GeoSpectrum Technologies Inc.

“A Technical Dive into C-Bass Sound Projectors”

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1 Introduction

C-Bass are Very Low Frequency (VLF), coherent sound projectors with resonance frequencies ranging from 15 Hz to 300 Hz depending on diameter. Compared to alternative VLF sources, of which there are few, they are smaller, lighter, more reliable, more powerful, more efficient and have greater bandwidth. As such, they open up experimental possibilities that were not practical before. This document describes the various C-Bass and provides information and explanations that users may find useful.

Figure 1 illustrates the differences between older technology and C-Bass. The VLF source on the left was used in the mid 1990s for acoustic tomography experiments in the Arctic. It could produce 195 dB re 1 µPa @ 1m at 20 Hz with a 1 Hz bandwidth. The 1.2 m diameter C-Bass shown in the tow body on the right can produce 200 dB re 1 µPa @ 1m at 20 Hz with a -3 dB bandwidth of 4 Hz and electroacoustic efficiency greater than 10%.

Figure 1: Comparison of VLF sources.
If a single C-Bass is not powerful enough, they can be combined in any quantity you like. Figure 2 shows four of the largest C-Bass in a frame being calibrated in Halifax Harbour. Use of more than one C-Bass increases the SPL, of course, but also increases the electroacoustic efficiency because of acoustic interactions amongst the projectors.

Figure 2: Quadruple C-Bass System
2 The C-Bass Family and Its Uses

C-Bass is a family of VLF sound projectors with diameters ranging from 1.2m to 0.22 m and resonances ranging from 15 Hz to 300 Hz, see Figure 3. The larger sources produce greater power at lower frequencies. Each has a useful bandwidth of about a decade.

Generally speaking, larger diameters produce lower resonance frequencies and greater power. With a fixed diameter, though, we can move the resonance around a bit at the time of manufacture so the table below is a guideline only.

Table 1: Selection Guidelines for C-Bass sources.

<table>
<thead>
<tr>
<th>C-BASS MODEL</th>
<th>DIAMETER</th>
<th>SHALLOW RESONANCE</th>
<th>USAGE</th>
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<tbody>
<tr>
<td>M72-300</td>
<td>22 cm</td>
<td>300 Hz</td>
<td>UUVs or compact towed systems where size or weight constraints cannot support the M72-110.</td>
</tr>
<tr>
<td>M72-110</td>
<td>33 cm</td>
<td>110 Hz</td>
<td>General purpose calibration source, moderate power. Man-portable and easily packaged into moderately sized tow bodies, can operate to 30 meters without compensation and 200 meters with passive-only compensation. Effective from 10 Hz to above 1 kHz.</td>
</tr>
<tr>
<td>M72-50</td>
<td>68 cm</td>
<td>50 Hz</td>
<td>Intermediate source that is smaller and lighter than the largest systems, but provides 20 dB more power below 60 Hz than the M72-110. Not man portable and requires active compensation; best used in tow bodies, moorings, or integrated into customer systems.</td>
</tr>
<tr>
<td>M72-30</td>
<td>106 cm</td>
<td>30 Hz</td>
<td>Powerful VLF system. Not man portable and requires active compensation; best used in tow bodies, moorings, or integrated into customer systems. <em>This source should be selected if the goal is to provide high-power VLF signals while maintaining the widest operating band; the source response remains smooth up to 600 Hz.</em></td>
</tr>
<tr>
<td>M72-40</td>
<td>120 cm</td>
<td>40 Hz</td>
<td>Powerful VLF system. Not man portable and requires active compensation; best used in tow bodies, moorings, or integrated into customer systems. <em>This source should be selected if the highest absolute source level is desired; it can provide in excess of 200 dB across 10 Hz bandwidth.</em></td>
</tr>
<tr>
<td>M72-25</td>
<td>120 cm</td>
<td>25 Hz</td>
<td>Powerful VLF system. Not man portable and requires active compensation; best used in tow bodies, moorings, or integrated into customer systems. <em>This source should be selected if the goal is to provide the highest source level at 25 Hz and below.</em></td>
</tr>
</tbody>
</table>
Figure 3: C-Bass Family

Clockwise, from top left: M72-25, M72-30, M72-50, M72-110, M72-300.
3 Typical Acoustic Responses

Figure 4 shows measured Transmitting Current Responses (TIRs) of various C-Bass. Note that the shapes of the TIRs are similar but shifted in frequency. They all rise at 12 dB/octave below resonance, peak at resonance, and then flatten out for a decade above resonance. To calculate the maximum SPL obtainable, you must add $20 \log_{10}(\text{drive current})$ to the TIR. The maximum current depends on the thermal and mechanical limits, which depends on which C-Bass it is. The limits will be explained later in this document.

![Figure 4: TIRs of various C-Bass.](image)

4 How does a C-Bass work?

In VLF projectors, the only parameters that control the SPL are the volume of water displaced by the projector, $V$, and the frequency, $f$. The radiated acoustic power is proportional to $V^2 \cdot f^4$. To provide a benchmark, a source level of 200 dB re 1μPa @ 1m at 20 Hz requires a rms volume displacement of 11 litres. The $f^4$ dependence explains why VLF sources are large.

To achieve the large displacements of water, the designer has two choices. Use a smaller radiating area and a larger displacement, or a larger radiating area and a smaller displacement. The C-Bass takes the latter approach as the smaller displacement makes motors and water seals simpler, more linear, and more reliable.

Figure 5 shows a conceptual drawing of the C-Bass. It comprises a rim, two skins that seal the rim on either end to form an air cavity, and a motor assembly that applies equal force to a large area of each skin. The GTI-patented motor is modular to fit larger or smaller configurations. Also noteworthy is the wide area over which the force is applied. The distributed force suppresses higher-order resonances, the lack of which creates a decade of smooth response above resonance.
5 Electromagnetic versus Piezoelectric Drive

The two common means to drive underwater sound projectors are piezoelectric ceramics and magnetic motors. Comparing these two, magnetic motors produce greater displacement than ceramics, but less driving force. As already discussed, VLF projectors must displace large volumes of water so a magnetic motor with its greater displacement is the appropriate choice. On the other hand, piezoelectric ceramics are the appropriate choice for higher frequency projectors because higher force is required.

6 Coherence

The C-Bass has been designed to be a coherent source; the sound pressure is a faithful reproduction of the input signal to the power amplifier. Think of it as an underwater loudspeaker.

Figure 6 shows that the C-Bass is coherent. The left-hand side of shows a timeseries of a 14-tone input signal to the power amplifier; the right-hand side shows the FFT of the monitoring hydrophone. The vertical axis of the FFR spans 70 dB.

Figure 6: Time series of drive signal on the left; FFT of hydrophone signal on the right.
7    Drive limits

The maximum current that you can drive a C-Bass with are imposed by mechanical and thermal constraints. Near resonance, where the amplitude of vibration is greatest, the current limit is determined by metal fatigue. The current limits at resonance that GTI has specified do not produce metal fatigue. The limit can be exceeded, but at the cost of a shorter life. The other limit is thermal; the DC resistance of the coils generates more heat than can be dissipated. This current limit applies below and above resonance. Thermal and fatigue limits for each C-Bass model are described in the specification sheets for continuous and pulsed operation.

In almost all instances, the motors have enough linear range that you cannot drive them to the point where they produce significant distortion.

8    What is maximum SPL from a C-Bass

The maximum SPL depends on so many factors that it is difficult to answer this question. Nevertheless, the maximum SPL of a single C-Bass is between 180 and 200 dB re 1µPa at 1 m at resonance, with the larger C-Bass capable of achieving just over 200 dB.

Whatever the limit for an individual C-Bass, it can be increased by use of more than one C-Bass. For example, the C-Bass system shown in Figure 2 can produce SPL in excess of 200 dB re 1µPa at 1 m over the entire decade from 10 to 100 Hz.

9    Cavitation

Cavitation occurs when the peak acoustic pressure on the source exceeds the static pressure. For the maximum SPL for each C-Bass, cavitation will never occur at any depth in the water. This is because the ratio of surface area to SPL for C-Bass is much larger than that of smaller, higher-frequency ceramic sources.
10 Pressure compensation

VLF sound projectors are mechanically compliant so an excessive pressure difference between inside and outside can damage them. The means of maintaining a small pressure difference is called pressure compensation. There are two main ways of achieving pressure compensation: active and passive. Figure 7 shows these two types of compensation systems combined.

![Diagram of active/passive pressure compensation](image)

Figure 7: Schematic of an active/passive pressure compensation

In an active system, air from an external source, which can be a hose to the surface or a bottle of pressurized gas, supplies dry gas to the interior of the projector. A valve opens when gas is required: another valve opens when gas must be discharged from the projector. There is no theoretical limit to depth, although practical considerations, such as the size of the gas bottle, do impose themselves. The only significant downside to the use of gas bottles is the possible failure of the valves, e.g., because of fouling. Careful design of the valves minimizes this issue.

In a passive system there is no gas bottle. In its place is a compliant bladder contained within a rigid housing with small holes. When descending, the increasing static pressure causes the bag to collapse, forcing its volume of gas into the projector; the reverse happens when ascending. When the bladder is completely flattened, you have reached your maximum depth. To increase the depth limit, the system is pressurized prior to deployment. The relative volumes of the projector and bladder, and the maximum pre-pressure determine the maximum depth.

Active and passive pressure compensation systems can be combined. The advantages of this approach are greater depths and less consumption of air when the variations in operating depth (from variable tow speed) exceed the trigger pressures of the valves.

Figure 8 shows the M72-110 C-Bass connected to a passive pressure compensation system. This system enables the C-Bass to be used to 200 m depth.
Figure 8: Passive pressure compensation for the M72-110 cm C-Bass, 200 m depth limit.
## 11 Depth limit and resonance shift

Theoretically, there is no depth limit, but in practical systems there is. It all depends on how much resonance shift and number of gas bottles you can tolerate.

Figure 9 shows the shift in resonance for two C-Bass projectors. The lower the shallow-depth resonance, the greater the percentage resonance shift. The resonance shift is unavoidable because the air internal to the C-Bass is a component of the stiffness that determines the resonance. The shift can be minimized by increasing the internal volume.

The other practical limit to depth is the volume of gas required for pressure compensation.

![Figure 9: Change in TIR with depth for the M72-110 and M72-30 C-Bass.](image)
12 Impedance and Power Amplifiers

A typical impedance of a C-Bass is shown in Figure 10. Below the peak at resonance, the resistance is flat and the reactance of the inductive coil is zero. The low impedance of the C-Bass enables it to be driven with a COTS audio amplifier, although the maximum current cannot be achieved with an amplifier meant for home use. At higher frequencies, the increasing reactance of the C-Bass make it difficult to drive full current, although the reactance can be minimized with a capacitor in parallel.

![Impedance Graph]

Figure 10: Impedance of the M72-110.

13 Can the C-Bass be driven hard in air?

Yes, so long as it is not driven hard at the in-air resonance, which is substantially higher than the in-water resonance. Thus, it is usually possible to activate your system on deck to check that it is working prior to deployment.

The C-Bass cannot cool itself as efficiently in air as it can in water, so while it can be operated at full power in air, the duty cycles short enough to avoid overheating.

14 Can the C-Bass be driven with a long cable?

Yes, but the low impedance of the C-Bass implies that the cable must also be of low round-trip resistance; otherwise, most of the energy will be dissipated in the cable instead of the C-Bass. Cables must be chosen to ensure they do not overheat.
15  Can the C-Bass be used in a moored system?

Yes. A good example of this is the system we co-designed with Scripps for the CAATEX experiment. Figure 11 shows the projector system being calibrated in Halifax harbour. The system comprises an M72-30 C-Bass, power amplifier, active-passive pressure compensation, gas bottles, lithium battery pack and electronics package. This was one of two systems successfully deployed in the Arctic. The bottom mooring was at 2-3 km depth with the source at 60 m depth. The sources were deployed in the autumn of 2019 and operated autonomously before recovery one year later.

Figure 11: Scripps CAATEX projector system, 35 Hz at 60 m depth.