

[54] **ELECTRONIC TIMEPIECE AND METHOD OF MAKING THE SAME**
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[22] Filed: **June 1, 1973**
[21] Appl. No.: **366,012**
[52] U.S. Cl. **58/23 AC; 58/50 R; 331/176**
[51] Int. Cl. **G04c 3/00; G04b 19/30**
[58] Field of Search **58/23 R, 23 A, 23 AC; 331/110, 113, 116, 176**

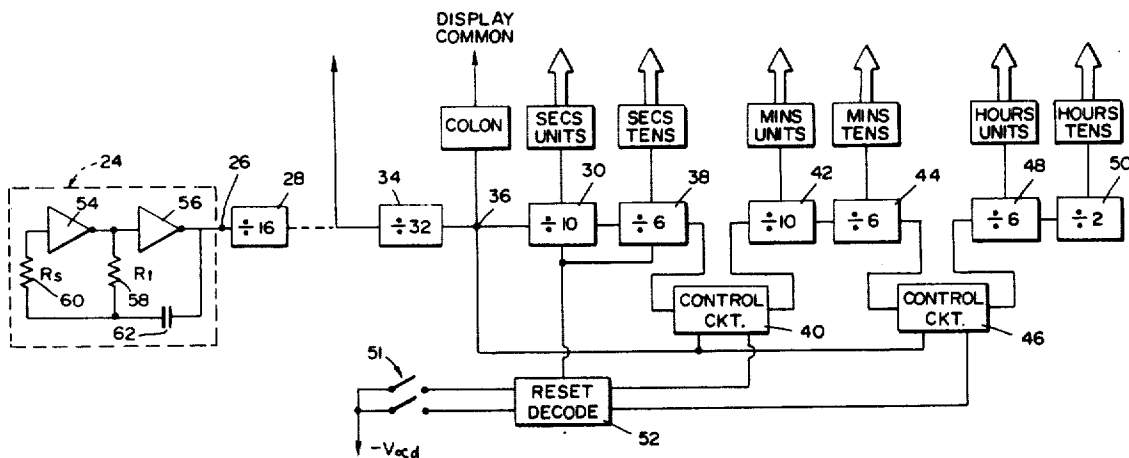
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[57] **ABSTRACT**
An electronic digital timepiece comprises a liquid crystal display on which is directly mounted the time base generator and logic circuitry in the form of an integrated circuit. The time base generator comprises a resistor-capacitor oscillator wherein the timing resistor and/or the timing capacitor are laser trimmed to adjust the output frequency of the time base generator.

9 Claims, 9 Drawing Figures



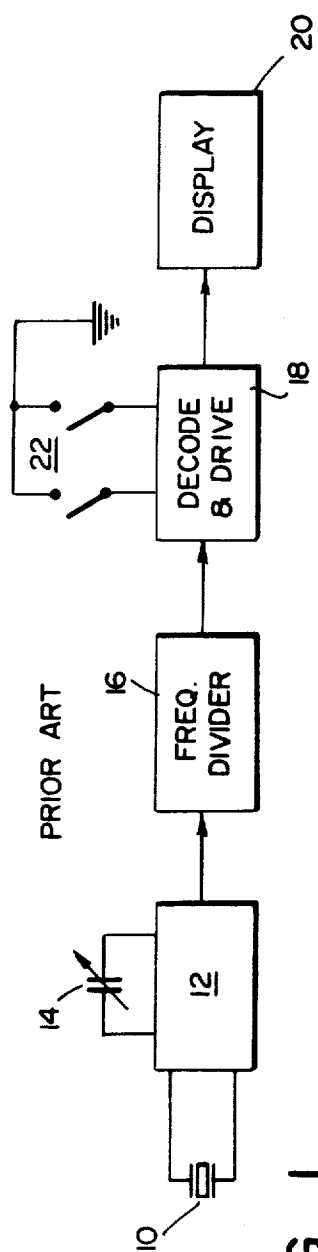


FIG. 1

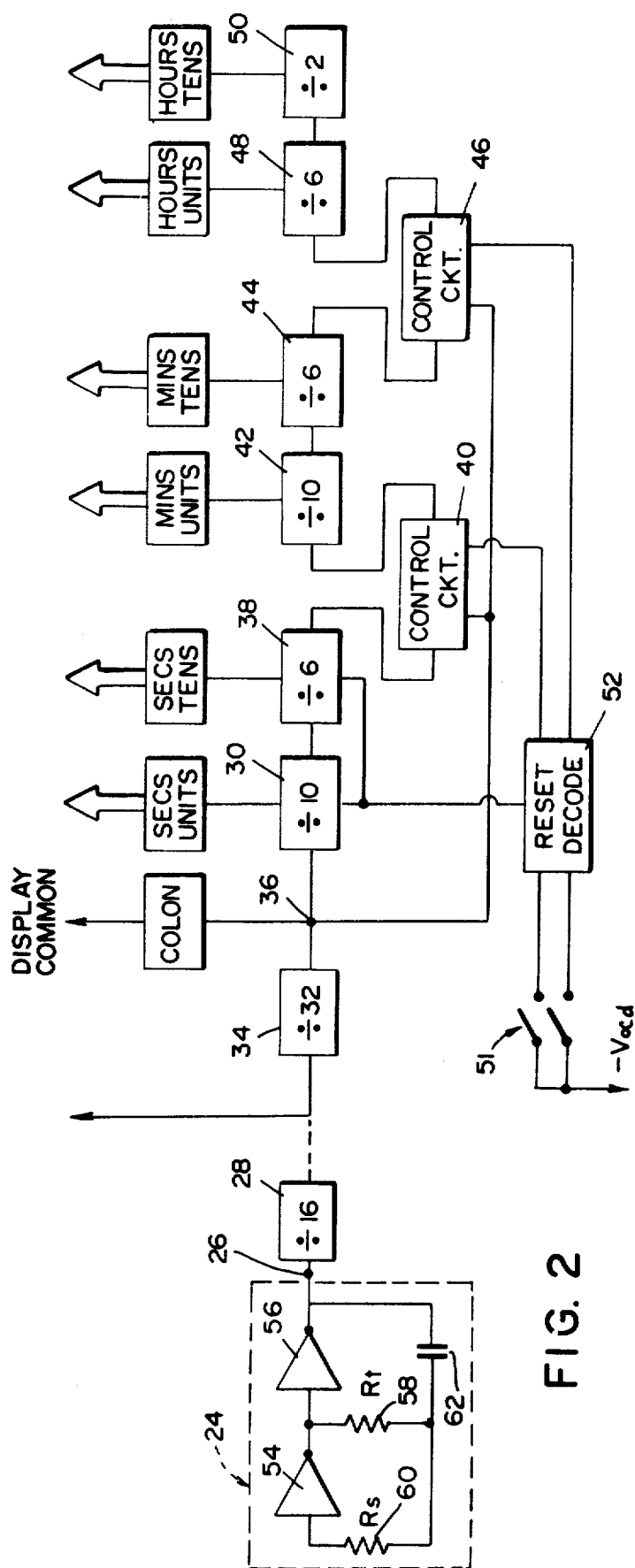


FIG. 2

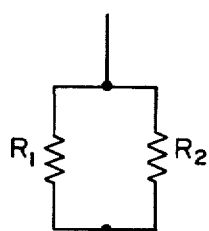


FIG. 5A



FIG. 5B

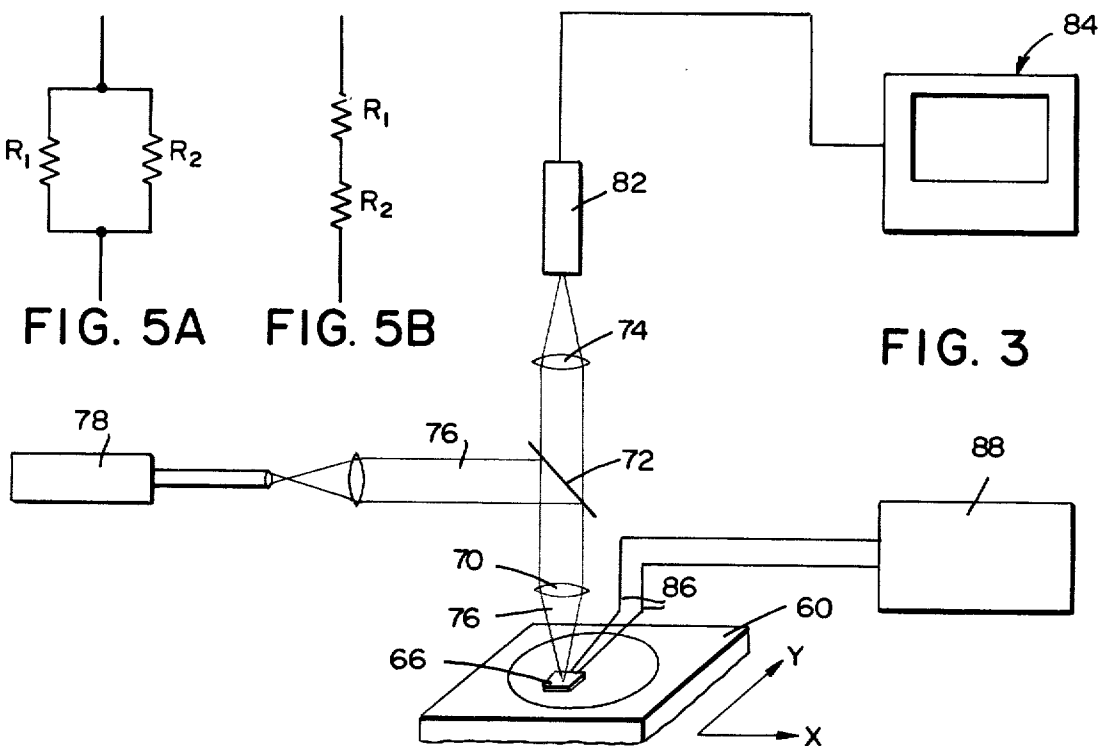


FIG. 3

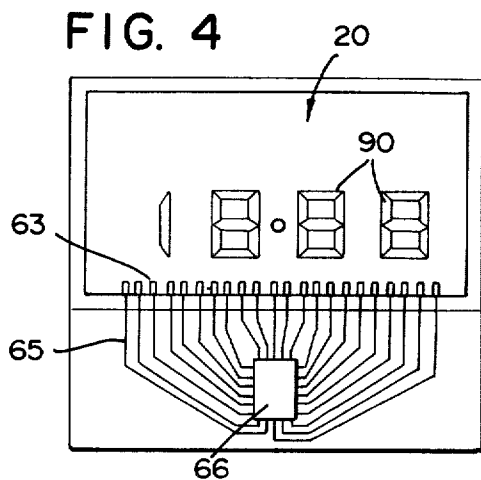


FIG. 4

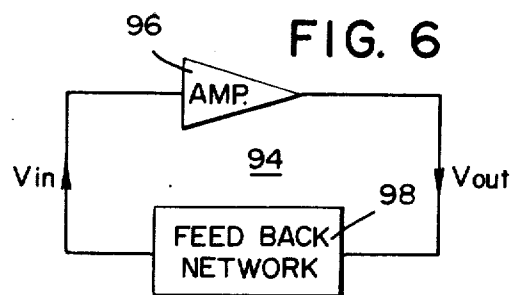


FIG. 6

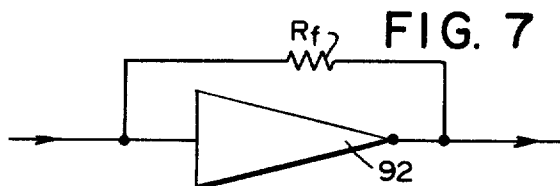


FIG. 7

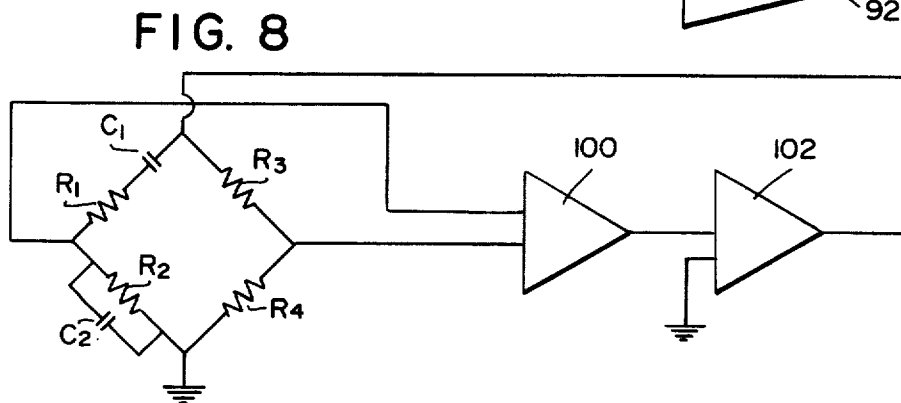


FIG. 8

ELECTRONIC TIMEPIECE AND METHOD OF MAKING THE SAME

BACKGROUND OF THE INVENTION

The present invention relates to electronic timepieces and more particularly to a novel low-cost electronic digital timepiece and methods of manufacture thereof.

Battery-driven electronic digital timepieces have recently become widespread in use, their popularity in part due to increased reliability and ease of reading the time as compared to conventional mechanical timepieces. Many of the currently available electronic timepieces utilize light emitting diodes (LED's) or liquid crystal displays (LCD's) for the digital face display. The relatively high cost of such electronic digital timepieces, however, particularly of the electronic digital watches, as compared to conventional mechanical watches, has limited their availability to many people. A primary contributing factor to the high cost of such presently available electronic watches is the cost of the time base generator which in most instances comprises a quartz crystal oscillator circuit. The use of other types of low-cost oscillators in lieu of the quartz crystal oscillator to serve as a time base generator has been inhibited due to the difficulty of rendering such oscillators sufficiently stable and accurate in their output frequency to enable them to serve as a satisfactory time base generator for electronic timepieces.

It is therefore an object of the present invention to provide a low-cost electronic timepiece of reduced size and relatively high time-keeping accuracy.

It is another object of the present invention to provide a method of manufacture of an electronic timepiece of the character described in the preceding object.

In accordance with the principles of the present invention there is provided an electronic timepiece comprising display means for displaying time in digital read-out form, and a time base generator which is operative to produce a train of output pulses having a preselected pulse repetition frequency and logic circuit means in the form of an integrated circuit mounted on the display means. The logic circuit means is connected to the output of the time base generator and is operative to count down the time base generator and is operative to count down the time base pulse train to provide first and second pulse trains having pulse repetition frequencies of one pulse per hour and one pulse per minute respectively. In the manufacture of the electronic timepiece of the present invention, the output frequency of the time base generator may be adjusted to a preselected value by directing an infra-red laser beam on the timing resistor and/or the timing capacitor thereof while monitoring the time base generator output frequency and maintaining the said time base generator output frequency stable by employing a timing resistor and a timing capacitor having opposite temperature coefficients respectively.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a functional block diagram showing the components of prior art electronic timepieces;

FIG. 2 is a combined schematic and functional block diagram of an electronic timepiece in accordance with the present invention in one embodiment thereof;

FIG. 3 is a schematic diagram illustrating the method of manufacture of an electronic timepiece in accordance with the present invention;

FIG. 4 shows a liquid crystal display mounting a MOS wafer comprising the electronic circuitry of FIG. 2;

FIGS. 5A and 5B are schematic diagrams of the possible arrangements of the resistors forming the timing resistor in the oscillator circuit of FIG. 2 in the process of adjusting the resistance value of the timing resistor;

FIG. 6 is a functional block diagram of an alternate type of oscillator circuit for use as the time base generator in the electronic timepiece of the present invention;

FIG. 7 is a schematic diagram of an oscillator circuit of the type illustrated in FIG. 6; and

FIG. 8 is a schematic diagram of another oscillator circuit suitable for use as the time base generator in the electronic timepiece of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Currently available digital display wrist watches commonly comprise the following components shown functionally in FIG. 1. A quartz crystal 10 in circuit with an oscillator circuit 12 serves as a reference time base, i.e., it acts as a source of clock pulses for the time system. A trimmer capacitor 14 associated with oscillator circuit 12 is operative to adjust the frequency of the pulse output from oscillator circuit 12, so that the pulse frequency is suitable for being counted down by frequency divider circuit 16 into pulse trains whose frequency corresponds to seconds, minutes and hours. Decoder and driver circuit 18 converts the pulse trains from divider and decoder circuit 18 into signals of suitable waveform and coding for driving the digital display 20 which may take the form of a LED (light emitting diode) or LCD (liquid crystal display) display 20. Additionally, a time-setting switch 22 is usually provided in circuit with decoder and driver circuit 18 for resetting, i.e., advancing the time display 20 to the correct reading. A miniature-sized battery (not shown) is also provided, either alone or with a voltage up-converter (not shown) as an electrical power source for the electrical circuit components just described. A principal drawback of the above-described electronic watches is the cost of manufacture thereof, which is due primarily to the use of a quartz crystal as the clock pulse sources. The present invention contemplates the substitution of a low-cost resistor-capacitor oscillator circuit for the above-described quartz crystal oscillator circuit. The substantial cost reduction made possible by this substitution can be better understood by recognizing that the RC (resistor-capacitor) time base circuit of the present invention may be manufactured integrally with the other logic circuitry, i.e., frequency divider and decoder circuits as a single semiconductor circuit chip. Presently, the quartz crystal must be individually assembled with the other logic circuitry, a procedure which is time consuming and costly. Thus, elimination of the quartz crystal and the substitution therefor of electronic circuitry of low manufacture cost, which is functionally equivalent thereto provides an electronic watch of substantially reduced cost.

The costs of manufacture of semiconductor circuitry in integrated circuit form has been greatly reduced in recent years and this trend of cost reduction is generally expected to continue in the foreseeable future. This trend in reduction of the cost of manufacture of semi-

conductor circuitry has been accompanied by great reductions in the overall size of electronic circuitry such that thousands of electronic components such as transistors, resistors, capacitors and diodes can be incorporated in a semiconductor chip of the order of 1 square inch. Such miniaturization is of great importance for electronic wrist watches where the overall size of the operational components is a critical factor. In fact, worn by women, stringent size limitations inherent therein, has severely limited the introduction of small sized electronic wrist watches such as those commonly favored by women. The elimination of the quartz crystal and the inclusion of the RC oscillator time base in its stead as an integral part of the logic circuitry in a single chip as contemplated by the present invention facilitates the size reduction necessary for such small sized watches.

In accordance with the foregoing requirements, reference being made to FIG. 2, the basic components of an electronic timepiece in accordance with the present invention include an RC controlled oscillator 24 serving as a time base, logic circuitry in the form of a CMOS wafer to provide the proper encoding for the time display (shown in FIG. 5), an extremely low power digital display such as a low voltage field effect liquid crystal display and a power source (not shown) such as a mercury or silver oxide battery to power the just-mentioned component.

An important factor in the present invention is the design of a time base generator which is low cost yet of sufficient precision for the purposes of a timepiece of at least conventional accuracy. For this purpose an RC oscillator 24 as shown in FIG. 2 was provided whereby the major portion thereof is an integral part of a low cost single CMOS wafer which incorporates the logic circuitry described hereinafter in greater detail.

Oscillator 24 comprises first and second inverter stages 54 and 56 which form an integral portion of the CMOS wafer just-mentioned. A timing resistor 58 is connected at one end thereof to the junction of inverter stages 54 and 56, a series resistor 60 is connected between first inverter stage 54 and timing resistor 58, and a timing capacitor 62 is connected between the output of inverter stage 56 and timing resistor 58. Oscillator 24 is operative to produce at its output a pulse train having a pulse repetition frequency (*prf*) of, for example, 512 HZ, which frequency is subsequently divided down by divider circuits 28 and 34 to derive a pulse train at junction point 36 having a *prf* of 1 HZ, i.e., providing an ON pulse every second. For this purpose, circuit 28 frequency divides by a factor of 16 and circuit 34 frequency divides by a factor of 32. The pulse output at junction 36 is further frequency divided down by divider circuits 30 and 38, whereby the output from divider circuit 38 has a PF of 1/60 HZ or one ON pulse every 60 seconds representing MINUTES readout. The output of divider circuit 38 is applied through control circuit 40 to divider circuits 42 and 44 to produce, at the output of divider circuit 44, a pulse train having a pulse repetition frequency of 1/3600 HZ, or one ON pulse every 60 minutes representing HOURS readout. The pulse output from divider circuit 44 is applied through control circuit 46 to divider circuits 48 and 50 to give the number of hours readout. Reset-decode circuit 52 is connected to divider circuits 30 and 38 to clear and reset these circuits upon occurrence of the pulse subsequent to readout of the number "59." Re-

set-decode circuit 52 is also connected to control circuits 40 and 46 to clear and reset divider circuits 42, 44 and 48, 50 respectively upon occurrence of the pulses subsequent to the numbers "59" and "11" respectively. A reset switch 52 is also provided to provide reset pulses to divider circuits 30 and 38, and control circuit 40 and 46 when it is desired to reset the "Seconds," "Minutes" and "Hours" counting circuits to zero.

The above-described countdown logic circuitry i.e., circuits 28, 34, 30, 38, 40, 42, 44, 46, 48, 50 and 52, is available as an integrated circuit on a CMOS, (an acronym for Complementary Metallic Oxide Semiconductor) chip such as, for example, Solid State Scientific Inc. Model No. SCL 5424.

In the manufacture of oscillator 24, it is desirable that the frequency of oscillation be low enough to obtain minimum power consumption, yet sufficiently high so as to avoid the necessity for large values of resistance and capacitance. If, for example, the selected oscillation frequency is 512 HZ, the required RC time constant will be about 0.88×10^{-3} seconds, for which a resistor of about 2.92 megohms and a capacitor of 300 pf will be called for. Thin film resistors can, in the present state of the art, such as gold-tantalum oxide film, be made to have a sheet resistance of slightly less than 10^5 ohms per square, with a temperature coefficient of resistance of about -200 ppm. Furthermore, thin film capacitors having silicon nitride as the dielectric can be made, in the present state of the art, to reach 1 pf/mil².

A commercially available four-digit liquid crystal display 20 is suitable for use in the electronic time-piece of the present invention. In accordance with the principles of the present invention, the thin film resistors 58 and 60 and thin film capacitor 62 of oscillator 24 may be fabricated directly on the glass substrate 64 which forms the display panel of display 20. The previously discussed CMOS wafer 66 which comprises inverters 54 and 56 as well as the logic circuitry elements 28, 30, 34, 38, 40, 42, 44, 46, 48, 50 and 52 may also be hybridized onto glass substrate 64 as shown in FIG. 4. The correct timing pulse output of oscillator 24 may be set either by the use of a trimmer capacitor 62 which may be set apart from the integrated circuit CMOS wafer 66 or by having trimmer capacitor 62 as an integral part of wafer 66, but trimming timing resistor 58 to obtain the desired *prf* for the timing pulse output of oscillator 24. Wafer 66, with its oscillator 24 adjusted to provide the proper output *prf* may be electrically connected to the terminators 63 on display 20 by means of leads 65.

In yet another embodiment of the present invention, timing resistor 58, series resistor 60 and timing capacitor 62 may be fabricated as an integral part of CMOS wafer 66, whereby the labor cost for manufacture of the electronic timepiece of the present invention is greatly reduced. In this embodiment, adjustment of timing resistor 58 to provide the desired *prf* for the timing pulse output of oscillator 24 may be achieved in the following manner, reference being made to FIG. 3 of the drawings.

As shown in FIG. 3, the processed CMOS wafer 66 is placed on an X-Y table 68 which, as its name suggests, may be controllably moved in directions parallel to the X and Y axes as shown. An optical arrangement comprising an objective lens 70, a half-silvered mirror 72 and a microscope lens 74, are located above wafer 66 so as to be in optical alignment with the timing resis-

tor 58 in wafer 66. An infra-red laser beam 76 produced by a conventional laser 78 is projected through lens 80 and is reflected downward by mirror 72 through objective lens 70 onto the resistive portion of timing resistor 58.

In order to monitor and ensure the correct alignment of wafer 66 with respect to laser beam 76 impinging thereon, a television camera 82, provided with a cross-hair sight therein (not shown) for sighting the resistive portion of timing resistor 58, is optically aligned with microscope lens 74, mirror 72 and objective lens 70. A television monitor 84 is connected to camera 82 and located at a remote position therefrom so as to remove the operator from the vicinity of laser beam 76. A pair of probes 86 making contact with the output of oscillator 24 at one end thereof are connected to a frequency meter 88 which is located together with television monitor 84 and the drive control (not shown) for X-Y table 68 at the operator's working position remote from laser beam 76. Mirror 72 is operative to reflect downward the infra-red laser beam 76 while being transparent to the visible light rays from wafer 66 which travel through microscope lens 74 to be picked up by television tube 82 whereby television monitor 84 displays timing resistor 58 in greatly magnified form.

Adjustment of timing resistor 58 is accomplished by turning on laser 78 whereby laser beam 76 creates local heat on timing resistor 58 to burn away a portion thereof thereby increasing the resistance thereof and thereby decreasing the output frequency of oscillator 24. This process is continued until the output frequency of oscillator 24 as shown by frequency meter 88 reaches the desired value.

In practice, in order to achieve sufficient accuracy of the electronic timepiece, it has been found necessary to trim timing resistor 58 to an accuracy of about 1 percent, which accuracy is ordinarily unattainable by means of the conventional commercially available trimmer resistor. Referring to FIG. 5A, this problem may be overcome by forming timing resistor 58 to comprise a pair of resistors R_1 and R_2 in parallel arrangement and having the resistance of resistor R_2 much greater than that of resistor R_1 . In such an arrangement the total timing resistance R_t is equal to the product of the resistances of resistors R_1 and R_2 divided by the sum thereof. Thus, if the resistance of resistor R_2 is three times the resistance of resistor R_1 and if resistor R_2 is trimmed to an accuracy of 2.5 percent, the total timing resistance R_t will be trimmed to an accuracy of 0.625 percent. Similarly, referring to FIG. 5B, if resistors R_1 and R_2 are in series arrangement, and if the resistance of resistor R_1 is three times the resistance of resistor R_2 , and if resistor R_2 is trimmed to an accuracy of 2.5 percent, the resulting accuracy of the total timing resistance R_t will be 0.625 percent. Thus, in FIG. 5A resistor R_2 serves as the "coarse" adjustment and resistor R_1 the "fine" adjustment, and in FIG. 5B resistors R_1 and R_2 serve as the "coarse" and "fine" adjustment resistors.

Wafer 66, when completely fabricated as described hereinabove, will have a total of 28 leads 65 for outside connections thereto, as follows. Twenty-four leads 65 will be necessary for the $3\frac{1}{2}$ digits display formed of the character elements 90, two for the power and ground connections respectively, and for the externally connected setting switch 51. The display 20 should require extremely low power consumption so that a single small

conventional mercury or silver oxide battery (not shown) will have a life of about 5 years when used as a power source for the electronic timepiece of the present invention.

Since the power consumption of a CMOS wafer, such as wafer 66, decreases with a reduction in operating frequency (due principally to the presence of stray capacitance), the total power consumption of an electronic timepiece in accordance with the present invention is estimated to be less than 3 watt for an oscillator 24 output frequency of 1,024 HZ. Thus, a battery having a 100 milliamp-hour capacity should have an operating life of at least 5 years in use with the electronic timepiece of the present invention.

After assembly of wafer 66 to display 20 as described hereinabove, the battery (not shown) and setting switch 51 are separately connected to the display 20 and a pair of unconnected metal strips (not shown) are run respectively from the battery and the power input terminals of the wafer 66 to the outside of the molded plastic case (not shown) in which the display 20, wafer 66, battery and setting switch 51 are encased. The just-mentioned metal strips are joined by the retail vendor of the electronic timepiece only when it is selected by the consumer, thereby avoiding unnecessary power drain on the battery during the shelf life of the electronic timepiece.

The time accuracy of the electronic timepiece of the present invention will be to an important degree determined by the precision of the timing resistor and timing capacitor in the time base oscillator circuit 24, which in turn are limited by the temperature coefficients thereof. In this connection, best results may be obtained by having the timing resistor made of thin film resistance material which typically has a temperature coefficient of about +200 PPM/°C, and having the timing capacitor of thin film capacitance material which has a temperature coefficient of about -200 PPM/°C, where PPM/°C refers to the change in oscillator frequency in pulses per minute per °C ambient temperature change. Thus, because the positive and negative temperature coefficients of the timing resistor and timing capacitor tend to balance each other, the net temperature coefficient will be very small and in any event is not expected to exceed 20 PPM/°C.

The precision of the electronic timepiece is also dependent on the transfer voltage of the circuitry in wafer 66 which affects the time required for inverters 54 and 56 to switch from the 0 state to the 1 state. It has been found that the transfer voltage of the CMOS inverters 54 and 56 varies by less than 10 percent over the temperature range of -55°C to 125°C which corresponds to a frequency drift of about 1,000 PPM or 1.5 minutes per day for the electronic timepiece.

Although the electronic timepiece of the present invention has been described hereinabove as employing an astable multivibrator type of oscillator 24 as the time base generator, other types of oscillators which employ an RC circuit and an amplifier to achieve oscillation may be used with satisfactory results. Thus, FIG. 6 shows a phase shift oscillator 94 comprising an amplifier 96 having a gain α and phase shift θ_1 and a feedback network 98 having an attenuation factor β and a phase shift θ_2 . In this circuit, if the net loop gain, i.e., the product of α and β , is equal to or greater than one, and the total phase shift, i.e., the sum of θ_1 and θ_2 is an integer multiple of 360°, oscillation will occur.

FIG. 7 is a schematic diagram of an oscillator circuit available in a CMOS wafer, whereby an inverter 92 has a high-resistance feedback resistor R_f connected between the output and input terminals thereof.

FIG. 8 is a schematic diagram of yet another type of oscillator circuit, known as the Wien Bridge oscillator, which is suitable as a time base generator to the present electronic timepiece. This oscillator circuit comprises two amplifier stages 100 and 102 in which case oscillation occurs when the phase angles of the two resistance-capacitance impedance in the bridge circuit are equal, whereby the oscillation frequency, f_o is given as

$$f_o = 1/2\pi \cdot 1/\sqrt{R_1 R_2 C_1 C_2}$$

The oscillator of FIG. 7 has been found to provide greater frequency stability than oscillator 24 of FIG. 2 but obviously requires a greater number of components than oscillator 24.

While preferred embodiments of the invention have been shown and described herein, it is obvious that numerous omissions, changes and additions may be made in such embodiment without departing from the spirit and scope of the invention.

What I claim is:

1. An electronic timepiece comprising display means for displaying time in digital readout form, a resistor-capacitor oscillator time base generator operative to produce a first train of output pulses having a preselected pulse repetition frequency, and logic circuit means connected to the output of said time base generator and operative to count down said first time base pulse train to provide second and third pulse trains having pulse repetition frequencies of one pulse per hour and one pulse per minute respectively, said time base generator and said logic circuit means being in the form of an integrated circuit mounted on said display means, said time base generator including a timing resistor comprising first and second resistors the resistance value of said first resistor being at least several times as large as the resistance value of said second resistor.

2. An electronic timepiece comprising display means for displaying time in digital readout form, a resistor-capacitor oscillator time base generator operative to produce a first train of output pulses having a preselected pulse repetition frequency, and logic circuit means connected to the output of said time base generator and operative to count down said first time base

pulse train to provide second and third pulse trains having pulse repetition frequencies of one pulse per hour and one pulse per minute respectively, said time base generator and said logic circuit means being in the form of an integrated circuit mounted on said display means, said time base generator including a timing resistor comprising first and second resistors in series arrangement, the resistance value of said second series resistor being at least several times as large as the resistance value of said first series resistor.

3. An electronic timepiece as defined in claim 1 wherein said resistor-capacitor oscillator comprises said timing resistor and a timing capacitor whose respective resistance values and capacitance values determine the pulse repetition frequency of said first train of output pulses.

4. An electronic timepiece as defined in claim 3 wherein said timing resistor has a positive temperature coefficient whereby the pulse repetition frequency of said first pulse train tends to decrease for an increase in the ambient temperature of said timing resistor and consequent increase in the resistance value thereof.

5. An electronic timepiece as defined in claim 4, wherein said timing capacitor has a negative temperature coefficient whereby the pulse repetition frequency of said first pulse train tends to increase for an increase in the ambient temperature of said timing capacitor and consequent decrease in the capacitance value thereof.

6. An electronic timepiece as defined in claim 5 wherein the absolute values of said positive and negative temperature coefficients respectively of said timing resistor and timing capacitor are substantially numerically equal whereby the pulse repetition frequency of said first pulse train tends to remain substantially constant in response to an increase or decrease in the ambient temperature of said time base generator.

7. An electronic timepiece as defined in claim 1 wherein said time base generator comprises a phase shift oscillator.

8. An electronic timepiece as defined in claim 1 wherein said time base generator comprises a Wien bridge oscillator.

9. An electronic timepiece as defined in claim 1 wherein said first and second resistors are in parallel arrangement.

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