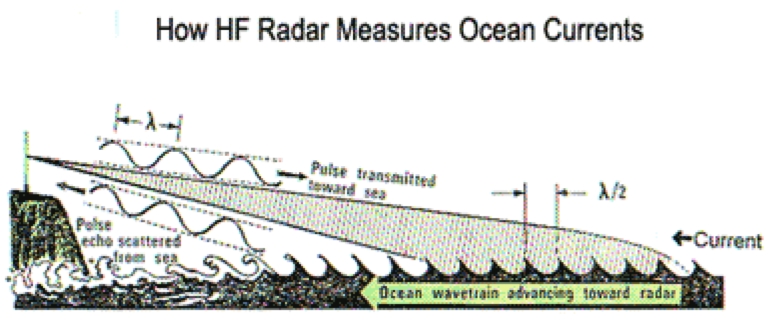
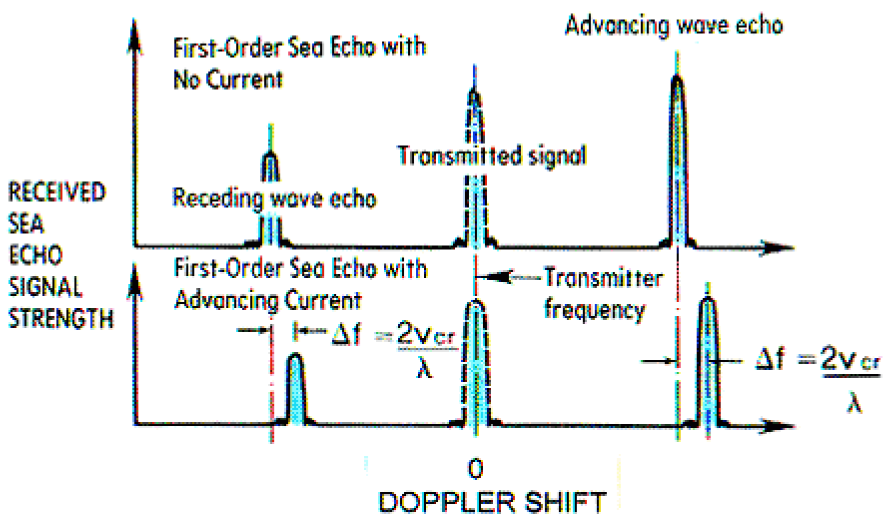
Principles of Operation

- Doppler Radar sends radio waves in the 10 to 50MHz band and listens to the scattered signal from the surface waves that have wavelengths in the 15 to 3m range
- System directly measures the speed of the waves that scatter the radar signal
- Differences between the measured speed and the known speed of the waves are the ocean surface currents





The Unique Nature of HF Radar

High-frequency (HF) radio formally spans the band 3-30 MHz (with wavelengths between 10 meters at the upper end and 100 meters at the lower end). For our radars, we extend the upper limit to 50 MHz. A vertically polarized HF signal is propagated at the electrically conductive ocean water surface, and can travel well beyond the line-of-sight, beyond which point more common microwave radars become blind. Rain or fog does not affect HF signals.

$$\lambda_w = \frac{\lambda_t}{2\cos(\theta)}$$

Where :

λ_w = *Wavelength of Surface Waves*

λ_t = *Wavelength of Transmitted Signal*

θ = *Incident* ∠ *of the Signal*

The ocean is a rough surface, with water waves of many different periods. When the radar signal hits ocean waves that are 3-50 meters long, that signal scatters in many directions. In this way, the surface can act like a large diffraction grating.

But, the radar signal will return directly to it's source only when the radar signal scatters off a wave that is exactly half the transmitted signal wavelength, AND that wave is traveling in a radial path either directly away from or towards the radar. The scattered radar electromagnetic waves add coherently resulting in a strong return of energy at a very precise wavelength. This is known as the Bragg principle, and the phenomenon 'Bragg scattering'. At the SeaSonde's HF/VHF frequencies (4-50 MHz), the periods of these Bragg scattering short ocean waves are between 1.5 and 5 seconds.

What makes HF RADAR particularly useful for current mapping is that the ocean waves associated with HF wavelengths are always present. The following chart shows three typical HF operating frequencies and the corresponding ocean wavelengths that produce Bragg scattering.

25 MHz transmission -> 12m EM wave -> 6m ocean wave
12 MHz transmission -> 25m EM wave -> 12.5m ocean wave
5 MHz transmission -> 60m EM wave -> 30m ocean wave

So far three facts about the Bragg wave are known: its wavelength, period, and travel direction. Because we know the wavelength of the wave, we also know it's speed very precisely from the deep water dispersion relation.

The returning signal exhibits a Doppler-frequency shift. In the absence of ocean currents, the Doppler frequency shift would always arrive at a known position in the frequency spectrum. But the observed Doppler-frequency shift does not match up exactly with the theoretical wave speed. The Doppler-frequency shift includes the theoretical speed of the speed of the wave PLUS the influence of the underlying ocean current on the wave velocity in a radial path (away from or towards the radar).

The effective depth of the ocean current influence on these waves depends upon the waves period or length. The current influencing the Bragg waves falls within the upper meter of the water column. So, once the known, theoretical wave speed is subtracted from the Doppler information, a radial velocity component of surface current is determined.

By looking at the same patch of water using radars located at two or more different viewing angles, the surface current radial velocity components can be summed to determine the total surface current velocity vector.Basic HF Radar for Current Mapping At a SeaSonde HF radar station there is one transmitting antenna and one receiving antenna unit. The antennas are connected to the radar transmit chassis and receive chassis, which are controlled by a small desktop computer.

The transmitting antenna is omni-directional, meaning that it radiates a signal in all directions. The receive antenna unit consists of three co-located antennas, oriented with respect to each other on the x, y, and z-axes (like the sensors on a pitch and roll buoy). It is able to receive and separate returning signals in all 360 degrees.

For mapping currents, the radar needs to determine three pieces of information:
1. Bearing of the scattering source (which we'll refer to as 'Target'),
2. Range of the Target, and
3. Speed of the Target

To determine bearing, range and speed of the Target, a time series of the received sea echo is processed.

The first determination is Range to target.
The distance to the patch of scatterers in any radar depends on the time delay of the scattered signal after transmission. The SeaSonde employs a unique, patented method of determining the range from this time delay. By modulating the transmitted signal with a swept-frequency signal and demodulating it properly in the receiver, the time delay is converted to a large-scale frequency shift in the echo signal. Therefore, the first digital spectral analysis of the signal extracts the range or distance to the sea-surface scatterers, and sorts it into range 'bins' (typically set to 32 bins, but capable up to 64 bins). In HF versions of the SeaSonde, these bins are typically set between 1 and 12 km in width. In the VHF version of the SeaSonde, these bins are typically set between 300 m and 1.5 km.

The second determination is Speed from Doppler of the target.
Information about the velocity of the scattering ocean waves (which includes speed contributions due to both current and wave motions) is obtained by a second spectral processing of the signals from each range bin, giving the Doppler-frequency shifts due to these motions. The length of the time series used for this spectral processing dictates the velocity resolution; at 12 MHz for a 256-second time-series sample, this corresponds to a velocity resolution ~4cm / s. (The velocity accuracy is a separate quantity; it can be better or worse than this depending on environmental factors.) The SeaSonde or any radar can measure only the velocity component from Doppler 'radial' to the radar from the target on the ocean, meaning that component pointing toward or away from the radar.

The third determination is the Bearing of the target.
After the range to scatterers and their radial speeds have been determined by the two spectral processing steps outlined above, the final step involves extraction of the bearing angle to the patch of scatterers. This is done for the echo at each spectral point (range and

speed) by using simultaneous data collected from the three colocated directional receive antennas. The complex voltages from these three antennas are put through a 'direction-finding' (DF)algorithm to get the bearing. The particular, patented algorithm adapted and perfected for the SeaSonde is referred to as MUSIC. At the end of these three signal-processing algorithms, surface-current radial speed maps are available in polar coordinates. That is, the radial speeds on the ocean are specified vs range and bearing about the origin, which is the radar site.

Radial data is produced at interfals varying between 18 minutes for the low-frequency systems to 4 minutes at the upper frequencies. These data are then averaged over a user-selected time period (typically an hour), to create a radial vector map at the radar station. A computer called the central data combining station, located at the users office, connects to the radar station computer at user-selectable time intervals, and retrieves the radial vector map data files.

From radial speed map to total surface current velocity vector map

Radial speed maps from each radar site alone are not a complete depiction of the surface current flow, which is two-dimensional. This is why at least two radars are normally used to construct a total vector from each site's radial components. At the central data combining station, the radial vector maps from multiple radar stations are merged to create a total velocity vector current map.