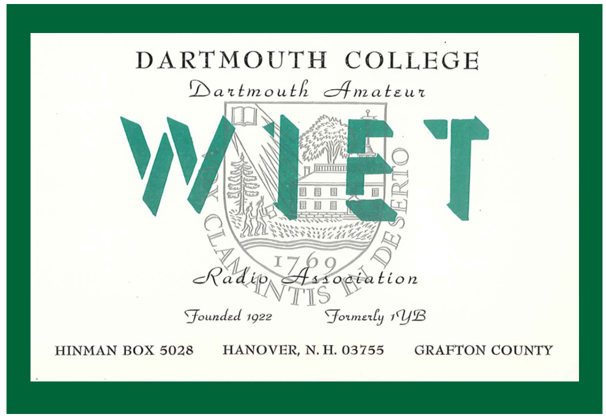

Propagation 101

Eric Hansen, KB1VUN

How does radio work?

- Transmitter: Convert message to radio frequency (RF) voltage
- Antenna: Convert RF to propagating electromagnetic (EM) wave
- Propagation path
- Antenna: Convert EM wave to RF voltage
- Receiver: Extract message from RF

- **This session: Radio wave propagation**

Some illustrations are reproduced from the *ARRL Handbook* and the *ARRL Antenna Handbook* and are used by permission.

Figure from *ARRL Antenna Handbook, 22nd edition*

Dipole radiation pattern

- Dipole in "free space" (way above the earth)
- Upper plot shows relative field strength (dB) vs **azimuth**
- Lower plot shows pattern is isotropic with respect to **elevation** (no ground effects)

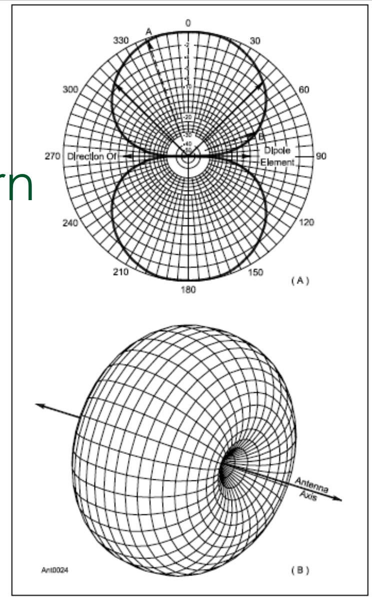

Figure 1.10 — Radiation patterns of a half-wavelength dipole in free-space. At A, the pattern in the plane containing the wire axis. The length of each dashed-line arrow represents the relative field strength in that direction, referenced to the direction of maximum radiation at right angles to the wire's axis. The arrows at approximately 45° and 315° are the half-power or –3 dB points. At B, a wire grid representation of the solid pattern for the same antenna.

Figure from *ARRL Antenna Handbook, 22nd edition*

Review: Dipole near ground

- Boundary condition (zero E-field at ground) distorts the free-space radiation pattern.

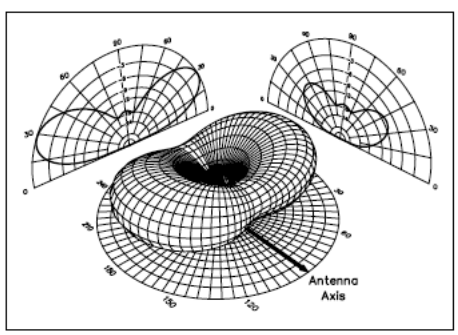

Figure 2.5 — Three-dimensional representation of the radiation patterns of a half-wave dipole, ½ λ above ground.

Figure from *ARRL Antenna Handbook, 22nd edition*

Dipole near ground

- Higher antenna gives lower **takeoff angle**, good for DX. Rule of thumb: at least a half-wavelength above ground.
- Lower antenna is more omnidirectional in azimuth, and good for "near vertical-incidence skywave" (**NVIS**).
- Low antenna also called a "cloudwarmer".

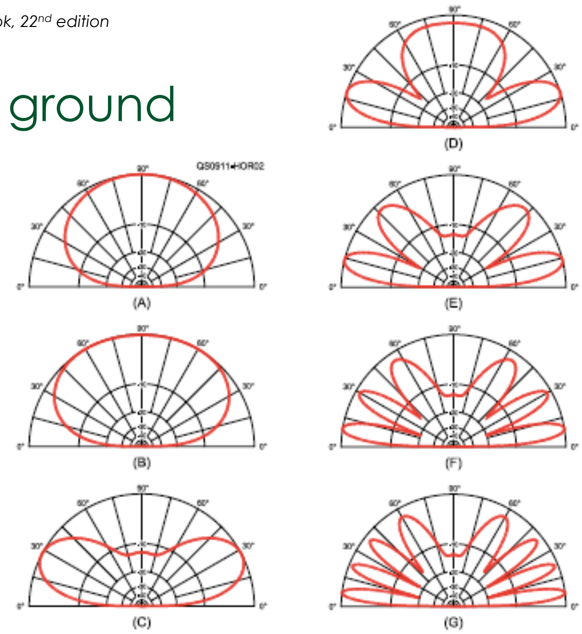

Figure 2.4 — Six radiation patterns for the dipole at different heights: (A) $\frac{1}{8}\lambda$, (B) $\frac{1}{4}\lambda$, (C) $\frac{1}{2}\lambda$, (D) $\frac{3}{4}\lambda$, E) 1λ, (F) $1\frac{1}{2}\lambda$, (G) 2λ.

How does a wave travel?

A wave can propagate via several means. A few of them are:

- Direct (line-of-sight)
- Reflected off the ground
- Along the surface of the earth ("ground wave")
- Refracted (ducted) through the troposphere
- Refracted ("bounced") by the ionosphere ("sky wave")

We will concentrate on sky wave propagation.

What's up?

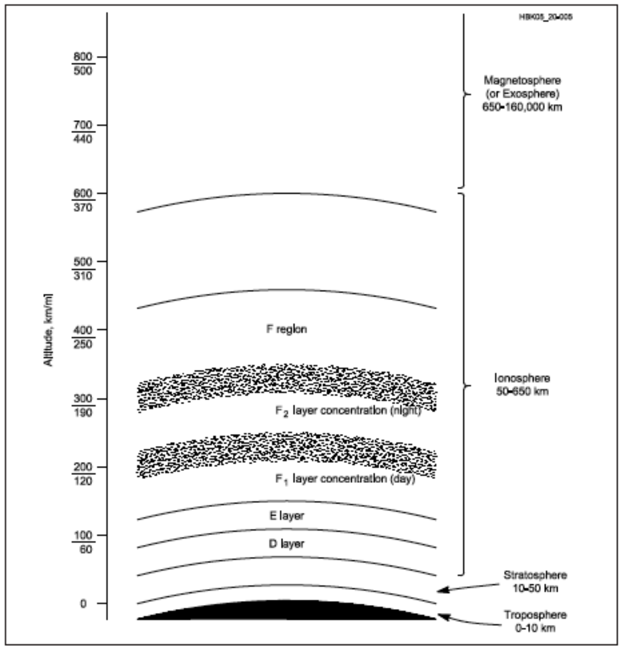

Fig 20.5—Regions of the lower atmosphere and the ionosphere.

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Ionosphere

Competing mechanisms, in equilibrium

- Ionization of atmospheric gases (O, O_2, NO, N_2) by solar radiation. (It's called the ionosphere, but it's the free electrons that matter to us.)
- Recombination of free electrons and ions.

Ionization is strongest on the day side of the earth, but may persist on the night side if recombination rate is low enough.

- "D layer" (90 km up) is densest, easiest recombination; goes away at night. Absorptive.
- "F2 layer" (300 km up) is least dense, persists after dark. Reflective.
- E & F1 layers in between, also go away at night. Reflective.

Ionization is solar-driven

- Ionosphere affected by day and night. More ionization on the day side of the earth.
- Ionosphere affected by the amount of solar radiation available (sunspot cycle) — curves shift left during low point of cycle.

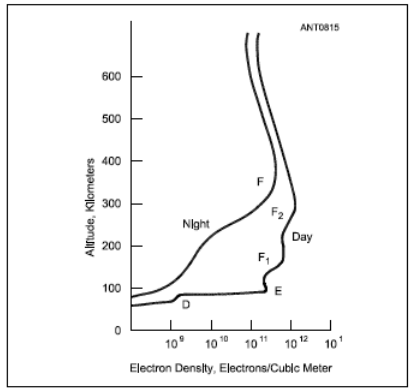

Figure 4.17 — Typical electron densities for nighttime and daytime conditions in the various ionospheric regions.

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Effect on radio waves

Radio waves make free electrons oscillate.

- Response is frequency dependent
  - Below the so-called plasma frequency (which increases with electron density), waves are reflected, don't propagate.
  - Above the plasma frequency, waves pass through.
- A radio wave sent straight up will bounce off the electron layer — completely or partially — until the frequency gets too high (**critical frequency**), then it passes through to the next layer (or out to space).

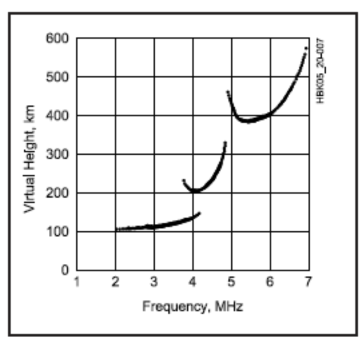

Fig 20.7—Simplified vertical incidence ionogram showing echoes returned from the E, F_1 and F_2 layers. The critical frequencies of each layer (4.1, 4.8 and 6.8 MHz) can be read directly from the ionogram scale.

Wave refraction

- Electron density gradient (increases with height) bends a wave over and send it back to earth—upper part of wave sees a higher density and has higher wave speed.

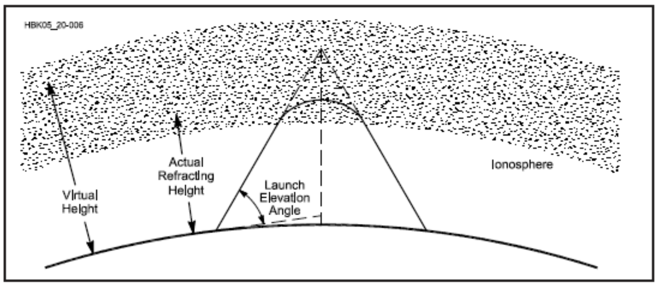

Fig 20.6—Gradual refraction in the ionosphere allows radio signals to be propagated long distances. It is often convenient to imagine the process as a reflection with an imaginary reflection point at some virtual height above the actual refracting region. The other figures in this chapter show ray paths as equivalent reflections, but you should keep in mind that the actual process is a gradual refraction.

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Wave refraction (2)

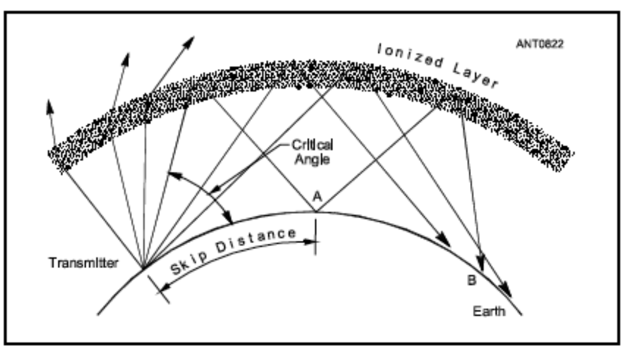

Figure 4.23 — Behavior of waves encountering a simple curved ionospheric layer over a curved Earth. Rays entering the ionized region at angles above the critical angle are not bent enough to be returned to Earth, and are lost to space.

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Maximum usable frequency

- Wave at oblique incidence "sees" a thicker layer, will reflect at higher than the critical frequency.
- Above the **maximum usable frequency**

  MUF = critical frequency / cos (incident angle)

  the wave passes through to the next layer (or into space).
- MUF is higher for lower launch angles from the antenna.
- MUF increases during periods of high sunspot activity (more ionization, higher electron density). Expect good 10 meter DX at solar maximum (except this cycle, so far).

Wave attenuation

On the other hand, excited electrons can lose energy by collisions with neutral atoms. The field is attenuated, "absorbed".

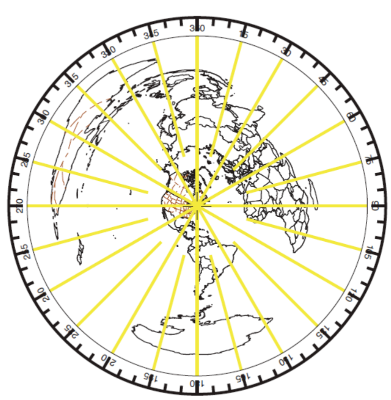
- D layer is dense, lossy. Goes away after sundown, allowing waves to propagate to upper layers of ionosphere.
- Electron response is frequency-dependent: D layer absorbs high frequencies less than low (e.g., 15-meter DX in the daytime).
- E and F layers have higher electron density, but fewer collisions, so losses are lower.
- For lowest loss, pick a frequency close to the MUF.
- Below the **lowest usable frequency** (LUF), signals are weakened to the point of being lost in the noise.

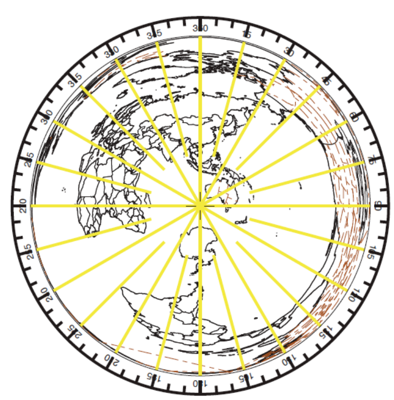
How far can I work?

- On a single hop, the maximum distance is about 4000 km (2500 mi) for the F2 layer and 2300 km (1400 mi) for the E layer.
- Multiple hops between sky and earth are needed for long DX (e.g., to VK and ZL, 16700+ km).
- Because MUF is proportional to 1/cos(angle of incidence), short hops are harder than long hops at a given frequency. If you work a short hop on 10 meters, look for a long hop on 6 meters.

AEP maps

- Azimuthal Equidistant Projection — shows great circles as lines





http://www.wm7d.net/az_proj/az_html/azproj_form_short.shtml

Sporadic-E

- Intensely ionized “clouds” in the E layer, physical reasons not well-understood (meteors burning up?). Can last minutes to hours.
- Peak season is May-August (about the time of the June VHF contest)
- Typified by a MUF in the VHF range (6m and 2m DX).
- Double-hops to the west coast and to Europe are possible.
- www.dxmaps.com shows contacts reported on different bands.

Scatter

- **Skip zone** is between farthest extent of ground wave propagation and nearest single-hop propagation.
- But signals can **scatter** off irregularities in the ionosphere and reach points in the skip zone.
- Signals can also scatter off the ground and reflect back through the ionosphere into the skip zone.
- Scatter signals usually sound fluttery (multiple paths).

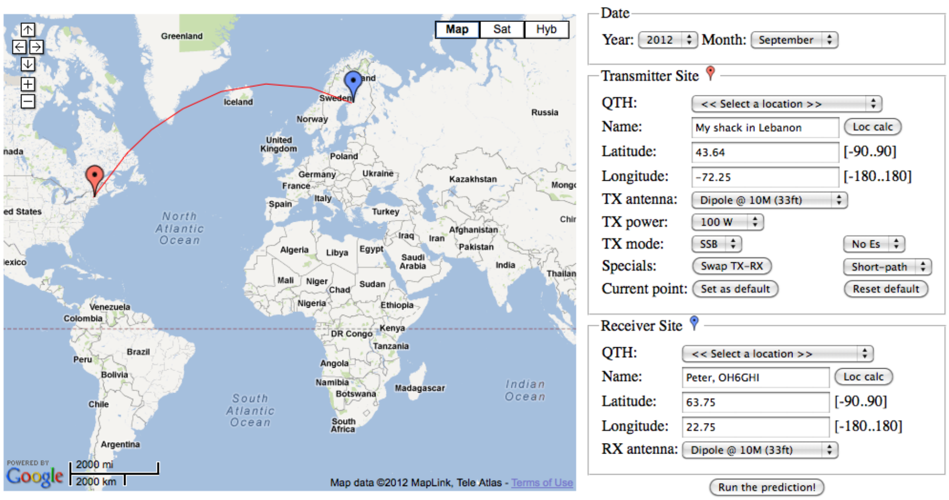
Disturbed ionosphere

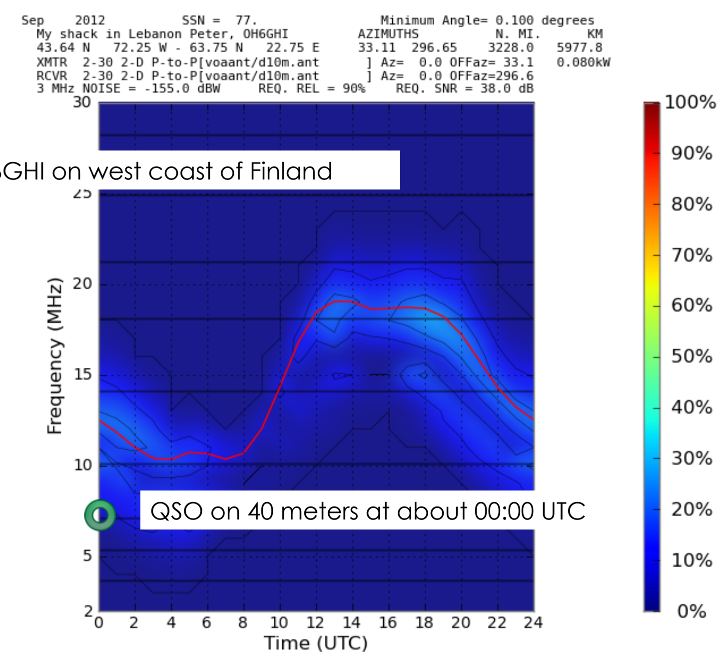
- Solar flares throw off large amounts of X-rays, which ionize the D layer (high absorption, radio blackout, **sudden ionospheric disturbance**). Try a higher frequency.
- **Geomagnetic storms** (ionospheric storms): Charged particles (plasma) thrown off by a solar storm disrupt the earth's magnetic field and especially propagation in the polar regions.
- **Solar indices** K and A measure the geomagnetic activity (low is quiet, high is unsettled).

Propagation prediction

- Computer programs use smoothed sunspot numbers to predict MUFs for specified paths.
- VOACAP available for free, http://www.voacap.com/
- Use VOACAP online, http://www.voacap.com/prediction.html

Online VOACAP example

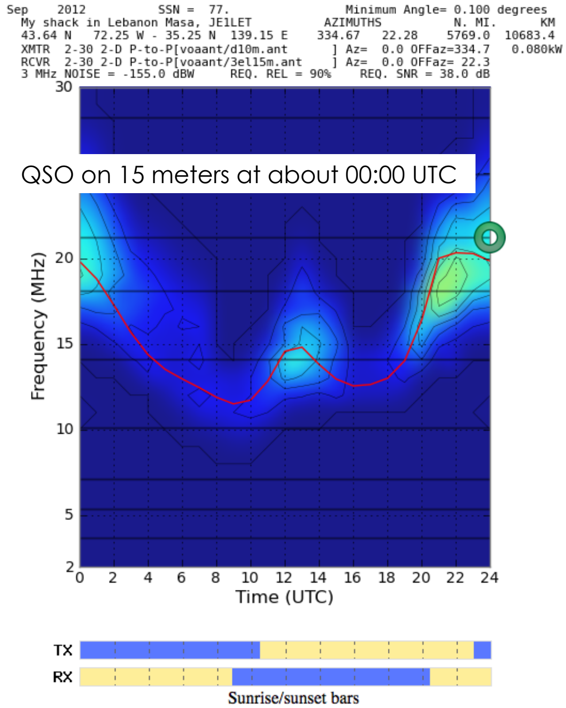




Contact with OH6GHI on west coast of Finland

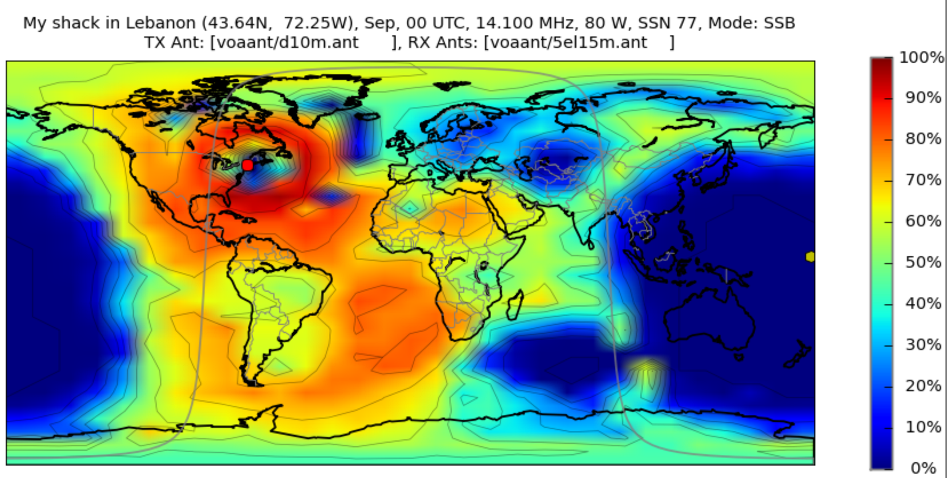
QSO on 40 meters at about 00:00 UTC

Another contact: JE1LET in Tokyo.



Predicted probability of good service on 20 meters, 00:00 UTC. My antenna is a dipole at 25', his is a 5-element Yagi at 50'.

VOACAP coverage map



For further reading

- Good online source: www.radio-electronics.com, section on antennas and propagation.
- *ARRL Handbook*, Chapter 20
- *ARRL Antenna Book*, Chapter 4
- (Very technical), Jordan and Balmain, *Electromagnetic Waves and Radiating Systems*, Chapters 9, 16, 17.
- (Also quite technical), Tascione, *Introduction to the Space Environment*, Chapters 7-9.