Infrared Vibration Sensitive LED Drum and Metronome: L.U.D.S. - Light-up Drum System

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***Abstract* — This paper covers the main design elements and methodology required to build an infrared sensitive light-up drum system to effectively add a visual component to the music making process. Specifically, this paper will cover four catagories: (1) The infrared sensor array design; (2) The embedded system software and coding methodology; (3) The power supply design including the implementation of multiple power sources; (4) The methodology required to realize the circuitry to amplify embedded systems' output signals for LED input power signals.**

***Index Terms* — Infrared detectors, operational amplifiers, embedded systems, vibrational signal, power supply quality, & liquid crystal displays.**

I. Introduction

While singers, guitarists, bassists, and most musical performers have the freedom to walk, run, dance and jump around on stage to improve their stage presence, drummers are forced to stay in the same place throughout their musical performance causing them to be significantly less noticeable on stage. The L.U.D.S. device aims to fix this by adding a vibration sensitive LED array within the drums to make every drum the drummer strikes, light up in a stunning fashion. Additionally, drummers require metronomes while practicing in order to stay on beat. One common issue with metronomes is that the sound they create can often be drowned out by the sound of the instrument. The L.U.D.S. device has a visual metronome component which allows a metronome to be seen instead of heard so the consistent beat will always be perceived by the drummer. These are the two main issues that L.U.D.S. will fix. When a drum is struck by a drummer, the skin on the surface of the drum will oscillate up and down, the more force applied by the drummer, the louder the drum vibrates, the more the skin will oscillate. The L.U.D.S. uses infrared sensors inside the drum to measure the intensity of the drum strike to then subsequently light up an LED strip located inside the drum. The L.U.D.S. provides the infrared sensor framework for future engineers to track when, where, and how hard the drum is hit. In metronome mode, the L.U.D.S.' user interface requires the user to input the BPM (beats per minute) and time signature of the desired rhythm and will then light up the LED strip in a pattern consistent with the chosen parameters thus creating a visual metronome. To stay within the scope of a senior design project, the L.U.D.S. acts as a proof of concept for future development of similar devices. The L.U.D.S. has been built for one single drum head but can potentially be scaled to be integrated into a full drum kit. The L.U.D.S. as it currently exists is made up of four main peripheral components and an MCU (main computational unit): the sensor array, the user interface, the power supply, and the LED array. The sensor array is the array of infrared sensors for detecting drum beats which is located within the drum head. The user interface is a collection of switches, rotary encoders, and a liquid-crystal display for the user to input their desired parameters. The power supply is made up of both a rechargeable battery and wall outlet power supply which both lead to a power regulator and can be seamlessly switched between via a rotary switch. The LED array is an LED strip which is placed inside the drum and acts as the output of the system. Each of these peripheral components are connected to the MCU which is located on the device's PCB (printed circuit board). The L.U.D.S. meets certain engineering specifications relating to durability, battery life, LED luminosity, and metronome accuracy.

II. System Components

A. Microcontroller

The primary component that controls the entire project is the microcontroller which for this project is the Texas Instrument MSP430FR6989. This MCU offers various features for this project and one primary part is the GPIO pins. There are 40 pins that can be connected to the other hardware components of this project, which includes the reflectance sensors, the beam break sensors, the LED strip, switches, rotary encoders, and display (LCD). Each component requires individual pins while some require multiple pins such as the switches and knobs since they have multiple features. Regardless, this microcontroller has enough pins for all the components of the project.

The microcontroller will be programmed in Code Composer Studio application in C language. The embedded programming allows to implement many features for the output by taking the input values or detection of the vibration from the sensors. The output is made based on the switches and knobs values. The display features mode and bpm value in its two available lines, while the LED strip flashes in specific mode, frequency, and more based on the user input.

B. Liquid Crystal Display (LCD)

The display is an output based component which makes it a crucial part of the project. It continuously displays the mode in which the LED is flashing on the first line. Then, the beats per minute value (BPM) on the second line. Overall, the only function is to display the selections made by the user using the switches and knobs for mode selection and bpm value, respectively.

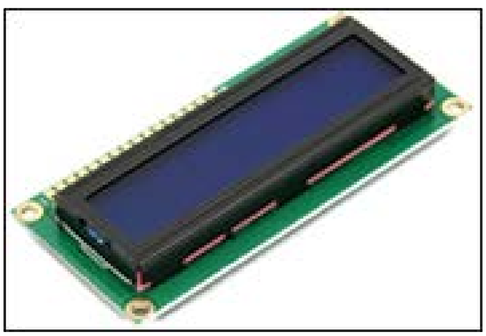

Fig. 1. HiLetgo 16x2 LCD Display Module

This display that works for this project will be a 3.3V input based module. In that case, a HiLetgo 16x2 display is used which can fit an overall of sixteen characters in each line, so it is optimal enough and as well as doesn't consume too much power. Below is a text example of how the display shows the characters:

Line 1-`[Mode: Metronome]` or `[Mode: Sensing]`
Line 2-`[xxx bpm]`

The first line shown above has two options which are both less than sixteen characters each. One of these options will be programmed to be displayed based on the mode selected by the user with the switch. Then, the second line shows the bpm value represented as "xxx" which will be replaced by the number that is selected by the user with the knob.

C. Voltage Amplifier

The voltage amplifier is an important part of the project because it amplifies the 3.3V output signal of the main computational unit to the required 12V input for the LED strip that is located inside the drum. The LED strip brightness must be able to be controlled by the MCU which is done via a pulse width modulator. This means that the amplifier design must not attenuate frequencies less than 100kHz. (100KHz being the point where the LED strip has the same luminosity as a 12V DC input) The design chosen to meet these specifications in a non-inverting operational amplifier. The gain of a non-inverting operational amplifier is equal to one plus the ratio of its R1 and R2 resistors. (Amplifier configuration is shown in figure 2 and calculations are shown in equations 1-2)

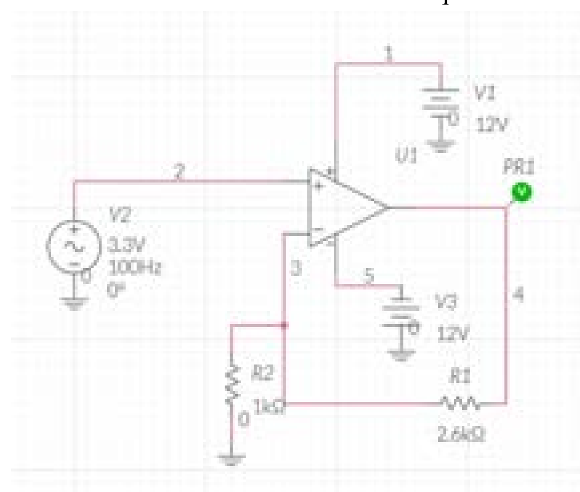

Fig. 2. Configuration of non-inverting operational amplifier.

$$A = \frac{V}{V_s} = \frac{12V}{3.3V} = 3.6 \qquad (1)$$

$$A = 1 + \frac{R1}{R2} \qquad (2)$$

The values chosen for R1 and R2 are 2.6KΩ and 1kΩ respectively. The output of an operational amplifier can only be as high as the rail power supply to the amplifier component so the amplifier is supplied by a +12 in the VCC terminal and -12 in the -VCC terminal. Also, shown in figure 3 is the AC sweep of the non-inverting operational amplifier circuit to show zero attenuation at frequencies less than 100KHz.

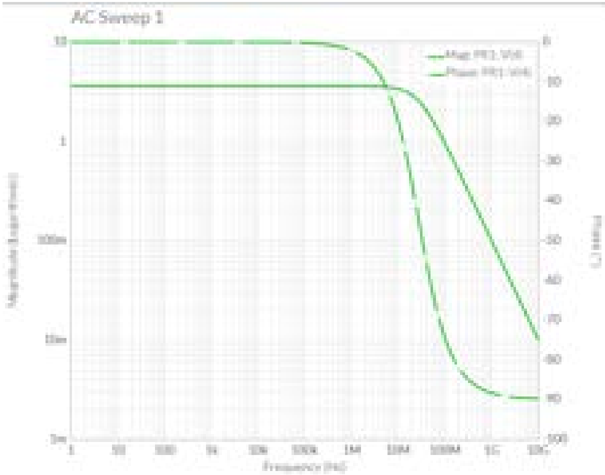

Fig. 3. AC sweep of non-inverting operational amplifier design showing no attenuation until 1MHz

D. Sensor Array

The IR sensor array is a core aspect of the LUDS. It is composed of six reflectance sensors mounted inside the drum and six sets of beam break sensors mounted outside. These sensors will be used to detect when the drum is hit as well as track the contact point and velocity of the drum sticks, which will be saved and could be used to generate replay data in the form of a MIDI file.

The reflectance sensors are QRE1113 analog sensors from Onsemi. The QREs are small sensors with a short effective range of around just a few millimeters (between 1-3mm). They will be mounted on a ring so that they can face upward toward the drum skin to “see” the skin of the drum deforming in response to vibration, which is shown in figure 5. The ring will have a radius of 3.5 inches or half that of the drum’s and the sensors will be spaced evenly along it to maximize the sensor's ability to gather data.

The beam break sensors are OPB856Z digital sensors Optek. The OPBs come in two parts, a transmitter that projects a beam of IR light and a detector which reacts to that beam. The sensors will be arranged with pairs aligned across the diameter of the drum from each other, alternating between transmitter and receiver around the outer rim of the drum. The 856Zs have a unique casing that will allow them to better mount to the drum as well as increasing their durability, shown in figure 4 below.

Fig. 4. OPB856Z’s show with their special housing.

The sensors will be connected to the MCU to process the data. Since both the QRE and OPB sensors are IR sensors, they will use similar circuit design, which is also shown in figure X.

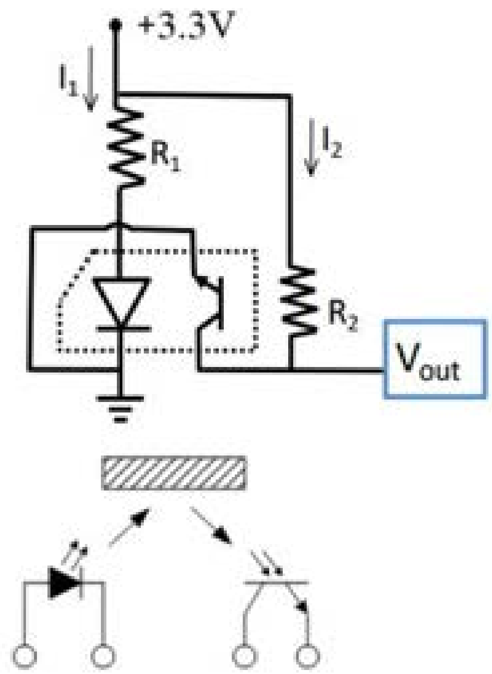

Fig. 5. The circuit connecting the sensors to the power supply and the MCU. R1 is 33 ohms and R2 is 10k ohms. Vin is

+3.3V and Vout is the connection point to the MCU. The bottom diagram shows how the QRE1113 sensor will reflect off the skin of the drum.

The data set to the MCU will first and foremost be used to flash the LEDs in performance mode, which is as simple as checking for when then sensors are activated. The recording of replay data is a bit more complicated. By using the reflectance sensors as a points of reference, the origin of the vibration can be located by a program using time difference of arrival calculations. This exact method was shown to be not only a very viable method of tracking by Janis Sokolovskis and Andrew P. McPherson [1]. The beam break sensors will be used by recording the amount of time the beam was broken and using that to calculate the velocity of the drum stick, and thereby the force.

E. Voltage Regulator

There are two voltage regulators that are necessary for this project. The first regulator is a buck boost converter that is responsible for stepping down the voltage from the 12V DC sources to a regulated 3.3 V output signal. The design was created through the TI Webench Designer program [2]. It is a significant part of the project as the majority of the peripherals are dependent on the stepped down voltage signal. The main chip that is integral to the design of the regulator is the TPS563212DRLR The regulator will directly connect the incoming DC signal from the power related switch to the VCC pins of the MCU. The schematic for this voltage regulator is shown in Figure 6 below.

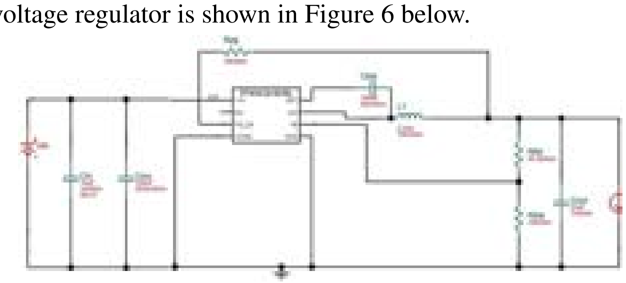

Fig. 6. Schematic for the buck boost converter

The second regulator would be an inverting buck boost converter. The regulator chip used for this design is the TPS62136RGXR. This regulator is responsible for supplying a negative 12V into the -VCC pin of the voltage amplifier design. The input parameters surrounding this design allows for an input signal between 3 to 4.5 V to output an inverting 12V signal. The output from the first buck boost converter will input to this to effectively get the voltage signal needed.

F. Power Supply

The power supply is an integral part of the LUDS project. The project is powered by two different voltage sources, a 12V 6000mAh battery from BATTERYINT and a 12V AC adapter from COOLMC. Included with the AC adapter is a 5.5mm x 2.1mm female connector allowing for easy connection with the power related switch. The battery is rechargeable and has a composition of lithium-ion. In addition, the 12V battery from BATTERYINT includes the two leads that allow for easy access to solder to the rotary switch. Figure 7 shows the battery below along with the leads.

Fig. 7. 12V 6000mAh Battery with leads

In addition to the 2 power sources, is also a power related rotary switch. This project utilizes the A40315RNZQ to safely switch between the 2 mentioned DC voltage sources. The rotary switch has 3 positions and 4 poles. This effectively allows the switch to connect 4 different circuits and have on-off-on positions . In addition, the A40315RNZQ switch is rated for much higher voltage and amp ratings than this project will provide to ensure the safe interruption.

III. System Concept

A. Project Control Interface

The below diagram shows the wide scope logic flow of the user control interface for the project device. The user interface is part of the housing of the device where all non-peripheral parts will be placed. All inputs, excluding the infrared sensor's output and the battery, are switches and knobs that will be controlled by the user of the device. The author in charge of each block is also in charge of the inputs leading into each block. If the input flows into blocks of two different authors, then both authors will collaborate on the design of the inputs. Designation of the design from each block in the diagram are explained in Figure 8 .

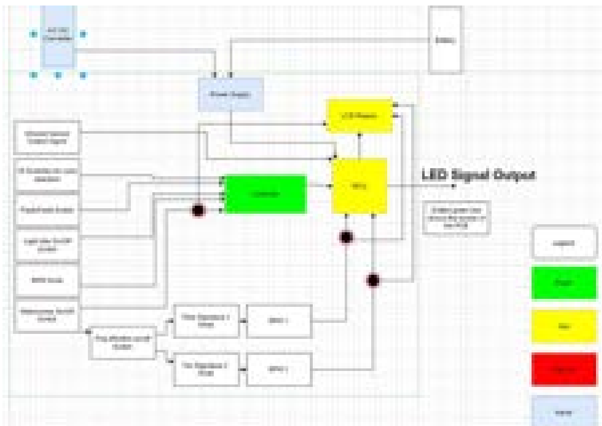

Fig. 8. Block Diagram with each group members respective design

B. Software Design

For programming the MSP430, the plan is to divide the entire program into minor parts. These small parts include the code individually for switches, knobs, each type of sensor, LED strip and the display (LCD). After each component is programmed separately, then all of them will be merged together to create one file.

For reflectance sensors, there are six separate outputs that individually connect to six pins on the microcontroller. The code begins with initializing each sensor with the designated pins connected. Then, set each pin as the input and set the pull-up resistor low when no object is near 3mm of the sensor. Next, the infinite loop checks for the sensor output which if detected then output the specific function is implemented.

For display, there are multiple parts which allow the specific characters displayed. It also has a total of six output pins from the LCD connected to the MCU. Each function will be called from the main function or from other functions to display each character. Regardless, the infinite loop in the main function constantly displays the contents in two separate lines.

For switches, initially the two pins are initialized for each of its outputs as ON or ON. Basically the program checks for which side the user flips the switch to and output based on its function. For knobs, it is initialized the same way as the switches with two pins, except in this case, it will be used to detect the direction of the rotation as to clockwise (CW) or counter-clockwise (CCW). This allows the program to be able to increase or decrease the value based on the user input of the knob rotation.

Overall output of the entire project depends on the flashing of the LED strip around the drum. This will be programmed slightly differently since it takes in many inputs and delivers a specific output of LED flashes. Only pins connect to the microcontroller that will be used to send output information to the strip.

Overall, these are the major programming processes for the entire project, and it will also be the most important task since it controls everything that happens throughout. After each component is programmed individually, each of it will be merged together, then it will be loaded onto the MCU to perform the final output.

C. Information Storage of Vibrations

All the vibrations detected by the reflectance and beam break sensors will be stored as velocity of the beat. This is a calculation that will be performed in the code, which will be then sent via the UART module from the microcontroller to the computer. A flash drive that will have enough storage which will be connected to the computer to use as the location of the text file (.txt) that stores all the information. This will be an optional part of the project since it doesn't have any major functionality but rather just to collect technical information for later usage in the future.

IV. Hardware Detail

A. LED strip assembly

The L.U.D.S. uses the "Non-Waterproof IP20 LED Flex Strip: R6060-IP20-RGB-06" as the output of the system. The LED strip is bought as a 6ft long strip and cut down to 44" to meet the circumference of the inside of the drum. The LED strip comes with double sided tape on one side. The tape is taken off of the strip and then the strip is carefully placed around the middle inside of the drum head. Next, the 4-pin RGB plug of the LED strip is connected to a 4-pin RGB jumper cable. A 1" diameter hole is then drilled into the side of the drum, allowing the jumper cable to be fed through and out of the drum head. Next, the 4-pin RGB jumper cable is connected to the output of a "LED Flex Strip - RGB Controller: DIMMER-3CH" that is located within the housing . This dimming module allows the user to control the color selection of the LED strip. The input of the dimming module is a 2.1mm power cable which is then connected to a 2.1mm pigtail cable with a female 2.1mm port on one end, and red and black wires on the other. Those red and black wires are then soldered onto the PCB board. The red wire is soldered to the connection that is wired to the non-inverting OP amp output on the MCU and the black wire is soldered to the ground of the PCB.

B. IR Sensor Assembly

The process of building up the sensor array has gone through multiple phases. The first phase was making sure each sensor worked individually. This was simple enough but also highly instructive. This phase not only involved finding if each sensor worked, but also trouble shooting the circuit design that the sensor was placed in. This was done with a DC power supply for Vin and a digital multimeter at Vout to check for a change in voltage from the sensor.

In initial tests, it was hard to tell if the sensors were working at all, but it became clear that R1 is key because it has the largest effect on the performance of the sensors. Originally we were using a 200 ohm resistor for R1, but for the sensors to work, R1 must be under 100 ohms and the smaller the resistance, the more sensitive the sensor. This is due to more power being provided to the IR LED in the transmitter, making it stronger and easier to detect. 33 ohms was selected to be the resistance value.

The next phase was based on connecting the sensor to the dev board to test how they work with the code. Eventually the code got worked out so the sensor would turn an LED on the dev board on and off.

The current phase of testing is connecting six sensors at once and making sure that the system works all together. At first they did not work. In the figure shown below, the six sensors were connected with each individual circuit connected in parallel with the intent that the LED on the bottom of the dev board would turn on when a sensor is covered and, also shown in the figure, the LED is on when no sensors are covered. This is because the LED would rapidly blink when the sensor was not covered. We discovered that the dev board when connected into a laptop could not drive enough power to properly work the sensors.

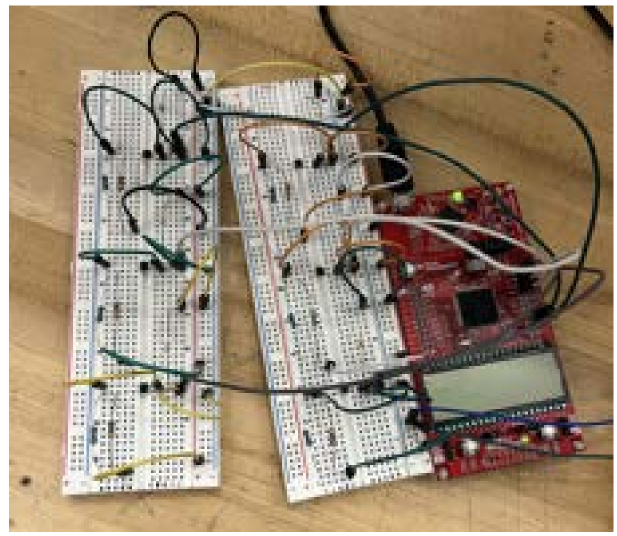

Fig. 9. Full reflectance sensor array connected to a dev board

We connected the circuit to a stronger power supply and the sensor worked properly. The next step is to find a way to test the optimal distance for the sensors in the drum to find the optical distance from the drum head. The way we plan to go about this is to disassemble a drum to lower the drum head over the sensors. This method of testing will give us more control and more accurate measurements.

C. Power Switch Assembly

The L.U.D.S will utilize the A40315RNZQ rotary switch to safely switch between the two DC voltage signals. The four poles of the switch are grouped alphabetically as A through D. Poles A and B are connected to the input of the first buck boost converter and ground, respectively. The other two poles connect to the positive and negative leads of the battery respectively.

Position 1 of the rotary switch allows the buck boost converter to receive power from the AC adapter. Position 2 disconnects any power from being received by poles A and B, effectively making it the off position. However it connects the positive and negative leads of the battery and AC adapter respectively. This allows the battery to charge while the rotary switch is in the off position. The third and final position receives the 12V signal from the battery.

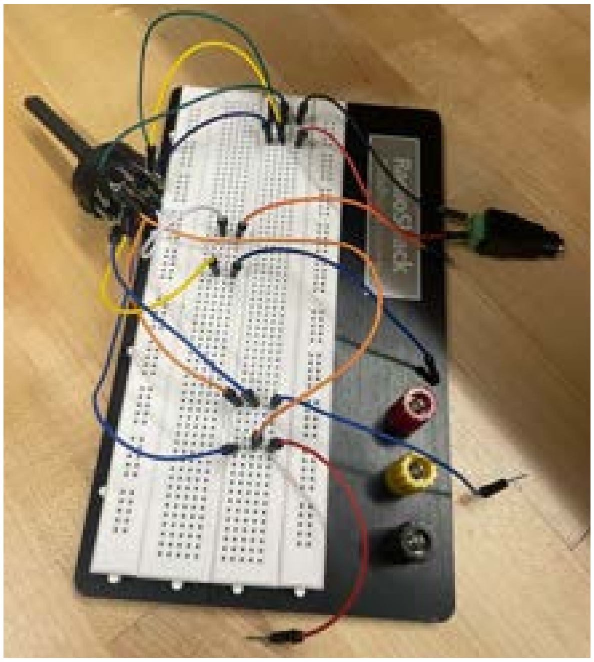

Fig. 10. A40315RNZQ rotary switch with connection to both DC voltage sources. Tope connections are the one connecting to the AC adapter. Bottom connections are those related to the battery.

Tests show that a 12V regulated voltage signal is being distributed from position 1 and 3. Position 2 has no output signal coming from the two pins that relate to the input of the buck boost converter. However tests in fact show that the battery is being charged while in this off position. The rotary switch with the connections to both DC voltage signals is shown in Figure 10 above.

Acknowledgement

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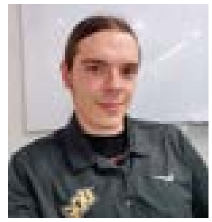
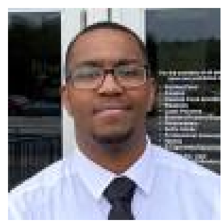
V. Biography



Elijah Peterman, a graduating senior receiving his BSEE from the University of Central Florida. He works at C.M. Arrington and Associates, a civil engineering firm located in Kissimmee, Florida. Following graduation he intends to find work supporting clean energy infrastructure.

Malcolm Donaldson, a CREOL student graduating with his bachelor's degree in Photonic Science and Engineering. He intended to work on LiDAR systems after graduation and hopes to move out of Florida to see more of the world.



Aaron Holloway, a ECE student graduating with his bachelor of science in electrical engineering from the University of Central Florida. He intends to work within the renewable energy sector following graduation.

Ajay Nattanmai, a 21-year old graduating student with bachelor of science in electrical engineering from the University of Central Florida. He intends to work in the IT field after graduation.

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