Calibration

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Calibration Objective

Generic Goal:

- a comparison between measurements: one of known magnitude or correctness made or set with one device and another measurement made in as similar a way as possible with a second device.

source: Wikipedia

Acoustic instruments (e.g. echosounder):

- compensate for differences between theoretical and empirical performance of an instrument. Track instrument performance over time.

Two data streams: single targets, ensemble backscatter

Echosounder Calibration

Prior to 1980's major source of error

Foote *et al*. (1987) Calibration of acoustic instruments for fish density estimation: a practical guide ICES CRR 144

Demer *et al*. (2015) Calibration of acoustic instruments. ICES CRR 326

3 Components: transmit, receive, system

3 Methods: reciprocity, calibrated hydrophone, standard target

Reciprocity

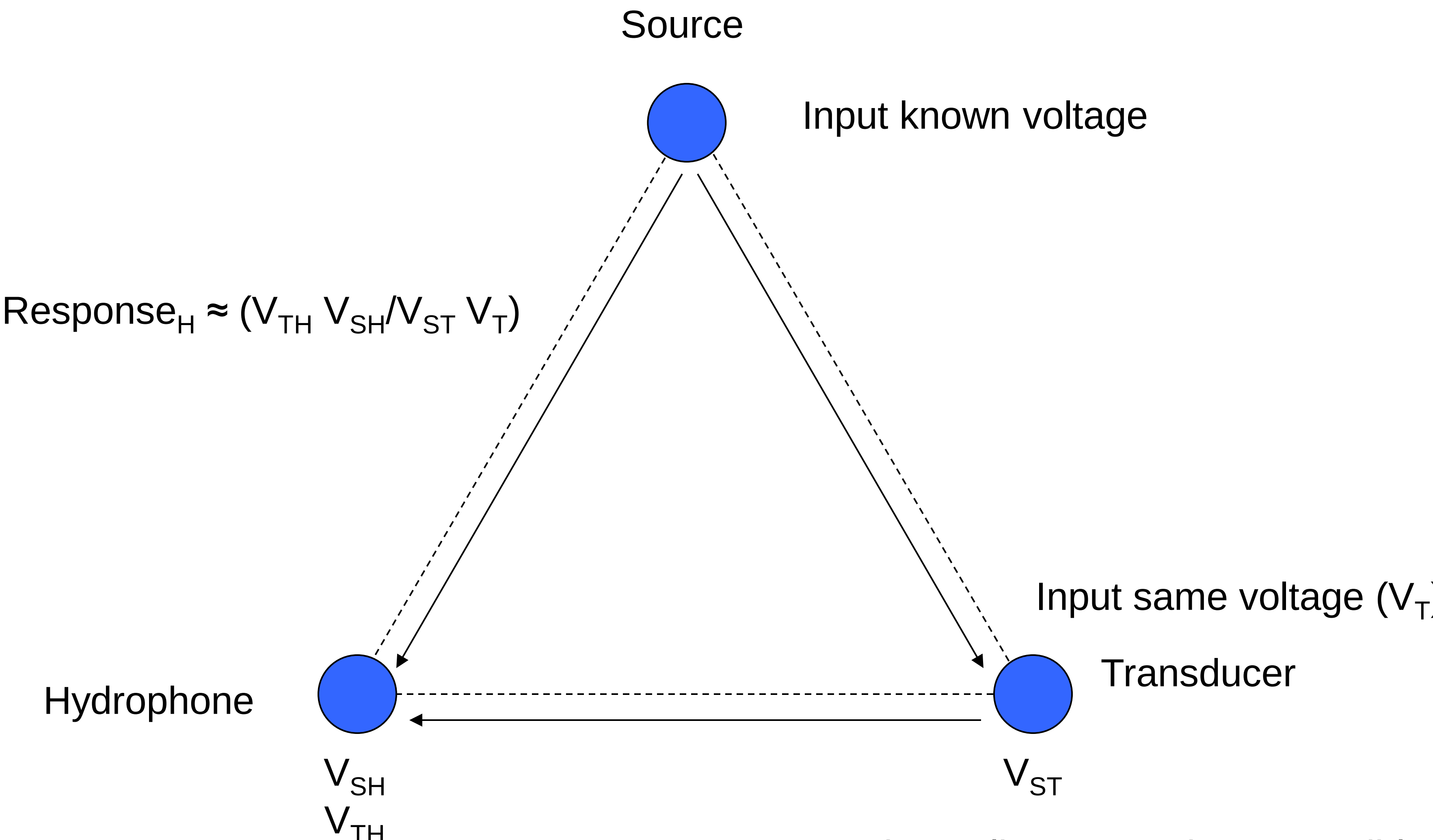
- absolute method of calibration (Foldy and Primakoff 1945, 1947)
- based on electroacoustic reciprocity principle using physical quantities (voltage, impedance, frequency, range, temperature, pressure)
- 3 possible components: projector (i.e. source), hydrophone (1 kHz to 500 kHz), transducer

3 Methods:

- 3 devices: ratio of the voltage across the terminals of the receiving device to the current driving the transmitting device.
- 2 transducers: transmit over known distance
- 1 transducer: single transducer and perfect reflector

see MacLean (1940); Carstensen (1947)

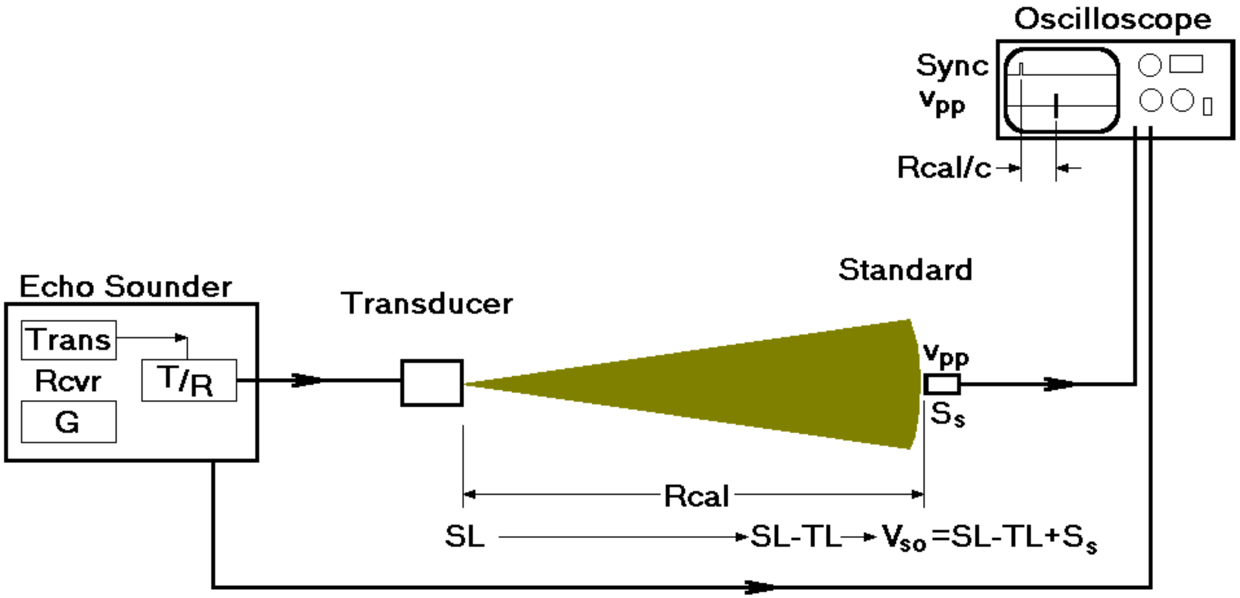
Reciprocity Calibration



Transducer: linear, passive, reversible

Calibrated Hydrophone: transmit

Source Level



The oscilloscope vpp (volts) is converted to V_{so} (dB_V):

$V_{so} = 20 \cdot \log(v_{pp}/2/1.414)$

The Sonar equation for the one-way transmission to the standard:

$V_{so} = SL - TL + S_s$

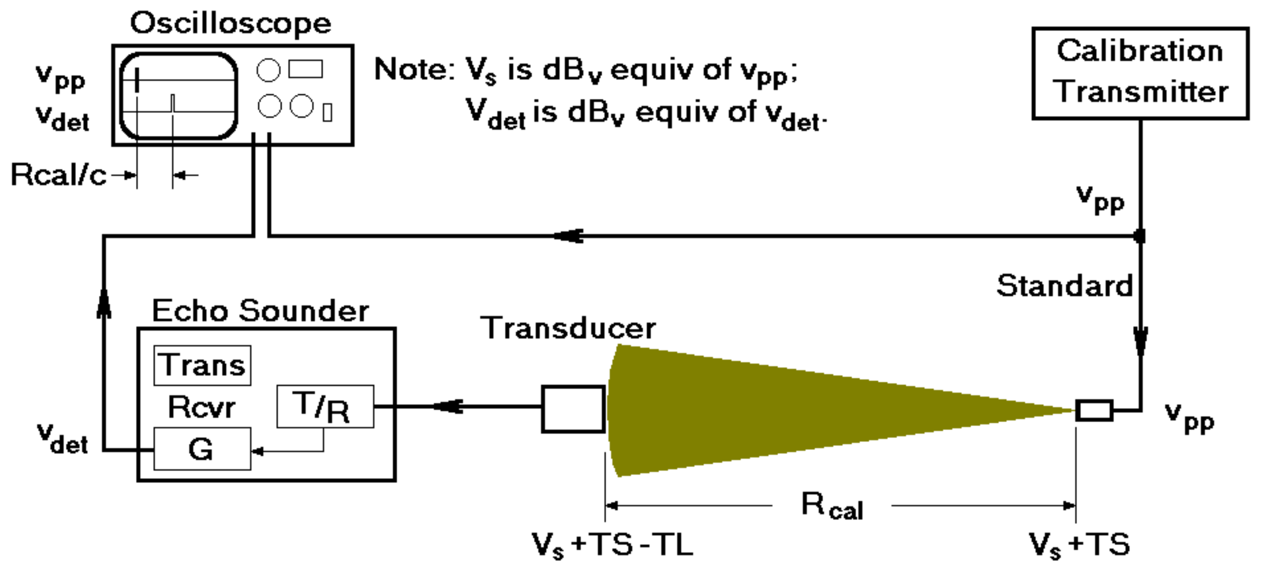
$TL_{cal} = 20 \cdot \log(R_{cal}) + \alpha R_{cal}$

SS is a calibration value provided with the standard, therefore:

$SL = V_{so} + TLcal - S_s$

Calibrated Hydrophone: receive

G_1



$v_{det} = G + V_s + TS - TL$

$TL_{cal} = 20 \log(R_{cal}) + \alpha R$

TS is a calibration value supplied with the standard.

Remembering that $G = G_1 + G_{tvg} + RG$,

with a 40 log TVG characteristic:

$G_{tvg} = 40 \log(R_{cal}) + 2\alpha R_{cal}$

$G_1 = v_{det} - G_{tvg} - RG - V_s + TS - TL_{cal}$

Laboratory Calibration Results

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TRANSDUCER MEASUREMENTS

	Part 1	Part 2	Part 3	Part 4	All Parts
Measured at: f (kHz)	38,0	38,0	38,0	38,0	38,0
Beamwidth					
Longitudinal: ß1 (deg)					11,9
Transversal: ß2 (deg)					11,8
Directivity index (dB): 10 log(2.5/(sin(ß1/2)*sin(ß2/2)))					23,7
Equivalent two way beam angle (dB): 10 log(ß1*ß2/5800)					-16,1
Impedance					
|Z| (ohm) :	58,6	60,5	62,6	52,5	14,6
Phase (deg) :	-1,6	6,4	0,5	-0,5	8,3
Transmitting response (at 1 metre)					
Si (dB re 1 µPa/A):	205,1	205,1	205,6	204,9	205,2
Su (dB re 1 µPa/V):	169.8	169.5	169.7	170.5	181.9
Receiving sensitivity					
Theoretical open circuit (Si-354.1-20 log f): (dB re 1 V/µPa)	-180,6	-180,6	-180,1	-180,8	-180,5
Leaking resistance (Mohm) :	OK	OK	OK	OK	OK
Type: ES38-12					
Serial no: 28096					
Watertemp: 19,0 °C					
Tested by: S Date: 24. jan. 2005					

Transducer Beam Pattern

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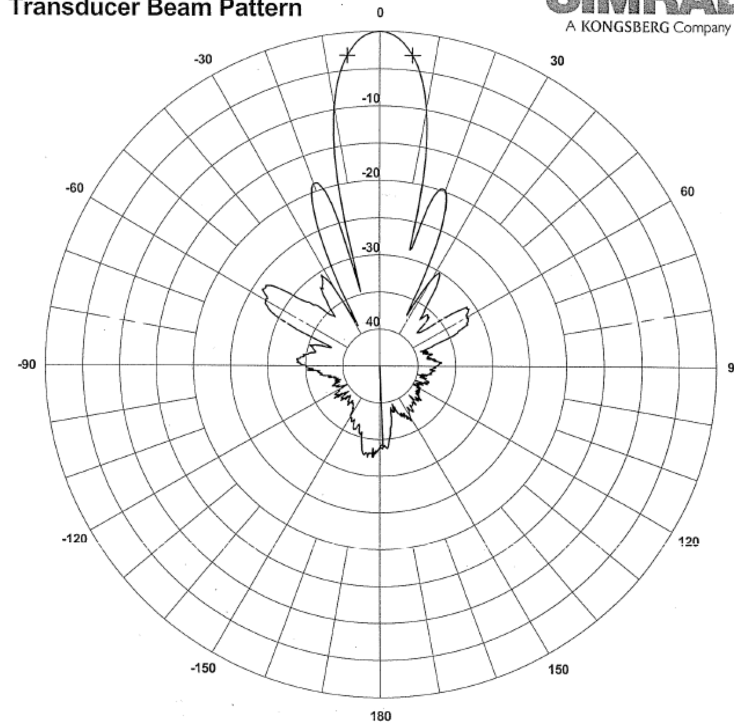


Transducer Type:	ES38-12 312-110035	**Plane:**	Transversal
Serial no.:	28096	**Hydrophone Type:**	B&K 8104
Frequency:	38,0 kHz	**Hydrophone Serno.:**	2393692
Tested by:	SN	**Hydrophone Cal.Date:**	25.10.04
Date/time:	24.01.2005 12:24:27	**Distance to Hydrophone:**	6,00 m
Voltage Generator:	1000 mV	**Water Temperature:**	19 °C
Amplifier Gain:	21 dB	**Module:**	1
Beam Width:	11,85°	**Element:**	5
Source Level:	215,13 dB		
DI:	23,95 dB		

Standard Target Method

- ensure system output is constant relative to a standard target
- measure transmit-receive sensitivity of system on axis and over main lobe
- calibrate as system (i.e. platform, power supply, echosounder) is used in the field

Calibration components: sensitivity, directivity

Operationally: on axis, map beam pattern

Gain g_o and $S_a corr$ Values

$$S_v = P_{er} + 20\log_{10}(r) + 2\alpha_a r - 10\log_{10}\left(\frac{(p_{et}\lambda^2 {g_0}^2 c_w \tau \psi)}{32\,\pi^2}\right) - \ 2S_a corr \text{ , and}$$

$$TS = P_{er} + 40\log_{10}(r) + 2\alpha_a r - 10\log_{10}\frac{(p_{et}\lambda^2 {g_0}^2)}{16\pi^2} - 20\log_{10}\left(\frac{g(\alpha,\beta)}{g_0}\right) \text{ ,}$$

where P_{er} is power, r is range, α is absorption coefficient, λ is wavelength, g_o is gain, c_w is speed of sound in water, τ is pulse duration, ψ is the equivalent two way beam angle,

http://support.echoview.com/WebHelp/Reference/Algorithms/Echosounder/Simrad/EK60_Power_to_Sv_and_TS.htm

Calibration Outcome

$$S_v = P_{er} + 20\log_{10}(r) + 2\alpha_a r - 10\log_{10}\left(\frac{(p_{et}\lambda^2 g_0{}^2 c_w \tau \psi)}{32\pi^2}\right) - 2S_a corr \text{ , and}$$

$$TS = P_{er} + 40\log_{10}(r) + 2\alpha_a r - 10\log_{10}\frac{(p_{et}\lambda^2 g_0{}^2)}{16\pi^2} - 20\log_{10}\left(\frac{g(\alpha,\beta)}{g_0}\right) \text{ ,}$$

Operationally:

ER60/70/80 software: Update S_v gain and S_a correction values

Echoview: Update .ecs file with new G_0 and S_a correction values

Sa Correction

- integration value (i.e. correction factor) required to make the theoretical and measured Sv match.
- accomplished by adjusting pulse length

Sa correction = theoretical gain - system gain

theor Sa/meas Sa = 1, if not then adjust Sa correction

$$S_{a,corr} = \frac{1}{2}\frac{\frac{\tau_{nom}}{4}\sum_i P_i}{\tau_{nom}P_{\max}} = \frac{1}{2}\frac{\sum_i P_i}{4P_{\max}}$$

where P is power, τ is pulse length, nom is nominal

Determining g_0 and $S_a corr$ Values

$$\text{calc. TS gain} = \frac{TS_{measured} - TS_{theory}}{2} + g_{old}$$

$$\text{calc. Sv gain} = \frac{10\log(Sa_{measured} / Sa_{theory})}{2} + g_{old} + Sa_{old}$$

calc. Sa correction = calc. Sv gain – calc. TS gain

new g_0 = calc. Sv gain
new Sa correction = calc. Sa correction

Field Calibration Procedure

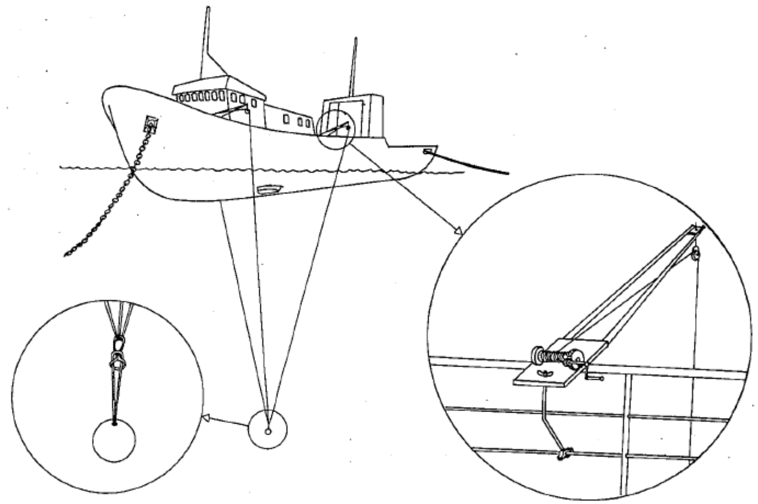
- at start of each survey, recommended at end of survey

- set up downriggers/stepper motors and place calibration sphere under transducers

- on axis (~10 min) and swing (~40 min) for each pulse length (typically 0.512, 1.024 ms) for each frequency

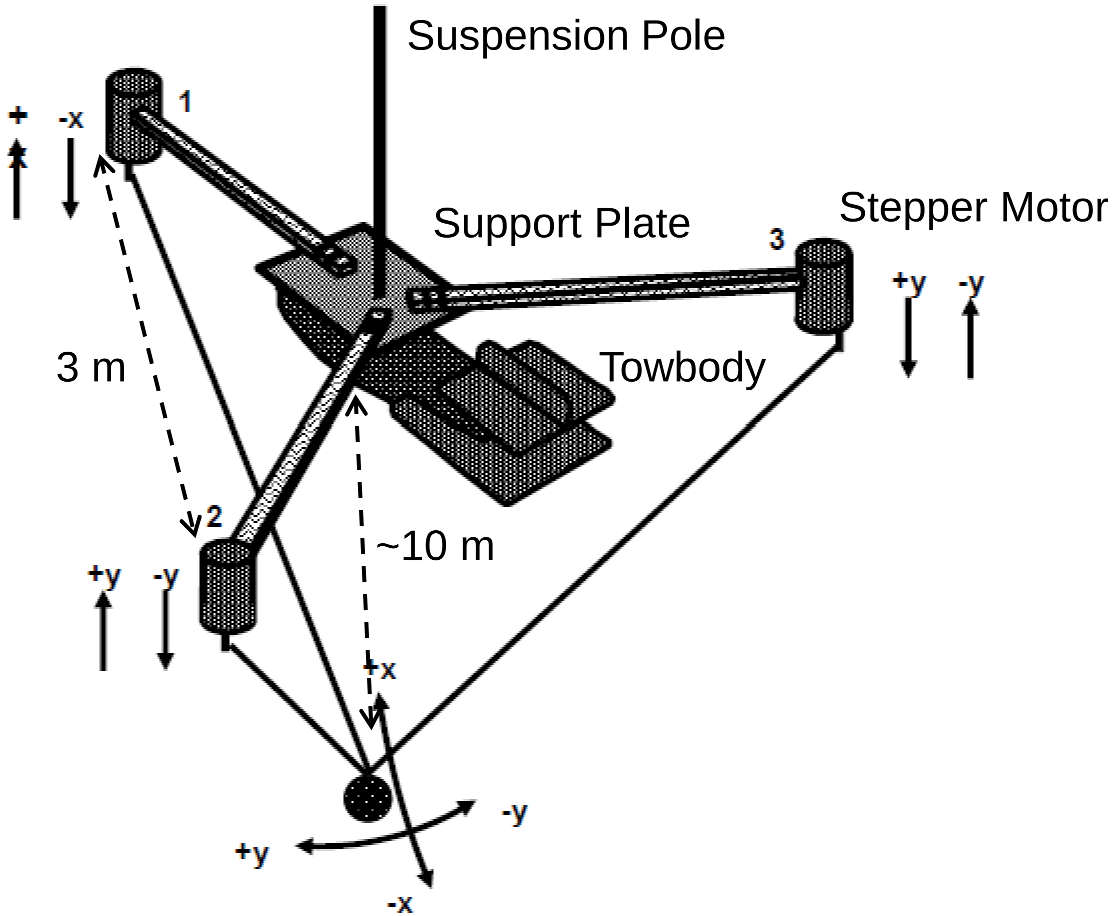
- analyze data using LOBES program, within Echoview, and/or tabulate in Excel

Calibration Setup



- 2 point anchor
- 3 down riggers/stepper motors
- harness and calibration sphere

Towbody Setup



Distance to Calibration Sphere?

minimum

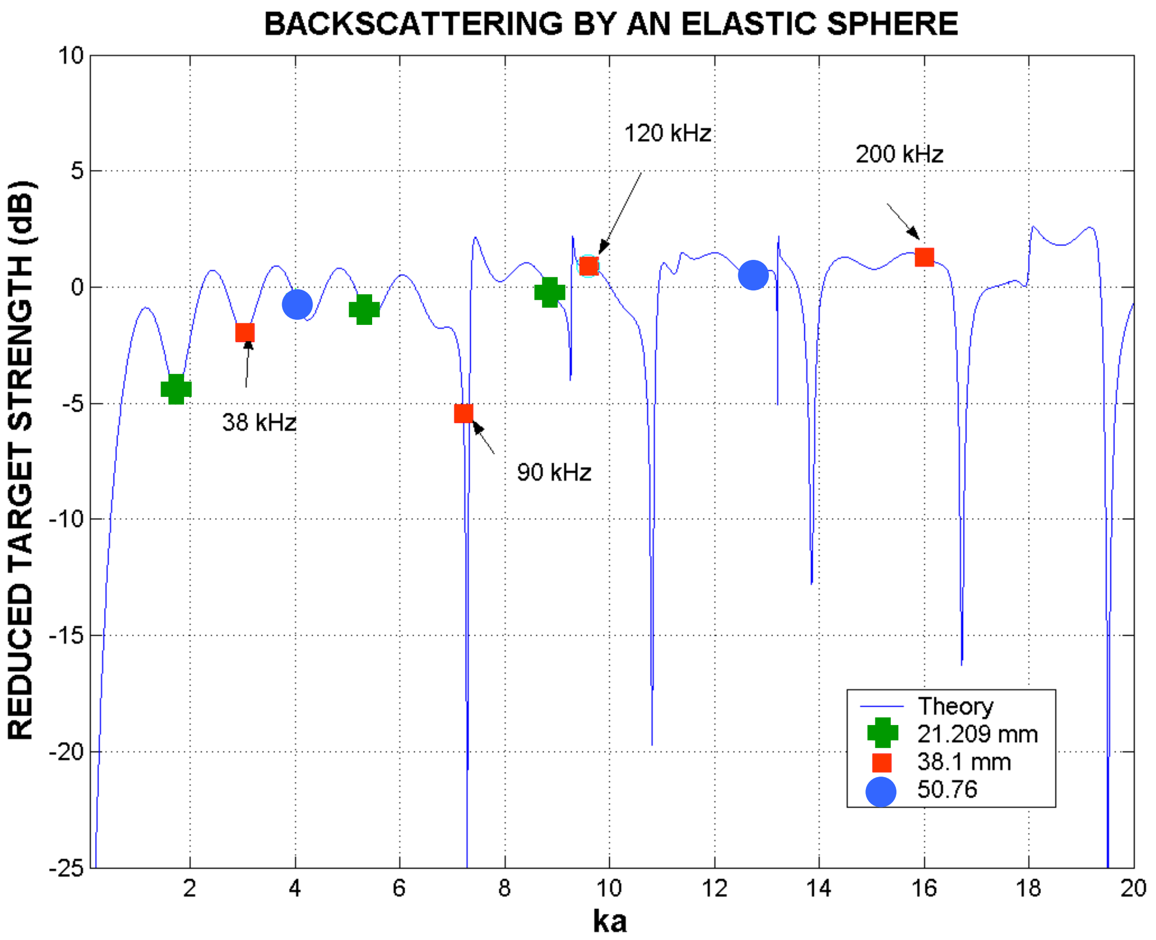
Transducer	Freq.	Wavelength	Beamwidth	Eff. radius	Diameter	Nearfield	2xNearfield
model							
	kHz	cm	degrees	cm	cm	m	m
12-16/60	12	12.42	16	22.9	45.8	1.7	3.4
ES18	18	8.28	11	22.2	44.4	2.4	4.8
38-7	38	3.92	7	16.5	33.0	2.8	5.6
38-9	38	3.92	9	12.9	25.7	1.7	3.4
ES38 B	38	3.92	7	16.5	33.0	2.8	5.6
ES38-10	38	3.92	10	11.6	23.1	1.4	2.7
ES38-12	38	3.92	12	9.6	19.3	0.9	1.9
50-7	50	2.98	7	12.6	25.1	2.1	4.2
ES70-11	70	2.13	11	5.7	11.4	0.6	1.2
ES70-7C	70	2.13	7	9.0	17.9	1.5	3.0
ES120-7C	120	1.24	7	5.2	10.5	0.9	1.8
ES200-7C	200	0.75	7	3.1	6.3	0.5	1.1
ES333-7C	333	0.45	7	1.9	3.8	0.3	0.6

$R = D^2/\lambda$: … ield

where R = near fiel … ngth,
f = frequen …

Calibration Sphere

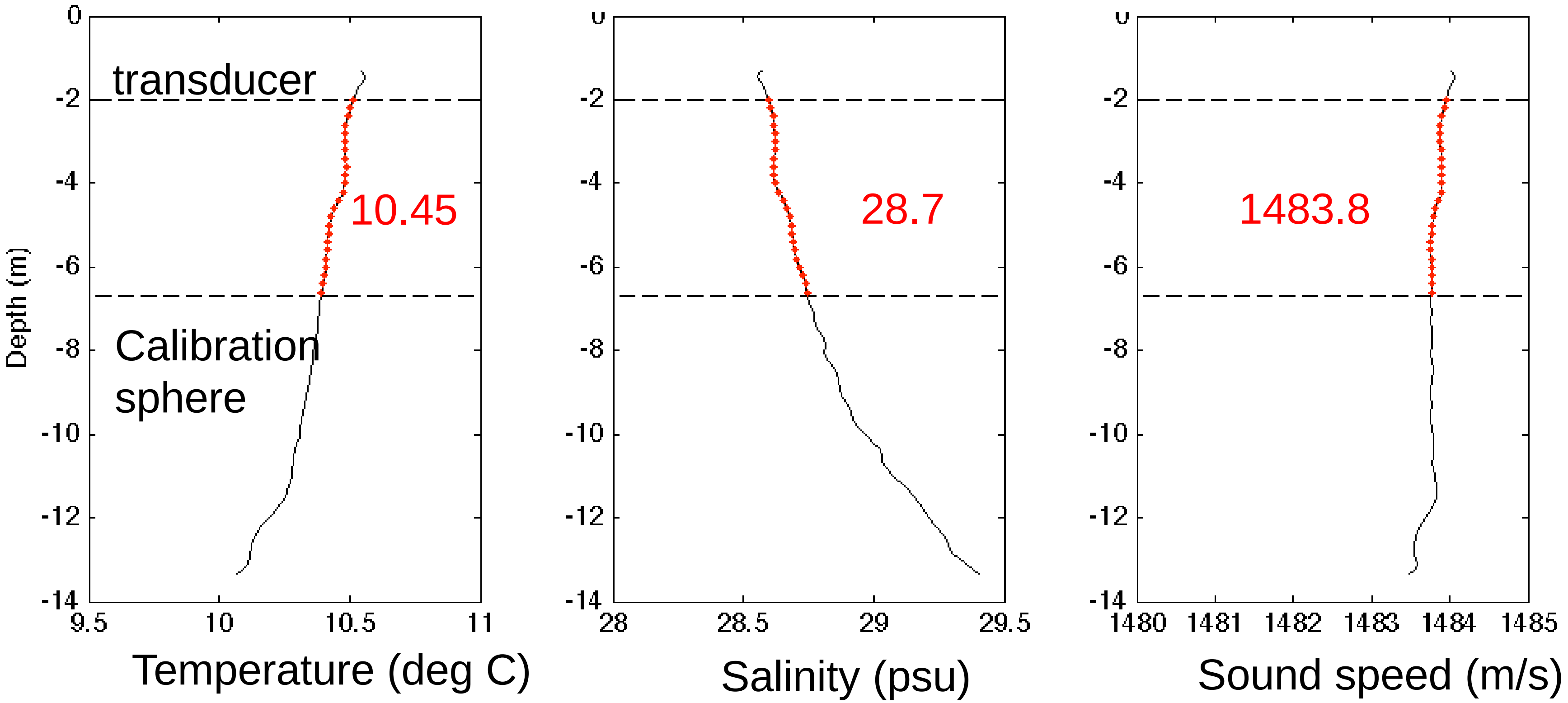
- Copper or Tungsten Carbide
- known diameter, known material properties



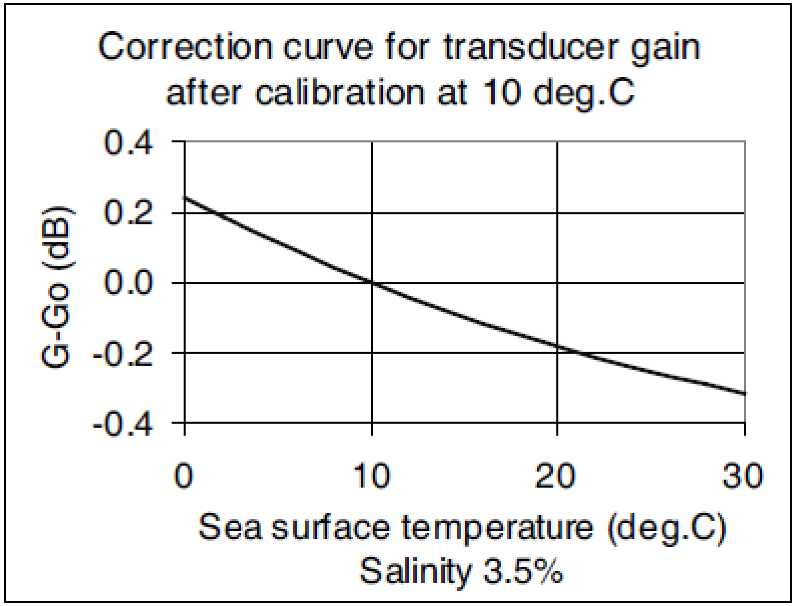
D. Chu & R. Thomas

What Sound Speed to Use?

Average value between transducer and calibration sphere

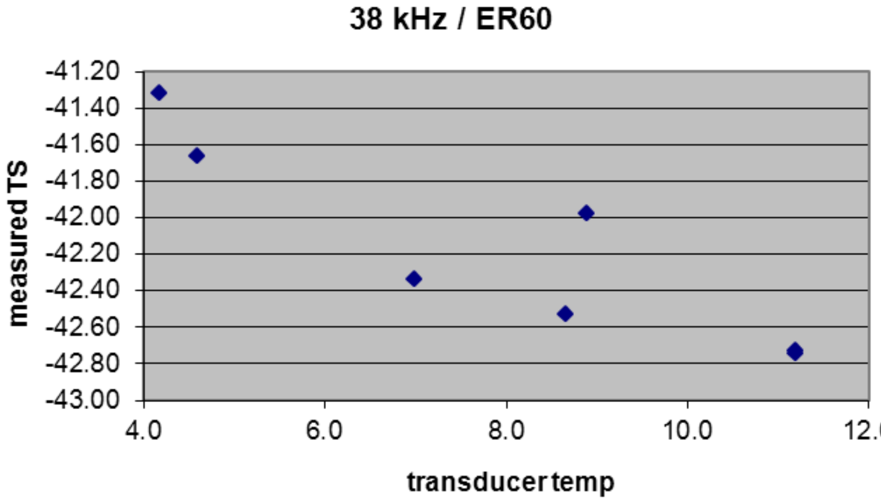


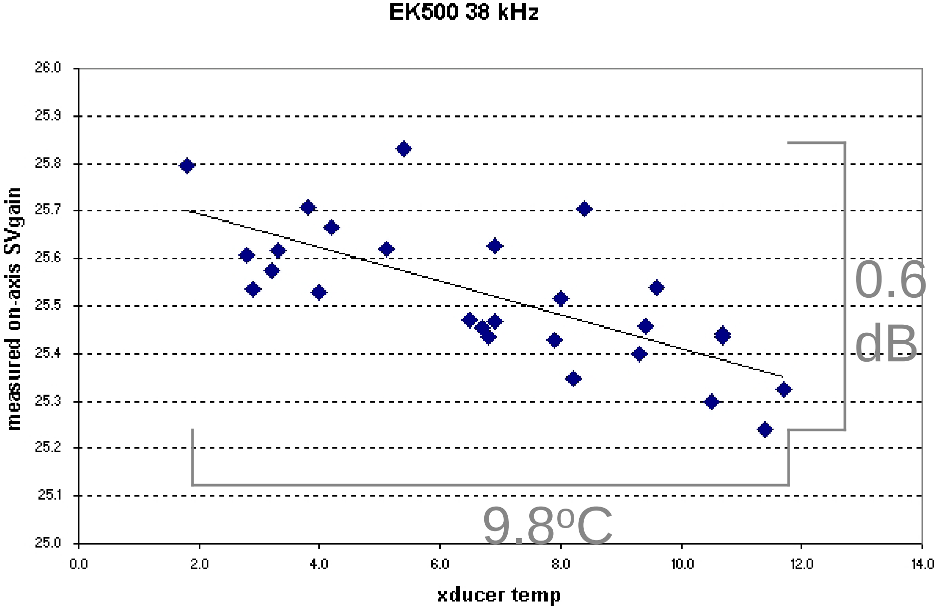
Effect of Temperature on Gain



Bodholt 2002

AFSC: Seattle - Alaska



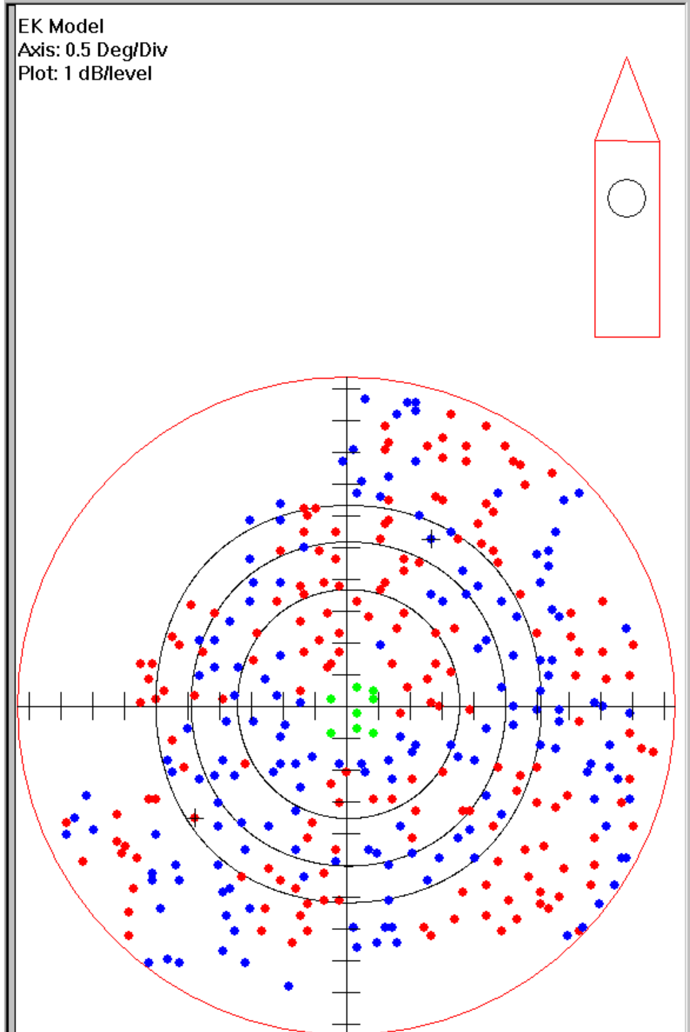


Lobes Output 120 kHz

flood tide

Calibration

File View Stop Help




```
# Calibration  Version   2.1.0.11
#
# Date:  7/24/2009
#
# Comments:
#   120 swing including on axis data, 512 pulse length
#
# Reference Target:
#   TS                   -39.50 dB       Min. Distance           9.50 m
#   TS Deviation           6.0 dB        Max. Distance          14.50 m
#
# Transducer:  ES120-7C  Serial No.   272
#   Frequency            120000 Hz       Beamtype                Split
#   Gain                  25.57 dB       Two Way Beam Angle    -20.9 dB
#   Athw. Angle Sens.      23.00         Along. Angle Sens.      23.00
#   Athw. Beam Angle      6.90 deg       Along. Beam Angle     6.90 deg
#   Athw. Offset Angle    0.00 deg       Along. Offset Angle   0.00 deg
#   SaCorrection          -0.44 dB       Depth                   3.00  m
#
# Transceiver:  GPT 120 kHz 009072016d81 1 ES120-7C
#   Pulse Duration        0.512 ms       Sample Interval      0.095   m
#   Power                   500  W       Receiver Bandwidth   5.56 kHz
#
# Sounder Type:
#   EK60 Version  2.1.2
#
# TS Detection:
#   Min. Value            -50.0 dB       Min. Spacing            100 %
#   Max. Beam Comp.         6.0 dB       Min. Echolength          80 %
#   Max. Phase Dev.         8.0          Max. Echolength         180 %
#
# Environment:
#   Absorption Coeff.  37.6 dB/km        Sound Velocity     1487.0 m/s
#
# Beam Model results:
#   Transducer Gain     = 25.15 dB       SaCorrection         = -0.38 dB
#   Athw. Beam Angle    = 6.10 deg       Along. Beam Angle    = 6.27 deg
#   Athw. Offset Angle = 0.03 deg        Along. Offset Angle= 0.04 deg
#
# Data deviation from beam model:
#   RMS =     0.37 dB
#   Max =     1.43 dB  No. =    337  Athw. = -2.4 deg  Along = -1.8 deg
#   Min =    -1.58 dB  No. =    177  Athw. =  1.3 deg  Along =  2.6 deg
```

Simrad LOBES

- software program to model gain and beam pattern
- beam pattern 4th order polynomial
- ongoing discussion of technique to estimate gains

```
#  Calibration  Version   2.1.0.11
#
#  Date:  7/22/2007
#
#  Comments:
#    70 kHz 512 swing
#
#  Reference Target:
#    TS                     -43.00 dB       Min. Distance           6.00 m
#    TS Deviation             6.0 dB        Max. Distance           7.00 m
#
#  Transducer:  ES70-7C  Serial No.   150
#    Frequency               70000 Hz       Beamtype               Split
#    Gain                    27.00 dB       Two Way Beam Angle   -21.0 dB
#    Athw. Angle Sens.        23.00         Along. Angle Sens.     23.00
#    Athw. Beam Angle        6.83 deg       Along. Beam Angle    6.78 deg
#    Athw. Offset Angle      0.00 deg       Along. Offset Angle  0.00 deg
#    SaCorrection             0.00 dB       Depth                 0.50  m
#
#  Transceiver:  GPT  70 kHz 009072058c9d 3 ES70-7C
#    Pulse Duration         0.512 ms        Sample Interval     0.095   m
#    Power                   1000  W        Receiver Bandwidth   4.69 kHz
#
#  Sounder Type:
#    EK60 Version  2.1.1
#
#  TS Detection:
#    Min. Value             -50.0 dB        Min. Spacing            100 %
#    Max. Beam Comp.          6.0 dB        Min. Echolength          80 %
#    Max. Phase Dev.           8.0          Max. Echolength         180 %
#
#  Environment:
#    Absorption Coeff.  20.0 dB/km          Sound Velocity     1488.8 m/s
#
#  Beam Model results:
#    Transducer Gain    = 27.48 dB          SaCorrection          = -0.48 dB
#    Athw. Beam Angle   = 6.50 deg          Along. Beam Angle   = 6.55 deg
#    Athw. Offset Angle = 0.03 deg          Along. Offset Angle= 0.01 deg
#
#  Data deviation from beam model:
#    RMS =     0.11 dB
#    Max =     0.33 dB  No. =   176  Athw. =  3.2 deg  Along = -2.4 deg
#    Min =    -0.32 dB  No. =   270  Athw. =  4.8 deg  Along =  0.1 deg
#
#  Data deviation from polynomial model:
#    RMS =     0.07 dB
#    Max =     0.21 dB  No. =   178  Athw. =  3.8 deg  Along = -3.2 deg
#    Min =    -0.24 dB  No. =    80  Athw. =  3.1 deg  Along = -3.1 deg
#
#  Data:
#  No.     Time      Distance  TS-c     TS-u       Athw.    Along     sA
#                       [m]    [dB]     [dB]       [deg]    [deg]  [m2/nm2]
#
   1  15:21:30.32   6.66    -43.79  -55.69     -4.65     1.47       315
   2  15:21:30.57   6.65    -43.25  -52.93     -4.16     1.41       591
   3  15:21:30.74   6.64    -42.92  -50.78     -3.73     1.28       972
```

LOBES Conundrum

Designed to estimate: gain, acoustic axis, beam width

- locations based on phase (i.e. lag time) differences and parameter that converts electronic (i.e. phase) to mechanical angle

but no independent measurement of angle against phase

- phase is used to obtain target angles and to identify main lobe of beam

Calibration Procedure Conundrum

LOBES parameters results in compensated TS values for beam pattern

- physical location may be incorrect but the TS will be correct because beam pattern is shifted

2 Choices:

- use LOBES calculations
- calculate on axis gain and Sa correction values and beam angles from tank calibration

FAR Lab Calibration Calculations

Microsoft Excel - FHL Calibration Jul 2009.xls

AF10 | used hybrid approach (jkh)

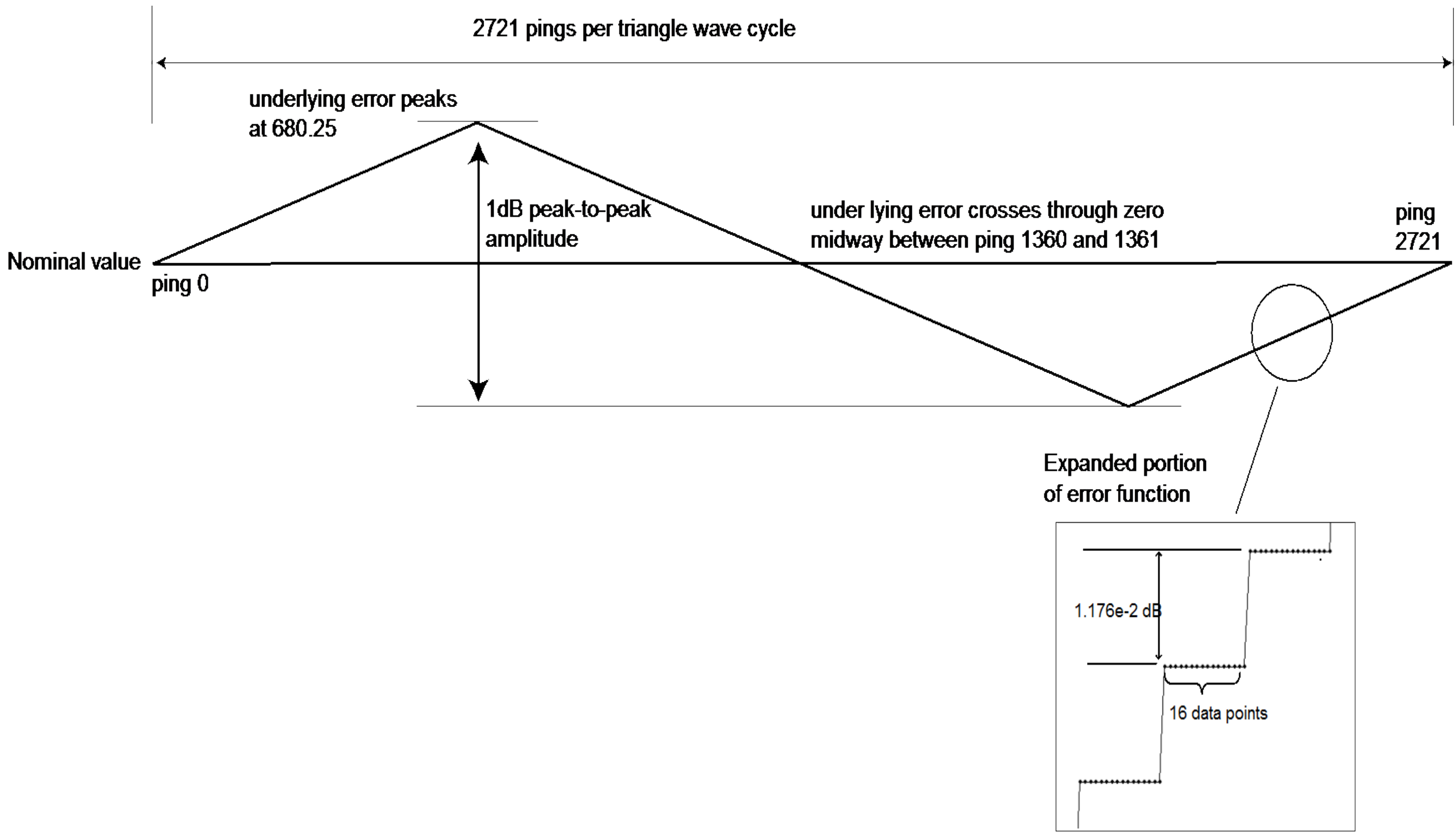
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
4–5													Input system values			Echoview values		On-axis Theoretical values							Swin EK lobe	
6	Date	Location	Pulse length	Time	Xducer temp	Xducer depth	Sphere temp	Salinity	Sound speed	Sphere type	Sphere TS	Range (m)	Power (W)	System gain	System Sa corr	Meas'd TS	Meas'd Sa	Calc TS gain	Calc Sa	Calc Sa corr	Calc Sv gain	Lobes gain +Sa corr	Xducer gain	Sa corr	3dB along	3dB athwart
7	512 ms																									
8	18-Oct-05	North Sound	512				10.0				-39.48	13.5	500	27.00	0.00	-39.87	2559	26.81	3205	-0.29	26.51					
9	20-Jul-07	FHL	512	15:37-15:55	10.2	3.0	10.1	30.2	1485.0	WC	-39.48	12.2	500	26.81	-0.34	-41.20	2604	25.95	3924	-0.37	**25.58**	**25.99**	26.35	-0.36	6.26	6.28
10	24-Jul-09	FHL	512	15:36-15:53	10.6	3.0	10.6	30.5	1486.0	WC	-39.48	7.5	500.0	25.57	-0.44	-39.85	8069	25.39	10524	-0.83	**24.55**	**24.77**	25.15	-0.38	6.27	6.10
11																										
12	1024 ms																									
13																		0.00	#DIV/0!	#DIV/0!	**#DIV/0!**	**0.00**				
14																		0.00	#DIV/0!	#DIV/0!	**#DIV/0!**	**0.00**				
15																					Note: Lobes gain + sa corr *should* = Calc Sv gain					
16																	-20.8		2-way beam							
17																										
18																					Average	0.512 ms	26.35	-0.36	6.26	6.28
19																						1.024 ms	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
20																							spec sheet		6.94	6.92

	A	E
23	Sphere TS	theoretical TS value for the calibration sphere, taken from Foote (1990) for the tungsten carbide (WC) sphere.
24	Range	the distance from the surface to the calibration sphere
25	System gain	value in echosounder at time of calibration
26	System Sa corr	value in echosounder at time of calibration
27	Meas TS	measured, average on-axis TS value taken from Echoview (with 0.1 dB filter)
28	Meas Sa	measured integration value obtained from Echoview (with 0.1 dB filter)
29	Calc gain	(measTS – sphere TS)/2 + system gain - value needed to correct System gain to match Standard TS value
30	Calc Sa	theoretical integration value from equation using expected TS value (in ICES cal. manual)
31	Calc Sv Gain	what integration value needed to make theoretical Sv and measured values match – System Gain + Sa corr = Integration Gain (Sv gain). Adjust value for the ratio of theor Sa/ meas Sa
32	Lobes gain + Sa corr	should match Calc Sv Gain

File info / Factory Defaults / Current settings / 38_28096 SW / **120_272 SW** / Noise levels

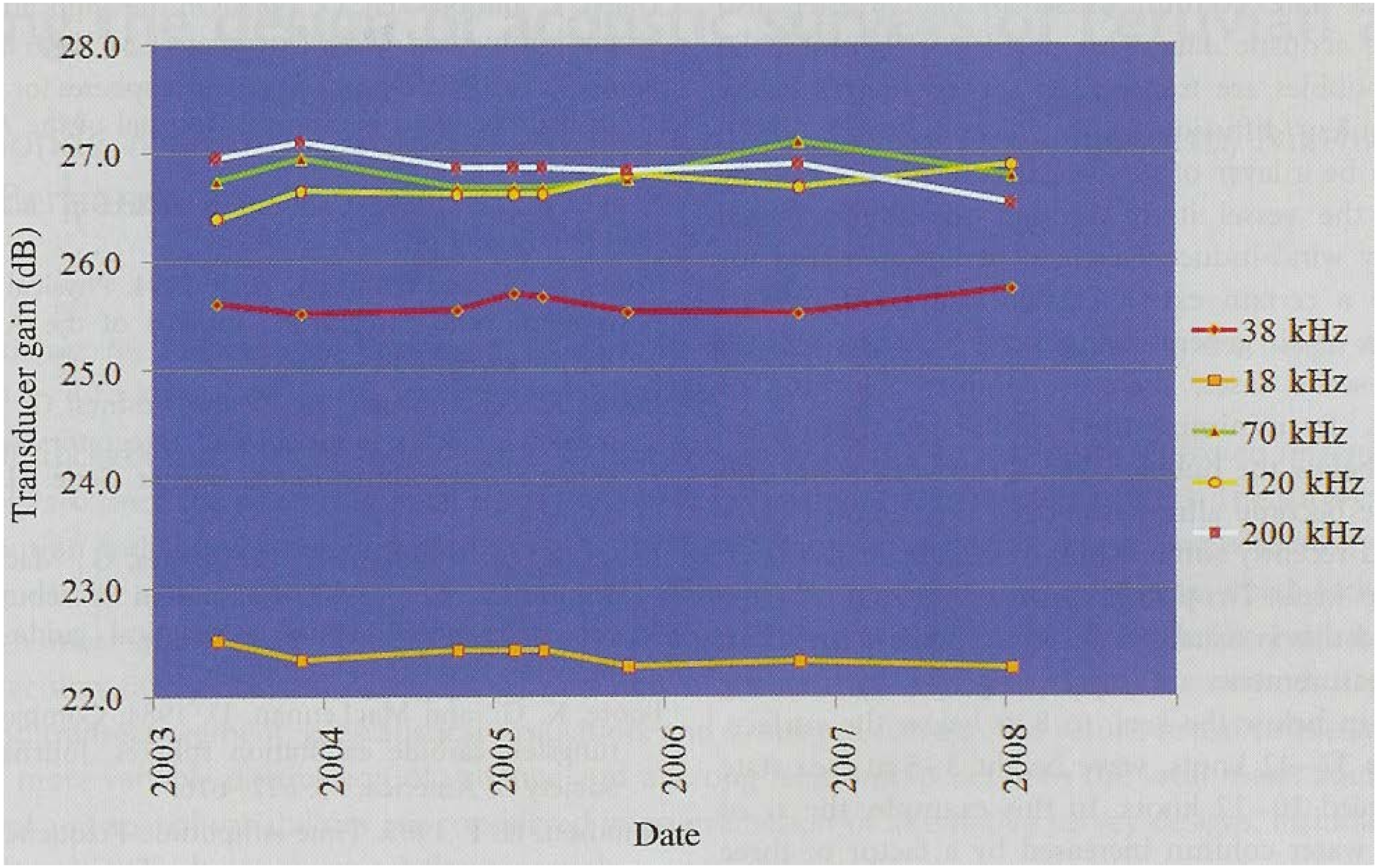
Ready

ES-60 Triangle Wave



see Ryan and Kloser 2004

Transducer Stability



Knudsen 2009

Calibration Analysis Synopsis