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B8-4 Chip Test & Reliability
16:45-17:00
Nov. 1, 2019(Fri)

Evaluation of Null Method for Operational Amplifier Short-Time Testing

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ROHM Semiconductor

Outline

- Research Background
- Basic Operational Amplifier Measurement Circuit
- Null Method Prototype Circuit
- Investigation with SPICE Simulation and Experiment
  - Frequency Characteristics
  - Offset Voltage
  - Open Loop Gain (A_{OL})
  - Common-Mode Rejection Ratio (CMRR)
  - Power Supply Rejection Ratio (PSRR)
- Conclusion

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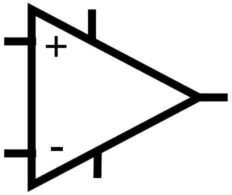
Operational Amplifier is Everywhere !

Operational Amplifier

Differential inputs



Single-ended output

Extremely high gain

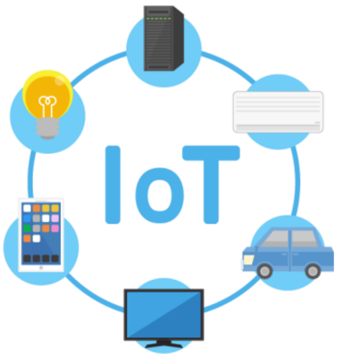
Past

Analog computers

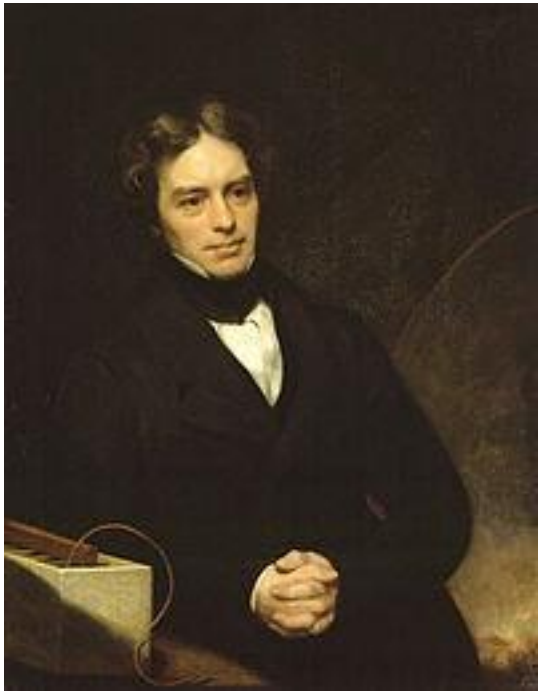
Present

Sensor・Interface analog circuit

Spread of IoT (Internet of Things) technology



Faraday’s Experiment

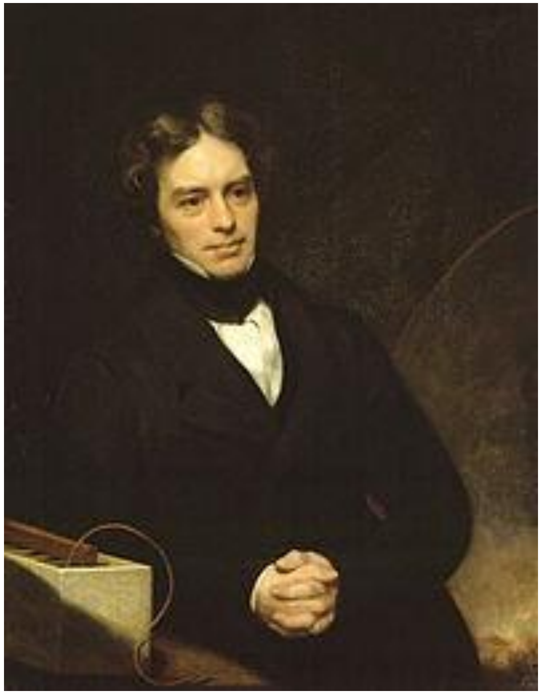


Michael Faraday
(1791 ~ 1867)
British Chemist / Physicist

Flow velocity measurement
on the principle of electromagnetic flowmeter

River Thames

Faraday’s Experiment



Michael Faraday
(1791 ~ 1867)
British Chemist / Physicist

Flow velocity measurement
on the principle of electromagnetic flowmeter

Impossible

River Thames

Reason

No electronic amplifier
of the detected weak electrical signal

Importance of
operational amplifier,
analog signal conditioning circuits

Research Goal

Low-cost , high-quality testing of operation amplifier

Goal

Null Method → Apply for mass production testing

Null Method

Measurement time : Long

Mass production testing : Difficult

1 second test time for
1 US dollar chip

Good capacitor value selection → Fast, stable operation

Problem and Approach

Operational Amplifier : Accurate measurement

Problem

Open loop gain : High

Small voltage error generation

Verification of **Null method circuit**

Minus input voltage of amplifier
→Zero potential with servo loop

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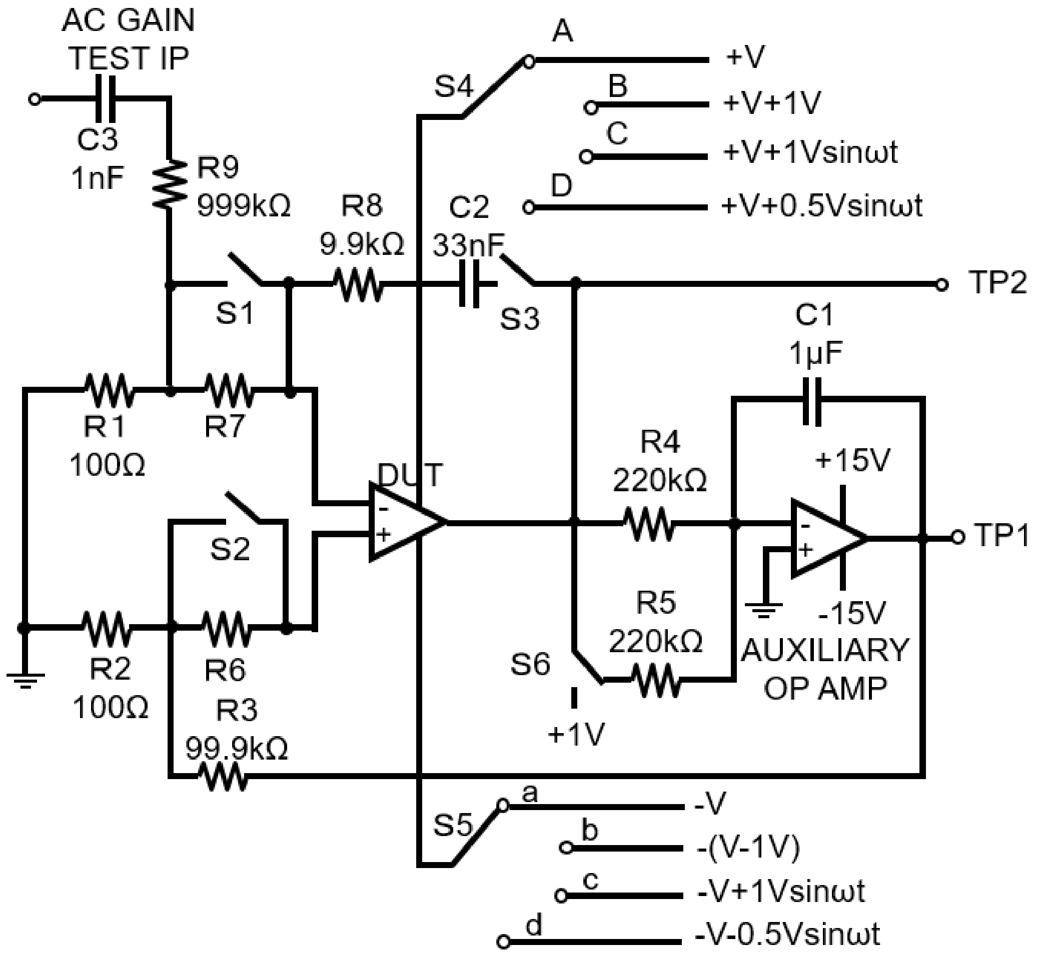
Basic Measurement Circuit



Operational Amplifier Measurement Circuit
using the Null Method

Switches (S1,.., S6)

- Offset
- Bias Current
- DC gain
- AC gain
- DC CMRR
- DC PSRR
- AC CMRR
- AC PSRR etc.

can be measured accurately

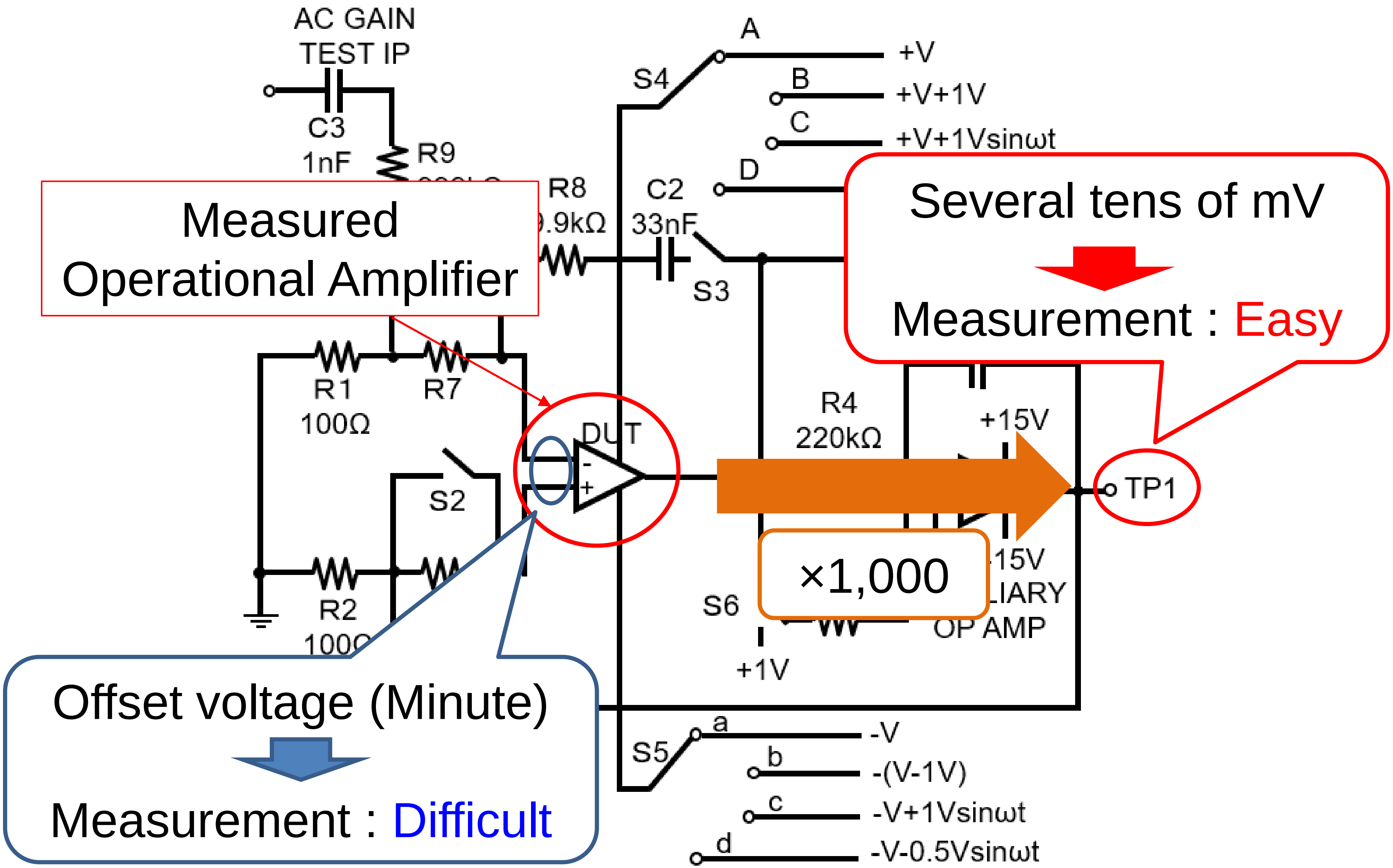
Source：Analog Dialogue Vol 45 Apr.2011 Analog Devices

Operational Amplifier Measurement Items

Switch States and Operational Amplifier Measurement Items

Parameter	S1	S2	S3	S4	S5	S6
Offset	short	short	open	A	a	open
Offset and bias current	short/open	short/open	open	A	a	open
DC gain	short	short	open	A	a	open/short
AC gain	short	short	open	A	a	open
DC CMRR	short	short	open	A/B	a/b	open
DC PSRR	short	short	open	A/B	a/b	open
AC CMRR	short	short	short	C	c	open
AC PSRR	short	short	short	D	d	open

Operational Amplifier Measurement Circuit using Null Method



Measured Operational Amplifier

Several tens of mV

Measurement : Easy

×1,000

Offset voltage (Minute)

Measurement : Difficult

Source：Analog Dialogue Vol 45 Apr.2011 Analog Devices

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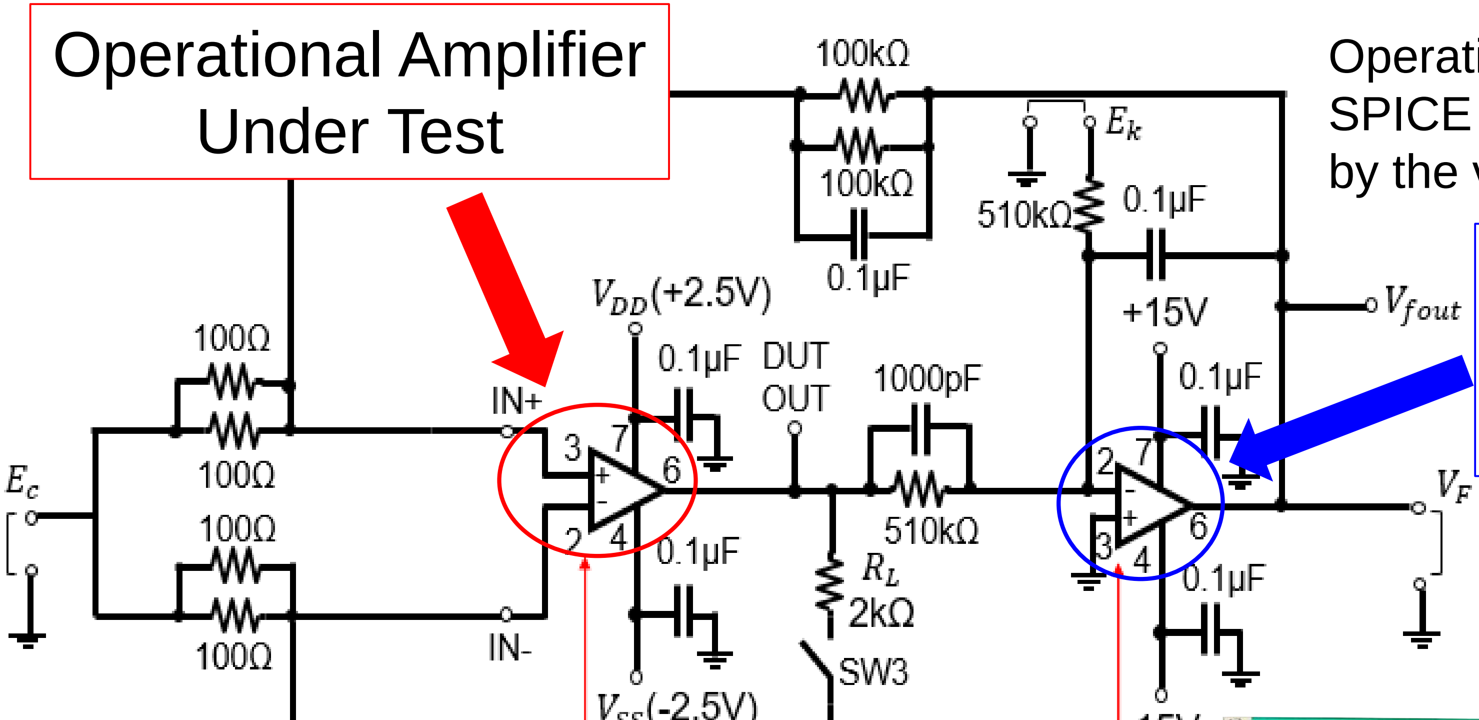
Null Method Prototype Circuit



Operational Amplifier Under Test

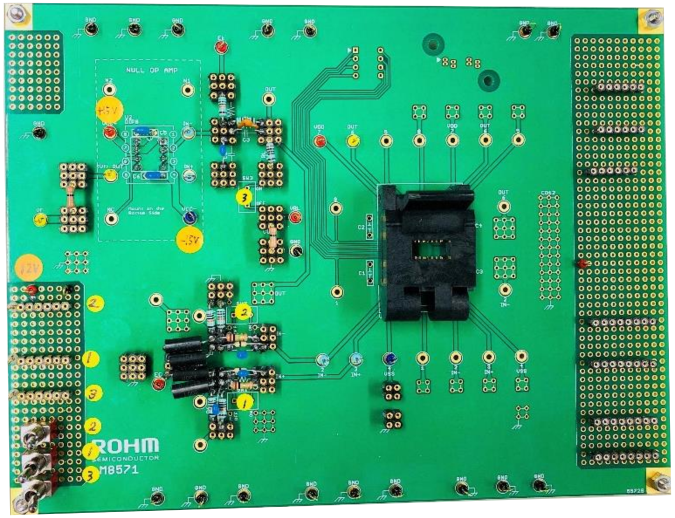
Operational Amplifier:
SPICE model provided
by the vendor

Auxiliary Operational Amplifier

DUT
AD8571

LF356

Experimental Circuit
using the Null Method



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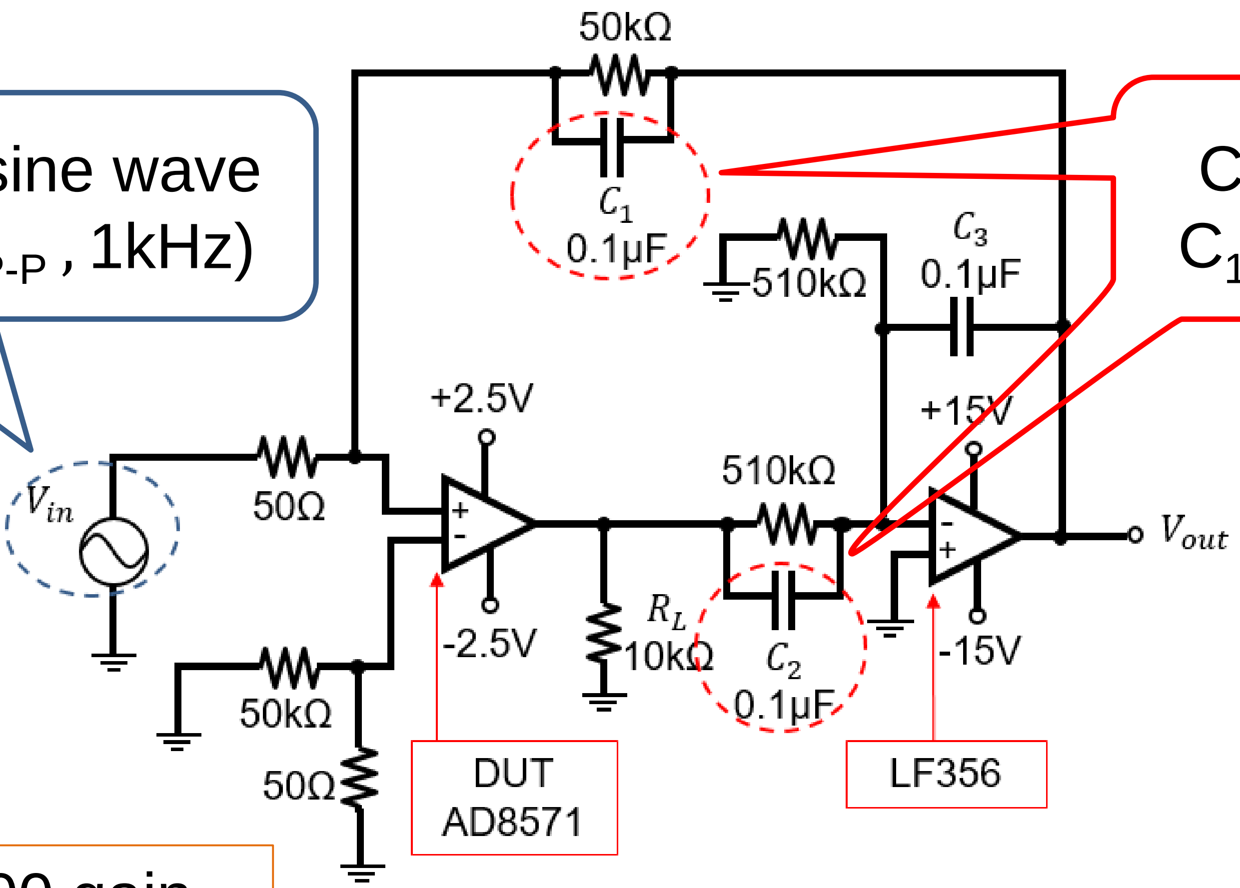
Frequency Characteristics



Input sine wave
($1mV_{P\text{-}P}$, 1kHz)

Change
C_1 and C_2

DUT
AD8571

LF356

x 1,000 gain
amplifier circuit

Frequency Characteristics
Simulation Circuit

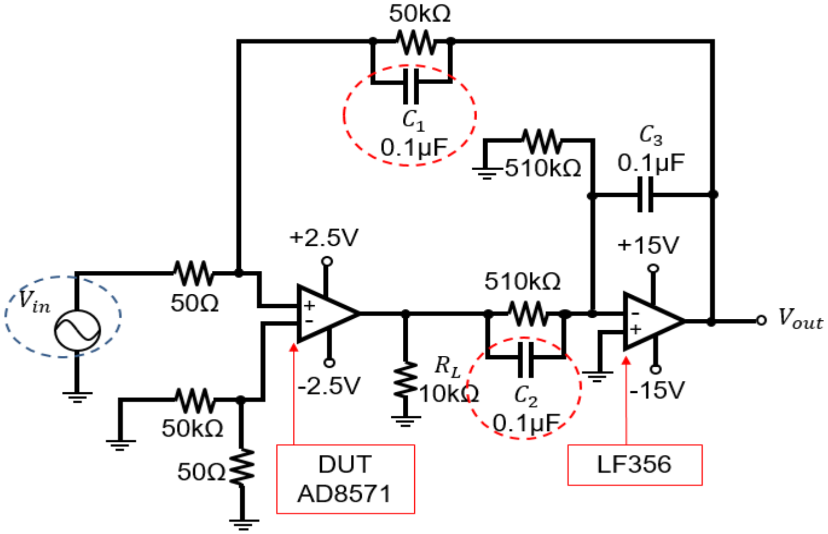
Simulation Result (C_1=0.1µF, C_2=0.1µF)

Frequency characteristics
of the Null circuit (SPICE simulation)

Amplifier

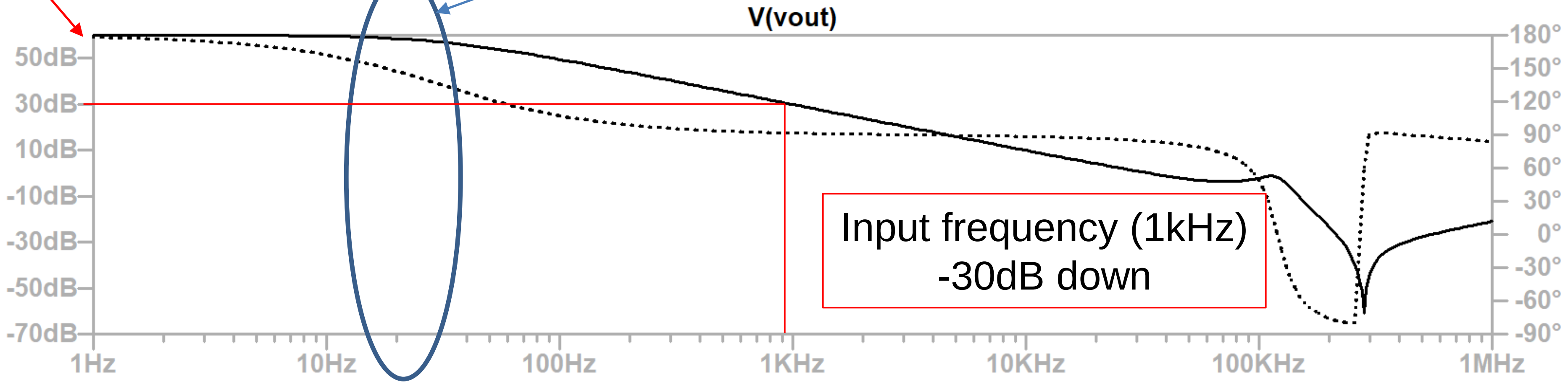
Gain＝20log1000=60dB

No peak ⇒ Stable



60dB

Cutoff frequency f_c≅30Hz ⇒ Slow response



Input frequency (1kHz)
-30dB down

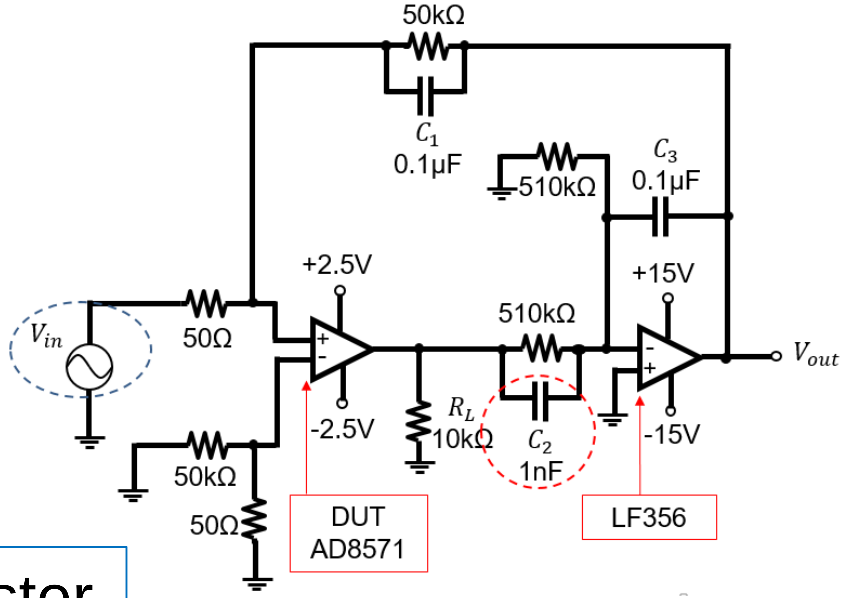
Frequency Characteristics when C_1=0.1µF, C_2=0.1µF

Simulation Result (C_1=0.1μF, C_2=1nF)

Frequency characteristics
of the Null circuit (SPICE simulation)

C_1 → 0.1μF (fixed)
C_2 → Small

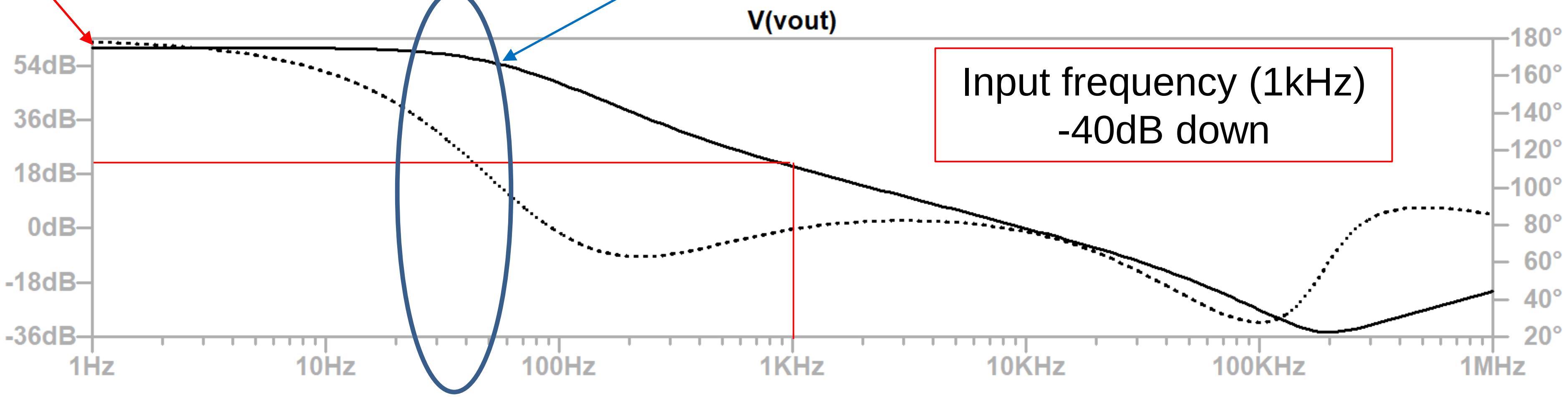
Slightly faster response



60dB

Slightly faster

Input frequency (1kHz)
-40dB down



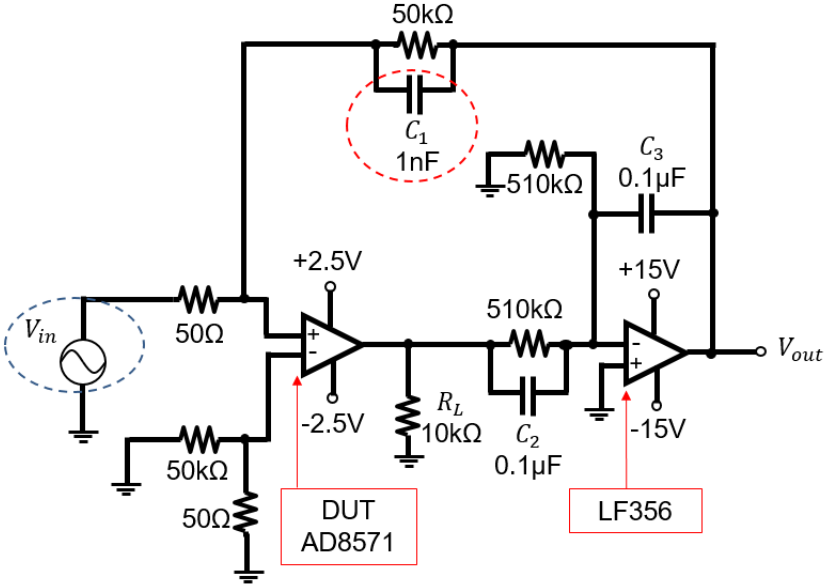
Frequency Characteristics when C_1=0.1μF, C_2=1nF

Simulation Result (C_1=1nF, C_2=0.1µF)

Frequency characteristics
of the Null circuit (SPICE simulation)

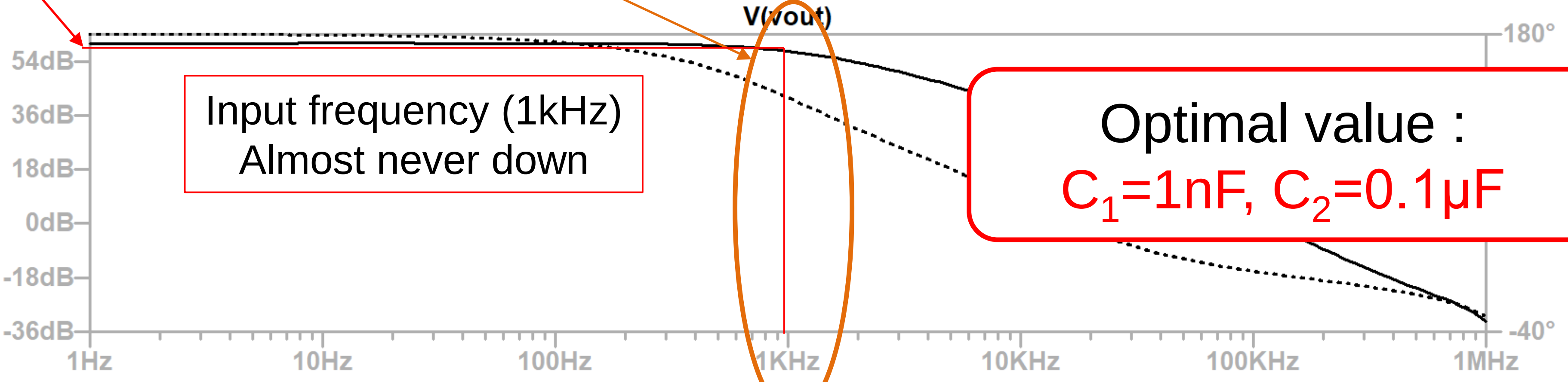
C_1 → Small
C_2 → 0.1µF (fixed)

30 times faster
than when C_1, C_2=0.1µF（f_c≅30Hz）



60dB

Cutoff frequency f_c≅1kHz ➡ Fast response



Input frequency (1kHz)
Almost never down

Optimal value :
C_1=1nF, C_2=0.1µF

Frequency Characteristics when C_1=1nF, C_2=0.1µF

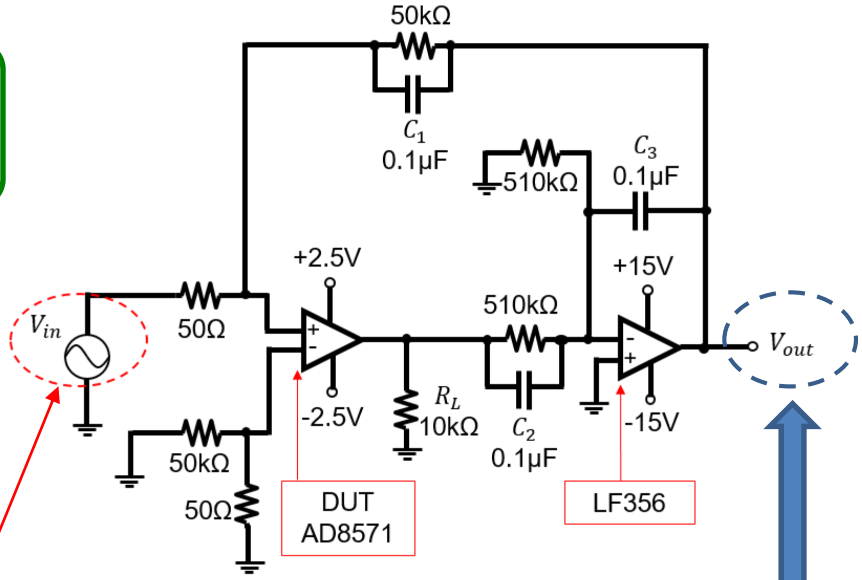
Transient Characteristics (Sine wave input) (1)

Transient response
of the Null circuit (SPICE simulation)

C_1=0.1μF, C_2=0.1μF

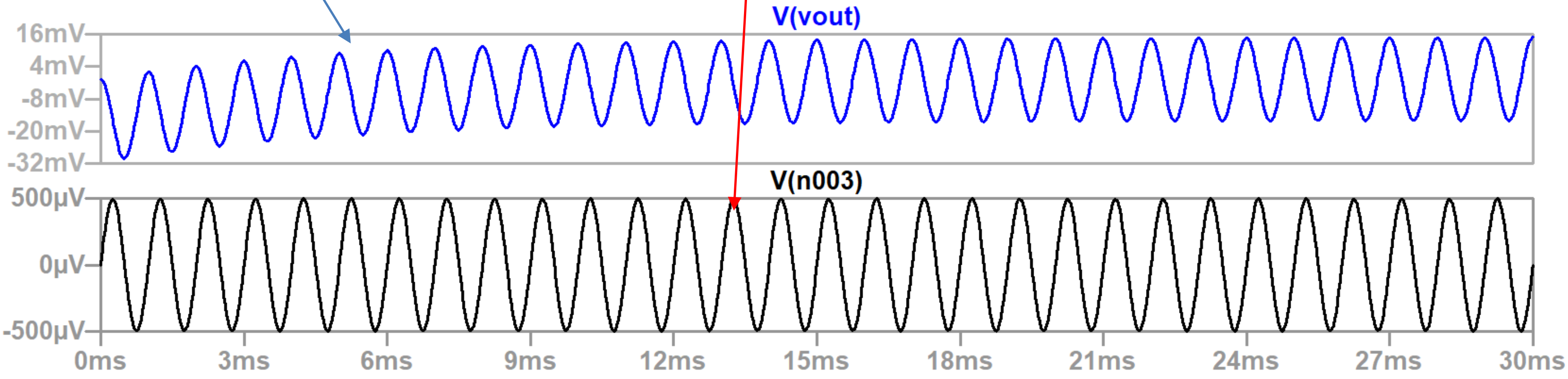
Input frequency (1kHz)
-30dB down (P.17)

30mV$_{P\text{-}P}$ (About 1/30)



Sine wave input
(1mV$_{P\text{-}P}$, 1kHz)

Observe
output waveform V_{out}

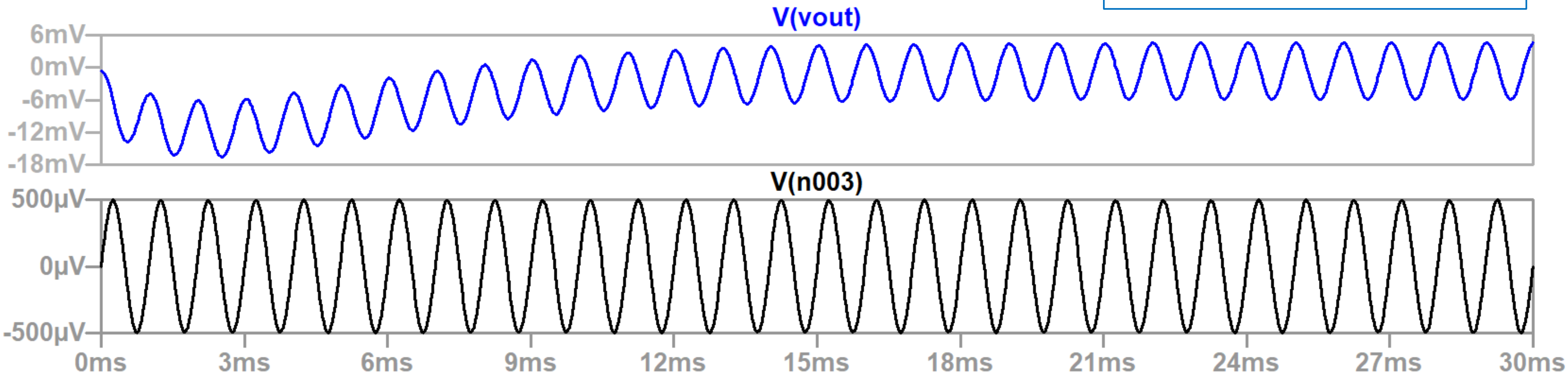


Transient Characteristics (Sine wave input) (2)

C_1=0.1μF, C_2=1nF

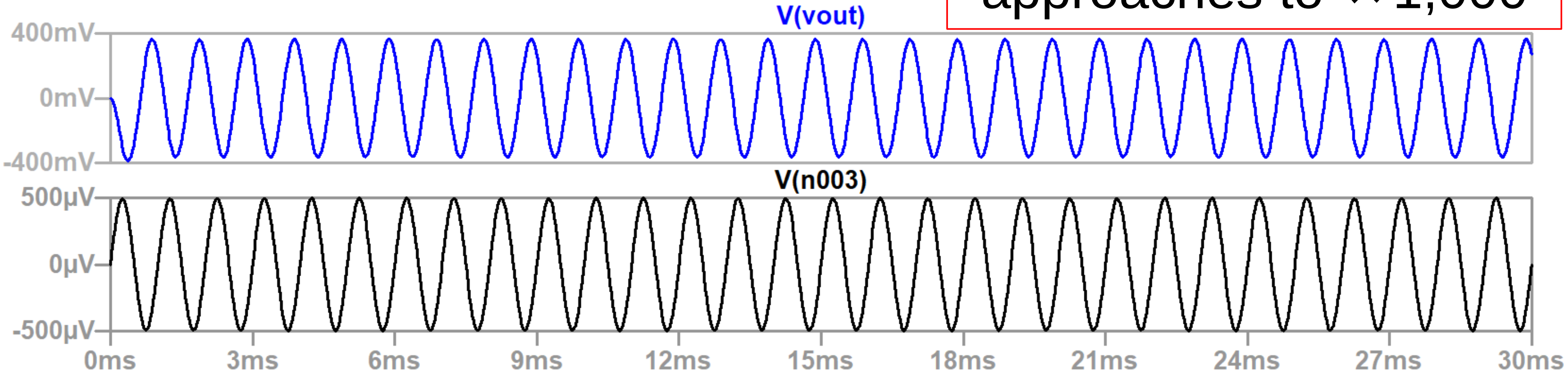
SPICE simulation

10mV$_{P\text{-}P}$
≠ ×1,000



C_1=1nF, C_2=0.1μF (Optimal value)

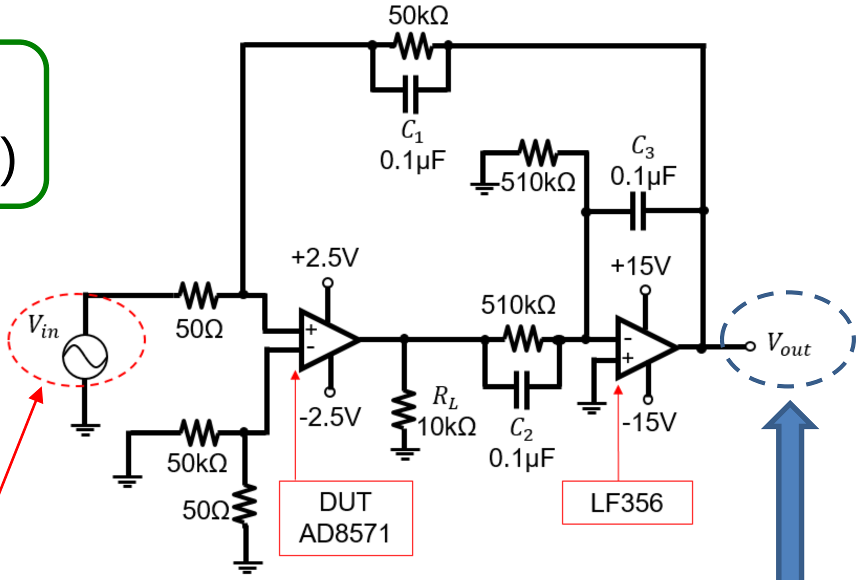
700mV$_{P\text{-}P}$
approaches to ×1,000



Transient Characteristics (Square wave input)(1)

Transient response
of the Null circuit (SPICE simulation)

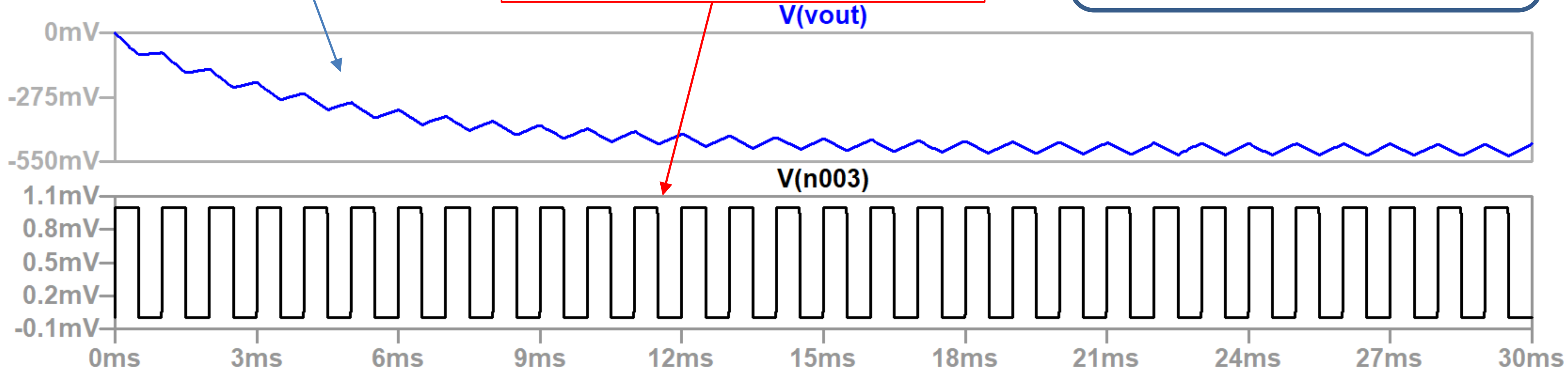
C_1=0.1µF, C_2=0.1µF



50mV$_{P-P}$
≠ ×1,000

Square wave input
(1mV$_{P-P}$, 1kHz)

Observe
output waveform V_{out}

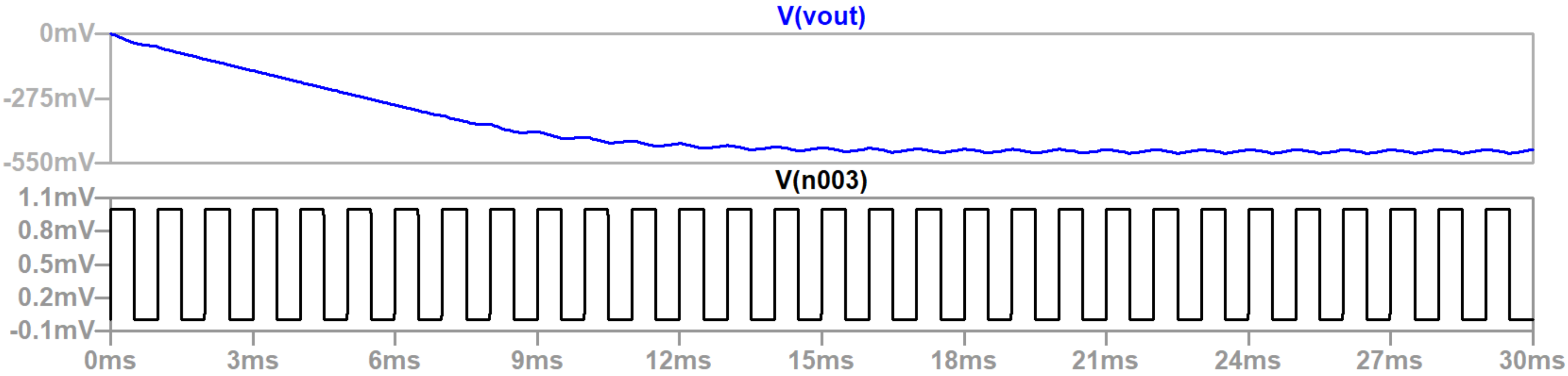


Transient Characteristics (Square wave input) (2)

C_1=0.1μF, C_2=1nF

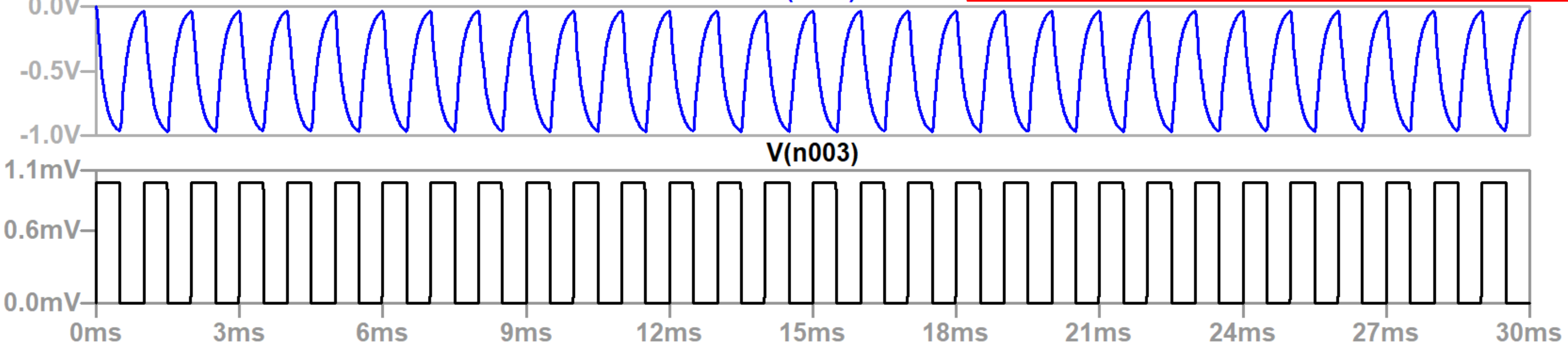
SPICE simulation

17mV$_{P-P}$
≠ ×1,000



C_1=1nF, C_2=0.1μF (Optimal value)

950mV$_{P-P}$
approaches to ×1,000



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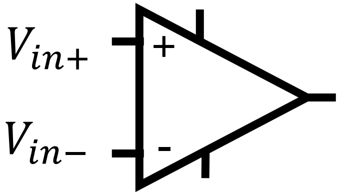
Offset Voltage Simulation Circuit



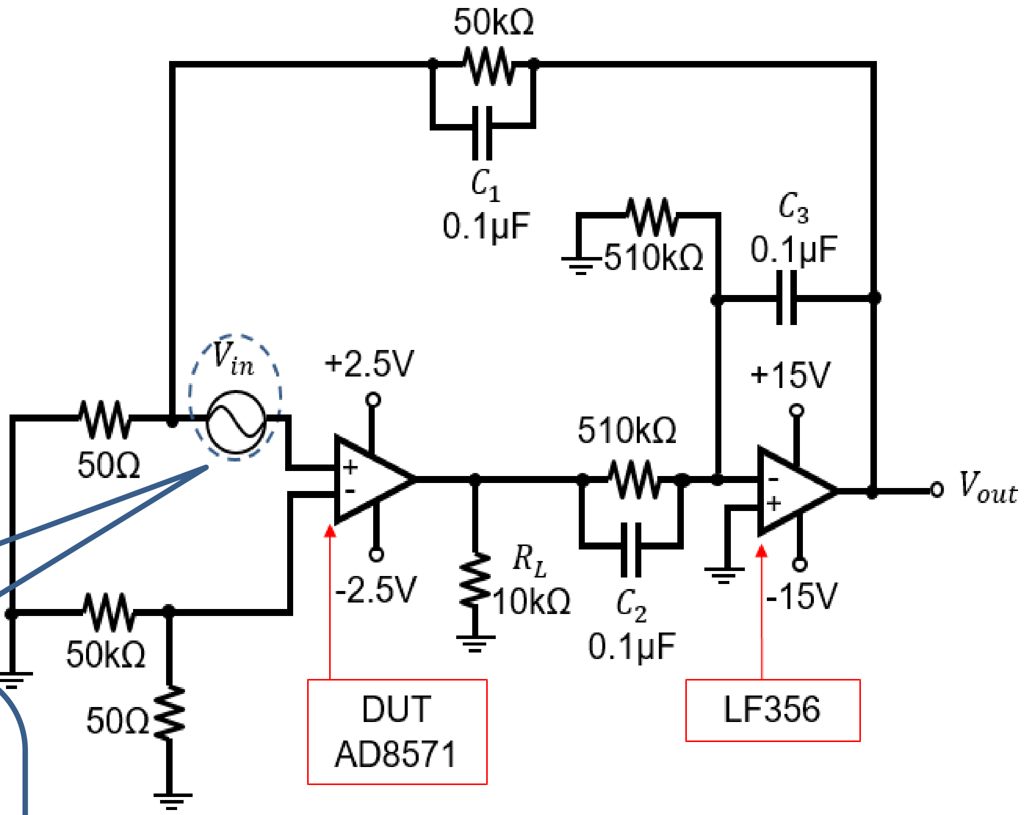
Ideal $V_{in+} = V_{in-}$

In practice $V_{in+} \neq V_{in-}$

Simulate input-referred offset voltage

Square wave input
($1\mu V_{P\text{-}P}$, 1Hz)

Equivalently
Apply DC Offset Voltage

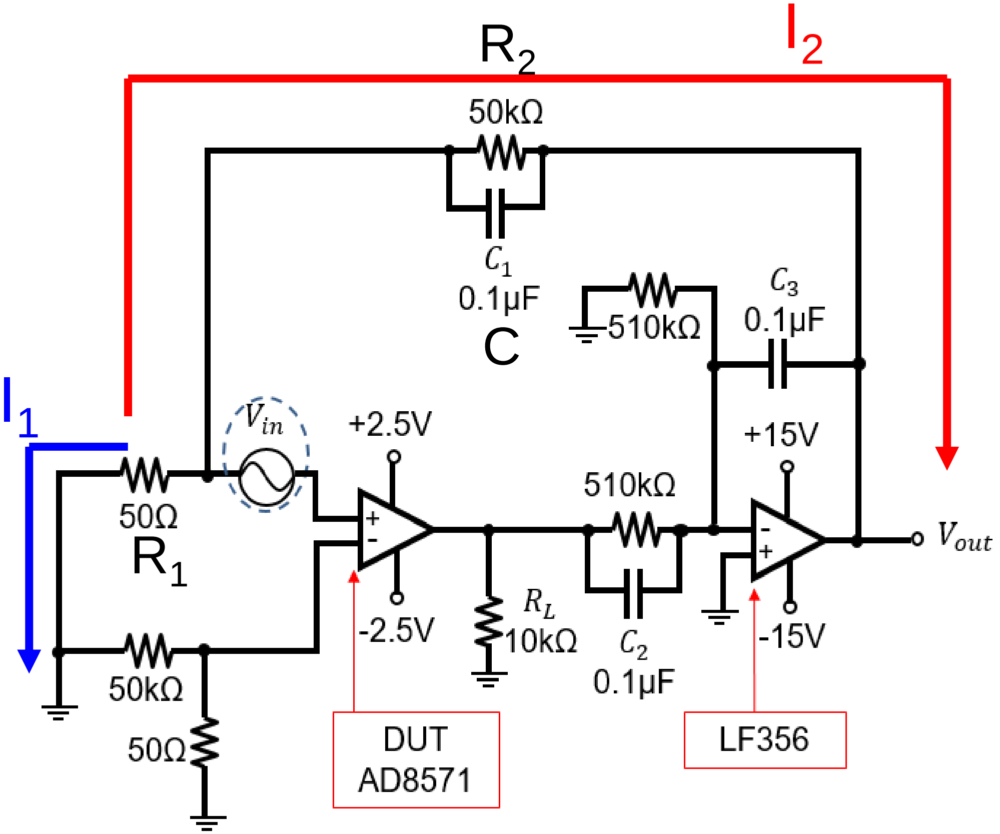


Offset Voltage
Simulation Circuit

Transfer Function

$$\begin{cases} I_1 = \dfrac{V_{in}}{R_1} \\[2ex] I_2 = \left(\dfrac{1}{R_2} + \dfrac{1}{1/j\omega C}\right)(V_{in} - V_{out}) \\ \quad = \dfrac{1 + j\omega C R_2}{R_2}(V_{in} - V_{out}) \\[2ex] I_1 = -I_2 \end{cases}$$

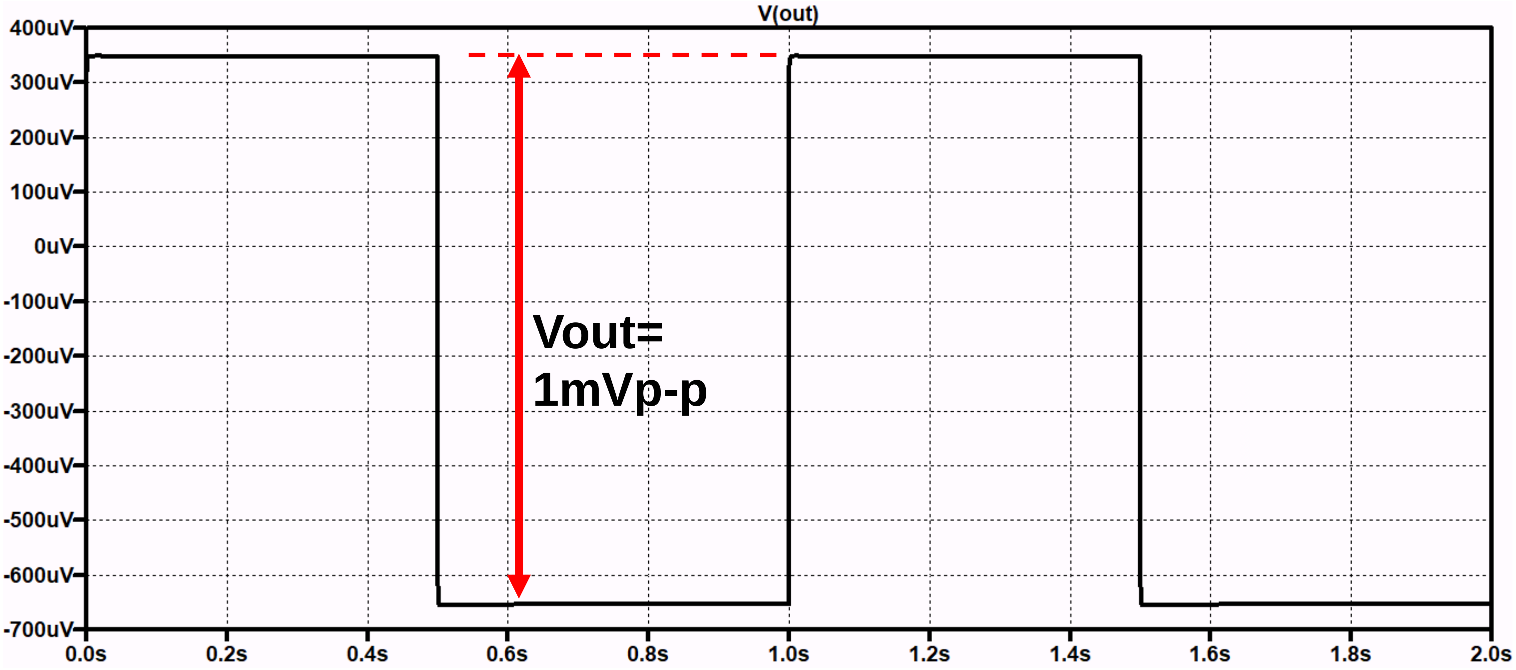
$$\therefore \left|\frac{V_{out}}{V_{in}}\right| = \frac{R_2}{\sqrt{{R_1}^2 + (\omega C R_1 R_2)^2}} + 1$$



At $R_1 = 50\Omega,\quad R_2 = 50k\Omega,\quad C = 0.1\mu F,\quad f = 1Hz$

$$\left|\frac{V_{out}}{V_{in}}\right| = 1{,}000.5068\cdots \cong 1{,}000$$

Offset Voltage Simulation Result



Offset Voltage Simulation Result

Minute error

$1\mu V_{P\text{-}P}$ → $1mV_{P\text{-}P}$ → Easy Measurement

x 1,000

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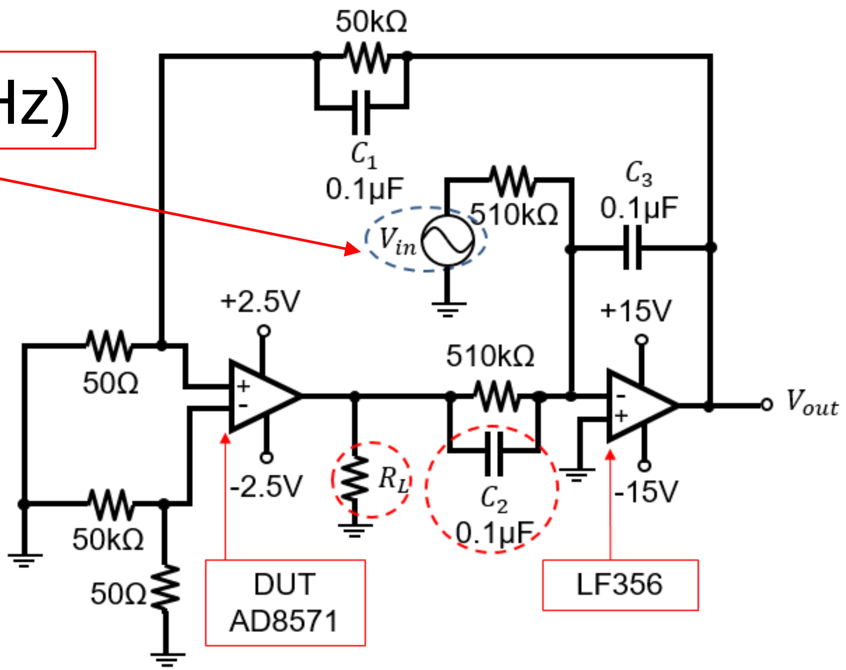
A_{OL} Simulation Result (1)

Square wave input ($1V_{P\text{-}P}$, 1Hz)

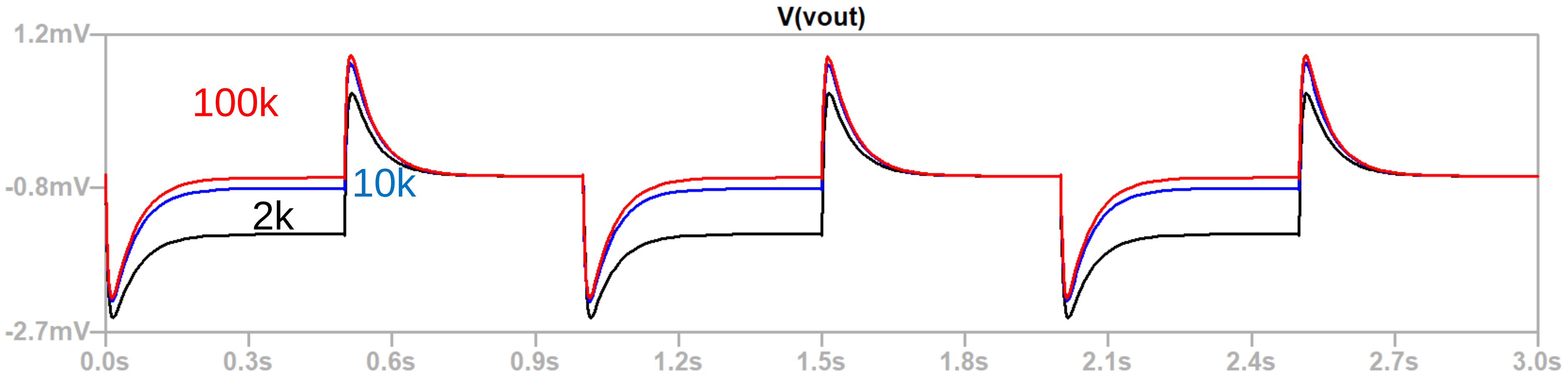
Open Loop Gain Simulation Result

R_L[kΩ]	A_{OL}[dB]
2	122
10	136
100	154

R_L → Large ⇨ A_{OL} → High



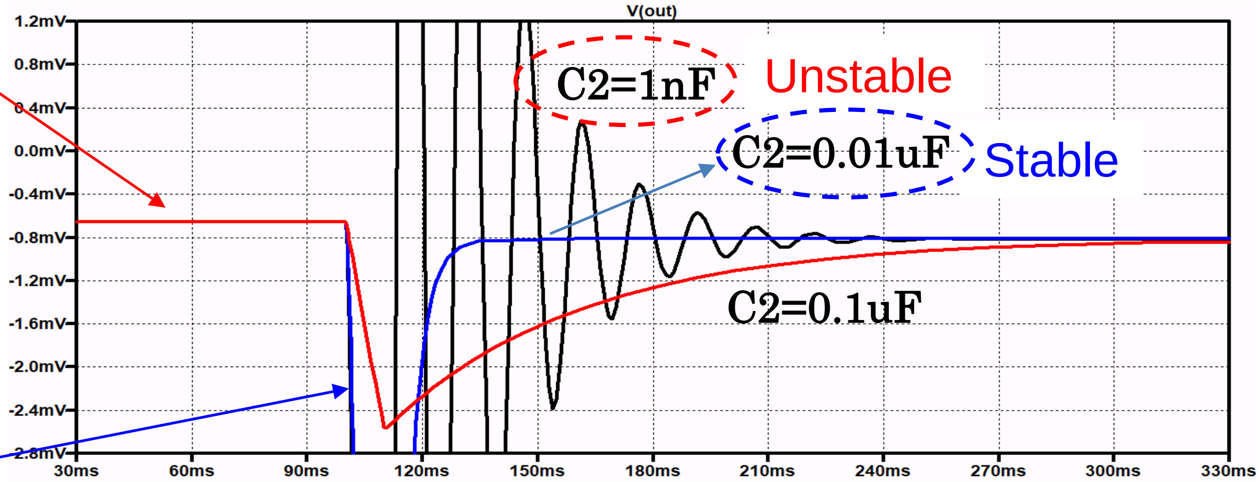
Open Loop Gain Measurement Circuit



A_{OL} Simulation Result (2)

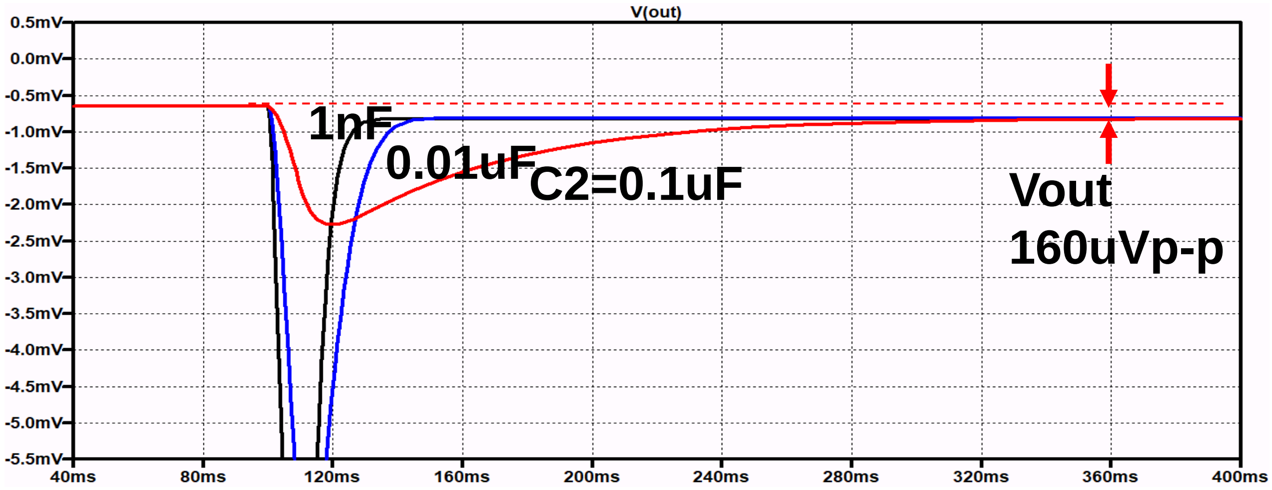
Settling time
→ 200ms

Settling time
→ 30ms



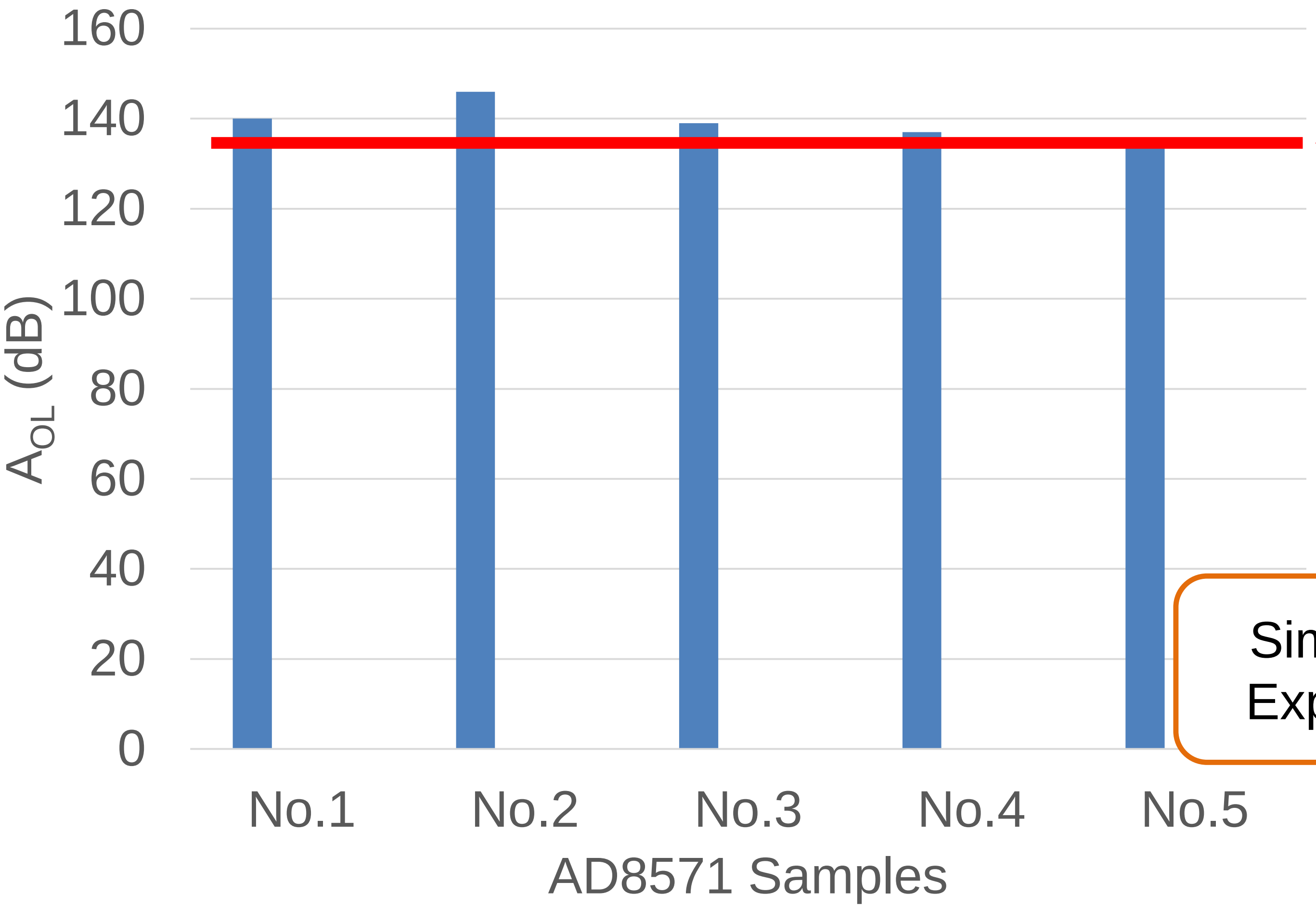
R_L=10kΩ, C_1=1nF, C_2 is varied

Settling time
1/10



R_L=10kΩ, C_1=0.1μF, C_2 is varied

A_{OL} Experimental Result



←Simulation Result
136dB

Simulation Result ≅
Experimental Result

Open Loop Gain Experimental Result for R_L=10kΩ

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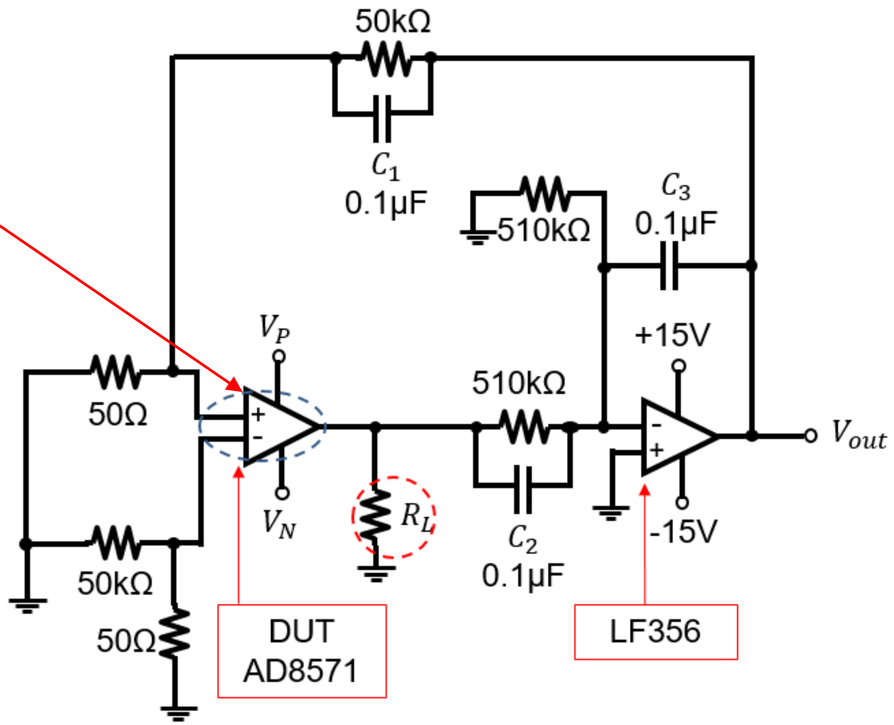
CMRR Simulation Result (1)

Shift power supply voltages
Find CMRR equivalently
V_P ... +2.5V → +3.0V
V_N ... -2.5V → -2.0V

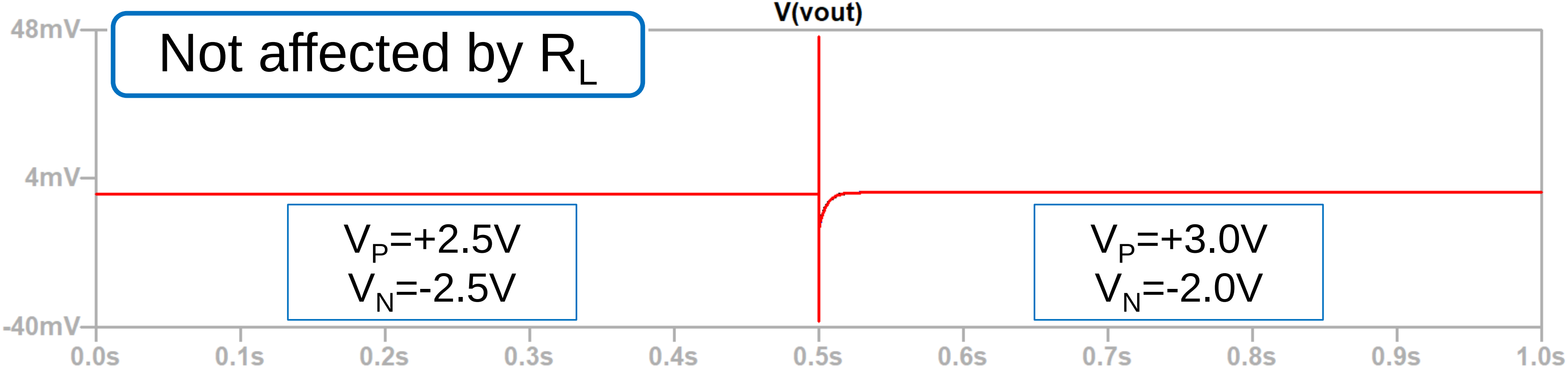


CMRR Measurement Circuit

CMRR Simulation Result

R_L[kΩ]	CMRR[dB]
2	126
10	126
100	126

Not affected by R_L



V_P=+2.5V
V_N=-2.5V

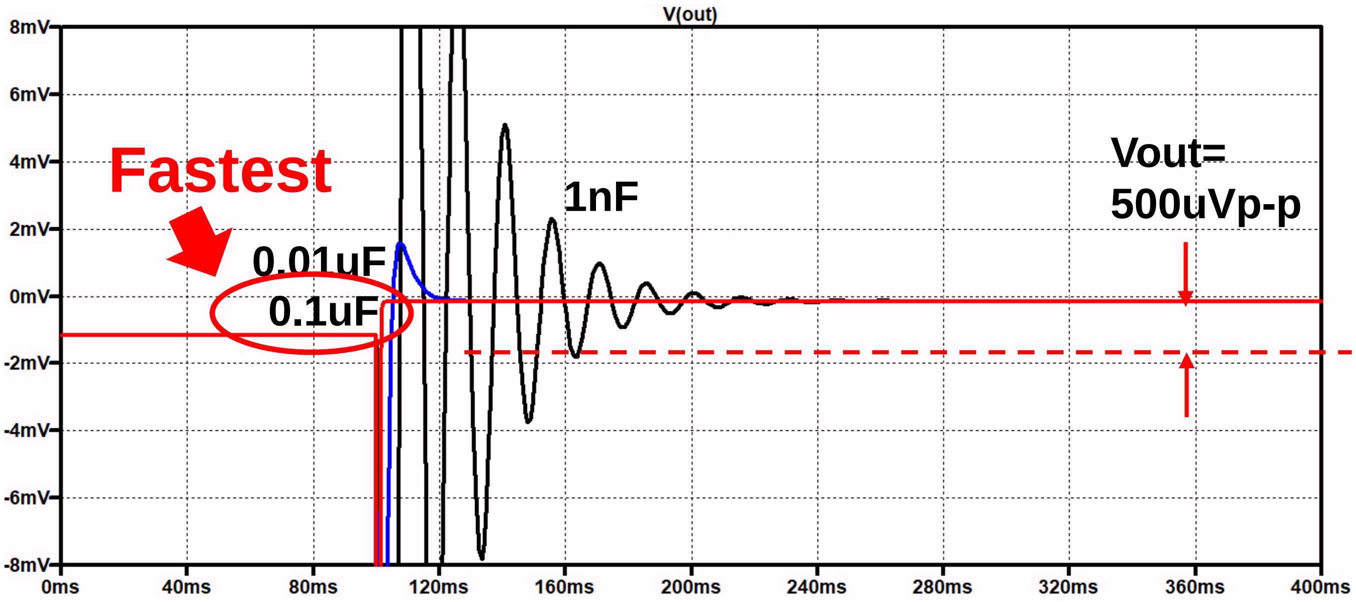
V_P=+3.0V
V_N=-2.0V

CMRR Simulation Result (2)

R_L → 10kΩ, C_1 → 1nF

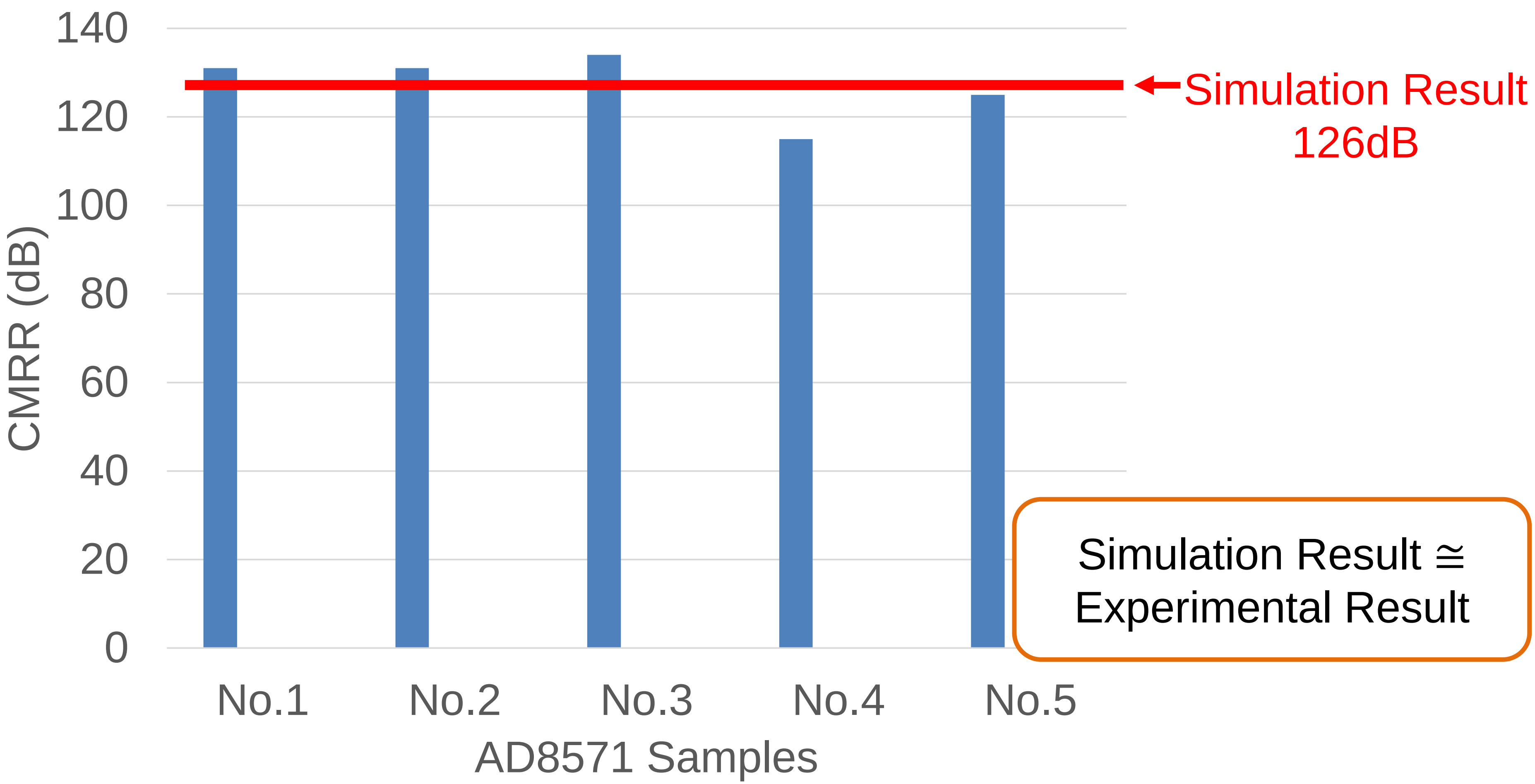
C_2 → Large

CMRR → Fast response



CMRR Simulation Result when C_1=1nF, C_2 is varied.

CMRR Experimental Result



Simulation Result ≅ Experimental Result

CMRR Experimental Result for R_L=10kΩ

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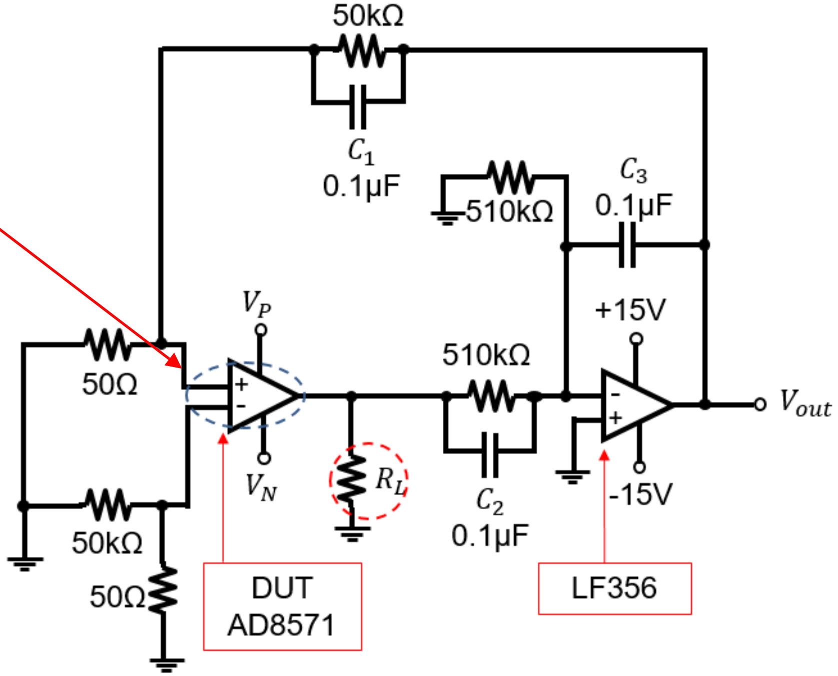
PSRR Simulation Result (1)

Same configuration as CMRR
V_P ... +2.0V → +2.5V
V_N ... -2.0V → -2.5V

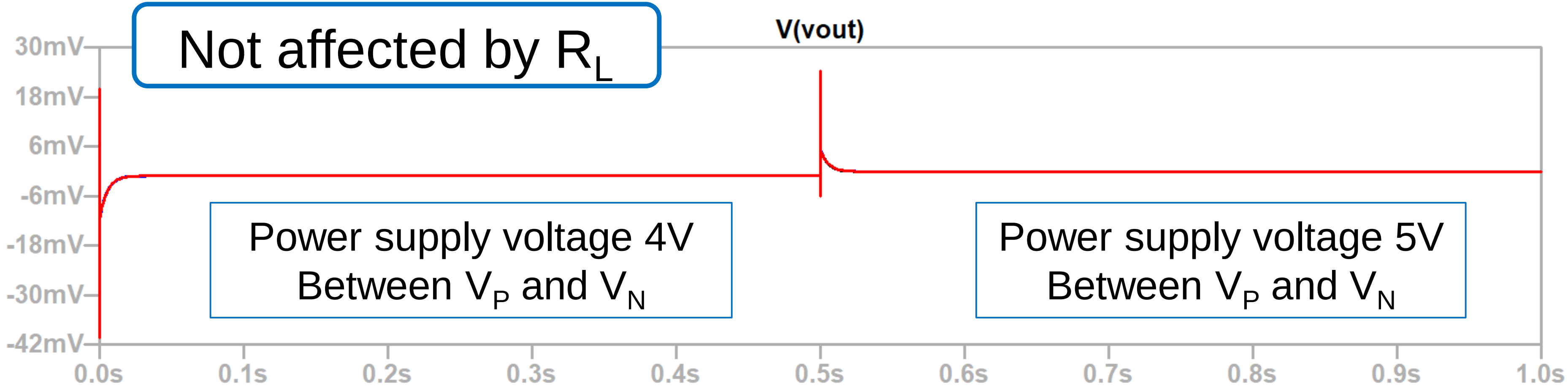
PSRR Simulation Result

R_L[kΩ]	PSRR[dB]
2	120
10	120
100	120



Same as CMRR Measurement Circuit

Not affected by R_L



Power supply voltage 4V
Between V_P and V_N

Power supply voltage 5V
Between V_P and V_N

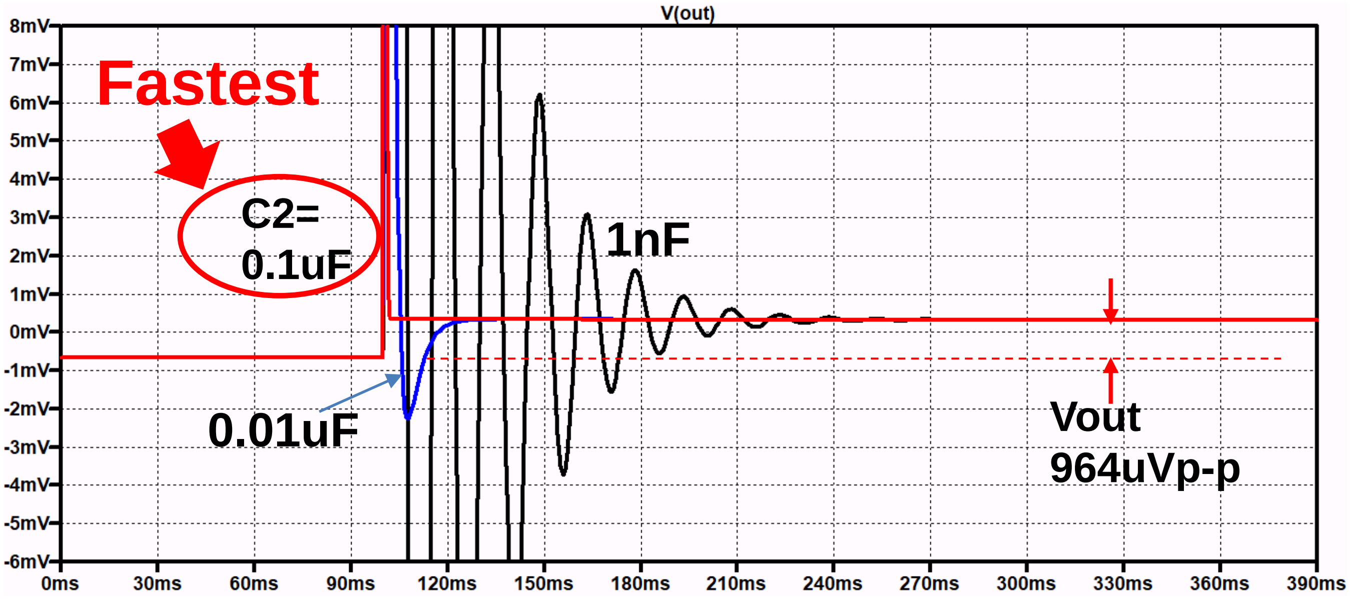
PSRR Simulation Result (2)

$R_L \rightarrow 10k\Omega$, $C_1 \rightarrow 1nF$

$C_2 \rightarrow$ Large

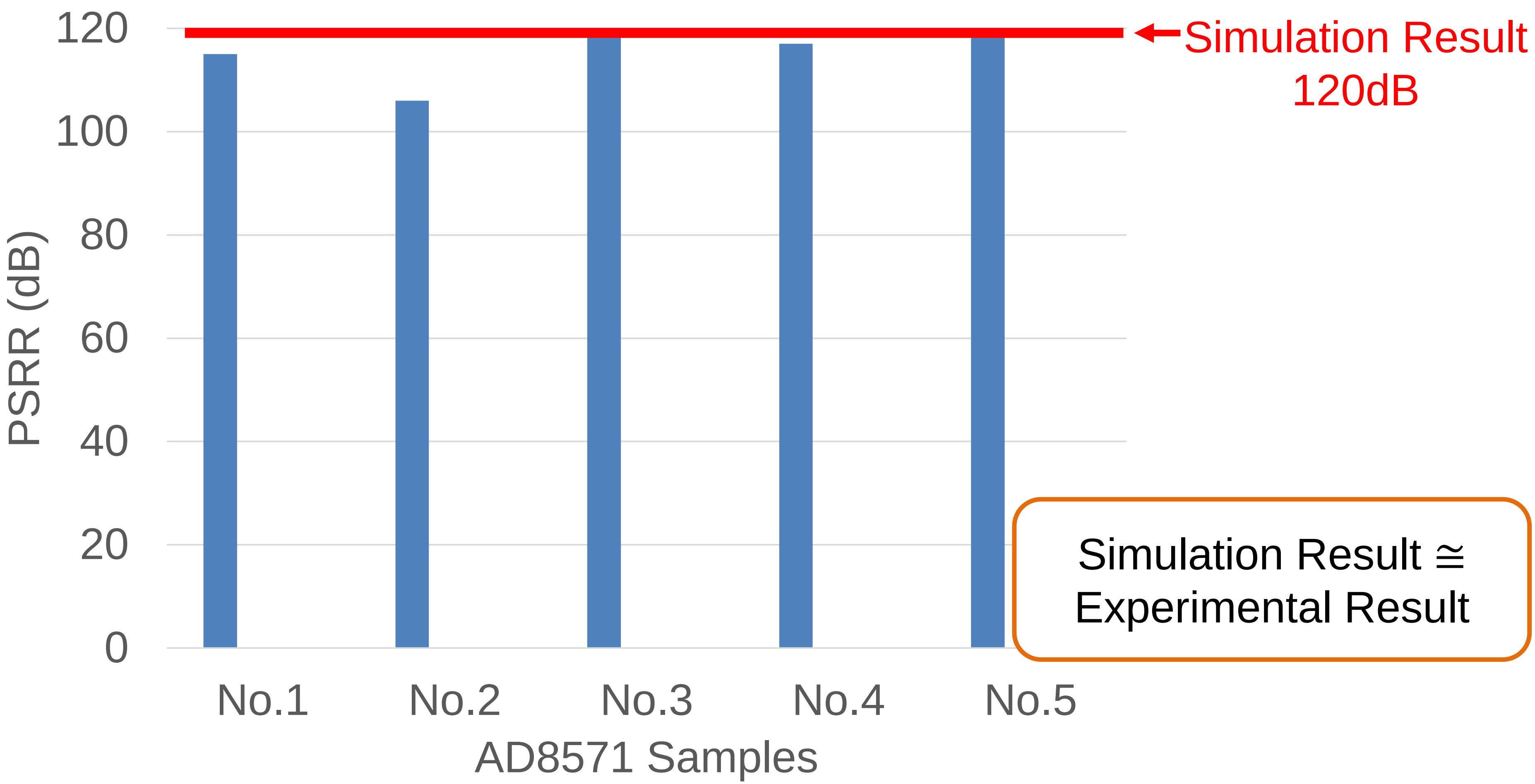
PSRR → Fast response

(Same as CMRR)



PSRR Simulation Result when C_1=1nF, C_2 is varied.

PSRR Experimental Result



Simulation Result ≅ Experimental Result

PSRR Experimental Result for R_L=10kΩ

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Conclusion

- Optimization of phase compensation constants

C_1=1nF, C_2=0.1μF

⇩

Null Circuit → Fast and Stable

- Null Circuit : Change of signal application point
  depending on the measurement item

Signal input change (C_1, C_2 : Fixed)

⬇

Different response characteristics of each input / output

- Switching C_1 and C_2 depending on the measurement item

⇩

Settling time reduction → ≒ 1/10

Thank you for attention

Q&A

Q. オープンループゲインはどのようにして求めるのか？

A. （P.29のスライドを表示して）図のこの部分に 1$V_{p\text{-}p}$、1Hzの矩形波を入力した時のVoutから求めています。