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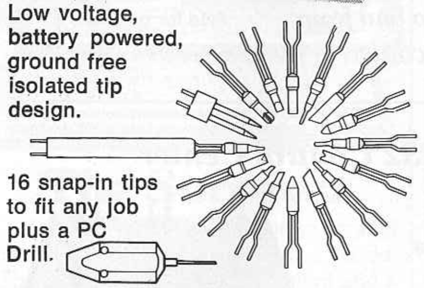

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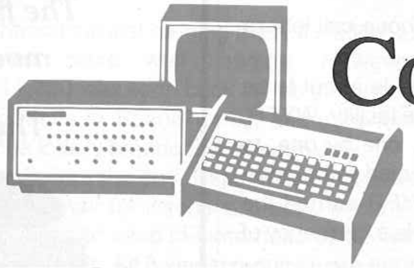

Computer Bits

By Hal Chamberlin

COMPUTER ARITHMETIC—FLOATING POINT

IN OUR September 1978 column, we discussed multiple precision computer arithmetic in which two or more bytes were used to hold a single number. But why would one want to go to the trouble of using multiple precision arithmetic?

Many applications may involve numbers that are larger than the −128 to +127 range of a single byte. For applications using binary fractions, accuracy better than the 0.4% of full-scale figure attainable in a single byte is required. However many, if not most, applications requiring computation may include mixed numbers of widely varying magnitude as well.

Scale Factor. One method of handling mixed numbers involves the concept of a scale factor. Most of us have used this concept without realizing it. For example, one does not ask a sales person in an electronics shop for a 0.0000001-farad capacitor. Instead, a "point one microfarad" capacitor would be requested. The term *micro* implies a scaling factor of 1/1,000,000. When using scaling factors, the real number (0.0000001) is equal to the scaled number (0.1) multipled by the scaling factor (1,000,000). When people use scale factors, it is in an attempt to make the scaled number close to unity. Thus 100,000 picofarads would also be an unnatural expression. In a computer, the scale factor concept can be used to reduce numbers, no matter how large or small, to a range around unity. If they are kept less than 1.0, fractional arithmetic can be used for all computations.

The arithmetic routines given earlier of course do not recognize scale factors. It is the responsibility of the programmer to keep track of scale factors. The situation is much like having a calculator with no decimal point logic. The machine calculates the digits and it is up to the user to figure out where the decimal point should be. For example, if two scaled numbers are multipled together, the scale factor of their product is the product of the scale factors. For division it is the quotient of the scale factors. This means that if both dividend and divisor scale factors are the same, the quotient scale factor is one.

When performing addition or subtraction, the scale factors of the operands *must* be equal and the scale factor of the answer will be the same as the operands. If the operands do not have the same scale factor, one of them must be rescaled. For example the series combination of 3.3k ohms and 51 ohms can either be 3300 ohms plus 51 ohms or 3.3k ohms plus 0.051k ohms. Rescaling in either case is usually accomplished by shifting the decimal point.

A good programmer may be able to sit down with a definition of the problem to be solved and select scale factors for the variables that simultaneously prevent overflow and maintain the maximum number of significant bits throughout the computation. To do this however, a good knowledge of the magnitude of the numbers in the *intermediate results* is required. This usually means that the problem must be solved before programming it. If the calculation is well defined and highly repetitive, this may not be much of a limitation, but it is unsuitable for experimental computation.

Floating-point arithmetic is an ingenious way of having the computer keep track of scaling factors as well. In addition, it provides for automatically rescaling intermediate results based on the size of the numbers at the time. Thus the programmer can become less concerned about the magnitude of intermediate results. The floating point method of doing computer arithmetic is so powerful and popular that it is an expected feature of any high-level computer language. In assembly language programming however, it is only used as a last resort because of the memory requirements and execution time of floating point arithmetic subroutines.

Number Format. Floating-point numbers are represented in a computer much like scientific notation. Basically the number is split into two parts usually called the *mantissa* and the *characteristic*. These are actually rather poor, misapplied names derived from logarithm theory so the term *fraction* will be used instead of mantissa and *exponent* will replace characteristic. The fraction part of a floating-point number is just what its name implies; a number above 0 and just shy of 1.0 in magnitude. The exponent is simply a signed integer. The value of the entire floating-point number is the fraction multiplied by the *base* raised to the exponent power. The base is a constant integer chosen by the person who wrote the floating-point arithmetic routines being used and never changes. A floating-point number is said to be *normalized* when the fraction is greater than the reciprocal of the base but less than unity.

Perhaps an example will clear things up a bit. Using decimal numbers, consider the floating-point number 0.454×10^4. The 0.454 is the fraction, the 10 is the base, and the 4 is the exponent. Since 10 to the fourth power is 10,000, this number is equal to 4540 in conventional notation. Other floating point numbers might be 0.789×10^{-2} which is the same as 0.00789 and 0.065×10^2. which is equal to 6.5. Note that the preceeding number is not normalized since the fraction is less than 1/10; in normalized form it would be 0.65×10^1. Note also that normalization simply amounted to moving the decimal point right one position which multiplied the fraction by 10 and then reducing the exponent by 1, which divided the number by 10 leaving the overall number unchanged in value.

When writing a floating-point arithmetic package for a computer, the choice of the *base* is very important. When people do calculations they naturally choose 10 for the base because of familiarity with decimal numbers. Computers on the other hand are more at home with 2 as a base because of their binary nature. Other popular bases are 8 and 16 which, because they are powers of two, are as easily handled by a computer as 2. When using a microcomputer, the only advantage of 8 or 16 as a base is exact emulation of the floating-point arithmetic of large machines which use these bases to make their hardware floating-point instructions faster.

A typical binary (base=2) floating-point number format is shown in Fig. 1. Four bytes are used to represent the

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number. The first byte is devoted to the exponent which can range between −128 and +127. This means that the scale factor applied to the fraction (base to exponent power) can range between 2^{-128} and 2^{127} which is equivalent to about 10^{-38} to 10^{37}. The fraction is a simple triple precision binary fraction ranging between, but not including, −1 and +1. This format gives an accuracy equivalent to 6 to 7 decimal places. Another popular format requires 8 bytes and simply extends the fraction to 56 bits which is equivalent to about 17 decimal digits. Note that the fraction of a normalized base-2 floating-point number must be between 1/2 and 1 which means that the most significant fraction bit will always be a one. Some floating-point software packages take advantage of this fact and omit this bit. The fraction can then be shifted left one bit making room for an additional bit of accuracy at the right end with no increase in storage space.

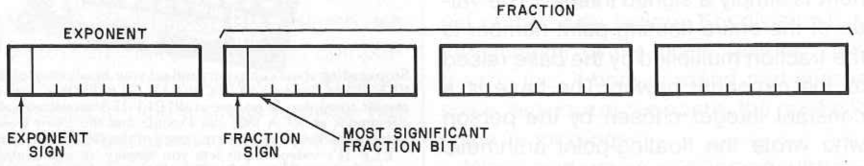

Fig. 1. Typical four-byte floating-point format.

Normalization is a very important operation in floating-point arithmetic. As previously stated, a normalized binary floating-point number has a fraction between 1/2 and 1. An arithmetic operation however can produce an un-normalized result or even a "fraction" greater than 1. Normalization is accomplished by *shifting* the fraction in the appropriate direction and then either incrementing or decrementing the exponent to compensate, thus leaving the *value* of the number unchanged. For example, if an addition operation left the result $0.0813{\times}2^9$ (decimal representation of binary floating point) one would want to shift the fraction *left* which multiplies it by two for each shift. To compensate, the exponent must be decremented by one for each shift. After three shifts, the fraction becomes 0.6504 and the exponent becomes 6 which leaves the equivalent number, 41.6256, unchanged.

Arithmetic Operations. Floating-point number representation makes arithmetic on such numbers more difficult since now both the fraction and the exponent enter the arithmetic. Multiplication is probably the simplest floating-point operation. One simply *multiplies* the fractions together using a fractional multiply routine and *adds* the exponents together. Since the product of the fractions may be less than 1/2, normalization of the result might be necessary. In fact, only normlize left is ever required since the product will always be between 1/4 and 1.

Overflow is also possible. An *overflow* condition exists if the exponent ever exceeds 127 either as the result of the multiplication or during the normalization process. Overflow is a serious error which renders any results useless. If the exponent should ever become more negative than −128, then *underflow* is said to have occurred. This means that the number has become so small that it cannot be distinguished from zero. This is a much less serious error and is usually handled by setting the result equal to zero and continuing.

Division is nearly as simple. One *divides* the fractions and *subtracts* the divisor exponent from the dividend exponent. Unnormalized results are again possible but this time they may range between 1/2 and 2 which means that a right shifting normalize may be required.

Floating add and subtract are more difficult and in fact may be nearly as slow as multiply and divide on a microcomputer.

Conversion Binary and Decimal. Even though base-2 floating point is most efficient for the computer, people demand the use of decimal numbers. The conversion process, while relatively straightforward, is too complex to explain in detail here. One difficulty with the conversion is that round decimal fractions, such as 0.1, cannot be represented exactly in binary floating-point form. Likewise, round binary fractions such as 1/32,768 cannot be represented exactly by fewer than 14 decimal digits. Integers smaller than about 8,000,000 for the 4-byte format discussed earlier are however converted exactly in both directions. The important point to remember is that the conversions are as accurate as the number of bits or digits allow, and that real-world data seldom involves "exact fractions" such as 0.1. ◇

Software Sources

Data File for 8080/Z80 *and* 6800. The DATA FILE, which runs in 1K, is a data entry and search system, available for all 6800 and 8080/Z80 systems. Cross-referencing provisions allow such retrieval methods as finding phone numbers or addresses by entering the initials of the person desired. Other features include editing, for updating files, automatic top-of-memory check, continuous display of memory addresses (for saving data on tape or disk). Program comes with hex/assembly listing, and patches for most popular I/O boards. Listing only (specify 6800 or 8080) is $10. Tapes (6800 KC-Std, 8080 Tarbell or National Multiplex cassettes or 8080 Intel format paper tapes) are $15. SWTP or North Star disk versions are $16. Practical Programming Co., Box 3069, North Brunswick, NJ 08902.

6800 Extended BASIC Compiler. Not an interpreter (like most BASIC's) but a compiler, this program generates compact application programs (about 60% of source size) which run with increased speed. The code can be stored in ROM, and can also be distributed without revealing the source code.

Other features include formatted output, strings, file I/O, 10-digit decimal arithmetic, floating point, PEEK/POKE and long variable names. The compiler (used only to generate code, not used at run time) requires 16K; the runtime package requires 10K, plus approximately 2K for an I/O package. A 16K machine can run a 225-line BASIC program, a 32K machine can run an 1100-line. On Smoke Signal floppy disk, $325, with manual and assembler. BASIC and Assembler manuals only, $10. Smoke Signal Broadcasting, Box 2017, Hollywood, CA 90028.

BASIC Programs for Pet. Nineteen tapes of BASIC programs for the Commodore Pet computer are now available from Don Alan enterprises. Most of the cassettes (which are priced from $4.95 to $19.95) are game programs, but the series also includes biorhythm, loan amortization, sketch-pad plotting, and a checkbook program. Don Alan Enterprises, Box 401, Marlton, NJ 08053.

Heathkit H8 Utilities and Games. This series of 10 programs for the H8 includes 2 cassettes of games in BH BASIC, 3 cassettes of machine-language games using

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Iselin, NJ 08830
(201) 283-0600

NEW YORK
Computer Mart of New York
First In The East
118 Madison Avenue
(30th Street Entrance)
New York, NY 10016
(212) 360-686-7923
Byte Shop Of New York
The Affordable Computer Store
130 East 40th Street
New York, NY 10016
(212) 889-4204

OKLAHOMA
Microlithics, Inc.
Medical Systems-Differential Diagnosis
2918 North MacArthur Boulevard
Oklahoma City, OK 73127
(405) 947-5646

OHIO
Digital Design
Cincinnati's First Computer Store
7694 Camargo Road, Madeira
Cincinnati, OH 45243
(513) 561-673
Ohio Microcomputer Specialists, Inc.
IMSAI Personal and Business Systems
1265 Grandview Avenue
Columbus, OH 43212
(614) 488-1849

PENNSYLVANIA
Personal Computer Corporation
First In Pennsylvania
Frazer Mall
Lancaster Avenue & Route 352
Frazer, PA 19355
(213) 647-8463

SOUTH CAROLINA
Byte Shop #32
The Affordable Computer Store
1920 Blossom Street
Columbia, SC 29205
(803) 771-7824

VIRGINIA
The Computer Hardware Store
Alpha-Micro, Apple II, S-100
818 Franklin Street
Alexandria, VA 22314
(703) 584-8085

CANADA
TJB Microsystems LTD
Your Commodore PET Headquarters
10991-124th Street
Edmonton, Alberta, Canada
T5M OH9
(403) 455-5298

Dealers: For information about how to have your store listed in THE MICROCOMPUTER MART, please contact: POPULAR ELECTRONICS, One Park Ave., New York, N.Y. 10016 • (212) 725-3568.