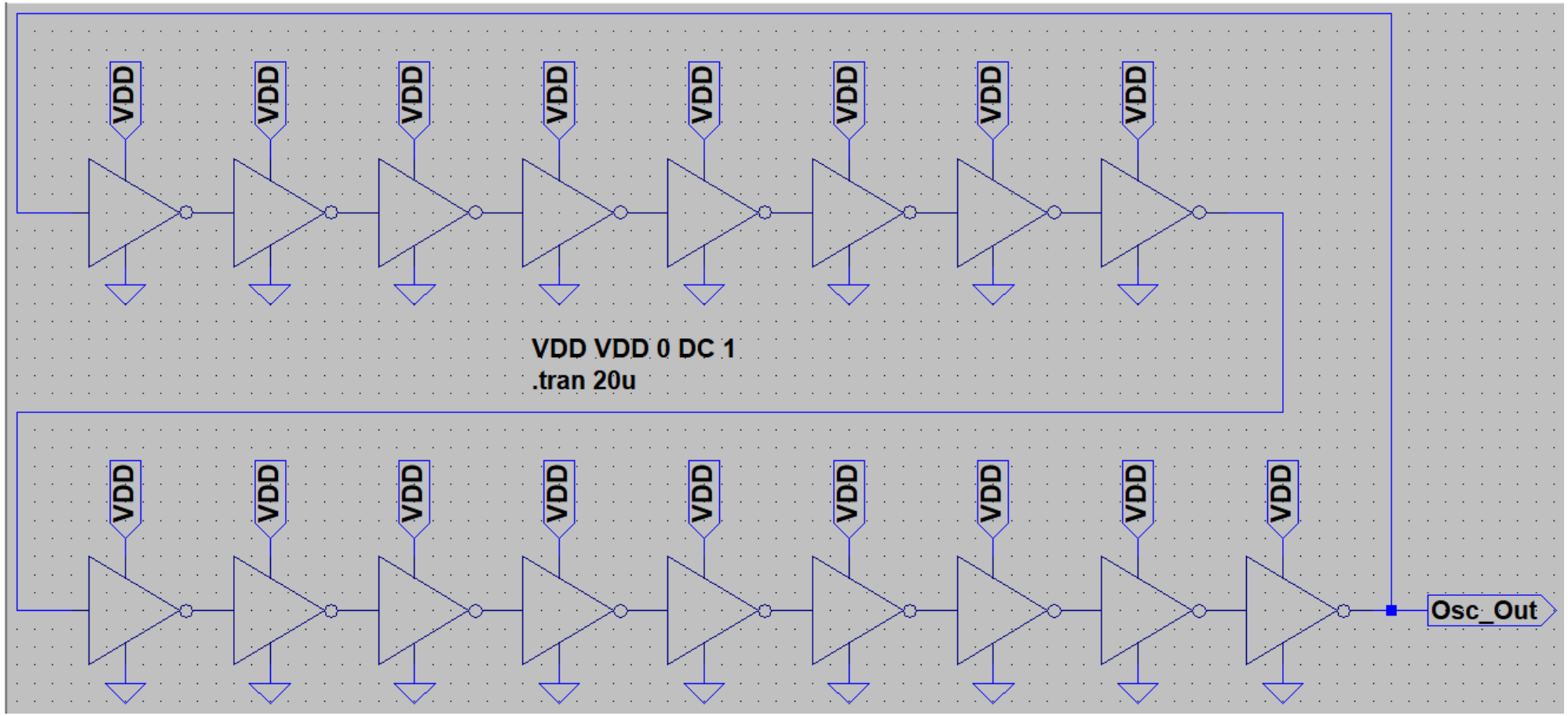
VI. Simulation on LTspice



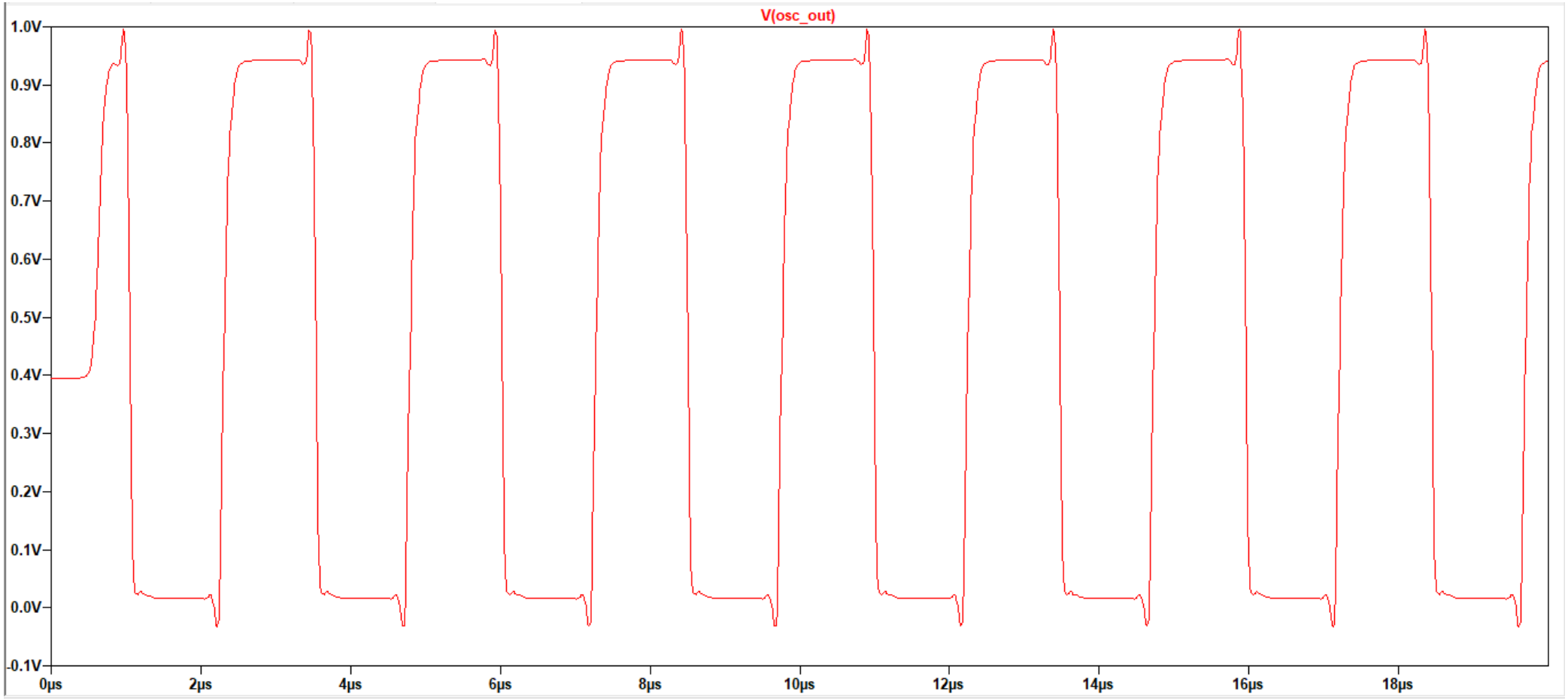
VI. Simulation on LTspice



VI. Simulation on LTspice



VI. Simulation on LTspice



VII. Simulation on Ngspice

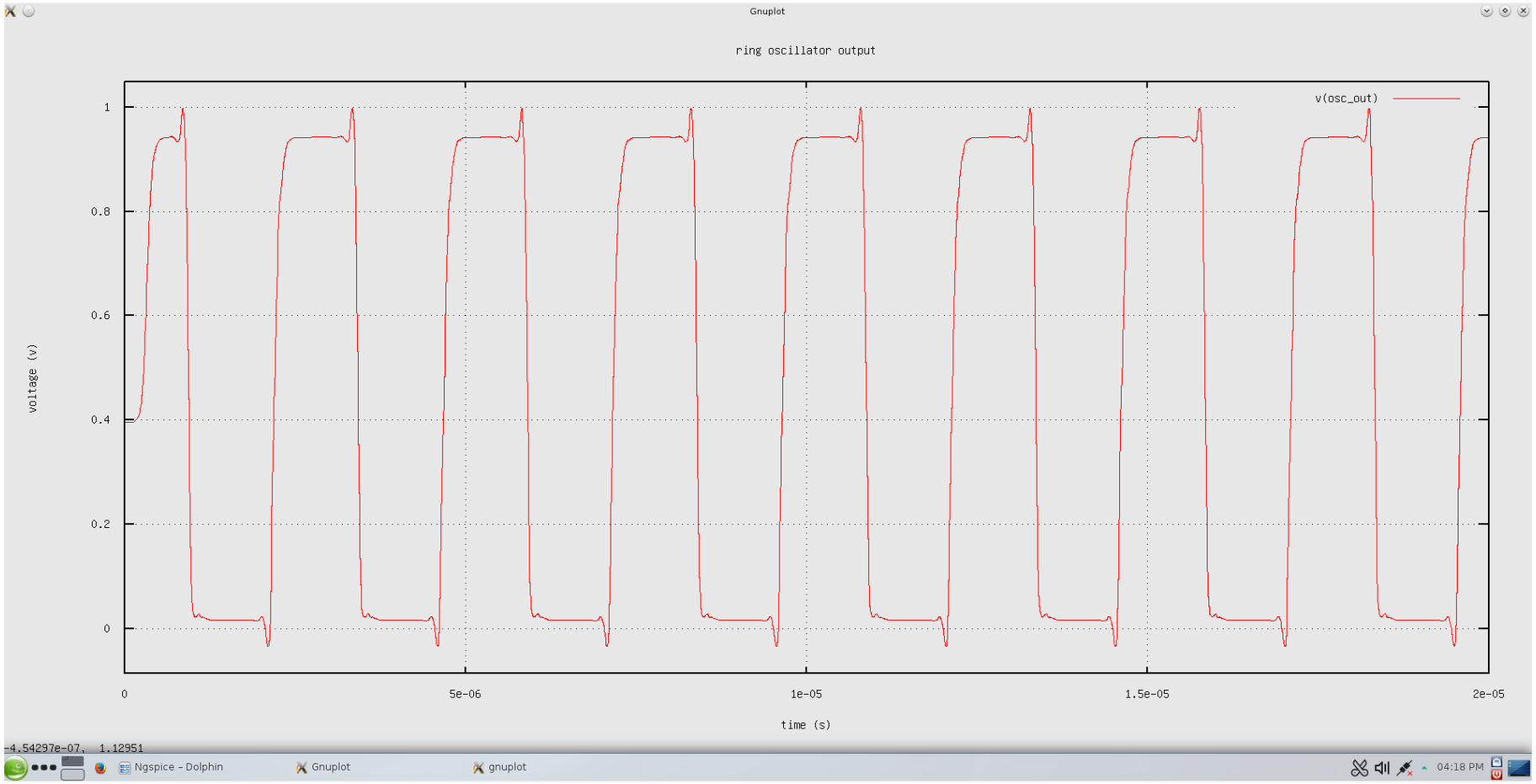
RingOscillator.cir

```
Ring Oscillator Design

*
* Independent Voltage Source
*
VDD NVDD GND DC 1

*
* Inverter Sub Circuit Definition
*
.SUBCKT INVERTER IN OUT VDD DGND
.include cmosedu_models.txt
M1 OUT IN VDD  VDD  P_50n
M2 OUT IN DGND DGND N_50n
.ENDS INVERTER


*
* Ring oscillator circuit consisting
* of 17 inverters.
*
X01 Osc_Out IN02    NVDD GND INVERTER
X02 IN02    IN03    NVDD GND INVERTER
X03 IN03    IN04    NVDD GND INVERTER
X04 IN04    IN05    NVDD GND INVERTER
X05 IN05    IN06    NVDD GND INVERTER
X06 IN06    IN07    NVDD GND INVERTER
X07 IN07    IN08    NVDD GND INVERTER
X08 IN08    IN09    NVDD GND INVERTER
X09 IN09    IN10    NVDD GND INVERTER
X10 IN10    IN11    NVDD GND INVERTER
X11 IN11    IN12    NVDD GND INVERTER
X12 IN12    IN13    NVDD GND INVERTER
X13 IN13    IN14    NVDD GND INVERTER
X14 IN14    IN15    NVDD GND INVERTER
X15 IN15    IN16    NVDD GND INVERTER
X16 IN16    IN17    NVDD GND INVERTER
X17 IN17    Osc_Out NVDD GND INVERTER

```

RingOscillator.cir

```

*
* The following features must be set for the Ngspice simulation
* to have the same properties as LTSpice simulation.
*
.OPTIONS GMIN=1e-012    ABSTOL=1e-012       RELTOL=0.001
+        CHGTOL=1e-014  VOLTTOL=1e-006      TRTOL=1
+        SSTOL=0.001    MINDELTAGMIN=0.0001 METHOD=trap
+        ACCT           LIST                NODE OPTS

*
* Use initial condition if oscillation does
* not start.
*
*.NODESET V(NVDD)=1 V(Osc_Out)=0.71
*.IC V(NVDD)=1 V(Osc_Out)=0.71
*.TRAN 0 20us 0  20us UIC
.TRAN 0 20us 0  20us

*
* Control statement for running simulation and
* plotting the Osc_Out result
*
.control
echo ****************************************
echo *** Ring Oscillator Simulation Started ***
echo ****************************************
run
*print V(Osc_Out)
gnuplot RingOscillator V(Osc_Out) title "Ring Oscillator Output"
+       xlabel "Time (s)" ylabel "Voltage (V)"
echo ****************************************
echo *** Ring Oscillator Simulation Finished ***
echo ****************************************
.endc

.END
```

VII. Simulation on Ngspice



VIII. References

[1] http://www.iue.tuwien.ac.at/phd/entner/node35.html

[2] https://en.wikipedia.org/wiki/Ring_oscillator

[3] http://cmosedu.com/

[4] https://www.youtube.com/watch?v=7ShqMMWj-WI&list=PLZuGFJzpFksCaPBHdNqThrkAiQ5AyY4SJ&index=4

[5] http://ngspice.sourceforge.net/docs/ngspice-manual.pdf

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THANK YOU FOR LISTENING…