United States Patent [19]

Chapman

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[54] **ACCURACY ADJUSTMENT FOR TIME-OF-DAY CLOCK USING A MICROCONTROLLER**

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[22] Filed: **Sep. 5, 1989**

[51] **Int. Cl.⁴** **G04C 13/08**; G04B 17/12

[52] **U.S. Cl.** **368/156**; 368/200

[58] **Field of Search** 368/155–157, 368/200–202; 364/569; 331/47, 66, 176

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,282,595	8/1981	Lowdenslager et al.	368/200
4,321,698	3/1982	Gomi et al.	368/202
4,407,589	10/1983	Davidson et al.	368/200
4,448,543	5/1984	Vail	368/202
4,502,790	3/1985	Yokoyama	368/200
4,513,259	4/1985	Frerking	331/176
4,644,484	2/1987	Flynn et al.	368/200
4,708,491	11/1987	Luitje	368/156

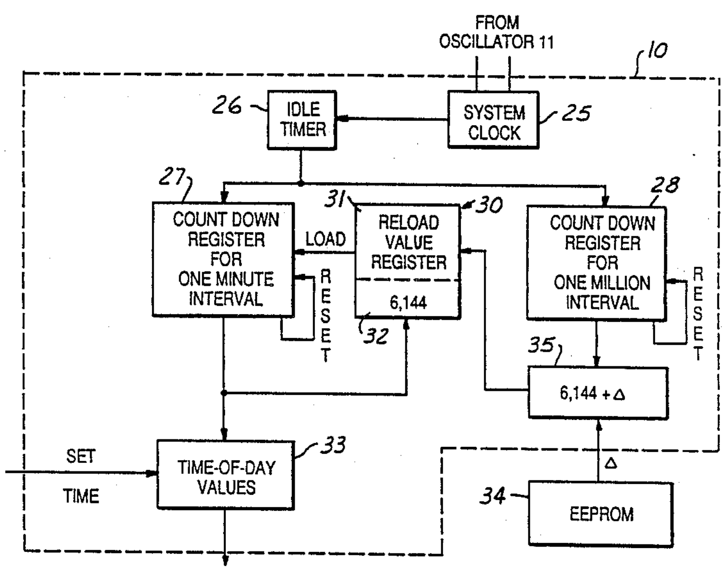
Primary Examiner—Vit W. Miska

Attorney, Agent, or Firm—Mark L. Mollon; Paul K. Godwin

[57] **ABSTRACT**

A microcontroller, software-based time-of-day clock compensates for inaccurate oscillator frequency by periodically correcting the time-of-day value using a calibration offset measured by manufacturing test equipment and permanently stored in nonvolatile memory. A high degree of time keeping accuracy is achieved without the use of trimming capacitors or presorted piezoelectric crystals in the oscillator. Furthermore, frequency error compensation is incorporated into the microcontroller system without requiring a significant amount of processing time overhead.

11 Claims, 3 Drawing Sheets



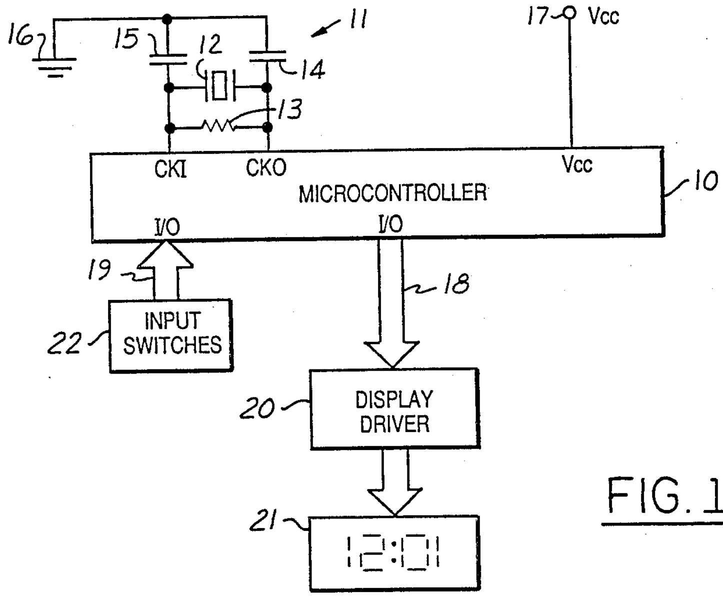
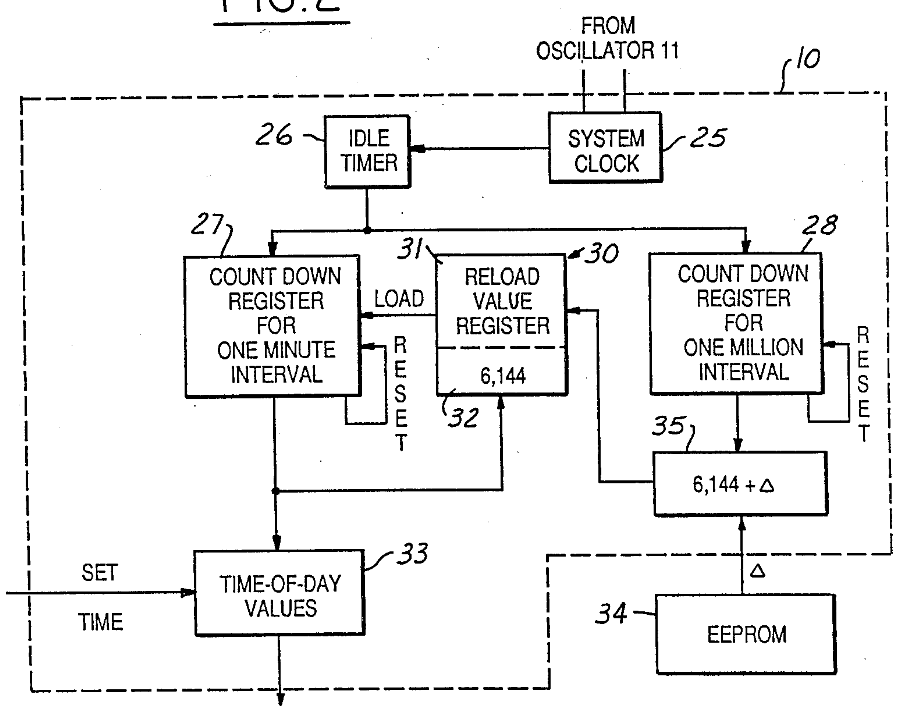
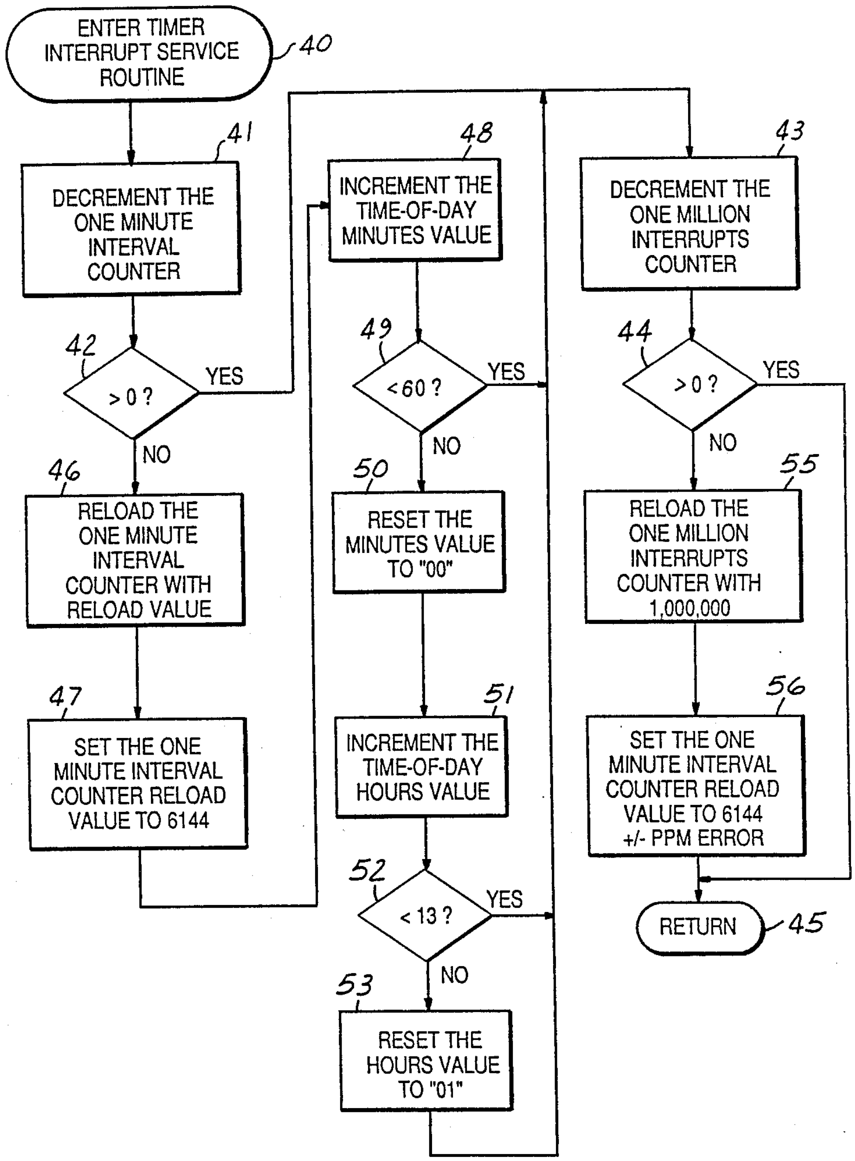

11
16
15
12
14
13
17
Vcc
CKI
CKO
Vcc
MICROCONTROLLER
10
I/O
I/O
19
18
INPUT SWITCHES
22
DISPLAY DRIVER
20
21
12:01

FIG. 1

FIG. 2


FROM OSCILLATOR 11
10
26
IDLE TIMER
SYSTEM CLOCK
25
27
28
31
30
COUNT DOWN REGISTER FOR ONE MINUTE INTERVAL
LOAD
RELOAD VALUE REGISTER
6,144
COUNT DOWN REGISTER FOR ONE MILLION INTERVAL
RESET
32
35
6,144 + Δ
RESET
SET
TIME
TIME-OF-DAY VALUES
33
Δ
34
EEPROM



ENTER TIMER INTERRUPT SERVICE ROUTINE
40
41
DECREMENT THE ONE MINUTE INTERVAL COUNTER
42
> 0 ?
YES
NO
46
RELOAD THE ONE MINUTE INTERVAL COUNTER WITH RELOAD VALUE
47
SET THE ONE MINUTE INTERVAL COUNTER RELOAD VALUE TO 6144
48
INCREMENT THE TIME-OF-DAY MINUTES VALUE
49
< 60 ?
YES
NO
50
RESET THE MINUTES VALUE TO "00"
51
INCREMENT THE TIME-OF-DAY HOURS VALUE
52
< 13 ?
YES
NO
53
RESET THE HOURS VALUE TO "01"
43
DECREMENT THE ONE MILLION INTERRUPTS COUNTER
44
> 0 ?
YES
NO
55
RELOAD THE ONE MILLION INTERRUPTS COUNTER WITH 1,000,000
56
SET THE ONE MINUTE INTERVAL COUNTER RELOAD VALUE TO 6144 +/- PPM ERROR
RETURN
45

FIG. 3

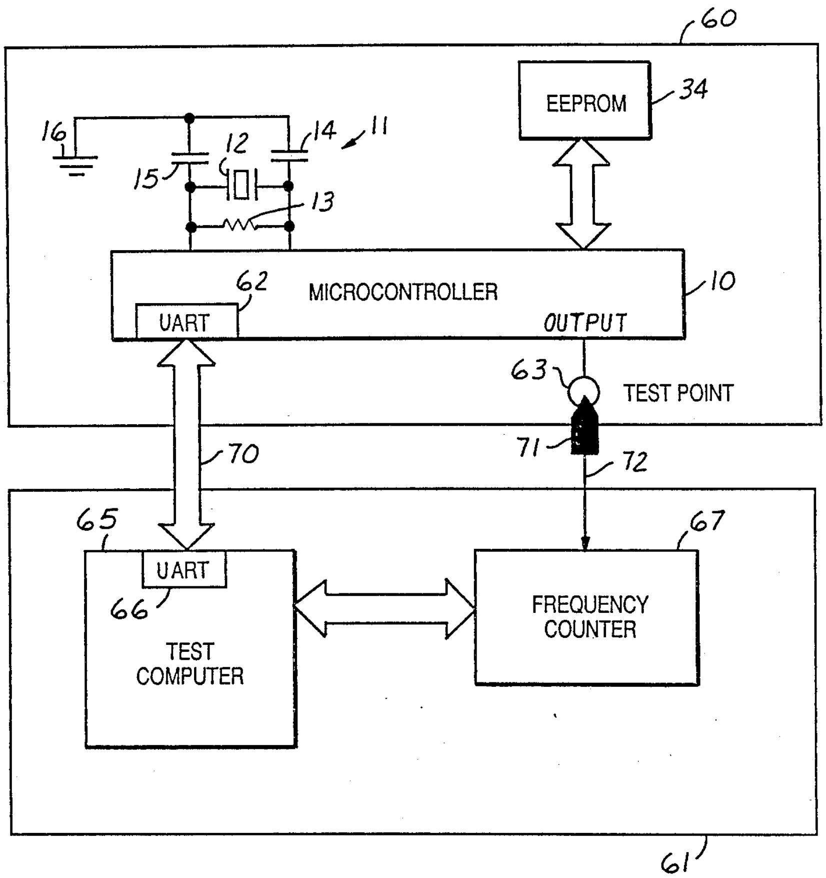

60
EEPROM
34
16
12
14
11
15
13
MICROCONTROLLER
62
10
UART
OUTPUT
63
TEST POINT
70
71
72
65
67
UART
66
FREQUENCY
COUNTER
TEST
COMPUTER
61

FIG.4

ACCURACY ADJUSTMENT FOR TIME-OF-DAY CLOCK USING A MICROCONTROLLER

BACKGROUND OF THE INVENTION

The present invention relates in general to a time-of-day clock implemented using a microcontroller, and more specifically to correcting for time keeping inaccuracies resulting from frequency errors of a crystal oscillator.

Microprocessor and microcontroller systems operate using internal timing circuits for coordinating processing operations and establishing machine timing cycles for execution of instructions. A crystal oscillator is frequently employed to provide timing signals for the microprocessor due to the relatively high accuracy and stability of piezoelectric crystals.

One of the functions that is often performed using a microprocessor or microcontroller is that of a time-of-day clock. Such a clock is implemented using time values stored in memory which are updated periodically by the microprocessor which counts timing signals received from the crystal oscillator. Typically, the time-of-day function is incidental to some other primary control function being implemented using the microcontroller, such as control of an automotive audio system. Proper operation of that primary control function is not highly dependent upon the accuracy of the internal clock which is driven by the piezoelectric crystal oscillator. However, in implementing a time-of-day clock using the microcontroller, a crystal oscillator error amounting to even a few parts per million causes a significant timing error to eventually be accumulated in the time-of-day clock.

Typical manufacture of piezoelectric crystals results in a variability of the crystal's resonant frequency of about 20 parts per million (ppm). In order microcontroller time-of-day clocks, crystals can be presorted into various value ranges by the crystal manufacturer and subsequently matched with particular values of load capacitors for constructing each individual crystal oscillator. Such sorting and matching of components increases the cost of the clock.

Another method for obtaining accurate oscillator signals is to provide a variable load capacitor to allow adjustment (i.e., trimming) of the oscillator frequency. However, the variable capacitor and the need for manual calibration add expense to the oscillator.

It is preferable to manufacture an oscillator using unmatched, standard tolerance components without special trimming capacitors. Therefore, there have been attempts to allow the oscillator to run at an incorrect frequency, measure the frequency error, and compensate for the error within the microcontroller as it keeps track of time-of-day. For example, Luitje (U.S. Pat. No. 4,708,491), discloses an untrimmed crystal circuit connected to the oscillator of a microcomputer. After frequency prescaling, the timing signal is measured to determine an error value. A correction term is stored in the microcomputer via entry from a keyboard. During clock operation, the value in a free-running counter is compared to a programmable register. Interrupts are generated when the number in the programmable register equals the number in the free-running counter. The interrupts provide a time base for keeping track of time-of-day. The correction term is used in loading the programmable register once each second so that the time

intervals of the interrupts themselves are error corrected.

The ability to change the period between interrupt signals is essential to the technique disclosed in Luitje. However, not all microcontrollers provide user access to the interrupt interval. For example, the COP888 family of microcontrollers manufactured by National Semiconductor Corporation use an idle timer for providing a time base. The idle timer is a free-running 16-bit timer which is clocked from the crystal oscillator via a divide-by-10 circuit. Whenever the 12th bit toggles its value, an interrupt is generated by the idle timer which can be used to update various time-of-day counters. The period between these interrupts is not programmable and depends only upon oscillator frequency. Therefore, the technique described in Luitje cannot be used. Furthermore, the calculations required to apply error correction to the programmable register value and the need to correct for inaccuracies each and every second increases the processor overhead associated with use of the Luitje technique to an undesirable level.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to improve time-of-day clock accuracy for a microcontroller software-based clock in an inexpensive manner.

It is another object of the present invention to provide a method and apparatus for correcting for time-of-day inaccuracies resulting from the use of unmatched, unsorted components in a crystal oscillator.

It is a further object of the invention to reduce microcomputer processing time overhead associated with correction of time-of-day measurement.

These and other objects are achieved in an apparatus comprising idle timer means for generating interrupts separated by a fixed time period which differs from an ideal time period by an error. First counting means are coupled to the idle timer means and have a first register for counting the interrupts and for generating an increment signal when a number of interrupts have occurred equal to a load value which is loaded into the first register. Reload means are coupled to the first counting means for storing a reload value and for (1) transferring the reload value to the first register as the load value upon the occurrence of the increment signal and (2) then resetting the reload value to a predetermined value. Second counting means are coupled to the idle timer means and to the reload means for counting the interrupts and for transfering an adjusted reload value including an accumulated error value to the reload means as the reload value when a number of interrupts have occurred equal to a large count number relatively greater than the predetermined value. Time means are coupled to the first counting means and receives the increment signal for keeping track of time-of-day. Preferably, the apparatus further comprises nonvolatile storage means coupled to the reload means for storing the accumulated error value or the adjusted reload value. The accumulated error value is substantially equal to the algebraic sum of the predetermined value (i.e., normal reload value) and the quantity resulting from the time period error times the large count number divided by the ideal time period.

The invention also provides a method for maintaining accurate time keeping with an interrupt-driven clock, the interrupts being separated by a fixed time period. The method includes the steps of maintaining a first count of interrupts corresponding to a first time interval

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