ELECTROSCIENCE LABORATORY OVERVIEW

Robert J. Burkholder
ECE Research Professor, ESL Interim Director
December 2017
The ElectroScience Laboratory is a premier center focused on all aspects of wireless communications and electro-optics, including remote sensing, radar signal processing, sensors and sensor fusion, antennas, radio frequency (RF) integrated circuits, terahertz, millimeter waves, optics and photonics.
ESL Background
Established in 1942, the ElectroScience Laboratory is one of the oldest and largest RF and optics laboratories in the United States. ESL employs 155 faculty, researchers, students, and staff, and encompasses more than 60,000 square feet of laboratory and work space, including state-of-the-art measurement and computational facilities.
1940 - 1990 Timeline

1942
Antenna Laboratory is founded by Bill Everett and George Sindair. Research on the war-time requirements of aircraft antennas begins.

1955
Experimental facilities moved to Kinnear Road.

1954
Techniques for Airborne Radome Design was prepared under Dr. Thomas E. Tice.

1961
New areas of study: Lasers, Quantum Detectors, Satellite Communications, and Plasmas.

1967
Antenna Lab renamed ElectroScience Lab to reflect broad research programs.

1967
ElectroScience researchers introduced The Uniform Geometrical Theory of Diffraction.

1984
Stealth Era: Compact antenna and radar measurement range development begins.

1983
NASA contracts enable ESL to further expand its research areas and grow.
1995
The advent of supercomputers merged with advanced computational electromagnetics algorithms enabled numerical analysis of large and complex structures.

2004-2005
The communication and imaging system for NASA’s New Horizon Spacecraft were measured and characterized at ESL’s anechoic chamber before their integration into the spacecraft.

2011
Ribbon cutting ceremony is held on September 30, 2011 for the new ESL building on 1330 Kinnear Road.

2013
ESL Researchers develop a THz camera that can “see” through practically any material.

2014
Researchers led by Dr. Joel Johnson receive a grant from NASA to develop an Ultra Wideband Software Defined Microwave Radiometer.

2010
ESL Faculty, Researchers, and Students

- Faculty and Researchers: 28
- Postdocs and Visiting Scholars: 14
- Graduate Students: 86
- Undergraduate Students: 13
# ESL OVERVIEW

## GRADUATION METRICS

As of Summer 2017

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ESL Facilities

- Atmospheric & Oceanographic Electromagnetics and Marine Systems (ATOM) Laboratory
- Ceramics Fabrication Facility
- Cognitive Remote Sensing Laboratory*
- Compact Range*
- Distributed Memory Parallel Supercomputer & Software
- Hyperspectral Engine Lab for Integrated Optical Systems (HELIOS) Laboratory*
- Integrated Optics Lab
- PCB Prototyping Facility
- RF/Microwave Facility
- RFID Laboratory
- Radar & Remote Sensing Lab
- Software Defined Radios/Radars
- Textile Antennas & Electronics Lab
- Circuit Laboratory for Advanced Sensors & Systems (CLASS)

*Major earnings centers.
ESL Research Areas

ESL has consistently maintained a national and international presence in electromagnetics and electro-optics, influencing radio research like no other institution in the world. Our faculty, research scientists and students are involved in all aspects of electromagnetic and RF technologies.

https://electroscience.osu.edu/research-areas
Antennas and Arrays

ESL PIs & Research Highlights
- Dr. Elias Alwan
- Prof. Chih-Chi Chen
- Prof. Nima Ghalichechian
- Dr. Teh-Hong Lee
- Prof. Niru K. Nahar
- Prof. Kubilay Sertel
- Prof. Inder “Jiti” Gupta

ESL conducts a wide range of research on antennas, radomes and arrays. Some projects include:

- Conformal antennas
- Reconfigurable systems
- Electronically-scanned arrays
- Beam forming techniques
- Shaped reflector antennas
- Antenna patterns on platforms such as aircraft, tanks and boats
- Ultra-wideband antennas, operating with high performance from 50 MHz up to millimeter wave
- Band rejection and band-pass radomes
- Miniature and embedded antennas
RF Measurements

ESL PIs & Research Highlights
- Prof. Chih-Chi Chen
- Prof. Inder “Jiti” Gupta
- Dr. Teh-Hong Lee

ESL is a leader in the design and development of compact range and other facilities for precision microwave measurements. The compact radar range at the ElectroScience Laboratory is:
- A state-of-the-art system which can measure the scattering and radiation characteristics of objects as large as eight feet long or as small as a straight pin.
- Used to gain a deeper understanding of electromagnetic scattering mechanisms including the relationship of signal frequency and polarization to an object’s size and shape.
- Available for commercial/defense department use.
- Capable of measurements up to 110 GHz.
ESL PIs and Research Highlights
• Prof. Waleed Khalil
• Dr. Shane Smith

Integrated Circuits Research at ESL capitalizes on a systems-view approach that spans high-performance digital, analog, and RF architectures and circuit design techniques to realize state of the art solutions for current and future wireless/wireline applications.
• Interdisciplinary program that marries advanced DSP principles with, novel transistor-level circuit design, and Electromagnetic analysis to construct frequency-agile flexible hardware.
• State of the art infrastructure including CAD tools, computing clusters, wafer/package test facilities, and access to in house and external foundries.

Current research includes the development of:
• Direct Digital-to-RF circuits
• High-resolution GHz DACs and ADCs
• High-performance Digital ASICs
• High-efficiency Transmitters (GaN,CMOS)
• Architectures and Sensors for Ultra-Wideband Receivers
• Read out integrated circuits (ROIC)
• Radiation hard circuits
• Trusted electronics
**Optics and Photonics**

Optics and photonics spans telecommunications, medicine, sensors, national defense, and consumer electronics. It is based on electromagnetic waves with wavelength on the order of one micrometer.

**Engineering technologies are being developed for high speed communications, biomedical applications, energy efficient phased arrays, and microscopic laboratories.**

Research activities span materials science, optical physics, electromagnetics, and computational methods.

**ESL PIs & Research Highlights**
- Prof. Ron Reano
- Prof. Niru Nahar
- Prof. Fernando Teixeira
THz & Millimeter-Wave Sensing Spectroscopy and Imaging

The Hyperspectral Engine Lab for Integrated Optical Systems (HELIOS) Laboratory is focused on exploring the uncharted THz spectrum. Created by a grant from the State of Ohio, HELIOS Laboratory houses high-tech instrumentation for testing, imaging and spectroscopy in the mmW and THz bands (DC-to-5THz).

Ongoing projects at HELIOS include compressive imaging, biomedical imaging using THz waves, next generation THz integrated circuits and phased arrays for high data rate communications, and non-contact probing of electronic wafers.

The primary goal of the HELIOS Laboratory is to facilitate development of faster, smaller, higher power and cheaper terahertz devices; and to engage private companies and government agencies in collaborative projects.

ESL PIs & Research Highlights
• Prof. Niru K. Nahar
• Prof. Kubilay Sertel
ESL PIs & Research Highlights
• Prof. Graeme Smith
• Prof. Joel Johnson

Bio-inspired cognitive concepts and advanced system design can enhance performance and realize new application areas for radar.
• Current technology allows virtually all radar parameters to be varied on a pulse-by-pulse basis.
• This flexibility offers the opportunity for adaptive approaches on both transmit and receive.
• But full exploitation requires the radar itself to make the necessary, near instantaneous, decisions as to how to set these parameters.

The cognitive notions of “perception-action,” memory, attention, intelligence and knowledge all have the potential to be beneficially exploited.
• This research is applying cognition-like concepts with specific aims to enhance system performance and generate new radar applications based on autonomous operation.
Remote Sensing

ESL PIs & Research Highlights
- Dr. Chris Ball
- Prof. Robert Burkholder
- Prof. Joel Johnson
- Dr. Andrew O’Brien
- Prof. Fernando Teixeira
- Dr. Caglar Yardim

RF and microwave remote sensing uses active and passive RF and microwave systems to observe:
- ocean,
- atmosphere,
- terrain,
- earth crust, and
- other environments.

Data from these sensors are critical for:
- earth science,
- land use monitoring,
- oil and gas exploration and
- global climate studies.

We collaborate with industry, NASA and other agencies in modeling and testing of new sensors and in data analysis for current sensors.
Global Navigation Satellite System (GNSS)

Major emphasis of our research effort is precise navigation in electromagnetically challenged environments.

Current research efforts include:
- Software defined GNSS receiver
- Interference suppression,
- Multipath characterization and mitigation,
- Platform induced effects,
- Designing light weight, ultra wideband antenna arrays for GNSS receivers,
- In-situ as well as on-the-fly- antenna calibration,
- Optimal adaptive filtering,
- Electronic support with GNSS antennas

ESL PIs & Research Highlights
- Prof. Inder “Jiti” Gupta
- Dr. Andrew O’Brien
Fibers, referred to as E-fibers, offer high surface conductivity (nearly equivalent to copper), are flexible and mechanically strong, and can be inconspicuously integrated into the garments to realize several functionalities.

Example E-fiber applications that have been considered recently are:

• Antennas for body-worn communications
• **Wearable medical sensors**
• Antennas for Unmanned Aerial Vehicles (UAVs)
• **RFID tag antennas**
• Stretchable and flexible antennas embedded in polymer
Medical Sensing

...for monitoring patients with epilepsy, Parkinson’s, Alzheimer’s, brain injury, etc.

- Exterior Interrogator
- Signal generator
- Demodulator
- 2.4GHz
- 4.8GHz + f_{neuro}
- Smart phones, PDAs, Laptops, etc.

ESL PIs & Research Highlights
• Prof. Asimina Kiourti
Computational Electromagnetics and Multi-Physics

ESL PIs & Research Highlights
- Prof. Jin-Fa Lee
- Prof. Fernando Teixeira
- Prof. Robert Burkholder
- Prof. Kubilay Sertel

Diverse range of applications including:

- **Radiation from antennas on platforms such as aircraft and automobiles**
- Printed circuit antennas
- Analysis and design of extremely low-frequency shielding
- Cavity backed antennas
- Scattering from airborne targets
- Artificial media
- Analysis of radomes designed for wide bandwidth and minimum distortion of the antenna radiation pattern
UWB and 5G Secure Communications

At ESL, we develop secure and high data rate communication systems operating across large bandwidths up to the millimeter wave bands.

Our research includes the design, fabrication, and measurement of transceivers with emphasis on UWB applications.

UWB systems that have been considered recently are:

- Low power hardware reduced digital beamformers
- Simultaneous transmit and receive system (STAR)
- High Data Rate Communication with Interference Suppression and MIMO applications
- 5G Millimeter Wave Systems
RF MEMS and Microsystems

This research is interdisciplinary and centers around two areas of micro/nanotechnology and electromagnetics. Our approach is to use novel materials, designs, and microfabrication techniques to develop small scale, high frequency (>30GHz) electromagnetic devices and systems.

Example projects include:
- Multi-physics (electrical-structural-thermal) simulations
- MEMS-based reconfigurable antennas and arrays
- Reconfigurable microsystems based on phase change materials
- Electrical characterization of materials at millimeter wave and terahertz
- RF sensors and actuators
Student Opportunities
Student Training

ESL student researchers are actively enrolled as students within the Department of Electrical and Computer Engineering (ECE). We have exciting research opportunities for both graduate and undergraduate students. While centering on all aspects of wireless communications and sensing, ESL is a cross-disciplinary center integrating research in electrical engineering, materials science, mechanical engineering and medical sciences.

Student Organizations

ESL Student Committee
Institute of Electrical and Electronics Engineers (IEEE) Student Organizations

Funding Through Special Programs and Industry

University Fellowships
Industrial Fellowships
Government Fellowships
Graduate Research Associate (GRA) appointments
ESL Partnerships

ESL promotes and engages research partnerships with well-known defense and commercial companies. ESL has consistently maintained strong interactions with government labs, and federally funded research and development center commercial sectors. Our faculty and researchers work with small companies and startups as well as consortiums.
### Examples of ESL Partnerships

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<thead>
<tr>
<th>Government</th>
<th>Industry</th>
<th>Consortiums</th>
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<tr>
<td>Defense Advanced Research Project Agency (DARPA)</td>
<td>MIT Lincoln Laboratory</td>
<td>Consortium on Electromagnetics and Radio Frequencies (CERF)</td>
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<td>National Science Foundation (NSF)</td>
<td>Bridgestone</td>
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<td>Air Force Research Lab (AFRL)</td>
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<td>Air Force Office of Scientific Research (AFOSR)</td>
<td>ANSYS</td>
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<td>U.S. Dept. of Agriculture</td>
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<td>Naval Research Lab (NRL)</td>
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Recognition

FY17 National and International Awards
### Professional Awards

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<tr>
<th>Student Awards</th>
<th>Venue/Event/Sponsor</th>
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<tr>
<td>Nandhini Srinivasan, 3rd place</td>
<td>2017 IEEE APS/URSI Student Paper Competition</td>
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<td>Ramandeep Vilkhu, Student Poster Award</td>
<td>2017 OSU Materials Week</td>
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<tr>
<td>Ushemadzoro (Ushe) Chipengo, 3rd place</td>
<td>2017 Kraus Memorial Poster Competition</td>
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<tr>
<td>Markus Novak Receives Doctoral Research Grant</td>
<td>IEEE Antennas and Propagation Society</td>
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<tr>
<td>Ushemadzoro (Ushe) Chipengo, 1st place Top Engineering Award</td>
<td>OSU Hayes Graduate Research Forum</td>
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<tr>
<td>Shubhendhu Bhardwaj, 1st place best paper award</td>
<td>iWAT2017</td>
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<tr>
<td>Markus Novak, 3rd place best paper award</td>
<td>iWAT2017</td>
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<td>Nicole Tchorowski, Professional Development Award</td>
<td>iREDEFINE Professional Development Award</td>
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<td>Ramandeep Vilkhu, Prestigious Scholarship Award</td>
<td>IEEE MTT-S Undergraduate Scholarship</td>
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<td>Nicholas Host, Best Dissertation Award</td>
<td>2016 ESL Annual Awards</td>
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<td>Syed An Nazmus Saqueb, Best Paper Award</td>
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<td>Shubhendhu Bhardwaj, Student of the Year Award</td>
<td>2016 ESL Annual Awards</td>
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<td>Dong Yeop Na, Presidential Fellowship</td>
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<td>Markus Novak, 1st place</td>
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<td>Ushemadzoro Chipengo, 2nd place</td>
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<td>Matthew Buchanan, 3rd place</td>
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<td>Shubhendhu Bhardwaj, Louise B. Vetter Award</td>
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### Faculty and Researcher Awards

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<tr>
<td>Graeme Smith, Above and Beyond Award</td>
<td>2016 ESL Annual Awards</td>
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<td>John Volakis, George Sinclair Award</td>
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<td>Chi-Chih Chen, 2016 Distinguished Achievement Award</td>
<td>AMTA</td>
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ESL Alumni

ElectroScience Laboratory has graduated over 1,000 Ph.D. and Master’s students. Numerous alumni are now recognized academic leaders worldwide. Most prominent authors, faculty, and industry leaders in RF/Wireless have come from ESL.
Some Notable ESL Alumni

Brian Kent – CTO of AFRL/Retired
Stephen Schneider – Acting Chief Scientist of AFRL Sensors Directorate
Charlie Rhoads – CTO at Raytheon-Dallas
Eric Evans – Director, MIT Lincoln Labs
Matt Ganz – Boeing Company European Operations President
Levent Ersoy – CTO, Lorral Corp.
Jim Armitage – VP and Chief Technology Officer at Northrop Grumman/Retired
Tom Miller – Chief Technology Officer at Raytheon West Coast/Retired
William Lee – former CTO of Airtouch, now part of Verizon, author of popular wireless communication book and wideband CDMA inventor

Celebrated authors in microwaves and electromagnetics
Roger Harrington, Gary Thiele, Warren Stutzman, Dave Pozar, Costantine Balanis

Many company start-ups:
Gene Bulman, Wayne Masters, Al Dominek, Harry Shamansky, Jeff Berrie, Paul Swetnum, Bob Puskar, Errol English, Carl Mentzer, Tom Kornbau, Bill Kent, Terry Fry, Yakup Bayram, Johnson Wang