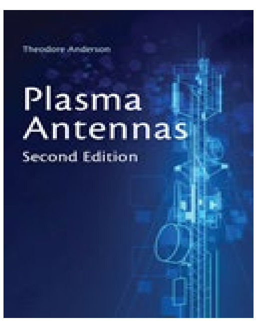
DoD SBIR 2024.2: N242-090-0663 - Low-Cost, High-Power Microwave Plasma Switches for Radar and Electronic Warfare (EW)

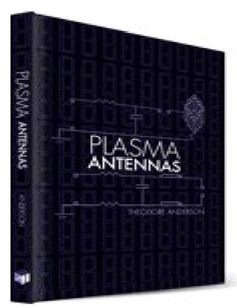
N242-090: <u>Low-Cost, High-Power Microwave Switches for Radar and Electronic Warfare (EW) Applications</u>

1.0 Description of Proposed Phase I Technical Effort

Haleakala R&D, Inc. will design, optimize, and fabricate prototypes for a low-cost, low-loss, high-power microwave plasma switch with fast-switching speeds over large instantaneous bandwidths for radio frequency (RF) surveillance and Electronic Warfare (EW) applications. We have already done theoretical calculations, experiments, and prototyping on plasma switches and plasma switches based on plasma frequency selective surfaces from the years 2000-2007. This R&D is reported in chapter 8 and in sections 9.1. 9.4. 9.5, and 9.6 in the two books by the CEO and PI, Dr. Theodore Anderson,: FOR PLASMA SWITCHES SEE CHAPTER 8 (PLASMA FREQUENCY SELECTIVE SURFACES) SECTIONS 9.1. 9.4, 9.5 AND 9.6.

Some Relevant Publications. Two Books and Book Chapters written by the PI, Dr. Theodore Anderson. *<u>(FOR PLASMA SWITCHES SEE CHAPTER 8 (PLASMA FREQUENCY SELECTIVE SURFACES) SECTIONS 9.1. 9.4, 9.5 AND 9.6) IN BOTH BOOKS)</u>*





Second Edition, Dr. T Anderson
PLASMA ANTENNAS

First Edition, Dr. T. Anderson
PLASMA ANTENNA

***<u>Book</u>*: Theodore R. Anderson, Plasma Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House, ISBN: 9781630817503; FOR PLASMA SWITCHES SEE CHAPTER 8 (PLASMA FREQUENCY SELECTIVE SURFACES) AND SECTIONS 9.1. 9.4, 9.5 AND 9.6.**
***<u>Book:</u>* Theodore R. Anderson , *<u>Plasma Antennas</u>*, Artech House, ISBN 978-1-60807-143-2; 2011. FOR PLASMA SWITCHES SEE CHAPTER 8 (PLASMA FREQUENCY SELECTIVE SURFACES) AND SECTIONS 9.1. 9.4, 9.5 AND 9.6.**
***<u>Book Chapter</u>*: Theodore Anderson, *Plasma Antennas,* Open access peer-reviewed chapter, *Selected Topics in Plasma Physics,* Submitted: October 21st 2019Reviewed: March 2nd 2020 Published: July 14th 2020, DOI:10.5772/ Intechopen.91944;** https://www.intechopen.com/chapters/71638
***<u>Book Chapter</u>*: Theodore R. Anderson, chapter 10; *Plasma Antennas*, <u>Frontiers in Antennas: Next Generation Design & Engineering</u>,, McGraw -Hill, Frank Gross editor. ISBN 0071637931 / 9780071637930**
***<u>Journal article:</u>* T. Anderson, I. Alexeff, "Plasma frequency selective surfaces", IEEE Transactions on Plasma Science, Vol. 35, no. 2, p. 407, 2007**

***Conference article*: Anderson, T., IEEE APS/URSI 2014 Paper #1928: *Plasma Frequency Selective Surfaces*, Conference Proceedings, July 2014.**
***Conference article:* Anderson, T., *Plasma Antennas: Plasma Frequency Selective Surfaces for Antenna Radomes,*, AMTA Conference Proceedings, October 2014. See: http://amta2014.org/**

1.1 Phase I Technical Objectives

Haleakala R&D, Inc. will develop a preliminary design of hardware for a novel, low-cost, high-power microwave plasma switch that significantly exceeds the current state-of-the-art and improves the performance of current switches. Star System Holdings will develop a design approach and produce simulated results of a high-power, fast microwave switch that meets or exceeds the following metrics as shown in the SOW.

1.2 Phase I (Base and Option) Statement of Work

SOW			
Task No.	**Title**	**Description**	**Performer or Subcontractor**
1	Model and simulate a plasma waveguide switch by inserting a plasma tube in a rectangular metal waveguide. BASE.	When the plasma in the plasma tube is on, electromagnetic waves propagate as in a coaxial cable. When the plasma is off, transmission is stopped. See figures 1, 2, and 3.	Haleakala R&D, Inc
2.	Variable density plasma to get a reconfigurable waveguide and plasma switch. BASE	The plasma in fig 4 is the dark color. The white color is a nonconducting gas like air. We will change the density of the plasma and change the reactive skin depth equal to the speed of light divided by the plasma frequency. This means that we will change the dimensions of the waveguide by changing the density of the plasma and thus the wavelengths and frequencies that can pass. This is a reconfigurable plasma switch.	Haleakala R&D, Inc
3.	Operating frequency, Power handling, Threshold Power, Insertion loss. BASE	We will show that the operating frequency: Any one octave over 2-12 GHz (Threshold), entire 2-18 GHz band (Objective); Power handling (1-dB compression point) - Operative above a curve defined by the following frequency & power points; Threshold Power: 250 W @ 3GHz // 50 W @ 10 GHz Objective Power 750 W @ 3GHz // 150 W @ 10 GHz	Haleakala R&D, Inc
4.	Isolation, Switching speed, Targeted unit costs, Isolation, Switching speed, Cycles. BASE	We will show that the insertion loss: < 1dB (Threshold), < 0.3 dB (Objective); Isolation: > 20 dB (Threshold), > 40 dB (Objective); Switching speed: 500us (Threshold), 50 ns (Objective); Cycles: > 3e9 (Threshold), > 30e9 (Objective)	Haleakala R&D, Inc

5.	Linearity, Duty cycle. OPTION	We will show the linearity such that input third order intercept approximately 10dB above P1dB point; Duty cycle: Greater than 20% (Threshold), to CW (Objective)	Haleakala R&D, Inc
6.	Plasma FSS reconfigurable switch. OPTION	We will design and build an electronic switch such that when the plasma is on, the plasma FSS does not pass a bandwidth of frequencies.	Haleakala R&D, Inc

1.3 Related Work.

Our coaxial plasma closing switch, shown in **Figure 1, Coaxial Plasma on Switch.**

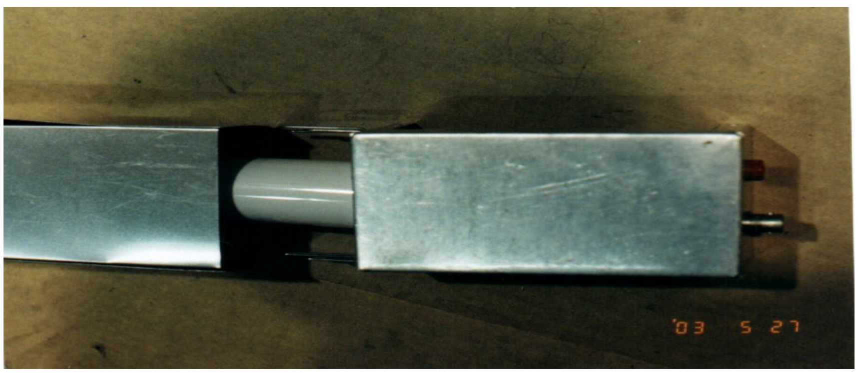


Figure 1. Coaxial Plasma Switch.

In this switch, the outer conductor was a metal shell, and the inner conductor was a plasma discharge tube. When the tube was not energized, the outer shell comprised a metal waveguide beyond cutoff, and no radiation was transmitted. When the plasma discharge tube was energized, the apparatus became a coaxial waveguide, and transmission of radio signals was excellent.

1.3.1 Plasma Waveguide Switches.

A second, antenna related, plasma application is a plasma waveguide, as shown in **Figure 2, Plasma Waveguide.** Here an inner conductor comprises one plasma tube surrounded by an outer shell of eight plasma tubes.

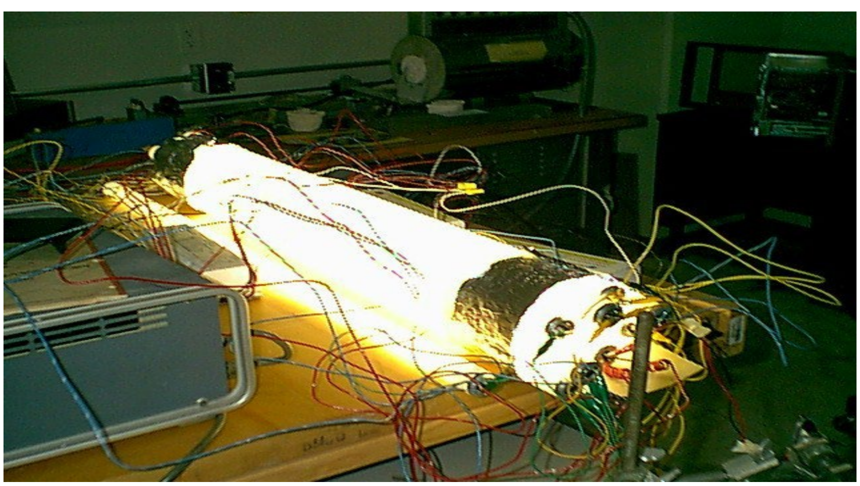


Figure. 2. Plasma waveguide switch

When on, the structure transmits radiation almost as well as a coaxial cable, but when off, the transmitted signal decreases by over 100 dB –a factor of 10 exp 10 Such plasma waveguides could convey radiation to the antennas on the mast of a ship, yet become transparent to radiation when de-energized.

Conceptual Models of Plasma Waveguides Switches.

Inside Plasma Switch Tube Concept

Plasma in Blue (Dark Area) Inside Waveguide. White area is a metal waveguide with a dielectric gas like air.

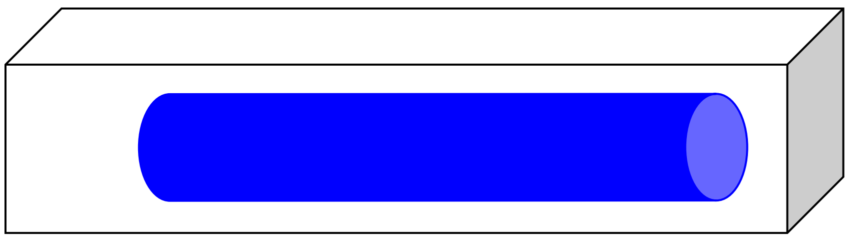


Fig.3 An inside plasma tube in a metal or plasma waveguide switch.
When the plasma in the inner tube is on, electromagnetic waves propagate down the waveguide. When inner plasma tube is turned off, the waveguide is below cutoff and no propagation occurs.

A Second Plasma Switch Waveguide Design. Blue or dark area is plasma. White area is an annular dielectric tube.

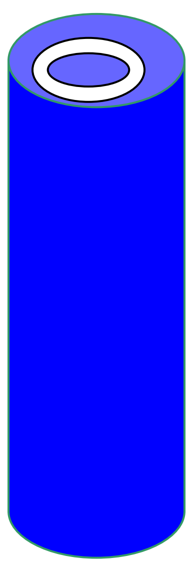


Figure.4 A second plasma switch waveguide design.

The inner cylinder is filled with plasma (blue) and the outer annular ring is filled with plasma. A non conducting region (white) in between inner cylinder and outer cylindrical annular ring. The plasma skin depth is reconfigurable creating a reconfigurable waveguide.
Radar signals would pass through a de – energized waveguide rather than be reflected. In fact, these waveguides could pass in front of operating antennas and be virtually invisible when off.

1.3.2 Plasma Frequency Selective Surface Switches

A third plasma antenna application is reconfigurability. The effects of a reconfigurable plasma frequency selective surface (FSS) filter are shown in **Figure. 9.16**

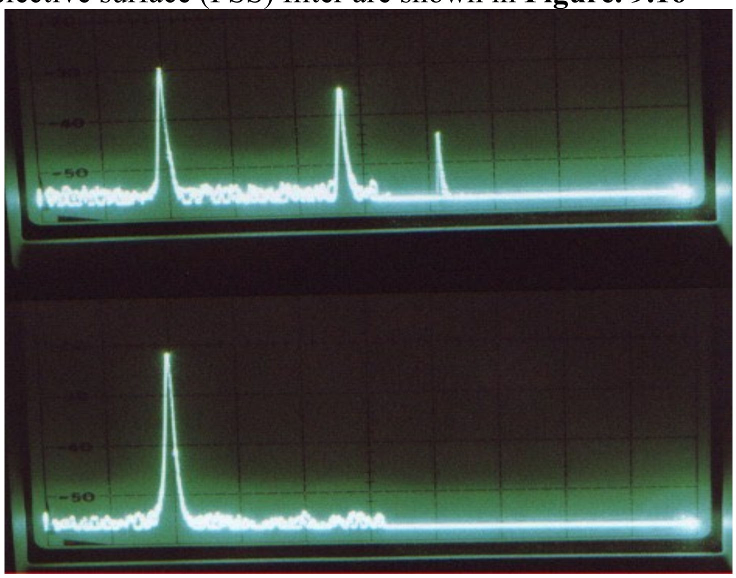


Figure 5. Plasma Frequency Selective Surface (FSS) Reconfigurable Filter and Switch
Putting a plasma FSS between transmitter and receiver removes the 2nd and higher harmonics. (2 dB per square)
In one oscilloscope trace, we observe several spectral lines emitted from an oscillator driven to a non – linear limit. In the second oscilloscope trace, several of the higher – frequency lines have been removed by the energizing of a plasma FSS filter placed between the transmitter and receiver. Figure 6 and Figure 7 are photographs of the plasma frequency selective surfaces setup. Please see chapter 8 on plasma frequency selective surfaces for more detail.

Figure 6. Photograph of the lab setup showing the built plasma dipole reconfigurable FSS with the horn receiver antenna.

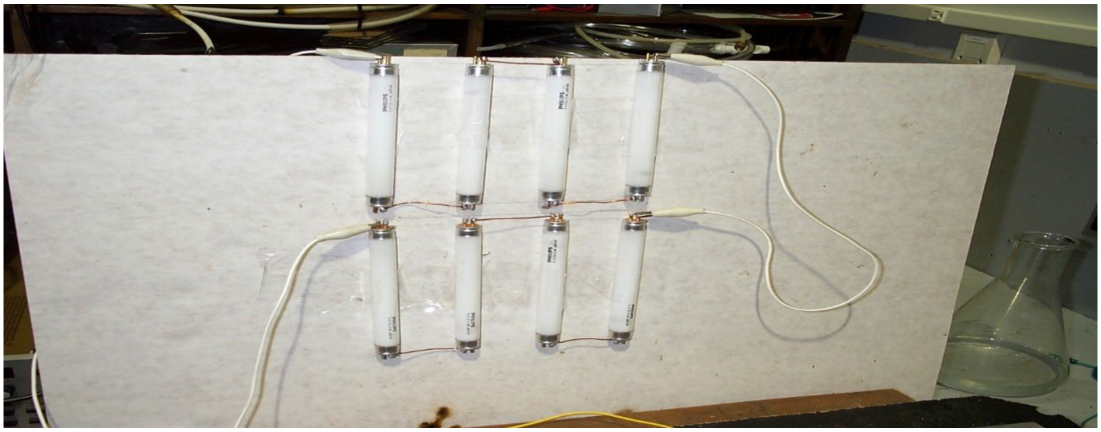


Figure 7. Close up photo of experimental setup plasma reconfigurable FSS switch and filter.

PHASE II:
Star Systems will produce a prototype or set of prototypes of the Phase I switch design. Laboratory based testing shall be completed under the Phase II effort to demonstrate that the technology meets performance metrics set at the end of Phase I. Efforts should characterize devices against metrics set forth in Phase I, identify and iterate on designs to improve performance, and provide a recommended path for higher-volume production.

2.0 Key Personnel

activate and enhance rain to solve the devastating droughts.

TWO MOST IMPORTANT KEY PERSONNEL SUMMARY				
Name and Title	**Employer**	**Qualifications**	***Foreign National (Y/N)**	**Publications Two most important**
Dr Theodore Anderson	Haleakala R&D, Inc	PhD physics, PI Haleakala R&D, Inc	*N*	**1. T. Anderson, I. Alexeff, "Plasma frequency selective surfaces", IEEE Transactions on Plasma Science, Vol. 35, no. 2, p. 407, 2007** **2. T. Andrson, Plasma** **Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House,** **ISBN: 9781630817503**

Dr. Larry Barnett	Haleakala R&D, Inc	PhD Electrical Engineering, Chief Engineer, Haleakala R&D, Inc	N	**1. Larry R. Barnett, "A broadband gyrotron backwardwave oscillator with tapered interaction structure and magnetic field," Phys. of Plasmas (November, 2015).** **2. Larry R, Barnett, "A microwave applicator for uniform irradiation by circularly polarized waves in an anechoic chamber" Review of Scientific Instruments 85, 084703 (2014).**
Fred Dyer Jeff Peck	Haleakala R&D, Inc Haleakala R&D, Inc	MS Electrical Engineer MS Electrical Engineer	N N	IEEE APS/URSI 2014 Paper #1547: Theory, Measurements, and Prototypes of Plasma Antennas and Plasma FSS.

Brief Resume of Dr. Theodore (Ted) R. Anderson (PI)

Security Clearance (possibly not current) DOD and DOE
Citizenship United States
O***ffice address: 7 Martin Road, Brookfield, MA 01506-1762***
Phones: office and cell: 508 450 7540 and 518 409 1010
e-mail: tedanderson@haleakala-research.com; website: www.haleakala-research.com
Highest degree **PhD in physics** from New York University in 1986.

CURRENT STATUS: I am founder, Chief Executive Officer, principal investigator, and Chief Technology Officer of *Haleakala Research and Development Inc.*(www.haleakala-research.com **)2002-present.** I have won 9 phase 1 SBIR (Small Business Innovative Research) contracts and 2 phase 2 SBIR contracts with the US Air Force, US Army, US Navy, and US Marine Corp. This amounted to over 2 million dollars in R&D funds. Scientific American published an article on my technology and company in the February 2008 issue on page 22. The Air Force wrote a success story on my company and technology which appeared on the Air Force website. See my website for all the details: ***(*** www.haleakala-research.com)

RECENT PUBLICATIONS

1. **Anderson, Theodore, "Antenna Beam Focusing and Steering with Refraction Through a Plasma", EuCAP 2019, presentation and conference symposium. March 2019.**
2. **Anderson, Theodore, "Magnetic Imaging Resolution and Positron Emission Tomography Using Plasma Antennas", EuCAP 2019, presentation and conference symposium. March 2019.**

Books

1. **Theodore R. Anderson, Plasma Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House, ISBN: 9781630817503**
2. **Theodore R. Anderson , *Plasma Antennas*,** Artech House, ISBN 978-1-60807-143-2; 2011.

http://www.artechhouse.com/Plasma-Antennas/b/2130.aspx

1. **Book Chapter** *Frontiers in Antennas: Next Generation Design & Engineering*, chapter 10; Plasma Antennas, Theodore R. Anderson, McGraw -Hill, Frank Gross editor. ISBN 0071637931 / 9780071637930
2. **Book Chapter: Theodore Anderson, *Plasma Antennas,* Open access peer-reviewed chapter, *Selected Topics in Plasma Physics,* Submitted: October 21st 2019Reviewed: March 2nd 2020 Published: July 14th 2020, DOI:10.5772/ Intechopen.91944;** https://www.intechopen.com/chapters/71638

1 **Journal article: T. Anderson, I. Alexeff, "Plasma frequency selective surfaces", IEEE Transactions on Plasma Science, Vol. 35, no. 2, p. 407, 2007**

2 **Symposium article: 1. Anderson, T., IEEE APS/URSI 2014 Paper #1928: *Plasma Frequency Selective Surfaces*, Conference Proceedings, July 2014.**

3 **Symposium article: 2. Anderson, T., *Plasma Antennas: Plasma Frequency Selective Surfaces for Antenna Radomes,*, AMTA Conference Proceedings, October 2014. See: http://amta2014.org/**

4 **Scientific Magazines. 1. Scientific American, *Aerial Stealth*,** https://www.scientificamerican.com/article/aerial-stealth/

5 **Scientific Magazines. 2. Popular Mechanics Article On Haleakala R&D, Inc or Dr. Ted Anderson plasma antennas:** Hambling, D.; *Scientists Control Plasma for Practical Applications*; Popular Mechanics; July 2010; page 18; http://www.popularmechanics.com/technology/engineering/news/scientists-control-plasma-for-practical-applications

PHASE III DUAL USE APPLICATIONS:

Haleakala R&D, Inc will design, build, and deliver higher level subassemblies including the new switching technology, with assistance from the Navy. Possible subassemblies may include high-power phase shifters, low-loss antenna tuners, or switch-tuned filters. These efforts will target components and subassemblies that support both DoD applications (e.g., phased array radar or electronic warfare systems), and commercial applications (e.g., adaptive arrays for high power 5G/6G cellular base stations).

3.0 Commercialization/Transition Plan Summary

1.Communicating through the plasma sheath in hypersonic speeds by treating the plasma sheath as a plasma antenna. 2. Smart plasma frequency selective surfaces as RFID readers 3.Superior fixed satellite plasma frequency selective surfaces and satellite plasma frequency selective surfaces for RVs and yachts. 4.Base stations. 5. Last mile applications. 7. Medical applications: MRI(magnetic resonance imaging) and PET (positron emission tomography) 8 Multipole expansion plasma frequency selective surfaces to fit in cell phones as miniature smart frequency selective surfaces 9. 5G improvements using my smart plasma antennas. 10. Improved Magnetic resonance imaging using my plasma coils. 11. Improved positron emission technology to help find tumors using my plasma coils 12. Plasma antennas as Far-UVC at 222nm to inactivate SARS-CoV-2 virus, which causes Covid-19. To stop pandemics. My plasma antennas operating at 95 GHz to non-lethally stop shooters in schools. Using atmospheric plasma antennas to activate and enhance rain to solve the devastating droughts.

4.0 Facilities/Equipment.

has a plasma physics lab for experimentation and prototyping. Haleakala has an antenna lab and open field for antenna testing. We are building an anechoic chamber. The Haleakala lab has an HP 85 10B. Network Analyzer for measurements from 10 MHz to 1000 GHz, a photolithographic layout and fabrication facilities, several PCs and workstations, Alcatel DryTel 31 Vacuum Pump, Xenon Gas Cylinder, HP 8757E Scalar Network Analyzer, HP 8350B with 83595A sweep Generator 26.5 GHz, HP 83572A Microwave Plug-In 40 GHz, WR22 Waveguide Crystal Detector 33-50 GHz, 1000V 300mA Compact Power Supply, Spellman SL1200 2KV 600mA Power Supply, Agilent 8722ES 50 MHz- 40 GHz S-PARAMETER NETWORK ANALYZER OPT 085 010 W/ CAL, 12 kV 50 amp switches from Behike Corporation, 300 series resistors, SynFoam Miscellaneous waveguide parts, 12-14 GHz low noise amplifier, Anechoic chamber parts, and Miscellaneous machinery parts.

5.0 Letters of Support.

Northrop Grumman Systems Corporation
Mission Systems Sector
880 Elkridge Landing Road
Linthicum, MD, 2109
May 29, 2024

Northrop Grumman Systems Corporation (NGSC), acting through its Mission Systems Sector, is pleased to provide this letter of support for Haleakala R&D, Inc., and their proposal in response to SBIR proposal number N242-090-0663 and topic number N242-090.

Northrop Grumman is a leading global security company providing innovative systems, products and solutions in aerospace, electronics, information systems and technical services to Government and commercial customers worldwide. Northrop Grumman is actively supporting Department of Defense programs throughout our enterprise to develop a network of reliable, resilient, and adaptive capabilities. Through its existing airborne platforms and other innovative technology approaches, Haleakala R&D, Inc. can support our efforts and provides a unique opportunity to enhance plasma switches, plasma antennas, plasma frequency selective surfaces, plasma metamaterial antennas, and EMI protection with plasma physics and plasma FSS.

We have had multiple interactions with Dr. Theodore Anderson, CEO of Haleakala R&D, Inc., and his team, and we were impressed with their capabilities. NGSC is in process of identifying potential DoD customers and programs to align with Haleakala R&D, Inc. to include Air Force, Army, and Navy program offices. NGSC looks forward to interacting with Haleakala R&D, Inc. as this work evolves, to communicating with Haleakala R&D, Inc. on product capabilities throughout our DoD network, and integrating Haleakala R&D, Inc's capabilities into real world use cases.

Yours truly,

M. Fitelson

Dr. Mike Fitelson
Chief Scientist
Advanced Technology
ECD
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Star System Holdings, Inc
13168 Thumbprint Court, Colorado Springs CO 80921
719-231-8993 (m) jhawley@gans.us

May 28, 2024

To Whom it may concern:

Star System Holdings, Inc., an advanced research and development company, is pleased to provide this letter of support for Haleakala R&D, Inc., and their proposal in response to SBIR proposal number N242-090-0663 and topic number N242-090.

Star System Holdings (SSH) specializes in developing innovative technologies and system solutions to meet important operational needs for government and commercial customers worldwide. We have worked closely with Dr. Theodore Anderson, the CEO of Haleakala R&D, Inc., for over a decade and have been extremely impressed with Haleakala's disciplined research and development capabilities. Haleakala is presently working with SSH in the areas of plasma physics, plasma switches, electromagnetics, antennas, and protection against EMI with plasma FSS. and is well qualified to produce positive outcomes for the United States Navy on this proposed SBIR program.

As a former senior member of the U.S. military R&D community, I strongly recommend you immediately award SBIR topic number N242-090 to Dr. Anderson and his Haleakala R&D team. Haleakala is a talented and highly qualified small business that is postured to produce huge successes for the Department of Defense and the United States MDA.

Sincerely,

John W Hawley, USAF Maj Gen Retired
Chief Executive Officer
Star System Holdings, Inc.

6.0 Foreign Citizens. None.

7.0 Subcontractors and Consultants. None

8.0 Prior, Current, or Pending Support of Similar Proposals or Awards. None.

REFERENCES

Book: **Theodore R. Anderson, Plasma Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House, ISBN: 9781630817503; FOR PLASMA SWITCHES SEE CHAPTER 8 (PLASMA FREQUENCY SELECTIVE SURFACES) AND SECTIONS 9.1. 9.4, 9.5 AND 9.6.**
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