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(54) **METHOD AND SYSTEM FOR DATA SYNCHRONIZATION**

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(57) **ABSTRACT**

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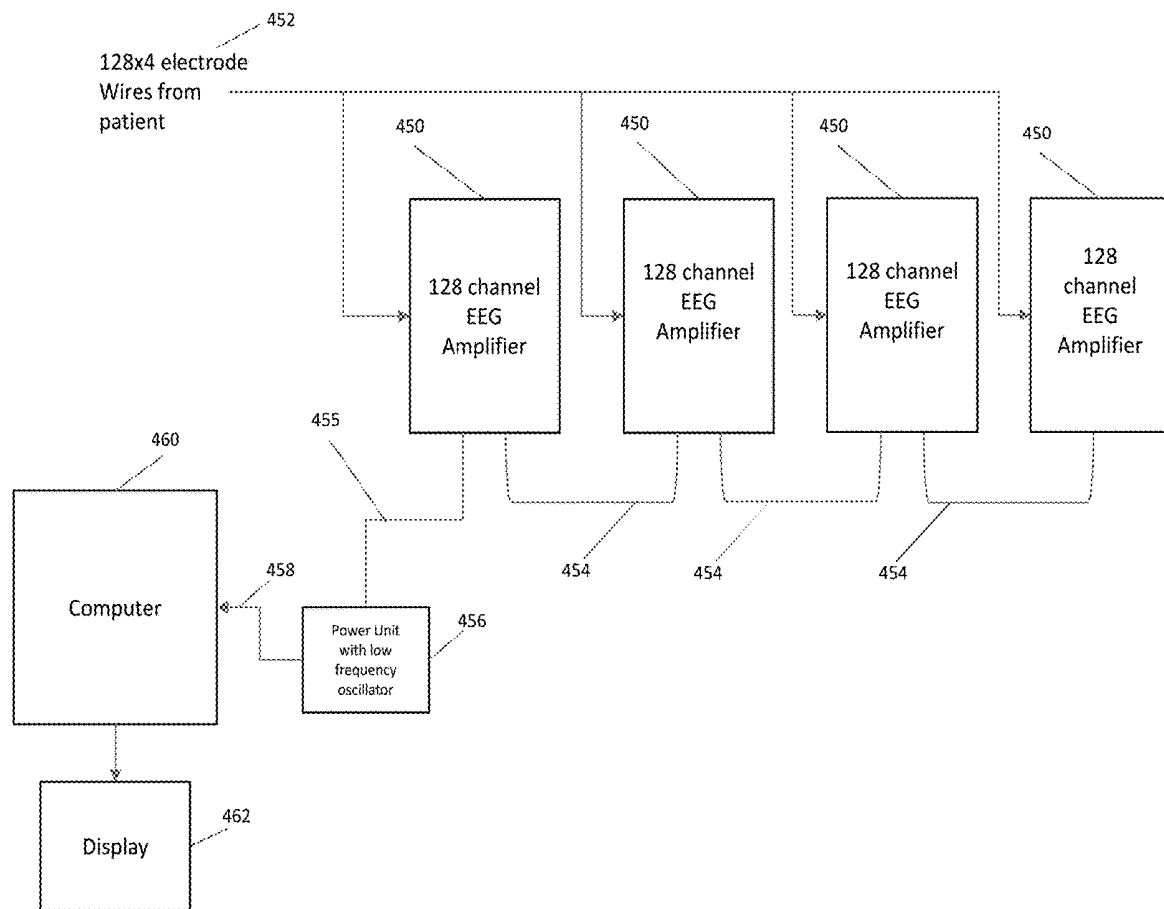
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A system for monitoring includes: multiple EEG sensors spatially positioned on a layer of tissue for capturing EEG signals of a patient; multiple amplifiers coupled with the EEG sensors for amplifying the captured signals; and a low frequency oscillator for generating a synchronizing signal which is distributed to the amplifiers for synchronizing the digitization of the captured signals; wherein each amplifier includes: a voltage controlled oscillator for an adjustable frequency reference; an analog to digital converter for converting the amplified signal to a digital value; and a microcontroller for controlling the frequency of the voltage controlled oscillator and operation of the analog to digital converter by using the synchronizing signal.



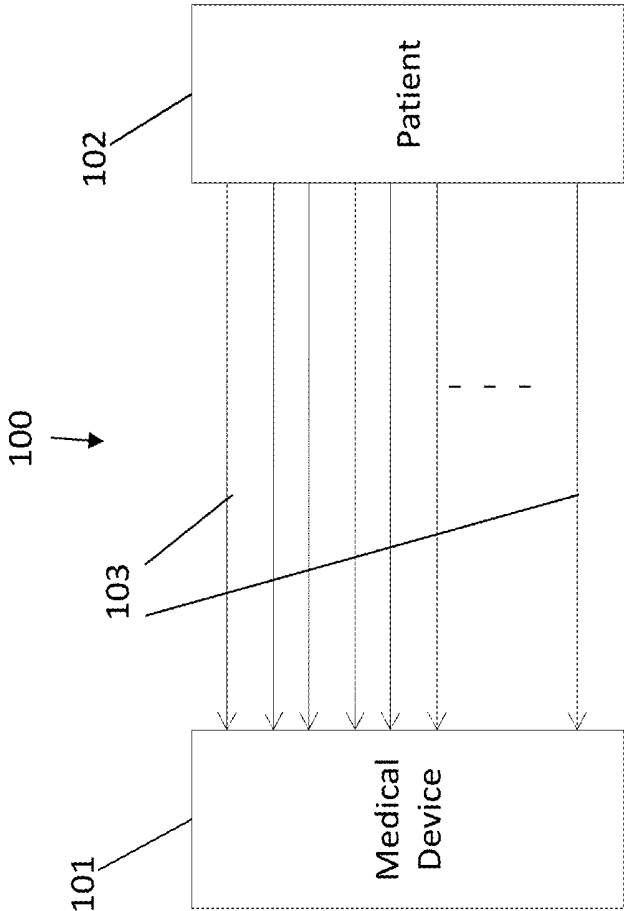


FIG. 1

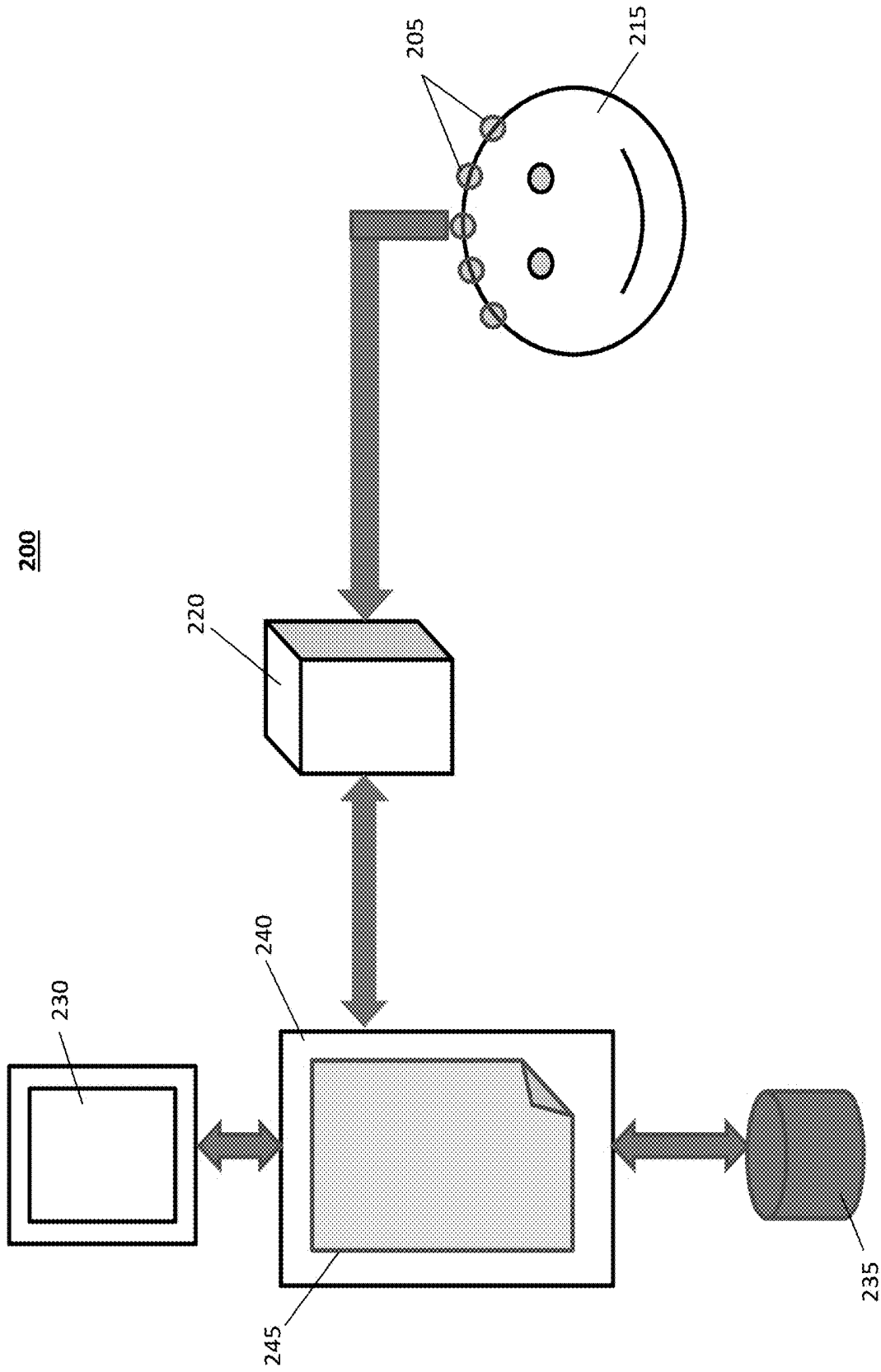


FIG. 2

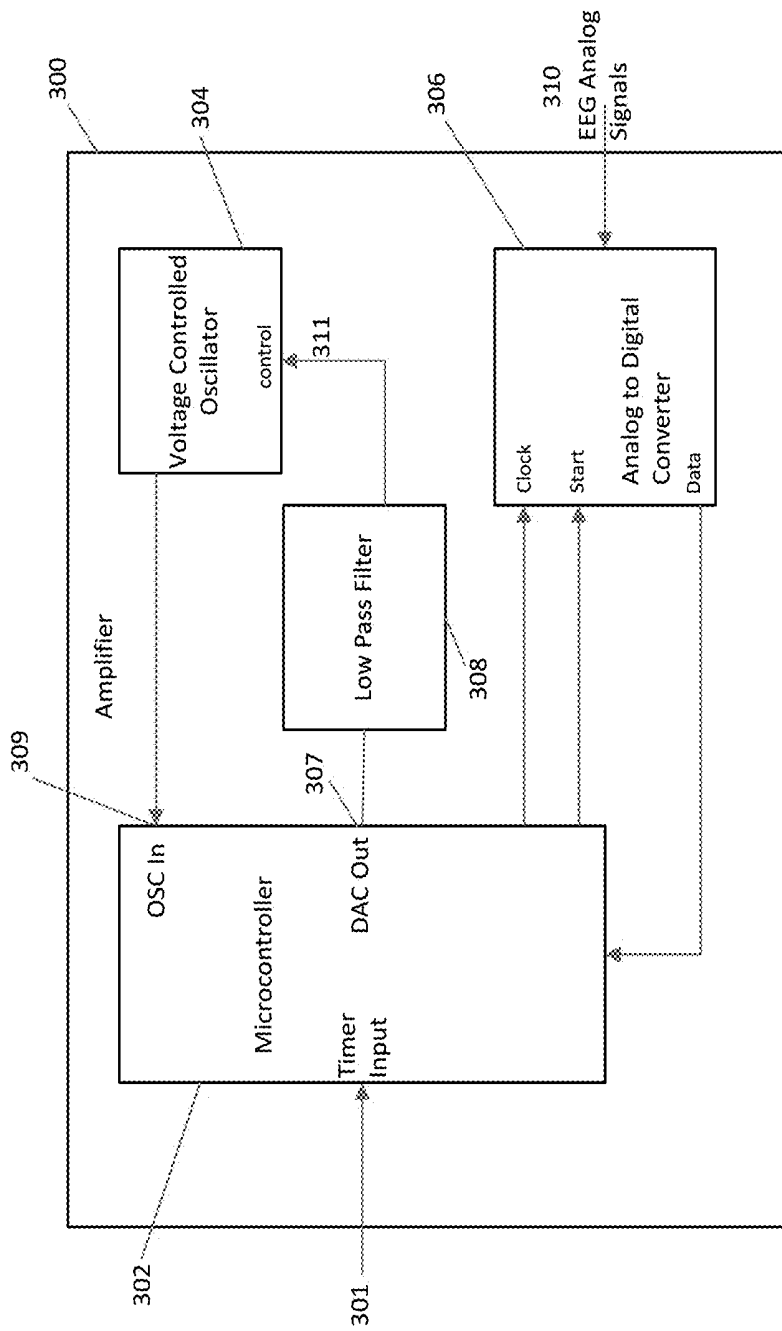


FIG. 3

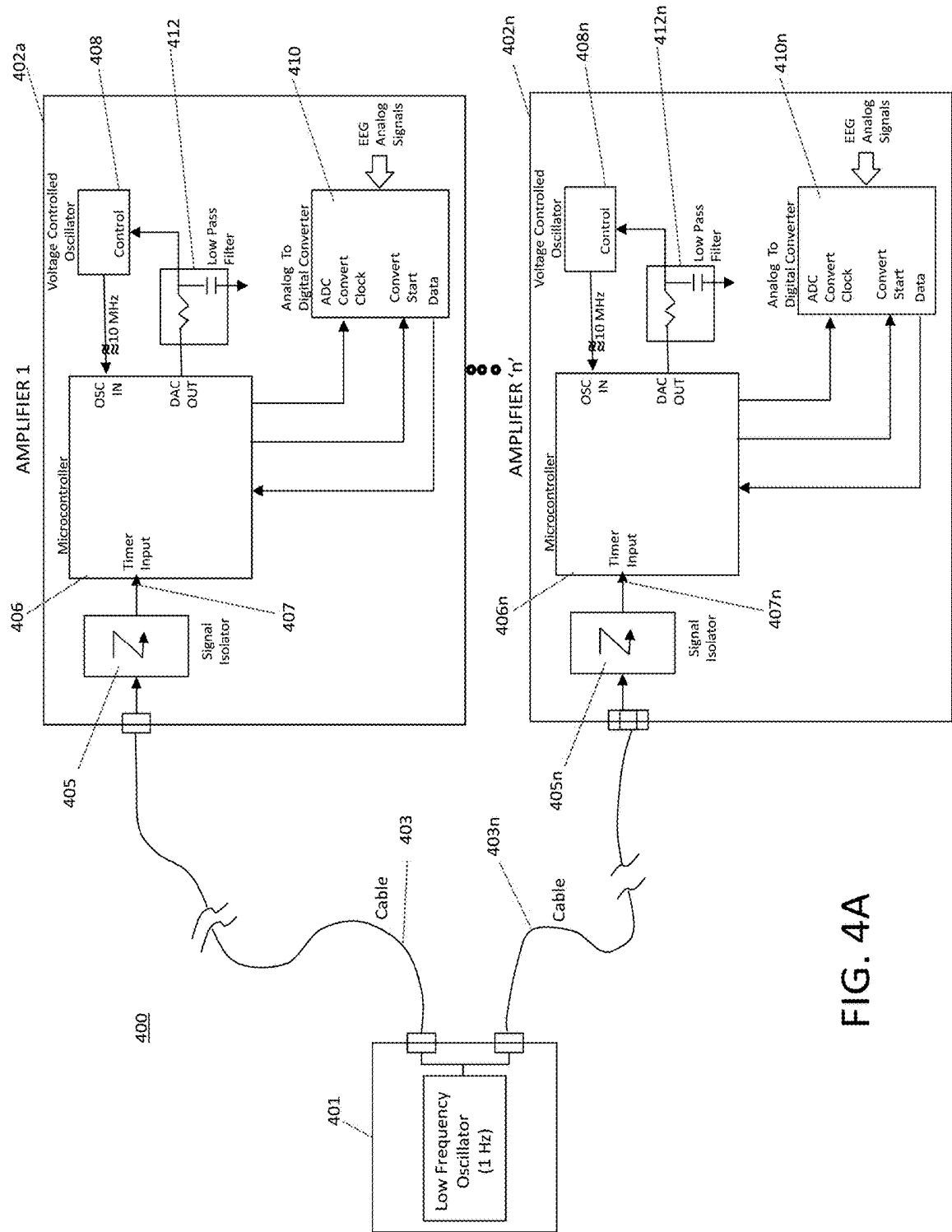


FIG. 4A

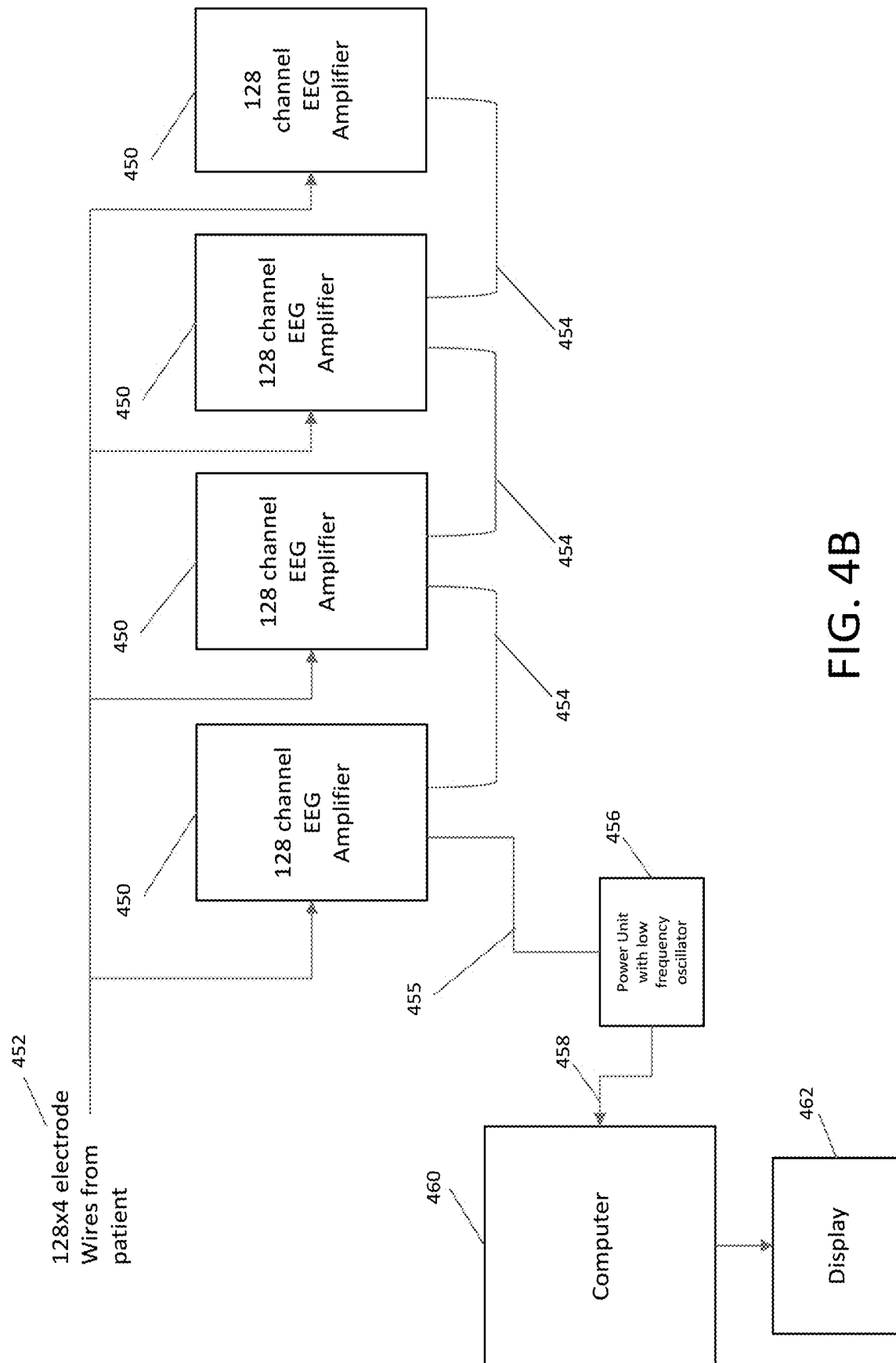


FIG. 4B

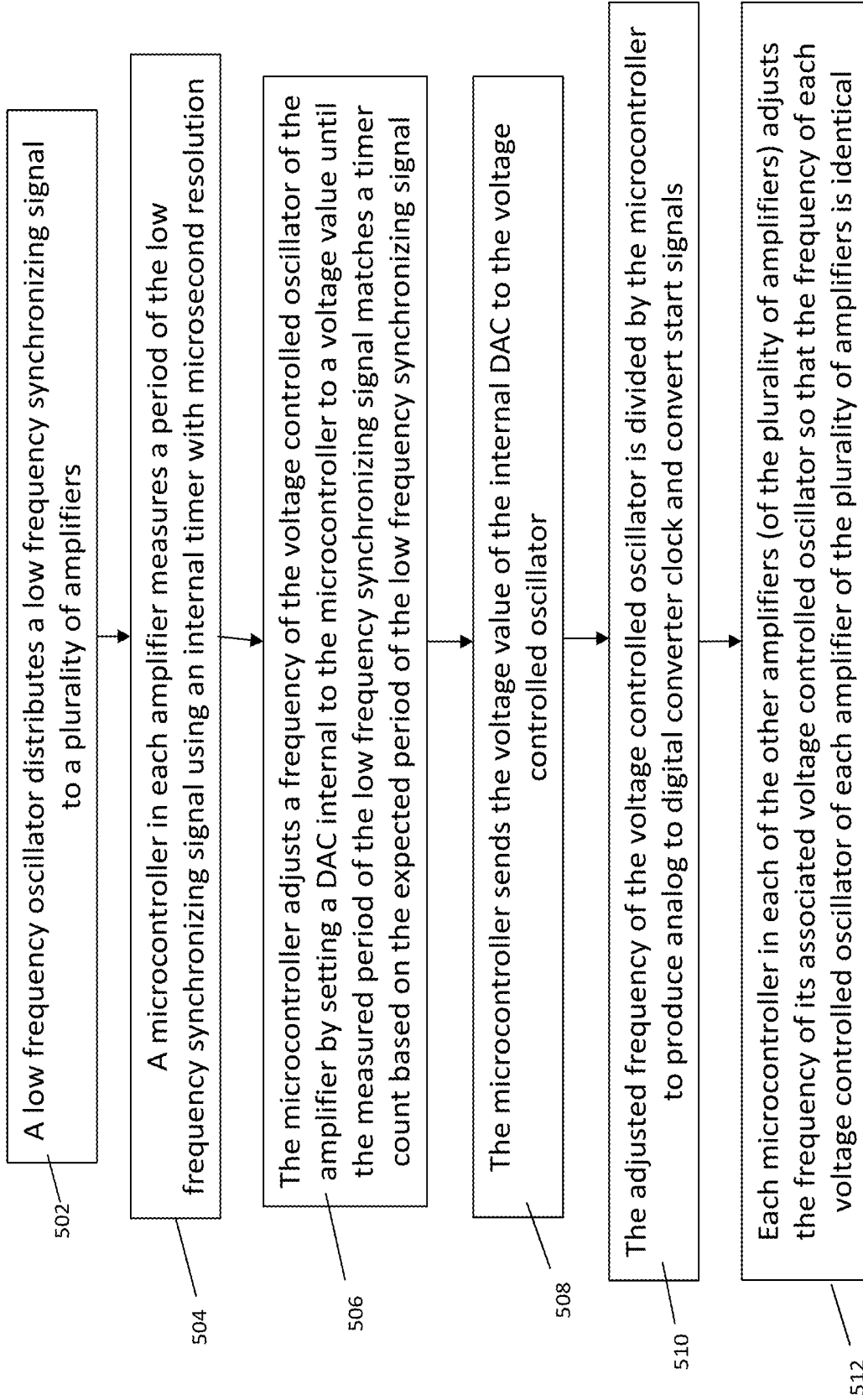


FIG. 5

## METHOD AND SYSTEM FOR DATA SYNCHRONIZATION

### CROSS REFERENCE

**[0001]** The present application relies on U.S. Patent Provisional Application No. 62/752,675, entitled "Method and System for Data Synchronization" and filed on Oct. 30, 2018, for priority, which is herein incorporated by reference in its entirety.

### FIELD

**[0002]** The present specification generally relates to the field of neuro-monitoring applications and more specifically to a system and method for synchronizing multiple amplifiers being used in conjunction for amplifying captured electroencephalography (EEG) signals and other biopotential signals.

### BACKGROUND

**[0003]** Several medical procedures involve deploying multiple sensors on the human body for the recording and monitoring of data required for patient care. Information, such as vital health parameters, cardiac activity, bio-chemical activity, electrical activity in the brain, gastric activity and physiological data, is usually recorded through on-body or implanted sensors/electrodes which are connected through a wired or wireless link. Typical patient monitoring systems comprise a control unit connected through a wire to one or more electrodes coupled to the specific body parts of the patient. In some applications, such as with pulse oximeter or EKG (electrocardiograph) devices, the electrodes coupled to the body are easily managed as there are not too many. However, with procedures that require a large number of electrodes to be coupled to the human body, the overall set up, placement and management of electrodes is a cumbersome process.

**[0004]** One such procedure that requires a large number of electrodes is Long Term Electroencephalography (EEG) Monitoring (LTM). The purpose of LTM is to detect abnormal brain activity. The presence of abnormal brain activity may require medications and/or surgical interventions. During surgical procedures, LTM may reduce the risk to the patient of iatrogenic damage to the nervous system, and/or to provide functional guidance to the surgeon. Generally, neuromonitoring procedures such as EEG involve a large number of electrodes coupled to the human body. In an EEG procedure, the electrodes are used to record and monitor the electrical activity corresponding to various parts of the brain for detection and treatment of various ailments such as epilepsy, sleep disorders, tumors and coma. EEG procedures are either non-invasive or invasive. In non-invasive EEG, a number of surface electrodes are deployed on the human scalp for recording electrical activity in portions of the underlying brain. In invasive EEG, through surgical intervention, the electrodes are placed directly over sections of the brain, in the form of a strip or grid, or are positioned in the deeper areas of the brain in the form of a depth electrode. All of these electrode types are coupled to a wire lead which, in turn, is connected to a medical system adapted to receive and transmit electrical signals. The electrical activity pattern sensed by various electrodes is analyzed using standard algorithms to localize or spot the portion of brain which is responsible for causing the specific ailment.

**[0005]** The number of electrodes in EEG systems typically varies between 21 and 256. Increasing the number of electrodes in EEG procedures helps decrease the localization error and thus more ably assist the physician to better plan for surgical procedures. Accordingly, advanced EEG systems involve a high density electrode configuration with more than 256 electrodes, possibly 1024 electrodes, for separately mapping the electrical activity corresponding to every portion of the brain. However, the overall set up and verification process becomes more time consuming and error prone as the number of electrodes increases in the EEG procedures.

**[0006]** Most EEG monitoring systems comprise an amplifier for amplifying and digitizing the recorded signals before analyzing the signals. In EEG systems consisting of more than one amplifier, the data from each amplifier must be time synchronized with each other. Data synchronization is important since cerebral events such as seizures have a temporal significance and the EEG signals recorded from a patient may be acquired by more than one amplifier, as is the case in high channel count intracranial EEG monitoring systems. Also, any difference in sample rate between the amplifiers will result in beat frequency noise when the EEG channels in one amplifier are fed as reference to the EEG channels of another amplifier. Beat frequency noise is a periodic artifact added to the EEG signal and is a result of one amplifier's digitizer's (ADCs) sampling a common mode noise of another amplifier as a differential signal. The noise may inhibit analyzing the EEG signals.

**[0007]** Known methods of synchronizing multiple amplifiers include running multiple synchronizing clocks and signals from one amplifier to another or using high precision temperature controlled oscillators in each of the amplifiers, the latter of which requires extremely stable clock oscillators that are typically temperature controlled and an order of magnitude higher in cost than a voltage controlled oscillator, require much more power than a voltage controlled oscillator, and are also physically much larger in size.

**[0008]** The other method of synchronizing the data from different amplifiers comprises sharing the sample clocks of the amplifiers and sharing the 'convert start' signals among all the analog to digital converters (ADC) of all the amplifiers. Though it is possible to share such signals between all of the amplifiers, this is not a desirable topology because specialized and high current consumption equipment and cables would be required to do so and also because the ADC signals can be corrupted by electromagnetic interference, resulting in unexpected functioning of the ADCs.

**[0009]** Hence what is needed is a less complex method of synchronizing the data acquisition from multiple amplifiers than that provided by prior art. What is also needed is a method of synchronization that does not require specialized components, is cost effective and is not susceptible to interference from electrostatic discharge (ESD) interference, electric fast transient (EFT) interference, or other electromagnetic interferences. Such a method would preferably eliminate the need for distributing data from a high speed clock to each of the amplifiers. Distribution of high speed clock data between amplifiers is not desirable since this requires differential circuitry and cabling, and is susceptible to interference from ESD, EFT, and other electromagnetic interference.

## SUMMARY

[0010] The following embodiments and aspects thereof are described and illustrated in conjunction with systems, tools and methods, which are meant to be exemplary and illustrative, and not limiting in scope. The present application discloses numerous embodiments.

[0011] The present specification discloses a system for monitoring EEG signals comprising: a plurality of EEG sensors positioned on a layer of tissue for capturing EEG signals of a patient; at least one amplifier coupled to each of the plurality of EEG sensors, wherein the at least one amplifier is configured to amplify the captured EEG signals; and a first oscillator configured to generate a synchronizing signal; wherein the at least one amplifier comprises: an input for receiving the synchronizing signal transmitted from the first oscillator; a second oscillator; an analog to digital converter coupled with the second oscillator and configured to digitize the captured EEG signals; and a microcontroller configured to control a frequency of the second oscillator and an operation of the analog to digital converter (ADC) based on the synchronizing signal.

[0012] Optionally, the first oscillator is configured to generate the synchronizing signal having a frequency in a range of 0.1 Hz to 10 kHz.

[0013] Optionally, the second oscillator is voltage controlled.

[0014] Optionally, the plurality of EEG sensors are configured to monitor intracranial EEG signals.

[0015] Optionally, the system further comprises a computing device in data communication with the plurality of amplifiers for processing the amplified EEG signals. Optionally, the system further comprises a display in data communication with the computing device for displaying the amplified EEG signals.

[0016] Optionally, the input comprises a signal isolator configured to receive the synchronizing signal. Optionally, the signal isolator comprises one or more isolated DC-DC power converters.

[0017] Optionally, the synchronizing signal has a frequency of 1 Hz.

[0018] Optionally, the microcontroller comprises a digital to analog (DAC) converter and the microcontroller is configured to adjust the second oscillator by setting the DAC to a corresponding voltage.

[0019] Optionally, the at least one amplifier further comprises an internal timer and the microcontroller is configured to measure the period of the synchronizing signal using the internal timer. Optionally, the internal timer has a resolution in a microsecond numerical range.

[0020] Optionally, the at least one amplifier further comprises a filter configured to filter out high frequency noise present in an analog voltage transmission from the microcontroller, wherein the high frequency noise has a frequency greater than 2 kHz.

[0021] Optionally, the at least one amplifier comprises at least one unique amplifier in dedicated data communication with each of the plurality of EEG sensors.

[0022] The present specification also discloses a method for synchronizing EEG signals measured by an EEG monitoring system, wherein the EEG monitoring system comprises a plurality of EEG sensors positioned on a layer of tissue and wherein each of the plurality of EEG sensors is configured to capture EEG signals of a patient, at least one amplifier coupled to each of the plurality of EEG sensors and

configured to amplify the captured EEG signals, and a first oscillator, wherein the at least one amplifier comprises an input for receiving a synchronizing signal from the first oscillator, the method comprising: distributing the synchronizing signal from the first oscillator to each of the at least one amplifier; measuring a period of the synchronizing signal; adjusting a second oscillator, having a frequency, in the at least one amplifier to match a timer count based on the period of the synchronizing signal; determining a function of the frequency of the second oscillator frequency to produce a clock signal; and adjusting a frequency of each of the second oscillators such that the frequencies of the second oscillators are identical.

[0023] Optionally, the first oscillator is configured to generate the synchronizing signal having a frequency in a range of 0.1 Hz to 10 kHz.

[0024] Optionally, the second oscillator is voltage controlled.

[0025] Optionally, the function of the frequency of the second oscillator frequency is determined by dividing the frequency to produce the clock signal. Optionally, the method further comprises using the clock signal to drive the analog to digital converter clock signal. Optionally, the at least one amplifier comprises the second oscillator, the analog to digital converter coupled to the second oscillator and configured to digitize the captured EEG signals, and a microcontroller configured to control the frequency of the second oscillator and an operation of the analog to digital converter based on the synchronizing signal. Optionally, the microcontroller comprises a signal isolator wherein the signal isolator comprises isolated DC-DC power converters.

[0026] Optionally, the method further comprises transmitting the amplified EEG signals to a computing device, wherein the computing device is configured to process the amplified EEG signals.

[0027] Optionally, the synchronizing signal has a frequency of 1 Hz.

[0028] Optionally, the microcontroller includes a digital to analog (DAC) converter and the microcontroller is configured to adjust the second oscillator by setting the DAC to a corresponding voltage.

[0029] Optionally, the at least one amplifier further comprises an internal timer having microsecond resolution and the microcontroller is configured to measure a period of the synchronizing signal using the internal timer.

[0030] Optionally, the at least one amplifier further comprises a filter configured to filter out high frequency noise, having a value range greater than 2 kHz, present in an analog voltage signal from the microcontroller output.

[0031] The present specification also discloses a system for monitoring EEG signals comprising: a plurality of EEG sensors spatially positioned on a layer of tissue for capturing EEG signals of a patient; a plurality of amplifiers coupled with the EEG sensors for amplifying the captured signals; and a low frequency oscillator; wherein each amplifier comprises: an input for receiving a low frequency synchronizing signal from the low frequency oscillator wherein the low frequency synchronizing signal is configured to be distributed to each amplifier of the plurality of amplifiers; a voltage controlled oscillator; an analog to digital converter coupled with the voltage controlled oscillator for digitizing the captured signals; and a microcontroller for controlling a

frequency of the voltage controlled oscillator and operation of the analog to digital converter (ADC) based on the synchronizing signal.

**[0032]** The system may be used to monitor intracranial EEG signals.

**[0033]** Optionally, the system further comprises a computing device in data communication with the plurality of amplifiers for processing the amplified signals. Optionally, the system further comprises a display in data communication with the computing device for displaying the amplified signals.

**[0034]** Optionally, the input comprises a signal isolator for receiving the synchronizing signal. The signal isolator may comprise isolated DC-DC power converters.

**[0035]** Optionally, the synchronizing signal has a frequency of 1 Hz.

**[0036]** Optionally, the microcontroller includes an internal digital to analog (DAC) converter wherein the microcontroller is configured to adjust the voltage controlled oscillator by setting the internal DAC to a corresponding voltage.

**[0037]** Optionally, each amplifier further comprises an internal timer with microsecond resolution wherein the microcontroller is configured to measure the period of the synchronizing signal using the internal timer.

**[0038]** Optionally, each amplifier further comprises a low pass filter configured to filter out high frequency noise on analog voltage from the microcontroller output.

**[0039]** The present specification also discloses a method for synchronizing EEG signals measured by a an EEG monitoring system, wherein the EEG monitoring system comprises a plurality of EEG sensors spatially positioned on a layer of tissue for capturing EEG signals of a patient, a plurality of amplifiers coupled with the EEG sensors for amplifying the captured signals, and a low frequency oscillator, wherein each amplifier comprises: an input for receiving a low frequency synchronizing signal from the low frequency oscillator wherein the low frequency synchronizing signal is configured to be distributed to each amplifier of the plurality of amplifiers; a voltage controlled oscillator; an analog to digital converter coupled with the voltage controlled oscillator for digitizing the captured signals; and a microcontroller for controlling a frequency of the voltage controlled oscillator and operation of the analog to digital converter (ADC) based on the synchronizing signal, the method comprising: distributing a low frequency synchronizing signal from the low frequency oscillator to each of the plurality of amplifiers; measuring a period of the low frequency synchronizing signal; adjusting the voltage controlled oscillator of an amplifier of the plurality of amplifiers to match a timer count based on the period of the low frequency synchronizing signal; dividing a voltage controlled oscillator frequency to produce analog to digital converter clock and convert start signals; and adjusting the frequency of each voltage controlled oscillator of each of the plurality of amplifiers such that the frequency of each voltage controlled oscillator is identical.

**[0040]** The method may be used to monitor intracranial EEG signals.

**[0041]** Optionally, the EEG monitoring system further comprises a computing device in data communication with the plurality of amplifiers for processing the amplified signals. Optionally, the EEG monitoring system further comprises a display in data communication with the computing device for displaying the amplified signals.

**[0042]** Optionally, each input comprises a signal isolator for receiving the synchronizing signal. The signal isolator may comprise isolated DC-DC power converters.

**[0043]** Optionally, the synchronizing signal has a frequency of 1 Hz.

**[0044]** Optionally, the microcontroller includes an internal digital to analog (DAC) converter wherein the microcontroller is configured to adjust the voltage controlled oscillator by setting the internal DAC to a corresponding voltage.

**[0045]** Optionally, each amplifier further comprises an internal timer with microsecond resolution wherein the microcontroller is configured to measure the period of the synchronizing signal using the internal timer.

**[0046]** Optionally, each amplifier further comprises a low pass filter configured to filter out high frequency noise on analog voltage from the microcontroller output.

**[0047]** The aforementioned and other embodiments of the present shall be described in greater depth in the drawings and detailed description provided below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0048]** These and other features and advantages of the present specification will be further appreciated, as they become better understood by reference to the following detailed description when considered in connection with the accompanying drawings:

**[0049]** FIG. 1 shows a block diagram of a conventional medical system comprising a large number of electrodes deployed on a patient body;

**[0050]** FIG. 2 illustrates an electroencephalography (EEG) system for detecting, diagnosing, or predicting neurological events from EEG signals, in accordance with some embodiments of the present specification;

**[0051]** FIG. 3 is a block diagram illustrating an amplifier used for amplifying EEG signals recorded from a patient's brain, in accordance with an embodiment of the present specification;

**[0052]** FIG. 4A is a block diagram illustrating a system comprising a plurality of amplifiers synchronized operatively for amplifying EEG signals recorded from a patient's brain, in accordance with an embodiment of the present specification;

**[0053]** FIG. 4B illustrates a block diagram of an EEG system incorporating a plurality of amplifiers, in accordance with an embodiment of the present specification; and

**[0054]** FIG. 5 is a flowchart illustrating the steps involved in a method of distributing a low frequency signal to a plurality of synchronized amplifiers to measure EEG signals, in accordance with an embodiment of the present specification.

#### DETAILED DESCRIPTION

**[0055]** The present specification enables synchronization of EEG data between two or more amplifiers using a low frequency synchronizing signal that is shared using low power circuits and standard cables. By using the method of the present specification, electromagnetic interferences are filtered out since the frequencies of the low speed shared signal and of the interferences do not overlap.

**[0056]** In various embodiments, the present specification provides a simple and low cost method of synchronizing the data acquisition of multiple amplifiers during EEG monitoring. This method eliminates the need for distributing data

from a high speed clock to each of the multiple amplifiers, thereby eliminating the need for high power consumption and specialized components/cables.

**[0057]** In an embodiment, the method of the present specification comprises distributing a low frequency clock among a plurality of amplifiers for synchronizing the data acquired by said amplifiers during EEG monitoring. The low frequency clock uses single ended circuitry and cabling whereby high frequency electromagnetic interference can be filtered out from the clock signal.

**[0058]** In various embodiments, the methods and systems of the present specification enable the synchronizing of a sample rate of EEG data acquired on different devices (amplifiers) with only a low frequency synchronizing signal. In some embodiments, a low frequency synchronizing signal is transmitted to the devices to be synchronized, wherein the term low frequency, in the context of a synchronizing signal, refers to a range of 0.1 Hz to 10 kHz, with a preferred range of 0.5 Hz to 2 Hz. It should be appreciated that the 0.5 Hz to 2 Hz range leads to a more accurate synchronization process. Each device measures the period of the synchronizing signal using an internal timer with microsecond resolution. The device then adjusts its microcontroller clock so that the expected number of ticks occurs between the low frequency synchronizing signal edges (for example, 1,000, 000). This is done by adjusting the voltage to an external voltage-controlled oscillator in finite steps using a digital to analog converter (DAC) internal to the microcontroller. These adjustments can continue, to counter clock drift over time, in order to maintain synchronization.

**[0059]** A “computing device” is at least one of a cellular phone, PDA, smart phone, tablet computing device, patient monitor, custom kiosk, or other computing device capable of executing programmatic instructions. It should further be appreciated that each device and monitoring system may have wireless and wired receivers and transmitters capable of sending and receiving data. Each “computing device” may be coupled to at least one display, which displays information about the patient parameters and the functioning of the system, by means of a GUI. The GUI also presents various menus that allow users to configure settings according to their requirements. The system further comprises at least one processor to control the operation of the entire system and its components. It should further be appreciated that the at least one processor is capable of processing programmatic instructions, has a memory capable of storing programmatic instructions, and employs software comprised of a plurality of programmatic instructions for performing the processes described herein. In one embodiment, the at least one processor is a computing device capable of receiving, executing, and transmitting a plurality of programmatic instructions stored on a volatile or non-volatile computer readable medium. In addition, the software comprised of a plurality of programmatic instructions for performing the processes described herein may be implemented by a computer processor capable of processing programmatic instructions and a memory capable of storing programmatic instructions.

**[0060]** “Electrode” refers to a conductor used to establish electrical contact with a nonmetallic part of a circuit such as a patient’s body. EEG electrodes are small metal discs, grids, strips or cylinders usually made of stainless steel, platinum, tin, gold or silver covered with a silver chloride coating. They are typically placed on the scalp on predetermined

locations but may also be placed as intracranial electrodes directly on the surface of the brain or implanted into the brain to record electrical activity from the cerebral cortex.

**[0061]** An “electrode grid” is a thin sheet of material with multiple small (roughly a couple mm in size) recording electrodes implanted within it. These are placed directly on the surface of the brain and have the advantage of recording the EEG without the interference of the skin, fat tissue, muscle, and bone that may limit scalp EEG. Shapes and sizes of these sheets are chosen to best conform to the surface of the brain and the area of interest.

**[0062]** A “depth electrode” refers to small wires that are implanted within the brain itself. Each wire has electrodes which surround it. These electrodes are able to record brain activity along the entire length of the implanted wire. They have the advantage of recording activity from structures deeper in the brain. They can be implanted through small skin pokes.

**[0063]** The present specification is directed towards multiple embodiments. The following disclosure is provided in order to enable a person having ordinary skill in the art to practice the invention. Language used in this specification should not be interpreted as a general disavowal of any one specific embodiment or used to limit the claims beyond the meaning of the terms used therein. The general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the invention. Also, the terminology and phraseology used is for the purpose of describing exemplary embodiments and should not be considered limiting. Thus, the present invention is to be accorded the widest scope encompassing numerous alternatives, modifications and equivalents consistent with the principles and features disclosed. For purpose of clarity, details relating to technical material that is known in the technical fields related to the invention have not been described in detail so as not to unnecessarily obscure the present invention.

**[0064]** In the description and claims of the application, each of the words “comprise” “include” and “have”, and forms thereof, are not necessarily limited to members in a list with which the words may be associated. It should be noted herein that any feature or component described in association with a specific embodiment may be used and implemented with any other embodiment unless clearly indicated otherwise.

**[0065]** As used herein, the indefinite articles “a” and “an” mean “at least one” or “one or more” unless the context clearly dictates otherwise.

**[0066]** FIG. 1 shows a block diagram of a conventional medical system **100** comprising a large number of electrodes deployed on the body of a patient **102**. The medical device **101** represents a conventional neuromonitoring medical system, such as an EEG (electroencephalography) system, which comprises a large number of electrodes for monitoring a neurological state of a patient for diagnosis and preventive treatment of certain diseases and for monitoring patients during anesthesia, among other procedures. As shown in FIG. 1, the medical device **101** is coupled to the patient **102** through a plurality of electrical leads **103** such that each of the leads **103** is coupled to an electrode (not shown) positioned at an appropriate location on the body of the patient **102**.

**[0067]** FIG. 2 illustrates an electroencephalography (EEG) system **200** for detecting, diagnosing, or predicting

neurological events from EEG signals, in accordance with some embodiments of the present specification. The figure shows a plurality of EEG sensors or electrodes 205 spatially positioned on a layer of tissue such as the scalp of a patient 215. In other embodiments, the plurality of electrodes is positioned intracranially, directly on the brain. For example, in some embodiments, the plurality of electrodes is placed on the brain by skull resection or via burr holes. The plurality of electrodes 205 are electrically connected with a multi-channel amplifier 220 that is in data communication with a computing device 240. The computing device 240 is in data communication with a display unit 230 and at least one database 235.

[0068] In various embodiments, the plurality of electrodes 205 are small metal discs, strips, grids, and/or cylinders typically made of stainless steel, platinum, tin, gold or silver covered with a silver chloride coating. The plurality of electrodes 205 sense electrical signals (EEG signals) from the patient's brain and conduct the analog signals over an electrical connection link to the multi-channel amplifier 220 that amplifies the signals, converts the signals from an analog EEG data set to a digital EEG data set, and communicates the resultant digital EEG signal to the computing device 240 over a communication link. In embodiments, the communication link may be wired or wireless links. In various embodiments, more than one amplifier 220 may be used for acquiring and amplifying the voltage sensed by the electrodes 205 in the EEG system.

[0069] The computing device 240 includes an input/output controller, at least one communications interface and system memory. The system memory includes at least one random access memory (RAM) and at least one read-only memory (ROM). These elements are in communication with a central processing unit (CPU) to enable operation of the computing device 240. In various embodiments, the computing device 240 may be a conventional standalone computer or alternatively, the functions of the computing device 240 may be distributed across multiple computer systems and architectures. For example, in a distributed architecture, the at least one database 235 and processing circuitry are housed in separate units or locations. Some units perform primary processing functions and contain at a minimum a general controller or a processing circuitry and a system memory.

[0070] The computing device 240 executes EEG software 245 that implements a plurality of programmatic instructions or code to process, store, retrieve and display, on the display unit 230, the patient's EEG data. In embodiments, the EEG software 245 processes the received digital EEG signals, extracts parameters that characterize the EEG data, and generates a display of the data for a user. The processed EEG data is either displayed on the display unit 230 in real-time or stored in at least one database 235 for later analyses.

[0071] In some embodiments, execution of sequences of programmatic instructions enables or causes the CPU to perform various functions and processes. In alternate embodiments, hard-wired circuitry may be used in place of, or in combination with, software instructions for implementation of the processes of systems and methods described in this specification. Thus, the systems and methods described are not limited to any specific combination of hardware and software.

[0072] FIG. 3 is a block diagram illustrating an amplifier 300 used for amplifying EEG signals recorded from a patient's brain, in accordance with an embodiment of the

present specification. The amplifier 300 comprises a microcontroller 302, a voltage controlled oscillator 304, an analog-to-digital converter (ADC) 306 and a low pass filter 308. As shown, EEG analog signals 310 recorded from a patient's brain by using a plurality of EEG electrodes are transmitted to the ADC 306 which converts the input analog signals to digital signals for output to the microcontroller 302. The microcontroller 302 controls the operation of the voltage controlled oscillator 304 by controlling the voltage on the DAC output 307, thereby adjusting the frequency of the voltage controlled oscillator 304 to a predefined frequency. More specifically, the microcontroller 302, at the DAC output 307, modulates the voltage amplitude and/or frequency which, in turn, controls the frequency at which the voltage controlled oscillator 304 oscillates. The microcontroller 302 controls the ADC 306 by generating the clock and start signals of the ADC 306. The microcontroller 302 bases the control of the voltage control oscillator 304 and the ADC 306 on the input timer/frequency 301. The low pass filter 308 filters out high frequency noise above 2 kHz on the analog voltage from the microcontroller DAC output 307 so as to provide a useful DC signal input 311 to the oscillator 304 thereby enabling the oscillator 304 to produce a stable oscillator frequency at an oscillator (OSC) input 309 of the microcontroller 302.

[0073] FIG. 4A is a block diagram illustrating a system 400 comprising a plurality of amplifiers synchronized operatively for amplifying EEG signals recorded from a patient's brain, in accordance with an embodiment of the present specification. Each of the plurality of amplifiers 402a through 402n comprises a signal isolator 405, a microcontroller 406, a voltage controlled oscillator 408, an analog to digital converter 410 and a low pass filter 412. As shown, a low frequency oscillator 401 provides a low frequency synchronizing signal which is distributed to each of the plurality of amplifiers 402a through 402n that operate in conjunction to amplify and digitize intracranial EEG signals. In some embodiments, the synchronizing signal has a frequency in a range of 0.1 Hz to 10 kHz, more preferably in a range of 0.5 Hz to 2 Hz, and most preferably around 1 Hz.

[0074] In some embodiments, the low frequency oscillator 401 is external to the amplifiers 402a through 402n. Each signal isolator 405, associated with each of the plurality of amplifiers 402a through 402n, electrically isolates each of the plurality of amplifiers 402a through 402n from ground. In some embodiments, each signal isolator 405 comprises isolated DC-DC power converters and provides an isolation barrier over which a low frequency signal can be easily coupled. Each voltage controlled oscillator 408 provides a master clock to the microcontroller 406 of its respective amplifier. In various embodiments, any synchronizing signal frequency may be provided by the low frequency oscillator 401. However, a synchronizing signal frequency lower than 1 Hz increases the time taken to synchronize the signal while a synchronizing signal frequency higher than 1 Hz requires more microcontroller resources.

[0075] In embodiments, cables 403 are used to supply the synchronizing signal from the low frequency oscillator 401 to each of the plurality of amplifiers 402a through 402n. In an embodiment, the synchronizing signal is carried by a 28AWG cable/conductor. In alternate embodiments, cables having other AWG values may also be used.

[0076] During operation, a microcontroller 406 of each of the amplifiers 402a through 402n receives the 1 Hz syn-

chronizing signal from the low frequency oscillator 401 via a timer input 407 and measures the period of the 1 Hz synchronizing signal using an internal timer. In some embodiments, the internal timer measures the period of the 1 Hz synchronizing signal with microsecond resolution. The microcontroller 406 then adjusts an operational frequency of the voltage controlled oscillator 408 by setting its internal DAC to a voltage value within a predefined range until the measured period of the synchronizing signal at timer input 407 matches a defined timer count based on the expected period of the synchronizing signal.

[0077] In some embodiments, the synchronization signal is a square wave with a frequency of 1 Hz and 50% duty cycle (high for half of the period, low for half of the period). The square wave is defined by “signal edges” referring to the rising edges of the square wave. Alternatively, “signal edges” may also refer to the falling edges of the square wave. In embodiments, one million “ticks” occur in a timer since a previous 1 Hz sync edge. In embodiments, if a timer is operated with microsecond resolution and the value of the timer is captured at each rising edge of the 1 Hz synchronization signal, one would expect a delta of 1,000,000 between consecutive timer captures since there are 1,000,000 microseconds in 1 second (1 Hz). Since the voltage controlled oscillator 408 is providing the master clock to the microcontroller 406, adjusting the operational frequency of the voltage controlled oscillator 408 will adjust the frequency of all microcontroller clocks and timing signals produced by the microcontroller 406. The microcontroller 406 adjusts the operational frequency of the voltage controlled oscillator 408 by setting the internal DAC of the microcontroller 406 to a certain voltage value which is then sent to the voltage controlled oscillator 408 by the microcontroller 406. In embodiments, to maintain synchronization, the adjustments of the operational frequency of the voltage controlled oscillator 408 continue as the clocks drift over time and temperature. In some embodiments, the internal DAC of the microcontroller 406 is set to a voltage value in a range of 0 to 3.3 V.

[0078] Thereafter, the operational frequency of the voltage controlled oscillator 408 is divided by the microcontroller 406 to produce clock and ‘convert start’ signals of the analog to digital converter (ADC) 410. Both the clock and ‘convert start’ signals determine the sample rate and timing of the analog to digital conversion within the ADC 410. Thus, the ADC 410 is synchronized to the 1 Hz signal.

[0079] Each microcontroller 406 in each of the other amplifiers 402 $n$  adjusts the frequency of its associated voltage controlled oscillator so that its frequency is identical to the frequency of the voltage controlled oscillator 408. In some embodiments, the voltage controlled oscillator 408 can be adjusted after multiple 1 Hz synchronizing signal periods or at any other frequency interval that results in a desired accuracy of synchronization of the amplifiers. For example, in an embodiment, the microcontroller 406 counts, using its internal timer, the number of microsecond ticks that occur over four 1 Hz synchronizing signal periods and adjust its clock until it reaches the desired count. This allows for greater accuracy of synchronization but with a tradeoff of more time elapsed to reach synchronization.

[0080] Without the voltage controlled oscillator 408, the use of low frequency synchronizing signal is restricted to an accuracy of approximately 10  $\mu$ sec of synchronization using calculations done on a host PC system for time-stamped data

and stimulations. The microcontroller clocks are allowed to drift in this timing scheme with the host PC correcting the timestamps for the calculated drift. With the addition of the voltage controlled oscillator 408 and the method of measuring and compensating for oscillator inaccuracy, synchronization better than 1  $\mu$ sec is achieved at the microcontroller clock level. This tighter frequency accuracy is necessary to avoid beat frequencies.

[0081] FIG. 4B illustrates a block diagram of an EEG system incorporating a plurality of amplifiers, in accordance with an embodiment of the present specification. Referring to FIG. 4B, a plurality of 128 channel amplifiers 450 receive input EEG signals via 128x4 electrode wires captured by a plurality of electrodes 452 connected to a patient. Digitized and amplified signals travel via a plurality of power/signal synchronization cables 454 between each of the plurality of amplifiers 450. A first power/signal synchronization cable 455 carries the digitized and amplified signal communicated between each of the plurality of amplifiers 450 to a power unit comprising a low frequency oscillator 456 which is used to synchronize the signals received from the plurality of amplifiers 450. The synchronized signals are transferred via data cables 458 to a computing device 460 (similar to computing device 240 described with reference to FIG. 2A) and are displayed for analysis on a display device 462 coupled with the computing device 460.

[0082] FIG. 5 is a flowchart illustrating a plurality of exemplary steps involved in a method of distributing a low frequency signal to a plurality of amplifiers for synchronization and to measure EEG signals, in accordance with an embodiment of the present specification. At step 502, a low frequency oscillator of an EEG monitoring system of the present specification distributes a low frequency synchronizing signal to a plurality of amplifiers that are in data communication with the low frequency oscillator. In some embodiments, the low frequency synchronizing signal is a 1 Hz synchronizing signal.

[0083] At step 504, a microcontroller in each of the plurality of amplifiers measures a period of the low frequency synchronizing signal using an internal timer. In some embodiments, the internal timer measures the period of the low frequency synchronizing signal with microsecond resolution. The microcontroller then adjusts an operational frequency of a voltage controlled oscillator of the amplifier by setting an internal DAC of the microcontroller to a voltage value, at step 506, until the measured period of the low frequency synchronizing signal matches a timer count based on the expected period of the low frequency synchronizing signal. At step 508, the microcontroller sends the voltage value of the internal DAC to the voltage controlled oscillator to enable the voltage controlled oscillator to produce a stable frequency to at an oscillator (OSC) input of the microcontroller.

[0084] At step 510, the adjusted operational frequency of the voltage controlled oscillator is divided by the microcontroller to produce clock and convert start signals of an analog to digital converted (ADC) of the amplifier. Finally, at step 512, each microcontroller in each of the other amplifiers (of the plurality of amplifiers) adjusts the frequency of its associated voltage controlled oscillator so that the frequency of each voltage controlled oscillator of each amplifier of the plurality of amplifiers is identical. In some embodiments, the frequency adjustment occurs at twice the low frequency

synchronizing signal or at any interval that will result in the desired accuracy of synchronization of the amplifiers.

[0085] The above examples are merely illustrative of the many applications of the system and method of present specification. Although only a few embodiments of the present specification have been described herein, it should be understood that the present specification might be embodied in many other specific forms without departing from the spirit or scope of the specification. Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive, and the specification may be modified within the scope of the appended claims.

We claim:

1. A system for monitoring EEG signals comprising: a plurality of EEG sensors positioned on a layer of tissue for capturing EEG signals of a patient; at least one amplifier coupled to each of the plurality of EEG sensors, wherein the at least one amplifier is configured to amplify the captured EEG signals; and a first oscillator configured to generate a synchronizing signal; wherein the at least one amplifier comprises:
  - an input for receiving the synchronizing signal transmitted from the first oscillator;
  - a second oscillator;
  - an analog to digital converter coupled with the second oscillator and configured to digitize the captured EEG signals; and
  - a microcontroller configured to control a frequency of the second oscillator and an operation of the analog to digital converter (ADC) based on the synchronizing signal.
2. The system of claim 1, wherein the first oscillator is configured to generate the synchronizing signal having a frequency in a range of 0.1 Hz to 10 kHz.
3. The system of claim 1, wherein the second oscillator is voltage controlled.
4. The system of claim 1, wherein the plurality of EEG sensors are configured to monitor intracranial EEG signals.
5. The system of claim 1, further comprising a computing device in data communication with the plurality of amplifiers for processing the amplified EEG signals.
6. The system of claim 5, further comprising a display in data communication with the computing device for displaying the amplified EEG signals.
7. The system of claim 1, wherein the input comprises a signal isolator configured to receive the synchronizing signal.
8. The system of claim 7, wherein the signal isolator comprises one or more isolated DC-DC power converters.
9. The system of claim 1, wherein the synchronizing signal has a frequency of 1 Hz.
10. The system of claim 1, wherein the microcontroller comprises a digital to analog (DAC) converter and wherein the microcontroller is configured to adjust the second oscillator by setting the DAC to a corresponding voltage.
11. The system of claim 1, wherein the at least one amplifier further comprises an internal timer and wherein the microcontroller is configured to measure the period of the synchronizing signal using the internal timer.
12. The system of claim 11, wherein the internal timer has a resolution in a microsecond numerical range.
13. The system of claim 1, wherein the at least one amplifier further comprises a filter configured to filter out

high frequency noise present in an analog voltage transmission from the microcontroller, wherein the high frequency noise has a frequency greater than 2 kHz.

14. The system of claim 1, wherein the at least one amplifier comprises at least one unique amplifier in dedicated data communication with each of the plurality of EEG sensors.

15. A method for synchronizing EEG signals measured by an EEG monitoring system, wherein the EEG monitoring system comprises a plurality of EEG sensors positioned on a layer of tissue and wherein each of the plurality of EEG sensors is configured to capture EEG signals of a patient, at least one amplifier coupled to each of the plurality of EEG sensors and configured to amplify the captured EEG signals, and a first oscillator, wherein the at least one amplifier comprises an input for receiving a synchronizing signal from the first oscillator, the method comprising:

- distributing the synchronizing signal from the first oscillator to each of the at least one amplifier;
- measuring a period of the synchronizing signal;
- adjusting a second oscillator, having a frequency, in the at least one amplifier to match a timer count based on the period of the synchronizing signal;
- determining a function of the frequency of the second oscillator frequency to produce a clock signal; and
- adjusting a frequency of each of the second oscillators such that the frequencies of the second oscillators are identical.

16. The method of claim 15, wherein the first oscillator is configured to generate the synchronizing signal having a frequency in a range of 0.1 Hz to 10 kHz.

17. The method of claim 15, wherein the second oscillator is voltage controlled.

18. The method of claim 15, wherein the function of the frequency of the second oscillator frequency is determined by dividing the frequency to produce the clock signal.

19. The method of claim 18, further comprising using the clock signal to drive the analog to digital converter clock signal.

20. The method of claim 18, wherein the at least one amplifier comprises the second oscillator, the analog to digital converter coupled to the second oscillator and configured to digitize the captured EEG signals, and a microcontroller configured to control the frequency of the second oscillator and an operation of the analog to digital converter based on the synchronizing signal.

21. The method of claim 20, wherein the microcontroller comprises a signal isolator and wherein the signal isolator comprises isolated DC-DC power converters.

22. The method of claim 15, further comprising transmitting the amplified EEG signals to a computing device, wherein the computing device is configured to process the amplified EEG signals.

23. The method of claim 15, wherein the synchronizing signal has a frequency of 1 Hz.

24. The method of claim 15, wherein the microcontroller includes a digital to analog (DAC) converter and wherein the microcontroller is configured to adjust the second oscillator by setting the DAC to a corresponding voltage.

25. The method of claim 15, wherein the at least one amplifier further comprises an internal timer having microsecond resolution and wherein the microcontroller is configured to measure a period of the synchronizing signal using the internal timer.

26. The method of claim 15, wherein the at least one amplifier further comprises a filter configured to filter out high frequency noise, having a value range greater than 2 kHz, present in an analog voltage signal from the micro-controller output.

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摘要(译)

一种用于监测的系统，包括：在空间上位于组织层上的多个EEG传感器，用于捕获患者的EEG信号；以及 与EEG传感器耦合的多个放大器，用于放大捕获的信号；低频振荡器，用于产生同步信号，该同步信号分配给放大器，以使捕获信号的数字化同步。其中每个放大器包括：用于可调频率基准的压控振荡器；以及 模数转换器，用于将放大后的信号转换为数字值；微控制器通过使用同步信号来控制压控振荡器的频率和模数转换器的操作。

