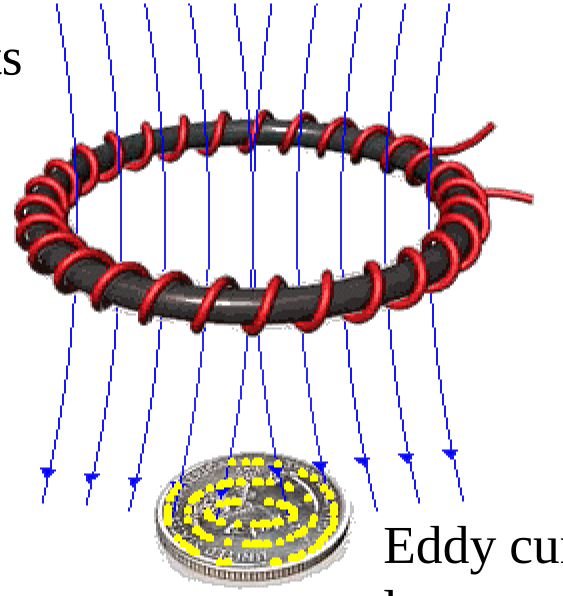
Metal Detector

$$f_0 = \frac{1}{2\pi}\sqrt{\left(\frac{1}{LC} - \frac{r^2}{L^2}\right)}$$

Any "losses" (even eddy-current losses in all kinds of metals) are summarized by the symbol r !

Iron objects affects the magnetic field and thus also L !

The parallel resonant frequency is affected by the coil losses. That's how hidden treasures are found!



Eddy current losses

Metal Detector

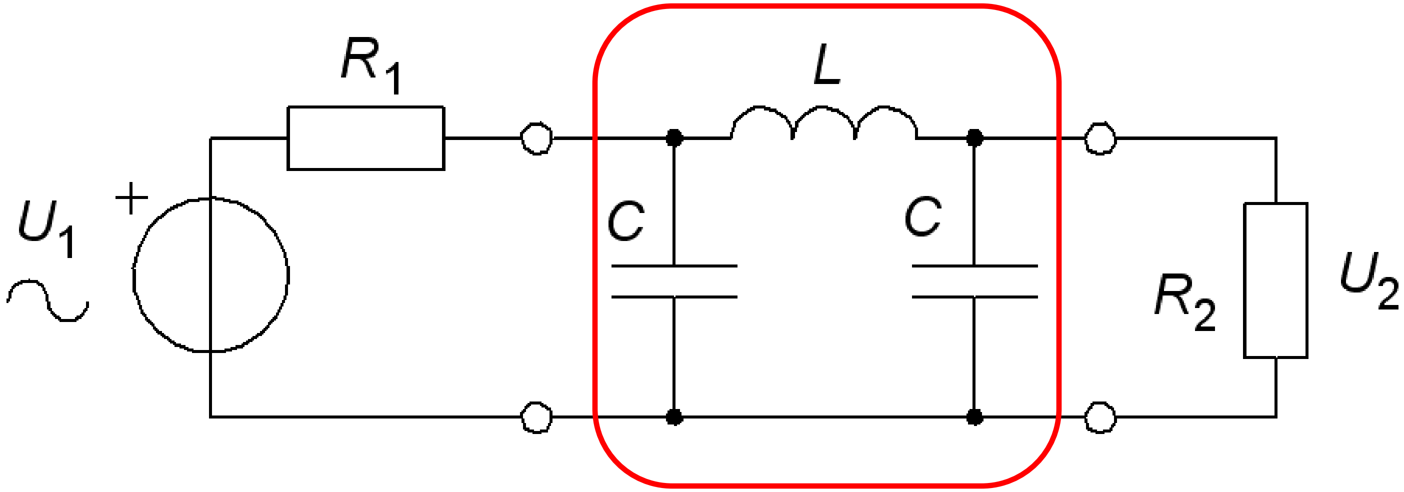
A metal detector consists of an oscillator (a transmitter) with an LC resonant circuit. Metal objects that are within the magnetic field of inductance affects the resonance frequency so that the oscillator frequency changes.

A microprocessor with a frequency measurement program indicates the frequency changes.

- Ahead of the lab, we now need to study resonant circuits and amplifiers – oscillators.

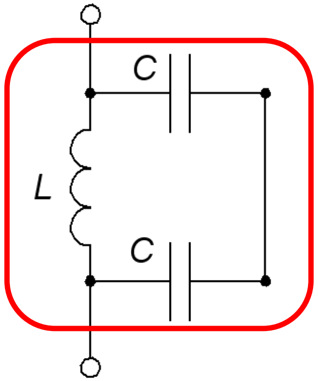
A circuit with resonance

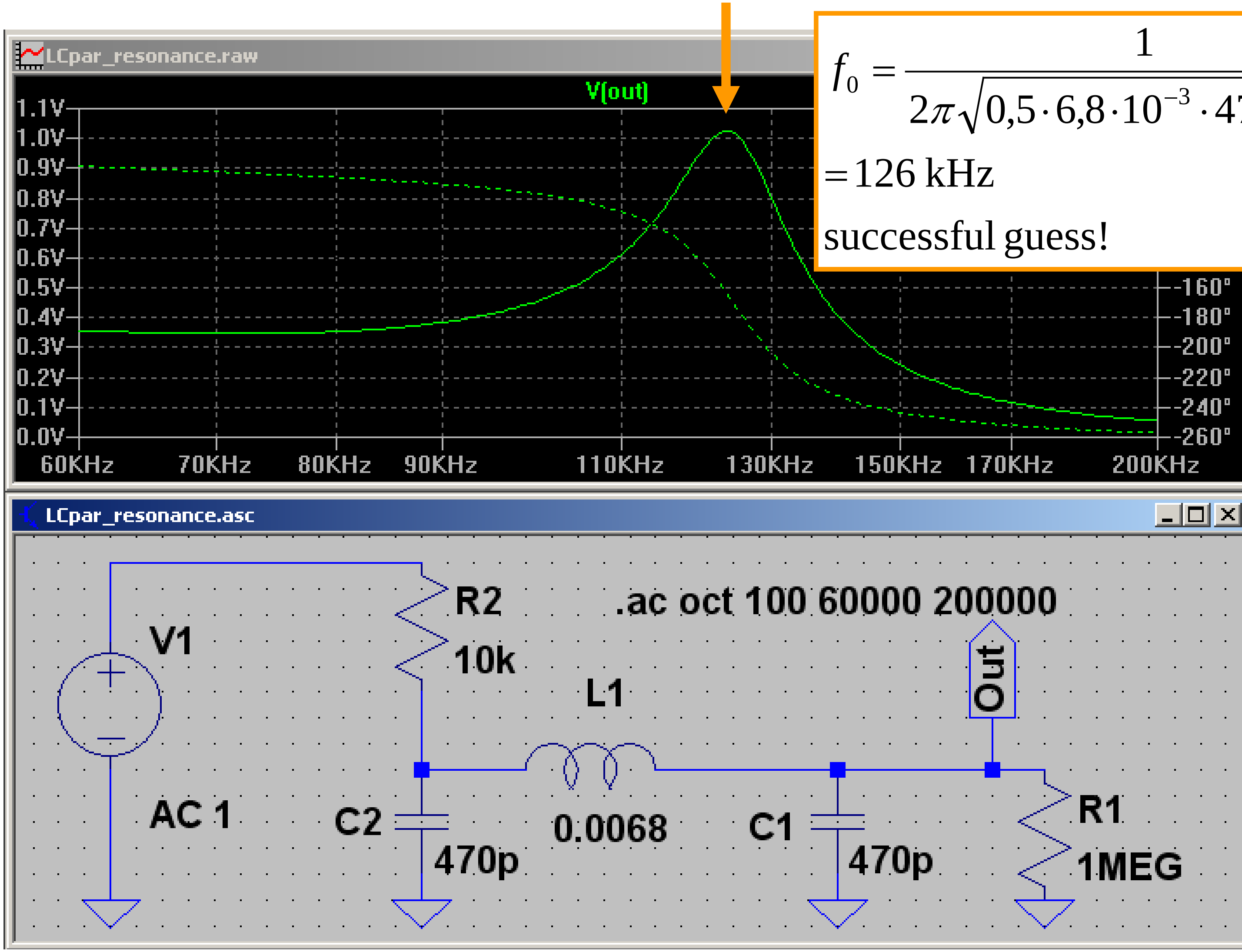
$$f_0 = \frac{1}{2\pi\sqrt{L \cdot C}}$$



The calculations of the circuit is really quite complicated - but we could try a "**guess**":

$$C_{ERS} = \frac{C \cdot C}{C + C} = \frac{C}{2} \qquad f_0 \approx \frac{1}{2\pi\sqrt{L \cdot \frac{C}{2}}}$$



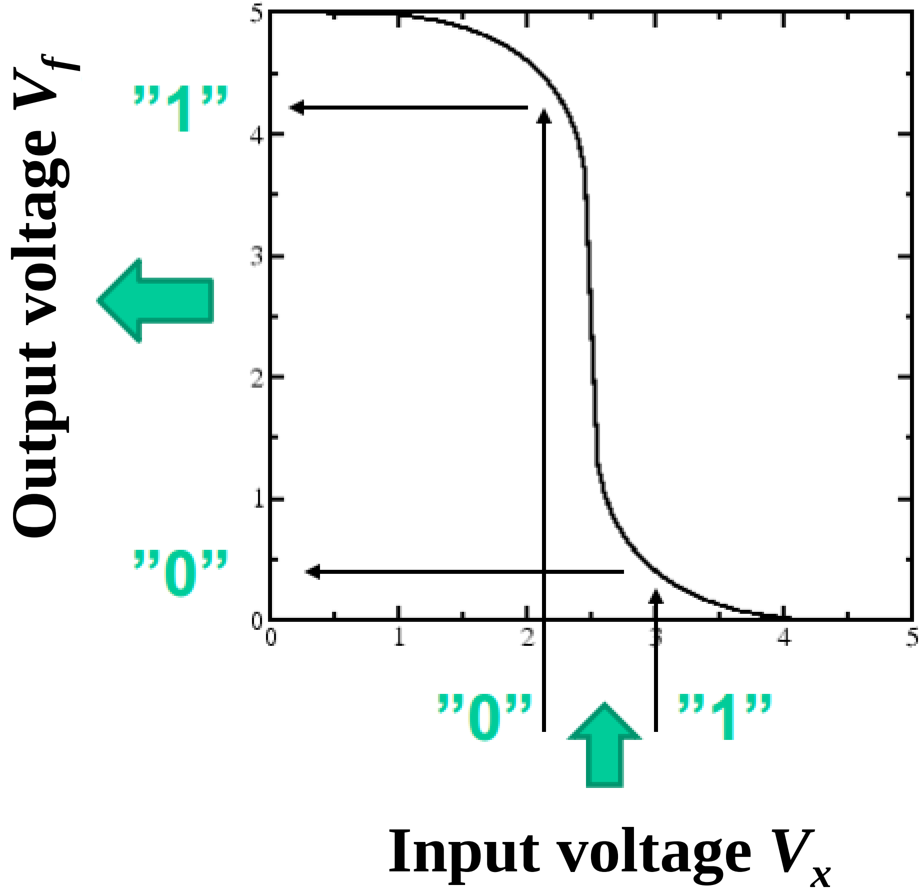


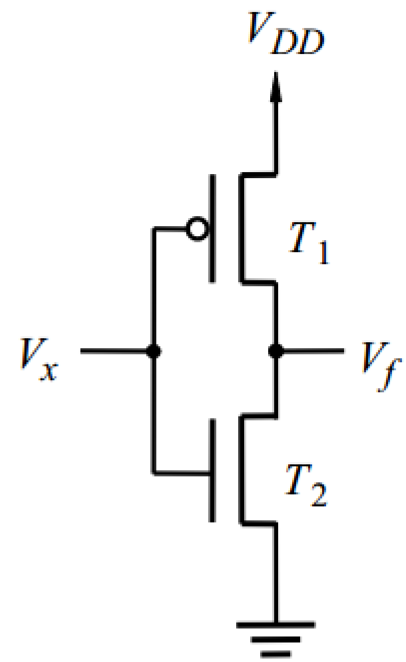
$$f_0 = \frac{1}{2\pi\sqrt{0{,}5\cdot 6{,}8\cdot 10^{-3}\cdot 470\cdot 10^{-12}}}$$

$$= 126\ \text{kHz}$$

successful guess!

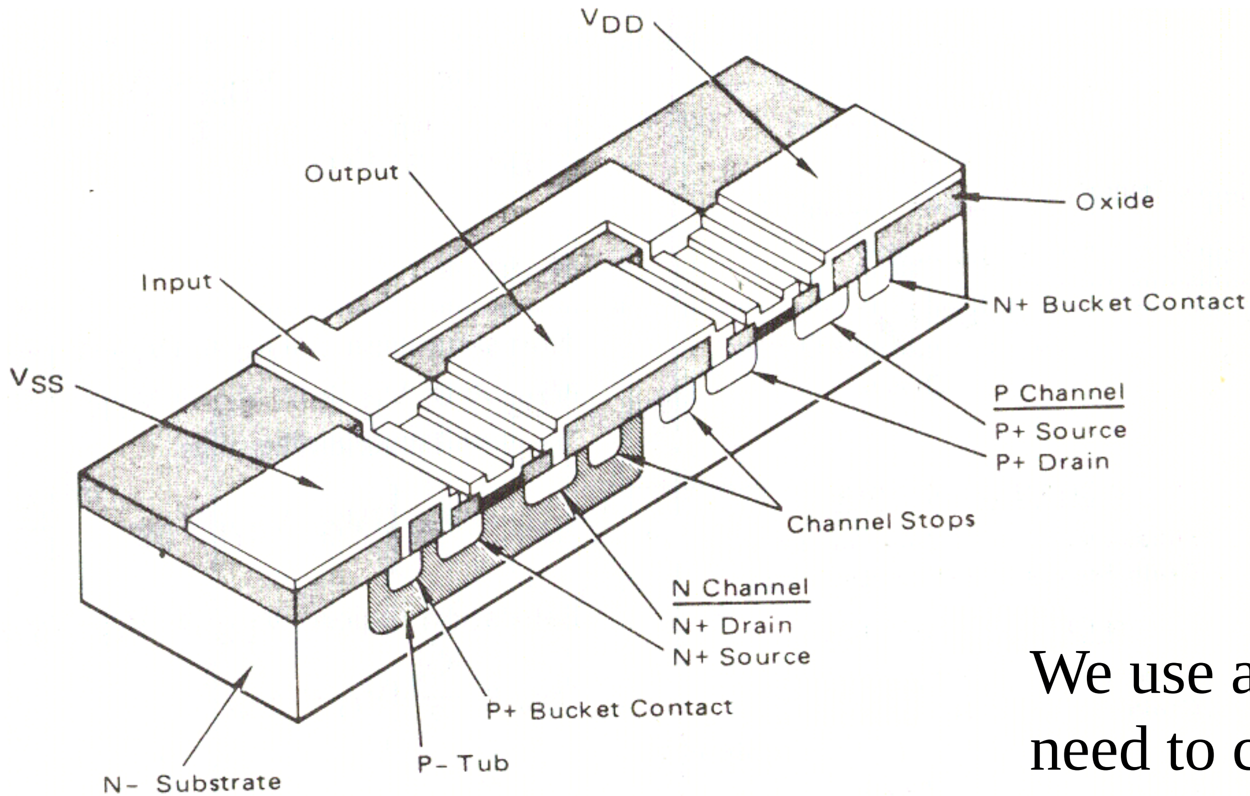
Digital design – inverter

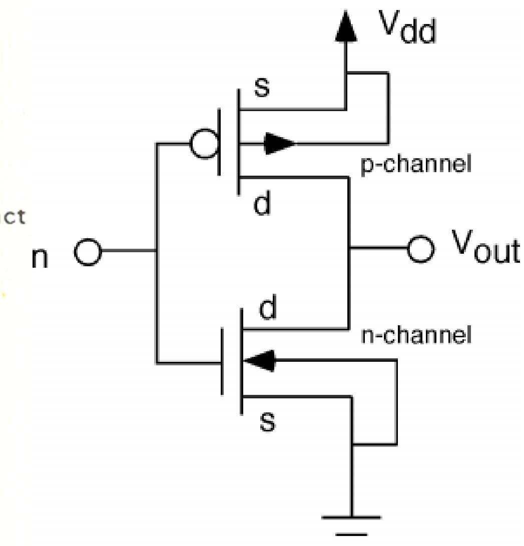




Do you remember the CMOS-inverter from Digital Design?

CMOS-inverter

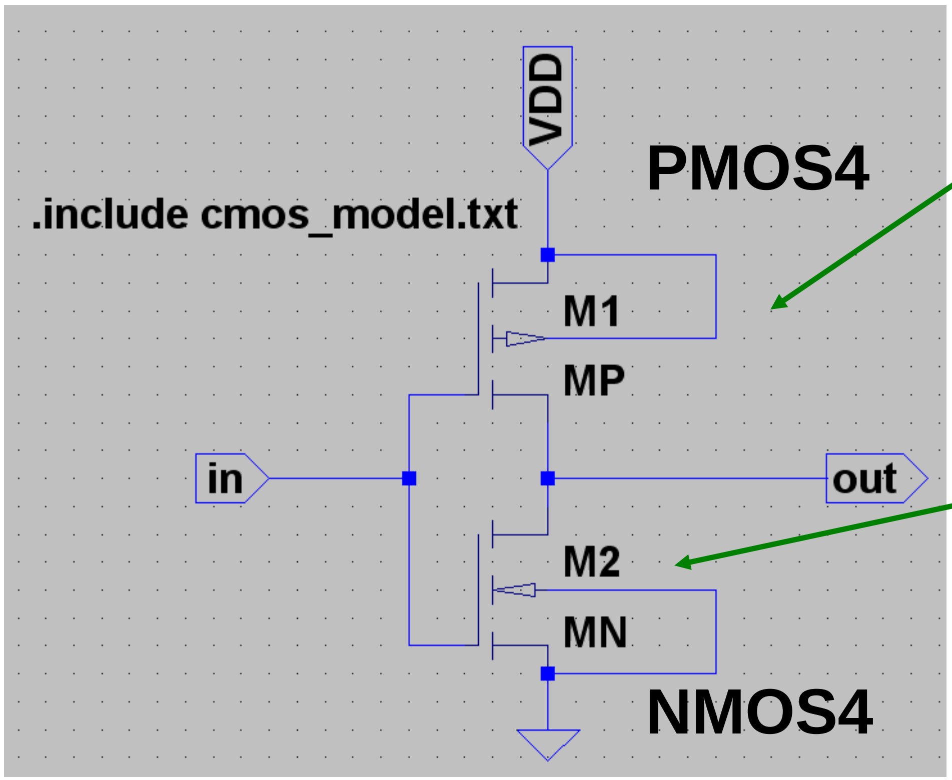


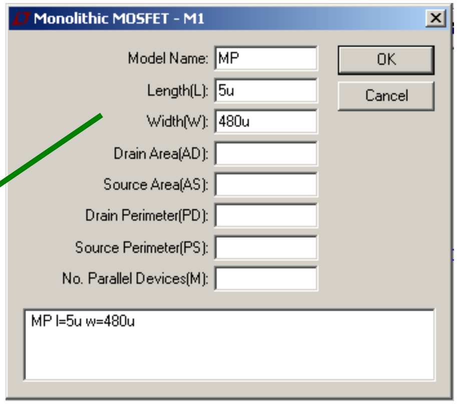


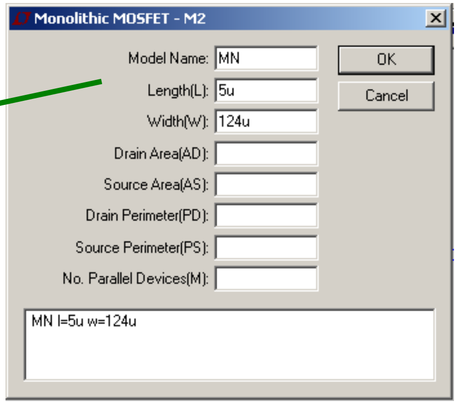
We use an "old" chip – and need to choose simulation parameters accordingly!

- ***Do you remember the CMOS-inverter from Digital Design??***

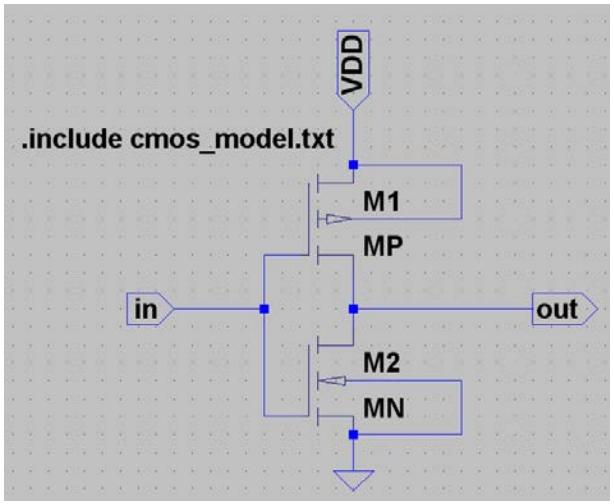
(MOS-Old school)





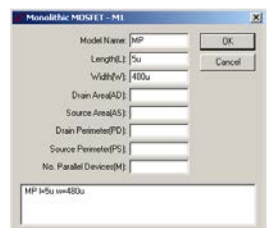


(MOS-Old school)



Put the file **`cmos_model.txt`** in your work folder. It containes ”scalable” models. Write the directive:

`.include cmos_model.txt`



- **NMOS**

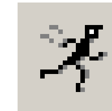
Model Name: **MN**
Length (L): **5u**
Width (W): **124u**

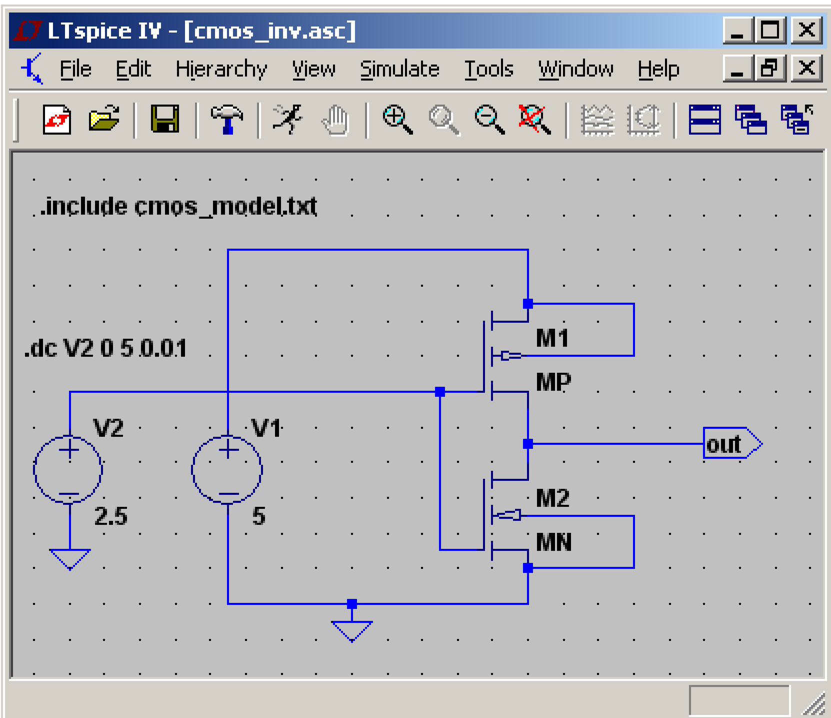
- **PMOS**

Model Name: **MP**
Length (L): **5u**
Width (W): **480u**

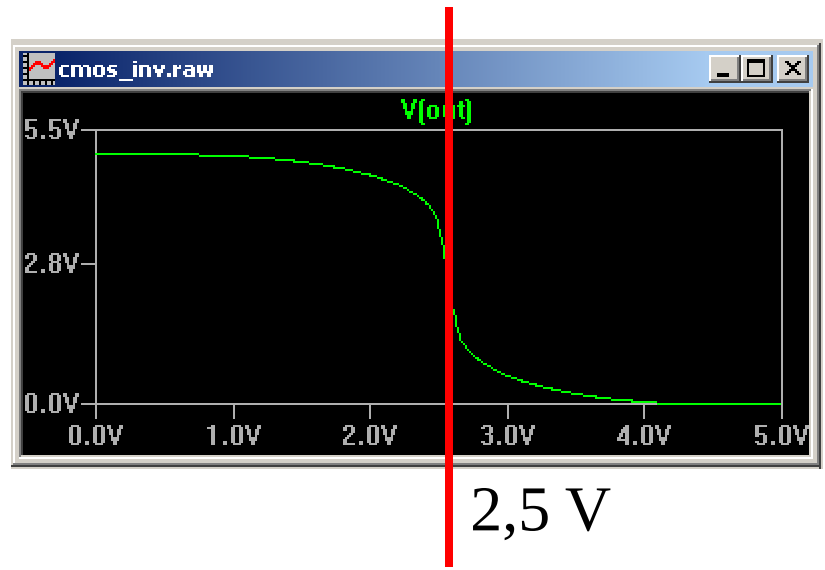
With these choices the two transistors will get equal strength!

(CMOS-inverter)





Simulate with dc- sweep :
`.dc V2 0 5 0.01`

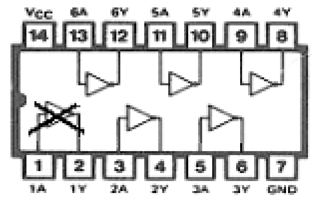


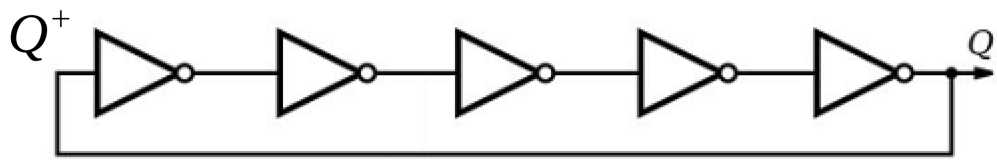
2,5 V

Transistors with equal strength will have the transition at 2,5V.

Ring-oscillator

Written exam in DigDes!



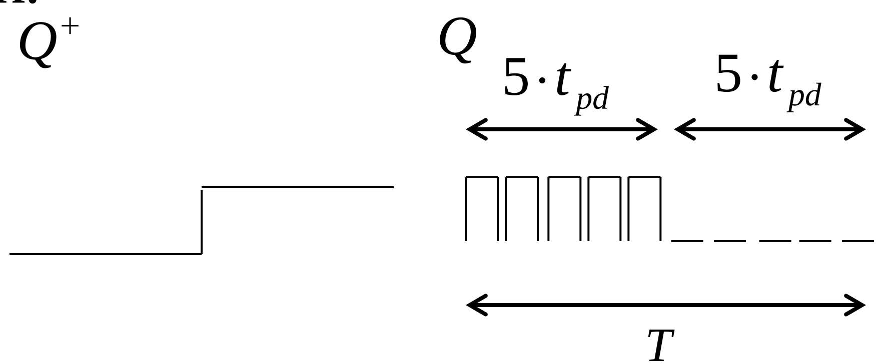


- A ring oscillator consisting of an odd number inverters connected in feedback.

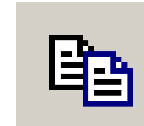
$Q^+ = f(Q)$

Q	Q^+
0	1
1	0

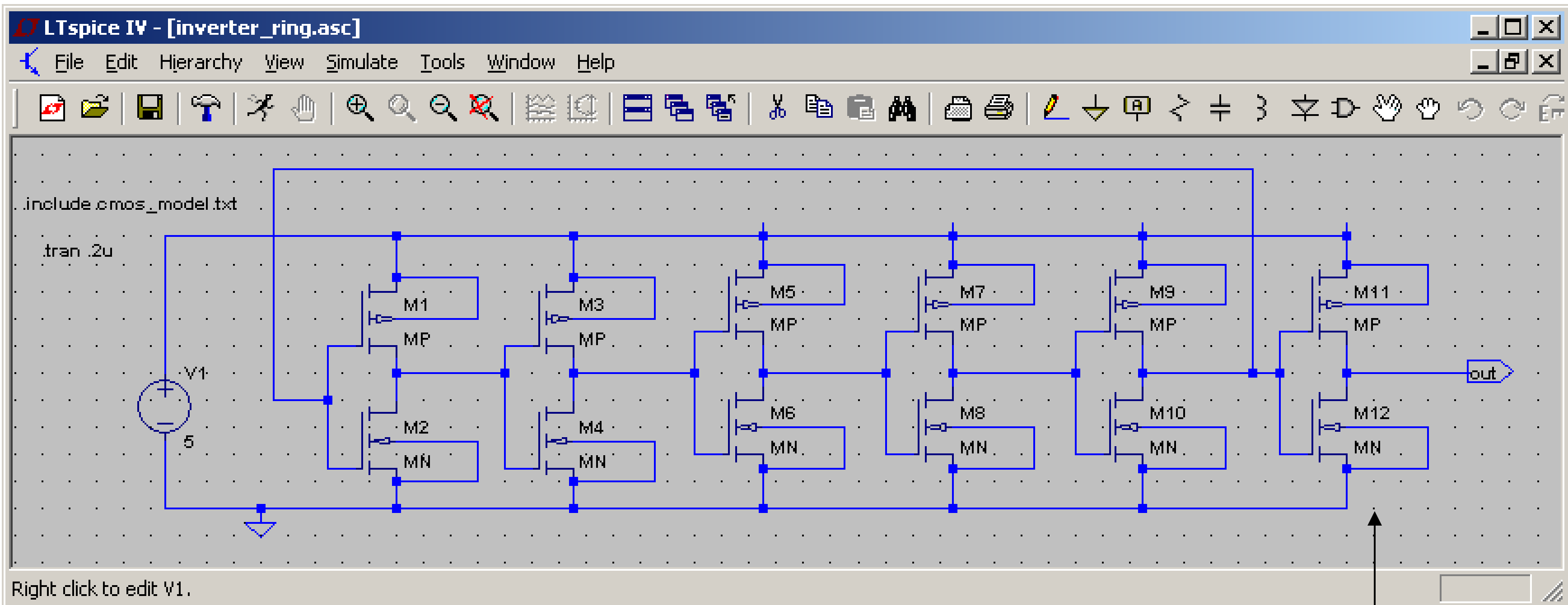
$T = 2 \cdot 5 \cdot t_{pd} \quad f = \frac{1}{T}$



Ring-oscillator



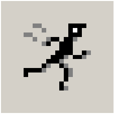
Copy the inverter 5 times! (Vi have a chip with 6 inverters)



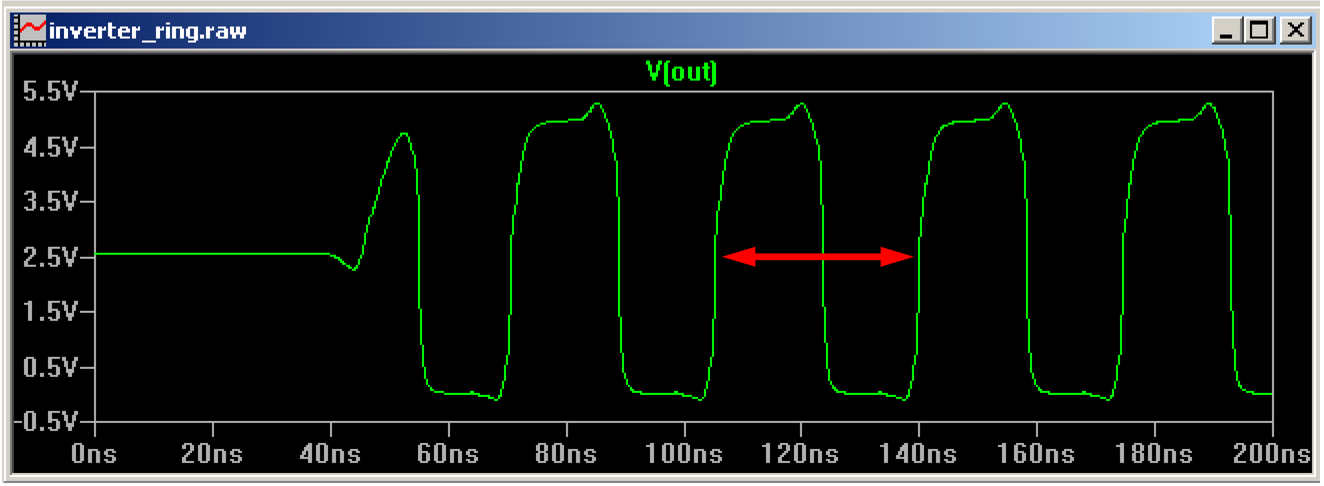
5 inverters in ”ring”

+ Buffer

Ring-oscillator



Simulate with: `.tran .2u`

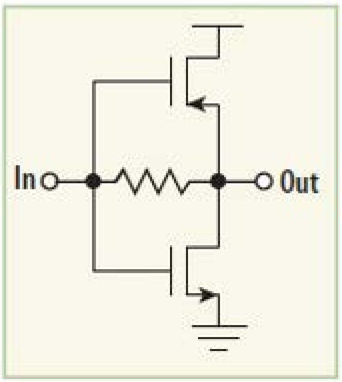


Propagation delay of one inverter:

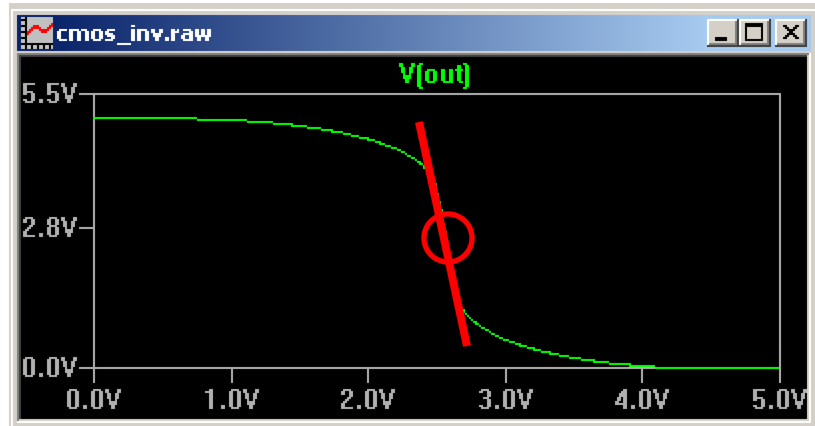
$$t_{PD} = \frac{35}{5+5} = 3{,}5 \text{ ns}$$

The ring oscillator can be used to indirectly measure the gate delay of the logic circuits!

Amplifier



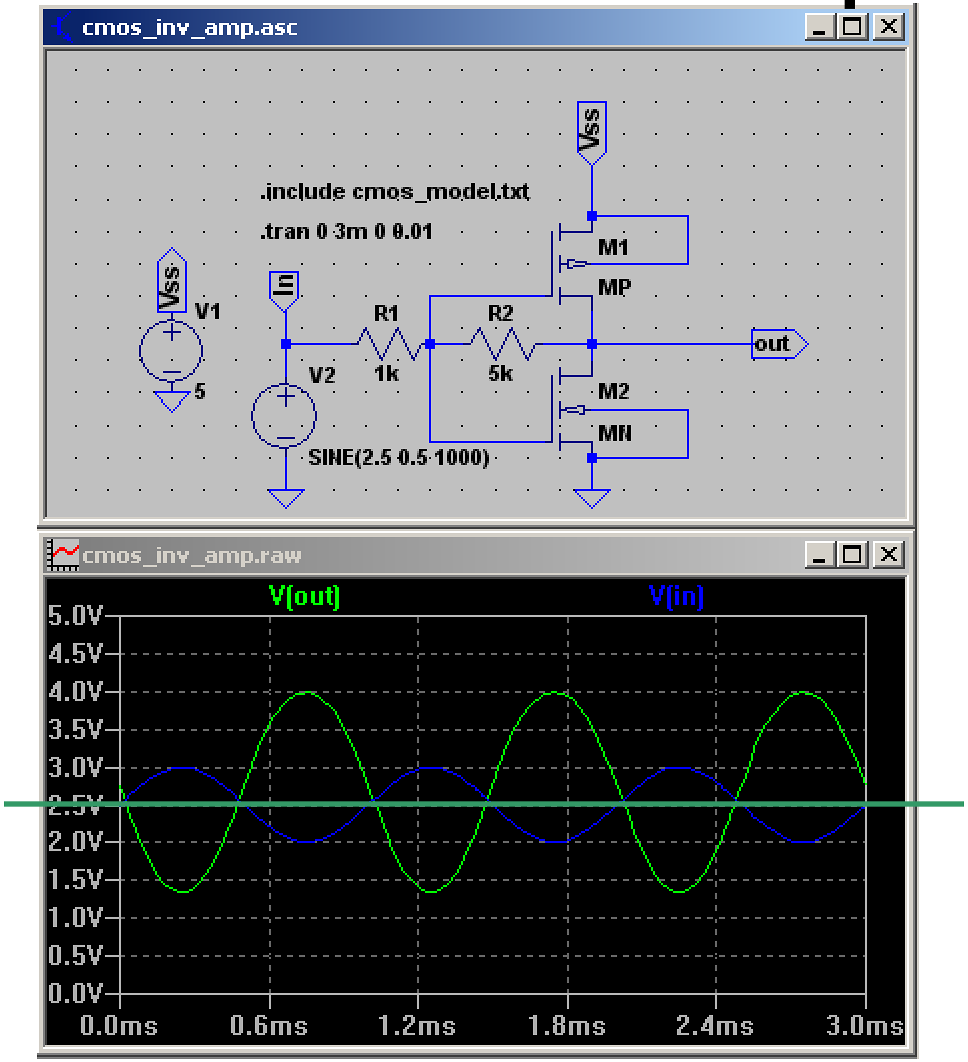
U_{out}



U_{in}

If feedback the output to the input $U_{out} = U_{in}$ on a inverter then the voltage will the voltage end up between ”1” and ”0”. The slope is steep, so an input voltage variation is greatly enhanced. A positive input signal shift gives rise to an enhanced negative output voltage change, so we have 180° phase shift.

Amplifier



U_{in}: 0,5 V (top value) sinusoidal voltage (at the 2,5V level)

U_{out}: 1,5 V (top value) sinusoidal voltage with opposite sign **180°** phase shift.

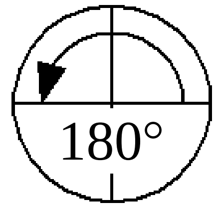
Amplification 0,5:1,5 **1:3**

R1 = 1k R2 = 5k

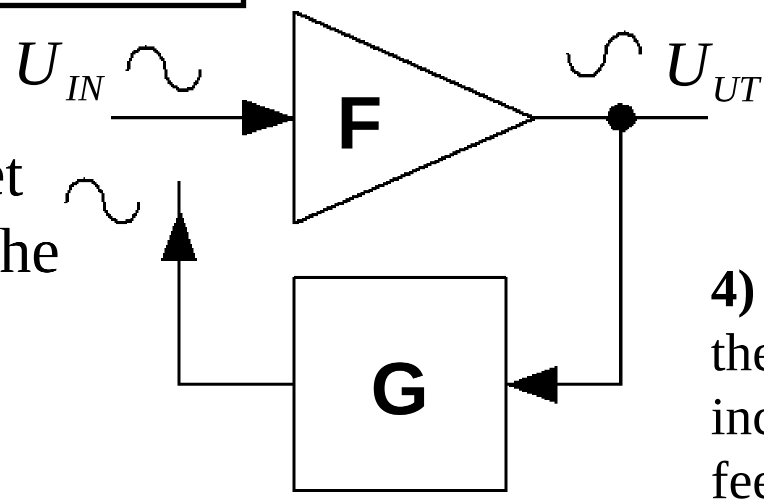
(The resistors are damping the CMOS inverter amplification to a stable value)

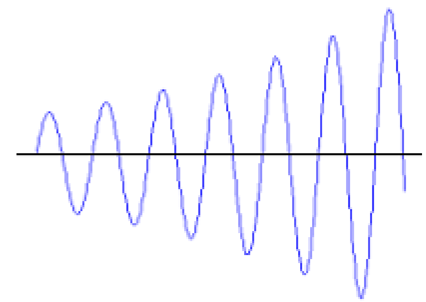
Can an amplifier become an oscillator?

A feedback amplifier can begin to "oscillate".



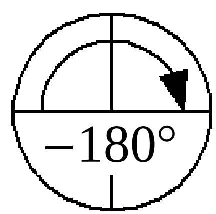
1) Amplifier phase shifts signalen 180° (= opposite sign)





3) Then we get an ”copy” of the input signal.

4) If this ”copy” is amplified, then the output signal will be increased – for every lap in a feedback loop.



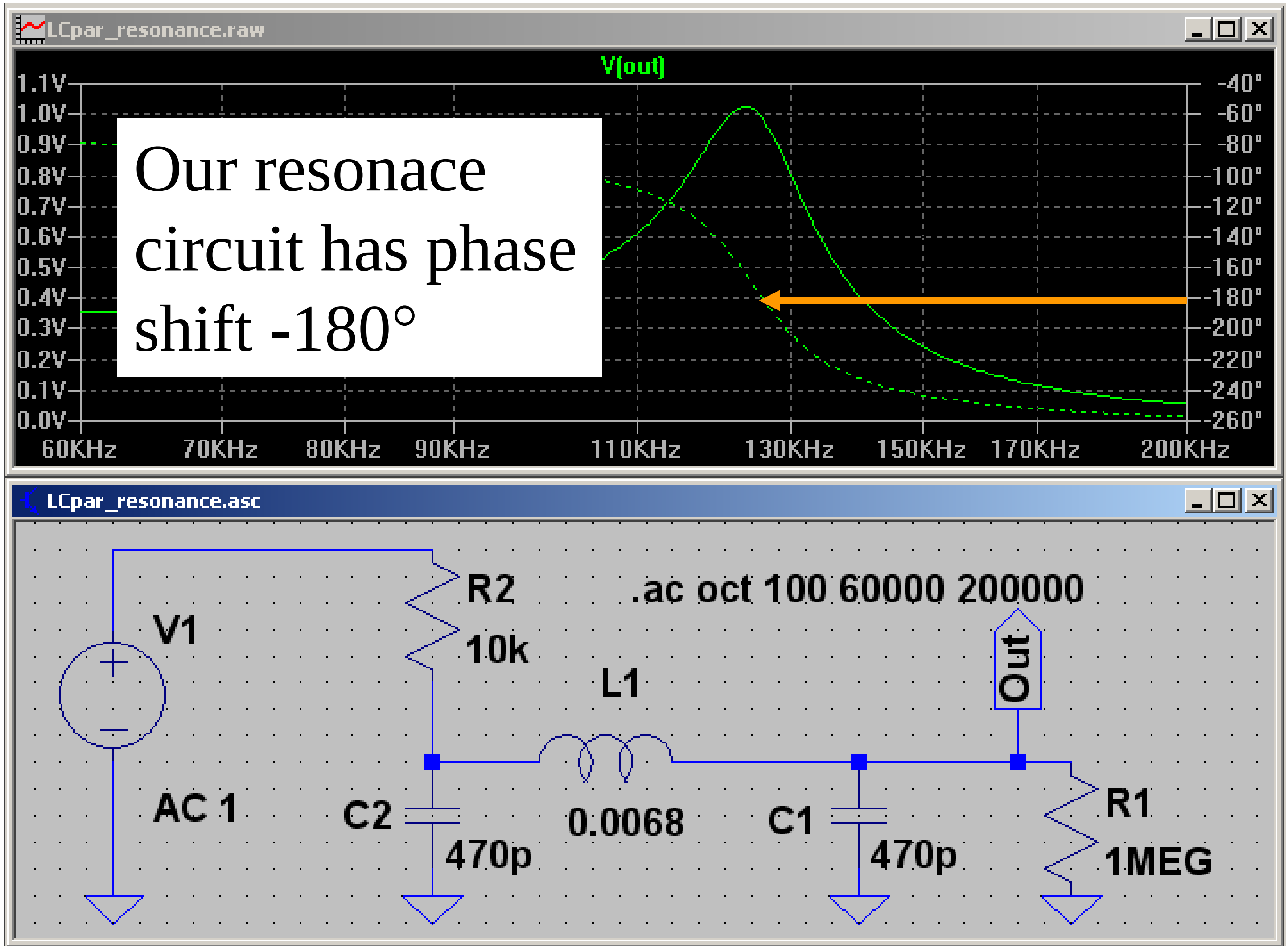
2) If the feedback network phase shifts the signal -180° for some frequency …

Can an amplifier become an oscillator?

If the total phase shift in the blocks F and G is 0° for some frequency, and at the same time there is a net gain (>1) for that frequency – then the amplifier will oscillate with that frequency!

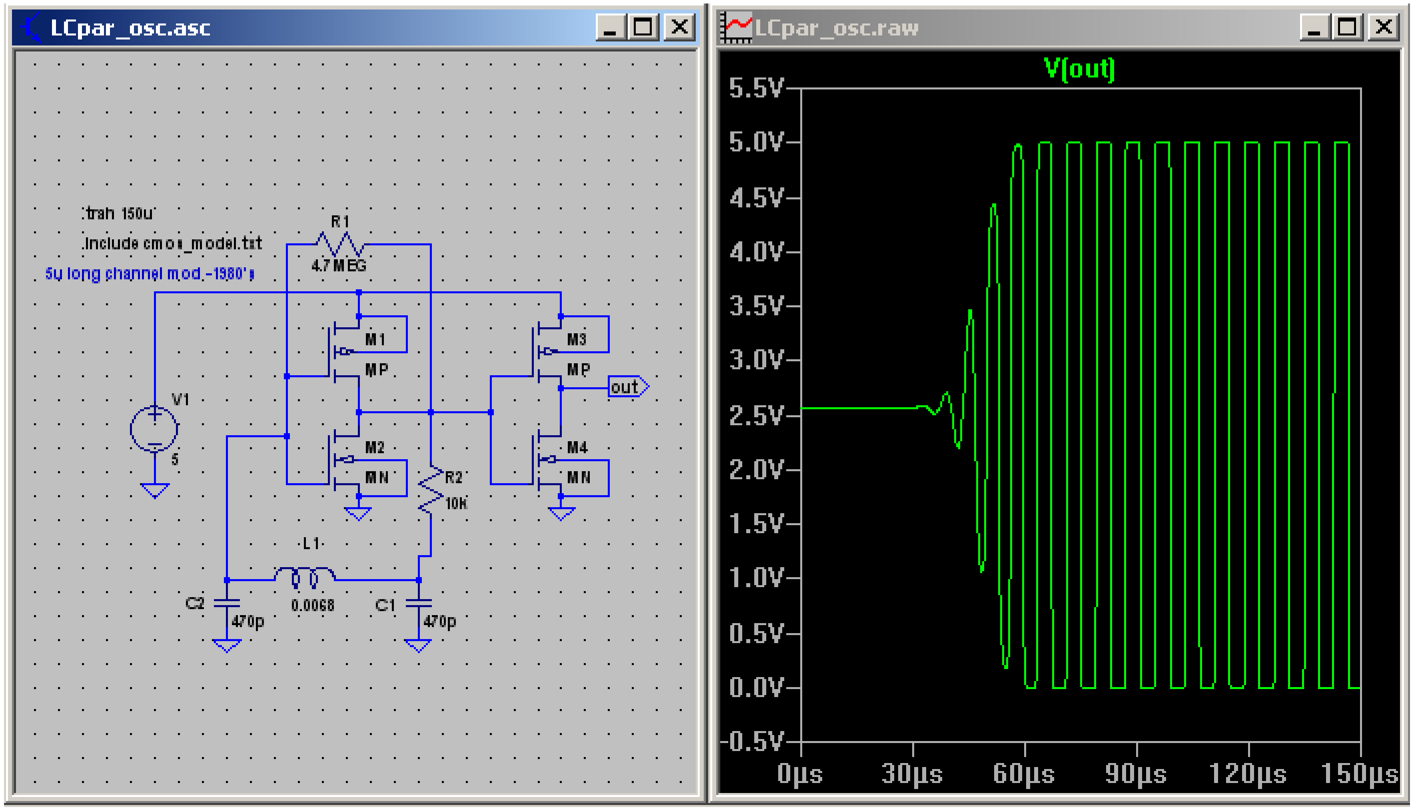
Harry Nyquist

This is known as the Nyquist criterion for stability!



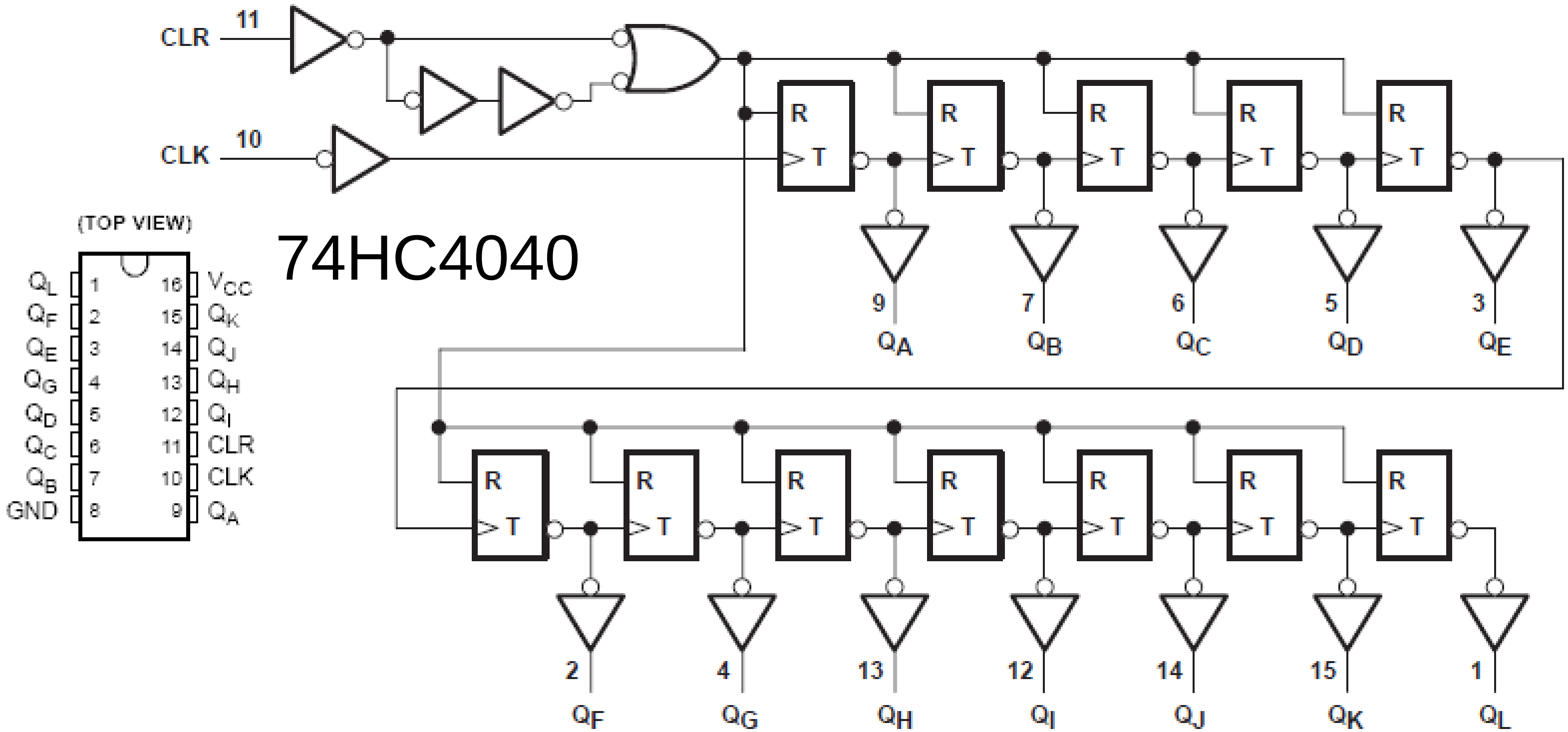
LCpar_resonance.raw
V(out)
1.1V
1.0V
0.9V
0.8V
0.7V
0.6V
0.5V
0.4V
0.3V
0.2V
0.1V
0.0V
-40°
-60°
-80°
-100°
-120°
-140°
-160°
-180°
-200°
-220°
-240°
-260°
60KHz
70KHz
80KHz
90KHz
110KHz
130KHz
150KHz
170KHz
200KHz
Our resonace circuit has phase shift -180°
LCpar_resonance.asc
R2
10k
.ac oct 100 60000 200000
V1
L1
Out
AC 1
C2
470p
0.0068
C1
470p
R1
1MEG

Oscillator



Oscillator at lab. One inverter has feedback from the resonance filter. One extra inverter acts as a buffer to make the signal digital.

A counter chip



At lab we use a cheap counter chip. Oscillator frequency is divided with up to 12 stages – to an audible signal. (You've heard about this chip in the Digital Design Course).