Table 1. Baudot code characters

Letters	Code	Figures
A	10000	1
B	00110	8
C	10110	9
D	11110	Ø
E	01000	2
F	01110	NA
G	01010	7
H	11010	+
I	01100	NA
J	10010	6
K	10011	(
L	11011	=
M	01011	)
N	01111	NA
O	11100	5
P	11111	%
Q	10111	/
R	00111	-
S	00101	.
T	10101	NA
U	10100	4
V	11101	'
W	01101	?
X	01001	,
Y	00100	3
Z	11001	:
LS	00001	LS
FS	00010	FS
CR	11000	CR
LF	10001	LF
ER	00011	ER
NA	00000	NA

Symbols: LS = Letter Shift, FS = Figure Shift, CR = Carriage Return, LF = Line Feed, ER = Error, NA = Not Assigned, Space = LS or FS.

DOLLARS, if the "figure shift" character between the PAY and the 810 were transformed into, say, a J (i.e. 00010 to 10010), then the message would be received as PAYJBAD DOLLARS (*see* Table 1 for letter-shift and figure-shift equivalents). In order to alleviate this problem, telegraph systems frequently retransmit at the end of the message all figures that occur in the message.

The five-level code most used today is the International Telegraph Code No. 2 (Murray code), invented about 20 years after the Baudot code. In computer manufacturers' literature, there is some confusion concerning the use of the term "baudot code." It is sometimes used to apply to all five-level codes and is frequently applied to International Telegraph Code No. 2.

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BCD (BINARY-CODED DECIMAL)

See CODES.

BELL LABS RELAY COMPUTERS

For articles on related subjects *see* DIGITAL COMPUTERS, HISTORY OF: EARLY; ENIAC; and STIBITZ, GEORGE.

Between 1939 and 1951, Bell Telephone Laboratories (Bell Labs) built a total of seven digital computing machines of ever-greater sophistication. Each used electromechanical relays and switching equipment for its basic computing elements. The last computers of this series were as functionally powerful as the electronic computers being built elsewhere at that time, but their use of relay switching meant that they would always remain an order of magnitude slower in arithmetic speeds. The inspiration for the initial machines came from George Stibitz, a mathematician at Bell Labs, with the engineering design due at first to Sam Williams and later to E. G. Andrews.

The Model I contained about 400 relays and performed the operations of complex arithmetic on 8-digit decimal numbers. Numbers were internally coded in excess-three binary-coded decimal (Stibitz code). The machine was accessed through a modified teletype terminal (Fig. 1). At Bell Labs, three such terminals allowed multiple (but not simultaneous)

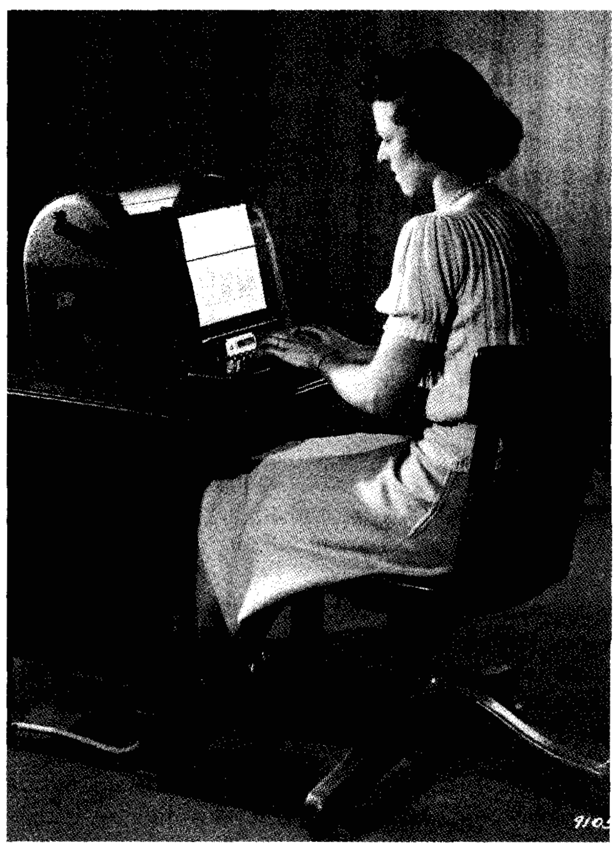

Figure 1 Operator H. L. Marvin seated at one of three consoles for the Bell Labs Complex Number Computer, 1940. (Photo: AT&T Bell Laboratories)

access. That the terminals need not be physically near the processor was dramatically demonstrated at a 1940 meeting of the American Mathematical Society in Hanover, New Hampshire, where a terminal was connected to the computer back at the Labs in New York City. Such remote access to digital equipment would not occur again for ten years.

The Model II, completed in 1943, contained about 440 relays and was optimized for work relating to the development of the M-9 gun director during the Second World War. It used paper tape for input, output, and simple sequences of operations related to interpolation of functions. Its memory capacity was seven decimal numbers of from two to five digits in length.

The Models III and IV were somewhat more powerful, containing about 1,400 relays each and having a memory capacity of ten numbers. They were installed in 1944 at Fort Bliss, Texas, and in 1945 at the Naval Research Laboratory in Washington, DC. Like the Model II, these computers were optimized for fire-control problems, although their programmability meant they could be (and were) reprogrammed to solve many other problems once the war ended.

The Model V was the most ambitious of all the Bell Labs machines, and ranks with the "Giant Brains" of the era, such as the ENIAC or Harvard Mark I (*q.v.*). Two copies were built in 1946–1947, and were installed at the National Advisory Committee for Aeronautics at Langley Field, Virginia, and the Ballistic Research Laboratory at Aberdeen, Maryland. Each machine contained over 9,000 relays, a memory capacity of 30 numbers, and hard-wired floating-point arithmetic unusual for the time.

Decimal numbers were encoded as groups of two and five relays, somewhat like the beads on a Chinese abacus. This *bi-quinary* code allowed for elaborate error checking, which ensured that the machine would stop and alert an operator before ever delivering a wrong answer. Relay computers, unlike their electronic counterparts, had to have error-detecting circuits because a relay can fail intermittently, usually when a piece of dust interferes with a few contact cycles before being dislodged. Such intermittent errors would have been almost impossible to detect without some sort of internal redundancy. By contrast, vacuum tubes failed catastrophically, with a resulting computer failure obvious to its operators.

A Model V could be configured so that several problems could be coded, each on a different paper tape, all of them ready to go. If an error was detected during the run of one problem, the machine would automatically switch over to another tape and begin solving another problem, using different parts of the processor and memory. This early and rudimentary form of *multiprogramming* (*q.v.*) allowed the machine to be run unattended through the night with the assurance that in the morning most, if not all, of the computing work would have been done. That, plus the floating-point arithmetic, helped compensate for the machine's inherently slow speed of about one multiplication per second as compared to the ENIAC's 360 multiplications per second.

The final machine in the series, the Model VI, was built and installed at the Labs for internal use in 1949. It was essentially a simplified version of the Model V, without the multiple independent processors. Apparently it was felt that the complexity of the Model V was not worth it. The Model VI did have an ability to execute short sequences of arithmetic with single commands punched on the tape, a concept new at the time and one rediscovered and named later as "macro" commands. It interpreted these commands through ingenious electromagnetic circuits that, in effect, "microprogrammed" the machine. It is not historically misleading to use that term, since those features were seen and noticed by Maurice Wilkes (*q.v.*), who later developed that concept for stored program electronic computers.

None of the Bell machines used the stored program principle, although the Models V and VI had full conditional branching capabilities. But that made the solving of complex, iterative problems a somewhat baroque exercise involving loops of tape, multiple tape drives, partitioned processors, and other mechanical tricks. Thus, the Model V went about as far as one could with not only relay technology, but also external, paper tape programming.

The Bell Labs computers were powerful, reliable, and balanced machines. They often outperformed their vacuum tube contemporaries in solving problems for which slower speed was not decisive. But once the von Neumann-inspired notions of computer architecture (*q.v.*) became known and accepted, that advantage was lost, as designers elsewhere learned to build electronic computers with none of the architectural drawbacks suffered by machines like the ENIAC. Thus, the Bell Labs machines represent an evolutionary dead end, although their contribution to the mainstream history of digital computing was profound.

Bibliography

1951. Andrews, E. G. "A Review of the Bell Laboratories' Digital Computer Developments," in *Review of Electronic Digital Computers*. Joint AIEE-IRE Computer Conference, 10–12 December, Philadelphia (New York: AIEE, 1952), 101–105.

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Figure 1 Operator H. L. Marvin seated at one of three consoles for the Bell Labs Complex Number Computer, 1940. (Photo: AT&T Bell Laboratories)