THE BENDIX G-15 GENERAL PURPOSE COMPUTER

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Introduction

The Bendix Model G-15 general purpose computer is a stored program machine with over 2000 words of high speed memory. All memory switching is electronic and there are sixteen words of quick access memory with average access of 600 microseconds per word. With this quick access memory and using minimum access coding it is possible to approximate a rate of 2000 additions or subtractions per second. The components of a vector may be summed using a single command per vector at the rate of 3000 terms per second. Sixty single precision multiplications or divisions may be done each second.

Standard input and output equipment includes an electric typewriter, a five hole paper tape punch, a high speed photo-electric tape reader. The computer is designed to accommodate several magnetic tape units as auxiliary memory or as input and output. With some extra equipment punched card input and output may be added. Input and output take place while computation is in process.

As available auxiliary equipment, but mounted in the same cabinet, a digital differential analyzer may be had. This digital differential analyzer has a capacity of 54 integrators and 54 constant multipliers. It may be easily programmed and accepts input and produces output in the decimal system. It produces the signals required to actuate an incremental type graph plotter.

The standard machine, except for this typewriter, is all mounted in a cabinet 27" by 30" by 60" high.

The Bendix G-15 general purpose computer is noted for the following characteristics:

First, it is small in physical size, it occupies the space of about two four-drawer letter-size filing cabinets plus a typewriter.

Second, it makes use of modern printed circuit construction.

Third, a very flexible command structure is used in the computer.

Fourth, the speed of the computation is high due to the ease of minimum access coding.

Fifth, another factor producing increased speed is the ability for the computer to carry on computation while input and output are in process.

Sixth, double precision operations generally take no more commands and less than twice the time of single precision operations.

Seventh, one cycle operations, the use of break point and of marked place operations, as well as print and type into accumulator facilitates efficient program checking.

Memory

The memory of the G-15 is a magnetic drum that rotates at 1800 revolutions per minute. On this drum there are 20 blocks of 108 words each. Each block is cyclic in character since it represents a single recirculating track on the drum. Thus, the information in each track passes through a reading amplifier, the drum is erased, and the signal is re-recorded continuously. This provides a system wherein the switching for transferring information to and from the memory is all done at high signal level. All such switching is done electronically and at high speed, there being no gaps between words. Besides this 2160 word block of memory, there is a 16 word block of quick access memory. This is in the form of 4 four-word lines. The recirculation time for a four-word line is 1.2 milliseconds. So the average access time for a number in this part of the memory is only 600 microseconds. By making use of minimum access coding, two numbers not in the same or consecutive word positions in the fast memory may be added and the answer placed in an arbitrary word position there in an average of 1.7 milliseconds.

The Command Structure

Each command in the G-15, generally, specifies a transfer type operation. That is, information is picked up from one place in the computer and sent to another place. Not only do all memory positions serve as sources and destinations for information, but all arithmetic registers may be used as well. For example, when no multiplications or divisions are being done, the multiply register may be used as a temporary storage. Any time that information is transferred it may be modified by the sign circuits. The actual modification is specified by a part of the command and the possibilities are 1) to transfer the information unchanged; 2) to transfer the absolute value of the numbers involved; 3) to add, in which case all negative numbers are converted to complementary form; and 4) to subtract wherein negative numbers are made positive and positive are made negative and complemented with respect to 2^{28} or 2^{57}. Each command specifies whether the information being handled is to be considered a single length (29 binary digits) or double length (58 binary digits).

A single command in the computer may transfer a consecutive set of n numbers in one memory block where n is any number between 1 and 108. In this transfer the individual numbers may be considered as either single length or double length numbers. Information transferred from one memory block to another will, in general, show up in corresponding positions in the later block.

One binary position of each command is used to specify breakpoint. Breakpoint is a means of halting computation at certain points in the problem in order that the operator may check the values of numbers or see how the computation is proceeding. If things are operating satisfactorily, the flip of the switch will allow the computation to proceed and all breakpoints may be ignored. Since a particular digit in each command specifies whether that command involved breakpoint or not, it is possible to insert and remove breakpoints at will any place in the entire program. This means that the operator doesn't have to anticipate in advance the optimum place for the placing of breakpoints. Since the computer may do a maximum of almost 2000 commands in a second, it is necessary to have this breakpoint facility in order to go through the computation to a given point. It would be impractical to reach such points by one cycle operation. At such speeds it is also impractical for the operator to halt the machine at any moment and expect to be within more than a few hundred commands of where he would like to be.

It has been indicated that each command specifies a transfer from one place in the computer to another. In general, this is a matter of specifying certain long lines or blocks in the memory or one of the arithmetic registers, and of specifying a time when the transfer is to take place so that the particular word in the block is transferred.

Normally, the successive commands that the computer obeys will come from line zero or block zero or block number 1. Whether it is block 1 or 0 is determined by a flip-flop which may be set or reset by the commands. In the general mode of operation, it is expected that the main routine will be stored in block 0, and that subroutines may be stored in block number 1. The fact that commands must come from one of these two lines is no real limitation in the computer, since it requires only one command to completely replace the contents of one of these lines with the contents of any other line in the computer.

The Arithmetic Circuits

In the computer there are two accumulators, one to handle single word operation, and one to handle double word operation. The single word accumulator is used for addition and subtraction operations of single length numbers, the double word accumulator is used for addition and subtraction operations of double length numbers. The double word accumulator is also used for shift operations and in multiplication and division of both single and double length numbers.

During an execution of the addition command, the number comes from the memory and passes through the sign circuits into the accumulator. The sign circuits inspect the sign of the number and complements the number as required. The number can be added directly into the accumulator with no delay, and in fact, this makes it possible in one pass to add a sequence of consecutive numbers coming from a particular memory block. Thus, there are commands in the computer which will give the sum of all the numbers stored in one block or any smaller set of consecutive numbers stored in such a block. In the same fashion consecutive double length numbers may be added in the double length accumulator. In a similar way, minus the sum may be computed or the sum of the absolute values of consecutive numbers in a block of the memory may be computed by the use of a single command.

Besides the accumulator, there are two other two word registers used in multiplication and division. In multiplication these two registers store the multiplicand and the multiplier, and in division they store the denominator and the quotient. The numerator and the partial products are stored in the double word accumulator.

In multiplication the multiplier and the multiplicand shift and the partial products remain fixed in position. This makes it possible to terminate the product earlier than normal, multiplying by fewer than the number of significant digits in the multiplier and still producing an answer in the proper positions for use in subsequent computation. After the multiplier and multiplicand are in position, a single precision multiplication producing a double length answer may be accomplished in just 56 word times, which is approximately one-half a drum revolution in the computer. If desired, by means of two commands the multiplication may be continued another 56 word times in which case, effectively, a double precision multiplier and a double precision multiplicand have been used. However, there has been truncation of the partial products, since only double length results can be retained. This can be corrected in a statistical manner by adding in a value for the average carry that is lost in the truncation process. This produces a reasonable approximation to a double precision answer. Of course, if exact double precision results are desired, it is possible to carry out the multiplication piece-wise, doing three single precision products and accumulating the answers as is done in many other computers. Division is carried out by repeated subtraction and addition process without restoration of the sign of the numerator. This makes it possible to develop a digit in the quotient each two word times so that a single precision quotient may be obtained in 56 word times. As in other computer, it is required that the denominator be greater than half the numerator before the division process is started. A double precision quotient may be obtained by repeating the division command with no further manipulation in between.

Operation Times

The time for addition and subtraction operations depends upon access to the memory. If minimum access coding could be fully utilized, it has been mentioned above that an addition may be performed in as little as 540 microseconds, counting the time for picking up the next command. After the operands have been obtained, a single length multiplication or division may be performed in half a drum revolution, which is approximately 15 milliseconds. If the operands are picked up from the fast access memory, and the commands are placed appropriately the complete time for a multiplication or division will not be more than 16 milliseconds.

Conditional Transfer of Control

A very flexible conditional transfer of control has been designed into the computer. The conditional transfer can be made to depend upon a number of different situations. In parts of the quick access memory there are logical facilities that give logical products and logical addition. These may be used in conjunction with the conditional transfer control to make it depend upon the presence of a digit in one number or another number. For example, conditional transfer of control may be made to depend upon the sign of the number in the accumulator, upon the sign of the number in the two word accumulator, or upon the presence of information in any particular word position in the memory, or even the presence of certain digits in the parts of the memory. The effect of a conditional transfer is to cause the next command to be one position later than usual in line 0.

Shift

There are shift commands to multiply effectively numbers by powers of 2. It is possible to multiply a number by any power of 2 between +54 and -54. When numbers are shifted, a counting process takes place in the accumulator, which makes it possible to keep track of scale factors easily, and later on to reshift automatically numbers into the appropriate position. There is also a normalize command which will shift numbers until they lie between 1/2 and 1 in size when the binary point is considered to be at the beginning of the single or double length number. During this process of normalization, counting takes place in the accumulator so that there is a record of how far the number had to be shifted. This particular command makes it easy to carry out floating point operations in this computer.

The Input and Output Circuitry

The standard version of the computer has a tyepwriter, a photo-electric tape reader, and a mechanical tape punch as input and output equipment. As an accessory, a magnetic tape unit will be available, which may be used for auxiliary storage or input and output purposes. Also available as an auxiliary equipment is circuitry which will permit punch cards to be used as input and output medium.

A very important feature of the input and output circuitry is the ability for the computer to carry on computation while input and output is in process. Generally, output takes place by placing the information to be sent out into memory line 19 and starting the output device. Input fills line 19 with new information. The appropriate input or output process may be started by execution of a command in the computer. Thereafter, the computer may proceed with its program carrying out its own computation doing any operations that do not refer to line 19. At any point in the computation the input and output circuits may be queried by execution of a command to find out if that step in the input or output process is complete. If not complete, at the programmers option, computation may be continued or the computer may wait until the input and output circuits are ready. This method of inter-lock prevents any trouble from early transfers to or from line 19 before the input or output process is complete. The speed of the typewriter is approximately 10 characters per second, and of the mechanical tape punch is approximately 15 characters per second. The speed of the photo-reader is approximately 200 characters per second. The magnetic tape will operate at 350 characters per second. These are relatively modest speeds as far as input and output equipment is concerned, but the expectation is that with such modest speeds correspondingly more reliable operation over much longer periods of time may be had.

Manual Control

Manual control of the computer is available from keys and switches on the typewriter. In general, the computer may be operated at full speed, it may halt due to break points, in which case the operator may cause the computer to start again, or the computer may be operated in a 1 cycle mode, wherein for each operation of the key on the typewriter the computer carries out the next following command. Such a facility will be used in checking out new programs. When operating in the 1 cycle mode other keys in the typewriter may cause the information in the accumulator to be printed or may cause the next command to be transferred to the accumulator and be printed. It is also possible to type new information into the accumulator, and in particular to type new commands into the computer and obey them. To facilitate this last operation, a marked place operation is available. Upon operation of a key on the typewriter, the information which determines location of the next command is stored in the memory and the operator may go on and obey a sequence of commands from the accumulator or from another location in the memory of the computer, and at some later time return to the proper place in the main program as determined by the mark place operation. This is another facility that is expected to be particularly useful in code checking.

Physical Design

All the discussions so far have been in terms of the logical design of the computer. Consider now the electronic design. It has been mentioned that it occupies the space of two filing cabinets. The lower portion of the cabinet contains the power supplies, the magnetic drum, and ventilating equipment. The upper part has two gates which swing open. These gates carry all the electronic circuitry in the form of printed circuit plug-in packages. The photo-electric tape reader is on the front of this cabinet. Probably the computer will usually be set at the end of a desk with a typewriter being located on the desk and connected to the computer with a cable. Neon lights on the computer cabinet itself indicate the state of various flip-flops in the computer. The unit uses approximately 3 kw of power and has forced air ventilation. For installation in offices where the range in temperature is such that this extra amount of heat cannot be tolerated, a special top will be supplied on the computer which makes it possible to connect a ventilating duct to exhaust the hot air outside the room. There are nine kinds of plug-in units used in the computer. These units are denumerated and their functions briefly explained below.

The flip-flop is schematically represented in Figure 1. Note that the circuit is cathode biased to assure satisfactory operation over a wide range of tube characteristics. The flip-flop proper is isolated from load current fluctuations by means of the series resistors R_1 and the germanium diode clamps. The input circuit composed of the resistors R, the capacitors C, and associated germanium diodes provide for a given side of the flip-flop to be triggered to the non-conducting state by the negative-going clock pulse CP if the corresponding input terminal A or B is at the upper gate potential. The networks RC serve to give a brief signal delay so that a single-phase clock system is used. This method of diode triggering has the advantage that the flip-flop operating point is independent of the back resistance of the triggering diode.

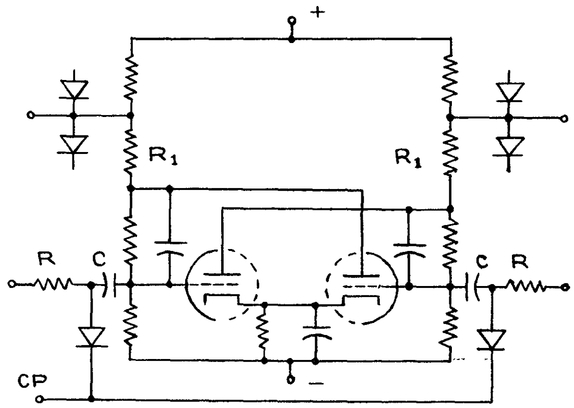

Fig. 1

The buffer-inverter is a Schmidt-trigger type of circuit employing the same circuit constants and output circuit as does the flip-flop. However, the input to one grid is from the plate of a single triode amplifier. Thus, for example, if the input signal to the grid of this amplifier is high, one clamped output will be at the upper clamp level and the other output will be at the lower clamp level. The purpose of this circuit is then two-fold. It restores signal levels to standard, and it gives the logical complement or inverse of the input signal.

The cathode follower circuit is conventional and serves two functions. The first is simply to increase the available current. The second is as a common cathode mixer or "or" gate.

The main computing network is composed of the above three tube packages and the diode packages of which there are four types. The first of these is a clamp package which actually contains all clamping diodes such as those shown in the flip-flop schematic Figure 1.

There are in addition three different configurations of diodes and resistors which are used to realize the logical gate network of the computer. These gates are conventional DC circuits by which the logical "and" and "or" are realized.

The two remaining plug-in units are the magnetic drum reading and writing amplifiers. The drum memory system used employs separate reading and writing heads on each channel along with an associated permanent magnet erasing head. A return-to-zero recording system is used in which the write-pulse to represent each "one" has a duration of about 1.5 microseconds. A write amplifier is composed of a cathode follower which operates an "and" gate to pass a standard positive write pulse to a pentode which is normally biased beyond plate current cut off.

The read amplifier has its first stage located on the pre-amplifier chassis which is near to the drum itself. The pre-amplifier for each channel consists of a triode class A amplifier followed by a cathode follower to drive the cable to the read amplifier. The input to the read amplifier proper is transformer coupled. In the read amplifier a pulse is formed from the signal to set a flip-flop which again has the same component values as above. The read flip-flop is set in this manner by each "one" signal and reset each clock period by the clock pulse. In this manner an economical memory system is obtained in which there exists adequate margin for reliability. The amplifier itself is stabilized against tube aging by degenerative feed-back.

In order to minimize faulty operation due to defective components; vacuum tubes, germanium diodes, resistors, and capacitors are used conservatively with most components having their voltage, current, or dissipation limited to half of the manufacturers rating. Vacuum tubes may deteriorate to one half their initial specifications, and germanium diodes may deteriorate by a factor of three without impairing computing accuracy. This conservative use of components coupled with the built-in marginal checking will help to minimize down time.

The mechanical design of the memory drum is novel. The individual heads which have both radial and tangential adjustment are small and entirely located on one side of the drum housing. The other side of the housing has a removable dust cover. With this cover removed, it is possible to inspect, clean, or even replace the drum coating without disturbing the head adjustment. In fact, it is never necessary to disassemble the memory, even if it becomes necessary to grind the drum surface.

A standard installation of a G-15 computer will include a number of spare packages of each sort so that normal breakdown of the computer may be repaired by simply replacing the appropriate plug-in unit. It might be well to mention here that due to the multiciplicy of lines which may serve as a source of commands, a relatively small fraction of the computer needs to be operating in order to run test routines, so that normal expectation is that most faults in the computer can be identified by a diagnostic sub-routine, and the appropriate packages causing the trouble may be replaced and the calculator will be operable again. Faulty plug-in packages may be repaired by the customer or may be returned to Bendix for repair. The general philosophy of design in the computer has been to use modest speeds and modest pulse packing to give maximum tolerances in the various aspects of the design. It is expected that this will pay off in substantial increase in reliability of operation.