Exhibit R-2, RDT&E Budget Item Justification: FY 2018 Defense Advanced Research Projects Agency	**Date:** May 2017
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 2: *Applied Research*	**R-1 Program Element (Number/Name)** PE 0602716E / *ELECTRONICS TECHNOLOGY*

COST ($ in Millions)	Prior Years	FY 2016	FY 2017	FY 2018 Base	FY 2018 OCO	FY 2018 Total	FY 2019	FY 2020	FY 2021	FY 2022	Cost To Complete	Total Cost
Total Program Element	-	168.233	221.911	295.447	-	295.447	234.685	192.923	219.473	223.973	-	-
ELT-01: *ELECTRONICS TECHNOLOGY*	-	168.233	221.911	295.447	-	295.447	234.685	192.923	219.473	223.973	-	-

A. Mission Description and Budget Item Justification

This program element is budgeted in the applied research budget activity because its objective is to develop electronics that make a wide range of military applications possible. The Electronics Technology Project focuses on turning basic advancements into the underpinning technologies required to address critical national security issues and to enable an information-driven warfighter.

Advances in microelectronic device technologies continue to significantly benefit improved weapons effectiveness, intelligence capabilities, and information superiority. The Electronics Technology project therefore supports continued advancement in microelectronics, including electronic and optoelectronic devices, microelectromechanical systems (MEMS), semiconductor device design and fabrication, and new materials and material structures. Particular focuses of this work include reducing the barriers to designing and fabricating custom electronics and exploiting improved manufacturing techniques to provide low-cost, high-performance sensors. Programs in this project will also greatly improve the size, weight, power, and performance characteristics of electronic systems; support positioning, navigation, and timing in GPS-denied environments; and develop sensors more sensitive and robust than today's standards.

This project also recognizes that phenomenal advancements in electronics will face the fundamental limits of silicon technology in the early 21st century, presenting a barrier that must be overcome in order for progress to continue. Beyond Scaling programs within the Electronics Technology project will look at reducing barriers to making specialized circuits in today's silicon hardware. These programs will also explore alternatives to traditional circuit architectures, for instance by exploiting chip-scale heterogeneous integration of differing material technologies, using "sticky logic" devices that combine computation and memory functions, and vertical circuit integration to optimize electronic devices.

The project will also investigate the feasibility, design, and development of powerful devices, including non-silicon-based materials technologies to achieve low-cost, reliable, fast, and secure computing, communication, and storage systems. Rapid design and utilization of these new technologies will be a critical focus of ELT-01, as DoD looks for mechanisms to speed the development and fielding of advanced technologies.

This project has six major focus areas: Electronics, Photonics, MicroElectroMechanical Systems, Architectures, Algorithms, and other Electronic Technology research.

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B. Program Change Summary ($ in Millions)	FY 2016	FY 2017	FY 2018 Base	FY 2018 OCO	FY 2018 Total
Previous President's Budget	174.798	221.911	234.424	-	234.424
Current President's Budget	168.233	221.911	295.447	-	295.447
Total Adjustments	-6.565	0.000	61.023	-	61.023
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	-0.999	0.000			
• SBIR/STTR Transfer	-5.566	0.000			
• TotalOtherAdjustments	-	-	61.023	-	61.023

Change Summary Explanation

FY 2016: Decrease reflects reprogrammings and the SBIR/STTR transfer.

FY 2017: N/A

FY 2018: Increase reflects Beyond Scaling - Materials and Architectures and Design programs, which focus on reducing barriers in making specialized circuits.

C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
Title: Common Heterogeneous integration & IP reuse Strategies (CHIPS)	8.000	28.500	28.000

Description: The Common Heterogeneous integration & IP reuse Strategies (CHIPS) program aims to develop the design tools and integration standards required to better leverage leading-edge commercial sector technologies in DoD systems. The program aims to realize modular integrated circuits (ICs) that integrate designs using different commercial suppliers, silicon technologies, and compound semiconductor (CS) materials. Although integrating CS and silicon has been shown to increase the performance of radio frequency devices, integration is both costly and time consuming. CHIPS will therefore pursue standardized interfaces for integrating a variety of intellectual property (IP) blocks, including for CS and silicon materials, in the form of prefabricated chiplets. The chiplets could be reused across applications, manufacturers, and transistor types, allowing DoD to amortize IC design costs across programs, better align electronics design and fabrication with military performance goals, and expand beyond its traditional reliance on the proprietary capabilities of a few on-shore manufacturers.

FY 2016 Accomplishments:
- Investigated technology choices for analog and digital technologies and the best methods of integration in order to achieve program objectives.
- Identified partners for fabrication and integration.
- Evaluated technology for various analog functional blocks for optimal use of mixed technologies.

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Investigated tradeoffs for various integration strategies for analog and digital technologies, focusing on performance, form factor, and cost. - Developed a cost model to analyze the impact of IP re-use using insight gained from large defense contractor development cycle study. - Studied the system level impact of IP re-use for the optimal use of radio frequency (RF) mixed technology functional blocks. ***FY 2017 Plans:*** - Finalize standards for high-bandwidth interfaces of digital and analog chiplet-based interconnections. - Study the system level impact of IP re-use for the optimal use of digital and analog functional blocks. - Initiate heterogeneous circuit demonstrations to verify interface standards for chiplet-based integration of digital and analog IP blocks, including commercial and DoD blocks. - Initiate module design activities to determine performance and program benefits of new processes enabled by the program. ***FY 2018 Plans:*** - Complete heterogeneous circuit demonstrations to verify interface standards for chiplet-based integration of digital and analog IP blocks, including commercial and DoD blocks. - Complete module design activities to determine performance and program benefits of new processes enabled by the program. - Initiate fabrication of approved modules to determine performance and program benefits of new processes enabled by the program. - Continue the study of the system level impact of IP re-use for the optimal use of digital and analog functional blocks.			
Title: Direct On-Chip Digital Optical Synthesis (DODOS) ***Description:*** The Direct On-chip Digital Optical Synthesis (DODOS) program will integrate diverse electronic and photonic components to create a compact, robust, and highly-accurate optical frequency synthesizer for various mission-critical DoD applications. Frequency synthesis and accurate control of radiofrequency and microwave radiation is the enabling technology for radar, satellite and terrestrial communications, positioning and navigation technology, and many other core DoD capabilities. Frequency synthesis and control of light or optical waves, however, has been constrained to laboratory experiments due to the size, fragility, and cost of optical frequency synthesizers. DODOS will leverage recent developments in the field of integrated photonics to enable the development of a ubiquitous, low-cost optical frequency synthesizers. The program could lead to disruptive DoD capabilities, including high-bandwidth optical communications, higher performance light detection and ranging (LiDAR), portable high-accuracy atomic clocks, and high-resolution detection of chemical/biological threats at a distance. Basic research for this program is funded within PE 0601101E, Project ES-01. ***FY 2016 Accomplishments:***	9.000	13.000	13.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Validated device-level performance requirements, such as the control-loop bandwidths and optical link budget, needed to reach the DODOS program metrics at the system level. - Prototyped critical photonic components in processes consistent with subsequent co-integration. - Demonstrated tabletop DODOS system, utilizing microscale components. ***FY 2017 Plans:*** - Validate prototype photonic integrated circuits containing all optical components required by the DODOS system architecture. - Implement off-chip electronics and algorithms and demonstrate DODOS electro-optic functionality. - Develop packaging techniques to co-integrate DODOS photonics and electronic control circuits. ***FY 2018 Plans:*** - Demonstrate and deliver DODOS prototypes with co-integrated photonic and electronic components meeting the performance metrics. - Complete proof-of-concept lab demonstrations of DoD-relevant applications employing DODOS technology.			
Title: Arrays at Commercial Timescales (ACT) ***Description:*** The Arrays at Commercial Timescales (ACT) program will develop standardized, fully digital phased array system components to enable rapid upgrades to DoD communications, electronic warfare, and radar systems. Phased arrays, which control and steer radio signals, have helped the DoD maintain technological superiority in nearly every theater of conflict. However, current phased array components are based on custom analog electronics, making them expensive to develop, difficult to upgrade, and time-consuming to deploy. ACT will address this challenge by leveraging programmable, commercial-off-the-shelf, digital components that can undergo yearly technology refreshes in response to a continually changing threat environment. This approach can dramatically reduce the time and cost required to develop and update DoD phased arrays. Further, the ongoing cost reductions and performance improvements typical in the commercial sector could enable the DoD to place phased arrays on inexpensive platforms such as Unmanned Aerial Vehicles where they have previously proven prohibitively expensive to develop or maintain. ***FY 2016 Accomplishments:*** - Demonstrated a highly digital common hardware module serving up to 32 elements of a phased array. - Demonstrated software configuration of the common module radio frequency performance (e.g. frequency, bandwidth, waveform) to meet the needs of a wide range of DoD radar, electronic warfare, signals intelligence, and communications applications. - Demonstrated radio frequency (RF) beam steering in a near field antenna range using the ACT highly digital common module interfaced to a 1x16 element C-band antenna.	25.551	20.000	10.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Demonstrated an antenna element with > 100 reconfiguration switches that can tune center frequency from 6-12 GHz, polarization and steer RF beams and beam nulls. - Developed a plan and preliminary designs to migrate the common module to the 14 nm Global Foundries process node where a nearly 50% reduction in power consumption is expected. ***FY 2017 Plans:*** - Demonstrate common module hardware viability through government testing in three different government furnished phased array demonstrations. - Develop the ACT common module using an advanced 14 nm process node and demonstrate the performance improvement compared to the common module developed with an earlier 32 nm node in Phase 1. - Demonstrate rapid technology refresh of the common modules developed in Phase 1. - Drive the ACT common module technology transition process by gathering and sharing test results with potential users. - Develop a reconfigurable 16 element antenna array that can tune center frequency and polarization. ***FY 2018 Plans:*** - Demonstrate arbitrary control of the surface current in a 16 element antenna array. - Demonstrate five or more common modules interfaced together to form a phased array with greater than 100 elements.			
Title: High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) ***Description:*** The High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) program seeks to develop compact radio frequency (RF) signal amplifiers for air, ground, and ship-based communications and sensing systems. HAVOC amplifiers would enable these systems to access the high-frequency millimeter-wave portion of the electromagnetic (EM) spectrum, facilitating increased range and other performance improvements. Today, the effectiveness of combat operations across all domains increasingly depends on DoD's ability to control and exploit the EM spectrum and to deny its use to adversaries. However, the proliferation of inexpensive commercial RF sources has made the EM spectrum crowded and contested, challenging our spectrum dominance. Operating at higher frequencies, such as the millimeter-wave, helps DoD to overcome these issues and offers numerous tactical advantages such as high data-rate communications and high resolution and sensitivity for radar and sensors. Opportunities for transferring HAVOC technology to the Services will be identified during the execution of the early phases of the program. Technology transfer efforts will follow a spiral development process to mitigate risk and provide the opportunity to incorporate new technological developments as they occur. Basic research for this program is funded within PE 0601101E, Project ES-01. ***FY 2016 Accomplishments:*** - Initiated the design and modeling of a wide-bandwidth, high power mm-wave vacuum electronic amplifier.	12.000	18.000	18.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Identified performance parameters and engineering tradeoffs required to meet or exceed the program metrics for both power and bandwidth in a compact form factor, incorporating new concepts for novel beam-wave interaction structures and advanced thermal management. ***FY 2017 Plans:*** - Assess state of the art in cathodes, vacuum windows, and magnetic structures for electron beam transport and identify components and technologies that meet or exceed design requirements. - Design, fabricate, and test high current-density cathodes capable of producing beam current consistent with amplifier output power requirements. - Design, fabricate, and test wide bandwidth interaction structures with high beam-wave interaction efficiency and high power handling capability. ***FY 2018 Plans:*** - Design, fabricate, and test wide bandwidth vacuum windows with high power handling capability. - Investigate new magnetic materials and magnet configurations that enable compact, integrated beam focusing and transport architectures. - Integrate components into prototype amplifiers and begin testing.			
Title: Precise Robust Inertial Guidance for Munitions (PRIGM) ***Description:*** The Precise Robust Inertial Guidance for Munitions (PRIGM) program aims to develop inertial sensor technologies for positioning, navigation, and timing (PNT) in GPS-denied environments. When GPS is not available, these inertial sensors can provide autonomous PNT information. The program will exploit recent advances in integrating photonic (light-manipulating) components into electronics and in employing microelectromechanical systems (MEMS) as high-performance inertial sensors for use in extreme environments. Whereas conventional MEMS inertial sensors can suffer from inaccuracies due to factors such as temperature sensitivity, new photonics-based PNT techniques have demonstrated the ability to reject these inaccuracies. PRIGM will focus on two areas. By 2020, it aims to develop and transition a Navigation-Grade Inertial Measurement Unit (NGIMU), a state-of-the-art MEMS device, to DoD platforms. By 2030, it aims to develop Advanced Inertial MEMS Sensors (AIMS) that can provide gun-hard, high-bandwidth, high dynamic range navigation for GPS-free munitions. These advances should enable navigation applications, such as smart munitions, that require low-cost, size, weight, and power inertial sensors with high bandwidth, precision, and shock tolerance. PRIGM will advance state-of-the-art MEMS gyros from TRL-3 devices to a TRL-6 transition platform, eventually enabling the Service Labs to perform TRL-7 field demonstrations. Basic research for this program is funded within PE 0601101E, Project ES-01 and advanced technology development for the program is budgeted in PE 0603739E, Project MT-15. ***FY 2016 Accomplishments:***	10.000	21.911	20.500

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Developed preliminary models and designed architectures for chip-scale, waveguide optical gyroscopes, which combine the essential components and functionality of ring-laser gyroscopes into a photonic integrated circuit. - Developed preliminary models for optically interrogated MEMS inertial sensors, leveraging the high sensitivity of optical interrogation with precision machining and low-cost, size, weight, and power (SWaP) enabled by MEMS. ***FY 2017 Plans:*** - Develop processes for co-fabrication of MEMS and photonic integrated circuits. - Design and simulate photonic and MEMS-photonic sensors suitable for high shock survival. - Integrate component technology and demonstrate integrated photonic-MEMS inertial sensors with beyond navigation grade performance. ***FY 2018 Plans:*** - Design and fabricate heterogeneously integrated, chip-scale waveguide optical gyroscopes. - Demonstrate navigation grade accuracy and stability of integrated inertial sensors.			
Title: Near Zero Energy RF and Sensor Operations (N-ZERO) ***Description:*** The Near Zero Power RF and Sensor Operations (N-ZERO) program will develop and demonstrate the technologies required to extend the lifetimes of remotely-deployed sensors from months to years. Today's state-of-the-art sensors can be pre-placed and remain dormant until awoken by an external trigger or stimulus. However, the active electronics that monitor for external triggers consume power, limiting sensor lifetimes to between weeks and months. N-ZERO seeks to replace these electronics with passive or extremely low-power devices that continuously monitor the environment and wake up active electronics upon detection of a specific trigger. This would eliminate or significantly reduce standby power consumption, ensuring that sensor lifetimes are limited only by the power required to process and communicate confirmed events. In doing so, N-ZERO could enable wireless sensors with drastically increased mission life and help meet DoD's unfulfilled need for a persistent, event-driven sensing capability. N-ZERO's applied research component will focus on developing radio frequency (RF) communications and physical sensor systems that use energy from an external trigger to collect, process, and detect useful information while rejecting spurious signals and noise. A basic research component is budgeted under PE 0601101E, Project ES-01. ***FY 2016 Accomplishments:*** - Designed and fabricated hardware components and microsystems for detecting RF signals with received power levels less than 1 nano-Watt while consuming less than 10 nW of power. - Designed and fabricated hardware components and microsystems for detecting and discriminating the presence of a specific machine at a distance of less than 0.5 m while consuming less than 10 nW of power consumption. - Identified government application spaces and transition paths that will make use of N-ZERO detection and signal processing. ***FY 2017 Plans:***	4.500	15.000	20.000

C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Evaluate the detection performance and power consumption of the RF and physical sensor microsystems. - Perform data collection measurements for the purpose of designing and evaluating the performance of N-ZERO devices and microsystems in higher noise, DoD relevant environments. - Design, fabricate and evaluate microsystems enabling passive or near zero energy collection, processing and detection of RF communications and physical sensor signatures at reduced (10 fold from the original specifications) signal strength. ***FY 2018 Plans:*** - Design, fabricate and evaluate microsystems enabling passive or near zero energy collection, processing and detection of RF communications and physical sensor signatures at reduced (100 fold from the original specifications) signal strength. - Identify and engage potential users in the national security space to develop N-ZERO transition opportunities. - Initiate development of a near zero power wake-up circuit designed for a specific DoD application.			
Title: Wafer-scale Infrared Detectors (WIRED) ***Description:*** The WIRED program addresses the need for low-cost, high-performance imaging sensors in the short-wave and mid-wave infrared (SWIR/MWIR) bands. These sensors will provide increased standoff distances for small unmanned aerial vehicles, low-cost missiles, handheld weapon sights and surveillance systems, helmet-mounted systems, and ground-vehicle-mounted threat warning systems. WIRED proposes to manufacture these sensors at the wafer scale, which reduces costs by processing dozens to hundreds of camera imaging arrays at a time. Wafer-scale manufacturing has already driven a revolution in optical imaging in the long-wave infrared thermal (LWIR) spectrum, with high-resolution digital cameras and LWIR sensors having become commonplace or widely-available. However, no similar technologies exist for the SWIR/MWIR bands. WIRED could therefore drive a similar revolution in SWIR/MWIR. The program aims to significantly reduce the weight and volume of MWIR detectors, which today require heavy cryogenic cooling systems, and increase the resolution of SWIR detectors by dramatically reducing their pixel size relative to the state-of-the-art. ***FY 2016 Accomplishments:*** - Explored the fundamental properties of disordered materials, and investigated the processes that affect sensor performance at elevated operating temperatures. - Investigated MWIR sensor technology for compatibility with wafer-scale processing and high performance at operating temperatures suitable with low-cost thermoelectric coolers. - Investigated SWIR sensor technology for compatibility with wafer-scale processing and scalability to a near diffraction-limited pixel pitch. ***FY 2017 Plans:*** - Develop models that describe the fundamental behavior of disordered materials and apply them to device-level simulations.	10.000	14.000	18.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Demonstrate imaging from MWIR detectors that are integrated directly onto readout integrated circuits (ROICs) and evaluate detector performance/characteristics at temperatures of 230 K. - Demonstrate imaging from small pixel SWIR detectors that are integrated directly onto ROICs and evaluate detector performance/characteristics. ***FY 2018 Plans:*** - Demonstrate imaging from MWIR detectors that are integrated directly onto ROICs and evaluate detector performance/characteristics at temperatures of 250 K. - Demonstrate improved imaging from small pixel SWIR detectors that are integrated directly onto ROICs and evaluate detector performance/characteristics. - Update cost models based on detector performance. - Develop materials and device physics models to design LWIR devices. - Demonstrate performance of a LWIR device at temperatures of 298 K.			
Title: Modular Optical Aperture Building Blocks (MOABB) ***Description:*** The Modular Optical Aperture Building Blocks (MOABB) program aims to greatly improve the cost, size, weight, and performance of free-space optical systems. These systems enable applications such as light detection and ranging (LIDAR), laser communications, laser illumination, navigation, and 3D imaging. Specifically, MOABB aims to construct millimeter-scale optical building blocks that can be coherently arrayed to form larger, higher power devices. These building blocks would replace the traditional large and expensive precision lenses and mirrors, which require slow mechanical steering, that form conventional optical systems. MOABB will develop scalable optical phased arrays that can steer light waves without the use of mechanical components. These advances would allow for a 100-fold reduction in size and weight and a 1,000-fold increase in the steering rate of optical systems. ***FY 2016 Accomplishments:*** - Designed and simulated non-mechanically steered millimeter-scale transmit and receive unit cells with 5mW of output power. - Performed preliminary thermal modeling of the device, demonstrating a path to air-cooling. ***FY 2017 Plans:*** - Complete architecture design and application study for chip-scale LIDAR. - Fabricate and test a millimeter-scale unit cell transmit and receive elements. ***FY 2018 Plans:*** - Simulate low-loss grating design. - Demonstrate a scalable optical tile with integrated amplification.	12.000	16.911	22.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Complete preliminary LIDAR system designs.			
Title: Circuit Realization At Faster Timescales (CRAFT)	15.000	26.000	20.000

Description: The Circuit Realization At Faster Timescales (CRAFT) program will develop novel integrated circuit (IC) design flows to reduce by ten times the design and verification effort required for high-performance military electronics. CRAFT will also reduce barriers to the design and fabrication of custom ICs in leading-edge complementary metal oxide semiconductor (CMOS) technology. When selecting electronics for advanced systems, DoD currently must choose between high-performing custom ICs that take years to design and verify or significantly lower-performing general purpose ICs that can be implemented in a few months. The need to protect sensitive IC information further limits DoD's ability to access certain leading-edge commercial electronics. To reduce the design and verification effort, CRAFT will investigate and leverage novel design flows that utilize recent advances in electronic design automation and software design methodologies. These design flows could reduce the manual labor required to develop and verify custom ICs. CRAFT will also explore increased design reuse and flexibility, which will allow DoD to migrate chip fabrication between different foundries or to more advanced technology nodes. Finally, CRAFT will develop and validate various techniques for obscuring sensitive information during the IC manufacturing process, allowing DoD to leverage more of the available onshore semiconductor market. These capabilities can help to ensure that the DoD has multiple potential suppliers for critical ICs and help keep military electronics at the leading edge.

FY 2016 Accomplishments:
- Completed design submissions for the first Fin Field Effect Transistor (FinFET) multi-project wafer shuttle run for technology evaluation.
- Completed initial definition of the design flow for the object oriented design methodology.
- Established a repository where the intellectual property (IP), methodology, and tools required to implement the object oriented design flow will be stored and distributed.

FY 2017 Plans:
- Complete the first two FinFET multi-project wafer shuttle runs.
- Evaluate designs from first FinFET multi-project wafer shuttle run.
- Initiate efforts to transfer design elements between foundries and across technology nodes.
- Complete initial testing of at least two full object oriented design flows.
- Start design and intellectual property transfer to the repository for storage and distribution.
- Implement and examine the effectiveness of existing, commercially-available IP obfuscation techniques on a DoD-relevant chip.

FY 2018 Plans:
- Complete the third FinFET multi-project wafer shuttle run with design fabrication done at multiple foundries and at multiple technology nodes.

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Evaluate designs from the second and third multi-project wafer shuttle runs. - Utilize design flow and IP from the CRAFT repository to complete the DoD reference design. - Mature new and existing IP obfuscation techniques, evaluate them on DoD-relevant chips, and develop the technologies and techniques required to deploy them for DoD needs.			
Title: Atomic Clock with Enhanced Stability (ACES) ***Description:*** The Atomic Clock with Enhanced Stability (ACES) program aims to develop extremely stable chip-scale atomic clocks for unmanned aerial vehicles and other low size, weight, and power (SWaP) platforms with extended mission durations. Atomic clocks provide the high-performance backbone of timing and synchronization for DoD navigation; communications; electronic warfare (EW); and intelligence, surveillance, and reconnaissance (ISR) systems. However, atomic clocks are limited, particularly by temperature sensitivity, aging over long timescales, and a loss of accuracy when power cycled. By employing alternative approaches to confining and measuring atomic particles, ACES could yield a 100x - 1000x improvement in key performance parameters related to each of these limitations. ACES will also focus on developing the component technologies necessary for low-cost manufacturing and for deployment in harsh DoD-relevant environments. Among its many benefits, program success could help reduce the risk posed by a growing national dependence on GPS, allowing systems to maintain their timing accuracy in the event of temporary GPS unavailability. ***FY 2016 Accomplishments:*** - Developed preliminary block diagrams, component specifications, and physics models for candidate ACES architectures. ***FY 2017 Plans:*** - Develop component specifications and schematics to support ACES devices. - Fabricate and test prototype component technology for ACES devices. - Perform physics simulations and modelling to establish predicted compliance of ACES clock architectures with ACES program objectives. ***FY 2018 Plans:*** - Perform laboratory demonstration of functioning ACES clock meeting Phase 1 metrics of power consumption, retrace, and instability. - Design integrated physics package meeting Phase 2 size, weight, and power (SWaP) objectives. - Fabricate and test an integrated physics package meeting the ACES Phase 2 SWaP, retrace, and aging goals.	3.127	10.589	21.000
Title: Limits of Thermal Sensors (LOTS) ***Description:*** The Limits of Thermal Sensors (LOTS) program aims to demonstrate long-wave infrared (LWIR) detector technologies with both high performance and low-size, weight, power, and cost (SWaP-C). The resulting technologies could	-	9.000	9.000

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C. Accomplishments/Planned Programs ($ in Millions)	**FY 2016**	**FY 2017**	**FY 2018**
enable improvements in imaging systems such as night-vision goggles, infrared-guided missiles, and missile threat warning systems. Currently, LWIR-enabled systems must choose between large and expensive cryogenically-cooled detectors, which offer high sensitivity and response times, and uncooled detectors called microbolometers, which offer significant SWaP-C reductions. LOTS seeks to develop microbolometers that can compete with larger detectors in terms of sensitivity required to detect signals over long ranges and response time to avoid image blur. These technologies should allow DoD to deploy smaller, lighter, and cheaper sensors on critical, high-value assets while maintaining or improving their ability to engage fast-moving or distant targets. ***FY 2017 Plans:*** - Investigate preliminary architecture and design parameters to achieve sensitive microbolometer performance. - Demonstrate performance improvement in uncooled microbolometers over current production devices. - Demonstrate sensor fabrication in a production environment. ***FY 2018 Plans:*** - Build LWIR cameras with refined focal-plane array and calibrate for operation over -40 C to 65 C temperature range. - Test cameras for radiometric performance and sensitivity and deliver camera hardware.			
Title: Atomic Magnetometry for Biological Imaging In Earth's Native Terrain (AMBIIENT) ***Description:*** The Atomic Magnetometry for Biological Imaging In Earth's Native Terrain (AMBIIENT) program will develop novel magnetic sensors capable of providing high-sensitivity signal measurements in the presence of ambient magnetic fields. In recent years, the value of magnetic imaging, for example for cardiac and other biological signals, has shown tremendous potential for advanced research and clinical diagnosis. Practical application, however, has been limited. Interference from natural and manmade ambient magnetic fields has required that the measurements be performed in specialized, magnetically-shielded research facilities. The AMBIIENT program will exploit novel physical architectures that are resistant to the impact of common noise sources. The AMBIIENT sensor itself must be able to detect the gradient of a local magnetic field while subtracting the much larger ambient signal, preferably using the sensing mechanism to do this subtraction. This would enable low-cost, portable, high-sensitivity measurements for in-the-field applications. In addition to medical research and clinical diagnosis, AMBIIENT sensors promise to enable diverse sensing applications including magnetic gradient navigation, anomaly detection, perimeter monitoring, and ultralow frequency (ULF) communications. ***FY 2018 Plans:*** - Develop preliminary architectures for direct gradient sensing of magnetic fields. - Develop and test quantitative models of gradient sensor physics.	-	-	9.247

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Perform laboratory validation of proof-of-principle of gradient sensor physics performance.			
Title: Dynamic Range-enhanced Electronics and Materials (DREaM) ***Description:*** The Dynamic Range-enhanced Electronics and Materials (DREaM) program will develop intrinsically linear radio frequency (RF) transistors with improved power efficiency and extremely high dynamic range. Linearity, power efficiency, and dynamic range are fundamental characteristics that allow RF systems to reliably transmit clear signals. Improving these characteristics is essential to operating in a crowded RF environment and to enabling next-generation communication, sensing, and electronic warfare systems. By contrast, existing RF transistor technologies amplify RF signals but produce undesired interference in the RF spectrum due to their poor linearity. Traditional RF transistor design typically requires a trade-off between high linearity and broadcast range. DREAM will overcome this tradeoff by employing new ultra-wide band gap and high carrier mobility materials in novel transistor-level designs and highly-scaled transistor structures. The resulting device technology should allow future RF electronics to increase their operating range without polluting the already-congested RF spectrum while consuming less system power. ***FY 2018 Plans:*** - Explore novel device structures and emerging materials that will result in high power, high linearity and high power efficiency RF transistors. - Develop high power and linear power transistor prototype that provide three times more power density and linearity than the state of the art. - Develop low noise and lower power linear transistor prototype that provide 10 times improvement of linearity figure of merit than the state of the art.	-	-	14.000
Title: Wireless Autonomous Vehicle Power Transfer (WAVPT) ***Description:*** The Wireless Autonomous Vehicle Power Transfer (WAVPT) program will develop small footprint, efficient receivers to enable power beaming from a ground-based transmitter to a remote unmanned aerial vehicle (UAV). UAVs are currently powered by large, heavy chemical batteries or an engine, with associated liquid fuel. This consumes a large percentage of the UAV's weight budget and places strict limitations on its range. Wireless power transfer represents a paradigm-changing solution to power distribution by alleviating the need to carry all energy sources on-board, drastically reducing UAV weight, and increasing aircraft endurance. Additional power can also be made available for the UAV's payload, allowing use of higher-functionality sensing and computing systems and enabling better data exploitation and threat response. Previous wireless power transfer experiments have demonstrated delivery of over 30 kilowatts of power over a distance of one kilometer but have seen limited adoption due to the prohibitively large, meter-sized receivers required. WAVPT will leverage recent advances in directed energy sources and beam-forming capabilities and develop new receiver architectures to demonstrate efficient wireless power transfer in a small form-factor. Advanced semiconductor materials and processing techniques will be used to develop low-cost, centimeter-	-	-	9.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
sized receivers with high efficiency and energy densities, enabling integration within a small platform. The program will culminate with a demonstration of hundreds of watts of power being transferred from a ground-based transmitter to a UAV at least one kilometer away. The technology that is developed within this program can break the inherent tradeoff between mission duration and weight for unmanned vehicles and transform next-generation military systems. ***FY 2018 Plans:*** - Devise a detailed CONOPs for wireless power beaming, including selected UAV, dwell time needed for charging, payload power requirements, and platform integration. - Identify link budget for wireless power transfer over one kilometer and begin initial circuit design for high efficiency receivers. - Determine best choices for transmitter technology based on initial simulations of beam transmission through mission-relevant atmospheric conditions.			
Title: Intelligent Design of Electronic Artifacts (IDEA) ***Description:*** The Intelligent Design of Electronic Artifacts (IDEA) program aims to develop intelligent, free, and open-source development tools and building blocks to provide custom integrated circuits (IC) for mission critical DoD systems. Currently, leading-edge IC development requires large teams of domain experts and costs up to $100M per IC design. These hurdles limit DoD s ability to rapidly access high-performance electronic components and encourage the use of sub-optimal or insecure alternatives. IDEA would reduce the cost and expertise barriers to IC design by leveraging 50 years of chip design knowledge, ongoing advances in machine intelligence, and the incredible growth in public, cloud-based computational resources. The program would develop evolvable, open-source IC design tools and IC building block libraries that can be stored in publicly available cloud infrastructure. This would enable small teams of system and algorithm experts without chip design experience to develop custom ICs at a very low cost and quickly implement these designs in hardware. IDEA would therefore facilitate the development of critical, custom components for the vast majority of DoD missions, including for imaging, communication, electronic warfare, radar, and security applications. ***FY 2018 Plans:*** - Demonstrate the use of open source tool Verilog to chip compiler and a library of open source digital building blocks to create a viable application specific circuit. - Demonstrate technology independent generation of physical standard cell, IO, and memory libraries using a set of open source tools. - Develop preliminary methods and algorithms for integrating intelligence/learning into the development tools - Develop methods and algorithms that make chip development tools performance scalable across publicly available cloud infrastructure.	-	-	9.700
Title: Beyond Scaling - Materials	-	-	19.000

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Description: The Beyond Scaling - Materials program will demonstrate the integration of novel materials into next-generation logic and memory components. Historically, the DoD had taken the lead in shaping the electronics field through research in semiconductor materials, circuits, and processors. However, as DoD focuses on military-specific components and commercial investments eschew the semiconductor space, U.S. fundamental electronics research is stagnant just as an inflection point in Moore's Law (silicon scaling) is about to occur. This program will pursue potential enhancements in electronics that do not rely on Moore's Law, including research not only into new materials but also into the implications of those materials at the device, algorithm, and packaging levels. Research areas will include heterogeneous integration of multiple materials, "sticky logic" devices that combine elements of computation and memory, and leveraging three-dimensional vertical circuit integration to demonstrate dramatic performance improvements with older silicon technologies. The program aims to demonstrate the manufacturability of functioning switches, memory, and novel computational units in a large-scale system. Previous DARPA work on unconventional computing, integration, and reprogrammable memory give confidence in this approach. Basic research for this program is funded within PE 0601101E, Project ES-01. ***FY 2018 Plans:*** - Quantify the value of vertical integration using modern and older technology nodes. - Demonstrate the ability to store the results of computer processing in close proximity to computer logic blocks.			
Title: Beyond Scaling - Architectures and Designs ***Description:*** The Beyond Scaling - Devices and Architectures program will significantly increase the ease with which DoD can design, deliver, and eventually upgrade critical, customized electronics hardware. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics cost, speed, and power derived from silicon scaling, the DoD will need to maximize the benefits of available silicon technologies by using design tools that enable circuit specialization. This program will develop and demonstrate the tools required for rapidly designing and deploying specialized circuits. Research efforts will explore technologies and techniques such as new domain-specific circuit architectures; co-design of electronics hardware and software; tight integration of chip-scale processing blocks and artificial intelligence-enabled processing controllers; and open-source circuit designs. Further research will also develop tools to create exact representations of outdated hardware in the field and to rapidly, cheaply, and safely upgrade these systems with next-generation electronics. Previous DARPA and commercial programs on tightly integrated heterogeneous systems, high-speed simulation software, and open-source hardware development provide confidence in this approach. Advances under this program will demonstrate a new DoD capability to create specialized hardware and provide benefits by improving electronics systems that do not depend on continued rapid improvements in silicon transistors. Basic research for this program is funded within PE 0601101E, Project ES-01. ***FY 2018 Plans:*** - Execute machine generation of physical objects to demonstrate a reduction in circuit design time.	-	-	35.000

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Demonstrate the ability to construct a system with decomposable pieces that can be rapidly upgraded. - Establish and exhibit the capability to manage specialized accelerators for a variety of codes and applications.			
Title: Adaptive Radio Frequency Technology (ART) ***Description:*** The Adaptive Radio Frequency Technology (ART) program will develop a technology base to enable real-time-adaptable radios for individual warfighters and small unmanned systems. ART technologies would provide capabilities for next-generation communications, sensing, and electronic warfare, including reconfigurable radios and efficient and compact signal identification capabilities. Goals of the ART program include (1) developing a technology base enabling future radios to survey and adapt to the electromagnetic environment; (2) enabling the rapid deployment of radios in response to changing operational requirements; and (3) significantly reducing the size, weight, and power (SWaP) of such radios. ART will enable the use of a single design pathway for multiple, unique radio frequency (RF) systems, thus dramatically reducing military procurement and sustainment costs. ART will also advance the hardware and software used in radio frequency (RF) systems by developing a flexible, reconfigurable architecture that can adapt to various RF waveforms. ***FY 2016 Accomplishments:*** - Investigated transition paths for phase change switch technology including potential transitions into a commercial semiconductor foundry. - Developed transition paths for Radio-Frequency Field-Programmable Gate Arrays reconfigurable RF front-ends including the supplying of demo units to DoD end users and the investigation of commercialization paths for supplying the technology to the DoD. - Increased power handling of phase change switch technology to > 0.6W and improved the reliability to > 0.5 million cycles to meet the performance requirements of military and commercial communications systems. ***FY 2017 Plans:*** - Demonstrate an RF front-end reconfigurable between five different RF systems with performance approaching (> 90%) that of a fixed point solution. - Finalize transition plans for a fully reconfigurable RF circuit technology at the component and system levels. - Develop enhanced version of an existing RF-FPGA chip and integrate it onto a wideband reconfigurable RF system that can be used to develop and test advanced radio capabilities.	9.040	8.500	-
Title: Diverse & Accessible Heterogeneous Integration (DAHI) ***Description:*** The Diverse Accessible Heterogeneous Integration (DAHI) program is developing the design and manufacturing capabilities required to seamlessly integrate various semiconductors, microelectromechanical systems, photonic (light-manipulating) devices, and thermal management structures into true systems-on-a-chip (SOC). This capability would enable dramatic size, weight, and volume reductions and higher performance for DoD electronic warfare, communications, and radar	16.000	11.500	-

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
systems. Historically, chip designers have had to decide between the availability, development, and low cost of silicon circuits or the high performance of compound semiconductor (CS) materials. DAHI, however, builds on previous DARPA and commercial efforts, which demonstrated that heterogeneously integrating CS and silicon can yield significant performance improvements over silicon or CS alone. DAHI's applied research program focuses on developing and demonstrating high-performance SOC for DoD-specific applications. The program should also enhance the manufacturing yield and reliability of heterogeneous integration capabilities and demonstrate innovative, advanced microsystems that leverage heterogeneous integration. Relevant manufacturing processes would be made available to a wide variety of designers from the DoD laboratories, federally funded research and development centers, academia, and industry. This program has advanced technology development efforts funded in PE 0603739E, Project MT-15. ***FY 2016 Accomplishments:*** - Demonstrated heterogeneous integration of advanced node silicon complementary metal-oxide semiconductor (CMOS) processes achieved with diverse types of compound semiconductor transistors and MEMS, including interconnect and thermal management approaches. - Transitioned multi-user foundry interface to independent design service from proprietary foundry model to enable community access to diverse heterogeneous integration processes. - Demonstrated sustainable model and accessibility via foundry/customer engagements, including detailed cost models and quotations. ***FY 2017 Plans:*** - Demonstrate heterogeneous integration process with more sophisticated circuit demonstrations using silicon interposer technology combining heterogeneously integrated multi-technology circuits with high Q passive technologies. - Demonstrate integration of emerging device technologies into established heterogeneous integration process flow with minimal process deviation.			
Title: Vanishing Programmable Resources (VAPR) ***Description:*** The Vanishing Programmable Resources (VAPR) program will create microelectronic and mechanical systems capable of physically vanishing in a controlled, triggerable manner. This advance could help avoid problems associated with unrecovered devices, including their potential use by unauthorized individuals and the compromise of intellectual property. The resulting technologies could enable a range of applications including vanishing sensors for monitoring large areas of the environment and transient airborne vehicles for emergency resupply without requiring pack out of the air delivery vehicle. To support this new class of electronics and mechanical structures, VAPR will develop and establish an initial set of transient materials and components along with the required manufacturing processes. The resulting systems should perform comparably to commercial-off-the-shelf systems while demonstrating system transience that can be programmed, adjusted, triggered, or made to respond to the deployment environment. VAPR technologies will be demonstrated through two final test platforms. A	9.000	9.000	-

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
vanishing air delivery vehicle capable of precise, gentle drops of small payloads (~3 lbs.) seeks to demonstrate the feasibility of transient structural materials. A sensor with a wireless link seeks to demonstrate the manufacturability of transient electronics. Both demonstrations are intended to fully function on their own and to serve as a leading indicator of the potential systems and concepts-of-operation that VAPR could enable. ***FY 2016 Accomplishments:*** - Completed integration of transient devices and materials to form fully functional microsystems. - Achieved a transience time of less than or equal to 30 seconds for transient functional microsystems. - Improved the variability of transience time to less than or equal to 10 seconds. - Realized reliable operation of transient microsystems for greater than 100 hours after deployment, with subsequent controlled transience. ***FY 2017 Plans:*** - Optimize novel transient materials for application in the air delivery vehicle to meet structural requirements while guaranteeing full and complete transience. - Initiate commercial-scale production of novel transient materials. - Complete preliminary design reviews of air delivery system that meets program-defined air-release and landing specifications.			
Title: IntraChip Enhanced Cooling (ICECool) ***Description:*** The IntraChip Enhanced Cooling (ICECool) program incorporated thermal management techniques directly into microelectronics. This enabled operation of military electronic systems at higher powers while significantly reducing their size and weight. Today, the high-power operation of military electronics is restricted by the amount of heat created. ICECool overcame these limitations by significantly increasing the rate of heat removal in microelectronics. Areas of focus included overcoming the limits of existing thermal management techniques, determining the feasibility of exploiting these techniques within a single chip or stack of chips, and ensuring the reliable operation of microelectronics that produce high levels of heat. ICECool integrated chip-level thermal management techniques into prototype, high-power electronics in radio frequency arrays and embedded computing systems. Successful program completion will meet the capability needs of next-generation military systems, enabling increased radar range, improved target tracking, and accelerated processing using high power computing. ***FY 2016 Accomplishments:*** - Completed reliability simulations of ICECool electrical demonstration modules to establish mean time to failure and compatibility with relevant military specifications. - Demonstrated minimal degradation of electrical demonstration vehicles under 100 hour life tests and 1000 temperature cycle tests.	9.750	-	-

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
- Tested and demonstrated fully-functional High Power Amplifiers with a 6x increase in output power and 2-3x improvement in efficiency over the baseline GaN-on-SiC approach. - Designed application-ready ICECool modules and subarrays to facilitate transition of ICECool enabled components into relevant systems. - Engaged in transition activities for the ICECool technology to enable insertion of ICECool enabled components in relevant subsystems such as transmit/receive modules and embedded airborne computing platforms. - Demonstrated a fully functional microprocessor with embedded two phase cooling, showing a decrease in chip temperature of 25C for the same workload as an air cooled processor, providing higher reliability and performance enabled by high hot spot cooling capabilities.			
Title: In vivo Nanoplatforms (IVN) ***Description:*** The In vivo Nanoplatforms (IVN) program developed the nanoscale systems necessary for in vivo sensing and physiologic monitoring and delivery vehicles for targeted biological therapeutics against chemical and biological (chem-bio) threat agents. The nanoscale components enabled continuous in vivo monitoring of physiological biomarkers. A reprogrammable therapeutic platform that targets gene regulatory sequences enabled tailored therapeutic delivery to specific areas of the body (e.g., cells, tissue, compartments) in response to traditional, emergent, and engineered threats. The key challenges to developing these systems included safety, toxicity, biocompatibility, sensitivity, response, and targeted delivery. The IVN program achieved diagnostic and therapeutic goals that enabled a versatile, rapidly adaptable system to provide operational support to the warfighter in any location. ***FY 2016 Accomplishments:*** - Demonstrated enhanced therapeutic performance via molecular targeting approaches in an animal model. - Demonstrated the ability of skin-based sensors to detect physiologically relevant molecules (e.g., pH, ions, glucose, lactate, and cortisol) in an animal model. - Demonstrated the ability of an in vivo nanoplatform to protect against infectious disease in an animal model. - Continued to update regulatory approval pathway with results from animal model safety and efficacy testing.	8.265	-	-
Title: Pixel Network (PIXNET) for Dynamic Visualization ***Description:*** The Pixel Network (PIXNET) for Dynamic Visualization program enabled individual warfighters with a compact, versatile, and affordable camera for target detection, recognition, and identification (DRI) in both daylight and no-light conditions. The camera eliminates limitations posed by current camera systems. PIXNET enabled real-time fusion of thermal and reflected infrared (IR) imagery, allowing the warfighter to better detect camouflaged targets and distinguish decoys. The program focused on significantly reducing the size, weight, and power (SWaP) of IR sensors, enabling new capabilities for small unmanned aerial vehicles, rifle sights, and vehicle-mounted, helmet-mounted, and handheld systems. In the future, PIXNET capabilities will also	4.000	-	-

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C. Accomplishments/Planned Programs ($ in Millions)	FY 2016	FY 2017	FY 2018
enable real-time wireless sharing of video data, which may support a peer-to-peer image-sharing system for establishing a better common operating picture of the battlefield. ***FY 2016 Accomplishments:*** - Demonstrated multi-band fusion with the visible and near infrared/long-wave infrared (VNIR/LWIR) camera. - Demonstrated the short-wave infrared/long-wave infrared (SWIR/LWIR) helmet mounted camera with real-time, on-board multi-band fusion. - Demonstrated a bench-scale brassboard SWIR/MWIR camera with image fusion algorithms on an external laptop to show functionality.			
Title: Hyper-wideband Enabled RF Messaging (HERMES) ***Description:*** The Hyper-wideband Enabled RF Messaging (HERMES) program developed architectures and technologies to maintain assured radio frequency (RF) links in contested environments. Today, RF links are allocated and confined to slices of spectrum to prevent interference among users; this however facilitates enemy attempts to jam the link. HERMES explored a combination of techniques to suppress enemy jammers and guarantee communications in situations where the RF link is critical. Technology developed under the HERMES program enabled RF links to access tremendous amounts of bandwidth without jeopardizing other links. Advances under the HERMES program will prove increasingly important given the growing dependence of modern weapons systems on RF links for communications, command and control, geolocation and battle management. ***FY 2016 Accomplishments:*** - Conducted a demonstration of prototype direct-sequence spread-spectrum receiver with 6 GHz of instantaneous bandwidth and suppression of multi-path interference.	3.000	-	-
Accomplishments/Planned Programs Subtotals	168.233	221.911	295.447

D. Other Program Funding Summary ($ in Millions)

N/A

Remarks

E. Acquisition Strategy

N/A

F. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.