Systems architectures for the Elliott 400 Series computers.

General characteristics of the 400 seriesfamily.

The Borehamwood Research Laboratories of Elliott Brothers (London) Ltd. produced four types of computer in the 400 series: the 401, 402, 403 and 405. A paper specification for an Elliott 404 was produced in 1956 [12] but the design never materialised. In any case, the architecture was similar to that of the 405.

The general properties of the 400 series computers are compared in Table 1 below. This Table should be read in conjunction with the further details that follow. Note that in the Table *B lines* is the name given to *Index registers.*

	401	***402E and 402 F***	***403 (WREDAC)***	***405***
Word length, visible bits	32	32	34	32
Word length incl. gap bits if any	34	34	34	34
Digit period, microseconds	3	3	3	3
Instruction length	32	32	17	16
Instruction format, addresses	1 + 1	1 + 1	1	1
No. of instructions/word	1	1	2	2
Visible central registers, (apart from Accumulator, Acc extn., Multiplier & handkeys)	2 (X, Y)	7 B-lines	3 B-lines chosen from 12 fast registers	3 B-lines
Fixed-point ADD time, min., milliseconds	0.204	0.204	0.204 *(but see text)*	0.306
Fixed-point MPY time, min., milliseconds	7 *(first version)*	3.3	3.3 *(but see text)*	3.3
Max. Primary store (*Immediate Access* plus *Quick Access*), words	(none)	15 words	512 words	512 words
Backing store, words, max.	2,944	3K	16K	32K
Typical power requirements	5 KVA	7 KVA (11KVA for 402F)	15KVA, plus ?? KVA for WREDOC	? (varies)
Date first delivered	1953, 1954	1955	1955 (1956 for WREDOC)	1956

Table 1. General characteristics of Elliott 400 series computers.

A good first-hand account of the engineering environment in which the 400 series machines were developed at Borehamwood is given by Laurence Clarke in [13]. The logic circuits were derived from a family of packages designed by Charles Owen for the Elliott 153 computer – (the *DF computer* built for GCHQ and the Admiralty – see section E1). Laurence Clarke re-designed these circuits to make use of the much cheaper 12AT7 triode vacuum tubes, in place of the miniature pentodes. The working registers used the

Borehamwood invention of nickel delay lines, based on the magneto-strictive properties of nickel wire.

The family of Elliott 400 series printed-circuit packages is described in [14]. The 401 computer used standard logic packages of just three types for its arithmetic and control purposes. Another three types of package were used for the nickel delay line registers. Specifically:

For the ALU: Type A package: twin delay
Type B package: gated delay & gated inverter
Type C package: gate & cathode follower units

For central registers:
Type D package: amplifier
Type E package: driver & regenerator
Type F package: nickel line & pre-amplifier.

For example, the 401's adder/subtracter was composed of two Type B packages.

Magnetically-coated discs or drums were used for backing storage. In 1956 Elliotts introduced their magnetic film system, similar to the more usual magnetic tape decks but based on magnetically-coated 35mm film stock – (See also below). The Elliott system was slower than contemporary tape decks but much more reliable.

Input/output for the Elliott 400 series was in the first instance via 5-track paper tape, based historically on Creed teleprinter equipment. Different manufacturers used different 5-track conventions. The complete Elliott coding of alphanumeric characters, called Elliott Telecode, is given in section E2X4 for the Elliott 402, 403 and 405 computers. Punched card equipment for input/output was subsequently introduced for the 402 and 405 computers. A Table of Elliott 405 punched card character codes and lineprinter codes is given in http://www.ourcomputerheritage.org/E2ExtraManuals.pdf

The Elliott 401 computer.

Under contracts from the National Research development Corporation (NRDC) [5], this computer was designed as a pilot model to test a number of new techniques. These were:

1. The use of packaged units for all logical functions.
2. The use of short nickel delay lines as single-word stores.
3. The use of a magnetic disc as a main store, with a capacity only sufficient to provide a general-purpose computer.
4. The use of a construction giving transportability and as much reliability as possible at a reasonable cost.

The 401 was designed and built at Borehamwood in the period 1951 – 1953. The target price was 'in the region of £20K', at a time when the only UK-designed computer on the market (the Ferranti Mark I) which cost about £90K.

The Elliott 401 is a two's complement, bit-serial, machine having a clock rate of 330KHz synchronised to the drum. The word length is 32 bits. CPU has a two-beat fetch-execute rhythm. That is to say, instructions are selected and obeyed alternatively. The basic *beat* is 34 digit-times of 3 microseconds each (thus allowing for a two-digit gap). The total fetch-execute sequence is therefore 204 microseconds and the basic fixed-point add time is also 204 microseconds. However, two-successive *ADD* instructions could only be executed at this rate if optimum programming had been used to position these two instructions appropriately on the disk. If the second instruction was 'missed', the disk may have to complete a revolution (13.1 milliseconds) before the required instruction became available. In view of this, and disk paralysis period noted below, it seems reasonable to take an average add-time for practical programs of perhaps 3 milliseconds if attempting to compare the 401 with the instruction speeds of other contemporary machines with random-access primary memory (eg CRT Williams Tube storage).

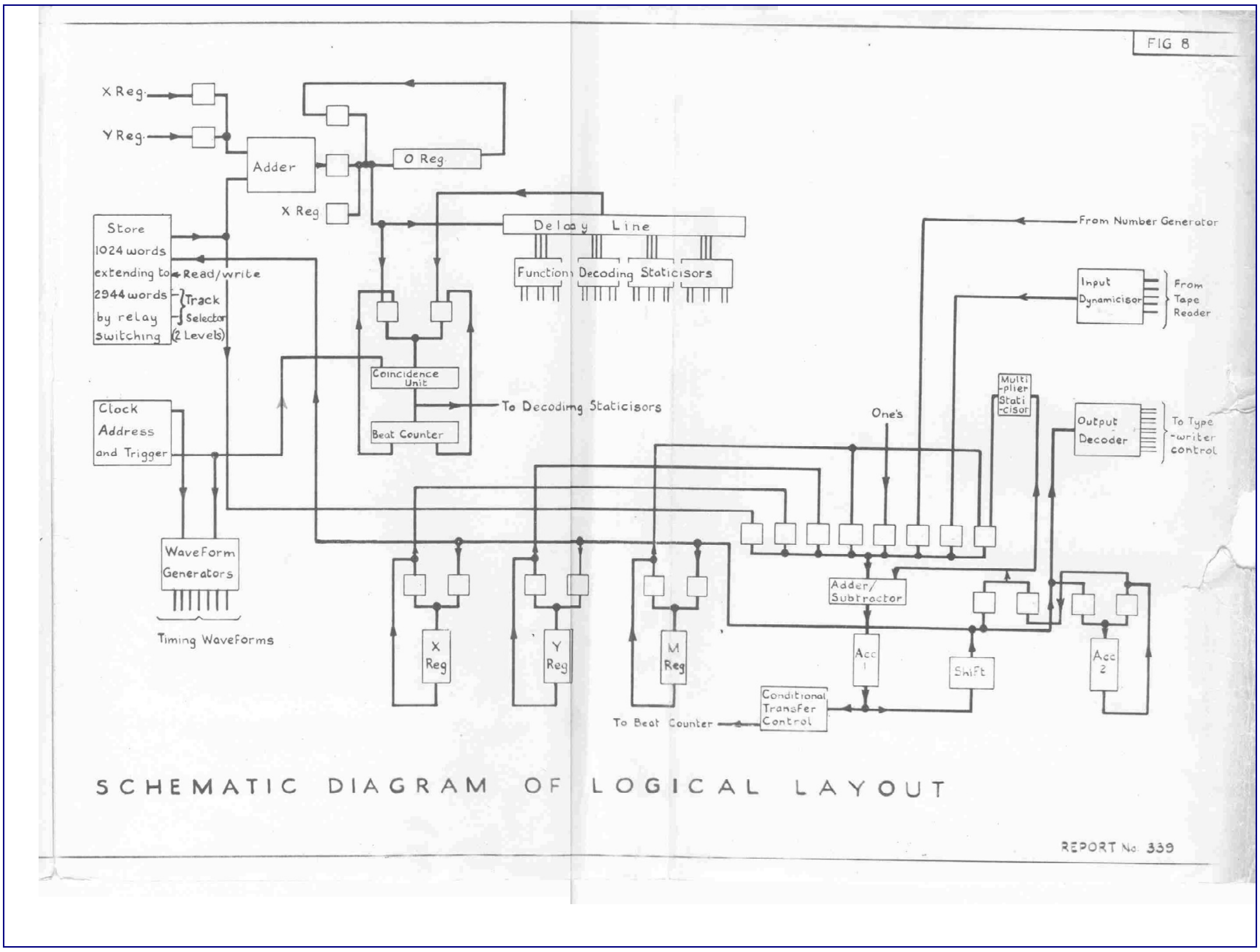

Figure 1. Schematic register-level diagram of the Elliott 401.

A schematic diagram of the 402’s central processor is shown in Figure 1, which is taken from an original Elliott report [14]. The main user-accessible registers are:

R1 = accumulator;
R2 = accumulator extension;
R3 = Multiplier register, M;
R4 = general register X;
R5 = general register Y.

In 1953 the Elliott 401 was one of the earliest non-Manchester computers to employ an index register for address-modification. An incoming instruction could be modified by adding the contents of either the X or Y register to the instruction before it was obeyed.

The X or Y register could also be either the source or the destination for an arithmetic operation, as specified by bits in the 401's generalised instruction (see below). Unlike the Manchester-designed computers of section F1, however, Borehamwood used a single ALU for both address-calculations and for main computation.

The general layout for the Elliott 401's 32-bit instruction was as follows:

10	3	3	3	3	10
A2	**S**	**F**	**D**	**C**	**A1**
Address of next instruction	Acc source	Op. code	Acc dest.	Control (K)	Operand address (also called *timing)*

The 10-bit addresses A1 and A2 refer to locations on the 401's disc store. A 10-bit address is formed as three track-digits followed by seven location-digits. The instruction set is described in section E2X3.

The Elliott 401's main (and only) store was a disc (a fixed-head device*,* in more recent terminology). When track switching occurred, and when information was written to the disc, the reading amplifiers were temporarily 'paralysed' for three or four word times. If a program requested a read during a paralysis period, hardware automatically delayed reading for a complete revolution of the disk. One revolution-time equalled 13.1 milliseconds.

The original disc store for the Elliott 401 "comprised 8 tracks closely spaced near the outer rim of a 9-inch diameter disc, each track carrying 128 words". This was soon increased to 23 tracks, each holding 128 words. Since only ten address bits are provided in the 401's instruction, only eight tracks are available to the programmer at any one time. Tracks 0 – 6 are by convention fixed tracks and 'track 7' can dynamically be made to refer to any of the 16 remaining tracks, logically numbered 0 – 15, by means of the *Track 7* instruction. When switching between one *track 7* and another *track 7*, the programmer needed to allow for a full drum revolution of approximately 13 milliseconds.

The Elliott 401 had a long and useful life at the Rothamsted Research Establishment. As far as can be ascertained [5], the main changes to the hardware over the years were as follows:

- Re-designing the character code;
- Installing a high-speed paper tape reader;
- Replacing the typewriter by a tape punch, to be read by a teleprinter off-line;
- Installing a card reader which was linked to the 401's hand-switches;
- Adding a controlled sequential addition facility in 1958. This formed the sum of a specified number of consecutive numbers stored on a given track, starting at A1 and ending at A2;
- Adding an extra set of immediate access registers S3 – S5, usable instead of R3 – R5 without losing information;
- Replacing the disc by a drum;
- Introducing *track 6* switching, thereby allowing eight more tracks to become available.

The Elliott 402 computer.
Apart from constructional improvements in the chassis and cabinets, the 402 differed from the 401 prototype in the following respects:

- Improved multiplier design, multiplication taking 3 milliseconds regardless of sign.
- Provision of hardware division, taking 3 milliseconds.
- 15 words of immediate-access storage (as nickel delay-lines) – see below.
- Capacity of magnetic store (called a *drum* rather than a *disc*) increased from 1024 words (as 8 tracks of 128 words) to 2,944 words (as 23 tracks of 128 words, selected electronically in groups of eight tracks).
- A motor-alternator set, installed a short distance away from the computer, was provided for better AC mains-transient isolation.

The Elliot 402 computer's provision of a set of 15 *Immediate Access* registers was a generalisation of the 401's X and Y registers. This was most probably the first step towards what later became known as a *general register-set* architecture. The *Immediate Access* registers were mapped into the first 16 locations of the 402's address space – (location 0 always contained zero). Locations 0 – 7 could be used for address-modification purposes.

The Elliott 402's 32-bit instruction had a similar format to that of the 401. For more details of the instruction set, see section E2X3.

The Elliott 403, also known as WREDAC.
This computer, designed for the Long Range Weapons Research Establishment in Australia, was a one-off project. It was larger and faster than the 402 by virtue of the following factors:

(a). The Elliott 403 had a fast, four-word, instruction buffer so that decoding of a following instruction took place whilst the current instruction was being executed – (a form of pipelining). It also included a degree of look-ahead at branch instructions.
(b). It had a comparatively large 512-word *Immediate-Access* store implemented as 12 single-word delay lines (effectively random-access) in the first sub-section, followed by 127 delay lines each of four words.
(c). It had three visible index registers (B-lines), pre-selected by program from four sets held in the 12 fastest storage locations.

The 403's instruction format for arithmetic orders was as follows:

5	9	2	1
F	**A**	**B**	**C**
Op code	Operand-address	Modifier register	Code

When C = 0, the instruction refers to arithmetic operations. When C = 1 *input/output transfer* instructions are specified. More details are given in section E2X3.

Together with its special bulk input/output unit called WREDOC, the Elliott 403 was much more able to handle large quantities of data that its predecessor. WREDOC consisted of seven cabinets of electronics plus two Pye ¼-inch magnetic tape units, a fast Bull lineprinter (printing two 92-character lines every second) and four graphical output units made by adapting standard Muirhead 11-inch fax machines (giving plotting densities of 20 or 40 points per inch). WREDOC's main mode of use was to accept from WREDAC the analysis results (via magnetic tape), for off-line printing and graphical display.

Much additional and interesting information on the Elliott 403 in Australia is given in http://www.ourcomputerheritage.org/E2Extra403.pdf

The Elliott 405 computer.
The architecture of the Elliott 405, which represented the company's first excursion into the commercial data processing arena, defined a computer system of several sub-units, which could be configured to suit a customer's data-processing requirements and budget. An overview of the system is shown in Figure 2.

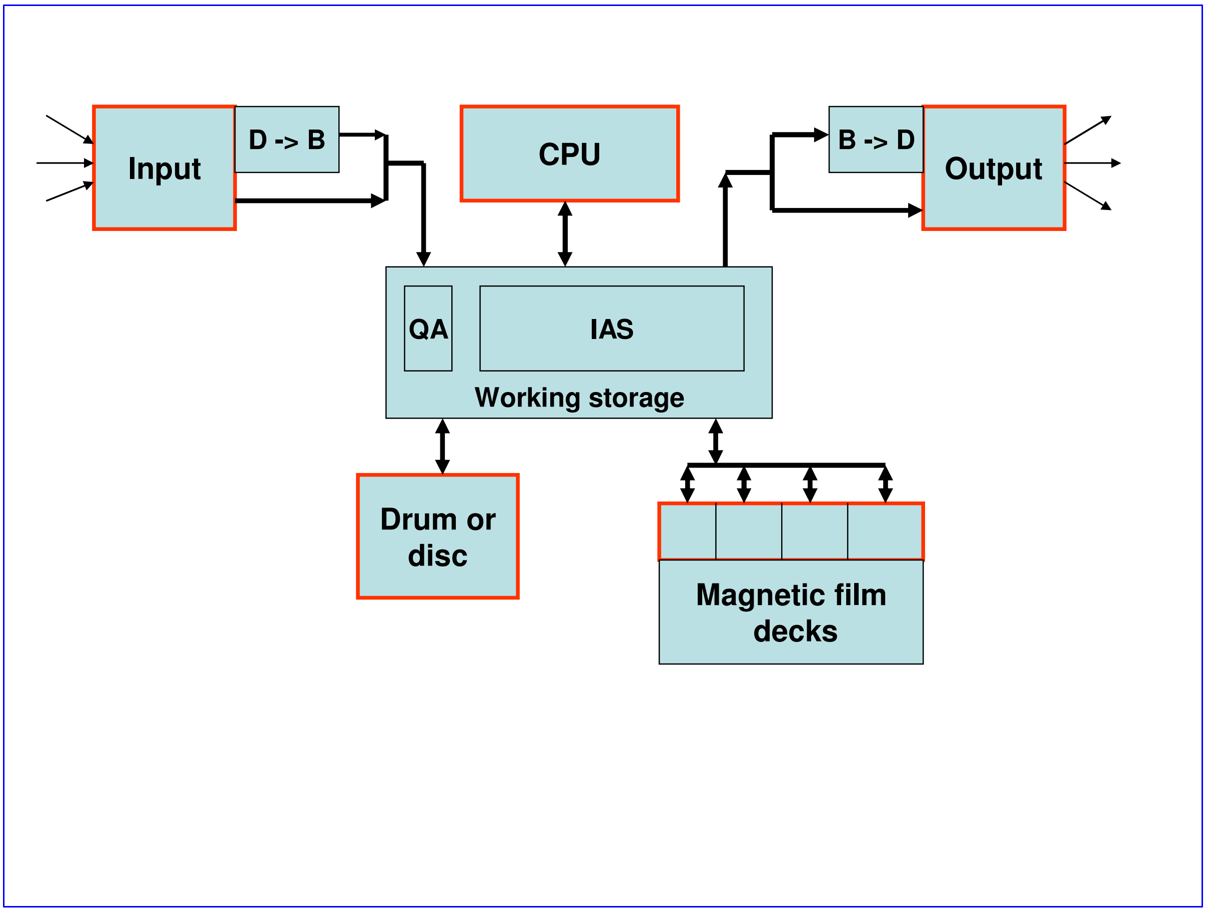

Figure 2: The principal units of the Elliott 405.

In Figure 2, the boxes labelled *Input, Output* were semi-autonomous units with decimal-to-binary (D->B) or binary-to-decimal (B->D) conversion provided. QA

Physically, an Elliott 405 consists of a number of cabinets [10, 11], each measuring about 6 ft 6 inches high on a 2 ft square base (about 2 metres high by 0.6 metres square) and each weighing about 320 pounds (145 kg). In addition to the operator's console, an installation could be build up from the following units, where *QAS* signifies Quick Access Storage composed of 16-word nickel delay lines, of which there could be a maximum of 512 words spread throughout the whole computer – (this was in addition to either 4 or 20 single-word lines of Immediate Access Storage (RAM)):

Unit and description	***no. of cabinets***
System Centre (CPU and 128 words of IAS)	2
Drum Store, 4K words (including 128 words of IAS buffer)	2
Disc Store, either 16K or 32K words (incl. 128 words of IAS)	3
35mm Film Store – Master (incl. 64 words of IAS & 2 decks)	3
35 mm Film Store – Slave (including one film deck)	1
Simple Input-Output (character-at-a-time)	1
Input/Output Compiler (including 16+ words of IAS)	2
Power Supply – master unit	1
Power Supply – slave unit	1

A small 405 system, such as the one first delivered to Norwich City Council, had about nine cabinets and a control console. A medium installation would have at least 15 cabinets plus console. In theory the largest Elliott 405 could have 82 cabinets, most of which would be magnetic film units.

At http://www.ourcomputerheritage.org/E2Extra405.pdf can be found a most interesting set of contemporary articles about a second-hand Elliott 405 computer called *Nellie*, installed at Forest Grammar School, Winersh, Berkshire. These illustrated articles, and a BBC film clip featuring the same installation [16], give a vivid picture of the 'sight, sound and feel' of a typical Elliott 405.

A word should be said about the differences between computer storage systems based on magnetic *film*, compared with the more usual magnetic *tape.* The mid-1950s was still an era of experimentation before any attempt at international standardisation. Thus there were at least seven varieties of American magnetic tape systems in operation, using tape widths that varied between a half-inch to three inches, giving transfer rates ranging from 6K to 40K characters/second. The reliability of some of these systems was questionable. The UK lagged behind America in this area. At Borehamwood, Elliott's laboratory was familiar with the 35mm film stock used by all the nearby Elstree Studios both for optical images and, when suitably coated with magnetic material, for sound recording. Borehamwood adapted the medium for digital recording, producing a system that was reliable but relatively slow. Elliott's 35mm Magnetic Film system had a very pedestrian performance of 0.3K characters/second in normal use, or 1.8K characters/second when used in a special off-line unit for direct printing of data to lineprinter. Each Elliott 1,000-feet reel held approximately 1.2 million characters.

An Elliott 405 could have up to four magnetic film *Master* units, controlling a total of up to 16 decks. In addition, there was an off-line output device which allowed a magnetic film deck to write at high speed to either a lineprinter or to a cluster of paper tape punches or to punched cards. The more demanding, high-performance, lineprinters available for the 405 printed 300 lines/minute, with 140 characters per line.

The Elliott 400 series computers used fixed-head magnetic drums or discs. The physical characteristics given in Table A3.4 are for the Elliott 405 computer. However, the 'drum' column is similar to the backing-store arrangement for the Elliott 402 and the 'small disc' column is similar to that of the Elliott 403.

	Drum	Small disc
Diameter	8.5 inches	19.25 inches
Width	1.5 inches	0.5 inches
RPM	4,600	2,300
Tracks	32	64
Sectors	64	256
Words	4,096	16,384
1 rev. time	13.2 msec	26.4
Packing density	166 digits/inch	166 digits/inch

Table 2. Backing store options for the Elliott 405 computer. A larger disc of capacity 32K words was also available.

Machine timing and memory addressing.
The Elliott 405's CPU had a three-beat rhythm: fetch instruction, read/write from/to store; perform operation. Therefore, the minimum instruction time was 306 microseconds. The Primary Store had two sections: a fast *Immediate-Access* section and a not-so-fast *Quick-Access* section. The *Immediate Access Store (IAS)* consisted of either 4 or 20 one-word nickel delay lines. If there were 20 words of IAS, then the *Quick Access* store had one of its 16-word delay lines replaced by 16 of these 1-word delay lines. The *Quick Access Store c*onsisted of at least 20 16-word nickel delay lines (each of total circulation-time 1.6 milliseconds) and up to a maximum of 32 such lines, giving a maximum of 512 words. The actual amount for any specific machine depended upon the physical configuration chosen at installation-time. Since it was quite possible to hold a small routine and its working-space in the immediate-access store, it might be thought reasonable to take 306 microseconds as the Elliott 405's average fixed-point add time. However, the picture is somewhat more complex.

The physical addressing of each 16-word delay line in the Elliott 405 is so arranged that the timings of successive words in the *Quick Access* store differ by three word times in the 16-word cycle. The total time taken by two successive instructions depends very much on the relative positions of the two instructions and their operands in these 16-word delay lines. For example, assuming that a pair of simple ADD instructions is stored at address 4, here are two extreme cases to illustrate how the choice of operand-address can dramatically alter the total time taken by the pair:

	First instruction	***Second instruction***	***Total time taken***
Case (a)	Acc = Acc + addr(10)	Acc = Acc + addr(15)	3 word-times (total 0.918 millisec.)
Case (b)	Acc = Acc + addr(20)	Acc = Acc + addr(5)	35 word-times (total 10.71 millisec.)