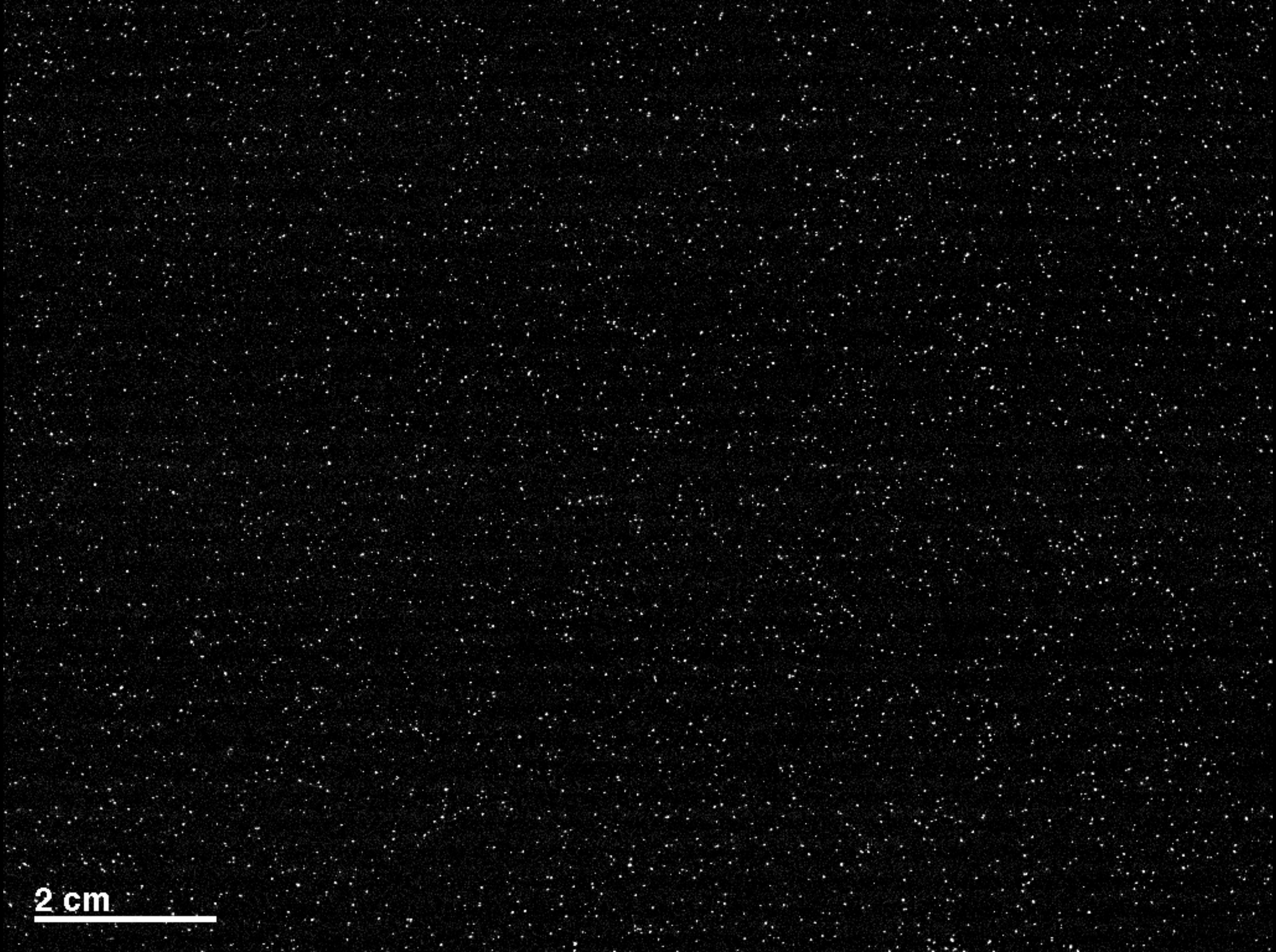
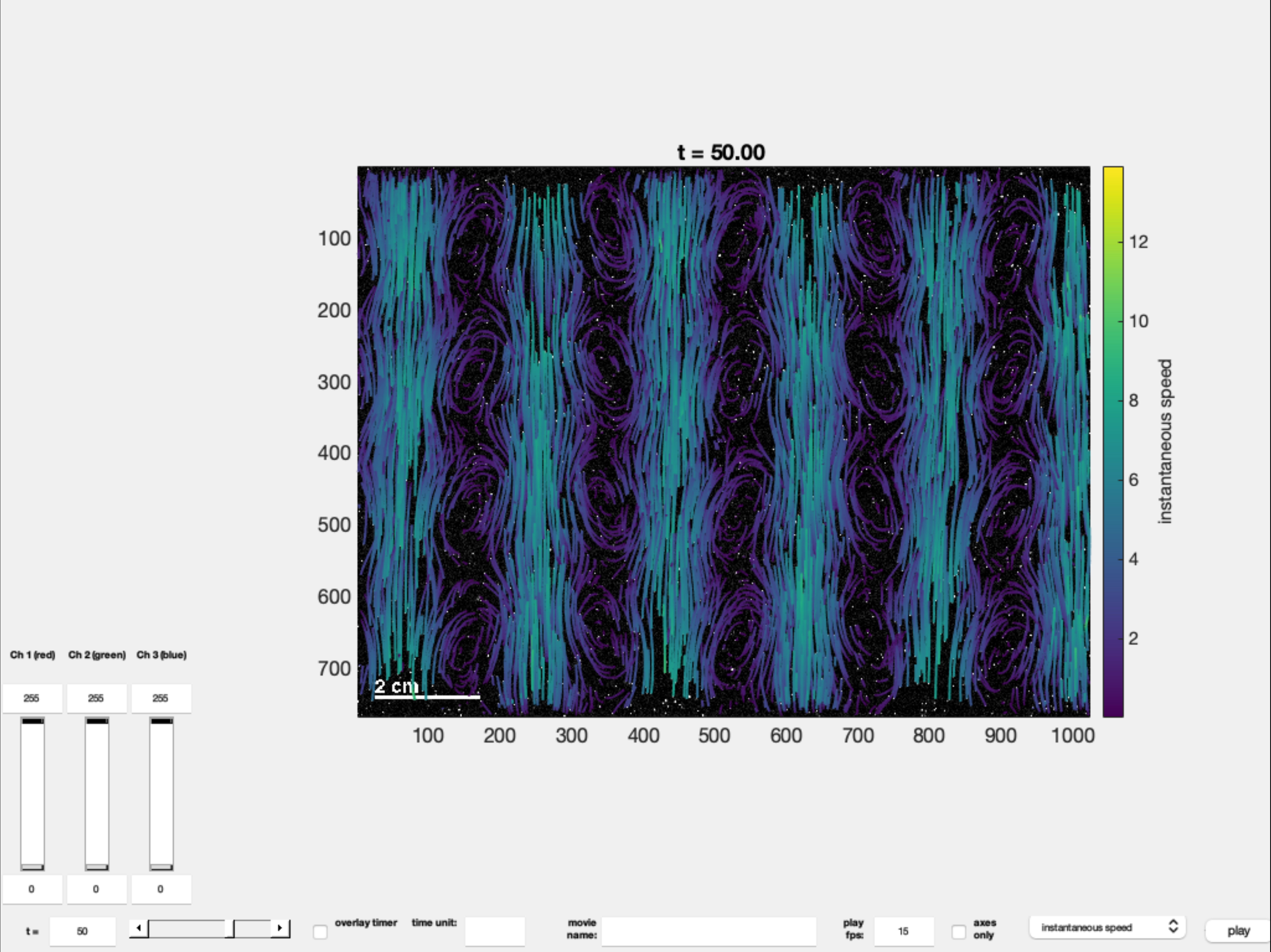
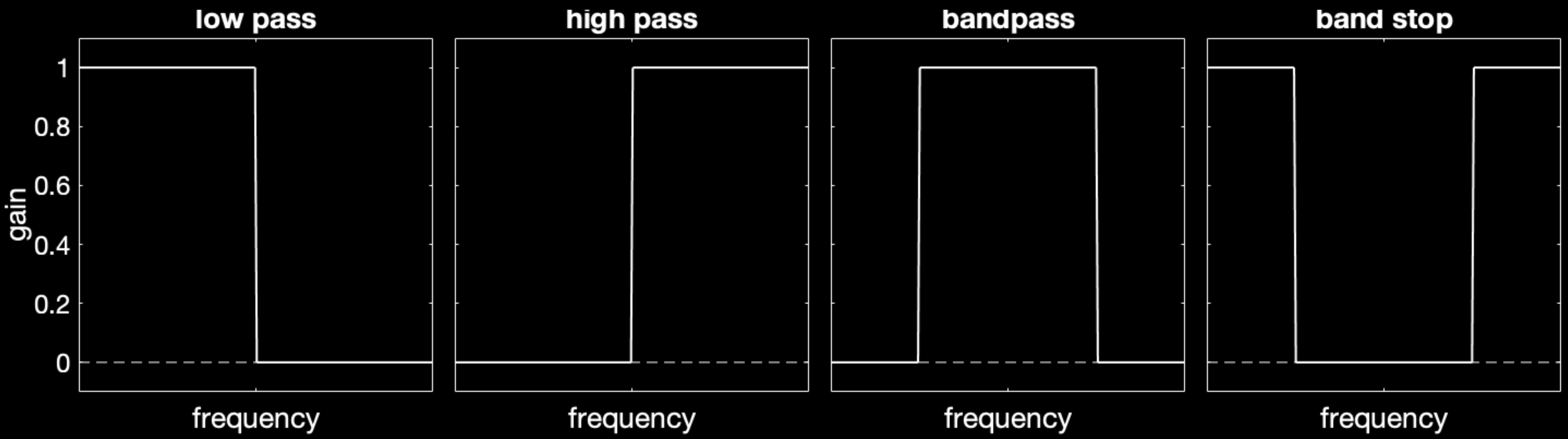

2 cm


t = 50.00
100
200
300
400
500
600
700
2 cm
100
200
300
400
500
600
700
800
900
1000
12
10
8
6
4
2
instantaneous speed
Ch 1 (red)
Ch 2 (green)
Ch 3 (blue)
255
255
255
0
0
0
t =
50
overlay timer
time unit:
movie name:
play fps:
15
axes only
instantaneous speed
play

# Filters

- Any time-varying voltage can be expressed as a superposition of sinusoids of different frequencies
- A *filter* removes undesired frequencies
  - Noise (e.g. 60 Hz, high-frequency hiss)
  - Irrelevant frequencies (e.g. < 20 Hz or > 20 kHz for audio) to prevent aliasing
- Types:



# The simplest low-pass filter

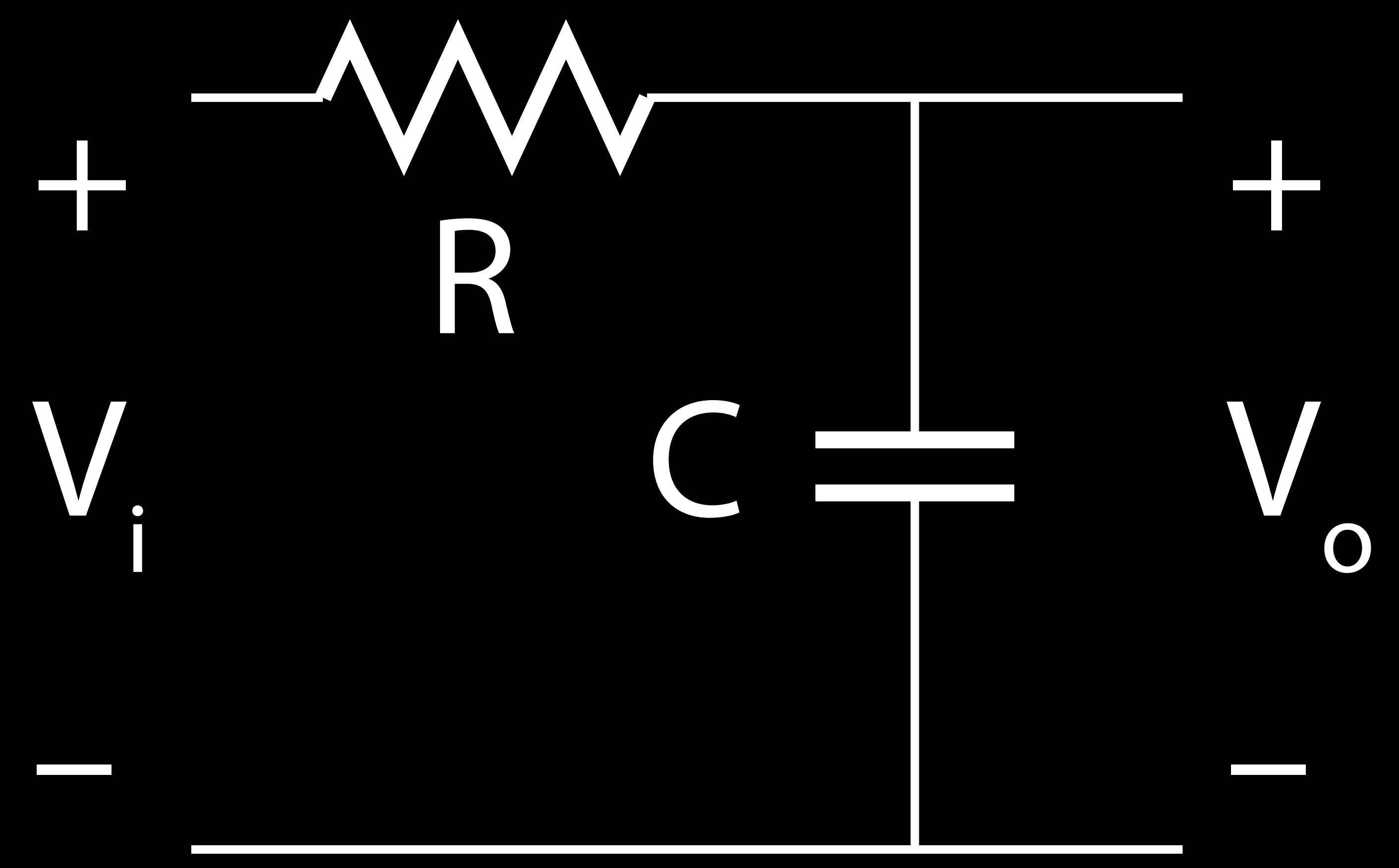
- First-order Butterworth, aka RC
- Voltage law: $RC\frac{\partial V_o}{\partial t} + V_0 = V_i$
- If $V_i = A\sin\omega t$, the long-term output is

$$V_o = \frac{A}{\sqrt{1+(RC\omega)^2}}\sin\left(\omega t - \arctan RC\omega\right)$$

still a sin! phase shift

reduced amplitude

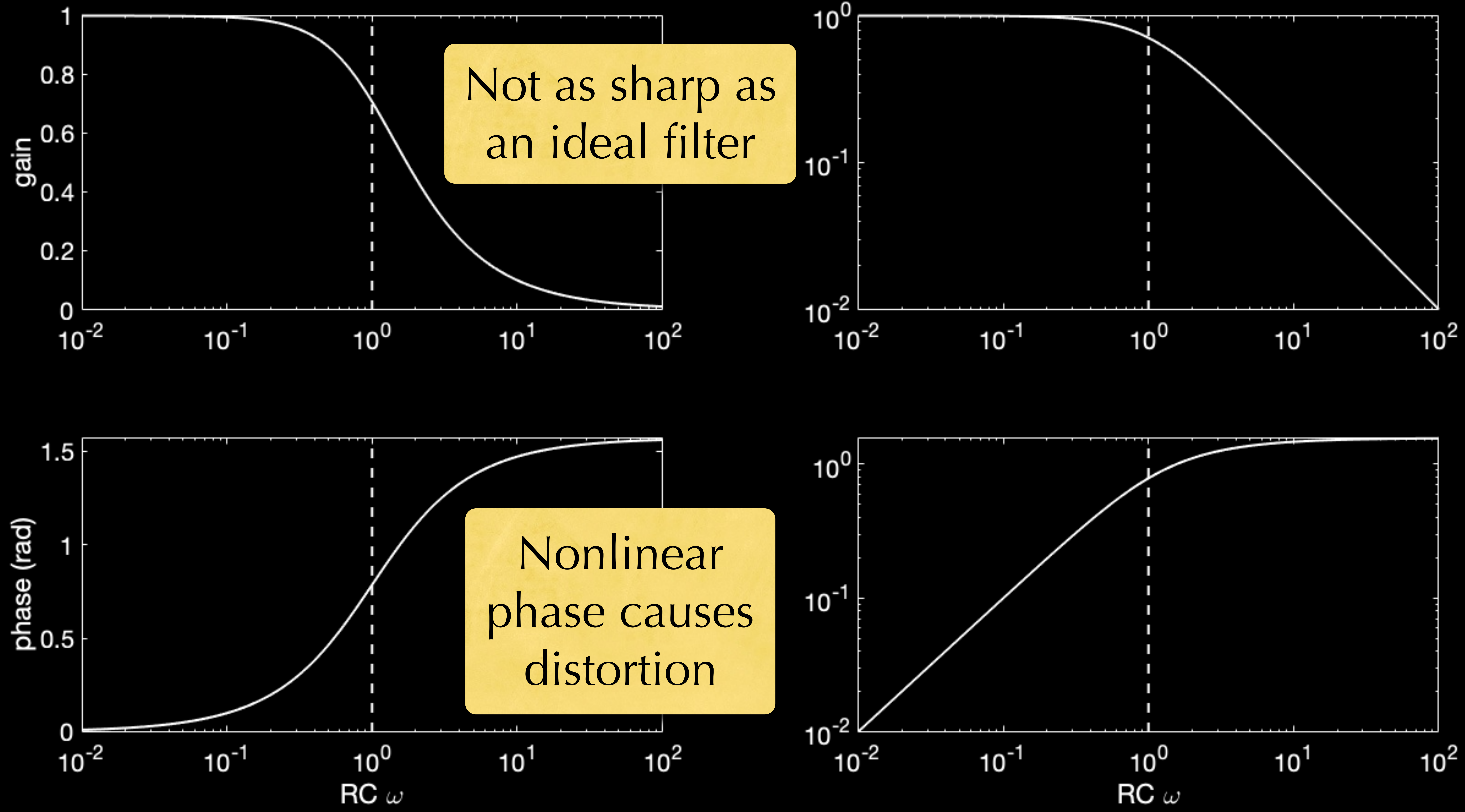
- Amplitude of $V_o$ at frequency $\omega = 0$? $A$
- Amplitude of $V_o$ at frequency $\omega = \infty$? $0$
- Cutoff frequency? $\frac{1}{RC}$



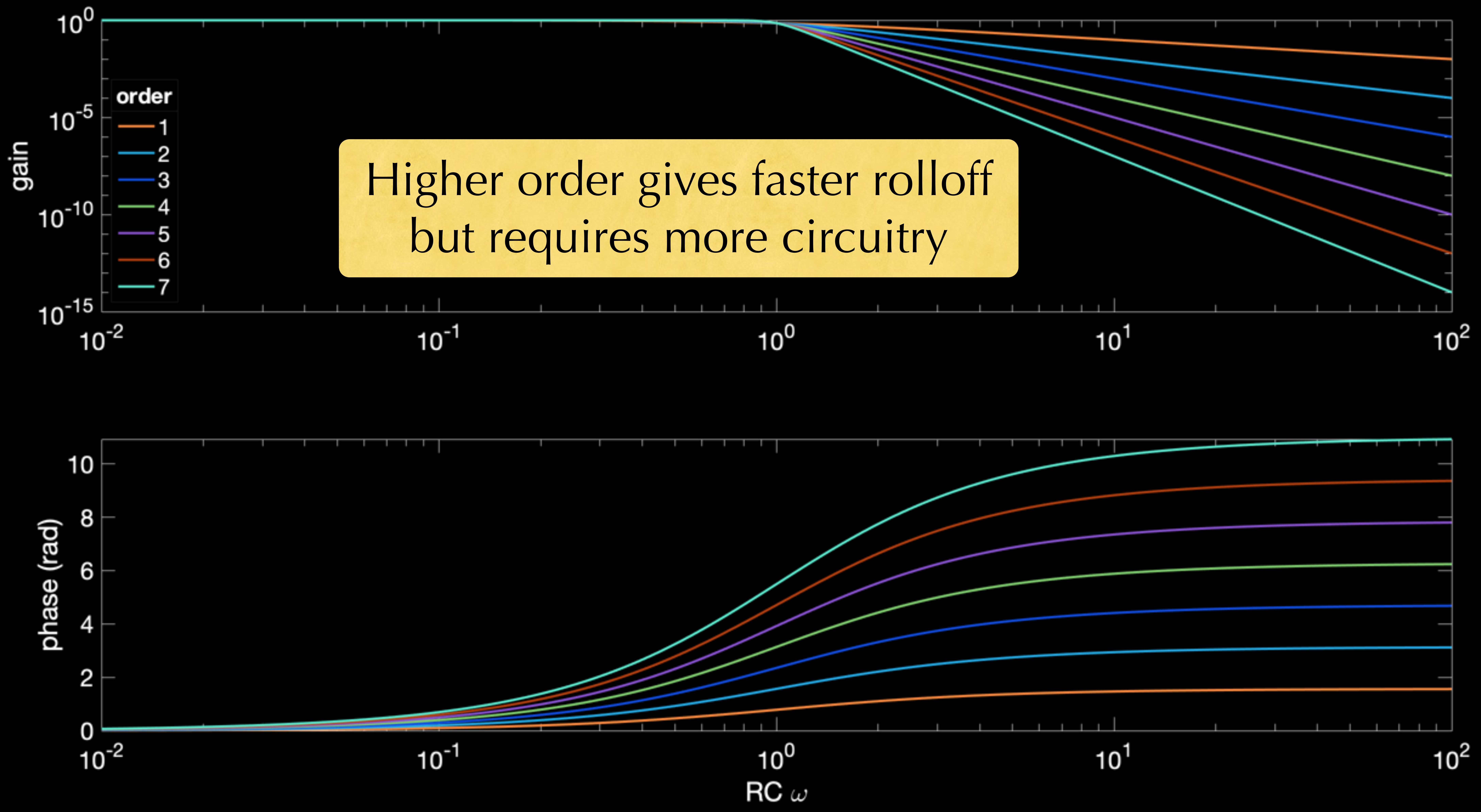

$$G = \frac{1}{\sqrt{1+(RC\omega)^2}}$$

$$\phi = \arctan RC\omega$$

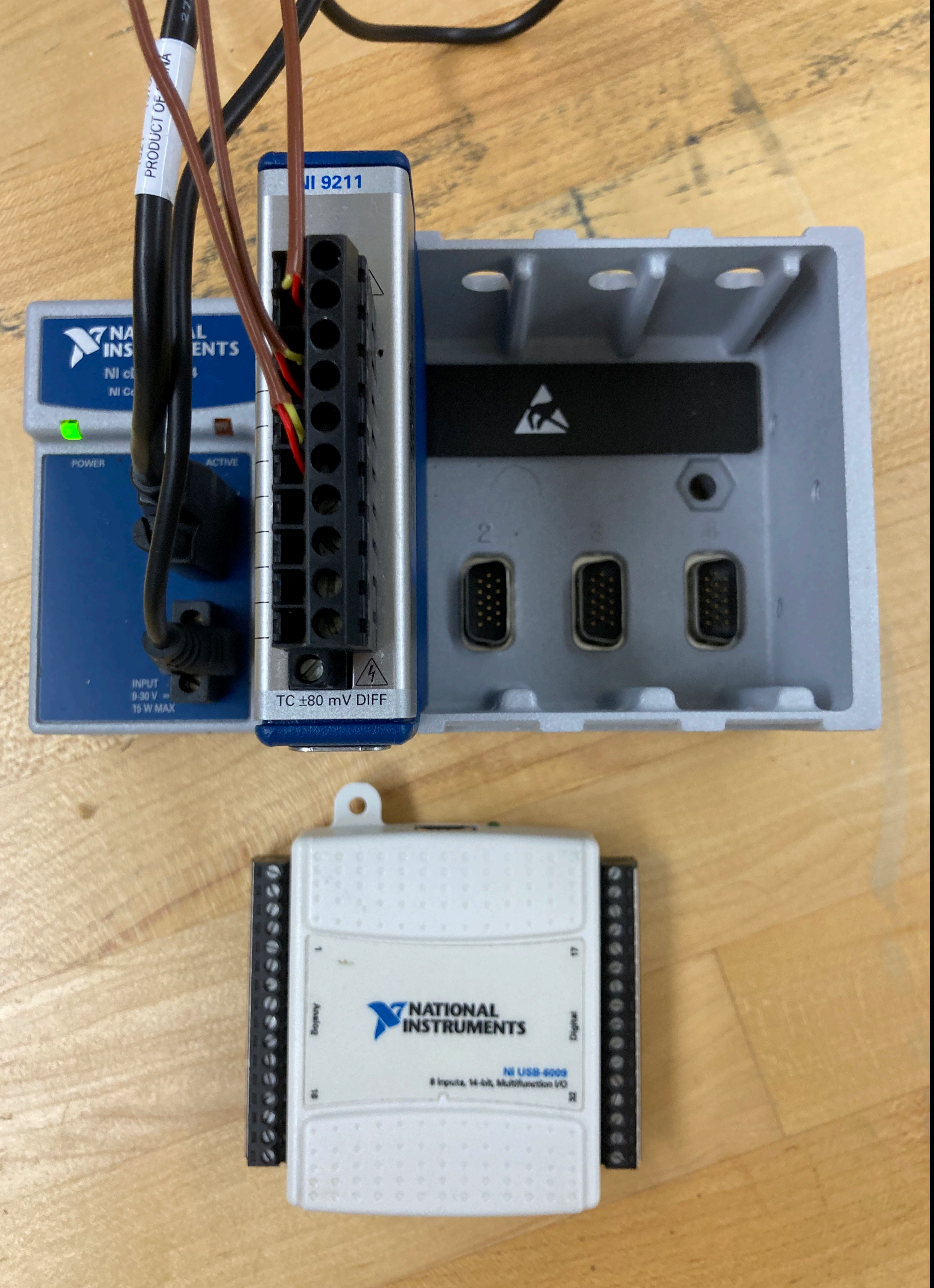
# First-order low-pass Butterworth filter



# Low-pass Butterworth filters



# Computerized data acquisition




- Often connect via USB; sometimes internal
- Wires from sensors connect to screw terminals
- Range often -5 V to 5 V or 0 V to 10 V
- Special ports for thermocouples
- Analog inputs, digital input/output, occasionally analog outputs
- Varying channel count (1 to ~30), bit depth (8, 12, 16), sampling rates (~100 to ~1000 kS/s)
- Software interface (LabView, Matlab, …)
- National Instruments, Measurement Computing, Keyence, Arduino, …