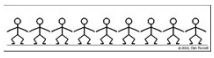
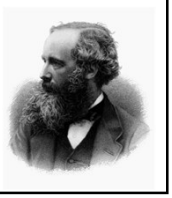
THE LONDON AMATEUR RADIO CLUB INC. LARC VE3LON 1920 - 2020

LARC BASIC AMATEUR RADIO COURSE - 2019

WAVES and PROPAGATION

Mike Cook© VE3ZMC





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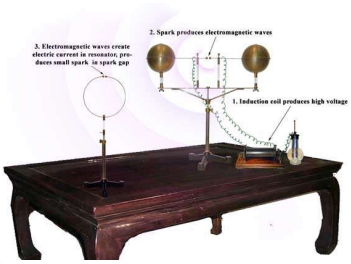
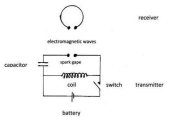


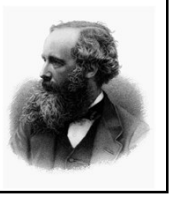
Heinrich Hertz



3

$$\nabla \bullet \varepsilon \mathbf{E} = \rho$$
$$\nabla \bullet \mu \mathbf{H} = 0$$
$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

James Clark Maxwell



2

ELECTRIC WAVES

BEING

RESEARCHES ON THE PROPAGATION OF ELECTRIC ACTION WITH FINITE VELOCITY THROUGH SPACE

BY

DR. HEINRICH HERTZ

PROFESSOR OF PHYSICS IN THE UNIVERSITY OF BONN

AUTHORISED ENGLISH TRANSLATION

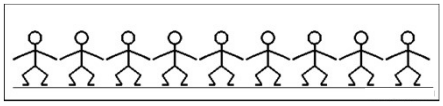
By D. E. JONES, B.Sc.

WITH A PREFACE BY LORD KELVIN, LL.D., D.C.L.

London
MACMILLAN AND CO.
AND NEW YORK
1893

4

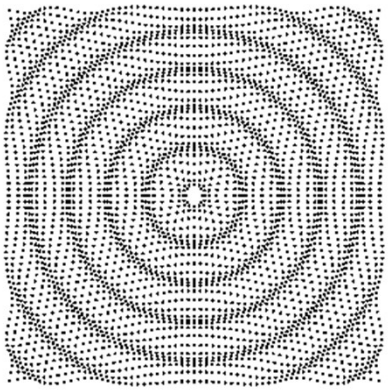
Chapter 5



What is a wave?

5

6



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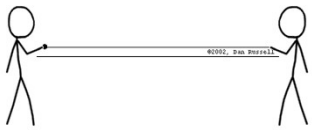
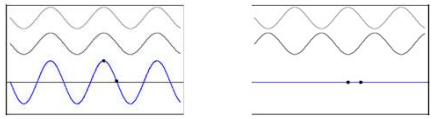


8

Waves can interact with each other

Destructive and constructive interference

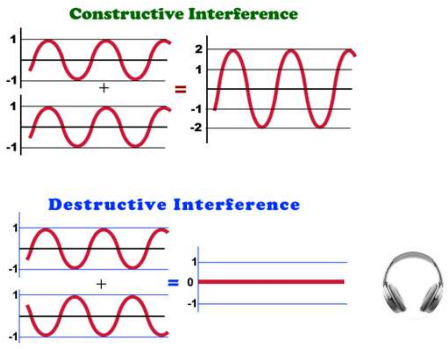
9



Travelling Wave Standing Wave

Diagrams by Dan Russell

11



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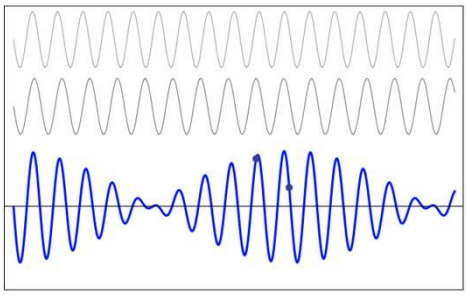


Beat frequency

Diagram by Dan Russell

12

Waves can be reflected

13

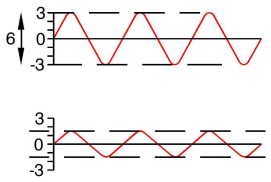
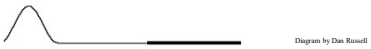


Fig 5-1

Amplitude

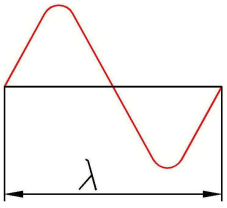
15

Waves encountering different impedance (resistance)



Standing Wave Ratio (SWR) *You will hear much more about this*

14

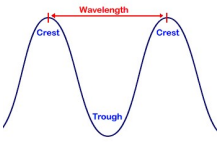


Α α	alpha	Ν ν	nu
Β β	beta	Ξ ξ	ksi
Γ γ	gamma	Ο ο	omicron
Δ δ	delta	Π π	pi
Ε ε	epsilon	Ρ ρ	rho
Ζ ζ	zeta	Σ σς	sigma
Η η	eta	Τ τ	tau
Θ θ	theta	Υ υ	upsilon
Ι ι	iota	Φ φ	phi
Κ κ	kappa	Χ χ	chi
Λ λ	lambda	Ψ ψ	psi
Μ μ	mu	Ω ω	omega

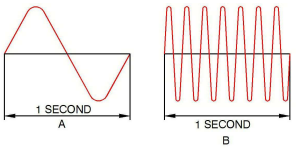
Fig 5-4

Wavelength
e.g. λ = 2 meters

16



17



f

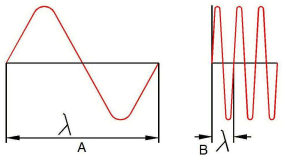
Fig 5-3

Frequency
f = 1 Hz

Frequency
f = 7 Hz

1,000 Hz = 1 kHz
1,000,000 Hz = 1 MHz

19



λ

Fig 5-5

½ ¼

18

Scientific Notation *Remember 1.0*

1,000 Hz = 1 kHz (10^3)
1,000,000 Hz = 1 MHz (10^6)

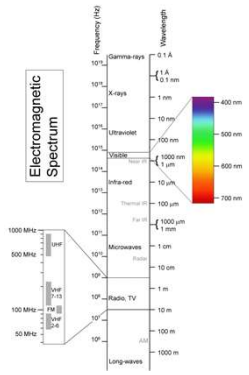
eg. 1,000,000 Decimal point moves 6 places to the right

10^{-6}
0.000001 Decimal point moves 6 places to the left

1.0 / Orders

20

EM waves



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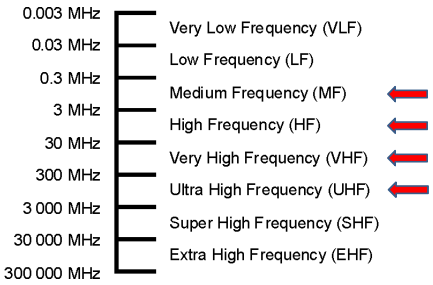

22

23

We need one other thing to describe a radio wave, its velocity.

C

C stands for *Celeritas*, latin for swiftness or speed.
We use it now to stand for the speed of light

It is also a Constant value – 300,000,000 m/s ($3x10^8$ m/s)

24

The relationship between wavelength, frequency and velocity is:

$$\lambda f = C$$

Wavelength x Frequency = Speed of light (C)

Wavelength = $\frac{\text{Speed of light}}{\text{Frequency}}$ $\lambda = \frac{C}{f}$

Frequency = $\frac{\text{Speed of light}}{\text{Wavelength}}$ $f = \frac{C}{\lambda}$

25

Example calculations:

What is the frequency associated with the 80m band?

$f = \frac{C}{\lambda} = \frac{300}{80} = 3.75$ MHz

A transmitter operating at 146.5 MHz is using which band?

$\lambda = \frac{C}{f} = \frac{300}{146.5} = 2.05$ m

26

Example calculations:

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$f = \frac{C}{\lambda} = \frac{300}{80} = 3.75$ MHz

A transmitter operating at 146.5 MHz is using which band?

$\lambda = \frac{C}{f} = \frac{300}{146.5} = 2.05$ m

27

Useful conversions

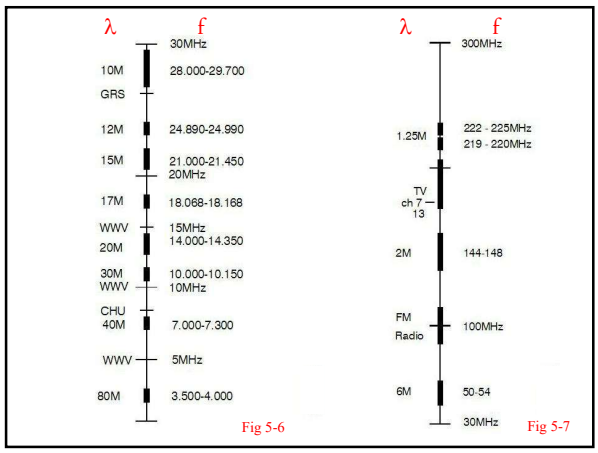
To convert kHz to MHz, divide by 1,000

1050 kHz = $\frac{1050}{1000}$ = 1.05 MHz

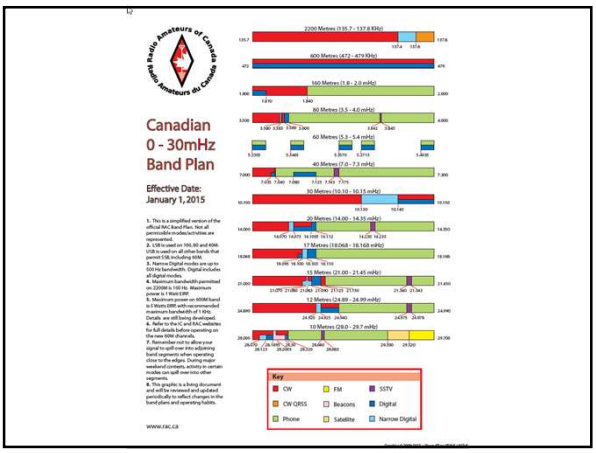
To convert MHz to kHz, multiply by 1000

14.10 MHz = 14.10 x 1000 = 14,100 kHz

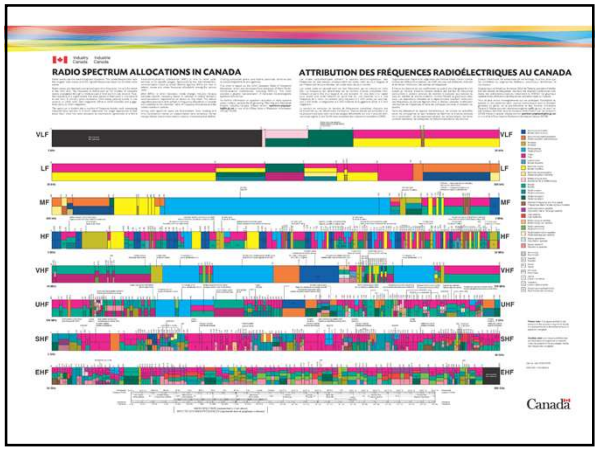
28


λ
f
30MHz
10M
28.000-29.700
GRS
12M
24.890-24.990
15M
21.000-21.450
20MHz
17M
18.068-18.168
WWV
15MHz
20M
14.000-14.350
30M
10.000-10.150
WWV
10MHz
CHU
40M
7.000-7.300
WWV
5MHz
80M
3.500-4.000
Fig 5-6
λ
f
300MHz
1.25M
222 - 225MHz
219 - 220MHz
TV
ch 7
13
2M
144-148
FM
Radio
100MHz
6M
50-54
30MHz
Fig 5-7

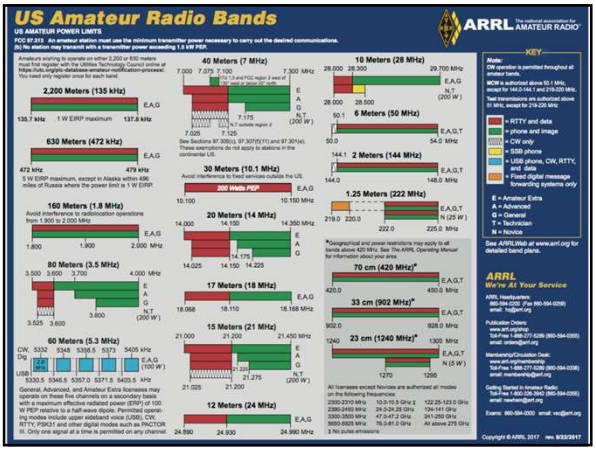
29


Canadian
0 - 30mHz
Band Plan
Effective Date:
January 1, 2015
Key
CW
FM
SSTV
CW QRSS
Beacons
Digital
Phone
Satellite
Narrow Digital

31


RADIO SPECTRUM ALLOCATIONS IN CANADA
ATTRIBUTION DES FRÉQUENCES RADIOÉLECTRIQUES AU CANADA
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
Canada

30


US Amateur Radio Bands
US AMATEUR POWER LIMITS
ARRL
AMATEUR RADIO
2,200 Meters (135 kHz)
630 Meters (472 kHz)
160 Meters (1.8 MHz)
80 Meters (3.5 MHz)
60 Meters (5.3 MHz)
40 Meters (7 MHz)
30 Meters (10.1 MHz)
20 Meters (14 MHz)
17 Meters (18 MHz)
15 Meters (21 MHz)
12 Meters (24 MHz)
10 Meters (28 MHz)
6 Meters (50 MHz)
2 Meters (144 MHz)
1.25 Meters (222 MHz)
70 cm (420 MHz)*
33 cm (902 MHz)*
23 cm (1240 MHz)*
KEY
ARRL
We're At Your Service

32

33

What are radio waves?

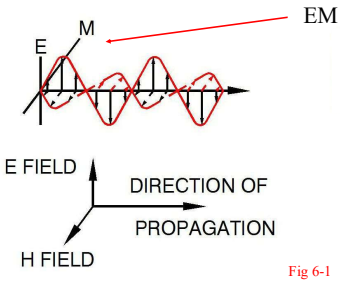
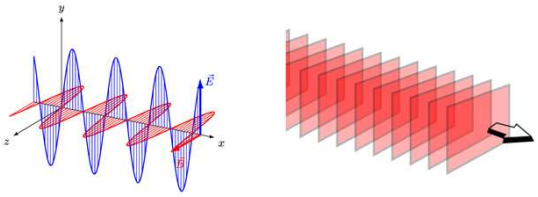


Fig 6-1

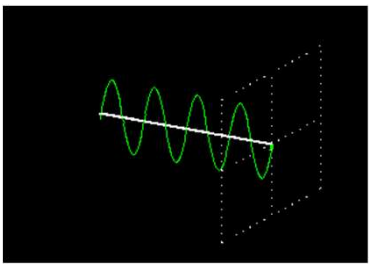
35

Waves can be longitudinal or transverse

34

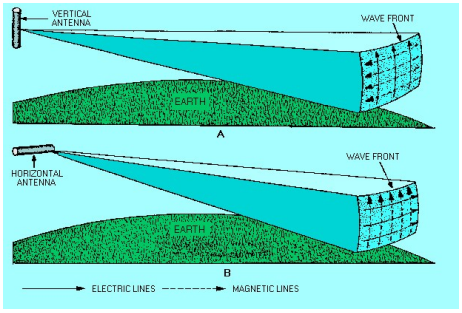


36



Plane Waves

37



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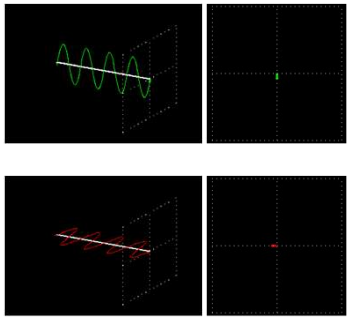
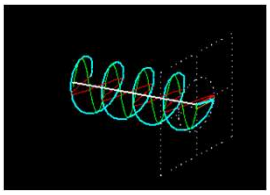


Polarization…. Use plane of E field

38

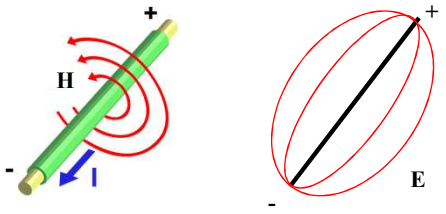


40

41

42

So how do you make a radio wave?

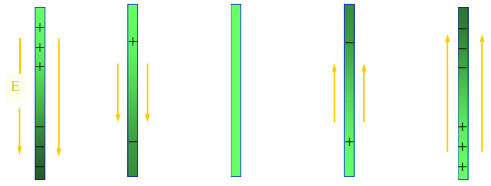


E and H fields grow and collapse with each I reversal

$B = \mu_0(H + M)$

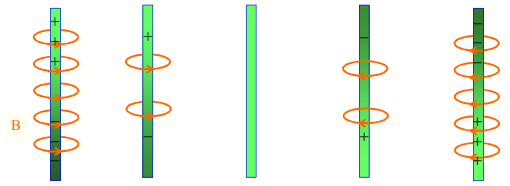
43

So how do you make a radio wave?



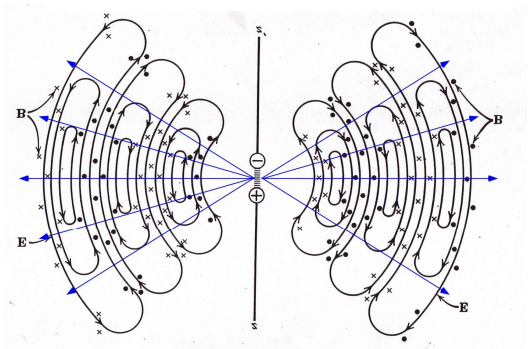
44

So how do you make a radio wave?



45

When the f is high enough….



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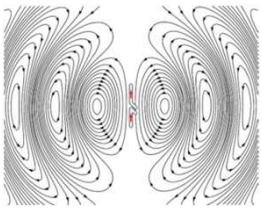

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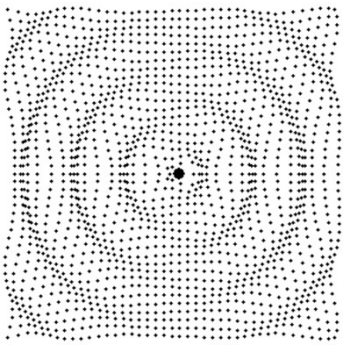


48

$$\nabla \bullet \varepsilon \mathbf{E} = \rho$$
$$\nabla \bullet \mu \mathbf{H} = 0$$
$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t}$$

A charged particle is a source of an electric field

When that particle moves it changes the (*spatial distribution of*) the electric field

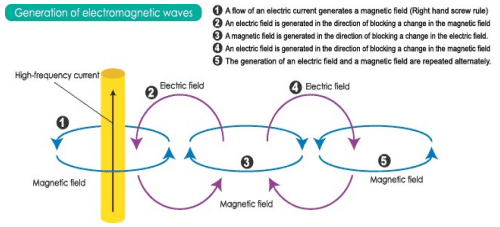
When the electric field changes it produces a circulating magnetic field

If the particle accelerates, this circulating magnetic field will change

A changing magnetic field produces a circulating electric field

The circulating electric field becomes the source of a circulating magnetic field

49



No medium is required

50

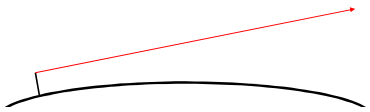
Chapter 6

And now…….

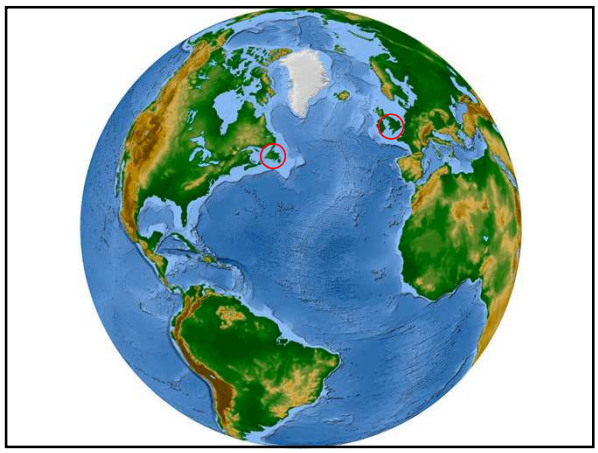
PROPAGATION

51

EM waves travel in straight lines….
…unless acted on by outside forces.

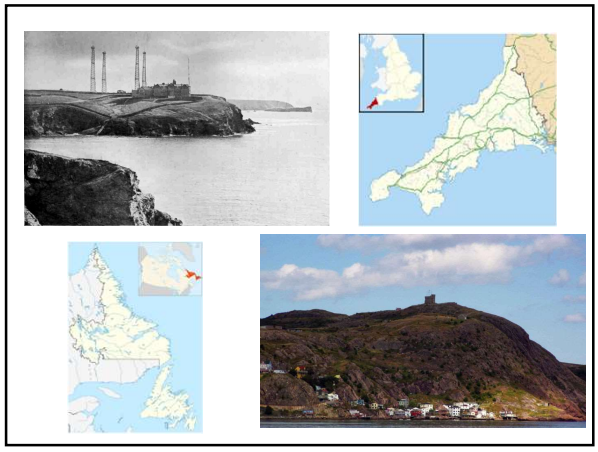


52



53

55



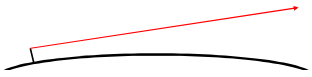
54

56

57

Marconi (1901) sent radio signal from Poldhu, Cornwall, UK, to St. Johns, Newfoundland.

Signal was Morse code letter "S" ...



How the signal got there was not understood at the time.

We now know about the ionosphere and its role in the propagation of radio waves

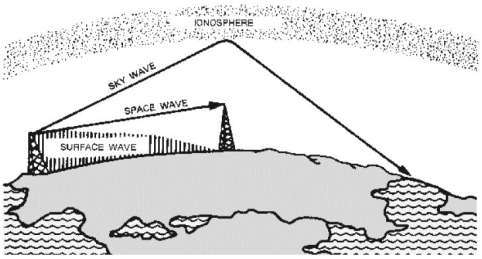
58

59

60

61

PROPAGATION



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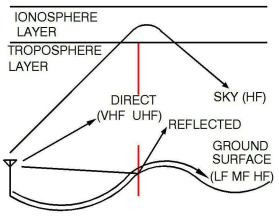


Fig 6-2

Tropospheric waves

Ionospheric waves

63

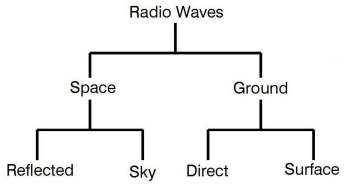


Fig 6-3

64

Ground Waves are surface waves that propagate close to the surface of the Earth.

Ground waves (*or Direct Waves*) travel in straight lines (*line of sight*). These waves may be deviated or reflected by obstructions and cannot travel over the horizon or behind obstacles. Most common propagation mode at VHF and higher frequencies.

At higher frequencies and in lower levels of the atmosphere, any obstruction between the transmitting and receiving antenna will block the signal.

65

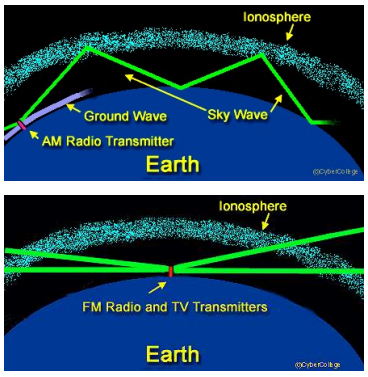
Space Waves travel directly from an antenna to another without reflection at the ground. Occurs when both antennas are within line of sight of each another. Distance is longer than line of sight because most space waves bend near the ground and follow practically a curved path.

Antennas must display a low angle of radiation so that power is radiated in direction of the horizon. A horizontally polarized antenna is most often used on the HF bands while VHF/UHF use vertical polarization.

66

Sky Wave (*Skip/ Hop/ Ionospheric Wave*) is the propagation of radio waves refracted back to the Earth by the ionosphere. HF radio communication (between 3 and 30 MHz) is the result of skywave propagation.

67



68

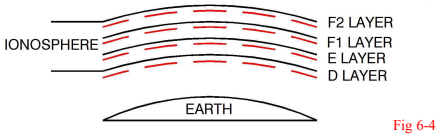


Fig 6-4

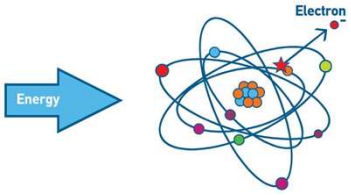
Structure of the ionosphere

How does it arise?

We'll start with atoms

69

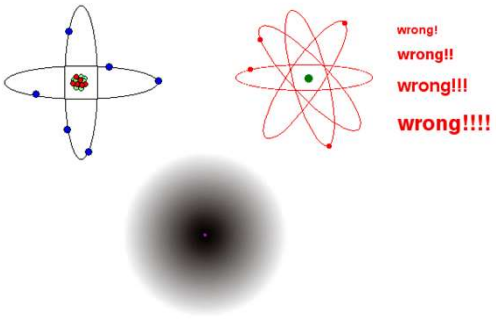
Solar radiation creates ions from the atoms in the upper atmosphere



The atoms include: Oxygen, Nitrogen, Hydrogen and Helium

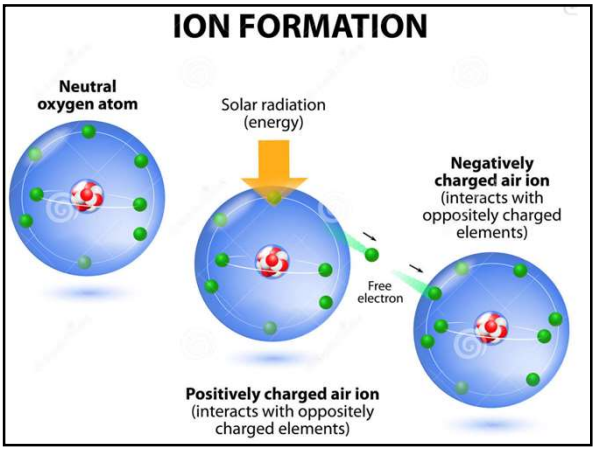
Free electrons are also formed.

71

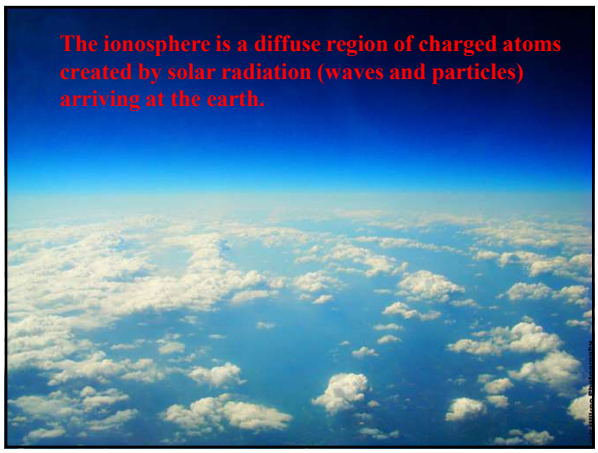


Atoms with an extra electron or a missing electron are known as ions

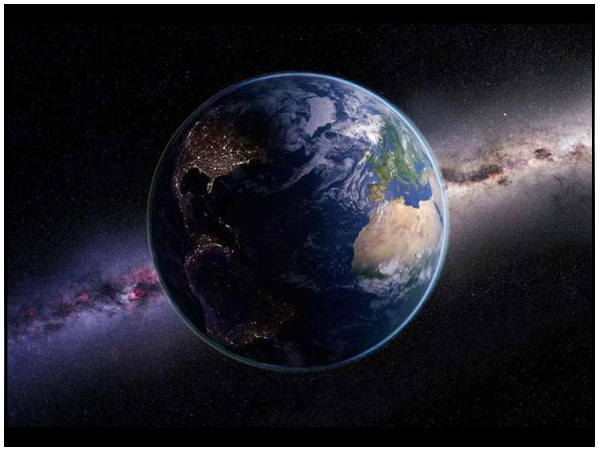
70



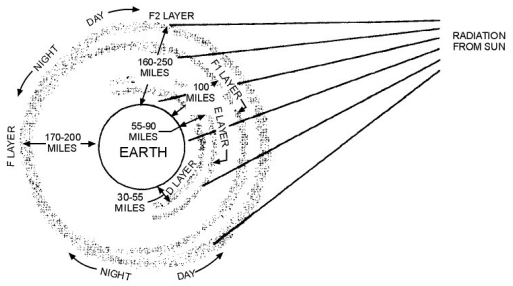
72



73



74



NB: Not layers within which the earth rotates!

75

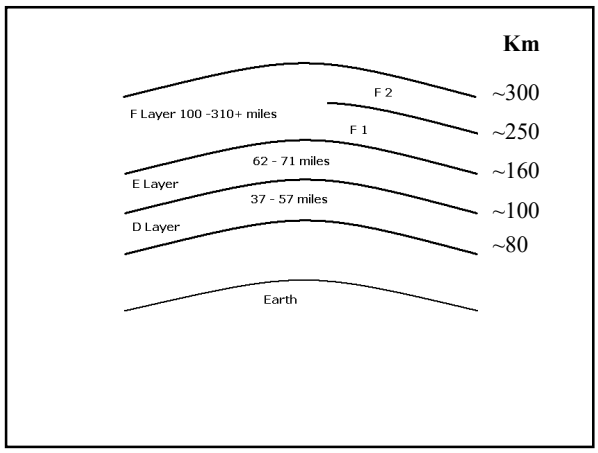
The ionosphere is most ionized at midday and is least ionized just before dawn

The D layer is closest to the earth and absorbs radio waves, especially the lower frequencies. Least useful for DX (long distance communication)

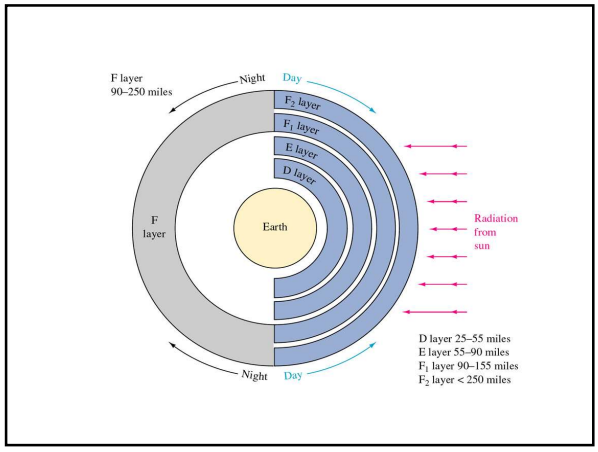
The E layer refracts radio waves but is lower than the F layer(s). Some absorption too. *(Grey line = less D @ terminator)*

The F layer splits into two sub-regions, F1 and F2, during the day. At night only a single F layer exists. It is the highest region of the ionosphere and by refracting waves is responsible for worldwide DX propagation

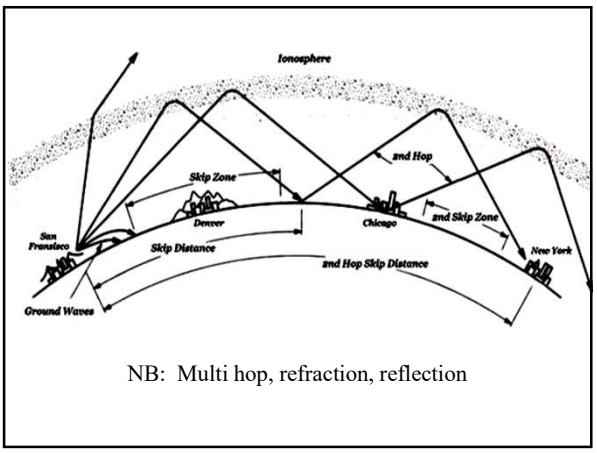
76



77

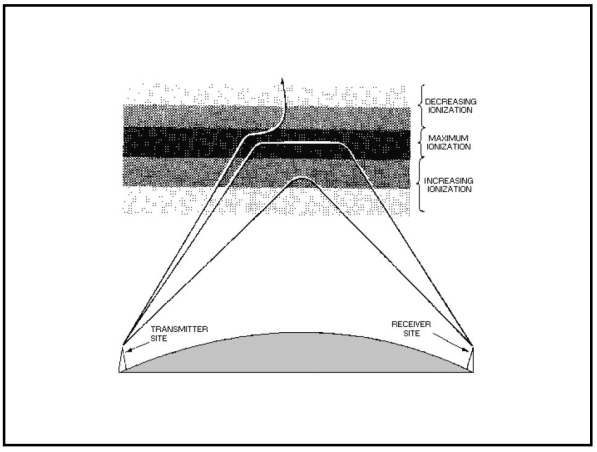


78



NB: Multi hop, refraction, reflection

79



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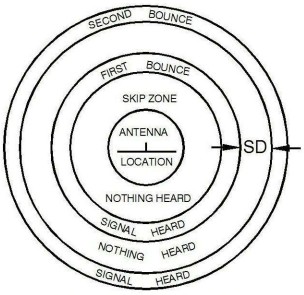
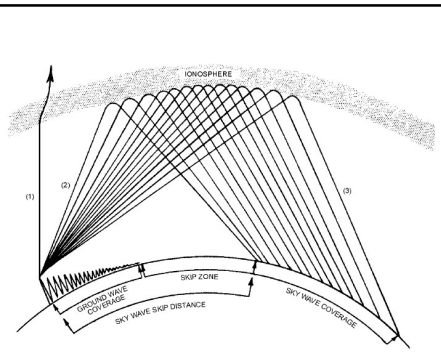


SD = SKIP DISTANCE

Fig 6-6

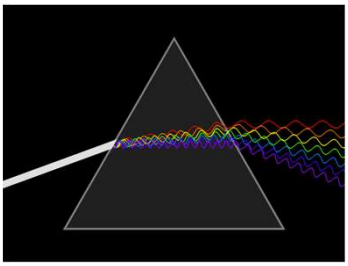
81



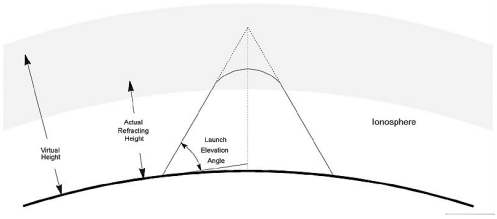
∠ may change causing fading

82

Refraction (not reflection) at the ionosphere



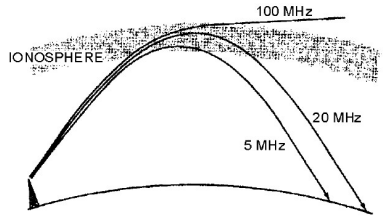
83



Refraction is frequency- and angle-dependent

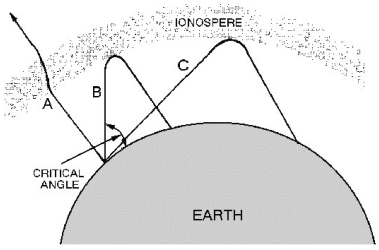
f ∠

84



f-dependence

85



∠-dependence

86

Effects of solar activity on HF propagation are summarized on page 6.5, and Fig 6.7

Attenuation of radio waves (Field strength)

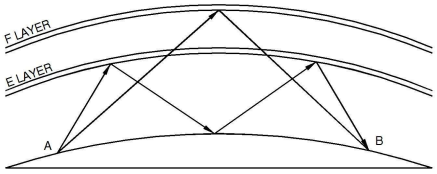


Fig 6-8

87

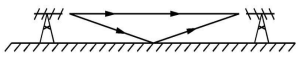


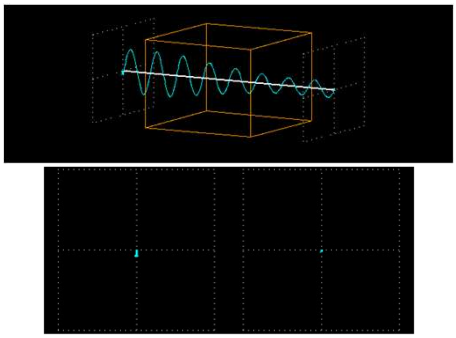
Fig 6-9

Multiple signal paths contribute to fading

The processes involved are absorption, phase shifting and changes in polarization.

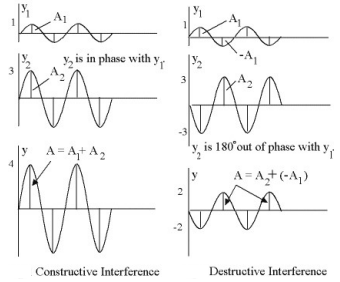
88

Absorption is a straightforward concept.



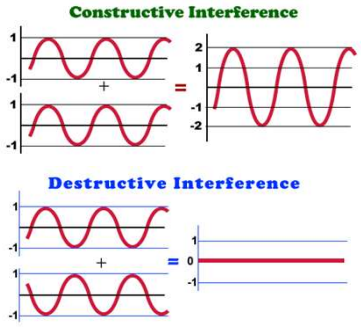
89

Phase shifts are responsible for constructive or destructive interference of waves

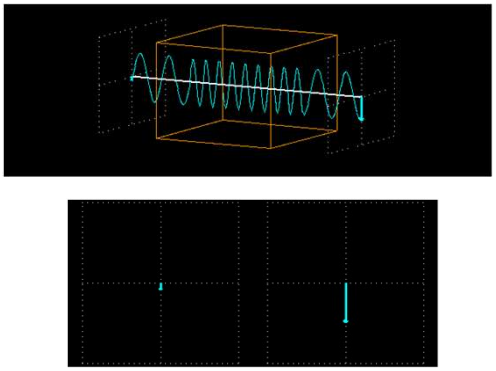


91

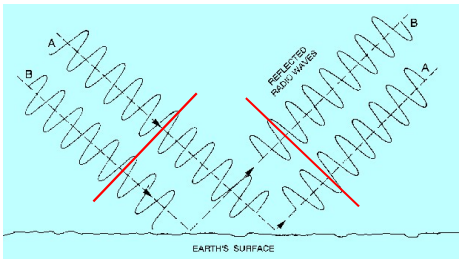
Phase shifts are responsible for constructive or destructive interference of waves



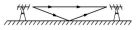
90



92

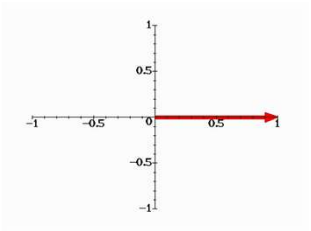


Notice phase change



93

Polarization changes occur on refraction, reflection (HF) and scattering (VHF).

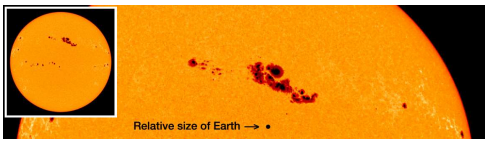


Random changes in polarization are known as Faraday rotation

94

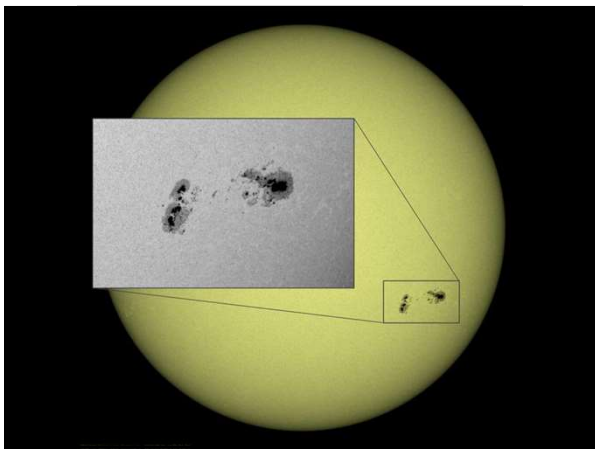
95

Solar activity is responsible for the degree of ionization of the ionosphere, especially sunspots which produce a lot of UV radiation

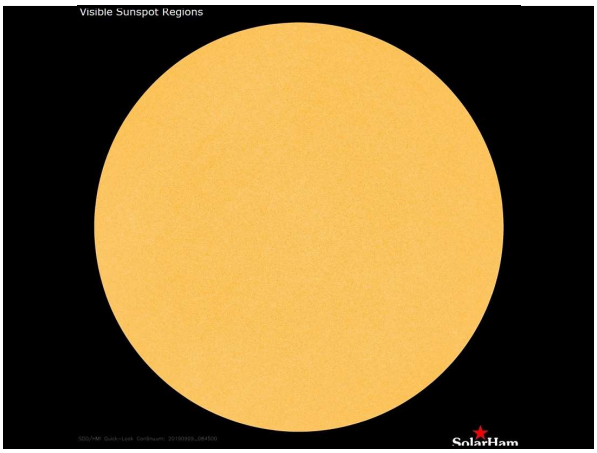


Cycle is ~11 years

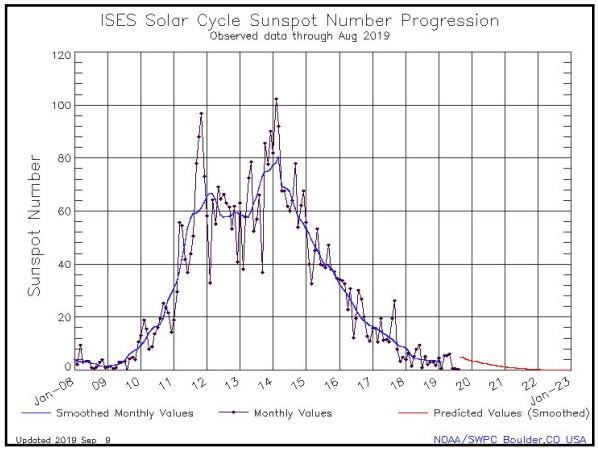
96



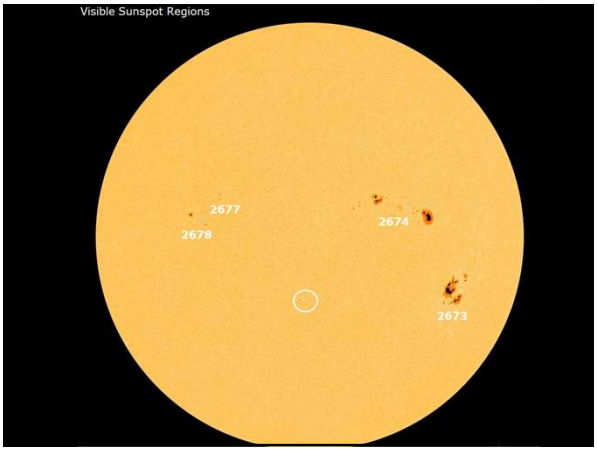
97


Visible Sunspot Regions
SolarHam

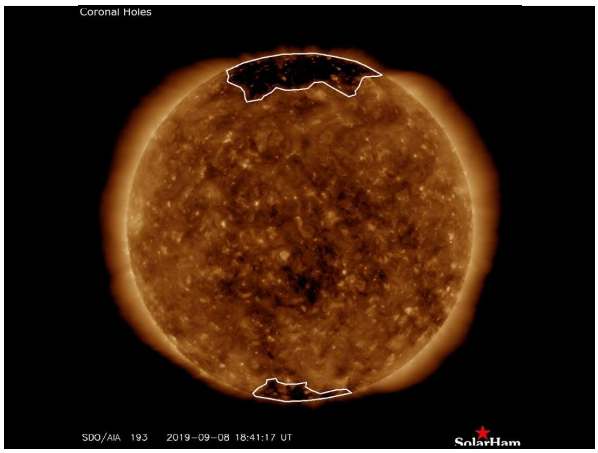
99


ISES Solar Cycle Sunspot Number Progression
Observed data through Aug 2019
Sunspot Number
120
100
80
60
40
20
0
Jan-08
09
10
11
12
13
14
15
16
17
18
19
20
21
22
Jan-23
Smoothed Monthly Values
Monthly Values
Predicted Values (Smoothed)
Updated 2019 Sep 9
NOAA/SWPC Boulder,CO USA

98

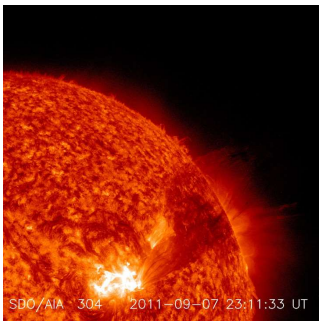

Visible Sunspot Regions
2677
2678
2674
2673

100

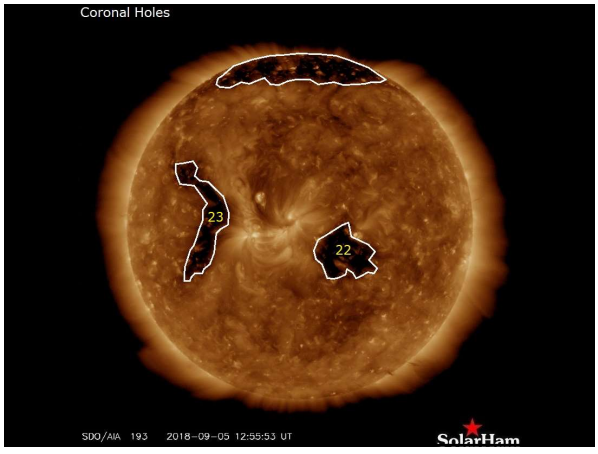


101

Solar flares (coronal mass ejections) produce EM and particles which can disrupt radio communications

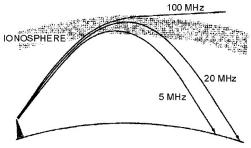


103



102

Predicting propagation on MF and HF



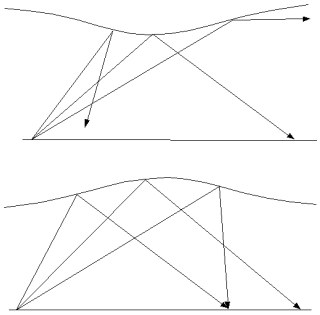
Critical f_c is that above which no refraction back to earth occurs

NVI

The maximum usable frequency (MUF) is closely related to the critical frequency $MUF = f_c(\csc\theta)$

The optimum working frequency is ~85% of the MUF

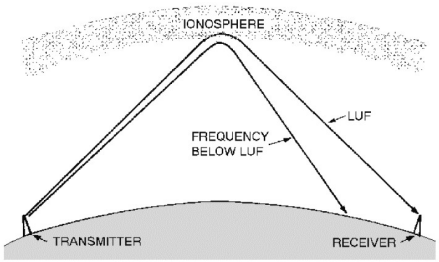
104



Ionospheric undulation

105

There is also a lowest usable frequency (LUF)

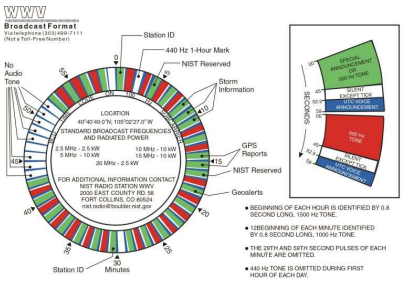


106

Many beacon and time stations can be used to predict propagation conditions

107

WWV (Fort Collins, Co):2.5, 5, 10, 15, 20 MHz +18min♂; WWVH (Hawaii): 2.5, 5, 10, 15 MHz +45 min♀



108

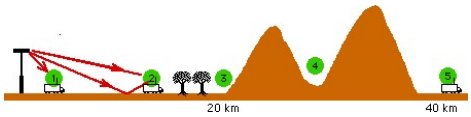
CHU (Ottawa) 3.33, 7.850, 14.67 MHz

NCDXF beacons (page 6.20 and Fig 6.10)

109

VHF and UHF propagation

Line-of-sight propagation, refraction at ionosphere not involved

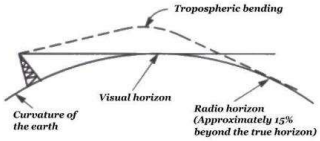


However, refraction by temperature, reflection, diffraction and scattering occur

Some special modes of propagation exist

110

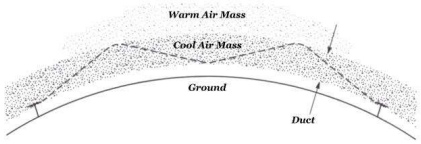
Some tropospheric bending occurs on VHF and UHF



Temperature differences at various altitudes affect signal path

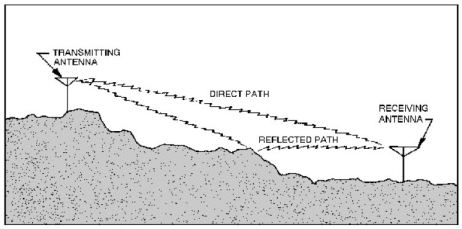
111

Ducting for some distance is possible

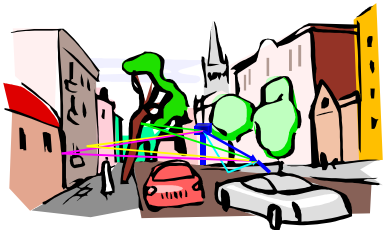


112

Reflection contributes to multi-path propagation and fading

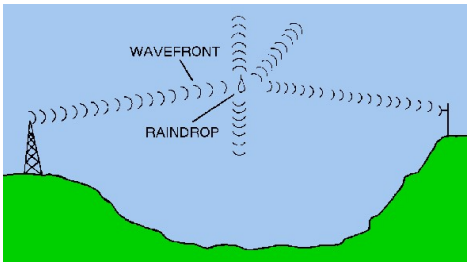


113



Reflection from buildings also causes multi-path propagation

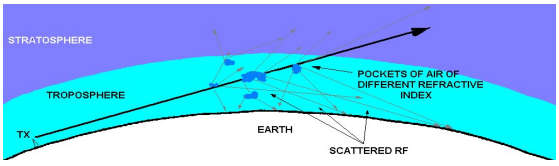
114



At VHF and UHF frequencies scattering by raindrops is important. Also absorption by leaves

115

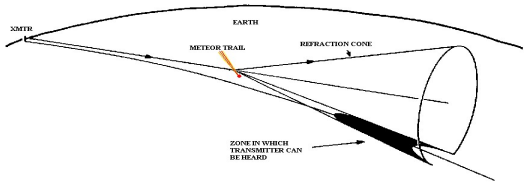
Tropospheric scatter (troposcatter) can occur.



116

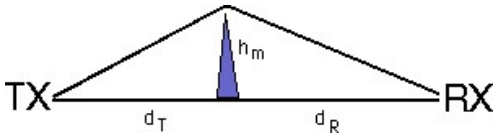
Special modes on VHF and UHF

Sporadic E, Auroral, Meteor scatter, Sleet scatter, Lightning, Aircraft, Trans-equatorial, EME….

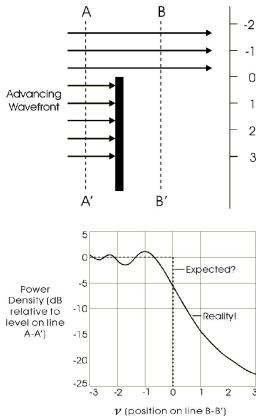


117

Diffraction (Quantum effect)



118



119

Review the properties of MF and HF bands on pages 6.12 – 6.14 and VHF and UHF bands on pages 6.17 – 6.18.

How about a few questions from the IC question bank?

120

B-005-1-1 If a dial marked in megahertz shows a reading of 3.525 MHz, what would it show if it were marked in kilohertz?
1. 35.25 kHz
2. 3525 kHz
3. 3 525 000 kHz
4. 0.003525 kHz

121

B-005-7-4 Electrical energy at a frequency of 7125 kHz is in what frequency range?
1. Radio
2. Audio
3. Hyper
4. Super-high

122

B-005-7-7 What happens to a signal's frequency as its wavelength gets longer?
1. It disappears
2. It stays the same
3. It goes down
4. It goes up

123

B-007-3-5 The distance to Europe from your location is approximately 5000 km. What sort of propagation is the most likely to be involved?
1. sporadic "E"
2. back scatter
3. multihop
4. tropospheric scatter

124

B-007-3-6 For radio signals, the skip distance is determined by the:
1. power fed to the final
2. angle of radiation
3. type of transmitting antenna used
4. height of the ionosphere and the angle of radiation

125

B-007-3-10 The skip distance of a sky wave will be greatest when the:
1. polarization is vertical
2. ionosphere is most densely ionized
3. angle between ground and radiation is smallest
4. signal given out is strongest

126

B-007-4-2 What causes the ionosphere to absorb radio waves?
1. The presence of ionized clouds in the E region
2. The ionization of the D region
3. The splitting of the F region
4. The weather below the ionosphere

127

B-007-4-7 On the VHF and UHF bands, polarization of the receiving antenna is very important in relation to the transmitting antenna, yet on HF bands it is relatively unimportant. Why is that so?
1. The ionosphere can change the polarization of the signal from moment to moment
2. The ground wave and the sky wave continually shift the polarization
3. Anomalies in the earth's magnetic field produce a profound effect on HF polarization
4. Greater selectivity is possible with HF receivers making changes in polarization redundant

128

B-007-6-1 What happens to signals higher in frequency than the critical frequency?
1. They pass through the ionosphere
2. They are absorbed by the ionosphere
3. Their frequency is changed by the ionosphere to be below the maximum usable frequency
4. They are reflected back to their source

129

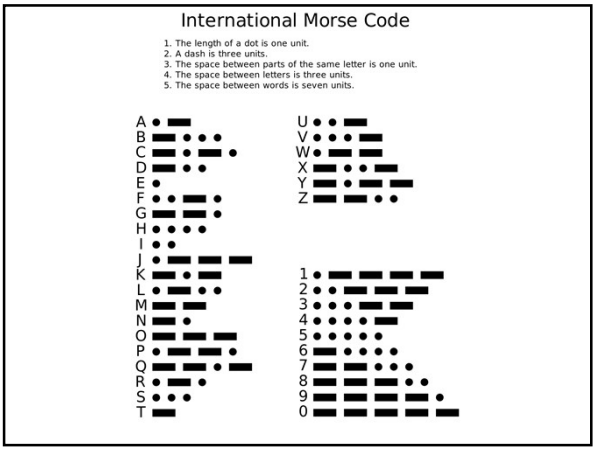
B-007-6-4 What can be done at an amateur station to continue HF communications during a sudden ionospheric disturbance?
1. Try a higher frequency
2. Try the other sideband
3. Try a different antenna polarization
4. Try a different frequency shift

130

Thanks for listening and Good luck on the exam!

CW

131

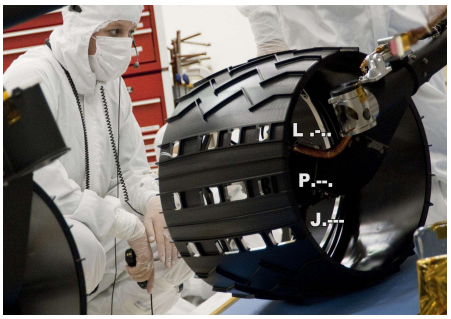


132

A great program for learning Morse code is G4FON

If you have an Android phone, an app by IZ2UUF will allow you to practice anywhere and anytime.

133



135

<u>Morse Code is dead?</u>

Airports/Heliports (Pilots)
Navigational beacons
Hospitals etc
Gets through when SSB fails
Repeater ID
Beacons
Simpler equipment
Lower bandwidth
SOS
Language/Q codes
Military (Aldis lamp)
Secrecy (High speed burst, Jeremiah Denton Jr.)
Mars Rover (Curiosity) tread pattern

134