FIELD SERVICE APPLICATION NOTE 010 (FSA-010)
USING WINDOWS ON SEA CHESTS FOR ADCPs MOUNTED ON VESSELS
1 NOVEMBER 2001

CONTENTS

I. Introduction – What is an Acoustic Window?

RD Instruments (RDI) builds Acoustic Doppler Current Profilers (ADCP) for use on vessels. Installation of an ADCP in a vessel is done in many ways, but typically the ADCP transducer is mounted inside of a sea chest or well. The opening of the sea chest or well can be open to the ocean or it can be covered by an *acoustic window*.

An acoustic window is a covering that can seal the opening of the sea chest but still allow the acoustic signal (both transmit and received signals) to be transferred through the window. The type, thickness, orientation, and other installation issues of the acoustic window are important to understand. If the wrong material is used or the wrong installation used then the performance obtained by the ADCP will be severely limited.

II. Background - Should I use an Acoustic Window?

Like any vessel-mount, acoustic system, the performance of the ADCP is sensitive to acoustic noise. For best performance, the transducer is mounted in its own well, recessed in the vessel hull, with an opening slightly larger than the transducer. An Acoustic Window, mounted across the well opening, is required to isolate the transducer face from flow noise, as the vessel moves through the water. Acoustic windows (or simply windows) can produce overall performance improvements in vessel-mounted ADCPs through the following advantages.

ADVANTAGES

- Well will not fill with air bubbles caused by the ship moving through the surface water.
- Flow noise is reduced.
- The well can be filled with fresh water to limit corrosion.
- Barnacles cannot grow on the transducer faces. Barnacle growth is the number one cause of failure of the transducer beams.
- The transducer is protected from debris floating in the water.

Although these advantages are important, it should be known that if the wrong window is used or if the window is not installed properly then the following disadvantages are possible.

DISADVANTAGES

- The range of the ADCP can be reduced because the window will absorb some of the transmit and receive energy.
- The transmit signal could be reflected into the well, causing the well to “ring” like a bell. This will cause the data being collected during the ringing to be biased. Some ships have reported a loss in range as great as 50 meters. Applying sound absorbing material on the well walls may dampen the ringing.
- The transmit signal could be reflected off of the window and back into the other beams.

However, even though there are disadvantages possible our experience has shown that when the correct window is used and it is properly installed that the window advantages are far more important. The remainder of this Application Note will focus on how to choose the window for your vessel, how to mount the window, how to maintain the window, and any other associated concerns when using a window.

III. What Window should I use?

While we cannot claim to understand every window, we do believe that we can recommend a material that will work. We have developed a simple model for an acoustic window made from polycarbonate material. Over the past 2 decades we have obtained feed back from customers that has allowed us to prove the model is a fair estimation of what to expect for performance. Polycarbonate was chosen because it can provide enough strength for most installations, is readily available in most countries, it has been shown to last a long time (over 7 years in some installations), and it can be used on all ADCP models (NarrowBand *(NB)*, BroadBand *(BB)*, WorkHorse *(WH)*, and Ocean Surveyor *(OS)*).

The type of ADCP model is very important when choosing a window. The bandwidth of the acoustic signal from the ADCP must be maintained. Different window materials have different losses over a band of frequencies. As an example, the OS ADCP uses a bandwidth of 6% or 1% about the system's center frequency. A BB or WH ADCP uses a bandwidth of 25% or 6% about the system's center frequency. The material polycarbonate has a fairly uniform loss about these frequency bandwidths.

It should be noted that we have no knowledge about the variability of polycarbonates. And so, the acoustic model that we run is for a particular polycarbonate manufactured by Zelux. This is a window-grade, polycarbonate and has a high tensile strength (~9000psi) to resist cracking.

Even when choosing this particular window it is important to choose the proper thickness of window material. A window will absorb sound and reduce the range of the ADCP. Therefore, we always recommend using the thinnest window possible. However, depending on your application a thicker material may be necessary. The following table indicates the expected loss (two-way) of polycarbonate at different frequencies and thickness.

Frequency (kHz)	Thickness mm (in.)	One-way loss @ 0°,20°,40°C (dB)			Two-way loss @ 0°,20°,40°C (dB)			Expected Loss in Range (meters)
38	76.2 (~3.0)	2.7	2.6	2.3	5.4	5.2	4.6	173
38	63.5 (~2.5)	3.0	2.9	2.5	6.0	5.8	5.0	192
38	50.8 (~2.0)	2.9	3.2	2.9	5.8	6.4	5.8	205
38	***38.1 (~1.5)***	***1.4***	***1.2***	***1.0***	***2.8***	***2.4***	***2.0***	***90***
38	25.4 (~1.0)	2.9	3.3	3.3	5.8	6.6	6.6	211
38	**19.1 (~0.75)**	**1.0**	**0.9**	**0.8**	**2.0**	**1.8**	**1.6**	**64**
38	12.7 (~0.5)	5.3	5.8	5.6	10.6	11.6	10.2	371
38	9.5 (~0.375)	1.8	1.8	1.8	3.6	3.6	3.6	115
38	6.4 (~0.25)	0.7	0.7	0.6	1.4	1.4	1.2	45
75	76.2 (~3.0)	4.2	4.3	3.8	8.4	8.6	7.6	138
75	63.5 (~2.5)	3.9	4.0	3.5	7.8	8.0	7.0	128
75	50.8 (~2.0)	3.6	3.6	3.0	7.2	7.2	6.0	115
75	38.1 (~1.5)	2.7	2.6	2.3	5.4	5.2	4.6	83
75	25.4 (~1.0)	3.1	3.3	2.9	6.2	6.6	5.8	106
75	***19.1 (~0.75)***	***1.4***	***1.2***	***1.0***	***2.8***	***2.4***	***2.0***	***45***
75	12.7 (~0.5)	3.1	3.5	3.3	6.2	7.0	6.6	112
75	**9.5 (~0.375)**	**1.0**	**0.8**	**0.7**	**2.0**	**1.6**	**1.4**	**32**
75	6.4 (~0.25)	5.9	6.3	5.5	11.8	12.6	11.0	202
150	50.8 (~2.0)	5.0	5.2	4.6	10.0	10.4	9.2	83
150	38.1 (~1.5)	4.2	4.4	3.8	8.4	8.8	7.6	70
150	25.4 (~1.0)	3.6	3.6	3.0	7.2	7.2	6.0	58
150	***19.1 (~0.75)***	***2.7***	***2.6***	***2.3***	***5.4***	***5.2***	***4.6***	***43***
150	12.7 (~0.5)	3.1	3.3	2.9	6.2	6.6	5.8	53
150	**9.5 (~0.375)**	**1.4**	**1.2**	**1.0**	**2.8**	**2.4**	**2.0**	**22**
150	6.4 (~0.25)	3.2	3.6	3.3	6.4	7.2	6.6	58
300	25.4 (~1.0)	5.0	5.2	4.5	10.0	10.4	9.0	42
300	19.1 (~0.75)	4.2	4.3	3.8	8.4	8.6	7.6	34
300	12.7 (~0.5)	3.6	3.6	3.0	7.2	7.2	6.0	29
300	***9.5 (~0.375)***	***2.7***	***2.6***	***2.3***	***5.4***	***5.2***	***4.6***	***22***
300	6.4 (~0.25)	2.9	3.4	3.2	5.8	6.8	6.4	27

Table 1 – Expected Loss for ADCPs with 30Degree Beam Angle

RDI's recommended thickness is in **bold**. RDI's recommended maximum thickness is in ***italic and bold*** in the above table. All other items will result in poor overall performance or a loss in range that most customers find unreasonable.

One-way insertion loss curves for all items above in **bold** (RDI's recommended thickness) are found in Appendix A of this application note. All other plots are available from RDI upon request.

Note all of the losses and expected ranges are estimated and some of the assumptions we make may not be true in your installation. However, based on several actual installations the values shown have proven to be good estimations. Your actual loss may be higher or lower than what is shown.

Frequency (kHz)	Thickness mm (in.)	One-way loss @ 0°,20°,40°C (dB)			Two-way loss @ 0°,20°,40°C (dB)			Expected Loss in Range (meters)
38	76.2 (~3.0)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	63.5 (~2.5)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	50.8 (~2.0)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	***38.1 (~1.5)***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***	***N/A***
38	25.4 (~1.0)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	**19.1 (~0.75)**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
38	12.7 (~0.5)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	9.5 (~0.375)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
38	6.4 (~0.25)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
75	76.2 (~3.0)	3.1	3.2	2.8	6.2	6.4	5.6	102
75	63.5 (~2.5)	2.7	2.8	2.6	5.4	5.6	5.2	90
75	50.8 (~2.0)	2.6	2.6	2.3	5.2	5.2	5.6	90
75	38.1 (~1.5)	2.0	2.0	1.8	4.0	4.0	3.6	64
75	25.4 (~1.0)	2.2	2.1	1.8	4.4	4.2	3.6	70
75	***19.1 (~0.75)***	***0.9***	***0.9***	***1.0***	***1.8***	***1.8***	***2.0***	***32***
75	12.7 (~0.5)	2.8	2.9	2.4	5.6	5.8	5.4	93
75	**9.5 (~0.375)**	**1.0**	**0.9**	**0.8**	**2.0**	**1.8**	**1.6**	**32**
75	6.4 (~0.25)	4.2	3.7	2.7	8.4	7.4	5.4	134
150	50.8 (~2.0)	3.6	3.8	3.4	7.2	7.6	6.8	61
150	38.1 (~1.5)	3.1	3.2	2.8	6.2	6.4	5.6	51
150	25.4 (~1.0)	2.6	2.6	2.3	5.2	5.2	4.6	42
150	***19.1 (~0.75)***	***2.0***	***2.0***	***1.8***	***4.0***	***4.0***	***3.6***	***32***
150	12.7 (~0.5)	2.2	2.1	1.8	4.4	4.2	3.6	35
150	**9.5 (~0.375)**	**0.9**	**0.9**	**0.9**	**1.8**	**1.8**	**1.8**	**14**
150	6.4 (~0.25)	2.9	2.9	2.3	5.8	5.8	5.6	46
300	25.4 (~1.0)	3.6	3.8	3.4	7.2	7.6	6.8	30
300	19.1 (~0.75)	3.1	3.2	2.8	6.2	6.4	5.6	26
300	12.7 (~0.5)	2.6	2.6	2.3	5.2	5.2	4.6	21
300	***9.5 (~0.375)***	***2.0***	***2.0***	***1.8***	***4.0***	***4.0***	***3.6***	***16***
300	6.4 (~0.25)	2.2	2.1	1.8	4.4	4.2	3.6	18

Table 2 – Expected Loss for ADCPs with 20Degree Beam Angle

RDI’s recommended thickness is in **bold**. RDI’s recommended maximum thickness is in ***italic and bold*** in the above table. All other items will result in poor overall performance or a loss in range that most customers find unreasonable.

One-way insertion loss curves for all items above in **bold** (RDI’s recommended thickness) are found in Appendix A of this application note. All other plots are available from RDI upon request.

Note all of the losses and expected ranges are estimated and some of the assumptions we make may not be true in your installation. However, based on several actual installations the values shown have proven to be good estimations. Your actual loss may be higher or lower than what is shown.

IV. Are there any other windows that I can consider?

RDI has only limited experience with other materials. As a result there is not much information we can provide about other materials. However, we can state that different materials will behave differently, depending on both the frequency and bandwidth of the acoustic ADCP signal. The absorption curves of various materials have significant amplitude fluctuations with frequency, which can change in both frequency and amplitude with changes in temperature.

Important acoustic properties of the window include acoustic refractive index (which should be as close as possible to that of water), insertion loss (which should be as small as possible) and speed of sound. There are two acoustic refractive indices: one for shear waves and one for plane waves. The acoustic refractive indices are simply the ratios of speed of sound in water to speed of sounds in the material. Insertion loss combines absorption and reflection of sound, and it depends on both the thickness and the material properties of the window. In particular, you should avoid using window thickness equal to odd multiples of shear mode quarter-waves (Dubbelday and Rittenmeyer, 1987; Dubbleday, 1986). Refer to Selfridge (1985) and Thompson (1990) for more information. Note that the speeds of sound in plastics decrease with increasing temperature and that causes the resonant frequencies to shift. This can be a large effect. Neither Selfridge nor Thompson has much information on the temperature coefficients of sound speeds.

The life of the material must also be considered as well as its overall strength. We have had customers design their own windows out of Kevlar. They required Kevlar because they required a material that was very strong both for temperature and for strength against heavy seas, objects in the water, and striking the bottom or ice. Kevlar can provide this strength without having to be very thick thus minimizing loss.

Kevlar windows have been successfully built and used by 2 different institutes (Monterey Bay Aquarium Research Institute (MBARI) in the United States, and the Institut National des Sciences de l'Univers (INSU) in France. The procedure to build the window is not known by RDI. The properties of the Kevlar windows are not well understood and so a lot of experimentation with different thickness windows was required before these customers were satisfied with the Kevlar window.

INSU used a graduate student, Roche Frederic in 1997, to perform a study to determine the best thickness and composite of Kevlar to provide a window for a BB VM150kHz ADCP. The report states that the material KEVLAR K49 made with Resine Vinylester ATLAC 580 was used. The following French company produced this material:

Brest-Composite Industrie
124 Rue Auatole Frauce
29200 – Brest, France
Tel: 02-98-05-19-09
Fax: 02-98-34-06-02

RDI only knows that this single window was produced for INSU and does not know of any others who are using this material. It is RDI's understanding that the above mentioned company can produce the Kevlar window but cannot give the acoustic properties required to determine the losses through the window. Contacting this company is done with the knowledge that RDI is not recommending them, but only offering this as a source for the material.

V. What are the acoustic window installation considerations?

In Section 3 we provided the recommended window material and thickness. In this section we will provide installation recommendations. Installation of the window must be done properly so that the best performance is possible. The following discussion is broken into sections so that each point can be considered individually.

A. What should the window shape be?

The window should be smooth without cracks or deformities. Typically the window is round and of a diameter that is large enough to clear all 4 beams. To determine the proper diameter of the window see the RDI Document *Conceptual Transducer Well Design Rev5.Doc.*

The acoustic window should be flat and parallel to the transducer mounting plate. This will result in a constant angle of 20 or 30 degrees (depending on the transducer beam angle) to the transducer on both the inside and outside window face.

Dome shaped windows have been used successfully. However, if the water temperatures inside the window and outside the window are not the same, all four beams will be refracted and actual velocity components will be rotated into a new coordinate system. In particular, some of the horizontal velocity will appear as a vertical velocity.

B. Can I add strengthening to the window?

Adding a strengthening member across the window is not recommended because this can cause similar behavior as a cracked window (see Section VII-B for more information) or can actually block the acoustic transmit and receive signals.

C. How do I secure the window to the well opening?

We recommend that a steel ring around the outside of the window be used because you do not want the screw heads to come in direct contact with the window material as it may crack under the strain.

It is recommended that window be designed so that the ring will sit flush with the entire window face as shown in the Figure 1. Flat headed bolts or recessed bolts should be used. All of these will maintain a smooth surface around the entire window and will prevent any chance for cavitation (see Section VII-B for more information).

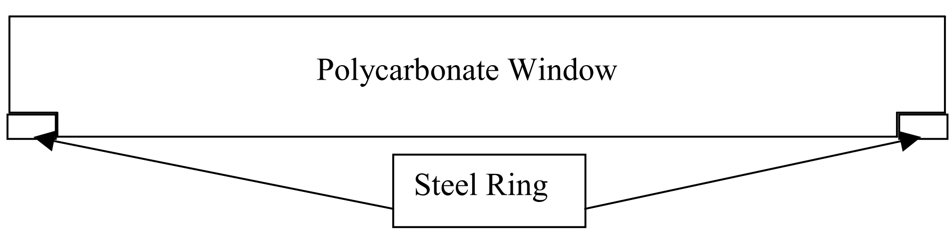


Fig 1 – Conceptual drawing of acoustic window with mounting ring.

Do not thread the polycarbonate window. Use bolt through holes spaced evenly around the window. The number of bolt through holes (typically 16-24 holes) should be enough to prevent leakage and will provide equal pressure on the window to prevent cracking. The bolt circle should be located a distance from the edge of the window that is a minimum of twice the diameter of the bolt through holes, see Figure 2.

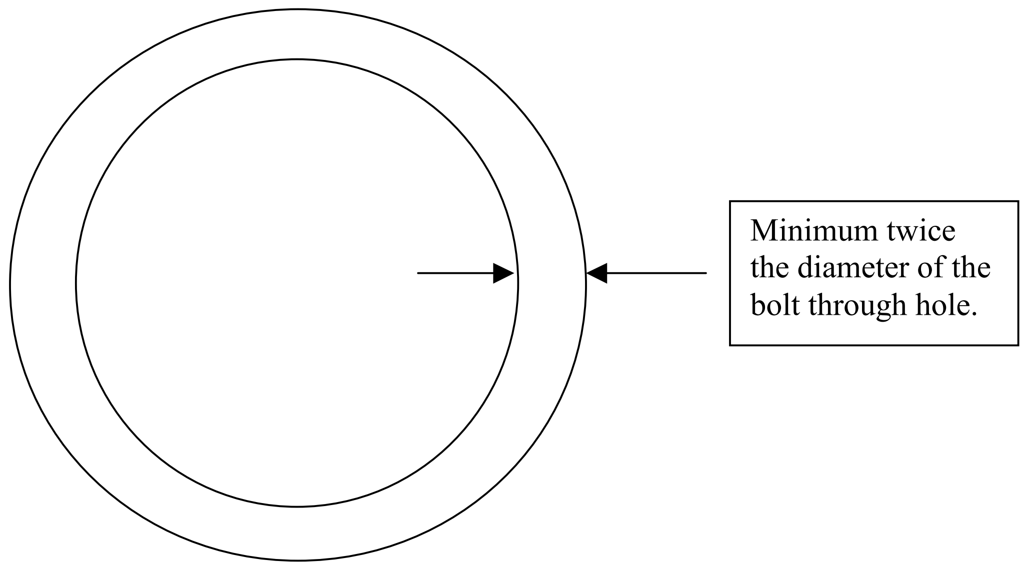


Fig 2 – Location of the Window Bolt Hole Circle Diameter.

D. How do prevent the window from cracking when going into dry dock?

Using as thin a window as possible may mean that the window will not be able to support the water inside the sea chest when the vessel goes into dry dock. This means that you must either be sure to have a way to drain the sea chest prior to going into dry dock or allow a way for the water to drain out of the sea chest during dry dock. The former must be done as part of the sea chest design and the latter can be accomplished by placing holes in the window face.

The holes in the window face will allow water to freely flow in and out of the well. However, drilling holes in the window will increase your chances of flow noise, air bubbles in sea chest, corrosion, bio-fouling, and will make the sea chest non-hydrostatic. The bio-fouling will require that you have regular transducer inspections and cleanings. If you make the sea chest non-hydrostatic then in heavy seas the window can crack as it flexes from wave slamming. Dave Taylor Model Basin has measured slamming pressures as high as 300 psi with durations of a few milliseconds. If the sea chest behind the window is hydrostatic, no pressure gradient will exist across the window and no substantial deflections will occur.

With those considerations in mind you may still want to drill holes in the window. If you drill holes in the window then you must make sure that they are outside of the acoustic beam pattern of the beams, see Figure 3. As long as the holes remain outside of the beams they can be as large as is required to prevent the window from flexing when in heavy seas.

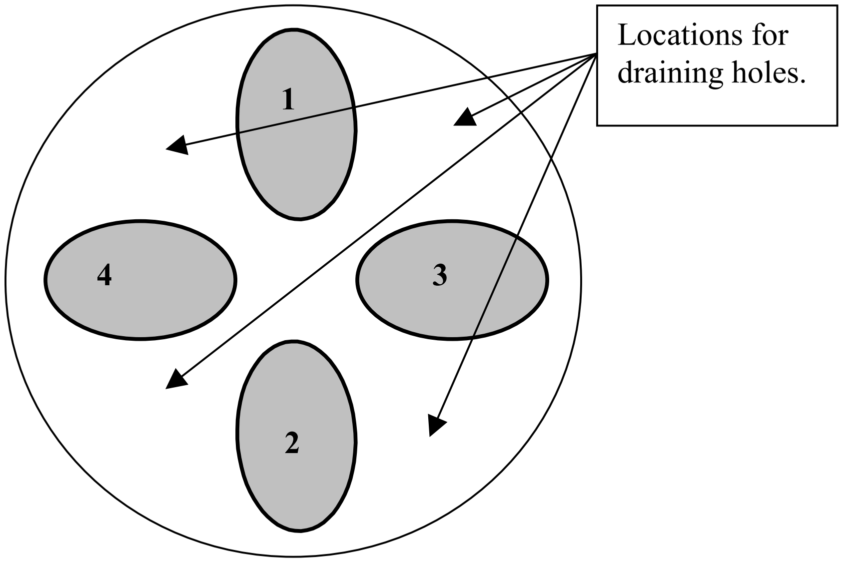


Fig 3 – Draining holes locations around beams 1-4 intersection with the window.

E. How much space should I have between the window and transducer?
Never allow the transducer to touch the window. Separation is good for reducing the strength of the multipole fields of flow noise. However, we must limit the separation to prevent the reflection of a beam off of the window into another beam. This causes cross talk between the beams.

Therefore, with all ADCP models and frequencies the recommended distance between the transducer and the inside face of the window should be between 6.4mm to 12.7mm. This will ensure that there is no cross talk between beams and will provide adequate spacing to reduce flow noise. See the RDI Document *Conceptual Transducer Well Design Rev5.Doc.* for more sea chest design issues.

VI. What other issues should be considered when using an acoustic window?

Once you decide to use a window there are many issues that no longer are a worry but there other new things you do need to worry about. This section will outline each of these items and the issues related to them.

A. What fluid should I fill the sea chest with?

If you have not placed holes in the window and you are not going to work in an area where freezing is an issue then the sea chest should be filled with fresh water. Fresh water decreases the issues of corrosion in the sea chest. If you will be in an area where freezing of fresh water would be an issue then seawater can be used.

Some users have placed ethylene glycol into the fresh water well to prevent freezing. Although this will not harm the transducers you will have to perform post processing on the data sets from the NB, BB, and WH ADCPs (this issue is not present for the OS ADCP). The NB, BB, and WH ADCPs must have the velocity data scaled properly based on the speed of sound in the sea chest. Ethylene glycol causes the water to have an inverted speed of sound change to that of fresh water or salt water. This means that RDI's standard software programs will not be scale the data properly. You will have to record separately the speed of sound in the sea chest and then in post processing correct the ADCP velocity data appropriately. However,

B. How much fluid should I use in the sea chest?

The transducers must be completely immersed in water. No air should be in front of the transducers and the pressure within the sea chest should be adjusted to keep the window from bowing in and out, and thereafter, the volume should be kept constant.

C. Should I use absorption material when using a window?

The window causes some of the transmit signal to reflect back into the well due to the difference in impedance between the window and the water. When the transmit signal is reflected in the well it becomes trapped and this results in what is called ringing. To keep from processing this signal, the blanking of the ADCP will have to be increased.

However, in extreme cases, ringing can last a period that will cause the first 50-100 meters of data to be unusable. Therefore, a sound absorbing material should be used inside the sea chest to minimize the effects of sound ringing within the sea chest. The material should be a minimum of one wavelength thick (include the sound speed of the absorbing material when calculating the size of a wavelength). Approximate wavelengths of sound in seawater are given below in Table 2. Using standard neoprene wet suit material has been found to work well with 75 and 150hKz frequency ADCPs.

Frequency (kHz)	Wavelength (mm)
38	40
75	20
150	10
300	5

Table 3: Wavelength of sound in seawater (1500 m/s sound speed)

D. Do I need to worry about corrosion when using a window?

Corrosion is always possible. However, our transducers are made of a material that has shown to corrode very little over time when the above precautions are met. There is nothing that you can do to protect the transducer from corrosion. However, if the well is covered with a window and then filled with fresh water corrosion is can be further minimized. You should inspect the transducer regularly for signs of corrosion.

Note, never attach any anodes directly to the transducer head. Additional anodes or impressed voltage systems can cause the urethane to separate from the transducer (cathodic disbondment) or cause the material of the transducer to break down. Standard anode protection used for the ship should be installed outside of the well of the transducer head. Mounting of ship's standard anode protection outside of the transducer well will typically not cause any problems.

E. Do I need to worry about air bubbles when using a window?

All vessels create air bubbles in the water as the ship moves through the water. Ships with a deep draft or a non-flat bottom have fewer problems with bubbles. If you are using a window these bubbles will still be present. If the window is sealed then this air will not fill the sea chest. However, if the window is not sealed then air can fill the sea chest. You must make sure to vent air from the sea chest periodically if there is a possibility that air will become trapped in your sea chest.

To avoid air bubbles from getting into the front of the window you should mount the transducers below or away from the bubble layer. The flow layer is usually within the first two feet below the hull. Bubbles can be trapped in this layer. Mounting the transducer head amid ship on the fore-to-aft centerline may help. Another technique is to divert the bubble layer so it flows around the transducers. A fairing around the sea chest can help with this, but care must be taken so that you do not cause cavitation.

F. Do windows improve flow noise problems?

Water flowing over the transducer faces increases the acoustic noise level, which decreases the profiling range of the ADCP. A window reduces the coupling of flow noise to the transducer. This is because of the gap filled with fluid between the inside of the window face and the transducer faces attenuates the flow noise. By reducing flow noise you are increasing the signal to noise ratio. The higher the signal to noise ratio the better the stronger the returned signal will appear. This will result in better data reception and longer ranges.

VII. What maintenance is required when using windows?

In general, a window provides protection to the transducer from the most common sources of problems such as bio-fouling and corrosion. However, the window can still become covered with bio-fouling or could become damaged. The following section discusses these issues.

A. How often should I inspect the window?

Since growth of mussels, barnacles, and other bio-fouling occurs on all vessels the window should be inspected and cleaned by divers on a regular interval. This interval should be often enough to prevent the growth of anything on the window and to allow inspection for damage to the window. It is recommended that this interval be at least once per year, but may be required more often in areas that have heavy bio-fouling growth.

When inspecting the window you should inspect for bio-fouling growth, cracks, damage, for air pockets, and for mud on the inside of the window. We have seen cases where the inside of the well became filled with mud. The mud entered through a crack in the window and where the holes were drilled in the window. Bio-fouling should be cleaned off, air should be purged from the sea chest, and mud should be removed from the sea chest.

B. If I find that the window is damaged can I keep operating the ADCP?

In general, any window that is cracked or is damaged so that it is not smooth should be replaced as soon as possible.

A window that is damaged causes a problem with the acoustic transmission. The exact problem or problems seen because of this damage will vary depending on where the break is and the way a beam would strike the damage. All windows have losses because of an impedance difference to the water inside the well and outside the well. There are also losses that are built up in the window. An important loss is due to the shear wave that is created as our acoustic signal passes through the window at an angle. This shear wave traps sound in the thickness of the window as the acoustic signal tries to pass through the window. If the window has a crack in it then the window can cause this trapped energy to bounce in all directions rather than remain trapped in the window. Depending on the size of the crack, the location of the crack, and what the window does around the crack this reflected energy may even go into other beams.

Regrettably, there is no way to predict on what can happen as a crack will have a strange pattern to it. A single beam or all 4 beams may be affected. However, in either case it is enough to know that a crack in the window is very bad and will cause the energy that is transmitted and received in a beam to be deflected at strange angles.

Additionally, cracks can cause the window to have a rough surface. This can result in cavitation around the window. Cavitation results in air being trapped near the crack. This air can cause energy to be reflected back into the transducer well instead of traveling through the water.

C. Does the use of a window effect my warranty?

The use of a window has no impact on warranty. The window is primarily an aid to optimal performance. A window isolates the transducer face from flow noise when the vessel is moving and provides protection from bio-fouling. These all increase the performance and reliability of the transducer. The window will also absorb some of the transmitted and returned signals. This will have an adverse effect on performance. However, when the proper window is used this adverse effect is minimal compared to the benefits of using a window. RDI cannot be responsible for the acoustic design of the vessel, but that design and the installation of our transducer certainly can adversely affect the ADCP system performance.

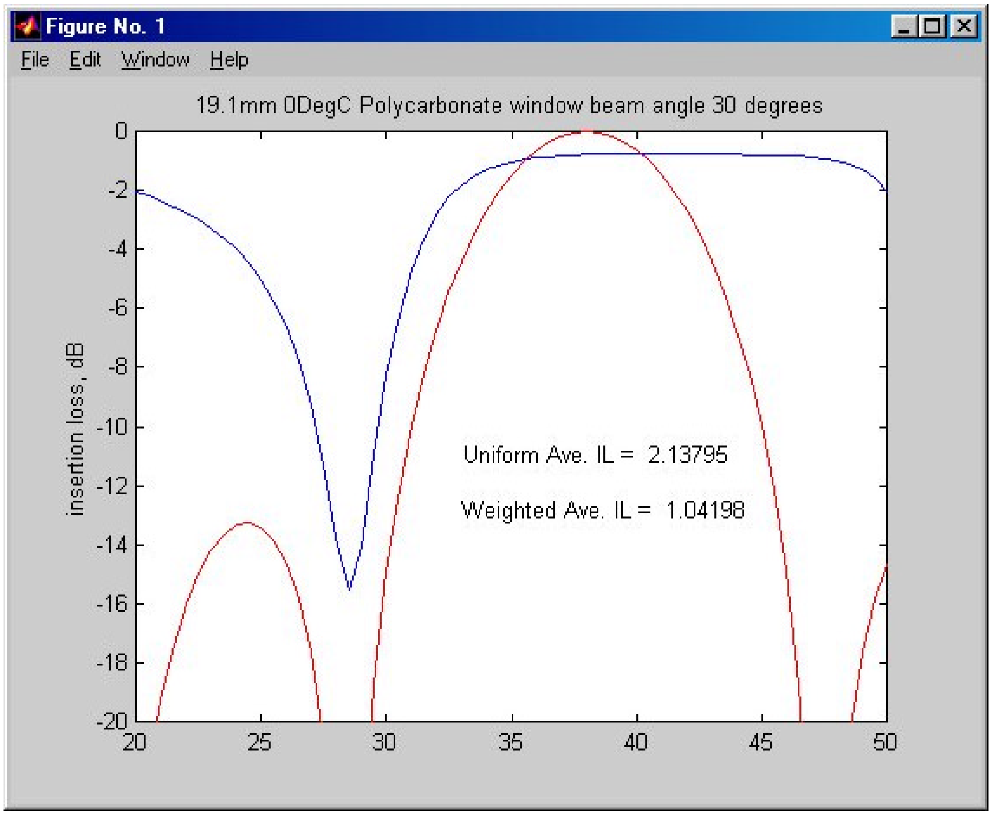
Appendix A

The following appendix contains insertion (one-way) loss graphs for each of the ADCP frequencies at each transducer beam angle at 0°C. These graphs are provided as an example of the expected insertion loss.

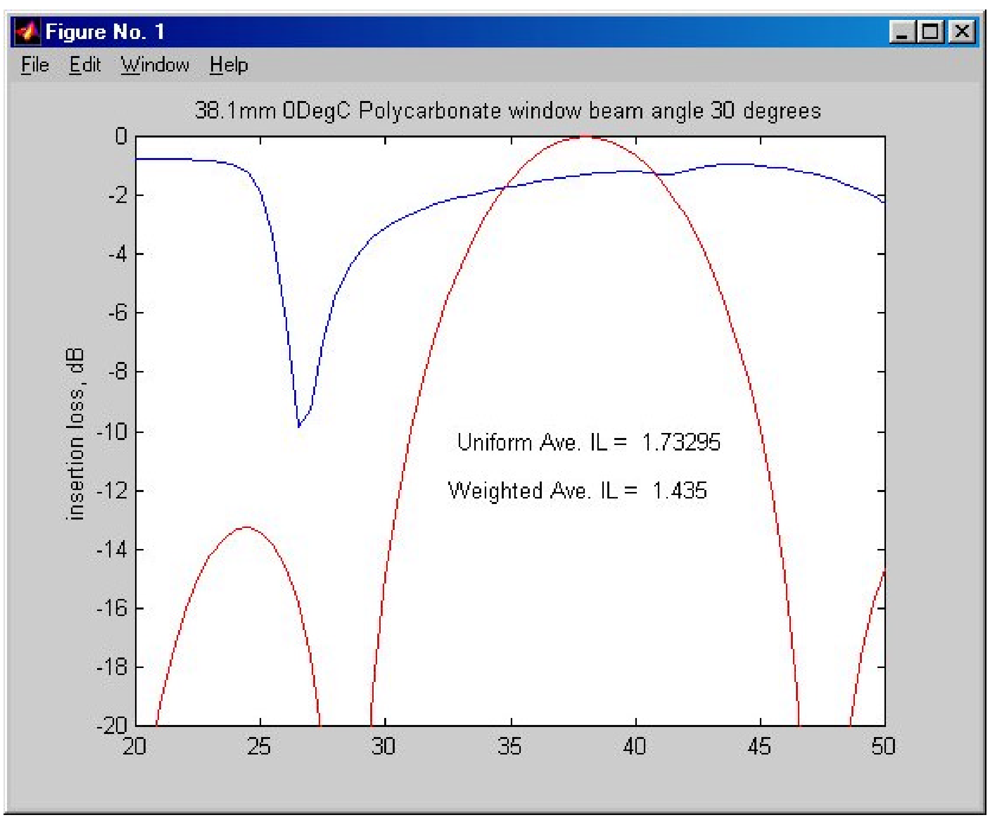
The main beam of each ADCP system at its maximum bandwidth is displayed as the red line on each graph (the sin X/X is represented by the smaller bumps in red). The minimum and maximum frequencies used on the X-axis of the graph were chosen so that this bandwidth would be approximately centered on the graph.

The blue line represents the expected loss across this bandwidth of frequencies for this thickness of polycarbonate. The Y-axis of each graph represents the expected insertion loss. See the example below for descriptions.

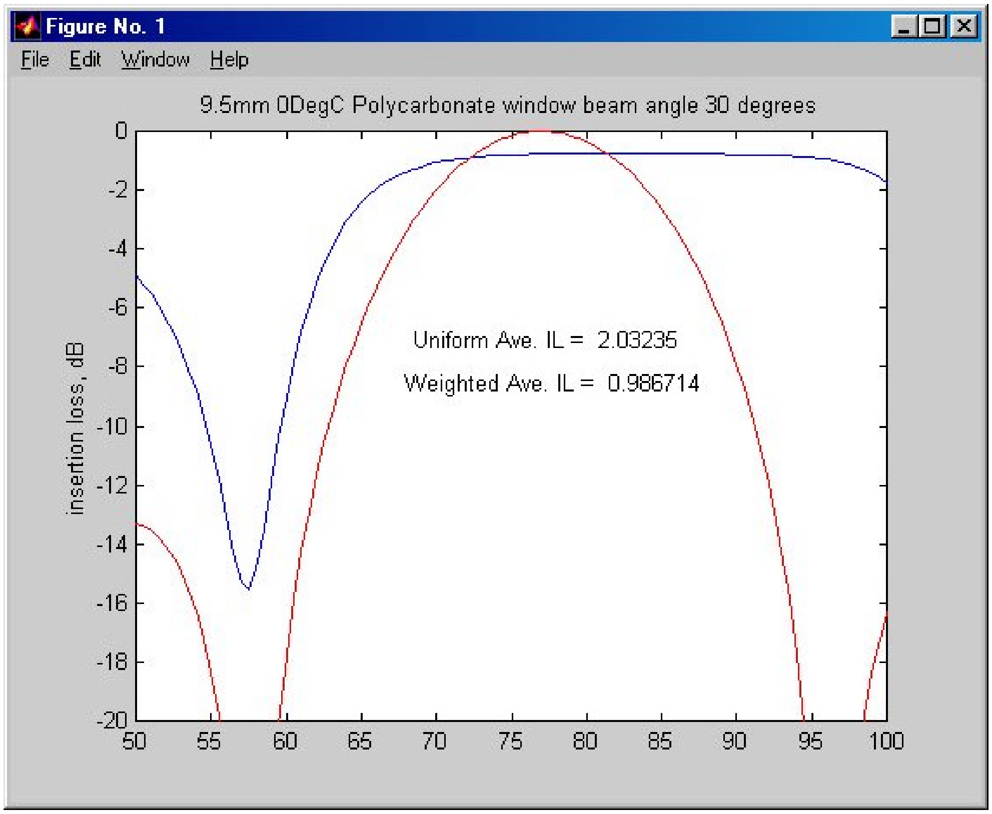
Uniform Ave. IL represents the entire average insertion loss over the entire frequency (X-axis) shown. The Weighted Ave. IL represents the average insertion loss over the bandwidth of the ADCP frequency. The Weighted Ave. IL is used to complete tables 1 and 2 of this document.



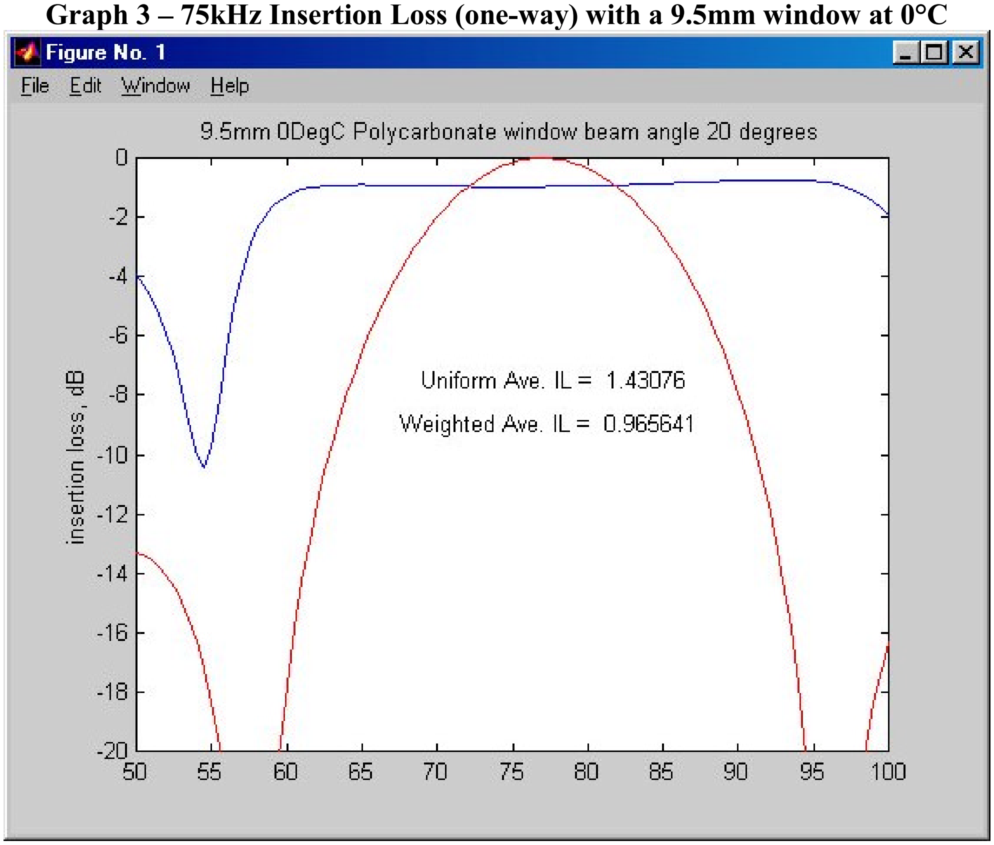
Graph 1 – 38kHz Insertion Loss (one-way) with a 19.1mm window at 0°C



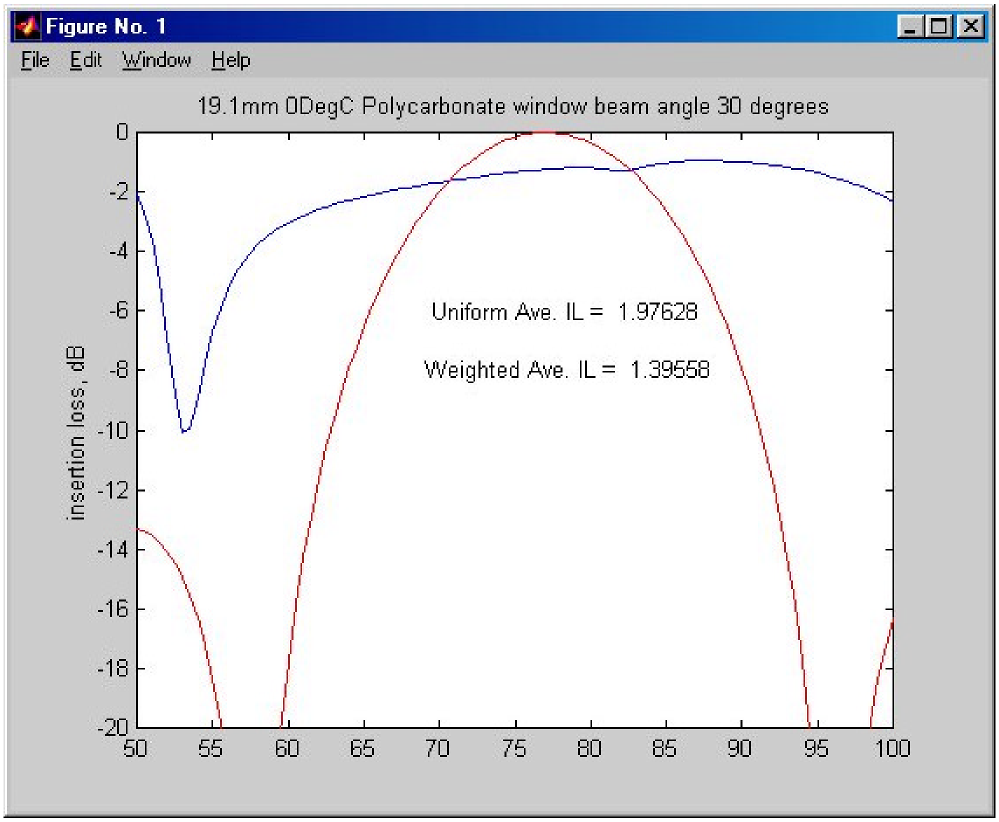
Graph 2 – 38kHz Insertion Loss (one-way) with a 38.1mm window at 0°C



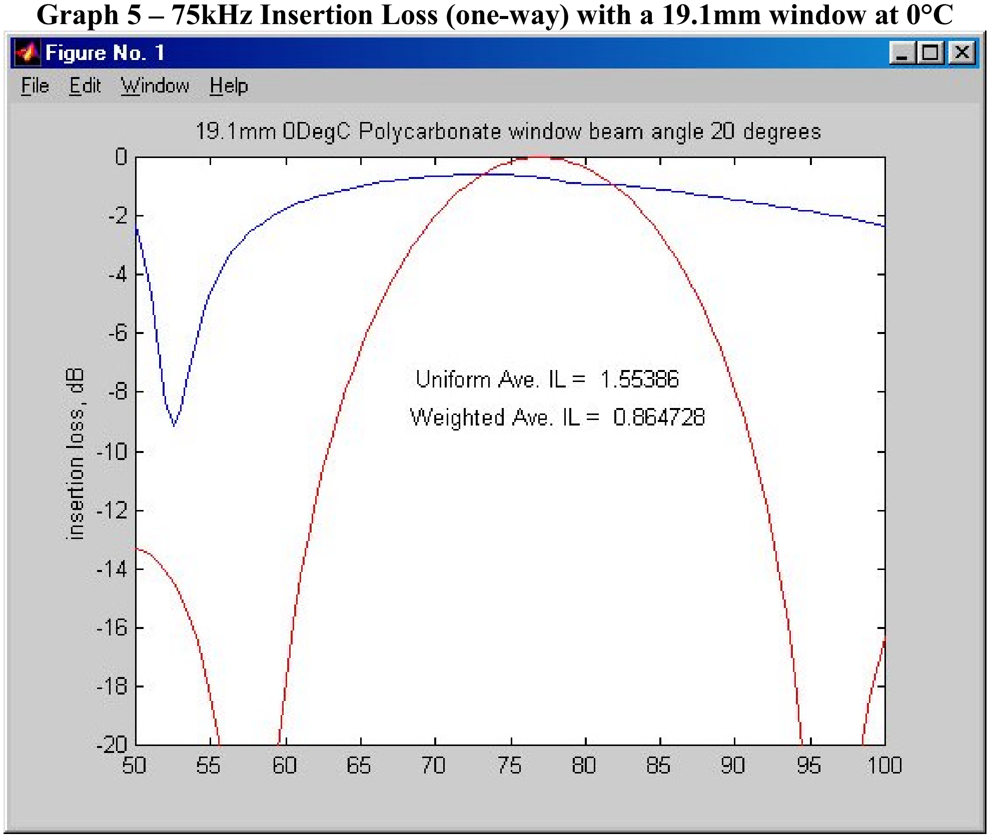
Graph 3 – 75kHz Insertion Loss (one-way) with a 9.5mm window at 0°C



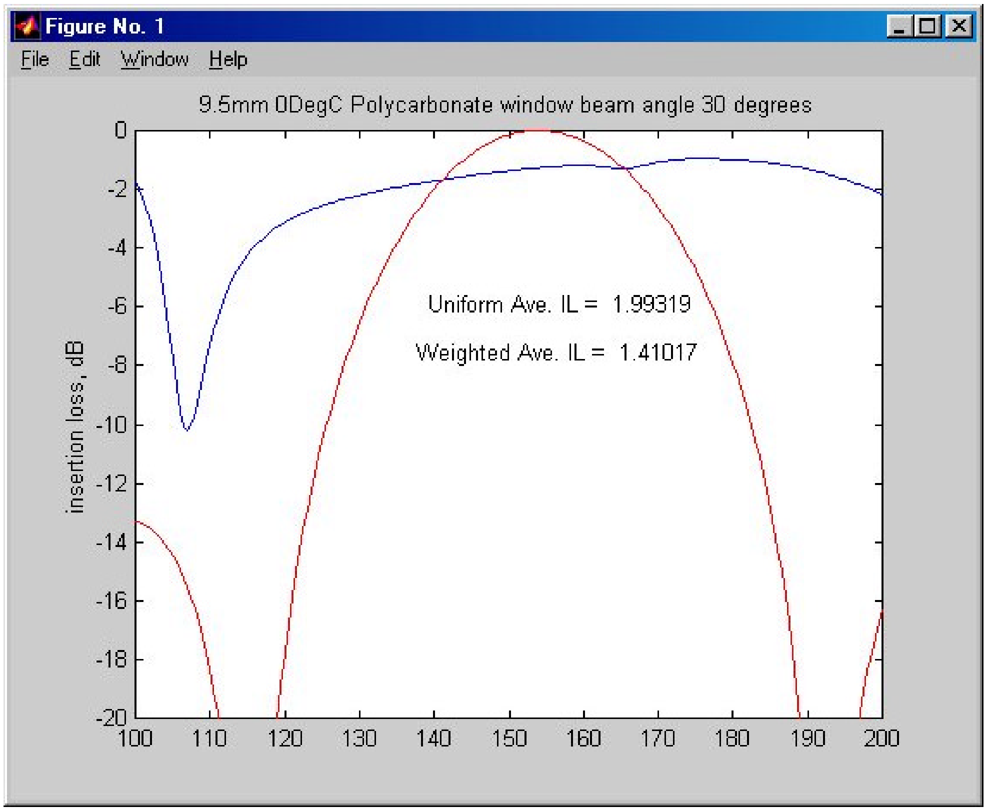
Graph 4 – 75kHz Insertion Loss (one-way) with a 9.5mm window at 0°C



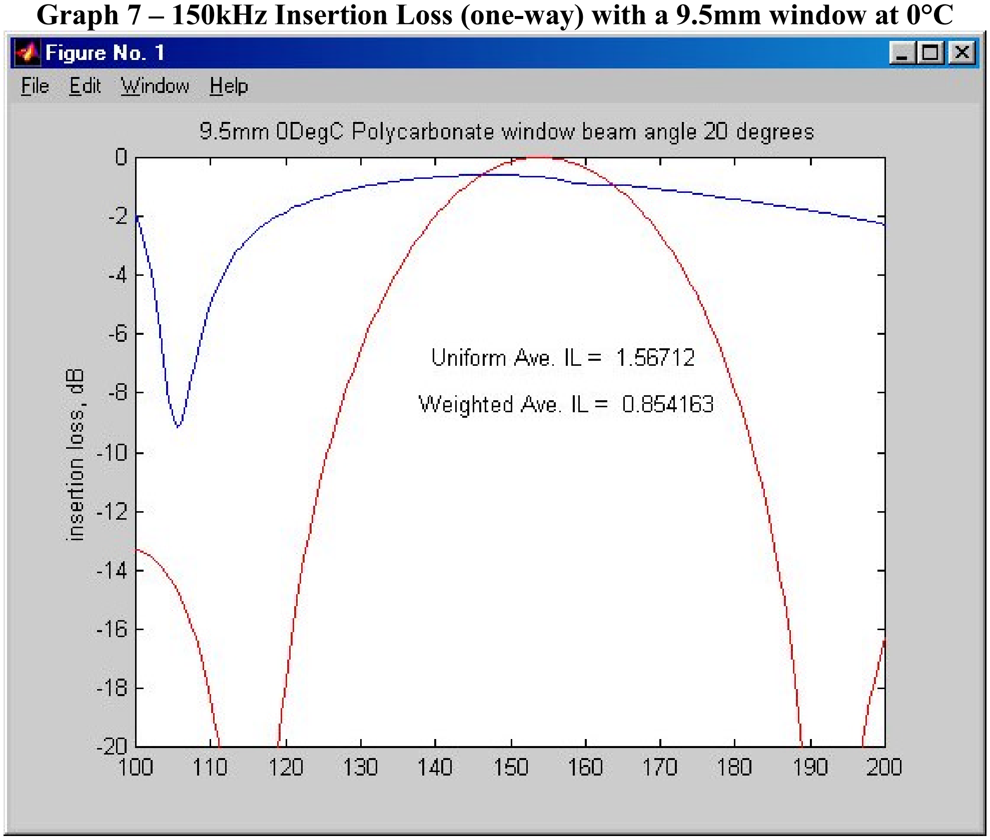
Graph 5 – 75kHz Insertion Loss (one-way) with a 19.1mm window at 0°C



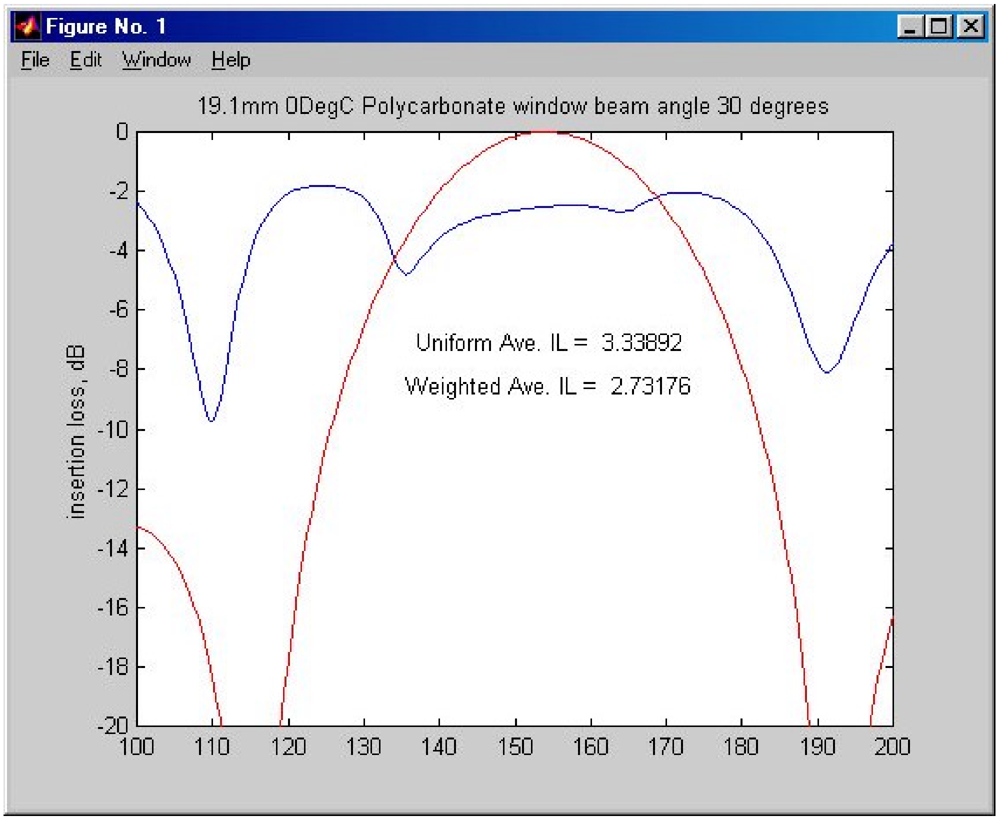
Graph 6 – 75kHz Insertion Loss (one-way) with a 19.1mm window at 0°C



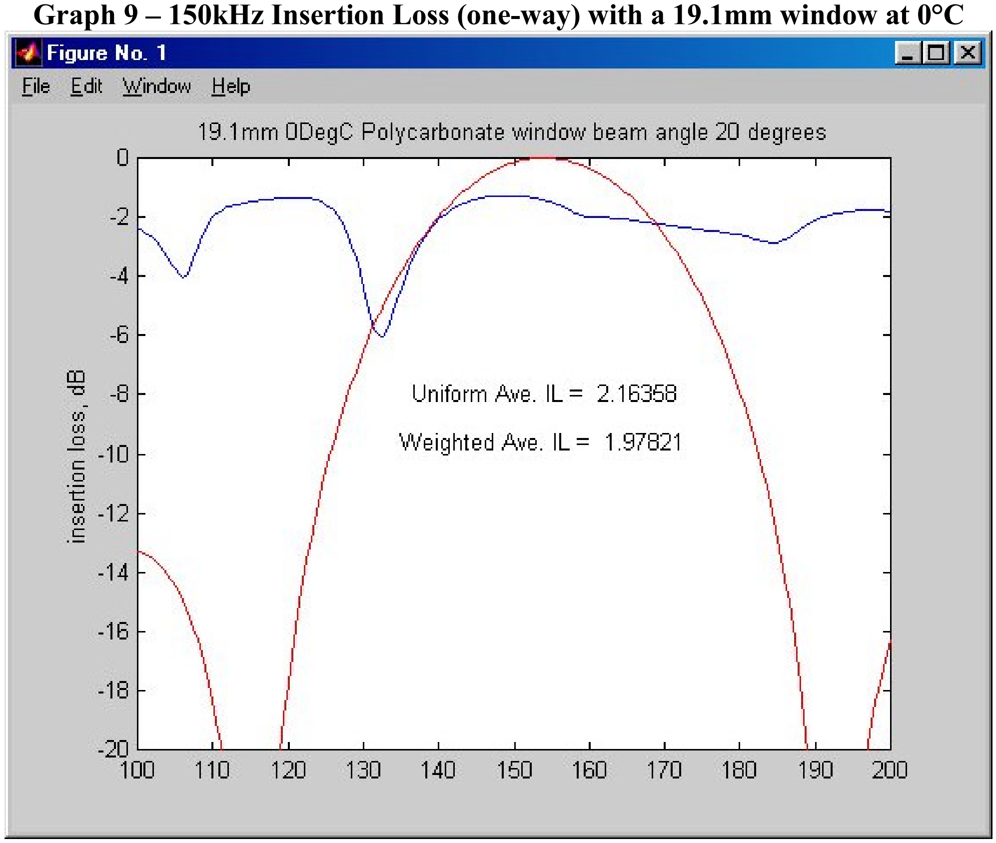
Graph 7 – 150kHz Insertion Loss (one-way) with a 9.5mm window at 0°C



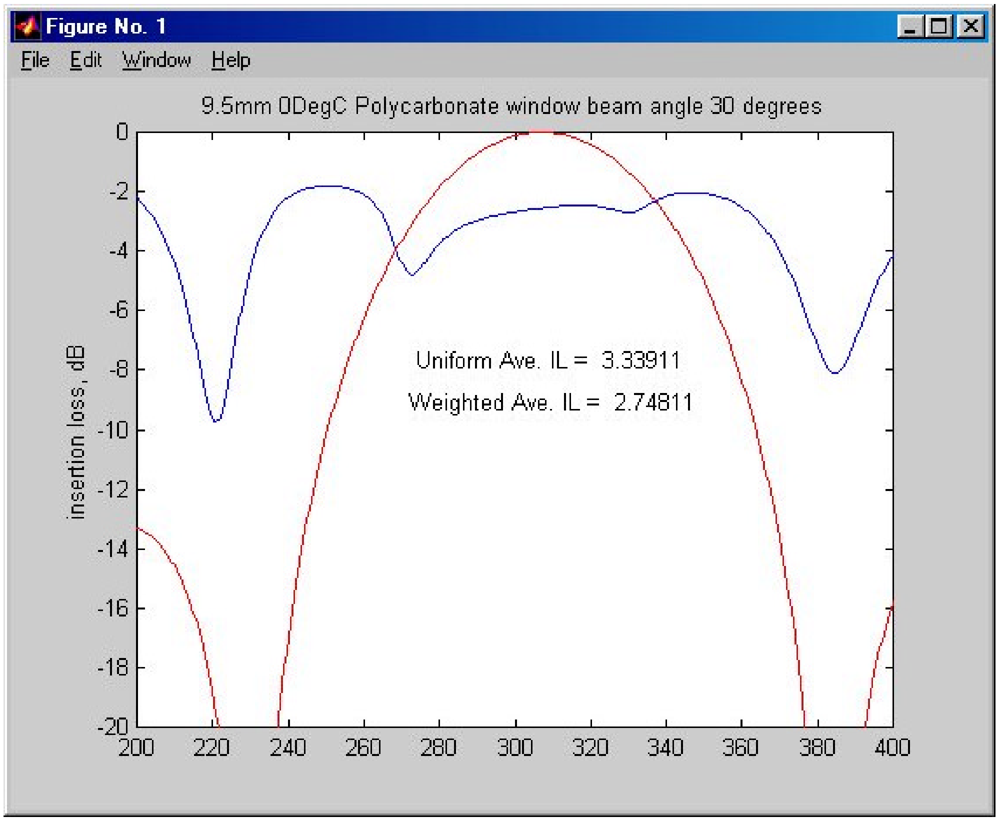
Graph 8 – 150kHz Insertion Loss (one-way) with a 9.5mm window at 0°C



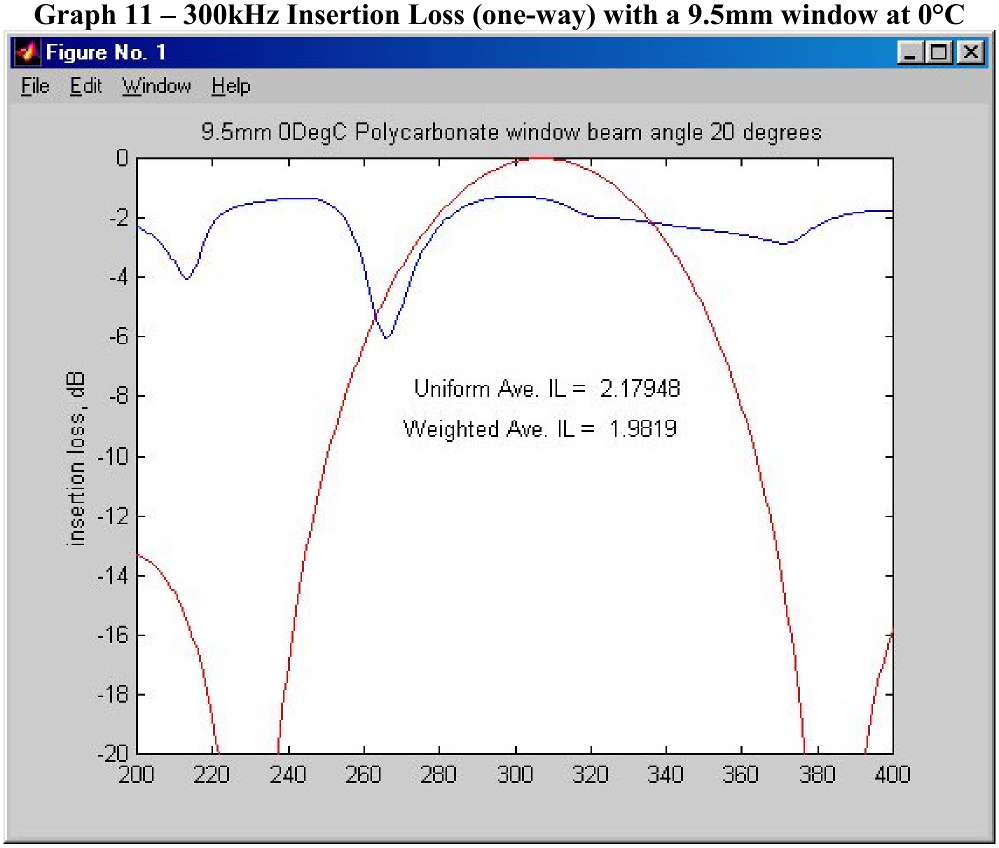
Graph 9 – 150kHz Insertion Loss (one-way) with a 19.1mm window at 0°C



Graph 10 – 150kHz Insertion Loss (one-way) with a 19.1mm window at 0°C



Graph 11 – 300kHz Insertion Loss (one-way) with a 9.5mm window at 0°C



Graph 12 – 300kHz Insertion Loss (one-way) with a 9.5mm window at 0°C