1

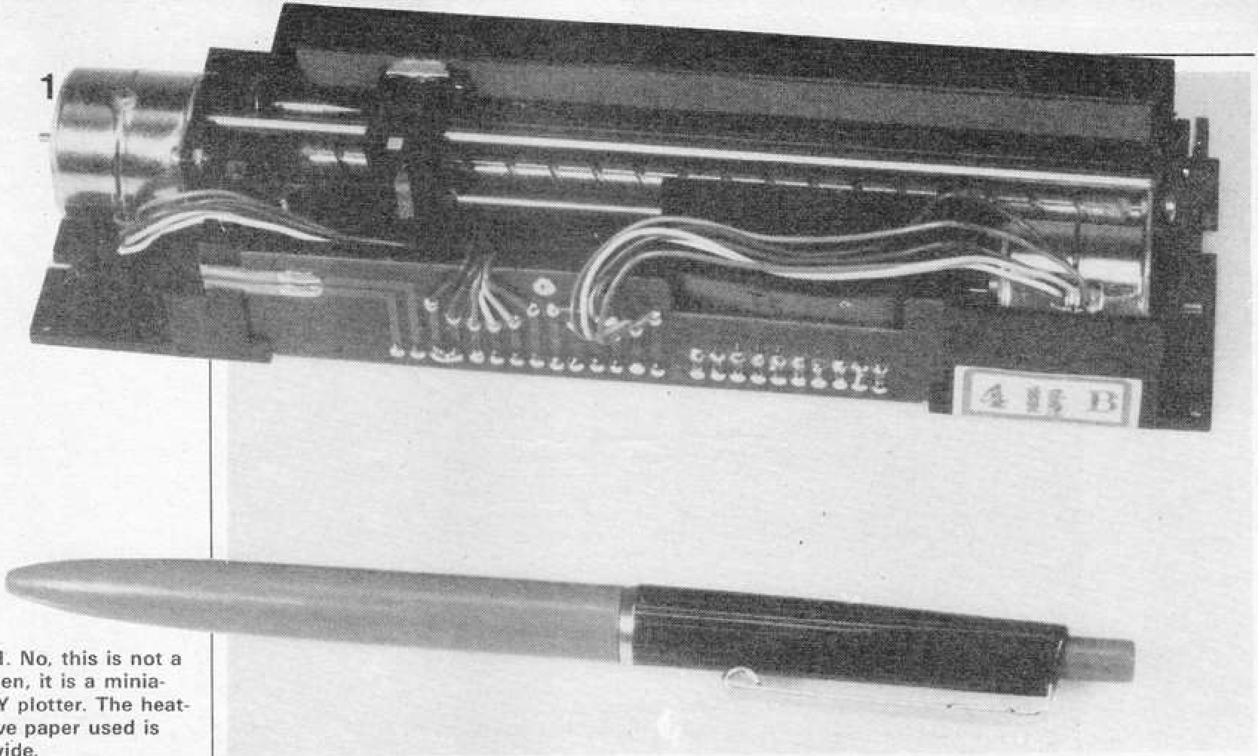


Photo 1. No, this is not a giant pen, it is a miniature X-Y plotter. The heat-sensitive paper used is 9 cm wide.

Most of us would never even consider the idea of building an X-Y plotter or a matrix printer with a Centronics input. That, however, is exactly what this article proposes: a combined X-Y plotter and matrix printer. Probably the most important point is that you do not have to be a genius with your hands to construct the mechanical section. Not only that, but the electronics is straightforward and the cost of the design is not prohibitive.
The concept of this d.i.y. project is made possible by the availability of the entire printer mechanism, complete with two bi-directional motors that drive a thermal print-head. All that remains is to fix all this in place with four small bolts. The circuit is quite simple, consisting of the Centronics interface, an input data buffer, and a character generator. The software included provides the means of drawing vectors point-to-point with a high resolution.

X-Y graphic plotter

an elegant solution to the problem of how to make your own graphics printer

This project is very original, even by Elektor standards. It is a complete matrix printer and high-resolution X-Y plotter, affordable enough to be a solution for the 'impoverished' but at the same time it is a very interesting design in its own right. The idea of making an X-Y plotter is by no means new but to achieve a good result there is one essential prerequisite, namely a very precise mechanical section.

A realistic compromise

Designing the circuit and writing the necessary software for this project comes easily to the Elektor designers. The mechanical part is a different matter, however. You cannot expect to be good at everything, after all. However, just as with our mini-printer published in the December 1984 issue, Seiko supply a complete X-Y plotter (minus electronics). This is shown in photo 1. We used the STP411 printer mechanism for our prototype but we must stress that the electronics and the software could also be used with different mechanical modules. This leaves plenty of options open for those fortunate readers who are skilled in the arts of salvaging or even making the whole unit.
Before becoming involved with the details of this project we have to define what we mean by a matrix printer and X-Y plotter. Most commercial matrix printers (Epson, Seikosha, Nec, etc.) have a (pseudo) graphics mode to enable them to print designs. The resident software, however, does not enable them to handle the co-ordinates of a vector on a cartesian (X-Y) grid direct, as happens with a drawing table. What these printers do is produce a hard copy of a memory (generally the screen or video memory) in which the design to be traced is stored. Just as the design exists **pixel by pixel** on the screen,

Characteristics

■ **Bidirectional thermal printer mechanism**
containing:
2 stepping motors
8 or 9 element thermal print head
friction drum to hold the paper
worm-drive shaft to hold the print head
'home position' microswitch

■ **6502 CPU complete with software**
to control operation in:
7 × 5 or 9 × 5 matrix printer mode
X-Y graphics plotter mode (with automatic test procedure)

■ **Character generator stored in EPROM**
ready for reception of:
alphanumeric characters (in ASCII code)
X-Y vectorial coordinates (decimal values in ASCII code)
control characters

■ **Input buffer**
1½ K bytes or 7½ K bytes *(depending on the RAM capacity — 2K or 8K)*

■ **Printing speed**
on average 0.5 s per line of text.

■ **Horizontal resolution**
256 or 320 dots
45 or 56 characters per 9 cm line.

■ **Printer mechanism**
dimensions: 153 × 45 × 20 mm
weight: 135 g
expected lifespan: 500 000 lines [1)]
expected print-head lifespan: 300 000 lines [1)]
AC supply: 5 V/5 A (max.)

1) at a 50% printing speed

it exists **bit by bit** in the memory. By sending the contents of the memory one **byte** at a time to the matrix printer (which must be in graphics mode), it is possible to obtain a **copy** of the design on paper. It is, however, impossible to trace the design directly on the printer based on the vector coordinates. That is exactly what the plotter proposed here can do.
The procedure used is quite simple. We start by sending the ESC character to the printer via the Centronics port. This signifies that the following ASCII codes are not characters for printing but the co-ordinates of a vector that has to be traced. The coordinates of the vector are then sent, separated by ASCII character "/" and beginning with the origin of the vector.
For example, the vector starts at X = 2, Y = 6, and finishes at X = 15, Y = 12 (see figure 1).
The sequence of instructions needed to print the vector is:
PRINT CHR$(27); "/"; '2'; "/"; '6'; "/"; '15'; "/"; '12'; "/"
It is worth noting at this point that most BASIC interpreters accept the PRINT instruction without the semi-colons between strings of characters (which are in quotes) and variables (which are not enclosed by quotes).
If the end-point of a vector is the same as its origin a single dot is printed. The parameters needed to trace vectors are as follows:
(ESC)/OX/OY/EX/EY/(CR)

1

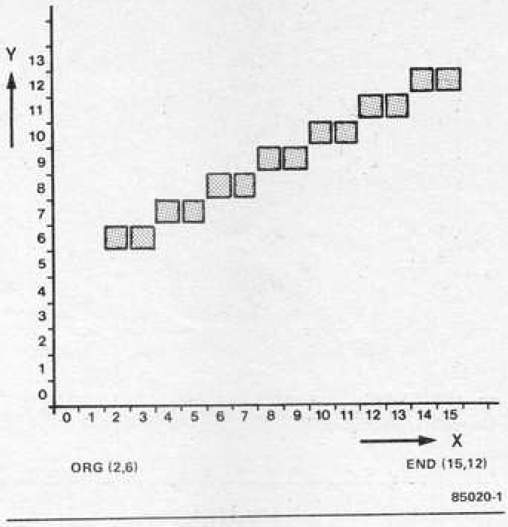


Figure 1. As it is almost impossible to plot a straight line from an ORG point to an END point, this is achieved by using segments of successive approximations.

2

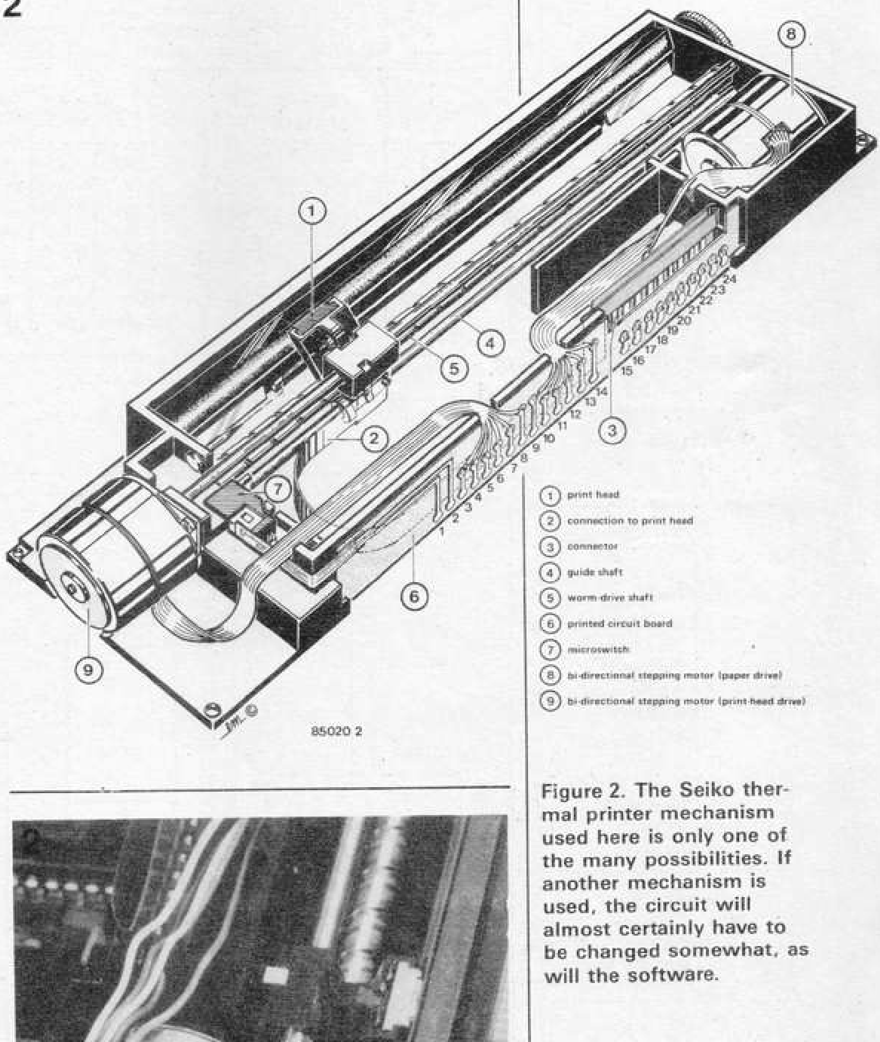


Figure 2. The Seiko thermal printer mechanism used here is only one of the many possibilities. If another mechanism is used, the circuit will almost certainly have to be changed somewhat, as will the software.

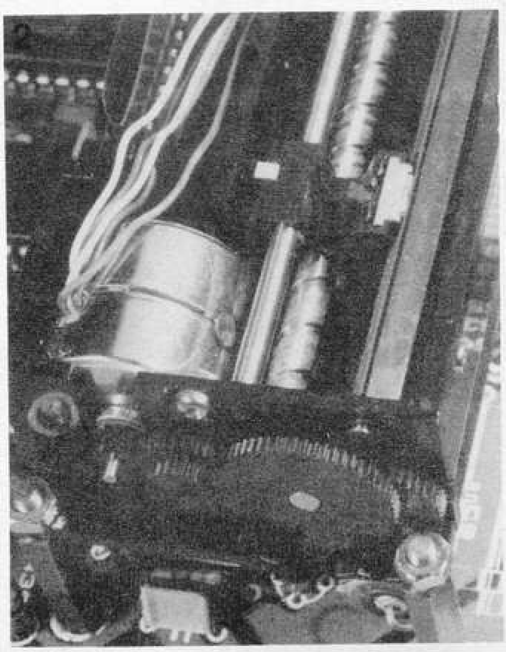


Photo 2. The print head rides on the worm-drive shaft seen here. This photo also shows the flexible connection to the print head.

3

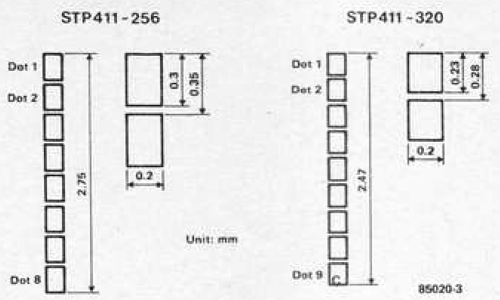


Figure 3. The dimensions of the two types of printer, STP411-256 or STP411-320, are different. The higher resolution of the 320-dot version makes it more suitable for precise traces.

Table 2.

Correction; 256/320

PL4 (closed = "1"; open = "Ø")	
1-2	"1" = STP 411-320 "Ø" = STP 411-256
3-4	bit 2 binary coded
5-6	bit 1 7 step correction
7-8	bit Ø on paper feed

bits 2 1 Ø	number of steps	plugs 3-4	5-6	7-8
Ø Ø Ø	Ø	no	no	no
Ø Ø 1	1	no	no	yes
Ø 1 Ø	2	no	yes	no
Ø 1 1	3	no	yes	yes
1 Ø Ø	4	yes	no	no
1 Ø 1	5	yes	no	yes
1 1 Ø	6	yes	yes	no
1 1 1	7	yes	yes	yes

where OX and OY define the origin of the vector and EX and EY signify its end. That all seems very simply but the desired result is achieved only if electronics, mechanics, and software are perfectly co-ordinated.

The printer mechanism

The sketch in figure 2 shows the printer mechanism with its two bi-directional stepping motors, worm-drive shaft, and thermal print-head. We will not deal with this mechanism in any great detail. As photo 2 shows, it is a fine example of precision engineering but, because it has been kept as simple as possible, it is pleasantly inexpensive. The horizontal motor is connected direct to the drive shaft; every pulse to the motor causes the head to move one step to either the left or the right. The horizontal resolution is 256 or 320 dots depending on the type of mechanism chosen and the size of step is 0.35 mm in the former and 0.28 mm in the latter case (see figure 3). The manufacturer indicates that there is a 'dead' angle of two or three dots according to the type of mechanism used. This means that nothing happens for 2 or 3 pulses after the head changes direction. The software that drives the printer must take this into account.

Table 1.

Centronics input PL2	
1	STROBE
2	DATA Ø
3	DATA 1
4	DATA 2
5	DATA 3
6	DATA 4
7	DATA 5
8	DATA 6
9	DATA 7
10	BUSY
11	N.C.
12	Paper empty (see PL3)
13	SELECT
14	GND
Paper empty PL3	
1-2	PAPER EMPTY
3-4	PAPER EMPTY

4

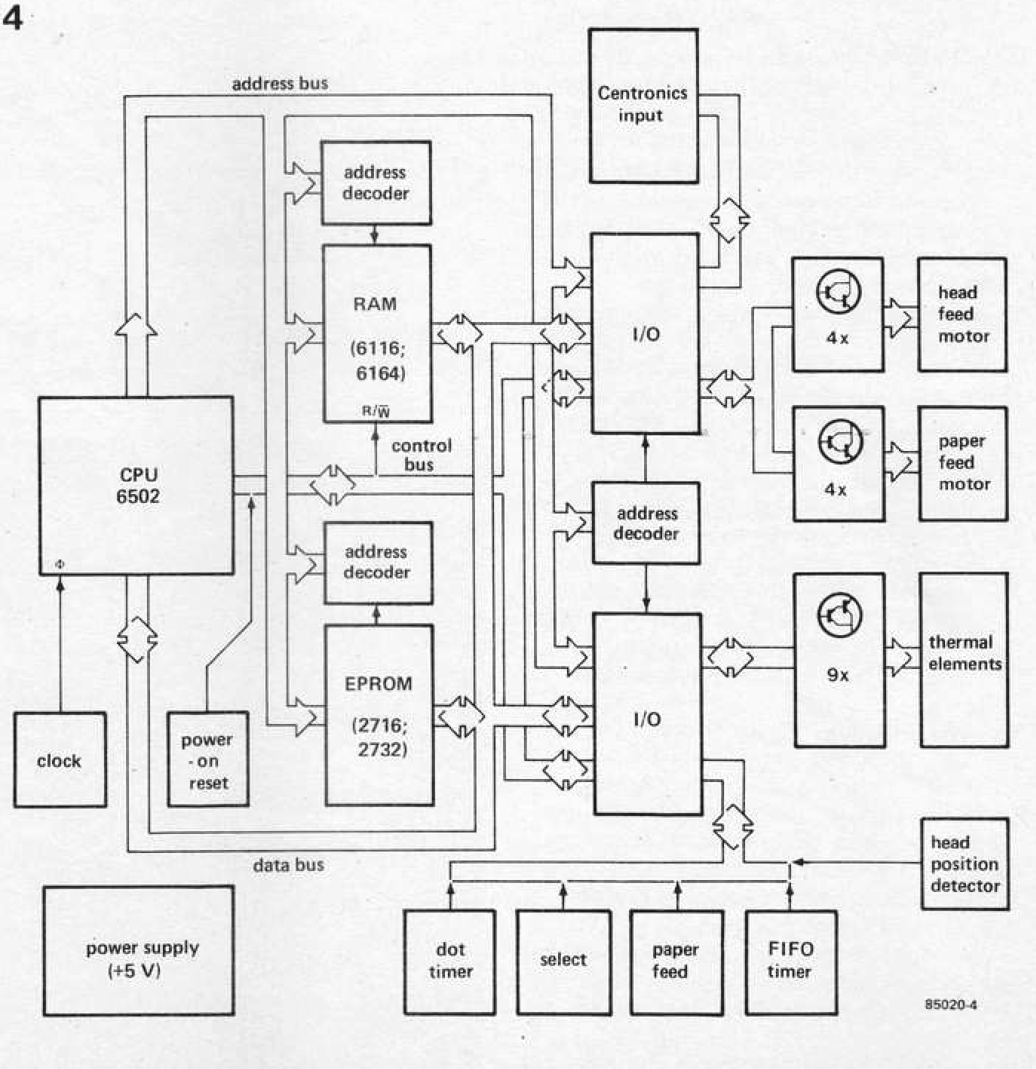


Figure 4. As this block diagram shows, the circuit of the printer/plotter is actually a complete microcomputer.

Like the head movement, the paper feeding occurs in steps, which are the same size as the steps the head makes. In this case the motor is not directly coupled to the paperdrum. A miniature 'gearbox' is used that gives a reduction factor of 4 : 1. This means that the motor has to receive four pulses for the paper to move by one step.
This reduction (illustrated in figure 3) is also subject to a 'dead' period every time the motor direction is changed. If uncorrected, this would, of course, make rubbish of any design that is being drawn. Unfortunately, Seiko, did not mention this detail in their data sheet for the STP411, which caused a few headaches for our designers. They were, of course, very reluctant to modify the otherwise excellent mechanics to cure the problem. As it happens, this was not necessary: the software was made clever enough to iron out this little difficulty.
Our final comment about the motors is to note that each has a maximum current consumption of 500 mA at 5.5 V.

We have already mentioned that there are two different printer mechanisms available. The main difference between them is in the print head. The 256 dot version has 8 thermal elements while the 320 dot type has 9. The sketch in figure 3 shows how the size of the dots consequently varies. The current applied to the heating elements is corrected to compensate for changes in the ambient temperature. This current regulation is achieved by varying the frequency of the signal applied to the print head. The maximum current drain is 3.5 A when all the thermal elements are on simultaneously.
The final feature of the printer mechanism we will mention is the 'home' detector. This is a micro-switch which is open when the print head is at the extreme left. As our designers were not fully satisfied with this arrangement, they added a further precaution. After receiving a 'head-home' indication, the head is first moved several steps to the right, then brought left until 'home' is again detected, and finally moved three steps to the right. This is then taken to be the initial position for the head. This precaution ensures that the head's 'home' position is always correct even if the mechanism is moved or stopped accidentally by hand.
So much for the mechanics of the printer; now for the electronics.

A complete microcomputer

The electronics section of this project is no less than a complete microcomputer, as the block diagram of figure 4 shows. It has a CPU (6502), random access memory (2K or 8K), read-only memory (4K or 8K), input and output ports (18 lines), a clock, and the 'home' detector already mentioned. The layout requires no comment. There are, however, some points in the

3

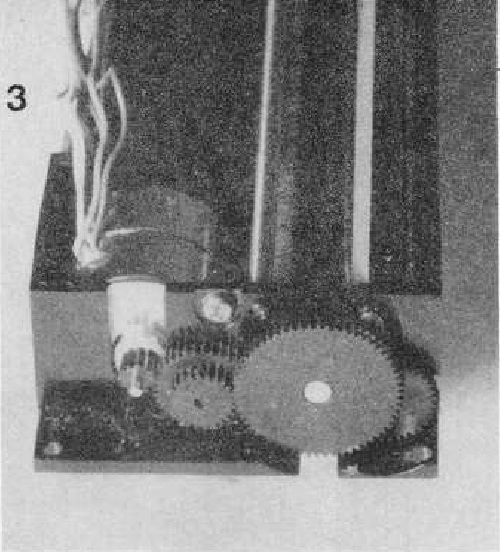


Photo 3. The gearing mechanism on the printer has a 'dead angle' (the mechanical equivalent of hysteresis) that Seiko has neglected to mention in their literature on the STP411.

Table 3.

Inputs-Outputs

6821/IC4	**Port A**		**Centronics interface**
40	CA1	(in)	STROBE
39	CA2	(out)	BUSY
2 … 9	PA0 … PA7	(out)	Data 0...7
6821/IC4	**Port B**		**Motor control**
18	CB1		not used
19	CB2	(out)	BUSY indicator
10 … 13	PB0 … PB3	(out)	Head drive motor
14 … 17	PB4 … PB7	(out)	Paper feed motor
6821/IC5	**Port A**		**Switch/timing control**
40	CA1	(in)	Select/deselect
39	CA2	(in)	FIFO timer
2 … 5	PA0 … PA3	(in)	PL4: paper feed error
6	PA4	(out)	FIFO timer
7	PA5	(out)	Select indicator
8	PA6	(in)	Home switch
9	PA7	(in)	Paper feed switch
6821/IC5	**Port B**		**Dot control**
18	CB1	(in)	Dot timer
19	CB2	(out)	Thermal head: dot 9
10 … 17	PB0 … PB7	(out)	Thermal head: dots 1...8

Table 4.

	STP411-256			STP411-320
1	Home switch			
2				
3 Green	C	Motor for head driving		
4 Green	C			
5 Blue	$\phi1$			
6 White	$\phi2$			
7 Yellow	$\phi3$			
8 Red	$\phi4$			
9 Green	C	Motor for paper feeding		
10 Green	C			
11 Blue	$\phi1$			
12 White	$\phi2$			
13 Yellow	$\phi3$			
14 Red	$\phi4$	SEIKO	ELEKTOR	
15		NC	Dot 1	Dot 1
16		Dot 1	Dot 2	Dot 2
17		Dot 2	Dot 3	Dot 3
18		Dot 3	Dot 4	Dot 4
19		Dot 4	Dot 5	Dot 5
20		Dot 5	Dot 6	Dot 6
21		Dot 6	Dot 7	Dot 7
22		Dot 7	Dot 8	Dot 8
23		Dot 8	Common	Dot 9
24		Common		Common

5

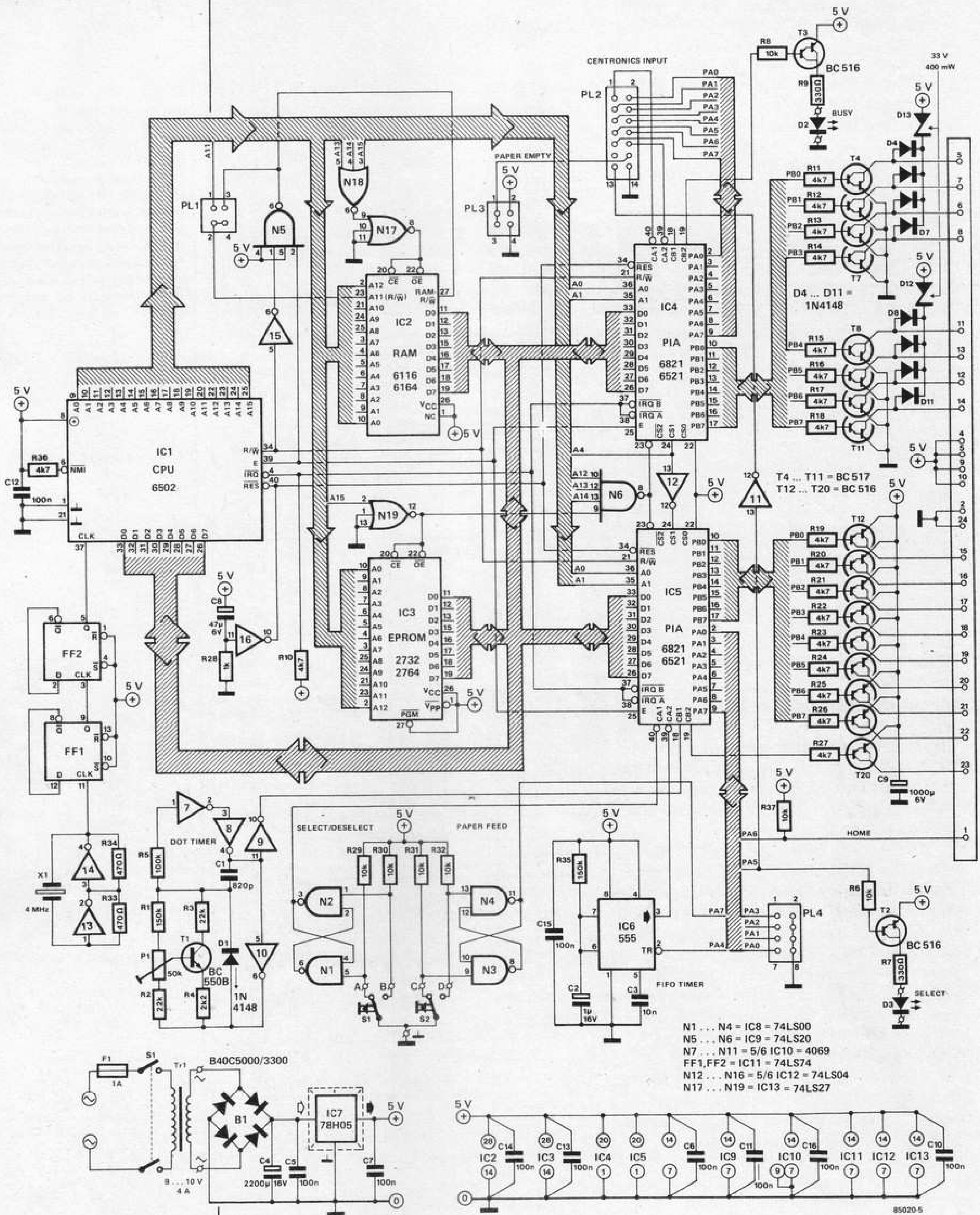


Figure 5. Although designed to suit the Seiko printer, this circuit is universal enough to be easily modified if another type of mechanism is to be used.

diagram of specific importance to this project. There is a select switch to turn the plotter on and off, a manual paper-feed switch, the Centronics interface, the transistorized power stages, the clock used to control the head-current based on the ambient temperature (dot timer), and a timer (FIFO timer) that determines the printing speed for characters received via the input buffer. At the right-hand side of figure 4 we see the printer sections: two motors (one for the paper, one for the head), the head itself, and the 'home' switch.

Once you have seen the block diagram, the actual circuit (shown in figure 5) holds few surprises. On power-up the circuit is reset by R28 and C8. The 4 MHz clock signal generated by N13 and N14 is reduced to 1 MHz by FF1 and FF2. A RAM R/$\overline{W}$

signal is obtained via N5 and N15, while N19 provides the address decoding signal for read-only memory IC3. If an 8K EPROM chip is used, it is located in addresses $E000_{HEX}$ to $FFFF_{HEX}$. If a 4K EPROM is used (as is shown here), the addresses occupied are F000. . .$FFFF_{HEX}$. The possibility of using 8K of ROM (twice the standard size) leaves room to expand the resident software. Address decoding for the RAM is taken care of by N17 and N18. Depending on the choice of IC2, either 2K or 8K of RAM is available, occupying addresses 0000. . .07FF or 0000. . .1FFF respectively. If 2K RAM is used, the input buffer is only 1½K bytes; with 8K RAM the buffer size grows to 7½K bytes. If IC2 is a 6116, pins 3 and 4 of PL1 must be linked, whereas in the case of a 6164 a link is made between pins 1 and 2. Address decoding of input-output circuits IC4 and IC5 is taken care of by N6 and N19 (up to the general selection of page 7XXX) in combination with N12. This latter NOT gate is needed to choose either:
7010_{HEX} (IC4) or
7000_{HEX} (IC5)
Simple anti-bounce flip-flops are located around S1 and S2. The logic levels output by these flip-flops is fed to lines CA1 and PA7 of IC5, via which the processor can examine them. In this way S1 switches the plotter on and off and S2 controls the manual paper feed.

The printer's Centronics interface, the pin designation of which is given in table 1, is based on port A of IC4 and connector PL2. The BUSY and SELECT LEDs are controlled by lines CB2 of IC4 and PA5 of IC5. The printer mechanism we used does not signal whether there is paper present or not, so the Centronics interface does not have a PAPER EMPTY signal as such. Making one of the links in PL3 as shown below causes the inverse level at the Centronics PE line of that expected by the computer.
1-2, if the computer expects a $\overline{PE}$ signal (Centronics = PE)
3-4, if the PE signal is expected (Centronics = $\overline{PE}$).

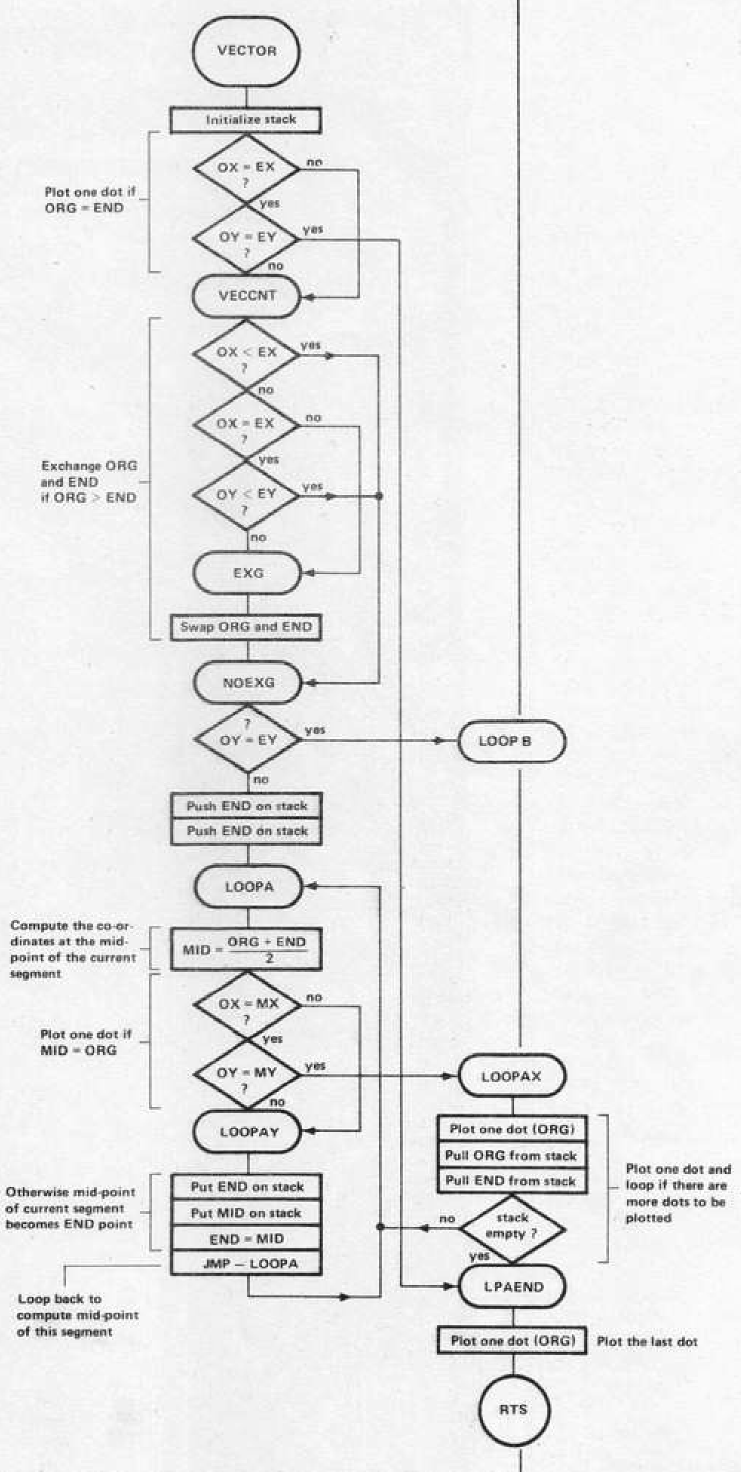
The compensation for the paper feed mechanism's 'dead' angle is achieved by placing links in PL4. We have dedicated a box here to deal with this. The dead angle of the 256-dot mechanism is 2 dots and of the 320-dot type is 3 dots. In practice or with use these values may change so we have allowed for a compensation of up to 7 steps.

The links at PL4 also select either the 256 or the 320 point mechanism. This is determined by the logic level on line PA3, which also ensures that the software is suitable for the version used.

All this brings us to the input-output lines and to the actual operation of the circuit. The 6821s, used here because of their favourable price, do not have any internal timer like their more expensive counterparts so a 555 is needed for this. The timer generates a pulse used to control the speed at which the 6502 deals with the input buffer. The processor is continually divided between two tasks: receiving and storing characters in the buffer and outputting these same characters for printing. The sequence of events can be summarized as follows.

- The printer has just been initialized and is ready to receive data; before starting to receive data the software sends a trigger pulse to monostable IC6.
- During the IC6 pulse the printer is in the receive mode; characters that appear at the input are saved in a FIFO (first in first out) buffer.
- As soon as the pulse has passed a line of characters is printed if there is one in the buffer (if a CR is present).
- The software resets the monostable and

Table 5.



6

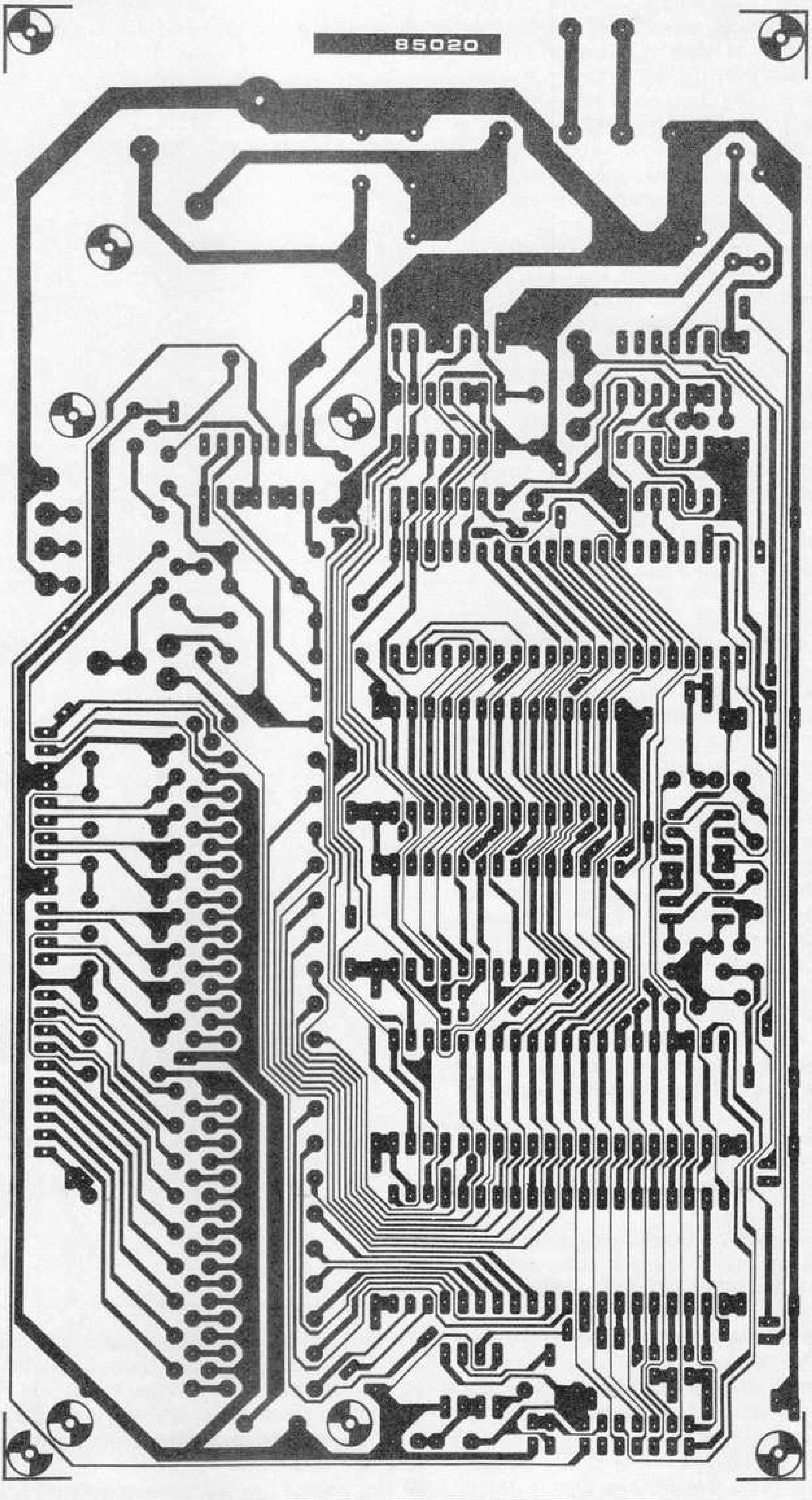
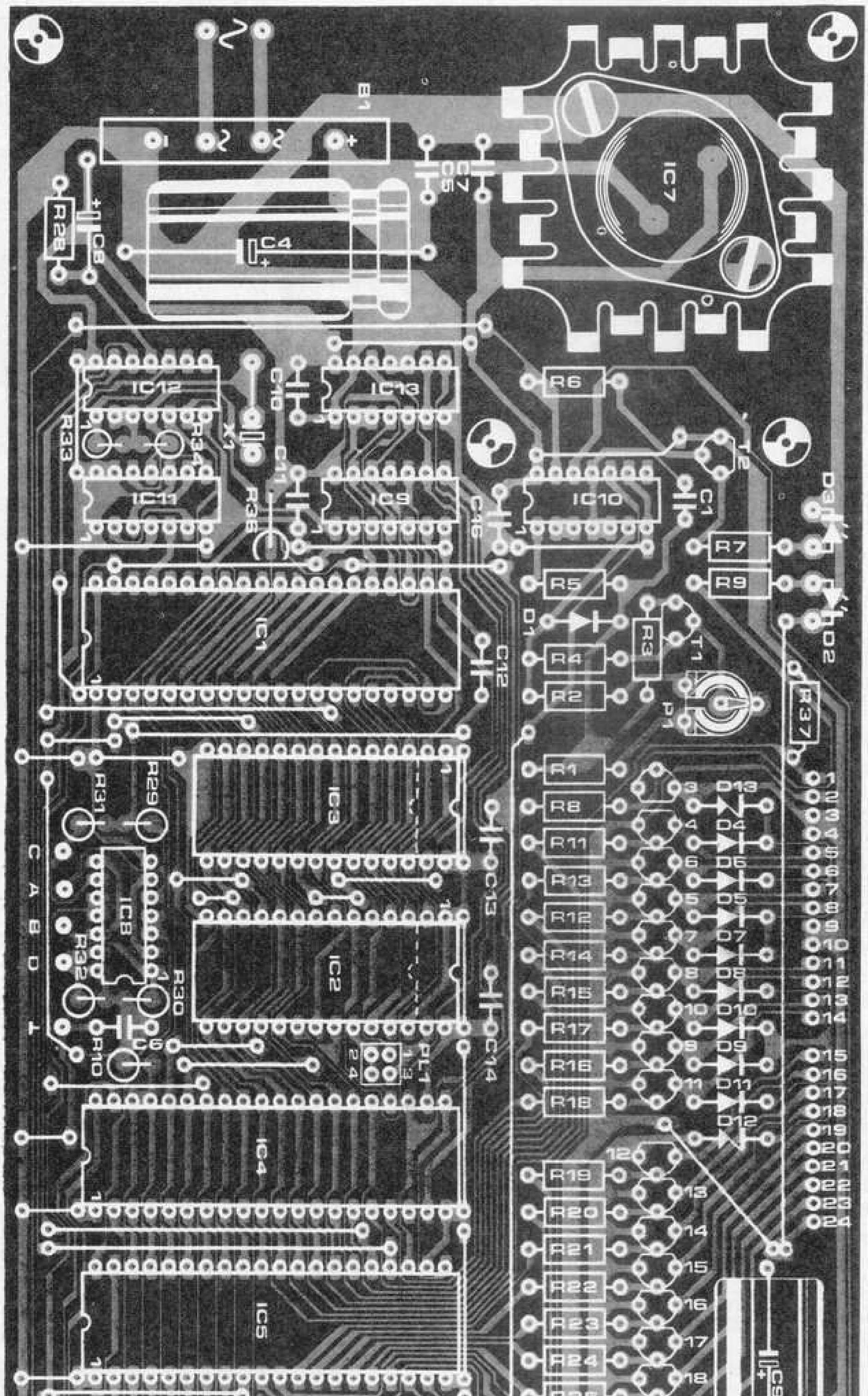


Figure 6. All the components except the mains transformer fit onto this printed circuit board. Even the Seiko printer is bolted to the board. When fitting the completed circuit into a case, be careful not to forget that the paper needs an entry and an exit point.

examines the Centronics interface: if a new character has appeared it is loaded into the buffer and reception continues until the end of the pulse; if there is no new character to receive, the program continues to print the lines of characters already received until the buffer is empty or the timing pulse supplied by the 555 ends.

This cycle continues indefinitely. The software constantly examines the buffer pointer to avoid a skip that would result in an irreparable loss of data.

The oscillator based on N6...N9 is also an essential timing element during printing. Its frequency determines the cyclic relationship of the pulses applied via T12...T20 to the print-head elements. The energy applied to these elements is scrutinized closely as the current cannot be



constantly present or it would cause a burn-out. Compensation for changes in ambient temperature is achieved with preset P1, whose wiper is connected to the base of transistor T1. Moving the wiper of P1 changes the biasing on T1 and thereby increases or decreases the frequency of the associated multivibrator.
This section of the circuit also enables the electronics for the printer to be tuned to the different types of thermal elements that Seiko mount in the mechanism. The suffix used (A, B or C) designates the resistance of the print head. The exact value is unimportant as P1 compensates for it in any case. The smaller the resistance of the thermal elements the lower the multivibrator oscillating frequency (upon which the current directly depends).

Parts list

Resistors:
R1 = 150 k
R2,R3 = 22 k
R4 = 2k2
R5 = 100 k
R6,R8,R29...R32, R37 = 10 k
R7,R9 = 330 Ω
R10,R19...R27,R35, R36 = 4k7
R11...R18 = 5k6
R28 = 1 k
R33,R34 = 470 Ω
P1 = 50 k preset

Capacitors:
C1 = 820 p
C2 = 1 μ/16 V
C3 = 10 n
C4 = 2200 μ/16 V
C5,C6,C7,C10...C16 = 100 n
C8 = 47 μ/6 V
C9 = 1000 μ/16 V

Semiconductors:
D1,D4...D11 = 1N4148
D2 = LED red
D3 = LED green
D12,D13 = 33 V/400 mW zener
B1 = bridge rectifier 40 V/5 A
T1 = BC 550B
T2,T3,T12...T20 = BC 516
T4...T11 = BC 517
IC1 = 6502
IC2 = 6116 (6164)
IC3 = 2732 (2764)
IC4,IC5 = 6821 (6521)
IC6 = 555
IC7 = 78H05 (TO3)
IC8 = 74LS00
IC9 = 74LS20
IC10 = 4069
IC11 = 74LS74
IC12 = 74LS04
IC13 = 74LS27

Miscellaneous:
F1 = fuse, 1 A slow-blow
Tr1 = mains transformer, 9...10 V/4 A
X1 = quartz crystal, 4 MHz
Seiko X-Y plotter mechanism, STP411-256 or STP411-320
heat sink for IC7, TO3 type
dual-row links: 2 off 4-way
1 off 8-way
1 off 14-way
PCB 85020

The stepping motors are controlled via two groups of four transistors (T4...T7 and T8...T11), each fitted with a diode circuit as a protection against any reverse inductive charges the motors may generate. An article is dedicated to this sort of motor elsewhere in this issue so we will not duplicate any of the details here.
Before moving on from figure 5 we would like to point out the power supply section based on IC7. This provides power for the processor and its peripherals, of course, but also for the motors and thermal elements. Because of that is dissipates a lot of heat. During printing the peak current consumption is actually about 4.5 A.

Small, but...

Of no little merit is the fact that this printer/plotter is small in size. The layout of the printed circuit board is seen in figure 6. The four corners of the printer mechanism are bolted to this board at the positions provided. Connecting the mechanism to the board is a matter of making 24 direct links between the two, on a one-to-one basis. Before doing this, however, it is wise to test the power supply (without the other components), and then the clock, anti-bounce flip-flops, and oscillator N6...N9. After mounting P1 on the printed circuit board, its wiper should be turned fully to the right. In this position the printing contrast is minimal and there is no danger of burning out the print-head elements. Initialize (reset) the circuit and check that the logic level at the bases of T12...T20 is high. These transistors are then switched off so no current can flow through the thermal elements.
The 'electronics' can now be connected to the 'mechanics'. If an STP411-320 is used, make links 1...24 as indicated. If the lower-resolution STP411-256 is chosen, make all the links except 23 and then solder pins 23 and 24 together **at the printer mechanism** (not on the printed circuit board). The mechanism of the STP411-256 must also be modified slightly. As table 4 shows, pins 15...23 are offset on the '256' compared to the '320'. Rather than correct this by software, we prefer to move the internal connector on the printer block. The print head is connected to the chassis by a small piece of flexible printed circuit board (this can be seen in photo 4). The '320' version uses all of the ten available tracks, whereas with the '256' only nine of the lines in the female connector are used by the male connector. In this way, there is a line free either at the left or at the right of the female connector. The Seiko version leaves the empty line at the left (pin 15 in table 4), but in our design we have moved the space to the extreme right (pin 24). This change is easily made: carefully extract the female connector from the chassis, move it one step to the left, and re-insert it. Do not use any sharp (or toothed) tools for this — it is far better to just use your fingers.

If the wiper of P1 is turned fully clockwise, this electronico-mechanical assembly is now ready for the baptism of fire.

The software

The program stored in EPROM IC3 cannot be properly dealt with in this article so we will only describe it in a very general way. The software is the same no matter

Table 6.

Important addresses
Owing to lack of space, we are not able to give you the complete source listing; the hex dump of the EPROM in the plotter is given instead. Vector NMI in $FFFA_{hex}$ and $FFFB_{hex}$ points to the origin of a test routine in $FB41_{hex}$. The remainder of the EPROM content is divided into two: the routines for receiving and printing (alphanumerically) with the character generator, and the routines for plotting the vectors.
Table 6 gives the principal addresses in hexadecimal.

F000...F02C: *internal jump-table*
F02D...F034: *stepper look-up tables*
F039: *delay subroutine*
F041: *SIGMA initialisation (reset vector)*
F092: *turn paper feed stepper right*
F0AC: *turn paper feed stepper left*
F0BC: *step print head left*
F0D6: *step print head right*
F0E6: *feed paper and increment*
F10D: *eat paper and increment*
F13B: *head right and increment*
F144: *head left and decrement*
F154: *home head*
F194: *print character in A*
F308: *print line buffer*
F384: *load head*
F393: *receive a character*
F41A: *printer main program*
F586: *character generator*
F935: *graphic sigma*
F976: *plot origin*
FA4F: *graphic handler*
FB41: *test program (NMI vector)*
FB90: *vector plotter*

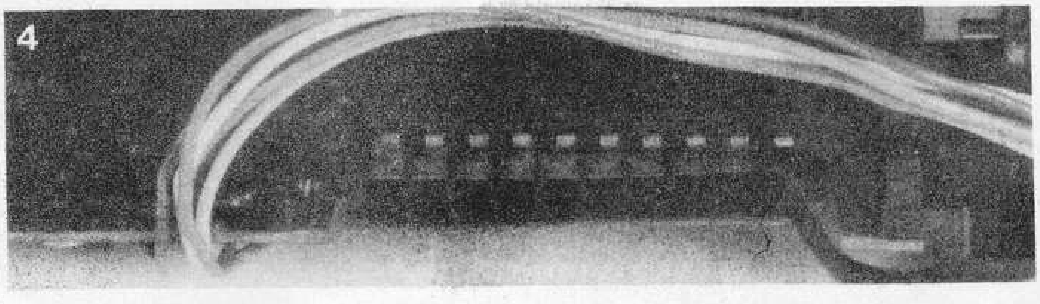


Photo 4. To use the same character generator for both types of printer mechanism (256 or 320 points), the connector of the 256-point version must be moved one space to the left.

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
000:	4C	D5	F2	4C	57	F2	4C	93	F2	4C	54	F1	4C	84	F3	4C
010:	D6	F0	4C	BC	F0	4C	92	F0	4C	AC	F0	4C	3B	F1	4C	44
020:	F1	4C	E6	F0	4C	0D	F1	4C	41	F0	4C	22	F4	A0	60	50
030:	90	0A	06	05	09	A5	C8	00	02	48	68	48	68	CA	D0	F9
040:	60	D8	A9	00	8D	01	70	8D	03	70	8D	11	70	8D	13	70
050:	8D	10	70	A9	30	8D	00	70	A9	FF	8D	02	70	8D	12	70
060:	A9	04	8D	01	70	A9	3E	8D	03	70	A9	FF	8D	02	70	A9
070:	2C	8D	11	70	A9	3C	8D	13	70	A2	DF	8E	00	70	A9	00
080:	A2	07	95	0E	CA	10	FB	A9	24	85	21	A9	00	85	00	85
090:	01	60	A6	00	E8	E0	04	F0	16	86	00	AD	12	70	29	0F
0A0:	1D	2D	F0	8D	12	70	AE	36	F0	4C	39	F0	A6	00	CA	30
0B0:	07	4C	99	F0	A2	00	F0	E1	A2	03	D0	DD	A6	01	E8	E0
0C0:	04	F0	18	86	01	AD	12	70	29	F0	1D	31	F0	8D	12	70
0D0:	AE	35	F0	4C	39	F0	A6	01	CA	10	07	4C	C3	F0	A2	00
0E0:	F0	E1	A2	03	D0	DD	A5	65	29	20	D0	12	24	65	30	0E
0F0:	A4	63	20	92	F0	88	D0	FA	A5	65	09	60	85	65	E6	04
100:	D0	02	E6	05	A0	04	20	92	F0	88	D0	FA	60	A5	65	29
110:	20	D0	12	24	65	10	0E	A4	63	20	AC	F0	88	D0	FA	A5
120:	65	29	7F	85	65	38	A5	04	E9	01	85	04	A5	05	E9	00
130:	85	05	A0	04	20	AC	F0	88	D0	FA	60	E6	02	D0	02	E6
140:	03	4C	D6	F0	38	A5	02	E9	01	85	02	A5	03	E9	00	85
150:	03	4C	BC	F0	2C	00	70	B0	06	20	BC	F0	4C	54	F1	A0
160:	20	20	D6	F0	88	D0	FA	2C	00	70	70	06	20	BC	F0	4C
170:	67	F1	A0	03	20	BC	F0	88	D0	FA	A0	02	20	D6	F0	88
180:	D0	FA	A0	10	20	92	F0	88	D0	FA	A0	10	20	AC	F0	88
190:	D0	FA	60	60	C9	20	90	FB	C9	80	B0	F7	38	E9	20	A8
1A0:	A9	00	AA	48	A9	05	48	8A	48	98	48	20	93	F2	A9	F5
1B0:	48	A9	86	48	20	57	F2	68	85	0C	68	85	0D	A0	04	B1
1C0:	0C	99	0E	00	88	10	F8	A4	18	D0	47	20	3B	F1	AD	02
1D0:	70	B9	0E	00	A2	28	2C	03	70	10	FB	48	A5	65	29	10
1E0:	D0	24	68	49	FF	8D	02	70	AD	02	70	2C	03	70	10	FB
1F0:	CA	D0	F5	A9	FF	8D	02	70	AD	03	70	09	38	8D	03	70
200:	C8	C0	06	90	C6	60	AD	03	70	29	F7	8D	03	70	68	4C
210:	E5	F1	AD	02	70	B9	0E	00	A2	28	2C	03	70	10	FB	48
220:	A5	65	29	10	D0	25	68	49	FF	8D	02	70	AD	02	70	2C
230:	03	70	10	FB	CA	D0	F5	A9	FF	8D	02	70	AD	03	70	09
240:	38	8D	03	70	20	44	F1	88	10	C8	60	AD	03	70	29	F7
250:	8D	03	70	68	4C	29	F2	68	85	16	68	85	17	68	85	06
260:	68	85	07	68	18	65	06	A8	68	65	07	48	98	48	A5	17
270:	48	A5	16	48	60	68	85	16	68	85	17	68	85	06	68	85
280:	07	68	38	E5	06	A8	68	E5	07	48	98	48	A5	17	48	A5
290:	16	48	60	68	85	16	68	85	17	68	85	08	68	85	09	68
2A0:	85	06	68	85	07	A9	00	85	0A	85	0B	A2	11	18	66	0B
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2D0:	48	A5	16	48	60	68	85	16	68	85	17	68	85	06	68	85
2E0:	07	68	85	08	68	85	09	A5	17	48	A5	16	48	A5	08	C5
2F0:	06	F0	09	A5	09	E5	07	09	01	70	08	60	A5	09	E5	07
300:	70	04	60	49	80	09	01	60	A5	24	F0	07	20	01	F4	C6
310:	24	D0	F9	A5	02	05	03	D0	19	85	18	A0	01	84	20	B9
320:	81	01	C9	0A	F0	03	20	94	F1	E6	20	A4	20	C4	1F	D0
330:	EE	60	A9	00	AA	48	A5	1E	48	8A	48	A9	06	48	20	93
340:	F2	68	85	22	AA	68	85	23	48	8A	48	A5	03	48	A5	02
350:	48	20	D5	F2	F0	0A	B0	22	20	44	F1	20	0A	F4	D0	F8
360:	A9	05	85	18	A6	1F	CA	86	20	A4	20	B9	81	01	C9	0A
370:	F0	03	20	94	F1	C6	20	D0	F0	60	20	3B	F1	20	0A	F4
380:	D0	F8	F0	DC	A0	04	20	D6	F0	88	D0	FA	A9	00	85	02
390:	85	03	60	2C	11	70	10	35	AD	13	70	29	F7	8D	13	70
3A0:	AD	10	70	48	AD	13	70	09	08	8D	13	70	68	C9	1B	F0
3B0:	18	C9	04	F0	14	C9	09	F0	10	C9	0D	F0	0C	C9	0A	F0
3C0:	08	C9	20	90	08	C9	80	B0	04	85	1D	38	60	18	60	E6
3D0:	1B	D0	02	E6	1C	A5	25	C5	1C	D0	04	A9	02	85	1C	60
3E0:	E6	19	D0	02	E6	1A	A5	25	C5	1A	D0	04	A9	02	85	1A
3F0:	60	A5	1C	48	A5	1B	48	A5	1A	48	A5	19	48	20	D5	F2
400:	60	A4	21	20	92	F0	88	D0	FA	60	A5	03	48	A5	02	48
410:	A5	23	48	A5	22	48	20	D5	F2	60	A9	08	D0	57	A9	2B
420:	D0	30	70	A2	FF	9A	E8	86	65	86	63	20	41	F0	20	54
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440:	A5	65	09	20	85	65	D0	03	EA	85	63	8A	29	08	F0	CE
450:	A9	3A	85	64	A9	00	85	3C	AD	37	F0	85	19	85	1B	AD
460:	38	F0	85	1A	85	1C	A9	00	85	00	A9	AA	8D	00	08	C5
470:	00	F0	A7	A9	20	85	25	A9	7F	85	32	A9	01	85	33	A5
480:	65	09	40	85	65	20	3D	F5	20	61	F5	A2	00	86	1E	86
490:	24	E8	86	1F	20	3D	F5	A5	65	29	40	F0	22	20	93	F3
4A0:	90	18	C9	04	F0	2F	C9	09	F0	31	C9	0D	F0	E6	A0	00
4B0:	91	1B	20	CF	F3	20	F1	F3	F0	0A	2C	01	70	50	D5	20
4C0:	F1	F3	F0	D0	A0	00	B1	19	48	20	E0	F3	68	C9	1B	D0
4D0:	13	05	3C	F0	13	20	00	F8	4C	85	F4	A5	65	49	10	85
4E0:	65	4C	85	F4	C9	0A	F0	16	A6	1F	9D	81	01	E6	1E	E6
4F0:	1F	A6	1E	E4	64	F0	24	20	F1	F3	D0	C8	F0	96	A6	1F
500:	9D	81	01	E6	24	E6	1F	A5	3C	C9	1B	F0	27	20	08	F3
510:	2C	11	70	10	03	4C	85	F4	4C	8B	F4	A6	1F	A9	0A	9D
520:	81	01	E6	24	E6	1F	20	08	F3	A2	00	86	1E	86	24	E8
530:	86	1F	D0	C3	20	03	F8	A9	00	85	3C	F0	D3	2C	01	70
540:	10	12	A5	65	48	40	85	65	AD	00	70	49	20	8D	00	70
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560:	60	AD	00	70	29	EF	8D	00	70	09	10	8D	00	70	60	AD
570:	00	70	10	11	20	54	F1	AD	00	70	10	06	20	92	F0	4C
580:	77	F5	4C	84	F3	60	00	00	00	00	00	00	00	00	5F	00
590:	00	07	00	07	00	0A	1F	0A	1F	0A	24	2A	7F	2A	12	23
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5B0:	22	41	00	00	41	22	1C	00	2A	1C	7F	1C	2A	08	08	3E
5C0:	08	08	00	00	00	B0	70	00	08	08	08	08	00	C0	C0	00
5D0:	00	20	10	08	04	02	3E	51	49	45	3E	00	02	7F	00	00
5E0:	62	51	49	49	46	41	41	49	4D	33	0F	08	08	7F	08	47
5F0:	45	45	45	39	3C	4A	49	49	30	61	11	09	05	03	36	49
600:	49	49	36	06	49	49	29	1E	00	36	36	00	00	00	B6	76
610:	00	00	08	14	22	41	00	14	14	14	14	14	00	41	22	14
620:	08	02	01	51	09	06	3E	41	5D	55	5E	7E	09	09	09	7E
630:	7F	49	49	49	36	3E	41	41	41	22	7F	41	41	41	3E	7F
640:	49	49	49	41	7F	09	09	09	01	3E	41	49	49	7A	7F	08
650:	08	08	7F	00	41	7F	41	00	20	40	40	40	3F	7F	08	14

660:	22	41	7F	40	40	40	40	7F	02	0C	02	7F	7F	02	04	08
670:	7F	3E	41	41	41	3E	7F	09	09	09	06	3E	41	51	21	5E
680:	7F	09	19	29	46	26	49	49	49	32	01	01	7F	01	01	3F
690:	40	40	40	3F	1F	20	40	20	1F	7F	20	18	20	7F	63	14
6A0:	08	14	63	07	08	70	08	07	61	51	49	45	43	00	7F	41
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6D0:	40	7F	44	44	3C	00	38	44	44	48	38	44	44	7F	40	00
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6F0:	04	04	78	00	00	7A	00	00	80	40	80	7A	00	00	7E	10
700:	28	44	00	02	7E	40	00	7C	04	7C	04	78	00	7C	04	04
710:	78	00	38	44	44	38	00	FC	24	24	18	18	24	24	FC	80
720:	00	7C	08	04	04	00	48	54	54	24	00	04	3E	44	20	3C
730:	40	40	7C	40	0C	30	40	30	0C	3C	40	30	40	3C	44	24
740:	38	48	44	00	1C	A0	A0	FC	40	64	54	4C	04	00	08	36
750:	41	41	00	00	77	00	00	00	41	41	36	08	08	08	08	08
760:	38	55	2A	55	2A	55	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
770:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
780:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
790:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
7A0:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
7B0:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
7C0:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
7D0:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
7E0:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
7F0:	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
800:	4C	35	F9	4C	4F	FA	4C	9E	F9	A0	00	A5	2D	91	32	20
810:	24	F8	A5	2C	91	32	20	24	F8	A5	2B	91	32	20	24	F8
820:	A5	2A	91	32	38	A5	32	E9	01	85	32	B0	02	C6	33	60
830:	A0	00	A5	31	91	32	20	24	F8	A5	30	91	32	20	24	F8
840:	A5	2F	91	32	20	24	F8	A5	2E	91	32	4C	24	F8	20	6D
850:	F8	A0	00	B1	32	85	26	20	6D	F8	B1	32	85	27	20	6D
860:	F8	B1	32	85	28	20	6D	F8	B1	32	85	29	60	E6	32	D0
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880:	B1	32	85	2B	20	6D	F8	B1	32	85	2C	20	6D	F8	B1	32
890:	85	2D	60	18	A5	26	65	2A	85	2E	A5	27	65	2B	85	2F
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8B0:	31	46	31	66	30	60	A9	01	48	A9	7F	48	A5	33	48	A5
8C0:	32	48	20	00	F0	60	A5	27	48	A5	26	48	A5	2F	48	A5
8D0:	2E	48	20	00	F0	60	A5	29	48	A5	28	48	A5	31	48	A5
8E0:	30	48	20	00	F0	60	A5	27	48	A5	26	48	A5	2B	48	A5
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900:	2C	48	20	00	F0	60	A5	27	48	A5	26	48	A5	2B	48	A5
910:	2A	48	A5	29	48	A5	28	48	A5	2D	48	A5	2C	85	28	68
920:	85	29	68	85	2C	68	85	2D	68	85	26	68	85	27	68	85
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940:	04	85	05	86	02	85	03	A0	0A	20	15	F0	88	D0	FA	A5
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970:	02	48	20	00	F0	60	20	56	F9	F0	0B	90	06	20	21	F0
980:	4C	86	F9	20	24	F0	20	66	F9	F0	0E	90	06	20	18	F0
990:	4C	76	F9	20	1E	F0	4C	76	F9	20	56	F9	D0	D8	AD	02
9A0:	70	A2	28	2C	03	70	10	FB	AD	02	70	29	FE	8D	02	70
9B0:	2C	03	70	10	FB	AD	02	70	CA	D0	F5	AD	02	70	09	01
9C0:	8D	02	70	60	85	35	84	34	A0	00	B1	34	AA	A9	01	85
9D0:	36	A9	00	85	37	85	38	85	39	8A	D0	03	4C	49	FA	A4
9E0:	36	B1	34	C9	2D	D0	0C	A9	FF	85	39	E6	36	CA	F0	59
9F0:	4C	FC	F9	C9	2B	D0	09	E6	36	CA	F0	4D	A4	36	B1	34
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A30:	E6	36	CA	D0	C7	A5	39	10	0D	A9	00	38	E5	37	85	37
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A50:	FF	85	3C	A9	01	85	3A	85	3B	A2	18	A9	00	95	47	CA
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A70:	2F	F0	2F	C9	0A	F0	3C	48	A9	00	48	A9	47	48	A9	00
A80:	AA	48	A5	3C	48	8A	48	A9	07	48	20	06	F0	20	03	F0
A90:	68	85	45	68	85	46	A4	3B	68	91	45	E6	3B	E6	3A	4C
AA0:	62	FA	E6	3C	F0	F7	A6	3B	CA	8A	A0	00	91	45	C8	84
AB0:	3B	D0	EA	A5	3C	C9	04	D0	37	A0	47	A9	00	20	C4	F9
AC0:	B0	2E	84	26	85	27	A0	4E	A9	00	20	C4	F9	B0	21	84
AD0:	28	85	29	A0	55	A9	00	20	C4	F9	B0	14	84	2A	85	2B
AE0:	A0	5C	A9	00	20	C4	F9	B0	07	84	2C	85	2D	20	90	FB
AF0:	60	30	00	30	00	40	01	30	00	40	01	30	00	70	01	50
B00:	00	70	01	50	00	60	00	50	00	60	00	50	00	30	00	30
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B20:	01	70	01	50	00	00	01	40	01	60	00	50	00	00	01	40
B30:	01	30	00	30	00	70	01	50	00	40	01	30	00	60	00	50
B40:	00	A2	FF	9A	20	4A	FB	4C	27	F0	20	35	F9	A9	00	85
B50:	3A	A6	3A	BD	F1	FA	85	26	E8	BD	F1	FA	85	27	E8	BD
B60:	F1	FA	85	28	E8	BD	F1	FA	85	29	E8	BD	F1	FA	85	2A
B70:	E8	BD	F1	FA	85	2B	E8	BD	F1	FA	85	2C	E8	BD	F1	FA
B80:	85	2D	E8	86	3A	E0	51	B0	06	20	90	FB	4C	51	FB	60
B90:	A9	7F	85	32	A9	01	85	33	20	E6	F8	D0	05	20	F6	F8
BA0:	F0	42	20	E6	F8	90	0A	D0	05	20	F6	F8	90	03	20	06
BB0:	F9	20	F6	F8	B0	3A	20	09	F8	20	09	F8	20	93	F8	20
BC0:	C6	F8	D0	05	20	D6	F8	F0	0C	20	09	F8	20	30	F8	20
BD0:	27	FC	4C	BC	FB	EA	20	76	F9	20	4E	F8	20	74	F8	20
BE0:	B6	F8	D0	D8	20	76	F9	A0	04	20	18	F0	88	D0	FA	60
BF0:	20	09	F8	20	09	F8	A0	04	20	15	F0	88	D0	FA	20	38
C00:	FC	20	C6	F8	D0	05	20	D6	F8	F0	0C	20	09	F8	20	30
C10:	F8	20	27	FC	4C	FE	FB	EA	20	76	F9	20	4E	F8	20	74
C20:	F8	20	B6	F8	D0	D8	60	A4	2E	A5	2F	84	2A	85	2B	A4
C30:	30	A5	31	84	2C	85	2D	60	18	A5	26	65	2A	85	2E	A5
C40:	27	65	2B	85	2F	18	A5	28	65	2C	85	30	A5	29	65	2D
C50:	85	31	E6	30	D0	02	E6	31	46	2F	66	2E	46	31	66	30
C60:	60															

	A	B	C	D	E	F	0	1	2	3	4	5	6	7	8	9
FFA:	41	FB	2A	F0												

which type of RAM is used. After initialization it determines how much random access memory is available for the input buffer (spooler). This buffer is used both in matrix printer mode and in X-Y plotter mode. The computer connected to the Centronics printer can transmit data very quickly and does not have to wait for it to be printed. The average transmission rate is about 300 baud. The printing speed varies with the frequency of the clock, which itself determines the degree of contrast. On average two lines of characters per second are printed.

The parameters for tracing a vector, as we have already mentioned, must be preceded by the ASCII ESC character. Four parameters are specified, separated by the ASCII character "/". The order is:

- coordinate of the origin on the X-axis

- "/"
- coordinate of the origin on the Y-axis
- "/"
- coordinate of the end on the X-axis
- "/"
- coordinate of the end on the Y-axis
- "/"

If none of these parameters is left out or if there is an error in the syntax the complete instruction is simply ignored. Be especially careful not to forget the last "/" after the end Y coordinate.
Before starting to trace a design the pointers and timers for the plotter program must be initialized. This is achieved with the CTL-D (CHR$4) command.
It will now be apparent just how easy this printer is to use in either mode. It is also a simple matter to combine alphanumeric characters and graphic traces.
Lines are traced using an algorithm that makes successive approximations for the coordinates of all points between the origin and the end of the vector (table 5). In theory this algorithm allows vectors to be 32768 dots. If the vectors end coordinates are lower than the origin (on one axis or both), the X-Y plotter itself automatically reverses the direction of the plot.
In printer mode the CTL-I (CHR$9) instruction flips a 'switch' in the program: all characters received after this command are printed in white on a black background. The inversion continues until another CTL-I is received. Note that an ASCII LF (line feed) is not needed after CR (carriage return) but it does not affect the operation of the printer. On the other hand, the characters fed into the buffer are dealt with one line at a time so the program can determine the position of the print head when the CR arrives. This information is then used to decide whether the next line will be printed from left to right or right to left. This so-called 'bi-directional logical seek' simply looks at which choice requires the least head movement.

Printer

This printer/plotter can be tested even without a Centronics interface. An automatic test program included in EPROM IC3 takes care of this. The test draws a three-dimensional pyramid and is started by a short negative pulse on the 6502's NMI (non maskable interrupt) input. A push-button can be connected from pin 6 of IC1 to ground for this.
The printing contrast is increased by moving the wiper of P1 left-ward. The contrast changes very gradually only.
There may be a noticeable drift at the corners of the test pyramid's base. If this is the case, insert the link between pins 7 and 8 of PL4 and give another NMI pulse. The drift is then reduced by one step. If this is not enough, insert the next link. Continue like this, following table 2, until the pyramid is as perfect as possible.
When this correction is made, the push-button can be removed. Now all the printer/tracer needs is to be put into a suitable case.

Final note

If the power-on reset does not always work error-free, this may be remedied by (a) replacing the 74LS04 in the IC12 position by a 74LS14, or (b) connecting an additional pull-up resistor of 1 k between the +5 V line and pin 10 of IC12 (output of N16).