United States Patent

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[54] **FETAL HEART MONITOR WITH PARTICULAR SIGNAL CONDITIONING MEANS**

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[52] **U.S. Cl.**.....**128/2.06 R,** 128/2 S, 307/233, 333/76

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

[58] **Field of Search**.....128/2.06 B, 2.06 F, 2.06 G, 128/2.06 R, 2 S; 333/7 G; 330/69; 307/233

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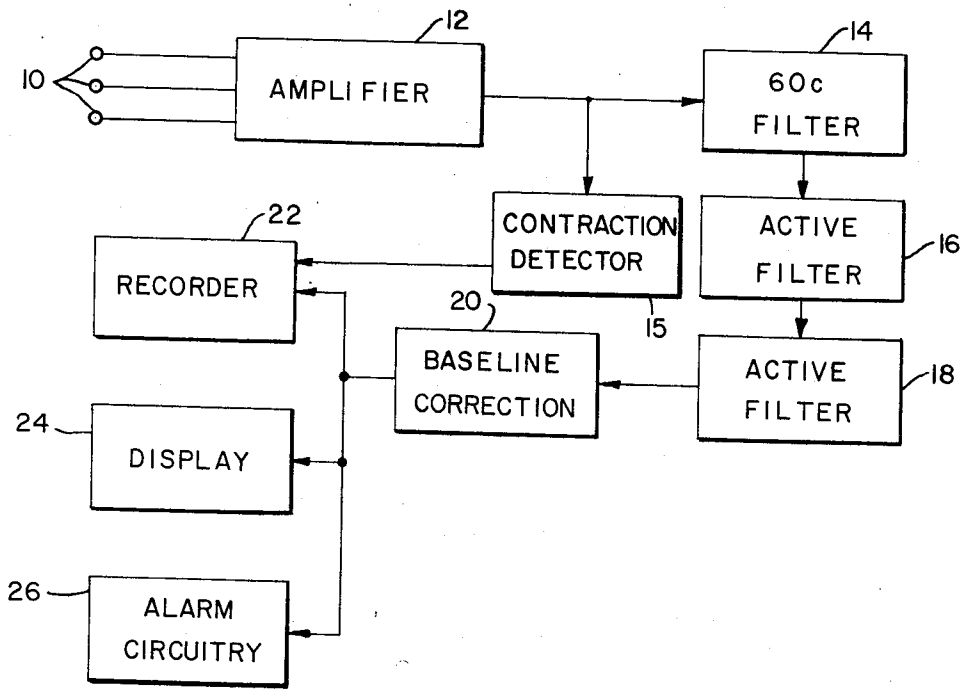
[57] **ABSTRACT**

A fetal heart monitor capable of detecting fetal heart activity in a non-invasive manner and in the presence of noise and substantially stronger maternal heart signals. The system is also operative to simultaneously monitor labor contractions in a non-invasive substantially noise free manner, and additionally provides means for selectively displaying the rhythm ECG.

4 Claims, 8 Drawing Figures



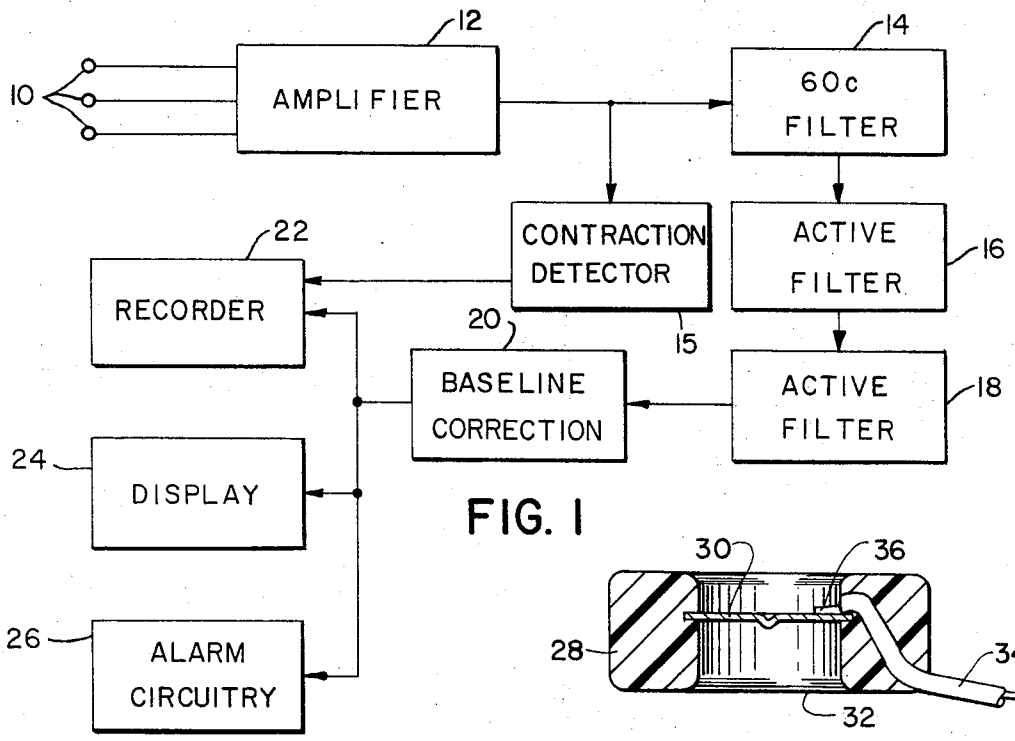


FIG. 1

FIG. 2

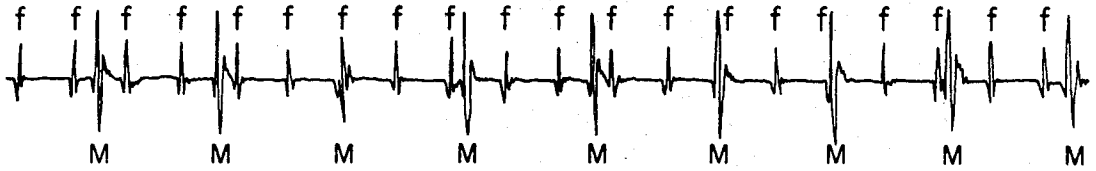


FIG. 5

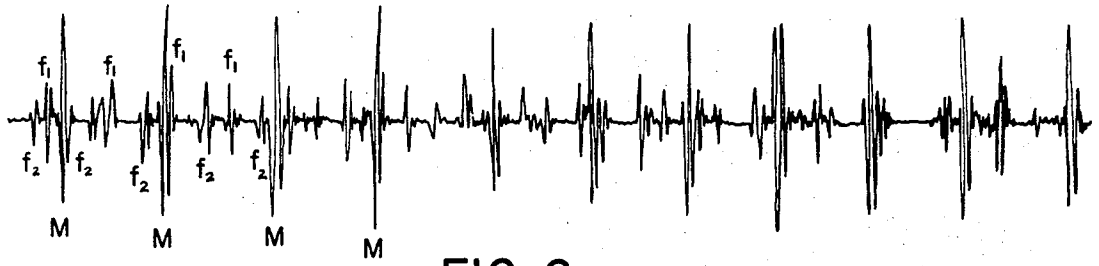


FIG. 6

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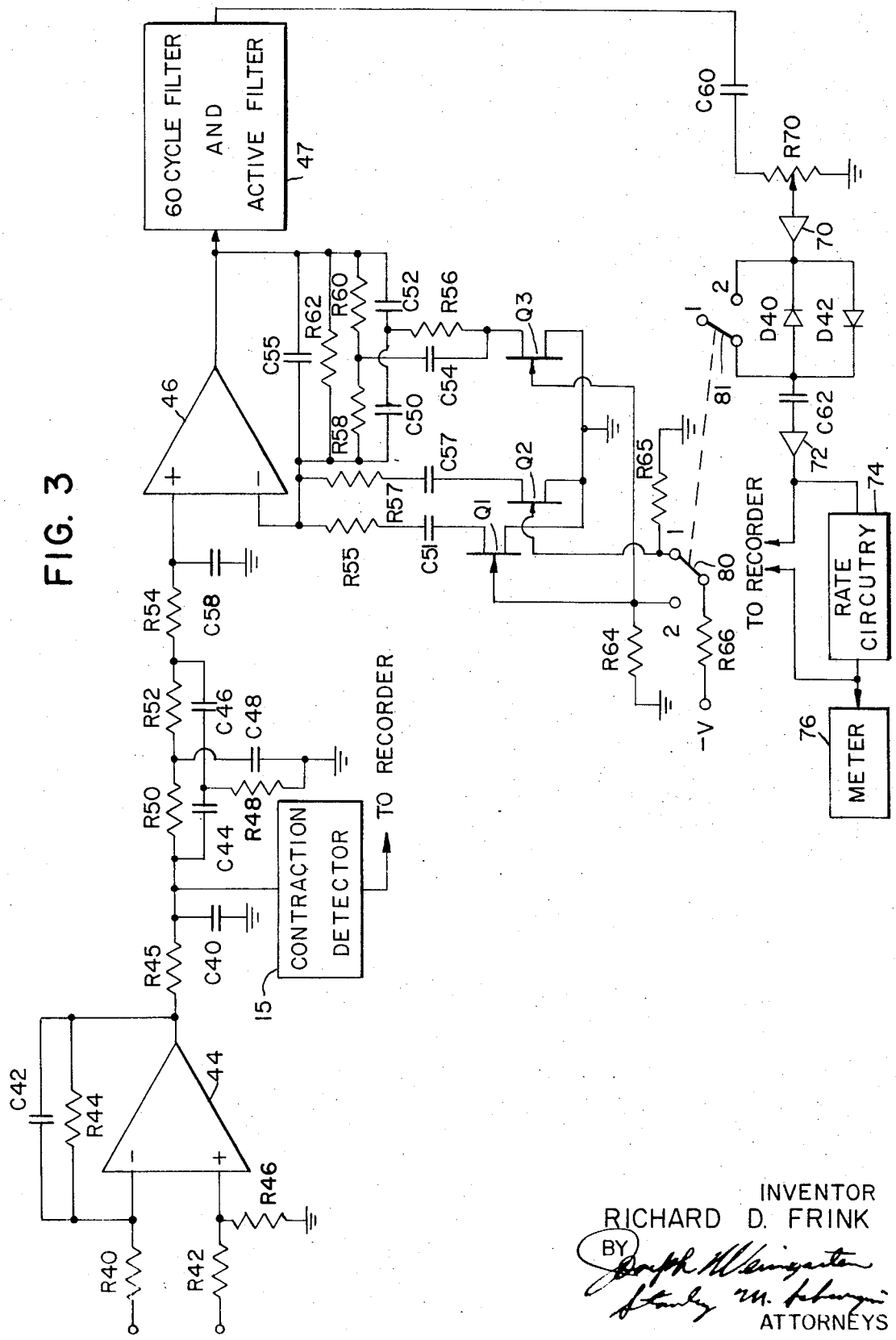
FIG. 3



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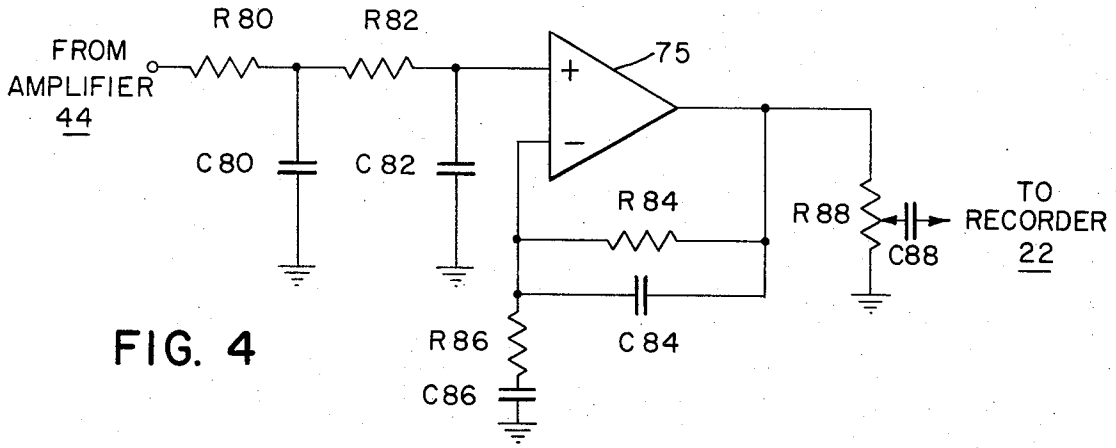

FIG. 4

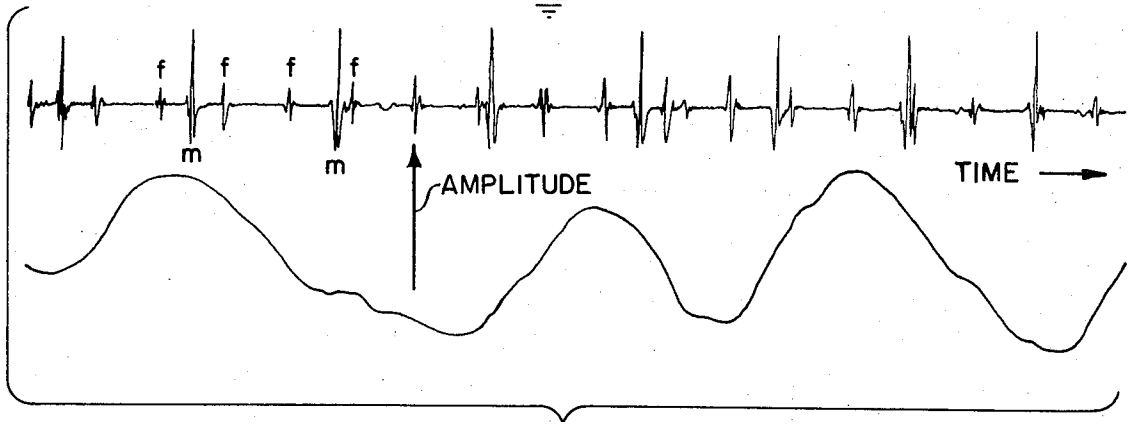

FIG. 7

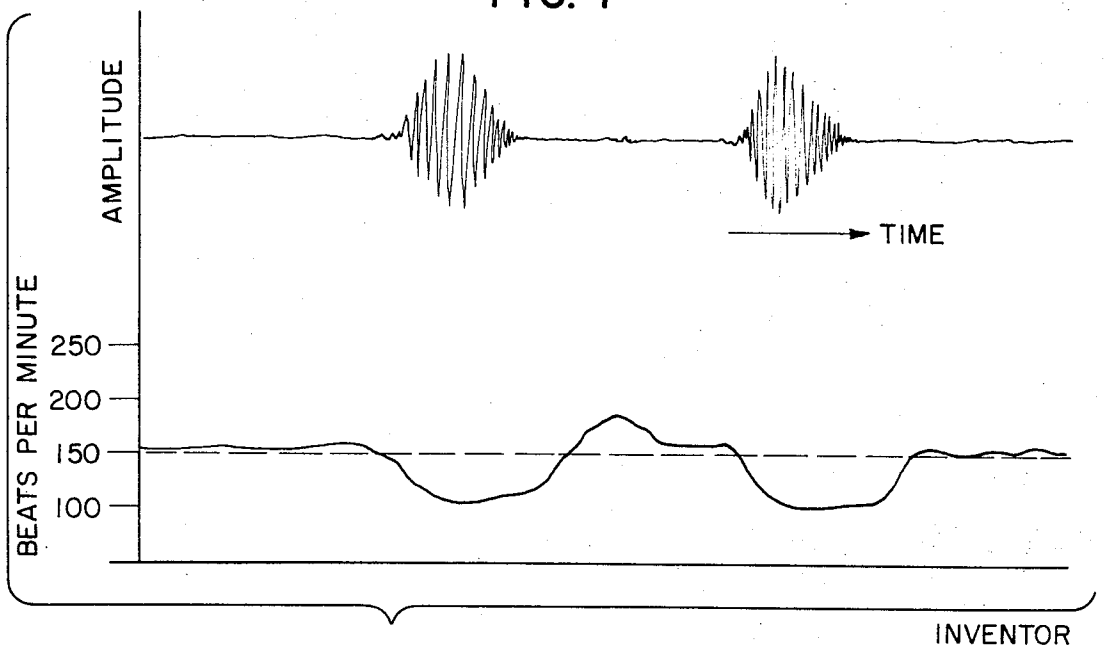

FIG. 8

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FETAL HEART MONITOR WITH PARTICULAR SIGNAL CONDITIONING MEANS

FIELD OF THE INVENTION

This invention relates to electrocardiographs and more particularly to electrocardiographs for detecting fetal heart signals in the presence of maternal signals and noise.

BACKGROUND OF THE INVENTION

Indirect fetal heart monitoring can be accomplished by means of electrodes attached to the skin of the mother to detect the fetal heartbeat and provide signals to an electrocardiograph. Presently known systems for fetal heart monitoring are not, however, wholly satisfactory since the fetal signal is usually masked in background noise caused, for example, by abdominal movement and labor contractions and masked by the substantially stronger maternal heartbeat. Indirect heart monitoring systems have generally employed rather complex signal averaging techniques to minimize spurious signals and such systems often depend upon critical placement of electrodes and require considerable skill in utilization of the apparatus and interpretation of the output display. Signal averaging systems also suffer from loss of heart rate information.

In order to detect fetal heart activity in a manner less subject to noise, invasive monitoring has been employed by means of electrodes attached directly to the fetus. Such invasive techniques can usually be employed only during the last stages of pregnancy prior to delivery. There has heretofore been no convenient means for reliable non-invasive monitoring of fetal heart activity from early stages of pregnancy through delivery.

SUMMARY OF THE INVENTION

In accordance with the present invention, a non-invasive fetal heart monitor is provided in which fetal heart activity is easily and reliably detected in the presence of background noise and considerably stronger maternal heart signals. A plurality of low noise surface electrodes are attached at selected positions on the skin of the mother's body and are connected by low noise shielded cable to signal processing circuitry which is of low input impedance to match the source impedance and which employs narrowband filtering to discriminate between the intended fetal signals and unwanted signals. The system also includes automatic baseline correction for the display of the detected fetal complex at a stable reference level.

The invention employs high-Q active filter means which is responsive to the fetal complex and which is operative to provide an enhanced fetal R-wave and to discriminate against other waveforms. The complete fetal electrocardiograph is not displayed; rather, the invention provides accurate detection and display of the R-wave which contains necessary information for obstetrical monitoring to determine presence or absence of electrocardiograph activity, fetal heart rate, multiple pregnancy and fetal distress.

The novel system, which can also be employed to monitor the heart activity of newborn infants, includes bandwidth control circuitry for selectively providing narrowband operation for R-wave detection and display, and wideband operation for detection and display of the rhythm ECG. The invention further includes means for detecting labor contractions non-invasively and simultaneously with heart activity to provide a display of labor contraction signals correlative with display of fetal heart signals and useful in obstetrical monitoring.

DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood from the following detailed description taken in conjunction with the accompanying drawings in which:

FIG. **1** is a block diagram of a fetal heart monitor according to the invention;

FIG. **2** is a pictorial view, partly in section, of an electrode of a type useful in practicing the invention;

FIG. **3** is a schematic diagram of a fetal heart monitor according to the invention;

FIG. **4** is a schematic diagram of the labor contraction detector according to the invention;

FIG. **5** is an electrocardiogram of fetal and maternal heart signals provided in accordance with the invention;

FIG. **6** is an electrocardiogram provided by the invention and indicating the fetal heart activity of twins;

FIG. **7** is an electrocardiogram of fetal and maternal heart signals and labor contraction signals provided in accordance with the invention; and

FIG. **8** is a plot of contraction and heart rate signals provided in accordance with the invention.

DETAILED DESCRIPTION OF THE INVENTION

A fetal heart monitor according to the invention is illustrated in diagrammatic form in FIG. **1**. Signals are detected from the skin of the mother's body by surface electrodes **10**, three of which are generally employed to provide a differential signal input and an electrical ground connection. Signals detected by the electrodes are applied to an amplifier **12** having low input impedance, typically 10,000 ohms, and a gain sufficient to achieve a signal level suitable for subsequent signal processing. The output signals from amplifier **12** are applied to a 60-cycle filter **14** which substantially eliminate any 60-cycle components in the processed signal due for example to power line noise. The signal is next applied to an active filter **16** which is a high-Q, critically damped filter operative to provide maximum response to the fetal complex and to discriminate against other waveforms. The output of active filter **16** is applied to a like active filter **18** to provide an additional stage of filter processing, and increased rejection of unwanted signals.

The active filters **16** and **18** each exhibit a narrow bandpass characteristic having a half power passband of approximately 20–30 Hz. The filter characteristic is non-symmetrical, having a more gradual low frequency slope of typically 18 db/octave, as compared to a relatively steep high frequency cutoff of typically 50–60 db/octave. The more gradual low frequency cutoff reduces tendencies toward oscillation.

The output of filter **18** is applied to a baseline correction circuit **20** which is operative to maintain the detected fetal signal at a substantially constant reference level and to discriminate against signal variations near the baseline level. The output signal from circuitry **20** is

then applied to suitable utilization apparatus such as an electrocardiograph recorder **22** and/or a display **24** such as a cathode ray tube. The output signal may also be applied to alarm circuitry **26** for indicating an abnormal signal condition, which may signify abnormal heart activity.

In obstetrical monitoring, it is often useful to simultaneously monitor labor contractions which can be for example, displayed on a separate channel of recorder **22**, which in this case can be a multi-channel electrocardiograph recorder. Contraction monitoring is useful for example in detecting umbilical cord compression which may occur during a contraction and which may endanger the child. As seen in FIG. **1**, a contraction detector **15** is coupled to the output of amplifier **12**, the output of detector **15** being coupled to recorder **22**. The contraction detector **15** is operative in response to the signals derived from surface electrodes **10** to provide a substantially noise-free representation of labor contractions. It is significant that labor contractions can be monitored non-invasively and an accurate signal provided even in the presence of noise generated by abdominal muscle activity. The detector **15** will be described in detail hereinafter.

In practicing the invention it is preferable to minimize, so far as practical, surface noise at the electrode locations and in accordance with the invention electrodes are employed of a construction to minimize such surface effects. Such an electrode is illustrated in FIG. **2** and includes a cylindrical ring **28** of electrically insulative material such as Nylon, with a solid silver electrode plate **30** mounted within the annular space of ring **28** and removed from the surface **32** which is to be attached to the patient's skin. A coaxial cable **34** is disposed within an opening provided in the ring with its center conductor **36** soldered or otherwise connected to electrode plate **30**. The coaxial cable is of low noise construction to further reduce system noise. In operation, a conductive jelly is placed in the space defined by ring **28** and electrode plate **30**. As is well known, the conductive jelly melts at body temperature, and electrical signals are conducted through this medium from the skin surface to the electrode plate. Electrical noise generated by movement of the skin surface against an electrode surface is substantially reduced by this electrode construction. Low noise wire and gold plated contacts further decrease interface noise. The electrode is typically secured to the patient's skin with an adhesive surgical tape.

In general, the electrodes are placed along the midline of the mother's body. The largest fetal R-wave is usually obtained when one electrode is over the head of the fetus while the other is over the buttocks of the fetus; therefore, one electrode is usually placed above the pubis of the patient, with the second electrode being placed above the umbilicus in late pregnancy or below the umbilicus in early pregnancy. The ground electrode typically is placed on the thigh. In particular cases, it may be necessary to adjust the placement of the electrodes to achieve desired signal detection. Electrode placement, however, is not as critical as in conventional monitoring schemes. Fine adjustment of the electrode placement can be accomplished simply by moving the electrodes while observing the fetal monitor display for the desired waveform. Once a satisfactory signal is obtained, further adjustment is not generally needed even in the presence of changes in fetal position and/or vigorous maternal movement, such as occurs during labor. It will be appreciated that the invention provides clear detection of a fetal signal even during the extreme electrical activity exhibited during labor.

The signal processing circuitry is illustrated in FIG. **3**. Signals detected by the two active electrodes are applied via input resistors **R40** and **R42** to the differential input terminals of an operational amplifier **44**. A resistor **R46** is connected between the positive input of amplifier **44** and a source of reference potential such as ground. A resistor **R44** is connected between the output of amplifier **44** and the negative input thereof, and a bypass capacitor **C42** is connected across resistor **R44**. The output of amplifier **44** is coupled via a series resistor **R45** and shunt capacitor **C40** to a parallel-T notch filter operative to eliminate 60-cycle noise. This filter includes series connected capacitors **C44** and **C46** and a resistor **R48** connected between the junction of capaci-tors **C44** and **C46** and ground. A pair of series connected resistors **R50** and **R52** are connected in shunt across capacitors **C44** and **C46**, with a capacitor **C48** connected between the junction of resistors **R50** and **R52** and ground.

The output of the 60-cycle filter is connected via series resistor **R54** and shunt capacitor **C58** to the resistive input of operational amplifier **46**, which with its associated circuitry functions as a high-Q filter, such as described hereinabove. The negative input of amplifier **46** is connected via resistor **R55** and capacitor **C51** and an FET transistor switch **Q1** to ground. A critically damped parallel-T filter network is provided between the negative input and the output of operational amplifier **46** and includes series connected capacitors **C50** and **C52** and resistor **R56** between the common junction of **C50** and **C52** and through an FET switch **Q3** to ground.

Series connected resistors **R58** and **R60** are connected in parallel across capacitors **C50** and **C52**, with a capacitor **C54** connected between the common resistor junction to the junction between resistor **R56** and transistor switch **Q3**. A resistor **R62** is connected across resistors **R58** and **R60** to limit the Q of the circuit to prevent oscillation. A capacitor **C55** is connected across resistor **R62**. A resistor **R57** and capacitor **C57** are series connected between the negative input of amplifier **46** and an FET switch **Q2** which, in turn, is connected to ground. The gate electrodes of switches **Q1** and **Q3** are connected together and are also connected via a resistor **R64** to ground and to a switch contact **2** of a switch **80**. The gate electrode of FET switch **Q2** is connected to contact **1** of switch **80** and is also connected via a resistor **R65** to ground. A source of negative potential -V is applied to the common terminal of switch **80** via a resistor **R66**. As will be described, the FET switches are operative to alter the bandwidth of the active filter to permit narrow band operation for monitoring the fetal heart rate and relatively wideband operation for monitoring the fetal rhythm ECG.

The output of the active filter is coupled to circuitry **47** which includes a like 60-cycle notch filter and active filtering as just described. The additional notch filter provides further discrimination against 60-cycle noise,

while the additional active filter provides further discrimination between the fetal R-wave and noise. The output of filter circuitry **47** is coupled via a capacitor **C60** to a potentiometer **R70**, which functions as a level control, the output of the potentiometer being applied to an amplifier **70**. The output of amplifier **70** is applied to a pair of oppositely poled diodes **D40** and **D42**. The output from the diode network is coupled via a capacitor **C62** to an amplifier **72**, the output of which is the system output for application to utilization apparatus, such as an electrocardiogram recorder or cathode ray tube display.

The output from amplifier **72** is also applied to rate circuitry **74** operative to provide an output signal proportional to the fetal heart rate signals applied thereto. Rate circuitry **74** is operative to drive a suitable rate meter **76** for providing a visual indication of fetal heart rate, and is also operative to provide fetal heart rate signals for the electrocardiogram recorder. A switch **81** connected across the diode network has its switch arm mechanically linked to the switch arm of switch **80** such that the switches are operative in tandem. Switch **80** is employed together with FET switches described above to provide narrowband and wideband operation of the circuitry in a manner to be described in detail hereinafter.

As discussed, the invention is also operative to simultaneously detect labor contractions and to provide a substantially noise free signal representative of these contractions which can be displayed concurrently with display of the fetal heart signals. The labor contraction detector **15** is illustrated in greater detail in FIG. **4** and includes an input filter network comprising series connected resistors **R80** and **R82** connected to the positive input of an operational amplifier **R85** and shunt capacitors **C80** and **C82** connected to ground. The negative input of operational amplifier **75** is coupled via series connected resistor **R86** and capacitor **C86** to ground and is also connected via the parallel combination of resistor **R84** and capacitor **C84** to the output of amplifier **75**. The amplifier output is coupled via a potentiometer **R88** and capacitor **C88**, to the electrocardiograph recorder **22** or other suitable output utilization apparatus.

The filter of FIG. **4** is a bandpass filter having a passband of approximately 0.1 to 1 Hz. The filter has a low frequency roll-off of approximately 6 db per octave and a high frequency roll-off of approximately 18 db per octave. The high frequency characteristics of the amplifier are essentially determined by resistor **R86**, capacitor **C86** and coupling capacitor **C88**. The remaining resistive and capacitive elements essentially determine the low frequency characteristics of the filter.

The invention also provides means for varying the bandwidth of the active filter circuitry in order to selectively provide narrowband operation for enhanced detection of the fetal R-wave, even in the presence of noise and the stronger maternal heart signals, and relatively wideband operation to detect the P, QRS and T waves of the fetal complex to determine the presence or absence of normal sinus rhythm. The FET switches shown in FIG. **3** provide the bandwidth control. Referring to FIG. **3**, with switches **80** and **81** in position **1**, as illustrated, FET switch **Q2** is biased off, while switches **Q1** and **Q3** are conductive. In this mode of operation, the active filter provides narrowband operation for discrimination between the fetal R-wave and noise. In this mode of operation, diodes **D40** and **D42** are in circuit to provide the intended baseline correction. With switches **80** and **81** in switch position **2**, the FET switches **Q1** and **Q3** are biased off while switch **Q2** is conducting to alter the filter characteristics such that relatively wideband operation is achieved to process the PQRST fetal complex. In this wideband mode of operation, the active filter has a bandwidth of approximately 1 to 30 Hz. The diode network, in the wideband mode, is shunted out of circuit, with a result that no baseline correction is employed to permit processing of the rhythm complex.

The illustrated embodiment provides signal sensitivity down to one microvolt to easily detect fetal heart signals which are typically in the 3–5 microvolt range. Maternal heart signals are generally in the 600–700 microvolt range and are also efficiently processed to provide accurate indication of maternal heart activity.

For purposes of illustrating the greatly enhanced signal discrimination provided by the invention, there is shown in FIG. **5** an electrocardiogram of fetal and maternal heart signals provided in accordance with the invention. As seen in FIG. **5**, a normal fetal R-wave, labeled f, is displayed along with the maternal complexes, labeled M. It is evident that the fetal heart signal is clearly distinguishable from the maternal heart signal and provides an accurate and easily analyzed representation of fetal heart activity.

The enhanced detection of fetal heart activity provided by the invention also permits the early detection of twins, and the heart activity of each twin can be easily detected and monitored in accordance with the invention. An electrocardiogram of the fetal heart activity of twins is depicted in FIG. **6**. The waveform labeled f_1 indicates the heart activity of one twin, while the waveform labeled f_2 indicates the heart activity of the second twin. The maternal heart complex, labeled M, is also clearly evident. It will be noted that the fetal complex of each twin is of opposite polarity to the other, denoting that the twins are in opposite disposition one in a vertex position, the other in a breech position. The position of the fetus is easily determined in accordance with the invention since the polarity of the enhanced fetal R-wave provides accurate indication of fetal position.

The simultaneous display of fetal heart signals and labor contraction signals is shown in FIG. **7**. The upper waveform represents the fetal R-wave, labeled *f*, along with the maternal complex, M, while the lower waveform shows the periodic signal caused by the uterine contractions and derived from contraction detector **15**.

It is also useful in obstetrical monitoring to simultaneously display labor contractions and fetal heart rate. Such a display is shown in FIG. **8**, in which the upper plot represents a contraction, while the lower plot depicts heart rate, as derived from rate circuitry **74**. As illustrated, the heart rate is decreased during a contraction, as would occur for example when the umbilical cord is compressed. Such an indication would signal a possibly dangerous situation which should be corrected.

Various modifications and alternative implementations will occur to those versed in the art without departing from the spirit and true scope of the invention. For example, in instances where only fetal R-wave detection is desired, the invention can be practiced without the contraction monitor and bandwidth selection means. Accordingly, it is not intended to limit the invention by what has been particularly shown and described.

What is claimed is:

1. A non-invasive fetal heart monitor comprising:
an amplifier having low input impedance and adapted for connection to a plurality of surface electrodes attached to a mother's skin;
filter means coupled to said amplifier and operative to substantially eliminate 60-cycle signal components;
high-Q critically damped active filter means responsive to the fetal complex and operative to provide an enhanced fetal R-wave and to substantially reject spurious signals;
said active filter means including first switching means operative to alter the bandwidth of said active filter means to provide relatively wideband operation for detection of rhythm ECG;
baseline correction circuitry coupled to said active filter means and operative to maintain the output signal of said active filter means at a stable reference level; and
second switching means for bypassing said baseline correction circuitry when said first switching means is operative;
said output signal being adapted for application to utilization means.

2. A non-invasive fetal heart monitor according to claim 1 including
active bandpass filter means coupled to said amplifier and having a passband of approximately 0.1 to 1.0 Hz for providing a signal representative of labor contractions simultaneously with the output signal of said high-Q active filter means.

3. A non-invasive fetal heart monitor comprising:
an amplifier having low input impedance and adapted for connection to a plurality of surface electrodes attached to a mother's skin;
filter means coupled to the output of said amplifier and operative to substantially eliminate power line noise frequencies;
multistage variable bandwidth active filter means each stage being a high-Q critically damped active filter operative to provide maximum response to the fetal complex and to discriminate against other waveforms;
said active filter means being operative in a narrowband mode to provide a first output signal representing an enhanced fetal R-wave and to substantially reject spurious signals, and operative in a relatively wideband mode to provide a second output signal representing a rhythm ECG;
first switching means coupled to said active filter means and operative to select said narrow band or wideband mode;
baseline correction circuitry coupled to the output of said active filter means and operative to maintain the output signals of said active filter means at a stable reference level; and
second switching means cooperative with said first switching means for bypassing said baseline correction circuitry when said wideband mode is selected by said first switching means.

4. A non-invasive fetal heart monitor according to claim 3 including
a contraction detector coupled to the output of said amplifier and operative to detect labor contractions simultaneously with detection of fetal heart activity, said contraction detector comprising
an active bandpass filter having a low frequency narrow passband in the vicinity of 1.0 Hz for providing a signal representing labor contractions and to substantially reject spurious signals.

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