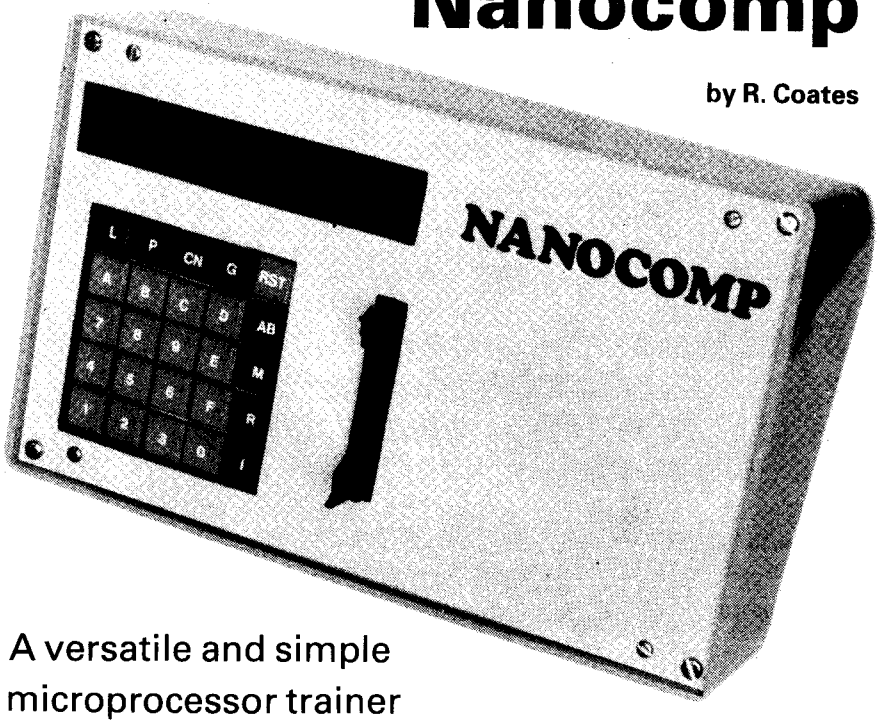
Nanocomp

by R. Coates

Using the 6802 microprocessor and only 8 other i.cs, this microcomputer design provides up to 4K of e.p.r.o.m., 1K of r.a.m., p.i.a., six digit display and up to eight monitor commands. Although ideal as a trainer, the Nanocomp is also a useful tool for general microprocessor applications. The unit can be built on one printed circuit board and housed with a power supply in a small case.



A versatile and simple microprocessor trainer

Two problems which prevent many electronic engineers from learning to use microprocessors are the complexity and cost of taking the first step. Constructing a unit can reduce the cost but may require some troubleshooting if it doesn't work. A simple unit that can be built easily may have limitations which restrict its use. With these points in mind, a microprocessor trainer has been designed which is suitable for a novice but provides sufficient facilities for use as a tool.

A block diagram of the design is shown in Fig. 1. Only 9 i.cs are used, which makes construction quite easy for anyone with the minimum of experience. The central processing unit is a Motorola 6802. Although not a particularly well known microprocessor, it is based on the popular 6800 device and includes clock generation and 128bytes of r.a.m. This reduces the cost and simplifies construction because only one crystal is required to complete the clock generation circuit. For programming, the 6802 is identical to the 6800 and is therefore well supported with software. Apart from the c.p.u. r.a.m., there are two other blocks of memory available. An e.p.r.o.m. permanently stores the monitor program, which takes care of the general "housekeeping" duties such as scanning the keypad, refreshing the display and providing debugging facilities to help with program development. The monitor occupies about 850bytes of the e.p.r.o.m. To improve flexibility, the unit has been designed to accept 1K, 2K and 4K e.p.r.o.ms so that the user can write programs and have them permanently stored for an application such as a dedicated controller. The second memory block is a 1K r.a.m. for developing and running programmes.

The final section of the block diagram contains the input/output (i/o) circuit which drives the keypad and display, and allows interfacing to other circuits.

The complete circuit is shown in Fig.2. A clock reference is provided by the 3.2786 MHz crystal and C_1. However, other crystals between 400kHz and 4MHz can be used with an adjustment to C_1 for reliable oscillation. The 6802 clock circuit divides the oscillator frequency by 4 to provide an 819kHz system clock signal (Ø2 of the 6800) at E. This frequency leaves a small safety margin for the devices, which have a maximum operating frequency of 1MHz. A 74LS00 gates the E signal with VMA (valid memory address) to provide VMA.E which is used by the address decoder IC_9 to ensure that other devices on the bus are only accessed when a valid address is present on the address bus. The address decoder generates select lines for the memories and i/o chips by decoding the three most significant address lines. This provides selection of 8 4K address blocks, of which Y1, Y4 and Y7 are used. Note that the most significant address line, A15, from the c.p.u. is not used because sufficient address space is available without it.

Data pins D0 to D7 of the c.p.u. are connected to the data bus. The control bus comprises E, VMA.E, read/write, reset (connected by a push switch and used to start the monitor program at switch-on, and to initialise the i/o chip for programming), $\overline{IRQ}$ and $\overline{NMI}$ interrupt lines which allow program execution to be interrupted or, in the case of $\overline{NMI}$ (non-maskable interrupt), termination of a monitor command with the Abort key which returns the processor to the monitor switch on point. Both interrupts are connected to external pins for use by an external circuit if required.

As mentioned previously, three sizes of e.p.r.o.m. can be used. Although the 2708 is the cheapest device it will provide only a small amount of spare memory space, and it requires +5V, -5V and +12V supply rails. The 2516 and 2532 only require +5V and leave just over 1K and 3K respectively for expansion.

The main r.a.m. is provided by two 4-bit 2114 i.cs. With the 819kHz clock, slow

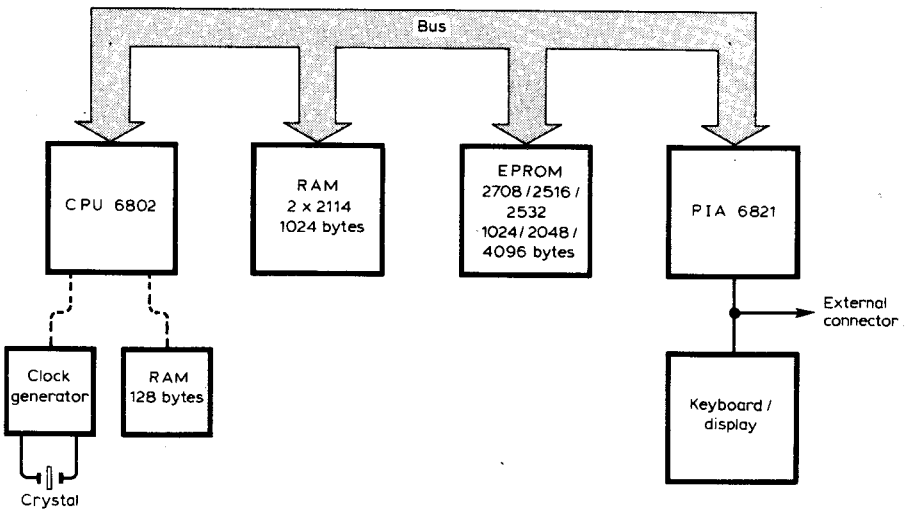
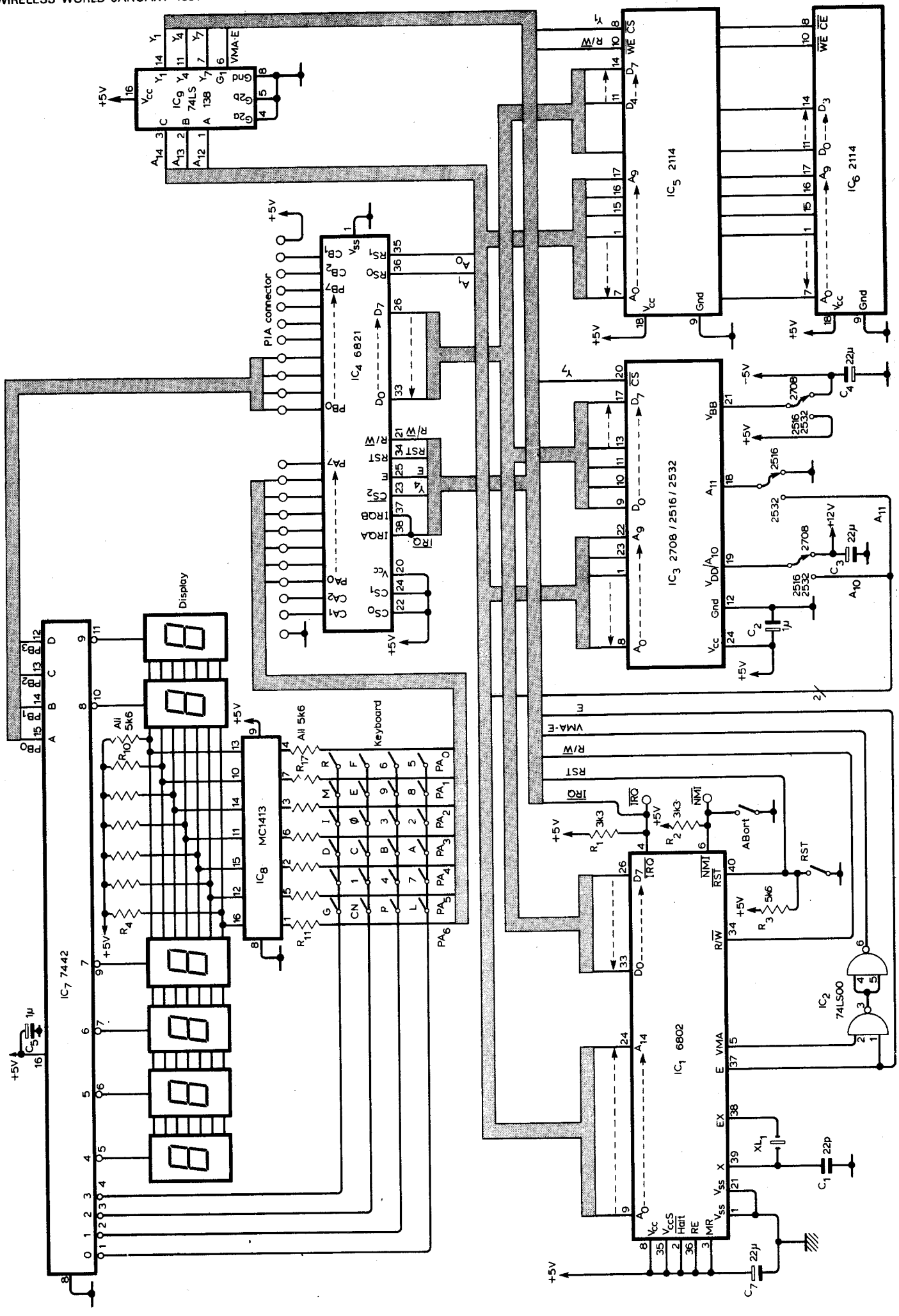


Fig. 1. Block diagram. The 6802 is similar to the 6800 but contains a clock generator and 128bytes of r.a.m.

Fig. 2. Complete logic diagram. Although the circuit can use a 1K 2708 e.p.r.o.m., 2 or 4K devices are recommended because they provide spare memory space and require only one supply rail. ▶


IC9 74LS 138
IC4 6821
PIA connector
IC5 2114
IC6 2114
IC3 2708 / 2516 / 2532
IC1 6802
IC2 74LS00
IC7 7442
IC8 MC1413
Display
Keyboard
All 5k6
ABort
RST
+5V
+12V
-5V
22p
22μ
1μ

(450ns) devices will work without trouble. An input/output device, IC_4, the MC6821 peripheral interface adaptor (p.i.a.), provides two sets of 8 data lines for communicating with external circuits. One set of lines (PA) is t.t.l. compatible, and the other (PB) is m.o.s. compatible. The lines can be individually programmed as inputs or outputs and can for example, with suitable buffering, drive relays or read the states of microswitches. Also available are four control lines, two for each set of data lines, which can be used to control transfers of data between the p.i.a. and external devices. Two are inputs only, and two are inputs or outputs. The inputs can drive the $\overline{IRQ}$ line so that the c.p.u. can service them immediately if required. All of these lines, together with ground and +5V, are available at a multiway connector.

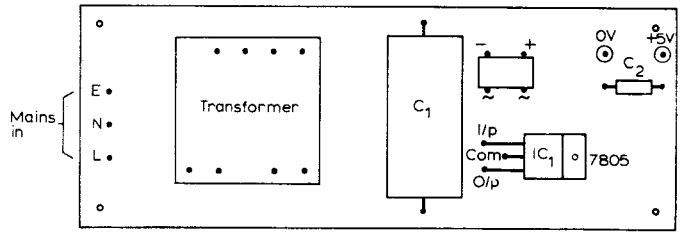
Twelve of the p.i.a. data lines are also used to drive the display and keypad. The display comprises six common-cathode l.e.d. numerals which can show a 4-digit address and 2-digit data. The display data is not latched but multiplexed, so a constant refresh is required. This is achieved by the monitor which has a sub-routine that can be used to display data in a program. Data lines PB0–PB3 select which digit is to be refreshed, the binary numbers are decoded by IC_7 which sinks one of its outputs low. Six of the 7442 outputs are connected to the cathodes of the displays, thus the appropriate digit is selected. Segment drive information is provided by PA0-PA6. Resistors R_4 to R_{10} turn the segments on, and the segments are turned off by a logic 1 on the p.i.a. line which turns on one of the seven shunt transistors in IC_8. Although this arrangement is a little wasteful on power, (the consumption is highest with the display off) it provides a simple drive circuit which in this design is more important.

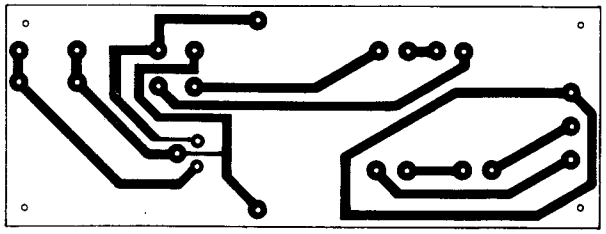
Table 1. Memory map.

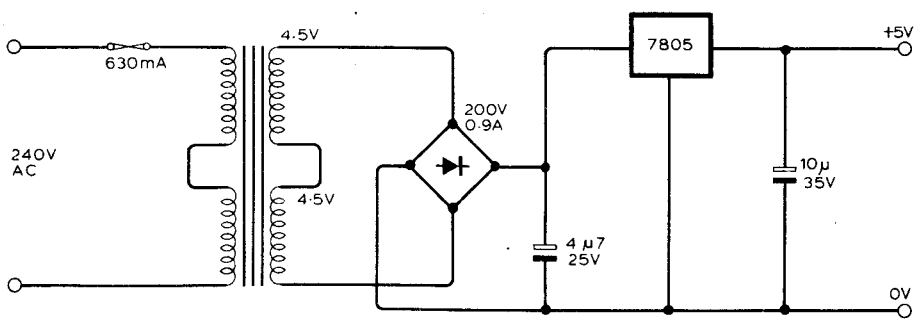
e.p.r.o.m.	monitor	7FFF 7C00
	user e.p.r.o.m.	7800 7400 7000
	p.i.a.	4003 4000
	program r.a.m.	13FF 1000
c.p.u. r.a.m.	display buffer	007F 007A
	monitor workspace	006A
	monitor stack	0060 0040
	user stack	
	spare	0000

p.i.a.
4000 output/data direction register A
4001 output/data direction register B
4002 control register A
4003 control register B

Fig. 3. Single rail power supply. The p.c.b. measures 160 x 60 mm.







The p.i.a. lines are also used to read the keypad switches, but for this operation they are programmed as inputs. With no keys pressed, no loads are presented on the t.t.l. compatible inputs which are therefore pulled up by internal resistors. The keys are arranged in a matrix and IC_7 selects one of four rows in the same way that display digits are selected. If a key is pressed in that row, the appropriate PA0-PA6 input is pulled low. To read the keypad, each row is selected in turn and the inputs monitored for a low on one line. By identifying the row selected and the column pulled low, the pressed key can be determined.

Although the p.i.a. lines are available externally, they cannot be used to drive an external device while servicing the keypad or display. This is a small penalty for a simple design, and does not normally present a problem.

Construction is straightforward because all components, except for the power supply, can be mounted on one p.c.b. Sockets are recommended for the m.o.s. devices and pins for all external connections. The switches are a tight fit, but if the holes are drilled a little oversize they can be manoeuvred in place. If the circuit is to be housed in a box, the switches should be raised as much as possible. The legends on the switch caps are transfers such as Letraset. All components are mounted on the top side of the board together with four wire links to select the e.p.r.o.m. For a 2708 no links are used, for the 2516 and 2532, C_3 and C_4 are omitted and the two links from their positions inserted along with the link by the e.p.r.o.m. socket.

The power supply in Fig.3 is a simple 5V design intended for use with the single-rail e.p.r.o.ms. The complete unit can be housed in a case, see component notes, or used on an open printed circuit board.

Testing

For initial testing, the r.a.ms need not be inserted. Connect the power supplies to their respective pins (note that if a 2708 e.p.r.o.m. is used with separately switched supplies, the -5V should be switched on first and off last). After switch on, press Reset (RST) and a dash should light up on the far left display. This symbol is a prompt and indicates that the unit is waiting for a command. If it does not light with a correctly programmed e.p.r.o.m., check that power is reaching the i.cs. Next, with an oscilloscope connected to pin 38 of IC_1, check that the crystal is oscillating. If the crystal is alright but there is no oscillation, check C_1 and experiment with different values, particularly if the frequency is not as specified. If the oscillator is operating, test the E output of IC_1 which should be a square wave at one quarter of the crystal

frequency. This waveform will contain some ripple. If an oscilloscope is not available, a high-impedance voltmeter connected to pin 37 should read between 24 and 25V. If the fault still persists, it is likely to be a dry joint or a board fault. Because many of the tracks on the top side of the board are covered by components, it is advisable to carefully examine the board before the components are mounted.

Operation

The memory map for the unit is shown in Table 1. Note that the e.p.r.o.m. occupies 7000 - 7FFF, although the monitor program only occupies 7C00 - 7FFF. Addresses 7E63 to 7FE7 are unused because, in the original unit, routines for a paper-tape punch and load were stored there. This space can be used for load and dump routines to suit the users storage medium.

The reset button is used at switch-on, or if control of a program is lost, to run the monitor program. Sixteen hexadecimal keys enter data, and the remaining eight keys enter monitor commands. L and P are spare keys, used in the original for load and punch with the paper-tape unit, which can be used for extra facilities.

These do not need to be storage routines, but any routine the user wishes to write and include in the monitor. Locations 7DC4/5 should contain the 16-bit start address of the routine to be run on pressing the L key, and 7DCB/C the address for the P key. For testing the unit these keys can be ignored.

The memory (M) command allows a memory location to be examined and altered if required. This key is acknowledged by 17 in the far right display. A 4-digit hex address, when entered, appears on the left four digits, and the data in that location appears on the right two digits. To alter the contents of the location, enter two hex digits, which will be shifted into the data display from the right (if a mistake is made, keep entering appropriate digits until the correct data appears in the display). Next press the Increment (I) key, which stores the displayed data in the memory location and advances the display to the next memory location. If the memory contents do not need altering, press I to advance or Abort to terminate command and return to monitor start.

Register display (R) displays the contents of the various c.p.u. registers following a SWI instruction in a program. The command is automatically entered after a SWI, but may be re-entered with the R key. The condition code register contents are first displayed, the right two digits denote the register being displayed (CC= condition code register, B= AccB, A= AccA, IX= Index register, PC= program counter, SP= stack pointer position) and the left four digits show the register contents. The I key will increment through the various registers or AB will abort. After displaying SP, the unit will automatically return to monitor start.

Go (G) is used to go to a user program and A will acknowledge command. When the 4-digit hex start address of the program is entered the program will run. If a program is interrupted by a SWI instruction, the continue (CN) key will run the program from the instruction following SWI. If a program is interrupted by the abort key, CN will make it continue from the interruption provided the abort key (NMI) has not been modified by the user program for a different purpose.

Abort (AB) stops the current command/program by operating the non-maskable interrupt line. The program then jumps to the location specified by memory location 0072/0073. These are set, during Reset operation, to the monitor start address but may be altered to use the NMI facility.

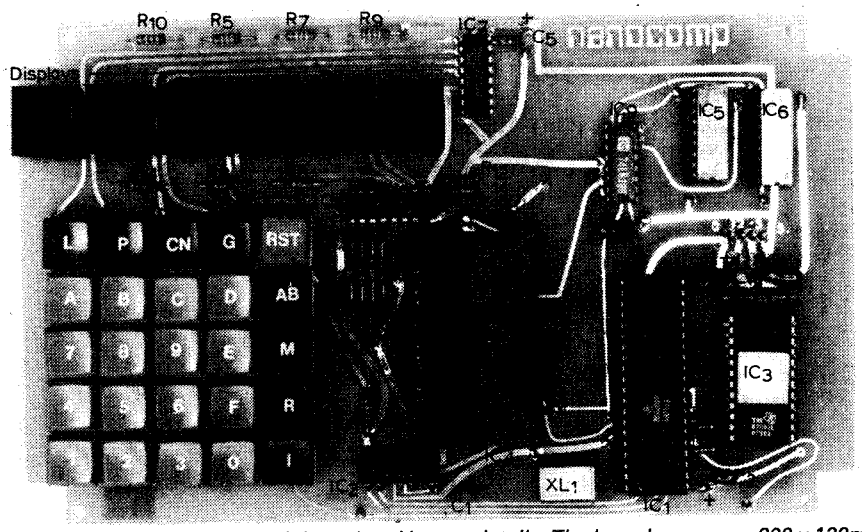
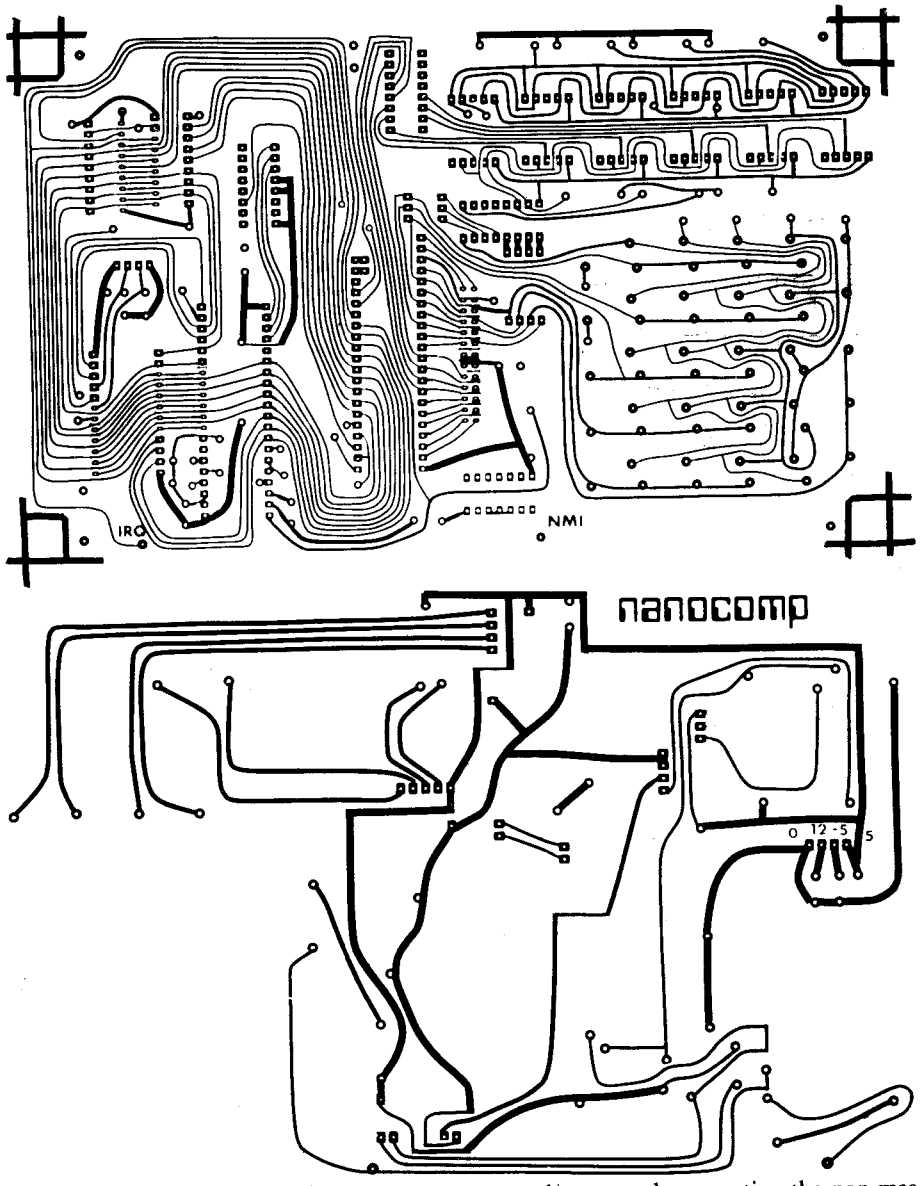


Fig. 4. Assembled printed circuit board and layout details. The board measures 200 x 120mm.

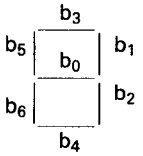


Programs

If one of the larger e.p.r.o.ms is used, the programs at 7800 - 7BFF can be run immediately. Two of these are games and two

Table 2. Useful monitor subroutines.

7C7B	DISPRESH	Refreshes display with contents of display buffer (six locations of r.a.m., one for each display digit) which contains the seven segment information for the display. For a program to use the multiplexed display, the data must be written in locations 007A (left digit) to 007F (right digit) and DISPRESH continually accessed. Each segment of a digit is allocated to a bit in the data word, to turn a segment on set that bit to 1. The bit/segment allocation is



7C20	GETKEY	Alternately scans keyboard and refreshes display until a key is pressed. It then waits for the key to be released, and returns with the key code in accumulator A. The codes for the keys are

0 1 2 3 4 5 6 7 8 9 A B C D E F L P CN G M R I
22 24 02 12 14 00 10 04 01 11 03 13 23 33 21 20 05 15 25 35 31 30 32

7CE7	HEXCON	Converts a key code in Acc A into the hex equivalent for that key and returns with it in Acc A. If a non-hex (command) key code is entered, the routine defaults back to the monitor start.
7CE4	KEYHEX	Combines GETKEY and HEXCON.
7CB5	BADDR	Builds a 4-digit hex address entered from keyboard, refreshing display whilst doing so, and returns with that address in index register.
7CFF	L7SEG	Converts the left hex digit of a byte in Acc A to the seven segment code required by the display, and returns with it in Acc A.
7D03	R7SEG	As above but for right hex digit of byte.
7D15	7TOHEX	Converts a seven segment hex code in Acc A to that hex digit and returns with it in Acc A. Defaults to monitor start if code is not hex.
7CCC	7HEXIN	Uses KEYHEX to accept two hex key entries, and combines the two hex digits into one byte in Acc A.

are useful programming aids. To run a program, press Reset to obtain a prompt in the display, press G and then enter the start address. The program at 7800 converts hexadecimal numbers to decimal and vice-versa. After pressing G 7800, the display will be blank. For a decimal to hex, press L and then enter a decimal number from 1 to 65535 followed by I, and the hex equivalent will be displayed. Press I again and enter L for another decimal to hex, or P for a hex to decimal conversion. After each conversion press I to prepare for another.

A tedious aspect of machine code programming is calculation of the two's complement offset for branch instructions. This task is simplified by the branch calculator program at 7A00. When the program is entered S appears on the far right display, which indicates that the program is waiting for the 4-digit start address of the branch instruction.

Enter this followed by I, and d will appear on the display to request the 4-digit destination address. When this is entered, the two's complement offset appears on the two far right displays. If two dashes appear, the branch is outside the range of a branch instruction. Press I to prepare for another calculation.

The two games programs are at 7A80 and 7930. The first is "Mastermind", and after entering, I will appear on the display. After a few seconds, required for generation of the secret code, press I and try to solve the 4-digit code using numbers 0 to 7. After entering the first 4-digit guess, a 2-digit number will appear on the two right hand displays. The first indicates the number of correct digits in the correct positions (called bulls). The second indicates the correct numbers in the wrong places (called cows). Press I and enter another number. The game finishes when four bulls have been deduced, and pressing I will indicate the number of tries. Pressing I again starts a new game.

The second game is called duckshoot and locations 0000 and 1 have to be set with a number to control the speed of the game. With 0020 as a starting point, run the program and two ducks will traverse the display. To shoot the ducks the display number (1 to 6 from left to right) must be entered when the duck is present. When hit, the duck disappears and the game finishes when no ducks are left. To terminate the demonstration programs, press AB or RST and the monitor program will be re-entered.

Although this unit was originally designed as a versatile training aid, it can be used as a desktop computer and as a software development tool. The spare e.p.r.o.m. space allows it to be used as a form of calculator or a controller. Useful programming information is available in the M6800 Microprocessor Instruction Set Summary from Motorola distributors, and an ideal book is the *6800 Programming Reference Manual* which gives details of the c.p.u. and p.i.a. devices together with a full description of the instructions. □

Component notes

Keyswitches

Grey	RS 337-611
Blue	RS 337-605
Red	RS 337-598

Displays
FND500 or FND560

Case
RS 508-475

Connector plug
26 way insulation displacement type RS 467-352

Software
A software listing for the Nanocomp can be obtained by sending a stamped addressed envelope to Wireless World, Room L303, Quadrant House, The Quadrant, Sutton, Surrey.

Printed circuit boards
A set of p.c.bs (1 double sided, 1 single sided) will be available for £9.00 inclusive of v.a.t and UK postage from M. R Sagin, 23 Keyes Road, London N.W.2.

The Author

Bob Coates studied electronics at the Rolls-Royce Aero Engine Division where he gained a HND. In 1974 he joined a research & development establishment and is currently working on microprocessor systems design for industrial control and data acquisition. Apart from electronics, Bob's interests include amateur radio (G4DIH).

Component kit
We understand that Technomatic, 17 Burnley Road, London N.W.10, will be offering a kit of components including a programmed r.o.m. for the Nanocomp.