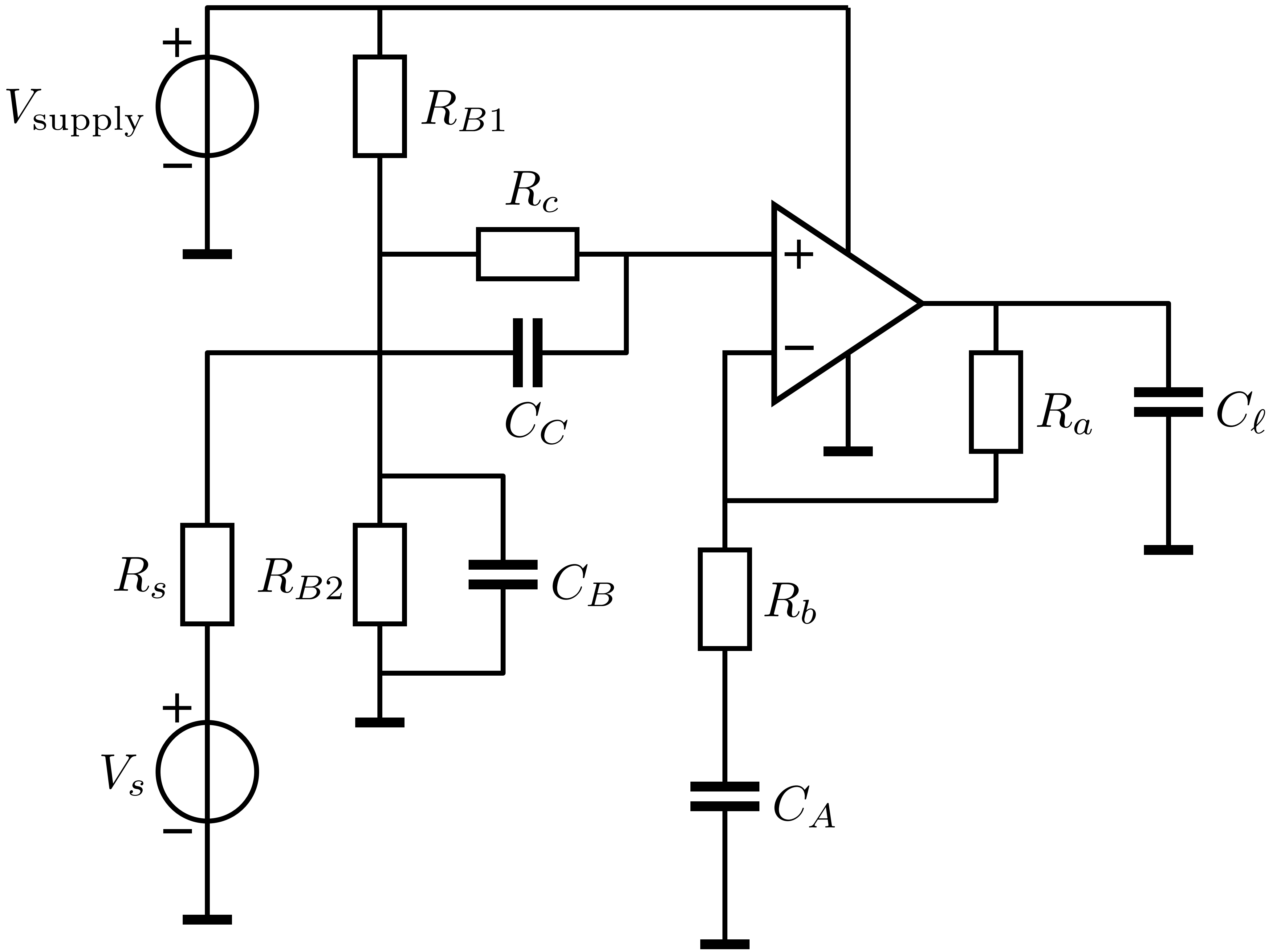
Component selection



- Noise: $R_b < 600\Omega$, $R_c \gg 600\Omega$, $\frac{1}{2\pi f C_C} \ll R_s$, $S_{V_n} < 3.15 \frac{\text{nV}}{\sqrt{\text{Hz}}}$, $S_{I_n} < 5.25 \frac{\text{pA}}{\sqrt{\text{Hz}}}$
- Bandwidth: $\frac{1}{2\pi f_{\text{low}} C_A} \leq R_b$

  $\text{GB} > 45\ \text{MHz}$

  $\frac{1}{2\pi f_{\text{low}} C_A} \leq R_b$
- Accuracy: $R_c \gg R_s$

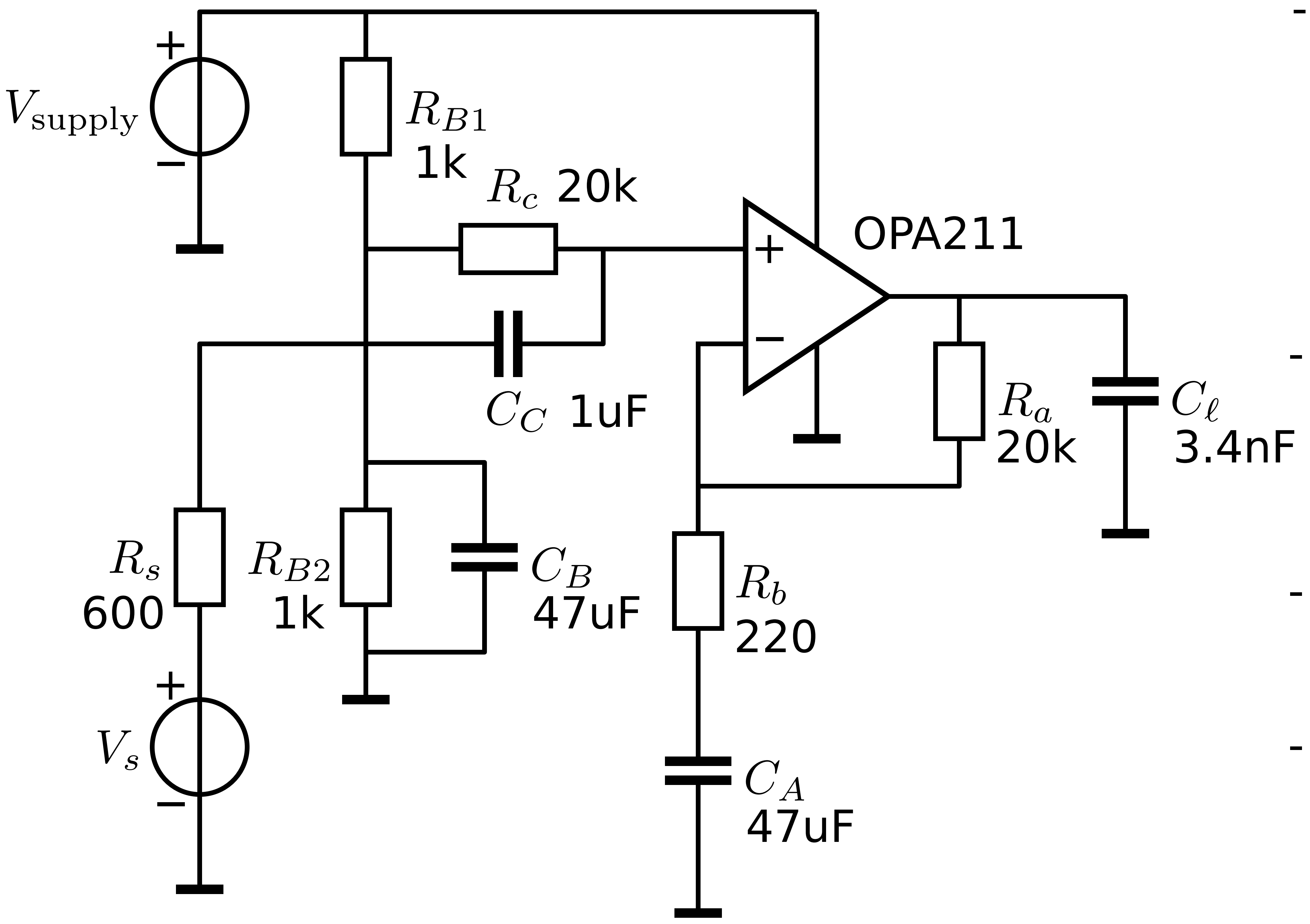
  $A_0 \gg 33 \times 90 \approx 3000$
- Drive capability:

  $I_{\text{source,sink}} > 5\ \text{mA}$

  $\text{SR} > 1.5\ \text{V}/\mu\text{s}$

  $V_{\text{sat}} < 0.25\ \text{V}$

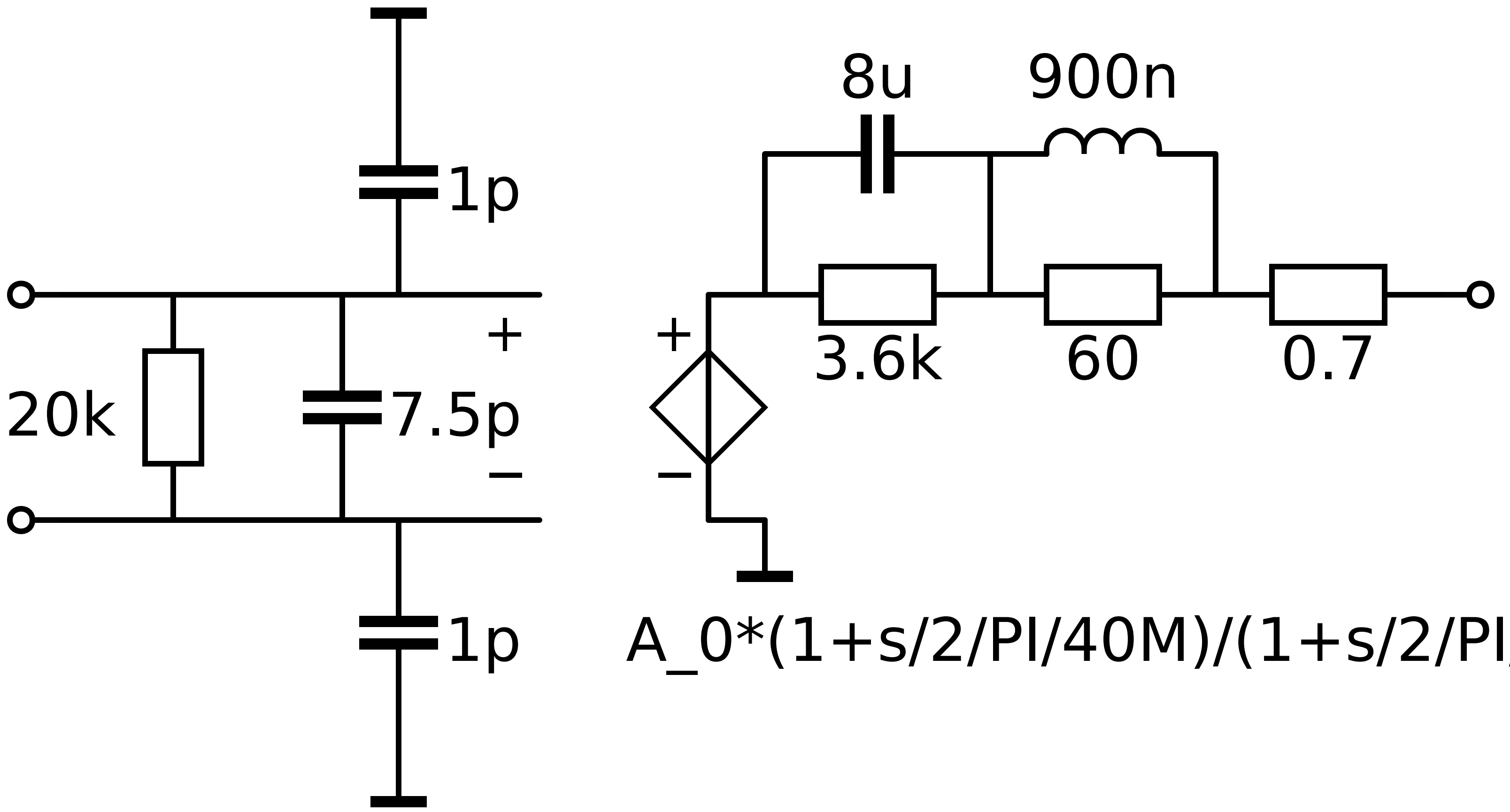
Component selection



- Noise: $R_b < 600\Omega$, $R_c \gg 600\Omega$, $\frac{1}{2\pi f C_C} \ll R_s$, $S_{V_n} < 3.15 \frac{\text{nV}}{\sqrt{\text{Hz}}}$, $S_{I_n} < 5.25 \frac{\text{pA}}{\sqrt{\text{Hz}}}$
- Bandwidth: $\frac{1}{2\pi f_{\text{low}} C_A} \leq R_b$, $\text{GB} > 45$ MHz, $\frac{1}{2\pi f_{\text{low}} C_A} \leq R_b$
- Accuracy: $R_c \gg R_s$, $A_0 \gg 33 \times 90 \approx 3000$
- Drive capability:
  $I_{\text{source,sink}} > 5$ mA
  $\text{SR} > 1.5\ \text{V}/\mu\text{s}$
  $V_{\text{sat}} < 0.25$ V

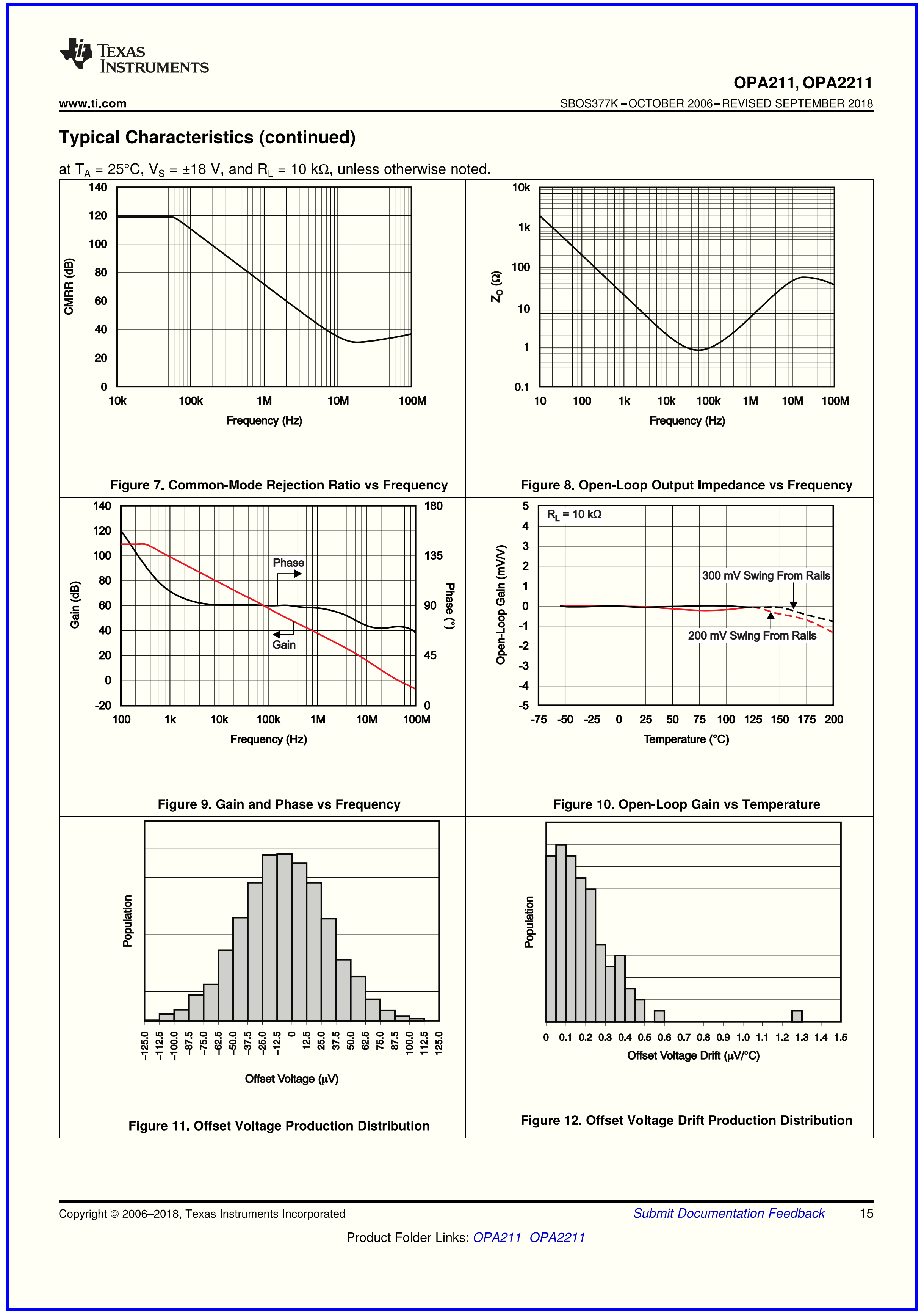
Modeling OpAmp

Small-signal dynamic behavior OPA211



A_0*(1+s/2/PI/40M)/(1+s/2/PI/120)/(1+2/2/PI/20M)

```
.model OPA211_A0 OV
+ cd = 8p  ; differential-mode input capacitance
+ gd = 50u ; differential-mode input conductance
+ cc = 2p  ; common-mode input capacitance
+ av = {A_0*(1+s/2/PI/40M)/(1+s/2/PI/120)/(1+s/2/PI/20M)}   ; voltage gain
+ zo = {3.6k/(1+s*3.6k*8u) + 0.7 + s*900n*60/(60+s*900n)}   ; output impedance
```



Modeling OpAmp

TEXAS INSTRUMENTS

OPA211, OPA2211

SBOS377K – OCTOBER 2006 – REVISED SEPTEMBER 2018 www.ti.com

6.6 Electrical Characteristics: V_S = ±2.25 to ±18 V (OPAx211)

at T_A = 25°C, R_L = 10 kΩ connected to midsupply, V_{CM} = V_{OUT} = midsupply, (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OFFSET VOLTAGE						
V_{OS}	Input offset voltage	OPA211: V_S = ±15 V		±30	±125	µV
		OPA2211: V_S = ±15 V		±50	±150	µV
dV_{OS}/dT	Input offset drift	V_S = ±15 V, T_A = –40°C to +125°C		±0.35	±1.5	µV/°C
PSRR	Input offset voltage vs power supply	T_A = 25°C		0.1	1	µV/V
		T_A = –40°C to +125°C			3	µV/V
INPUT BIAS CURRENT						
I_B	Input bias current	V_{CM} = 0 V		±60	±175	nA
		OPA211: V_{CM} = 0 V, T_A = –40°C to +125°C			±200	nA
		OPA2211: V_{CM} = 0 V, T_A = –40°C to +125°C			±250	nA
I_{OS}	Input offset current	V_{CM} = 0 V		±25	±100	nA
		V_{CM} = 0 V, T_A = –40°C to +125°C			±150	nA
NOISE						
e_n	Input voltage noise	f = 0.1 to 10 Hz		80		nV_{PP}
	Input voltage noise density	f = 10 Hz		2		nV/√Hz
		f = 100 Hz		1.4		nV/√Hz
		f = 1 kHz		1.1		nV/√Hz
I_n	Input current noise density	f = 10 Hz		3.2		pA/√Hz
		f = 1 kHz		1.7		pA/√Hz
INPUT VOLTAGE RANGE						
V_{CM}	Common-mode voltage range	V_S ≥ ±5 V	(V–) + 1.8		(V+) – 1.4	V
		V_S < ±5 V	(V–) + 2		(V+) – 1.4	V
CMRR	Common-mode rejection ratio	V_S ≥ ±5 V, (V–) + 2 V ≤ V_{CM} ≤ (V+) – 2 V, T_A = –40°C to +125°C	114	120		dB
		V_S < ±5 V, (V–) + 2 V ≤ V_{CM} ≤ (V+) – 2 V, T_A = –40°C to +125°C	110	120		dB
INPUT IMPEDANCE						
	Differential			20 ‖ 8		kΩ ‖ pF
	Common-mode			10 ‖ 2		GΩ ‖ pF
OPEN-LOOP GAIN						

SLiCAP noise and bias models

SLiCAP O_dcvar
nullor with offset and bias

Standard deviation offset voltage $svo = 40 \times 10^{-6}$

Standard deviation offset current $sio = 30 \times 10^{-9}$

Mean value bias current $iib = 0$

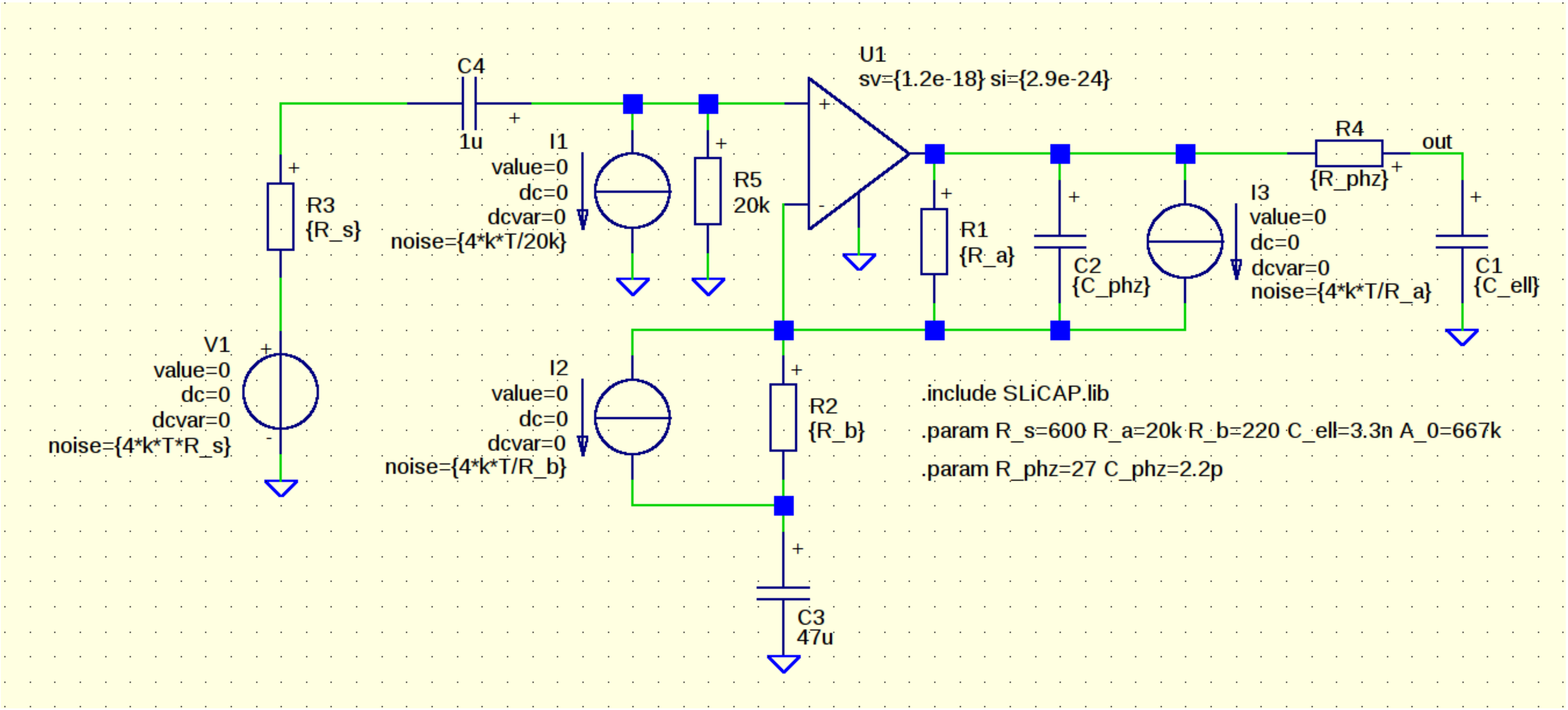
Standard deviation bias current $sib = 60 \times 10^{-9}$

SLiCAP O_noise
nullor with equivalent input noise sources

Spectral density noise voltage $sv = 1.2 \times 10^{-18}$

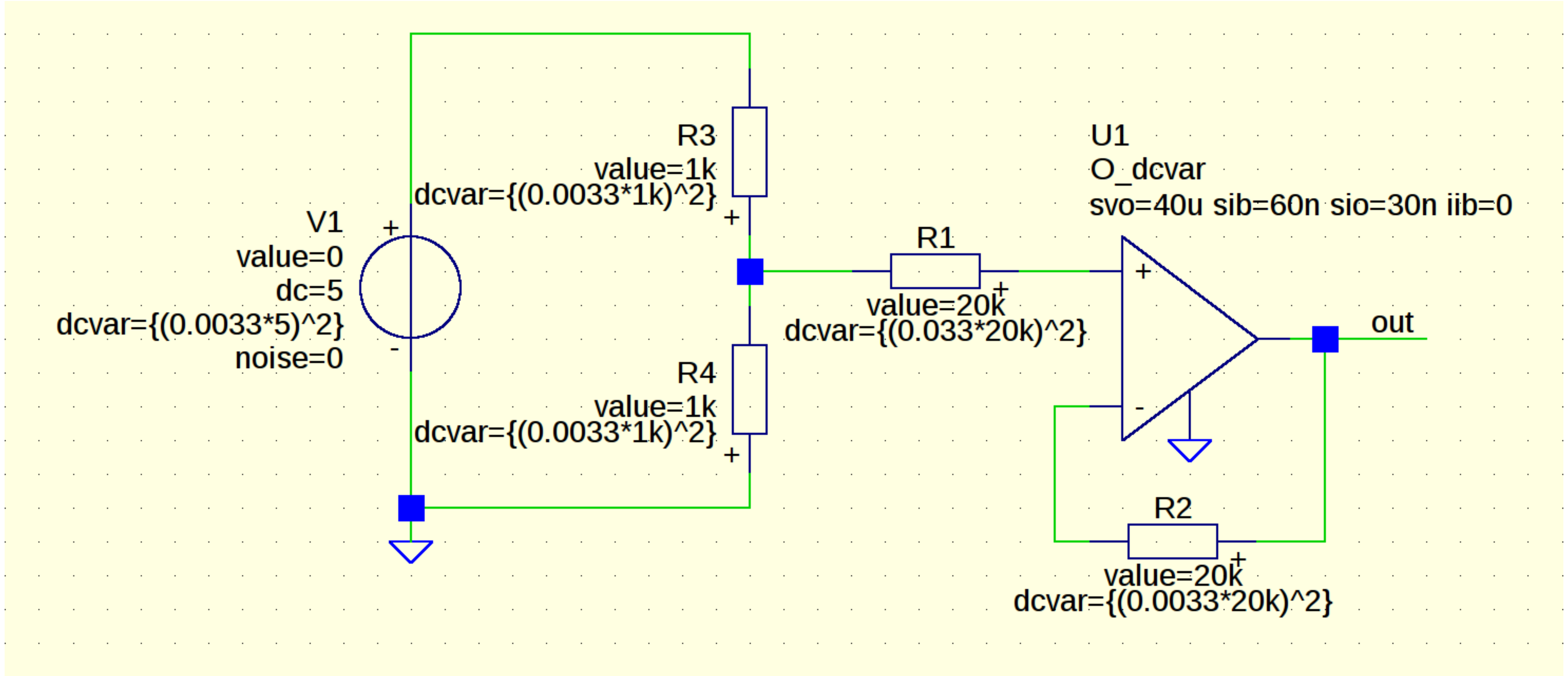
Spectral density noise current $si = 2.9 \times 10^{-24}$

SLiCAP noise verification



Noise figure 2.4dB over 1.57x500kHz bandwidth.

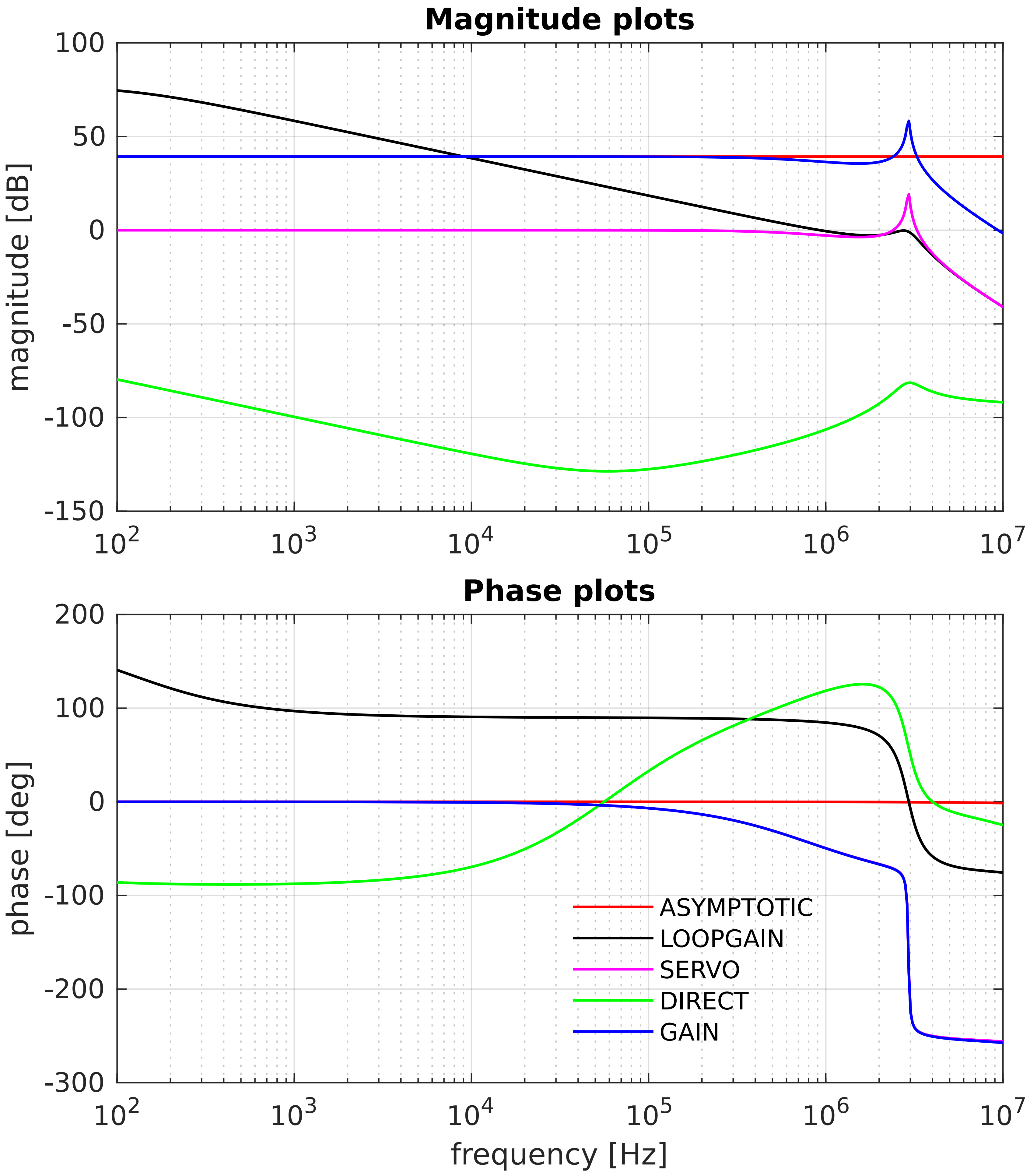
SLiCAP biasing verification

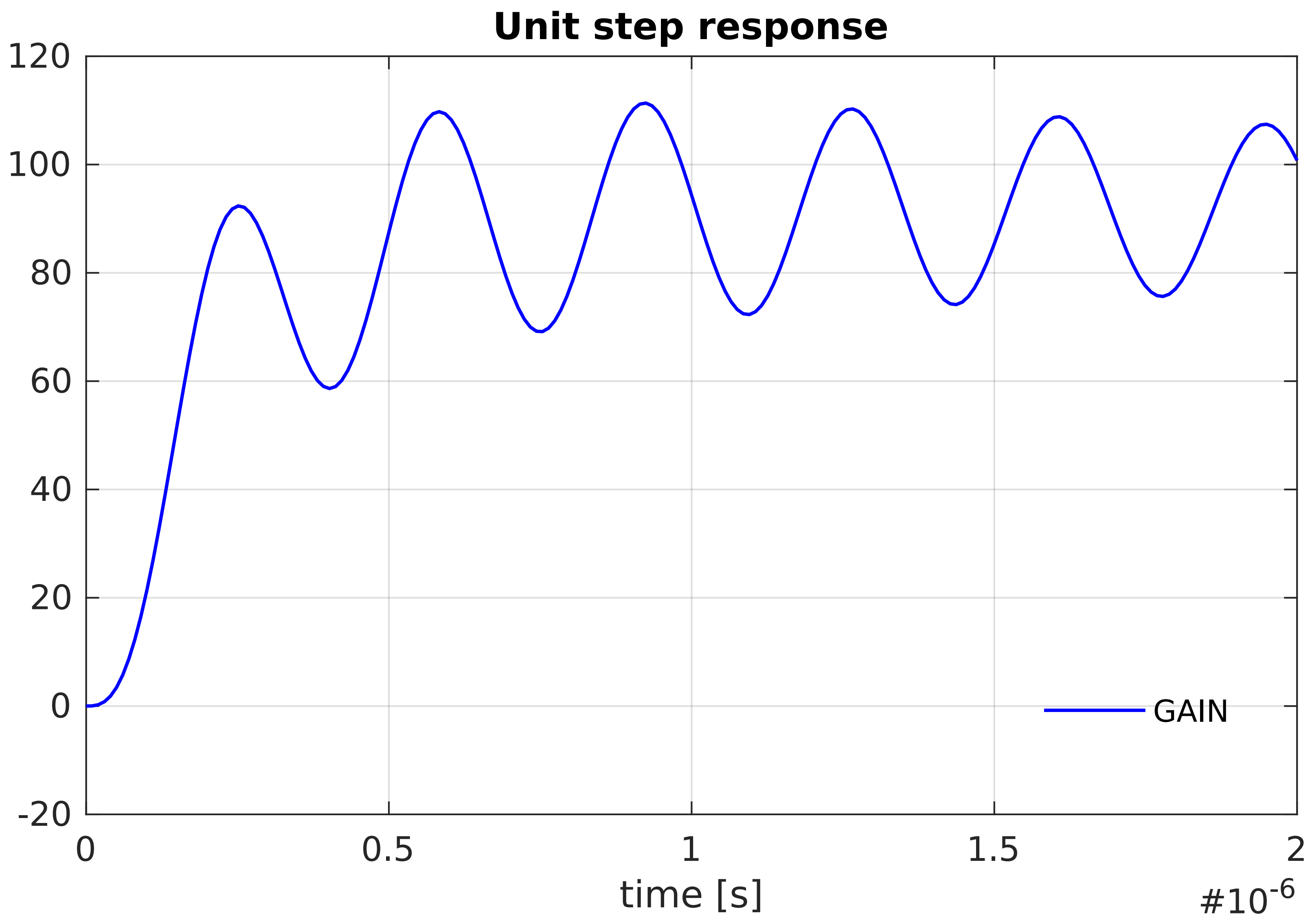


All component tolerances 1% (3-sigma)

Standard deviation of the output voltage: 10mV

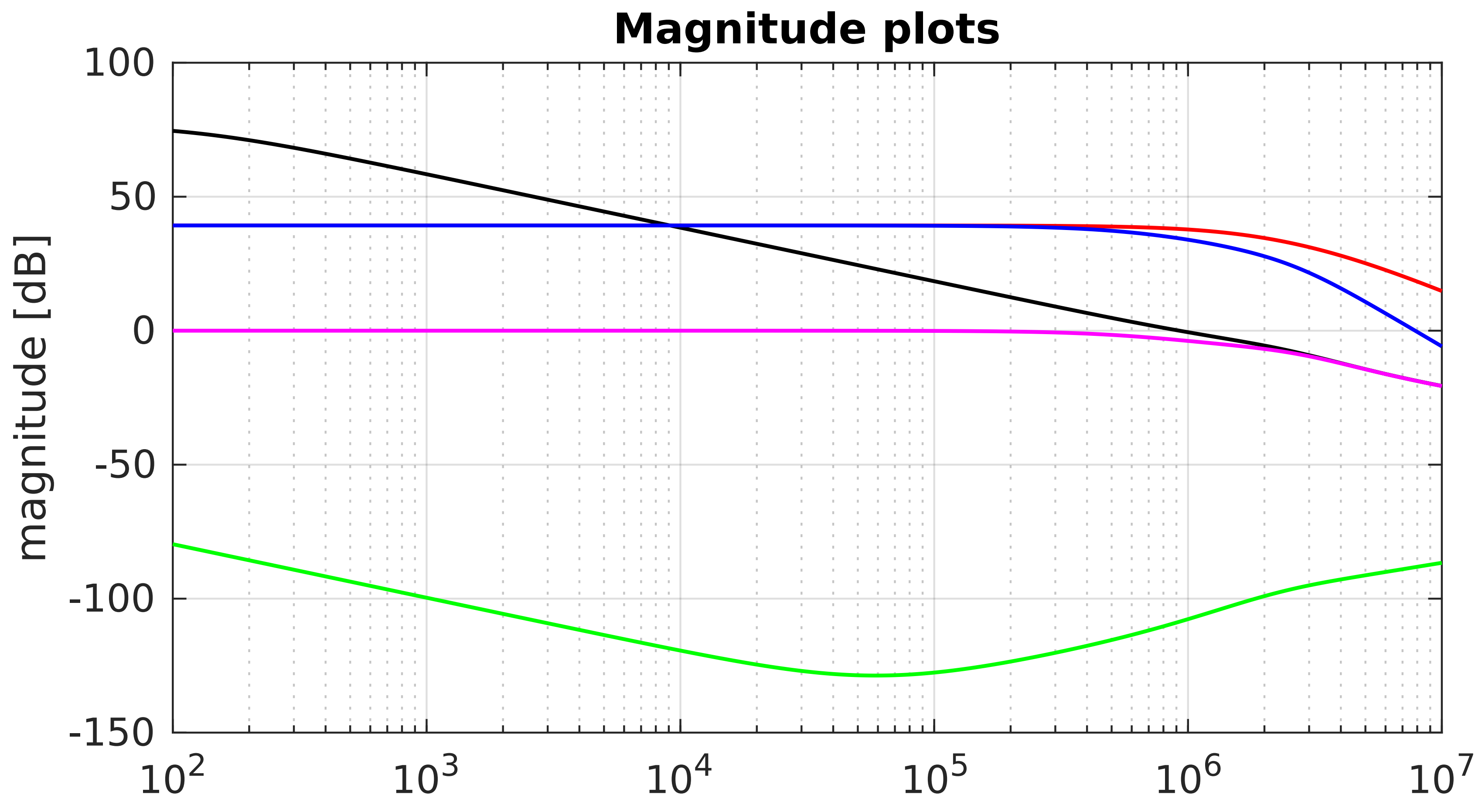
Frequency response

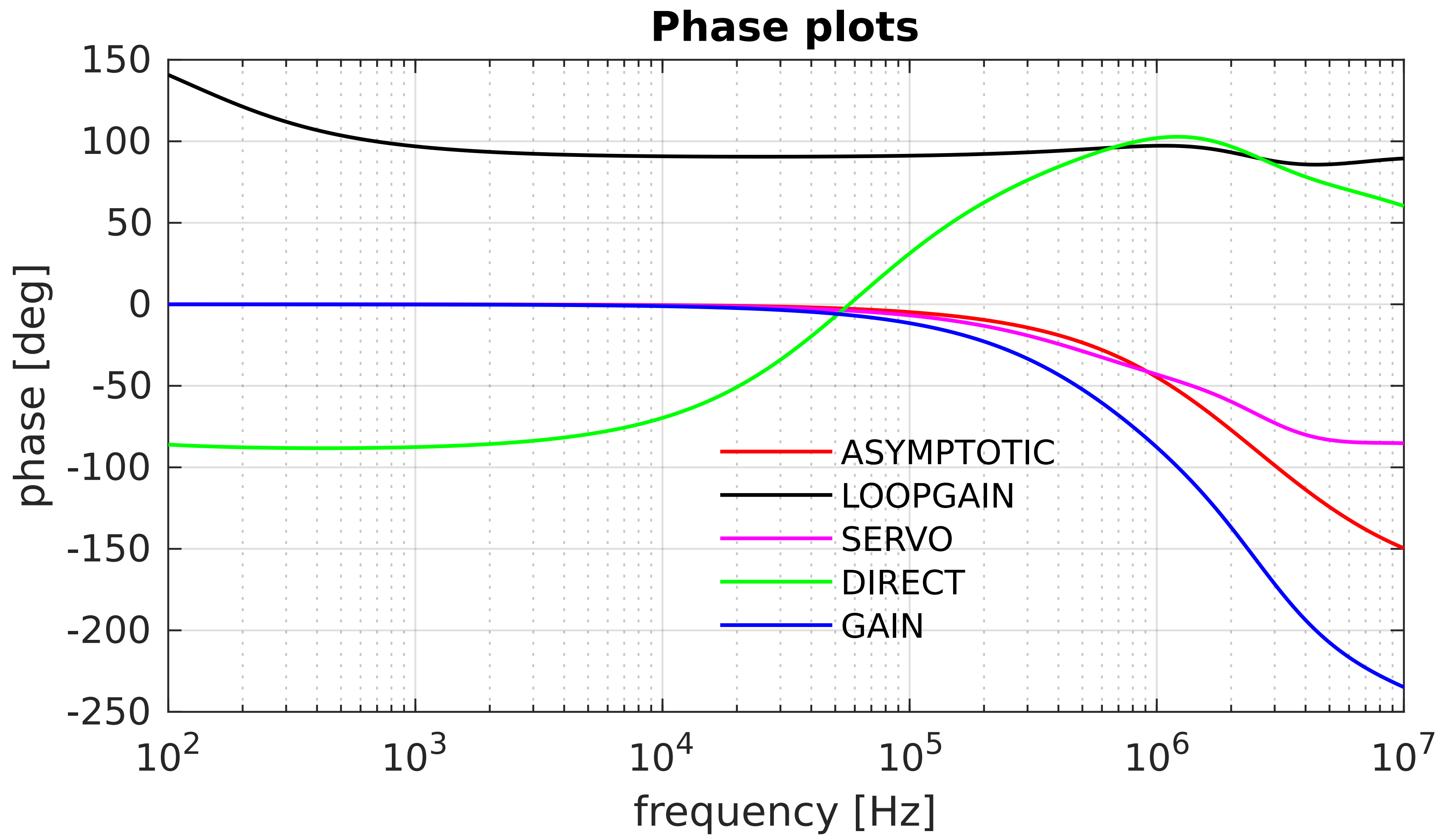


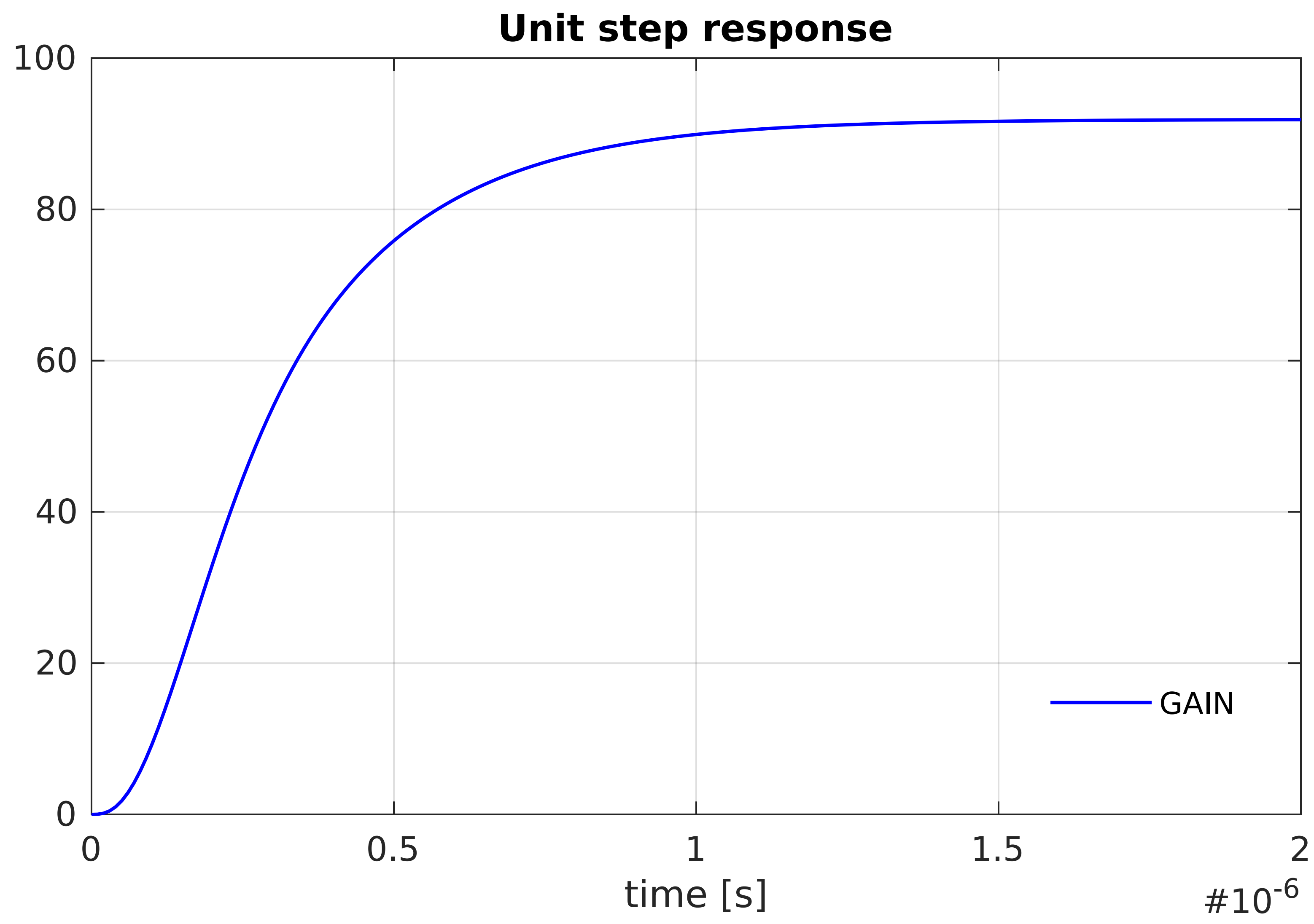


Uncompensated amplifier

Frequency compensation

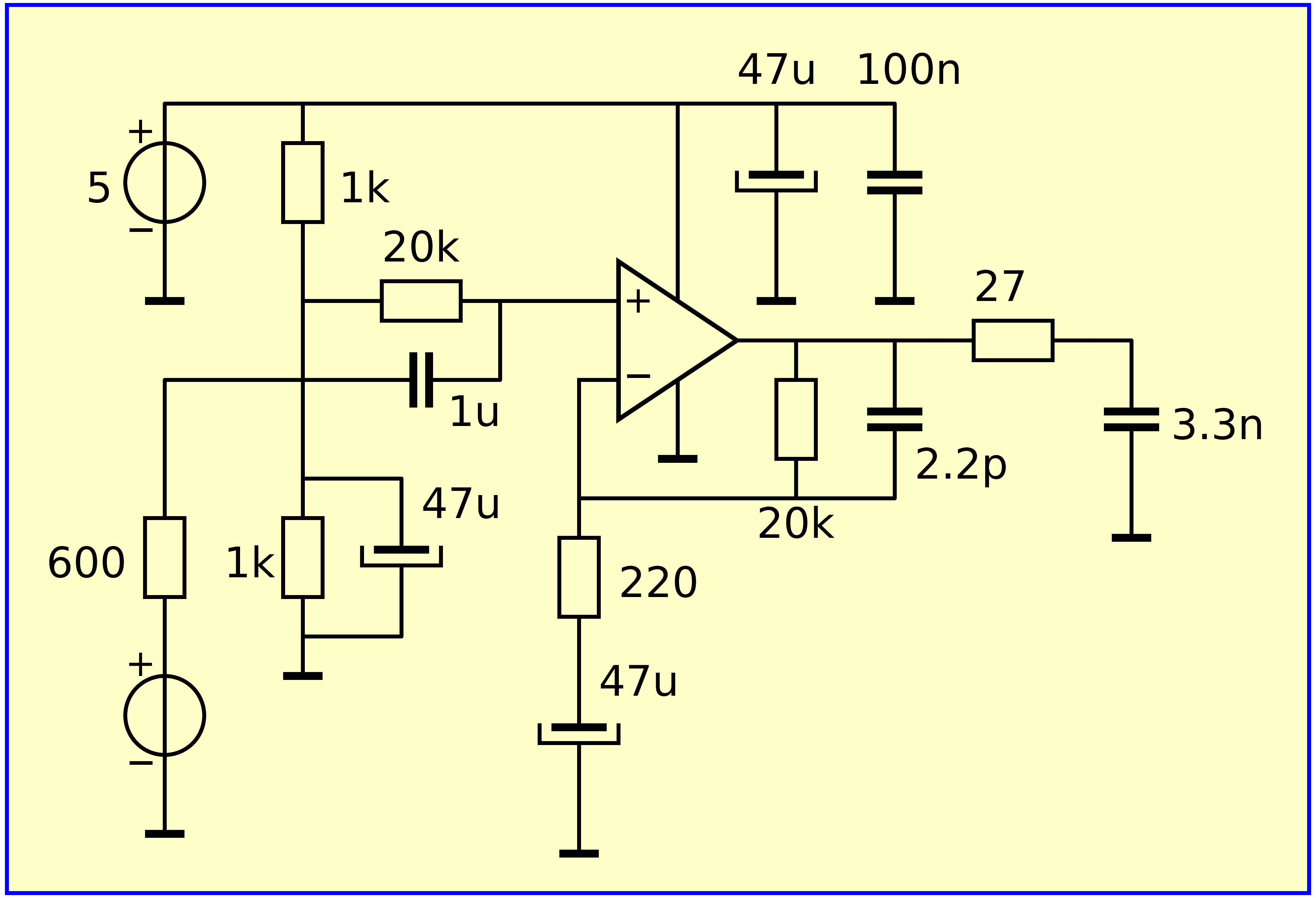


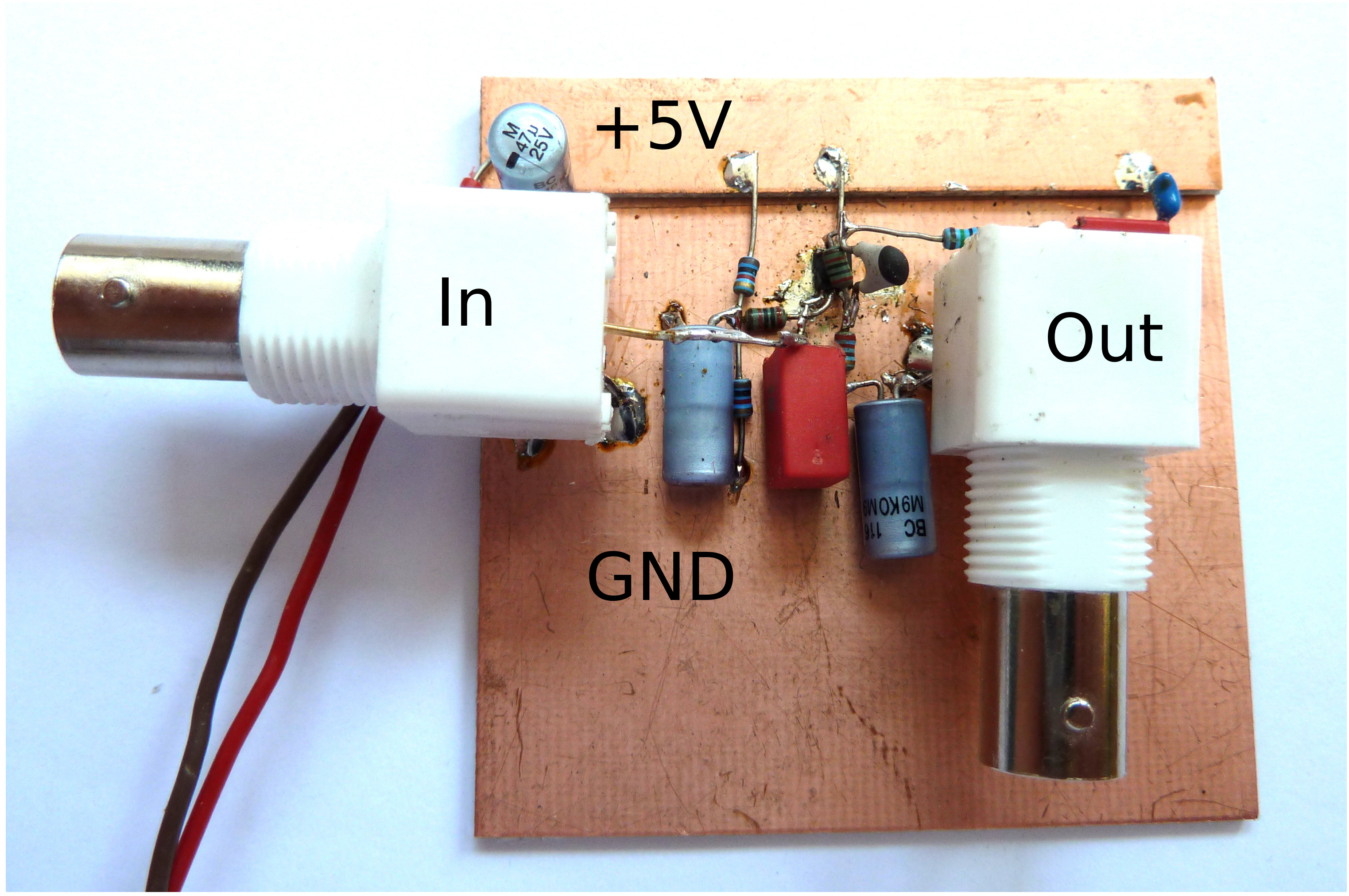




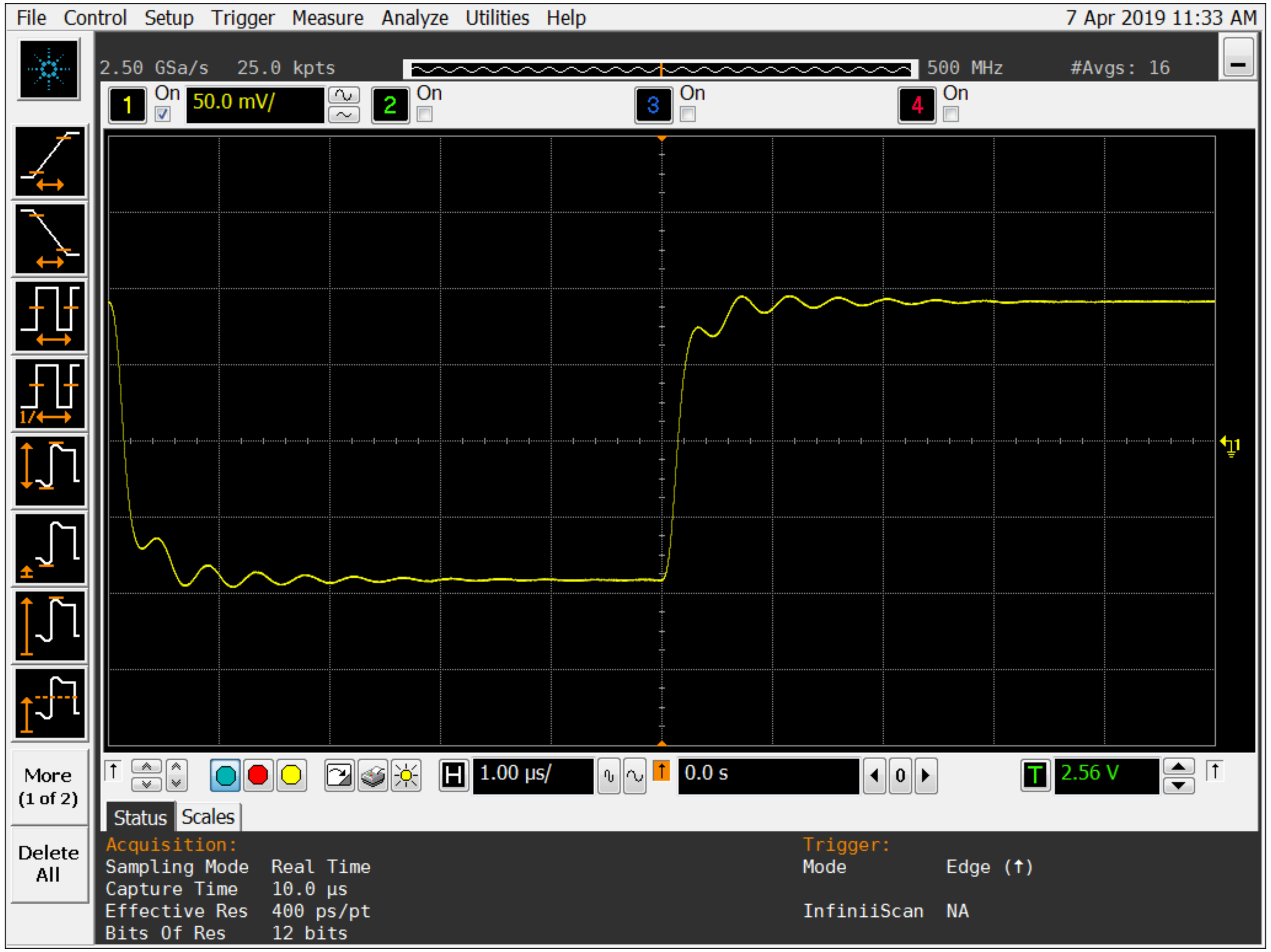
Compensated amplifier

Construction





Test results

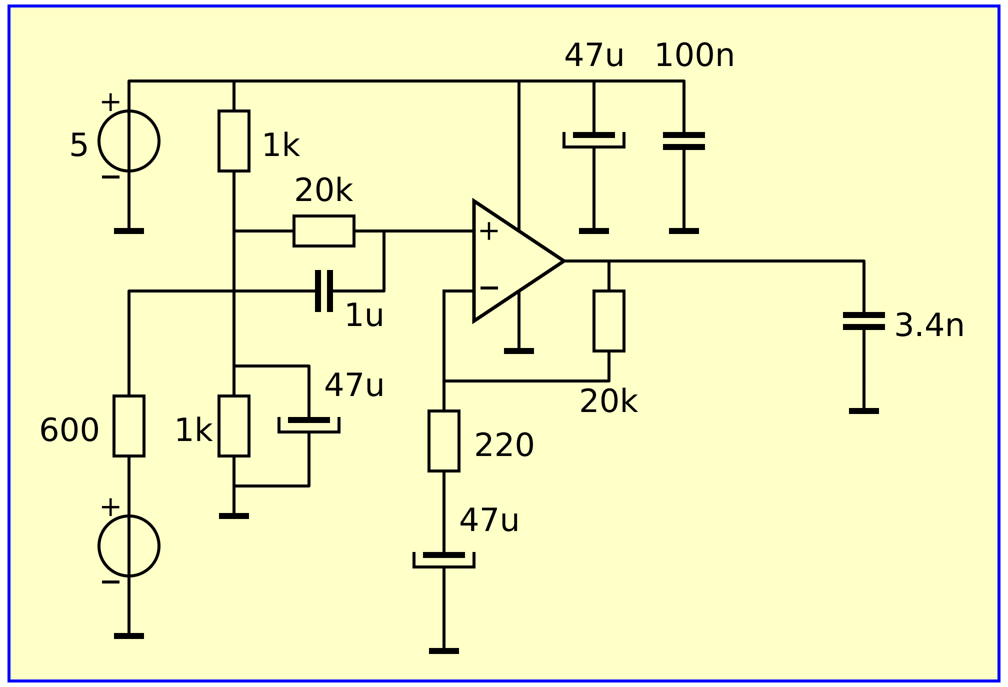


Small-signal step response

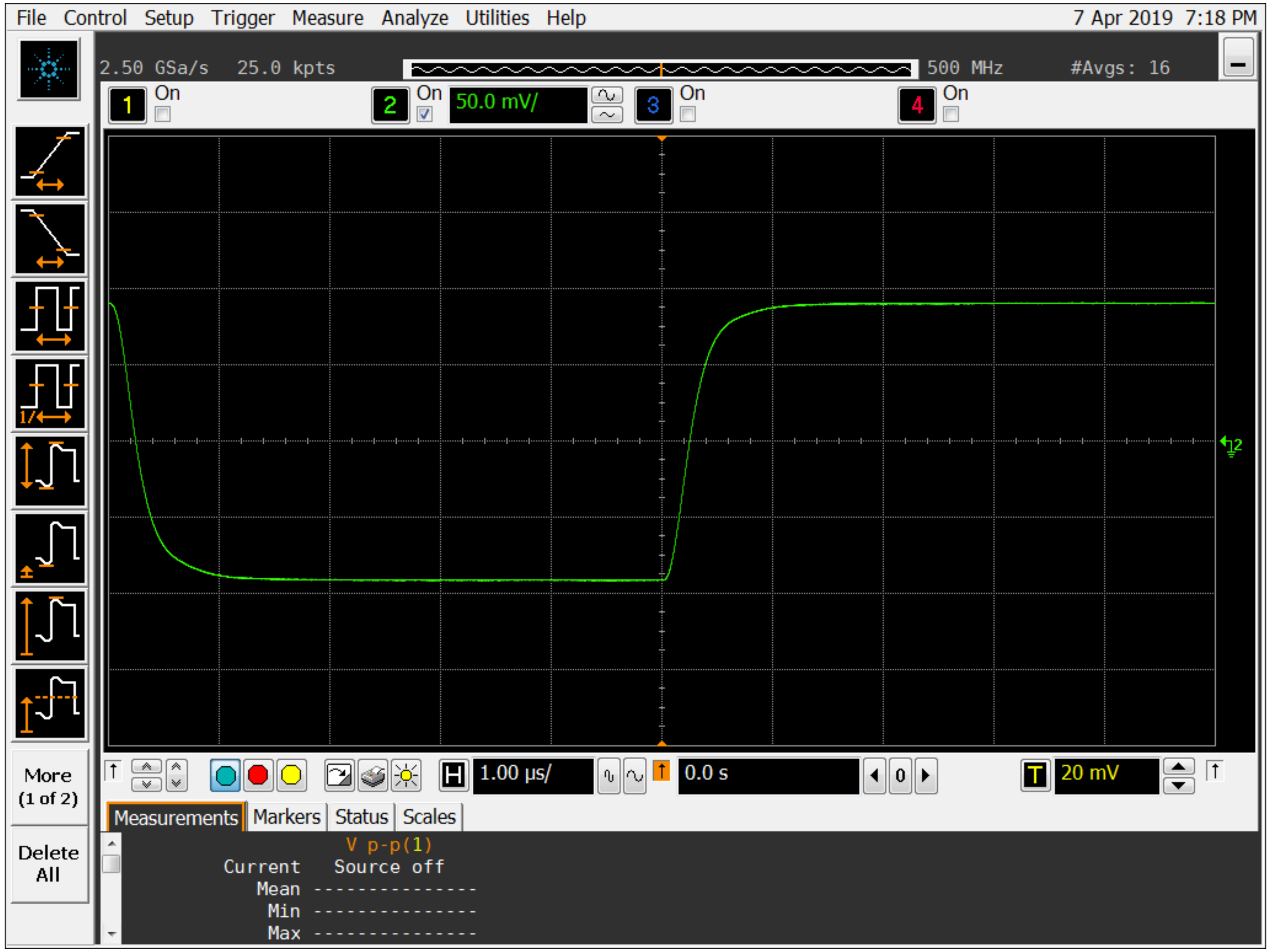
Source: $2mV_{pp}$, 100kHz, 50%

Uncompensated amplifier

Total load capacitance 3.4nF



Test results

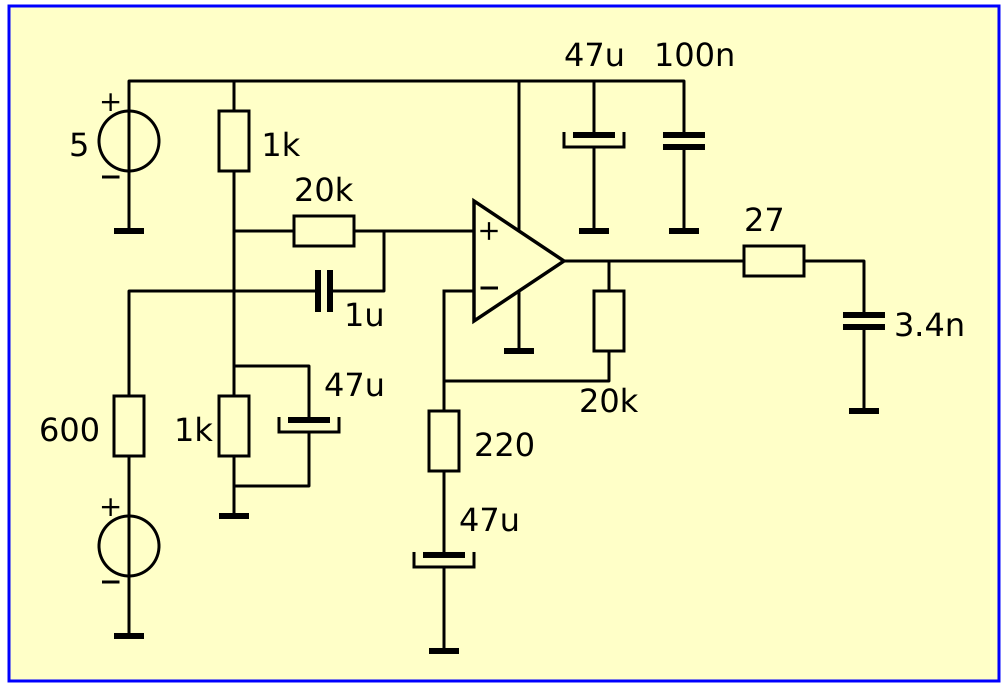


Small-signal step response

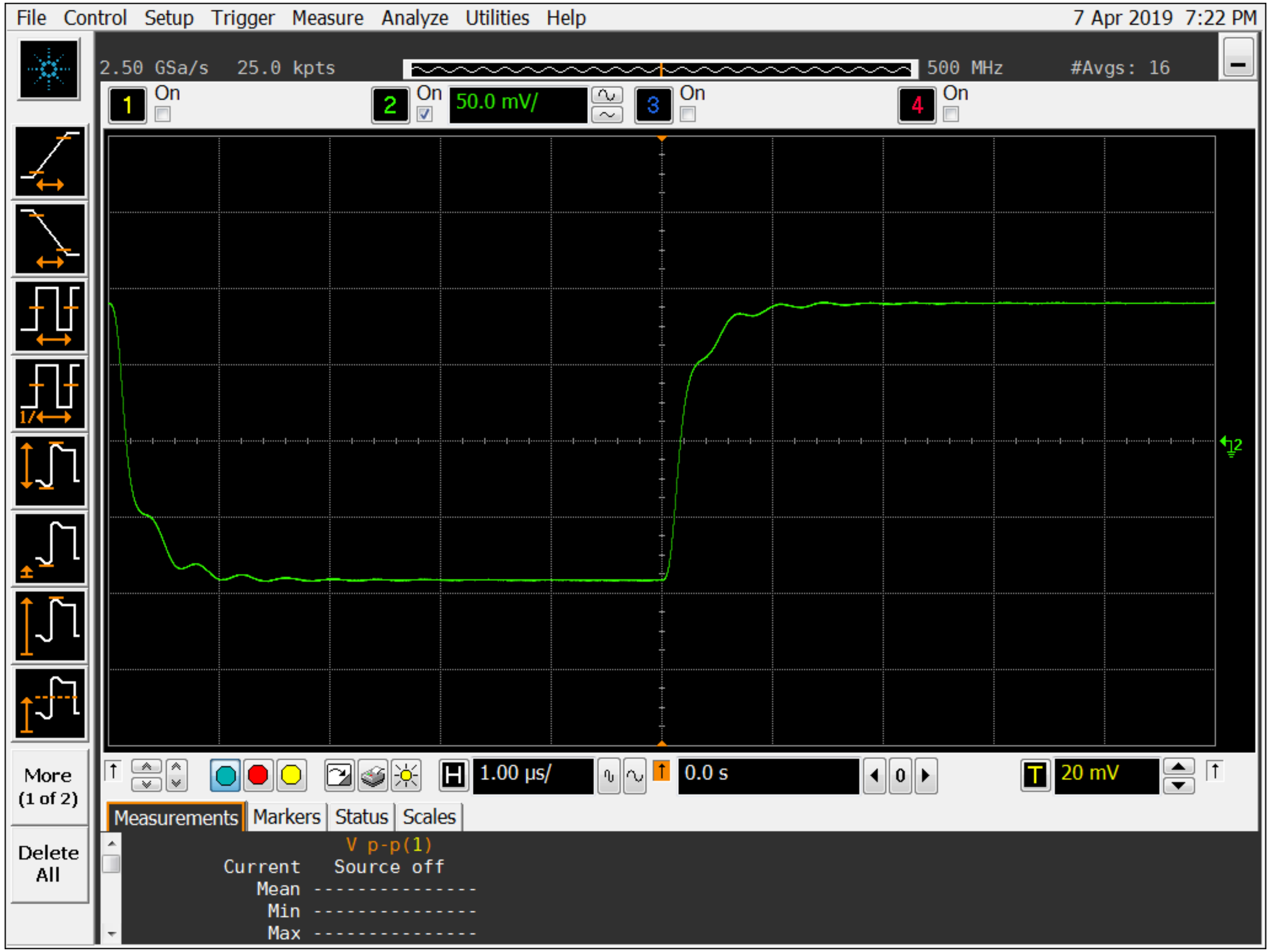
Source: 2mV$_{pp}$, 100kHz, 50%

Partly compensated amplifier

Total load capacitance 3.4nF



Test results

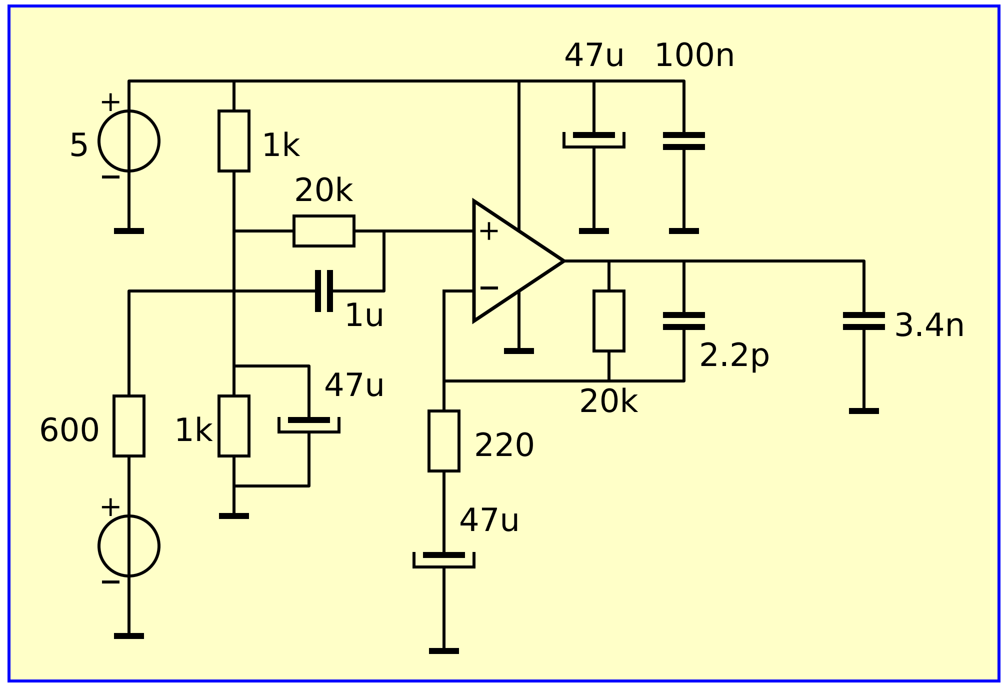


Small-signal step response

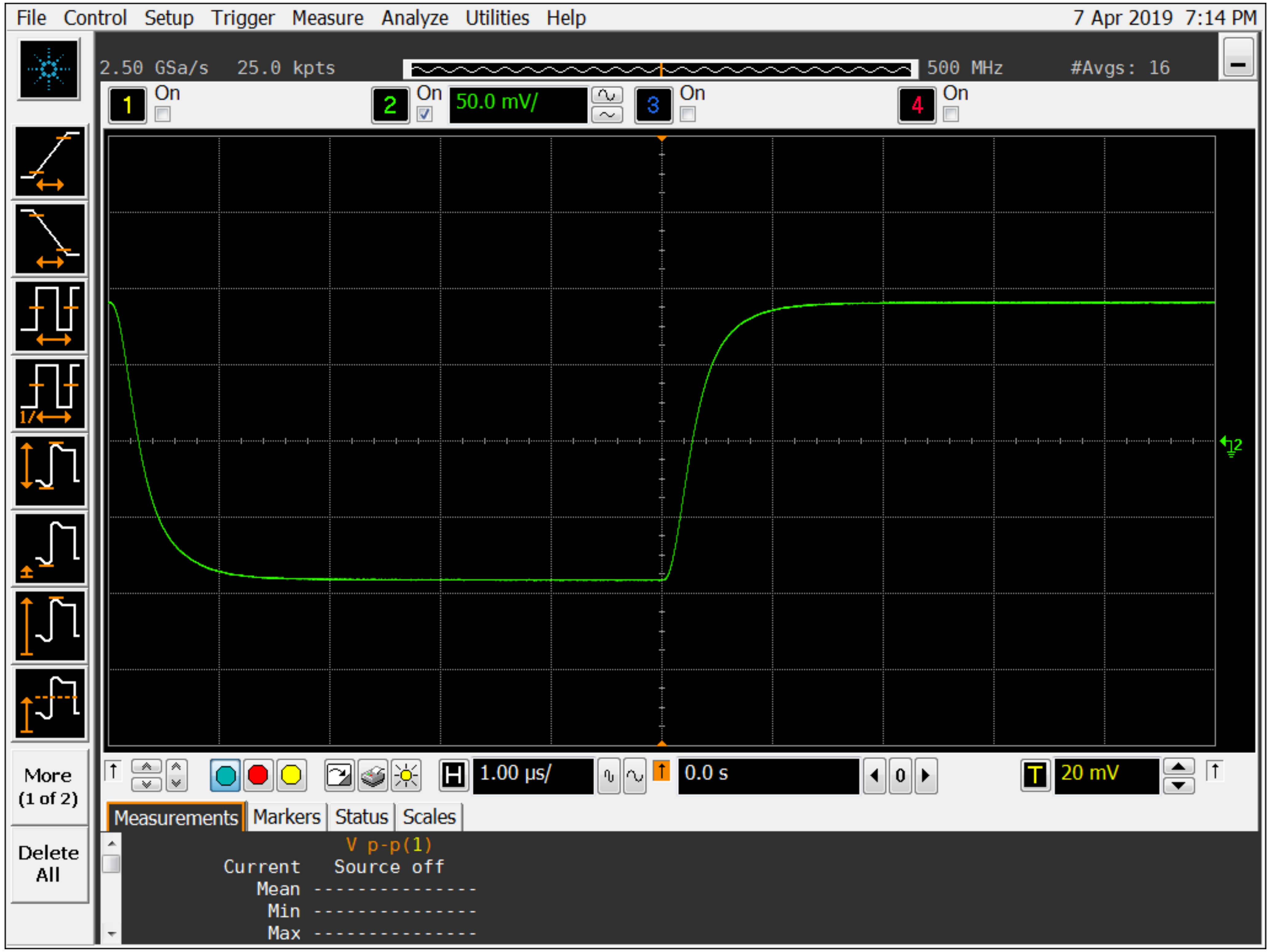
Source: 2mV$_{pp}$, 100kHz, 50%

Partly compensated amplifier

Total load capacitance 3.4nF



Test results

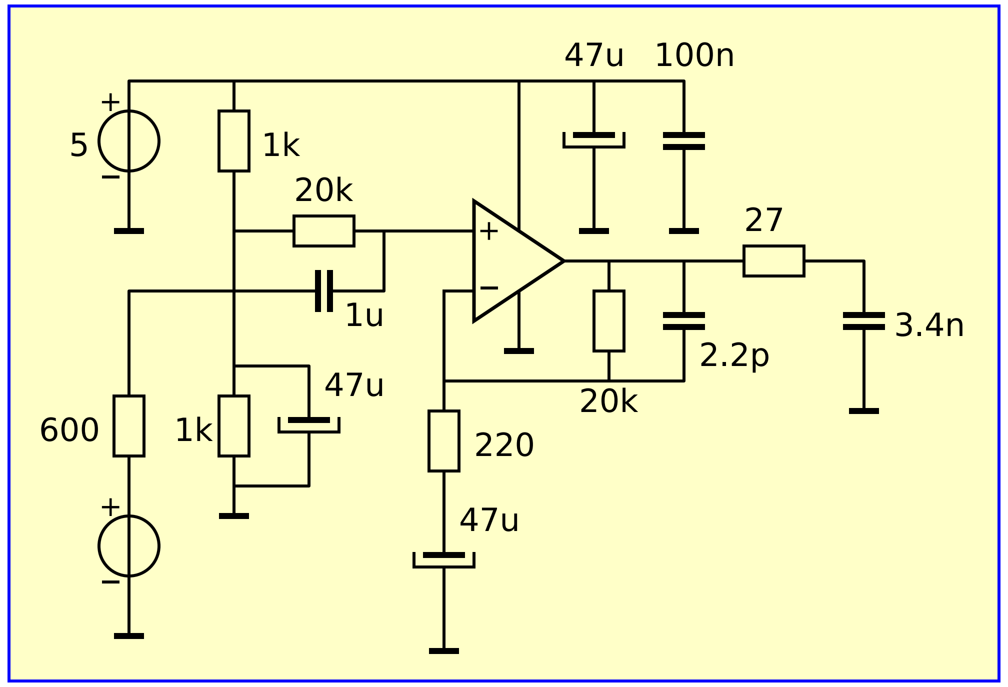


Small-signal step response

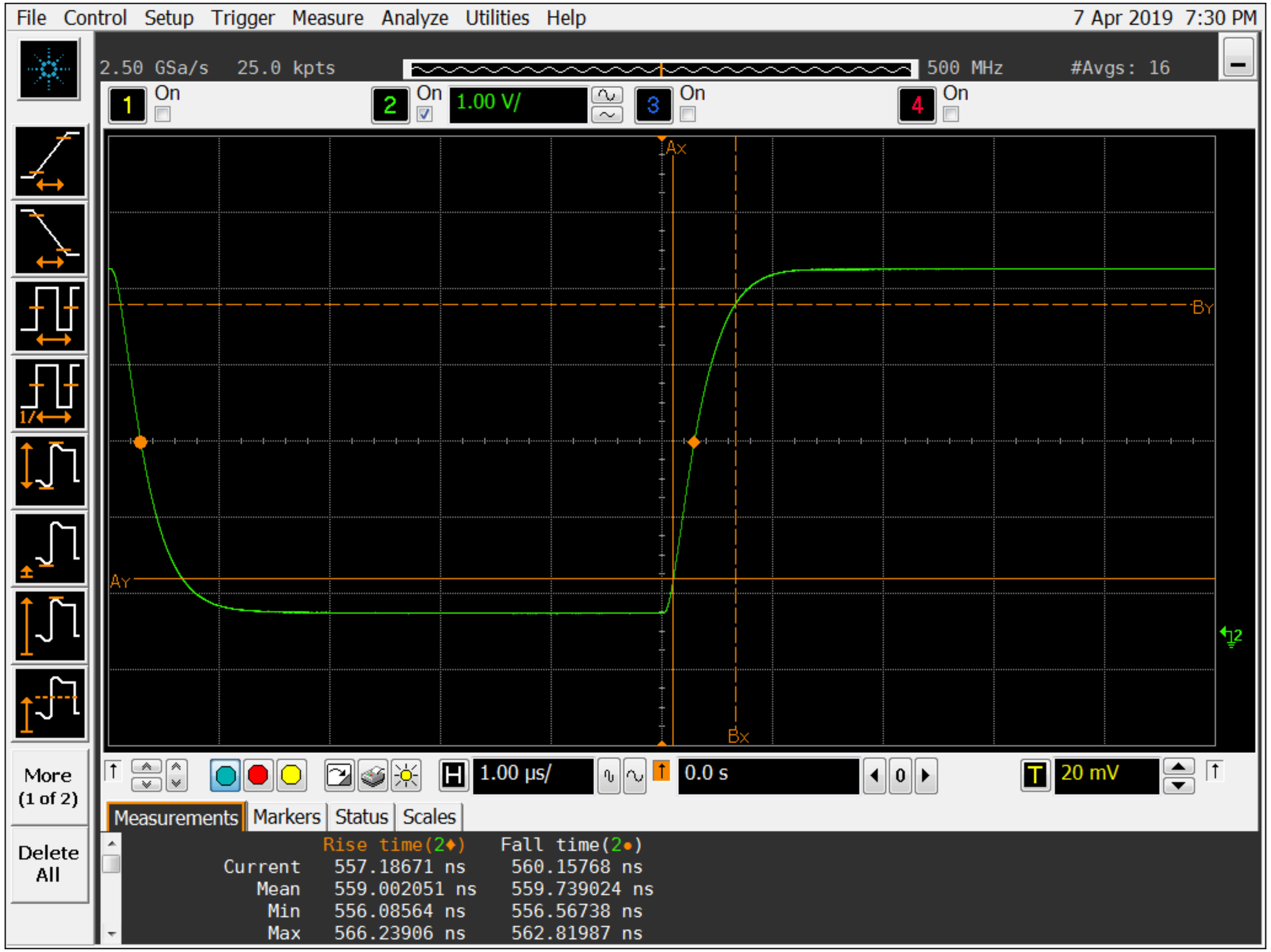
Source: 2mV$_{pp}$, 100kHz, 50%

Compensated amplifier

Total load capacitance 3.4nF



Test results

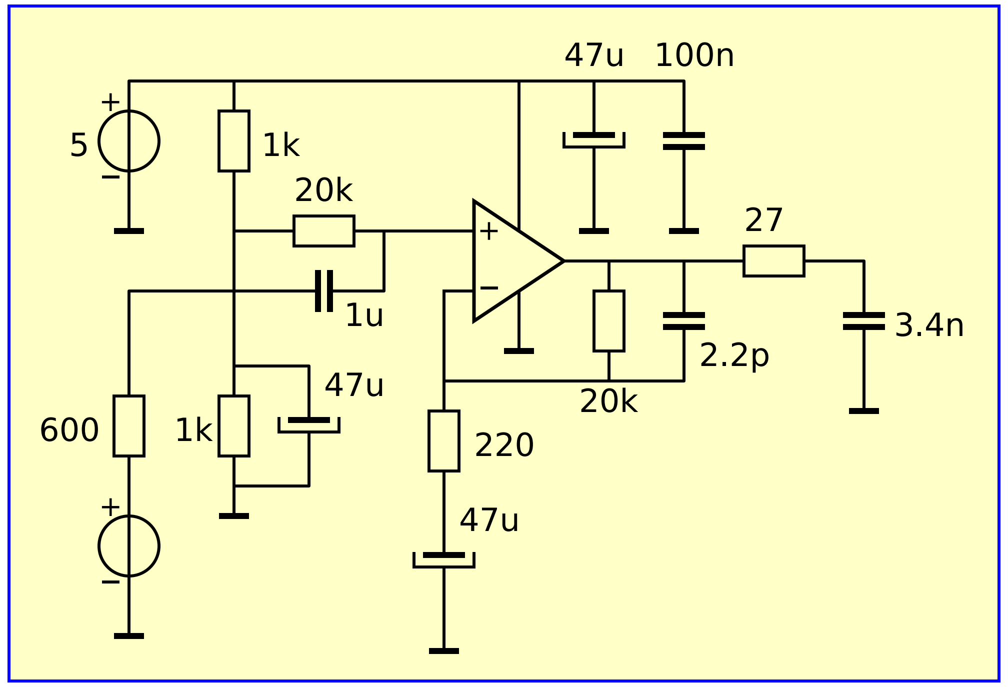


Large-signal step response

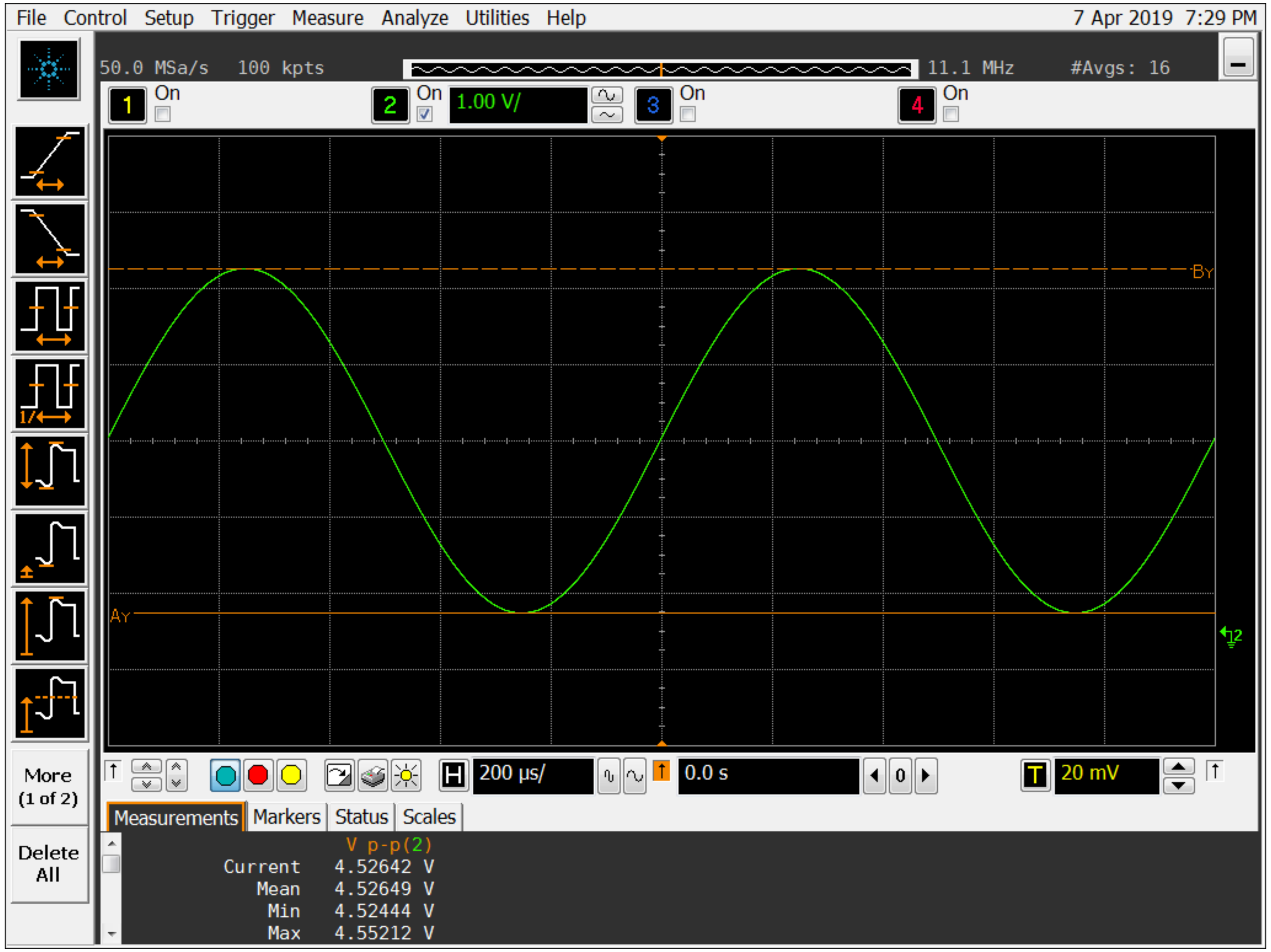
Source: 50mV$_{pp}$, 100kHz, 50%

Compensated amplifier

Total load capacitance 3.4nF



Test results

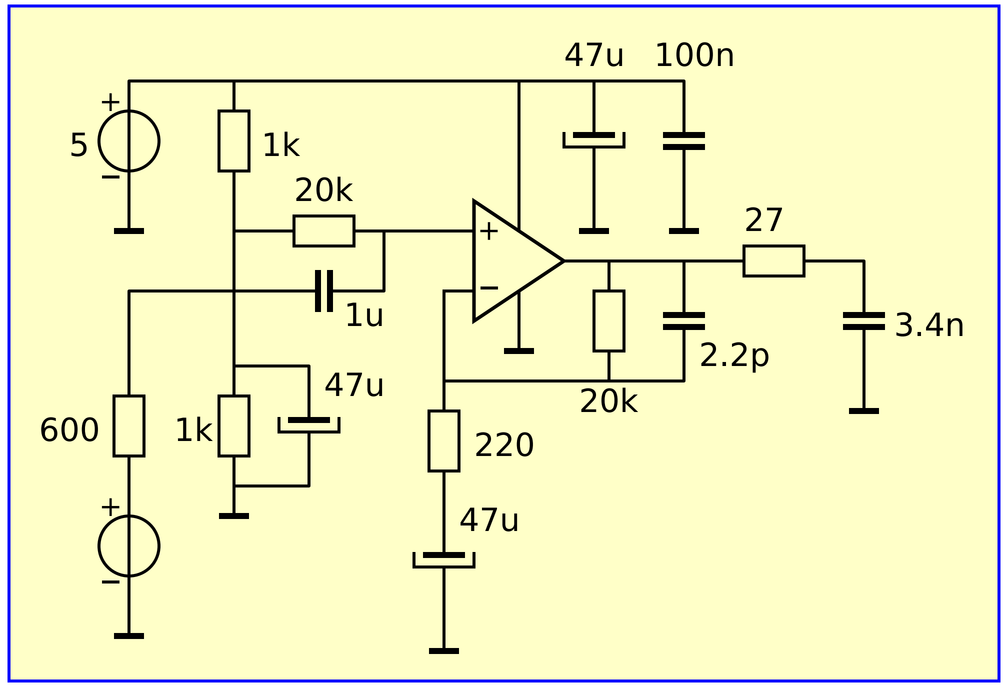


Large-signal sine response

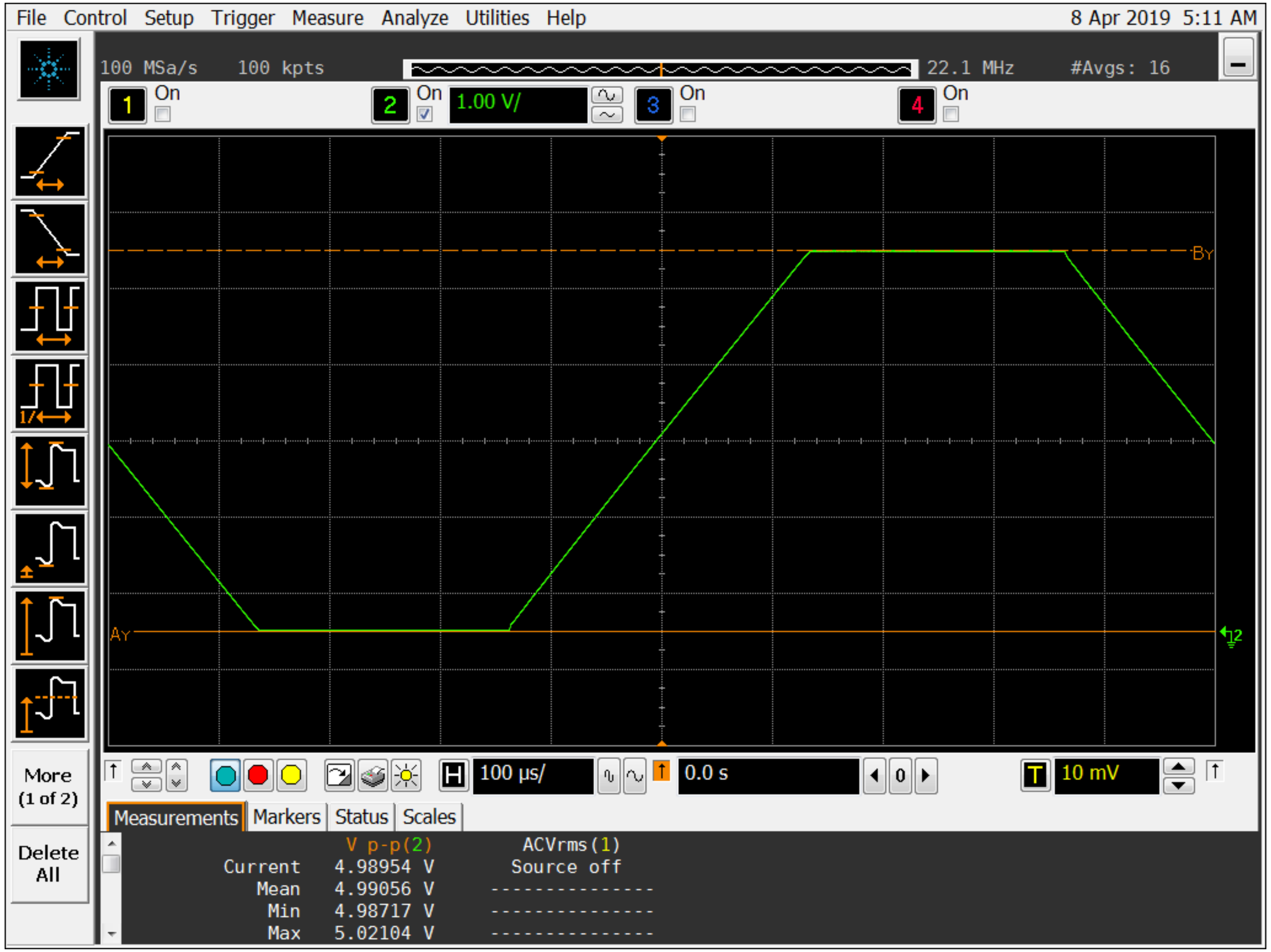
Source: 50mV$_{pp}$, 100kHz

Compensated amplifier

Total load capacitance 3.4nF



Test results



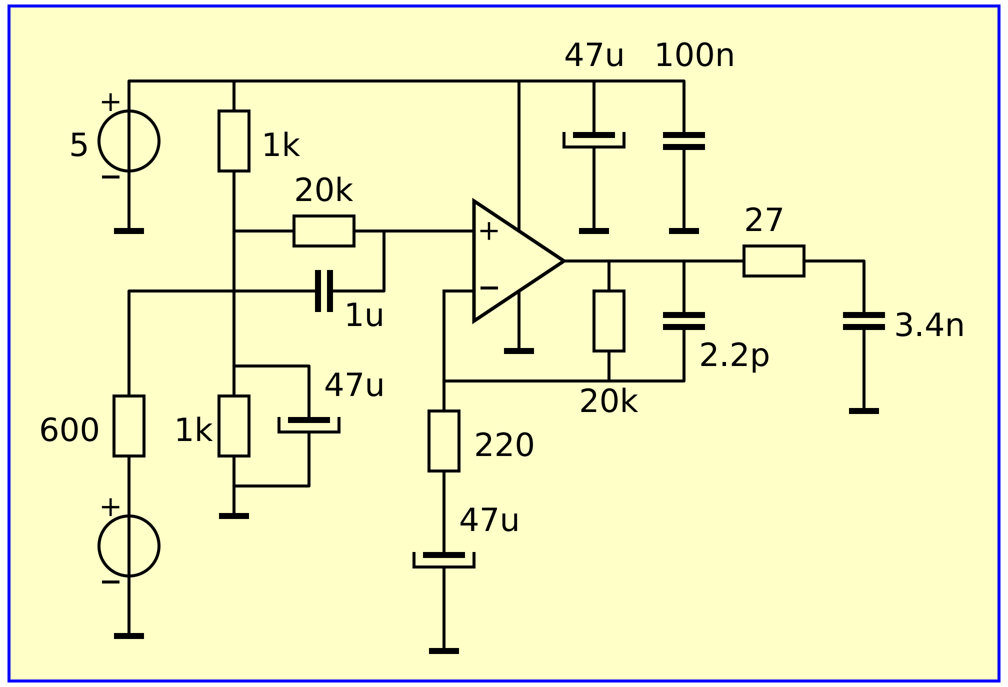
Large-signal overdrive

Source: 100mV$_{pp}$, 1kHz, triangle

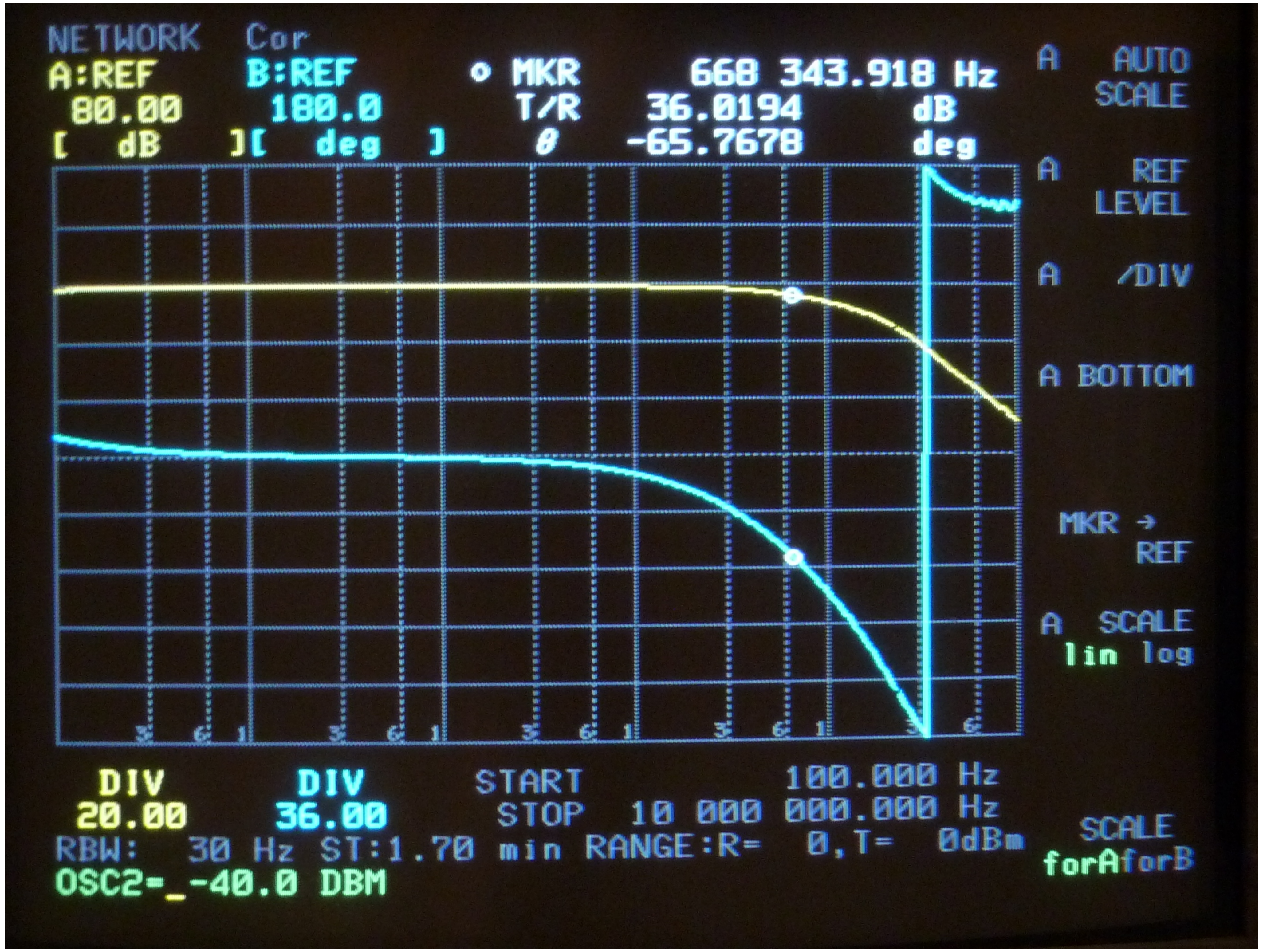
Compensated amplifier

Total load capacitance 3.4nF

Source/sink voltage drop < 10mV



Test results

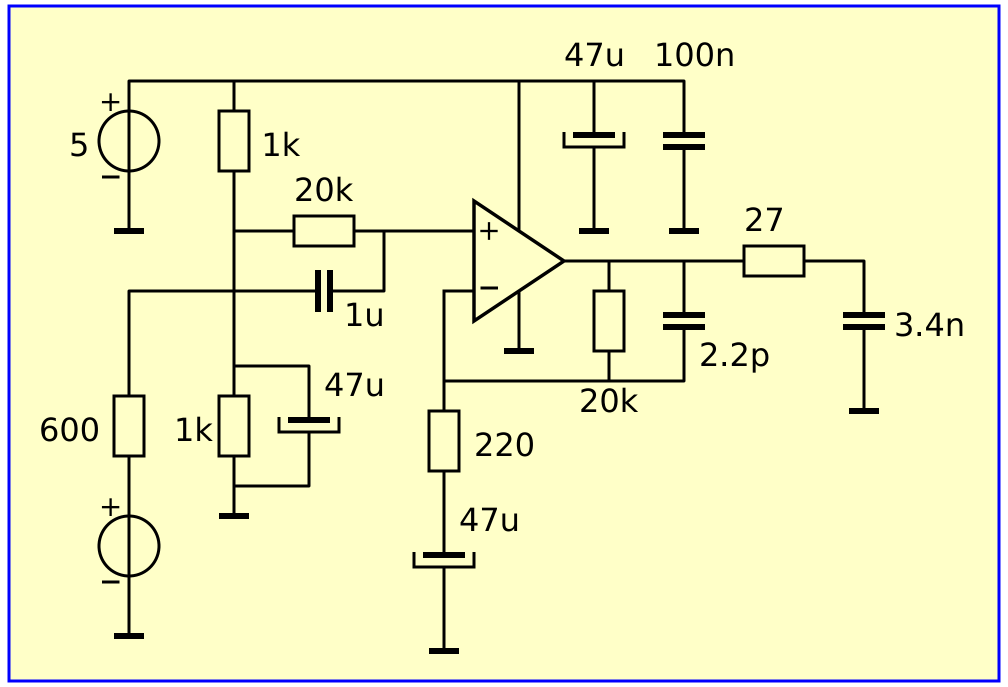


Small-signal transfer

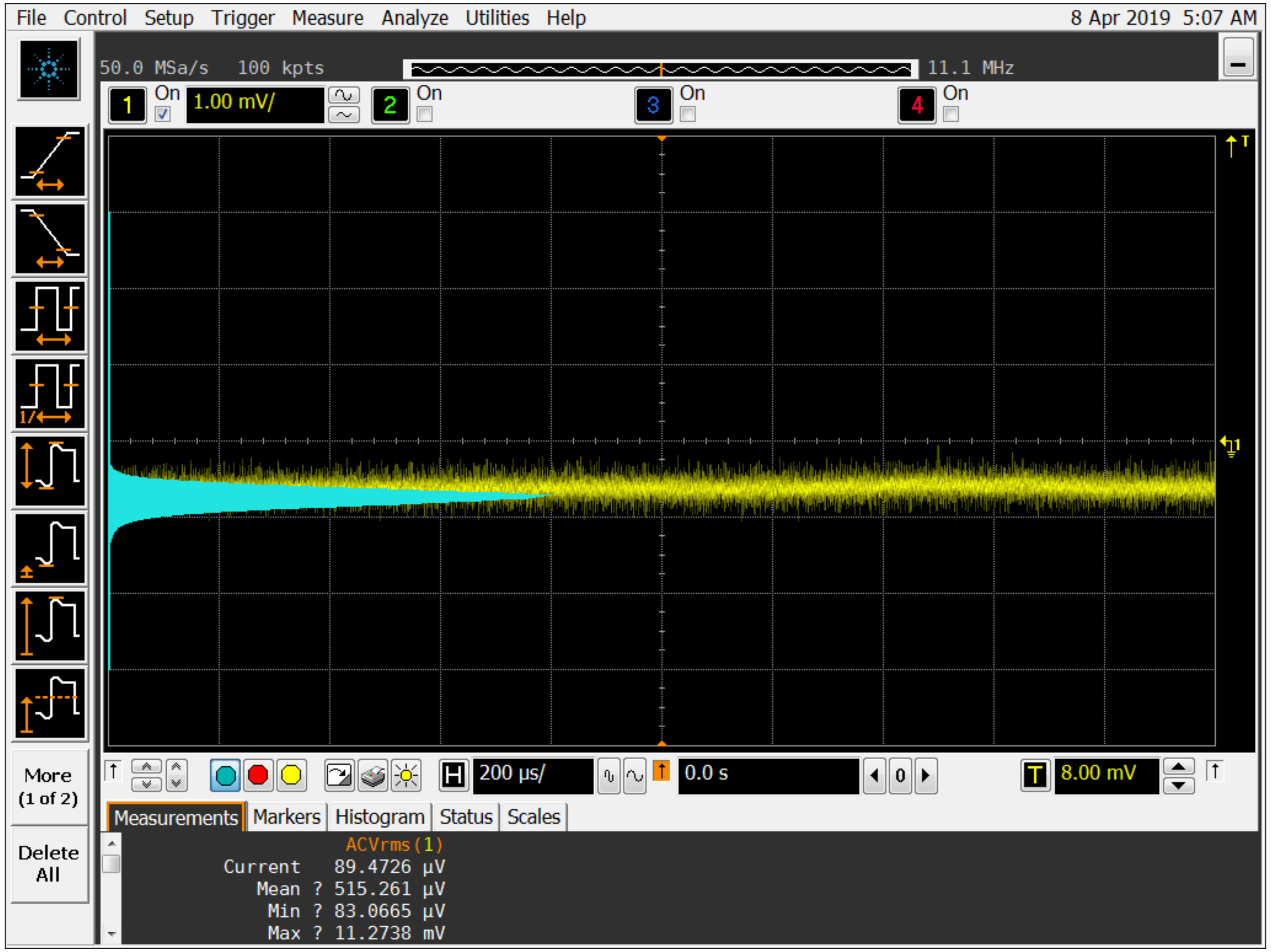
HP4195A, source -40dBm

Compensated amplifier

Total load capacitance 3.4nF



Test results

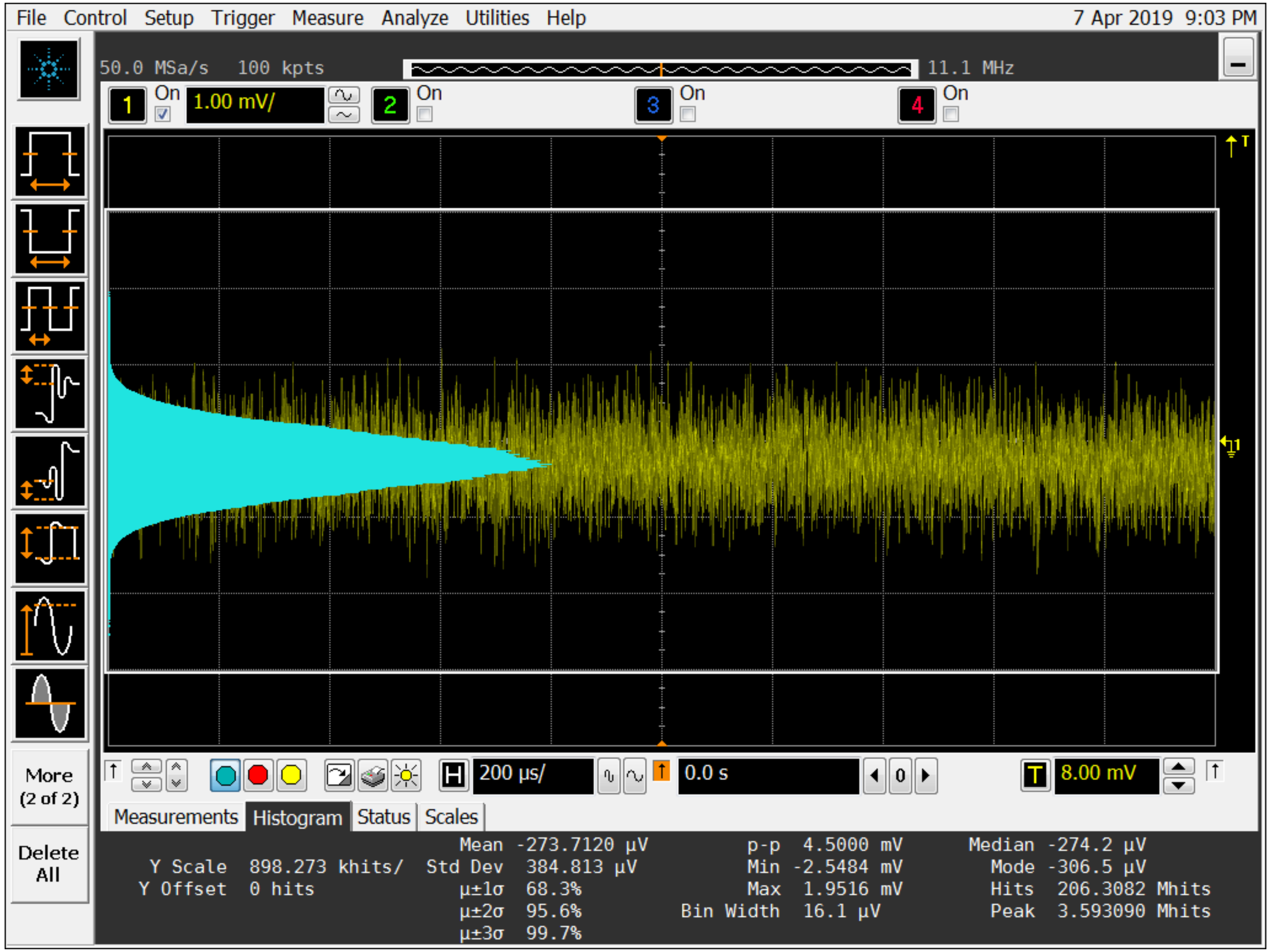


Oscilloscope noise

83uV RMS

Shorted input

Test results



Output noise

385uV RMS

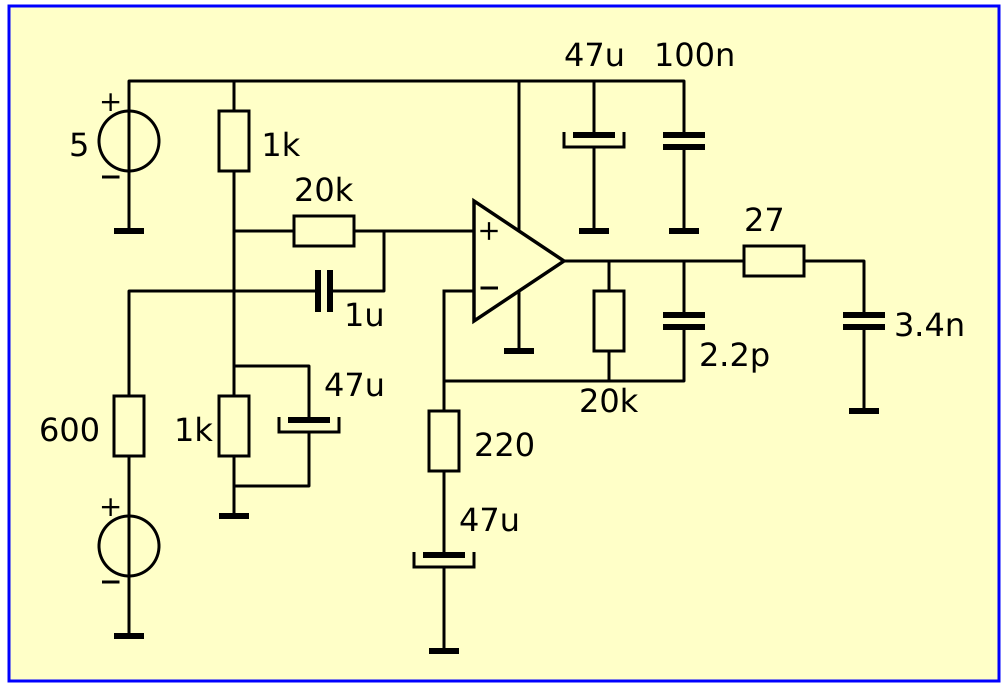
Compensated amplifier

Total load capacitance 3.4nF

Corrected for scope noise: 376uV

N=2.3dB @ 1MHz NBW

N=2.7dB @ 900kHz NBW



Conclusions and remarks

1. Amplifier performance complies with requirements
2. Spice simulation with TI macro model did not show small-signal instability
3. Modeling of individual performance aspects seems successful approach

