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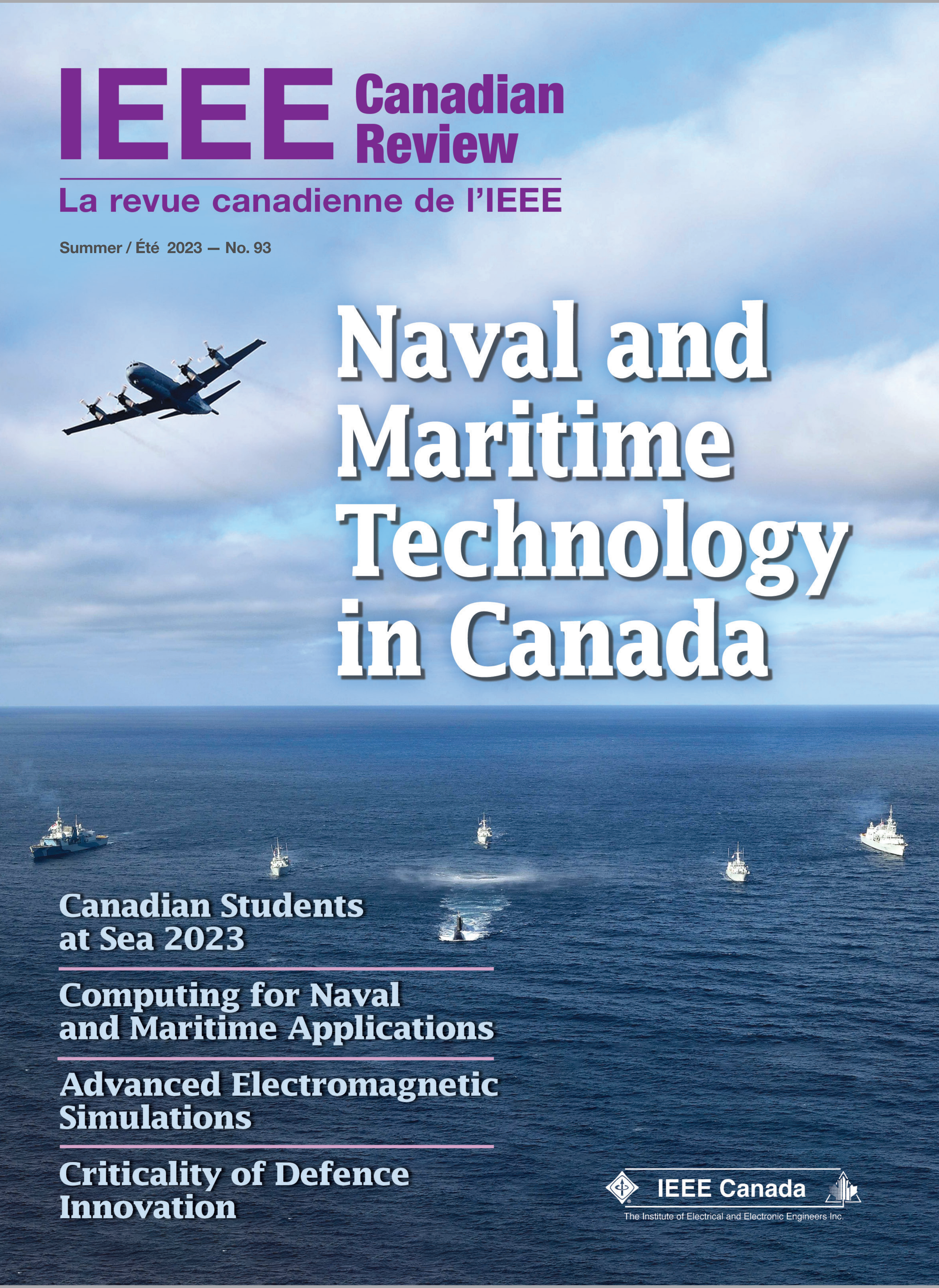
Summer / Été 2023 — No. 93



Naval and Maritime Technology in Canada

Canadian Students at Sea 2023

Computing for Naval and Maritime Applications

Advanced Electromagnetic Simulations

Criticality of Defence Innovation

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Intensive program
Industry-focused
Global opportunities
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President's Message/Message du Président

Robert (Rob) Anderson
P.Eng., SMIEEE

2022–2023 IEEE Canada President and Region 7 Director
2022–2023 Président de IEEE Canada et Directeur de la Région 7

I will start my message with a brief look back at activities. Back in January, we ran a series of training sessions for all returning and new volunteers on the IEEE Canada Board. I am pleased to say that we recorded the highest number of participants in training sessions since I became president-elect. Hopefully, this trend continues. From 31 March to 2 April, we held the Spring Caucus and Board Meeting, where the operation plans were shared and solidified for the balance of the year.

Winter jumped right into summer, bypassing spring (unless you are one of the lucky ones who live in Vancouver and never get winter)—which, for most readers, got us thinking about being outside and enjoying the greenery. Green and, more specifically, climate change have been the thrust and focus of IEEE. IEEE President Saifur Rahman engaged with climate change leaders in Egypt at UN COP 27. IEEE, with its global membership reach and breadth of electrotechnologies, can bring significant resources and knowledge to tackling the issues of climate change. This

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Je commencerai mon message par un bref retour sur les activités. En janvier dernier, nous avons organisé une série de séances de formation pour tous les anciens et les nouveaux bénévoles du conseil d'administration de l'IEEE Canada. J'ai le plaisir d'annoncer que nous avons enregistré le plus grand nombre de participants aux séances de formation depuis ma nomination à la présidence. J'espère que la tendance va se maintenir. Du 31 mars au 2 avril, nous avons tenu le caucus printanier et la réunion du conseil d'administration, où les plans opérationnels ont été partagés et consolidés pour le reste de l'année.

L'hiver est passé directement à l'été, contournant le printemps (à moins que vous ne soyez l'un des chanceux qui vivent à Vancouver et qui ne passent jamais l'hiver), ce qui, pour la plupart des lecteurs, nous a incités à sortir et à profiter de la verdure. La protection de l'environnement et, plus particulièrement, le changement climatique est au cœur des préoccupations de l'IEEE. Le président de l'IEEE Saifur Rahman s'est entretenu avec des

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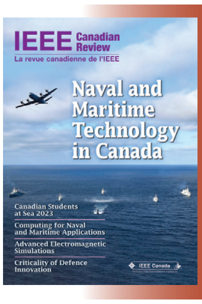

ON THE COVER
Summer 2023

Image supplied by the Royal Canadian Navy

President's Message/Message du Président

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focus gives IEEE purpose and direction that every Member can support. To learn more about IEEE's response to climate change, visit https://climate-change.ieee.org.

Your insights and feedback are needed: A former IEEE Canada president, Dr. Maike Luiken, shared with me the first draft of "Planet Positive 2030 Initiative: Strong Sustainability by Design: Prioritizing Ecosystem and Human Flourishing With Technology-Based Solutions." This compendium identifies specific issues and pragmatic recommendations for specific ecosystems regarding sustainability and climate change to achieve "planet positivity" by 2030.

The document and details on how to submit your comments and feedback can be found at https://sagroups.ieee.org/planetpositive2030/our-work/. Please, share this opportunity widely; insights are welcome from everyone. Feedback will be accepted until 31 August. It will be posted with the author's name on the Planet Positive 2030 website. This initiative is supported by the IEEE Standards Association, and more information about them and their involvement can be found at https://sagroups.ieee.org/planetpositive2030.

I am pleased to say that we recorded the highest number of participants in training sessions since I became president-elect.

Large and small, we need every little bit and every contribution to help regenerate and then preserve the planet for many generations to come. On a personal level, the "low-hanging fruit" is to "use fewer" resources and, especially, to be less wasteful. Here is a small personal example. I am not a big fan of electric toothbrushes. This is not because they are electric; I am just old school and can use muscle power. I am a big fan of the fact you only must replace the brush head. When recently shopping at local drugstore, I found a similar manual toothbrush product—a metal handle with a replaceable head. I reduced my personal waste footprint. Not a significant amount for an individual, but, when added up around the globe, the difference it makes might be surprising.

Turning back to the great outdoors, if we are lucky enough to have a yard, we have tools that we use during much of the year on a weekly basis for yard work (trimmers, edgers, leaf blowers, and lawn mowers). Traditionally, these types of devices have been powered by fossil fuels. If you are replacing and purchasing, there have been great advances in rechargeable battery-powered equipment. This equipment is also much better for your health, as there are no direct emissions, and you would be working in clean air.

As the world moves to more electricity-driven items, with the greatest impact coming from electric vehicles (EVs), the electricity grid faces new challenges. In a lot of areas, the distribution system will not support the additional demand added by EV charging. One could argue that distributed generation, in the form of solar panels, might be a solution for distribution system capacity. A possible solution, yes—however, if everyone with distributed generation is a net generator (supplying to grid), you have not solved the distribution capacity issues. These are the challenges

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acteurs du changement climatique en Égypte lors de la COP 27 des Nations Unies. L'IEEE, avec sa portée mondiale et son éventail d'électrotechnologies, peut fournir des ressources et des connaissances importantes pour aborder les questions relatives au changement climatique. Cette orientation offre à l'IEEE un but et une orientation que chaque membre peut appuyer. Pour de plus amples informations sur la réponse de l'IEEE au changement climatique, rendez-vous sur https://climate-change.ieee.org.

Your insights and feedback are needed: A former IEEE Canada president, Dr. Maike Luiken, shared with me the first draft of "Planet Positive 2030 Initiative: Strong Sustainability by Design: Prioritizing Ecosystem and Human Flourishing with Technology-Based Solutions." This compendium identifies specific issues and pragmatic recommendations for specific ecosystems regarding sustainability and climate change to achieve "planet positivity" by 2030.

Nous avons besoin de vos observations et de vos commentaires : Un ancien président de l'IEEE Canada, le Dr. Maike Luiken, m'a fait parvenir la première ébauche de «l'Initiative Planet Positive 2030 : La durabilité forte grâce à la conception : Faire de l'écosystème et du développement humain une priorité avec des solutions technologiques.» Ce compendium recense des enjeux spécifiques et des recommandations pragmatiques pour des écosystèmes spécifiques concernant la durabilité et le changement climatique afin d'atteindre la «positivité planétaire» d'ici 2030.

Le document et les modalités de soumission de vos commentaires se trouvent à l'adresse https://sagroups.ieee.org/planetpositive2030/our-work/. Merci de partager largement cette opportunité; tout le monde est le bienvenu. Nous accueillerons les commentaires jusqu'au 31 août. Ils seront mis en ligne avec le nom de l'auteur sur le site Planète positive 2030. Cette initiative est soutenue par l'Association des normes de l'IEEE, et vous trouverez plus d'informations à leur sujet et sur leur participation à https://sagroups.ieee.org/planetpositive2030.

Petites ou grandes, nous avons besoin de la moindre contribution pour régénération et à la préservation de la planète pour de nombreuses générations à venir. D'un point de vue personnel, la «façon la plus simple» consiste à «utiliser moins de ressources» et, surtout, à réduire le gaspillage. Je ne suis pas un grand fan des brosses à dents électriques. Ce n'est pas parce que c'est électrique; je suis vieux jeu et je peux utiliser la force musculaire. J'aime beaucoup le fait qu'il suffit de remplacer la tête de brosse. Au cours de mes achats récents à la pharmacie locale, j'ai trouvé une brosse à dents manuelle semblable — une poignée en métal avec une tête remplaçable. J'ai réduit mon empreinte écologique. Ce n'est pas une quantité importante pour une personne, mais si on additionne tout cela à l'échelle mondiale, la différence peut être surprenante.

Pour en revenir aux grands espaces, si nous sommes assez chanceux d'avoir une cour, nous possédons des outils que nous utilisons pendant une grande partie de l'année sur une base hebdomadaire pour les travaux de cour (taille-haies, coupe-bordures, souffleuses à feuilles et tondeuses à gazon). Traditionnellement, ces types d'appareils sont alimentés par des combustibles fossiles. Si vous remplacez et achetez, il y a eu de grands progrès dans l'équipement alimenté par batterie rechargeable. Cet équipement est aussi bien meilleur pour votre santé, parce qu'il n'y a pas d'émissions directes, et vous travailleriez dans un air propre.

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that all technical disciplines within IEEE with must address in the very near future. As I am writing this article, I have an appointment scheduled to explore the feasibility of adding photovoltaic solar generation to my home. If you are interested in learning more about my experience, feel free to reach out to me.

Looking toward future 2023 activities of IEEE Canada, these are upcoming:

- *IEEE Canada Summer Board Meeting, 21 July 2023*: This is an operations meeting where the Nominations and Appointments Committee will present the candidates for the 2024 chairs of operating committees.

IEEE, with its global membership reach and breadth of electrotechnologies, can bring significant resources and knowledge to tackling the issues of climate change.

- *Region Executive Committee Meeting, 8 September 2023*: This is the strategic planning meeting for 2024, which includes a budget review session. Themed around "Leadership and Innovation," this year's Student Congress will foster collaboration between the generation of students and professionals and discuss the transition from student electrotechnologists to professional practitioners, technologists, or technical professionals.
- *Canadian Conference on Electrical and Computer Engineering, 24–27 September 2023 in Regina, Saskatchewan*: The theme for this year's conference is "Engineering and Technology for a Better Tomorrow." The annual Awards Gala Night will take place in conjunction with this conference. Electrotechnologists from a variety of disciplines will be recognized for their leadership excellence and/or contributions to science, technology, engineering, and other IEEE designated fields of interest (see https://vtools.ieee.org/ieee-fields-of-interest/). Additional details can be found at https://ccece2023.ieee.ca.
- *2023 IEEE International Humanitarian Technologies Conference (IEEE IHTC 2023), 1–3 November 2023, Cartagena de Indias, Colombia*: This is an interdisciplinary conference series organized by IEEE Region 7 (Canada), IEEE Region 8 (Africa, Europe, and the Middle East), and IEEE Region 9 (Latin America and the Caribbean). Stakeholders from the public, private, education and research, and societal sectors around the world are invited to submit their contributions focused on showcasing challenges, success stories, lessons learned, case studies, and technological innovation related to achieving the United Nations' Sustainable Development Goals, ICT4D, and the application of humanitarian technologies (including disaster relief and disaster recovery).

Looking further into the future, IEEE Canada is exploring signing on to another interdisciplinary conference, IEEE HISTELCON: History of Electrotechnology Conference. HISTELCON is a flagship conference started by IEEE Region 8 and is currently held every two years. It is dedicated to any aspects of the history of electrical engineering, electronics, computing, and their impact on social and economic development. For a glimpse into the possibility, please check out https://2023.ieee-histelcon.org.

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Alors que le monde se tourne vers davantage d'équipements électriques, avec l'impact le plus significatif est dû aux véhicules électriques (VEs), le réseau électrique fait face à de nouveaux défis. Dans de nombreuses régions, le réseau de distribution ne répondra pas à la demande additionnelle découlant de la recharge des VEs. On pourrait faire valoir que la génération distribuée, sous forme de panneaux solaires, pourrait être une solution pour la capacité du réseau de distribution. La solution est envisageable, oui. Cependant, si chacun avec la production répartie est un générateur net (alimentant le réseau), vous n'avez pas résolu les problèmes de capacité de distribution. Voilà les défis auxquels toutes les disciplines techniques de l'IEEE seront confrontées dans un futur proche. En écrivant cet article, j'ai un rendez-vous prévu pour explorer la faisabilité de l'ajout de la production solaire photovoltaïque à ma maison. Pour en savoir davantage sur mon expérience, n'hésitez pas à me contacter.

En prévision des prochaines activités de l'IEEE Canada en 2023, voici ce qui s'en vient :

- *IEEE Canada Summer Board Meeting, 21 July 2023*: This is an operations meeting where the Nominations and Appointments Committee will present the candidates for the 2024 chairs of operating committees.
  - *Réunion d'été du conseil d'administration de l'IEEE Canada, 21 juillet 2023*: Il s'agit d'une réunion opérationnelle au cours de laquelle le Comité des candidatures et des nominations présentera les candidats aux postes de président des comités opérationnels pour 2024.
  - *Réunion du Comité exécutif régional, 8 septembre 2023*: Il s'agit de la réunion de planification stratégique de 2024, qui comprend une séance de revue du budget. Le thème de la conférence étudiante de cette année, «Leadership et innovation», encouragera la collaboration entre la génération d'étudiants et de professionnels et discutera de la transition des étudiants en électrotechnique vers des professionnels, des technologues ou des professionnels de la technologie.
  - *Conférence canadienne sur le génie électrique et informatique, du 24 au 27 septembre 2023 à Regina, en Saskatchewan*: sous le thème «Ingénierie et technologie pour un avenir meilleur». La soirée annuelle de remise des prix sera organisée dans le cadre de cette conférence. Les électrotechniciens de diverses disciplines seront reconnus pour leur excellence en leadership et/ou leurs contributions aux sciences, à la technologie, à l'ingénierie et à d'autres domaines d'intérêt désignés par l'IEEE (voir https://vtools.ieee.org/ieee-fields-of-interest/). D'autres renseignements sont disponibles à l'adresse https://ccece2023.ieee.ca.
  - 2023 IEEE International Humanitarian Technologies Conference (IEEE IHTC 2023), 1-3 novembre 2023, Cartagena de Indias, Colombie : Il s'agit d'une série de conférences interdisciplinaires organisées par la région 7 de l'IEEE (Canada), la région 8 de l'IEEE (Afrique, Europe et Moyen-Orient) et la région 9 de l'IEEE (Amérique latine et Caraïbes). Les intervenants des secteurs public, privé, éducatif, de la recherche et de la société du monde entier sont invités à présenter leur contribution axée sur la présentation des défis, des réussites, des leçons apprises, des études de cas et de l'innovation technologique liées à la réalisation des objectifs de développement durable des Nations Unies, des TIC-4D et de l'application des technologies

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President's Message/Message du Président

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I want to thank the volunteers who put their hearts and souls into processing every single edition of *IEEE Canadian Review*, and I hope you enjoy it as much as I do. Take time to enjoy the summer months with your family, and stay well and stay safe. I can be reached at president@ieee.ca. ■

Robert (Rob) Anderson, P.Eng., SMIEEE
2022–2023 IEEE Canada President
2022–2023 Region 7 Director

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humanitaires (y compris les secours en cas de catastrophe et la reprise après sinistre).

L'IEEE Canada prévoit d'accueillir une autre conférence interdisciplinaire intitulée IEEE HISTELCON: History of Electrotechnology Conference. HISTELCON est une conférence phare lancée par la Région 8 de l'IEEE, qui se tient à l'heure actuelle tous les deux ans. elle est consacré à tous les aspects de l'histoire de l'ingénierie électrique, de l'électronique, de l'informatique et de leur impact sur le développement social et économique. Pour un aperçu de l'opportunité, visitez https://2023.ieee-histelcon.org.

Je tiens à remercier les bénévoles qui se sont investis corps et âme dans chaque édition de la Revue canadienne de l'IEEE. J'espère que vous en profiterez autant que moi. Prenez le temps de passer les mois d'été en famille et restez en forme et en sécurité. Vous pouvez me joindre à président@ieee.ca. ■

Robert (Rob) Anderson, ing., SMIEEE
Président de l'IEEE Canada 2022–2023
Directeur de la région 7 de l'IEEE 2022–2023

IEEE Canadian Review
La revue canadienne de l'IEEE

IEEE Canadian Review is published three times per year: Spring, Summer, and Fall.

Its **principal objectives** are:
To inform Canadian members of IEEE on issues related to the impacts of technology and its role in supporting economic development and societal benefits within Canada. To foster growth in the size and quality of Canada's pool of technology professionals to serve our increasingly knowledge-based economy.

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A Few Words From the Guest Editor / Quelques mots de l'éditeur invité

David G. Michelson, SMIEEE
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Naval and Maritime Innovation in Canada

These are exciting times for the Royal Canadian Navy (RCN) as it oversees a once-in-a-generation opportunity to renew its fleet of combat and noncombat vessels. Under the aegis of the National Shipbuilding Strategy and the partnerships that the federal government has formed with three Canadian shipyards, namely, Irving Shipbuilding Inc., Seaspan Vancouver Shipyards, and Chantier Davie Canada Inc.:

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L'innovation navale et maritime au Canada

C'est une période excitante pour la Marine royale canadienne alors qu'elle supervise une occasion unique de renouveler sa flotte de navires de combat et de navires non destinés au combat. Cette initiative sera mise en œuvre dans le cadre de la Stratégie nationale de construction navale et des partenariats établis par le gouvernement fédéral avec trois chantiers navals canadiens : Irving Shipbuilding Inc., Seaspan Vancouver Shipyards et Chantier Davie Canada Inc.:

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A Few Words From the Guest Editor / Quelques mots de l'éditeur invité

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- the first of the Arctic and offshore patrol ships have been launched and are now in service
- the first of the eagerly awaited joint supply ships will soon be launched at Seaspan Shipyards in Vancouver
- construction of the first block of Canadian Surface Combatants will soon begin.

At the same time, the first steps to replace Canada's Victoria-class submarines and Kingston-class Maritime Coastal Defence Vessels have also recently been taken.

The engineering effort required to design and build these vessels is immense. Marine systems engineering focuses on hull structure and design; the ship's stability, propulsion, and ancillary systems; power generation and distribution; auxiliary systems; the ship's service systems; ship and machinery control systems; damage control; and the integration of these systems, and remains core to the task. Naval combat systems engineering focuses on command-and-control systems, communication systems, navigation systems, above-water and underwater sensor systems, data processing systems, electronic warfare systems, and above-water and underwater warfare systems and their ammunition.

As requirements have become ever more demanding and new technologies offer ever-increasing opportunities to meet them, electrical and computer engineers are playing ever-increasing roles and assuming greater responsibility in both of these branches. This includes opportunities to pursue careers as naval combat systems engineers, defence scientists, or with the many defence contractors involved with this effort.

From 9 to 10 May 2023, under a joint effort by IEEE Canada and the RCN, 30 IEEE Student Members and other students, and five civilian academic and industry leaders had the unique opportunity to experience life aboard a modern warship (*HMCS Ottawa*, one of our 12 Canadian patrol frigates) and ashore at Canada's West Coast naval base, CFB Esquimalt, under the Canadian Students at Sea program. The diverse group included both

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(Quelques mots de l'éditeur invité suite de p. 5)

- Les premiers navires de patrouille de l'Arctique et en haute mer ont été mis à l'eau et sont maintenant opérationnels.
- Le premier des navires de soutien interarmées tant attendus sera lancé prochainement au chantier naval Seaspan à Vancouver.
- La construction du premier pavillon des navires de combat canadiens débutera bientôt.

Par ailleurs, les premières étapes visant à remplacer les sous-marins canadiens de classe Victoria et les navires de défense côtière de classe Kingston ont également été franchies récemment.

Les efforts d'ingénierie nécessaires à la conception et à la construction de ces navires sont immenses. L'ingénierie des systèmes de marine se concentre sur la structure et la conception de la coque, la stabilité du navire, la propulsion et les systèmes accessoires; la production et la distribution d'énergie; les systèmes auxiliaires; les systèmes d'opérations du navire; les systèmes de contrôle des navires et des machines, le contrôle des dommages et l'intégration de ces systèmes; et les autres opérations essentielles. Le génie des systèmes de combat naval se concentre sur les systèmes de commande et de contrôle, les systèmes de communication, les systèmes de navigation, les systèmes de capteurs en surface et sous-marins, les systèmes de traitement des données, les systèmes de guerre électronique et les systèmes de guerre sous-marine et de surface, ainsi que leurs munitions.

Bien que le cahier des charges soit de plus en plus exigeant et que les nouvelles technologies offrent de plus en plus d'opportunités pour y répondre, les ingénieurs électriciens et informaticiens jouent un rôle de plus en plus important et assument de plus en plus de responsabilités au sein de ces deux branches. Cela inclut des occasions de poursuivre une carrière comme ingénieur des systèmes de combat naval, à titre de scientifique de la défense ou auprès des nombreux entrepreneurs de la défense impliqués dans cet effort.

Du 9 au 10 mai 2023, dans le cadre d'un effort conjoint de l'IEEE Canada et de la MRC, trente étudiants membre de de

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A Few Words From the Guest Editor / Quelques mots de l'éditeur invité

(A Few Words From the Guest Editor cont'd from p. 6)

undergraduate and graduate students from several universities in Western and Central Canada. Programs in arts, commerce, science, and applied science were all represented.

Aboard *HMCS Ottawa* during a one-day sail from North Vancouver to CFB Esquimalt, the students and their academic and industry leaders saw a sampling of the people, machinery, and systems that ensure that the RCN is always *ready to help, ready to lead, and ready to fight* when called upon by the government of Canada. They saw the bridge and operations teams at work, visited the machinery control and engine rooms, witnessed flying operations by the ship's helicopter, and learned about various aspects of shipboard operations, including damage control. After an overnight stay at the CFB Esquimalt officer's wardroom, they visited a Maritime Coastal Defence Vessel and some of the shore facilities that support the West Coast fleet: the Naval Electronic Systems Test Range, Fleet Maintenance Facility, and Naval Officers Training Centre.

So impressive was the students' experience, that we have devoted this issue of *IEEE Canadian Review*, including our regular features on "History Matters" and "Radio Science in Canada," to "Naval and Maritime Innovation in Canada" so that the entire IEEE Canada community, and beyond, can learn of and benefit from their experience.

In our "History Matters" column, we review some of the many innovations that the RCN introduced during the post- and Cold War eras, many of which have been adopted by other navies.

In our "History Matters" column [A1], we review some of the many innovations that the RCN introduced during the post- and Cold War eras, many of which have been adopted by other navies.

In [A2], six of the students who participated in CSaS 2023, and one of their civilian leaders, describe their experiences on behalf of the group.

In [A3], Jeff MacMillan and Rudi Carolsfeld, cofounders of Green Edge Computing Corp., explain how the OpenVPX VITA65 standards developed and adopted by the defence and aerospace sectors present an ideal architecture for shipboard and land-based deployments where size, weight, power, cooling, and ruggedness are critical considerations.

In [A4], C. J. Reddy, vice president, business development (electromagnetics)—Americas with Altair, explains how the naval and shipbuilding industry is becoming increasingly reliant on electromagnetic simulation tools such as Altair's Feko to improve design efficiency and reduce physical testing costs.

In [A5], Lee Vessey, a retired commander in the Royal Navy who also served as an exchange officer with the RCN, and is the founder of Rothera Innovate, an independent innovation consultancy based in Ottawa, shares his first-hand insights concerning innovation in the defence sector.

(Continued on p. 8)

(Quelques mots de l'éditeur invité suite de p. 6)

l'IEEE et autres étudiants, ainsi que cinq chefs de file universitaires et industriels civils, ont eu une chance unique de découvrir la vie à bord d'un navire de guerre moderne (NCSM Ottawa – l'une de nos douze frégates de patrouille canadiennes) et sur la rive de la base navale de la côte Ouest du Canada (BFC Esquimalt) dans le cadre du programme Étudiants canadiens en mer. Le groupe diversifié comprenait des étudiants de premier cycle et de deuxième cycle d'un certain nombre d'universités de l'Ouest et du Centre du Canada. Les programmes liés aux arts, aux affaires, aux sciences et aux sciences appliquées y étaient représentés.

À bord du NCSM Ottawa pendant une journée de navigation entre North Vancouver et à la BFC Esquimalt, les étudiants et leurs chefs de file universitaires et industriels eu un aperçu des personnes, des machines et des systèmes qui assurent que la MRC est toujours prête à intervenir, prête à assister et prête à combattre sur demande du gouvernement du Canada. Ils ont vu le pont et les équipes opérationnelles au travail, visité les salles de contrôle des moteurs et des machines, ils ont assisté aux opérations de vol de l'hélicoptère et ont pris connaissance de divers aspects des opérations à bord du navire, y compris le contrôle des dommages. Après un séjour d'une nuit au carré des officiers de la BFC Esquimalt, ils ont visité un navire de défense côtière et certaines des installations à terre qui soutiennent la flotte de la côte Ouest : zone d'essai des systèmes électroniques navals, installation de maintenance de la flotte et centre de formation des officiers de marine.

L'expérience étudiante a été tellement impressionnante que nous avons dédié cette édition du magazine canadien de l'IEEE, notamment nos articles réguliers sur «l'histoire importe» et «La science radio au Canada» et «l'innovation navale et maritime au Canada», afin que la communauté entière de l'IEEE Canada – et au-delà – puisse bénéficier de leur expérience.

Dans notre colonne «l'histoire importe» [A1], nous examinons certaines des nombreuses innovations que la MRC a introduites au cours des années qui ont suivi et au cours de la guerre froide, dont plusieurs ont été adoptées par d'autres marines.

Dans [A2], six des étudiants qui ont participé au programme d'étudiants canadiens en mer 2023 – ainsi qu'un de leurs leaders civils – décrivent leurs expériences au nom du groupe.

Dans [A3], Jeff MacMillan et Rudi Carolsfeld, co-fondateurs de Green Edge Computing Corp., expliquent comment les standards OpenVPX VITA65 qui ont été élaborés et adoptés par l'industrie de la défense et de l'aérospatiale présentent une architecture idéale pour les déploiements embarqués et terrestres où la taille, le poids, la puissance, le refroidissement et la robustesse sont des considérations essentielles.

Dans [A4], C. J. Reddy, vice-président, Business Development (Electromagnetics) – Americas with Altair, explique comment l'industrie navale et maritime se fie de plus en plus aux outils de simulation électromagnétique (EM) tels que le Feko d'Altair pour améliorer l'efficacité de la conception et réduire les coûts d'essais physiques

Dans [A5], Lee Vessey, commandant à la retraite de la Marine royale qui a également servi comme officier d'échange avec la MRC et fondateur de Rothera Innovate, un cabinet-conseil indépendant en innovation basé à Ottawa, partage ses propres connaissances sur l'innovation dans le domaine de la défense.

(Suite p. 8)

A Few Words From the Guest Editor / Quelques mots de l'éditeur invité

(A Few Words From the Guest Editor cont'd from p. 7)

In our regular feature on "Radio Science in Canada," [A6] we describe the development of two complementary maritime communications systems: the Global Maritime Distress and Signalling System and recent efforts to adapt systems developed by the 3rd Generation Partnership Project to function well in the maritime environment, including ship to shore, ship to ship, and intraship.

The balance of this issue includes two stories concerning various awards and recognition given to IEEE Canada members, our regular "EE Humor" column, [A7] a report from the IEEE Canadian Foundation, and an Engineering Management feature [A8] by Terrance Malkinson on the engineering practices that underlie modern tunnelling projects. ■

Appendix: Related Articles

[A1] D. G. Michelson, "Post- and cold war innovation in the Royal Canadian Navy [History Matters]," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 9–11, Summer 2023, doi: 10.1109/MICR.2023.3298115.

[A2] D. Nadeem et al., "Canadian students at sea 2023," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 12–17, Summer 2023, doi: 10.1109/MICR.2023.3298118.

[A3] J. MacMillan and R. Carolsfeld, "VPX-aligned, small-footprint, general-purpose computing for naval and maritime applications," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 18–21, Summer 2023, doi: 10.1109/MICR.2023.3298119.

[A4] C. J. Reddy, "Advanced electromagnetic simulations for the naval and shipbuilding industry," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 22–31, Summer 2023, doi: 10.1109/MICR.2023.3298117.

[A5] L. Vessey, "The criticality of defence innovation for Canada," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 32–35, Summer 2023, doi: 10.1109/MICR.2023.3298116.

[A6] D. G. Michelson, "Radio science in Canada," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 36–37, Summer 2023, doi: 10.1109/MICR.2023.3304147.

[A7] D. Green, "We just couldn't resist… [EE Humor]," *IEEE Canadian Rev.*, vol. 35, no. 2, p. 40, Summer 2023, doi: 10.1109/MICR.2023.3297803.

[A8] T. Malkinson, "Tunnelling—A journey of engineering success and opportunity," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 43–48, Summer 2023, doi: 10.1109/MICR.2023.3297802.

(Quelques mots de l'éditeur invité suite de p. 7)

Dans notre article régulier sur «La science radio au Canada», [A6] nous décrivons le développement de deux systèmes de communications maritimes complémentaires : le Système mondial de détresse et de sécurité en mer (SMDSM) et les récents efforts déployés pour adapter les systèmes 3GPP afin qu'ils fonctionnent bien dans le milieu marin, y compris de navire à navire et à l'intérieur du navire.

Le reste du numéro contient deux articles sur les différents prix et reconnaissances accordés aux membres de l'IEEE Canada, notre chronique humoristique régulière «EE Humor», [A7] un rapport de la Fondation canadienne de l'IEEE et un article de gestion de l'ingénierie [A8] de Terrance Malkinson sur les pratiques techniques sur lesquelles reposent les projets modernes de développement de tunnels. ■

Appendix: Related Articles

[A1] D. G. Michelson, "Post- and cold war innovation in the Royal Canadian Navy [History Matters]," *IEEE Canadian Rev.*, vol. 35, no. 2, pp. 9–11, Summer 2023, doi: 10.1109/MICR.2023.3298115.

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IMPORTANT UPDATES

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History Matters

Post- and Cold War Innovation in the Royal Canadian Navy

by David G. Michelson
IEEE Canada Historian

Our sense of who we are, our values and beliefs, and our ambitions for the future are guided, in large part, by the stories and anecdotes concerning the past that we share with each other. In this light, history may be viewed as a formal process by which we preserve, organize, and interpret the stories that both matter to and define us.

While historical fact is immutable, historical evidence is inherently fragile and often irreplaceable. Accordingly, efforts to preserve and interpret the past are among the most valuable of legacies. In this column, we consider innovation in the Royal Canadian Navy during the post- and Cold War eras.

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Innovation has always been an important part of the Royal Canadian Navy's (RCN's) culture. Many readers of *IEEE Canadian Review* are familiar with some of the iconic naval innovations introduced by the RCN during the post- and Cold War period (1945–1990), including the following:

- the development of the variable-depth sonar that allowed surface vessels to more reliably detect submarines situated between layers of water of differing temperature and salinity (1947–1971)
- the introduction of the St. Laurent class destroyer escorts, which introduced many important elements to small warship design that are still in use today (1955–1957)
- the invention of the beartrap system, which allowed small warships equipped with stern-mounted flight decks to reliably recover helicopters under a range of sea states (1956–1964)
- the development of a fast hydrofoil escort that could travel faster than the new and more capable submarines that began to appear (1968–1971).

However, fewer readers are likely familiar with the contributions made by the RCN on the electrical and computer engineering side during this period, many of which remain quite significant today. In this issue, we consider the role of the RCN in the chain of events that led to the following:

- *Alouette 1*, Canada's first satellite
- DATAR, a pioneering naval tactical data system
- the track ball and the rolling-ball computer mouse
- SHINPADS, a pioneering shipboard distributed computer system
- SHINCOM, a widely adopted system for shipboard internal communications
- the first processing of synthetic aperture radar (SAR) imagery using digital techniques.

The RCN and Canada's First Satellite, *Alouette I*

For much of the 20th century, long-distance radio communication between ships at sea and bases ashore was based on shortwave propagation through the ionosphere. During the Second World War, Section 6 of the RCN's Operational Intelligence Centre (OIC/6) was tasked with building upon earlier work by the National Research Council (NRC) and developing the insights and techniques required to make long-distance communications via the ionosphere more reliable. OIC/6, supported by the NRC, the Department of Transport, and the other two services, established a network of ionospheric sounders or ionosondes to measure the local properties of the ionosphere at various stations across Canada. In 1944, the Canadian Radio Wave Propagation Committee (CRWPC) was set up under the leadership of the RCN with a mandate to formally coordinate the research of the three services in this area.

After the war ended, the need to continue this work to support peacetime applications and operational needs was recognized. The Radio Propagation Laboratory (RPL) was established under the CRWPC and housed at Naval Headquarters. After the Defence Research Board was created in 1947, RPL became part of the newly formed Defence Telecommunications Research Establishment (DTRE). By the late 1950s, DTRE was ready to start developing—and, by the early 1960s, to launch—Canada's first satellite. *Alouette I* was a topside ionospheric sounder that, among other things, clarified the nature of the ionosphere in northern regions, helped to define the International Reference Ionosphere (an international project sponsored by the Committee on Space Research and the International Union of Radio Science), and became the focal point from which Canada's new space industry rapidly developed.

By the late 1950s, DTRE was ready to start developing—and, by the early 1960s, to launch—Canada's first satellite.

Not only was *Alouette I* developed by a lab that, fewer than 15 years earlier, had been operated under the direct supervision of the RCN, but many of the key DTRE personnel involved in *Alouette I* (and, three years later, *Alouette II*), including DTRE Superintendent Frank T. Davies, had begun their careers as RCN civilian scientists. During this period, the RCN still relied on shortwave propagation via the ionosphere to communicate with the fleet, and RCN personnel contributed to efforts to analyze and interpret the data returned by the Alouettes. In 1969, the DTRE became the Communications Research Centre when it was transferred to the newly formed Department of Communications.

The RCN and First Naval Tactical Data System, DATAR

The RCN emerged from the Second World War with a keen awareness of the need for ships engaged in antisubmarine warfare (ASW) to operate as a unit and to exchange tactical data easily and efficiently. At about the same time that the Royal Navy (RN) began to develop a command, control, and coordination system for antiair warfare based upon the type 984 radar and analog computing technology, Commander James Belyea of the RCN advocated for development of a similar but much more advanced system for ASW.

The RCN system, called *DATAR* (*digital automated tracking and resolving*), was intended to share radar and sonar data between ships and process the data so that a unified view of the battlefield relative to any particular ship's current heading and location could be presented. The RN's analog system was insufficient for this purpose. DATAR would be the first to use wireless data links—in this case, based upon pulse code modulation—to share tactical data between ships as well as digital computers to process the data and generate tactical displays in real time.

According to one account, a U.S. Navy officer in attendance became concerned that the demonstration was too good to be true and briefly wondered whether the display was being faked.

Work on this incredibly forward-looking system began in 1949. Ferranti Canada signed on and set up a new facility under the direction of Kenyon Taylor in Malton (near the Avro Canada plant) to pursue it. Everything from the wireless data links to the digital computers to the digital displays had to be invented by the RCN–Ferranti team. The first demonstrations of the system were conducted in Lake Ontario in 1953. Two Bangor-class minesweepers, HMCS *Digby* and HMCS *Granby*, and a shore station were used to simulate an ASW task force.

The DATAR demonstrations were almost flawless. According to one account, a U.S. Navy officer in attendance became concerned that the demonstration was too good to be true and briefly wondered whether the display was being faked. The RCN hoped that DATAR's stunning success would lead to adoption of the technology by the Royal Canadian Air Force, the United States, the United Kingdom, and others. Unfortunately, like the Avro Arrow a few years later, the hoped-for export sales did not materialize, and DATAR development was halted. Instead, many of DATAR's key ideas would be adopted by others, including the U.S. Navy's Navy Tactical Data System and later versions of the RN's Comprehensive Display System.

The RCN and the Computer Mouse

While Douglas Engelbart is credited with the invention of the computer mouse in the mid-1960s, the rolling-ball computer mouse, developed by researchers at Telefunken a few years later, is the version that was most widely adopted in the decades that followed. The rolling-ball mouse is essentially a small, upside-down trackball. The trackball concept itself was originally proposed as a user input device for the RN's Comprehensive Display System but was abandoned in favour of a conventional joystick.

The RCN's DATAR tactical data system project is widely credited as the first to fully appreciate the potential of the trackball concept and to reduce it to practice. The success of the RCN's demonstrations of DATAR to the international defence community did much to raise awareness of the trackball and to promote the widespread adoption of trackballs as user input devices. In this manner, the RCN played a key role in the chain of events that led to the modern computer mouse.

The RCN and Shipboard Distributed Computing

By the early 1970s, command, control, and coordination systems had become an essential component of naval task forces, and digital computers had become well established in shipboard operations. The next big step was introduction of the Shipboard Integrated Processing and Data System (SHINPADS) concept, which promoted the adoption of distributed computing using standardized tactical displays and computers interconnected by a shipwide fault-tolerant data bus to increase system reliability, redundancy, and resiliency. Championed by Capt(N) Jim Carruthers, SHINPADS started slowly but rapidly gained traction. By the late 1970s and early 1980s, this Canadian approach to systems integration in warships had become a guiding design principle of the Canadian Patrol Frigate program and influenced the practice of other major navies as well.

The RCN's DATAR tactical data system project is widely credited as the first to fully appreciate the potential of the trackball concept and to reduce it to practice.

The RCN and Shipboard Internal Communications

SHINCOM is a naval intraship and external communication system that was developed for the RCN's Halifax class frigates. The underlying technology was adopted by the U.S. Navy's Aegis Combat System, through which it was exported to Australia, Japan, New Zealand, and South Korea. In the U.S. Navy, SHINCOM is referred to as the Integrated Voice Communications System. By 2017, SHINCOM had been installed on more than 150 warships.

The RCN and Spaceborne SAR

During the mid-1970s, as NASA, the U.S. Naval Research Lab, and other stakeholders were planning and preparing for the launch of Seasat, the first spaceborne SAR, the RCN and researchers at Defence Research Establishment Ottawa (DREO) played a key role in discussions concerning the application of spaceborne SAR for oceanography; ocean surveillance and the monitoring of sea ice; and, importantly, the selection of the inclination of Seasat's orbit.

At the time Seasat was launched, the standard method for processing the raw data stream from SAR to construct an image of a scene involved transferring the raw data to film and processing the result using a complicated set of lenses referred to as an *optical SAR processor*. It was recognized that processing the data digitally instead offered significant advantages, but the general-purpose minicomputers available to engineers in the late 1970s were only barely capable of supplying the enormous processing power required. DREO decided to try, but hedged by contracting with Vancouver-based MacDonald, Dettwiler, and Associates (MDA) to pursue a parallel effort.

After Seasat was launched in June 1978, the race was on. It was widely expected that a large, well-funded team from NASA's Jet Propulsion Laboratory would prevail. Instead, the small upstart team from MDA that had begun their task two years earlier won the race in November 1978. So significant was the accomplishment that this first image was featured on the cover of the 26 February 1979 issue of *Aviation Week & Space Technology*. In 2014, it was recognized as an IEEE Milestone.

MDA's accomplishment marked a turning point in the history of SAR. By reducing the cost but increasing the quality of SAR processing, the digital approach made the routine application of SAR imagery practical. It led directly to Canada's decision to invest in the RADARSAT series of Earth observation satellites and assess the merits of SAR in meeting the needs of a variety of use cases, including the monitoring of polar sea ice, ocean surveillance, and vessel detection. Since 2011, the Polar Epsilon project has provided the RCN with enhanced capabilities for surveillance of Canada's Arctic region and maritime approaches, including the detection of vessels, and turned the RCN into RADARSAT's single biggest customer. ■

About the Author

David G. Michelson is the IEEE Canada historian and chair of the IEEE Canada History Committee. An active contributor to the history of technology for two decades, he has been either a member or corresponding member of the IEEE History Committee since 2012 and is responsible for one quarter of the 18 IEEE Milestones that recognize Canadian technology achievements. He is also a member of the Society for the History of Technology (and its Special Interest Group on Telecommunications History) and a member of the History and Archives Committee of the Engineering Institute of Canada. His research interests in this area include the historiography of contemporary science and technology, the development and impact of Canadian science and technology since the Second World War, and the development and impact of both wireless technology and space technology since the Second World War. He can be contacted at dmichelson@ieee.org *or* historian@ieee.ca.

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Canadian Students at Sea 2023

Daniel Nadeem, Elaine Rennick, Luke Gallant, Alexander Chudinov,
Joshua Sam, Sherwin Tiu, and David G. Michelson

The Canadian Students at Sea (CSaS) program provides postsecondary students with an opportunity to experience elements of the Royal Canadian Navy (RCN) both at sea and ashore. In May 2023, 28 students and five civilian leaders participated in a day sail from North Vancouver to Esquimalt aboard the Canadian Patrol Frigate *HMCS Ottawa*, stayed overnight in the officer's wardroom at Canadian Forces Base (CFB) Esquimalt, and then visited several facilities at CFB Esquimalt, including the Naval Electronic Systems Test Range at Albert Head, the Maritime Coastal Defence Vessel *HMCS Saskatoon* and Fleet Maintenance Facility Cape Breton at His Majesty's Canadian (HMC) Dockyard, and the bridge simulators and various facilities operated by the Naval Personnel and Training Group at *HMCS Venture* at Work Point.

The University of British Columbia and IEEE Canada led the effort to recruit the remarkably diverse cohort of students and civilian leaders who participated in CSaS 2023. Eight universities were represented, including the University of British Columbia, University of Victoria, Simon Fraser University, University of Calgary, McMaster University, University of Toronto, Toronto Metropolitan University, and Queen's University. Three of the students are pursuing master's degrees in electrical and computer engineering, while the remaining are pursuing bachelor's degrees in a variety of disciplines including electrical engineering, computer engineering, computer science, integrated engineering, mechanical engineering, mechatronics, civil engineering, engineering physics, physics, commerce, and communications.

Many of the CSaS 2023 students are either pursuing or expect to pursue co-op work terms with defence contractors in the Vancouver area where, among other things, they are contributing to work on the new Canadian Surface Combatant, new joint support ships, and the Electronic Chart and Display Information Systems used by HMC ships. Such pregraduation co-op work experience can count for up to 12 months of the four-year experience requirement for registration as a professional engineer. For these students, CSaS 2023 represented a unique and welcome opportunity to experience the environment within which their work will ultimately be applied. Other CSaS 2023 students simply sought an opportunity to see how the RCN is using leading-edge technology to accomplish its mission of securing Canadian interests in the maritime environment and keeping Canada safe and secure. The five civilian leaders represent both the students' academic homes and their co-op employers and include representatives from the University of British Columbia, Seaspan Vancouver Shipyards, MDA, and Cellula Robotics.

In the remainder of this article, six of the students who participated in CSaS 2023 describe their experience on behalf of the group.

HMCS Ottawa

The CSaS 2023 program began in the early morning on 9 May 2023 at Burrard Dry Dock Pier in North Vancouver. Several vessels from Canada's Pacific Fleet had assembled there for Fleet Weekend 2023 and the annual commemoration of the Battle of the Atlantic. After a quick briefing from Lieutenant Commander (LCdr) Chris Elliott and Lt(N) Zach Lipinski, the strategic outreach officers assigned to our group, we crossed the brow and stepped aboard *HMCS Ottawa*, one of Canada's 12 *Halifax*-class frigates. With a length of 134 m, displacement of 4,770 tons, and crew of approximately 225, it is typical of the multirole surface combatants currently operated by other allied navies. We assembled on the flight deck used by the ship's Cyclone CH-148 helicopter and were briefed on the essential aspects of safety aboard the ship, as shown in Figure 1. We were divided into three groups of roughly 11 people each and spent the next 7 h learning about the ship, its systems, and crew.

For these students, CSaS 2023 represented a unique and welcome opportunity to experience the environment within which their work will ultimately be applied.

A Warship Must Be Able to Float

Preventing a ship from losing its ability to float requires good pilotage and seamanship skills, strong defensive capability, and, if all else fails, effective damage-control capability. On the bridge, we saw how a trained crew aided by state-of-the-art navigation tools ensures that the ship makes safe passage amidst a range of marine traffic and underwater hazards. On the upper deck, we were briefed on the ship's self-defence capabilities, including the ship's Electronic Warfare suite; 16 Evolved Sea Sparrow Missiles that provide medium-range air self-defence capability; the Bofors 57-mm Mk 3 antiaircraft gun, which is designed to engage either surface or air targets at closer range; the Phalanx Close In Weapon System that provides the last line of defense against incoming missiles; Mk 46 torpedo launchers that provide medium-range antisubmarine capability; and the remotely controlled .50-calibre machine guns mounted at various places on the upper deck. Below decks, we were briefed on the tools used by damage-control teams, while on flight deck we were briefed on firefighting strategies, and many of us were given the opportunity to operate a high-pressure fire hose, as shown in Figure 2.

A Warship Must Be Able to Move

We visited the machinery control room and were briefed on the instrumentation used to monitor the ship's propulsion plant and other systems. We had an opportunity to visit the forward engine room and see the gas turbine engines that allow *Ottawa* to cruise at greater than 30 knots. We also saw the gear boxes that allow *Ottawa* to switch between using a diesel engine, or one or both gas turbines for propulsion.

A Warship Must Be Able to Fight

On the upper deck, we were briefed on the ship's eight Harpoon Block II missiles, which are used to engage either surface or land targets at ranges of more than 100 km. We learned that warships often travel in groups, and that each ship in a task force has a specific role to play in protecting the rest. Air defence destroyers and cruisers protect the task force from airborne threats. Antisubmarine frigates, like *HMCS Ottawa*, protect the task force from hostile submarines. The ship's helicopter allows *Ottawa* to detect and engage hostile submarines at great distances from the

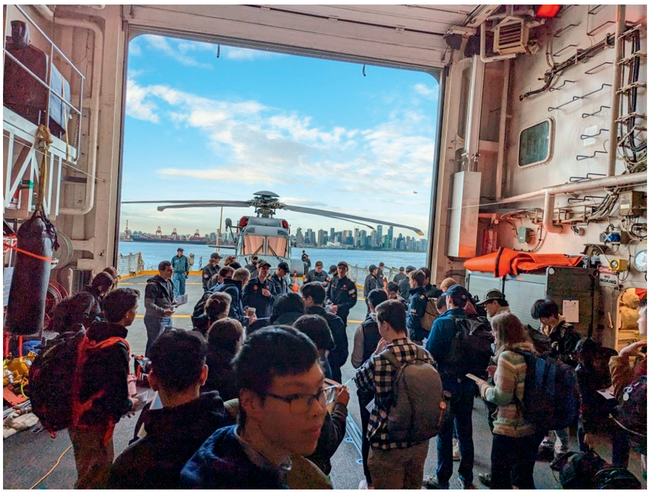

Figure 1: CSaS students muster in *HMCS Ottawa*'s helicopter hangar.

Figure 2: A firefighting demonstration on *HMCS Ottawa*'s flight deck.

ship. In the operations room, we learned about the key role that the ship's radar, electronic warfare receivers, and sonar play in detecting and tracking hostile forces. We also learned that ships and aircraft in a task force can seamlessly share the information gained through their own sensors with other elements of the task force using various NATO-standardized wireless data link technologies such as Link 11, Link 16, and Link 22. The crew members who operate the consoles in each ship's operations room are tasked with collecting, managing, and interpreting all of these data so that effective decisions can be made, and actions taken. To ensure effective coordination, sailors from the task force commander's staff serve within the operations room, ensuring that *HMCS Ottawa* adheres to directives from higher command when sailing in a task force.

Although one can learn much about *Halifax*-class frigates from a variety of online sources, there is no substitute for being aboard the ship for an extended period and hearing directly from the men and women who serve aboard. As we pulled alongside F Jetty at HMC Dockyard at the end of the day and disembarked, we were able to reflect on the unique opportunity that we had to see how engineers turn requirements into practice, and how a trained and dedicated crew turn a metal hull into a fighting ship. Our sincere thanks to Cdr Sam Patchell, commanding officer; LCdr Justin Simmons, executive officer; and the ship's company of *HMCS Ottawa* for their enthusiasm, patience, and hospitality.

—Daniel Nadeem

Powered by a diesel generator, the Z-drives are much more fuel efficient, and can be controlled with greater precision, than conventional propulsion systems.

HMCS Saskatoon

HMCS Saskatoon is one of six Kingston-class Maritime Coastal Defence Vessels (MCDVs) in Canadian Fleet Pacific. Approximately 50 m in length and displacing roughly 970 tons, *Saskatoon* and its sister ships each carry a crew of approximately 50, including both regular and reserve force personnel. After going aboard, as shown in Figure 3, we learned that instead of a traditional rudder for steering and a screw propellor driven by shafts and gears for propulsion, MCDVs employ a pair of azimuth thrusters mounted below the aft section of the hull in pods that can rotate through 360°. The propellor within each thruster is larger and turns slower than conventional units, which significantly reduces the overall noise due to turbulence and vibration.

We learned that the electric motor that drives each thruster is mounted within the main hull and connected to the thruster by a series of shafts and couplers. The configuration is referred to as a *Z-drive* due to its characteristic shape. We were able to see the couplers by descending through a hatch in the aft part of the ship where the Z-drive couplers are installed. The space was cramped for a small group of four people. Powered by a diesel generator, the Z-drives are much more fuel efficient, and can be controlled with greater precision, than conventional propulsion systems.

We further learned that their extraordinary maneuverability and control and relatively compact size make MCDVs ideal for use in conducting coastal patrols, performing pollution surveillance, conducting search and rescue duties, and conducting mine countermeasures activities such as route surveying, minesweeping, and mine hunting. As such, their missions and capabilities are complementary to those of the much larger Canadian Patrol Frigates. In recent years, MCDVs have also deployed overseas to West Africa, Europe, Central America, and the Caribbean to participate in maritime security operations.

—Elaine Rennick

Fleet Maintenance Facility Cape Breton

Ships require various types of maintenance and repairs during their service life. Some maintenance and repair activities are relatively minor and routine and can be performed by the ship's crew. The Fleet Maintenance Facility (FMF) can handle complex repairs and maintenance that require extensive shop facilities, specialized equipment, and highly skilled technical and engineering personnel. These activities may include major overhauls and modifications of systems and equipment, including installation of new or improved components and manufacturing parts that are unavailable in the private sector.

During our visit, we learned that FMF Cape Breton (FMFCB) was formed in 1996 through the amalgamation of three separate engineering, maintenance, and repair units: Ship Repair Unit Pacific, Naval Engineering Unit Pacific, and Fleet Maintenance Group Pacific. The recently constructed FMFCB building is shown in Figure 4. It is an impressive structure that covers 50,000 m^2 and is one of the largest buildings on the West Coast of North

Figure 3: CSaS students aboard *HMCS Saskatoon*.

Figure 4: An aerial view of Fleet Maintenance Facility Cape Breton.

America by volume. The FMFCB is composed of seven departments: operations, engineering, production, unit support, finance, strategy, and process integration. The production department's numerous capabilities include woodworking, painting, machining, hull maintenance and repair, command and control systems, communications systems, above-water and underwater weapon systems, hydraulic systems, marine diesel, gas turbine, electrical propulsion and auxiliary systems, electrical generation and distribution systems, and submarine systems.

We also learned about the many challenges that the FMFCB faces over the lifecycle of a ship and its systems. FMFCB staff include military and civilian engineers, tradespeople, project planners, and other workers. Because of the nature of military postings, RCN members may not stay at a facility like the FMFCB for more than 3–4 years. Civilian employees generally stay much longer and can remember lessons learned and apply this experience to solve future problems. Also, as equipment ages, the original manufacturer may no longer be able to service it. This makes it necessary for the RCN to have facilities to repair, maintain, and test their equipment as they cannot rely on external suppliers to support equipment indefinitely. Although most of the repairs and maintenance are conducted at the main FMFCB facility, crews can be dispatched to remote sites as required. FMFCB's facilities are flexible and can assist with the challenges experienced by other Canadian institutions, such as using the sail-making facilities to manufacture fabric masks during the COVID-19 pandemic.

—*Luke Gallant*

A modern warship's fighting capabilities are highly dependent on the correct function and operation of its communication, radar, and electronic warfare and support systems.

Naval Electronic Systems Test Range (Pacific)

A modern warship's fighting capabilities are highly dependent on the correct function and operation of its communication, radar, and electronic warfare and support systems. Whenever these systems undergo a repair or change, they must be tested both alongside and at sea by FMFCB staff to verify that the affected systems are operating correctly. At-sea tests and trials are conducted at the Naval Electronic Systems Test Range (Pacific) (NESTRP) located at Albert Head, roughly a 30-min drive west of HMC Dockyard. The same FMFCB staff members operate other ranges at Pat Bay and near Esquimalt Harbour for testing the ship's acoustic and magnetic signatures, respectively.

The NESTRP range building is built on the foundation of a former

Figure 5: The entrance to NESTRP (Pacific).

Figure 6: CSaS students touring NESTRP's range operations room.

Figure 7: The Navigation and Bridge Simulator at *HMCS Venture.*

Figure 8: Naval wargaming at *HMCS Venture.*

coastal gun emplacement and overlooks the Strait of Juan de Fuca. The waters next to the site provide ample space for a ship under test to trace a circular path around a set point several kilometres offshore, where marine traffic is relatively sparse while data are collected. At the same time, the relatively few neighbours and a clear shot to the southeast allow signals to be radiated from the site without fear of causing harmful interference.

Our visit began on the large platform mounted adjacent to the range building where various radio and radar antennas are mounted, as shown in Figure 5. Two towers with log-periodic dipole arrays mounted atop are located in a grassy field immediately below the building. Next, we visited the range operations room and viewed the many racks of equipment used to transmit and receive test signals, along with the radars used to track the ship under test during the course of the trials, as shown in Figure 6. Constantine Angelopoulos, the range manager, noted that a full set of trials completed after a major refit may take weeks to complete. “A ship at sea is in a very hostile environment, and the safety of the crew depends entirely on the proper functioning of the many systems: electronic and mechanical. Testing and trials prove to the crew and to the admiral that these systems are functioning correctly, thereby giving us confidence that their missions can be performed successfully and safely.”

—*Alexander Chudinov*

Figure 9: The radar engineering classroom at *HMCS Venture.*

HMCS Venture—Bridge Simulators

During the course of their training, Naval Surface Warfare Officers face the daunting task of learning how to direct the movements of a vessel that may range in length from 50 to 200 m and displace between 970 and 20,000 tons under a variety of sea states and weather conditions. For decades, Maritime Forces Pacific relied on a dedicated training squadron to provide junior officers with opportunities to acquire experience in ship handling, applying the rules of the road, and fleet maneuvering with other vessels.

As in other disciplines, however, the advent of high-fidelity computer-based simulators has made it easier to provide more realistic training at a lower cost, and, importantly, without consequences in case of failure. Since 1997, the RCN has operated a set of navigation and bridge simulators in the Andrew Collier building at *HMCS Venture*. We visited the largest simulator, a full-size ship’s bridge equipped with a suite of projectors that display a 360° view of the surrounding water and coastline. The smaller simulators can be linked to each other and/or to the large simulator so that junior officers can practice maneuvers with other vessels.

As we entered the large simulator, shown in Figure 7, we were struck by how realistically it depicted our “ship” travelling inbound into Vancouver harbour. As the displays began to simulate the rolling that the ship would experience if it were sailing through rough seas, many people in the group started to sway slightly, anticipating the rocking of the boat despite the fact that the bridge was actually stationary.

Although navigation and bridge simulators cannot replace real-world training and experience, their value in helping the next generation of RCN officers become familiar with and proficient in bridge watchkeeping procedures under realistic conditions is apparent.

—Joshua Sam

Naval Personnel and Training Group

The RCN's Naval Personnel and Training Group (NPTG) has embraced the use of modern technology for training the next generation of RCN officers and sailors. For our visit, NPTG set up multiple demonstrations in *HMCS Venture*'s gymnasium. We experienced how Microsoft's HoloLens and Meta's Quest headset could be used to enable training that uses augmented and virtual reality. We were also shown a new board game, similar to *Battleship*, which included details such as helicopters and sea krakens.

We also learned how 3D printing is revolutionizing training and had an opportunity to handle a large and detailed 3D-printed model of a *Halifax*-class frigate in which portions of each deck can be removed to reveal details of the decks below. Later, we visited the print shop where the 3D printers and large format printers used by NPTG are located. The exhibit that may have piqued the most interest was the turn-based war strategy game based on a Norwegian model. The game scenario was laid out on an ultralarge nautical chart of the waters surrounding Southern Vancouver Island (see Figure 8) and detailed scale models of attacking warships, submarines, and aircraft that could be moved across the chart as the game progressed.

The RCN's Naval Personnel and Training Group has embraced the use of modern technology for training the next generation of RCN officers and sailors.

We also visited a classroom where junior officers were being trained in radar technology. In addition to traditional classroom instruction, the junior officers were conducting laboratory lab experiments using benchtop radars that tracked targets attached to a large-format XY scanner, as shown in Figure 9. We were also briefed on how junior officers are trained in *HMCS Venture* and various training opportunities available upon joining the RCN, including opportunities to pursue master's degrees at the RCN's expense.

—Sherwin Tiu

Acknowledgment

Both the civilian leaders and student participants express their sincere thanks to the RCN for arranging the CSaS 2023 program with support from the University of British Columbia and IEEE Canada. Special thanks to both IEEE Canada and the RCN Strategic Outreach team [LCdr Michelle Dunlop, LCdr Chris Elliott, and Lt(N) Zach Lipinski] for their organizational efforts, and to the commanding officers of the various units that we visited for providing us with such an immersive and engaging experience. ■

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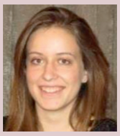

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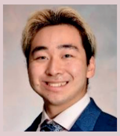

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VPX-Aligned, Small-Footprint, General-Purpose Computing for Naval and Maritime Applications

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by Jeff MacMillan and Rudi Carolsfeld

Naval and maritime demand for increasingly advanced computational capabilities continues to grow with the higher volumes of data from sensors, cameras, and other systems as well as the increasingly sophisticated decision-making tools that are used for command-and-control purposes. The OpenVPX VITA65 standards that have been developed and adopted by the defense and aerospace sectors present an ideal architecture for many shipboard and land-based deployments.

Introduction

The use of digital computers aboard naval ships has expanded rapidly since the development of pioneering computer-based naval battlefield management systems by the Royal Canadian Navy and, later, the U.S. Navy during the 1950s. As demand for advanced computing resources trends inexorably upward in both shipboard and land-based environments, space, weight, power, and cooling become limiting factors. In addition to the dramatic increase in data volumes from more complex sensors, digital signal processing, and vision systems, applications and the operating systems they run have become more complex and computationally intensive to operate.

Conventional system vendors often approach this challenge by using increasingly capable embedded computers in proprietary system designs. Over time, these systems have taken advantage of interconnections through networking in what is now known as *the Internet*, leveraging more powerful centralized, shared computing resources. The resulting data centres offer a number of cloud computing benefits through virtualization and containerization, such as

- speed and simplicity of system configuration
- data backup and redundancy
- flexible resource allocation
- lower total cost of ownership.

These advantages offered by cloud computing introduce additional layers of complexity and require significant space, power, and cooling infrastructure—all of which are difficult and expensive to provide for large shipboard data centres.

The migration of data and processing from on-premises data centres to networked data centres continues for a wide range of commercial, industrial, and government organizations.

Here, we introduce the OpenVPX VITA65 standards that have been developed and adopted by the defense and aerospace sectors; they present an ideal architecture for shipboard and land-based deployments where size, weight, power, and cooling (SWaP/C) and ruggedness are critical considerations. Further benefits accrue from significantly reduced power and cooling requirements when compared to conventional equipment designed for data centres and the resulting 80% reduction in operational footprint and 90% reduction in greenhouse gas (GHG) emissions over the lifetime of the systems.

SWaP/C for Rugged Shipboard IT Systems

Naval and maritime shipboard deployments of IT equipment are challenging due to space limitations and the need to minimize weight. Generating adequate electricity to power the equipment and keep it cool adds to the complexity of shipboard systems. Not only are SWaP/C key challenges, but the ability to withstand vibration, shock, wide temperature fluctuations, and humidity generally present significantly higher challenges than land-based deployments.

When a dedicated IT system is supplied by a vendor to address a specific purpose, a common approach is to ruggedize the IT components to handle the environment where they are used; as a result, a wide variety of ruggedized computers are in widespread use for naval and maritime applications. Dozens or hundreds of dedicated—but disparate—single-purpose systems create another level of difficulty for maintenance and repairs, managing spares and upgrades, and providing suitable mounting for varied shapes and sizes of equipment, bulkhead, and equipment spaces.

Though popular, the standard 19-in. rack-mount approach does not generally address vibration and shock and does not address the need to minimize space. In many data centre designs, these racks are deployed half empty in anticipation of expanded demand over time, as seen in Figure 1. In a large modern warship, designs with dozens of 19-in. racks containing hundreds of servers and their corresponding space, weight, power, and cooling demands have become problematic. A better approach is needed.

VITA65 OpenVPX

In 2003, the VMEbus International Trade Association (VITA) launched the VITA 46 working group to develop a new module standard to address the challenges of high performance when constrained by SWaP/C. Now known as the *VPX standard* [3], it has guided the development of rugged commercial off-the-shelf (COTS) modules for the defense and aerospace industries, featuring numerous high-speed serial interfaces. More recently ratified in 2010, VITA65 (OpenVPX) is a system-level specification that defines how VPX modules are connected through a backplane with standard system topologies, or profiles [4], providing vendor-neutral architectural guidelines for designers and integrators.

In September 2021, the U.S. Air Force, Army, and Navy ratified the adoption of VITA65/OpenVPX and numerous other ANSI/VITA VPX standards, releasing the first version of the Sensor Open Systems Architecture (SOSA v1.0) for widespread defense adoption. SOSA and other modular defense technology standards, such as MOSA and FACE, all embrace rugged, modular, and compact architectures, in particular VPX. These standards elegantly address the need for an IT hardware architecture that can handle the challenges of shipboard systems

Figure 1: Common in data centres, 19-in. racks and cabinets are not ideal for shipboard use (Source: [2]; used with permission.)

and other deployments that require low SWaP/C, ruggedness, modularity, and cost-efficient upgradeability.

VPX-Aligned COTS General-Purpose Computing Systems

Since the advent of large data centres, the trend toward increasingly powerful computational abilities in the cloud has spawned the growth of very capable systems that efficiently share centralized resources. The migration of data and processing from on-premises data centres to networked data centres continues for a wide range of commercial, industrial, and government organizations.

> **Maintaining shipboard or on-premises land-based facilities with a logical air gap that segregates and protects network-connected digital assets can be beneficial and will generally be preferred.**

For security, technical, operational, and economic reasons, the processing of data generated in naval and maritime environments is generally not practical or suitable for cloud-based processing, particularly when ships are at sea. Maintaining shipboard or on-premises land-based facilities with a logical air gap that segregates and protects network-connected digital assets can be beneficial and will generally be preferred. This edge computing approach is evolving and expanding rapidly to address the need for local, uninterrupted, real-time data processing in harsh environments subject to SWaP/C constraints, with low (or no) bandwidth, and that require low-latency response times (such as tactical or navigational response).

Bringing together interconnected edge computing systems that are aligned to the OpenVPX standard and that can offer the computational flexibility of on-premises rack-based computing delivers immediate advantages to the naval and maritime environment.

Designed to be installed in a compact edge computing pod, such as the example shown in Figure 2, these palm-sized 3U OpenVPX-aligned servers are 90% smaller and lighter than conventional blade and rack-mount servers. Spares are easier to source, send to a site, store onsite, remove, and install—this is extremely important for shipboard use, where the need for replacement may occur far from the home port. The modular and standardized general-purpose design of VPX servers allows all computing in a shipboard environment to be conducted on a single, interchangeable VPX server type, thus greatly simplifying the cost, user complexity, and logistical complexity.

Figure 2: The compact VPX-aligned edge computing reference design, measuring less than 35 cm per side.

Using 75% less power and cooling can have a substantial impact on the design of the power system and cooling plant. This is especially relevant for shipboard systems and their related fuel consumption, but it can also have a meaningful impact on land-based deployments, where reliable shore power may be limited or costly. Integrated networking on the VPX backplane eliminates wiring errors and connector failures that may be caused by ship vibrations, defense operations, or user error.

The current state of the art for advanced computing architecture that is used in VPX-aligned servers will feature Intel XEON or AMD Epyc, enterprise-class CPUs, and in-server GPU accelerators for video analytics and artificial intelligence processing. Onboard memory to 64 GB (DDR4) and storage memory to 16 TB per hand-sized VPX Server (NVMe) is currently available. Long-term archival data storage is commonplace in cloud data centres, and this need can be essential for air-gapped shipboard systems that may be deployed far from the home port for weeks or months. The ability to share storage among multiple servers calls for easily replaced solid-state storage modules (64 TB or more) within the edge computing pod.

Communications interfaces to shipboard or land-based networks using wireless, wired, or fiber-optic networking is a minimal requirement for any VPX-aligned computing pod. Additional input–output capability to provide interfacing to monitoring and control systems is commonplace.

Modularity Reduces Risk

Easy replacement of compact edge computing components increases the operational resilience of shipboard and land-based systems, and the size and modularity can be leveraged to reduce the operational risk onboard warships in other ways. Starting with the overall design of the ship, architects have been faced with few alternatives to ever-increasingly large data centre spaces and the centralization of computing resources, with the corresponding need for additional power and cooling. The alternative is to deploy decentralized and redundant edge computing pods throughout the ship that can operate closer to where the computing power is needed, greatly reducing risk during warfighting scenarios.

Miniaturization Benefits to the Environment

In addition to the obvious benefits of reduced SWaP/C and increased ruggedness that can be attained using a VPX-aligned edge computing pod, such deployments will result in a meaningful reduction in GHG emissions when compared to conventional technology that is common in land-based facilities (Figure 3).

Scope 1 GHG emissions are directly related to the fuel consumption of the ship's propulsion system, electricity generation system, and cooling infrastructure. Lower demand for electricity and cooling (by using more compact, lighter, and lower power edge computing pods) is directly linked to lower scope 1 emissions; reducing the weight, heat signature, and fuel consumption also improves the range and fighting ability of naval vessels.

Integrated networking on the VPX backplane eliminates wiring errors and connector failures that may be caused by ship vibrations, defense operations, or user error.

Scope 2 GHG emissions relate to the fuel consumed to generate the electricity used over the lifetime of the IT systems. For shipboard systems, scope 2 may be included in the scope 1 emissions previously discussed or can be apportioned from the overall fuel consumption. For land-based naval and maritime facilities that do not have propulsion systems, power and cooling loads are supplied by the local electrical grid or microgrid as well as the fossil fuel consumed by connected generators. A compact VPX-aligned computing pod can attain 80% reduction in operating costs and in scope 2 emissions when compared to conventional 19-in. rack-mounted IT equipment. The low power demand might also allow solar or wind power to be considered.

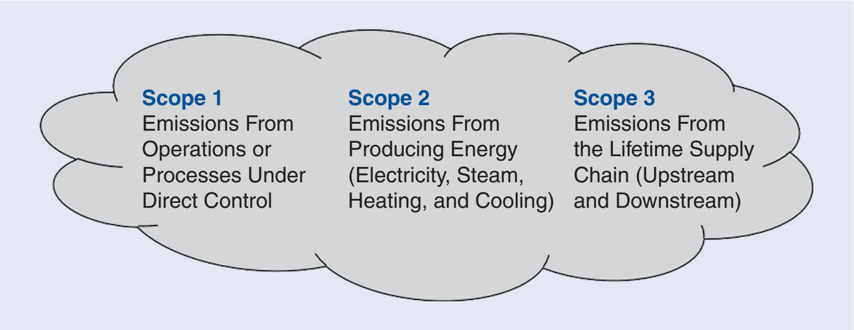

Figure 3: GHG emissions by source.

Scope 3 emissions include all other sources of GHGs, from manufacturing, to logistics (shipping and handling) and installation, to decommissioning and recycling or disposal at end of life. A compact VPX-aligned computing pod contains far less material and requires far less energy to manufacture than a conventional 19-in. rack full of IT equipment. It also needs far less energy for shipping and handling, installation, upgrades, and disposal. The result is that scope 3 GHG emissions can be dramatically lower, possibly as much as 90%.

Conclusions

The VITA65 (OpenVPX) standard offers a robust architecture for the design of IT systems that are suitable for naval and maritime deployments. Due to the mobile nature of shipboard systems, these deployments have, until now, been largely unable to take advantage of the significant advancements in cloud and on-premises cloud-like computing environments unless there is a willingness to commit to the substantial demands of SWaP/C.

By aligning a compact edge computing pod with OpenVPX design principles, it is now possible to deploy compact, highly capable, multiserver systems that meet the ruggedness and SWaP/C requirements of naval and maritime applications. ■

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Advanced Electromagnetic Simulations for the Naval and Shipbuilding Industry

by C. J. Reddy

Advances in computational electromagnetic (EM) tools simplified the task of designing and integrating antennas for use on various land, sea, air, and space platforms. Now, numerical simulations can be performed to evaluate the effects of antenna design, placement, radiation hazard, EM compatibility (EMC)/EM interference (EMI), etc. for wide-ranging industry applications. With every platform becoming increasingly connected, the naval and shipbuilding industry is no exception, with numerous complex communication systems. The use of EM simulation technologies to improve design efficiency and reduce physical testing costs continues to be one of the best ways to address engineering challenges in the naval industry. Here, various case studies of antenna placement, co-site interference, EMI/EMC, and radiation hazard simulations applicable to the naval industry are discussed, and simulation solutions are presented.

Introduction

Recent advances in computational EM tools have simplified the task of designing and integrating antennas for use on various land, sea, air, and space platforms. Further, such tools permit designers to evaluate and mitigate issues that may arise due to antenna design and placement, including radiation hazards, EMC/EMI, etc., in a wide range of practical scenarios. As shipboard environments becoming increasingly connected, the naval and shipbuilding industry is becoming increasingly reliant on EM simulation tools, such as Altair's Feko [1], to improve design efficiency and reduce physical testing costs.

Naval applications in which EM simulations can play a significant role, including 1) antenna placement, 2) co-site interference, 3) EMC, 4) radiation hazards, 5) radar cross section (RCS), and 6) ship magnetization, are summarized in Figure 1. These applications are reviewed in the remainder of this article. All of the EM simulations presented here were performed using the commercial EM simulation tool Altair Feko. The ship magnetization simulations were performed using Altair's Flux software.

Antenna Placement

A typical naval platform may support more than 70 antennas that are used by communication systems, radars, and weapon systems. These antennas may operate at frequencies ranging from high frequency (HF) (a few megahertz) to extremely HF (tens of gigahertz) [2]. Advances in EM simulation technology have greatly simplified the analysis of such antennas during the design phase and vastly reduced the time and costs associated with antenna measurements.

EM simulations can be broadly categorized into full-wave and asymptotic solutions. Full-wave techniques solve the Maxwell equations accurately and provide reliable results, provided a good geometric CAD model and mesh are available. Such techniques include the method of moments (MoM), adaptive cross approximation (ACA), multilevel fast multipole method (MLFMM), finite element method, and the finite difference time domain method.

Asymptotic techniques also solve the Maxwell equations, but with assumptions and approximations appropriate to cases where the problem size is large in terms of wavelength. They also can provide reasonably accurate results, provided the approximations and assumptions are properly considered during the simulation process. Such techniques include physical optics (PO), large-element PO (LE-PO), ray launching geometrical optics (also known as the *shooting and bouncing ray method*), and the uniform theory of diffraction (UTD).

Hybrid EM solutions that combine both full-wave and asymptotic solvers allow the simulation of naval antenna systems with fewer computational resources but, at the same time, provide the required accuracy. Here, we present results for antenna performance on an electrically large ship over a very wide frequency range (20 MHz to 30 GHz) using various hybrid computational methods and thereby illustrate the accuracy and power of these methods when computational resources are limited. All numerical simulations in this section have been carried out on a typical commodity desktop costing <$3,000—specifically, a Dell Precision 5720 computer running the Windows 10 operating system with a 3.7-GHz quad-core 64-b processor using all four processor cores and with 64 GB of random-access memory (RAM).

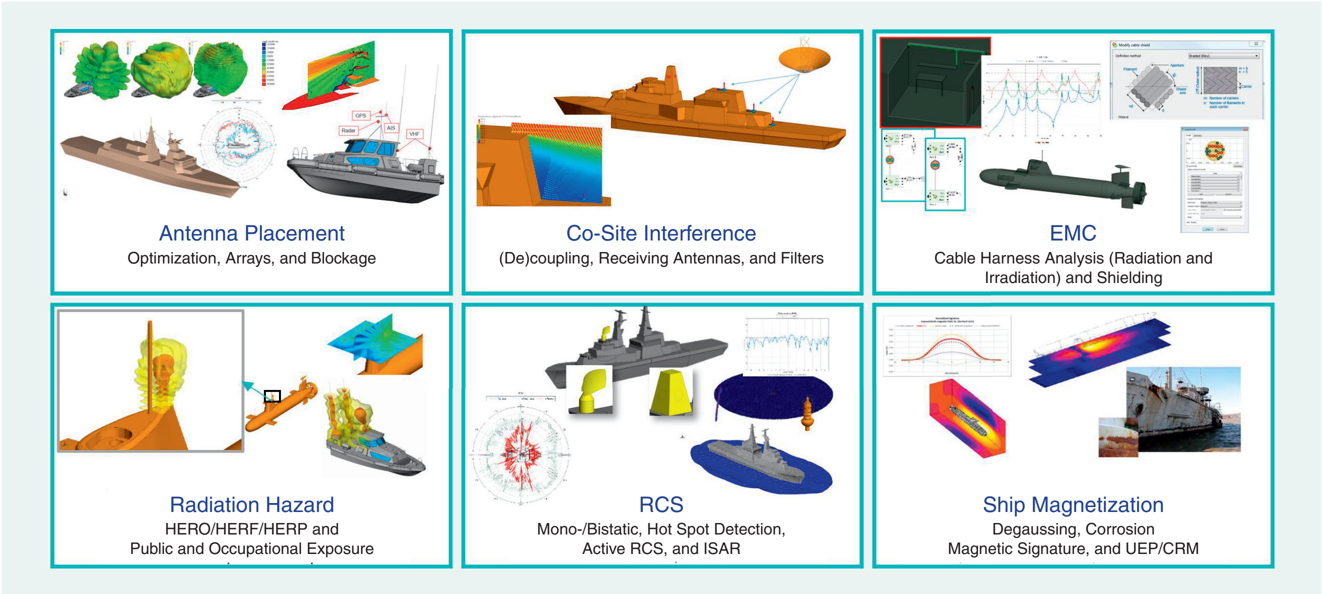
Naval Ship Model

The generic ship model with surrounding sea surface (with nominal values of $\varepsilon_r = 80$ and $\sigma = 4$ S/m [3] corresponding to seawater) shown in Figure 2 was used in the simulations. The ship is 120 m in length, 14 m in width, and 37 m in height, and it is assumed to be constructed from perfectly conducting materials. The sea surface is modeled as a thin dielectric sheet with the thickness equal to the skin depth. A wire monocone antenna is mounted on the uppermost deck of the shop. Analysis of the antenna pattern while the antenna is attached to the ship is carried out from 20 MHz to 30 GHz. A template of the monocone at different frequencies can be found in Altair Feko's Component Library.

A typical naval platform may support more than 70 antennas that are used by communication systems, radars, and weapon systems.

Full-Wave EM Simulations

At 20 MHz, the ship is 8 λ in length, 0.93 λ in width, and 2.5 λ in height. Applying the MoM technique to solve this problem took 26.5 GB of RAM and 1 h of CPU time. At 40 MHz, the ship is 16 λ in length, 1.9 λ in width, and 5 λ height, resulting in 89,727 triangles. Applying the MoM required 135 GB of RAM, far more than what is available on the computer used. On the other hand, the problem was solved in 1.3 h using ACA with 10.4 GB of RAM. Extending to 100 MHz, ACA could solve this problem in 8.2 h using 50.7 GB of RAM. To reduce both memory and CPU time, MLFMM is applied at 100 MHz. MLFMM could solve this problem with 5.2 GB of RAM and in



Antenna Placement
Optimization, Arrays, and Blockage

Co-Site Interference
(De)coupling, Receiving Antennas, and Filters

EMC
Cable Harness Analysis (Radiation and Irradiation) and Shielding

Radiation Hazard
HERO/HERF/HERP and Public and Occupational Exposure

RCS
Mono-/Bistatic, Hot Spot Detection, Active RCS, and ISAR

Ship Magnetization
Degaussing, Corrosion Magnetic Signature, and UEP/CRM

Figure 1: An overview of EM simulations in naval applications. CRM: corrosion-related magnetic field; HERF: hazards of EM radiation to fuel; HERO: hazards of EM radiation to ordnance; HERP: hazards of EM radiation to personnel; RCS: radar cross section.

5 min. The current distribution and 3D radiation patten of the wire monocone at 100 MHz and a comparison of both ACA and MLFMM solutions for the principal plane cuts are shown in Figure 3.

Hybrid MoM/PO Solution

At 200 MHz, the MLFMM solution of the wire monocone on the ship deck problem took 45 GB of RAM and was completed in 6.8 h. The same problem was then solved using the hybrid MoM/PO solution, where MoM is applied to the wire monocone and PO to the ship structure. The hybrid MoM/PO solution took 5 GB of RAM and 12 min of the CPU time. The current distribution and 3D radiation patten of the wire monocone at 200 MHz and a comparison of the PO and MLFMM solutions for the principal plane cuts are shown in Figure 4. There is a disagreement in the $\varphi = 0°$ plane where PO can only provide an approximate solution in the shadow region.

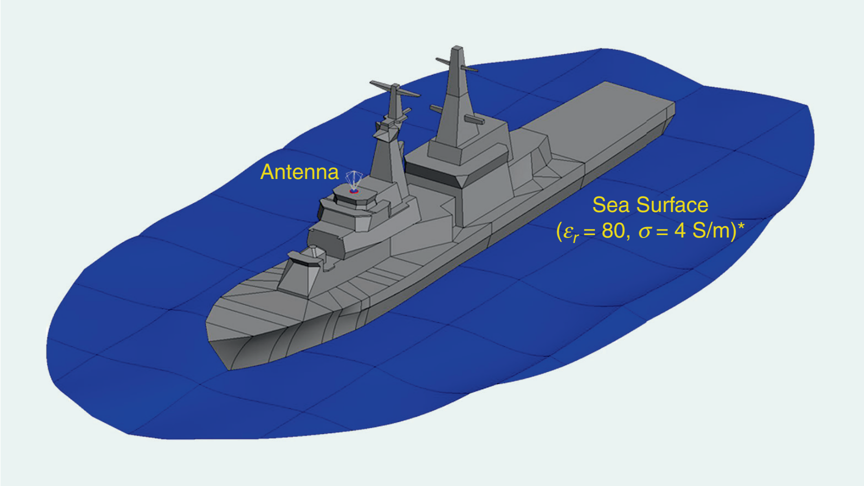


Figure 2: A generic CAD model of a ship with the surrounding sea surface. A monocone antenna is mounted on the deck of the ship.

Hybrid MoM/LE-PO Solution

With decreased memory and time requirements for the MoM/PO solution, the wire monocone on the ship can be solved at 500 MHz with 33 GB of RAM and in 1.1 h. We could reduce the computational resources required further by applying a hybrid MoM/LE-PO solution, where the MoM is applied to the wire monocone and LE-PO to the ship structure. For the MoM/LE-PO simulations, sea surface is not considered. The hybrid MoM/LE-PO solution took only 238 MB of RAM and 2.7 min of the CPU time at 500 MHz. The current distribution and 3D radiation patten of the wire monocone at 500 MHz and comparison of the PO and LE-PO solutions for the principal plane cuts are shown in Figure 5. With decreased memory and time requirements for the MoM/LE-PO solution, this problem is solved at 5 GHz with 4.4 GB of RAM in 5 h.

Hybrid MoM/UTD Solution

At 5 GHz, this problem is also well suited for solution by hybrid MoM/UTD techniques. The model reduction shown in Figure 6 is applied as at 5 GHz, where only structures close to the antenna will impact the performance. Using the hybrid MoM/UTD solution, this problem

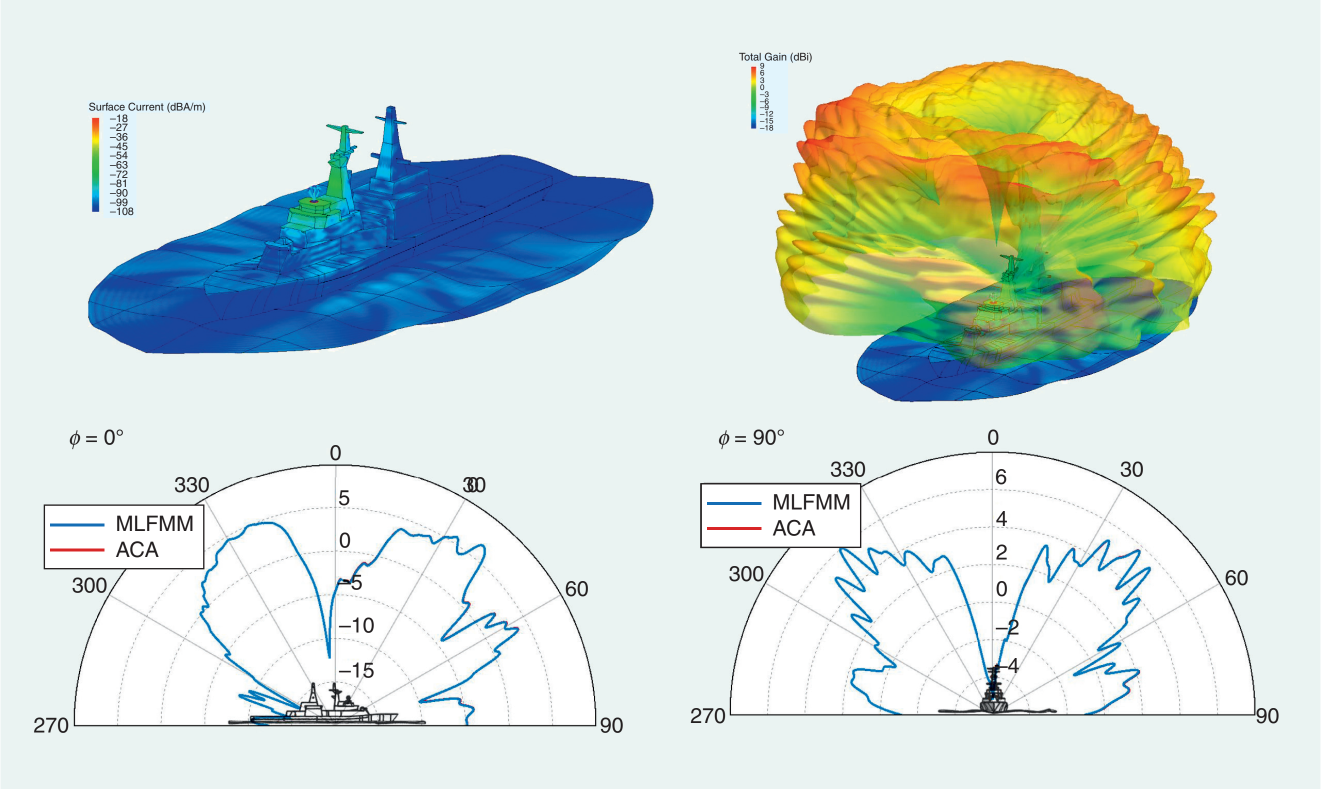


Figure 3: The current distribution and 3D radiation pattern of the wire monocone at 100 MHz and a comparison of the principal plane radiation pattern cuts for the ACA and MLFMM solutions.

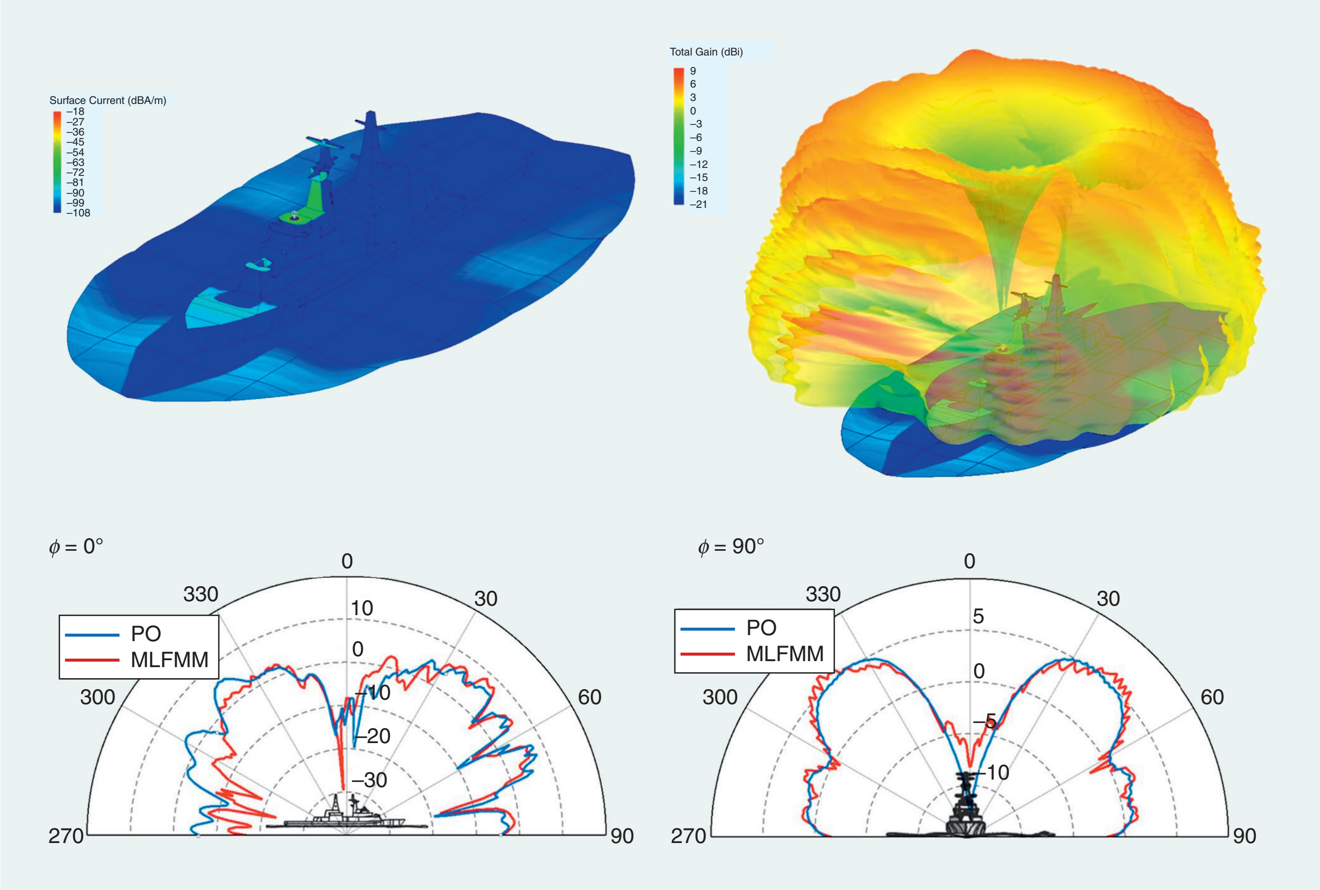


Figure 4: The current distribution and 3D radiation pattern of the wire monocone at 200 MHz and a comparison of the principal plane radiation pattern cuts for the PO and MLFMM solutions.

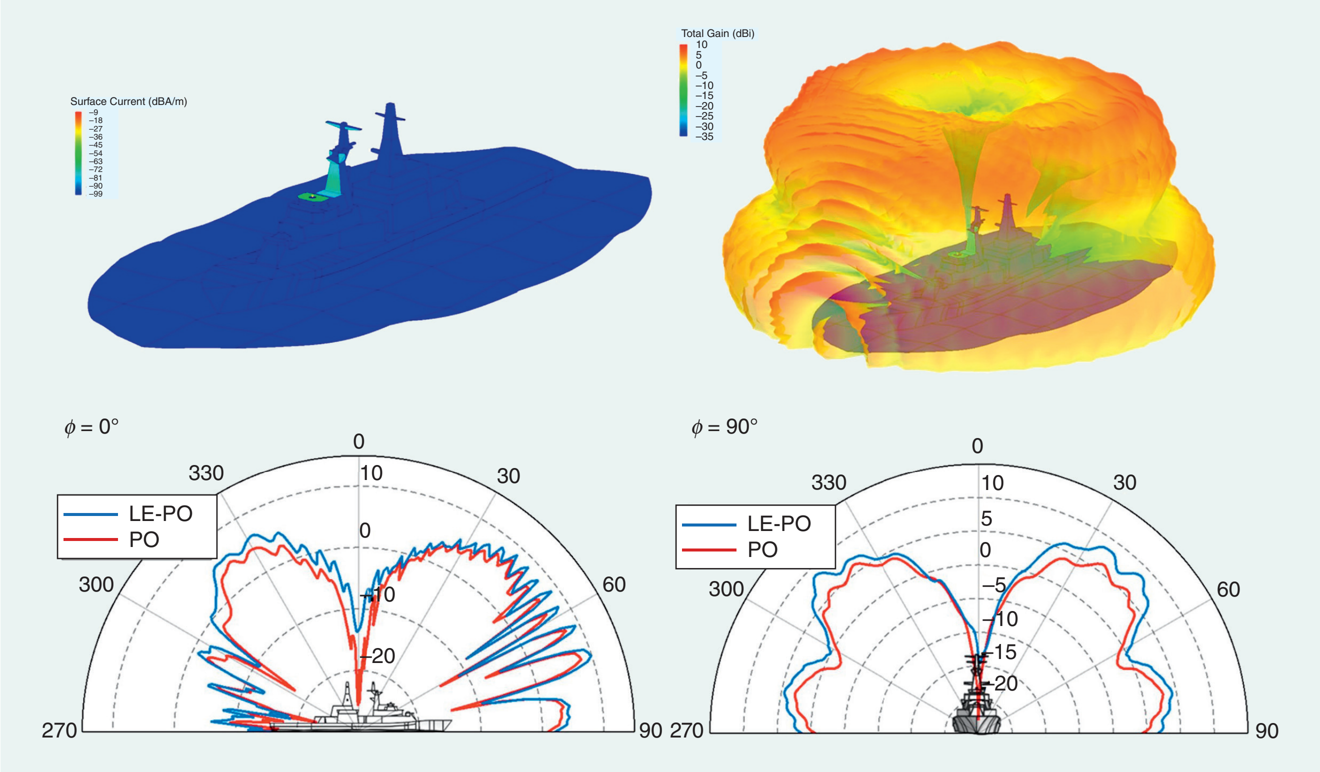


Figure 5: The current distribution and 3D radiation pattern of the wire monocone at 500 MHz using the hybrid MoM/PO simulation and a comparison of the principal plane radiation pattern cuts for the PO and LE-PO solutions.

is solved with 4.3 MB of RAM and 21.5 min of computation time for 722 far-field points (1.8 s per far-field point). The 3D radiation patten of the wire monocone at 5 GHz is shown in Figure 7, where a comparison of both LE-PO and UTD solutions for the principal plane cuts are also shown. There is a disagreement in the $\varphi = 0°$ plane where LE-PO only provides an approximate solution in the shadow region. As UTD computations are not dependent on frequency, the same amount of memory and computation time is also taken at higher frequencies.

Table 1 summarizes the scaling of hybrid full-wave and asymptotic solutions from 2 MHz to 30 GHz on a commodity desktop (cost of <$3,000) with 64 GB of RAM and four cores. Table 1 also provides the number of elements used in simulations. The antenna is scaled with respect to the frequency, thus resulting in the same number of wire segments for all frequencies. For all methods, the ship is discretized with triangles, and, for UTD, the ship is modeled with polygonal plates.

Co-site Interference

Naval platforms contain numerous transmitting and receiving antennas. These serve a variety of electronic systems, such as communication systems (including

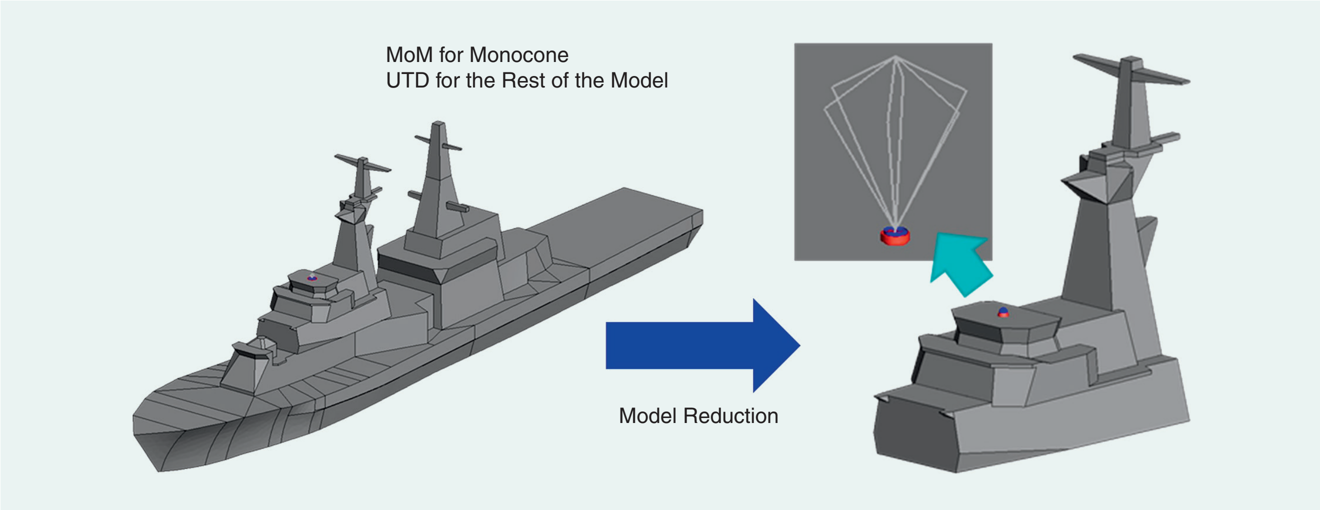


Figure 6: A model reduction for the application of the hybrid MoM/UTD solution.

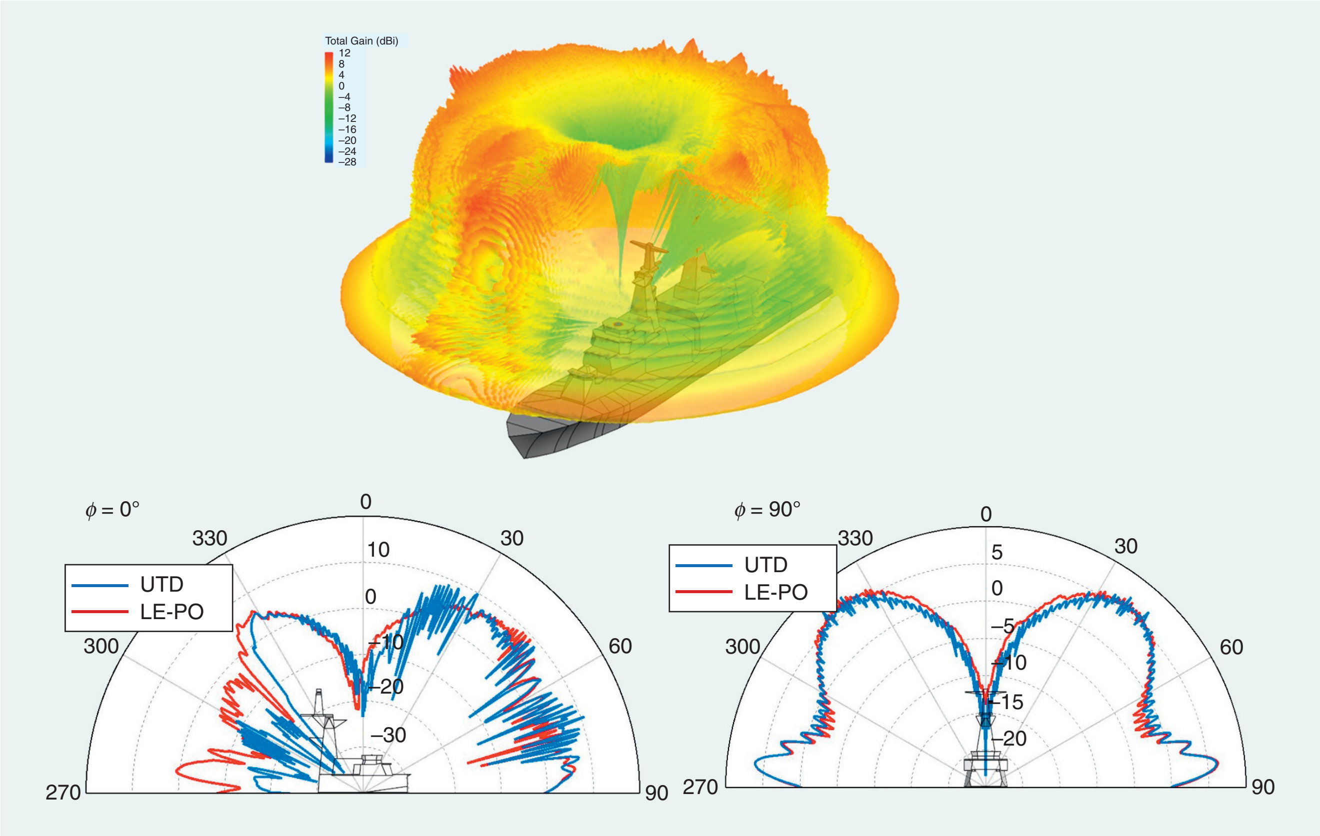


Figure 7: The 3D radiation pattern of the wire monocone at 5 GHz using the hybrid MoM/LE-PO simulation and a comparison of the principal plane radiation pattern cuts for the LE-PO and UTD solutions.

Satcom), radar, positioning systems, and more. Even when operating on different frequencies, these antennas may interfere with each other due to their proximity to each other. Figure 8 shows an example of coupling between a high-power transmitter and victim receivers.

Analyzing co-site interference using EM simulation solutions requires the following:

- the accurate determination of the coupling between antennas over a broad frequency range— even when platform geometries are complicated, and no direct line of sight may exist
- the evaluation of the impact of nonlinear electronic effects, including harmonics, intermodulation, intermediate frequency breakthrough, image frequency, transmitter and receiver spectra, and receiver blocking.

Altair Feko's WRAP technology [4] is designed to help engineers analyze and mitigate antenna collocation interference. First, coupling between antennas on naval platforms can be computed using Altair Feko. Next, the WRAP toolset within Feko is used to quantify that interference. The results are

Table 1: The scaling of hybrid full-wave/asymptotic EM solver techniques.

Frequency	Length (λ)	Width (λ)	Height (λ)	Method	Memory	Time
2 MHz	0.8	0.1	0.25	**MoM**	225 MB	14 s
20 MHz	8	0.93	2.5	**MoM**	26.5 GB	1 h
40 MHz	16	1.9	4.9	**MoM**	135 GB	Not solved
				ACA	10.4 GB	1.3 h
100 MHz	40	4.7	12.3	**ACA**	50.7 GB	8.2 h
				MLFMM	5.2 GB	5 min
200 MHz	80	9.3	24.7	**MLFMM**	45 GB	6.8 h
				MoM-PO	5 GB	12 min
300 MHz	120	14	37	**MoM-PO**	12 GB	24 min
500 MHz	200	23.3	61.7	**MoM-PO**	33 GB	1.1 h
				MoM/LE-PO	238 MB	2.7 min
1 GHz	400	46.7	123.3	**MoM/LE-PO**	936 MB	15 min
				MoM/UTD	4.3 MB	1.8 s/far-field point
5 GHz	2,000	233.3	616.7	**MoM/LE-PO**	4.4 GB	5 h
				MoM/UTD	4.3 GB	1.8 s/far-field point
20 GHz	8,000	933.3	2,466.7	**MoM/UTD**	4.3 MB	1.8 s/far-field point
30 GHz	12,000	1,400	3,700	**MoM/UTD**	4.3 MB	1.8 s/far-field point

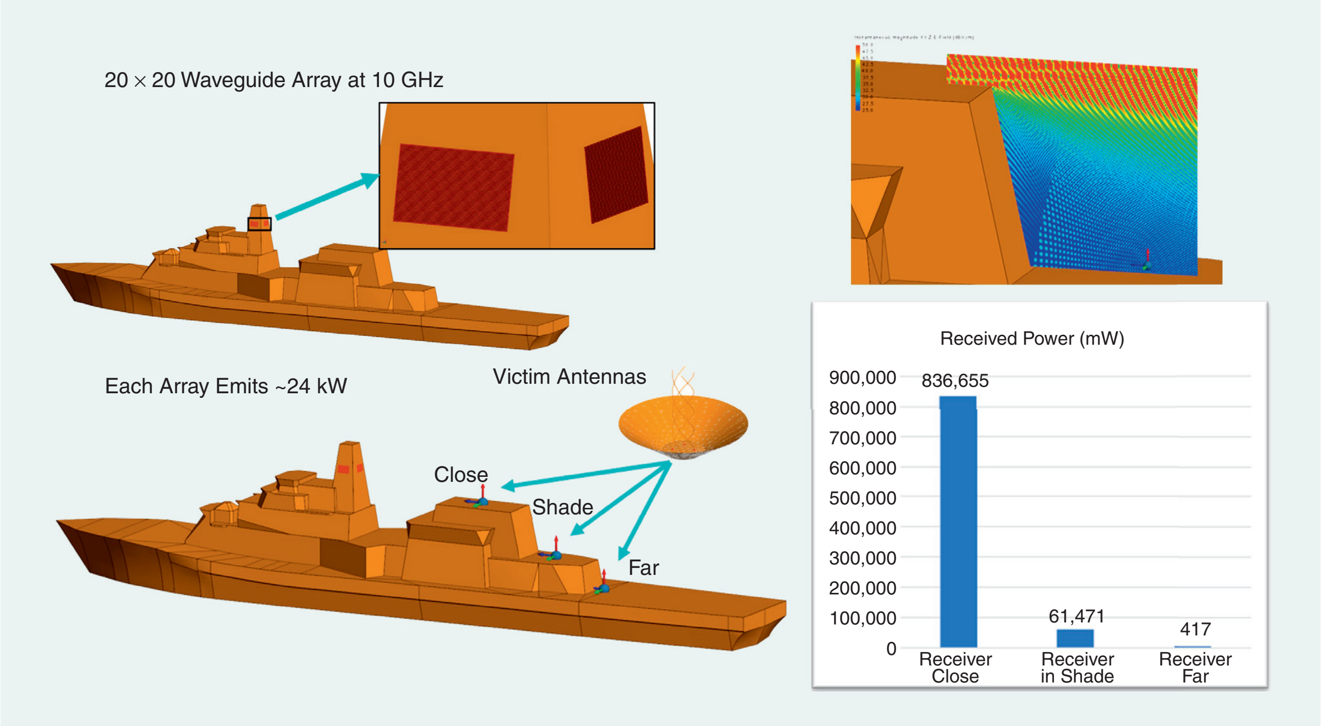


Figure 8: An example of coupling between a high-power transmitter and victim receivers.

shown in the dialogue box. For example, co-/adjacent channel interference and interference from the harmonics of the ultra-HF/very HF transmitters can get into the GPS receiver, as shown in Figure 9. One possible solution is to put a filter on the GPS receiver to improve out-of-band rejection. Another solution is to put filters on the transmitters to improve the suppression of out-of-band transmissions.

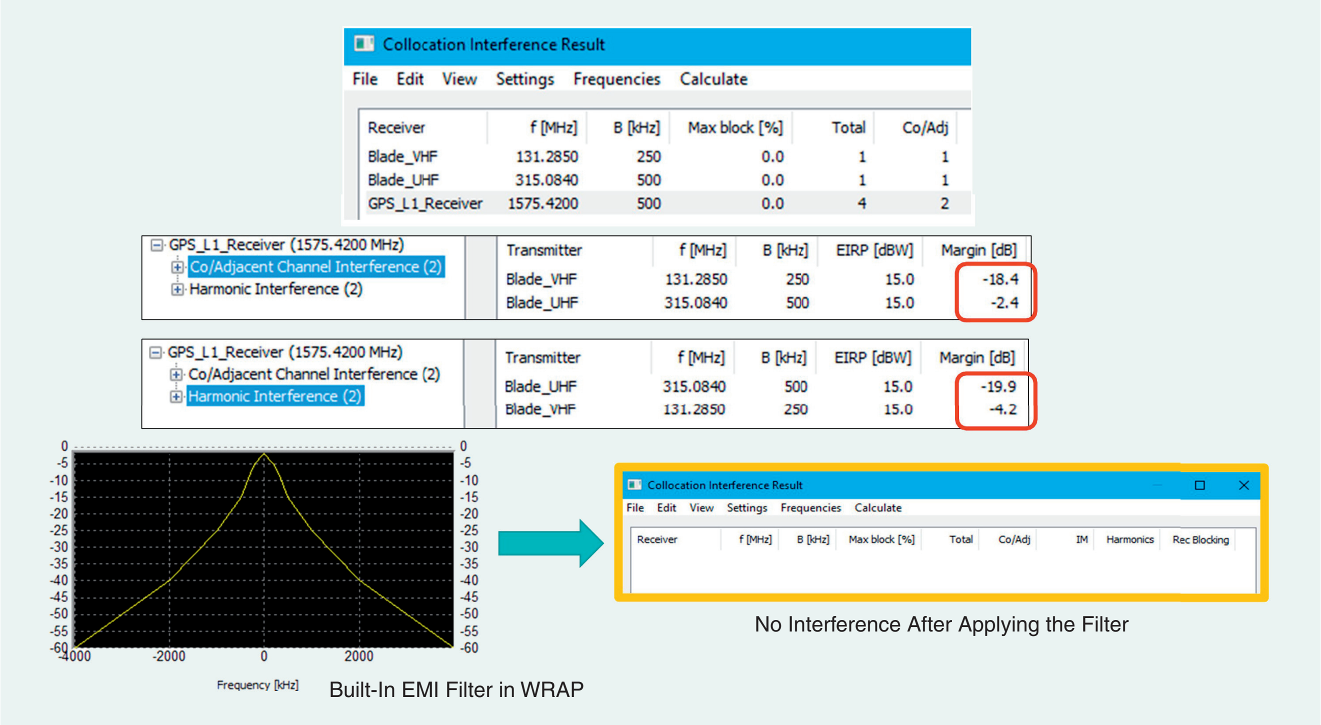
EM Compatibility

A modern naval platform may contain several kilometers of electrical wiring, bundled in many wiring harnesses. Design engineers must ensure, well before the first prototype is built, that many kinds of EMC and EMI problems are avoided. Such EMC problems include the following:

The reduction of the RCS of a naval ship is an important design issue when considering survivability in a hostile environment.

- Communication signals on one cable may exhibit crosstalk onto another cable.
- Radiation or near fields from a power cable may interfere with communication signals in a nearby cable.
- Radiation from strong nearby sources, including from a lightning strike, may be picked up by a cable harness and delivered to sensitive electronic equipment.

Using the multitransmission line method combined with MoM allows EMI/EMC scenarios associated with complex cable harnesses to be analyzed with practical amounts of memory and CPU time [5]. Figure 10 shows an example of coupling between a power cable (aggressors) into a signal cable



Receiver	f [MHz]	B [kHz]	Max block [%]	Total	Co/Adj
Blade_VHF	131.2850	250	0.0	1	1
Blade_UHF	315.0840	500	0.0	1	1
GPS_L1_Receiver	1575.4200	500	0.0	4	2

Transmitter	f [MHz]	B [kHz]	EIRP [dBW]	Margin [dB]
Blade_VHF	131.2850	250	15.0	-18.4
Blade_UHF	315.0840	500	15.0	-2.4

Transmitter	f [MHz]	B [kHz]	EIRP [dBW]	Margin [dB]
Blade_UHF	315.0840	500	15.0	-19.9
Blade_VHF	131.2850	250	15.0	-4.2

Receiver	f [MHz]	B [kHz]	Max block [%]	Total	Co/Adj	IM	Harmonics	Rec Blocking

No Interference After Applying the Filter

Built-In EMI Filter in WRAP

Figure 9: The quantification of co-site interference in Altair's WRAP toolset and mitigation using built-in EMI filters in WRAP.

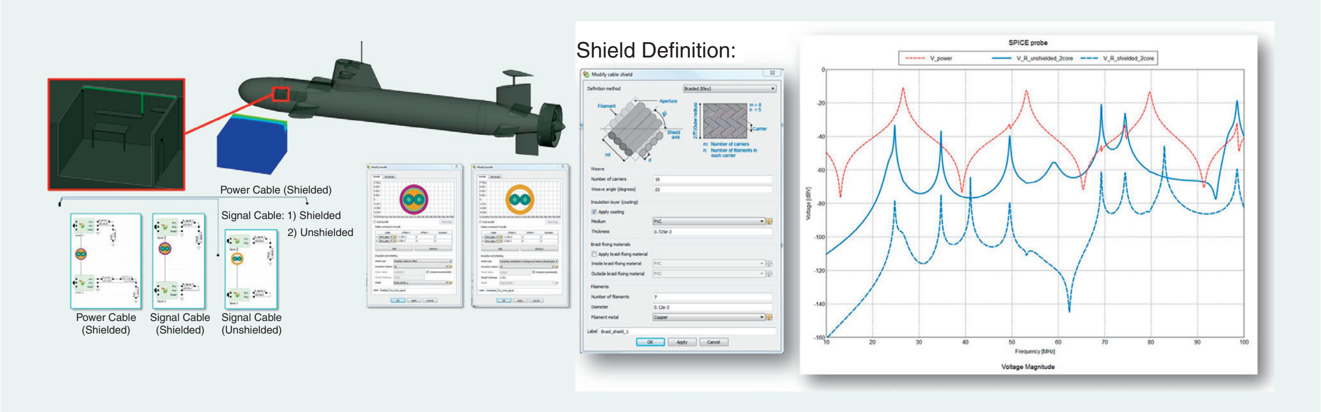
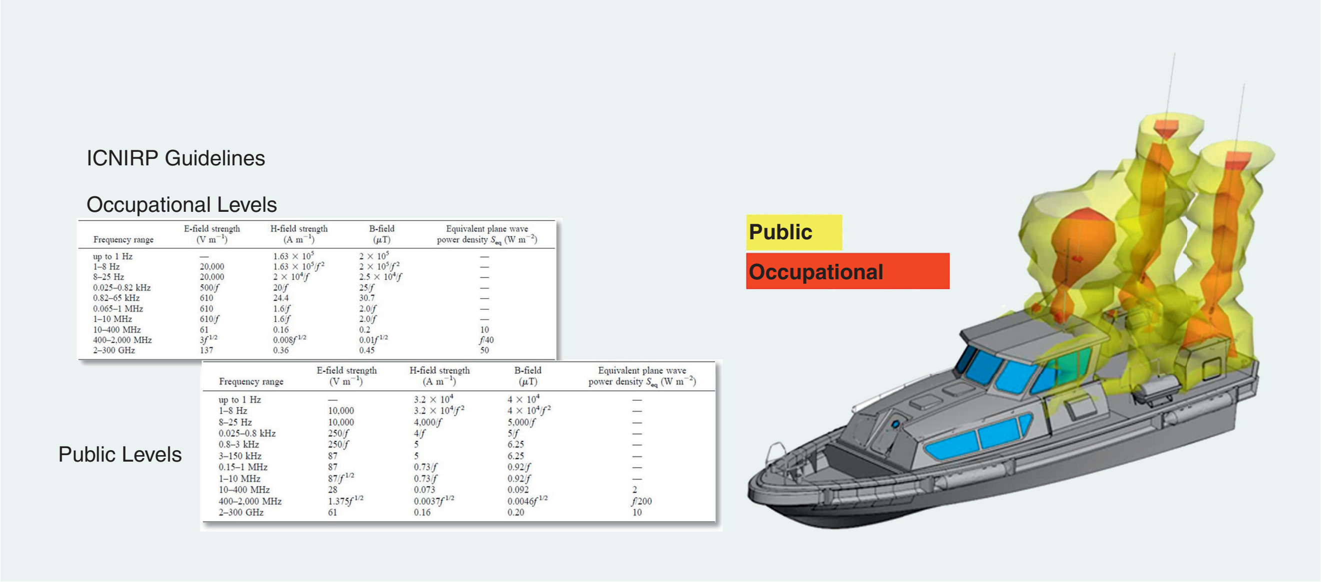


Figure 10: An example of coupling between a power cable (aggressor) into a signal cable (victim) in a submarine and the results of simulations that show a reduction of coupling into the signal cable with proper shielding.



ICNIRP Guidelines

Occupational Levels

Frequency range	E-field strength ($V m^{-1}$)	H-field strength ($A m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W m^{-2}$)
up to 1 Hz	—	1.63×10^5	2×10^5	—
1–8 Hz	20,000	$1.63 \times 10^5/f^2$	$2 \times 10^5/f^2$	—
8–25 Hz	20,000	$2 \times 10^4/f$	$2.5 \times 10^4/f$	—
0.025–0.82 kHz	$500/f$	$20/f$	$25/f$	—
0.82–65 kHz	610	24.4	30.7	—
0.065–1 MHz	610	$1.6/f$	$2.0/f$	—
1–10 MHz	$610/f$	$1.6/f$	$2.0/f$	—
10–400 MHz	61	0.16	0.2	10
400–2,000 MHz	$3f^{1/2}$	$0.008f^{1/2}$	$0.01f^{1/2}$	$f/40$
2–300 GHz	137	0.36	0.45	50

Public Levels

Frequency range	E-field strength ($V m^{-1}$)	H-field strength ($A m^{-1}$)	B-field (μT)	Equivalent plane wave power density S_{eq} ($W m^{-2}$)
up to 1 Hz	—	3.2×10^4	4×10^4	—
1–8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	—
8–25 Hz	10,000	$4,000/f$	$5,000/f$	—
0.025–0.8 kHz	$250/f$	$4/f$	$5/f$	—
0.8–3 kHz	$250/f$	5	6.25	—
3–150 kHz	87	5	6.25	—
0.15–1 MHz	87	$0.73/f$	$0.92/f$	—
1–10 MHz	$87/f^{1/2}$	$0.73/f$	$0.92/f$	—
10–400 MHz	28	0.073	0.092	2
400–2,000 MHz	$1.375f^{1/2}$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	$f/200$
2–300 GHz	61	0.16	0.20	10

Figure 11: An example of a radiation hazard zoned as per ICNIRP's public and occupational exposure limits on a patrol boat. Worst case field levels are considered with multiple antennas radiating simultaneously.

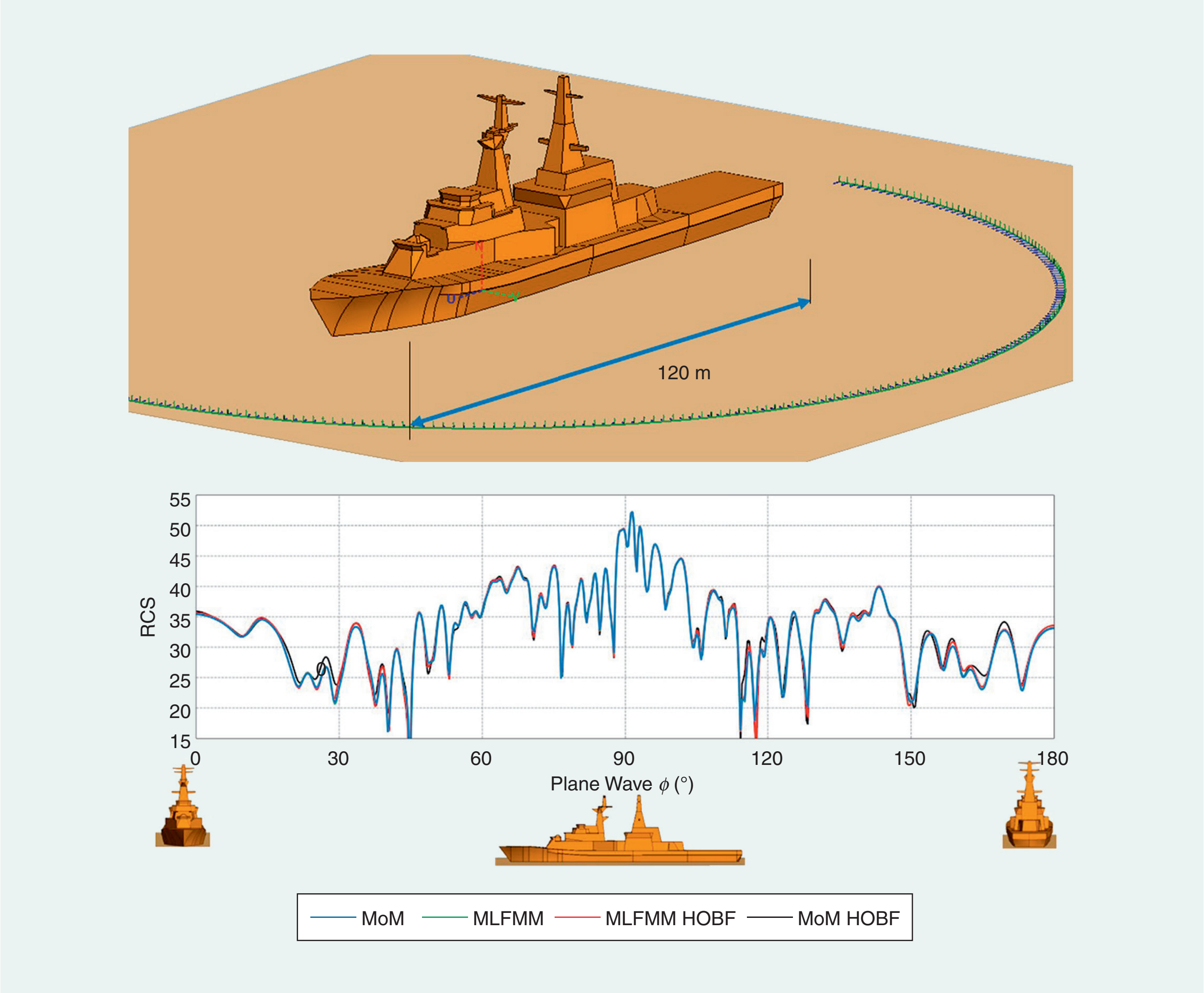


Figure 12: The monostatic RCS of a generic ship at 75 MHz using various full-wave methods in Altair Feko, including higher order basis functions (HOBF).

(victim) in a submarine. The results of the simulations show a reduction of coupling into the signal cable with proper shielding.

Radiation Hazard

Protection against the hazards associated with high levels of radio-frequency (RF) radiation is an important part of any system design process that involves RF transmitters. The dangers of overexposure for humans are foremost in the mind of the general public (HERP—hazards of EM radiation to personnel), but engineers also deal with dangers relating to the accidental ignition of highly combustible liquids (for example, fuels) (HERF—hazards of EM radiation to fuel) or ordnance in military environments (HERO—hazards of EM radiation to ordnance). Various standards or guidelines, such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [6], are enforced around the world to ensure that the levels of radiation in any environment are safe (Figure 11).

RCS

RCS, also called the *radar signature*, is a measure of how much signal is reflected by a target and, as a result, how detectable a target is by radar. A larger RCS

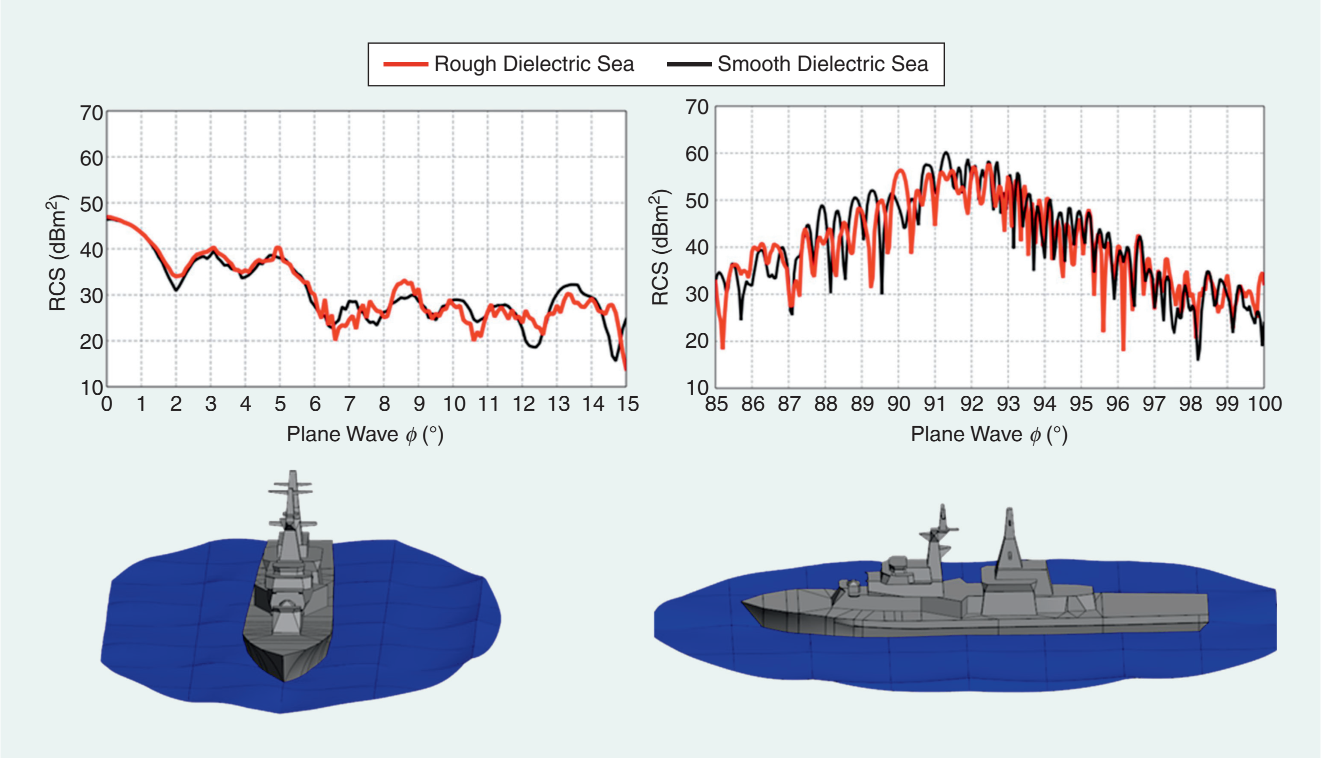


Figure 13: The monostatic RCS of a ship at 600 MHz with an oblique incident angle ($\theta = 60°$) with simulations using a flat/smooth sea surface versus a rough sea surface.

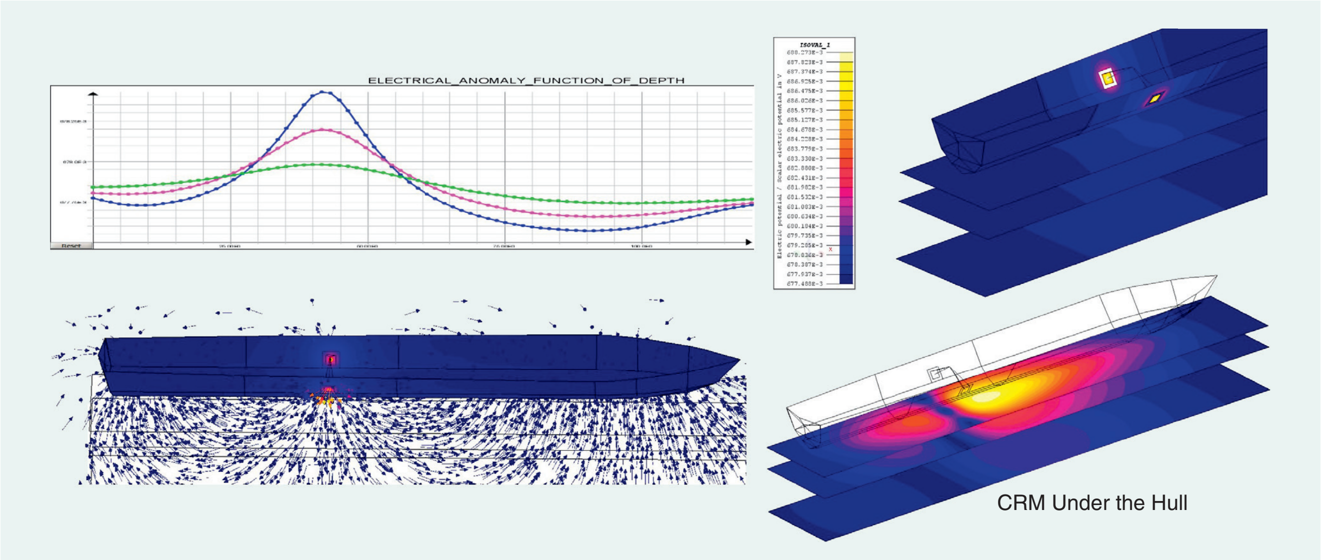


Figure 14: An example of Altair Flux simulations of the electric potential distribution on the hull, corrosion currents with or without cathodic protections, underwater electric potential, and corrosion-related magnetic field (CRM).

indicates that an object is more easily detected. The reduction of the RCS of a naval ship is an important design issue when considering survivability in a hostile environment.

Figure 12 shows the monostatic RCS of a generic ship at 75 MHz using various full-wave methods in Altair Feko, including higher order basis functions. Figure 13 shows the monostatic RCS of a ship at 600 MHz with an oblique incident angle ($\theta = 60°$) with simulations using a flat/smooth sea surface versus a rough sea surface.

Ship Magnetization

Naval ships have magnetic signatures due to the ferromagnetic steel used in their construction. The high permeability of ferromagnetic steel causes ships to offer low reluctance paths for Earth's static magnetic field, distorting the field in the process. Such anomalies in Earth's field can be detected and exploited by magnetic anomaly detection (MAD) sensors. Accordingly, it becomes important to accurately predict the magnetic signatures during the initial design phase. The critical part of the prediction of an induced magnetic signature is the accurate modelling of the internal ship structure, machinery, and other equipment aboard the naval vessel.

The only available techniques for assessing the magnetic signature of a ship are by field measurements or by using numerical tools [7]. For many years, degaussing systems onboard naval vessels have been used to reduce the static magnetic signature and, thus, reduce the threat of mines equipped with MAD sensors. However, due to recent developments in sensor technology, the emission of alternating electric and magnetic fields has become a concern in efforts to electromagnetically silence ships. For example, in high sea states, a ship's magnetic signature can vary considerably from that in calm seas [8]. The accurate simulation of a ship's magnetic signature under a variety of conditions, thus, becomes critical for survivability.

Altair Flux [9] is widely used for simulating and predicting ship magnetization effects [10]. Figure 14 shows an example of Altair Flux simulations of the electric potential distribution on the hull, corrosion currents with or without cathodic protections, underwater electric potential, and corrosion-related magnetic field.

Conclusions

Numerical simulations can be performed to evaluate the effects of antenna design and placement on antenna performance, co-site interference, radiation hazards, EMC/EMI, RCS, ship magnetization, etc. for naval and ship building applications to improve the design efficiency and reduce physical testing costs. As the number of EM systems on naval platforms increases, the field testing of these systems can be either cost prohibitive or, in many cases, impossible. Simulations of the type presented in this article are being successfully used in the naval and ship building industry today, and their role will continue to grow in the future. ■

> **Simulations of the type presented in this article are being successfully used in the naval and ship building industry today, and their role will continue to grow in the future.**

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The Criticality of Defence Innovation for Canada

by Lee Vessey

Innovation gives military options and political choice to Canada in an increasingly precarious world. Although I am fortunate to now reside in Canada, I come from an assertive and continuously transforming organisation in the United Kingdom: the proud Royal Navy. We have 600 years of fighting tradition to uphold, deep historic roots that steel our resolve and calibrate our expectation to fight hard and to succeed conflict—as a tool our of nation's equally assertive ambition to do good in the world. In this Navy, I was a navigator, combat officer ("PWO"), training officer, and headquarters staff officer, and I held the privilege of Sea Command of RN warships twice. I spent many years at sea and in hostile and dangerous places, striving to collectively succeed. When on land and not generating for operations, I had roles chairing transformation projects, coordinating cross-government policy decisions, commanding training units, and initiating procurements—and I stood on all five continents.

I then came to Ottawa as an exchange officer, where I became central to technology pilot projects, naval innovation, and driving culture change towards innovation for the Royal Canadian Navy. At every stage I have learned like my life depended on it (more than once it did); sought to develop the confidence, competence, and potential of my crew, myself, and those around me; and applied a critical approach to problem solving. What have I learned? The criticality of military advantage: how it is directly proportional to political choice and the ability of nations to do practical good in the world and how bags of money, and other strong key national ingredients alone, are not enough.

This is a serious and dangerous world, and it has recently shifted from a competitive to, now, a contested domain. The likelihood of Canada needing to engage in a medium- or major-scale conflict is arguably higher now than it has been for decades, while, at the same time, old alliances and assumptions (including the assumptions of inclusion and protection) are being thrown up in the air (see the AUKUS submarine and disruptive technology international agreement). Our most likely adversaries are no longer just developing nations, pirates, or nationless terrorists but peer adversaries asserting their often malign will with significant "freedom" to manoeuvre. Their actions and intent seem to be in direct conflict with Canada's proud and world-leading liberal values (and often international law), and I believe in the various quotations and lessons: those around evil prosper only because it is insufficiently challenged by good.

Military Advantage

We, collectively (government and industry), are in the high-stakes business of the force generation of military capabilities. This includes training and equipping the best people with equipment so that they can risk their own lives and do good where the government sends them. It is a high-stakes business—not because of anything in the enterprise, but because those sailors, flyers, and soldiers are going to fight with the tools that we give them against ruthless, well-funded, and technologically advanced adversaries who want a very different outcome than we do. At the strategic level, something in the world will present itself as needing to be addressed: peacekeeping between warring parties, the evacuation of entitled persons from a war zone, or a blockade of an aggressor country. There are extremes and almost infinite scenarios, from rescuing a sinking ship in the Canadian Arctic to being obliged to respond to an enormous call for collective defence.

The military operational planners will offer a schematic of "effects" that the government can chose to apply to an area ("rescue," "interdict," "deny," etc.), but the available effects are based on a risk calculation that Canadian forces can enter the geographical area to execute their mission and not be immediately outmatched (and likely destroyed). The country that has generated and fielded the most capability has the advantage—and that capability comprises hardware, knowledge, tactics, logistics, training, people, and morale. The government will not have the option to send forces to do good in the world if the adversary has a technological advantage—because the operational risk is too high to commit them. Our ships, aircraft, land forces, etc. would not survive day one. Even if we had technological parity with an adversary, the risk calculation would be significantly high, and the likelihood of the government committing forces to the operation, confronting evil, contributing with our allies, and doing good in the world would be reduced.

Military advantage is only ever temporary. We have all enjoyed the paradox question: "Which has the advantage? The spear that can pierce anything? Or the impenetrable shield?" My answer: the one that holds, fleetingly, the most recent technological iteration. Arms races are bad—but technological inferiority, likely through unwarranted comfort with "late adoption," means you cannot even make it to the starting line. Technology development both has never been this fast and will never be this slow again—especially at the computing end of the spectrum of technologies. Often, however, there is a significant dilemma: procurement systems are shaped to replace current capabilities—and they really, really struggle to bring in something entirely new. You may encounter this in interpersonal exchanges in the following way: "I recommend this new technology, as it is incredible and a game-changer." "I agree, but which ship would it replace?" Sometimes, and, in fact, more often than not, the new technologies arriving with obvious military merit are so new that they cannot be a replacement, or an iteration, or even a bolt-on—they are an innovation and need their own new category.

The Innovation Landscape

The Material group in DND or ADM(MAT) is responsible for administering the buying and support of military equipment for which the Navy, Army, or Air Force have created requirements, concepts, and prioritization—and those services supply sailors and soldiers to work alongside the public servants to achieve this. Programme timelines typically start at 10 years because, unlike some of Canada's allies, the single services do not have a fully delegated budget. The Navy, for example, cannot initiate large programmes and spend big money without other government departments' consent. ISED (Innovation, Science, and Economic Development Canada) is a powerful department and force in ensuring that contract benefits, from activity in all government departments, go to the Canadian economy and industrial sector—especially ensuring that any money spent abroad can be positively offset in Canada (through the ITB policy). PSPC and their diligent commercial staff hold the pen on all contracts to ensure value for Canada and that all contract risk is avoided—and there are pros and cons when compared to countries where commercial activities are delegated with budgets. Treasury Board, Finance, and Cabinet will make the top decisions on submissions from the DND, ISED, etc. below.

It is a complicated and federated system that has not recently been aggressively transformed, in high profile, like the U.K. and U.S. equivalents. Perhaps the independence of the federated structure and the additive nature of most small reforms (i.e., adding rules and stakeholders rather than reductive transformation efforts, such as streamlining) are contributors to the procurement difficulties I have seen internally and that we see in the news. Replacement programmes are difficult to push through the process despite their concepts, requirements, ministerial submissions, and outlay already being well established and tangibly visible.

The country that has generated and fielded the most capability has the advantage—and that capability comprises hardware, knowledge, tactics, logistics, training, people, and morale.

Government and military procurement programmes have a really hard time with the unscoped—despite this often being where the most military advantage lies. There is not a baseline set of standards and requirements for a current or legacy in-service platform to copy and improve with "extra range" etc. The technology is not written in the policy; the briefings and ministerial endorsement have not been won and banked; and the business cases struggle to reference much more than observed merit, potential, and hope (perhaps in comparison against allies and potential adversaries if we are clever and have strong visibility of their development areas). New capability is also harder for government because of people capacity—and because of the absence of confidence that comes from seeing a predecessor working. "New" represents much higher risk to Ottawa—which means it is less likely to be endorsed in a system that incentivises risk avoidance.

Happily, the government has created a handful of innovation programmes that help this dilemma and recognise that governments no longer enjoy a WW2-style monopoly on new frontier technologies—the state of the art. In DND, DRDC's IDEaS programme offers government funding by commercially outsourcing research and development projects to Canadian industry—although R&D money is proving difficult to convert into follow-on procurement due to financial rules. ISED's ISC testing stream programme funds Canadian technology that is almost ready for commercialisation and does a simple, rapid 12-month contract to get it straight into end users' hands. There, it undergoes practical testing to determine its merit and refine it with expert feedback. Critically, government can buy the innovation without further competition if it genuinely has merit, shaving years off the conventional procurement way of doing things, though it would still need to absorb some programmatic risk to bring it into service without the full supporting project lines being worked out in advance.

NATO DIANA coming to Canada is very promising and will hopefully be a similar scheme to pilot new innovations with a way to buy them afterwards, and there are many other opportunities through provincial schemes, technology superclusters, NSERC grants, and even some of the big defence companies to create a healthy ecosystem to partner with and pull through mutually beneficial small and medium enterprises. A combination of public announcements, LinkedIn posts, and trawling Canadbuys.ca is normally adequate for businesses to spot these opportunities. Most of the technology and capability in this area are unscoped and opportunity led—which means there is an ability for the projects to fail and an expectation of risk versus reward to obtain military advantage. The Navy, Army, and Air Force requirements folks, who are delivering the aforementioned big replacement programmes, do so against highly accountable no-fail expectations and minimum 10-year timescales. They currently look across at "innovation" with a mix of scepticism, jealousy, and resignation. The goal, however, is to bridge these two worlds of the scoped (replacement) and the unscoped (innovation) pursuit of military capability and advantage.

Challenges

Large programmes need new technology to be derisked and inserted; otherwise, they risk delivering equipment obsolete on day one. Innovation tests need somewhere to go once they have proven merit to become a sustained military capability (and become accountable). Still, the innovation will, more often than not, need to cross into the big, slow, procurement world to become a sustained military capability. That is because we will need to force generate it into a deployable sustained capability that requires people, training, doctrine, logistics, and sometimes infrastructure and integration. Some helpful unconvinced stakeholders will even insist, to the point of veto, on rejecting a new initiative because of the absence an end-of-life disposal plan! Programmes like the ISC Testing Stream and its world-leading Pathway to Commercialisation are critical to bridging this gap—and the Navy, Army, and Air Force give ISC, IDEaS, etc. the themes for those calls from the list of challenges and opportunities they are aware of and have prioritised.

The DND and CAF personnel work incredibly hard, with the weight of the world and the constant worry of rule infraction on their shoulders. The CAF personnel are incredibly well trained for operations—but surprisingly poorly trained (relatively) for the internal business of the enterprise and even local business processes. Going from a tank to a procurement desk requires a switch of maybe 25 years of engrained managerial context, from reactive, life-or-death, preplanned responses to complex, obfuscated, counterintuitive rule sets and judgment criteria. They are not provided with enterprise management tools or even customer relations tools but have to navigate a perilous journey, engaging with dozens of red-card-holding stakeholders from isolated federations within defence (silos), each of which have their own microrules, procedures, and risk intolerance.

Government and military procurement programmes have a really hard time with the unscoped—despite this often being where the most military advantage lies.

It is nearly impossible to map out the business processes from start to finish (believe me—my old team and I have tried!)—and important initiatives often die. The job of senior leaders is to drive positive transformation and organisational progress. There has, however, been a huge turnover in senior DND leaders recently, and the atmosphere is quite different from the bold and brutal-but-professional style that I am familiar with in the United Kingdom. Accordingly, it may take time for some of those new leaders to find their disruptive voices and be able to boldly champion risk. Similarly, it is always beneficial to remind the wider workforce that we work for the end users, but, more than once, I have felt the need to express disagreement to a team who presents their primary objective as "to remove risk" rather than "to help get the best equipment to our people" (and, in doing so, hold appropriate risk).

The starting line is important too. It is a fallacy to take comfort in an ability to energise and enlarge an industrial base should a medium- or major-scale conflict commence. There is, for example, a medium-scale war in Europe right now that could escalate terrifyingly easily. Our allies—and our adversaries—conduct their planning and make their judgments, based on what we have force generated and can put out of the door today. Our friends are not reassured and bad guys are not deterred by an assertion that we could "spin things up" in six to 24 months—and we do not have the organisational muscle memory to buy and scale quickly. We have to maximise today to be credible, have the best chance of deterrence, and give our government options.

A Way Forward

When innovating with the government, industry should seek to help steer their technology towards a place where it can first be understood for its potential (normally by getting it into end users' hands) and then demonstrate its merit and seek to help it become a capability and accountable. Only then will it stick and be sustained as a military capability beneficial for temporary military advantage. We can look at our allies and our national competitors, too, for their good practice and collaborate with our friends and between government and industry, small and large scale, wherever we can offer mutual benefit (requiring a mutual interest in each other to begin with). Canada truly has a world-leading population of highly educated and diverse people; incredible universities, associations, and companies; a strong, well-funded government; vast resources; and domestic stability that allows focus on advancement. At the tactical level, however, even promising and merit-worthy innovations may not advance into capabilities unless they have some have some extra ingredients:

- *Senior advocation*: A senior officer's personal and emotional investment is crucial. Middle ranks and desk officers can only drive things so far before the culture and social rules of risk avoidance will kill the initiative—even one of high merit. They must have someone willing to internally lobby and support their desk officers in pushing through the thousands of mini barriers, initiate others to support it, and give mandate and top cover to those below that they are acting within the leadership's intent.
- *Policy inclusion*: Business cases must be able to refer to a line in top-level policy that validates the adoption of the

new innovation. We have the ability to influence what goes into policy by making the case strongly, loudly, and repeatedly for those just causes. An example: perhaps the new technology is an ocean-crossing, underwater, uncrewed submarine. It has no predecessor to replace, and it is not suitable for launching from a ship—but it still represents significant military advantage and should be included—so policy needs to create a separate new space for it. The normal initiator for shaping policy is a "concept." Military staff in the Force Development divisions have directors of strategy with teams who write these—though they often struggle to keep pace with the physical arrival of technology.

- *Matching*: The innovation needs to genuinely solve a challenge, scoped or unscoped, and that "match" needs to be confirmed by the most appropriate end users. This actually has a name in the military—in fact, it even has a form! It is called a *Statement of Capability Deficiency*. Although military end users have no ability to start buying stuff, they can articulate that they have experienced advantageous technology, perhaps through the ISC Testing Stream, and have their chain-of-command superiors enhance and endorse that newly understood "deficiency" of sustained capability to Ottawa. Faith in this process is important not only for military advantage but also for our front-line people and their expectations of being equipped with the best.

Merit

I should say what I (and many others) define as "merit" in military innovation and technology. It is a long list, but I shall summarise it as follows: "What increases the risk and cost to the enemy and/or decreases risk and cost to us." For this definition, "cost" is not financial (as Canada is, relatively, very wealthy) but is human time or cognition savings; reductions in errors; or more resiliency, durability, etc. Likewise, "risk" is not the institutional bias towards reputational or programmatic risk. It is hard, warfighting battlefield survivability risk and includes lethality, redundancy, etc. I should also emphasise that there is an unwritten "understanding" with our front-line people for equipping them with the best equipment in a way that matches their unlimited personal liability—but that it is undermined by the two decades of more modern personal devices in each of their pockets. Retaining people is actually even more critical to military advantage than technology!

Engaging more with end users should be a shared government and industry goal to try to find military advantage more quickly—and the only real cost of engagement is the careful management of time/capacity and expectations of those end users. They will be keen to not exceed their authority or to embarrass or trap their organisation (after all—their day job is to achieve the mission though exercising control and reducing risk), and they will have enormous amounts of feedback that must be properly captured. If the government organisation is good, they will have an internal process for harvesting challenges and ideas from their ranks that accelerates engagement with industry. As an undertaking to seek to empathise with the unique factors that government people face, industry could also consider helping with the cognitive load of envisioning the route to market for the staff they engage with—especially those in operational roles detached from spending authorities.

> **Everyone needs to hand over better than what was inherited, and that always requires investment in the future—from all ranks and areas.**

I am not saying that you need to know the myriad of processes inside government (as, currently, these are themselves siloed and almost secretive, with separate red-card-wielding stakeholders!) Simple steps through the innovation programmes, however, can be helpful to lay out to give assurance in these engagements as well as upfront clarity on where commit points specifically are and where freedom to explore without obligation can be enjoyed. In the middle ranks, you will find some scepticism from the battle scars of people who have tried to do "new" and been defeated. You will also encounter a genuine expression of the feeling, "We are too busy delivering our no-fail mission—I haven't the capacity to think about unscoped advantage for the future." Articulating the "penalty of inaction" is sometimes a useful go-to, but, less patronisingly, a general rule is more helpful: everyone needs to hand over better than what was inherited, and that always requires investment in the future—from all ranks and areas.

We must succeed in our effort to accelerate the ability to generate military advantage. The stakes are no less than grand: what Canada wants the world to look like (or not look like) and what Canada is able to do about it. We have an incredible set of national ingredients—from education to geography, history to values, resources to skills. Our allies are seized with this undertaking and are enhancing their posture, capabilities, and readiness with urgency, but, conversely, countries like China are patenting more new technologies in a year than all other countries combined. We must strive now to create a factory conveyor belt of new (not just replacement) capability. We must create organisational muscle memory and a culture of obtaining military advantage, and we must generate those new capabilities with urgency to be ready today and continually more quickly thereafter.

If we do this, we give Canada freedom to manoeuvre and do good in the world because we have ensured that we, represented by our armed forces, will not be outmatched. We can then confront bad guys, be present where we are needed, and allow the government greater choice in what effects it can apply in an increasingly dangerous planet that, frankly, needs more "Canada." ■

About the Author

Lee Vessey (leevessey@gmail.com) is a retired commander in the Royal Navy (RN) and a former RN exchange officer to the Royal Canadian Navy (RCN). Following a stint as the RCN's director of naval innovation, Lee left the RN and founded Rothera Innovate, an independent defence innovation consultancy based in Ottawa.

The International Union of Radio Science (abbreviated URSI, after its French name, Union Radio-Scientifique Internationale) has a long history of cooperating with IEEE to advance international cooperation in the study of electromagnetic fields and waves. This month's column focuses on the evolution of maritime communications and the opportunity for Canada to participate in the next wave of innovation in this space.

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3RD GENERATION PARTNERSHIP PROJECT AND NEXT-GENERATION MARITIME COMMUNICATIONS

The Early Days of Maritime Communications

During the latter part of the 1890s, the Royal Navy used Marconi wireless telegraphy equipment to assess the value of ship-to-ship and ship-to-shore communications for practical applications. Because communications ranges were limited to tens of nautical miles, the Royal Navy initially used the new technology for ship-to-ship communications with special emphasis on its use by scouts to report the position of enemy forces. During the annual fleet maneuvers that were conducted in 1899 and 1900, the value of wireless telegraphy in such applications was confirmed. As the range of wireless telegraphy systems increased to hundreds of nautical miles, it soon became practical for warships to exchange messages with nearby shore stations that would act as a link to conventional telegraph network and, eventually, directly to naval coastal radio stations.

The value of maritime wireless communications to ships in distress soon become apparent when, in January 1909, two passenger ships, *SS Republic* and *SS Florida*, collided under thick fog southwest of Nantucket, Massachusetts. *SS Republic* was equipped with Marconi radio equipment and quickly sent out a distress message. *SS Gresham* responded and a disaster was averted. In April 1912, *SS Titanic* struck an iceberg as it made its way from England to New York. It was also equipped with Marconi radio equipment and quickly sent out a distress message but the lack of standards or conventions for radio watchkeeping meant that at least one nearby ship, *SS Californian*, had stood down its ship station and did not receive the message. Subsequent inquiries recommended sweeping changes to maritime regulations, leading in 1914 to the establishment of the International Convention for the Safety of Life at Sea, which still governs maritime safety today.

The Global Maritime Distress and Safety System

During the late 1970s and 1980s, the International Maritime Organization (IMO) and the International Telecommunication Union (ITU) collaborated to fundamentally change the nature of maritime wireless communications. The Global Maritime Distress and Safety System (GMDSS) was an early adopter of digital communication technologies to automate what had previously been a very labour-intensive enterprise. It made obsolete the routine transmission of messages in the medium-frequency (MF) and high-frequency (HF) maritime frequency bands using Morse code.

The GMDSS includes

- terrestrial communication systems operating in the very HF (VHF), MF, and HF maritime frequency bands using analog technologies such as radiotelephony for person-to-person communications, and digital technologies such as digital selective calling capability and MF/HF narrow-band direct printing (NBDP) for automated watchkeeping and alerting.
- satellite communication systems using geostationary and nongeostationary satellites operating the ultra HF and superhigh frequency bands to provide reliable global coverage, although the cost of providing such service remains high and can only be justified for specialized applications.

> **The Global Maritime Distress and Safety System was an early adopter of digital communication technologies to automate what had previously been a very labour-intensive enterprise.**

- satellite-based localization of 406-MHz emergency position-indicating radio beacons.
- maritime safety information services provided via Navigational Telex (NAVTEX) systems (518 kHz international, 490 kHz and 4.2095 MHz national), MF/HF NBDP, and satcom-enhanced group call service.
- automated location of ships in distress using either radar search and rescue transponders (SARTs) (9.2–9.5 GHz) or VHF automatic identification system (AIS-SART) transmitters.

The GMDSS was soon complemented by technologies such as

- the automatic identification system (AIS), which enhances the safety of navigation and prevention of collision by providing identification, tracking, and other information about the ship to other ships and to coastal destinations automatically.
- long-range identification and tracking systems that allow global identification and tracking of ships up to 1,000 nautical miles from coast.

- ship security alert systems that provide covert alerts to competent authorities when the security of the ship is jeopardized by acts of terrorism and piracy.
- provision number 5.287 of the Radio Regulations, which allows the use of the frequency bands 457.5125–457.5875 MHz and 467.5125–467.5875 MHz by the maritime-mobile service for onboard communications

New Developments

In recent years, the IMO and the ITU Radiocommunication Sector have introduced several new concepts and technologies, including

- e-navigation, which is defined as *the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment*. In short, e-navigation systems will update information on computerized bridge displays in real time by interconnecting ships and shore facilities using various terrestrial and satellite-based digital communication links.
- the VHF Data Exchange System, which uses both terrestrial and satellite links to integrate the functions of VHF data exchange, application-specific messages, and the AIS in the VHF maritime band (156.025–162.025 MHz).
- navigational data (NAVDAT), a digital system operating in MF/HF maritime bands for broadcasting maritime safety and security information. NAVDAT systems may complement, or possibly replace in the future, current NAVTEX systems.

Several key agenda items at World Radio Conference 2019 (WRC-19) and the upcoming WRC-23 are focused on defining these services and allocating spectrum to them.

3rd Generation Partnership Project Systems in the Maritime Domain

Cellular-based communication systems have long been used to provide low-cost ship-to-shore communications when ships are in coastal waters and within range of shore-based base stations. With the advent of 5G cellular systems, however, 3rd Generation Partnership Project (3GPP)-based systems began to support 1) industrial vertical markets, 2) private networks that could be hosted by industrial end users, and 3) nonterrestrial networks. The 3GPP was quick to see the potential for such systems to provide services in the maritime domain at a far lower cost but potentially higher performance than previous maritime communications systems.

One of the strengths of the 3GPP approach is the manner in which common requirements are reused by different groups.

The first 3GPP Technical Specification covering service requirements (Stage 1) for the support of maritime communication (MARCOM) over 3GPP systems (TS 22.119) was approved in December 2018 at the Technical Specification Group Service and System Aspects Plenary meeting in Sorrento. It represents one of several 3GPP initiatives that aim to ensure that future 3GPP/5G systems meet the needs and requirements of a variety of vertical domains and result in a unified communication platform for a broad set of industrial applications. In particular, TS 22.119 has the potential to support both a new wave of GMDSS modernization and broader 5G maritime services.

One of the strengths of the 3GPP approach is the manner in which common requirements are reused by different groups. To this end, wherever possible, the groups will take existing service requirements from 3GPP Stage 1 specifications. Maritime is a good example of this principle, with more general mission-critical needs covered in other specifications, allowing TS 22.119 to be the deliverable that identifies only specific maritime needs, including the service requirements for the support of autonomous shipping and the broader digitalization and mobilization of maritime shipping. Despite efforts by the 3GPP to engage IALA, IMO, and other groups within the maritime community, much work remains to realise the full potential of this effort.

Despite the lack of initial progress, the 3GPP remains committed to supporting maritime communication over 3GPP systems, and the work continues. For Canada, this represents a significant opportunity to make an important contribution to a technology that aligns well with the goals of the National Shipbuilding Strategy and Canada's historical role as a telecommunications innovator. The Canadian National Committee of URSI hopes to take a leading role in encouraging and supporting work in this area by academic, government, and industry researchers in Canada. ■

The National Research Council of Canada is the adhering body for Canadian membership in URSI and appoints the members of the Canadian National Committee of URSI.

For more information about URSI International, please visit http://www.ursi.org/. For more information about URSI Canada, please visit http://www.ursi.ca/.

About the Author

David G. Michelson is president of the Canadian National Committee of the International Union of Radio Science (2018–2026) and past chair of the URSI–International Telecommunication Union Inter-Union Working Group. He has led the Radio Science Lab at the Department of Electrical and Computer Engineering, University of British Columbia (UBC), since 2003. His current research focuses on short-range/low-power wireless networks for industrial vertical and transportation applications, millimetre-wave channels and systems, and satellite networks for communications and remote sensing. Prof. Michelson currently serves as a member of the Board of Governors of the IEEE Vehicular Technology Society, as a member of the Steering Committee of the National Institute of Standards and Technology-sponsored NextG Channel Model Alliance, as director of both the AURORA Smart Transportation Testbed and UBC's Marine Systems Initiative, and as principal investigator of the Campus as a Wireless Living Lab project at UBC.

2023 Engineering Institute of Canada Awards Gala

The 2023 Engineering Institute of Canada (EIC) Awards Gala was held on 22 April 2023 at the Hilton Lac-Leamy hotel in Gatineau/Ottawa. The ceremony is held to announce the winning recipients of the EIC's 2023 senior engineering awards and fellowship inductees.


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Presentations at the EIC Awards Gala.


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Attendees at the EIC Awards Gala.


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The senior awards of the EIC are the highest distinctions made by the Institute and are awarded to deserving members of its 14 constituent societies. IEEE Canada is one of the 14 societies that make up the EIC.

2023 Engineering Medals

Six exceptional engineers were awarded the EIC's 2023 engineering medals in recognition of their outstanding achievements and service to the engineering profession. In addition, a total of 22 outstanding engineers were inducted as 2023 EIC fellows for their exceptional contributions to engineering in Canada.

The following medals were awarded:

- The 2023 Sir John Kennedy Medal was awarded to Delwyn Fredlund (CGS), Ph.D., O.C., FEIC, FCAE, P.Eng. emeritus professor, University of Saskatchewan, and senior geotechnical specialist, Golder Associates, for outstanding service to the profession or noteworthy contributions to the science of engineering.

- The 2023 Julian C. Smith Medal was awarded to the following two recipients: Michael W. Carter (IISE Cda Region), Ph.D., FEIC, FCAE, FACHS, professor, University of Toronto, ON, and Jamal Deen (IEEE Cda), Ph.D., FEIC, FCAE, FRSC, FIEEE, distinguished professor, McMaster University, ON, for their achievements in the development of Canada. Jamal Dean is a member of IEEE Canada.
- The 2023 K.Y. Lo Medal was awarded to Jingxu (Jesse) Zhu (CSChE), Ph.D., FEIC, FCAE, FRSC, FCIC, distinguished professor, Western University, London, ON, for significant engineering contributions at the international level.
- The 2023 John B. Stirling Medal was awarded to Jerzy Maciej Floryan (CSME), Ph.D., FEIC, FCAE, FCSME, professor, Western University, London, ON, for leadership and distinguished service at the national level.
- The 2023 CPR Engineering Medal was awarded to Jocelyn Hayley (CGS), Ph.D., FEIC, professor and department head, University of Calgary, AB, for leadership and distinguished service at the regional/local levels.

2023 EIC Fellowships

The following professionals were granted fellow status in the EIC in 2023:

- David Berger (IISE Cda Region), Criterium Group, Calgary, AB
- Pascale Champagne (CSChE), National Research Council of Canada, Boucherville, QC
- Anthony Chan (CMBES), British Columbia Institute of Technology, Burnaby, BC
- Ehab El-Salakawy (CSCE), University of Manitoba, Winnipeg, MB
- Natalie Enright Jerger (IEEE Canada), University of Toronto, Toronto, ON
- Yang Gao (IEEE Canada), University of Calgary, Calgary, AB
- Henry Leung (IEEE Canada), University of Calgary, Calgary, AB
- Xinyu Liu (CSME/IEEE Canada), University of Toronto, Toronto, ON
- David Mack (CDA), Klohn Crippen Berger Ltd., Calgary, AB
- Venkatesh Meda (CSBE), University of Saskatchewan, Saskatoon, SK
- Anil Mehrotra (CSChE), University of Calgary, Calgary, AB
- Bill Rosehart (CSSE/IEEE Canada), University of Calgary, Calgary, AB
- Mario Ruel (CGS), private consultant, Ville de Mont Royal, QC
- Abdallah Shami (IEEE Canada), Western University, London, ON
- Abdelhamid Tayebi (IEEE Canada), Lakehead University, Thunder Bay, ON
- Velko Tzolov (IEEE Canada), National Research Council of Canada, Ottawa, ON
- Mohammad Nasir Uddin (IEEE Canada), Lakehead University, Thunder Bay, ON
- Nicholas Vlachopoulos (CGS), Royal Military College of Canada, Kingston, ON
- Gaozhi (George) Xiao (IEEE Canada), National Research Council of Canada, Ottawa, ON
- Chunbao (Charles) Xu (CSChE), Western University, London, ON
- Alfred Yu (IEEE Canada), University of Waterloo, Waterloo, ON
- Baiyu (Helen) Zhang (CSCE), Memorial University, St-John's, NL

About the EIC

The EIC is a not-for-profit corporation originally founded in 1887 under the name "Canadian Society of Civil Engineers" (not to be confused with today's CSCE, which is the Canadian Society for Civil Engineering). At the time, the reference to "civil engineers" was chosen to differentiate the society's members from "military engineers." The original society name was changed to EIC in 1918 to reflect the diversity of engineering it represented as a learned society.

From 1887, the EIC's membership was made up of engineers of various disciplines of mechanical, civil, geotechnical, chemical, and electrical engineering. Starting in 1970, subgroups decided to incorporate as independent societies that also remained as EIC constituent societies. Hence started the slow transition to what the EIC officially became in 1986: a federation of technical societies. Since then, the EIC has not offered individual memberships. To belong to the EIC "family" and qualify for EIC awards, one must join at least one of its 14 constituent societies in the federation. Currently, 30,000 Canadian engineers and engineering students belong.

—Rob Anderson
IEEE Region 7 Director, 2022–2023
President IEEE Canada, 2022–2023

We Just Couldn't Resist …

David Green
St. John's NL
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A group of recently graduated electrical engineers started a new business. Their idea was an eye health-monitoring application. A user would periodically take selfies using their smartphone. The app would then infer certain metrics from the photo, such as pupil dilation and iris size, and keep a time series of the data. Anything out of the ordinary would be brought to the attention of the user and automatically sent to their optometrist for examination.

This group consisted of deep learning specialists, image and signal processing experts, and software developers. They consulted with a number of optometrists and ophthalmologists to better understand any visible symptoms of common ocular disorders. For one year, this dedicated start-up company worked long hours to gather data, develop the application, and test it.

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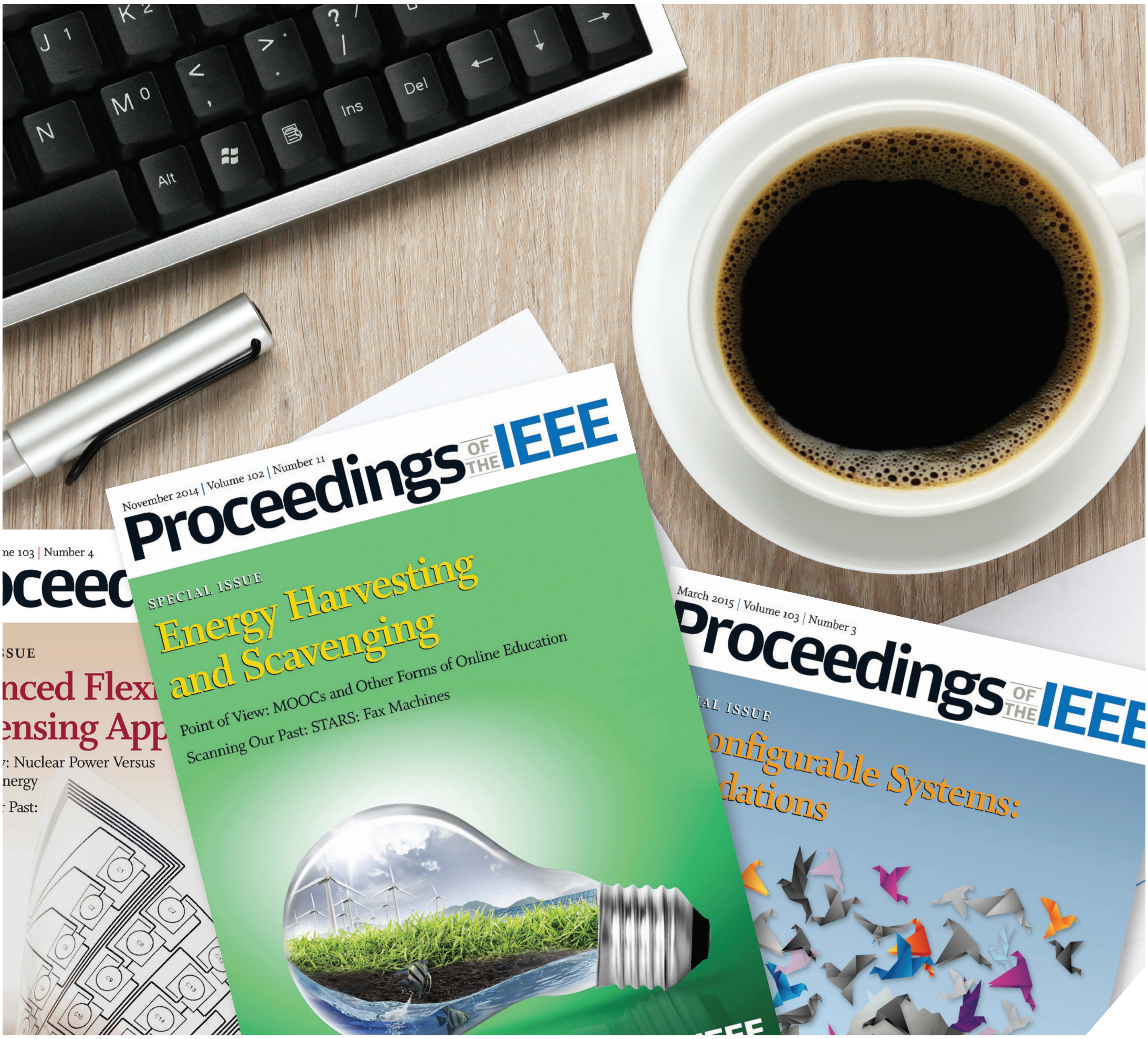
Finally, it came time to demonstrate the application to a larger audience and solicit feedback. They arranged for a large number of interested parties to attend from all over the world: medical professionals, occupational therapists, fellow engineers, and potential users. They had a choice of two venues with availability: one was at the famous Ritz Hotel in Paris, France, and the other one was at the Delta Hotel in downtown Toronto.

Most of the group wanted to attend the glamorous destination in Paris. However, the signal processing engineer was adamant that they attend the one in Toronto. When asked why, he replied: "The best way to get the response to a healthy eye system is with a Delta function." ■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IEEE Canadian Foundation

2023 Gargantini–Strybosch Scholarship Award Recipient

About the Scholarship

The nominee is expected to demonstrate

- brightness, in a broad well-rounded sense, not just academic course marks.
- integrity, the fundamental values of which are honesty, trust, fairness, respect, responsibility, and courage as well as trustworthiness. These values are central to the development and sharing of knowledge.
- engagement with his or her community, e.g., electrical and computer engineering and humanitarian use of technology, campus life, and the local, national, or international community.
- commitment to and enthusiasm for undergraduate study in fields of interest to IEEE.

This scholarship was established in 2020 by Dr. Irene Gargantini, IEEE Life Senior Member, IEEE London Section, and professor emeritus at Western University. She is the first (or tied for first) woman in Canada to chair a computer science department and has continued as a solid supporter of IEEE in Canada.

Aziz Rakhimov 2023 Recipient

Aziz Rakhimov is chair of the IEEE Okanagan Student Branch, and his role has been instrumental to the branch. Rakhimov was the driving force in reconnecting the branch following our return to classes after the COVID-19 pandemic. He was instrumental in rallying his peers and rebuilding the organization. Rakhimov was nominated by Dr. Jonathan Holzman, Student Branch counsellor at the University of British Columbia Okanagan (UBCO).

Aziz Rakhimov is chair of the IEEE Okanagan Student Branch, and his role has been instrumental to the branch.

Student Testimonial

"The news of the scholarship came as a wonderful surprise to me. I am grateful for the assistance that it offers and the support by the UBCO IEEE team and our supervisor, Dr. Holzman, over this past year. I am fortunate, indeed, to be surrounded by these individuals."

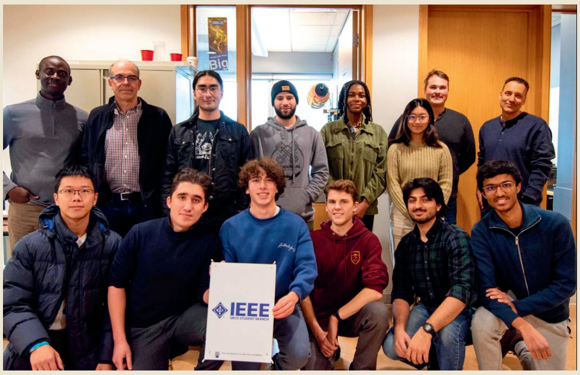
"The scholarship will allow me to continue the study of electronic technologies and step up the development of my prototypes. Truly exciting times lie ahead of me! Additionally, the scholarship will reignite my passion for work with IEEE and help me in my efforts to get others involved with the organization."

Establish a New Award to Implement Your Vision

Please consider endowing an award; there are many options.

The IEEE Canadian Foundation welcomes directed gifts from individuals, associations, corporations, and foundations. These are used to endow annual appropriately named awards that meet worthy but unfilled needs and further the purpose of the IEEE Canadian Foundation (https://www.ieeecanadianfoundation.org/EN/endowments.php).

Aziz Rakhimov, IEEE Student Branch chair, UBCO.



The IEEE Student Branch team, UBCO (Rakhimov is second from the left, bottom row).

Dr. Irene Gargantini, IEEE Senior Life Member, professor emeritus, Western University.

Tunnelling—A Journey of Engineering Success and Opportunity

by Terrance Malkinson

A tunnel is an underground route or passage excavated through the ground with an entrance and, for most tunnels, an exit. Humans have been tunnelling for many years, dating back to ancient times. Tunnelling was likely first accomplished by prehistoric people enlarging their caves. In Babylonia, tunnels were constructed for irrigation. A brick-lined pedestrian passage 900 m long was constructed (2180–2160 B.C.) under the Euphrates River connecting the royal palace with the temple. The Romans and Greeks built tunnels to reclaim marshes by drainage and for water aqueducts. The largest tunnel in ancient times (36 B.C.) was the 1,463-m road tunnel Pausilippo, between Naples and Pozzuoli. During these times, tunnelling was a very dangerous activity often using slaves and accompanied by many accidents and fatalities.

Innovative engineering practices now allow the safe construction of longer, deeper, and wider tunnels through difficult underground terrain. Tunnels are particularly useful in mountainous terrain, under heavily populated areas, and under bodies of water. Tunnels are often the shortest, fastest, safest, and most cost-effective route between locations avoiding disruption to surface property. Tunnel engineering is a rapidly growing industry because of its increasing importance to urban densification and the efficient rapid transit of people and goods between locations. Tunnelling presents many employment opportunities. In this article, a selection of global and Canadian tunnel projects is discussed.

The Tunnel Engineer

The complexity of tunnelling necessitates innovation, practical expertise, and technical proficiency. The global demand for specialists in this area is increasing. Specialization most often occurs after a graduate degree in civil or geotechnical engineering. Many of the skills are acquired through work experience under the guidance of a mentor because the scope of these megaprojects is nearly incomprehensible, requiring adaptability, creativity, and innovation. Highly skilled tunnel engineers are involved at every stage of the tunnel-construction process, from design through completion, accurately assessing and managing the engineering requirements needed to execute the project. The primary duties of the tunnel engineer include

- understanding the project's scope and scale
- comfortability with working in confined spaces
- developing and assessing design options, engineering tasks, cost estimates, and feasibility analyses
- preparation of engineering documents, modelling, and geotechnical and structural engineering analyses
- approving the tunnel design for durability, strength, safety, and compliance with codes
- acquiring the project's requisite permissions and approvals
- creating the project's bid documentation, including design, tender, and contract documents
- assisting with the determination of prospective contractors
- supplying engineering drawings and relevant paperwork to contractors
- evaluating on-site progress, executing the work schedule, and safety assessments
- resolving construction-related problems
- controlling construction activity, communication with diverse project teams, and worker management
- producing end-of-project closure documentation and archiving all records
- demonstrable skills in project management and with relevant software.

Types of Tunnels

The following are six primary types of tunnels, categorized by their purpose:

1) *Traffic tunnels*: Railway, highway, and pedestrian tunnels are examples of traffic tunnels. The obstacles to traffic include mountains, hills, water, and densely populated areas. Tunnels divert traffic from the surface to a subsurface route, facilitating the rapid and efficient flow of vehicles and people.
2) *Hydropower tunnels*: These tunnels were created for electricity generation. They carry water under gravity from a high elevation exiting at a low elevation after passing through electrical generation turbines. Often an underground rock chamber is created to accommodate the hydro powerhouse, such as one of the world's largest (300 m long × 25 m wide × 50 m high), the 11-turbine Churchill Falls, with its 300-m head (www.ewh.ieee.org/reg/7/millennium/churchill/cf_home.html).
3) *Public utility tunnels*: These tunnels were created for pipeline transport of urban waste as well for conduiting pipes, electrical/communication cables, and supplies of oil, natural gas, or water. Increasing urban densification is requiring urgent replacement and upgrading of public utilities to meet the service demand.
4) *Archival/protection tunnels*: These tunnels were created to protect documents and property from catastrophic events such as war, floods, and earthquakes. One example of this type of tunnel is the Svalbard Global Seed Vault (www.seedvault.no) located in Norway. This is a secure tunnel facility built into the side of a mountain. It is intended to safeguard the seeds of the world's food plants in the event of a global crisis. Currently, it contains more than 1,194,944 seeds from more than 5,000 plant species. Many large museums and governments have underground storage facilities to protect their collections and documents.
5) *Military tunnels*: These are secure secret tunnels used by governments as part of their national defense infrastructure. They are also built as a place where government officials can move to in the event of a global military conflict. The Canadian "Diefenbunker" is a massive four-story underground bunker (currently decommissioned) built

between 1959 and 1961 (https://diefenbunker.ca/en). During the Cold War, top officials were to take shelter within the bunker in the event of a nuclear war.

6) *Shafts*: These one-primary-entrance vertical tunnels are used to remove (mine) minerals and other natural resources from the depths of the earth. Oil well drilling, although not technically a tunnel, is a small-diameter shaft created with a rotary cutting head. Shafts are also used to access underground scientific laboratories such as the Sudbury Neutrino Observatory Laboratory (SNOLAB) (www.snolab.ca).

Preliminary Surveys

Before a tunnel is constructed, a number of exploratory steps must be completed to give a clear picture of the topographical, geological, and hydrological properties of the proposed route. Preliminary surveys establish the topography of the area by marking the highest and lowest points and occurrence of valleys, depressions, slopes, and slide areas. Surface and underground utilities are located and documented. Geological surveys provide information about the composition and thickness of rocks within the proposed tunnel alignment. These establish the structural features of rocks, such as strength folding, faulting, unconformities, jointing, and shearing planes. Hydrological surveys provide information on the depth of the water table, possibility of the occurrence of major and minor aquifers, and hydrostatic heads, which might occur along the proposed alignment. Even with the most comprehensive surveys, surprises often occur during construction, challenging engineers to create innovative problem solutions.

Methods of Tunnelling

Various techniques can be used for the design and building of a tunnel. The results of the preliminary surveys will determine the best method to use, including the following:

- *Open cut*: This method, often known as *cut and cover*, works well for short tunnels. It entails creating an open trench within which the tunnel conduit is inserted. The trench is then backfilled.
- *Immersed tube*: For tunnels that span deep water, prefabricated concrete or steel tunnel segments are lowered into a trench dug out on the floor of the body of water, connected together, and the trench is then backfilled.
- *Pipe jacking*: A driving pit is built using a trenchless process known as *pipe jacking*. Segments of steel or concrete tube are hydraulically jacked forward from the pit to create the tunnel lining. Box jacking is similar to pipe jacking, however, instead of a pipe, a box-shaped segment is jacked forward, which allows for creation of a larger tunnel.
- *Microtunnel*: Microtunnelling machines, which can operate in nearly any type of ground condition, are generally used to bore small-diameter tunnels. Microtunnelling machines can be operated from the surface, and spoil is removed from the cutting face by a conveyor inserted into the pipeline as it is being built. This is frequently utilized in smaller-diameter situations required for urban drainage systems.
- *Auger (whole face) boring*: This is mostly used for installing large-tunnel wall conduit. The boring machine has a directed, spinning cutting head. The excavated material is moved back, and a rail-mounted machine conveys the excavated material to the surface where the material is collected and repurposed. A cement or metallic tube or sleeve follows the cutter through the ground. These form the wall of the tunnel.

Large Global Tunnel Infrastructures

Throughout history, numerous tunnels have been constructed, overcoming seemingly insurmountable engineering challenges. This is not intended to be a comprehensive list of all international tunnel projects, but rather a selection of the more interesting, unique, and significant milestone tunnels that have been completed and are in progress.

Figure 1: A commemorative plaque at the Rotherhithe underground station. (Source: Sunil060902, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons)

The Thames Tunnel (United Kingdom)

The Thames Tunnel (1825) was the world's first tunnel under a river, a significant accomplishment at the time (www.ltmuseum.co.uk/blog/brief-history-thames-tunnel-and-east-london-line). After numerous failed attempts in the soggy soil, an engineer, Marc Bunel, developed a cast-iron tunnel shield, a revolutionary advance in tunnelling technology. Digging under the river provided many challenges, including tunnel flooding, fatalities, and a seven-year abandonment during the 18-year construction process (see Figure 1).

Channel Tunnel (United Kingdom/France)

One of the best-known tunnels is the 37.9-km undersea Channel Tunnel connecting England with continental Europe (www.theconstructor.org/case-study/channel-tunnel-construction/199091). French engineer Albert Mathieu first proposed a tunnel under the English Channel in 1802. Plans were abandoned in 1882 as politicians feared that a tunnel would compromise the country's defense. After numerous false starts following World War II in 1987, the British and French parliaments agreed to the project, comprising two rail tunnels and a third service tunnel. More than 13,000 workers took six years to build the tunnel using boring machines. At the time, it was the longest of its kind in the world. The engineering and manpower costs grew to 80% more than originally estimated. The Channel Tunnel opened on 6 May 1994. The Channel Tunnel was named one of the "Seven Wonders of the Modern World" by the American Society of Civil Engineers. This tunnel changed the geography of Europe. More than 4.5 million passengers use the Channel Tunnel every year, and the goods transported via it contribute to the U.K. and European economies. The Channel Tunnel, with its political, diplomatic, financial, and technical success, became a milestone for engineering megainfrastructure projects.

Gotthard Base Tunnel (Switzerland)

The world's longest and deepest tunnel, at a distance of 57 km underneath the Swiss Alps, was 17 years in the making (www.railway-technology.com/projects/gotthard-base-tunnel). It cost approximately US$12 billion using multiple tunnel boring machines simultaneously and opened on 11 December 2016. Reaching a depth of 2,300 m, the tunnel runs between the towns of Erstfeld in the north and Bodio in the south, moving passenger and freight rail cars between Zurich, Switzerland, and Milan, Italy. Trains at speeds of up to 250 km/h travel the distance in 20 min.

Laerdal Tunnel (Norway)

The 24.5-km Laerdal Tunnel in West Norway is the world's longest road tunnel and cost US$153 million to build (www.roadtraffic-technology.com/projects/laerdal-tunnel). Drilling the tunnel was accomplished using computer-controlled hydraulic drilling as well as traditional drilling and blasting. It opened in 2000, connecting Oslo and Bergen. The length of the tunnel required engineers to include innovative features designed to alleviate claustrophobia and monotony, reducing driver fatigue and improving safety.

Tokyo Bay Aqua-Line (Japan)

The Aqua-Line, crossing Tokyo Bay, opened in 1997 and connects the cities of Kawasaki and Kisarazu (www.nccnet.co.jp/english/introduction/tokyobay.html). The structure comprises a 4.4-km bridge span as well as the 9.6-km subsea shield conduit tunnel. The resilience of the construction was proven during the 2011 Tōhoku-Pacific Ocean earthquake, which caused severe damage to Tokyo Bay.

Eisenhower Tunnel (Colorado, USA)

The 2.7-km Eisenhower Road Tunnel in Colorado is one of the world's highest, located 3,401 m above sea level at the highest point on the U.S. interstate highway system (www.codot.gov/travel/ejmt/eisenhower-memorial-bore.html). Two twin bores stretch 2.7 km at distances of 35–70 m apart. Opened in the 1970s, the tunnels rise toward the west and at times approach grades of 7%.

Spiralen Tunnel (Norway)

The 1.65-km Spiralen Tunnel, built in 1961, comprises six spirals covering 1,649 m winding around its own axis 6.5 times while rising 213 m (www.dangerousroads.org/europe/norway/9347-spiralen-tunnel.html). This eight-year construction project opened in 1961.

Stormwater Management and Road Tunnel (Malaysia)

The Stormwater Management and Road Tunnel (SMART) is a combined road and flood relief 9.7-km tunnel opened in 2007 (www.roadtraffic-technology.com/projects/smart). The tunnel was built to solve the problem of flash flooding in Kuala Lumpur. SMART can operate in three ways: 1) when there's no flooding, it serves as a road tunnel; 2) when there are floods, rainwater can be diverted into a lower channel, and the upper level will remain open to traffic; and 3) when exceptionally heavy floods occur, the tunnel closes to all traffic and watertight gates open to allow floodwater to flow through. It can be returned back into a road in a few hours. The tunnel prevents billions of dollars of flood damage and reduces costs from traffic congestion.

Marmaray Tunnel (Turkey)

Connecting Europe to Asia via tunnel was a nine-year construction project for the Turkish government (www.railway-technology.com/projects/marmaray). The Marmaray Tunnel is 76 km long with a maximum depth of 55 m. Opened in 2013, Marmaray gives Istanbul a new rail line in and out of the city. Crews used the immersed tube strategy to fabricate portions of the tunnel on the surface and then sunk and joined them on the seabed. Flexible joints made of rubber-reinforced steel plates were designed to absorb any earth movement.

Large Hadron Collider Tunnel (France/Switzerland)

At 27 km in circumference and buried 174 m below the France–Switzerland border, the Large Hadron Collider is the world's largest and most powerful particle accelerator. (www.home.cern/science/accelerators/large-hadron-collider). The enormous tunnel is a marvel of engineering deep under the Alps and was completed in 2008, facilitating scientific investigations. Guided around the accelerator ring by a strong magnetic field maintained by superconducting electromagnets, two high-energy particle beams travel in opposite directions in separate, ultrahigh vacuum beam pipes at close to the speed of light before they are made to collide.

Fehmarnbelt Fixed Link (Baltic Sea)

When completed in 2029, the 18-km Fehmarnbelt Fixed Link will be the longest combined road and rail tunnel anywhere in the world (www.geoengineer.org/news/fehmarnbelt-tunnel-europes-new-shortcut-links-germany-and-denmark). Descending up to 40 m beneath the Baltic Sea, it will link Denmark and Germany across the Fehmarn Belt, a strait between the German island of Fehmarn and the Danish island of Lolland. It will comprise two double-lane motorways separated by a service passageway and two electrified rail tracks. After more than a decade of planning, construction started on the Fehmarnbelt Tunnel in 2020. A temporary harbor has been completed on the Danish side and will be the site of the factory that will build the 89 massive concrete sections that will make up the tunnel. Beginning in 2024, the first tunnel element will be immersed in the trench. Each section will be 217 m long, 42 m wide, and 9 m tall, weighing 73,000 metric tonnes and moved into place by barges and cranes.

The Great Escape Tunnel (Poland)

The Stalag Luft III prisoner-of-war (POW) camp was located in Lower Silesia, near the town of Żagań, Poland, 160 km southeast of Berlin. This location was chosen to house a German POW camp because it was a difficult area to escape from. It was built on top of yellow sand, which was tough and weak to tunnel through. In the spring of 1943, more than 600 prisoners began digging tunnels, led by Royal Air Force pilot Roger Bushell (www.businessinsider.com/true-story-of-76-allied-prisoners-great-escape-from-nazis-2021-3). The squadron leader had hoped to get 200 men out in a single attempt by digging three separate tunnels. The tunnels were approximately 9 m below the surface. The tunnels were shored by wooden bed boards. Stolen wire was used to hook up illumination to the camp's electrical supply. A total of 76 prisoners were able to crawl through the tunnel to freedom before the early morning of 25 March; however, a German soldier on patrol exposed their escape plan. Within two weeks of the escape, 73 of the 76 men were recaptured, many of whom were executed. Only three prisoners successfully escaped (www.pbs.org/wgbh/nova/greatescape/three.html). Beside the marked tunnels there is not much left of the former prison camp (www.landmarkscout.com/the-great-escape-stalag-luft-iii-zagan-poland). Nearby is a museum, and near the woods is a memorial for the 50 executed prisoners. This true event is a testament to those who fought to defend freedom.

Elizabeth Line (United Kingdom)

London's US$25 billion, 41 station railway, which took 23 years to build, achieved 100 million passenger journeys on 1 February 2023, only eight months after opening in May 2022 (www.cnn.com/travel/article/crossrail-london-2022-launch/index.html). It stretches 97 km east to west across the city and comprises 42 km of new tunnels up to 40 m underground under central London. Eight 1,000-tonne tunnelling machines were used. The twin tunnels, 6 m in diameter and up to 40 m deep, weave around building foundations, London's underground tunnels, and countless other structures and utilities. Roughly 600,000 journeys are made each day on the railway on trains capable of carrying 1,500 passengers at up to 90 mi/h. More than 63,000 sleepers and 51,419 m of rail were installed.

The Canadian Tunnelling Experience

The Tunnelling Association of Canada (www.tunnelcanada.ca) brings together Canadian, North American, and international communities to promote and advance Canadian tunnelling and technologies. The Association encourages excellence and safety in the design, construction, and maintenance of tunnels and underground excavations and is the Canadian representative to the International Tunnelling Association. A book from the Tunnelling Association of Canada, marking its 40th anniversary in 2020, celebrates Canadian Tunnelling (www.youtube.com/watch?v=ft4BwPH6niM). Once again, this is not intended to be a comprehensive list of all the tunnel projects in Canada, but rather a selection of the more interesting, unique, and significant milestone tunnels that have been completed and are in progress.

Toronto Hydro One Electrical Transmission Conduit Tunnel (Ontario)

On 23 January 2023, Hydro One lowered its 68,000-kg, 3.5-m-diameter tunnel boring machine into a shaft at the Toronto Esplanade transmission station (www.msn.com/en-ca/news/world/celtic-tiger-tunnels-under-downtown-core-to-improve-electricity-grid/ar-AA16FvSe?ocid=msedgntp&cvid=a6daf7b0bba44b0689f5386dce7ecf02). The boring machine will dig a 2.5-km tunnel 25 m below the surface. The US$120 million project will replace aging transmission cables to improve the electrical grid. After the tunnelling, it will take roughly two years to install electrical cabling.

Canadian Pacific Spiral Tunnels (British Columbia)

The Canadian Pacific Spiral Tunnels are located in the Kicking Horse Pass of Yoho National Park at an elevation of 1,643 m (www.yourrailwaypictures.com/Tunnels). The Spiral Tunnels replaced "The Big Hill," constructed in 1884, which experienced many derailments on the 4.4% downhill grade. In 1907, an engineer named *J.E. Switzer* designed a rail configuration based on some famous tunnels in Switzerland, where a train could proceed down a hill by going through a series of loops. This route consisted of two tunnels constructed as three-quarter circles into the valley walls. Without the use of modern technology, workers carved out the tunnels at both ends, deviating by only 5 cm off the mark when they met in the middle. This doubled the length of the climb and reduced the gradient to 2.2%. The work ended in 1909 and cost US$1.5 million. On average, 25–30 trains pass through the tunnels each day.

Ripple Rock Explosives Tunnel (British Columbia)

Ripple Rock was an underwater hazard located on British Columbia's (BC's) Seymour Narrows. It was a major marine navigational hazard in a very important waterway on the inside BC coast. The twin peaks of an underwater mountain located just below the water in the narrow waterway left only 3 cm of clearance at low tide. The peaks also created whirlpools that sucked smaller boats into the depths and threw larger ones off course. Ripple Rock claimed the lives of at least 114 people. In 1953, the National Research Council of Canada commissioned a feasibility study on the idea of placing a large explosive charge underneath the peaks by drilling vertical and horizontal shafts from nearby Maud Island. Between November 1955 and April 1958, 75 men created 150 m of vertical shaft from Maud Island, 720 m of horizontal shaft to the base of Ripple Rock, and two main vertical shafts up into the twin peaks, from which shafts were drilled for the explosives. One thousand two hundred seventy metric tonnes of Nitramex 2H explosive was placed in these shafts. The demolition on 5 April 1958 that removed the peaks was a major engineering feat (www.cbc.ca/news/canada/british-columbia/60-years-later-a-major-underwater-explosion-in-b-c-still-fascinates-1.4598172). It was also one of the first events to be broadcast live across Canada. It sent 635,028 tonnes of rock and water 305 m into the air in 10 s. The blast successfully increased the waterways' clearing at low tide to roughly 14 m.

Niagara Tunnel (Ontario)

On 25 June 2004, the Ontario government announced approval for Ontario Power Generation to proceed with the creation of a third 10,400-m-long tunnel under the city of Niagara Falls (www.niagarafallsinfo.com/niagara-falls-history/niagara-falls-power-development/the-niagara-tunnel-project/the-summary-of-the-tunnel-project). At an expected cost of US$600 million, this hydro tunnel is expected to be one of the largest tunnels built in North America. The project involves boring a tunnel 14.4 m to a maximum depth of 140 m below the city of Niagara Falls. This tunnel will allow an additional 500 m^3 of water per second to be diverted for power generation, enhancing the Sir Adam Beck Hydroelectric Generating Stations by producing an additional 1.6 TWh of electricity.

SNOLAB (Ontario)

SNOLAB (www.snolab.ca) is Canada's deep underground research laboratory located in Vale's Creighton Mine near Sudbury, Ontario. At 2 km, SNOLAB is the deepest lab in the world, comprising 5,000 m^2 of clean space underground for experiments and supporting infrastructure. A staff of more than 100 support the science, providing business processes, engineering design, construction, installation, technical support, and operations. The laboratory provides a low-background environment for the study of extremely rare physical interactions. SNOLAB's science program focuses on astroparticle physics, specifically neutrino and dark matter studies, and because of its unique location is also well suited to biology and geology experiments. The entrance to the underground facility is on the 2,073-m level of Vale's Creighton Mine via 9 Shaft, and SNOLAB's underground facility is 1.8 km from the shaft itself. The ambient rock temperature at this level is 42 °C, and there is a 2,070-m granite rock overburden. Among the other investigations scientists and engineers are conducting are multimillion dollar experiments on why the universe exists (www.cbc.ca/radio/ideas/particle-astrophysics-studying-origin-of-universe-1.6733153?cmp=newsletter_The%20IDEAS%20Newsletter_8332_877318).

Green Line Rapid Transit Tunnel (Alberta)

The Green Line is a three-stage light rail train line under construction in Calgary (www.calgary.ca/green-line.html). The rail line will run between Calgary's northern and southeastern boundaries and comprises 29 stations spanning 46 km. Construction began in April 2022 with the relocation of utilities along the alignment. The line will be tunnelled 4 km through downtown Calgary with four underground stations. Tunnelling has its risks because of the threat of severe water damage and leaks in this preglacial valley, as has been shown by precedent downtown construction. A considerable amount of water flows through underground gravels, sands, and siltstones beneath the downtown area. The current plans suggest using a tunnel boring machine, coupled with the conventional cut-and-cover method (see Figures 2 and 3).


(a)
(b)

Figure 2: Photos of the construction of the Calgary public utility northwest inner city local and community drainage improvement project using the open cut method (www.calgary.ca/planning/water/sunnyside-cdi.html). (a) A crew digs the 5-m-deep trench along a residential street. (b) The trench has a concrete 0.6-m-diameter drainage conduit.

George Massey Tunnel Replacement (BC)

A new eight-lane immersed-tube tunnel will replace the George Massey Tunnel on Highway 99, providing people a toll-free crossing that aligns with regional interests and improves transit, cycling, and walking connections across the Fraser River (https://news.gov.bc.ca/releases/2021TRAN0124-001624). The tunnel will be in operation in 2030, with the cost estimated at US$4.15 billion. For the immersed tunnel, two side-by-side tubes will each contain four vehicle lanes, with two lanes dedicated for bus rapid transit. A smaller third tube with a width of 5 m will be dedicated for pedestrians and cyclists. The tunnel will have a depth equal to that of the existing tunnel to meet navigational requirements in the Fraser River, and to reduce construction costs. It will have a length of 1.1 km, with 660 m being the immersed tunnel segment under the river. The existing tunnel will be removed upon completion.

Stanley Park Water Supply Tunnel (BC)

Vancouver is planning a US$100 million water infrastructure project, called the *Stanley Park Water Supply Tunnel*, 30–50 m below ground level and 1.4 km long through Stanley Park (www.cbc.ca/news/canada/british-columbia/proposed-water-tunnel-beneath-stanley-park-to-replace-aging-pipes-1.4342829). Water will enter the tunnel at Burrard Inlet, and the end of the tunnel will be adjacent to the existing Secondary Disinfection station at Chilco Street. This new tunnel will meet seismic standards; ensure the continued reliable delivery of clean, safe drinking water to the region; and increase the capacity of the existing system. Construction is expected to start in 2022 and finish in 2027.

Newfoundland to Canada Mainland Tunnel (Labrador/Newfoundland)

A fixed transportation link between the Island of Newfoundland and Labrador across the Strait of Belle Isle has been discussed for many years. In April 2004, a contract to study the feasibility of the concept was awarded to Hatch Mott MacDonald (www.gov.nl.ca/publicat/fixedlink). Three basic fixed-link concepts were studied: bridge, causeway with bridges, and tunnel. A tunnel bored using modern tunnel boring machines under the Strait of Belle


(a)
(b)
(c)

Figure 3: The Calgary public utility northwest inner city community drainage improvement project (www.calgary.ca/planning/water/sunnyside-cdi.html). (a) Photos of the 4-m-diameter boring machine. (b) A boring machine being lowered into the 20-m-deep × 13-m-diameter launch shaft caisson. (c) The 4-m-diameter cement conduit insert segments, which follow the boring machine. The conduit terminates at the Bow River.

Isle, at its narrowest point, is the most technically and economically attractive alternative. The tunnel would be bored through the ground deep under the strait and safe from icebergs. The construction cost of a bored tunnel would be approximately US$1.2 billion (in 2004 dollars). The construction period would be six years, and an additional five years would be required for planning, additional studies, and investigations and environmental assessments, for an overall development period of 11 years. Based on traffic projections over a 30-year period, the most economic tunnel arrangement would be an electric train shuttle, operating through a single tunnel with staged operation in each direction, which conveys road vehicles on custom-designed rail cars. Currently, governments are evaluating funding for this project (www.cbc.ca/news/canada/newfoundland-labrador/pov-fixed-link-food-security-1.5520172).

Conclusion

Ageing infrastructure and densification of urban areas will require innovative engineering solutions such as nondestructive tunnelling. This article presented a snapshot of a selection of unique, milestone international and Canadian tunnelling projects from ancient times through to those proposed in the future. New projects are being announced frequently, such as those made by U.S. President Biden in January 2023 to address bottlenecks at century-old train tunnels in Baltimore and New York City. The 150-year-old Baltimore and Potomac tunnel will be replaced by two new tubes for Amtrak and Maryland Area Regional Commuter trains. A new rail tunnel will be constructed beneath the Hudson River and rehabilitation of the existing tunnel is planned, which will be known as the *North River Tunnel*.

The unique challenges presented with each tunnel project can be overcome through innovation and the application of engineering principles. The examples presented in this article clearly demonstrate that regardless of the challenges, engineers have the skills to solve complex problems. Tunnel engineering is a growth industry and presents many interesting and challenging employment opportunities not only for engineers but also many other skilled tradespeople. ■

About the Author

Terrance Malkinson (malkinst@telus.net), the author of more than 600 peer- and editorial-reviewed earned publications, is now retired. His diverse career path included 26 years in medical research as a founding member of the Faculty of Medicine at the University of Calgary, a three-year appointment as a business manager with the General Electric Company, followed by a one-year applied research appointment with SAIT Polytechnic. He is an alumnus of continuing professional education programs with Outward Bound International, Banff Centre for Management, the Massachusetts Institute of Technology, and the University of Colorado. During his long career, he has advanced both basic and applied medical, health and wellness, scientific, and engineering knowledge. He has trained and mentored undergraduate, graduate, and postdoctoral students as well as staff in the business sector and government. He is a 50-year Life Senior Member of IEEE. He has served in many professional public and private governance and publication roles. He is a founding member of *IEEE USA Insight*. He is the recipient of several peer-selected earned awards including induction into the Order of the University of Calgary, IEEE achievement medals, and APEX awards for publication excellence. In retirement, he vigorously continues basic and applied research, with an extensive portfolio of projects. He is a manuscript reviewer and a special topic editor for several journals. Other passions include communicating emerging technologies to the public, investigative journalism, philanthropy, and mentorship. His current research interests in emerging technologies and health and wellness extends to being an accomplished multisports triathlete, including among other events, the completion of 11 full-distance Ironman Triathlons.

Dr. Donna Strickland Receives IEEE Honorary Membership

IEEE Canada is excited to share the news that Dr. Donna Strickland, colaureate of the 2018 Nobel Prize in Physics, has received IEEE Honorary Membership. This was awarded on 5 May 2023 at the IEEE Vision, Innovation, and Challenges Summit and Honors Ceremony, held at the Hilton Atlanta. It was cited that “Donna is a true role model to legions of engineers around the world. She is an extremely giving person and a shining example of what an IEEE honorary member should be.”

IEEE Canadian Review published an article in the Spring 2020 issue on Dr. Strickland’s work. This feature article, authored by Dr. Daryoush Shiri, is available at https://tinyurl.com/bdcrb9b9.

Dr. Maike Luiken Receives 2023 MGA William W. Middleton Distinguished Service Award

On 17 June 2023, the IEEE Member and Geographic Activities (MGA) Board approved the recipient of the 2023 MGA William W. Middleton Distinguished Service Award:

Maike Luiken
Region 7 – London Section, Canada
"For exemplary leadership and commitment to MGA, IEEE members, and the public and for championing technological solutions to sustainable development and climate change challenges"

The purpose of the MGA William W. Middleton Distinguished Service Award (https://mga.ieee.org/awards/mga-awards-and-recognition-program/mga-william-w-middleton-distinguished-service-award) is to honor an individual who, over a long and sustained period of leadership, contributed in an exemplary manner to MGA, its activities and achievements, and the attainment of its strategic goals (https://mga.ieee.org/board-committees/mga-strategic-plan).

The award, presented every three years, is named for William W. Middleton (https://mga.ieee.org/awards/biography-of-william-w-middleton), who for more than 40 years was associated with and contributed to the growth and maturation of the Regional Activities Board (now MGA) through service on it and its various committees and task forces; he was chosen to be the first recipient.

IEEE South Saskatchewan Section Receives 2023 MGA Outstanding Small Section Award

On 17 June 2023, the IEEE Member and Geographic Activities Board selected the recipients of the 2023 MGA Outstanding Large, Medium, and Small Section Awards, based on 2022 activities. IEEE Canada is delighted to share the news that the 2023 MGA Outstanding Small Section Award recipient is the IEEE South Saskatchewan Section from Region 7.

Congratulations to all of the Sections that were selected for these awards "for successful efforts in fulfilling the educational and scientific goals of IEEE for the benefit of the public by maintaining, enhancing, and supporting the Student Branches, Technical Chapters, and Affinity Groups within their geographic boundaries."

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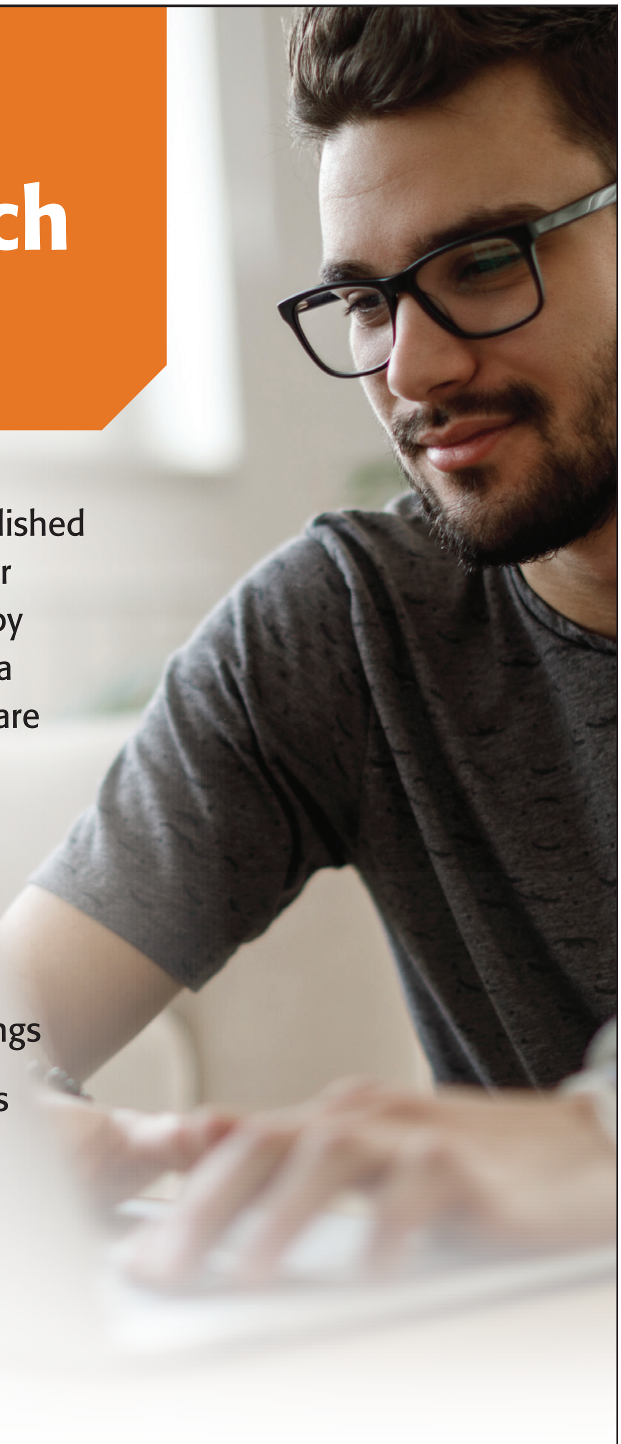

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