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# Using Mobile Devices to Improve Engineering Education: A Process Control Laboratory Example

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# Using Mobile Devices to Improve Engineering Education: A Process Control Laboratory Example

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**Abstract:** Most college students routinely carry a sophisticated computer in their smart phone and/or tablet. Instead of viewing these devices as a distraction from our educational goals, it is possible to incorporate these devices into the curriculum, and thereby enhance the educational experience. This is particularly true in the context of the engineering laboratory, as most mobile devices can be viewed as a miniaturized mobile engineering laboratory, with integrated accelerometers, magnetometer, gyroscopes, and optical cameras. In this work, we show how the optical flash can be incorporated into a process control laboratory to enhance the learning outcomes. Our students were tasked with building a transimpedance amplifier for a photodiode detector. The students then tested these detection systems using the camera flash and commercially-available apps. These apps can modulate the flash as a strobe light, with frequencies up to tens of Hz. Alternatively, there are apps available to modulate the flash to send Morse code messages. Students tested their detection systems using variable-frequency strobe modulation and via the sending and receiving of short Morse code messages. This lab demonstrates many of the curricular goals for our process control class: operational amplifiers, remote optical sensing, and analog signal conditioning. With different combination of resistors and capacitors, students can quickly see the effects of RC time constants on their Morse code transmission/receiver system. This lab could be expanded to teach basic digital acquisition and signal processing concepts when combined with an inexpensive DAQ platform. Our future goals include developing additional lab experiments that are enhanced with mobile devices, such demonstrations of flow sensing based on the device's accelerometer.

## 1. Introduction

Most college students routinely carry at least one sophisticated computer with them at all times, in the form of their smartphone and/or tablet. A 2016 survey of adults aged 18-24 in the U.S. shows that only 3 % answered "none" when asked about access to smartphones, laptops, tablets, internet connections, and cell phones [1]. Surveys about attitudes towards smartphones show a high level of attachment among this age cohort, with a lost or broken device triggering feelings similar to a lost limb. Although the term smartphone is only loosely defined, some devices that might be described as smartphones were released in the early 1990s, but the term smartphone was coined in the late 1990s. The first iPhone was introduced in 2007, and smartphones were adopted rapidly by consumers. Many of today's young adults have little memory of the era before smartphones. As children, the young adults of today would sometimes be loaned their parents' or caregivers' smartphone to quiet or entertain them when they were distressed or simply bored [2]. This has created a generation of young people who often report feeling soothed by their smartphone.

Smartphones and other devices can be a distraction in the classroom, and, given the opportunity, students often overestimate their ability to multitask by attempting to divide their attention between classroom activities and smartphone entertainment. This distraction is a valid concern for educators, and there are many classroom settings in which students need to put their devices away. However, there may be situations in which educational outcomes are aided by these technologies. One example is recording classroom notes: cameras can be used to photograph whiteboard lectures, and note-taking apps with optical character recognition (OCR) simplify future reviews with automated keyword searches. Another example, and the focus of this paper, is the engineering and/or physics laboratory. Most smartphones can be viewed as a mobile engineering/physics laboratory, equipped with accelerometers, magnetometers, rapid-frame camera, optical flash, ambient light sensors, microphone, and speaker [3]. The application of these smartphone features has been demonstrated in teaching a broad range of topics, including basic physics [4-9], mechanics [10], kinematics [11], pendulum motion [12], elevator oscillations [13], radial acceleration [14], Coriolis acceleration [15], magnetometry [16], flow visualization [17], and Doppler effects [18]. Combined with a few inexpensive parts, such as LEDs, optical slits, and diffraction gratings, the smartphone's optical camera can be used to teach spectrometry principles [19]. In this paper, we demonstrate the application of the optical flash to teach analog signal conditioning and optical sensing in a process control laboratory.

## 2. Background Information

This teaching laboratory exercise was applied to an upper-division engineering technology class at Metro State of Denver. The class title is Process Control Systems, and the topics covered include basic control theory, analog signal conditioning, digital signal conditioning, and a broad range of sensing technologies, including temperature, optical, acceleration, flow, and position sensors. The students in this class are mostly junior- and senior-level students, and all were from our Department of Engineering Technology. Most of the students were majoring in electrical engineering technology, while a handful of students were majoring in mechanical engineering technology or sustainable systems engineering.

## 3. Experiment

This lab experiment is intended to reinforce students' understanding of optical sensing and analog signal conditioning principles. Students were tasked with designing and building a transimpedance amplifier as an analog signal conditioner for an optical sensing system. The optical flash of the students' smartphones and an inexpensive photodiode comprise the optical sensor. This combination of the LED and photodiode is analogous to the safety sensor system that is required for garage doors to automatically stop the garage door if a child or other object is in the path of the door.

The transimpedance amplifier circuit design is shown in Fig. 1. The students were introduced to the transimpedance amplifier, or current-to-voltage amplifier, in the analog signal conditioning portion of our class. The photodiode detector converts the incident photons to electrons, and the transimpedance amplifier converts this current to an output voltage. The output voltage of this circuit is given by

$$V_{out} = -IR_1 \tag{1}$$

where I is the current from the photodiode and $R_1$ is the feedback resistor shown in Fig. 1.

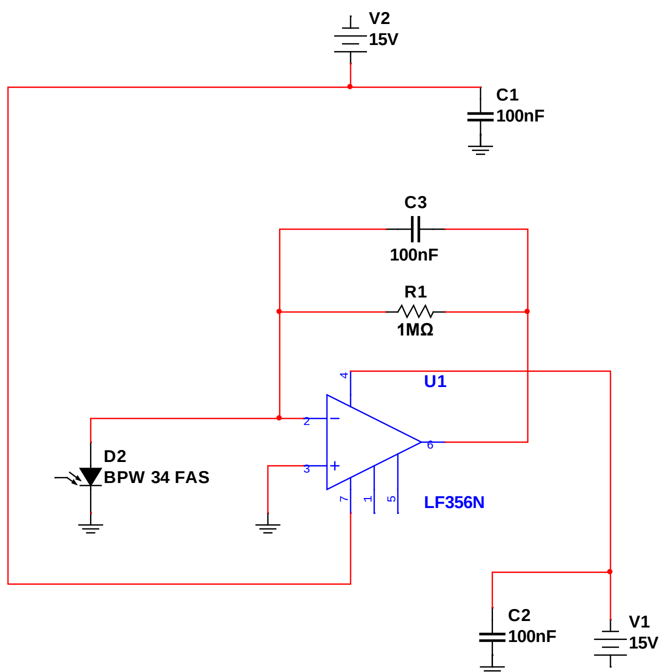


*Fig. 1. Circuit diagram for the transimpedance amplifier. D2 is the photodiode detector. LF356 is an operational amplifier.*

The optical signal is provided by the flash of the students' smartphone.  Many apps are available to strobe the smartphone flash, as well as to send Morse code signals using the flash. The cost of the app installation was the responsibility of the students, but all of the students were able to find free apps that worked well enough for this lab exercise.

A typical smartphone has a powerful flash, on the order of 10s of mW, but also has a strong divergence angle, on the order of 45°. The collection area of most photodiode detectors is relatively small, particularly if an inexpensive photodetector is used.  Students had to place their smartphone optical flash in very close proximity to their photodiode detector in order to get a signal.  Based on an estimated optical responsivity of 0.5 W/A for the photodiode detector, a typical measured output voltage of -1 V, and a feedback resistance of 1 MW, we estimate that the optical power intercepted by the photodiode detector was on the order of 2 mW.

This lab exercise can also be used to demonstrate the effects of low-pass filtering.  The feedback capacitor C3, combined with the feedback resistor R1, form a low-pass RC filter.  Students were able to see the tradeoff between fast time response and noise filtering by changing the value of the C3 capacitor.

The orientation of the photodiode shown in Fig. 1 is not critical for this experiment.  If the orientation of the anode and cathode are reversed, the circuit will still act as on optical detection circuit.  If response time was a critical factor, one would typically reverse-bias the photodiode detector by applying a small voltage to the cathode shown in Fig. 1.  In this lab experiment, response time is not critical, and the reverse bias voltage source was omitted for simplicity.

One potential pitfall in this lab exercise is that the transimpedance amplifier is ringing, or unwanted oscillations.  This ringing is a complex function of specifications of the operational amplifier, the specifications of the photodiode, and the values of resistors and capacitors used in the circuit [20].  The capacitors on the power supply are sometimes used to curb ringing effects for these circuits. An analysis of these ringing effects was beyond the scope of our course.  We were able to find a combination of parameters that worked well enough to demonstrate this concept, but still some students had difficulties with their circuits ringing.  This is likely a result of parasitic capacitance introduced in the optical breadboards used to build the circuit.

## 4. Results

Students were required to use an optical app that had variable frequency strobe.  Most apps were able to strobe with variable frequencies up to a 10s of Hz.  As students varied the frequency of their optical strobe with their app, they were able to measure the strobe frequency by connecting the output of their transimpedance amplifier to their oscilloscope.  An example of the measured strobe signal is shown in Fig. 2.

The students were also tasked with measuring output of the transimpedance amplifier with a short optical Morse code input provided by their smarphone app.  Some examples of simple

Morse code messages were: SOS, Metro State, or the student's first name. Students were required to choose a simple message with a good combination of Morse code dots and dashes. An example of the output for a Morse code message is shown in Fig. 3.

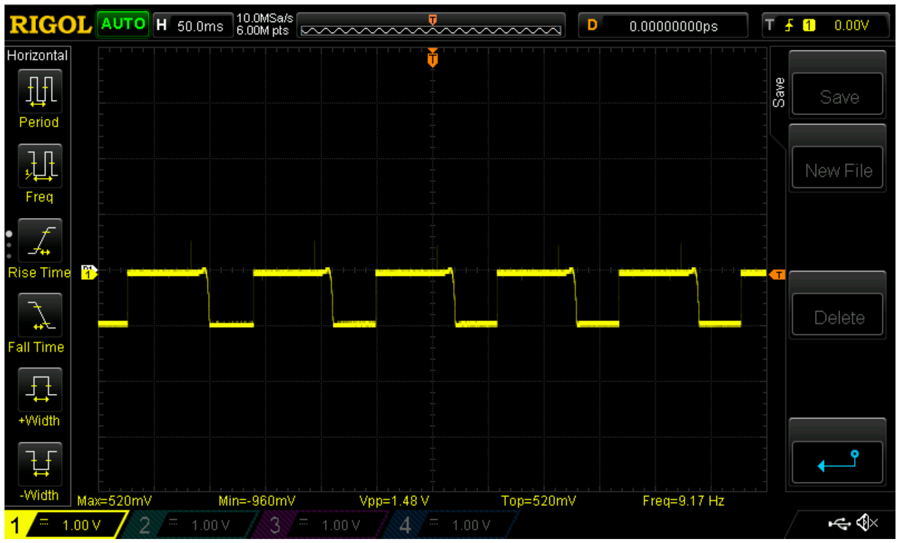


*Fig. 2. Example output voltage of the transimpedance amplifier with an optical strobe input created by the flash of a smartphone.*

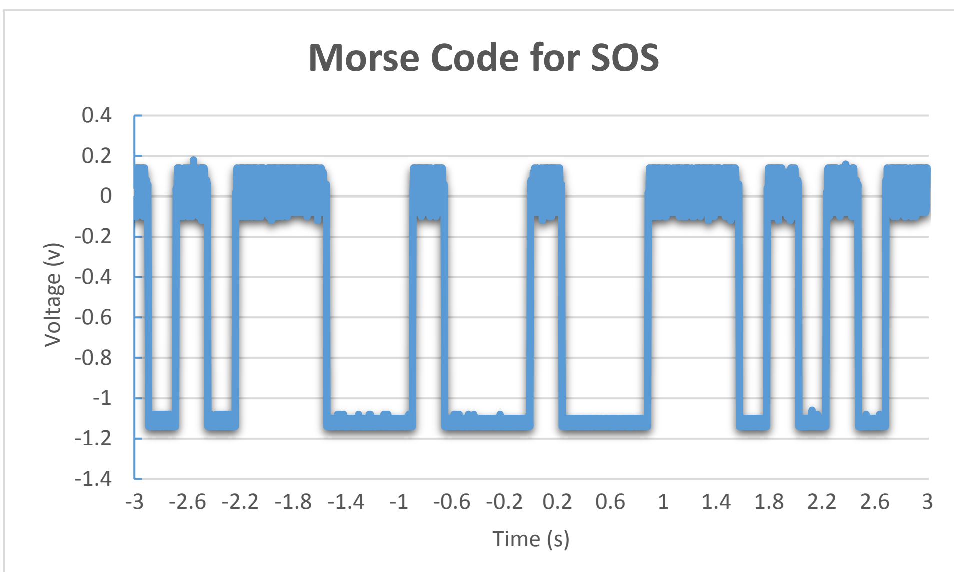


*Fig. 3. Example output voltage of the transimpedance amplifier with an optical Morse code signal input created by the flash of a smartphone. In this case, the Morse code signal is SOS. In Morse code, an S is three dots, and an O is three dashes. The first dot*

*of the first S is off the plot in this example. The output voltage of this circuit is expected to be negative (see Eq. 1), as shown in this plot.*

## 5. **Discussion and Summary**

One common concern in education is the dilemma of providing a solid educational foundation at a low cost. One advantage of using the capabilities of existing equipment, such as student's smartphones or other mobile devices is that it can provide considerable cost savings. We were able to provide this lab exercise to the students at a very low cost. All of the students enrolled in this class had their own smartphone, and they are all able to find free apps to control the optical flash and provide strobed and Morse code signals. The components used in the transimpedance amplifier shown in Fig. 1 are all very inexpensive and are often readily available in a typical electrical engineering laboratory.

Other required equipment includes power supplies and oscilloscopes, which are common in a typical electrical engineering lab setting. Alternatively, this circuit could be powered with a pair of 9V batteries, or students could compare noise performance using power supply versus batteries.

The optical transimpedance amplifier can be a tricky circuit for a novice electronics student, partly because of the problems with ringing discussed above. Many students enter our labs with the expectation that everything will work on the first try, and that troubleshooting skills should not be required of them. This expectation is contrary to the working world that many students will experience after graduation, and any practical troubleshooting experience that they gain in this and other labs will likely serve them well in their futures. One improvement that we have implemented is to break this experiment into smaller steps: the students start with a simple inverting amplifier by replacing the photodiode of Fig. 1 with a function generator and series resistor (100 kΩ works well enough). Then students can observe the performance of their inverting amplifiers on an oscilloscope before moving on to the transimpedance amplifier. This intermediate step works particularly well for students who have little or no experience with op amp circuits.

One concern for educational opportunities that focus on students' smartphones or mobile devices is the "digital divide." This term describes the students whose socio-economic background currently limits their access to technology. These students will face a steeper barrier to education as mobile-device educational opportunities become the norm, and these students may fall further behind their classmates as a result of their lack of access. Some potential solutions: pairing students with a lab partner who has device access, loaner equipment, and/or grants from technology companies. However, despite these accommodations, the challenges faced by students from disadvantaged socio-economic backgrounds should always be considered.

One challenge is the quantification of the impact on learning outcomes. The small class sizes at our school limit create challenges in the accumulation of a statistically valid sample size. We can only estimate the learning outcomes based on the small sample size of students available. Our estimate of the impact on student outcomes is based on the exams given during the semester. We use the outcomes from a midterm exam administered prior to the lab experiment and from the final exam, administered after the lab experiment. Only 50 % of our students were fully successful in their answer to an op amp design problem on the first midterm, while over 80 % of the students were able to successfully solve a significantly more complex op amp design problem on the final exam. We believe that this improvement in performance can be attributed, at least in part, to this laboratory experience.

In summary, we have demonstrated a novel electronics laboratory experiment in which we have integrated the students' smartphones and/or other mobile devices into our educational goals. The result is an accessible demonstration of some of the major topics covered in the classroom, including analog signal processing, optical sensing. Given students' enthusiasm for their mobile devices, and the ever-increasing capabities of these devices, we expect many future revolutions in engineering and physics education will be aided by these devices. Our future efforts will focus on expanding the laboratory educational opportunities provided by these devices, particularly on developing lab exercises that use the acceleration sensors included in most devices.

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