EE313 ANALOG ELECTRONICS LABORATORY

2024-2025 FALL TERM PROJECT

Introduction:

This document contains the project definition of the EE313 laboratory. Here are the important points about the project:

• Note that this is not a weekend project. You should start working on it as early as possible. If you would like to test your designs, you can use the equipment in the EE313 lab during scheduled hours. The lab availability schedule will be announced later.

• The aim of this project work is to make you more familiar with some subjects you were introduced to in analog electronics class. However, you may need to do some research and study extra materials to accomplish the task. This will be a good first step towards the 4th year graduation projects.

• The project groups will contain at most 2 students. Although it is not recommended, you may do your project alone. So, you are encouraged to determine your project partner as soon as possible. It is not necessary that your lab partner and project partner are the same person.

• You are free and encouraged to use your own ideas. Although your design approach is not limited, the systems are supposed to be economical.

• You are not required to implement your circuit designs on a printed circuit board. Doing so will not increase your grade, nor will it negatively affect your grade. But your projects should have an organized look (even a circuit on a protoboard can have an organized look).

• The primary contact mechanism for the project is the forum on ODTUClass.

• Early demonstrations are possible and encouraged. Please contact one of the following assistants in advance for scheduling. Mehmet Ali Kumral (alikum@metu.edu.tr), Ömer Faruk Dalaslan (ofarukd@metu.edu.tr), Seral Buse Atak (ataks@metu.edu.tr).

Important Dates, Deliverables, and Grading:

-January 3rd, 23:59: Proposal Report	(10%)
-January 21-23rd: Project Demonstrations	(50%)
-January 20th, 23:59: Video Presentation	(5%)
-January 20th, 23:59: Final Report Submissions	(35%)

Report Format

Proposal Report: The aim of the proposal report is for you to start your research early on so that you can have a solid idea about the project. A good report should include your proposed way to solve the problem, the equipment required for the solution, some block diagrams of the overall system, and any additional info (circuit schematics, mathematical calculations, etc.) you see fit. The maximum page limit for the proposal report is 3 pages without including the cover page (Times New Roman, 10 pt). Longer reports will be rejected. You have to upload your proposal report in PDF format to ODTUClass until the **3rd of January, 23:59**. Late submissions will not be accepted.

Final Report: The final report should be in the IEEE double-column paper format, and it should not exceed 10 pages in total; any more pages will decrease your grade. The formatting is one of the most important parts of the final report. **If the final report is not in IEEE double-column paper format, it will not be graded.** Any formatting mistake (such as no figure captions, no referral to the figure in your main text, no introduction, no conclusion, etc.) will result in a grade deduction. You have to upload your final report in PDF format to ODTUClass by the **20th of January, 23:59.** Late submissions will not be accepted. Your report should include the following items:

- Theoretical background and literature research,
- Design methodology and mathematical analysis of the subsystems,
- Simulation results verifying that your subsystems and overall system are working properly,
- Experimental results,
- Comparison of the experimental results with the simulation results and mathematical calculations, and explanation of any discrepancies.

Project Definition

Design of an Optical Wireless Communication System: Photophone

Background & Motivation: Optical wireless communication (OWC) is a wireless communication method that utilizes visible, infrared, or ultraviolet light in an unguided manner to transmit and receive data. Wireless communication typically employs radio frequency (RF) bands in the range of kHz–GHz of the electromagnetic (EM) spectrum. Common examples are AM & FM radio, TV broadcasting, cellular phone communication, and Wi-Fi links. Moving from the RF band to optical parts of the EM spectrum brings multiple advantages and possibilities in certain applications. These include having a very large bandwidth and the ability to operate in EM-sensitive areas such as aircrafts. Note that the wired version of optical communication is fiber optics, and it is currently widespread.

Interested readers are encouraged to look online for keywords: Optical wireless communication, Free-space optical communication, Li-Fi, and Photophone. Also, see the article in the footnote[1].

In 1880, Alexander Graham Bell invented the first wireless telephone system, realizing the transmission of speech through the modulation of a light beam: the photophone. According to Bell, it was his most important invention. Its operation relies on the shape modulation of a mirror attached to a flexible material upon which the speaker's voice is directed. In this project, you will design and implement a modified version (a reimagination) of Bell's photophone by electrical modulation of transmitted light using analog electronics.

Aim: To design and implement an optical wireless communication system as depicted in Figure A1 (Appendix 1) schematically. First, a quick summary is given:

1. The system will include two main parts: transmitter and receiver.
2. The speech signal generated in the microphone should be converted into an electrical audio signal.
3. There is a constant high-frequency reference signal summed with the audio signal: multiplexing.
4. This multiplexed signal should be converted into an information-preserving modulated light signal and then transmitted through air by the optical transmitter module.
5. The modulated light will be received, and the optical information will be converted back into the speech signal and reference signal in the optical receiver module: demultiplexing.
6. The recovered audio signal should be amplified and converted into sound by a speaker.
7. Depending on the amplitude level of the recovered reference signal, a measure of signal strength (or the degree of transmitter-receiver coupling) will be determined and indicated.

A comprehensive explanation of each module is as follows:

Microphone: There are different types of microphones on the market. Most of the microphones you will use are resistive microphones. Its resistance changes with the intensity of the sound. You need to convert resistance change into voltage. If you are using a different type of microphone, you should use different approaches. You can use any microphone that does not have integrated drive circuitries.

[1] M. Uysal and H. Nouri, "Optical Wireless Communications – An Emerging Technology", 16th International Conference on Transparent Optical Networks (ICTON), Graz, Austria, July 2014

Microphone Driver with Gain Control: You need to drive the microphone in order to convert the sound vibrations into an electrical audio signal. Since the output of the microphone is distance and frequency dependent, you need a configuration that controls the gain and adjusts the amplitude of the microphone signal. Mostly, the frequency response of microphones is not sharp, and the output amplitude of microphones changes with time as well as the distance of the sound source to the microphone. High-amplitude signals can exceed the AC operating range of the light sources and cause clipping; please refer to Appendix 2 for more information. To obtain a relatively constant amplitude audio signal, the gain of the amplifier should be controlled by a configuration of your choice.

One way to achieve these desired characteristics is using an automatic gain controller (AGC) circuit. The AGC technique is frequently used in communication systems to maintain a consistent signal strength level. Even though using AGC in your design is recommended, you can use other solutions to keep the amplified sound signals within the desired range.

Although the frequency range of human voice is from 80 Hz to 14 kHz, narrowband telephony only uses a portion of up to 3.4 kHz. You will use this narrow portion of the bandwidth. Therefore, you may need some low-pass filtering before the addition of the high-frequency reference signal, so that the audio signal and the reference signal do not overlap in the frequency spectrum.

Summation with the Reference Signal: You will add a constant-amplitude, high-frequency reference sine wave to your 3.4 kHz bandwidth audio signal. This reference signal will be taken from the signal generator. At the receiver, the amplitude of this signal will be treated as the measure of signal strength (like in cellular phones) since it is constant[2]. Any decrease or increase detected in the receiver will be the indicator of the degree of coupling of transmitted light into the receiver.

Optical Transmitter and Receiver Modules[3]: You need to convert the electrical signal to a modulated light signal in the transmitter and vice versa in the receiver stage. The modulated light should travel through the air. For the emission of the light in the transmitter, you can use lasers and LEDs. For detection of the light in the receiver, you can use photodiodes and phototransistors. The receiver and transmitter modules should be compatible with each other. For example, if you send visible light and try to use an infrared-sensitive detector, the system will not work.

Low-Pass Filter (LPF): The output of the optical receiver includes both the reference signal and the audio signal. For the audio amplifier and speaker part, we only need the audio signal that was obtained from the microphone. Therefore, you need to implement a low-pass filter that filters out the reference signal.

Power Amplifier (Audio Amplifier): Before you amplify the audio signal you obtained, you should buffer the signal. Note that the amplified signal should not be clipped. To achieve 1W, you need to use power transistors and maybe power resistors. Also, the speaker output should include a volume control unit on the receiver, allowing for convenient adjustment of sound levels for the user listening to the audio.

High-Pass Filter (HPF): The output of the optical receiver includes both the reference signal and the audio signal. For the signal level indicator part, we only need the reference signal information. Therefore, you need to implement a high-pass filter that filters out the sound information.

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[2] Note that the amplitude of an audio signal cannot be used for signal strength directly because speech waveforms change in amplitude and frequency as people talk. Or, in pausing instances, there is no talk at all.

[3] See Appendix 2 for a discussion on light emission and detection.

Signal Level Indicator: Depending on the amplitude information of the reference signal, the reception of your system (signal level) must be displayed by using a single RGB LED display. Think of these cases as the signal bars in cellular phones. There must be different colors representing the cases as follows:

- **(i)** no signal,
- **(ii)** weak signal,
- **(iii)** moderate signal,
- **(iv)** good signal,
- **(v)** excellent signal.

Full Specifications

Note that the following are complete and concise specifications for the project. They assume that you have fully understood the content of the project. Please read the previous explanations first.

- The microphone has to be driven with a **gain control** circuit. Without proper control of the gain, the audio signal may experience clipping when the amplifier is overdriven by a large input signal. Clipping occurs when the output amplitude exceeds the limits of the amplifier, flattening the waveform peaks. This not only distorts the signal but also introduces high-frequency harmonics, which degrade the overall quality of the transmitted audio.

- The output of the microphone driver in the transmitter should have a bandwidth that includes frequencies between 300 Hz to 3.4 kHz. You can decrease and increase the cutoffs of low-frequency (even down to 0 Hz) and high-frequency of your filter, **respectively**. Increasing the high-frequency cutoff too much is not recommended since you might have an overlap between audio and reference signals. (i.e. You might need some low-pass filtering before the addition of the high-frequency reference signal.)

- The reference signal will be supplied from the signal generator. The frequency you can use is between **10 kHz–30 kHz**. You can use **any amplitude**. The reference signal will be added to the audio signal.

- From the transmitter, you will send a modulated light that contains the audio signal and the reference signal. This modulated light should contain two different pieces of information by using frequency-division multiplexing. In the frequency domain, you will have a low-frequency audio signal component and a high-frequency reference signal component. This corresponds to summation in the time domain.

- At the receiver, you will pick up the modulated light and convert it to an electrical signal. Since this signal contains two different pieces of information in different frequency bands, you need to separate them by using an LPF and an HPF. This can be called frequency-division demultiplexing. From the LPF, we get the audio signal. From the HPF, we get the reference signal. Note that you can also use band-pass filtering if you like.

- For the optical transmitter, you can use **only**:
    - Visible light lasers whose power is **smaller than 5 mW**.
    - Visible light LEDs of any color.
    - Infrared LEDs with low power.

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CAUTION!

➢ Ultraviolet and infrared lasers of any power are **strictly forbidden!**

➢ Visible light lasers generating a power greater than 5 mW are **strictly forbidden!**

➢ Any experimentation with such instruments will be treated as a violation of laboratory safety rules, and **disciplinary action** will follow.

SAFETY FIRST!

➢ **Do not look** right into the infrared LEDs, ever!

➢ **Do not look** into any laser!

➢ **Do not stare** into the diffused light of a laser on a surface!

➢ **Do not direct** the laser on any **reflective surface** for the safety of other students present in the lab!

➢ **Do not modify or remove** the lens of the laser!

➢ Infrared, visible, or ultraviolet electromagnetic radiation, in sufficient concentrations, can cause damage to the human eye. Since infrared and ultraviolet radiation cannot be detected by the human eye, they pose a greater risk: **The blink reflex does not work!**

➢ The lab and its management are **not responsible** for any injuries or damage resulting from improper use of equipment or failure to follow the safety guidelines provided.

➢ It is the responsibility of each student to ensure they adhere to these precautions to maintain their own safety and the safety of others in the lab.

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- For the optical receiver, you may use:
  - Photodiodes
  - Phototransistors

Note: Typical light-dependent resistors (LDR) cannot switch fast enough to detect either the audio or the reference signal. You may use solar cells IF you can find one that can switch reasonably fast enough to sense the high-frequency reference signal. However, the use of solar cells is discouraged because typical silicon ones might have a wide switching speed of 1 µs to 1 ms. So, solar cells are not recommended.

- The modulated light should travel through the air. The minimum distance between your transmitter and receiver should be **at least 20 cm**. It is highly suggested that you use a tube, box, or similar enclosure to cover your light emitter and detector. This setup helps block environmental and background light interference and reduces the risk of hazardous exposure to the light source.

- The filtered audio signal should not contain the components of the high-frequency reference signal and vice versa. In order to accomplish this, you might need to have a sharp frequency response for the LPF and HPF filters.

- Overall, the recovered audio and the reference signal should not have a significant harmonic distortion. For example, if we send a pure sine waveform from the microphone input, we should get an almost pure sine waveform at the same frequency at the receiver end.

- The gain of the previous stages should be arranged such that the input signal of the audio amplifier is not clipped. **The frequency response of the audio amplifier should be flat between 300 Hz and 3.4 kHz**. Output power of **1 Watt** must be obtained.

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CAUTION!

Please note that components such as power amplifiers may dissipate too much power and be too hot to touch during operation. You may consider passive cooling solutions such as heat sinks.

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- Depending on the amplitude level of the reference signal, your receiver should indicate the signal strength in 5 different cases: (i) no signal, (ii) weak signal, (iii) moderate signal, (iv) good signal, and (v) excellent signal. These cases should be indicated by a **SINGLE RGB LED**. Each case should be discrete so that the transition between any case should be abrupt (digital transition). Think of it as signal bars in your cellular phones. You should determine the threshold voltages for each of the 5 cases from (i) to (v) by considering the amplitude of the reference voltage and overall receiver gain.

- If the reference signal is smaller than a certain threshold, your circuit should indicate (i) no signal, and the speaker should be turned off. Any buzzing sound should not be present at the output. Think of this case as a no incoming call, so that the photophone is turned off.

- Your speaker output should have a volume control on the receiver end[4].

- If the audio signal gets clipped at any stage in the receiver, your receiver should indicate it by using another LED (different than the RGB LED signal level indicator). Clipping occurs when signal amplitude at any time reaches the supply voltages.

Components Allowed:

- You can use any microphones that do not have integrated drive circuitries.
- You can use <u>general-purpose</u> op-amps, any transistor (BJT, MOSFET, JFET, etc.), regulators, diodes, resistors, capacitors, inductors, light-dependent resistors, LEDs, and relays.
- You are **NOT** allowed to use audio op-amps.
- For components of the optical transmission and receiving part, please refer to the "Full Specifications" part of this manual.
- The instruments available in the laboratory. (Maximum allowed DC Voltage: ±15 Volts).
- If you are not sure whether you can use a component you are considering, please verify this by mailing the assistants before using it.

Remarks

- This project is proposed in a modular fashion. If you have trouble designing or implementing some parts of it, attend to other parts instead. Partial credit will be given.

If you use a laser diode for your transmitter:

- Just buy a cheap, low-power laser (**visible light, power < 5 mW**). They can switch fast enough for this project.
- In order for a laser diode to emit light, a certain current level should be supplied: threshold current. After the threshold current is reached, linear lasing starts.
- Pay attention to the coupling of the laser into your detector. A small displacement of the laser beam can cause large changes in the amount of received power.

[4] Depending on the signal level, you are allowed to modify the gain of your receiver manually. However, this gain adjustment should be easy and practical. For example, by switches, potentiometers, etc.

- In certain cases, a large intensity of laser beam can easily saturate the detector response, especially if you use phototransistors. Take proper care and either decrease the output power, the transmitter-receiver coupling, detector responsivity, or detector gain.
- The light should not be reflected back into the laser. You might observe a large distortion in the output power. This is because the laser operation is quite different from LEDs. A small tilt angle between the detector and the laser should resolve the issue.

And we would like to remind the cautions one more time:

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CAUTION!

➢ Ultraviolet and infrared lasers of any power are **strictly forbidden!**
➢ Visible light lasers generating a power greater than 5 mW are **strictly forbidden!**
➢ Please note that components such as power amplifiers may dissipate too much power and be too hot to touch during operation. You may consider passive cooling solutions such as heat sinks.
➢ Any experimentation with such instruments will be treated as a violation of laboratory safety rules, and **disciplinary action** will follow.

SAFETY FIRST!

➢ **Do not look** right into the infrared LEDs, ever!
➢ **Do not look** into any laser!
➢ **Do not stare** into the diffused light of a laser on a surface!
➢ **Do not direct** the laser on any **reflective surface** for the safety of other students present in the lab!
➢ **Do not modify or remove** the lens of the laser!
➢ Infrared, visible, or ultraviolet electromagnetic radiation, in sufficient concentrations, can cause damage to the human eye. Since infrared and ultraviolet radiation cannot be detected by the human eye, they pose a greater risk: **The blink reflex does not work!**
➢ The lab and its management are **not responsible** for any injuries or damage resulting from improper use of equipment or failure to follow the safety guidelines provided.
➢ It is the responsibility of each student to ensure they adhere to these precautions to maintain their own safety and the safety of others in the lab.

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APPENDIX 1

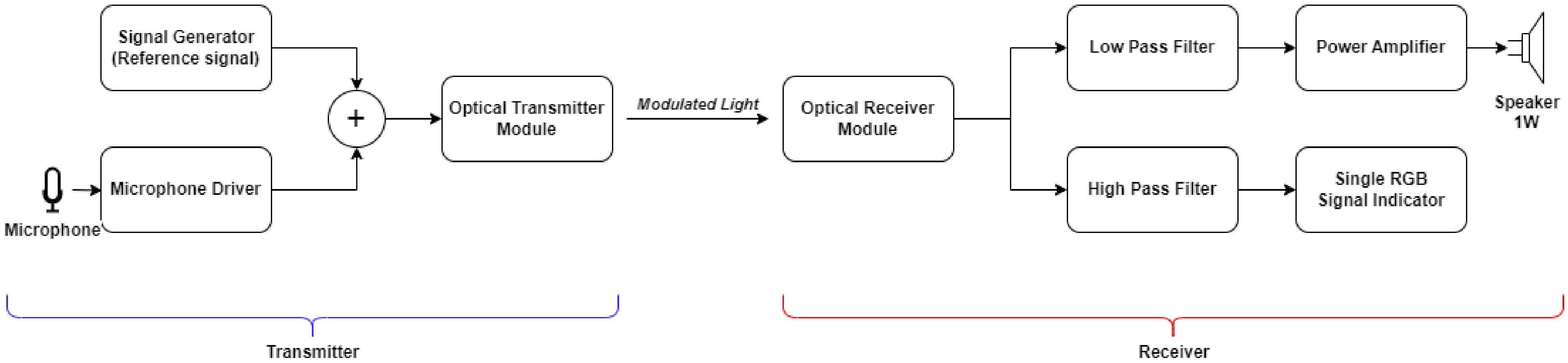

Figure A1. *Block Diagram of the Photophone*

APPENDIX 2

In this part, the input-output characteristics of lasers and LEDs are discussed.

Optoelectronic light-emitting devices are controlled by the means of injected electrons in general. Therefore, the light intensity is somewhat linearly dependent on the current, NOT the voltage. In Figure A2, typical LED current-voltage (a) and current-light intensity (b) plots are given.

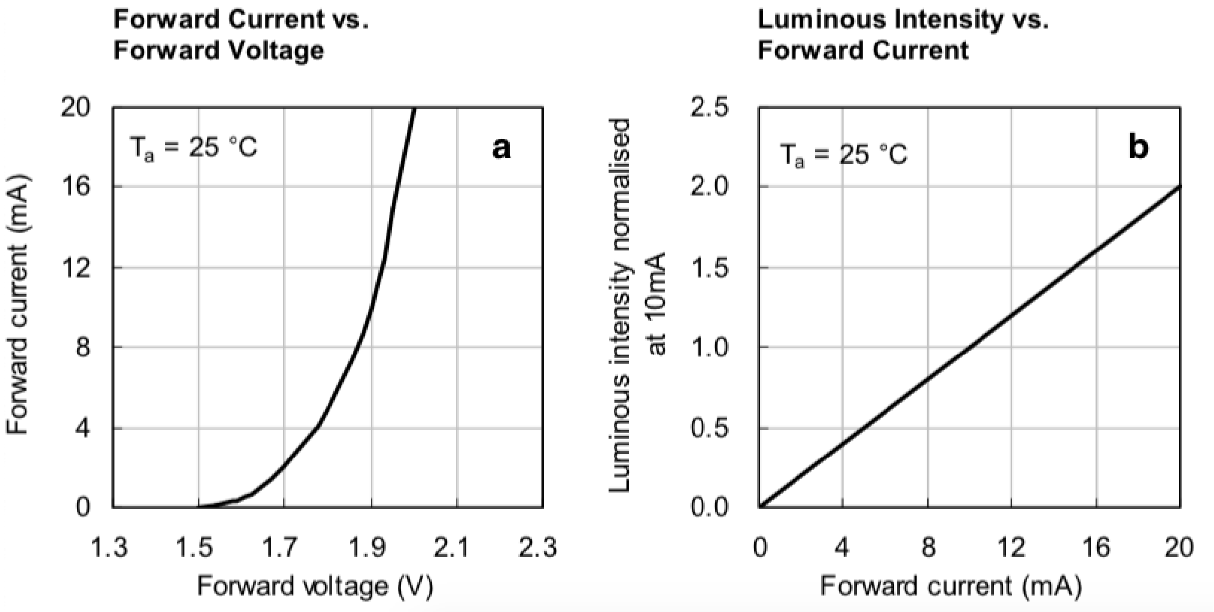

Figure A2. *Current-voltage (a) and current-light intensity (b) characteristics of a typical LED*

As you observe, the current-voltage relation is strongly non-linear since it is in fact a diode. However, the light intensity is linearly related to the applied current.

Similarly, Figure A3 depicts the typical diode laser current-voltage (a) and current-light intensity (b) characteristics. Again, the current-light intensity characteristics are linear (after a certain bias current).

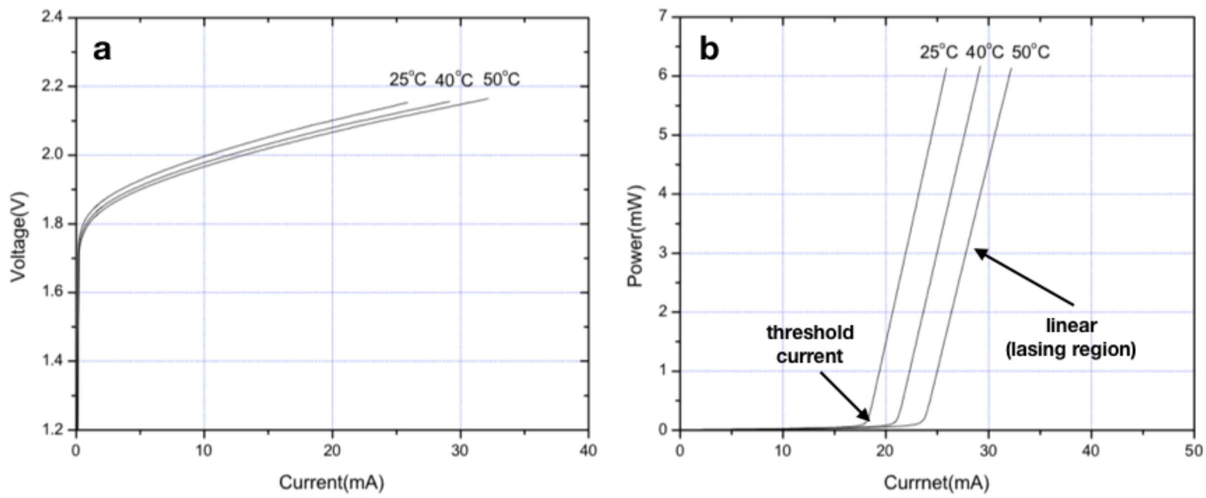

Figure A3. *Current-voltage (a) and current-light intensity (b) characteristics of typical laser diode*

For both cases of LED and laser, the light intensity is proportional to the current, NOT the voltage. Therefore, it is strongly suggested that you use a current driving method. In the same manner, you will pick up the modulated light by sensing the current generated in the photodiode or phototransistor at the receiver stage. For this purpose, please study transconductance and transimpedance amplifiers.

Another important note is that, since laser diodes and LEDs exhibit rectifying behavior, they emit light in the forward bias. Therefore, you might need to have a DC bias current on top of your AC signal (audio + reference). See Figure A4 for a graphical explanation. Note that this explanation is just an example.

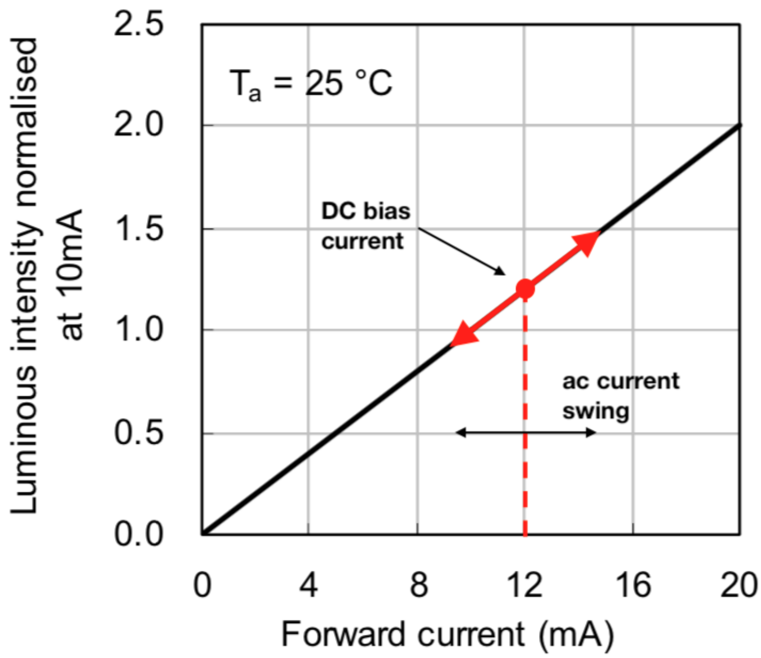

Figure A4. *Graphical depiction of DC biasing of an LED*