

# UNDERSTANDING RF PROPAGATION

BY TIM KUHLMAN, PE

KD7RUS



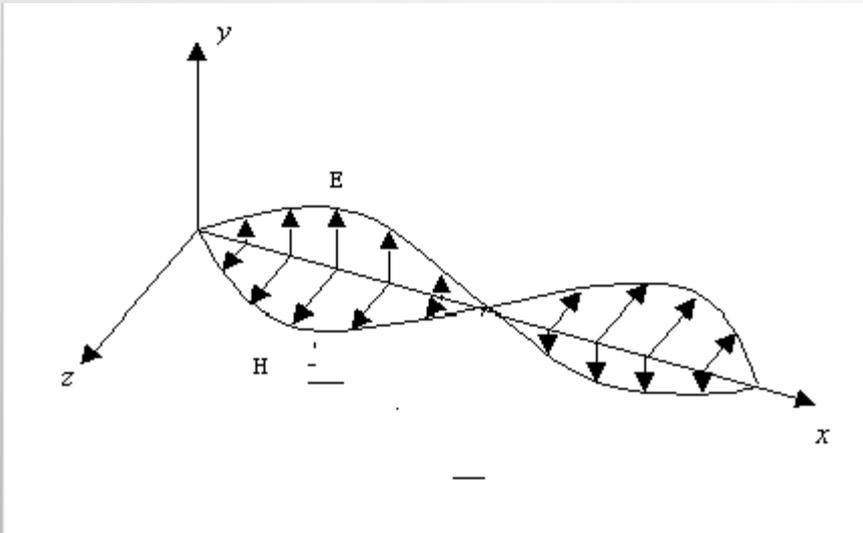
# RF PROPAGATION

- WHAT IS RF PROPAGATION?
- WHAT ARE THE DIFFERENT TYPES OF PROPAGATION?
- HOW DOES OUR ENVIRONMENT AFFECT PROPAGATION?
- HOW TO PREDICT PROPAGATION
- WHAT ARE RADIO SIGNALS AND HOW THEY REACT?



# WHAT IS RF PROPAGATION?

- IT IS THE MEANS IN WHICH RADIO SIGNALS TRAVEL.
- RADIO SIGNALS ARE ELECTROMAGNETIC WAVES. THEY WERE STUDIED AND QUANTIFIED BY JAMES MAXWELL IN A SET OF EQUATIONS NAMED AFTER HIM.



$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

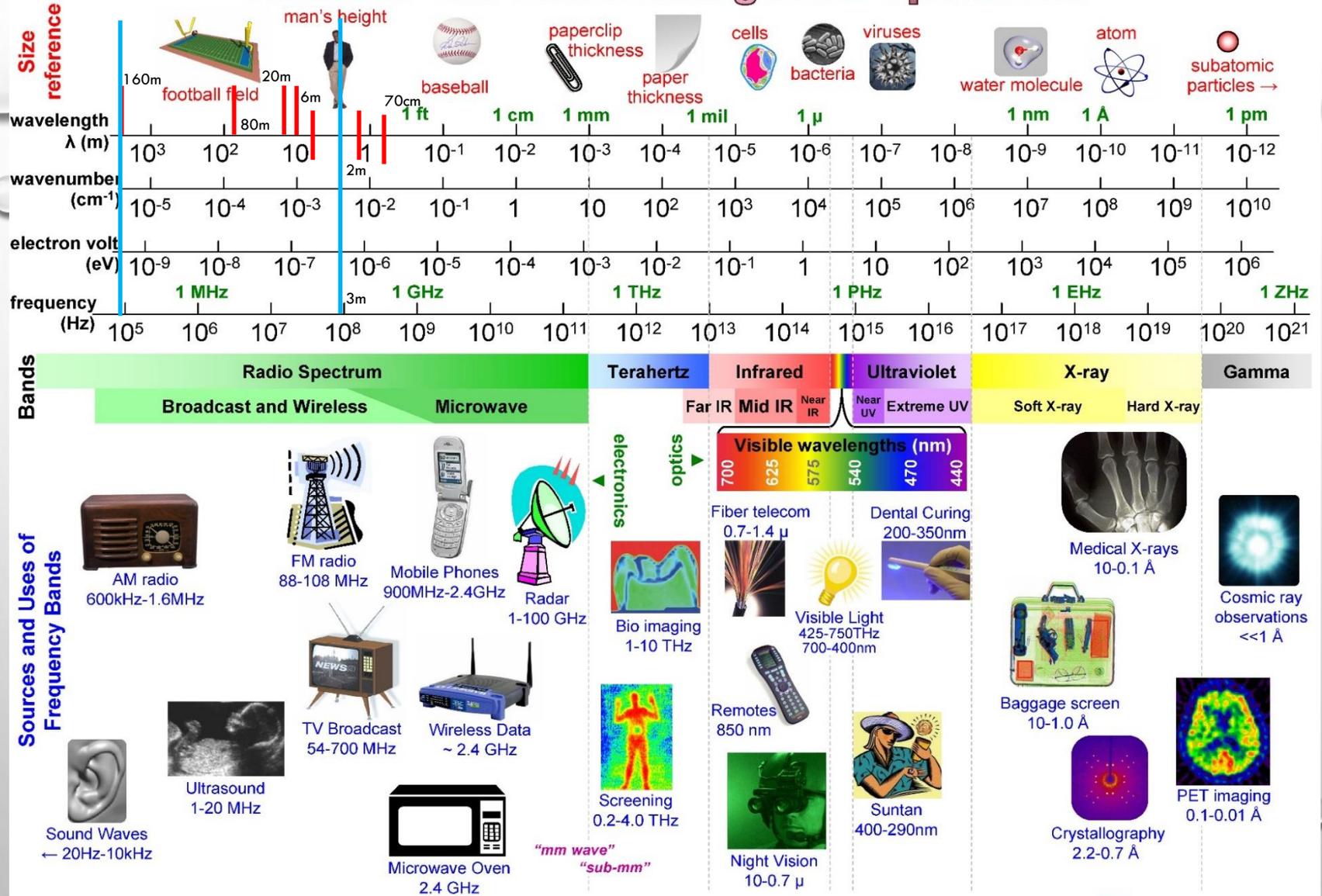


# WHAT IS RF PROPAGATION?

- EXPERIMENTS RELATING TO THE WORK OF MAXWELL WERE PERFORMED BY HEINRICH HERTZ.
- THE RESEARCH OF BOTH MEN, AND OTHER SCIENTIST SHOWED A RELATIONSHIP BETWEEN THE ELECTRIC FIELD AND MAGNETIC FIELD OF A RADIO WAVE AS IT TRAVELS.
- AS A WAVE TRAVELS, IT WANTS TO TRAVEL IN A STRAIGHT LINE AND WILL BE:
  - CONDUCTED
  - ATTENUATED (ABSORBED, SCATTERED)
  - REFLECTED
  - REFRACTED



# Chart of the Electromagnetic Spectrum



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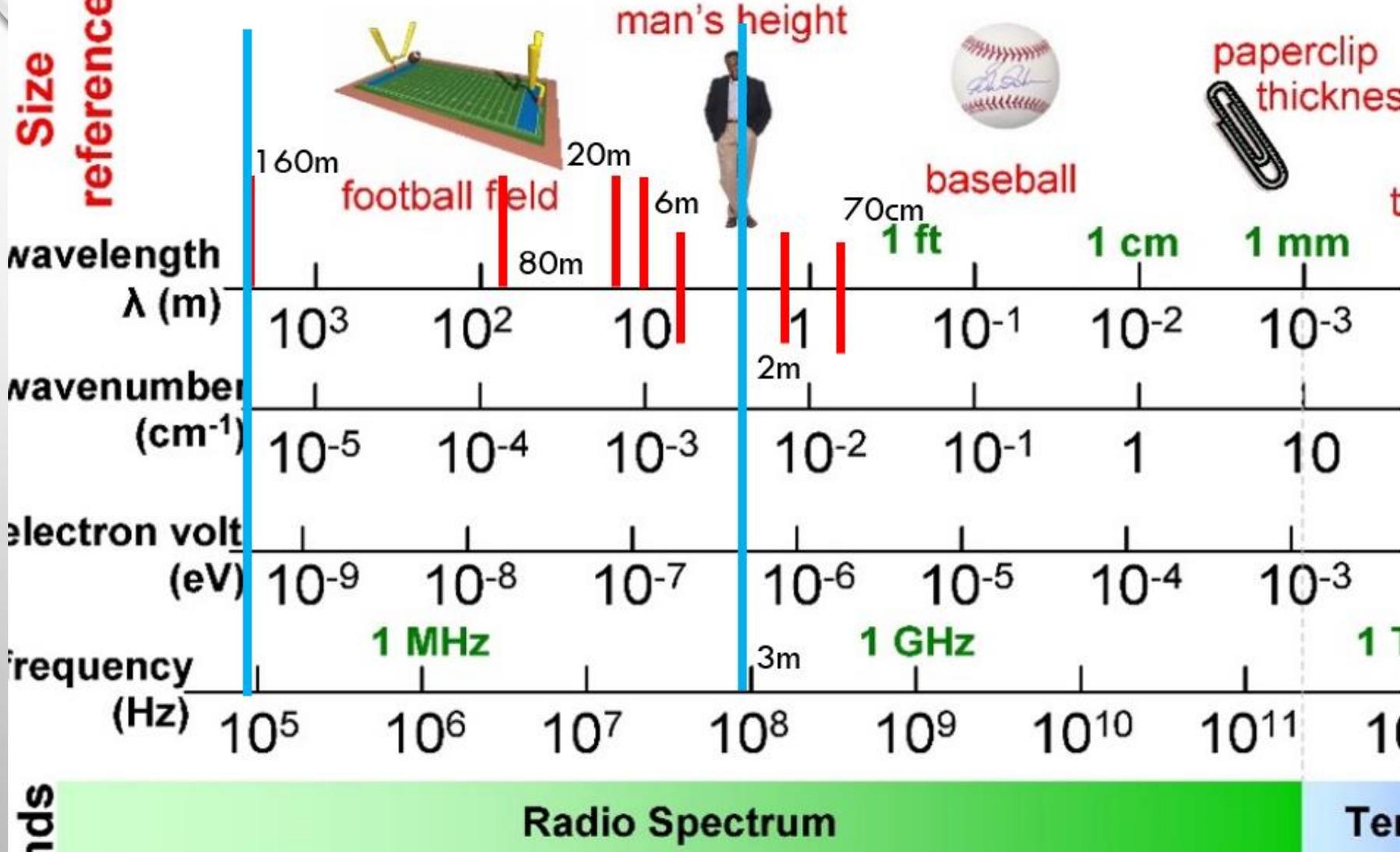
$$\lambda = 3 \times 10^8 / \text{freq} = 1 / (\text{wn} \times 100) = 1.24 \times 10^{-6} / \text{eV}$$

**SURA** Southeastern Universities Research Association ©



# Chart of the Electri

Size  
reference



# TRAVELING SIGNALS - BASIC

Reflected Wave -  $T_r$

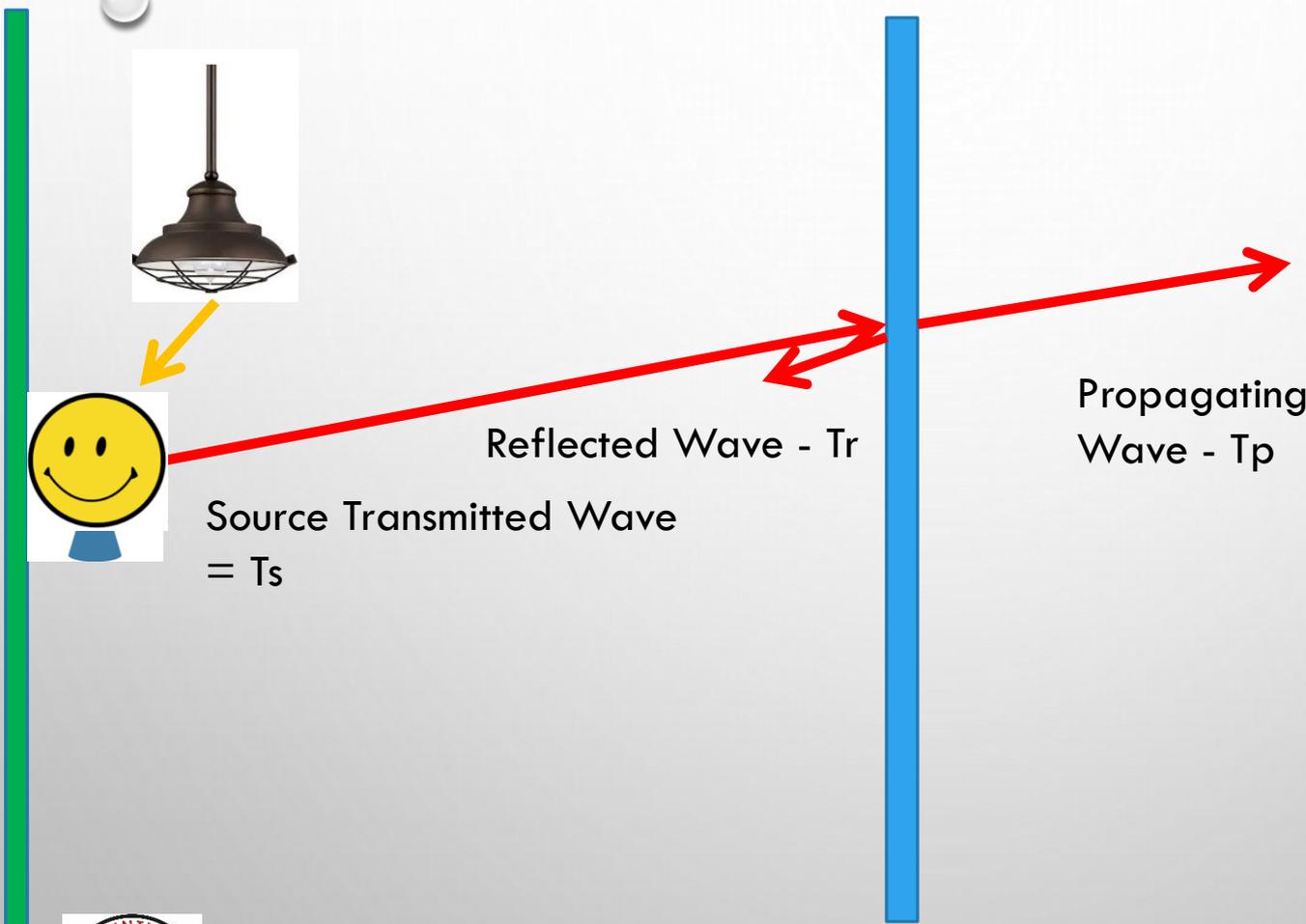
Propagating Wave -  $T_p$

Source Transmitted Wave  
=  $T_s$

Ideal Material



# TRAVELING SIGNALS - BASIC



Ideal Material

# TRAVELING SIGNALS - BASIC

Reflected Wave -  $T_r$

Source Transmitted Wave  
 $= T_s$

Propagating  
Wave -  $T_p$

Some of the  
source wave is  
absorbed -  $T_a$

Non-Ideal Material  
(such as glass)

$$T_s = T_r + T_p + T_a$$

or

$$T_p = T_s - T_r - T_a$$

or

$$T_r = T_s - T_p - T_a$$



# TRAVELING SIGNALS – WITH REFRACTION

Reflected Wave -  $T_r$

Propagating Wave -  $T_p$

Source Transmitted Wave  
=  $T_s$

Some of the  
source wave is  
absorbed -  $T_a$

Some Material or  
space....



Reflected Wave -  $T_r$

Propagating Wave -  $T_p$

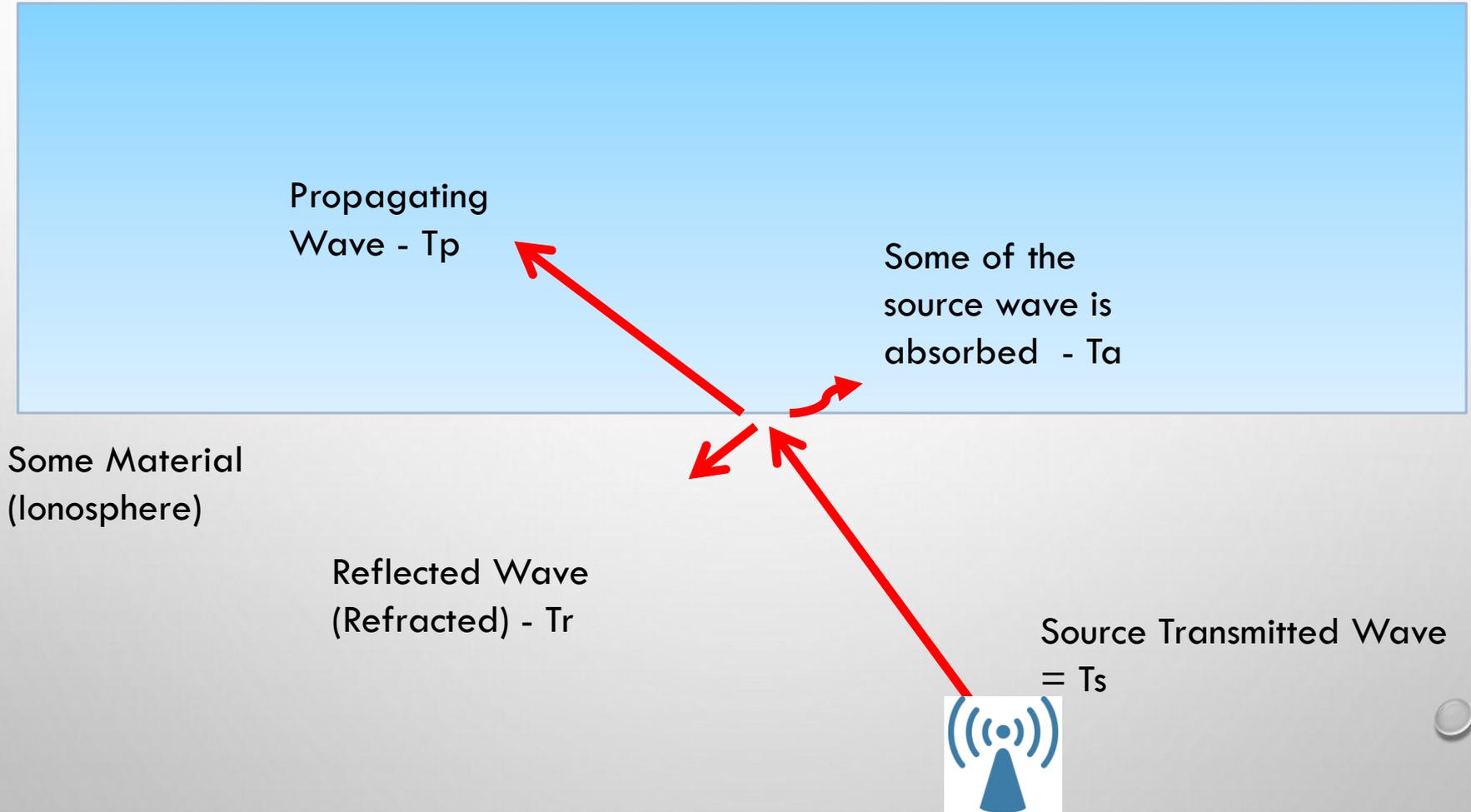


Source Transmitted Wave  
=  $T_s$

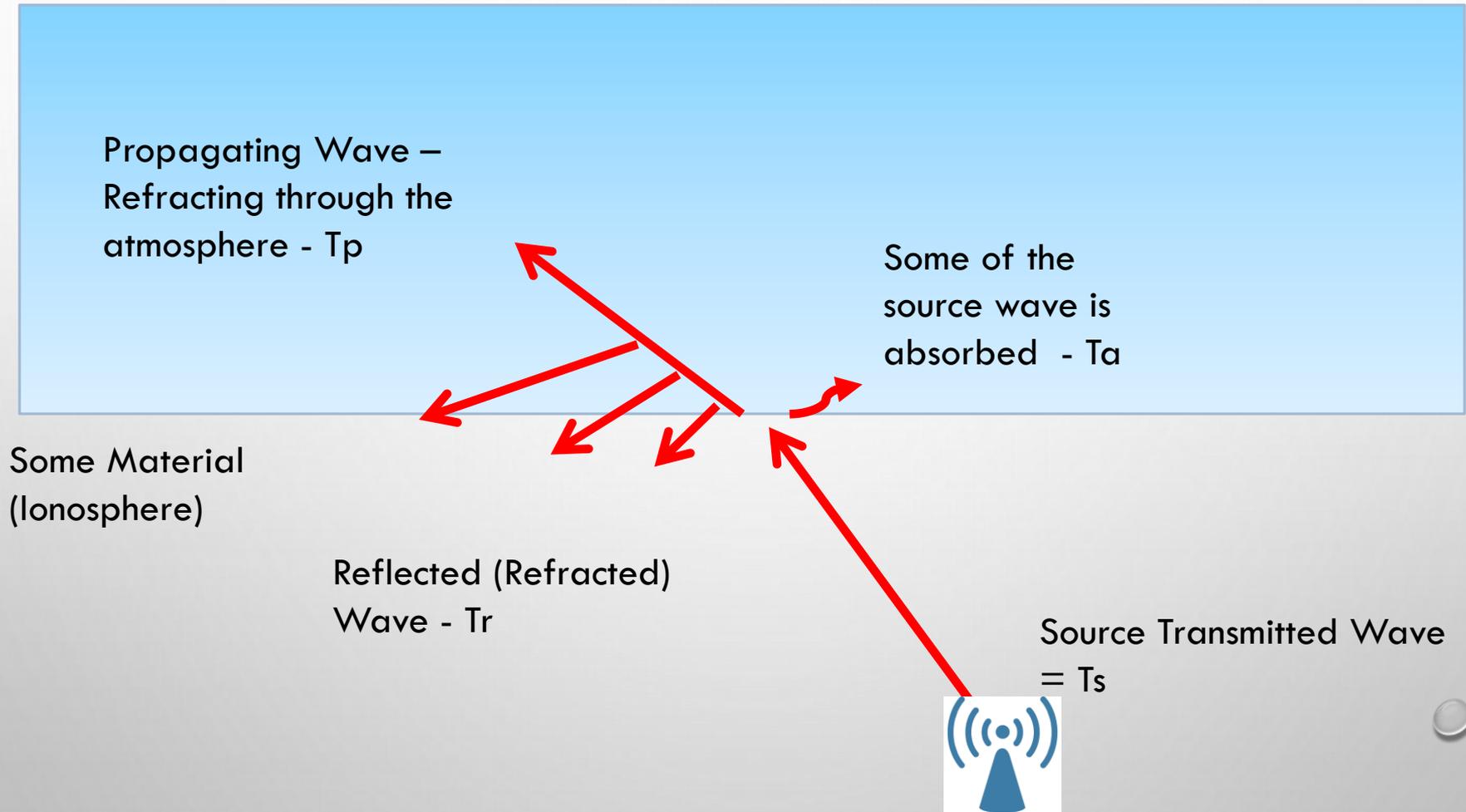
Some of the  
source wave is  
absorbed -  $T_a$



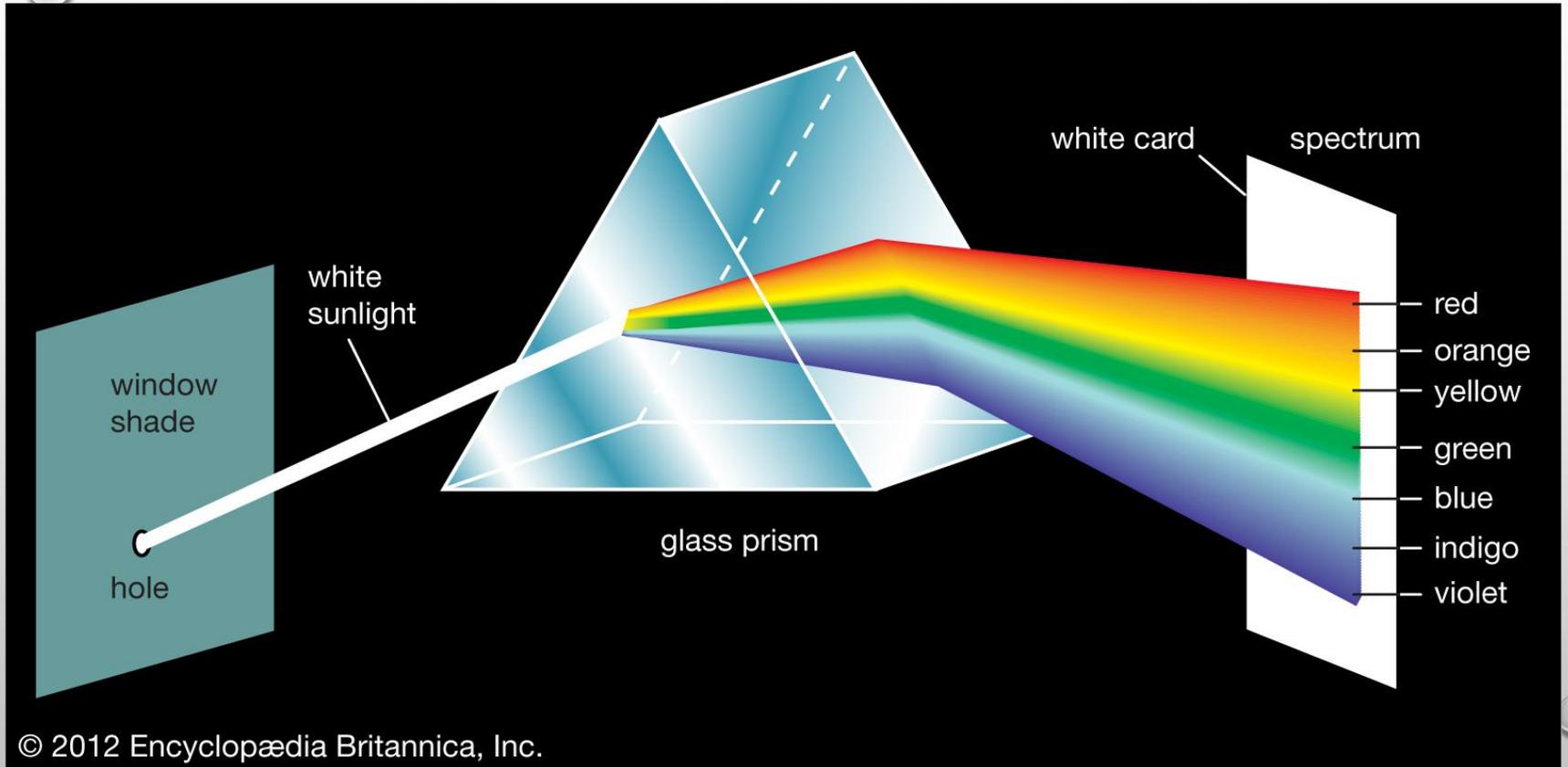
# TRAVELING SIGNALS - BASIC



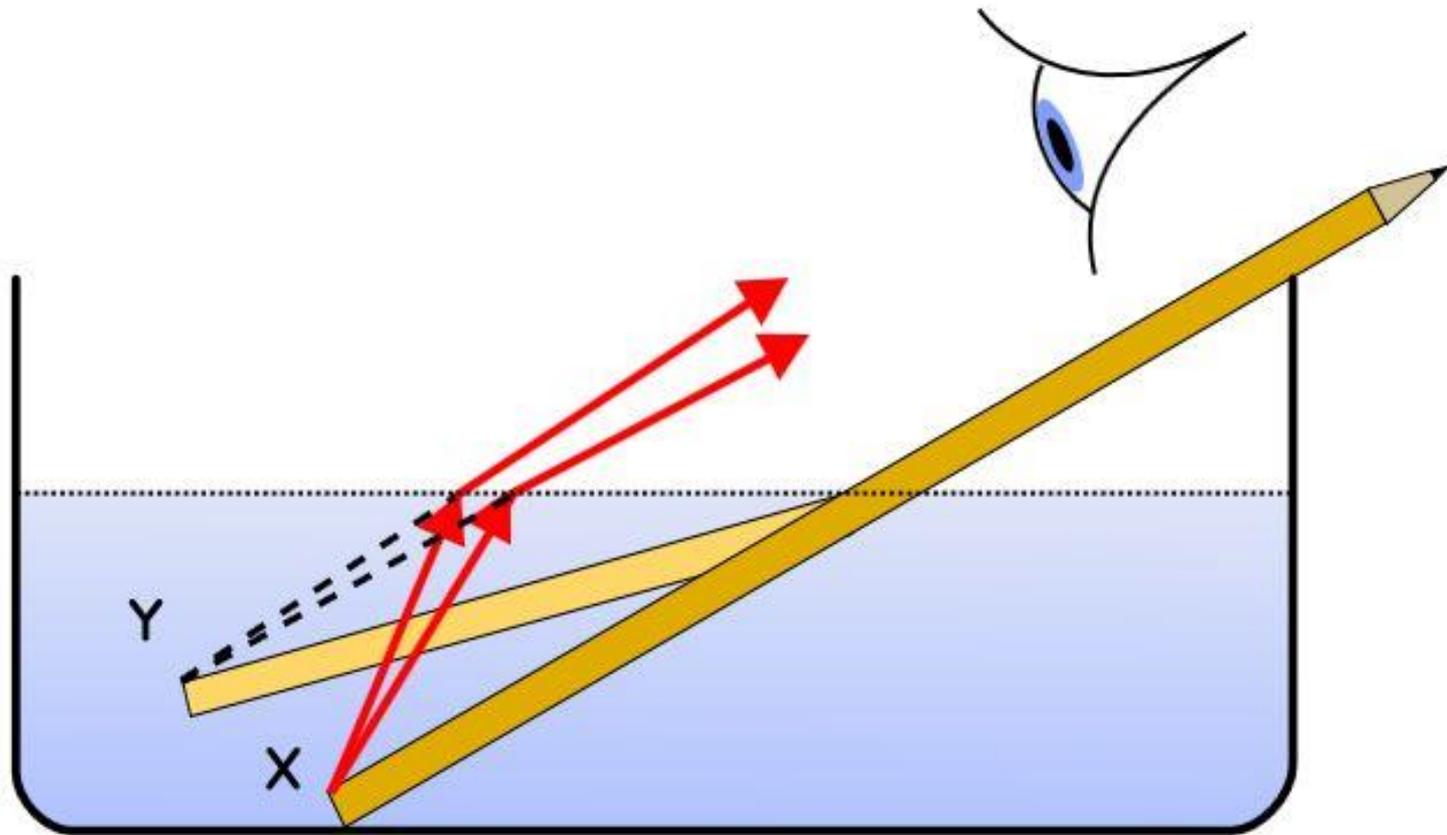
# TRAVELING SIGNALS - BASIC



# MORE ON REFRACTION



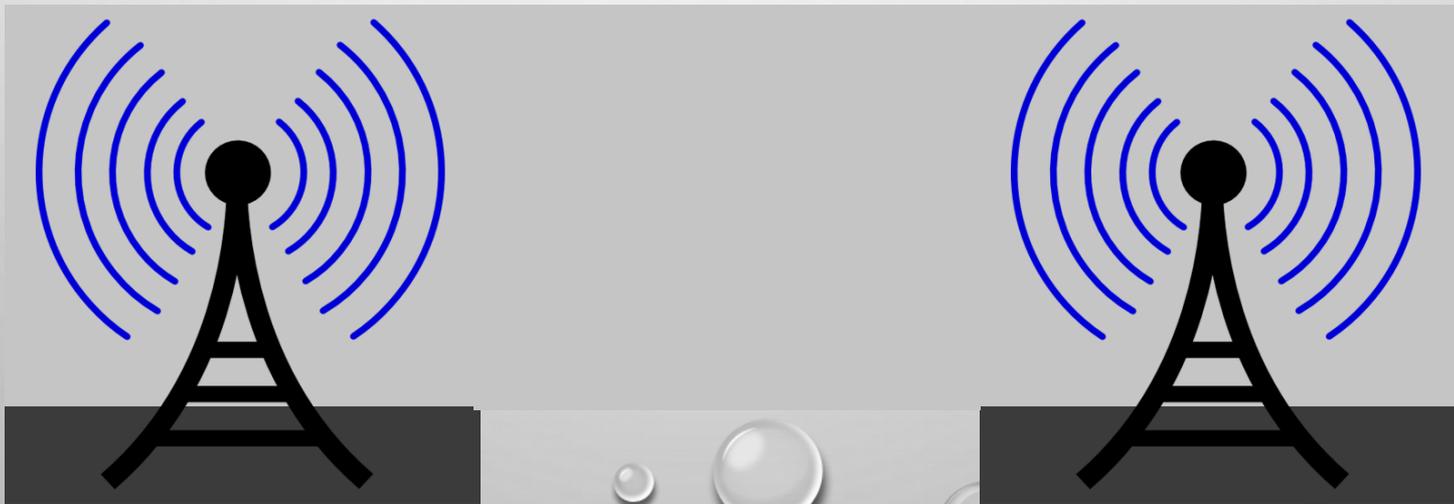
# MORE ON REFRACTION



# MODES OF RADIO SIGNAL TRAVEL.

- FREE SPACE –

- THIS IS THE IDEAL MODE OF WAVE PROPAGATION. THERE IS NOTHING TO GET IN THE WAY OR TO INTERACT WITH THE SIGNAL. IN REALITY, THIS RARELY EVER OCCURS.
- THE BEST ENVIRONMENT TO TEST THIS IS IN OUTER SPACE, OUTSIDE OUR SOLAR SYSTEM. ON EARTH, IN AN ANECHOIC CHAMBER.
- FREE SPACE AND OPEN SPACE ARE FORMS OF “DIRECT WAVE” PROPAGATION.



# MODES OF RADIO SIGNAL TRAVEL.

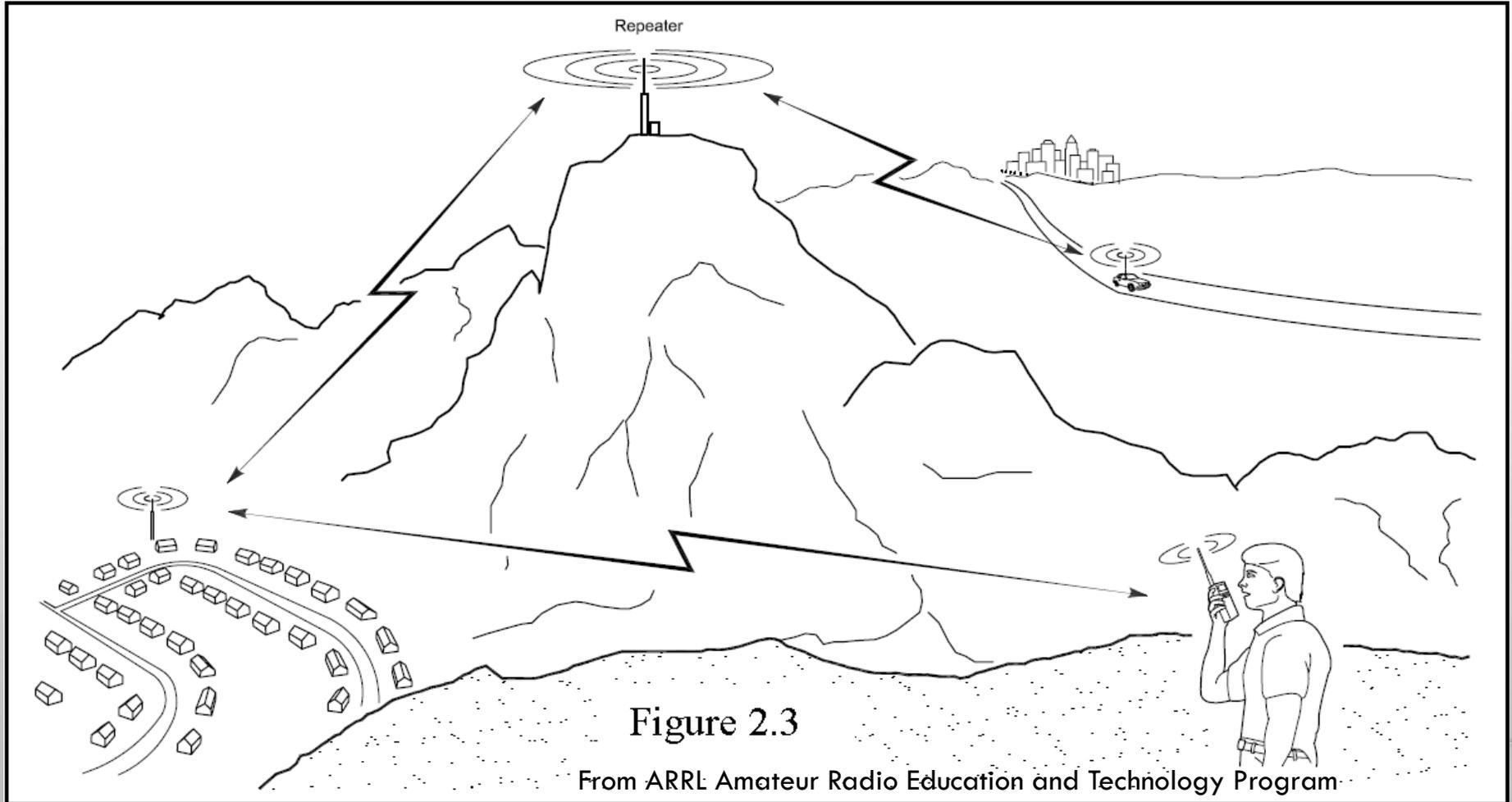
- OPEN SPACE

- SIMILAR TO FREE SPACE EXCEPT THERE ARE OBSTACLES SUCH AS BUILDINGS, TREES, HILLS, PEOPLE....
- BUILDINGS AND HILLS CAN CAUSE SIGNALS TO BE REFLECTED OR ABSORBED DEPENDING ON THE FREQUENCY. A PHENOMENON CALLED KNIFE EDGE REFRACTION CAN DIFFRACT A SIGNAL AROUND A CORNER.
- TREES, HILLS AND PEOPLE CAN ABSORB SIGNALS.
- THESE PROPERTIES ARE MOST LIKELY TO BE OBSERVED AT VHF FREQUENCIES (50 MHZ) AND HIGHER.
- REFLECTED SIGNALS CAN CAUSE A RECEIVER TO SEE MULTIPLE SIGNALS OF THE SAME TRANSMISSION (MULTIPATH).



# MODES OF RADIO SIGNAL TRAVEL.

- OPEN SPACE



# MODES OF RADIO SIGNAL TRAVEL.

- GROUND WAVE

- GROUND WAVE PROPAGATION OCCURS AT LOW FREQUENCIES. TYPICALLY 4 MHZ AND BELOW. (THINK 80M, 160M BANDS AND AM BROADCAST).
- IN GROUND WAVE PROPAGATION, THE MAGNETIC FIELD OF THE RF SIGNAL COUPLES WITH THE EARTH. A VERTICALLY POLARIZED ANTENNA WORKS WELL FOR THIS TYPE OF PROPAGATION.
- OFTEN GROUND WAVE PROPAGATION IS CONFUSED FOR OPEN SPACE (DIRECT WAVE) PROPAGATION.



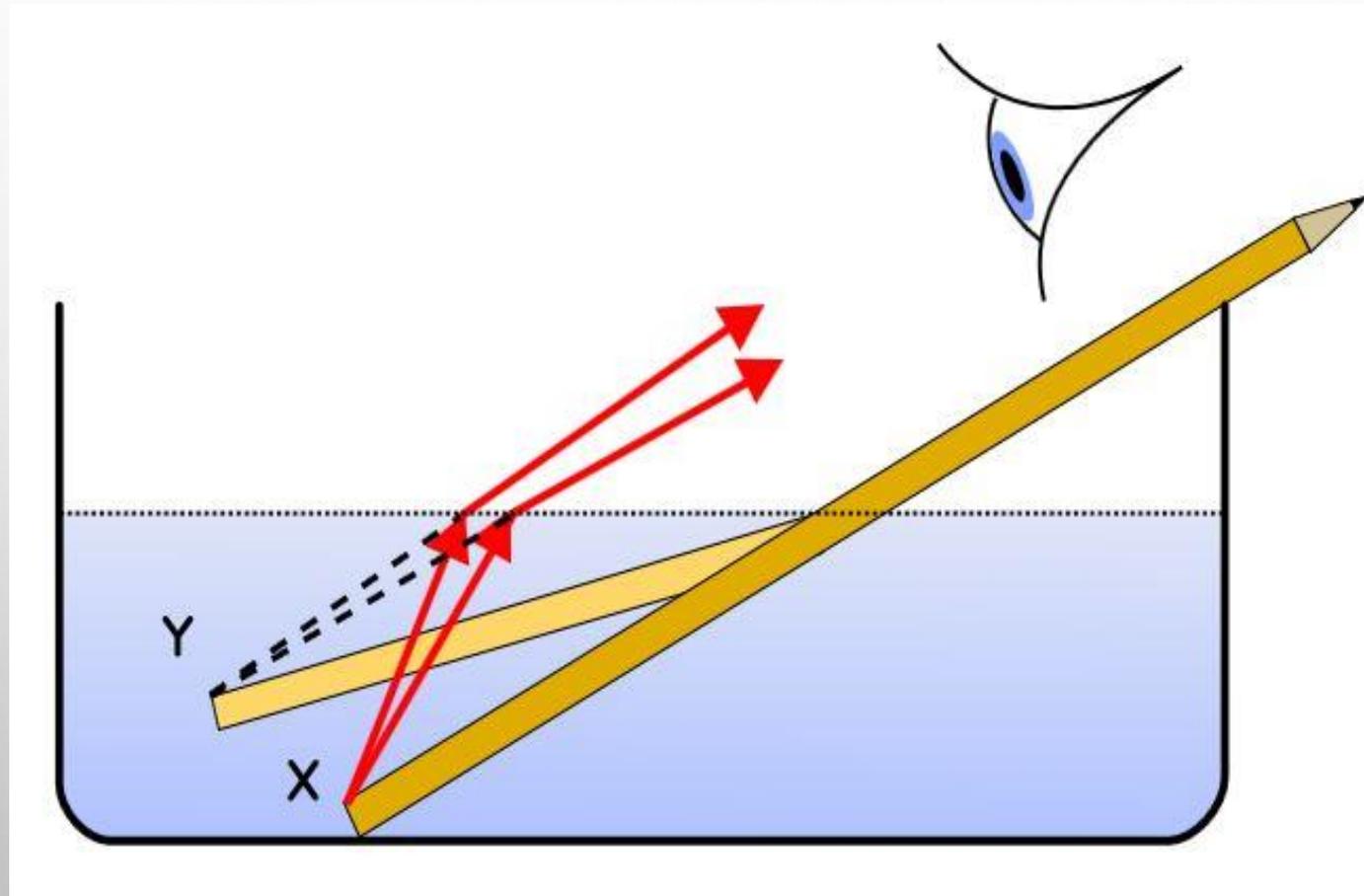
# MODES OF RADIO SIGNAL TRAVEL.

- SKY WAVE

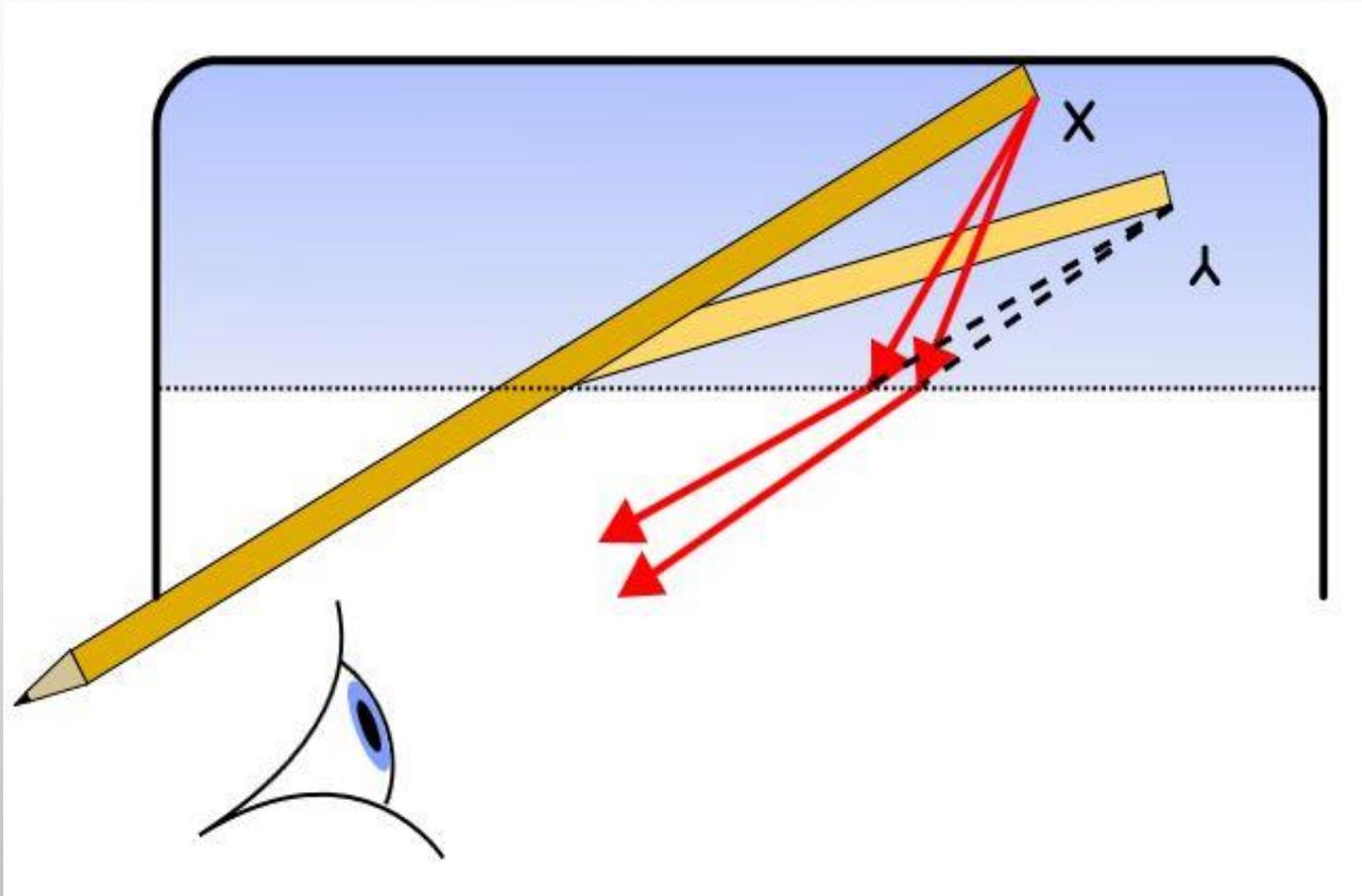
- RADIO SIGNALS ARE REFRACTED OR REFLECTED OFF OF THE EARTH'S UPPER ATMOSPHERE – THE IONOSPHERE.
- BY BOUNCING A SIGNAL OFF THE IONOSPHERE, RADIO SIGNALS CAN TRAVEL GREAT DISTANCES.
- THE SUN'S RADIATION ACTS DIRECTLY ON THE ATMOSPHERE TO IONIZE GAS PARTICLES.
- THE HIGHER THE IONIZATION, THE MORE RADIO SIGNAL REFLECTION.
- THE SUN'S EFFECT ON THE ATMOSPHERE CHANGES BASED ON THE TIME OF DAY AND THE SOLAR ACTIVITY AS INDICATED BY THE SUN SPOTS.



# SKY WAVE & REFRACTION



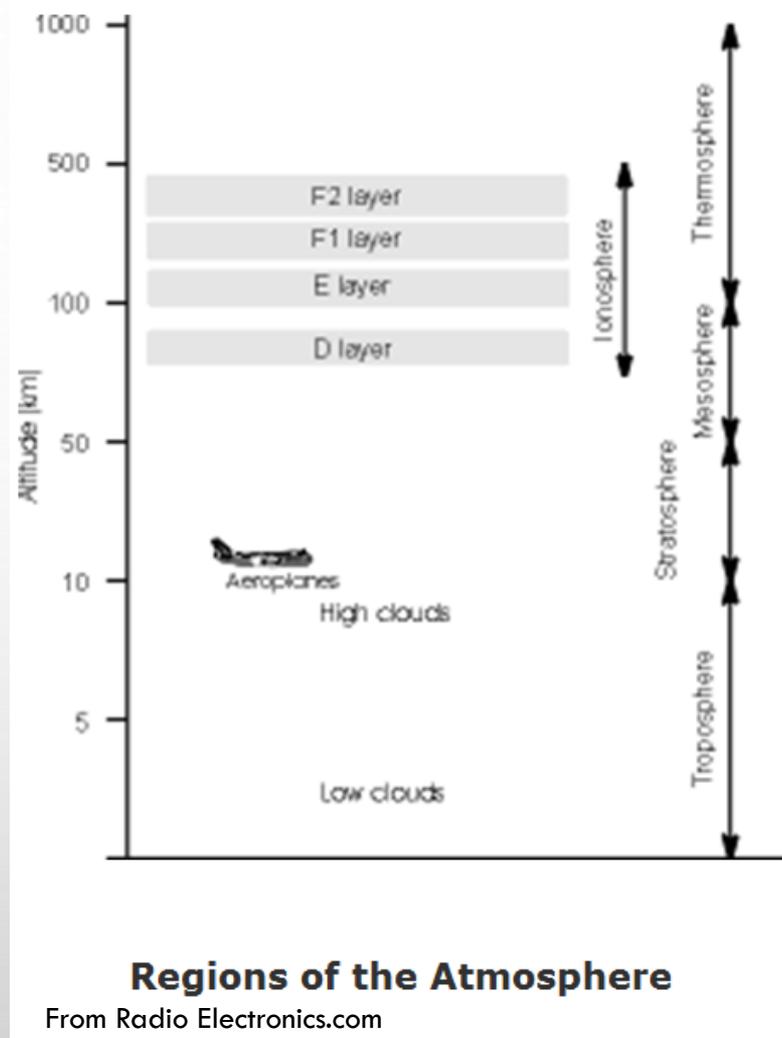
# SKY WAVE & REFRACTION



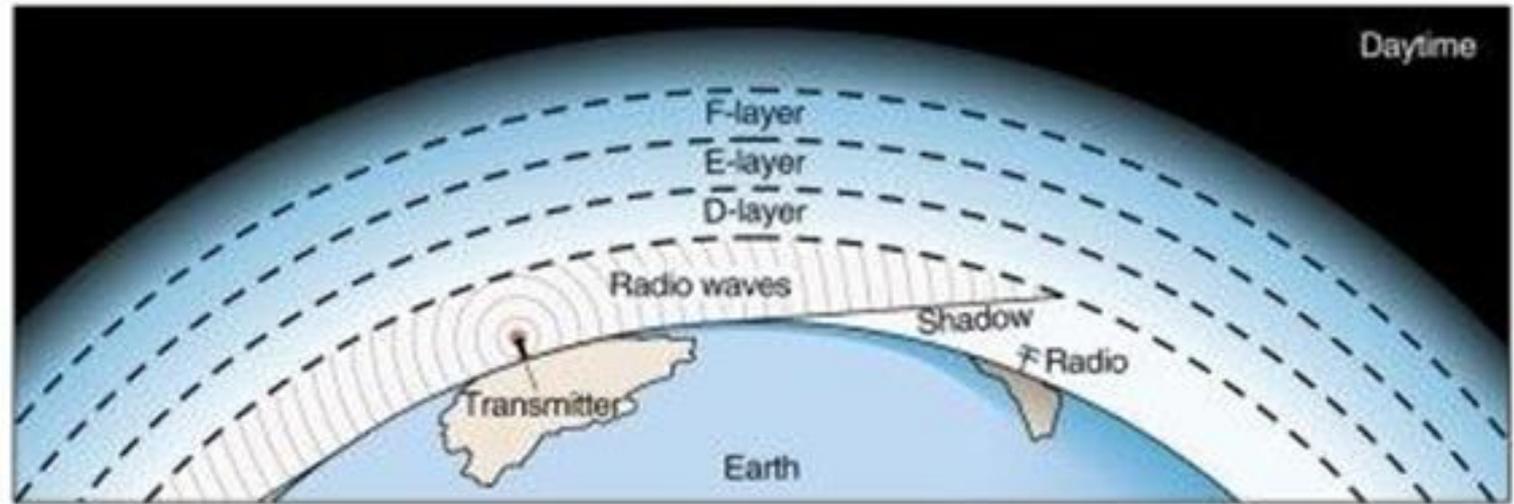
# THE ATMOSPHERE

F1 and F2 Layers combine at night to form 1 layer.

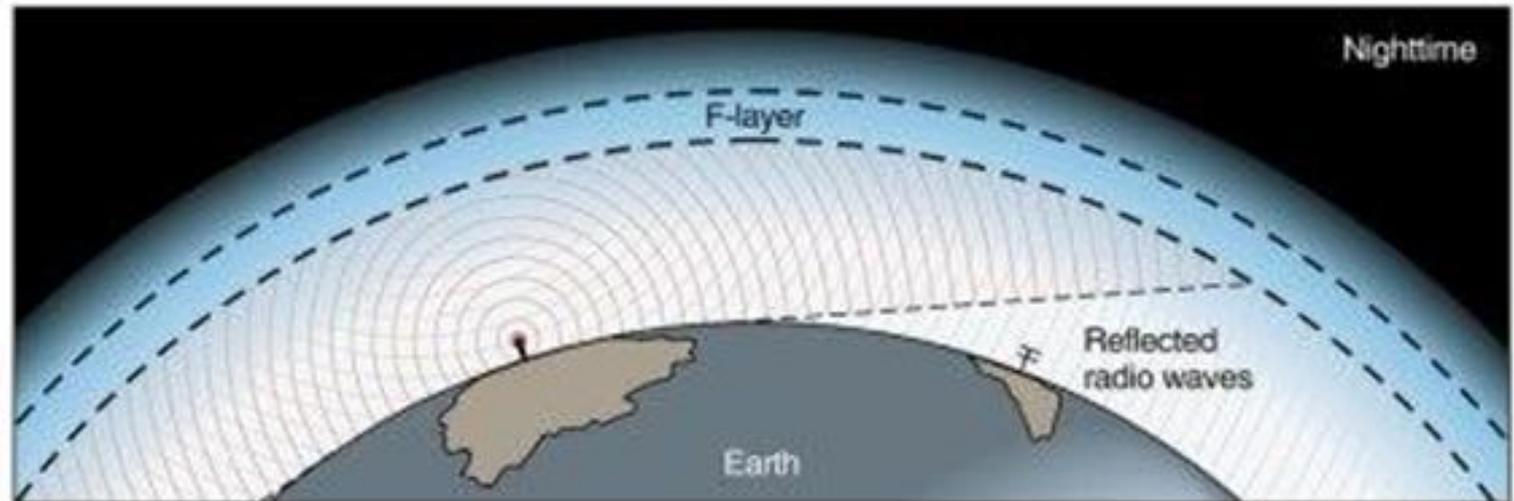
D Layer exists during the day.



# THE ATMOSPHERE



(a)

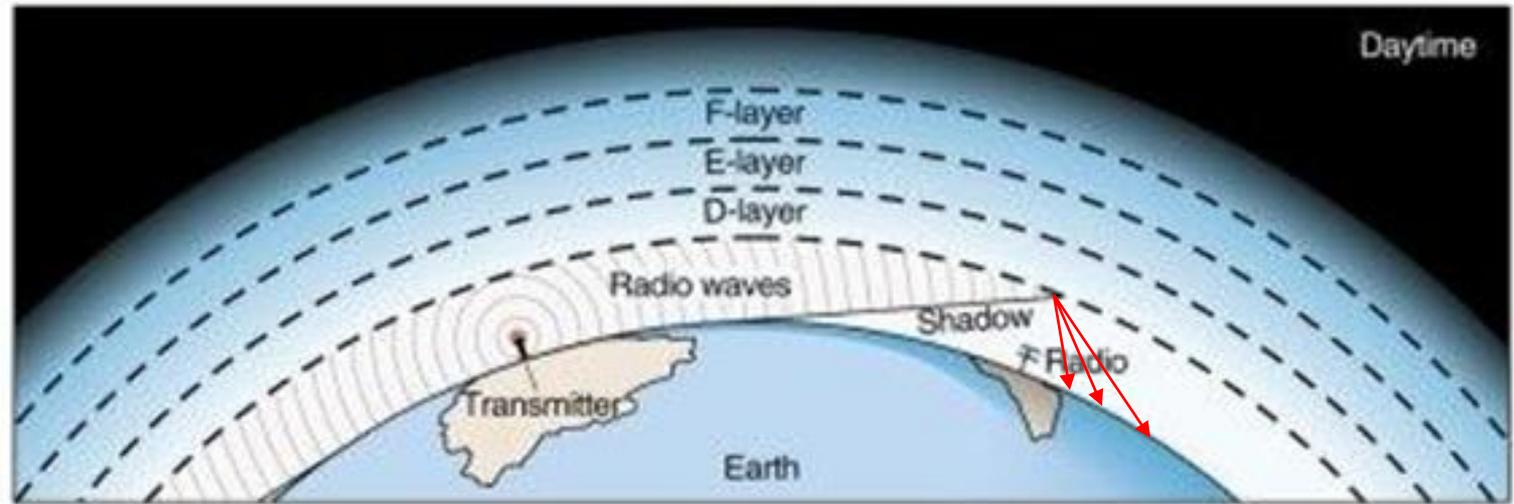


(b)

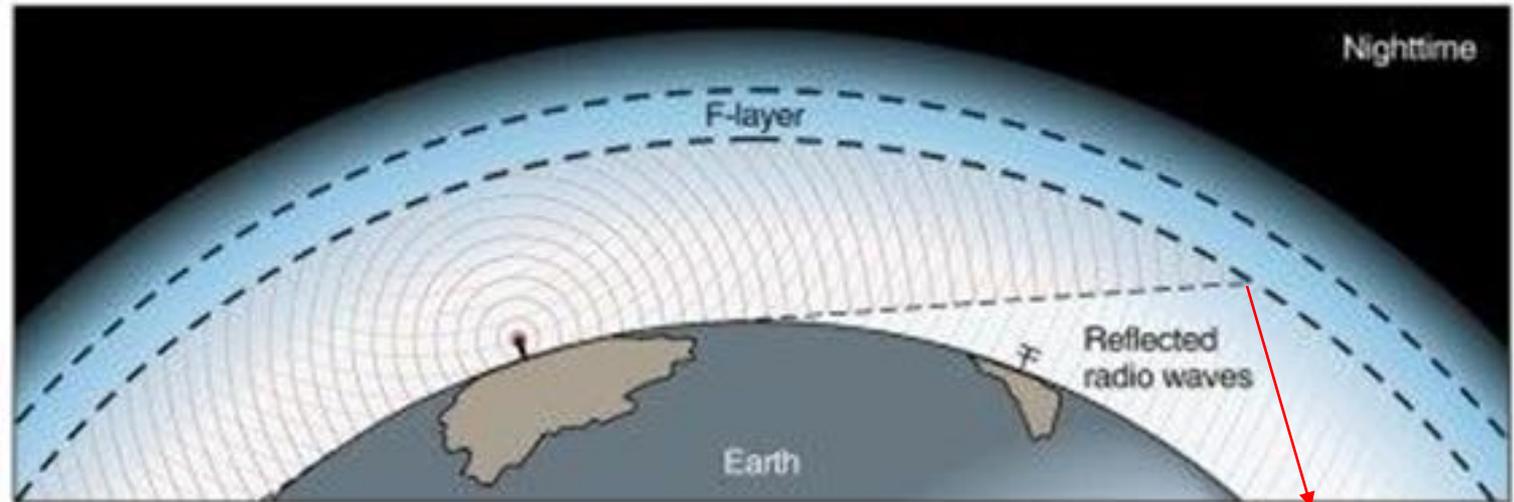
From the G7LRR Web Page



# THE ATMOSPHERE



(a)



(b)

From the G7LRR Web Page

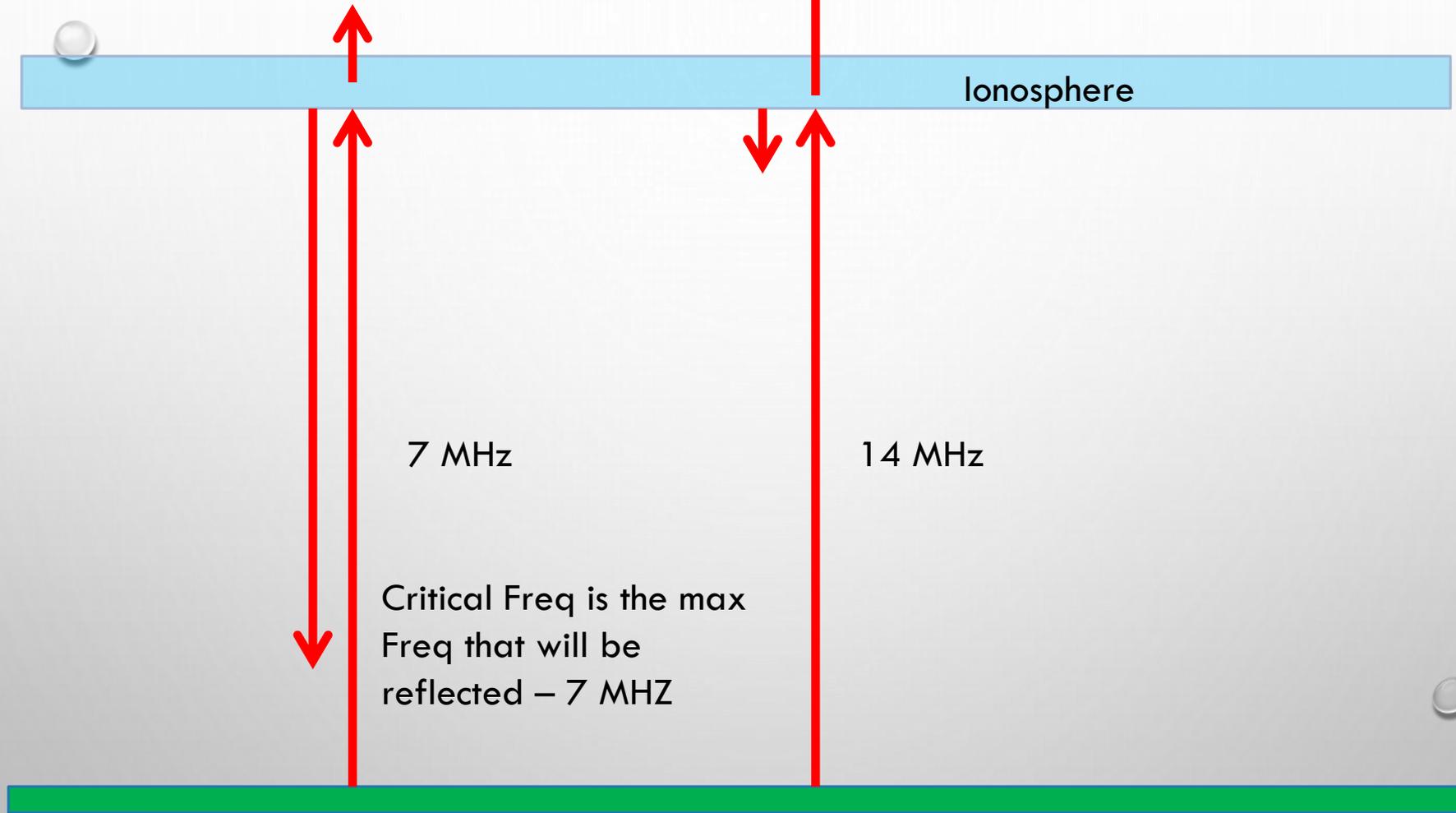


# SKY WAVES

- AS THE CHARGED PARTICLES OF THE IONOSPHERE INCREASES, THE AMOUNT OF RF REFLECTION (REFRACTION) ALSO INCREASES.
- THIS IS CALLED THE CRITICAL FREQUENCY AND IS MEASURED BY LOOKING AT THE HIGHEST FREQUENCY THAT CAN BOUNCE OFF THE ATMOSPHERE.



# CRITICAL FREQUENCY

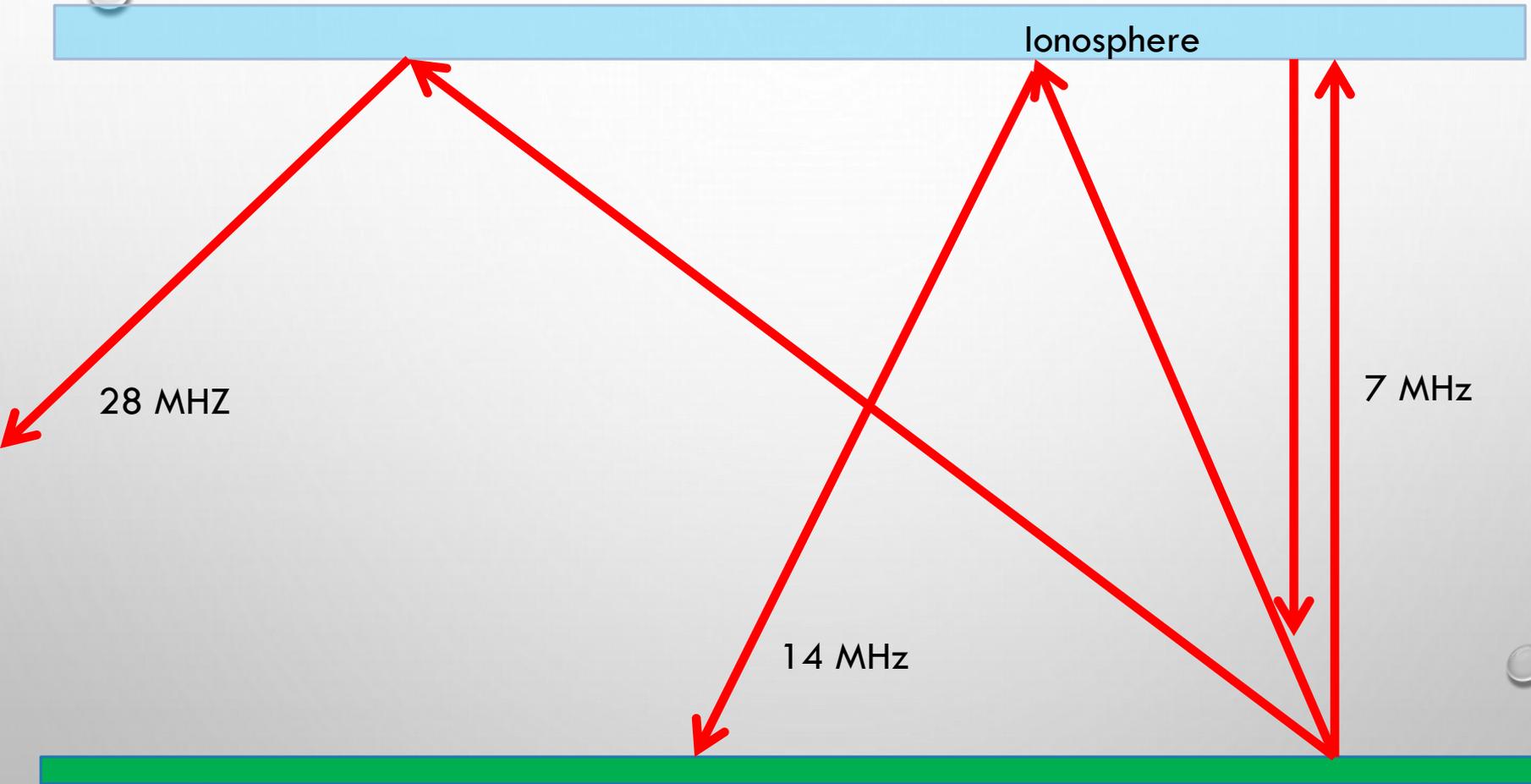


# SKY WAVES

- THE CRITICAL FREQUENCY IS MEASURED WITH A VERTICAL SIGNAL, A SIGNAL POINT STRAIGHT UP. (THINK NVIS ANTENNA.)
- THE UPPER LIMIT OF FREQUENCY THAT CAN BE REFLECTED CAN BE INCREASED BY CHANGING THE ANGLE THAT IT HITS THE IONOSPHERE.
  - (SNELL'S LAW)
- THE SHARPER THE ANGLE, THE HIGHER THE FREQUENCY UNTIL THE MAXIMUM USEABLE FREQUENCY (MUF) IS ACHIEVED.



# MAXIMUM USABLE FREQUENCY (MUF)

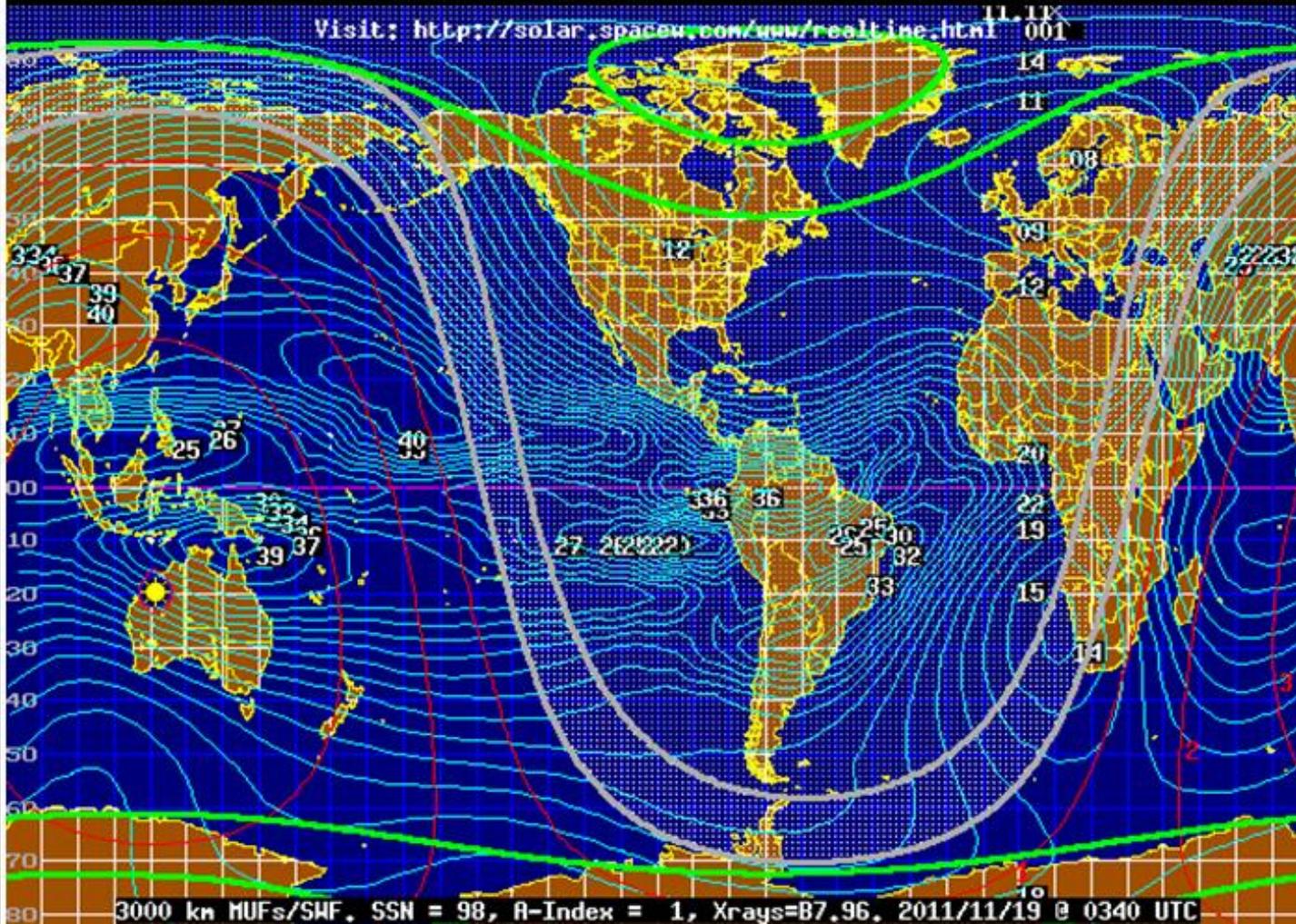


# MUF MAP — [WWW.SPACEW.COM/WWW/REALTIME.PHP](http://WWW.SPACEW.COM/WWW/REALTIME.PHP)

## NEW Proplab-Pro Version 3.0

<http://www.spacew.com/proplab>

*Full Windows compatibility and more horse-power under the hood than you can imagine!*



# PREDICTING PROPAGATION

- FOLLOW THE RULES OF THE PROPAGATION SUMMARY.
  - HIGHER FREQUENCIES DURING THE DAY, 14MHZ – 29 MHZ.
  - LOWER FREQUENCIES AT NIGHT. 1.6MHZ TO 14 MHZ
  - DURING THE SOLAR MINIMUM, POOR PROPAGATION ON 10 MHZ AND HIGHER, GOOD LOW FREQUENCY AT NIGHT DUE TO LESS ATMOSPHERIC NOISE.
  - DURING THE SOLAR MAXIMUM, GOOD PROPAGATION ON 14 MHZ AND HIGHER EVEN INTO THE EVENING. POOR LOW FREQUENCY DUE TO HIGHER ATMOSPHERIC NOISE.



# PREDICTING PROPAGATION

- MUF FORECAST
- MONITOR THE SOLAR INDEX
  - [HTTP://WWW.WM7D.NET/HAMRADIO/SOLAR/INDEX.SHTML](http://www.wm7d.net/hamradio/solar/index.shtml)
  - [HTTP://WWW.ANZADX.NET/](http://www.anzadx.net/)
  - [WWW.ARRL.ORG](http://www.arrl.org) K7RA SOLAR UPDATE
  - SOLAR FLUX INDEX OF 70 IS LOW = POOR DX
  - SOLAR FLUX OF 110 IS MODERATE = GOOD DX
  - SOLAR FLUX OF 150 IS HIGH = GREAT DX
- LISTEN TO HF BANDS
- LISTEN TO WWV
- POOR DX DOES NOT MEAN NO DX. WEAK SIGNAL MODES CAN PROVIDE A LOT OF DX FUN.



# PREDICTING PROPAGATION

- LISTEN TO BEACONS SUCH AS

- [HTTP://WWW.NCDXF.ORG/BEACON/BEACONSCHEDULE.HTML](http://www.ncdxf.org/beacon/beaconschedule.html)

## NCDXF/IARU Beacon Transmission Schedule

Each beacon transmits every three minutes, day and night. This table gives the minute and second of the start of the first transmission within the hour for each beacon on each frequency. A transmission consists of the callsign of the beacon sent at 22 words per minute followed by four one-second dashes. The callsign and the first dash are sent at 100 watts. The remaining dashes are sent at 10 watts, 1 watt and 100 milliwatts.

Search the [DX Summit Database](#) for recent reception reports by callsign.

If you can hear a beacon now, [send a report](#) to DX Summit.

Call		Location	14.100	18.110	21.150	24.930	28.200	Operator	Status
4U1UN		United Nations	00:00	00:10	00:20	00:30	00:40	UNRC	OFF <sup>3</sup>
VE8AT		Canada	00:10	00:20	00:30	00:40	00:50	RAC/NARC	OK <sup>1</sup>
W6WX		United States	00:20	00:30	00:40	00:50	01:00	NCDXF	OK
KH6WO		Hawaii	00:30	00:40	00:50	01:00	01:10	KH6BYU	ON
ZL6B		New Zealand	00:40	00:50	01:00	01:10	01:20	NZART	OK
VK6RBP		Australia	00:50	01:00	01:10	01:20	01:30	WIA	OFF <sup>4</sup>

# PREDICTING PROPAGATION

- SPOTTING NETWORKS - [HTTP://WWW.DXSCAPE.COM](http://www.dxscape.com)

## DXSCAPE

### Index

[Selectable multiple DX Cluster](#) | [Data Base Search](#)

[DX] [WW25](#) | [WW500](#) | [JA25](#) | [JA500](#) | [US25](#) | [US500](#) | [For Mobile Phone](#)

[IOTA] [WW25](#) | [WW500](#) | [JA25](#) | [JA500](#) [Digital] [WW](#) | [JA](#) | [US](#) [\[TopTen\]](#)

[BAND Repot] [DX-JA](#) | [IOTA-JA](#) [OTHERS] [SOLAR](#) | [COMPACT WINDOW](#) | [SEND SPOT](#)

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[JAS] [All](#) [HF](#) [High](#) [WARC](#) [VHF](#) [Low](#) [DIGI](#) [IOTA](#) [1.8](#) [3.5](#) [7](#) [10](#) [14](#) [18](#) [21](#) [24](#) [28](#) [50](#) [144](#)

[DX-PED] [ZD8/NOV2011](#) [J79KT](#) [T2T](#) [9N7MD](#) [ZK2V](#)

[DX] [WW25] Last 25 spots from World Wide <refreshes every minute>

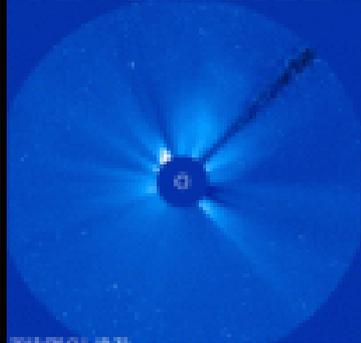
<a href="#">9N7MD</a>	0528Z	18103.6	RTTY via	IK2VUC	up	SP3RBG
<a href="#">RU2FZ</a>	0528Z	7006.7	FB IN AR.	CQCQ		W5TZC
<a href="#">VK7RST</a>	0528Z	50296.0	Beacon....	519...		VK5AYD
<a href="#">JT1DA</a>	0527Z	28008.0				VK7ZE
<a href="#">XV2RZ</a>	0527Z	28001.9	cq cq	qsx up but	Lonely	UA4FCO
<a href="#">VK4KUS</a>	0527Z	14190.0	dreaming of	59		VK2GJC



# PREDICTING PROPAGATION

**Solar-Terrestrial Data/Predictions at [www.qrz.com](http://www.qrz.com)**

<b>11 Jun 2015 2128 GMT</b>		<b>Current Solar</b>	<b>Band</b>	<b>Day</b>	<b>Night</b>	
SFI	137	SN	185	80n-40n	Fair	Good
A	012	K	2	30n-20n	Good	Good
XRY	C2.3	304A	161.3	17n-15n	Good	Good
Aur	1	Lat	67.5°	12n-10n	Fair	Poor
Bz	-0.0	SW	516.8	Geomag Field QUIET		
PF	0.2	EF	4670.0	Sig Noise Lvl S1-S2		
MUF Bdr	22.02	@ 2045				
EHE Deg	Good					



(C) P Herrman NONBH 2013

- SFI – Solar Flux Index
- A Index
- K Index
- Signal Noise Level
- Geomagnetic Field

**31 Aug 2017 1359 GMT**

SFI	87	SN	42	<b>VHF Conditions</b>
A	5	K	2/PIntry	<b>Iten Status</b>
X-Ray	B1.7	Aurora Band Closed		
304A	107.7 @ SEM	6n EsEU	Band Closed	
Ptn Flx	0.25	4n EsEU	Band Closed	
Elc Flx	2.81	2n EsEU	Band Closed	
Aurora	1/n=1.99	2n EsNA	Band Closed	
Aur Lat	67.5°	EHE Deg	Very Poor	
Bz	0.9	SW	358.0	



Solar-Terrestrial Data  
Provided by NONBH

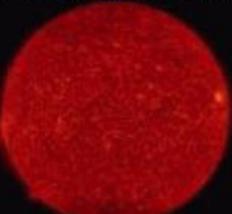
<b>HF Conditions</b>			<b>Current Solar Image</b>
Band	Day	Night	
80n-40n	Fair	Good	
30n-20n	Fair	Fair	
17n-15n	Poor	Poor	
12n-10n	Poor	Poor	
Geomag Field QUIET			
Sig Noise Lvl S1-S2			
MUF US Boulder 6.62			
Solar Flare Prb 73%			

**02 Mar 2018 2323 GMT**

SFI	66	SN	11	<b>VHF Conditions</b>
A	6	K	1/PIntry	<b>Iten Status</b>
X-Ray	A2.7	Aurora Band Closed		
304A	93.9 @ SEM	6n EsEU	Band Closed	
Ptn Flx	0.14	4n EsEU	Band Closed	
Elc Flx	697.00	2n EsEU	Band Closed	
Aurora	1/n=1.99	2n EsNA	Band Closed	
Aur Lat	67.5°	EHE Deg	Good	
Bz	-0.9	SW	334.8	



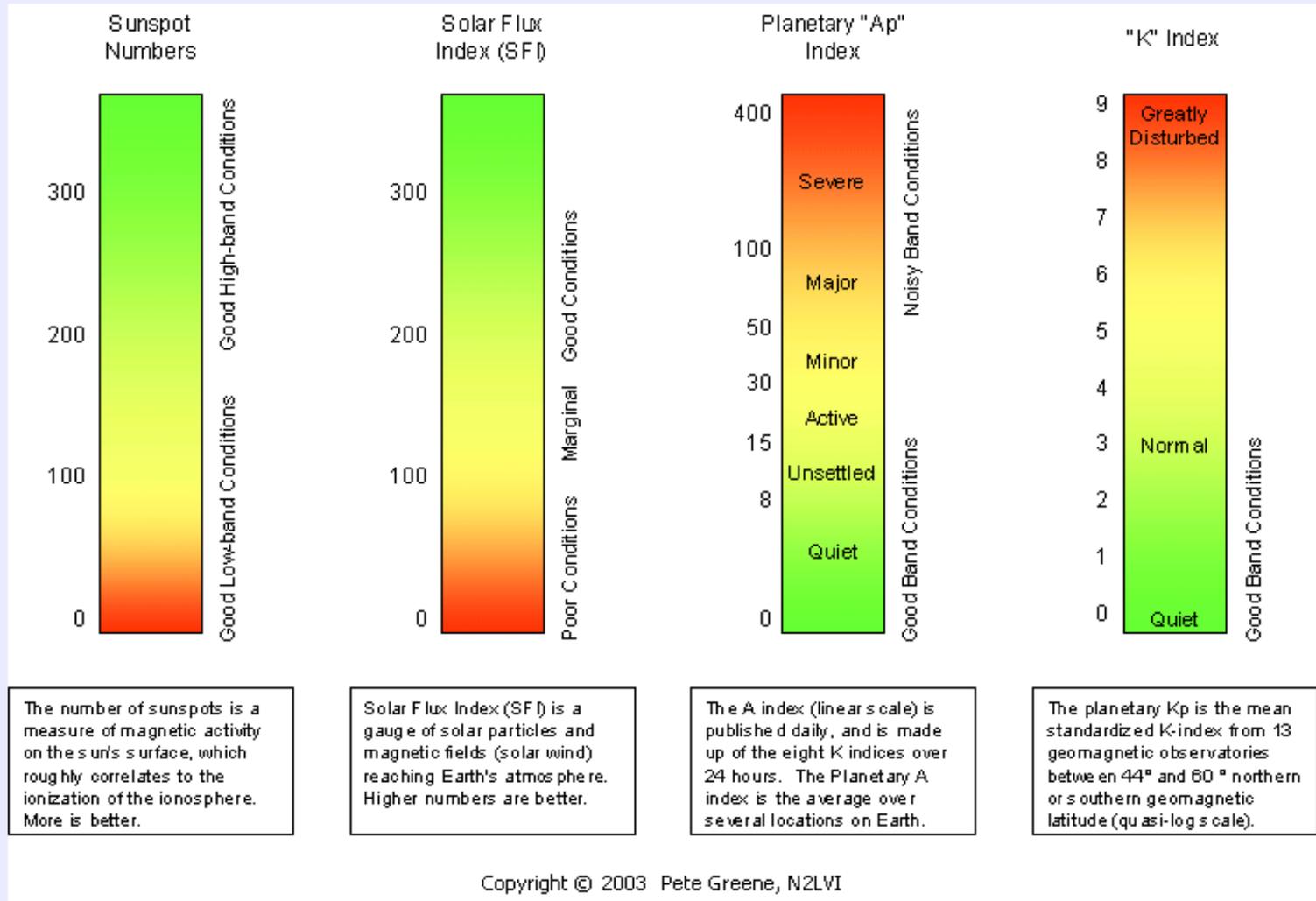
Solar-Terrestrial Data  
Provided by NONBH

<b>HF Conditions</b>			<b>Current Solar Image</b>
Band	Day	Night	
80n-40n	Fair	Good	
30n-20n	Poor	Poor	
17n-15n	Poor	Poor	
12n-10n	Poor	Poor	
Geomag Field VR QUIET			
Sig Noise Lvl S0-S1			
MUF US Boulder 20.12			
Solar Flare Prb 40%			



# N2LVI's Quick Guide to HF Propagation Using Solar Indices

Graphics: [Auroral Activity](#) | [Solar X-Ray Flux](#) | [Sunspots](#) | [SOHO](#) | [D-Region Asorbtion](#) | [MUF](#) | [Solar X-Ray Absorption](#) | [E-Layer](#)



# ATMOSPHERIC DISTURBANCE

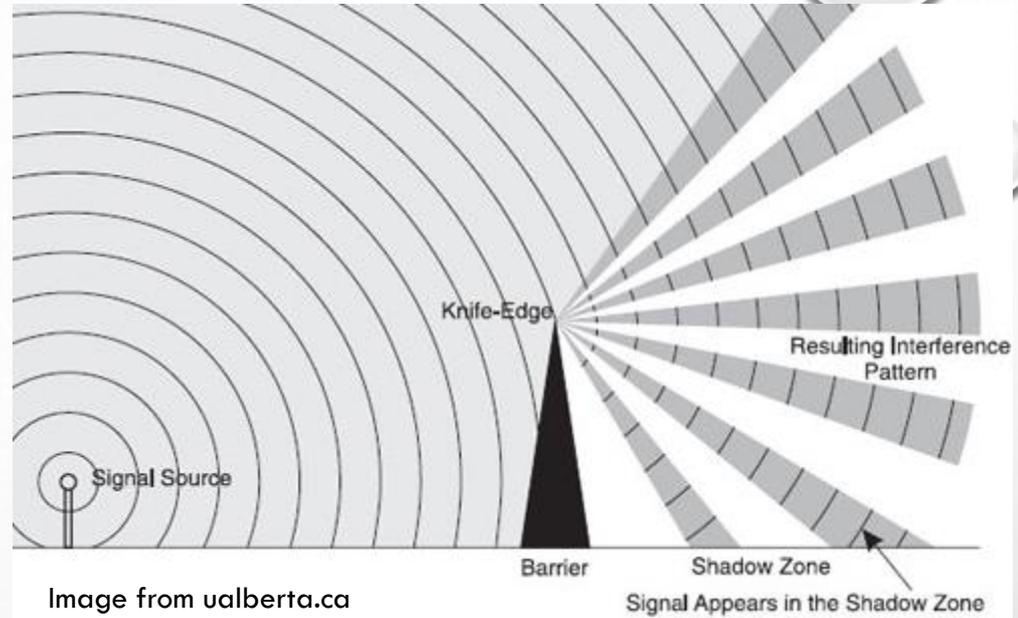


# ATMOSPHERIC DISTURBANCE



# THE STRANGE

- KNIFE EDGE DIFFRACTION
- FRESNEL ZONE

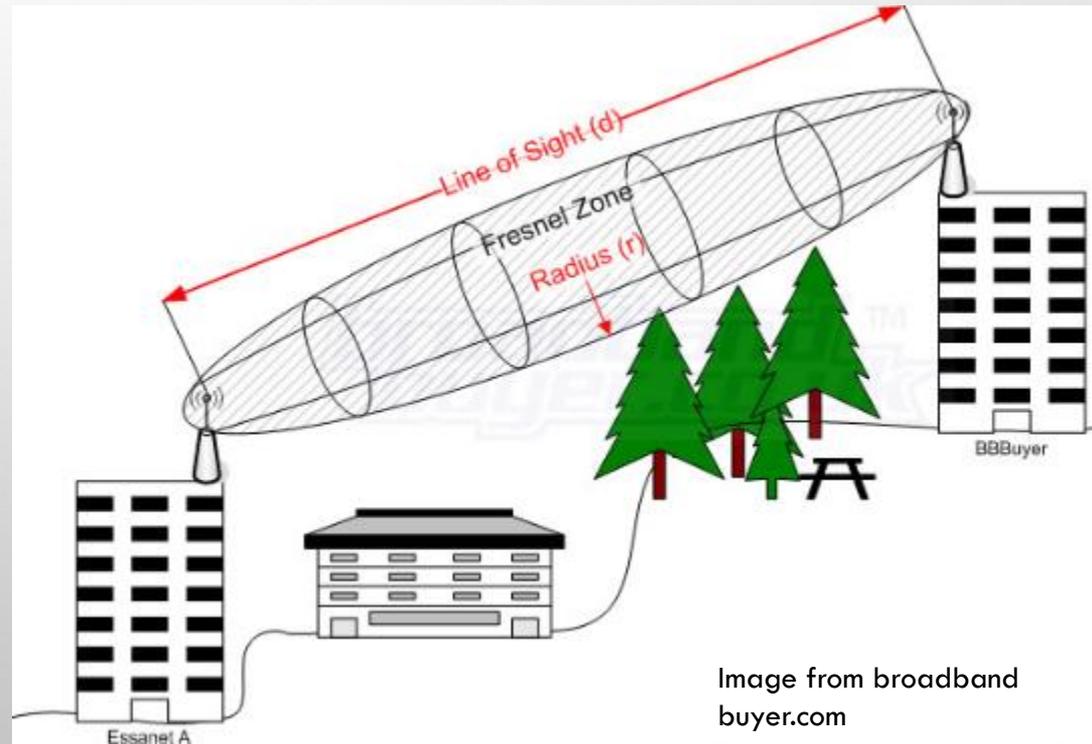


## Fresnel Zone in Feet

Link distance between antennas (d) in Miles

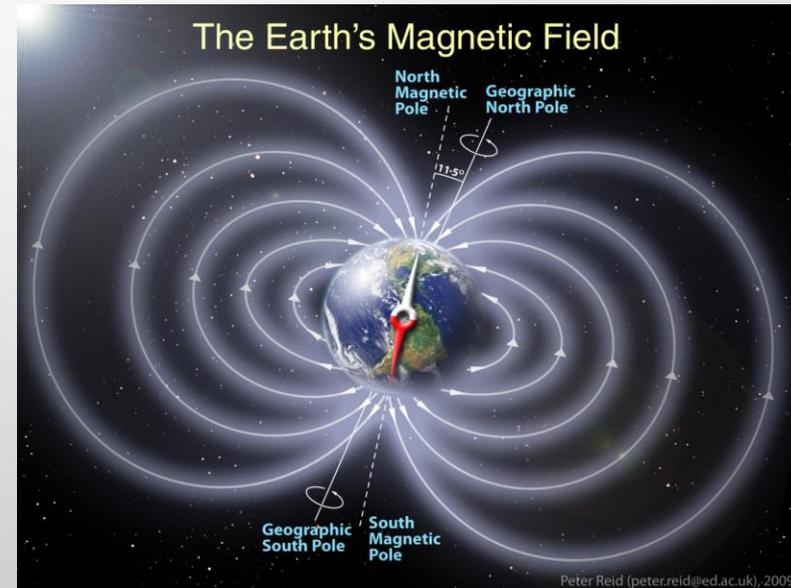
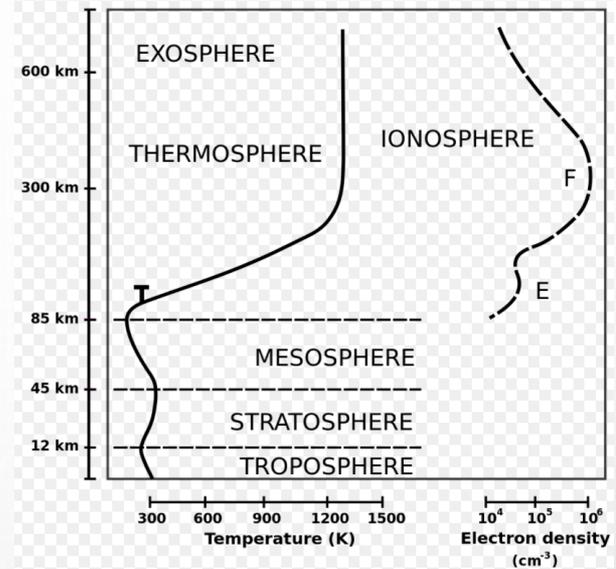
Link frequency (f) in GHz

$$r = 72.05 \times \sqrt{\frac{d \text{ (Miles)}}{4f \text{ (GHz)}}$$



# THE UNPREDICTABLE

- SPORADIC E
  - AFFECTS FREQUENCIES 28 MHZ TO 222 MHZ
  - MAY BE INTENSE FOR SHORT PERIODS
  - OFTEN MORE FREQUENT DURING THE SOLAR MINIMUM
- TROPOSPHERIC DUCTING
  - CAN OCCUR FROM CHANGES IN TEMPERATURE, HUMIDITY AND PRESSURE.
  - OCCURS WHEN REFRACTION IS SO GREAT RADIO WAVES ARE BENT BACK TO THE SURFACE.
- MAGNETOSPHERIC DUCTING
  - A STRANGE PHENOMENON WHERE RADIO SIGNALS ARE BELIEVE TO FOLLOW THE EARTH'S MAGNETIC FIELD LINES.



# THE END

- REFER TO THE ARRL HANDBOOK CHAPTER 21 FOR MORE INFORMATION ON PROPAGATION.
- REFER TO “RADIO PROPAGATION PRINCIPLES AND PRACTICE” BY IAN POOLE, G3YWX
- QUESTIONS???
- TIM KUHLMAN, KD7RUS [KD7RUS@ARRL.NET](mailto:KD7RUS@ARRL.NET)

