Power Supply di/dt Measurement using On-chip di/dt Detector Circuit

Toru Nakura[#], Makoto Ikeda*, Kunihiro Asada*

[#]*Dept. of Electronic Engineering,*
**VLSI Design and Education Center,*
University of Tokyo, Tokyo, Japan

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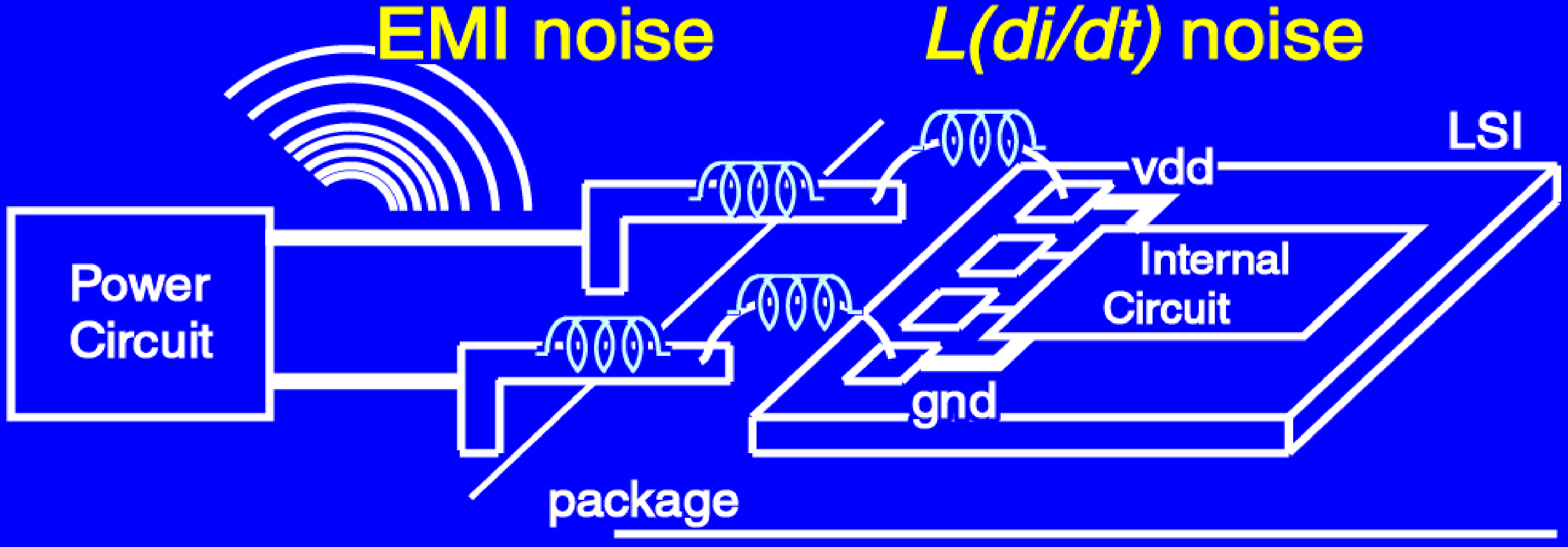
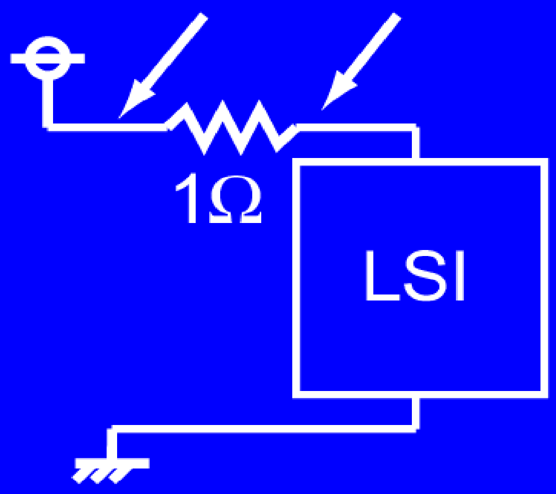
Background

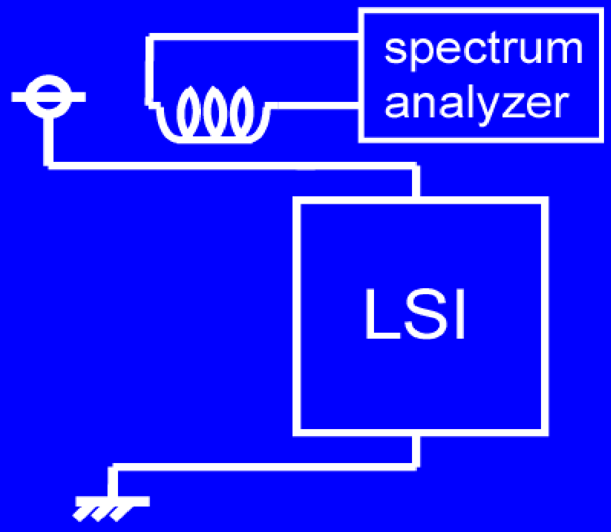
- di/dt is becoming a critical issue
  - L(di/dt) noise of low voltage LSIs
  - EMI noise of high-speed operation LSIs
- Need to measure the di/dt



Conventional Current Meas.

- Probe the voltage difference of the R
  - Needs numerical calculation
- Probe the magnetic field by pickup coil
  - Phase information is lost



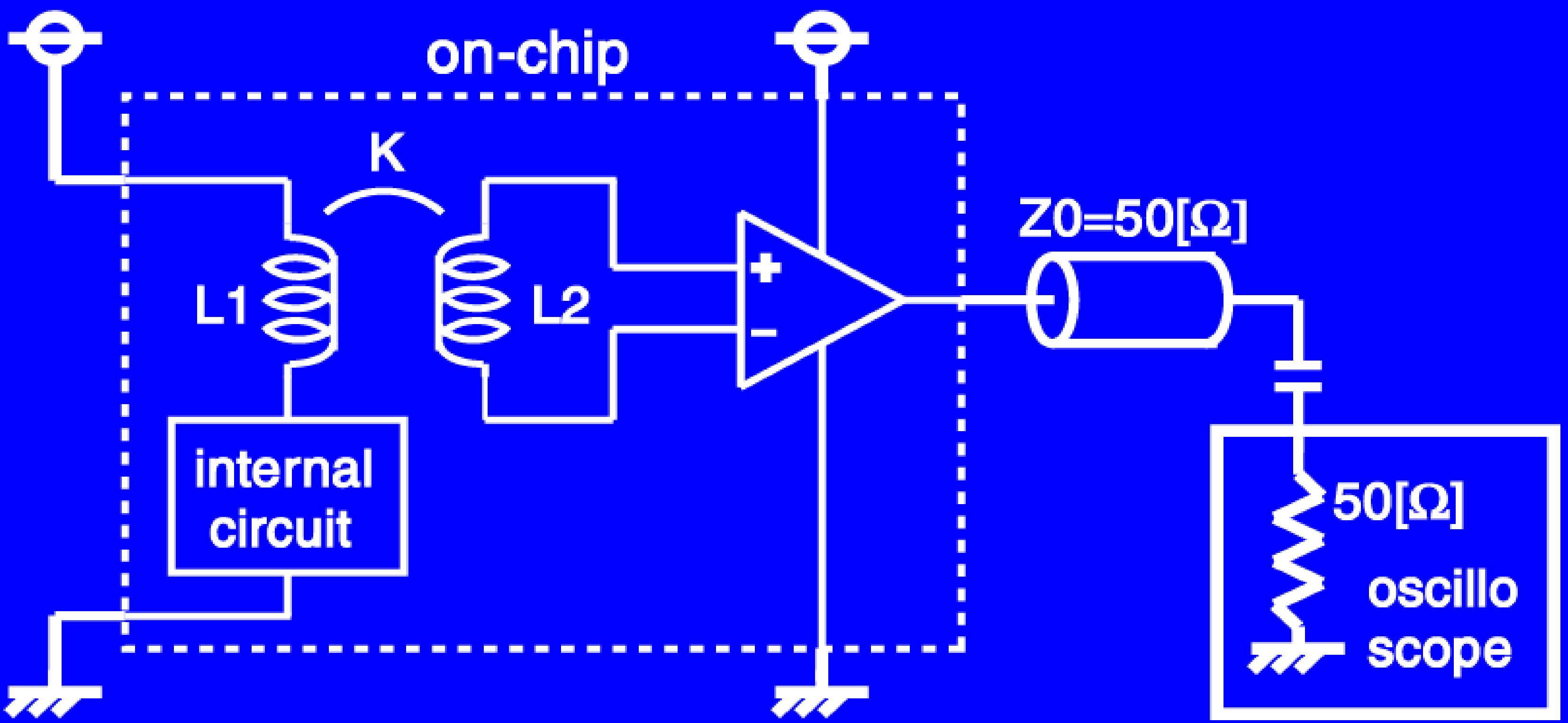


Contents

- di/dt detector circuit design
  - Mutual Inductor
  - Amplifier
  - Setup for measurement
- Measurement results
- Summary

Block Diagram

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

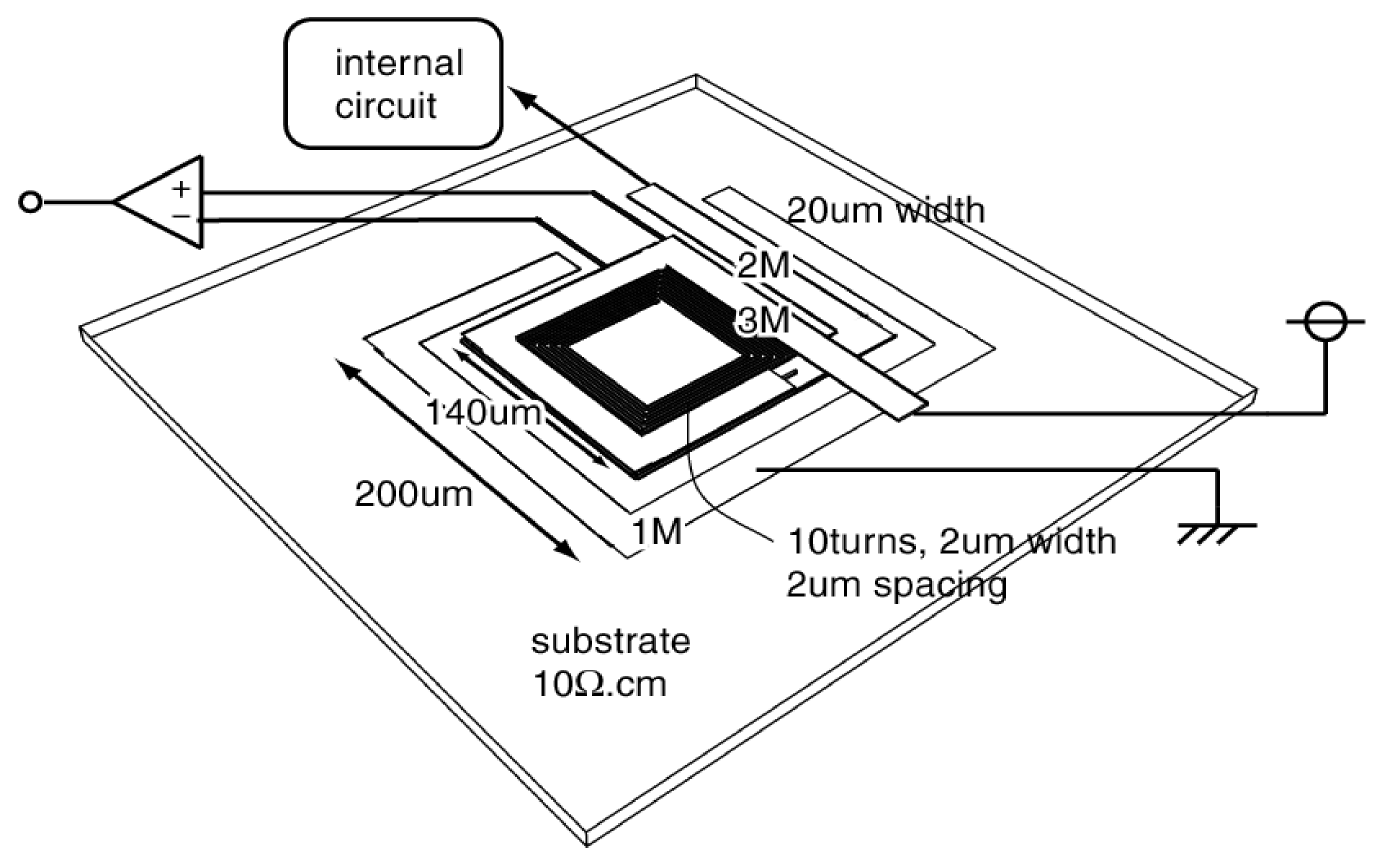


Advantage

- On-chip
- di/dt waveform without numerical calculation
- Real time
- Feedback di/dt control is possible

Mutual Inductor

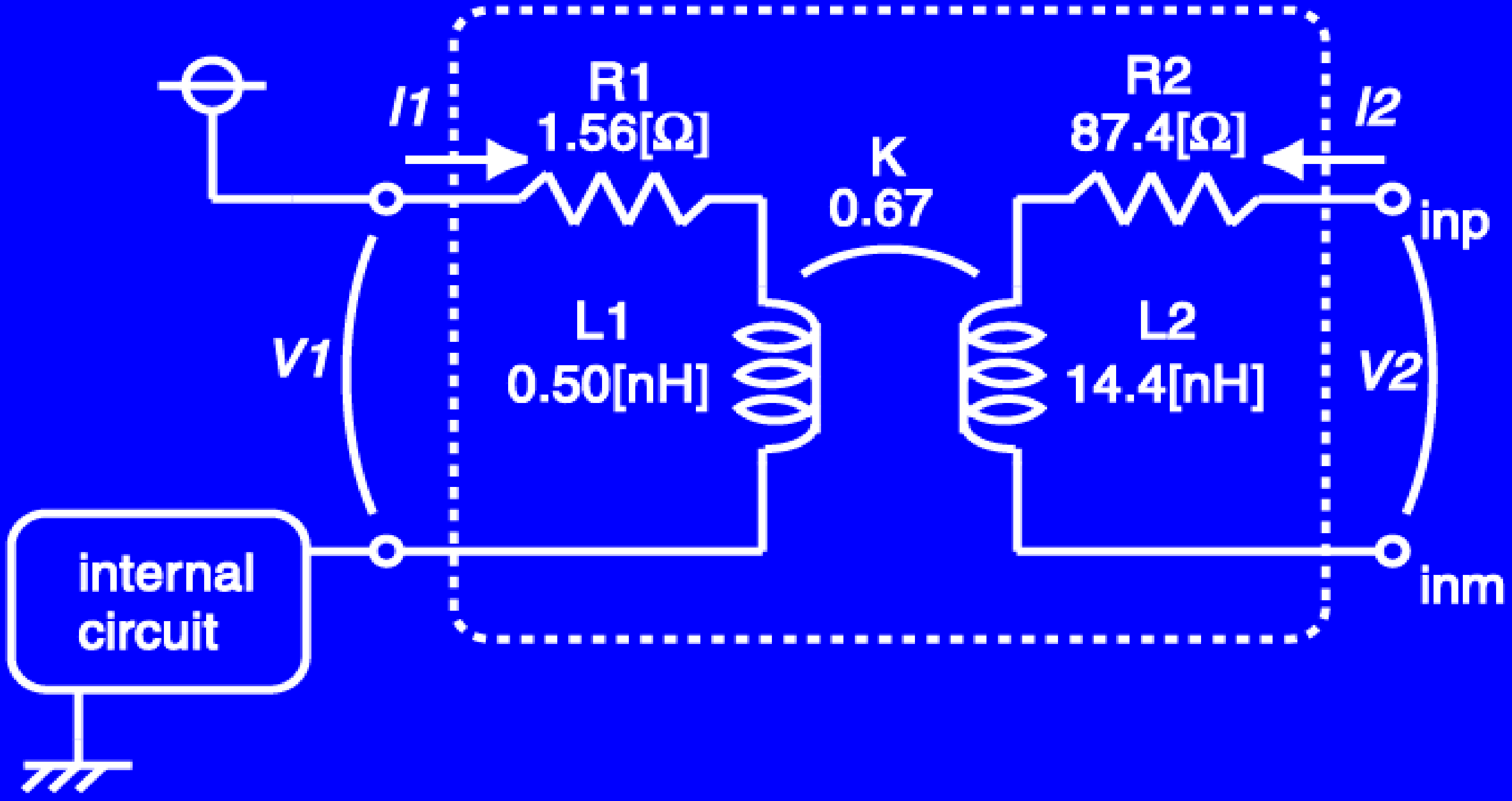
- 0.35um, 3ML standard CMOS process



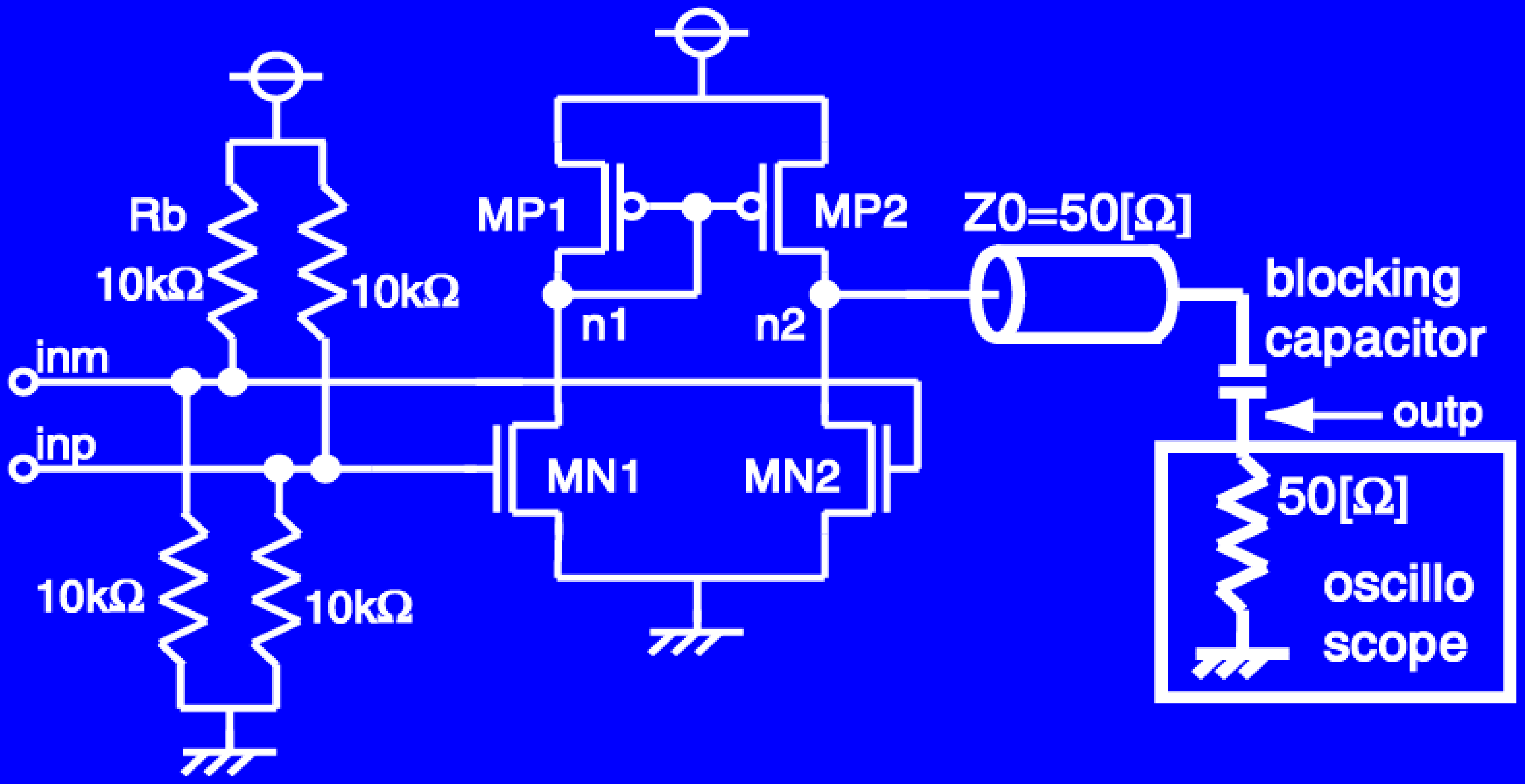
- Large: 200um diameter, 24 turns

Equivalent Circuit

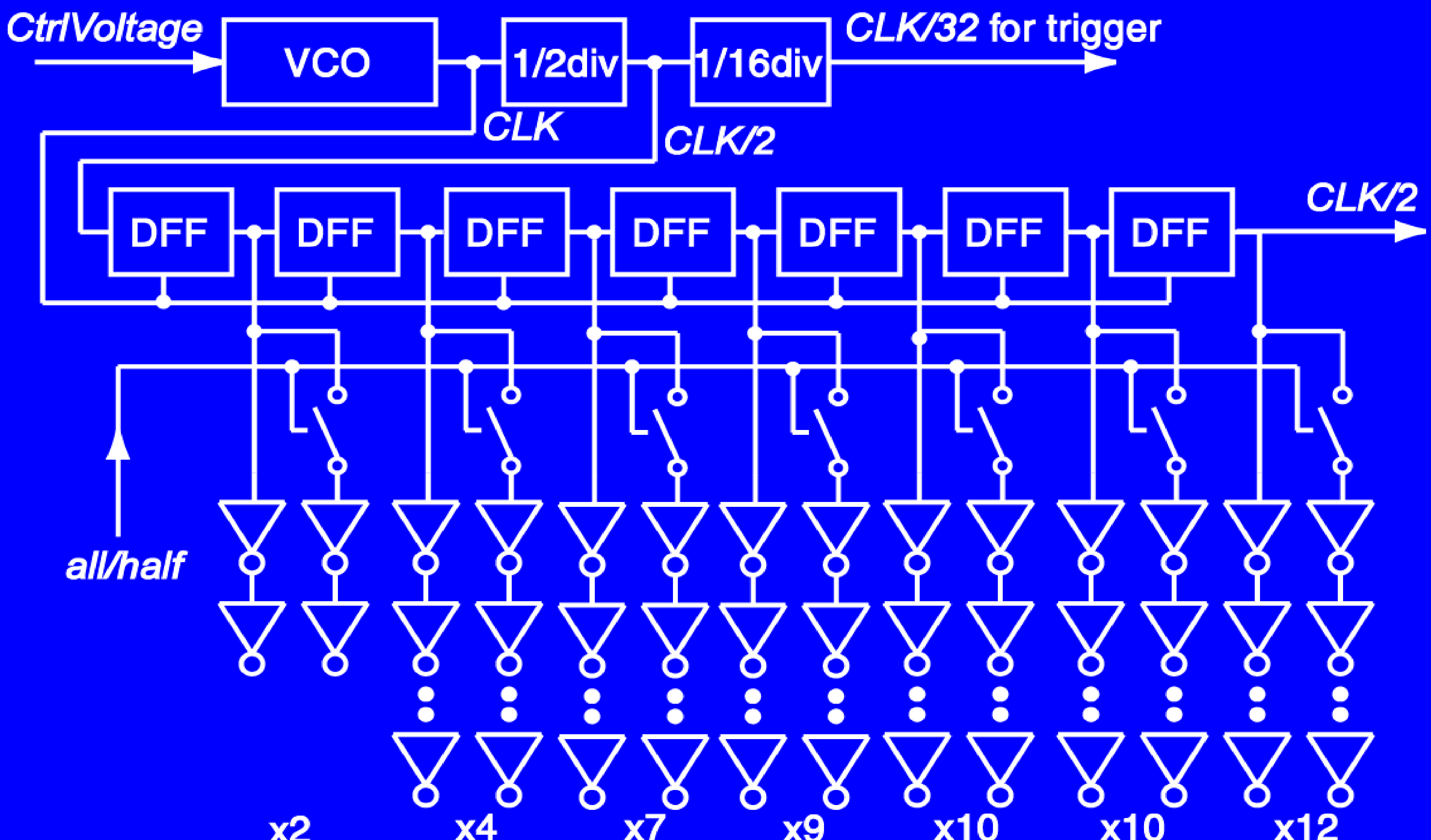
- Extracted by FastHenry



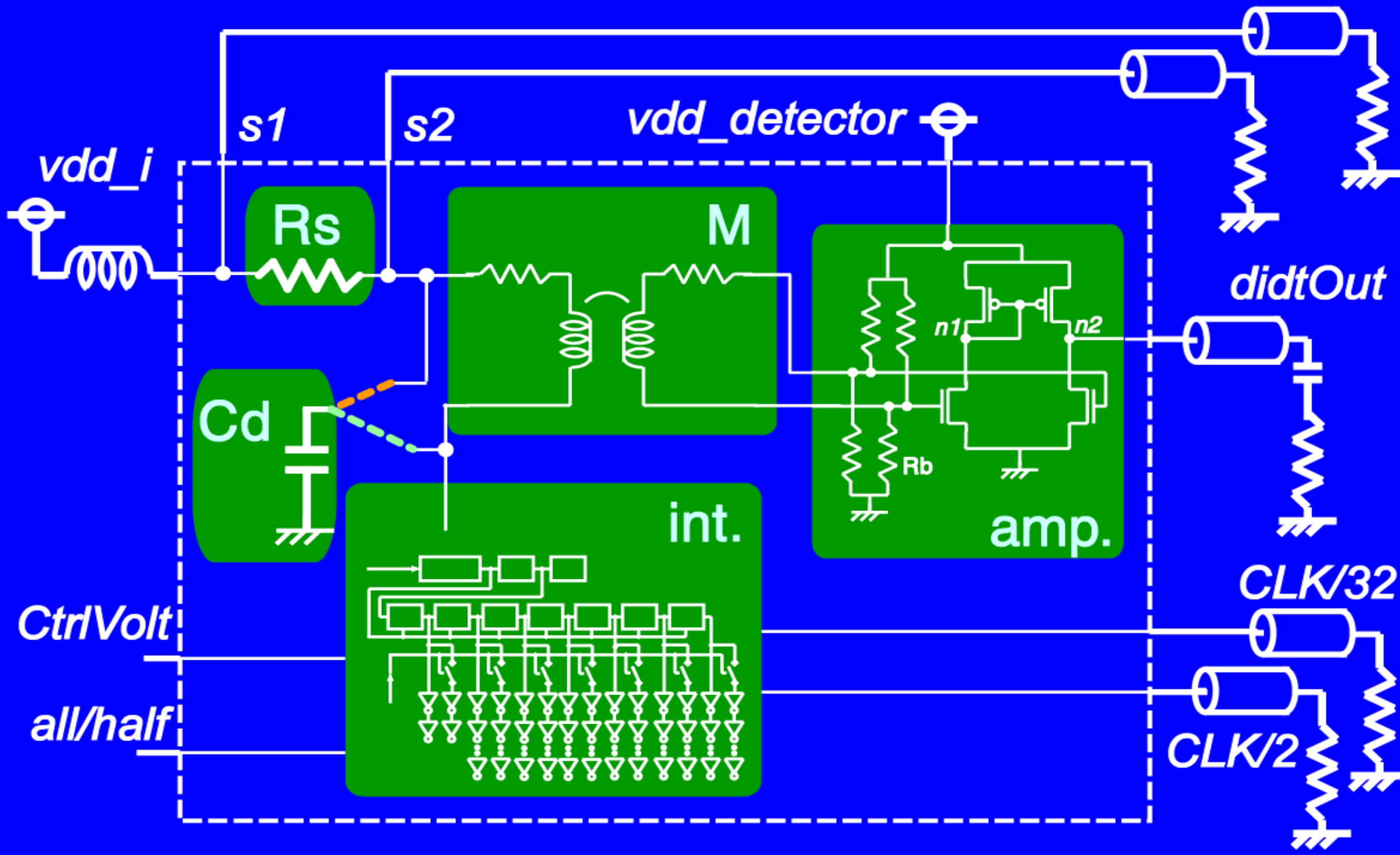
Amplifier/Output buffer



Internal Circuit as Noise Source



Whole Circuit / Meas. Setup



Equations

$$V_2 = K\sqrt{L_1L_2}\frac{dI_1}{dt}$$

$$V_{didtOut} = GV_2 = GK\sqrt{L_1L_2}\frac{dI_1}{dt}$$

$$\frac{dI_1}{dt} = \frac{1}{GK\sqrt{L_1L_2}}V_{didtOut} = A_{v2didt}V_{didtOut}$$

$$A_{v2didt} = \frac{1}{GK\sqrt{L_1L_2}}$$

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

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

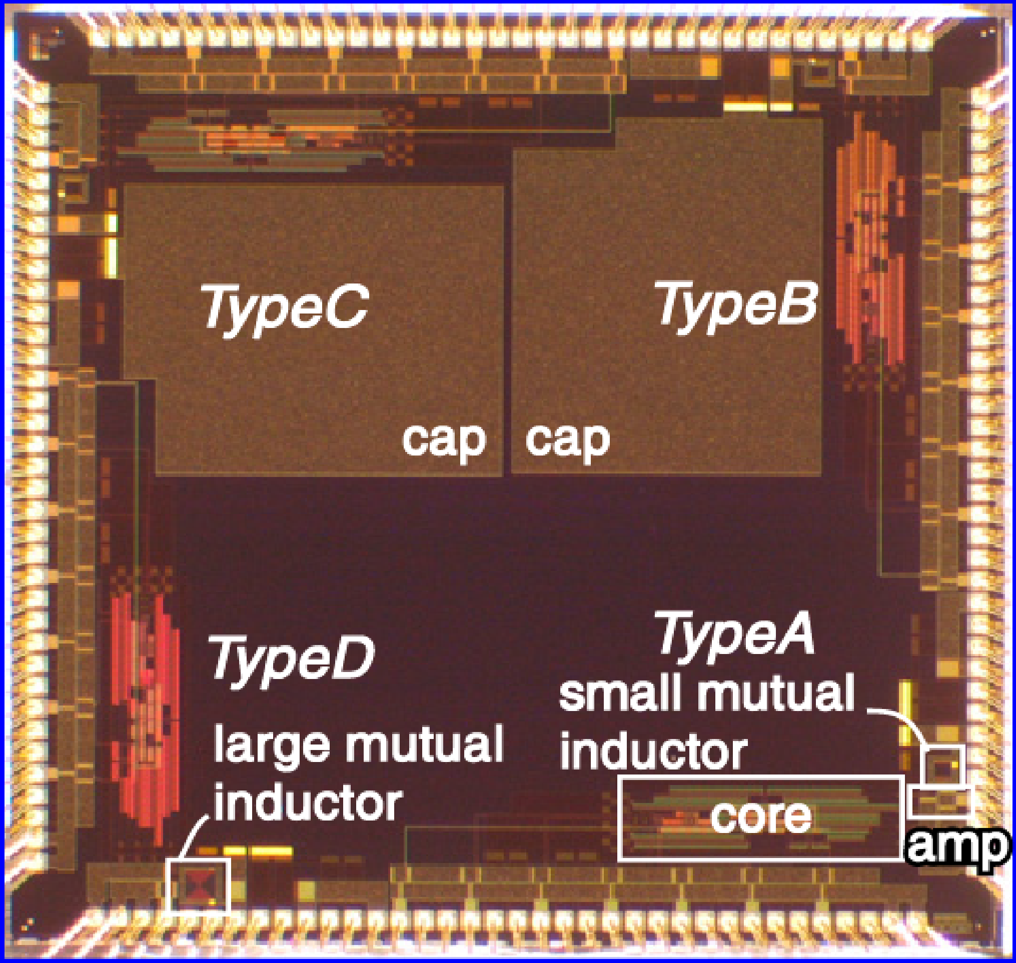
$$\frac{dI_1}{dt}_{range} = A_{v2didt}V_{amp\_outRange\_lin}$$

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

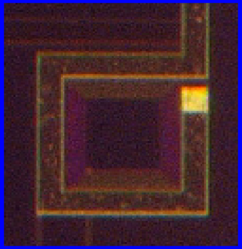
- **L1=0.5nH, L2=14.4nH, K=0.67, G=0.385,**
- **Rs=0.78Ω, Rt=50Ω**
- **Vamp_lin=±0.35V, di/dt_range=±0.5x10^{9}A/s**

Chip Photograph

- 0.35um 3ML 2P standard CMOS

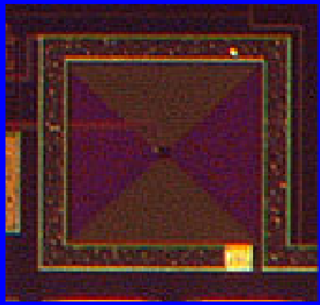


small



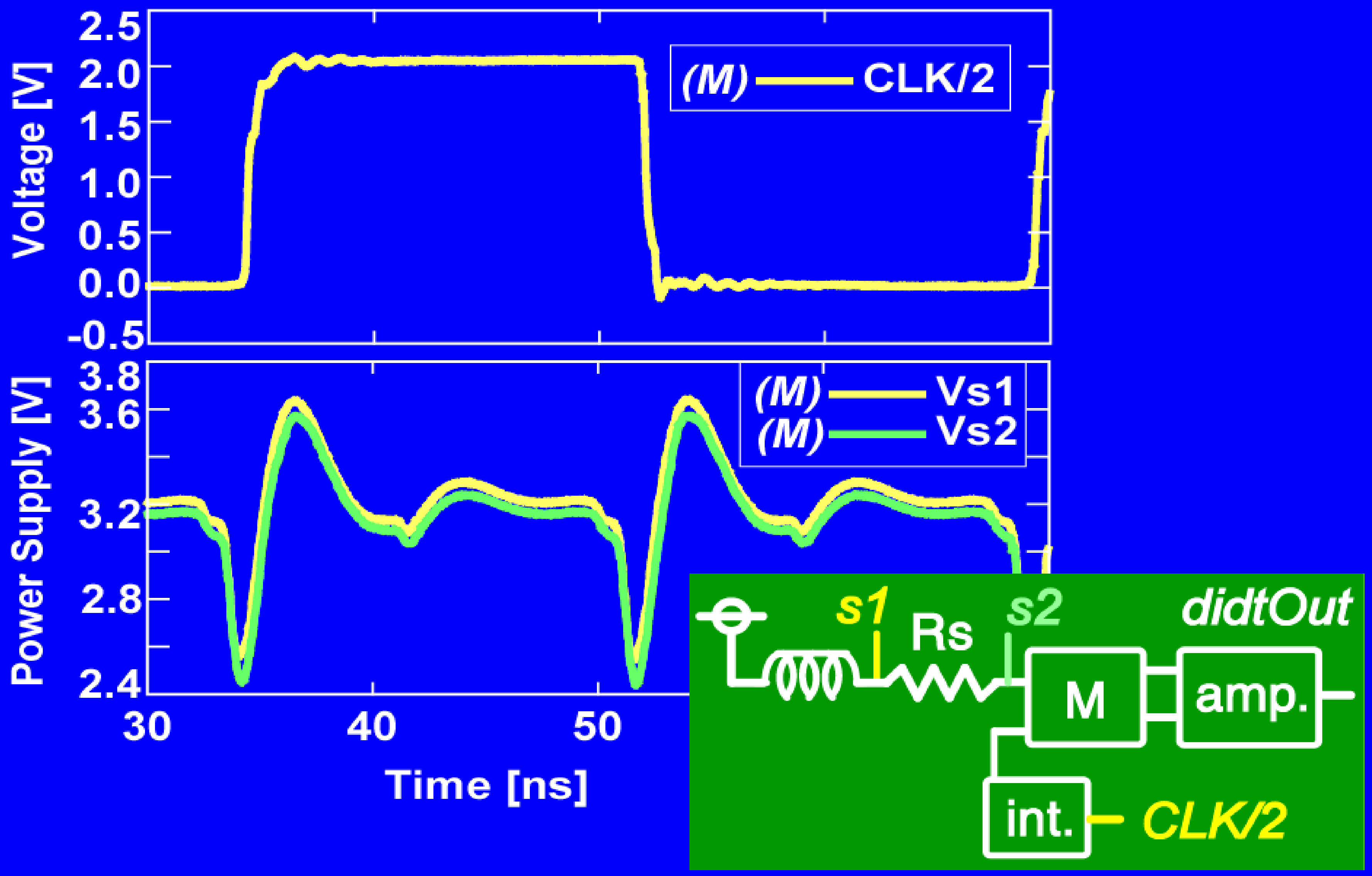
140um

large



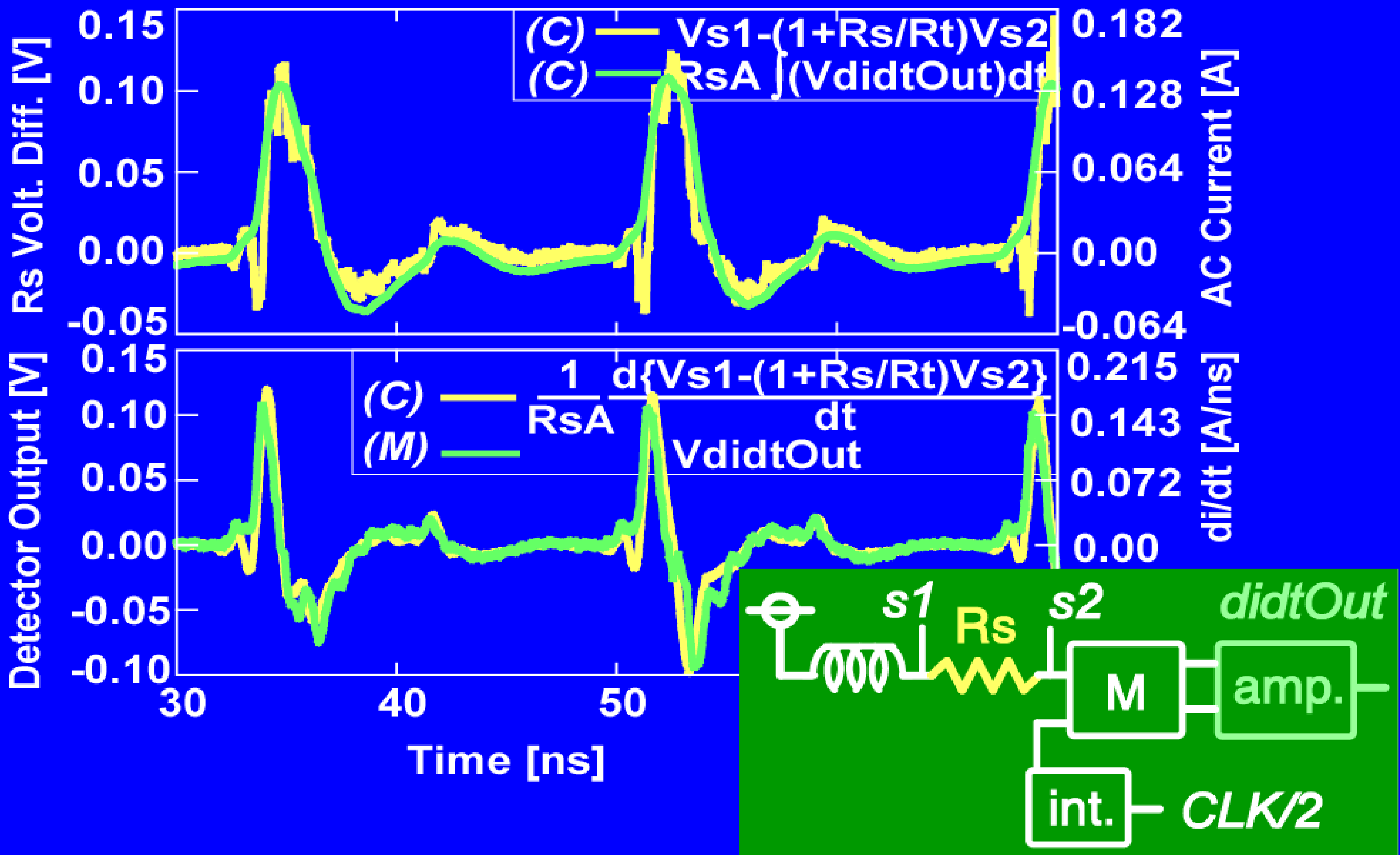
200um

Waveforms #1



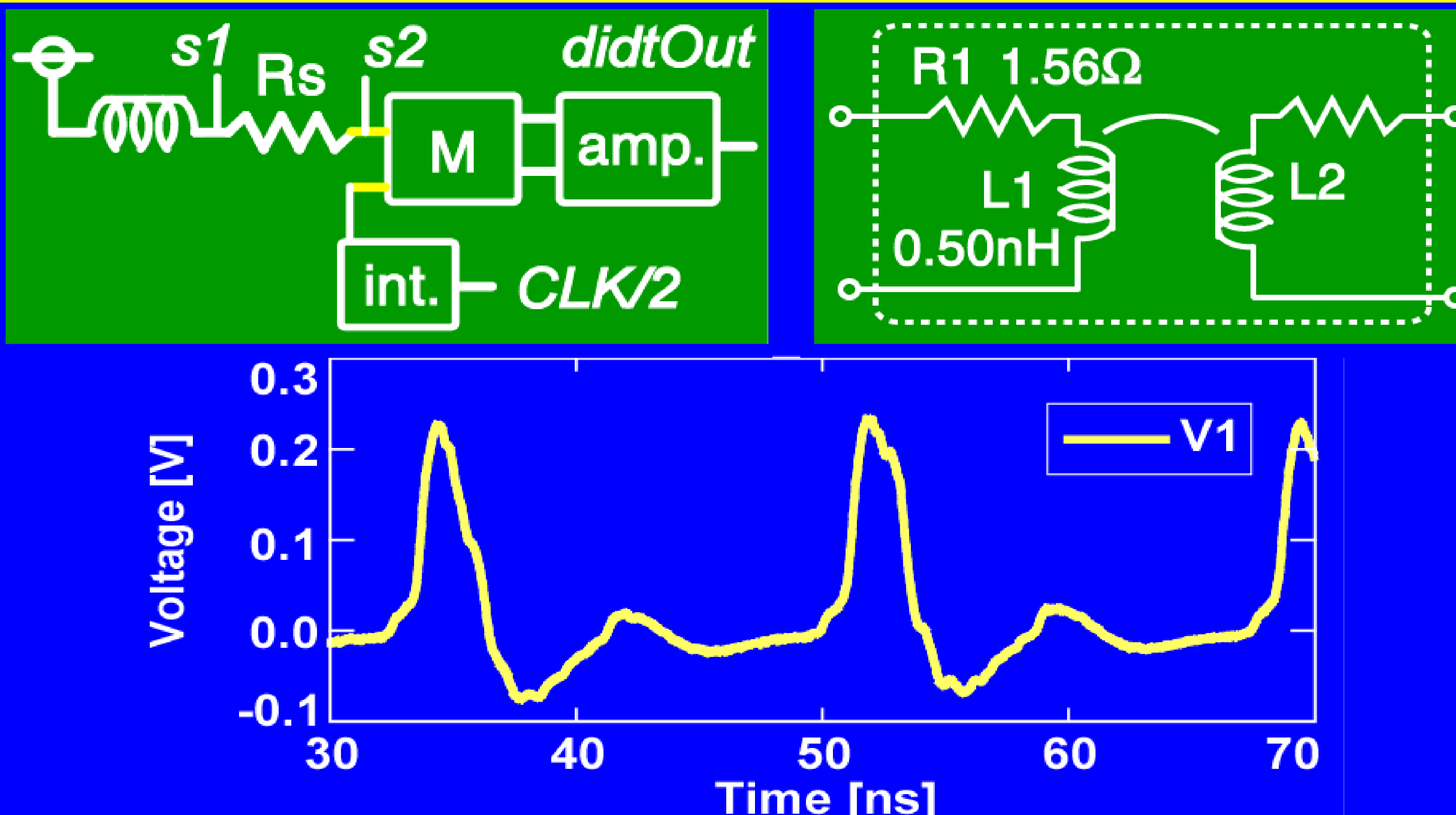
Voltage [V]
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
(M) CLK/2
Power Supply [V]
3.8
3.6
3.2
2.8
2.4
(M) Vs1
(M) Vs2
30
40
50
Time [ns]
s1
Rs
s2
didtOut
M
amp.
int.
CLK/2

Waveforms #2



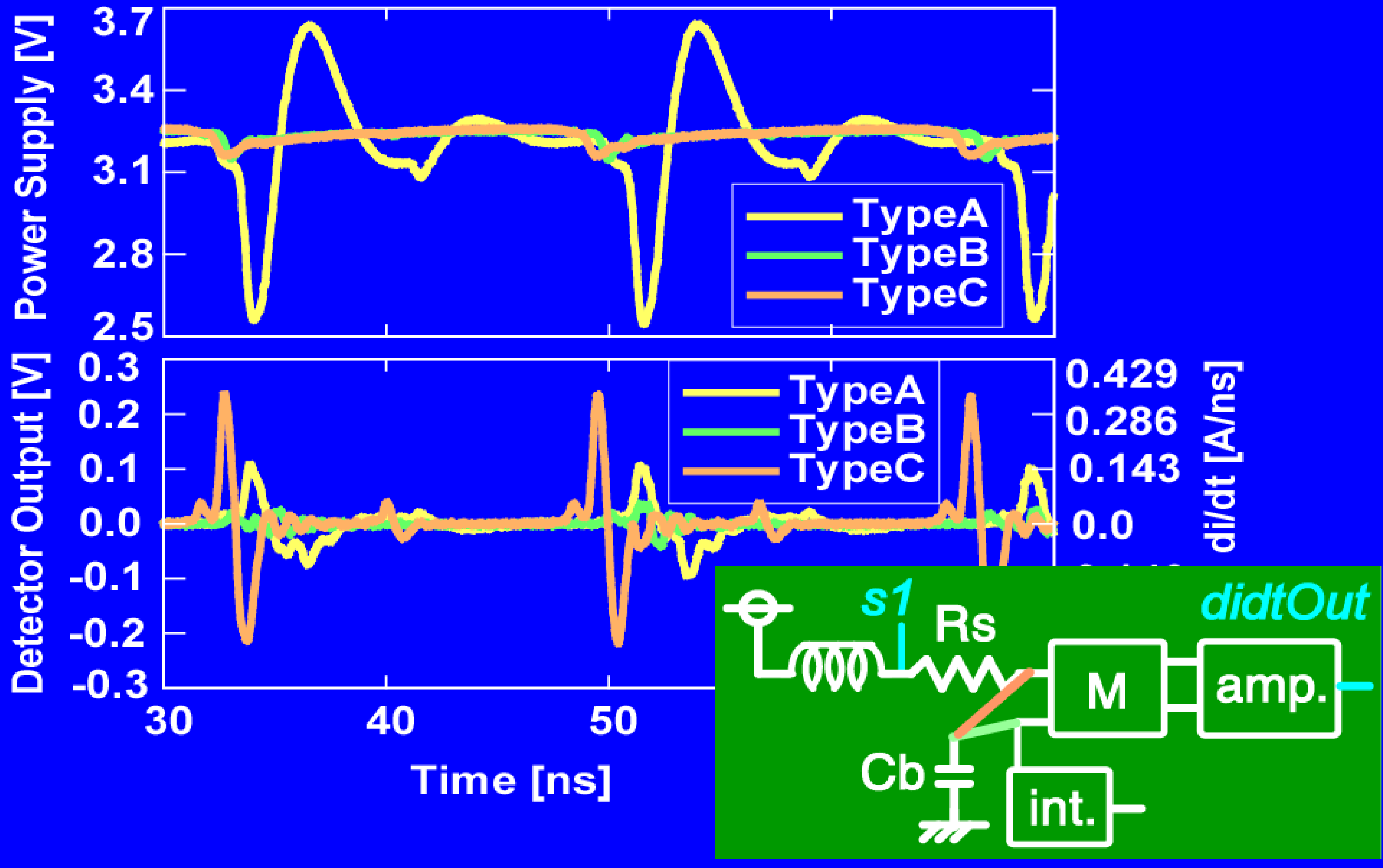
0.15
0.10
0.05
0.00
-0.05
Rs Volt. Diff. [V]
(C) Vs1-(1+Rs/Rt)Vs2
(C) RsA ∫(VdidtOut)dt
0.182
0.128
0.064
0.00
-0.064
AC Current [A]
0.15
0.10
0.05
0.00
-0.05
-0.10
Detector Output [V]
(C) 1/RsA d{Vs1-(1+Rs/Rt)Vs2}/dt
(M) VdidtOut
0.215
0.143
0.072
0.00
di/dt [A/ns]
30
40
50
Time [ns]
s1
Rs
s2
didtOut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

di/dt Detector Impedance

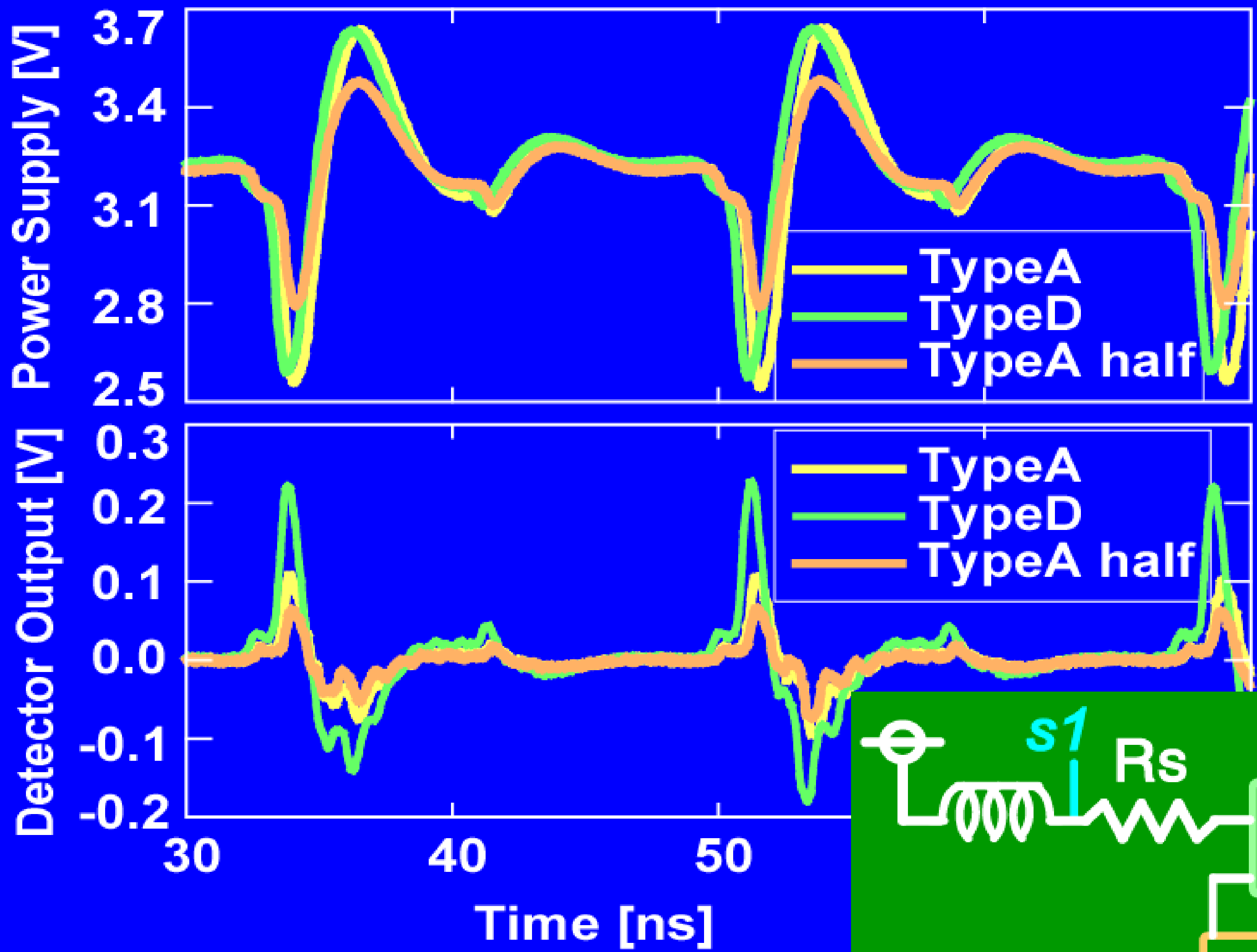


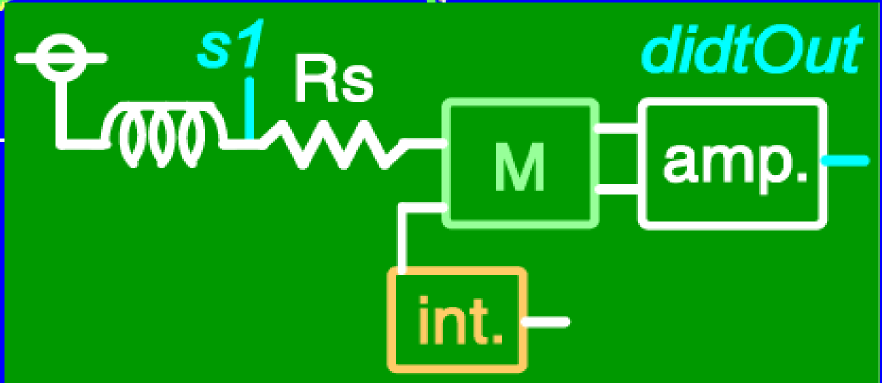
- **Multi-layer metal, wider line or low sensitivity can reduce the voltage drop**

Decoupling Capacitor Effects



Activation, M dependence



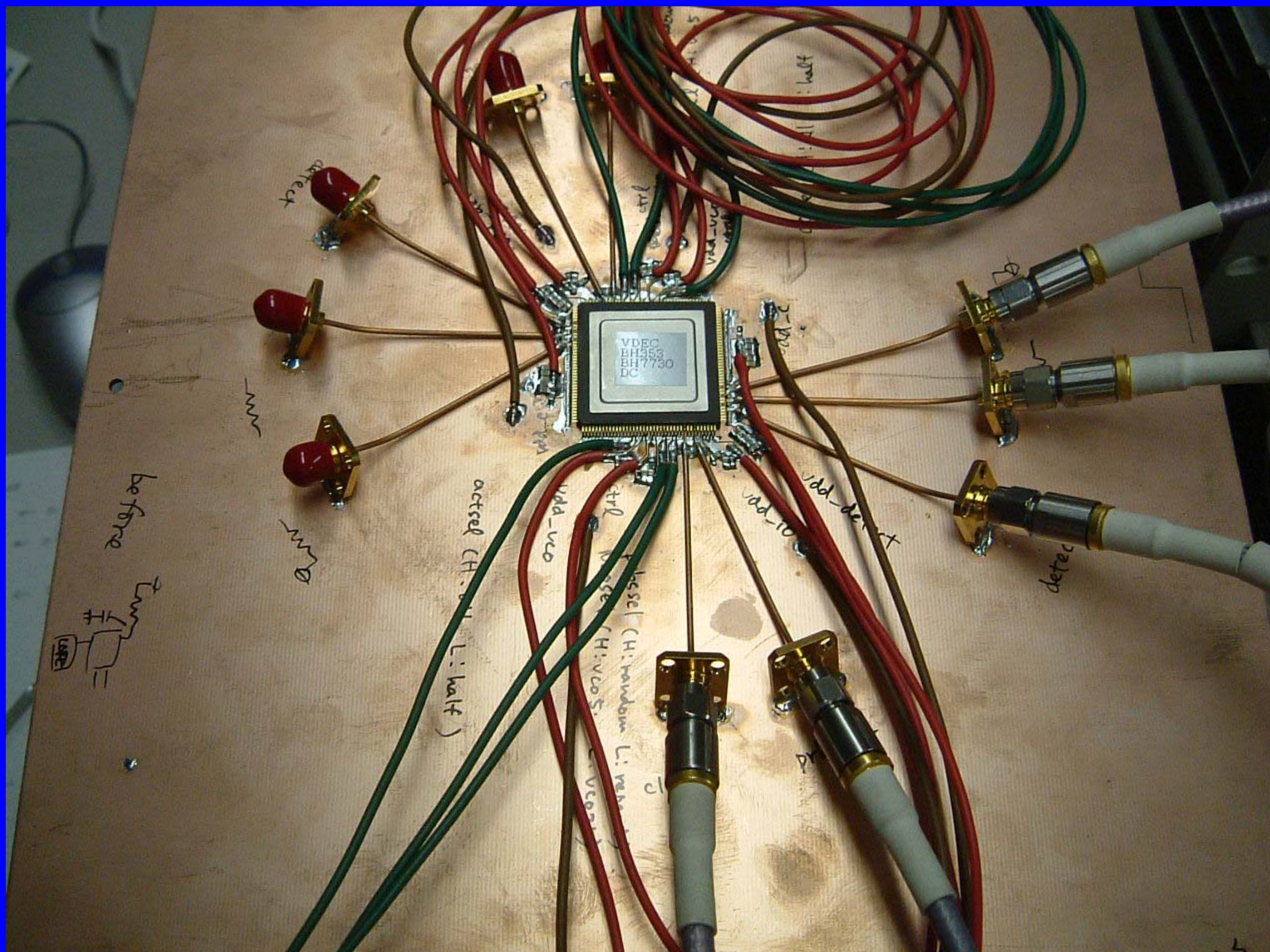


Summary

- 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
- The di/dt detector circuit detects the decoupling capacitor effects as well.

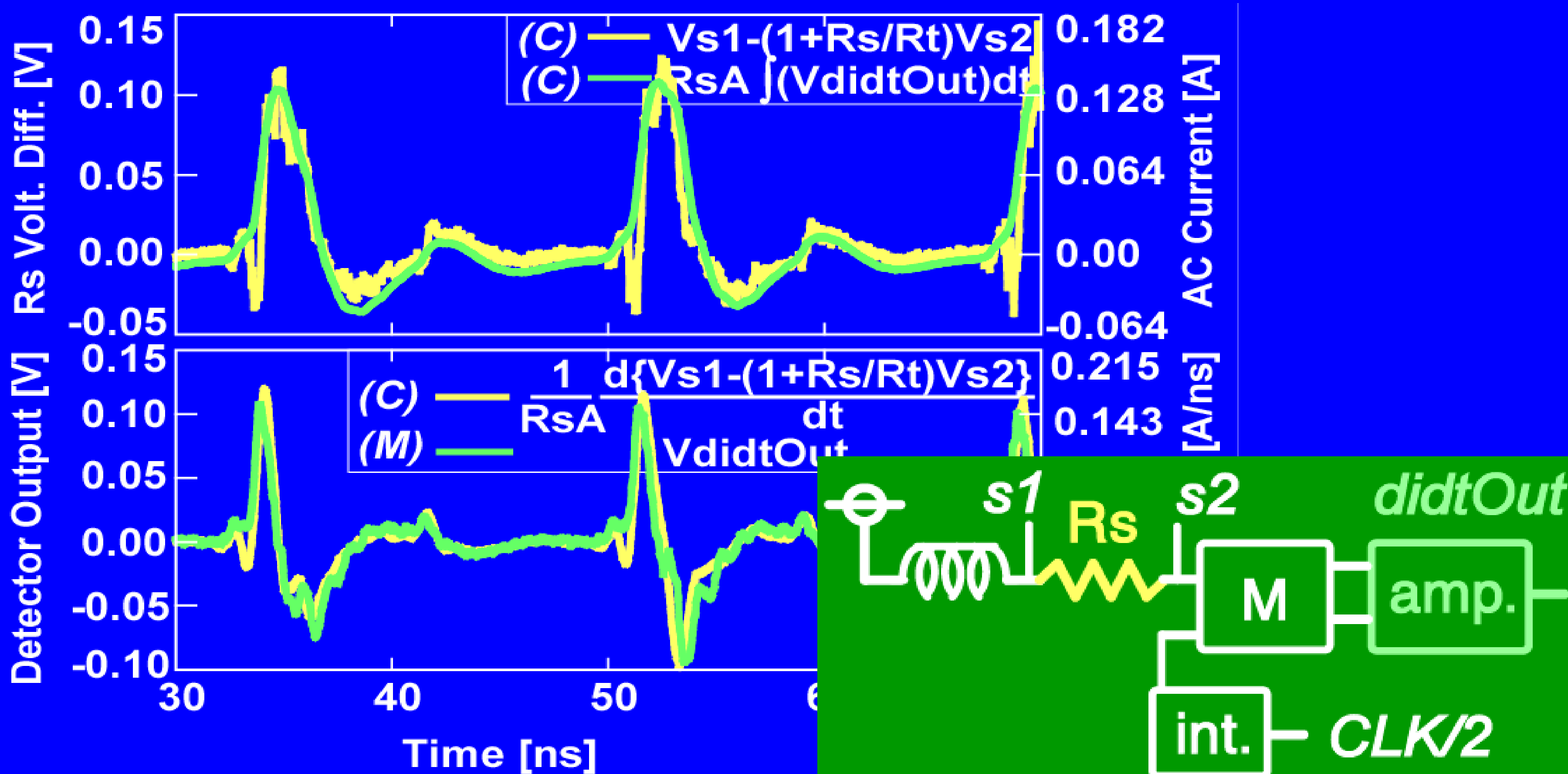
Q&A

Measurement Setup



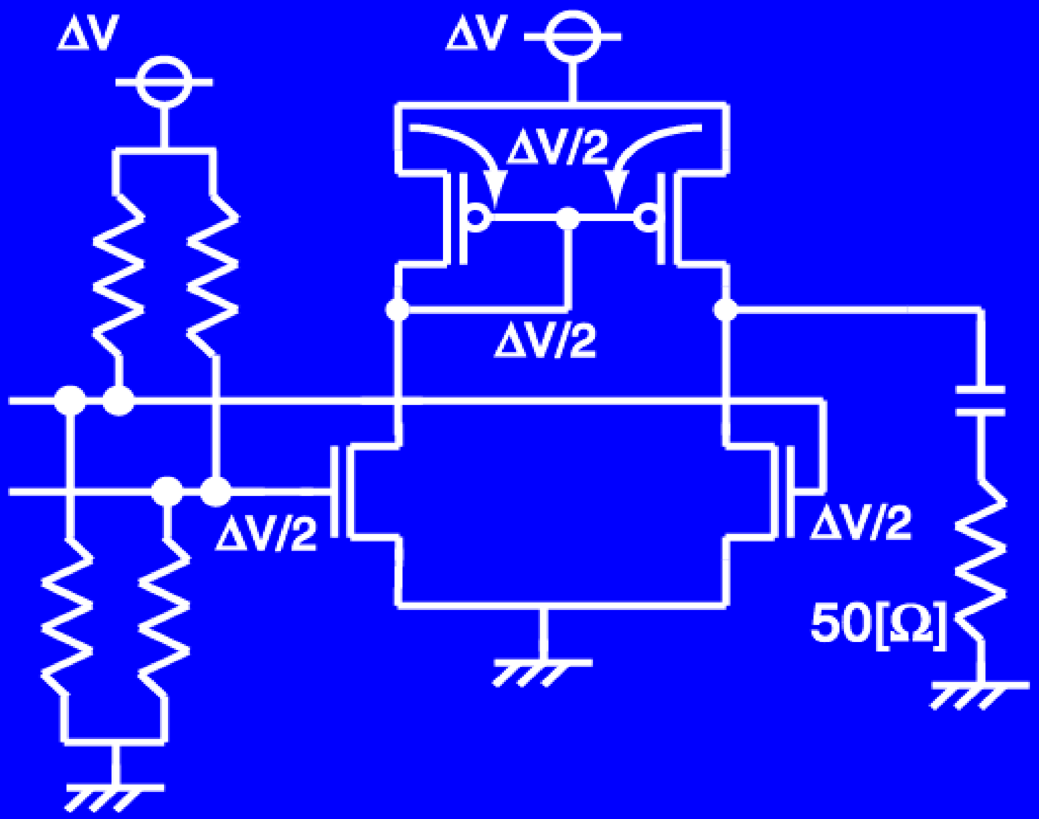
Error

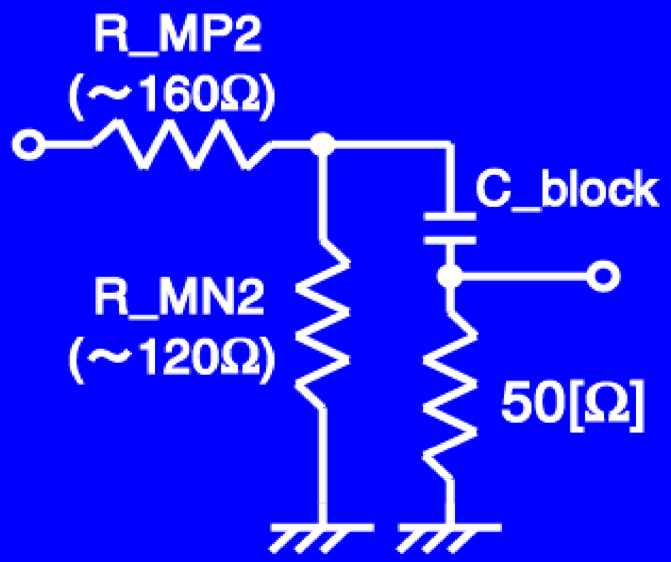
- δ=4.49mV, I=5.8mA
- δ=4.38mV, dI/dt=6.3mA/ns



Noise Tolerance

- Common mode noise is eliminated
- Vdd noise is suppressed to 18% (by 82%)





Single or Dual?

- Noise immunity, Sensitivity, Symmetric
- Require two pins, numerical calculation