



(86) Date de dépôt PCT/PCT Filing Date: 1999/01/13

(87) Date publication PCT/PCT Publication Date: 1999/07/22

(45) Date de délivrance/Issue Date: 2003/12/02

(85) Entrée phase nationale/National Entry: 2000/07/13

(86) N° demande PCT/PCT Application No.: US 1999/000879

(87) N° publication PCT/PCT Publication No.: 1999/036124

(30) Priorité/Priority: 1998/01/16 (09/008,636) US

(51) Cl.Int.⁶/Int.Cl.⁶ A61N 1/362

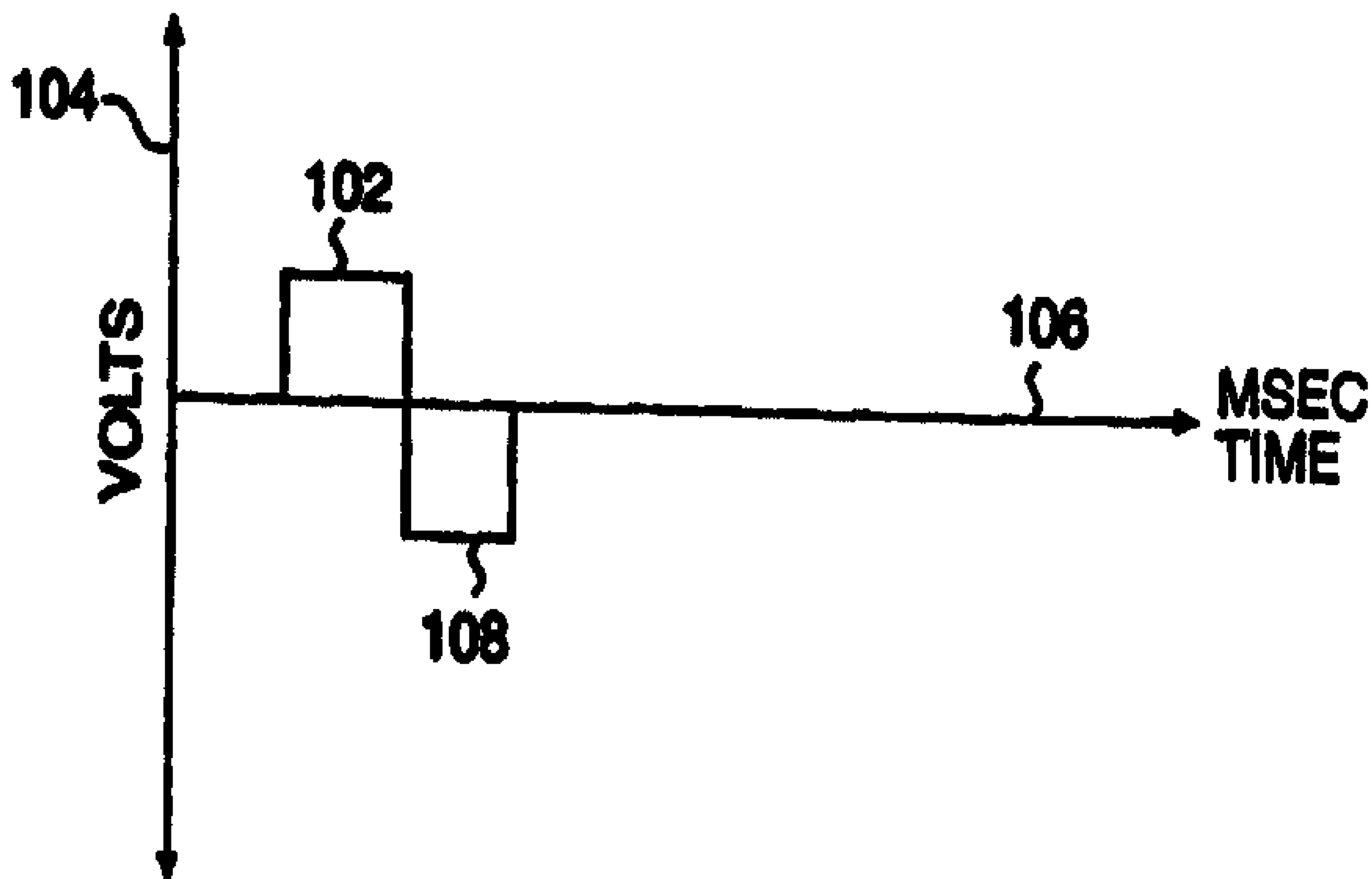
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(54) Titre : AUGMENTATION DE LA CONDUCTION ELECTRIQUE ET DE LA CONTRACTILITE PAR STIMULATION CARDIAQUE BIPHASIQUE ADMINISTREE A TRAVERS LE POOL SANGUIN INTRACARDIAQUE

(54) Title: AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTIBILITY BY BIPHASIC CARDIAC PACING ADMINISTERED VIA THE CARDIAC BLOOD POOL



(57) Abrégé/Abstract:

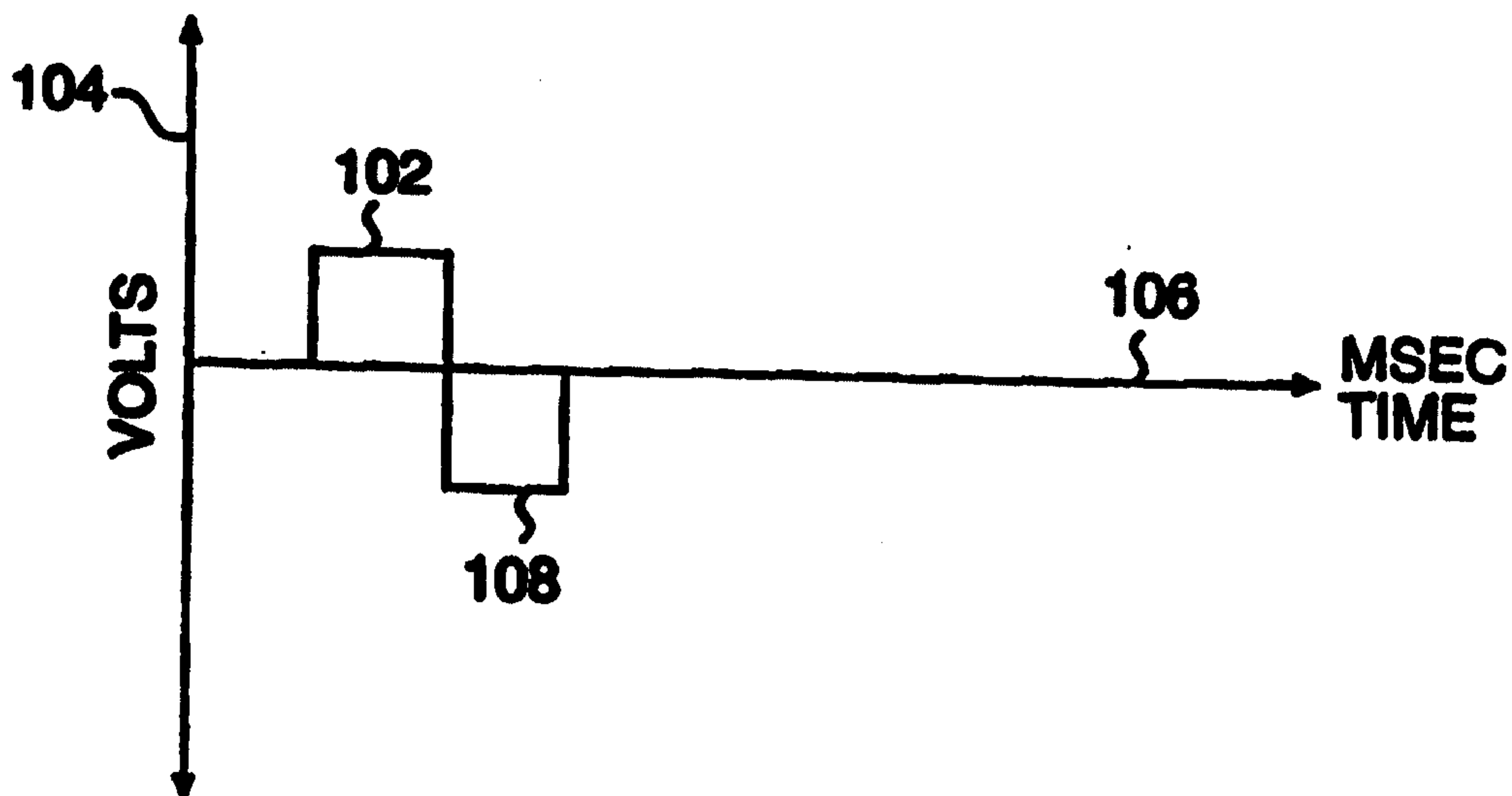
Augmentation of electrical conduction and contractibility by biphasic cardiac pacing. A first stimulation phase is administered to the cardiac blood pool. This first stimulation phase has a predefined polarity, amplitude and duration. A second stimulation phase is then administered to the cardiac blood pool. This second phase also has a predefined polarity, amplitude and duration. The two phases are applied sequentially. Contrary to current thought, anodal stimulation is first applied and followed by cathodal stimulation. In this fashion, pulse conduction through the cardiac muscle is improved together with the increase in contractibility.

PCTWORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : A61N 1/362	A1	(11) International Publication Number: WO 99/36124 (43) International Publication Date: 22 July 1999 (22.07.99)
(21) International Application Number: PCT/US99/00879 (22) International Filing Date: 13 January 1999 (13.01.99) (30) Priority Data: 09/008,636 16 January 1998 (16.01.98) US (71)(72) Applicant and Inventor: MOWER, Morton, M. [US/US]; 3908 North Charles Street #1001, Baltimore, MD 21218 (US). (74) Agent: ROBERTS, Jon, L.; Roberts & Brownell, LLC, Suite 212, 8381 Old Courthouse Road, Vienna, VA 22182 (US).		(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i>

(54) Title: AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTIBILITY BY BIPHASIC CARDIAC PACING ADMINISTERED VIA THE CARDIAC BLOOD POOL

**(57) Abstract**

Augmentation of electrical conduction and contractibility by biphasic cardiac pacing. A first stimulation phase is administered to the cardiac blood pool. This first stimulation phase has a predefined polarity, amplitude and duration. A second stimulation phase is then administered to the cardiac blood pool. This second phase also has a predefined polarity, amplitude and duration. The two phases are applied sequentially. Contrary to current thought, anodal stimulation is first applied and followed by cathodal stimulation. In this fashion, pulse conduction through the cardiac muscle is improved together with the increase in contractibility.

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**AUGMENTATION OF ELECTRICAL CONDUCTION AND CONTRACTIBILITY BY
BIPHASIC CARDIAC PACING ADMINISTERED VIA THE CARDIAC BLOOD
POOL**

FIELD OF THE INVENTION

5 This invention relates generally to a method for the stimulation of muscle tissue. In particular, this invention relates to a method for cardiac stimulation and pacing with biphasic waveforms wherein the stimulation is administered via the cardiac blood pool.

10 **BACKGROUND OF THE INVENTION**

 The function of the cardiovascular system is vital for survival. Through blood circulation, body tissues obtain necessary nutrients and oxygen, and discard waste substances. In the absence of circulation, cells begin to
15 undergo irreversible changes that lead to death. The muscular contractions of the heart are the driving force behind circulation.

 In cardiac muscle, the muscle fibers are interconnected in branching networks that spread in all
20 directions through the heart. When any portion of this net is stimulated, a depolarization wave passes to all of its parts and the entire structure contracts as a unit. Before a muscle fiber can be stimulated to contract, its membrane must be polarized. A muscle fiber generally remains
25 polarized until it is stimulated by some change in its environment. A membrane can be stimulated electrically, chemically, mechanically or by temperature change. The minimal stimulation strength needed to elicit a contraction is known as the threshold stimulus. The maximum stimulation

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amplitude that may be administered without eliciting a contraction is the maximum subthreshold amplitude.

Where the membrane is stimulated electrically, the impulse amplitude required to elicit a response is dependent upon a number of factors. First, is the duration of current flow. Since the total charge transferred is equal to the current amplitude times the pulse duration, increased stimulus duration is associated with a decrease in threshold current amplitude. Second, the percentage of applied current that actually traverses the membrane

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1 known as the threshold stimulus. The maximum stimulation amplitude that may be
2 administered without eliciting a contraction is the maximum subthreshold amplitude.

3 Where the membrane is stimulated electrically, the impulse amplitude required to
4 elicit a response is dependent upon a number of factors. First, is the duration of current flow.
5 Since the total charge transferred is equal to the current amplitude times the pulse duration,
6 increased stimulus duration is associated with a decrease in threshold current amplitude.
7 Second, the percentage of applied current that actually traverses the membrane varies
8 inversely with electrode size. Third, the percentage of applied current that actually traverses
9 the membrane varies directly with the proximity of the electrode to the tissue. Fourth, the
10 impulse amplitude required to elicit a response is dependent upon the timing of stimulation
11 within the excitability cycle.

12 Throughout much of the heart are clumps and strands of specialized cardiac muscle
13 tissue. This tissue comprises the cardiac conduction system and serves to initiate and
14 distribute depolarization waves throughout the myocardium. Any interference or block in
15 cardiac impulse conduction may cause an arrhythmia or marked change in the rate or rhythm
16 of the heart

17 Sometimes a patient suffering from a conduction disorder can be helped by an
18 artificial pacemaker. Such a device contains a small battery powered electrical stimulator.
19 When the artificial pacemaker is installed, electrodes are generally threaded through veins
20 into the right ventricle, or into the right atrium and right ventricle, and the stimulator is
21 planted beneath the skin in the shoulder or abdomen. The leads are planted in intimate
22 contact with the cardiac tissue. The pacemaker then transmits rhythmic electrical impulses to
23 the heart, and the myocardium responds by contracting rhythmically. Implantable medical
24 devices for the pacing of the heart are well known in the art and have been used in humans
25 since approximately the mid 1960s.

26 Either cathodal or anodal current may be used to stimulate the myocardium. However
27 anodal current is thought not to be useful clinically. Cathodal current comprises electrical
28 pulses of negative polarity. This type of current depolarizes the cell membrane by
29 discharging the membrane capacitor, and directly reduces the membrane potential toward
30 threshold level. Cathodal current, by directly reducing the resting membrane potential toward
31 threshold has a one-half to one-third lower threshold current in late diastole than does anodal

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1 current. Anodal current comprises electrical pulses of positive polarity. The effect of anodal
2 current is to hyperpolarize the resting membrane. On sudden termination of the anodal pulse,
3 the membrane potential returns towards resting level, overshoots to threshold, and a
4 propagated response occurs. The use of anodal current to stimulate the myocardium is
5 generally discouraged due to the higher stimulation threshold, which leads to use of a higher
6 current, resulting in a drain on the battery of an implanted device and impaired longevity.
7 Additionally, the use of anodal current for cardiac stimulation is discouraged due to the
8 suspicion that the anodal contribution to depolarization can, particularly at higher voltages,
9 contribute to arrhythmogenesis.

10 Virtually all artificial pacemaking is done using stimulating pulses of negative
11 polarity, or in the case of bipolar systems, the cathode is closer to the myocardium than is the
12 anode. Where the use of anodal current is disclosed, it is generally as a charge of minute
13 magnitude used to dissipate residual charge on the electrode. This does not affect or
14 condition the myocardium itself. Such a use is disclosed in U.S. Patent No. 4,543,956 to
15 Herscovici.

16 The use of a triphasic waveform has been disclosed in U.S. Patent Nos. 4,903,700 and
17 4,821,724 to Whigham et al., and U.S. Patent No. 4,343,312 to Cals et al. Here, the first and
18 third phases have nothing to do with the myocardium per se, but are only envisioned to affect
19 the electrode surface itself. Thus, the charge applied in these phases is of very low amplitude.

20 Lastly, biphasic stimulation is disclosed in U.S. Patent No. 4,402,322 to Duggan. The
21 goal of this disclosure is to produce voltage doubling without the need for a large capacitor in
22 the output circuit. The phases of the biphasic stimulation disclosed are of equal magnitude
23 and duration.

24 What is needed is an improved means for stimulating muscle tissue, wherein the
25 contraction elicited is enhanced and the damage to the tissue adjacent to the electrode is
26 diminished.

27 Enhanced myocardial function is obtained through the biphasic pacing of the present
28 invention. The combination of cathodal with anodal pulses of either a stimulating or
29 conditioning nature, preserves the improved conduction and contractility of anodal pacing
30 while eliminating the drawback of increased stimulation threshold. The result is a
31 depolarization wave of increased propagation speed. This increased propagation speed

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1 results in superior cardiac contraction leading to an improvement in blood flow. Improved
2 stimulation at a lower voltage level also results in reduction in power consumption and
3 increased life for pacemaker batteries. Lastly, the improved stimulation achieved through the
4 practice of the present invention allows for cardiac stimulation without the necessity of
5 placing electrical leads in intimate contact with cardiac tissue. Standard stimuli delivered
6 to the cardiac blood pool are ineffective in capturing the myocardium because it does not
7 meet the stimulation threshold. While voltage of the pulse generator can be increased, when
8 it does capture it is often so high that it also stimulates skeletal muscles thereby causing a
9 painful twitching of the chest wall when only the heart stimulation was desired. As will be
10 further discussed, through the practice of the present invention, one can enhance myocardial
11 function through cardiac blood pool stimulation.

12 As with the cardiac muscle, striated muscle may also be stimulated electrically,
13 chemically, mechanically or by temperature change. Where the muscle fiber is stimulated by
14 a motor neuron, the neuron transmits an impulse which activates all of the muscle fibers
15 within its control, that is, those muscle fibers in its motor unit. Depolarization in one region
16 of the membrane stimulates adjacent regions to depolarize also, and a wave of depolarization
17 travels over the membrane in all directions away from the site of stimulation. Thus, when a
18 motor neuron transmits an impulse, all the muscle fibers in its motor unit are stimulated to
19 contract simultaneously. The minimum strength to elicit a contraction is called the threshold
20 stimulus. Once this level of stimulation has been met, the generally held belief is that
21 increasing the level will not increase the contraction. Additionally, since the muscle fibers
22 within each muscle are organized into motor units, and each motor unit is controlled by a
23 single motor neuron, all of the muscle fibers in a motor unit are stimulated at the same time.
24 However, the whole muscle is controlled by many different motor units that respond to
25 different stimulation thresholds. Thus, when a given stimulus is applied to a muscle, some
26 motor units may respond while others do not.

27 The combination of cathodal and anodal pulses of the present invention also provides
28 improved contraction of striated muscle where electrical muscular stimulation is indicated
29 due to neural or muscular damage. Where nerve fibers have been damaged due to trauma or
30 disease, muscle fibers in the regions supplied by the damaged nerve fiber tend to undergo
31 atrophy and waste away. A muscle that cannot be exercised may decrease to half of its usual

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1 size in a few months. Where there is no stimulation, not only will the muscle fibers decrease
2 in size, but they will become fragmented and degenerated, and replaced by connective tissue.
3 Through electrical stimulation one may maintain muscle tone, such that upon healing or
4 regeneration of the nerve fiber, viable muscle tissue remains. Enhanced muscle contraction is
5 obtained through the biphasic stimulation of the present invention. The combination of
6 cathodal with anodal pulses of either a stimulating or conditioning nature results in
7 contraction of a greater number of motor units at a lower voltage level, leading to superior
8 muscle response.

10 SUMMARY OF THE INVENTION

12 It is therefore an object of the present invention to provide improved stimulation of
13 cardiac tissue.

14 It is another object of the present invention to increase cardiac output through superior
15 cardiac contraction leading to greater stroke volume.

16 It is another object of the present invention to increase impulse propagation speed.

17 It is another object of the present invention to extend pacemaker battery life.

18 It is a further object of the present invention to obtain effective cardiac stimulation at
19 a lower voltage level.

20 It is a further object of the present invention to eliminate the necessity of placing
21 electrical leads in intimate contact with tissue to obtain tissue stimulation.

22 It is a further object of the present invention to provide improved stimulation of
23 muscle tissue.

24 It is a further object of the present invention to provide contraction of a greater
25 number of muscle motor units at a lower voltage level.

26 A method and apparatus for muscular stimulation in accordance with the present
27 invention includes the administration of biphasic stimulation to the muscle tissue, wherein
28 both cathodal and anodal pulses are administered. According to one aspect of this invention,
29 this stimulation is administered to the myocardium in order to enhance myocardial function.
30 According to a further aspect of this invention, this stimulation is administered to the cardiac
31 blood pool and thereafter conducted to the cardiac tissue. This enables cardiac stimulation

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1 without the necessity of placing electrical leads in intimate contact with cardiac tissue.

2 According to a still further aspect of this invention, the stimulation is administered to striated
3 muscle tissue to evoke muscular response. Pacemaker electronics needed to practice the
4 method of the present invention are well known to those skilled in the art. Current pacemaker
5 electronics are capable of being programmed to deliver a variety of pulses, including those
6 disclosed herein.

7 The method and apparatus of the present invention comprises a first and second
8 stimulation phase, with each stimulation phase having a polarity, amplitude, shape and
9 duration. In a preferred embodiment the first and second phases have differing polarities. In
10 one alternative embodiment, the two phases are of differing amplitude. In a second alternative
11 embodiment, the two phases are of differing duration. In a third alternative embodiment, the
12 first phase is in a chopped wave form. In a fourth alternative embodiment, the amplitude of
13 the first phase is ramped. In a fifth alternative embodiment the first phase is administered
14 over 200 milliseconds after completion of a cardiac beating/pumping cycle. In a preferred
15 alternative embodiment, the first phase of stimulation is an anodal pulse at maximum
16 subthreshold amplitude for a long duration, and the second phase of stimulation is a cathodal
17 pulse of short duration and high amplitude. It is noted that the aforementioned alternative
18 embodiments can be combined in differing fashions. It is also noted that these alternative
19 embodiments are intended to be presented by way of example only, and are not limiting.

20 BRIEF DESCRIPTION OF THE DRAWINGS

21
22
23 Fig. 1 is a schematic representation of leading anodal biphasic stimulation.

24 Fig. 2 is a schematic representation of leading cathodal biphasic stimulation.

25 Fig. 3 is a schematic representation of leading anodal stimulation of low level and long
26 duration, followed by conventional cathodal stimulation.

27 Fig. 4 is a schematic representation of leading anodal stimulation of ramped low level and
28 long duration, followed by conventional cathodal stimulation.

29 Fig. 5 is a schematic representation of leading anodal stimulation of low level and short
30 duration, administered in series followed by conventional cathodal stimulation.

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1 Fig. 6 graphs conduction velocity transverse to the fiber vs pacing duration resulting from
2 leading anodal biphasic pulse.

3 Fig. 7 graphs conduction velocity parallel to the fiber vs pacing duration resulting from
4 leading anodal biphasic pulse.

5 6 DETAILED DESCRIPTION

7
8 The present invention relates to the biphasic electrical stimulation of muscle tissue.

9 Fig.

10 1 depicts biphasic electrical stimulation wherein a first stimulation phase comprising anodal
11 stimulus 102 is administered having amplitude 104 and duration 106. This first stimulation
12 phase is immediately followed by a second stimulation phase comprising cathodal stimulation
13 108 of equal intensity and duration.

14 Fig. 2 depicts biphasic electrical stimulation wherein a first stimulation phase
15 comprising cathodal stimulation 202 having amplitude 204 and duration 206 is administered.
16 This first stimulation phase is immediately followed by a second stimulation phase
17 comprising anodal stimulation 208 of equal intensity and duration.

18 Fig. 3 depicts a preferred embodiment of the present invention wherein a first
19 stimulation phase comprising low level, long duration anodal stimulation 302 having
20 amplitude 304 and duration 306 is administered. This first stimulation phase is immediately
21 followed by a second stimulation phase comprising cathodal stimulation 308 of conventional
22 intensity and duration. In an alternative embodiment of the invention, anodal stimulation 302
23 is at maximum subthreshold amplitude. In yet another alternative embodiment of the
24 invention, anodal stimulation 302 is less than three volts. In another alternative embodiment
25 of the invention, anodal stimulation 302 is a duration of approximately two to eight
26 milliseconds. In yet another alternative embodiment of the invention, cathodal stimulation
27 308 is of a short duration. In another alternative embodiment of the invention, cathodal
28 stimulation 308 is approximately 0.3 to 0.8 milliseconds. In yet another alternative
29 embodiment of the invention, cathodal stimulation 308 is of a high amplitude. In another
30 alternative embodiment of the invention, cathodal stimulation 308 is in the approximate range
31 of three to twenty volts. In yet another alternative embodiment of the present invention,

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1 cathodal stimulation 308 is of a duration less than 0.3 milliseconds and at a voltage greater
2 than twenty volts. In another alternative embodiment, anodal stimulation 302 is administered
3 over 200 milliseconds post heart beat. In the manner disclosed by these embodiments, as
4 well as those alterations and modifications which may become obvious upon the reading of
5 this specification, a maximum membrane potential without activation is achieved in the first
6 phase of stimulation.

7 Fig. 4 depicts an alternative preferred embodiment of the present invention wherein a
8 first stimulation phase comprising anodal stimulation 402 is administered over period 404
9 with rising intensity level 406. The ramp of rising intensity level 406 may be linear or non-
10 linear, and the slope may vary. This anodal stimulation is immediately followed by a second
11 stimulation phase comprising cathodal stimulation 408 of conventional intensity and
12 duration. In an alternative embodiment of the invention, anodal stimulation 402 rises to a
13 maximum subthreshold amplitude. In yet another alternative embodiment of the invention,
14 anodal stimulation 402 rises to a maximum amplitude that is less than three volts. In another
15 alternative embodiment of the invention, anodal stimulation 402 is a duration of
16 approximately two to eight milliseconds. In yet another alternative embodiment of the
17 invention, cathodal stimulation 408 is of a short duration. In another alternative embodiment
18 of the invention, cathodal stimulation 408 is approximately 0.3 to 0.8 milliseconds. In yet
19 another alternative embodiment of the invention, cathodal stimulation 408 is of a high
20 amplitude. In another alternative embodiment of the invention, cathodal stimulation 408 is in
21 the approximate range of three to twenty volts. In yet another alternative embodiment of the
22 present invention, cathodal stimulation 408 is of a duration less than 0.3 milliseconds and at a
23 voltage greater than twenty volts. In another alternative embodiment, anodal stimulation 402
24 is administered over 200 milliseconds post heart beat. In the manner disclosed by these
25 embodiments as well as those alterations and modifications which may become obvious upon
26 the reading of this specification, a maximum membrane potential without activation is
27 achieved in the first phase of stimulation.

28 Fig. 5 depicts biphasic electrical stimulation wherein a first stimulation phase
29 comprising series 502 of anodal pulses is administered at amplitude 504. In one embodiment
30 rest period 506 is of equal duration to stimulation period 508 and is administered at baseline
31 amplitude. In an alternative embodiment, rest period 506 is of a differing duration than

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1 stimulation period 508 and is administered at baseline amplitude. Rest period 506 occurs
2 after each stimulation period 508 with the exception that a second stimulation phase
3 comprising cathodal stimulation 510 of conventional intensity and duration immediately
4 follows the completion of series 502. In an alternative embodiment of the invention, the total
5 charge transferred through series 502 of anodal stimulation is at the maximum subthreshold
6 level. In yet another alternative embodiment of the invention, the first stimulation pulse of
7 series 502 is administered over 200 milliseconds post heart beat. In another alternative
8 embodiment of the invention, cathodal stimulation 510 is of a short duration. In yet another
9 alternative embodiment of the invention, cathodal stimulation 510 is approximately 0.3 to 0.8
10 milliseconds. In another alternative embodiment of the invention, cathodal stimulation 510 is
11 of a high amplitude. In yet another alternative embodiment of the invention, cathodal
12 stimulation 510 is in the approximate range of three to twenty volts. In another alternative
13 embodiment of the invention, cathodal stimulation 510 is of a duration less than 0.3
14 milliseconds and at a voltage greater than twenty volts.

16 EXAMPLE 1

18 Stimulation and propagation characteristics of the myocardium were studied in
19 isolated hearts using pulses of differing polarities and phases. The experiments were carried
20 out in five isolated Langendorff perfused rabbit hearts. Conduction velocity on the
21 epicardium was measured using an array of bipolar electrodes. Measurements were made
22 between six millimeters and nine millimeters from the stimulation site. Transmembrane
23 potential was recorded using a floating intracellular microelectrode. The following protocols
24 were examined: monophasic cathodal pulse, monophasic anodal pulse, leading cathodal
25 biphasic pulse and leading anodal biphasic pulse.

26 Table 1 discloses the conduction speed transverse to fiber direction for each
27 stimulation protocol administered, with stimulations of three, four and five volts and two
28 millisecond pulse duration.

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TABLE 1

Conduction Speed Transverse to Fiber Direction, 2 msec

duration

3 V

4 V

5 V

Cathodal Monophasic

 18.9 ± 2.5 cm/sec 21.4 ± 2.6 cm/sec 23.3 ± 3.0 cm/sec

Anodal Monophasic

 24.0 ± 2.3 cm/sec 27.5 ± 2.1 cm/sec 31.3 ± 1.7 cm/sec

Leading Cathodal Biphasic

 27.1 ± 1.2 cm/sec 28.2 ± 2.3 cm/sec 27.5 ± 1.8 cm/sec

Leading Anodal Biphasic

 26.8 ± 2.1 cm/sec 28.5 ± 0.7 cm/sec 29.7 ± 1.8 cm/sec

Table 2 discloses the conduction speed along fiber direction for each stimulation protocol administered, with stimulations of three, four and five volts and two millisecond pulse duration.

TABLE 2

Conduction Speed Along Fiber Direction, 2 msec stimulation

3 V

4 V

5 V

Cathodal Monophasic

 45.3 ± 0.9 cm/sec 47.4 ± 1.8 cm/sec 49.7 ± 1.5 cm/sec

Anodal Monophasic

 48.1 ± 1.2 cm/sec 51.8 ± 0.5 cm/sec 54.9 ± 0.7 cm/sec

Leading Cathodal Biphasic

 50.8 ± 0.9 cm/sec 52.6 ± 1.1 cm/sec 52.8 ± 1.7 cm/sec

Leading Anodal Biphasic

 52.6 ± 2.5 cm/sec 55.3 ± 1.5 cm/sec 54.2 ± 2.3 cm/sec

The differences in conduction velocities between the cathodal monophasic, anodal monophasic, leading cathodal biphasic and leading anodal biphasic were found to be significant ($p < 0.001$). From the transmembrane potential measurements, the maximum upstroke ((dV/dt)_{max}) of the action potentials was found to correlate well with the changes in conduction velocity in the longitudinal direction. For a four volt pulse of two millisecond duration, (dV/dt)_{max} was 63.5 ± 2.4 V/sec for cathodal and 75.5 ± 5.6 V/sec for anodal pulses.

EXAMPLE 2

The effects of varying pacing protocols on cardiac electrophysiology were analyzed using Langendorff prepared isolated rabbit hearts. Stimulation was applied to the heart at a constant voltage rectangular pulse. The following protocols were examined: monophasic

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1 anodal pulse, monophasic cathodal pulse, leading anodal biphasic pulse and leading cathodal
2 biphasic pulse. Administered voltage was increased in one volt steps from one to five volts
3 for both anodal and cathodal stimulation. Duration was increased in two millisecond steps
4 from two to ten milliseconds. Epicardial conduction velocities were measured along and
5 transverse to the left ventricular fiber direction at a distance between three to six millimeters
6 from the left ventricular free wall. Figs. 6 and 7 depict the effects of stimulation pulse
7 duration and the protocol of stimulation administered on the conduction velocities.

8 Fig. 6 depicts the velocities measured between three millimeters and six millimeters
9 transverse to the fiber direction. In this region, cathodal monophasic stimulation 602
10 demonstrates the slowest conduction velocity for each stimulation pulse duration tested. This
11 is followed by anodal monophasic stimulation 604 and leading cathodal biphasic stimulation
12 606. The fastest conductive velocity is demonstrated by leading anodal biphasic stimulation
13 608.

14 Fig. 7 depicts the velocities measured between three millimeters and six millimeters
15 parallel to the fiber direction. In this region, cathodal monophasic stimulation 702
16 demonstrates the slowest conduction velocity for each stimulation pulse duration tested.
17 Velocity results of anodal monophasic stimulation 704 and leading cathodal biphasic
18 stimulation 706 are similar with anodal monophasic stimulation demonstrating slightly
19 quicker speeds. The fastest conduction velocity is demonstrated by leading anodal biphasic
20 stimulation 708.

21 In one aspect of the invention, electrical stimulation is administered to the cardiac
22 muscle. The anodal stimulation component of biphasic electrical stimulation augments
23 cardiac contractility by hyperpolarizing the tissue prior to excitation, leading to faster impulse
24 conduction, more intracellular calcium release, and the resulting superior cardiac contraction.
25 The cathodal stimulation component eliminates the drawbacks of anodal stimulation,
26 resulting in effective cardiac stimulation at a lower voltage level than would be required with
27 anodal stimulation alone. This in turn, extends pacemaker battery life and reduces tissue
28 damage.

29 In a second aspect of the invention, biphasic electrical stimulation is administered to
30 the cardiac blood pool, that is, the blood entering and surrounding the heart. This enables
31 cardiac stimulation without the necessity of placing electrical leads in intimate contact with

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1 cardiac tissue, thereby diminishing the likelihood of damage to this tissue. The stimulation
2 threshold of biphasic stimulation administered via the blood pool is in the same range as
3 standard stimuli delivered directly to the heart muscle. Through the use of biphasic electrical
4 stimulation to the cardiac blood pool it is therefore possible to achieve enhanced cardiac
5 contraction, without skeletal muscle contraction, cardiac muscle damage or adverse effects to
6 the blood pool.

7 In a third aspect of the invention biphasic electrical stimulation is applied to striated
8 muscle tissue. The combination of anodal with cathodal stimulation results in the contraction
9 of a greater number of muscular motor units at a lower voltage level, resulting in improved
10 muscular response.

11 Having thus described the basic concept of the invention, it will be readily apparent to
12 those skilled in the art that the foregoing detailed disclosure is intended to be presented by
13 way of example only, and is not limiting. Various alterations, improvements and
14 modifications will occur and are intended to those skilled in the art, but are not expressly
15 stated herein. These modifications, alterations and improvements are intended to be
16 suggested hereby, and within the spirit and scope of the invention. Further, the pacing pulses
17 described in this specification are well within the capabilities of existing pacemaker
18 electronics with appropriate programming. Accordingly, the invention is limited only by the
19 following claims and equivalents thereto.

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CLAIMS:

1. An apparatus for electrical cardiac pacing, the apparatus comprising:

leads for applying electrical stimulation to a
5 cardiac blood pool; and

stimulation generator connected to the leads,
wherein the stimulation generator produces a biphasic
electrical waveform to stimulate the cardiac blood pool via
the leads to effect cardiac pacing, the electrical waveform
10 comprising:

a first stimulation phase with a first phase
polarity, a first phase amplitude, a first phase shape and a
first phase duration; and

a second stimulation phase with a second phase
15 polarity, a second phase amplitude, a second phase shape and
a second phase duration;

wherein the first phase polarity is positive.

2. The apparatus for electrical cardiac pacing of
claim 1, wherein the first stimulation phase and the second
20 stimulation phase are applied in sequence to the cardiac
blood pool.

3. The apparatus for electrical cardiac pacing of
claim 1, wherein the first phase amplitude is at a maximum
subthreshold amplitude.

25 4. The apparatus for electrical cardiac pacing of
claim 3, wherein the maximum subthreshold amplitude is about
0.5 to 3.5 volts.

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5. The apparatus for electrical cardiac pacing of claim 1, wherein the first phase duration is at least as long as the second phase duration.

6. The apparatus for electrical cardiac pacing of claim 1, wherein the first phase duration is about one to nine milliseconds.

7. The apparatus for electrical cardiac pacing of claim 1, wherein the second phase duration is about 0.2 to 0.9 milliseconds.

10 8. The apparatus for electrical cardiac pacing of claim 1, wherein the second phase amplitude is about two volts to twenty volts.

9. The apparatus for electrical cardiac pacing of claim 1, wherein the first stimulation phase is initiated greater than 200 milliseconds after completion of a cardiac beating cycle.

10. An apparatus for electrical cardiac pacing, the apparatus comprising:

leads for applying electrical stimulation to a cardiac blood pool; and

stimulation generator connected to the leads, wherein the stimulation generator produces a biphasic electrical waveform to stimulate the cardiac blood pool via the leads to effect cardiac pacing, the electrical waveform comprising:

a first stimulation phase with a first phase polarity, a first phase amplitude, a first phase shape and a first phase duration; and

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a second stimulation phase with a second phase polarity, a second phase amplitude, a second phase shape and a second phase duration;

wherein the first phase amplitude is less than the
5 second phase amplitude.

11. An apparatus for electrical cardiac pacing, the apparatus comprising:

leads for applying electrical stimulation to a cardiac blood pool; and

10 stimulation generator connected to the leads, wherein the stimulation generator produces a biphasic electrical waveform to stimulate the cardiac blood pool via the leads to effect cardiac pacing, the electrical waveform comprising:

15 a first stimulation phase with a first phase polarity, a first phase amplitude, a first phase shape and a first phase duration; and

a second stimulation phase with a second phase polarity, a second phase amplitude, a second phase shape and
20 a second phase duration;

wherein the first phase amplitude is ramped from a baseline value to a second value.

12. The apparatus for electrical cardiac pacing of claim 11, wherein the second value is equal to the second
25 phase amplitude.

13. The apparatus for electrical cardiac pacing of claim 11, wherein the second value is at a maximum subthreshold amplitude.

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14. The apparatus for electrical cardiac pacing of claim 13, wherein the maximum subthreshold amplitude is about 0.5 to 3.5 volts.

15. The apparatus for electrical cardiac pacing of claim 11, wherein the first phase duration is at least as long as the second phase duration.

16. The apparatus for electrical cardiac pacing of claim 11, wherein the first phase duration is about one to nine milliseconds.

10 17. The apparatus for electrical cardiac pacing of claim 11, wherein the second phase duration is about 0.2 to 0.9 milliseconds.

18. The apparatus for electrical cardiac pacing of claim 11, wherein the second phase amplitude is about two
15 volts to twenty volts.

19. The apparatus for electrical cardiac pacing of claim 11, wherein the second phase duration is less than 0.3 milliseconds and the second phase amplitude is greater than 20 volts.

20 20. An apparatus for electrical cardiac pacing, the apparatus comprising:

leads for applying electrical stimulation to a cardiac blood pool; and

stimulation generator connected to the leads,
25 wherein the stimulation generator produces a biphasic electrical waveform to stimulate the cardiac blood pool via the leads to effect cardiac pacing, the electrical waveform comprising:

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a first stimulation phase with a first phase polarity, a first phase amplitude, a first phase shape and a first phase duration; and

a second stimulation phase with a second phase polarity, a second phase amplitude, a second phase shape and a second phase duration;

wherein the second phase duration is less than 0.3 milliseconds and the second phase amplitude is greater than 20 volts.

21. An apparatus for electrical cardiac pacing, the apparatus comprising:

leads for applying electrical stimulation to a cardiac blood pool; and

stimulation generator connected to the leads, wherein the stimulation generator produces a biphasic electrical waveform to stimulate the cardiac blood pool via the leads to effect cardiac pacing, the electrical waveform comprising:

a first stimulation phase with a first phase polarity, a first phase amplitude, a first phase shape and a first phase duration; and

a second stimulation phase with a second phase polarity, a second phase amplitude, a second phase shape and a second phase duration;

wherein the first stimulation phase further comprises a series of stimulating pulses of a predetermined amplitude, polarity and duration; and

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wherein the first stimulation phase further comprises a series of rest periods.

22. The apparatus for electrical cardiac pacing of claim 21, wherein applying the first stimulation phase further comprises applying a rest period of a baseline amplitude after at least one stimulating pulse.

23. The apparatus for electrical cardiac pacing of claim 22, wherein the rest period is of equal duration to the duration of the stimulating pulse.

10 24. An apparatus for electrical cardiac pacing while enhancing contractility of cardiac muscle tissue, the apparatus comprising:

leads for applying electrical stimulation to a cardiac blood pool; and

15 stimulation generator connected to the leads, wherein the stimulation generator produces a biphasic electrical waveform to stimulate the cardiac blood pool via the leads to effect cardiac pacing, the electrical waveform comprising:

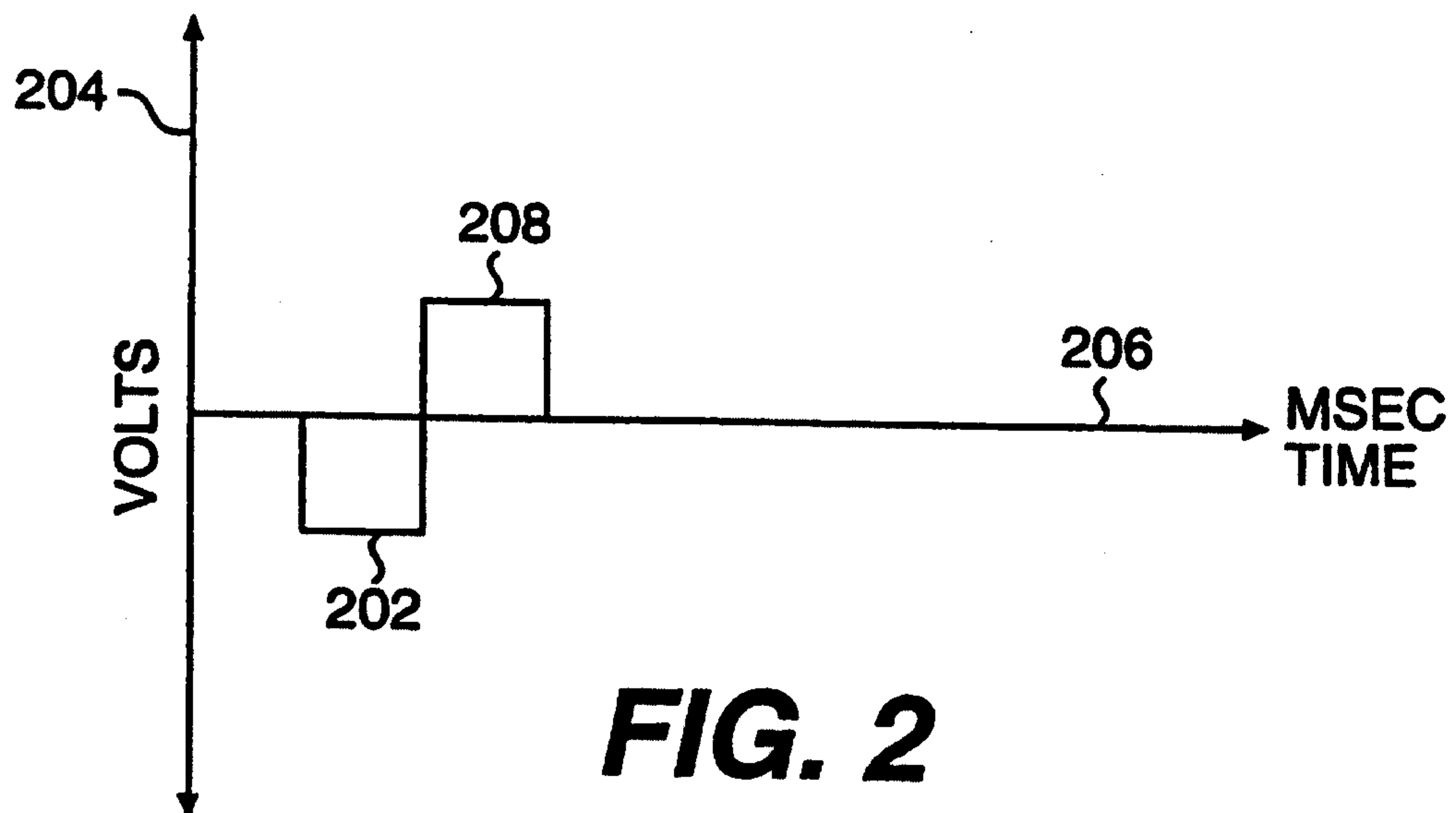
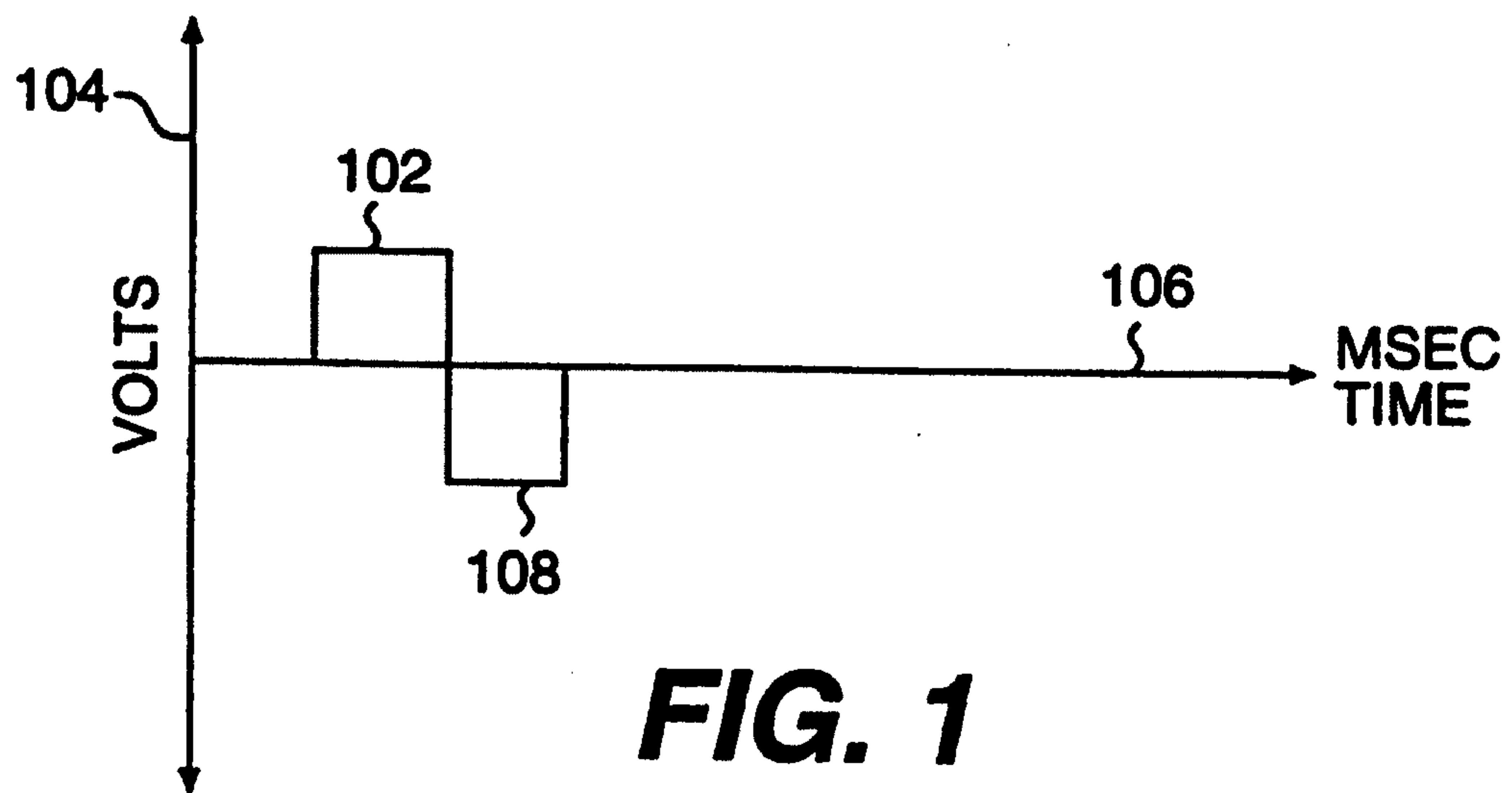
20 a first stimulation phase with a first phase polarity, a first phase amplitude, a first phase shape and a first phase duration; and

a second stimulation phase with a second phase polarity, a second phase amplitude, a second phase shape and
25 a second phase duration;

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wherein the first stimulation phase comprises anodal stimulation, thereby enhancing contractility of cardiac muscle tissue via stimulation of the cardiac blood pool.

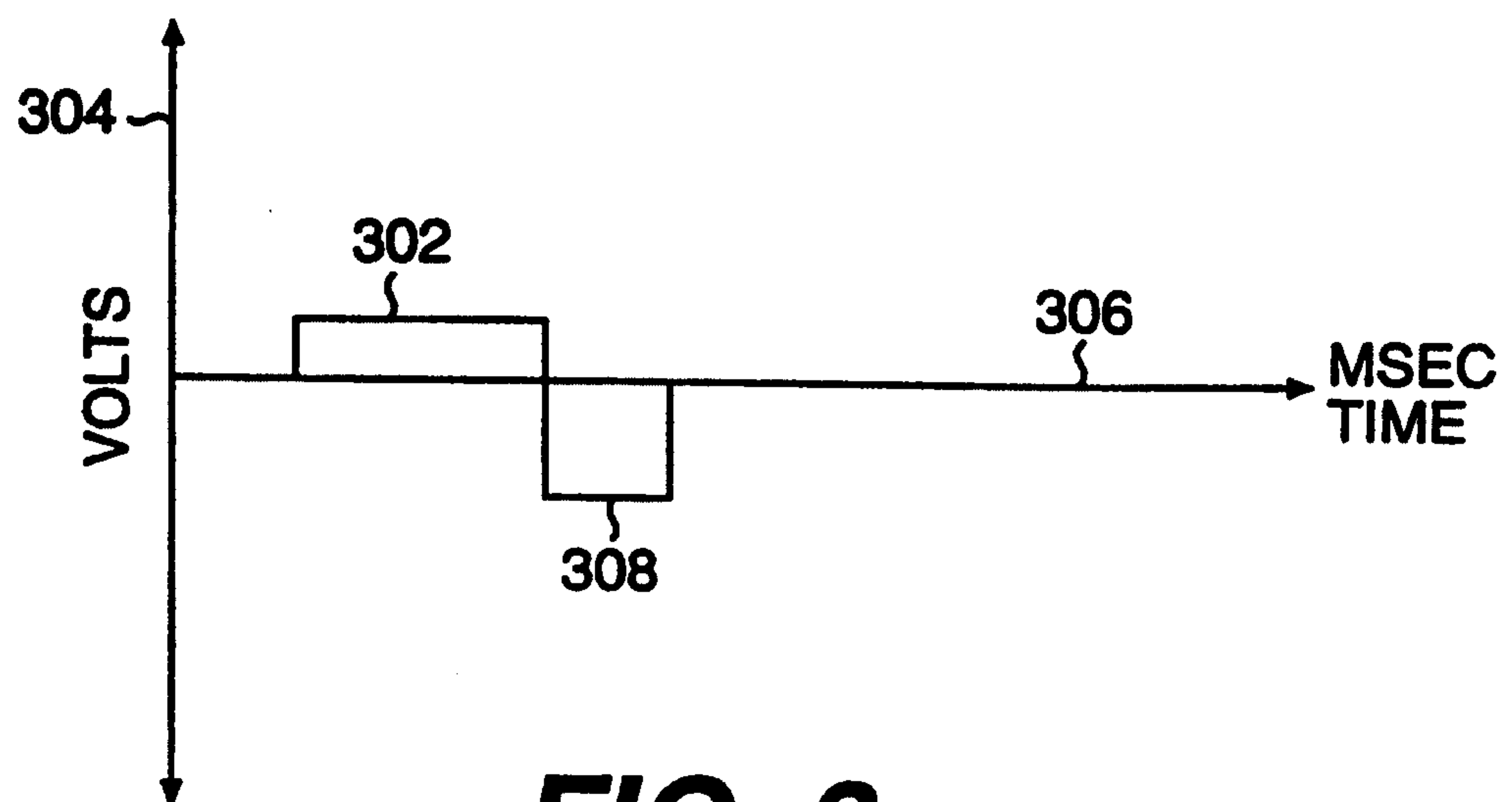
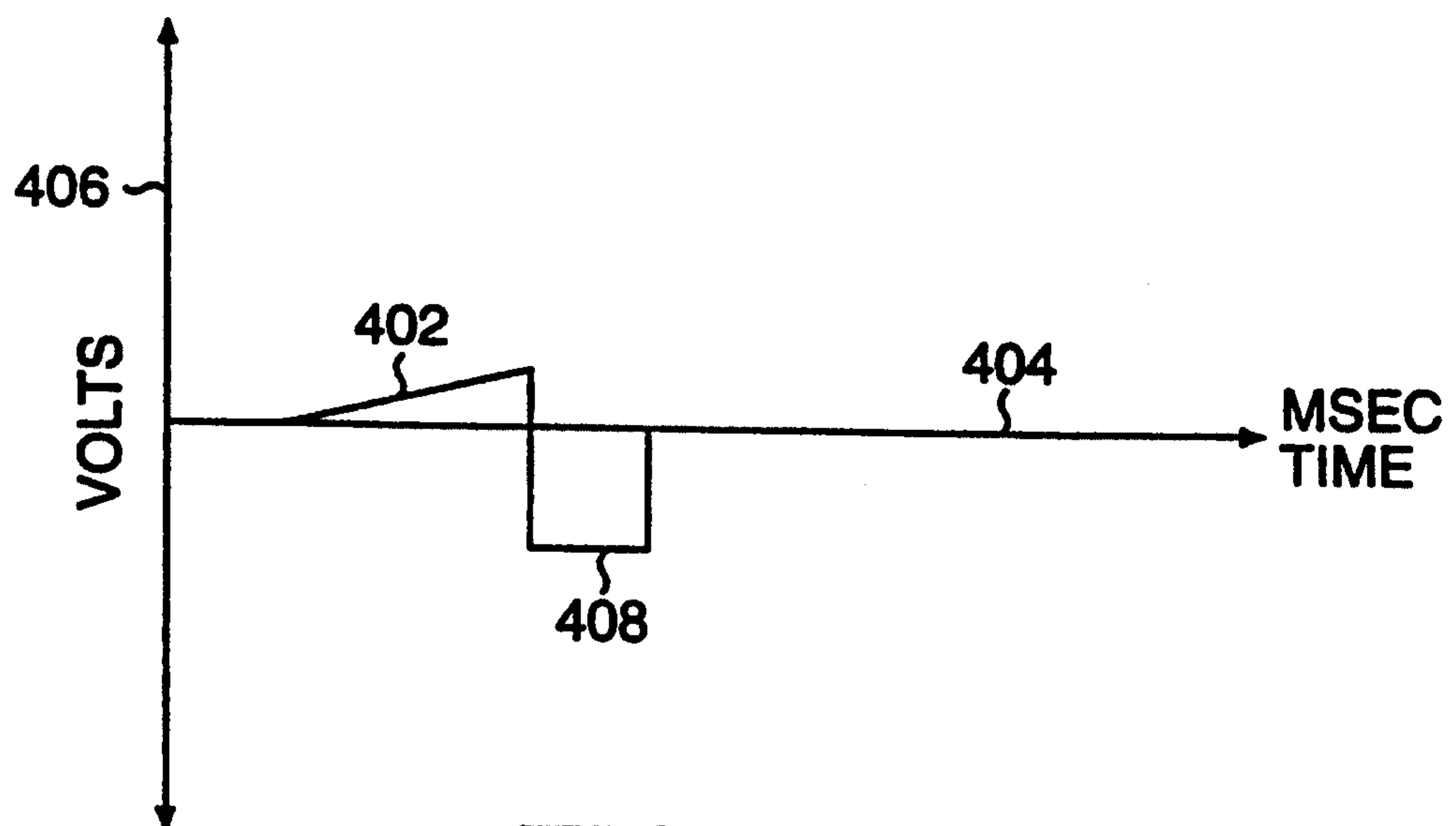
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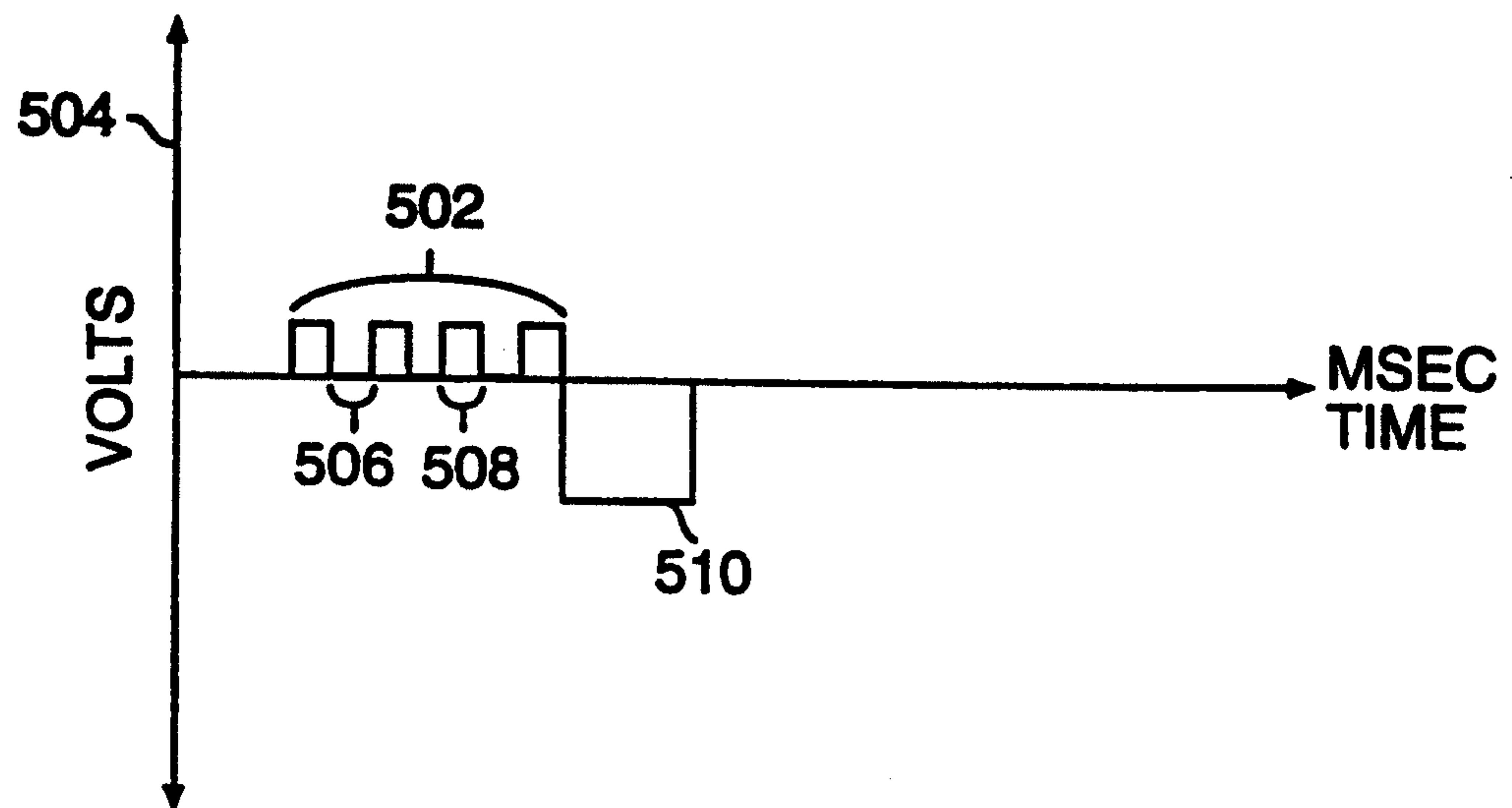
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**FIG. 3****FIG. 4**

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**FIG. 5**

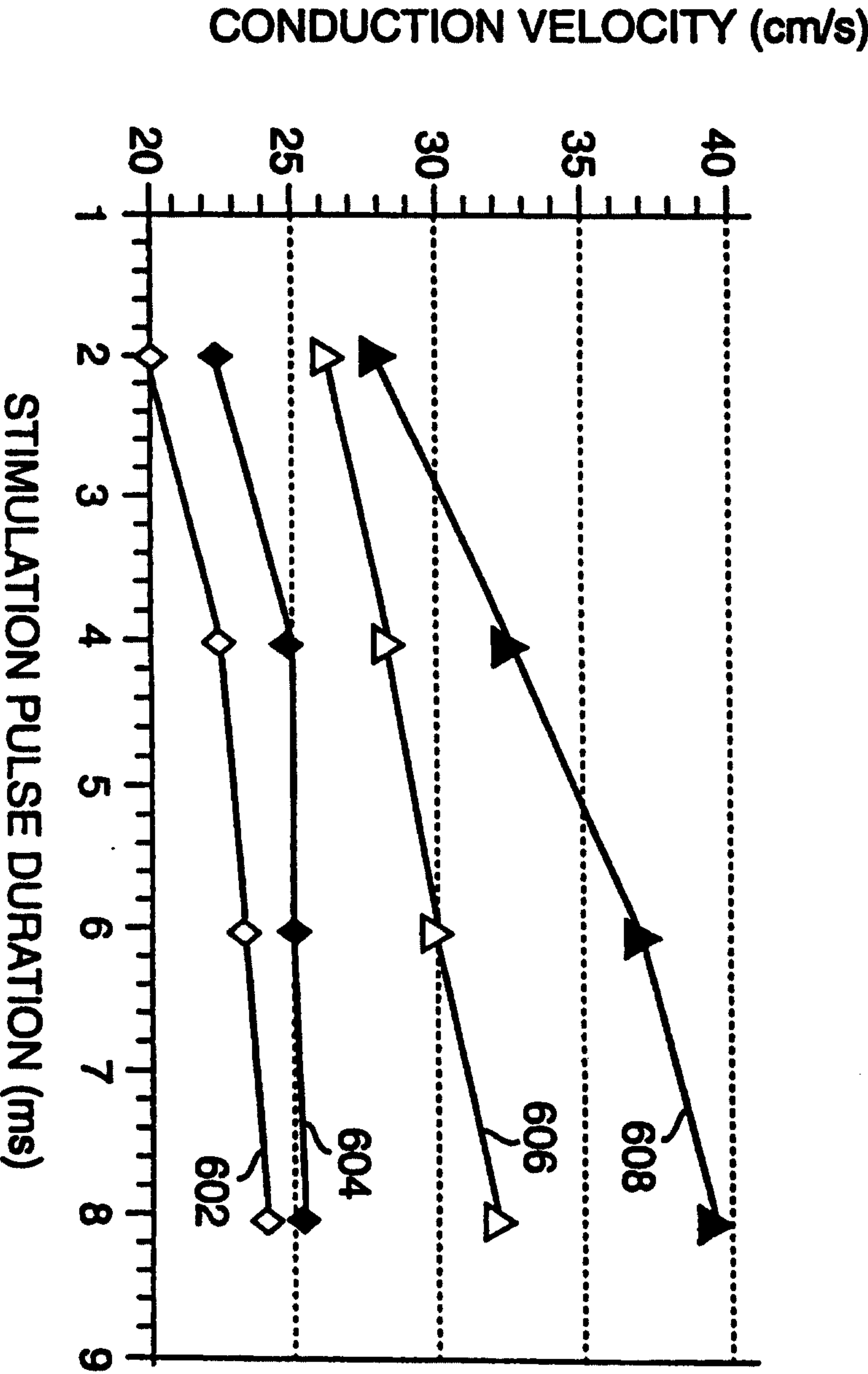


FIG. 6

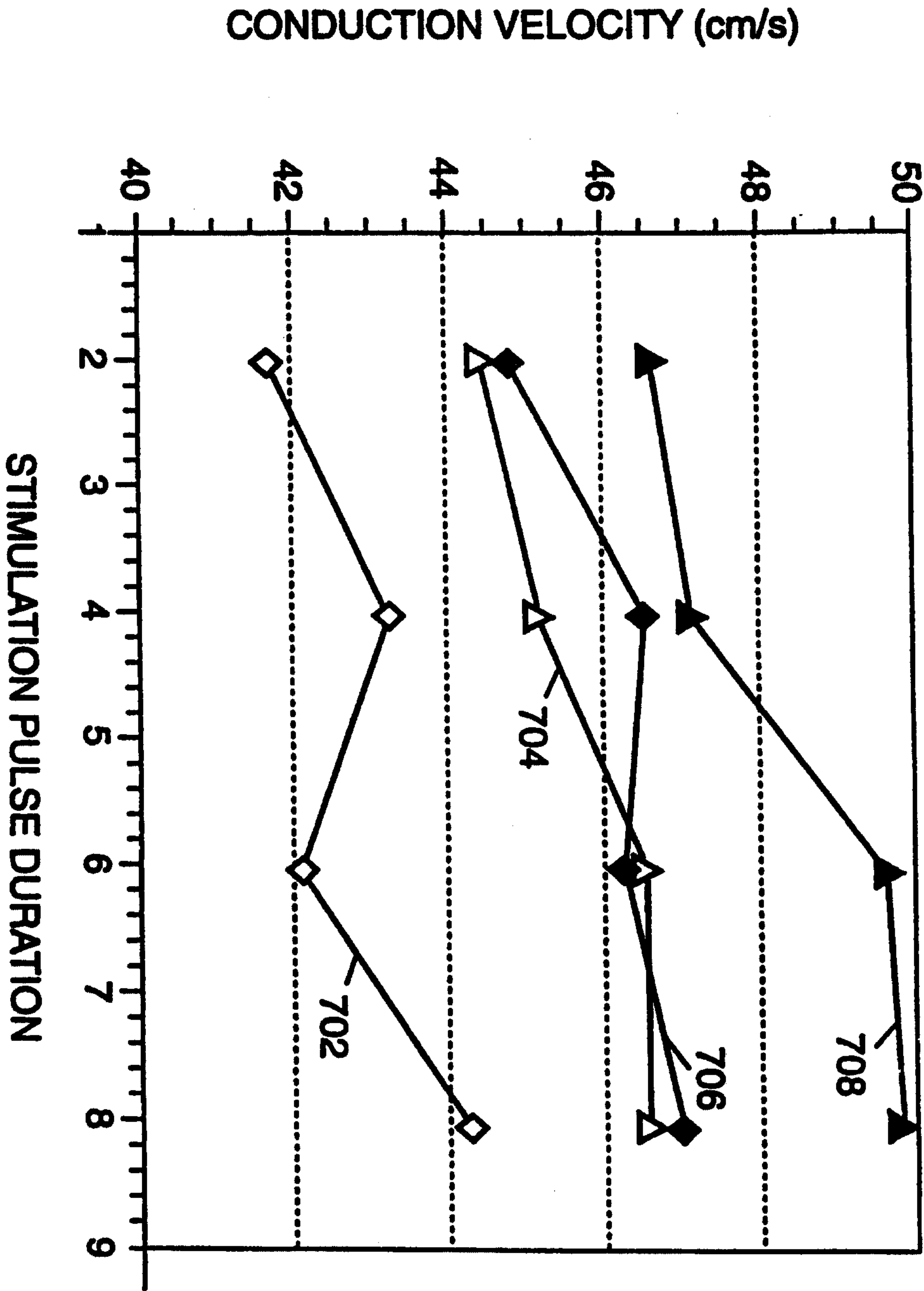


FIG. 7

