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AUTOMATIC RADIO CONTROL FOR CLOCKS

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2 Sheets-Sheet 1

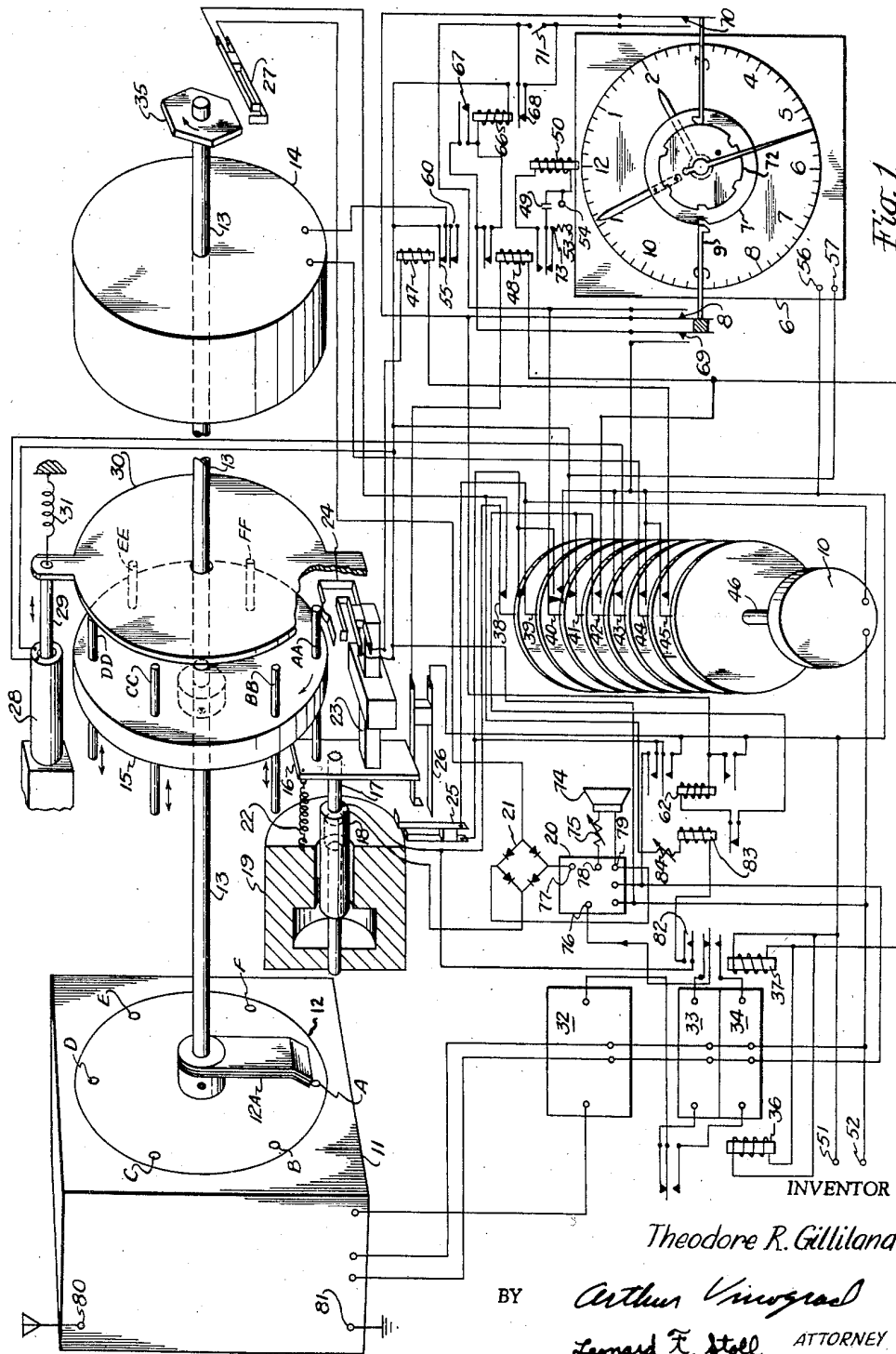


Fig. 1

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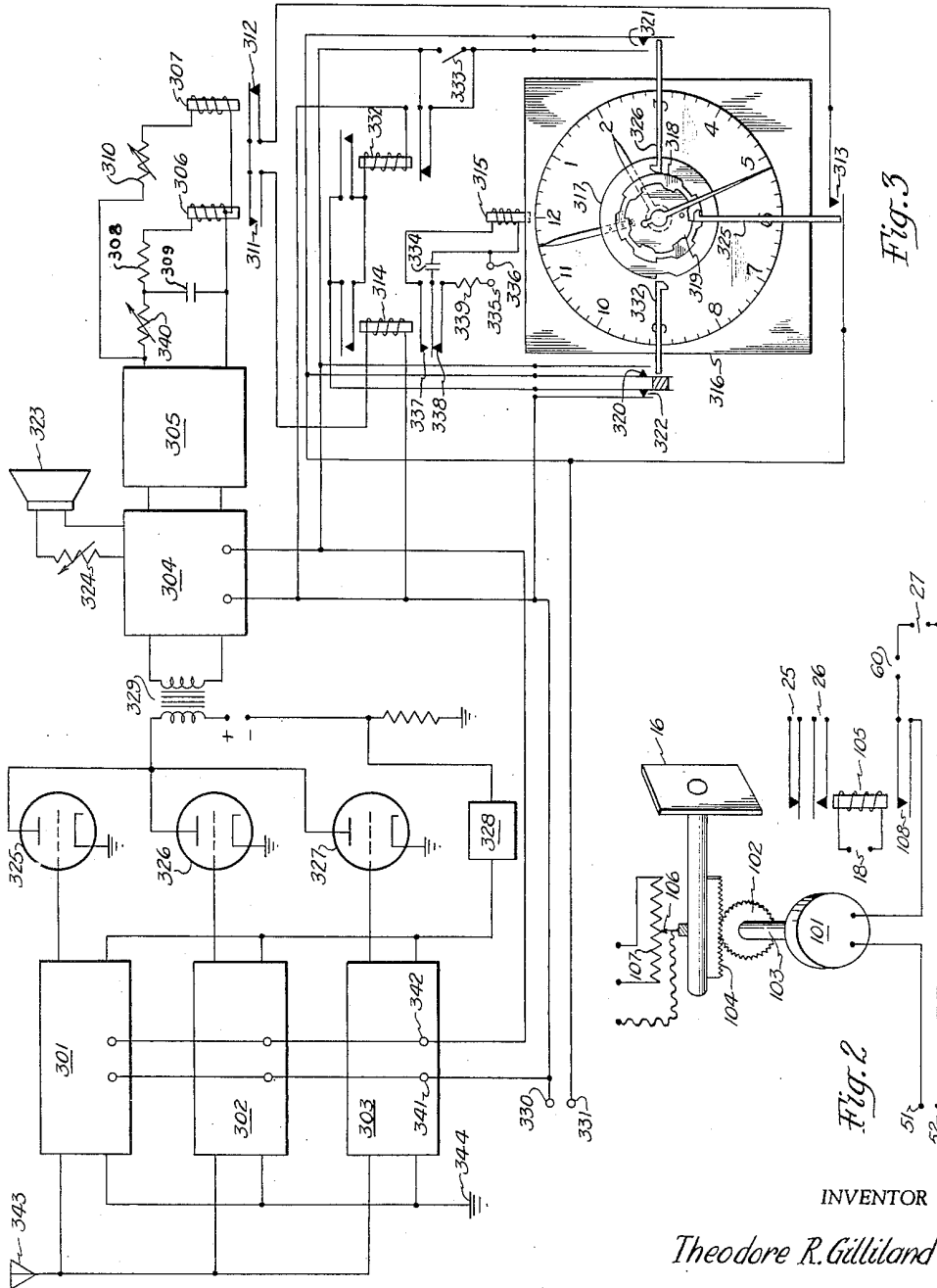


Fig. 3

Fig. 2

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**AUTOMATIC RADIO CONTROL FOR CLOCKS**

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Application May 22, 1956, Serial No. 588,205

21 Claims. (Cl. 250-2)

This invention relates to automatic correction of clocks or other timing devices and more particularly to automatic correction of such clocks or timing devices by means of radio frequency energy received from a remote source or sources.

Specifically, this invention is designed to utilize the regular radio broadcasts of time signals from stations WWV and WWVH of the National Bureau of Standards (near Washington, D. C., and in Maui, Territory of Hawaii, respectively) but the method is applicable to other emissions of a similar nature where available.

All the embodiments of this invention employ means for automatically adjusting the clock radio receiving means to the best received of several emissions from remote radio transmitters. In the present invention the best received time signal emission is selected and used to correct a clock or other timing device but the selection feature may be used for selection of the best received of other types of radio emissions such as used in telegraphic or telephonic communications or in broadcasting.

The need for a device that can automatically select the best received of several emissions is evident when a study is made of the characteristics of propagation of radio waves over long distances. For example, the time signals from station WWV, Washington, D. C., are emitted, continuously at six radio frequencies: 2.5; 5.0; 10; 15; 20, and 25 megacycles. In the vicinity of Washington the steady ground wave could be used and a single frequency might be selected which would be dependable at all times so that no radio-frequency selector such as described would be necessary. However, beyond the dependable ground-wave range which, under favorable conditions may extend out to 50 or 100 miles from the transmitter, it is necessary to depend upon the sky wave which reaches the receiver by reflection or refraction from one or more layers of the ionosphere. The characteristics of the ionosphere are such that at any receiving site beyond the dependable ground-wave range some of the transmitted frequencies may be well received at a certain time while others may not. At any receiving site the frequency or frequencies that are well received will change with time of day, with season, and from year to year. Thus beyond the ground-wave range any device that utilizes these emissions for the purpose described must be capable of selecting a usable frequency at the time of setting the timing device. The characteristics of propagation are such that the time of failure of one or another frequency at a given receiving site cannot be accurately predicted. For example, at the distance of New York city during the winter daytime the 10 or 15 megacycle emission from Washington might give the most consistent results but during much of the night waves at these and higher frequencies will skip over New York city and a lower frequency will be necessary. During the late night the 5.0 megacycle waves will skip so that the 2.5 megacycle frequency will have to be used. Because the pattern for these changes will vary from day-to-day, season-to-season and with disturbed conditions it is necessary to have a

device that can utilize the optimum frequency at any time of setting. Beyond the ground-wave range it is not likely that a single frequency or even a pair of frequencies could be found that would give satisfactory results at all times. If only the low frequencies are used to avoid failure caused by skipping, difficulties will be experienced with noise and daytime absorption, characteristic of the low frequencies. One type of irregular disturbance will cut out high frequencies while another type will cut out the low frequencies.

In addition to the features that provide for the selection of the best received radio frequency it is necessary to provide means for discrimination against incorrect setting of the clock by interfering stations or atmospheric and other types of radio noise. This discrimination is accomplished by using filters in the audio-frequency circuits that favor passage of the correct setting impulse. By switching filters at the proper time in an interlocking arrangement a high degree of discrimination is realized.

This invention is useful in electric power stations, factories, laboratories, radio stations, and other places where it is necessary to maintain a clock or other timing device more accurately on time than is ordinarily possible when depending on the rate of conventional timing devices. Correction can be made at hourly intervals or as frequently as every ten minutes if desired.

It is therefore an object of the present invention to provide an improved radio-controlled clock capable of automatically selecting the most favorable of a predetermined number of radio frequency signals for time adjustment purposes.

Another object of this invention is to provide radio-controlled clock adjusting means capable of automatically selecting the strongest radio signal of a predetermined number of signals.

An additional object of this invention is to provide improved radio-controlled clock adjusting means capable of discriminating against signals from interfering stations, atmospheric, and other types of radio noise.

Still another object of this invention is to provide improved radio-controlled clock adjusting means employing an interlocking arrangement of filters and switches capable of operating just prior to and during the period of clock setting to obtain a high degree of discrimination in favor of the correct timing pulse.

Another object of this invention is to automatically correct a timing device by providing means for utilizing to the best advantage radio broadcasts of time signals.

A further object of this invention is to provide an improved radio-controlled clock in which the clock setting impulse is derived from the beginning of a modulation signal.

A still further object of this invention is to provide an improved radio-controlled clock suitable for use at distances from the transmitter in excess of dependable ground-wave reception.

Other uses and advantages of the invention will become apparent upon reference to the specification and drawings in which:

Fig. 1 is a schematic diagram of one embodiment of the present invention showing a complete radio-controlled clock system.

Fig. 2 shows a modified embodiment of the frequency selector portion of the system of Fig. 1, and

Fig. 3 shows another embodiment of the radio-controlled clock system of the present invention.

The embodiment of the invention shown in Fig. 1 consists of four main parts:

- (a) The clock to be set.
- (b) A radio receiving set and antenna or antennas suitable for receiving the time signal broadcasts at the various frequencies emitted.

(c) The selector for automatically setting the radio receiver to the most suitable radio frequency at each time of correction.

(d) An interlocking arrangement of audio-frequency filters and switches to operate during the period just before and during the time of setting to obtain a high degree of discrimination in favor of the correct timing impulse and thus avoid incorrect setting by spurious impulses such as atmospheric or impulses from interfering stations.

Fig. 1 is a schematic drawing of one embodiment of the complete system, showing the relative positions of the mechanical parts and the system of connections between the electrical components. A description of the various parts is given here to be followed by the method of operation.

#### Description

Referring to Fig. 1 at 6 is shown the clock which is corrected at regular intervals (once each hour in this example). This clock should be a fairly precise instrument which would not ordinarily be expected to drift more than a second or two at the most in the interval between corrections. However, the setting mechanism can correct errors as great as 12 seconds, fast or slow. Cam 7, a part of the clock rotates once an hour and by means of rod 9 closes contactor 8. Closing of contactor 8 about 4½ minutes before the time of setting turns on the receiving set for warm-up and starts the program timer motor 10, thus starting the sequence of the setting operation. Numeral 11 designates that part of the radio receiving set consisting of the antenna coupling circuits, the radio frequency amplifiers, crystal-controlled oscillator and first detector. The frequency selector switch 12 is a schematic representation of the system of switches used for switching the antenna coupling circuits, the radio frequency amplifiers, oscillator and first detector from one radio frequency to another. In this specific example the six positions correspond respectively to the 2.5; 5.0; 10; 15; 20, and 25 megacycle frequencies broadcast from station WWV. The frequency selector switch arm 12A is caused to rotate by means of shaft 13, driven by means of electric motor and speed reducer combination 14. Also attached to shaft 13 and rotated simultaneously with the frequency selector switch is disc 15 containing six equally spaced actuator pins AA, BB, CC, DD, EE, and FF corresponding respectively to frequency selector switch positions A, B, C, D, E, and F. The pins, in addition to being revolved with disc 15 are movable parallel to shaft 13 through holes in the disc. Each pin can be removed to the right individually by push plate 16 during the time the pin is opposite the plate. In the form of the invention shown in Fig. 1 push plate 16 is attached by rod 17 to moving coil 18 so that the plate and coil move to left and right together. The coil is mounted in the magnetic field of stationary magnet 19 so that rectified alternating current from the audio-frequency power amplifier 20 of the receiving set will cause the coil (and plate) to move to the right with increase in amplitude of the audio-frequency voltage. The alternating signal current from amplifier 20 is rectified by a rectifier 21. Motion of the coil 18 to the right is opposed by spring 22 so that the distance the coil will move to the right will be greater as the amplitude of the audio-frequency voltage is increased. At its limit of motion to the left plate 16 closes contactor 25 and at a selected position in its motion to the right it closes contactor 26. The functions of these contactors are explained later under "Method of operation." Rotating on shaft 13 is a cam 35 which opens contactor 27 between operative positions of frequency selector switch 12. Opening switch 27 disconnects moving coil 18 and allows it with push plate 16 to move to the left to place the push plate 16 in position to start moving each pin as it comes opposite the plate with successive connection of each frequency channel of the receiver. As shaft 13 revolves, each radio frequency channel is operative for a sufficient

time interval to allow moving coil 18 with plate 16 to move one of the pins to the right to a position corresponding to the amplitude of the audio-frequency voltage output of the receiver at that radio frequency. As the push plate moves to the right it also causes the sliding bar 23 carrying contactor 24 to move to the right. The motion of contactor 24 will correspond to the maximum motion of the pins. As an example, suppose the 2.5 megacycle frequency is being received so that it furnishes a higher audio-frequency voltage than any of the other radio frequencies. Then pin AA will be moved further to the right than any of the other pins and contactor 24 will be moved a corresponding amount. Thus pin AA can cause contactor 24 to close as disc 15 revolves to bring pin AA into contact with the contactor on the next revolution of the disc. Because the other frequencies are not being as well received as the 2.5 megacycles the pins corresponding to these frequencies will not have been moved far enough to the right to actuate contactor 24 on the second revolution of disc 15. The function of contactor 24 is to stop the frequency selector switch at the frequency providing the best reception so that this frequency will be in operation during the setting operation. After the end of each setting operation solenoid coil 28 actuating plunger rod 29 causes plate 30 to simultaneously reset contactor 24 and all of the pins to their initial positions in readiness for the next setting operation. After the resetting operation plate 30 is returned to its extreme right position by spring 31. In this example the coil of solenoid 28 is stationary.

Referring still to Fig. 1, other parts of the radio receiver are shown at 32, 33, and 34. Element 32 is the intermediate frequency amplifier and 2nd detector. Elements 33 and 34 are part of the audio-frequency amplifier and filter system. The element 33 contains filters arranged to favor passage of the 440 cycle per second modulation while element 34 contains filters to favor passage of the 600 cycle modulation, these being two modulation frequencies used in the time signal broadcasts. Since one of these modulation frequencies is cut off at the transmitter exactly one minute before the time of setting the clock and the other modulation frequency begins exactly at the time of setting it is possible, by switching from one frequency pass to the other at the proper time to obtain a setting impulse that has a high degree of discrimination against any spurious impulses such as might come from an interfering radio station or from atmospheric or other types of radio noise. Relays 36 and 37 are for the purpose of switching from one of the modulation frequencies to the other. Elements 38, 39, 40, 41, 42, 43, 44, and 45 are program timer contactors each operated by a separate cam on shaft 46 driven by motor-speed reducer 10. The functions of these contactors are described later under the description of the operation of the various parts. Relay 47 controls motor 14 which drives the frequency selector switch 12, disc 15 and cam 35. Relay 48 which operates at the time of setting connects charged capacitor 49 to solenoid 50 which sets the hands of clock 6 to the proper time. 51 and 52 are terminals of the source of electric power. The components described here would ordinarily be designed for use with a 115-volt-60-cycle source but can be designed for use with other voltages and frequencies or can be adapted for a direct-current source of power. Terminals 53 and 54 are connected to a source of direct current potential (not shown) for charging condenser 49. This direct-current potential can be conveniently obtained from the power supply of the radio receiver. Relay 62 is provided for the purpose of avoiding incorrect setting of the clock if a power failure occurs during the setting operation. This relay also provides for proper resetting of program timer controls for the next cycle should a power failure occur during the setting operation.

If for some reason, such as weak signals, interference, or power failure, no setting impulse is obtained on the hour, relay 66 and auxiliary clock contactor 70 will pro-

vide for attempted setting each ten minutes after the failure until a successful setting is accomplished. Contactor 69 on the clock provides for opening the circuit of relay 66 at the beginning of the hourly setting cycle. Spare contacts 60 of relay 47 are to be used with the alternate method of setting the pins of disc 15 (Fig. 2, described later).

Relay 83 and contactor 82 are provided to prevent incorrect setting when interference prevents program timer motor 10 from restarting at the proper time during the setting operation. Relay 83 also permits a sampling of the received signal just before the time of setting. If interference is present setting is prevented.

In Fig. 1 contactors 25 and 26 are operated by moving coil 13. In some installations it may be more convenient to have these contactors operated by one or two separate relay coils. These relays would be operated from the output of rectifier 21 and could be adjusted separately for sensitivity and speed of action as required.

In localities where the Hawaiian station WWVH is used it will be necessary to have the settings each hour (by method of Fig. 1) at a time other than on the hour or half hour because WWVH is silent for 4 minutes beginning on the hour and half hour. This can be done by shifting cam 7 to initiate the setting cycle for setting at any of the other 10 minute points.

#### Method of operation

The following is a description of the method of operation of the embodiment of the invention shown in Fig. 1. It is assumed that the clock will not drift ahead or behind the correct time by more than 12 seconds in the interval between times of correction (one hour interval in this example). In this description the time of correction is to be at 2 o'clock (i. e. 02 hours, 00 minutes, 00 seconds or 02:00:00).

Referring to Fig. 1, cam 7 which rotates once an hour with the minute hand of the clock 6 causes contactor 8 to close by means of rod 9. If the clock is on time contactor 8 will close at 01:55:30 or 4½ minutes before 2 o'clock. But allowing for the clock to be as much as 12 seconds fast or slow contactor 8 will close sometime between 01:55:18 and 01:55:42. On closing, contactor 8 operates power-failure relay 62 through contactors 40 and 41. The pair of contacts at the bottom of relay 62 are holding contacts which hold the relay on until the power source is disconnected from the coil. Relay 62 connects the radio receiver and amplifiers (11, 20, 32, 33, and 34) and program timer motor 10 to the power source terminals 51 and 52. The program timer discs require five minutes running time for one complete revolution but in operation the complete cycle for the discs is somewhat over five minutes because the motor is turned off for a short waiting period during the setting operation. A few seconds after the closing of contactor 8 one of the program timer cams closes the lower pair of contacts of contactor 40 and a few seconds later the top and bottom contacts are opened. With this arrangement, a power failure during the setting operation will cause relay 62 to open. With return of power the program timer motor will resume (by connection through the lower contacts of contactor 40), continue to the end of its motion and stop in position for the next cycle (by opening the lower contacts of contactor 40). There will be no setting impulse because the receiving set will be inoperative (with relay 62 de-energized). If a power failure occurs after the top and bottom contacts of contactor 40 have opened, the clock (through contactor 8 or 79) cannot initiate a new setting cycle until the program timer cams have returned to position for the next cycle.

Allowing one minute for receiver warm-up contactor 44 is closed by its program timer cam sometime between 01:56:18 and 01:56:42. Closing contactor 44 starts motor-speed reducer 14, thus rotating the frequency se-

lector switch arm 12A, disc 15, and cam 35 by means of shaft 13. Shaft 13 rotates at a rate of one revolution per minute so that the frequency selector switch allows each radio-frequency channel to be operative for about six seconds. During the period from 01:55:00 until 01:59:00 the 440-cycle modulation is being transmitted so relays 36 and 37 (with coils de-energized) connect filter 33 which favors passage of the 440-cycle modulation. Thus during the time each radio frequency is operative the rectified 440-cycle output of the audio-frequency power amplifier (corresponding to that radio frequency) is applied to moving coil 18. Coil 18 is in the field of stationary magnet 19 so that the rectified current flowing in the coil will cause the coil, attached to push plate 16 by rod 17 to move to the right. Successively each of the 6 pins in disc 15 will be opposite the push plate 16 during the time the corresponding radio frequency is made operative by the frequency selector switch 12. As the push plate 16 moves to the right it will cause the pin opposite to move to the right through a hole in the disc 15. Likewise in its motion to the right plate 16 will move bar 23 carrying contactor 24, to the right. After disc 15 has made one complete rotation the various pins will have moved to the right various amounts with the pin corresponding to the best received radio frequency having moved the farthest to the right. Here best received radio frequency is considered to be that frequency for which the highest audio-frequency voltage is obtained at the output of the audio-frequency power amplifier. This is taken as the criterion for the best received frequency because the audio-frequency output furnishes the energy for the final setting impulse and by filtering in favor of the two modulation frequencies and by switching from one to the other at the proper time a high degree of discrimination is attained against interference from spurious impulses from other stations and from atmospheric and other types of radio noise. Since sliding bar 23 carrying contactor 24 is always opposite push plate 16 the bar and contactor will be moved to the right by an amount equal to the motion of the pin with the greatest displacement. During the first revolution of the disc contactor 45 is open making contactor 24 inoperative. Allowing six seconds over one minute for the frequency selector switch to make slightly over one complete revolution, contactor 45 is closed and contactor 38 is opened by the program timer cams between 01:57:24 and 01:57:48 (i. e. 2 min., 6 sec. after closing of contactor 8). The closing of contactor 45 connects one end of the coil of relay 47 to power source terminal 51, making contactor 24 ready for operation. Opening contactor 38 opens the circuit of moving coil 18 so that it will be inoperative during the time the band switch is advancing to stop at the best received frequency. The frequency selector switch will continue to advance into the second revolution until the pin with the greatest motion (corresponding to the best received frequency) closes contactor 24, energizing relay 47 and stopping motor 14 (by the opening of contacts 55 of relay 47). Thus the frequency selector switch will stop with the receiver set at the best received of the six frequencies sampled. The pins corresponding to the frequencies less well received will not have moved far enough to the right to actuate contactor 24. The program timer motor continues, closing contactor 38 where the program timer cams have 65 seconds running time (approximately) before the position for the setting impulse. Closing contactor 38 makes moving coil 18 operative. The program timer motor continues until stopped by the opening of contactor 39 by its program timer cam between 01:58:30 and 01:58:54. Contactor 39 is opened at a point where the program timer cams have 60 seconds remaining running time before the position for the setting impulse. At the time the program timer motor stops the receiver is set to receive the most favor-

able frequency and coil 18 is expected to be at some position to the right of zero position allowing contactor 25 to remain open. At exactly 01:59:00 the 440-cycle modulation is cut off at the transmitter causing coil 18 to move to the extreme left position closing contactor 25 and restarting program timer motor 10. About three seconds after the program timer motor 10 restarts contactor 38 is opened by its program timer cam. This disconnects moving coil 18 from the output of rectifier 21 so that code and voice announcements or any other interference will not cause coil 18 to interrupt motor 10 by opening contactor 25. At about 01:59:48 contactor 39 is closed by its program timer cam. With contactor 39 closed the program timer motor will not be interrupted when contactor 25 is opened by the beginning of the 600-cycle modulation at 02:00:00.

Relay 83 and contactor 82 of relay 37 are used as a further precaution against possibility of incorrect setting by interfering signals or radio noise. It is possible that strong interference might prevent contactor 25 from closing at 01:59:00 at the end of the 440-cycle emission, so that program timer motor 10 would be late in restarting and allow for the possibility of a late setting impulse. Normally contactor 42 will close at 01:59:54 but if the program timer motor 10 is late in restarting contactor 42 will close later than 01:59:54 but in any event it will close when the cams have reached a position approximately six seconds before the position for setting, i. e., three seconds before the closing of contactor 38. When contactor 42 closes the filters will be shifted to the 600-cycle pass and contactor 82 will be closed (by relays 36 and 37). Closing of contactor 42 also connects one end of the coil of setting relay 48 to one side of the power source in readiness for the setting impulse. If the program timer motor starts more than six seconds late because of interference preventing contactor 25 from closing at 01:59:00 the 600-cycle modulation will already be coming through when contactor 42 closes and the rectified 600-cycle output will operate relay 83 thus opening coil of relay 62. This will shut the receiver off and no setting impulse can be obtained during the six second interval intended for setting (i. e. between closing of contactor 38 and opening of 41). Thus the incoming signal is sampled to determine if 600 cycles or interference that can get through the 600-cycle filter is present before contactor 38 closes (normally three seconds before the time of setting), and if the 600-cycle modulation or interference should get through the filters relay 83 will be operated and setting will be prevented. Setting will occur only if there is no signal getting through the 600-cycle filter immediately before the closing of contactor 38. The coil of relay 83, adjusting resistor 84 and contactor 82 make a series circuit connected across contactor 38. When contactor 38 is open these elements (coil of relay 83, resistor 84, and contactor 82) are in series with moving coil 18 in the rectifier output. Relay 83 is relatively much more sensitive than coil 18 so that weak signals will operate relay 83 without disturbing coil 18. When contactor 38 closes relay 83 of course becomes inoperative.

Contactor 38 will close when the program timer cams reach a position three seconds ahead of the position for setting. This reconnects coil 18 so that it will be ready for the setting impulse when the 600-cycle modulation comes on at 02:00:00.

If there was no interference to delay the starting of program timer motor 10 and if there was no interference to operate relay 83 just before the closing of contactor 38 the connections are made and ready for the setting impulse at exactly 02:00:00, when reception of the 600-cycle modulation begins. The rectified 600-cycle output of the audio-frequency power amplifier 20 causes coil 18 to move to the right closing contactor 26 which is adjustable so that its closing can take place at a selected

amplitude position in the motion of the moving coil. This adjustment serves as a threshold below which any weak spurious signals will not actuate the contactor to cause incorrect setting of the clock. Closing of contactor 26 operates setting relay 48 which connects charged capacitor 49 to the coil of the setting solenoid 50 and actuates the mechanism that sets the hands of the clock to the correct time of 02:00:00. Capacitor 49 allows only a single impulse with one charging. A second impulse cannot occur until capacitor 49 has had time to recharge through resistor 73. The setting mechanism that sets the hands of the clock to the correct time can be of the type already in use (such as used for Western Union clocks). If more energy is needed for setting than can be provided by the capacitor a relay can be interposed between the capacitor operated device and the actual setting mechanism. The contacts of relay 48 which operate capacitor 49 are arranged to break before make so that the capacitor will not recharge during the time of the setting impulse.

At 02:00:03, i. e., three seconds after the time of setting, contactor 41 opens, disconnecting setting relay 48 so that any interference or spurious signals occurring after that time cannot cause incorrect setting. Thus to have a completed setting operation the impulse must occur during the six-second interval centered at 60 seconds after the end of the 440-cycle transmission and since the filters are set to favor the 600-cycle modulation frequency only that frequency will be expected to come through the receiver with sufficient amplitude to operate the setting relay. Opening contactor 41 also returns the filters to the 440-cycle pass and opens the power-failure relay 62 shutting off the receiver and amplifiers. At 02:00:08 contactor 42 is opened and at 02:00:13 (approximately) contactor 41 is closed placing these contactors in readiness for the next cycle. Contactor 45 is opened at 02:00:30 and contactor 44 is opened at 02:00:36, placing these switches in readiness for the next cycle. In the interval between opening of these two contactors motor 14 will move the frequency selector switch to a neutral position between frequency settings facilitating resetting of the pins and contactor 24. Contactor 43 is closed at 02:00:36 and opened at about 02:00:40, operating solenoid 28 to reset contactor 24 and the pins in disc 15 to their zero signal positions ready for the next cycle. At 02:00:48 the top and bottom contacts of contactor 40 close and the middle and bottom contacts open in that order, stopping the program timer motor. Thus the cycle is completed and all contactors are in readiness for the next cycle.

The auxiliary circuit made up of relay 66 and contactors 69 and 70 on the clock provide for additional setting operations if, because of weak signals, interference, power failure or some other reason no setting impulse is obtained on the hour. The relay 66 is open during the hourly setting cycle until the setting impulse operates relay 48. Operation of relay 48 energizes the coil of relay 66, and holding contacts 67 keep it energized until the coil is opened by opening of contacts 69 by the clock at the beginning of the next hourly cycle. If there is no setting impulse on the hour to operate relay 48, relay 66 will remain de-energized and contacts 68 remain closed. With contacts 68 closed contactor 70 is connected in parallel with clock contactor 8 so that contactor 70 will have the same function as contactor 8 in initiating a setting cycle. Contactor 70 is operated by a cam 72 that is attached to cam 7 and rotates with it once an hour. Cam 72 has five detents to operate contactor 70 every 10 minutes except for the hourly cycle. Thus if no setting impulse is obtained at 02:00:00 contactor 68 will remain closed and contactor 70 will initiate a cycle at 02:05:30 (plus or minus 12 seconds) and the same sequence as that for the hourly cycle will occur with setting at 02:10:00 if a setting impulse is obtained. If setting is accomplished at 02:10:00 setting relay 48 will cause relay 66 to operate,

holding contacts 68 open and thus making contactor 70 inoperative so that no setting cycle can be initiated until the next hourly cycle is initiated by clock contactor 8. If no impulse was obtained at 02:10:00 other attempts will be made every 10 minutes until a successful setting is obtained. Closing of manual switch 71 will provide for setting every ten minutes if desired.

By using different arrangements of detents on cams 7 and 72 other setting plans are possible, e. g. with two detents on cam 7 and four on cam 72 regular setting will occur on the hour and half hour and in case of failure supplementary setting each ten minutes until successful setting is obtained. It is possible to change from one setting plan to another merely by substituting different cams for 7 and 72.

A loudspeaker 74 is provided for monitoring the voice and code announcements. The speaker volume is controlled by variable resistor 75. A manual switch in the receiver (not shown) provides for by-passing filters when monitoring announcements. For convenience radio-frequency, intermediate-frequency, and audio-frequency connections between components of the receiver are shown as single lines. Element 76 represents the single audio-frequency input terminal of the audio-frequency power amplifier 20, while elements 77, 78, and 79 are output terminals. In the example, terminals 77 and 79 represent a 500-ohm output while terminals 78 and 79 represent an 8-ohm output. The unnumbered terminals (in pairs) on each component of the receiver are the connections to the source of electrical power (not shown but in this example: 115 volts, 60 cycles A. C.). Elements 80 and 81 are the antenna and ground terminals, respectively. In some localities where reception is poor separate and sometimes directional antennas may be desirable. In this case frequency selector switch 12 can provide for switching antennas for each frequency.

#### *Alternate method for setting pins of disc 15*

Fig. 2 shows apparatus involving an alternate method for setting the pins of disc 15 during the selection of the best received frequency. The like numbers of Fig. 2 indicate connections or positions identical with those of Fig. 1. With the alternate method push plate 16 is identical with that of Fig. 1 and occupies the same position with respect to disc 15, but is driven to the right by a motor-speed reducer 101 which drives a pinion 102 by means of a shaft 103. Pinion 102 engages a gear rack 104 attached to plate 16. Motor-speed reducer 101 is the type (well known in the art) that rotates in opposition to a spiral spring and when the electrical power source is disconnected the spring returns the driven shaft to its initial position. In this alternate method moving coil 18 (Fig. 1) is replaced by relay coil 18 of a relay 105 and contactors 25 and 26 of relay 105 replace contactors 25 and 26 of Fig. 1.

In addition to push plate 16 rack 104 carries a sliding contactor 106 which slides in contact with a resistor 107. Sliding contactor 106 and resistor 107 make up a gain control of the receiving set. In place of this type of gain control a rotary type attached to shaft 103 will serve equally well.

#### *Operation of alternate method*

Referring to Fig. 2, with motor 101 disconnected from the electrical power source contactor 106 (and plate 16) will be at the extreme left of their motion and the connection of the gain control to the receiver will be such that maximum gain is realized. The controls and sequence of operation are practically the same as described for Fig. 1.

After the one-minute warm-up period, rotation of the frequency selector switch begins. As the receiver becomes operative at the first frequency, e. g. 2.5 megacycles, the push plate drive motor 101 will be operative if that frequency is being received with sufficient amplitude to operate relay 105 at the output of rectifier 21. This out-

put is the rectified 440-cycle modulation from the receiver. Motor 101 will cause plate 16 to move to the right pushing pin AA (corresponding to the 2.5 mc. frequency being received) to the right. As the motion to the right continues the gain control is reducing the receiver gain and will do so until the rectified audio-frequency output is low enough to cause relay 105 to drop out (opening contactor 26 and relay contacts 108, and closing contactor 25) thus disconnecting motor 101 from the electrical power source and allowing push plate 16 to return to its initial position at the extreme left of its motion (by action of the spiral spring). Hunting is minimized by slowing the action of the push plate in its motion to the right compared to the rate of motion to the left. As with the method of Fig. 1 the amount that each pin is moved is a direct function of the rectified audio-frequency output voltage. With the method of Fig. 2 the higher the voltage the greater the motion of the push plate to the right because the push plate must move until the gain control reduces the receiver output low enough for relay contacts 108 to open.

As the frequency selector switch arm 12A continues its rotation each frequency will be sampled and the pin corresponding to the frequency giving the best output will be moved farthest to the right. As with the first method the pin setting action is made inoperative between active positions of the selector switch by opening of contactor 27 by cam 35. Stopping the frequency selector switch in the second revolution at the best frequency is done in the same way as described for Fig. 1, i. e., closing of contactor 24 operates relay 47 opening contactors 55 and 60. Opening of contactor 55 stops the frequency selector switch drive motor 14 and opening of contactor 60 disconnects motor-speed reducer 101, leaving push plate 16 at its extreme left position with the receiver gain control in full gain position.

Setting the clock is also done in the same way as for Fig. 1 except that contactors 25 and 26 are operated by coil 18 of relay 105 (corresponding to contactors 25 and 26 operated by moving coil 18 of Fig. 1).

After the setting operation the various controls are reset for the next cycle in the same way as described for Fig. 1. With the opening of contactor 41 at 02:00:03 the receiver is turned off, making motor 101 inoperative until the next setting cycle.

With the alternate method of Fig. 2 the power output of the receiver needs to be sufficient only to operate relay 105 while with the first method of Fig. 1 the receiver power output must be sufficient to move the actuating pins and contactor 24 by means of moving coil 18.

Another form of the device for setting a clock by means of radio-frequency energy received from a remote source utilizes two or more radio receiving sets, each tuned to one of the transmitted time signal frequencies, with provision for selecting electronically the one receiving the most favorable frequency, to control the setting operation.

This form of the invention is illustrated in Fig. 3. Any number of receivers may be employed. Three receivers (301, 302, and 303) are used in this example. Each receiver may have a separate antenna or a common one may be used for all three. Each receiver is tuned to one of the time signal frequencies. For example, the first may be tuned to 2.5 megacycles, the second to five megacycles, and the third to 10 megacycles. The second detectors of the three receivers are connected in the way shown so that the automatic gain control for all receivers is operated from the rectified current in the common output of the three detectors. This method of combining outputs to operate the automatic gain control has been used in one type of diversity reception as described in the "Radio Engineers' Handbook" by F. E. Terman, sec. 9, par. 7, page 661, first edition, 1943. With this method the receiver receiving the strongest signal will control the other receivers so that their contribution of both signal and noise will be small compared to that of the controlling receiver.

The resultant audio-frequency output is passed through



a filter-amplifier 304 and then a rectifier 305, and into relays 306 and 307 which are used in the setting operation. Variable resistors 340 and 310 are for adjustment of sensitivity of relays 306 and 307 respectively. The resistor-capacitor combination 308 and 309 allows for slow drop-out of relay 306. Relay contactors 311 and 312 and clock contactor 313 control the setting impulse as described later under "Method of operation." Relay 314, solenoid 315, and capacitor 334 are used in the setting operation in a manner similar to that described for Fig. 1. Element 316 is the clock to be corrected. It may be mechanically or electrically driven. The limit which the clock may drift, fast or slow, and still be automatically corrected is arbitrarily set at 12 seconds for this example. Clock 316 is provided with three cams, 317, 318, and 319 which rotate once an hour with the minute hand. Cam 317 operates contactor 320 to initiate the setting cycle once an hour. Loudspeaker 323 is provided for monitoring voice and code announcements. The speaker volume is adjusted by control 324. A manual switch in the receiver (not shown) provides for by-passing filters when monitoring announcements. Elements 325, 326, and 327 are square-law detectors of receivers 301, 302, and 303 respectively. Element 328 is the automatic gain control of all the receivers operating from the rectified current in the common output of the detectors. Element 329 is the transformer that couples the audio-frequency output of the detectors to the audio-frequency filter-amplifier 304. Elements 330 and 331 are terminals of the source of electric power (not shown).

If because of interference or other reasons no setting impulse is obtained on the hour, relay 332 with cam 318 and contactor 321 will provide for additional attempts at setting each ten minutes until a setting impulse is obtained. Opening of contactor 322 by cam 317 at the beginning of the hourly cycle resets relay 332 so that a setting cycle will be initiated for setting on the hour whether or not a successful setting was obtained during the preceding hour. By closing manual switch 333 a setting cycle will be initiated every ten minutes. Elements 335 and 336 are terminals of a D-C. potential (not shown) for charging capacitor 334.

Under bad radio interference conditions the performance of the diversity system can, where necessary, be improved by providing each receiver with a separate audio-frequency filter-amplifier and by operating the common gain control of all receivers from the rectified current in the common output of the three amplifiers rather than from the three detectors of Fig. 3. In this way improvement results from the discrimination obtained by the filters designed to favor passage of the emitted modulation frequency. The rectified current that operates the gain control may be used to operate the relays employed in the setting operation or further amplification for the relays may be used if required.

#### *Method of operation*

The following is a description of the method of operation of the form of the invention shown in Fig. 3. It is assumed, for example that the clock will not drift ahead or behind the correct time by more than 12 seconds in the interval between times of correction (one hour interval in this example). In this description the time of correction is to be 01:59 o'clock (i. e., 01 hrs., 59 min., 00 sec. or 01:59:00).

Referring to Fig. 3 cam 317 which rotates once an hour with the minute hand of the clock 316 causes contactor 320 to close by means of rod 332. If the clock is on time contactor 320 will close at 01:57:30. Allowing for the clock to be as much as 12 seconds fast or slow contactor 320 will close between 01:57:18 and 01:57:42. On closing, contactor 320 connects the radio receivers 301, 302, and 303 (including detectors 325, 326, and 327) and filter-amplifier 304 to the power source for warm-up. After warm-up the receiver receiving the strongest signal will control the other receivers because its

detector output will control the automatic gain control of all three receivers. The output of both signal and noise of the other receivers will be small compared to that of the controlling receiver. The filter-amplifier 304 contains filters to favor passage of the 440-cycle modulation which is emitted for exactly four minutes beginning with the fifth minute of each 10-minute interval, i. e., the 440-cycle modulation begins at 5; 15; 25; 35; 45, and 55 minutes past the hour, and ends at 9; 19; 29; 39; 49, and 59 minutes past the hour. In this example the ending of the modulation at 01:59:00 is used to furnish the impulse that sets the clock.

A one minute warm-up interval will be completed between 01:58:18 and 01:58:42 so that after 01:58:42 the controlling receiver will normally be supplying an audio-frequency voltage at 440 cycles per second to the filter amplifier 304. With the filter designed to favor passage of 440 cycles discrimination will be realized against interfering signals having any other modulation frequencies and against atmospherics and other types of radio noise. The 440-cycle voltage is rectified by means of rectifier 305 the output of which is passed to relays 306 and 307 as shown in Fig. 3. If the rectifier output is sufficient contactor 311 of relay 306 will be held closed. By use of variable resistor 340 or other means the operation of relay 306 may be controlled so that its contactor 311 will close only when the rectified 440-cycle output voltage is above a selected level. By this means attempted settings will be avoided when the received signal is weak, since contactor 311 is in series with the setting circuit. Avoiding attempted setting when the receiver output is low is advisable because at such times normal fading may cause the output to drop low enough to cause premature closing of contactor 312 of relay 307 which is intended to give the setting impulse with the ending of the 440-cycle modulation at 01:59:00. Capacitor 309 and resistor 308 prevent contactor 311 of relay 306 from opening on short fades. This is necessary because contactor 311 is intended to be closed only for signal outputs above the selected level. Relay 307 is faster and more sensitive than relay 306 so that when resistor 310 is properly adjusted contactor 312 will close before contactor 311 opens when the 440-cycle output level drops to zero with the ending of modulation at the transmitter at 01:59:00. A third series contactor 313 in the setting circuit is operated by clock cam 319. This contactor allows setting only during a limited interval since solenoid 315 is arranged to correct the clock only if it is within 12 seconds of the correct time. Limiting the time interval for correction minimizes possibility of premature setting by fading and also minimizes the possible error in event of premature setting by fading. Contactor 313 is closed for an interval of 24 seconds by cam 319. If on time contactor 313 would close at 01:58:48 and remain closed until 01:59:12 and the setting impulse at 01:59:00 would occur at the middle of the interval. Allowing for the clock to be 12 seconds fast contactor 313 will close at 01:58:36 and open at 01:59:00 allowing the setting impulse to operate just at the end of the 24-second interval. If the clock is 12 seconds slow closing of contactor 313 at 01:59:00 will allow for the setting impulse just at the beginning of the 24-second interval during which contactor 313 is closed. Thus no setting impulse can operate unless the clock is within 12 seconds of the correct time. To obtain a setting impulse contactors 313 and 311 must be closed so that the setting circuit operating relay 314 can be completed by the closing of contactor 312 with the ending of the 440-cycle modulation at 01:59:00. Operation of setting solenoid 315 by means of charged capacitor 334 is the same as described for Fig. 1. By having the resistance of resistor 339 sufficiently high the time for recharging capacitor 334 can be made great enough to avoid any additional setting impulses that might be caused by static crashes or other interfering signals (i. e., the resistance of resistor 339 is



made high enough so that capacitor 334 cannot recharge enough to reoperate setting solenoid 315 before contactor 313 is opened by clock cam 319).

In the event that no setting impulse is obtained at 01:59:00 provision is made for additional attempts at setting each ten minutes thereafter until a successful setting is accomplished. Cam 318, contactor 321, and relay 332 are used for this purpose. The method of operation is the same as that described for Fig. 1. A few seconds after the opening of contactor 313 the receivers and amplifier will be shut off by the opening of contactor 320 (or 321). Elements 341 and 342 are the electrical power terminals of the three receivers and the amplifier. Elements 343 and 344 are the antenna and ground terminals of the receivers.

In addition to the apparatus for selecting the most favorable frequency and the method for setting the clock shown in Fig. 1 two additional means for selecting the best received radio frequency and one additional means for setting the clock have been disclosed. Any of the three means described for selecting the best received radio frequency (i. e., Fig. 1. Using a multichannel receiver with actuating pins set by moving coil, Fig. 2. Using multichannel receiver with actuating pins set by motor-driven rack, Fig. 3. Diversity system using multiple receivers) may be used in combination with either of the two means of setting the clock, i. e., with the setting method of Fig. 1 using an interlocking arrangement with two modulation frequencies and where the beginning of the second modulation produces the setting impulse or with the setting method of Fig. 3 using one modulation frequency with the ending of the modulation providing the setting impulse.

Also within the dependable ground-wave range a single radio receiving set tuned to one of the consistently received radio time signal frequencies may be used in combination with either of the two setting methods described.

Changes in the broadcast schedule of stations WWV or WWVH such as the change in the schedule of station WWV of January 1956 may require slight modifications in the switching schedule of the program timer. Such modifications fall within the scope of the present invention as apparent to one skilled in the art and do not affect the basic principles of operation of the embodiments herein disclosed.

It will be apparent that the embodiments shown are only exemplary and that various modifications can be made in construction and arrangement within the scope of invention as defined in the appended claims.

What is claimed is:

1. A radio-controlled clock comprising time measuring means, receiver means for receiving time signals at various frequencies, adjusting means for periodically correcting said measuring means in accordance with said signals and means for periodically sampling said signals and automatically applying to said adjusting means the most suitable of said various frequency signals.

2. A radio-controlled clock comprising clock means, receiver means for receiving time signals at a plurality of frequencies, adjusting means for periodically correcting said clock means in accordance with said signals and means for periodically sampling said signals and automatically applying to said adjusting means the most suitable of said signals.

3. A radio-controlled clock comprising clock means, receiver means for receiving a plurality of time signal broadcasts at different frequencies, adjusting means for periodically correcting said clock means in accordance with one of said broadcasts and means for periodically sampling said signals and automatically applying to said adjusting means the strongest of said broadcasts.

4. A radio-controlled clock comprising clock means, receiver means for receiving a plurality of radio time

signals broadcast at different radio frequencies, adjusting means for periodically correcting said clock means in accordance with one of said broadcasts, and means for periodically sampling said signals and automatically applying the strongest received broadcast to said adjusting means.

5. A radio-controlled clock comprising clock means, receiver means for receiving a plurality of time signal broadcasts at different frequencies, adjusting means for periodically correcting said clock means, automatic sampling means for selecting the most favorably received broadcast and means for applying said selected broadcast to said adjusting means.

6. A radio-controlled clock comprising clock means, receiver means for receiving a plurality of time signal broadcasts at different radio frequencies, each of said broadcasts including at least two modulation signals, adjusting means responsive to the modulation signals of one of said broadcasts for periodically adjusting said clock means and means for automatically applying the strongest of said received broadcasts to said adjusting means.

7. A radio-controlled clock as defined in claim 6 in which said adjusting means includes an interlocking arrangement responsive to the end of one of said modulation signals and the beginning of another.

8. A radio-controlled clock as defined in claim 7 in which said interlocking arrangement comprises means sensitive to the time interval between the end of one of said modulation signals and the beginning of another of said modulation signals and in which said latter modulation signal provides the actuation signal for said adjusting means.

9. A radio-controlled clock as defined in claim 8 in which said adjusting means includes a charged capacitor responsive to said latter modulation signal for applying a single setting impulse to said clock means during the setting operation.

10. A radio-controlled clock comprising clock means, receiver means for receiving a plurality of time signal broadcasts, automatic sampling means for periodically sampling said broadcasts, a displacement member corresponding to each of said broadcasts, selector means for moving each of said displacement members in proportion to the magnitude of the received voltage from each corresponding broadcast, means responsive to the displacement member corresponding to the strongest of said broadcasts for excluding all other broadcasts and adjusting means responsive to said strongest broadcast for correcting said clock.

11. A radio-controlled clock as defined in claim 10 in which said selector means comprises a moving coil.

12. A radio-controlled clock as defined in claim 10 in which said selector means is a motor-driven rack.

13. A radio-controlled clock comprising clock means, receiver means for receiving a radio time signal broadcast having first and second time spaced modulation signals, and adjusting means responsive to the time interval between said first and second modulation signals for correcting said clock means.

14. A radio-controlled clock comprising clock means, receiver means for receiving a radio time signal broadcast having first and second time spaced modulation signals, adjusting means including timer means for detecting the time interval between said first and second modulation signals, and means sensitive to said time interval for applying a correction pulse to said clock means upon reception of said second modulation signal.

15. A radio-controlled clock as defined in claim 14 in which said first and second modulation signals are of different frequencies.

16. A radio-controlled clock comprising clock means, receiver means for receiving a plurality of time signal broadcasts at different radio frequencies, program timer means periodically responsive to said clock means, sam-

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pling means responsive to said program timer means for periodically sampling said signal broadcasts, a displacement member for each of said broadcasts, means responsive to said broadcasts for transversely displacing said displacement members in proportion to the magnitude of the received voltage of the broadcast being sampled, adjusting means for said clock means, charged capacitor means for energizing said adjusting means, and means responsive to said program timer means for coupling the one of said broadcasts corresponding to the most displaced of said displacement members to said capacitor means.

17. A radio-controlled clock as defined in claim 16 in which said displacing means comprises a moving coil.

18. A radio-controlled clock as defined in claim 16 in which said displacing means comprises pinion-driven gear rack means including means for reducing the gain of said receiver means in proportion to the displacement of said rack means.

19. A radio-controlled clock comprising clock means, receiver means for receiving a radio time signal broadcast having first and second time spaced modulation signals, adjusting means responsive to the time interval between said first and second modulation signals for correcting said clock means, and sampling means connected to said adjusting means for rendering said adjusting means in-

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operative upon the reception of a signal during said time interval.

20. A radio-controlled clock comprising clock means, receiver means for receiving a radio time signal broadcast having first and second time spaced modulation signals, adjusting means for detecting the time interval between said first and second modulation signals, means sensitive to said time interval for applying a correction pulse to said clock means upon reception of said second modulation signal and sampling means coupled to said correction pulse applying means for rendering said latter means inoperative upon the reception of a signal near the end of said time interval.

21. A radio-controlled clock as defined in claim 20 in which said first and second modulation signals are of different frequencies.

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