REPORT DOCUMENTATION PAGE

Form Approved OMB NO. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
02-11-2017	Final Report	15-Jul-2016 - 14-Jul-2017

4. TITLE AND SUBTITLE
Final Report: DURIP: An Ultrafast Testbed for Comprehensive Characterization of Photonics, Electronic, and Optoelectronic Properties of Inegrated Nanophotonic Structures

5a. CONTRACT NUMBER
W911NF-16-1-0140

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
611103

6. AUTHORS

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES)
U.S. Army Research Office
P.O. Box 12211
Research Triangle Park, NC 27709-2211

10. SPONSOR/MONITOR'S ACRONYM(S)
ARO

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
68602-EL-RIP.1

12. DISTRIBUTION AVAILIBILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ali Adibi
UU	UU	UU	UU		19b. TELEPHONE NUMBER 404-385-2738

RPPR Final Report
as of 17-Nov-2017

Agency Code:

Proposal Number: 68602ELRIP **Agreement Number: W911NF-16-1-0140**
INVESTIGATOR(S):

Name: Ali Adibi Ph.D.
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DUNS Number: 097394084 EIN: 580603146
Report Date: 14-Oct-2017 Date Received: 02-Nov-2017
Final Report for Period Beginning 15-Jul-2016 and Ending 14-Jul-2017
Title: DURIP: An Ultrafast Testbed for Comprehensive Characterization of Photonics, Electronic, and Optoelectronic Properties of Inegrated Nanophotonic Structures
Begin Performance Period: 15-Jul-2016 **End Performance Period:** 14-Jul-2017
Report Term: 0-Other
Submitted By: Volker Sorger Email: sorger@gwu.edu
Phone: (202) 994-7186

STEM Degrees: **STEM Participants:**

Major Goals: In this DURIP program an ultrafast characterization testbed for the characterization of high-speed integrated photonic devices such as high-speed integrated photonic modulators and detectors was developed.

Accomplishments: Please see the attached report file.

Training Opportunities: Nothing to Report

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Ali Adibi
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

RPPR Final Report
as of 17-Nov-2017

Final Report: DURIP Grant Number: W911NF1610140
Sponsor: Army research Office (ARO), PI: Ali Adibi
Program Title: An Ultrafast Testbed for Comprehensive Characterization of Photonics, Electronic, and Optoelectronic properties of Integrated Nanophotonic Structures

I. Abstract

In this DURIP program an ultrafast characterization testbed for the characterization of high-speed integrated photonic devices such as high-speed integrated photonic modulators and detectors was developed. A major requirement in performing successful research in this field is the availability of ultra-fast optoelectronic characterization tools that facilitate the study of ultrafast low-power devices and systems (e.g., modulators, switches, detectors). This characterization set-up has been an enabling platform for development of ultrafast, compact, and low-power high speed optoelectronic devices under several DoD grants, including ARO-funded program for the development of ultrafast graphene-based modulators and several other programs supported by ONR, DARPA, and AFOSR. The developed characterization testbed has provided Adibi's group at Georgia-Tech with an integrated ultrafast characterization tools, which has greatly enhanced its capability in fast and accurate characterization of high-speed integrated optoelectronic for the study of the device physics and high-speed device optimizations. The tool is also available to other research group at Georgia-Tech and outside researches as a shared facility.

II. Characterization Setup and Budget

The high speed setup is realized by integrating high-speed characterization equipment to an already available photonic characterization setup. The following table details of the spent budget and the list of purchased equipment that are used in this setup. The extra $231.14 over the $145,000 budget was paid from the PI's chair account in the School of ECE, Georgia Tech.

Item	Part #	Description	Manufacturer	Vendor	Quant.	Unit($)	Price ($)
1	86100D	Infiniium DCA-X Oscilloscope Mainframe	Keysight	Keysight	1	$8,622.16	$8,622.16
2	N1045A	60 GHz 2/4 Port Electrical Remote Sampling Head	Keysight	Keysight	1	$28,716.88	$28,716.88
3	M8195A	Arbitrary Waveform Generator 65GSa/s	Keysight	Keysight	1	$85,866.87	$85,866.87
4	i50-GS-150	50 GHz infinity probe	Cascade	Cascade	1	$ 920.00	$ 920.00
5	IO-H-1550FC	IR Fiber Optic Isolator with SM Fiber	Thorlabs	Thorlabs	2	$188.00	$376.00
6	S7FC1013S	Benchtop Fiber-Coupled Semiconductor Optical Amplifiers	Thorlabs	Thorlabs	1	$2,720.00	$2,720.00
7	SPA-180-37-01-SMAA	300 MHz to 18 GHz, Medium Power Broadband Amplifier	Fairview Microwave	Fairview Microwave,	1	$4,999.00	$4,999.00
8		Cable and connectors		Fairview Microwave	1	$1,436.23	$1,436.23
9	XPDV2320R-VM-FP	50 GHz single photodetector	Finisar	XSoptix	1	$4,396.00	$4,396.00
10	2614B	Source Measurement Unit (SMU)	Keithley	Microlease	1	$6,364.00	$6,364.00
11	2614B-probe	SMU Probe	Keithley	Microlease	1	$814.00	$814.00
Total							$145,231.14

III. Supporting Information

III.A. High-speed optoelectronic characterization testbed for integrated nanophotonic structures

Figure 1 shows the schematic of the realized characterization testbed, which is used to measure the optical, electronic, and optoelectronic properties of an integrated photonic structure. The sample under test (SUT) placed on a highly functional 5D stage (with full positioning control over translation in three directions, rotation, and tilt. It is also monitored by a spatially designed microscope from the top that is connected to a camera to monitor different devices fabricated in the SUT (typically, 10s to 100s of devices are fabricated in a single substrate). On the optical side, the input light from a tunable laser source (in the optical communications wavelength window of 1450-1650 nm) is coupled into an integrated photonic waveguide on a chip either from the top (through a grating) or from the side (through a butt-coupled fiber). The light in the input waveguide will go through the photonic structure and will be coupled out either from the side (to a butt-coupled fiber) or from the top (through a grating into a fiber). The output light is analyzed by an ultra-fast detector or an ultrafast oscilloscope as shown in Figure 1. The testbed is capable of both input/output coupling formats with minimal modifications. By sweeping the wavelength of the input laser, the spectral characteristic of the device (e.g., resonance properties of a resonator or the transfer function of a filter) can be studied.

On the optoelectronic side, the electronic signal for modulating, tuning, or controlling the optical signal comes from a fast arbitrary wave generator (AWG) (65 GS/s M8195A Keysight), and it is applied to the photonic structure after the amplification by power amplifier (30 dBm Fairview Microwave SPA-180-37-01-SMAA) through the high speed probes (50 GHz Infinite Cascade i50-GS-150) as shown in Figure 1. The output optical signal of the nanophotonic (or plasmonic) is measured by first amplifying the optical signal using a low-noise optical semiconductor amplifier (SOA, 14 dBm gain Thorlabs S7FC1013S) and then detected by a high speed detector (50GHz, Finisar XPDV2320R-VM-FP). Finally, the output signal is sampled and detected using a high-speed sampling oscilloscope (60 GS/s Keysight 86100D with N1045A sampling head), which can provide time-domain and spectral information such as eye diagram and spectral transfer function of the device. The testbed in Figure 1 can also be used to characterize the electronic properties (e.g., current-voltage characteristics, resistance measurement, and capacitance measurement) of the integrated structures using the source measurement unit (SMU Keithley 2614B). Such measurements are very important in working with emerging materials such as graphene where the electronic properties (e.g., conductivity) have profound effects on the optoelectronic characteristics of the device (e.g., modulation speed of a photonic modulator). The electronic characterization is performed by using two high-speed probes for applying the desired voltage and measuring the resulting current. The developed testbed enables to characterize different electronic, (passive) photonic, and (active) optoelectronic properties of an integrated optoelectronic device/system. The implementation of the proposed set up was based on integration of high-speed RF/microwave signal generation/measurement equipment acquired through this DURIP program funding with a scanning laser characterization setup for integrated photonic devices that was already available in Adibi's lab. Adibi's lab is also equipped with a series on other high speed characterization equipment such as high-speed spectrum analyzers (20 GHz) and Network Analyzer (6 GHz) that can be used for supplementary characterizations.

The implemented high-speed characterization setup provides a high flexibility that can be used for different characterization configuration for different optoelectronic devices. Figure 2 shows the schematic of an example of such configurations for characterization of a high-speed modulators. Very similar architecture with the application of a wideband off-chip modulator can be used to characterize high-speed integrated photodetector structures or to measure the response of a high-speed optical signal processing platform. The same architecture also can be used to characterize high-speed optoelectronic systems such as optoelectronic oscillators (OEO) or high-speed optical signal processing systems. The same characterization system with a different configuration also ca be used to characterize all-optical signal modulation and switching based on nonlinear integrated optoelectronic devices. The high flexibility of the proposed testbed along with the ability to excite and detect the signals at very high speeds make the proposed testbed a unique tool that can facilitate the study of several state-of-the-art integrated photonic structures that are

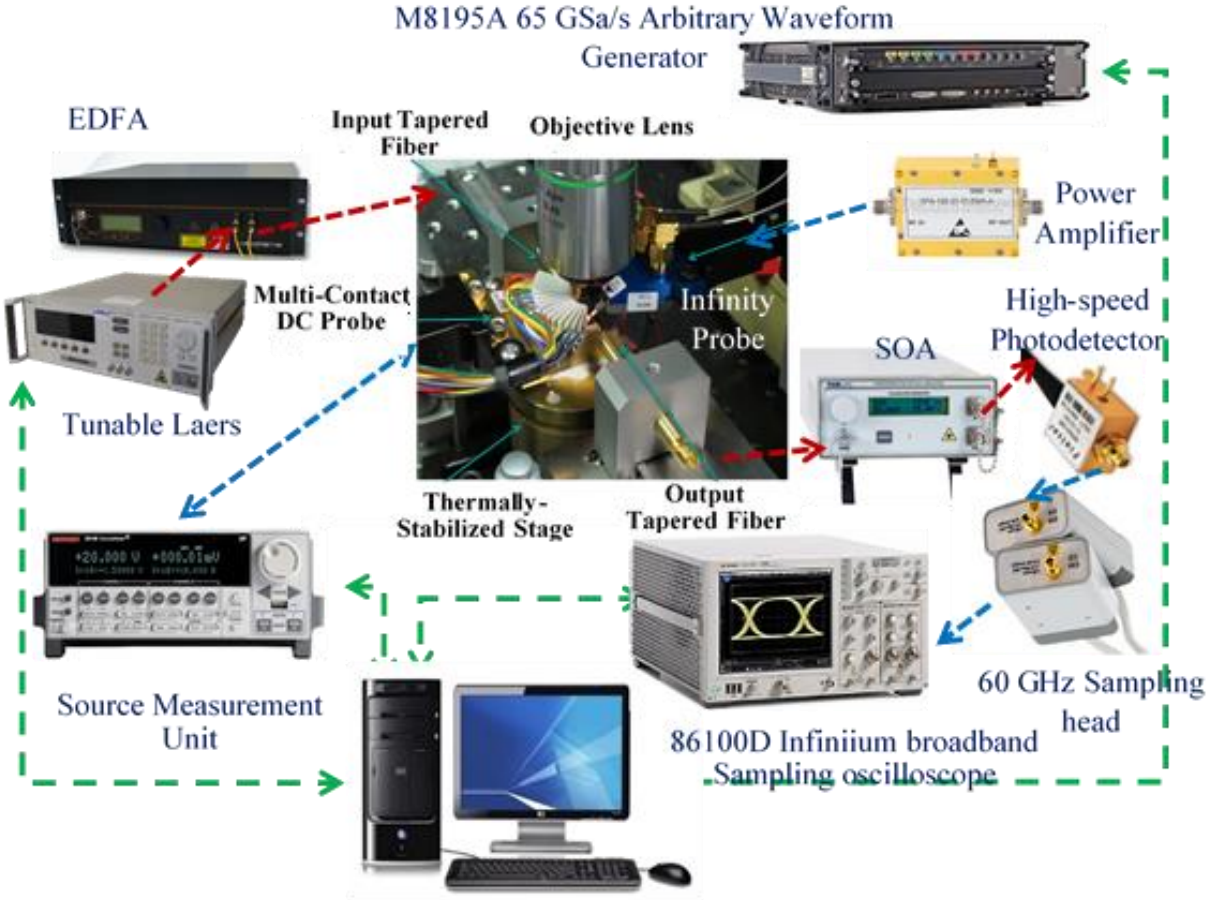

Figure 1. Schematic of the realized high-speed characterization setup with multi-contact and high-speed probes based on tapered fiber or grating input/output coupling. The output light from a wideband tunable laser, amplified by an EDFA, is used to excite the integrated optical structure through a tapered fiber or grating coupler. The output of the integrated photonic structure is amplified using as OSA and then coupled to a high-speed photodetector. The optoelectronic properties of the high-speed integrated photonic device including, the transmission spectrum and input/output characteristic of the integrated photonic device, I/V characteristic of the optoelectronic devices, the optoelectronic transfer function of the device is measured under different applied electrical voltages to the device. The temperature of the devices is controlled using a TEC with heating and feedback control. The RF/Microwave output of the AWG is amplified by a power amplifier and is applied to the optoelectronic device and output of the detector is measured by an ultra-wideband and low-jitter sampling oscilloscope.

of high demand for DoD applications. In addition, the proposed testbed can be utilized for the characterization of a large variety of electronic and photonic structures beyond integrated optoelectronic system.

III.B. Example of the characterization results for high-speed photonic device characterization

The developed characterization setup in Figure 2 was used to characterizes different modulators fabricated in our group including a low-power and high-speed modulator based on hybrid Si/SiN material platform (Figure 3.a). The developed hybrid Si/SiN modulator integrates high Q resonators in SiN with high-speed phase modulator in Si based carrier dispersion in vertical depletion-mode PN-junction-based modulators in Si waveguide to develop high-speed, low-power, and highly linear modulators based coupling modulation. The characterized devices have Q factors in the range of 7×10^4 to 2.1×10^5. The high RF characterization is done sing the setup in Figure 2, The isolated insertion loss of the modulator device is measured to be between 3 to 6 dB depending on the modulation depth level, and additional insertion loss is due to the input/output grating losses, which are not necessarily optimized to work at 1550 nm SCL telecom band. The setup is built in the synchronous mode, in which a reference clock synchronizes the bit pattern generated by AWG and the digital sampling scope. The AWG can generate different PRBS patterns, and here we mainly used NRZ PRBS (2^7-1 pattern) with tunable speed through clocking. As the design of the modulator implies, the device can be characterized in on-off-keying (OOK) mode, and therefore the detection can be simplified to use a high-speed photodetector directly fed into the sampling scope through a transimpedance amplifier (TIA) stage for electronic signal amplification and matching.

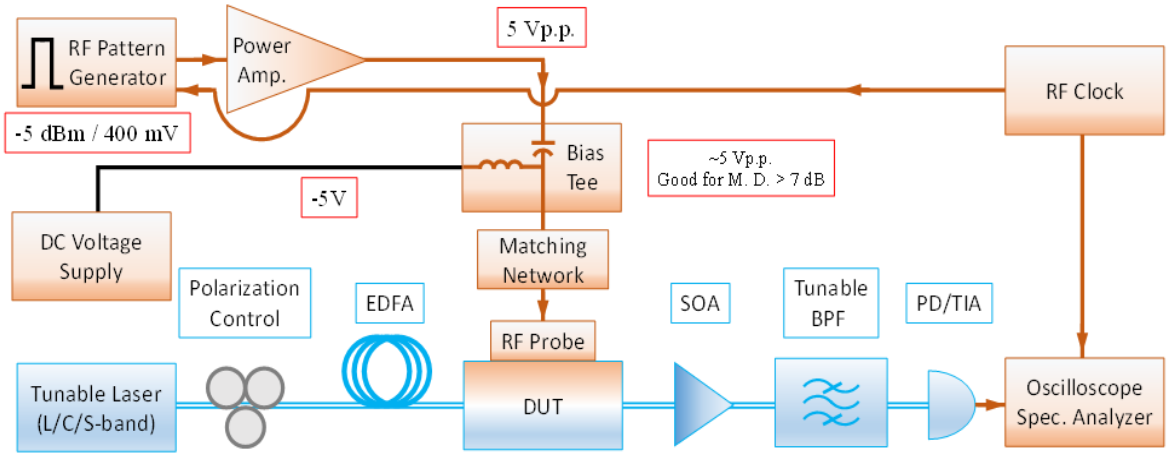

Figure ~~16~~2. Schematic of the high-speed characterization setup for measurement of the response of a high speed optoelectronic devices. In this schematic the transmission amplitude of an integrated high-speed modulator is measured using a direct detection schema. Similar configuration can be used for coherent detection of the output signal by mixing the optical signal with local oscillator (LO) laser before detection.

A typical eye diagram result of the device is depicted in Figure 3(b). Here, the measurement is performed at 10 Gbaud/s OOK input signal. The microresonator Q factor of the device under test is measured to be 1.55×10^5, which leads to the 3-dB bandwidth limit of 1.26 GHz if the cavity

modulation was employed. Figure 3(c) shows the corresponding S_{21} measurement of the EO device, in which the 3-dB bandwidth is located well above 10 GHz. This manifests the successful demonstration of coupling modulation for the device, as well as the RC bandwidth of the PN junction exceeding 10 GHz. We believe that the device is capable of working beyond 10 GHz if the RC limit is addressed through revised PN junction design to reduce parasitic capacitances. BER is also computed through eye diagram Q factor measurements, with the eye Q value of

3.087. The corresponding BER is 1.02×10^{-3} accordingly, which is well below hard decision FEC limit. The increased value of noise is mainly introduced through SOA, which is added to compensate the insertion loss of unoptimized I/O grating couplers. The SOA can be eliminated if the design of I/O ports is optimized, hence opening the path for PAM modulations and enabling higher signal rates.

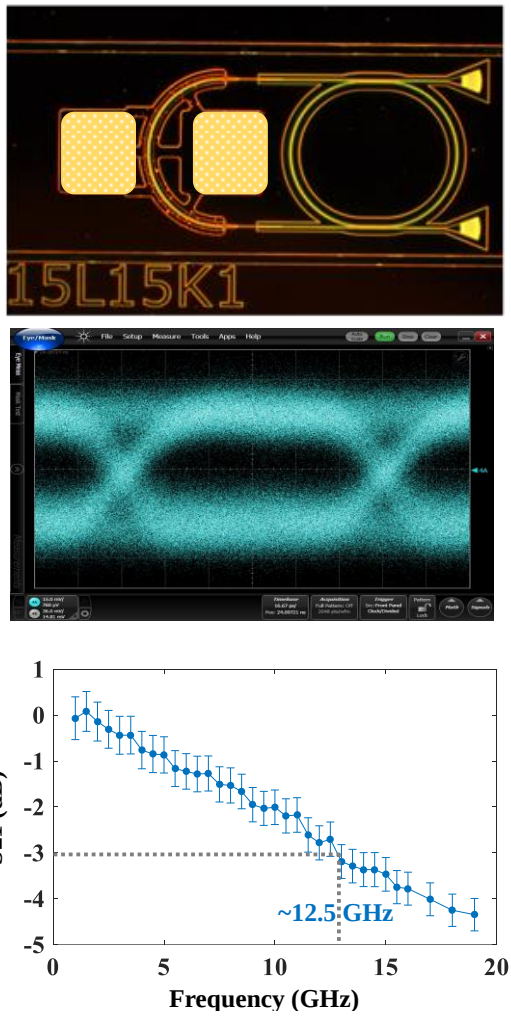

Figure. 3. (a) The dark-field micrograph image of the fabricated modulator. (b) Measured eye diagram of PRBS (27-1 pattern) at 10 Gb/s generated using AWG. (c) The measured EOE S21 of the modulator after direct detection. The curve is normalized to S21 value at 1GHz.

III.C. The impact of the developed testbed on the past, current, and future ARO-funded research

Adibi is h PI of the ARO-funded research entitled: Compact, Low-power, and High-speed Graphene-based Integrated Modulator Technology. This project is focused on the realization of a new class of modulators based on hybrid silicon-graphene (HSG) material platform. By taking advantage of the high carrier mobility and the strong plasma dispersion effect of graphene combined with high light confinement in compact Si-photonic devices, this ARO-funded project targets modulators with modulation speeds exceeding 100 Gb/s and sub-100 fJ/bit energy consumption.

Successful development of the proposed modulators requires detailed knowledge about the electronic properties of the graphene layers integrated on top of the Si or SiN substrates as well as those at different graphene layers in multi-layer graphene structures. In addition, the performance of the proposed modulators has to be studied at high modulation speeds with the ability to shape the input signal. Previously different aspects of these devices were characterized at different locations within the Georgia Tech campus as there was no experimental facility with all the required equipment for all the required characterization, which did not allow for the needed simultaneous measurement of different parameters of the devices. The developed characterization testbed has solved this issue by enabling to perform a complete high-speed characterization and has considerably transferred over flexibility in doing different high-speed characterization using different characterization configurations.

This high-speed characterization will be also very useful for another pending proposal submitted to ARO for he high-speed characterization of optoelectronic properties of 2D heterostructure materials.

III.D. Role of the Developed test setup in other DoD-funded projects

The developed testbed has also greatly enhanced our characterization capability for several other projects on campus. Due to its importance for multiple projects, a separate lab in Adibi's group is dedicated to this testbed, and the lab will be made accessible to other researchers on-campus. Both Georgia Tech and Georgia Tech Research Institute have strong DoD-funded research portfolios in the areas of photonics, electronics, and optoelectronics, and the presence of this comprehensive characterization testbed will be highly beneficial for a large range of researchers involved in these projects. Two of the other DoD-funded projects in Adibi's group that have and will benefit from this research are listed below:

1) Project Title: "A New Material and Device platform for Compact, High-gain Integrated Photonic Modulator Technology," funded by the Office of Naval Research (ONR), start date: 3/1/2015, duration 3 years; PI: Adibi, Co-PI: Eftekhar:

This ONR-funded project is focused on the development of high-gain modulators at high modulation speeds in hybrid silicon carbide/silicon nitride (SiC/SiN) and double-layer SiC material platforms. This project will heavily benefit from the proposed characterization testbed for both electronic characterization of the SiC layers and detailed investigation of the modulation performance (especially the modulation speed).

1) Project Title: "Nonlinear Optical Signal processing On Chip: A New Paradigm for Implementation of Optical logic Functionality," funded by the Air Force Office of Scientific Research (AFOSR), start date: 9/1/2015, duration 3 years; PI: Adibi, Co-PI: Eftekhar:

The AFOSR-funded project is focused on the development of the foundation for a new digital signal processing/computing platform in the optical domain through the development of innovative high-speed and low-power nonlinear optical processing cores that can be co-integrated with digital signal processors to enable new functionalities such as very-high-speed signal processing and direct optical signal processing. The core material platform for this project is hybrid Si/SiN-based materials with potential infiltration with nonlinear optical polymer. Most of the devices that form the infrastructure for the proposed nonlinear signal processing functionalities have to operate at ultrahigh speeds, and they require a reliable testbed for the characterization of their optoelectronic properties. Thus, the AFOSR-funded project will considerably benefit from the availability of the proposed testbed in this DURIP proposal.

III.E. Final quotations of the purchased equipment

KEYSIGHT TECHNOLOGIES

Quotation

Customer Reference		
Quote for Georgia Institute of Technology		
Quotation Number	**Quotation Date**	**Expiration Date**
3028648-1	25-Oct-2016	31-Oct-2016
Agreement Number/Expires		**Final Destination Country**
GEORGIAIN-G8S98-01-DEC-16		United States
Payment Terms		**Incoterms**
NET 30 DAYS		DDP United States

Attention: Ali Eftekhar
Customer Address:
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MICHAEL C LARSEN
Telephone: 1 866 650-9516
Email: mike_larsen@keysight.com

Please Direct Inquiries/Send Purchase Orders To:
KEVIN NAHODYL
Email: usa_orders@keysight.com

Keysight Sales Office:
Keysight Technologies Inc. / US
PO Box 4026
Englewood CO 80155-4026
United States

Due to the expiration date of a special discount offer, this quote expires 10/31/2016. Delivery dates are estimated and subject to availability at the time of order placement. Please reference this quotation, requested delivery date, AND INDICATE IF YOU WILL ACCEPT EARLY DELIVERY on your purchase order.

Item	Product Number/Description	Unit Price	Unit Adjustment	Unit Net Price	Quantity	Extended Price USD
1	86100D Infiniium DCA-X Oscilloscope Mainframe	24,210.00	-24,210.00	0.00	1	0.00
	Return to Keysight Warranty - 3 years					
	Marketing Program 100 %					
	Notes: "This is a one-time special offer that will not apply to any future order(s). The sale of products outlined in this document is predicated upon ordering the products and quantities as specified herein. Changes to product mix and/or quantities may affect the offer amounts."					
	86100D-ETR Enhanced trigger, 13 GHz BW, pattern and module trigger	8,637.00	-3,351.16	5,285.84	1	5,285.84
	Regional Discount 38.8 %					
	86100D-SIM InfiniiSim-DCA Waveform Transformation SW, Fixed Perpetual License	4,960.00	-1,924.48	3,035.52	1	3,035.52
	Regional Discount 38.8 %					
	86100D-092 Internal hard drive (default option)	0.00	0.00	0.00	1	0.00
	Purchase Agreement Discount 20 %					
	86100D-GPI GPIB Card Interface - Installed	376.00	-75.20	300.80	1	300.80
	Purchase Agreement Discount 20 %					
	Estimated Weeks Delivery: 5				**Item Net Total:**	**8,622.16**
2	N1045A 60 GHz 2/4 Port Electrical Remote Sampling Head	0.00	0.00	0.00	1	0.00
	Return to Keysight Warranty - 3 years					
	Purchase Agreement Discount 20 %					
	N1045A-02F 2 Channel Remote Head, 1.85mm, Female	46,923.00	-18,206.12	28,716.88	1	28,716.88
	Regional Discount 38.8 %					
	Notes: ***Special discount applied. See terms and conditions below.***					

1 / 3

Quotation

KEYSIGHT TECHNOLOGIES

Customer Reference	
Quote for Georgia Institute of Technology	
Quotation Number	**Quotation Date**
3028648-1	25-Oct-2016

Item	Product Number/Description	Unit Price	Unit Adjustment	Unit Net Price	Quantity	Extended Price USD
	N1045A-LOJ Ultra-low Jitter Performance Purchase Agreement Discount 20 %	0.00	0.00	0.00	1	0.00
	Estimated Weeks Delivery: 5				**Item Net Total:**	**28,716.88**
3	M8195A Arbitrary Waveform Generator 65GSa/s Return to Keysight Warranty - 3 years Power cord, United States and Canada - 120V Purchase Agreement Discount 20 %	0.00	-561.60	-561.60	1	-561.60
	M8195A-16G Upgrade to 16 GSa Memory Regional Discount 38.8 %	21,497.00	-8,340.84	13,156.16	1	13,156.16
	Notes: ***Special discount applied. See terms and conditions below.***					
	M8195A-SEQ Sequencer Regional Discount 38.8 %	5,385.00	-2,089.38	3,295.62	1	3,295.62
	M8195A-001 Arbitrary Waveform Generator, 1 Channel, 65 GSa/s Regional Discount 38.8 %	102,110.00	-39,618.68	62,491.32	1	62,491.32
	M8195A-SCD Standard Calibration Document Purchase Agreement Discount 20 %	0.00	0.00	0.00	1	0.00
	M8195A-BU2 Bundle consisting of one M9502A 2-slot AXIe Chassis with USB Option Regional Discount 38.8 %	9,000.00	-3,492.00	5,508.00	1	5,508.00
	M8195A-810 Matched Cable Pair for M8195A AWG, 2.92 mm Regional Discount 38.8 %	3,231.00	-1,253.63	1,977.37	1	1,977.37
	Estimated Weeks Delivery: 8				**Item Net Total:**	**85,866.87**

	Unit Price Total	226,329.00
	Adjustment Total	-103,123.09
	Total	**USD 123,205.91**

Comments:

Special terms are included with this quotation since special discounts are being granted. Your concurrence with these special terms will be required with any resulting order under this quotation.

Products purchased under this quote must be placed on one purchase order and no products may be added at a later date. This is a one-time special discount that will not apply to any future order(s). In the event Keysight reduces the list price of a product on this quotation during the validity of this quotation or prior to shipment, the list price for such products will not be reduced.

The sale of products under this quotation will be governed by the Terms and Conditions of the agreement between Customer and Keysight Technologies, Agreement Number G8S98 ("Master Agreement"). Since special discounts are being granted under this quotation, products purchased under this quotation with special discounts will not be further discounted under the Master Agreement. The sale of products under this quotation is predicated upon ordering the products and quantities as specified on the quotation. Changes in the product mix and/or quantities may affect the discount percentage.

This quotation and any resulting purchase order are subject to the terms and conditions of Purchase Agreement G8S98. Products on this quote with zero (0) percent discount may be a Distribution Preferred Product available through Keysight's Authorized Distributors. A list of Distributors can be found at http://www.keysight.com/main/contactInformation.jspx?tmprop=TM&pageMode=PF&cc=US&lc=eng

The Terms, Conditions and Discounts of the above Purchase Agreement apply to this quotation. This quotation does not extend the contractual End Date of the Purchase Agreement.

Issue Order to:

XSoptix, LLC
800 Village Walk #316
Guilford, CT 06437
Sales@xsoptix.com

Fax: 800 878-7282
Phone: 203-401-8093

F.O.B. Madison, CT
(small, woman owned business)
DUNS# 011138174
Cage Code - 3MQC6

Prepared By	Tom Mahoney	Quote Number	00007767
Phone	4043076486	Created Date	3/15/2017
		Expiration Date	4/14/2017
For questions, quotes, orders and info: sales@xsoptix.com		Terms	Net 30
		Availability	2-8 weeks ARO
Contact Name	Reza (Ali) Eftekhar	Ship To Name	GA Tech
Email	eftekhar@gatech.edu		
NOTES:	Factory stock at the time of quoting.		

Quantity	Product	Product Description	Sales Price	Total Price
1.00	XPDV2320R-VM-FP	Finisar - 50 GHz single photodetector, single input: FC/PC connector, output: V-male connector, dual wavelength 1310/1550nm	$4,396.00	$4,396.00

Subtotal	$4,396.00
Discount	0.00%
Total Price	$4,396.00
Grand Total	$4,396.00

Quotation for New Test Equipment

Quotation No:	RUNQ88293-0
Quotation Date:	November 1, 2016
Expiration Date:	December 1, 2016
Payment Terms:	30 Days (Subject to Credit Approval)
Reference No:	

Customer Contact Details

Contact Name: Mr. Tianren Fan
Telephone: 4044020895
Email: tianren.fan@gatech.edu
Company: GEORGIA INSTITUTE OF TECHNOLOGY
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GA 30332
United States
Account No: G209

Microlease Contact Details

Contact Name: Maria Macias
Telephone: 510-264-0887
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Company: Microlease
Address: 25841 Industrial Blvd., Suite 200
Hayward
California 94545
Equipment Return Address: 9221 Globe Center Drive, Suite 105
Morrisville
North Carolina 27560
United States

Thank you for the opportunity to quote for the purchase of test equipment. Microlease provides a complete range of test equipment products and services. We sell, rent, lease, and buy test and measurement equipment as well as offer a full range of Asset Management services and solutions.

We believe you will find our prices competitive and we back our test equipment with quality and service few suppliers can match.

Product Details

Item	Manufacturer	Model	Description	List Price	Net Price	Qty	Line Total (USD)
1	Keithley	2614B	SOURCEMETER - DUAL CHANNEL, 200V	$8,600.00	$6,364.00	1	$6,364.00
		Estimated Delivery: Stock Item Warranty: Manufacturer's Warranty			**Item Total:**		$6,364.00
					Sub Total (USD)		$6,364.00
					Grand Total		$6,364.00

Terms & Conditions of Sale: https://www.microlease.com/us/termsandreturns?key=distributionterms

Quotation for New Test Equipment

Quotation No:	RUNQ92093-2
Quotation Date:	December 27, 2016
Expiration Date:	January 26, 2017
Payment Terms:	30 Days (Subject to Credit Approval)
Reference No:	

Customer Contact Details

Contact Name: Mr. Tianren Fan
Telephone: 4044020895
Email: tianren.fan@gatech.edu
Company: GEORGIA INSTITUTE OF TECHNOLOGY
Address: 711 Marietta Street
Atlanta
GA 30332
United States
Account No: G209

Microlease Contact Details

Contact Name: Maria Macias
Telephone: 510-264-0887
Email: maria.macias@microlease.com
Company: Microlease
Address: 25841 Industrial Blvd., Suite 200
Hayward
California 94545
Equipment Return Address: 9221 Globe Center Drive, Suite 105
Morrisville
North Carolina 27560
United States

Thank you for the opportunity to quote for the purchase of test equipment. Microlease provides a complete range of test equipment products and services. We sell, rent, lease, and buy test and measurement equipment as well as offer a full range of Asset Management services and solutions.

We believe you will find our prices competitive and we back our test equipment with quality and service few suppliers can match.

Product Details

Item	Manufacturer	Model	Description	List Price	Net Price	Qty	Line Total (USD)
1	Keithley	8606 **Promotions:** Educational Discount	High Performance Modular Probe Kit	$67.00	$49.58	2	$99.16
		Estimated Delivery: 6.00 weeks Warranty: Manufacturer's Warranty			**Item Total:**		**$99.16**
2	Keithley	2600-BAN **Options Fitted:** BAN **Promotions:** Educational Discount	Banana Jack Interface Cable for 2600 Series	$183.00	$135.42	2	$270.84
		Estimated Delivery: Stock Item Warranty: Manufacturer's Warranty			**Item Total:**		**$270.84**
3	Keithley	2600-TRIAX **Promotions:** Educational Discount	Triax Adapter for 2600 Series	$300.00	$222.00	2	$444.00
		Estimated Delivery: Stock Item Warranty: Manufacturer's Warranty			**Item Total:**		**$444.00**

Quotation for New Test Equipment

microlease

Quotation No:	RUNQ92093-2
Quotation Date:	December 27, 2016
Expiration Date:	January 26, 2017
Payment Terms:	30 Days (Subject to Credit Approval)
Reference No:	

Product Details

Item	Manufacturer	Model	Description	List Price	Net Price	Qty	Line Total (USD)
					Sub Total (USD)		**$814.00**
					Grand Total		**$814.00**

Terms & Conditions of Sale:	https://www.microlease.com/us/termsandreturns?key=distributionterms

Quotation

EOX Sales
7071 Glen Cove Ln
Stone Mountain, GA 30087
kevinm@eoxsales.com

Quotation To:		Date	Quote #	Terms
Amir Hosseinnia	a.hosseinnia@gatech.edu	5/30/17	GIT KM053017	Net 30
Georgia Tech		Cust Ref	Validity	Ship Via
778 Atlantic DR Room 252		1050	30 Days	B/W
Atlanta GA 30332		F.O.B. Point		Delivery
4047299803		FCA Factory		4 DAYS ARO

Item	Quantity	Description	Unit Price	Extension
1	1	ACP50-GS-150RC 50 GHz reduced contact probe, GS	$995.00	$995.00
2	1	i50-GS-150 50 GHz Infinity probe, GSG, GS, SG	$1,150.00	$1,150.00
		20% GIT Discount		-$429.00
			Total:	$1,716.00

Delivery times are valid at time of quotation, and are subject to change at time of order

Please make your purchase order out to:

Cascade Microtech
9100 SW Gemini Dr
Beaverton, OR 97006
FAX (503) 601-1002

Kevin Mays
Name: Kevin Mays

- Net 30 Upon Approved Credit
- Prices quoted are for products with the ultimate destination within the United States, Mexico, or South America.

If the product's ultimate destination is outside the U.S. Mexico, or South America, this quotation is void.
Please contact Cascade Microtech, CMI_Sales@cmicro.com, for correct pricing.

- Please note Cascade Microtech has factories in both Oregon, USA and Sacka, Germany.
- If agreeable, please list "Partial Okay and Early Delivery Acceptable" on your purchase order.
- Any purchase of Cascade Microtech products and/or services stated in this quotation is expressly limited to,

and expressly made conditional on, customer's acceptance of Cascade Microtech's Terms and Conditions of Sale (available at: : http://www.cmicro.com/company/legal-information/terms-and-conditions/cascade-microtech-terms-and-conditions-of-sale). Cascade objects to and rejects any different or additional terms contained in this purchase order, unless agreed to in writing by Cascade.

Fairview Microwave
RF COMPONENTS ON DEMAND.

RF Components on Demand
1130 Junction Drive #100
Allen, TX 75013
Web: www.fairviewmicrowave.com
Phone: 972-649-6678
Fax: 972-649-6689
Email: sales@fairviewmicrowave.com

Sales Quote No	Date
FMSQ24931	7/6/2017
Page(s)	1

Federal ID #272610210
Cage Code #3FKR5

SALES QUOTATION

PLEASE REMIT PAYMENT TO: Fairview Microwave, Inc., PO Box 205405, Dallas, TX 75320-5405

Bill To: GEORGIA INSTITUTE OF TECHNOLOGY
778 Atlantic Dr., Rm 252
ATLANTA, GA 30332
USA

Ship To: GEORGIA INSTITUTE OF TECHNOLOGY
TIANREN FAN
778 Atlantic Dr., Rm 252
ATLANTA, GA 30318
USA

Sales Person	F.O.B.	Terms	Quote Validity	Ship Via	Freight Terms	Reference No
Anthony Cerda	Origin	NET 30 DAYS	8/5/2017	2day	Prepaid	RFQ

Contact	Email Address	Phone No.	Fax No.	Customer No.
TIANREN FAN	tianren.fan@gatech.edu	(404) 402-0895		FMC108258

Item No.	Cable UOM	Description	HTS No. / ECCN Code	UOM	Quantity	Unit Price	Total Price
SPA-180-37-01-SMA-A		300 MHz to 18 GHz, Medium Power Broadband Amplifier with 1 Watt, 37 dB Gain and SMA	8536.50.9065 EAR99	EA	1	4,999.00	4,999.00

Delivery: Ships within 24 hours after receipt oforder.
FOB: Allen, TX.

If you would like to place this order, please fax, mail or email your purchase order with the following information:
1. Complete shipping address and billing address.
2. Payment Terms Net 30 days or Credit Card
3. FOB: Allen, TX. (origin)
4. Shipping method (and shipping account number if using own account).

Products adhere to the most current specifications available on the Fairview website at www.fairviewmicrowave.com.

Thank you for considering Fairview for your all RF, microwave and millimeter-wave product requirements. Should you have any additional questions, please do not hesitate to contact our sales department.

Thank you,
ANTHONY CERDA

Fairview Microwave
RF COMPONENTS ON DEMAND.

RF Components on Demand
1130 Junction Drive #100
Allen, TX 75013
Web: www.fairviewmicrowave.com
Phone: 972-649-6678
Fax: 972-649-6689
Email: sales@fairviewmicrowave.com

Sales Quote No	Date
FMSQ24932	7/6/2017
Page(s)	1

Federal ID #272610210
Cage Code #3FKR5

SALES QUOTATION

PLEASE REMIT PAYMENT TO: Fairview Microwave, Inc., PO Box 205405, Dallas, TX 75320-5405

Bill To: GEORGIA INSTITUTE OF TECHNOLOGY
778 Atlantic Dr., Rm 252
ATLANTA, GA 30332
USA

Ship To: GEORGIA INSTITUTE OF TECHNOLOGY
TIANREN FAN
778 Atlantic Dr., Rm 252
ATLANTA, GA 30332
USA

Sales Person	F.O.B.	Terms	Quote Validity	Ship Via	Freight Terms	Reference No
Vincent Banh	Origin		8/5/2017	UPS Next Day Air Saver®	Prepaid	RFQ

Contact	Email Address	Phone No.	Fax No.	Customer No.
TIANREN FAN	tianren.fan@gatech.edu	(404) 402-0895		FMC108258

Item No.	Cable UOM	Description	HTS No. / ECCN Code	UOM	Quantity	Unit Price	Total Price
SM3960		2.92mm Female to 1.85mm Male Adapter	8536.69.4010 EAR99	EA	2	273.92	547.84
FMC3030988-06		1.85mm Male to 1.85mm Male Cable RG405 Coax in 6 Inch	8544.20.0000 EAR99	EA	1	299.57	299.57
FMC3030988-09		1.85mm Male to 1.85mm Male Cable RG405 Coax in 9 Inch	8544.20.0000 EAR99	EA	1	301.76	301.76
SM3952		SMA Male to 1.85mm Female Adapter	8536.69.4010 EAR99	EA	2	143.53	287.06

IN STOCK READY TO SHIP

Products purchased or received under these Terms and Conditions are subject to export control and economic sanctions laws, restrictions, regulations and orders of the United States. Customer agrees to comply with all applicable export control laws, restrictions and regulations of the United States and shall not export, or transfer for the purpose of re-export, any product to any embargoed country or region, including but not limited to Cuba, the Crimean Region of Ukraine, Iran, North Korea, Sudan, and Syria, or to any denied, blocked, or designated person or entity as mentioned in any such United States or EU law or regulation. Customer represents and warrants that it is not on the Denied Persons, Specially Designated Nationals or Debarred Persons List (as identified by the U.S. Treasury Office of Foreign Asset Control (OFAC) and by the U.S. Department of Commerce, Bureau of Industry and Security (BIS), or any other United States list of prohibited persons; is not owned or controlled by any person that is on one of those lists, or is otherwise prohibited by United States or other law from purchasing the products or services hereunder. Customer shall be solely responsible to obtain any license to export, re-export or import as may be required. Customer also agrees that it will not use these products in connection with the proliferation of weapons of mass destruction, including missiles, nuclear, chemical or biological weapons.

All Purchase Orders are subject to final acceptance by Fairview Microwave Inc. Fairview Microwave Inc. Terms and Conditions of Sale posted on its website at www.fairviewmicrowave.com apply.

By placing an order for products from Fairview, or by accepting delivery of products described on the applicable packing slip, bill of lading and/or invoice received with the products, you agree to be bound by and accept Fairview Terms and Conditions of Sale.

Subtotal:	**1,436.23**
Total Sales Tax:	0.00
Freight:	0.00
Total:	**1,436.23**

S7FC1013S - Semiconductor Optical Amplifier, 1528 - 1562 nm, Polarization Insensitive

Zoom

Complete Product Details

Part Number:	S7FC1013S -Ask a technical question
Package Weight:	7.23 lbs / Each
Available / Ships:	3-5 Days
RoHS:	RoHS✓
Price:	$2,720.00
Add To Cart:	Qty: 1 Add To Cart
Release Date:	Sep 22, 2009

Drawings and Documents:

Auto CAD PDF	
Auto CAD DXF	
Solidworks	
eDrawing	
Step	
Manual:	
Software Download:	
RoHS:	RoHS✓

Download all support documents

Download

Building a Setup?
One-Click download of multiple documents available from the shopping cart. No purchase necessary.

Warranty (Subject to our General Terms and Conditions)

Two year warranty. Incorporated light sources are warrantied for the lesser of one year or (to the extent applicable) the number of hours stated in the specifications.

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Product Feedback - Let us know what you think about our S7FC1013S product. Click here to leave us your feedback.

Sales: 1-973-300-3000
Technical Support: 1-973-300-3000