# Digital elektronik och inbyggda system

**Per Larsson-Edefors**

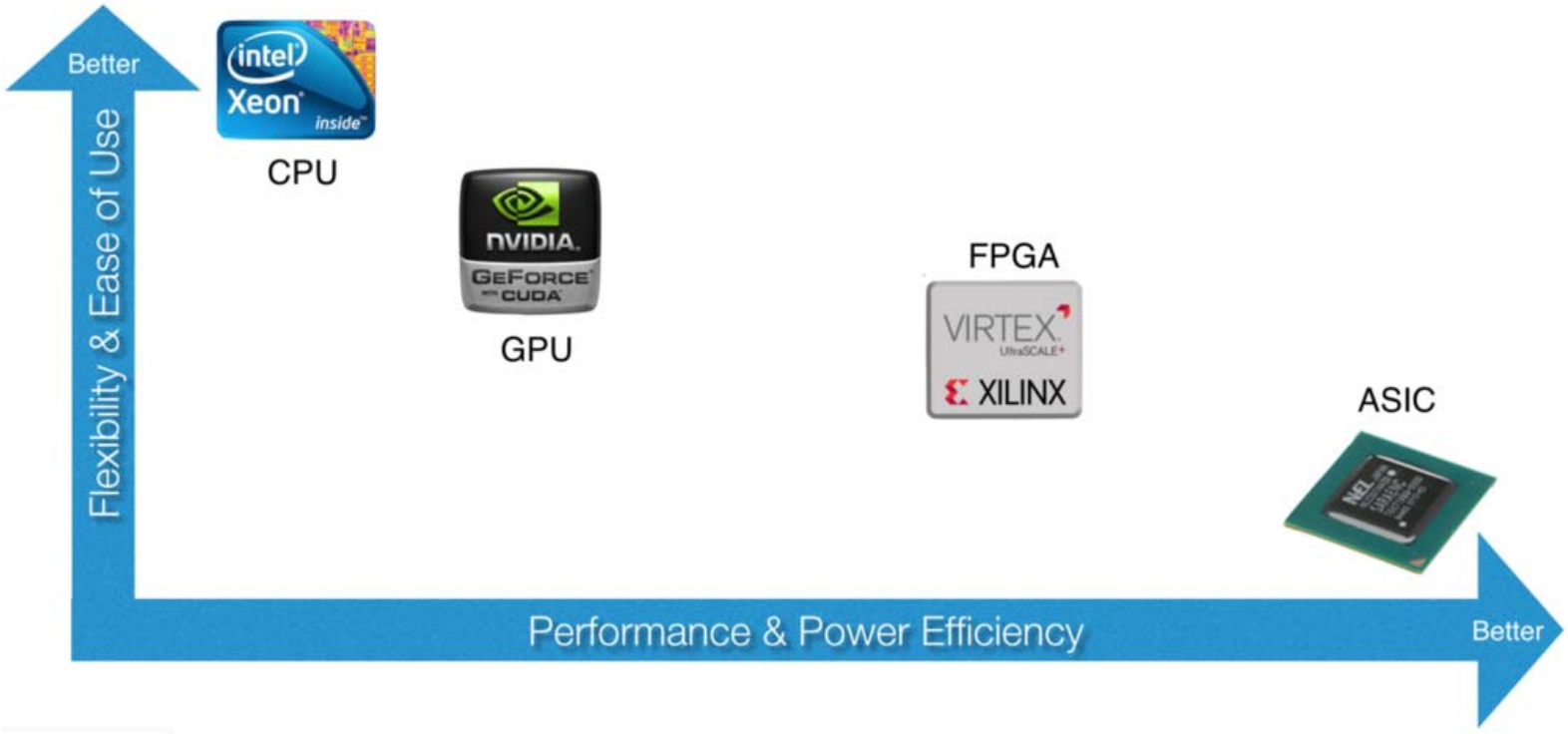
**perla@chalmers.se**


- Ett inbyggt system är uppbyggt kring en eller flera processorer, med en omgivning av skräddarsydd analog och digital elektronik.

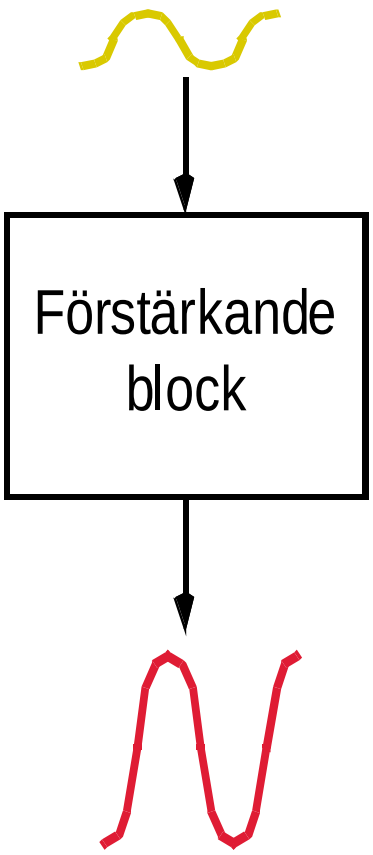
# Konstruktionsutmaning

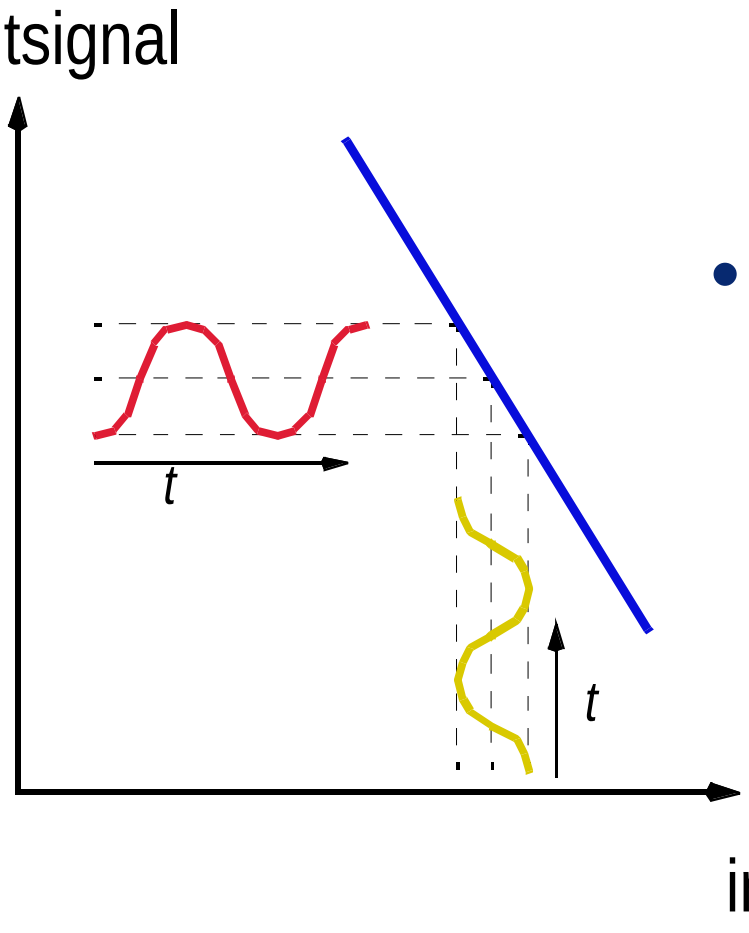
- Specifik tillämpning/domän + inbyggnadskrav $\Rightarrow$ konstruktören måste optimera systemet m.a.p. prestanda, tillförlitlighet, storlek, effekt, kostnad, etc.
  - Från ASICs, för de striktaste kraven,
  - via FPGAs,
  - till system med COTS-processor (CPU, GPU).

# Varianter av hårdvara



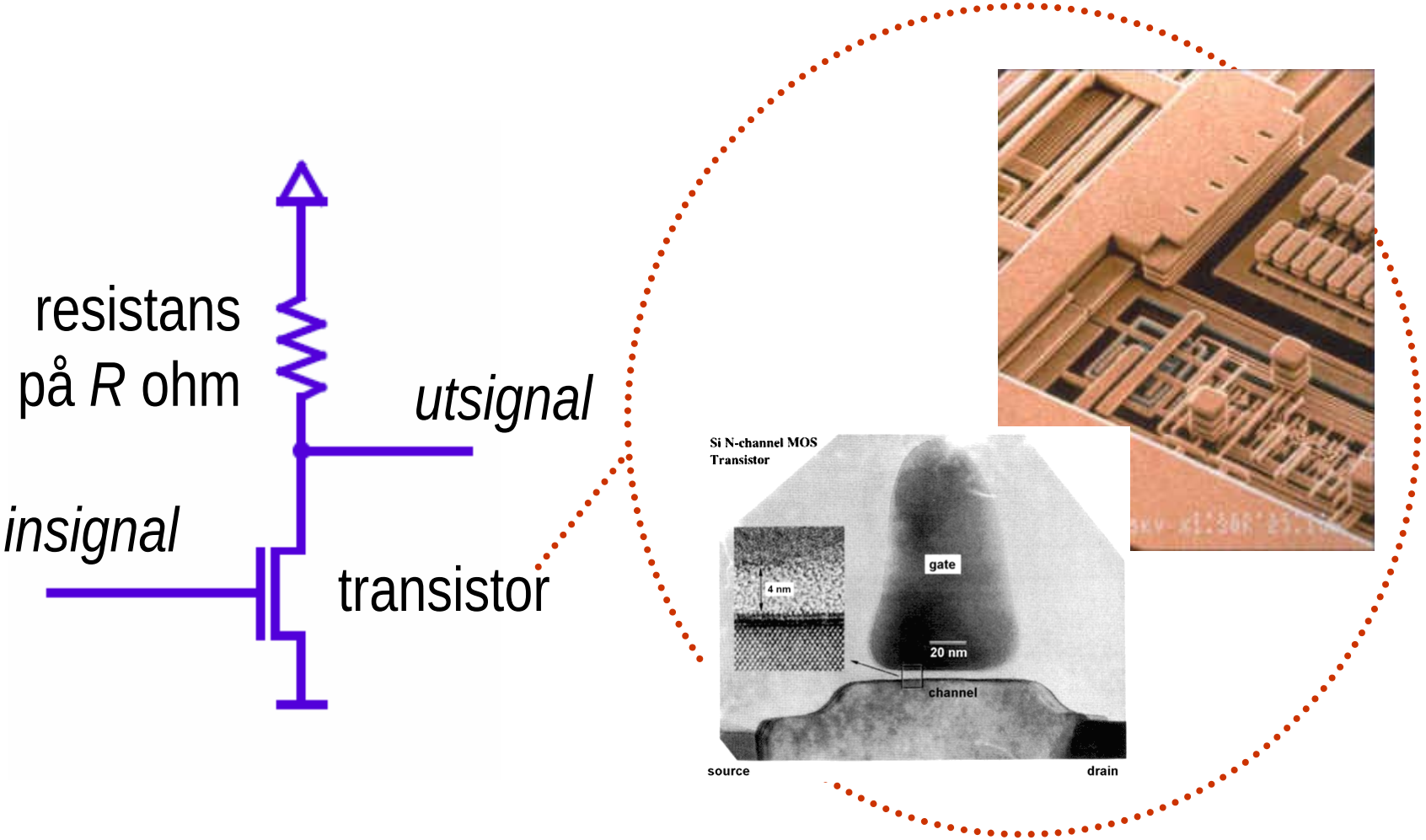
# Grunden: Förstärkning



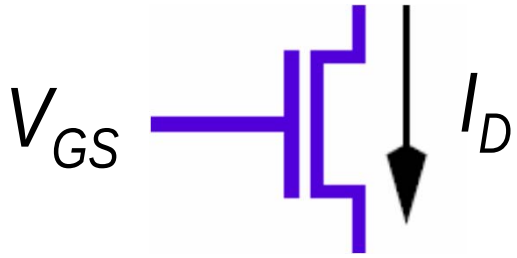



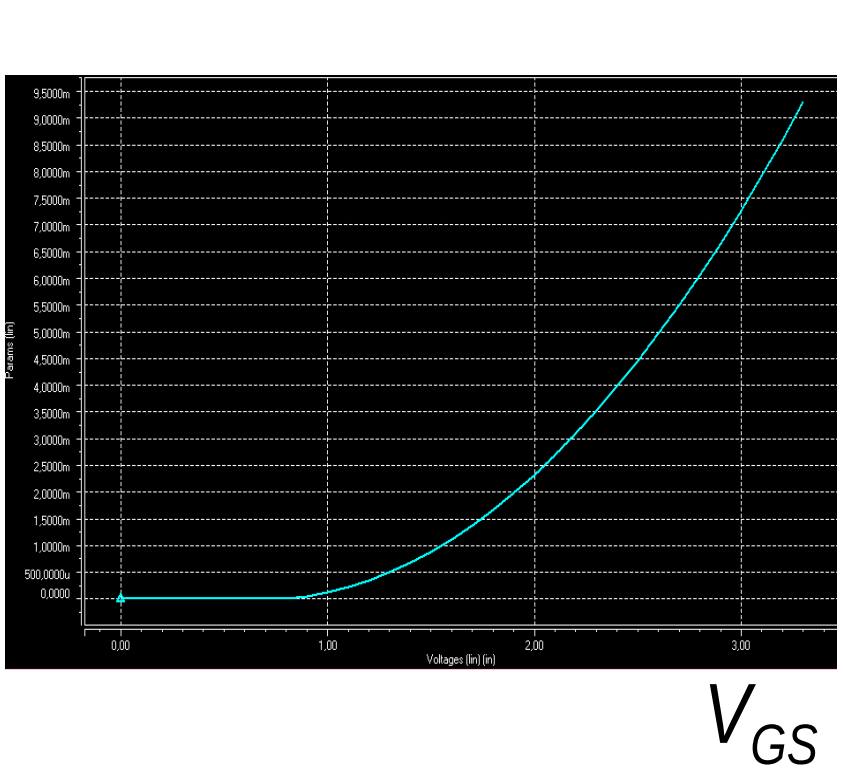

- Brant lutning => stor förstärkning

# Den enklaste förstärkaren



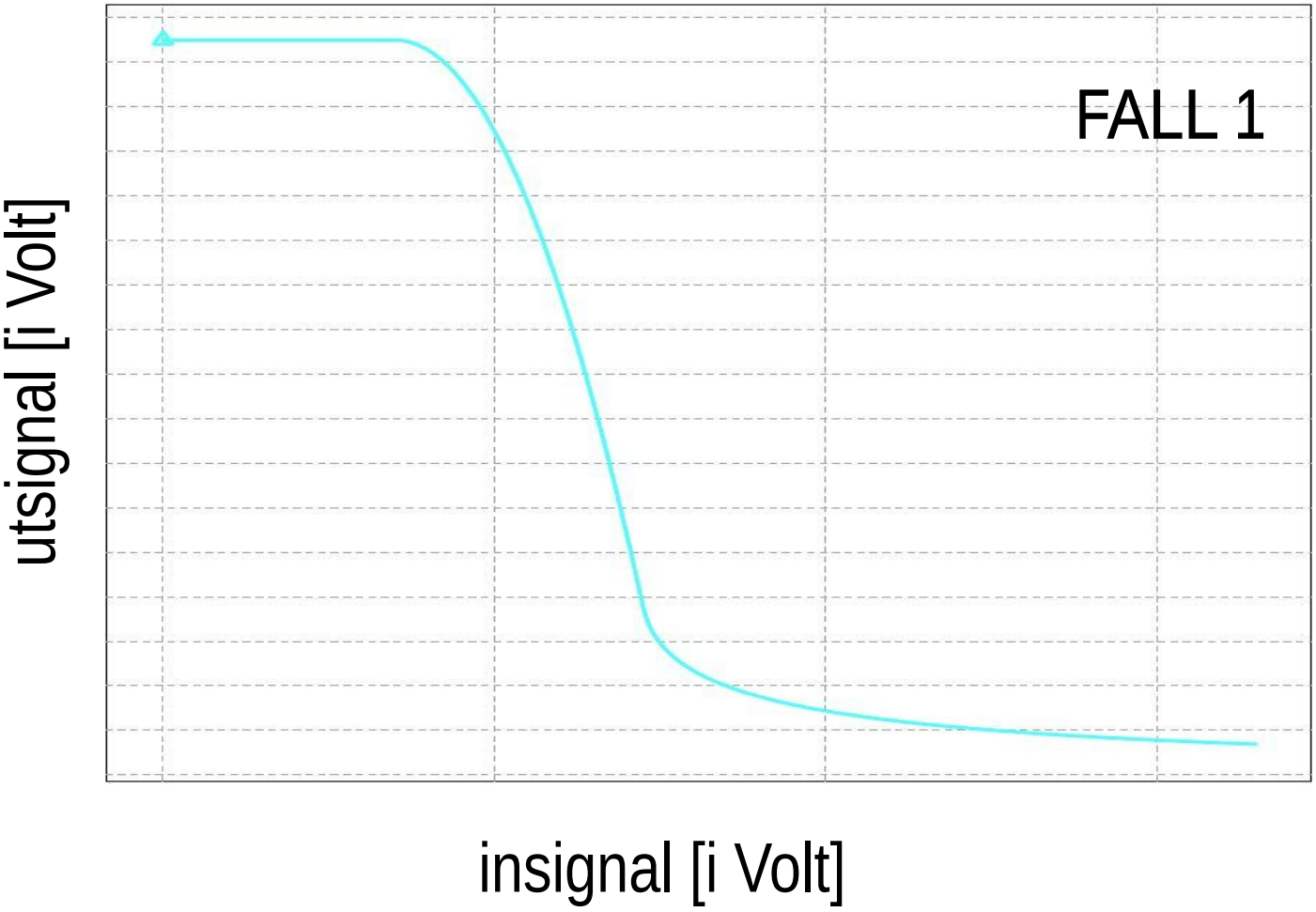
# Vi behöver icke-linjära komponenter ...



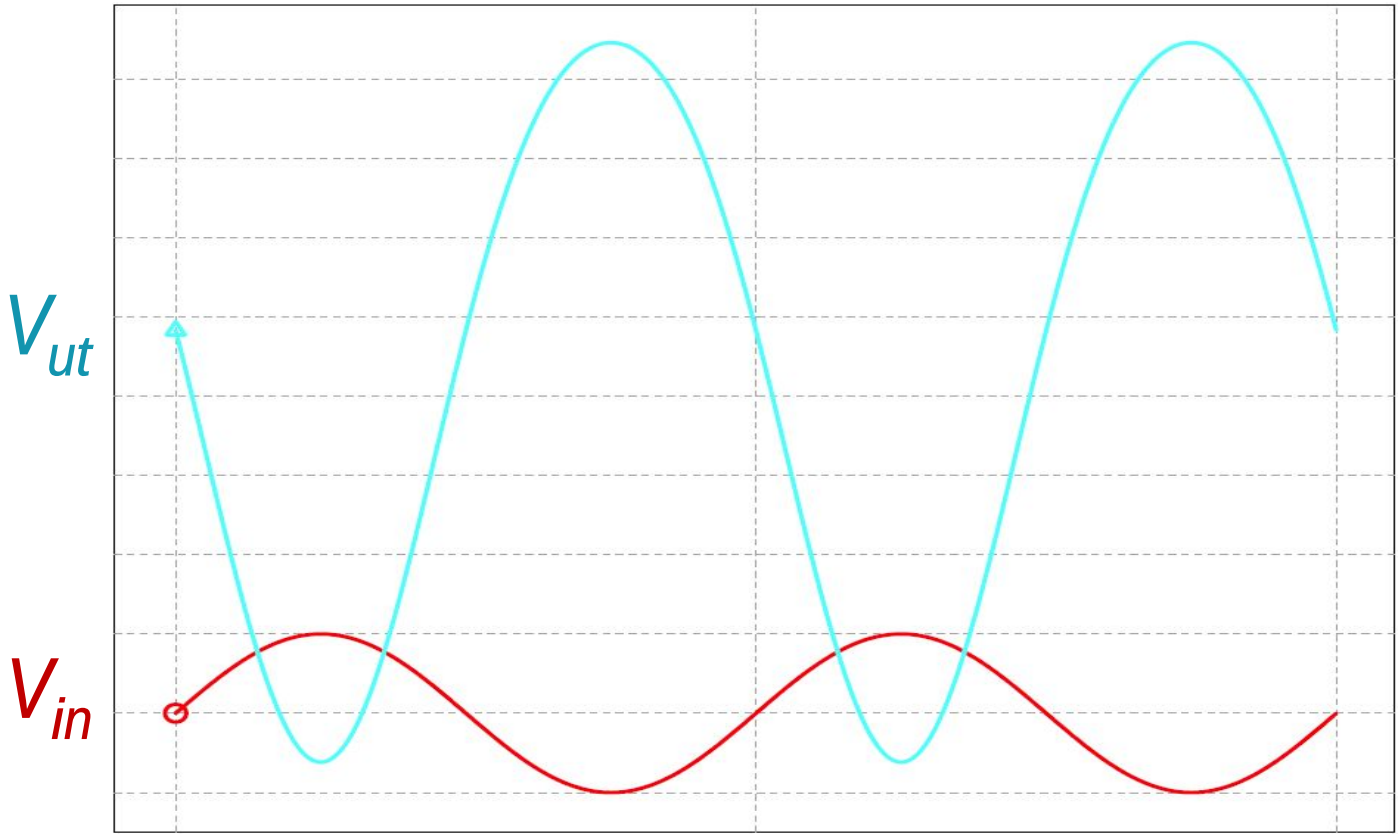




$$I_D = \frac{k}{2}(V_{GS} - V_T)^2$$

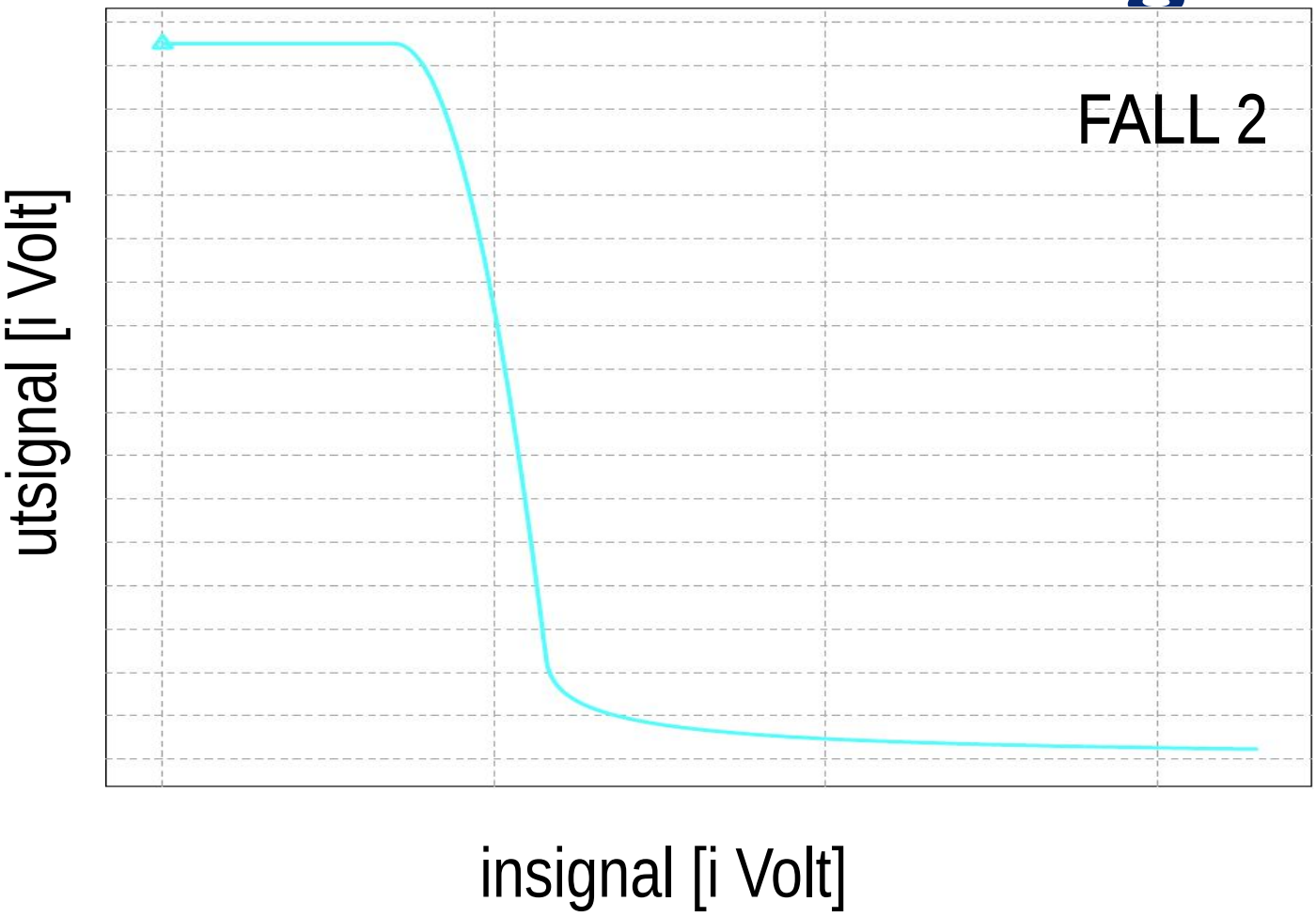
# … för då kan vi få hög förstärkning!



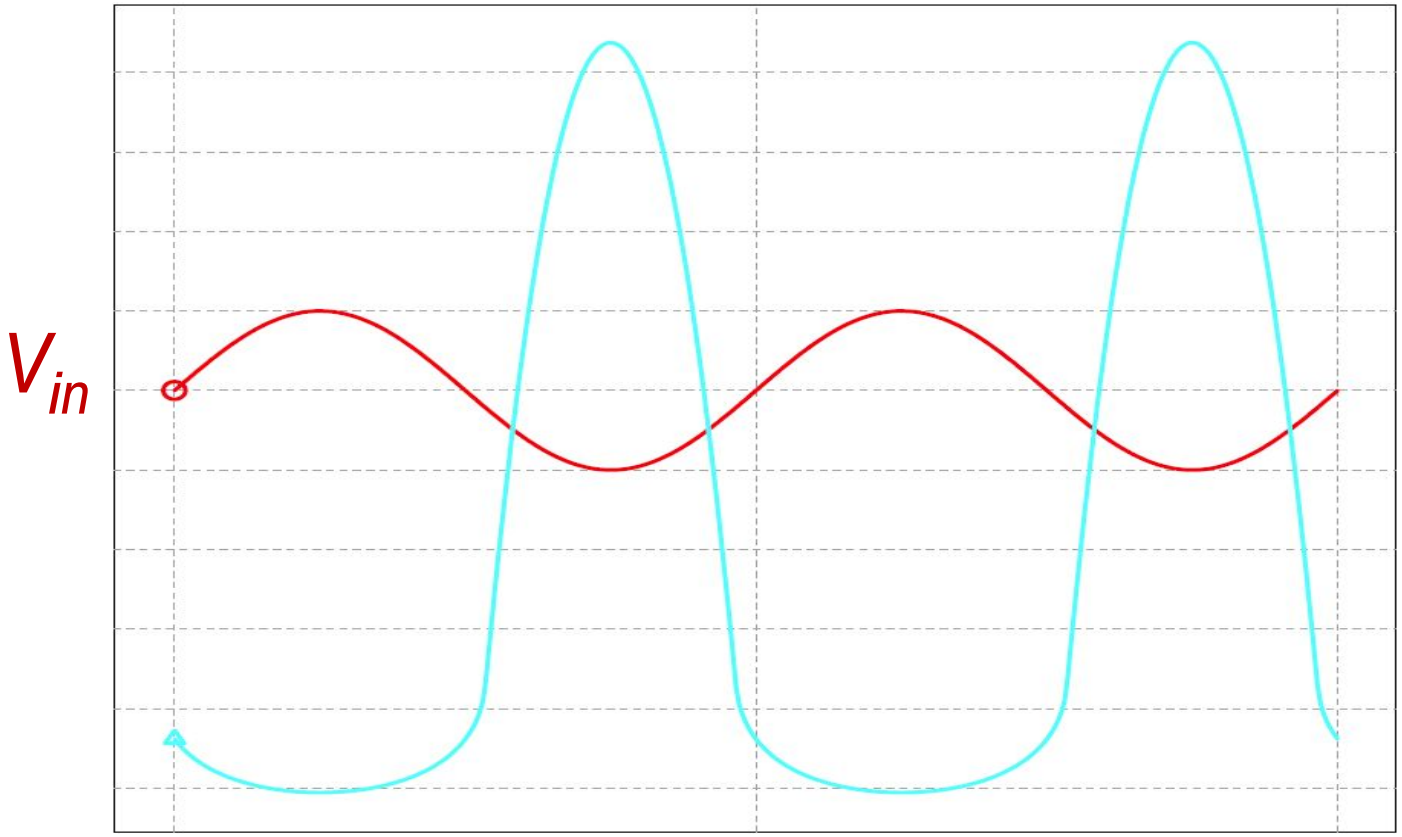
# Simulering av FALL 1



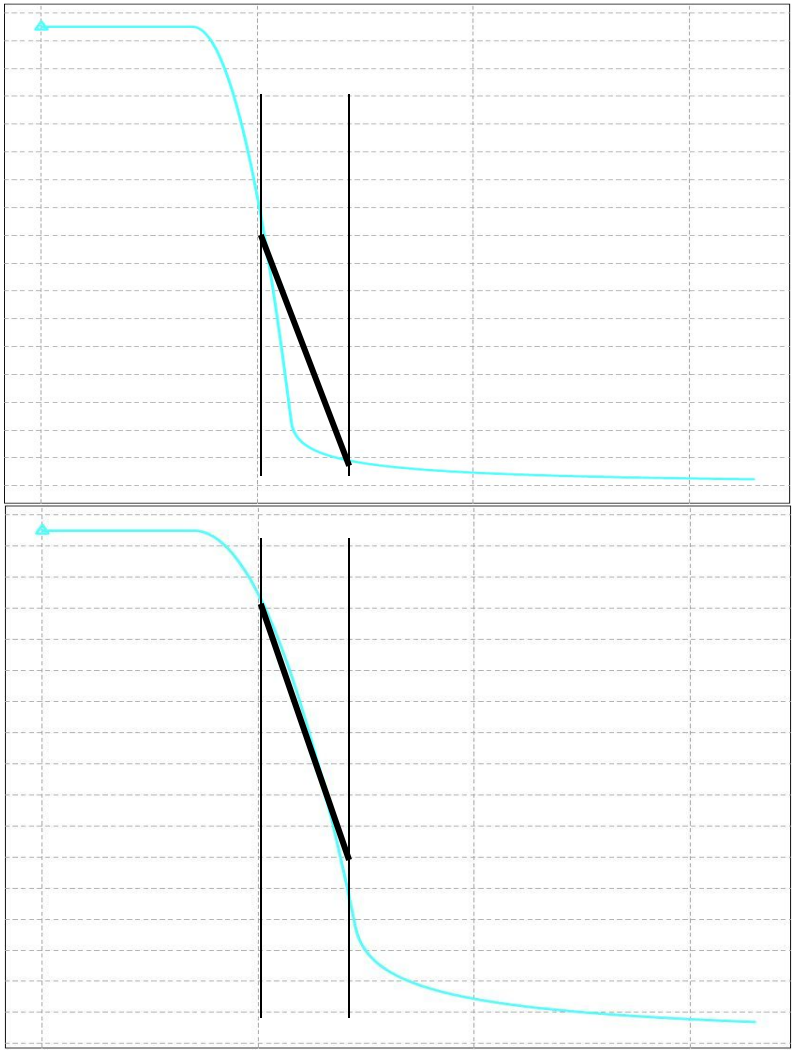
# Större transistor ⇒ större förstärkning



# Simulering av FALL 2



# Vad hände?



# Digitala grindar är förstärkare

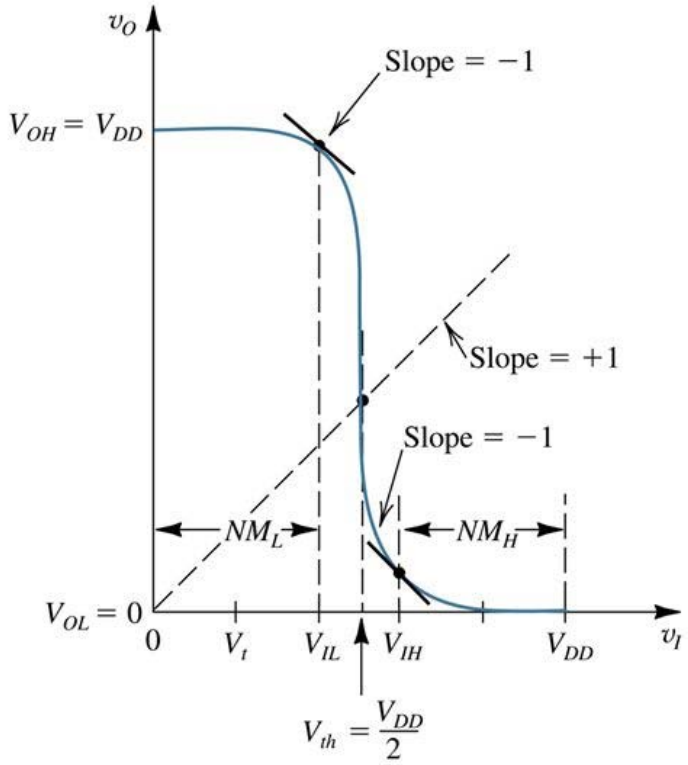
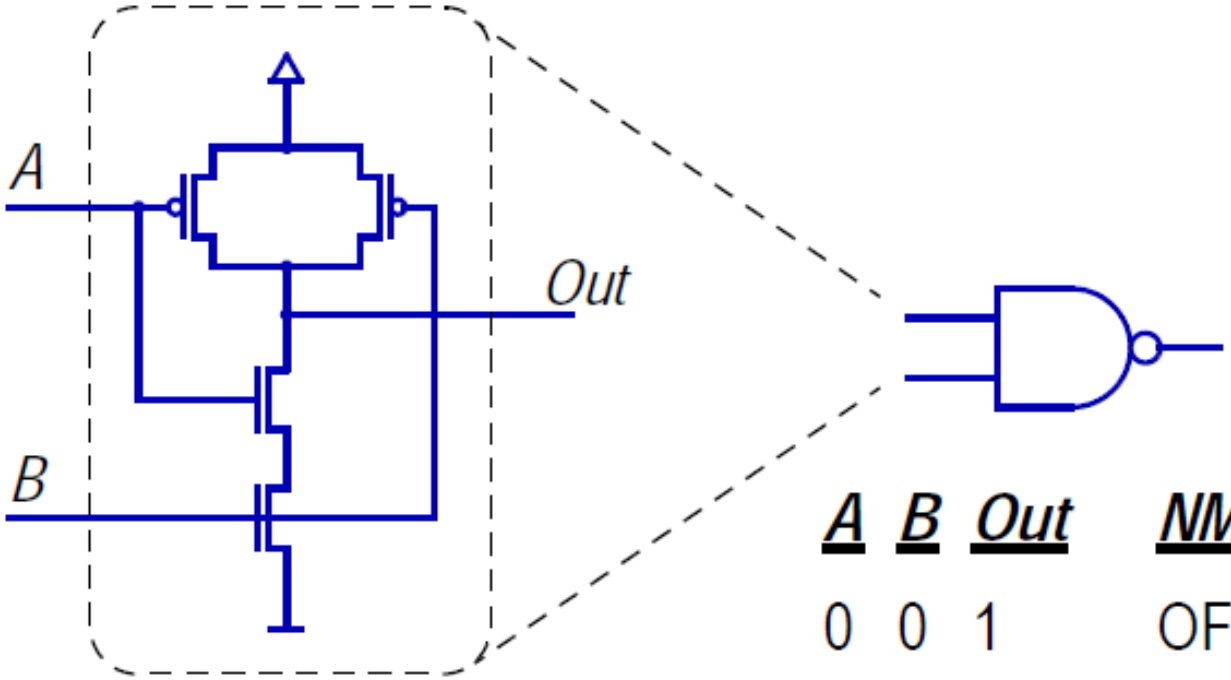



**Fig. 13.5** The voltage transfer characteristic (VTC) of the CMOS inverter when $Q_N$ and $Q_P$ are matched.

Digital teknik är robust mot brus:

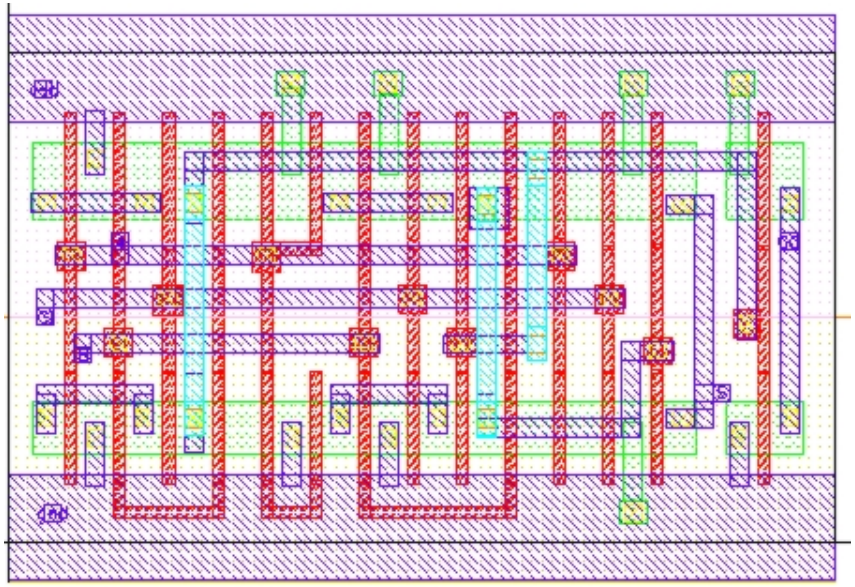
Hög störmarginal.

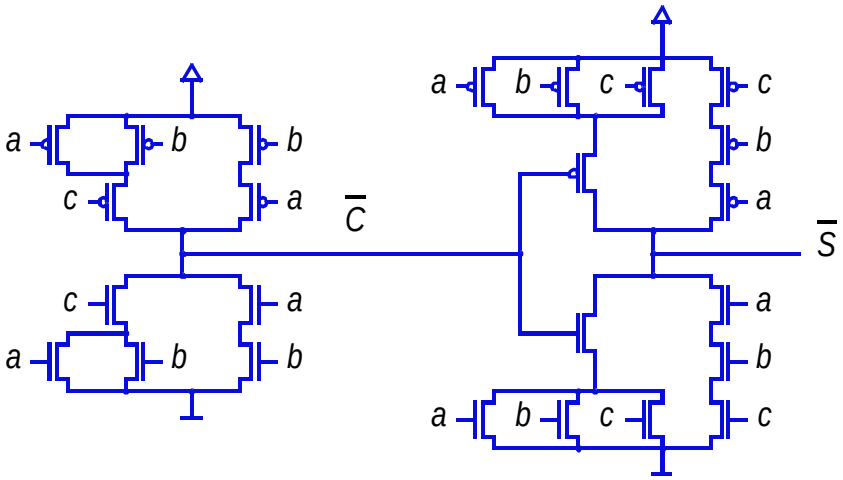
# NAND-grind



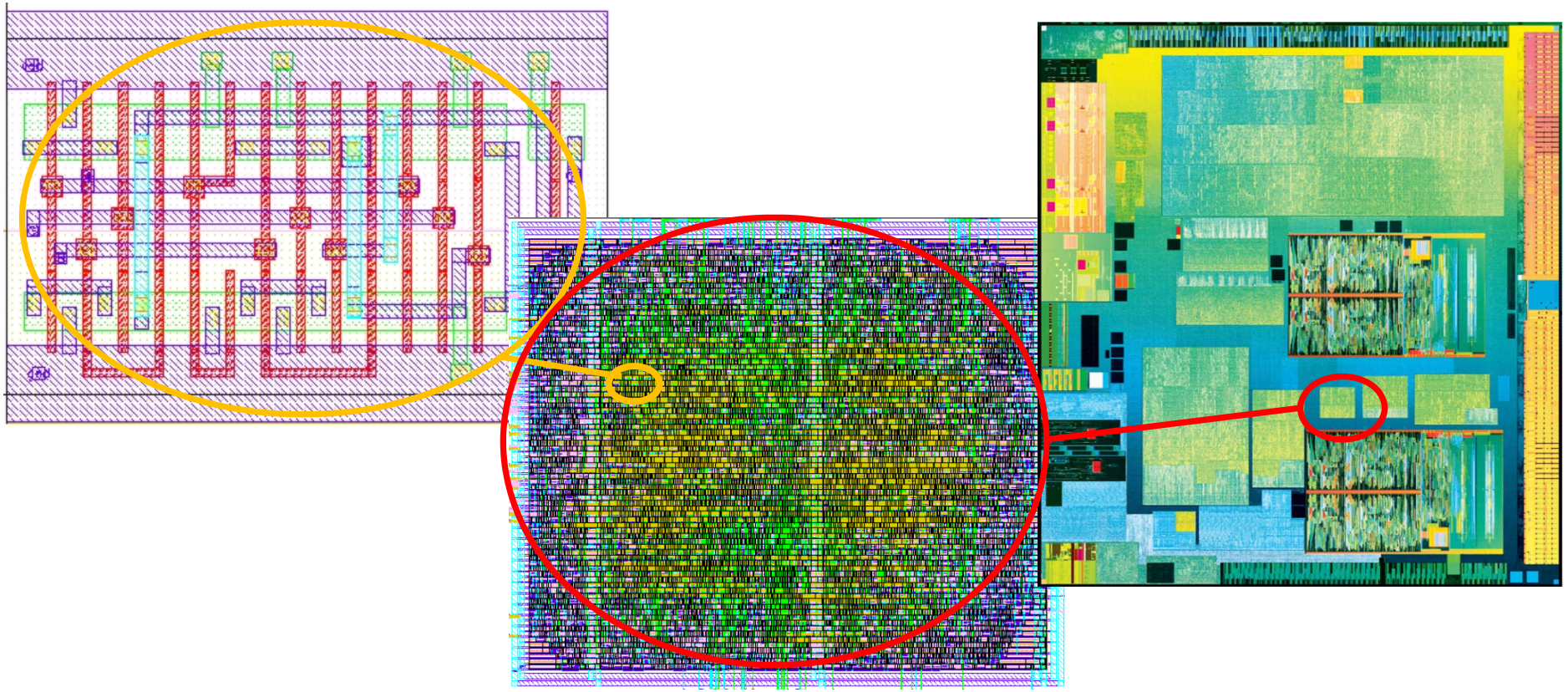

| A | B | Out | NMOS | PMOS |
|---|---|---|---|---|
| 0 | 0 | 1 | OFF | ON |
| 0 | 1 | 1 | OFF | ON |
| 1 | 0 | 1 | OFF | ON |
| 1 | 1 | 0 | ON | OFF |

# Schema och layout för heladderare

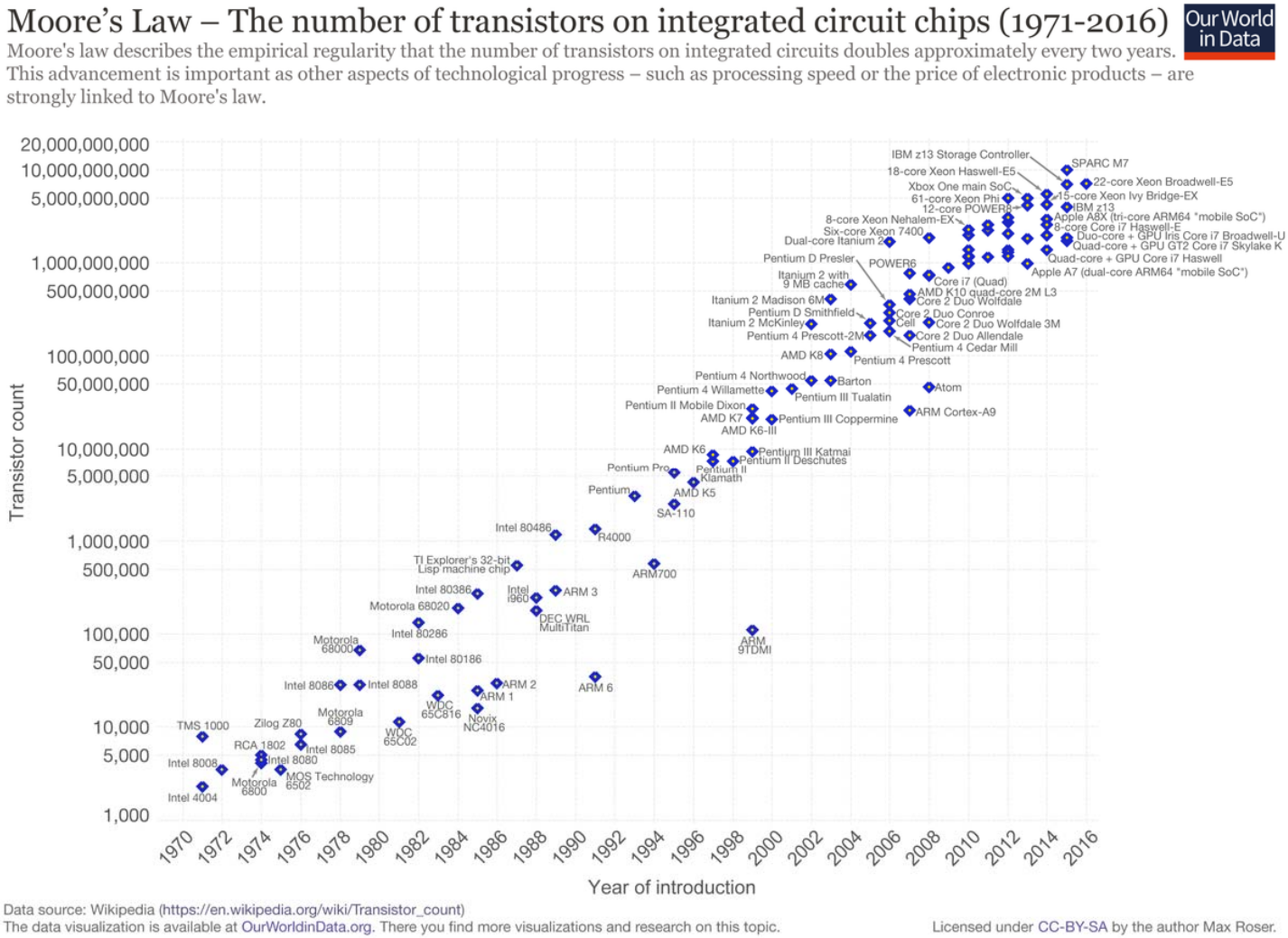




# Jakt på densitet = funktionalitet

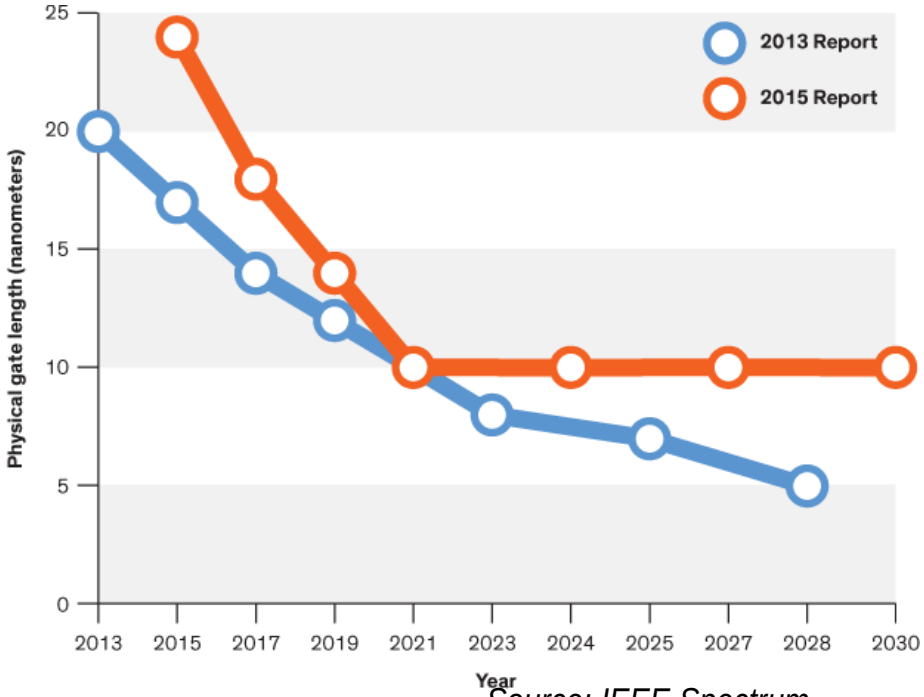


# Skalning … Moore’s lag




Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

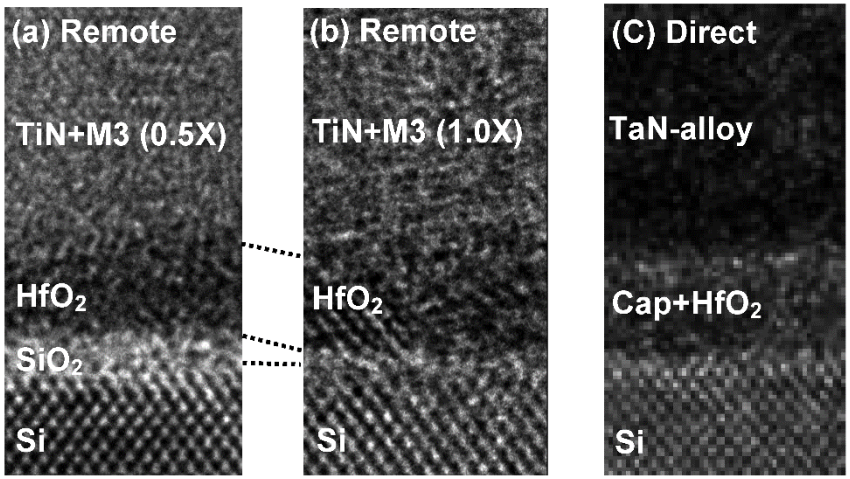
# Slutet på en era

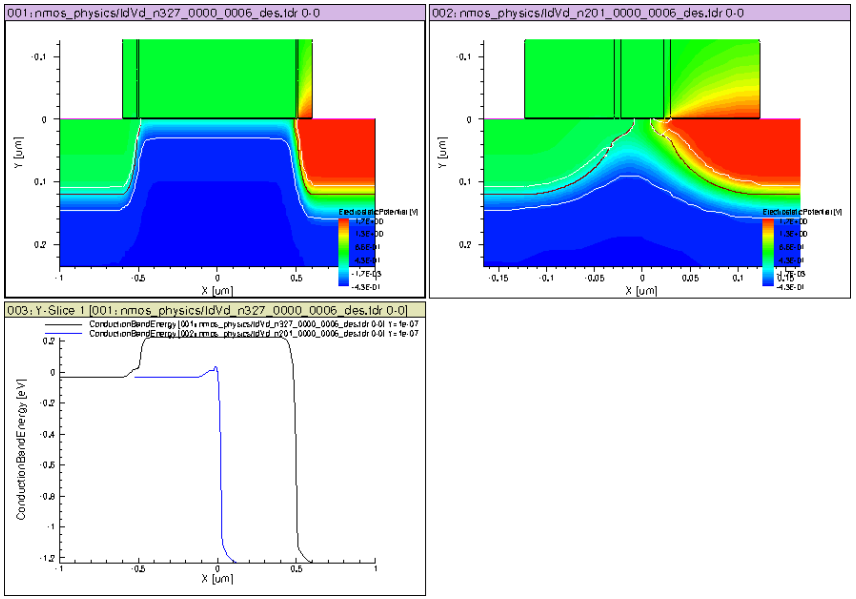



*Source: IEEE Spectrum*

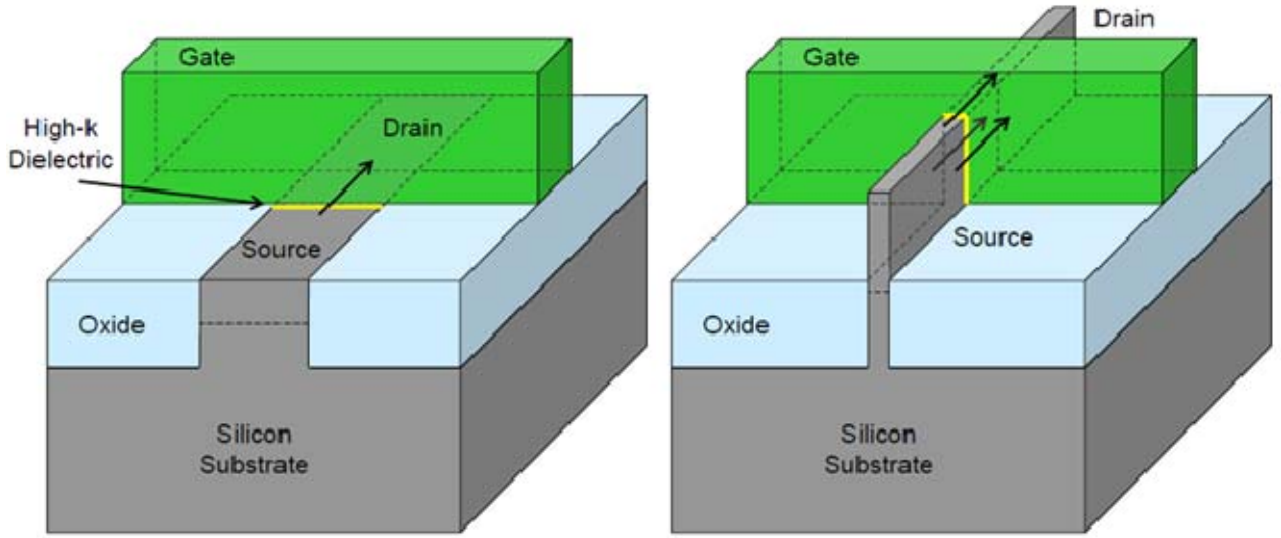
- Kiselatomen ~¼ nm
- Hittills har endast två chipstillverkare nått 7 nm.

# Tunna lager, korta kanaler



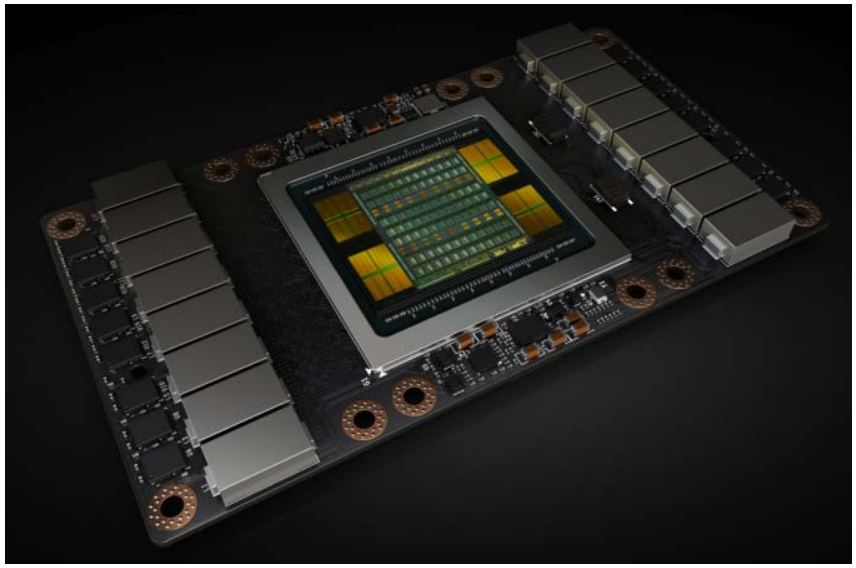



# 2D -> 3D: FinFET




Source: tek.no

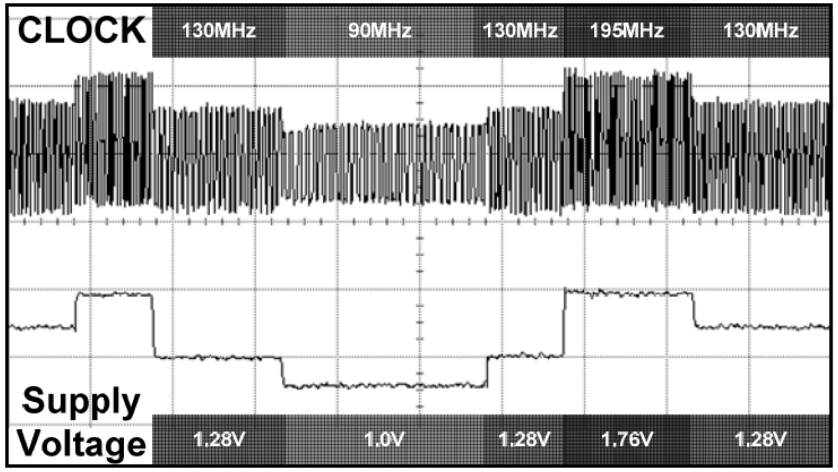
# Investera eller avvakta ?

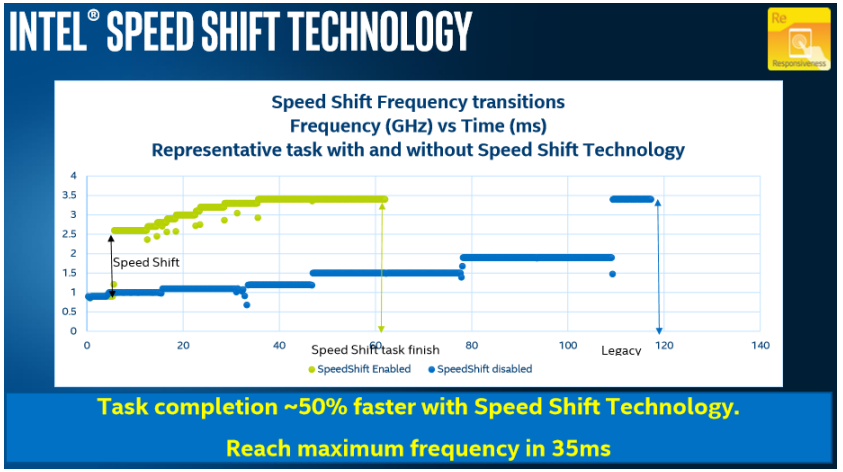


*Source: NVIDIA*

- NVIDIA Volta GPU @ 12 nm
  - 815 $mm^2$
  - 21 miljarder transistorer
  - TDP 300 W …
    vid 1 V, vad blir strömmen?

# Adaptiva tekniker allt viktigare



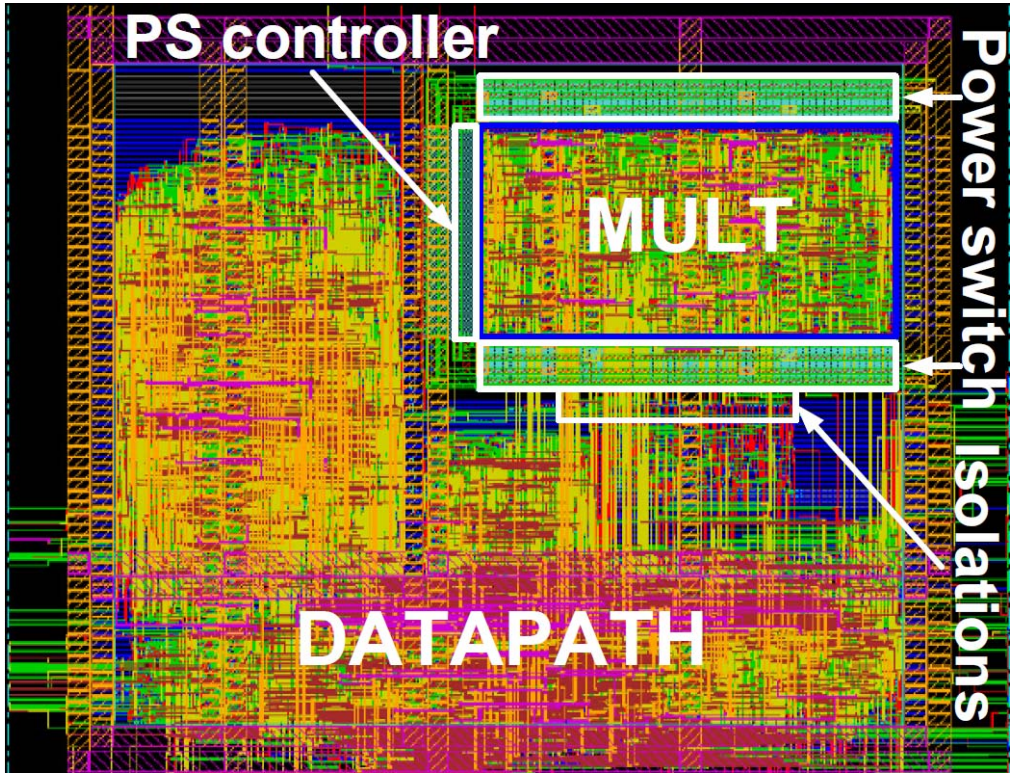




- Spara ström genom att anpassa spänningen till workload: $P_{sw} = f\,\alpha C\,V_{DD}^2$

# Accelerera delar av koden

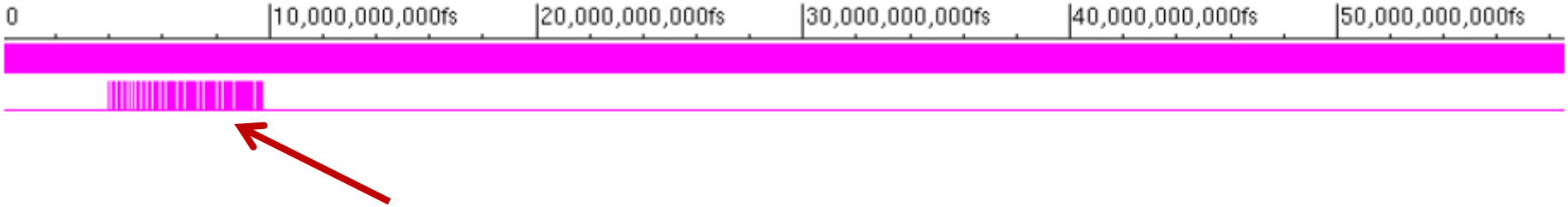
```
1319 00000000AE4240000000340101880 - 000057 [PCGetPC,PCJumpSA 13,RegRead2 ...
1320 000000F040000000000039003E0 - 000058 [LSWrite LSW 4 Alu Rslt ...
1321 00000000000000000000029000 - 000013 [RegRead1 R5,RegRead2 R4]
1322 0EC0000000800000002000F8000 - 000014 [MultRegWrite,Mult Regbank_Out2 ...
1323 000C00040000C000000005800000 - 000015 [PCJumpDA Regbank_Out1,LSRead LSW_4
1324 0000000AA000000000003900040 - 000016 [LSWrite LSW 4 Ls Read Mult LSW ...
1325 00000000000000000080004000 - 000059 [PCImm (Just 2),RegRead2 R16]
1326 000000000E400000000080088001 - 000060 [PCImm (Just 2),RegRead1 R17,ALUOpc
   ⋮              ⋮              ⋮                    ⋮
1337 00000000AE4240000000340101880 - 000057 [PCGetPC,PCJumpSA 13,RegRead2 R6 ...
1338 000000F040000000000039003E0 - 000058 [LSWrite LSW 4 Alu Rslt ...
1339 00000000000000000000029000 - 000013 [RegRead1 R5,RegRead2 R4]
1340 0EC0000000800000002000F8000 - 000014 [MultRegWrite,Mult Regbank_Out2 ...
1341 000C00040000C000000005800000 - 000015 [PCJumpDA Regbank_Out1,LSRead LSW_4
1342 0000000AA000000000003900040 - 000016 [LSWrite LSW 4 Ls Read Mult LSW ...
1343 00000000000000000080004000 - 000059 [PCImm (Just 2),RegRead2 R16]
1344 000000000E400000000080088001 - 000060 [PCImm (Just 2),RegRead1 R17,ALUOpc
```

# Dedicerad accelerator

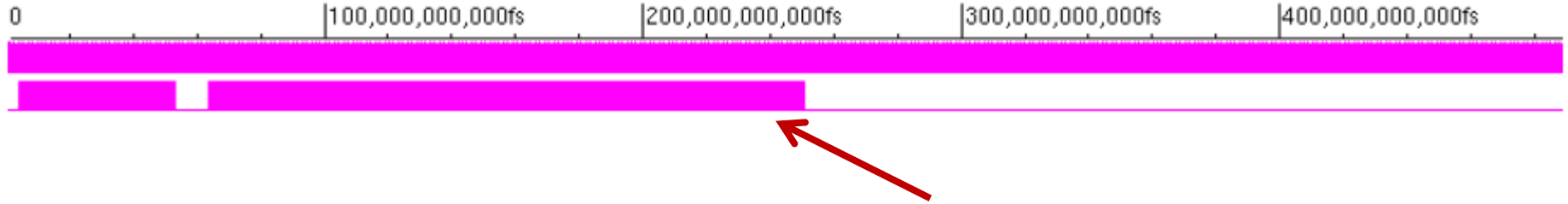


# Start-stopp av accelerator

Benchmark: EEMBC Autocorrelation




Benchmark: EEMBC FFT

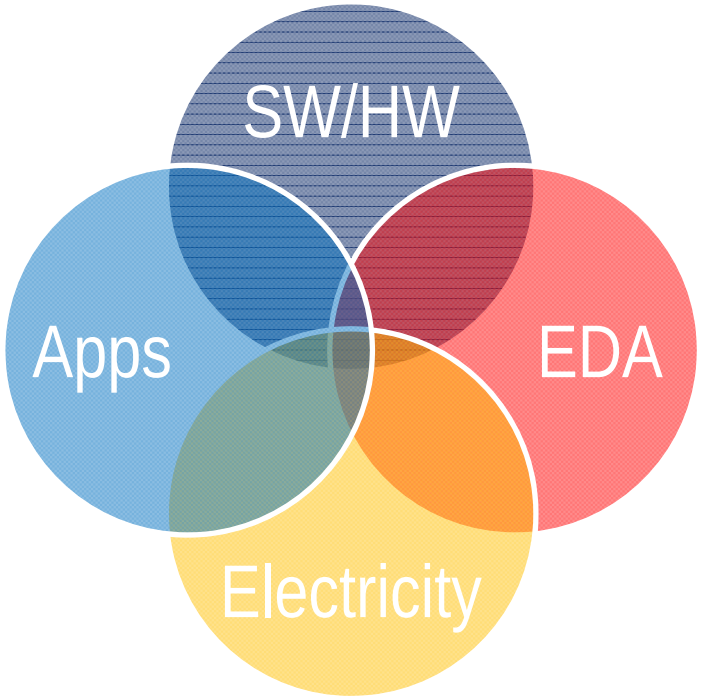


# Digital elektronik …en utmaning

- Mer funktionalitet förväntas.
- Högre prestanda förväntas.
- Samtidigt, håll ned energiförbrukning.

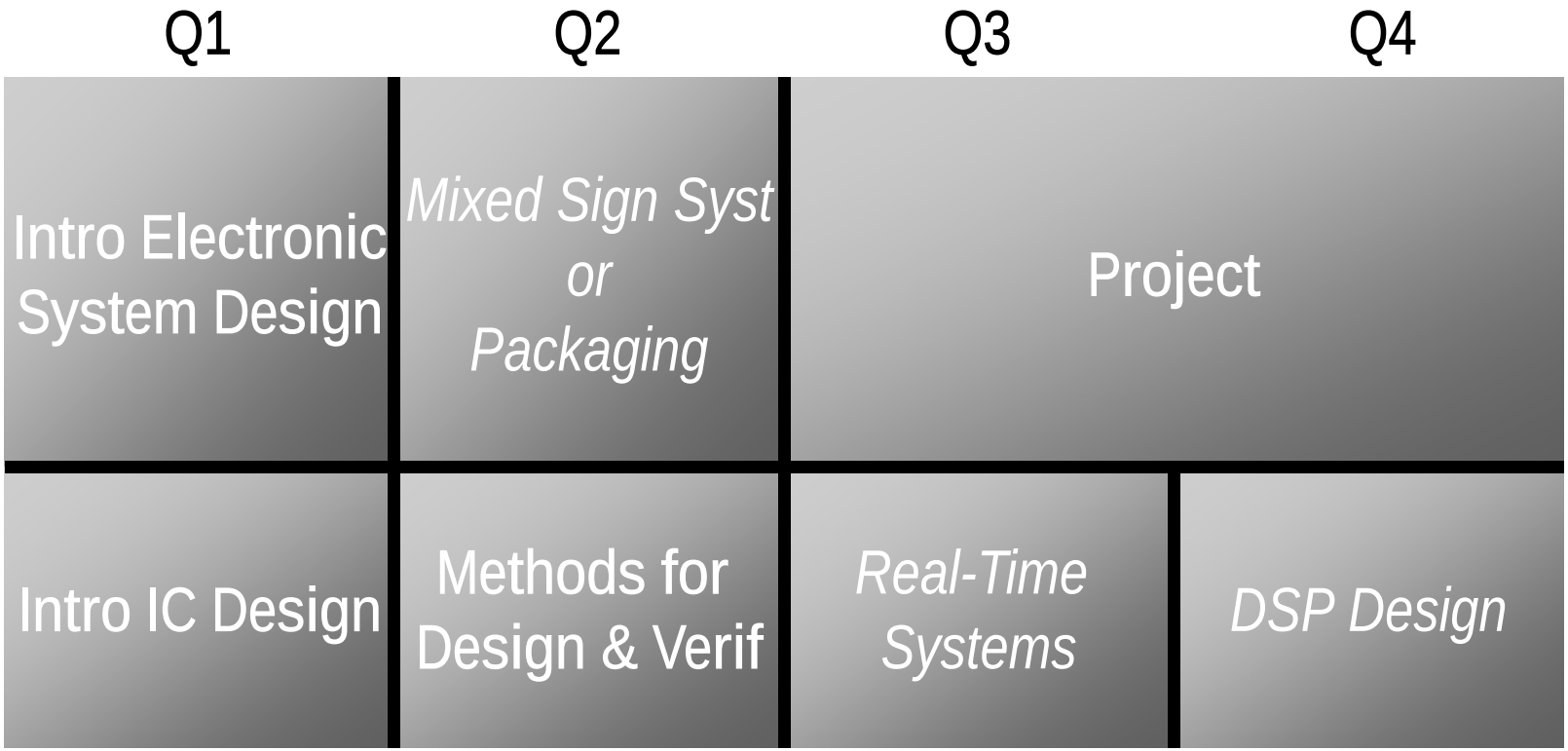
- Hårdvara bättre än mjukvara för prestanda och energi.
- Mjukvara bättre än hårdvara för funktionalitet, speciellt vid förändring av funktionalitet.

# Embedded Electronic System Design (MPEES)




Komplex teknologi och metodik ⇒
möjligheter & begränsningar

# MPEES åk 1


Q1
Q2
Q3
Q4
Intro Electronic System Design
Mixed Sign Syst or Packaging
Project
Intro IC Design
Methods for Design & Verif
Real-Time Systems
DSP Design