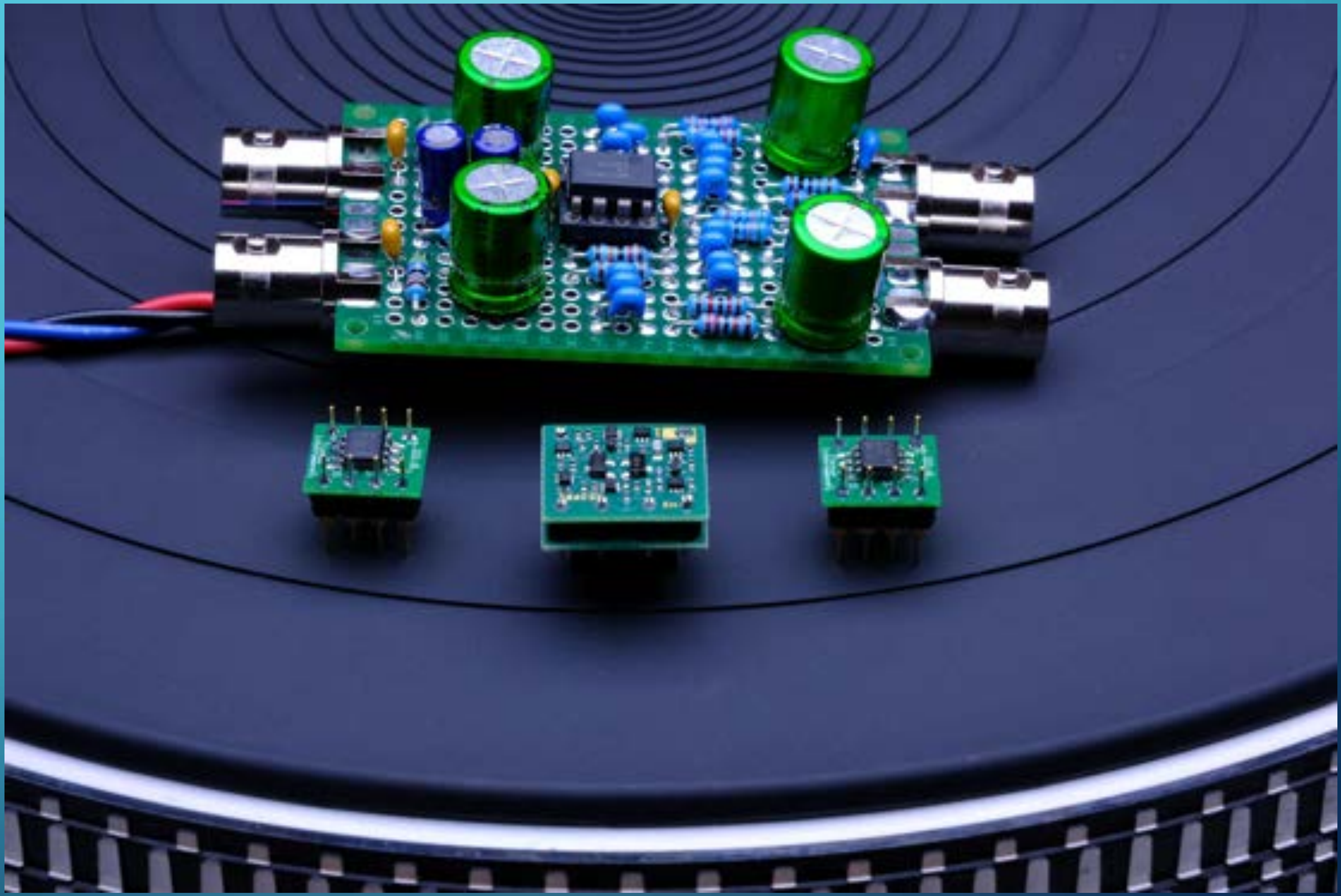
♫ROLLING, ROLLING, ROLLING♬



OPAMP ROLLING IN AUDIO APPLICATIONS

TOM CHRISTIANSEN

INTRODUCTION

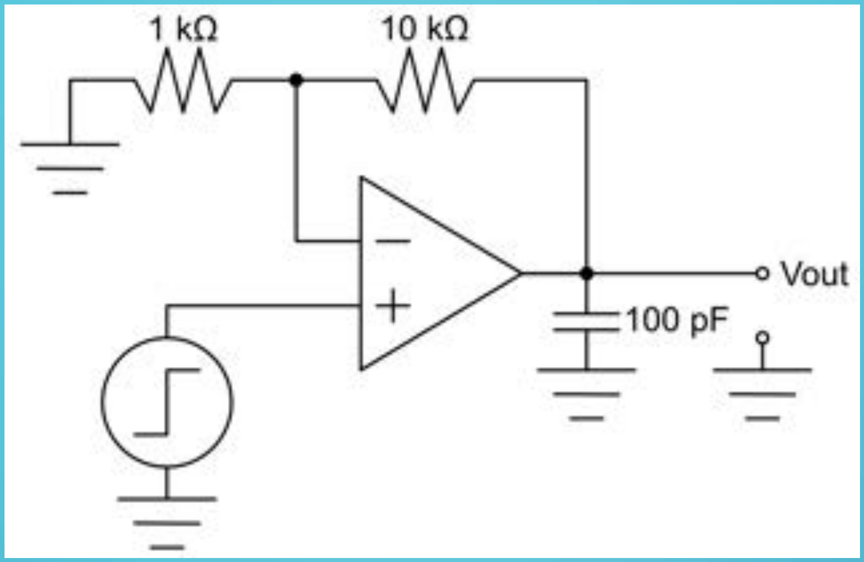
Tom Christiansen (tomchr)

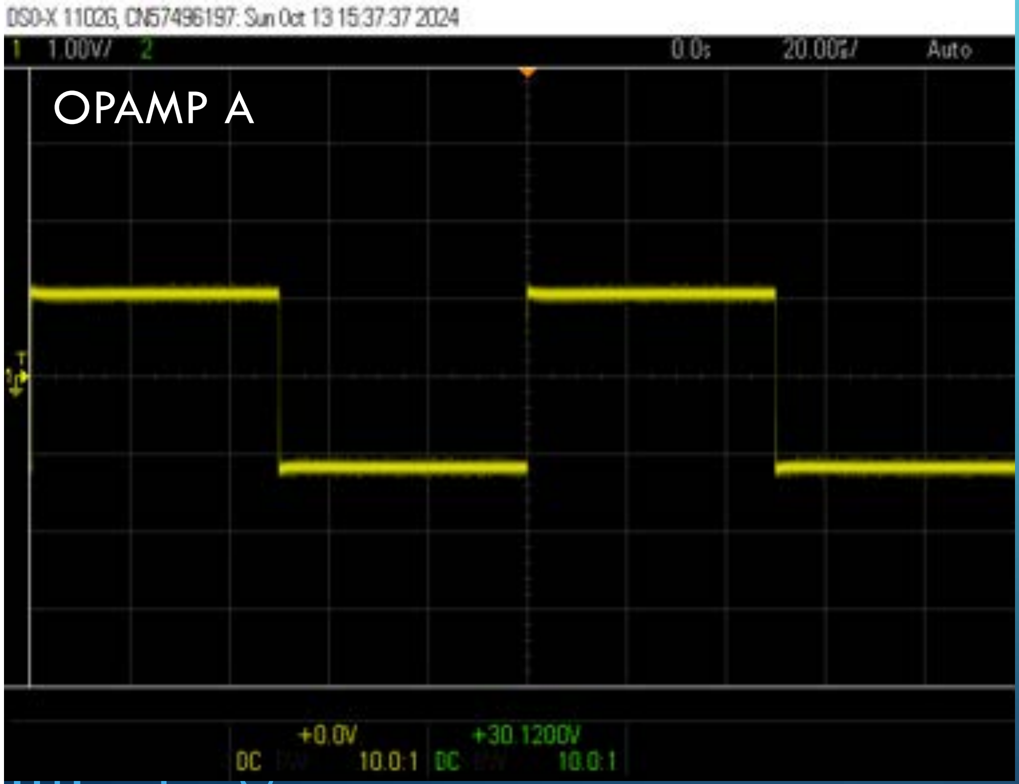
- BScEE – Engineering College of Copenhagen – 1999
- MScEE – University of Washington, Seattle – 2002
- BA (Psych) – University of Calgary – 2019

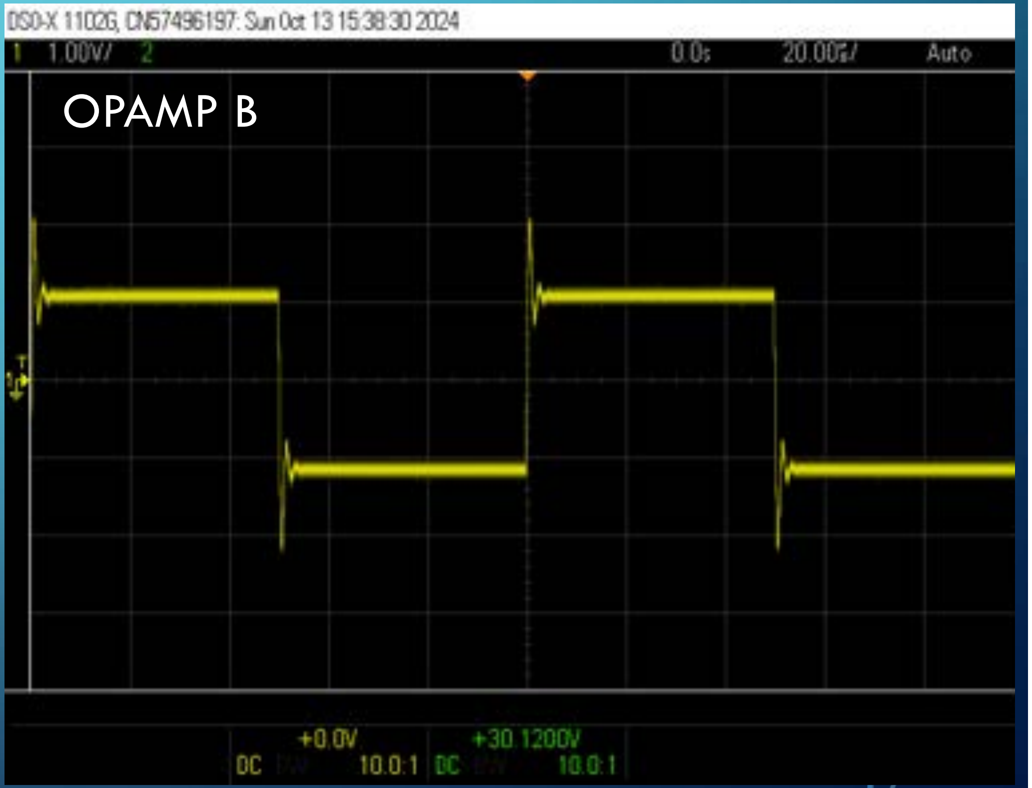
- National Semiconductor – Federal Way, WA – 2005 - 2011
- Texas Instruments – Federal Way, WA – 2011 - 2015
- Neurochrome – Calgary, AB – 2010 - present

NEUROCHROME
ENGINEERING · DONE · RIGHT

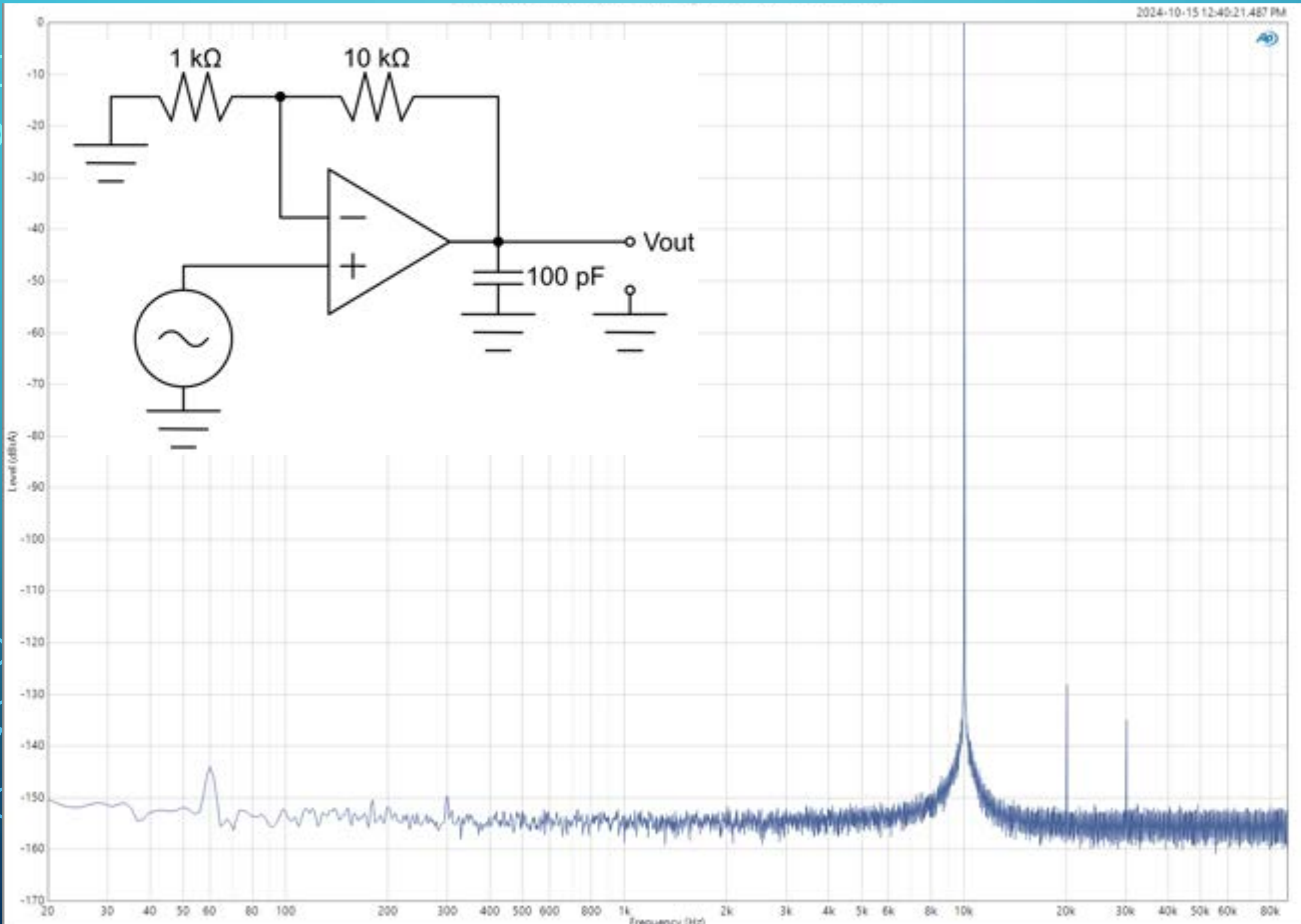
INTRODUCTION


1 kΩ
10 kΩ
Vout
100 pF


DSO-X 1102G, CN57496197: Sun Oct 13 15:37:37 2024
1.00V/
0.0s
20.00$/
Auto
OPAMP A
+0.0V
+30.1200V
DC
10.0:1
DC
10.0:1

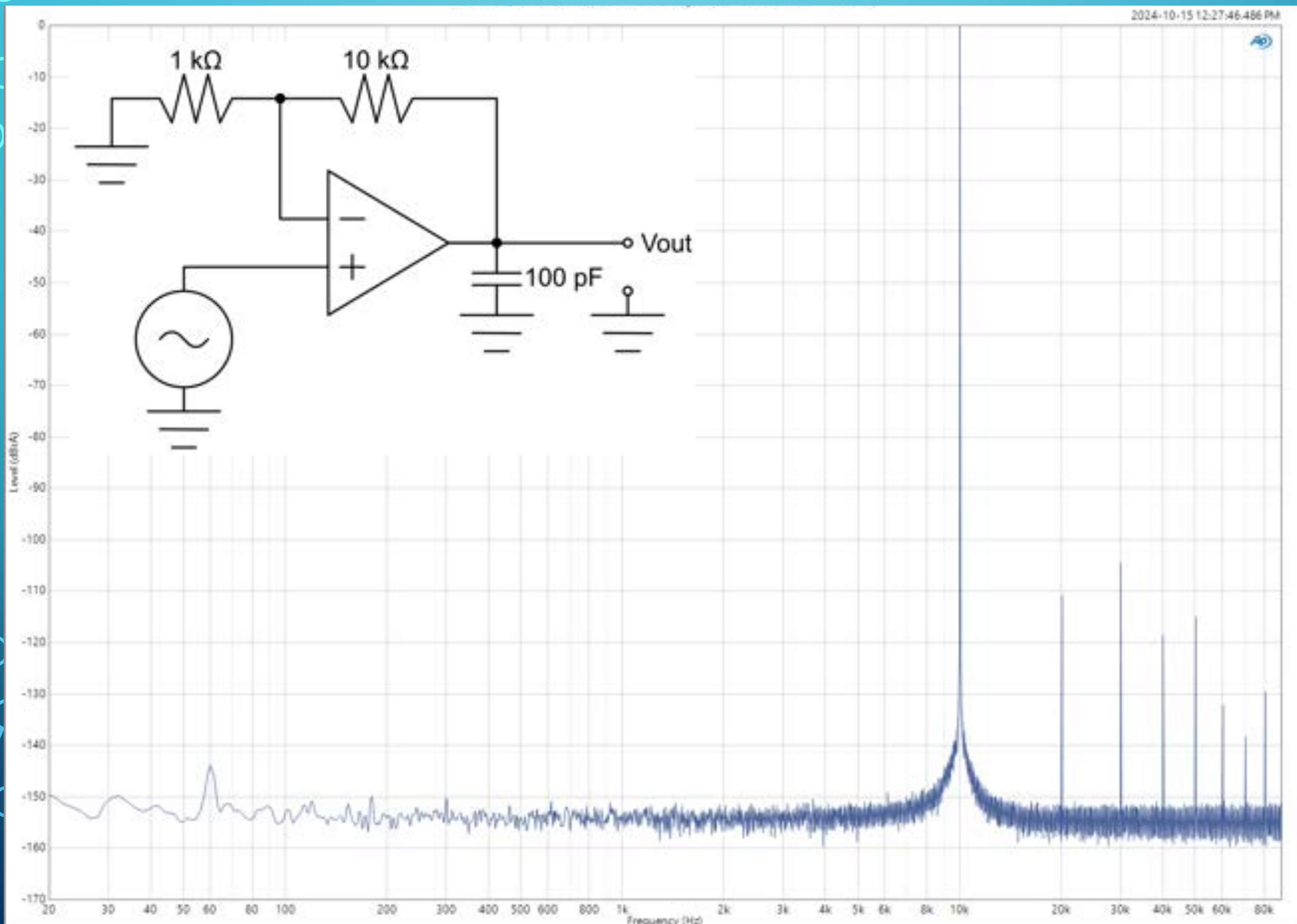

DSO-X 1102G, CN57496197: Sun Oct 13 15:38:30 2024
1.00V/
0.0s
20.00$/
Auto
OPAMP B
+0.0V
+30.1200V
DC
10.0:1
DC
10.0:1

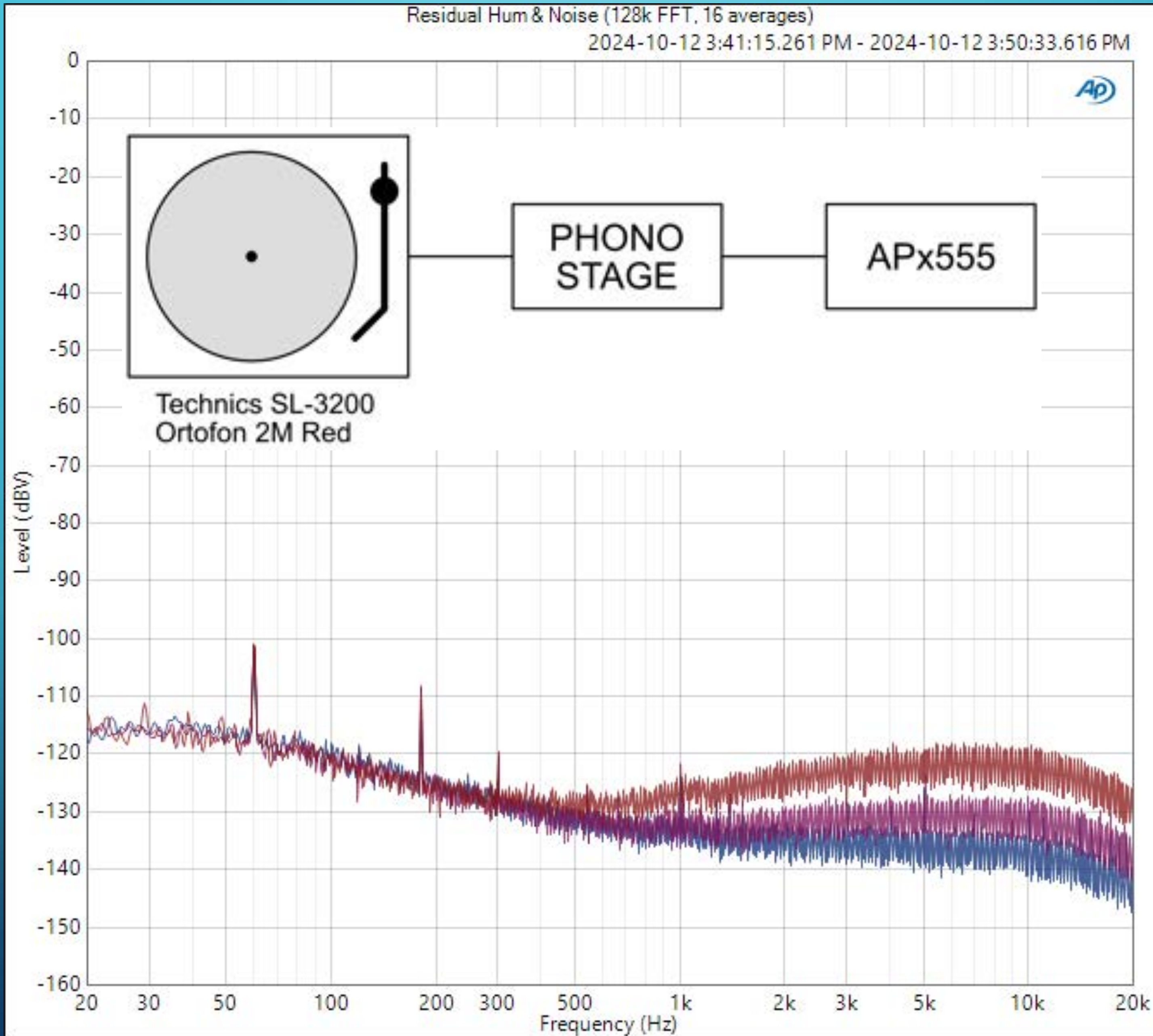
OPAMP A



2024-10-15 12:40:21.487 PM
1 kΩ
10 kΩ
Vout
100 pF
Level (dBrA)
Frequency (Hz)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
20
30
40
50
60
80
100
200
300
400
500
600
800
1k
2k
3k
4k
5k
6k
8k
10k
20k
30k
40k
50k
60k
80k

OPAMP B

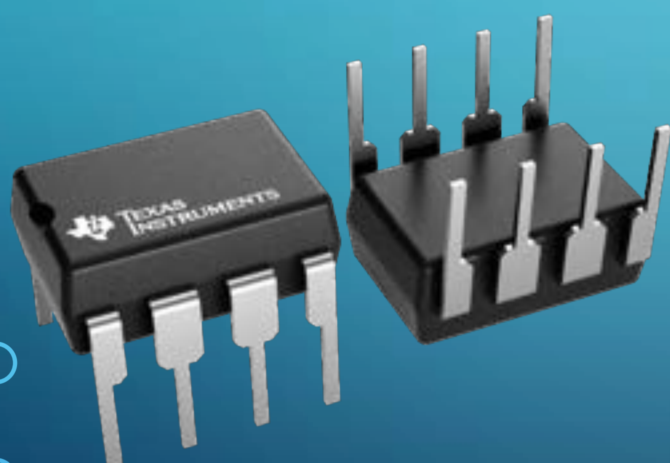

2024-10-15 12:27:46.486 PM
1 kΩ
10 kΩ
Vout
100 pF
Level (dBrA)
Frequency (Hz)



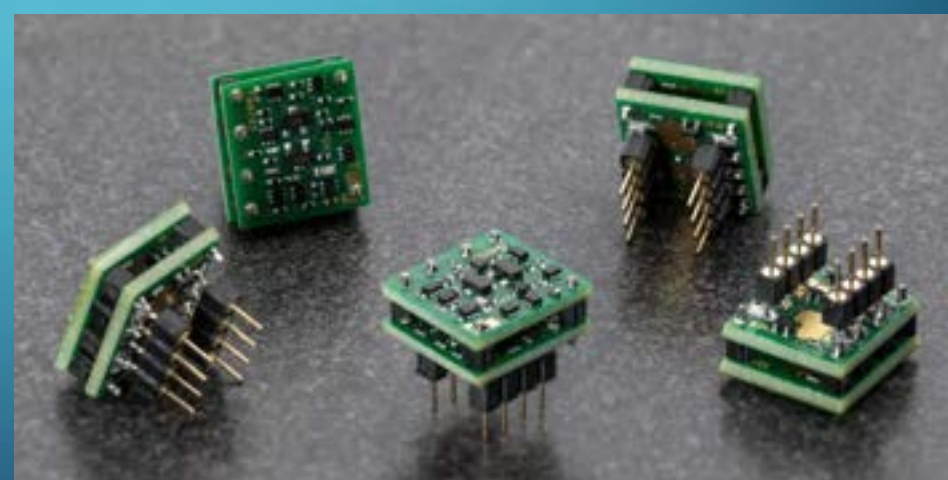
OPAMP A
OPAMP B
OPAMP C

OUR CONTESTANTS ARE …

- OPAMP A $6.59 TI OPA1612AIDR
- OPAMP B $79.80 Sparkos SS3602 (Discrete)
- OPAMP C $2.10 TI OPA1642AIDR



(Texas Instruments)


(Sparkos)

ROLL THE OPAMP – ROLL THE DICE

- Discrete vs Integrated
- Stability Analysis
- Real World Example #1 – Gain Stage
- Real World Example #2 – Phono Stage
- Lessons Learned
- Questions

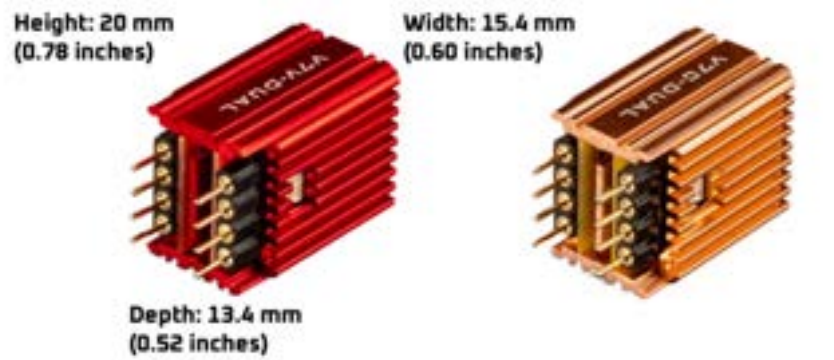
DISCRETE VS INTEGRATED

Supreme Sound Opamp V7 Data

The Supreme Sound V7 Operational Amplifier (SS Opamp) is the produ
development, leveraging a legacy of 20 years of expertise in audio techr
operational amplifier is designed with a singular focus on delivering sup
contrast to conventional integrated circuit operational amplifier designs
Burson's approach for the SS Opamp emphasises minimising open-loop
drift, and achieving low offset. Furthermore, the SS Opamp distinguishe
versatile power supply compatibility, key features for outstanding analo

The design's input stage features a pair of meticulously matched field-e
two-stage screening process to ensure optimal compatibility and perfor
consistent, high-quality amplification. The amplification core of the SS O
moving away from traditional voltage amplification methods. This desig
current limiting resistor's value, effectively reduces the RC parameter of
response.

Enhancing its capabilities further, the SS Opamp includes another set of
stage, facilitating a high drive current and low output impedance. This
adaptable and suitable for various audio applications, providing robust
impedance.

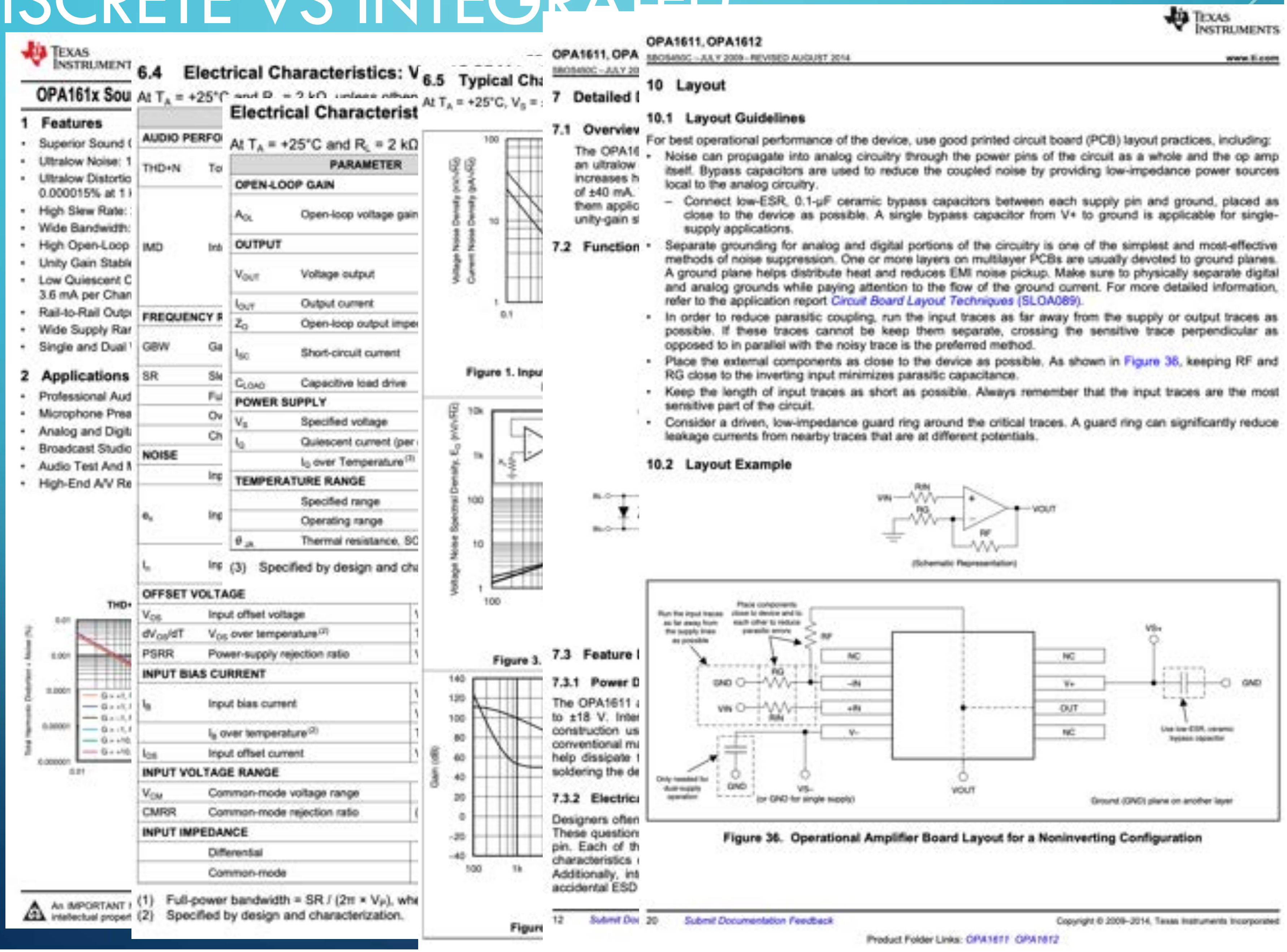


Dual: 5.7g (0.2 Ounce) Single: 4.5g (0.26 Ounce)

		Measurement			
Absolute Maximum Ratings		Min		Typ	Max
Supply Voltage		+/-4 V		+/-15V	+/- 16V
Operating Ambient Temperature		−25°C			60°C
Storage temperature range		−65°C			80°C
DC Characteristics	Conditions	Testing Temperature 25°C Supply Voltage +/-15V			
Quiescent Current (mA)				Single 10mA Dual 20mA	
Input offset voltage (mV)	$R_L = 0$	0.05 mV		0.1 mV	
Input offset current (mA)		0.08 mA		0.12 mA	0.15 mA
Input BIAS current (µA)		120 µA		150 µA	300 µA
Common-Mode Rejection Ratio				100 dB	
Power Supply Rejection Ratio				15 µV/V	
AC Characteristics	Conditions	Testing Temperature 25°C Supply Voltage +/-12V			
Open-loop gain (dB)				66 dB	
Open-loop bandwidth (dB)	RL=600Ω			48 Khz	
Gain Bandwidth Product (MHz)	@ 100KHZ			55 MHz	
Slew Rate (V/µS)	f = 10kHz; RS = 2KΩ	35V/µS			5V/µS
Input Resistant (KOhm)				50MΩ	
Crosstalk distortion (dB)(Dual Opamp)	f = 1kHz; RS = 600Ω			>96dB	
Total Harmonic Distortion (%) 1Khz @ 2V output	1Khz @ 2V output; RL=600Ω			0.018%	
Output Impedance (Ohm)	AV = 30dB Closed-loop f = 10kHz, RL = 600Ω			0.40Ω	

(Burson)

DISCRETE VS INTEGRATED


OPA161x SoundPlus™

1 Features
- Superior Sound
- Ultralow Noise: 1
- Ultralow Distortion 0.000015% at 1 k
- High Slew Rate:
- Wide Bandwidth:
- High Open-Loop
- Unity Gain Stable
- Low Quiescent C 3.6 mA per Chan
- Rail-to-Rail Output
- Wide Supply Range
- Single and Dual

2 Applications
- Professional Aud
- Microphone Prea
- Analog and Digit
- Broadcast Studio
- Audio Test And M
- High-End A/V Re

6.4 Electrical Characteristics: V

Electrical Characterist

At T_A = +25°C and R_L = 2 kΩ

PARAMETER	
OPEN-LOOP GAIN	
A_{OL}	Open-loop voltage gain
OUTPUT	
V_{OUT}	Voltage output
I_{OUT}	Output current
Z_O	Open-loop output impe
I_{SC}	Short-circuit current
C_{LOAD}	Capacitive load drive
POWER SUPPLY	
V_S	Specified voltage
I_Q	Quiescent current (per
	I_Q over Temperature(3)
TEMPERATURE RANGE	
	Specified range
	Operating range
θ_{JA}	Thermal resistance, SO

(3) Specified by design and cha

OFFSET VOLTAGE	
V_{OS}	Input offset voltage
dV_{OS}/dT	V_{OS} over temperature(2)
PSRR	Power-supply rejection ratio
INPUT BIAS CURRENT	
I_B	Input bias current
	I_B over temperature(2)
I_{OS}	Input offset current
INPUT VOLTAGE RANGE	
V_{CM}	Common-mode voltage range
CMRR	Common-mode rejection ratio
INPUT IMPEDANCE	
	Differential
	Common-mode

(1) Full-power bandwidth = SR / (2π × V_P), whe
(2) Specified by design and characterization.

6.5 Typical Cha

7 Detailed

7.1 Overview

7.2 Function

7.3 Feature

OPA1611, OPA1612

10 Layout

10.1 Layout Guidelines

For best operational performance of the device, use good printed circuit board (PCB) layout practices, including:
- Noise can propagate into analog circuitry through the power pins of the circuit as a whole and the op amp itself. Bypass capacitors are used to reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1-μF ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
- Separate grounding for analog and digital portions of the circuitry is one of the simplest and most-effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Make sure to physically separate digital and analog grounds while paying attention to the flow of the ground current. For more detailed information, refer to the application report Circuit Board Layout Techniques (SLOA089).
- In order to reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If these traces cannot be keep them separate, crossing the sensitive trace perpendicular as opposed to in parallel with the noisy trace is the preferred method.
- Place the external components as close to the device as possible. As shown in Figure 36, keeping RF and RG close to the inverting input minimizes parasitic capacitance.
- Keep the length of input traces as short as possible. Always remember that the input traces are the most sensitive part of the circuit.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.

10.2 Layout Example

Figure 36. Operational Amplifier Board Layout for a Noninverting Configuration

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DISCRETE VS INTEGRATED

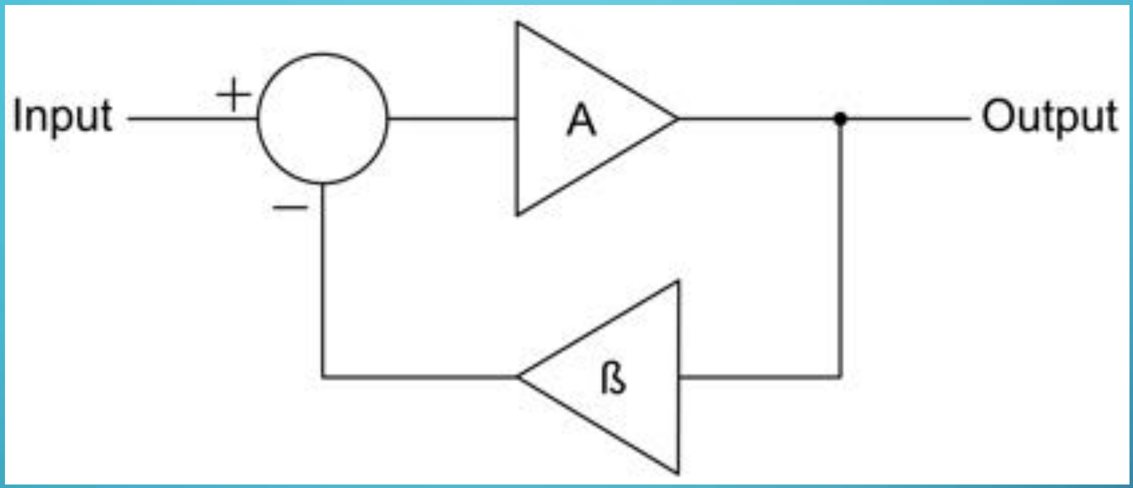
DISCRETE (DUAL)

- Sparkos SS3602: $79.80
- Staccato OSH-DHA: $89.00
- Burson V7 Pro, Vivid: $89.28

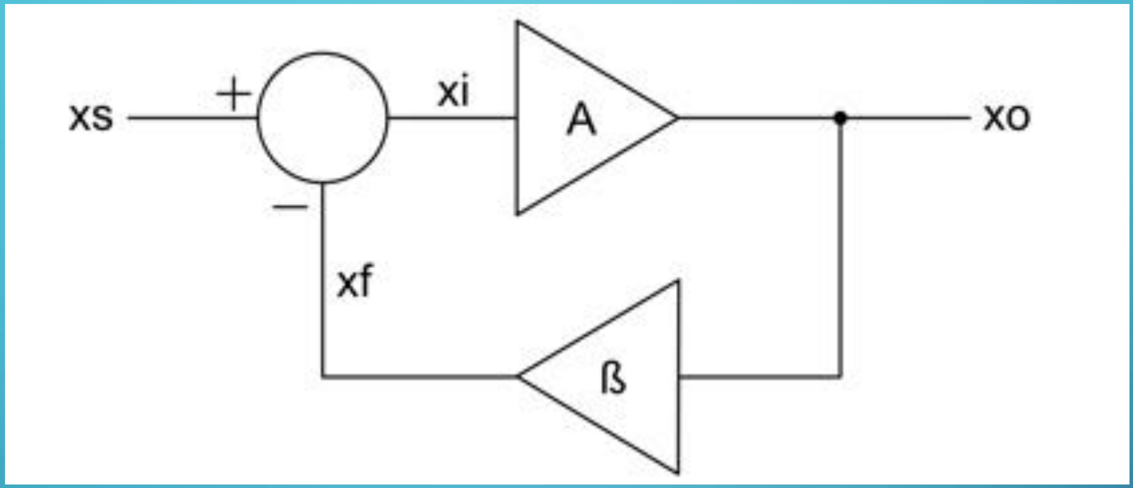
INTEGRATED (DUAL) – QTY 1 (Mouser)

- TI OPA1642AIDR: $2.10
- TI LME49720NA/NOPB: $3.69
- TI OPA1612AIDR: $6.59

STABILITY ANALYSIS



STABILITY ANALYSIS

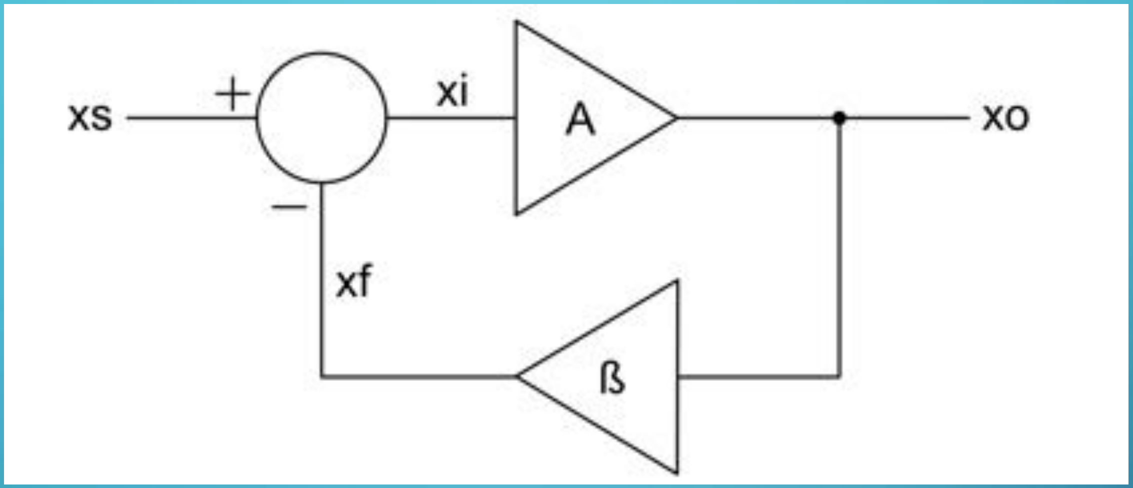


$$xo = A \cdot xi$$

$$xf = \beta \cdot xo$$

$$xi = xs - xf$$

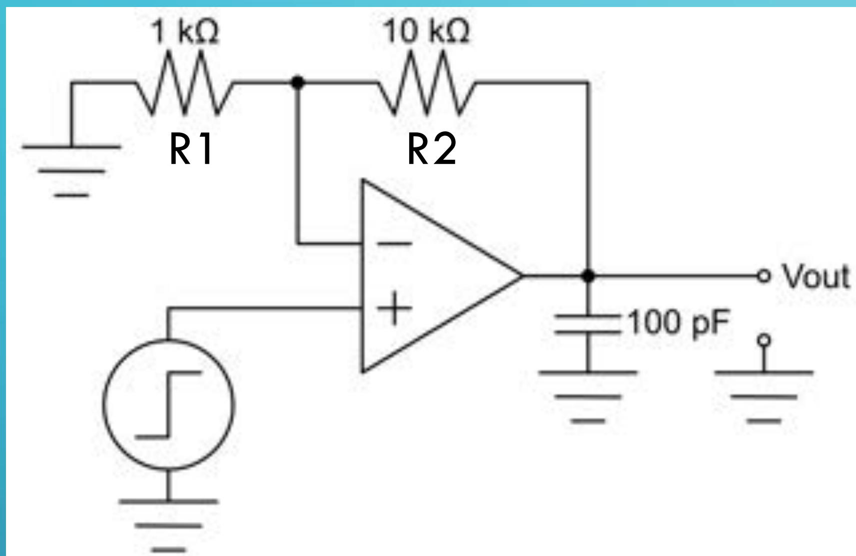
STABILITY ANALYSIS



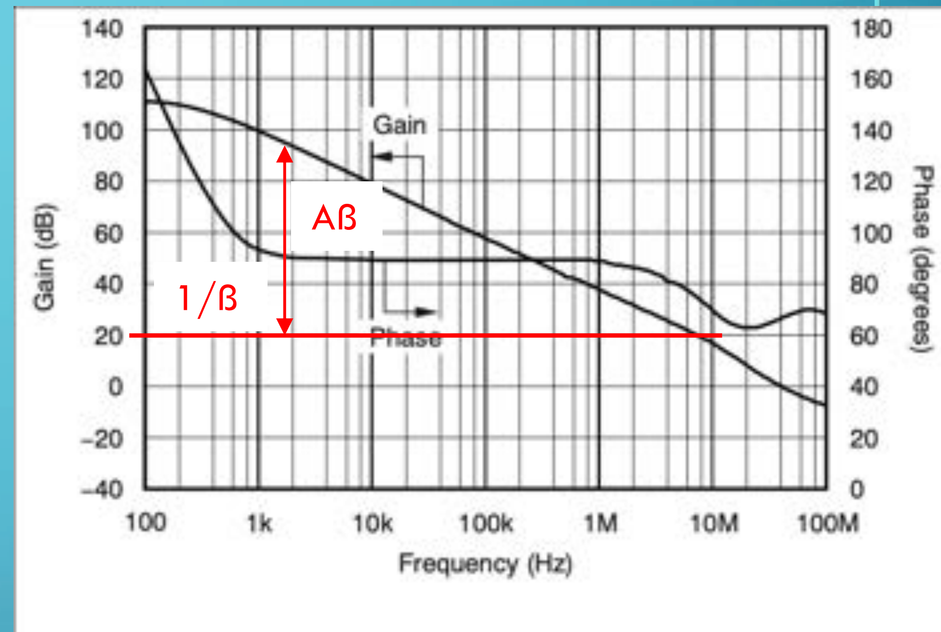
$$A_{CL} = \frac{xo}{xs} = \frac{A}{1 + A\beta}$$

For Aß >> 1 $$A_{CL} \approx \frac{1}{\beta}$$

REAL WORLD EXAMPLE I – GAIN STAGE



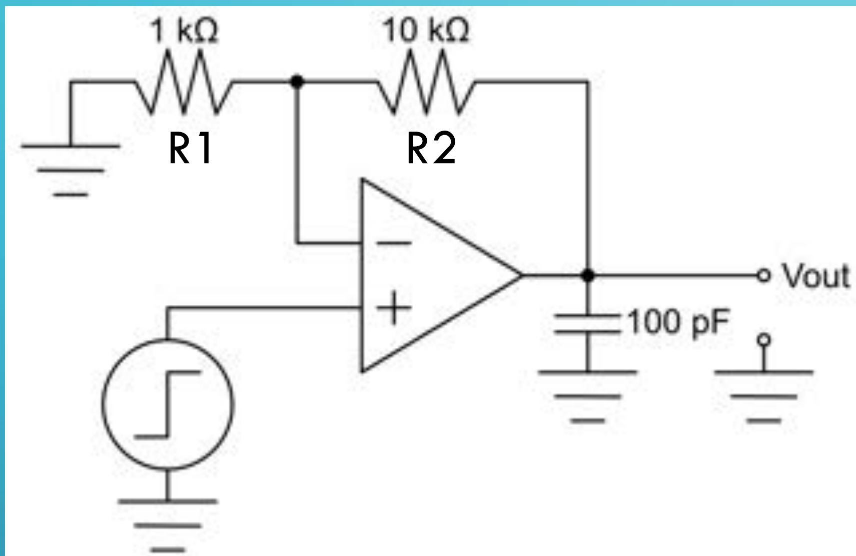
$$\beta = \frac{R1}{R1 \cdot R2} = \frac{1}{10}$$

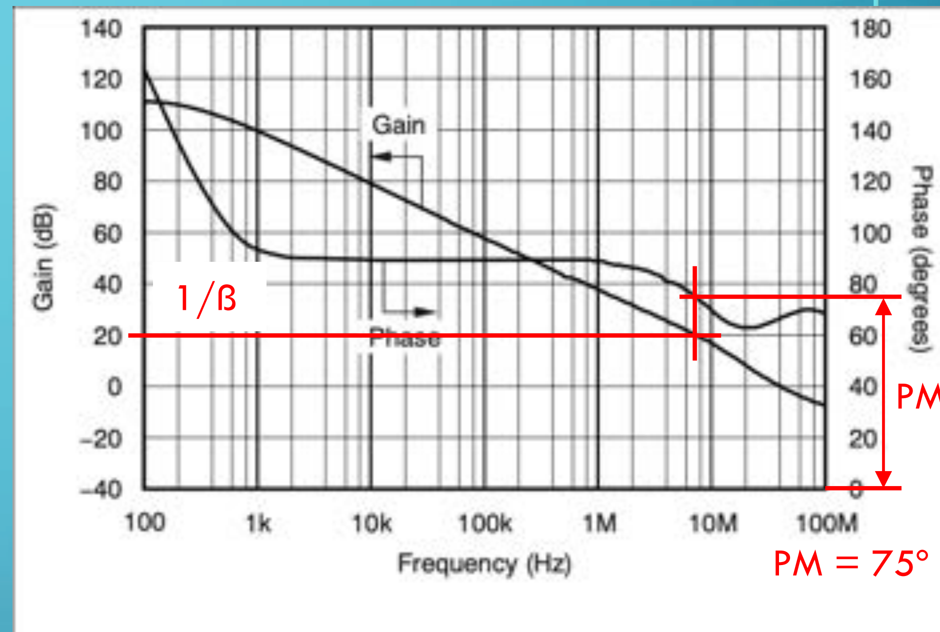


OPA1612

Figure 5. Gain and Phase vs Frequency

REAL WORLD EXAMPLE I – GAIN STAGE



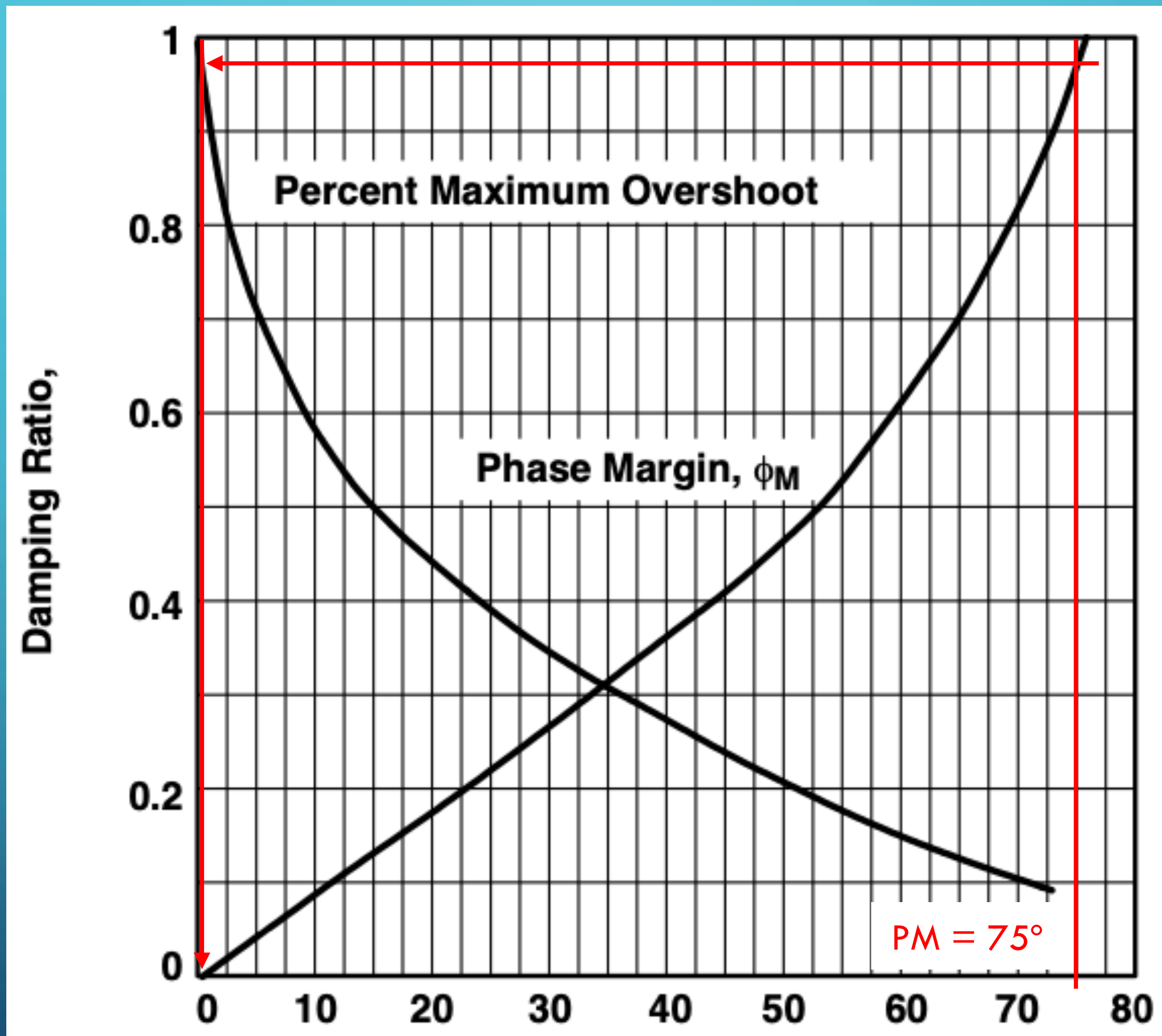


OPA1612

Figure 5. Gain and Phase vs Frequency

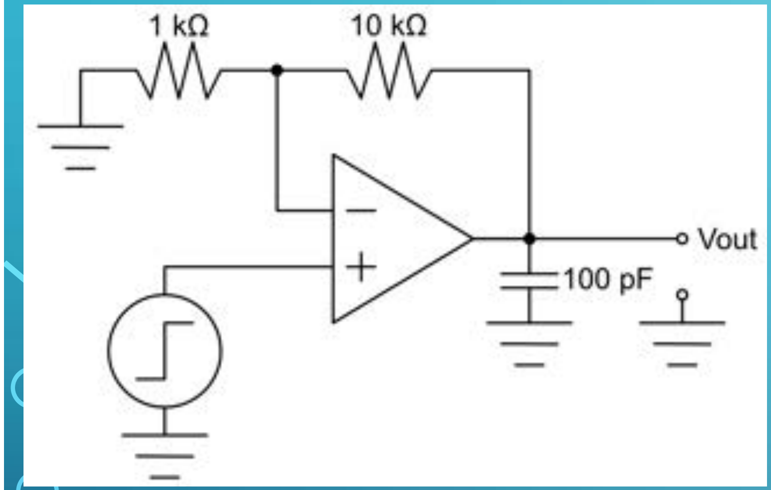
$$\beta = \frac{R1}{R1 \cdot R2} = \frac{1}{10}$$

REAL WORLD EXAMPLE I – GAIN STAGE

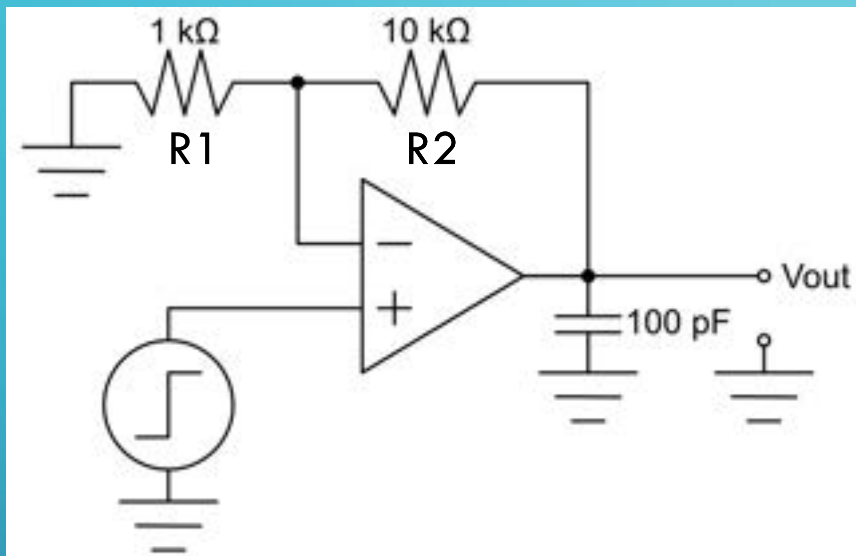


(TI: Opamps for Everyone, Fig. 5-18)

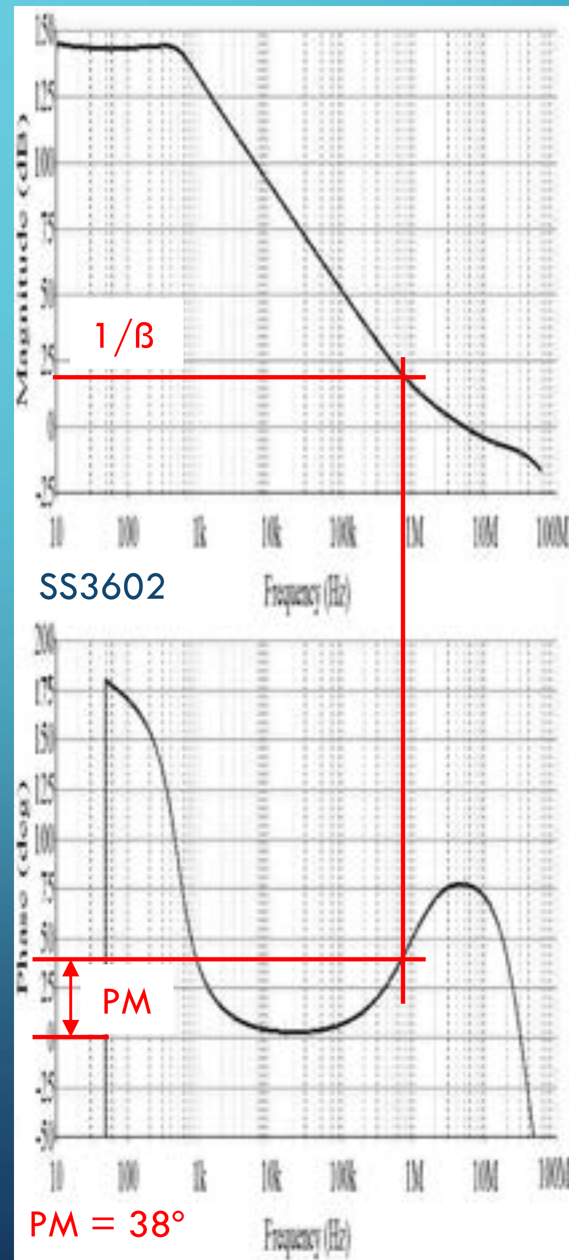
REAL WORLD EXAMPLE I – GAIN STAGE



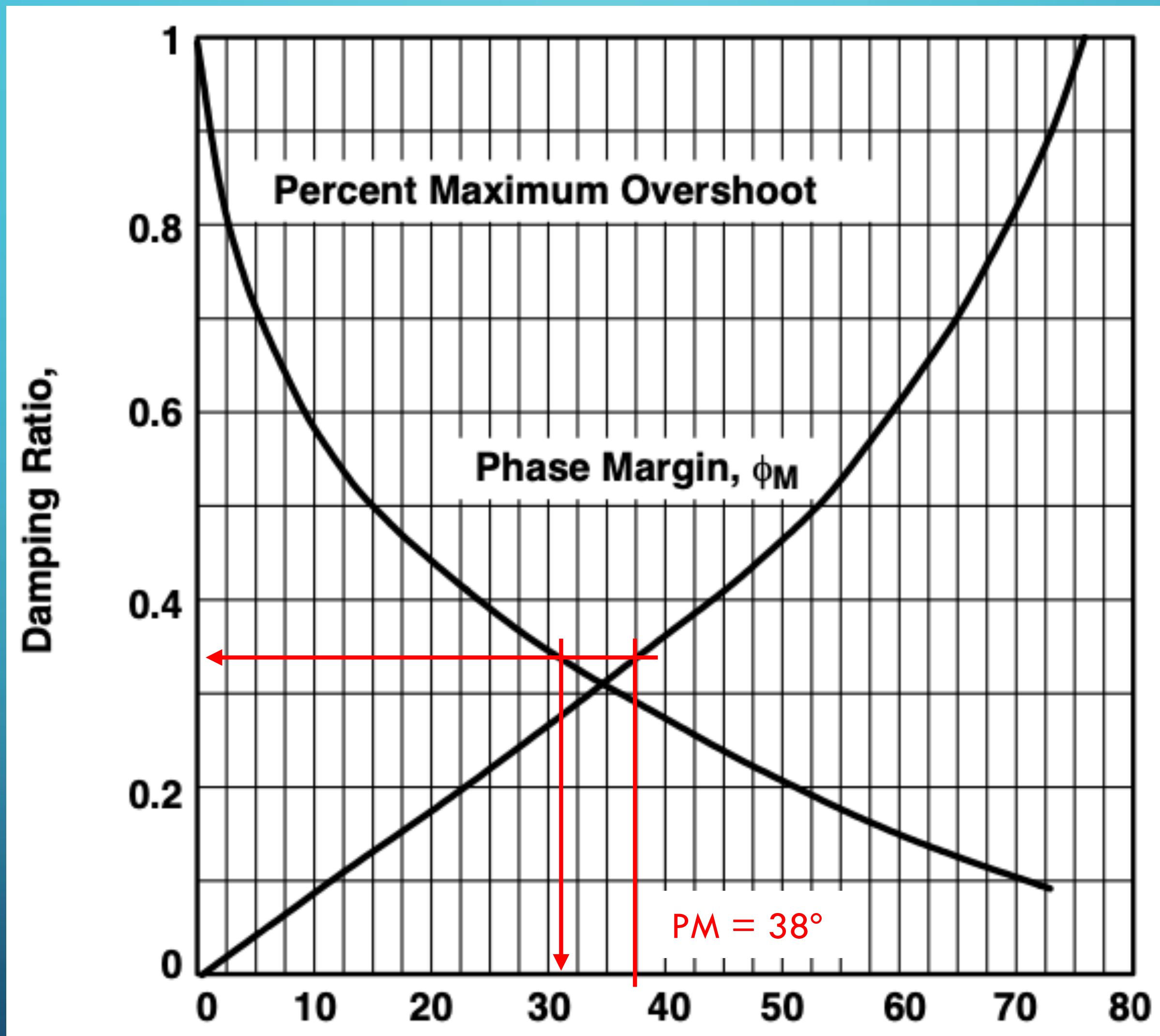
REAL WORLD EXAMPLE I – GAIN STAGE



$$\beta = \frac{R1}{R1 \cdot R2} = \frac{1}{10}$$

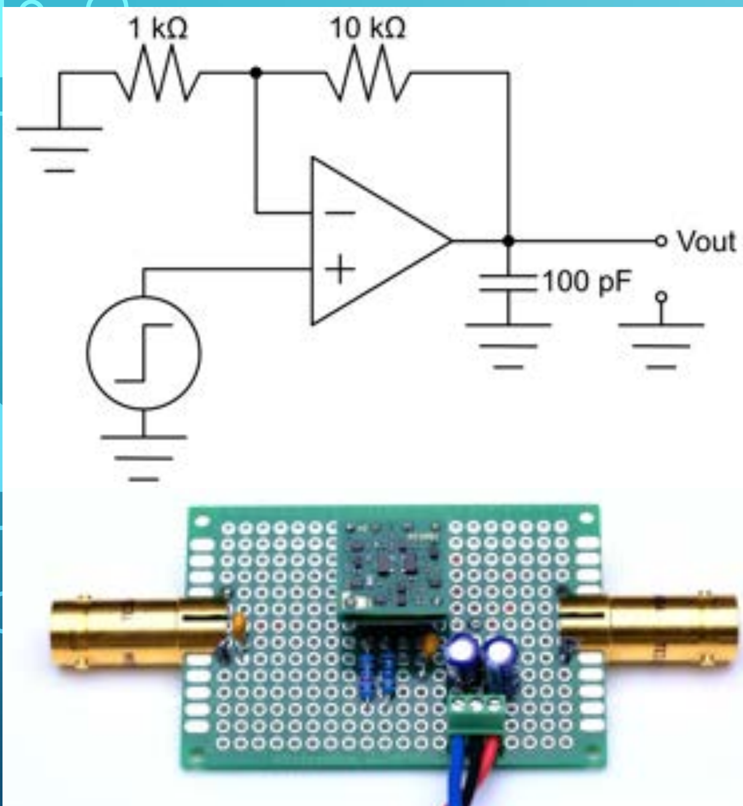


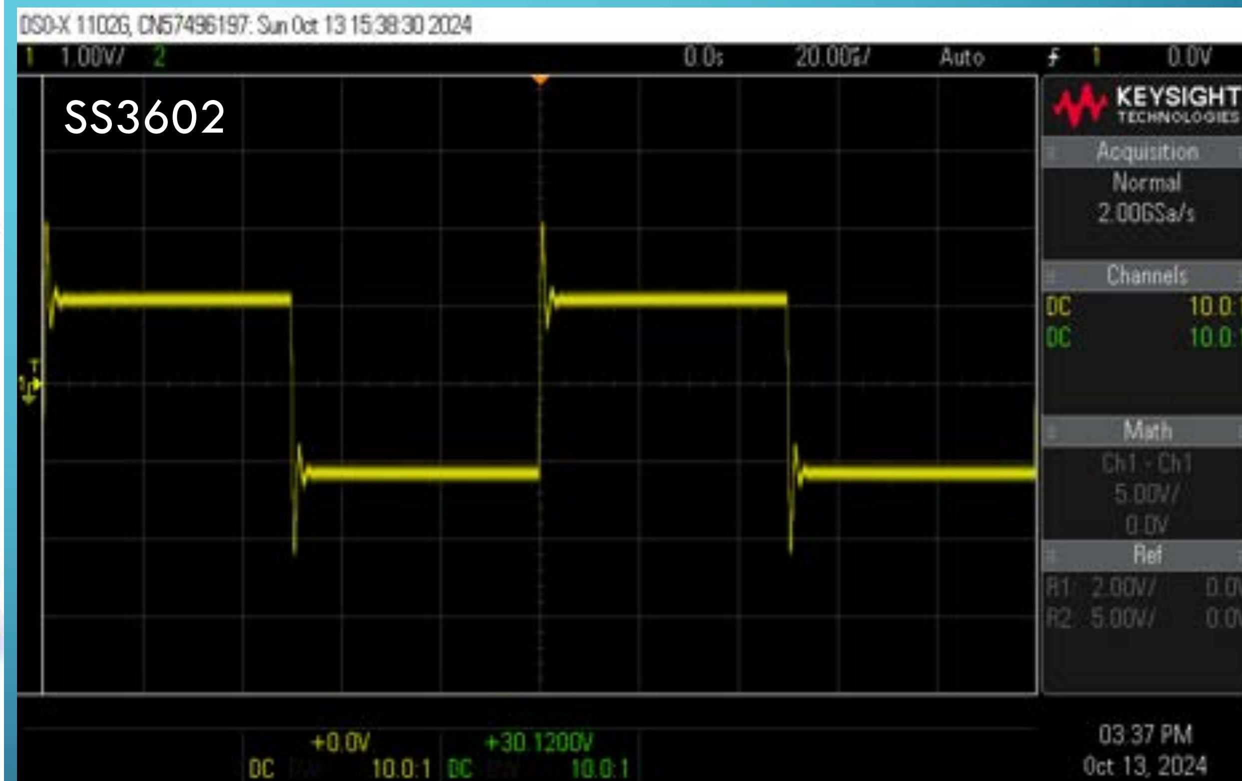
REAL WORLD EXAMPLE I – GAIN STAGE



(TI: Opamps for Everyone, Fig. 5-18)

REAL WORLD EXAMPLE I – GAIN STAGE





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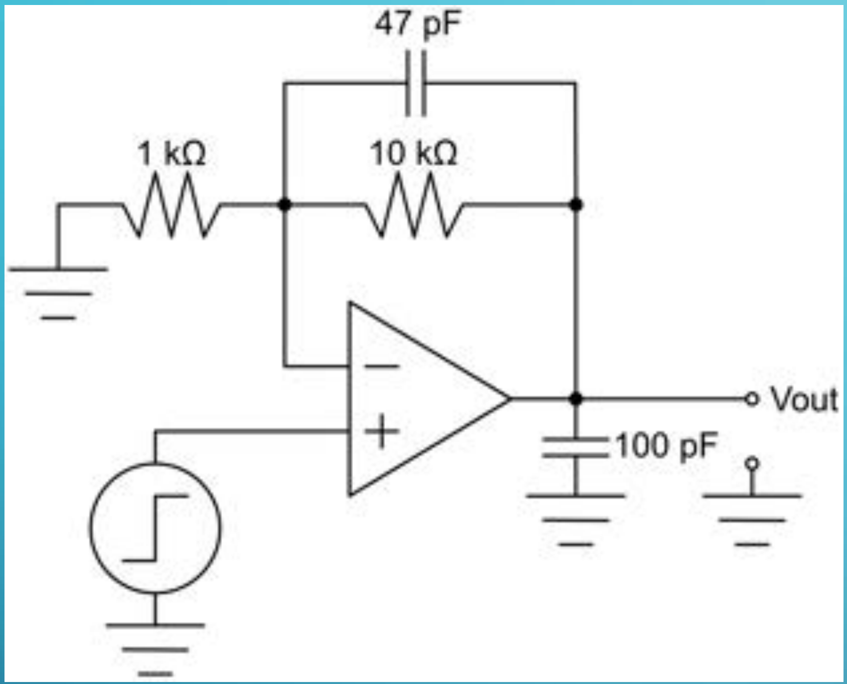
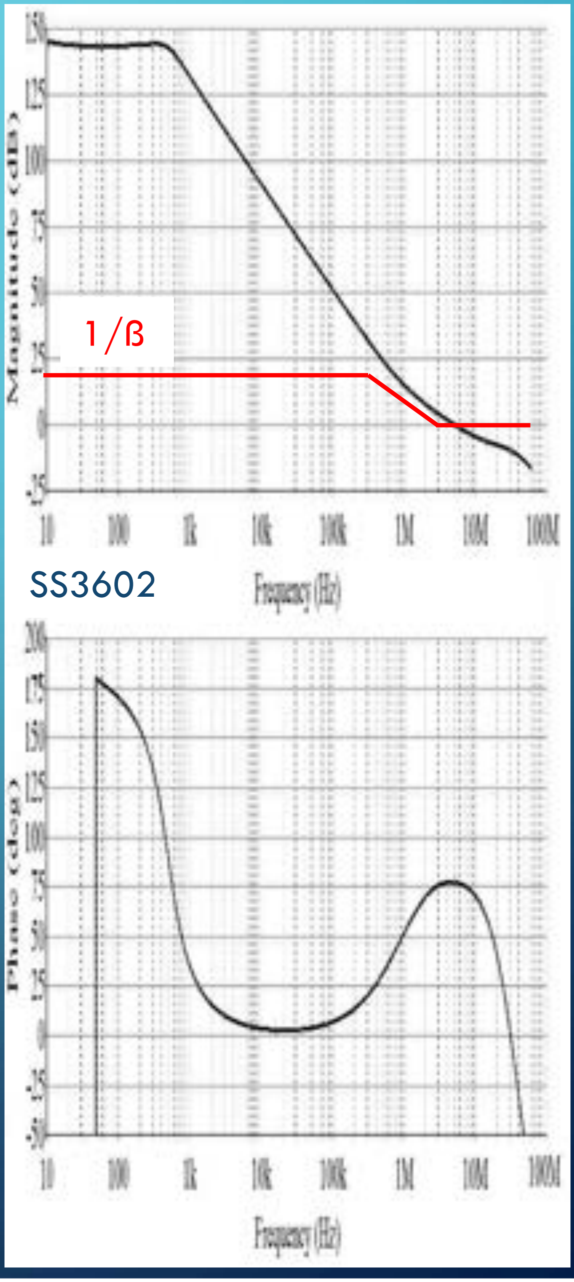
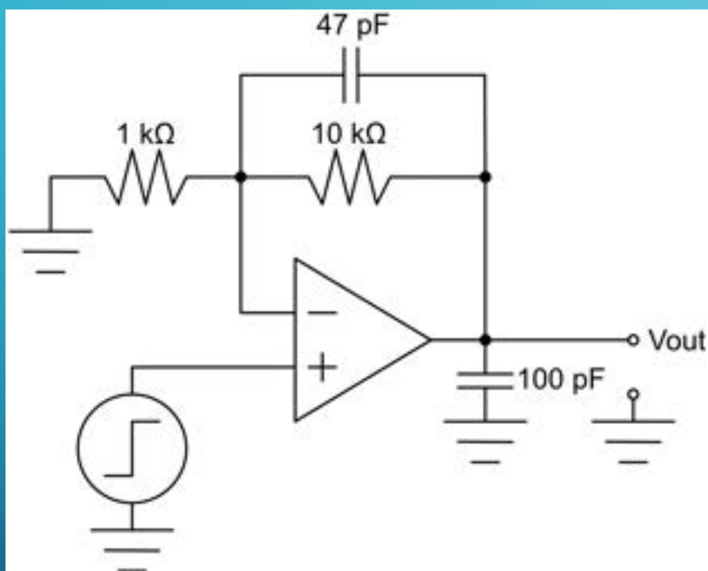
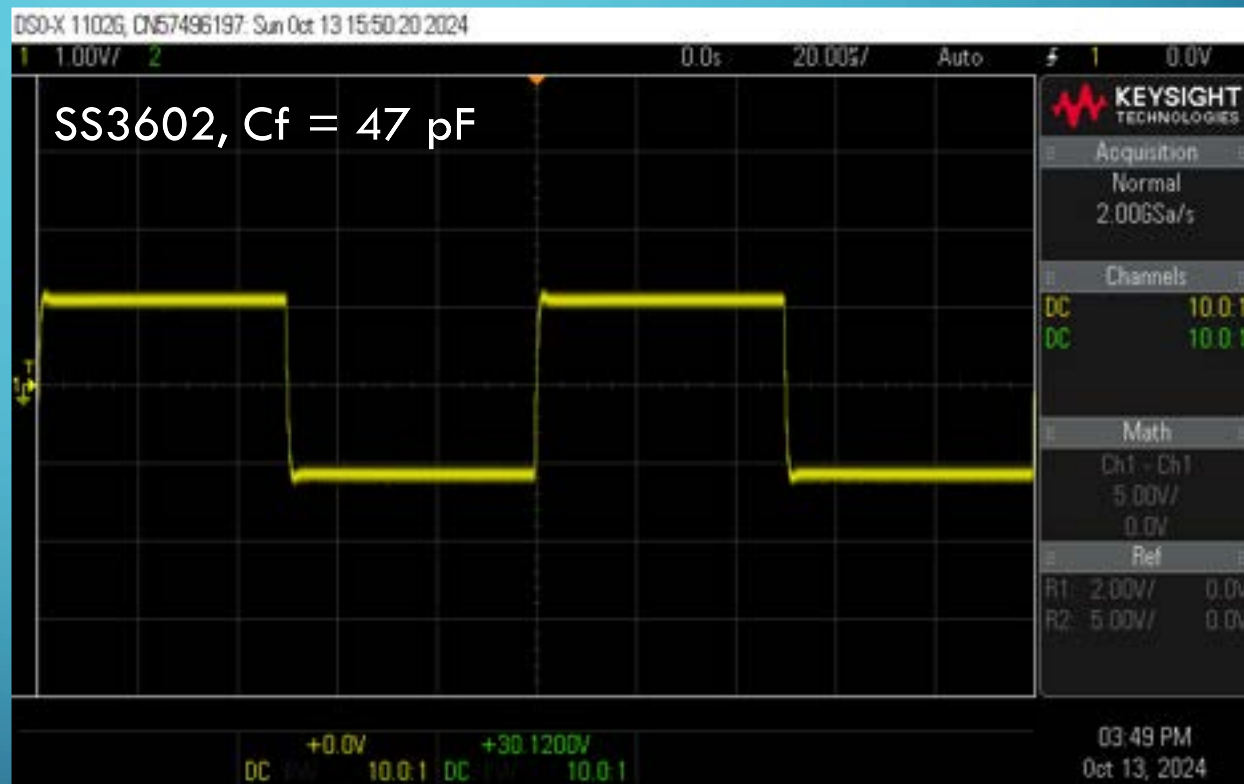




REAL WORLD EXAMPLE I – GAIN STAGE





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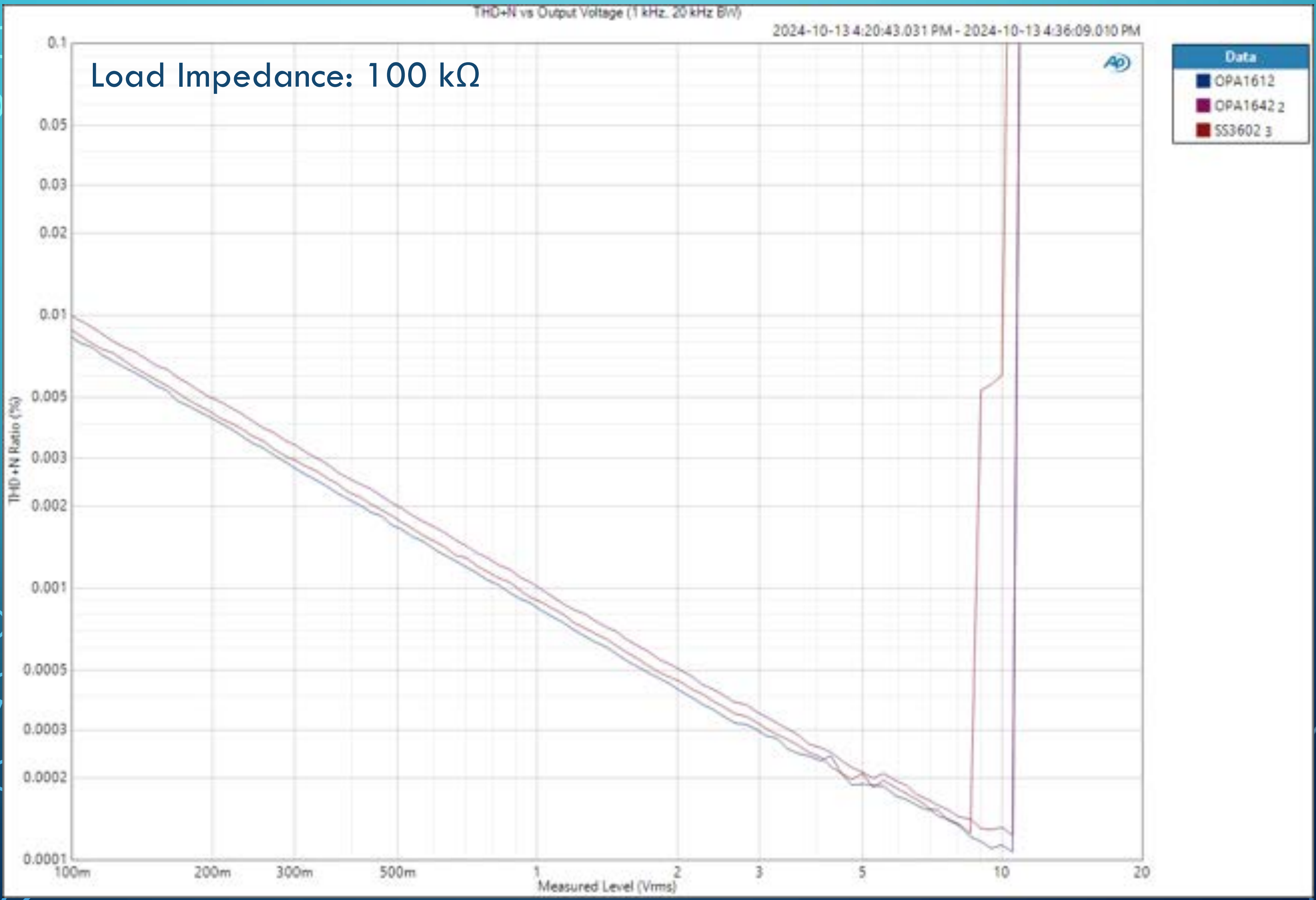

REAL WORLD EXAMPLE I – GAIN STAGE

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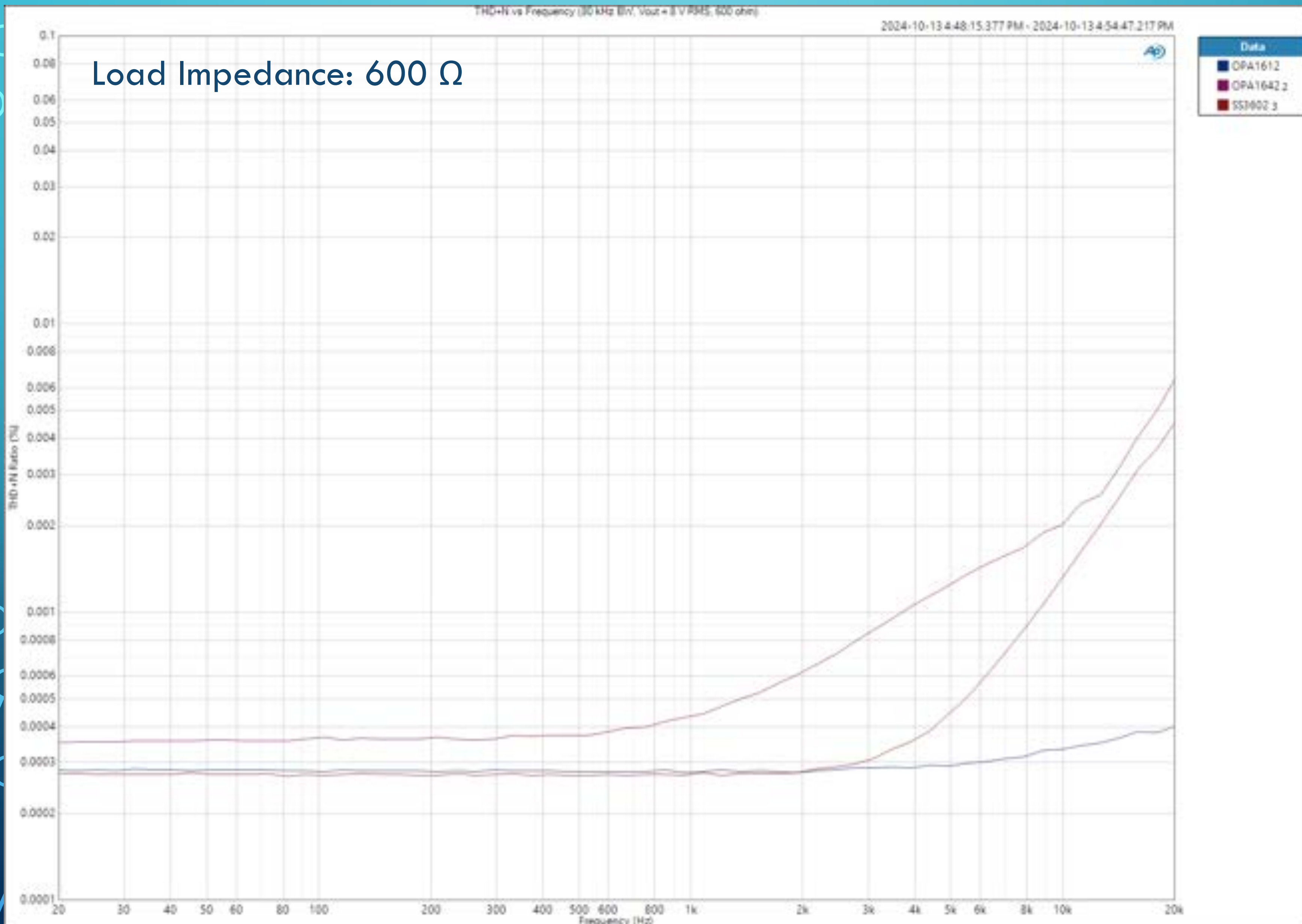
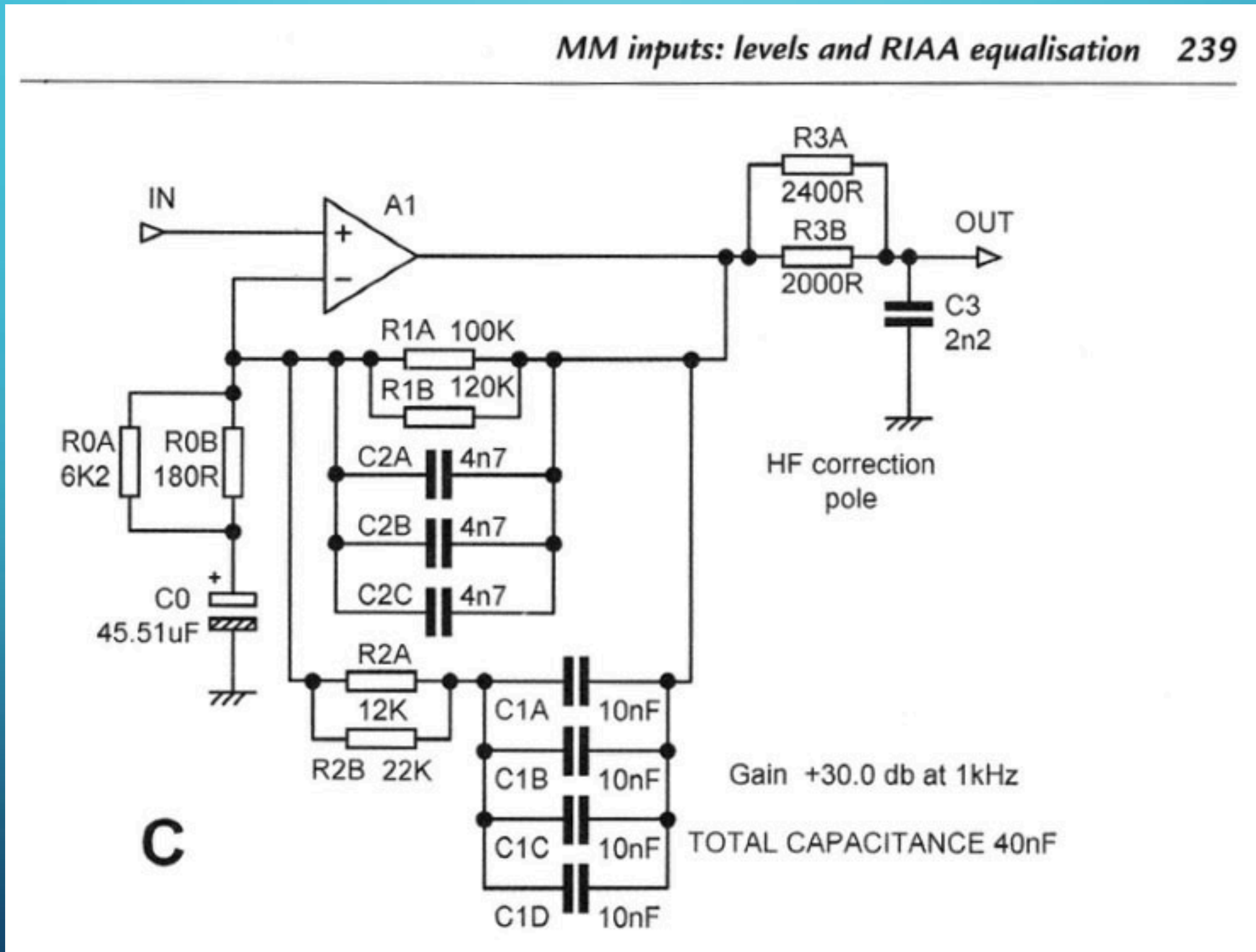
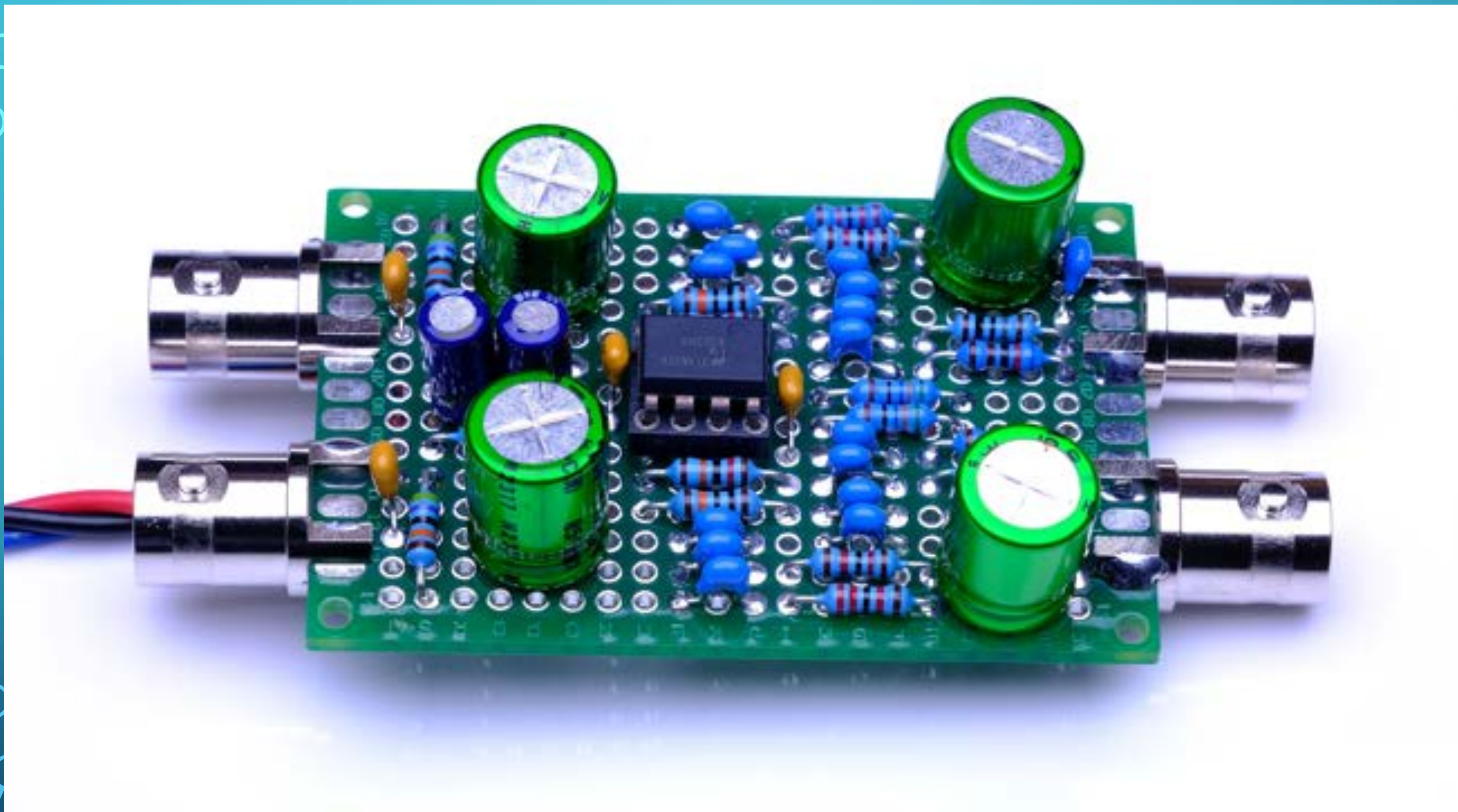


REAL WORLD EXAMPLE II – PHONO STAGE

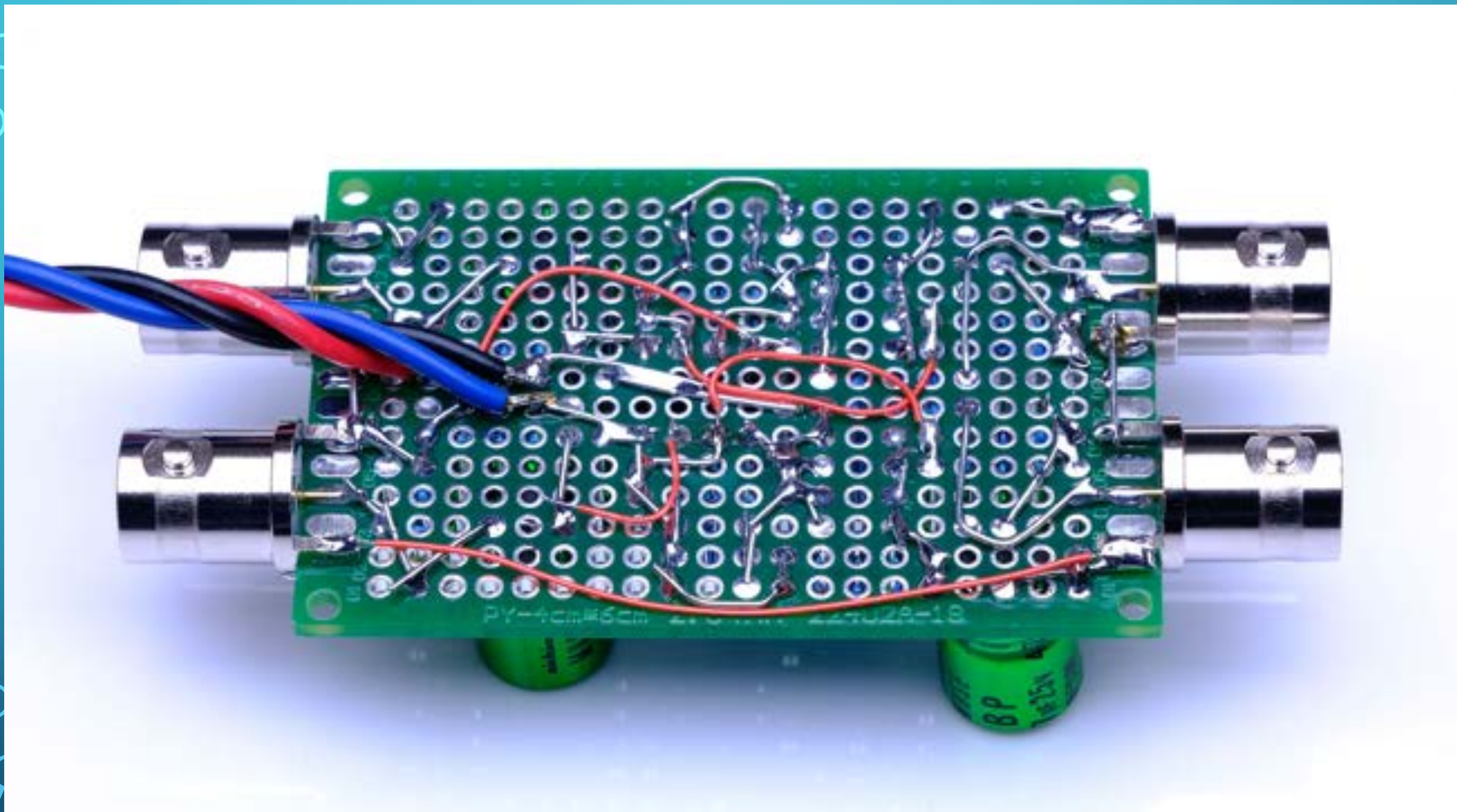


(Self (2014) *Small Signal Audio Design*, 2nd Ed)

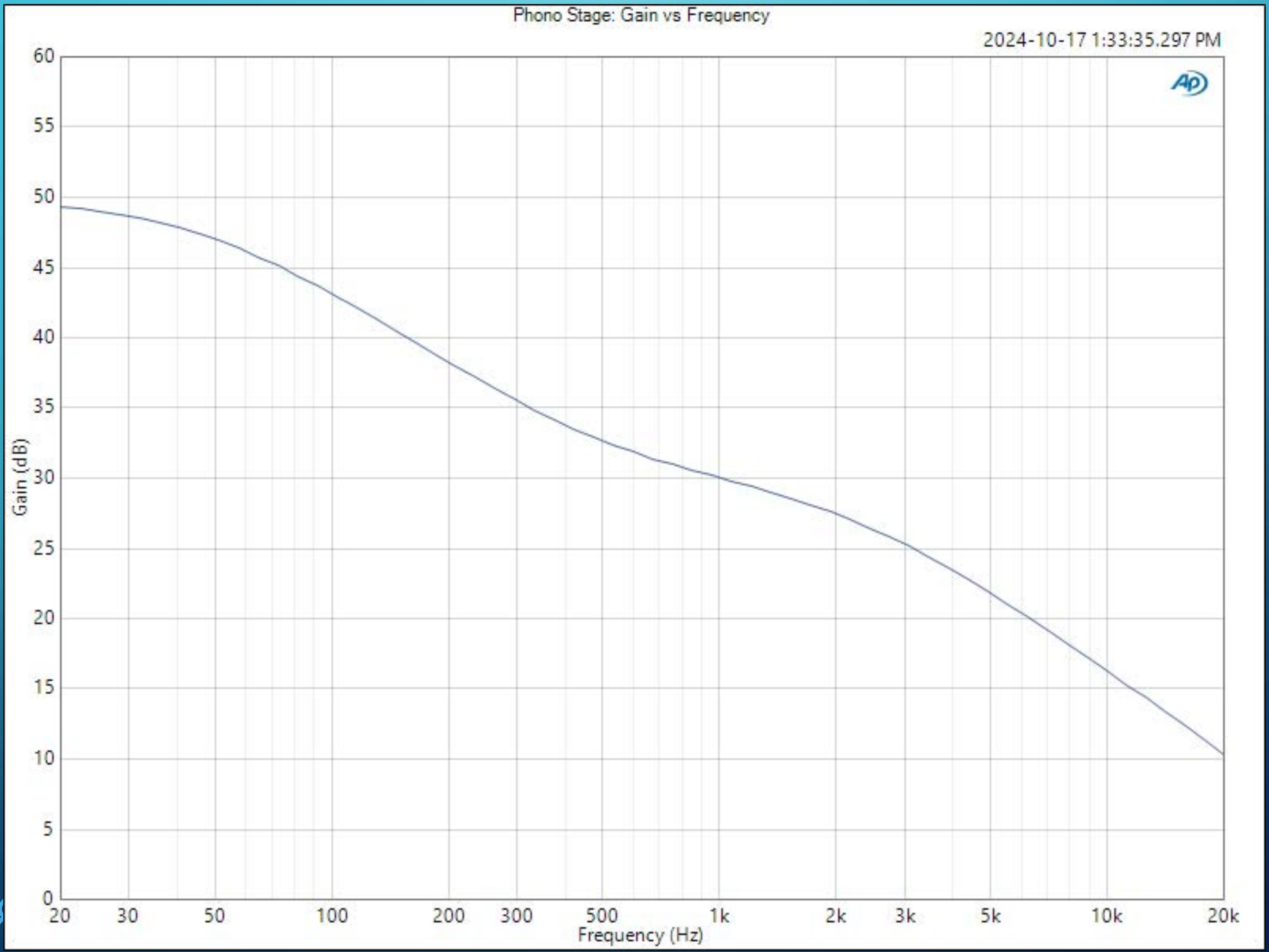
REAL WORLD EXAMPLE II – PHONO STAGE



REAL WORLD EXAMPLE II – PHONO STAGE



REAL WORLD EXAMPLE II – PHONO STAGE



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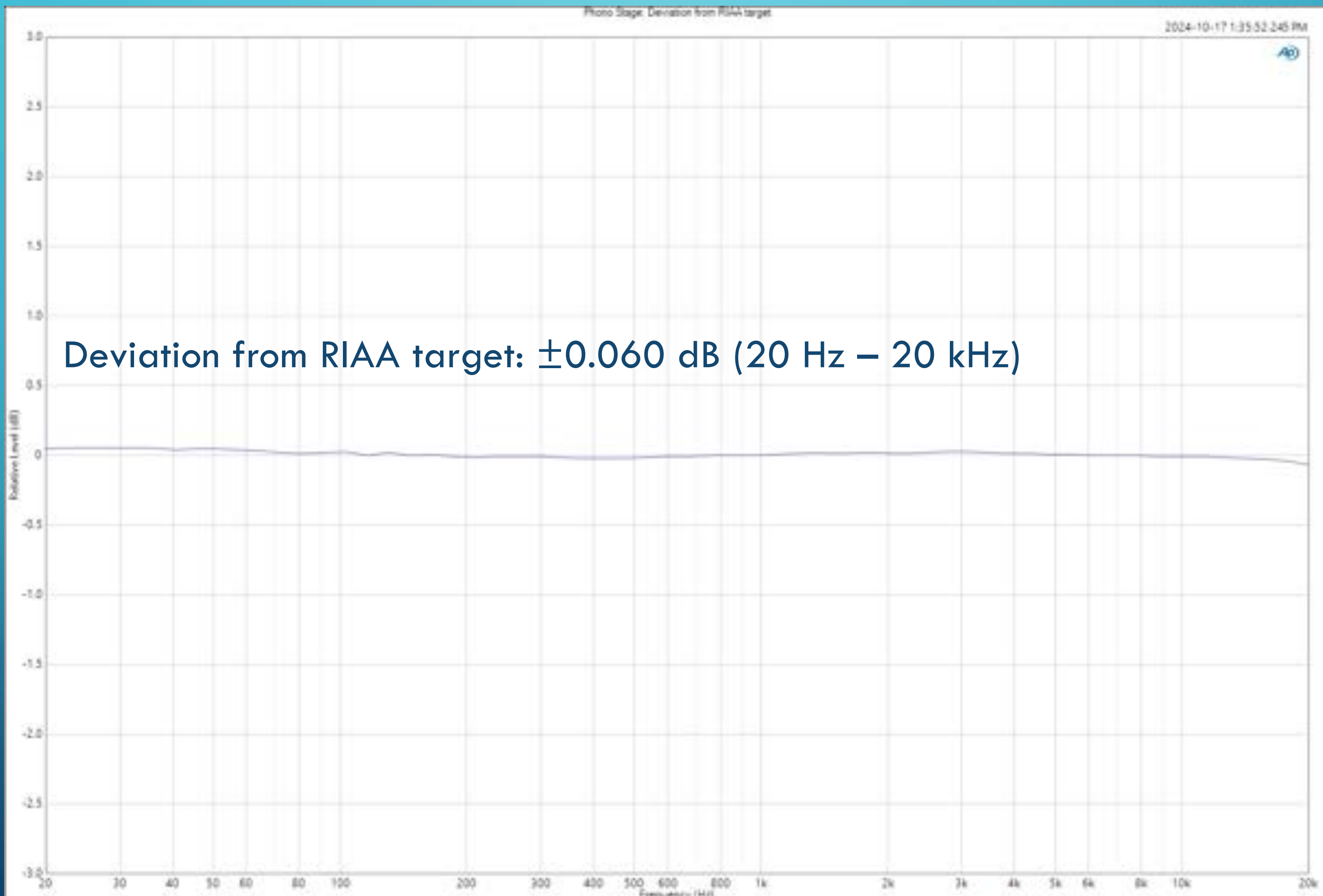
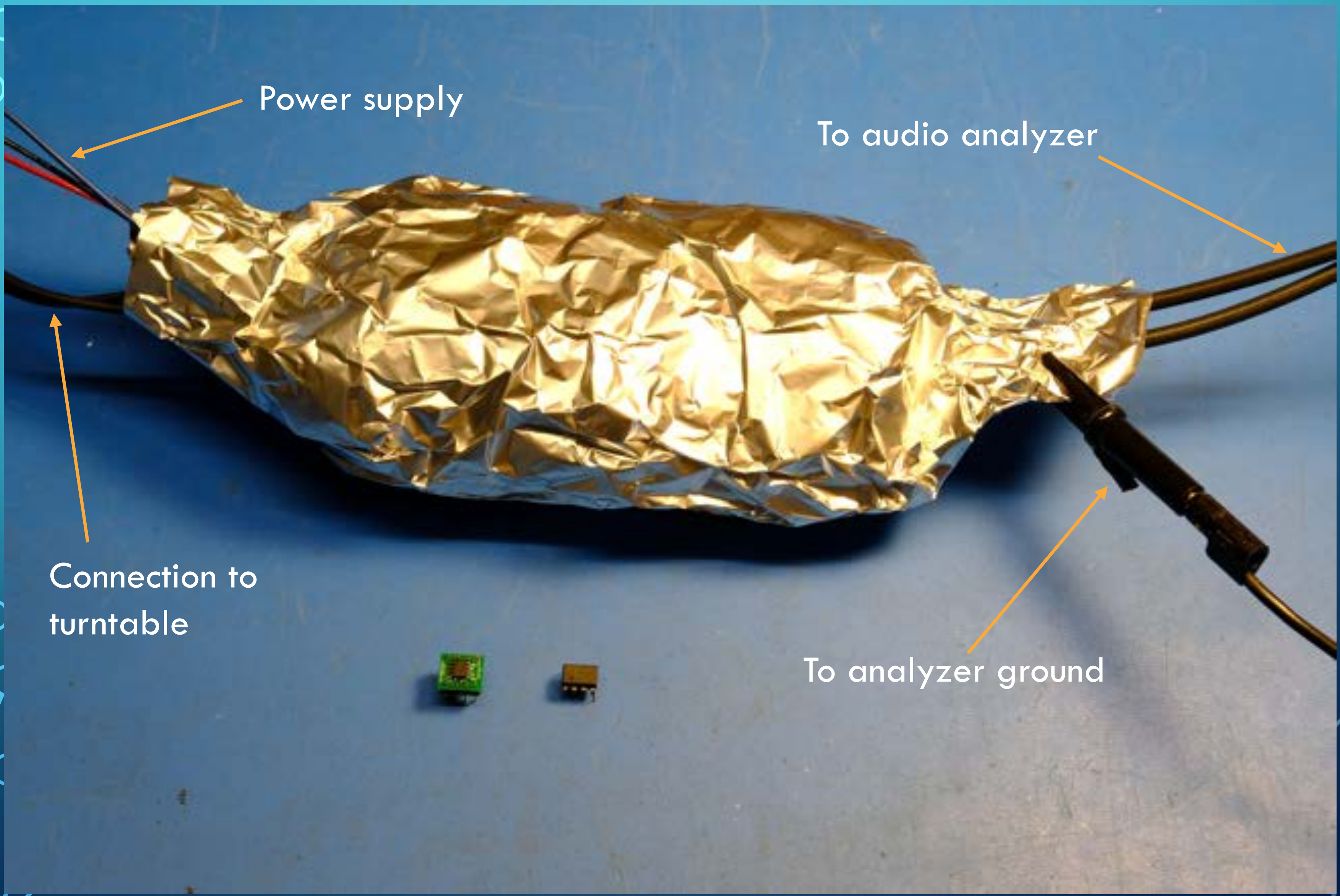


Deviation from RIAA target: ±0.060 dB (20 Hz – 20 kHz)

REAL WORLD EXAMPLE II – PHONO STAGE



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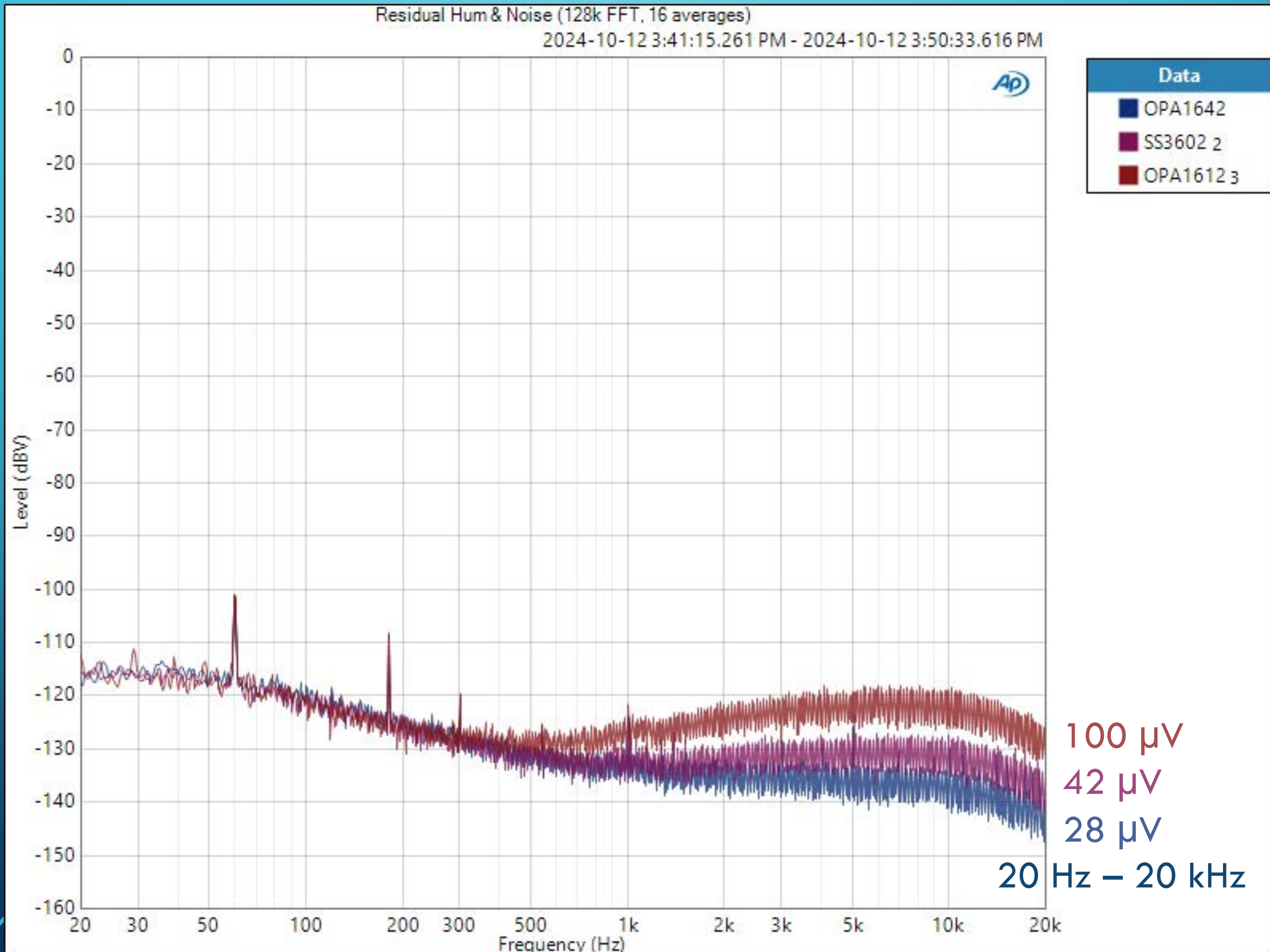


REAL WORLD EXAMPLE II – PHONO STAGE

OPA1612

NOISE					
	Input voltage noise	f = 20 Hz to 20 kHz	1.2		μV$_{PP}$
e_n	Input voltage noise density[2]	f = 10 Hz	2		nV/√Hz
		f = 100 Hz	1.5		nV/√Hz
		f = 1 kHz	1.1	1.5	nV/√Hz
I_n	Input current noise density	f = 10 Hz	3		pA/√Hz
		f = 1 kHz	1.7		pA/√Hz

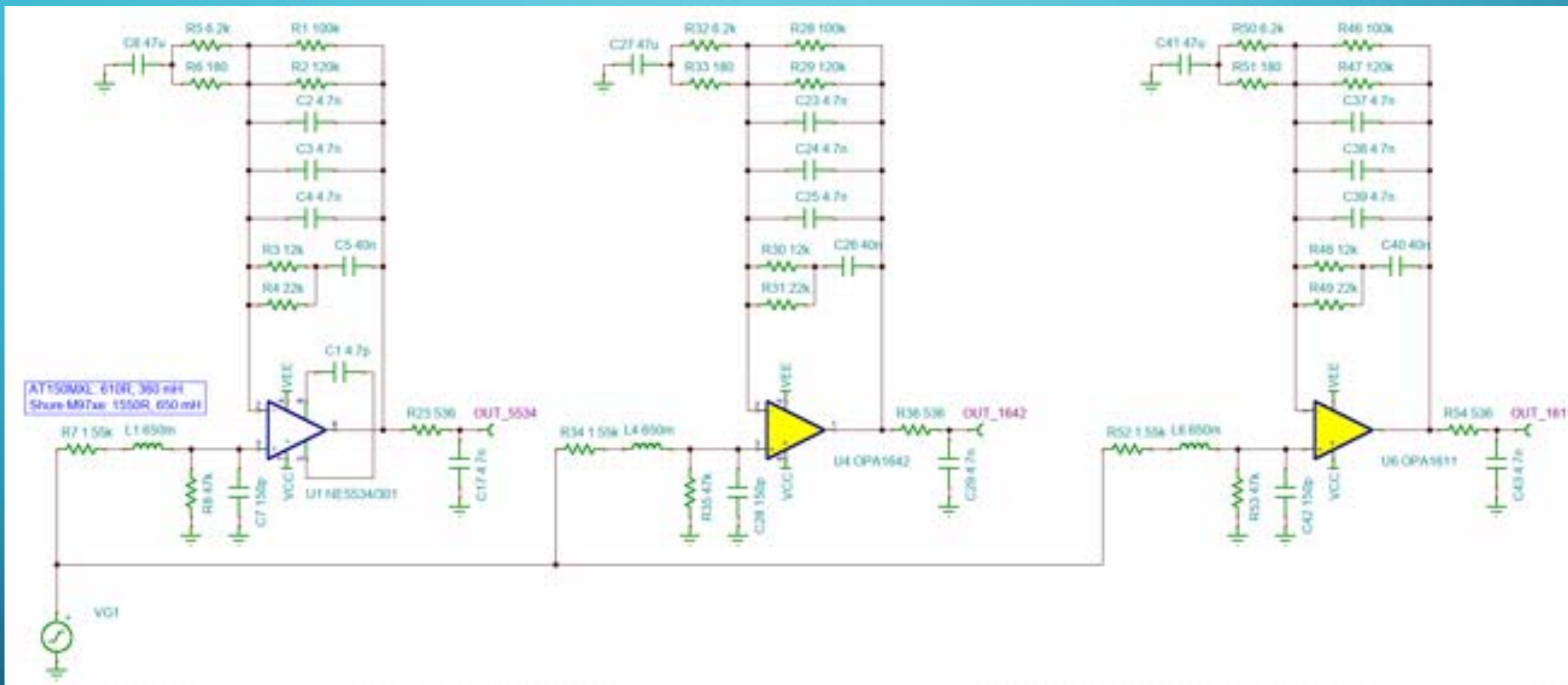
OPA1642

NOISE				
	Input voltage noise	f = 20 Hz to 20 kHz	4.3	μV$_{PP}$
e_n	Input voltage noise density	f = 10 Hz	8	nV/√Hz
		f = 100 Hz	5.8	
		f = 1 kHz	5.1	
I_n	Input current noise density	f = 1 kHz	0.8	fA/√Hz

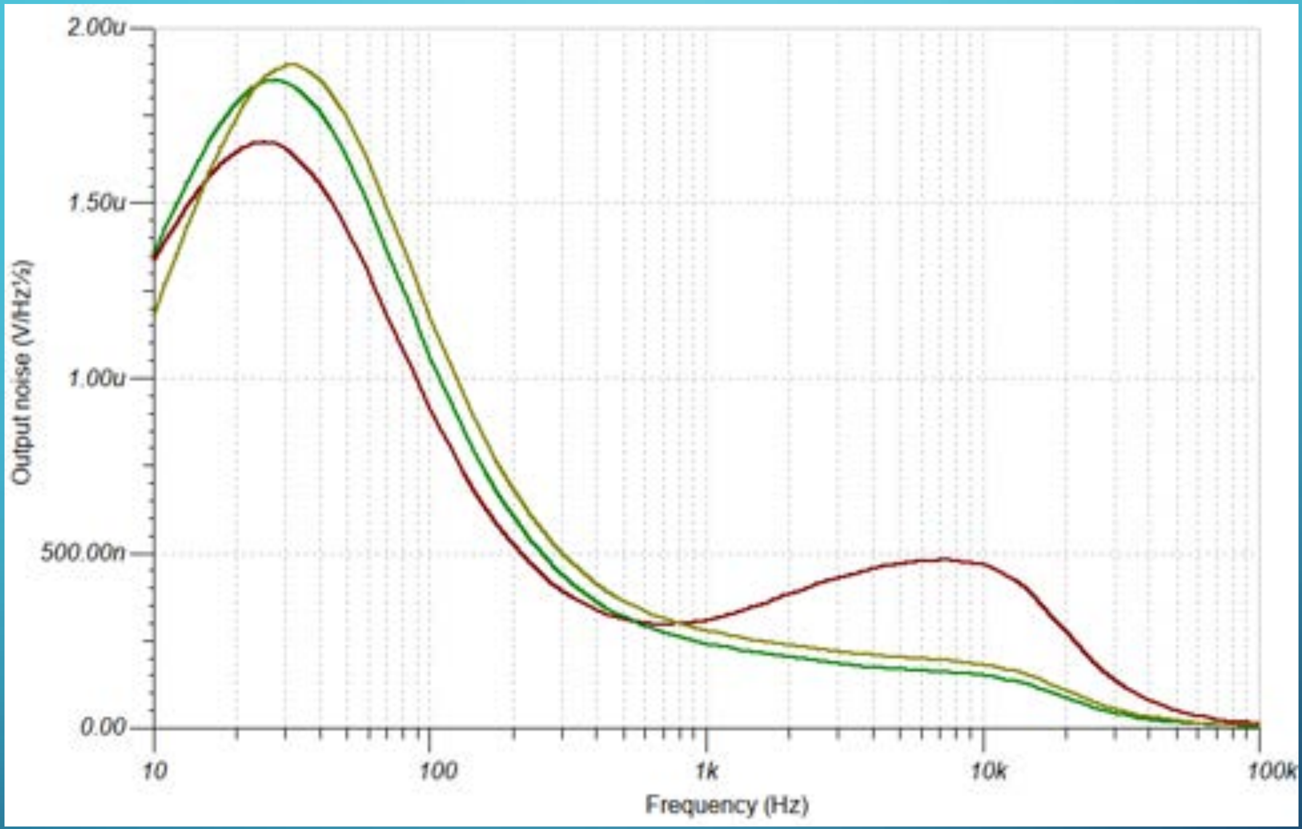
NE5534

V_n	Equivalent input noise voltage	f = 30 Hz	7	5.5	7	nV/√Hz
		f = 1 kHz	4	3.5	4.5	
I_n	Equivalent input noise current	f = 30 Hz	2.5	1.5		pA/√Hz
		f = 1 kHz	0.6	0.4		

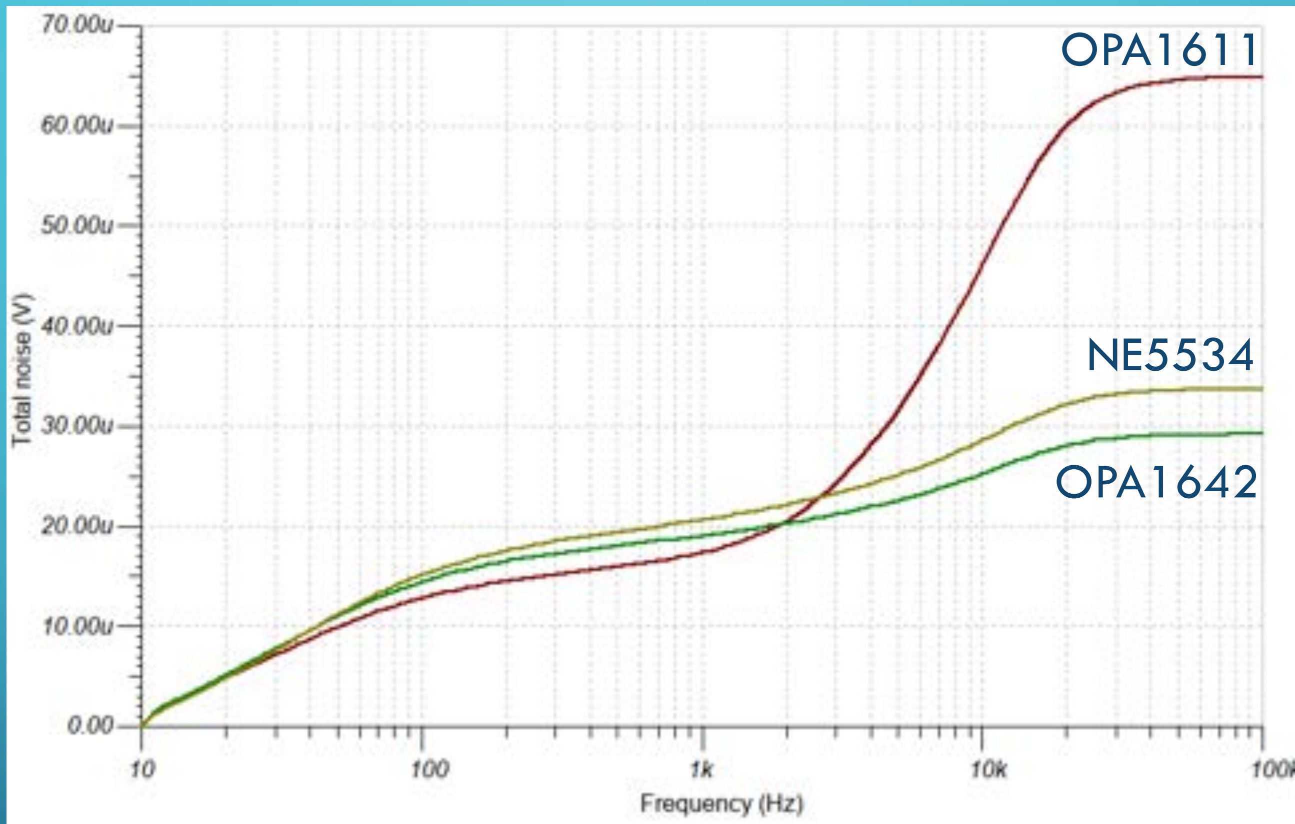
REAL WORLD EXAMPLE II – PHONO STAGE



REAL WORLD EXAMPLE II – PHONO STAGE



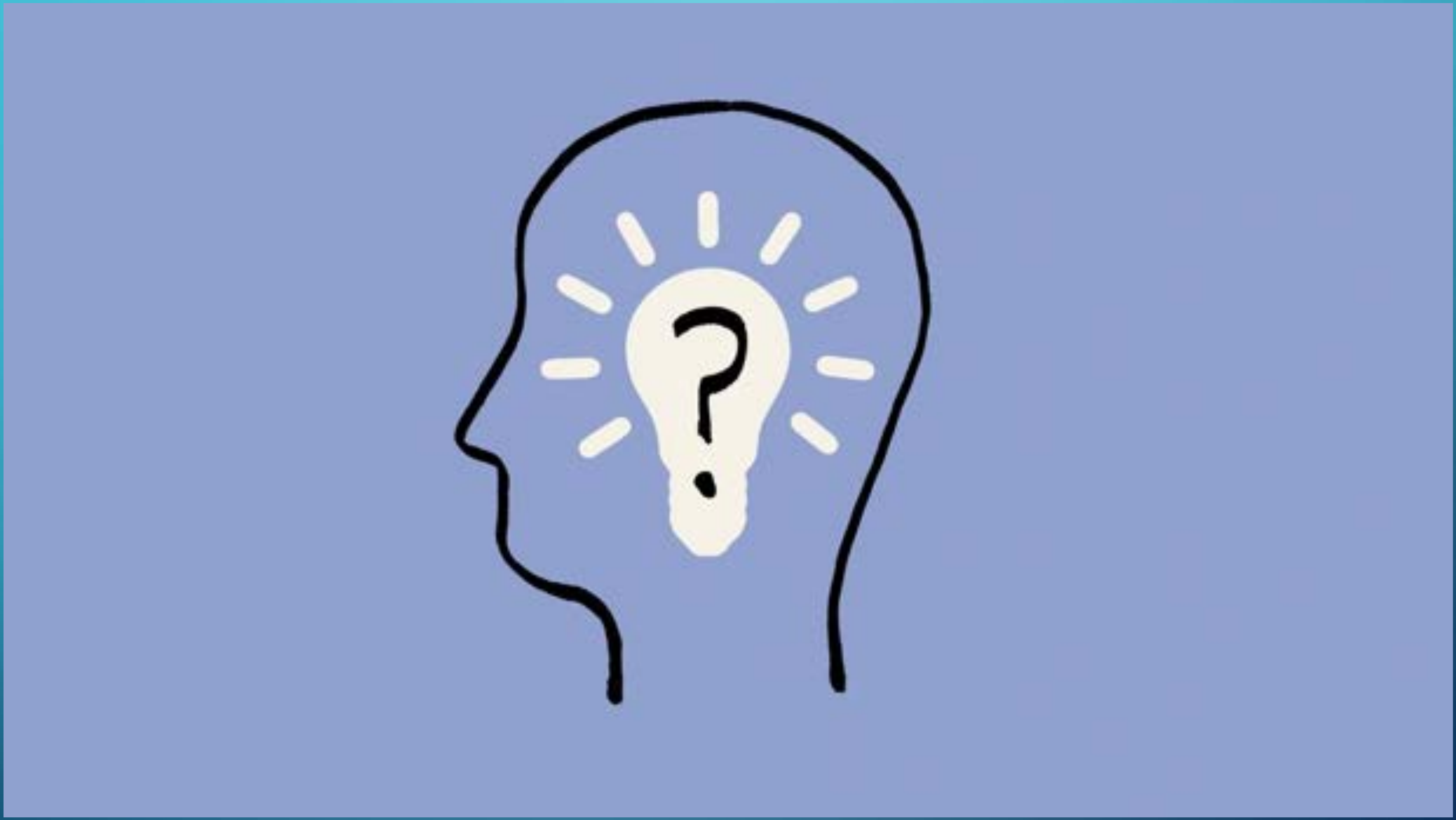
REAL WORLD EXAMPLE II – PHONO STAGE



LESSONS LEARNED

- Mind the stability, especially with discrete opamps
- More expensive is not always better
- Choose an opamp appropriate for the application
- Opamp rolling changes circuit performance … but not always for the better

QUESTIONS



(The Atlantic)