Center for
Wireless and Microwave Information Systems

http://wami.eng.usf.edu/

Department of Electrical Engineering
University of South Florida

Annual Report 2018

Members: Dr. Huseyin Arslan, Dr. Lawrence Dunleavy (Co-Director), Dr. Richard Gitlin, Dr. Gokhan Mumcu, Dr. Ismail Uysal, Dr. Jing Wang (Co-Director)

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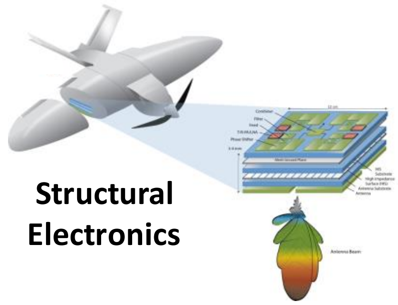

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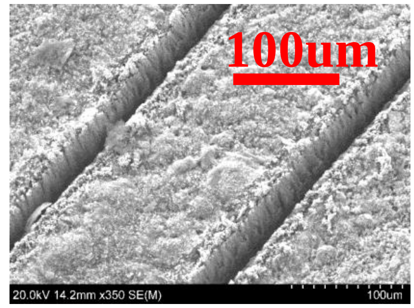

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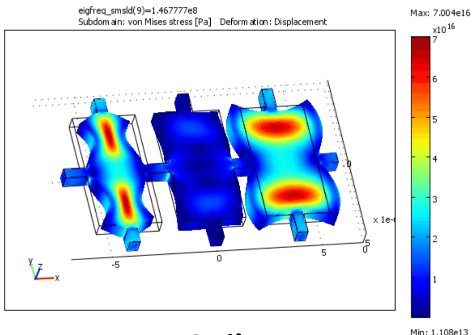

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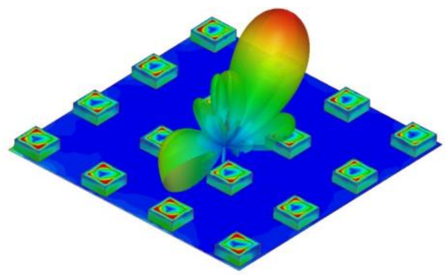

Mm-Wave Antenna Arrays

Summary

Now in its 21th year, the Center for Wireless and Microwave Information Systems conducts research across a broad range of technical areas that include device modeling and characterization, micro electromechanical systems, advanced materials and nanoscale devices, active antennas, cognitive radio, next generation wireless architectures and RF identification (RFID). Research projects focus on basic scientific development as well as applications such as biomedical sensing, communications, robotics and transportation. Active collaborations are pursued with multiple industry and university partners as well as several centers at the University of South Florida.

In 2017/18 the Center supported 40 MS and PhD students, 2 post-doctoral fellows and 7 undergraduate students. Center faculty submitted 33 research proposals in the past year; of these 11 proposals were funded. The WAMI faculty had more than 80 publications in journals, conferences and book chapters, 17 patents and gave 19 invited talks. The students and faculty received 4 awards and distinctions including best paper/poster awards and recognition for professional achievement. Since 2012, the productivity of the center includes:

- Paper published: 528
- Patents granted: 81
- Invited talks: 87

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Newsworthy Notes

- Dr. Jing Wang, the Co-Director of the WAMI Center, has been recognized with the 2018 Outstanding Research Achievement Award and 2017-2018 Outstanding Electrical Engineering Educator Award (http://www.research.usf.edu/absolute-news/templates/usfri-template.aspx?articleid=7255&zoneid=1). By collaborating with Keysight Technologies the USF WAMI center initiated the Keysight RF and Microwave Industry-Ready Certification Program in 2013 as the first university to develop and implement this program. Until now, more than 100 USF students have earned Keysight RF Industry Ready certificates, while 39 other universities followed our footstep to join this program. At the ASEE 2018 conference, Dr. Wang contributed to a panel discussion entitled *Different Strategies for Preparing Students to Tackle the RF Engineering Challenges of Tomorrow* along with fellow panelists from University of Notre Dame, University of Arizona, Pennsylvania State University, and Georgia Institute of Technology (https://peer.asee.org/different-strategies-for-preparingstudents-to-tackle-the-rf-engineering-challenges-of-tomorrow-a-panel-discussion). Dr. Wang has also been very active in mentoring graduate and undergraduate students to conduct crosscutting research funded by external federal agencies or companies. So far, 14 Ph.D. students have successfully defended their dissertations and graduated under his supervision, and there are 7 undergraduate students who are conducting research in his lab funded by a NSF REU program.

- Dr. Sourabh Khandelwal joined USF WAMI Center as a Research Faculty since beginning of 2019. His research interests include characterization and modeling of semiconductor devices and circuits focused on ASM-GaN-HEMT and his expertise in this field is well-recognized by the research community. In particular, his effort has created industry standard model for GaN RF and power devices, which was detailed in his recent paper entitled ASM GaN: Industry Standard Model for GaN RF and Power Devices—Part 1: DC, CV, and RF Model, which was just published in *Transactions on Electron Devices* in January 2019.

- Former WAMI Center Director and EE Department Chair Dr. Tom Weller has moved to Oregon State University. While this is a loss for USF and gain for Oregon, the USF WAMI Center remains strong and we have many exciting developments to share with our external affiliates at our next meeting.. On related news, starting this same semester Dr. Dunleavy resumed full-time faculty responsibilities at USF, and is now working closely with Jing Wang as Co-Director of the Center

- Mini Circuits continues to be a strong supporter of the WAMI teaching laboratory by contributing microwave components. The Center also acknowledges the continuing strong support of Keysight Technologies, National Instruments and Modelithics for providing our students with no-cost access to their exceptional software tools. Also, Keysight supports the equipment modernization of the WAMI teaching laboratory by offering the special educational discount on 2 pairs of PXI Vector Network Analyzers and PXI Signal Analyzers up to 26.5GHz that allow the completion of the equipment updates for all the seven test benches in this lab.

- Recent masters and Ph.D. graduates from the WAMI Center are now working for Embry Riddle Aeronautical University, Georgia Tech Research Institute, II-VI Incorporated, ANSYS, Maxlinear, Harris Corporation, Intel, Samsung Research, Qorvo, Qualcomm, Cummins, Vectra AI (Silicon Valley startup), Sandia National Laboratories, and NTIA (The National Telecommunications and Information Administration).

- The **2018 Rudolf E. Henning Distinguished Mentoring Award** was presented to ***Dr. Robert Weigel*** at WAMICON 2018. Dr. Robert Weigel was born in Ebermannstadt, Germany, in 1956. He received the Dr.-Ing. and the Dr.-Ing.habil. degrees, both in electrical engineering and computer science, from the Munich University of Technology in Germany where he respectively was a Research Engineer, a Senior Research Engineer, and a Professor for RF Circuits and Systems until 1996. During 1994 to 1995 he was a Guest Professor for SAW Technology at Vienna University of Technology in Austria. From 1996 to 2002, he has been Director of the Institute for Communications and Information Engineering at the University of Linz, Austria where, in August 1999, he co-founded the company DICE, meanwhile split into an Infineon Technologies (DICE) and an Intel (DMCE) company which are devoted to the design of RFICs for mobile radio and MMICs for vehicular radar applications. Since 2002 he is Head of the Institute for Electronics Engineering at the University of Erlangen-Nuremberg, Germany. Since 2017, he is Dean of the university's Department of Electrical Engineering. In Erlangen, respectively in 2009, in 2012, and in 2015 he co-founded the companies eesy-id, eesy-ic and eesy-innovation. Dr. Weigel has published more than 900 papers. He received the 2002 VDE ITG-Award, the 2007 IEEE Microwave Applications Award and the 2016 IEEE MTT-S Distinguished Educator Award. Dr. Weigel is a Fellow of the IEEE, an Elected Member of the German National Academy of Science and Engineering (acatech), and an Elected Member of the Senate of the German Research Foundation (DFG). He served in many roles for the IEEE MTT and UFFC Societies. He has been Founding Chair of the Austrian COM/MTT Joint Chapter, Region 8 MTT-S Coordinator, Distinguished Microwave Lecturer, MTT-S AdCom Member, and the 2014 MTT-S President.

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Student Recognition

- **Mohamed Mounir Abdin**, who is co-advised by Drs. Wang and Weller, has been awarded the prestigious IEEE Microwave Theory and Techniques Society (MTT-S) Graduate Fellowship for 2018. He was recognized during the 2018 International Microwave Symposium (IMS) (https://ieeexplore.ieee.org/iel7/6668/8425049/08425095.pdf). His research interests include mm-wave circuit design using additive manufacturing (AM) and 3D printing to facilitate the wide-spread adoption of 5G technologies by reducing the overall cost and complexity. He is currently working on demonstrating a 75-110 GHz (W-band) transceiver for broadband communications using additive manufacturing for packaging. His research focuses on the RF electronics, system-level design, and packaging.

- **Poonam Lathiya,** a WAMI Ph.D. student advised by Dr. Jing Wang, received the Best Poster Award in the 2018 International Conference on Magnetism (ICM 2018) at San Francisco in July 15-20, 2018. Recently, she has also been awarded a travel grant to attend 2019 IEEE Magnetics Society Summer School. Her research interests include development and characterization of soft magnetic materials for RF, microwave and mm-wave device applications.

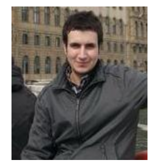
- **Enrique González,** a WAMI Ph.D. student advised by Dr. Gokhan Mumcu, received Honorable Mention for this paper submitted to the IEEE International Antennas and Propagation Society (APS) Symposium that will be held in Atlanta in July 2019. This year's student paper competition received 195 applicants from all over the world. Enrique is awarded $1,500 travel grant by the Symposium. His research focuses on mm-wave reconfigurable devices and beam-steering antenna arrays.

- **Arya Menon,** a WAMI Ph.D. student advised by Dr. Tom Weller, has been awarded the prestigious Provost's Award for Outstanding Teaching by a Graduate Teaching Assistant in the STEM category for the 2017-2018 academic year. Her teaching portfolio can be found here-https://youtu.be/cFgEDd0Hljk. Arya's research is focused on the development of a security scanner that combines radar and radiometric techniques for imaging. She has been working towards demonstrating the technique by building prototype systems in the K band (18-26 GHz). Arya has served as TA for several courses offered by the WAMI center. It is worthwhile mentioning that Arya has also been awarded the prestigious IEEE Microwave Theory and Techniques Society (MTT-S) Graduate Fellowship for 2019. Arya will be recognized during the 2019 International Microwave Symposium.

- **Merve Kacar,** a WAMI Ph.D. student advised by Dr. Gokhan Mumcu, has been awarded a $500 travel grant for attending the International Workshop on Antenna Technology (IWAT) held in Miami on March 3rd – 6th, 2019.

- **Ismail Uluturk,** a WAMI Ph.D. student advised by Dr. Ismail Uysal has been awarded a $1,500 international Travel Grant by the Office of Graduate Studies to present his work at the D4R – Data for Refugees – International Forum which was organized as a global big data competition. Researchers from around the world worked on using a large dataset of anonymized mobile phone data to provide a better insight into (and ultimately improve) the living conditions of more than 3.5 million refugees living in Turkey. The competition has received 100 submissions of which only 26 were accepted for presentation at the international forum which was held in Istanbul in January 2019.

- **Omer Faruk Firat,** a WAMI Ph.D. student co-advised by Drs. Weller and Wang, has been awarded a the best poster presentation award during the USF Graduate Student Research Symposium on March 4th, 2019 while receiving a $500 confcerence travel grant.



- It is worthwhile mentioning that the WAMI Center students has managed to sustain a six year winnning streak for wining the prestigious IEEE Microwave Theory and Techniques Society (MTT-S) Graduate Fellowship since 2013. This prestigious fellowships have been granted to 12 awardees globally each year during the International Microwave Symposium. Since 2014, WAMI Center students also won prestigious IEEE Antennas and Propogation Society (APS) Doctoral Fellowships that are granted globally up to 10 awardees each year.

  - Arya Menon, awarded IEEE MTT-S Graduate Fellowship 2018
  - Mohamed Abdin, awarded IEEE MTT-S Graduate Fellowship 2017
  - Juan Castro, awarded IEEE MTT-S Graduate Fellowship 2016
  - Abhishek Dey, awarded IEEE APS Doctoral Fellowshuip 2016
  - Maria Cordoba Erazo, awarded IEEE MTT-S Graduate Fellowship 2015
  - Maria Cordoba Erazo, awarded 2014 ARFTG Roger Pollard Memorial Student Fellowship in Microwave Measurement
  - Michael Grady, awarded IEEE MTT-S Graduate Fellowship 2014
  - Ahmad Gheethan, awarded IEEE APS Doctoral Fellowship 2014
  - Ibrahim Nassar, awarded IEEE MTT-S Graduate Fellowship 2013
  - Bryce Hotalen, awarded IEEE MTT-S Undergraduate/Pre-graduate Scholarship 2013
  - Evelyn Benabe, awarded Automatic Radio Frequency Techniques Group Student Fellowship Award – Silver
  - Evelyn Benabe, awarded IEEE MTT-S Graduate Fellowship 2010
  - David Cure, awarded NASA GSRP Fellowship 2010 and 2011.
  - Quenton Bonds, awarded NASA GSRP Fellowship 2009.

Professional Activities

- **Dr. Gitlin** was inducted into the Florida Inventors Hall of Fame. (Dr. Weller accepted the award on his behalf...)

- **Dr. Uysal's** article (senior author) on temperature monitoring technologies was chosen as one of the most downloaded articles of 2017 in the Journal of Comprehensive Reviews in Food Science and Safety (ranked 1st among 307 Food Science and Technology Journals in the world with IF 7+).

- **Dr. Uysal** served as a TPC Co-Chair for the Software and Applications track of IEEE RFID 2019 – IEEE's flagship conference on RFID technology and applications – to be held in Phoenix, AZ, April 2-4th, 2019.

- **Dr. Uysal** was an EE faculty advisor for IEEE SoutheastCon 2018, which was held in Tampa, FL, April 19-22nd, 2018.

- **Dr. Arslan** has offered tutorials in various IEEE conferences on 5G and Beyond Waveforms. He is also guest co-editor on the same topic for a special issue in PHY Communications Journal during 2018.

- **Dr. Mumcu** had invited talks in 2018 URSI National Radio Science Meeting (NRSM) and 2018 IEEE International Microwave Symposium (IMS). His URSI NRSM talk was on X-band conformal antenna arrays using additive manufacturing techniques. His IEEE IMS talk was part of a workshop on tunable passive devices for multi-band systems. It focused on mm-wave beam-steering antennas and frequency tunable RF band pass filters using microfluidics based reconfiguration techniques.

- **Dr. Mumcu** authored two book chapters:
  1) G. Mumcu, "Microfluidically reconfigurable antennas," in Electromagnetic Waves, Developments in Antenna Analysis and Design: Volume 1: Institution of Engineering and Technology, 2018, pp. 203-241
  2) G. Mumcu and T. Weller, "Small Antennas and Miniaturization Techniques," in Antenna Engineering Handbook 5th Edition: McGraw Hill, 2018, pp. 233-264.

- **Dr. Mumcu** served as Student Paper Competition Chair for the IEEE International Workshop on Antenna Technology (IWAT) that was held in Miami on March 3rd – 6th, 2019.
- **Dr. Dunleavy** has worked closely with Keysight Technologies and others to organize and deliver the highly successful "RF Boot Camp" at the IEEE MTT-S International

Microwave Symposium. The RF Boot camp is a one day “crash course”held during IMS week each year, introducing newcomers to the field the basics of RF and microwave principles, measurements and simulations. This activity began with IMS2015, has had between 100 and 200 participants each year with very good reviews, and now offers CEU credits to boot. The next boot camp will be held in Boston in conjunction with the IEEE MTT-S IMS event there in June 2019. Former USF Department Dr. Tom Weller has also been involved as one of the featured tutorial speakers.

Research Highlights from Current & Recent Projects

Title: Fully Packaged Wideband Phased Arrays Using Direct Digital Manufacturing

Collaborators: USF (Gokhan Mumcu and Jing Wang);
OSU (Thomas Weller);
Sciperio Inc. (Casey Perkowski and Kenneth Church);
AFRL (Bae-Ian Wu).

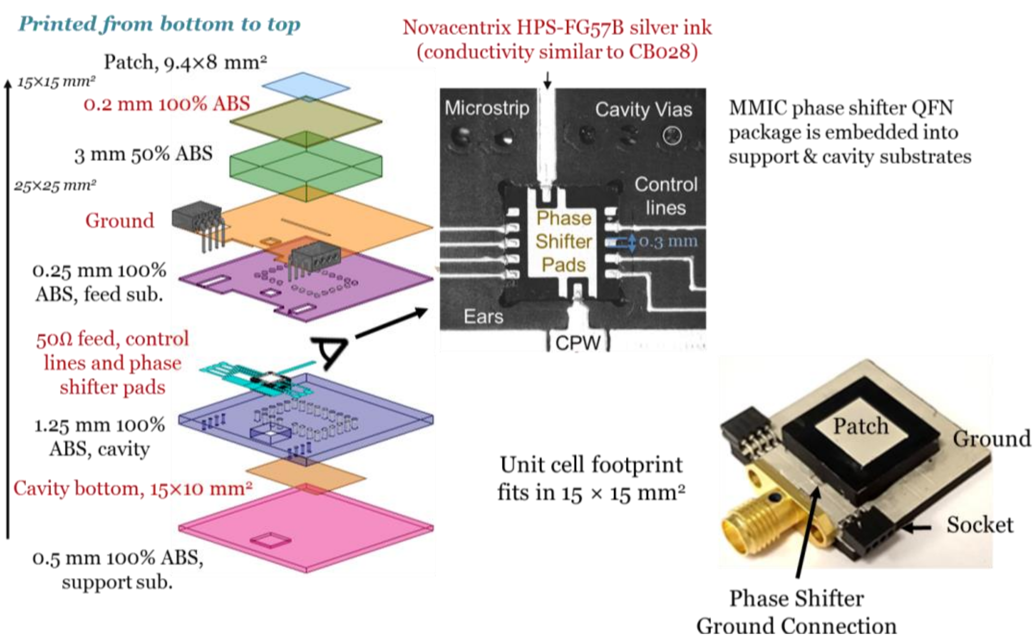


Fig.1. Fully packaged X-band antenna element with embedded cavity for platform installations and MMIC phase shifter for beam-steering capability within a phased array. It consists of nine material layers with customized dielectric constants and thicknesses. Demonstrates 24% impedance bandwidth, >80% radiation efficiency, >20 dB front-to-back radiation ratio. Phase shifting states (6 bit) are successfully verified.

Overview: Under multiple research awards from Air Force and Army SBIR programs, USF WAMI Center and Sciperio, Inc. are developing fully packaged, low-cost, low-profile and conformal wideband phased arrays. These phased arrays are enabled by strategically utilizing the unique capabilities of the Direct Digital Manufacturing (DDM) in the design and fabrication stages of the array. DDM is an additive manufacturing technique that allows implementing compact, cost-effective, lightweight multilayer RF devices exhibiting alternating dielectric and conductive layers with design flexibilities in making material choices, layer thicknesses, and material shapes. These flexibilities allow the additively manufactured RF device performance to meet or exceed the performance level of those implemented with the well-established traditional manufacturing approaches. Our on-going work at X-band successfully demonstrates phased array unit cells fully packaged with MMIC phase shifters and embedded cavities as shown in Fig. 1. The unit cells are characterized to operate with 24% impedance bandwidth and >80% radiation efficiency with > 20 dB front-to-back radiation ratio. The unit cell overall consists of nine material layers. Five of these are dielectric material layers with customized thicknesses and dielectric constant properties. Remaining four layers are conductive with minimum feature sizes down to 150 µm to integrate the commercial-of-the-shelf (COTS) MMIC QFN package within the unit cell volume with the required bias, control and RF in/out lines. It is important to note that USF and Sciperio, when necessary, utilize a picosecond laser capability within the DDM process to perform IC and antenna packaging in the die level with minimum feature sizes reaching down to 10 µm as seen in Fig. 2. The project has successfully moved into Phase II and unit cells are being now utilized towards realization of beam-steering subarrays with the inclusion of more material layers and necessary design modifications. Subarray details are currently not available for public release.

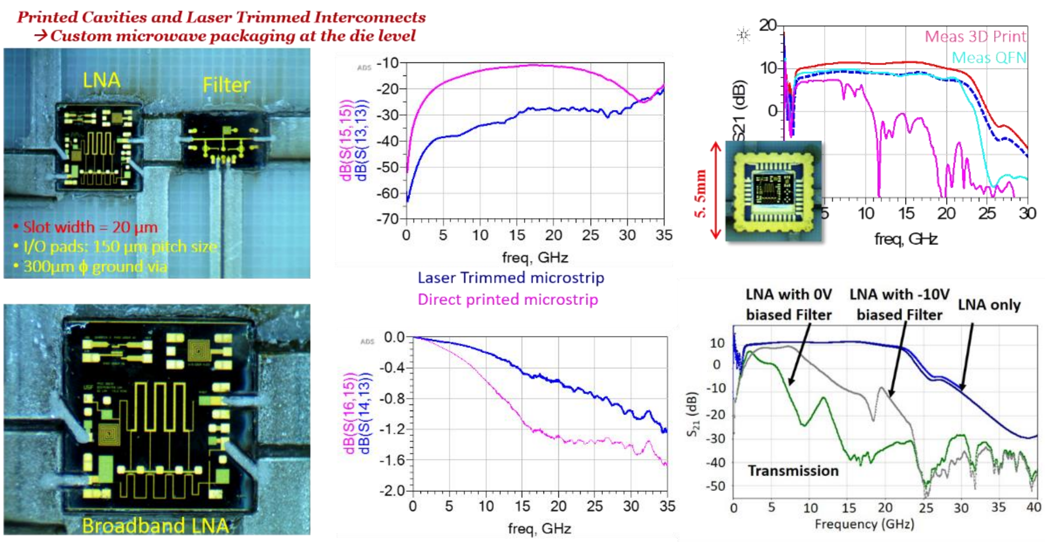
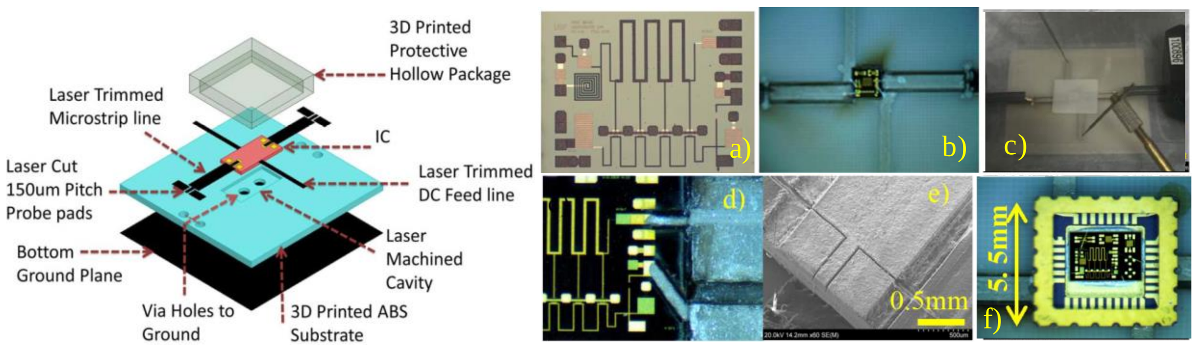


Fig. 2. Fully packaged multi-chip mm-wave front-end module demonstration through laser enhanced direct print additive manufacturing (LE-DPAM) has been successfully implemented and verified. This example includes one broadband distributed amplifier followed by a tunable filter that are laterally integrated via a LE-DPAM process.

Title: MMIC packaging and on-chip low-loss lateral interconnection using additive manufacturing and laser machining

PIs: USF (Jing Wang);
OSU (Thomas Weller).

A new and versatile 3D printed on-chip MMIC integration approach using laser machining is demonstrated in this paper for microwave and mm-wave systems. The integration process extends interconnects laterally from a MMIC chip to a 3D printed chip carrier. Laser machining techniques are studied and characterized to enhance the 3D printing geometry in terms of feature size and dimension accuracy down to sub-5um. Specifically, the width of microdispensed printed traces is accurately controlled within micrometer range and probe pads are formed by laser cutting to facilitate RF measurement. S-parameters of a distributed amplifier integrated into the package are simulated and measured from 2 to 30 GHz. The overall performance is significantly better than traditional wire-bonded QFN package. The attenuation of the microstrip line interconnects is only 0.2 dB/mm at 20 GHz and return loss with the package is less than 10 dB throughout the operating frequency band. The measured S-parameters of the QFN-packaged distributed amplifier (DA) are plotted in comparison with the 3D printed packaged DA. Due to strong parasitic effects of the wirebonds and the frequency limitation of the QFN package, the bandwidth of the DA is limited to 12 GHz showing a gain reduction of 2 dB when compared to the DA integrated in the 3D printed package. Fig. 3 summarizes the obtained attenuation results of the interconnection (i.e. 0.2dB/mm at 20 GHz) as compared to prior works. The LE-DPAM package outperforms previous printed interconnects in terms of insertion loss by at least 0.125 dB at 5 GHz and 1.2 dB at 20 GHz.



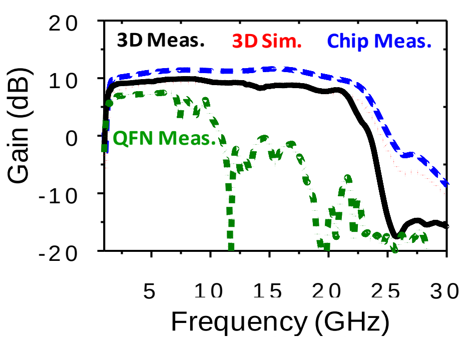


TABLE I
COMPARISON OF MEASURED PERFORMANCE

Reference	Substrate	IC Pad width (um)	Attenuation (dB/mm) 5GHz	20GHz
DPAM	ABS	100	0.125	0.20
Tehrani [6]	Glass	200	0.25	1.45
Tehrani [7]	SU-8	230	0.40	0.60
Mehta[8]	Kapton	90	0.5	1.5
QFN_P	ABS	100	0.32	NA

Fig. 3. First ever demonstration of MMIC packaging and on-chip low-loss lateral interconnection using additive manufacturing and laser machining, which has achieved best of its kind RF performance at mm-wave frequencies.

Title: Microfluidically Reconfigurable Millimeter Wave Switches and Beam-Steering Antenna Arrays

PI: Gokhan Mumcu

Overview: Microfluidics based reconfiguration techniques can be harnessed to design and construct RF devices with large frequency tuning ranges and low insertion losses while providing significantly higher power handling capabilities. Dr. Mumcu's work on this research area dates back to 2013 with his initial work on liquid metal based frequency tunable RF band pass filters and antennas. Since then, his work has continued under three National Science Foundation (NSF) grants one of them being the prestigious CAREER award. A significant milestone of his research was the demonstration of devices that replaced liquid metals with metallized plates to perform at much higher frequencies without reliability issues of the liquid metals. Most recently, another milestone has been reached by actuating the metallized plates within the microfluidic channels with piezoelectric disks as shown in Fig. 4. This *internal actuation* mechanism removes the need for external microfluidic pumps while providing very low actuation time – initially characterized as ~1 ms for mm-wave SPST switches with possibilities to reduce further as research progresses. To the best of knowledge, these are the fastest microfluidically actuated RF devices reported to date with very high reliability. Such switches can handle continuous RF power levels up to 25 W with no addition of thick ground planes or heat sinks. Realization of multi-throw switches for efficient mm-wave beam-steering has recently been proposed as shown in Fig. 3 and recognized with an honorable mention from the highly competitive IEEE APS symposium student paper competition (student author: Enrique González). Other application areas being pursued are mm-wave reconfigurable filters, phase shifters, and focal plane beam-steering arrays.

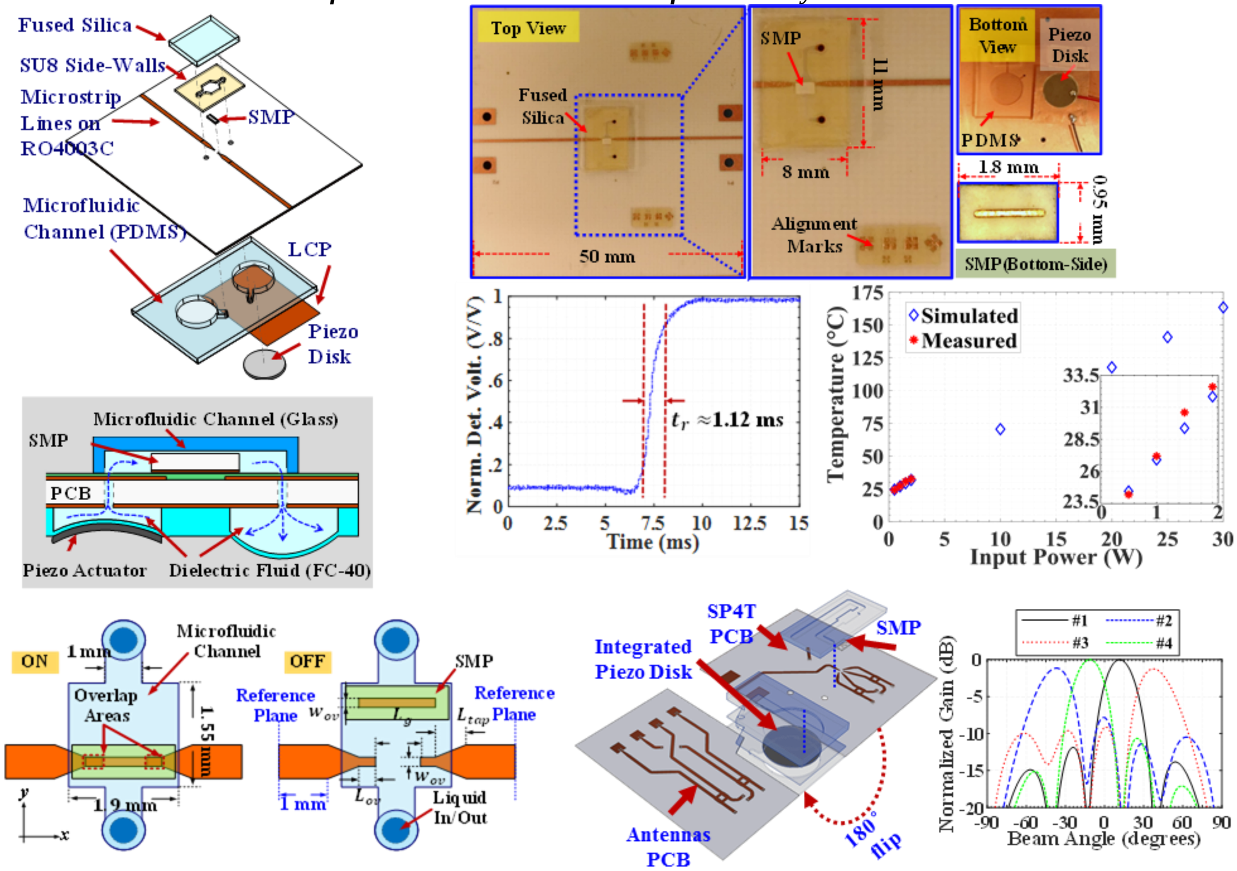


Fig. 4. Mm-wave (22 – 40 GHz) SPST switch microfluidically actuated with piezoelectric disk (12.7 mm diameter under the ground plane). Characterized to operate with: 0.42 dB insertion loss, 20 dB isolation, 12 mW power consumption (only during actuation), 25 W continuous RF power handling. The concept is being extended to multi-throw switches and beam-steering arrays.

Title: Sensor-assisted Sustainable and High-Quality Strawberry Production with Wireless Real-Time Field Monitoring

Project: United States Department of Agriculture / PI: Ismail Uysal

Abstract— Florida is the second largest strawberry producing state in the nation. However, the retail prices are high compared to the production volume of other states and they are getting higher each year (NASS, 2015). The ultimate goal of this project is to inform and guide specialty crops growers in real-time from planting through harvesting to achieve the measurable OMB outcomes of i) enabling a more sustainable and higher quality strawberry production while ii) improving our state's economy with higher and more profitable yields. To accomplish these goals, a smart monitoring platform with integrated sensors and algorithms will be developed with the following objectives in mind:

Obj 1. [determine the optimal combination of moisture levels, temperatures, and electrical conductivity (EC) levels of the soil for high quality strawberry plants],
Obj 2. [create a smart algorithm which processes moisture level, temperature, and the EC level data and indicate precisely when there is additional need for watering or fertilization],
Obj 3. [design a low cost, self-sufficient wireless monitoring device to implement the algorithm for real-time field applications. When these devices are scattered throughout the field they will also provide the opportunity for micro management of the field to further improve sustainability and quality], and finally;
Obj 4. [assess and compare the strawberry production practice that uses the proposed technology platform with wireless monitoring devices and smart algorithm with the traditional strawberry production practice to scientifically determine system level improvements in terms of yield, quality and resource management.]

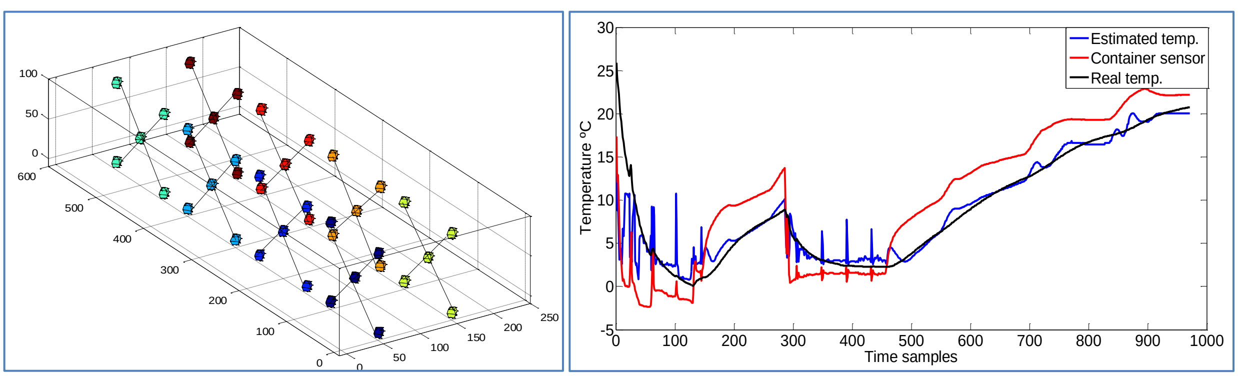


Fig 5. A wireless sensor network implemented in a perishable shipping container to monitor and ultimately predict temperatures at different physical locations inside the container – a similar algorithm will be studied as part of this project.

Title: Algorithmic Prediction and Recognition of Human Activity and Falls from Wireless Accelerometer Data

Project: Florida High Tech Corridor Matching Grant / PI : Ismail Uysal

Abstract: The speed and scope of innovation and advancement created by the recent developments in AI technology have caught the science world by surprise. Particularly, the technology we now call Deep Learning can now achieve unparalleled performance in popular cognitive tasks previously only reserved for humans, such as speech recognition (like Siri and Alexa), language translation (Google Translate), image recognition (like Face ID) and others. This is accomplished by a technology called neural networks which imitate the way the human brain works for cognition. Figure 1 displays the architecture of the neural network which consists of an input layer which accepts sensory data as input and an output layer which predicts the motion type (or whether there was a fall). In the middle are the hidden layers of the neural network which "learns", just like humans do, from the data being presented to establish highly complex relationships between the input and output and identify different motion clusters similar to the visual presented in the figure on the right. Even though Deep Learning/AI has great promise in solving some of today's most pressing challenges, a significant amount of data is usually required to "train" these algorithms to achieve robust real-life performance. Hence, as part of this project, we will first i) collect or otherwise obtain large amounts of accelerometer data using both publicly available resources and equipment and supplies provided to us by the company to then ii) train deep neural networks to achieve state-of-the-art performance in motion and fall recognition using advanced AI technology. The first part of the third objective (data collection) will take place during the first six months of the project and the second part (AI/data processing) will take place during the latter half. We will also consider and compare different learning technologies such as reinforcement learning.

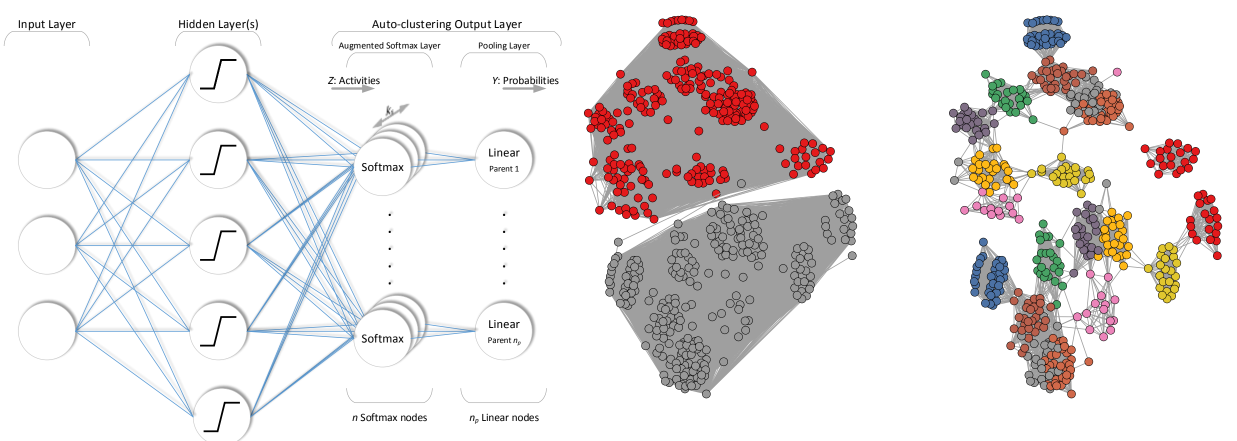
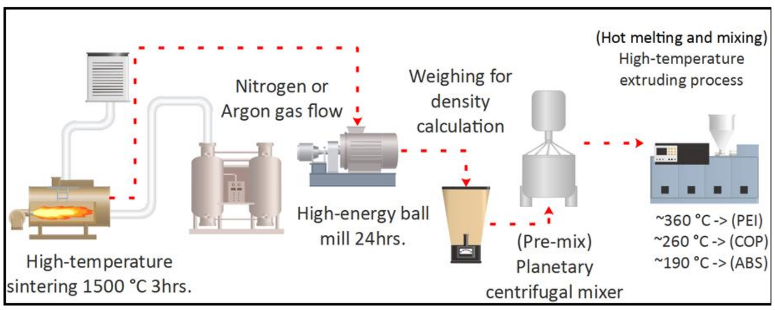


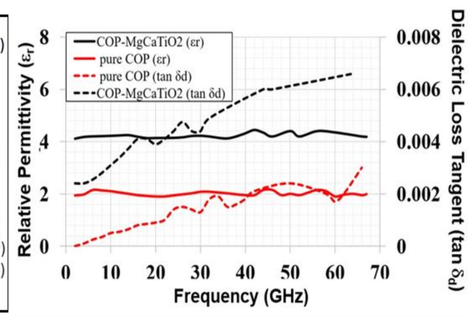
Fig 6. The architecture of an artificial neural network (left) and how it can identify unique clusters in data (right)

Title: Fabrication, Modeling, and Application of Ceramic Thermoplastic Composites for 3D Printing (Fused Deposition Modeling) of Microwave Devices and Functional Packaging

PI: Jing Wang

A new kind of high permittivity (high-k) and low-loss composite material has been prepared in the form of feedstock filaments for a 3D printing process known as fused deposition modeling (FDM) technology. The thermoplastic composites are made of cyclic olefin polymer (COP) loaded with ceramic particle fillers, which are characterized at different frequencies using complex permittivity test fixtures. Previously, FDM printed specimen such as composite#1 shown in Fig. 7 has exhibited superb dielectric and loss properties at microwave and mm-wave frequencies up to 100 GHz on par or better than the best microwave laminates. Recently, FDM printed samples made of 50-55 vol.% COP-high-k ceramic composites have be successfully developed, which have shown relative permittivity (ε_r) of 12-15 along with a loss tangent (tan δ) below 0.003. Evidently, these newly developed ceramic-thermoplastic composites are well suited for microwave device applications at mm-wave frequencies and can be adapted to 3-D printing technologies or device packaging.



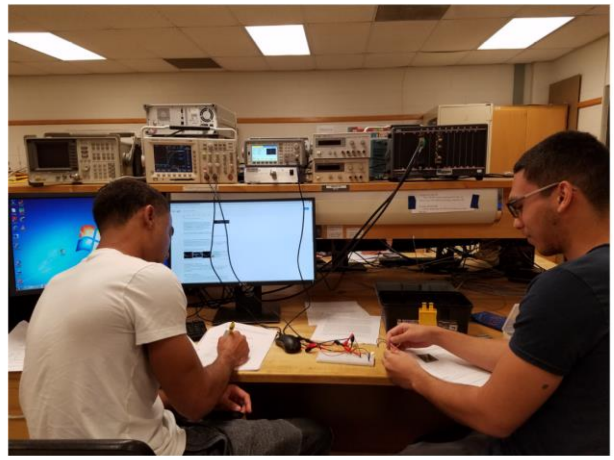


FDM of Test Specimen

Sample	Thickness (mm)	ε_r	Test f (GHz)	Loaded Q	Unloaded Q	Loss Tangent
Plastic #1	1.082	2.15	93.7620	77097	241234	0.001018
Plastic #2	1.102	2.12	90.2817	92128	258967	0.000786
Pure ABS	1.095	2.18	82.5162	10469	250255	0.010506
Composite #1	0.721	4.78	95.1977	36596	264509	0.003849
Composite #2	0.656	4.82	101.8766	29318	277986	0.005456

Fig 7. An overview of the preparation process of 3D printable thermoplastic-composites (upper left), which have been characterized to exhibit excellent dielectric and loss properties at mm-wave frequencies.

Selected Curriculum Activities



The instrumentation in the Wireless Circuits and Systems Design Laboratory had a major upgrade at the end of 2017, thanks to a very generous discount (90%) on $0.5M in new network and spectrum analyzers. Five of the seven benches in the lab are now equipped with 9 GHz network analyzers and 26.5 GHz spectrum analyzers, both controlled through a PXI chassis. The teaching assistants managed to update all experiments and documents in time for the spring 2018 semester. More recently, two more benches in the lab also haven been equipped with 9 GHz/26.5 GHz vector network analyzers and 26.5 GHz spectrum analyzers, which complete the major lab equipment upgrade project. A modulation/demodulation lab was newly introduced in the fall 2017 semester, as well.

One of the major curriculum activities that involved WAMI faculty during 2016-2017 was the restructuring of the undergraduate course on electromagnetics. The USF EE Department decided to drop Physics II (taught by the Physics Department) as a pre-engineering requirement, because there is significant overlap with the EE course on electromagnetics. When this change was made, the EE course was renamed EE Science II – Electromagnetics and it was increased to a 4 credit-hour course. With the additional 1 credit hour it is now possible to teach a weekly laboratory session that gives students hands-on experience with EM concepts. (Ironically, in 1997, what was then a 1 credit hour "EM Laboratory" was converted to the Wireless Circuits and Systems Design Laboratory, i.e. our well-known WAMI Lab.) WAMI faculty and graduate students were heavily involved with developing the new laboratory content, and we believe this has been a great addition to the EM course. Along with this change, the WAMI Lab was changed from a 2 credit hour course to a 3 credit hour course. The net result is that we gained 2 credit hours in the WAMI-related curriculum.

The RF & Microwave Power Amplifier Design Course (EEEL6368), currently offered once a year (both in-class and on-line) focuses on leading students through the process of completing a fabrication-ready high power GaN amplifie r design. Selected designs are fabricated and tested by Modelithics, other sponsors that offset some of the cost related to this fabrication are Qorvo and Transline.

To keep up with a growing student interest in wireless communications, Dr. Arslan has been offering a new wireless course on Foundation Technologies on LTE advanced and Beyond for the first time in Spring 2018 semester.

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4. D. Zaiden, J. Granfield, T. Weller, and G. Mumcu, "Compact and Wideband MMIC Phase Shifters Using Tunable Active Inductor Loaded All-Pass Networks," IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 2, pp. 1047 – 1057, Feb. 2018.
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6. M. Beygi, G. Mumcu and S. E. Saddow, "Neural Implant Materials: Safety Evaluation in Implanted Neural Probes Under MRI," SoutheastCon 2018, St. Petersburg, FL, 2018, pp. 1-2.
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13. E. González and G. Mumcu, “Mm-Wave Beam-Scanning Focal Plane Arrays with Microfluidically Switched Feed Networks,” URSI - National Radio Science Meeting, Boulder, CO, USA, Jan. 2018.
14. M. Kacar, C. Perkowski, P. Deffenbaugh, K. Church, T. Weller and G. Mumcu, “X-Band Conformal Antenna Fabrication Using Direct Digital Manufacturing,” URSI - National Radio Science Meeting, Boulder, CO, USA, Jan. 2018 **(invited)**.
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