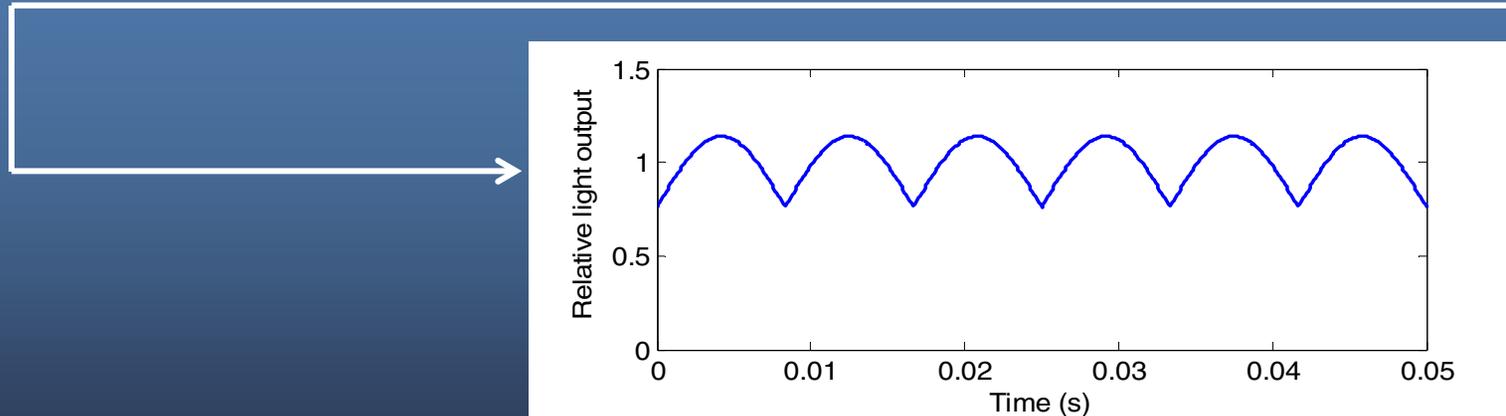
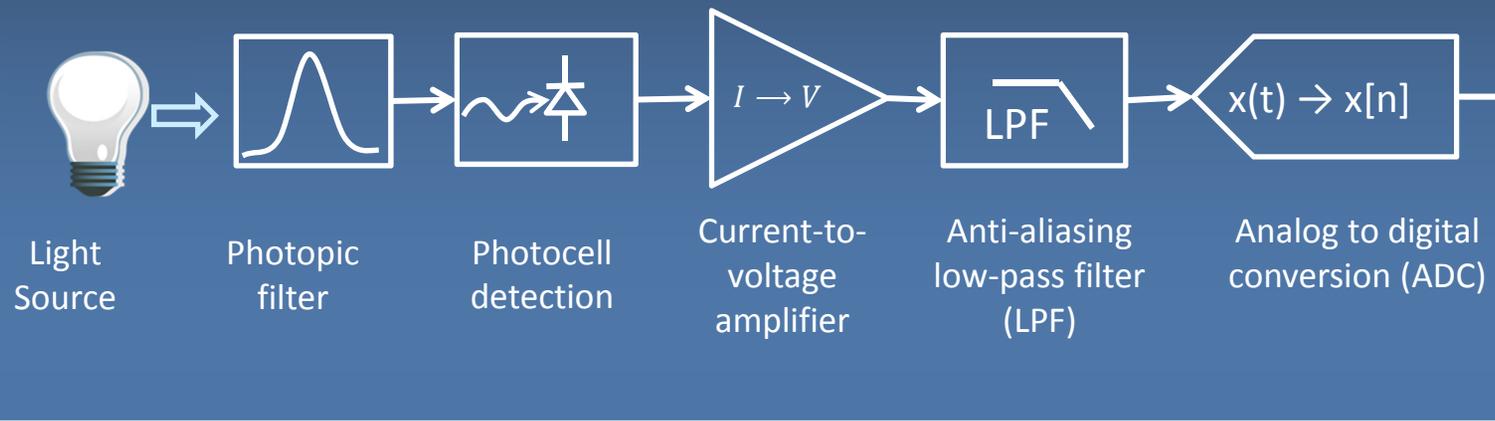


Waveform Acquisition Basics

Andrew Bierman, MS
Lighting Research Center, Rensselaer Polytechnic Institute

ENERGY STAR[®] Flicker Testing Tutorial
September 22, 2017

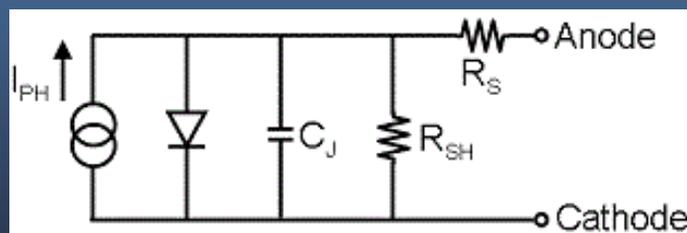
Elements of Light Waveform Acquisition



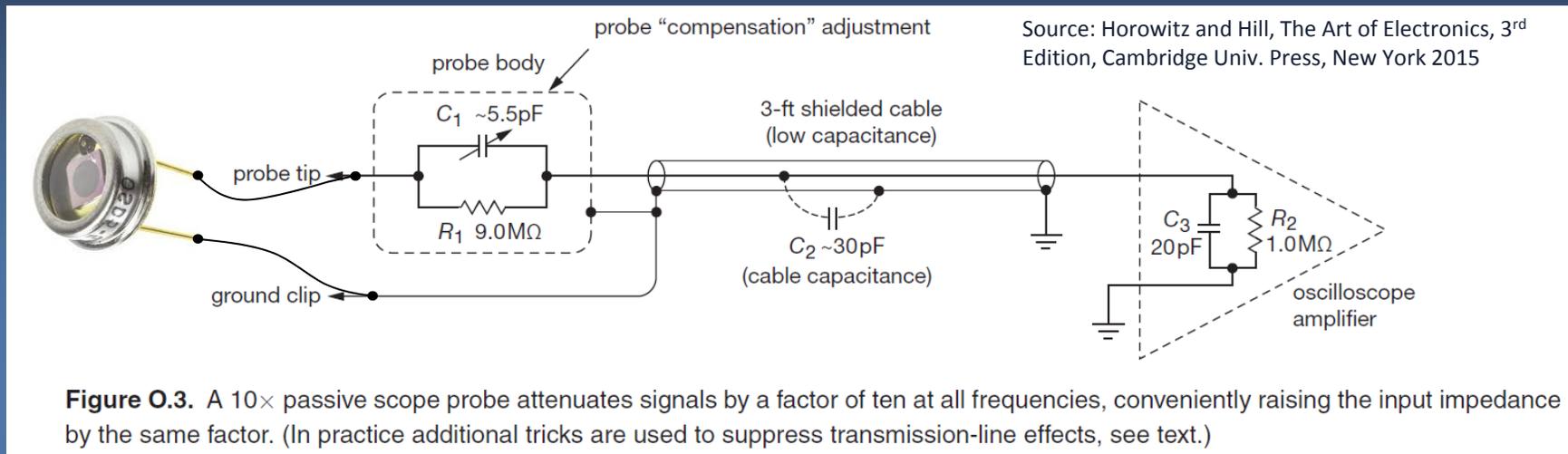
Photodetector



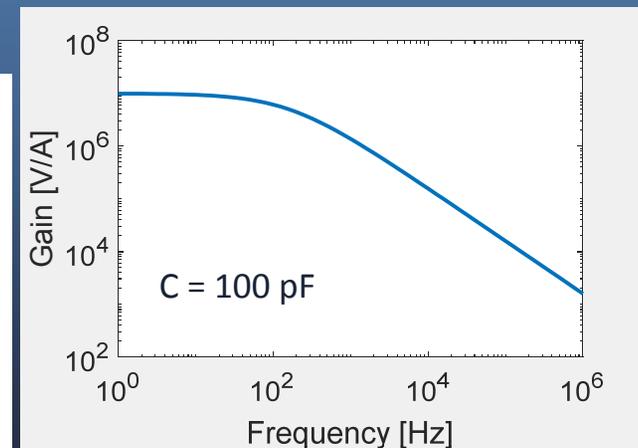
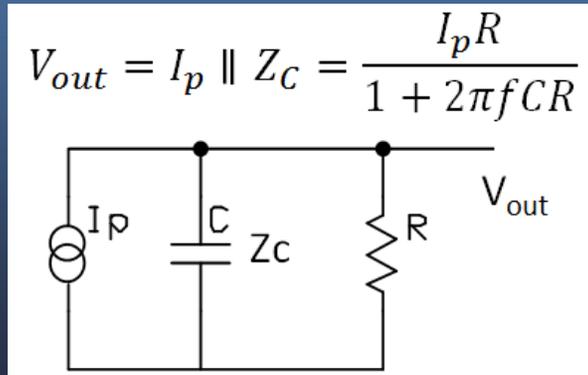
- ◆ Fast response
 - Photodiode or PMT (photomultiplier tube)
 - For diodes, lowering capacitance increases speed
 - PIN diodes optimized for speed
 - Reverse bias voltage (5 V to 20 V)
 - Small active area
 - Increases speed, but sacrifices sensitivity
 - May need additional optical gain (e.g. lenses)
- ◆ $V(\lambda)$ spectral response
 - Requires absorptive glass filter module (most expensive part)



Amplifier: Using passive probe



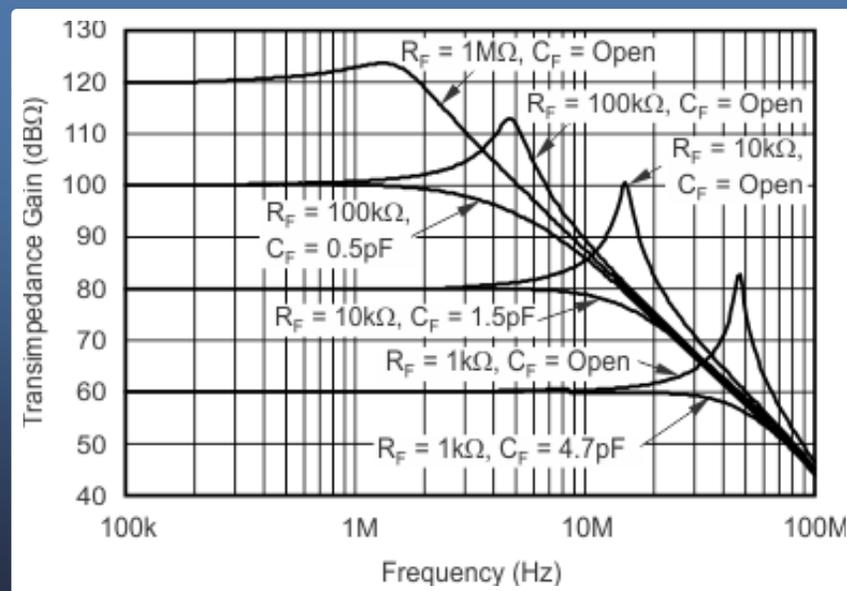
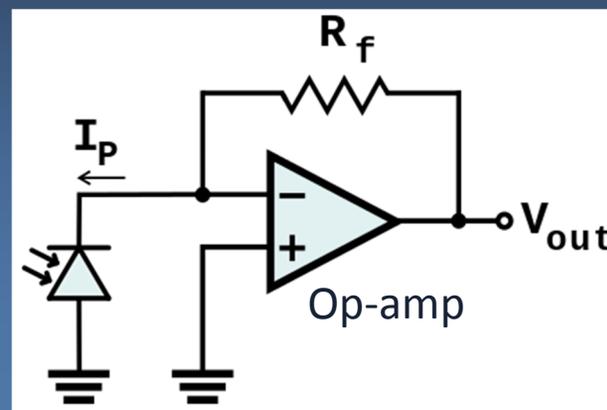
- ◆ Gain = (9M + 1M) = 10⁷ V/A
- ◆ Maximum Vin ≈ 0.2 volts or less; not very linear
- ◆ Speed limited by diode capacitance



Transimpedance Amplifier

Advantages

- ◆ Op-amp maintains linearity of photodiode (virtual short-circuit current)
- ◆ Feedback produces flat gain up to frequency cut-off
 - > kHz to MHz depending on Op-amp and R_f
- ◆ Provides low impedance voltage output for anti-aliasing filter and ADC



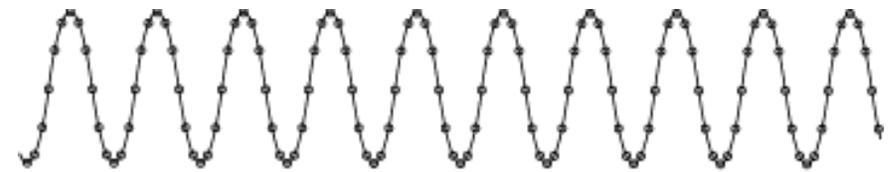
Antialiasing Filter

What is aliasing?

- ◆ The introduction of “fake” frequency content at frequencies lower than the $\frac{1}{2}$ the sampling rate due to frequency content above $\frac{1}{2}$ the sampling rate.

Solution

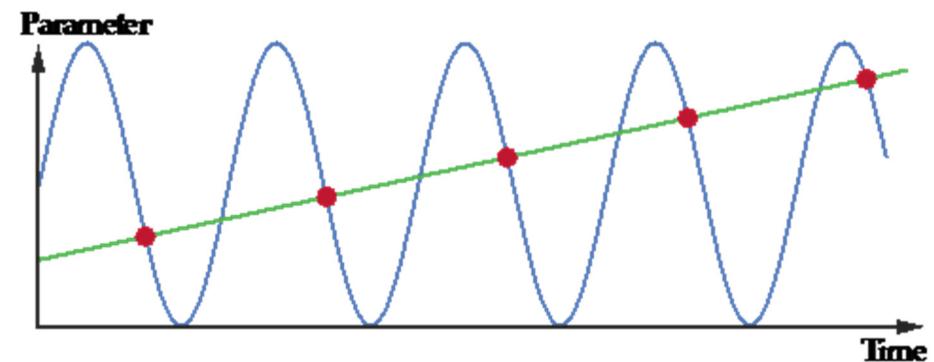
- ◆ Remove frequency content above $\frac{1}{2}$ the sampling rate before digitally sampling



Adequately Sampled Signal



Aliased Signal Due to Undersampling

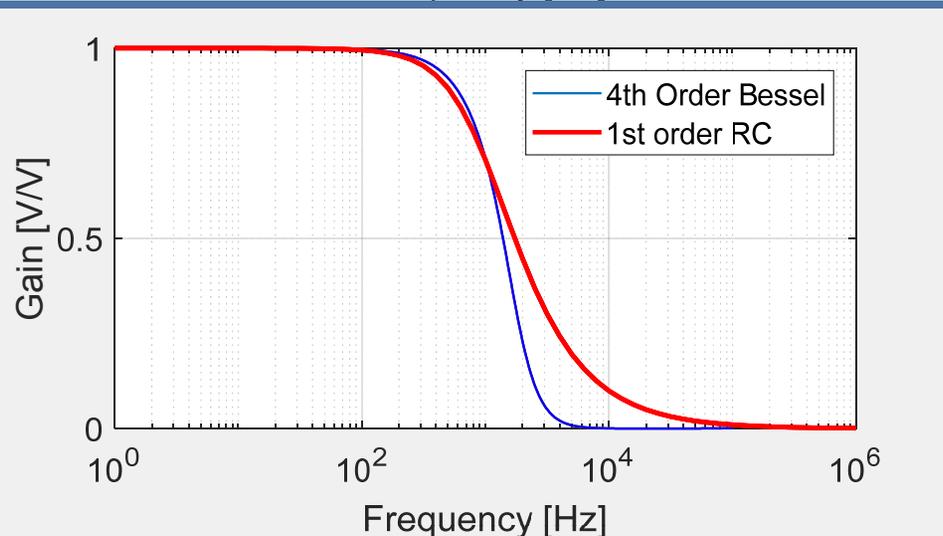
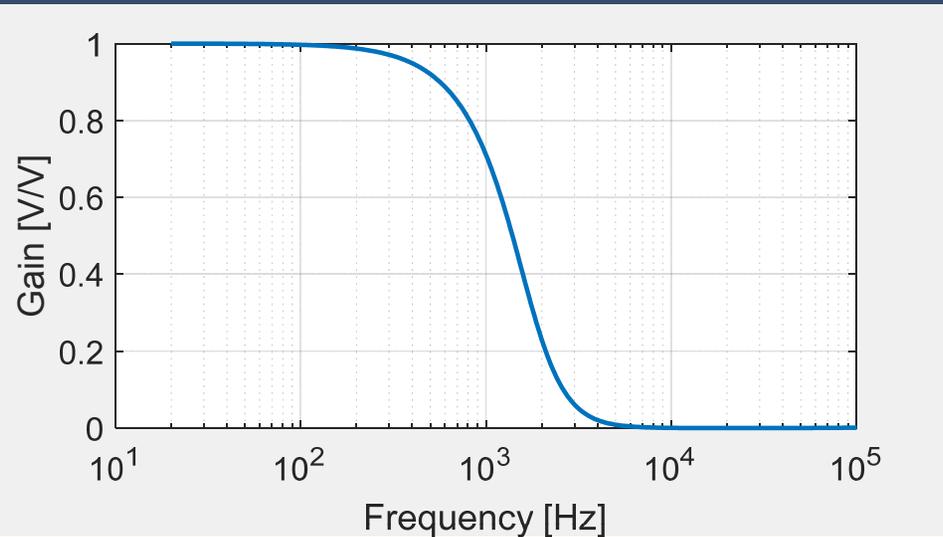


Antialiasing Filter Examples

- ◆ Filter for measuring direct flicker
- ◆ 4th order Bessel Low Pass Filter
- ◆ Frequencies of interest
 - > $f < 100$ Hz
- ◆ For sampling rate > 5 kHz

Oversampling

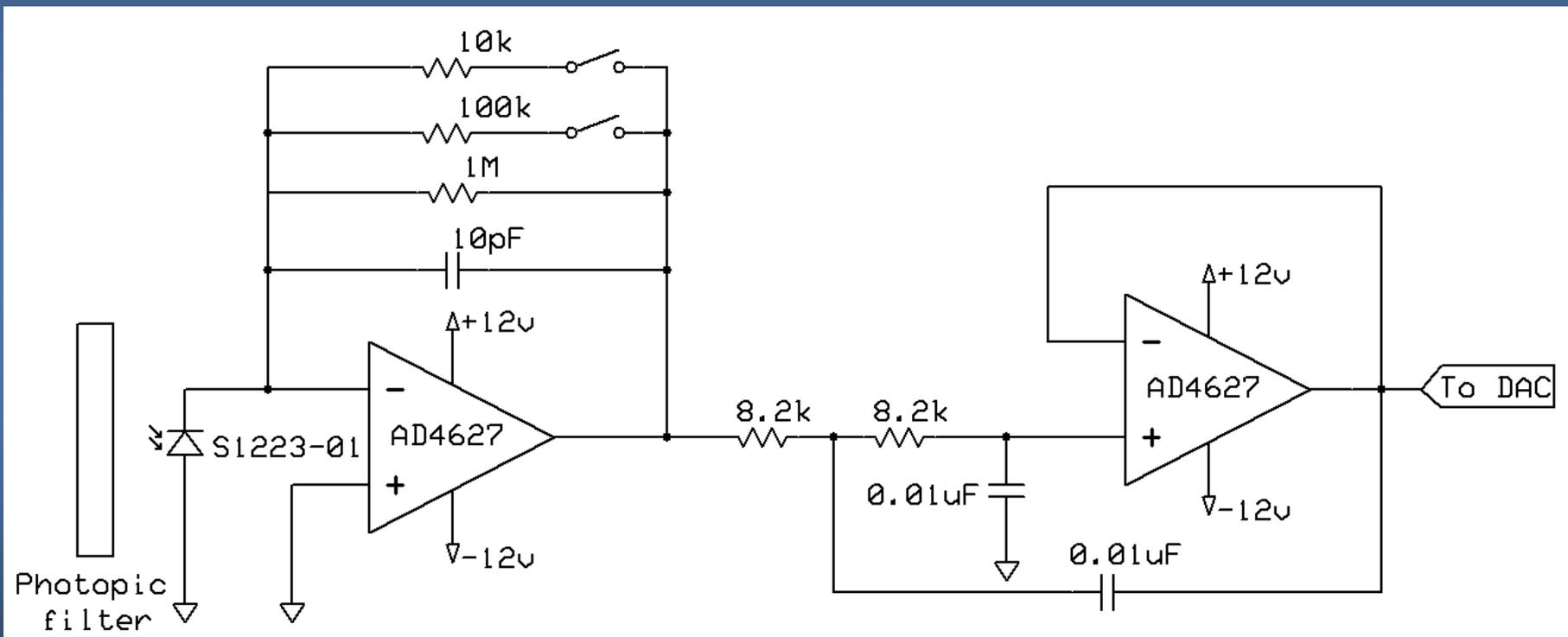
- ◆ Simple RC filters can be used if sample rate is very high, $f_s > 100$ kHz
- Some filter types can cause phase distortions, ripples and overshoot



Analog Front-end

Transimpedance Amplifier

Anti-aliasing Filter



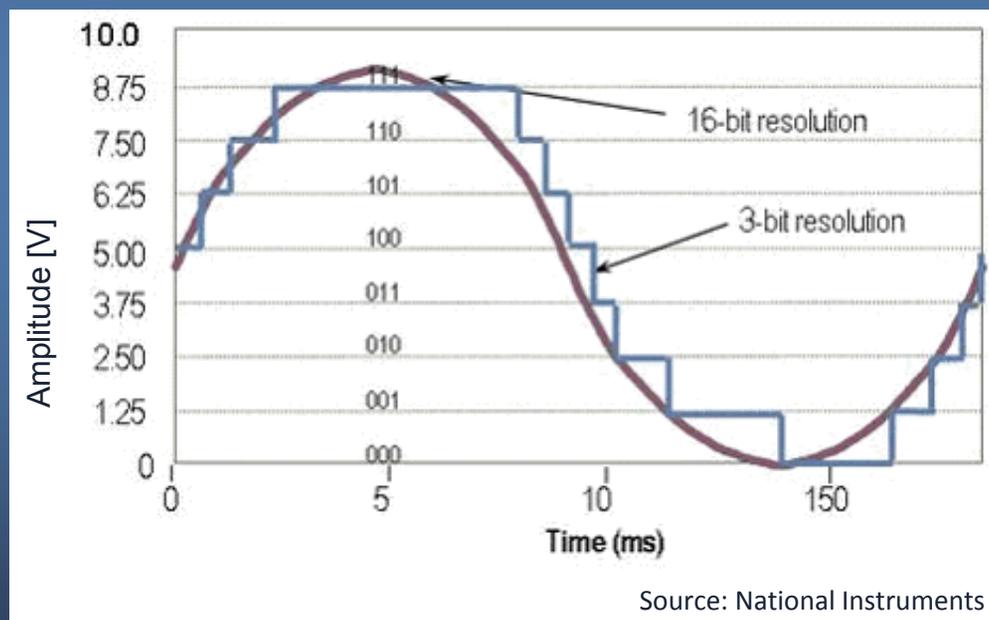
Analog-To-Digital Conversion (ADC)

Sampling Rate, f_s [samples/second]

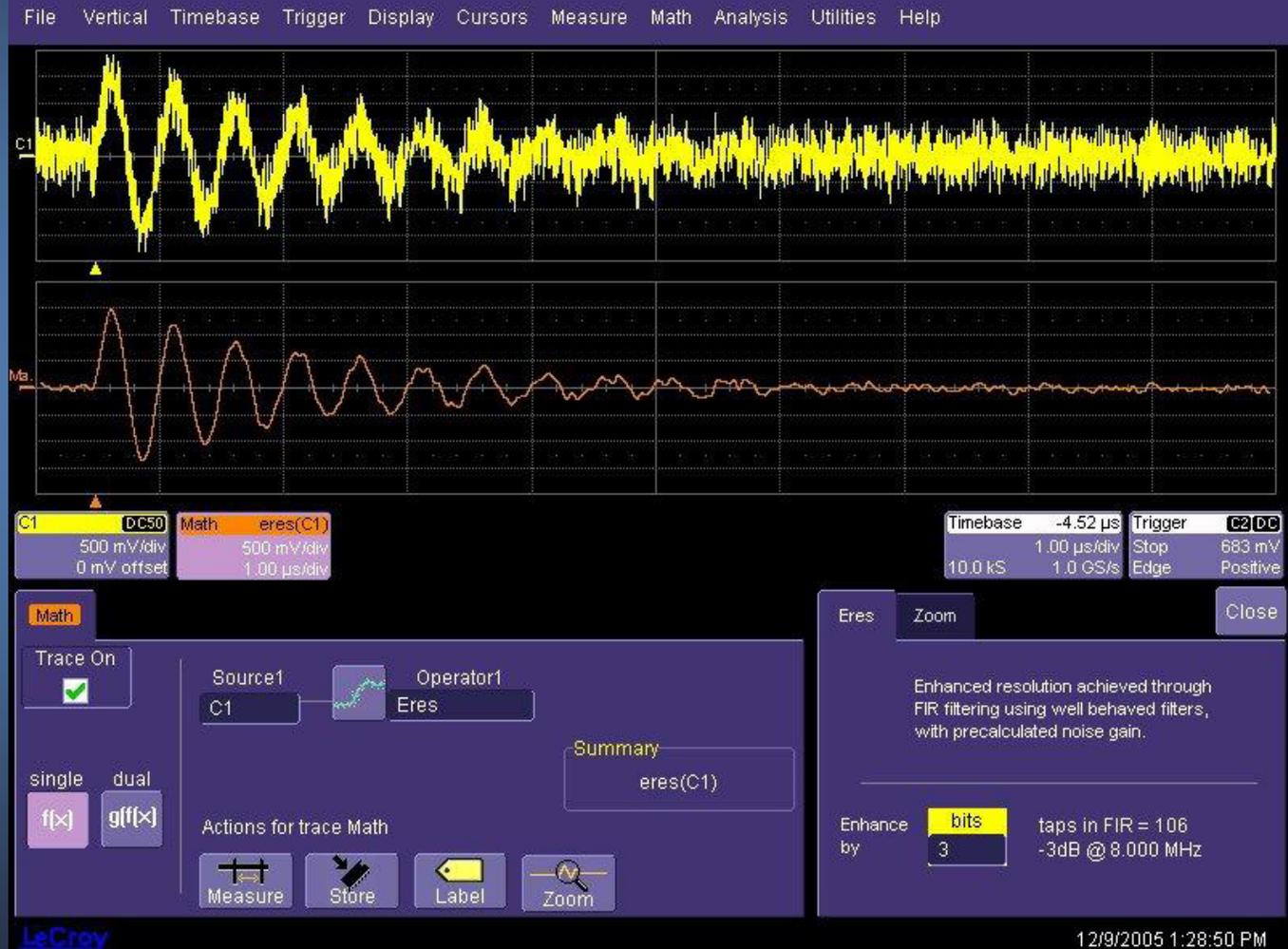
- ◆ Nyquist criterion: $f_{\max} = \frac{1}{2} f_s$, but practically much lower due to anti-aliasing filter

Amplitude resolution: How many bits?

- ◆ Most O-scopes are 8-bit = $2^8 = 256$ levels
 - > Resolution is at most $1/256 = 0.4\%$
 - > Practically $> 1\%$ due to noise and scaling limitations
- ◆ Need $\approx 0.2\%$ resolution for direct flicker measurements
 - > 12-bit ADC are common for sampling rates < 1 MHz
 - > Some high-end O-scopes offer “Enhanced resolution” signal processing



ADC Enhanced Resolution



Thank you!

◆ Acknowledgments

- ASSIST program sponsors
- US Environmental Protection Agency
- LRC faculty, staff and students

Questions?

<http://www.lrc.rpi.edu/programs/solidstate/assist/recommends/flicker.asp>

