Designing a Lock-in Amplifier with Analog to Digital Conversion

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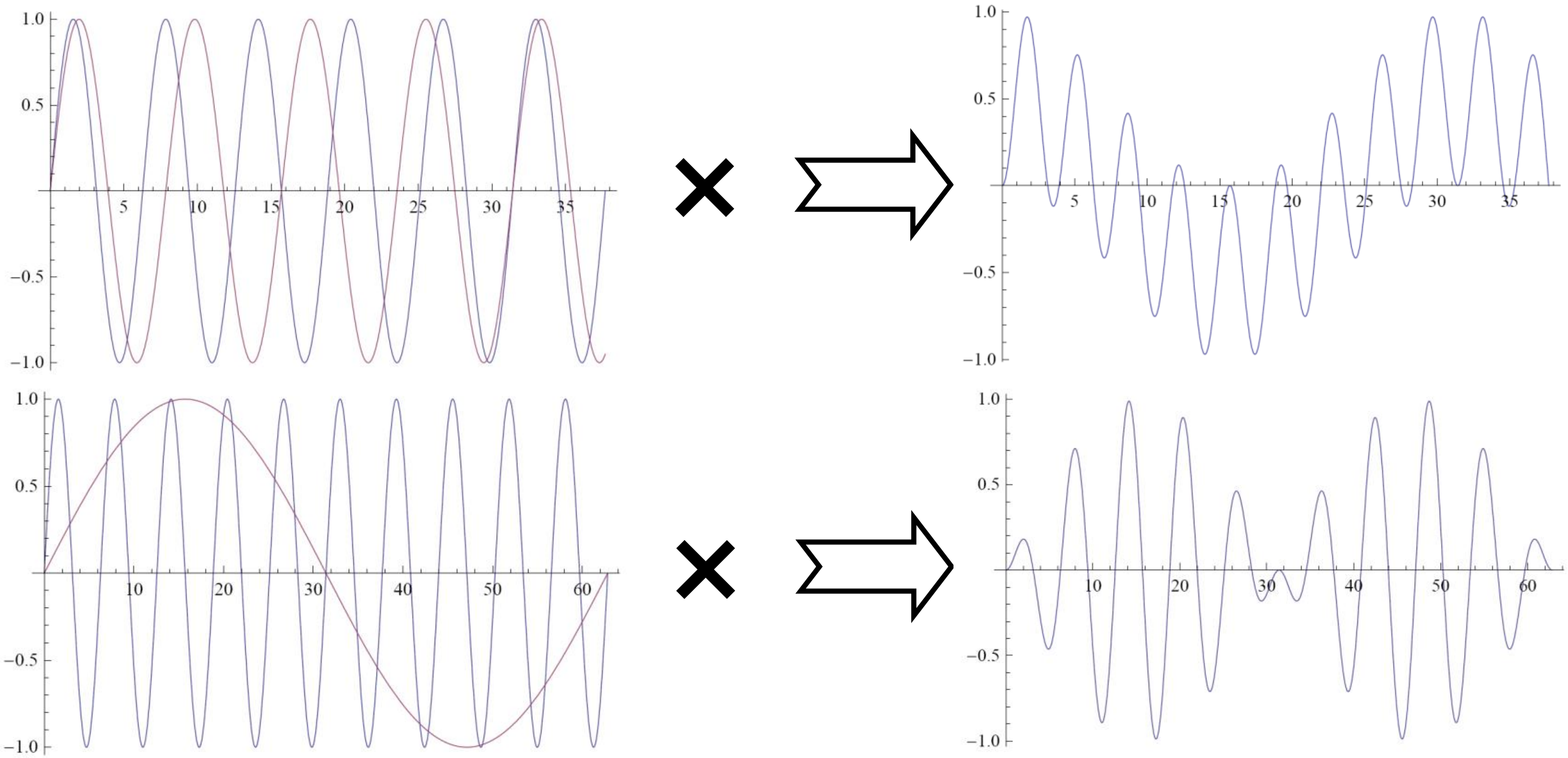
Outline

- What is a lock-in? Why is it useful?
- Design & implementation of the analog circuit
- Digital electronics, very briefly
- Analog to digital conversion
- Concluding, and future work

Motivation & Lock-in Basics

- An example: measuring spectral response of LEDs, 10-100μV signal in few mV noise
- Possible with a lock-in, using phase-sensitive detection
- The key idea: make signal AC at known frequency, multiply waveforms

Lock-in Basics-Multiplying Sines



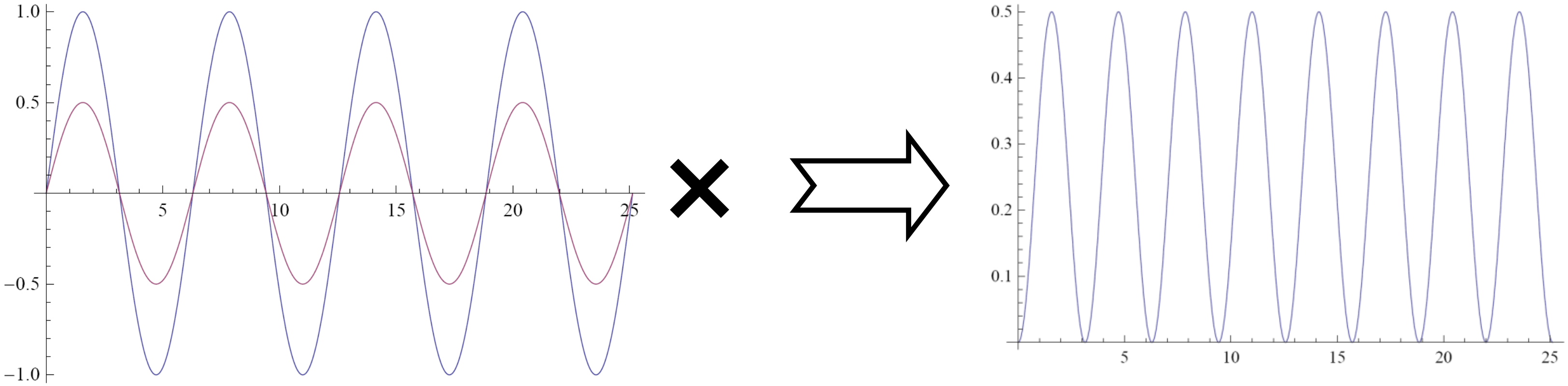
$V_{sig}\sin(\omega_{sig}t) \times V_{ref}\sin(\omega_{ref}t) = 0.5V_{ref}V_{sig}\cos(\omega_{ref} - \omega_{sig}) - 0.5V_{ref}V_{sig}\cos(\omega_{ref} + \omega_{sig})$

if $\omega_{ref} = \omega_{sig}$, then $\quad = 0.5V_{ref}V_{sig} - 0.5V_{ref}V_{sig}\cos(2\omega)$

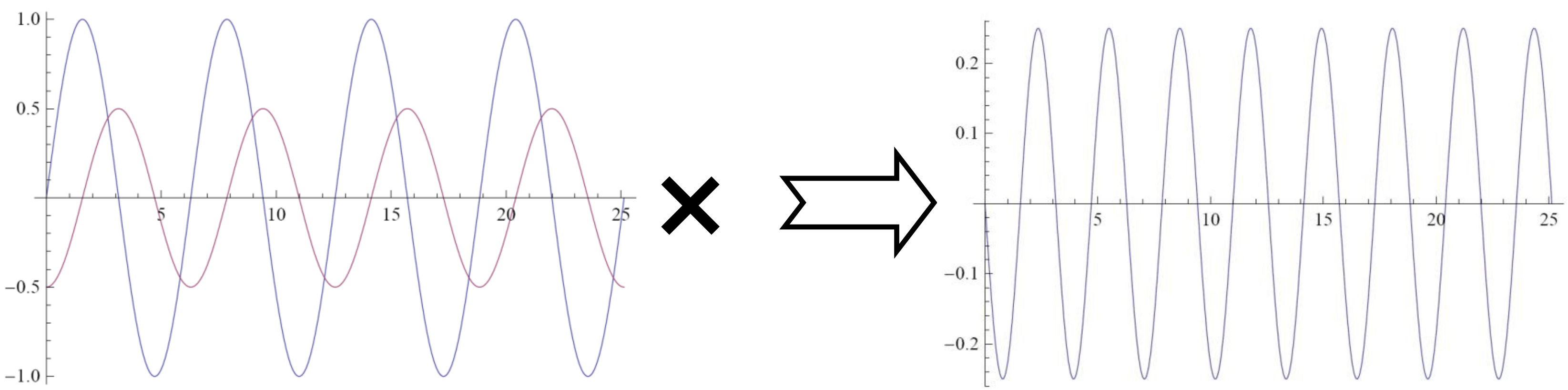
Retrieving the Signal

- Low pass filter: remove AC signals, DC remains, DC out is $\propto$ input in
- Fourier Analysis: *any* signal can be written as sum/integral over frequencies, apply PSD to each component
- A narrow band-pass filter (easily get $Q \sim 10^5$ or more, compared to $Q \leq 100$)
- But what about phase?

Phase



If signal and ref out of phase, DC signal vanishes on output!



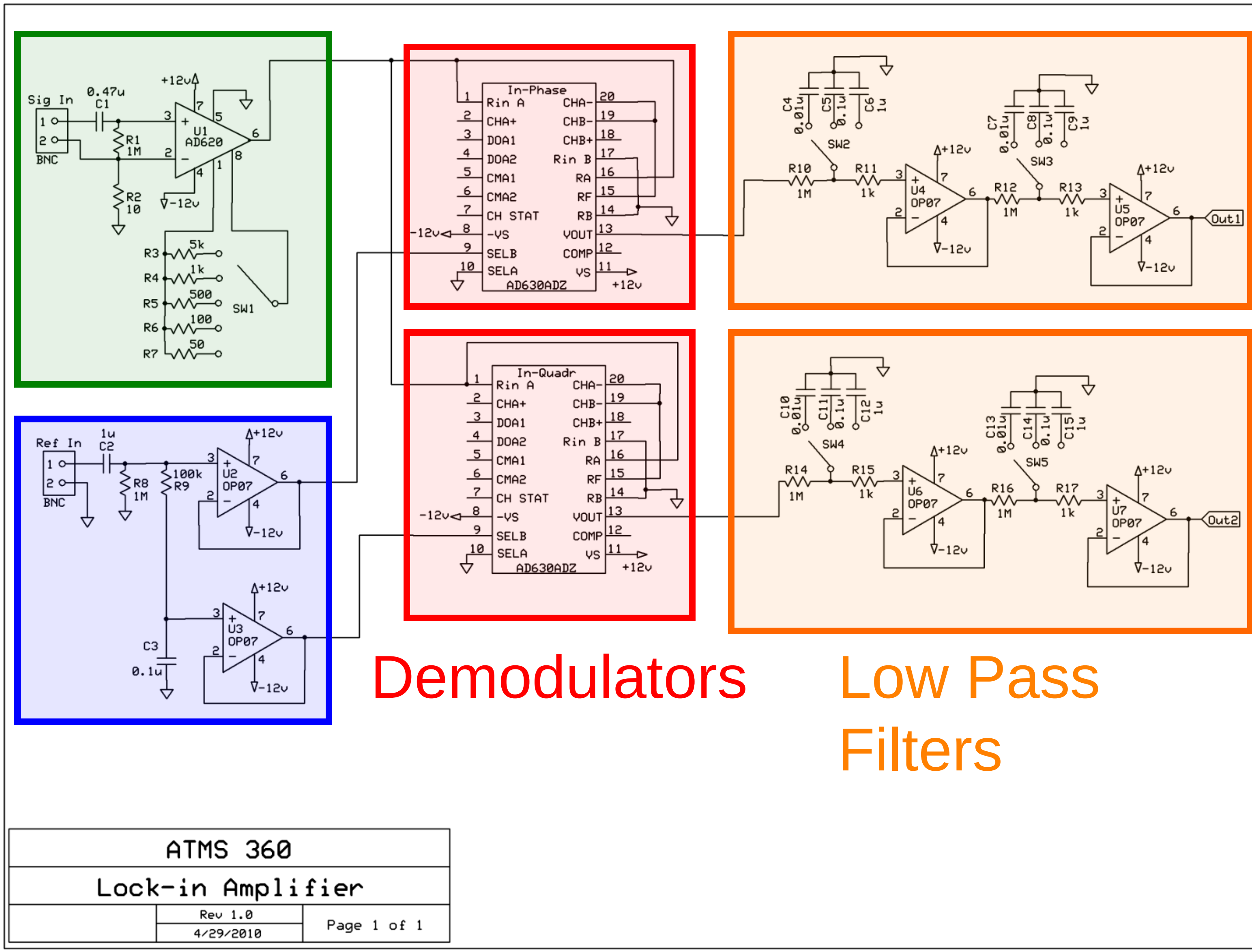
In-Quadrature

- Solution: build a second lock-in, in parallel, with reference phase-shifted 90°
- Signal as a vector in complex space, where X↔in-phase and Y↔in-quadrature
- Magnitude: $R = \mathrm{sqrt}(X^2 + Y^2)$
- Phase: $\theta = \tan^{-1}(Y/X)$

Lock-in Amplifier Schematic

Input Signal

Ref Signal: In Phase + Out of Phase

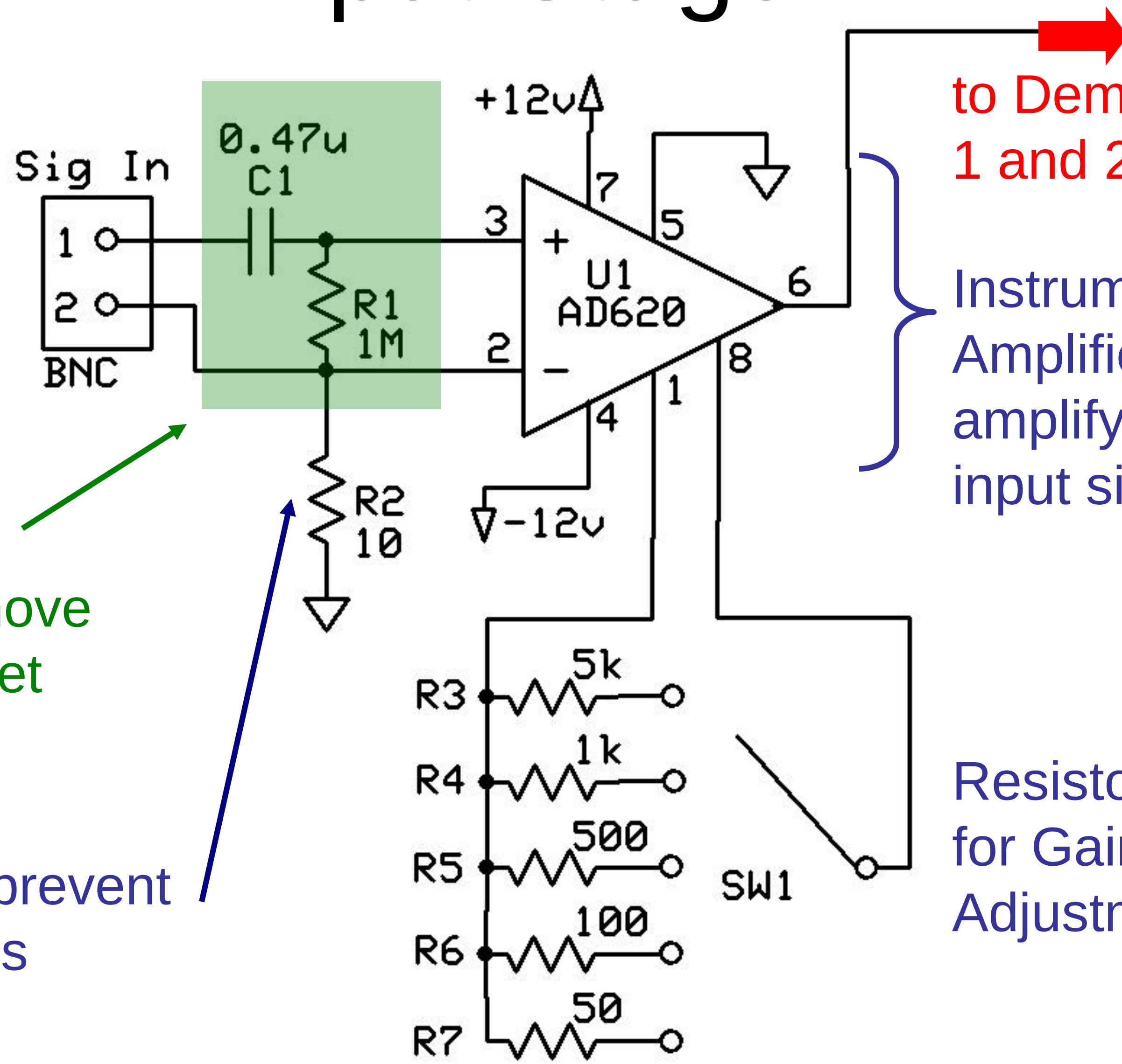


Demodulators

Low Pass Filters

Input Stage

Input for noisy signal



to Demodulators 1 and 2

Instrumentation Amplifier for amplifying the input signal

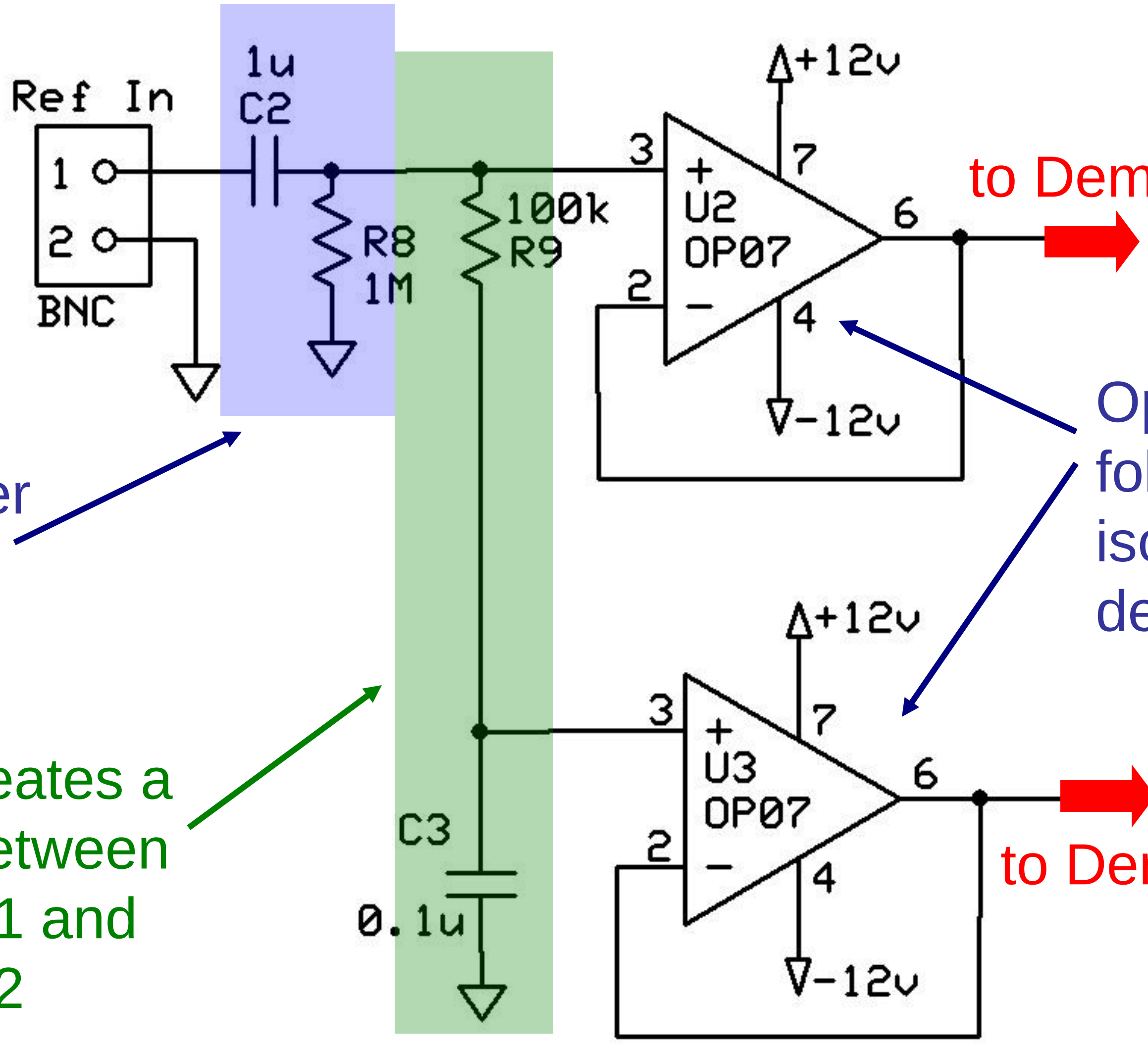
High Pass Filter to remove any DC offset

Resistor to prevent ground loops

Resistor Bank for Gain Adjustment

Ref Input and Phase-Shift Stage

Input for reference signal



to Demodulator 1

Op Amps as followers to isolate demodulators

High Pass Filter to remove any DC offset

RC Circuit creates a phase shift between demodulator 1 and demodulator 2

to Demodulator 2

Phase Shift at Low Frequency
(noticeable below 500Hz for our setup)

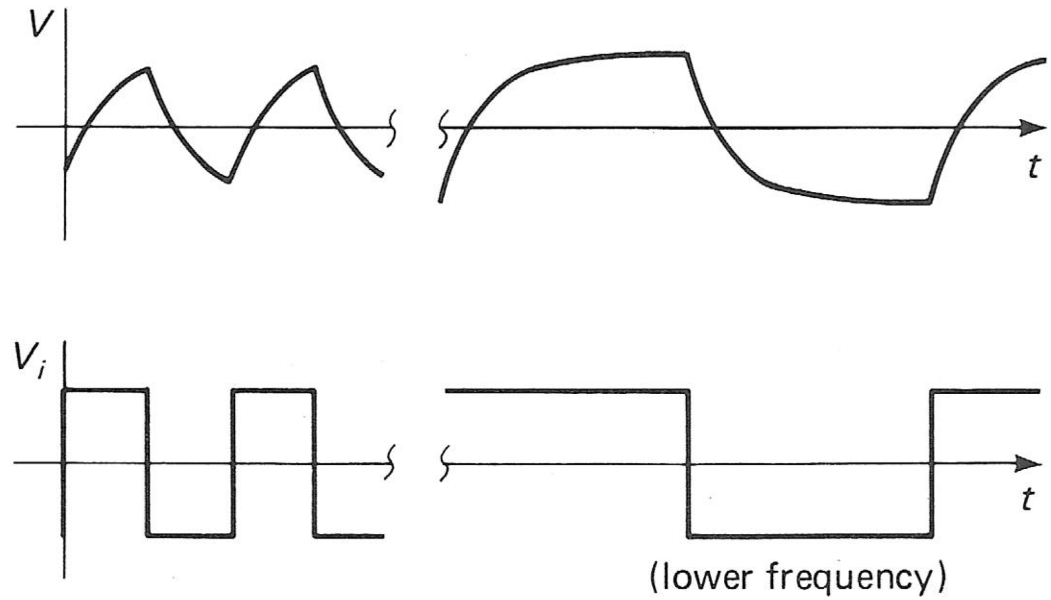
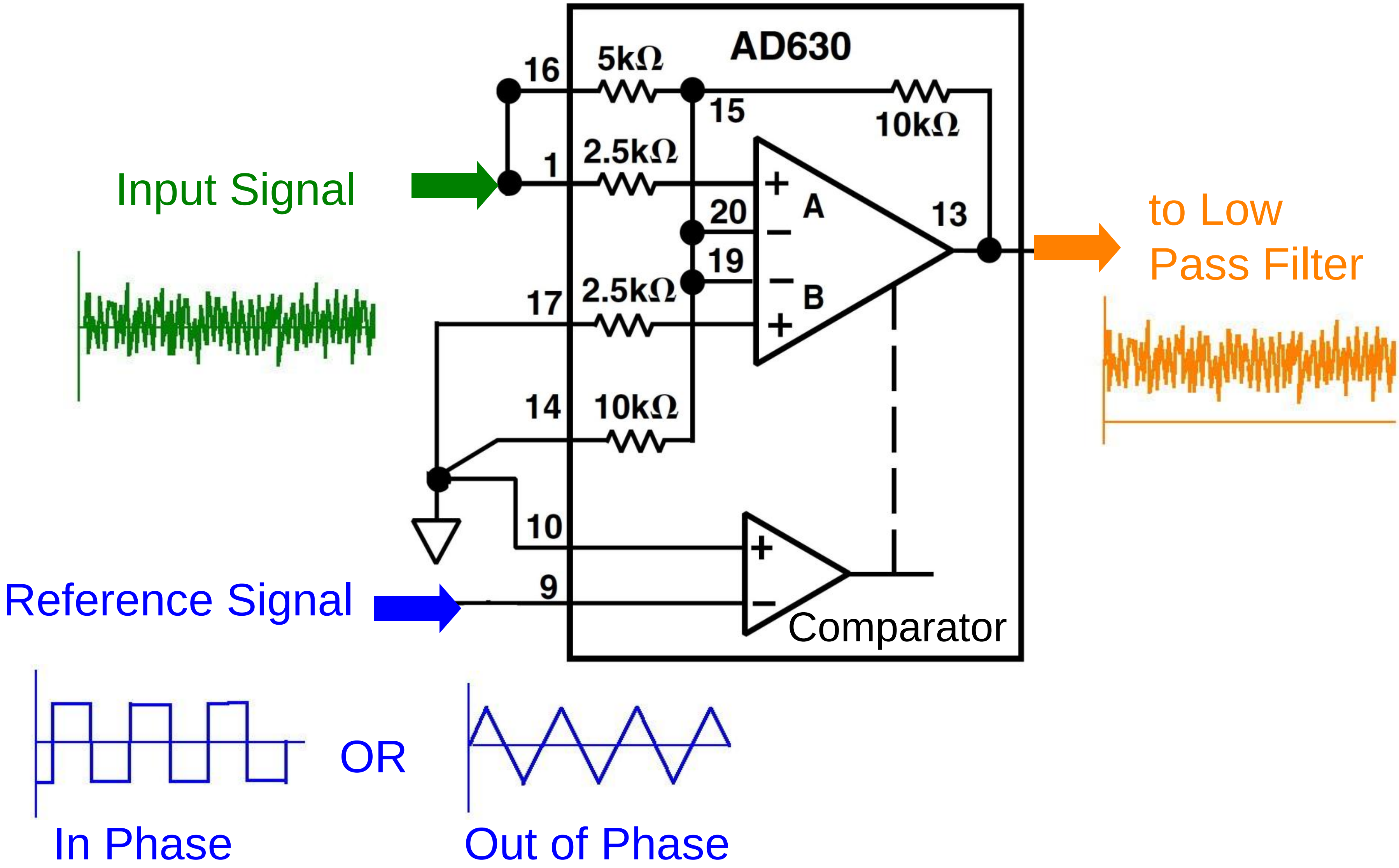


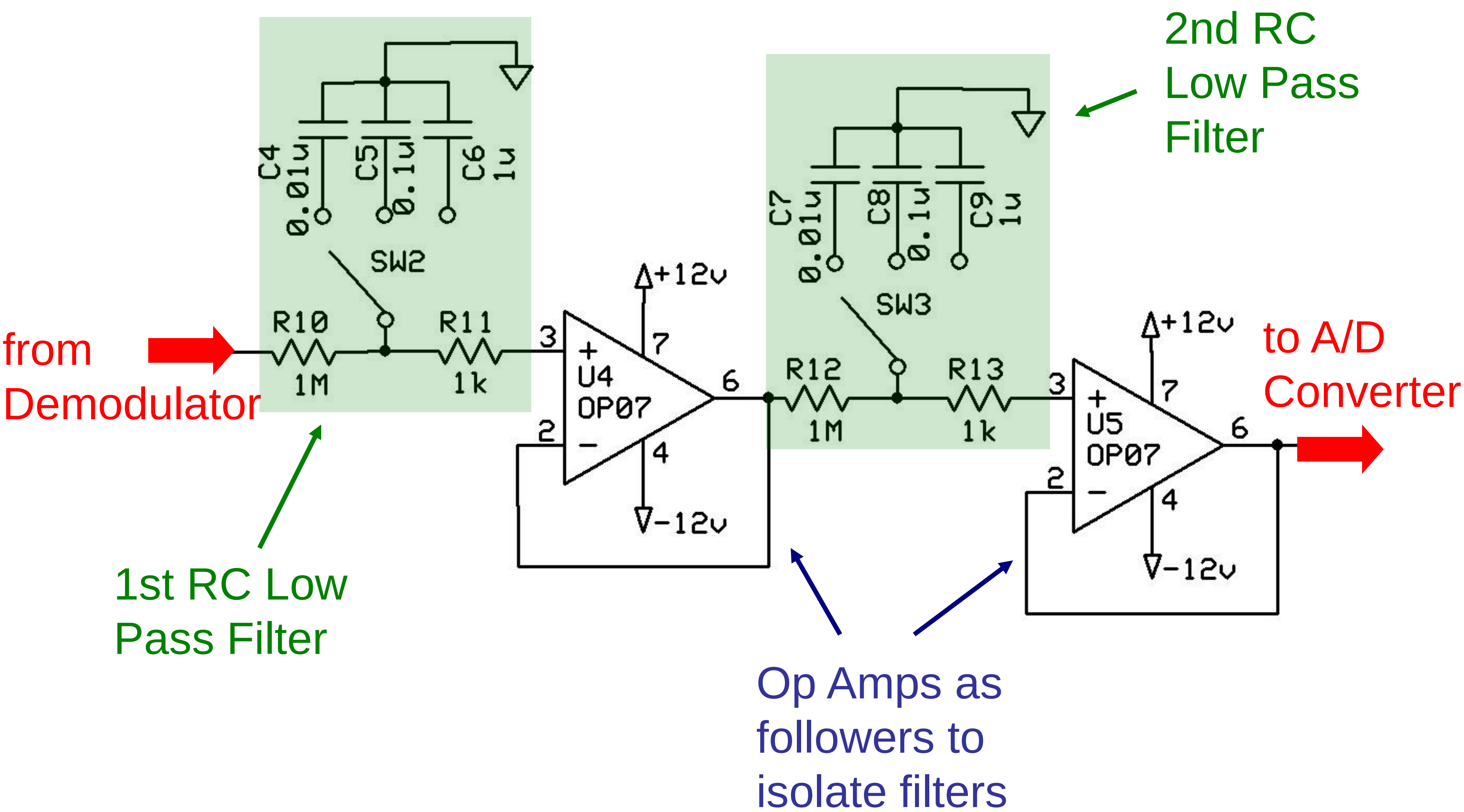
Figure 1.33. Output (top waveform) across a capacitor, when driven by square waves through a resistor.

At high frequencies (approx. above 500Hz), the signal approximates a triangle wave which can be used for the demodulator.

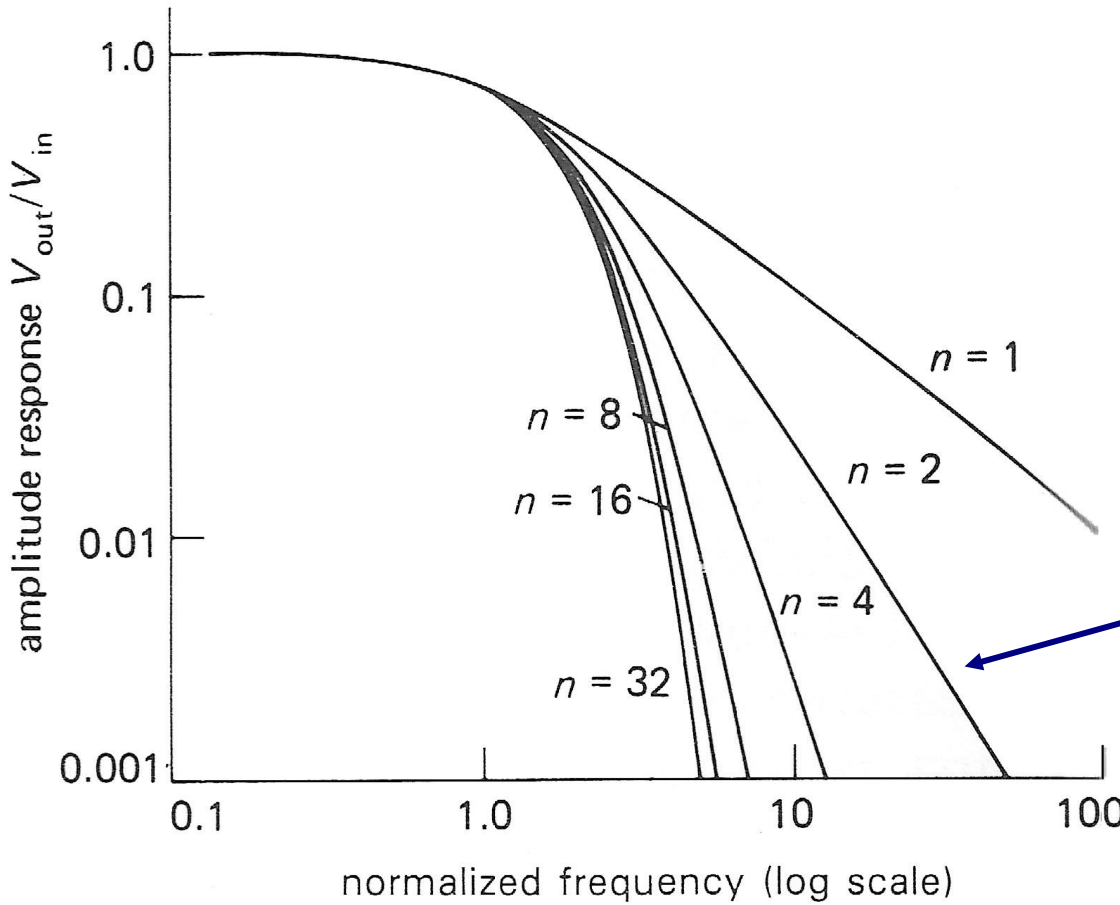
Demodulator: AD630



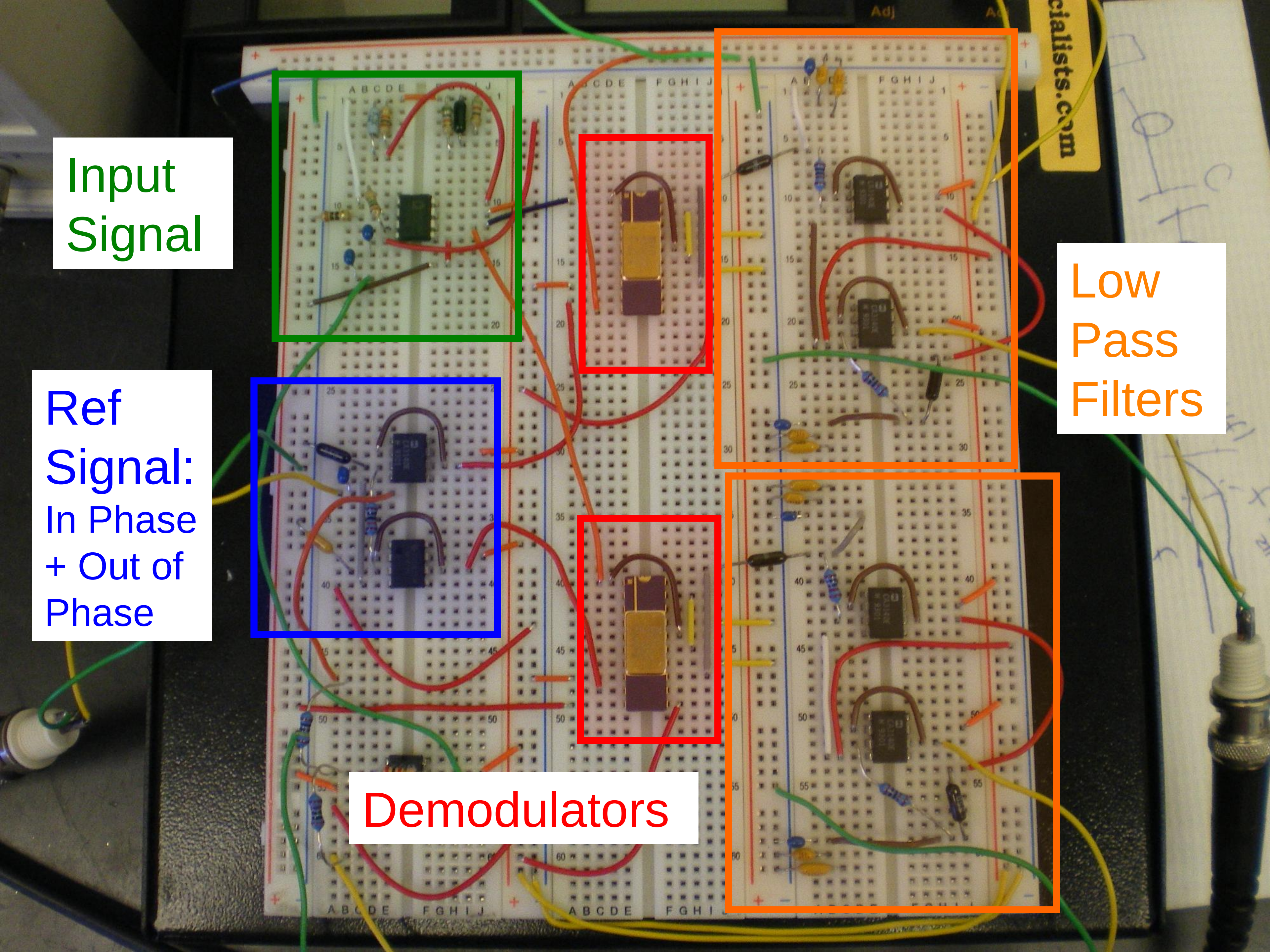
Low Pass Filter

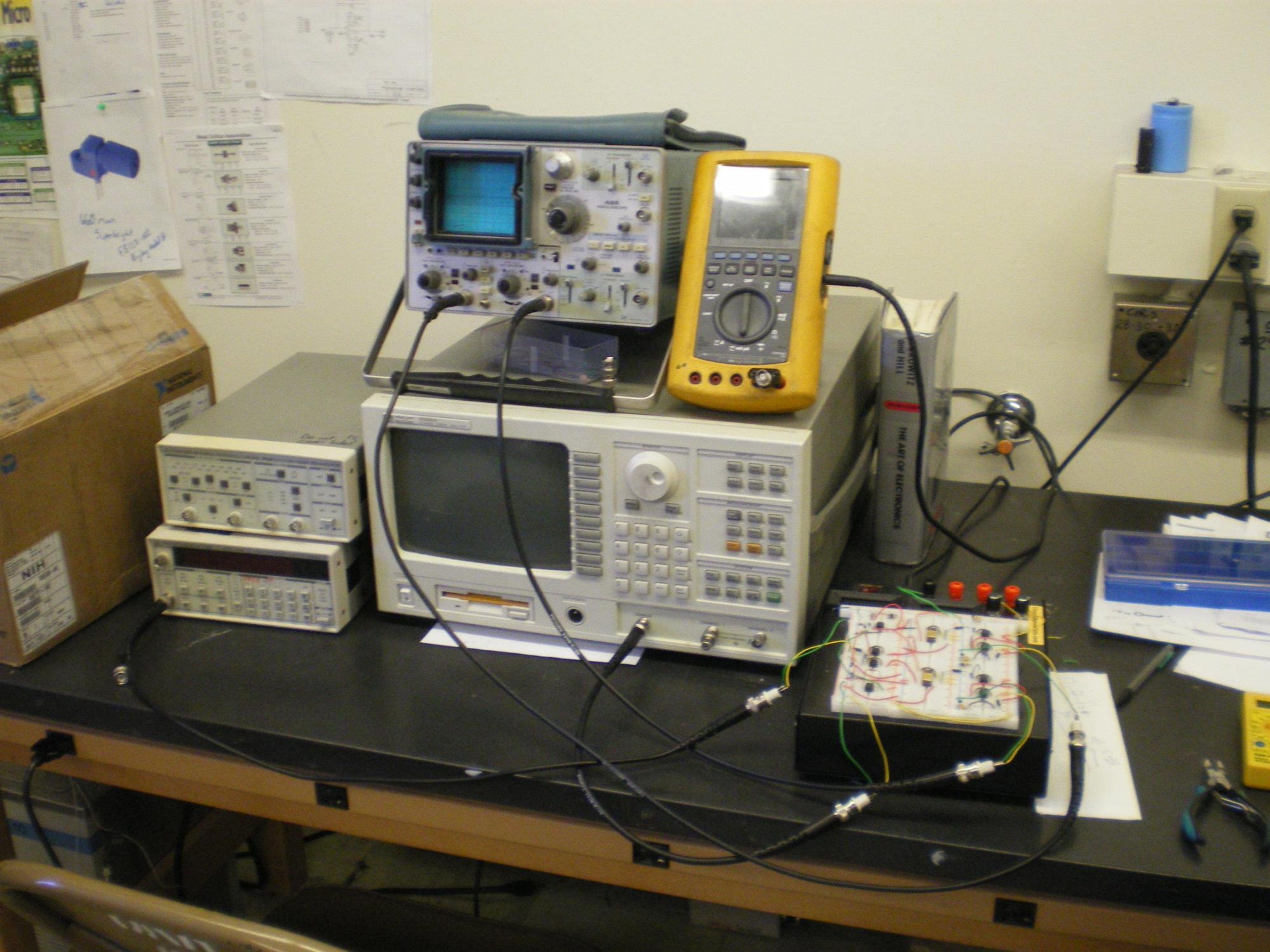


Rolloff of RC Low Pass Filters



Our
Filter


Input Signal
Ref Signal:
In Phase + Out of Phase
Demodulators
Low Pass Filters


Micro
NIH
and HILL
THE ART OF ELECTRONICS

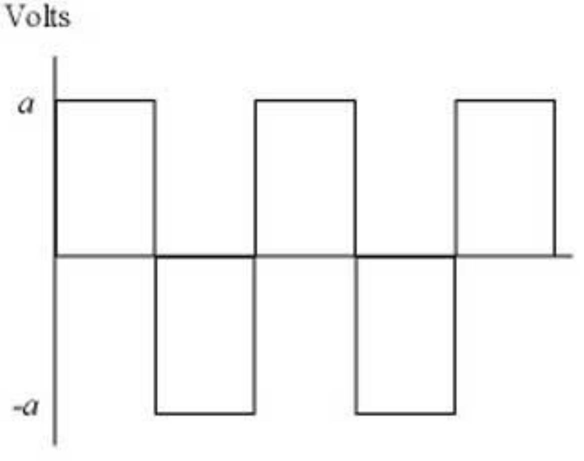
Digital Electronics

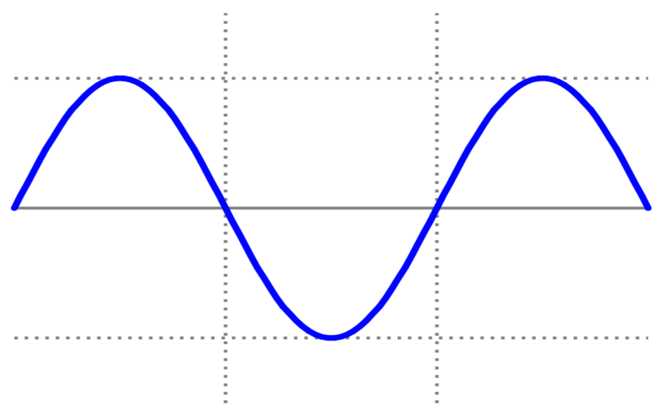
A fad?

Or the way of the future?

Analog vs. Digital

- Analog responses (a voltage, for instance) are arbitrary functions of the input.
- A digital signal is either on or off... no intermediary state.





Digital Logic and Bits

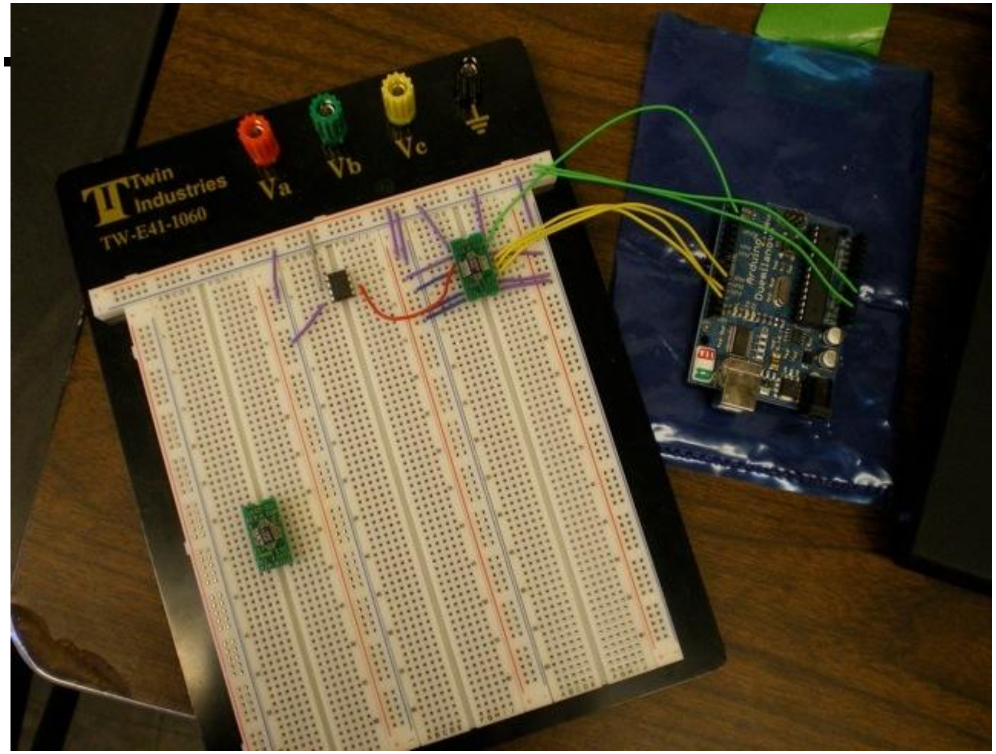
- Digital electronics use digital logic...
  - One voltage (usually 5 or 3.3 volts) represents logic HIGH.
  - Another (usually ground, or slightly above ground) represents logic LOW.
- A bit is the fundamental unit of data for electronics.
  - It's either HIGH or LOW

Binary and Digital Data

- Binary numbers can be represented as a sequence of bits.
  - Each bit corresponds to a digit.
  - For each digit 1 = HIGH, 0 = LOW.
  - Thus 101 (binary) = 4 + 0 + 1 = 5 (decimal)
- LTC 2440 stores digital conversion data in 24 place-value bits and one sign bit.

LTC 2440

- A little chip that converts an analog signal (a voltage) into a digital signal (a sequence of bits).



More on LTC 2440

- After powering on, the LTC 2440 converts an analog signal into a 24-bit integer, based off a reference signal.
  - There is a linear relationship between the reference signal and the full range of integers that 24 bits (plus a sign) can represent
- After conversion the LTC sits idle until it receives a clock pulse.
  - A clock is a dedicated digital channel that simply pulses on and off—this signals a change of state.
  - All processors are glorified clocks.
- At each clock pulse, one bit of data is shifted out.

Conclusion & Future Efforts

- Lock-in with >60dB dynamic range, computer interfacing, wide bandwidth operation
- Low cost (<$100 for components)
- Still to do
  - Computer controlled switches
  - Low-pass filters with sharper rolloff
  - Construction of actual PCB board
  - Case/housing
  - Further testing

References

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- *LTC2440 24-Bit Analog-to-Digital Converter*. Linear Technology Corp. Milpitas, CA.
- Horowitz, P. and W. Hill. *The Art of Electronics*. Cambridge University Press,

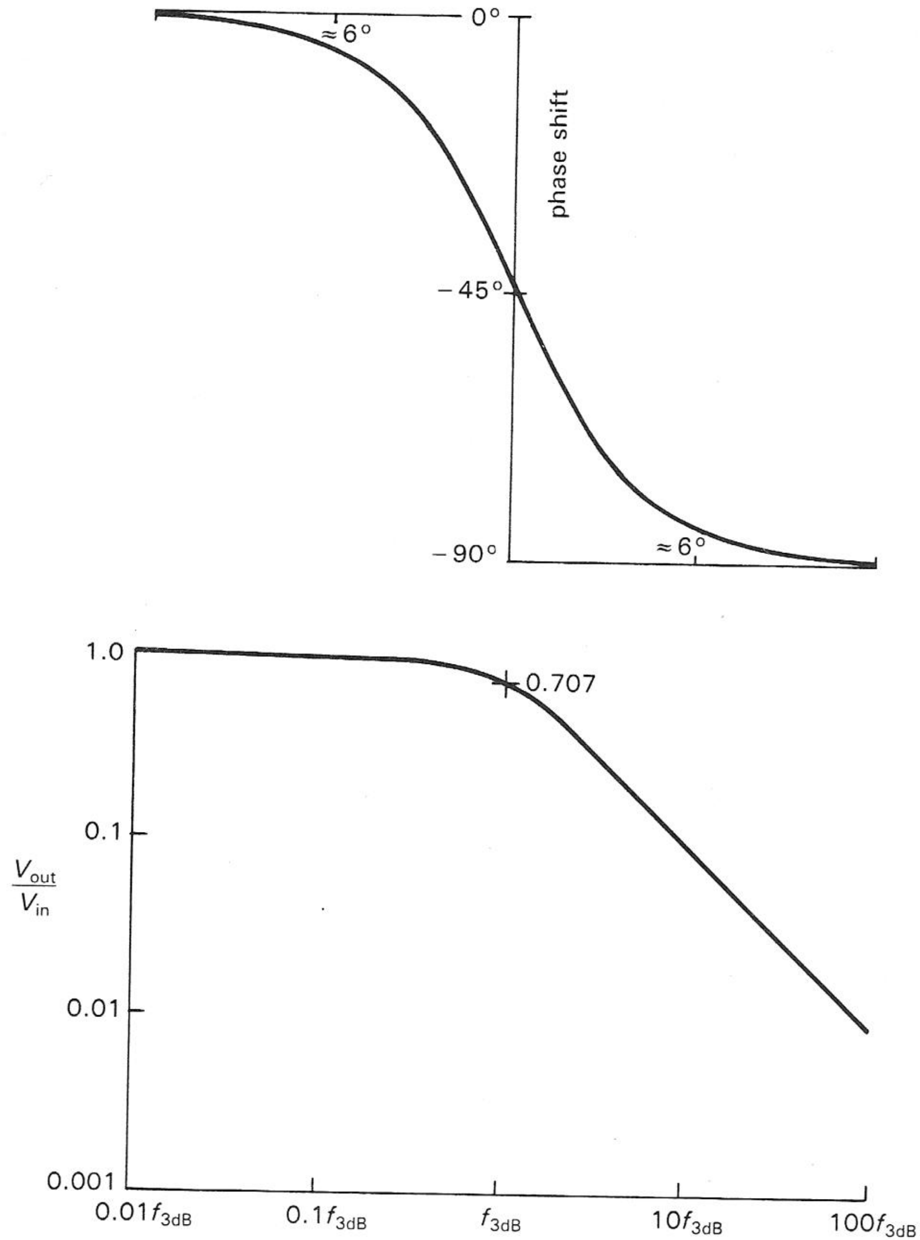
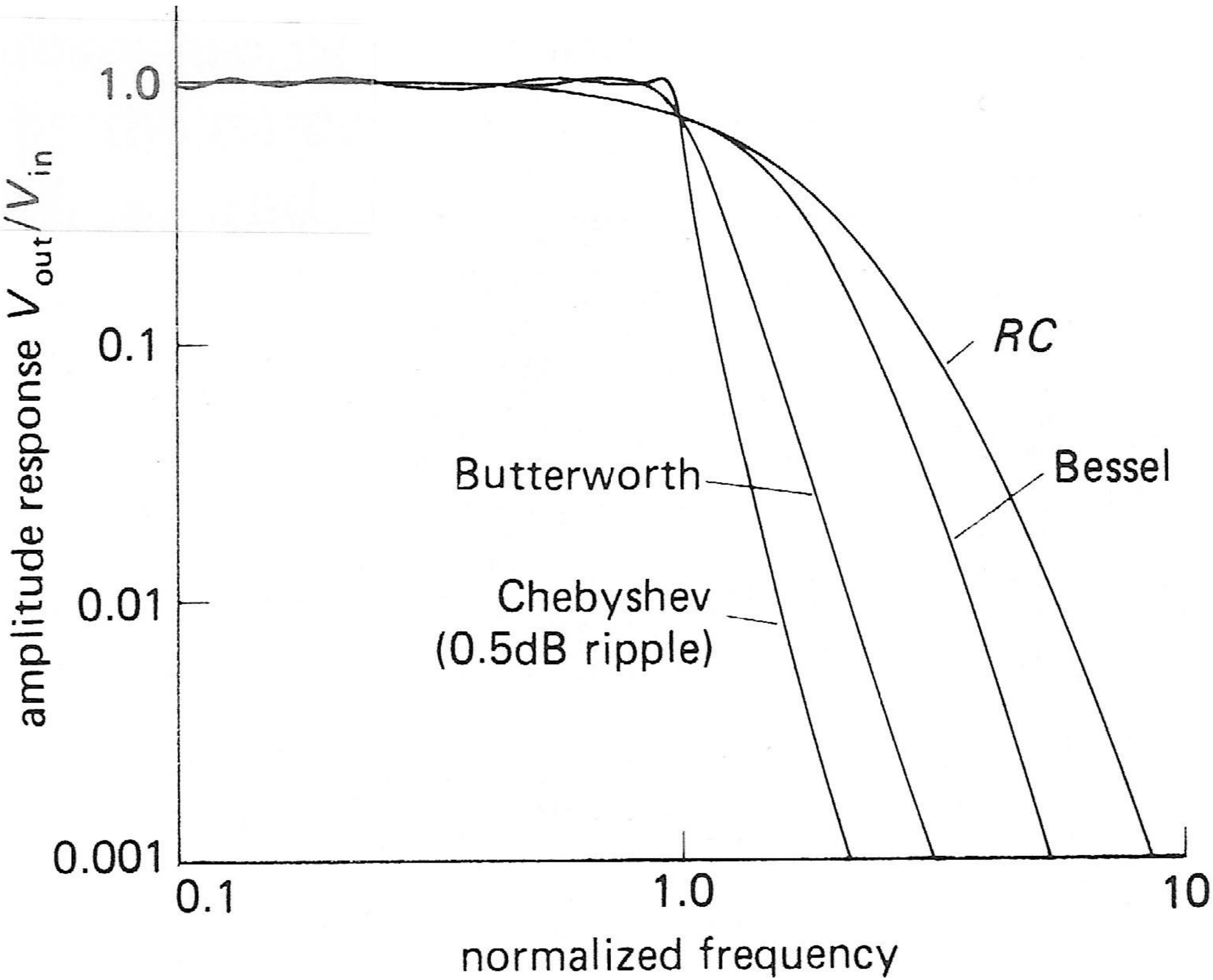
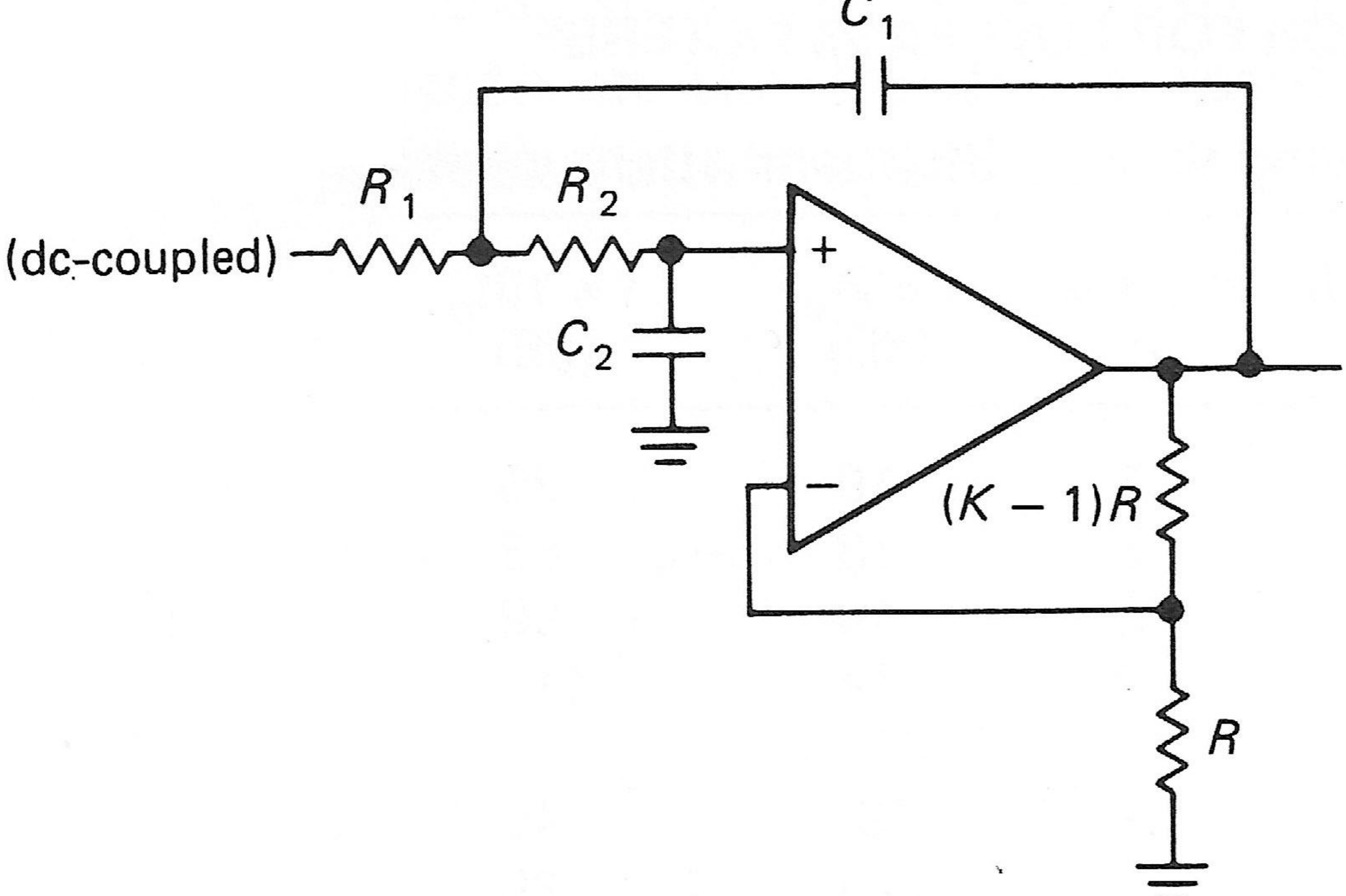


Figure 1.60. Frequency response (phase and amplitude) of low-pass filter, plotted on logarithmic axes. Note that the phase shift is 45° at the 3dB point and is within 6° of its asymptotic value for a decade of frequency change.



amplitude response V_{out}/V_{in}
1.0
0.1
0.01
0.001
0.1
1.0
10
normalized frequency
RC
Bessel
Butterworth
Chebyshev
(0.5dB ripple)



low-pass filter