High Frequency Communications – An Introductory Overview - Who, What, and Why?

12 April, 2012

Abstract: *Over the past 60+ years the use and interest in the High Frequency (HF -> covers 1.8 – 30 MHz) band as a means to provide reliable global communications has come and gone based on the wide availability of the Internet, SATCOM communications, as well as various physical factors that impact HF propagation. As such, many people have forgotten that the HF band can be used to support point to point or even networked connectivity over 10's to 1000's of miles using a minimal set of infrastructure.*

This presentation provides a brief overview of HF, HF Communications, introduces its primary capabilities and potential applications, discusses tools which can be used to predict HF system performance, discusses key challenges when implementing HF systems, introduces Automatic Link Establishment (ALE) as a means of automating many HF systems, and lastly, where HF standards and capabilities are headed.

Course Level: *Entry Level with some medium complexity topics*

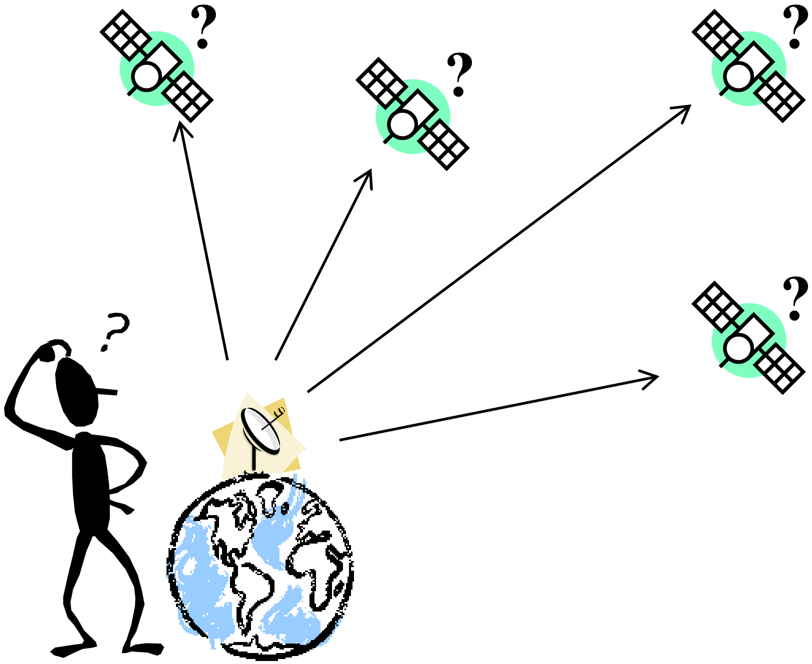
Agenda

- HF Communications – Quick Summary
- How does HF Propagation work?
- HF - Who uses it?
- HF Comms Standards – ALE and Others
- HF Equipment - Who Makes it?
- HF Comms System Design Considerations
  - General HF Radio System Block Diagram
  - HF Noise and Link Budgets
  - HF Propagation Prediction Tools
  - HF Antennas
- Communications and Other Problems with HF Solutions
- Summary and Conclusion
- I’d like to learn more

= “Critical Point”

I Love HF, just about anybody can operate it!

On the other hand…



HF Communications – Quick pretest

- **How does HF Communications work?**
  a. Magic
  b. Voodoo
  c. I have no idea?
  d. Reflections between the ionosphere and the ground

- **Is HF Communications 100% reliable?**
  a. Yes
  b. No
  c. Depends

- **Can HF Communications be used to support internet communications?**
  a. Yes
  b. No
  c. Depends

- **Are HF antennas Large, overwhelming, and Ugly?**
  a. Yes
  b. No
  c. Depends

- **Who uses HF Communications?**
  a. Aircraft
  b. Ships
  c. Amateur Radio Operators
  d. People
  e. Governments
  f. Political entities
  g. Shortwave broadcasters
  h. Relief Agencies
  i. Cars
  j. Military
  k. Bad guys
  l. All of the above

HF – Quick Summary

HF & Communications (1 of 2)

- **What Does HF Mean?**
  - HF stands for HIGH FREQUENCY
  - HF Frequencies range from ~1.8MHz - 30MHz, these reside just ABOVE the AM Radio broadcast band to slightly ABOVE the CB Radio Bands.
    - AM Radio Broadcast -> 550 – 1600 KHz
    - Very High Frequency (VHF) -> 30 – 300MHz (land mobile, Line of site links)
    - Ultra High Frequency (UHF) -> 300 – 3000 MHz (land mobile, line of site, WiFi, cellular…)
  - HF is also known as *SHORTWAVE*.
    - HF wavelengths are approx. 10 – 160meters long (33' –> 525')

- **What is HF Communications?**
  - Use of the HF spectrum to design and implement communications systems that take advantage of the physical properties of the HF Radio Channel.

- **Why use HF for Communications?**
  - HF's single greatest value is its ability to provide reliable short AND long-range Beyond Line Of Sight (BLOS) communications.
  - HF can support Point-Point and P-Multipoint data rates up to ~10kbps w/o relays – Integrates with many COTS products.
  - HF is generally available, rapidly and readily deployable – requires very little infrastructure and can be made extremely reliable.

HF & Communications (2 of 2)

- **Who Uses HF Communications?**
  - Users that that need long or short comms unaffected by terrain:

Aircraft	Commercial Interests	Bad Guys (e-Bay purchases)
Ships	Relief Agencies	Amateur Radio Operators
Vehicles	Political Entities	
Military	Governments	

- **How Does HF Communications work?**
  - Iononized (charged) layers > 85km above the earth are created by the suns interaction with neutral air with each layer having varying properties.
  - Radio waves are bent back to earth when they interact with the layers.

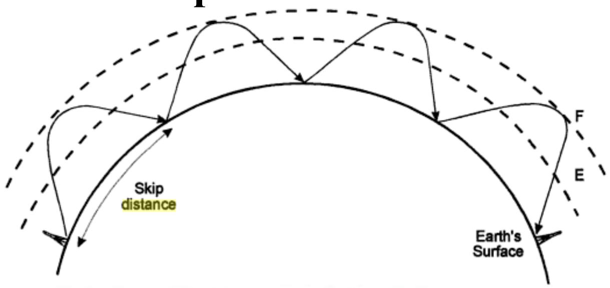
- **Ok, if HF is so Great, why doesn't everyone use it??**
  - HF propagation is impacted by the actions of the Sun via "Sunspots"
  - Data throughputs from 75bps->19.2kbps under poor-> very good conditions,
  - From 2-10MHz, the noise environment can rise 33 – 70dB ABOVE thermal noise (kTB) due to manmade and atmospherics„ (fluorescent lights, T-storms, fish tanks, electric fences, Xmas lights, old electric motors, etc)
  - Common perception is that data rates are "low" and antennas are LARGE

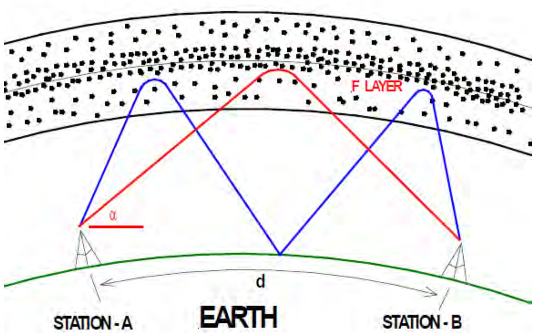
Breaking NEWS: MIL-STD-188-110C Appendix D Data Waveform Suite (approved Sept 2011) supports HF Channel bandwidths ranging from 3 – 24KHz in 3kHz steps, allowing 75bps -> 120Kbps.

HF Propagation Modes - SUMMARY

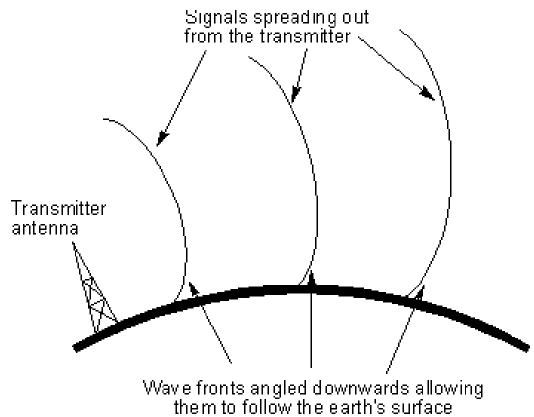
- There are 3 primary modes of HF propagation (NOTE: LOS not shown):

Sky-wave	Ground / Surface Wave	Near Vertical Incidence Skywave (NVIS)
Provides Single (<4000km) or Multi-hop (7 hops, 15,000km) communications via ionospheric reflections	Provides communications along the earths surface out to distances approaching 100's of km	Provides reliable communications out to 400km by directing energy almost straight up (60 – 90º) and it being reflected back to earth

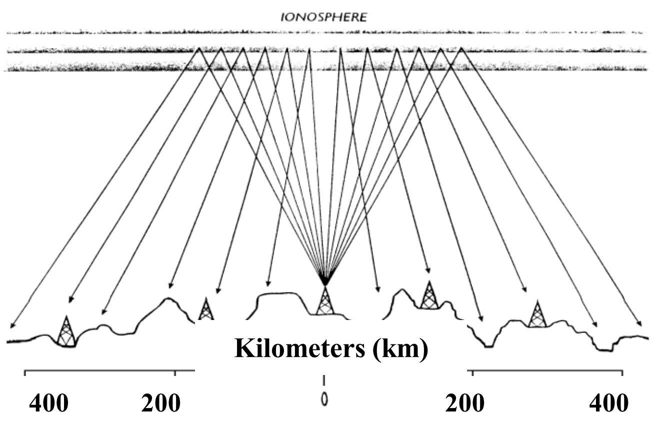




Uses 2-30MHz w Day/Night frequency band transitions.



Typically use frequencies <10MHz, better over seawater, worse over desert, distances <150km using Vertical Polarization



Uses frequencies <10MHz (2-5MHz Night, 5-10MHz Day), radiation must be focused directly overhead

Did You Know?

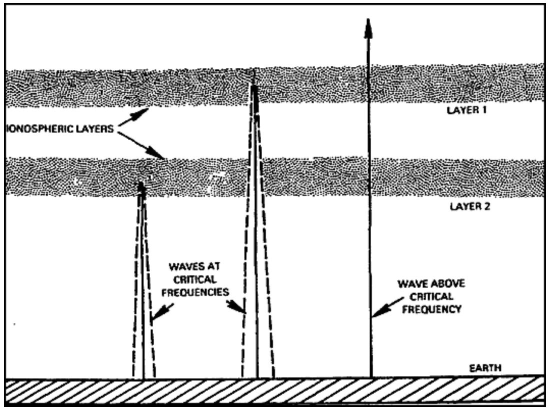
B-17 Bombers (WWII Vintage)

- Used HF comms with other aircraft and ground stations out to 3000miles
- Usual reliable distances were 250/750 miles voice/CW (Morse Code).
- Frequency coverage was1.5 -12.5MHz.
- Antenna was either the skin of the aircraft, a long wire on top OR a trailing antenna slid out from the bottom of the aircraft belly (a 10lb+ weight hung on this)

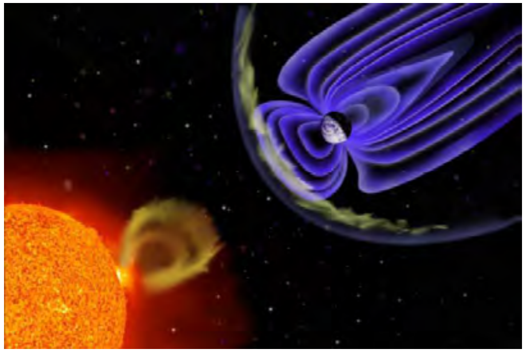
WWII German Recon / Scout Vehicles

- Visible over the top of the vehicle is the open-frame HF antenna in use for these types of recon vehicles.
- This is the earliest-known implementation of HF NVIS which allowed for high-angle sky wave operations.
- The "cage” type structure would appear to be a support for camo netting, but is in fact the HF radio antenna.
- Operational Frequencies were in the 2 – 9MHz range

How Does HF Propagation Work?



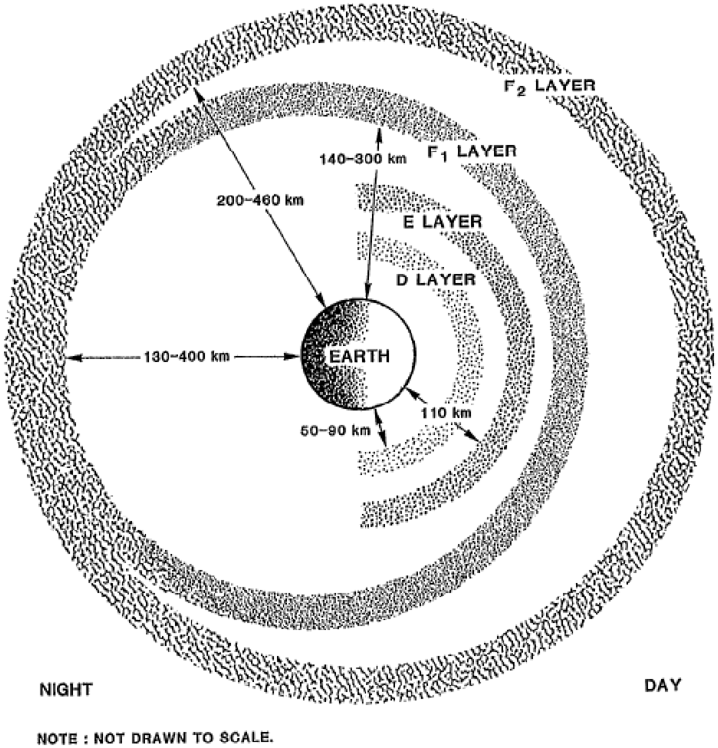
The Role of The Sun……How the Sun Opens & Closes HF Communications

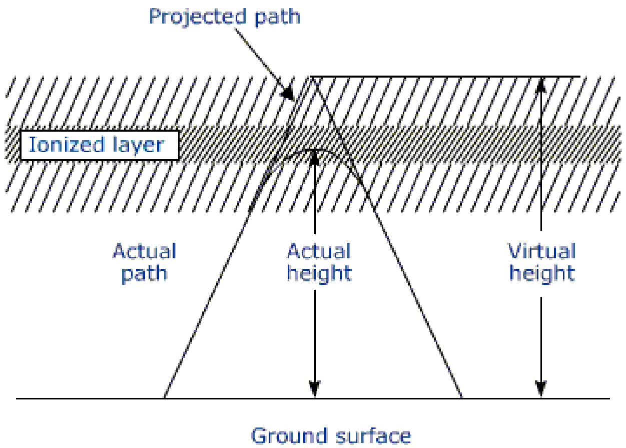


The Sun's energy causes atoms in the upper atmosphere to become charged. These charged particles are called **ions**.

This charged region of the upper atmosphere is called the **ionosphere.**

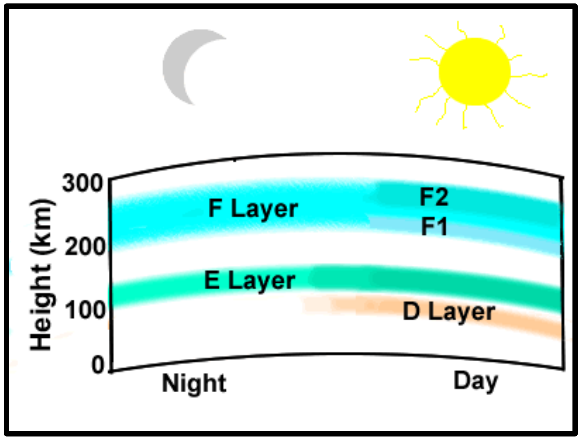
So…….when a radio wave enters this region of charged particles, its direction of travel is altered.





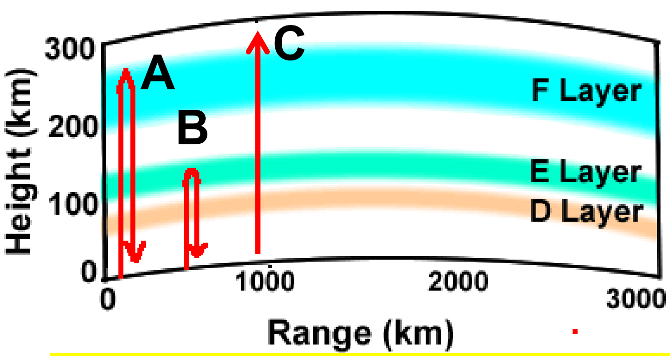
HF Radio Waves interact with the charged particles, at some point, the interaction causes the wave to be reflected / refracted BACK DOWN to the earth

The Critical Frequency – The "Foundation" for HF Propagation



- ~4 Ionized layers get established based on the sun/earth interaction
  - D layer strong during the day, layer disappears at night
- Layers fairly well understood – heights approx.
- Calculating useable paths between any 2 points is fairly well understood – may be multiple paths

In the Real World, Critical Frequency calculations are automated

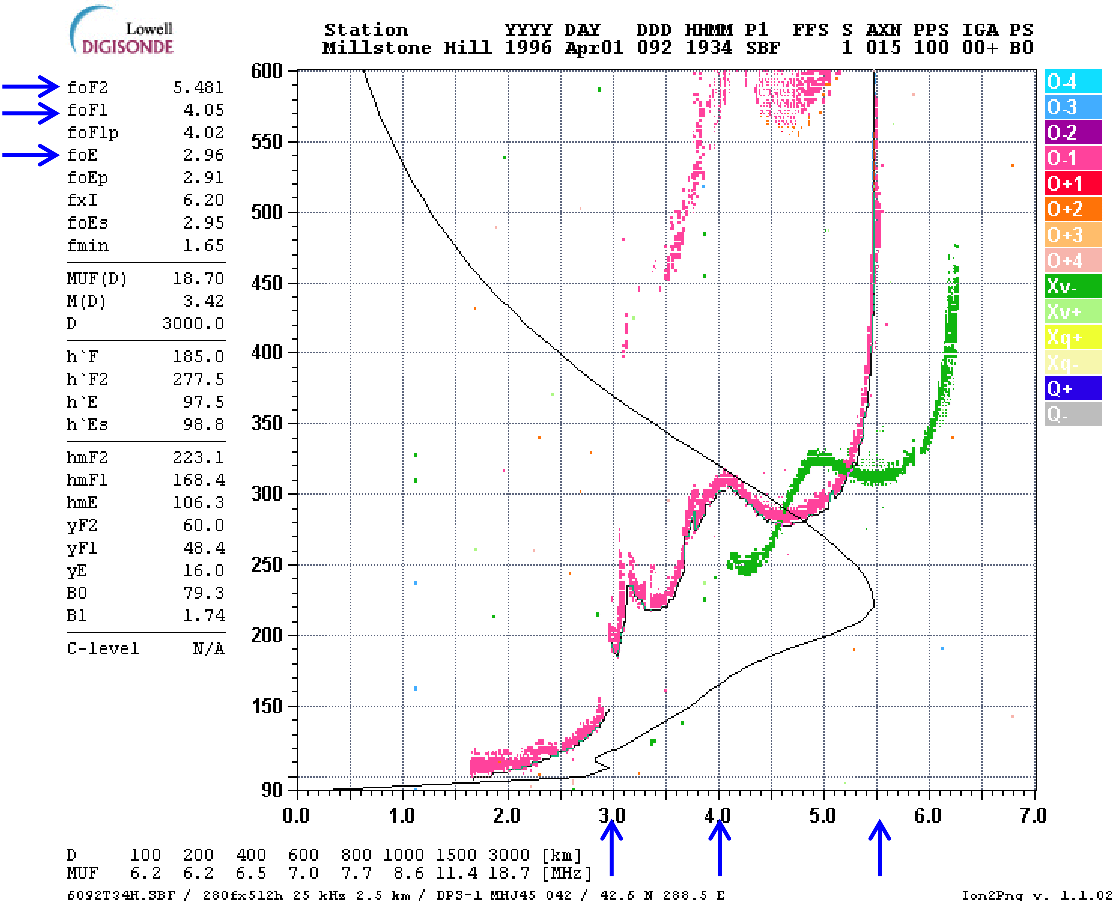


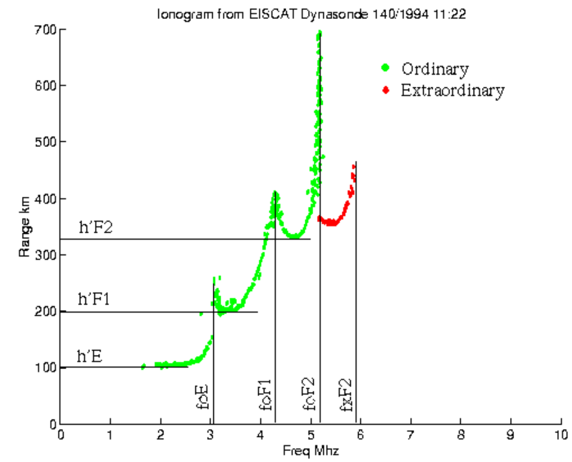
- Critical Frequency (fo) – Frequency (F) where a vertically incident (90º) ray refracted back to earth,
  - **Ray A** -> F > foE (E layer critical frequency) and < foF,
  - **Ray B** -> F < foE.
  - **Ray C** -> F > foE AND foF (often referred to as foF1 and foF2)
    - Frequency'ss > foF2 will not be reflected and will go into space.

The Physics of HF Propagation is well understood

Above Figures and text adopted from: **HF and Lower Frequency Radiation Course** Offered free online by the Naval Postgraduate School
http://www.weather.nps.navy.mil/~psguest/EMEO_online/module3/

Ionosoundes – Measuring the Critical Frequency





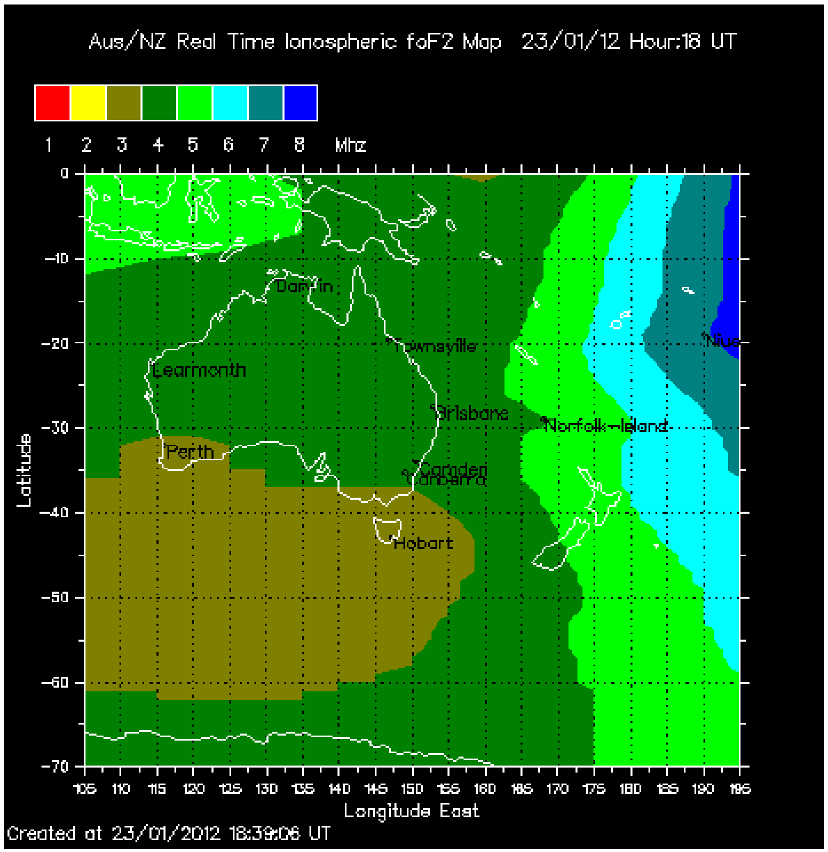
- *Typical critical values are 9 MHz at noon and 5MHz at night.*
- *During periods with low sunspot activity the critical frequency can be as low as 3MHz.*

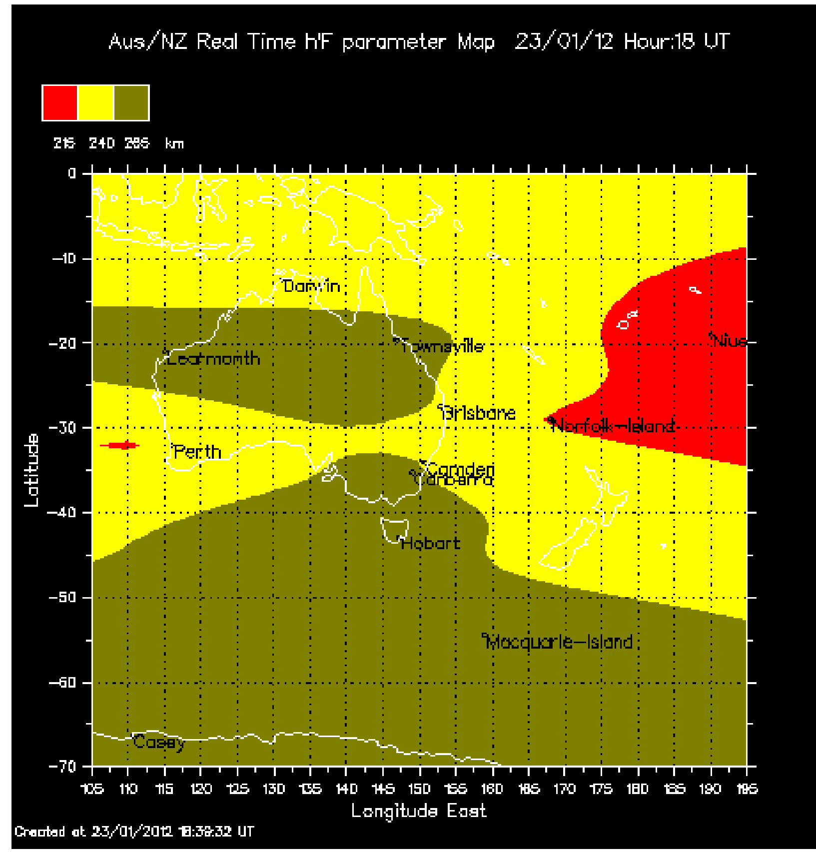
Critical frequencies are continuously measured in **several hundred** places around the world by devices called ionosondes.

Ionograms in 2-D

Critical Frequency Map for Australia / NZ using a series of Channel sounders

Ionospheric F-layer Virtual Height

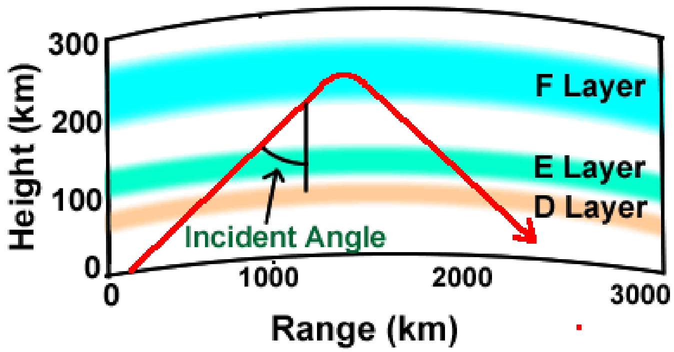




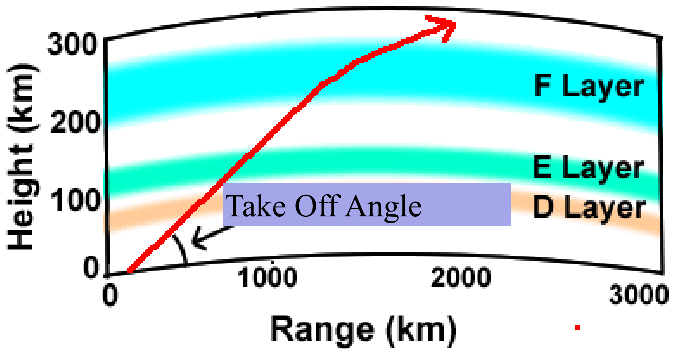
http://www.ips.gov.au/HF_Systems/1/1

"Virtual heights" are obtained from the time of flight of the transmitted radio pulse from transmitter, ionospheric reflection and back to the receiver.

HF Maximum Useable Frequency



Ray at a lower frequency than the F layer MUF, but higher than the E layer MUF.



Ray at a frequency higher than E layer MUF and F Layer MUF

- Maximum Useable Frequency (MUF)
  - Highest frequency that can be used to communicate between two locations.

    MUF = [f_c/Cos (Incident Angle)]

    = [f_c/Sin(Take Off Angle)] where

    fc = critical frequency at the time of the communications for the specific layer

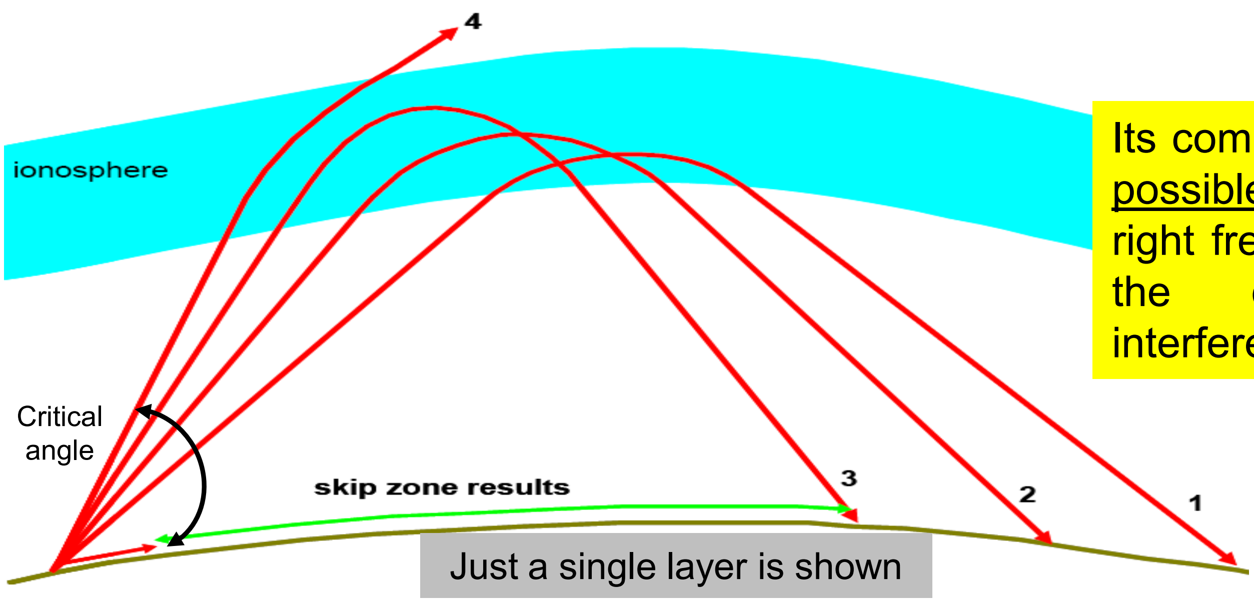
    Take Off Angle (TOA) = angle of the signal wrt the ground (NOTE: TOA = 90º - Incident Angle)
  - MUF changes with time and geographic location of the ionospheric refraction points.

The MUF for a given path with multiple refraction points will be equal to the lowest MUF along the path.

Above Figures and text adopted from: **HF and Lower Frequency Radiation Course** Offered free online by the Naval Postgraduate School http://www.weather.nps.navy.mil/~psguest/EMEO_online/module3/

HF Propagation Paths – Many Possibilities

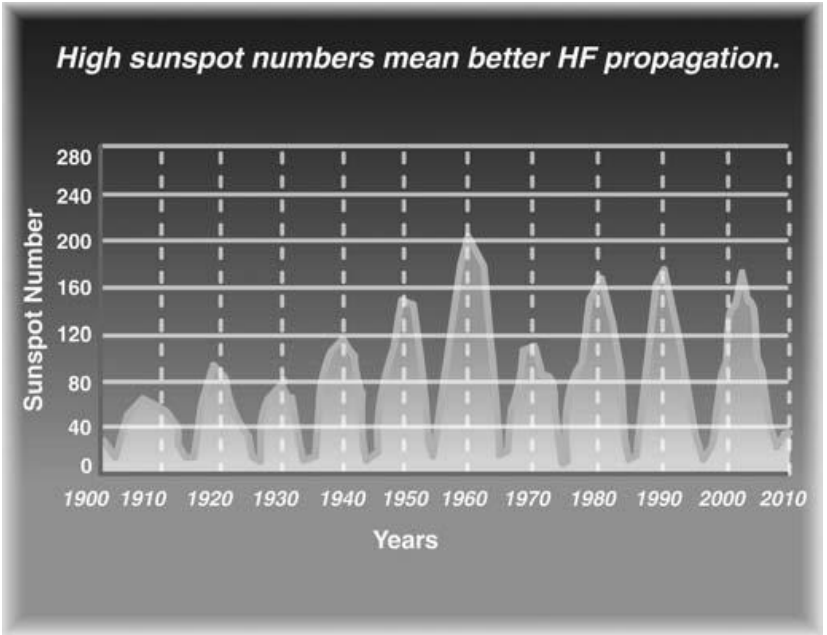
- **PATH 1** - at low elevation angles the path length is greatest (longest "skip")
- **PATH 2 and PATH 3** - as the elevation angle is increased, the path length decreases and the ray is reflected from higher in the ionosphere
- **PATH 4** - If the elevation angle is increased beyond the critical elevation angle for that frequency then the wave penetrates the ionosphere and there is an area around the transmitter within which no sky wave communications can be received
  - (U) To communicate within this so called "skip zone", the frequency must be lowered.



Its common for multiple paths to be possible, however, selection of the right frequency and TOA minimizes the chances for multipath interference

Sunspots

- HF propagation conditions are tied directly to the state of the Sunspot activity.
  - More sunspots, the higher the ionization of the F2 Layer
  - Observed sunspots follows an 11 year cycle (no spots –> MAX # SPOTS –> no spots).
  - Our ability to estimate HF link performance is based on our knowledge of statistics tied to sun spots.

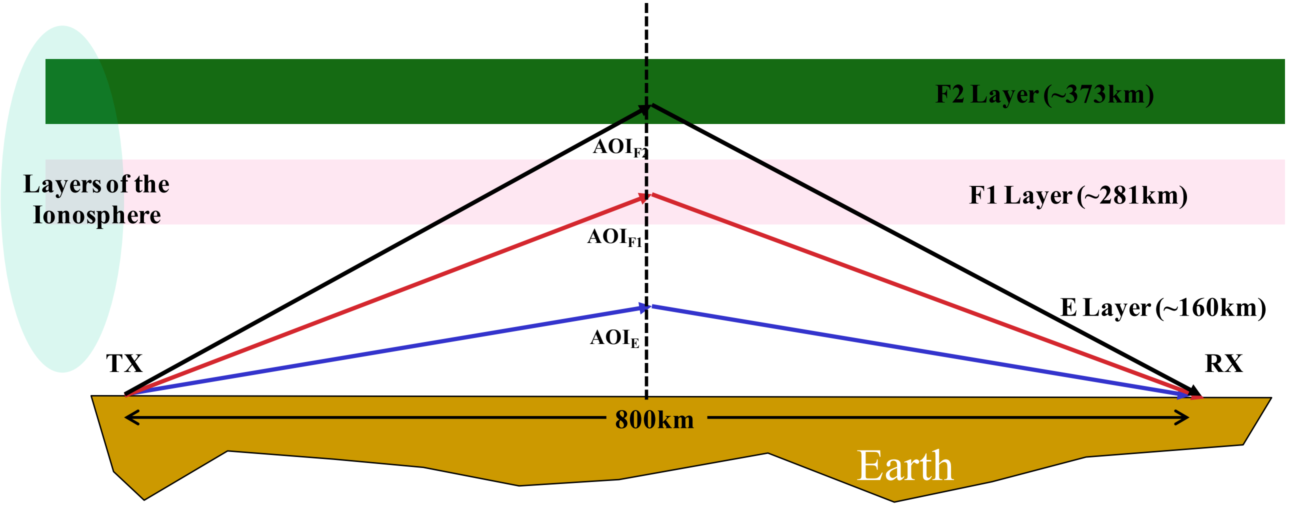


- Solar storms (intense cosmic activity) can change the critical frequency in a matter of minutes -> hrs
  - One minute the link is fine, in a matter of minutes, its GONE

During a sunspot maximum, the highly ionized F2 layer acts like a mirror, refracting the higher HF frequencies (above 20 MHz) with almost **no loss** above that due to free space with communications at distances in excess of 10,000miles commonplace using 10watts or less with frequencies in the 20 – 30MHz range.

During short summer evenings, the MUF can stay above 14 MHz and it can support communications to some point in the world around the clock.

REAL WORLD HF Propagation Example – Using Ionsound Results



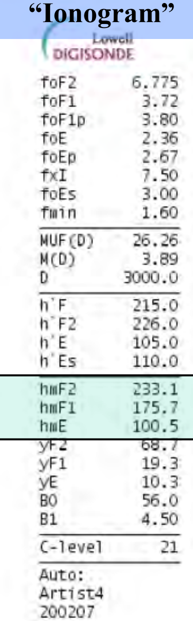
Example:
- Path length = 800km
- 1 - Layer Heights and f_c measured using an automatic channel sounder (See Item Below) – min Virtual Ht used
- 2 - Angles calculated using simple geometric principles
- Q: What is the MUF <u>AND</u> the Target Operating Frequency (TOF) or Frequency of Optimum Transmission defined to be = 85% of the MUF?

$$MUF = [f_c/\text{Cos (Incident Angle)}] = [f_c/\sin(TOA)]$$

Layer	Layer Height[1]	Critical Frequency[1]	AOI -> Angle of Incidence[2]	Take Off Angle[2]	Cosine(AOI)	MUF (MHz)	Target Operating Frequency (MHz)
E	160km	2.36MHz	68	22	.37	6.38	5.42
F1	281km	3.72MHz	55	35	.57	6.53	5.55
F2	373km	6.775MHz	47	43	.68	9.96	8.47

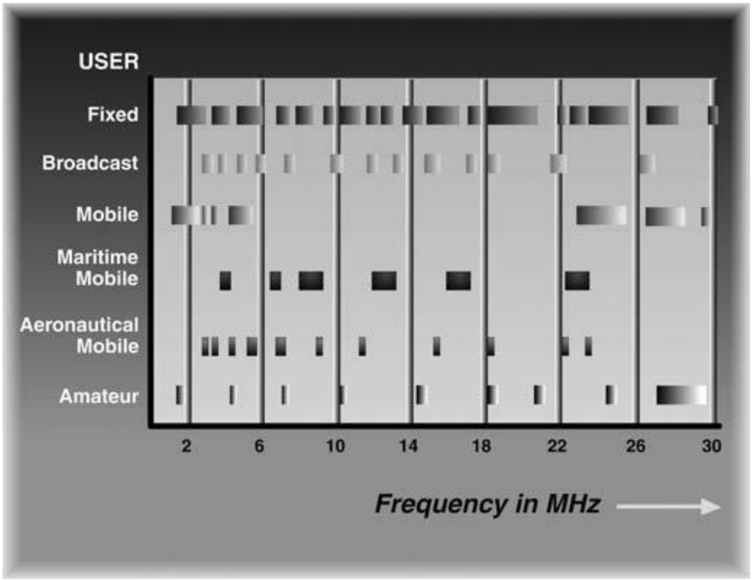
For the above scenario – Choose the TOF to be equal to ~8.5MHz to minimize time spent in the D layer (not shown)

Real World "Ionogram"



Units in Miles

Who Uses HF?

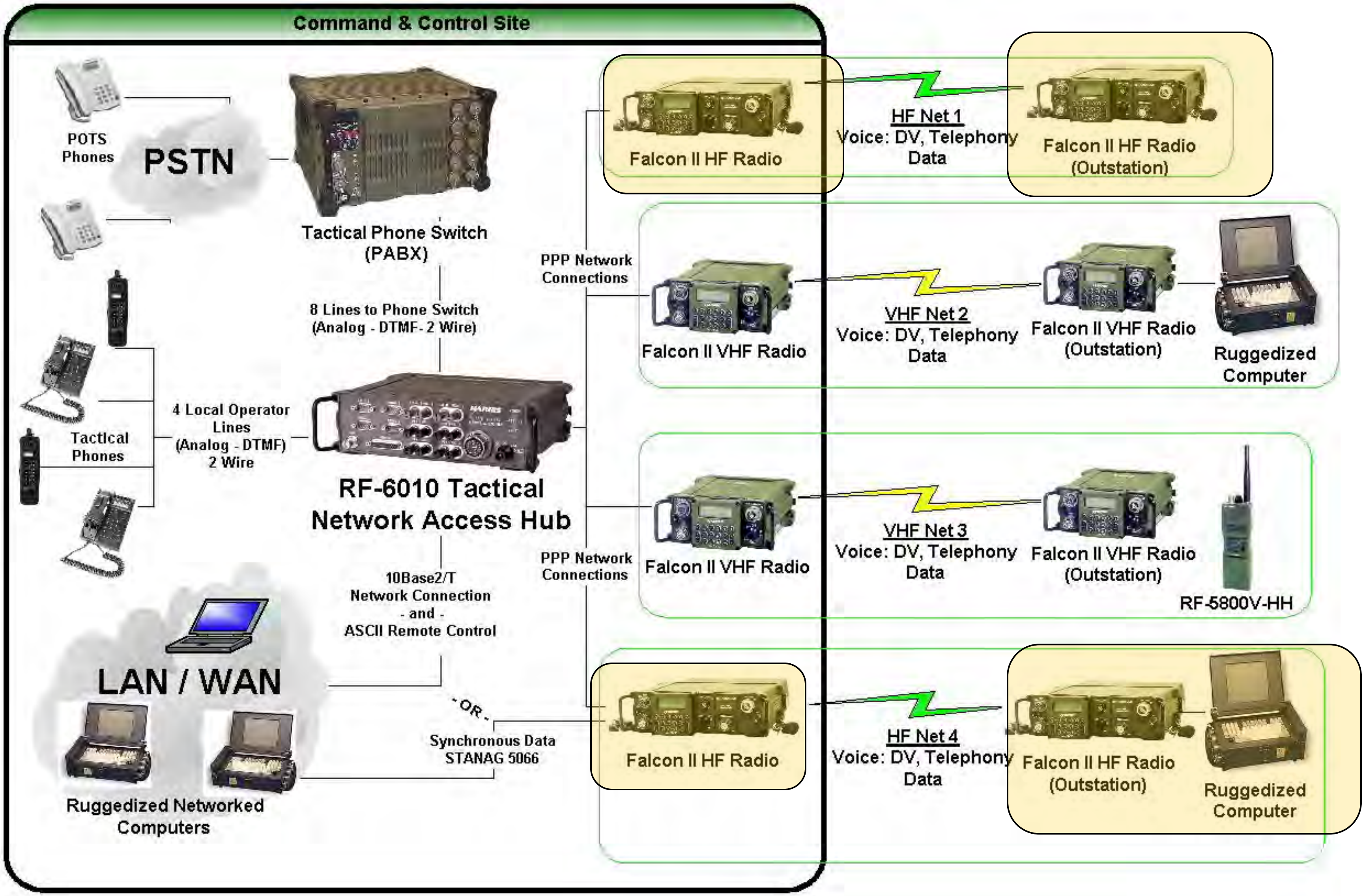


USER
Fixed
Broadcast
Mobile
Maritime Mobile
Aeronautical Mobile
Amateur
2
6
10
14
18
22
26
30
Frequency in MHz

HF Communications Users

- **Ham Radio Operators WORLDWIDE**
  - Every country in the world EXCEPT North Korea allows amateur radio operation
- **Military**
  - Special Forces
  - Government entities (DoD, IC…)
- **Government**
  - Emergency Operations centers
- **Aeronautical Interests**
  - HF provides ATC coverage in the polar regions where SATCOM coverage is unreliable.
    - HF is the standard for ATC en route services over approximately 75 percent of the Earth's surface.
  - HF used for personal phone calls over long distances, for flight following and for the receipt of pertinent weather forecasts and communications.
- **Shortwave Broadcasters**
  - BBC, VOA, HCJB,…
- **Worldwide Weather Broadcasts**
- **Commercial Interests**
  - Australian Outback
  - CB Radio (27MHz)
- **Various Relief Organizations**
  - UN
  - Red Cross
- **Others:**
  - Terrorists
  - Drug dealers
  - Para-Military
- **Maritime Interests**
  - SHIPCOM – privately held HF V&D network for coast to coast comms for use in disasters by local, state, and federal public agencies.
  - Global Wireless - 24 radio stations strategically located to provide world-wide maritime coverage.

Example Harris Corporation FALCON® II Tactical Networking



HF Communication STANDARDS – ALE, Data Modems, …..

HF Data Standards

- In the HF bands, in a 3KHz channel, communications between sites is limited by current HF Data standards to be:
  - MAX of 19.2kbps -> under very good propagation conditions,
  - MIN of 75bps -> under poor conditions (if the link exists at all)
  - Typical skywave rates usually limited to ~4.8 kbps with <2.4 kbps more realistic for mutihopped skywave paths,
  - Groundwave Paths (i.e. over seawater) may exhibit rates averaging > 9.6kbps, with higher rates observed as the platforms move closer together
  - Current HF data systems dynamically adapt the data rate to the available channel as conditions change

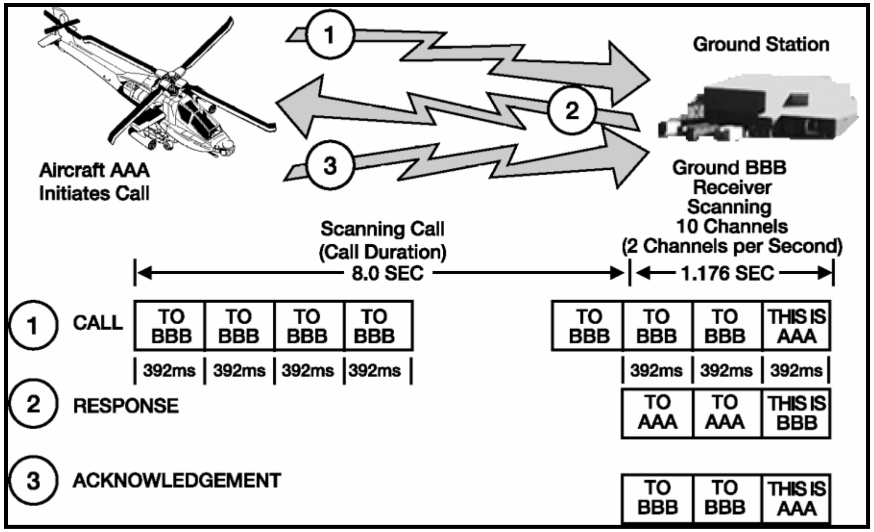
- Primary "most often seen" comms data modems on HF includes serial and Parallel Tone modems of the PSK, FSK families:
  - MIL-STD-188-110B, STANAG 4539 - MIL-STD-188-110B and MIL-STD-188-110C Appendix D, STANAG 4285, STANAG 4539, to name just a few
  - Other modes exist on the bands, but these tend to support specialized applications
  - Radar, specialized burst modes, others tend to have limited followings

- For Voice, most common standards are USB, LSB, AM, with some FM

But wait….. There's MORE!!

Automatic Link Establishment (ALE)

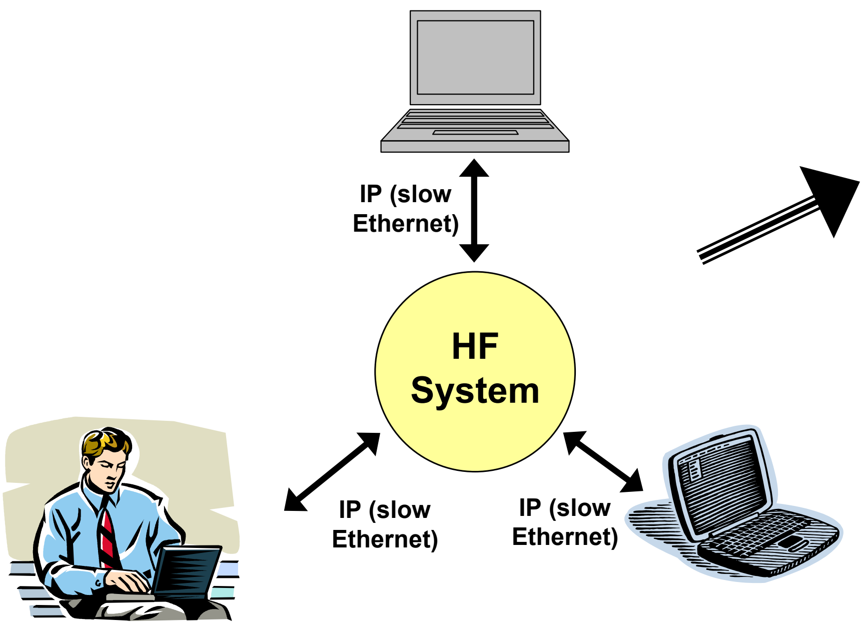
- Automatic Link Establishment (ALE)
  - Developed to address limitations of conventional/manual HF radio ops
    - Operators must pick the RIGHT FREQUENCY at the RIGHT TIME
  - With ALE, radios “sound” each other, and store “best channel” in memory
    - Radio uses the best frequency when establishing a link (typically has 10 - 20 to search over)
    - If the 1st frequency doesn’t work, it tries the next one and so forth
- 2 different versions of ALE deployed worldwide:
  - 2G ALE=> MIL-STD-188-141A and B
  - 3G ALE => MIL-STD-188-141B,
  - ALE uses the same serial waveforms as used for Data.



HF ALE helps 2 radios link up on the RIGHT CHANNEL at the RIGHT TIME. Once Linked, data communications can begin!

IP Over HF

- IP over HF isn't all that complicated as it 1^{st} seems…….
  - 2 primary COTS standards (STANAG[1] 5066 and STANAG 4538) manage it very well using 2G & 3G ALE
  - Many IP applications will work just fine using the above STANAG's



- The HF System has individual components that manage the throughput and delays versus the channel conditions, and lastly, the components that make it all happen
- ALE
- STANAG 5066
- MIL-STD-188-110B (Data modem)
- STANAG 4538 (Data modem)
- HF Radio

Many COTS Appliqués can work over IP / Ethernet based HF networks w slight adjustments

[1] NATO abbreviation for Standardization Agreement

The Sounds of HF

Many Sound Files grabbed from IARU Region 1 Monitoring System Soundfiles Collection http://www.dxzone.com/cgi-bin/dir/jump2.cgi?ID=20355

Standards

2G ALE Audio Recording (FSK) (.wav)

3G ALE (PSK) (.wav)

300baud AX.25 Packet Radio (FSK) (.wav)

MIL-STD 188-110B 1200 baud FSK

Commonly Heard

20WPM CW Audio Recording (.wav)

Over The Horizon Radar (.wav)

ACARS (Aircraft Comms Addressing reporting System) (.wav)

Inverted Audio Scrambling (.wav)

Unusual / But Heard

Radio Echoes – BOTH Short and Long Path: it takes roughly 137 milliseconds for a HF radio signal to travel around the world once.

Olivia (.wav)

Broadband Over Powerline (.wav)

Throb 4X (.wav)

Large LCD-TV on 3515 kHz (USB)

VARIABLE PULSE REPETITION FREQUENCY (16 x 64 SWEEPS @3 kHz BW) IONOSPHERIC SOUNDER (.wav)

FSKHELL

Voyager Aircraft Round the World (1986)

Future of HF Data Standards

MIL-STD-188-110C Appendix D Data Waveform Suite (approved in Sept 2011):

- Data Modem (Serial Tone)
- Supports 8 HF Channel bandwidths ranging from 3 – 24KHz in 3kHz steps, allowing 75bps -> 120Kbps
- Waveforms fully auto baud across the available data rates interleaver options available

Results of recent measurements made between Palm Bay, FL and Rochester, NY (a ground distance of 1055 statute miles) demonstrated reliable HF communications over a 3 day period with data transfer rates averaging ~96kbps over extended periods, used 64QAM modulation, and transferring over 300MB of data from one site to another over the 3-day period:

- Measurements included a Custom developed HDRHF modem that utilizes the new MIL-STD-188-110C standard along with an enhanced version of 3rd Generation Automatic Link Establishment (3G-ALE),
- Measurements included a proprietary capability to "cognitively sense" the HF spectrum being used at BOTH ends to determine if a nearby channel might be better suited to support a desired data rate.

MIL-STD-188-110C Appendix D Data Rates (bps)

Bandwidth (kHz)	Waveform Number													
	0 Walsh	1 BPSK	2 BPSK	3 BPSK	4 BPSK	5 BPSK	6 QPSK	7 8PSK	8 16QAM	9 32QAM	10 64QAM	11 64QAM	12 256QAM	13 QPSK
3	75	150	300	600	1200	1600	3200	4800	6400	8000	9600	12000	16000	2400
6	150	300	600	1200	2400	3200	6400	9600	12800	16000	19200	24000	32000	
9	300	600	1200	2400	-	4800	9600	14400	19200	24000	28800	36000	48000	
12	300	600	1200	2400	4800	6400	12800	19200	25600	32000	38400	48000	64000	
15	300	600	1200	2400	4800	8000	16000	24000	32000	40000	48000	57600	76800	
18	600	1200	2400	4800	-	9600	19200	28800	38400	48000	57600	72000	90000	
21	300	600	1200	2400	4800	9600	19200	28800	38400	48000	57600	76800	115200	
24	600	1200	2400	4800	9600	12800	25600	38400	51200	64000	76800	96000	120000	

WHO Makes HF Equipment?

HF Equipment Summary Table - by Country (no Amateur eqpt)

Nationality	Vendor	Radio	Crypto	Integrated 2G ALE Capability	Integrated 3G ALE Capability	SW	Data Modem	ALE Modem	ALE Controller	Notes
Australia	**Barrett**	YES		YES		YES	YES			
Australia	**Codan**	YES	YES	YES		YES	YES			
Australia	**QMac**	YES	YES			YES	YES			
China	**CEIEC**	YES								
China	**Sampson Telecom**	YES	YES	YES			YES			
China	**Panda**	YES		YES						
Finland	**Skysweeper**					YES	YES (SW)	YES (SW)		
Germany	**TELEFUNKEN RaComs**	YES		YES	YES	YES	YES			
Germany	**Rohde and Schwarz**	YES	YES	YES	YES		YES	YES		
Germany	**Hagenuk Marinekommunikation**	YES		**YES, unkown STD**			YES			
Italy	**Selex**	YES	YES	YES	YES	YES	YES			
Italy	**Marcoini / Selex**									See Selex
Israel	**Mobat (Motorola)**	YES	YES	YES			YES			
Israel	**Tadiran**	YES	YES	YES	YES	YES	YES			
Iran	**IRAN Electronics Industries**	YES		YES			YES			
Same as IEL	**CSS**									**Same as IEL**
Japan	**Vertex**	YES		Yes – UNK STD						
Japan	**Icom**	YES	YES							
Poland	**CTM**	YES		YES	YES	YES	YES			
Russia	**Spirit**					YES	YES			
South Africa	**RapidM**					YES	YES	YES		
South Africa	**Saab Grintek**	YES	YES	YES			YES			
Turkey	**Aselsan**	YES		UNKNOWN	YES		YES			
UK	**PC ALE**					YES		YES, v SW		Amateur Application
US	**ITT**									**Nothing found**
US	**L-3**	YES	YES	YES			YES			
US	**Sunair**	YES		YES	YES (SW)	YES	YES			
US and France	**Thales**	YES		YES	YES	YES	YES	YES	YES	
US	**Titan**	YES		**YES**		YES	YES	YES		
US	**Datron**	YES	YES	YES		YES	YES			
US / Italy	**DRS**						YES			
US	**General Dynamics**	YES	YES	YES			YES			
US	**NSGdata**						YES	YES	YES	
US	**Hall Communications Corp**					YES	YES			
US	**Harris**	YES	YES	YES	YES	YES	YES		YES	
US	**IP Unwired**					YES	YES			
US	**Rockwell Collins**	YES	YES	YES	POSSIBLE	YES	YES			

HF Noise and Link Budgets

HF Link Budgets

- Several ways to complete an HF NVIS / Skywave / GW Link Budget (BLOS links)
  - Let the models tell you what will happen (will it work / support the type of communications you want, if yes, at what reliability!!!)

    Preferred

  - Work through the math and estimate what "should" happen
    - Sunspots /other real time conditions will dictate what works
    - Use <u>estimated</u> values for D layer losses and max/min noise values for representative operational areas (man made and Atmospheric)
- For LOS links, you can still do the normal link budget things (in dbm)
  - TX PWR + Gains (antenna) – losses (HF channel) => PWR RX'd
  - Noise PWR in required Bandwidth (from tables / use formulas)
  - Link Quality = PWR RX'd – Noise PWR => C/N + Margin

From one Senior System Engineer Familiar with HF Link Budget issues:

I wouldn't push link budgets unless you include

- 0-40 dB for D Layer (maybe more)
- 0-20 dB Rx pattern
- 0-20 dB Tx Pattern
- 20 dB Lightning
- 20 dB manmade noise urban vs rural

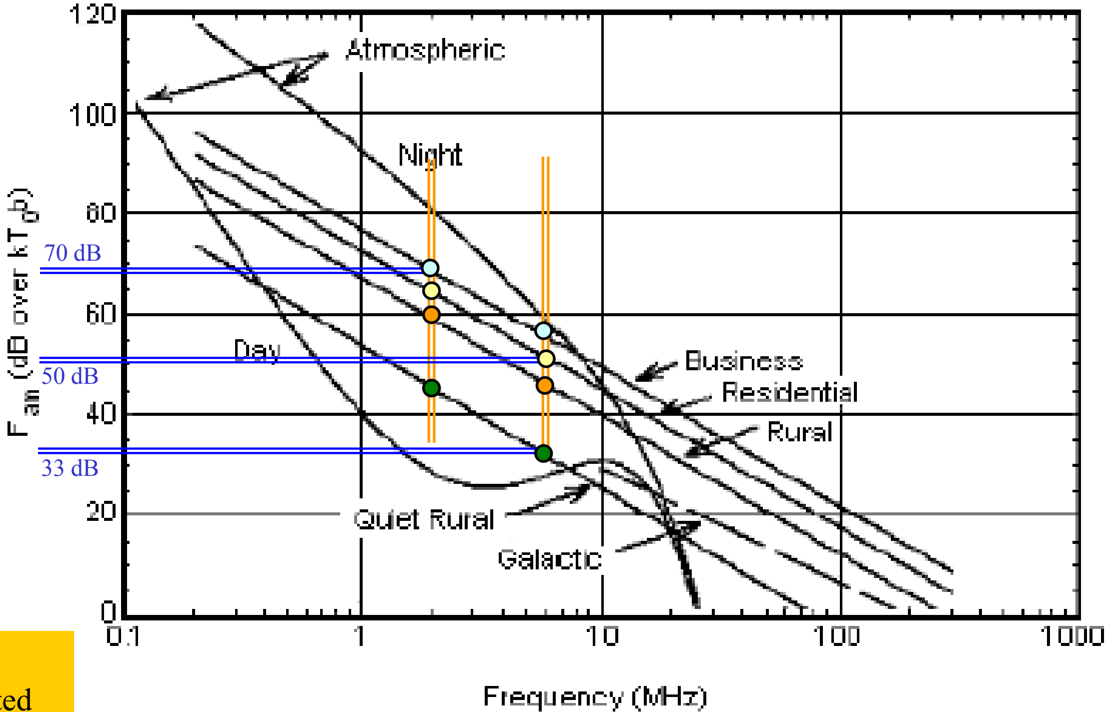
Kinda makes for a useless budget… Yeah, add 120 dB and you're guaranteed link closure….

At HF, Link budgets give you an Idea if it might work, in the real world, its only a guideline – OFTEN impractical to add LARGE margins to cover all cases

Link characteristics – HF Performance & Environmental Noise

- Excess Manmade HF noise can be 33 dB (quiet Rural area) - 70 dB (Business area) above that of thermal noise (kTB) in the range from 2 – 10 MHz for NVIS applications
- Quiet day rural areas contribute little above galactic sources for frequencies above 10 MHz.
- **Day** ➔ Man-made noise can impact reception in weak signal areas (for F's<10MHz),
- **Night** ➔ Atmospheric Noise can make the link almost unusable

Note – why more Atmospheric noise at night vs the day?

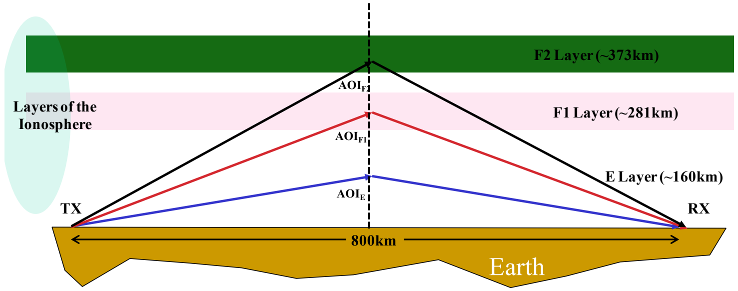


This is why Receivers at HF can use Tiny Antennas – its usually a matter of being noise limited **NOT** signal limited

From 2 – 10 MHz, Daytime Manmade Noise is the primary limiting factor to Calculating HF link Performance – **HOWEVER, at Night**, Atmospheric Noise can dominate all noise when conditions warrant (at night w T-storms)

Estimating NVIS Link Losses

SAMPLE HF NVIS RADIO LINK BUDGET



- From previous Example, assume:
  - 100W TX Power (50dBm)
  - Operating Frequency = 8.47MHz
  - NVIS Antenna Gain (both TX and RX) = 0dB
  - Total Path Length Traveled = 547 + 547km = 1094km
  - Free Space Loss L_{bf} = 32.44 + 20log(f) + 20log(d) calculated to be = 79.3dB
  - Effective TX power = 50dBm + 0dB = 50dBm

- Additional Considerations
  - NVIS wave power loss due to absorption in ionosphere D layer is from 10dB to 20dB (this is a 2 way loss value – once going UP and one coming DOWN. Value is typical, much more in some heavily ionized situations. Received wave depolarization loss reaches up to 3dB.

- Calculations:
  - Total median power level of **wanted signal** at receiving antenna output is 50dBm - 20dB - 3dB – 79.3dB = -52.3dBm (worst Case)
  - The available noise power from an equivalent lossless antenna, Pn expressed in decibels referred to 1W is: $P_n = F_a + 10*\log(B) + 10*\log(kT_o) = F_a - 169.2$ dB in W or $= F_a - 139.2$ dB in dBm

    where external noise factor Fa is in decibels, receiving system bandwidth B=3kHz, Boltzmann's constant k=1.38·10−23J/K and reference temperature To=290K. The external Noise factor can be computed using the WORST case values from the attached charts
  - If atmospheric noise, man-made noise **and** galactic noise is taken into consideration then total external noise factor mean value can be calculated to be F_a=51.1dB and the available noise power from an equivalent lossless antenna is P_n=−88.1dBm.

NVIS Signal Power = -52.3dBm
Noise Power = -88.1dBm

∴ S/N Ratio = 35.8dB

HF Link – What can you do with it?

- The required signal-to-noise ratio in an HF system for various capabilities is now analyzed:
  - For AM voice transmission, required Signal-to-noise ratios are (SNR) are
    - 6dB - “just usable”
    - 15dB - “marginally commercial”
    - 33dB - “good commercial”
  - For digital 8-PSK modulation and data rate 2400bit/s, the required SNR is 18dB (per MIL-STD-188-110B SPEC) for a Coded BER of 1.0E-5 (assuming a 3kHz channel and the fading environment shown).
  - Since HF radio systems are affected by external rather than internal noise levels, internal receiver noise factors can be ignored when calculating performance.

MIL-STD-188-110B

TABLE XX. Serial (single-tone) mode minimum performance.

User bit rate	Channel Paths	Multipath (ms)	Fading (Note 1) BW (Hz)	SNR (Note 2) (dB)	Coded BER
4800	1 Fixed	-	-	17	1.0 E-3
4800	2 Fading	2	0.5	27	1.0 E-3
2400	1 Fixed	-	-	10	1.0 E-5
2400	2 Fading	2	1	18	1.0 E-5
2400	2 Fading	2	5	30	1.0 E-3
2400	2 Fading	5	1	30	1.0 E-5
1200	2 Fading	2	1	11	1.0 E-5
600	2 Fading	2	1	7	1.0 E-5
300	2 Fading	5	5	7	1.0 E-5
150	2 Fading	5	5	5	1.0 E-5
75	2 Fading	5	5	2	1.0 E-5

Good Commercial AM Voice requires 33dB SNR
Digital 2.4kbps 8-PSK Data throughput w fading requires 18dB SNR

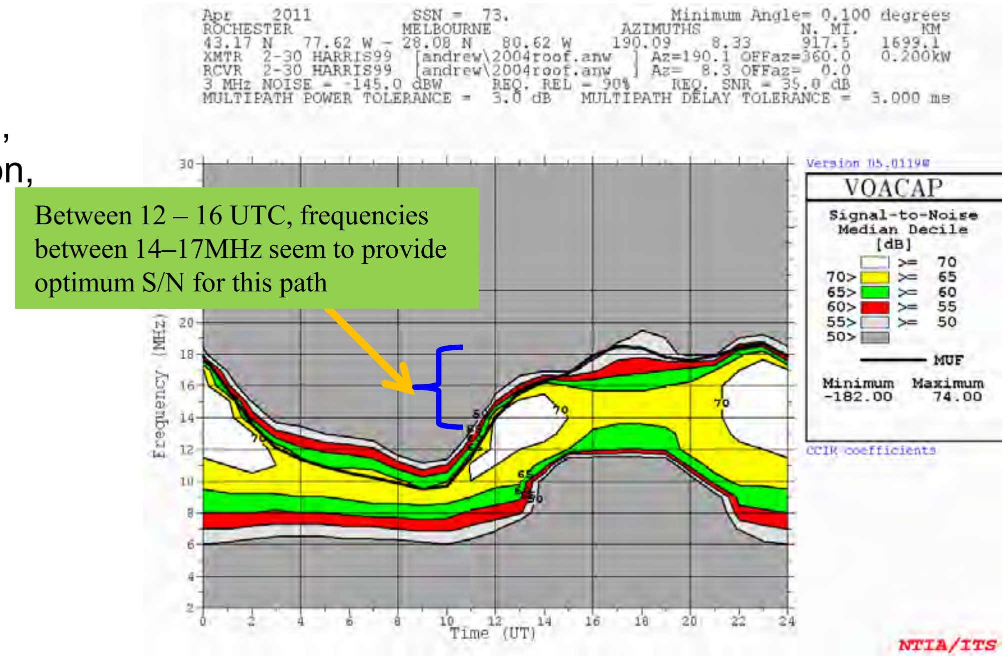
Based on the available SNR = 35.8dB, we have an additional 2.8dB of margin for Voice and 17.8dB of margin for Data

Above adapted from:
http://bib.irb.hr/datoteka/429005.AN_ASSESSMENT_OF_HF_NVIS_RADIO_SYSTEM_RELIABILITY.pdf

HF Prediction Tools

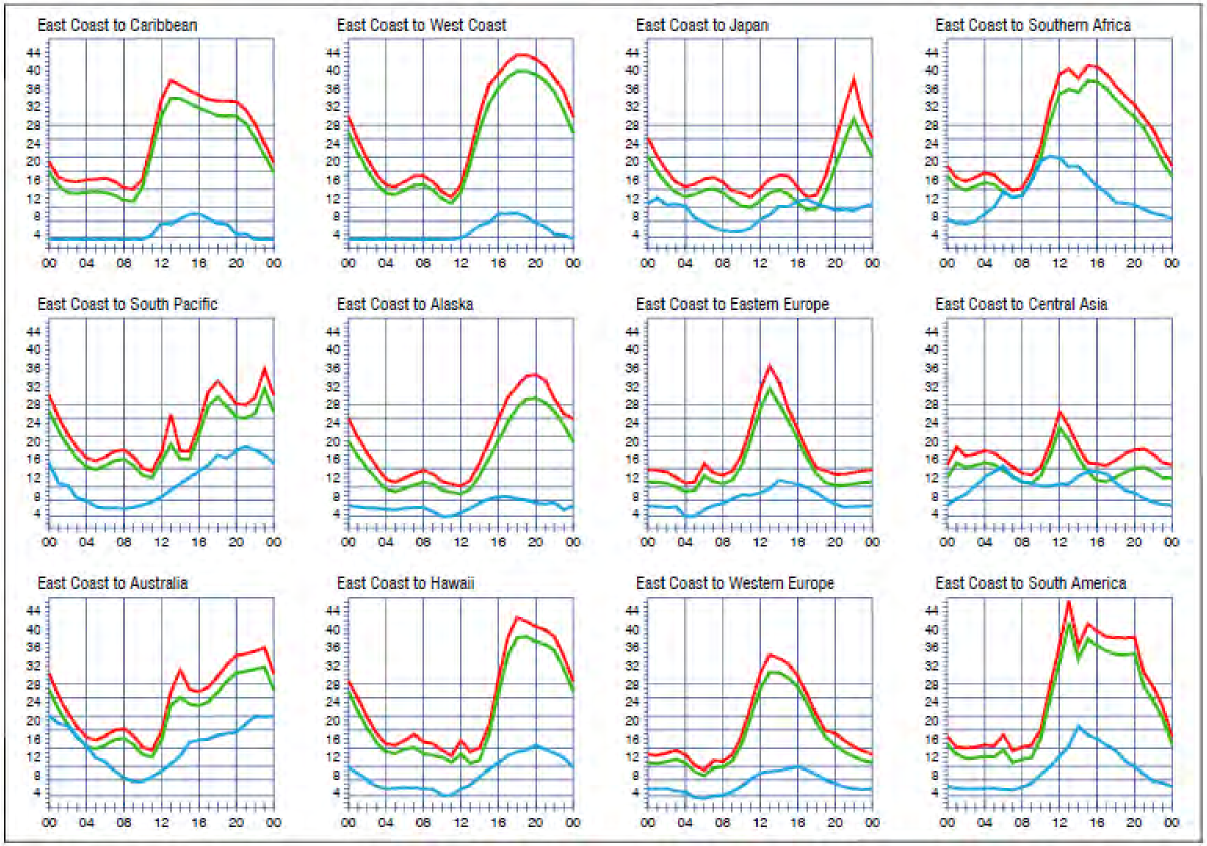
HF Coverage Predictions

- A wide variety of HF propagation Prediction programs are available both as stand alone products as well as online (many for free):
  - Typical Inputs:
    - Sunspot #,
    - Ground conditions (seawater / desert),
    - Antenna types / mounting configuration,
    - Transmit power,
    - Circuit type (voice / CW)
  - Typical Outputs:
    - Optimum frequency selection,
    - Link reliability,
    - Area Coverage
    - Station configurations,
    - Short vs long path
    - NVIS



- Voice of American Coverage Prediction Program (VOACAP), provided for free by the US Government, is one the commonly accepted GOLD STANDARD for HF propagation prediction tools.
- HF Propagation prediction is mostly a plug and play effort – you input the values, click go, and lots of pretty pictures come out at you.

HF Propagation Predictions - Area to Area Predictions



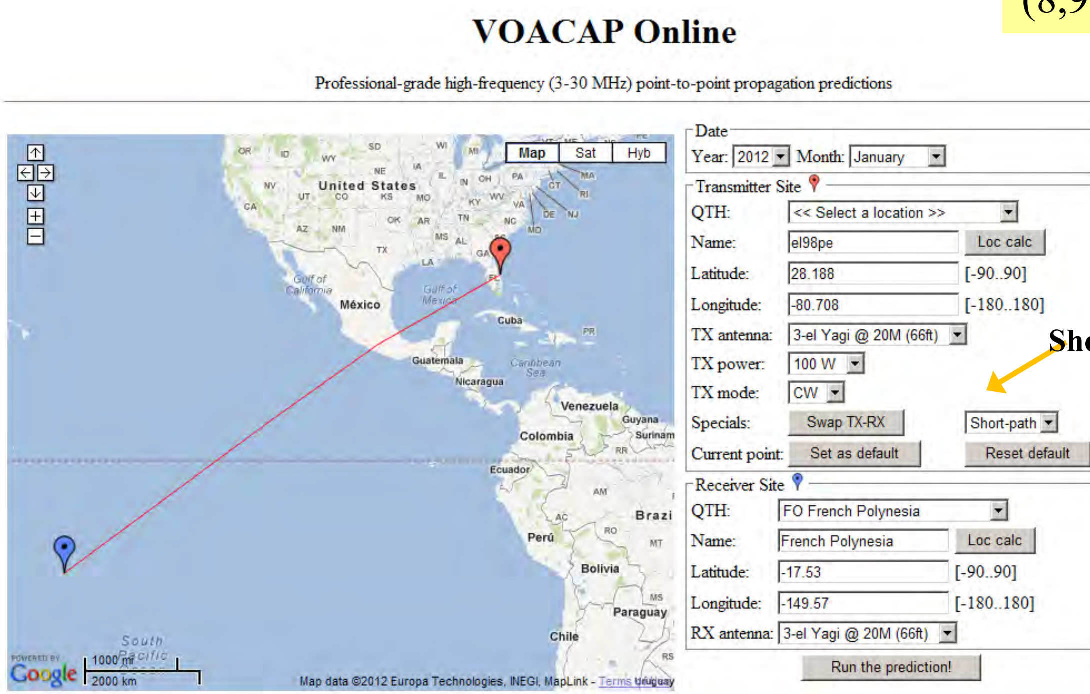
http://www.arrl.org/propagation

- Charts show probabilities for average propagation in the Month of January.
  - On 10% of the days of this period, the highest frequencies propagated will be at least as high as the upper red curves (HPF, highest possible frequency) and on 50% of the days they will be at least as high as the green curves (MUF, classical maximum usable frequency).
- The blue curves show the lowest usable frequency (LUF) for a 1.5Kw CW transmitter. The horizontal axes show Coordinated Universal Time (UTC) and the vertical axes frequency in MHz.

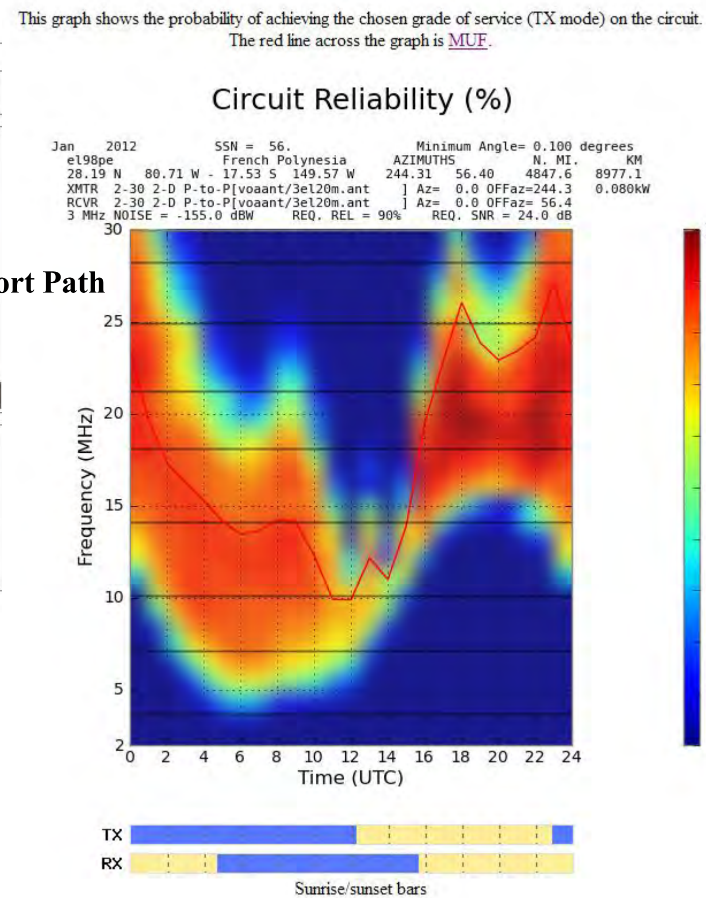
HF Propagation Predictions - Point to Point via the SHORT PATH (VOACAP)

Melbourne, FL <-> French Polynesia

SHORT PATH Distance: 4,847.6nmi (8,977.1km)



Short Path



- **Both** TX and RX Antennas are 3 Element Yagi's at 20m AGL,
- Circuit type is CW (Morse Code)
- TX Power is 80W

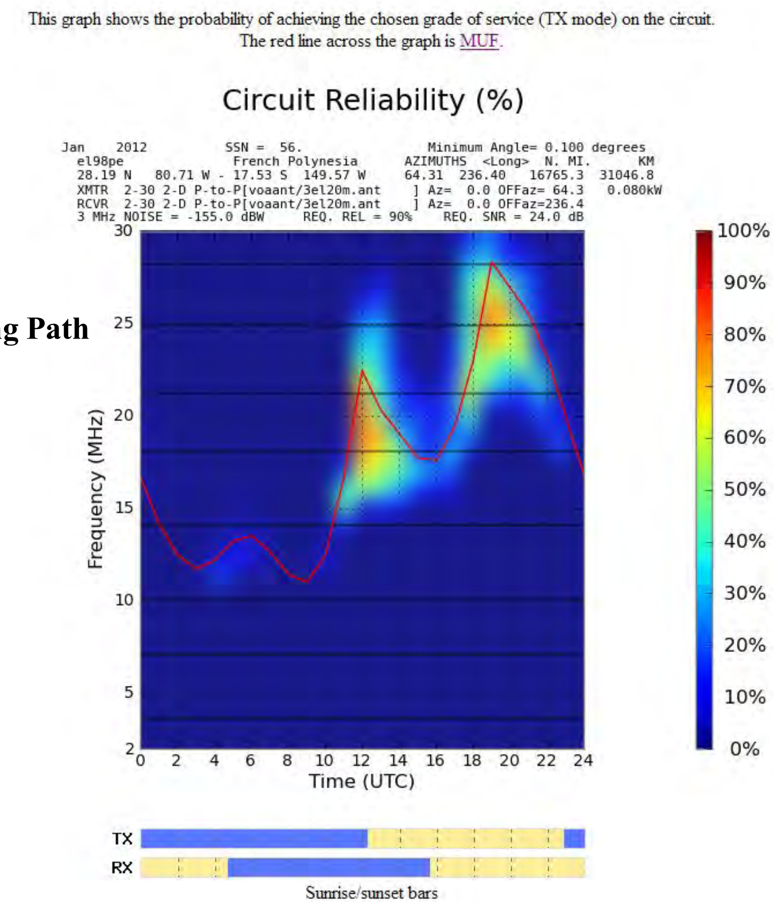
http://www.voacap.com/prediction.html

HF Propagation Predictions - Point to Point via the LONG PATH (VOACAP)

Melbourne, FL <-> French Polynesia

LONG PATH Distance: 16,756nmi (31,046km)

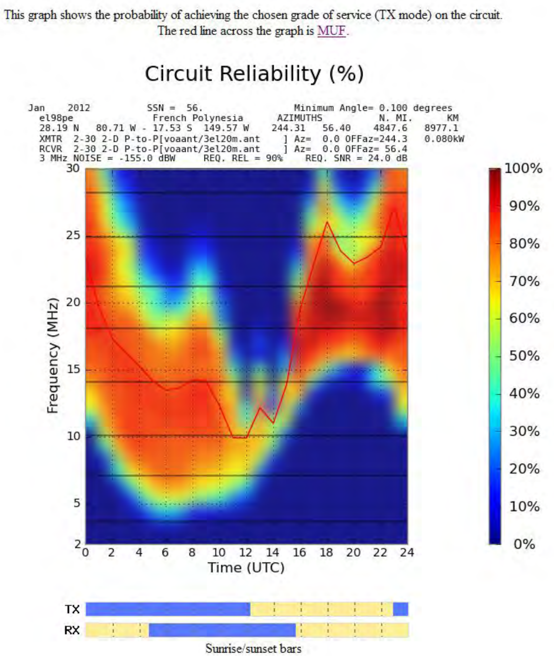
Long Path

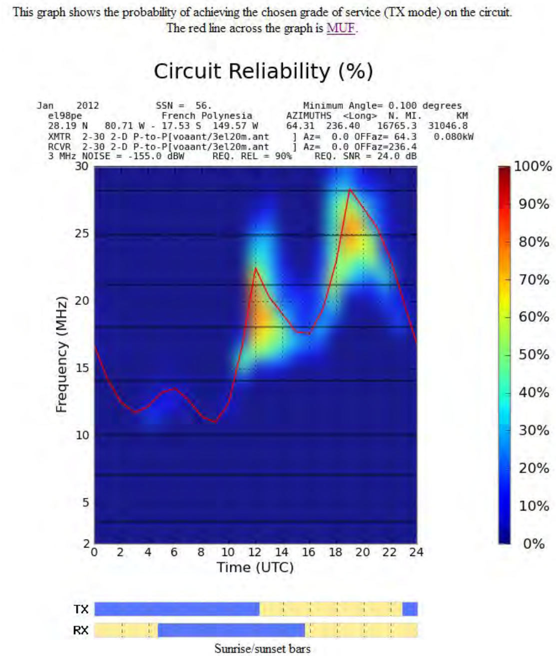


- **Both** TX and RX Antennas are 3 Element Yagi's at 20m AGL,
- Circuit type is CW (Morse Code)
- TX Power is 80W

http://www.voacap.com/prediction.html

Reading the Predictions

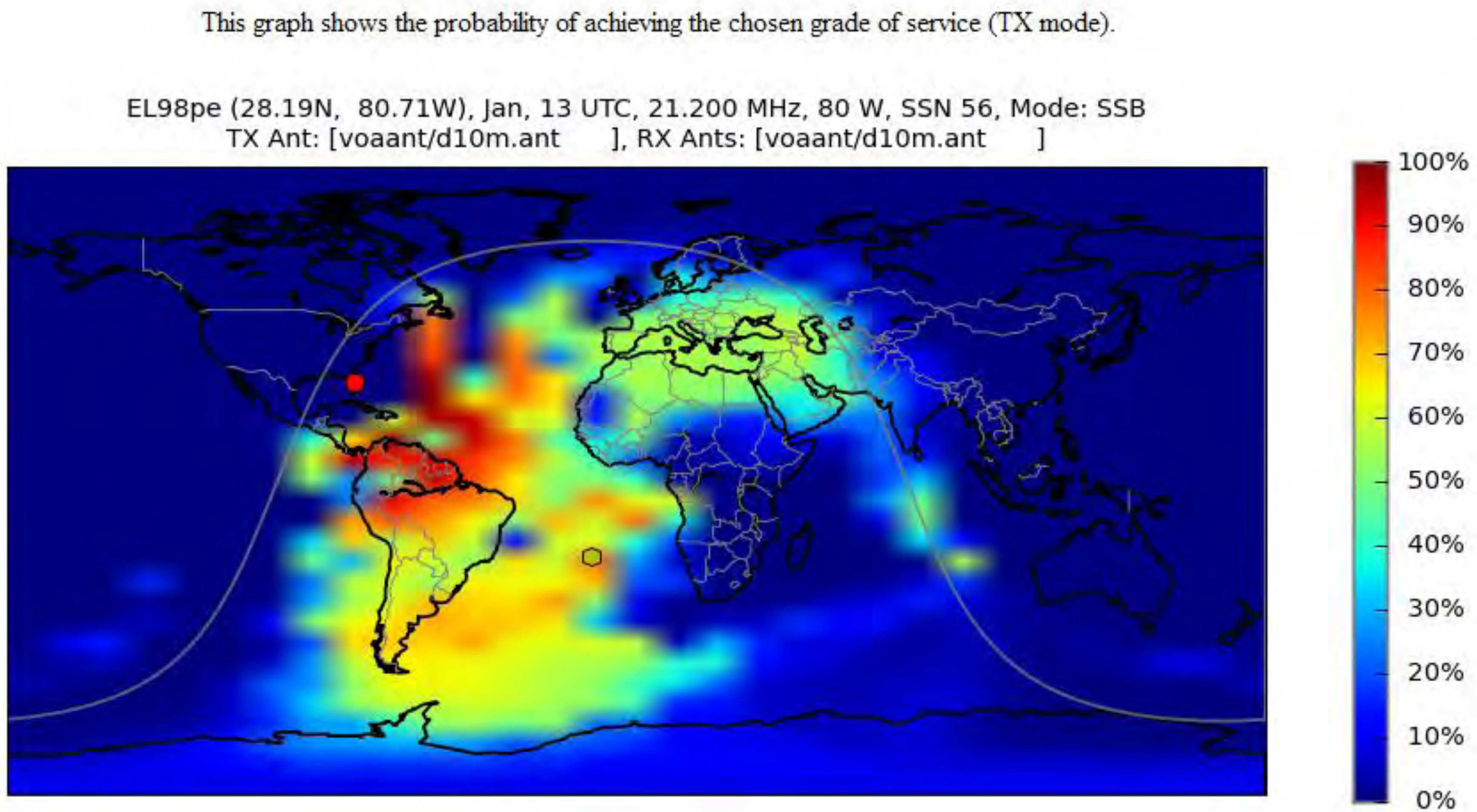




Short Path:
There appears to be a >70% reliable path to French Polynesia from Florida for all hours EXCEPT 10:00 – 16:00 UTC. There are many frequency choices available.

Long Path:
There appears to be slight chance of a path to French Polynesia at a >70% reliable path from 12:00-14:00 on 18-20MHz and from 18:00-20:00 on 25-27MHz

HF Propagation Predictions – Area Coverage @ 21MHz (VOACAP)



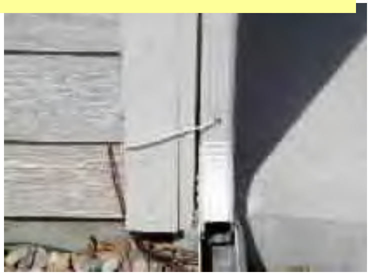
http://www.voacap.com/coverage.html

Antennas

HF Antennas – Lots of Choices

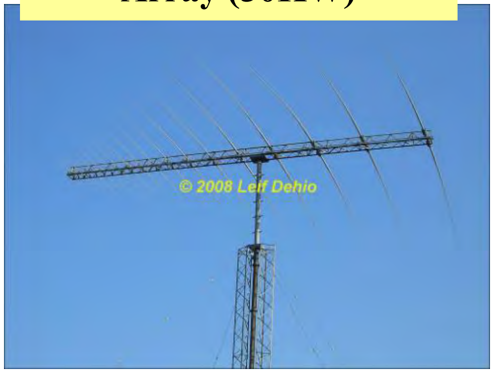
- At HF, because of the propagation modes that exist, almost <u>anything</u> metallic can be loaded to accept energy from a connected radio and it will function as both a TX and a RX
  - **Verticals** -> spurt energy at low angles, typically used for Long range communications as well as Ground/Surface wave links
  - **Single Element Wires** -> when placed “low” above the ground (typically at <$.2\lambda$) the radiation tends to be straight up
  - **Multi Element Wires** – directional radiation
  - **Beams / Yagis** – multiple elements, directional, great front to back
  - **Unique:**
    - Bed Springs, Rain Gutters, Folding Chairs, Painting Easels, Chicken Wire,
    - Lightening Suppression systems
    - Aluminum skin of an aircraft
    - Dog kennel, and the neighborhood fence.

Rain Gutter vertical



Kayak vertical

Large HF Log Periodic Array (50KW)



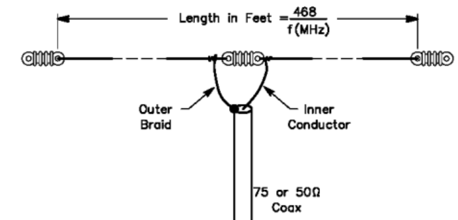
Back Pack vertical

Conformal HF Manpack Antenna 2 – 30 MHz

Other Antenna Things

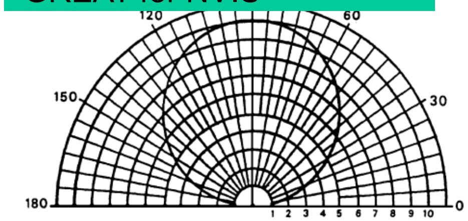
- NVIS – want RF to go straight up:
  - Horizontal Dipole antenna low to the ground
  - Vertical must be bent over, if not, there is a NULL at the zenith

Loop Antenna (low freq noise reduction)

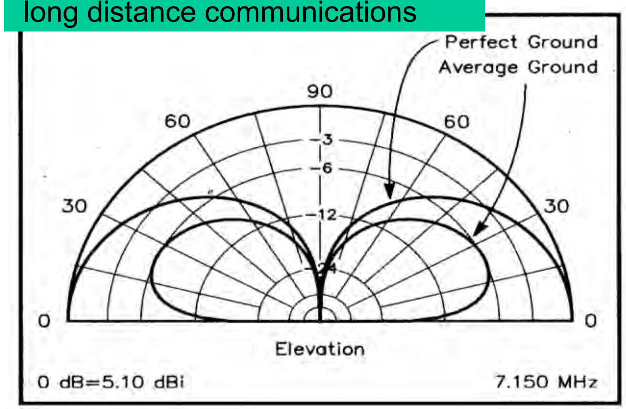


Dipole Antenna

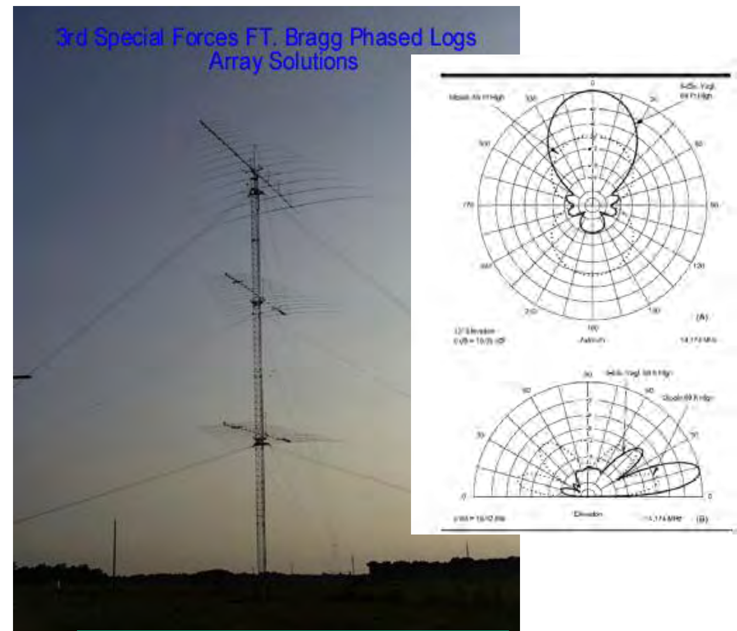
Low Height Dipole – GREAT for NVIS



Vertical = No High Angle Radiation for NVIS, but <u>great</u> for long distance communications

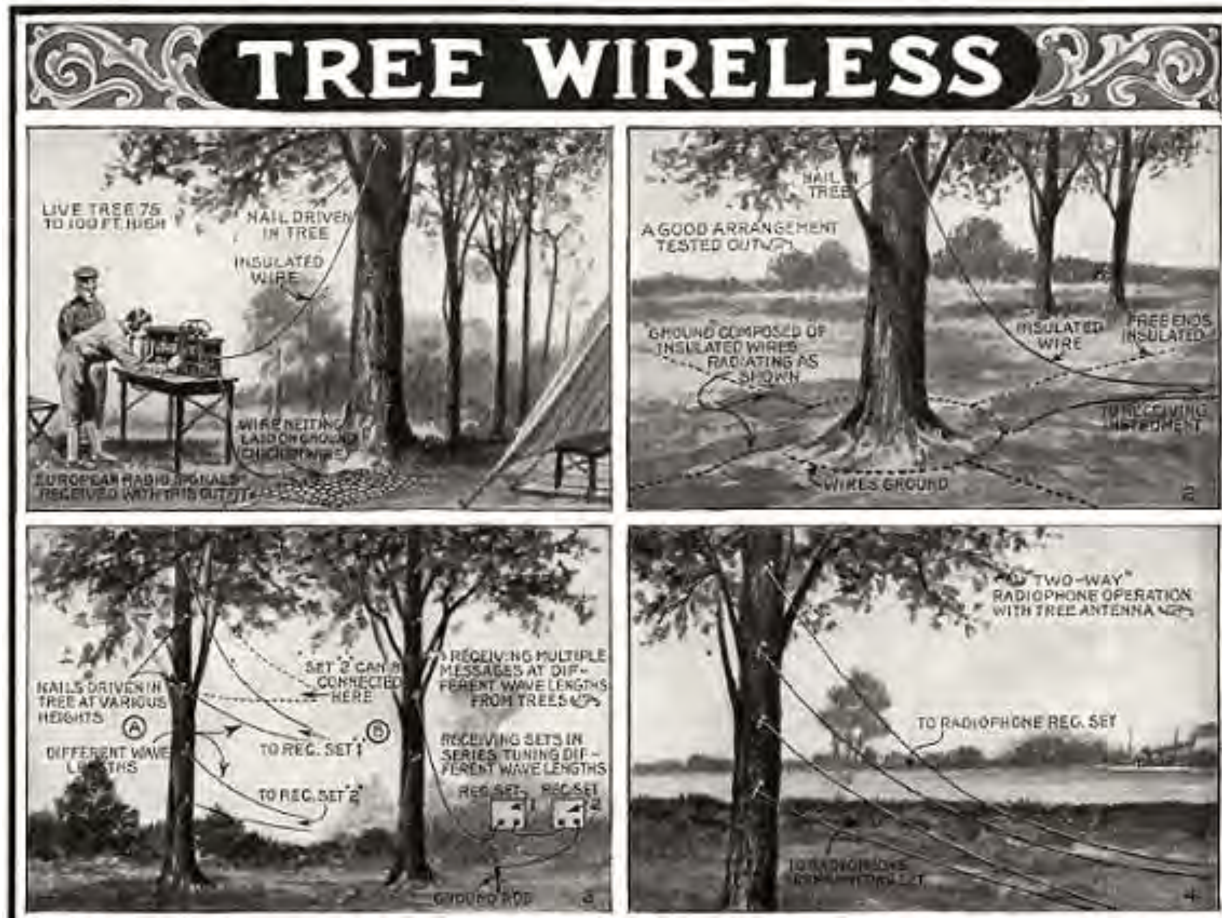


Mobile multi-frequency Beam Antenna (Field Day in Grant)



Stacked Beam Antenna

Tree Antennas



The Mother of All HF Antennas…

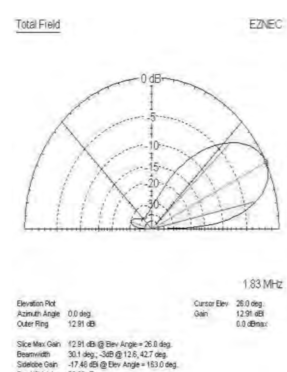
Height and weight of the system
Tower height 100 m (330 ft)
80 m beam 90 m (300 ft)
160 m beam 80 m (270 ft)
Total weight 39 600 kg (80 000 lbs)

Elements, gain and take off angles
160 m 3 elements, 12.9dBi, 26°
80 m 5 elements, 15.7dBi, 12°

Front to Back ratio
160 m 20-30 dB
80 m 20 dB

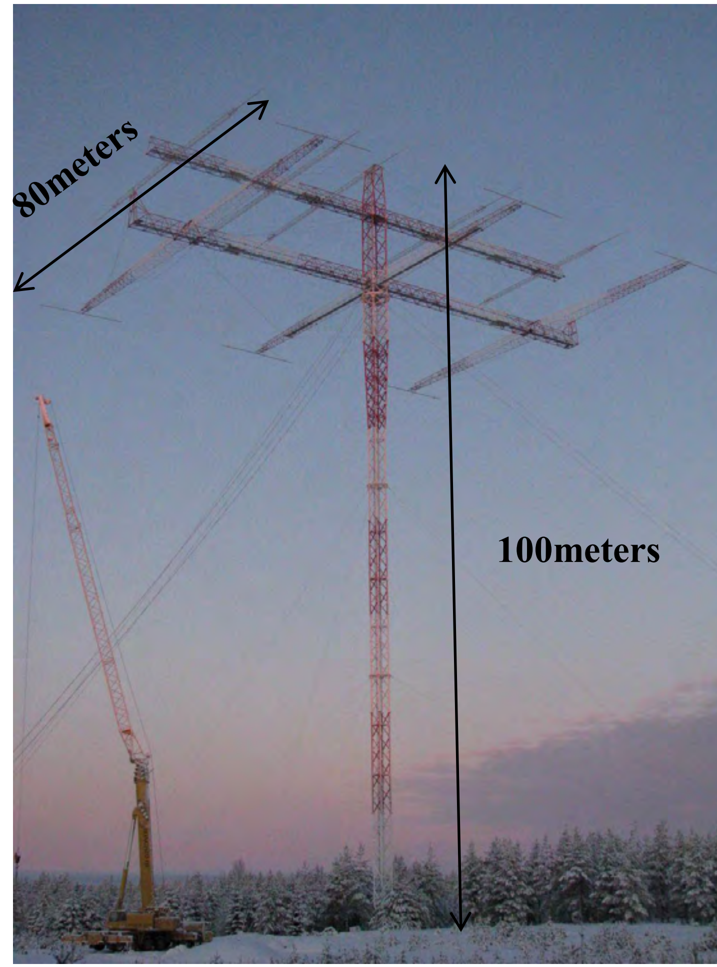
Operating frequencies
1810-1845, 1845-1880 kHz (SWR < 1.6)
3500-3560 kHz (Lmatch)
3700-3800 kHz (50 ohm / current balun)

160 m elements
Weight 1600 kg, (3800 lbs), each
Length 59 m (190 ft), all elements 12m (36ft) capacitive hats
Each use 700 m (2100 ft) of tubing
Tuned with 06 µH coils at the centre
Relay switches for turning the ant 180°



80 m elements
Length 46 m (140 ft), longest
10 m from the 160 m antenna
max windload, 70 m/s.

Boom dimensions
160 m length 71 m (215 ft)
80 m length 60 m (200 ft)
The triangular 160m boom (2.2 m, 7.3 ft) comes with a rail for walking inside it.



Privately Owned!

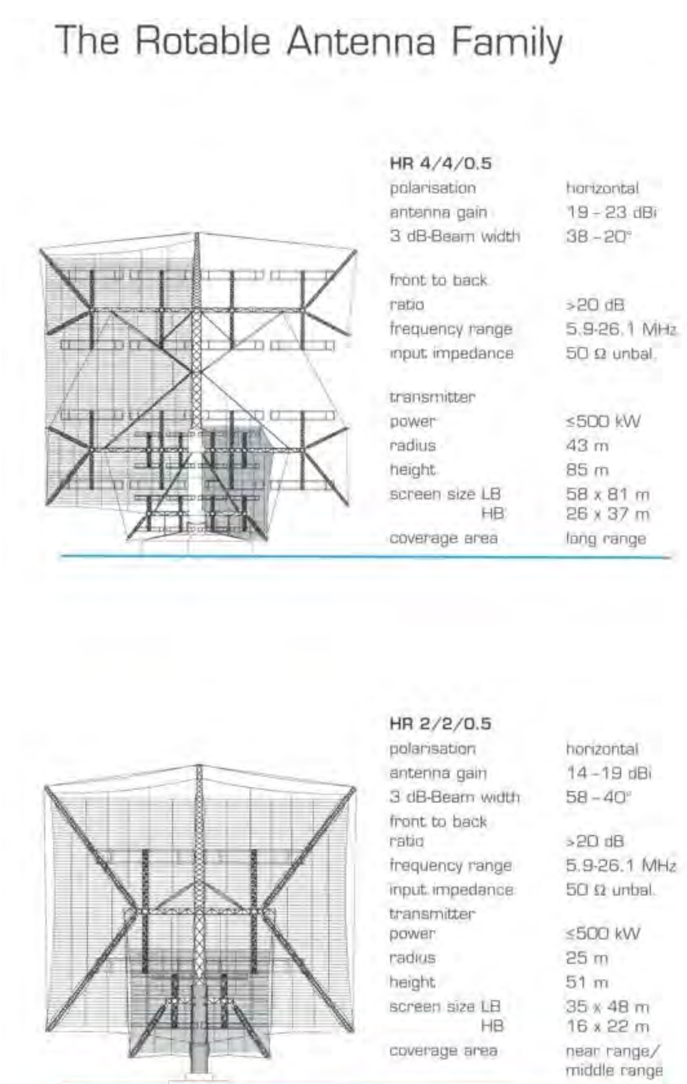
EXTREMELY Large Rotatable Wideband Antenna

Typically ALLISS modules possess a 500 kW polyphase shortwave transmitter.
List of Broadcasters who's using ALLISS modules

- BBC World Service
- RFI, Radio France International
- Deutsche Welle
- China Radio International
- Radio France International

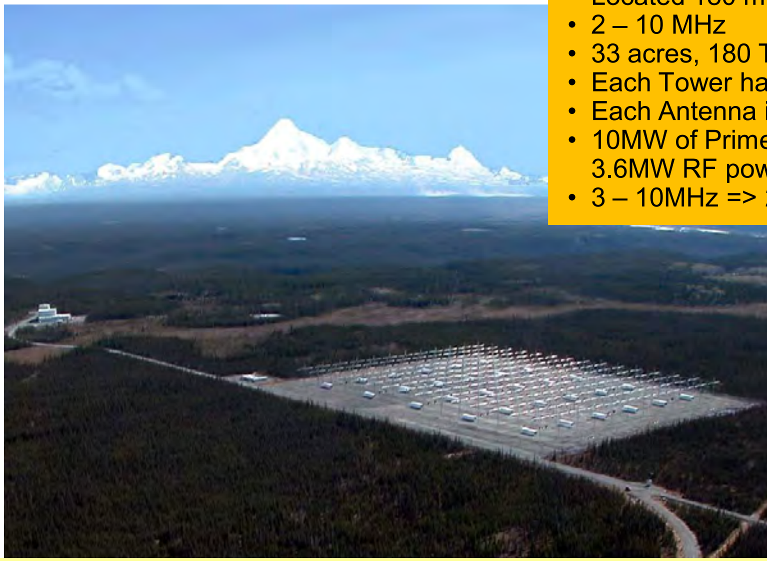
Price of one ALLISS module antenna is $10.000.000 USD

http://www.cqdx.ru/ham/ham_radio/alliss-module-the-largest-fully-rotatable-sw-antennas-in-the-world-by-5n7q/



More Large HF Antennas - HAARP

- Located 180 miles ENE of Anchorage, Alaska
- 2 – 10 MHz
- 33 acres, 180 Towers 72' high
- Each Tower has 2 Crossed Dipole Antennas
- Each Antenna is phase controlled
- 10MW of Prime Power -> Class AB PA's, approx 3.6MW RF power (45%)
- 3 – 10MHz => 20 –> 30dB Gain…..



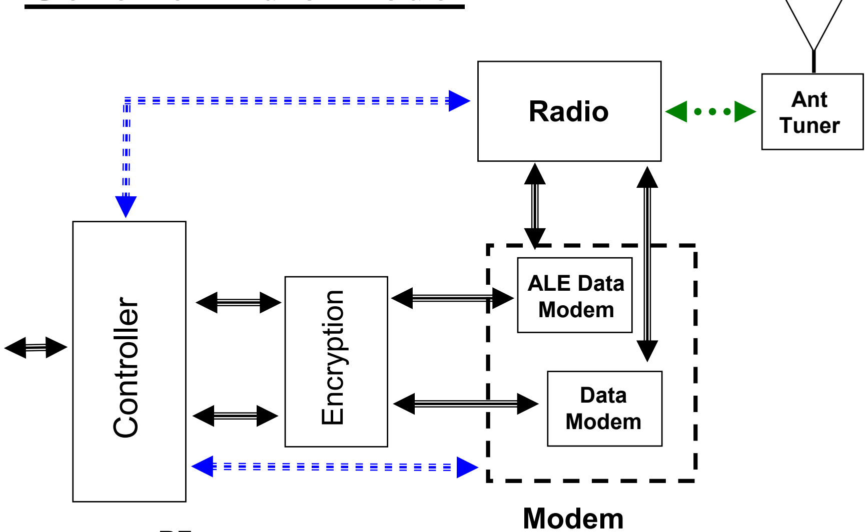
HAARP can influence the „auroral electrodynamic circuit', a natural flow of electricity with ranges from 100,000 to 1 million megawatts ("equivalent to 10 to 100 large power plants"). Messing with the electrical properties of the ionosphere means some of this tremendous flow of power can be changed at the flick of a switch. *In effect, the natural flow can be modulated to create a gigantic low-frequency radio transmitter.* Extremely low frequency, or ELF, waves can be used for submarine communications and for probing the planet; because of the way they propagate, HAARP can cover "a significant fraction of the Earth." The HAARP facility does not directly transmit signals in the ELF frequency range. Instead, ELF signals are generated in the ionosphere at an altitude of around 100 km. *Frequencies ranging from below one Hz to about 20 kHz can be generated through this ionospheric interaction process.*

General HF Radio System Block Diagram

Standard HF ALE Node Configurations

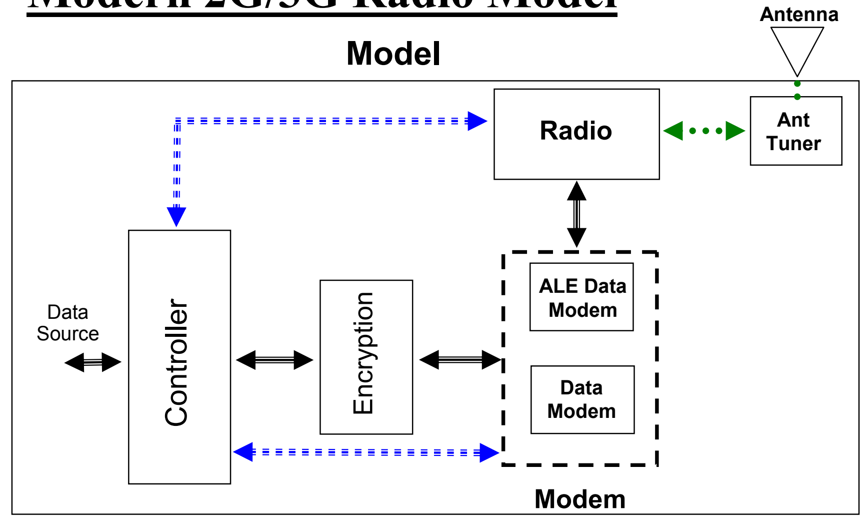
Generic Radio Model

Generic Radio Model



RF
Control + Status
Data

Modern 2G/3G Radio Model



RF
Control + Status
Data

NOTE: General Observation - Shift has taken place from individual boxes to all-in one radio equipment

- **Key Focus Points when looking at equipment**
  - Many vendors offer Integrated 2G or 3G solutions that usually include some or all of these items integrated into “one box”:
    - Data modems, Crypto, Hopping, Software (SW) that can be used to expand the feature set, and many, many other accessories
  - Many vendors also offer “building blocks” or “piece parts” as separate items:
    - Data & ALE Modems
    - ALE Controller
    - Crypto
  - SW that can be installed onto a PC OR as part of vendors offering

What Can HF Do for You?

HF Capabilities

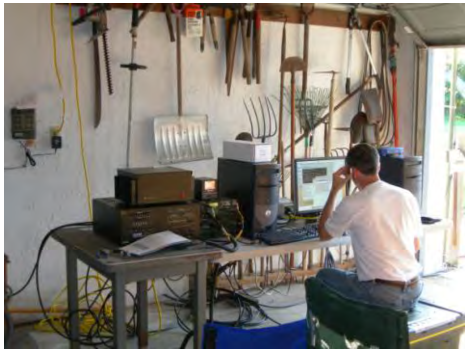
- **NVIS** – Provides Extremely Robust and reliable communications between platforms in the 50 – 400km range
  - Radio inside vehicles, antennas on the platform
  - RF sprayed straight UP
- **1 way message broadcast** - propaganda, information for a high power broadcaster to a large number of people using very inexpensive SW radios
  - Voice of America, BBC, HCJB in Quito Ecuador (religious)
- **Data Communications**
  - Point to Point
  - Multi-broadcast
  - 1 Way data transfer
  - Networked, email,
- **IP over HF** with the use of COTS Ethernet Appliqué's
  - Yes… there is buffering involved and the throughputs at not at "TRUE" internet speeds
- **Other Cool Stuff** - HF can be used for:
  - Heating of small areas,
  - Tracking solutions
  - Automated networking using ALE

But wait….. There's MORE!!

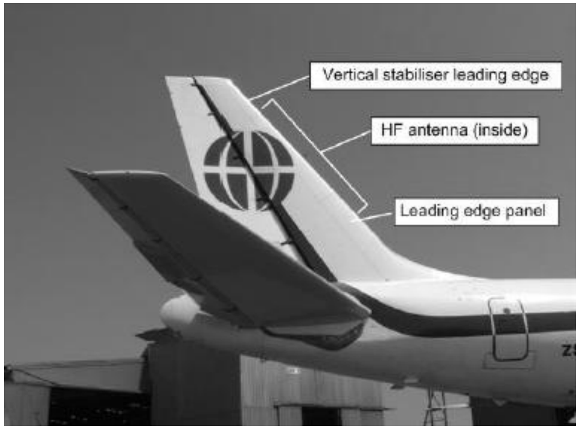
HF Platform Examples

Suburban with Bent Over Whip for NVIS Communications

Russian Radio Vehicle with NVIS Antenna



Worldwide HF from a Garage

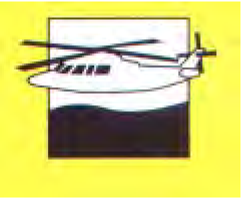


Large Jet with HF Antenna Located inside the Tail Fin for Automated Reporting and Comms

Sabreliner Jet with 23' Wire Antenna for Global HF ALE Comms

GKN Desert Warrior HF and VHF

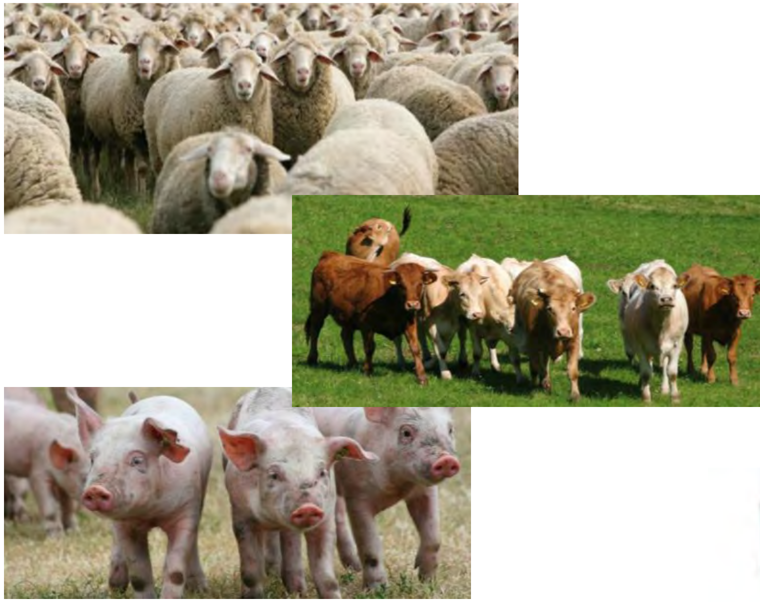
Communications & Other Problems with HF Solutions



Communications & Other problems with HF Solutions

- **Problem #1** - Tracking objects with possibly high water content. Need to track Library Books and various Livestock.
- **Problem #2** - Directed Broadcast to a specific area of the world – Entity (Christian Broadcaster) wants to send their message to a large population on the African Continent
- **Problem #3 -** Utilize Home Wiring to provide High Speed Internet
- **Problem #4** - Provide Reliable Networked Communications over Mountainous Terrain Local reliable communications between / amongst various vehicles spread out over several hundred km
- **Problem #5** - Global Comms to the World from a small rock-> Provide 360º global Comms to the ENTIRE world from an isolated "small rock" in the middle of nowhere 24/7 using up to a 3KHz Channel, MUST HAVE self sufficient operational capability
- **Problem #6** - Provide LONG RANGE Ethernet "Reach Back"
- **Problem #7** - Detecting Sea surface conditions and objects up to 2000km away

Problem #1 – *Tracking objects with possibly water content*



13.56 MHz Animal Ear Tag

- Well suited for use in monitoring each animal's history: feeding, location, vaccination, etc.
- HF ear tag is waterproof and resistant to immersion in salt water, alcohol, oil, 10% HCL and ammonia.

13.56 MHz Book Tag

High Frequency (HF) Passive RFID Tag

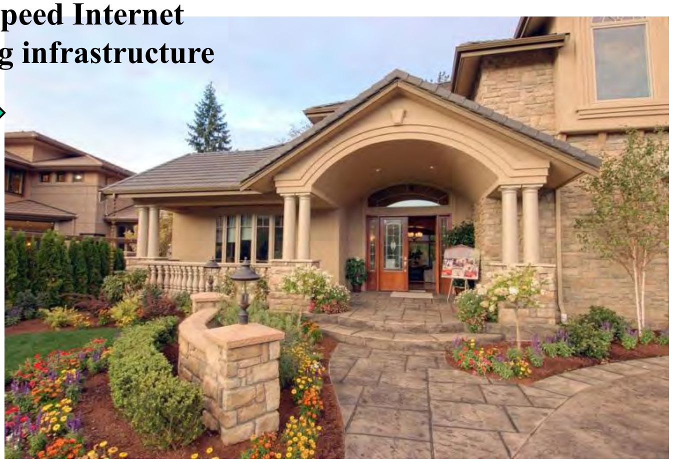
HF (High Frequency) Tags, Labels and Cards operate at a frequency of 13.56 MHz. These types of tags are also "Passive" – no onboard power source. RFID applications that use HF RFID tags are typically the applications that require read distances of less than three feet. HF tags work better on objects made of metal (RFID Metal Tag) and can work around goods with high water content. Applications include smart cards and smart shelves for item level tracking, and are also currently used to track library books, healthcare patients, product authentication and airline baggage. Another common application is maintenance data logging for sensitive equipment that needs regular checking such as fire suppression systems. There are several standards concerning HF systems, including the ISO 15693 standard used for tracking items.

Problem #2 – Directed Broadcast to a specific area of the world

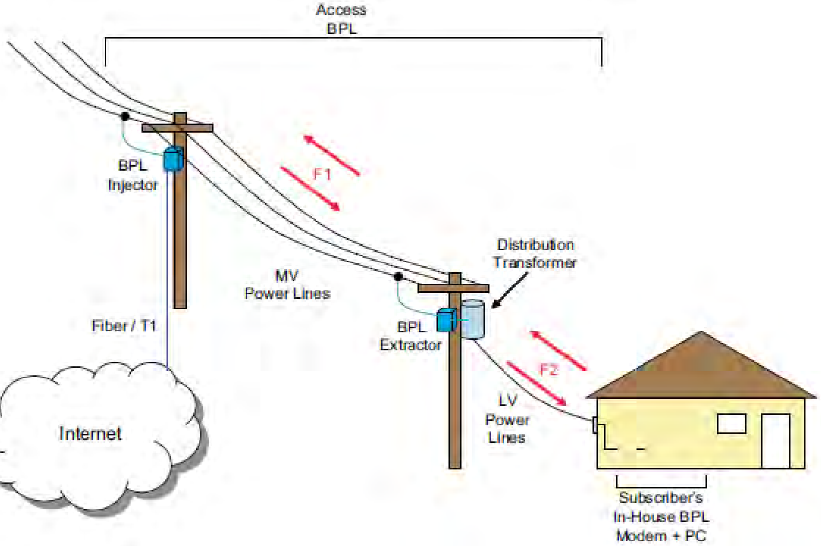
http://www.signals.taunus.de/IMAGES/CVA5.jpg

Problem #3 – Utilize House wiring to provide High Speed Internet

? – High Speed Internet using existing infrastructure

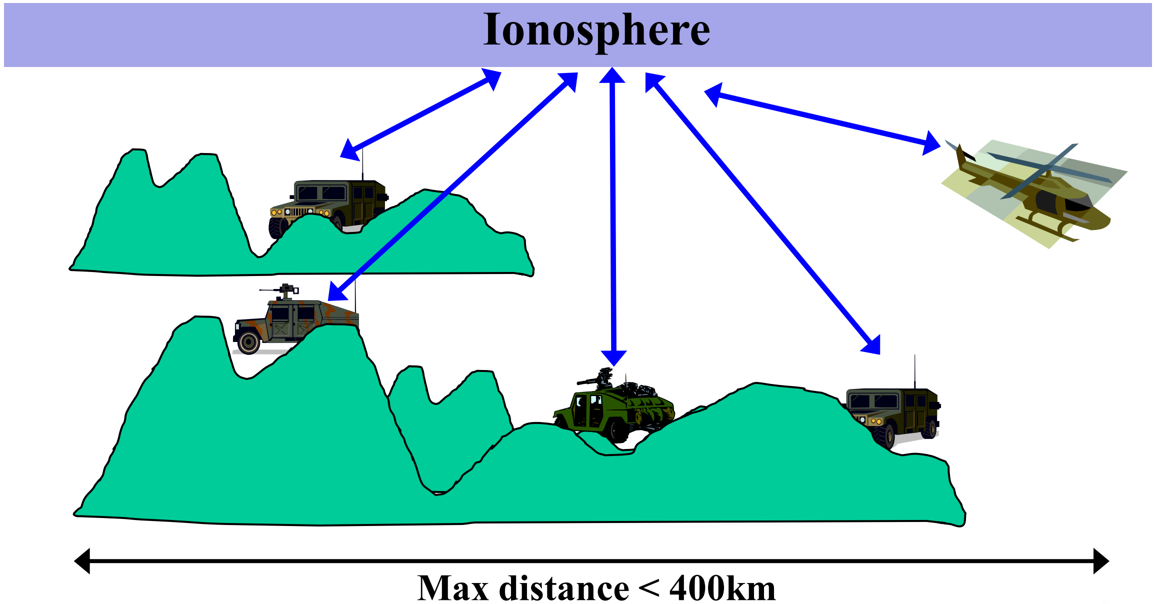


Use Broadband Over Power Lines (BPL)



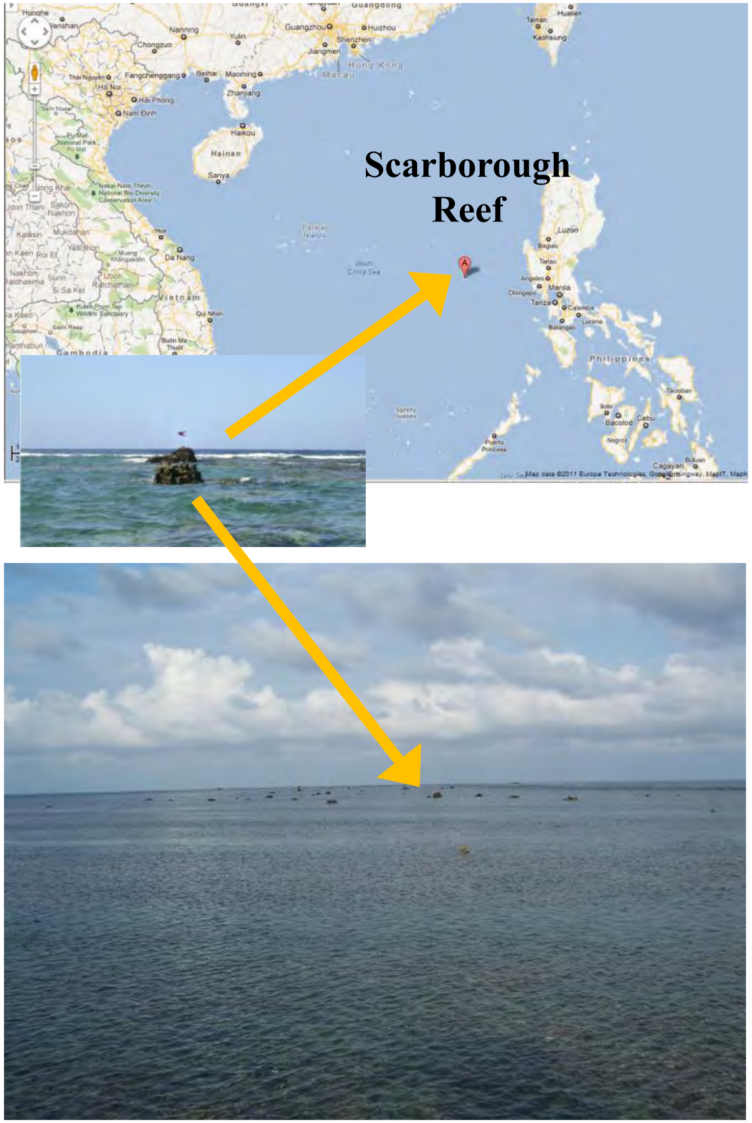
- BPL – technology allows voice and Internet data to be transmitted over utility power lines (often called Power-line Communications or PLC)
- FCC chose to use the term “broadband over power line” for consumer applications.
- Frequencies used for BPL are in the HF Band and propagate along the power infrastructure rather easily
- Power Lines are unshielded, therefore, every power line, street light, traffic signal, house, and business is receiving and possibly BROADCASTING the internet signal.
- In order to make use of BPL, subscribers use neither a phone, cable nor a satellite connection. Instead, a subscriber installs a modem that plugs into an ordinary wall outlet and pays a subscription fee similar to those paid for other types of Internet service.

Problem #4 – Reliable Networked Comms over Mountainous Terrain

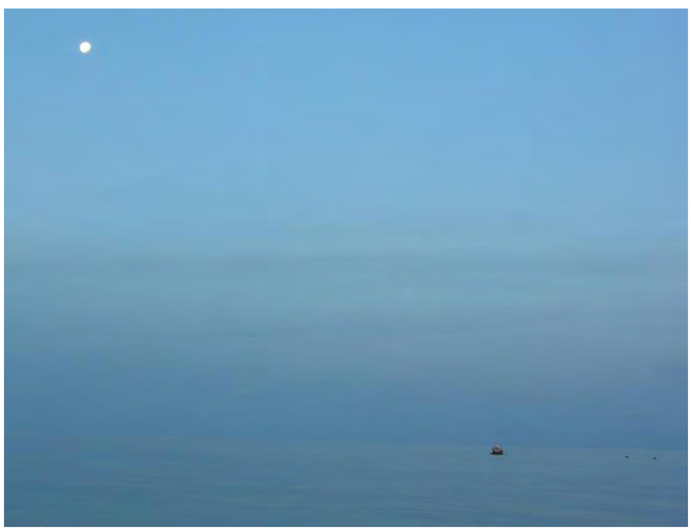


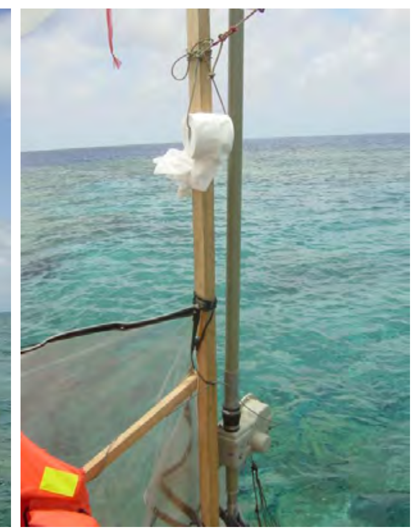
Use ALE with 5 – 12 frequencies between 3 – 10MHz (2-5MHz night, 5-10MHz day) that are preprogrammed in the radios
Project RF almost STRAIGHT UP, USE NVIS Mode

Problem #5 – *Global Comms to the World from a small rock*



Problem #5 – *Global Comms to the World from a small rock* ***Continued***

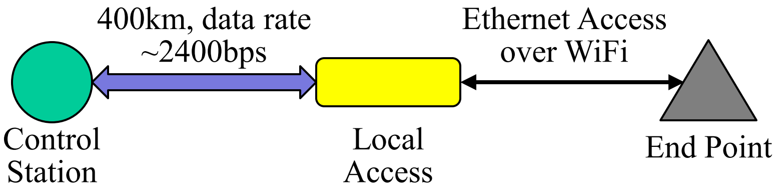




http://www.scarboroughreef.com/srphotos.html

Problem #6 – Provide LONG RANGE Ethernet "Reach Back"

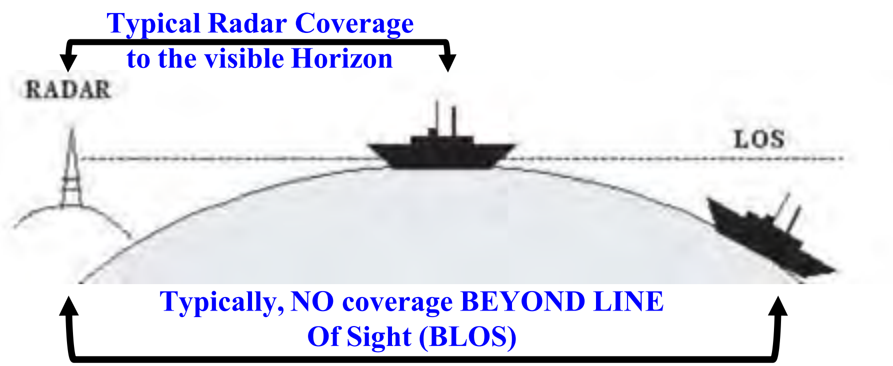
Need to support remote "long range" (400km away) standoff access to an Closed Ethernet system



Use ALE, NVIS, Multiple frequencies between 2 – 10MHz

Problem #7 – Detecting Sea Surface Conditions and Objects up to 2000km away

Need to provide BLOS detection of moving objects as well as determine sea surface conditions



- BLOS detection of targets can be achieved by radars operating in the high-frequency (HF) band (3 to 30 MHz).
- Two kinds of stationary Over-The-Horizon-Radar (OTHR) systems have been developed:
  - **surface-wave (or ground wave) radar** - uses the surface-wave propagation mode over salt water to look over the immediate horizon up to ranges of 400 km for targets and characterizing the sea state conditions.
  - **skywave radar** - make use of the ionosphere to scatter radio waves very long distances. The minimum range is about 1000 km and the maximum useful range is about 4000 km.

Transmission power on some OTHR "woodpecker" transmitters can be as high as 10 MW EIRP.

Summary

- HF Systems are easy to set up and configure– minimum infrastructure, low cost…. **HF is EASY**,
- HF has many uses – comms, heating, tracking, high speed internet….. **2-30MHz has many uses**
- HF Comms depends on Sunspots, but it can allow 24/7 communications => **At HF, Noise can be a killer!**

- Automatic Link Establishment (ALE) automates the ability to link HF stations w/o the need for human intervention – HF, the "**That was Easy Solution**"
- Yes, bigger is better and more power is king………. HOWEVER, even with just a few watts of Transmit power and a wire global communications is possible
- **Current "real world" throughput rates are capped at 19.2kbps (via standards), HOWEVER, new WBHF standard can support up to 120Kbps in a 24KHz channel**

HF Radio can be fun!

HF makes a comeback!!

Once pushed aside by satellite communications, this radio type using the HF spectrum is still relevant for over-the-horizon communications.

http://urgentcomm.com/mobile_voice/mag/hf-radio-use-201103/index.html

I'd Like to Learn More

More Information About HF and HF Communications

- **Amateur Radio**
  - ARRL Web Site
    - http://www.arrl.org/what-s-ham-radio
  - ARRL PowerPoint "Discover The Magic of HF Radio"
    - http://www.barriearc.com/CBSS_ARES_files/HF-Radio.pdf
    - http://www.emergencyradio.ca/course/HF-Radio.ppt
  - Low Band Dx'ing – probably the best source of ALL THINGS HF you'll ever need
    - http://vss.pl/lf/00.pdf

- **HF Propagation and Propagation Prediction**
  - VOACAP Website
    - http://www.astrosurf.com/luxorion/qsl-perturbation6.htm
  - HF Radiation - Choosing the Right Frequency
    - http://www.weather.nps.navy.mil/~psguest/EMEO_online/module3/module_3_2b.html
  - Learning about Space Weather and Predicting HF Propagation
    - http://www.spacew.com/

- **HF ALE**
  - http://www.navymars.org/central/reg4/al/ALE%20Introduction.pdf

- **Useful HF Noise Models complete with Formulas**
  - http://ftp.rta.nato.int/public//PubFullText/RTO/TR/RTO-TR-IST-050///TR-IST-050-02.pdf

- **NVIS**
  - http://tcares.org/tcares/images/presentations/nvis%20propagation%20theory.pdf

Also, try Google searches on "HF", "HF ALE", "HF Propagation", "Ham Radio"