ZOYA POPOVIĆ
Distinguished Professor and Lockheed Martin Endowed Chair
Department of Electrical, Computer and Energy Engineering
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EDUCATION

Ph.D., Electrical Engineering, Caltech, 1990. Thesis advisor: Prof. David Rutledge.
Dipl.Ing. (B.S.), Electrical Engineering, University of Belgrade, Serbia, Yugoslavia, 1985.

Zoya Popović received her Dipl. Ing. degree from the University of Belgrade, Serbia, in 1985, and the M.S. and Ph.D. degrees from Caltech, Pasadena, California, in 1986 and 1990, respectively. Her doctoral thesis was on large-scale quasi-optical microwave power combining. She joined the faculty of the University of Colorado in Boulder in August 1990, where she became a full professor in 1998, and received the Hudson Moore Jr. endowed professorship in 2006. She was named Distinguished Professor in 2010 and Lockheed Martin Endowed Chair in 2017. She has developed five undergraduate and graduate electromagnetics and microwave laboratory courses and co-authored (with her late father) *Introductory Electromagnetics* for the junior-level core course for electrical and computer engineering students, translated to several foreign languages. Her research interests include high-efficiency linear microwave power amplifiers, low-loss broadband microwave and millimeter-wave circuits, medical applications of microwaves, intelligent RF circuits, active antenna arrays, cryogenic circuits, microwave radiometry, and wireless powering for low-power sensors. She was a Visiting Professor at the Technische Universitat Muenchen, Munich, Germany, in 2001 and 2003, and at Supaero (ISAE), Toulouse, in 2014 and a Chair of Excellence at Carlos III University in Madrid, Spain, in 2018/19.

RECOGNITION

- Fellow, National Academy of Inventors, 2023
- Member, National Academy of Engineering, 2022
- *Doktora Honoris Causa* (Honorary PhD), Carlos III Univ. of Madrid, Spain, 2022
- Chair of Excellence, Carlos III University of Madrid, Spain, 2018-2019
- University of Colorado Distinguished Research Lecturer, 2015
- Univ. of Utah Judd (2015) and Carnegie Mellon Judith Resnik (2017) Distinguished Lectures
- IEEE Rudy Henning Distinguished Mentoring award, 2015
- IEEE MTT Distinguished Educator Award, 2013
- Holland Teaching Award, University of Colorado, 2011 and 2013
- Distinguished Professor, University of Colorado, 2010
- Coleman Research Fellow, Coleman Institute, 2008
- Faculty Research Award, College of Engineering and Applied Science, 2007
- Elected Foreign Member of Serbian Academy of Sciences and Arts, 2006
- Microwave Prize, IEEE MTT Society, 2005, best journal paper award and
- Microwave Prize, IEEE MTT Society, 1993, best journal paper award
- Fellow, IEEE, 2002
- ASEE HP/Terman Award 2001, for combined teaching and research excellence
- Humboldt Research Award for Senior Scientists, German Humboldt Foundation, 2000/2001
- Margaret Willard Award, University of Colorado, 1997, as female role model
- Eta Kappa Nu professor of the year award, 1997, by student vote
- URSI Issac Koga Gold Medal, Lille, France, 1996, awarded once every three years
- White House NSF Presidential Faculty Fellow Award, 1993
- URSI Young Scientist, Kyoto, Japan, 1993
- City of Belgrade October Award for the Diploma Thesis in 1985

FUNDING SUMMARY

- Current funding sources: NSF, DARPA, ONR, Navy CRANE, AFOSR, Lockheed Martin, Qorvo, Analog Devices, ColdQuanta, National Instruments, MIT Lincoln Laboratory, HRL Laboratories, CEI, NIST, LumenAstra, OEDIT.
- Average expenditures >$1.2M/year since 1995.

GRADUATE STUDENTS

- 70 Ph.D. students graduated and happily employed.
- 18 students currently doing their Ph.D. dissertations, 6 are women.
- Over 85% of the graduated and current graduate students are U.S. citizens.
- Former students contributing at MIT Lincoln Lab (10), Sandia (5), Keysight (2), Infineon/Wolfspeed (3), Lockheed (5), Qorvo (3), NIST, NI, ARL, NASA, TI, Qualcomm, Raytheon, various other companies and in academia (e.g. Notre Dame, Univ. of Hawaii).

Personal tidbit: wife of physics professor and JILA Fellow Dana Anderson and mother of three daughters (ages 23 to 32) who can all solder. The oldest has a PhD in electrical engineering (my contribution to diversity – 33% of my female children are EE PhDs, and 67% will have PhDs in STEM fields).

TOTAL CITATIONS (Google Scholar, January 2024)**: 16,560,** h-index**: 58**

BOOKS, EDITED BOOKS AND BOOK CHAPTERS

Introductory Electromagnetics, Zoya Popovic and Branko Popovic, Prentice Hall, 2000.
Introductory Electromagnetics, Practice Problems and Labs, Zoya Popovic and Branko Popovic, Prentice Hall, 2000, *Student workbook*.

Active and Quasi-Optical Arrays for Solid-State Power Combining, eds. Robert A. York and Zoya B. Popovic, John Wiley and Sons, 1997.

- "Quasi-optical antenna array amplifiers," Zoya Popovic, Robert York, Emilio Sovero, Jon Schoenberg, Chapter 5, pp. 187-244.
- "Grid oscillators," Zoya Popovic, Wayne Shiroma, Robert M. Weikle, II, Chapter 8, pp. 293-330.
- "Quasi-optical subsystems," Zoya Popovic and Gerald Johnson, Chapter, pp. 455-484.

- "Analysis and design of oscillator grids and arrays," W. Shiroma, E. Bryerton, Z. Popovic, chapter in Analysis and Design of Integrated Circuit/Antenna Modules, eds. K.C. Gupta and P. Hall, Wiley and Sons, 2000, pp 301-332
- "Power amplifier approaches for high-efficiency and linearity," with Peter Asbeck, Larry Larson and Tatsuo Itoh, Chapter in "RF Technologies for Low-Power Wireless Communications," Eds. T. Itoh, G. Haddad, Wiley and Sons, pp.189-228, Wiley, 2001.
- "Magnetostatics", with B. Popovic and M. Popovic, Chapter 3 in Handbook of Engineering Electromagnetics, ed. Rajeev Bansal, Marcel Dekker, 2004, pp 89-122
- "Electromagnetic induction," with B. Popovic and M. Popovic, Chapter 4 in Handbook of Engineering Electromagnetics, ed. Rajeev Bansal, Marcel Dekker, 2004, pp 122-162
- "Active Antennas," with S. Rondineau and N. Lopez, in Antenna Engineering Handbook, ed. John Volakis, 2007 (30 pages).
- "Active Antennas,", in Antenna Engineering Handbook, ed. John Volakis, 2018 (30 pages).

JOURNAL ARTICLES

1. Z. Popovic, A. Markovic, "The THD Characteristics of the Phase Detector," *IEEE Trans. on Consumer Electronics, CE-32*, No.1, pp. 20-25, Feb. 1986.
2. R. C. Compton, R. C. McPhedran, Z. Popovic, G. M. Rebeiz, P. P. Tong, D. B. Rutledge, "Bow-tie antennas on a dielectric half-space: Theory and Experiment," *IEEE Trans. on Antennas and Propagation, AP-35*, pp. 622-631, June, 1987.
3. Z. Popovic, M. Kim, D. B. Rutledge, "Grid Oscillators," *International Journal for Infrared and Millimeter Waves 9*, pp. 647-654, 1988.
4. Z. Popovic, R. M. Wiekle, M. Kim, K. A. Potter, D. B Rutledge, "Bar-Grid Oscillators," *IEEE Transactions on Microwave Theory and Techniques, MTT-38*, No.3, March 1990.
5. R. J. Hwu, C. F. Jou, N. C. Luhmann Jr., M. Kim, W. W. Lam, Z. Popovic, D. B. Rutledge, "Array Concepts for Solid-State and Vacuum Microelectronics Millimeter-Wave Generation," *IEEE Transactions on Electron Devices, Vol. 36*, No. 11, Nov. 1989.
6. Z. Popovic, R. M. Wiekle, M. Kim, D. B Rutledge, "A 100-MESFET Planar Grid Oscillator," *IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-39*, No. 2, pp. 193-200, Feb. 1991. ***(Winner of IEEE Microwave Prize for best paper of the year)***
7. R.M. Weikle, II, M. Kim, J.B. Hacker, M.P. DeLisio, Z Popovic, D.B. Rutledge, "Transistor Oscillator and Amplifier Grids," *Invited paper, Proc. IEEE, Vol. 80*, No. 11, pp 1800-1809, Nov. 1992.
8. S. Bundy, T. Mader, Z. Popovic, "Quasi-Optical VCOs," *IEEE Transactions on Microwave Theory and Techniques, Special Issue*, Vol. 41, No. 10, pp 1775-1781, October 1993.
9. V. Radisic, D. Hjelme, A.R. Mickelson, Z. Popovic, "Experimentally Variable Modeling of Coplanar Waveguide Discontinuities," *IEEE Transactions on Microwave Theory and Techniques, Special Issue, Vol 41,* No. 9, pp 1524-1533, September 1993.
10. V. Radisic, V. Jevremovic, Z. Popovic, "CPW Oscillator Conjuration for an Electro-Optic Modulator," *IEEE Transactions on Microwave Theory and Techniques, Special Issue*, *Vol 41,* No. 9, pp 1645-1647, September 1993.
11. T. Mader, J. Schoenberg, L. Harmon, Z. Popovic, "Planar MESFET Transmission Wave Amplifier," *IEE Electronic Letters, Vol. 28*, No. 19, pp. 1699-1701, September 1993.
12. Z. Popovic, B. D. Popovic, "Time-efficient modeling of the effect of metal packages on electrical circuits," *IEEE Transactions on Microwave Theory and Techniques, Special Issue on Packaging and Interconnects, Vol.42*, No.9, pp. 1820-1826, September 1994.
13. W. A. Shiroma, B. L. Shaw, Z. Popovic, "A 100-transistor quadruple grid oscillator," *IEEE MTT Microwave and Guided Wave Letters, Vol.4*, *No.10*, pp. 350-352, October 1994.
14. J. S. H. Schoenberg, S. C. Bundy, Z. Popovic, "Two-level power combining using a lens amplifier," *IEEE Transactions on Microwave Theory and Techniques, Vol.42, No.12*, pp. 2480 -2485, December 1994.
15. S. C. Bundy, Z. B. Popovic, "A generalized analysis for grid oscillator design," *IEEE Transactions on Microwave Theory and Techniques, Vol.42*, No.12, pp. 2486-2491, December 1994.
16. T.B. Mader, Z. B. Popovic, "The transmission-line high-efficiency class-E amplifier," *IEEE MTT Microwave and Guided Wave Letters, Vol.5*, *No.10*, pp. 290-293, October 1995.
17. B.D. Popovic, J. Schoenberg, Z.B. Popovic "Broadband Quasi-Microstrip Antenna,", *IEEE Trans. on Antennas and Propagation, Vol.43, No.10*, pp.1148-1152, October 1995.
18. W. Shiroma, S. Bundy, S. Hollung, B. Bauernfiend, Z.B. Popovic, "Cascaded active and passive quasi-optical grids," W *IEEE Trans. on Microwave Theory and Techniques, Vol.43, No.12,* pp. 2904-2909, December 1995.
19. S. Hollung, M. Markovic, W. Shiroma, Z.B. Popovic, "A quasi-optical isolator," *IEEE Microwave and Guided Wave Lett.,* pp. 205-207, April 1996.
20. E. Bryerton, W. Shiroma, Z.B. Popovic, "A 5-GHz high-efficiency class-E oscillator," *IEEE Microwave and Guided Wave Lett., Vol.6, No.12*, pp. 441-443, December 1996.

21. S. Hollung, A. Cox, Z. Popovic, "A bi-directional quasi-optical lens amplifier," *IEEE Trans. on Microwave Theory and Techniques, Vol.45, No.12*, pp. 2352-2357, December 1997.
22. W.A. Shiroma, Z. Popovic, "Analysis and optimization of grid oscillators," *IEEE Trans. on Microwave Theory and Techniques, Vol.45, No.12*, pp. 2380-2386, December 1997.
23. T. Mader, E. Bryerton, M. Markovic, M. Forman, Z.B. Popovic, "Switched-mode high-efficiency microwave power amplifiers in a free-space power combining array," *IEEE Trans. on Microwave Theory and Techniques, Vol.48*, *No.10*, pp. 1391-1398, October 1998.
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25. M. Markovic, A. Kain, Z. Popovic, "Nonlinear modeling of class-E microwave power amplifiers," *Journal of the RF and Microwave Computer-Aided Engineering, Vol.9*, Issue 2, pp 93-103, March/April 1999.
26. S. Djukic, D. Maksimovic, Z. Popovic, "A planar 4.5-GHz DC to DC power converter," *Special Issue on Low-Power/Low-Noise Circuits of the IEEE Trans. Microwave Theory Techn*., pp.1457-1460, July 1999.
27. E. Bryerton, M. Weiss, Z. Popovic, "Efficiency of chip-level versus external power combining," *Special Issue on Low-Power/Low-Noise Circuits of the IEEE Trans. Microwave Theory Techn.*, pp.1482-1485, July 1999.
28. J. Mix, J. Dixon, Z. Popovic, M. Piket-May, "Incorporating non-linear lumped elements in FDTD: the equivalent source method," *International Journal of Numerical Modeling: Electronic networks, devices and fields, Int. J. Numer. Model. 12* , pp.157-170, 1999.
29. M. Forman, T. Marshall, Z. Popovic, "Two Ka-band quasi-optical amplifier arrays," *IEEE Trans. on Microwave Theory and Techniques, Vol.47*, No.12, pp.2568-2573, December 1999.
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31. M. McDonald, R. A. York, E. Grossman, Z. Popovic, "Spectral transmittance of lossy printed resonant-grid terahertz bandpass filters," *IEEE Trans. on Microwave Theory and Techniques, Special Issue on Terahertz Electronics, Vol 48*, No. 4, pp 712-718, April 2000.
32. B. Notaros, B. Popovic, J. Peeters Weem, R. Brown, Z. Popovic, "Efficient large-domain MOM solutions to electrically large practical EM problems," *IEEE Trans. on Microwave Theory and Techniques, Vol. 49*, No. 1, pp 151-159, Jan 2001.
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37. D. Popovic, Z. Popovic, "Multibeam antennas with polarization and angle diversity," *IEEE Trans. Antennas and Propagation, Special Issue on Wireless Communications,* pp. 651-657, May 2002.
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39. F. H. Raab, P. Asbeck, S. Cripps, P.B. Kenington, Z. Popovic, N. Pothecary, J. F. Sevic, N. O. Sokal, "Power amplifiers and transmitters for RF and microwave," *IEEE Trans. Microwave Theory and Techn., Vol. 50, No. 3,* pp. 814-826, Mar 2002.

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41. H. Loui, J. Peeters Weem, Z. Popovic, "A dual-band dual-polarized nested Vivaldi slot array with multilevel ground plane," *IEEE Trans. Antennas and Propagation,* Sept. 2003.
42. J.A. Hagerty, F. Helmbrecht, W. McCalpin, R. Zane, Z. Popovic, "Recycling ambient microwave energy with broadband antenna arrays," *IEEE Trans. Microwave Theory and Techn.,* pp. 1014-1024, March 2004. ***(Winner of IEEE Microwave Prize for best paper of the year)***
43. N. Wang, V. Yousefzadeh, S. Pajic, D. Maksimovic, Z. Popovic, "60-% efficient 10-GHz power amplifier with dynamic drain bias control," *IEEE Trans. Microwave Theory and Techn,* 2004, Vol 52(3) pp 1077 - 1081, March 2004.
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45. S. Pajic, N. Wang, P.M. Watson, T. K. Quatch, Z. Popovic, "X-band Two-Stage High-Efficiency Switched-Mode Power Amplifiers," *Microwave Theory and Techniques, IEEE Transactions on*, Vol 53 (9), Sept. 2005 Page(s):2899 – 2908
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47. V. Yousefzadeh, N. Wang, Z. Popović, D. Maksimović, "A digitally controlled DC-DC converter for an RF power amplifier," *IEEE Transactions on Power Electronics,* Vol.21, No.1, January 2006, pp. 164-172.
48. M. Lukic, S. Rondineau, Z. Popovic, D. Filipovic, "Modeling of realistic rectangular micro-coaxial lines," *IEEE Trans. Microw. Theory Techn.*, vol. 54, no. 5, pp. 2068-2076, May 2006.
49. K. Vanhille, D. Fontaine, C. Nichols, D. Filipovic, Z. Popovic, "Quasi-planar high-Q millimeter wave resonators," *IEEE Trans. Microw. Theory Techn.*, vol.54, no.6, pp.2439-2446, June 2006.
50. P. Bell, N. Hoivik, R. Saravanan, N. Ehsan, V. Bright, Z. Popovic, "Flip-chip assembled air-suspended inductors," *IEEE Trans. On Advanced Packaging, Vol. 30, No. 1,* Feb. 2007.
51. K.Vanhille, D. Fontaine, C. Nichols, Z. Popovic, D. Filipovic, "Ka-band Miniaturized Quasi-Planar High-Q Resonators," *IEEE Trans. Microw. Theory Techn.*, vol.55, no.6, pp. 1272-1279, June 2007.
52. X. Zhao, T. Qian, G. Mei, C. Kwan, R. Zane, C. Walsh, T. Paing, Z. Popovic, "Active health monitoring of an aircraft wing with an embedded piezoelectric sensor/actuator network: II. Wireless approaches," *Smart Materials and Structures,* 16(2007), pp. 1218-1225, June 2007.
53. C. Dietlein, A. Luukanen, Z. Popovic, E. Grossman, "A W-band polarization converter and isolator," *IEEE Trans. Antennas and Prop.,* vol.55, No.6, pp. 1804-1809, June 2007.
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59. L. Ranzani, P. Boffi, R. Siano, S. Rondineau, Z. Popovic, M. Martinelli, "Microwave-domain analog predistortion based on chirped delay lines for dispersion compensation of 10-Gb/s optical communication signals," *Journal of Lightwave Techn.*, vol.26, no.15, pp. 2641-2646 , Aug. 2008.

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69. M. Roberg, Z. Popovic, "Analysis of High Efficiency Power Amplifiers with Arbitrary Output Harmonic Terminations" *IEEE Trans. Microwave Theory Techn.,* pp. 2037-2048, Aug. 2011.
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165. J. Molles, M. Robinson, E. Kwiatkowski and Z. Popović, "A 10-GHz Single-Supply GaAs MMIC Self-Synchronous Rectifier," *2022 17th European Microwave Integrated Circuits Conference (EuMIC)*, Feb. 2022, London.
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174. M. C. Robinson, G. Lasser and Z. Popović, "Tunable Dual-Frequency Interference Suppression Circuit with GaN MMIC Delay Lines," *2023 53rd European Microwave Conference (EuMC)*, Berlin, Germany, 2023, pp. 247-250.
175. S. Mvokany, J. Molles and Z. Popović, "Broadband RF Interconnects in a Multi-Layer Advanced Packaging with a Si Interposer," *2023 IEEE 32nd Conference on Electrical Performance of Electronic Packaging and Systems (EPEPS)*, Milpitas, CA, USA, 2023, pp. 1-3.
176. G. Sandidge, G. S. Botello and Z. Popović, "Field Enhancement for Sensitivity Improvement of a Room-Temperature Rydberg-Atom Receiver," *2023 IEEE/MTT-S International Microwave Symposium - IMS 2023*, San Diego, CA, USA, 2023.

Hardware photographs and main results, along with pdf versions of the papers can be seen or downloaded from https://www.colorado.edu/faculty/popovic-zoya/

RESEARCH OVERVIEW

Graduated 70 Ph.D. students over the past 33 years, with 18 Ph.D. students, 2 MS students, and 4 undergraduate research students and 1 post-doctoral fellow currently working in the following areas of microwave/millimeter-wave engineering: (1) high-efficiency PAs and adaptive PAs for radar and communications; (2) three-dimensional heterogeneously integrated microwave circuits; (3) multibeam active antenna arrays for radar and communications; (4) wireless powering for batteryless sensors; (5)

microwave radiometry for medical applications; (6) microwave waste management; (7) millimeter-wave circuits and quasi-optical techniques; and (8) atomic quantum sensors.

Research interests statement

I am interested in continued work in reducing power consumption in analog front ends with new circuit topologies that give higher efficiency. Our first publications in this area were in 1995, with the first demonstrated microwave-frequency class-E power amplifier. Our results for X-band and UHF power amplifiers had record published efficiencies, and we are continuing a strong effort in this direction with MMIC PAs implemented in GaN with integrated dynamic supplies and with increased power levels at higher frequencies. A new direction that we are expanding in is in maintaining linearity with high efficiency at high power levels, and this work has gained a lot of industry attention. We are also working on broadband and low additive phase noise power amplifiers. My ultimate long-term goal is to address efficiency, linearity and bandwidth in a single transmitter component. Another related area is intelligent transmitters, which involves sensing, control algorithms, and dynamic adaptation to varying loads.

An area in which we have a best paper award and licensed patent is in RF energy harvesting and wireless powering of wireless sensors. The applications are for low-maintenance batteryless sensors for manufacturing environments, structural monitoring, green buildings and healthcare. We have shown that broadband statistically varying randomly polarized background microwave radiation can be efficiently rectified and the stray energy stored over time for useful electronic applications. We have also shown that FCC-compliant low-power transmitters can be strategically placed to enable constant very low power density energy delivery and storage. My goals related to this research are to improve the integration of our current hybrid demonstrations, and to expand the circuit-antenna library so that we can address many concrete applications with an optimized architecture. This work is mostly industry funded with a small NSF component and a new project in low-power large-area microwave rectenna arrays for space power beaming for NRL.

Another area of increasing interest is in microwave radiometry for internal body temperature measurements (funded by NSF, state of Colorado, LumenAstra). This approach provides a solution to a problem that has not yet been solved. We use a very sensitive receiver and near-field probe placed on the skin to measure the total radiometric power received from a stack of tissues, and then estimate the power emitted (and therefore temperature) of a buried tissue layer, based on electromagnetic simulations of the tissues. Our patent in this technology resulted in a Colorado start-up LumenAstra founded by Mr. Jim Pollock, currently an early-stage technology company. My group at CU Boulder continues research in this area to improve temperature resolution and spatial resolution.

I am interested in continuing the work in multibeam arrays for communication and radar systems, especially taking advantage of the increase in dynamic range, increase in transmitter power with simultaneous increase in reliability, and decrease in sensitivity to multipath fading. The group has demonstrated multibeam antenna arrays with greatly reduced cost and increased reliability as compared to standard phased arrays, funded by NASA. We are continuing this work for electronic warfare transmit phased array.

Two new areas of interest are in microwave quantum engineering and microwave pyrolysis for converting waste to useable fuel. Areas of quantum engineering include Josephson Junction dc and AC voltage standards (with NIST) and room-temperature and laser-cooled Rydberg atom microwave and millimeter-wave electrometry (ColdQuanta, DARPA, Lockheed Martin).

TEACHING

Radio-Frequency Undergraduate Sequence:

Students who complete this sequence graduate in the "RF track" and can immediately get a job in the RF industry. An example is the *RF Academy* which I have helped institute with Lockheed Martin (as Lockheed Martin Endowed Chair), in which students can start an internship after the first sophomore course and continue with summer internships and/or part-time work that fits their academic schedule during the year, with a guaranteed job after graduation. Since 2016, over 70 students have passed through this program and a large fraction are now working at Lockheed Martin Space Systems in Denver.

ECEE 2420, *Electronics for Wireless Communications*, sophomore elective for electrical and computer engineering majors. Developed in 2011, offered every Spring semester, 40 students maximum, usually there is a long wait list and I let more students into the course. The course has an extensive laboratory component and follows the textbook "The Electronics of Radio" by Prof. David Rutledge which is designed around the NorCal40A superheterodyne transceiver. The course was revised at CU Boulder for easier de-bugging by replacing the single >200 component radio board with 9 sub-boards which students can test one at a time and finally assemble a working radio. The goal of the course is to motivate later courses in circuits, electromagnetic and communications, while teaching some basic practical and lab skills. The students spend the semester learning about analog electronics through the building of a pcb-based 7-MHz radio. As a part of the final exam, they take the Technician and General Amateur Radio test and get their licenses. In 2016, for example, all students (over 50) received their amateur radio licenses. Presented at IMS workshop, 2017.

ECEN 3400, *Electromagnetic Fields and Waves*, 1st semester junior course, was taught for many years as a 5-credit class (lectures, labs, recitations) core course. Currently it is a 3-credit core class for all EE and most ECE majors, with an annual enrolment of about 100. I wrote a textbook (about 450 pages) and workbook (about 200 pages) for the course published by Prentice Hall in 2000. The book was translated to Korean and Portuguese. After the death of my co-author (also my father), I have negotiated to own the copyright and the text is distributed free to students. I developed a series of 12 labs, which are used as practical homework projects and demos. Over the years, partnerships with Texas Instruments, SpectraLink, Keysight, Rhode and Schwartz and Qorvo have enabled equipment, parts and student project awards.

ECEN 3410, *Electromagnetic Waves*, 2nd semester junior course, developed the theoretical background and a set of practical problems and laboratory exercises that cover EM wave topics in the radio and optical parts of the spectrum, as pre-requisite for the microwave lab. Class projects, which are in part theoretical and in part self-paced experimental (requiring only equipment in our standard undergraduate circuits lab) start and end with uniform plane waves, closing the circle through nonuniform waves in a coaxial line, quasi-TEM waves in microstrip, TE/TM waves in metal waveguides, evanescent waves in dielectric waveguides including fibers, Gaussian beams, antennas and propagation. The experiments are designed to be in-part open ended with a significant practical design component.

ECEN 4363/5634, *Microwave Lab,* senior/beginning graduate level lab, annual enrolment over 40. Developed most of the labs, wrote the lab manual and notes, obtained equipment donations from HP/Agilent, Qorvo, FIRST RF and Rhode and Schwartz over the years (over $2M). Labs include artificial transmission lines in time and frequency domain, power measurements in X-band waveguide, network analysis and calibration (6GHz), multi-port networks (waveguide and microstrip), Gunn diode oscillators in waveguide, linear and power amplifiers, antenna measurements, superheterodyne link with voice (FM, single upconversion) and digital data (including SDRs), and radar (FMCW and Doppler).

Courses developed for the graduate program in microwave engineering

ECEN 5104, *CAD of Microstrip Circuits*, Re-designed completely an existing course in Fall 2003. Typical enrolment is 15-20 graduate students who completed 6 design projects using commercial CAD tools

(Agilent ADS, Ansoft Advanced Designer, AWR Microwave Office): matching circuits, couplers, filters, resonators, bias networks and a final larger project in an area of the student's choice.

ECEN 5014, *Active Microwave Circuits*, graduate class with strong design component, taught every other year, enrolment about 25/semester. Wrote a lab manual and lecture notes. Class includes six two-week design projects using industry-standard software, circuits are fabricated and measured. Obtained software donations for class from AWR. Each student also does an independent MMIC design final project which can be fabricated in the TriQuint GaAs pHEMT TQPED process. The design and final projects from several semesters available electronically in IEEE publication format.

ECEN 5004, *MMIC design and measurements*, graduate class with strong design component, taught every other year, enrolment about 25/semester. Obtained free MMIC TriQuint GaAs foundry fabrication (a $35,000 value per run, since 2006) and WIN Semiconductor GaAs and GaN fabrication ($100k/year for 2018-2021). Students spend the semester designing a MMIC in the 10-30GHz range, the MMIC is fabricated during the summer and they test it in the fall semester. Several papers have been published as a result of this class at IMS and EuMW.

ECEN 5024, *Advanced Electromagnetics,* developed in Fall 2020, with 20 graduate students. The class does not follow a textbook, but is rather focused on theoretical topics that the students will need in their research. It is centered on electromagnetic theorems, starting from equivalence, duality and reciprocity and including compensation and electrodynamic similitude. Through the theorems, various types of EM waves are studied: uniform and non-uniform plane waves in lossless and lossy media, quasi-TEM, TE and TM in metallic waveguides, waves in dielectric waveguides including optical fibers, and Gaussian beams.

Other undergraduate course development

ECEE 1500, *Sustainable energy*, for non-engineering majors. The class has been taught since 2010 and is approved as the Arts and Sciences QRMS (quantitative reasoning math and science) elective. The course material was shared with and is currently being used at the University of Washington (Prof. Peyman Arabashahi) and Ohio State University (Prof. Betty Lise Anderson). The course includes experimental group projects focused on energy issues related to engineering.

ECEN 2010, *Electrical Engineering in Biology and Medicine*, sophomore elective seminar course. Developed course with Prof. Meyer, including lectures, homeworks, practical design problems and about 10 visits from local companies during the semester. The course covers three components: electrical processes in the body (signaling), electrical engineering diagnostics and treatment (including MRI, EEG), and effects of electromagnetic fields on the body (e.g. heating).

Other graduate course development

- *Special topic, Practical antenna design*, graduate lab, taught irregularly, enrolment about 20/semester. The students use pc-based CAD to design about 15 different kinds of wire and printed antennas that they fabricate and measure. A part of this course is a field trip to the Very Large Array (VLA), the radio telescope in Socorro, New Mexico.

- *Special topic, RF/optical techniques*, graduate course, taught irregularly. Covers some common methods and components used at both RF and optical frequencies (wavelengths). The objective of the course is to present two different views of the same electromagnetic technique, phenomenon, or circuit component. Examples of methods that are compared include: Fourier optics and antenna analysis; Gaussian beams at optical and millimeter waves; diffraction theory; and basic field theorems. Examples of components that are compared include polarizers, lenses, waveguides, directional couplers, retrore ectors, phase conjugators, and soliton transmission structures. The course concludes with a conference at which students present projects they have worked on during the last month of the course. Colleagues from industry judged the

presentations, and Best Paper Award was given. A digest of this mini conference was published for assessment purposes.

Fellowships obtained for my students at CU Boulder

- "Radio Frequency Research Fellowship", to fund one graduate student (Jacques Hung Loui) for a year, funded by FIRST RF, Fall 2003-Fall 2004, $32,202
- Sandia National Laboratory, "Excellence in Science," Fellowship to support graduate student, Nicola Kinzie, 8/04 - 8/05, $25,000
- MIT Lincoln Laboratories Fellowship - $15K per year for support of exceptional graduate student, yearly for 5 years (2005-2010)
- Rohm and Haas Electronics, 1-year graduate fellowship, John O'Brien, $33,500, 2006 - 2007
- NSF Graduate Fellowship for Alan Brannon, 2005-2008
- NIST PREP for Ph.D. advisee Alan Brannon, $50,000/year for 3 years, 2006 – 2008
- NIST PREP fellowship for PhD advisee Jonathan Chisum, August 2006 - June 2007
- NIST-PREP for Michael Elsbury, Voltage standards, 2007-2010, $50,000/year
- NIST-PREP, Bryan Babcock, 2009-2010, $50,000
- NSF, International supplement (with Finland and Argentina), $20k, 2008-2009
- NSF, REUs totaling over $150,000
- NSF AGEP Minority Fellowship for PhD advisee Mabel Ramirez Velez, August 2006 - June 2007
- NIST/CU MSE Graduate Fellowship for Robert Scheeler, 2011 and 2012
- NIST PREP graduate fellowship for PhD advisee Dan Kuester, 2008-2012
- NSF, International supplement (with Switzerland), William Haines and Patrick Bluem, $20k, 2016
- NIST PREP graduate fellowship for PhD advisee Akim Babenko, quantum electronics, 2018-2022
- NIST PREP graduate fellowship for PhD advisee Amy Robinson, quantum electronics, 2019-2023
- NDSEG Fellowship for PhD advisee Paige Danielson, phased array, 2018-2023
- NSF Graduate Fellowship for PhD advisee Kaitlin Hall, microwave thermometry, 2021-2024
- GAANN Graduate Fellowship for PhD students Georgia Sandidge (2023) and Alec Russell (2024)

International Teaching

I believe it is very important to expose my students in Colorado to a variety of cultures and have worked hard on enabling many visiting students from Europe (Italy, Spain, France, Germany, Finland, the Netherlands, Sweden, Norway, Serbia), Asia (Korea, Japan), South America (Argentina, Brazil, Venezuela) to work and spend extended visits in my group.

As visiting professor at the Technische Universitat Muenchen, Munich, Germany, I taught a version of the *RF Optics* graduate course in Spring 2001, and *Active Microwave Circuits* in Summer 2003, to a total of 30 graduate students. In the years following 2001, a total of 11 students from Germany spent at least 3 months each in my group, which resulted in about 10 joint papers (one of them is the 2004 winner of the IEEE MTT Microwave Prize).

As a visiting professor at ISAE (Supaero) in Toulouse, France, I taught a seminar course on antennas in Spring 2014 to approximately 40 students. This course was taught in French. I had 5 students from France (Limoges and Toulouse) spend at least 6 months each in my group, with a number of resulting joint publications.

As a Chair of Excellence professor at Carlos III University in Madrid, Spain, in Fall 2018, I taught a seminar course *Selected topics in active microwave circuits* to approximately 15 graduate students. We just got a paper accepted and two of the Spanish students will be spending time in my group this summer, finishing a joint journal paper. I have hosted 4 other graduate students from Spain in the past.

Outreach activities

- K-12 students know little about what engineering is and it is important to get this information out to both students and parents. I helped in many science fairs as coach (project advisor), as well as judge, in local elementary, middle and high-schools.
- I have created lab kits for high-school physics classes, in collaboration with Dr. Helen Petach, the Fairview high school physics teacher, Fairview High School, Boulder.
- I have worked with Jay Donegy and Dr. Helen Petach, the high-school instructors for the senior/junior class "Research Seminar in Science". This all-year class teaches students how to approach a research problem and places them in research labs around Boulder. I hosted several students in the past few years, and they have all received prizes at the State science fairs and all are currently doing PhDs. The students working with me spent regular weekly times in the lab.
- I organized "a day in the lab" for elementary and middle-school students, where up to 100 students come to visit electrical engineering laboratories with 10-12 hands-on experiments. This was a yearly effort and involved Eisenhower elementary school (3^{rd} and 4^{th} grades), Summit middle school (7^{th} grade), and High-Peaks elementary school (4^{th} grade), all in Boulder.

SELECTED SERVICE

- Member of Editorial Board, *Proceedings of the IEEE*, January 1, 2019 – present
- Steering Committee and Technical Program Committee, *2022 IEEE International Microwave Symposium*, Denver, CO, June 2022
- Technical Program Committee, *2022 IEEE International Microwave Symposium*, 2020 – present
- Member of External Advisory Board, *Southwest Research Institute*, Houston, Texas, 2018 - present
- Member of Technical Program Committee, *IEEE MTT-S International Symposium*, 1994 to present.
- General Chair for *IEEE Wireless Power Transfer Conference*, held in Boulder, May 2015.
- Member, *IEEE MTT Microwave Prize committee*, 2008 to 2018.
- Member, *IEEE Electromagnetics Award committee*, 2014-2018, chair 2016-2018.
- Member, IEEE MTT-5 and MTT-26 technical committees, 2010 to present. MTT-5 Vice chair 2014-2016, Chair 2017-2019.
- Associate Editor, *IEEE Trans. on Microwave Theory and Techniques*, January 2005 – December 2010.
- Technical Program Co-Chair (with the late K.C. Gupta) for the *IEEE MTT-S International Microwave Symposium* in Denver, June 1997 (about 8000 attendees).
- Chair, Commission D or URSI (2015-2017), Member at Large of URSI, 2009 -2018.
- Member of National Academies panel on ARL, Sensors and Electronics, 2006 and 2007.
- Member of Sandia National Laboratories Microsystems (Division 1700) review panel, 2007-2015.
- Organizer of workshops: WARC '95, Denver; 1997 ARO/DARPA Workshop on Quasi- Optical Combiners, Santa Barbara; Optical and Microwave Packaging Workshop, Estes Park, 1993.
- Organized numerous URSI, IMS, AP conference sessions.
- University of Colorado Chancellor's Committee on Conflict of Interest, 1996 to 2009, Chair in 1999.
- University of Colorado Distinguished Professor selection committee, 2015-present.
- College of Engineering Dean's FLAG (Future Leaders) committee, 2002-2005.
- ECEE Department Chair Search, 2019-2020.
- ECEE department Executive Committee, 1995 to 2000, and 2002-present. Various hiring committees 2001-present. Department Chair search committee chair, 2018-2019.
- College of Engineering First Level Review Committee, 2020- present.
- College of Engineering Diversity, Equity and Inclusion Faculty search, 2020 – 2021.
- Department Graduate Committee, 2020 – present