ELECTRONIC CIRCUIT SYMBOLS & NOTATIONS

by Ray Marston

Ray Marston looks at some controversial aspects of modern circuit symbology in this special feature article.

INTRODUCTION

Back in May '97, I started writing regular 'circuit application' feature articles for *Nuts & Volts* magazine. All of these articles are specifically aimed at experienced design engineers and competent electronics enthusiasts (rather than at novices or complete beginners), and are unusual in two special respects.

They are unusual, first, because most of them carry (on average) about 20 illustrations or practical circuit diagrams, and second, because all of the circuit diagrams use International style — rather than US Customary — circuit symbols and component notations.

All of these articles have been well received by most *Nuts & Volts* fans, but some readers (who admit to being electronics novices) have complained that they are quite bemused by the component notations that I use in these articles. I suspect that quite a few other *Nuts & Volts* fans may feel the same way so, in this special article, I aim to explain the operation of the International style electronic circuit diagram system, and to explain the system's advantages over the US Customary system. This is a fairly controversial subject and may annoy some readers, so I will start off by presenting my qualifications for writing about it, as follows:

MY QUALIFICATIONS

I have been an electronics design engineer and writer/author for over 30 years. During that period, I have — amongst other things — been editor or technical editor of four different electronics magazines, have written about 2,000 technical articles, and have written 31 electronics engineering books. Many of my magazine articles are published internationally, and — in various periods — have appeared regularly in magazines in the UK, Germany, Holland, Australia, Canada and the USA.

Of my 31 books, two were first published in Germany, and the rest in the UK; several were later published in the USA. Between them, these books have been translated into about a dozen different languages (often with suitably modified circuit diagrams), including Russian, Hindustani, and most major European tongues.

Throughout the past five years, I have produced most of the artwork and circuit diagrams that accompany my books and magazine articles (including those used in *Nuts & Volts*), using a *Corel DRAW 3* artwork/CAD package and my private symbols library. I generate an average of about 350 diagrams a year, and have thus produced about 1,750 technical illustrations and diagrams in the past five years.

As a consequence of all the above, I have lots of professional experience in the technical publishing business and in generating modern circuit diagrams, and am familiar with many of the different electronic circuit symbol and notation systems that are used in various parts of the world and with their specific advantages and disadvantages compared to other systems.

TYPICAL CIRCUIT DIAGRAMS

In the western world, most major industrial countries have their own individual preferred styles for electronic circuit symbols and notations, but these styles are not too rigidly applied and often vary considerably between one technical publisher and another, according to the 'house style' of the individual publishing company. In the USA, for example, the so-called 'US Customary' system is normally used, but the precise details of the system vary significantly between different electronics magazines.

Figures 1 to *5* show examples of how exactly the same circuit diagram can vary when published by particular electronics magazines in particular parts of the western world. The circuit is that of a simple LM386 audio power amplifier, with its voltage gain set at x200 by C4 and with its output protected by the C3-R1 Zobel network and loaded by an eight-ohm speaker.

Figure 1 shows the diagram drawn using the familiar US Customary system, using the basic house style of *Electronics Now* magazine, and *Figure 2* shows the same diagram drawn in the house style of the German electronics magazine *Elrad*, which uses a simple rectangular symbol (rather than a zig-zag) to represent a resistor.

Regarding the German capacitor symbols, the two parallel lines used to represent C1 and C3 indicate that these are ordinary non-electrolytic components, and the black and white rectangles used to represent C2 and C4 indicate that these are electrolytic capacitors; the '+' signs associated with C2 and C4 indicate that the capacitors are polarized types, and that the white

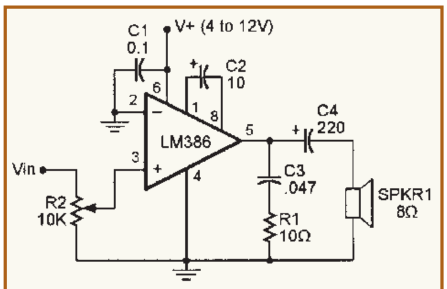

Figure 1. Circuit in the house style of Electronics Now magazine (USA).

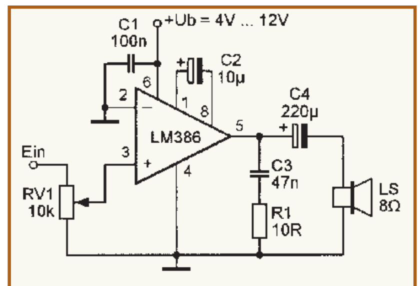

Figure 2. Circuit in the house style of Elrad magazine (Germany).

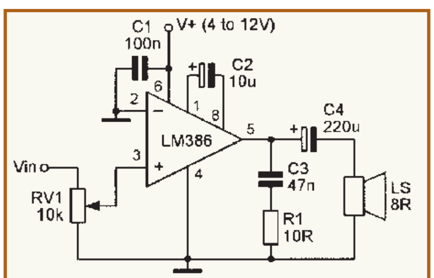

Figure 3. Circuit in the house style of Electronics Today International magazine (UK).

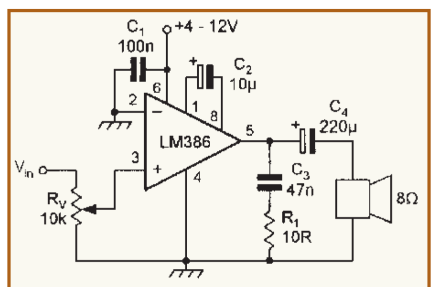

Figure 4. Circuit in the house style of Electronics World magazine (UK).

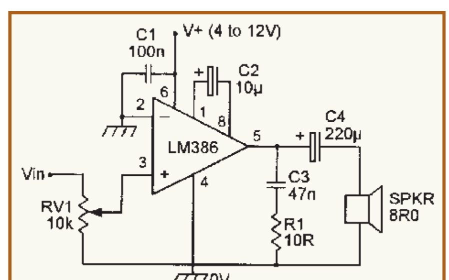

Figure 5. Circuit drawn in typical International style.

terminal is positive.

In the UK, British electronics magazine sales are dominated by six popular titles. Half of these use the zig-zag resistor symbol in their circuit diagrams, and half use the simple rectangular symbol. *Figure 3* shows the *Figure 1* diagram redrawn in the house style of one of the most popular British electronics magazines, *Electronics Today International*, which uses the simple rectangle to represent a resistor, and uses two black rectangles to represent an ordinary non-electrolytic capacitor.

The most prestigious British electronics magazine is *Electronics World*, which is aimed directly at professional engineers and managers; it has its own basic house style for circuit diagrams, but varies the style slightly from article to article. *Figure 4* shows *Figure 1* redrawn in this magazine's basic house style; note the awkward mixture of upper-case and subscript characters used to denote component numbers, etc.

Finally, *Figure 5* shows *Figure 1* drawn in my own particular version of the International circuit diagram style (which I use in my *Nuts & Volts* articles), in which resistors are drawn as zig-zags, capacitors are in simplified European style, and component values are given in formal 'International' style, which is explained in a later major section of this article.

Note in *Figures 1* to *5* that all five basic diagrams are quite easy to understand, in spite of the variations in the styles of the symbols used to represent resistors, capacitors, ground points, and loudspeakers. Also note that the variable resistor is notated by RV (Resistor, Variable) in the four non-US diagrams, but by a simple R in *Figure 1*. Finally, note that the *Figure 2* to *5* diagrams use a plain R instead of the symbol to indicate a resistor's value in ohms, and (in *Figures 2* and *4*) use the symbol only to indicate the loudspeaker's nominal *impedance* value.

The easily-understood *Figure 1* to *5* circuits are analog designs. Foreign digital designs can be far harder to understand. *Figure 6*, for example, shows some of the crazy official symbols used to represent simple logic gates in Europe. In practice, most European electronics book and magazine publishers sensibly adhere to the American MIL/ANSI symbol system, which is also used in the normal 'International' diagram system.

For most American readers, the only problems presented by the non-US *Figure 2* to *5* diagrams relate to the International component value notation systems that they use, which all notate the 10 resistor as 10R, and notate 0.047µF capacitor C3 as 47n (the odd 220u — rather than 220µ — notation used on C4 in *Figure 3* is simply a house style peculiarity used by one UK magazine). Before explaining how the International notation system works, I will explain *why* it was developed.

EVOLUTION OF THE 'INTERNATIONAL' SYSTEM

Prior to the mid 1970s, the electronic component notation systems used by most European countries were similar to the present US Customary system and were loosely based on the metric scientific notation system that — in 1960 — became officially known as SI (Système Internationale d'Unités).

In the 1960s, however, major developments in the semiconductor industry resulted in a great increase in the complexity of practical circuit designs, and industry and commerce began looking for ways of producing the resultingly complex circuit diagrams and literature with greater efficiency.

Matters reached a historic peak in 1975 when the British Standards Institute (BSI) published — after a very long period of study and consultation — a list of recommendations concerning this subject.

Many of the 1975 BSI recommendations — particularly those relating to the use of new digital circuit symbols — were pretty stupid, and were rejected by most of the electronics industry, but those relating to an international system of electronic component-value notation were excellent, and were soon adopted by most of the world's industrial nations, with the notable exception of the USA.

This new notation system was, in effect, an improved and streamlined version of the existing SI-based system, and was thus quite easy to learn. When its basic form was first specified, it was required to be designed as a simple easily-printed code that indicates an electronic component's value clearly, briefly, without ambiguity, and with a minimum loss of clarity if poorly printed.

This last requirement immediately ruled out the use of decimal points in the new code system, and the requirement for brevity called for (1) the elimination of all superfluous information from the code, and (2) for sensible compression of the remaining data.

Regarding point (1) in the 'brevity' requirement, note that in circuit diagrams, when indicating the value of a symbolic resistor, capacitor, or inductor, it is self-evident that the component's value is expressed in basic units of ohms, Farads, or Henrys, and the new code's design specification thus demanded the elimination of this superfluous 'postscript' data from the printed code *when used in circuit diagrams* (but not necessarily in normal printed text).

Regarding point (2) in the 'brevity' requirement, this was to be aided by using a fixed three-decade spacing between the decimal 'multiplier' units used to indicate a component's value.

Figure 7 lists the range of decimal multiplier units — using basic SI scientific notation and three-decade spacing — that are normally used in electronics, together with their normal prefixes, etc., and *Figure 8* shows how they are applied in the modern US Customary notation system (which was also widely used in pre-1975 Europe).

Note in *Figure 8* that the US Customary system uses three-decade multiplier spacing when notating values of resistance, inductance, frequency, and time, but inexplicably uses six-decade spacing (between µF and pF) when notating values of capacitance. This six-decade spacing is a major cause of the cumbersome capacitance-value notations (such as 0.001µF) that often appear in US circuit diagrams.

These, then, were the basic ideas behind the creation and development of the 1975 BSI component notation system, which today is known as the 'International' system. Let's now look at the details of the modern version of this system.

THE 'INTERNATIONAL' SYSTEM

RESISTANCE NOTATION

The standard unit of resistance is the ohm, named after a Bavarian, George Simon Ohm who, in 1827,

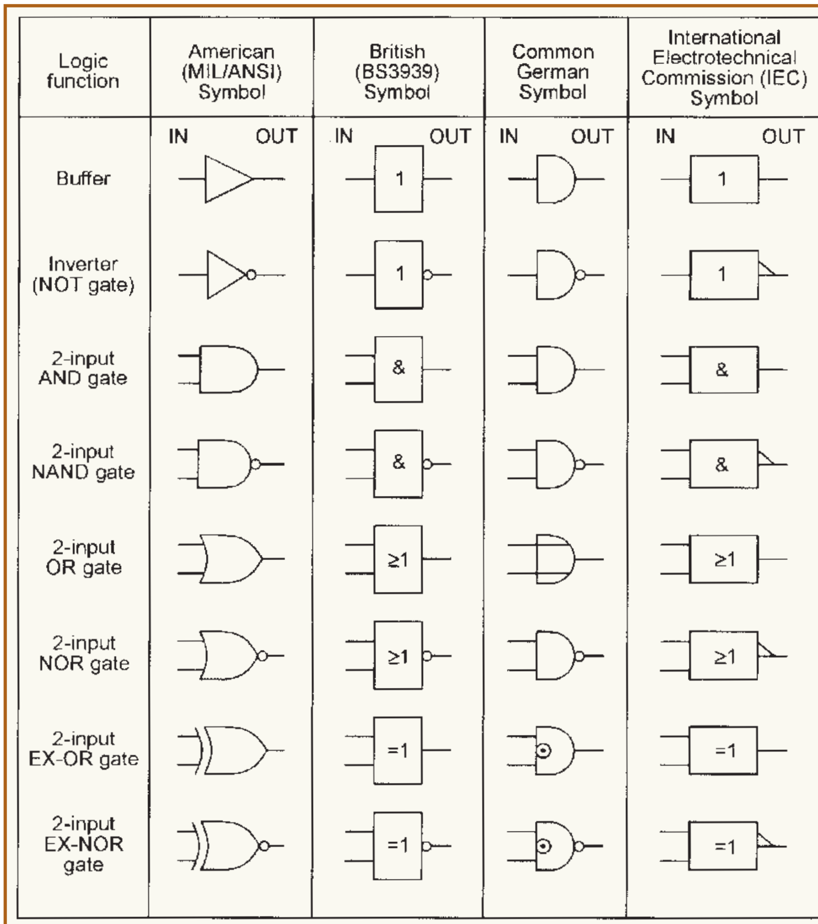

Figure 6. A selection of widely used logic symbols.

published the results of his research into electrical resistance and whose name is commemorated by the symbol Ω (omega), which is the Greek equivalent of the Bavarian letter Ö. In 1975 (prior to the advent of the wordprocessor and CAD drawing), the symbol Ω was not carried on normal typewriters and was time-consuming to produce using normal drawing techniques.

Consequently, in 1975, the BSI recommended that the symbol Ω should no longer be used *on circuit diagrams* as a postscript when denoting resistance values, that *units* of resistance should be notated by the capital letter R, that *thousands* of units be notated by the lower-case letter k (for kilohm), and *millions* of units be notated by the upper-case letter M (for megohms). Thus, in this system, 47Ω, 47kΩ, and 47MΩ become 47R, 47k, and 47M.

Prefix	Symbol	Multiplier
giga	G	10^9
mega	M	10^6
kilo	k	10^3
(unit)	(unit)	10^0
milli	m	10^{-3}
micro	µ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Figure 7. Decimal multiplier scientific notations.

Multiplier	R	C	L	*f*	Time (seconds)
10^9	—	—	—	G	—
10^6	M	—	—	M	—
10^3	k	—	—	k	—
10^0	Ω	F	H	Hz	S
10^{-3}	m	—	m	—	m
10^{-6}	—	µ	µ	—	µ
10^{-9}	—	—	—	—	n
10^{-12}	—	p	—	—	p

Figure 8. Multiplier symbols used in the US Customary notation system.

Multiplier	R	C	L	*f*	Time (seconds)
10^9	—	—	—	G	—
10^6	M	—	—	M	—
10^3	k	—	—	k	—
10^0	R	F	H	Hz	S
10^{-3}	m	—	m	—	m
10^{-6}	—	µ	µ	—	µ
10^{-9}	—	n	—	—	n
10^{-12}	—	p	—	—	p

Figure 9. Multiplier symbols used in the International notation system.

CAPACITANCE NOTATION

The standard unit of electrical capacitance is the Farad, represented by the symbol F. In electronics, the Farad is too large a unit for general use and, prior to 1975, most capacitors had values that were expressed in units of a millionth of a Farad (µF) or a millionth of a millionth of a Farad (pF). Thus, 1µF equals 1,000,000pF. This six-decade space between basic multiplier units obviously results in excessively long component notations, and BSI recommended that this problem be eliminated by reducing the spacing between multiplier units to three decades, by introducing a unit known as the nanofarad (fully notated as nF), and equal to 1000pF. Thus, 1nF equals 0.001µF, and 1000nF equals 1µF.

In circuit diagrams, when indicating the value of a capacitor, it is self-evident that the component's value is expressed in Farads, and it is thus superfluous to re-state the fact in the diagram.

Consequently, the BSI recommended that, for component notation purposes, the symbol F should no longer be used *on circuit diagrams* as a postscript when denoting capacitance values, and that the scientific symbols µ, n, and p be used as basic multiplier units. Thus, in this system, 4,700µF, 47µF, 0.047uF, and 47pF become 4,700µ, 47µ, 47n, and 47p.

INDUCTANCE NOTATION

The standard unit of electrical inductance is the Henry, represented by the symbol H. In circuit diagrams, when indicating the value of an inductor, it is self-evident that the component's value is expressed in Henrys, and it is thus superfluous to restate the fact in the diagram. Consequently, in 1975, the BSI recommended that — *on circuit diagrams* — the capital letter H should only be used to notate actual *units* of inductance, that *thousandths* of units be notated by the lower-case letter m (= millihenry), and *millionths* of units be notated by the symbol µ (= microhenry). Thus, in this system, 47H, 47mH, and 47µH become 47H, 47m, and 47µ.

100% scale

Component number	U.S. Customary	International style
C1	22pF	22p
C2	0.001µF	1n0
C3	0.01µF	10n
C4	0.047µF	47n
C5	.1µF	100n
C6	1µF	1µ0
C7	470µF	470µ
R1	8 Ω	8R0
R2	220Ω	220R
R3	1.2kΩ	1k2
R4	4.7k	4k7
R5	100k	100k

77% scale

Component number	U.S. Customary	International style
C1	22pF	22p
C2	0.001µF	1n0
C3	0.01µF	10n
C4	0.047µF	47n
C5	.1µF	100n
C6	1µF	1µ0
C7	470µF	470µ
R1	8 Ω	8R0
R2	220Ω	220R
R3	1.2kΩ	1k2
R4	4.7k	4k7
R5	100k	100k

66% scale

Component number	U.S. Customary	International style
C1	22pF	22p
C2	0.001µF	1n0
C3	0.01µF	10n
C4	0.047µF	47n
C5	.1µF	100n
C6	1µF	1µ0
C7	470µF	470µ
R1	8 Ω	8R0
R2	220Ω	220R
R3	1.2kΩ	1k2
R4	4.7k	4k7
R5	100k	100k

50% scale

Component number	U.S. Customary	International style
C1	22pF	22p
C2	0.001µF	1n0
C3	0.01µF	10n
C4	0.047µF	47n
C5	.1µF	100n
C6	1µF	1µ0
C7	470µF	470µ
R1	8 Ω	8R0
R2	220Ω	220R
R3	1.2kΩ	1k2
R4	4.7k	4k7
R5	100k	100k

Figure 10. A selection of US Customary notations and their International system equivalents, reproduced at 100%, 77%, 66%, and 50% scales.

DECIMAL POINTS

Decimal points sometimes become so severely degraded during the printing process that they cease to have a final practical value. As an example of this process, take the case of the decimal point associated with C1 in *Figure 1*. I originally generated this diagram in Corel DRAW vector format, with the C1 notations set in Arial text at 10-point size, under which conditions the decimal point takes the form of a 0.3mm x 0.3mm square.

To prepare this vector diagram for *minimum-cost* publishing, I then converted the drawing to Tiff 5.0 bitmap format at 300 dpi (in which the decimal point measures 4 x 4 pixels), and then scaled the bitmap to the '77% of original' size at which it is meant to be printed in *Nuts & Volts* (at which scale the point size reduces to 3 x 3 pixels). The complete bitmap was then printed out on high quality paper using a Laserjet printer and mailed off to *Nuts & Volts*.

On receipt of my artwork, *Nuts & Volts* scanned my bitmap into the magazine's printer, which then transferred the diagram to the printed page, where the decimal point probably measures 2 x 2 pixels, i.e., its size has fallen from 16 pixels to 4 pixels in the production process.

Thus, this minimum-cost artwork production process results in severe loss of the decimal point's definition. This problem can be reduced, at a much increased cost, by supplying the publisher with a disk copy of the full-scale Tiff 5.0 bitmap, which can then be fed — at an appropriate scale — directly into the publisher's printer, but even this process results in a final decimal point size of no more than 9 pixels at 77% scale.

The important thing to note from the above is that decimal points often become severely degraded during the printing process and, in their 1975 report, the BSI recommended that, for component/parameter value notation purposes, the decimal point should no longer be used and should be replaced by the basic component/parameter multiplier symbol (such as V, k, n, µ, etc.) applicable to that value. Thus, in this system, values such as 4.7V, 4.7kΩ, and 4700pF (= 0.0047µF or 4.7nF) become 4V7, 4k7, and 4n7.

AN OVERVIEW

There are four major differences between the International and US Customary notation systems, and two of these are illustrated in *Figure 9*, which shows the multiplier symbols that are used in the International system; compare this diagram with that of *Figure 8*, and note that the International system uses the symbol R to indicate basic resistance units, and uses the symbol n to indicate '*thousandths* of a µF' capacitance units.

Of the remaining two differences, one is that — in circuit diagrams — the International system does not use basic component 'type' symbols (such as Ω, F, or L) as component postscript notations, and the other is that the International system used the component's multiplier symbol in place of a decimal point in the actual component-value notation.

SPECIAL NOTES

Note that, although the BSI 'International' style of parameter-value notation was originally developed in the days when text was typewritten and circuit diagrams were hand-drawn, it still has great validity today, when text is generated on a wordprocessor and drawings are generated via a CAD package.

The US Customary notation '0.0047µF,' for example, looks clumsy, takes up lots of valuable text or drawing space, and takes 10 keystrokes to produce; the equivalent '4n7' International notation is, on the other hand, crystal clear, takes up a minimum of space, and takes only three keystrokes to produce.

Most real-life International component notation codes consist of two or more digits plus one symbolic 'multiplier' notation; thus, in *Figure 5*, resistance values of 10k and 10R and capacitance values of 100n, 10µ, and 220µ are used. When below-unity values such as 0.1 or 0.5µH occur, they are notated 0R1 or 0µ5 in the International system. Note that the use of a two-digit code loosely implies a two-digit degree of component precision; thus, if an 8Ω resistor is to be used in a semi-precision application, its value should be notated 8R0, but if it is only a very approximate value (such as a speaker impedance value), it can legitimately be simply notated as 8R.

The most important real-life tests regarding 'International' versus 'US Customary' component value notation systems are those relating to ease-of-use and final appearance on the printed page. You can only pass a fair comment on the first of these tests by making a genuine effort to get used to the International system, which is used by most engineers and electronics hobbyists throughout Europe and much of the rest of the world.

Regarding the second test, you can make a quick decision on this with the help of *Figure 10*, which shows a matching selection of International and US Customary component notations reproduced in extra-high-quality at 100% scale (full size), at 77% scale (the normal *Nuts & Volts* size), at 66% scale (the normal paperback handbook size), and at 50% scale (the normal small pocketbook size). Note the way in which the decimal points degrade in the smaller-scale US Customary notations.

I think the International notation system is the best of the two, and to help novice readers get used to it, future articles will, when appropriate, carry a small 'Beginner's Guide' box, giving a concise explanation of the International notation system (see *Figure 11*). If lots of readers continue to have problems, I will revert to the US Customary notation system in a future series. **NV**

Beginner's Guide to Component Notations

In this article, the values of resistors and capacitors, etc., are notated in International — rather than US Customary — style.

In resistance notation, the symbol R represents units of resistance, k represents thousands of units, and M represents millions of units. Thus, 10R = 10Ω, 47k = 47kΩ, 47M = 47MΩ.

In capacitance notation, the symbols µ, n (= 1000pF), and p are used as basic multiplier units. Thus, 47µ = 47µF, 47n = 0.047µF, 10n = 0.01µF, and 47p = 47pF.

In the International notation system, decimal points are not used in notations and are replaced by the multiplier symbol (such as V, k, n µ, etc.) applicable to the individual component value. Thus, 4V7 = 4.7V, 4k7 = 4.7kΩ, 4n7 = 4.7nF, and 1n0 = 1.0n.

Figure 11. 'Beginner's Guide' box, giving a concise explanation of the International notation system.

