Parametric Acoustic Source Beamwidth Control

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Abstract—In addition to its narrow beamwidth and wide-band capability, the underwater parametric acoustic source has the advantage of maintaining a relatively constant beamwidth over a wide range of difference frequencies. However, for some applications, the beamwidth of the difference frequency is narrower than desired or an adjustable beamwidth is required. This article describes techniques by which the beamwidth at a given difference frequency can be increased and varied over a 3-to-1 range by controlling the input waveform and amplitude to the transducer. The effect of the waveform changes on the harmonic content of the difference-frequency energy is also discussed.

I. INTRODUCTION

CONVENTIONAL MODELS of underwater acoustic behavior assume that signals propagate without modifications other than linear ones, such as spreading, absorption, and scattering. A more complete model, however, takes into account the nonlinear effects of the medium. In nonlinear propagation, variations in sound speed caused by pressure changes over the waveform result in noticeable distortion. At a distance from a sinusoidal source, this distortion can result in a well-developed sawtooth wave [1]. Because energy is lost in the shock fronts of such a wave, an excess attenuation due to nonlinearity occurs and is accompanied by a saturation effect, in which further increases in source level cease to affect the sound pressure level measured at a distant point.

The use of the medium’s nonlinearity to generate intermodulation products when two or more frequencies are mixed is especially interesting and valuable. Of these intermodulation products, which include the sum and difference of two frequencies mixed in the medium, the difference frequency has properties of great interest for practical underwater applications. A parametric source generates a difference-frequency signal in the medium by driving a transducer at two closely spaced frequencies (called primary frequencies) [2].

The major advantages of parametric sources include high directivity from a relatively small aperture, absence of side lobe structure, and an inherent broad-band capability. Furthermore, the directivity factor varies approximately directly with the difference frequency, in contrast with the conventional source where the directivity changes with the square of the frequency. The relatively constant beamwidth of the parametric source can be advantageous in systems requiring large bandwidths. Since the beamwidth of the parametric source is determined primarily by the length of the virtual end-fire array where the primaries interact, the beamwidth can be varied by changing the level or amplitude composition of the primary components, i.e., saturated primary waves produce broader difference-frequency beams than nonsaturated primaries [3], [4].

II. EXPERIMENTAL RESULTS

One of the effects of saturation in the parametric source is that the effective length of the virtual array and, hence, the difference-frequency beamwidth can be controlled by the primary input power to the projector. The results of an early experiment, Fig. 1, demonstrate the difference-frequency beamwidth variation obtained when the primary source level ranged from mildly saturated to very heavily saturated. The primary scaled source level is the sum of the source level of one primary component in dB/μPa·m and 20 log of the mean primary frequency (kHz). Although saturation has no definite threshold, saturation effects become important at scaled source levels above 275–280 dB/μPa·m·kHz.

In Fig. 1, the 3-dB beamwidth at the 25-kHz difference frequency varies from 6° for scaled 284 dB/μPa·m·kHz to 15° for scaled 294 dB/μPa·m·kHz. At the 294-dB level, the primary side lobes begin to contribute noticeably to the shape of the pattern. For many parametric sources, especially those operating at lower frequencies, it is not practical to operate to such high scaled levels because of power or transducer limitations, so the degree of beam widening shown here is not usually obtainable.

Recently, however, experiments have been conducted which illustrate another technique used to control the pattern

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Fig. 1. Parametric source beam patterns for three drive levels.

<table>
<thead>
<tr>
<th>CURVE</th>
<th>SCALED SOURCE LEVEL (dB/μPa·m·kHz)</th>
<th>DIFFERENCE FREQUENCY SOURCE LEVEL (dB/μPa·m·kHz)</th>
<th>3 dB BEAMWIDTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>284</td>
<td>168</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>292</td>
<td>179</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>297</td>
<td>181</td>
<td>15</td>
</tr>
</tbody>
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PROJECTOR DIAMETER = 10 cm
PRIMARY MEAN FREQUENCY (f1) = 670 kHz
DIFFERENCE FREQUENCY (f1 − f2) = 25 kHz

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width. This second technique makes use of unequal amplitude primary components to shorten the effective array length and therefore increase the beamwidth. By combining this second technique with primary-level variation where the primary components are maintained at equal amplitude (as in the preceding experiment), a total beamwidth variation of approximately 3 to 1 can be obtained over a narrower range of scaled source levels without requiring impractically high source levels.

Theoretical treatment for the case of unequal primary amplitudes is not complete; however, the effect can be explained qualitatively as follows. When the two primary components are equal, the waveform is modulated 100 percent, i.e., the instantaneous envelope amplitude goes from some maximum value to zero. The point at which saturation occurs (and most of the difference-frequency generation ends) therefore, is not a single distance from the projector but is spread over a range of distances with the saturation point for the lower amplitude portions of the envelope occurring at the longer distances [5]. This effectively increases the average
length of the array and decreases the beamwidth over that which would be obtained if the waveform were less than 100-percent modulated.

If unequal primary amplitudes are used, the envelope exhibits less modulation, the array is shortened, and its beamwidth broadened. The results of this experiment are given in Figs. 2-8. A 25-cm diameter projector operating at a mean-primary frequency of 260 kHz and a maximum source level of 231 dB/µPa·m rms per frequency was used (i.e., 240-dB/µPa·m maximum peak source level).

The beamwidths are plotted in Figs. 2 and 3 for the unequal- and equal-amplitude cases, respectively. Fig. 2 shows the broadening that occurs for unequal components as the amplitude ratio is increased, whereas Fig. 3 shows the narrowing that accompanies reduced levels of equal-amplitude primaries. By using both techniques, the beamwidth varied from 1.7 to 4.5° at 13 kHz and from 1.5 to 3.1° at 52 kHz. The corresponding source levels are given in Figs. 4 and 5.

Fig. 6 illustrates the beam patterns obtained in the above experiment for a 13-kHz difference frequency. The wide pattern is the result of a 30-dB primary amplitude ratio while the narrow pattern occurs when equal but reduced primary amplitudes are used.

In addition to beamwidth control by primary level and composition, the levels of the harmonics of the difference frequency can also be controlled [5]. Figs. 7 and 8 illustrate the variation in the relative amplitude for the second- and third-harmonics for a step-down ratio of 10 corresponding to a fundamental difference frequency of 26 kHz. It should be noted that greater harmonic reduction can be obtained for a given loss in the difference-frequency source level by using unequal components rather than by reducing the level of equal components. For example, if the source level is reduced 10 dB by reducing the equal amplitude components, the second-harmonic is 15 dB down while the same reduction in source level accomplished by unequal components results in a 20-dB relative second-harmonic level. The unequal component technique has the penalty of requiring greater input power.

III. CONCLUSIONS

Beamwidth control of the parametric source can be accomplished by controlling the equal-amplitude primary frequency amplitude or by modifying the primary energy waveform by changing the relative amplitude of the primary components. A combination of both of these techniques permits the greatest change of beamwidth without excessive changes in drive power. Furthermore, harmonic distortion can be materially reduced through the use of unequal components.

ACKNOWLEDGMENT

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REFERENCES