

SBIR INVESTMENTS

in RADIOFREQUENCY (RF) COMMUNICATION
TECHNOLOGY

2006 to 2014



SPACE COMMUNICATIONS AND NAVIGATION



*Cover photo: Deep Space Radiofrequency (RF)
Communication Scenario.*

FOREWORD



NASA's mission to pave the future of space exploration through innovations in science and technology is reflected in a balanced technology development and maturation program supported by all NASA Mission Directorates. Stimulating technology innovation through Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) programs, NASA has empowered U.S. small businesses to make significant contributions to the future of space exploration.

This technology investment portfolio highlights SBIR Phases I and II investments in radiofrequency (RF) communication technology development for the Space Operations Mission Directorate (SOMD)/Human Exploration and Operations Mission Directorate (HEOMD) from 2006 to 2014. This report summarizes technology challenges addressed and advances made by the SBIR community in RF technology. The goal of this document is to encourage program and project managers, stakeholders, and prime contractors to take advantage of these technology advancements to leverage their own efforts and to help facilitate infusion of technology advancements into future NASA projects. A description of NASA's SBIR Program can be found at www.sbir.nasa.gov.




SMALL BUSINESS
INNOVATION RESEARCH



The Small Business Innovation Research (SBIR) Program provides opportunities for small, high-technology companies to participate in Government-sponsored research and development efforts in key technology areas of interest to NASA. The SBIR Program provides significant sources of seed funding to foster technology innovation. The SBIR Phase I contracts are awarded for 6 months with funding up to \$125,000; Phase II contracts are awarded for 24 months with funding up to \$750,000.



HUMAN EXPLORATION

A person wearing a space helmet is looking out of a window. The background is dark, suggesting space or a night sky. The person's face is partially visible through the helmet's visor.

The Human Exploration and Operations Mission Directorate (HEOMD) is chartered with the development of core transportation elements, key systems, and enabling technologies required for beyond-low-Earth-orbit (LEO) human exploration that will provide the foundation for the next half-century of American leadership in space exploration.

This new space exploration era starts with increasingly challenging test missions in cislunar space, including flights to the Lagrange points, followed by human missions to near-Earth asteroids (NEAs), the Moon, the moons of Mars, and Mars as part of a sustained journey of exploration in the inner solar system. HEOMD was formed in 2011 by combining the Space Operations Mission Directorate (SOMD) and the Exploration Systems Mission Directorate (ESMD) to optimize the elements, systems, and technologies of the precursor directorates to the maximum extent possible.

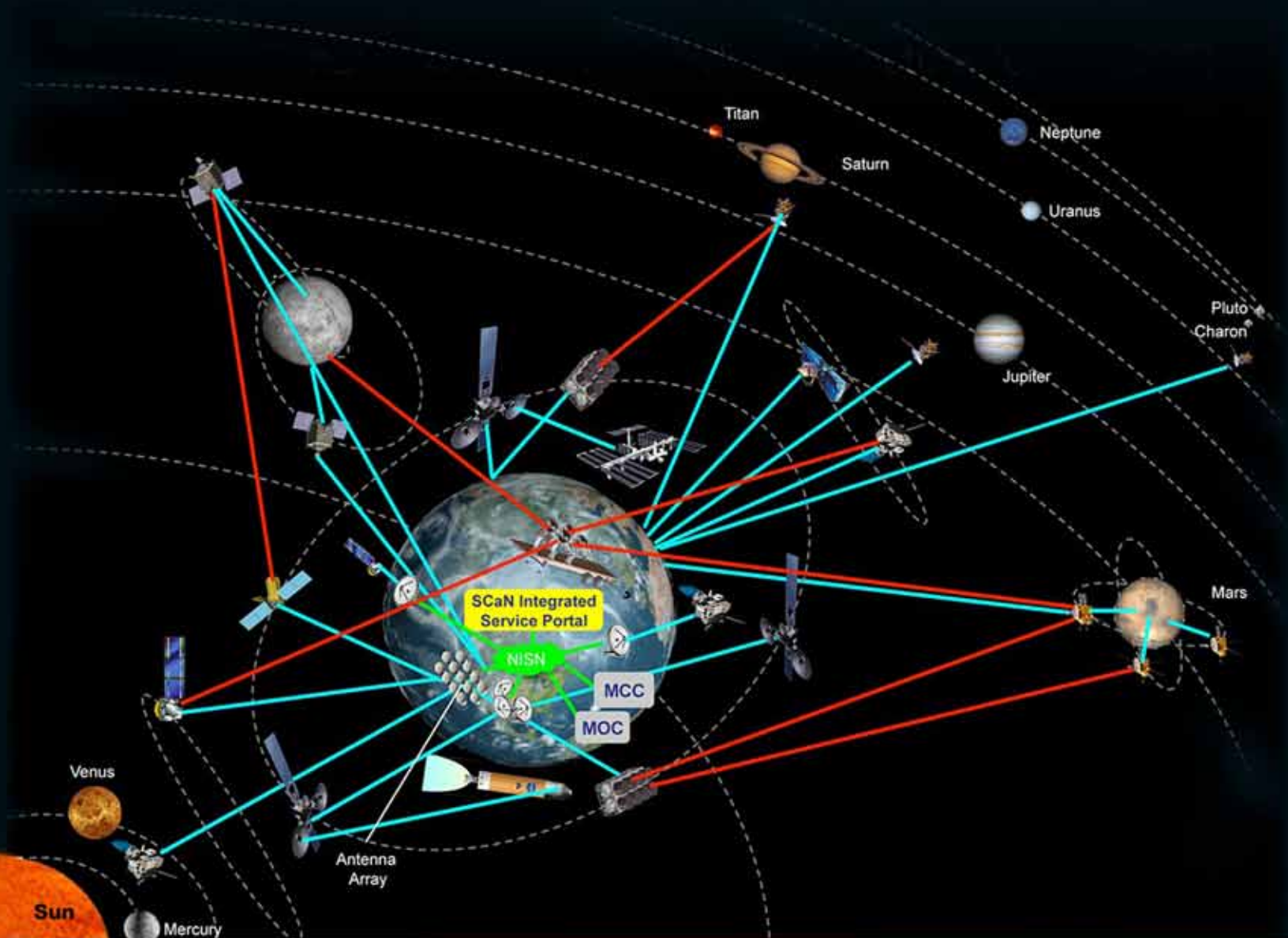
HEOMD mission goals include key technology developments in Space Communications and Navigation, Space Transportation, Human Research and Health Maintenance, Radiation Protection, Life Support and Habitation, High-Efficiency Space Power Systems, and Ground Processing/International Space Station (ISS) Utilization.

HEOMD looks forward to incorporating SBIR-developed technologies into current and future systems to contribute to the expansion of humanity across the solar system while providing continued cost-effective space access and operations for its customers, with a high standard of safety, reliability, and affordability.

AND OPERATIONS MISSION DIRECTORATE

SCaN: KEEPING THE

SCaN NOTIONAL INTEGRATED NETWORK ARCHITECTURE



Microwave Links

Optical Links

NISN

UNIVERSE CONNECTED

PROGRAM AND TECHNOLOGY DEVELOPMENT OVERVIEW

The Space Communications and Navigation (SCaN) Program resides within HEOMD and is responsible for the development of technologies and capabilities to support all current and future NASA missions. The SCaN Program provides the communication, navigation, and mission science data transfer services that are vital to the successful operation of NASA space flight missions. To accomplish this, SCaN operates three networks: the Deep Space Network (DSN), the Near Earth Network (NEN), and the Space Network (SN). Combined together, the services and network assets provide capabilities that enable space exploration for over 100 NASA and non-NASA missions. SCaN also provides scheduling services to new missions through the Network Integration Management Office (NIMO) and Deep Space Network Commitment Office (DSNO).

To accomplish the above, the SCaN Program's vision is to build and maintain a scalable, integrated, and mission support infrastructure that can evolve to accommodate new and changing technologies, while providing comprehensive, robust, cost effective, and exponentially higher data rate services to enable NASA's science and exploration missions. Today NASA communication and navigation capabilities using radiofrequency technology can support spacecraft to the fringes of the solar system and beyond. The anticipated new missions for science and exploration of the universe are expected to challenge the current data rates of 300 Mbps in LEO and of 6 Mbps at Mars to rise significantly. The SCaN Program aims to

- Develop a SCaN infrastructure capable of meeting both robotic and human exploration mission needs.
- Evolve infrastructure to provide the highest data rates feasible.
- Develop internationally interoperable data communications protocols for space missions.
- Offer communications and navigation infrastructure for lunar and Mars surfaces.
- Offer communications and navigation services to enable lunar and Mars human missions.

SCaN technology development interests include optical communications, advanced antenna technology and Earth stations, cognitive networks, access links, reprogrammable communications systems, spacecraft positioning, navigation, and timing (PNT), and communications in support of launch services. Innovative solutions to operational issues are needed in all of the areas. Emphasis is placed on size, weight, and power improvements. All SBIR technologies developed under the SCaN topic area are aligned with the SCaN Program technical directions.

This document catalogs SCaN SBIR investments in **radiofrequency (RF) communication technology** development from 2006 to 2014.

SBIR PHASE I AWARDS



CONTENTS

Radiofrequency (RF) Communication Technology	1
Radiofrequency (RF) Communication Technology SBIR Phase I Awards (2006 to 2014)	4
Solid-State Power Amplifiers (SSPAs) Using Reduced Conduction Angle Techniques on Wide-Bandgap Devices for Ultra-High Efficiency <i>Hittite Microwave Corporation</i>	4
Integrated Monolithic Microwave Integrated Circuit (MMIC) for Phase-Locked Oscillators and Frequency Synthesizers <i>Hittite Microwave Corporation</i>	5
Reconfigurable Miniature Transponder for Multimode L-, S-, and X-Band Space Communication <i>Space Micro, Inc.</i>	6
Development of Epitaxial Gallium Nitride (GaN) Films for Radiofrequency (RF) Communications <i>Neocera, LLC</i>	7
Integrated Production of Ultra-Low Defect Gallium Nitride (GaN) Films and Devices for High-Power Amplifiers <i>SVT Associates</i>	8
Monolithic Microwave Integrated Circuits (MMICs) for High-Efficiency Ka-Band Gallium Nitride (GaN) Power Amplifiers <i>Hittite Microwave Corporation</i>	9
Three-Dimensional (3D) Microfabricated Low-Loss Reconfigurable Components <i>Nuvotronics, LLC</i>	10
A 60 to 85% Efficient X- and K-Band 1-Kilowatt Solid-State Power Amplifier (SSPA) Using Gallium Nitride (GaN)-on-Diamond <i>Group 4 Labs, LLC</i>	11
High-Power Wide-Bandgap Engineered Millimeter-Wave (MMW) Monolithic Microwave Integrated Circuit (MMIC) Transceiver <i>TLC Precision Wafer Technology, Inc.</i>	12
Nanoparticle Scandate Cathode for Space Communications. <i>ebeam, Inc.</i>	13
Gallium Nitride (GaN) Bulk Growth and Epitaxy from Ca-Ga-N Solutions <i>The IIIAN Company, LLC</i>	14
DD-Amp for Deep Space Communications <i>MaXentric Technologies</i>	15
High-Efficiency, High-Power Ka-Band Elliptic-Beam Traveling-Wave-Tube Amplifier (TWTA) for Long-Range Space Radiofrequency (RF) Telecommunications <i>Beam Power Technology, Inc.</i>	16
Size, Weight and Power (SWaP) Optimized Space Transceivers <i>Nuvotronics, LLC</i>	17
X-Band Gallium Nitride (GaN) Power Amplifiers (PAs) for Long-Range Space Radiofrequency (RF) Telecommunications <i>Nitronex Corporation</i>	18

SBIR PHASE I AWARDS CONTINUED



High-Power X- and Ka-Band Gallium Nitride (GaN) Amplifiers With Exceptional Efficiency	19
<i>Auriga Measurement Systems (Auriga Microwave)</i>	
Klystron Amplifier Utilizing Scandate Cathode and Electrostatic Focusing	20
<i>ebeam, Inc.</i>	
Self-Biased Radiation Hardened Ka-Band Circulators for Size, Weight, and Power-Restricted Long-Range Space Applications	21
<i>Metamagnetics, Inc.</i>	
Millimeter-Wave (MMW) Intersatellite Transceiver	22
<i>MaXentric Technologies, LLC</i>	
Radiation Hard Multichannel Aluminum Nitride (AlN)/Gallium Nitride (GaN) High Electron Mobility Transistor (HEMT) for High-Efficiency X- and Ka-Band Power Amplifiers	23
<i>Agnitron Technology</i>	
High-Efficiency, Ka-Band Solid-State Power Amplifier (SSPA) Utilizing Gallium Nitride (GaN) Technology.	24
<i>QuinStar Technology, Inc.</i>	

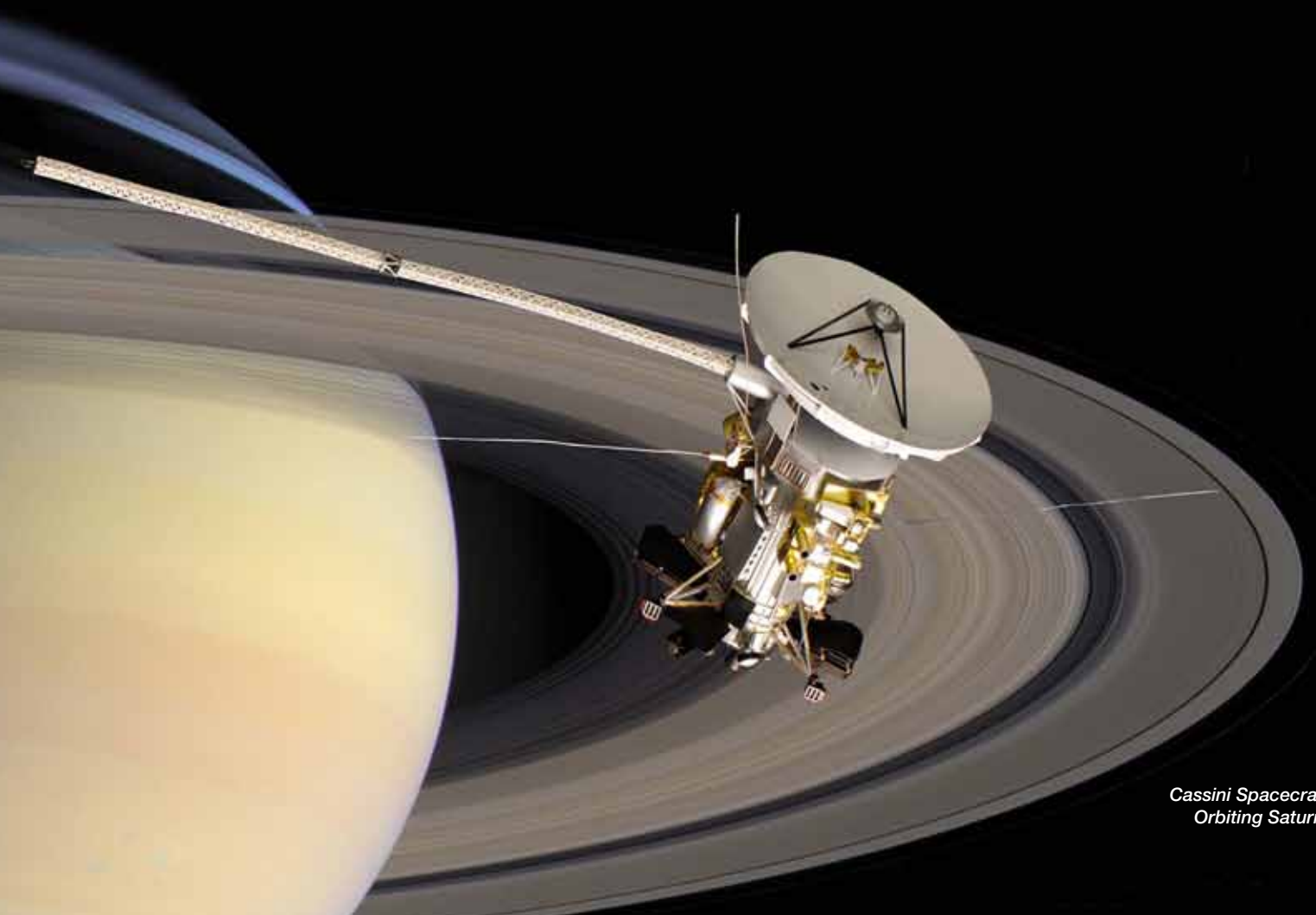
SBIR PHASE II AWARDS



CONTENTS (CONTINUED)

Radiofrequency (RF) Communication Technology	1
Radiofrequency (RF) Communication Technology SBIR Phase II Awards (2006 to 2014)	25
Integrated Production of Ultra-Low Defect Gallium Nitride (GaN) Films and Devices for High-Power Amplifiers <i>SVT Associates</i>	26
Three-Dimensional (3D) Microfabricated Low-Loss Reconfigurable Components <i>Nuvotronics, LLC</i>	27
Nanoparticle Scandate Cathode for Space Communications Phase 2 <i>e-beam, inc.</i>	28
Gallium Nitride (GaN) Bulk Growth and Epitaxy From Ca-Ga-N Solutions. <i>The IIIAN Company, LLC</i>	29
X-Band Gallium Nitride (GaN) Power Amplifiers for Long-Range Space Radiofrequency (RF) Telecommunications <i>Nitronex Corporation</i>	30
Self-Biased Radiation-Hardened Ka-Band Circulators for Size, Weight, and Power-Restricted Long-Range Space Applications <i>Metamagnetics, Inc.</i>	31
Company Names.	33
SBIR Points of Contact	34

RADIOFREQUENCY (RF) COMMUNICATION TECHNOLOGY



*Cassini Spacecraft
Orbiting Saturn.*

In the future, robotic and human exploration spacecraft with increasingly capable instruments producing large quantities of data will be visiting the Moon and the planets. These spacecraft will also support long duration missions, such as to the outer planets, or extended missions with new objectives. They will possess reconfigurable avionics and communication subsystems and will be designed to require less intervention from Earth during periods of low activity. Concurrently, the downlink data rate demands from Earth science spacecraft will be increasing. The communication needs of these missions motivate higher data rate capabilities on the uplink and downlink, as well as more reliable RF and timing subsystems. Innovative long-range telecommunications technologies that maximize power efficiency, reliability, receiver capability, transmitted power, and data rate, while minimizing size, mass, and direct current (DC) power consumption are required. The current state of the art in long-range RF deep space telecommunications is 6 Mbps from Mars using microwave communications systems (X and Ka-band) with output power levels in the low tens of Watts and DC-to-RF efficiencies in the range of 10 to 25%. Due to the applicability of communication components and subsystems with science instruments such as radar, technologies that can benefit both RF communication and advanced instruments are within the scope of this subtopic.

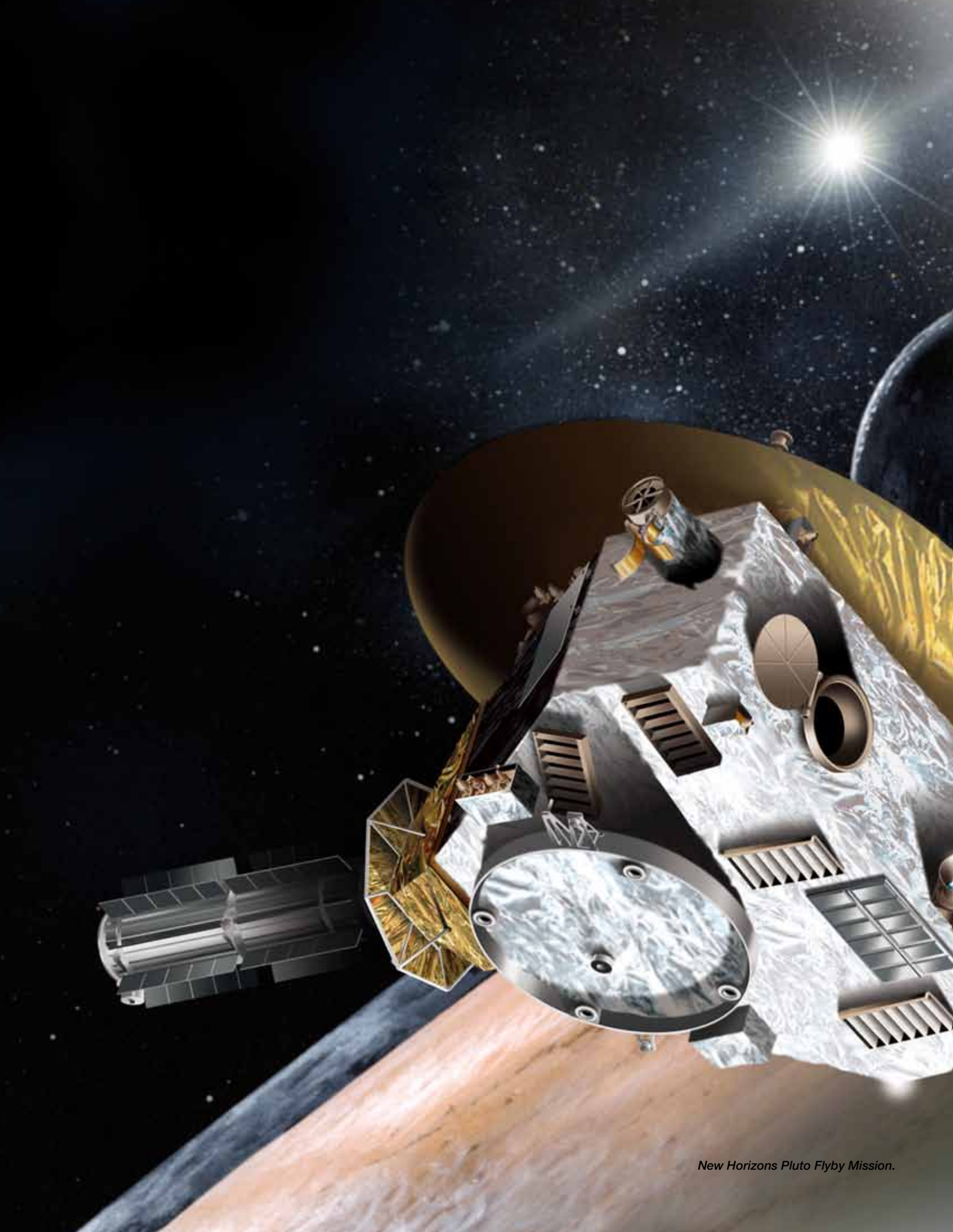
Technologies of interest:

- Ultra-small, lightweight, low-cost, low-power, modular deep space and near-Earth transceivers, transponders, amplifiers, and components, incorporating monolithic microwave integrated circuits (MMICs), microelectromechanical system (MEMs), and Bi-CMOS circuits.
- MMIC modulators with drivers to provide a wide range of linear phase modulation (greater than 2.5 rad), high-data-rate (10 to 200 Mbps) BPSK/QPSK modulation at X-band (8.4 GHz), and Ka-band (26, 32, and 38 GHz).
- High DC-to-RF-efficiency (>60%), low-mass solid-state power amplifiers (SSPAs), of both continuous wave (CW) medium output power (10 to 15 W) and CW high-output power (15 to 35 W), using power combining and/or wide-bandgap semiconductors at X-band (8.4 GHz) and Ka-band (26, 32, and 38 GHz).
- Solid-state multifunction modules that can be commanded to toggle between amplifying conventional digital modulation format signals for communications to pulsed operation for synthetic aperture radar (SAR) with resolution on the order of a few meters.
- Ultra-low-noise amplifiers (MMICs or hybrid, uncooled) for RF frontends (<50 K noise temperature).
- High dynamic range (>65 dB), data rate receivers (>20 Mbps) supporting BPSK/QPSK modulations.
- MEMS-based integrated RF subsystems that reduce the size and mass of space transceivers and transponders. Frequencies of interest include UHF and X- and Ka-band. Of particular interest is Ka-band from 25.5 to 27 GHz and 31.5 to 34 GHz.
- Novel approaches to mitigate RF component susceptibility to radiation and electromagnetic interference (EMI) effects.
- Innovative packaging techniques that can lead to small-size, lightweight compact SSPAs with integrated heat extraction for thermal stability and reliability.

For all above technologies, research should be conducted to demonstrate technical feasibility during Phase I and show a path towards Phase II hardware/software demonstration with delivery of a demonstration unit or software package for NASA testing at the completion of the Phase II contract.

Phase I Deliverables—Feasibility study, including simulations and measurements, proving the proposed approach to develop a given product (Expected technology readiness level (TRL) 3 to 4). Verification matrix of measurements to be performed at the end of Phase II, along with specific quantitative pass-fail ranges for each quantity listed.

Phase II Deliverables—Working engineering model of proposed product, along with full report of development and measurements, including populated verification matrix from Phase I (TRL 5 to 6). Opportunities and plans should also be identified and summarized for potential commercialization.



New Horizons Pluto Flyby Mission.

The background of the page is a composite image. On the left, there is a dark, cratered celestial body, likely the Moon, partially obscured by a bright, glowing atmospheric or plasma sheath. Below this, a portion of a satellite or spacecraft is visible, featuring a gold-colored thermal blanket and various metallic components. The right side of the page is a plain, light-colored background.

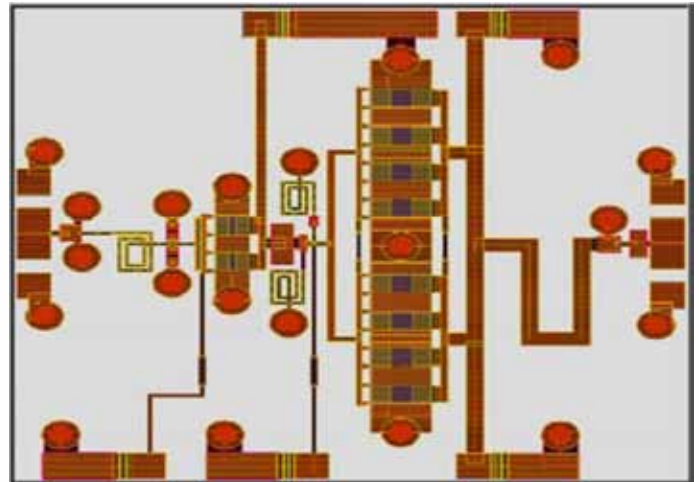
RADIOFREQUENCY (RF)
COMMUNICATION TECHNOLOGY
SBIR PHASE I AWARDS

2006 TO 2014

SOLID-STATE POWER AMPLIFIERS (SSPAs) USING REDUCED CONDUCTION ANGLE TECHNIQUES ON WIDE-BANDGAP DEVICES FOR ULTRA-HIGH EFFICIENCY

Hittite Microwave Corporation

2006 Phase I
01.09-9379



8 GHz, 20 Watt, 55% efficient power amplifier.

Identification and Significance of Innovation

- The power amplifier will provide tube-like power levels at efficiencies that are at a tube level, but it will have greater frequency bandwidth and a more graceful degradation.
- Can operate with standard power supplies; does not require the high-voltage power supplies the traveling-wave-tube amplifiers (TWTAs) require.
- Provides a very small, very lightweight package.

Technical Objectives

- Phase II Objective: fabricate Phase I designs, load-pull redesign, and layout, and refabricate power amplifiers and hybrid modules.
- Process amplifiers.
- Measure load pull and optimize load.
- Improve model to include harmonics.
- Gallium nitride (GaN) design and fabrication.
- Characterize designs.
- Build package and test.
- Build second array and test.
- Summarize data and report.

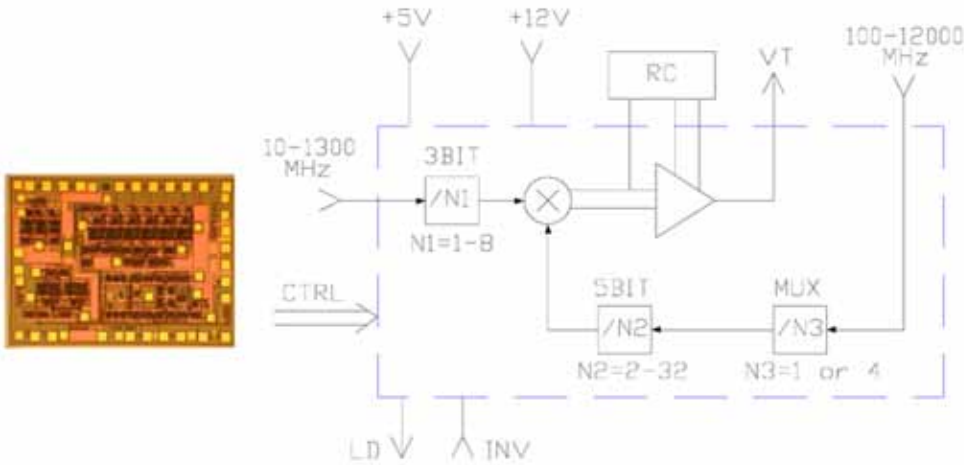
NASA Applications and Non-NASA Applications

- Ground-based terminal transmitters
- Deep space probes transmitters
- Rover transmitters
- WLNA transmitters

INTEGRATED MONOLITHIC MICROWAVE INTEGRATED CIRCUIT (MMIC) FOR PHASE-LOCKED OSCILLATORS AND FREQUENCY SYNTHESIZERS

Hittite Microwave Corporation

2006 Phase I
01.09-9380



Generic MMIC.

Technical Objectives

- The objective of the program is to design, fabricate, and demonstrate a fully integrated X-band MMIC that can be used to synthesize local oscillator (LO) signals required for existing and future deep space transponders.
- The intent is to integrate this chip with any voltage-controlled oscillator (VCO) in the 100 MHz to 12 GHz frequency range.
- The work plan is to use a very high fT_{SiGe} MMIC process (>75 GHz) and operate the digital logic cells at very low current density while still maintaining excellent bandwidth and low noise performance.
- The MMIC chips will be designed, fabricated, and evaluated prior to being integrated into PLLs for demonstration.

NASA Applications and Non-NASA Applications

- LO synthesis for deep space transponders
- LO synthesis for microwave test equipment
- Military and space markets

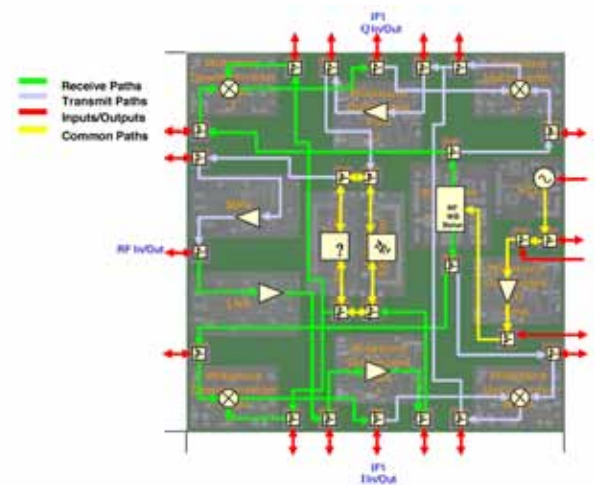
Identification and Significance of Innovation

Space vehicles for deep space exploration rely on small, lightweight, low-power microwave communication systems for command control and data transfer. There has been only a limited supply of MMICs for these functions. Hittite recognized this and developed a product line of frequency synthesis components. A single generic synthesizer MMIC with no needed external ICs that can interface to any VCO and provide phase locking will minimize space qualification cost, size, and direct current (DC) power of current and future deep space probe missions.

RECONFIGURABLE MINIATURE TRANSPONDER FOR MULTIMODE L-, S-, AND X-BAND SPACE COMMUNICATION

Space Micro, Inc.

2006 Phase I
01.09-9523



Identification and Significance of Innovation

- FPMAs
- Reconfigure macro radiofrequency (RF) functions
- Reconfigure as S- or X-band
- Reconfigure as receiver or transmitter
- Modular, reusable 0.1-8 GHz building blocks
- Tunable microelectromechanical system (MEMS) RF/IF filters
- SiGe BiCMOS process FPMA chip development

Technical Objectives

- Demonstrate feasibility of reconfigurable Field Programmable Microwave Arrays (FPMAs).
- Demonstrate FPMA capabilities by circuit design and simulation.

NASA Applications

- Lunar and Martian applications
- S and X-band transponders, Spacecraft Tracking and Data Network (STDN), and Tracking and Data Relay Satellite System (TDRSS)
- Reconfigurable deep space probe communication links

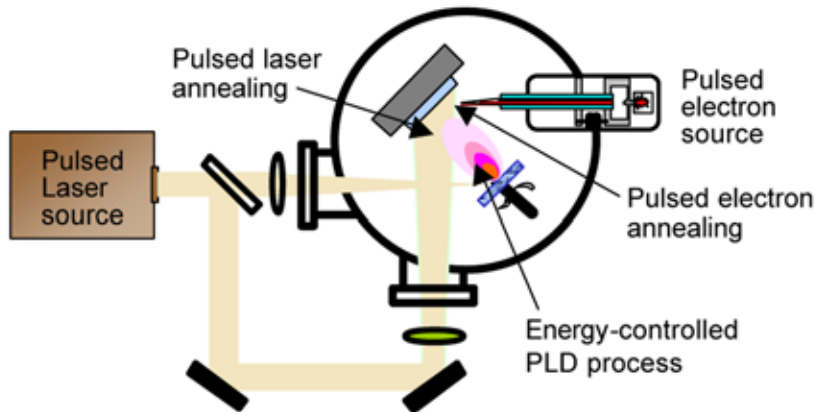
Non-NASA Applications

- SGLS and X-band transponders
- Tacsat, Space Situational Awareness Sats

DEVELOPMENT OF EPITAXIAL GALLIUM NITRIDE (GaN) FILMS FOR RADIOFREQUENCY (RF) COMMUNICATIONS

Neocera, LLC

2007 Phase I
01.09-8325



Technical Objectives

- Development of plasma-energy-controlled Pulsed Laser Deposition (PLD) process to optimize the GaN film structures and properties
- Development of pulsed energy annealing processes using pulsed electron and pulsed laser beams to reduce the dislocation density in GaN layer
- Development of Hybrid Pulsed Energy Deposition (HPED) process to combine above two pulsed energy technologies
- Evaluation of current leads
- AlN film deposition on c-Al₂O₃ via HPED process
- GaN film deposition on AlN-buffered c-Al₂O₃ via HPED process
- Patterning of HPED process for low dislocation density GaN
- Delivery of test results to NASA

NASA Applications

- High dislocation density limiting the current GaN technology from space RF communication applications can be resolved by proposed in situ pulsed energy annealing processes on high-quality epitaxial GaN films that Neocera succeeded with plasma-energy-controlled Pulsed Laser Deposition process, resulting in strong photoluminescent emission properties even at room temperature.

Non-NASA Applications

- The successful Phase I will create a new market for hybrid pulsed energy deposition process systems to fabricate high-quality thin films with significantly reduced structural imperfections. The improved GaN films via the proposed process will expedite the current GaN industrial markets including high-power electronic components and optoelectronic devices.

Identification and Significance of Innovation

- Proposed HPED technology combines two pulsed energy technologies: plasma-energy-controlled PLD to deposit high-quality GaN films and in situ pulsed energy annealing to decrease the dislocation density ($<10^6 \text{ cm}^{-2}$). PLD's pulsed plasma can be controlled in a wide energy range to accomplish the best film quality, and Neocera-fabricated high-quality epitaxial GaN films result in strong photoluminescent emission at room temperature. The combined in situ pulsed energy annealing will reduce GaN threading dislocation density, using the energetic "pulsed" annealing in ultrashort time.

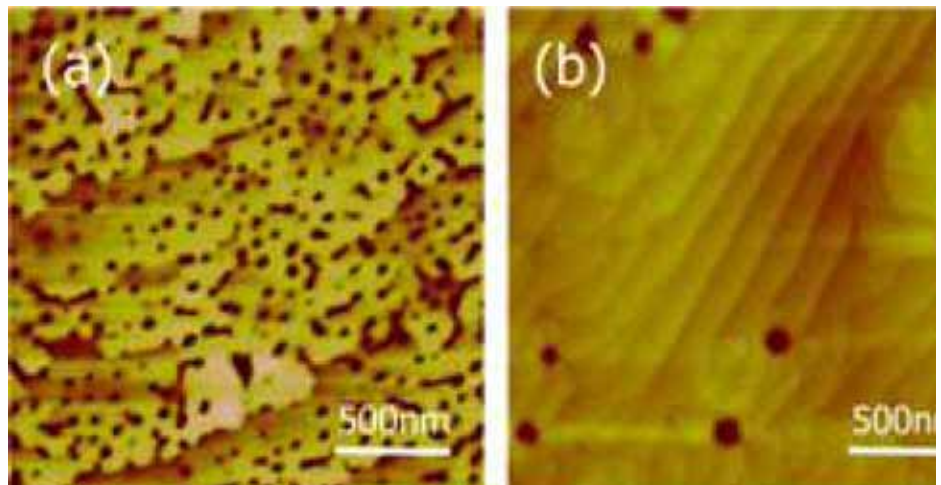
Expected technology readiness level (TRL) range at the end of contract

- 3 to 4

INTEGRATED PRODUCTION OF ULTRA-LOW DEFECT GALLIUM NITRIDE (GaN) FILMS AND DEVICES FOR HIGH-POWER AMPLIFIERS

SVT Associates

2007 Phase I
01.09-9383



GaN grown on sapphire substrates. (a) No dislocation filter. (b) With one dislocation filter.

Identification and Significance of Innovation

- GaN epitaxial films with threading dislocation $<10^7$ per cm^2 will be prepared using a novel defect filter technology for fabrication of high-speed and high-power amplifiers. This vacuum-process integrated dislocation reduction method is developed for efficient, fast, and low-cost production of ultra-low defect materials.
- The method is based on controlled formation of nanoripples by a low-energy ion beam to filter the dislocations.
- It does not require out-of-vacuum processing steps such as photolithography, etching, or insertion of foreign materials.
- This method is applicable to other III-nitride films, including technologically important InGaN and AlGaN.

Expected technology readiness level (TRL) range at the end of contract

- 4 to 5

Technical Objectives

- Optimized dislocation filtering layer
- Ion-assisted molecular beam epitaxy (MBE) growth of GaN high electron mobility transistor (HEMT) on low-defect templates ($\text{TD} <10^7$ per cm^2)
- GaN high-power amplifier device processing and characterizations
- Based on the Phase I objectives, three milestones will be complete in the timeframe listed below
 - Prepare defect nanofilters and do characterizations and optimizations in first 3 months
 - By month 3, optimized dislocation layer will be used to grow low TD nitride films (less than 1E^6 cm^2)
 - Characterizations of TD and further reduce the TD; characterization of films and devices

NASA Applications

- High-speed and high-power amplifiers; radiation-hard and ultra-low-noise amplifiers; HEMT devices for radar and range finding, collision avoidance, and digital transmission; ultraviolet (UV) photo detectors for free-space optical communications; astrophysics; and biological agent detection, flame detection, and missile launch monitoring

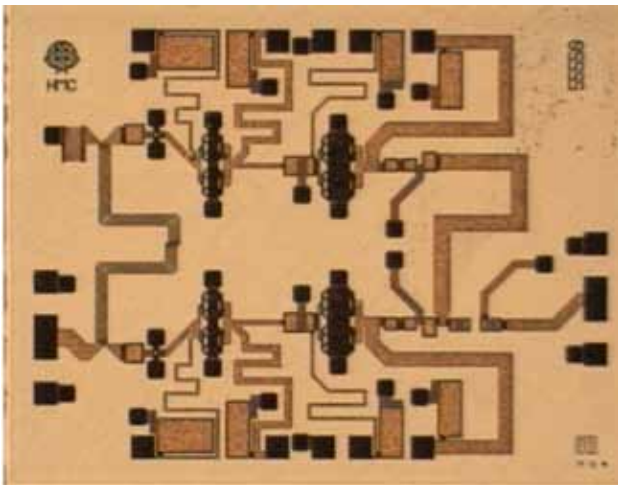
Non-NASA Applications

- HEMT device for radiofrequency (RF) and microwave mobile wireless communications
- Blue lasers, high brightness visible light-emitting diodes (LEDs), UV detectors for chemical and biological agent spectroscopy and threat detection, ozone detection and environmental monitoring

MONOLITHIC MICROWAVE INTEGRATED CIRCUITS (MMICs) FOR HIGH-EFFICIENCY Ka-BAND GALLIUM NITRIDE (GaN) POWER AMPLIFIERS

Hittite Microwave Corporation

2007 Phase I
01.09-9627



10 W, 20 GHz GaN Doherty amplifier.

Technical Objectives

- Establish design baseline for GaN MMIC amplifiers for transmitters used in lunar and deep space explorations.
- Evaluate and select optimum foundry process for GaN MMIC amplifiers.
- Select amplifier topology, class of operation, and device gate periphery.
- Design amplifiers and simulate.

NASA Applications

- Efficient transmitters in spaceborne platforms for communications and surveillance radars

Non-NASA Applications

- Satellite communications for both spaceborne and ground-based terminals (Boeing Space Systems and Hughes Network Systems)
- Automotive radar

Identification and Significance of Innovation

- GaN technology for millimeter-wave (MMW) amplifiers enables design of compact, high-efficiency transmitters for Ka-band space communications providing a significant improvement in the power output capability of the transmitter, but without a significant impact on the payload size and the power consumption.

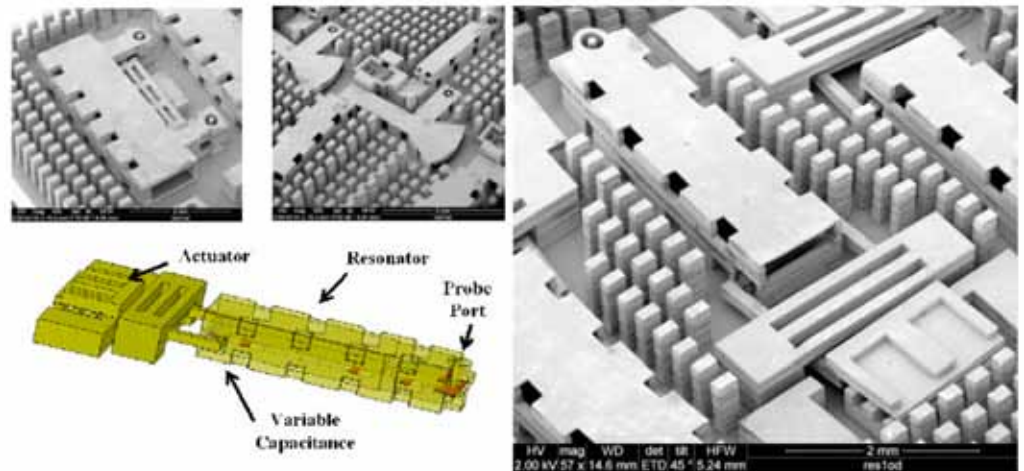
Expected technology readiness level (TRL) range at the end of contract

- 3

THREE-DIMENSIONAL (3D) MICROFABRICATED LOW-LOSS RECONFIGURABLE COMPONENTS

Nuvotronics, LLC

2008 Phase I
01.07-8443



- Combining new wafer-level air-core micro-coax with integrated MEMS will create lowest insertion loss analog and digital 360 degree phase shifters and tunable filters with 10% tuning bandwidth capable of being designed to operate anywhere in the microwave and millimeter-wave spectrum (1 to >100 GHz).
- Batch manufacturing and automated testing using this high-yield process (99.8%) leads to cost-effective products in both low and high volumes.
- Monolithic actuator development in this program is key to enabling this capability.

Technical Objectives

- 4-month Phase I effort
 - Design, simulation, and fabrication of new beams support for PolyStrata tunable
 - Design and simulation of Ka- and W-band tunable filter
 - Design, simulation, and fabrication of new V-band microelectromechanical system (MEMS) socket for monolithic microwave integrated circuits (MMICs) integration
 - Design, simulation of V-band digital phase shifter
- 18-month Phase II effort
 - Fabricate Ka- and W-band tunable filter
 - Fabricate V-band digital phase shifter
 - Reliability test on first-run components
 - Second fabrication iteration to improve performances

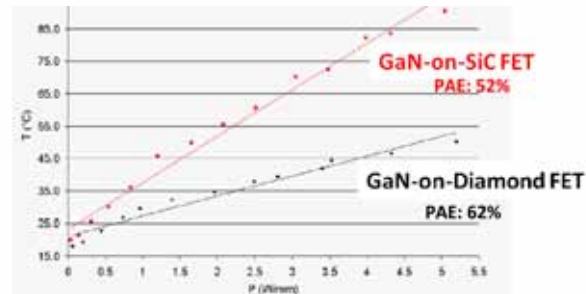
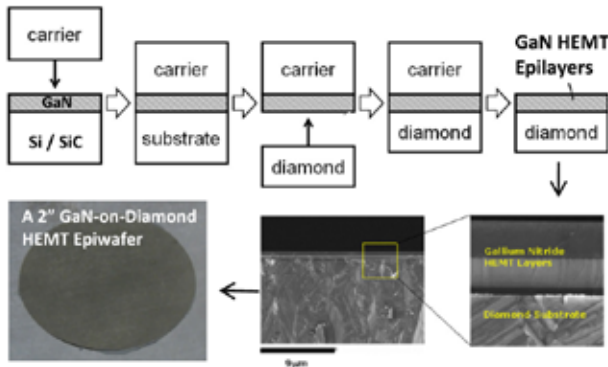
NASA Applications and Non-NASA Applications

- Communications and exploration satellites and missions
- Advanced military radars
- Cellular base stations
- Automotive anticollision radar

A 60 TO 85% EFFICIENT X AND K-BAND 1-KILOWATT SOLID-STATE POWER AMPLIFIER (SSPA) USING GALLIUM NITRIDE (GaN)-ON-DIAMOND

Group 4 Labs, LLC

2008 Phase I
01.07-9782



Technical Objectives

- Goal—To demo the world's most efficient (60 to 85%) solid-state X and Ka-band power amplifiers using GaN-on-Diamond
- Phase I Objective—Demo a 10-W, 60%+ power-added efficiency (PAE), GaN-on-Diamond power amplifier at X-band (8.4 GHz) and Ka-band (36 GHz)
- Phase II Objective—Demo a 1-kW, 60 to 85%+ PAE, GaN-on-Diamond power amplifier at X-band (8.4 GHz) and Ka-band (26, 32, and 38 GHz)

NASA Applications

- Long-range microwave communications from Mars
- SSPAs and monolithic microwave integrated circuits (MMICs) for 26 GHz Ka-band lunar communications
- Replacing vacuum electronics amplifiers (e.g., traveling-wave-tube amplifiers (TWTAs), and Klystrons)

Non-NASA Applications

- Radiofrequency (RF) power amps for 3G/EDGE/WiMax cellular base stations
- GaN-on-Diamond-based THz sources (for security, biosensors, etc.)
- GaN-on-Diamond blue/white light-emitting diodes (LEDs)/laser

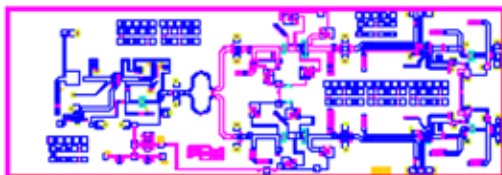
Identification and Significance of Innovation

- We have created the first GaN-on-Diamond Epi-wafers for high-efficiency/high-power RF transistors.
- We have fabricated and measured a 200% boost to a GaN transistor's output power density for a given junction temperature. This is due to Diamond's extreme thermal conductivity—1200 W/m/K. SiC, Si are 400, 150 W/m/K, respectively. Early results: PAE jumped 10 points to 62%. We expect to reach 85% shortly.

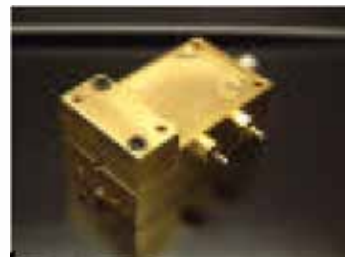
HIGH-POWER WIDE-BANDGAP ENGINEERED MILLIMETER-WAVE (MMW) MONOLITHIC MICROWAVE INTEGRATED CIRCUIT (MMIC) TRANSCEIVER

TLC Precision Wafer Technology, Inc.

2009 Phase I
01.07-8064



TLC Multi-frequency tunable
T/R MMIC (12 – 100 GHz)
Patents pending



Identification and Significance of Innovation

- High-power tunable transceiver/radar MMIC on engineered GaN wafers

Technical Objectives

- Demonstrate ultra-high-power, stable wide-band rad-hard MMW MMICs on lattice engineered epi gallium nitride (GaN).
- Fabricate and test frequency tunable high-performance single-transceiver MMIC on latticed engineered epi wafers (GaN).
- Demonstrate innovative high-performance interim transceiver modules (Ka- and V-band).
- Convert designs and fab for NASA and key customer applications on GaN.
- Develop advanced high-power/rad-hard InAlN/InGaN/GaN epi wafers.
- Fabricate on GaN epi existing device mask set.
- Develop low-cost fabrication methods.
- Begin adjusting existing MMW MMIC design for GaN processing.

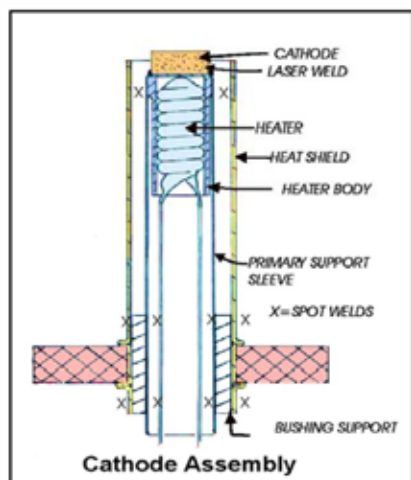
NASA Applications and Non-NASA Applications

- MMW wireless links
- Automotive radar
- Radar chip
- Satellite T/R chip
- Military

NANOPARTICLE SCANDATE CATHODE FOR SPACE COMMUNICATIONS

ebeam, inc.

2009 Phase I
01.07-9345



Technical Objectives

- Auger analysis of existing scandate cathode to determine surface segregation of scandia.
- Refine understanding of electrochemistry of scandate cathode and determine cathode composition.
- Fabricate nanocrystals of scandium oxide.
- Synthesize and test top layer scandate cathode.
- SEM test of existing scandate cathode; in situ multilevel auger scan of top surface of existing scandate cathode.
- Study methods of nanoparticle formation; precipitate scandia from solution; repeat using sol-gel; spray pyrolysis on smooth substrate; and analysis of coating.
- Fabricate tungsten matrix cathodes; spray pyrolysis of nanoscandia on tungsten.
- Seal, pump, and test.
- Evaluate data and propose improvements.

NASA Applications

- For high-data-rate transmissions from deep space, especially for high-resolution video imaging at real-or near-real time rates, such as Mars exploration and fly-bys of planets.
- Terahertz amplifiers for atmospheric investigations.

Non-NASA Applications

- Terahertz sources and amplifiers for explosives detection.
- Traveling-wave tubes for geostationary communications satellites.

Identification and Significance of Innovation

- A scandate modified impregnated cathode based on the view that a thin layer of nanoparticle scandia, elevated in temperature and impregnated with barium, forms a conductor. Moreover, barium on scandia at the vacuum interface is a very low work function surface. Consequently, a top layer of scandia nanoparticles on top of a tungsten impregnated cathode should provide superior emission without the drawbacks of previous cathodes.
- Significance—The innovation provides substantial improvements in cathode life and emission current density. Cathodes are now limiting power, bandwidth, frequency, and life current density. Cathodes are now limiting power, bandwidth, frequency, and life in microwave linear beam amplifiers. These, in turn, limit data rates of space communications to much less than current data generation capabilities.

Expected technology readiness level (TRL) range at the end of contract

- 3 to 6

GALLIUM NITRIDE (GaN) BULK GROWTH AND EPITAXY FROM Ca-Ga-N SOLUTIONS

The IIIAN Company, LLC

2009 Phase I
01.07-9857

Graphic unavailable

Identification and Significance of Innovation

- This SBIR proposal addresses the LPE of GaN films using nitrogen-enriched metal solutions. Growth of GaN from solutions offers the possibility of drastically reducing the density of line defects. As these defects adversely affect both breakdown voltages and electron velocities, their reduction can significantly increase the performance of high-power Ka-band high electron mobility transistor (HEMT) structures used for satellite communications.

Expected technology readiness level (TRL) range at the end of contract

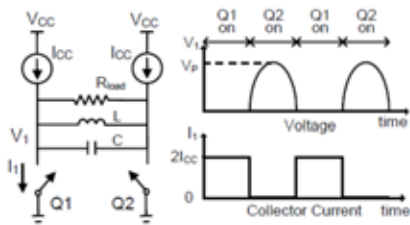
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Technical Objectives

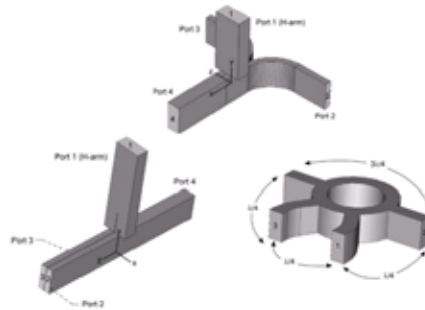
- Demonstration of liquid phase epitaxy (LPE), or seeded growth, of GaN from Ca-Ga-N solutions
- Evaluation of defect density in the LPE-grown GaN film
- Evaluation of the surface morphology of LPE-grown GaN
- Characterization of the thermodynamic and reaction/crystallization kinetics of Ca-Ga-N solutions
- Refinement of CALPHAD analysis of the Ca-Ga-N ternary phase diagram
- Evaluation of atomistic modeling of GaN crystallization in the Ca-Ga-N ternary system

NASA and Non-NASA Applications

- High-power, high-frequency transistors for X- and Ka-band telecommunications.
- Sensors, particularly visible-blind, ultraviolet sensitive photodiodes
- Short wavelength emitters, light-emitting diodes (LEDs), and lasers



Current-Mode Class D (CMCD)



High-power power combiners

Technical Objectives

- Switch-mode amplifier device evaluation and modeling
- Explore the best configuration to mitigate the loss in switch-mode amplifier
- Power amplifier module design consideration
- Conduct trade studies on combiner topologies
- Simulate chosen combiner topologies
- Compare combiner complexity versus power amplifier size
- Simulate and design combiners with power amplifier models

NASA and Non-NASA Applications

- Portable long-range communications
- X- and Ka-band radar systems
- X- and Ka-band commercial systems
- Phoenix mission
- Two NASA Mars Exploration
- Mars Reconnaissance Orbiter
- Cassini
- Voyager status reports

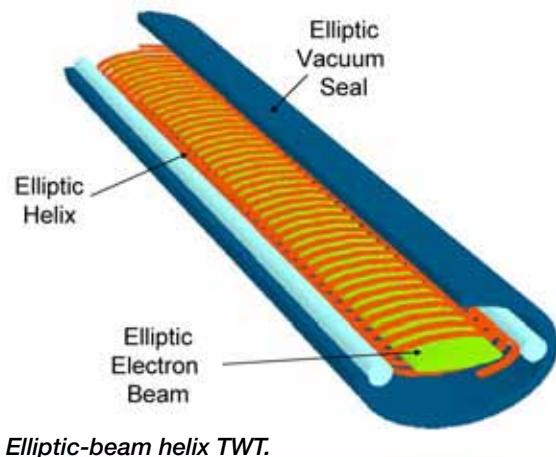
Identification and Significance of Innovation

- Highly linear power-efficient power amplifiers for NASA's next generation deep space missions
- High-power-added efficiency >60%, constant envelope waveforms
- Medium output power version 10 to 50 W peak envelope power
- High-output power version, 150 W to 1 kW peak envelope power
- X-band 8.4 GHz and Ka-band 26, 32, and 38 GHz

HIGH-EFFICIENCY, HIGH-POWER Ka-BAND ELLIPTIC-BEAM TRAVELING-WAVE-TUBE AMPLIFIER (TWTA) FOR LONG-RANGE SPACE RADIOFREQUENCY (RF) TELECOMMUNICATIONS

Beam Power Technology, Inc.

2010 Phase I
01.05-9226



Identification and Significance of Innovation

- Elliptic-beam helix TWT technology
- Higher efficiency—75%
- Higher power—500 W
- Higher power-to-mass ratio—180 W/kg
- Lower voltage—9.2 kV
- Reducing volume by 30%

Expected technology readiness level (TRL) at the end of contract

- 3

Technical Objectives

- Phase I—Determine the feasibility of high-efficiency, high-power, lightweight Ka-band elliptic-beam traveling-wave tube (TWT) via design and engineering.
- Phase II—Demonstrate the device and measure the efficiency and power output.

NASA Applications

- Long-range space RF telecommunication

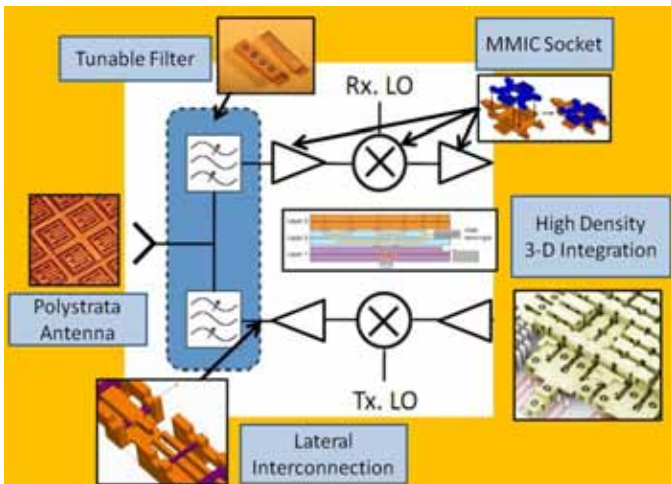
Non-NASA Applications

- Commercial satellite TWTAs
- Radar TWTAs
- Communication TWTAs

SIZE, WEIGHT AND POWER (SWaP) OPTIMIZED SPACE TRANSCEIVERS

Nuvotronics, LLC

2010 Phase I
01.05-9321



PolyStrata transceiver backplane.

Technical Objectives

- Design Ka-band receiver architecture optimized for PolyStrata interconnections.
- Design Ka-band transmit architecture optimized for PolyStrata interconnections.
- Demonstrate modular functional blocks.
- Develop initial system architecture for Ka-band receiver.
- Develop initial system architecture for Ka-band transmitter.
- Design Ka-band subassemblies for fabrication.
- Mask layout of subassemblies.
- Fabricate subassemblies in PolyStrata.
- Assemble component ICs and passives into subassemblies.
- Test and characterize the subassemblies.

NASA Applications

- Space Communications and Navigation Integrated Network (SCaN)
- NASA decadal survey missions
- Aerosol-Cloud-Ecosystems (ACE)
- Snow and Cold Land Processes (SCLP)
- Precipitation and All-Weather Temperature and Humidity (PATH)

Non-NASA Applications

- Commercial satellite communications systems
- Unmanned aerial vehicle (UAV) communications
- Wireless and point-to-point

Identification and Significance of Innovation

- Miniaturization of satellite transceivers
- Substantial reduction of system size and weight
- PolyStrata microfabrication process for the fabrication of intricate microwave and millimeter-wave devices. Devices have been demonstrated with the following characteristics:
 - Insertion loss 5 to 10 times lower than traditional planar circuits
 - Isolation better than 60 dB for lines that share separating walls
 - Multiple levels of densely packed coaxial circuits
 - Low-parasitic attachment to active devices and traditional circuit boards
- PolyStrata allows three-dimensional (3D) routing of high density of transmission lines
- Low-loss broadband PolyStrata recta-coax creates high-performance transceiver backplane in miniature package
- Copper backplane structure improves heat transfer in space environment
- Batch microfabrication approach for low cost
- Building blocks for future systems using PolyStrata circuit backplanes

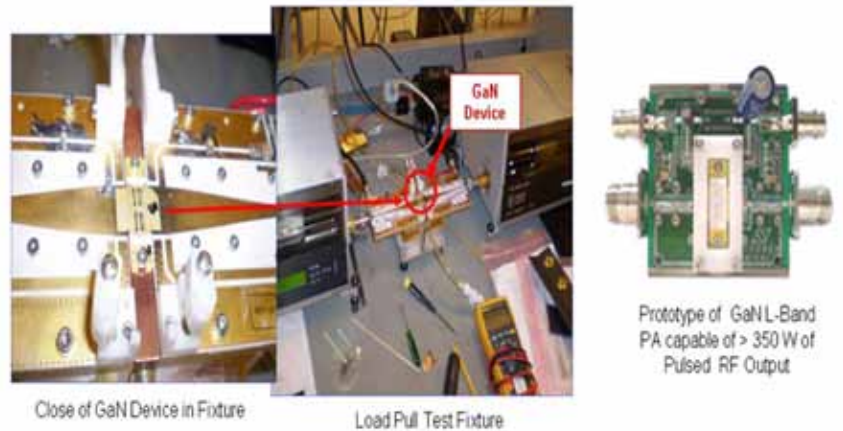
Expected technology readiness level (TRL) range at the end of contract

- 3 to 4

X-BAND GALLIUM NITRIDE (GaN) POWER AMPLIFIERS (PAs) FOR LONG-RANGE SPACE RADIOFREQUENCY (RF) TELECOMMUNICATIONS

Nitronex Corporation

2011 Phase I
01.05-9304



Identification and Significance of Innovation

- The future deployment of sensors in space will increase, resulting in a need for higher data rate communications from space to Earth at X-band. Increases to the overall system gain of the communication link will be required, which can be accomplished by increasing the transmitted RF power. However, the challenge is to maximize power efficiency of the power amplifier with higher RF output levels, e.g., 50-W at X-band, while reducing the size, weight and power (SWaP) size. The innovation will be to produce a linear 50-W SSPA MMIC with high direct current (DC)-to-RF efficiency (>60%) and low SWaP using GaN RF semiconductors at X-band (7 to 9 GHz). The significance of GaN is it is a wide-bandgap RF semiconductor with very high RF power density that is robust to the high-radiation environment of space. The 50-W GaN PA MMIC will improve performance of NASA's long-range space RF communication and is estimated to be >50% smaller in size and >20% lower in power.

Expected technology readiness level (TRL) range at the end of contract

- 3 to 5

Technical Objectives

- Develop 50-W GaN PA monolithic microwave integrated circuit (MMIC)
 - X-band frequency: 8.0 to 9.0 GHz
 - PA Output Power: >50 W continuous wave (CW) (linear)
 - PA System Output IP3: >+55 dBm
 - PA System Gain: >20 dB (includes RF power combining)
 - Efficiency (Pout/Pin): >60%
 - Input Operating Voltage: 28 Vdc
 - Input Operating Current: <3 A
 - Size: <30 in³
 - Weight: <2 lb
- Phase I detailed project plan with project Statement-of-Work (SOW) (interim report)
- Survey of X-band PA MMIC topologies; Trade and study of X-band GaN MMIC vs. GaN hybrid PA designs (interim report)
- Develop and derive detailed specification for GaN 50-W solid-state power amplifier (SSPA) MMIC or hybrid (interim report)
- Define potential architectures for detailed GaN PA designs (interim report)
- Summary report on simulation and modeling of GaN X-band SSPA MMIC and/or hybrid (interim report)
- Identify project risks going into Phase II (e.g., radiation hardness)
- Generate and publish final report for Phase I

NASA Applications

- Long-range space RF communication systems

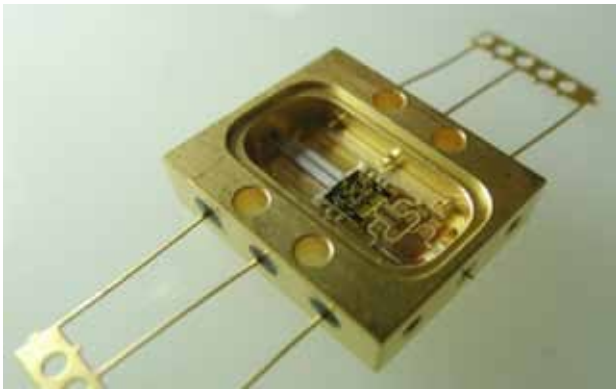
Non-NASA Applications

- Long-range space RF communication systems for customers such as Rockwell Collins, Harris Corporation, and ViaSat

HIGH-POWER X- AND Ka-BAND GALLIUM NITRIDE (GaN) AMPLIFIERS WITH EXCEPTIONAL EFFICIENCY

Auriga Measurement Systems (Auriga Microwave)

2011 Phase I
01.05-9434



Technical Objectives

- Auriga will use GaN high electron mobility transistors (HEMTs) to meet the frequency band and power level required. GaN HEMTs are high-voltage and high-power density devices, resulting in smaller, more efficient power amplifiers (PAs). Competing GaAs pHEMT technology is more mature and readily available, but cannot compete with GaN's electrical and thermal performance. As GaN transitions from leading-edge to industry standard, its usage is expanding and the cost of entry is diminishing.
- Two PAs will be made during this program to operate at X- and Ka-band. The X-band PA will provide 50 W output power with 50 to 60% efficiency. The Ka-band PA will provide 15 W output power at 30 to 50% efficiency. The final deliverable will be a packaged module.
- The proposed work plan includes the following five tasks: device characterization, device model development, PA combining scheme investigation, X- and Ka-band PA design, and preliminary monolithic microwave integrated circuit (MMIC) layout. All work will be performed at the Auriga Microwave facility in Massachusetts.

NASA Applications

- Satellite communication uplink, radar, spaceborne platforms (i.e., spacecraft telecommunication, data link for planetary exploration, etc.)

Non-NASA Applications

- Radar, weather monitoring, air traffic control, maritime vessel traffic control, and vehicle speed detection for law enforcement

Identification and Significance of Innovation

- Achieving very high-power amplification with maximum efficiency at X- and Ka-band is challenging using solid-state technology. Gallium arsenide (GaAs) has been the material of choice for high-power microwave systems at these frequencies for decades. Until only recently, GaAs was unchallenged at Ka-band for solid-state amplification. Unfortunately, the low power density of GaAs requires extensive combining networks contributing to large amplifier size and low efficiency; neither is acceptable in next-generation high-performance systems.
- This program intends to push the limits of current technology to achieve extremely high power levels while obtaining efficiency performance typical of much lower frequency amplifiers. Doing so will require the use of modern materials and sophisticated passive networks to achieve this performance. Auriga's experience with device physics, transistor modeling, and high-power design make us uniquely qualified to overcome the challenges in this program.

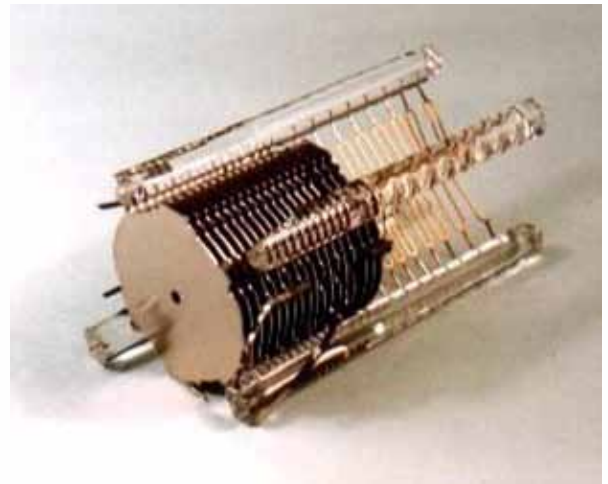
Expected technology readiness level (TRL) range at the end of contract

- 2 to 4

KLYSTRON AMPLIFIER UTILIZING SCANDATE CATHODE AND ELECTROSTATIC FOCUSING

ebeam, inc.

2012 Phase I
01.02-9612



Identification and Significance of Innovation

- Scandate cathodes are proposed as a way to boost performance and life in linear beam amplifiers such as klystrons and traveling-wave tubes (TWTs) for space communications. Our company has recently demonstrated breakthrough performance on these cathodes. We have demonstrated 100 Amps/cm² at 1050° Cb and 5 Amps/cm² at 850° Cb. This is 200° Cb below conventional cathodes. At 850° Cb, the cathode will live at least 100,000 hours. This makes it a candidate for deep space missions. Because of low beam convergence, the cathode also permits electrostatic focusing of amplifiers, which will reduce size and mass in spaceborne systems. In Phase I we construct and test cathodes in a realistic environment consisting of a Pierce gun, an electrostatic focusing stack, and two depressed collectors.

Expected technology readiness level (TRL) range at the end of contract

- 2 to 4

Technical Objectives

- Diode tests—Cathode pellets will be made with scandia-doped tungsten powder. Cathode assemblies and diode test vehicles will be constructed. Diode testers will be tested and life tested.
- Pierce gun tests—Computer modeling will be done, parts acquired, and devices assembled. Devices will be pumped and tested at low voltage and high voltage and then life tested.
- Design beam tester—Pierce gun design will be adjusted, focusing stack will be designed. Pierce gun and focus stack designs will be integrated. Beam parameter range and collectors will be modeled.
- Construct beam tester—Parts will be acquired and beam tester will be constructed, pumped, baked, and sealed.
- Electron beam test and focus characterization—Beam tester will be activated and tested. Focusing will be tested and optimized. Data will be analyzed and conclusions reached.

NASA Applications

- Vacuum linear beam amplifiers and sources, allowing high data rates, higher frequencies, and more power.
- Ion thrusters for discharge and neutralization, both for near-Earth and long-range space flights.
- Their small size and high loading make them essential in terahertz amplifiers used for upper atmosphere studies, as well as communications.

Non-NASA Applications

- Geocentric communications satellites—Scandate cathodes will raise the frequency and power of traveling-wave tubes (TWTs). Longer life will reduce maintenance costs on these systems.
- Earth-based communications networks.
- Micro-focus x-ray tubes and in ultraviolet (UV) electron-beam-pumped lasers.

SELF-BIASED RADIATION-HARDENED Ka-BAND CIRCULATORS FOR SIZE, WEIGHT, AND POWER-RESTRICTED LONG-RANGE SPACE APPLICATIONS



Metamagnetics, Inc.

2012 Phase I
01.02-9699

Technical Objectives

- Development of self-biased, low-loss circulators at frequencies above 27 GHz. Self-biased circulators hold great promise for reduced size, weight, cost, increased temperature stability, and power consumption necessary for the development of next generation transmit/receive modules (TRM) and long-range space communication systems. This research builds upon a knowledge base in self-biased circulator and substituted hexagonal ferrite development spanning more than 30 years. Key challenges in this research include realization of self-biased materials with sufficiently low loss and zero field ferromagnetic resonance frequency.
- Materials fabrication—Refinement of composition, microstructure, and properties
- Device simulation—Iterative design specification, evaluation, and refinement
- Device prototyping—Fabrication and testing of simulated designs

NASA Applications

- DESDynI (Deformation, Ecosystem Structure and Dynamics of Ice)
- SWOT (Surface Water and Ocean Topography)
- HypSIIRI (Hyperspectral Infrared Imager)

Non-NASA Applications

- Ground-based TRMs utilized in active electronically steered arrays (AESAs)

Identification and Significance of Innovation

- Ferrite control components including circulators and isolators are fundamental building blocks of TRM utilized in high-data-rate active space transceivers and transponders for both long-range (LR) and low-Earth orbit (LEO) systems. As such, performance specifications of these ferrite control components, such as bandwidth, insertion loss, isolation, power handling, temperature stability, radiation hardness, and linearity impose strict limitations on the overall system performance. Over the course of the proposed Phase 1 SBIR program self-biased ferrite control components based on Metamagnetics' proprietary highly textured hexagonal ferrite compacts, which have the potential to eliminate biasing magnets and significantly reduce the size, cost, and weight of the TRM while concurrently increasing power handling capability, and improving temperature stability and radiation hardness will be investigated at Ka-band (>27 GHz—31.5 to 34 GHz targeted).

Expected technology readiness level (TRL) range at the end of contract

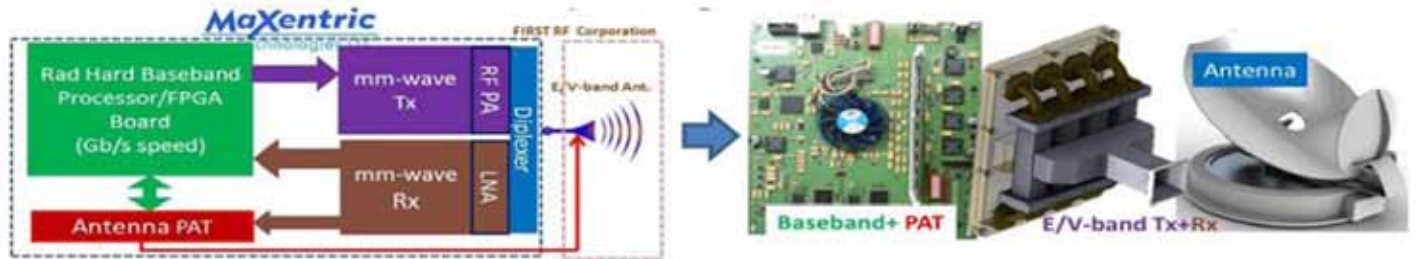
- 2 to 3

MILLIMETER-WAVE (MMW) INTERSATELLITE TRANSCEIVER

MaXentric Technologies, LLC

2014 Phase I

01.03-8714



Identification and Significance of Innovation

- Future spacecraft require higher data rates with improved size, weight and power (SWaP) and performance. The lack of interference-free spectrum complicates the introduction of these services. While the incremental advances in equipment performance requested in X- and Ka-bands may meet these future needs, previous Defense Advanced Research Projects Agency (DARPA) investments in the F6, Mobile Hotspot, and Microscale Power Conversion programs can be used as a basis to develop equipment operating in the underutilized intersatellite band 59 to 71 GHz, with almost 12 GHz of spectrum available. The rapid commercialization of the E- and V-bands for terrestrial use has driven down the costs and increased the variety of RF components. As a Phase 1 and 2 participant in these DARPA programs, MaXentric is in a unique position to design, develop, and demonstrate a small, low-SWaP, high-data-rate, power-efficient, 59-to 71-GHz transceiver that could be incorporated into NASA's SCan Integrated Network Architecture in the future.

Expected technology readiness level (TRL) range at the end of contract

- 3 to 4

Technical Objectives

- Spectrum coexistence study—Study will be made to identify what, if any, restrictions might be applicable for operation at these frequencies.
- Develop 59- to 71-GHz transceiver link budgets—MaXentric will create a link budget model to quantify the range and tradespace of transmit powers and receiver parameters available at 59 to 71 GHz and map them to distances and appropriate use cases within Space Communications and Navigation (SCaN).
- Environmental study—Analysis will be made of the suitability of the available component ecosystem for 59 to 70 GHz for use in the SCan space environment.
- Detail design (electrical)—Detailed circuit design will be made of a transceiver subsystem capable of operation in the 59 to 71 GHz band. Important findings from the F6, MHS, and MPC programs will be included in the design.
- Detail design (mechanical)—Detailed mechanical design will be made of a transceiver subsystem capable of operation in the 59 to 71 GHz band.
- Demonstration of high-data-rate link—Laboratory-based demonstration will be performed using prototype hardware from the F6 and MHS programs.

NASA Applications

- SCan network
- Future Tracking and Data Relay Satellite (TDRS) platform

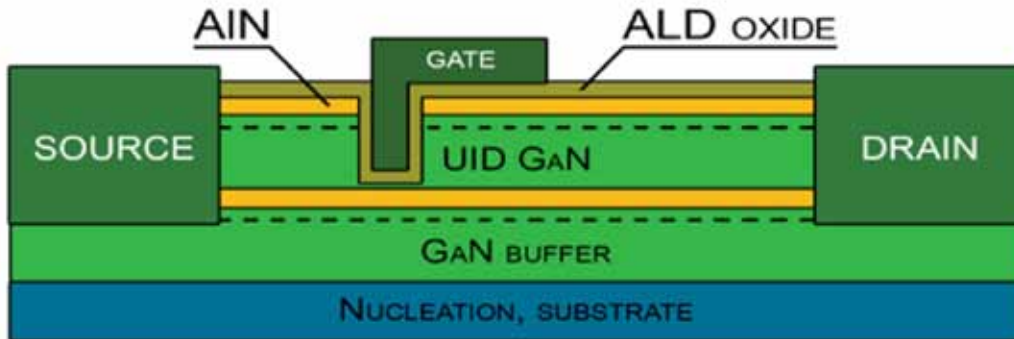
Non-NASA Applications

- Small commercial satellites, unmanned aerial vehicle (UAVs), or in a different mechanical format for cellular back haul and microwave point-to-point links

RADIATION HARD MULTICHANNEL ALUMINUM NITRIDE (AlN)/GALLIUM NITRIDE (GaN) HIGH ELECTRON MOBILITY TRANSISTOR (HEMT) FOR HIGH-EFFICIENCY X- AND Ka-BAND POWER AMPLIFIERS

Agnitron Technology

2014 Phase I
01.03-9112



Technical Objectives

- Epitaxial growth of high-quality AlN/GaN heterostructures by metalorganic chemical vapour deposition (MOCVD)
- Dual-channel AlN/GaN HEMT device process development and optimization
- HEMT device characterization
 - Device structure design and optimization by heterostructure modeling
 - MOCVD growth of dual-channel AlN/GaN HEMT structures
 - HEMT process development and optimization
 - › Ohmic contact resistance minimization
 - › Built-in T-gate recess process optimization
 - HEMT device characterization
 - › DC characterization
 - › Pulsed response and small signal characterization

NASA Applications

- Active phased-array antennas
- Communications systems for robotic and human exploration spacecraft
- Satellite communications

Non-NASA Applications

- Civilian aerospace radar
- Communication applications

Identification and Significance of Innovation

- This project is directed to the development of low-loss, high-power-density AlN/GaN heterostructure based transistors for enabling high-efficiency solid-state power amplifiers (SSPAs) needed for advancing capabilities of future robotic and human exploration spacecraft. The AlN/GaN heterostructure is a particularly attractive system for switch-mode applications due to the extremely high charge density, high electron mobility, high intrinsic breakdown field, and physical thinness achievable and has seen widespread investigation toward solid-state amplifiers in recent years. A new patent-pending multichannel AlN/GaN field-screening (FS) HEMT design is described. Preliminary experimental results are presented validating design principles that will eliminate current collapse phenomenon at X- and Ka-band frequencies that has plagued traditional HEMT designs and will ultimately deliver a low-loss switch-mode device.

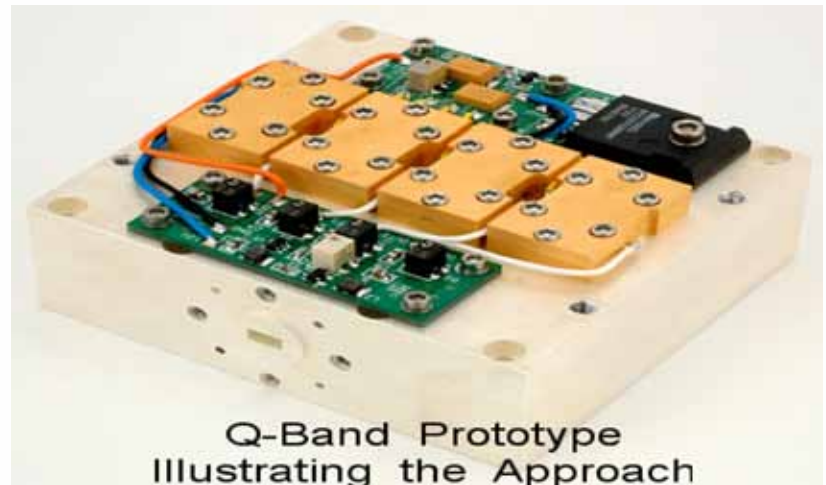
Expected technology readiness level (TRL) range at the end of contract

- 3 to 5

HIGH-EFFICIENCY, Ka-BAND SOLID-STATE POWER AMPLIFIER (SSPA) UTILIZING GALLIUM NITRIDE (GaN) TECHNOLOGY

QuinStar Technology, Inc.

2014 Phase I
01.03-9656



Identification and Significance of Innovation

- Future NASA robotic and manned space exploration missions require high-efficiency (60%) SSPAs, operating at Ka-band, for high-data-rate, long-range space communications
- Employing state-of-the-art GaN MMIC technology to fabricate a high-efficiency SSPA operating at Ka-band frequencies (31.5 to 34 GHz)
- GaN devices are operating in a Class F switching mode for highest efficiencies; simulations with commercial foundry models show that it is possible to realize power-added efficiency (PAE) levels above 60%
- Employing a high-efficiency (95%) four-way planar combiner to achieve 20 W output power

Expected technology readiness level (TRL) range at the end of contract

- 1 to 3

Technical Objectives

- Develop a GaN-based, high-efficiency SSPA operating at Ka-band frequencies (31.5 to 34 GHz) for high-data-rate, long-range space communications.
- Reach 20 W output power and 60% power-added efficiency.
- Conduct a SSPA architecture study to examine the tradeoffs between power and efficiency.
- Evaluate and select a GaN foundry partner for Phase II.
- Perform switching-mode simulations of the high-efficiency GaN monolithic microwave integrated circuit (MMIC) amplifier.
- Design, simulate, and lay out the GaN MMIC.
- Design and simulate the four-way, high-efficiency combiner network.
- Submit Phase I final report.

NASA Applications

- Robotic and manned space exploration missions requiring high-efficiency SSPAs, operating at Ka-band, for high-data-rate, long-range space communications
- Ka-band radar sensors for a wide variety of Earth science applications

Non-NASA Applications

- Department of Defense (DoD) applications include SATCOM for the Army in the 29.5 to 31 GHz band and military radar applications unmanned aerial vehicles (UAVs) and airborne in the 33 to 38 GHz band
- SATCOM terminals
- Airborne terminals for commercial airlines
- Weather and environmental monitoring radars
- Aircraft landing systems

RADIOFREQUENCY (RF) COMMUNICATION TECHNOLOGY SBIR PHASE II AWARDS

2006 TO 2014

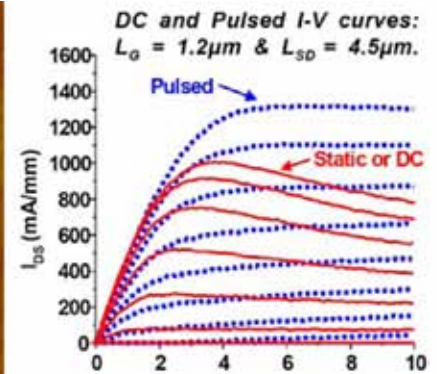
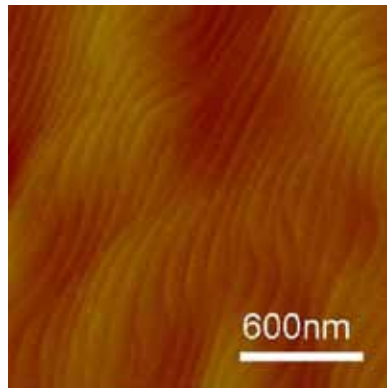


*Traveling-wave-tube amplifier (TWTA)
for Lunar Reconnaissance Orbiter.*

INTEGRATED PRODUCTION OF ULTRA-LOW DEFECT GALLIUM NITRIDE (GaN) FILMS AND DEVICES FOR HIGH-POWER AMPLIFIERS

SVT Associates

2007 Phase II
01.09-9383



GaN films grown with two filter layers. Large area scans show the dislocation density is about $5.0 \times 10^6 \text{ cm}^{-2}$ measured by counting etch pits. Characteristic DC (solid lines) and Pulsed (dotted lines) I-V curves of an AlN/GaN MOS-HEMT.

Identification and Significance of Innovation

- GaN epitaxial films with threading dislocation less than $1 \text{E}6$ per cm^2 will be prepared using a novel defect filter technology for high-speed and high-power amplifiers. This vacuum-process integrated dislocation reduction method is developed with high efficiency of defect reduction rate in terms of film thickness, process steps, and cost. This method takes advantage of defect nanofilter induced by off-normal ion beam to bend/terminate the dislocations, which did not require out-of-vacuum processing steps, foreign material insertion, nor lithography/etching. This method is applicable to other III-nitride films, including high InGaN and AlGaN.

Expected technology readiness level (TRL) range at the end of contract

- 4 to 5

Technical Objectives

- Optimized dislocation filtering layer
- Ion-assisted molecular beam epitaxy (MBE) growth of GaN high electron mobility transistor (HEMT) on low defect templates (TD less than $1 \text{E}6$ per cm^2)
- GaN high-power amplifier device processing and characterizations
- Based on the Phase I objectives, three milestones will be complete in the timeframe listed below
 - Prepare defect nanofilters and do characterizations and optimizations in first 3 months
 - By month 3, optimized dislocation layer will be used to grow low TD nitride films (less than $1 \text{E}6 \text{ cm}^2$)
 - Characterizations of TD and further reduce the TD; characterization of films and devices

NASA Applications

- High-speed and high-power amplifiers
- Radiation-hard and ultra-low noise amplifiers
- HEMT devices for radar and range finding, collision avoidance, and digital transmission
- Ultraviolet (UV) photo detectors for free-space optical communications, astrophysics, and biological agent detection, flame detection, and missile launch monitoring

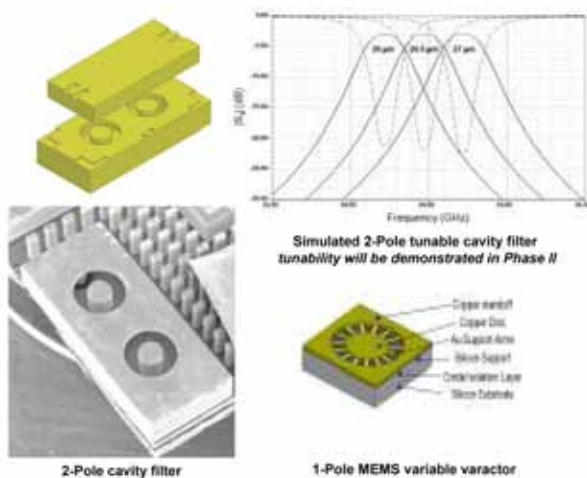
Non-NASA Applications

- HEMT device for radiofrequency (RF) and microwave mobile wireless communications
- Blue lasers, high brightness visible light-emitting diodes (LEDs), UV detectors for chemical and biological agent spectroscopy and threat detection, ozone detection, and environmental monitoring

THREE-DIMENSIONAL (3D) MICROFABRICATED LOW-LOSS RECONFIGURABLE COMPONENTS

Nuvotronics, LLC

2008 Phase II
01.07-8443



Technical Objectives

- Deliver high-performance, low-weight, and compact filters, which could be integrated into the DSN (Deep Space Network) uplink transponder for the X- and K-band uplink receiver frontend.
- Design and fabricate tunable filters at X- and Ka-band; extremely narrow band filters in the range of 0.3 to 0.7% bandwidth will enable new uplink channels in the X- and Ka-band.
- Package and measure the Ka-band filters fabricated during Phase I; radiofrequency (RF) performance and reliability results will drive the design geometry of the first build.
- Tune the two Ka-band filters designed in Phase I.
- PolyStrata filters and microelectromechanical system (MEMS) components will be integrated to realize X- and Ka-band tunable circuits.
- As a platform technology, the elements that are developed in this program can be integrated as building blocks into future programs and system architectures.

NASA Applications

- Satellite communications systems
- Wide-band military handsets
- Airborne and space communication

Non-NASA Applications

- Commercial satellite communications systems (phones, TV, and apps)
- Airborne and mobile communications
- Wireless and point-to-point

Identification and Significance of Innovation

- Novel high-performance miniature tunable filters for transponders
- Microfabrication approach for manufacturability
- Substantial reduction of system size and weight
- Reduction of required filters and system complexity
- Building blocks for future systems using Polystrata circuit backplanes

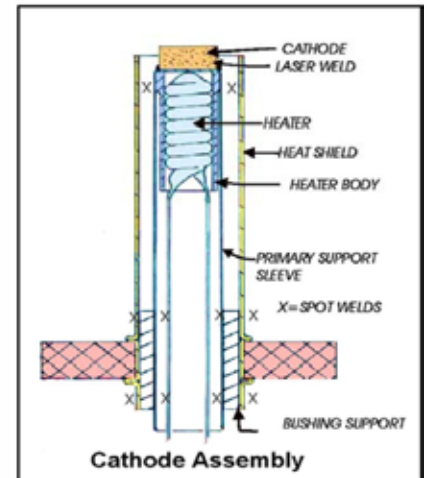
Expected technology readiness level (TRL) range at the end of contract

- 4 to 5

NANOPARTICLE SCANDATE CATHODE FOR SPACE COMMUNICATIONS PHASE 2

ebeam, Inc.

2009 Phase II
01.07-9345



Identification and Significance of Innovation

- An impregnated cathode with top layer of scandium oxide 50-nanometer particles on porous tungsten substrate with barium impregnation. This innovation depends on a process to produce unagglomerated scandium nanoparticles that was developed in Phase I. Scandate cathodes have demonstrated emission levels 10X current art, but performance has been unreliable and nonrepeatable, with no self-consistent theory for their operation. All workers agree that scandium must reach the surface to provide its beneficial effect. Our approach deposits scandium oxide at the surface in the beginning rather than depend on obscure processes to transport it from the bulk. We offer a theory that explains known properties and provides a path to optimization. Wireless communications are limited by power, frequency, and bandwidth of linear amplifiers. These in turn are limited by cathode performance, size, and life.

Expected technology readiness level (TRL) at the end of contract

- 7

Technical Objectives

- Process for generating isolated nonclumped 50-nanometer particles of scandium oxide by spray pyrolysis
- A top layer of scandium oxide nanoparticles on tungsten impregnated cathode by spray pyrolysis
- A top layer cathode by laser ablation
- Emission tested, working top-layer cathodes
- Deliverable sealed test devices containing top-layer cathodes with emission data and life test
- Miniature top-layer cathode
- Improved quantitative model capable of calculating optimal cathode properties

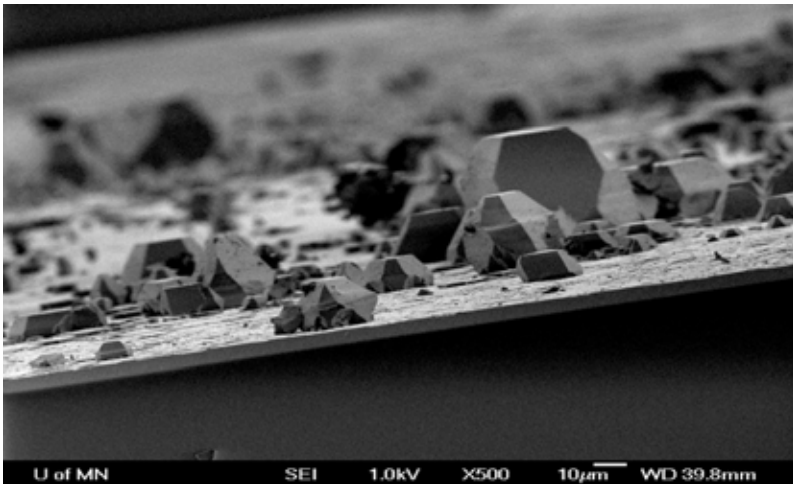
NASA Applications

- High-speed wireless transmission of video images from space probes
- Terahertz amplifiers for atmospheric investigations

Non-NASA Applications

- Terahertz sources and amplifiers
- Traveling-wave tubes (TWTs) for geosynchronous communications satellites
- High-speed x-ray imaging, e.g., computerized tomography (CT) scans of moving organs
- Backlights and projectors using e beam-stimulated laser screens

GALLIUM NITRIDE (GaN) BULK GROWTH AND EPITAXY FROM Ca-Ga-N SOLUTIONS



The IIAN Company, LLC

2009 Phase II
01.07-9857

Technical Objectives

- Ka-band transistor—broad performance targets
 - Gate length: <100 nm
 - Maximum drain voltage: 48 V
 - Gain at 38 GHz: 8 dB, minimum
 - Power density at 38 GHz: 5 W/nm
 - Power-added efficiency (PAE): 60%
 - Ft: 98 GHz
 - Maximum power (discrete transistor): 10 W

NASA and Non-NASA Applications

- Solid-state power amplifiers for Ka-band communications
- Robust, low-noise receivers
- Ultra-high-frequency (500-GHz) transistors
- Liquid Phase Epitaxy (LPE) of GaN has potential to drastically reduce line dislocation densities—relevant to blue and ultraviolet (UV) diode lasers

Identification and Significance of Innovation

- This Phase II proposal addresses the development of processing and epi-technologies for delivery of high-power and high-reliability AlGaIn/GaN Ka-band field effect transistors (FETs) for applications in long-range space communications.

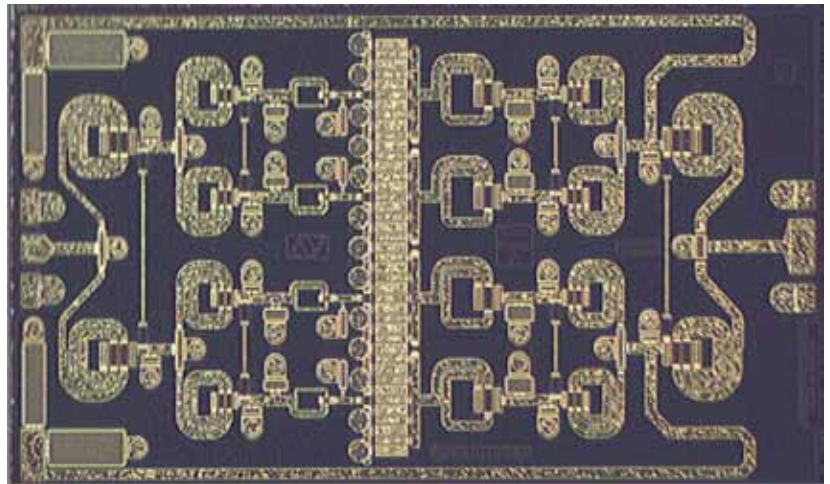
Expected technology readiness level (TRL) at the end of contract

- 3

X-BAND GALLIUM NITRIDE (GaN) POWER AMPLIFIERS FOR LONG-RANGE SPACE RADIOFREQUENCY (RF) TELECOMMUNICATIONS

Nitronex Corporation

2011 Phase II
01.05-9304



Identification and Significance of Innovation

- The innovation will be to develop a SSPA that produces 50 W of linear RF at X-band (8.4 GHz) with high direct current (DC)-to-RF efficiency (>60%) and low mass. The significance will be the utilization of wide-bandgap RF semiconductors to efficiently create high RF power that is robust to the high radiation environments of space. A wide-bandgap compound semiconductor material such as GaN will provide this required innovation. GaN-based field effect transistors (FETs) have the potential to operate at power densities of up to 10 times that of conventional RF semiconductor technologies, which will enable compact PAs with higher RF output power to be implemented. The proposed GaN PA design is estimated to be >50% smaller in both size and weight compared to other solid-state solutions and almost 20% lower in power consumption for typical designs used in long-range space RF telecommunications.

Expected technology readiness level (TRL) at the end of contract

- 7

Technical Objectives

- The proposed technical objective will be a core GaN-based 100-W power amplifier (PA) monolithic microwave integrated circuit (MMIC) or hybrid building blocks with greater than 50% power added efficiency (PAE) while operating off power supply less than or equal to 48 V.
- The results from this study will translate into innovative PA specifications and requirements for long-range space RF communications applications.
- The notional system technical objectives for Phase I of this project
 - Device optimization and test cell design, fabricate, and test.
 - Modeling of optimized unit cell—Status Report 1 detailing model validity
 - Amplifier component design, fabrication, and test—Status Report 2 detailing amplifier component performance
 - Design, assembly, and test of 100-W, X-band amplifier—Final Report showing results of 100-W amplifier assembly
- Phase II Technical Objectives
 - X-band frequency: 8.4 to 8.5 GHz
 - PA output power: Linear 50 W continuous wave (CW) and 100 W saturated
 - PAE: >50%
 - Input operating voltage: 48 V DC

NASA Applications

The primary NASA application is to replace sub 100- to 200-W traveling-wave-tube amplifiers (TWTAs) with a GaN-based solid-state power amplifier (SSPA) that is much more power efficient. While this SBIR is focused on 8.4 to 8.5 GHz, the technology development should be able to be extended to frequencies as high as 12 GHz

Non-NASA Applications

Alternative applications include broadband satellite communications (SATCOM), radar, and electronic warfare (EW) that span both C- and X-band frequency ranges. Nitronex has demonstrated parts operating under high voltage and achieving high robustness (15:1 voltage standing wave ratio (VSWR) that can be applied to higher frequency systems. Backlights and projectors using e beam-stimulated laser screens.

SELF-BIASED RADIATION-HARDENED Ka-BAND CIRCULATORS FOR SIZE, WEIGHT, AND POWER-RESTRICTED LONG-RANGE SPACE APPLICATIONS



Metamagnetics, Inc.

2012 Phase II
01.02-9699

Technical Objectives

- Materials fabrication efforts included refinement of hexaferrite composition, microstructure, and magnetodielectric properties towards reducing the material's inherent losses. In particular the substrate material's dielectric loss tangent and magnetic line width were targeted as these values were shown through simulation as the largest overall contributors to loss in fabricated devices.
- Device simulations were performed utilizing both in-house and commercial FEM solvers and included iterative design specification, evaluation, and refinement based on interactions with Jet Propulsion Laboratory (JPL) TMs and prime industrial partners. Over the course of the Phase 1 effort, four separate device designs were designed with varying frequencies by Metamagnetics to show the horizontal scope of the technology.
- Device prototyping included fabrication and complex testing of simulated designs. In the fabrication of these devices Metamagnetics relied on standard existing low-cost photolithography techniques, which served to limit programmatic risk and device cost. All fabricated devices were thoroughly characterized utilizing in-house equipment with respect to electrical performance, phase linearity, and response to high and low temperatures.

NASA Applications

- TDRS (Technical Data Relay Satellite System), ACE (Aerosol, Cloud and Ecosystems Radar), SWOT (Surface Water and Ocean Topography), DESDynI (Deformation, Ecosystem Structure and Dynamics of Ice), and DSC (Ka-band Deep Space Communication).

Non-NASA Applications

- Commercial and defense communication systems
- Next-generation transmitter/receiver (T/R) modules

Identification and Significance of Innovation

- In order to realize increased data rates, higher resolutions, and other desired long-range communication metrics in current and next-generation phased-array systems, the trend has been towards higher frequencies of operation. Unfortunately, this requires redesigning and/or retrofitting the thousands of expensive T/R modules used in the phased-array architectures. A disproportionately large percentage (~30%) of surface area within these modules is devoted to biased ferrite circulators. At high frequencies these devices necessitate large biasing magnets, which introduce severe size, weight, and cost concerns. As a solution Metamagnetics has developed an innovative circulator technology capable of operating with no biasing magnets. The enabling technology developed and demonstrated over the course of the Phase 1 SBIR effort is low microwave and dielectric loss hexaferrite materials that lower device complexity, increase supply chain security, decrease manufacturing time, and lower costs.

Expected technology readiness level (TRL) range at the end of contract

- 5 to 6



COMPANY NAMES

Agnitron Technology, Eden Prairie, MN	23
Auriga Measurement Systems, Lowell, MA	19
Beam Power Technology, Inc., Boston, MA	16
ebeam, Inc., Beaverton, OR	13, 20, 28
Group 4 Labs, LLC, Menlo Park, CA	11
Hittite Microwave Corporation, Chelmsford, MA	4, 5, 9
MaXentric Technologies, San Diego, CA	15, 22
Metamagnetics, Inc., Canton, MA	21, 31
Neocera, LLC, Beltsville, MD	7
Nitronex Corporation, Durham, NC	18, 30
Nuvotronics, LLC, Radford, VA	10, 17, 27
QuinStar Technology, Inc., Torrance, CA	24
Space Micro, Inc., San Diego, CA	6
SVT Associates, Eden Prairie, MN	8, 25
The IIIAN Company, LLC, Minneapolis, MN	14, 29
TLC Precision Wafer Technology, Inc., Minneapolis, MN	12

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