Transimpedance Amplifier (TIA) Design for 400 Gb/s Optical Fiber Communications

Maruf Newaz Ahmed

Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
In
Electrical Engineering

Dong S. Ha, Co-Chair
Kwang-Jin Koh, Co-Chair
Majid Manteghi

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Description of item under review for fair use: Figure 2: Modified transmitter and receiver, Behzad Razavi-"Design of Integrated Circuits for Optical Communications". Used under fair use 2013.

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Description of item under review for fair use: Figure 4: (a) Conversion of photodiode current to voltage by a resistor, (b) equivalent circuit for noise calculation, (c) effect of resistor value, Behzad Razavi-"Design of Integrated Circuits for Optical Communications". Used under fair use, 2013.

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Description of item under review for fair use: Figure 5: Common Gate TIA, Behzad Razavi-"Design of Integrated Circuits for Optical Communications". Used under fair use, 2013.

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Description of item under review for fair use: Figure 8: (a) Pseudo-differential CG stage, (b) output waveforms, Behzad Razavi-"Design of Integrated Circuits for Optical Communications". Used under fair use, 2013.

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Description of item under review for fair use: Figure 9: Single-ended to differential conversion, Behzad Razavi-"Design of Integrated Circuits for Optical Communications". Used under fair use, 2013.

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Description of item under review for fair use: Figure 10: (a) Modified regulated cascode, (b) Small signal equivalent of modified RGC, S. Bashiri, C. Plett, J. Aguirre and P. Schvan "A 40 Gb/s Transimpedance Amplifier in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp- 757-760, May 2010. Used under fair use, 2013.

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 11: Effect of Lf on the bandwidth of TIA, S. Bashiri, C. Plett, J. Aguirre and P. Schvan "A 40 Gb/s Transimpedance Amplifier in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp- 757-760, May 2010. Used under fair use, 2013.

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 12: En-In model for noise analysis, S. Bashiri, C. Plett, J. Aguirre and P. Schvan "A 40 Gb/s Transimpedance Amplifier in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp- 757-760, May 2010. Used under fair use, 2013.

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 13: Gain and noise comparison of the modified RGC with typical RGC and RGC with series peaking inductor , S. Bashiri, C. Plett, J. Aguirre and P. Schvan "A 40 Gb/s Transimpedance Amplifier in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp- 757-760, May 2010. Used under fair use, 2013.

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Description of item under review for fair use: Figure 14: Push-pull TIA proposed by by J. Kim and J. F. Buckwalter "A 40-Gb/s Optical Transceiver Front-End in 45 nm SOI CMOS", IEEE Journal of Solid-State Circuits, vol. 47, no. 3, pp. 1-4, March 2012. Used under fair use, 2013.

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Description of item under review for fair use: Figure 15: Simulated unity gain cut-off frequency for 45 nm SOI NMOS and PMOS devices [10], J. Kim and J. F. Buckwalter "A 40-Gb/s Optical Transceiver Front-End in 45 nm SOI CMOS", IEEE Journal of Solid-State vol. 47, no. 3, pp. 1-4, March 2012. Used under fair use, 2013.

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Description of item under review for fair use: Figure 16: Small signal model of push-pull TIA , J. Kim and J. F. Buckwalter "A 40-Gb/s Optical Transceiver Front-End in 45 nm SOI CMOS", IEEE Journal of Solid-State vol. 47, no. 3, pp. 1-4, March 2012. . Used under fair use, 2013.

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Description of item under review for fair use: Figure 17: Analytical results of transimpedance and group delay , J. Kim and J. F. Buckwalter "A 40-Gb/s Optical Transceiver Front-End in 45 nm SOI CMOS", IEEE Journal of Solid-State vol. 47, no. 3, pp. 1-4, March 2012. Used under fair use, 2013.

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Description of item under review for fair use: Figure 18: Simulated input referred noise current density J. Kim and J. F. Buckwalter "A 40-Gb/s Optical Transceiver Front-End in 45 nm SOI CMOS", IEEE Journal of Solid-State vol. 47, no. 3, pp. 1-4, March 2012. Used under fair use, 2013.

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Description of item under review for fair use: Figure 19: TIA core amplifier, S. T. Chou, S. H. Huang, Z. H. Hong, and W. Z. Chen "A 40 Gbps Optical Receiver Analog Front-End in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp.-1736-1739, May 2012. Under fair use, 2013.

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Description of item under review for fair use: Figure 20: Simulated frequency response of core amplifier, "A 40 Gbps Optical Receiver Analog Front-End in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp.-1736-1739, May 2012. Under fair use, 2013

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Description of item under review for fair use: Figure 21: Circuit schematic of TIA proposed by Chou et al. "A 40 Gbps Optical Receiver Analog Front-End in 65 nm CMOS", International Symposium on Circuits and Systems (ISCAS), pp.-1736-1739, May 2012. Used under fair use,2013.

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 22: Circuit schematic of TIA proposed by C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

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Factor 4

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 23: (a) Model of the RTRN, (b) simplified version, (c) final equivalent circuit C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 24: Model of the TRN, C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 25: Equivalent Ztot when resonance occurs at two different frequencies, C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

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Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

Draft 09/01/2009

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 26: (a) and (b) gain at for different , C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 14:53:58

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

Draft 09/01/2009

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 27: (a) and (b) gain at for different , C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

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Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

Draft 09/01/2009

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 28: for different , C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 – 655, March 2008. Used under fair use, 2013.

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Based on the information you provided:

Factor 1

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Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 29: Comparison of simulated frequency response of RTRN, TRN and TIA without inductor C. F. Liao and S. L. Liu, "40 Gb/s Transimpedance-AGC Amplifier and CDR Circuit for Broadband Data Receivers in 90 nm CMOS", IEEE Journal of Solid-State Circuits, vol. 43, no. 3, pp. 642 - 655 March 2008. Used under fair use, 2013.

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Based on the information you provided:

Factor 1

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Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 30: Series inter-stage inductor and equivalent small signal model, J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 14:58:22

Based on the information you provided:

Factor 1

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Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 31: Normalized transimpedance response of inductive series peaking pi-network with varying m, J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

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Based on the information you provided:

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Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

Draft 09/01/2009

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 32: Normalized group delay response of inductive series peaking pi-network with varying m, J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 15:03:27

Based on the information you provided:

Factor 1

Your consideration of the purpose and character of your use of the copyright work weighs: ***in favor of fair use***

Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 33: Circuit schematic of TIA proposed by J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 15:07:06

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Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 34: Small signal equivalent circuit of TIA proposed by J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 15:05:48

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Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 35: Simulation and analytical results of transimpedance response , J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 15:09:04

Based on the information you provided:

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Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*

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Name: Maruf Newaz Ahmed

Description of item under review for fair use: Figure 36: Group delay response of TIA, J. Kim and J. F. Buckwalter, "Bandwidth Enhancement with Low Group-Delay Variation for a 40-Gb/s Transimpedance Amplifier", IEEE Transactions on Circuits and Systems—I: Regular Papers, vol. 57, no. 8, pp.- 1964 – 1972, August 2010. Used under fair use, 2013.

Report generated on: 05-13-2013 at : 15:10:13

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Factor 1

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Factor 2

Your consideration of the nature of the copyrighted work you used weighs: ***in favor of fair use***

Factor 3

Your consideration of the amount and substantiality of your use of the copyrighted work weighs: ***in favor of fair use***

Factor 4

Your consideration of the effect or potential effect on the market after your use of the copyrighted work weighs: ***against fair use***

Based on the information you provided, your use of the copyrighted work weighs: *in favor of fair use*