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Green

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[54] **HAND-HELD CARDIAC SOUND TONE DIAGNOSTIC DEVICE AND METHOD**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 550,666, May 17, 1966, abandoned.

[52] **U.S. Cl.** ..... **128/2.06 R,** 128/2.06 E

[51] **Int. Cl.** **A61b 5/04**

[58] **Field of Search** ..... 128/2.05 P, 2.05 D, 2.05 S, 128/2.05 T, 2.06 A, 2.06 K, 2.06 E, 2.06 F, 2.06 R, 2.1 R

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[57] **ABSTRACT**

A compact self-contained and completely portable hand-held unit employs electrical signals generated by the heart to produce variations in a normally constant or even sound tone produced by the unit. Every type of heart arrhythmia generates a characteristic pitch variation or sound tone which can be readily recognized by the physician for cardiac diagnosis. The unit embodies plural spaced electrodes which are simply pressed against the patient's chest without the necessity for any external electrical connections.

8 Claims, 6 Drawing Figures

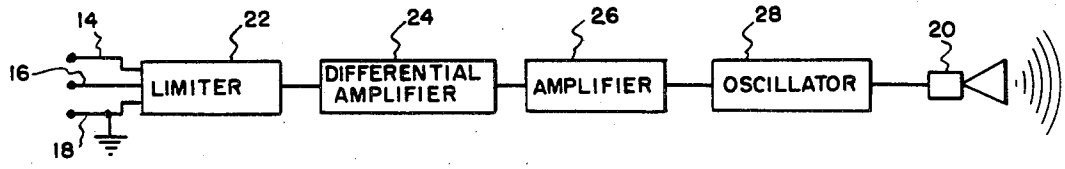


FIG. 1

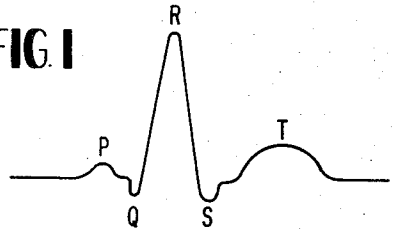


FIG. 2

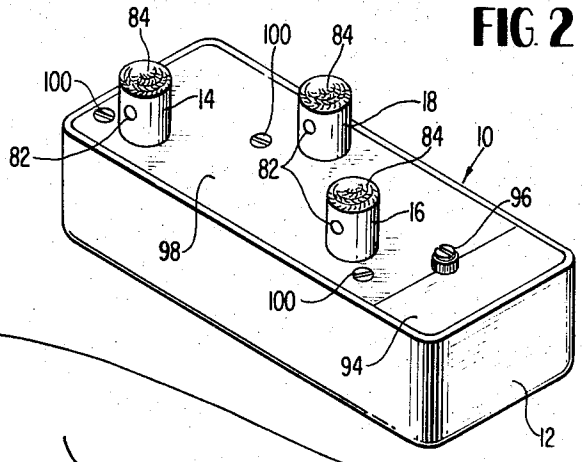
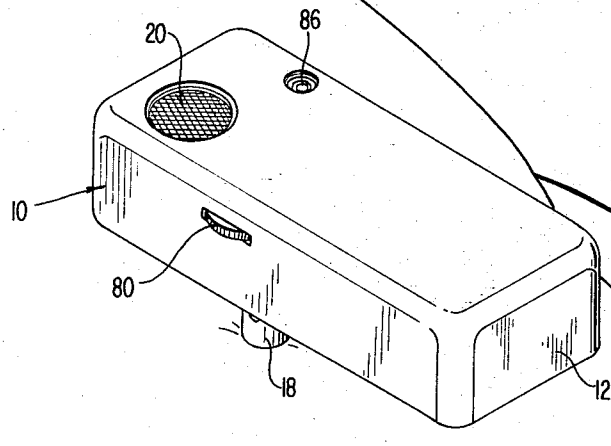


FIG. 3



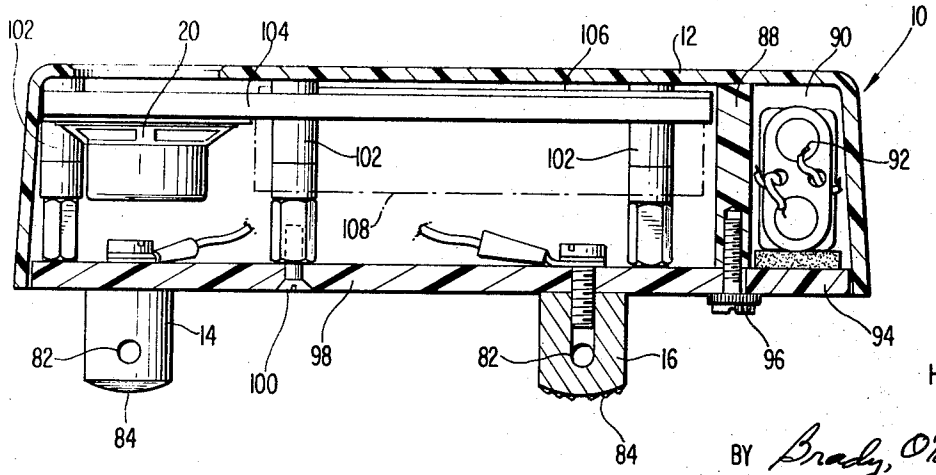


FIG. 4

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FIG. 5

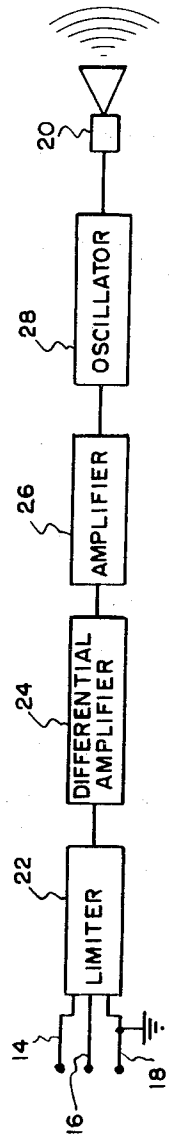
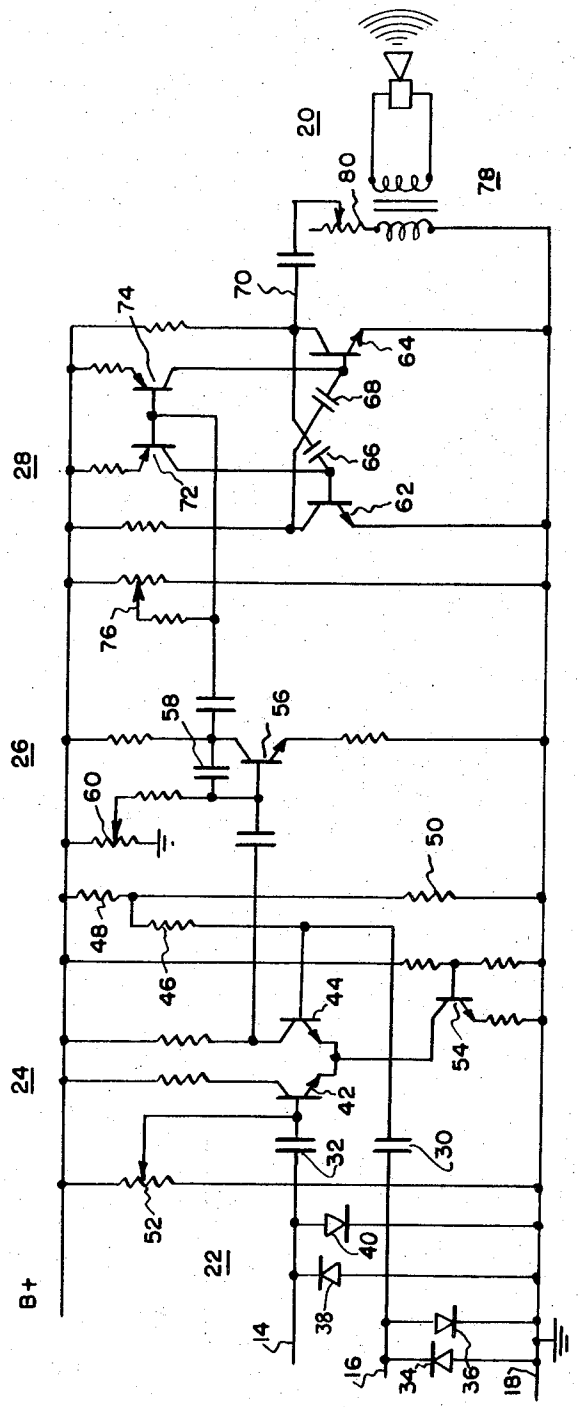


FIG. 6



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HAND-HELD CARDIAC SOUND TONE DIAGNOSTIC DEVICE AND METHOD

This application is a continuation-in-part of prior copending application Ser. No. 550,666, filed May 17, 1966, for CARDIAC MONITORING DEVICE, now abandoned.

This invention relates to a device and method for diagnosing heart arrhythmias through variations in sound tones.

A variety of methods have beem employed for detecting and analyzing heart rhythm. Actual heart sounds may be monitored by a stethoscope or they may be amplified through various electronic means. Electrical potentials generated by the action of the heart may be monitored by electrocardiagraphic methods. In such a technique, electrodes are fastened to the skin of the patient, and the voltages generated by the action of the heart are recorded on a continuous roll of graph paper by a galvanometer stylus which deflects in proportion to the voltage signal. Alternatively, the signal picked up by the electrodes can be fed into an oscilloscope to provide a visual display of heart voltage.

Although the electrocardiograph provides the most complete information, several disadvantages are inherent in its use. The equipment is somewhat bulky, and is therefore difficult to transport. It is impossible for a doctor to carry one in his bag when he is out on calls or making hospital rounds. If a hospital patient is not in a recovery or emergency room, there may be a time-consuming delay before an electrocardiograph can be brought to him. Furthermore, several minutes are generally required to connect the machine to the patient and set it into operation. The delays can be crucial in emergency situations.

To overcome these disadvantages of the electrocardiograph, various portable devices have been developed. However, such devices do not provide the qualitative information which is often essential, but may simply produce a flashing light or an audible beep to represent the heart beat rate.

Accordingly, it is an object of this invention to provide a completely portable cardiac diagnostic device which produces qualitative as well as quantitative information and which enables the physician to distinguish among a variety of forms of heart arrhythmias.

It is a further object of this invention to provide a cardiac monitoring device which is capable of producing a signal without need of the time-consuming connection of electrodes to the patient's body.

It is another object of this invention to provide an improved means for monitoring and analyzing heart rhythm which is inexpensive to produce and simple and reliable in operation.

It is another object of this invention to provide a cardiac monitoring device which is protected from strong currents used for restoring normal heart rhythm.

Other objects, advantages and novel features of this invention will become apparent from the following specification, when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWING FIGURES

FIG. 1 is an electrocardiogram fragment produced by a normal heart.

FIG. 2 is a perspective view of the cardiac diagnostic device of this invention, the device being inverted to reveal the electrodes.

FIG. 3 is a perspective view showing the device in place on the chest of a patient.

FIG. 4 is an enlarged vertical cross section through the device.

FIG. 5 is a block diagram of the electrical system embodied in the invention.

FIG. 6 is a circuit diagram of the device embodying this invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

Briefly stated, the technique of cardiac diagnosis contemplated by this invention comprises the production of a clearly audible signal or tone which is frequency or pitch modulated in response to the voltage generated by the heart. The device normally generates a steady, plainly audible, sound tone of constant pitch. When the heart signal is superimposed upon this steady pitch, the waves or fluctuations which appear on the conventional electrocardiograph will appear as variations in the frequency or pitch of the sound tone produced by the device. Thus, the device produces a tone pattern which can be audibly analyzed to identify and diagnose various known types of heart arrhythmias.

FIG. 1 represents the electrocardiogram produced by a normal heart. It comprises a series of peaks and valleys corresponding to the voltage generated by the myocardium (heart muscle), each deflection of the stylus of the electrocardiograph being proportional to the amplitude of the corresponding voltage signal. The principal normal waves of the characteristic electrocardiograph are generally identified in the art by the letters P, Q, R, S and T as shown in FIG. 1. The P wave represents the depolarization of the auricles. The QRS complex represents the depolarization of the ventricles, while the T wave represents the repolarization of the ventricles. For diagnostic purposes a physician is concerned not only with the pulse rate of the patient, but also with the individual rates of auricular and ventricular contraction, the regularity and relationship of these rates to one another, and the shapes of these complexes.

Referring now to FIGS. 2 and 3 of the drawings, the cardiac monitoring device **10**, which I call an Electrocardiophone, generally comprises a casing **12** to which are rigidly fixed electrodes **14, 16** and **18**, in the form of blunt, rigid pin elements of considerable width. Like the electrocardiograph, the Electrocardiophone is sensitive to voltage changes at the body surface. The spacing between the electrodes **14** and **16** has been selected as approximately four inches, this being considered the minimum distance for easily measuring the difference of potential between two points on the surface of the skin. The length of the electrodes must be sufficient, taking into consideration the curvature of the chest surface, to prevent contact between casing **12** and the chest of the patient. A length of approximately three-quarters of an inch is considered adequate to assure firm contact.

The diameter of the electrodes is preferably a minimum of five-eighths of an inch, so as to provide sufficient contact area to prevent discomfort to the patient. For this purpose, the electrodes may also be provided with hemispherical tips. The tips of the electrodes are

preferably knurled, so that if conductive paste is used it may be applied directly to the electrodes and then the electrodes rubbed against the skin to achieve the desired abrading of the skin. This saves the separate step of roughening the skin prior to application of the instrument, and permits the use of non-abrasive pastes.

The third electrode **18** serves a dual purpose. It functions as a ground to provide improved electrical stability and also as a third supporting leg to permit the device to be self-supporting, or physically stabilized on the patient's chest.

FIG. **5** is a block diagram of the electrical componnt stages of an embodiment of the invention in which electrical voltages generated by the heart are coupled to a limiter stage **22** via the electrodes **14, 16** and **18.** The output of the limiter is presented to a differential amplifier **24,** a further stage of amplification **26,** and thereafter to a voltage sensitive oscillator circuit **28.** The oscillator output is suitably coupled to the speaker **20.**

The limiter stage **22** serves to protect the Electrocardiophone if it should be left on the chest during the application of a high voltage shock for the restoration of normal heart rhythm.

Differential amplifier **24** is an amplifier which rejects voltage signals occurring simultaneously between ground electrode **18** and each of signal electrodes **14** and **16,** while signals occurring out of phase at both electrodes **14** and **16** will be amplified by the device. The output of the differential amplifier **24** is typically of the shape shown in FIG. **1.** This cardiac signal is thereafter further amplified in amplification stage **26.**

The output of amplifier **26** is presented to the voltage variable frequency oscillator **28.** The oscillator, without an input signal present, will generate a frequency well within the audible range, for example 800 cycles per second. These signals are coupled to speaker **20,** which transduces the electrical energy to an audible signal or sound tone of constant frequency or pitch. When input signals are presented to the oscillator, the frequency of oscillation will vary in direct proportion to the value of the signal. Thus, an audible change in frequency will be evident to the listener in the form of an audio representation of the voltage generated by the heart.

Referring now to FIG. **6** for a detailed consideration of circuitry employed in this embodiment, the electrical cardiac signals are obtained directly from electrodes **14** and **16;** electrode **18** providing a ground or reference. These signals are fed from electrodes **14** and **16** to the differential amplifier inputs via coupling capacitors **30** and **32,** respectively. The diodes **34, 36, 38** and **40,** serve to limit the signal to those less than a predetermined amplitude, to protect the remaining circuitry in the device from strong currents which might accidentally be applied to the input electrodes **14** or **16.** That is, the threshold value of the diodes is such that until they are rendered conductive, all signals will pass through the coupling circuit to the input terminals of differential amplifier **24.** Once the threshold value is exceeded, for example by signals of one volt or more, and depending upon the polarity of the signal, one of these diodes will appear as a short circuit and the signal will pass between signal electrode **14** or **16** and ground electrode **18.**

The differential amplifier **24** consists of a matched pair of transistor amplifiers **42** and **44.** The collector electrodes are suitably biased from the B+ bus via dropping resistors. The base electrodes are provided a biasing potential via fixed resistors **46, 48** and **50** and an adjustable resistor or potentiometer **52.** The emitter electrodes are tied together and connected to a further transistor **54,** as shown.

A differential amplifier is simply an amplifier which amplifies the difference between input voltages and transmits such differences. Thus, identical signals from electrodes **14** and **16** are not passed by the amplifier and signals occurring out of phase are passed or transmitted to the next circuit component.

The major limitation to the ultimate sensitivity of a direct coupled amplifier is the drift caused by variation of transistor bias as the temperature changes. The amplifier controls drift by equal drift of both transistors thus extending the sensitivity of the device by many orders or magnitude. Two matched transistors **42** and **44** are used to achieve equal thermal conditions.

To assure proper and identical biasing, the collector **42** may be preset in transistor **41** via potentiometer **52** to equal the current at the collector of transistor **44.** Obviously, either or both resistance components **46** and **52** could be made adjustable.

One of the more important features of a differential amplifier as mentioned in conjunction with the description of the block diagram is common-mode rejection. Theoretically if all conditions are perfect, an equal or common mode voltage on both inputs would produce no output signal. This may be closely approximated by placing a constant current source between the junction of the emitters and ground. Therefore, transistor **54,** which behaves as a constant current source, is placed in this position. The most common source of noise, 60 cycle per second electrical power signals, and other stray radiation which are inductively coupled to the device, is thereby eliminated.

The output signal from the device is thereafter coupled to a further stage of amplification **26** via a suitable coupling capacitor. This stage of amplification consists of a conventional transistor amplifier **56** having a feedback capacitor **58** between collector and base.

The capacitor **58** functions as a negative feedback path at higher frequencies to progressively attenuate such frequencies. This serves to further eliminate noise signals and allows the lower frequency heartbeat signal to pass therethrough.

The bias to the transistor **56** is provided via a potentiometer or adjustable resistor **60,** thereby allowing the transistor to be properly biased.

The original heartbeat signal, as limited, filtered and amplified, is applied to the voltage sensitive oscillator **28** via a coupling capacitor. The oscillator **28** is a conventional capacitor cross-coupled astable or free-running multivibrator consisting of transistors **62** and **64,** the base to collector junctions of which are cross-coupled by capacitors **66** and **68,** respectively.

When the multivibrator is operating, transistors **62** and **64** are alternately conducting and non-conducting. The voltage at the base of transistors **72** and **74** determines the collector current in each of these transistors. If **62** is on and **64** is off the collector current of **74** discharges capacitor **68** until the base of **64** becomes forward biased relative to the emitter. At this time **64** switches on, turning off transistor **62.** The function of

the collector currents of 72 and 74 are then interchanged. The collector current of 74 keeps transistor 64 on. The collector current of 72 discharges capacitor 66 until the base of 62 becomes forward biased relative to the emitter. At this time 62 switches on, turning off transistor 64. The cycle is repeated indefinitely. The time between successive cycles is determined by the values of the coupling capacitors 66 and 68, the resistors between the emitters of 72 and 74 and B+, and the instantaneous voltage at the base of 72 and 74. With no current input from the amplifier stage 26, a constant audio frequency output is generated over output lead 70. This frequency is determined by the voltage on the bases of transistors 72 and 74 due to the setting of potentiometer 76. Voltage from amplifier stage 26 adds to or subtracts from the voltage on the bases of the transistors set by potentiometer 76. This addition or subtraction modulates the output frequency.

The output signal over lead 70 is coupled to speaker 20 via output transformer 78. The volume is made adjustable by potentiometer 80.

In my Electrocardiophone, the qualitative analysis of the voltage signal generated by the heart is achieved not by visual inspection of the deflection of an electrocardiograph stylus, but rather by variations in the frequency or pitch of the audible tone produced. That is, the steady tone normally produced by the device, preferably about 800 cycles per second, is frequency modulated in response to the superimposed voltage produced by the action of the heart. A signal is thereby produced which could be described as a melody. An increase in voltage produces a rise in pitch, while a drop in voltage lowers the pitch. The Electrocardiophone is calibrated to produce a signal or tone which varies approximately two octaves in putch, or about one octave per millivolt of voltage variation at the body surface. Normal heart rhythm and each of the simple arrhythmias have their own characteristic melody or tone when monitored by the Electrocardiophone. Because of the detection ability and the memory potential of the human hearing system. the very striking and vivid tone patterns produced through the Electrocardiophone by these various heart rhythms may be readily learned and identified by a physician.

When compared with the transient visual display produced by a deflecting needle or a flashing light, the frequency modulated tone is extremely effective in transmitting heart data. The human ear is quite sensitive to pitch and rate variations in the range here involved, while the eye is relatively unable to follow and distinguish fluctuations in light intensity occurring at this rate.

The P wave produces a very brief and relatively small upward deflection or rise in pitch of the base tone. The QRS complex produces a very distinctive chirp or squeak sound. The T wave generates a sound which is readily distinguished by its relatively long duration and greater frequency change than that of the P wave.

A very simple use of the Electrocardiophone is in the differentiation of ventricular fibrillation from asystole. Ventricular fibrillation occurs when the normal rhythmical contractions of the ventricles are replaced by rapid irregular twitchings of the ventricular muscule wall, and presents an electrocardiographic pattern of an undulating line rather than a more conventional looking electrocardiogram. Asystole is cardiac standstill or the absence of heart contractions, and presents an electrocardiographic pattern of a straight line. The corresponding Electrocardiophone responses are a warbling tone for ventricular fibrillation and an unmodulated steady tone for cardiac standstill (asystole). This differentiation is readily made by even fairly unskilled personnel using the device of the invention. In performing cardiac resuscitation, the Electrocardiophone permits immediate diagnosis of the situation as cardiac arrest or ventricular fibrillation. This differentiation is most urgently needed un the situation of cardiac arrest, and the device of the invention performs better in making this differentiation quickly than any other existing instrument. Seconds count in such circumstances. Application of the stethoscope or feeling the pulse would reveal no cardiac activity whether this was due to ventricular fibrillation or cardiac standstill, and no differentiation could be made with these means.

If countershock (defibrillation) is applied without having an exact diagnosis of the situation of the heart, and it turns out that the heart is in asystole, this treatment cannot benefit the patient and in the opinion of most people it would reduce the possibility of survival of the patient. This exact diagnosis can be made with application of an oscilloscope or electrocardiograph but this wastes a good deal of vital time and such bulky and expensive equipment is not always readily available. With the small portable device of this invention the differentiation can be made in a few seconds so that countershock can be effectively used or withheld, thus preventing possible detrimental effects resulting from application of unappropriate treatment when the exact condition of the heart is not known, and enabling the vital seconds to be effectively used for appropriate treatment.

Premature beats are easily identified as supraventricular or ventricular in origin by the characteristic tone or pitch patterns. That form of rapid heart beating known in the art as supraventricular tachycardia produces a rapid, perfectly regular tone pattern which is monotonously similar from cycle to cycle. Ventricular tachycardia differs in that the cycle lengths generally are lees uniform and the QRS and T signals are less uniform from moment to moment. In some cases P signals can be recognized sporadically between the ventricular signals.

Atrial flutter waves result in a tremolo quality of the base requency produced by the Electrocardiophone. Atrial fibrillation also induces a quivering quality, but it is less marked and more variable from moment to moment.

In complete heart block the P signals can be heard and counted independently of the QRS and T signals. If a Pacemaker is in use its impulses are heard as clicks or squeaks. The relationship of Pacemaker signals to ventricular activity and the condition of the Pacemaker may be easily determined. Advanced first degree block and second degree heart block have also been diagnosed with the Electrocardiophone.

Artifacts or spurious signals are rarely a problem with the Electrocardiophone. Somatic tremor is minimized by the precordial application, but can occasionally be heard as a "hoarse" or impure quality of the base frequency, quite different from any of the patterns described above. Respiratory variation is slight unless a positive pressure breathing device is being used. The effect is merely that of transposing the tone patterns as the diaphragm moves. Sixty cycle interference, recog-

nizable as a "hoarse" quality, can be minimized by good skin contact. Also poor skin contact can produce an interrupted or irregular tone of reduced amplitude. Although the device works best when a conductive paste is applied to the skin, this is not essential.

The rigid electrodes permit rapid application of the instrument to the patient. No straps need be connected, but rather the electrodes are merely set firmly against the chest of the patient. These electrodes are each provided with a transverse hole **82** near their tips so that conventional limb electrodes can be easily connected by means of banana plugs. The conventional electrode is so connected when the chest of the patient is inaccessible due to cardiac massage or covered with bandages which would prevent the establishment of an adequate electrical contact. The conventional electrodes also enable the device to be used to monitor cardiac activity during surgery and during transportation of the patient where the device itself might otherwise fall off the patient's chest. These holes are also used for the connection of a pre-amplifier when the device is used for monitoring brain signals. As above described, the knurled roughened tips **84** of the electrodes speed up and improve the establishment of proper electrical contact with the skin, and eliminate the need for a grit-containing paste.

As can be seen from FIG. **3** of the drawings, the size of the Electrocardiophone (approximately 6 × 2½ × 1½ inches) permits it to be readily portable and held in one hand. It may, therefore, be carried about by a physician in his medical bag when he is on calls or making hospital rounds. The low cost of the instrument makes it economically feasible for a hospital to have a sufficient supply on hand so that no delay would be incurred in bringing one to a patient in an emergency. The very compact and lightweight nature of the device further permits it to be carried with a patient while he is in transit, as between an ambulance and the emergency room, or between surgery and a recovery room, so that his heart action may be continuously audibly monitored, the sound being loud enough so that it can be easily heard at a substantial distance.

The production of a qualitative audible tone permits a patient's heart action to be transmitted by telephone from the hospital to the doctor's office or a central monitoring station, by merely holding the telephone receiver adjacent the output loudspeaker **20** in housing **12** with the housing resting on the patient's chest.

A variety of additional features have been incorporated into the basic Electrocardiophone as accessories. A "translator" comprising, for example, a microphone and conversion unit is utilized to convert the audible output of the Electrocardiophone into an input for a conventional electrocardiograph to permit more thorough analysis of complex heart signals. Alternatively, a jack **86** is provided in the casing to permit direct pick-up of a signal suitable for the input of the conversion unit. The same jack is used for connecting a tape recorder to the Electrocardiophone to permanently record the audible signals, and also as a connection for stethophones.

Another accessory which may be employed is a counter for continuously indicating the pulse rate. Since the P waves do not always occur at the same rate as other constituent waves in certain abnormal heart rhythms, the counter would be combined with a selector switch and a frequency responsive filter network for permitting the physician to have a rate readout of the various constituent waves.

An important additional application of the device of this invention as a means for producing audio-electroencephalograms. The same basic unit could be employed with the addition of a further amplification stage. Such a unit would be usable to provide a rapid means for distinguishing between epileptic seizures and hysterical or other types of fits. It could also be used to ascertain the presence or absence of brain activity during cardiac arrest, so that futile lengthly attempted resuscitation might be avoided.

Referring to FIG. **4**, additional details of the apparatus unit **10** are shown. These details include a divider wall **88** within the housing **12** forming an end compartment **90** for a suitable battery **92** secured by a removable cover section **94** held in place by a thumb screw **96** which also engages the edge of main cover plate **98** carrying electrodes **14, 16** and **18,** as shown. The main cover plate **98** is further secured by screws **100** which may engage within conventional adjustable screw-threaded insulating spacers or stand-offs **102** whose opposite ends are suitably anchored to the casing or housing **12.**

Within the main compartment of the housing separated from the battery compartment **90** is a printed circuit board **104** supported by the stand-offs **102** and having a printed circuit layer **106** on one face thereof. The various electrical components detailed in FIG. **6** are disposed in the zone indicated by the phantom lines **108** at the rear side of the printed circuit board. Other details of the unit are conventional and unimportant to a full understanding of the invention.

I claim:

1. An on-the-spot method of diagnosing cardiac arrhythmias comprising the steps of generating an audio frequency signal, receiving electrical signals generated by the heart and amplifying said signals, frequency modulating the generated audio frequency signal with said amplified electrical signals, transducing the frequency modulated signals to produce a variable frequency audible tone whose frequency will vary automatically in response to changes in the amplitude of the electrical signals generated by the heart, and listening directly with the human ear to the variations in said audible tone due to variations in frequency of the audible signal to directly detect and analyze cardiac arrhythmias at the patient's side from the variations in the audible tone.

2. An on-the-spot cardiac diagnostic method comprising the steps of generating a normally even and unvarying sound tone, receiving and amplifying electrical signals generated by the heart and allowing variations in the heart generated signals to alter the frequency of the sound tone at intervals responsive to the action of the heart, and listening directly with the human ear to the changes in the sound tones to effect the direct diagnosis of said cardiac arrhythmias from the changes in the sound tones at the patient's side.

3. A cardiac diagnostic apparatus comprising a completely self-contained electrical battery-powered, portable, hand-held unit including a housing, electrical means in said housing producing a normally even and unvarying audible tone, said housing having a generally flat bottom wall portion, three electrodes projecting substantially equidistantly from said bottom wall portion and arranged in triangular configuration thereon

to thereby physically stabilize said housing in free-standing relation while directly engaging the chest of a patient to receive and conduct electrical signals generated by the heart, amplifier means in said housing connected to said three electrodes to receive and provide at an output amplified electrical signals generated by the heart, said output connected to said electrical means to produce variations in said audible tone with said amplified electrical signals generated by the heart, said housing having another wall portion with an aperture therethrough, audio transducer means connected in said housing to said electrical means to receive and transmit said variations in said audible tone through the aperture in said another wall portion, whereby said variations in said audible tone are representative of cardiac arrhythmias thereby enabling a physician hearing said audible tone variations to directly diagnose said arrhythmias at the patient's side.

4. The structure of claim **3,** and said electrodes being blunt, wide, rigid pin elements and having wide skin contact faces to assure firm and adequate electrical contact with the chest wall of the patient.

5. The structure of claim **4,** and said electrodes projecting approximately three-quarters of an inch beyond said bottom wall portion of said housing to enable all of the electrodes to firmly engage the patient's chest irrespective of chest curvature and flesh irregularities.

6. The structure of claim **3,** and the intermediate electrode in the triangular configuration being a grounding contact, and said other two contacts spaced apart approximately 4 inches.

7. The structure of claim **6,** and said wide skin contact faces of the electrodes being roughened.

8. The structure of claim **3,** and said transducer means being a loudspeaker.

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