Design and Measurement of On-chip di/dt Detector Circuit for Power Supply Line

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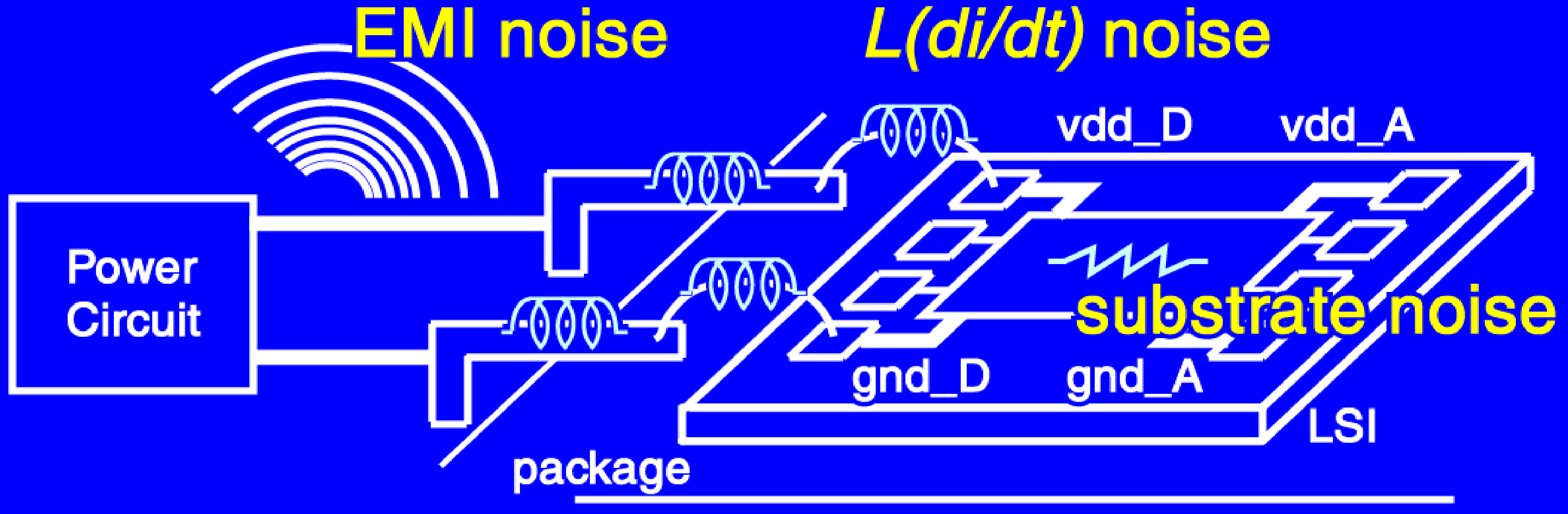
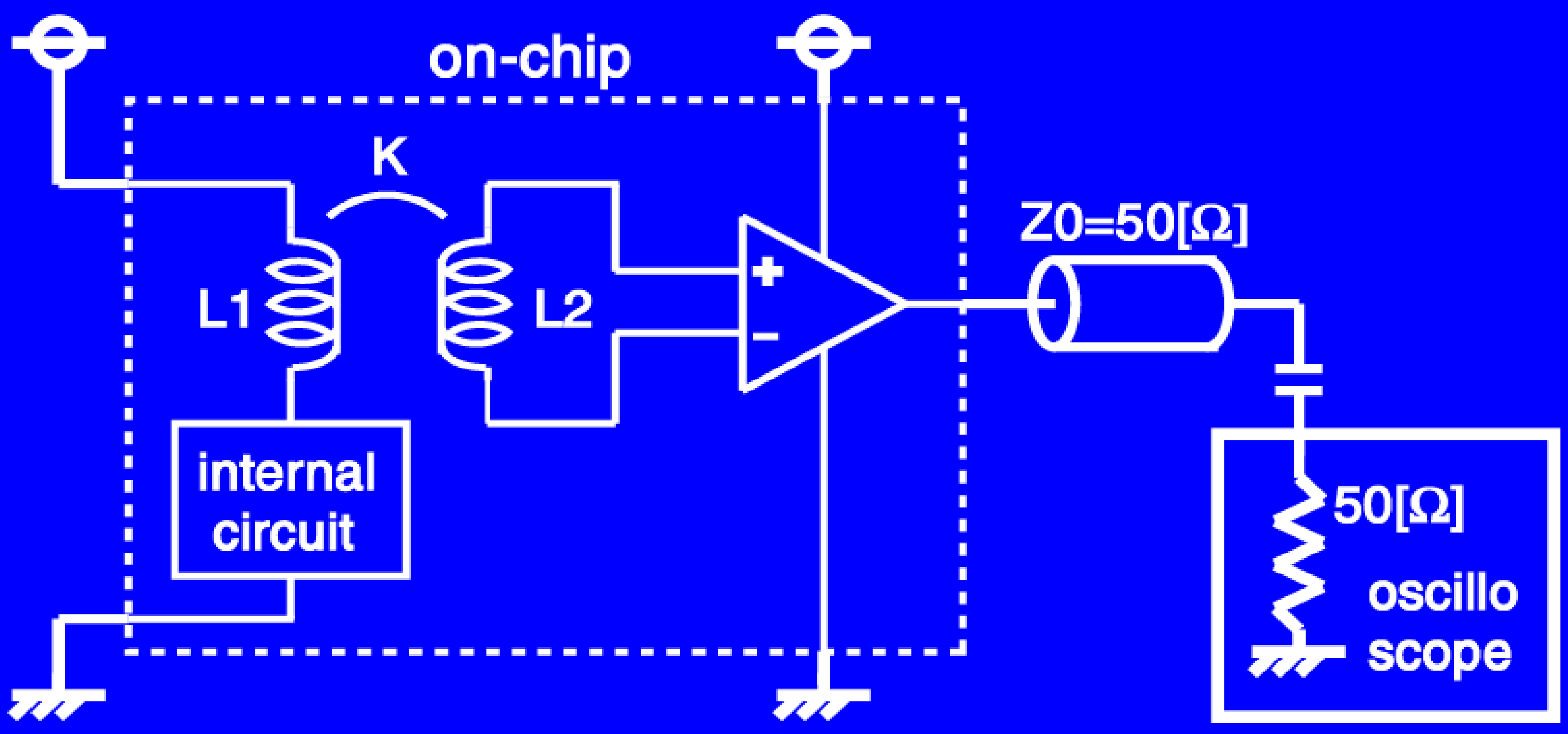
Background – di/dt and SI

- Power supply noise : L(di/dt), RI noise
- EMI noise : caused by di/dt
- Substrate noise : related to power noise
- Need to measure di/dt

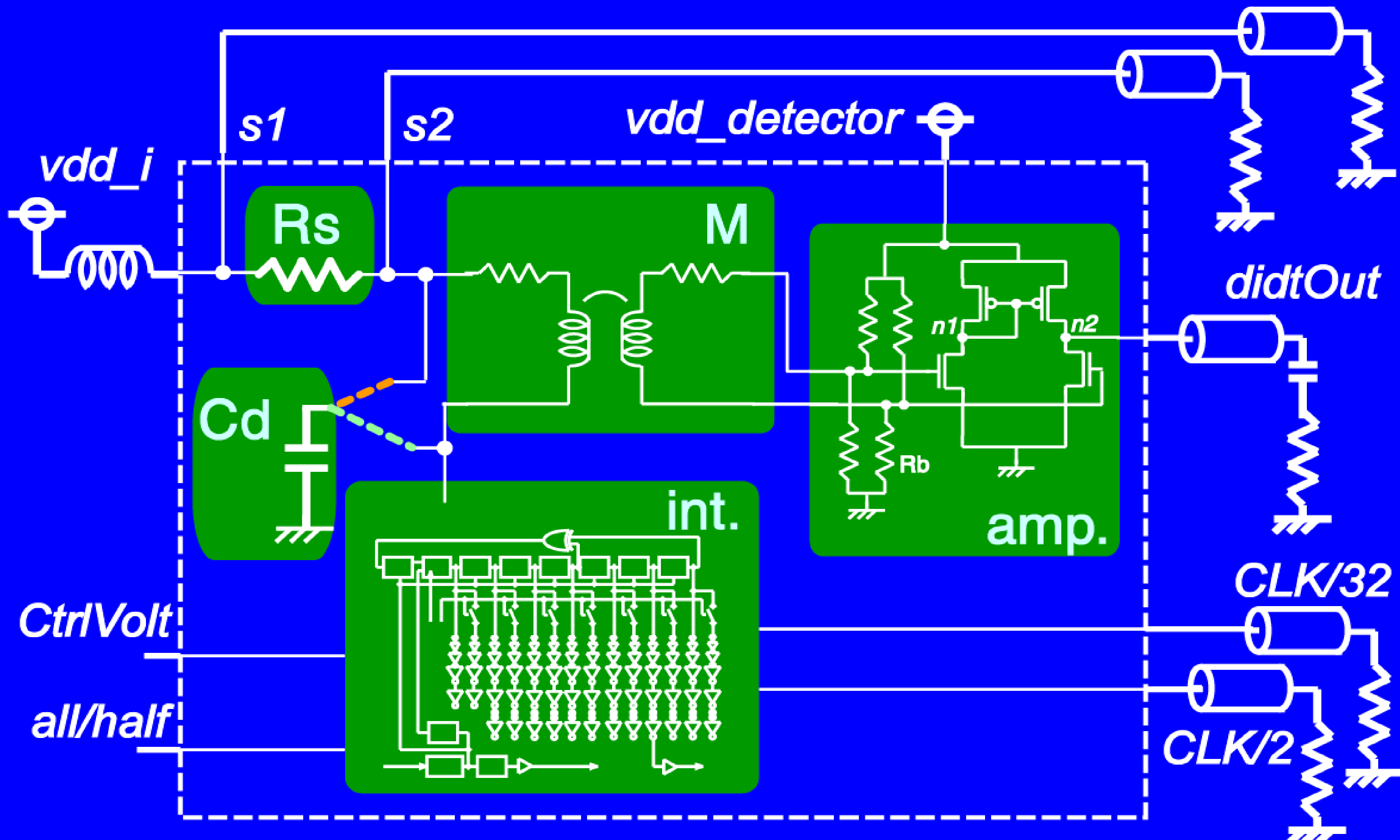


Block Diagram

- L2 picks up the di/dt, induce the voltage
- Amplifier amplifies/output the voltage

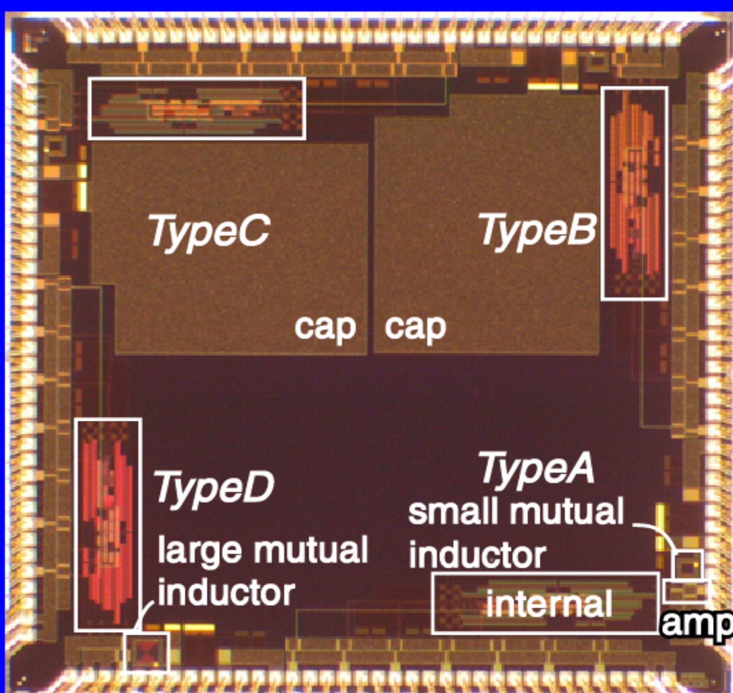


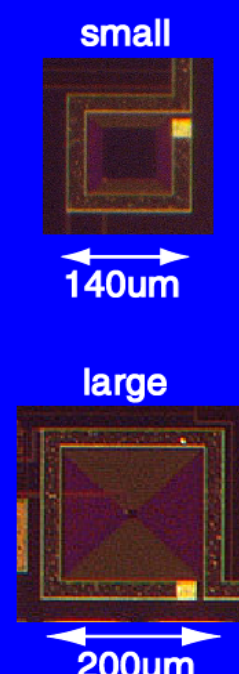
Whole Circuit / Meas. Setup

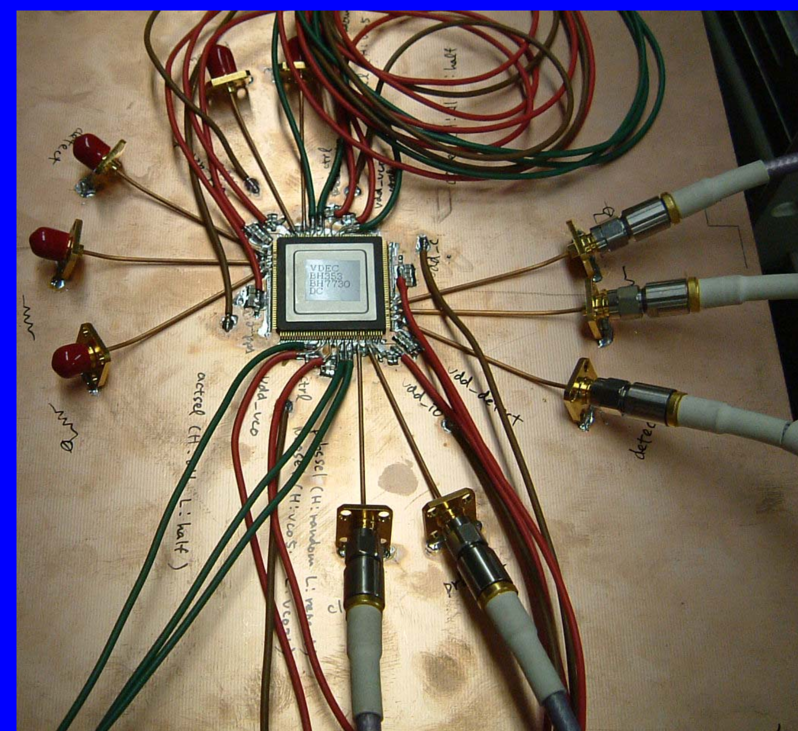


Chip Photograph

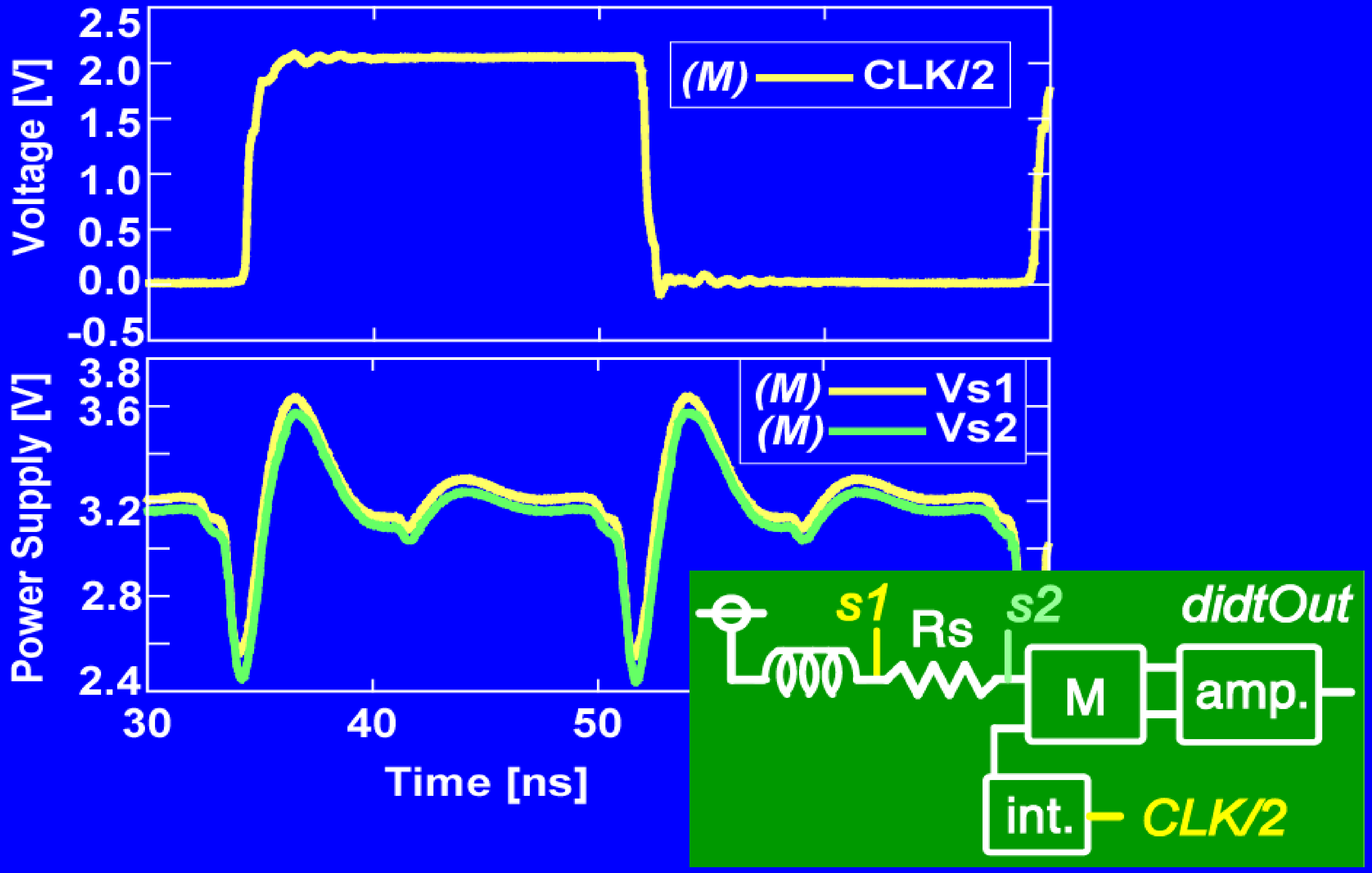
- 0.35um 3ML 2P standard CMOS
- The chip is mounted on a Cu board





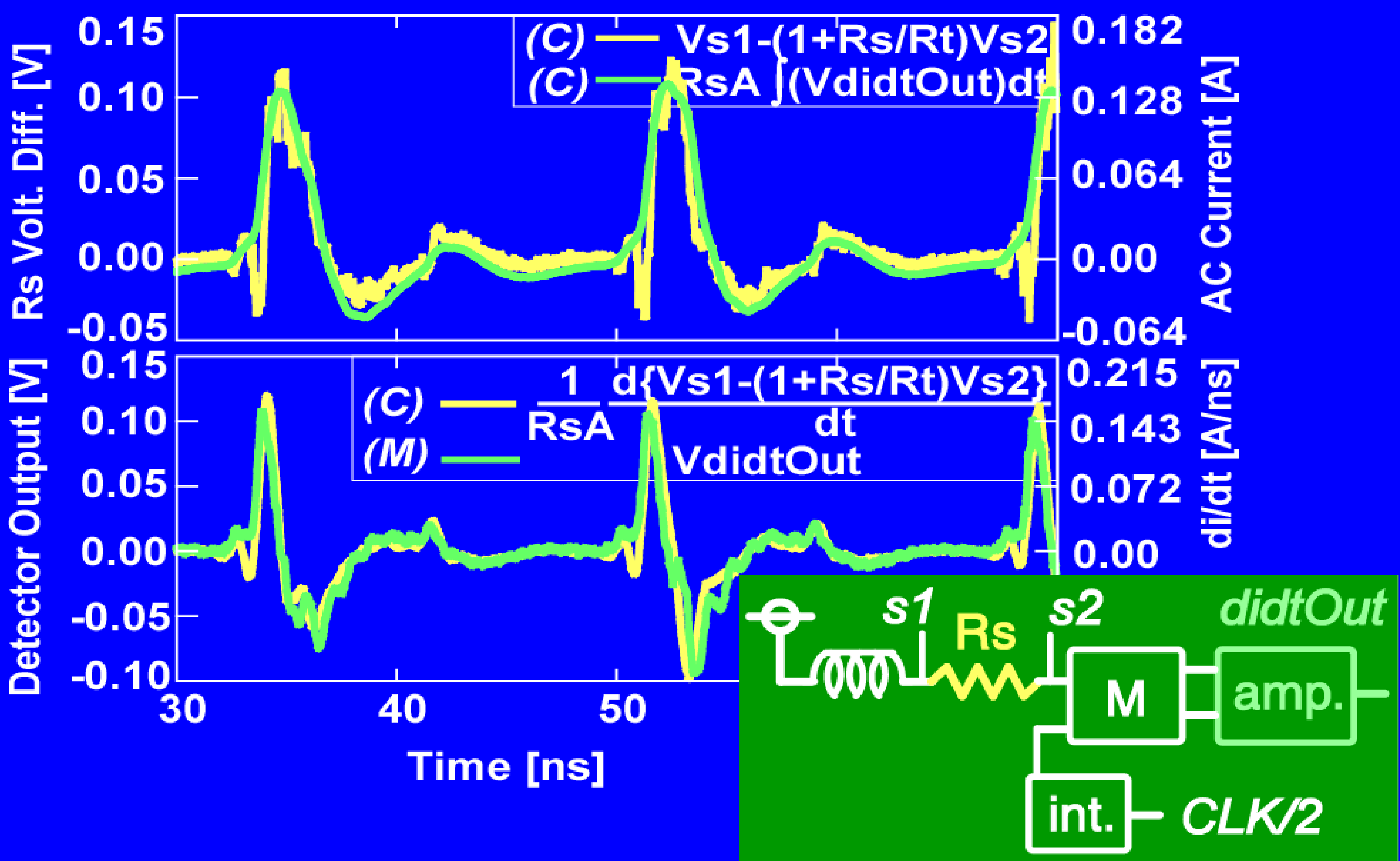


Waveforms #1



2.5
2.0
1.5
1.0
0.5
0.0
-0.5
Voltage [V]
(M) CLK/2
3.8
3.6
3.2
2.8
2.4
Power Supply [V]
(M) Vs1
(M) Vs2
30
40
50
Time [ns]
s1
Rs
s2
didtOut
M
amp.
int.
CLK/2

Waveforms #2



(C) Vs1-(1+Rs/Rt)Vs2
(C) RsA ∫(VdidtOut)dt
Rs Volt. Diff. [V]
AC Current [A]
0.15
0.10
0.05
0.00
-0.05
0.182
0.128
0.064
0.00
-0.064
(C) 1/RsA d{Vs1-(1+Rs/Rt)Vs2}/dt
(M) VdidtOut
Detector Output [V]
di/dt [A/ns]
0.15
0.10
0.05
0.00
-0.05
-0.10
0.215
0.143
0.072
0.00
30
40
50
Time [ns]
s1
Rs
s2
didtOut
M
amp.
int.
CLK/2

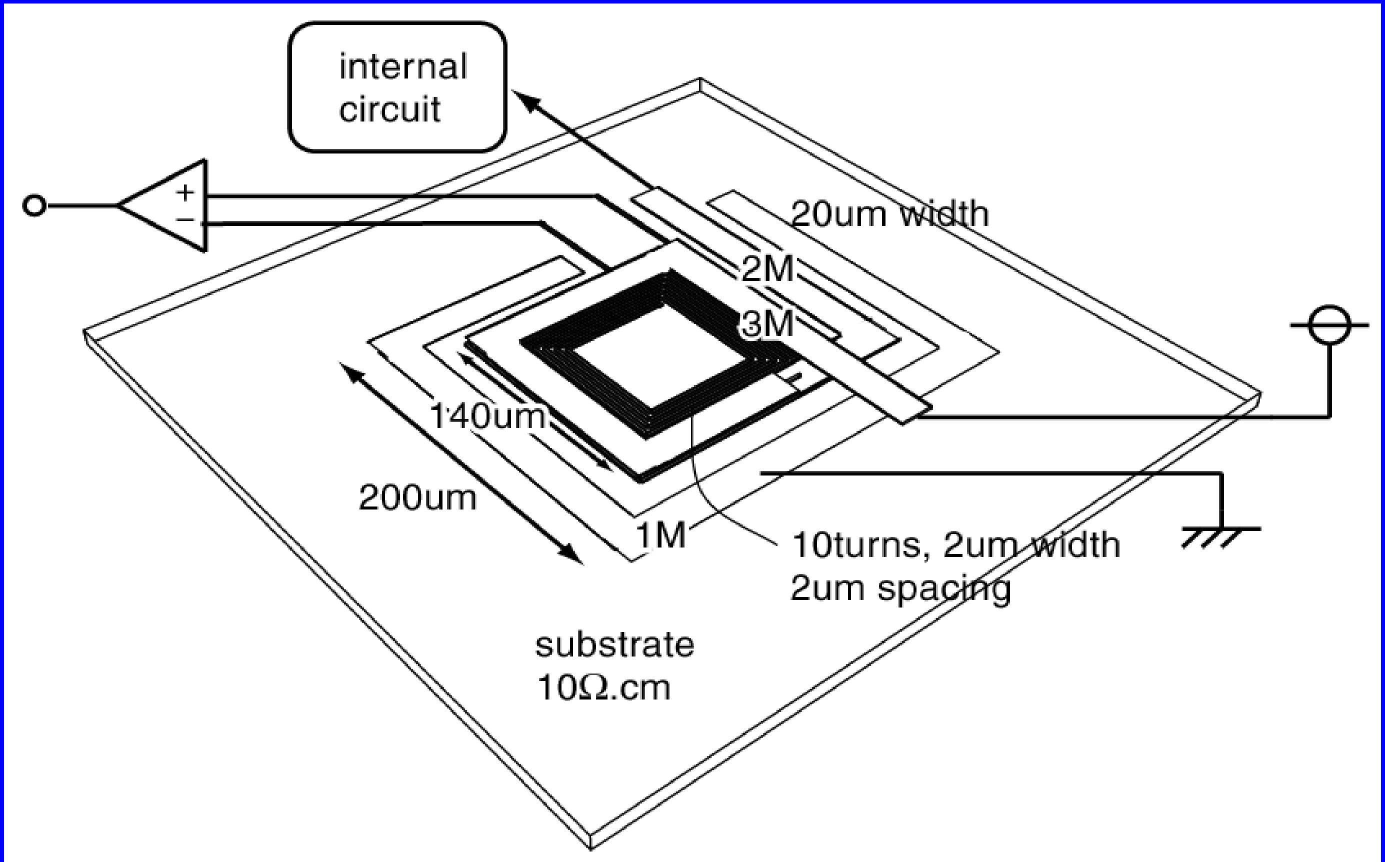
Summary

- On-chip di/dt detector is demonstrated
- It consists of a power supply line, underlying spiral inductor, an amplifier
- di/dt waveforms obtained from the di/dt detector and the resistor agree well
- Current waveform can be calculated by integrating the detector output by time

Small Slides

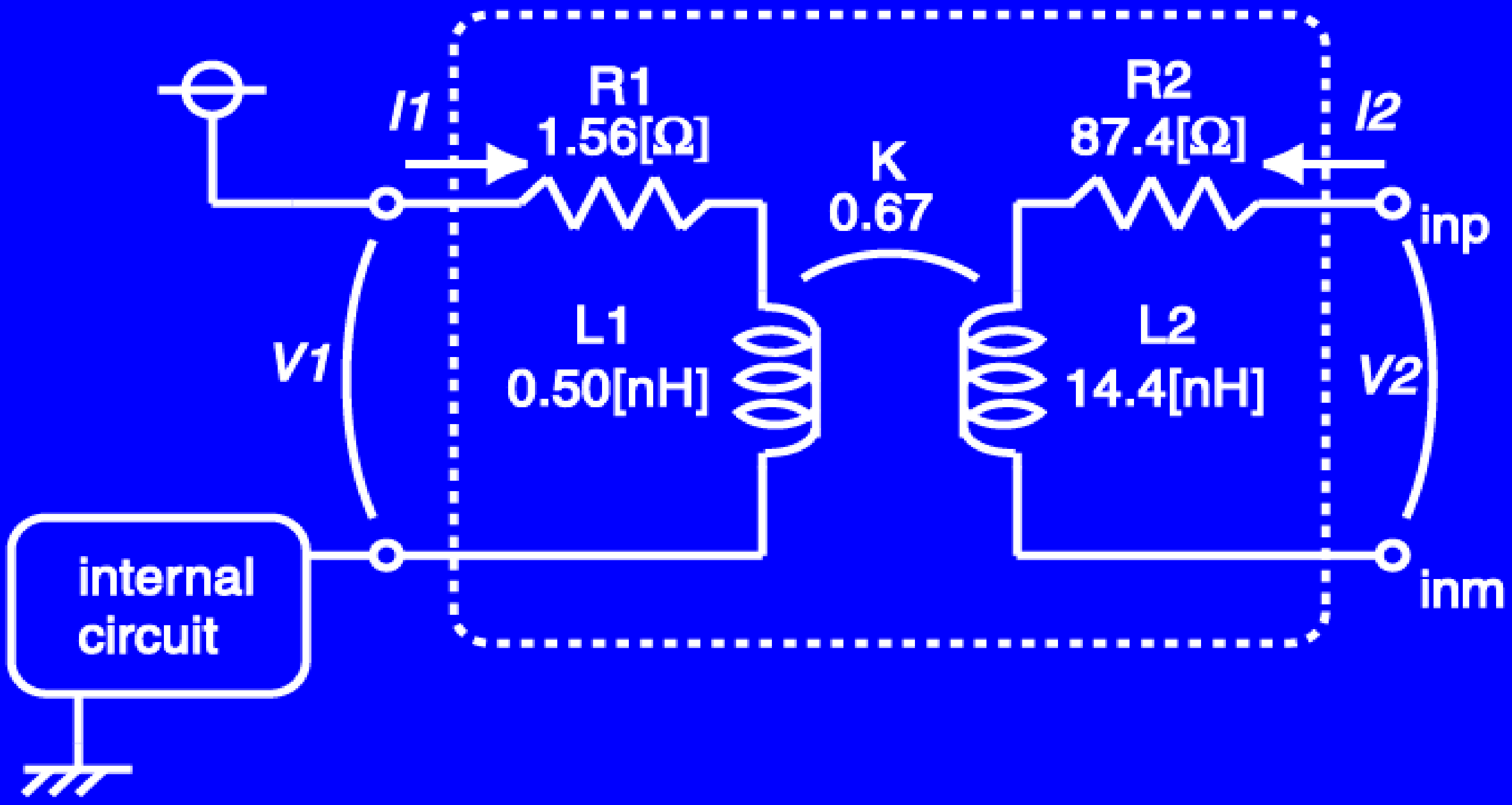
Mutual Inductor

- 0.35um, 3ML standard CMOS process



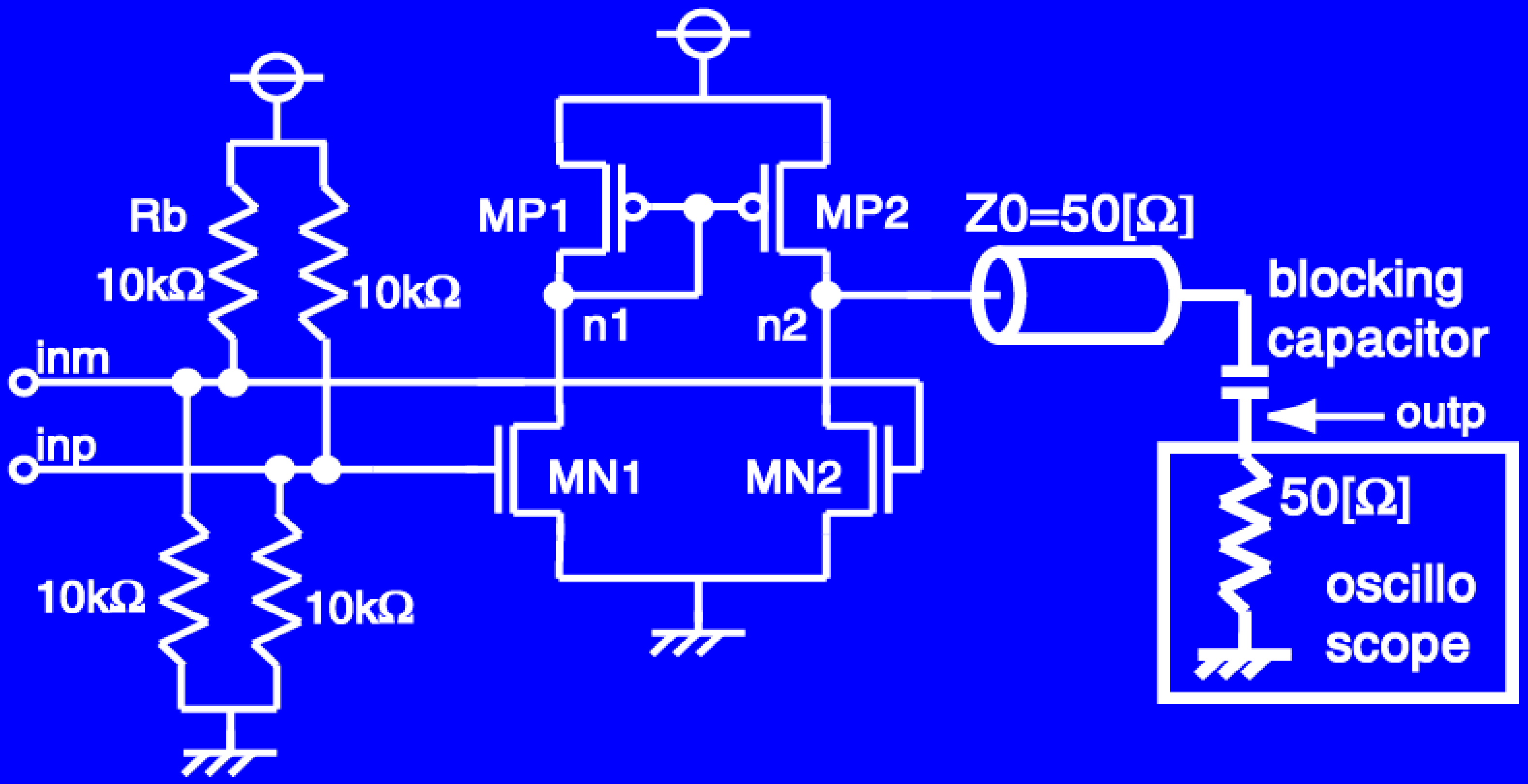
Equivalent Circuit

- Extracted by FastHenry

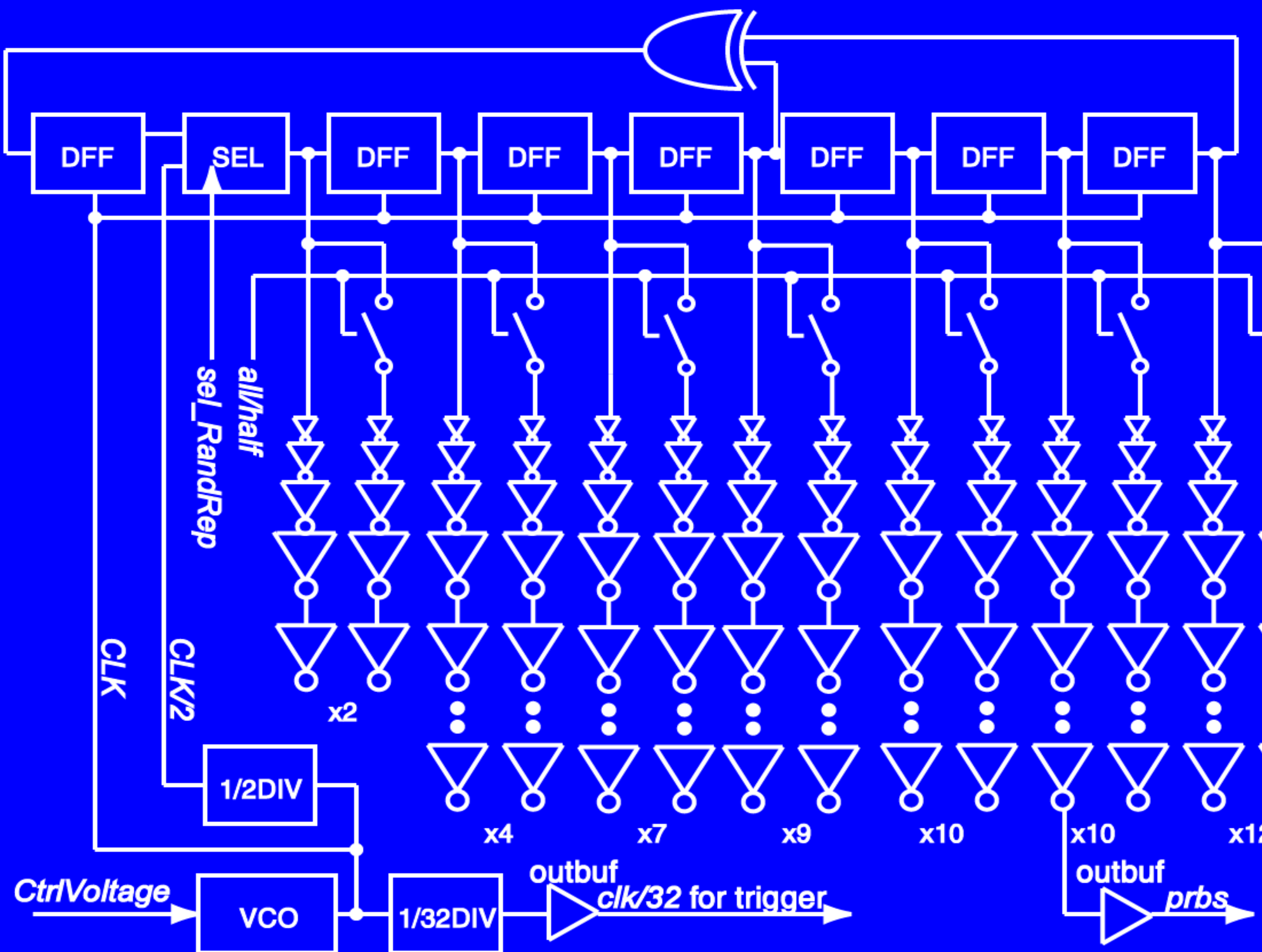


Amplifier/Output buffer

- **Gain: 0.39, fcut-off: 2.2GHz**
  output linearly: ±0.35V



Internal Circuit as Noise Source



Equations

$$V_2 = K\sqrt{L_1 L_2}\frac{dI_1}{dt}$$

$$V_{s1} - (1+\frac{R_S}{R_t})V_{s2} = R_S I_1$$

$$V_{didtOut} = GV_2 = GK\sqrt{L_1 L_2}\frac{dI_1}{dt}$$

$$\frac{dI_1}{dt} = \frac{1}{GK\sqrt{L_1 L_2}} V_{didtOut} = A_{v2didt} V_{didtOut}$$

$$A_{v2didt} = \frac{1}{GK\sqrt{L_1 L_2}}$$

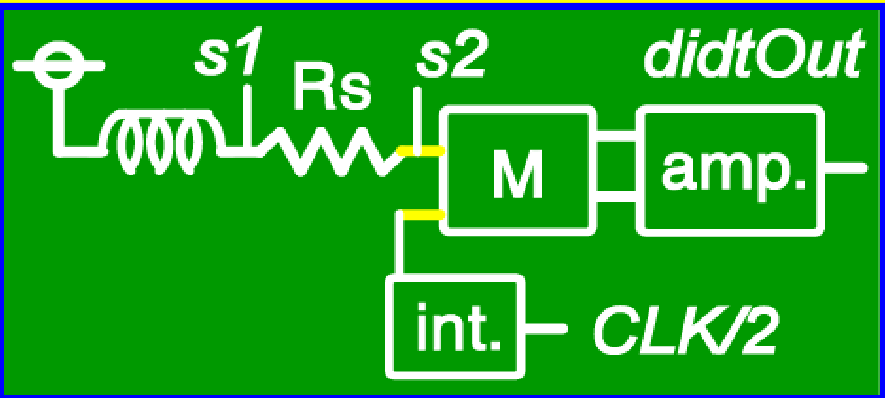
$$\frac{dI_1}{dt}_{range} = A_{v2didt} V_{amp\_outRange\_lin}$$

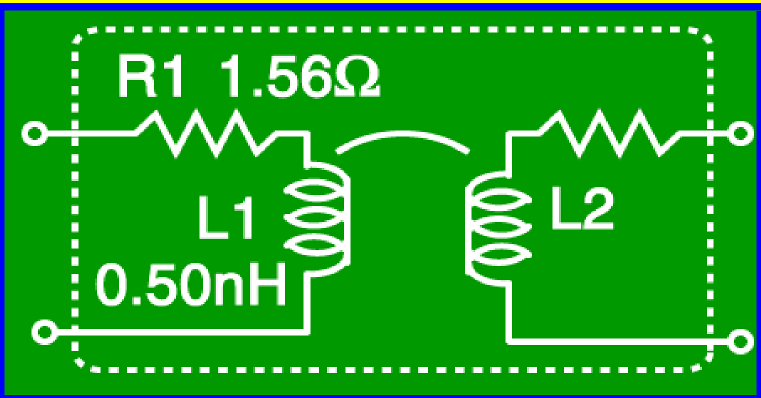
$$I_1 = A_{v2didt}\int V_{didtOut}\, dt + C$$

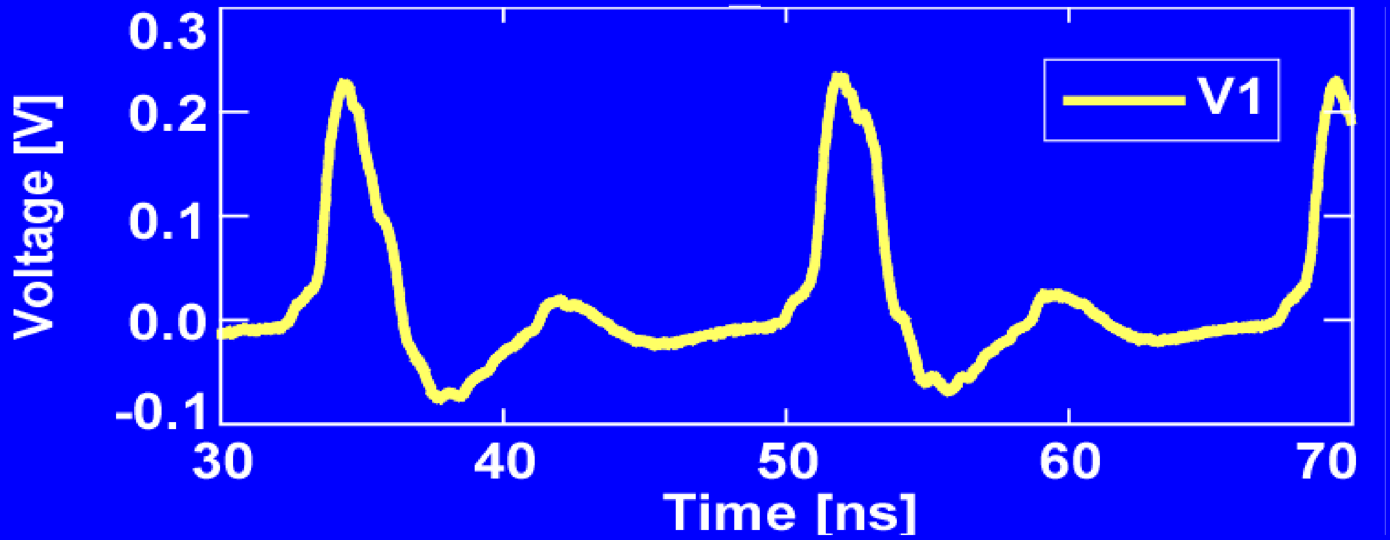
$$\frac{dI_1}{dt}_{res} = A_{v2didt} V_{didtOut\_res}$$

- **L1=0.5nH, L2=14.4nH, K=0.67, G=0.385,**
- **Rs=0.78Ω, Rt=50Ω**
- **Vamp_lin=±0.35V, di/dt_range=±0.5x10^{9}A/s**

di/dt Detector Impedance

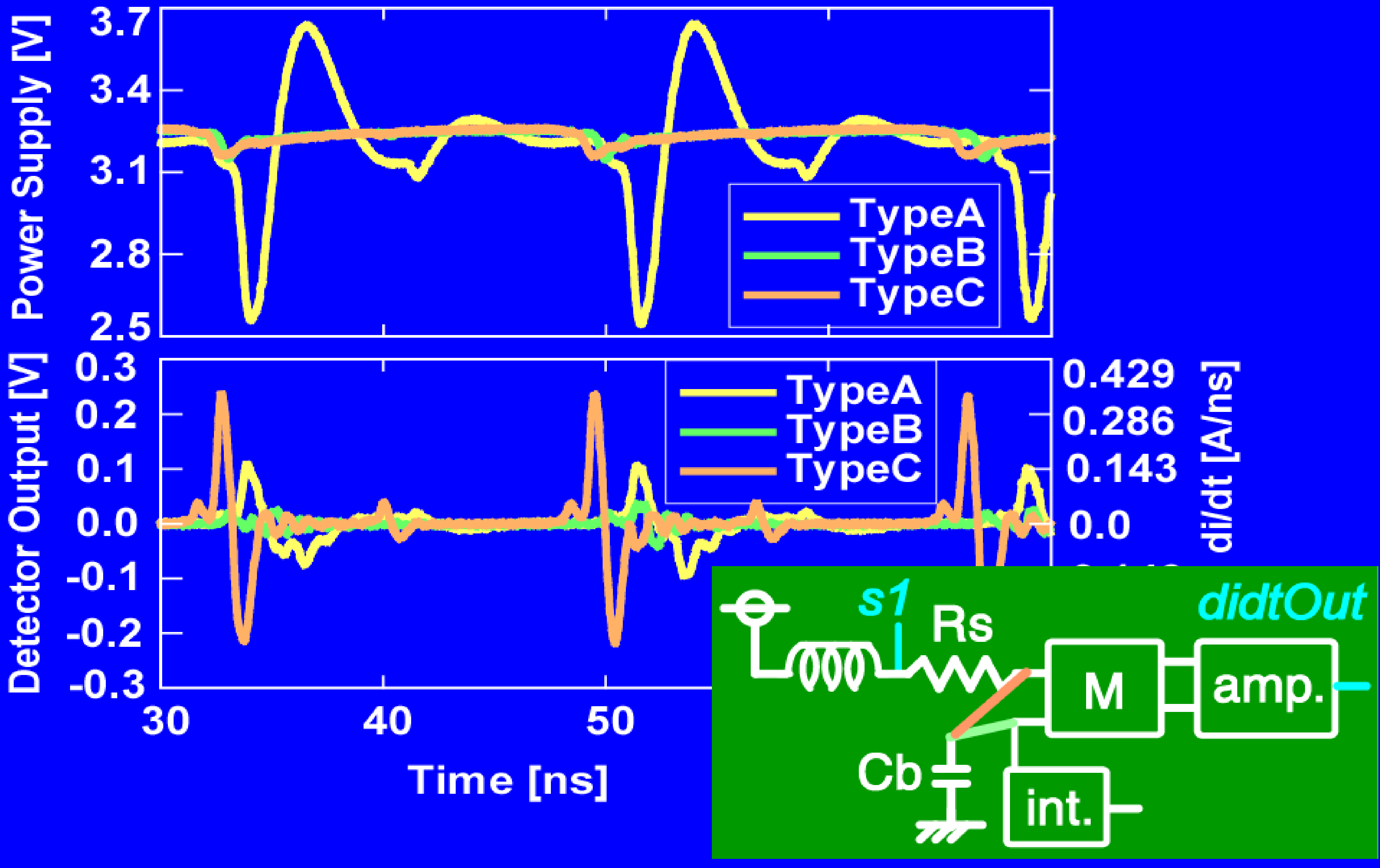






- **Multi-layer metal, wider line or low sensitivity can reduce the voltage drop**

Decoupling Capacitor Effects



Activation, M dependence