Faculty of Engineering, Chulalongkorn University

2102-447 Electronics Engineering Laboratory

Broken Beam System

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Abstract

A broken beam system **detects** when an optical beam is blocked and **acts** upon it.

Objectives

To **design**, **build**, and **test** a practical electronics system whose building blocks include electronic materials (2102-308), devices (385), circuits (386), and other components.

Introduction

A broken beam system (BBS) detects when a line of sight between an optical source and a detector is broken, and then does something about it. BBS is installed at entry/exit gates throughout Bangkok's BTS and MRT systems. BBS is a critical feature in production lines as it counts things (can, bottle, box) along fast-moving conveyors. Variations of broken-beam systems include reflected-beam systems (RBS) found in toilets (auto flush), iPhones (facial recognition). In this Lab session (two experimental periods, 6 hours), only BBS is involved, but the concepts are applicable to RBS.

This labsheet has 3 main sections. First, the block diagram of the BBS is explained. Second, the devices & circuits of all the blocks are given. The values of many parts are non-optimal due partly to convenience (I use parts available in my office to prototype the experiments) but mainly to **design** objectives. In this part, you will **build** and **test** given circuits, then re**-design, build** and **test** some parts of the circuit, too. Third is the System part where you will integrate everything.

A separate section (Results & Discussion) is provided as an editable file (docx). You are required to take snapshots[1] of waveforms (indicated by 🖫), videos of the BBS in action (🎥), and insert them into the file. In the following, required actions will be signalled by the sign ▶.

1. Block Diagram

The system consists of beam generation and detection parts as shown in Fig. 1. This section gives a brief overview of the two parts

[1] Use the oscilloscope "File/Save" button to take screenshots and write directly to a USB drive. A single press captures the screen output in high resolution, with a small file size, contains date/timestamps, measures frequency (1/Δx), peak-to-peak voltage (Δy), etc. Do **not** use your mobile device to take snapshots (large file size, poor resolution, no timestamps, hence proof of own results).

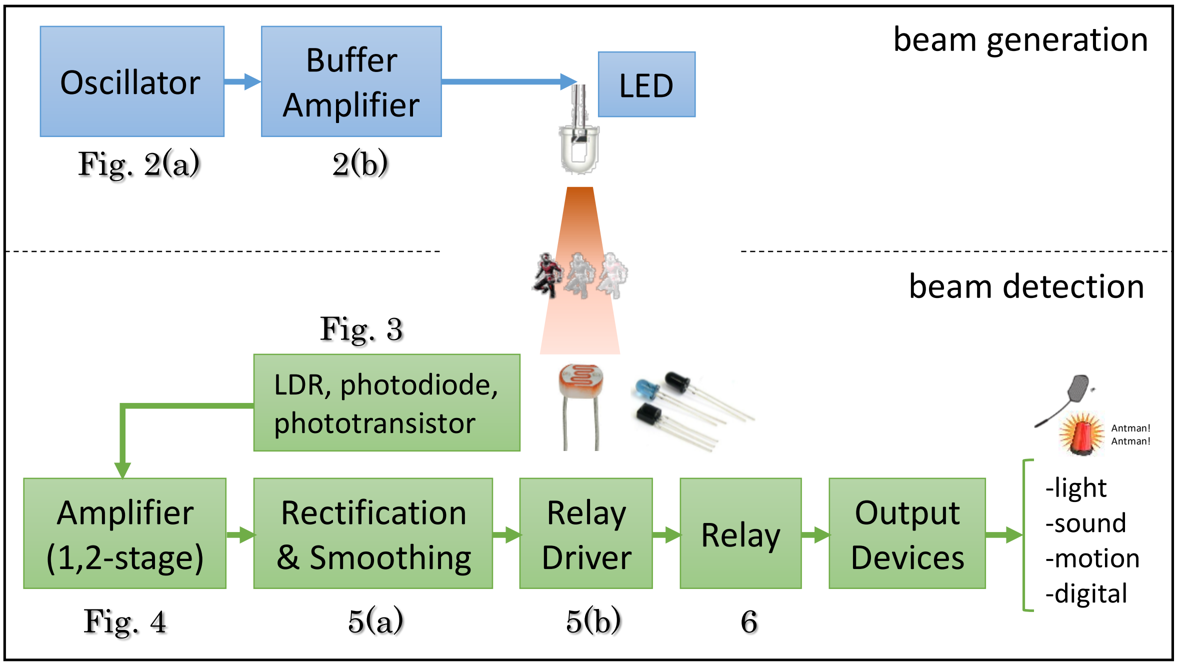

Fig. 1. Block diagram of the Broken Beam System. The circuits for each building block will be separately described in Figs. 2-6 as labelled.

1.1 Beam Generation

The beam is generated by an infrared light-emitting diode (*IR LED*), wavelength ~940 nm. ▶ Fill in necessary details in Table 1 to remind yourself of the relationship between colors and voltages. The LED is pulsed (it blinks); it is driven by a *buffer amplifier* which in turn is driven by an *oscillator*. The oscillator controls how fast the LED blinks (the frequency f). The buffer amplifier controls the LED brightness (the current I_{LED}).

1.2 Beam Detection

The beam is detected by an *IR detector*, see Table 2. The detector must be biased to yield as large a signal as possible. In many cases, the signal amplitude is low and must be amplified, at least once, probably twice. After appropriate *amplification*, the signal amplitude is sufficiently large and can be processed by a *rectification and smoothing circuit* to yield a dc output which indicates whether the beam is present or blocked. The dc output is then fed to a *relay driver* which, as the name suggests, drives a *relay*, activating one or more output devices, see Table 3. This part thus **detects** an object and **acts** on it through analog (light, sound, motion) and/or digital output.

Table 1. Wavelength-energy-voltage relationship

color	**wavelength λ (nm)**	**energy E (eV)**[1]	**voltage (V)**[2]
green	570		
red	630		
infrared (IR)	940		

[1] Planck relation: $E = hc/\lambda$
[2] built-in voltage (V_o) across a semiconductor p-n junction that can emit such λ

Table 2. Semiconductor-based optoelectronic detectors

Detectors	**Structures (material, E_G)**	**Mechanisms**
light-dependent resistor	bulk (CdS, 2.4 eV)	absorption ($E \geq E_G$)*, photoconductivity
photodiode	p-n junction with optical window into the junction (Si, 1.1 eV)	absorption, carrier separation, photocurrent
phototransistor	npn or pnp BJT with optical window into the base (Si, 1.1 eV)	absorption, carrier separation, photocurrent, amplification

* E: photon energy; E_G: Energy gap of semiconductors

Table 3. Output devices used in this experiment

Modes	**Devices**
light	LED, multi color
sound	buzzer, loudspeaker
motion	motor, actuator
digital	counter, display

2. Devices & Circuits

Each building block in Fig. 1 is described below. Each block serves a specific function and should be understood on its own. The system will operate if each and every block is free from errors. A single loose connection or a damaged component will render the system inoperable. You should make sure that each block functions as expected before connecting them up. There are 7 blocks in total and since each group has 3 members, each member should concentrate on 2 or 3 blocks and learn from one another.

2.1 Oscillator

The oscillator generates a square wave voltage varying between a maximum and minimum value. To generate a square wave, you can use a Function Generator, convenient but impractical (big) in actual system deployment which requires minimum size to keep costs down. Here, you will build your own oscillator using a small integrated circuit (IC): the 555 timer IC, one of the most useful chips [1,2].

The 555 can be configured to operate as a *monostable* or an *astable* circuit [3]. Figure 2(a) shows a 555 *astable* circuit: its output (pin 3) switches between V_{max} and V_{min} at a frequency f = 1.44/((R1+2R2)C2) [4]. V_{max} is typically the positive supply rail (9 V), V_{min} the negative or ground (0 V). The 555 output drives the buffer amplifier as shown in Fig. 2(b). The pin configuration of the 555 IC is shown in Fig. 2(c).

▶ **Design** (determine R1, R2, C2) a 5-Hz oscillator. **Build** it on a protoboard. **Test** it (observe the 555 output, pin 3 or ① in Fig. 2(a)) using a cathode-ray oscilloscope (CRO). Save the screenshot 🖫①. This low-frequency oscillator will be used to drive a visible LED later.

R1 = …………………, R2 = …………………, C2 = …………………… (5 Hz)

▶ Repeat the above (**Design, Build, Test**) for a 5-kHz oscillator. 🖫① This high-frequency oscillator will be used to drive an IR LED later.

R1 = …………………, R2 = …………………, C2 = …………………… (5 kHz)

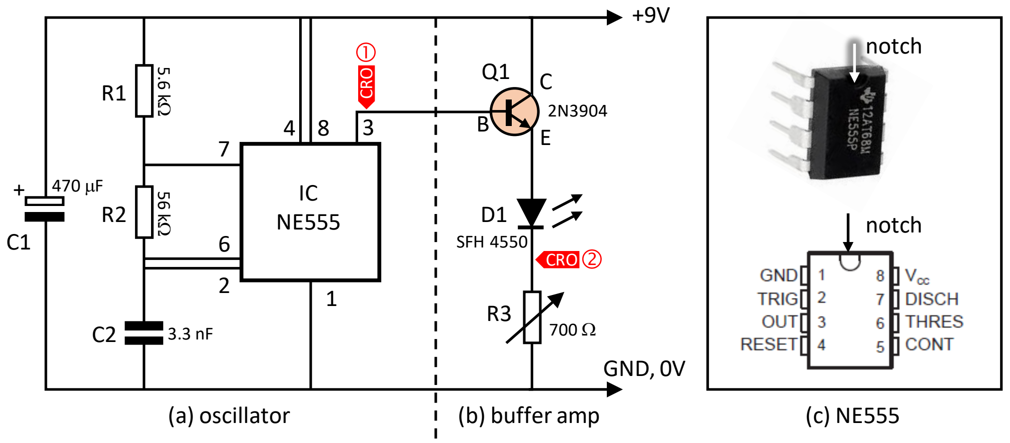

Fig. 2. The beam generator: (a) the oscillator, (b) the buffer amplifier, and (c) the picture and pinout diagram of the 555.

2.2 Buffer Amplifier

The buffer amplifier does “buffer” but does not “amplify”. It consists of a single bipolar junction transistor (BJT), an npn type is selected as an example, see Fig. 2(b). The buffer acts as an interface between the 555 and the LED (D1). The BJT is connected in a *common-collector* mode. The emitter voltage (V_E) “follows” that of the base (V_B) thus the configuration is also called an *emitter follower*. “Follows” means approximately equal, not equal. In fact V_E is lower than V_B by the amount close to the forward voltage drop of a Si p-n junction (~0.7 V), i.e. in the on state V_{BE} ~0.7 V. The main purpose of “buffering” (instead of connecting the LED directly to 555 pin 3) is that the LED current I_{LED} can be adjusted (by varying R3) independently from the 555.

▶ **Design** (determine R3) the buffer such that the LED intensity is enough (for visible LEDs and daylight observation, I_{LED} = 20 mA). To guide your design, use the table:

Parameters	**Red LED on**	**IR LED on**
Transistor state	on	on
V_{CE} (V), (see Q1 datasheet)		
I_{LED} (mA)	20	20
V_{LED} (V), (see Table 1)		
R3 (Ohm), (use KVL)		

▶ **Build** it (red LED blinks at 5 Hz). **Test** it: 1) visual inspection—watch it and use your phone to save a video of the blinking LED , 2) use the CRO to probe the voltage *V* at ① and also across R3 (②, this is the *current waveform*; *V*/R3 = I_{R3} = I_{LED}). ①②

▶ **Build** it (IR LED blinks at 5 Hz). **Test** it: 1) visual inspection (view though smartphone camera—Si-based camera can respond to IR while human’s retina cannot) .

▶ **Build** it (IR LED blinks at 5 **k**Hz). **Test** it: 1) check the waveforms ①②.

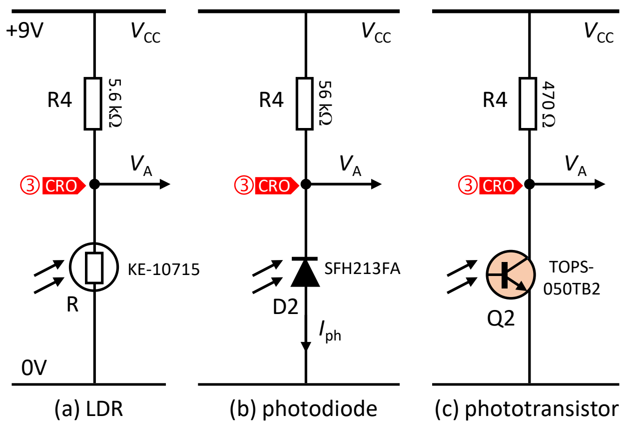

Fig. 3. The front-end of photodetection circuits when light-sensing elements are (a) LDR, (b) photodiode or (c) phototransistor.

2.3 Detector

The detectors of interest here are limited to optoelectronic devices which receive light (opto-) and output (-electronics) signal. The 3 basic detectors as summarized in Table 2 can be biased as part of a *voltage divider* shown in Fig. 3.

1. The *light-dependent resistor* (LDR) is resistive (MΩ) in the dark but quite conductive (< kΩ) when exposed to ambient light. With connection as shown in Fig. 3(a), the light-dependent voltage V_A can be determined from $[R/(R+R4)]\times V_{CC}$

   ▶ **Build** the LDR detector as shown in Fig. 3(a). Put a red LED (blinks at 5 Hz) close to the LDR surface. **Test** it: 1) use the CRO to probe the voltage across the LDR ③, observe it with respect to I_{LED} ②, 2) block the beam and note how the waveform changes. $\boxed{\text{🖫②③(1,0)}}$ where 1 means with beam, 0 without beam (broken beam)

   ▶ Increase the LED blink frequency to 5 kHz. **Build** & **Test**. $\boxed{\text{🖫②③(1,0)}}$

2. The *photodiode* (D2) operates in the third quadrant in the *I-V* space, 385 Chapter 8, and is thus reverse biased in Fig. 3(b). In the dark, the resistance of the photodiode is so high the current is practically zero. With light exposure, the diode passes a small photocurrent I_{ph}, thus the voltage across it drops by $I_{ph}\cdot R4$.

   ▶ **Build** the photodiode detector as shown in Fig. 3(b). Put an IR LED (blinks at 5 kHz) close to the diode surface. **Test** it: 1) use the CRO to probe the voltage across the diode, 2) block the beam and note how the waveform changes. $\boxed{\text{🖫②③(1,0)}}$

   ▶ (Re-) **Design** it: vary the bias resistors (R3 for the emitter, R4 for the detector) to get a signal (V_A) with "better shape and size". "Better shape" means the waveform at the detector (V_A) is as close to those at the emitter as possible (square wave). "Better size" means the waveform has a large peak-to-peak voltage, $V_{p\text{-}p}$. Ideally, V_{Low} should be as close to the negative rail or GND (0 V) and V_{High} should be as close to the positive rail (9 V) as much as possible. Then, **Build** & **Test** as above. $\boxed{\text{🖫②③(1,0)}}$

3. The *phototransistor* (Q2) provided is an npn BJT with a transparent window, allowing light to fall on to the base, generating the base current I_B as in standard (windowless) BJT. The phototransistor thus does not require electrical connection to the base, leaving only two terminals for bias as shown in Fig. 3(c). In the dark, the transistor is off, the collector voltage (V_C or V_A in Fig. 3(c)) is pulled up (reaches the supply

voltage). With light exposure, the transistor is switched on and V_C is pulled down (to V_E, note when the transistor is on V_{CE} ~ 0.2 V, check BJT datasheet).

▶ **Build** the phototransistor detector as shown in Fig. 3(c). Put an IR LED (blinks at 5 kHz) close to the transistor surface. **Test** it: 1) use the CRO to probe the voltage across the transistor, 2) block the beam, note how waveform changes. 🖫②③(1,0)

▶ (Re-) **Design** it to get "better shape and size": (same as the photodiode part described above). Then, **Build** & **Test** as above. 🖫②③(1,0)

2.4 Amplifier

Amplification is necessary when the signal amplitude is low. This is usually the case for signals from photodiodes. Phototransistors have internal amplification (current gain, h_{FE}) due to its npn structure and do not require external amplification for the purpose of this lab. For photodiodes, it is possible to increase the signal amplitude by increasing the surface area, but this is impractical in most cases. Amplification is thus needed for photodiodes. In this lab, the aim of the amplifier is to increase $V_{p\text{-}p}$ at ③ such that it is enough to drive the output stage later. The amplifier is a two-stage (cascaded) *common-emitter* (CE) BJTs as shown in Fig. 4. The basics of CE amplifier has been covered in 2102386 and will not be repeated here. The first of the CE stage uses a pnp BJT (Q3, 2N3906), the second uses an npn BJT (Q4, 2N3904). This serves to familiarize students with both types of BJTs though in practice you can use just one type to simplify life.

Success with CE amplifiers rests on two **design** rules: bias and bias. First, the *input bias* (the voltage divider R5, R6 for Q3; R7, R8 for Q4) must be appropriate. This means V_{BE} for npn (or V_{EB} for pnp) must be sufficient to turn the transistor on (~0.7 V). Second, the *output bias* (R_E, R_C) must provide gain (R_C/R_E > 1).

▶ **Build** the two-stage amplifier as shown in Fig. 4. **Design** (determine R's) the first stage to have a gain of 5, the second 10 (thus effective gain of 50). **Test** it: use a Function Generator or the oscilloscope ("GenOut" BNC, press "WaveGen" to configure) to produce a sinusoidal waveform (Vp-p = 100 mV, 5 kHz) and apply at the input of the amplifier ③. Record the waveforms at the outputs (collectors) of the first ④ and second ⑤ stage. 🖫③④⑤

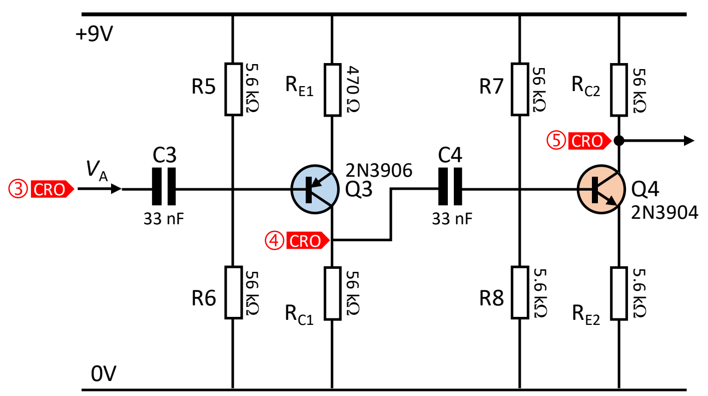

Fig. 4. Two-stage (cascaded) common-emitter amplifier.

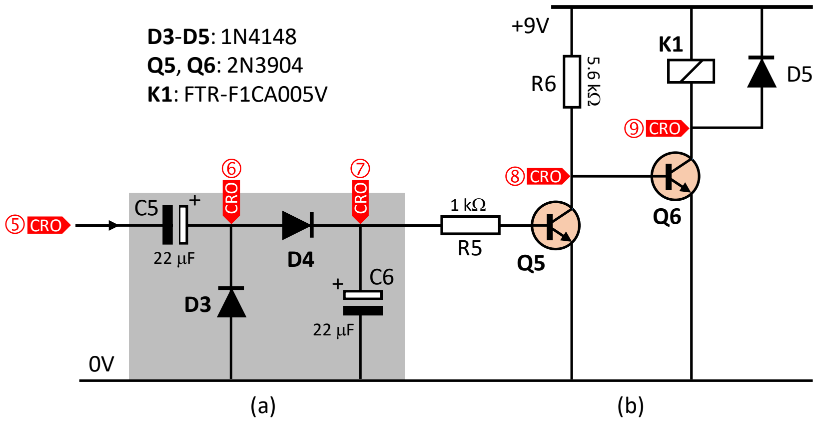

Fig. 5. (a) Rectification and smoothing circuit, also known as a *voltage doubler* (shaded). (b) Relay driver circuit (unshaded). Only the coil side of the relay (K1) is shown.

2.5 Rectification and Smoothing

The rectification and smoothing circuit shown in Fig. 5(a) receives a waveform from the previous stage (⑤), then rectifies, doubles the amplitude, and smoothens the signal. This *voltage doubler* circuit is just one implementation of *voltage multipliers* [5-6]. It is used here to provide a sufficient dc voltage to drive Q5 of the next stage.

▶ **Build** the rectification and smoothing circuit as shown in Fig. 5(a). **Test** it: apply a 5-kHz sinusoidal wave at the input of the rectifier. Record the waveforms before ⑤ and after the rectification and smoothing ⑦ when the amplitude is small (Vp-p = 1 V), medium (Vp-p = 3 V), and large (Vp-p = 5 V) 🖫⑤⑦

2.6 Relay driver

The relay driver receives the dc voltage (from the smoothing circuit, ⑦) and uses it to switch the transistor Q5 on-off via the bias resistor R5. Q5 then switches Q6 off-on (note the phase reversal). The output of Q6 drives the relay K1. On-off switching of the relay input (a coil) creates back EMF which can be large (Lenz's law: $E = -d\phi/dt$) and damage the drive transistor Q6 unless protected by a diode (D5).

▶ **Build** the relay driver as shown in Fig. 5(b). **Test** it: apply various dc bias (say 0.5V, 1V, 1.5V) at its input (R5) and listen for the clicking sound of the electromagnet contact. What is the minimum voltage required to switch the relay?

2.7 Relay output

The relay is an electromagnet switch: a current through its input coil generates a magnetic field which attracts or repels a lever. There are many types of relays. We will use the *double pole double throw* (DPDT) type as pictured in Fig. 6(a). The schematic in Fig. 6(b) shows the following terminals: the control coil (4,5), COM for common (2,7), NO for normally open (1,8), and NC for normally closed (3,6). The two outputs (NO and NC) can be used to drive two complementary events (cannot occur at the same time). To appreciate this, let's play.

▶ **Build** the relay circuit as shown in Fig. 6(c). **Test** it: apply various dc bias (between 0.5-9V) across the coil (4,5), listen (for the clicks), watch (the LEDs on alternately, 🎥⓿), and think (of how it works).

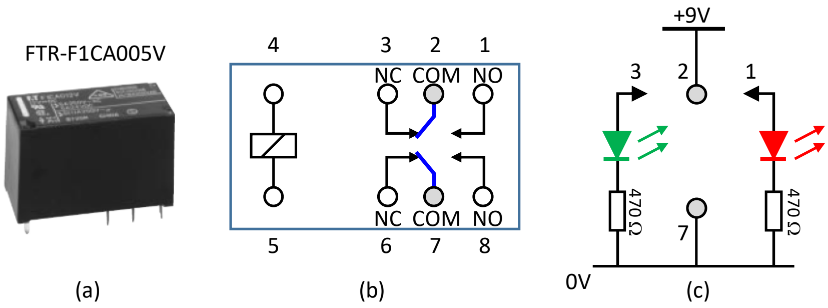

Fig. 6. Fujitsu's DPDT relay (FTR-F1CA005V) (a) picture, (b) schematic, and (c) sample connection with two LEDs that can be switched on one at a time.

▶ Answer three questions:

1. If initially the relay is not operating (COM-NC), what's the minimum voltage required to operate the relay (COM-NO)?
2. If initially the relay is operating (COM-NO), what's the minimum voltage required to release the relay (COM-NC)?
3. How does the circuit work?

3. System

This section requires you to integrate everything. Now that you understand all the components of the BBS, and the basic operation of the relay, let's put all the blocks together and make it work.

Putting all the blocks together, assuming each and every block works, is simple. You can put all the blocks in the previous section in the order 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7 in case the expected signal amplitude is low (photodiode) and you need amplification. Or remove 2.4 (Amplifier) if the expected signal amplitude is high (phototransistor).

Making it "work" is up to the designer (you). You must decide (**design**) *what* action(s) to take when the beam is broken. This depends on *why* the beam is broken. Four scenarios:

1. Sound warning. The system is to be installed at a vault in a bank. You want a warning sound when a line is crossed. Suggested output device: *buzzer*.
   ▶ Study the buzzer datasheet, experiment with it (make it buzz, but not too loud: load it by putting a suitable R in series), note the bias (I,V), integrate it into the relay output (the remaining pins #6,8). Record it in action 🎥❶
2. Sound welcome. The system is to be installed at the entrance to your cave. You want a pleasing sound to lure your victims. Suggested output devices: *loudspeaker* driven by a *musical chip*.
   ▶ Study the datasheets, experiment with them (make the loudspeaker sing "Small World"), integrate everything into the relay output (the remaining pins #6,8) 🎥❷
3. Mechanical motion. The system is to be installed at a garage, as a car approaches, the system detects it, switches the motor which then lifts the door. Suggested output device: *motor*.

▶ Study the datasheet, experiment with it (make it spin, but not too fast: load it by putting a suitable R in series), note the bias (I,V), integrate it into the relay output (the remaining pins #6,8) ❸

4. Number counting. The system is to be installed at a production line. You want to count the number of boxes that whiz pass a certain point. Suggested output device: *7-segment display* driven by a *BCD-to-7-segment decoder/driver* (74LS47) which is in turn driven by a *decade and binary counter* (74LS390).
   ▶ Study the datasheets, Google the Internet, experiment with them (make the 7-segment display count up with each control pulse into the SN74LS390), integrate everything into the relay output (the remaining pins #6,8) ❹
   ▶ (Re-) **Design** the number counting module in order to remove the relay (and its bouncing contacts during switching). ❺

You are free to design, copy a design, or even copy and improve on a design from the Internet (provide web links).

4. Miscellaneous

This section gives you some practical advice and pieces of useful information.

Resistors are rated by value in Ohm, precision, and maximum wattage (1/4W, 1/2W, 1W, typical). It is important to choose the correct values with sufficient wattage (I^2R) otherwise it will be damaged.

Capacitors are rated by value in Farad (pF, nF, μF), precision, and maximum voltage. Since the positive rail in this lab is 9V, all Cs should be rated at least 10V, to be on a safe side. Capacitors can be non-polar (both leads are equivalent) or polar (one of the lead marked with a minus sign). Electrolytic capacitors are polar and the marked (negative) terminal must be connected to the minimum voltage point (usually GND).

Inside **relays**, large currents can be switched on and off without arcing or sparks (fire hazard). Relay provides a convenient means of separating the control electronics (low power) from the output circuitry (medium or high power). This function is similar to an *optocoupler*. When relays are mishandled (dropped), the hermetic seal can be broken yet the switching mechanism may survive. This is the most dangerous situation if it is fitted in a flammable environment (oil rig) it may cause fire or explosion.

Protoboard wirings. Convention: use black wires for GND, red for the positive supply rail (V_{CC} or +9V in most circuits in this lab). Recommendation: use Color1 *inside* each building block, use Color2 *between* building blocks. Color1 ≠ Color2 ≠ (black, red). "Convention" is universal, adopted by all EEs. "Recommendation" is personal, adopted here to allow lab supervisors (and you) to quickly locate problematic components.

Power Supply operates in either *constant voltage* (CV) or *constant current* (CC) mode. In CV mode, the supply outputs a voltage V equal to the setting ($V = V_{set}$), if (I repeat, if) the circuit does not consume current beyond the current limit setting ($I < I_{limit}$). If a device is damaged or a circuit is faulty it may short circuit and draw the maximum current ($I = I_{limit}$), in this case the actual output voltage will be less than the voltage setting ($V < V_{set}$) and the power supply is said to operate in the CC mode. However, operation under CC mode does not always mean that the circuit/device is faulty.

Optical alignment. The emitting surface (LED) and the detecting surface (LDR, photodiode, photodetector) should be properly aligned to obtain strong signal. Study the radiation pattern of the light source, and the expected angle of incidence of the detector.

5. Parts List

The table below lists major parts and brief descriptions. For detail, refer to the datasheets provided in a separate PDF [7].

Part #	Description
Discretes	
1N4148	diode (Si), small signal 100V/200mA
2N3904	transistor, BJT, npn 40V/0.2A
2N3906	transistor, BJT, pnp 40V/0.2A
PT10LV10102A2020	potentiometer, 0.15W, 1 kΩ±20% 1 Turn, Top Adjustment
PT10LV10103A2020	potentiometer, 0.15W, 10 kΩ±20% 1 Turn, Top Adjustment
Integrated Circuits	**(ICs)**
NE555	Timer IC
74LS390	decade and binary counter
74LS47	BCD-to-7-segment decoder/driver
M66T-68-L3	IC Melody, Transistor Type, "*Small World*" song
Optoelectronics	
TOL-30AUREDAA-U4M	LED, red, 630 nm, Round 3 mm,150 mcd
TOL-30AUGBCAA-U4M	LED, green, 574 nm Round 3mm, 1000 mcd,
TOIR-50B94BCEA	LED, infrared (IR), 940 nm, 5mm, V_F = 1.45 V, I_F = 100 mA
SFH 213FA	photodiode
TOPS-050TB2	phototransistor
KE-10715	light-dependent resistor (LDR)
Output Devices	
FTR-F1CA005V	relay 5V coil
TOD-2281BG-4G	7-Segment, 2 Digit, Common Anode, 0.28", Green Segment 570 nm
OBO-1206C-A2	buzzer, Magnetic Transducer 6Vdc/Current Max 30mA
QP50CP08-66-R	Speaker, Waterproof, Diameter 50mm, 8Ω/1W
TRE-280SA	Motor, Vibration, 12V DC, Load Speed 4150 rpm

6. Plans & Submission

Students are expected to submit results at the end of each week:
Week 1: upto topic 2.3 (Detector | Phototransistors)
Week 2: upto topic 2.6 (Relay driver)
Week 3: everything (System integration).

Before you submit, check that 1) the snapshots are appropriate (see Fig. 7), 2) the clips embedded in the pdf file can be played (see Fig. 8), and 3) the file is a pdf (not docx). Failure to follow these simple warnings will affect your scores.

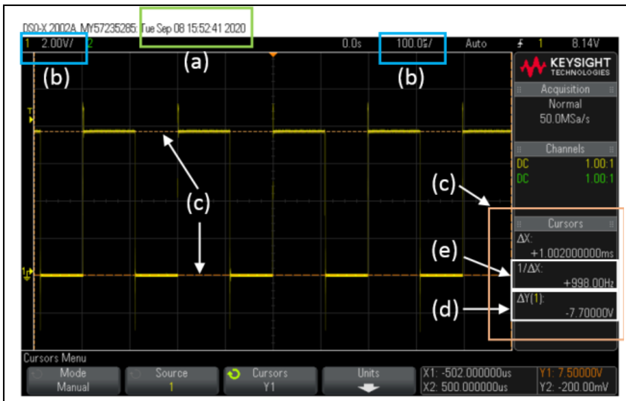

Fig. 7. Screenshot taken by the CRO, clearly showing (a) timestamp, (b) scales, (c) cursors, and measured values (for example (d) peak-to-peak voltage and (e) frequency). (See the footnote on page1.)

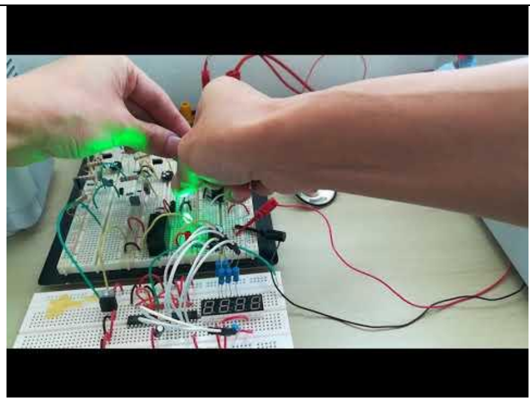

Fig. 8. Example of Movies/link uploaded to cloud, and accessible via pdf (this file)

7. Summary

Students get hands-on and design experience with *Broken Beam Systems* using ICs and discretes, diodes and transistors, electronics and optronics, sound and motors, analog and digital parts. These are key elements in EE systems. The most valuable part of this lab exercise is the opportunity to integrate disparate parts into a seamless whole.

8. Acknowledgement

This experiment is inspired by R. A. Penfold [8]. Suggestions can be included in the Results & Discussion part when you submit. Or you can email suggestions to songphol.k [at] chula.ac.th.

9. References

[1] http://www.ti.com/lit/gpn/na555
[2] https://spectrum.ieee.org/static/chip-hall-of-fame
[3] https://electronicsclub.info/555astable.htm
[4] http://www.ohmslawcalculator.com/555-astable-calculator
[5] http://www.creative-science.org.uk/multipliers.html
[6] http://www.electricalbasicprojects.com/voltage-multiplier-circuits-half-wave-voltage-doubler
[7] The datasheets are taken mostly from a local distributor https://www.es.co.th. Some manufacturers provide very detailed datasheets and instruction, some very little.
[8] R. A. Penfold, *Practical opto-electronic projects*, Bernard Babani (1994).

Version History

2024/3 (R4, this version), 2023/11 (R3), 2023/1 (R2), 2021/1 (R1), 2019/8 (R0, Original release)

Faculty of Engineering, Chulalongkorn University

2102-447 Electronics Engineering Laboratory

Broken Beam System

Section ____ Group ____ Week ____ *

Members

Name	ID

*Possible values: Section (1-3), Group (1-12), Week (1-3). When uploading reports into CourseVille, name your files accordingly; e.g. S1G2W3.pdf for Section 1, Group 2, containing results for Week 3.

Date Submitted:......................................

Results & Discussion

Table 1. Wavelength-energy-voltage relationship

color	wavelength λ (nm)	energy E (eV)[1]	voltage (V)[2]
green	570		
red	630		
infrared (IR)	940		

[1] Planck relation: $E = hc/\lambda$
[2] built-in voltage (V_o) across a semiconductor p-n junction that can emit such λ

2.1 Oscillator

▶ 5-Hz oscillator

R1 = …………………, R2 = …………………, C2 = …………………… (5 Hz)

🖫① Actual frequency: …… Hz (from CRO | Cursors | 1/Δx)

▶ 5-kHz oscillator

R1 = …………………, R2 = …………………, C2 = …………………… (5 kHz)

🖫① Actual frequency: …… Hz (from CRO | Cursors | 1/Δx)

2.2 Buffer Amplifier

▶ **Design** (determine R3)

Parameters	**Red LED on**	**IR LED on**
Transistor state	on	on
V_{CE} (V), (see Q1 datasheet)		
I_{LED} (mA)	20	20
V_{LED} (V), (see Table 1)		
R3 (Ohm), (use KVL)		

▶ **Build** & **Test**: red LED blinks at 5 Hz

🎥 :

💾①②

The CRO screen shows two waveforms, put labels onto the waveforms to identify what they are measuring. Do this throughout the report.

Actual values:

R3: Ω

Vertical scale for trace ①: V/div

Vertical scale for trace ②: A/div (hint: I = V/R3)

Frequency: Hz (CRO | Cursors | 1/Δx)*

$I_{LED\text{-}On}$ (red): mA (Δy/R3, CRO | Cursors | Δy)*

*CRO shows the distance between two horizontal (vertical) cursors as Δx (Δy)

▶ **Build** & **Test**: IR LED blinks at 5 Hz

🎥 :

▶ **Build** & **Test**: IR LED blinks at 5 **k**Hz

🖫①② $I_{LED\text{-}On}$ (IR): mA (from Δy: V, R3: Ω)

2.3 Detector

Reminder: Best results are achieved in the dark (light-tight box/setup)

▶ **Build** & **Test**: *LDR* detecting red LED blinking at 5 Hz

🖫②③(1)	🖫②③(0)

Increase the LED blink frequency to 5 kHz.

🖫②③(1)	🖫②③(0)

Discuss: (frequency limitation, why so low?)

▶ **Build** & **Test**: *photodiode* detecting IR LED blinking at 5 kHz

Original Design as shown in Fig. 3(b): R3 = …700Ω…….., R4 = …56 kΩ…….

🖫②③(1)	🖫②③(0)
rise time t_r: ; fall time t_f: $V_{p\text{-}p}$(③):	

Improved Design: R3 = …………….., R4 = ……………….

🖫②③(1)	🖫②③(0)
rise time t_r: ; fall time t_f: $V_{p\text{-}p}$(③):	

Discuss 1: ("improved design" vs "original design", really "improved"? how & why)

…

Discuss 2:
(frequency performance comparison: photodiode above vs LDR the previous page)

…

▶ **Build** & **Test**: *phototransistor* detecting IR LED blinking at 5 kHz

Original Design as shown in Fig. 3(c): R3 = …………….., R4 = ……………….

🖫②③(1)	🖫②③(0)
rise time t_r: ; fall time t_f: $V_{p\text{-}p}$(③):	

Improved Design: R3 = …………….., R4 = ……………….

🖫②③(1)	🖫②③(0)
rise time t_r: ; fall time t_f: $V_{p\text{-}p}$(③):	

Discuss 3:

(signal amplitude comparison: phototransistor vs photodiode vs LDR results, your results)

…

2.4 Amplifier

▶ **Design**

1st stage (gain = 5):   R5 = ………, R6 = …………., R_{C1} = ………., R_{E1} = ………….

2nd stage (gain = 10): R7 = ………, R8 = …………., R_{C2} = ………., R_{E2} = ………….

▶ **Build** & **Test** it: note ③ = sinusoidal wave (Vp-p (input) = 100 mV, 5 kHz).

🖫③④

Results 2.4.1: (Output from the *first* amplifier stage only; do <u>not</u> connect the second stage)

DC level:

ac amplitude (V_{p-p} (output)):

ac gain, measured (V_{p-p} (output) / V_{p-p} (input)):

ac gain, theoretical:

🖫③④

Results 2.4.2: (Output from the *first* amplifier stage when connected to the second stage)

DC level:

ac amplitude (V_{p-p} (output)):

ac gain, measured (V_{p-p} (output) / V_{p-p} (input)):

ac gain, theoretical:

🖫③⑤

Results 2.4.3: (Output from the *second* amplifier stage; both stages connected as in Fig.4)

DC level:

ac amplitude (V_{p-p} (output)):

ac gain, measured (V_{p-p} (output) / V_{p-p} (input)):

ac gain, theoretical:

Discuss: (amplitude/phase relationships between outputs and input, the gains in 2.4.1-2.4.3)

2.5 Rectification and Smoothing

For direct visual comparison between both channels (⑤,⑦), set the signal ground at the same level, and set the vertical scale to be identical.

▶ **Build** & **Test** it:

🖫⑤⑦ when Vp-p = **1** V, 5 kHz at ⑤

🖫⑤⑦ when Vp-p = **3** V, 5 kHz at ⑤

🖫⑤⑦ when Vp-p = **5** V, 5 kHz at ⑤

Discuss: (do you agree with the name "*voltage doubler*"? why or why not?)

2.6 Relay driver

▶ **Build** & **Test** it

The minimum voltage required to switch the relay: …………

2.7 Relay output

▶ **Build** & **Test** it:

DC voltage at switching threshold: ………………V

VDO shows that only one LED is on at any moment, and by manually sweeping the DC voltage across the threshold, the two LEDs switch states

▶ Answer three questions:

1. …………..V
2. …………..V
3.

3. System

(upload videos to cloud, then in MS Word: Insert > Media > Online Video)

1. Sound warning: buzzer

❶ VDO shows when the beam is broken, the buzzer sounds the alarm

2. Sound welcome: *loudspeaker* driven by a *musical chip*

❷ VDO shows when the beam is broken, the speaker sings

3. Mechanical motion: *motor*

❸ VDO shows when the beam is broken, the motor spins

4. Number counting: *7-segment display*, 74LS47, 74LS390

❹ Original Design (with Relay)
VDO shows when the beam is broken, the display counts up (possibly with errors)

❺ Improved Design (without Relay)
VDO shows when the beam is broken, the display counts up (without errors)

4. Conclusion

Version History

2024/3 (Revised 3, this version), 2023/11 (Revised 2), 2021/1 (Revised 1), 2019/7 (Original release)

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