

# GUNDALF array modelling suite - Array report

## Sleeve 320 cuin 1m depth, 6m separation

Gundalf revision AIR8.1k, Date 2016-04-18, Epoch 2016-04-18

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### Report pre-amble

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## Signature filtering policy

For marine environmental noise reports, Gundalf performs no signature filtering other than that inherent in modelling at a sample interval small enough to simulate an airgun array signature at frequencies up to 50kHz, and any requested marine animal weighting functions.

For all other kinds of reports, Gundalf performs filtering in this order:-

- If a pre-conditioning filter is chosen, for example, an instrument response, it is applied at the modelling sample interval.
- If the output sample interval is larger than the modelling sample interval, Gundalf applies appropriate anti-alias filtering. (This can be turned off in the event that anti-alias filtering is included in the pre-conditioning filter, in which case Gundalf will issue a warning.)
- Finally, Gundalf applies the chosen set of post-filters, Q, Wiener and band-pass filtering as specified, at the output sample interval. If none are specified, (often known as unfiltered), only the above anti-alias and/or pre-conditioning

are applied.

In reports, when filters are applied, they are applied to the notional sources first so that signatures, directivity plots and spectra are all filtered consistently. The abbreviation muPa is used for microPascal throughout.

Finally note that modelled signatures always begin at time zero for reasons of causality.

### **Anti-alias and pre-condition filtering**

In this case, no pre-conditioning filter has been applied.

In this case, an anti-alias filter has been applied with the following parameters:-

High-cut, 75 % Nyquist; Slope, 72 db/oct;

### **Post filtering**

Details of the post-filtering used in this report follow. Post filters are applied at the output sample interval after any pre-conditioning and anti-alias filters have been applied.

#### **Q filtering**

No Q filtering performed.

#### **Wiener filtering**

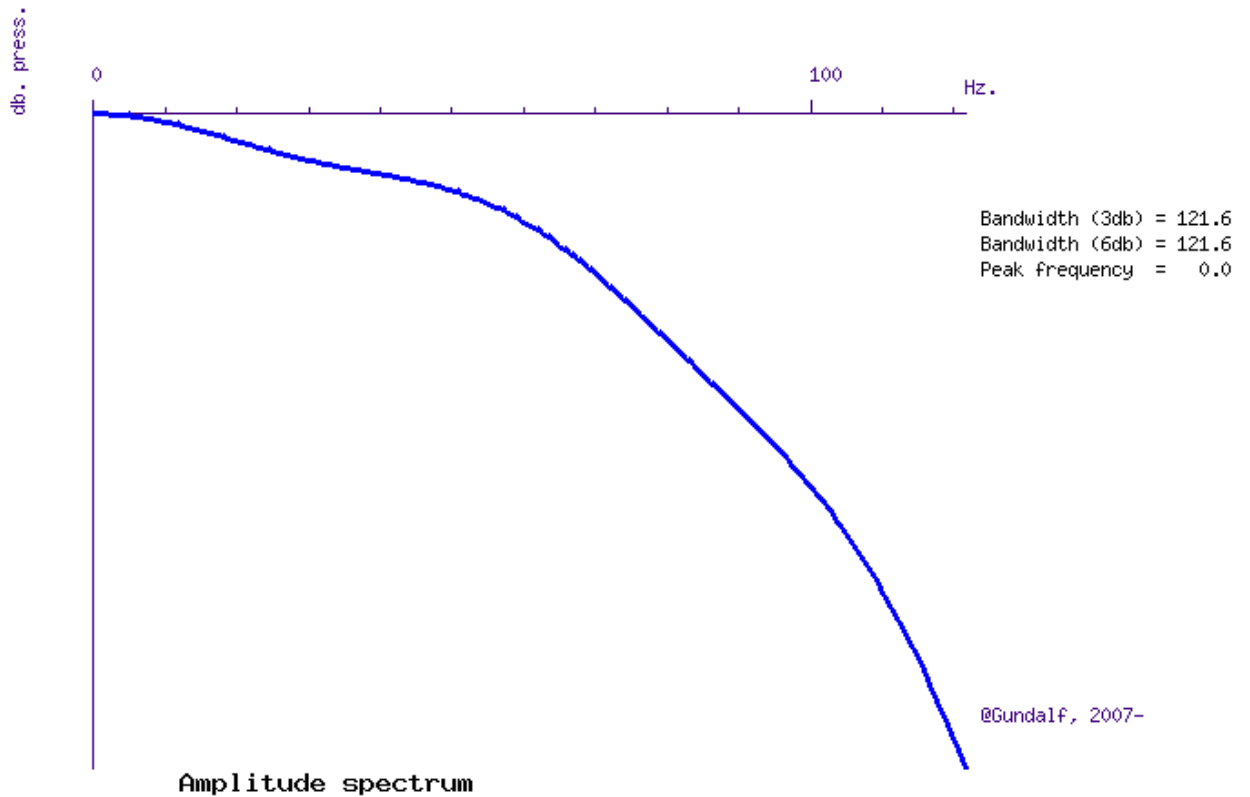
No Wiener filtering performed.

#### **Band-pass filtering**

Signatures were band-passed filtered using the following parameters:-

Filter file : [ser408\\_2p0min\\_impulse.flt](#)

The amplitude spectrum of the band-pass filter used is shown below.



## Some notes on the modelling algorithm

The Gundalf airgun modelling engine is the end-product of 15 years of state of the art research. It takes full account of all air-gun interactions including interactions between sub-arrays. No assumptions of linear superposition are made. This means that if you move sub-arrays closer together, the far-field signature will change. The effect is noticeable even when sub-arrays are separated by as much as 10m.

The engine is capable of modelling airgun clusters right down to the 'super-foam' region where the bubbles themselves collide and distort. It has been calibrated against both single and clustered guns for a number of different gun types under laboratory conditions and accurately predicts peak to peak and primary to bubble parameters across a very wide range of operating conditions.

In many cases, the predicted signatures are good enough to be used directly in signature deconvolution procedures.

## Array summary

The following table lists the statistics for the array quoted in various commonly used units for convenience. Note that the rms value is computed over the entire modelled signature. Conservative error bounds for the main signature characteristics of peak to peak, primary to bubble and bubble period are also shown. These represent 95% confidence intervals for the Gundalf model against its calibration data.

### Array parameters ...

Number of guns	8
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Total volume (cu.in).	320.0 ( 5.24 litres)
Peak to peak in bar-m.	9.29 +/- 0.164 ( 0.929 +/- 0.0164 MPa, ~ 239 db re 1 muPa. at 1m.)
Zero to peak in bar-m.	5.68 ( 0.568 MPa, 235 db re 1 muPa. at 1m.)
RMS pressure in bar-m.	0.403 ( 0.0403 MPa, 212 db re 1 muPa. at 1m.)
Primary to bubble (peak to peak)	23.3 +/- 0.801
Bubble period to first peak (s.)	0.144 +/- 0.00748
Maximum spectral ripple (dB): 10.0 - 50.0 Hz.	18.4
Maximum spectral value (dB): 10.0 - 50.0 Hz.	185
Average spectral value (dB): 10.0 - 50.0 Hz.	182
Total acoustic energy (Joules)	55450.9
Total acoustic efficiency (%)	76.6

## Array geometry and gun contribution

The following table lists all the guns modelled in the array along with their characteristics. The last column is completed only if the array has actually been modelled during the interactive session and contains the approximate contribution of that gun as a percentage of the peak to peak amplitude of the whole array. Please note the following:-

- The peak to peak varies only as the cube root of the volume for the same gun type so that even small guns contribute significantly. This is particularly relevant to drop-out analysis.
- The peak to peak can also be depressed due to clustering effects as reported by Strandenes and Vaage (1992), "Signatures from clustered airguns", First Break, 10(8).

Gun	Pressure (psi)	Volume (cuin)	Type	x (m.)	y (m.)	z (m.)	delay (s.)	sub-array	p-p contrib (pct.)
1	2000.0	40.0	Sleeve	0.000	0.000	1.000	0.00000	1	13.9
2	2000.0	40.0	Sleeve	2.000	0.000	1.000	0.00000	1	13.2
3	2000.0	40.0	Sleeve	3.000	0.000	1.000	0.00000	1	12.8
4	2000.0	40.0	Sleeve	4.000	0.000	1.000	0.00000	1	12.6
5	2000.0	40.0	Sleeve	5.200	0.000	1.000	0.00000	1	11.9
6	2000.0	40.0	Sleeve	5.700	0.000	1.000	0.00000	1	11.6
7	2000.0	40.0	Sleeve	6.200	0.000	1.000	0.00000	1	11.7
8	2000.0	40.0	Sleeve	6.700	0.000	1.000	0.00000	1	12.4

The array is shown graphically below.

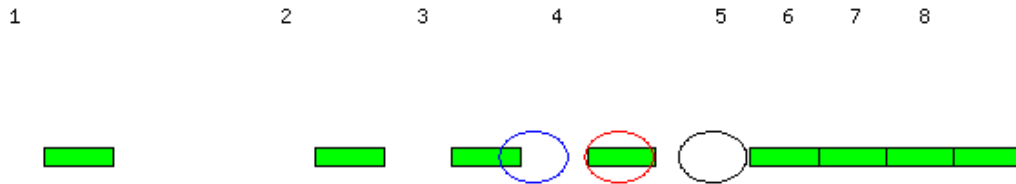
Hydrophone position: Infinite vertical far-field

<----- Direction of travel ----- --, 1 m. grid, plan view



Dropped out guns are shown as orange rectangles whilst live guns are shown as green rectangles.

### Array centres



The geometric centre is at ( 3.35, 0, 1)

The centre of pressure is at ( 3.98, 0, 1)

The centre of energy is at ( 4.67, 0, 1)

Note that Gundalf by default uses the deepest gun to define time zero for the vertical far-field and it uses the nearest gun to the observation point to define time zero if an observation point is specified. This means that if one gun is accidentally run deep, this will cause the bulk of the signature to appear to be delayed. It is still a research question how an airgun array should be timed. There are several candidates as defined above but it is not currently clear which if any is appropriate in complex scenarios such as Ocean Bottom Deployment.

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## Array directivity

The following tables show the inline and crossline directivity of the array in both (angle-frequency) and (angle-amplitude) form and optionally, the azimuthal directivity (theta-phi) form.

*Note that the effects of cable ghosting if present are not shown in Gundalf directivity displays although source ghosting is included. This matches common practice in such displays.*

For inline directivity displays, the x-axis is the inline angle from the vertical with the word **fore** indicating the end nearest the boat. For crossline directivity displays, the x-axis is the crossline angle from the vertical with the word **port** indicating the port side.

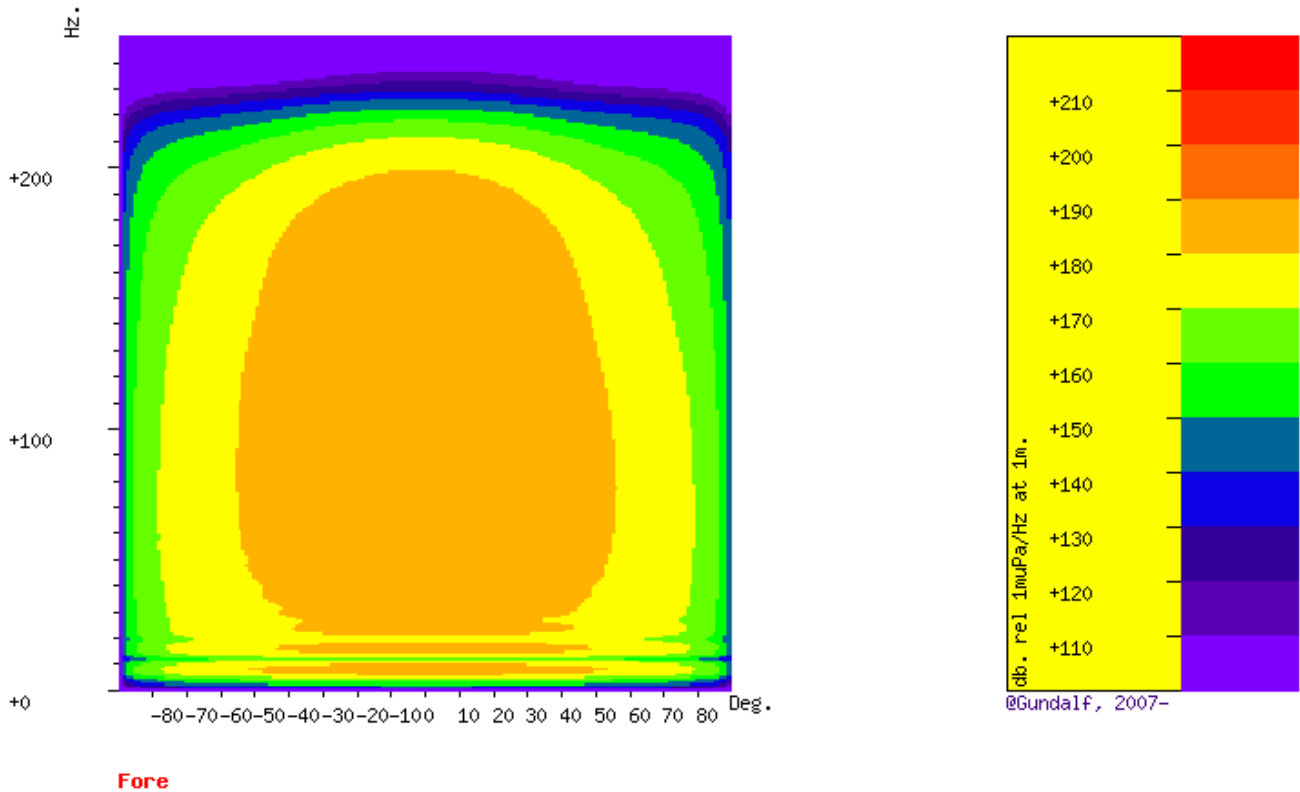
Note that *inline* is used nominally to mean any angle within +/- 45 degrees of the boat direction (which corresponds to a bearing of zero degrees). Similarly, *crossline* is used nominally to mean any angle within +/- 45 degrees of the perpendicular to the boat direction which is measured as a bearing of 90 degrees, (i.e. starboard). The nominal inline and crossline angles can be set by the user in the report options. The values used are indicated in the diagram titles below as bearings.

Where shown, the azimuthal plots show contours at four chosen frequencies as a function of phi (angle from the x-axis, opposite to the boat direction) and theta (the angle from the vertical). A bearing of zero degrees corresponds to a value of phi of 180 degrees.

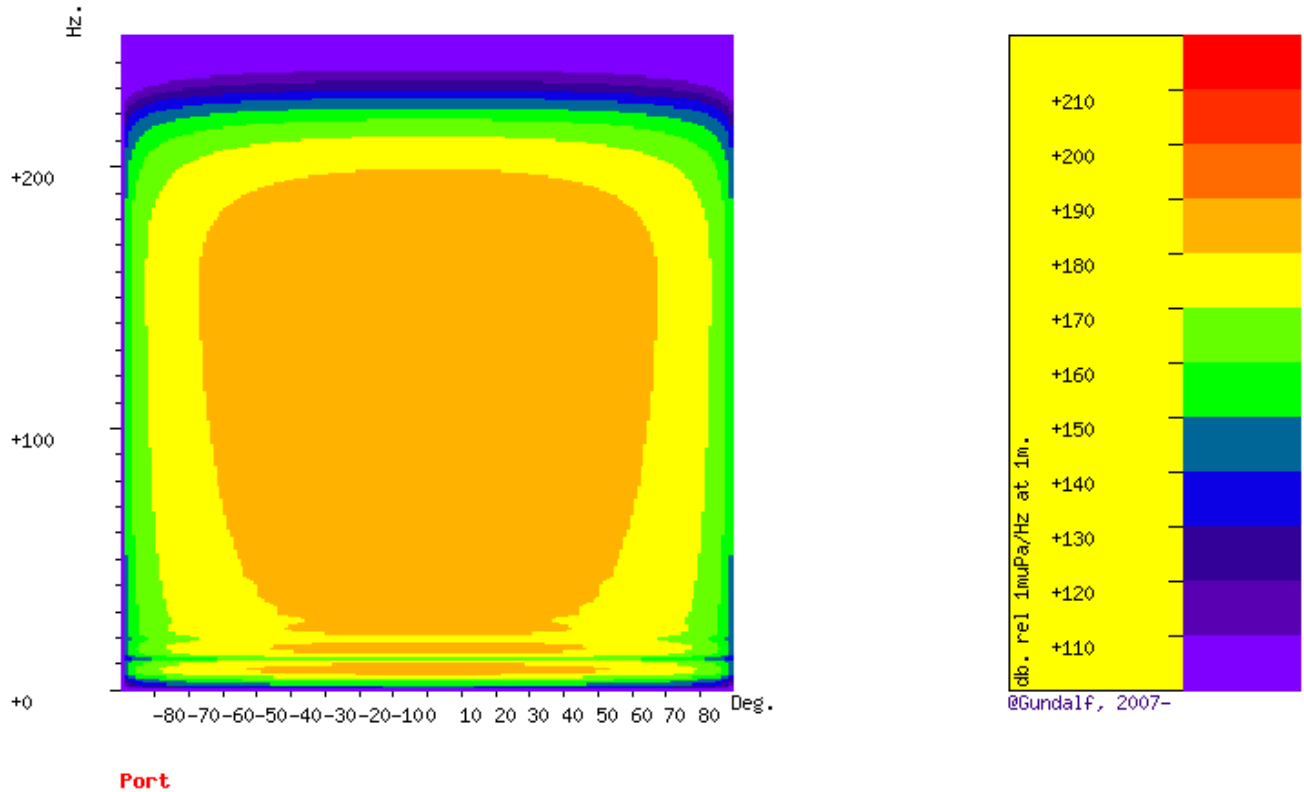
**Angle-frequency form**

The following tables show the inline and crossline directivity of the array in (dip angle-frequency) form. Both plots are scaled as dB. relative to 1 muPa. per Hz. at 1m.

**Inline directivity, bearing = 0 degrees**



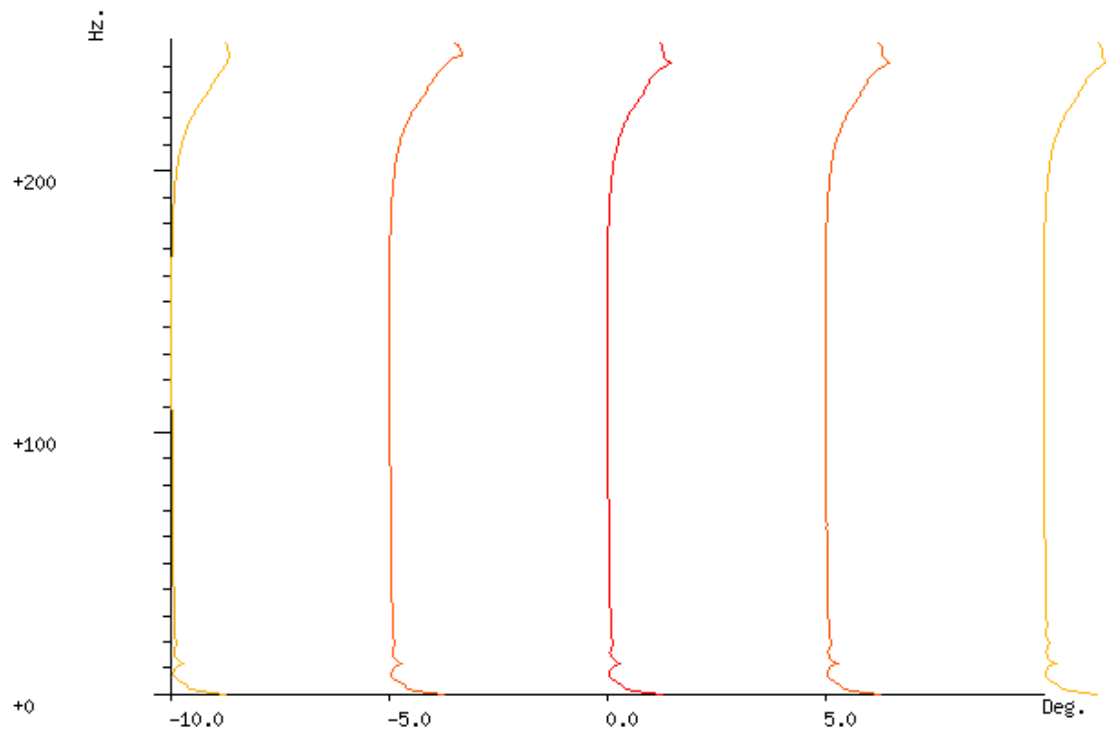
**Crossline directivity, bearing = 90 degrees**



### Angle-amplitude form

The following tables show the inline and crossline directivity of the array in (dip angle, amplitude) form. The computed signature (or under option the amplitude spectrum) for each angle is shown in colour varying form with red signatures shown in the centre, shading to blue at the furthest angles computed. The vertical scale indicates the type of plot, time or frequency. Both types of plot are individually scaled and plotted with the same units as the corresponding plots in the Signature Characteristics section.

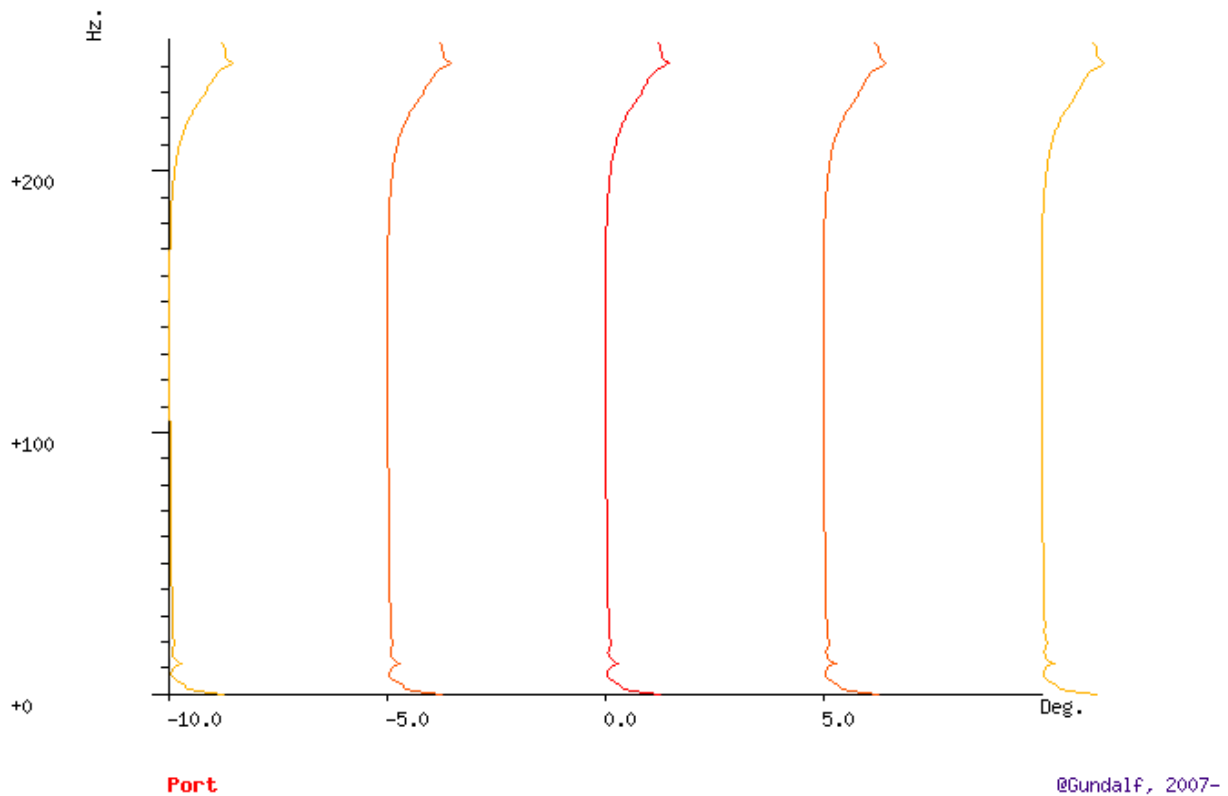
#### Inline directivity, bearing = 0 degrees



Fore

@Gundalf, 2007-

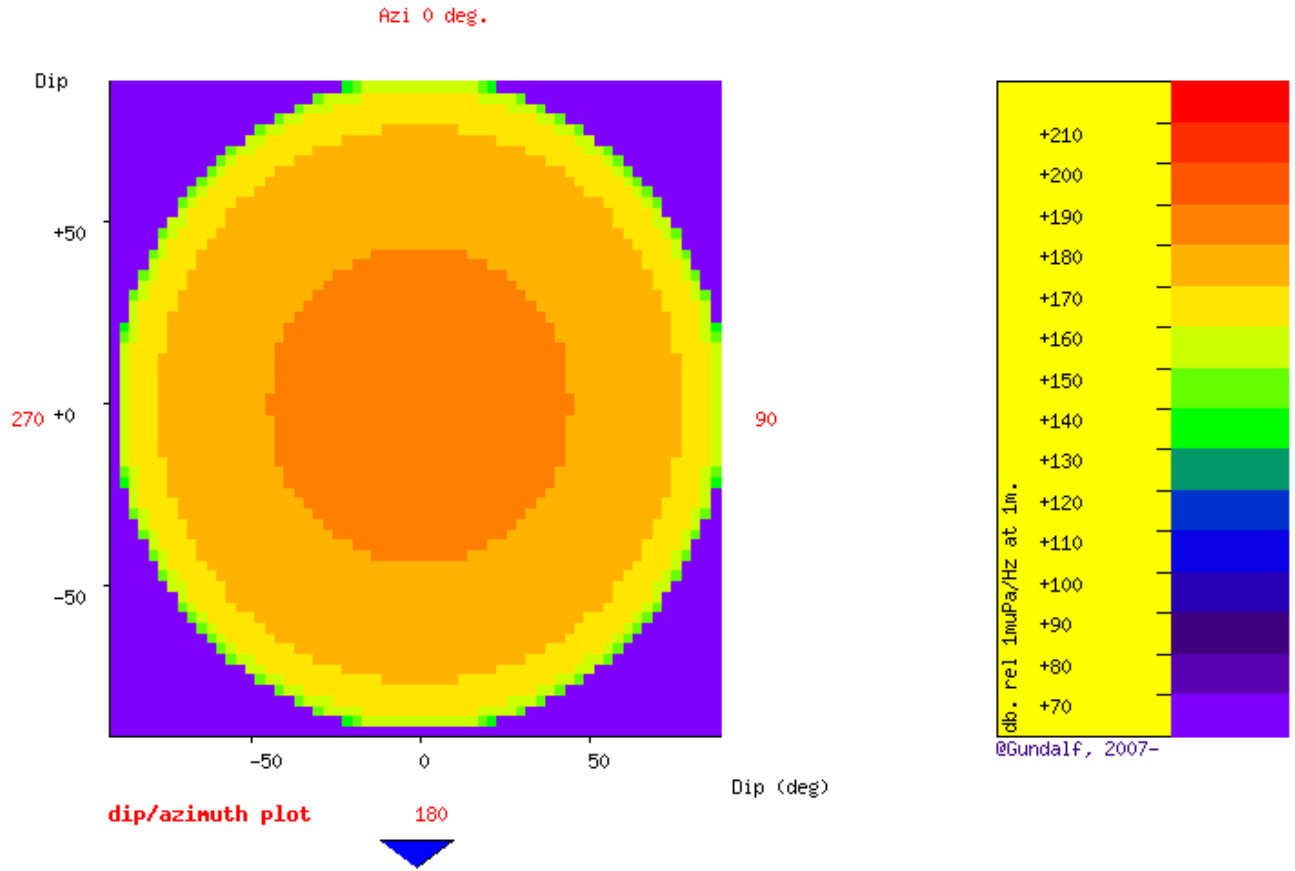
**Crossline directivity, bearing = 90 degrees**

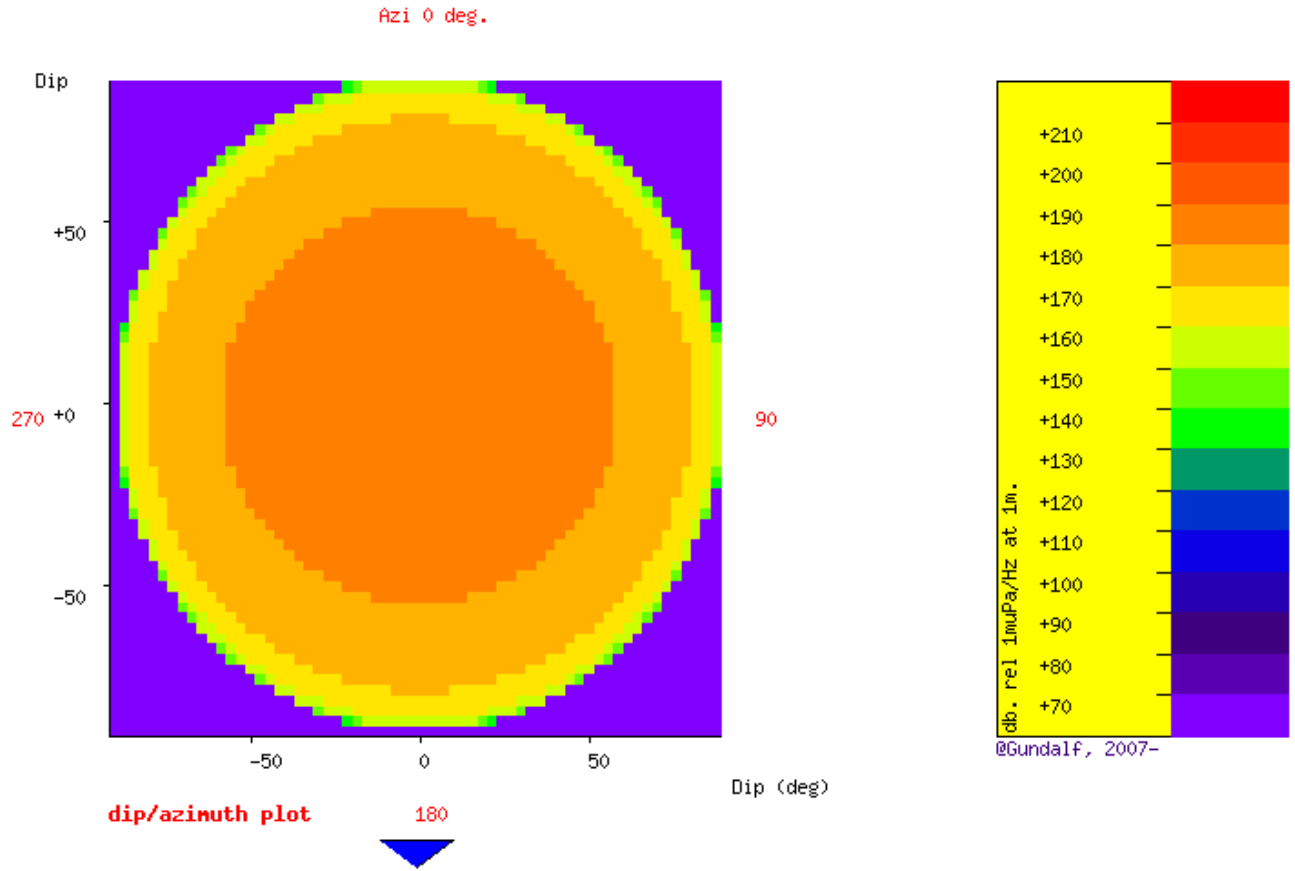


## Dip-azimuthal form

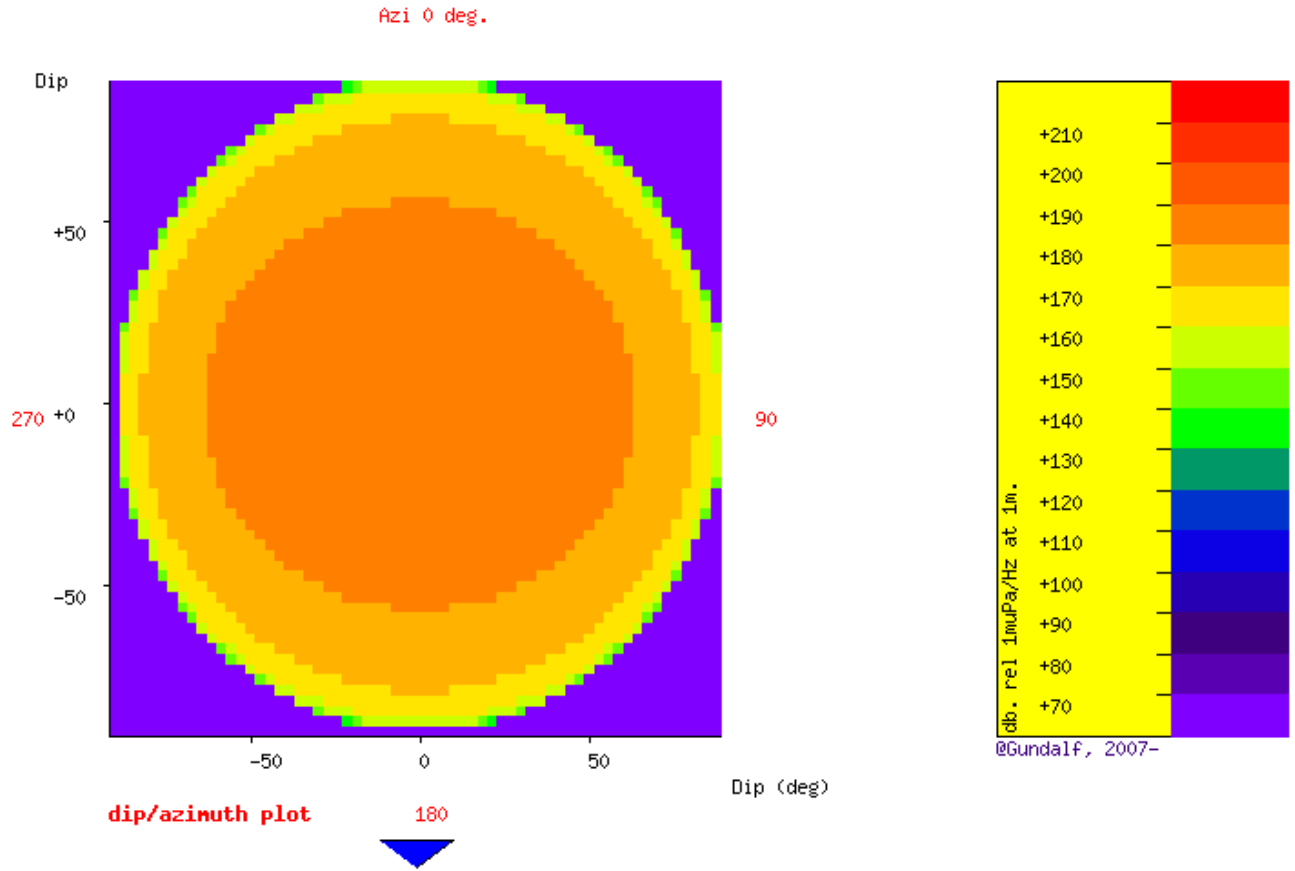
The following tables show the azimuthal directivity (i.e. plan view) theta-phi plots, at four user-specified frequencies. The dip, theta is the angle to the vertical so a value of zero corresponds to vertically down, (the centre of the plot). The azimuthal angle phi is measured relative to the positive x axis so the boat direction corresponds to a value of phi of 180 degrees as indicated by the blue triangle. The plots are scaled as dB. relative to 1 muPa. per Hz. at 1m.

### Azimuthal response at: 30 Hz.

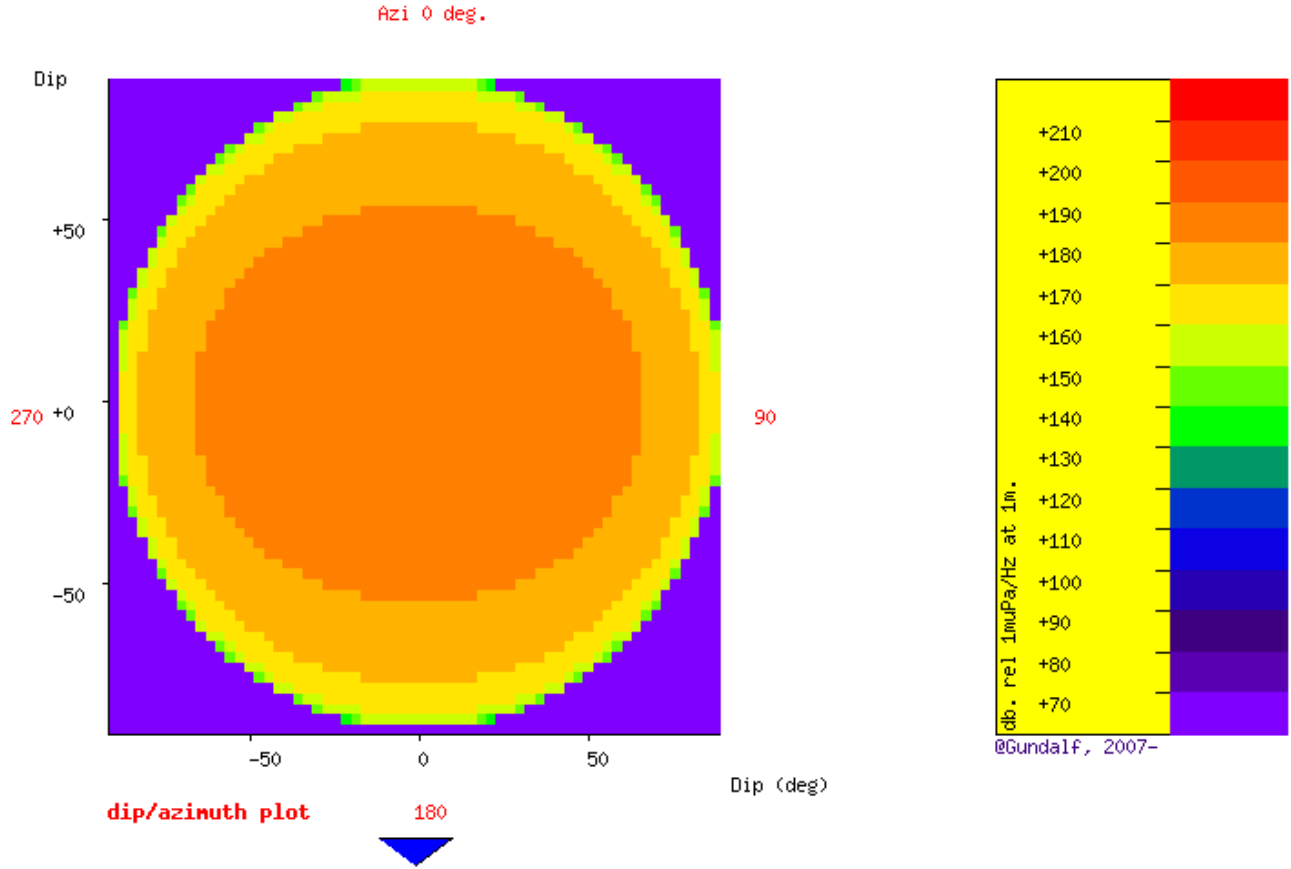




**Azimuthal response at: 90 Hz.**



**Azimuthal response at: 120 Hz.**



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## Signature characteristics

The following tables show the signature parameters, the signature and the amplitude spectrum of the modelled signature.

The amplitude spectrum is shown in units of dB. relative to 1 muPa. per Hz. at 1m.

The position of the bubble by default is determined internally but can be overridden by interacting with the modelled signature using the right hand mouse button to determine the start of the bubble.

## Signature and statistics

The following table includes error bounds for the primary characteristics of an airgun signature: peak to peak, primary to bubble and bubble period.

Airgun modelling programs like Gundalf must be calibrated against real data and no computational model is any better than the quality of that calibration. Calibration datasets however are themselves subject to experimental error so Gundalf is calibrated to best fit the various datasets which are used across the extensive range of volumes, pressures and depths available.

In practice, such experimental errors arise for a variety of reasons including

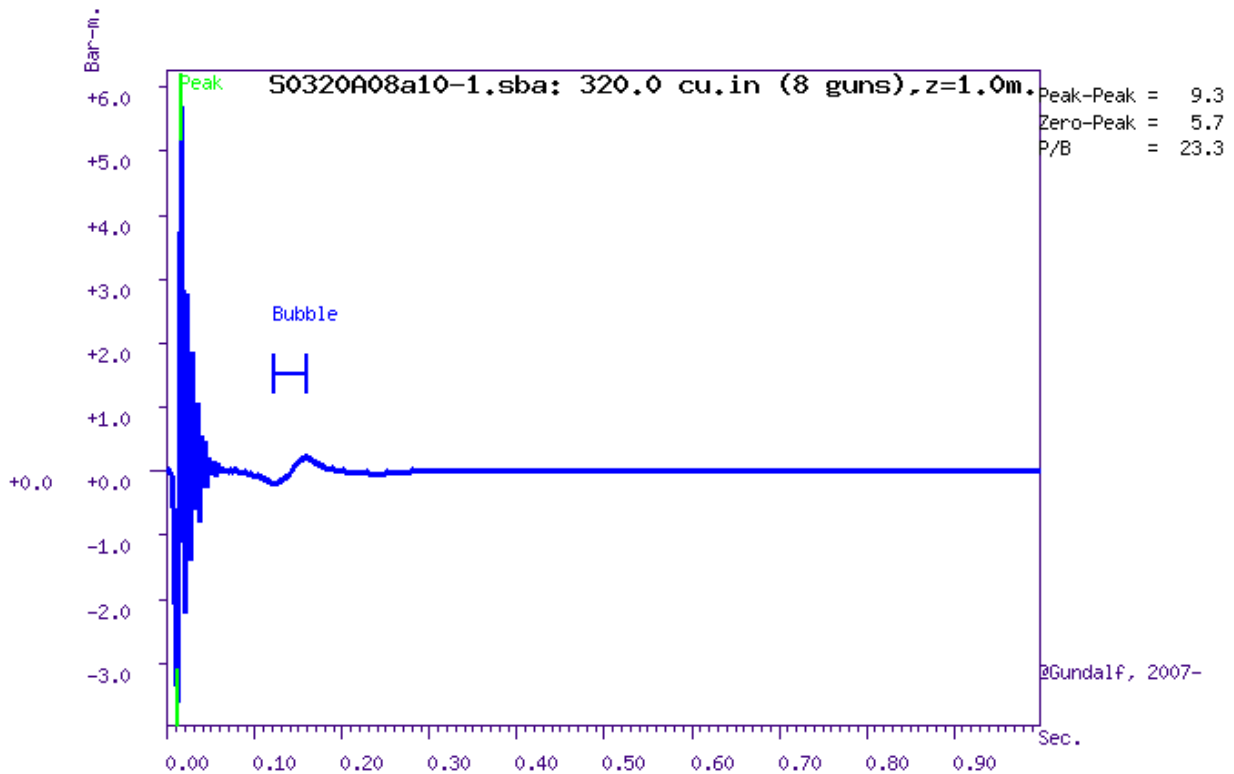
- Depth inaccuracies. These are usually around 3-5% even in the best facilities particularly if there is sea surface movement.
- How frequently the gun is being cycled during measurement. This is rarely recorded but a warmed up gun might be 50deg C warmer than the sea, changing its normal peak-to-peak and other parameters by 5-10% compared with when it is first fired.
- Filtering differences. Filtering is recorded but filtering errors are still more frequent than we would like and analog filter v. digital filter differences are also sometimes a factor.

As a guideline, typical individual errors across different measurement datasets for the best-calibrated guns are of the order of 5% for peak to peak, 15% for primary to bubble and 2% for bubble periods.

Individual gun errors are calculated from the data shown in Help -> Calibration (which themselves accumulate gun data from different sources) and the resulting array error bounds are calculated by accumulating these errors for each gun in the array. The error bounds are calculated as 95% error bounds and for simplicity assume that errors are non-correlated although in practice some are systematic. The total error bound is always greater than any of the individual error bounds and is strongly influenced by the largest gun contributions.

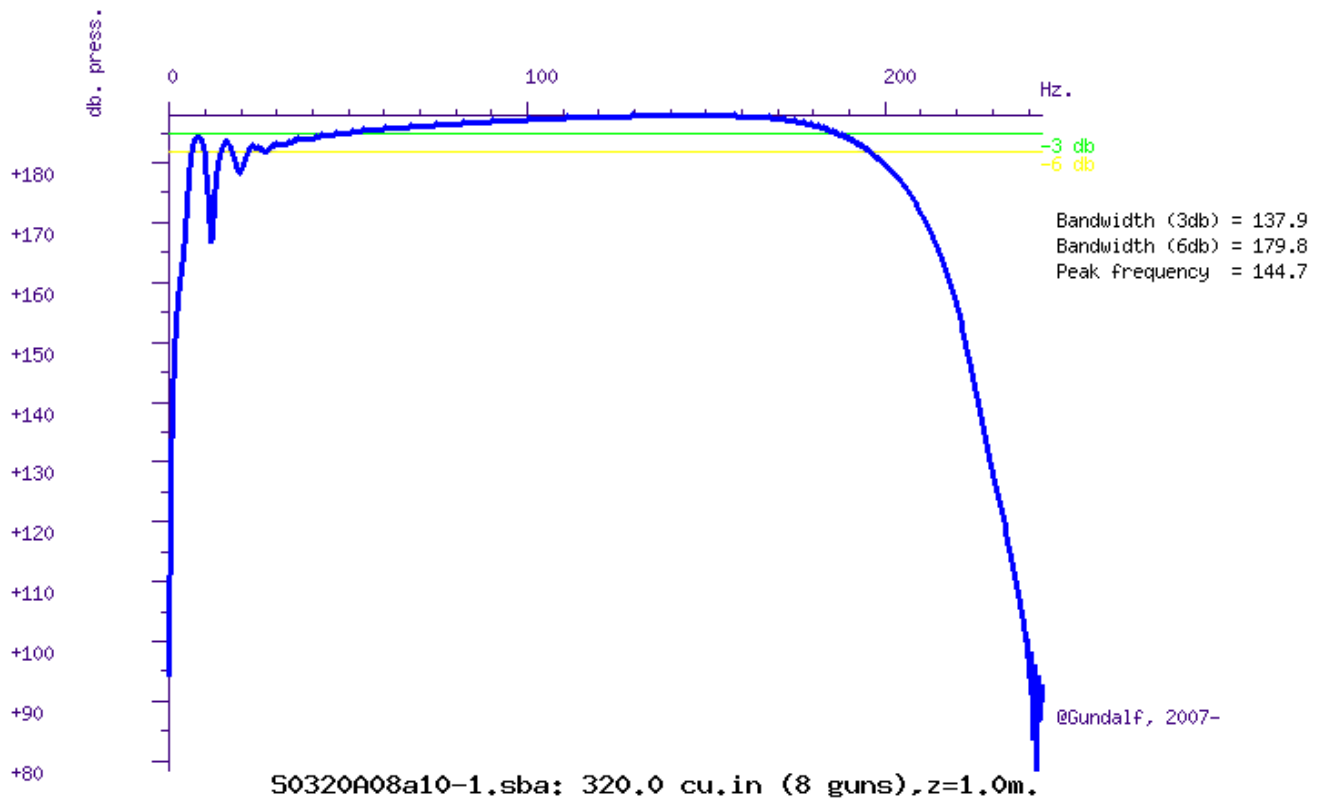
The error bounds simply mean that *it is very likely that the true values for these primary characteristics will be within the ranges shown, but it is not possible to be more precise.* If other comparison data or models indicate values outside this range, this means that those data or models are very likely to be *incompatible* with Gundalf's calibration data. This may be due to several causes as described above. For more on calibration see Gundalf's calibration Help pages.

Peak to peak in bar-m.	Zero to peak in bar-m.	Primary to bubble (peak to peak)	Bubble period to first peak (s.)
9.29 +/- 0.164	5.68 +/- 0.0822	23.3 +/- 0.801	0.012 +/- 0.00748



## Filtered amplitude spectrum

Amplitude spectrum. Amplitude Units are dB. relative to 1 muPa / Hz. at 1m.



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## Modelling summary

The following table lists the modelling parameters for the array quoted in various commonly used units for convenience.

### Signature parameters ...

Output sample interval (s.)	0.002
Number of samples in signature	500
Duration of signature (s.)	1.000
Modelling sample interval (s.)	0.0005
Observation point	Infinite vertical far-field
Bubble search start time (s.)	0.026 (Auto)

### Filter parameters ...

Signature filtering details	ser408_2p0min_impulse.flr
Q filtering	OFF
Wiener deconvolution	OFF

### Sea Surface parameters ...

Source ghost	ON
Reflection coefficient	-1.00
Source ghost estimation method	Direct
Streamer 1 ghost	OFF
Streamer 2 ghost	OFF
<b>Physical parameters ...</b>	
Sea temperature (C)	30
Velocity of sound in water (m./s.)	1545
Expected dominant frequency in signature (Hz)	20.0
Observed wave height (m)	0.0
<b>Gun controller parameters ...</b>	
RMS gun controller variation (s.)	0.0

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## Acoustic energy characteristics

The following table lists the individual gun contributions to the acoustic energy field in joules. A negative value means the gun is actually absorbing energy. This is very common in interacting arrays. It does not however mean that the gun is damaging the array performance. Rather it is acting as a catalyst to allow the other guns to perform more efficiently. The total acoustic energy gives the true performance of the array as a whole. See Laws, Parkes and Hatton (1988) Energy-interaction: The long-range interaction of seismic sources, Geophysical Prospecting, (36), p333-348 and 38(1) 1990 p.104 for more details. Note that internal energy is not included in the data below. The true acoustic efficiency of airgun arrays is typically < 5% of the total initial energy.

### Overall acoustic energy contribution

Total acoustic energy output (j.)	Acoustic energy output due to energy-interaction (j.)	Total potential energy available in array(j.)	Percentage of total potential energy appearing as acoustic energy
55451.0	-5179.1	72377.9	76.6%

### Individual acoustic energy contributions

Volume (cuin)	x (m.)	y (m.)	z (m.)	Acoustic energy contribution (j.)
40.0	0.00	0.00	1.00	3778.4
40.0	2.00	0.00	1.00	7785.2
40.0	3.00	0.00	1.00	3827.9
40.0	4.00	0.00	1.00	7188.7
40.0	5.20	0.00	1.00	5625.2
40.0	5.70	0.00	1.00	4690.2
40.0	6.20	0.00	1.00	7442.9
40.0	6.70	0.00	1.00	15112.4

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## Drop-out characteristics

Information not requested

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## Inventory usage

Information not available

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## Gun period analysis

The following table compares the bubble periods for each gun fired in isolation with its modified period due to interaction with the full array. In general interaction with other guns in an array lengthens the period of a particular gun compared with its period when fired in isolation, as reported by Laws, Hatton and Haartsen (1990), "Computer modelling of clustered airguns", First Break 8(9).

Gun	Volume (cuin)	Type	x (m.)	y (m.)	z (m.)	Isolation period (s.)	Interacting period (s.)
1	40.0	Sleeve	0.000	0.000	1.000	0.110	0.114
2	40.0	Sleeve	2.000	0.000	1.000	0.110	0.126
3	40.0	Sleeve	3.000	0.000	1.000	0.110	0.134
4	40.0	Sleeve	4.000	0.000	1.000	0.110	0.138
5	40.0	Sleeve	5.200	0.000	1.000	0.110	0.136
6	40.0	Sleeve	5.700	0.000	1.000	0.110	0.138
7	40.0	Sleeve	6.200	0.000	1.000	0.110	0.138
8	40.0	Sleeve	6.700	0.000	1.000	0.110	0.132

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## Gundalf calibration details

All modelling software requires calibration against convincing experimental data. Gundalf provides accurate modelling of airguns across a wide range of gun types, gun parameters and operating environments, however, we do not expect you to take this simply on trust. It is therefore our policy to keep users of Gundalf aware of its latest calibration status and up to date information is available under Help -> Calibration.

The latest information, including technical references can be found [here](#).

For sales enquiries please contact: [Gundalf sales](#).

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## Modelling parameters used

This section is not meant for human consumption. It is a dump of the internal parameters used to create this report. If present, Gundalf can read this section when you use the 'Read Geometry from HTML file' option to recreate the conditions under which the report was generated. If external filters were used which are not shipped with Gundalf, then the option to save external filters should also be used for full repeatability.

```

PARM set parms(filtername) "C:/Program Files (x86)/Oakwood
Computing/Gundalf8.1/Filters/two_msec/Sercel/ser408_2p0min_impulse.ft"
PARM set parms(filtershort) "ser408_2p0min_impulse.ft"
PARM set parms(mfiltername) ""
PARM set parms(mfiltershort) ""
PARM set parms(fpphase) "Minimum phase"
PARM set parms(filter_mode) "Use externally defined filter"

```

PARM set parms(b\_mode) "Apply band-pass filtering"  
PARM set parms(q\_mode) "Do not apply Q filtering"  
PARM set parms(w\_mode) "Do not apply Wiener deconvolution"  
PARM set parms(ns) 500  
PARM set parms(dt) 0.002  
PARM set parms(mdt) 0.0005  
PARM set parms(df) 1.0  
PARM set parms(iz) 0  
PARM set parms(nyqpct) 75  
PARM set parms(nyqslp) 72  
PARM set parms(spopt) db  
PARM set parms(adepth) 6.0  
PARM set parms(lwrcut) 6.0  
PARM set parms(lwrslp) 18.0  
PARM set parms(uprcut) 128.0  
PARM set parms(uprslp) 72.0  
PARM set parms(qvalue) 100.0  
PARM set parms(twtvalue) 3.0  
PARM set parms(wsvalue) 1  
PARM set parms(wtvalue) 1  
PARM set parms(wlvalue) 25  
PARM set parms(wgvalue) 1  
PARM set parms(wwvalue) 0.5  
PARM set parms(pdffriendly) 1  
PARM set parms(showsigr) 0  
PARM set parms(showparms) 1  
PARM set parms(novols) 0  
PARM set parms(defsubtime) 0.01  
PARM set parms(lwf) 10.0  
PARM set parms(hgf) 50.0  
PARM set parms(timeupr) 1.0  
PARM set parms(fspecupr) 250.0  
PARM set parms(tampupr) 0.0  
PARM set parms(aampupr) 0.0  
PARM set parms(maxdip) 90  
PARM set parms(sigdip) 5  
PARM set parms(inangle) 0  
PARM set parms(xangle) 90  
PARM set parms(frickemin) 100  
PARM set parms(frickemax) 210  
PARM set parms(mindbah) 60  
PARM set parms(maxdbah) 210  
PARM set parms(mindbbr) 60  
PARM set parms(maxdbr) 210  
PARM set parms(mindbzr) 60  
PARM set parms(maxdbzr) 210  
PARM set parms(mindbi) 60  
PARM set parms(maxdbi) 210  
PARM set parms(pvmin) 80  
PARM set parms(pvmax) 170  
PARM set parms(diramp) 1  
PARM set parms(wantazi) 1  
PARM set parms(wantdir) 1  
PARM set parms(freq1) 30  
PARM set parms(freq2) 60  
PARM set parms(freq3) 90  
PARM set parms(freq4) 120  
PARM set parms(aziarange) 1000  
PARM set parms(slayrange) 1000

PARM set parms(annrange) 1000  
PARM set parms(sweeptrange) 5000  
PARM set parms(slaydepth) 20  
PARM set parms(sweptdepth) 5000  
PARM set parms(sweptlof) 0  
PARM set parms(swepthif) 25000  
PARM set parms(audiogram) 0  
PARM set parms(cetacean) Uncorrected  
PARM set parms(absorb) 1  
PARM set parms(mxfreq) 25  
PARM set parms(rangeslider) 19  
PARM set parms(msoption) 0  
PARM set parms(smsvalue) 1000  
PARM set parms(adrop) 10.0  
PARM set parms(pbmin) 10.0  
PARM set parms(pbdrop) 10.0  
PARM set parms(avdbdrop) 1.5  
PARM set parms(mddbdrop) 3.0  
PARM set parms(nxmin) 0.99  
PARM set parms(pb\_type) 1  
PARM set parms(ndropmx) 1  
PARM set parms(mamexec\_boem) 1  
PARM set parms(mamexec\_epbc) 1  
PARM set parms(mamexec\_jncc) 1  
PARM set parms(mamexec\_pon14a) 0  
PARM set parms(domfreq) 20.0  
PARM set parms(waveht) 0.0  
PARM set parms(noghost) 0  
PARM set parms(cdepth) 6.0  
PARM set parms(cdepth2) 0.0  
PARM set parms(cghost) 1  
PARM set parms(refco-type) 2  
PARM set parms(refco-dir) -1.0  
PARM set parms(refco) 100  
PARM set parms(rmsdelay) 0.0  
PARM set parms(seatemp) 30  
PARM set parms(vsound) 1545  
PARM set parms(obscd) 1  
PARM set parms(obscd-last) 1  
PARM set parms(obspt) 1  
PARM set parms(obsx) 0.0  
PARM set parms(obsy) 0.0  
PARM set parms(obsz) 10.0  
PARM set parms(ntries) 1  
PARM set parms(ncool) 50  
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PARM set parms(xsymm) 1  
PARM set parms(sbsymm) 1  
PARM set parms(fixx) 0  
PARM set parms(avgcorr) 1  
PARM set parms(mnvol) 500.0  
PARM set parms(mxvol) 3000.0  
PARM set parms(mndep) 4.0  
PARM set parms(mxdep) 7.0  
PARM set parms(ncdep) 0.5  
PARM set parms(mnx) 0.0  
PARM set parms(mxx) 10.0  
PARM set parms(ncx) 0.5  
PARM set parms(mxdel) 0.1

PARM set parms(ncdel) 0.01  
PARM set parms(check-p2p) 0  
PARM set parms(lsel-p2p) 0  
PARM set parms(lent-p2p) 0.0  
PARM set parms(rent-p2p) 500.0  
PARM set parms(rsel-p2p) 0  
PARM set parms(extremal-p2p) 0  
PARM set parms(slider-p2p) 1  
PARM set parms(check-p2b) 0  
PARM set parms(lsel-p2b) 0  
PARM set parms(lent-p2b) 0.0  
PARM set parms(rent-p2b) 500.0  
PARM set parms(rsel-p2b) 0  
PARM set parms(extremal-p2b) 0  
PARM set parms(slider-p2b) 1  
PARM set parms(check-bpr) 0  
PARM set parms(lsel-bpr) 0  
PARM set parms(lent-bpr) 0.0  
PARM set parms(rent-bpr) 1.0  
PARM set parms(rsel-bpr) 0  
PARM set parms(extremal-bpr) 0  
PARM set parms(slider-bpr) 1  
PARM set parms(check-rip) 0  
PARM set parms(lsel-rip) 0  
PARM set parms(lent-rip) 0.0  
PARM set parms(rent-rip) 200.0  
PARM set parms(rsel-rip) 0  
PARM set parms(extremal-rip) 0  
PARM set parms(slider-rip) 1  
PARM set parms(check-mpb) 0  
PARM set parms(lsel-mpb) 0  
PARM set parms(lent-mpb) 100.0  
PARM set parms(rent-mpb) 300.0  
PARM set parms(rsel-mpb) 0  
PARM set parms(extremal-mpb) 0  
PARM set parms(slider-mpb) 1  
PARM set parms(check-apb) 0  
PARM set parms(lsel-apb) 0  
PARM set parms(lent-apb) 100.0  
PARM set parms(rent-apb) 300.0  
PARM set parms(rsel-apb) 0  
PARM set parms(extremal-apb) 0  
PARM set parms(slider-apb) 1  
PARM set parms(check-ten) 0  
PARM set parms(lsel-ten) 0  
PARM set parms(lent-ten) 0.0  
PARM set parms(rent-ten) 1000000000.0  
PARM set parms(rsel-ten) 0  
PARM set parms(extremal-ten) 0  
PARM set parms(slider-ten) 1  
PARM set parms(check-thf) 0  
PARM set parms(lsel-thf) 0  
PARM set parms(lent-thf) 0.0  
PARM set parms(rent-thf) 1000000000.0  
PARM set parms(rsel-thf) 0  
PARM set parms(extremal-thf) 0  
PARM set parms(slider-thf) 1  
PARM set parms(check-eff) 0  
PARM set parms(lsel-eff) 0

PARM set parms(lent-eff) 0.0  
PARM set parms(rent-eff) 100.0  
PARM set parms(rsel-eff) 0  
PARM set parms(extremal-eff) 0  
PARM set parms(slider-eff) 1  
PARM set parms(ovar-vol) 1  
PARM set parms(ovar-del) 0  
PARM set parms(ovar-inl) 0  
PARM set parms(ovar-dep) 1  
PARM set parms(dmode) 2  
PARM set parms(sep\_in\_y) 2.0  
PARM set parms(excesstemp) 0.000000  
PARM set max\_inv\_item 256  
PARM set parms(drawgrid) 1  
PARM set parms(pbzero) 0  
PARM set parms(siggrid) 0  
PARM set parms(linethick) 2  
PARM set parms(plotres) 1  
PARM set parms(indivsig) 1

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Maximum users : 1