**Mutual Enhancement of Laser Communications and Plasma Metamaterial Antennas and Frequency Selective Surfaces.**

**Dr; Theodore Anderson**

**Abstract:** Laser communications is straight line of site communications. Laser beams cannot diffract or refract around objects as rf waves from a plasma antenna can.

Line of site communications can be very useful in space. The data rates are high in laser communications.

However when you communicate back to earth where you need to diffract around mountains, buildings, trees etc. then rf has to be used. Also on the moon and Mars there are mountains, canyons, and craters which obstruct line of site communications. There is now a lot of space junk. Maybe that's an obstruction problem for line of site laser communications.

The plasma antenna can be reconfigured to operate at ELF (100 Hz say) to Far-UVC frequencies at 222 nm. Our Far-UVC device is essentially a plasma antenna operating at 222 nm and this could be a line of site communications with high data rates.

Plasma antennas and plasma FSS are reconfigurable. Comms plasma antennas can be quickly converted to ground penetrating Radar antennas. This would be useful for mining on the moon and other planets like Blue Origin wants to do on the moon. Comms plasma antennas can be converted into Far-UFC antennas operating at 222 nm to inactivate viruses and bacteria in case that viruses get on board from earth or other planets. Anything brough back to earth has to be virus and bacteria free.

Plasma antenna technology can be used to communicate through the plasma sheath around a hypersonic vehicle by treating the plasma sheath as a leaky wave plasma antenna.

Lasers can be steered using motors, but metal phased array antennas and plasma antennas can be steered electronically. This is because an antenna array creates regions of construction and destructive interference. The constructive interference is the antenna beam. The beam is steered by changing the phase shifting. The smart plasma antenna also has the option of using plasma physics to shape and steer the antenna beam. In this way you can make the plasma antenna smart. If you add AI, the smart plasma antenna can make decisions and utilize neurological algorithms to enable thinking. Electronic steering is much faster than motor mechanical steering.

Laser wavelengths are damped by fog, rain, dust, pollutants, etc. Maybe the solar wind which is plasma can do some damping. Visible light which is longer than laser light gets damped by fog, rain, clouds, pollutants, etc.

Much of the rf spectrum that the plasma antenna uses doesn’t get damped at all.

Our smart plasma antenna is compact and can steer 360 degrees in the azimuthal direction and can be made to steer in the z direction. It is much more compact than the corresponding metal antenna phased array antenna. This can be done by placing an omnidirectional antenna in the center of a ring of plasma tubes. By opening and closing these tubes in sequence we can steer the antenna beam. The antenna beam can also be steering and focused by the physics of refraction of the antenna beam in a plasma.

Any EMI problem internal or external to the spacecraft could be solved by using plasma antennas and plasma antenna arrays, but if that is not possible, metal and plasma electromagnetic devices with reconfigurable plasma frequency selective surfaces can be a solution. We can develop lightweight, extremely thin electromagnetic shielding with reconfigurable plasma FSS capable of defending from 20MHz to 20GHz at a level of 48 dB or higher. Shielding must be suitable for hypersonic applications, to include thermal considerations. The reconfigurable plasma FSS can filter out bad EMI and filter in useful signals. The plasma FSS can be reconfigured as the EMI source changes. As the intensity of the EMI source increases the plasma density in the reconfigurable plasma FSS increases as a natural response to this increase in intensity of the source. The increase in the density of the plasma in the plasma FSS makes it more protective against EMI. In other words, you are making undesirable energy useful.

Any space mission having a combination of laser communications and plasma antenna communications will give you everything you need.

**Introduction**

High frequency plasma antennas can transmit and receive through lower frequency plasma antennas. This is not possible with metal antennas. Because of this principle, higher frequency plasma antennas can be nested inside lower frequency plasma antennas and the higher frequency plasma antennas can transmit and receive through the lower frequency plasma antennas. Higher

frequency plasma antenna arrays can transmit and receive through lower frequency plasma antenna arrays. Cosite interference occurs when larger frequency antennas block or partially block the radiation patterns of smaller higher frequency antennas. With plasma antennas, cosite interference can be eliminated or reduced because higher frequency plasma antennas can transmit

and receive through lower frequency plasma antennas. Interference among plasma antennas can be reduced or eliminated by turning all the plasma antennas off (extinguishing the plasma) except the plasma antennas that are transmitting and/or receiving. This is not possible with metal antennas. As stated above, one should be careful not to confuse the operating frequency

of the plasma antenna with the plasma frequency. The plasma frequency is proportional to the square root of the density of unbound electrons in the plasma. As previously indicated, in a metal the plasma frequency is fixed in the X-ray frequency region, but in plasma antennas, the plasma frequency can be made to vary throughout the electromagnetic spectrum and in particular

the RF region. This property gives plasma antennas some of their reconfiguration properties. A general rule is that when an incident electromagnetic wave upon a plasma antenna is such that the frequency of the incident electromagnetic wave is greater than the plasma frequency of the plasma,

the incident electromagnetic wave passes through the plasma with or without attenuation depending on the relative magnitude of the plasma frequency and incident frequency. If the incident electromagnetic wave has a frequency much less than the plasma frequency, the plasma behaves similar to a metal.The frequency at which plasma behaves like a metal or a dielectric is reconfigurable. The plasma frequency is a natural frequency of the plasma and it is a measure of the amount of ionization in the plasma. It is defined and used throughout this book. Both plasma antennas and metal antennas increase in size as the frequencies they operate go down to maintain geometric resonance and high efficiency. However as the frequency of operation of the plasma antenna decreases, the density of the plasma needed to operate the plasma antenna also

goes down. A rule of thumb is that the plasma frequency should be about twice or greater than the operating frequency of the plasma antenna to consider the plasma antenna to behave as an effective metal antenna. Hence the plasma frequency can be engineered to go down as the frequency

of the plasma antenna goes down. As the plasma frequency decreases, theplasma antenna becomes transparent to a greater bandwidth of electromagnetic waves. In short as the plasma antenna increases in size, the RCS of the plasma antenna goes down whereas for the corresponding metal antenna, the RCS goes up as the metal antenna increases in size. This gives the plasma antenna some great advantages at low frequencies over the corresponding metal antenna. In addition plasma antennas do not receive electromagnetic noise greater than the plasma frequency since these frequencies pass through the plasma antenna. Thermal noise in a plasma antenna is less than the thermal noise in a metal antenna at the higher frequencies. Higher frequencies mean that there is a point in the RF spectrum in which the thermal noise of plasma antennas is equal to the thermal noise of metal antennas. At higher frequencies than this point, the plasma antenna thermal noise decreases drastically compared to a metal antenna. Below this point the thermal noise of the plasma antenna is greater than a metal antenna. For a flourescent tube that is used as a plasma antenna, the point where the thermal noise of the plasma antenna is equal to the metal antenna is about 1.27 GHz. This point can be decreased in frequency by decreasing the plasma pressure. The plasma in the plasma antennas are inert gases that operate at energies and frequencies in which

Ramsauer–Townsend effects apply. Ramsauer–Townsend effects mean that the electrons in the plasma diffract around the ions and neutral atoms in the plasma. This means that the collision rate of the unbound electrons in the plasma with ions and neutral atoms is small and much smaller than in a metal. This phenomenon contributes to the lower thermal noise that plasma antennas have over corresponding metal antennas. Satellite plasma antennas benefit from the lower thermal noise at the frequencies they operate. Ground-based satellite antennas point at space where the thermal noise is about 5K. A low thermal noise, a high data rate satellite plasma antenna system is possible with low noise plasma feeds and a low noise receiver. Satellite plasma antennas can operate in the reflective or refractive mode. Satellite plasma antennas need not be parabolic but can be flat or conformal and effectively parabolic. Electromagnetic waves reflecting off of a bank of plasma tubes get phase shifted as a function of the plasma density in the tube. This becomes an effective phased array except that the phase shifts are determined by the plasma density. If the plasma density in the tubes is computer controlled, the reflected beam can be steered or focused even when the bank of tubes is flat or conformal. In the refractive mode, the refraction of electromagnetic waves depends upon the density of the plasma. In the refractive mode, steering and focusing can be computer controlled even when the bank of tubes is flat or a conformal shape. For two-dimensional steering and/or focusing, two banks of plasma tubes are needed. Feed horns and receivers can be put behind satellite plasma antennas operating in the refractive mode. This eliminates the problem of the blind spot and feed losses caused by the feed horn and receiver in front of a metal satellite antenna. The above phenomena of using a bank of plasma tubes to focus electromagnetic waves is also known as a convergent plasma lens. A convergent plasma lens can focus electromagnetic waves to decrease beamwidths, increase directivity, and increase antenna range. A divergent plasma lens can also be created. Both convergent and divergent plasma lenses lead to reconfigurable beamwidths. High powered plasma antennas have been developed which transmit 2 MW and more in the pulsed mode. Pulsing techniques instead of applying continuous energy were developed to increase the plasma density and decrease the amount of energy to

maintain the plasma. The early techniques used spark gap techniques for pulsing. This technique produced some EMI noise, which was suppressed using circuit techniques. Techniques that did not use spark gap techniques to produce pulsing did not produce EMI noise. Continuous energy applications to ionize and maintain ionization did not produce EMI noise. No infrared signature of the plasma antenna when the plasma is contained

in glass tubes has been observed. This is partly due to infrared radiation not penetrating glass and that the plasma in a plasma antenna is not a blackbody radiator. Related to plasma antennas, plasma frequency selective surfaces, plasma waveguides, and plasma coaxial cables have been developed. Unlike metal frequency selective surfaces, plasma frequency selective surfaces have the properties

of reconfigurable filtering of electromagnetic waves. This could have tremendous advantages to radome design. Plasma frequency selective surfaces can be reconfigured by varying the plasma density, varying the shape of the elements, or tuning any number of the plasma FSS elements on or off. Plasma wave guides and plasma coaxial cables can be stealth-like plasma antennas, they

can operate at low frequencies, and be invisible at high frequencies. Plasma waveguides and coaxial cables can be feeds for plasma antennas. Plasma feeds as well as the plasma antennas have reconfigurable impedances. If the impedance of the plasma antenna is changed, the impedance of the plasma feeds can be changed to maintain impedance matching. In the history of antennas, it has been difficult to develop low frequency directional and electronically steerable antennas that fit on land vehicles and aircraft. Low frequency means the wavelength is on the order or larger than the vehicle. With plasma antennas this is possible with multipole expansions of clusters of plasma antennas that are all within a wavelength of each other. This depends on the ability of turning plasma antennas on or off (extinguishing the plasma) to create reconfigurable multipoles of plasma antennas that can be rotated in time creating directional and steerable antenna beams. This is not possible with metal antennas because the metal cannot be turned on and off. In this book, plasma antennas were fed by capacitive sleeves placed around the plasma tubes. Plasma antennas can also be fed inductively. For research purposes, fluorescent and neon tubes have been used to build plasma antennas since they are inexpensive. The fact that you can use COTS tubes as plasma antennas gives the plasma antenna an advantage. COTS tubes may be all that is needed for many applications or deployments. This makes the technology less costly and more appealing. In addition fluorescent and neon tubes are not trivial technologies. The proliferation and commonalty of fluorescent and neon tubes may make them seem like unsophisticated technologies. However, they are sophisticated. Plasma antennas have been housed in a synthetic foam called SynFoam. When this synthetic foam hardens it makes very strong and lightweight tubes that can be used as plasma tubes to make plasma antennas. These rugged tubes can be readily manufactured. SynFoam has been tested to have an index of refraction close to one and hence is very transparent to electromagnetic waves. SynFoam is very heat resistant. The ruggedized smart plasma antenna uses SynFoam to house the plasma. Gorilla glass by Corning and Lexan glass tubes are also options for housing plasmas. Plasma antennas can also be miniaturized and contained in commercially available cold cathode tubes used for liquid crystal displays. Ball and socket glass tubes inserted inside plastic tubes can be used to make flexible plasma antennas that can be shaped in various forms. In summary, the plasma of plasma antennas can be housed in Synfoam, miniaturized cold cathode tubes, ball and socket glass tubes, Lexan glass, and Gorilla glass by Corning.

**Background.**

**Plasma Metamaterials and Plasma Photonic Band Gaps for Plasma Antennas and Plasma Frequency Selective Surfaces. [1]**

Plasma metamaterials could enhance the lensing of EM waves by significantly reducing the diffraction limit and enhancing cloaking by using a combination of plasma antenna and metamaterial technology. Plasma photonic band gap crystals and plasma metamaterials are much more reconfigurable than photonic band gap crystals and metamaterials and offer much larger degrees of freedom and possibilities for antenna technology. Photonic crystals and plasma photonic crystals have been covered in various patents . The difference between metamaterials and photonic bandgaps is essentially the wavelength. In photonic bandgaps the wavelengths are of the order of the lattice spacing, and in metamaterials the wavelengths are longer than the spacing between the lattice points. More specifically the difference between photonic crystals and metamaterials is that to have the photonic bandgap the atoms and the lattice constant in bandgaps have to be comparable in size with the wavelength, a ≈ λ, because the effect of the bandgap arises from diffraction. In the case of metamaterials artificial atoms (sub-units) and lattice constant have to be much smaller than the wavelength, a << λ, because diffraction should not appear. Plasma metamaterials have a photonic-crystal-like behavior, a negative refractive index state, and a nonlinear bifurcated electric response. The wavelength passing through a metamaterial influenced by the effective parameters of the material, such as effective magnetic permeability, μ, and effective electric permittivity, ε. It is the wavelength which determines if a collection of atoms or sub-units is a material. Metamaterials can have a negative refractive index. The index of refraction is given as n, where n2=εμ. It has two components: electric permittivity, ε, and magnetic permeability, μ. A pioneer in metamaterials, Veselago, found that there are only two available solutions for the refractive index. When both ε and μ are positive then n>0. When both are negative then n<0. A conventional material has n>0. Materials with n<0 bend rays of incident light to the same side (as the incident beam) of the normal. Naturally-occurring materials with ε<0 include metals like silver and gold. The negative epsilon exist in the visible wavelengths. In order to obtain negative ε at longer wavelengths, a periodic structure composed of thin infinite wires arranged in a simple cubic lattice has been designed. In addition the magnetic response has been presented for the split-ring structure. Microwave frequencies with n<0 at is covered in. Recently, negative ε and μ were demonstrated in the visible region for a material made of nanorod pairs . Metamaterials with n<0 have applications as flat lenses. In conventional lenses with n>0 the resolution is limited by the wavelength. This is because only the far field is transmitted through a lens while the near field decays as evanescent fields. In order to increase the resolution of an image the near field has to be transmitted and amplified. This is possible with a lens made of n<0 material and has many applications . By mixing a powder of BaTiO3 with nanoparticles of nickel in an appropriate ratio yields a structure with a very large dielectric constant. The dielectric constant increases enormously at the percolation threshold . In the field of cloaking, it has been shown that, when an object is covered by a metamaterial made of special metal elements, the reflection (back scatter) and the shadow (forward scatter) are reduced by what is called a metamaterial cloak . Fantini et al published data collected for a 2D array of resonators operating in the 6–7 GHz range for separation distances of 0.25 mm and 0.5 mm in a 1–10 Torr argon gas environment. Gas breakdown data for two dielectric resonators configurations are compared to the Raizer theory at 1.1 GHz and 6.5 GHz. Plasma modulation of the reflection and transmission of dielectric resonator arrays with plasma on and off indicates possible future applications as a frequency selective surface and particularly a plasma frequency selective surface. .Kumar has an excellent paper on plasma photonic crystals . Kumar has done very good research on plasma photonic crystals and did experiments to study the electromagnetic bands gaps (EBGs) of X band microwave through different configurations of triangle structure of MPC with and without plasma columns, and measured transmitted power of 18 GHz with electrodes (without plasma between electrodes) and with plasma between the electrodes. Kumar further showed by switching ON and OFF the plasma column, propagation of microwave in metallic photonic crystal can be controlled in such a way that positive and negative refraction can be achieved and concluded from the fact that plasma can be used to form tunable / controllable photonic crystals. A fully tunable plasma photonic crystal and plasma metamaterials can be used to control the propagation of free space electromagnetic waves and can be used in antenna technology. Light propagation in photonic crystals is the result of Bragg diffraction for each atom which is a result of the periodic structure of the photonic crystals.. Light waves in photonic crystals can be modeled as Bloch waves. An effective index of refraction including a negative index of refraction for the crystal is used to describe the overall reflectivity form the photonic crystal. A plasma photonic crystal can be an array of discharge plasma tubes which form a lattice structure with the individual plasma dielectric constant tuned through variation in the plasma density. Plasma photonic crystals can be used to tune and control microwave propagation. A schematic of a plasma photonic bandgap crystal can be found in which if the wavelengths of the EM waves are longer than the distances between the lattice points becomes a plasma metamaterial. Plasma photonic band gap crystals and plasma metamaterials are much more reconfigurable than photonic band gap crystals and metamaterials and offer much larger degrees of freedom and possibilities for antenna technology. Plasma metamaterial pass wavelengths longer than the lattice spacing in a plasma photonic bandgap. In the same way, metamaterials are used in antennas to form metamaterial antennas, plasma metamaterials can be used to form plasma metamaterial antennas. Kumar developed a schematic of a hybrid plasma photonic crystal if the wavelengths of the electromagnetic waves are on the order of the spacing between the lattice points. If the wavelengths of the EM waves are longer than the distances between the lattice points this is a schematic of a plasma hybrid metameterial. Figure 1 is schematics for EM waves passing through plasma bulk, plasma photonic bandgaps and plasma metamaterials, hybrid plasma photonic bandgap crystals and hybrid plasma metamaterials, and plasma photonic bandgaps and plasma metamaterials with plasma resonators. Plasma photonic bandgap crystal through simulations and experiments have shown that transverse electric mode bandgaps exist, arising from the positive and negative dielectric constant regimes of the plasma Wang et al. This showed that the respective bandgap frequencies shifted through changing the dielectric constant by varying discharge current density.



Figure 1. (a).A schematic of EM waves passing through a bulk plasma. (b). A schematic of EM waves passing through a plasma photonic bandgap crystal which If the wavelengths of the EM waves are longer than the distances between the lattice points becomes a plasma metamaterial. (c). A schematic of EM waves passing a hybrid plasma photonic crystal if the wavelengths of the electromagnetic waves are on the order of the spacing between the lattice points. If the wavelengths of the EM waves are longer than the distances between the lattice points this is a schematic of a plasma hybrid metamaterial. (d). ). A schematic of EM waves passing through a plasma photonic bandgap crystal with micro-plasma resonators which If the wavelengths of the EM waves are longer than the distances between the lattice points becomes a plasma metamaterial.Tan et al [21] by using finite-element methods, did research on the effect of plasma density on the photonic bandgap of 1-D plasma photonic crystals.. Below the cutoff frequency, the transverse electric (TE) mode bandgaps exist due to the surface modes such as the bandgaps in metallic photonic crystals. Above the cutoff frequency the positive permittivity bandgaps for TE mode such as the bandgaps in conventional photonic crystals are a consequence of the periodic distribution of dielectric constant in plasma and background medium. The bandgaps of the all plasma photonic crystals are strongly dependent on the plasma density.

**1.0 Description of Proposed Phase I Technical Effort**

We will design, develop, simulate and demonstrate an electrically small antenna using plasma metamaterials (plasma is a type of metamaterial) that can operate in a spacecraft.

**Advantages of Plasma Antennas and Plasma Frequency Selective Surfaces Radomes**

1. ***Plasma is lighter than metal.***
2. ***Plasma antennas and plasma FSS can steer and shape the antenna beam so that heavy phase shifters are not needed but plasma antennas and plasma FSS can be used with single antennas or AESA with phase shifters.***
3. ***Plasma FSS can steer the antenna beam 360 degrees in the azimuthal direction (achieved) and ideally steer 180 degrees in the vertical directions (although not achieved yet) giving full coverage. This is not possible with heavy metal frequency selective surface arrays.***
4. ***The smart plasma antenna and plasma frequency selective surface can reconfigure an antenna beam from single to multibeam in microseconds and to omnidirection in microseconds.***  ***We are trying to achieve nanosecond times.***
5. ***Smart plasma antennas and plasma frequency selective surfaces are much more compact than corresponding metal frequency selective surface arrays because plasma physics steers and shape the antenna beam.***

***Our publications on plasma frequency selective surfaces:***

***Journal article:* 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:**

**1.1 Technical Objectives**

We. will do research and development that will result in a compact, lightweight smart plasma metamaterial antenna that can operate inside and outside a spacecraft and that can work harmoniously with laser communications.. We will do modeling and simulation, and experimentation. As icing on the cake will do experiments of Vincent Laquerbe and Romain Pascaud of an electrically small high aperture monopole plasma antenna immersed in plasma. See section 1.3.13 and reference [2].

**1.2 Phase I Statement of Work**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **SOW** | | | | |
| **Task No.** | **Title** | **Description** | **Performer or Subcontractor** |
| 1 | Show beam steering of 360 degrees in the azimuthal direction and 180 degrees in the z (vertical) direction. | We will model and simulate the antenna properties of a plasma metamaterial antenna operating at 2MHz to FAR UV frequencies ( 222 nm). By modeling and simulations we will predict the resonance in a dipole plasma metamaterial antenna. |  |
| 2. | Reconfigurable beam width | Use the resonances to simulate the plasma metamaterial antenna aperture and compare with a metal antenna. By simulations, find the smallest size a` plasma metamaterial antenna can be and maintain large aperture.  INCORPORATE ARTIFICIAL INTELLIGENCE IF POSSIBLE. |  |
| 3. | Reconfigurable band width. | By experimentation determine the resonances and aperture in a plasma metamaterial antenna. Determine experimentally the smallest size a plasma metamaterial antenna can be and maintain large aperture. |  |
|  | Electromagnetic interference reduction | For the smallest size plasma metamaterial antenna with large aperture, we will find the best VSWR by simulations. We will minimize weight and volume and maximize gain by simulations. |  |
| 5. | Back and side lobe reduction | For the smallest size plasma metamaterial antenna with large aperture, we will find the best VSWR by experiments. We will minimize weight and volume and maximize gain by experiments. INCORPORATE ARTIFICIAL INTELLIGENCE IF POSSIBLE. |  |
| 6. | Ruggedization and corrosion resistance in a marine environment | Field testing. As icing on the cake, Haleakala R&D, Inc. will do experiments of Vincent Laquerbe and Romain Pascaud of an electrically small high aperture monopole plasma antenna immersed in plasma. See section 1.3.2 and reference [2]. Final report. |  |

**1.3 Related Work.**

**Our Previous Research of Establishing Aperture Enhancement while Antenna Size Decreases with Plasma Metamaterial Antennas. [1].**

**1.3.1 Plasma Resonances.**

Resonances were observed by Tonks in scattering electromagnetic waves off of a cylindrical column of plasma. Experiments on scattering off of cylindrical plasmas can give valuable information on the utility of plasma antennas and plasma FSS. Tonks studied plasma discharge cylindrical columns and performed experiments of scattering electromagnetic waves off of a plasma cylindrical column. A schematic of the basic physical interaction is given in Figure 4. The experimental setup of the Tonks experiment is given in Figure 5. An electromagnetic wave from a signal source is propagated into a waveguide with dimensions corresponding to a cutoff wavelength of 10 cm. A thermionic-arc discharge column is situated at right angles to the incident waveguide electric field. Two direction couplers sample the amplitude of the incident wave and the amplitude of the reflected wave. The experiment consists of measuring the ratio of the scattered power reflected by the plasma to the power incident on the plasma as a function of the density of the plasma. The discharge column is a thermionic-arc discharge in mercury vapor at a pressure (10^-3 Torr) such that the plasma electron density is proportional to the dc current in the discharge. The plasma is collisionless since the mean free path of plasma electrons is much greater than the diameter of the plasma columns. The wavelength of the incident wave is much greater than the radius of the plasma column so that the electric field in the vicinity of the plasma column is nearly irrotational and the electric field can be derived from a scalar potential. The electrical potential satisfies Laplace’s equation with no z variation, both inside and outside the plasma. The boundary conditions at a dielectric-vacuum interface are that the normal component of the displacement and tangential component of the electric field be continuous. These conditions are satisfied at the plasma-air boundary. Diagram of a diagram of a machine

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Figure 5. Experimental set up of the Tonk’s scattering experiment of electromagnetic waves off of a plasma cylindrical column.

A diagram of a waveform

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Figure 6. Amplitude of Scattered waves as a function of discharge current or plasma density. The peak resonance occurs at the plasma frequency divided by the square root of two. The square root of two factor comes in on the cylindrical geometry.

**1.3.2 Simulations and experiments of resonances in a plasma dipole antenna with a 100 MHz to 5 GHz sweep.** The plasma dipole antenna has a length of 7.5 cm and a diameter of .25 cm. There are two capacitive bands connecting the feeds to the plasma dipole antenna in the center. In a simulation, a frequency sweep was done on the plasma dipole antenna from 100 MHz to 5 GHz. The plasma has a density of 10^19m^-3. The resonances in the radiated powerare given are given in Figure 7 as well as a comparison to the same dipole antenna as a perfectly electric conductor (PEC). The resonance in the impedance is shown in[1]. An experiment was done by scattering electromagnetic waves off of a cylindrical plasma and sweeping from 100 MHz to 5 GHz. The results shown in [1] shows the results of this scattering experiment with major and minor resonances similar in form to the simulation [1].



Figure 7. Simulation with frequency sweep from 100 MHz to 5 GHz on the plasma dipole antenna with density 10^19^m-3 showing the radiated power. The background pressure of the plasma was 15mT and the electron temperature is 3 eV. This also shows the result of the PEC ( perfect electrical conductor) dipole of the same length.

**The numerical simulations in Fig 7 are compatible with the experimental results of Fig 6. This resonance peaks may indicate that the resonances in the plasma could lead to enhanced aperture. This means a plasma metamaterial antenna that is small compared to its geometric length, may have a large aperture by operating the plasma metamaterial antenna at the resonances as shown above. Notice the PEC ( perfectly conducting metal antenna) has no resonances as expected.**

**1.3.2 Electrically Small High Aperture Monopole Plasma Antennas by Immersing in Plasma.** Vincent Laquerbe and Romain Pascaud et al [2] have developed an innovative way to build antennas that are electrically small using plasma physics. The Vincent Laquerbe and Romain Pascaud team [2] were able to create a λ/9 monopole antenna as an equivalent to a λ/4 monopole antenna. The S11 for the electrically small antenna was very close to the S11 λ/4 . The hemispherical dome was filled with a mixed gas of 99% Neon and 1 % Xenon and was ionized The gas was ionized into a plasma by an RF spiral coil. The antenna was inside the dome and surrounded by plasma of 10 mT. The hemispherical dome was configured such that the relative permittivity is equal to -2. Under these conditions, a localized surface plasmon resonance was formed. When the plasma frequency is greater than the operating frequency, the collision frequency is much less than the operating frequency, and when the relative permittivity is equal to -2, the operating frequency will equal to the plasma frequency divided by the square root of 3. This is the same result that is obtained for the resonant peak in scattered waves from a sphere . For scattering of electromagnetic waves off of a cylinder the resonant peak occurs when the operating frequency equals the plasma frequency divided by the square root of 2.

A person in a white shirt

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**Smart plasma frequency surface radome before and after ruggedization.**

**Air Force Success Story for Haleakala R&D, Inc.**

A magazine with a white container

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A person in a white shirt

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**Relevant Publications** **by Dr. Theodore R Anderson (PI and CEO Haleakala R&D, Inc.)**

***Book***: **Theodore R. Anderson, Plasma Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House, ISBN: 9781630817503;** **chapter 18 on Plasma Metamaterial Antennas.**

 **Chapter 18 (both books) Plasma Metamaterial Antennas** 

**Second Edition, Dr. T Anderson First Edition, Dr. T. Anderson**

**PLASMA ANTENNAS PLASMA ANTENNA**

***Book:* Theodore R. Anderson** **, *Plasma Antennas*,** Artech House, ISBN 978-1-60807-143-2; 2011.

<http://www.artechhouse.com/Plasma-Antennas/b/2130.aspx>; **chapter 18 on Plasma Frequency Selective Surfaces.**

***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>

***Book Chapter*: Theodore R. Anderson, chapter 10; *Plasma Antennas*, *Frontiers in Antennas: Next Generation Design & Engineering,*, McGraw -Hill, Frank Gross editor. ISBN 0071637931 / 9780071637930**

***Journal article:* 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/**

***Book***: **Theodore R. Anderson, Plasma Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House, ISBN: 9781630817503; *Chapter 18, Plasma Metamaterial Antennas and Plasma Frequency Selective Surfaces.***

***Plasmas are metamaterials, Reference:*** *IOP PUBLISHING PLASMA SOURCES SCIENCE AND TECHNOLOGY*

*Plasma Sources Sci. Technol.* ***21*** *(2012) 013001 (18pp) doi:10.1088/0963-0252/21/1/013001*

***Plasmas as metamaterials: a review***

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*Received 10 June 2011, in final form 4 November 2011*

*Published 31 January 2012*

*Online at stacks.iop.org/PSST/21/013001*

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To verify and/or buy my PhD thesis go to: <http://disexpress.umi.com/dxweb> and type in: **TURBULENT WALL PRESSURE FLUCTUATIONS IN TERMS OF SPECTRAL DENSITIES CALCULATED FROM DISCRETE AND CONTINUOUS ORR-SOMMERFELD EIGENFUNCTIONS (ECKHAUS, TOLLMIEN-SCHLICTING)**  
by *Anderson, Theodore Robert*, **New York University**, 1986, 173 pages; You can also type in: UMI Publication Number  8706713

**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](http://www.haleakala-research.com)

***I AM CURRENTLY WORKING ON RAIN ACTIVATION AND ENHANCEMENT USING MY ATMOSPHERIC PLASMA ANTENNAS TO SOLVE THE WORLDWIDE DROUGHT PROBLEM. I HAVE WRITTEN A REPORT ON THIS TOPIC WHICH HAS BEEN PEER REVIEWED. I CAN PROVIDE THOSE.***

***I AM CURRENTLY WORKING ON A FAR-UVC TECHNOLOGY TO KILL COVID-19 AND OTHER VIRUSES WITHOUT HARMING HUMANS. I TREAT THE FAR-UVC DEVICE AS A PLASMA ANTENNA IN THE FAR-UVC SPECTRUM.***

**RECENT PATENTS:**

**Magnetic Resonance Imaging and Positron Emission Tomography Work.**

**Theodore Anderson, *MRI Device with Plasma Conductor***

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| : | |  |  | | --- | --- | | Appl. No.: | **15/531645** | | Filed: | **June 15, 2016** | | PCT Filed: | **June 15, 2016** | | PCT NO: | **PCT/US2016/037568**  **Allowed is US June 2019; filed internationally.** | |

**Theodore Anderson*, International Patent: Plasma elements for MRI/PET***

International Application Number PCT/US2016/037568, filed June 15, 2016;

<<https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2016205326>>.

16 out of 21 claims allowed at international patent office in Geneva, Switzerland.

**Theodore Anderson*, US Patent: Plasma elements for MRI/PET***

US Application Number 15/183,323,filed, June 15, 2016,

To see published application on the Internet, go to the PTO web site at <<http://appft1.uspto.gov/netahtml/PTO/srchnum.html>> and enter the Publication Number 2016/0370442 without the slash.

**RECENT PUBLICATIONS**

**Anderson, Theodore, "Antenna Beam Focusing and Steering with Refraction Through a Plasma", EuCAP 2019, presentation and conference symposium. March 2019.**

**Anderson, Theodore, "Magnetic Imaging Resolution and Positron Emission Tomography Using Plasma Antennas", EuCAP 2019, presentation and conference symposium. March 2019.**

**Books**

**The Second Edition of my book titled “Plasma Antennas”.**

**See:** [**https://us.artechhouse.com/Plasma-Antennas-Second-Edition-P2101.aspx**](https://us.artechhouse.com/Plasma-Antennas-Second-Edition-P2101.aspx)

**The Second Edition of my book titled “Plasma Antennas”:**



**Plasma Antennas, Second Edition,**

**Theodore Anderson, Copyright: 2020 Artech House,**

**ISBN: 9781630817503 My original book titled “Plasma Antennas”, Theodore Anderson, ISBN: ISBN 978-1-60807-143-2**

**Copyright 2011, Artech House**

**Book chapters on plasma antennas by Theodore Anderson.**

Theodore Anderson, ***Plasma Antennas,*** Open access peer-reviewed chapter, ***Selected Topics in Plasma Physics,*** Submitted: October 21st 2019Reviewed: March 2nd 2020Published: July 14th 2020, DOI:10.5772/intechopen.91944

Theodore R. Anderson, chapter 10; *Plasma Antennas*, *Frontiers in Antennas: Next Generation Design & Engineering,*, McGraw -Hill, Frank Gross editor. ISBN 0071637931 / 9780071637930

**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>

**Anderson, T., *An Overview of Experimental and Numerical Results on Plasma Antenna Arrays,* EuCAP Conference Proceedings, April 2015.**

**Anderson, T., *Numerical Investigation into the Performance of Two Reconfigurable Gaseous Plasma Antennas,* EuCAP Conference Proceedings, April 2014.**

**Anderson, T., *Plasma Antennas Co-site and Parasitic Antenna Interference Reduction Using Plasma Antennas,* AMTA Conference Proceedings, October 2013**

**Anderson, T., *Plasma Antennas: Theory, Measurements, and Prototypes****,* **AMTA Conference Proceedings, October 2013**

**Anderson, T., IEEE APS/URSI 2014 Paper #1547: *Theory, Measurements, and Prototypes of Plasma Antennas,* Conference Proceedings, July 2014.**

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

**Anderson, T., IEEE APS/URSI 2014 Paper #1538*: Plasma Antenna VSWR and Co-Site and Parasitic Interference Reduction or Elimination*, Conference Proceedings, July 2014.**

**Anderson, T., *Smart Plasma Antennas,* AMTA Conference Proceedings, October 2014, See:**

[**http://amta2014.org/**](http://amta2014.org/)

**Anderson, T., *Plasma Antennas: Plasma Satellite and Reflector Antennas****,* **AMTA Conference Proceedings, October 2014. See: http://amta2014.org/**

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

**Presented on plasma antennas at the Antenna Systems Conference in 2008, 2009, 2010, 2011, 2012, 2013, and will present in November 2014. See:**

[**http://www.antennasonline.com/conferences/program/conference-sessions/**](http://www.antennasonline.com/conferences/program/conference-sessions/)

**Recent Conferences with presentations and booths.**

1. **2019 IEEE APS/URSI Conference, Atlanta, Georgia July 7 to July 12, 2019.**

**Booth with prototypes:**

I will have booth displaying prototypes for my company Haleakala R&D of my plasma antenna technology at the 2019 IEEE APS Conference in Atlanta July 7 to July 12. See the link and scroll down to Booth 32

<https://www.2019apsursi.org/Exhibitors.asp>

1. **5 G Antenna Systems Conference September 26, 2019.**

**Presentation and publication:**

**Anderson, Theodore; *Antenna Beam Focusing & Steering with Refraction Through a Plasma with Corresponding Circuitry for the Advancement of 5G***

<https://antennasonline.com/conference-schedule>/

1. **IEEE International Symposium on Phased Array Systems and Technology, Waltham, Massachusetts October 15-18, 2019.**

**Presentations and publications:**

**Anderson, Theodore; *New Smart Plasma Antenna with Radiation Patterns and VSWR Measurements***

**Anderson, Theodore *Antenna Beam Focusing and Steering with Refraction Through a Plasma with Corresponding Circuitry***

**GOVERNMENT AND INDUSTRIAL EXPERIENCE**

***I received my PhD in physics from New York University in 1986. I taught at the University of Connecticut for 12 years and Rensselaer Polytechnic institute for 16 years. I worked on antennas at Naval undersea Warfare Center for 12 years, and I taught antennas and EMI at RPI for several years. I have done extensive antenna testing with network analyzers and Diamond Engineering equipment in various anechoic chambers. I have published more work and have more patents on the plasma antenna than anyone.***

**Haleakala Research and Development Inc. founder, CEO and president. 2002 to present**

**Exponent, Inc; Army Land Warrior Technical Supervisor and Coordinator. Exponent press release:**

**“Exponent, Inc. (Nasdaq: EXPO),** is pleased to announce the addition of **Dr. Theodore R. Anderson,** Senior Systems Engineer, to Exponent's Technology Development Practice. Dr. Anderson's focus will be on Exponent's Land Warrior project with the U.S. Army. Dr. Anderson has a strong technical background and a lengthy record of creativity in the areas of electronics design and analysis, particularly in antenna systems, which are critical to the successful development of a Land Warrior system. ***He will supervise the design, analysis, and testing of the electronic components of the Land Warrior system, and its future variants.”*** **2000-20002**

**Knolls Atomic Power Laboratory** May, 1999-December 2000

1. worked with the University of Michigan on finite element electromagnetic codes to solve frequency selective surface filtering. in the infrared spectrum.
2. I used the electromagnetics code called FSDA\_PRISM

**Naval Undersea Warfare Center**—New London, CT / Newport, RI 1988 – 1999

Electromagnetic compatibility, digital signal processing, antenna research and design. Fluid dynamics, flow noise, acoustics, and hydroacoustics.

1. Used ANSOFT, NEC, and various finite difference time domain codes, and project management for submarine electromagnetics
2. I program managed this work
3. Began to pioneer plasma antenna technology**.**
4. Pioneered flow noise and hydroacoustices work for towed arrays and SONAR domes. (see publications section).

**Electric Boat, General Dynamics, Groton, CT**. 1983 -1988

Worked in CFD, flow noise, hydrocaoustics, and acoustics.

**Gibbs and Hill Inc., NY, NY**  1980-1983

Worked on and designed commercial nuclear power plants.

**TEACHING AND UNIVERSITY POSITIONS.**

**Rensselaer Polytechnic Institute — Troy, NY.**

* I taught radar, antennas, and electromagnetic compatibility in the ECSE Dept. 1999-2015
* I taught at the Rensselaer Polytechnic Institute, Hartford, CT Branch. 1986- 1999.

**I taught mechanical and electrical engineering. I taught several antenna and EMC courses, several fluid dynamics courses including CFD.**

* **I taught in the RPI Navy Nuclear Program. I taught fusion, reactor physics, Monte Carlo Techniques, shielding, and radioactive waste. 1999-2015.**

**Plug Power.** I taught in house course at Plug Power in Electromagnetic Compatabilty. 2003.

**University of Tennessee, ECE Dept. Research professor. September 2003 to present time.**

**Union College—Schenectady, NY** 1999 – 2001

I taught mathematical methods for engineers and systems engineering

**University of Connecticut Mechanical engineering, Ocean Engineering, and EE Departments—Avery Point, CT** 1983 – 1995

Taught physical acoustics, underwater sound with signal processing, special topics in acoustics, acoustical oceanography, and mathematical methods for engineers, hydroacoustics, fluid dynamics and astronomy

**University of Bridgeport**—Bridgeport, CT 1990 – 1999

* I taught mechanical, aeronautical, and management engineering
* I taught project management, quality control, quantitative methods, heat transfer, gas turbines, turbomachinery

**Uniphase Telecommunications Products**—Bloomfield, CT 1997

1. I taught opto-electronics (on-site)

**University of New Haven**—New Haven, CT 1983 – 1988

1. I taught electrical and mechanical engineering

**Hunter College**—NYC, NY 1980 – 1983

1. I taught general physics and astronomy

**Cooper Union School of Engineering**—New York, NY. 1980

1. I taught electronic circuits

**OPTICS BACKGROUND.**

1. **I modeled the t-matrix for electron-atom scattering in a laser field.**
2. **I taught optoelectronics at RPI, Hartford, CT. I used texts:** 
   1. [**Principles of Quantum Electronics**](http://www.amazon.com/Principles-Quantum-Electronics-Dietrich-Marcuse/dp/0124710506/ref=la_B001HCX3RM_1_3?s=books&ie=UTF8&qid=1394590577&sr=1-3)**by Dietrich Marcuse (Jul 1980)**
   2. [**Optical Electronics in Modern Communications (Oxford Series in Electrical and Computer Engineering)**](http://www.amazon.com/Electronics-Communications-Electrical-Computer-Engineering/dp/0195106261/ref=la_B001IZPPMO_1_6?s=books&ie=UTF8&qid=1394590773&sr=1-6)**by Amnon Yariv (Mar 13, 1997).**
   3. [**Quantum Electronics**](http://www.amazon.com/Quantum-Electronics-Amnon-Yariv/dp/0471609978/ref=la_B001IZPPMO_1_1?s=books&ie=UTF8&qid=1394590773&sr=1-1)**by Amnon Yariv (Jan 17, 1989)**
3. **I taught fiber optics at RPI, Hartford, CT. I used texts:** 
   1. [**Theory of Dielectric Optical Waveguides (Quantum electronics--principles and applications)**](http://www.amazon.com/Dielectric-Optical-Waveguides-electronics--principles-applications/dp/0124709508/ref=la_B001HCX3RM_1_2?s=books&ie=UTF8&qid=1394586889&sr=1-2)**by Dietrich Marcuse (Apr 10, 1974).**
   2. [**Light Transmission Optics (Van Nostrand Reinhold electrical/computer science and engineering series)**](http://www.amazon.com/Transmission-Nostrand-Reinhold-electrical-engineering/dp/0442263090/ref=la_B001HCX3RM_1_1?s=books&ie=UTF8&qid=1394586889&sr=1-1) by Dietrich Marcuse (Aug 1982**).**
   3. [**Principles of Optical Fiber Measurements**](http://www.amazon.com/Principles-Optical-Measurements-Dietrich-Marcuse/dp/0124315674/ref=la_B001HCX3RM_1_4?s=books&ie=UTF8&qid=1394586889&sr=1-4)**by Dietrich Marcuse (Jul 28, 1981).**
   4. [**Fiber-Optic Communication Systems (Wiley Series in Microwave and Optical Engineering)**](http://www.amazon.com/Fiber-Optic-Communication-Systems-Microwave-Engineering/dp/0470505117/ref=sr_1_8?s=books&ie=UTF8&qid=1394591271&sr=1-8&keywords=Fiber+optics)**by**[**Govind P. Agrawal**](http://www.amazon.com/Govind-P.-Agrawal/e/B000AQ1T6I/ref=sr_ntt_srch_lnk_8?qid=1394591271&sr=1-8)**(Oct 19, 2010)**

1. **I taught courses on lasers at RPI, Hartford, CT.** 
   1. [**Laser Fundamentals**](http://www.amazon.com/Laser-Fundamentals-William-T-Silfvast/dp/0521833450/ref=sr_1_31?s=books&ie=UTF8&qid=1394592650&sr=1-31&keywords=Lasers)**by William T. Silfvast (Jan 12, 2004)**
   2. [**Laser Physics**](http://www.amazon.com/Laser-Physics-Murray-Sargent-III/dp/0201069032/ref=sr_1_8?s=books&ie=UTF8&qid=1394593262&sr=1-8&keywords=Lasers)**by Murray Sargent III,**[**Marlan O. Scully**](http://www.amazon.com/Marlan-O.-Scully/e/B001IXNU46/ref=sr_ntt_srch_lnk_8?qid=1394593262&sr=1-8)**and Willis E. Jr." Lamb (Jan 22, 1978)**

**EDUCATION**

PhD, Physics, New York University, New York, NY

(electrodynamics, opto-electronics, atomic physics and fluid dynamics) 1986

MS, Applied Science, New York University 1983

MS, Physics, New York University 1979

Studied engineering at Columbia University, New York City, 1979-1981

Studied Mathematical Physics at the Department de Physique Theorique, Universite de

Geneve, Geneva, Switzerland.

**PATENTS BY DR. TED ANDERSON**

**ISSUED PATENTS (Several of my patents have appeared in the Antennas and Propagation Magazine. )**

|  |  |  |  |
| --- | --- | --- | --- |
| 1 | 6,710,746 |  | Antenna having reconfigurable length |
| 2 | 6,700,544 |  | Near-field plasma reader |
| 3 | 6,674,970 |  | Plasma antenna with two-fluid ionization current |
| 4 | 6,657,594 |  | Plasma antenna system and method |
| 5 | 6,650,297 |  | Laser driven plasma antenna utilizing laser modified maxwellian relaxation |
| 6 | 6,624,719 |  | Reconfigurable electromagnetic waveguide |
| 7 | 6,512,496 |  | Expandible antenna |
| 8 | 6,369,763 |  | Reconfigurable plasma antenna |
| 9 | 6,169,520 |  | Plasma antenna with currents generated by opposed photon beams |
| 10 | 6,118,407 |  | Horizontal plasma antenna using plasma drift currents |
| 11 | 6,087,993 |  | Plasma antenna with electro-optical modulator |
| 12 | 6,087,992 |  | Acoustically driven plasma antenna |
| 13 | 6,046,705 |  | Standing wave plasma antenna with plasma reflector |
| 14 | 5,963,169 |  | Multiple tube plasma antenna |

15. 6,876,330 Reconfigurable antennas

16. 6,870,517 Configurable arrays for steerable antennas and wireless network incorporating the steerable antennas

17. 6,842,146 Plasma filter antenna system

18. [7,342,549](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=5&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22). Configurable arrays for steerable antennas and wireless network incorporating the steerable antennas.

19. [6,922,173](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=34&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22). Reconfigurable scanner and RFID system using the scanner

20. [6,700,544](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=2&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=57&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22). [Near-field plasma reader](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=2&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=57&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22)

21. [6,870,517](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=41&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22). [Configurable arrays for steerable antennas and wireless network incorporating the steerable antennas](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=41&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22)

22.. [7,292,191](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=10&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22). [Tunable plasma frequency devices](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=10&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22)

23. [7,453,403](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=5&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+antenna%22&s2=%22plasma+antennas%22&OS=%22plasma+antenna%22+OR+%22plasma+antennas%22&RS=%22plasma+antenna%22+OR+%22plasma+antennas%22). Tunable plasma frequency devices.

24. 8,077,094 Plasma device with low thermal noise

Recently Issued patents.

1.Reconfigurable scanner and RFID. Patent number RE43,699.

2. Plasma Devices for Steering and Focusing Antenna Beams; U.S. Patent Issue Number: 8,384,602

.

**Issued plasma waveguide patents.**

|  |  |  |  |
| --- | --- | --- | --- |
| 1. | [6,812,895](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=6&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+waveguide%22&s2=%22plasma+waveguides%22&OS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22&RS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22) |  | [Reconfigurable electromagnetic plasma waveguide used as a phase shifter and a horn antenna](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=6&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+waveguide%22&s2=%22plasma+waveguides%22&OS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22&RS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22) |
| 2. | 6[,624,719](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=7&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+waveguide%22&s2=%22plasma+waveguides%22&OS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22&RS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22) |  | [Reconfigurable electromagnetic waveguide](http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=7&f=G&l=50&co1=OR&d=PTXT&s1=%22plasma+waveguide%22&s2=%22plasma+waveguides%22&OS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22&RS=%22plasma+waveguide%22+OR+%22plasma+waveguides%22) |

**Non-plasma physics patents.**

1. Method And Apparatus For Detecting Misaligned Railroad Tracks, filed 4/11/01, serial number 09/832,087

1. Passive Magnetic Field Sensor Using The Barkhausen Effect To Measure Velocity (Angular Or Linear) Of A Moving Body-filed 4/11/00 serial number 09/548387
2. Portable And Lightweight Ramp Structure, issued 3/4/03, US Patent number 6526614

Take note: I presented my smart plasma antenna at the “Booz Allen Hamilton Technology Petting Zoo” in 2007. See: https://www.pressreader.com/usa/the-washington-post/20071224/282415574952689

My point of contact “Booz Allen Technology Petting Zoo” at Booz Allen Hamilton in Mclean, VA was William Barnett.

**PUBLICATIONS (Partial List)**

1. Anderson, T., Perturbation Model for EMC Sources in the Near Field and Shielded by a Ferromagnetic Material, August, 1997. IEEE EMC Society, Catalog Number 97CH36113. Presented at the International Symposium on Electromagnetic Compatibility, August 1997, Austin, TX.
2. Anderson, T., Iterative Model for EMC Sources in the Near Field and Shielded by Composite Materials, August 1997. IEEE EMC Society, Catalog Number 97CH36113. Presented at the International Symposium on Electromagnetic Compatibility, August 1997, Austin, TX.
3. Anderson, T., and Choo V., The Development of a Large Three-Axis Magnetic Field Susceptibility Test (L-TAMFEST), August 1997. IEEE EMC Society, Catalog Number 97CH36113. Presented at the International Symposium on Electromagnetic Compatibility, August 1997, Austin, TX.
4. Anderson, T., Model for Near Field Electromagnetic Shielding by Cylindrical Shells of Composite Materials, NUWC-NPT Technical Report 10,634, 16 October 1996.
5. Anderson, T., Models for the Near Field Interaction of a Magnetic Field Interaction of a Magnetic Field from Point Sources Representing Transformers and Power Supplies and a Ferromagnetic Cylindrical Shell. IEEE EMC Society. Presented at the Santa Clara Convention Center, August 21, 1996.
6. Anderson, T., The Use of Vector Fields to Model the Physical Blockage from Power Supply, Cable, and Transformer Sources. NUWC-NPT Technical Report 11,091, 18 March 1996.
7. Anderson, T., Turbulent Wall Pressure and Wall Shear Fluctuations Calculated from the Orr-Sommerfeld Equation with Nonlinear Forcing Terms. American Institute of Physics, “Chaotic, Fractal, Nonlinear Signal Processing,” AIP Press, Proceedings Number 375, ISBN Number 1-56396-443-0. Presented at the Third Technical Conference on Nonlinear Dynamics (Chaos) and Full Spectrum Processing, July 1995.
8. Anderson, T., Model for Washover of a Buoyant Cylindrical Antenna Towed in Calm and Various Sea States, NUWC-NPT Technical Report 10,753, 23 September 1994.
9. Anderson, T., Wavenumber—Frequency Spectral Densities of Turbulent Wall Pressure Fluctuations, NUWC-NPT Technical Report 10,135, 11 June 1993.
10. Anderson, T., Properties of Continuous Orr-Sommerfeld Waves in a Turbulent Boundary Layer, Bulletin of the American Physical Society, Volume 36, No. 10, November 1991.
11. Anderson, T., Wavenumber—Frequency Spectral Densities of Turbulent Wall Pressure and Wall Shear Fluctuations, Bulletin of the American Physical Society, Volume 35, No. 10, November 1990.
12. Anderson, T., Wavenumber—Frequency Spectral Densities of Turbulent Wall Pressure and Wall Shear Fluctuations, International Union of Theoretical and Applied Mechanics, “Structure of Turbulence and Drag Reduction,” A. Gyr (editor), Springer-Verlag ISBN 3-540-50204-1 and ISBN 0-387-50204-1, July 1989.
13. Anderson, T., Wavenumber—Frequency Spectral Densities of Turbulent Wall Pressure Fluctuations, American Society of Mechanical Engineers, Volume 6, “Acoustical Phenomena and Interaction in Shear Flows over Compliant and Vibrating Surfaces,” 1988.
14. Anderson, T., Time Domain Modeling and Experimental Verification of the Barkhausen Effect used as a Magnetic Field Sensor. Published and presented at the IEEE EMC Society Meeting, August 1998.
15. Anderson, T., and Javor, E., The Design and Modeling of a Large Helmholtz Coil for Low Frequency Magnetic Field Susceptibility Testing. Published and presented at the IEEE EMC Society Meeting, August 1998.
16. Anderson, T., and Derewainy, C., Electrostatics Discharge Sensitive (ESDS) Equipment Susceptibility to Welding Generated Electromagnetic Fields. Published and presented at the IEEE EMC Society Meeting, August 1998.
17. Anderson, T., Development of a Large Three-Axis DC Magnetic Field Susceptibility Test System, ITEM, the International Journal of EMC, 1998.
18. Anderson, T., ELF Plasma Antenna, NUWC Technical Report Number 10,892, May 1998.
19. Anderson, T., Theory, Design, and Submarine Applications of a Plasma Antenna, NUWC Technical Report Number 10,832, May 1998.
20. Anderson, T., Optimal Design of Helmhotz Coils using Variational Principles. Published and presented at the IEEE EMC Society Meeting, August 1999.
21. Anderson, T., Control of Electromagnetic Interference from Arc and Electron Beam Welding by Controlling the Physical Parameters in Arc or Electron Beam: Theoretical Model, 2000 IEEE Symposium Record, Volume 2, pages 695-698, ISBN 0-7803-5677-2
22. Anderson, T, and James Raynolds, Frequency Selective Surfaces Used as Infrared Filters, APS meeting, March 2001
23. Anderson, T, and James Raynolds, Losses in Frequency Selective Surfaces, APS meeting, March 2001
24. Anderson, T., Alexeff, I., Reconfigurable Plasma Frequency Selective Surfaces,

Submitted to IEEE Transactions on Plasma Science

1. Anderson, T. Antenna Intensity Patterns Through open Plasma Windows,

Submitted to IEEE Transactions on Antennas and Propagation

1. Anderson, T, and Alexeff, I., Theory and Experiments of Plasma Antenna Radiation Emitted Through Plasma Apertures or Windows with Suppressed Back and Side Lobes, International Conference on Plasma Science 2002
2. Anderson, T, and Alexeff, I., Storage And Release Of Electromagnetic Waves by Plasma Antennas and Waveguides, 33rd AIAA Plasmadynamics and Lasers Conference 2002
3. Anderson, T. and Alexeff, I., Plasma Frequency Selective Surfaces, International Conference on Plasma Science 2003
4. Anderson, T., Alexeff, I., Reconfigurable Plasma Frequency Selective Surfaces,

Submitted to IEEE Transactions on Plasma Science

1. Anderson, T. Antenna Intensity Patterns Through open Plasma Windows,

Submitted to IEEE Transactions on Antennas and Propagation

1. Anderson, T. Plasma Frequency Selective Surfaces, 2003 IEEE International Conference on Plasma Science, published in the IEEE Conference Record, IEEE catalog number 03CH37470
2. Anderson, T. , Alexeff, Igor. Theory of Plasma Windowing Antennas, IEEE ICOPS, Baltimore, June 2004
3. Anderson T, Alexeff T, Adavnces in Plasma Antenna Design, in IEEE Int Conf. Plasma Sci., Monterey, CA, Jine 20-23, 2005
4. Anderson, Alexeff, Plasma Antennas I , presented at the SMi 8th annual Stealth Conference, London March 15-16, 2004
5. Anderson, Alexeff, Plasma Antennas II , presented at the SMi 9th annual Stealth Conference, London April 11 -12, 2005
6. Anderson, Alexeff, Plasma Antennas III , presented at the SMi 10th annual Stealth Conference, London April, 2006
7. Anderson, T, Alexeff, I , Plasma Antennas-New Developments, , in IEEE Int Conf. Plasma Sci., Traverse City, Michigan, June, 2006
8. Anderson, T., Alexeff, I., Experimental and Theoretical Results with Plasma Antennas, IEEE Transactions on Plasma Science,. Vol. 34 No. 2, April 2006
9. Anderson, T., Alexeff I., Plasma Frequency selective Surfaces, IEEE Transactions on Plasma Science, Vol. 35, no. 2, p. 407, April 2007.
10. Alexeff I., Anderson, T., Recent results for Plasma antennas, Physics of Plasmas, 15, 057104, (2008)
11. Anderson, T., Alexeff I. Plasma Antenna Windowing: Theoretical and experimental Analysis, IEEE Transactions on Plasma Science, being processed for publication.
12. Anderson, Theodore, "Antenna Beam Focusing and Steering with Refraction Through a Plasma", EuCAP 2019, presentation and conference symposium. March 2019.
13. Anderson, Theodore, "Magnetic Imaging Resolution and Positron Emission Tomography Using Plasma Antennas", EuCAP 2019, presentation and conference symposium. March 2019.

**Books**



**Plasma Antennas, Second Edition**

**By (author):** [Theodore Anderson](https://us.artechhouse.com/cw_contributorinfo.aspx?ContribID=32&Name=Theodore+Anderson)

Copyright: 2020  
Pages: 350  
ISBN: 9781630817503

**The Second Edition of my book titled “Plasma Antennas”.**

**See: https://us.artechhouse.com/Plasma-Antennas-Second-Edition-P2101.aspx**

Theodore R. Anderson , *Plasma Antennas*, Artech House, ISBN 978-1-60807-143-2; 2011.

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

**http://www.amazon.com/Plasma-Antennas-Theodore-Anderson/dp/160807143X/ref=sr\_1\_1?s=books&ie=UTF8&qid=1313592208&sr=1-1**

**http://www.barnesandnoble.com/w/plasma-antennas-theodore-anderson/1100484810?ean=9781608071432&itm=2&usri=plasma%2bantennas#CustomerReviews**



**Plasma Antennas**

**Theodore Anderson, Haleakala Research and Development, Inc.**

**ISBN 978-1-60807-143-2**

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**Book Chapters**

*Frontiers in Antennas: Next Generation Design & Engineering,* chapter 10; Plasma Antennas, Theodore R. Anderson, McGraw -Hill, Frank Gross editor. ISBN 0071637931 / 9780071637930

Theodore Anderson, ***Plasma Antennas,*** Open access peer-reviewed chapter, ***Selected Topics in Plasma Physics,*** Submitted: October 21st 2019Reviewed: March 2nd 2020Published: July 14th 2020, DOI:10.5772/intechopen.91944

**HOBBIES**

Theater enthusiast, amateur playwright, national park buff.. I was a power lifting champion.. I have set several state records in Connecticut in power lifting between 1985 and 1997. I continue to do powerlifting and bodybuilding.

**References:**

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**More references on request.**

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**3.0 Commercialization**

The technology would be helpful for situations where SATCOM is too expensive, not viable (e.g., Polar Regions or deep valleys), and if the SATCOM hardware is too large. Commercial Technology Overview: *Target Markets* 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 my atmospheric plasma antennas to activate and enhance rain to solve the devastating droughts.

**4.0 Facilities/Equipment.**

Haleakala Research and Development, INC has a plasma antennas lab for experimentation and prototyping. 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, and general purpose microwave test equipment.

**5.0 Letters of Support.**

**References:**

**[1]. Theodore R. Anderson, Plasma Antennas, Second Edition, Theodore Anderson, Copyright: 2020 Artech House, ISBN: 9781630817503; chapter 18 on Plasma Metamaterial Antennas.**

**[2]. Vincent Laquerbe, Romain Pascaud, Thierry Callegari, Laurent Liard, Olivier Pascal; *Towards Antenna Miniaturization Using Plasma;* 13th European Conference on Antennas and Propagation (EuCAP 2019).**