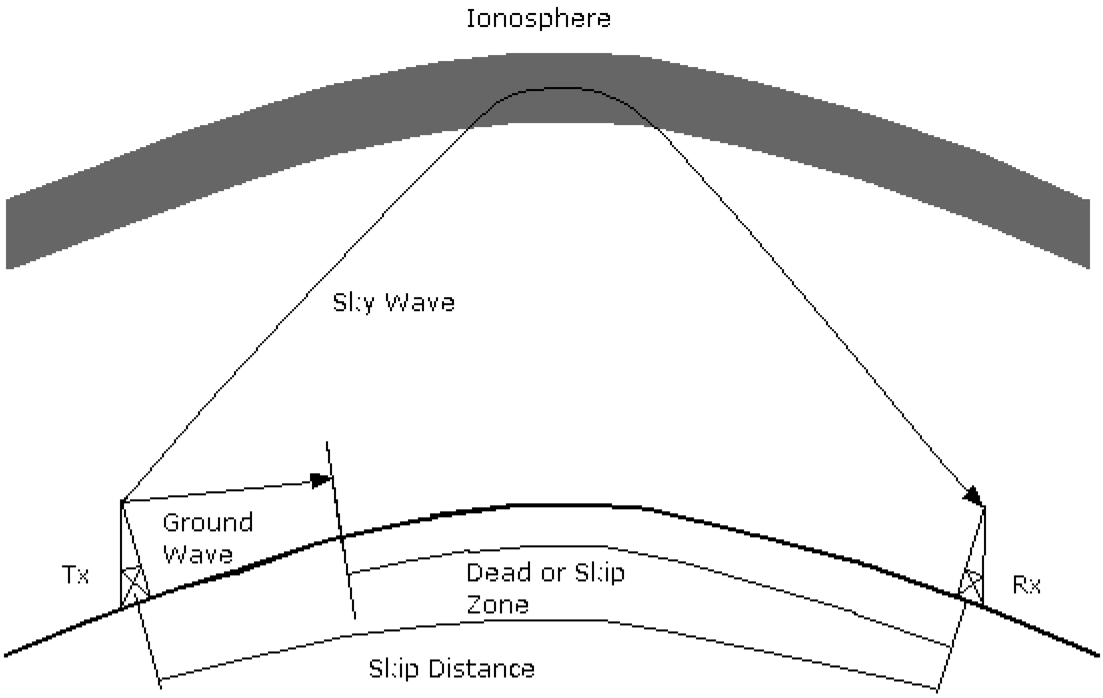
South Bristol Amateur Radio Club
Lesson 22 - Propagation
Syllabus 6a.1, 6a.2, 6a.3, 6a.4, 6a.5, 6a.6, 6a.7, 6a.8



The diagram above represents the propagation model employed in the Foundation Course. Two stations operating on HF rely on the ionosphere to reflect or refract the radio waves from one station back to earth to be received by the second station.

There are, however, a few new terms that we didn't cover on the Foundation Course, so let's introduce these now, and recap on a few of the things you should recall:

TX:	The transmitting station.
RX:	The receiving station.
Ionosphere:	An area of the atmosphere extending from about 70km to about 400km that becomes charged by the incidence of Ultra Violet rays from the sun.
Sky Wave:	The main mode of propagation for HF transmissions. The wave is sent into the sky to be reflected or refracted by the ionosphere and returned to earth.
Ground Wave:	All HF transmissions also have a ground wave component that propagates out from the transmitting station along with the sky wave. The ground wave is of limited range as it is gradually absorbed by the ground it travels over.
Skip Distance:	The distance between the transmitting station and the point where the sky wave returns to earth. This distance is variable based on frequency, time of day, season and sunspot activity.
Dead or Skip Zone:	The area between the end of ground wave propagation and the point where the sky wave returns to earth. Stations situated in the dead or skip zone are unable to receive signals from the transmitting station.

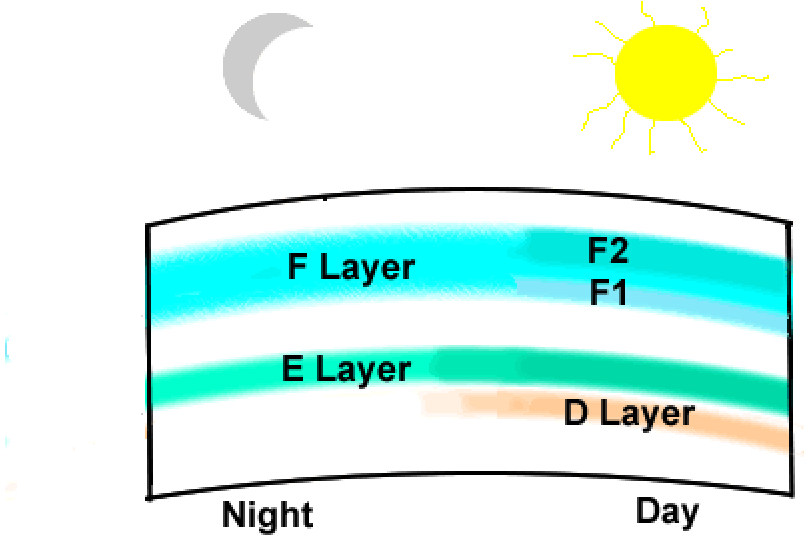
Clearly the ionosphere is important to HF propagation and we need to consider it in more detail. As you will be aware our planet Earth is surrounded by an atmosphere. It extends to perhaps 1000km above the surface of the earth, although it becomes unable to support human life at altitudes well below this.

The table below illustrates the various layers within the atmosphere and gives an indication of what might be expected to be within them.

Height of Commencement (km)	Height of Termination (km)	Thickness (km)	Name	Notes
0km	10km	10km	Troposphere	Low Cloud – aprx 2km Medium Cloud – aprx 6km High Cloud - aprx 8km Mt Everest – aprx 9km
10km	50km	40km	Stratosphere	Typical Passenger Aircraft aprx 10km – 11km Blackbird Spy Plane aprx 21km
50km	100km	50km	Mesosphere	Ionosphere starts aprx 70km
100km	1000km	900km	Thermosphere	Ionosphere extends to aprx 400km Space officially starts 100km

Ultra Violet radiation created by the sun strikes the atmosphere. The air molecules within the Ionosphere are split up and become charged (a process called Ionisation that gives this region of the atmosphere its name). It is the charge on the particles that reflects the radio waves which are of themselves electro-magnetic waves.

The ionosphere is made up of several distinct layers illustrated below:



As you can see the composition of the ionosphere is not fixed, it changes in response to the amount of ultra violet radiation falling upon it. As less radiation falls on it by night than by day the level of ionisation at night is markedly less than by day. Equally the longer winter nights with less day time radiation behave differently to shorter summer nights.

Finally the level of radiation from the sun varies. Sunspot activity increase and decreases on an approximate 11 year cycle. At times of high sunspot activity more radiation is produced resulting greater levels of ionisation allowing higher frequencies to be reflected by the ionosphere than occurs at lows in the cycle.

Each of the layers has a different effect on the propagation of signals. We'll start at the bottom and work our way up.

The D Layer is only present by day. Being at the lower end of the ionosphere, with proportionally greater air densities than the upper layer it takes longer for this layer to become ionised and equally this layer loses it ionisation quicker.

This is important because the D layer has the property of blocking radio waves when it is ionised. The effects vary but typically once the D layer is established during the day then anything below about **6MHz** will not break through but is simply absorbed. This leads to 40m being marginal by day and the lower bands (80m and 160m – top band) being next to useless except for ground wave propagation.

By night the D layer quickly loses it charge and ceases to block radio waves allowing these bands to become practical for long distance communication. This is why 20m is a favourite DX band by day since it is high enough in frequency to pass through the D layer.

The E Layer has little effect on HF propagation and can be discounted for the most part. Interestingly it can have an influence on VHF propagation, and is quite a sought after event for VHF DXers.

Within the E layer, as with all of the layers in the ionosphere, charged areas build up. As we have said these have little effect on HF but for VHF signals up to about 150MHz, making it ideal for 6m and 2m signals, when pockets or clouds of charge build up in the E-layer they become capable of reflecting these VHF signals. The effects are usually transient and the clouds seem to be able to move. As a consequence Sporadic-E contacts tend to be quite short.

Theories about when and how Sporadic-E occurs abound, it is certainly one of the less well understood aspects of propagation and consequently predicting the appearance of Sporadic-E is currently impossible with any degree of certainty. It is usually a summertime occurrence suggesting that it is associated with higher levels of ultra violet radiation and it does seem to be linked to weather, but beyond that little is understood.

The F Layer (F1/F2 Layers) are the most important layers for HF propagation. It is these layers that reflect HF signals allowing world-wide coverage using multiple hops. Being the highest layer the greatest range is achieved for the reflected signal, and unlike the sporadic effects associated with VHF signals in the E-layer the F layer is more reliable and predictable in both it's availability and consistency which is why HF has been relied on for world wide contacts.

By night as ionisation levels fall the two F layers tend to merge together, but as ionisation levels increase through the day there is a tenancy or the layer to split into two distinct but similar layers. Clearly the greatest range will be achieved by reflecting signals off the F2 layer, however in some cases shorter range may be required and then choosing a frequency that is reflected in the lower F1 layer may result in more reliable communication.

As the frequency of the transmission increase then the levels of ionisation required to reflect that signal also increase. In fact, although HF is the band relied on for HF communication once you get above about **15MHz** then the reliability of reflection becomes less. Again you will notice that 20m is below this cut off point which again indicates why it is a favourite DX band.

Signals above 15MHz will be reflected but the reliability of the reflection decreases. There is a parameter known as the **Maximum Usable Frequency (MUF)** that describes the levels of ionisation and the limits of reliable communication.

The F layer propagation model is reasonably well understood and it is possible to predict with some reliability what the MUF will be over the coming month. In fact the RSGB publish tables of MUF in each months RadCom, on-line sources for this information are also available (see http://www.rsgb.org/propagation/).

Below is an example of the information given:

The number indicates the circuit reliability in that it indicates the number of days the circuit is likely to be open. A '1' indicates 1 – 19% of days, '2' indicates 20% - 29% and so on. A '.' indicates no signal.

The colours indicate signal strength, a black signal strength is low to very low, blue is expected to be fair and red is strong.

The predictions are based on 100W and a dipole, so the table can be bettered with the right equipment.

HF F-Layer Propagation Predictions for June 2011

Compiled by Gwyn Williams, G4FKH

	3.5MHz	7.0MHz	10.1MHz	14.0MHz	18.1MHz	21.0MHz	24.9MHz	28.0MHz
Time	000011111220	000011111220	000011111220	000011111220	000011111220	000011111220	000011111220	000011111220
(UTC)	246802468020	246802468020	246802468020	246802468020	246802468020	246802468020	246802468020	246802468020
*** Europe								
Moscow	66	74......3688	87.32...7888	.57777777885	..6777.6786.	....	....	....
*** Asia								
Yakutsk	....	....	3.......3443	766666667777	...45444....	....	....	....
Tokyo	....	....	....	....	....	....	....	....
Singapore	.........22.	.........788.	.........553.	........4...	........4...	....	....	....
Hyderabad	....	255	2566	5665	........45..	....	....	....
Tel Aviv	9........799	98......7999	774....47888	..354..4786.	........56..	....	....	....
*** Oceania								
Wellington	....	....	....	....	....	....	....	....
Well (ZL) (LP)	....	48........5.	997......799	897......599	55........77	65	..........5.	....
Perth	....	2643	........35.6	5	....	....	....	....
Sydney	....	........37..	........67..	........34..	....	....	....	....
Melbourne (LP)	....	4992........	9998.......8	9998......69	8.8.......79	78	....	....
Honolulu	....	....	....	....	...45.......	....	....	....
Honolulu (LP)	....	....	....	....	....	....	....	....
W. Samoa	....	....	....	....	...454......	....	....	....
*** Africa								
Mauritius	2.........22	6.......4787	7886	.......4875.	.......464..	........5...	....	....
Johanesburg	....	242	.4......8886	.......586..	....	....	....	....
Ibadan	1.........11	66.......566	772.....2777	.37....37877	..76....785.	..47....78..	........67..	....
Nairobi	3.........34	82.......888	63.......666	.5......6676	..4....5666.	......4666..	........4...	....
Canary Isles	76.......167	886......788	8874....6888	8686....8888	..8998899998	...88787998.	...4....56..	....
*** S. America								
Buenos Aires	....	65.........3	887.......78	765.......88	576	.........56.	....	....
Rio de Janeiro	....	66.........6	883......289	76.......788	776	.........66.	.........5..	....
Lima	....	653........3	8882......58	6565......78	66	..........5.	....	....
Caracas	....	33.........3	8873......68	86873....488	65445687	774	....	....
*** N. America								
Guatemala	....	33..........	887........7	656.......37	45	....	....	....
New Orleans	....	65..........	775........5	74........46	....	....	....	....
Washington	2...........	762........3	8763......27	85..4....577	........456.	....	....	....
Quebec	3...........	76.........6	764.......57	......3.5675	....	....	....	....
Anchorage	....	....	32..........	666545556666	..65..566776	....	....	....
Vancouver	....	....	....	....	....	....	....	....
San Francisco	....	....	....	....	....	....	....	....
San Fran (LP)	....	....	....	....	....	....	....	....

KEY: Each number in the table represents the expected circuit reliability, eg '1' represents reliability between 1 and 19% of days, '2' between 20 and 30% of days, etc. No signal is expected when a '.' is shown. Black is shown when the signal strength is expected to be low to very low, blue when it is expected to be fair and red when it is expected to be strong. The RSGB Propagation Studies Committee provides propagation predictions on the internet at www.rsgb.org.uk/propagation/index.php. An input power of 100W and a dipole aerial has been used in the preparation of these predictions; therefore a better equipped station should expect better results. The predicted smoothed sunspot numbers for June, July and August are respectively (SIDC classical method – Waldmeier's standard) 56, 61 & 67 and (combined method) 62, 66 & 72. The provisional mean sunspot number for March 2011 was 56.2. The daily maximum / minimum numbers were 91 on 15 April and 40 on 5, 10 & 25 April.

The angle that signals strike the ionosphere can have an impact of whether or not they are reflected. Consider a stone and a pond. If the stone is dropped onto the surface of the water it will simply sink straight through. On the other hand if it is thrown at a low angle the stone can be made to skip off the surface and travel for a considerable distance.

However the angle can only compensate a certain amount for increases in frequency and as we get into the VHF and UHF ranges then these signals will always pass through the ionosphere. This is one of the reasons why they are employed in space based communications such as with the Space Shuttle, ISS or orbiting satellites.

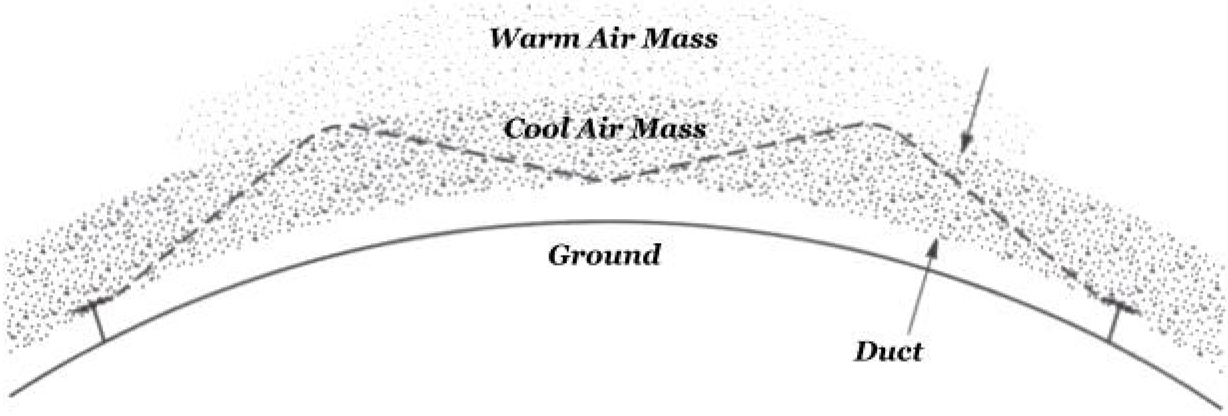
VHF/UHF and higher frequencies are generally line of sight, the boundary for the transition from HF style propagation and VHF style propagation is generally taken to be **30MHz**, but this is not fixed. Under the right conditions the lower VHF bands can be reflected and at other times signals in the 28MHz band will not be reflected.

As we have said for this reason day to day communications at VHF and certainly above this are treated as being line of sight. In practice the earth curvature and magnetic field does bend VHF signals a little and it is possible to get just over the horizon, but never the less reliable contacts are usually local.

We have already discussed Sporadic E VHF propagation which can increase the range of VHF signals to thousands of kilometres. There is another phenomenon that can increase the distance over which VHF signals can travel. This is known as **tropospheric ducting**.

The troposphere is the lowest of the regions in our atmosphere. Under normal circumstances temperature decreases as altitude increases. However sometimes and area of warmer air along with some humidity becomes trapped higher in the troposphere than would normally be the case.

When this happens signals can penetrate the duct and then be trapped forced to travel through the duct and emerge at the other end significantly increasing the normal distance. Being associated with warmer air these conditions occur more frequently in summer months.

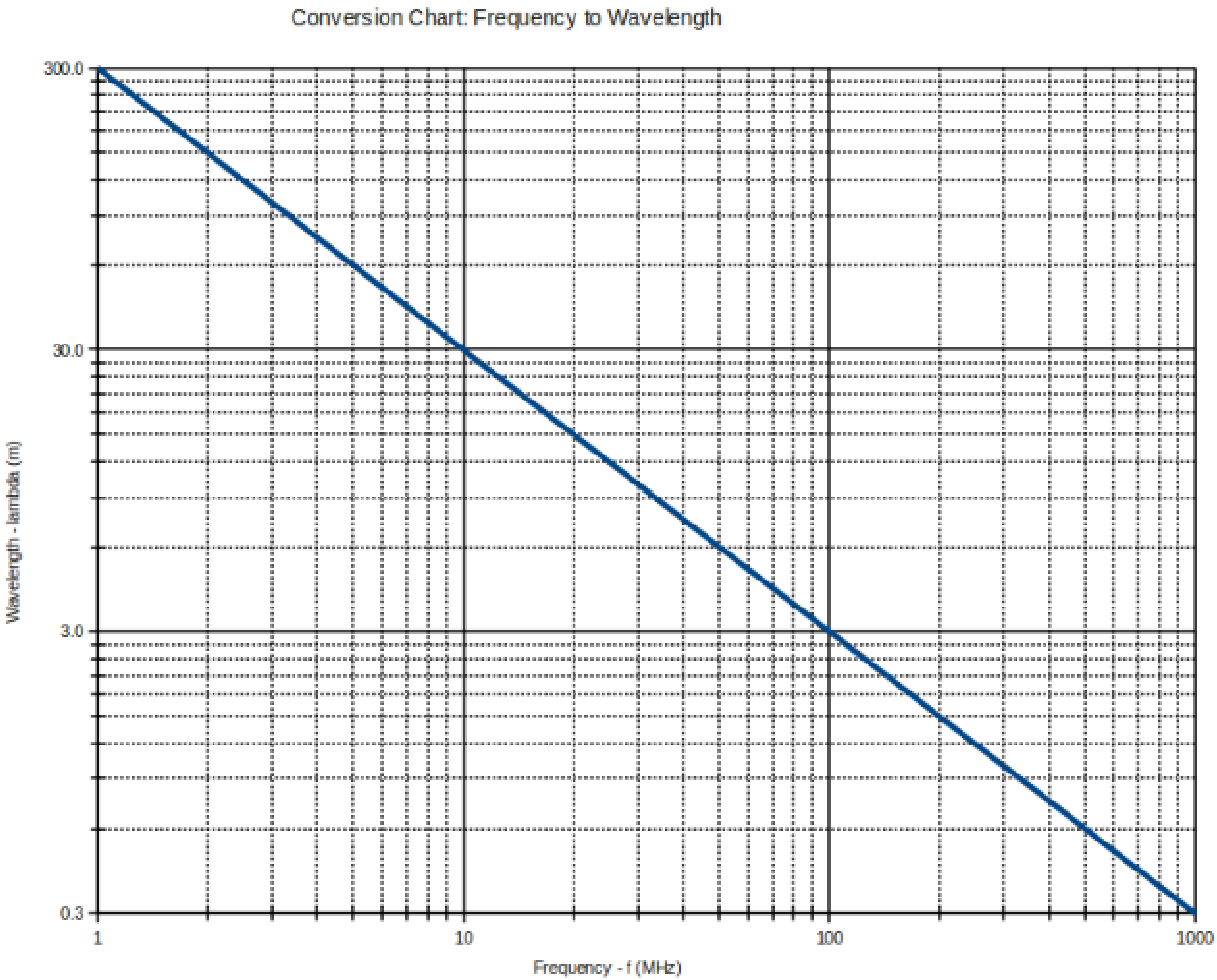


By contrast poor weather conditions such as rain, hail, sleet and snow absorb the higher frequency waves and can reduce the effective range of VHF/UHF signals very effectively.

Frequency and Wavelength

You will recall from the Foundation Course that there is a relationship between wavelength and frequency, and that as wavelength increases frequency decreases and vice versa.

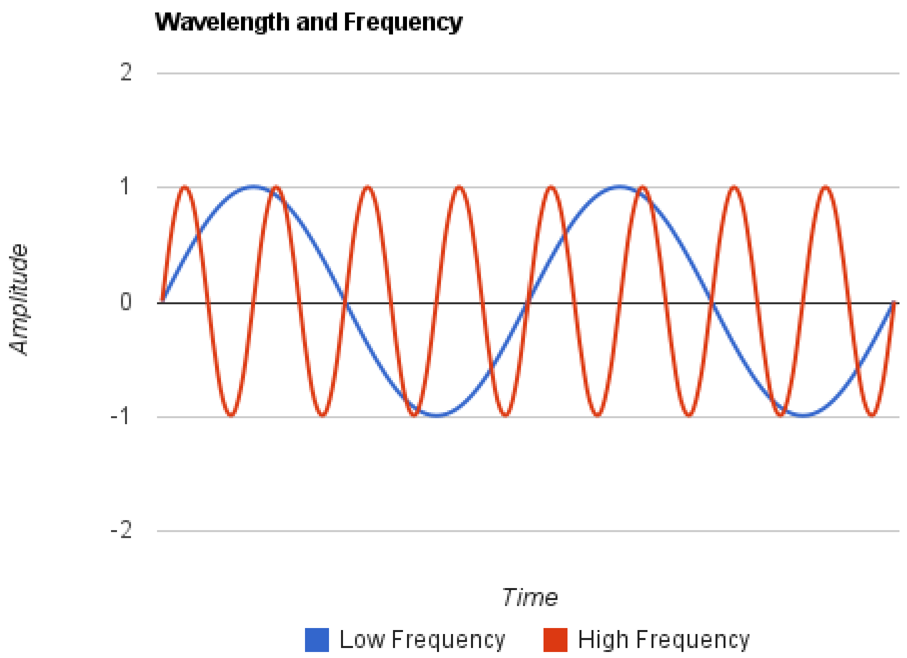
In order to relate one to the other we made use of a graph which is reproduced below for reference:



It will come as no surprise to learn that we must now look at the background to this graph.

Below is an example of two waves. The blue wave is a low frequency wave, whilst the orange wave is a high frequency wave. The wavelength is defined as the distance from one peak to an adjacent peak.

Clearly the wavelength of the higher frequency wave is less than that of the lower frequency wave.



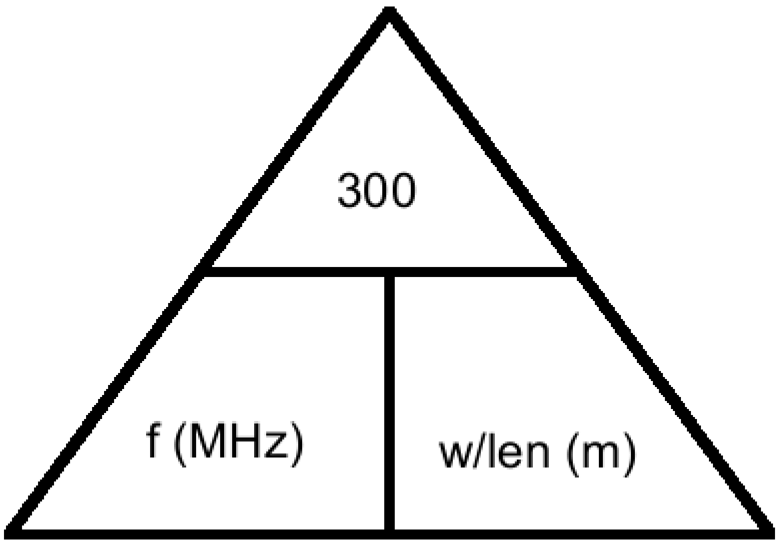
In fact radio waves as with all electro-magnetic waves have a relationship between their frequency and wavelength. This relationship is given by the formula:

$$v = f.\lambda$$

This says that the constant v is equal to the product of frequency and wavelength.

In the case of all electro-magnetic waves, including radio waves v is the speed of light in a vacuum, normally taken to be 300,000,000m/s (aprx 671,112,000 mph).

To aid remembering this a triangle similar to that used in Ohms Law is shown below:



This is used in exactly the same way as the triangles for Ohms Law and the Power Law. You will be asked to calculate either the frequency or the wavelength given the other term.

As an example or two:

A radio station is transmitting on 1500m, what frequency is it employing?

As we are trying to calculate frequency we cover the part of the triangle involving 'f'. This tells us that the formula we need to use is 300 divided by the wavelength in metres.

Thus, f = 300/1500 = 0.2MHz.

You will recall that 0.2Mhz is 0.2 million Hertz or 200,000Hz which would normally be expressed as 200kHz.

A signal is being received on 450MHz, what is it's wavelength?

This time the unknown quantity is the wavelength, so in the triangle we mask the wavelength and see that the formula we require is 300 divided by the frequency in MHz.

Thus, λ = 300/450 = 0.667m

this result could be approximated to 67cm.

Here's a few extras for you to try:

1. A transmitter is operating on a wavelength of 100m, what is it's frequency?
2. A receiver is picking up a signal with a frequency of 1.5MHz. What is the corresponding wavelength?
3. What is the wavelength of a signal at 10GHz. (Note watch out for the units of frequency)
4. What is the frequency of a signal on 40m?
5. What is the wavelength of a signal on 0.136MHz, and how long would a half wave dipole be for this band?

Next Lesson
Electromagnetic Compatibility (EMC)
Basics of EMC
Good Radio Housekeeping

Lesson 22 – Summary

At the end of this lesson you should be able to:

- Recall the basic structure of the ionosphere: D, E and F layers and their order.
- Understand that ionisation is cause mainly by ultra-violet rays from the sun.
- Remember that the level of ionisation changes with the time of day, the time of year, and according to the 11-year sunspot cycle.
- Understand that the sunspot number is an indicator of solar activity and that more sunspots give better HF propagation as a result of increased ionisation.
- Recall that reflection from the F layer is the main mode of HF propagation.
- Understand the meaning of ground wave, sky wave, skip distance and skip zone (dead zone).
- Recall that high atmospheric pressure can cause ducting in the troposphere, which increases the range of VHF and UHF signals.
- Recall that the range of VHF signals can occasionally be significantly increased by reflection from highly ionised areas in the E layer (Sporadic E).
- Recall that VHF and UHF signals normally pass trough the ionosphere, and at these frequencies propagation is within the troposphere situated below the ionosphere.
- Recall that snow, ice and heavy rain can attenuate signals at UHF and above.
- Recall and manipulate the formula $v = f \times \lambda$. Calculate frequency (f) or wavelength (λ) given the other parameter.
- For calculations, the velocity of radio waves will be given.