

The Search for Design in Electrical Engineering Education

David V. KERNS, Sherra E. KERNS, Gill A. PRATT,
Mark H. SOMERVILLE, Jill D. CRISMAN



*1735 Great Plain Avenue
Needham, MA 02492-1245*

david.kerns@olin.edu, sherra.kerns@olin.edu, gill.pratt@olin.edu,
mark.somerville@olin.edu, jill.crisman@olin.edu

The Problem

- Traditional Electrical Engineering Education:
 - **Learn-Do**
 - *First* Learn KVL, KCL, Norton, Thevenin
 - *Then* do a few simple labs with sources and resistors
 - *First* Learn about Non-Linear 2 terminal Devices
 - *Then* do a few simple labs with diodes
 - *First* Learn about Op-Amps
 - *Then* do a few simple labs with op-amps
 - ...
 - Junior or Senior Year: Build something interesting.
- What's wrong with this?
 - It assumes the carrot of: “you’ll need this later”
 - and the stick of: “you’ll be tested on this”
 - are sufficient motivators for material whose purpose is hazy.

 - Additionally, students today have little experience in circuits before college.
- Inevitably, many young EE students don't see the light at the end of the tunnel and become disaffected.

The Question:

- Can a ***Do-Learn*** instead of Learn-Do Methodology Work? e.g.:
 - First Consider a Real, Sophisticated, Useful Device to be made
 - Then learn what you need to learn about how to make it.
 - Pull, instead of push, learning.
 - Can EARLY Design Experiences work effectively in EE Education?
- Early design is already common in Mechanical Engineering
 - But: Freshmen tend to have much stronger mechanical than electrical intuition
- The Hope: Extend Benefits of Early Design to EE

Our Balanced Approach

- Early Guided Exploration and Design of a Sophisticated Electronic Device
- Guided Design
 - We Give Component Concepts and Circuit Topologies
 - Students Must Build and Explain *Qualitatively* How Circuits Work
 - Students Must Experiment With and Explain Final *Quantitative* Component Values They Choose

Our Example: A Pulse Oximeter

- First Exposure to Concepts of:
 - Optical Absorption Spectra of Oxygenated and Deoxygenated Blood
 - KVL, KCL
 - Op-Amps, LEDs, Photo-Diodes
 - 1st Order Hysteretic Oscillators (e.g. RC)
 - 1st Order Filters (e.g. RC)
 - Synchronous Detection
 - Null-Point Feedback
 - Using Bench Equipment

Phase 1 (Two Weeks)

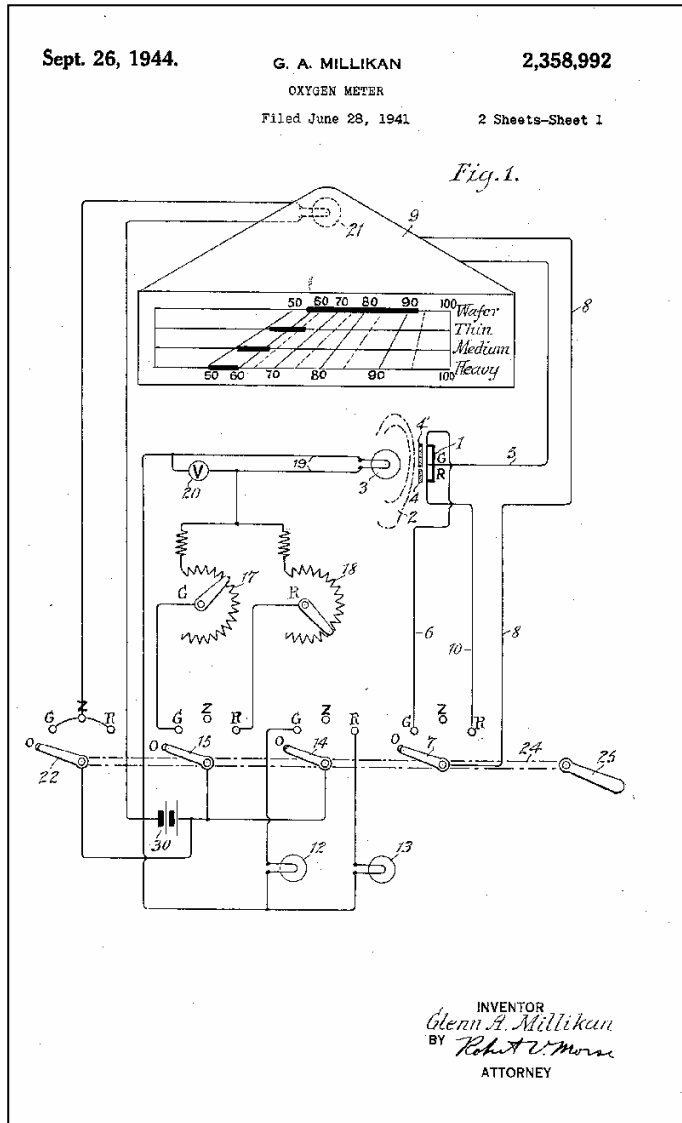
- First Generate Excitement by letting students experiment with a Commercial Oximeter (Nellcore N-200)



Phase 1 (continued)

- Then Break Students into Groups to Study
 - 4 Patents from ca. 1944 to 1986
 - Incredible Paper (ca. 2000) on Diffuse Optical Tomography
 - Optical Absorption Spectra of Oxygenated and Deoxygenated Hemoglobin
- Students present results of their study

Historical and Recent Patents



United States Patent [19]
New, Jr. et al.

[11] **Patent Number:** **4,621,643**
 [45] **Date of Patent:** **Nov. 11, 1986**

[54] **CALIBRATED OPTICAL OXIMETER PROBE** 4,266,554 5/1981 Hamaguri 128/633
 [75] **Inventors:** William New, Jr., Woodside; James 4,407,272 10/1983 Yamaguchi 128/6
 E. Corenman, Alameda, both of Calif. 4,407,290 10/1983 Wilber 128/633
 4,407,298 10/1983 Lentz et al. 128/713
 4,494,550 1/1985 Blazek et al. 128/664

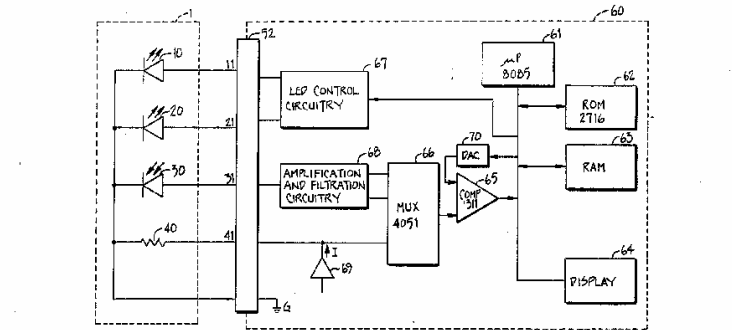
[73] **Assignee:** Nellcor Incorporated, Hayward, Calif.
 [21] **Appl. No.:** 827,478
 [22] **Filed:** Feb. 5, 1986

Related U.S. Application Data
 [63] Continuation of Ser. No. 695,402, Jan. 24, 1985, abandoned, which is a continuation of Ser. No. 414,176, Sep. 2, 1982, abandoned.
 [51] **Int. Cl.:** A61B 5/00
 [52] **U.S. Cl.:** 128/633; 128/666; 356/41; 250/252.1
 [58] **Field of Search:** 128/633, 634, 664-666; 73/1 R; 356/39-42; 250/252.1

OTHER PUBLICATIONS
 Yee et al, IEEE Trans. Biomed. Engr., vol. BME-24, No. 2, Mar. 1977, pp. 195-197.
 Grover, Conf. Proceed. of the 26th Annual Conf. on Engr. in Med. and Biol., Minn., Minn. Sep. 30-Oct. 4, 1973.
 Schibli et al, IEEE Trans. of Biomed. Engr., vol. BME-25, No. 1, (Jan. 1978), pp. 94-96.
 Primary Examiner—Kyle L. Howell
 Assistant Examiner—John C. Hanley

[57] **ABSTRACT**
 A probe apparatus for use with an optical oximeter is disclosed. A pair of light emitting diodes emit light of known narrow wavelengths through an appendage of a patient onto a photosensor. A resistor of coded known resistance is used to enable the oximeter to calculate the co-efficient of extinction of the wavelengths of the LEDs. The resistor, LEDs and photosensor are mounted on self-attaching hook and eye tape for mounting the probe onto the appendage of the patient. The probe is detachably wired to the oximeter, rendering the probe completely disposable. The oximeter is programmed at the factory to calculate the co-efficients of extinction of any LEDs which may be encountered in a series of disposable probes. From the co-efficients of extinction, the pulse rate and degree of arterial oxygen saturation is computed and displayed by the oximeter.

References Cited
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7 Claims, 7 Drawing Figures

The Incredible Related Paper: Imaging brain activity using IR light *through the skull*

Journal of Cerebral Blood Flow and Metabolism
30:491-507 © 2000 The International Society for Cerebral Blood Flow and Metabolism
Published by Lippincott Williams & Wilkins, Inc., Philadelphia

Noninvasive Functional Imaging of Human Brain Using Light

*†David A. Benaron, *Susan R. Hintz, ‡Arno Villringer, §David Boas, †Andreas Kleinschmidt, †Jens Frahm, ‡Christina Hirth, †Hellmuth Obrig, *John C. van Houten, †Eben L. Kerrit, †¶Wai-Pung Cheong, and *David K. Stevenson

*Biomedical Optics Group, Division of Neonatal and Developmental Medicine, Stanford University, Palo Alto, California, U.S.A.; †Medical Free Electron Laser Program, Department of Physics, Stanford University, Stanford, California, U.S.A.; ‡Department of Neurology, Division of Neuroimaging, Universitätsklinikum Charité, Berlin, Germany; †Massachusetts General Hospital, RMM Center, Charlestown, Massachusetts, U.S.A.; †Biomedical RMM at the Max Planck Institute for Biophysical Chemistry, Goettingen, Germany; and †Spectra Corporation, Menlo Park, California, U.S.A.

Summary: Analysis of photon transit time for low-power light passing into the head, and through both skull and brain, of human subjects allowed for noninvasive imaging of cerebral hemoglobin oxygenation based on photon diffusion theory. In healthy adults, imaging of changes in hemoglobin saturation during hand movement revealed focal, contralateral increases in motor cortex oxygenation with spatial agreement to activation maps determined by functional magnetic resonance imaging. In ill neonates, imaging of hemoglobin saturation revealed focal regions of low oxygenation after acute stroke, with spatial overlap to injury location determined by computed tomography

scan. Because such slow optical changes occur over seconds and co-localize with magnetic resonance imaging vascular signals whereas fast activation-related optical changes occur over milliseconds and co-localize with EEG electrical signals, optical methods offer a single modality for exploring the spatiotemporal relationship between electrical and vascular responses in the brain *in vivo*, as well as for mapping cortical activation and oxygenation at the bedside in real-time for clinical monitoring. **Key Words:** Functional imaging—Optical monitoring—Optical imaging—Functional MRI—Brain—Stroke.

The regional cerebral blood volume, regional CBF, and regional hemoglobin oxygen saturation (rSt_o) of human cortex vary over time (Ray and Sherrington, 1896; Olesen, 1971; Risberg and Iyngar, 1973; Iadecola, 1993; Fox and Raichle, 1985; Maloney and Grinvald, 1996).

Localized physiologic changes occur over seconds during neural activation, elevating blood volume and flow in excess of need over an area larger than the electrical activity. This acts to provide a putative neuroprotective effect (Kato et al., 1974; Greenberg et al., 1981; Sokoloff et al., 1973; Lueck et al., 1989; Sandman et al., 1984; Maloney and Grinvald, 1996) and affords a strong regional mapping signal that macroscopically co-localizes with neural activity (Peterson et al., 1988; Phelps and Mazziotta, 1985; Srinivas et al., 1992; Menon et al., 1992; Hennig et al., 1994; Belliveau et al., 1991). Localized pathologic changes also may lead to such regional variations as stroke, seizure, or watershed hypoperfusion, which can result in transient tissue dysfunction or irreversible injury.

Efforts to obtain a temporal and spatial understanding of regional oxygenation changes have been hampered by the difficulty of measuring such values both quantitatively and noninvasively *in vivo*. Surface optical mapping of exposed brain provides both quantitative and spatial resolution (Maloney and Grinvald, 1996) but is invasive and not suited to general clinical investigation; functional magnetic resonance imaging (fMRI) can map deoxyhemoglobin concentration, blood volume, and

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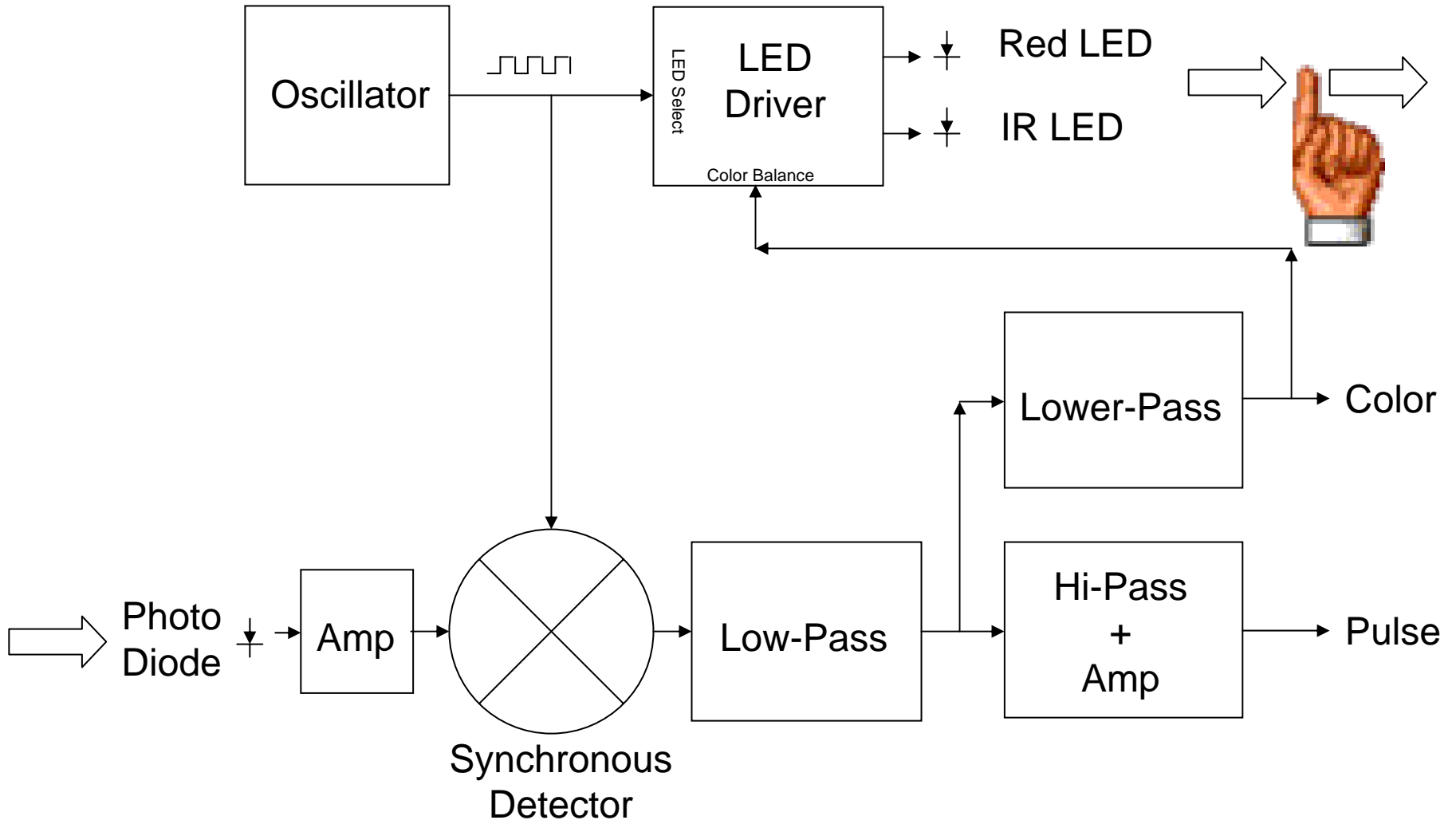
Address correspondence and reprint requests to David A. Benaron, MD, and Susan R. Hintz, PhD, Biomedical Optics Group, Department of Pediatrics, Stanford University School of Medicine, 780 Welch Road, Suite 315, Palo Alto, CA 94304, U.S.A.

Abbreviations used: CT, computed tomography; DORS, diffuse optical tomography system; fMRI, functional magnetic resonance imaging; fNIRS, functional near-infrared spectroscopy; MRS, magnetic resonance imaging; TDM, time-of-flight and absorbance.

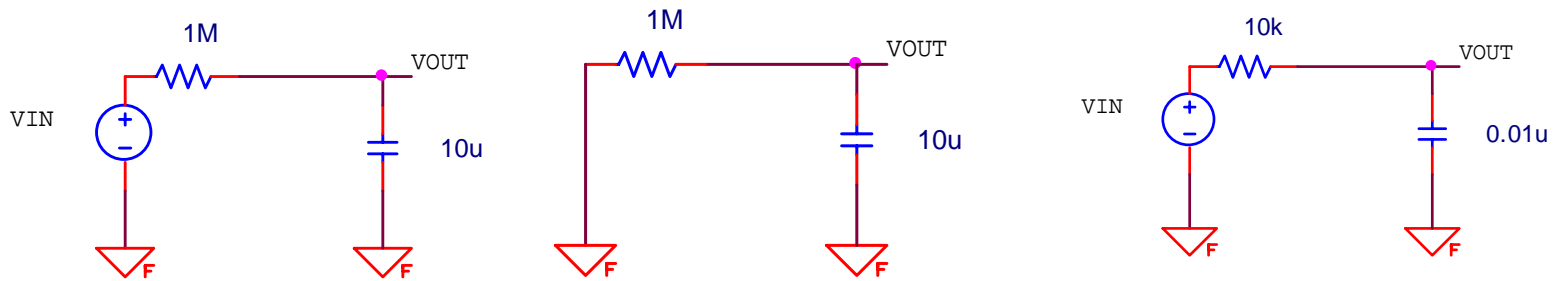
Next Three Weeks

- First Session: preliminary work on Voltage, Current, and RC circuits.
- Next 5 Sessions: Each Student Builds Oximeter Sub-Circuits
- Final Session: Connect all the parts and test

Block Diagram

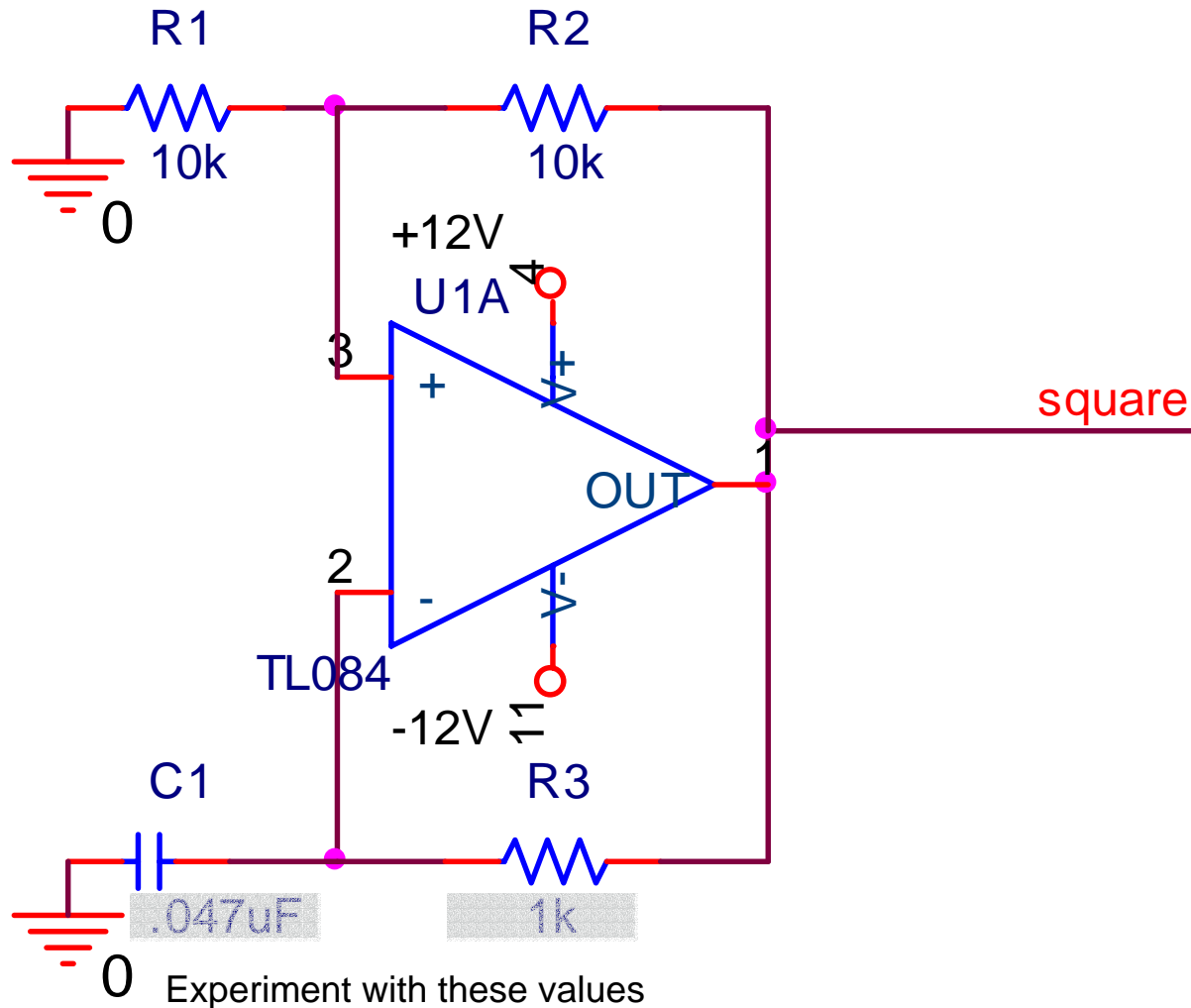


Preliminary Day on Rs and Cs



- Look at the first circuit above. Imagine that V_{IN} is 0 V, and then that you suddenly turn it up to 12 V.
 - What is going to happen? Why?
- Build the circuit and verify your intuition. Use the DC power supply for V_{IN} .
- Once you've done the test, consider the next circuit.
 - If the capacitor initially is charged to 12 V, will it stay at 12V? Why or why not?
 - Change your first circuit to the second by disconnecting the power supply and then connecting the resistor across the capacitor, and watch what happens to the voltage across the capacitor. Be sure that you are watching the voltage across the capacitor as you conduct this test!
- Question: what do you think will happen to the behavior of these circuits if you (1) make the resistor smaller (say 10k instead of 1M) or (2) make the capacitor bigger (say 100 μ F instead of 10 μ F)? Investigate your intuition to see if it's right (note: 100 μ F is a pretty big capacitor. You might want to investigate your intuition by using a smaller capacitor instead).
- Finally, build the last circuit, using the function generator as V_{IN} . Drive the circuit with a 1kHz square wave, and look at both V_{IN} and V_{OUT} on the scope. Explain the behavior of the circuit.

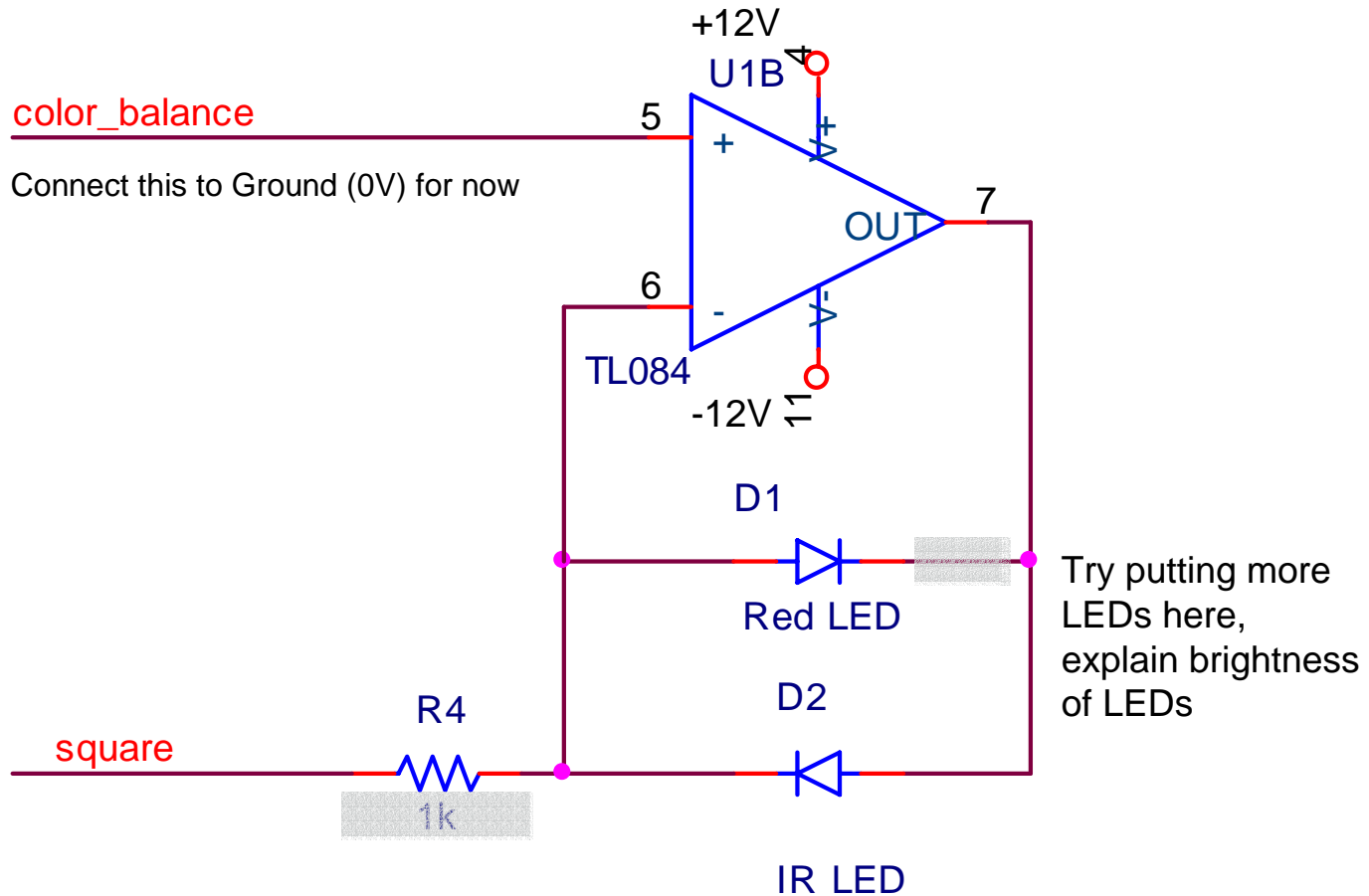
First Oximeter Circuit Hysteretic Oscillator



Oscillator Questions

- Considering the Op-Amp as a high-gain comparator, explain qualitatively how the circuit works.
- Observe the waveforms on pins 1, 2, and 3 of the op-amp. Explain what you see.
- Experiment with different values of $C1$ and $R3$. How do these affect the oscillation frequency?
- Determine a mathematic formula for predicting the oscillator frequency.

LED Current Driver



color_balance

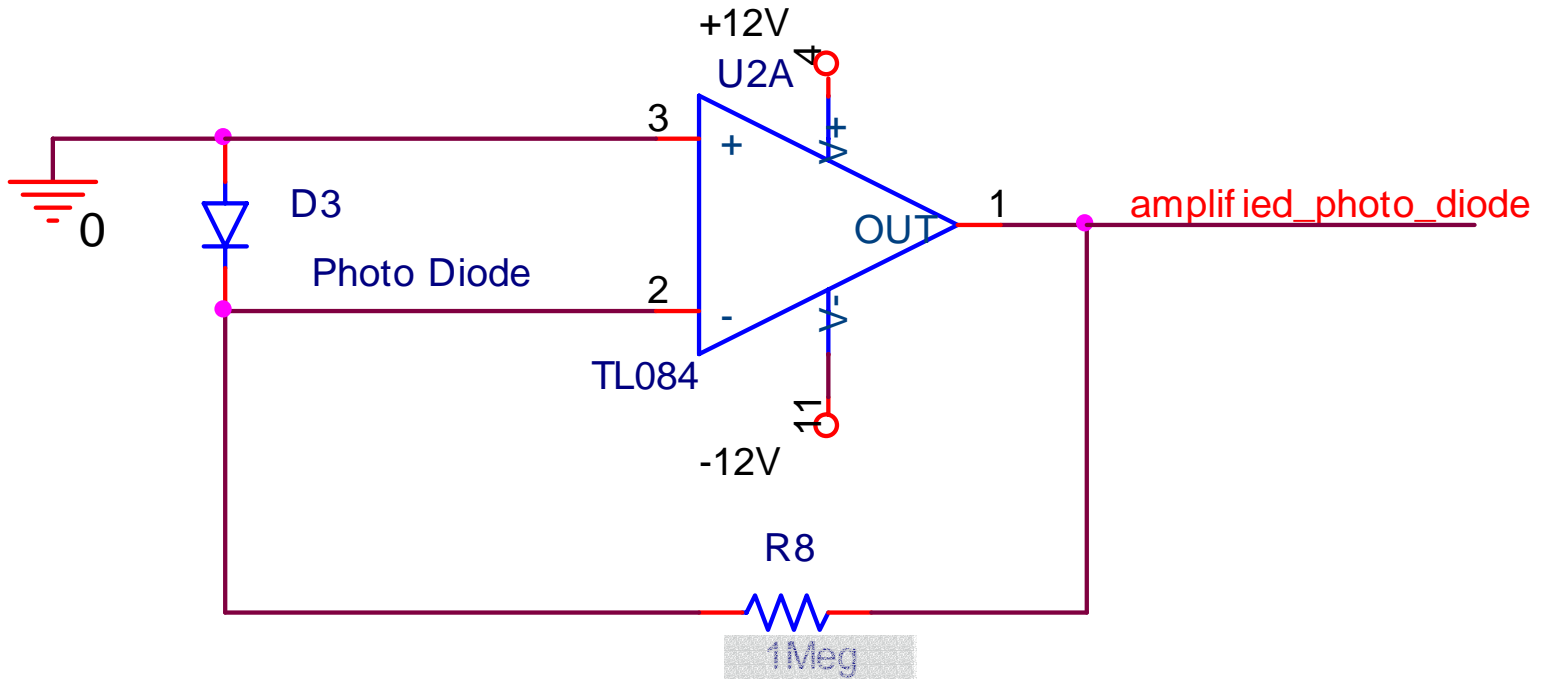
Connect this to Ground (0V) for now

square

Try putting more LEDs here, explain brightness of LEDs

Experiment with this value, explain brightness changes

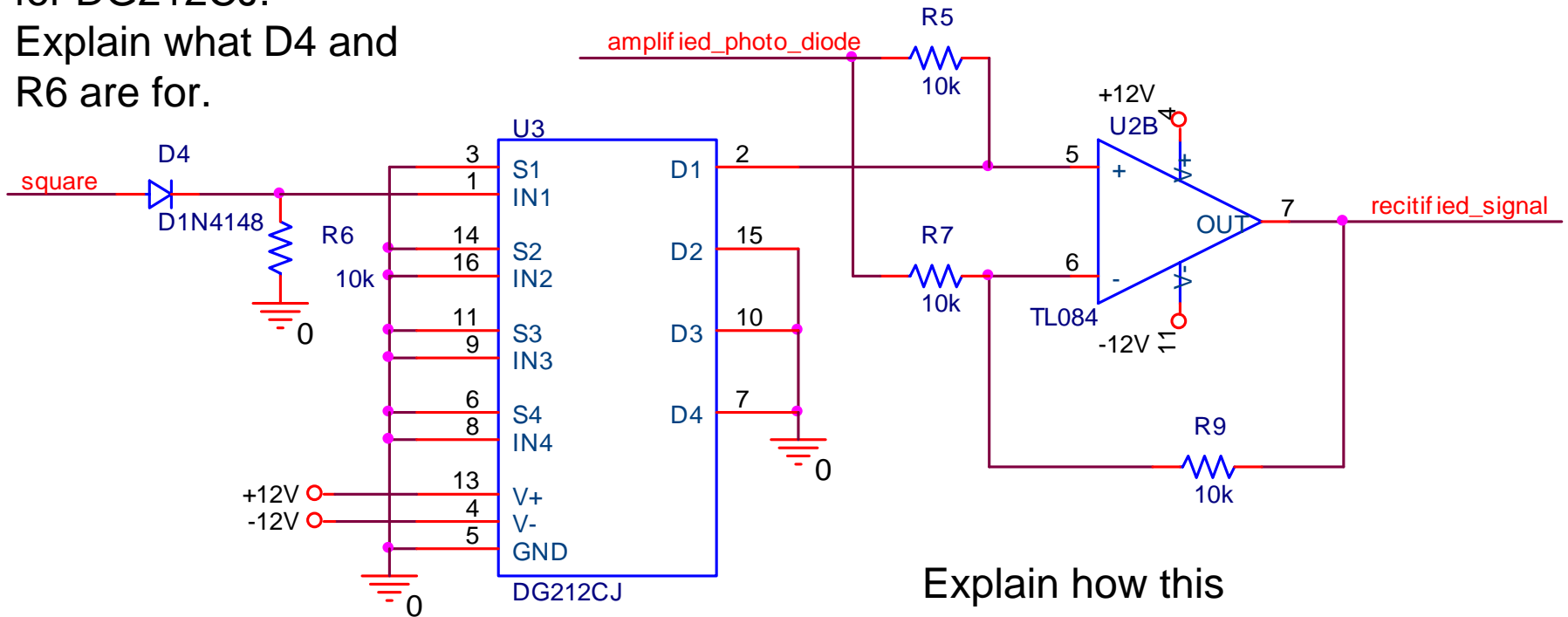
Photo-Diode Amplifier



Experiment with this value,
explain its effect on amplification

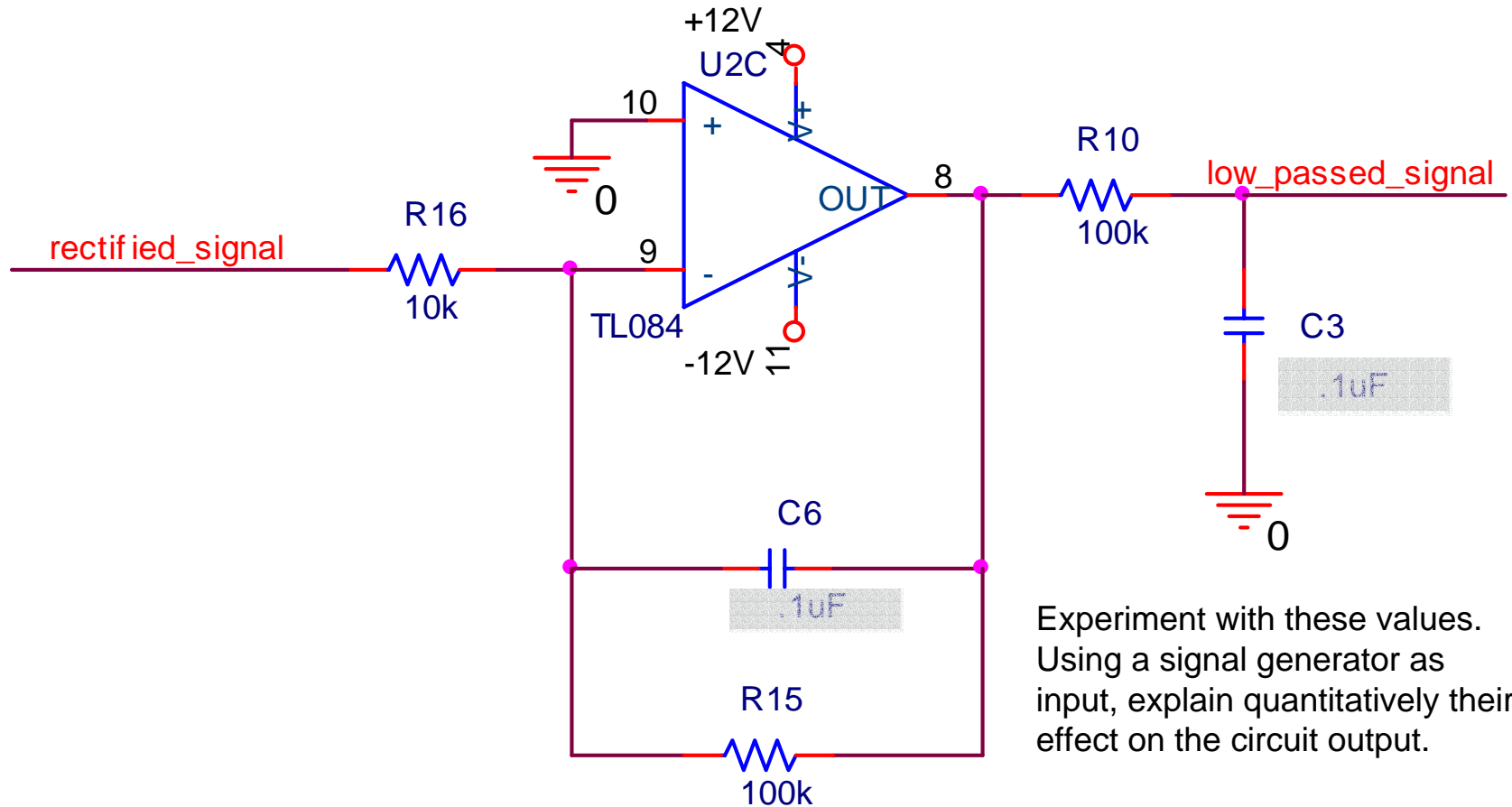
+/- 1 Multiplier

Look at Data Sheets for DG212CJ.
Explain what D4 and R6 are for.



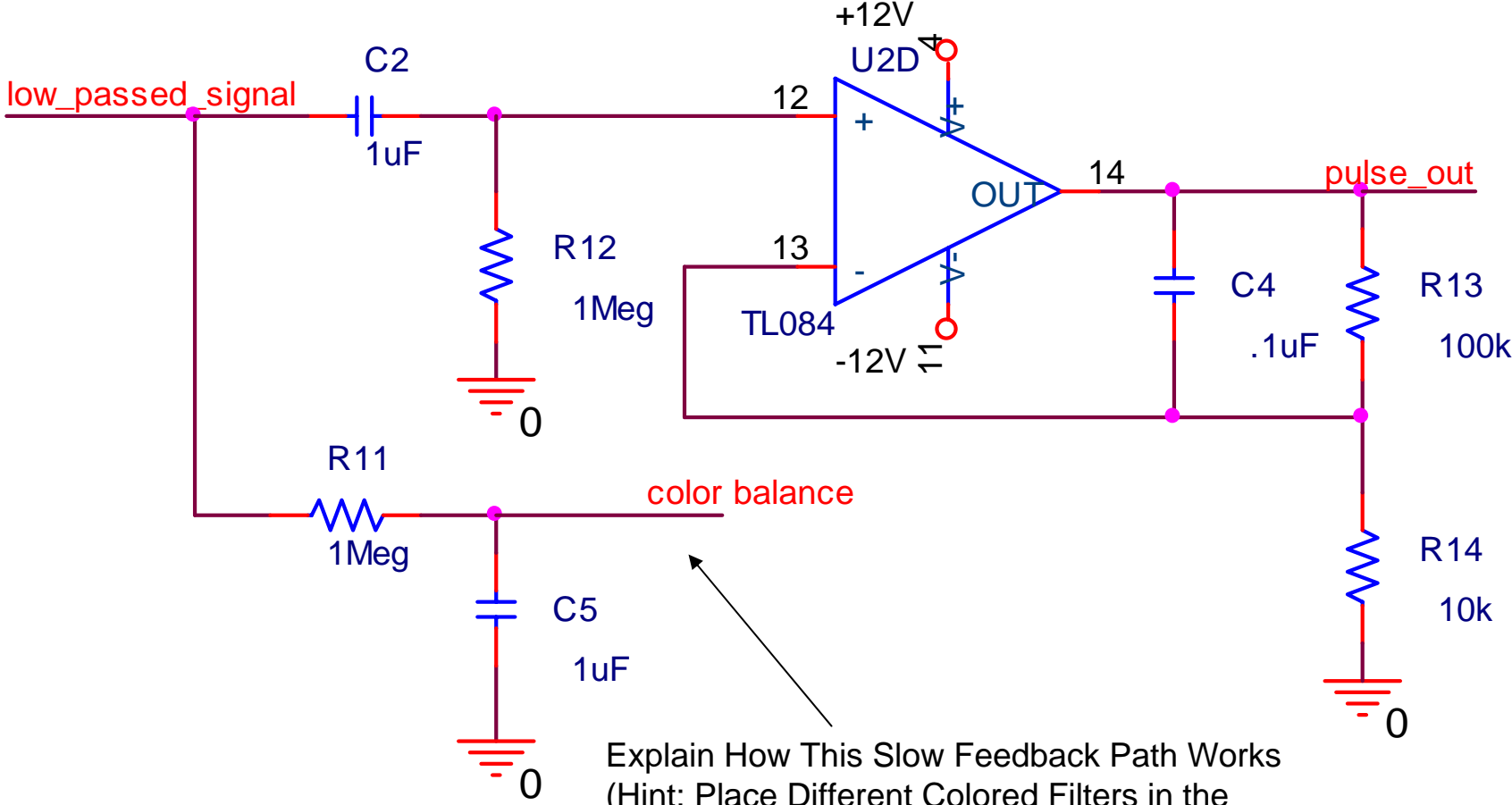
Explain how this circuit works.

Low-Pass Filter



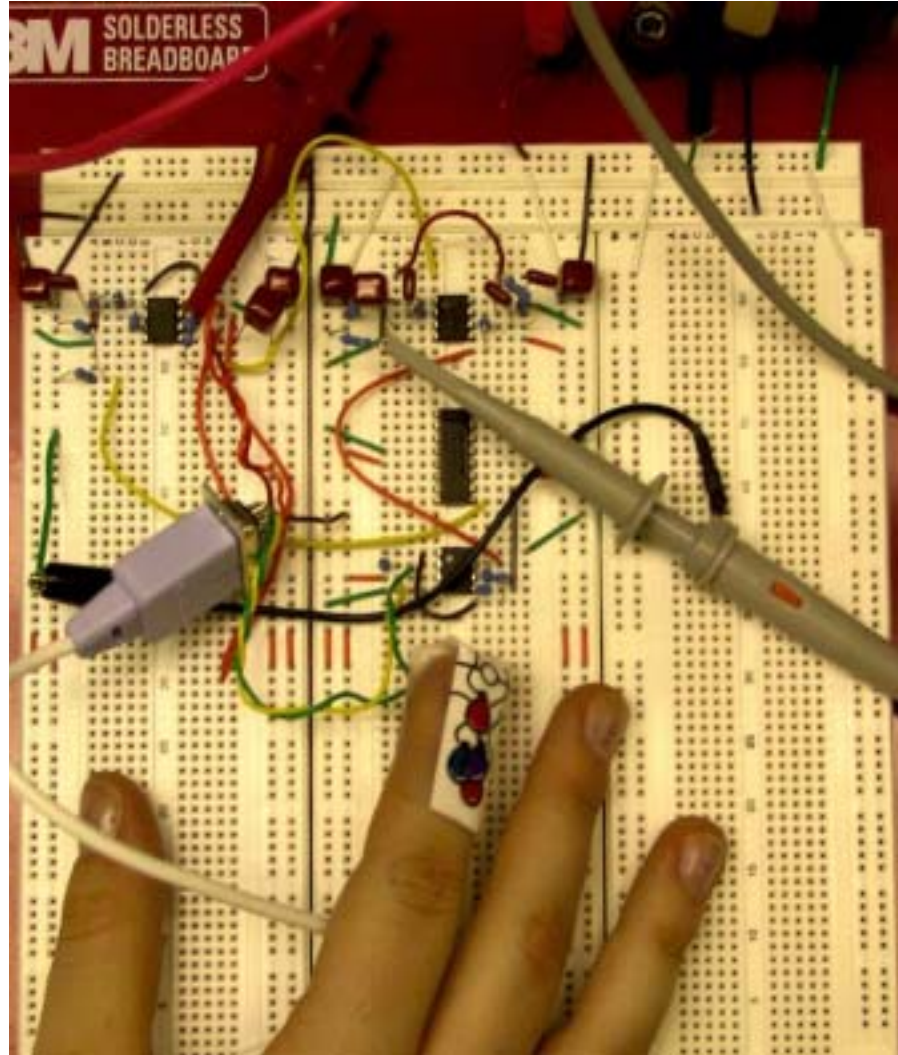
Experiment with these values. Using a signal generator as input, explain quantitatively their effect on the circuit output.

Color Balance Feedback Pulse Amplifier

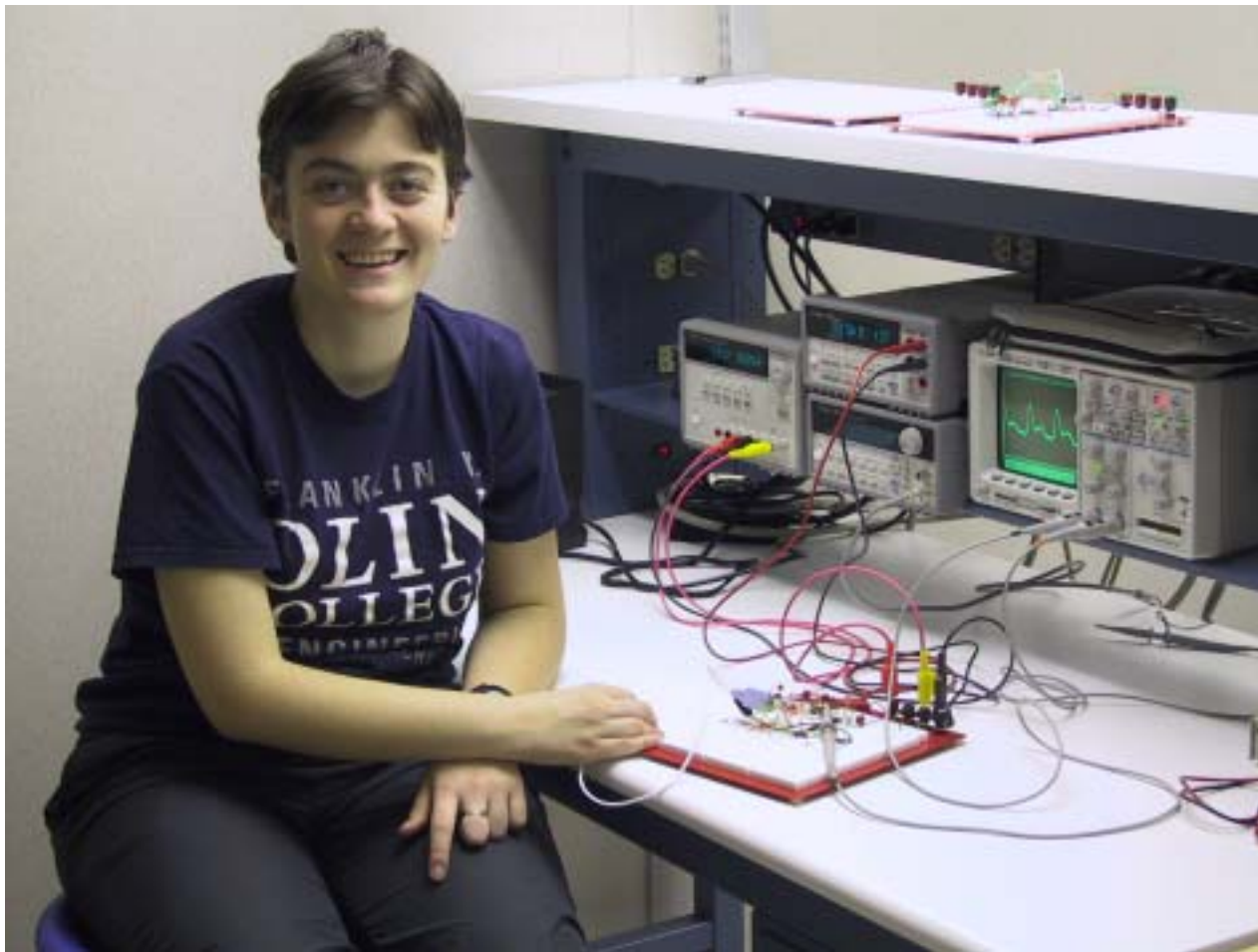


Explain How This Slow Feedback Path Works
(Hint: Place Different Colored Filters in the
Light Path and Observe the LED Response)

Completed Oximeter Breadboard



It Works!



Did We Succeed?

- 5 Weeks did not provide time for quantitative assessment
 - But subjectively we felt that despite all students having no previous experience, most (4/6) of the students obtained a very good comprehension of this advanced subject material.
 - The other 2 students had adequate understanding.
- Student's assessment of subject was also very good:

motivated me to learn	4.4 / 5.0
helped me develop teamwork skills	4.6 / 5.0
stimulated my intellectual curiosity	4.6 / 5.0
was fun	4.4 / 5.0
helped me gain new knowledge	4.8 / 5.0

Conclusions: What We Learned

- Do-Learn is more motivational (e.g. fun) and we believe more likely to result in understanding that lasts.
- More Frequent Assessment is Necessary
 - Do-Learn Assessment is difficult, as students have a complete understanding only at the end.
- Do-Learn is harder to teach, as the learning mode is deductive, not constructive,
 - The teacher's job is to guide students in their investigations, not to pour knowledge into their heads.
- As Learn-Do in the extreme can lead to boredom, Do-Learn in the extreme can lead to frustration.
 - But Do-Learn-Do-Learn ... is great. E.G. Do-Learn in bite-size chunks seems to be best.
 - Reminding the students of how the bite-sized chunks fit into the larger do-learn project then becomes essential.
- Giving the students good resources for their deductive work is essential.
 - We need new notes and text books written in the do-learn paradigm.