Virtual SATCOM, Skywave High-Frequency Communications at SATCOM Speeds Without Satellite Vulnerabilities

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8. PHaRLAP Model –Output
9. PHaRLAP Model –Data
10. Aperture
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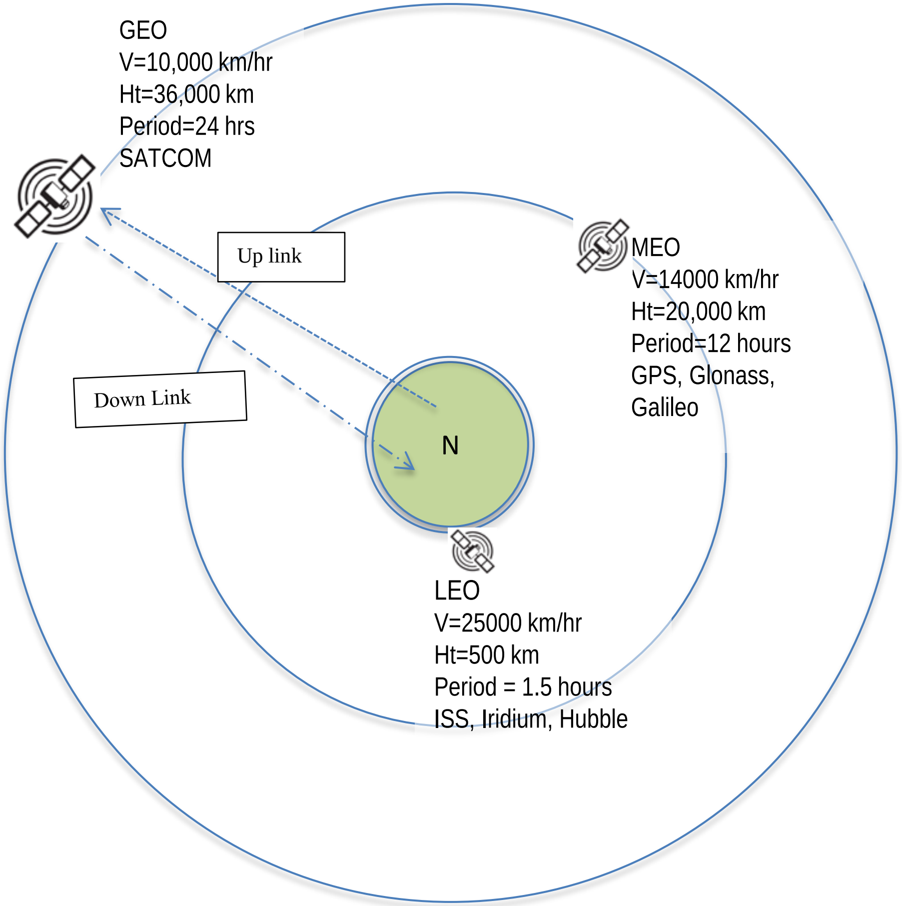
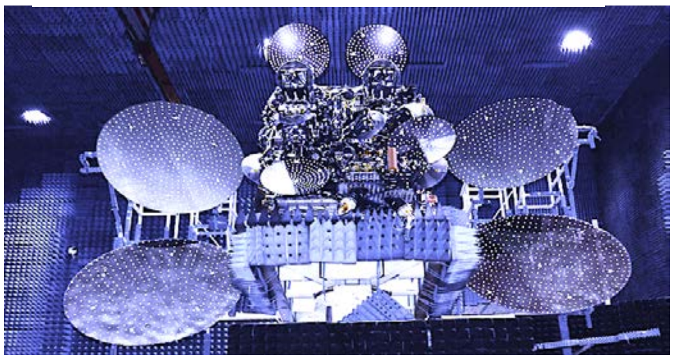


Current Limitations

Satellite Communications



HF Communications

- ↑ High data rate
- ↓ In war time – <u>vulnerable,</u> therefore unreliable
- ↓ High cost
- ↓ Complex hardware
- ↓ Difficult to upgrade hardware
- ↓ Low power downlink due to limits of solar power
- ↓ Limited maneuverability

- ↑ Beyond line of site Communications
- ↑ High Power—long range
- ↓ Narrow bandwidth
- ↓ Low data rate
- ↓ Dynamic Propagation
- ↓ Multipath Fading
- ↓ Vulnerable to SIGINT, GEO locate
- ↑ Low cost
- ↓ Difficult to operate

What's new? Is it risky? Are there mitigations?

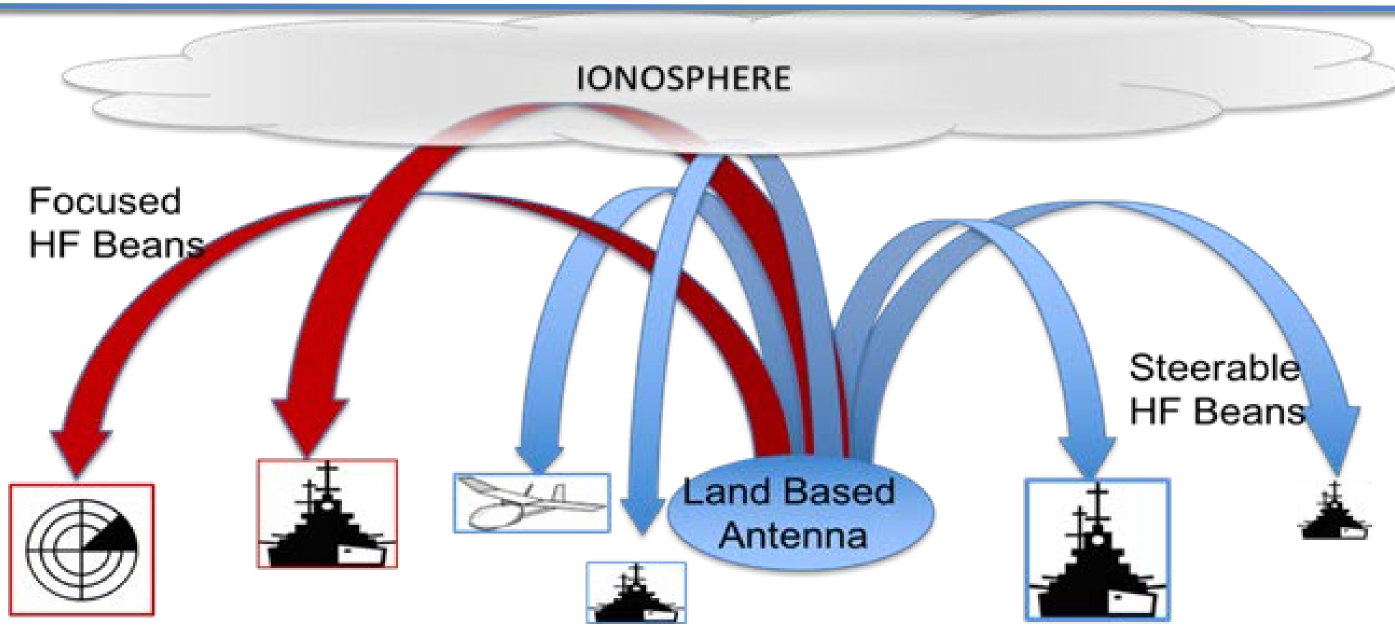
What's New

1. Spider Architecture- SDMA Space Division Multiple Access
2. Ultra wideband 3MHz vs 3kHz --- 32 Cap
3. acity Mbps
4. Hub and Spoke for tactical communications
5. Aperture architecture for ultra wideband frequency transmission through directional beams
6. Frequency agility to move with Ionosphere using 4th Gen wireless protocols at HF Frequencies
    1. FTE
    2. OFDM Orthogonal Frequency Division Multiple Access

Mitigation

1. Apply OTHR technology/ science
2. More comprehensive study of Ionosphere
3. Low risk assuming high operational availability
4. Digital Signal Processing, Software defined radio MIMO
5. Apply mobile cellular system protocols to this HF channel

Concept
Spider Architecture

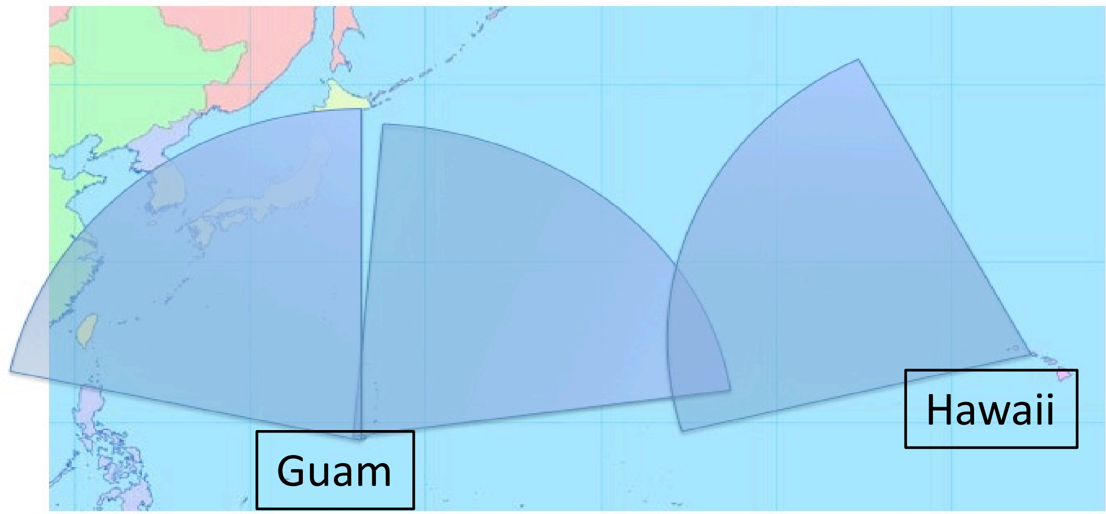


Spider Architecture- Focused beams from base station are bent by ionosphere to land on designated locations. Both friendly and adversary units can be serviced with network communications or electronic warfare (EW) techniques, e.g. jamming.

Concept:
Connect Pacific Ocean From California to China

Mission set;

- Assured communications
  - C2 with:
    - Maritime, Air, UAV, ISR
- Battle Space Awareness
  - SIGINT
  - Ocean surveillance--Radar
  - Surface Weather
    - Brag line determination
    - Sea State information
  - Airspace Awareness
- Integrated Fires
  - EW vs adversary OTHR, C2 & SIGINT



Customers:
- o Maritime (Navy)
- o Unmanned vehicles (air & surface)
- o Aircraft (Navy & Air Force)

Channel Capacity

Information is a commodity measured in bits per sec

Shannon Hartley Equation

$$C = B\log_2(1+SNR)$$

where

$$SNR = \frac{P_r}{BN_0}$$

Friis Transmission Equation

$$\frac{P_r}{P_t} = G_t G_r\left(\frac{\lambda}{4\pi R}\right)^2$$

Converting to decibels (dB)

$$Pr_{dB} = Pt_{dB} + Gt_{dB} + Gr_{dB} - P_L$$

$$P_{LdB} = 20\log\left(\frac{4\pi R}{\lambda}\right)$$

Scenario	C Mbps	B MHz	No dBw	Pt [W]	Gt dBi	Gr dBi	Freq MHz
Forward Link	58	3	-160	200,000	24	2	5
	42	3	-160	200,000	24	2	30
Back Link Tx=100W	25	3	-160	***100***	2	24	5
	9	3	-160	***100***	2	24	30
High Noise No= -140 dBm/Hz	38	3	***-140***	200,000	24	2	5
	22	3	***-140***	200,000	24	2	30
Low band width B=1 MHz	20	1	-160	200,000	24	2	5
	15	1	-160	200,000	24	2	30
Low Gain Gt=18 dBi	52	3	-160	200,000	***18***	2	5
	36	3	-160	200,000	***18***	2	30
Average	**31.8**						

PHaRLAP Model Output

$$\frac{dx}{d\tau} = \frac{c}{n}\left(\cos\chi + \sin\chi \frac{1}{n}\frac{\partial n}{\partial \chi}\right)$$

$$\frac{dz}{d\tau} = \frac{c}{n}\left(\sin\chi - \cos\chi \frac{1}{n}\frac{\partial n}{\partial \chi}\right)$$

$$\frac{d\chi}{d\tau} = \frac{c}{n^2}\left(\cos\chi \frac{1}{n}\frac{\partial n}{\partial z} - \sin\chi \frac{1}{n}\frac{\partial n}{\partial x}\right)$$

Where:

χ is the angle between the wave normal and the respective axis;

c is the speed of wave propagation in a vacuum,

n is the refractive index.

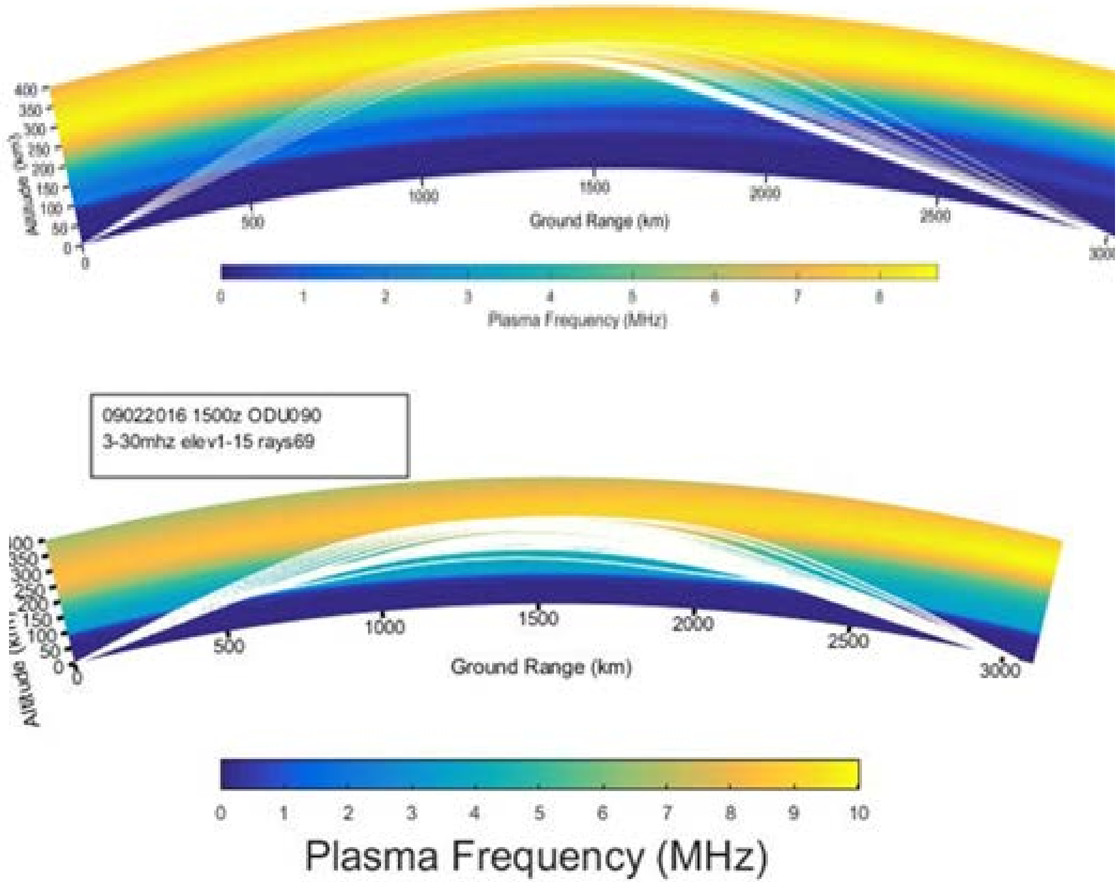
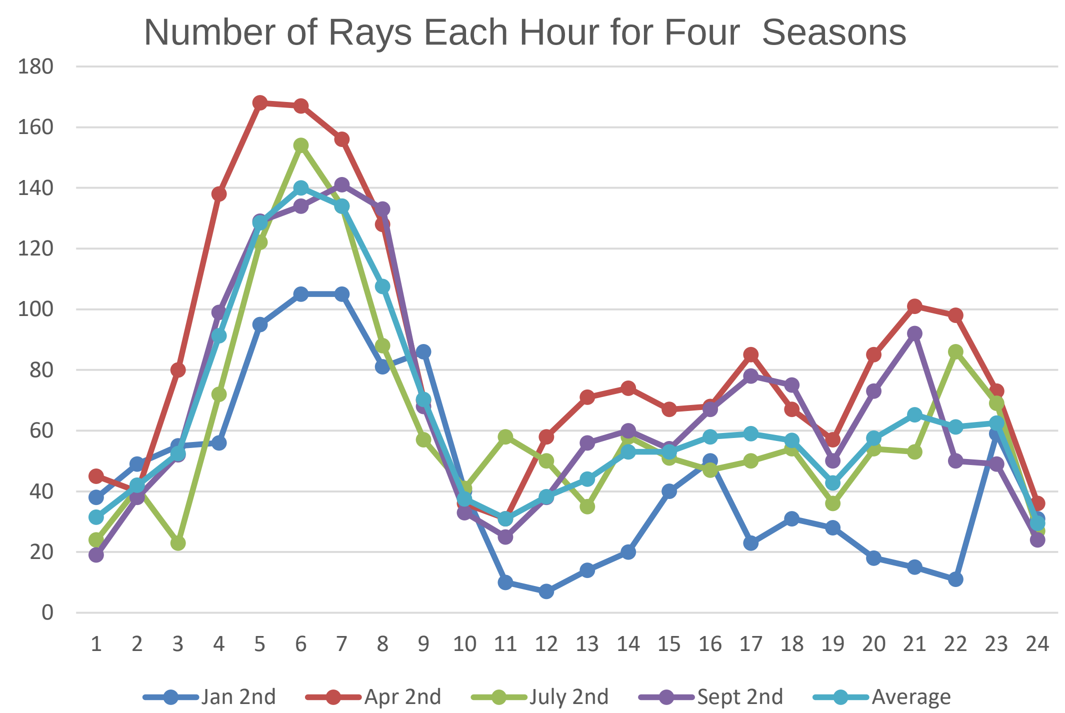


Figure 3 is a PHaRLAP plot that shows rays transmitted at different frequencies and elevations all "landing" at a precise predetermined location. The diagram also indicates the gradient of the ionosphere's plasma frequencies. The top graph is local midnight, and the lower graph is local noon. At night, the ion concentration is lower and at a higher altitude.

PHaRLAP Model Data

Number of Rays						
Time of Day		Number of Rays				
UT Hour	*Local Hour*	*Jan 2nd*	*Apr 2nd*	*July 2nd*	*Sept 2nd*	*Average*
0	5	38	45	24	19	31.5
1	6	49	40	41	38	42
2	7	55	80	23	52	52.5
3	8	56	138	72	99	91.25
4	9	95	168	122	129	128.5
5	10	105	167	154	134	140
6	11	105	156	134	141	134
7	12	81	128	88	133	107.5
8	13	86	70	57	68	70.25
9	14	40	36	41	33	37.5
10	15	10	31	58	25	31
11	16	7	58	50	38	38.25
12	17	14	71	35	56	44
13	18	20	74	58	60	53
14	19	40	67	51	54	53
15	20	50	68	47	67	58
16	21	23	85	50	78	59
17	22	31	67	54	75	56.75
18	23	28	57	36	50	42.75
19	0	18	85	54	73	57.5
20	1	15	101	53	92	65.25
21	2	11	98	86	50	61.25
22	3	59	73	69	49	62.5
23	4	31	36	27	24	29.5



Aperture

$$W(r,\theta,\phi) = \frac{1}{2}\mathrm{R}(E \times H) = \frac{1}{2\eta}\left|E\right|^2 \hat{r}$$

$$U(\theta,\phi) = r^2 W(r,\theta,\phi) = \frac{r^2}{2\eta}\left|E(r,\theta,\phi)\right|^2 \hat{r}$$

$$D(\theta,\phi) = \frac{4\pi U(\theta,\phi)}{\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta \, d\theta \, d\phi}$$

$$D_0 = 2N\frac{d}{\lambda}$$

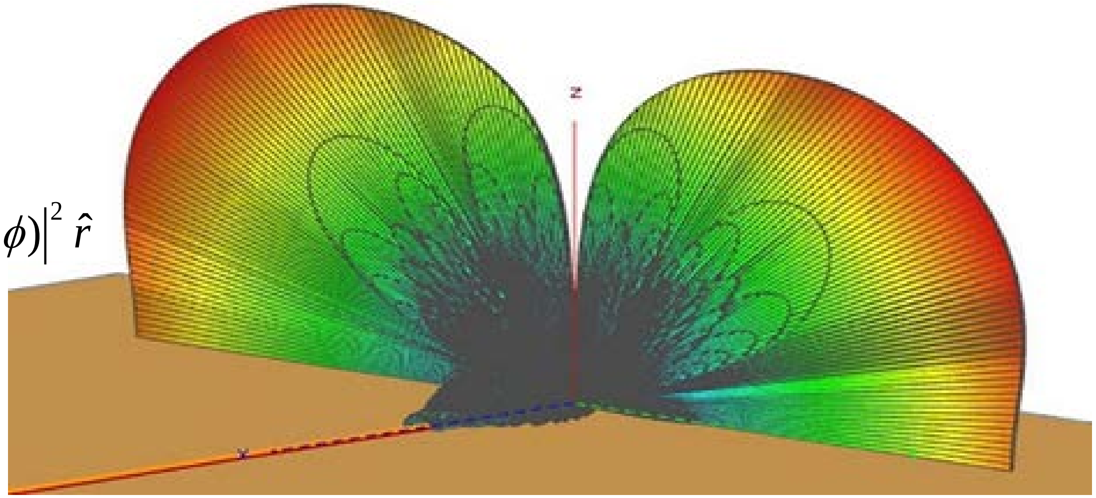


Figure 4: FEKO output of far field for 152 element HF array. This aperture has narrow azimuth focus and wide elevation focus.

1. Ionosphere can support ultra wide bandwidths
2. Sky wave communications can compete with SATCOM or at least mitigate SATCOM vulnerability
3. Digital Signal Processing and Software Defined Radio reduce the cost and risk

Bent Ray Communications

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Ray Bender

Iona S. Fear

Physics of Refraction

$$\mathbf{F} = -e\mathbf{E} \qquad (1)$$

$$\mathbf{F} = m\frac{d^2\boldsymbol{x}}{dt^2} = m\omega^2\mathbf{x}$$

$$x = \frac{-e}{m\omega^2}\mathbf{E}$$

$$\mathbf{P} = -N_e e\boldsymbol{x} \qquad (4)$$

$$\mathbf{P} = \frac{N_e e^2}{m\omega^2}\mathbf{E} \qquad (5)$$

Using the constitutive relations of Maxwell's equations, the electric flux density (**D**) is composed of a free space component, equal to $\boldsymbol{\varepsilon_0}\mathbf{E}$. Where ε_0 is the permittivity of the medium, and a material component, equal to the dipole moment (**P**).:

$$\mathbf{D} = \boldsymbol{\epsilon_0 E + P} \qquad (6)$$

$$\mathbf{D} = \boldsymbol{\epsilon_0 E + P} =$$

$$\mathbf{D} = \boldsymbol{\epsilon_0 E} - \frac{N_e e^2}{m\omega^2}\mathbf{E} = \boldsymbol{\epsilon_0}\{1 - \frac{\omega_p^2}{\omega^2}\}\mathbf{E}$$

$$\omega_p = \sqrt{\frac{N_e e^2}{m\epsilon_0}}$$

$$f_p = \frac{\omega_p}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{N_e e^2}{m\epsilon_0}}$$

$$f_p \cong 9x10^{-3}\sqrt{N_e}$$

$$\mathbf{D} = \epsilon_0\left\{1\frac{(2\pi f_p)^2}{(2\pi f)^2}\right\}\mathbf{E}$$

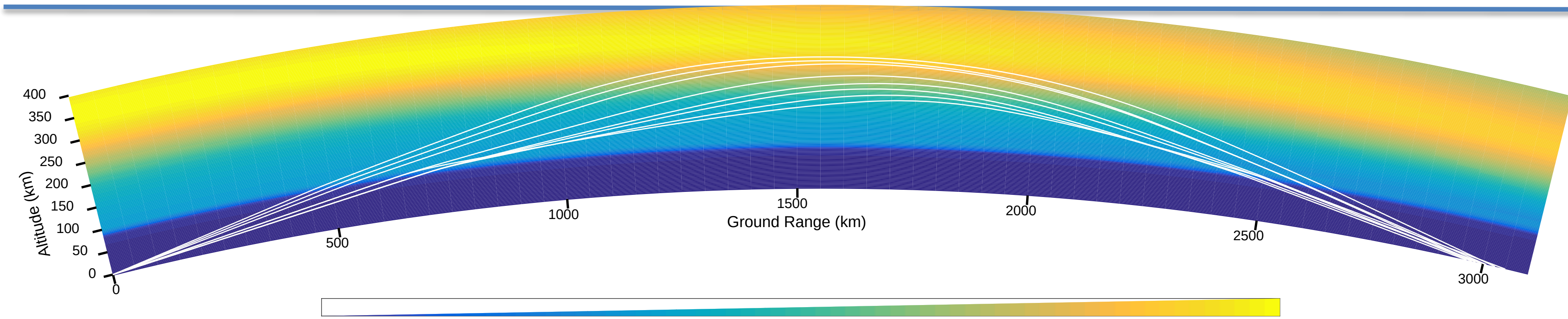
Let

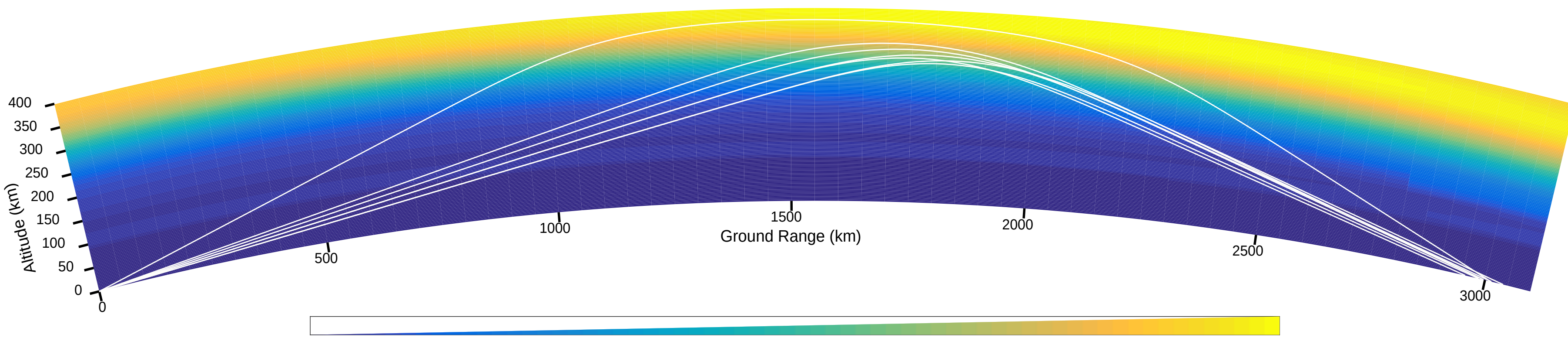
$$\left\{1 - \frac{(2\pi f_p)^2}{(2\pi f)^2}\right\} = \epsilon_r$$

$$\mathbf{D} = \epsilon_0\epsilon_r\mathbf{E}$$

$$k \equiv \frac{2\pi}{\lambda} = c\sqrt{\epsilon_r\epsilon_o\mu_o}$$

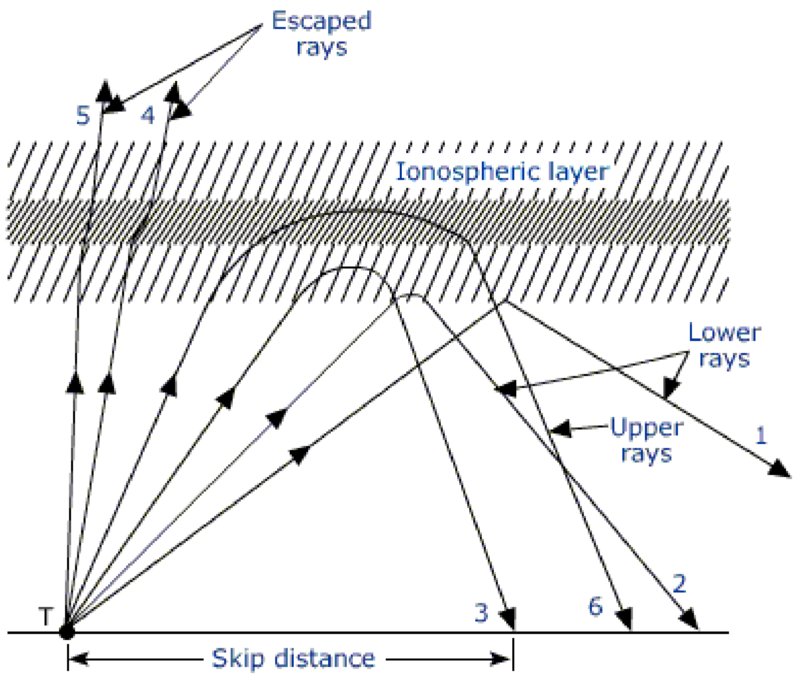
5. Why will it be successful?

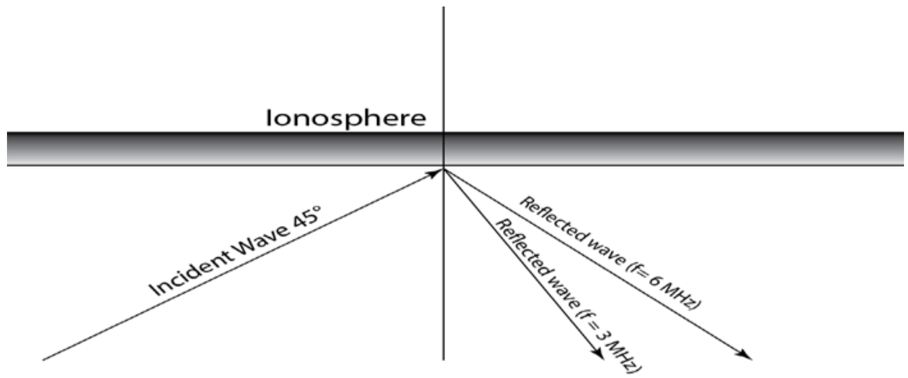




Beam forming to put high power at receiver
Wide bandwidth at receiver
Shannon equation proves it will work

5 Why will it be successful?





7. How much will it cost?
8. How long will it take?
9. What are the midterm and final "exams" to check for success?

How much will it cost?

- 200k in 2016—Modeling and Simulation
- 500k in 2017—Test on ROTHR or build prototype

How long will it take?

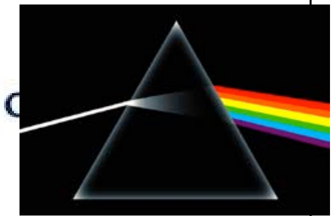
- Two years

What are the midterm and final "exams" to check for success?

- CONOPS and Technical Analysis @12 months
- Demonstration @ 24 months
- Fleet testing @ 36 months

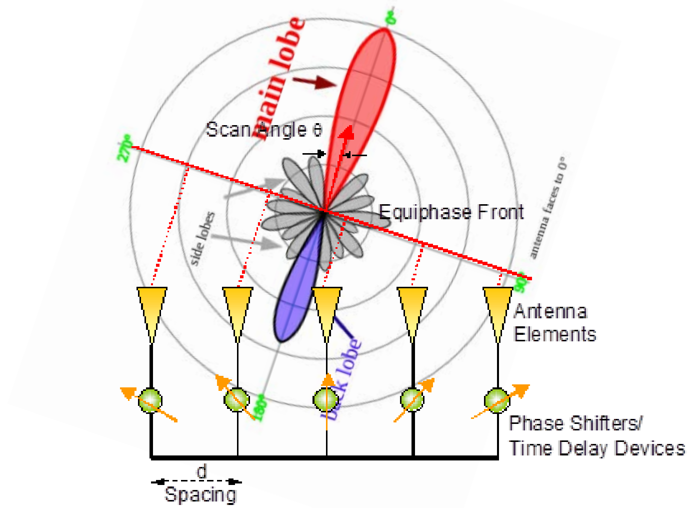
10. Why Bent Ray Communication?

- **Operational Naval experience**
  - EW Experience in Iraq (Desert Storm) and Kosovo
  - Warfare Commander of Carrier Strike Group, in Command and Control and N6
  - XO of CVN
  - CO of Navy Warship
  - EA-6B Commanding Officer
  - Acquisition - Deputy PM Logistics– NAVAIR
  - DARPA Intern
- **Education**
  - PhD student ODU- Electrical and Computer Engineering
  - Master on National Resource Strategy at National Defense University
    - Area of study : Space, China, Senior Acquisition course
  - MS System Eng. NPGS
    - Area of Study: Electronic Warfare
  - Defense Acquisition University PM Course
  - DAWIA Level 3 Certified
- **Industry Experience**
  - 8 years with Northrop in Cyber and EMW experience

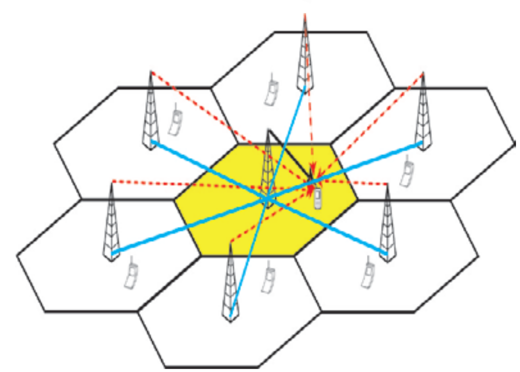


4. What's new in this approach?

Why Successful?
- Spider Architecture
- High power at receiver
- Wide Bandwidth at receiver
- Shannon equation proves it will work



- Land base segment: *Analogy---Cell Tower*
  - High Gain, High Power, Directional scanning (AESA)
  - High bandwidth within controlled beam
  - Direction beam allows:
    - LPI/LPD, Anti-Jam
    - Frequency reuse, ITU and FCC approval
  - High power at receive with high bandwidth yields high data rate



- Mobile segment: *Analogy – Cell Phone User*
  - Low power Transmit for Low Probability of Detection
  - Similar to Mobile Cell architecture where:
    - All comms travel via towers
    - Here the cell tower range is 2000 NM