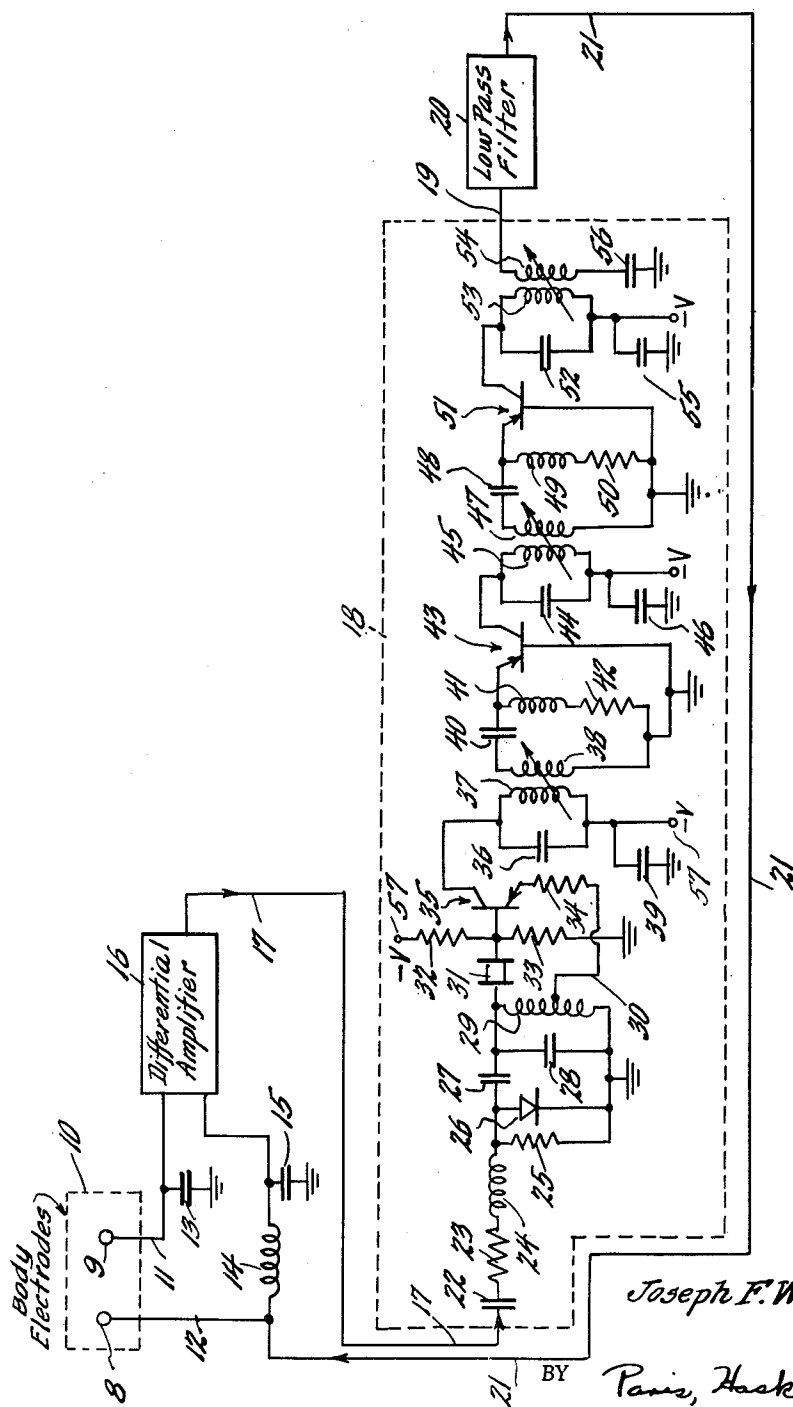


J. F. WESTERMANN

MINIATURE RADIATING ELECTROCARDIOGRAPH

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INVENTOR

Joseph F. Westermann,

Paris, Haskell and Levine
ATTORNEYS

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MINIATURE RADIATING ELECTRO-CARDIOGRAPH

Joseph F. Westermann, Abington, Pa., assignor, by mesne assignments, to United Aircraft Corporation, a corporation of Delaware

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This invention generally relates to electrocardiographs and is particularly concerned with miniature battery powered electrocardiograph apparatus adapted to be carried by or attached to the patient and to continuously monitor the patient and transmit the information obtained over radio waves to a remote receiving station.

It is accordingly a principal object of the invention to provide a radio transmitting electrocardiograph apparatus for providing dynamic measurements of the patient while the patient is experiencing the stresses of normal work and other activities.

Another object of the invention is to provide a portable radio beam generating electrocardiograph adapted to be worn by the patient whereby the patient is completely unrestrained in his activities while diagnostic measurements of the heart are being made.

A further object is to provide such apparatus in miniature size and weight adapted to be easily carried or worn by the patient without impeding his normal activities or body exercises and without being externally observable by others so as to cause discomfort or embarrassment to the patient.

A more specific object is to provide a radio electrocardiograph transmitter system comprised completely of battery powered transistor circuitry that is adapted to be worn in close proximity to the patient's body, yet is substantially unaffected by body heating or variations in voltage of the powering battery.

A still further object is to provide such a system for transmitting a frequency modulated carrier radio beam proportional to the patient's cardiac responses that is extremely stable in operation despite variations in temperature, battery voltage, and other external influences or body generated extraneous signals.

Other objects and additional advantages will be more readily comprehended by those skilled in the art after a detailed consideration of the following specification taken with the single accompanying drawing illustrating, partially in block diagram form and partially in electrical schematic diagram form, one preferred embodiment of the invention.

Referring now to the single drawing, there is shown one complete radio electrocardiograph apparatus adapted to be worn by the patient and to transmit by means of a frequency modulated radio wave, the electrocardiograph data to a remote radio receiver (not shown) that may be located at a hospital, a doctor's office or elsewhere at some distance from the patient.

As shown, the system generally includes a pair of electrodes or sensors 8 and 9, illustrated within dotted enclosure 10, adapted to be attached to closely spaced positions on the patient's body, a pair of small diameter flexible electrical conductors 11 and 12 for connection to the electrodes for the purpose of conveying the electrical body generated signals, and a complete radio transmitter

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and antenna system, including components generally designated 16, 18, 20 and 21 for responding to the desired signals from the body and for producing and radiating a frequency modulated radio wave to convey the cardiac information to a remote receiver (not shown).

All of the apparatus depicted in the drawing with the exception of the electrodes 8 and 9 and the connecting wires 11 and 12 is adapted to be contained within a single miniature housing approximating the size of a cigarette package whereby this housing may be easily concealed in a pocket of the wearer's clothing or suitably strapped to the body without being externally noticeable to others. The apparatus is also adapted to be completely powered for operation by means of a single small secondary battery, such as a cadmium nickel battery 57 or other as is presently available on the open market.

According to the invention, the body electrodes 8 and 9 are adapted to be continuously attached to the patient's body for a relatively long period of time and to maintain low electrical resistance coupling to the body despite various changes in body movement and body curvature occurring while the patient is performing a variety of activities. The preferred electrodes are also quite small in size and easily attached to the body without awkward straps or fastening means whereby they may be worn by the patient without impeding or interfering in any substantial measure with his activities, or causing him any discomfort. A preferred electrode construction providing these characteristics is disclosed in a copending application of Richard Berman and Bernard Schwartz, Serial No. 116,586, filed June 12, 1961, and assigned to the same assignee, now Patent No. 3,085,577.

The low voltage level signals being obtained from these electrodes are directed over flexible insulated conductors 11 and 12, and through suitable low frequency pass electrical filters in each conductor line, including capacitor 13 in line 11 and inductor 14 and capacitor 15 in line 12, to a pair of separate input terminals of a differential amplifier 16. In the differential amplifier 16, the pair of low voltage level electrode signals are filtered and combined in such manner as to eliminate any extraneous common mode signal that is transduced by both electrodes in common, thereby to produce a single signal representing the desired cardiac information. This single signal is amplified by a ratio of about 200 to 300 to one and thence conveyed over an input line 17 to frequency modulate the preferred radio transmitter shown within the dotted enclosure designated 18.

Due to the fact that the complete miniature transmitting system is adapted to be battery powered by a small secondary battery and is adapted to be strapped to or carried close to the patient's body, it is subjected to variations in the voltage of the battery as well as changes in temperature resulting from body heat and ambient temperature variations. For this reason, the differential amplifier 16 is compensated to prevent such variations from affecting the characteristics of the amplified cardiac signals produced over line 17 since otherwise, the transmitted signals would be subject to error and would not accurately reflect the condition of the patient. One preferred differential amplifier 16 providing the functions described and being compensated against such extraneous influences is disclosed in the copending application of Lyman Bethke, Serial No. 115,711, filed June 8, 1961,

and assigned to the same assignee, although, as will be apparent to those skilled in the art, other amplifiers having these characteristics may be employed.

The amplified and stabilized intelligence signal over line 17 is then directed to a variable frequency oscillator and modulator 18 operating in the radio frequency band, where this intelligence signal is employed to frequency modulate a radio frequency carrier signal. The modulated carrier is then directed over output line 19 to a low pass filter to remove any extraneous higher frequency signals and is then passed outwardly over line 21 leading to a radiating antenna means whereby the radio beam may be propagated to a remote receiving and monitoring station (not shown).

At the remote receiving station, which may be located at a distant hospital, doctor's office or the like, the frequency modulated radio beam is received and detected to reproduce the intelligence signal and enable the heart wave signals to be recorded and displayed on a recording oscilloscope or other recorder as is well known in the art.

It is preferred to minimize the number of external leads and connection wires so that the apparatus may be installed and put into use by doctors and medically trained technicians without the need for special electronic training in the use of the equipment. For this reason the external flexible connector 12, interconnecting the body electrode 8 with the differential amplifier 16, is also preferably employed as the radiating antenna for the system by being connected to the radio output line 21. Since the input intelligence signal from the body electrode 8 and over line 12 leading to the amplifier 16 is in the low frequency range of cycles per second, whereas the modulated radio output signal over line 21 is in the high frequency range of kilocycles or higher per second, this output radio signal is effectively blocked from entering the input of the amplifier 16 by the low pass filter comprising inductor 14 and by-pass capacitor 15. Consequently, the preferred system requires but two external leads or connectors 11 and 12 leading from the electrodes 8 and 9 to the miniature housing for the system to serve as both input leads from the electrodes and as a radiating antenna for the system.

The preferred transmitter shown within the dotted enclosure designated 18 is preferably comprised of three cascaded stages, each including a single transistor 35, 43 and 51, respectively.

The first stage, including transistor 35, is connected as a crystal stabilized variable frequency oscillator that responds to the amplitude of the incoming intelligence signal over line 17 to produce a variable frequency alternating current signal, in the low radio frequency band, across its output tank circuit, including parallel connected capacitor 36 and inductor 37.

In the second stage, this variable frequency radio signal is proportionally increased in frequency by a factor of about two to one to double the frequency of the oscillator, and in the third stage, the resulting radio signal is further multiplied in frequency by a factor of about three to one, thereby to provide an output radio signal at an increased frequency of about six times the frequency being produced by the stabilized oscillator.

The purpose of providing this rather high ratio of frequency multiplication in the transmitter is to provide a wide range of frequency deviation in the output radio signal in response to the incoming intelligence signals originating from the electrodes 8 and 9, or in other words, to provide a highly sensitive transmitting system wherein a small change in the amplitude of the electrode signals produces a relatively large variation in the frequency of the propagated radio beam.

Returning now to the drawing and tracing through the preferred transmitter circuit 18, the incoming intelligence signal from the amplifier 16 and over line 17 is first directed through a filter including a series connected capacitor 22, resistor 23 and inductor 24 for the purpose

of eliminating any extraneous signals from entering the transmitter 18. The capacitor 22 is a high capacity electrolytic type capacitor for providing a low reactance to the passage of the desired low frequency intelligence signals while at the same time blocking the passage of any extraneous direct current signals that may be carried over line 17. The inductor 24, on the other hand, provides a large reactance to prevent the passage of any undesired higher frequency signals to and from line 17 to the transmitter but permits the lower frequency intelligence signals to pass through to the transmitter. Since the overall circuit is adapted to be miniaturized in size, it is preferred that the capacitor 22 be a titanium electrolytic capacitor for providing the desired high capacity needed and being obtainable in a very small size unit.

After being filtered, the intelligence signal is applied across a voltage variable capacitance diode 26 whose alternating current capacitance is varied in proportion to the amplitude of the low frequency intelligence signal. This variable capacitance diode effectively functions as part of the modulator whereby the variations in the capacitance of this diode 26 are employed to vary the frequency of the oscillator as will be more fully discussed below.

The transistor 35 in the first stage of the transmitter is connected in a Hartley oscillator type configuration with its base electrode being connected in series with a piezoelectric crystal 31 to the upper terminal of a feedback tank circuit, including capacitor 28 and inductor 29, and with a tap or terminal on inductor 29 being connected through a resistor 34 to the emitter electrode. The collector electrode of transistor 35 is connected to the upper terminal of the output tank circuit, comprising parallel connected capacitor 36 and inductor 37, with the lower terminal of this tank circuit being connected to the negative terminal of the battery 57 and alternating current coupled to the positive terminal at ground through a capacitor 39. It is to be noted at this point, however, that the complete portable system is adapted to be carried by the patient and is not connected to actual ground at any position, and that the ground symbols on the drawing, therefore, signify only the positive terminal of the portable battery. It will also be noted that throughout the transmitter, alternating current by-pass capacitors 39, 46 and 55 are employed to prevent the alternating current signals from passing through the battery terminals.

Returning to the first stage oscillator, the lower terminal of the input tank circuit is alternating current coupled to the lower terminal of the output tank circuit through capacitor 39 and the direct current battery potential is applied across these terminals. For providing direct current biasing of the base electrode, a voltage divider comprising resistors 32 and 33 is energized across the terminals of the battery and the junction of these resistors is connected to the base electrode of transistor 35.

In operation, the resonant frequency of the tank circuit comprising the voltage variable diode capacitor 26, fixed capacitor 28, and inductor 29, operating with the crystal 31, normally determines the stable frequency of oscillation of the first stage and this oscillating signal, together with its harmonics, is produced across the output tank circuit comprising capacitor 36 and inductor 37. The incoming low frequency intelligence signal over line 17 varies the capacity of the voltage variable diode 26 and, therefore, changes the resonant frequency of this tank circuit thereby to vary the oscillation frequency. This low frequency modulating signal over line 17 is blocked from reaching the base electrode of transistor 35 by the coupling capacitor 27 which serves to couple the higher oscillator frequency to the variable capacitor diode 26 but decouples the modulating signal from transistor 35. The series connected inductor 24 on the other hand prevents the oscillator signal from being transmitted backwardly to the amplifier 16.

Thus the oscillator frequency in the first stage is varied

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in proportion to the amplitude of the incoming intelligence signal over line 17. This variable frequency oscillator signal is produced across the output tank circuit, comprising capacitor 36 and inductor 37, which tank circuit is tuned to resonance over a narrow band at the second harmonic frequency of the oscillator. The variable oscillator signal is thus doubled in frequency at the output of the first stage.

To provide an oscillator signal that is rich in the higher frequency harmonics, a resistor 34 is placed in the emitter circuit of transistor 35 whereby the oscillator stage functions in the class C region to provide the necessary harmonics for the frequency multiplication stages.

Since the transistor 35 is subject to variation with temperature change as may result from the body heat of the patient or other external temperature variation, the present invention provides compensation for this effect to insure that the oscillator frequency remains stable and varies only according to the intelligence signal as desired. This compensation is provided by employing a capacitor 28 in the tank circuit possessing a negative temperature coefficient whereby its capacity decreases with increase in temperature. Since this capacitor 28 serves as one parameter in controlling the frequency, and it functions in opposition to the temperature changes in transistor 35, the oscillator frequency is stabilized against undesired variations due to temperature variations.

From the output tank circuit of the first stage oscillator, the frequency modulated radio signal is coupled to the second stage by a secondary winding 38 that is inductively coupled to inductor winding 37, as shown. From the secondary winding 38, the radio signal passes through a coupling capacitor 40 and is applied between the emitter and base electrodes of transistor 43. The transistor 43 is connected in a common base configuration, with the base electrode being connected directly to the positive terminal of the battery and the collector electrode being energized by the negative terminal thereof through a resonant tuned circuit comprising a capacitor 44 shunted by an inductor winding 45. Direct current biasing is applied between the base and emitter by means of a series connected resistor 42 and inductor 41 connecting these electrodes, with the inductor 41 being in circuit to prevent the radio signal from affecting the direct current biasing of the transistor.

This common base configuration of the second stage transistor 43 provides maximum amplification at the high radio frequency involved due to the more favorable interelectrode capacities of the transistor being provided with the transistor in this configuration. It also provides optimum stability despite variation in the potential of the battery voltage as well as improved frequency response for the frequency variable radio signal being conveyed.

The output tuned circuit comprising capacitor 44 and inductor 45 is made resonant at the third harmonic frequency to provide an additional frequency multiplication of the radio signal.

The third or final stage of the transmitter, and including transistor 51, is essentially in the same circuit configuration as is the second stage with the transistor 51 being connected in a common base configuration to provide optimum gain compatible with the desired frequency response and stability of the circuit despite variations in the potential of the battery. The input and output circuits thereof are provided with tuned tank circuits to provide additional frequency multiplication of the radio signal as is desired. Thus the output radio signal being produced by the transmitter over line 19 is a frequency modulated radio signal having a wide range of frequency deviation in proportion to the cardiac intelligence signal obtained from the electrodes.

As generally discussed above, the frequency modulated radio signal over line 19 is then passed by a low pass filter 20 to remove any extraneous higher frequency noise and finally directed over line 21 to the radiating antenna input

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connector 12 where it is propagated as a radio beam to a remotely located frequency modulation receiver.

Although but one preferred embodiment of the invention has been illustrated and described, many variations may be made by those skilled in the art without departing from the spirit and scope of the invention. Accordingly, this invention should be considered as being limited only by the following claims.

What is claimed is:

1. In a portable self-contained radio electrocardiograph apparatus adapted to be completely carried by the patient and free of external electrical wiring interconnecting the patient with a fixed location for monitoring the patient's heart characteristics in a dynamic fashion while the patient is subjected to stresses encountered by unrestrained activity, transducer electrodes adapted to be bonded to the patient's skin and being flexible to maintain low resistance contact with the same location on the body despite variations in body curvature, and transmitter means producing a carrier radio-frequency responsive to electrical signals obtained from the electrodes to produce a frequency modulated ultra high frequency radiation to be detected at a remote location, said transmitter means comprising a battery, a radio frequency oscillator powered by the battery, and a housing containing said oscillator and battery and adapted to be carried by the patient during unrestrained activity in intimate heat transferring relationship with the patient's body and means for stabilizing said transmitter means to prevent heating by body temperature and variations in battery potential from producing spurious variations in the radiation, said stabilizing means including a temperature sensitive electrical component in said oscillator for varying the oscillator frequency in opposition to the change normally produced by heat.

2. In a self-contained electrocardiograph system adapted to be completely carried by the patient and having no external electrical wiring interconnecting the patient with a fixed location, small electrodes for attachment to the patient's skin and providing substantially constant low electrical resistance with the same skin locations despite variations in body curvature with unrestrained movement of the patient, and a battery powered radio transmitter operating in the ultra high frequency bandwidth, said transmitter being modulatable according to the electrode produced signals to vary its frequency of radio transmission, and means for compensating said transmitter against spurious variations, said transmitter including a lower frequency crystal controlled oscillator and frequency multiplier stages for proportionately increasing the frequency of the oscillator for transmission in the ultra high frequency bandwidth, and means for varying the frequency of the oscillator according to the electrode produced signals.

3. In a self-contained electrocardiograph system adapted to be completely carried by the patient and having no external electrical wire interconnecting the patient with a fixed location, small electrodes for attachment to the patient's skin and providing substantially constant low electrical resistance with the same skin locations despite variations in body curvature with unrestrained movement of the patient, and a battery powered radio transmitter operating in the ultra high frequency bandwidth, said transmitter being modulatable according to the electrode produced signals to vary its frequency of radio transmission, and means for compensating said transmitter against spurious variations, said transmitter including a lower frequency crystal controlled oscillator and frequency multiplier stages for proportionately increasing the frequency of the oscillator for transmission in the ultra high frequency bandwidth, and means for varying the frequency of the oscillator according to the electrode produced signals, said means including a voltage variable capacitor diode.

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RICHARD A. GAUDET, *Primary Examiner.*
RICHARD J. HOFFMAN, JORDAN FRANKLIN,
Examiners.