(U) Effective Quantitative Antenna Limits for Performance (EQuAL-P)

Request for Information:
Effective Quantitative Antenna Limits for Performance (EQuAL-P)

RFI Number: IARPA-RFI-21-01

Agency: Office of the Director of National Intelligence
Office: Intelligence Advanced Research Projects Activity
IARPA-RFI-21-01

Synopsis:

Request for Information (RFI): Effective Quantitative Antenna Limits for Performance

The Intelligence Advanced Research Projects Activity (IARPA) seeks information regarding innovative approaches to enhance the effective performance of antennas with an emphasis on electrically small antennas (ESAs) and antenna arrays with strongly coupled electrically small elements.

It is known from various fundamental theorems, such as the Chu Limit,[1] that there is a fundamental limit on ESA bandwidth and gain-bandwidth product, provided that the system is linear, passive, and time-invariant. It is also known that surpassing these limits is possible by breaking any of the three aforementioned assumptions.

One way to circumvent these assumptions is to activate the antenna with non-linear and/or time-varying elements or materials.[2-4] These techniques require active elements or materials which change the effective size, weight, and power (SWaP) of the passive antenna that is being replaced. Another common method of breaking the assumptions is by employing non-Foster circuits as antenna drivers.[5]

Despite allowing for a greatly-enhanced ESA bandwidth in theory, such configurations have several drawbacks that prevent one from reaching these performances in practice. Current electromagnetic theory, numerical solvers, and measuring techniques for passive antennas are not ideally suited for non-LTI

[1] L.J. Chu, “Physical limitations of omni-directional antennas,” Journal of Applied Physics, vol. 19, pp. 1163-1175, Dec. 1948.

[2] J. Galejs, "Switching of Reactive Elements in High-Q Antennas," in IEEE Transactions on Communications Systems, vol. 11, no. 2, pp. 254-255, June 1963.

[3] B. K. Meadows et al., "Nonlinear antenna technology," in Proceedings of the IEEE, vol. 90, no. 5, pp. 882-897, May 2002.

[4] Weijun Yao and Yuanxun Wang, "Direct antenna modulation - a promise for ultra-wideband (UWB) transmitting," 2004 IEEE MTT-S International Microwave Symposium Digest (IEEE Cat. No.04CH37535), Fort Worth, TX, USA, 2004, pp. 1273-1276 Vol.2.

[5] S. E. Sussman-Fort and R. M. Rudish, "Non-Foster Impedance Matching of Electrically-Small Antennas," in IEEE Transactions on Antennas and Propagation, vol. 57, no. 8, pp. 2230-2241, Aug. 2009.

antenna-like structures, and commercial active elements have performance limitations. Non-Foster circuits are plagued by a number of issues, such as power instability, generation of unwanted circuit harmonics and inter-modulations, large dispersion in their frequency-impedance curves, and practical limitations of commercial circuit components such as nonlinearities and parasitic capacitances/inductances. Additionally, the design and simulation of coupled antenna/load circuit systems is significantly hindered by the lack of integrated design tools capable of co-simulation of both the electromagnetic and circuit behavior of such systems as well as the complex interplay between the two.

Background & Scope:

ESAs – i.e., antennas whose dimensions are considerably smaller than the antenna's resonant wavelength – are of interest in numerous applications. Fundamental physics limits the performance of ESAs. This performance limit, explored by Harold Wheeler[6] and refined over the years by Lan Jen Chu[1] and others,[7-11] has proven to be indomitable against passive antenna designs.[12] One approach to beat this fundamental limit is to contravene the assumptions it is based upon, specifically linearity and time-invariance (LTI). Wheeler reasoned that the volume of a passive ESA limits the power it can extract from an incident field as indicated by a small radiation resistance ($P = I^2R$) and a corresponding small bandwidth.[6] However, the power extraction potential of antenna-like structures with time-varying resistive or reactive loads has yet to be established, theoretically, numerically, and/or experimentally. As an example, it is possible that an improved signal-to-noise ratio in a non-LTI antenna-like structure could be indicative of a larger effective bandwidth as related by Shannon's theorem for channel capacity.[13,14] There may be other possible performance advantages beyond bandwidth. Advances in the field of non-LTI antenna-like structures could result in a paradigm shift, significantly impacting how the Intelligence Community (IC) collects radio frequency (RF) information wirelessly.

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[6] H. A. Wheeler, "Fundamental Limitations of Small Antennas," in Proceedings of the IRE, vol. 35, no. 12, pp. 1479-1484, Dec. 1947.

[7] R. F. Harrington, "Effect of antenna size on gain, bandwidth and efficiency," J. Res. Nat. Bur. Stand., vol. 64-D, pp. 1-12, Jan./Feb. 1960.

[8] R. Collin and S. Rothschild, "Evaluation of antenna Q," in IEEE Transactions on Antennas and Propagation, vol. 12, no. 1, pp. 23-27, January 1964.

[9] A. D. Yaghjian and S. R. Best, "Impedance, bandwidth, and Q of antennas," in IEEE Transactions on Antennas and Propagation, vol. 53, no. 4, pp. 1298-1324, April 2005.

[10] M. Gustafsson, C. Sohl, and G. Kristensson, "Physical limitations on antennas of arbitrary shape," Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, vol. 463, issue 2086, pp. 2589-2607, 2007.

[11] H. L. Thal, "Gain and Q Bounds for Coupled TM-TE Modes," in IEEE Transactions on Antennas and Propagation, vol. 57, no. 7, pp. 1879-1885, July 2009.

[12] D. F. Sievenpiper et al., "Experimental Validation of Performance Limits and Design Guidelines for Small Antennas," in IEEE Transactions on Antennas and Propagation, vol. 60, no. 1, pp. 8-19, Jan. 2012.

[13] C. E. Shannon, "A mathematical theory of communication," in The Bell System Technical Journal, vol. 27, no. 3, pp. 379-423, July 1948.

[14] C. E. Shannon, "Communication in the Presence of Noise," in Proceedings of the IRE, vol. 37, no. 1, pp. 10-21, Jan. 1949.

Another goal of this RFI is to develop deeper insights into breaking the passivity assumption of the Chu limit through approaches such as non-Foster circuits. Specifically, this RFI aims to identify fundamental limits to gain-bandwidth product of broadband ESAs and identify ways to circumvent or surpass these limitations while maintaining power stability of the system.

This RFI seeks innovative approaches to improve the effective performance limits of ESAs and other antennas with active elements. In order for the USG to evaluate the promise of such approaches, it is necessary to consider the following:

a. A theoretical determination of the effective performance limits (accounting for SWaP) of the approach compared to traditional antenna approaches.
b. Advanced modeling tools for co-simulation of the electromagnetic and circuit behavior of the antenna/load circuit system.
c. The development of experimental techniques to characterize the performance of the approach.
d. Methods of increasing antenna bandwidth using non-LTI, non-Foster circuit-based, or other approaches in practice.
e. Novel non-Foster circuit designs and design methodologies.
f. Practical and theoretical limitations of various non-Foster implementations (e.g., transistorized and non-transistorized non-Foster circuits).
g. The applicability of metamaterials and metamaterial circuits in broadband ESA design.
h. Fundamental limitations of current commercially-available circuit elements used in non-Foster circuits and potential solutions to these limits (e.g., conceptually new circuit elements and materials or implementations of current circuit elements).
i. Performance barriers to implementation such as limits on stability, power-handling, and dynamic range.

Responses can address any one or multiple of these challenges. Other non-traditional approaches such as those employing quantum or plasma physics may be of interest so long as they can address any of these essential considerations. Approaches suitable to receive only, transmit only, or transmit/receive are all of interest.

An IARPA virtual invitation-only workshop cosponsored with DARPA is being planned for 19 January 2021 for the purpose of reviewing and discussing current and future research relevant to this RFI. Information discussed at this workshop may assist in the formulation of possible future areas of USG research with the objective of developing broadband antennas based on non-LTI approaches. Space for the workshop is limited, and attendance will be by invitation only. Invitations will be based on white papers submitted per the instructions below. Some participants may be asked to make formal presentations. White papers invited for

the workshop should identify key areas that currently limit implementation of ESAs and/or traditional broadband antennas and propose methods to overcome such limitations. White papers should also provide a rough estimate of achievable performance and indicate specific issues to be addressed, such as those listed earlier.

Preparation Instructions to Respondents:

IARPA requests that respondents submit ideas related to this topic for use by the Government in formulating a potential program. IARPA requests that submittals briefly and clearly describe the potential approach or concept, outline critical technical issues/obstacles, describe how the approach may address those issues/obstacles and comment on the expected performance and robustness of the proposed approach. If appropriate, respondents may also choose to provide a non-proprietary rough order of magnitude (ROM) estimate regarding what such approaches might require in terms of funding and other resources for one or more years. This announcement contains all of the information required to submit a response. No additional forms, kits, or other materials are needed.

IARPA welcomes responses from all capable and qualified sources from within and outside of the U.S.

Because IARPA is interested in an integrated approach, responses from teams with complementary areas of expertise are encouraged.

Responses must meet the following formatting requirements:

1. A one page cover sheet that identifies the title, organization(s), respondent's technical and administrative points of contact - including names, addresses, phone and fax numbers, and email addresses of all co-authors, and clearly indicating its association with RFI-21-01;

2. A substantive, focused, one-half page executive summary;

3. A description (limited to 5 pages in minimum 12 point Times New Roman font, appropriate for single-sided, single-spaced 8.5 by 11 inch paper, with 1-inch margins) of the technical challenges and suggested approach(es);

4. A list of citations (any significant claims or reports of success must be accompanied by citations);

5. A single quad-chart depicting the approach, key ideas, and impact.

Submission Instructions to Respondents:

Responses to this RFI are due no later than **5:00 p.m., Eastern Time, 24 December 2020**. All submissions must be electronically submitted to dni-iarpa-rfi-21-01@iarpa.gov as a PDF document. Inquiries to this RFI must be submitted to dni-iarpa-rfi-21-01@iarpa.gov no later than 5:00 p.m., Eastern Time, 21

December 2020. Do not send questions with proprietary content. No telephone inquiries will be accepted.

Disclaimers and Important Notes:

This is an RFI issued solely for information and planning purposes and does not constitute a solicitation. Respondents are advised that IARPA is under no obligation to acknowledge receipt or provide feedback to respondents with respect to any information submitted under this RFI. Responses to this notice are not offers and cannot be accepted by the Government to form a binding contract. Respondents are solely responsible for all expenses associated with responding to this RFI. IARPA will not provide reimbursement for costs incurred in responding to this RFI. It is the respondent's responsibility to ensure that the submitted material has been approved for public release by the information owner. The Government does not intend to award a contract on the basis of this RFI or to otherwise pay for the information solicited, nor is the Government obligated to issue a solicitation based on responses received. **No proprietary and no classified concepts or information shall be included in the submittal.** However, should a respondent wish to submit classified concepts or information, prior coordination **must** be made with IARPA Security. Email the Primary Point of Contact with a request for coordination with IARPA Security. Input on technical aspects of the responses may be solicited by IARPA from non-Government consultants/experts who are bound by appropriate non-disclosure requirements.

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