Efficiency of parametric ultrasound generation in relaxing media for very shallow-water echo sounders

Patricia Ordóñez Cebrián, Noé Jiménez González, Víctor Espinosa Roselló, Vicente Puig-Pons, Ester Soliveres González
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1. INTRODUCTION

45kHz Primary source

222.5kHz Primary beam

177.5kHz Primary beam 2

45kHz Parametric beam

\[ \alpha = 30^\circ \]
1. INTRODUCTION

• Parametric acoustic generation is a non-linear effect introduced P. Westervelt in the 60’s.

• Generation of spectral components: high frequency harmonics, difference-frequency harmonics and sum harmonics.
1. INTRODUCTION

• Difference-frequency harmonic:
  • Low attenuation
  • Narrow and nearly side-lobe acoustic beams

• Applications:
  • Fish Biomass Estimation and behavior characterization in very shallow water (<20m)
1. INTRODUCTION

- Sea water ultrasound absorption:

  - Thermo viscous and ionic relaxation losses
  - Primary beam (due to magnesium sulfate presence) and at lower frequencies (boric and acetic)

\[ B(OH)_3 \]

\[ MgSO_4 \]

\[ H_2O \]
1. INTRODUCTION

OBJECTIVE:
1. Design of parametric echosounder for shallow water with 20° to 30° of aperture
2. Study the efficiency of the parametric sound generation

COMPUTATIONAL FINITE DIFFERENCES METHOD

EXPERIMENTAL RESULTS

INTRODUCTION OF RELAXATION LOSSES

MODEL FOR SEA WATER
2. METHODS

- Navier-Stockes equation (momentum conservation)

\[
\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \mathbf{v})
\]

\[
\rho \left( \frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p + \eta \nabla^2 \mathbf{v} + \left( \zeta + \frac{1}{3} \eta \right) \nabla (\nabla \cdot \mathbf{v})
\]

\[
\frac{\partial S_n}{\partial t} = -\frac{1}{\tau_n} S_n + \frac{\eta_n c_0^2}{\tau_n} \rho'
\]

\[
p = c_\infty \rho' + \frac{c_0^2}{\rho_0} \frac{B}{2A} \rho'^2 - \sum_{n=1}^{N} S_n
\]

- Divergence
- Diffraction (Beams)
- Model in 2 directions (Back Scattering)
- Complex field (Multiple scattering)
2. METHODS

$$\text{SLp} = 10 \log W_0 + 171 + 10 \log \frac{4 \pi S}{\lambda p^2} \ (\text{ref. dB/µPa @ 1m})$$

$$\text{SLs} = 2 \text{SLp} + 20 \log (f_s)_{\text{kHz}} + 20 \log \Delta - 287$$

$$2 \theta_{3dB} = \max \left\{ 4 \sqrt{\frac{\alpha_T \lambda_s}{4\pi}}, 1.03 \frac{\lambda_p}{d} \right\}$$
3. EXPERIMENTAL SETTINGS

TRANSMISOR:
- AIRMAR P19, fr: 195kHz, $\Phi=75\text{mm}$
- SENSORTEC SX20 fr: 210kHz, $\Phi=40\text{mm}$

RECEPTOR:
- RESON TC4034 (Omnidirectional spherical hydrophone)

MEASURE PROCEDURE:
- **DIRECTIVITY**: Acoustics waves are evaluated along the axis transducer axis in three different axial lines (-200 to 200 mm) with a spatial resolution of 25 mm.
- **ATTENUATION**: Acoustics waves are evaluated along the transducer axis, from 100 to 500 mm with a resolution of 50 mm.
4. RESULTS

DIRECTIVITY:
PRIMARY BEAM Vs SECUNDARY BEAM

![Graph showing amplitude vs radial position for numerical, primary, numerical, parametric, experimental, primary, and experimental, parametric data. The graph illustrates the comparison between primary and secondary beams in terms of directivity.]
4. RESULTS

DIRECTIVIDAD:

SECONDARY BEAM Vs E-R DISTANCE
4. RESULTS

DIRECTIVITY:
SECONDARY BEAM Vs FREQUENCY

AIRMAR P19
- Normalized Pressure
- Angle [°]

SENSORTECH SX20
- Normalized Pressure
- Angle [°]

S. beam at 75kHz
S. beam at 60kHz
S. beam at 45kHz
S. beam at 30kHz
S. beam at 15kHz

α = 30°
4. RESULTS

SPREADING AND ATTENUATION:

- Primary beam at 15kHz
- Secondary beam at 15kHz

Distance [mm]

Normalized Pressure

- \((x/100)^{-0.9171}\)
- \((x/92)^{-0.5084}\)
4. RESULTS

ANALITICAL APPROACH Vs EXPERIMENTAL RESULTS

- **TRANSDUCERS:**
  1. Airmar P19 Φ: 75mm
  2. Sensortech Sx20 Φ: 40mm
- **FREQUENCY:** 45kHz
- **DISTANCE T-R:** 350mm

<table>
<thead>
<tr>
<th></th>
<th>2θ3dB (measure)</th>
<th>2θ3dB (analitical solution)</th>
</tr>
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<tbody>
<tr>
<td>6°</td>
<td></td>
<td>5.88°</td>
</tr>
<tr>
<td>10°</td>
<td></td>
<td>11°</td>
</tr>
</tbody>
</table>
4. RESULTS

SEA WATER:

45kHz

No relaxation
No losses
Relaxation losses

\[ p/p_0 \]

\[ z \text{ (mm)} \]
4. RESULTS

SEA WATER:

75kHz
4. RESULTS

SEA WATER:

![Graph showing parametric gain versus SPL primary beam for different relaxation frequencies. The graph displays lines for fp: 45 kHz relaxation, fp: 45 kHz, fp: 75 kHz relaxation, and fp: 75 kHz.]
4. RESULTS

BIG APERTURE SIMULATION:
5. CONCLUSION

- A preliminary design for shallow water echosounders has been setup.

- Relaxation losses do not offer important changes in SHALLOW water.
6. FUTURE LINES

- Experimental measures with transducers with big apertures
- Multiple and back scattering calculation
- Design parametric array (Experimental and simulation)
7. BIBLIOGRAPHY


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THANK YOU! 😊