Lab 3

Design of Optical Communication System

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*Abstract*—We explored the trans-impedance amplifier, derived it’s closed loop gain and explained why it is unstable if there’s a finite capacitance Cpd. Then we simulated the circuit to verify our observations. Then we built a Optical Communication System with the components we designed.

Keywords—TransImpedance Amplifier; Optical Communication System; Analog Systems; Visible Light Communication; VLC;

Note — All graphs and figures also appended at the ending of this document for larger viewport. You can navigate there by clicking on the image.

# Introduction

Trans Impedance Amplifier is a current to voltage converter, most often implemented using an operational amplifier. The TIA can be used to amplify the current output of photo detector to voltage. The trans-impedance amplifier presents a low impedance to the photodiode and isolates it from the output voltage of the operational amplifier. [1]

# Analysis of the TIA

## Closed Loop Gain

The closed loop gain is A(s). β(s)

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| Fig. 1 – The Trans-Impedance Amplifier |

A(s) is the amplification when the feedback is removed. This is equal to AOL(s), the open loop gain.

β(s) is the fraction of output voltage that reaches the inverting pin of the amplifier.

This is equal to [Eq. 1a]

The loop gain is [Eq. 1b]

## The cause of instability

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Amplifiers have a -20dB slope after their 3dB frequency (Bandwidth). Like so

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| Fig. 2 – Frequency response of LM358 – Slope: -20 dB/dec |

The parasitic capacitance causes a zero that causes a slope of +20 dB/sec in the bode plot of 1/ β

The result is, Rate of Closure is -40 dB/dec, which is unstable as calculated from its phase margin. The ‘zero’ occurs because of the non-zero parasitic capacitance Cp, so the TIA is unstable when there is a finite Cp.

To make the TIA stable, a compensating capacitor Cf is connected in the feedback path.

## Simulation and Analysis

**AC analysis**

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| Fig. 3a – AC analysis of TIA  Bode plot of uncompensated TIA |

**Transient Analysis**

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| Fig. 3b – Transient analysis of TIA |

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| Fig. 3c – Ringing in an uncompensated TIA - Zoomed |

**Input Impedance**

Open-loop-gain of LM358 from ti.com [2] is 100 dB = 10^5

* On substitution, input impedance is close to 1.
* From Simulation .TF, the input impedance is 1.0005.

The value resultant from simulation is in agreement with the calculated value.

# Frequency Compensation

The gain peaks in AC analysis and the ringing in the Transient analysis [Fig 3b, and 3c] indicate instability of the TIA. To make the TIA stable, we compensate by adding a pole – a capacitor on the feedback path.

This pole counter-acts the effect of the zero caused by the parasitic capacitance Cp and makes slope of the Bode plot of 1/ β, 0. Making the Rate of Closure -20 dB/dec. This makes the TIA stable.

We add a feedback capacitor Cf. Finding the loop gain by splitting into A and β circuits. The A(s) of the circuit is same as the previous case – AOL. For β, there is another impedance in parallel with feedback resistance Rf. [Eq. 2a]

Now there is a pole and a zero and the Bode plot of the TIA looks like this:

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| Fig. 4 – Compensated TIA Bode plot [3] |

The frequency at the intercept is [Eq. 2b]

The equation 2b has two unknowns. The intercept frequency and the feedback capacitance. To solve for Cf, we need another simultaneous equation.

Since both the curves in Fig. 4 are at an absolute slope of 20dB/dec, the triangle is more or less isosceles, so the intercept frequency is the average of the other two vertices.

The frequency is in a logarithmic scale, so [Eq. 2c]

Ff being the frequency of ‘zero’ in the Bode plot of 1/ β andcan be calculated by finding the ‘zero’ frequency [Eq. 2d]

Since we know Gain-Bandwidth product of an amplifier is constant and gain at 0dB is 1, FU is the unity gain frequency of the amplifier.

The equation Eq. 2c can be rewritten as [Eq. 2e]

Solving the equations Eq. 2b and Eq. 2e, we get a quadratic equation, which on solving yields Cf [Eq. 2f]

According to TI.com [2], the gain-bandwidth product of LM358 opamp is 0.7 MHz So the unity gain frequency is 0.7 MHz

Our circuit uses a feedback resistance Rf = 100 K.

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| Fig. 5a – TIA circuit diagram – Ltspice |

Using the equation Eq. 2f, we calculate Cf to be 7.97 pF.

Simulating post compensation, we get

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| Fig. 4a – AC analysis of a compensated TIA |

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| Fig. 4b – AC analysis zoomed |

There are no gain peaks in the AC analysis showing that the amplifier is now stable. [Fig. 4a and 4b]

Similarly, on zooming on the transient analysis, we find the no ringing takes place after we added a compensating capacitor in the feedback loop. [Fig. 4c]

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| Fig. 4c – Transient analysis of a compensated TIA - Zoomed |

# Building an Optical Communication Circuit

Now that we know how to stabilize a TIA, we can build an optical communication circuit with an LED and a TIA connected across a photo diode.

The photo diode acts as a current source – producing current in proportion to the intensity of light it receives and the TIA converts this to voltage.

Using the same Rf and Cf values as in the previous section (100 K Ohm and 8 pF), we observed the output of the TIA for an input square wave of 1 KHz.

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| Lab%203/Oscilloscope_readings/Fw__Oscilloscope_readings/1knFile0.csv.png  Fig. 5a – TIA 1KHz |

The above is the plot [Fig. 5a] of 1 KHz input vs output at the TIA. After the TIA, a comparator is placed to get better output. Fig. 5b shows a 1KHz input vs the output collected at the comparator.

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| Lab%203/Oscilloscope_readings/Fw__Oscilloscope_readings/1kfFile0.csv.png  Fig. 5b – Comparator output – 1Khz |

And then we took samples at a few other frequencies to observe how the TIA behaved.

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| Lab%203/Oscilloscope_readings/Fw__Oscilloscope_readings/10kfile0.csv.png  Fig. 5c – TIA 10 KHz |

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| Lab%203/Oscilloscope_readings/Fw__Oscilloscope_readings/49kfile0.csv.png  Fig. 5d – Comparator output at 49 KHz |

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| Lab%203/Oscilloscope_readings/Fw__Oscilloscope_readings/50knile0.csv.png  Fig. 5e – TIA 50 KHz |

Then, the distance between the transmitter and the receiver is altered with a fixed input signal to study how the system is affected. We took readings at 3cm, 4cm, and 5cm.

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| Lab%203/Oscilloscope_readings/the_three/comp4cmtia.csv.png  Fig. 6a – TIA and comparator – 10 KHz & 3 cm |

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| Lab%203/Oscilloscope_readings/the_three/comp5cmtia.csv.png  Fig. 6b – TIA and comparator – 10 KHz & 4cm |

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| Lab%203/Oscilloscope_readings/the_three/comp6cmtia.csv.png  Fig. 6c – TIA and comparator – 10 KHz & 5 cm |

As expected, increase in distance produced more noise and distorted the signal. The decrease of intensity of light incident on the photodiode, as the distance increases is the reason for the reduced Signal to Noise Ratio.

*a**b*    

Note that the equation is centered using a center tab stop. Be sure that the symbols in your equation have been defined before or immediately following the equation. Use “(1),” not “Eq. (1)” or “equation (1),” except at the beginning of a sentence: “Equation (1) is ...”

## Some Common Mistakes

* The word “data” is plural, not singular.
* The subscript for the permeability of vacuum **0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter “o.”
* In American English, commas, semi-/colons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
* A graph within a graph is an “inset,” not an “insert.” The word alternatively is preferred to the word “alternately” (unless you really mean something that alternates).
* Do not use the word “essentially” to mean “approximately” or “effectively.”
* In your paper title, if the words “that uses” can accurately replace the word using, capitalize the “u”; if not, keep using lower-cased.
* Be aware of the different meanings of the homophones “affect” and “effect,” “complement” and “compliment,” “discreet” and “discrete,” “principal” and “principle.”
* Do not confuse “imply” and “infer.”
* The prefix “non” is not a word; it should be joined to the word it modifies, usually without a hyphen.
* There is no period after the “et” in the Latin abbreviation “et al.”
* The abbreviation “i.e.” means “that is,” and the abbreviation “e.g.” means “for example.”

An excellent style manual for science writers is [7].

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## Authors and Affiliations

The template is designed so that author affiliations are not repeated each time for multiple authors of the same affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization). This template was designed for two affiliations.

### For author/s of only one affiliation (Heading 3): To change the default, adjust the template as follows.

#### Selection (Heading 4): Highlight all author and affiliation lines.

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#### Deletion: Delete the author and affiliation lines for the second affiliation.

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#### Change number of columns: Select the “Columns” icon from the MS Word Standard toolbar and then select “1 Column” from the selection palette.

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Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include ACKNOWLEDGMENTS and REFERENCES, and for these, the correct style to use is “Heading 5.” Use “figure caption” for your Figure captions, and “table head” for your table title. Run-in heads, such as “Abstract,” will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

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### Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 1,” even at the beginning of a sentence.

1. Table Styles

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1. Sample of a Table footnote. *(Table footnote)*
2. Example of a figure caption. *(figure caption)*

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization,” or “Magnetization, M,” not just “M.” If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write “Magnetization (A/m)” or “Magnetization (A ( m(1),” not just “A/m.” Do not label axes with a ratio of quantities and units. For example, write “Temperature (K),” not “Temperature/K.”

##### Acknowledgment *(Heading 5)*

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g.” Avoid the stilted expression “one of us (R. B. G.) thanks ...”. Instead, try “R. B. G. thanks...”. Put sponsor acknowledgments in the unnumbered footnote on the first page.

##### References

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Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the reference list. Use letters for table footnotes.

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For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

1. https://en.wikipedia.org/wiki/Transimpedance\_amplifier

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To have non-visible rules on your frame, use the MSWord “Format” pull-down menu, select Text Box > Colors and Lines to choose No Fill and No Line.

1. <http://www.ti.com/product/LM358>
2. <https://www.maximintegrated.com/en/app-notes/index.mvp/id/5129>
3. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
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5. M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.