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[21] Appl. No. **819,083**
 [22] Filed **Apr. 24, 1969**
 [45] Patented **Dec. 21, 1971**

Continuation-in-part of application Ser. No. 651,864, July 7, 1967, which is a continuation-in-part of application Ser. No. 592,582, Nov. 7, 1966, now abandoned. This application Apr. 24, 1969, Ser. No. 819,083

[51] Int. Cl. **G01t 1/15**
 [50] Field of Search **250/71.5,**
83.3, 106, 83.6; 58/23

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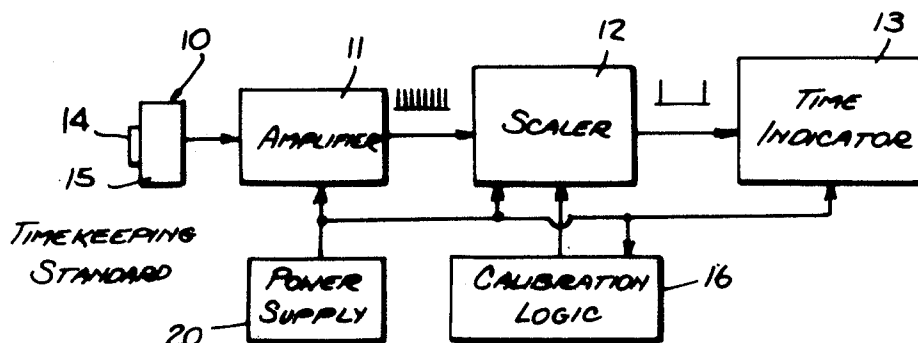
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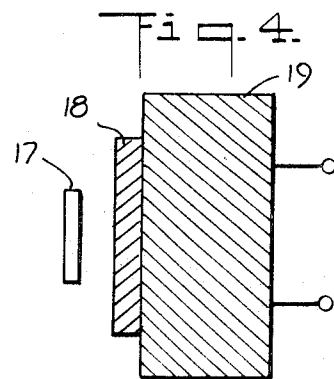
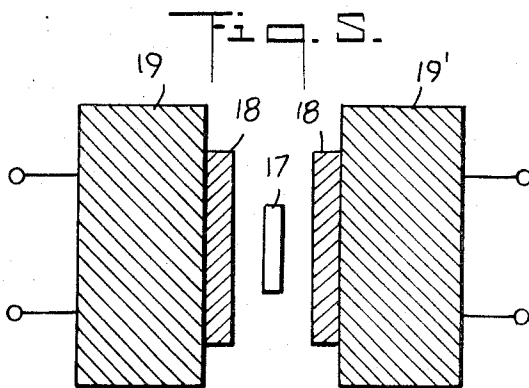
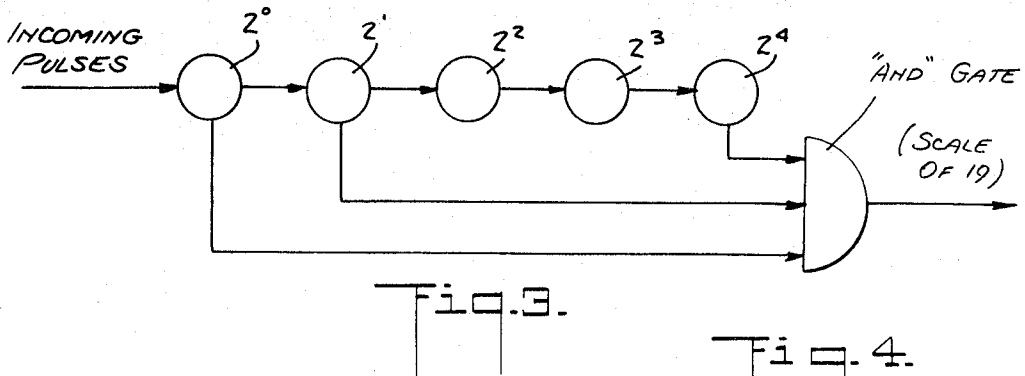
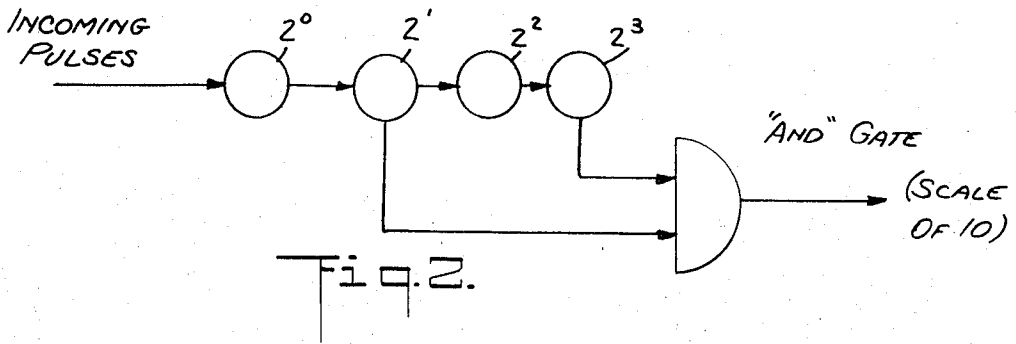
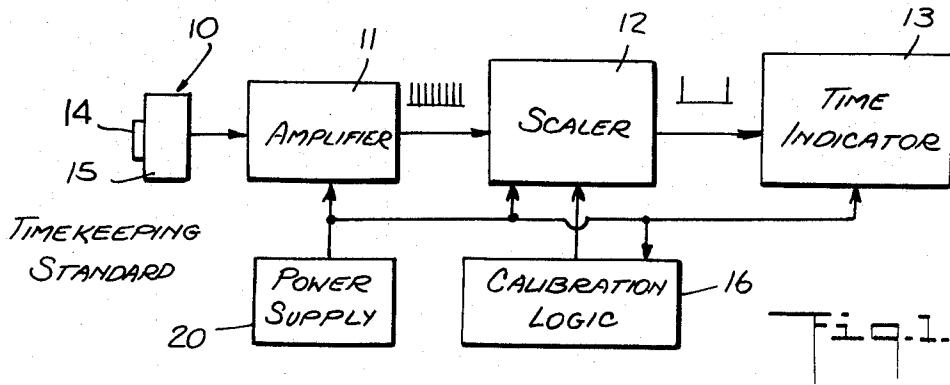
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[54] **TIMEPIECE WITH RADIOACTIVE TIMEKEEPING STANDARD**
16 Claims, 5 Drawing Figs.

[52] U.S. Cl. **250/71.5,**
58/23, 250/83.3, 250/106

ABSTRACT: A timepiece wherein the frequency standard takes the form of a radioactive source having a prolonged half-life, the alpha particulate emanations from the source being converted into electrical pulses, the pulses then being scaled down to produce low-frequency control pulses at a constant rate, which operate a time indicator.





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TIMEPIECE WITH RADIOACTIVE TIMEKEEPING STANDARD

RELATED APPLICATION

This application is a continuation-in-part of the application Ser. No. 651,864, filed July 7, 1967, which in turn is a continuation-in-part of application Ser. No. 592,582, filed Nov. 7, 1966 (now abandoned).

BACKGROUND OF INVENTION

This invention relates generally to timekeeping systems, and more particularly to an electronic timepiece wherein particulate emanations from a radioactive source are converted into electrical pulses, these pulses being scaled down to produce control pulses for operating a time indicator.

The era of modern timekeeping, which begins with the use of periodic processes for time measurement, may be traced directly to Galileo's discovery of the isochronism of the pendulum. In the earliest clocks, a pendulum functioned as the frequency standard for controlling the movement of the gear train. When it was later found that a balance wheel turning against a spring also had a constant period, it became possible to reduce the size of a clock and also to produce watches.

The extent to which errors inherent in pendulums and balance wheels can be minimized is subject to practical limitations, and in the search for higher orders of accuracy, other forms of frequency standards have recently been developed. At present, the most accurate timekeeper is the atomic clock, which exploits various periodic processes in atoms and molecules. Such clocks are capable of accuracies in the order of one part in 10^{12} . However, the great complexity and high cost of an atomic clock, precludes its use for other than laboratory purposes and in special applications.

A high degree of accuracy is also obtainable with piezoelectric crystal-controlled timepieces. With proper temperature control, a crystal is capable of generating high-frequency oscillations at a substantially constant rate. By the use of frequency dividers, one is able to derive low-frequency pulses which may be used to synchronize or actuate a time display device. But size limitations and other factors render the crystal-controlled system unsuitable for wristwatches.

The most accurate time keeper commercially available in wristwatch size is the tuning-fork type. The tuning fork is sustained in vibration at its natural frequency by a transistor-controlled, electromagnetic drive arrangement, the vibrations of the fork being converted into rotary motion to operate the time-indicating hands. Such timekeepers, sold under the trademark ACCUTRON, have an accuracy of about one part in $4(10^4)$.

Features other than accuracy which are desirable in a timekeeping system are relative immunity to environmental factors such as altitude, gravity and shock. These factors can be important in influencing the timekeeping ability of the system as well as the reliability of the system. Tuning fork timepieces are by no means immune from environmental factors.

BRIEF DESCRIPTION OF INVENTION

Accordingly, it is the main object of this invention to provide a timekeeping system based on radioactivity from an alpha source and capable of miniaturization both physically and electrically.

A salient feature of the invention is that the system has accuracies competitive with existing devices representing the present state of the art in practical timepieces of miniature size, the system furthermore being very rugged and insensitive to environmental factors.

Attempts have heretofore been made to exploit radioactivity as a time reference. Thus in the clock manufactured by Associated Nucleonics, Inc. and installed in the Chase Manhattan Bank Building in New York City, a Geiger tube acts to detect gamma rays emitted by a Cesium-137 source and to send electrical pulses to a counting circuit which totalizes these pul-

ses. When a preset number of pulses is reached, a single control pulse is fed to a relay which advances an electromechanical impulse clock. Because Cesium-137 has a short half-life (30 years), a device operating on this principle is highly inaccurate, it does not lend itself to miniaturization, and it is not usable within the confines of a watch. Moreover, gamma radiation presents a serious hazard which can be overcome only by heavy shielding. Such shielding is not feasible in the confines of a small timepiece. For this reason and various others, a gamma-ray based system in miniaturized form is not feasible.

The U.S. Pat. to Lazrus et al. No. 3,370,414 discloses a time reference based on beta radioactivity. However, while beta sources yield a radioactive emanation not as penetrating as gamma rays, beta particles are nevertheless more penetrating than alpha particles and consequently require thicker detectors with their associated prohibitive electrical requirements. Furthermore, the beta particles emerge with a continuum of energies further aggravating the associated electronic requirements. As will be demonstrated hereinafter in greater detail, the problems associated with a beta based timekeeping system are such as to make it inferior (if feasible) to an alpha based system.

More particularly, therefore, it is an object of the invention to provide a timekeeper using an alpha particle radioactive source as a timekeeping standard, particulate emanations from the source being converted by a solid-state detector into electrical pulses which are then scaled down to produce control pulses for actuating a time-indicator.

Also an object of the invention is to provide a scaler which may readily be calibrated to produce a scale ratio appropriate to a given radioactive mass.

Briefly stated, these objects are attained in a timekeeping system in which the timekeeping standard is constituted by a radioactive source having a relatively long half-life and producing alpha particle emanations, the source operating in conjunction with a solid-state detector responsive to the alpha particle emanations to generate a number of electrical pulses per second, the pulses being scaled down to produce a low number of control pulses such as one per second, which control pulses are applied to an electronic or electromechanical time register to actuate or control same to indicate time.

BRIEF DESCRIPTION OF DRAWINGS

For a better understanding of the invention, as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawing, wherein:

FIG. 1 is a block diagram of a timekeeping system in accordance with the invention;

FIG. 2 is a diagram of one form of binary scaler in accordance with the invention;

FIG. 3 is a diagram of another form of binary scaler;

FIG. 4 is a schematic illustration of a preferred embodiment of a detector; and

FIG. 5 is a schematic illustration of another detector embodiment.

DESCRIPTION OF INVENTION

"Radioactivity" is the term applied to the spontaneous disintegration of atomic nuclei. Of the various properties possessed by radioactive substances, emitted radiations merit special consideration.

A nucleus that is unstable with respect to its size will emit alpha particles which are positively charged. These particles are shot off from the interior of the atoms of certain elements with a definite velocity and a definite range for each element. The range is the distance traversed in a homogeneous medium before absorption and is a function of among other parameters, the cube of the velocity. Alpha particles are only slightly deflected by electrical and magnetic fields, these particles being nuclei of helium carrying two-unit positive charges. The

loss of a single alpha particle by an atom leaves the residual atom four units less in mass number and two units less in atomic number.

A nucleus which is unstable with respect to its neutron-proton ratio may emit negatively charged beta particles, whereas if it is unstable with respect to its total energy, the excess energy may be given off as gamma radiation. Beta particles are electrons with a mass $1/1,800$ of that of the hydrogen atom and are deflected by electric and magnetic fields, whereas gamma rays are similar to X-rays but more penetrating, they constitute electromagnetic wave energy, and are undeflected by electric and magnetic fields.

The rate of radioactive decay is proportional to the amount of material present. This is expressed by the equation $A=N\lambda$, where A is the disintegration rate, N the number of atoms present in the material, and λ the proportionality constant characteristic of each radioactive species.

The time required for one half of the atoms in a given material to decay, is called the half-life. If the half-life of a given material is in the order of 10^6 years, then by the end of one year the decay rate decreases by approximately one part in 10^6 . Thus in long-lived natural or artificial radioactivity there exists a repetitive phenomenon which is virtually constant with time and is therefore suitable for timekeeping. The change in rate, over, say, a 5 to 10-year period, is so miniscule as to be insignificant for timekeeping purposes.

The statistical nature of the decay process must now be considered. Given a true mean decay rate, m per year, the standard fractional error in an actual measurement of m is one part in $\sqrt{m}$. If therefore the source rate m is large, the statistical uncertainty given by $1/\sqrt{m}$ is very small. Thus in using the statistical process of radioactive decay for timekeeping purposes, one needs "good" statistics. This may be attained by simply controlling the amount or number of radioactive atoms present in the timekeeping source.

In order to attain an accuracy tantamount to that of a tuning fork timepiece, that is about one part in $4(10)^4$, the requisite mean activity is $16(10)^8$ per year. This is approximately 50 per second or about 0.001 to 0.002 microcuries of radioactivity (the unit of activity, one curie = $3.7(10)^{10}$ disintegrations per second). Using such a source and looking at the uncertainty in an interval of a second, we are led to an accuracy of one part in $\sqrt{50}$ or about one part in 7. Hence while we have an accuracy over a period of a year equal to one part in $4(10)^4$, over a second interval the accuracy is one part in 7.

If therefore we raise the counting rate to $5(10^3)$ per second, we decrease the uncertainty and now have an accuracy for each second of one part in $\sqrt{5}(10)^3$ or one part in 70. Similarly, over a year period, with this increased counting rate, one would have a similar decrease in uncertainty of one part in $4(10)^5$.

Particles emerging from a nucleus have an energy level in the mev. range (million electron volt), whereas the kinetic energies of atoms at room temperatures are 0.025 electron volts. Thus the processes of radioactive decay are eight orders of magnitude more energetic than thermal energies, and are altogether independent of temperature. This factor is of importance in a timepiece subject to changes in ambient temperatures. Moreover environmental factors such as gravity, altitude, attitude, magnetism and shock have no influence whatever on the decay rate. While the electronic circuits associated with the radioactive source may be dependent on these factors, the decay process itself is immune therefrom.

Referring now to Fig. 1, there is shown a basic timekeeping system in accordance with the invention, the system comprising a radioactive timekeeping standard, generally designated by numeral 10, an amplifier 11, a scaler 12 and a time register or indicator 13.

Timekeeping standard 10 is constituted by a radioactive mass 14 of predetermined weight which is deposited onto the face of a solid state detector 15, which in turn produces electrical impulses corresponding in number to the particles emitted by the mass. This radioactive source may for example

be PLUTONIUM-242 with a half-life of $3.79(10)^5$ years or URANIUM-233 with a half-life of $1.62(10)^5$ years.

Preferably the source is NEPTUNIUM-237 with a half-life of $2.2(10)^6$ years. With this radioactive material, the change in the emission rate at the end of the year would be one part in $3.1(10)^6$. Thus the frequency standard, would be effectively invariant with time to a degree corresponding to an accuracy for the system of the order of one part in 10^6 . In one working embodiment, the mass can be about 10 micrograms deposited on the face of a solid-state detector of 50 mm.^2 face area with a thickness of 200 microns.

Solid-state detector 15 may be of the diffused junction, silicon surface barrier type, or a transistor counter, all being extremely high resolution devices. That is, the uncertainty in the signal pulse $\Delta \nu$ divided by the magnitude of the signal pulse ν is less than 1 percent, and the signal magnitude itself is two orders of magnitude greater than the noise level (e.g., for natural radioactive alpha emitters).

In the solid-state detector, an electric field is set up across a semiconducting medium of low electrical conductivity. Usually the low conductivity region is the charge depletion region in a semiconductor diode operating at reverse bias. The thickness, or width, of this depletion region is a function of the voltage across the junction, to the one-half power. This voltage is the sum of the built-in potential difference existing across the junction interface, arising from the formation of a space charge related to the relative density of the holes on the two sides of the junction, and the applied (external) reverse bias. Typical values of this built-in potential difference are of the order of 0.5 volt. When a charged particle passes through the semiconductor, electron hole pairs are produced therein. The charges are caused to separate by the electric field, and the resultant signal in the output of the detector reflects the presence and energy of the impinging particle.

For a more detailed discussion of semiconductive radiation detectors reference is made to "Nuclear Radiation Detection" by W. J. Price—McGraw-Hill Book Co. Inc. 1964. In addition to high resolution, these detectors have other important properties including linearity of pulse height vs. energy, and very rapid response time as well as insensitivity to magnetic fields. From a total system standpoint, the main desideratum is that the signal at each stage be as large as possible and that a minimum amount of power be consumed in achieving this end. Furthermore, it is desired that the electronics introduce no extraneous electrical pulses into the counting process.

Let us look again at radiation detector 15. When the source particles are incident to the detector, the electrical pulses of current produced are very minute in magnitude. They therefore must be amplified to be of use in carrying out mechanical or electronic functions, for example, in a binary counting circuit. However, the amplification factor (gain) of any known electronic amplifier is not an unchanging parameter but rather is a constantly varying quantity, subject to variations in temperature, battery voltage and other variables. Now, in alpha decay, the radioactive nucleus has a fixed single-valued energy which is imparted to the alpha particle at the instant of decay. In beta decay, the radioactive nucleus also has a fixed single-valued energy, but because the beta decay process consists of the emission of a neutrino along with the electron (beta particle), there is an infinite number of ways in which this radioactive energy can be shared between the neutrino and the beta particle. Therefore, the beta particles emerge with a continuum of energies from zero energy up to a maximum energy, which maximum is the fixed single-valued energy of the parent radioactive nucleus.

Referring again to the counting circuit, there is inherent in its operation, by design or otherwise, a voltage threshold sensitivity, that is to say a voltage level below which an electrical pulse if fed into the counter will not be counted by the counter. If designed into the system we have what is called a discriminator. One of the counting problems associated with a beta source then becomes clear. Because of this voltage threshold, all of the beta particle pulses will not be counted;

only those above the threshold. Since the varying gain of the amplifier causes a variation in the number of beta particle pulses above the threshold, an error is introduced into the counting rate as measured by the electronic counter. In other words, the timekeeping accuracy of a timekeeping system employing a beta source as the time base is largely dependent upon the degree to which the threshold of the counting system can be maintained constant, rather than upon the time base itself.

With a single-valued energy particle, as for alpha radiation, this problem is overcome. For example, with a one volt particle pulse and a 0.1 volt threshold sensitivity, a 50 percent change in threshold sensitivity from 0.1 volt to 0.15 volt will have no effect on the alpha counting rate since the alpha particle voltage pulse at 1 volt still exceeds the new threshold at 0.15 volt and will certainly be counted.

Another point of interest is related to the rate at which the particle loses, or gives up, its energy in the detector. The total distance a particle travels in a detector material before it comes to rest (i.e., gives up all of its energy) is proportional to its original energy and to the rate at which it loses energy. For a 1 mev., beta particle, for example, the range (distance traveled before coming to rest) in silicon is 2 millimeters, while for a 5 mev. alpha particle, the range in silicon is $2.8 (10)^{-1}$ millimeter. Now for a silicon semiconductor detector, the sensitive depth (the depth usable for detecting radiation) is a function of the voltage across the junction interface in the detector. If one uses for example, some of the purest silicon available (resistivity P-type) $=40,000\Omega\text{-cm.}$ it requires a voltage of 970 volts to achieve a depletion, or sensitive, depth of 2 millimeters. This is to be contrasted with 0.19 volts to achieve $2.8 (10)^{-2}$ millimeter sensitive depth. The 970 volts requirement is obviously a grossly impractical figure in the context of compact timepieces such as watches. The 0.19 volt, on the other hand, is so small that no external bias voltage is necessary at all because this potential difference is built into the detector.

It can be argued that one can use a lower-energy beta-particle source and thus achieve a smaller range and consequently a lower bias voltage requirement for total beta-energy detection. Let us look at this situation. If one chooses a range equal to that of the 5 mev. alpha particle the resultant beta particle of 0.060 mev. will come to rest in $2.8 (10)^{-2}$ millimeter of silicon. But now the signal to noise ratio problem comes to the fore.

In the best semiconductor detector systems there are present at any time in the material of the detector, free electrons generated primarily by thermal agitation, which give rise to electrical pulses which are called noise pulses in the detector output. These can be distinguished from the radiation electrical pulses only if they differ in magnitude from the signals generated by the radiation. If one has a good signal to noise ratio, the signal pulses (radiation pulses) are many times as large as the noise pulses and no confusion results. If, however, the signal pulses are comparable in magnitude to the noise pulses, the counting process becomes confounded. In this instance, since the noise pulses are counted along with the radiation pulses, the counting rate, which is our time measuring index, is subject to whatever variations the noise undergoes. Large errors are introduced and timekeeping radically deteriorates.

Referring to state of the art semiconductor detectors a low noise figure of 0.020 mev. is achievable. With such a noise figure the counting rate due to noise pulses at 0.040 mev. is 1,000 per minute. That is, at two-thirds of the above mentioned beta particle energy, 0.060 mev., there are present in the detector as many as 1,000 noise pulses per minute. Keeping in mind the continuous nature of the distribution of beta particle pulses one appreciates how the noise contributes to and confuses the pulse counting process. It seems clear that to eliminate the possibility of confusion by noise pulses one needs a threshold level of at least 0.060 mev. This level should be no more than approximately one third of the beta end point energy. In other words one would need a beta source of at

least 0.180 mev. end point energy. But the range of a 0.180 mev. beta particle is $1.50 (10)^{-1}$ millimeter requiring an applied voltage of 6 volts (a requirement of at least five 1.3 volt mercury cells). The alpha particle pulse on the other hand, at 5 mev., is 83 times as large as the threshold setting of 0.060 mev. and therefore can be quite readily distinguished from the noise. Again an alpha source is critical to the design of a workable timepiece.

Finally it should be pointed out that, on an absolute basis, the gain of the amplifying stage preceding the counter when using a beta source would have to have approximately 28 times the gain that one would need when using an alpha source due to the difference in energies: 5 mev. as opposed to 0.180 mev. The practicality considerations decidedly dictate an alpha source.

From the foregoing discussion it can be seen that the present invention constitutes an improvement over the known beta source system in at least the four following respects: (1) The detector bias supply for the alpha system, if necessary at all, can be supplied by a low voltage battery such as one whose voltage is 1.5 volts; (2) The nature of the alpha source spectrum results in a superior signal-to-noise ratio; (3) The alpha system allows much lower gain amplifiers; (4) The alpha source timekeeper results in a system which is insensitive to voltage threshold.

The pulse height of the output of detector 15, which is constituted by pulses equal in number to those emitted radioactive alpha particles impinging on the detector, is therefore increased in amplifier 11 to a level sufficient to trigger scaler 12. Scaler 12 may in practice consist of two-state binary stages in cascade relation, with as many stages are necessary to scale down the input pulse rate to the predetermined time stepping rate. Thus two input pulses must be applied to the first binary stage in order to activate it to apply a pulse to the next binary stage, and before the next stage can apply a pulse to the third stage two additional pulses must be applied to the first stage, and so on. In practice, relatively elaborate scalers can be made by micromodule or integrated circuit techniques using transistors to provide a self-contained miniature unit which may be accommodated within the confines of a watch casing.

Scaler 12 produces at its last output stage a single output pulse for a predetermined number of input pulses from the amplifier. This output pulse is applied to the register 13, which may be any pulse-actuated device adapted to provide a visual or other indication of time. Thus the register may be an electromagnetic stepping device which operates time indicating hands or an electronic display device. In practice, scaler 12 may be arranged to yield one pulse per second or a fraction thereof. The invention is by no means limited to binary scalers and other types, such as 10 or 12 state devices, may be used to reduce the number of stages necessary.

The actual number of pulses at the input of the scaler required to produce an output pulse is determined by calibrating the timekeeping system, and this information is preset in the calibration logic 16 which controls the scaler output. The amplifier, scaler and calibration logic may all be in the form of transistorized and integrated circuits. It will be appreciated that the entire system may be operated by a small battery.

Calibration of the timekeeping system depends on a determination of the mean counting rate. For nuclear alpha radiation, the solid-state detector has a 100 percent detection efficiency for those particles striking the detector; hence it is necessary only to specify the mean source rate. The simplest technique is to prepare by chemical means or otherwise a given source mass. One may for example weigh out a predetermined amount of radioactive material, since the number of radioactive atoms decaying per second is proportional to the number of atoms present. Hence a given source mass gives rise to a given source activity to provide a prechosen rate or count per second to correspond to the stepping time interval of the clock.

Another approach which may be more practical is to begin with an approximately correct amount of the material, and

then, having determined the existing count rate, to increase or decrease the effective area of the radioactive source seen by the detector by means of an adjustable mask. The control of the mask would have to be accurate to the same order of accuracy desired of the system. The mask may be in the form of an adjustable shutter whose position is varied with respect to the source by a Vernier screw arrangement.

A preferred calibration technique is electronic in nature. In this technique one first determines the actual count rate of an approximately weighed source and then arranges the scale-down value of a binary scaler system to respond to the source and to produce the desired low pulse rate. Thus referring to FIG. 3, there is shown a scaler formed by four binary stages, 2^0 , 2^1 , 2^2 and 2^3 in cascade relation coupled to the radioactive detector such that for the first incoming pulse, an output is obtained in stage 2^0 , for two incoming pulses an output is obtained in stage 2^1 , for four incoming pulses an output is obtained in stage 2^2 and for eight input pulses an output is obtained in stage 2^3 . By connecting the output of stage 2^3 and 2^1 to an "AND" or coincidence gate, which produces a single pulse only when these stages are concurrently activated, an output pulse will be produced once for every 10 incoming pulses, thus providing a scale of 10. However, if instead of connecting 2^1 to the "AND" gate, 2^2 were connected so that an output pulse is produced only when 2^2 and 2^3 are operative, then the scale would be 12.

In FIG. 3 there is shown another example of how the scaler may be adjusted to provide a desired output pulse for a given number of incoming pulses. In this instance, the binary cascade includes a fifth stage 2^4 which is activated every 16 pulses. By applying the output of stage 2^4 as well as stages 2^2 and 2^1 to the "AND" gate, a single pulse is yielded for every 19 incoming pulses. Thus by selective combinations of scaler stages with an "AND" gate, any desired scale may be obtained to adjust the countdown scale of the scaler to the output of the detector.

The solid-state detector is not responsive to gamma-radiation but only to particulate radiation of the alpha and beta type. While detectors such as Geiger counters are available which are sensitive to gamma-radiation, this type of detector is relatively inefficient and does not lend itself to use in the confines of a wristwatch or a small timepiece, for among other reasons it requires a very high operating voltage.

The solid-state detector is subject to radiation damage, for the bombardment of the solid-state material by the particles can knock atoms out of their crystal lattice sites, and thereby degrade the operation of the device which is sensitive to or dependent on these imperfections. The damage is not significant, in most instances, for the degradation of the solid material occurs over a prolonged period and does not materially affect the output thereof, particularly since a degree of internal healing takes place in the material. Although the rate of damage production is less for beta particles the system is more sensitive to the spectral changes which result since the damage manifests itself in a way which is equivalent to a change in threshold sensitivity with a concomitant change in count rate (and therefore timekeeping accuracy) as previously discussed.

Some solid-state detectors give a response to light as well as to particulate radiation. It is possible by the use of a scintillator, which is less subject to radiation damage, to produce light impulses in response to the radiation particles and to detect these light impulses, in the manner shown in FIG. 4 where a scintillator 18, mounted on a solid-state detector 19, is exposed to the mass 17 of radioactive material.

Various scintillators are currently available including crystals of inorganic and organic materials, as well as liquids, powders, plastics and glasses. The designer has access to a wide range of sizes and shapes as well as compositions and he can therefore optimize conditions for a wide spectrum of radiation sources and energy levels. If a solid-state detector is used in combination with a scintillator, the nature of the solid state material must be photoelectric such that it is sensitive to the scintillator light impulses to produce corresponding elec-

tric pulses. Obviously with a scintillator, other photosensitive detectors may be employed.

In order to detect as much of the source activity as possible, a sandwich arrangement may be used, as shown in FIG. 5, wherein the radioactive source 17 is interposed between a pair of scintillation detectors 18, 19 and 18', 19'. These detectors may be connected in parallel relation to provide a combined pulse output. The sandwich arrangement may be used also without scintillators by attaching the radioactive mass directly to the adjacent surfaces of the two solid-state detectors.

It is also possible to integrate the radioactive source with the scintillator. This can be done in various ways.

For example, in a liquid scintillator, the radioactive source material may be dissolved in the liquid so that it is uniformly dispersed therein. In the case of a plastic scintillator, one may dissolve the radioactive material in the plastic solution before it is solidified. In a crystal scintillator, the radioactive mass may be introduced before crystal growth occurs.

It is difficult ordinarily to calibrate the timekeeping system by precisely weighing the exact mass of radioactive material required for an individual unit for we are dealing with masses in the microgram region. But by dissolving radioactive material in a scintillator matrix, one may initially prepare a relatively large measured volume of such material incorporating a uniformly dispersed radioactive substance, and then divide this volume into individual units having a known amount of radioactivity.

As pointed out previously, the invention resides in the use of alpha particulate radiation from a radioactive source rather than gamma rays. In practice, the detector combined with the radioactive mass is enclosed by an opaque shield formed of such materials as tantalum, tungsten and gold which act as a light barrier. Such encapsulation prevents external light and other influences from penetrating the detector as well as providing a shield against radiation emitted from the mass. As distinguished from gamma rays, an extremely thin layer of gold or other shielding material will protect against external particle radiation, whereas relatively heavy shielding would be required for gamma rays. Inasmuch as many alpha emitting radioisotopes also emit associated gamma rays, it should be pointed out that an "alpha source with associated gamma rays" is to be distinguished from a "gamma ray source" in both the energy and number of gamma rays emitted. It can be shown that in the former case the gamma radiation level is so low as to be completely innocuous.

While the use of radioactive material having a highly prolonged half-life is preferable in obtaining a high order of accuracy, it is also possible to use masses having a shorter half-life, such as PA-231 whose half-life is 3.4×10^4 years. Since in this instance, a decay in count rate will arise in a relatively short time, corrective electronic circuits may be used to introduce supplementary pulses into the system when a predetermined number of pulses have been counted. Thus additional stages may be coupled to the scaler which acts to count the incoming pulses to generate after say every 10,000 counts, extra pulses to supplement the input pulses.

Furthermore, when the source counting rate m is such that $1/m$ is less than the desired accuracy, for example a source counting rate of 100 per second and a desired accuracy of one part in $4(10)^4$, then additional stages to generate correction pulses must be used to realize the full accuracy potential.

With regard to power sources for microelectronic systems in watches, one is concerned in the main with low power consumption. In particular, for timekeeping systems one of the most important, if not the most important, element is the scaling, or dividing, circuitry. The scaling system is a logic circuit as opposed to a linear circuit and at the present state of the art, logic-circuit power-consumption is minimized by MOSFET, or complementary MOSFET, technology. This technology, while yielding a minimum power consumption, however, requires from 5 to 15 volts for operation. Present research is directed toward lower voltage systems but at the moment off-the-shelf circuitry requires the voltage indicated.

Thus in FIG. 1, the power supply 20 is a battery whose output is five to fifteen volts for energizing amplifier 11, scaler 12, time indicator 13 and the calibration logic 16. The solid state detector 15 may, as previously pointed out, not require an external voltage bias, but should such a bias be required, it will be at a low voltage and will be derived from the same battery.

While there have been disclosed, preferred embodiments of the invention, it will be obvious that many changes may be made therein, without departing from the essential features of the invention.

We claim:

1. A compact timekeeping system operated by a battery whose voltage is less than 15 volts comprising:

A. a timekeeping standard including a mass of radioactive material having a prolonged half-life, and emitting alpha particles at a relatively high statistical rate, a solid-state detector to detect said alpha particles to produce a corresponding number of electrical pulses, the bias voltage, if any, applied to said detector, being no greater than the voltage of said battery, and means to amplify all of said pulses,

B. scaler means coupled to said standard to produce for a predetermined number of said electrical pulses a single control pulse, the control pulses being yielded at a constant low rate, and

C. a time register coupled to said scaler means and responsive to said control pulses to produce time indications.

2. A system as set forth in claim 1, wherein said radioactive mass has a half-life of at least 10^3 years.

3. A system as set forth in claim 1, wherein said radioactive mass is Uranium-233.

4. A system as set forth in claim 1, wherein said radioactive mass is Plutonium-242.

5. A system as set forth in claim 1, wherein said radioactive mass is Neptunium-237.

6. A system as set forth in claim 1, wherein said mass is selected from the group consisting of U-238, Th-230, Th-232, Pa-231 and Pu-239.

7. A system as set forth in claim 1, wherein said standard is encapsulated in a shield which prevents light from entering the detector and which prevents radiation particles from penetrating said shield.

8. A system as set forth in claim 1, wherein said mass is directly mounted on said solid-state detector.

9. A system as set forth in claim 1, wherein a scintillator is interposed between said mass and said solid-state detector, said detector being formed of photosensitive material.

10. A system as set forth in claim 9, wherein said mass is uniformly dispersed in said scintillator.

11. A system as set forth in claim 10, wherein said scintillator is of plastic material.

12. A system as set forth in claim 1, wherein said scaler is formed by a series of binary stages.

13. A system as set forth in claim 12, wherein the scale of said binary stages is adjustable to provide a desired output for a given mass.

14. A system as set forth in claim 13, wherein said adjustment is effected by an "AND" gate coupled to selected stages of the scaler.

15. A system as set forth in claim 1, further including an adjustable mask to vary the exposure of the detector to said mass.

16. A system as set forth in claim 1, wherein said scaler is formed by integrated circuits.

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