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HIGH EFFICIENCY PARAMETRIC SONAR

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT ANTHONY A. RUFFA, citizen of the United States of America, employee of the United States Government, resident of Hope Valley, County of Washington, State of Rhode Island, has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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DISTRIBUTION STATEMENT A
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HIGH-EFFICIENCY PARAMETRIC SONAR

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

This invention generally relates to a device for increasing the efficiency of parametric sonar. More particularly this device utilizes characteristic effects of a cavitating transducer and alternatively introduce an outside stimulant to enhance the non-linear effects of a transmission medium.

Parametric sonar is well known. FIG. 1 shows a typical parametric sonar 10 positioned in a liquid environment 12. A first transducer 14 and a second transducer 16 are provided in acoustic communication with the environment 12. First and second transducers 14, 16 are joined with amplifiers 18 and 20, respectively. Amplifier 18 is joined to a first oscillator 22, and amplifier 20 is joined to a second oscillator 24. The oscillators 22, 24 are joined to a controller 26. In use,
controller 26 activates first and second oscillators 22, 24 which provide a signal to the associated amplifier 18, 20 and then to the associated first transducer 14 and second transducer 16. The signal provided to first transducer 14 is at a first frequency, \( F_1 \). This results in a first acoustic wave 28 at this frequency. The second transducer 16 receives a signal at a second frequency, \( F_2 \), resulting in a second acoustic wave 30 at this frequency. Transducers 14 and 16 are oriented so that transmitted acoustic waves 28 and 30 overlap in an overlap region 32. In overlap region 32, an additive acoustic wave (not shown) having frequency, \( F_1 + F_2 \), and a difference acoustic wave 34 having frequency, \( F_1 - F_2 \), is created. Frequencies \( F_1 \) and \( F_2 \) are chosen so that the additive acoustic wave frequency dissipates over a short range while the difference acoustic wave 34 is transmitted at the desired range. Production of the difference acoustic wave 34 is very inefficient. Transducers 14 and 16 need to transmit a large amount of power in order to create a difference acoustic wave 34 having the desired power.

(2) Description of the Prior Art

The current art of parametric sonar takes advantage of the non-linearity associated with a transmission medium. It involves a generation of two frequencies, \( F_1 \) and \( F_2 \), which interact to form sum and difference frequency components. In a water medium, the sum frequency components (and the \( F_1 \) and \( F_2 \) components) quickly attenuate leaving only the difference frequency
components. The main advantage of parametric sonar is that the beam width is based on \( F_1 \) and \( F_2 \) (not the difference frequency \( F_1 - F_2 \)), so that very narrow beams can be generated at low frequencies (even with a small aperture). One of the main disadvantages of parametric sonar in water is that the efficiency is very low, leading to a reduction in source level that can typically be 30dB or more.

The following patents, for example, disclose parametric sonar devices utilized underwater:

- U.S. Patent No. 3,870,988 to Turner;
- U.S. Patent No. 3,882,444 to Robertson; and
- U.S. Patent No. 3,964,013 to Konrad.

Specifically, Turner discloses an underwater detection and identification method and apparatus utilizing the principle of parametric cross-modulation of ultrasonic frequencies within a non-linear propagation medium for obtaining an acoustical signature of an object under observation. The object is illuminated by ultrasound of suitable, high frequency projected from the observation platform and echo signals are received composed of side bands generated by combining the illuminating frequency with the relatively low signature frequency. The received ultrasonic side band frequency signals are then processed electronically to yield a signal representative of a characteristic of the object. The apparatus is essentially a
hybrid, active-passive sonar operating in a continuous
uninterrupted mode.

The patent to Robertson discloses a system for detecting and
isolating incoming acoustic waves. The system includes means for
transmitting a random noise signal that will intersect the
incoming waves. Cross modulation products, particularly the
first order sum and difference frequencies, occurring in the
volume where the incoming low frequency and transmitted high
frequency signals meet and intersect are propagated back toward a
receiver where the modulated noise signals are correlated with
the transmitted noise signal to isolate the lower frequency
incoming signal. The interaction between the transmitted and
incoming signals takes place at a plurality of volumetric
segments which are located at various distances from the
transmitter. By correlating the modulated return signals, which
are received at selected intervals, with properly delayed
replicas of the transmitted signal, the interaction, or cross
modulation products, at any selected range can be isolated in the
receiver. By summing these isolated signals, the incoming
frequency can be detected, the overall system acting as a virtual
receiving array.

Konrad discloses a cavitating parametric underwater acoustic
source for generating acoustic energy at low and medium
frequencies. The source comprises a plurality of electro-
aoustic transducer elements which are electrically energized in
a liquid medium such as water at two or more primary frequencies. Changes in the ambient liquid pressure at or adjacent the transducer cause cavitation in the liquid medium which produces a high degree of non-linearity resulting in the generation of sum and difference frequencies of the primary frequencies in the liquid. The difference frequency is used to transmit acoustic energy in the liquid medium.

It should be noted that Konrad '013 uses the same transducers to provide cavitation bubbles that are used to create the difference acoustic wave. Use of a transducer to create the large amplitude acoustic waves that are needed for cavitation can damage the transducer. Furthermore, control of low amplitude transducers is more precise for signal transmission.

SUMMARY OF THE INVENTION

Therefore it is an object of this invention to provide parametric sonar having increased efficiency in the transmission medium.

Another object of this invention is to provide parametric sonar having increased efficiency in the transmission medium by utilizing cavitation bubbles to increase the non-linearity of the transmission medium.

Still another object of this invention is to provide cavitation bubbles in a transmission medium in response to
driving transducers at a power sufficient to generate the
cavitation bubbles.

Yet another object of this invention is to provide
parametric sonar having independently introduced bubbles in the
transmission medium at a location of the projecting transducers
to increase the non-linearity of the transmission medium.

In accordance with one aspect of this invention, there is
provided a parametric sonar source operating in a fluid
transmission medium. An improvement is provided for selectively
increasing the efficiency of signals generated by transducers of
the parametric source. This improvement includes an acoustic
cavitation wave generated to intersect the acoustic waves emitted
by the transducers of the parametric source. Interaction of the
frequencies $F_1$ and $F_2$ of the acoustic transducer waves with the
acoustic cavitation wave will generate subharmonics having a
greater amplitude than in an absence of the acoustic cavitation
wave. Preferably, the acoustic cavitation wave is introduced at
a right angle or transverse to the acoustic waves emitted by the
transducers of the parametric source, thereby providing an
enhanced parametric sonar device.

BRIEF DESCRIPTION OF THE DRAWINGS

The appended claims particularly point out and distinctly
claim the subject matter of this invention. The various objects,
advantages and novel features of this invention will be more
fully apparent from a reading of the following detailed
description in conjunction with the accompanying drawings in
which like reference numerals refer to like parts, and in which:

FIG. 1 is a schematic view of a parametric sonar according
to the Prior Art; and

FIG. 2 is a schematic view of a parametric sonar assembly
according to a preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In general, the present invention is directed to the purpose
of increasing the efficiency of parametric sonar, and has by way
of explanation the embodiment shown in FIG. 2.

It has been found by the inventor that an increased
efficiency of parametric sonar from a system generally indicated
at element 40 will depend upon the degree of non-linearity in the
transmission medium 42. In a fluid, the degree of non-linearity
is described by the Navier-Stokes equations and the equation of
state. When two finite-amplitude acoustic signals F₁ and F₂ are
generated (having differing frequencies), both subharmonics and
superharmonics are also generated with amplitudes that depend on
the magnitude of the nonlinear terms in the Navier-Stokes
equation and the equation of state (compared to the magnitude of
the linear terms).

In FIG. 2, there is shown a first embodiment of the
invention. This provides an enhanced parametric sonar set up 40
positioned in a liquid environment 42. In this embodiment first
and second signal transducers 44 and 46 are provided in
communication with the liquid environment 42. First transducer
44 is joined to a first amplifier 48, and second transducer 46 is
joined to a second amplifier 50. Amplifiers 48, 50 are joined to
first and second oscillators 52, 54. First oscillator 52 is
capable of generating a signal at a first frequency, F₁. Second
oscillator 54 is capable of generating a signal at a second
frequency, F₂. Transducers 44 and 46 are oriented so that
transmitted acoustic waves 56 and 58 overlap in an overlap region
60.

As is known in the art, frequencies F₁ and F₂ are chosen so
that the additive acoustic wave frequency dissipates over a short
range while the difference acoustic wave 61 is transmitted at the
desired range. A cavitation transducer 62 is joined to a
cavitation amplifier 64 which, in turn, is joined to a cavitation
oscillator 66. Cavitation oscillator 66 and cavitation
transducer 62 are preferably designed to transmit a cavitation
acoustic wave 68 at a frequency of 1-2 MHz at a sufficient power
level to cause cavitation of the liquid medium. Other cavitation
frequencies can be used dependent on the signal transducer
frequencies, F₁ and F₂; the size of the cavitation region needed;
and the available power. Preferably, cavitation transducer 62 is
oriented at a right angle to the plane of the overlap region 60.
All of the oscillators 52, 54 and 66 are joined to a common controller 70.

In operation, controller 70 activates cavitation oscillator 66. Pressure troughs in the cavitation acoustic wave 68 cause vaporization of the liquid medium 42 resulting in cavitation bubbles 72. Controller 70 activates oscillators 52 and 54 when cavitation bubbles 72 have been formed in the overlap region 60. Transducers 44 and 46 transmit acoustic waves 56 and 58. Acoustic waves 56 and 58 overlap in overlap region 60 which has been filled with cavitation bubbles 72. Interference between waves 56 and 58 produces difference acoustic wave 61. In the case of active sonar transmission, controller 70 then inactivates oscillators 52, 54 and 66 and their associated transducers 44, 46 and 66. In absence of the cavitation acoustic wave 68, cavitation bubbles 72 dissipate. Transducers 44, 46 wait to receive an echo from a target object (not shown). Alternatively, an additional transducer (not shown) can be provided to receive the echo.

Accordingly, the degree of non-linearity of the transmission medium 42 is increased significantly by the introduction of cavitation bubbles into the transmission medium 42 in the path of the generated signals 56, 58. This leads to a more efficient generation of subharmonics and thus an increased source level. This arrangement has the advantage of allowing more control over the transmitted waveforms, since the transducers do not also
have to create a cavitation field. The independent cavitation
bubbles are preferably vapor bubbles (due to cavitation) instead
of air bubbles. Vapor bubbles have the advantage of returning to
the liquid state when the acoustic field is turned off, so that
they are not present during operation of any receive array.

The primary advantage of the arrangement shown in FIG. 2 is
the much greater source levels than otherwise possible. This is
due to the greater amplitude associated with subharmonics due to
the cavitation bubbles. There is some disadvantage in that some
of the acoustic energy will be lost due to scattering of the
bubbles; however, the increased amplitudes at the subharmonic
frequencies should more than compensate for this loss. Also,
most of the energy loss due to scattering will be at the primary
frequencies $F_1$ and $F_2$ (due to bubble resonance at these
frequencies), not at the desired frequency $F_1 - F_2$.

This invention has been disclosed in terms of certain
embodiments. It will be apparent that many modifications can be
made to the disclosed apparatus without departing from the
invention. Therefore, it is the intent of the appended claims to
cover all such variations and modifications as come within the
true spirit and scope of this invention.
HIGH-EFFICIENCY PARAMETRIC SONAR

ABSTRACT OF THE DISCLOSURE

A parametric sonar for use in a liquid medium includes a first signal generator which transmits a first acoustic signal and a second signal generator transmitting a second acoustic signal which interact to produce a difference frequency signal at an interference region. A cavitation generator is provided to transmit a cavitation acoustic wave causing cavitation vapor bubbles in the liquid medium at the interference region. The cavitation vapor bubbles improve the efficiency of generating the difference frequency signal.