Increase QL System Speed by Adding Memory Boards…

by Sid Martin and Timothy Green

A comparitive evaluation of QL memory upgrades, along with the start of a resource file and updates on the Spectrum scene

QL INSTANT RECALL

A standard QL could run tasks such as the Psion software twice as fast if Sinclair hadn't taken a short cut in the machine's design. The speed of QL memory is deliberately slugged to simplify the design of the Computer.

Sinclair say the processor runs at 7.5 Megahertz — in other words, it receives 7.5 million timing. pulses a second — but in fact it goes at less than half that sped when reading code from the 128K of RAM inside the computer.

Luckily, this hidden kludge does not affect the memory in a well- designed expansion RAM unit, so the QL's performance can leap ahead when extra memory is fitted.

Some makes of add-on memory allow values to be stored or read at twice the rate at which the QL's standard 128K can work. This can have an obvious effect on the speed of tasks, utilities and RAM-based command libraries, such as Turbo Toolkit and the original Sinclair QL Toolkit.

RAM speed is one of the few useful benchmarks, as Simon N Goodwin pointed out in last month's *Computer Shopper.*

Your choice of QL RAM can make a big difference to system performance, yet few. QL firms mention the speed of their add-ons in advertisements.

This month, we've surveyed almost all, of the popular QL expansion units, and compared their speed. We've also tested CST's Thor range, and estimated the speed of the forthcoming, but still undelivered, CST Thor 16.

This survey was prompted by research done by QL software house Digital Precision, who discovered the wide range in QL speeds when they were testing their Turbo compiler.

Our test program is. listed here, so you can use it to check Out your own machine. If your system gives different results, please write in to let us know.

We've included calculated figures for the Z88 and all models of Spectrum, as well as Miles Gordon Technology's prototype SAM Spectrum-compatible computer.

Dynamic Display

Before we get involved in a discussion of .the test results it's worth indulging in a little contemporary industrial archeology, to find out why external RAM can run so much faster than standard QL memory.

 A standard Sinclair QL contains 16 standard 64K bit RAM chips, giving 128K bytes of memory. The computer uses so-called dynamic memory — this is cheap and consumes little puwer, but it can only store information reliably for a fraction of a second.. Dynamic memory uses a charge akin to static electricity to record information. The charge constantly leaks away, so it must be replenished regularly.

This isn't usually a major problem — dynamic memory is used in lots of other computers, from the IBM PC to the ZX Spectrum. Normally, a special circuit is used to refresh the memory, by cyclically reading values from every address and then writing them back. The Z80 processor in ZX range computers can do this automatically, but there is no such circuit in the QL's 68008 processor.

The QL doesn't forget all its data because all 128K of built-in memory is constantly being read and re-written by the Sinclair ZX8301 custom chip that controls the screen display.

Bats 'N' Beams

The first 32K of RAM in the QL is reserved as display memory. The ZX-830l converts the pattern of bits in that memory into rows of dots on the screen. A TV picture is built up as a single beam scans across the display, line by line. As the beam moves, the computer reads values from the memory and uses the values to determine the colour of each dot.

All the video memory is read and re-written fifty or sixty times a second, as the entire TV picture is re-drawn. This regular access is enough to ensure that the contents of the dynamic RAM don't leak away, without the need for a separate recharging circuit.

To save money, Sinclair used the video circuit to refresh the whole 128K. This reduces the cost of the computer, by decreasing the number of distinct signals flying around the circuit-board. The QL hardware took 14 months to design — six months of that time was spent doubling-up pins on the custom chips to save space and money.

The decision to re-use the video circuit has some annoying consequences.

Each memory chip can only talk' to one device at a time. Strange things would happen if the processor tried to set a bit to zero while the video generator was trying to refresh it with the previous value, which might be different. But both devices run at the same time and the processor will often need access to video memory — to write a message, for instance, or to clear a window.

You might make the video generator wait its turn when the processor is busy fiddling with memory. But the video chip can't just wait. The beam is still zooming across theTVscreen-by the time the data is ready the beam will be somewhere else, and the video chip should be reading a different-bit.

To get around this you might make the video chip- produces-a fixed colour whenever it- tried to read memory that was being used by the processor. This works, but it produces unsightly coloured streaks on the screen whenever the processor is printing text or otherwise using the display. This is the cause of the 'snow' which appears on the screen of early IBM PCs

(but not clones), and on the screen of other crude micros — Acorn Atoms, TRS-80s and many others.

THE ZX MICROFAIR

THE FEBRUARY ZX Microfair at the Horticultural. Halls was the usual feast for Spectrum and QL owners. Microfairs are a cross between computer shows and car- boot sales; all but the largest Sinclair hardware and software suppliers turn up, selling just about verything you can think of from hastily assembled stalls or trestle tables.

There are always lots of bargains at the Microfair, and there's a busy bring and buy stall run by the organisers, where users can sell off second-hand peripherals or programs.

In the main hail new and badged Spectrum Plus computers were selling for £45 complete by the end of the day,with the Amstrad Plus 2 at £85. Sixword and Miles Gordon Technology were selling fast Spectrum disk systems.

Spectrum video digitisers were much in evidence. These read a TV display from a video recorder or camera and convert it to appear on the computer screen - you can then edit or animate it with a Spectrum art package

A new low-cost digitiser called Rombo was .introduced by Zonefour (0707 334460) at a price of just £30, prompting Romantic Robot (01 200 8870) to cut the price of their well-established Videoface digitiser by £25 to £44.

The QL scene was similarly busy, with 3cveral new producti from Digital Precision (01 527 5493) including a small C compiler and the promised competitor for Sandy's CP/Mulator, Success, which we hope to review soon. Tony Firshman Services (01 724 9053) were showing hardware to enable the QL tc read and write bar codes 'as used by Huddersfleld Library'!

Creative CodeWorks (021 426 5199) were selling an even faster version of Speedscrecn, their speed-up package for the QL display, which has now been built into a £30 ROM cartridge. Utilising Software had several new packages including yet another QL command toolkit at an unusually low price of £12, a SuperBASIC error-trapping utility and an impressive sounding machine-code monitor.

We hope to review several ol the products launched at the Microfar in future issues of *Computer Shopper.*

QL SuperBASIC bus bandwidth test program

```
100 base=RESPR(16):RESTORE 170
110 FOR I=base T0 base+14 STEP 2: READ v: POKE_W  I, v
120 CLS: PRINT "Timing RAM at ";base
130 t=DATE+1: REPeat await_tick: IF DATE=t: EXIT await_tick
140 CALL base:t=DATE-t
150 PRINT "User mode read bus-bandwidth = ";
160 PRINT INT(.5+26214/(t-1.75));" KHz. "
170 DATA 28771,29439,20937,-2,20936,-8,28672,20085
```

This flicker is unacceptable on a modem computer, and there is an accepted way of getting rid of it. You use very fast memory, so that the processor AND the video generator can both read or write the same bit before the TV beam has time to move across the display.Unfortunately, the QL display uses a lot of memory. A complete 32K picture must be produced 50 or 60 times a Second, and this doesn't leave much time for the processor to get a look-in.

If we were to fit memory that could cope with the theoretical demands of the processor AND the video generator, it would have to allow for about six million accesses -iaond — two million for the processor, plus four million for the video — almost twice the top rate used by the BBC Micro.

That's the best possible case, assuming that the video generator and the processor are synchronised perfectly. In practice, the processor and video generator don't take turns at exactly the right moment, so you need even faster RAM to make up for the time wasted while the processor and video generator tare working out who's turn it is.

And this speed is required from ALL the internal memory, not just the 32K used for the video display, because Sinclair decided to make the video circuit refresh the entire 128K.

Thor 16

CST's new Thor 16 uses fast memory, so that the processor can run at about 85 per cent of full speed all the time; the Thor 16 runs few per cent faster than the QL anyway, and most importantly of all, it uses a 68000 processor which tan fetch two bytes for every one the normal QL can handle.

These effects combine to make the prototype Thor -16 typically 2.1 imes-faster than a Thor -1, or 4.3 times faster than a QL - and the new Thor has other advantages besides. We hope to be abe to review this machine - the first real SuperQL - in the next couple of months

Cheap Chips
Fast memory is not cheap — a -twin-disk Thor 16 will sell for over £800. High-speed chips would have been prohibitively expensive in 1984 when the QL was designed. So Sinclair boxed themselves into a corner. The QL had a whizzo high-speed processor, and a whizzo high-speed display — but the memory isn't fast enough to cope with both. There is a solution, but it's not a happy one.

Some manufacturers deliberately slug their circuits with extra delays, called 'wait states', to simplify design and manufacture.

The QL uses the opposite of the technique used on the old IBM PC. On the PC, whenever the processor has finished. Everything looks pretty, but the machine runs-slowly. The processor can spend as much as half of its time waiting for the video generator to get out of the way.

Sinclair were the victims of they own ambition. They took video generation and processing speed to the limits of the available components, and standard memories just could not keep up.

NEW DRUM DEAL FROM CHEETAH MARKETING

A couple of years ago joystick maanufacturers Cheetah Marketing (0222 555525) produced an add-on that propelled the firm, and the Spectrum, into, an entirely new market. Their £30 Spectrum SpecDrum interface and software turned the 48K Spectrum into a drum machine that sounded as good as most £200 semi-profesional machines. The package has since been heard on TV and radio programmes — even advertisements and has become a classic pectrum peripheral.

The original SpecDrum came with ten drum sounds, and Cheetah have since produced three tapes, each containing further kits of eight professionally recorded drum samples, plus software to let you nix and match drums from each kit.

Recently, Cheetah launched a software upgrade for the SpecDrum, the £10 System 2 that lets you play all the drums directly rom the keyboard, without proramming in a 'pattern'. You can also tweak existing sounds to change their volume and pitch, and transfer new samples into the drum oftware after recording them with another gadget, Cheetah's Sound Sampler.

Now Cheetah have packaged the whole lot together in a bundle consisting of the original software and interface, the Latin Kit of extra drum sounds plus the System 2 package. The whole lot retails for £35, and should be-in the shops by the middle of March.

The Apple Macintosh suffers from the same problem, but it only uses a monochrome screen and this helps to reduce the amount of display data that must be processed.

You can turn the QL's video display on and off with a POKE:

```
POKE 98403,2
```

The POKE only prevents the output of video information — not the process of reading it from RAM, which is vital to keeping the memory contents refreshed and intact. It's useful if you want a display to appear suddenly, but it does not affect the speed of programs in RAM.

The rnatching command to turn the display back on is:

```
POKE 98403,PEEK(163892)
```

Getting Faster

If you want to speed up the QL you must add an extra bank of memory with its own independent refresh circuitry, outside the control of the video chip. Many firms produce memory boards that work faster than the RAM inside a QL, but it takes considerable skill-to design a memory board that will work reliably at the maximum possible speed.

Some manufacturers deliberately slug their circuits with extra delays, called 'wait states', to simplify design and nianufacture. In fact there is some justification for this policy.

Few programs are limited entirely by the speed of the memory in which they run. Most programs stop and start reading memory many thousands of times a second; the delays occur while the processor works out where to go and what to do, and this is done at the same speed regardless of the type of memory.

The amount of time a program spends waiting for memory varies depending upon the exact machine-code instructions being performed. Simple instructions spend all their time waiting for memory, which complicated instructions, like division, spend only ten per cent of their time waiting for information. The Other nine tenths of the time, the.processor works out the answer without accesing memory.

So the QL's 68008 processor, much criticised as a cut down version of the Motorola: 68000 used in the Macintosh, Thor-16, ST and Amiga, performs complicated operations at virtually the speed of its big brother.

But complicated operations tend to be few and far between, except in maths and graphics routines, and the 68000 wins on brute strength — it can usually read or write twice as much memory as the 68008 in a given amount of time.

The higher the clock speed of the machine, the smaller that amount of time is. The QL uses 7.5MHz, which means that the basic timing pulse in the machine (the clock) occurs 7.5 million times a second. One character, or byte, can be read or written in three ticks of a clock, when the machine is running flat out. One extra tick passes while the processor is working out the next address.

At best, 1,875,000 bytes can be read or written by a QL processor in a second, if your memory runs at top speed and ideal instructions are used.

Code in ROM always runs at full speed — up to twice as fast as standard, built-in RAM. Utilities or extension commands loaded into RAM are usually limited by the speed of the RAM. which is why programs like Speedscreen and Supertoolkit are available in plugin ROM cartridges.

TIME TRIALS

We have written a short machine code routine as a test of memory speed. The routine, and a BASIC calling program which converts the timing into an approximate bus bandwidth figure, appear in Listing 1.

Type in the routine, then invoke it under the SuperBASIC interpreter by typing RUN. There will be a pause of between 15 and 30 seconds, then the computer will print out the calculated bus bandwidth — in other words, the number of characters of memory that could be read in each second.

The machine code is very simple —just a loop within a loop:

```
START       MOVEQ       #99,D0
LOOP1       MOVEQ       #-1,D1
LOOP2       DBRA        D1,LOOP2
            DBRA        D0,LOOP1
            MOVEQ       #0,D0
            RTS
```

The first loop (from LOOP1 to the second DBRA) is performed 100 times, as DO counts down from 99 to -1. The line labelled LOOP2 is performed 65536 times on each of those 100 tries, so the time taken by that line dominates the overall timing.

It is performed 65536 times because D1 contains a 16 bit count, and the loop keeps taking 1 away from the initial value, -1, until it gets back to -1. A 16 bit register can have 65536 possible values.

According to the 68008 datasheet, each step of the DBRA loop takes 18 clock pulses, during which time 4 instruction bytes are read from memory. Each byte fetch operation would take at least four pulses, so the loop is a good test of memory speed.

The code is stored in memory reserved with RESPR, which uses fast memory if possible, if you call it from BASIC. RESPR won't work if you've got tasks running, but that would confuse the results anyway. Use ALLOCATION or ALCHP to reserve some slow memory if you want to compare speeds.

Our timings for the routine, tested on all the popular makes of internal and external memory, appear in Table 1. The figures for the Megacard, Thor 16, Z88 and Spectrum are calculated rather than Measured.

The 48K Spectrum contains 16K of slow memory and 32K of faster memory from addresses 32768 to 65535. 128K Spectrum computers contain two 64K banks of memory — one runs at the speed of a 16K Spectrum, the other at the speed of a 48K machine.

Time Notes

Some manufacturers keep changing the detailed timing of their units in order to find the best compromise between speed, reliability and component cost. In general, older boards tend to be faster and less reliable. The CST RAM Plus has reliably been the fastest board, but it costs getting on for twice as much as Miracle's 512K ExpanderRAM.

If speed really concerns you, run this routine on boards you are considering buying. It's always a good idea to try new hardware before you buy it, although this can be hard to arrange.

Timings vary to some extent between individual machines, which is why we've put a range of values for the normal 128K QL. There's no direct relation between the speed of the machine and the version, and the ROM version fitted in your QL makes no difference to the RAM bus bandwidth.

The internal speed limit is imposed by the 8301 chip, which was originally designed to work at 8 MHz. Sinclair had to slow down the whole computer to 7.5MHz to make production machines reliable. This is the reason why display lines are longer than most TVs and monitors can handle — the 8301 transmits details of each line slower than a standard display circuit would.

There are two different types of internal RAM upgrade on the market. Some upgrade the QL's standard 128K by adding 256K chips in place of Sinclair's 64K components. These upgrades, such as the Quanta DIY project, run at the same slow speed as internal memory, because they must compete with the video circuit as if they were part of the standard 128K.

You can tell such a system because it will not contain the QLs normal 128K — either one 64K bank will be replaced, giving 320K of slow memory, or both will be replaced for a total of 512K. These upgrades are cheap but have little else to recommend them.

The more sophisticated Italian internal upgrades plug into the processor socket, rather than into the standard memory fittings. In effect, these work like external memory expansions, even though they are inside the QL case — they're usually faster than the other type of internal upgrade.

CODENAME SAM

We've now been to see the new Spectrum compatible computer prototype from Miles Gordon Technology (MGT), and can confirm that it exists and works. We tried loading a selection of Spectrum games into it, and it seemed very compatible, although there were one or two bad-tempered programs that wouldn't run, presumably because of checks for the Sinclair ROM. Most commercial titles — including hyperloads — worked first time.

In any case, it looks as if it will be a while before the £99 SuperSpectrum reaches the market. At the moment there's only one machine in existence, code-named SAM. The next step is for MGT to produce the custom chip around which the computer will be built. The design is finished, so it's just a matter of paying the money and waiting for one of the large semiconductor firms to make the part. After that, MGT need a case for the machine and ROM software that will intercept Spectrum system calls without infringing Amstrad's proprietary rights.

Amstrad have made a few bad- tempered noises about the machine, but they seem to be realising that it's more likely to help them, by keeping interest in the Spectrum ticking over, than to harm them — MGT could do very well indeed with the SAM, by their small-firm standards, without significantly cutting into Amstrad's sales through large retailers. In fact they are unlikely to have any grounds for complaint, especially as they sell clones of the IBM PC — SAM is much more of a new computer than Amstrad's PC range has ever been!

QL Bus Bandwidth test timings

Total RAM	System	Bandwidth (KHz)
640K	CST RAM Plus	1719
640K	GBC Italiana internal expansion	1295
640K	Inpholink internal expansion	1295
640K	Matthew Zenkar MZ512K (estimated)	1719
384/640K	Medic QL disk system	1295
640K	Micro Control Systems MCS Memodisk	1234
896K	Miracle Systems Trump card	1205
384—640K	Miracle Systems ExpanderRAM	1295 — 1520
384K	PCML QL disk system	1295
320/512K	QUANTA DIY project internally expanded QL	852
1056K	Sandy MegaCard (estimated)	1300
384/840K	Sandy SuperQboard	1178 - 1520
384/640K	Simplex Data QL RAM card	1038 - 1686
128K	Standard OL	813 - 867
Other computer bus bandwidth timings		
32K+	Cambridge Computer Z88 (estimated)	1000
640K	CST THOR 1	1719
512K	CST THOR 16 prototype (estimated)	3250
64-256K	MGT SAM prototype (estimated)	1300
16K	ZX Spectrum	650
48K	ZX Spectrum (original and Plus, top 32K)	860
126K	ZX Spectrum (all 128K versions)	650 - 860
Note: Small differences may stem from variations between computer production runs, and are unlikely to be significant.		

Theoretically, a 7.5MHz QL with fast memory should deliver a bus bandwidth of 7500/4 = 1875 KiloHertz.

Missing Speed

Theoretically, a 7.5MHz QL with fast memory should deliver a bus bandwidth of 7500/4 = 1875 KiloHertz. In practice you can't get QDOS to run a task that fast, because some time is spent doing other things.

The processor momentarily stops running your program 50 or 60 times a second (depending on the market your QL was made for), to do some housekeeping of its own. It checks the keyboard in case something has been typed, updates the date and time, checks whether or not there is data to be read and written by the file system — and switches between active tasks so that they all get a fair share of available resources.

All this work takes time. To some extent, the amount of time depends upon the number of tasks sunning, but it is usually pretty close to ten per cent of the total time available,, so your programs run a little slower than theory would suggest. You could turn off multi-tasking, but you'd lose many of the advantages of the QL.

QDOS lets you run several tasks at once, with background handling of file operations; you

can type things while the machine appears busy, without losing characters. You can switch between tasks,, perhaps to stop or start certain programs. This means you can get on with something else while time consuming work is done. The trade-off is usually well worth while.

Multi-tasking and housekeeping operations are not sped up much by fast RAM, because temporary values are stored in the 128K of slow memory while scheduling takes place. The slow RAM holds the supervisor stack, the slave block table, system variables, task ad channel details.

Megacard
There may be a cure for this, when the promised Megacard turns up. The Megacard is Sandy's attempt to steal the initiative from Miracle Systems, whose 768K plus floppy disk interface Trump Card has picked up a strong following.

Like the Trump Card, reviewed here last month, the Megacard expands the QL's memory beyond the official 640K limit by adding RAM in the space Sinclair reserved for up to 16 plug-in cards — EPROM programmers, controllers, toolkits or whatever.

The Megacard should be on sale this summer for about £500 — a remarkable price when you realise it includes interfaces for an Atari- style mouse, Centronics printer, floppy and hard disks, a 20 Megabyte hard disk drive, a megabyte of fairly fast RAM and 64K of ROM utility software. All of these features fit onto a board only 15 millimeters longer than a SuperQboard floppy disk and printer interface.

Last month we explained that the QL can only address a Megabyte of memory, including the 64K of ROM space and the 128K of internal memory. So how does the Megacard provide a Megabyte of extra QL memory?

Sandy have added 768K like Miracle Systems, then used some of the remainder to replace the last 96K of the QL's internal memory wlth faster RAM. The last 160K is controlled by the ROM software in the card, and can be used as a RAM disk.

The screen still uses slow memory, so that the video circuit can cope, but the system variables, channel information and so on use faster RAM; in theory this should make the Megacard slightly faster than the Trump Card.

In the table we've estimated the speed of the card on the basis of information provided by Sandy;. at the end of February they told us that the hardware was finished but the supporting software was not yet ready.

For an update, call Sandy on their new number 0234 273000.

Don't forget — if you've got any news, ideas or products for review, get in touch with us here at Computer Shopper 14 Rathbone Place, London, W1P 1DE, giving a phone number and a time for us to call you back if possible. Use the same address to send in your hints and tips...

We'd also be grateful if Club Secretaries could get In touch - Club Spot could become a regular feature!

CLUB NEWS

As promised last month, here's a summary of the better Spectrum, QL and Z88 user groups, with contact addresses. Send a stamped addressed envelope to the address shown to find out more about groups that interest you.

If you are in a group that you think we should be listing, please put Computer Shopper on its mailing list — this summary will be a regular feature.

BetaBASIC Newsletter
24 Wyche Avenue, Kings Heath, BIRMINGHAM B14 6LQ
This newsletter contains useful routines and information about BetaBASIC, the most comprehensive extension to Sinclair's ZX BASIC for the Spectrum. The newsletter is printed in Epson dot matrix type, reduced from A4 to A5, making it fairly easy to read.
If you enjoy programming for its own sake, and like writing in very flexible interpreted languages, BetaBASIC and its newsletter should provide you with many hours of happy hacking.

RAMM! Music Machine Owners Club
1 HIllcrest Court, Shoot-up Hill, London NW3 3PG
This group publishes a bimonthly newsletter, RAMM!, which discusses programs and applications for the RAM Electronics Music Machine — a combination of sampler and a MIDI interface for the Spectrum. The group, run by arch- enthusiast Al Straker, also distributes tapes of new software and impressive sampled sounds.
The Music Machine interface has always had much more potential than you could get at using the supplied software. RAMM! are well aware of this, so the club is worth contacting if. you're itching to get more out of your Music Machine.

INDUG
Independent Plus D/Disciple User Group
34 Bourton Road, Gloucester GL4 0LE
This group has strong links with Miles Gordon Technology, the firm behind the Plus D and Disciple Spectrum disk systems. The group helps users of these systems, publishing a monthly. newsletter, converting programs to run from disk and providing hotline telephone help. INDUG has 450 members and is run by Bob Brenchley.
INDUG publishes a monthly newsletter, FORMAT, clearly printed in a mixture of daisywheel type and dot-matrix graphics — and for once, the graphics are well- designed and clearly printed. The magazine is well edited and contains short articles, useful tips and routines, plus reviews of serious disk programs.

QUANTA
The independent QL User Group, 24 Oxford Street, Stony Stratford, Milton Keynes MK11 1JU
Once called IQLUG, this group dates from 1984 and is run by experienced hacks, Leon Heller and Brian Pain, formerly of the TRS-80, C and Z80 user groups. There are about 2,000 members and regular local and occasional 'national' meetings are held, usually in London, Birmingham, Swindon or Cambridge for some reason.
Quanta has built up a large software library, available on disks or over 100 microdrive cartridges. Most programs are free, although some of the better ones cost a few pounds. The quality is very mixed, but several library programs have been picked up by commercial publishers after a few weeks and re-surfaced in commercial form at £40 a copy.
The monthly Quanta newsletter usually runs to 40 pages of daisy- wheel printed text. The

content is often fascinating, but sometimes tedious or even misleading — it's a compendium of post received by the editor, with a few comments and adverts thrown in.

QL Super User Bureau
P0 Box 3, Shildon , Darlington, Co Durham DL4 2LW
This is a new group, run as a commercial service rather than a voluntary organisation. It recently produced issue zero of a 39-multicoloured-page newsletter, intelligently written but rather hard a
read because most of the text is dot-matrix printed in copies of the QL's low-resolution display typefaces. There has been some attempt to use an interesting layout, but the text is cramped and badly printed in our copy.
The first newsletter concentrates on rather general discussion of the QL market, interspersed with hopeful noises about the content of future issues, rather than the nitty-gritty detail that fills the Quanta magazine. This group has not yet really found its feet, but it is worth contacting if you're looking for information and advice about the QL, particularly as the group runs a free telephone advice service for members during office hours.

Z88 User's Club
68 Wellington Street, Long Eaton, N0TINGHAM NGIO 4NG
This independent club is aimed at new and potential users of the Z88. According o the organisers, it offers a club magazine, software library, discounts and specialist sèrvices.