Emerging Frontiers In Research And Innovation 2017 (EFRI-2017)

1. ADVANCING COMMUNICATION QUANTUM INFORMATION RESEARCH IN ENGINEERING (ACQUIRE)

2. NEW LIGHT, EM (ELECTRONIC) AND ACOUSTIC WAVE PROPAGATION: BREAKING RECIPROCITY AND TIME-REVERSAL SYMMETRY (NEWLAW)

PROGRAM SOLICITATION
NSF 16-612

REPLACES DOCUMENT(S):
NSF 16-502

National Science Foundation

Directorate for Engineering
Emerging Frontiers and Multidisciplinary Activities

Directorate for Computer & Information Science & Engineering
Division of Computing and Communication Foundations

Directorate for Mathematical & Physical Sciences
Division of Materials Research
Division of Mathematical Sciences
Division of Physics

Air Force Office of Scientific Research

Letter of Intent Due Date(s) ***(required)*** (due by 5 p.m. submitter's local time):

October 24, 2016

Preliminary Proposal Due Date(s) ***(required)*** (due by 5 p.m. submitter's local time):

December 21, 2016

Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

March 24, 2017

IMPORTANT INFORMATION AND REVISION NOTES

Letters of Intent and Preliminary Proposals submitted in response to this solicitation should be submitted in accordance with the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) (NSF 16-1).

Invited Full Proposals submitted in response to this solicitation should be submitted in accordance with the revised NSF Proposal & Award Policies & Procedures Guide (PAPPG) (NSF 17-1). NSF anticipates release of the PAPPG in the Fall of 2016 and it will be effective for proposals submitted, or due, on or after January 30, 2017.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

EMERGING FRONTIERS IN RESEARCH AND INNOVATION (EFRI)

1. **Advancing Communication Quantum Information Research in Engineering (ACQUIRE)**
2. **New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry** (NewLAW)

Synopsis of Program:

The Emerging Frontiers in Research and Innovation (EFRI) program of the NSF Directorate for Engineering (ENG) serves a critical role in helping ENG focus on important emerging areas in a timely manner. This solicitation is a funding opportunity for interdisciplinary teams of researchers to embark on rapidly advancing frontiers of fundamental engineering research. For this solicitation, we will consider proposals that aim to investigate emerging frontiers in the following two research areas:

- **Advancing Communication Quantum Information Research in Engineering** (ACQUIRE)
- **New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry** (NewLAW)

This solicitation will be coordinated with the Directorate for Mathematical & Physical Sciences (MPS) and the Directorate for Computer and Information Science and Engineering (CISE), within NSF.

EFRI seeks proposals with transformative ideas that represent an opportunity for a significant shift in fundamental engineering knowledge with a strong potential for long term impact on national needs or a grand challenge. The proposals must also meet the detailed requirements delineated in this solicitation.

INFORMATION WEBCAST: The Emerging Frontiers and Multidisciplinary Activities (EFMA) Office held an informational workshop on October 23, 2015 to discuss the EFRI program and answer questions about the FY 2016 ACQUIRE and NewLAW solicitation. Click here to view slides.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

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Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 12.800 --- Air Force Office of Scientific Research
- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences
- 47.070 --- Computer and Information Science and Engineering

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 13

(4-year awards)

Anticipated Funding Amount: $26,000,000

Pending the availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Universities and Colleges - Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.

Who May Serve as PI:

The lead Principal Investigator (PI) must be at the faculty level as determined by the submitting organization. A minimum of one PI and two co-PIs must participate.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

The principal investigator and co-principal investigators may participate in only one proposal per year submitted to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all co-PIs are participating in only one proposal per year submitted to this solicitation.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Submission of Letters of Intent is required. Please see the full text of this solicitation for further information.
- **Preliminary Proposals:** Submission of Preliminary Proposals is required. Please see the full text of this solicitation for further information.
- **Full Proposals:**
  - Full Proposals submitted via FastLane: NSF Proposal and Award Policies and Procedures Guide, Part I: Grant Proposal Guide (GPG) Guidelines apply. The complete text of the GPG is available electronically on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg.
  - Full Proposals submitted via Grants.gov: NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov Guidelines apply (Note: The NSF Grants.gov Application Guide is available on the Grants.gov website and on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide)

B. Budgetary Information

- **Cost Sharing Requirements:**

  Inclusion of voluntary committed cost sharing is prohibited.
- **Indirect Cost (F&A) Limitations:**

  Not Applicable
- **Other Budgetary Limitations:**

  Not Applicable

C. Due Dates

- **Letter of Intent Due Date(s)** ***(required)*** (due by 5 p.m. submitter's local time):

  October 24, 2016
- **Preliminary Proposal Due Date(s)** ***(required)*** (due by 5 p.m. submitter's local time):

  December 21, 2016
- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

  March 24, 2017

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review considerations apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Additional award conditions apply. Please see the full text of this solicitation for further information.

Reporting Requirements:

Additional reporting requirements apply. Please see the full text of this solicitation for further information.

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I. INTRODUCTION

The Office of Emerging Frontiers and Multidisciplinary Activities (EFMA) in the Directorate for Engineering provides funding opportunities for interdisciplinary teams of researchers to embark on rapidly advancing frontiers of fundamental engineering research. The Emerging Frontiers in Research and Innovation program (EFRI), the signature program of the EFMA Office, seeks proposals with potentially transformative ideas that represent an opportunity for a significant shift in fundamental engineering knowledge with a strong potential for long term impact on national needs or a grand challenge. For this solicitation, EFRI will consider proposals that aim to investigate emerging frontiers in the following two specific research areas: 1) Advancing Communication Quantum Information Research in Engineering (ACQUIRE), and 2) New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (NewLAW). Proposals must meet the detailed requirements delineated in this solicitation.

(1) Advancing Communication Quantum Information Research in Engineering (ACQUIRE)

Secure and efficient data communication is of utmost importance to the public welfare, societal benefit, and national security. This EFRI topic focuses on quantum information science and engineering, one of NSF's 10 Big Ideas for long-term discovery and innovation. It will support interdisciplinary research in quantum communication systems with a focus on fundamental engineering challenges to enable lossless, room temperature, point-to-point links combining components, repeaters, networks and architectures. Researchers should focus on scalable, chip-level functioning devices and systems capable of operating at single and entangled photon levels. Recent progress in quantum information science, resulting in communication feasibility demonstrations, and advances in optoelectronic integration at the nanoscale are translating the field of quantum information to the engineering realm. Indeed chip-level, room temperature single photon sources, entangled pairs, quantum memory and repeaters are foreseeable devices that can enable scalable quantum communication or other applications. This topic is intended to support research by teams of engineers, physicists, and computer scientists, to address fundamental research challenges in design, fabrication, and operation of such systems. The research should include trade-offs between key relevant metrics. Of particular interest are investigations into 1) reproducible single photon sources and detectors on a chip, at or near room temperature, directly coupled to waveguides, 2) low-energy quantum devices such as repeaters, single photon wavelength converters in the telecom wavelength, and integrated quantum memories, 3) generation of quantum entangled quantum bits (Qubits) scalable to multi Qubits, and demonstration of a fiber-based quantum communication link. The research should be highly integrated with the education and training of the next generation of engineers and scientists with a broad knowledge of quantum technology and engineering. The goal is to demonstrate a reliable quantum communication link that optimizes the different aspects of the network, with the potential to provide a transformative and highly secure future network.

(2) New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (NewLAW)

This topic supports engineering-led interdisciplinary research that challenges the notions of reciprocity, time-reversal symmetry and sensitivity to defects in wave propagation and field transport. The research is expected to disrupt ways in which electronic, photonic and acoustic devices are designed and employed, and to enable totally new functionalities. Platforms that may benefit from this fundamental research include electronic, photonic devices and circuits, filters, logic operators, circulators and their on-chip implementation, microwave communications, electromagnetic interference control as well as acoustic transducers for ultrasonic imaging, sonars, noise absorbing or enhancing devices, and material systems for impact and blast protection. The research will provide the opportunity to exploit physical principles that enable disruptive technologies, novel materials and new devices with higher functionality. The topic is inspired by the recent emphasis on uncovering classical materials that emulate atomic systems and condensed matter phenomena such as quantum Hall effect, topologically tuned Fano resonances, electromagnetically induced transparency, Heusler compounds, Kondo insulators, and topological insulators. Specifically, the recent discovery of electronic and photonic topological insulators is inspiring new directions in band engineering and wave manipulation through concepts guided by

inspiration from condensed matter analogues.

ENHANCING DIVERSITY IN ENGINEERING - THE BROADENING PARTICIPATION PLAN

The Directorate for Engineering (ENG) promotes diversity in all aspects of its programs. In keeping with ENG's priority to broaden the participation of underrepresented groups (see detailed definition below) in Engineering, the Office of Emerging Frontiers in Research and Innovation is addressing the need to enhance diversity in all fields of Engineering by **requiring all EFRI projects to include a "Broadening Participation Plan"** as part of the EFRI 2017 Solicitation. One goal is to increase the participation of underrepresented groups in the field of engineering and in engineering research. This requirement will not only promote diversity in the human resources engaged in these EFRI projects but will also expand diversity of thought, ideas, and approaches brought together by EFRI in defining and solving important research questions.

The term "underrepresented groups" refers to and includes the following: women, persons with disabilities, and ethnic and racial groups which are in the minority in engineering including African Americans, Hispanics, Native Americans, Alaska Natives, and Pacific Islanders.

The Broadening Participation Plan must be described as part of Broader Impacts of the proposal both in the Project Summary and in the Project Description. It may include, but is not limited to, any of the following menu of activities as appropriate for your project and the circumstances of your institution(s):

- PI, Co-PI, or other SENIOR PERSONNEL - Inclusion of persons from underrepresented groups as PI, Co-PI, and/or other senior personnel, as appropriate for the project;
- STUDENT AND POST-DOCs - Inclusion of persons from underrepresented groups as graduate student, undergraduate student, and post-doctoral researchers;
- RESEARCH EXPERIENCES FOR UNDERGRADUATES (REU) - A plan to apply for post-award supplements to engage undergraduate researchers, using REU supplement;
- RESEARCH EXPERIENCE AND MENTORING (EFRI-REM) - A plan to apply for post-award supplements to enhance research goals through diversification of the EFRI research teams (see, URL for related information from previous year);
- MINORITY SERVING INSTITUTIONS - Engaging faculty and/or student researchers at minority serving institutions in the research project;
- COMMUNITY COLLEGES - Engaging faculty and/or student researchers at community colleges in the research project;
- RESEARCH EXPERIENCES FOR TEACHERS (RET) - A plan to apply for post-award supplements to engage teachers and/or Community College Faculty through the RET program;
- RESEARCH EXPERIENCES FOR HIGH SCHOOL STUDENTS - Provide research opportunities for members of underrepresented groups at the high school level;
- EXISTING INSTITUTIONAL PROGRAMS - Enhance/collaborate with existing diversity programs at your home institution and/or nearby institutions;
- MENTORING - Senior Personnel serve as role models and mentors for an underrepresented student population;
- TUTORING OPPORTUNITY - Provide tutoring opportunities for underrepresented middle school, high school, and undergraduate students;
- K-12 OUTREACH - Outreach activities that will interest and attract underrepresented K-12 students to engineering undergraduate programs.

The EFRI Office encourages the proposers to be creative in the planning of activities to attract and retain members of underrepresented groups to the fields of engineering and engineering research when developing their Broadening Participation Plans.

II. PROGRAM DESCRIPTION

The "Required Elements" listed below for each topic are expected to be addressed in both the preliminary proposals as well as in the full proposals.

1) Advancing Communication Quantum Information Research in Engineering (ACQUIRE) - This emerging engineering area and the ensuing interdisciplinary activities will leverage established Quantum Information Science (QIS) and will impact fields such as materials science, mathematics, physics and engineering in the next decade. The lessons learned from QIS research will accelerate engineering of systems on a chip, and help define goals for successfully addressing the scientific and engineering challenges of ACQUIRE , as further outlined in Thrust Areas 1-3 below.

To date research on QIS has mostly remained at the fundamental level, demonstrating the promises of quantum information technology in performing tasks that cannot readily be performed using classical approaches. With the recent progress in fabrication and integration of optoelectronics at the nanoscale, a bridge between quantum physics and engineered quantum communication networks is foreseeable. As the leading enabler of innovation, NSF seeks to empower transformative research that combines all layers of quantum components, circuits and systems, to develop practical, robust, and scalable controlled communication systems. NSF has selected “Quantum Leap” as one of its top ten Big Ideas in its future research investment portfolio. Quantum communication systems require a mix of competencies in theoretical and experimental physics, computer science, electrical and communication engineering. In addition, leveraging national initiatives, such as the new Integrated Photonics Manufacturing Institute, will accelerate the progress towards industrial implementation.

Thrust Areas
Each of the proposals in response to this EFRI solicitation must address at least two of the three thrusts outlined below:

- Develop reproducible single photon sources and detectors on a chip at or near room temperature
- Develop low-energy quantum devices such as repeaters, memories, and other photonics
- Develop scalable quantum entangled Qubits, robust and secure communication links, and demonstrate a quantum circuit network, with noise correction algorithms

The various functions must be engineered towards integration at the chip level at or near room temperature and electrical pumping over optical pumping are strongly preferred. A competitive proposal must have a collaborative and highly integrated approach with innovative solutions.

Thrust 1
Any two-level quantum system can be the foundation of quantum technology, but quantum states are highly impacted by the environment. Over the past thirty years there has been active research in the area of Qubits based on various platforms, such as

cold atoms, superconducting Qubits, Nitrogen Vacancy (NV) in diamond, or Quantum Dots (QD) in photonic crystals, and several other configurations. Those platforms have enabled proof-of-concept of quantum information science. Significant progress has been made in recent years in enhancing Qubit lifetime. However, most platforms are plagued by high complexity or lack of scalability. This program seeks chip-scale platforms that can sustain robust, repeatable multi-Qubit sources, which allow quantum information communication via coherent photons. For example, the efficient information transfer between a single-atom and a single-photon requires that the atom is trapped in a high-reflectivity cavity, which sustains a strong atom-photon interaction. The trapped atom must emit a single coherent photon that communicates the information through an optical fiber.

This Thrust requires fundamental understanding of material and device properties at the quantum level, characterization at the nanoscale level, and engineered devices that can provide quantum bits with superior stability and coherence. Additionally, fundamental understanding of light-matter interfaces at the quantum state is required. Reproducible design tool kits, chip fabrication and integration with electronic controls, and characterization tools are important aspects of the research. Facilities that can provide the necessary design kits, integration, and testing tools, for reproducible fabrication, are recommended. Partnering with government laboratories such as NIST or Sandia or industrial collaborators equipped with the appropriate metrology capabilities, is encouraged.

Thrust 2
The generation and engineering of entangled Qubits requires development of the appropriate platform. For example photon pairs can be obtained by down-conversion of a pump laser through a nonlinear crystal. Current devices suffer from severe performance limitations. Efficient coupling of the photons into and out of a waveguide, polarization control, and low loss links are critical requirements of entangled photons quantum circuit engineering. Recent demonstrations of point-to-point direct quantum communication indicate the potentials of this technology. However some transmission losses are unavoidable. In order to increase the distance over which the Qubits can communicate, quantum repeaters (both quantum relay and quantum memories) must be developed. Quantum repeaters are typically based on photon detection and conversion by light-matter interaction. Critical functionalities include the development of chips providing efficient quantum frequency conversion to telecom wavelengths for transmission over optical fibers. Quantum memory nodes integrated on a chip with special properties will need to be developed for effective memory storage. These nodes must be able to store a Qubit for a period long enough to allow successful transmission of photons between several of them. Additionally, the photons must be releasable in an energy-efficient manner. This allows links concatenation as a means to extend the distance over which quantum information can be transported. The nodes can also provide means to purify the Qubit pairs to provide a highly entangled pair to the next link.

This Thrust requires non-linear light-matter interaction at the nanoscale, integratable non-linear materials, reproducible nano-scale controls in the fabrication stages, and high precision characterization tools.

Thrust 3
Since device performance requirements are being driven by the systems application, exploration of the sub-systems is highly pertinent to this program. The importance of secure communication is a clear requirement in most communication systems. In the conventional Alice-to-Bob (sender to receiver) communication links, secure communication is achieved by means of Quantum Key Distribution (QKD). Advanced quantum cryptography that is practical, inherently robust and implementable in actual fully secure communication links should be considered. Quantum communication systems based on single photon circuits and novel protocols, will provide means to securely communicate data over a traditional infrastructure. Two types of links can be selected, fiber-optic based optical telecommunication link, or short reach free space communication link. While an entangled state in a lossless environment can ensure secure communication, detection with appropriate noise correction algorithms provides the distance information transportation. Realistic quantum communication networks integrating the above thrusts, and engineered to be compatible with current fiber optic networks are sought.

Thrust 3 requires expertise in fiber communication networks, quantum cryptography, and access to an adequate testbed demonstration platform.

EFRI-ACQUIRE Programmatic Considerations

Quantum communication is beginning to emerge with recent advances in quantum information science and nanotechnology fabrication, allowing table top experiments to translate to early engineered systems. We strongly encourage developing solid-state quantum communication devices and circuits operating at or near room temperature and characterizing any trade-offs between robust and secure communication links and device temperature. Progress in this field will greatly benefit from active collaboration from experts on materials, components, device integration on a chip, and communication networking.

Engineering Challenges: In view of the current challenges included in the three thrusts, consideration should be given to addressing the critical trade-offs in the devices and systems envisioned, the actual performance targets of the complete system or sub-system, including fabrication challenges, reproducibility, scalability, and characterization methods.

Interdisciplinary Research: While the quantum communication research should be led by engineering investigators, innovative concepts to advance the field will benefit from teams with synergistic expertise in the following fields: photonics, physics of quantum materials and information, mathematics, and quantum cryptography. Preference will be given to teams that address all three thrusts.

International Exchange: We encourage collaboration with international scientific teams that are leaders in the field. Travel support for the Principal Investigators and students may be considered under the proposal application, or through travel supplements, during the course of the award.

2) New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (NewLAW) - This emerging technical area and the ensuing interdisciplinary activities should be coordinated by engineering-led teams that include contributions from researchers in material, mathematical and physical sciences. Highly innovative proposals are sought that build upon established and emerging research in non-reciprocity and topologically protected wave propagation, and that impact fields such as electromagnetics, electronics, photonics, opto-mechanics, acoustics, mechanics, material science, and dynamics and control. The exploration of concepts over a broad range of scales is expected to lead to new findings that support the design of “topologically nontrivial” photonic, electronic and acoustic systems. Projects should include relevant activities in the following three thrust areas, with clear innovation in at least one: 1) modeling, 2) analysis, design and control, and 3) fabrication, testing and characterization.

Background
Frequency, wave-vector, polarization and phase are properties often used to describe wave phenomena and the characteristics of the associated physical domains. Careful tailoring of these properties has led to exciting advances in the areas of electronics, photonics, acoustics and thermal transport. The application of topology has recently emerged as an additional degree of freedom for the analysis and design of new systems and for the discovery of states associated with unusual wave properties. In the context of this solicitation, topology refers to the properties that characterize the quantized behavior of some topological invariants, a specific property of the wavefunctions over the associated dispersion bands. Topological states in electronic materials have inspired recent developments in photonics, where studies have shown how the use of carefully designed systems with nontrivial topologies in the wave-vector (reciprocal) space can lead to the emergence of new states of light at their interfaces, with potentially useful properties as well as electronics where asymmetric scattering of Dirac electrons driven back and forth by a terahertz electric field results in DC

surface electron transport. Topological insulators are characterized by dissipation-free interfacial electron transport exhibiting robust propagation in the presence of impurities. Similarly, unidirectional waveguides that allow light to flow around defects without back-reflection have been pursued as potential enablers of numerous technological applications and devices. In recent years, topological effects have been investigated in photonic crystals, coupled resonators, metamaterials and quasicrystals. Investigations have also extended these concepts to photonics, mechanics and acoustics, where topologically protected propagation is obtained by exploiting rotating fluids, or Coriolis and gyroscopic effects.

Thrusts
The objective of this solicitation is to support the investigation of novel concepts guided by inspiration from condensed matter analogues or by exploration of new approaches to time/space symmetry breaking, non-reciprocity and topologically protected field transport. Highly interdisciplinary projects are sought that pursue breakthroughs in the following three thrusts:

1. Modeling
2. Analysis, design and control
3. Fabrication, testing and characterization

Proposals will be evaluated on the basis of their ability to describe activities relevant to all three thrust areas, and their effectiveness to define clear innovations in at least one thrust area.

Thrust 1: Modeling
Many of the preliminary studies rely on conceptual, simplified models that are often characterized by lumped parameters and low-dimensionality. While effective for physical insight and to illustrate key concepts, such models do not capture the full complexity of the physical systems under consideration, and cannot address outstanding challenges associated, for example, with the presence of multiple, coupled bands and polarizations, or with high dimensionality. A strong modeling component is needed to support analysis, design and control activities, and to subsequently guide fabrication and experimentation. Based on the available literature, it is envisioned that most configurations will consist of basic units, e.g. unit cells, assembled to form lattice-type structures. The properties of these assemblies, including several different media sustaining the transport of various field quantities (acoustic, electromagnetic, mechanical), should be inferred based on analyses conducted on unit cells, representative elements, or finite domains.

Proposals responding to this solicitation should discuss modeling approaches and analytical/numerical tools employed to predict and characterize dispersion topology in complex electronics, optical, acoustic, mechanical and coupled domains. Researchers may consider, for example, the application of innovative numerical techniques for the discretization of continuous systems, dynamic network models, or homogenization techniques that capture the complex dynamic behavior of lattice assemblies. Analytical and numerical procedures for the estimation of dispersion may need to account for spatially and time-varying properties, or for the presence of nonlinearities associated with constitutive properties or of geometrical nature, resulting from large deformations or exposure to high amplitude fields. Analysis and understanding of transport properties in the proposed materials as well as their interfaces with other materials are important. The dependence of various properties such as absorbance and transport from microwaves to optical wavelengths requires further fundamental understanding. Fundamental electronic structure analysis should assist in achieving room temperature operation and understanding the role of surface states. Ways of controlling the band gap and band inversion in topological materials could be better understood through modeling. Modeling efforts are expected to provide significant opportunities for leveraging multi-physics interactions, for example, through combined photo-elastic, magneto-elastic, piezo-elastic, electro-optical, and electro-mechanical effects, or by exploiting wave mode interactions across different polarizations. It is expected that the tools arising from this effort will encompass levels of complexity from low-dimension conceptual models up to high-fidelity 3D models. Projects may also propose homogenized or continuum models to accelerate performance assessment and design studies.

Thrust 2: Analysis, design and control
The models developed in Thrust 1 will support new results in analysis, design and control of non-reciprocal systems. Proposers should investigate conditions, configurations and physical systems that enable symmetry breaking, non-reciprocity and topologically protected transport to occur -- and potentially be controlled -- in various physical domains of interest. The objective is to define mechanisms that lead to non-conventional wave motion, such as magnetic spins, resonating systems and passive lattices possibly with internal rotational degrees of freedom and non-center symmetric geometries. Proposers are also encouraged to explore alternative approaches relying on the coupling among physical domains, among different propagation modes, or based on active control concepts. Control of local symmetries may be investigated in the framework of networked structures, with the goal of exploring the possibilities afforded by the ability to introduce “defects”, “boundaries” or “interfaces” that are controllable and that can be adapted based on feedback information. Innovations that leverage the ability of limited local actuation to achieve overall performance characteristics in terms of the propagation of perturbations within the network are relevant to this solicitation. Studies that are of interest within this context include distributed control concepts for reconfigurable non-reciprocal systems, optimal placement strategies for defect states and boundaries, and dynamics of reconfigurable systems over multiple time scales. These investigations could open new opportunities whereby the effects of local symmetries and symmetry breaking have implications on synchronization effects, stability and localization. Furthermore, nonlinear dynamic interactions among the constituents, or internal to the units, could lead to amplitude-dependent responses, time-dependent properties, stability, internal resonances -- in particular in the form of self-trapped states in the bulk and at interfaces -- multi-harmonic responses, and coupling across frequencies. Opportunities may also arise from symmetry breaking configurations resulting from spatial topological changes resulting from instability, or due to the presence of multiple stable equilibrium configurations. Studies assisting in the identification of the parameters dictating the topological properties and allowing their control for reproducible device implementation, including insulating properties robustness are a key. Tradeoffs in doping, composition and material phases for eliminating technological compromises require further work.

While the areas above are presented as examples of potential research avenues, proposers are strongly encouraged to consider alternative mechanisms, configurations, materials and physical systems that enable topological states associated with symmetry engineering and reduction, to occur and potentially be controlled in various physical domains of interest.

Thrust 3: Fabrication, testing and characterization
It is expected that the analysis, design and control studies of thrust 2 will be followed by experimental demonstration of the conceptual solutions. Experiments should support the validation of models developed in thrust 1. Because the level of technology readiness varies greatly across fields such as electronics, photonics, acoustics, mechanics, opto-mechanics etc., it is further expected that these experimental activities will span a broad range of objectives. In less developed areas, experimentation may be limited to demonstrating particular phenomena predicted by theory and modeling, such as one-way propagation, very large isolation, topological protected wave propagation, and scattering-free propagation. Other relevant dynamic behaviors may be explored as they are uncovered. In disciplines where substantial preliminary work already exists, for example, electronics, photonics, investigators may demonstrate device prototypes based on the uncovered functionalities. Concepts enabling or facilitating integration should be investigated in support of development efforts for integrated nanophotonic elements based on topological insulators with robust one-way propagation, integrated circuits for full-duplex communications, or defect-insensitive waveguiding. Electronic, photonic and acoustic device and material growth driven approaches should be explored for reproducible and controllable ways of bandgap energy and use of the conducting and insulating nature of topological insulators at room temperature. This should include design, growth, fabrication and characterization approaches that permit performance prediction and design compatible operation. Electronic

transport properties in topological insulators alone but also interfacing with other materials is of major importance for electronic device implementation and requires in-depth studies. Developments of this type should lead to the discovery of devices based on new materials, making topological insulators more suitable for practical implementation. Competitive teams addressing such disciplines should demonstrate expertise in the appropriate supporting functions, such as micro and nano fabrication, circuit integration, and experimentation and characterization of the envisioned devices. Testing and fabrication efforts should be also focused on the integration of symmetry breaking units within an equivalent acoustic or elastic material systems, possibly avoiding the need for external sources of energy that induce mean flows or internal rotations. Advancements in this area are expected to require innovations in fabrication and manufacturing of complex material configurations and structures that involve several length scales. Applications that may drive innovation and that may benefit from the findings in this area include new venues for ultrasound imaging, sonar interrogation, and acoustic-based signal conditioning and processing. Size and weight may become important driving factors for application of NewLAW concepts to novel sound-absorbing materials, protective layers for impact protection, or stealth systems. If applicable, practical advantages provided by concepts relevant to this solicitation should be addressed. Moreover, multi-physics interactions are likely to play important roles in controlling symmetries and wavefunctions topology. Thus, the fabrication techniques to be employed may consider the integration of active or smart materials with photo-elastic, magneto-elastic, piezo-elastic, electro-optical, and electro-mechanical properties. Furthermore, the integration of soft-materials compatible with large deformations and engineered instabilities should be considered as means to explore the importance of geometry and spatial topology and their adaptation in response to external stimuli.

To maximize the chances for post-EFRI support and the transition of most promising concepts, collaboration with industrial partners is highly encouraged. Proposals should demonstrate understanding of challenges in manufacturing, processing, scaling and commercialization. Projects that show a clear pathway to applications, including scalability, are especially encouraged. When appropriate, proposers may consider a formal mechanism for academic-industry collaboration, such as the NSF GOALI program.

EFRI-NewLAW Programmatic Considerations
Among the programmatic considerations, the following features are deemed important under this NewLAW research area in order to realize the promise of this field over the coming years:

Interdisciplinary Research: Progress in this field will benefit tremendously from research that draws on many disciplines including physics, chemistry and engineering; thus it is only natural to enable scientists and engineers to work together more effectively in research teams involving theory, modeling, design, characterization, and/or device fabrication and testing. Each team must address all 3 thrust areas, with clear indication of innovation in at least one of the thrust areas.

Industrial Partnerships: Reaching out to American industry partners will be critical to developing scalable techniques for synthesizing these materials and for outreach in training students who can work with the industrial partners. Creation of an academia-industry axis in the development of applications and subsequent commercialization of technologies based on NewLAW concepts is therefore encouraged.

Mathematical Sciences Partnerships: The ideas, tools, and language of mathematics and statistics play important roles in engineering research, and it is widely recognized that interactions between the mathematical sciences and engineering catalyze developments in both. Collaborative research projects involving mathematical scientists have the potential to lead to transformative results in EFMA projects. Researchers from mathematics and statistics are especially encouraged to participate in new collaborative projects in this important interdisciplinary area.

International Exchange: We encourage collaboration with international scientific teams that are leaders in the field. Travel support for the Principal Investigators and students may be considered under the proposal application, or through travel supplements, during the course of the award.

III. AWARD INFORMATION

The budget for this program solicitation is $26,000,000 in FY2017; each award will be funded as a ‘Standard Grant'. The anticipated number of awards for this solicitation is up to 13 awards. Each project team may receive support of up to a total of $2,000,000 spread over four years, pending the availability of funds. It is not expected that all awards will receive the maximum amount; the size of awards will depend upon the type of research program proposed.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Universities and Colleges - Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.

Who May Serve as PI:

The lead Principal Investigator (PI) must be at the faculty level as determined by the submitting organization. A minimum of one PI and two co-PIs must participate.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or Co-PI: 1

The principal investigator and co-principal investigators may participate in only one proposal per year submitted to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all co-PIs are participating in only one proposal per year submitted to this solicitation.

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Letters of Intent *(required)*:

A one-page Letter of Intent is required. The letter should be submitted via FastLane no later than the date specified in this solicitation. The subject heading of the letter should include a brief title of the proposal and the name of the lead institution. Each letter must include the following:

1. THE TITLE- Title of the EFRI proposal, preceded by the words "**EFRI ACQUIRE**:" or "**EFRI NewLAW**:".
2. THE TEAM- Names, departmental and university affiliation, and expertise of the Principal Investigator and at least two co-Principal Investigators.
3. THE SYNOPSIS (GOALS) - Brief description of the specific goals of the proposal (maximum of 250 words).

These letters of intent are not used as pre-approval mechanisms for the submission of preliminary proposals and no feedback is provided to the submitters. The Letters of Intent are not reviewed but are used to assess the overall response to the solicitation. They help NSF anticipate review requirements for preliminary proposals.

Letter of Intent Preparation Instructions:

When submitting a Letter of Intent through FastLane in response to this Program Solicitation please note the conditions outlined below:

- Submission by an Authorized Organizational Representative (AOR) is not required when submitting Letters of Intent.
- A Minimum of 2 and Maximum of 4 Other Senior Project Personnel are allowed
- A Minimum of 0 and Maximum of 3 Other Participating Organizations are allowed
- Submission of multiple Letters of Intent is not allowed

Preliminary Proposals *(required):* Preliminary proposals are required and must be submitted via the NSF FastLane system.

Preliminary proposals should provide a brief overview of the project focusing on its transformative aspect. It should include sufficient information to allow assessment of the main ideas and approaches and how it is appropriate as an EFRI proposal as opposed to existing programs. For the preliminary proposals the review criteria will have a higher weight on the transformative nature and impact of the proposed idea.

Preliminary Proposal Preparation Instructions:
Preliminary proposals must be submitted via FastLane in accordance with the instructions below. Preliminary proposals that are not compliant with this solicitation will be returned without review. It is the submitting organization's responsibility to ensure that the proposal is compliant with all applicable requirements. If there are multiple universities involved in a preliminary proposal, it must be submitted as a single proposal with subawards and not as separately submitted collaborative proposals. Preliminary proposals must contain the items listed below and strictly adhere to the specified page limitations. No additional information may be provided as an appendix or by links to web pages. Figures and tables must be included within the applicable page limit. All elements of the proposal, including legends and tables, must meet all formatting requirements for font size and characters per inch as specified in the NSF Grant Proposal Guide (GPG).

Preliminary proposals must include the following items:

Cover Sheet: Select the EFRI program solicitation number from the pull down list. Check the box indicated for preliminary proposal. Entries on the cover sheet are limited to the principal investigator and a maximum of four co-principal investigators. A minimum of two co-principal investigators must participate. Additional project leaders or senior personnel should be listed on the project summary page and entered into FastLane as senior investigators.

Title of Proposed Project: The title for the proposed EFRI project must begin, as appropriate, with either "**EFRI ACQUIRE Preliminary Proposal:**" or "**EFRI NewLAW Preliminary Proposal:**". The title must state clearly and succinctly the major emerging frontier in research and innovation that is the focus for the project.

Project Summary: The project summary may not be more than one page in length and must consist of three parts:

1. In the Overview section, include the title of the project, the name of the PI and the lead institution and a list of co-PIs and senior personnel along with their institutions;
2. Provide a succinct summary of the ***intellectual merit*** of the proposed project. This should include the transformative nature of the proposed research and the significant leap or paradigm shift in fundamental engineering knowledge it will achieve; and
3. Describe the ***broader impacts*** of the proposed work, including the potential long-term impact on national needs or a grand challenge.

Proposals that do not separately address in the project summary both intellectual merit and broader impacts will be returned without review.

Project Description: Project description of the preliminary proposal is limited to five pages and will include the following three sections:

1. **Vision and Goals -** Describe the vision and specific goals of the proposed research in approximately one page;
2. **Approach and Methodology** - Describe the approach and methodology that will be used to achieve the vision and goals in approximately three pages; and
3. **Transformative Impact** - In approximately one page, describe the transformative aspects of the project including how the synergy of experts from different disciplines in the proposed research will achieve a significant advancement in fundamental engineering knowledge and will have a strong potential for long-term impact on national needs or a grand challenge. Include a succinct statement of your preliminary Broadening Participation Plan.

References Cited: Indicate with an asterisk any cited publications that resulted from prior research funded by NSF for the PI, or co-PI (s).

Biographical sketches: The standard NSF two-page biographical sketches must be prepared for the PI, co-PIs and other senior personnel listed on the project summary page.

Current and Pending Support for the PI, co-PIs, and senior personnel must be included.

Budget: The preliminary proposal will include a budget for each of the four years proposed. FastLane will automatically provide a cumulative budget. Preliminary proposals should not include any subawards. However, the budget justification should include planned levels for subawards to any partner institution. Enter the anticipated total level of subaward support on line G5, Subawards.

In the **Supplementary Documentation** section, include the following:

1. List of **key personnel involved** (maximum one page), with a succinct description of what each person uniquely brings to the project and how they are integrated to produce positive synergies.

In the **Single Copy Documents** section, *in lieu of the instructions specified in the GPG "Collaborators and Other Affiliations Information" section,* upload the following:

1. An **Excel spreadsheet** (see link for template) containing *two list tabs*: one lists the last names, first names and institutional affiliations of all senior personnel (PI and co-PI's) and any named personnel whose salary is requested in the project budget; the second one lists the full names and institutional affiliations of all people **who have collaborated or are affiliated** with any senior personnel (PI and co-PI's) or named personnel whose salary is requested in the project budget. To be identified in this second list are (1) PhD thesis advisors or advisees, (2) collaborators or co-authors, including post-docs, for the past 48 months, and (3) any other individuals or institutions with which the investigator has financial ties (please specify type).

In addition, the proposers **must send the following two documents via email immediately after submission of their proposal**. After receipt of the proposal number from FastLane, send an email to: efri2017@nsf.gov . The subject heading of the email should note the proposal number and the lead institution. Attach the following documents prepared on templates hyperlinked below:

1. A copy of the completed Collaborators and Other Affiliations **Excel spreadsheet** (both tabs) which was uploaded in the Single Copy Documents section of your proposal (please refer to the previous paragraph for details). This spreadsheet will be used by NSF to help identify potential conflicts or bias in the selection of reviewers.
2. A single **PowerPoint slide** summarizing the vision of the EFRI proposal. This will be used during review panel discussions.

Preliminary proposals will be reviewed by panels of outside experts. Based on the reviews, a limited number of PIs will be invited to submit full proposals. By mid-February 2017, invited PIs should expect to receive an invitation from the EFRI program to submit a full proposal.

Remember to email these two documents to: efri2017@nsf.gov ; do not use FastLane.

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via Grants.gov or via the NSF FastLane system.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the NSF Grant Proposal Guide (GPG). The complete text of the GPG is available electronically on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg. Paper copies of the GPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.

- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov. The complete text of the NSF Grants.gov Application Guide is available on the Grants.gov website and on the NSF website at: (http://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

See Chapter II.C.2 of the GPG for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the GPG instructions.

Based on the review of preliminary proposals, a limited number of PIs will be invited to submit a full proposal. If multiple universities are involved in an invited full proposal, it must be submitted as a single full proposal with subawards, and not as separately submitted collaborative proposals.

The review of invited full proposals will include both *ad hoc* and panel reviews. The following exceptions and additions to the GPG or NSF Grants.gov Application Guide apply to full proposals submitted to this Program:

Full proposals will be accepted only from PIs who have submitted preliminary proposals in the current review cycle. Submission of full proposals by PIs whose preliminary proposals received a review recommendation of 'Not Invited' will be returned without review.

Cover Sheet: Select the EFRI program solicitation number from the pull down list. Entries on the cover sheet are limited to the principal investigator and a maximum of four co-principal investigators. Additional project leaders or senior personnel should be listed on the project summary page and entered into FastLane as senior personnel.

Title of Proposed Project: The title for the proposed EFRI project must begin with "**EFRI ACQUIRE:"** or "**EFRI NewLAW:"**. The title must state clearly and succinctly the major emerging frontier in research and innovation that is the focus for the project.

Project Summary (one-page limit): The Project Summary consists of an overview, a statement on the intellectual merit of the proposed activity, and a statement on the broader impacts of the proposed activity. Provide the following information:

1. In the Overview section provide the title of the project, the name of the PI and the lead institution or organization, and a list of co-PIs and senior personnel along with their institutions and organization or both;

2. A succinct summary of the **intellectual merit** of the proposed project. This should include the transformative nature of the proposed research, and the significant leap or paradigm shift in fundamental engineering knowledge; and
3. The **broader impacts** of the proposed work, including the potential long-term impact on national needs and a grand challenge or both. Include a summary of your Broadening Participation Plan.

Proposals that do not contain the Project Summary, including an overview and separate statements on intellectual merit and broader impacts will not be accepted by FastLane or will be returned without review.

Project Description (maximum 15 pages) must include the following subsections:

1. Results from **Prior Research**: Please follow the guidance provided in the NSF Proposal & Award Policies & Procedures Guide (PPAG) for reporting results from prior NSF support. Please also describe the prior research of each PI or co-PIs funded by NSF that is *directly* relevant to the proposed project.
2. **Proposed Research**: Describe the vision and goals of the proposed research, approaches and methodologies to attain the goals, and the expected outcomes.
3. The project description should end with a subsection labeled **"Impact"** that describes how the proposed project will lead to a significant shift in fundamental engineering knowledge and have strong long-term potential for significant impact on a national need or a grand challenge. The proposal should also discuss effective ways in which education and outreach are integrated within the research program to achieve societal impacts. Concisely articulate unifying and integrative aspects of the proposed research as well as the innovative ideas of the research. The **Impact** subsection must include a **Broadening Participation Plan**. The plan must aim to broaden participation of underrepresented groups in engineering research. For more information see: Enhancing Diversity in Engineering at the end of Introduction, Section I. If needed, you may include additional information, up to five pages, about your Broadening Participation Plan in the Supplementary Documentation section.

References Cited: Indicate with an asterisk any cited publications that resulted from prior research funded by NSF for the PI, or co-PI(s).

Biographical Sketches for key personnel (PI, co-PIs, and each of the senior personnel listed on the Project Summary page). Use the standard format.

Current and Pending Support information must be provided for the PI and each of the co-PIs and Senior Personnel listed in the Project Summary page.

Budget: Develop a realistic project budget that is consistent with the proposed activities. Provide detailed budget justifications separately for the lead institution's budget (up to three pages of budget justification), and for each subawardee budget (up to three pages of budget justification for each subaward). Proposed budgets must include funds for travel by at least one PI and at least one graduate student to attend an annual EFRI grantees' meeting.

Facilities and Equipment: Provide a description of available facilities and priorities for its use, if applicable. For EFRI projects requiring additional equipment, justify the need for these resources in the context of the innovative work proposed.

In the **Supplementary Documentation** section, include the following:

1. Provide a **list of key personnel** involved (maximum three pages), with a description of what each person uniquely brings to the project and how they are integrated to produce positive synergies;
2. Provide a detailed **management plan** (maximum three pages) including means of communication, data tracking, management of personnel within the project group, management of intellectual property resulting from the project, and timeline of activities;
3. Proposals must include a **data management plan** (maximum one page). The contents of the data management plan should include: (1) the types of data to be produced, (2) the standards that would be applied for data format and metadata content, and (3) access policies and provision;
4. For proposals that include support for post-doctoral researchers, provide a **post-doc mentoring plan**;
5. **Means of sharing the outcome** of the research with the rest of the scientific community, *e.g.* publications, web sites, and significant data bases, *etc*. (maximum two pages). The description should be specific and describe what, how, and when the community would have access to the outcome of the project. This is particularly important for the projects that will produce tangible research tools and resources; and
6. **Broadening Participation Plan** - You may include additional information, up to five pages, about the Broadening Participation Plan in the Supplementary Documentation section.

In the **Single Copy Documents** section, *in lieu of the instructions specified in the GPG "Collaborators and Other Affiliations Information" section,* upload the following:

1. An **Excel spreadsheet** (see link for template) containing two list tabs: one lists the last names, first names and institutional affiliations of all senior personnel (PI and co-PI's) and any named personnel whose salary is requested in the project budget; the second one lists the full names and institutional affiliations of all people **who have collaborated or are affiliated** with any senior personnel (PI and co-PI's) or named personnel whose salary is requested in the project budget. To be identified in this second list are (1) PhD thesis advisors or advisees, (2) collaborators or co-authors, including post-docs, for the past 48 months, and (3) any other individuals or institutions with which the investigator has financial ties (please specify type).

In addition, the proposers **must send the following two documents via email immediately after submission of their proposal**. After receipt of the proposal number from FastLane, send an email to: efri2017@nsf.gov . The subject heading of the email should note the proposal number and the lead institution. Attach the following documents prepared on templates hyperlinked below:

1. A copy of the completed Collaborators and Other Affiliations **Excel spreadsheet** (both tabs) which was uploaded in the Single Copy Documents section of your proposal (please refer to the previous paragraph for details). This spreadsheet will be used by NSF to help identify potential conflicts or bias in the selection of reviewers.
2. A single **PowerPoint slide** summarizing the vision of the EFRI proposal. This will be used during review panel discussions.

Remember to email these two documents to: efri2017@nsf.gov no later than 24hrs after the proposal submission deadline; do not use FastLane. Please submit these documents even if the information has not changed since submission of the preliminary proposal.

Pre-submission Check List:

- No principal investigator or co-principal investigator is listed as a principal investigator or co-principal investigator on any other EFRI proposal.

The Lead PI must be at the faculty level, as determined by the submitting institution.
- If the proposal has multiple organizations, it is not submitted as a separately submitted collaborative proposal but as a single proposal with subawards.
- Proposal has a minimum number of 3 PI/Co-PIs and a maximum of 5 PI/Co-PIs.
- Total budget does not exceed $2,000,000 and is spread over 4 years.
- **Broadening Participation Plan:** All proposals must describe a plan (both in Project Summary and Project Description) that promotes the participation of underrepresented groups in engineering.
- **Post-doctoral Researcher Mentoring Plan:** As a reminder, each proposal that requests funding to support postdoctoral researchers must include, as a supplementary document, a description of the mentoring activities that will be provided for such individuals.
- **Data Management Plan:** All proposals must describe plans for data management and sharing of the products of research, or assert the absence of the need for such plans.
- Immediately after submission, an E-mail is sent to: efri2017@nsf.gov with (a) a copy of the Excel spreadsheet that includes Collaborators and Other Affiliations information and (b) a one-page project summary as PowerPoint slide. The subject heading of the email should note the proposal number and the lead institution.

This checklist is provided to aid in the preparation of the proposal, the burden to ensure that the proposal is complete and meets all of the solicitation requirements remains with the Principal Investigator.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

C. Due Dates

- **Letter of Intent Due Date(s) *(required)*** (due by 5 p.m. submitter's local time):

  October 24, 2016

- **Preliminary Proposal Due Date(s) *(required)*** (due by 5 p.m. submitter's local time):

  December 21, 2016

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

  March 24, 2017

D. FastLane / Grants.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: https://www.fastlane.nsf.gov/a1/newstan.htm. For FastLane user support, call the FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of the FastLane system. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: http://www.grants.gov/web/grants/applicants.html. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane are strongly encouraged to use FastLane to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually

by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in the GPG as Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: http://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Investing in Science, Engineering, and Education for the Nation's Future: NSF Strategic Plan for 2014-2018*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (GPG Chapter II.C.2.d.i. contains additional information for use by proposers in development of the Project Description section of the proposal.) Reviewers are strongly encouraged to review the criteria, including GPG Chapter II.C.2.d.i., prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
    a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
    b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

In addition to the two NSF review criteria (intellectual merit and broader impacts), the following criteria will be used in the review of all EFRI proposals. For the preliminary proposals the review criteria will have a higher weight on the tranformative nature and impact of the proposed idea.

- ***TRANSFORMATIVE*** **-** Does the proposed research represent an opportunity for a significant leap or paradigm shift in fundamental engineering knowledge?
- ***NATIONAL NEED/GRAND CHALLENGE*** - Is there potential for making significant progress on a current national need or grand challenge?
- Responsiveness to "**Programmatic Considerations**" for **EFRI-ACQUIRE and EFRI-NewLAW** proposals as delineated in Section II. Program Description.
- **Broadening Participation Plan** - Does the plan actively promote, increase, and enhance the participation of underrepresented groups in the field of engineering and in engineering research?
- Effectiveness of the proposed **management plan**.

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by Ad hoc Review and/or Panel Review.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF is striving to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. The time interval begins on the date of receipt. The interval ends when the Division Director accepts the Program Officer's recommendation.

A summary rating and accompanying narrative will be completed and submitted by each reviewer. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

In developing its recommendations for awards, review panels as well as NSF staff will consider: the relative merit of the EFRI proposals using the criteria listed above, the potential national impact of the proposed activity, the balance of awards among scientific fields, geographical distribution, and the combined ability of the proposals to meet the objectives of the EFRI Office. The EFRI Office will not normally award more than one proposal from any one lead institution in this competition.

In all cases, after programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications and the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process).

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at http://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Award & Administration Guide* (AAG) Chapter II, available electronically on the NSF Website at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=aag.

Special Award Conditions:

Awardees must include in the proposal budget funds for travel by PI and one researcher or a student to attend an annual EFRI grantees' meeting.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the NSF *Award & Administration Guide* (AAG) Chapter II, available electronically on the NSF Website at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=aag.

Awardees will be required to attend and present their research results and plans annually at an annual EFRI grantees' conference for the duration for their award.

VIII. AGENCY CONTACTS

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- Sohi Rastegar, Director, ENG/EFMA, telephone: (703) 292-8305, email: srastega@nsf.gov
- Kerstin Mukerji, Program Manager, ENG/EFMA, telephone: (703) 292-5390, email: kmukerji@nsf.gov
- TOPIC 1:, Advancing Communication Quantum Information Research in Engineering (ACQUIRE), telephone: (703) 292-8339, email: ddagenai@nsf.gov
- Dominique Dagenais, (TOPIC 1 COORDINATOR), ENG/ECCS, telephone: (703) 292-2980, email: ddagenai@nsf.gov
- Mahmoud Fallahi, Program Director, ENG/ECCS, telephone: (703) 292-4555, email: mfallahi@nsf.gov
- Peter Atherton, Program Director, ENG/IIP, telephone: (703) 292-8772, email: patherto@nsf.gov
- Almadena Y. Chtchelkanova, Program Director, CISE/CCF, telephone: (703) 292-8910, email: achtchel@nsf.gov
- Charles C. Ying, Program Director, MPS/DMR, telephone: (703) 292-8428, email: cying@nsf.gov
- Alex Cronin, telephone: (703) 292-5302, email: acronin@nsf.gov
- TOPIC 2:, New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (NewLAW), telephone: (703) 292-7060, email: kpeters@nsf.gov

Kara Peters, (TOPIC 2 COORDINATOR), ENG/CMMI, telephone: (703) 292-7060, email: kpeters@nsf.gov

- Dimitri Pavlidis, Program Director, ENG/ECCS, telephone: (703) 292-2216, email: dpavlidi@nsf.gov
- Jordan M. Berg, Program Director, ENG/CMMI, telephone: (703) 292-5365, email: jberg@nsf.gov
- Lora Billings, Program Director, MPS/DMS, telephone: (703) 292-8039, email: lbilling@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@nsf.gov.

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

The following topic coordinators may also be contacted for content specific questions on the EFRI 2017 topics:

- TOPIC 1:, Advancing Communication Quantum Information Research in Engineering (ACQUIRE), **Dominique Dagenais**, telephone: (703) 292-8339, email: ddagenai@nsf.gov
- TOPIC 2:, New Light, EM (Electronic) and Acoustic Wave Propagation: Breaking Reciprocity and Time-Reversal Symmetry (NewLAW), **Kara Peters**, telephone: (703) 292-7060, email: KPETERS@nsf.gov

***AFOSR CONTACTS*:**

- Kenneth C. Goretta Program Officer, USAF/AFOSR/GHz-THz Electronics, (703) 696-7349, email: kenneth.goretta@us.af.mil
- Arje Nachman, Program Officer, USAF/AFOSR/Electromagnetics, (703) 696-8427, email: arje.nachman@us.af.mil
- Gernot Pomrenke, Program Officer, USAF/AFOSR/Optoelectronics and Photonics, (703) 696-8426, email: gernot.pomrenke@us.af.mil

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF Grants Conferences. Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on NSF's website.

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at http://www.grants.gov.

ABOUT THE NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

Facilitation Awards for Scientists and Engineers with Disabilities provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See Grant Proposal Guide Chapter II, Section D.2 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at http://www.nsf.gov

• **Location:**	4201 Wilson Blvd. Arlington, VA 22230
• **For General Information** (NSF Information Center)**:**	(703) 292-5111
• **TDD (for the hearing-impaired):**	(703) 292-5090
• **To Order Publications or Forms:**	
Send an e-mail to:	nsfpubs@nsf.gov
or telephone:	(703) 292-7827
• **To Locate NSF Employees:**	(703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by awardees will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding applicants or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004), and NSF-51, "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

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