2022 Issue 2 // Volume 118

THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

IEEE-Eta Kappa Nu

Electromagnetic COMPATIBILITY

IEEE

IEEE-HKN AWARDS PROGRAM

As the Honor Society of IEEE, IEEE-Eta Kappa Nu provides opportunities to promote and encourage outstanding students, educators, and members.

Visit our new website to view the awards programs, awards committees, list of past winners, nomination criteria, and deadlines.

ALTON B. ZERBY AND CARL T. KOERNER OUTSTANDING STUDENT AWARD (OSA)

Presented annually to a senior who has proven outstanding scholastic excellence and high moral character, and has demonstrated exemplary service to classmates, university, community, and country.
(Deadline: 30 June)

C. HOLMES MACDONALD OUTSTANDING TEACHING AWARD (OTA)

Presented annually to electrical engineering professors who have demonstrated, early in their careers, special dedication and creativity in their teaching, as well as a balance between pressure for research and publications.
(Deadline: Monday after 30 April)

DISTINGUISHED SERVICE AWARD (DSA)

Recognizes members who have devoted years of service and lifetime contributions to Eta Kappa Nu (or IEEE-HKN), resulting in significant benefits to all of the Society's members.
(Deadline: Monday after 30 April)

OUTSTANDING CHAPTER AWARD (OCA)

Recognizes chapters for excellence in activities and service at the department, university, and community levels. The award is based on the content contained in their Annual Chapter Report for the preceding academic year.
(Deadline: 31 July)

OUTSTANDING YOUNG PROFESSIONAL AWARD (OYP)

Presented annually to an exceptional young engineer who has demonstrated significant contributions early in his or her professional career.
(Deadline: Monday after 30 April)

IEEE-HKN ASAD M. MADNI OUTSTANDING TECHNICAL ACHIEVEMENT AND EXCELLENCE AWARD

Presented annually to a practitioner in the IEEE technical fields of interest who has distinguished himself or herself through an invention, development, or innovation that has had worldwide impact.
(Deadline: Monday after 30 April)

IEEE-Eta Kappa Nu (IEEE-HKN) was founded by Maurice L. Carr at the University of Illinois at Urbana- Champaign on 28 October 1904, to encourage excellence in education for the benefit of the public. IEEE-HKN fosters excellence by recognizing those students and professionals who have conferred honor upon engineering education through distinguished scholarship, activities, leadership, and exemplary character as students in electrical or computer engineering, or by their professional attainments. *THE BRIDGE* is the official publication of IEEE-HKN. Ideas and opinions expressed in *THE BRIDGE* are those of the individuals and do not necessarily represent the views of IEEE-HKN, the Board of Governors, or the magazine staff.

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THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

2022 ISSUE 2 | Electromagnetic Compatibility

Features

Departments

IEEE-HKN INTERNATIONAL HEADQUARTERS

Editorial inquiries: IEEE-Eta Kappa Nu,
445 Hoes Lane, Piscataway, NJ 08854, USA
US Toll Free: +1 800 406 2590
Outside US: +1 732 465 5846
Email: info@hkn.org | www.hkn.ieee.org

Subscription address and email changes: IEEE Contact Center
US Toll Free: +1 800 678 4333 | Outside US: +1 732 981 0060 | Fax: +1 732 562 6380 | Email: contactcenter@ieee.org

Dr. Sahra Sedigh Sarvestani

Beta Chapter

Dr. Steve E. Watkins

Gamma Theta Chapter

The Bridge, May 2022 Letter from the Editors-in-Chief

Dear IEEE-Eta Kappa Nu Members and Friends,

This issue of *THE BRIDGE* magazine highlights current research on electromagnetic compatibility.

We appreciate the efforts of our Guest Editor, Emily Hernandez, Gamma Theta Chapter, who serves on *THE BRIDGE* Editorial Board, and the authors of the feature articles on this important topic.

This issue also includes an article about the Alumni Engagement Committee, an exciting new addition to IEEE-HKN's governance structure. This committee is chaired by IEEE-HKN Governor At-Large Dr. Hulya Kirkici, Xi Chapter, who also serves as a member of *THE BRIDGE* Editorial Board

We are delighted to share another news item that involves the accomplished members of our Editorial Board: the National GEM Consortium has been honored with the 2022 Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring. Dr. Marcus Huggans, Gamma Theta Chapter, another member of *THE BRIDGE* Editorial Board, serves as the Senior Director of External Relations for the Consortium, a non-profit organization working collaboratively across education and industry sectors to advance the next generation of STEM professionals.

This issue includes articles about several dedicated and brilliant student members of IEEE-HKN. We encourage you to read about the winners of the 2020-2021 IEEE-HKN Outstanding Chapter Awards, the winner of the Best Student Paper Award at IEEE SoutheastCon 2022, and our Student Profile.

We have had the privilege of serving as Editors-in-Chief of *THE BRIDGE* for the past several years. We will be stepping down in December 2022 and are seeking nominations (including self-nominations) for the position. We look forward to seeing the magazine flourish and evolve under new leadership.

IEEE-HKN strives for effective communication with members through our website, our YouTube channel, our Facebook and LinkedIn pages, and *THE BRIDGE* magazine. Please check out the refreshed website for the newest online resources and news. Remember that the current, as well as recent, issues of the magazine are available on the IEEE App. The Editorial Board can be contacted by e-mail at info@hkn.org.

Letter from Guest Editor

Emily Hernandez, Gamma Theta Chapter

As academic and industry leaders push to add more smarts and sensors into consumer products, vehicles, and more, the topic of electromagnetics, more specifically electromagnetic compatibility (EMC), has become essential to consider in all stages of a product's design.

At its core, electromagnetics describes the way electrical circuits behave over the entire frequency spectrum. At low frequencies, power delivery can be considered instantaneous across wires. In reality, signals propagate as electromagnetic (EM) waves guided by physical structures. The higher in frequency a circuit operates, the more important it is to understand and pay attention to its wave behavior. EM waves are susceptible to inconsistencies in the medium in which they are traveling, and if circuits are not designed with this model in mind, signal waves may radiate outward and interfere with nearby electronics. It is no longer enough for chips, circuits, and systems to meet their ever-increasing performance demands. All current and future products must also meet rigorous electromagnetic emission and interference specifications to avoid causing system-level problems when integrating complex electronic components.

EMC covers a broad range of topics, much beyond the scope of a single magazine issue. The articles featured here provide an introduction to three separate EMC-related topics. First, we introduce the concept of common-mode current, how it differs from differential-mode current, what electromagnetic interference issues it can cause if left unchecked, and an approach for using current probes to measure common-mode current in physical devices. Next, we explore signal return paths, how to identify where discontinuities exist in return paths, a set of design guidelines to prevent return path discontinuities, and real-world examples of geometries that cause return path related EMC issues. Finally, we discuss EMC challenges specific to wireless devices, how to model EMI coupling for wireless devices, and an example of how printed circuit board (PCB) design changes can mitigate EMI in a smart speaker.

Emily Hernandez is a 2016 graduate of Missouri S&T and an editor of *THE BRIDGE* magazine. She currently is the New Product Introduction (NPI) Engineering Manager at CelLink Corporation, based in San Carlos, CA. Emily is the recipient of the IEEE-HKN's 2016 Alton B. Zerby and Carl T. Koerner Outstanding Student Award.

IEEE-Eta Kappa Nu **HKN Experience**

HKN's Technical Conference Kicks Off 9 June

Free, 2-Day Conference The HKN Experience (HKNx) is IEEE-HKN's premier technical conference focused on emerging technologies and their applications. Get inspired to become the next generation of engineering leaders by attending tech talks by industry experts. **Highlights include:** Keynote Address by HKN Eminent Member Vint Cerf, the co-designer of the TCP/IP protocols and the architecture of the Internet (in other words A FATHER OF THE INTERNET!), Recruitment Fair, Interactive Tech Talks, Small-Group sessions with experts, Graduation Procession, and Professional Member Induction.

Graduation Procession: Have your graduating students submit a photo of themselves to participate in the Virtual Graduation Procession to be held at 4 pm (ET) on 10 June. They can wear HKN attire if they have it!
Tech Time Capsule: Tell us about a project, product, or research topic you're working on in 2022 for our Tech Time Capsule video to be shown at the HKN Experience.

New HKN Committee Focuses on Engaging & Re-Engaging Alumni

Amy Jones, IEEE-HKN Young Alumni Subcommittee Chair and Hulya Kirkici, IEEE-HKN Alumni Engagement Committee Chair

For students, HKN is a touchpoint that both recognizes achievement and charges them to continue to excel in all areas of their lives. As they get older and transition into later phases of their careers, "the reasons that we need HKN don't necessarily change – we all are looking for connection, recognition, and support – but the way that HKN can serve those needs evolves with us," said Amy Jones, Gamma Theta Chapter and Chair of the IEEE-HKN Young Alumni Subcommittee.

Former Region 1 Director Charles Rubenstein and Charlotte Blair meet a student during the reception.

She continued: "One of the best pieces of advice I have ever received about networking is to have a few questions ready that you can ask anyone as an icebreaker. When it comes to HKN, my favorite question to ask at an event is 'What was it that made you want to be a member?' For those of us who joined as students, most of the answers are centered around connections: connections to our peers, professors, and a network of professional opportunities. I identify strongly with those answers, since mine is very similar. Over a decade later, I distinctly remember the nerves and uncertainty when walking into my first circuits class without recognizing anyone, and (a year later), the calm assurance I felt while planning out how my fellow HKN inductees and I would partner up in labs. That contrast has been an illustration to me of what HKN offers to us over the course of our lives."

Keeping all these in mind, the IEEE-HKN Board of Governors formed the Alumni Engagement Committee to explore how HKN can provide for the needs of members outside of their collegiate experience, including providing opportunities for networking and engagement after graduation. Specifically, the Committee's charter is to engage with alumni in general, facilitate Alumni Chapter formation, communicate with Alumni Chapters, and more.

Alumni connected with each other during the first HKN Alumni reception of 2022.

The committee will focus on supporting alumni-student networking, promoting best practices of alumni engagement, and providing opportunities for alumni to get together, said Hulya Kirkici, Chair of the IEEE-HKN Alumni Activities Committee.

One avenue for this connection is Alumni Receptions held at various locations or in conjunction with other IEEE events and conferences. The Committee and its Subcommittees have been working diligently to identify and meet the needs of HKN's members in the ways that only HKN can.

For example, young alumni are going through many major transitions as they begin to establish themselves as professionals. Many are defining their professional brand, balancing the demands of work and family, making decisions about continuing education, practicing soft skills in the workplace, or even moving companies for the first time.

These are experiences that are often characterized by trial and error and can bring with them a great deal of uncertainty. The Young Alumni Subcommittee has launched a podcast, "Career Conversations," that is aimed at making these obstacles a little easier to overcome by asking more experienced members to share their lessons learned.

HKN is eager to learn more about the challenges that members are facing, and how the challenges are changing with the workforce and environment of today. The first few episodes have covered topics such as Career Planning and Effective Mentoring, and many more are in the works.

Alumni gather at RadarConf in New York City in March.

While HKN alumni don't need study groups or lab partners, they are looking for chances to meet new people. One never knows if an HKN colleague will be the one to recommend them for their dream job, invite them to join their side gig, or even just make a conference dinner less awkward.

"As a candidate for induction, I remember being impressed by the responsibility that HKN members seemed to feel toward their fellow students in my department," Amy said, "Whether it was hosting a study session or offering a free doughnut, they always seemed to be extending a helping hand. While I still have fond memories of those young leaders, one thing that I didn't expect about being an alumna is how incredibly proud I have remained of the student members of HKN. I'm thrilled to hear about their achievements, and don't want to miss an opportunity to help them make a strong start towards their goals. Those feelings are not unique to me; I see that same pride and passion in the many HKN members who have supported me both in the past and present. Where else in our careers do we find a built-in network of supporters and cheerleaders, people who have been pre-vetted to share our common values of character, scholarship, and attitude?"

With this in mind, the Alumni Engagement Committee has already planned to host several Alumni Receptions this year. The first was held at RadarConf on 21 March in New York City. A second was held at the 2022 IEEE SoutheastCon in Mobile Alabama, on 2 April.

Our members are the best part of HKN. They form the history of which we are all so justly proud and they are our best and brightest who are working diligently on the problems that our world faces. We hope that you will reconnect with us, either by joining us for a reception, listening to a podcast, or sharing a need that we can help you meet.

HKN is for life. Once you are inducted, you are always an HKN member and that honor stays with you and is recognized wherever you go and whatever job you do. Our common values of character, scholarship, and attitude apply to us all, regardless of the part of our community with which you identify.

Amy Jones is an Engineering Supervisor in John Deere's Construction Division. She leads the Operator Station Systems & Module team and is responsible for supporting factory production of cabs as well as leading new development of common components and systems for the Construction division. In 12 years with John Deere, she's held roles in Software Test and Systems Design. One of her proudest accomplishments was leading the team that delivered eleven new models of excavator to production for global markets. Amy is a Senior Member of IEEE and a proud alumna of the Gamma Theta chapter of Eta Kappa Nu. In her spare time, she loves spending time with her family, watching Jeopardy, and supporting STEM outreach to build the next generation of engineers.

Hulya Kirkici is Professor and the Department Chair of Electrical and Computer Engineering at the University of South Alabama. She received B.S. and M.S. in physics from Middle East Technical University, Turkey; and Ph.D. in electrical engineering from Polytechnic University (currently NYU), NY. Previously, Dr. Kirkici was Professor of electrical and computer engineering at Auburn University, visiting scholar / Faculty Fellow at the Air Force Research Laboratory – Wright Patterson Air Force Base, and visiting scientist/engineer at NASA, Marshall Space Flight Center, Huntsville, AL. Dr. Kirkici's research interests are electrical insulation, high-frequency dielectric breakdown, and repetitive pulsed power.

Dr. Kirkici is a Fellow of IEEE and recipient of the IEEE Eric O. Forster Distinguished Service Award, IEEE William G. Dunbar Award, and the IEEE Sol Schneider Award. Dr. Kirkici is members American Physical Society (APS), Sigma Xi Scientific Honor Society, Eta Kappa Nu Honor Society, and American Association of University Women (AAUW).

Dr. Kirkici is Governor-at-Large of the IEEE-HKN Board, a member of the IEEE-HKN Bridge Magazine Editorial Board (2020 – present).

Alumni Receptions: An Invitation for HKN Members to Celebrate and Reconnect

HKN alumni, students and friends have been gathering to reconnect, reminisce, and rally in support of HKN at our first HKN Alumni Receptions.

Two events, held in conjunction with IEEE events and conferences, have already been held in 2022, with great success. The first was held at RadarConf'22 on 21 March in New York City. A second was held at the 2022 IEEE SoutheastCon in Mobile, Alabama, on 2 April.

The Alumni Receptions are made possible through a generous grant from HKN Eminent Member and HKN President (1998-2000), Dr. Richard Gowen and his wife, Nancy. Dick passed away in November 2021, but his love for HKN will live on through these gatherings.

"Dick and Nancy saw the importance of bringing together HKN members in all stages of their careers so that they may connect with one another and with HKN today," said IEEE-HKN Director Nancy Ostin. "It is in coming together they we exchange ideas, share stories, and strengthen the bonds between members of all ages, leading to a more fulfilling HKN experience for all. Alumni are our greatest untapped resources. By getting alumni involved in supporting HKN financially or through service, we can meet the changing and growing needs of current and future leaders of our profession."

Alumni gathered at IEEE Region 3's SoutheastCon in April.

The next HKN Alumni Reception will be held Tuesday, 19 July 2022, during the Annual PES Meeting in Denver, CO, from 5:30-7 pm (MT). If you would like to join us, please RSVP here.

To get involved in HKN or if you would like to host an HKN Alumni Reception at your event, contact Nancy Ostin at n.ostin@ieee.org.

Learn more about HKN and our members by visiting our website. To donate to HKN, follow this link.

22 Chapters Recognized for Excellence

IEEE-Eta Kappa Nu (IEEE-HKN) Announces Recipients of the 2020-2021 Outstanding Chapter Awards

IEEE-Eta Kappa Nu (IEEE-HKN), the honor society of IEEE, is excited to announce the recipients of its 2020-2021 Outstanding Chapter Award.

This prestigious award is presented to IEEE-HKN Chapters in recognition of excellence in their Chapter administration and programs. Just 22 of the 268 IEEE-HKN Chapters worldwide were recognized for their work during the 2020-2021 academic year.

Chapters are selected based on their activities, community service and outreach, and the impact they have had on the department, the university, and the community. Of vital concern to the Outstanding Chapter Awards evaluation committee are activities that advance professional development; raise instructional and institutional standards; encourage scholarship and creativity; provide a public service, and generally further the established goals of IEEE-HKN.

Plaques were presented on Monday, 28 March 2022 at the IEEE-HKN Awards Reception during the 2022 ECEDHA Annual Conference held in New Orleans, LA.

Congratulations to the 2020-2021 Outstanding Chapter Award recipients:

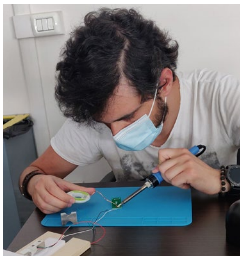
Alpha, University of Illinois, Urbana-Champaign
Beta, Purdue University
Mu, University of California, Berkeley
Nu, Iowa State University
Omicron, University of Minnesota
Beta Epsilon, University of Michigan
Beta Eta, North Carolina State University
Beta Mu, Georgia Institute of Technology
Gamma Theta, Missouri University of Science and Technology
Delta Omega, University of Hawaii, Manoa
Epsilon Epsilon, University of Houston
Epsilon Sigma, University of Florida
Kappa Omicron, State University of New York, New Paltz
Kappa Sigma, Boston University
Kappa Psi, University of California, San Diego
Lambda Zeta, University of North Texas
Mu Alpha, UCSI University - Kuala Lumpur
Mu Beta, Arab Academy For Science & Tech - Alexandria
Mu Kappa, University of Queensland
Mu Nu, Politecnico Di Torino
Mu Tau, Waseda University
Nu Alpha, Universidad Nacional De Educacion a Distancia

Mu Nu Chapter Uses IEEE Grant to Improve Natural Resource Usage

The IEEE Humanitarian Activities Committee (HAC) provides a suite of resources that inspire and enable IEEE volunteers around the world to carry out and support impactful humanitarian technology and sustainable development activities at the local level. One mechanism for this is the funding and support of such projects.

In 2021, the HKN Mu Nu Chapter at Politecnico di Torino University in Italy applied for and received a grant through a program that supports grassroots projects that utilize technology to address pressing needs of local communities.

Background: Over the past six years, the Politecnico di Torino University has been working to improve resource usage and waste reduction. The team of volunteers for this project works with two other university associations to monitor recycling waste quality. Together, the students have launched ThreekECO, a mixed hardware and software system that interfaces with users through a Telegram bot. The bot will show them where to dispose of their waste thanks to an image recognition algorithm. The bot also will log data directly from trash bins through sensors and Wi-Fi connected microcontroller units to understand if the user correctly recycled the item.



Former IEEE-HKN Student Governor Sandro Sartoni is part of the ThreekECO team developing the bot.

Progress: The team has conducted several studies on the recycling bin to understand where to put sensors and has started writing firmware that will allow retrieving data from such sensors. Work continues.

For more information about IEEE HAC/SIGHT calls for proposals and other funding opportunities, please visit the HAC website.

Call For Nominations: 2023 Board of Governors

The Nominations and Appointments Committee of IEEE-Eta Kappa Nu invites (IEEE-HKN) and encourages all Chapters to submit nominations for the following open positions on the 2023 Board of Governors. The deadline for these nominations is 1 June. Chapters are encouraged to nominate for all relevant positions.

The election for the positions will take place 1 October to 1 November, 2022.

Below are the criteria for positions for which nominations are being accepted and details regarding who can nominate.

2023 President-Elect

The nominee must:

- Have been inducted into IEEE-HKN or the Eta Kappa Nu Association
- Be an active IEEE Senior Member or Fellow
- **Nominations accepted from:**
  - Any active School Chapter (submitted by the Chapter President)
  - Any member of the 2022 IEEE-HKN Board of Governors
  - The IEEE Educational Activities Board Nominations & Appointments Committee

2023-2025 Region 1-2 Governor

The nominee must:

- Have been inducted into IEEE-HKN or the Eta Kappa Nu Association
- Be an active higher grade IEEE member
- Have not served previously as an IEEE-HKN Governor
- Have an IEEE primary address in IEEE Region 1 or IEEE Region 2
- **Nominations accepted from:**
  - Any University Campus or Alumni Chapter in IEEE Region 1 or IEEE Region 2
  - The IEEE-HKN Nominations and Appointments Committee

2023-2025 Regions 7-10 Governor

The nominee must:

- Have been inducted into IEEE-HKN or the Eta Kappa Nu Association
- Be an active higher grade IEEE member
- Have not served previously as an IEEE-HKN Governor
- Have an IEEE primary address in IEEE Region 7 through IEEE Region 10
- **Nominations accepted from:**
  - Any University Campus or Alumni Chapter in IEEE Region 7 through IEEE Region 10
  - The IEEE-HKN Nominations and Appointments Committee

2023-2025 Governor at-Large

The nominee must:

- Have been inducted into IEEE-HKN or the Eta Kappa Nu Association
- Be an active higher grade IEEE member
- Have not served previously as an IEEE-HKN Governor
- **Nominations accepted from:**
  - Any University Campus or Alumni Chapter
  - The IEEE-HKN Nominations and Appointments Committee

2023 Student Governor (2 Positions)

The nominee must be must:

- Have been inducted into IEEE-HKN or the Eta Kappa Nu Association
- Be full-time undergraduate or graduate student at the time of their initial candidacy
- Be a member in good standing of IEEE-HKN
- Be an active IEEE Student or Graduate Student Member in 2023
- **Nominations accepted from:**
  - Any University Campus or Alumni Chapter

The nomination form is available on the HKN.org website.

Call for Nominations: *THE BRIDGE* Editor-in-Chief

IEEE-Eta Kappa Nu is seeking nominations for the volunteer position, Editor-in-Chief (EIC), of its archival publication, *THE BRIDGE* magazine, with a start date of 1 January 2023. This electronic magazine is published in February, May, and October and provides content with organizational, professional, technical, and career relevance to student and professional members. The EIC reports to the IEEE-HKN Board of Governors and chairs the Editorial Board, which is a standing committee of the organization. Meetings of the Editorial Board are held by teleconference and oversee peer review of original features, to plan and proof content, to establish appropriate publication standards and policies, etc. A managing editor and other staff, support the work of the EIC and the Editorial Board. The EIC term is for one year and is renewable. See current issues on the HKN.org website.

Nominees must have been elected to membership in IEEE-HKN or HKN, must be current members of IEEE, and must have relevant experience as an author, reviewer, associate editor, or EIC. Please submit the following information:

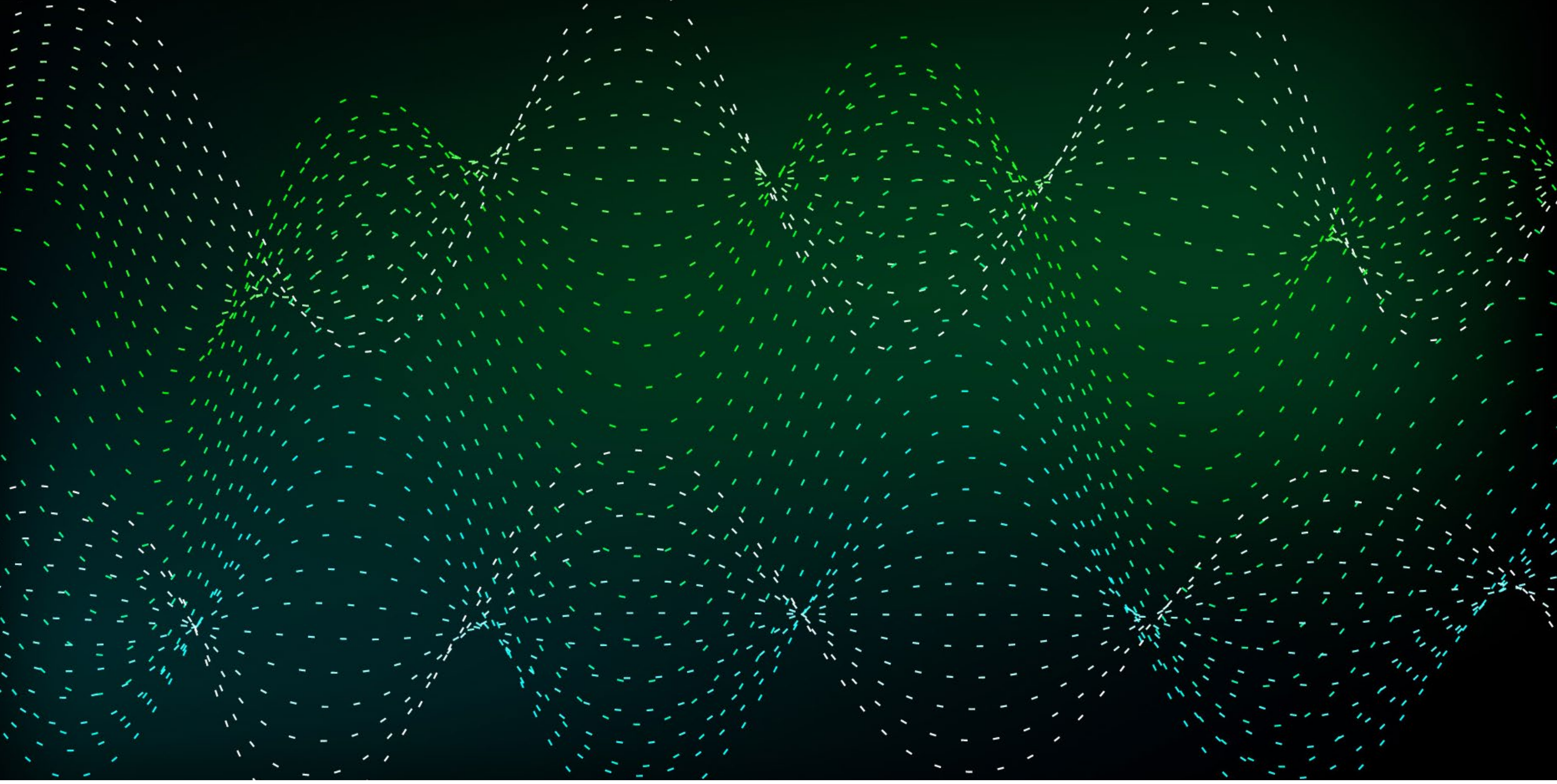
- Nominee name, IEEE member number, HKN Chapter of election, and contact information.
- A statement of interest and vision for the magazine.
- A CV (up to 10 pages) with emphasis on experience related to the EIC position.

Nominees must be responsive and be able to make timely decisions, meet publication deadlines, and coordinate the work of the Editorial Board.

Questions and these materials should be submitted to Steve E. Watkins at steve.e.watkins@ieee.org. Nominations will be considered **starting 30 June 2022** until the position is appointed by the Board of Governors.

Best Student Paper Award

Paul Bupe, Jr. (center) is the first recipient of the IEEE-HKN Best Student Paper Award at IEEE Region 3's SoutheastCon Technical Conference. Paul's entry was titled: "Electronically Reconfigurable Virtual Joints by Shape Memory Alloy-Induced Buckling of Curved Sheets." The Best Student Paper award was established to recognize outstanding achievement in writing and presenting original research at a professional level and carries a US$500 award. It is made possible through a gift from HKN Xi Chapter member and Governor At-Large, Hulya Kirkici. "(This) is a great honor and much needed encouragement as I push towards finishing my education," Paul said. Paul is pictured with 2022 IEEE-HKN President, Jim Conrad (left) and Governor At-Large, Hulya Kirkici.



Common-Mode Current is in Your Future!

Lee Hill, Founding Partner, SILENT Solutions LLC and GmbH

I. Introduction

Common-mode current is not taught in many undergraduate electrical engineering programs, yet it is a ubiquitous cause of radiated and conducted electromagnetic interference (EMI) problems in industry. This article describes the fundamental nature of common-mode current, contrasts it to differential-mode current, and gives a few simple models that can be used to understand and measure common-mode current in real electronic systems.

II. Current Fundamentals

Although Georg Ohm's law was published in May 1827, it was not until 1835 that James Lindsay demonstrated continuous light from an incandescent filament. Without the knowledge of Ohm's law, the light produced by that filament and the current that heated that filament would seem like magic. But 21st century electrical engineers know about Ohm's law, and so the existence of a conduction current forced out of a battery, along a conductor, and returned back to the battery (the source of the current), to create light using an obsolete technology, may not seem particularly magical.

Before we talk about a current that does seem magical, let's review the current that we did learn about in school. Along with Ohm's law, we were told that current is said to always flow in a loop, or to exist as an identical pair of currents, one flowing out from the source towards the load, the other returning back from the load to the source. A specific name for this current that we use to create ingenious circuits is called "differential-mode" current. This is the current that we want to create, one that produces a desired circuit function. In general, a closed path for this current is always implicitly shown on a circuit schematic, and it is easy to accurately predict in advance using SPICE or IBIS-based software.

Why this "closed path"? When analyzing circuits, we must "obey" Kirchhoff's current law, as well as the continuity of current / conservation of charge equation for steady currents. So, we are not allowed to "lose" electrons. We always build and analyze electrical circuits that are "closed", so these ideas of loops of current or pairs of outgoing and return currents are good mental crutches to make sure we don't break laws of physics. In the simple printed circuit board (PCB) diagram in Figure 1, a differential

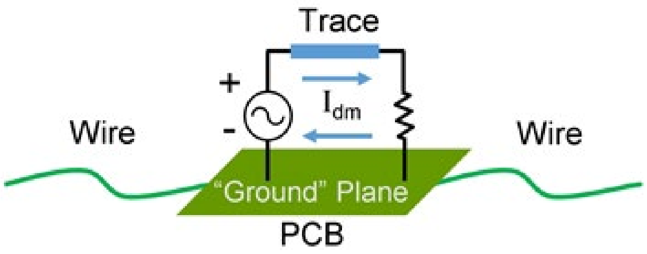


Fig. 1: Differential-mode current in a PCB.

mode current flows out of the source, down the trace, through the load, and back to the source through the "ground" plane.

III. Common-Mode Current

But there is another kind of current that does seem like magic. It is called common-mode current. It should be hyphenated because "common current" and "mode current" do not make any sense, we need to join those first two words together when they describe a particular type of current. What? A particular type of current?

Common-mode current is usually referred to as an "unintended" or "antenna" current. In contrast to differential-mode current, common-mode current flows in the same direction along a group of conductors. Its presence, and its path from source to load and back, is not obvious and usually not shown on a circuit schematic. Figures 2 and 3 illustrate differential-mode current and common-mode current, respectively.

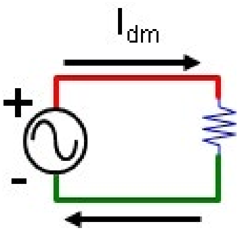


Fig. 2: Differential-mode current in a simple circuit.

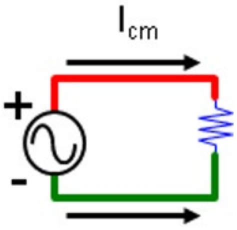


Fig. 3: Common-mode current in a simple circuit.

Where does it come from? In PCB design, a time changing current flowing on an external trace can magnetically couple a second loop, just like in a purpose-built transformer. The induced voltage then pushes a common-mode current out of the wires attached to the PCB "ground" plane. Common-mode current is still a current, so it must flow in a loop.

In Figure 4 we see the common-mode current flowing out one wire, and returning back to the (induced) source as a displacement current. The displacement current flows between the two wires because there is capacitance between the two wires. This loop, consisting of part common-mode conduction current plus displacement current is the same model we use to describe the flow of current along a dipole antenna as shown in Figure 5.

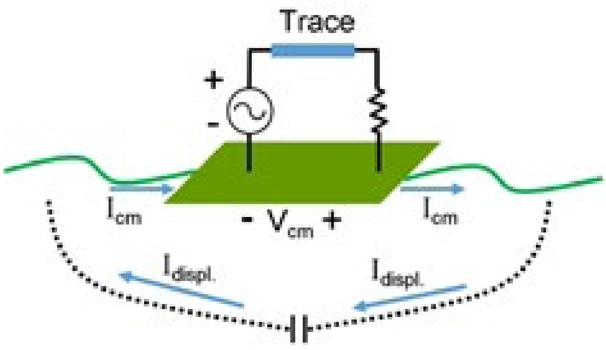


Fig. 4: Common-mode current in a PCB.

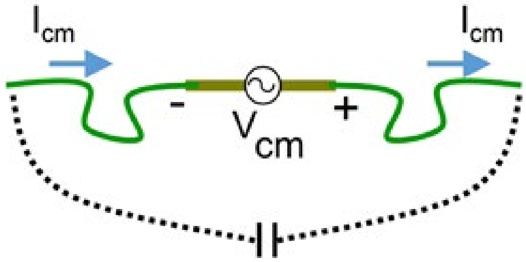


Fig. 5: Common-mode circuit model.

The presence of either common-mode current or displacement current often indicate the presence of far-field wave propagation. When we do not want this to happen, we call it a radiated EMI problem, which can cause our electronic system to fail mandatory U.S. (FCC CFR Part 15) and international (CISPR 11, 24, etc.) standards that limit radio wave "pollution". We do not want our switch-mode power supply or microprocessor PCB to interfere with communications systems, such as in an ambulance, helicopter, or spacecraft.

IV. Measurement of Common-Mode Current

Finally, it is relatively easy to measure actual common-mode current in physical wiring. In Figure 6, we see that if a current probe were placed around both conductors "1" and "2", the differential-mode current vectors would sum to zero, while the two common-mode current vectors would add. The common-mode current thus measured tells us the amount of "net" current that flows in one direction. Noise current measurements are a little different from the differential-mode current measurements in many undergraduate electrical engineering laboratories, where usually the current probe is placed around only one conductor at a time. When teaching or describing real noise troubleshooting examples that involve common-mode current, it is helpful to define whether I_{cm} represents the total noise current flowing in one direction, or the amount of noise current flowing on each conductor. If the former, we might assign $I_{cm}/2$ for each of the two wires, so that the measured noise current would equal just I_{cm}.

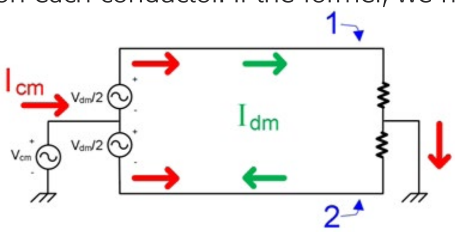


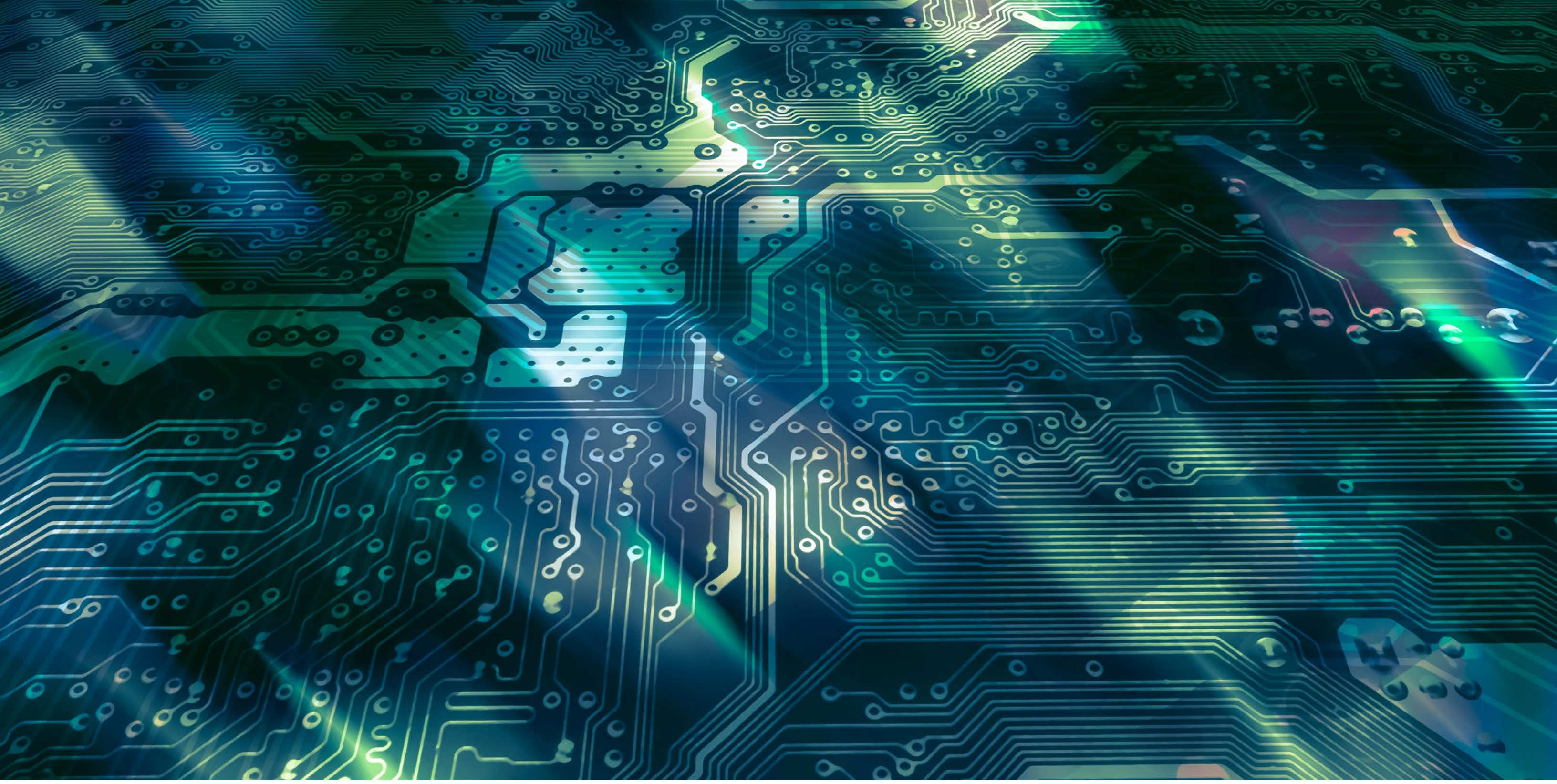
Fig. 6: Measurement approach for common-mode current.

FOR MORE INFORMATION, SEE:

Introduction to Electromagnetic Compatibility, Clayton R. Paul, 2nd Edition, Wiley Interscience, 2006.

Electromagnetic Compatibility Engineering, Henry W. Ott, Wiley Interscience, 2006.

Lee Hill has over 30 years of experience in hardware troubleshooting and design reviews to solve and prevent elusive regulatory and functional electrical noise problems. He is Founding Partner of SILENT Solutions LLC and GmbH, an electromagnetic compatibility (EMC) and RF design, troubleshooting, and training firm established in 1992, see https://silent-solutions.com/. Lee teaches EMC worldwide and is a member of adjunct faculty at Worcester Polytechnic Institute (WPI) and an EMC instructor at University of Oxford (England). He is active in the IEEE EMC Society and related conferences. He earned his MSEE in electromagnetics from the EMC Laboratory at Missouri University of Science and Technology, where he studied under Dr.'s Tom Van Doren, Todd Hubing, and James Drewniak.



Return Path Discontinuities and Common Return Path Issues

Dr. Michael Cracraft, IEEE Senior Member, Rose-Hulman Institute of Technology, Gamma Theta 1998

Abstract

Perusing any circuit design schematic is evidence enough to conclude that signal paths are essential in a design. The schematic tells a layout designer exactly which pins to connect. Then, there are the supply voltage and reference connections. A schematic does not convey that these supply and reference connections have physical size, nor does the schematic direct what the references should look like in the final design.

Herein lies a nonobvious design challenge in circuit layout. What happens to currents beyond the voltage and ground symbols on the schematic? From the schematic perspective, current is drawn from the voltage rails and deposited in the ground. However, the current must return to its source—complete the loop. This paper will discuss the hidden part of the current path and how it can hinder or break a design.

I. INTRODUCTION

Two related issues occur when the return path is neglected: discontinuities and crosstalk. These two may lead to a host of signal integrity (SI) and electromagnetic compatibility (EMC) issues [1]. Unfortunately, the signal path receives most of the attention, and the return path issues go unnoticed until there is an issue. If the return path is noticed at all, that is a positive sign that the designer is cognizant of its importance. In many situations, the return path may be checked only after every other avenue of debugging has been exhausted.

Return paths are not clearly defined like signal paths. The signal and return paths can be compared to the difference between SI and EMC. SI typically concerns delivering a quality, robust signal from a transmitter to a receiver. EMC requires checking everywhere else that the stray energy from that signal may go.

The signal path on a "printed circuit board (PCB)" and in most systems is a clearly defined path that can be traced from start to finish. The return path is more like two points with an open field between them. The logical direction is to travel in a straight line from start to finish on the other side. However, if the straight-line path is blocked (impeded), a longer route must suffice. A longer dry route would still be quicker and less messy than a shorter route through a mire, for example. Of course, there is not just one possible alternative route but numerous possible routes.

Another complication is that the return path does not always mean the reference plane. A voltage supply can be a return path, as well [2]. A push-pull driver topology is an example of a structure that utilizes both voltage supply and the reference. One way or another, the current will return to its source. The loop may not be obvious, but the current will find a way back to its origin. How much current flows is dependent on the impedance of the entire path. Pick the path, or the current will, whether by conduction or displacement. [3] employs a detailed plot of the return currents to analyze the return path discontinuity in the transition from PCB to an edge-mount coaxial connector. Such current paths are key to understanding any return path discontinuity. The remainder of this article will discuss return path discontinuities and the issues they present through basic theory and several modeling examples.

II. RETURN PATH DISCONTINUITIES

Return path discontinuities differ from signal discontinuities only in that they occur in the return part of the signal path. Return paths tend to have significantly different geometries than signal paths. The current is less constrained than on a signal trace, as is indicated by Fig. 1. The spread of the current is highly dependent on frequency. High frequency currents will ideally mirror their signal counterpart, which minimizes the inductance in the current loop. Low frequency currents spread out across reference conductors to reduce resistive losses, because inductance is less dominant. As a result, return path discontinuities can be subtle, like a trace near the edge of a reference plane, or they may be significant and acute like a missing return via a connector. Return path discontinuities may be misidentified as issues in the signal path. They also affect different signaling structures in different ways.

A. Misidentification

Misidentifying return path discontinuities as discontinuities in the signal path is a nontrivial problem. A transmission line model implies transverse electromagnetic (TEM) propagation (or quasi-TEM). One of the conditions for TEM propagation is cross-sectional invariance. The cross-section of the conductors cannot change along the length of the model. Deviation from the cross-section is, by definition, a discontinuity. Another property of the transmission line formulation is that a bundle of N conductors can support N-1 TEM modes [4]. The other way of viewing this condition is that any transmission line structure must have at least two conductors to support a TEM mode. Assume one of these conductors is a signal, and the other is a return. A change to the shape of either conductor introduces a discontinuity. The TEM mode requires both conductors to be cross-sectionally invariant to avoid a disturbance in propagation; however, changes to the signal path are less likely to be overlooked than those in the return path.

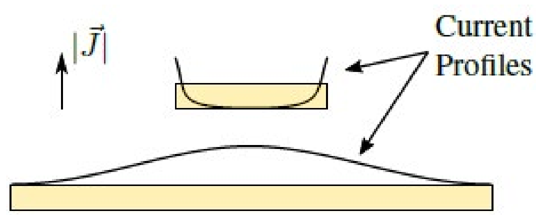


Fig. 1. A microstrip geometry with approximate current profiles overlaid

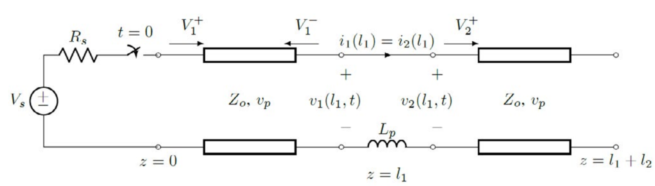


Fig. 2. A transmission line circuit with a parasitic inductance in the return path

Consider the transmission line circuit in Fig. 2. This circuit has an inductance in the return path between the two transmission line elements. The procedure for solving this circuit begins at finding the solution for the voltage on the first line for $t \leq \frac{l_1}{v_p}$, which results in

$$v_1(z,t) = V_1^+ \, u\left(t - \frac{z}{v_p}\right), \quad 0 < t \leq \frac{l_1}{v_p}, \tag{1}$$

where $u(t)$ is a step function. The corresponding current solution is

$$i_1(z,t) = \frac{V_1^+}{Z_0}\, u\left(t - \frac{z}{v_p}\right),\ 0 < t \leq \frac{l_1}{v_p}. \quad (2)$$

This solution is valid until $t\_d = l_1/v_p$ when the wave is incident at the end of the first line.

The boundary condition at $z = l_1$ is evaluated to determine the reflected wave on line 1 and the forward wave on line 2. The condition on the current at $z = l_1$ is

$$i_1(l_1, t_d) = i_2(l_2, t_d) \quad (3)$$

due to the continuity requirement. The boundary condition on the voltage can be determined by a KVL expression and is

$$-v_1(l_1, t_d) + v_2(l_1, t_d) + L\frac{di_1}{dt} = 0 \quad (4)$$

This boundary condition is the key concept in this section. Given the form of (4), there is no way to tell whether the voltage drop associated with the inductive discontinuity is in the signal path or the return path.

Time domain reflectometry (TDR) is one of the best measurement techniques to diagnose discontinuities in signal paths. However, the incident wave used by TDR is simply a less ideal version of the transmission line solution in (1). The TDR measurement will see the discontinuity in a circuit like Fig. 2, but it will not indicate that the discontinuity is in the return path. Such will be the case with most return path discontinuities. The TDR response will still show the delay to the location of the discontinuity. Then, the search for the cause of the disturbance can start, investigating the signal path and any possible return paths.

B. Considerations for Stripline Signaling

Microstrip and stripline structures are the most common signal configurations in PCB designs. Microstrip utilizes a single conductor for the signal and a reference plane for the return path. All return currents utilize this single reference plane and any break in the path will lead to a discontinuity as discussed in Section II-A. Stripline uses a single signal conductor sandwiched between two reference planes. As a result, return currents may use either reference, but the references may not be used equally, depending on the overall signal path.

Figs. 3 and 4 illustrate two different stripline cross-sections with return path discontinuities. The dominant return current paths are drawn for both cases. The first in Fig. 3 is positioned in the lower reference. There is a clear path for the return currents to mirror the signal currents without encountering the discontinuity in the lower reference. While there may still be a disruption in the stripline propagation mode due to the break in the lower reference, the discontinuity may be tolerable.

Fig. 4 includes a break in the upper reference. This break disrupts the lowest impedance return path for the currents. The current will find a path back to the source although possibly through a high impedance path. The question marks in Fig. 4 are there because the return path is unclear from what has been drawn. Placing return vias near the two signal vias shown in the cross-section may be sufficient to mitigate this return path discontinuity for lower speed signals. Without additional return vias, the return currents will find the nearest existing return vias and pass by displacement current paths. Neither will be as low impedance as a solid reference path or well-placed return vias.

Since return paths can be difficult to predict for complex designs with many PCB layers and signals, design rules commonly require reference vias within a certain radius of any signal via transition. Even without a break in either reference plane, return vias are beneficial. The return vias ensure that return currents have a better path to either reference, which is expected in the stripline propagation mode.

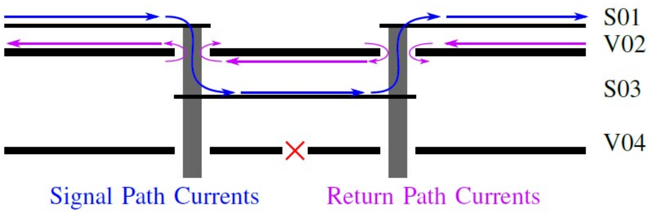


Fig. 3. Stripline cross-section with dominant signal and return current paths with a noncritical return path discontinuity

C. Considerations for Differential Signaling

Differential signaling utilizes at least three conductors to transmit signals: two signal conductors and at least one reference conductor. One might assume that the reference plays no part in signal propagation, but discontinuities can still affect the signal.

With differential signaling, the voltage and current on one conductor of the pair are ideally equal and opposite polarity of that of the other conductor. Many layout features can unbalance the signal in a differential pair. This unbalancing is more appropriately called mode conversion. The differential mode is converted to the common mode, which is subject to the return path discontinuities in the same way as a single-ended signal. EMC issues, such as unintended electromagnetic radiation, may result. A difference in the length of the differential pair, also known as skew, is one layout issue that causes mode conversion. As Section III-B explains, return path discontinuities may also cause mode conversion. Differential via transitions are subject to mode conversion from asymmetric return currents, as well [5]. Differential signals are less susceptible to return path issues, but they are not entirely immune.

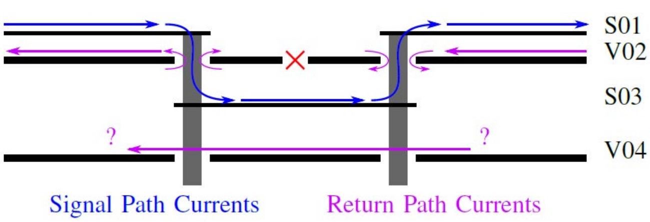


Fig. 4. Stripline cross-section with dominant signal and return current paths with a critical return path discontinuity

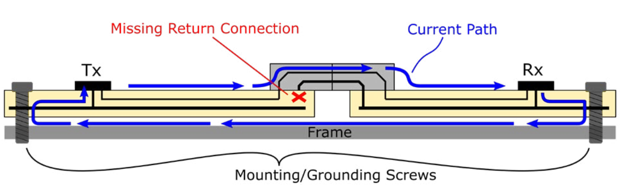


Fig. 5. The current path across two PCBs with a missing return path

D. System-Level Return Path Considerations

While this article focuses primarily on return path issues at the PCB level, the same concepts apply at the system-level. The scale and complexity increase, but the same strategies may be employed. Currents return to their sources; follow the current paths.

System-level has a different meaning depending on the device under test. The system-level pertains to buses routed between chips on the motherboard and adapter cards or routed on cables internally or to other frames for computers and servers. Maintaining reference continuity for the return path across these different types of connections is critical. Miscommunications between designers can lead to missing connections like the missing return connection at the connector shown in Fig. 5. Because the channel comprises multiple PCBs, the search space is larger and fraught with chances to cast blame and hurt feelings.

Historically, airplanes and automobiles have even used the chassis as a return path. Since these frames tend to be prominent conductors, they make sufficient returns for low frequencies. However, the paths may include large loops that invite coupling interference even at low frequencies. These large loops are extreme cases of what is presented later in Section III-A. Higher frequency signaling should maintain a separate return path for sensitive signals.

As more vehicles shift to composite materials, the conduction paths used in the past are missing. Designers must include return paths in the cable harnesses and make sure that the returns isolate sensitive signal paths from one another. One temptation is to include a single return wire in a cable bundle and declare it good. The harness will likely have the same issues as a ribbon cable with a single return. A frame return path has more in common with a PCB reference plane than with a return wire. Low frequency current can spread out more on a frame. Beware! This spreading and exposure invite interference from external signals. Higher frequency currents should still have their own dedicated return wires.

III. EXAMPLE RETURN PATH ISSUES

This entire article could easily focus on a single geometry. However, this article aims not to promote the best solution to a particular geometry, but rather to survey several potential trouble solutions. The following sections investigate geometries where the return structure has a significant effect on signal integrity, EMC, or both.

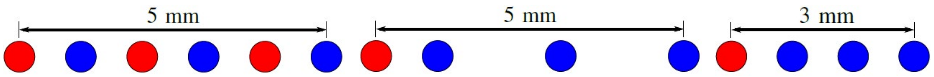


Fig. 6. Parallel wire (ribbon cable) configurations with references (red) and signals (blue)

A. Ribbon Cables

Ribbon cables were once a common structure to connect storage media to motherboards. Some ribbon cables are designed with many signal conductors and a single return conductor. All return currents flow on one single return wire. As a result, all signals are inductively coupled. (The signals are also capacitively coupled, but the focus will be on the inductive aspect here.)

Early revisions of the parallel ATA bus ran at relatively low baud rates with low slew rates, leaving most of the energy at lower frequencies. Since the crosstalk from mutual inductance is more pronounced at higher frequencies, one reference could be shared by several signals. As baud rates increased in later revisions of the ATA standard, this crosstalk became an issue. The solution to the inductive coupling problem was to introduce one return wire for every signal wire. Fig. 6 shows three configurations: one with one return for each signal (1:1 ratio) and two others with one return for three signals (3:1 ratio).

Fig. 7 shows the far-end crosstalk (FEXT) for the three configurations from Fig. 6. The FEXT of the configuration with multiple references is one order of magnitude lower than the other two configurations through most of the modeled bandwidth. Even so, individual return conductors are not always necessary.

Next, the FEXT was evaluated with a transient model for another perspective. The FEXT was measured on the middle signal conductor and plotted in Fig. 8. The left-most conductor of three channels was excited with a 1-volt, 4 Mbps signal and a 40 Mbps signal. The shape and amplitude of the crosstalk are affected by the source and load impedances at either end of the conductors (Fig. 8 includes 20 Ω at the source and 1 kΩ at the load). The crosstalk for any of the configurations is low enough to be ignored at 4 Mbps. Even at 40 Mbps, the crosstalk is likely tolerable, but the FEXT of the configuration with multiple returns is negligible, whereas that of the other two is on the order of 40 mV.

Coupling of the same type as in these ribbon cable geometries can occur in PCB structures. Replace the ribbon cable geometry with an array of vias. When return currents for multiple signals are forced to share return vias, there will be coupling. The dominant form of this coupling is inductive; the current paths have a common segment and will have magnetic flux coupling as a result. Connector footprints are another common geometry where signals may share return paths. In another example, the area within the footprint of large ASICs can become so perforated with antipads that narrow return path channels may be shared by some signals unfortunate enough to be buried in the interior of the pin array. These examples represent some but not all possible shared return path structures.

B. Splits in Reference Planes

A classic example of a return path discontinuity is crossing a split in a reference plane. The issue is the same whether the geometry is called a split, a slit, or a void. The current return path has an obstruction to conduction that must be circumvented or bypassed. Circumvention extends the current path away from the signal current path, which can be represented by a parasitic inductance, as in Fig. 2. If the capacitive coupling from one edge of the split to the other is strong enough or the signal frequency is high enough, currents may pass by displacement.

Fig. 9 shows the layout of the geometry considered in this section. The two microstrip traces shown are routed 40 mil above a reference plane with a 500 μm slit. The primary trace is centered vertically on the PCB. A secondary trace, used as a victim for crosstalk experiments, is below the primary with a dotted outline. The ideal return path is directly beneath the traces, but that path is unavailable for conduction current. The path of least impedance is around the edge of the slit at low frequencies, as seen in Fig. 10. As the frequency increases, capacitive coupling across the slit becomes the lower impedance path. This change is evident in the current density plot in Fig. 11.

The parasitic inductance for the path around the slit and the capacitance across the slit can be represented as a parallel LC circuit in the return path between two transmission lines for the microstrip on either side of the slit. More complicated models may be used to capture the higher order resonances. One such model would involve two slot lines. These transmission line models would be connected in parallel and attached across the return between the two microstrip transmission line models. One slot line would be terminated short and the other open to represent the slots propagating away from the microstrip. [6] uses a similar analysis method to represent the slot in the reference plane.

Splitting a reference plane is seldom a perfect situation, but there are methods to reduce the fallout when necessary. The impact of the split plane can be seen in the insertion loss (S_21) of the primary microstrip in Fig. 12. Along with the partial split shown in Fig. 9, three other variations are displayed. Alternative high-frequency return paths can be introduced, using SMT components attached through low inductance paths. Each of the alternatives has an SMT, represented by a small conducting block in the models. The proximity of the SMT to the microstrip heavily influences the effectiveness of this mitigation approach. Also, if the SMT is connected to the two sides of the reference plane by long vias, the parasitic inductance in the connection will impede current flow at high frequencies.

Another way of viewing the impact of the different mitigation methods is to observe the electric field in the slit. Fig. 13 shows the electric field across the gap at 10 MHz. The field is similar for each variation, with some spikes below and about the microstrip line. At 1 GHz, Fig. 14 shows a more significant difference.

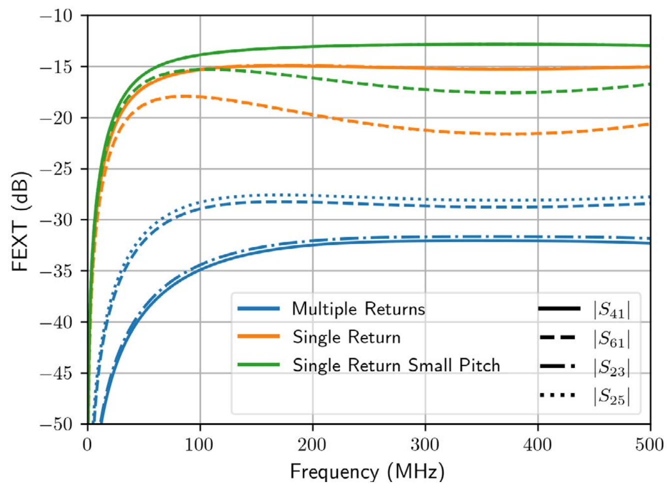


Fig. 7. Far-end crosstalk of the parallel wire geometries in Fig. 6

The electric field still drops to near zero where the SMT components are positioned, but the fields are much higher elsewhere. These larger fields indicate potential EMC issues. When there is a significant voltage drop between two conductors, there is the potential to radiate. The edge of the reference plane can act as elements of a dipole.

Crosstalk is also an issue with the split crossing. There is inductive coupling because the two microstrips share part of their return path. The far-end crosstalk between the two microstrip traces is shown in Fig. 15 and compared with the crosstalk observed for two microstrips routed over a solid reference plane of the same size. The crosstalk is approximately two orders of magnitude higher than without the split crossing, except for the frequency band between 5 GHz and 7 GHz. This band coincides with a null in the electric field around the location of the second microstrip.

While the reader may be considering why anyone would ever route a signal over a split in a return plane, there are reasons where the idea is less terrible than others. Consider that crossing a split in a reference plane may be unavoidable. The crossing may not be by design but due to process variation. An unintended split crossing can be introduced into a design by a row of large antipads. Lines of via antipads are shown in Fig. 16, like those in the footprint of a high-density signal connector. The vias are necessarily close together to match the pitch of the connector, but the vias may also require a significant antipad to minimize the excess capacitance in the via transition. This issue is common with differential connectors using compliant pin technology. Often signal vias of a differential pair share a larger common antipad. Regardless, if these large antipads are combined with excessive

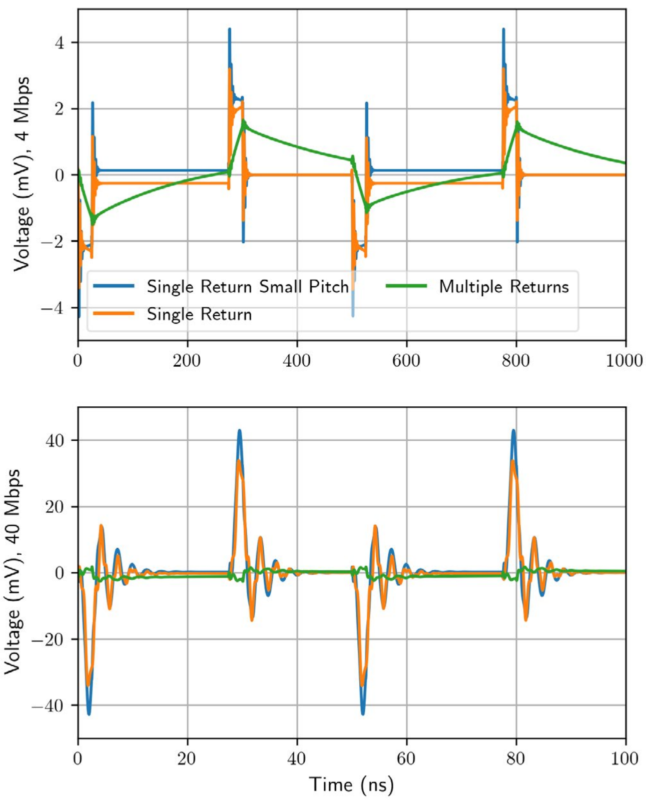


Fig. 8. Far-end crosstalk with different signaling rates for the different ribbon cable geometries

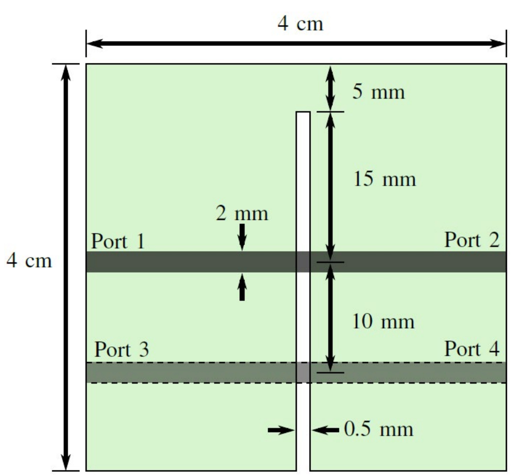


Fig. 9. Top view of a microstrip line crossing a split in the reference plane.

misregistration between layers in the PCB, signal traces may inadvertently cross the antipad.

This asymmetry will unbalance a differential pair, and a single-ended line will see an impedance change within the via array.

C. Return Via Discontinuities

While splits in return planes are one of the more apparent return path discontinuities, issues with return vias can be more challenging to diagnose. More complex does not mean subtle. The effect will be pronounced if the return via is missing entirely, including a sharp inductive discontinuity in a TDR trace. However, the TDR trace may not clarify whether the issue is the signal path or the return path. Fig. 5 showed a missing return via. Signals may also share return vias as part of the return path, like the crosstalk issues discussed in Section III-A.

Fig. 17 shows a microstrip-to-microstrip transition from the side and top. The signal path is clear. Presumably, the return path is clear as well. There is a return via placed at some distance from the signal via. The geometry in Fig. 17 was modeled at multiple frequencies and multiple via spacings. Current was measured using an Ampere's law calculation around the signal via and return via individually. At 10 kHz, the ratio of the return via current to the signal via current ranged from 0.55 at a 30 mm separation to 0.75 at 2.5 mm separation. At 1 GHz, the ratio of the return via current to the signal via current ranged from 0.08 at a 30 mm separation to 0.37 at 2.5 mm separation. These estimates are subject to meshing and modeling errors. The exact values are less important than the trend they indicate. A closer return via will pass a higher percentage of the return currents than one farther away. When the return via is too far away, higher frequency currents find another route to complete the loop displacement current between the planes. Placing one or more return vias near the signal via will mitigate, if not eliminate, most return path coupling and discontinuity effects.

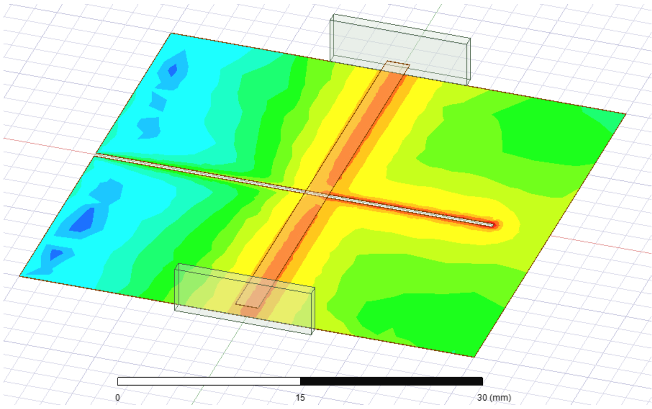


Fig. 10. Surface current magnitude on the reference plane of the model with a partial split at 10 MHz

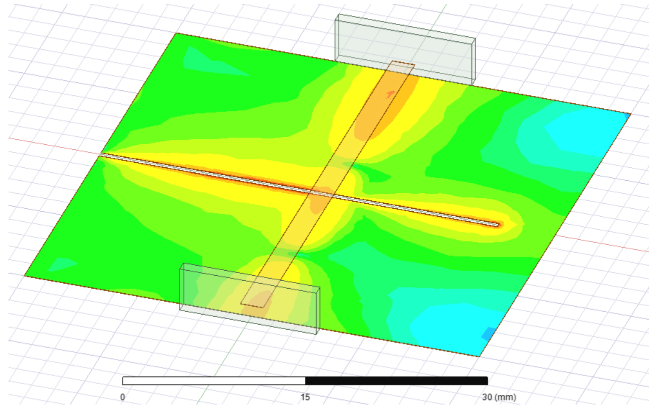


Fig. 11. Surface current magnitude on the reference plane of the model with a partial split at 4 GHz

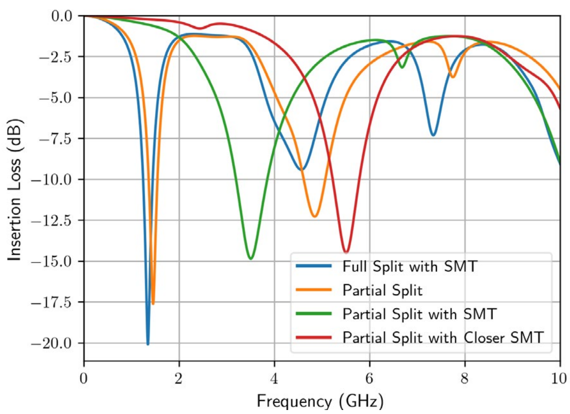


Fig. 12. Insertion loss for the different split crossing geometries

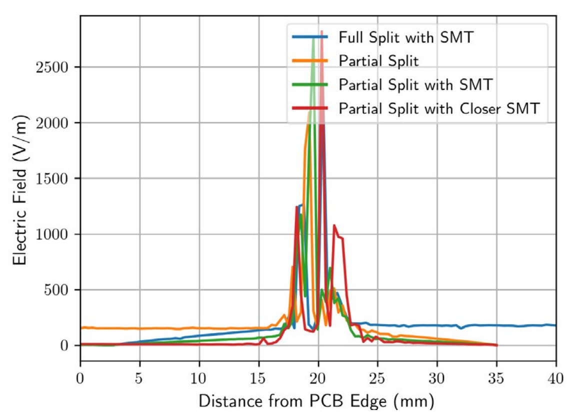


Fig. 13. Electric field in the gap of a PCB with a partial split at 10 MHz

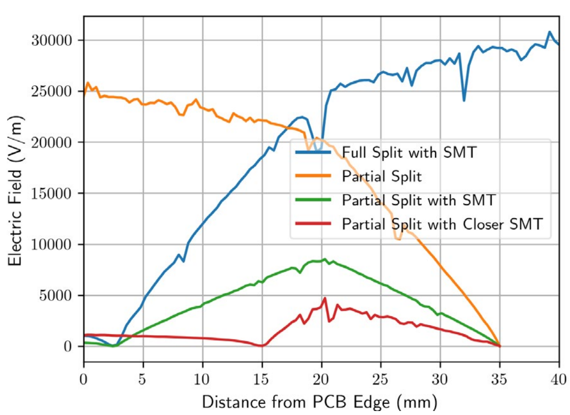


Fig. 14. Electric field in the gap of a PCB with a partial split at 1 GHz

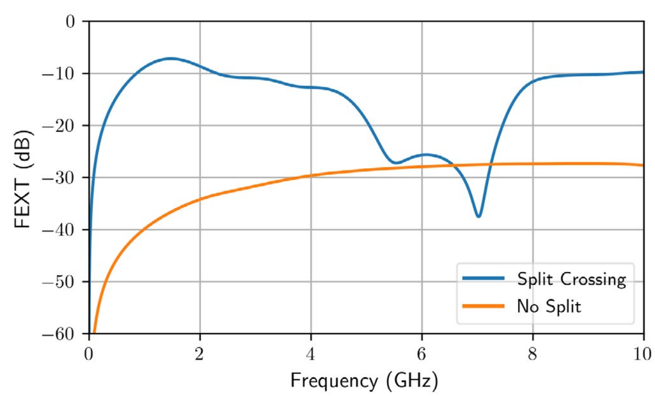


Fig. 15. Far-end crosstalk for two microstrip lines with and without a split crossing

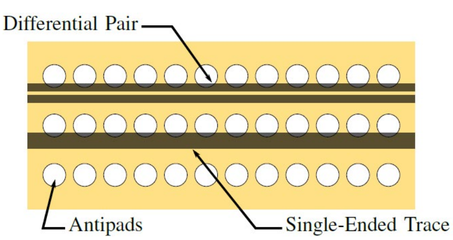
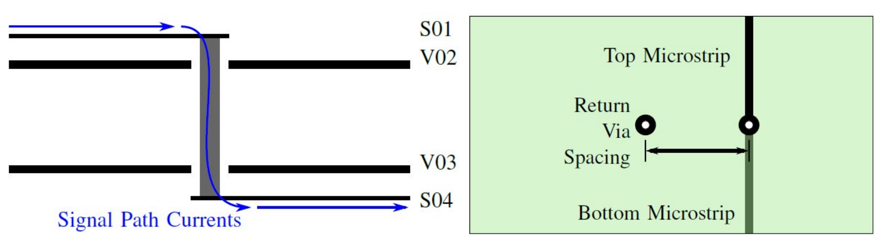


Fig. 16. A differential pair and a single-ended trace crossing antipads on an adjacent reference layer due to misregistration



(a) side view with signal current path (b) top view with return via placement

Fig. 17. Microstrip-to-microstrip transition with offset return via

IV. SUMMARY AND CONCLUSIONS

The goal of this article has been to present some of the challenges associated with controlling return path currents and the trouble that may ensue when they are not maintained. A key issue with many return path discontinuities is distinguishing their impact from those caused by discontinuities in the outgoing signal path. TDR and other measurement techniques may not be enough to zero in on the cause, but TDR can find the distance of a discontinuity from the measurement point to guide the search. How specific return path issues manifest in example geometries was presented. Ultimately, every situation will be subtly different, and the best solution may not precisely align with what was presented here. One piece of advice remains. Follow the currents from source to load and all the way from the load back to the source. Look for all paths, not just the obvious ones.

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Michael Cracraft received the B.S., M.S., and Ph.D. degrees in electrical engineering from the Missouri University of Science and Technology (formerly the University of Missouri–Rolla), Rolla, MO, USA, in 2000, 2002, and 2007, respectively. He received an NSF IGERT fellowship while working with the Electromagnetic Compatibility Laboratory, Missouri University of Science and Technology, as a graduate student. In 2007, he joined the IBM Systems & Technology Group in Poughkeepsie, NY, working in packaging and signal integrity on POWER and Z systems. Cracraft joined the Electrical & Computer Engineering department of the Rose-Hulman Institute of Technology in Terre Haute, IN in 2020 as an associate professor. He specializes in high-speed and high-frequency measurements, electromagnetic modeling, and model-to-hardware correlation.

Mitigating Self-generated EMI for Wireless Devices

Dr. Chulsoon Hwang, IEEE Senior Member, Missouri University of Science and Technology, Gamma Theta 2019

Wireless connection is the cornerstone for the Internet of things, a network allowing distant devices and sensors to communicate wirelessly with each other. The maximum physical distance across which two devices can communicate is called the "radio range." Although a long radio range is essential for the connectivity and portability of wireless devices, designers are finding that digital circuits within the same system often create sufficient electromagnetic interference (EMI) that decreases receivers' sensitivity; thereby, substantially degrading the radio range. This article discusses an electromagnetic (EM) framework to model the noise radiation from digital circuits and its coupling to on-board radio frequency (RF) antennas. A new approach, based on the EM framework to mitigate the self-generated EMI in wireless devices is introduced. The approach does not require absorbers/shielding cans and it does not compromise signal integrity. The success of the mitigation concept introduced in this article is demonstrated by applying it to a practical RF device, namely, the smart speaker.

I. Introduction

A fundamental requirement of wireless devices is a long RF range. Radio range is a function of multiple factors: transmitter power, antenna gain, path loss, and receiver sensitivity. Transmitter power and antenna gain are typically regulated by federal law. For instance, the Federal Communications Commission limits the specific absorption rate (SAR), the rate at which the body absorbs energy when exposed to an RF field, to 1.6 W/kg for cellular telephones [1]. Transmitters with higher power also consume more energy, whereas low power is critical for portable devices. Therefore, increasing the RF range of wireless devices by increasing transmitter power or antenna gain is not advisable. Because path loss is an environmental feature that is usually unmanageable, the only practical and feasible approach to increase RF range is improving receiver sensitivity. Increasing the receiver sensitivity can increase the radio range as much as transmitter power, without increasing the power consumption or causing harm to the human body.

Modern technology has enabled extreme levels of amplification to be easily achieved within a receiver; thus, receiver amplification is not a factor limiting receiver sensitivity. Instead, the limiting factor in modern receiving antennas or receiver systems is noise: a weak signal is not limited by the actual strength of the signal but rather by the noise that masks it out. This noise can come from a variety of sources. At frequencies above 30 MHz, the noise generated from neighboring electronic devices becomes far more important than external environmental noise. The main type of noise limiting receiver sensitivity is internally generated by digital integrated circuits (ICs), called self-generated EMI. For example, RF modules in smartphones, which are composed of an RF antenna and its receiver, can detect signals as weak as -120 dBm in a 200 kHz bandwidth if the module is not disturbed by nearby electronics. However, the clock frequencies of a smartphone can reach the GSM 880–1800 MHz band, as well as Bluetooth and Wi-Fi bands [2], thus limiting the receiver's ability to detect low-level signals and therefore decreasing the overall range of the receiver.

Because of the complexity of real products, there are several approaches, including trial and error approaches, that are available for troubleshooting EMI/EMC issues including for self-generated EMI. Typical solutions involve adding shielding or absorbing components (usually later in the development cycle), which not only can alter RF antenna performance (detuning its resonant frequency) when placed in proximity but also add extra cost to the product. An alternative mitigation solution is damping the signal edges (intentionally degrading signal quality) to decrease the energy of the noise radiation source; however, this approach comes at the cost of the data rate and thus is not desirable in modern high-speed digital systems. Departing from the conventional mitigation approaches, we introduce a new paradigm of self-generated EMI mitigation without absorbing/shielding components. Our approach also does not compromise signal integrity. The concept is based on and derived from a solid EM framework to model the self-interference EMI problems, and is demonstrated with real smart speaker designs.

II. Self-generated EMI

A three-step radiation source–coupling path–victim antenna process has been widely used to model EMI coupling. However, self-generated EMI requires a different approach. In wireless devices, the RF antennas are realized on the printed circuit board (PCB), called on-board antennas, by using the entire PCB as a part of the radiating structure. The digital ICs are also populated on the PCB, which is a part of the RF antenna. Thus, we use a two-step radiation source–transfer function process to model self-generated EMI. The transfer function represents how much noise couples to the RF antenna given the noise location and type, that is, the RF antennas' susceptibility depending on the location/type of noise source.

First, we model noise radiation from digital ICs and their interconnects. In the circuit domain, any circuit's sources can be represented by using either an equivalent voltage or current source, with corresponding source impedance, according toThevenin's and Norton's theorems. Modeling of EM radiation is quite different from circuit domain modeling and requires modeling of the EM field radiating out in three-dimensional space. The most common method uses Huygens' equivalence principle: an imaginary closed surface with impressed electric (J_s) and magnetic current (M_s) sources

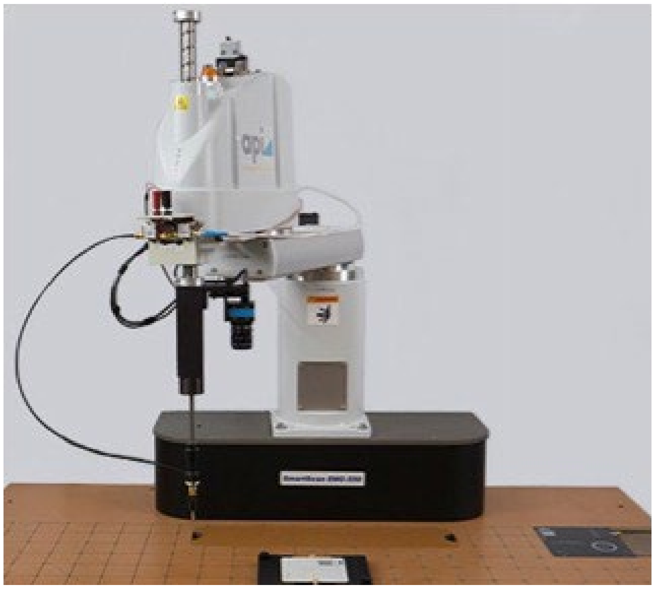

Fig. 1. A 2D orthogonal near-field scanner from API [3]

can generate the same external field distribution as in the original problem. This concept has been further evolved to reconstruct equivalent electric *(P)* and magnetic dipole *(M)* moments, replacing the radiating structure (inside the surface) according to the known relationship between the equivalent dipole moments and the fields on the surface. In this case, the surface need not necessarily be closed. Effective and accurate source reconstruction is an ongoing research topic. Many approaches are being investigated, such as the least squares method, genetic algorithms, and pattern recognition based on machine learning. The electric and/or magnetic fields can be measured on a surface grid with a near-field probe and an automatic near-field scanner. One widely used near-field scanner is shown in Fig. 1. Fig. 2 shows a comparison of measured and calculated magnetic fields *(H)*. The calculation was performed with the reconstructed dipole moment, *M* dipole in this example.

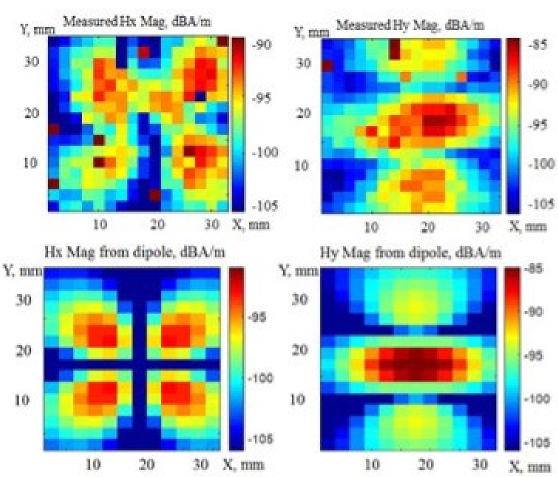

Fig. 2. H fields from measurement (top) and calculation (bottom) [4].

Second, the transfer function is needed. We derived a new EM framework to describe the relationship between the radiation source and the coupled noiseby using the reciprocity theorem. The reciprocity theorem is widely used in the circuit domain, but the circuit reciprocity theorem is a special case of reciprocity in electromagnetic field theory and is derived from Maxwell's equations. The electromagnetic reciprocity theorem describes a relationship between the fields produced by one current distribution on another, and vice versa. The detailed derivation process is as explained previously [5]. The coupling voltage at the victim antenna is described as

$$U = \sum_{i=1}^{N} \vec{f}_{P_i} \cdot \vec{P}_i + \sum_{i=1}^{N} \vec{f}_{M_i} \cdot \vec{M}_i \qquad (1)$$

where $\vec{f}_{P_i}$ is for each electric dipole moment $\vec{P}_i$, and $\vec{f}_{M_i}$ is for each magnetic dipole moment $\vec{M}_i$. The transfer functions $\vec{f}_{P_i}$ and $\vec{f}_{M_i}$ are associated with the E and H fields, respectively, at the noise source location when the victim antenna is excited. The E and H fields can be obtained in a full wave EM simulation or directly from measurements using near-field probes. The transfer functions represent how much noise is induced at the antenna port given the source location and type. In other words, the transfer functions are the susceptibility of the antenna. We do not consider the coupling path and victim antenna separately because the noise source is located "on" the antenna. The total coupled voltage is a linear combination of the contribution of each noise source. Therefore, when multiple sources exist, as is typically the case, their sum can be either destructive or constructive depending on their phase relationship. Of note, the interaction between the EM radiation of the digital ICs (i.e., the source) and the susceptibility of the RF antenna (i.e., the transfer function) is represented as an inner product. We use this relationship to mitigate the self-interference in the next section.

III. Interference Mitigation

As described before, owing to the complexity of real products, EMI/EMC troubleshooting, including that for self-generated EMI, has been widely based on experience or trial and error. Instead of introducing additions late in the development stage, we aim to "design" EMI performance at the product development stage. New ways to improve the EMI performance, i.e., by mitigating self-generated EMI, are discussed. A smart speaker, shown in Fig. 3 [6],is used as an example for demonstration.

Fig. 3. A circuit board with Wi-Fi antennas (black), a processor (orange), and memory (red) [6]

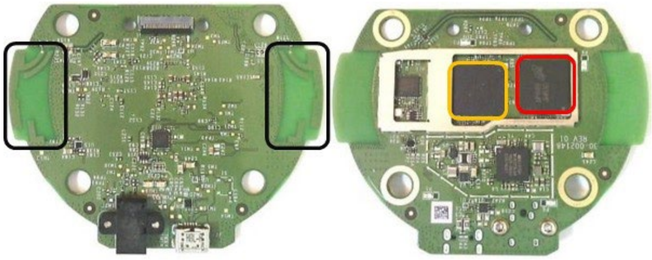

Fig. 3. A circuit board with Wi-Fi antennas (black), a processor (orange), and memory (red) [6]

Based on the understanding from (1), two approaches are possible to mitigate self-generated EMI from the system design perspective. First, the magnitude of the transfer function can be decreased by moving the digital ICs and interconnects to locations on the board that are less susceptible to EMI. Placing shielding/absorbing materials in the coupling path would reduce the transfer function, but the same goal can be achieved by shifting the location of the noise source. Second, the radiation/susceptibility interaction can be decreased by rotating the digital ICs and interconnects. Due to the inner product relationship, the coupling can be suppressed through orthogonality between two vectors (the noise vector and antenna susceptibility vector). Both solutions are discussed in greater detail below.

In the example shown in Fig. 3, the noise source type is My (a magnetic dipole pointing in the y-direction) [4]; therefore, the transfer function associated with Hy (the magnetic field in the y-direction) must be determined. The measured |Hy| with respect to the embedded Wi-Fi antenna's excitation is shown in Fig. 4 [4]. The near-field scanner shown in Fig. 1 was used for the measurement. From (1), we know that

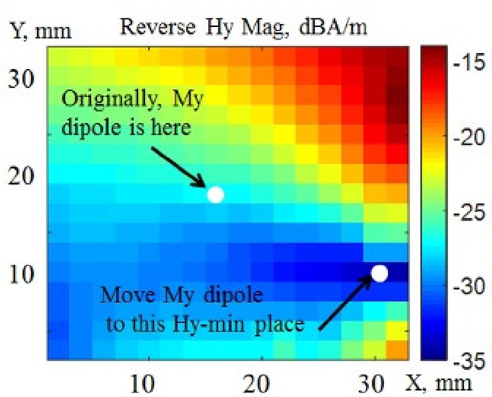

Fig. 4. Measured |Hy| field map of the circuit shown in Fig. 1.

weaker coupling occurs in the locations where the Hy fields are weaker in the field map. Thus, moving the noise source to the smallest Hy location candecrease self-generated EMI. However, the minimum transfer function location is not always possible for the actual layout. Because the processor and memory along with its interconnects must be moved as a group, the space might not be sufficient to place all components in practical designs.

A method that can work better in practical designs is rotating the digital ICs and interconnects. Because the entire circuit is rotated, substantial redesigning of the layout is unnecessary. To explain this concept, linearly polarized antennas are illustrated in Fig. 5. When two antennas communicate, the antennas must be similarly polarized to ensure optimal performance. Antennas operating with orthogonal polarization will not perform well, owing to substantial polarization losses. Orthogonality therefore allows an antenna with a given polarization to avoid interference created by energy from an antenna with an orthogonal polarization. In an ideal case, two orthogonally polarized antennas have infinite isolation (i.e., zero interference). Isolation using orthogonality is a well-known concept in the antenna community, but the case of self-generated EMI differs from antenna applications because 1) coupling occurs at the near-field region of an antenna, and 2) the noise source is not a well-defined antenna. Using the dipole moment representation of the digital noise radiation sources and the EM framework developed in [5] makes it clear and straightforward to exploit the orthogonality in self-generated EMI problems.

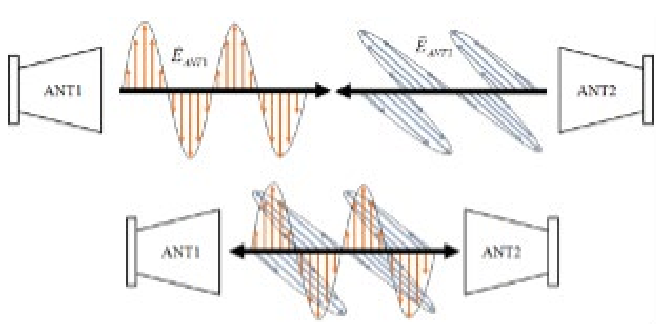

Fig. 5. Orthogonality to avoid interference between two linearly polarized antennas.

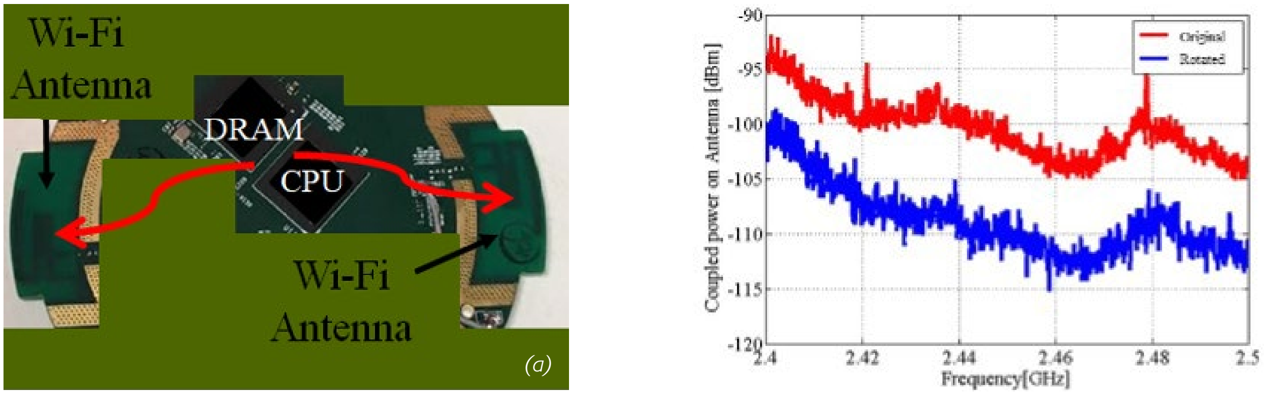

Fig. 6. Measured RFI reduction for the right-side antenna between the modified design and the original design [7].

The antenna susceptibility at the noise source location must be determined, but in this case, our concern is the angle rather than the magnitude of the antenna susceptibility vector, namely Hy in this example. According to measurements, the Hy vector has an angle of approximately 63°, and the rotation angle is determined to be 27°. The device with the new placement was fabricated as shown in Fig. 6(a) in collaboration with Amazon Lab126 Wireless Technology Group. The coupled voltages in the Wi-Fi frequency band for the original design and the rotated design are shown in Fig. 6(b) [7]. The measured data successfully validates the proposed mitigation methods.

IV. Conclusion

Self-generated EMI problems are becoming common and critical in wireless device design. The RF range can substantially change, depending on EMI performance. A theorical background for the electromagnetic framework, incorporating the radiation source and intra-system coupling models, was introduced here. Based on this framework, new approaches to mitigate the self-generated EMI were explained and demonstrated by using a real device.

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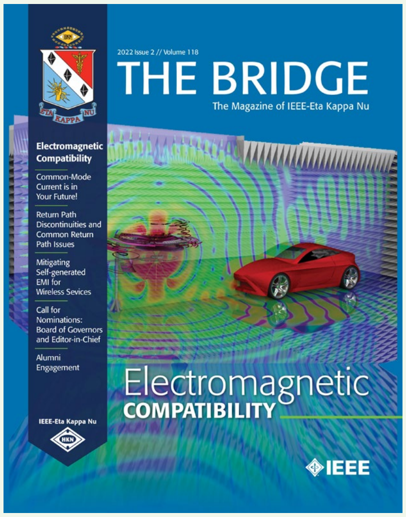
Chulsoon Hwang (S'08-M'13-SM'18) received the B.S., M.S., and Ph.D. degrees in electrical engineering from the Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea, in 2007, 2009, and 2012, respectively.

He was with Samsung Electronics, Suwon, South Korea, as a Senior Engineer from 2012 to 2015. In July 2015, he joined the Missouri University of Science and Technology (formerly University of Missouri-Rolla), Rolla, MO, USA, where he is currently an Assistant Professor. His research interests include RF desensitization, signal/power integrity in high-speed digital systems, EMI/EMC, hardware security and machine learning.

Dr. Hwang serves as the Vice Chair of the SC-5 Power Electronics EMI of the IEEE EMC Society and an associated editor for the IEEE Transactions on Signal and Power Integrity. Dr. Hwang was a recipient of the AP-EMC Young Scientist Award, the Google Faculty Research Award, and Missouri S&T's Faculty Research Award. He was a co-recipient of the IEEE EMC Best Paper Award, the AP-EMC Best Paper Award, and a two-time co-recipient of the DesignCon Best Paper Award.

About the Cover



The international ISO 11451-2 standard test is one of the most expensive and time-consuming EMC tests in the automotive industry. It consists of generating radiated electromagnetic fields using an antenna with a radio frequency source capable of producing field strengths ranging from 25V/m to 100V/m up to several GHz.

During the test, all embedded electronics must perform flawlessly. The cover illustration shows a full virtual ISO 11451-2 test using Ansys HFSS, including all the equipment used in a real test. Equipment includes antennas, connectors, absorber elements, and embedded electronics in the vehicle.

Ansys HFSS uses several exclusive technologies including Ansys Mesh Fusion and the Domain Decomposition Method that enables the full simulation of the ISO 11451-2 standard. Automakers are relying on Ansys HFSS to predict the electronics behavior embedded on vehicles during the test even before the first physical prototype is available, slashing development time and avoiding costly changes due to unexpected performance of the electronics during this radiated immunity test.

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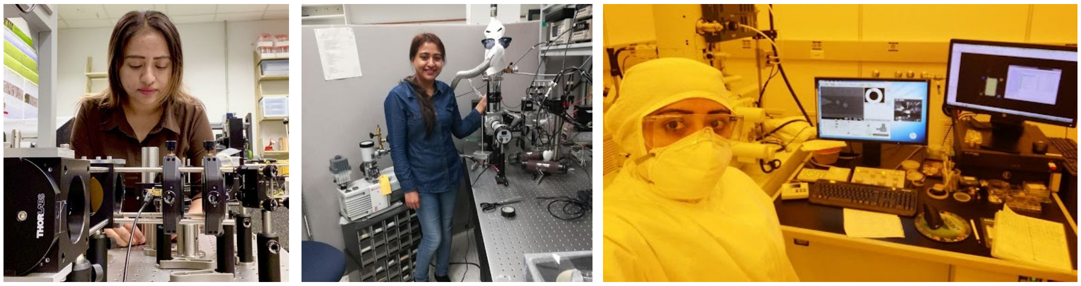
Naznin Akter

Kappa Delta Chapter
Florida International University, Ph.D. Candidate in Electrical Engineering

RESEARCH TOPIC
Novel Materials and Devices for THz Detection and Emission

Technological advances necessitate the use of previously unused and unregulated bandwidth to set a new standard for the highest data rates. To reach a high data transfer rate, it requires a wider frequency range and larger bandwidth. As a result, the THz spectrum (0.1-10 THz) has emerged as the next frontier of wireless communication for beyond 5G technologies. My research focused on investigating THz waves-plasmon interactions in novel field effect (FET) that could be used as a THz detector at room and cryogenic temperatures, with high responsivity, low noise, tunability, compact size, faster response time, and lower cost. In comparison to traditional table-top bulky and costly THz detector devices, these detector devices would be the best candidate for future THz on-chip applications. Furthermore, the same devices are expected to act as THz emitters under right biasing condition.



Left to right: Image-1: Working with THz-TDS setup. Image-2: Working with THz-BWO setup.Image-3: Working in cleanroom with EBL process.

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Md Razuan Hossain

Gamma Tau
University of Mississippi, Ph.D. Student in Electrical and Computer Engineering

RESEARCH TOPIC
Neuromorphic Computing

Reservoir Computing (RC) is a highly efficient machine learning algorithm specially suited for processing temporal datasets. RC systems extract features from input by projecting them into a high-dimensional space. A major advantage of the RC framework is that it only requires the readout layer to be trained which significantly reduces the training cost for complex temporal data. In recent years, memristors have become extremely popular in neuromorphic applications due to their attractive analogy to biological synapses. Alamethicin-doped, synthetic biomembrane can emulate key synaptic functions due to its volatile memristive property which can enable learning and computation.

In contrast to its solid-state counterparts, this two-terminal biomolecular memristor features a similar structure, switching mechanism, and ionic transport modality as biological synapses while consuming considerably lower power. Our goal is to develop a biomolecular memristor-based reservoir system to solve tasks such as classification and time-series analysis in a simulation-based environment.

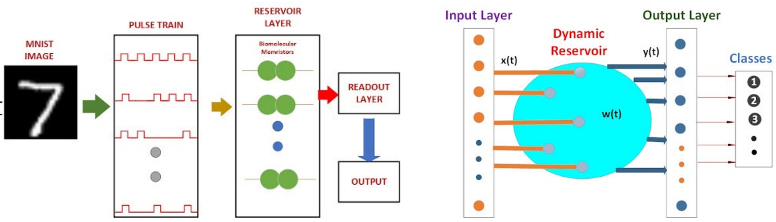

Image Left: "MNIST classification"- this photo shows that the biomolecular memristors have been doing MNIST classification. Image Right: "Reservoir Computing"- it describes the architecture of our reservoir to solve classification and dynamic problem

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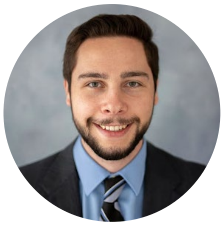


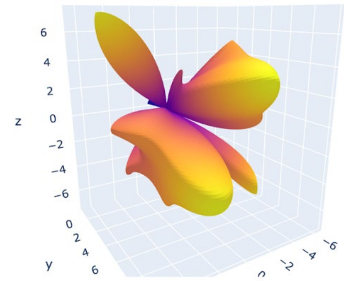
Ryan Dreifuerst

Iota Beta, North Carolina State University, Ph.D. Student in Electrical Engineering

RESEARCH TOPIC
Machine Learning-Assisted Signal Processing

Signal processing in wireless communications has traditionally been dominated by algorithms that are based on simplified system models. While these algorithms have been sufficient for previous systems, the requirements of next-generation networks make these algorithms insufficient for handling the complex correlations and nonlinearities obfuscating the signal. By augmenting machine learning (ML) with the domain knowledge inherent in dedicated signals (for example in time-frequency domain relationships), new algorithms can be developed to overcome extreme situations such as low resolution data sampling or limited feedback beam management. These are two examples of ways that ML can improve signal processing algorithms, thereby reducing the power consumption and achieving new levels of spectral efficiency in wireless domains.

Ryan's work has analyzed and developed algorithms for network optimization, low resolution signal deconstruction, and codebook design for 5G. He has proposed algorithms for extremely sample efficiency ML with Bayesian optimization and worked with industry leaders to advance the Open Radio Access Network (ORAN) initiative. Ryan's work has been supported by the NSF, Samsung Research America, and Facebook.



A learned 3D beamforming pattern covering a region with obstructions and interfering signals.

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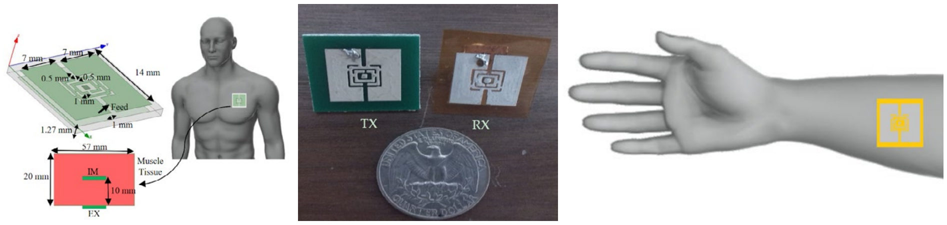
Mohammad Haerinia

Delta Rho Chapter
University of Massachusetts Lowell, Ph.D. Student in Electrical Engineering

RESEARCH TOPIC
Medical Optics, Metasurfaces, WPT for Medical Applications

Mohammad's research interest includes multidisciplinary areas of applied electromagnetics, including medical optics, metasurfaces, wireless power transfer (WPT), and WPT for medical applications. WPT technology has a variety of modern applications ranging from charging cell phones to medical implants. Mohammad's work has practical applications in medical implants such as pacemakers and biosensors. He designed a miniaturized printed flexible dual-band antenna for wireless power transmission in wearable electronics. He also designed a novel hybrid inductive power transfer and wireless communication compact system for biomedical implanted devices. In addition, he is currently focusing on enhancing the optical capabilities of metalenses that can enable more precise diagnostic imaging tools such as endoscopes, and new microscope form factors, enabling radiologists and physicians to see previously invisible details. His research is supported by the North Dakota Department of Commerce, Venture Phase I, and the National Science Foundation (NSF).



1-A miniaturized dual-band antenna implanted in the human body; 2- Transmitter (TX) and receiver (RX) fabricated prototypes; 3- Designed wearable antenna on hand.

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CONTACT
https://www.linkedin.com/in/mohammadhaerinia

Katelyn Brinker

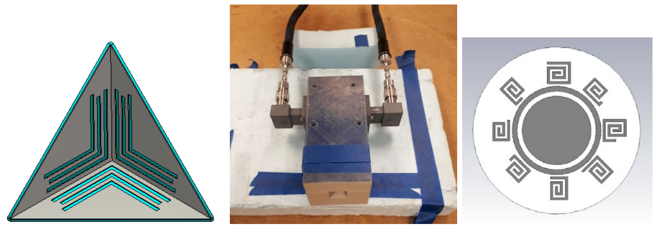
Gamma Theta, Iowa State University, Ph.D. Candidate in Electrical Engineering

RESEARCH TOPIC

Chipless RFID for Structural Health Monitoring (SHM)

Radio Frequency Identification (RFID) systems typically consist of a reader and a tag. The tag can provide identification information and/or information about the environment, such as temperature and humidity. Chipless RFID is a subset of the RFID field where these tags don't have any power source or electronics. Instead, their information is "stored" in their structure - that is they're designed to scatter in a specific way when interrogated with an electromagnetic wave. This scattered response can be viewed in the time-, frequency-, or spatial-domain and a binary code can be assigned to it. Changing the structure of the tag or the environment that the tag is in, produces changes in this binary code, and in this way, identification or sensing can be performed. The wireless passive nature of this technology results in less expensive and less invasive sensors, which can allow for more comprehensive monitoring of structures.

Katelyn's work, supported by a NASA Space Technology Research Fellowship, has more specifically examined how chipless RFID tags can be used for structural health monitoring applications in the space and aerospace realms. She has developed new tags that can be used for microwave materials characterization and rotation sensing, examined inkjet-printing for tag manufacturing, and developed new measurement methods to address some of the current challenges in the chipless RFID field.



Chipless RFID tags and custom 3D printed antenna for tag measurement.

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Shail Dave

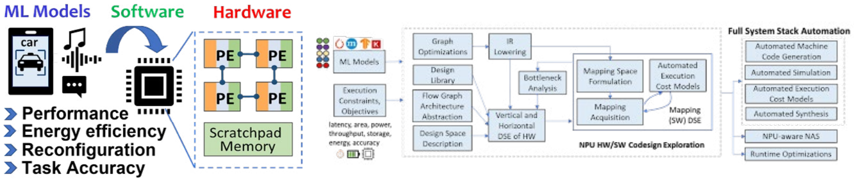
Epsilon Beta, Arizona State University, Ph.D. Student in Computer Engineering

RESEARCH TOPIC

Design Space Modeling and Optimizations for Dataflow Accelerators

Achieving efficient processing of commonly used computing applications is important, e.g., for improved performance and energy efficiency. Therefore, domain-specific hardware accelerators have been increasingly designed, especially for tasks involving intelligence through machine learning (ML). Techniques are required for mapping the application tasks on these hardware accelerators in a resource-efficient manner. Additionally, tools for modeling the accelerator's execution and its design exploration are also needed, and help the designers in characterizing the execution efficiency and improving it further.

Shail's research include sustainable techniques for execution modeling, task mapping, and agile design space exploration for reconfigurable dataflow accelerators. For instance, he has developed automation techniques for obtaining efficient mappings of ML operators and performance-critical loops of general-purpose applications on dataflow accelerators. Further, ML models can be sparse and compact, such that high task accuracy can be obtained at lower computing, communication, and memory requirements. Exploiting such benefits, however, usually requires additional hardware/software support. Shail's recent work, including a literature survey published in Proceedings of the IEEE, analyzes different techniques for accelerating such sparse and compact ML models and their execution efficiency.



1- Efficiently processing ML models on dataflow accelerators requires succinct modeling and optimized exploration of hardware/software; 2-Agile methodology for designing efficient accelerators with automated full-stack development.

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Randall Berry

Chair and John A. Dever Professor in the Department of Electrical and Computer Engineering at Northwestern University

Gamma Theta Chapter

Dr. Randall Berry is the Chair and John A. Dever Professor in the Department of Electrical and Computer Engineering at Northwestern University. His research interests include wireless communications, computer networking, network economics, and information theory. Dr. Berry received the M.S. and PhD degrees in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology in 1996 and 2000, respectively. His undergraduate education was at the University of Missouri-Rolla, where he received the B.S. degree in Electrical Engineering in 1993. In 1998, he was on the technical staff at MIT Lincoln Laboratory in the Advanced Networks Group and currently is a principal engineer for Roberson and Associates. Dr. Berry is the recipient of a 2003 CAREER award from the National Science Foundation and is an IEEE Fellow. He has served in several editorial roles, including for *IEEE Transactions on Wireless Communications* and *IEEE Transactions on Information Theory.* As an undergraduate, he was inducted into the Gamma Theta Chapter of HKN. In his current role as department chair, he values the service of the Beta Tau chapter of HKN for helping to mentor new students in the department.

Why did you choose to study the engineering field (or the field you studied)?

In high school, I enjoyed science and math, which meant engineering was a common path suggested to me (though admittedly, I did not know much about what engineers did). I also liked music and HiFi stereo systems (anyone under 30 may need to Google this). I knew this had something to do with Electrical Engineering, so I chose that as a major. Once, I began taking classes, I enjoyed the classes and was especially attracted to courses in signal processing and communications, as I liked seeing how elegant mathematics could be used to provide deep and practical insights into these areas.

What do you love about the industry?

I love working in an area as dynamic and ever-changing as ECE, which also has had such a profound impact on society.

What don't you like about the industry?

In the past, we have not always thought enough about some of the broader societal impacts of the technologies we are creating, such as the environmental impacts or the potential negative social impacts of people being always connected.

How has the engineering field changed since you entered it?

When I started working in wireless, third-generation cellular technologies were just being developed. Voice was the main application for these networks. People were debating if there was a "killer app" for cellular data, and sending video over cellular seemed like an exotic idea.

In what direction do you think the engineering and other IEEE fields of interest are headed in the next 10 years?

Computing and data have grown in importance in most fields of engineering, and I think this will only continue in the next 10 years. So, I think all engineers should have good toolsets to address these topics.

Profile Continued on page 36

Charlie Vidal

President, Gama Alpha Chapter
Manhattan College

Charlie Vidal, an Electrical Engineering major with concentrations in Power Grids and Green Energy Engineering, is president of the IEEE-HKN Gamma Alpha Chapter at Manhattan College. He is working with his fellow officers and members to revive the Chapter since COVID-19 had completely halted all its activities. Additionally, the team is working to build the foundation to set up for next year's Officer Board. A resident of Brooklyn, NY, Charlie has held internships at and received an offer of full-time employment from Meyers+. He is a member of the Epsilon Sigma Pi Honor Society. Charlie is constantly trying to improve himself. He loves to cook. Initially, he wanted to learn to be able to survive. But, as he became more comfortable, he learned new recipes for fun. Among his favorites, are curry chicken, pasta with vodka sauce, pão de queijo, yuca pancakes, enchiladas, birria tacos, and huevos rancheros. He hopes to move onto Japanese cuisine next.

Why did you choose to study the engineering field (or the particular field you are studying)?

I was first interested in the electrical field at a young age as my father was an electrician. I knew I wanted to do something in the same area, and as I knew I was good at mathematics and had taken courses in high school related to ECE such as robotics and web programming and design, I decided to try electrical engineering.

What do you love about engineering?

I honestly love how straight-forward it is. With every question, there is an answer. I admire the great thinkers who go into the arts, political science, psychology, and theoretical physics because of the creativity needed for those fields, but I am a right-brain thinker that uses logic and reasoning to come up with an answer, so engineering just makes sense to me.

What don't you like about engineering?

I do not like the stigma that engineering, or any other STEM major has, about being "hard." You do not pick up a pencil and become the next Picasso, nor do you have a thought and become the next Aristotle. Engineering requires work and dedication, just like any other major. As long as you are truly dedicated and passionate about completing your degree, you will do just fine.

What is your dream job?

My dream job is to own my own business. By being a Master License Electrician and completing my PE, I would be able to connect both construction and engineering and start up my own company. It would be very tough and would only be possible to consider when I'm in my late 20s or early 30s, but that doesn't mean it's impossible.

Whom do you admire (professionally and/or personally) and why?

Frankly, I admire lazy/carefree people. I give myself too many responsibilities and try so hard that I've come to the point where I want to live a happy, easy-going life without any worries. What's not to love about that? I try to follow that lifestyle by developing code on my computer to automate processes. One quote that truly speaks to me and I highly relate to is something Bill Gates once said: "I choose a lazy person to do a hard job. Because a lazy person will find an easy way to do it."

Profile Continued on page 36

Randall Berry Professional Profile Continued

What is the most important lesson you have learned during your time in the field?

We have been living in a time of exponential changes in things like computing power, memory, and communication. This makes many ideas that seemed impossible at one time, easily accomplished at a future time. I think learning to appreciate this is an important lesson.

What advice can you offer recent graduates entering the field?

Continue to learn and re-invent yourself. As I noted previously, we are in a very dynamic and ever-changing field.

What is your favorite Eta Kappa Nu memory?

I have fond memories of making a wooden HKN plaque as part of the requirement for joining the Gamma Theta Chapter.

Charlie Vidal Student Profile Continued

In what direction do you think the engineering and other IEEE fields of interest are headed in the next 10 years?

Automation and Virtual Reality are our future. Ever since the industrial revolution, automation has been a significant factor for working and everyday life. People are constantly thinking of new ways to make things easier and faster with less effort, and with self-driving cars, smart homes, and AI now in our everyday lives, we are really testing the limits as to how much we can achieve in such a short period of time. Virtual Reality is also becoming a bigger interest. My true hope though, is to focus on green energy and cut down on carbon emissions.

What is the most important thing you've learned in school?

Life isn't school. When you are close to graduation, you will start to see the world differently. Your professors you worked under for years become just other people. Your peers slowly progress into adulthood just as much as you do. All the stress of getting your assignments in on time and studying for your final slowly fade away as you realize you are progressing into a new stage of your life. Some might say I just have senioritis and I just want to have fun instead of do work, but that's not true. You slowly start to understand the real world and how small school is in relation to your life.

What advice would you give to other students entering college and considering studying your major?

My suggestion is to go out and enjoy your college experience as much as you can and be truly happy while you complete your degree instead of constantly worrying about tests and homework and getting the highest marks in the class. You can also learn more important skills that way such as speaking skills and having a charming personality, which are real-world skills. I would also suggest looking into what you want to do in the future to know where to focus your skills. If you want to work at Google, go on coding websites, and look up Google interviews so you can start practicing from the start. If you want to go into construction, make a lot of friends and learn to talk with a lot of people, because that's what you'll be doing in your future. Always remember to prepare yourself for success.

GEM Consortium Receives 2022 Presidential Award

The National GEM Consortium achieves top White House honor for outstanding efforts in promoting STEM.

Earlier this year, President Joe Biden announced that the National GEM Consortium, a nonprofit organization working collaboratively across education and industry sectors to advance the next generation of STEM professionals, has been honored with the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring (PAESMEM). The PAESMEM award is the nation's highest honor of its type. The prestigious award recognizes the exceptional efforts of mentors in encouraging the next generation of innovators and developing a science and engineering workforce that reflects the diverse talent of America.

IEEE-HKN congratulates *THE BRIDGE* Editor Dr. Marcus A. Huggans, who serves as Executive Director for Client Relations at The National GEM Consortium.

For more information, click here.

Source: The National GEM Consortium

A Tradition of Giving

The members of the IEEE-HKN Board of Governors believe so strongly in the impact and importance of IEEE-HKN that they each donate to one or more HKN funds every year. 100% Annual Giving from our Board is a proud tradition we celebrate. They take a leadership role in giving and invite other donors to do the same.

This tradition of giving extends to the staff. IEEE-HKN Director Nancy Ostin and Program Manager Stacey Bersani to the HKN funds every year.

Nancy says: "I get to see tangible results from the work I do and from my monetary donation. I am inspired by the leadership our Chapters display and the great work they do. I am happy to join other donors who support HKN."

Stacey adds: "I give to HKN because it is a society of people putting good into the world. I am heartened by the fact that our members use their talent, their innovation, and their ingenuity to make things better. I see my donation as an investment in a better future for all of us."

Join our Board members, Nancy and Stacey in championing the mission and vision of IEEE-Eta Kappa Nu by making a charitable donation.

Save the Date 28 to 30 October 2022

IEEE-HKN
2022
Student Leadership
CONFERENCE

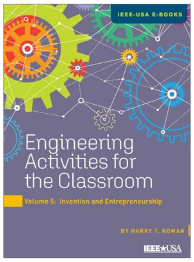
IN PERSON: University of North Carolina, Charlotte

The IEEE-HKN Student Leadership Conference (SLC) is a time-honored tradition that brings together leaders and members from HKN Chapters around the world. And, for the first time since 2019, we will gather in person! This three-day event features tracks for leadership training, faculty advisor programming, technical presentations, professional development, labs, workshops, and a career and graduate school recruitment fair. Stay tuned for details, or better yet, sign up to be kept in the loop!

Free E-Books Include the Fifth Book in a Series to Help Teachers, Students Foster Invention and Entrepreneurship; and the Launch of the "Famous Women Engineers in History" Series

by Georgia C. Stelluto

Free, New E-Book from IEEE-USA for Members Offers Fifth Book in Series to Help Teachers, Students Foster Invention and Entrepreneurship



Veteran educator Harry T. Roman's exciting new e-books offer teachers, students, and parents an educational series on engineering topics of timely interest for the classroom. Teachers can use the activities in these books to develop lesson plans or assignments for students to engage them in the classroom or via distance learning.

In the fifth volume of the series, "Engineering Activities for the Classroom—Volume 5: Invention & Entrepreneurship," the author draws on his 50 years as an engineer, and countless hours teaching students, as he focuses on discussions and activities a teacher (or parent) can use to help spark interest in and understanding of inventing, innovation, and entrepreneurship with students. Roman makes clear that he believes entrepreneurship and inventing/innovation go hand-in-hand: Inventing should lead to introducing new products into the marketplace.

This book gives teachers questions that can help guide discussion around what inventions and patents are, and why they are important; the need for finding markets for inventions; important business terms; and the fundamentals of launching a new product.

Activities include having students:

- Identify inventors past and present
- Hypothesize what characteristics set entrepreneurs apart from other people in business, or in society
- Identify how the inventing process differs now than in the time of the great U.S. inventor Thomas Edison

Roman suggests encouraging students to explore why there is a need for patents; and how patents can help or hamper innovation. He also suggests teachers ask students to monitor their creativity, as well as identify if there are times of the day when they are more creative than others, and theorize why their creative levels might fluctuate at different times of the day.

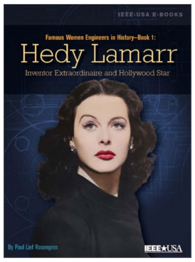
The author of dozens of IEEE-USA e-books, Roman understands the value of teaching, and especially of teaching STEM to children. His love of engineering and an extreme desire to ignite a passion for engineering in future generations come through on every page, and in every suggested activity.

Log in to your IEEE Web Account; add the book to your cart, and checkout! No promo code necessary. Non-members pay $2.99.

All five books in this series are now available free to members. Collect them for your reference library!

IEEE-USA Launches 'Famous Women Engineers in History' Series with Hedy Lamarr

"Jack Kennedy always said to me," Hedy, get involved. That's the secret of life. Try everything. Join everything. Meet everybody." - Hedy Lamarr



IEEE-USA E-Books' new series, "Famous Women Engineers in History," highlights extraordinary women engineers who helped shape and reshape the world. Each one made remarkable achievements during their lifetime that still have an impact on the systems and technology we use today. Book 1 in this new series explores the life and glamorous career of Hedy Lamarr, inventor extraordinaire and Hollywood star.

Author Paul Rosengren admits that when he agreed to write the book, the only thing he knew about Hedy Lamarr was that she was parodied in the movie, "Blazing Saddles," for which she sued director Mel Brooks.

Rosengren soon learned that Lamarr was a fascinating and multifaceted inventor as well as one of the leading movie stars of her day.

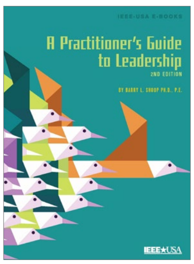
Lamarr was chosen to lead off the new series because her inquisitiveness and ideas have had a profound impact on our lives today, though the importance of her technology contributions was not recognized for decades.

Download this free e-book and find out about her inventions and how they were used to help make the world a better place. Later in life, Lamarr reflected:

"Hope and curiosity about the future seemed better than guarantees. The unknown was always so attractive to me… and still is."

Log in to your IEEE Web Account, add the book to your cart, and checkout! No promo code necessary! Non-members pay $2.99.

IEEE-USA's Free, New E-Book for Members Provides Updated, In-Depth Guide to Leadership



Drawing on his broad range of engineering and military experience, as well as his leadership role at IEEE, Barry L. Shoop Ph.D., has authored an updated, second edition of "A Practitioner's Guide to Leadership." The new edition includes many of the core ideas of his original work. However, Shoop adds insights gained since the first edition (published in 2008), including those drawn from his time as IEEE President and CEO. Shoop believes that anyone can become an effective leader through "self-study, education, training, experience and reflection."

As in the first edition, Shoop discusses principles of leadership, leadership traits, and building teams, and key differences between leaders and managers. In the second edition, he adds his views on the need for an expanded portfolio of skills for the modern leader; more depth on leadership theories; and a new section on a leader's role in a world dealing with global environmental issues.

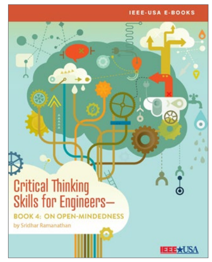
Shoop does not believe that leaders are born. While some individuals may possess traits that lead them to leadership, and others are propelled to leadership by a crisis; the author holds that most leaders result from an individual's conscious decision to become a leader. He writes that people can learn to be leaders through regular reflection and by actively developing leadership skills, not just to be a boss, but to lead a team or a company.

This book is a great way to kickstart your leadership journey, or to help you identify your next leadership move. IEEE-USA is offering "A Practitioner's Guide to Leadership—2nd Edition," which includes many valuable resources and references, free to members only, at IEEE-USA's online shop. Non-members pay $19.99. Don't miss this opportunity for such a great, free career resource!

Log in to your IEEE Web Account, add the book to your cart, and checkout! No promo code necessary.

IEEE-USA's New Audiobook Delves into Keeping an Open Mind when Solving Problems and Interacting with People

"A more inclusive workplace environment is good for both engineers and business -- and in the end -- it leads to better engineering results." - Sridhar Ramanathan



In his fourth audiobook in the series, author Sridhar Ramanathan builds upon his works thus far by examining open-mindedness. To think critically, he says, you need to be able to put aside any preconceived notions, assumptions, or judgments, and simply analyze the information you have.

In this new audiobook, Ramanathan dives into each of the following areas that collectively contribute to open-mindedness: overcoming cultural bias, objectivity, humility, inclusivity, observation, and reflection.

Download this book, and Ramanathan's other audiobooks, to listen when you are on a drive, going for a jog, or just relaxing at home. As with the other books, it is full of ideas designed to help you become an engineer who thinks more critically, "one who taps into fresh, new ideas -- whether they are generated from self-reflection, or from engaging colleagues in a new and novel way."

Download the new audiobook in MP3 format.

The companion E-Book is also available at no charge to members.

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Georgia C. Stelluto is IEEE-USA's Publishing Manager; Editor and Manager of IEEE-USA E-Books and Audiobooks; Department Editor of @IEEEUSA for IEEE-USA's flagship publication, Insight; and Co-Editor for IEEE-USA Conference Brief.

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