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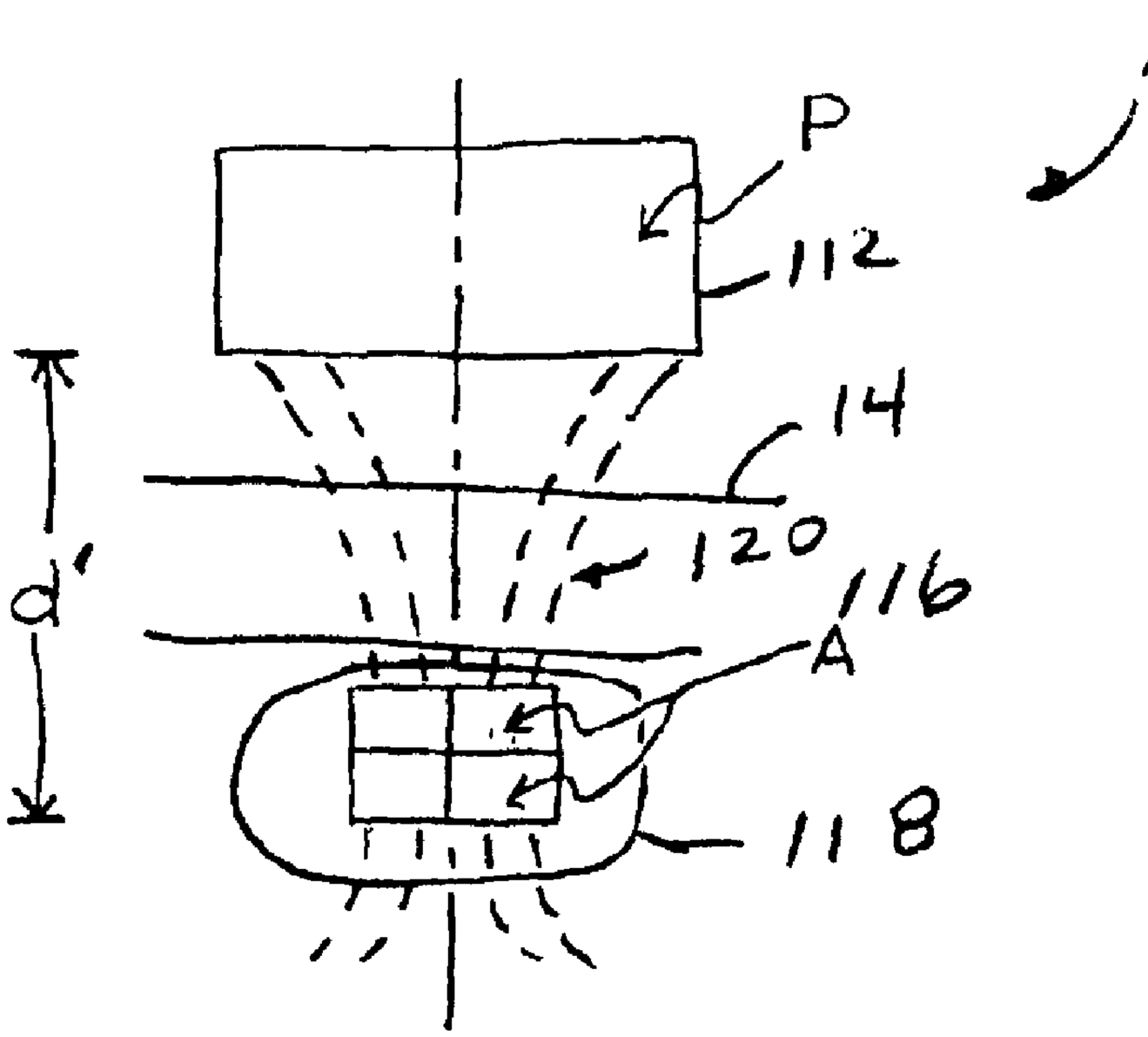
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(54) Titre : BOBINES SECONDAIRES JUMELEES A DECOUPLAGE SPATIAL PERMETTANT D'OPTIMISER LES CARACTERISTIQUES DE TRANSFERT DE PUISSANCE POUR LE TRANSFERT D'ENERGIE TRANSCUTANE (TET)

(54) Title: SPATIALLY DECOUPLED TWIN SECONDARY COILS FOR OPTIMIZING TRANSCUTANEOUS ENERGY TRANSFER (TET) POWER TRANSFER CHARACTERISTICS



(57) Abrégé/Abstract:
An implantable device, such as an infuser device for bi-directional hydraulically controlling a medical artificial sphincter, enhances power transfer characteristics to a secondary coil thereby allowing implantation to greater physical depths and/or enclosing the

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(57) Abrégé(suite)/Abstract(continued):
secondary coil within a housing of the infuser device. The enhanced power transfer is achieved with multiple coils that are longitudinally aligned and physical and electrical parallel to form the secondary loop of a transcutaneous energy transfer system (TET) instead of a single coil. It better optimizes the power transfer from a parallel tuned tank circuit primary coil to an implanted secondary series tuned tank circuit coil.

SPATIALLY DECOUPLED TWIN SECONDARY COILS FOR OPTIMIZING TRANSCUTANEOUS ENERGY TRANSFER (TET) POWER TRANSFER CHARACTERISTICS

Abstract of the Invention

An implantable device, such as an infuser device for bi-directional hydraulically controlling a medical artificial sphincter, enhances power transfer characteristics to a secondary coil thereby allowing implantation to greater physical depths and/or enclosing the secondary coil within a housing of the infuser device. The enhanced power transfer is achieved with multiple coils that are longitudinally aligned and physical and electrical parallel to form the secondary loop of a transcutaneous energy transfer system (TET) instead of a single coil. It better optimizes the power transfer from a parallel tuned tank circuit primary coil to an implanted secondary series tuned tank circuit coil.

SPATIALLY DECOUPLED TWIN SECONDARY COILS FOR OPTIMIZING TRANSCUTANEOUS ENERGY TRANSFER (TET) POWER TRANSFER CHARACTERISTICS

Field of the Invention

[0002] The present invention pertains to a transcutaneous energy transfer (TET) system, in particular, to a TET system used between an external control module and a deeply implanted medical implant.

Background of the Invention

[0003] It is known to surgically implant a medical device in a patient's body to achieve a number of beneficial results. In order to operate properly within the patient, a reliable, consistent power link between the medical implant and an external control module is often necessary to monitor the implant's performance or certain patient parameters and/or to command certain operations by the implant. This power link has

traditionally been achieved with TET systems that communicate across a small amount of tissue, such as relatively thin dermal tissue across the front of the patient's shoulder, such as for cardiac pacemakers.

[0004] In some instances, multiple coils have been suggested in regard to a TET or telemetry system in order to provide additional flexibility in aligning primary and secondary coils. For instance, U.S. Pat. No. 6058330 Borza discloses a transcutaneous system in which multiple coils were used in the secondary circuitry and perhaps also in the primary circuitry. However, in this instance secondary coils are spaced about the patient's body for the purpose of mitigating tissue damage due to long term exposure to strong electromagnetic fields in a continuous application wherein the medical implant is continuously TET powered or continuously engaged in telemetry. Thus, the '330 Borza patent teaches combining the power received from multiple secondary coils that are widely spaced, either a selected one of the secondary coils is receiving a strong electromagnetic signal or multiple secondary coils are simultaneously receiving weaker electromagnetic signals so that the dermal tissue overlying any one secondary coil is not continuously exposed to a strong electromagnetic signal.

[0005] Another problem with continuously coupling electromagnetic power to a secondary coil is the inconvenience to the patient of having the primary coil externally fixed in place, hampering movement and causing discomfort. U.S. Pat. No. 6366817 to Kung discloses using multiple coils in the primary spaced about the patient with circuitry that detects which primary coil is best oriented to efficiently couple electromagnetic energy to the implanted secondary coil and thus switching current to the selected primary coil.

[0006] U.S. Pat. No. 6463329 to Goedeke discloses multiple primary telemetry coils whose major surface, defined by their exterior, are parallel to one another and spaced apart. These coils are used to initiate telemetric communication between the programmer or monitor and the implanted device. At the frequencies disclosed, these coils are employed as loop antennas rather than inductively coupled coils. Since the antenna pattern of a loop antenna includes a "null" when very close to the loop, this approach is used to switch between primary coils when necessary to communicate with the secondary coil, thus primarily addressing problems with medical implants placed under a

thin layer of dermal tissue that could coincide with the null of a primary coil placed in contact with the patient.

[0007] U.S. Pat. No. 5,741,316 to Chen et al. discloses a transmitter coil that has half of the windings on one leg of a horseshoe magnetic conductor in series with another half of the windings on the other leg. The magnetic flux contribution of each winding portion is thereby combined. However, the corresponding requirement for a horseshoe-shaped magnetic core in the implanted device is undesirable due to the increased size. Thus, laterally offset, electrically serial windings would not be a benefit for a secondary coil integral to an implanted device that lacks a horseshoe shaped magnetic conductor.

[0008] While these approaches to improving the effectiveness of electromagnetic coupling to a medical implant have merit, we have recognized an application that does not benefit from spaced apart multiple primary coils and/or spaced apart secondary coils, yet a need exists for enhanced power transfer efficiency. An implantable medical device that may benefit from use of enhanced TET is an artificial sphincter, in particular an adjustable gastric band that contains a hollow elastomeric balloon with fixed end points encircling a patient's stomach just inferior to the esophago-gastric junction. These balloons can expand and contract through the introduction of saline solution into the balloon. In generally known adjustable gastric bands, this saline solution must be injected into a subcutaneous port with a syringe needle to reach the port located below the skin surface. The port communicates hydraulically with the band via a catheter. While effective, it is desirable to avoid having to adjust the fluid volume with a syringe needle since an increased risk of infection may result, as well as inconvenience and discomfort to the patient.

[0009] To that end, we have recently developed implanted infuser devices that regulate the flow of saline without requiring injection into the subcutaneous port. This system transfers AC magnetic flux energy from an external primary coil to a secondary coil that powers the pump in the implant connected to the gastric band within the abdomen. Although batteries may be used to power the device, these long-term devices benefit from use of TET, allowing an implanted device of reduced size and complexity. Moreover, these devices may remain unpowered between adjustments, which provides additional advantages. These implantable, bi-directional infusing devices that would

benefit from enhanced TET powering and/or telemetry are disclosed in four co-pending and co-owned U.S. patent applications filed on May 28, 2004, entitled (1) "PIEZO ELECTRICALLY DRIVEN BELLOWS INFUSER FOR HYDRAULICALLY CONTROLLING AN ADJUSTABLE GASTRIC BAND" to William L. Hassler, Jr., Serial No. 10/857,762 ; (2) "METAL BELLOWS POSITION FEED BACK FOR HYDRAULIC CONTROL OF AN ADJUSTABLE GASTRIC BAND" to William L. Hassler, Jr., Daniel F. Dlugos, Jr., Rocco Crivelli, Serial No. 10/856,971 ; (3) "THERMODYNAMICALLY DRIVEN REVERSIBLE INFUSER PUMP FOR USE AS A REMOTELY CONTROLLED GASTRIC BAND" to William L. Hassler, Jr., Daniel F. Dlugos, Jr., Serial No. 10/857,315 ; and (4) "BI-DIRECTIONAL INFUSER PUMP WITH VOLUME BRAKING FOR HYDRAULICALLY CONTROLLING AN ADJUSTABLE GASTRIC BAND" to William L. Hassler, Jr., Daniel F. Dlugos, Jr., Serial No. 10/857,763 .

[0010] Unlike the previously mentioned medical implants, an infuser device for an artificial sphincter is typically implanted below a thicker dermal layer of skin and adipose tissue. This is particularly true for patients that typically receive an adjustable gastric band as a treatment for morbid obesity. Moreover, being more deeply implanted may allow for greater client comfort. However, the thickness of tissue presents difficulties for effective power coupling from a primary TET coil.

[0011] It is desirable that the secondary coil be encompassed within an outer case of the infuser device to enhance the integrity of the device. It is especially desirable to not have one or more secondary coils detached from the infuser device and implanted more superficially, as this complicates the implantation and explantation of the infuser device. Consequently, these generally known approaches to having spaced apart secondary coils to additively contribute to received signals are not appropriate. Further, there are physical and electromagnetic constraints to configuration of a secondary coil that is encompassed within a medical implant, especially the diameter, the number of turns of the coil, and the diameter of each turn.

[0012] Consequently, in order to provide for a larger power transfer range between the primary and secondary TET coils a significant need exists for enhancing power

coupling with a deeply implanted medical device within the dimensional constraints imposed upon a secondary coil.

Brief Summary of the Invention

[0013] The invention overcomes the above-noted and other deficiencies of the prior art by providing a transcutaneous energy transfer (TET) system for an implantable medical device that increases the number of turns on the secondary coil while maintaining the same impedance and Q factor (i.e., ratio of bandpass center frequency to 3 dB cutoff frequency) as a single coil configuration. Power transfer is increased to the secondary coil while relatively maintaining the same power on the primary coil.

[0014] In one aspect of the invention, a medical implant benefits from enhanced power transfer between an external primary TET coil and its secondary TET coil by splitting the secondary TET coil into two physically and electrically parallel coils. The effective number of magnetic flux collecting turns was doubled while maintaining the impedance, the inductance, capacitance, total tank circuit Q and natural frequency of the original secondary coil and tank circuit. By virtue thereof, a medical implant may be implanted more deeply for therapeutic reasons and for simplified implantation and explantation purposes, yet perform satisfactorily.

[0015] In another aspect of the invention, a TET system that includes both the implantable medical device and an external primary coil assembly achieve an enhanced power efficiency by the twin, electrically and physically parallel secondary TET coils.

[0016] In yet another aspect of the invention, an inductive energy transfer system for powering a device separated by a barrier from an external primary coil is enhanced by including a pair of electrically and physically parallel front and back secondary coils that are part of a resonant tank circuit.

[0017] These and other objects and advantages of the present invention shall be made apparent from the accompanying drawings and the description thereof.

Brief Description of the Figures

[0018] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention, and, together with the

general description of the invention given above, and the detailed description of the embodiments given below, serve to explain the principles of the present invention.

[0019] FIG. 1 is a diagram of a generally known primary coil aligned for transcutaneous power transfer and/or telemetry to a single secondary coil contained in an implanted medical device for powering electrical components therein.

[0020] FIG. 2 is a diagram of a primary coil aligned for transcutaneous power transfer and/or telemetry to a twin secondary coil consistent with aspects of the present invention contained in an implanted medical device for enhanced powering electrical components therein.

[0021] FIG. 3A is a line graph comparing secondary power received at 20kHz by the generally-known single secondary coil of FIG. 1 versus the twin secondary coil electrically connected in parallel of FIG. 2.

[0022] FIG. 3B is a line graph comparing primary power of the 310 turn 32-gauge coil to the two 325 turn 34-gauge coils connected in parallel at 20kHz.

[0023] FIG. 4 is an impedance-phase plot of the twin secondary coil of FIG. 2.

[0024] FIG. 5 is an impedance-phase plot of the generally known single secondary coil of FIG. 1.

Detailed Description of the Invention

[0025] In FIG. 1, a generally-known transcutaneous energy transfer (TET) system 10 provides power and/or telemetry between a primary coil 12, which is external to a dermal layer 14, to a secondary coil 16 within an implanted device 18, which is under the dermal layer 14. The primary coil 12 is inductively coupled to the secondary coil 16, as depicted by magnetic flux lines 20.

[0026] In developing a more efficient TET and/or telemetry system, and in particular the secondary coils of the system, it is necessary to optimize the combination of coil turns, DC resistance, tank circuit capacitance, tank circuit impedance and total tank circuit Q. Spatially optimizing a secondary coil design is largely dictated by how closely the secondary coil may be placed (distance "D") and longitudinally aligned (longitudinal

axis "L") to the primary coil 12. Given constraints on the available volume and placement for the secondary coil 16 within implanted device 18, further maximization is generally available in this manner for a medical implant.

[0027] As an example of optimizing a single coil design, coils were wound with different wire gauges and turn ratios in order to create different impedances. These secondary coils 16 were made in a single coil configuration, the best configuration for a secondary coil 16. The best single coil configuration for the above mentioned infuser implant was 310 turns of 32-gauge magnet wire and was approximately 30 ohms DC resistance. The setup for the 310 turn 32 gauge secondary coil 16 is shown in FIG. 1. The highest power output that this coil provided to a fixed load under a set of test conditions was 3.96 Watts.

[0028] In FIG. 2, a TET system 110 consistent with aspects of the invention provides power and/or telemetry between a primary coil 112, which is external to the dermal layer 14, to a double secondary coil 116, within an implanted device 118, which is under the dermal layer 14. Magnetic flux lines 120 denote increased power efficiency at a distance d' between coils 112, 116. A secondary coil was made-up of two coils in parallel, each having 325 turns of 34-gauge wire. This coil was approximately 30 ohms DC resistance and is shown in FIG. 2. The highest power that the two 325 turn 34 gauge coils in parallel provided to a fixed load under the same test conditions as the 310 turn 32-gauge coil was 4.46 Watts. A comparison of the power transfer curves of both coil arrangements is shown in FIGS. 3A and 3B. The power transfer curve for the two 325 turn 34-gauge coil arrangement has higher secondary power output than the single coil arrangement. However, the two 325 turn 34-gauge coil arrangement drew only a slight increase in primary power and is relatively the same size, impedance, and Q as the single coil arrangement, giving it a better efficiency.

[0029] The total impedances at resonance of both coils were relatively the same. In the illustrative version, a parallel combination of two impedances of 60 OHMS is equivalent to a single impedance of 30 OHMS. It proves theoretically how the 310 turn 32-gauge coil and the two 325 turn 34 gauge coil have the same total impedance. The impedance-phase plots of both coil arrangements were compared and found to be

functionally equivalent as shown in FIGS. 4-5. Also, the total tank circuit Q value of the impedance plots of both coils were found to be relatively the same.

[0030] The two 325 turn 34-gauge coil arrangement gave a more optimum power transfer characteristic. It is not completely understood how this was accomplished, and it will probably require the use of electromagnetic finite element analysis (FEA) in order to fully understand this phenomenon. What is postulated is that by spatially spreading out the turns of the secondary coil as well as effectively doubling their number as far as coupling to the magnetic flux produced by the primary coil, the power transfer to the secondary was increased. This effect was not apparent by simple linear circuit analysis, which would conclude that the two coils were equivalent.

[0031] While the present invention has been illustrated by description of several embodiments and while the illustrative embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the invention to such detail. Additional advantages and modifications may readily appear to those skilled in the art.

[0032] For example, while the TET system 16 described has particular advantages for an implantable medical device system 10, aspects consistent with the present invention have application to other scientific and engineering scenarios including inanimate physical boundaries. For instance, in a processing apparatus it may be desirable to monitor and/or control an actuator that is contained within a vessel without compromising the integrity of the vessel with wires or conduits passing therethrough.

[0033] For another example, TET for the purposes of power transfer to operate implanted devices has been illustrated above, although applications consistent with aspects of the invention may be directed to TET for communication purposes (i.e., telemetry). Thus, the power coupling efficiencies enhance the reliability and performance of the resultant communication channel.

[0034] For a further example, additional power transfer efficiencies may be realized by adding additional coils in physical and electrical parallel to the two described above with circuit optimization to maintain an appropriate Q and impedance, and thus a secondary twin coil is not limited to only two coils.

[0035] What is claimed is:

Claims

1. An implantable medical device that communicates with a primary transcutaneous energy transfer (TET) circuit external to a patient via a transcutaneous energy transfer channel, the implantable medical device comprising:

a housing

a first TET coil received by the housing;

a second TET coil received by the housing, electrically coupled in parallel with the first TET coil, and physically proximate to and centered on a longitudinal axis of the first TET coil; and

control circuitry in electronic communication with the parallel first and second TET coils and operably configured to utilize power transferred to the first and second TET coils.

2. The implantable medical device of claim 1, wherein the housing includes a coil receptacle comprising a cylindrically recessed portion of the housing.

3. The implantable medical device of claim 1, wherein the housing includes a coil receptacle comprising a cylindrical bobbin.

4. The implantable medical device of claim 1, wherein the first and second TET coils each are comprised of a coil formed having about 325 turns.

5. The implantable medical device of claim 4, wherein the first and second TET coils comprise 34 gauge magnetic wire.

6. The implantable medical device of claim 1, wherein the control circuitry comprises a telemetry transceiver.

7. The implantable medical device of claim 1, further comprising a series capacitance in electrical communication with the first and second TET coils to form a resonant tank circuit having a center frequency of about 20 kHz.

8. The implantable medical device of claim 1, further comprising a third TET coil electrically coupled in parallel with the first and second TET coils, and physically proximate to and centered on the longitudinal axis of the first and second TET coils, wherein the control circuitry in electronic communication with the parallel first, second and third TET coils is further operably configured to utilize power transferred to the first, second and third TET coils.

9. A transcutaneous energy transfer (TET) system, comprising:

a primary transcutaneous energy transfer (TET) circuit external to a patient; and

an implantable medical device, comprising:

a housing including a coil receptacle having a longitudinally aligned and proximate first portion and second portion,

a first TET coil received by the first portion of the coil receptacle,

a second TET coil received by the second portion of the coil receptacle electrically coupled in parallel with the first TET coil,

resonance circuitry in electrical communication with the first and second TET coils to form a resonant tank circuit, and

control circuitry in electronic communication with the parallel first and second TET coils and operably configured to utilize power transferred to the first and second TET coils.

10. The transcutaneous energy transfer (TET) system of claim 9, wherein the coil receptacle comprises a cylindrically recessed portion of the housing.

11. The transcutaneous energy transfer (TET) system of claim 9, wherein the coil receptacle comprises a cylindrical bobbin.

12. The transcutaneous energy transfer (TET) system of claim 9, wherein the first and second TET coils each are comprised of a coil formed having about 325 turns.

13. The transcutaneous energy transfer (TET) system of claim 12, wherein the first and second TET coils comprise 34-gauge magnetic wire.

14. The transcutaneous energy transfer (TET) system of claim 9, wherein the control circuitry comprises a telemetry transceiver.

15. The transcutaneous energy transfer (TET) system of claim 9, further comprising a series capacitance in electrical communication with the first and second TET coils to form a resonant tank circuit having a center frequency of about 20 kHz.

16. An inductive energy transfer system, comprising:

a primary coil assembly operably configured to induce a magnetic field having a resonant frequency through a barrier; and

a separate device spaced apart from the primary coil assembly by the barrier, the separate device comprising:

a front secondary coil substantially longitudinally aligned to an axis of the primary coil,

a back secondary coil electrically coupled in parallel with, physically proximate to, and aligned parallel with the front secondary coil,

resonance circuitry in electrical communication with the front and back secondary coils to form a resonant tank circuit having a pass band selected to encompass the resonant frequency of the primary coil assembly, and

control circuitry in electronic communication with the parallel front and back secondary coils and operably configured to utilize electrical power received therefrom.

17. The inductive energy transfer system of claim 16, further comprising a housing encompassing the separate device and including a coil receptacle having a longitudinally aligned and proximate first portion and second portion to receive respectively the front and back secondary coils.

18. The inductive energy transfer system of claim 17, wherein the coil receptacle comprises a cylindrically recessed portion of the housing.

19. The inductive energy transfer system of claim 17, wherein the coil receptacle comprises a cylindrical bobbin.

20. The inductive energy transfer system of claim 16, wherein the front and back secondary coils each are comprised of a coil formed having about 325 turns.

21. The inductive energy transfer system of claim 20, wherein the front and back secondary coils comprise 34-gauge magnetic wire.

22. The inductive energy transfer system of claim 16, wherein the control circuitry comprises a telemetry transceiver.

23. The inductive energy transfer system of claim 16, further comprising a series capacitance in electrical communication with the first and second TET coils to form a resonant tank circuit having a center frequency of about 20 kHz.

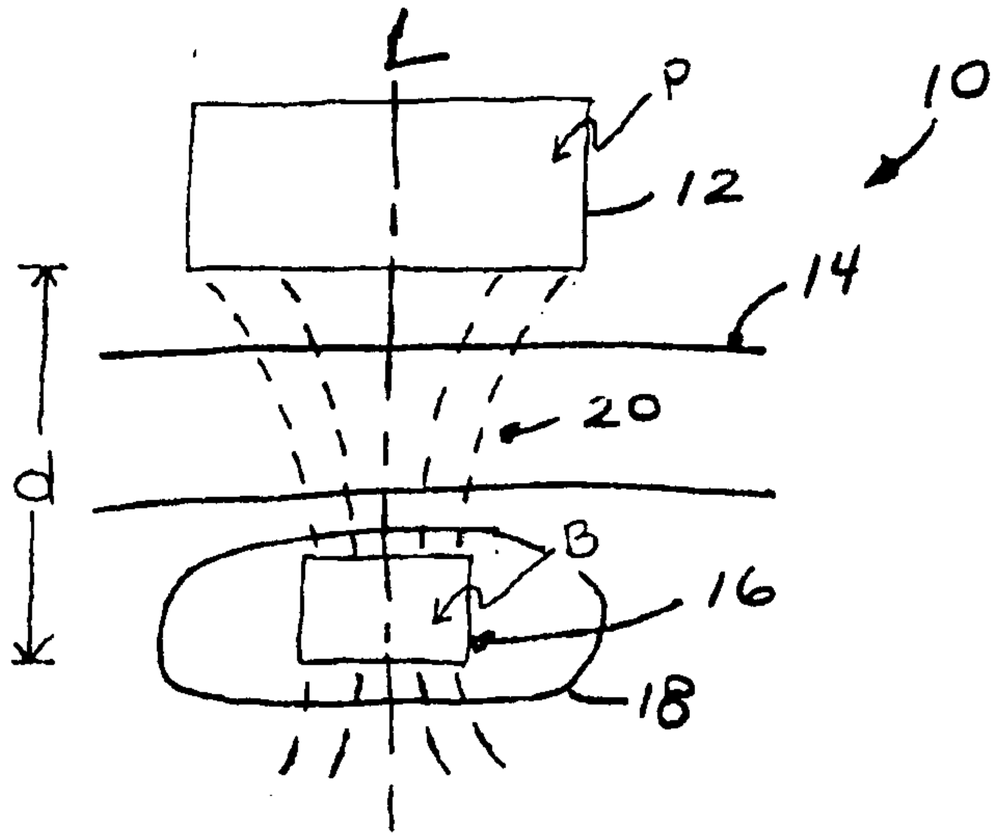


FIGURE 1. (PRIOR ART)

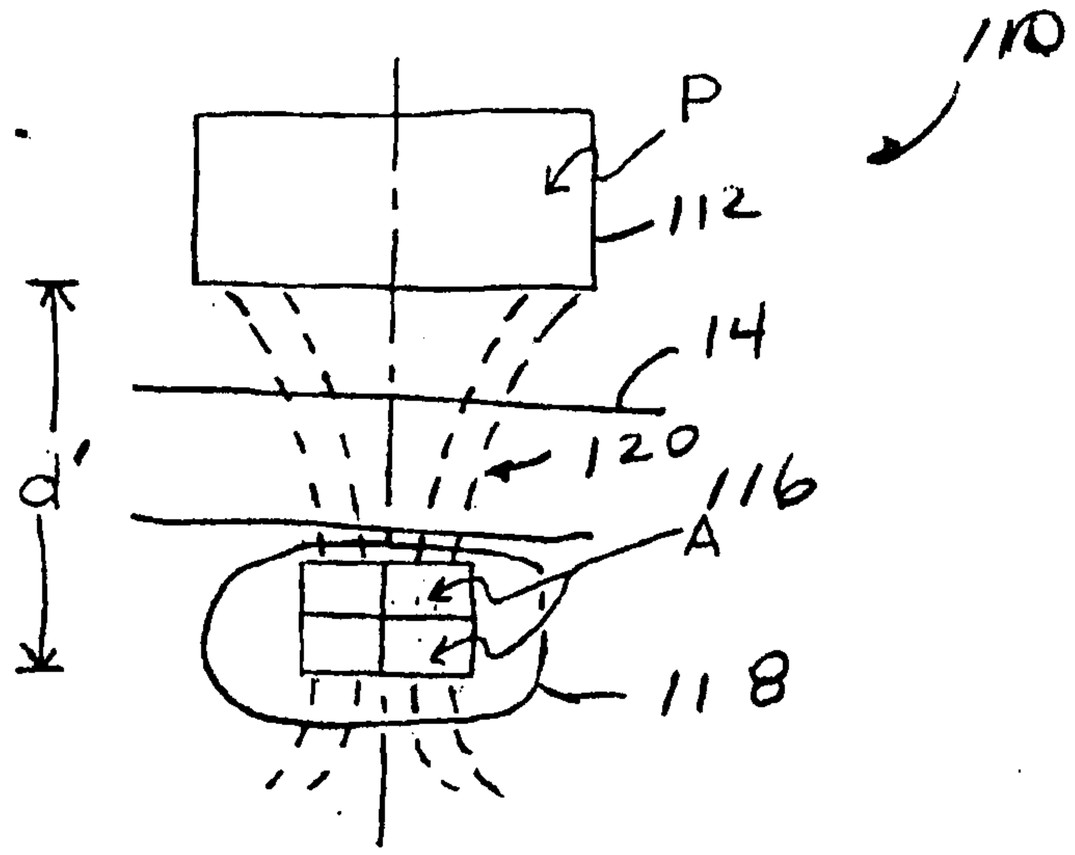


FIGURE 2.

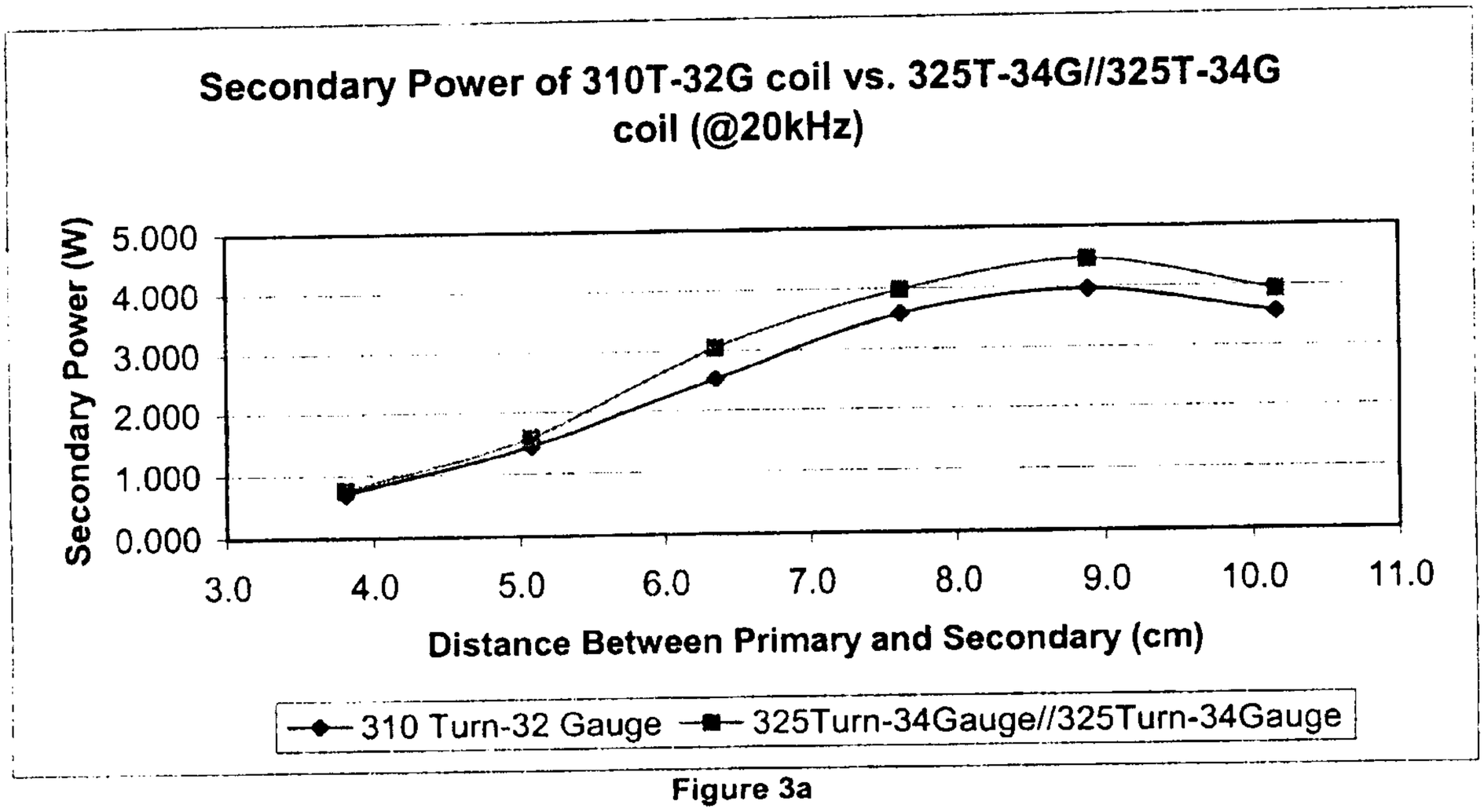


Figure 3a

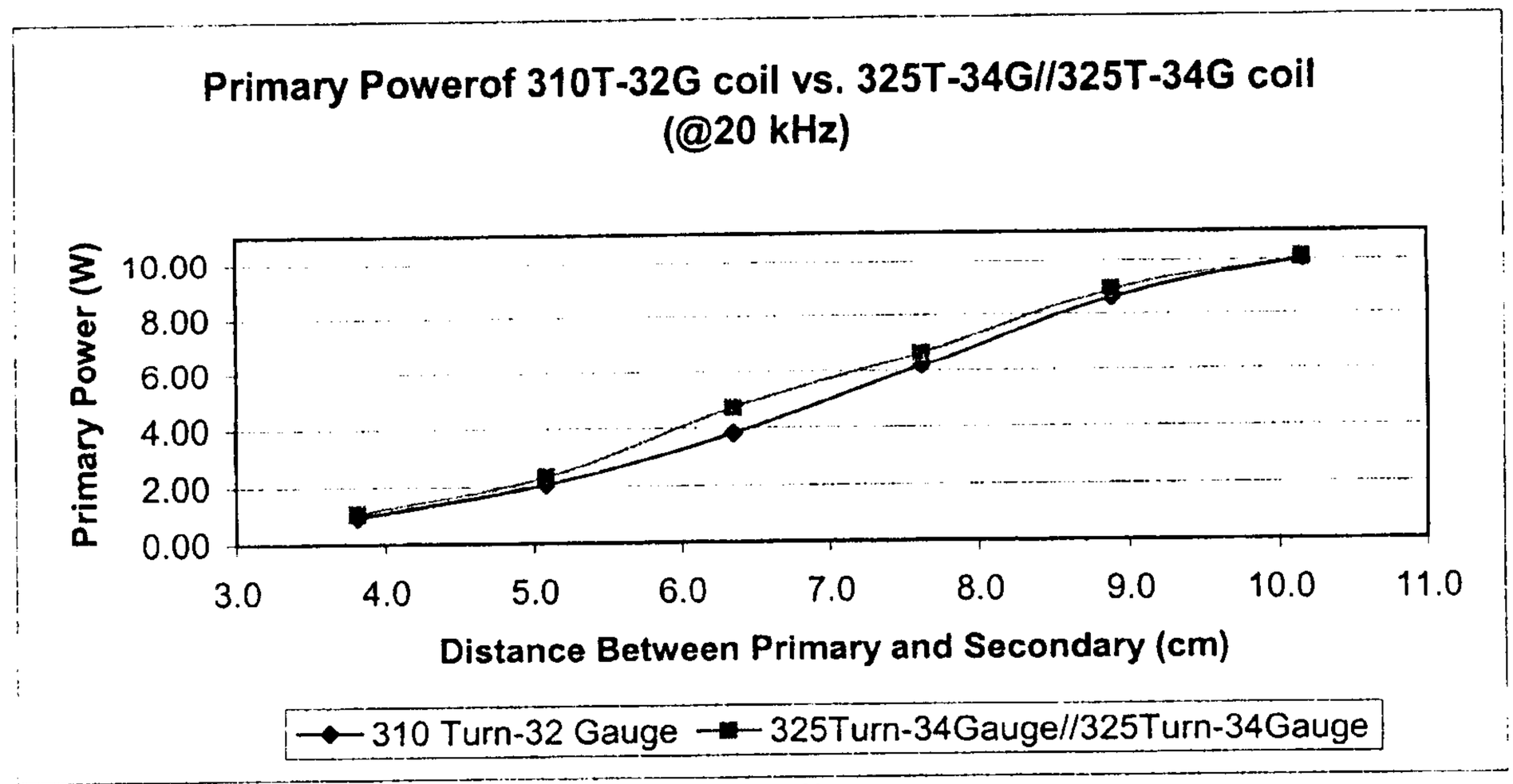


Figure 3b

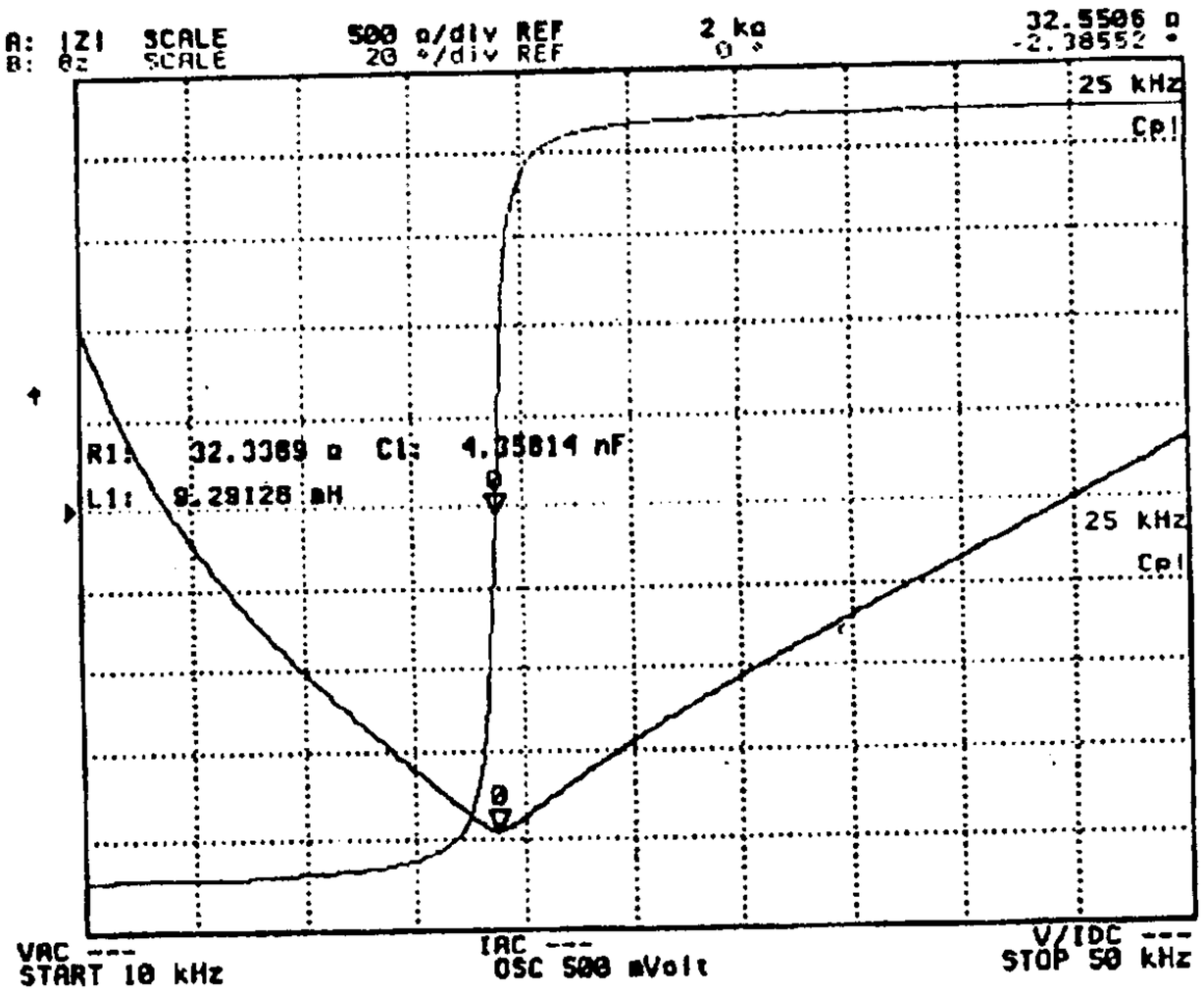


Figure 4

325Turns-34Gauge //325Turns-34Gauge (series tuned)

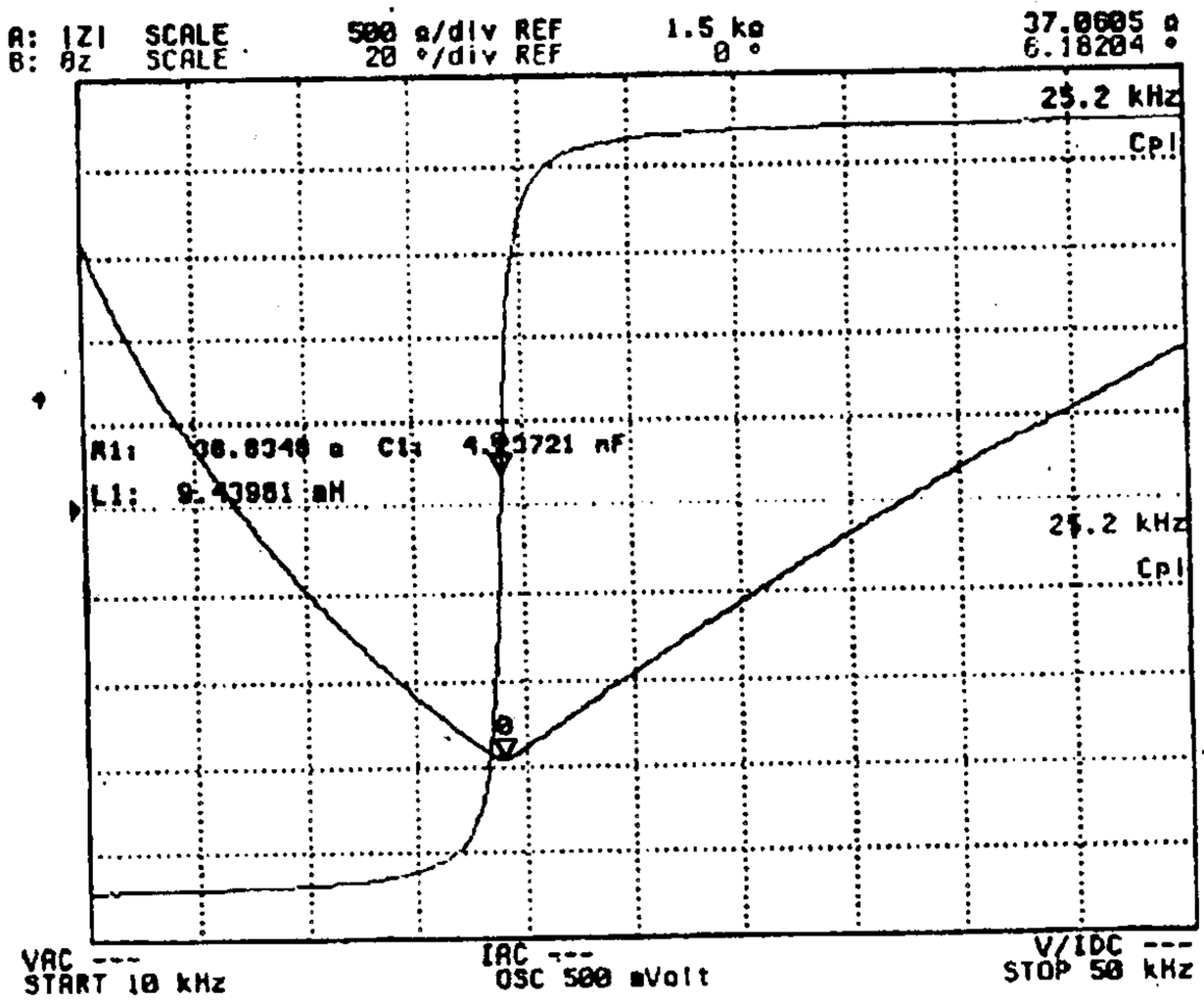
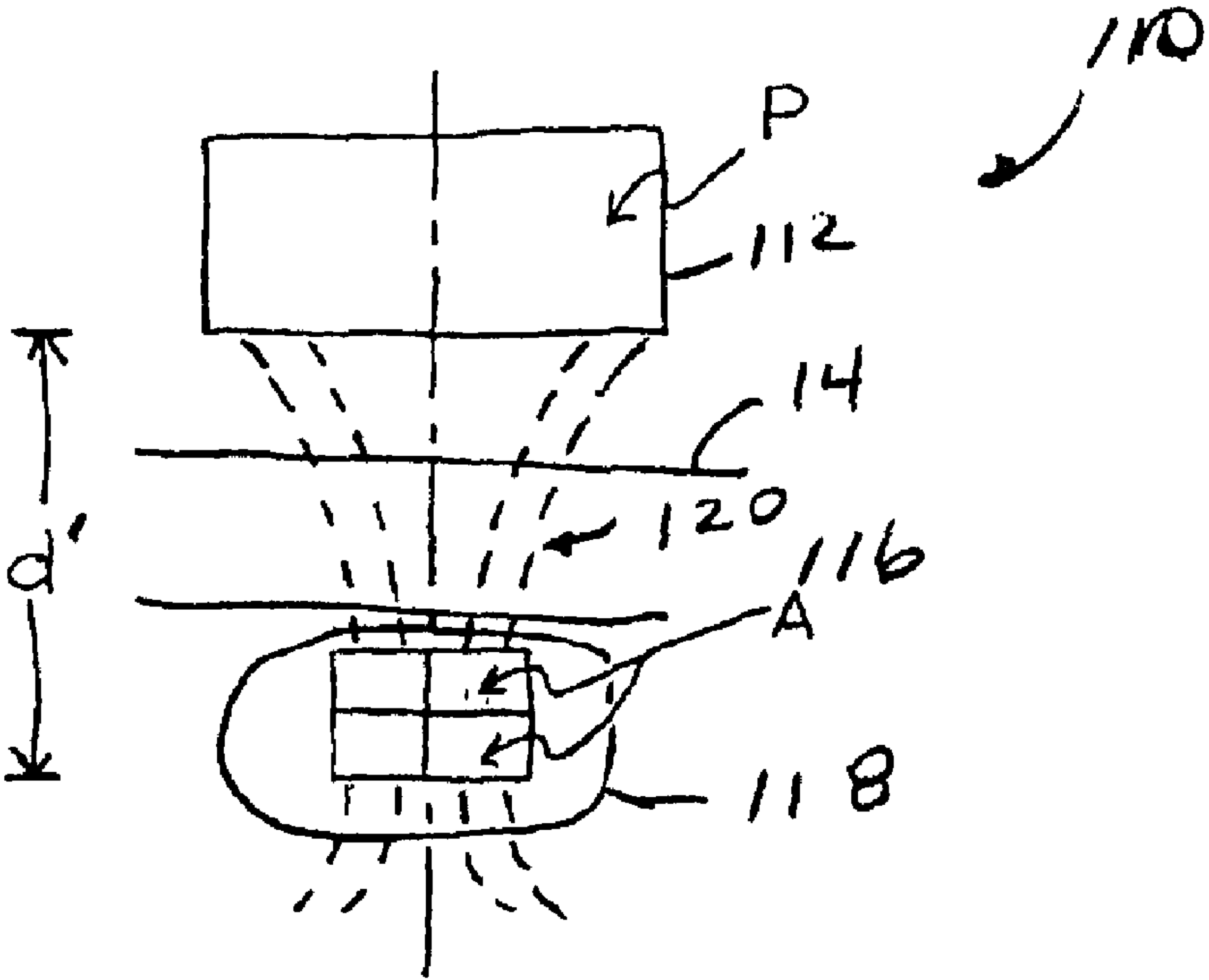


Figure 5

310Turns-32Gauge (series tuned)


110
P
112
14
d'
120
116
A
118