United States Patent

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[54] **PASSIVE TELEMETRY SYSTEM**
13 Claims, 5 Drawing Figs.

[52] U.S. Cl. 340/177, 340/195, 340/210, 128/2.1, 336/96, 336/188
[51] Int. Cl. G08c 19/04
[50] Field of Search 340/196, 177 (R); 179/82; 128/2.15; 340/210, 195, 38 (L), 177

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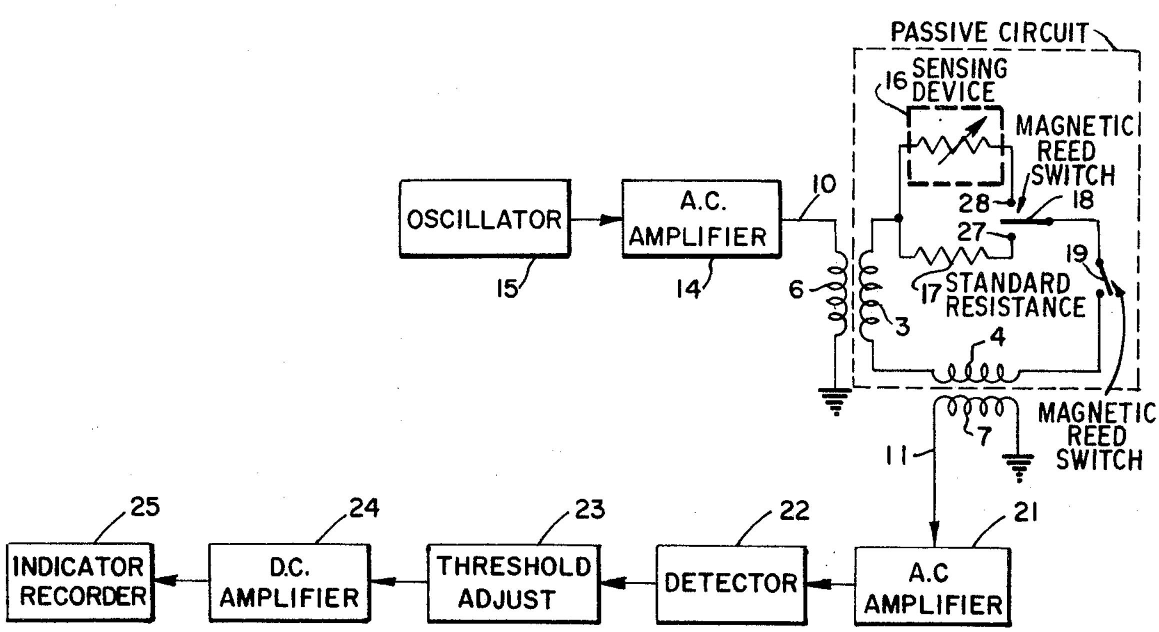
ABSTRACT: A telemetry system having a physically separate passive sensing circuit including a first magnetic coil which is coupled to the power source for supplying electrical current, a sensing device for modulating the electrical current in accordance with the variable sensed, and a second magnetic coil, for coupling the modulated current to the output device, the first and second magnetic coils being adjacent each other and oriented at substantially right angles in order to avoid interference between their respective magnetic fields.



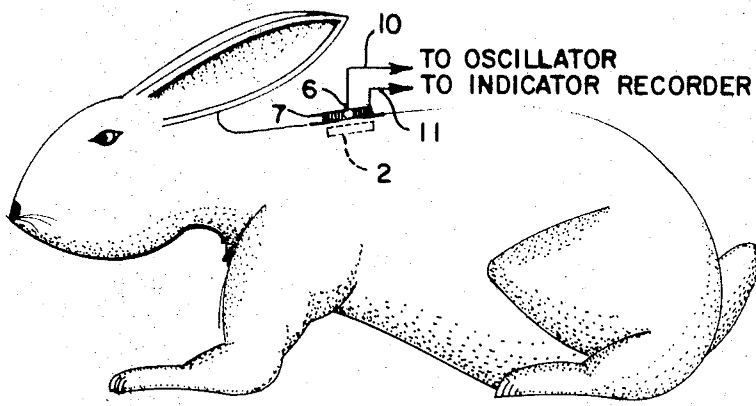


FIG. 1

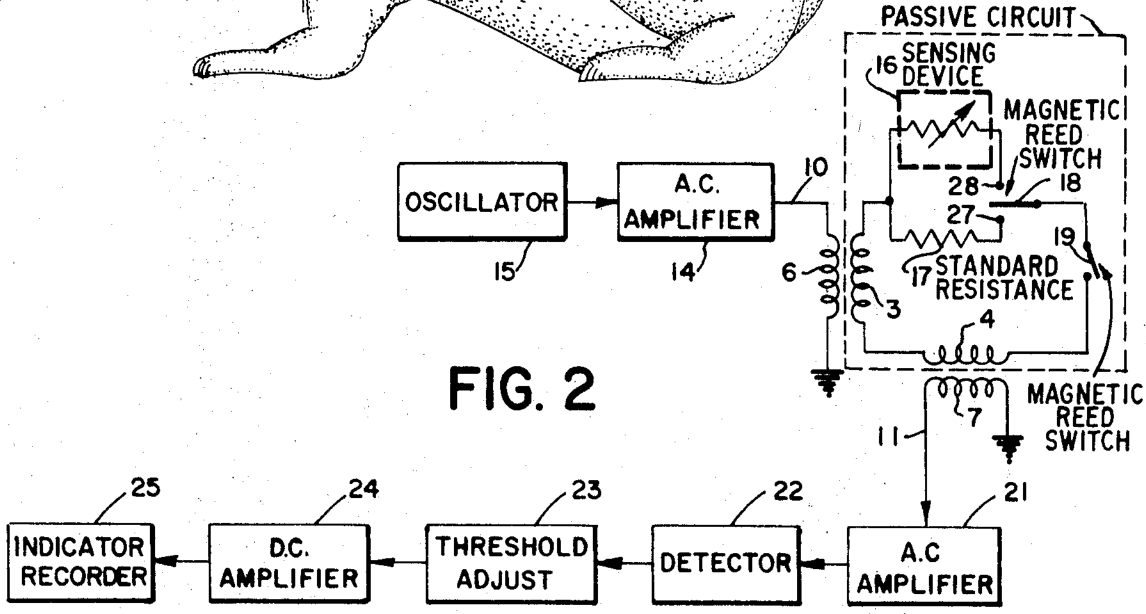


FIG. 2

FIG. 3

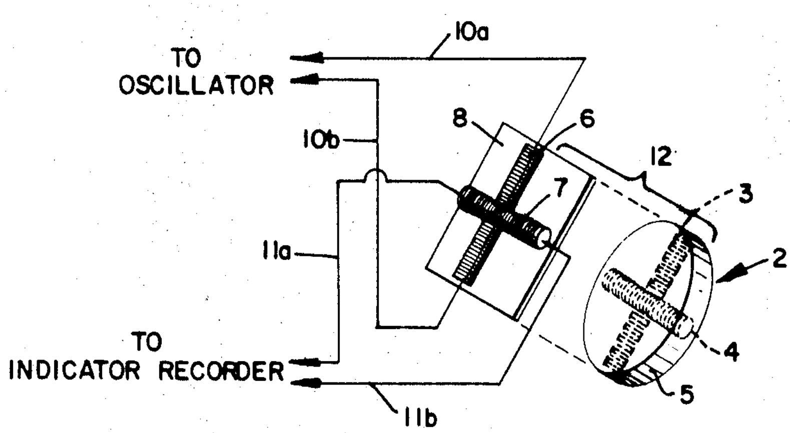


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FIG. 4

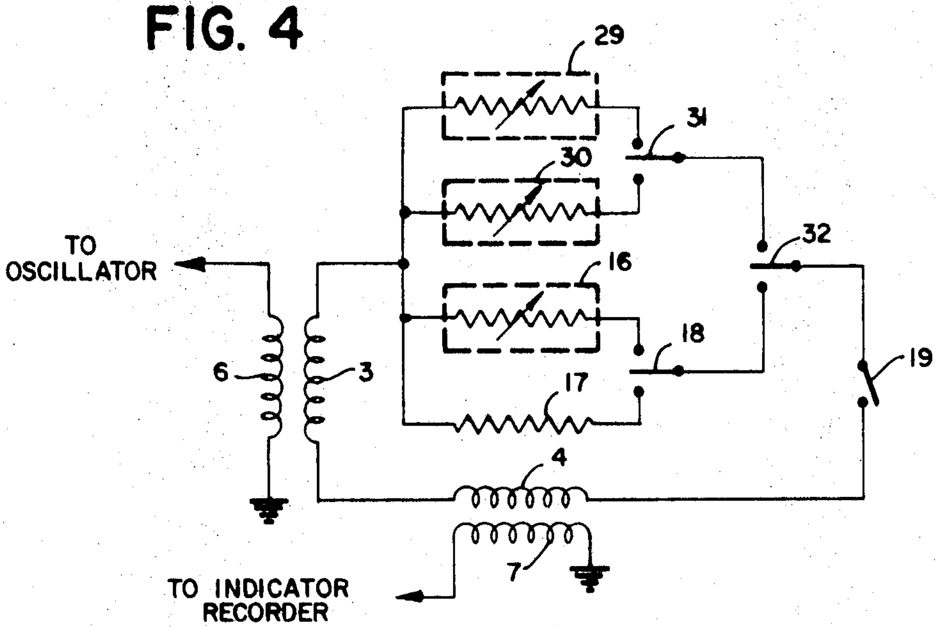
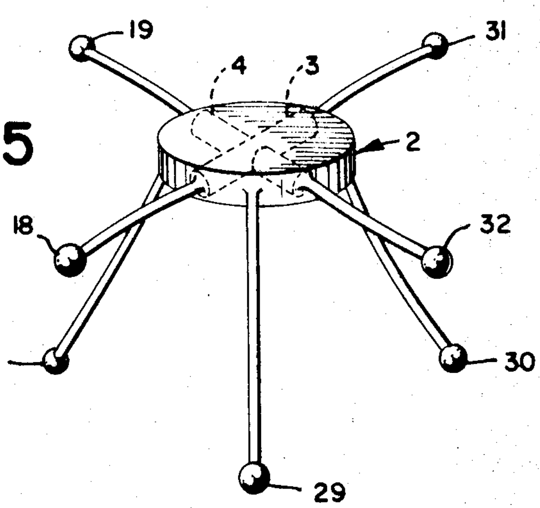


FIG. 5



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PASSIVE TELEMETRY SYSTEM

This invention relates to a telemetry system for remotely monitoring a selected variable parameter or condition. More particularly, this invention relates to a telemetry system including a physically separate sensing circuit which may be encased in an inert material suitable for long term implantation in a living animal, in order to continuously monitor various physiological variables of the animal such as, for example, temperature, blood pressure, respiration electrocardiographic and electroencephalographic signals, etc.

Various types of apparatus for measuring physiological variables have long been available to doctors and physiological researchers. In general, the prior art apparatus for measuring physiological variables is either of the external type such as, for example, the conventional thermometer, stethoscope and sphygmomanometer, or of the internal type which involves a sensing device implanted within the body of the patient or experimental animal and electrical wires leading out through suitable surgical incisions in the skin of the animal to a suitable external indicating device.

The external type of apparatus is of somewhat limited usefulness in that it is capable of measuring physiological parameters near the skin of the subject.

The internal type of apparatus, on the other hand, is capable of measuring parameters deep within the body, but involves a certain amount of physiological insult to the subject in that the incisions in the skin are not permitted to heal. This fact alone tends to limit the life of laboratory animals carrying the conventional type of internal measuring devices due to infection through the unhealed wound. Further, in order to avoid immediate and severe injury to the animal, extreme care must be exercised to insure that the electrical wires are not subjected to excessive stress.

Another method of monitoring physiological parameters deep within the body of a patient or experimental subject has been to implant a sensing circuit including a small energy source such as, for example, a battery. In this manner, the selected physiological parameter can be measured, and the resulting information can be transmitted to indicating or recording equipment located externally of the body without the usual connecting wires. Although the battery-powered sensing circuit avoids the problem of unhealed surgical incisions by eliminating the need for connecting wires, it is apparent that the useful life of such a sensing circuit is limited to the life of the battery which powers it. Therefore, it is apparent that a battery-powered sensing circuit cannot provide long term monitoring of internal physiological parameters.

It is therefore an object of this invention to provide an improved telemetry system for long term monitoring physiological parameters.

It is another object of this invention to provide a telemetry system in which the sensing device is physically separate from the indicating or recording device.

It is a further object of this invention to provide a passing sensing circuit which may be encased in an inert material suitable for long term implantation in a living animal, and which may be coupled to an external indicating or recording device through the intact skin of the animal.

It is still another object of this invention to provide apparatus for coupling a passive sensing circuit simultaneously to an external energy source and to an external indicating or recording device.

It is another object of this invention to provide a means for calibrating the implant in order to verify the accuracy of the measurement.

According to the above and other objects, the present invention provides a telemetry system including a physically separate sensing circuit consisting of passive elements which may be encased in an inert material suitable for long term implantation in a living animal. The sensing circuit includes a pair of adjacent magnetic coils disposed at substantially right angles to each other. One coil provides magnetic coupling to an external coil which is connected to a source of alternating current, and the other coil provides magnetic coupling to an external coil which is connected to an appropriate indicating and/or recording device. The external coils are similarly disposed at substantially right angles to each other and in parallel spaced relation to their associated internal coils. This arrangement provides for maximum coupling of power from the external source to the passive sensing circuit, and maximum coupling of the return signal to the external indicating and/or recording device, but minimum interference between the two magnetic coupling links. Calibration is accomplished by incorporating an environment-insensitive standard and a switching device in the implanted circuit.

One advantage of the present telemetry system is that the passive sensing circuit may remain implanted within the body without discomfort for periods of up to several years, so that the patient may return to the laboratory from time to time in the event that it is desired to measure the particular physiological variable only at long intervals.

These and other objects and advantages of the present passive telemetry system will be apparent to those skilled in the art from the following detailed description and accompanying drawings which set forth, by way of example, the principle of the invention and the best mode contemplated for carrying out that principle. IN THE DRAWINGS:

FIG. 1 is a side view of a laboratory animal showing the implanted passive sensing circuit and the external magnetic coupling coils of the telemetry system of the present invention.

FIG. 2 is a block diagram of the passive telemetry system of the present invention.

FIG. 3 is a detailed perspective view showing the relationship of the magnetic coils coupling the oscillator and the indicating device to the passive sensing circuit.

Although the following detailed description illustrates the principles of the present invention by reference to a passive telemetry system for monitoring physiological variables or parameters, it will be appreciated by those skilled in the art that the present invention is not limited to such uses. To the contrary, the passive telemetry system of the present invention may be employed in any of the wide variety of applications in which conventional telemetry systems known to those skilled in the art are presently employed. However, it will be apparent to those skilled in the art that the passive telemetry system of the present invention may be most advantageously employed in applications in which the physical separation of the sensing device or devices from the indicating and/or recording apparatus is either required or desirable. More particularly, it will be apparent that the passive telemetry system of the present invention possesses certain advantages over the conventional telemetry system for applications in which the sensing apparatus is separated from the indicated and/or recording apparatus by a relatively thin barrier or membrane.

Referring to FIG. 1, there is shown a laboratory animal **1**, in this case a rabbit, in which there is implanted a body **2** of inert material containing the passive sensing circuit of the telemetry system of the present invention. More particularly, as shown in greater detail in FIG. 3, body **2** contains a pair of magnetic coils **3** and **4** which are elements of the passive sensing circuit of the present invention. Magnetic coils **3** and **4** are disposed at substantially right angles to each other and are encased or potted in a nonconductive inert material **5** suitable for long term implantation within the body of a living animal. Materials suitable for this purpose including silicone rubbers such as, for example, silastic, are well known to those skilled in the art. Further, although only magnetic coils **3** and **4** are shown in FIG. 3, it will be appreciated that the entire passive sensing circuit of the present invention may be encased within implant body **2** shown in FIG. 3.

Referring again to FIG. 1, there is shown a pair of external magnetic coupling coils **6** and **7** mounted on plate **8** which is removably secured to the exterior of the body of the animal **1** by any suitable means such as, for example, straps or adhesive tape (not shown). Magnetic coil **6** is connected by leads **10** to a suitable source of alternating current (not shown in FIG. 1).

Magnetic coil 7 is connected by leads 11 to an indicating and/or recording device (also not shown).

As shown in greater detail in FIG. 3, magnetic coils 6 and 7 are preferably flat and helical in form and are disposed at substantially right angles to each other. Further, magnetic coil 6 is disposed in substantially parallel spaced relation to magnetic coil 3 in implant 2, and magnetic coil 7 is disposed in substantially parallel spaced relation to magnetic coil 4 in implant 2. This arrangement provides for maximum magnetic coupling between magnetic coil 6 and magnetic coil 3 and between magnetic coil 7 and magnetic coil 4 for any given distance 12 between amounting plate 8 and implant 2. At the same time, this arrangement provides for minimum coupling between magnetic coil 6 and coils 4 and 7. There is also minimum magnetic coupling between magnetic coil 7 and coils 3 and 6. In other words, there is maximum coupling of AC power from the external power source to the implanted passive sensing circuit of the present telemetry system. At the same time there is maximum coupling of the modulated signal from the implanted passive sensing circuit to the external indicating and/or recording device, but there is a minimum of interference or cross-coupling between the power signal and the information signal.

Briefly, the favorable magnetic coupling characteristics of the arrangement of magnetic coils shown in FIG. 3 is due to the fact that the coupling between a pair of magnetic coils is proportional to the cosine of the angle between their axes. Hence, since external magnetic coil 6 is substantially parallel to internal magnetic coil 3, the angle between their axes is substantially zero and the cosine of the angle between their is substantially unity. Therefore, the magnetic coupling between coils 3 and 6 is at its maximum. Similarly, because external coil 7 is disposed in substantially parallel space relation to internal coil 4, the cosine of the angle between their axes is substantially unity, and the magnetic coupling between the coils is at its maximum.

On the other hand, the axes of magnetic coils 3 and 6 are at substantially right angles to the axes of coils 4 and 7. Accordingly, the cosines of the angles between their axes are substantially zero and the magnetic coupling between them is at a minimum. Hence, it is seen that the arrangement of magnetic coils shown in FIG. 3 provides the maximum coupling of AC power from the external source to the implanted passive sensing circuit of the present telemetry system, and the maximum coupling of the modulated information signal from the implanted sensing circuit to the external indicating and/or recording apparatus, but minimum cross-coupling between the power signal and the information signal.

However, in accordance with the same theoretical principles of analysis, it will be apparent that if mounting plate 8 is rotated slightly with respect to implant 2, the magnetic coupling between coils 3 and 6 and between coils 4 and 7 will be reduced, while cross-coupling between magnetic coils 4 and 6 and between magnetic coils 3 and 7 will be increased. Hence, it is apparent that the relative orientation of mounting plate 8 with respect to implant 2 is of importance to the proper operation of the passive telemetry system of the present invention. The procedure for obtaining the optimum relative orientation shown in FIG. 3 will be explained in greater detail hereinafter.

Another factor which has an important influence on the performance of the system is the distance 12 between implant 2 and external mounting plate 8. Normally, in accordance with the preferred form of the present invention, distance 12 would be expected to be roughly one-eighth of an inch. Hence, it will be apparent that implant 2 should be implanted immediately beneath the skin of the experimental animal 1, as shown in FIG. 1. As the distance 12 increases, the magnetic coupling between external coils 6 and 7 and implanted coils 3 and 4 decreases rapidly. It will be appreciated, however, that, although implanted coils 3 and 4 should be located immediately beneath the skin of the experimental animal in order to achieve good coupling with external coils 6 and 7, the sensing device or devices of the implanted passive sensing circuit of the present invention may be located deep within the body of the animal as explained in greater detail in connection with FIG. 5.

Referring now to FIG. 2 of the drawings, there is shown a block diagram of the passive telemetry system of the present invention. Alternating current is supplied to external coil 6 by AC amplifier 14 which amplifies the output of oscillator 15. The operating frequency of oscillator 15 will depend, in general, upon the size of the magnetic coils employed in each particular application. More specifically, the smaller the coils employed, the higher must be the frequency of oscillator 15 in order to couple sufficient power across the gap between the external and internal coils. On the other hand, the distributed interwinding capacities of the coils tend to impose a practical upper limit on the frequencies which can be employed. Such distributed interwinding capacities act as effective current shunts at high frequencies, thus reducing power transfer efficiency. Hence, for each particular application, the choice of the operating frequency of oscillator 15 will represent a compromise between several design factors. For example, in an application employing implanted coils approximately 1 inch long and approximately three-eighths inch in diameter and having approximately 200 turns, an operating frequency of 50 kc., was found to provide good performance.

In addition to magnetic coils 3 and 4, the passive sensing circuit shown in FIG. 2 includes a sensing device 16 such as, for example, a thermistor. It will be appreciated, however, by those skilled in the art that other types of sensing devices may be employed within the spirit and scope of the invention such as, for example, devices sensitive to pressure, ionizlng radiation, electrical conductivity, pH, etc. The passive sensing circuit shown in FIG. 2 also includes a standard resistor 17 for comparison with the resistance of sensing device 16. A two-pole, two-position switch 18 permits switching between sensing device 16 and standard resistor 17, and a switch 19 is provided in order to make or break the circuit in accordance with the procedure for establishing the proper orientation of external coils 6 and 7 with respect to internal coils 3 and 4, as will be explained in greater detail hereinafter. It will be appreciated that switches 18 and 19 may be replaced by a single three-position switch or other multiple-pole, multiple-throw switch. If desired, such switches may be operated remotely by magnetic means or can be programmed for automatic operation.

When switch 19 is closed, alternating current will flow in the circuit in response to power applied through coil 3. If switch 18 is connected to sensing device 16, the amplitude of the alternating current will depend upon the magnitude of the particular variable sensed. This information signal will be coupled over to external coil 7, amplified by AC amplifier 21, and detected by detector 22 which may be, for example, a simple peak following circuit well known to those skilled in the art. A threshold adjustment device 23 is provided for adjusting the DC level of the output signal from detector 22. The output signal from threshold adjustment device 23 is amplified by a DC amplifier 24 and fed into the indicating and/or recording device 25.

The procedure for aligning and calibrating the passive telemetry system of the present invention is as follows: first, external mounting plate 8 carrying coils 6 and 7 is positioned on the exterior of the experimental animal 1 at the approximate location of the subcutaneous implant 2. The power is then turned on, and the position of the external coils 6 and 7 is adjusted until a suitably strong reading is obtained at indicator recorder 25. The maximum reading indicates maximum magnetic coupling and, hence, minimum distance between the implanted sensing circuit and the external coupling coils. Hence, the maximum meter reading indicates that the external coupling coils 6 and 7 are centered over coils 3 and 4 of the implanted passive sensing circuit.

The next step is to establish the proper orientation of the external coils 6 and 7 with respect to the implanted coils 3 and 4.

This is accomplished by opening switch **19** and then rotating external mounting plate **8** until a minimum meter reading is obtained. The minimum meter reading indicates that external power coil **6** is aligned in substantially parallel spaced relation with one of the implanted coils such as, for example, coil **3**, and is aligned at substantially right angles to the other internal coil such as, for example coil **4**. In this manner, little if any power is coupled from external coil **6** to internal coil **4**, and hence, little if any power is coupled from coil **4** to external coil **6**. At the same time, although the power coupling between external coil **6** and internal coil **3** is at a maximum, the coupling between coil **3** and coil **7** is at a minimum, thus producing a minimum meter reading.

The method of opening switch **19** of the implanted passive sensing circuit depends upon the type of switch employed. For example, if switch **19** is a magnetic reed switch of the type well known to those skilled in the art, it may be opened by applying an appropriate magnetic field. This may be accomplished by placing a suitable permanent bar magnet on the exterior of the experimental animal in the vicinity of the implanted switch **19**.

When external coils **6** and **7** are properly oriented and a minimum meter reading is obtained, threshold adjustment device **23** may be adjusted to produce a "zero" meter reading, so that any subsequent nonzero meter reading will be properly representative of the magnitude of the current circulating in the implanted passive sensing circuit.

After external coils **6** and **7** are properly oriented and the meter is "zeroed," switch **19** is closed so as to permit current to flow in the implanted circuit. The system may be calibrated by switching switch **18** to position **27**, so that the current flows through standard resistor **17**, and then noting the resulting meter reading. Measurements of the selected physiological parameter are then obtained by switching switch **18** to position **28**, so that the current flows through sensing device **16**. A comparison of the resulting meter readings with the standard meter reading obtained from resistor **17** in view of the known characteristics of sensing device **16** indicates the actual magnitude of the parameter sensed.

As in the case of switch **19**, the method of operating switch **18** depends upon the type of switch employed. For example, if switch **18** is a conventional magnetic reed switch, it may be operated by placing a suitable permanent bar magnet on the exterior of the animal in the vicinity of the implanted switch **18**. Alternatively, magnetically operated latching switches can be employed so that the operating magnet can be withdrawn after switching is completed. This feature permits the switch to be an integral part of the implant **2**.

Although the foregoing description of the operating procedures of the telemetry system of the present invention calls for the calibration of the system prior to the taking of readings of the parameter sensed, it is clear that the system may be calibrated after the actual measurements are taken or, in fact, from time to time during the taking of the measurements.

Although the passive sensing circuit shown in FIG. **2** includes only one sensing device, it will be apparent to those skilled in the art that several separate sensing devices may be employed within the spirit and scope of the present invention. For example, the passive sensing circuit shown in FIG. **4** includes three separate sensing devices **16**, **29** and **30** in addition to standard resistor **17**. Switches **18**, **31** and **32** permit any one of the sensing devices **17**, **29** and **30** or standard resistor **17** to be switched into the loop connecting coils **3** and **4** of the passive sensing circuit. Alternatively, a multiple-pole switch can be employed. In this manner a single implant can be used to monitor several different physiological parameters.

Although the implanted magnetic coils **3** and **4** should be located immediately beneath the skin of the animal **1**, in order to provide good coupling with external coils **6** and **7** as explained above in connection with FIGS. **1** and **3**, it will be appreciated that the implanted sensing device or devices may be located deep within the body of the animal if desired. FIG. **5** shows an implant **2** including three sensing devices **16**, **29** and **30** at the ends of flexible cables, so that they may be located deep within the body of the animal remote from subcutaneous magnetic coils **3** and **4**. Magnetic reed switches **18**, **19**, **31** and **32** are also located remote from magnetic coils **3** and **4**, at the ends of flexible cables so that the magnetic field produced by the permanent magnets used to operate switches **18**, **19**, **31** and **32** do not interfere with the magnetic fields coupling the implanted magnetic coils **3** and **4** to their associated external coils. Switches **18**, **19**, **31** and **32** are also located immediately beneath the skin of the animal and are widely separated from each other in order to facilitate their separate operation by suitable external magnets.

Although the principles of the present invention have been illustrated by reference to a preferred embodiment and several modifications thereof, it will be apparent to those skilled in the art that other modifications and adaptations of the present passive telemetry system may be made without departing from the spirit and scope of the invention as set forth with particularity in the appended claims.

We claim:

1. A passive telemetry system comprising:

a source of alternating current;

a first magnetic coil connected to said source of alternating current;

a second magnetic coil oriented for minimum magnetic coupling with said first magnetic coil;

indicating means responsive to voltage induced in second magnetic coil; and

a passive sensing circuit comprising:

- a sensing device for modulating alternating current in response to a variable,
- a third magnetic coil connected to said sensing device, said third magnetic coil being disposed in spaced relation to said first magnetic coil and oriented for magnetic coupling therewith in order to supply alternating current to said sensing device; and
- a fourth magnetic coil connected to said sensing device, said fourth magnetic coil being disposed in spaced relation to said second magnetic coil and oriented for magnetic coupling therewith in order to transmit the modulated alternating current from said sensing device through said second magnetic coil to said indicating means.

2. The passive telemetry system of claim **1** wherein said first magnetic coil and said second magnetic coil are disposed adjacent each other and are oriented at substantially right angles to each other for minimum magnetic coupling therebetween.

3. The passive telemetry system of claim **2** wherein said third magnetic coil and said fourth magnetic coil are disposed adjacent each other and oriented at substantially right angles to each other for minimum magnetic coupling therebetween.

4. The passive telemetry system of claim **3** wherein said first magnetic coil and said third magnetic coil are disposed in substantially parallel spaced relation for maximum magnetic coupling therebetween.

5. The passive telemetry system of claim **4** wherein said second magnetic coil and said fourth magnetic coil are disposed in substantially parallel spaced relation for maximum magnetic coupling therebetween.

6. The passive telemetry system of claim **3** further comprising a switch disposed in the current path between said third magnetic coil and said fourth magnetic coil for interrupting the flow of current therebetween.

7. The passive telemetry system of claim **6** wherein said switching means comprises a magnetic reed switch operable by an external magnet and wherein said magnetic reed switch is located remote from said magnetic coils to avoid distorting the magnetic fields induced by said magnetic coils during the operation of said magnetic reed switch by said external magnet.

8. The passive telemetry system of claim **3** further comprising a standard element and switching means for substituting said standard element for said sensing device in said passive sensing circuit.

9. The passive telemetry system of claim **8** wherein said switching means comprises magnetic reed switch located remote from said magnetic coils so as to avoid disturbing the magnetic fields induced by said magnetic coils during the operation of said magnetic reed switch by an external magnet.

10. The passive telemetry system of claim **8** wherein said sensing device comprises a thermistor connected in series with said third magnetic coil and said fourth magnetic coil, and wherein said standard element comprises a standard resistance connected in parallel with said thermistor.

11. The passive telemetry system of claim **3** wherein said passive sensing circuit is encased within an inert substance suitable for implantation in a living animal.

12. A two-way signal transfer system comprising:

a first magnetic coil for producing a magnetic filed in response to an electrical signal applied to its terminals,

a second magnetic coil for producing an electrical signal at its terminals in response to changes in the magnetic flux produced by said first magnetic coil, said second magnetic coil having its axis disposed in substantially parallel spaced relation to the axis of said first magnetic coil for maximum magnetic coupling therebetween,

a third magnetic coil for producing a magnetic flux in space in response to an electrical signal applied to its terminals, said third magnetic coil being adjacent said second magnetic coil and having its axis at substantially right to the axis of said second magnetic coil for minimum magnetic coupling between said third magnetic coil and said first and second magnetic coils, and

a fourth magnetic coil disposed adjacent said first magnetic coil for producing an electrical signal at its terminals in response to changes in the magnetic flux produced by said third magnetic coil, the axis of said fourth magnetic coil being disposed at substantially right angles to the axis of said first magnetic coil and in substantially parallel spaced relation to the axis of said third magnetic coil for minimum magnetic coupling with said first and second magnetic coils and for maximum magnetic coupling with said third magnetic coil.

13. The two-way signal transfer system of claim **12** wherein the plane of said first magnetic coil and said second magnetic coil is disposed in substantially parallel spaced relation to the plane of said second magnetic coil and said third magnetic coil.