Propagation, Antennas and Feedlines

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Joe's Background

- Licensed since 1961
  - Extra Class - WA2SFF
- Electrical Engineer
  - Studied Wireless Communications in Grad School
  - Thesis Topic: Mitigating the effects of multipath fading on FM radio signals
- Co-author of three books on Wireless Communications

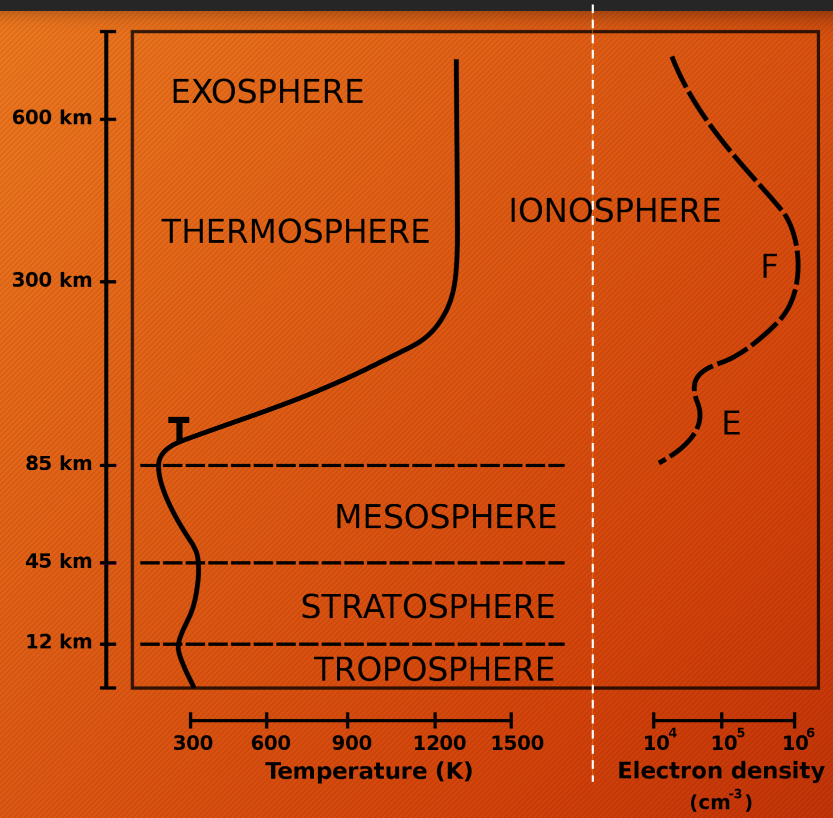
Outline

- HF Propagation
- Basics of Antennas, Feedlines and SWR
- Extras (time permitting)
  - VHF Propagation

Radio Waves

- Radio Waves, like light travel in a straight line
- But the earth is a sphere and is not flat
  - Sorry "Flat Earth" people
- To travel long distances, we need:
  - A "mirror" to reflect the waves – Ionosphere (HF/low VHF)
  - A way to bend the waves – Troposphere (VHF/UHF)
- For local communications, the atmosphere has some effect on bending the waves, depending on:
  - Antenna height (higher is better)
  - Frequency (lower is better)

Layers in Earth's Atmosphere



For long distance
HF propagation,
we are interested
primarily in the Ionosphere

For Long Distance
VHF/UHF propagation,
The Troposphere is of interest

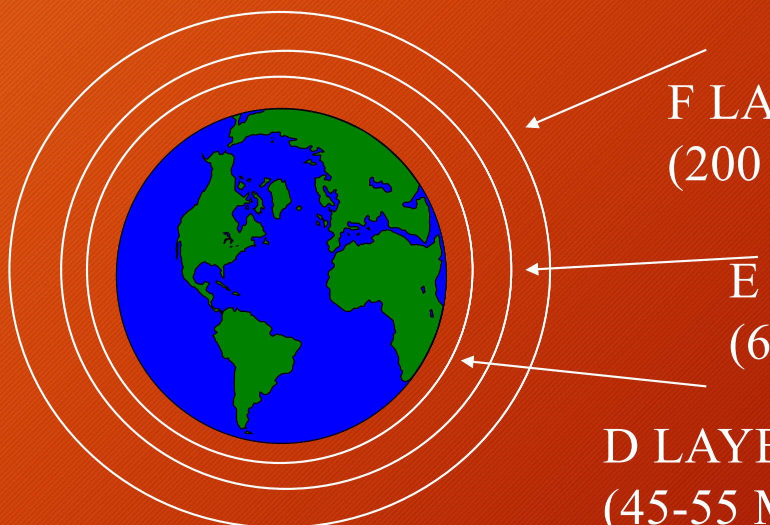
https://en.wikipedia.org/wiki/Ionosphere

The Ionosphere

- The ionosphere is a shell of electrons and electrically charged atoms and molecules that surrounds the Earth, stretching from a height of about 50 km (31 mi) to more than 1,000 km (620 mi).
- The amount of ionization in the ionosphere varies greatly with the amount of radiation received from the Sun.
- The ionization varies with:
  - Day or night
  - Location on the earth
  - Summer vs. Winter
  - The Sunspot Cycle of 11 years
- Solar Flares can disrupt the Ionosphere

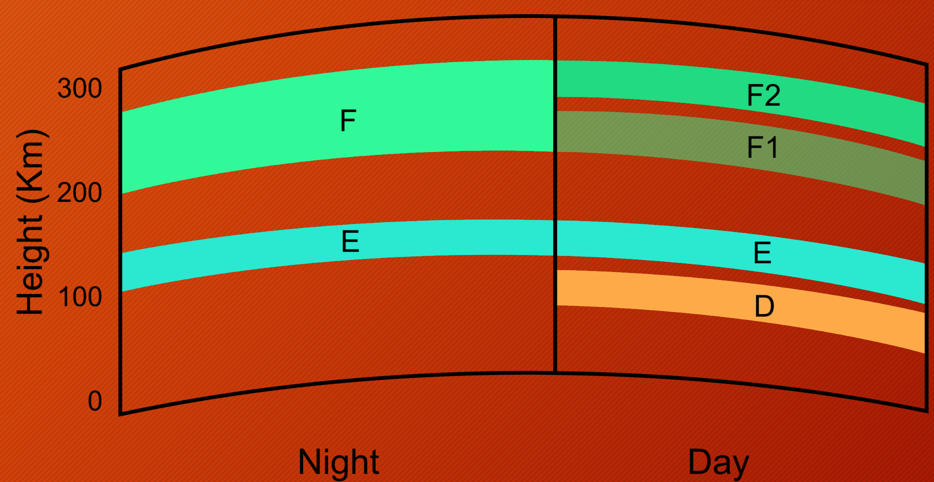
Fundamentals

- HF and low VHF propagation depends on the ionosphere
- Three layers are key
  - F
  - E
  - D



Layers of ionosphere

- F layer
  - Height ~ 200 miles
  - Reflects signals (HF & VHF)
- E layer
  - Height 65-75 miles
  - Reflects signals above ~ 15 meters
- D layer
  - Height 45-55 miles
  - Attenuates signals
  - Disappears at night

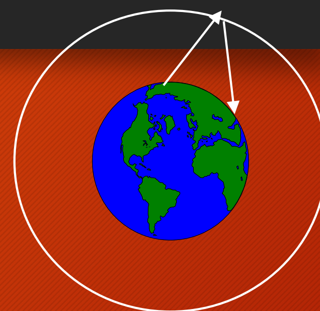


https://en.wikipedia.org/wiki/Ionosphere

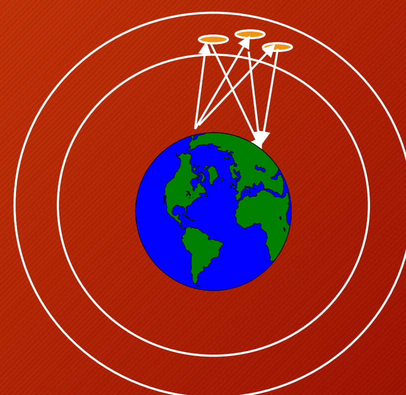
Ionosphere acts as mirror

- The mirror is not perfect
- Different parts of the ionosphere reflect signals at different times
- The received signal arrives from many spots in the Ionosphere
- The signals combine at the receiver
- As the ionosphere changes the paths change and the signal fades in and out
- This is called multipath fading

- Ideal

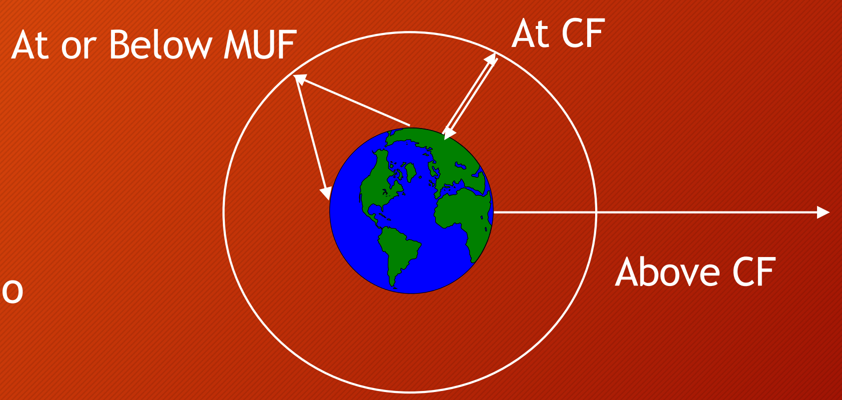


- Real



There are 3 frequencies of interest in HF propagation

- Critical frequency CF)
  - The highest frequency that will be reflected back to the earth when the antenna is aimed straight up
  - Higher frequencies are not reflected and pass through the Ionosphere
- Maximum Usable frequency (MUF)
  - The highest frequency that can be used to communicate between two points on the earth
  - The MUF is always lower than the critical frequency
- If we want to reflect at an angle, we need to use a lower frequency than the critical frequency
- Thus the further we want to talk, the lower the frequency



Lowest Usable Frequency (LUF)

- The D-layer attenuates signals
- The lowest frequency that will pass through the D-layer without significant attenuation is called the Lowest Useable Frequency (LUF)
- Frequencies lower than the LUF
  - Will not get though the D-layer
  - Therefore, will not be reflected off the F-layer or E-layer
- The D layer is primarily ionized by the Sun; so at night, the D layer disappears
- That's why we can hear AM broadcast from 1000's miles away at night.
- If the MUF is lower than the LUF: Then we can’t hear or talk

Single and Multiple Hops

- Long distance communications require multiple hops
  - The signal reflects off of the Ionosphere and then off the ground/ocean then off the Ionosphere
  - Around the world propagation requires 2-4 hops or more

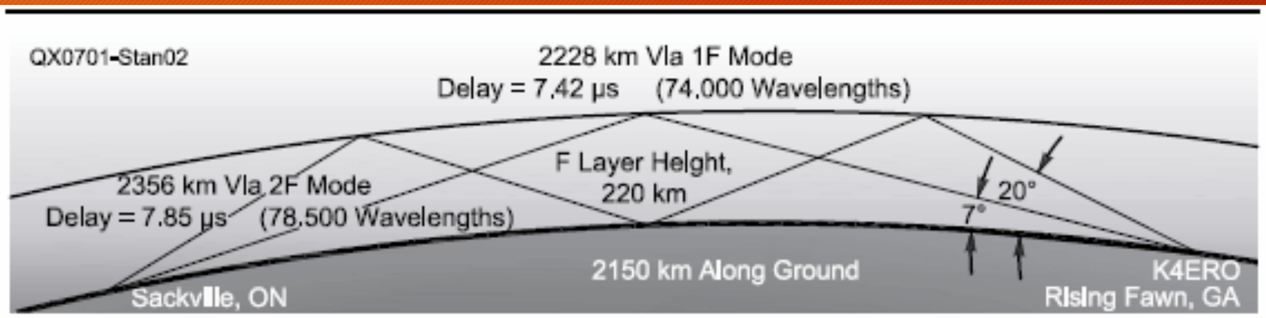


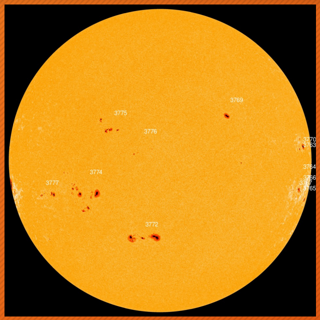
Figure 2 — Signals from Sackville, ON, can arrive at K4ERO in Rising Fawn, GA by one or two ionospheric hops.

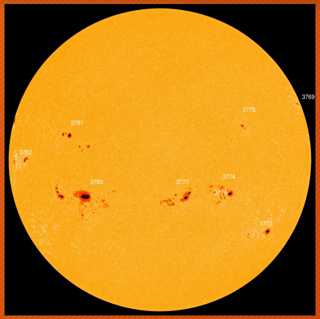
What are Sunspots

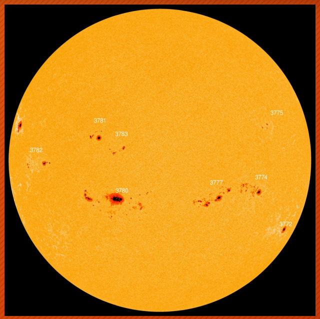
- Sunspots are dark/cooler areas on the Sun
  - Normal temperature of surface of Sun 5,500 °C
  - Sunspots are 2,700-4,200 °C
- But edges of sunspots radiate a lot of Ultra Violet Light
- Ultra Violet Light charges the ionosphere
- The more sun spots, the higher the charge, and the better the propagation
- Sunspots Increase and decrease in an 11 year cycle
  - There are other cycles as well
  - We are still learning about sunspots and predictions are often wrong
- During Sunspot maximums
  - MUF can exceed 50 MHz

Recent Sunspots

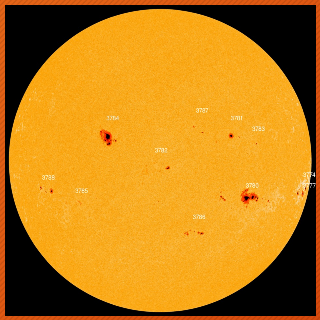
Never Look Directly at the Sun!

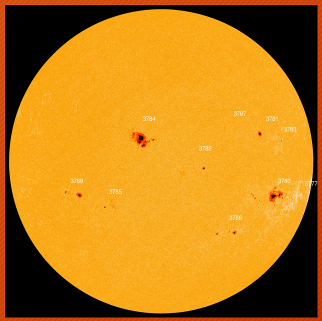


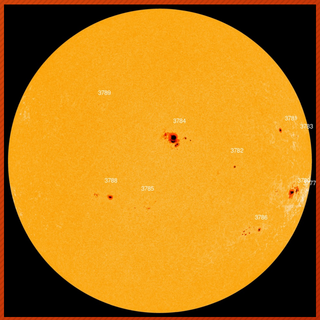


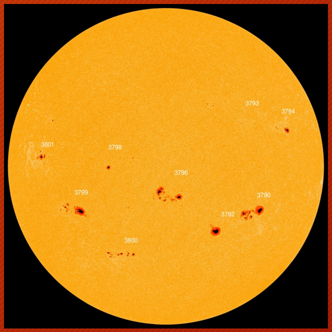


August 4-24, 2024



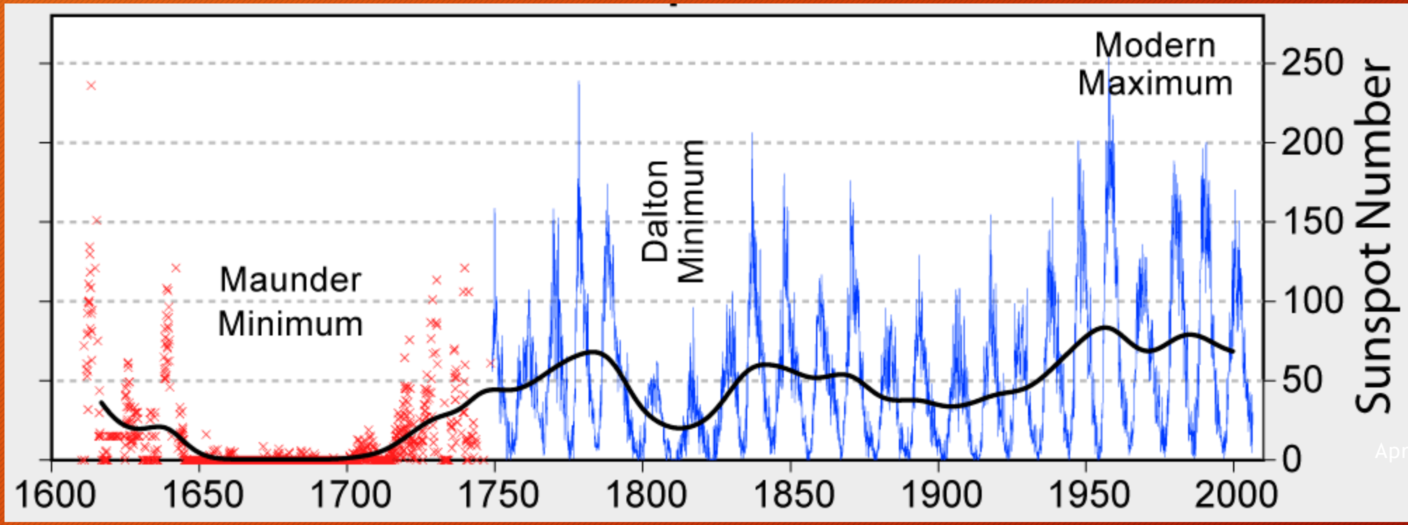






Highest Sun Spots Ever in last 400 years

- 1958: MUF>60 MHz
- Some lucky hams worked Japan on 6 meters
  - I started out on 6 meters in 1961
  - Other hams told me how I missed the peak



Local HF Communication Range

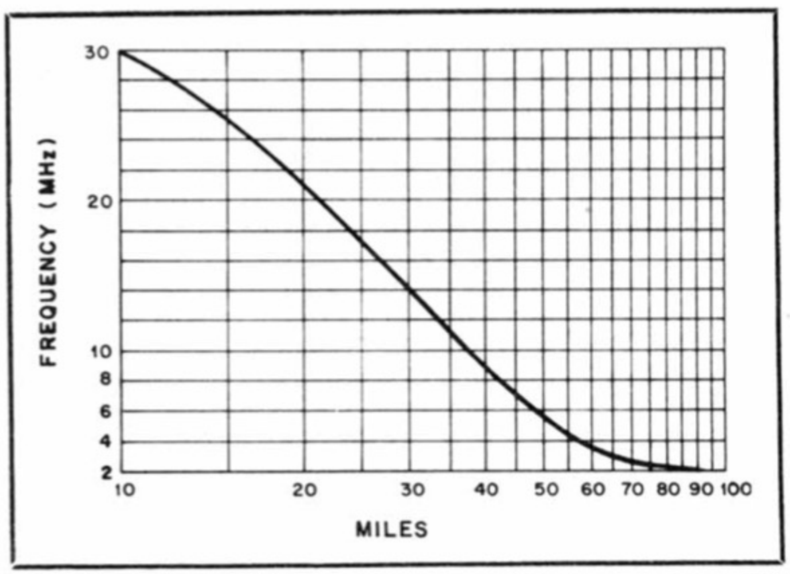


Fig. 1 — Typical high-frequency range, in miles, for ground waves compared to frequency. km = mi × 1.609.

QST
January 1985
"Radio Waves and Communications Distance," W1FB

Propagation

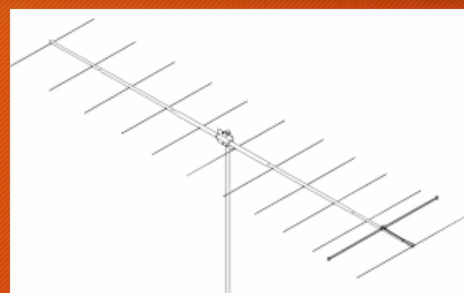
- Random
- Never guaranteed
- Somewhat Predictable
- Methods of predications
  - Computer programs
  - Website with receivers

Antenna Polarization

- Horizontal Polarization
  - HF
  - VHF
  - UHF

- Vertical Polarization
  - HF
  - FM

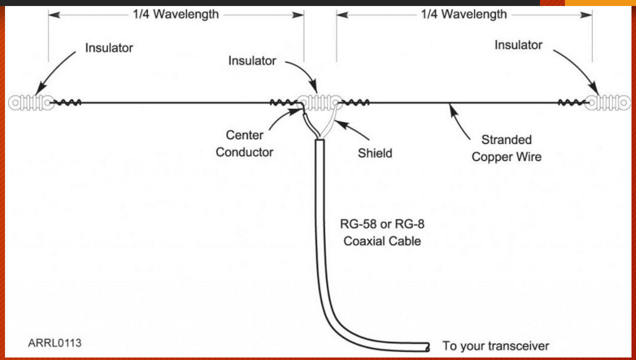
- Right Hand Circular
- Left Hand Circular
  - Satellites



- In most cases, the transmitter
  and receiver must use the same Polarization

Antenna Gain

- The simplest antenna is a dipole
- An isotropic antenna is a (fictional) simple antenna that radiates the same in all directions
- All other antennas are measured against either antenna:
  - Gain is measured in decibels (dB)
  - Gain measured in dBd is compared to a dipole
  - Gain measured in dBi is compared to the isotropic
- You can convert between dBi and dBd using the equation dBi = dBd + 2.15
- If you see an antenna gain expressed only as a number it is mostly likely dBi since it makes the gain look higher



Length of Antenna is 468/frequency (in MHz)

80 meters	125 feet
40 meters	65 feet
20 meters	33 feet
15 meters	22 feet
10 meters	16.5 feet

Feed Lines

- When connecting a transmitter or receiver to an antenna we need a feed line.
- The most common feedline is coaxial (coax) cable
- Another common type is open wire (or ladder line) feedline
- Feedline is measured by its loss in dB per 100 feet at different frequencies and its impedance.
- For Ham radio use we use 50 ohm coax
- Cable TV uses 75 ohm coax

Characteristics of Common Coax used by Hams

Frequency/ Size	LMR-1200	LMR-900	LMR-600	1/2" Superflex	LMR-400	Belden 9913F7	9914	RG214 RG213	LMR-240	Belden RG8X	LMR-200	LMR-195	RG-58/ U
	1.200"	0.870"	0.590"	0.520"	0.405"	0.405"	0.400"	0.405"	0.240"	0.242"	0.195"	0.195"	0.195"
30 MHz	0.209	0.288	0.421	0.561	0.7	0.8	0.8	1.2	1.3	2.0	1.8	1.8	2.5
50 MHz	0.272	0.374	0.547	0.730	0.9	1.1	1.1	1.6	1.7	2.5	2.3	2.3	3.1
150 MHz	0.481	0.658	0.964	1.29	1.5	1.7	1.7	2.8	3.0	4.7	3.9	4.0	6.2
220 MHz	0.589	0.803	1.18	1.58	1.8	2.1	2.1	3.5	3.7	6.0	4.8	4.8	7.4
450 MHz	0.864	1.17	1.72	2.32	2.7	3.1	3.1	5.2	5.3	8.6	6.9	7.0	10.6
900 MHz	1.27	1.70	2.50	3.41	3.9	4.4	4.5	8.0	7.6	12.8	9.9	9.9	16.5
1,500 MHz	1.69	2.24	3.31	4.57	5.1	6.0			9.9		12.7	12.9	

Characteristics of Common Coax used by Hams

Power Capacity (In watts 104°F, 40°C)									
	MHz:	**30**	**50**	**150**	**220**	**450**	**900**	**1500**	**2000**
#0985	**LMR-100A®**	230	180	100	80	60	40	30	25
#2619	**RG-58U**	400	300	160		80			
#3603	**LMR-200®**	1020	790	450	370	260	180	140	120
#2910	**RG-59**	500	400	250					
#2247	**RG-8X**	350	280	150		80			
#3604	**LMR-240®**	1490	1150	660	540	380	260	200	170
#3605	**LMR-240 Ultra®**	1490	1150	660	540	380	260	200	170
#2929	**RG-213**	1800	1200	620		300			
#0390	**RG-214**	1800	1200	620		300			
#3606	**LMR-400®**	2100	1700	1000	830	550	380	290	250
#3607	**LMR-400 Ultra®**	2100	1700	1000	830	550	380	290	250
#6512	**DRF-400**	3300	2570	1470	1200	830	580	440	370
#0075	**9913**	2200	1700	900		450	280	200	160

Values indicated are *approximate* and for comparison purposes only.
LMR® is a registered trademark of Times Microwave Systems.

Attenuation (dB per 100 feet)										
	MHz:	**30**	**50**	**100**	**146**	**150**	**440**	**450**	**1000**	**2400**
#2632	**RG-174**	5.5	6.6	8.8	13.0		25.0		30.0	75.0
#0985	**LMR-100A®**	3.9	5.1		8.8	8.9	15.6	15.8		
#2619	**RG-58A/U**	2.5	4.1	5.3	6.1	6.1	10.4	10.6	24.0	38.9
#3603	**LMR-200®**	1.8	2.3		3.9	4.0	6.9	7.0		16.5
#2910	**RG-59**		2.4	3.5			7.6		12.0	
#2247	**RG-8X**	2.0	2.1	3.0	4.5	4.7	8.1	8.6		21.6
#3604	**LMR-240®**	1.3	1.7		3.0	3.0	5.2	5.3		12.7
#3605	**LMR-240 Ultra®**	1.3	1.7		3.0	3.0	5.2	5.3		12.7
#2248	**RG-8/U FOAM**		1.2	1.8					7.1	
#2929	**RG-213**		1.5	2.1	2.8	2.8	5.1	5.1	8.2	
#0390	**RG-214**	1.2	1.6	1.9	2.8	2.8	5.1	5.1	8.0	13.7
#3606	**LMR-400®**	0.7	0.9		1.5	1.5	2.7	2.7		6.6
#3607	**LMR-400 Ultra®**	0.7	0.9		1.5	1.5	2.7	2.7		6.6
#6512	**DRF-400**	0.7	0.9		1.5			2.7		6.7
#5297	**Bury-FLEX™**		1.1	1.5					4.8	
#0812	**9086**			1.4			2.8	2.8		
#0075	**9913**	0.8			1.5		2.8			7.5

Values indicated are *approximate* and for comparison purposes only.
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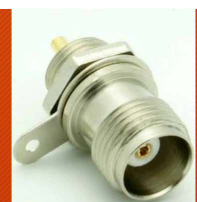
Coax Connectors

- SO-239/ PL259


- BNC


- TNC




- SMA


Standing Wave Ratio (SWR)

- The impedance of transmitter, antenna, and coax must be identical for the best performance of a radio station
- If there are any mismatches, then some of the power from the transmitter will not reach the antenna
- Some of the power reaching the antenna will be reflected back to the transmitter causing additional heat in the transmitter
- Circuitry in the transmitter will protect it by reducing the output power of the transmitter
- A measure of the mismatch is called the SWR

Ideal Setup

100 watts

0 watts, no reflection

Transceiver output 50 ohms
100 watts output

Coax cable 50 ohms

40 meter antenna 50 ohms

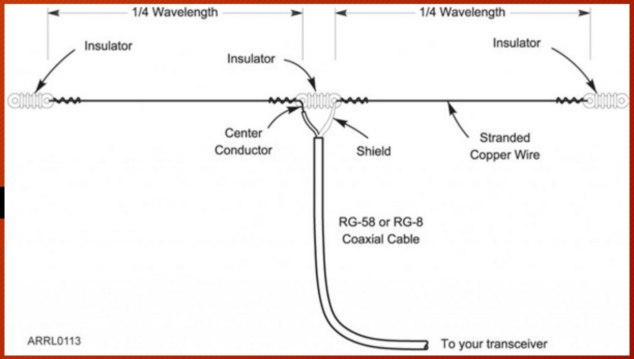
Radiated power 100 watts

SWR is perfect at 1:1

Non-ideal Setup

100 watts

3.30 watts



Transceiver output 50 ohms

Coax cable 50 ohms

40 meter dipole antenna 72 ohms

SWR is not perfect at 1.44:1

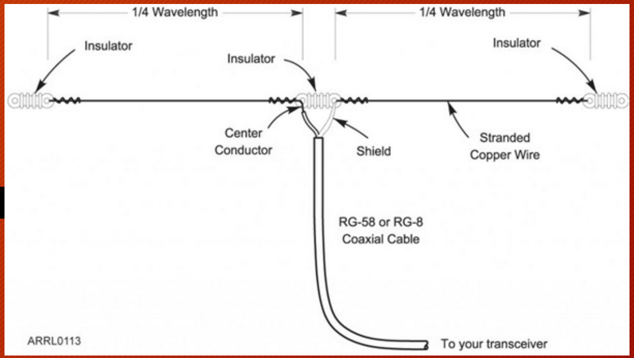
Radiated power 96.70 watts

Built-in Antenna Tuner keeps transmitter from lowering power output

Non-ideal Setup

Estimated 40 watts

18 watts



Transceiver output 50 ohms

Coax cable 50 ohms

40 meter dipole antenna 72 ohms

Radiated power 22 watts

SWR is not perfect at 5.0:1.0
Antenna tuner can not match beyond 3:1 SWR
Transceiver lowered power to protect itself

Non-ideal Setup with External Antenna Tuner

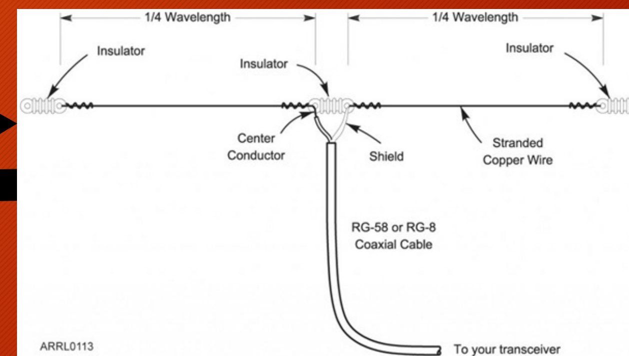
100
watts

0 watts

control cable

100
watts

45
watts



Transceiver output 50 ohms

Coax cable 50 ohms

40 meter dipole antenna 72 ohms

Max SWR for most transceivers is 3:1
If greater need external antenna tuner
SWR is not perfect at 5.0:1.0
External tuner allows transceiver to see 1:1 SWR
Antenna Tuner heats up from reflected power

Radiated power 55 watts

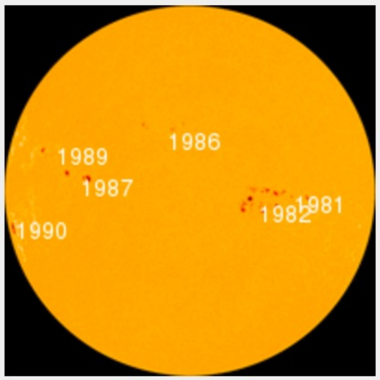
Questions?

Extras

Sunspots

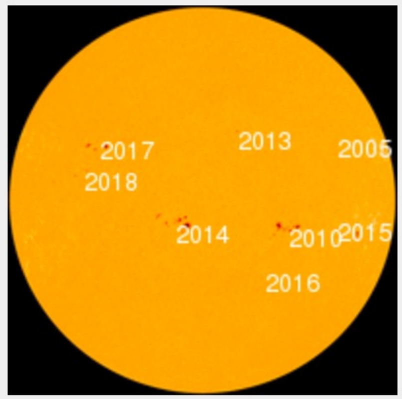
Never Look Directly at the Sun!

Daily Sun: 25 Feb 14



Active sunspot AR1990 (formerly AR1967) poses a threat for X-class solar flares. Credit: SDO/HMI

Daily Sun: 25 Mar 14



Sunspot AR2010 has a 'beta-gamma-delta' magnetic field that harbor energy for X-class solar flares. Credit: SDO/HMI

Daily Sun: 25 Feb 20

The sun is blank -- no sunspots. Credit: SDO/HMI

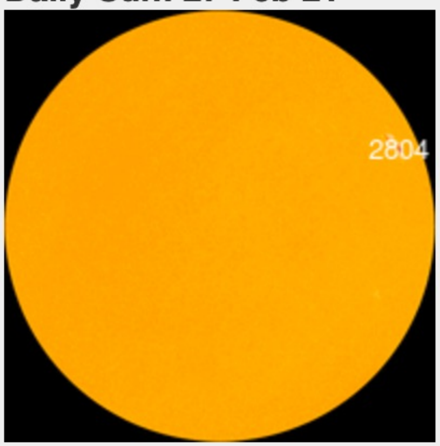
Last Solar Max 2014

Solar Min 2020

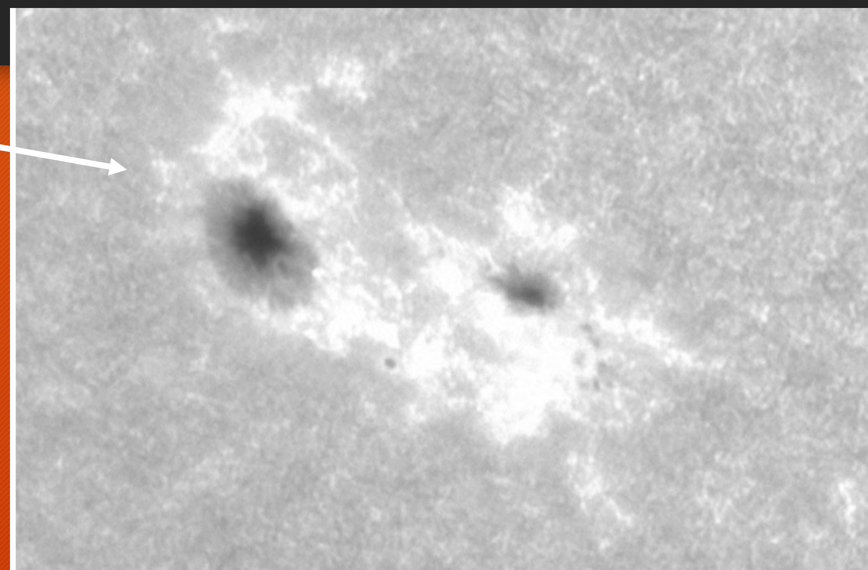
Never Look Directly at the Sun!

Expanded view of a Sunspot

Daily Sun: 27 Feb 21



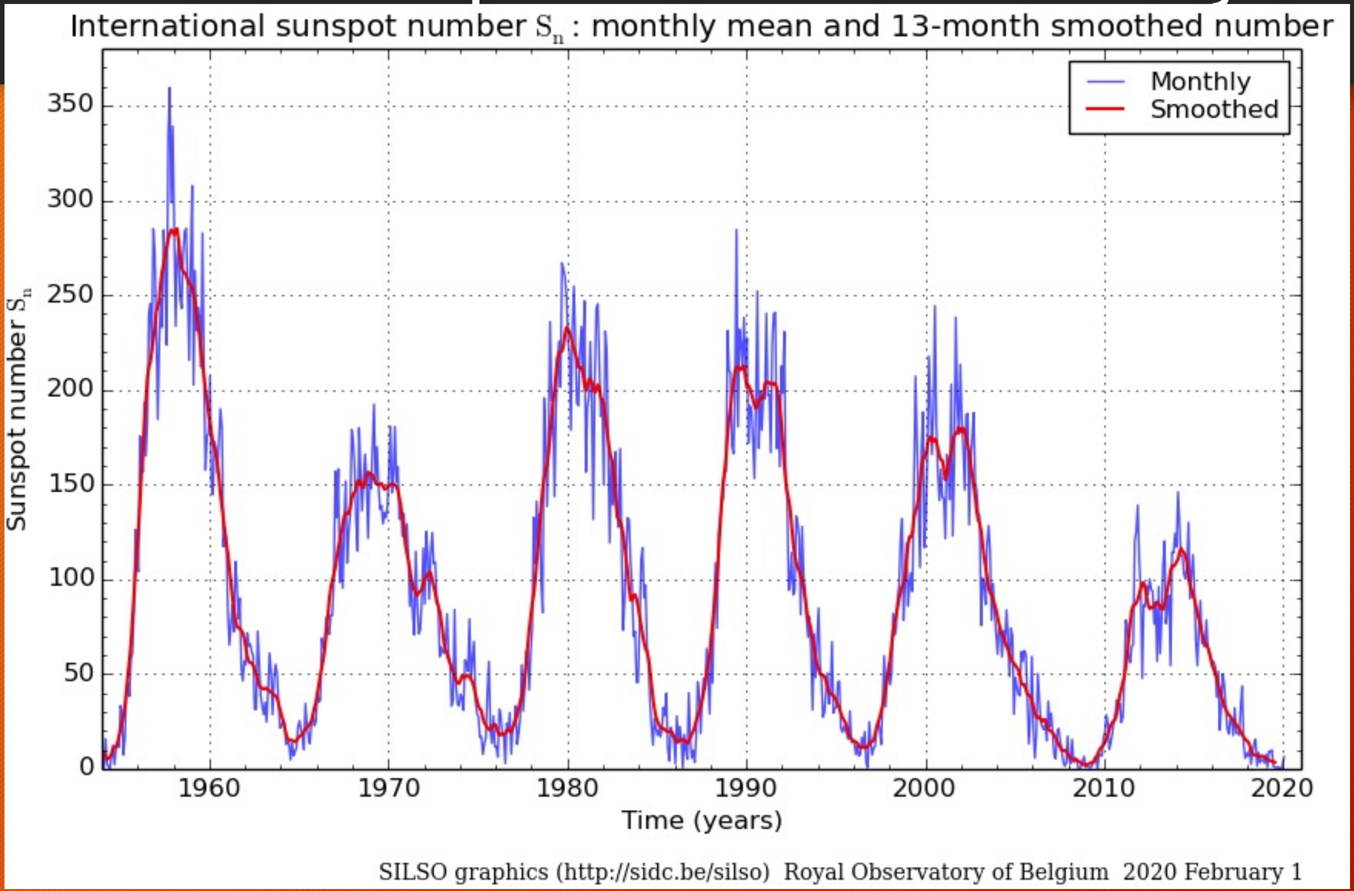
Sunspot AR2804 has a simple 'beta-class' magnetic field that poses little threat for strong flares. Credit: SDO/HMI



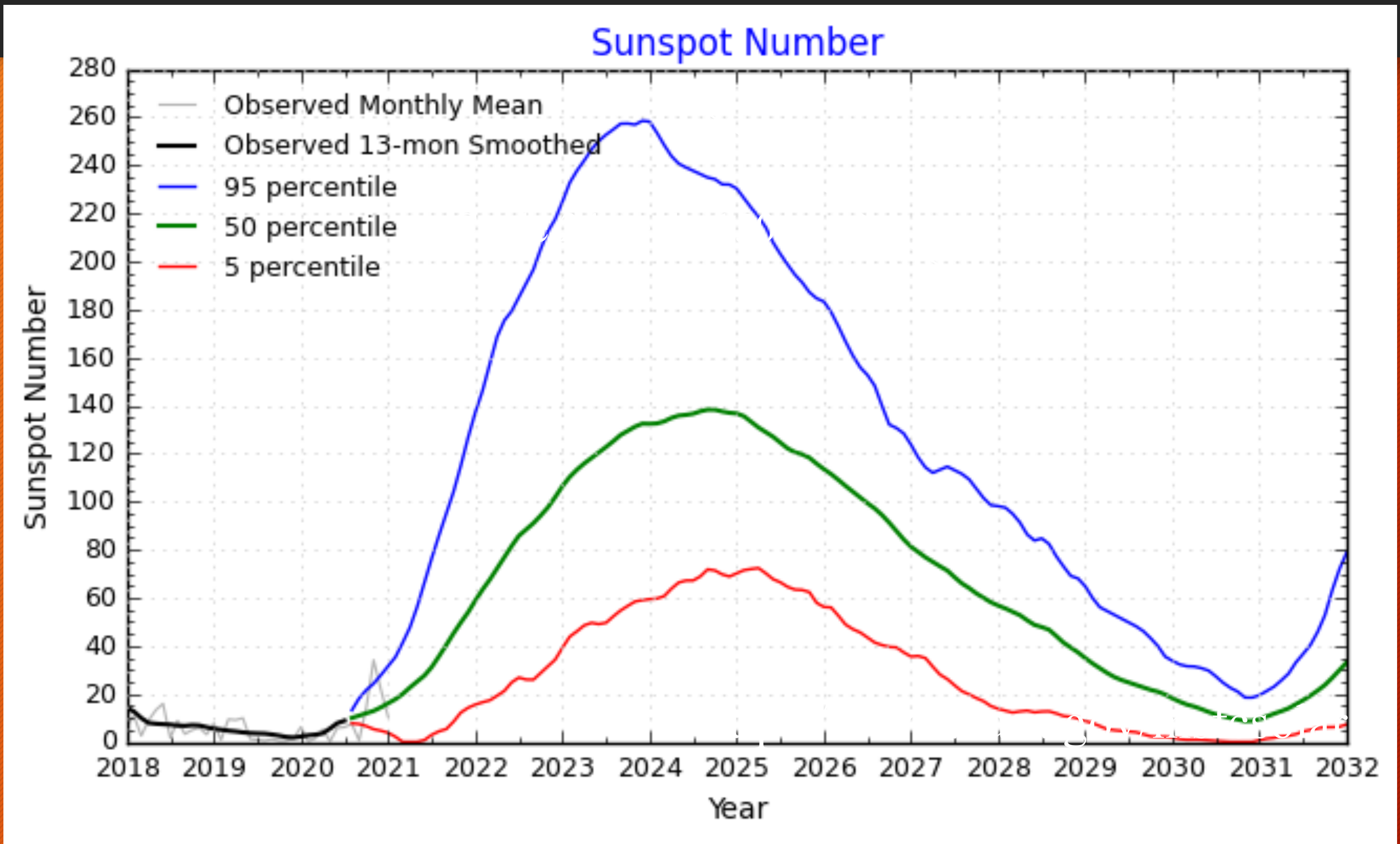
AR2804 is surrounded by a seething, white-hot foam of magnetized plasma.

https://www.spaceweather.com/

Recents Sunspots before current cycle

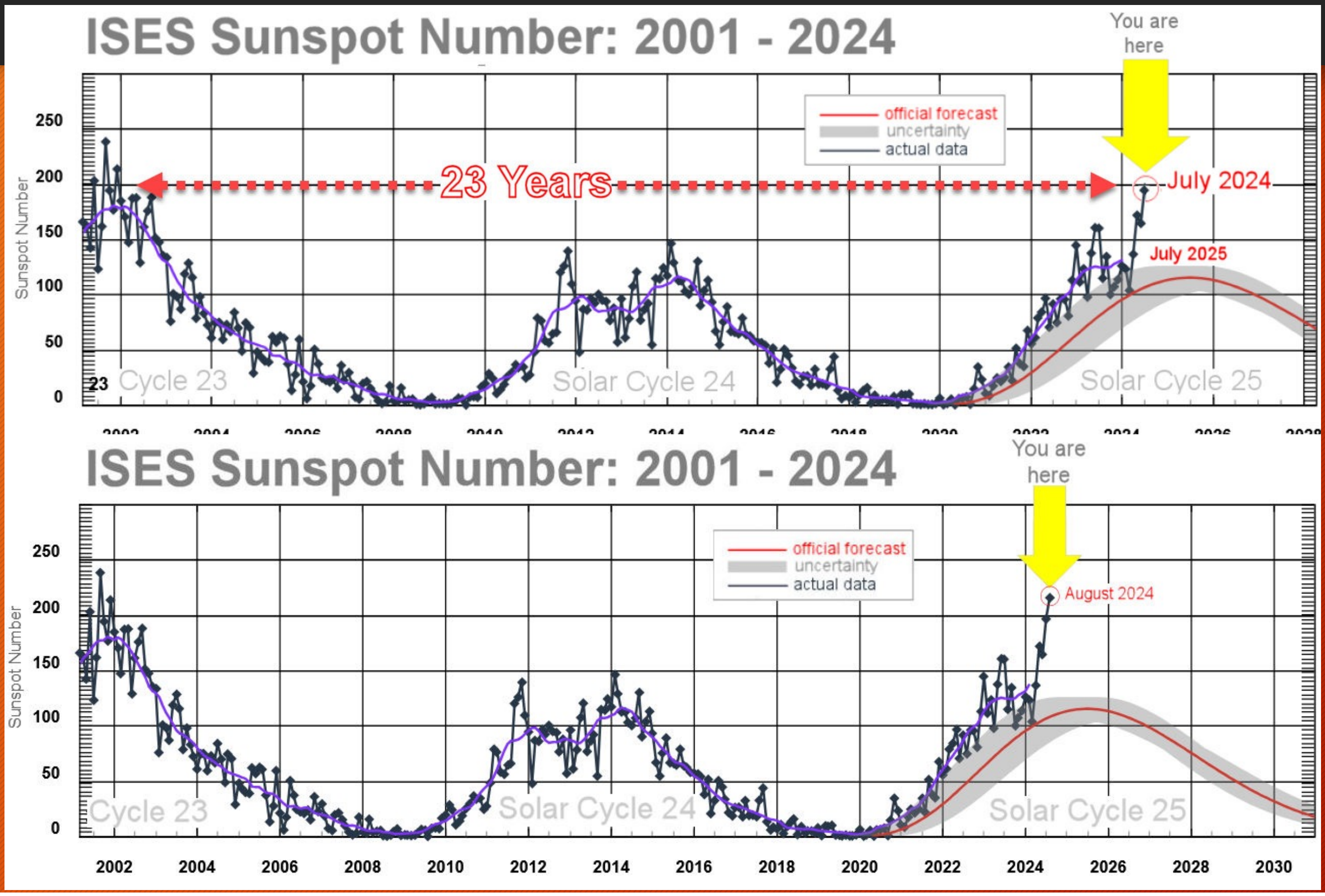


NASA Cycle 25 Predication



Before Cycle 25 started, most Scientists expected Cycle 25 to be about the same as Cycle 24 But there was at least one who disagrees

Cycle 25 So Far



The majority of the Scientists were wrong!

Only one person was right

VHF Propagation

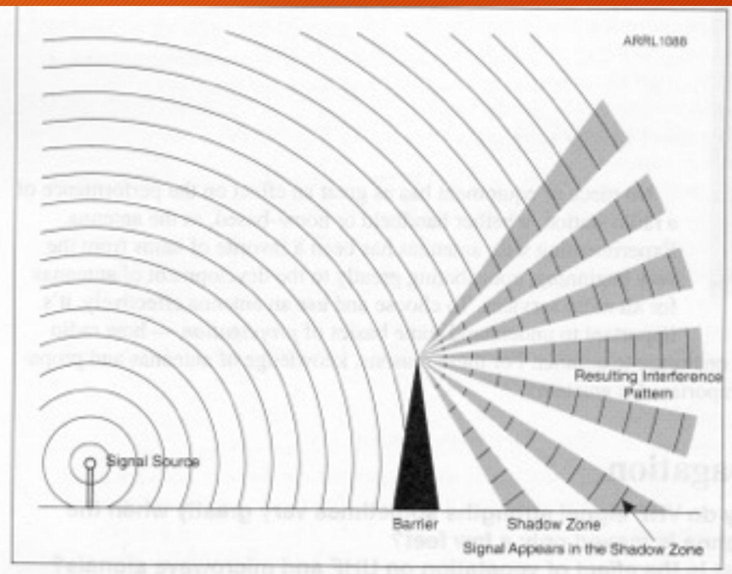


Figure 4.1 — VHF and UHF radio waves are diffracted by the edge of a solid object, such as a building, hill or other obstruction, bending them in different ways around the obstruction. The resulting interference pattern creates shadowed areas where little signal is present. If the edge of the object is small compared to a wavelength, the result is called "knife-edge diffraction."

From ARRL Tech Study Guide

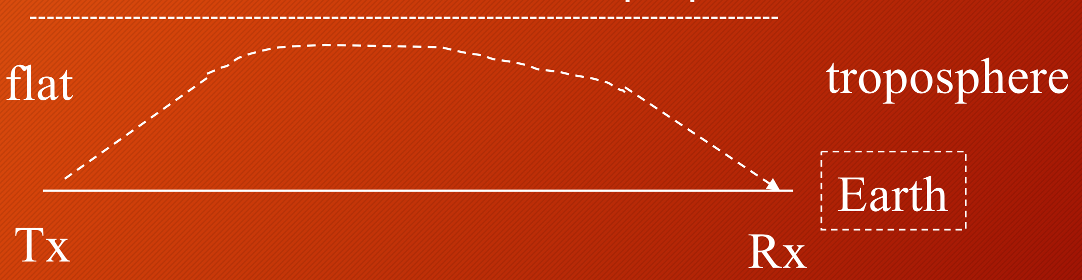
VHF Propagation

- E Skip
  - 10, 6 , 2, 1-1/4?? meters
- F Skip
  - 6 meters
  - rare: Needs very high suspot numbers
- Tropospheric ducting
- Aurora
- Meteor scatter
- Forward scatter
- Back scatter
- Moon bounce
- Satellites

Tropospheric ducting

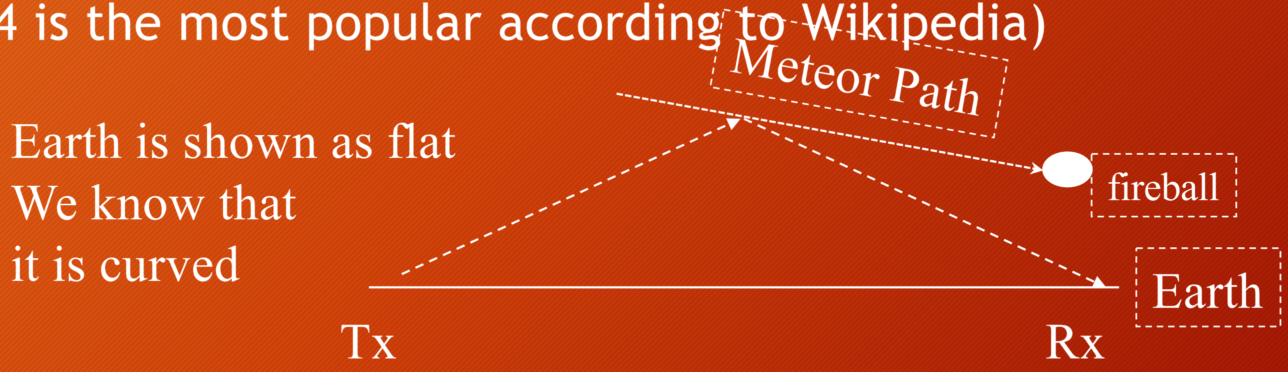
- As various times of the year and depending on weather conditions, the troposphere can act as a duct for VHF/UHF radio waves
  - 2 m, 1.25M, ¾ m
- Also known as as temperature inversion where the temperature of the atmosphere goes up the higher the altitude.
- This creates a condition where signals are bent by the troposphere and we get very good long range (500-1000 miles or more) propagation
- This was used to set range records for VHF and UHF by hams between California and Hawaii.
- The higher the antenna the better to connection to the troposphere

Earth is shown as flat
We know that
it is curved



Meteor Scattering

- As a meteor passes through the atmosphere it heats up the air and ionizes it.
- Radio waves can reflect off the ionized path
- Because these ionization trails only exist for fractions of a second to as long as a few seconds in duration, they create only brief windows of opportunity for communications.
- Today, mostly high speed digital communications are used – WSJT-X modes (MSK144 is the most popular according to Wikipedia)



Aurora

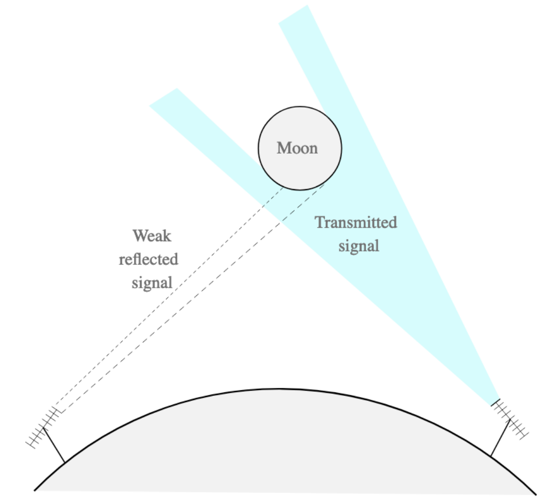
- When Aurora occurs, the upper atmosphere is charged and can reflect VHF/UHF signals
- Since the Aurora (or Northern Lights) are North of us, we need to point our antennas North (or at the Aurora)
- Aurora signals tend to be raspy because of the nature of the aurora, flickering

Forward and Back Scattering

- Scattering off of:
  - small ionized particles in the atmosphere,
  - ocean waves
  - Rain
  - Snow
- Path losses are very high
- Think of aiming a hose at a window screen: How much water is reflected off the screen

Moon Bounce (Earth-Moon-Earth/EME)

- With enough power and a big enough antenna, we can bounce our signals off the moon.
- the overall path loss is at best approximately
  252 dB on 144
  271 dB on 1296
- Need 1 KW, and 20-25 dBd antenna
- The ISEC antenna is great for Moon bounce
- With WSJT-X, lower power, and smaller antennas can be used



Concept of Moonbounce EME propagation

Planet Venus Bounce (Earth-Venus-Earth/EVE)

- Very very high path loss
- Some German hams have bounced their signal off of Venus
- Most recent was April 10, 2009
- They transmitted a continuous wave signal (no modulation) for about 5 minutes
- For receiving the EVE signals, an FFT analysis with an integration time of 5 minutes was used. After integrating for 2 minutes only, the reflected signals were clearly visible in the display.
- ISEC plans to try later next year when Venus is again close

https://amsat-dl.org/projects/venus-echos/

Satellites

- There are multiple ham radio satellites in orbit around the earth
  - Orbital Satellites Carrying Amateur Radio (OSCAR)
- Most current activity is on 2 m and ¾ m
- Can be done with an HT and a handheld antenna
- From a talk a few months ago
  - See https://www.work-sat.com/ for details