EE313 ANALOG ELECTRONICS LABORATORY

2018-2019 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. Start working on it now. If you would like to test your designs, you can use the equipment in the EE313 lab in working hours unless there is a laboratory session proceeding. During weekends, laboratory will be closed.

• The aim of this project work is to make you more familiar with some subjects you were introduced in analog electronics class. However, you may need to do some research and study extra material to accomplish the task. This will be a good first step for 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, determine your project partner as soon as possible. It is not necessary that your lab partner and project partner is 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 and you do not have to mount your circuits into a box. Doing so will not increase your grade, but nor will it negatively affect your grade. But your projects should have an aesthetic look (even a circuit on protoboard can have an aesthetic look).

• All assistants are responsible for the project. Primary contact mechanism with the assistants is via email.

•No early demonstration will be allowed (apart from the crucial reasons, such as Erasmus, foreign student, etc.).

Important Dates:

-28th December: Proposal Report

-19-20th January: Project Demonstrations

-22th January 17:00: Final Report and Video Submissions

Table of Contents

Report Format 3
Proposal Report 3
Final Report 3
Project Video 3
Grading 3
Project Definition 4
Aim 4
Module Definitions 4
Microphone 4
Microphone Driver with AGC 4
Summation with the Reference Signal 5
Optical Transmitter and Receiver Module 5
Low-Pass Filter (LPF) 5
Power Amplifier (Audio Amplifier) 5
High-Pass Filter (HPF) 5
Signal Level Indicator 5
Full Specifications 6
Components Allowed 8
Remarks 8
APPENDIX 1 10
APPENDIX 2 11

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. This report will contain preliminary work on your 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. Maximum page limit for the preliminary report is 3 pages (Times New Roman, 10 point font). Longer reports will be rejected. It is crucial that you determine your project partner, and do some brain storming to come out with solutions well before the preliminary report deadline. You have to upload your proposal report in pdf format to ODTUCLASS until 28th of December, 23:59. Late submissions will not be accepted.

Final Report: The final report should be in the IEEE double column paper format (please check the IEEE 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 project. If the final report is not in the IEEE paper format, the project will not be graded, and you will get zero from the whole project. Any formatting mistake (such as no figure captions, not referral to the figure in your main text, etc.) will result in grade deduction. You have to upload your proposal report in pdf format to ODTUCLASS until 22th of January, 17:00. 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 is working properly.
- Experimental results
- Comparison of the experimental results with the simulation results and mathematical calculations and explanation of any discrepancies.

Project Video: Each group must submit a video about their project. This video must be in English. The evaluation of the video will be based on the oral skills not the technical situation of the project. You do not have to show a working project. The explanation of the overall project, the solution method, and the final situation of the project are the main criteria. The total time of the video should be around 5 minutes and each group member must talk in this duration.

Grading

-Proposal Report: 10 pts

-Project Demonstrations: 50 pts

-Final Report: 40 pts

Project Definition

Design of an Optical Wireless Communication System: Photophone

Optical wireless communication (OWC) is a communication form using an unguided visible, infrared or ultraviolet light to transmit and receive information wirelessly. Wireless communication typically employs radio frequency (RF) bands in the range of kHz–GHz of electromagnetic (EM) spectrum. Common examples are AM, FM radio and TV broadcasting, cellular phone communication and Wi-Fi links. Moving from 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 ability to be operated under 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, Photophone. Also see the article in footnote[*].

In 1880, Alexander Graham Bell invented the first wireless telephone system realizing the transmission of speech through the modulation of a light beam: 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 parts: transmitter and receiver.
2. The speech signal generated in microphone should be converted into an electrical audio signal.
3. There is a constant 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 the sound by a speaker.
7. Depending on the amplitude level of recovered reference signal, a measure of signal strength (or the degree of transmitter–receiver coupling) will be determined and indicated.

Module Definitions

Microphone: There are different types of microphones in 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 which do not have integrated drive circuitries.

Microphone Driver with AGC: You need to drive the microphone in order to convert the sound vibrations into electrical audio signal. Since, the output of the microphone is distance and frequency dependent, you need an automatic gain controller (AGC) that controls gain and adjusts the amplitude of microphone signal: Mostly, frequency response of microphones is not sharp and output amplitude of

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

microphones change with time as well as distance of the speaker (person) to the microphone. To obtain a relatively constant amplitude audio signal, gain of the amplifier should be automatically controlled by the AGC.

Although the frequency range of human voice is from 80 Hz to 14 kHz, narrowband telephony only uses the portion of 300 Hz to 3.4 kHz. You will use this narrow portion of the bandwidth. Therefore, you will need some low-pass filtering before the addition of the high-frequency reference signal, so that the audio signal and the reference signal does not overlap in 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 the cellular phones) since it is constant[*]. 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 Module[†]: You need to convert the electrical signal to modulated light signal in the transmitter and vice versa in the receiver stage. The modulated light should travel through the air. For 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 module should be compatible with each other. For example, if you send visible light and try to use and infrared sensitive detector, the system will not work.

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

Power Amplifier (Audio Amplifier): Since you are using a loudspeaker, you should buffer the audio signal. The incoming signal should not be clipped. You will need to use power transistors (and maybe power resistors) at the output stage.

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

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. There must be different colors representing the cases (i) no signal, (ii) weak signal, (iii) moderate signal, (iv) good signal and (v) excellent signal. Think these cases as the signal bars in cellular phones.

After the explanation of each block, the full specifications follow:

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[*] Note that the amplitude of 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.

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

Full Specifications

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

- Microphone have to be driven with an **automatic gain controlled (AGC)** circuit. The signal level at the receiving loudspeaker should be relatively independent of the speaking person's loudness.

- The generated audio signal in the transmitter should have a bandwidth that includes[*] 300 Hz–3.4 kHz. **In worst case, you need to have a bandwidth of 300 Hz–3.4 kHz.**

- 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**. 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 information by using frequency-division multiplexing. In frequency domain, you will have a low-frequency audio signal component and a high-frequency reference signal component. This corresponds to summation in 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 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 LPF, we get audio signal. From HPF, we get 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.

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.

DANGER! **Do not look** right into the infrared LEDs, ever. **Do not look** into any laser. **Do not stare** into the diffused light of 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

[*] Note: You can decrease and increase the cutoffs of low-frequency and high-frequency, **respectively**. Increasing high-frequency cutoff too much is not recommended since you might have an overlap between audio and reference signal. You might need some low-pass filtering before the addition of the high-frequency reference signal.

human eye. Since the infrared and ultraviolet radiation cannot be detected by the human eye, they pose a greater risk: Eye blink reflex does not work.

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

- The modulated light should travel through the air. The minimum distance between your transmitter and receiver should be **at least 20 cm**. However, you can use a tube, box, etc. to enclose your light-emitter and detector. By this way, you can eliminate the environment and background light noise.

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

- Overall, the recovered audio and 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.

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

CAUTION! Please note that these components may dissipate much power and may be too hot to touch during operation.

- 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 cases 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 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 this case as a no incoming call, so that the photophone is turned off.

- Your loudspeaker output should have a volume control in the receiver end.

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* Note: Typical light dependent resistors (LDR) cannot switch fast enough to detect neither the audio nor the reference signal. You may use solar cells IF you can find one that can switch reasonably fast enough to sense 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, the solar cells are not recommended.

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

Components Allowed

- You can use any microphones which do not have integrated drive circuitries.
- You can use general purpose op-amps, any transistor (BJT, MOSFET, J, FET etc.), regulators, diodes, resistors, capacitors, inductors, light-dependent resistors, LEDs, relays.
- You are NOT allowed to use audio op-amps.
- For components of 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). You can use dual DC supply, but you cannot use the 6V terminal of the DC supply.
- If you are not sure whether you can use a component you consider, please contact Hande İbili (ibili@metu.edu.tr) or Cem Şahiner (csahiner@metu.edu.tr) before using it.

Remarks

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

If you use laser diode for your transmitter:

- Just buy a cheap, low-power laser (visible light, power < 5mW). They can switch fast enough for this project.
- In order for a laser diode to emit light, certain current level should be supplied: threshold current. After that current, linear lasing starts.
- Pay attention to the coupling of laser into your detector. Small displacement of laser beam can cause large change in the amount of received power.
- In certain cases, 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.
- 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 than LEDs.). Small tilt angle between the detector and the laser should resolve the issue.

And one more time:

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.

DANGER! **Do not look** right into the infrared LEDs, ever. **Do not look** into any laser. **Do not stare** into the diffused light of 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

* 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.

human eye. Since the infrared and ultraviolet radiation cannot be detected by the human eye, they pose a greater risk: Eye blink reflex does not work.

For further information, you should read provided reading material:

https://en.wikipedia.org/wiki/Laser_safety

APPENDIX 1

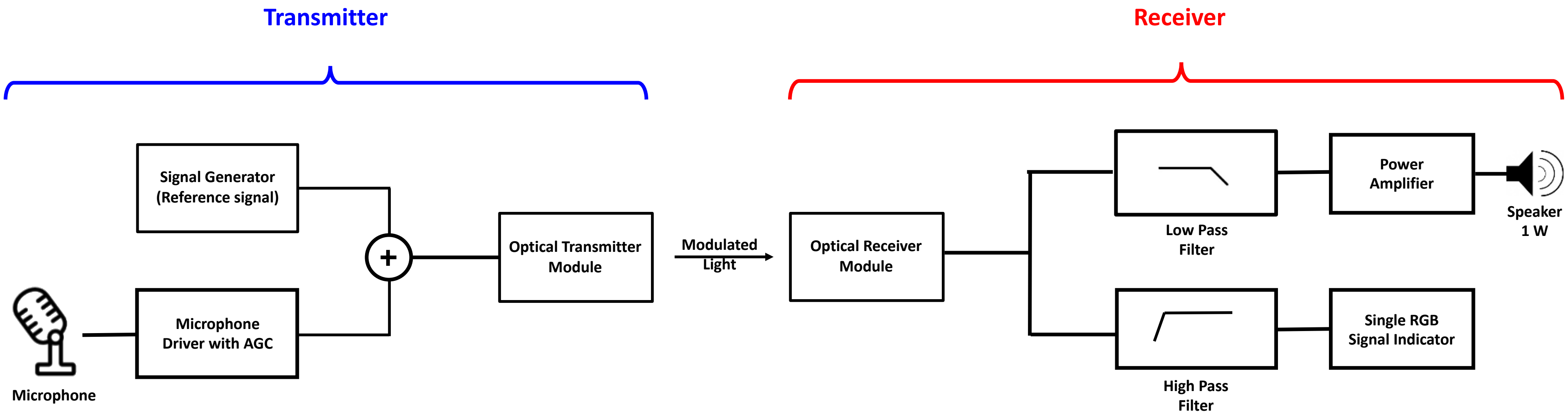

Figure A1. *Block Diagram of Photophone*

APPENDIX 2

In this part, 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.

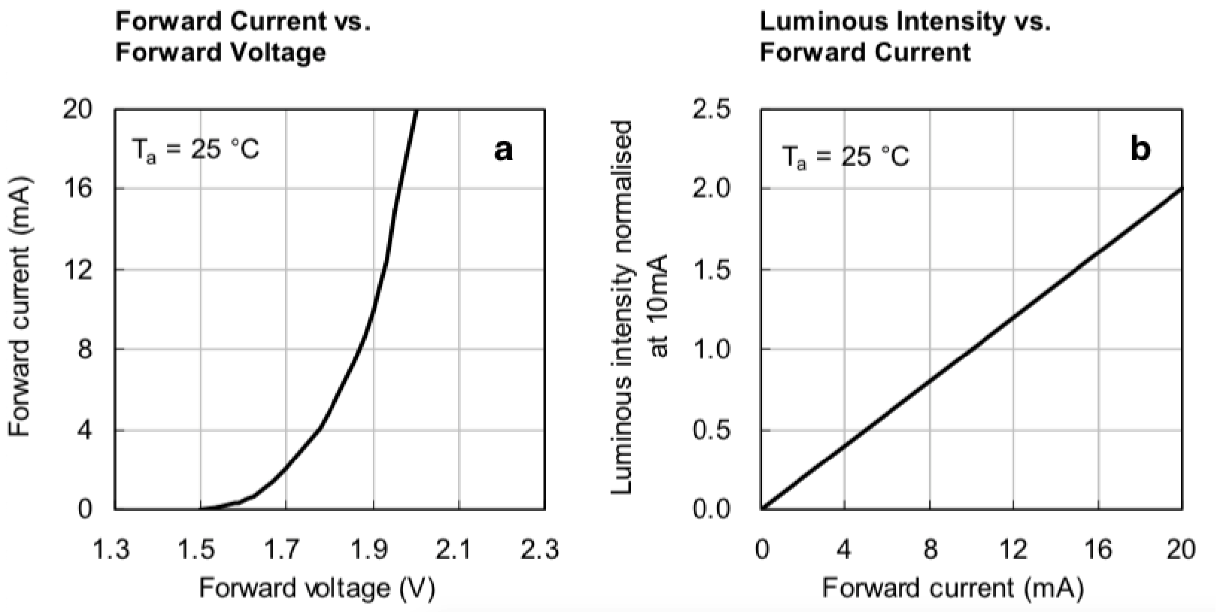

Figure A2, *Current–voltage (a) and current–light intensity (b) characteristics of a typical LED*

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).

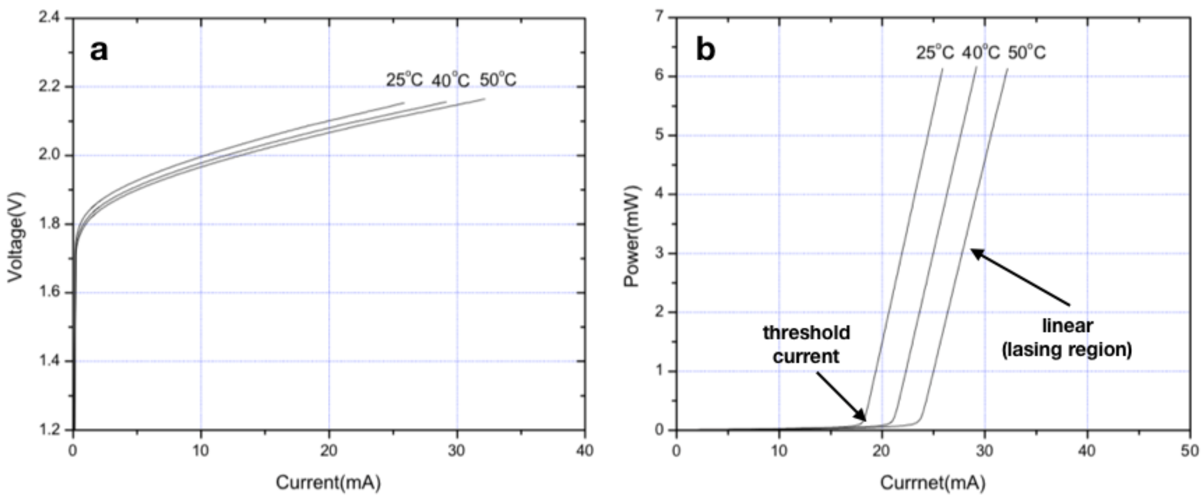

Figure A3, *Current–voltage (a) and current–light intensity (b) characteristics of typical laser diode*

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 + ref). See the Figure A4 for graphical explanation. Note that this explanation is just an example.

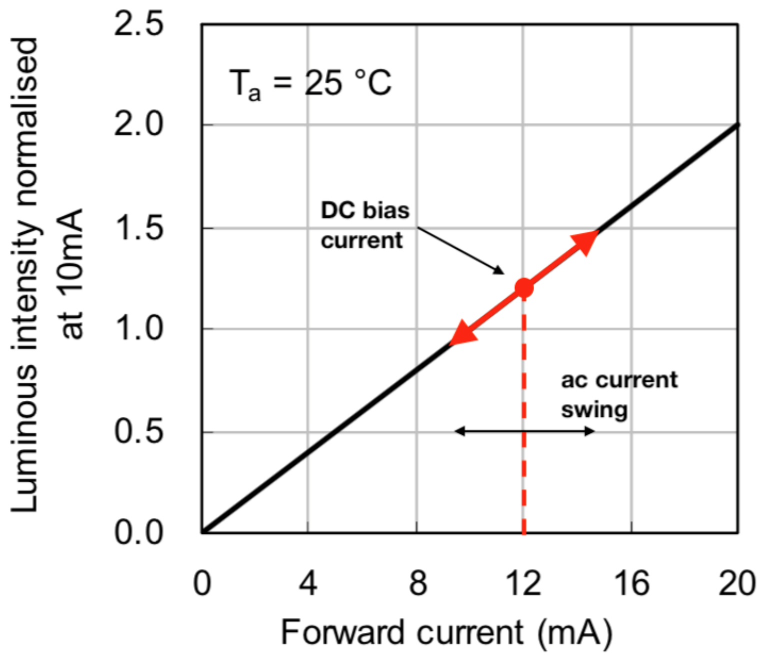

Figure A4, *Graphical depiction of DC biasing of an LED*