MARINE HIGH-FREQUENCY SINGLE SIDEBAND (HF/SSB) RADIO -- Part 5

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High Frequency (HF) Radio Propagation

Propagation Modes. Our familiar marine VHF/FM (very high frequency) radio waves propagate almost entirely in a straight line as a "direct wave", limited by line-of-sight distance to the horizon. High frequency waves have a much longer wavelength, which promotes two additional propagation modes: a "ground wave" and a "sky wave". The ground wave hugs the earth to travel well beyond the horizon. The sky wave refracts (reflects) in the earth's ionosphere, allowing it to travel thousands of miles around the world. Sometimes it even experiences a reflection from the earth's surface to provide a second hop. Approximate transmission distances for each mode are compared in Table 1.

Table l. Maximum Transmission Distances for Marine HF Band

Propagation Mode	**Transmission Distance** (miles)	
	Day	Night
Direct Wave	20	20
Ground Wave	50-100	200 or more
Sky Wave	250-1500	3000 or more

The Ionosphere. The ionosphere is the uppermost part of the earth's atmosphere.[1] The layers of the ionosphere exist at altitudes ranging from 30 to 250 miles above the earth's surface. They consist of gases containing atoms that have become electrically charged through the removal of an electron by solar radiation. This ionized region supports HF radio propagation to distant places on the earth. The ionosphere gradually refracts (bends) down radio waves traveling upward from the earth and returns some of them back to a distant point on the earth. To those of us on earth, the refraction of radio waves appears to be a simple reflection. During the daytime, the ionosphere has four layers: D, E, F_1, and F_2. At night the D and E layers dissipate, and the F_1 layer merges into the F_2, forming a single excellent refraction layer. Table 2 shows the altitudes of the several layers during day and night.

Table 2. Altitude of Ionospheric Layers above Earth

Ionospheric Layer	**Height above Earth's Surface** (miles)	
	Day	***Night***
D Layer	30-55	Disappears
E Layer	55-80	Disappears
F_1 Layer	100-130	Disappears
F_2 Layer	160-250	170-250

[1] USPS Marine Communication Systems Student Manual 2009, Chap. 2, pp. 12-14.

Not all radio waves are reflected by the ionosphere: There are upper and lower frequency bounds.[2] If the frequency is too high, the wave will pass directly through the ionosphere. If it is too low, the signal will be very weak, due to absorption in the D layer. The range of usable frequencies (lowest usable frequency to highest usable frequency) varies with the time of day, the seasons, the 11-year solar cycle, and the geographical locations of transmitter and receiver. The F_2 layer is the most important layer for HF radio propagation, because it is present day and night, and its high altitude allows the longest communication paths. The D layer does not reflect, but it absorbs or attenuates the radio waves passing through. D layer absorption is greater at lower frequencies, so it establishes the limit for the lowest usable frequency at a given time.

Sky Waves. Radio waves are electromagnetic waves. They will deflect in the presence of the electrical charges in the ionosphere, in much the same way that the flow of electrons in a conductor will deflect a magnetic compass needle or turn the rotor of an electric motor. Frequencies between about 3 MHz and 50 MHz will be refracted back to the earth's surface by the ionosphere. These refracted waves are called sky waves. The amount of bending decreases as frequency increases, so the wave will return to earth at a greater distance. The distance between the transmitter and the point where the sky wave returns to earth is called the "skip distance". If the ground wave does not propagate as far as the skip distance, there is a dead zone (called "skip zone") where no signal is received. These effects are shown in Figure 1.[3]

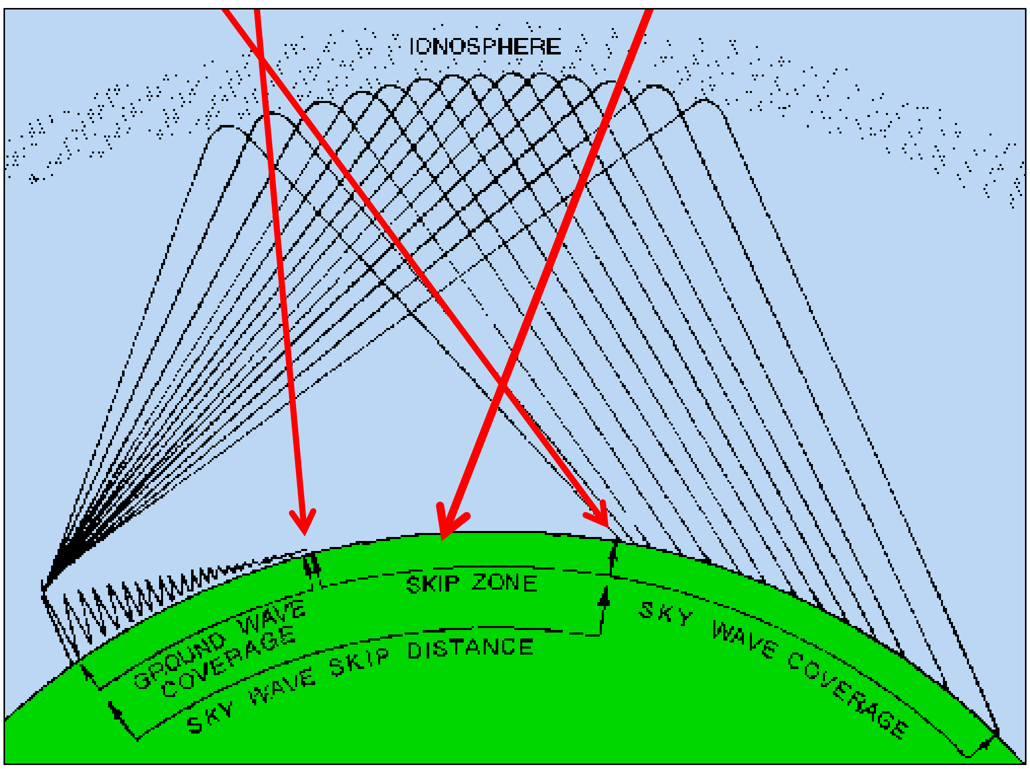

Figure 1. HF Ground Wave, Sky Waves, Skip Distance, and Skip Zone

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[2] www.ips.gov.au Australian IPS Radio and Space Services, "Introduction to HF Radio Propagation".
[3] USPS Marine Communication Systems Instructor Manual 2009, p. 12

Frequency Selection. Marine frequencies are located in narrow HF bands near 2, 4, 6, 8, 12, 16, 18, 22, and 25 MHz. Table 3 offers some general guidance for selecting a marine frequency band to communicate with a distant station.[4] Channel reciprocity usually applies: If you can hear them, they will probably be able to hear you transmitting on the same frequency.

Table 3. Recommended Frequency Band for Communicating with a Distant Station

Marine HF Band	**Typical Radio Ranges** (nm)	
Time of Day:	***Day***	***Night***
2 MHz	150	250
4, 6 MHz	200-250	150-1500
8 MHz	250-1500	400-3000
12, 16, 18, 22, 25 MHz	Thousands	Thousands

Computer Prediction Programs.[5] Personal computers with propagation prediction software can provide expert advice on selecting the best frequency for HF radio.

Inputs include: date, time of day, and distance and direction to desired destination.

- From the date: Sun cycle, seasonal variation, and sunspot variables are computed.
- From the time: Changes in ionospheric layer densities are computed.
- From the lat/long of the path ends: Path length and direction are computed.

Outputs suggest the best frequency. Three frequencies are given: MUF, LUF, and FOT.

- ***Maximum Usable Frequency*** (MUF) is the *highest* frequency that will reach the desired destination.

  Since the amount of bending decreases as frequency increases, waves at higher frequencies will return to earth beyond the desired destination, or could pass directly through the ionosphere into outer space.

- ***Lowest Usable Frequency*** (LUF) is the *lowest* frequency that will reach the destination.

  Waves at lower frequencies will not make it to the desired receiving station. They will return to earth short of the desired destination, or absorbed in the D layer.

- ***Frequency of Optimum Transmission*** (FOT) is the frequency lying between LUF and MUF with the highest probability of success in reaching the desired destination.

The radio operator should normally select a frequency in the Marine Radio Bands closest to the FOT. In addition to MUF, LUF, and FOT the computer program also provides path probability of success and other parameters. Output is usually displayed as a series of charts with time and frequency shown on the two axes. Several propagation software models are available. Two programs widely used by recreational boaters and amateur radio operators are: VOACAP, and ACE-F.

[4] USPS Marine Communication Systems Student Manual 2009, Chap. 7, p. 87

[5] *ibid*, Chap. 2, p. 14