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IN REPLY REFER TO:

Attorney Docket No. 84988
Date: 11 January 2005

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Serial Number 10/901,311
Filing Date 23 July 2004

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Attorney Docket No. 84988
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DISPLACEMENT CURRENT METHOD AND APPARATUS FOR REMOTE POWERING OF A SENSOR GRID

TO ALL WHOM IT MAY CONCERN

BE IT KNOWN THAT DAVID A. TONN and PAUL MEDEIROS, employees of the United States Government, citizens of the United States of America, and residents respectively of Charlestown, County of Washington, State of Rhode Island and Middleboro, County of Plymouth, Commonwealth of Massachusetts, have invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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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 therefore.

CROSS REFERENCE TO OTHER RELATED APPLICATIONS

Not applicable.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates in general to the powering of remote sensors, and more specifically to a wireless power transmission system for use with a network of sensing devices.

(2) Description of the Prior Art

Currently, underwater vehicles have on-hull sensor arrays connected to the inboard side of the underwater vehicles, particularly large submarines, by means of large, heavy expensive wiring harnesses. The sensors are embedded in an acoustic polymer material and are located several inches above the hull of the underwater vehicle. There is currently a need for a means of delivering power to the sensor arrays arranged over the exterior of the hull of an underwater vehicle without the use of wired connections in order to reduce costs and the overall weight of the system, and to improve reliability. What is needed is a displacement current method and apparatus for the remote powering of a sensor grid.

SUMMARY OF THE INVENTION

It is a general purpose and object of the present invention to provide a method and apparatus that efficiently delivers power to a large array of remote sensors in an on-hull sensor grid.

It is a further object to power the large array of remote sensors without the need of heavy expensive wired connections.

These objects are accomplished with the present invention by delivering electrical energy across the insulating gap that separates the sensor from the hull by means of a displacement current. The exterior hull of an underwater vehicle includes a conducting layer interposed between inner and outer decouplers and a ground plane interposed between a bonding layer and the inner decoupler. An application of alternating current to the ground plane will activate the conducting layer and provide power to the sensors at a location of the outer decoupler. The inner decoupler acts as a capacitor and the ground plane further provides an electrical path back to the hull.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

FIG. 1 is a depiction of a cross section of the materials stack in which sensors are embedded.

FIG. 2 shows a circuit diagram for the equivalent circuit of a network powered by displacement current.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown the materials stack 10 that the acoustic sensors 24 exist in, specifically an outer decoupler layer 12, an upper plate 14, an inner decoupler layer 16, a lower plate 18 and finally the bonding layer 20 that bonds the materials stack 10 to the hull 22 of the underwater vehicle (not shown). The inner and outer decoupler layers 12 and 16 should be made of an elastomeric dielectric insulator such as rubber or an acoustic polymer material that is urethane based.

The upper plate 14 and the lower plate 18 layers should be made of metal such as aluminum, copper, silver or other highly conductive material and approximately 1 millimeter thick.

The sensors 24 are located directly above the boundary between the upper plate 14 and outer decoupler layer 12 and are in contact directly or indirectly with the upper plate 14. By stacking the layers in the manner illustrated in FIG. 1, specifically by having a conducting layer in the form of upper plate 14 between the inner decoupler 16 and outer decoupler 12, then the inner decoupler 16 can function as a capacitor. Power can then be delivered across the inner decoupler 16 that function as a capacitor by exciting a *displacement current* across the inner decoupler 16. This is accomplished by exciting an alternating current voltage of sufficiently high frequency from voltage source 28 on the lower plate 18 relative to the underwater vehicle's hull 22. A displacement current is established through the electrical path back to the underwater vehicle's hull 22 from the conducting layer or upper plate 14 between the inner decoupler 16 and outer decoupler 12.

In the preferred embodiment, it is assumed that a physical penetration of the inner decoupler 16 and the bonding layer 20 by structural members of the hull 22 exists. These sorts of penetrations are places of opportunity where a ground connection can be easily obtained either with or without a custom penetration. The hull 22 is assumed to be 0 volts at all times, making it the true ground of the system.

The sensor packages 24 are placed electrically in series with the upper plate 14. An alternating current voltage of sufficient frequency is induced on the upper plate 14 by the excitation of the lower plate 18. This voltage is rectified and filtered by the sensor packages 24, making a direct current voltage available for biasing of the RF payloads in the sensor packages 24. The rectifiers in the sensor packages 24 can be either half wave or full wave rectifiers. The ground connections of the sensors converge to the nearest available grounding point. In the preferred embodiment the sensors 24 tie into the nearest available grounding point through a bus connection to a ground distribution network 30 which connects electrically back to the hull 22 which serves as the ground. A bus connection is preferred to a ground plane, since the capacitance between the upper plate 14 and the lower plate 18 tend to create a voltage divider effect with the capacitance formed by the inner decoupler 16, reducing the efficiency of the powering scheme.

An equivalent circuit of a network operating on displacement current is shown in FIG. 2. C_{UBL} is the capacitance between lower plate 18 and the hull 22 through the bonding layer 20. C_{ID} is the capacitance between lower plate 18 and upper plate 14 through the inner decoupler 16. C_{OD} is the capacitance exhibited across the outer decoupler 12 between upper plate 14 and the seawater surrounding the underwater vehicle. C_G is the capacitance between the upper plate 14 and the ground distribution network 30. Z_L is the load impedance presented by the sensors 24. V is the voltage stimulus between lower plate 18 and ships hull 22.

The capacitance of C_{UBL}, C_{OD} and C_G are all parasitic to the network and should be minimized as much as possible. The voltage across Z_L, the load impedance presented by the sensors, is determined in phasor notation using circuit theory according to equation (1) as set out below:

$$V_L = \left(\frac{j\omega C_{ID} Z_{EQ}}{1 + j\omega C_{ID} Z_{EQ}} \right) V \qquad (1)$$

where

$$Z_{EQ} = Z_L \parallel \frac{1}{j\omega(C_{OD} + C_G)} \qquad (2)$$

is the equivalent impedance formed by the parallel connection of the load impedance Z_L and the two capacitors, C_{OD} and C_G. The current flowing through the load Z_L is:

$$I_L = \frac{V_L}{Z_L} \quad (3)$$

and since the power delivered to the load Z_L , then is:

$$P_L = \frac{1}{2} V_L I_L^* \quad (4)$$

using equations (1) and (4), the power can be expressed as:

$$P_L = \frac{|V|^2}{2Z_L^*} \left| \frac{j\omega C_{ID} Z_{EQ}}{1 + j\omega C_{ID} Z_{EQ}} \right|^2 \quad (5)$$

For the case when the capacitive reactance of C_G and C_{OD} are large compared with the load impedance Z_L, these terms do not contribute appreciably to the overall expression in (2) and the equivalent impedance is approximately equal to Z_L. Equation (5) then reduces to:

$$P_L = \frac{|V|^2}{2Z_L^*} \left| \frac{j\omega C_{ID} Z_L}{1 + j\omega C_{ID} Z_L} \right|^2 \quad (6)$$

Equation (6) bears some closer scrutiny. The power delivered to the load Z_L is seen to be a familiar V^2/Z term representing the maximum power that can be delivered if the generator was connected directly to the load and a modifying term that depends on the frequency of operation. However, for situations where:

$$\omega C_{ID} Z_L >> 1 \qquad (7)$$

this modifying term approaches unity. This indicates that nearly total power delivery to the load is possible, almost as if the inner decoupler is not there at all. Theoretically, at least, nearly perfect power delivery efficiency is possible under ideal conditions, and that is the appeal that this method has.

The overall efficiency of the power delivery includes generator mismatches and the efficiency of the rectifier and filter stage in the sensors 24 that follows in order to convert the alternating current energy into direct current power used to drive the electronics packages in the sensors.

The advantage of the present invention over the prior art is primarily its simplicity in implementation and function. From this simplicity flows a savings in costs of materials for prior art wiring harnesses, time in implementation of wiring harnesses and time in maintenance. The invention also has a minimal impact on the acoustic properties of the overall system.

In light of the above, it is therefore understood that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

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ABSTRACT OF THE DISCLOSURE

This invention serves as a method and apparatus for delivering power to a series of remote sensors in an on hull sensor grid for the purpose of biasing the active circuitry on the sensors. It requires no physical connection between the source of power and the sensor. It works by delivering electrical energy across the insulating gap that separates the sensor from the hull by means of a displacement current. In particular, the method and device include a conducting layer interposed between inner and outer decouplers and a ground plane interposed between a bonding layer and the inner decoupler. An application of alternating current to the ground plane will activate the conducting layer and provide power to the sensors at a location of the outer decoupler. The inner decoupler acts as a capacitor and the ground plane further provides an electrical path back to the hull.

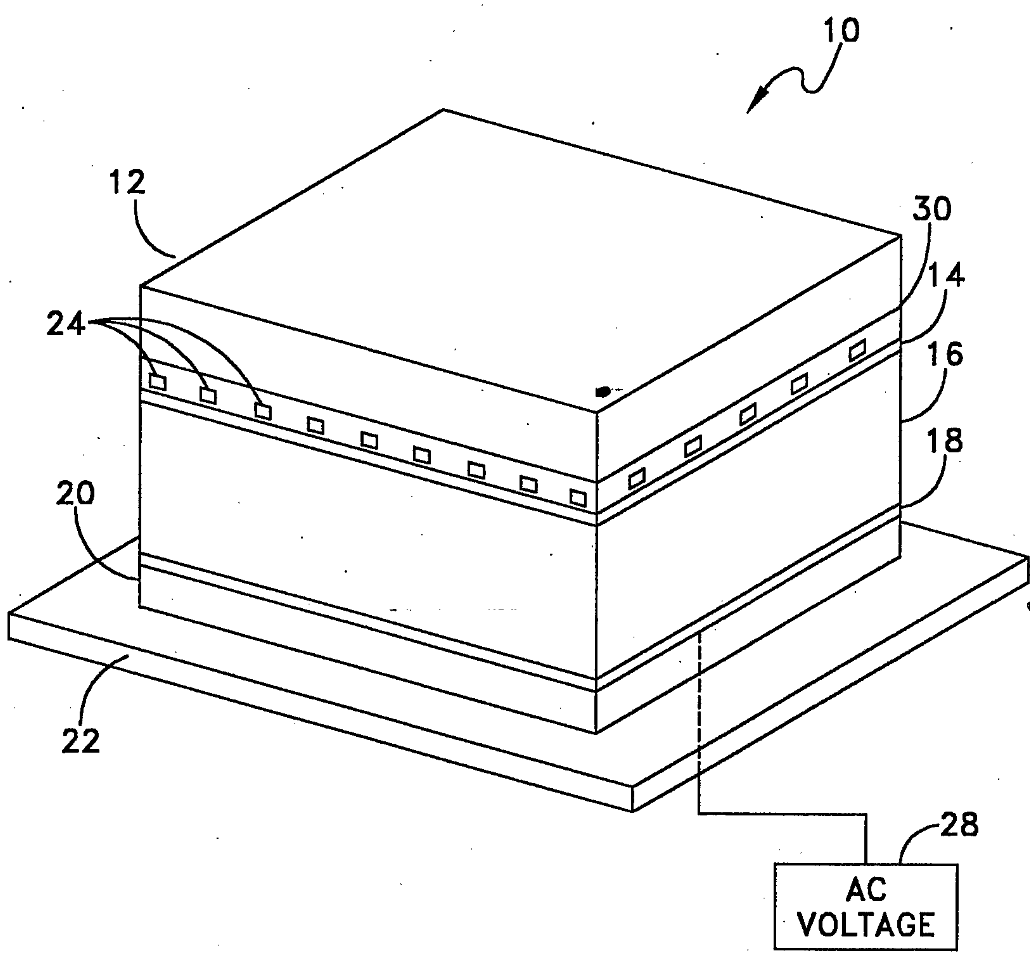

FIG. 1

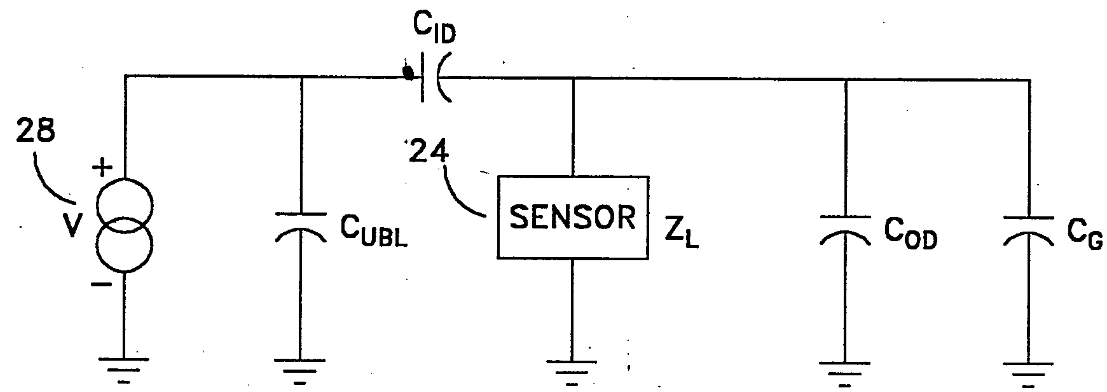

FIG. 2