Basic Acoustic Theory

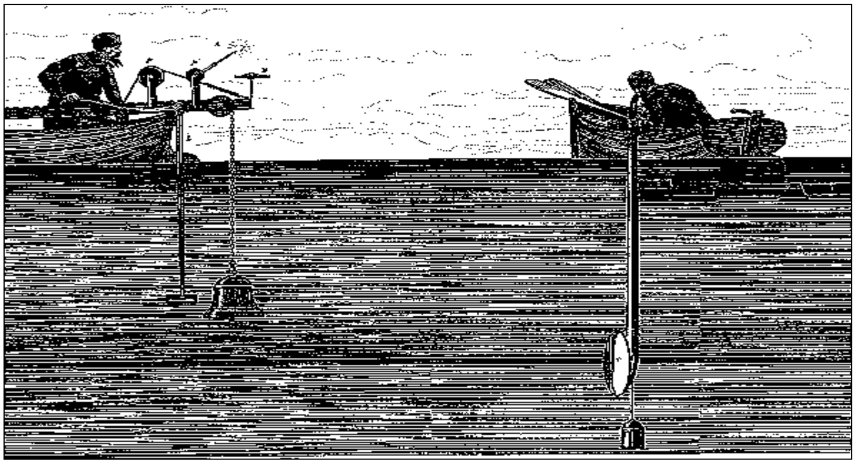

Figure 1: In 1822 Daniel Colloden used an underwater bell to calculate the speed of sound under water in Lake Geneva, Switzerland at 1435 m/Sec, which is very close to recent measurements.

1 Introduction

With multibeam, as with any echosounder, a main concern is: sound in water. Once the projector transmits the acoustic energy into the water, many factors influence that energy's velocity and coherence. The major influence is the velocity of sound in water.

1.1 Sound Velocity

The major influence on the propagation of acoustic energy is the sound velocity of the water column. As the acoustic pulse passes through the water column, the velocity of the wave front will vary based on the sound velocity; this is called refraction. If the sound velocity, through the water column, is not accounted for in the data collection software the depths will be in error. For this reason, sound velocity casts are an oft repeated routine during multibeam survey.

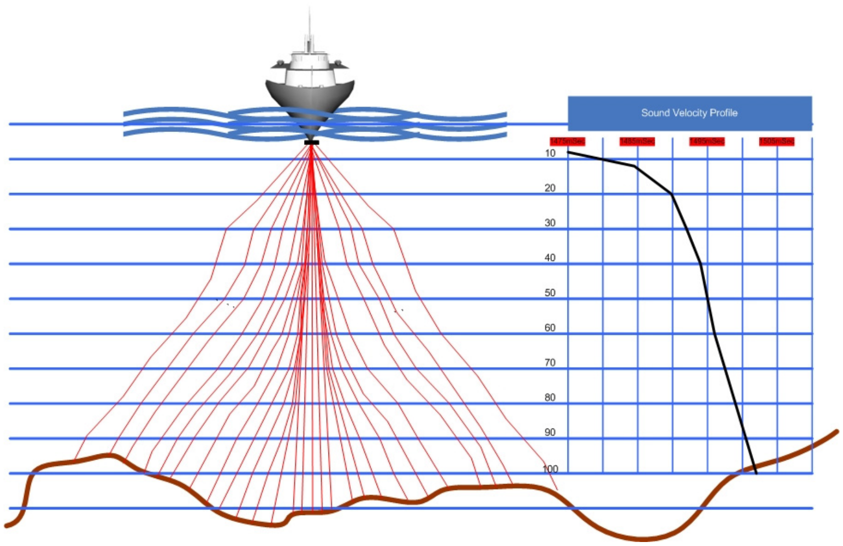

Figure 2: Concept of refraction due to different sound velocities in the water column

The velocity of sound in water varies both horizontally and vertically. It cannot be assumed that the velocity of sound in the water column remains constant over large areas or throughout the day in a more local area. The main influences on sound velocity are: Conductivity (salinity), Temperature and Depth (pressure).

1 ° C change in Temperature = 4.0 m/sec change in velocity
1 ppt change in Salinity = 1.4 m/sec change in velocity
100 m change in Depth (10 atm’s pressure) = 1.7 m/sec change in velocity

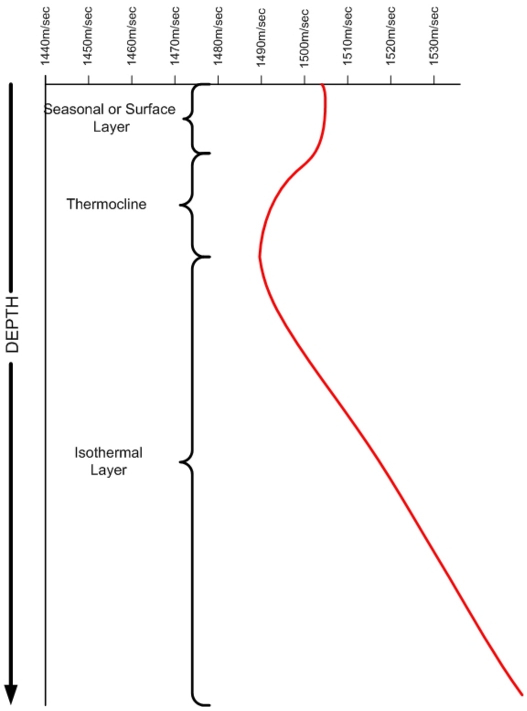

Figure 3: Sound velocity profile

1.1.1 Salinity

Generally, salinity ranges from 32 – 38 parts per thousand (ppt) in ocean water. A change in salinity will create density changes, which affect the velocity of sound. As a general rule, a change in salinity of only 1 ppt can cause a sound velocity change of 1.4m/sec. There are many influences on the salinity concentration in sea water.

1. Evaporation
2. Precipitation
3. Fresh water influx from rivers
4. Tidal effects (salt wedges)

1.1.2 Temperature

Temperature is the major influence on sound velocity in water. A 1°C change is equal to approximately a 4m/sec change in velocity. Once the upper layer is passed, the temperature normally decreases until pressure becomes the more dominating influence on the velocity of sound, which is approximately at 1000 metres. The normal influences on the temperature component of sound velocity include:

1. Solar heating
2. Night time cooling
3. Rain / run off
4. Upwelling

1.1.3 Refraction Errors

Refraction errors occur due to the wrong sound velocity profile being applied to the data. The error increases away from nadir and, as such, is more apparent in the outer beams. The visual effect is that the swath will curl up (smile) or curl down (frown). The actual representation is that the soundings are either too shallow or too deep.

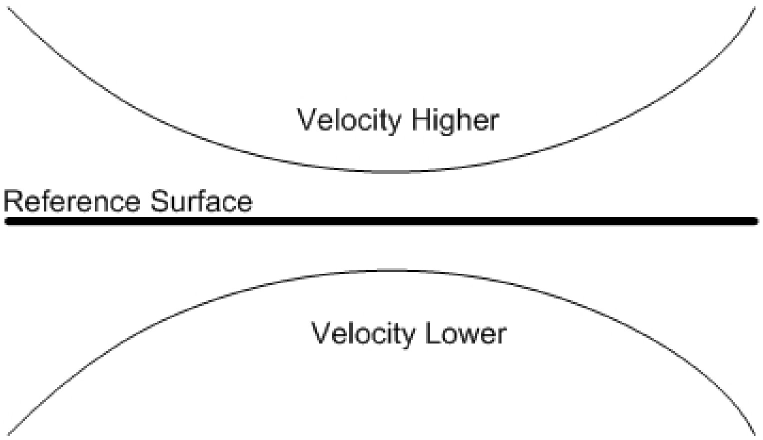

Figure 4: Refraction Error indication

At an angle of 45° in 10 meters of water, a ±10 meters per second velocity error will result in a depth error on the order of ± 4.6 cm.

- Convex (smiley face) = Sound velocity profile used higher than real profile
- Concave (frown face) = Sound velocity profile used lower than real profile

1.2 Transmission Losses

The transmission of an acoustic pulse is generally called a ‘ping’. When the projector sends out the acoustic pulse many factors operate on that pulse as it moves through the water column to the bottom and also on its return upward. The major influence of the water column sound velocity characteristics was detailed above; this affects the speed of transmission (and return). There are other influences that will affect acoustic energy in water and these are transmission losses.

1.2.1 Spreading Loss

Spreading loss does not represent a loss of energy, but refers to fact that the propagation of the acoustic pulse is such that the energy is simply spread over a progressively larger surface area, thus reducing its density. Spreading loss is not frequency dependent.

1.2.1.1 Spherical Spreading

Spherical spreading loss is the decrease in the source level if there are no boundaries (such as the water surface or sea floor) to influence the acoustic energy; all of the acoustic energy spreads out evenly, in all directions, from the source. The loss in intensity is proportional to the surface area of the sphere. The intensity decreases as the inverse square of the range for spherical spreading. With Spherical spreading, the transmission loss is given as: **TL = 20log(R)**, where R is range

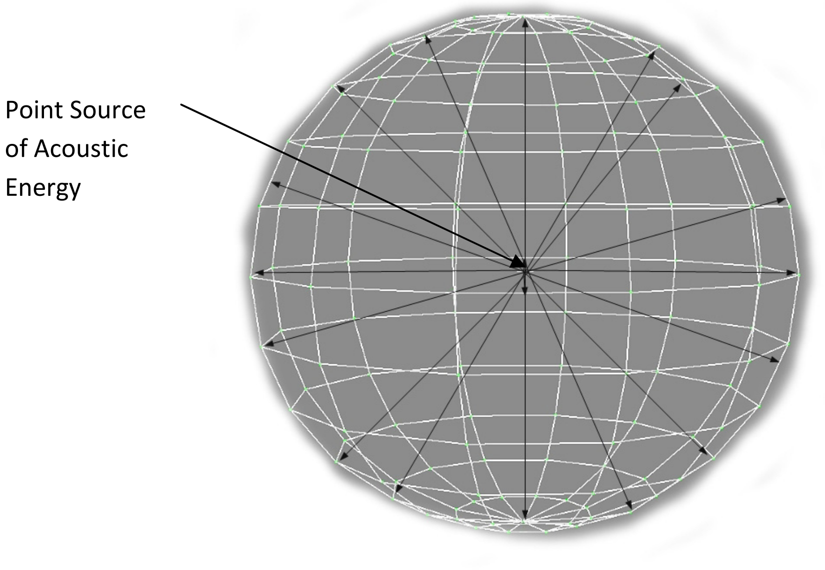

Figure 5: Concept of Spherical Spreading

1.2.1.2 Cylindrical Spreading

In reality the acoustic energy cannot propagate in all directions due to boundaries such as the sea floor and the water surface; this give rise to Cylindrical Spreading. Cylindrical spreading is when the acoustic energy encounters upper and lower boundaries and is ‘trapped’ within these boundaries; the sound energy begins to radiate more horizontally away from the source. With Cylindrical spreading the acoustic energy level decreases more slowly than with Spherical spreading. With Cylindrical spreading, the transmission loss is given as: **TL = 10log(R)**, where R is range.

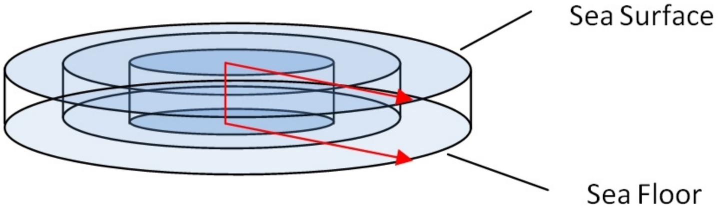

Figure 6: Concept of Cylindrical Spreading

1.2.2 Absorption

Absorption is frequency dependent and refers to the conversion of acoustic energy to heat when it strikes chemically distinct molecules in the water column. Magnesium Sulphate $MgSO_4$ predominates, with Boric Acid $B(OH)_3$ playing a major part at lower frequencies. Temperature is also an influence on absorption. Absorption is one of the key factors in the attenuation of the acoustic energy based on frequency; the higher the frequency, the greater the absorption. The higher the sonar operating frequency, the more rapid the vibration (or excitement) of the particles in the water and this leads to the greater transference of acoustic energy; thus, the attenuation of the acoustic wave. This is the reason why lower frequencies are used to obtain deeper data. At 400 kHz, the normal seawater absorption is approximately 100 dB/km, whereas at 200kHz the absorption is approximately 50 dB/km. These are values for normal sea water (with a salinity of 35 ppt). Fresh water has little, if any salinity (<0.5ppt), so absorption is considerably less.

The below table and charts illustrate how frequency, water temperature, and salinity affect absorption

Seawater Absorption Values: Salinity = 35ppt, pH=8[1] dB/km

	400kHz						200kHz				
Temp (C)	**5°**	**10°**	**15°**	**20°**	**25°**		**5°**	**10°**	**15°**	**20°**	**25°**
Depth (m)											
50	97	100	111	130	154		46	56	68	80	89
100	96	100	110	128	153		46	55	67	79	88
150	96	99	110	128	152		46	55	66	78	88
200	95	99	109	127	151		45	55	66	78	87
250	95	98	109	126	150		45	54	66	77	86
300	95	98	108	125	149		45	54	65	77	86
						400m	44	53	64	76	84
Mean Value	**96**	**99**	**110**	**127**	**152**		**45**	**55**	**66**	**78**	**87**

Freshwater Absorption Values: Salinity = 0.5ppt, pH=7 dB/km

	400kHz						200kHz				
Temp (C)	**5°**	**10°**	**15°**	**20°**	**25°**		**5°**	**10°**	**15°**	**20°**	**25°**
Depth (m)											
50	65	55	46	39	33		17	14	12	10	9
100	65	54	46	38	33		17	14	12	10	9
150	65	54	45	38	33		17	14	12	10	9
200	65	54	45	38	32		17	14	12	10	9
250	65	54	45	38	32		16	14	12	10	9
300	64	54	45	38	32		16	14	12	10	9
Mean Value	**65**	**54**	**45**	**38**	**33**		**17**	**14**	**12**	**10**	**9**

Table 1: Absorption Values for Seawater and Freshwater at 400 kHz and 200 kHz

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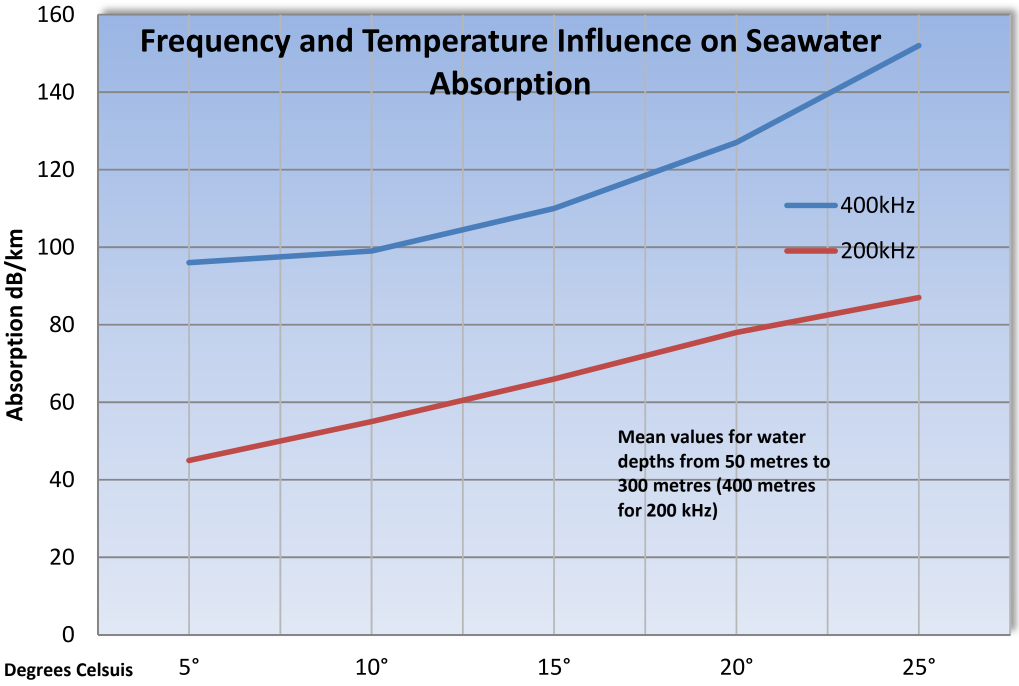
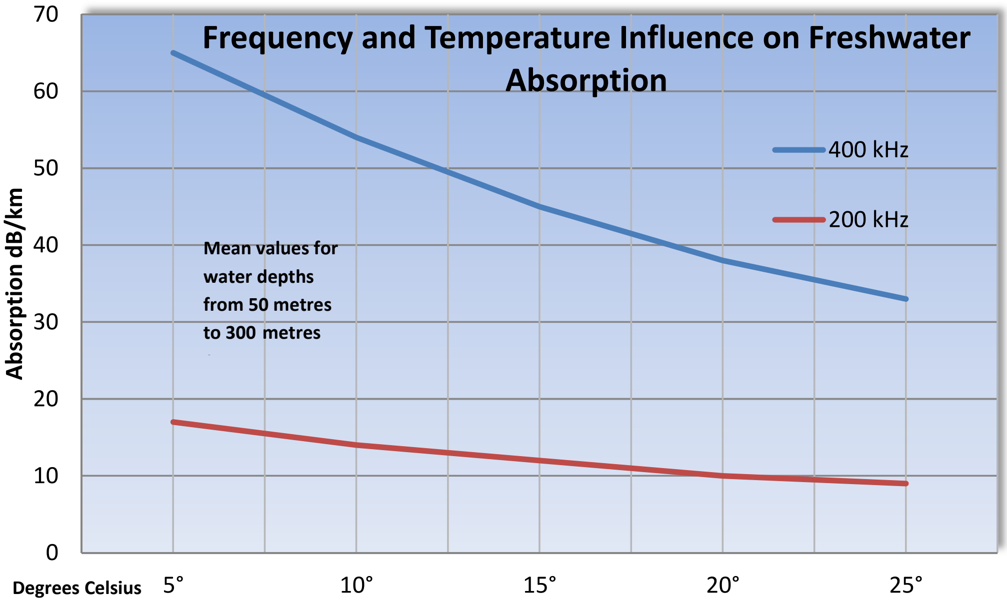
[1] Equation used for computation is from: Ainslie M.A., McColm J.G., "A simplified formula for viscous and chemical absorption in sea water", Journal of the Acoustic Society of America, 103(3), 1671-1672 as employed on the NPL website, op cit.

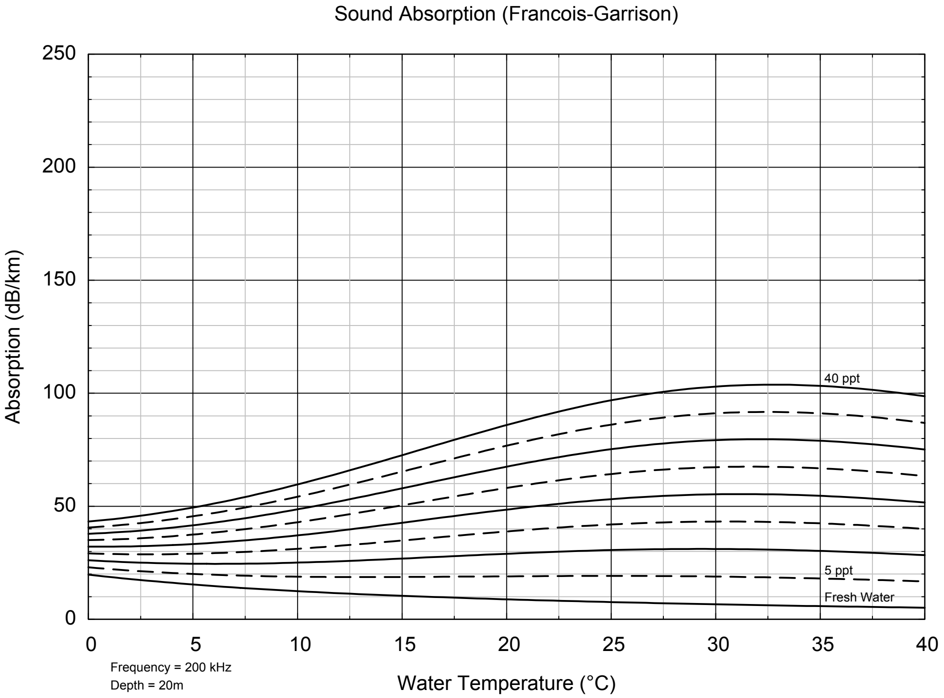


Graph 1: Seawater Absorption (Salinity 35ppt)

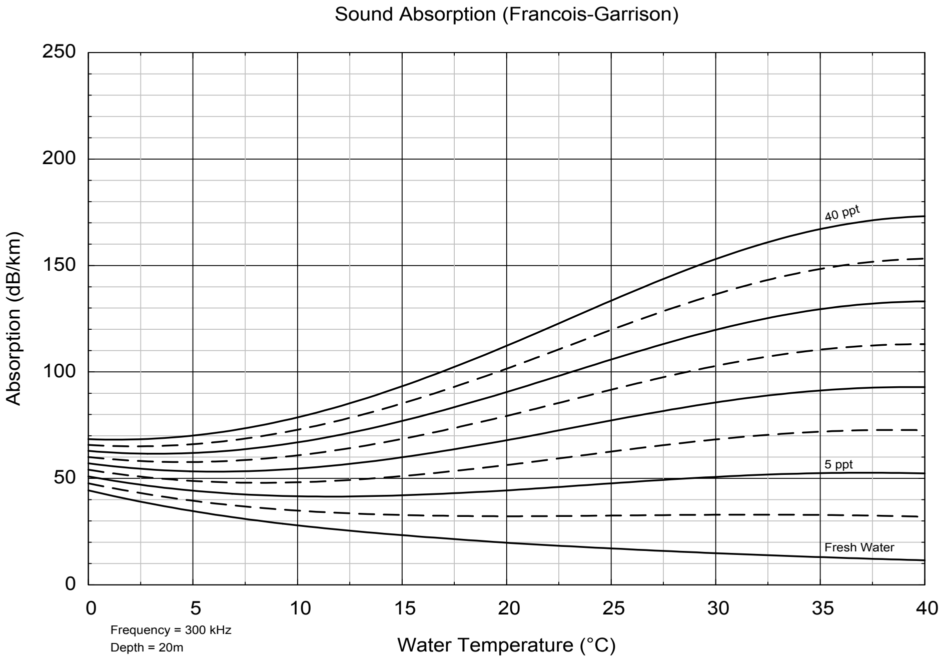


Graph 2: Freshwater Absorption

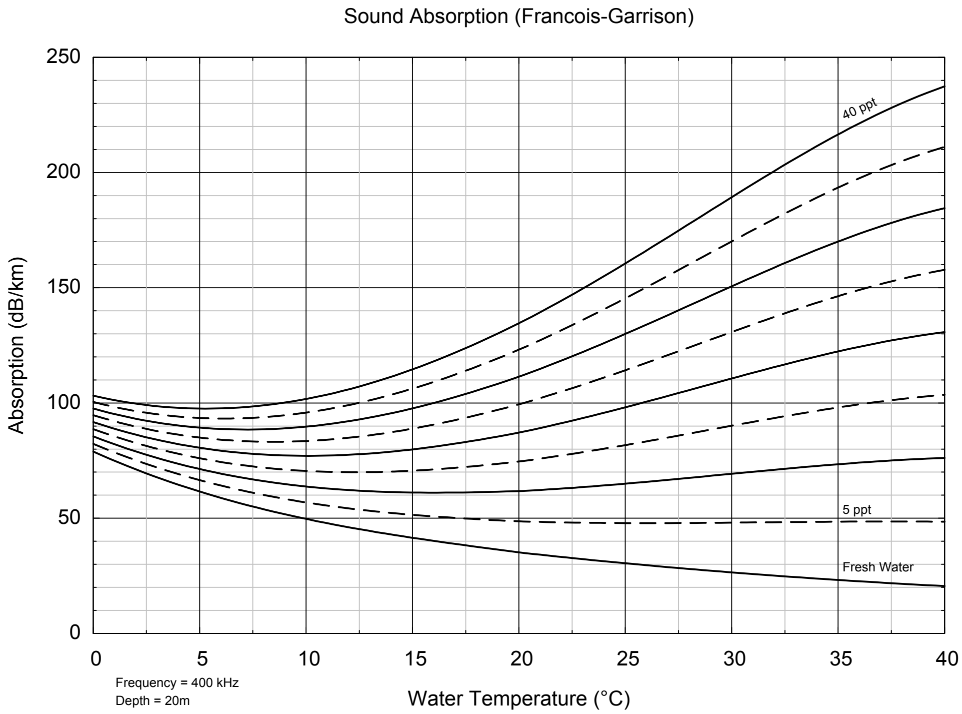
1.2.3 Sound Absorption Graphs at Select Frequencies



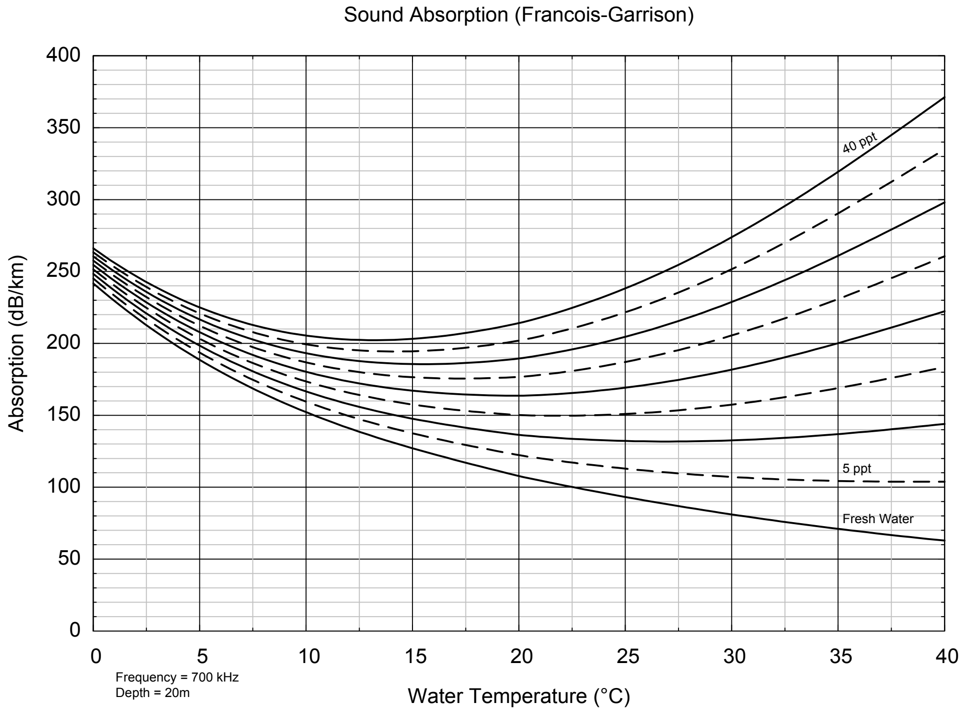
Graph 3: 200 kHz Sound Absorption



Graph 4: 300 kHz Sound Absorption



Graph 5: 400 kHz Sound Absorption



Graph 6: 700 kHz Sound Absorption

Seawater Absorption dB/km					
Freq.	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**
100	54	65	77	86	91
200	55	67	80	89	92
210	57	69	82	94	98
220	59	71	85	97	104
230	61	74	88	101	109
240	63	76	91	105	115
250	65	78	94	109	120
260	67	80	96	113	125
270	69	82	99	116	130
280	71	84	101	120	134
290	73	86	104	123	139
300	75	88	106	126	143
310	78	91	108	129	148
320	80	93	111	132	152
330	82	95	113	135	156
340	85	97	115	138	160
350	87	99	118	141	164
360	90	102	120	143	168
370	92	104	122	146	171
380	95	106	125	149	175
390	98	109	127	152	179
400	100	111	129	154	182
700	213	207[2]	214	235	270

Table 2: Operating Frequency - water temperature – absorption (@50m)

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[2] At 700 kHz, there is an absorption dip, in this temperature range

1.2.4 Reverberation and Scattering

The sea is not homogenous in nature. Everything from suspended dust particles to fish, from the sea surface to the sea floor will scatter, that is reradiate, the acoustic energy. All of the effects of individual scattering can be termed reverberation. The effect of reverberation is to lessen the acoustic energy and this leads to transmission losses.

Reverberation is divided into three main areas: sea surface reverberation, bottom reverberation, and volume reverberation (the body of water that the energy is passing through).

Both the sea surface and the sea bottom will reflect and scatter sound, thus affecting the propagation of sound. Sea surface scattering is influenced by how rough the sea is (which is related to wind velocity) and also the trapped air bubbles in the near surface region. The sea surface is also a good reflector of acoustic energy; this can lead to second and even tertiary bottom returns as the bottom return acoustic energy is reflected by the sea surface and is then reflected once more by the sea bottom.

In the case of the sea floor, the strength of the scattering depends on the type of bottom (composition and roughness), the grazing angle of the acoustic pulse and the operating frequency of the sonar.

There is also bottom absorption based on the sea floor terrain and composition. Bottom absorption is also dependent on the operating frequency of the sonar and the angle of incidence. Bottom absorption will be greater for a higher frequency and large angle of incidence. It is more or less intuitive that a mud bottom will absorb more of the acoustic energy than a rocky bottom. When the acoustic energy is absorbed it means there is less that will be reflected back to the Sonic 2024's receivers. The surveyor must be aware of the bottom composition as adjustments can be made to the Sonic 2024 operating parameters to help compensate for the bottom absorption.

In waters with a large sediment load, the suspended particles will scatter the sound wave, thus leading to transmission loss. In the scattering process, there is also a degree of energy that it is reflected (backscatter); this can be a cause for 'noise' in the sonar data. Again, the surveyor should be aware of this condition and, if need be, change the operating parameters of the Sonic 2024. When discussing the changing of the operating parameters, it is generally a matter of increasing transmit power or pulse length to get more total power into the water. In some circumstances, increasing the Absorption value will allow the system to rapidly increase gain to capture the reflected energy that has been dissipated by seafloor absorption or scattering in the water column.

As noted above many of the effects of absorption, scattering, and bottom absorption are frequency dependent. With the Sonic 2024, the operator can adjust the sonar frequency to optimise the system for the survey conditions. This will take some trial and error; however, lower frequencies tend to do best in areas of absorbent bottom and high sediment load (scatter).