High Gain Compact Plasma Antenna

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Proprietary Information

The Goal is to Build a Plasma Antenna with the Following Properties:

- Bandwidth: 25-27 GHz
- Radiation Power: 50W
- Gain: >25 dBi
- Size: ca. 200-300 mm x 200-300mm x 200-300mm

- We can achieve all these parameters except we have to modify our smart plasma antenna to have a Gain > 25 dBi. The highest gain we have for the smart plasma antenna is 19 dBi at 2.4 GHz.

What Needs to be Done to Increase the Gain to > 25 dBi.

- **Increase the density of the plasma in the ring of plasma tubes.**
- **Replace the plasma tubes with an annular ring of plasma to eliminate zero plasma where the tubes touch.**
- **Find the optimal radius by using radiation intensity vs radius such as seen in Figures 6.6 and 6.9 in Theodore Anderson, “Plasma Antennas second edition”, Artech House, 2020.**
- **Eliminate radiation leakage along the axis or z direction.**
- **Increase the frequency.**
- **Improve the effects of refraction including focusing and steering.**
- We can achieve this with modifications and improvements of our smart plasma antenna.

Goals For Improving the Smart Plasma Antenna

- Currently we can build a plasma antenna with bandwidth: 25-27 GHz, radiation power of 50 W, and size of 200-300 mm x 200-300mm x 200-300mm.
- We need to modify our smart plasma antenna to get a gain >25 dBi.

Recent Improvements on Original Smart Plasma Antenna to get the Gain to 19 dBi at 2.45 GHz.

Recent Improvements on Original Smart Plasma Antenna to get the Gain to 19 dBi at 2.45 GHz.

- Our initial work concentrated on eliminating issues that have caused our Smart Plasma Antenna to have less than optimal performance. The basic design and concept have not been changed.
- The plasma density has been increased by an order of magnitude by having a much higher peak current inside the tube. Average power dissipation remains low and there is very little heat generated.
- A small gap (~0.1 in.) between each tube has been closed by placing adjacent tubes in direct contact with each other.
- A new prototype was built using nine plasma tubes placed in a circle.
- A Zigbee 2.45 GHz transmitter with a ½ wave dipole is placed inside the circle of plasma tubes.

Improvements on our Original Smart Plasma Antenna

- Another ½ wave dipole (for receiving) is placed ~ 3 ft from the side of the antenna and connected to a B&K Precision 3 GHz spectrum analyzer.
- Our experiments consisted of a smart plasma antenna transmitting to a receiving dipole connected to a spectrum analyzer.
- Higher pulse current was achieved by pulsing with a higher peak voltage (3000 V) and higher peak current 20 A compared to our original Smart Antenna. This original Smart Antenna has a peak current of 1 A and peak voltage of 800 V.

Recent Improvements on Original Smart Plasma Antenna

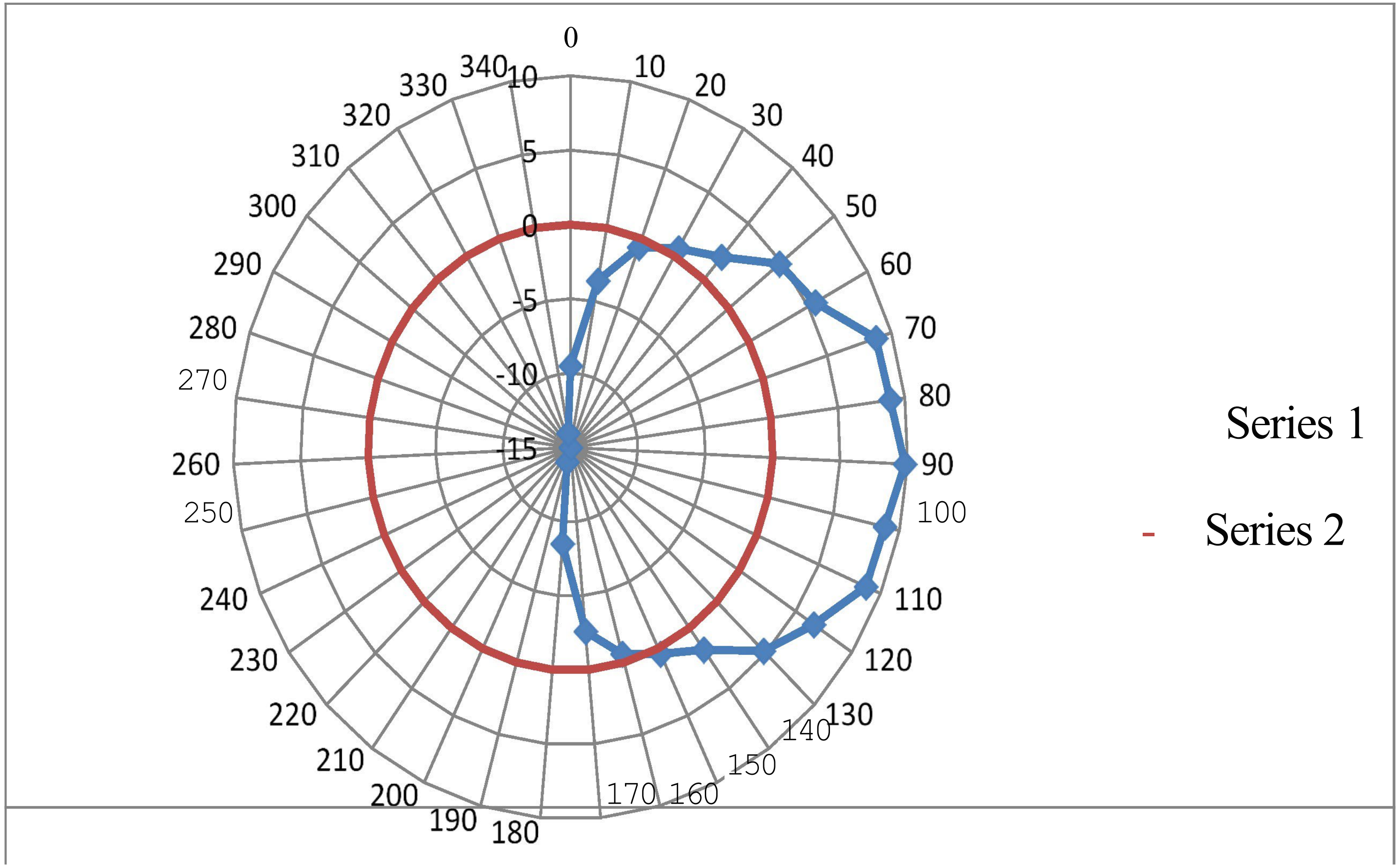
- Replaced Zigbee transmitter with video transmitter for higher power and narrower bandwitdth.
- The transmitter in the center of the smart antenna was a Zigbee 2.4 GHz with attached ½ wave dipole.
- This Zigbee transmitter is not the best device for our application:
  - It has low output power (for short range communication) and frequency-hops over a 2 MHz band; similar to WiFi devices. The low power and frequency shifting from the Zigbee transmitter limits our ability to accurately measure received power at the spectrum analyzer.

Recent Improvements on Original Smart Plasma Antenna

- We used a higher power transmitter for video applications with a higher power of about 700 mW.
  - It is compact, battery operated and will fit easily into the center of the smart plasma antenna. This change allowed us to have better measurements for testing the radiation pattern.
- The dipole at the center of the array of plasma tubes was attached to an RF connector, enabling the antenna to be connected to a signal generator or spectrum analyzer.
- Therefore the antenna can be used as either a transmitter or receiver. Currently a 2.4 GHz transmitter is mounted inside the antenna along with the dipole.

Recent Improvements on Original Smart Plasma Antenna

- In the next slide we show the results of these improvements.
- However, the radius is not optimized.
- There is leakage along the axis of the smart plasma antenna.
- There is leakage where the tubes touch since there is no plasma at these points.



Radiation Pattern {2.1 GHz). Unity gain is shown in red.

Recent Improvements on Original Smart Plasma Antenna

Conclusions

- We improved the results for by closing the gaps between the tubes and increasing the plasma density.
- As a result, the gain improved but by doing this we had to decrease the radius of the smart plasma antenna so that was no longer optimized.
- The only way to optimize all the parameters simultaneously is to use custom made plasma tubes for this purpose.
- Further optimizing can be done by using annular rings of plasma rather than tubes so that the plasma density in the cylindrical annular ring is uniform.
- Where the tubes touch, the plasma density and thickness is negligible and increases at the axes of the tubes.
- We redesigned the smart plasma antenna and developing new electronics and controls to increase the plasma density.

Improvements on Original Smart Plasma Antenna Conclusions continued

- The pulsed DC power supplies are being packaged more ruggedly and mounted at the base of the plasma tubes. Shorter wire connections between the power supplies and tubes are resulting in less stray capacitance and faster rise and fall times.

Alternative Smart Plasma Design

- We also determined that we could make the smart plasma much smaller by building a 4 beam smart plasma antenna with 4 plasma windows at right angles and creating a single or multibeam plasma antenna by switching the plasma windows on or off.
- This also allows us to use horizontal tubes with vertical tubes superimposed on the horizontal tubes. This would enable transmission and reception of vertical, horizontal, and circular polarizations.

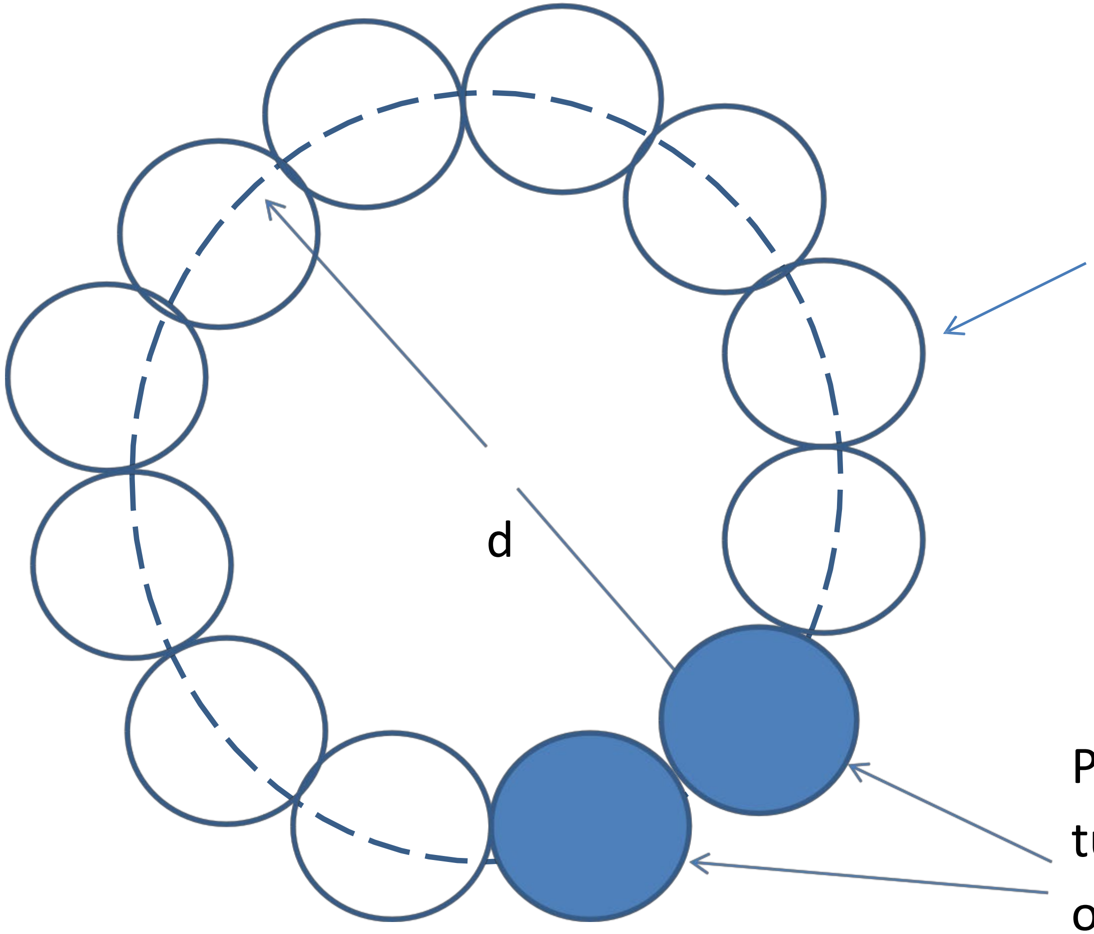
Current Gain of our Smart Plasma Antenna

Current Gain Of Our Smart Plasma Antenna 19 dBi

- We tested a 2.4 GHz co-linear dipole antenna (TP-Link) that has a gain of 8 dBi.
- We confirmed this advertised gain by testing the TP-Link antenna using a standard 2.1 dBi dipole antenna.
- We have replaced the metal antenna in the center of our smart antenna with the high gain col-linear dipole; and then performed gain and radiation pattern measurements for the smart antenna.
- Results are encouraging with a measured gain of 13 dBi and a front to back radiation ratio of 20 dB.
- Plasma lens focusing can increase the gain from 3 to 6 dBi for a total of 16dBi to 19dBi just short of our goal of getting 20 dBi .
- We still have a mismatch in the resonance of the TP Link dipole antenna and the smart plasma antenna. The gain will increase when this match is achieved.
- We have very good gain with a very compact steerable antenna.

Current Gain of our Smart Plasma Antenna at 19 dBi

Antennas used in current testing. A standard 2.15 dBi 1/2 wave dipole is at the bottom of the photo. The other two antennas show the TP Link 8 dBi collinear dipole. At the top is the TP Link antenna with plastic jacket removed
to show construction Dr. Ted Anderson; Haleakala R&D; Proprietary



Plasma
tubes turned
on.

Plasma
tubes turned
off.
(Aperture)

Circular cavity using plasma tubes. d is the diameter used for resonant frequency calculations.

Current Gain of our Smart Plasma Antenna is 19 dBi

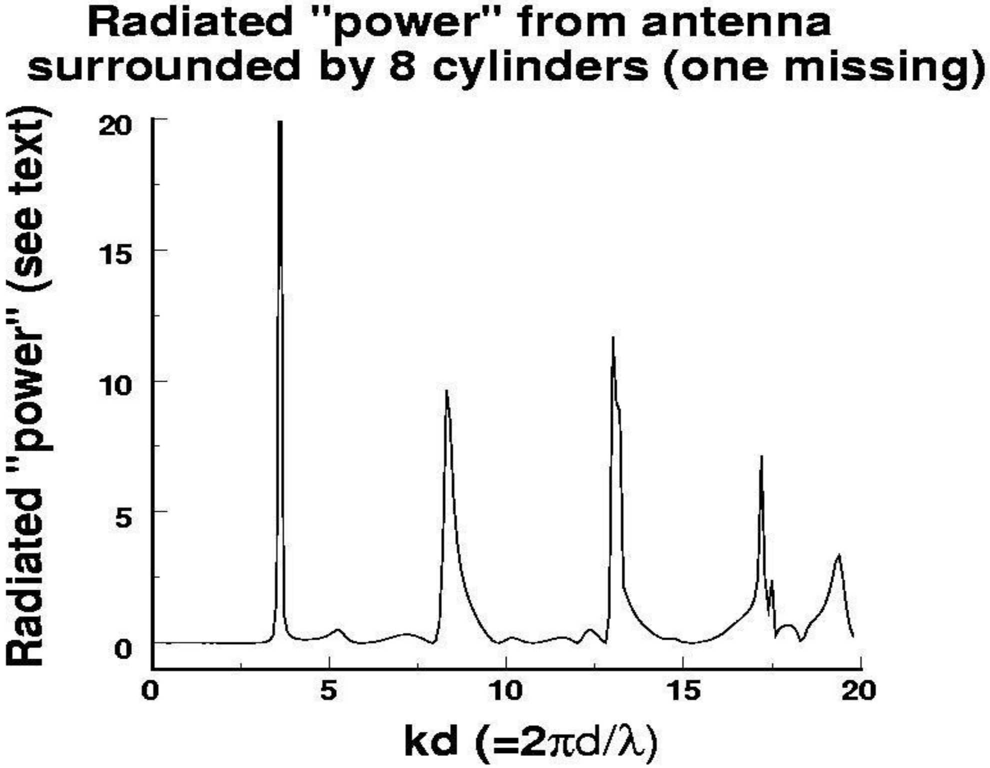


Figure 1. Plot of the radiated flux in the far field. This quantity is obtained by integrating the Poynting vector over a cylindrical surface of in the far field.

Current Gain of our Smart Plasma Antenna is 19 dBi

- We calculated, the anticipated resonant frequencies of the circular cavity created by the circular array of tubes.

- The second peak (kd= 8) appears to be the most useful for our new smart antenna.
  The circular cavity resonance corresponding to kd = 8 is:

  $\lambda = 2\pi d / k$ where d = diameter of cavity

  $\lambda = 2\pi\ 15\text{cm} / 8$ $\lambda = 11.7\text{cm}$

  and f = 2.56 GHz

- The cavity diameter, d, used in this calculation is assumed to be the circle through the centerline of each fluorescent tube.

- Use first resonance (kd=3) for smart plasma antenna to decrease size.

Current Gain of our Smart Plasma Antenna is 19 dBi.

- We did a network analyzer plot (HP 8753C) of VSWR vs. Frequency for the TP-link antenna, which shows a VSWR of less than 1.25 : 1 from 2.4 GHz to 2.6 GHz.
- Next we calculated the anticipated resonant frequencies of the circular cavity created by the circular array of plasma tubes.
- The second peak (kd= 8) appears to be the most useful for our new smart antenna. The circular cavity resonance corresponding to kd = 8 is:

Current Gain of our Smart Plasma Antenna is 19 dBi

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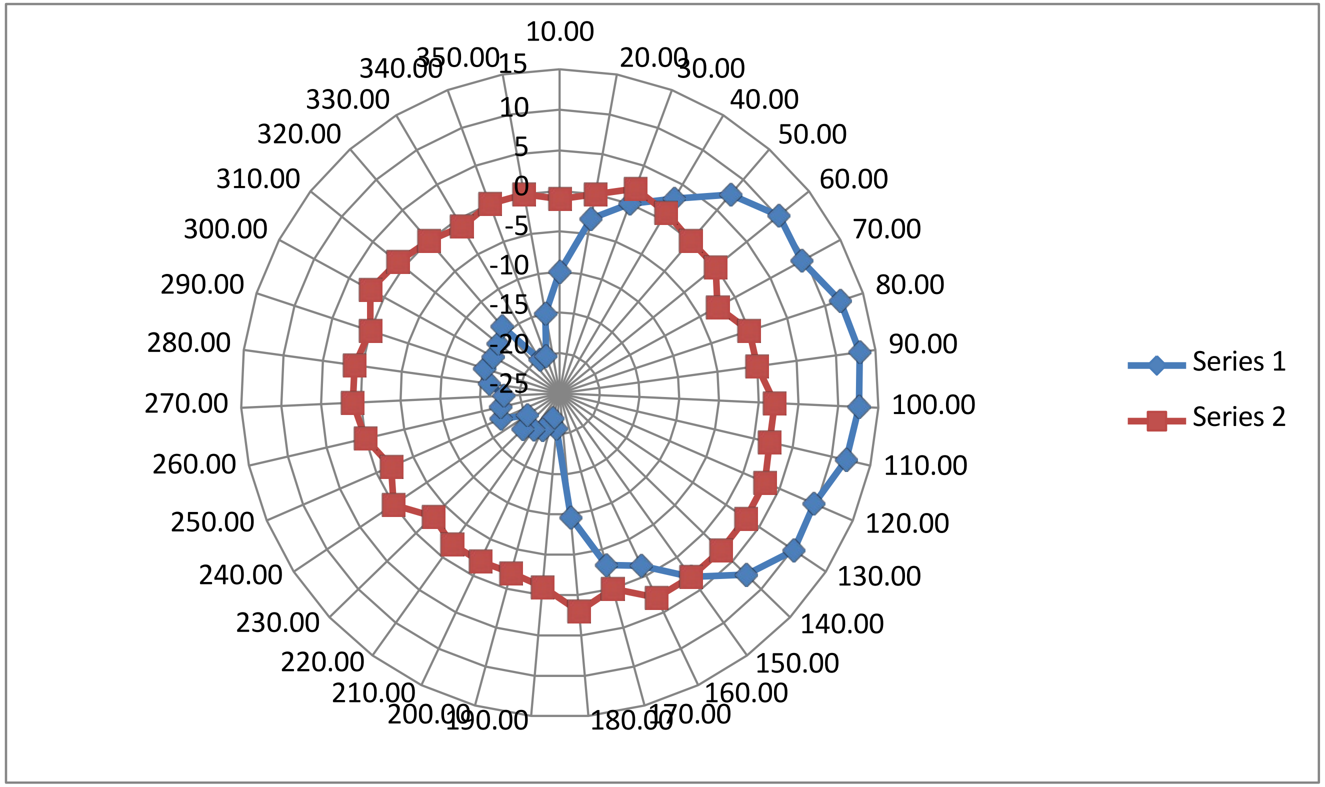

Figure 4. Radiation pattern for Smart Plasma Antenna with D-Link co-linear dipole in center. Signal levels in dBi.

Series 1 (Blue): Radiation pattern with D-Link antenna at center (dBi). D-Link antenna has gain of 8dBi.

Series 2 (Red): Zero dBi reference.

Current Gain of our Smart Plasma Antenna is 19 dBi

In summary:

- Cavity resonant frequency for maximum gain has been calculated and experimentally confirmed.
- A high gain co-linear dipole has been used as the center metal antenna to achieve a forward gain of 13 dBi which is comparable to many commercially available antennas at 2.4 GHz. Another 3 to 6 dBi is achieved using plasma lens focusing for a total of 16 dBi to 19 dBi. This is a very good gain for an antenna which is smart, steerable and compact.
- A simple field strength meter has been built to allow faster antenna setup and checkout.
- We used Ted Anderson theory for multiple resonances in the smart plasma antenna.

Current Gain of our Smart Plasma Antenna is 19 dBi
Field Strength Meter we Built for These Applications

- For measurements of radiated power we have been using a receiving antenna connected to a spectrum analyzer; however a simple Field Strength Meter is easier to use for quick measurements and to check that individual plasma tubes are functioning properly.
- These Field Strength Meters are readily commercially available for the VHF and UHF bands, but we have not found a reasonably priced analog meter for 2.4 GHz.
- We therefore built our own meter shown.
  - The block diagram is shown. A 2.4 GHz receives the transmitted signal and is detected by an HP 423 Crystal Diode.
    - The DC voltage from the crystal detector is amplified and displayed on a large analog meter.
    - This meter has made day to day measurements easier and faster

Antenna Beam Focusing and Steering with Refraction Through a Plasma to Increase Gain. With Hypersonic Applications

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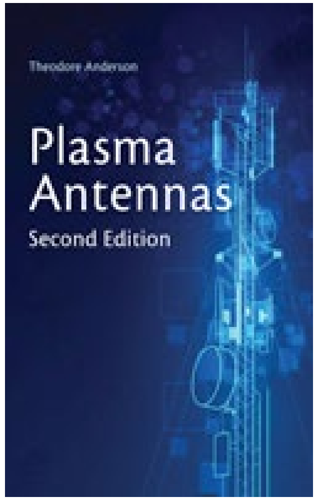
CEO Haleakala R&D, Inc

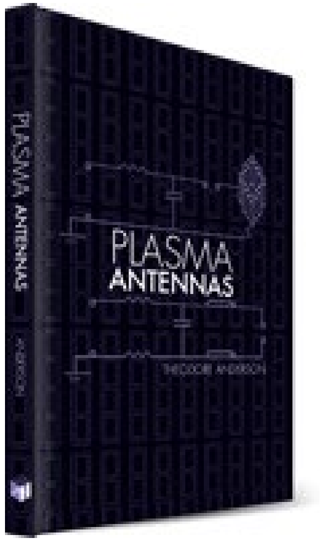
Proprietary Information

Two Plasma Antenna Books Authored by Dr. Ted Anderson

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

Reconfigurable Beam Lensing (beam focusing and spreading) and Reconfigurable Steering with Refraction through a Plasma

Basic Physics of the Conditions of Refraction in the Plasma

- The phase speed of electromagnetic waves in a plasma is given by:

$$v_p = \frac{c}{\sqrt{1 - \omega_p^2/\omega^2}},$$

- Where the plasma frequency is given by:

$$\omega_p = \sqrt{\frac{n_e\, e^2}{\epsilon_0\, m_e}}$$

- In this paper we are experimenting in the region where the antenna frequency is greater than the plasma frequency:

$$\omega > \omega_p$$

- In this region refraction and not reflection takes place.

Physical Processes under the Conditions of Refraction in the Plasma

- Under the conditions of refraction, the phase speed of electromagnetic waves in a plasma is greater than in free space.
- Under the conditions of refraction, the greater the density of the plasma, the greater the phase speed.
- Since the plasma density can be reconfigured, the steering and focusing of antenna beams by the physics of refraction through a plasma is reconfigurable.
- The amount of refraction through a plasma depends on the path length through a plasma and the change in plasma density over that path length
- This physical process can also be considered as a plasma lens.

Beam Lensing and Steering with Refraction

- Antenna beam focusing, beam spreading, and beam steering using refraction of RF waves in a plasma.
- This is our first iteration of the plasma lens work and it can only improve. We found it was easier to show the lensing effects of plasma at 24 GHz since the size and shape of COTS plasma tubes are amenable to a 24 GHz.
- These effects all scale according to wavelength.
- Cylindrical annular rings of plasma are the best way to control the plasma density variations of plasma to optimize the engineering effects of plasma refraction to control beam focusing, beam spreading, and beam steering

Beam Lensing and Steering with Refraction

- We have demonstrated the ability to use a plasma for manipulation of antenna signals by focusing a wide beam into a more narrow beam and also by steering the beam.
- Shows the experimental set-up for beam steering and lensing. A narrow-beam 24 GHz signal is directed into the side of a 1.5 inch diameter plasma tube.
- Metal shields are on both sides of the plasma tube to block any extraneous signals from passing through the plasma tube.
- If the electron plasma frequency of the plasma is lower than the signal frequency (24 GHz in our case) then the phase velocity of the signal is faster than the speed of light in a vacuum.
-

$$v_p = \frac{c}{\sqrt{1 - \omega_p^2/\omega^2}},$$

Beam Lensing and Steering with Refraction

- This change in velocity of the signal inside the plasma results in a lensing effect if the beam passes through varying lengths of plasma similar to light passing through glass of varying thickness to make a lens.
- But there is an important and interesting difference between an ordinary lens made of glass or plastic and a plasma lens:
- The glass lens slows-down the signal while a plasma lens speeds-up the signal.
- Therefore a convex glass lens focuses a signal to a point while a convex plasma diverges the signal similar to a concave glass lens that diverges the signal while a concave plasma lens focuses to a point.
- We have built converging and diverging plasma lenses using plasma tubes. A single plasma tube with the beam passing through its diameter acts as a diverging plasma lens and two plasma tube side-by-side form a converging (focusing) lens.
- ***Note: Plasma focusing lenses are concave and plasma spreading lenses are convex. The terms concave and convex in plasma lenses are opposite of the terms of lenses in optics.***

Beam Lensing and Steering with Refraction

- We have built the focusing set-up for beam shown.
- A 24 GHz, 5 mW Gunn diode is used as the microwave source with the signal radiating from the open waveguide, which gives a unfocused microwave output.
- This setup allows us to focus the beam in the forward direction resulting in a gain of 2 (3 dB).
- This is our first iteration of the engineering of plasma lensing and it can only get better.

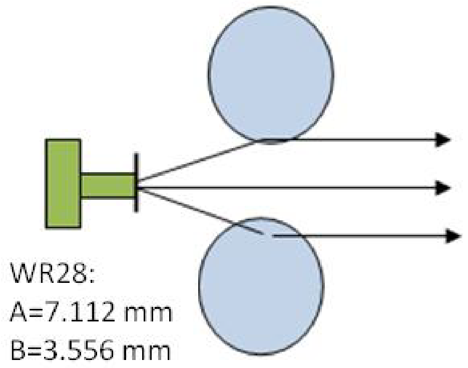
Beam Lensing and Steering with Refraction

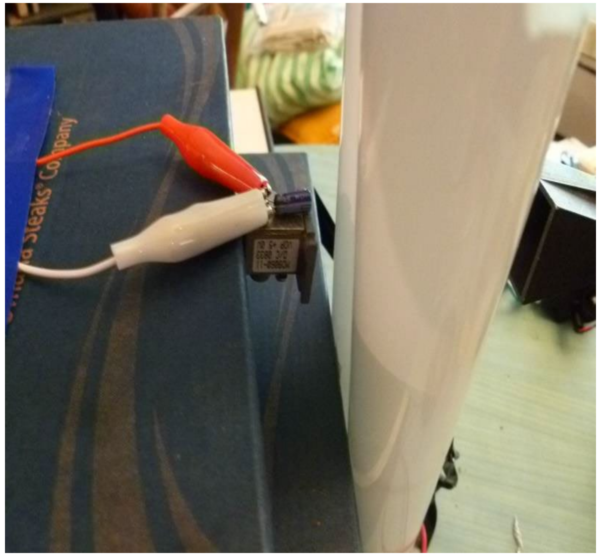
- We have utilized a pulsed high voltage power supply to give a much higher average plasma density.

Beam Lensing and Steering with Refraction

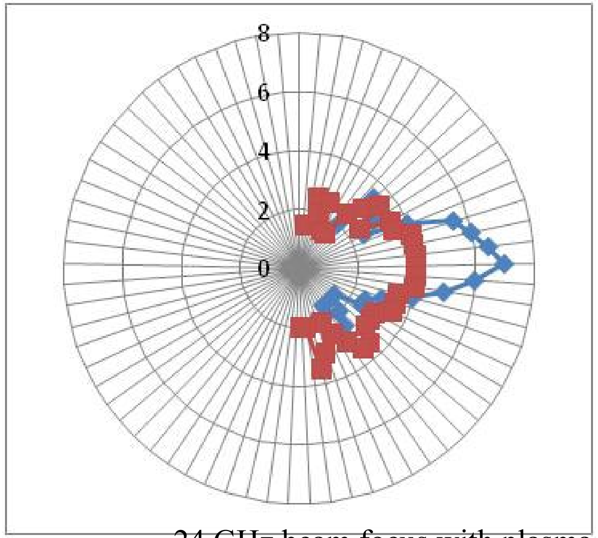
- In regard to a relatively lower pulse current:
  - The focusing effect occurs immediately after the current pulse but stops as current decreases.
  - Peak currents of 3 A and 10 A were used from our pulsing technique.
  - Focusing can be “tuned” by changing density of the plasma inside the tube.
- This ability to tune the focusing of a RF beam is very useful because the same lensing structure can be used with different frequencies and plasma densities to vary focal length as needed.

Project Plasma lenses antennas: **Focusing of Antenna Beams**



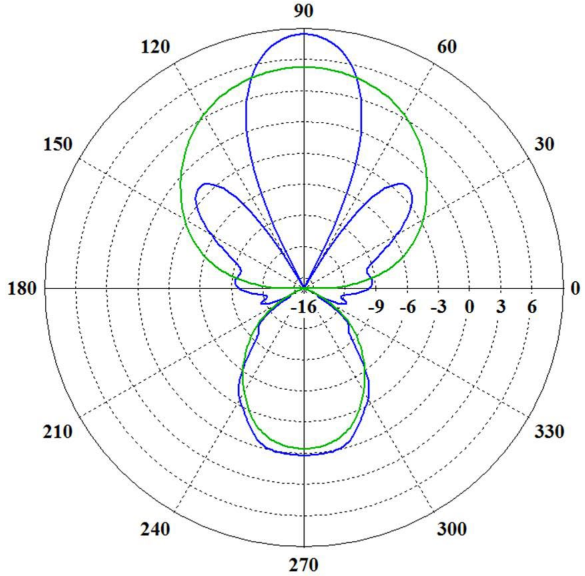


Plasma focusing experimental setup from a different angle. Gunn diode 24 GHz transmitter with fluorescent tubes used for plasma beam focus 1.5 inch (3.81cm).



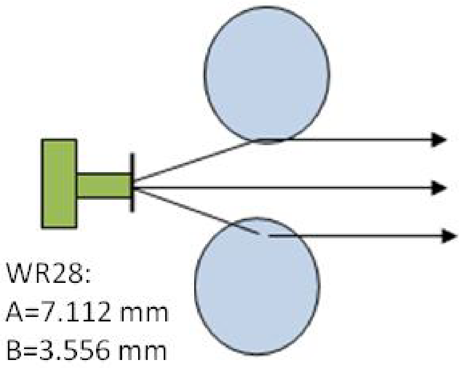
24 GHz beam focus with plasma.
Red line is with no plasma. Blue line is with plasma.
Note that the plasma focus increases beam amplitude
by a factor of two compared to no plasma (~3 dB gain).

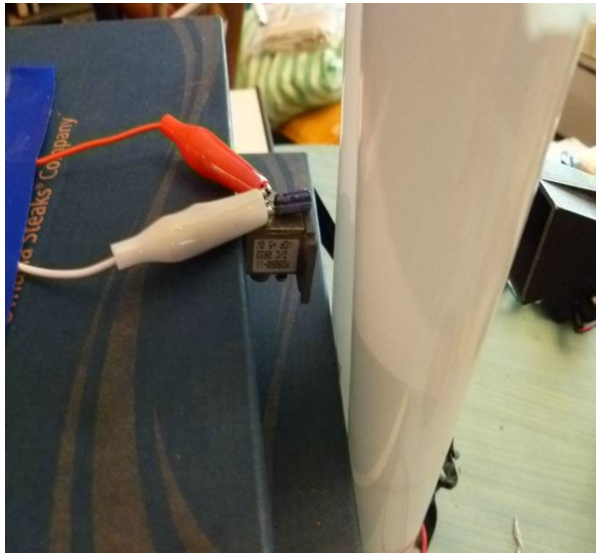
Simulations:
ω_p=62.831e9 rd/s
f_c=900 MHz
at 24 GHz
ε'_r= 0.827
ε''_r= 0.001
without plasma
with plasma



Theta / Degree vs. dB

Project Plasma lenses antennas: **Focusing of Antenna Beams**





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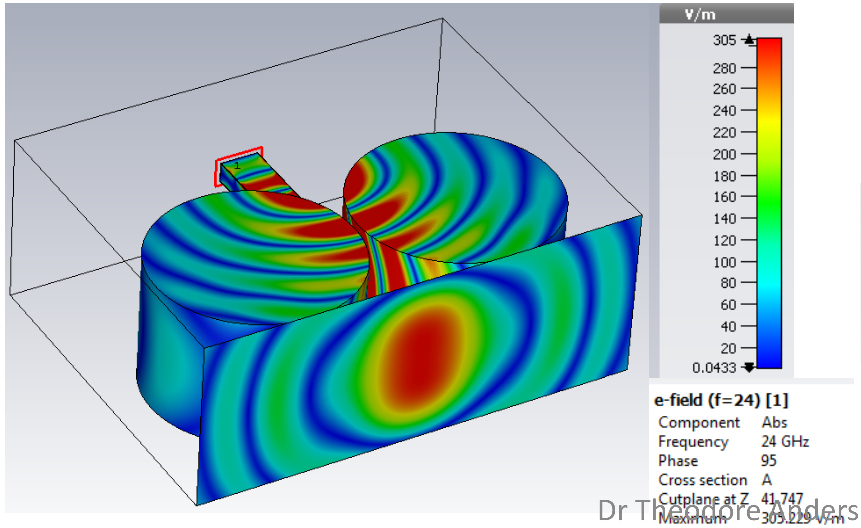
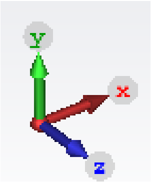
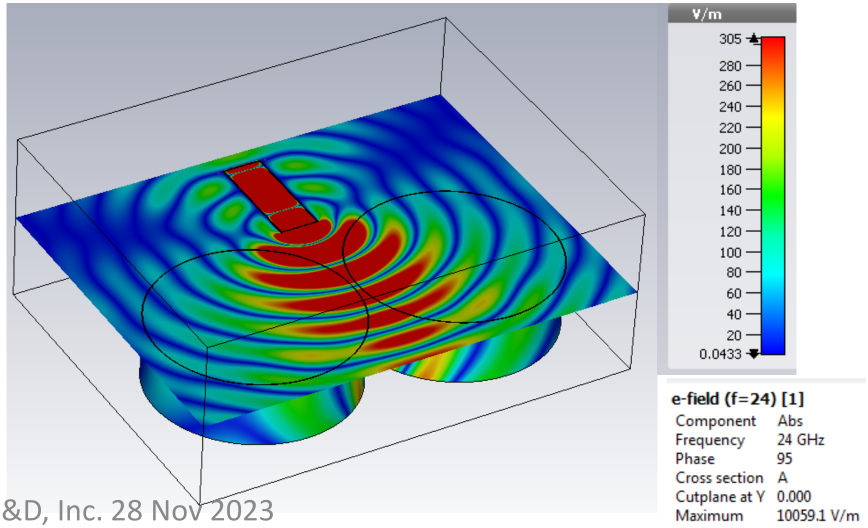


e-field (f=24) [1]

Component	Abs
Frequency	24 GHz
Phase	95
Cross section	A
Cutplane at Z	41.747
Maximum	305.229 V/m

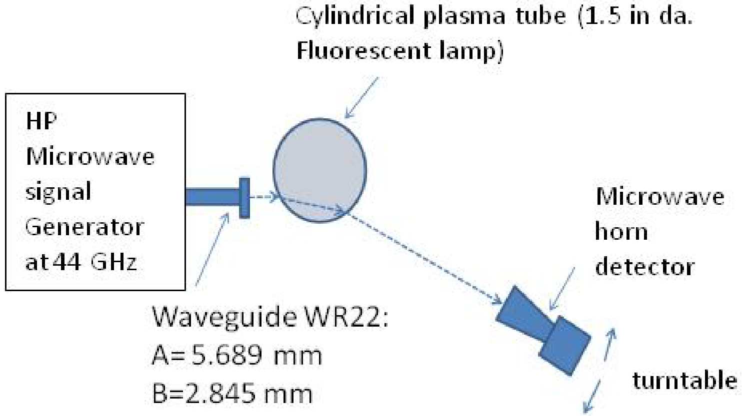




e-field (f=24) [1]

Component	Abs
Frequency	24 GHz
Phase	95
Cross section	A
Cutplane at Y	0.000
Maximum	10059.1 V/m

Project Plasma lenses antennas: **Steering of Antenna Beams**



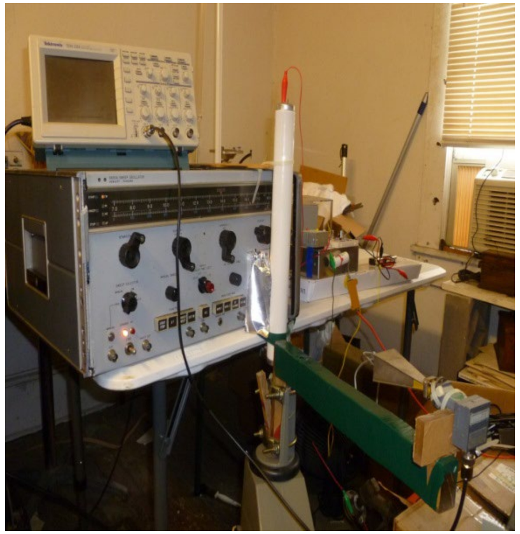
Cylindrical plasma tube (1.5 in da. Fluorescent lamp)

HP Microwave signal Generator at 44 GHz

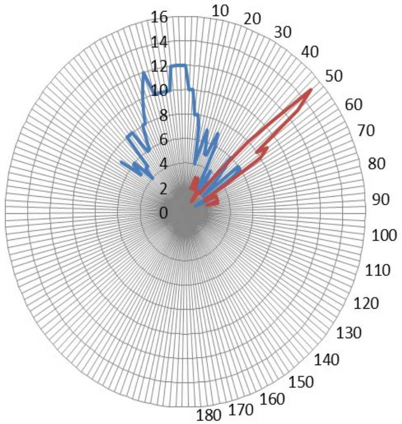
Microwave horn detector

Waveguide WR22:
A= 5.689 mm
B=2.845 mm

turntable



Plasma beam steering experiment. Antenna rotator with holder (green) and receiver horn/detector is in the foreground. The oscilloscope used to monitor the signal waveform



Plasma beam steering. Beam is steered ~45 degrees clockwise. Blue line: No plasma. Red line: 8 A peak ionizing current. A crystal waveguide detector is used as a receiver. Amplitude numbers are relative voltage readings from the crystal detector

Drude 62:
Plasma Frequency
ω_p=62.831e9 rd/s,
f_c=900 MHz,
at 44 GHz
ε'_r= 0.948
ε''_r= 0.000168

Drude 140:
ω_p=140e9 rd/s
f_c=900 MHz
at 44 GHz
ε'_r= 0.744
ε''_r= 0.0008

Drude 162:
ω_p=162.831e9 rd/s
f_c=900 MHz
at 44 GHz
ε'_r= 0.653
ε''_r= 0.0011

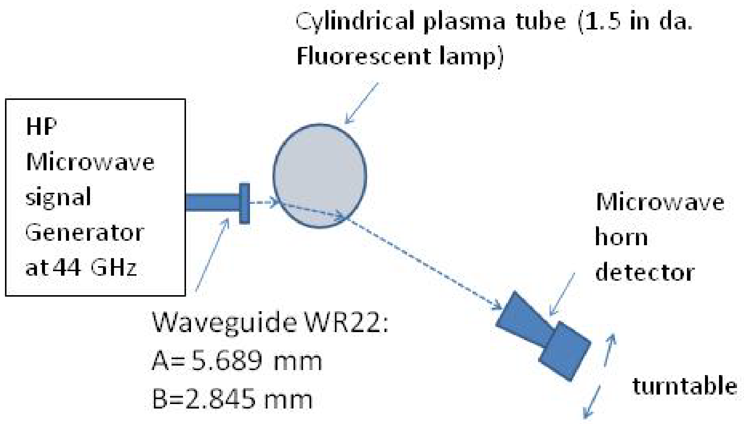
Drude 200:
ω_p=200e9 rd/s
f_c=900 MHz
at 44 GHz
ε'_r= 0.4766
ε''_r= 0.0017

Drude 262:
ω_p=262.831e9 rd/s
f_c=900 MHz
at 44 GHz
ε'_r= 0.0964
ε''_r= 0.00294

Drude 362:
ω_p=362.831e9 rd/s
f_c=900 MHz
at 44 GHz
ε'_r= -0.7224
ε''_r= 0.0056

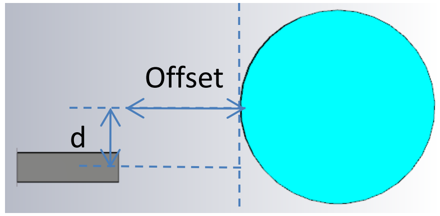
Project Plasma lenses antennas: **Focusing**

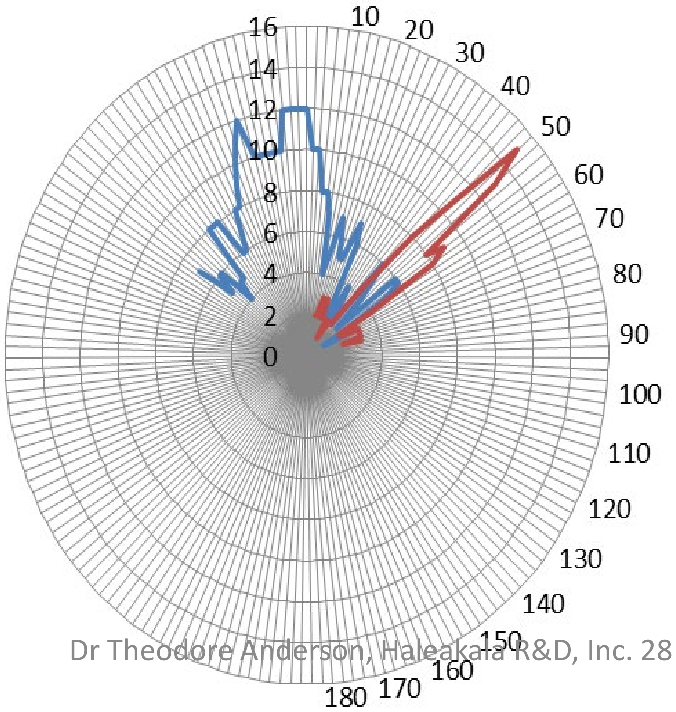
Steering, Focusing, and Spreading of Antenna Beams



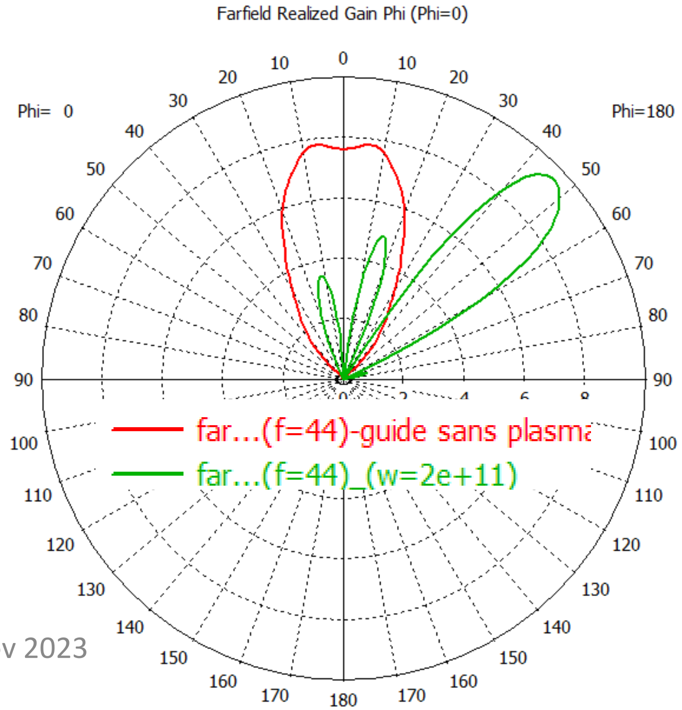
Plasma beam steering experiment. Antenna rotator with holder (green) and receiver horn/detector is in the foreground. The oscilloscope used to monitor the signal waveform

d=14 mm
Offset=0



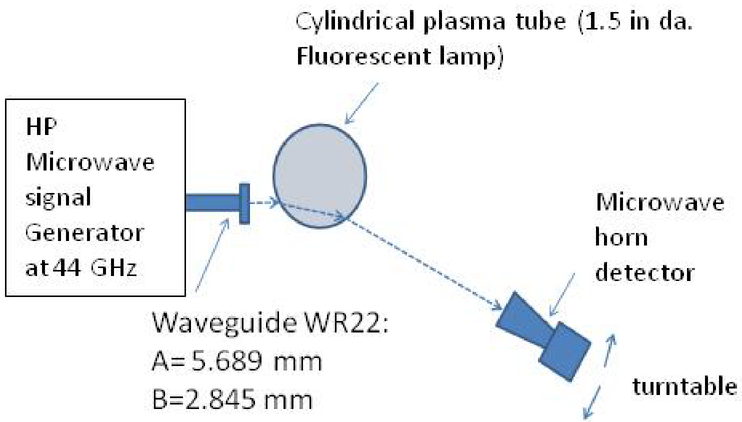


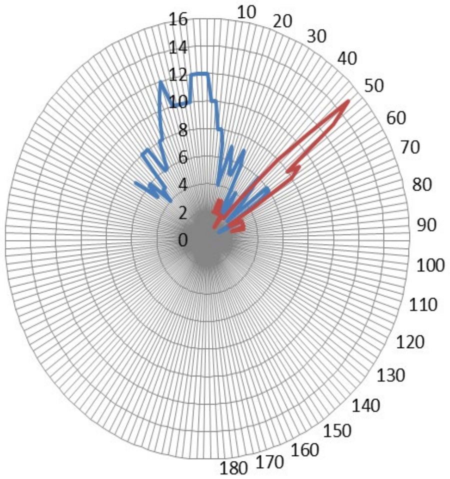
Plasma beam steering. Beam is steered ~45 degrees clockwise. Blue line: No plasma. Red line: 8 A peak ionizing current. A crystal waveguide detector is used as a receiver. Amplitude numbers are relative voltage readings from the crystal detector

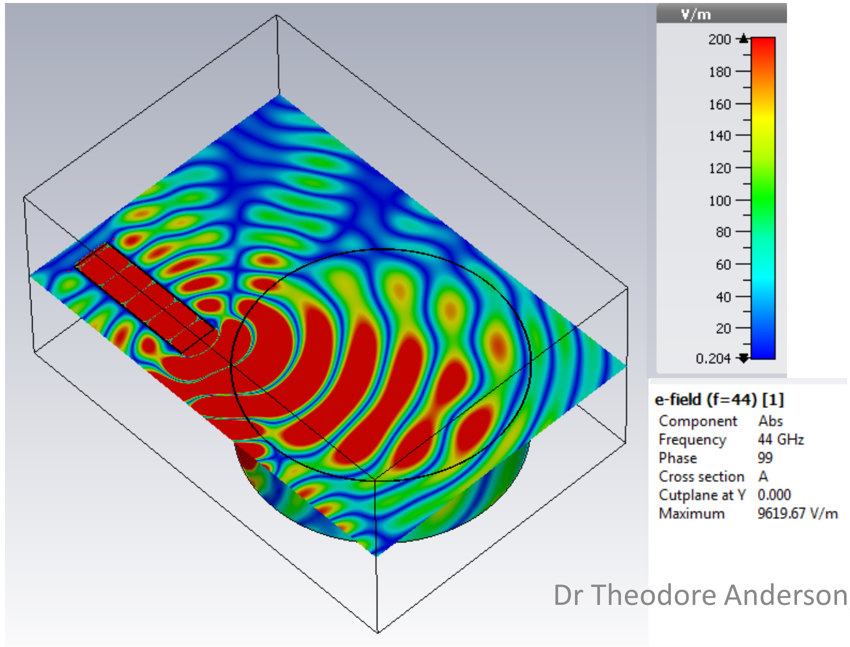


Project Plasma lenses antennas: **Focusing**

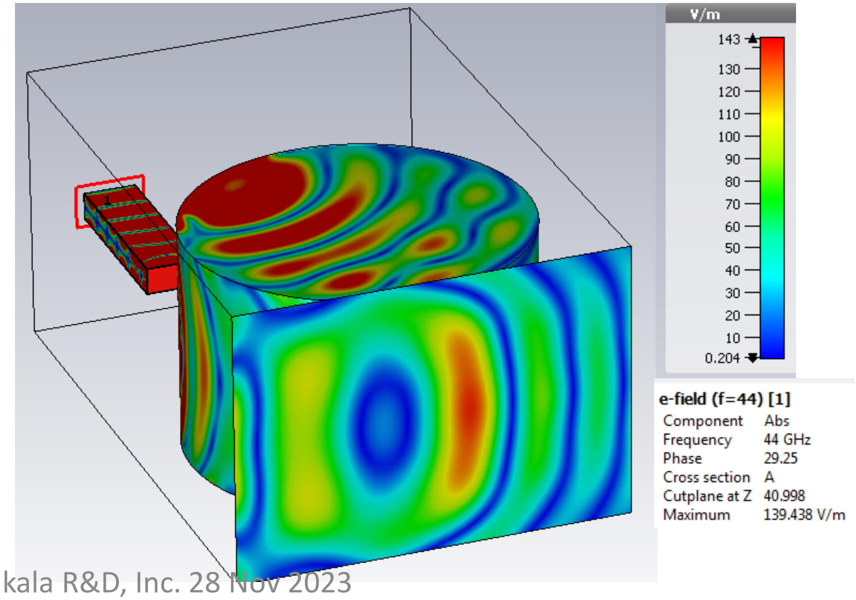
Steering, Focusing, and Spreading of Antenna Beams







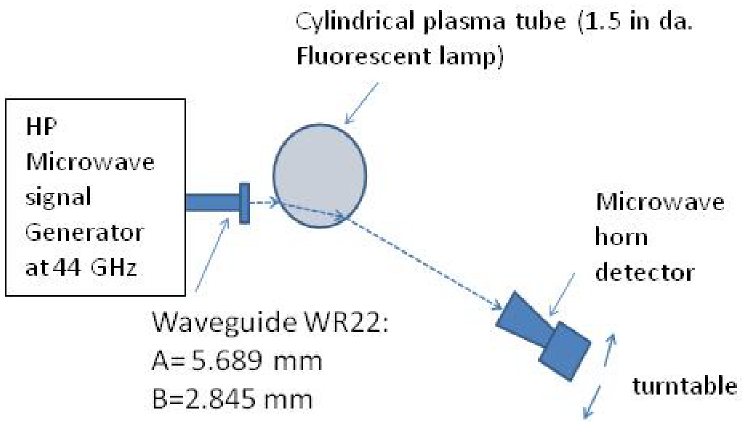
e-field (f=44) [1]
Component Abs
Frequency 44 GHz
Phase 99
Cross section A
Cutplane at Y 0.000
Maximum 9619.67 V/m



e-field (f=44) [1]
Component Abs
Frequency 44 GHz
Phase 29.25
Cross section A
Cutplane at Z 40.998
Maximum 139.438 V/m

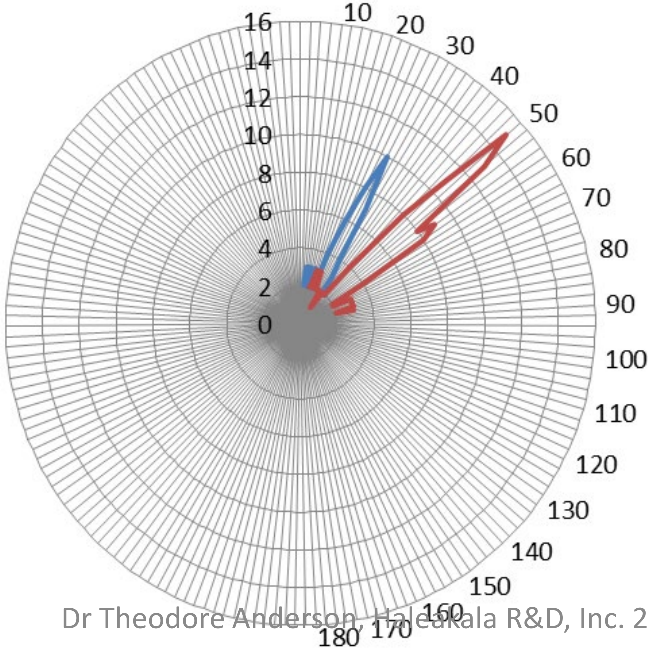
Project Plasma lenses antennas: **Focusing**

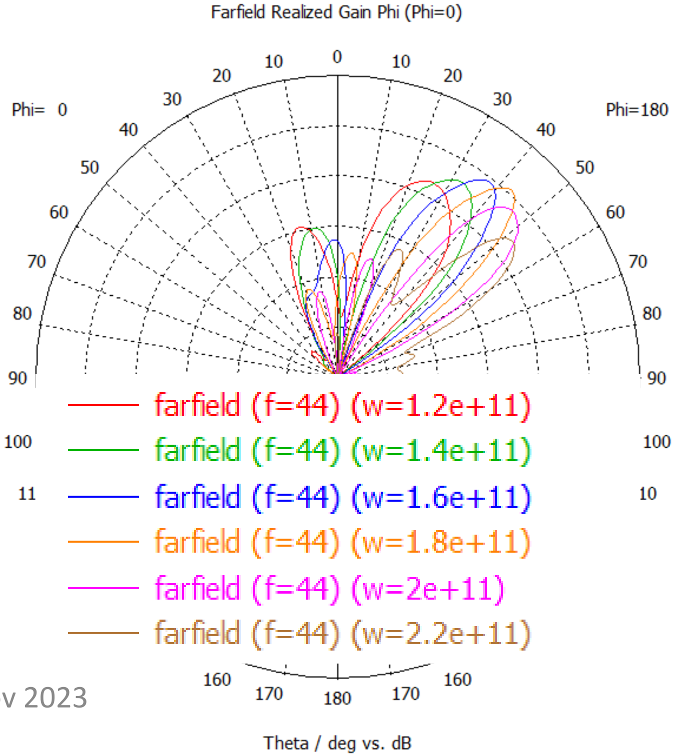
Steering, Focusing, and Spreading of Antenna Beams



Plasma beam steering experiment. Antenna rotator with holder (green) and receiver horn/detector is in the foreground. The oscilloscope used to monitor the signal waveform

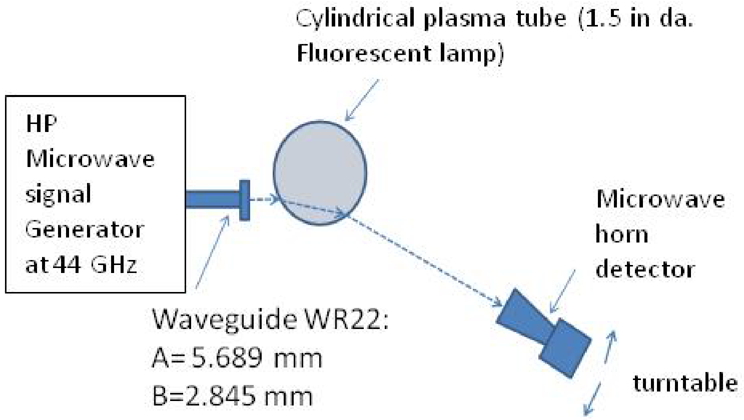
Beam steering (44 GHz) for two different plasma ionizing currents. Blue line: 5 A peak. Red line: 8 A peak. A crystal waveguide detector is used as a receiver. Amplitude numbers are relative voltage readings from the crystal detector





Project Plasma lenses antennas: **Focusing**

Steering, Focusing, and Spreading of Antenna Beams



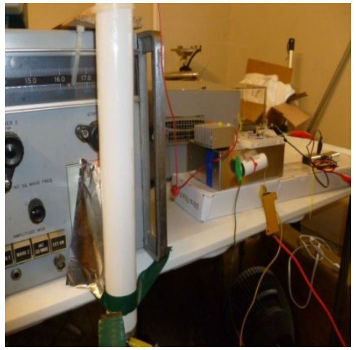
Cylindrical plasma tube (1.5 in da. Fluorescent lamp)

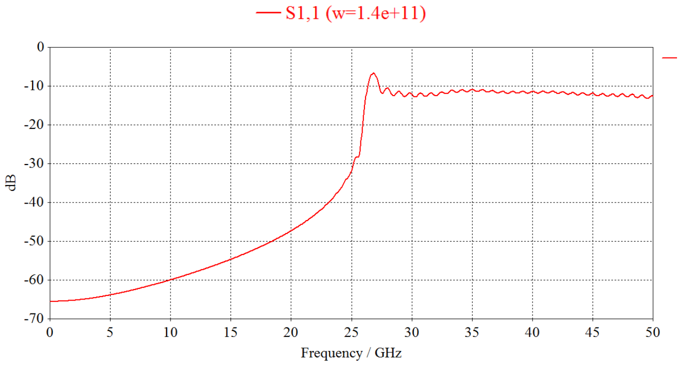
HP Microwave signal Generator at 44 GHz

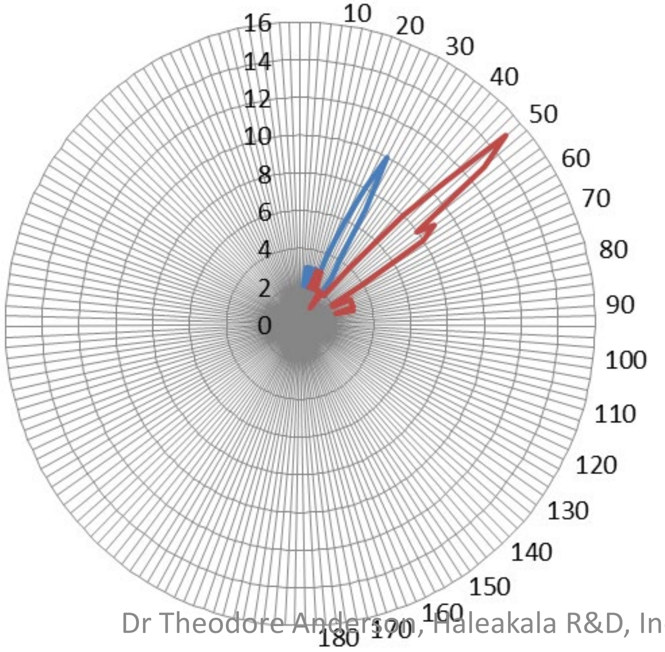
Microwave horn detector

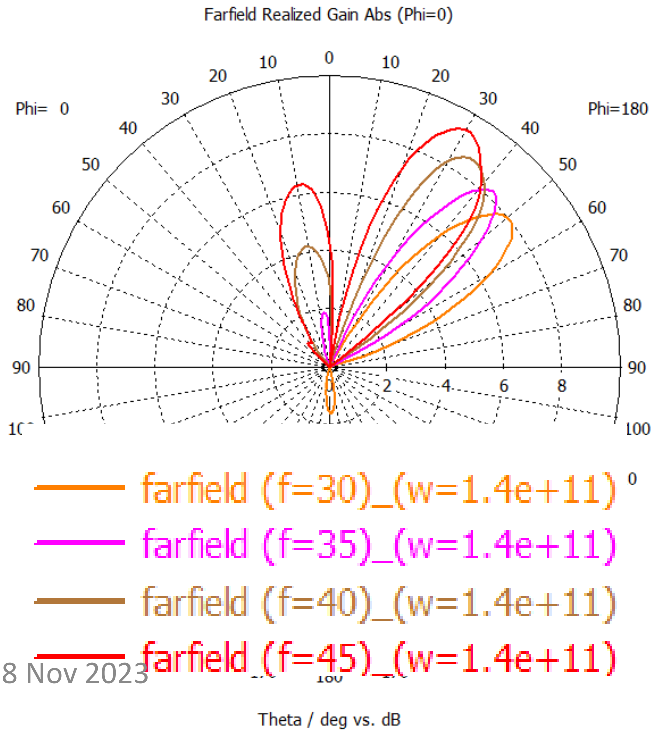
Waveguide WR22:
A= 5.689 mm
B=2.845 mm

turntable









Beam steering (44 GHz) for two different plasma ionizing currents. Blue line: 5 A peak. Red line: 8 A peak. A crystal waveguide detector is used as a receiver. Amplitude numbers are relative voltage readings from the crystal detector

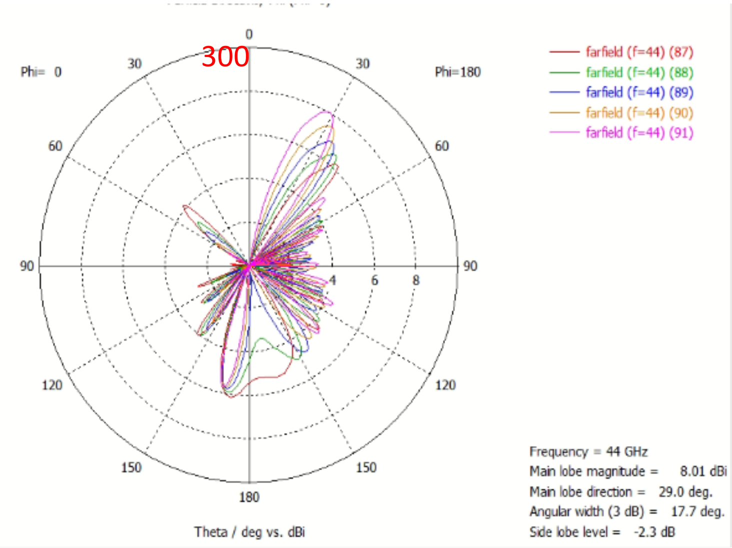
Project Plasma lenses antennas: **Focusing**

Steering, Focusing, and Spreading of Antenna Beams

d=4 to 12 mm

Offset=24 mm

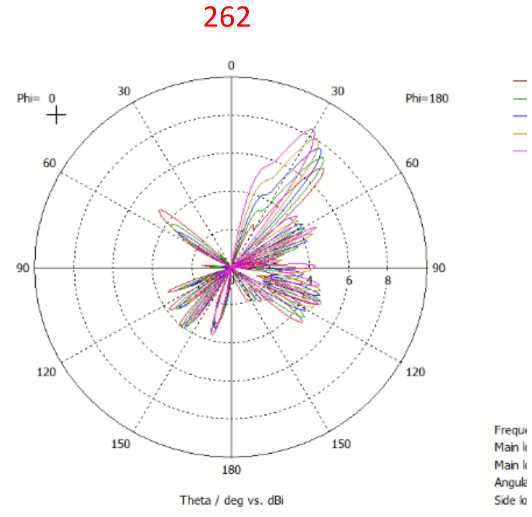
300



Frequency = 44 GHz
Main lobe magnitude = 8.01 dBi
Main lobe direction = 29.0 deg.
Angular width (3 dB) = 17.7 deg.
Side lobe level = -2.3 dB

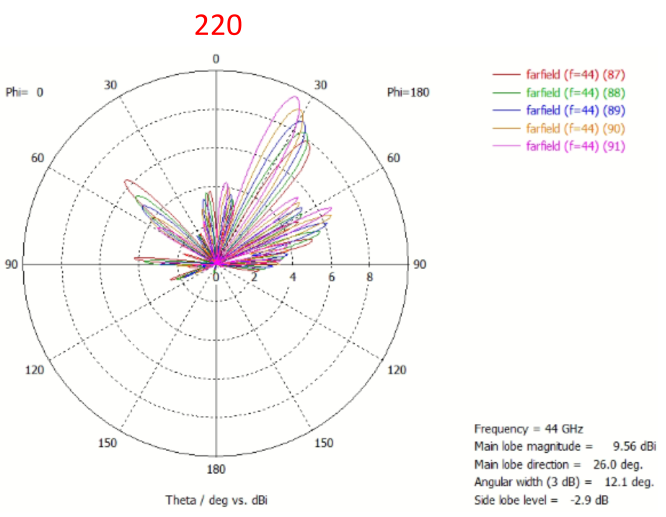
the scanning beam with acceptable side lobes level from 29 to 42°

262



Scanning beam with acceptable side lobes level from 30 to 43°

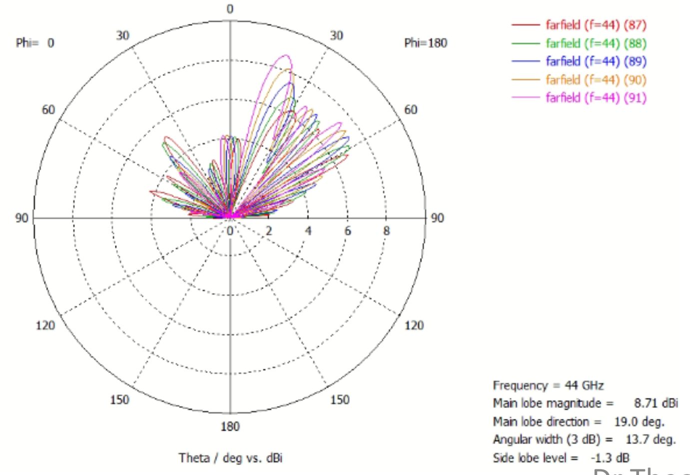
220



Frequency = 44 GHz
Main lobe magnitude = 9.56 dBi
Main lobe direction = 26.0 deg.
Angular width (3 dB) = 12.1 deg.
Side lobe level = -2.9 dB

Scanning beam with acceptable side lobes level from 26 to 37°

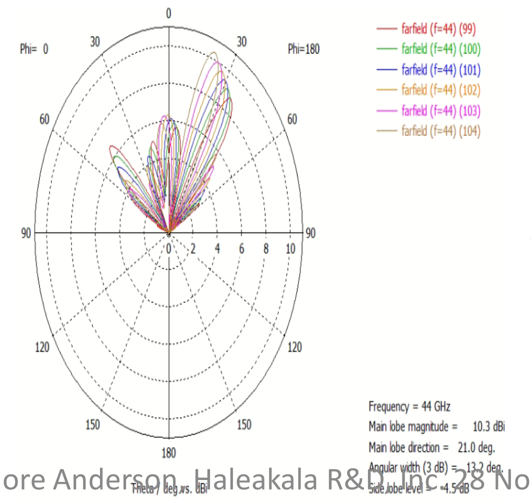
200



Frequency = 44 GHz
Main lobe magnitude = 8.71 dBi
Main lobe direction = 19.0 deg.
Angular width (3 dB) = 13.7 deg.
Side lobe level = -1.3 dB

bad side lobes level

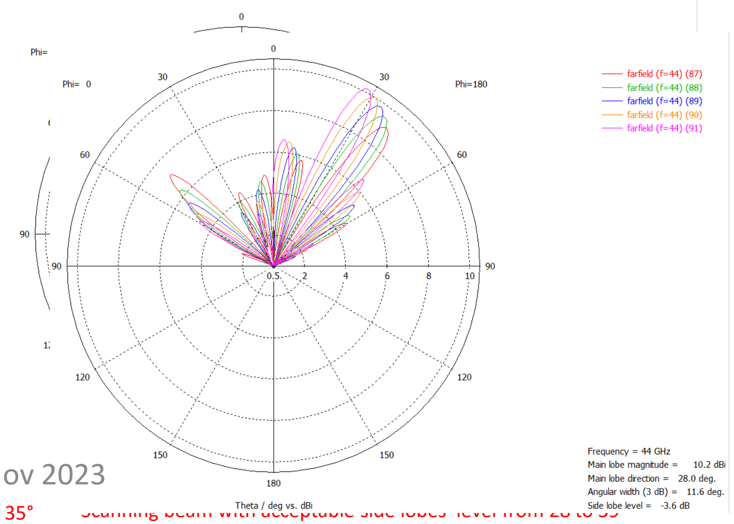
140



Frequency = 44 GHz
Main lobe magnitude = 10.3 dBi
Main lobe direction = 21.0 deg.
Angular width (3 dB) = 13.2 deg.
Side lobe level = -4.5 dB

the scanning beam with acceptable side lobes level from 24 to 35°

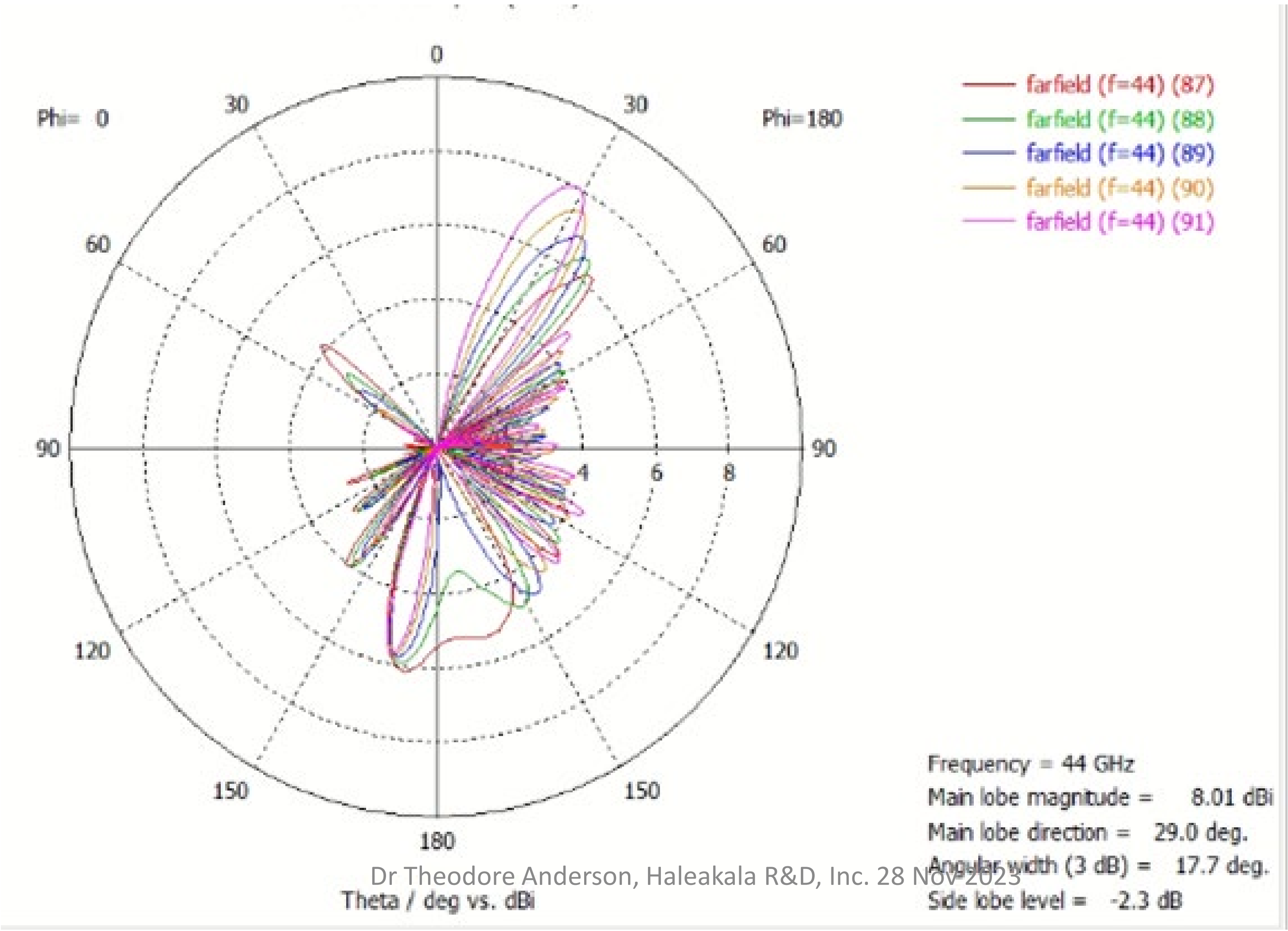
162



Frequency = 44 GHz
Main lobe magnitude = 10.2 dBi
Main lobe direction = 28.0 deg.
Angular width (3 dB) = 11.6 deg.
Side lobe level = -3.6 dB

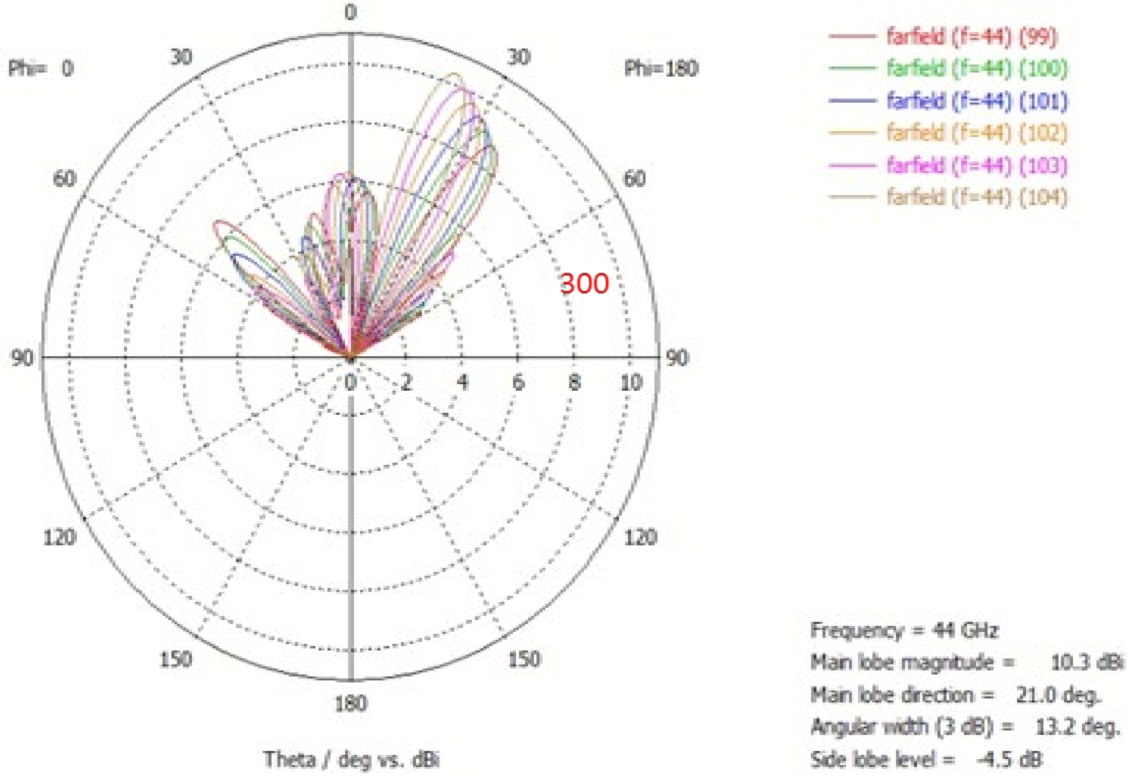
Scanning beam with acceptable side lobes level from 28 to 35

Drude 300



Frequency = 44 GHz
Main lobe magnitude = 8.01 dBi
Main lobe direction = 29.0 deg.
Angular width (3 dB) = 17.7 deg.
Side lobe level = -2.3 dB

Drude 200



```
Frequency = 44 GHz
Main lobe magnitude =     10.3 dBi
Main lobe direction =   21.0 deg.
Angular width (3 dB) =   13.2 deg.
Side lobe level =   -4.5 dB
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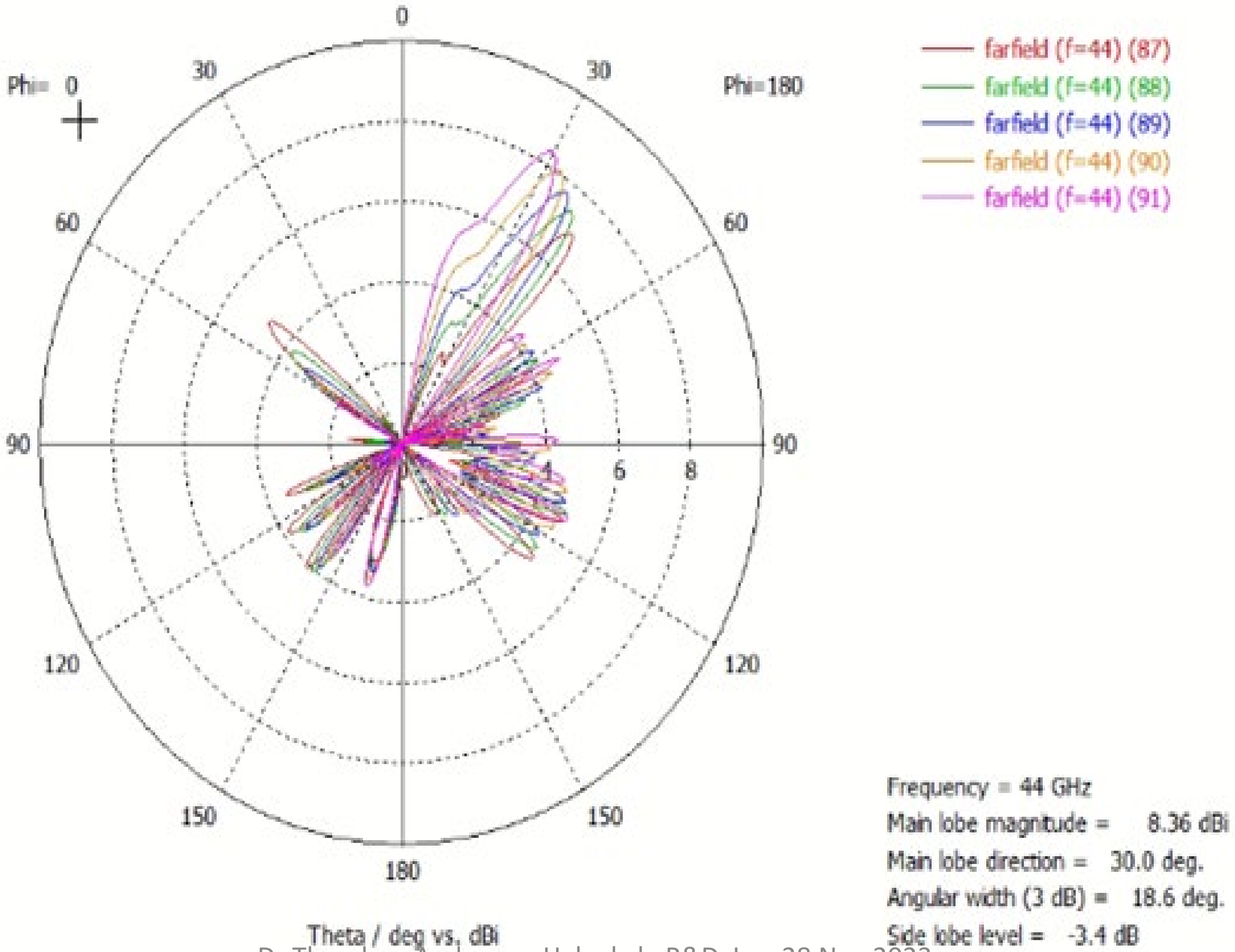
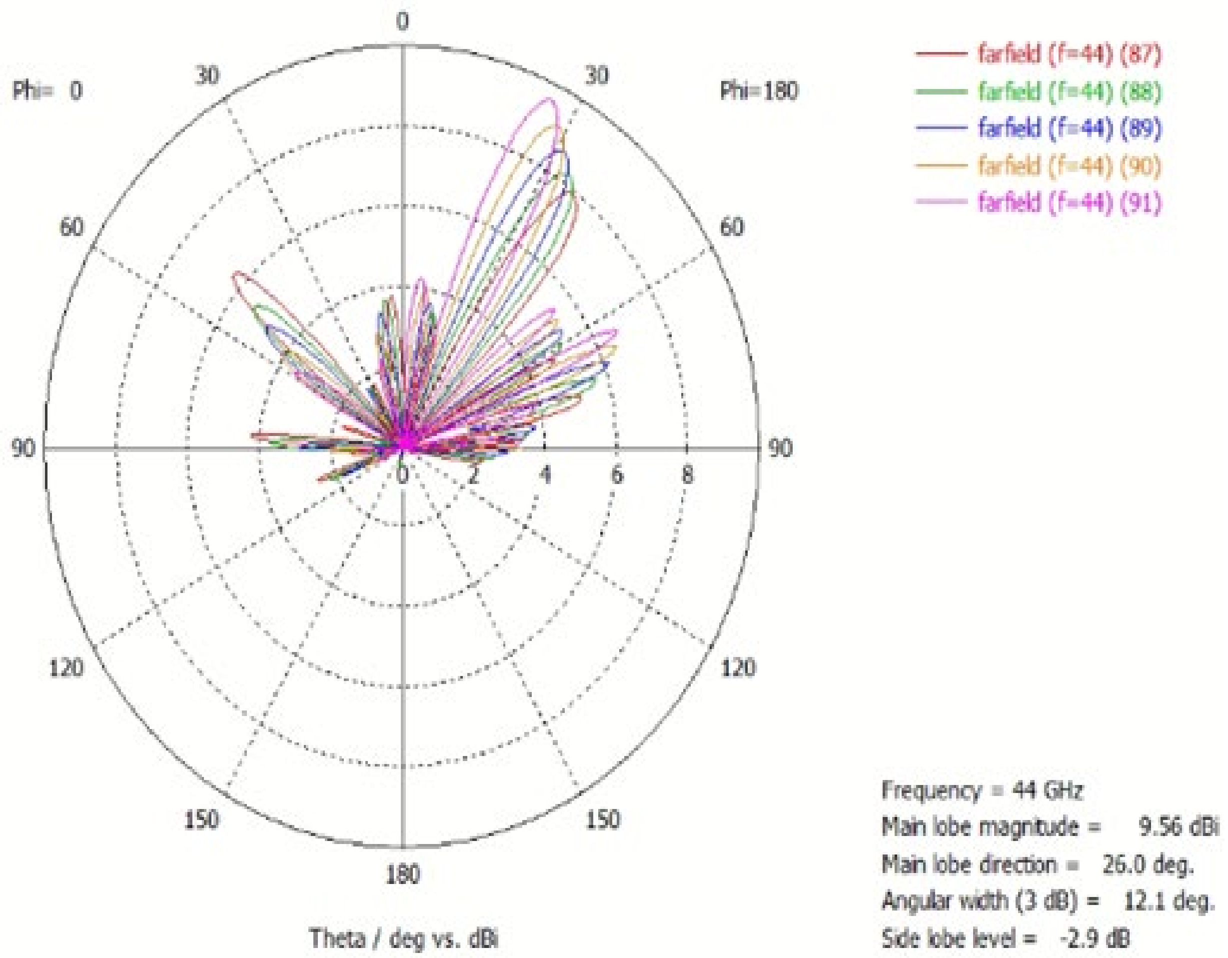
Drude 262



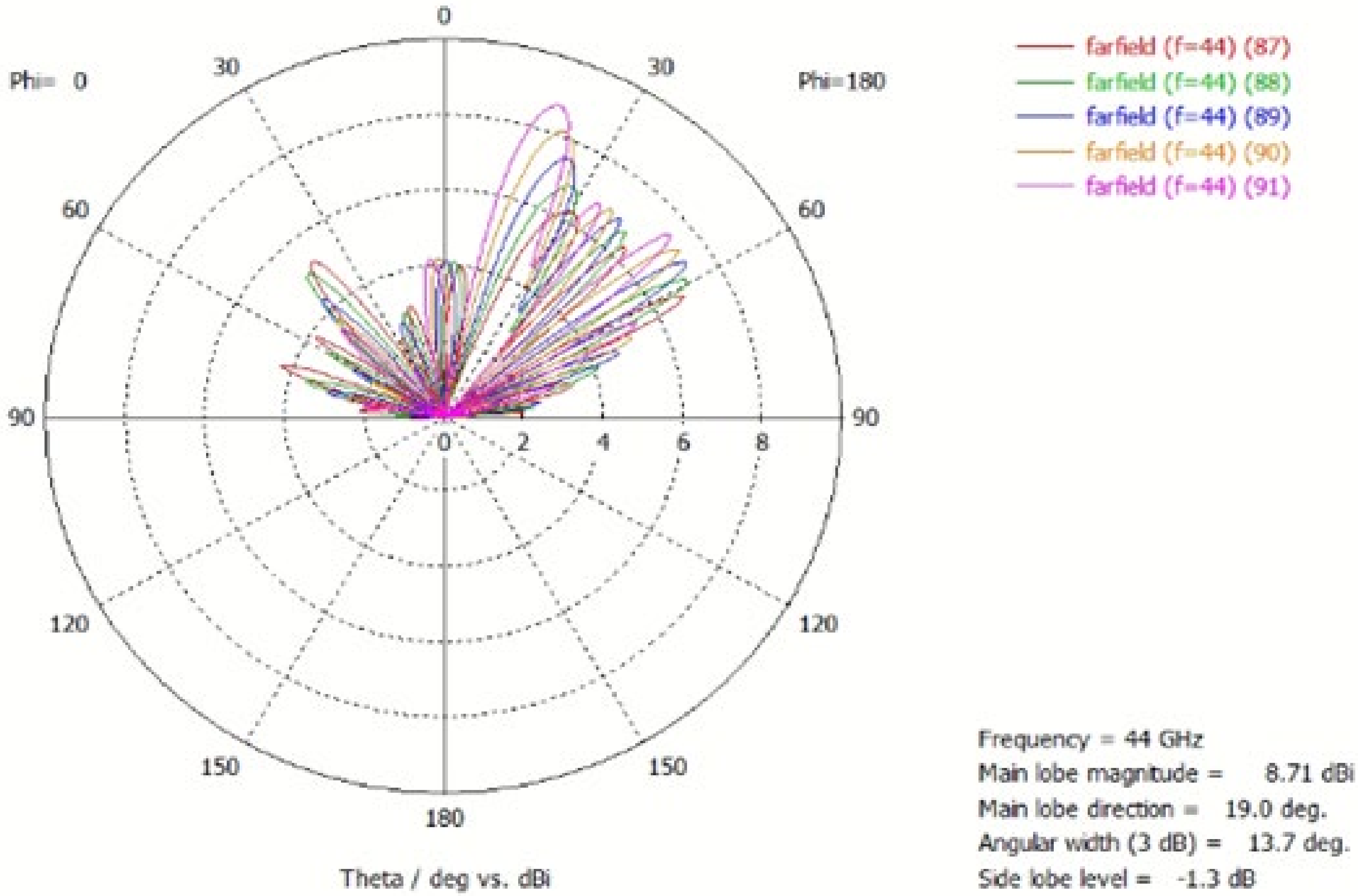
Frequency = 44 GHz
Main lobe magnitude = 8.36 dBi
Main lobe direction = 30.0 deg.
Angular width (3 dB) = 18.6 deg.
Side lobe level = -3.4 dB

Drude 220



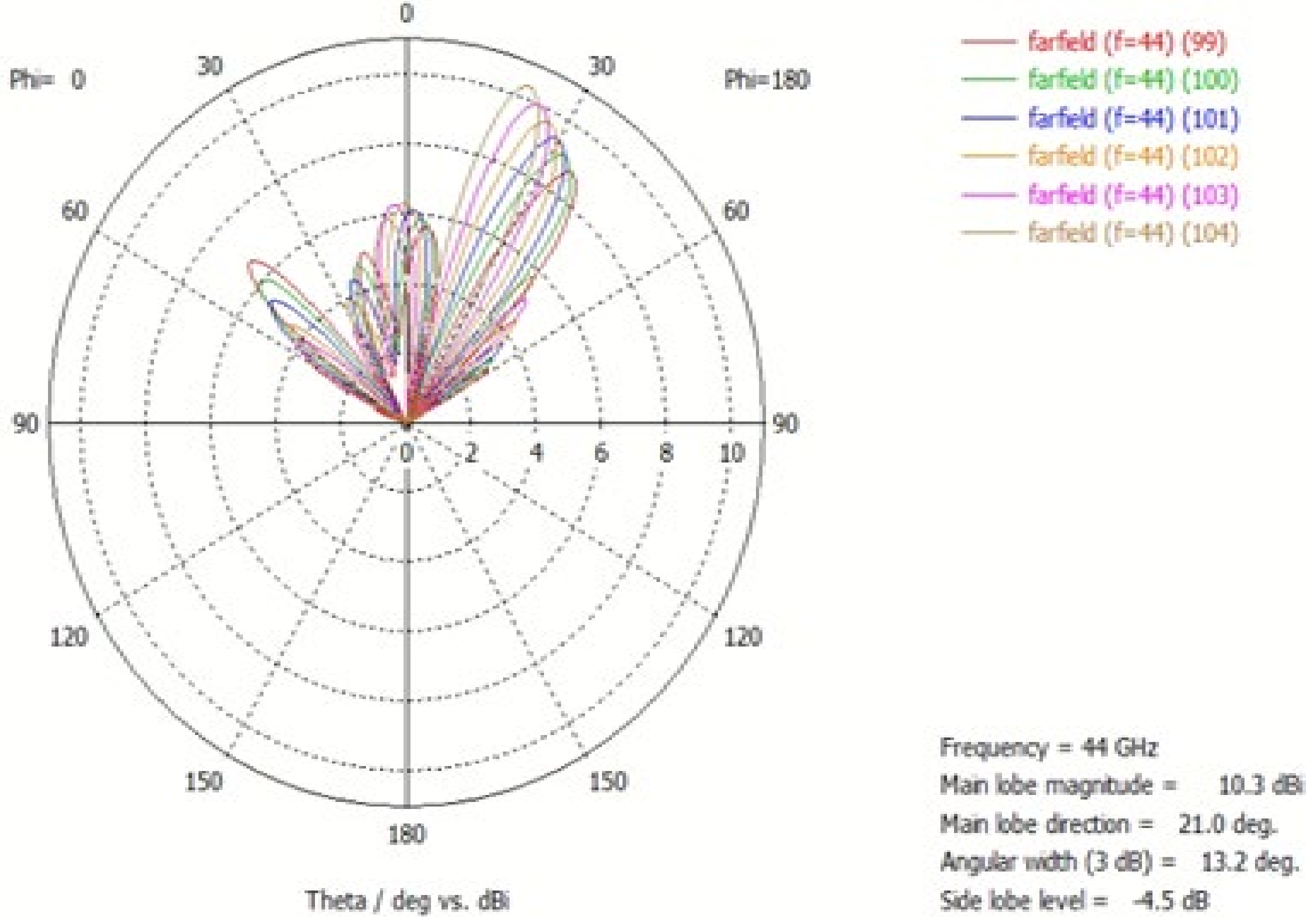
Frequency = 44 GHz
Main lobe magnitude = 9.56 dBi
Main lobe direction = 26.0 deg.
Angular width (3 dB) = 12.1 deg.
Side lobe level = -2.9 dB

Drude 140



Frequency = 44 GHz
Main lobe magnitude = 8.71 dBi
Main lobe direction = 19.0 deg.
Angular width (3 dB) = 13.7 deg.
Side lobe level = -1.3 dB

Drude 162



Frequency = 44 GHz
Main lobe magnitude = 10.3 dBi
Main lobe direction = 21.0 deg.
Angular width (3 dB) = 13.2 deg.
Side lobe level = -4.5 dB

Steering and Focusing Antenna Beams to Track Hypersonic Speeds Utilizing the Physics of Refraction.

Introduction

- We propose a plasma antenna concept that could have significant advantages for some advanced military applications.
- This concept is refraction of electromagnetic waves in a plasma in which the frequency of the electromagnetic waves is above the plasma frequency for steering and focusing antenna beams.
- The application is using this physics to track objects at hypersonic speeds.
- An array of tubes or plate containing plasma is placed in the antenna beam path, as in front of a conventional feed horn/small array
  - The phase shifting plasma channels focus and steer the antenna beam.
- In this application the operating frequency is above the plasma frequency, where the plasma is:
  - essentially a cold plasma with short relaxation time
  - the electromagnetic waves propagate through the plasma with a plasma frequency dependent phase velocity.
  - this will require high pulses per second (pps) power supply with pulsing (e.g. pps of MHz with nano-sec pulse widths) or direct current.

Steering and Focusing Antenna Beams to Track Hypersonic Speeds Utilizing the Physics of Refraction.

Array of tubes or plate containing plasma coupled with flat metal plate reflector design

- Related to the plasma sheet or an array of multiple plasma tubes of small diameter is the plasma sheet or an array of multiple plasma tubes of small diameter coupled with a metal flat plate reflector.
  - in which a plasma sheet or an array of small diameter tubes containing plasma encapsulated in ruggedized material is attached to a flat metal plate reflector.
  - the advantage of this is that the electromagnetic waves refract through the plasma, reflect off of the metal plate, and refract back through the plasma giving a double refraction and twice the steering and focusing effect.
  - The disadvantage is that the metal plate reduces stealth.
    - However, flat metal plates have a reduced RCS because of reduced back scattering differential and total cross section if oriented other than perpendicular to the antenna beam.
- A doubling of the total phase shift per thickness of the plasma plate would be achieved.
  - Doubling the steering and focusing effect by refraction through the plasma of the antenna beam.

Steering and Focusing Antenna Beams to Track Hypersonic Speeds Utilizing the Physics of Refraction.

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- A doubling of the total phase shift per thickness of the plasma plate would be achieved.
  - Doubling the steering and focusing effect by refraction through the plasma of the antenna beam.

Track While Scanning (TWS) Systems Applications

- The plasma l beam steering by refraction by many individual plasma channels is similar to phased array beam steering. i.e. by controlling the phase of the wavefront.

- Hence, systems developed for phased arrays could be conceivably implemented with plasma antennas such as:
  - Track While Scanning (TWS) systems where a beam, or beams, are generated that continuously track targets while simultaneously scanning for new targets.

Stealth and Resistance to Jamming.

- The plasma array of tubes with plasma with or without a reflector is very stealth.
- In the plasma/metal reflector design, a flat metal plate has very low effective radar cross section to adversary radar.
  - flat metal plates have a reduced RCS because of reduced back scattering differential and total cross section if oriented other than perpendicular to the antenna beam
- Whether the plasma is on (ionized state) or off (extinguished state) the array of tubes or plate containing plasma is little more than a flat dielectric plate that would have even lower radar cross section than a flat metal plate.

Stealth and Resistance to Jamming

- Broadband wave matching techniques, such as dielectric cones on the array of tubes or plate containing plasma, and RF absorber on the edges, could make this plasma system with or without a reflector virtually invisible.
- By comparison, a conventional phased array using metal elements has a very high radar cross section.

More Compact than a Comparable Metallic Phased Array.

- We anticipate a plasma system using refraction to steer and focus an antenna beam to be more compact than a comparable metallic phased array antenna.
  - *Plasma channels can be packed many per wavelength for:*
    - *Compactness.*
    - low sidelobe control.

Ruggedization

- The plasma refraction system/reflector can be made extremely rugged. Laboratory plasma antennas typically have used glass tubes, which has invited criticism for their fragility.
- While initial beam steering and focusing through refraction in a plasma experiments would likely start out with stacks of rectangular glass tubes and borosilicate or fused quartz plates to contain the plasma.
- The rectangular glass tubes and plates to contain the plasma would be ultimately made of tough ceramic plates.
  - The plates would have the plasma channels ground into them, and the plates sealed together at the edges.
  - Small gaps between the plates would allow equalized gas pressure, single port vacuum and gas processing (prior to pinching off as with microwave tubes), and thermal stress relief.

Ruggedization

- The plasma/metal reflector would have a plate or array of plasma tubes attached to a flat metal plate which provides higher ruggedization and conduction cooling.
- For even higher ruggedization, the front surface of the ceramic plate with lexan glass could be very thick
  - and also overcoated with soft, radome dielectric material, of several or (even many) cm thickness,
  - and provide very high resistance to bullets, shrapnel, and high pressure shock waves (as from nearby explosions)
    - that would easily disable a conventional antenna.
- Rather than being fragile, the array of tubes or plate containing plasma alone, or coupled with flat metal plate reflector design, could be more survivable than any fast tracking metal phased array type.

Possibilities of Offensive Hypersonic Capability
using the physics of refraction through plasma

- A plasma or conventional antenna DEW and/or jammer which can scan DEW and/or jamming beams using the physics of refraction of antenna beams through a plasma at hypersonic speeds.
- The DEW and jammer beams can be potentially coupled with plasma tracking beams and scan and attack in unison to disable missiles or other objects traveling at hypersonic speeds.
- ***The key is using the physics of refraction through plasma to potentially scan at hypersonic speeds.***