An accurate millisecond timer for the Commodore 64 or 128

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The use of the Commodore 64 or 128 as an accurate millisecond timer is discussed. BASIC and machine language programs are provided that allow the keyboard to be used as the response manipulandum. Modifications of the programs for use with a joystick or external switches are also discussed. The precision, flexibility, and low cost of these machines recommends their use as laboratory instruments.

Although timing routines with millisecond resolution are available for TRS-80 (Owings & Fiedler, 1979) and 6500 series (Price, 1979) microcomputers, none are specifically written for the Commodore 64 (C-64) or the more recent Commodore 128 (C-128). The programs presented below transform the C-64 or the C-128, operating in either its 64 or 128 mode, into an accurate millisecond timer. Using these programs does not, however, limit the computer to timing applications. The programs are designed to serve as subroutines that end users may incorporate into programs of their own design, thus allowing increased flexibility.

These Commodore computers are easy to program and interface with external equipment, and the C-64, especially, offers considerable computing power at a relatively modest cost (the C-64, a monochrome monitor, and the 1541 disk drive can currently be purchased for under \$400).

DESCRIPTION OF TIMER

Timers Within the C-64

The C-64 and C-128 are equipped with three timing sources, namely, a user-programmable time-of-day clock (resolution to .1 sec), a jiffy clock that counts the system-generated interrupts (resolution to .16 sec), and four 2-byte counter/timers located on two 6526 Complex Interface Adapters (CIAs) (resolution to 1 μ sec). The versatility of the C-64's and C-128's timers make the machines particularly useful as laboratory controllers.

CIA Timers as Millisecond Timers

The two 16-bit registers, referred to as timer A (TA) and timer B (TB), which are located on CIA #2, are free for use. They may be loaded with values between 0 and 65535, and may be set to decrement at a rate determined

by the system clock, which is 1.022727 MHz. In order to obtain resolution in the millisecond range, TA is loaded with the value 1022 (\$3FE) and is started in its recycling mode by setting bits 0 and 4 in control register A (CRA). This configuration results in TA's underflowing 1000.3 times per second (a value as close to 1 msec as can be achieved using binary registers). Since TB is counted down by TA underflows, initializing TB with 65535 (\$FFFF) permits elapsed times up to 1.5 min to be counted in milliseconds by complementing the value in TB, after TA has been stopped.

The millisecond timer was calibrated with a Systron Donner 1037 Series Counter (Model No. 1924). Using a sample rate of 1 sec, the timer was accurate to ± 0.05 msec.

HARDWARE REQUIREMENTS

The programs presented here are designed for use with both the C-64 and C-128 microcomputers. A disk drive (Commodore model 1541, 1571, or MSD SD1/2) and monitor (or television) are required accessories. Unless switches are used, no other hardware is needed.

THE SOFTWARE

Overview

The assembly language portion of the timer software was written to be located in the computer's cassette buffer (addresses 828-1019 in the C-64 or C-128 in the 64 mode; 2816-3007 in the C-128) but is fully relocatable to any convenient area of RAM. The program may be entered using any full-featured assembler, such as PAL64 (Proline Software); using an extended monitor, such as super- or micro-mon; or using the BASIC Loader program listed in Figure 1.

ML64 TIMER.LDR. When entering the BASIC loader listing in Figure 1, the user should treat the words within the brackets as cursor controls, not as literals. When run, this program sets up the machine code portion of the timer program in locations 828-928 of the cassette buffer and operates correctly on the C-64 or the C-128 in its 64 mode. This program should be loaded and run first. If the C-

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Requests for reprints and inquiries concerning the programs may be directed to either author at: Department of Psychology, University of Georgia, Athens, GA 30602.

```

10 REM BASIC LOADER FOR C-64 ML TIMER
20 FOR I=828 TO 928:READ X:POKE I,X:T=T+X:NEXT
30 IF T<>13377 THEN PRINT"<CLR><DWN><DWN><DWN><DWN>ENTRY ERROR: CHECK YOUR DATA
VALUES":STOP
40 END
1000 DATA 169,127,162,254,160,3,141,13
1001 DATA 221,142,4,221,140,5,221,169
1002 DATA 255,141,6,221,141,7,221,160
1003 DATA 81,140,15,221,96,120,169,1
1004 DATA 141,25,208,173,17,208,41,127
1005 DATA 141,17,208,173,25,208,41,1
1006 DATA 240,249,173,17,208,9,16,141
1007 DATA 17,208,162,17,142,14,221,32
1008 DATA 159,255,166,203,224,4,240,4
1009 DATA 224,3,208,243,169,0,141,14
1010 DATA 221,134,252,173,6,221,73,255
1011 DATA 133,250,173,7,221,73,255,133
1012 DATA 251,88,184,80,170

```

Figure 1. ML64 TIMER.LDR: Listing of BASIC loader program for loading the machine language timer program.
(Words in brackets should be interpreted as cursor control commands.)

128 is used in its regular mode, then the following lines must be substituted:

```

20 BANK 15: FOR I=2816 TO 2916: READ X: POKE I,X:
T=T+X: NEXT
1008 DATA 159,255,166,212,224,4,240,4

```

TIMER64.BAS. The program listed in Figure 2 sets up and measures the time in milliseconds required for a subject to assign words displayed serially on the monitor to one of two mutually exclusive cognitive categories, mammalian or nonmammalian. The two function keys F1 and F7 were arbitrarily selected to record the choice. Ten trials are presented; then the subject's reaction times and associated response choices are printed to the screen or a printer and then saved as the sequence file DATAFILE on a disk.

Stimulus displays to the screen can present a complex problem for accurate timing, since the screen is refreshed or updated only 60 times each second (Reed, 1979; Kallman, 1986). Thus the time between writing the stimulus to screen memory and its subsequent display to the screen can vary up to 16.67 msec, which, with a base reaction time of 250 msec, constitutes a 6.7% error in measurement. This problem can be solved by synchronizing the display driver with the monitor's scanning circuit. Each sweep requires a little more than 1 msec and scans the monitor with 256 rasters, with rasters 51 and 250 representing the top and bottom visible lines on the screen. Fortunately, the C-64 or C-128 continuously monitors the screen refresh, and the current raster can be accessed at any time from the raster register (location 53266) of the VIC chip. In fact, a value written to this register is latched and may be compared with the raster scan. When the current raster matches the value in the latch, a flag in the IRQ Sense Register (53273) is set. Thus a screen display can be timed to coincide with the proximity of the raster. For example, if one wishes to display the stimulus on row 12 of the screen, a value of 138 (11 rows $\times$ 8 raster lines per row + 50) must be POKEd into the raster register, and the raster IRQ flag will be set when the raster reaches the beginning of row 12.

Writing the display driver routine in BASIC affords the ease and simplicity of managing stimulus displays as character string arrays; however, printing a complex display would be too slow to synchronize reliably with the raster scan. A machine language (ML) display driver greatly speeds up display production and permits synchronization, but at the cost of setting up and managing complicated stimulus tables. A superior method is to use display blanking, a feature supported by the VIC chip. Clearing the display enable bit (bit 4) of register 53265 blanks the screen with the color of its border, allowing elaborate displays to be manufactured in BASIC and set up ahead of time. A machine language routine can then be used to instantly unblank the screen when the raster is in proximity with the first row of the display and then quickly jump to start the timer that measures reaction time.

This is the method used by the demonstration program in Figure 2. Program lines 10-90 dimension stimulus and data arrays, set the screen and border color to light gray, set the raster register to detect the 138th raster, and call the initializing routine of the ML timer program that configures the millisecond timer in the CIA chip. The user-written portion of the program begins with line 100. A stimulus word is randomly selected and printed in row 12. Important lines include line 240, which blanks the screen prior to filling screen memory with the stimulus display, and lines 260-290, which compute a random intertrial delay that is reset by random key holding. Entry to the ML display/timer program is gained in line 340 only after the keyboard buffer is emptied of stray characters that might be decoded by the ML program as 0-msec reaction times.

Upon return to BASIC, reaction times are extracted from locations 250-251 and assigned to a data array. Also, the key selected, F1 or F7, is returned in location 252, decoded, and assigned to an array. After 10 trials, the operator is given, in lines 420-500, the option of either printing the formatted reaction time and response choice data either to the screen or to a printer. Finally, lines 520-600 save the data to a sequence file named DATAFILE.

For those using a C-128 in 128 mode, the SYS address

```

10 REM *** MSEC TIMER DEMO PROGRAM ***
20 :
30 DIM RT(10),KY$(10),WRD$(10)
40 BLANK=53265:RASTLO=BLANK+1
50 CD$="<CLR><DWN><DWN><DWN><DWN><DWN><DWN><DWN><DWN><DWN><DWN><DWN>"
60 POKE 53280,15:POKE 53281,15:PRINT"<BLK>" :REM SCREEN & CHAR COLOR
70 POKE RASTLO,138
80 SYS 828 :REM INITIALIZE ML TIMER
90 :
100 REM *** DEMO PROGRAM BEGINS HERE ***
110 DATA LIZZARD,GECKO,MALLARD,OSTRICH,NEWT
120 DATA FOX,PLATYPUS,BEAR,LION,MONKEY,DOG
130 PRINT"<CLR>THIS IS A TEST OF CONCEPT RECOGNITION":PRINT
140 PRINT"ANIMALS WILL APPEAR ON THE SCREEN":PRINT
150 PRINT" IF MAMMALIAN, THEN"
160 PRINT" PRESS 'F1' KEY AS FAST AS YOU CAN":PRINT
170 PRINT" IF NOT MAMMALIAN, THEN"
180 PRINT" PRESS 'F7' KEY AS FAST AS YOU CAN"
190 PRINT:PRINT:PRINT"HIT ANY KEY TO BEGIN THE TASK."
200 GET A$:IF A$="" THEN 200
210 PRINT"<CLR>"
220 FOR I=1 TO 10:READ WRD$(I):NEXT
230 FOR K=1 TO 10
240 POKE BLANK,PEEK(BLANK) AND 239
250 CH=RND(0)*10+1:PRINTCD$TAB(15)WRD$(CH)
260 D=RND(0)*800+100:REM VAR INTERTRIAL INTERVAL
270 : FOR I=1 TO D
280 : IF PEEK(203)<>64 THEN 270:REM PREVENT KEY HOLDING
290 : NEXT I
300 :
310 REM *** CALL ML TIMER ROUTINE ***
320 :
330 GET A$:IF A$ THEN 330:REM DUMP KEYBUF
340 SYS 857
350 RT(K)=PEEK(250)+256*PEEK(251)
360 KY=PEEK(252)
370 KY$(K)="CORRECT"
380 IF KY=3 AND CH >5 THEN KY$(K)="ERROR"
390 IF KY=4 AND CH <6 THEN KY$(K)="ERROR"
400 NEXT K
410 :
420 REM *** PRINT OUT RESULTS OF DEMO PROG ***
430 INPUT"<CLR>OUTPUT TO (S)CREEN OR (P)RINTER S<LFT><LFT><LFT>";ANS$
440 UN=3:IF AN$="P" THEN UN=4
450 OPEN 3,UN:CMD3
460 PRINT"<CLR><DWN><DWN>TRIAL #";TAB(10)"RT (MSEC)";TAB(25)"RESP CHOICE"
470 FOR I=1 TO 10
480 PRINTTAB(1)I;TAB(11)RT(I);TAB(26)KY$(I)
490 NEXT I
500 PRINT#3:CLOSE3
510 :
520 REM *** SAVE DATA TO DISK ***
530 OPEN 1,8,2,"DATAFILE,S,W"
540 FOR I=1 TO 10
550 PRINT#1,RT(I)
560 PRINT#1,KY$(I)
570 NEXT I
580 CLOSE 1
590 PRINT"<DWN><DWN>DATA SAVED TO 'DATAFILE'"
600 END

```

Figure 2. TIMER64.BAS: Listing of BASIC controller/demonstration program. (Words in brackets should be interpreted as cursor control commands.)

in line 80 must be changed from 828 to 2816 and SYS 857 in line 340 must be changed to SYS 2845 to correspond to a relocated cassette buffer. Also, line 280 should be modified as follows:

```
280 : IF PEEK(212) <> 88 THEN 270.
```

The program will now run in the C-128's default mode using the 40-column screen only. A different chip altogether, the 8563 Video Controller, operates the C-128's 80-column screen. Although fully capable of synchroniz-

ing displays, the Video Controller requires different and more sophisticated driver routines than are required by either the 6566 or the 8564 VIC II chips that control the 40-column screens in the C-64 and C-128.

ML TIMER64.SRC. The source code for the ML timer program was written using the PAL64 assembler (Proline Software) and appears in Figure 3. As listed, it is designed for use with the keyboard (i.e., pressing either function key F1 or F7 stops the timer) and operates correctly on either the C-64 or the C-128 in 64 mode.

```

20: 033C          .OPT P4
;*****
;**    ACCURATE MSEC TIMER    **
;**    FOR C-64              **
;**    BY J ALLEN & C HORMANN **
;**    SEPT 15, 1986         **
;*****
;
; ** DEFINE SYSTEM VARIABLES **
;
120: 033C          TALO      =   $DD04
130: 033C          TAHI      =   $DD05
140: 033C          CTLO      =   $DD06
150: 033C          CTHI      =   $DD07
160: 033C          ICR       =   $DD0D
170: 033C          CRA       =   $DD0E
180: 033C          CRB       =   $DD0F
190: 033C          RASTHI    =   $D011
200: 033C          RASTLO    =   $D012
210: 033C          VICIRQ    =   $D019
220: 033C          SCNKEY    =   $FF9F
230: 033C          LATEN     =   $FA
240: 033C          KEYVAL    =   $FC
;
260: 033C          *=       $033C
;***** INITIALIZE CIA2 *****
;
290: 033C A9 7F          LDA   #$7F      ;MASK TO DEFEAT CIA IRQ
300: 033E A2 FE          LDX   #$FE      ;TIMER LO VALUE
310: 0340 A0 03          LDY   #$03      ;TIMER HI VALUE
320: 0342 8D 0D DD      STA   ICR       ;DISABLE TIMER FROM IRQ
330: 0345 8E 04 DD      STX   TALO      ;SET TIMER A TO 1 MSEC
340: 0348 8C 05 DD      STY   TAHI
350: 034B A9 FF          LDA   #$FF      ;SET UP COUNTER
360: 034D 8D 06 DD      STA   CTLO      ;RESET COUNTER TO FFFF
370: 0350 8D 07 DD      STA   CTHI
380: 0353 A0 51          LDY   #$51
390: 0355 8C 0F DD      STY   CRB       ;LINK TIME TO COUNT, ENABLE COUNTER
400: 0358 60          RTS
;
;***** MAIN PROGRAM *****
;
; ** DISPLAY SYNCH ROUTINE **
;
460: 0359 78          SEI           ;TURN OFF SYSTEM IRQ
470: 035A A9 01          LDA   #$01      ;RESET RASTER IRQ FLAG
480: 035C 8D 19 D0      STA   VICIRQ
490: 035F AD 11 D0      LDA   RASTHI    ;TURN OFF BIT 9 OF SCNLINE
500: 0362 29 7F          AND   #$7F
510: 0364 8D 11 D0      STA   RASTHI
520: 0367 AD 19 D0 SCAN LDA   VICIRQ    ;POLL RASTER IRQ FLAG
530: 036A 29 01          AND   #$01      ;IS RASTER AT DISPLAY LINE
540: 036C F0 F9          BEQ   SCAN      ;NO, KEEP POLLING
550: 036E AD 11 D0      LDA   RASTHI    ;UNBLANK SCREEN
560: 0371 09 10          ORA   #$10
570: 0373 8D 11 D0      STA   RASTHI
;
; ** TIME LATENCY TO RESPOND **
;
610: 0376 A2 11          LDX   #$11      ;SET & START TIMER A
620: 0378 8E 0E DD      STX   CRA
630: 037B 20 9F FF POLL JSR   SCNKEY    ;CHECK KEYBOARD
640: 037E A6 CB          LDX   $CB      ;CHECK KEYCODES FOR F1 OR F7
650: 0380 E0 04          CPX   #$04      ;IS 'F1' PRESSED
660: 0382 F0 04          BEQ   STOPCLOCK ; YES
670: 0384 E0 03          CPX   #$03      ;IS 'F7' PRESSED
680: 0386 D0 F3          BNE   POLL      ;NEITHER, SO POLL AGAIN
690: 0388 A9 00          STOPCLOCK LDA   #$00 ; STOP THE CLOCK
700: 038A 8D 0E DD      STA   CRA
710: 038D 86 FC          STX   KEYVAL    ;RECORD WHICH KEY PRESSED
720: 038F AD 06 DD      LDA   CTLO      ;GET COUNTER LO VALUE
730: 0392 49 FF          EOR   #$FF      ;COMPLEMENT FOR LATENCY &
740: 0394 85 FA          STA   LATEN     ;STORE IT
750: 0396 AD 07 DD      LDA   CTHI      ;SAME FOR COUNTER HI BYTE
760: 0399 49 FF          EOR   #$FF
770: 039B 85 FB          STA   LATEN+1
780: 039D 58          CLI           ;RETURN IRQS TO SYSTEM
790: 039E B8          CLV           ;BRANCH ALWAYS TO CNTSET
800: 039F 50 AA          BVC   CNTSET

```

Figure 3. ML TIMER64.SRC: Listing of millisecond timer and display synchronization source code for use with the keyboard.

```

10 REM ***** JOYSTICK MODIFICATIONS *****
:
30 IF T<>13611 THEN PRINT "<CLR><DWN><DWN><DWN><DWN>"
   ENTRY ERROR: CHECK YOUR DATA VALUES":STOP
:
1007 DATA 17,208,162,17,142,14,221,173
1008 DATA 0,220,133,252,201,119,240,4
1009 DATA 201,123,208,243,169,0,141,14
1010 DATA 221,234,234,173,6,221,73,255
:
:

;***** ML JOYSTICK MODIFICATIONS *****
:
:
037B LDA $DC00 ;CHECK JOY PORT #2
037E STA $FC    ;STORE IN Z-PAGE LOCATION
0380 CMP #$77   ;HAS STICK MOVED RIGHT
0382 BEQ $0388  ;YES, STOP TIMER A
0384 CMP #$7B   ;NO, HAS STICK MOVED LEFT
0386 BNE $037B  ;NO, KEEP POLLING
:
:
038D NOP        ;NO OPERATION
038E NOP        ;NO OPERATION
:
:

```

Figure 4. Modifications to ML64 TIMER.LDR and ML TIMER64.SRC necessary for use with a joystick. (Those lines of the original programs that do not change are indicated by colons.)

The first portion of the program (lines 290–400) configures the millisecond timer in CIA #2. It disables timer-generated interrupts, loads the appropriate countdown value (\$3FE) into timer A, sets timer B to count timer A underflows, and resets timer B to \$FFFF. This initialization routine is called at the beginning of the BASIC controller program and need only be executed once at start-up. The main portion of the program is broken into two parts, the display synchronization and the timer routines. Upon entry to the display synch routine (lines 460–570), the system IRQ is turned off and any raster-generated flag is cleared before the IRQ register is polled for a match between the raster location and the scan line (138) POKed into the raster register by the BASIC program. The match will occur when the raster scan is beginning line 12, which contains the hidden display. The program drops through the polling loop to unblank the screen, then executes the timing routine contained in lines 610–800.

The timer portion starts timer A and then polls the keyboard, decoding for F1 and F7 keypresses, using a kernel routine that completes a keyboard scan in less than 1 msec. The F1 and F7 keys are arbitrary choices and may be replaced with any keys that the investigator desires (see Timer Modifications below). Once either keypress is detected, timer A is stopped and the key code of the depressed key is temporarily stored in a zero-page memory location. The values in timer B are then complemented and stored in a 2-byte zero-page location (250–251) for later recovery and conversion by BASIC into a reaction time. The program then branches up to the latter part of the initialization routine, where timer B is reset to \$FFFF and control is returned to BASIC.

To use this program in the C-128's default mode, line 640 must be changed to read:

640 LDX #\$D4

Assembly should begin at \$0B00, the start of the C-128's cassette buffer.

Timer Modifications

The BASIC and ML programs may be easily modified so that either a joystick or external switches may serve

Figure 5. Illustration of the user port with an edge connector attached and associated schematic diagram for switch interfacing.

```

10 REM ***** SWITCH MODIFICATIONS *****
:
30 IF T<>13689 THEN PRINT "<CLR><DWN><DWN><DWN>"
    ENTRY ERROR: CHECK YOUR DATA VALUES:STOP
:
1007 DATA 17,208,162,17,142,14,221,173
1008 DATA 1,221,133,252,201,127,240,4
1009 DATA 201,191,208,243,169,0,141,14
1010 DATA 221,234,234,173,6,221,73,255
:
:
; ***** ML SWITCH MODIFICATIONS *****
:
:
037B LDA $DD01 ;CHECK USER PORT B CIA#2
037E STA $FC ;STORE IN Z-PAGE LOCATION
0380 CMP #$7F ;RIGHT BUTTON PRESSED?
0382 BEQ $0388 ;YES, STOP TIMER A
0384 CMP #$BF ;NO, LEFT BUTTON PRESSED?
0386 BNE $037B ;NO, KEEP POLLING
:
:
038D NOP ;NO OPERATION
038E NOP ;NO OPERATION
:
:

```

Figure 6. Modifications to ML64 TIMER.LDR and ML TIMER64.SRC necessary for use with external switches. (Those lines of the original programs that do not change are indicated by colons.)

as the response manipulandum. These modifications increase the versatility of the timer and obviate the need for having the computer in front of the participants.

Use with a joystick. In order to use the timer program with a joystick (attached to Joy Port #2), the polling loop in the main ML program must be modified. Lines 630-680 must be deleted and a different set of code inserted (see Figure 4 for the necessary BASIC and ML source code modifications). Once the modifications have been completed, the program will detect left and right movements of a joystick.

Use with an external switch. Use of this program with an external switch necessitates the purchase of SPST momentary switches (e.g., Radio Shack No. 275-1547), wire, and a 12/24 edge connector (0.156 in off center; a suitable connector is model 12/24SE, supplied by Jameco Electronics, 1355 Shoreway Rd., Belmont, CA 94002). Figure 5 is the schematic diagram for interfacing the switches with either the C-64 or the C-128 computer. One contact on each of the switches should be soldered (using enough wire to allow for freedom of movement) to pin N (ground) of the edge connector. The remaining contact of the switch, to be located on the right, is hooked to pin L (PB7), and the remaining contact of the switch on the left is hooked to pin K (PB6).

Once the soldering has been completed, the connector should be attached to the user port of the C-64 or C-128, with the lettered side on the bottom (attach and remove the connector only when the machine is off). When either switch is pressed, the input/output (I/O) line to which it is attached is grounded. Further information about the user port may be obtained by consulting West (1985) and De Jong (1984).

The ML program, for use with the switches, operates by checking the user port I/O lines for the presence of

grounded lines. In order for the program to accomplish this, lines 630-680 of the ML TIMER64.SRC program must be deleted and a different set of code inserted (see Figure 6 for the necessary BASIC and ML source code modifications).

Modifications to ML TIMER64.SRC. Some users may wish to change the keys used to enter a response. This may be accomplished by determining the keyboard buffer (not ASCII) code of the desired keys (values may be found in West [1985, p. 161]) and substituting their hexadecimal equivalents for the values in lines 650 and 670.

The values may also be changed using the BASIC loader program. Once the values of the keys are determined, the (decimal) value of one should be used in place of the first 4 in line 1008 of the BASIC program, and the value of the other should be substituted for 3 in line 1009.

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